BIBLIOGRAPHY

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1. MOON (Including aspects of the Earth-Moon System)

Binder, A. B. and Oberst, J. (Erde-Mond Forschergruppe, Institut für Mineralogie, Universität Münster, F.R.G.): 'High Stress Shallow Moonquakes: Evidence from an Initially Totally Molten Moon', *Earth Planet. Sci. Letters* **74** (1985), 149–154.

Thermoelastic stress calculations show that if the Moon was initially molten only in the outer few hundred kilometers as in the magma ocean model of the Moon, the highlands crust should be aseismic. In contrast, if the Moon was initially totally molten, high stress (1 to $\geq$3 kbar), shallow (0 to ~6 km deep), compressional moonquakes should be occurring in the highlands crust. Calculations of the minimum stress drops made for the 28 observed shallow moonquakes suggest that 3 of them probably have stress drops in the kbar range. Thus, these very limited seismic data are consistent with the model that the Moon was initially totally molten.

Buczynski, D. G. and Wade, P. (Fell Acre, Little Fell Lane, Conder Brow, Scotforth, Lancaster, LA2 0RQ): 'The Topography of the Phocylides and Nasmyth Area of the Moon', *Brit. Astron. Assoc. J.* **95** (1985), 106–109.

Methods of deriving the relative heights of features in the Phocylides/Nasmyth area from Earth-based drawings are outlined and discussed. Profiles across the craters in an east/west direction and of their east walls (IAU sense, as throughout) are presented and compared with explanations for dawn appearance of the craters proposed by BAA Lunar Section members in the 1950s.

Cameron, A. G. W. (Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138): 'Formation of the Prelunar Accretion Disk', *Icarus* **62** (1985), 319–327.

According to the single-impact hypothesis for forming the Moon, the angular momentum needed for the present Earth–Moon system can be imparted to the proto-Earth by a collision with a body having one-tenth of the mass or more. The collision must vaporize a large amount of rock which must stay in the form of vapor after expanding in density by a factor of several, so that pressure gradients can accelerate significant amounts of the matter into orbital motion about the proto-Earth. A successful

Earth, Moon, and Planets **46**: 31–105, 1989.

theory must put considerably more than a lunar mass into orbit, having considerably more angular momentum than is needed to assemble a lunar mass in orbit at 3 Earth radii. Such a collision has been simulated by a particular form of a particle-in-cell representation of hydrodynamics and 78 cases have been run representing variations in a variety of parameters. A significant fraction of the cases were successful in creating a satisfactory prelunar accretion disk. A fairly common characteristic of these cases was the presence of an excess velocity in the collision (above that of a parabolic orbit), implying that the projectile involved in the collision existed in an Earth-crossing orbit of significant ellipticity. A majority of the mass of the prelunar accretion disk is contributed by the projectile.

Collinson, D. W. (Inst. of Lunar and Planetary Science, School of Physics, The Univ., Newcastle upon Tyne, England): 'Primary and Secondary Magnetizations in Lunar Rocks – Implications for the Ancient Magnetic Field of the Moon', *Earth, Moon, and Planets* **33** (1985), 31–58.

The nature of the ancient magnetic field of the Moon, in which lunar rocks acquired their remanent magnetism, has emerged as an important potential source of evidence, if somewhat controversial, for a lunar core which at a period in the Moon's history was the source of the magnetic field. Many of the lunar rocks possess a stable, primary remanence (NRM) with characteristics consistent with and indicative of thermo-remanent magnetization, acquired when the rocks cooled in an ambient magnetic field. Also present are secondary components of magnetization, one type of which appears to have been acquired between collection on the Moon and reception in the laboratory and others which were apparently acquired on the Moon.

An important question to be answered is whether meteorite impacts play any part in lunar magnetism, either in modifying pre-existing magnetizations or by imparting a shock remanent magnetism (SRM) in a transient magnetic field associated with the impact. With current knowledge, SRM, in either a global lunar magnetic field or a transient field, and TRM cannot be distinguished, and in the paper the secondary magnetization characteristic of lunar rocks are examined to investigate whether their nature favours the presence of a permanent lunar magnetic field or whether they are consistent with an origin as a transient field-generated SRM.

Besides terrestrial processes of secondary magnetization, such as viscous, chemical and partial thermoremanent magnetization, possible processes peculiar to the Moon are discussed and their likely importance assessed in relation to lunar sample history. The nature of the secondary magnetizations appear to be best explained on the assumption that they are due to one or more of the processes that require an ambient lunar field, namely viscous, partial thermoremanent and shock magnetization. When associated with other types of evidence obtained from lunar magnetism studies, investigations of lunar sample remanent magnetism now favours the existence of an ancient lunar magnetic field.

Kollerstrom, N. (5 Pitch Place, Worplesdon, Surrey, GU3 3LD, U.K.): 'Newton's Lunar Mass Error', *Brit. Astron. Assoc. J.* **95** (1985), 151–153.

This paper discusses a hitherto undetected error of 100% in the Earth–Moon mass ratio by Newton, and suggests a reason why it has been overlooked.

Lumme, K., Karttunen, H. and Irvine, W. M. (Observatory and Astrophysics Lab., Univ. of Helsinki, Finland): 'Roughness of the Lunar Soil', *Earth, Moon, and Planets* **33** (1985), 19–29.

In situ measurements at the lunar surface at millimeter resolution by the Apollo astronauts have been analyzed. Several statistical parameters have been determined for the landing site. The surface roughness has been found to be very nearly gaussian. The root-mean-square slopes have been obtained over scales between 0.5 mm and 5 cm. They steadily decrease with increasing scale length from 58° to 2° and are in reasonable agreement with radar-measured values. The autocorrelation coefficient of the height distribution has also been obtained. It has a scale-length of 0.7 mm.

Mood, J. and Mood, S.: 'El Chichon and the Dark Lunar Eclipses of 1982 or the 2-Meinel Hypothesis Recovered', *Griffith Observer* **49**(2) (1985), 2–17.

Even those with short memories will recall that 1982 was a good year for lunar eclipses. And those who saw and remember the eclipses of July and December of that year may recall how unusually dark both of them were.

It wasn't your imagination or a byproduct of our ever-brightening urban skies. Those eclipses *were* dark, and Dr. John Mood and Stephanie Mood demonstrate here that the reason they were dark was short of due – but not exactly due – to what everyone thought. A volcano is certainly part of the story, but here's a case in which a lunar eclipse teaches us something about the earth's atmosphere.

Moore, P. (Farthings, Selsey, West Sussex, U.K.): 'How the Lunar Craters weren't Formed', *Brit. Astron. Assoc.* **95** (1985), 154–156.

A review of eccentric theories to explain the formation of the craters on the Moon.

No. Author Cited.: 'U.S. Proposes Lunar Mission with Soviets', *Aviation Week and Space Technology* **123**(17) (1985), 28.

The U.S. has made an informal offer to launch a spacecraft into lunar orbit to relay scientific data from a Soviet spacecraft orbiting the Moon's far side – where radio signals to Earth are blocked.

Schefter, J.: 'A Manned Base on the Moon?', *Popular Science* **227**(1) (1985), 56–59, 100.

Establishing a permanent Moon base would be a daunting engineering challenge, but experts say it can be done. Proponents point out that the Moon is an outstanding location for astronomical studies, an abundant source of raw materials, and a possible stepping stone to other planets. Others ask whether the effort is worth the price.

Wolbarsht, M. L. and Lockhead, G. R. (Duke Univ., Durham, North Carolina 27706): 'Moon Illusion: A New Perspective', *Applied Optics* **24** (1985), 1844–1847, 1852.

An illusion reported from classical times is that the horizon Moon or Sun is much larger than the zenith view of the same object. Explanation has been sought for this illusory magnification of the horizon object by examining the object color, position, and movements of the head or eyes, neural-muscular responses of the observer, sky and ground cues, etc. For the situation reported here, the Sun or Moon is viewed from an airplane at an altitude of 7 km or more with the head and eyes depressed and is seen as a very small, very red object on an unobstructed horizon. This horizon Moon viewed from the air, and the zenith Moon viewed from the ground, have in common the absence of a continuously textured field extending from the observer to the horizon, just those cues which prevent empty field myopia. We infer this absence of cues needed to reduce accommodation causes underestimation of the size of distant objects. The analysis, together with a review of the literature, indicates that the classical moon illusion is one of reduction in apparent size of the zenith object rather than overestimation of the size of the horizon object. Indeed, relatively proper judgments about the size of horizon objects are made by observers on the ground who have an unobstructed view to the horizon. The Sun and Moon really are large, but they appear that way only when viewed in a continuous environment. The moon illusion is considered here to be a part of a more general visual distortion, the toy illusion, in which large, distant objects are judged to be small when they are seen in conditions tending to produce empty field myopia. Thus, the size constancy normally recorded when ground objects are viewed from the ground is lost when these objects are viewed from an airplane at some altitude that separates the viewer from the environment. These ordinary objects are then perceived to be toys rather than full-sized familiar objects.

2. PLANETS (Articles about more than one body)

Arghavani, M. R., Russell, C. T., Luhmann, J. G. and Elphic, R. C. (Dept. of Earth and Space Sciences, Univ. of California, Los Angeles, CA 90024): 'Interplanetary Magnetic Field Enhancements in the Solar Wind: Statistical Properties at 1 au', *Icarus* **62** (1985), 230–243.

A new class of magnetic field signatures in the solar wind has been studied using interplanetary data obtained in the vicinity of Earth. Typical behavior of these signatures is a slow rise of the total magnetic field to a sharp peak and then a gradual and almost symmetric decrease to the background interplanetary magnetic field. These events last from a minimum of 30 min to a maximum of more than 11 hr. The background magnetic field is enhanced from 13 to up to 168%. However, there is no correlation between the amplification of the background field and the duration of each event. A total of 45 events have thus been found in a survey of the magnetometer data of two spacecraft (ISEE-3 and IMP-8), corresponding to a total of more than 6 yr of available survey data. The peak magnetic pressure of these events is always less than the solar wind dynamic pressure by a factor of 10 or more. These signatures are similar to those observed at Venus by the Pioneer Venus Orbiter. Based on these observations and the previously discovered signatures at Venus, the cause of these events is postulated to be small outgassing bodies which have passed by the spacecraft. These bodies must outgas enough to produce the field distortion observed and yet they must be small enough to be generally undetected by observers on Earth.

Boss, A. P. and Mizuno, H. (Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, N.W., Washington, DC 20015): 'Dynamic Fission Instability of Dissipative Protoplanets', *Icarus* **63** (1985), 134–152.

All theories of fission require a catastrophic, dynamic phase in order to produce two separate bodies. We have used nonlinear numerical and linear analytical calculations to show that the dynamic fission instability probably does *not* occur in dissipative protoplanets. The numerical calculations were performed with a three-spatial-dimension hydrodynamical code, with the protoplanet represented by a fluid with a Murnaghan equation of state. The kinetic energy in the protoplanet (other than rigid body rotation) is dissipated throughout the evolution in order to simulate the effects of viscous dissipation. Protoplanets rotating above the limit for dynamic instability were given initial asymmetric density perturbations; in each case the asymmetry did not grow during a time on the order of the rotational period. This dynamical stability has been verified by including the dissipative terms in the tensor-virial equation analysis for the stability of a Maclaurin spheroid: the dynamic instability vanishes when the dissipative terms are included, while the secular instability (with a growth time much larger than the rotational period) remains. The result applies to bodies of radius R with a kinematic viscosity $\nu \geqslant 4 \times 10^{13}\ (R/6400\ \text{km})^2\ \text{cm}^2\,\text{sec}^{-1}$, and hence may be applicable to any terrestrial protoplanet which is not totally molten. Current thermal histories for the Earth predict a partially molten mantle with a viscosity greater than this critical value. Depending on the detailed rheology of the early Earth, our results appear to rule out the possibility of forming the Earth–Moon system through a dynamic fission instability.

Brown, R. H. and Cruikshank, D. P. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'The Moons of Uranus, Neptune and Pluto', *Scientific American* **253**(1) (1985), 38–47.

When Voyager 2 flies by Uranus in January and by Neptune in 1989, it will send back closeup pictures of their icy moons. Ground-based studies of the outer solar system suggest what the probe might find.

Burša, M. and Šíma, Z. (Astronomical Inst., Czechoslovak Academy of Sciences, Prague, Czechoslovakia): 'Dynamic and Figure Parameters of Venus and Mars', *Adv. Space Res.* **5**(8) (1985), 43–46.

Parameters of the best-fitting tri-axial ellipsoids representing external equipotential surfaces of Venus and Mars have been determined from satellite data. The dynamic consequence of the equatorial flattening of Venus has been discussed from the point of view of the s.c. synodic resonance rotation. The major gravitational anomalies of Venus have been interpreted, space locations and magnitudes of anomalous masses determined and their contribution to the second zonal Stokes' constant in the gravitational potential computed. The conclusions were done: The figure of the aphroditoid is strange even if there is a relatively small polar flattening; an equatorial 'disc' of Venus is enormous. Recent space data do not support hypothesis that the Earth controls the spin of Venus.

Calcagno, L., Foti, G., Torrisi, L. and Strazzulla, G. (Istituto Dipartmentale di Fisica, Corso Italia 57, I-95100 Catania, Italy): 'Fluffy Layers Obtained by Ion Bombardment of Frozen Methane: Experiments and Applications to Saturnian and Uranian Satellites', *Icarus* **63** (1985), 31–38.

We present experimental results on some physical properties of thick organic residues obtained by bombarding frozen methane with 1.5 MeV protons. After proton fluences of ~1E + 16 protons cm^{-2} the synthesized layers appear to be amorphous and fluffy, and to have low density. Their IR transmission spectrum (2.5–10 μm) is typical of long-chain polymerlike substances. At higher fluences (~1E + 17 protons cm^{-2}) the residues evolve into a carbonlike dark material, the density as well as the stoichiometric ratio C:H increases and the IR features are decreased in strengths. Their reflectance spectrum (0.6–2.5 μm) resembles that of charcoal. We suggest that the new materials can be present on/in the surfaces of the Uranian satellites, of Hyperion, and the dark side of Iapetus. We show in fact that they could be synthesized in large quantities during the T Tau phase of the Sun when a copious emission of mega-electronvolt protons is plausible. This assumes that Saturnian and Uranian satellites were partially methane covered in the first evolutive stage of the Solar System.

Combrinck, W. L. (Cape Town, South Africa): 'Photometry: A Method for Extrasolar Planet Detection', *J. Brit. Interplanetary Soc. Space Chronicle* **38** (1985), 379–380.

A selection of photometric methods for the detection of extrasolar planets is described, elucidating their potentials and limitations.

Davies, G. F. (Research School of Earth Sciences, Australian National University, P.O. Box 4, Canberra, Act 2600, Australia): 'Heat Deposition and Retention in a Solid Planet Growing by Impacts', *Icarus* **63** (1985), 45–68.

This paper considers the scaling of impact effects with impactor size and velocity (or planetary radius) and the retention of heat deposited by impacts in a solid planet (i.e., with no convective motions). Some previously used scalings are inconsistent with the general scaling rules of Holsapple and Schmidt (1982), and no study of impact heating has considered the full permissible range of scalings. A simple physical impact model which spans this range is presented. There are three length scales which control impact heat retention: the depth scales of heat deposition and impact stirring and the ratio κ/v, where κ is the thermal diffusivity and v is the upward velocity of the accreting surface. These are evaluated in the contexts of the general scaling rules and Safronov's (1972) distribution of impactor sizes. It is found that the efficiency of heat retention (i.e., the fraction of deposited heat which is retained) is independent of the planetary growth rate. It may be low at small planetary radii, but tends to level out around 3000 km radius to values of 40–70%. Combined with an assumed heat deposition efficiency of 20%, this gives melting at a radius between about 2000 and 3000 km in terrestrial planets.

Dollfus, A. (Observatoire de Paris, 92195 Meudon, France): 'Photopolarimetric Sensing of Planetary Surfaces', *Adv. Space Res.* **5**(8) (1985), 47–58.

Polarization measurements over the surfaces of the Moon, Mercury, Mars and Saturn's rings, and global data for the Galilean satellites, have been recorded with telescopes in France. A number of asteroids were measured by B. Zellner in USA. The curves of polarization are diagnostic of the micro-texture of the surface, and demonstrate that all the atmosphereless Solar System objects so far observed (except Callisto trailing hemisphere) have their surfaces covered with a regolith of fines, as for the Moon, which is produced by the cumulative effect of meteroid impacts. For all the silicaceous objects down to a diameter of 700 km, namely Mars, Mercury, the Moon, Callisto (for the apex hemisphere), the mean grain sizes are no larger than 20 μm. The asteroids have coarser grained regoliths, apparently because of their smaller gravitational escape velocities. The C type asteroid surfaces, assumed to be carbon rich, appear finer grained than the silicaceous S types. The M asteroids, assumed to be metallic, are also covered with small fragments, because metals loose their ductile properties at low temperature and behave at impact like brittle silicates.

The trailing hemisphere of Callisto has a texture almost reminiscent of bare rocks. Orbital considerations to exclude significant impact effects, and a scenario for the past evolution of the satellite are implied.

The planet Mars, with wind effects due to a tenuous atmosphere, several intense past volcanic episodes, a high tectonic activity and a permafrost underground has a more diversified surface regolith. A detailed analysis was achieved with photopolarimeters placed on board the soviet Mars Orbiter Spacecraft MARS-5.

In Saturn's rings, anisotropic multiple scattering effects are observed and exhibit variations often in few days or weeks. Mutual interactions and gravitational forces are at work to produce organized structures, whereas disorganization forces occur and the competition produced ephemeral situations.

Ferris, J. P. and Khwaja, H. (Dept. of Chemistry, Rensselaer Polytechnic Inst., Troy, NY 12180-3590): 'Laboratory Simulations of PH_3 Photolysis in the Atmospheres of Jupiter and Saturn', *Icarus* **62** (1985), 415–424.

Photolysis of NH_3–PH_3 mixtures (11 Torr) at 175 °K resulted in the same initial rate of P_2H_4 formation as when the 11 Torr of pure PH_3 was photolyzed. A higher yield of P_2H_4 is obtained at 175 °K than at 298 °K because some of the P_2H_4 condenses on the cell wall at 175 °K and is not subject to further reaction. Some reaction of P_2H_4 is taking place as observed by the decrease in its yield and on the formation of red phosphorus on extended photolysis of PH_3 at 175 °K. No NH_2PH_2 or $(PN)_x$ were detected as photoproducts as indicated by the absence of change in the UV spectral properties of the P_2H_4 and red phosphorus fraction, respectively, when NH_3 is present. Although the pathway for PH_3 decomposition is changed, the outcome of the photochemical process is essentially the same in the absence or presence of NH_3. The formation of P_2H_4 and red phosphorus was not inhibited by small amounts of C_2H_4 and C_2H_2, so the low levels of hydrocarbons on Jupiter and Saturn will not have a significant effect on the course of PH_3 photolysis. The ratio of products of PH_3 photolysis are only slightly affected by the wavelength of light used. Use of a xenon lamp, with a continuous emission in the ultraviolet where P_2H_4 absorbs, results in only a modest decrease in the yield of P_2H_4 and a modest increase in the rate of formation of red phosphorus as compared to the rates observed with a 206.2-nm light source. The quantum yield of P_2H_4 formation is pressure independent in the 0.5–11 Torr range. This quantum yield is not affected by lowering the temperature to 157 °K or by the addition of 100 Torr of H_2. It is concluded that photolysis of PH_3 to P_2H_4 and the subsequent conversion of P_2H_4 to red phosphorus are likely processes on Jupiter and Saturn and that particles of P_2H_4 condense in the atmospheres of these planets. The conversion of some of the P_2H_4 to red phosphorus may take place on Jupiter.

Florenskiy, K. P. and Nikolayeva, O. V. (Vernadskiy Institute of Geochemistry and Analytical Chemistry, Academy of Sciences of the U.S.S.R., Moscow, USSR): 'Volatiles and Planetary Continental Material', *Geochem. International* **22**(2) (1985), 85–98.

The continental material of the planets of the terrestrial group is distinctive of each planet and varies regularly from one to another, being correlated with the amount and composition of the truly volatiles

(H_2O, CO_2, and so on) in their outer shells. These outer shells were established very early, namely at the end of planetary growth, when their geological history began, when the role of endogenous processes is problematic, and while the ongoing vigorous bombardment not only melted the surface but also partly or completely evaporated it under the conditions of a system open mainly in respect to space. The chemical features of the continental material can be related to fractionation not only during melting but also during volatilization. In the planets that have retained some amounts of true volatiles, the chemical reactions at that time were closely related to shock melting and, evaporation, as well as to the ordinary geological processes on the planet, such as aqueous or aeolian sedimentation. The details of these interactions on each planet may have been responsible for the individual features of the continental material.

Grivnev, E. M. (Institute of Astrophysics, Tadzhik Academy of Sciences, Dushanbe, U.S.S.R.): 'Density-Wave Interpretation of the Mars-7 and Venera-9 Intersteller-Gas Velocity Measurements', *Soviet Astron. Letters* **10** (1985), 382–383.

The interstellar-gas velocity in the solar system neighborhood measured by the *Mars-7* and *Venera-9* space probes evidently includes a random component together with a regular flow in the gravitational field of a spiral density wave. Nonlinear analysis, assuming a random gas velocity below the local sound speed, yields an angular spiral-pattern speed $\Omega_p \approx 12$–$16\ \mathrm{km\ sec^{-1}\ kpc^{-1}}$ and a perturbation $\varphi_1 \approx (5$–$10)\%$ in the underlying galactic potential.

Hartmann, W. K. (Planetary Science Inst., 2030 East Speedway, Suite 201, Tucson, AZ 85719): 'Impact Experiments: 1. Ejecta Velocity Distributions and Related Results from Regolith Targets', *Icarus* **63** (1985), 69–98.

Velocity distributions are determined for ejecta from 14 experimental impacts into regolithlike powders in near-vacuum conditions at velocities from 5 to 2321 $\mathrm{m\ sec^{-1}}$. Of the two powders, the finer produces slower ejecta. Ejecta include conical sheets with ray-producing jets and (in the fastest impacts at $V_{\mathrm{imp}} \gtrsim 700\ \mathrm{m\ sec^{-1}}$) high-speed vertical plumes of uncertain nature. Velocities in the conical sheets and jets increase with impact velocity (Sect. 6). Ejecta velocities also increase as impact energy and crater size increase; a suggested method of estimating ejecta velocity distributions in large-scale impacts involves homologous scaling according to R/R_{crater}, where R is radial distance from the crater (Sect. 7). The data are consistent with Holsapple–Schmidt scaling relationships (Sect. 8). The fraction of initial total impact energy partitioned into ejecta kinetic energy increases from around 0.1% for the slow impacts to around 10% for the fast impacts, with the main increase probably at the onset of the hypervelocity impact regime (Sect. 9). Crater shapes are discussed, including an example of a possible 'frozen' transient cavity (Sect. 10). Ejecta blanket thickness distributions (as a function of R) vary with target material and impact speed, but the results measured for hypervelocity impacts agree with published experimental and theoretical values (Sect. 11). The low ejecta velocities for powder targets relative to rock targets, together with the paucity of powder ejecta in low-speed impacts (<1 projectile mass for $V_{\mathrm{imp}} \sim 10\ \mathrm{m\ sec^{-1}}$) enhance early planetary accretion efficiency beyond that in some earlier theoretical models; 100% efficient accretion is found for certain primordial conditions (Sect. 12).

Hunt, G. E. (Centre for Remote Sensing and Atmospheric Physics Group, Imperial College, London, England): 'Exploration of Planetary Atmospheres: Current Knowledge, Future Opportunities and the Possible Role of Europe', *J. Brit. Interplanetary Soc.* **38** (1985), 217–221.

In the past 15 yr there has been a rapid advance in our understanding of planetary atmospheres through the wealth of data provided by missions that have observed Venus to Saturn, the continued improvements in ground-based and Earth orbiting telescopic studies and supporting numerical studies. We briefly review the current understanding of the planetary atmospheres where processes

may now be quantitatively compared with terrestrial phenomena. We further examine the possible future planetary atmospheres missions, the role of European space science in these goals.

Kharin, A. S., Minyailo, N. F. and Safronov, Yu. I. (Central Astronomical Observatory, Ukrainian Academy of Sciences, Goloseevo, Kiev Oblast', U.S.S.R.): 'The Equinox Correction, Based on Current Observations of the Sun, Venus and Mars', *Soviet Astron. Letters* **10** (1985), 392–394.

A total of 24 366 astrometric observations of the Sun, Venus, and Mars carried out with meridian circles, astrographs, and astrolabes during 1960–1977 have been analyzed. The disparity between the equinox adjustments derived from Mars and from the Sun and Venus is attributable to systematic night–day observational error. The results for the sun and Venus reveal no appreciable secular trend in the equinox.

Kondratyev, K. Ya. and Moskalenko, N. I. (The U.S.S.R. Academy of Sciences Inst. for Lake Research, Leningrad, U.S.S.R.): 'The Atmospheric Greenhouse Effect and Climates on Various Planets', *Adv. Space Res.* **5**(8) (1985), 37–40.

The greenhouse effect of the planetary atmospheres is considered and its evolution as a result of variations in the chemical composition and in gas abundances of the atmospheres as well as in the chemical composition, size distribution and concentration of aerosol components. A computer modelling gave the values of the greenhouse effect of the atmospheres of the Earth, Mars, Venus, Jupiter, and Titan. It is shown that the atmospheric greenhouse effect plays a decisive role in the formation of the planetary climates and that it has substantially changed in the process of the planetary evolution. The greenhouse effect mechanism has always been and still is a major factor of the mean global planetary climate.

Kwok, J. H. and Nacozy, P. E. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'Periodic Orbits of the General Three-Body Problem for the Sun-Jupiter-Saturn System', *Celestial Mechanics* **35** (1985), 289–303.

Two families of symmetric periodic orbits of the planar, general, three-body problem are presented. The masses of the three bodies include ratios equal to the Sun–Jupiter–Saturn system and the periods of the orbits of Jupiter and Saturn are in a 2:5 resonance. The (linear) stability of the orbits are studied in relation to eccentricity and mass variations. The generation of the two families of periodic orbits follows a systematic approach and employs (numerical) continuation from periodic orbits of the first and second kind in the circular restricted problem to the elliptic restricted problem and from the circular and elliptic problems to the general problem through bifurcation phenomena relating the three dynamical systems. The approach also provides insight into the evolutionary process of periodic orbits continued from the restricted problems to the general problem.

Mayr, H. G., Harris, I., Hartle, R. E., Schatten, K. H., Taylor, H. A., Jr., Chan, K. L. and Stevens-Rayburn, D. R. (NASA/Goddard Space Flight Center, Greenbelt, MD 20771): 'Conjecture on Superrotation in Planetary Atmospheres: A Diffusion Model with Mixing Length Theory', *Adv. Space Res.* **5**(9) (1985), 63–68.

Superrotation on Venus is discussed in the context of comparative planetary atmospheres. In our planetary system, the rigid shell component (global average) of superrotation is ubiquitous (Jupiter, Saturn, Earth, Venus, Mars, Titan). The largest equatorial values of the component are between 25 and 150 m sec^{-1}. We present a simplified, heuristic analysis, utilizing mixing length theory to describe the small scale non-linear advections of energy and angular momentum, thereby providing a closure of the dynamic system. This leads to the conjecture that the zonal velocity may be crudely estimated by $U = c\sqrt{aP_a}|S_0|(\gamma - 1)/\Gamma\gamma^2$, approximating the observed planetary trends; with c the speed of

sound, the parameter a being 1 or 2 for geostrophic or cyclostrophic conditions respectively, P_α an effective Prandtl number which becomes less than one when radiative cooling is important, S_0 the average stability, Γ the adiabatic lapse rate and γ the ratio of specific heats.

Melosh, H. J. (Lunar and Planetary Lab., Space Sciences Building, Univ. of Arizona, Tucson, AZ 85721): 'Impact Cratering Mechanics: Relationship between the Shock Wave and Excavation Flow', *Icarus* **62** (1985), 339–343.

This paper describes the relationship between the shock wave produced by an impact and the excavation flow that opens the crater. The excavation flow velocity is shown to be a nearly constant fraction of the peak particle velocity in the wave. The existence of an excavation flow is due to thermodynamically irreversilble processes in the shock. The excavation flow velocity is thus very sensitive to nonideal constitutive effects such as porosity, plastic yielding, and unreversed phase transformations. Cratering computations that do not model these effects correctly may produce misleading results.

Mian, Z. U. (Dept. of Earth Sciences, Quaid-I-Azam Univ., Islamabad, Pakistan): 'A Critique of Ramsey's Phase-Transition Hypothesis on Grounds of Comparative Planetology', *Earth, Moon, and Planets* **33** (1985), 105–107.

Recent interest in the Ramsey phase-transition hypothesis is examined and discussed with reference to the ideas of plate tectonics. Modern data on the densities and likely central pressures of the terrestrial planets combined with the occurrence of planetary magnetism in the Moon and Mercury are shown to conflict with the Ramsey phase-transition hypothesis.

Milani, A. and Nobili, A. M. (Dipartimento di Matematica, Universitá di Pisa, Italia): 'Resonant Structure of the outer Solar System', *Celestial Mechanics* **35** (1985), 269–287.

Hierarchical stability of the outer Solar System is monitored through its 3-body subsystems by using numerically computed ephemerides for 5×10^6 yr. It is found that the stability parameters of Sun–Jupiter–Saturn and Sun–Uranus–Neptune oscillate in anti-phase in $\sim 1.1 \times 10^6$ yr. The mechanism responsible for this locking is a secular resonance between Uranus' perihelion and Jupiter's aphelion: the difference between the two librates within $\sim \pm 70°$ with the same period of $\sim 1.1 \times 10^6$ yr.

Mink, D. J. and Klemola, A. (Dept. of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA 02139): 'Predicted Occultations by Uranus, Neptune, and Pluto: 1985–1990', *Astron. J.* **90** (1985), 1894–1899.

Predictions are presented for 54 occultations by Uranus' ring system, 24 occultations by Uranus, 22 occultations by Neptune, and ten possible occultations by Pluto during the period 1985 through 1990. Notable occultations by Uranus occur 24 May 1985, 16 April 1987, 27 May 1990, 21 June 1990, and 7 August 1990. The best Neptune occultations are on 7 June 1985 and 25 May 1990. Of the Pluto events, there are six which are nominally observable somewhere on the Earth, although uncertainties in Pluto's position combined with uncertainties in the star positions preclude prediction of a ground track until just before the events.

Mizuno, H. and Boss, A. P. (Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, N. W., Washington, DC 20015): 'Tidal Disruption of Dissipative Planetesimals', *Icarus* **63** (1985), 109–133.

Tidal disruption is a potentially important process for the accumulation of the planets from planetesimals. The fact that stable equilibria do not exist for circular orbits inside the Roche limit has often been hypothesized to mean that any object that passes within the Roche limit is totally disrupted. We have disproven this hypothesis by solving the dynamic problem of the tidal disruption of a dissipative planetesimal during a close encounter with a protoplanet. The solution consists of a numerical integration of the three-dimensional, nonlinear equations of motion, including an approximate treatment of viscous dissipation in the solid regions of the planetesimal. The numerical methods have been extensively tested on a series of one-, two- (Jeans), and three- (Roche) dimensional test problems involving the equilibrium of a body subjected to tidal forces. The results may be scaled to planetesimals of arbitrary size, providing that the scaled equation of state applies. The calculations show that a strongly dissipative planetesimal which passes by the Earth on a parabolic orbit with a perigee within the Roche limit ($\approx 3R_{\text{Earth}}$) is not tidally disrupted (even for grazing incidence), and loses no more than a few percent of its mass. This result applies to bodies of radius R which have a kinematic viscosity $\nu \gg 10^{12}(R/1000\,\text{km})^2$ cm^2 sec^{-1}. Less dissipative planetesimals ($\nu \approx 10^{13}(R/1000\,\text{km})^2$ cm^2 sec^{-1}) may lose up to about 20% of their mass. There are two coupled reasons why this result differs from previous hypotheses: (1) in a dynamic encounter, there is insufficient time to disrupt the planetesimal, and (2) even in circular orbit, the small velocities in the solid region imply that many orbital periods are necessary to completely disrupt the planetesimal. Hence solid and partially molten planetesimals will not experience substantial tidal disruption; completely molten bodies may be sufficiently inviscid to undergo tidal disruption.

Möhlamann, D. (Institut für Kosmosforschung der Adw, Berlin, D.D.R.): 'Origin and Early Evolution of the Planetary System', *Earth, Moon, and Planets* **33** (1985), 201–214.

It is shown by linear stability analysis that a preplanetary (presatellite) disk of dust and gas with Keplerian velocity field can become unstable due to the collective self-gravity of the disk. The radial distribution of rings, which may result from this instability, is derived. These rings later on can be the formation sites for planets around the Sun and for satellites around the planets. The derived orbits are shown to be in good agreement with that of the planets and the satellites (of Jupiter, Saturn, and Uranus). Predictions and conclusions seem to be possible for the existence of three yet unknown Uranian satellites, the origin of the early Moon and the possible radial extension of the planetary system.

Moseley, H., Conrath, B. and Silverberg, R. F. (NASA/Goddard Space Flight Center, Greenbelt, MD 20771): 'Atmospheric Temperature Profiles of Uranus and Neptune', *Astrophys. J.* **292** (1985), L83–L86.

We present for-infrared spectrophotometry of Uranus and Neptune in the 30–55 μm spectral range. The measurements in our six independent spectral bands allow us to derive atmospheric temperature profiles for these planets. Both planets are found to have tropopause temperatures near 53 K, with Neptune having a stronger stratospheric temperature inversion than Uranus. Effective temperatures of 57.7 ± 1.8 K and 58.2 ± 1.9 K are obtained for Uranus and Neptune, respectively, confirming the large internal heat source in Neptune.

Neff, J. S., Ellis, T. A., Apt, J. and Bergstralh, J. T. (Dept. of Physics and Astronomy, Univ. of Iowa, Iowa City, IA 52242): 'Bolometric Albedos of Titan, Uranus, and Neptune', *Icarus* **62** (1985), 425–432.

The geometric albedos of Titan, Uranus, and Neptune have been measured from 2000 to 3175 Å by J. Caldwell, T. Owen, A. R. Rivolo, V. Moore, G. E. Hunt, and P. S. Butterworth (1981, *Astron. J.* **86**, 298–305), from 3500 to 10 500 Å by J. S. Neff, D. C. Humm, J. T. Bergstralh, A. L. Cochran, W. D. Cochran, E. S. Barker, and R. G. Tull (1984, *Icarus* **60**, 221–235), and from 6440 to 25 360 Å by

J. Apt, R. N. Singer, and R. N. Clark (private communication). The integrated solar flux in this spectral interval amounts to 97% of the solar constant. These data sets were combined and integrated to find the bolometric geometric albedo of each object. Preliminary determinations of the phase functions were used to compute the Bond albedos and effective temperatures. The effective temperatures are compared with bolometric temperatures determined from brightness temperatures in the 10-μm to 5-mm region of the spectrum. An improved value for the internal luminosity of Neptune is $(3.9 \pm 1.1) \times 10^{15}$ W and an upper limit to the internal luminosity of Uranus is $<(0.6 \pm 1.4) \times 10^{15}$ W. Titan was found to have an effective temperature greater than the observed brightness temperatures in the thermal infrared indicating that the emissivity in this spectral region is less than unity.

Neukum, G. (DFVLR, Forschungszentrum Oberpfaffenhofen, Institut für Optoelektronik, Abteilung Planetare Erkundung, 8031 Wessling, F.R.G.): 'Cratering Records of the Satellites of Jupiter and Saturn', *Adv. Space Res.* **5**(8) (1985), 107–116.

The surfaces of most of the satellites of Jupiter and Saturn show marks of large-meteoroid impacts produced over much of solar system history and partly stemming from the early post accretional heavy bombardment. An analysis of the crater size distributions shows that (i) crater densities on the most ancient terrains are comparable to those found on the lunar highlands, (ii) crater size distributions differ somewhat from those in the inner solar system but exhibit striking similarities in shape, (iii) the crater size distributions on all terrain types from oldest to youngest are very similar, i.e. the underlying impactor size distribution does not seem to have changed over time, (iv) there is no obvious difference in crater densities between apex and antapex parts of the satellites, (v) the cratering record can better be explained by impacts from bodies in planetocentric orbits rather than by bodies in heliocentric orbits.

O'Keefe, J. D. and Ahrens, T. J. (Seismological Lab., California Inst. of Tech., Pasadena, CA 91125): 'Impact and Explosion Crater Ejecta, Fragment Size, and Velocity', *Icarus* **62** (1985), 328–338.

A model was developed for the mass distribution of fragments that are ejected at a given velocity for impact and explosion craters. The model is semiempirical in nature and is derived from (1) numerical calculations of cratering and the resultant mass versus ejection velocity, (2) observed ejecta blanket particle size distributions, (3) an empirical relationship between maximum ejecta fragment size and crater diameter, (4) measurements of maximum ejecta size versus ejecta velocity, and (5) an assumption on the functional form for the distribution of fragments ejected at a given velocity. This model implies that for planetary impacts into competent rock, the distribution of fragments ejected at a given velocity is broad; e.g., 68% of the mass of the ejecta at a given velocity contains fragments having a mass less than 0.1 times a mass of the largest fragment moving at that velocity. Using this model, we have calculated the largest fragment that can be ejected from asteroids, the Moon, Mars, and Earth as a function of crater diameter. The model is unfortunately dependent on the size-dependent ejection velocity limit for which only limited data are presently available from photography of high explosive-induced rock ejecta. Upon formation of a 50-km-diameter crater on an atmosphereless planet having the planetary gravity and radius of the Moon, Mars, and Earth, fragments having a maximum mean diameter of $\approx$30, 22, and 17 m could be launched to escape velocity in the ejecta cloud. In addition, we have calculated the internal energy of ejecta versus ejecta velocity. The internal energy of fragments having velocities exceeding the escape velocity of the Moon ($\sim$2.4 km sec^{-1}) will exceed the energy required for incipient melting for solid silicates and thus, the fragments ejected from Mars and the Earth would be melted.

Rinnert, K. (Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, F.R.G.): 'Lightning on Other Planets', *J. Geophys. Res.* **90** (1985), 6225–6237.

The necessary conditions for producing lightning discharges, the experimental possibilities for investigating extraterrestrial lightning, and the scientific objectives of planetary lightning research are briefly discussed. Present knowledge on the composition, structure, and dynamics of the atmospheres for the extraterrestrial planets and the satellites Io and Titan are reviewed in terms of their importance for the production of lightning. From the knowledge on planetary atmospheres, intensive lightning activity can be expected to exist in the Jupiter and Saturn cloud systems; this is less conclusive for Venus and unlikely for the other bodies. Electrical activity is not completely ruled out for Martian dust storms. Optical and RF wave measurements from spacecraft have yielded evidence of possible lightning activity on Venus, Jupiter, and Saturn. These observations are reviewed and discussed. The conclusion that the optical and or RF emissions are definitely from lightning is not unambiguous and based on poor data bases. There are no coincidence measurements of optical and RF pulses, and there is no information on the characteristics of individual pulses, which would help to clarify the source.

Schultz, P. H. and Gault, D. E. (Lunar and Planetary Inst., 3303 NASA Road 1, Houston, TX 77058): 'Clustered Impacts: Experiments and Implications', *J. Geophys. Res.* **90** (1985), 3701–3732.

Impact by clusters of projectiles rather than a single projectile can result from several processes: atmospheric breakup, tidal breakup, and ejecta from a large primary impact. Experiments have been performed in order to establish the characteristics of such events over a wide range of impact velocities (15 m/s to 6 km s^{-1}). At very low impact velocities (15–200 m s^{-1}), clustered impacts were produced by launching a grouped projectiles of aluminum shot, steel shot, iron filings, and sand. At moderate to high velocities (0.8–6 km s^{-1}), pyrex spheres were shattered above the target during passage through aluminum foil or paper, thereby forming a well-defined cluster of fragments of overall radius r_c. The ratio of the overall radius r_c of the cluster to the radius r_s of a solid impactor of the same mass provides a measure of the cluster dispersion. Sand and compacted pumice targets were used in order to compare qualitatively the additional effect of slight differences in target strength. The experiments reveal marked contrasts between impacts by clusters of projectiles and impacts by a single solid body. 'Tight' clusters ($r_c/r_s < 3$) displace a factor of 2 less than a single impactor of the same mass, 'open' clusters ($r_c/r_s \sim 9$) displace a factor of 5 less mass, and 'dispersed' clusters ($r_c/r_s > 20$) displace a factor of 10 less mass. This reduction in cratering efficiency is largely expressed as a shallow crater with an aspect ratio (diameter/depth) as large as 30 for open clusters. The size and velocity of the cluster (as well as the density and strength contrast between the impactor and target) can dramatically affect crater morphology. Open clusters impacting compacted pumice produce a flat, hummocky floor with an incipient multiring pattern, whereas a tight cluster impacting the same target produces a central floor mound. Oblique impacts by symmetrical clusters form a characteristic array of V-shaped ridges pointing uprange. The apex angle of the ridges depends on the cluster dispersion and impact angle. Inventories of postimpact projectile material reveal that the projectile is largely retained on the surface and spread downrange from the impact direction. The amount of projectile material retained on the surfaces increases with decreasing impact angle (from the horizontal) and with increasing strength of the target relative to the projectile. Clustered impact craters and lunar secondary craters bear striking similarities over a broad range of morphologic features. On this basis and on the basis of reasonable models of ejecta curtain structure, we suggest that these experiments provide new clues for understanding ejecta emplacement around large lunar impact craters. When the ejecta curtain around large impacts is viewed as a thick wall of debris and clustered impactors are viewed as a unit section of such a curtain, then experimental results indicate that the continuous ejecta facies even for lunar craters larger than 100 km could contain as much as 90% primary material. Such a conclusion contrasts with many existing models that derive mixing ratios implicitly based on single, noninteracting impact events. Beyond the continuous ejecta facies, impacting clusters of ejecta provide a physical basis for understanding the wide variety of secondary morphologies and the large range in spectral signatures of primary material in crater rays.

Sharpton, V. L. and Head, J. W. (Dept. of Geological Sciences, Brown Univ., Providence, RI 02912): 'Analysis of Regional Slope Characteristics on Venus and Earth', *J. Geophys. Res.* **90** (1985), 3733–3740.

Regional slope values for Earth and Venus are calculated for each 3° × 3° region of topography, and the global characteristics of these magnitudes are examined and compared. The effects on terrestrial regional slope due to ocean loading are treated by approximating the component of seafloor depth due to the weight of the overlying water column and removing this component from the ocean topography. Although regional slopes on Venus and Earth span the same range, 0.0°–2.4° (±0.07°), the slope frequency distributions for the two planets differ significantly. The most abundant regional slope values for the terrestrial cases (Earth and unloaded Earth) are 0.0° and reflect the presence of vast plains associated with the continental interiors and ocean abyssal plains. In contrast, Venus exhibits a peak in slope frequency at approximately 0.09°, perhaps indicating less effective planation processes in the absence of a hydrosphere. Surfaces with regional slope values of 0.07°–0.24° are substantially more common on Venus than on earth. Slopes in this range are associated with discrete features in the lowland and upland rolling plains provinces of Venus and may be indicative of a geologic process that is not commonly observed on Earth. Only 14 ± 1% of all Venus surfaces have regional slopes above 0.24°, compared to 26 ± 1% for Earth. When mean regional slope is calculated as a function of elevation, a distinctive positive correlation is expressed on Venus. In contrast, the terrestrial cases exhibit a complex relationship marked by four modes related to the presence on Earth of an active hydrosphere-driven weathering regime, a distinctive crustal dichotomy, and plate tectonics. The distinctions in the regional slope characteristics between Venus and Earth point to a simpler, less diversified geology on Venus.

Slavin, J. A., Smith, E. J., Spreiter, J. R. and Stahara, S. S. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'Solar Wind Flow about the Outer Planets: Gas Dynamic Modeling of the Jupiter and Saturn Bow Shocks', *J. Geophys. Res.* **90** (1985), 6275–6286.

Pioneer 10 and 11 and Voyager 1 and 2 observations are used to study global aspects of the solar wind interaction with Jupiter and Saturn. Solar wind measurements before and after the encounters are used to determine average upstream flow parameters at 5 and 9 AU. Bow shock and magnetopause position are found to vary as the fourth root of dynamic pressure at Jupiter and the sixth root at Saturn. The average distances to the nose of the magnetopause based upon the Pioneer and Voyager boundary crossings for Jupiter and Saturn are 68 R_J and 19 R_S, respectively, after correction for varying solar wind pressure. In shape, the Jovian bow shock and magnetopause surfaces are similar to their terrestrial counterparts, but the width of the magnetosheath is 45% less than predicted by axisymmetric gas dynamic theory. This result is interpreted as evidence for strong polar flattening of the Jovian magnetosphere. The Saturnian magnetopause and bow shock boundaries are significantly more flared than at the Earth with a subsolar magnetosheath that is 20% thinner than predicted by gas dynamic theory. On the basis of these results it is suggested that Saturn is intermediate between the Earth and Jupiter in terms of polar flattening, with the unusual flaring of the Saturn magnetopause being due to the low ratio of static to dynamic pressure in the distant heliosphere.

Takashima, T. (Meteorological Research Inst., Tsukuba, Ibaraki, Japan): 'Polarization Effect on Radiative Transfer in Planetary Composite Atmospheres with Interacting Interface', *Earth, Moon, and Planets* **33** (1985), 59–97.

A procedure of computing the radiance and the polarization parameters of radiation diffusely reflected and transmitted by an inhomogeneous, plane-parallel terrestrial atmosphere bounded by a ruffled ocean surface is discussed with the aid of the adding method. If the atmosphere and the ocean are simulated by a number of homogeneous sublayers, the matrices of radiation reflected and

transmitted diffusely by the atmosphere-ocean system can be expressed in terms of these matrices of sublayers by using only a couple of iterative equations in which the polarity effect of radiation is included. Furthermore, the upwelling radiance and the polarization degree of radiation at the top of the atmosphere can be calculated by using a single iterative equation without requiring the equation for the diffuse transmission matrix of radiation. The ruffled ocean surface can be treated as an interacting interface, where the transmitted radiation from beneath the ocean surface into the atmosphere is also taken into account in the derivation of equations. Finally, sample computations of the upwelling radiance and the polarization degree of radiation from the top of the atmosphere are carried out at the wavelength of 0.60 micron.

Tozer, D. C. (University of Newcastle upon Tyne, Newcastle upon Tyne, England): 'Heat Transfer and Planetary Evolution', *Geophys. Surv.* **7** (1985), 213–246.

The object of this account is to show how much one can interprete and predict about the present state of material forming planet size objects, despite the fact we do not and could never have the kind of exact or prior knowledge of initial conditions and in situ material behaviour that would make a formal mathematical analysis of the dynamical problems of planetary evolution an efficient or meaningful exercise. The interest and usefulness of results obtained within these limitations stem from the highly non linear nature of planetary scale heat transfer problems when posed in any physically plausible form. The non linearity arising from a strongly temperature dependent rheology assumed for in situ planetary material is particularly valuable in deriving results insensitive to such uncertainties. Qualitatively, the thermal evolution of a planet is quite unlike that given by heat conduction calculation below a very superficial layer, and much unnecessary argument and confusion results from a persistent failure to recognise that fact. At depths that are no greater on average than a few tens of kilometers in the case of Earth, the temperature distribution is determined by a convective flow regime inaccessible to the laboratory experimenter and to the numerical methods regularly employed to study convective movement. A central and guiding quantitative result is the creation in homogeneous planet size objects having surface temperatures less than about half the absolute melting temperature of their material, of internal states with horizontally averaged viscosity values $\sim 10^{21}$ poise. This happens in times short compared with the present Solar System age. The significance of this result for an understanding of such processes and features as isostasy, continental drift, a minimum in seismic S wave velocity in Earth's upper mantle, a uniformity of mantle viscosity values, the survival of liquid planetary cores and the differentiation of terrestrial planet material is examined. After a discussion and definition of 'lithospheric' material, it is concluded that endogeneous tectonic activity only continues on Earth's surface on account of water enhancing the deformability of its rocks.

Metal silicate differentiation of terrestrial planet material is predicted to have been a global scale catastrophic process in the many objects it formed predating the existing planets, but intersilicate and volatile silicate separations are necessarily protracted, quasi continuous processes arising from local shear instabilities in the convective flow of such a viscous material. In particular, these local magma producing instabilities require the involvement of 'lithospheric' planetary material in convective movements and it is shown how this unsteadiness accounts for the distribution and salient features of planetary seismicity and vulcanicity at the present time.

The picture that emerges for the state of Earth's silicate shell material after more than four billion years of average viscosity regulation and shear instability is one of chemical and isotopic heterogeneity on a wide range of length scales. The larger length scales of this range are introduced by the pattern of heterogeneity remixing rather than its generation. For example, at the largest scale, the predicted heterogeneity is radial and a feature indirectly arising from properties conferred on the shell material by major mineral phase transitions at depths ~ 700 km. These increase the adiabatic temperature gradient and have the effect of a barrier adequate in strength to prevent wholesale mixing of the material above and below for at least a large fraction of the Earth's history in which radiogenic heat has been the dominant cause of large scale internal movements. That such a barrier actually marks a chemical and isotopic heterogeneity of the mantle is because only the convective movements above it are prone to the shear heating instabilities on which differentiation absolutely

depends. Many millions of such instabilities in this shallower shell material would by now have created a three dimensional heterogeneity extending downward in length scale to ~1 km. However, only 10% of this shell material has yet experienced these highly localised shear heating instabilities and one would predict a continuing emission of primitive volatile phases and a widespread metasomatism even if the same convective movements had no recycled material from the hydrosphere. Such recycling is a further aspect of convective self regulation.

Ziglina, I. N. (Institute of Earth Physics, U.S.S.R. Academy of Sciences, U.S.S.R.): 'Eccentricities and Inclinations of the Orbits of Growing Planets', *Soviet Astron.* **29** (1985), 81–87.

The evolution of the eccentricity e and inclination i of the orbit of a planet of the terrestrial group as a result of collisions and encounters with bodies of the swarm during the process of accumulation is discussed in the paper. Encounters, being more numerous than collisions, had the main influence. Differential equations are derived describing the variation of the expected average values of e^2 and i^2 with the growth of the planet's mass. The rms eccentricity and inclination of the planet's orbit prove to be smaller than the corresponding quantities for bodies of the swarm by about $\sqrt{\bar{m}'/m}$ times, where $\bar{m}'$ is the average mass of bodies in the swarm and m is the planet's mass. The Fokker-Planck equation for the distribution density of the eccentricity and inclination of the orbit of a growing planet is solved. The problem of comparing the theoretical results with observations is discussed.

3. JUPITER

Aubier, M. G. and Genova, F. (DASOP, UA CNRS 324, Observatoire de Paris, Section de Meudon, F-92195 Meudon Principal Cedex, France): 'A Catalogue of the High Frequency Limit of the Jovian Decameter Emission Observed by Voyager', *Astron. Astrophys. Suppl.* **61** (1985), 341–351.

This catalogue lists the high frequency limit of the jovian decameter emissions in the range 7–40 MHz, measured at regular longitude intervals from the data of the Voyager Planetary Radio Astronomy experiment, during periods close to the two encounters with Jupiter, 1979. The position of the emissions is shown in the Io phase – central meridian longitude diagram, and is compared with previous catalogues. The Io-control of the emissions is discussed, with reference to the shape of the dynamic spectrum. A list of the Io-dependent emissions is given.

Burns, J. A., Schaffer, L. E., Greenberg, R. J. and Showalter, M. R. (Cornell Univ., Ithaca, NY 14853): 'Lorentz Resonances and the Structure of the Jovian Ring', *Nature* **316** (1985), 115–119.

Charged dust orbiting through spatially periodic planetary magnetic fields will experience time-variable electromagnetic forces. When the forcing frequencies are nearly commensurate with the particle's orbital frequency, the particle undergoes large out-of-plane and radial excursions. Specific 'Lorentz' resonances, corresponding to particular spatial periodicities in the magnetic field, occur on either side of synchronous orbit. We describe here Lorentz resonance locations and strengths for the jovian and saturnian rings. The boundaries of the halo of the jovian ring, and perhaps other ring structure, are near resonances.

Desch, M. D. and Kaiser, M. L. (Lab. for Extraterrestrial Physics, Goddard Space Flight Center, Greenbelt, MD 20771): 'On the Proposed Triggering of Jovian Radio Emissions', *Geophys. Res. Letters* **12** (1985), 621–624.

Calvert (1985) has proposed that solar type III radio bursts can trigger the onset of certain Jovian hectometer wavelength emissions. We show, using the data obtained by the Voyager Planetary Radio Astronomy experiment, that this triggering hypothesis is not supported statistically. Furthermore, we question the causality of this proposed triggering because much of the Jovian hectometer emission is

due to a quasi-continuous radio source rotating, in lighthouse fashion, with Jupiter. Thus, an observed 'onset' of emission is simply a function of the observer's position in local time around Jupiter.

Drossart, P., Lacy, J., Serabyn, E., Tokunaga, A., Bezard, B. and Encrenaz, T. (Observatoire de Paris, Section de Meudon, F-92190 Meudon, France): 'Detection of $^{13}C^{12}CH_2$ on Jupiter at 13 Microns', *Astron. Astrophys.* **149** (1985), L10–L12.

We report the first detection of $^{13}C^{12}CH_2$ on Jupiter. The spectra were obtained at the IRTF in July 1984 with a Fabry-Pérot high resolution interferometer operating at 13 μm. Two lines of $^{13}C^{12}CH_2$ were observed in emission at 753.46 and 758.03 cm^{-1}. A comparison with C_2H_2 indicates that the $C_2H_2/^{13}C^{12}CH_2$ ratio is apparently lower than the value derived from a terrestrial $^{12}C/^{13}C$ ratio, but it is still uncertain because of the strong intensity of C_2H_2 emission and uncertainties in the vertical profiles of C_2H_2. On the other hand, the assumption of a terrestrial ratio for $^{12}C/^{13}C$ indicates that fractionation produced by selective photochemical reactions may increase the $^{130}C^{12}CH_2/^{12}CH_2$ ratio above the expected ratio.

Goertz, C. K. and Baker, D. N. (Dept. of Physics and Astronomy, Univ. of Iowa, Iowa City, IA 52242): 'Polar Cap Photoionization and the Ten-hour Clock at Jupiter', *J. Geophys. Res.* **90** (1985), 6304–6310.

We show that the clocklike modulation of the spectral index of energetic electrons (>2 MeV) in the outer Jovian magnetosphere is due to a periodic shift of the particle energy spectrum toward higher and lower energies. This shift results in a modulation of the spectral index when the spectrum is not a pure power law in energy. We suggest that the periodic energization is due to a periodic modulation of the magnetic field in the outer magnetosphere. This modulation is caused by a variation of the longitudinally averaged Pedersen conductivity due to the asymmetric solar illumination of the trace of the magnetodisc in high-latitude ionospheres. Such a modulation requires the presence of a surface magnetic anomaly.

Maxworthy, T. (Div. of Earth and Planetary Sciences, Jet Propulsion Lab., Pasadena, CA 91109): 'Measurements and Interpretation of a Jovian, Near-Equatorial Feature', *Planet, Space Sci.* **9** (1985), 987–991.

We present evidence to suggest that the large, rapidly moving features in Jupiter's equatorial currents are manifestations of Rossby solitary waves. Their morphological and dynamical similarity to the great red spot and the white ovals is revealed and discussed in the context of the available theory.

Moses, S. L., Coroniti, F. V., Kennel, C. F. and Scarf, F. L. (TRW Space and Technology Group, Redondo Beach, CA 90278): 'Estimation and Comparison of Quasilinear Electron Heating in the Shock Foot at Jupiter and Earth', *Geophys. Res. Letters* **12** (1985), 609–612.

We develop a simple quasilinear model to estimate the electron heating that occurs in the foot of a supercritical, quasiperpendicular shock through interactions with electrostatic waves generated by reflected ions. At Earth the increase in electron thermal energy calculated using the measured wave amplitudes is negligible, while at Jupiter it is comparable with the observed temperature gain across the shock. The anisotropic quasilinear heating should destabilize whistler mode waves in the foot. These have been detected by the plasma wave instrument on Voyager with amplitudes sufficient to isotropize the electron distribution.

Oya, H. and Aoyama, T. (Geophysical Inst., Tohoku Univ., Sendai, Japan): 'Theoretical Study on Plasma Wind and Convection in Jovian Magneto-Disc', *J. Geomag. Geoelectr.* **37** (1985), 37–64.

The macroscopic MHD equation for the dynamic balance of the flowing plasma in the Jovian magnetodisc region has been solved for the aligned rotator model where the magnetic field rotates with the symmetrical configuration with respect to the magnetic equator that coincides with the perpendicular direction to the rotation axis. The equatorial region of the magnetodisc studied here is restricted in a limited azimuthal extent called 'flow region'. The results indicate that the plasma is flowing out due to the centrifugal force forming the disc wind that blows outward with super magnetosonic velocity when the plasma approaches a critical region. The expansion of the disc current is also made as a result of the outflow of the plasma with slight differences of electron and proton velocity. In the region of the disc plasma, the magnetic field is frozen in the flowing plasma; there is a transient region, therefore, called here the internal magnetopause that separates the magnetic lobe of the Jovian magnetosphere from the flowing disc plasma. The plasma flow is interrupted at the inner boundary of the magnetopause forming the balance of the dynamic pressure between the solar wind and the disc wind. This inner boundary is sandwiching the intrinsic Jovian magnetic field with the outer boundary which is formed due to the solar wind interaction with the Jovian magnetic field.

When the solar wind pressure increases, the position of the magnetopause is compressed with heating up effects on the disc plasma. The plasma flow can not, then, exceed the magnetosonic velocity and no disc wind is formed. The balance feature of the disc wind and the solar wind, thus, controls the location of the Jovian magnetopause so called spongy nature after the observation by the field and particle instruments onboard Pioneer 10, 11, Voyager 1 and 2.

Sanchez-Levega, A. and Rodrigo, R. (Instituto de Astrofisica de Andalucia, APDO. 2144, E-18080 Granada, Spain): 'Ground Based Observations of Synoptic Cloud Systems in Southern Equatorial to Temperate Latitudes of Jupiter from 1975 to 1983', *Astron. Astrophys.* **148** (1985), 67–78.

Ground based telescopic observations of Jupiter's atmosphere have been carried out from 1975 to 1983 in order to analyse, in a temporal framework, the morphology and dynamics of cloud synoptic systems in southern equatorial to temperature latitudes. The main features described in this paper are: (a) The evolution of a cyclonic region inside the South Temperate Belt; (b) The triple outburst of activity in 1975 of a South Equatorial Belt Disturbance with another single event in 1979. Moreover, the emergence of white clouds in the wake of the Great Red Spot was a continuous phenomenon during these years; (c) The development of columns and streaks, known as South Tropical Disturbances, triggered after conjunction between ovals BC and FA with the Great Red Spot, and the periodic apparition of spots in the South edge of the South Equatorial Belt; (d) The formation of a white cloud system from the South Equatorial Belt Disturbance 1975 eruption, near the jovian equator, which persisted for eight years or more. A possible correlation between some of these features and the main role played by the presence of the Great Red Spot in their genesis is suggested.

Showalter, M. R., Burns, J. A., Cuzzi, J. N. and Pollack, J. B. (Center for Radiophysics and Space Research, Cornell Univ., Ithaca, NY 14853): 'Discovery of Jupiter's 'Gossamer' Ring', *Nature* **316** (1985), 526–528.

Jupiter's ring system has previously been described as being composed of a 'bright' narrow ring and an interior, vertically-extended halo. The one image which reveals this morphology most clearly is Voyager 2's parting shot of the Jupiter system, a wide-angle (WA) view of the ring ansa in forward-scattered light (FDS 20693.02). The bright ring is plainly visible, and the halo appears after slight contrast enhancement. By further enhancement of this image we have discovered an additional ring, which is far fainter than either of the (already faint) components previously identified, extending to a radius of 210 000 km.

Walker, R. J. and Russell, C. T. (Inst. of Geophysics and Planetary Physics, Univ. of California, Los Angeles, CA 90024): 'Flux Transfer Events at the Jovian Magnetopause' *J. Geophys. Res.* **90** (1985), 7397–7404.

Recent evidence indicates that magnetic reconnection at the Earth's magnetopause may not be a steady process, but rather it is frequently impulsive and limited in spatial extent. These limited reconnection events are called flux transfer events (FTE's). We have searched the magnetic field observations at Jupiter from Pioneer 10 and 11 and Voyager 1 and 2 for evidence of FTE's and have found 14 possible events. The FTE's at Jupiter are associated with northward magnetosheath fields. The electric fields generated by Jovian FTE's are small in comparison with the corotation **E** field throughout much of the magnetosphere. Thus FTE's are probably not an important source of flow within the Jovian magnetosphere.

4. SATELLITES OF JUPITER

Agafonova, I. I. and Drobyshevski, E. M. (A. F. Ioffe Physical-Technical Inst., USSR Academy of Sciences, Leningrad, USSR): 'Implications of the Galilean Satellites Ice Envelope Explosions II. The Origin of the Irregular Satellites', *Earth, Moon, and Planets* **33** (1985), 1–17.

Secondary explosions of the primary ice fragments ejected in the explosion of the electrolyzed massive ice envelopes of the Galilean satellites are capable of imparting velocities of up to $\sim 5\ \mathrm{km\ s^{-1}}$ to the secondary fragments. As a result, the secondary fragments can enter the orbits of the irregular satellites (Agafonova and Drobyshevski, 1984b) and the Trojan libration orbits. In the latter case a perturbation velocity of $\Delta V \approx 0.3\text{–}2\ \mathrm{km\ s^{-1}}$ is sufficient.

The primary fragments ejected by the gravitational perturbations due to the Galilean satellites sunward from Jupiter's sphere of action move faster relative to the Sun than Jupiter does and therefore reach their first aphelion ahead of Jupiter in the neighborhood of L_4. At the same time the fragments propelled from Jupiter's sphere of action beyond the planet's orbit approach it again in their perihelia behind Jupiter in the region of L_5. The concentration of the fragments and, hence, the frequency of their collisions and explosions at L_4 turn out to be much greater than those at L_5. As a result, the number of the secondary fragments of diameter $\geqslant 15$ km captured into libration orbits ahead of Jupiter can be as high as many hundreds and should exceed by more than a factor 3.5 that captured behind Jupiter.

Since the icy mix of the fragments contains hydrocarbons and particulate material (silicates and the like), after ice sublimitation from the surface layers the Trojans should reveal type C and RD spectra typical for Jupiter's irregular satellites, comet nuclei and other distant ice bodies of similar origin. Among the Trojans there cannot be rocky or metallic objects which are known to exist in the main asteroid belt.

It is shown that a velocity perturbation of $150\text{–}200\ \mathrm{m\ s^{-1}}$ resulting from a purely mechanical impact of two bodies may be sufficient to move collision fragments from he orbits of the Trojans to horseshoe-shaped trajectories with a subsequent transfer to the cometary orbits of Jupiter's family.

Agafonova, I. I. and Drobyshevski, E. M. (A. F. Ioffe Physical-Technical Inst., USSR Academy of Sciences, Leningrad, USSR): 'Implications of the Galilean Satellites Ice Envelope Explosions: III. The Origin of the Trojans and of Some Comets', *Earth, Moon, and Planets* **33** (1985), 111–132.

The problem of the origin of the irregular satellites is solved readily in the context of a hypothesis involving explosion of the massive ice envelopes of the Galilean satellites saturated by electrolysis products. The thrown-off unexploded (primary) ice fragments of the outermost cold layers of the envelopes are also saturated by electrolysis products. In the course of explosive ejection their internal energy increases due to shock wave heating, as a result of which they will be able to detonate in subsequent sufficiently energetic collisions. The secondary fragments from new explosions may acquire additional velocity up to a few $\mathrm{km\ s^{-1}}$ without breakup into small pieces.

Gravitational perturbations by the parent satellites can eject the primary fragments moving near their orbits into the periphery of or beyond Jupiter's sphere of action. If such a fragment explodes in the outer zone of the sphere, then secondary fragments may become irregular satellites resulting in the so-called internal capture (the possibilities of capture considered earlier involved only bodies entering the sphere of action from outside).

The mass of the primary fragment responsible fo the inner (direct) group of Jupiter's irregular satellites is estimated as $\geqslant 10^{19}$ kg, and the additional velocity acquired by secondary fragments as $\geqslant 1.3$ km s^{-1}; evaluation of the mass of the fragment responsible for the outer (retrograde) group yields $\geqslant 10^{18}$ kg, and that of the additional velocity of secondary fragments, $\geqslant 2$ km s^{-1}.

The ice envelopes of the Galilean and similar moonlike satelites should contain impurities corresponding to the composition of type C1 carbonaceous chondrites; therefore after sublimitation of water ice the irregular satellites (just C asteroids, the Trojans and comets) exhibit spectrophotometric properties similar to those of C-type objects.

Bianchi, R. and Pozio, S. (I.S.A. Reparto di Planetologia, Viale dell'Universitá, 11, Roma, Italy): 'Morphometrical Analysis of Craters with Domed Central Pit on Ganymede', *Annales Geophysicae* **3** (1985), 129–134.

Impact craters on Ganymede exhibit a wide range of morphological features due probably to the complex surface evolution of the satellite. We have concentrated our study on a particular kind of impact craters, which generally appear to consist of three structural elements: an outer rim, a wide central pit and a circular dome inside the pit.

The morphometrical analysis of these structural elements allowed us to obtain the distribution of these elements taking into account the different state of viscous relaxation. From this study, it results that the morphometry of the analyzed craters appears to be conditioned by the variation of the characteristics of Ganymede's crust during its evolution.

Colburn, D. S. and Reynolds, R. T. (Space Science Div., NASA-Ames Research Center, Moffett Field, CA 94035): 'Electrolytic Currents in Europa', *Icarus* **63** (1985), 39–44.

Electrical currents should flow in Europa because of its presence in Jupiter's corotating magnetosphere. The possible magnitudes of these currents are calculated assuming that Europa is a differentiated body consisting of an outer H_2O layer and a silicate core. Two types of models are considered here: one in which the water is completely frozen and a second in which there is an intermediate liquid layer. For the transverse electric mode (eddy currents), the calculated current density in a liquid layer is approximately 10^{-5} A m^{-2}. For the transverse magnetic mode (unipolar generator), the calculated current density in the liquid is severely constrained by the ice layer to only 10^{-10} to 10^{-11} A m^{-2}, for a total H_2O thickness of 100 km, provided that neither layer is less than 4 km thick. The current density is less for a completely frozen H_2O layer. If transient cracks were to appear in the ice layer, exposing liquid, the calculated current density could rise to a range of 10^{-6} to 10^{-5} A m^{-2}, depending on layer thicknesses, requiring an exposed area of 10^{-9} to 10^{-8} of the Europa surface. Electrical heating would be significant only if the ice layer thickness were on the order of 1 m, such as might occur if an exposed liquid surface were to freeze over; the heating under this condition could hinder the thickening of the ice layer.

Genova, F. and Aubier, M. G. (Dasop, UA CNRS 324, Observatoire de Paris, Section de Meudon, F-92195 Meudon Principal Cedex, France): 'Io-Dependent Sources of the Jovian Decameter Emission', *Astron. Astrophys.* **150** (1985), 139–150.

The high frequency limit of the jovian decameter emission is studied statistically from the data of the Voyager Planetary Radio Astronomy experiment. It is compared to the gyrofrequency at the foot of the field lines which intersect Io orbit. We deduce that several isolated spectral structures are emitted along the Io field line itself: a particular arc (Riddle, 1983) in the northern hemisphere, and the Io-D and -C emissions in the southern one, these two last emissions appearing as the two edges of a single hollow emission cone. The diffuse, more common right-handed polarized Io-B and Io-AA'C emissions, from the northern hemisphere, are produced along flux tubes which intersect Io orbit 70 behind Io in average. The energetic electrons which trigger the emission are probably accelerated by the kinetic Alfvén waves due to Io movement in the planetary magnetic field, and we find an estimation

of the average Alfvén velocity in the Io torus 3 times lower than usually admitted. The Io-B and IO-AA'C emissions correspond also to the two edges of a given hollow emission cone. No Io-related diffuse emission is detected from the southern hemisphere at frequencies greater than 15 MHz. Our observations allow us to discuss also the magnetic field model in the southern hemisphere.

Goguen, J. D. and Sinton, W. M. (Univ. of Hawaii, Inst. for Astronomy, Honolulu, HI 96822): 'Characterization of Io's Volcanic Activity by Infrared Polarimetry', *Science* **230** (1985), 65–69.

The thermal emission from Io's volcanic hot spots is linearly polarized. Infrared measurements at 4.76 μm show disk-integrated polarization as large as 1.6%. The degree and position angle of linear polarization vary with Io's rotation in a manner characteristic of emission from a small number of hot spots. A model incorporating three hot spots best fits the data. The largest of these hot spots lies to the northeast of Loki Patera, as mapped from Voyager, and the other spot of the trailing hemisphere is near Ra Patera. The hot spot on the leading hemisphere corresponds to no named feature on the Voyager maps. The value determined for the index of refraction of the emitting surface is a lower bound; it is similar to that of terrestrial basalts and is somewhat less than that of sulfur.

Hagfors, T., Gold, T. and Ierkic, H. M. (National Astronomy and Ionosphere Center, Space Sciences Building, Cornell Univ., Ithaca, NY 14853): 'Refraction Scattering as Origin of the Anomalous Radar Returns of Jupiter's Satellites', *Nature* **315** (1985), 637–640.

Three satellites of Jupiter, Callisto, Ganymede and Europa, give anomalous radar returns. We show here that this behavior would arise as a consequence of 'refraction scattering' rather than the familiar 'reflection scattering' and discuss mechanisms that lead to the predominance of such scattering on these satellites.

Howell, R. R. and McGinn, M. T. (Inst. for Astronomy, Univ. of Hawaii, Honolulu, HI 96822): 'Infrared Speckle Observations of Io: An Eruption in the Loki Region', *Science* **230** (1985), 63–65.

Speckle observations of Jupiter's satellite Io at a wavelength of 5 μm during July 1984 resolved the disk and showed emission from a hot spot in the Loki region. The hot spot contributed a flux approximately equal to 60% of that from the disk. Images reconstructed by means of the Knox–Thompson algorithm showed the spot moving across the disk as the satellite rotated. It was located at $301° \pm 6°$ west longitude, $10° \pm 6°$ north latitude, and had a radiance of $(2.96 \pm 0.54) \times 10^{22}$ ergs sec^{-1} cm^{-1} sr^{-1}/A where A is the area of the spot. For an assumed temperature of 400 K, the area of the source would be 11 400 km^2. An active 'lava lake' similar to that seen by Voyager may be the source of the infrared emission.

Johnson, R. E. (Dept. of Nuclear Engineering and Engineering Physics, Univ. of Virginia, Charlottesville, VA 22901): 'Polar Frost Formation on Ganymede', *Icarus* **62** (1985), 344–347.

The suggested models of polar frost formation on Ganymede are reviewed. A model in which plasma bombardment changes the reflectance characteristics of the icy surface is proposed.

Linker, J. A., Kivelson, M. G., Moreno, M. A. and Walker, R. J. (Inst. of Geophysics and Planetary Physics, Univ. of California, Los Angeles, CA 90024): 'Explanations of the Inward Displacement of Io's Hot Plasma Torus and Consequences for Sputtering Sources', *Nature* **315** (1985), 373–378.

Radial profiles of the ion density and flux-tube content in the Io torus have peak values inside Io's orbit, even though Io is the effective source of these ions. Formation of an inward peak constrains either the velocity distributions or source regions of sputtered neutrals. A further constraint is that the

ionization of neutrals on trapped trajectories that return to Io's surface must be limited. A dominant sulphur source is most easily reconciled with these constraints.

Moos, H. W., Skinner, T. E., Durrance, S. T., Feldman, P. D., Festou, M. C. and Bertaux, J.-L. (Johns Hopkins Univ., Laural, MD 20707): 'Long-Term Stability of the Io High-Temperature Plasma Torus', *Astrophys. J.* **294** (1985), 369–382.

The short-wavelength camera of the *International Ultraviolet Explorer* satellite was used to monitor the S II λ1256, S III λ1199, S III] λ1729, and S IV] λ1406 emission from the high-temperature portion of the Io plasma torus. Thirteen observations obtained over a 5 yr period from 1979 March 1 (near the time of the *Voyager 1* encounter with Jupiter) to 1984 March 21 show that the plasma parameters of the high-temperature portion of the torus have surprisingly small variations. In particular, the mixing ratio for the dominant constituent, S^{++}, and the electron temperature are quite stable. The observed brightnesses are sensitive to changes in both the viewing geometry and the intrinsic properties of the torus. To correct for the geometric effects, a simple three-dimensional model of the plasma torus is used to obtain the ion mixing ratios and the plasma density for each observation. A comparison of three contiguous observations at elongations of 5.0, 6.0, and 7.0 R_J in order to test the radial profiles used in the model shows good agreement. For the 13 observations, the plasma density shows a mean ratio of the *Voyager 1* values of 1.11 with a variability, expresses a fractional standard deviation, of ±14%. The mean mixing ratio (the ion density divided by the electron density) for $S^+$is 0.11 with a variability of ±28%. S^{++} dominates the plasma charge balance with a mean mixing ratio of 0.36; the variability is small, ±4%. S^{+3} is a lesser component with a mean mixing ratio of 0.023 and a variability ≤21%. Although the mixing ratios depend somewhat on the model parameters, the variabilities do not increase significantly with changes in the parameters. A comparison of the measured ionization balance with that predicted by the effects of ionization, recombination, and the plasma confinement time indicates that the variability of the electron temperature over the 5 yr period is small, ≤ ± 10%. The same comparison leads to a rough upper limit on the variability of the plasma confinement time of ≤ ± 50%.

Morgan, J. S. (Inst. for Astronomy, Univ. of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822): 'Temporal and Spatial Variations in the Io Torus', *Icarus* **62** (1985), 389–414.

Spectrographic data on the Io torus from 15 nights of observations spread over a 4-month period in 1981 are presented here. The [SII] λλ6716, 6731; [SII] λλ4069, 4076; [OII] λλ3726, 3729; and [SIII] λ3722 lines were simultaneously measured on each spectrogram. An east–west asymmetry was observed in the optical emissions, showing larger western intensities and a more diffuse and radially extensive nebula to the east. Two configurations of [SII] longitudinal asymmetry that were stable over at least 4 days were observed. The magnetic longitudes of ~180 and 300° are shown to be of particular interest. Longitudinal structure was not detected in either the [OII] intensity or the plasma density as measured by the [OII] doublet ratios. Errors in the line ratios could mask density variations as large as a factor of ~1.5. A radial variation in the ratio of OII/SII was observed, with the ratio being largest near Io's orbit. Monthly variability was detected in both the intensity and density of the torus. The [SII] line ratios indicated an increase in n_e over the 4-month period that was accompanied by increased intensities. For single measurements, no correlation between the [SII] intensities and the [SII] λ6716/λ6731 line ratio was detected, but this could be a result of errors in the line ratio determinations. Extremely low values of this same ratio were measured. These appear to indicate errors in the presently accepted [SII] transition probabilities. These [SII] line ratios indicate that very-high-density regions are present in the torus, and it is shown how these regions could have significantly influenced these measurements.

Sieveka, E. M. and Johnson, R. E. (Dept. of Nuclear Engineering and Engineering Physics, Univ. of Virginia, Charlottesville, VA 22903): 'Nonisotropic Coronal Atmosphere on Io', *J. Geophys. Res.* **90** (1985), 5327–5331.

A model is presented for calculating nonisotropic coronal atmospheres. This is tested by comparison with the analytic results for an isotropic atmosphere. It is then used to consider differences between sublimated and sputtered corona on Io with reference to the ion and electron bombardment of such coronae when the exobase is at or near the surface.

Thorne, R. M. and Moses, J. J. (Dept. of Atmospheric Sciences, Univ. of California, Los Angeles, CA 90024): 'Resonant Instability Near the Two-Ion Crossover Frequency in the Io Plasma Torus', *J. Geophys. Res.* **90** (1985), 6311–6318.

The propagation characteristics of electromagnetic waves below the proton gyrofrequency are strongly influenced by the changing ion composition in the Io plasma torus. Obliquely propagating waves experience a natural reversal of their dominant sense of polarization when their frequency becomes equal to the crossover frequency. This dramatically modifies both the wave growth characteristics and their effect on scattering resonant particles. A numerical simulation of the path-integrated gain of unducted waves in the torus has confirmed the importance of L mode ion cyclotron instability as the most likely mechanism for wave excitation. Whistler (R mode) instability is insignificant and it should be totally quenched by strong ion cyclotron damping. The favored region for wave excitation is at intermediate latitudes ($\lambda \geq 12°$) on field lines passing through the outer torus ($L \geq 6$). Unstable waves can subsequently propagate toward lower latitude following the natural polarization reversal (to R mode waves) at the wave crossover frequency. But the wave amplitudes observed in the low-latitude region sampled by Voyager 1 are expected to be significantly lower those that in the source region due to strong ion cyclotron damping. This is consistent with recent observational evidence on the power spectral intensity of low-frequency waves in the torus.

5. MARS

Chicarro, A. F., Schultz, P. H. and Masson, P. (Lunar and Planetary Inst., 3303 NASA Road 1, Houston, TX 77058): 'Global and Regional Ridge Patterns on Mars', *Icarus* **63** (1985), 153–174.

Over 16 000 wrinkle ridges on Mars have been classified, mapped, and digitized to provide a large computer-accessible data base for analyzing regions subjected to possible compressive stresses. The survey has revealed major compressive structures that occur well beyond the Tharsis-dominated hemisphere. The large variety of affected geologic terrains indicate stresses not simply localized in the intercrater plains. One major area of inferred compression occurs in the southern cratered highlands near longitude 180° W where major ridges and scarps extend over 3000 km. The occurrence and orientation of many ridges are locally controlled by ancient impact basins. The Chryse basin in particular has an important effect on ridges in northern Lunae Planum. The removal of all basin-concentric ridges reveals, however, a complex global pattern. Although such patterns may yet be controlled by heavily degraded impact basins, major regional trends also emerge that appear to require broader scale global stresses. Most ridges in the Western Hemisphere are shown to be orthogonal to three centers corresponding to Tharsis (1° N, 122° W), Syria (12° S, 104° W), and Chryse (19° N, 47° W). Ridges not included in these three sets are generally more random and highly localized. Most, but by no means all, ridges in the Eastern Hemisphere are controlled by the Hellas and Isidis basins. A simple global grid is not yet identifiable and may not be recognizable owing to the large number of regional patterns.

Comer, R. P., Solomon, S. C. and Head, J. W. (Seismological Lab., California Inst. of Tech., Pasadena, CA 91125): 'Mars: Thickness of the Lithosphere from the Tectonic Response to Volcanic Loads', *Rev. Geophys.* **23** (1985), 61–92.

We determine the thickness (or flexural rigidity) of the elastic lithosphere on Mars in the vicinity of large volcanic loads, including six volcanoes and the Isidis basin mascon. Starting from the hypothesis that graben concentric to each volcanic feature formed as a result of stresses induced by flexure of the

lithosphere in response to loading, we relate predicted surface stresses to the range of radial distances between the graben and the load centers in order to derive local estimates of the elastic lithosphere thickness at the time of loading. The basic method involves the selection of graben of likely flexural origin and the calculation of vertical displacement and surface horizontal stresses produced by the loading and flexure of a shell or plate. Bounds on thickness are obtained from a formal inversion of graben positions as well as from a consideration of important time-dependent effects, including viscoelastic relaxation, volcano growth, and lithospheric thickening. Assuming Young's modulus to be 10^{12} dyn/cm^2, we find preferred values of elastic lithosphere thickness in the range 20 to 50 km (or flexural rigidities from 10^{30} to 10^{31} dyn cm) for regions surrounding Ascraeus Mons, Pavonis Mons, Arsia Mons, Alba Patera, and Elysium Mons. For the Isidis basin region the elasttic lithosphere thickness must have exceeded 120 km at the time of graben formation; for Olympus Mons the absence of circumferential graben requires the elastic lithosphere to have been at least 150 km at the time of loading (these thicknesses correspond to a flexural rigidity greater than approximately 10^{32} dyn cm). Because the derived lithospheric thicknesses do not show any relationship to the relative ages of the loads, we interpret the results as an indication of a pronounced local thinning of the lithosphere beneath the central regions of the Tharsis and Elysium volcanic provinces.

Dreibus, G. and Wänke, H. (Max-Plank-Institut für Chemie, Saarstrasse 23, D-6500 Mainz, FRG): 'Mars: A Volatile-rich Planet', *Meteoritics* **20**, (1985) 367–381.

The detection of a trapped Martian atmosphere-like component in the shergottite EETA 79001 provides the most conclusive evidence that SNC-meteorites are rocks from Mars. If we assume that the parent body of the SNC-meteorites is indeed Mars, these meteorites can be used to estimate the abundance of volatile elements on Mars. It is found that Mars contains a number of volatile elements in concentrations exceeding those of the Earth. The low abundance of primordial rare gases on Mars is explained by drastic depletion during the escape of the early Martian atmosphere.

Hunt, G. E. and James, P. B. (Centre Remote Sensing, Atmospheric Physics Group, Imperial College of Science and Tech., London SW7 2AZ, UK): 'Martian Cloud Systems: Current Knowledge and Future Observations', *Advances in Space Research* **5**(8) (1985), 93–99.

In this paper we summarise the current understanding of Martian condensate and dust clouds. The paper is particularly concerned with the spatial, temporal and seasonal characteristics of the clouds. The condensate clouds are composed of water and ice particles and occasionally CO_2 particles. Dust clouds are composed of material from the surface and redistributed over the planet through the weather systems. The apparent lack of annual reproductivity of these dust storms forms a major unresolved problem. We discuss in this paper the types of observations needed in future space missions, in particular the requirements for the NASA Mars Geochemical Climatolology Orbiter Mission planned for the end of this decade.

Jakosky, B. M. (Lab. for Atmospheric and Space Physics, Univ. of Colorado, Boulder, CO 80309): 'The Seasonal Cycle of Water on Mars', *Space Science Rev.* **41** (1985), 131–200.

A review of the behavior of water in the Mars atmosphere and surface is appropriate now that data from the Mariner and Viking spacecraft have been analyzed and discussed for several years following completion of those missions. Observations and analyses pertinent to the seasonal cycle of water vapor in the atmosphere of Mars are reviewed, with attention toward transport of water and the seasonal exchange of water between the atmosphere and various non-atmospheric reservoirs. Possible seasonally-accessible sources and sinks for water include water ice on or within the seasonal and residual polar caps; surface or subsurface ice in the high-latitude regions of the planet; adsorbed or chemically-bound water within the near-surface regolith; or surface or subsurface liquid water. The stability of water within each of these reservoirs is discussed, as are the mechanisms for driving exchange of the water with the atmosphere and the timescales for exchange. Specific conclusions are

reached about the distribution of water and the viability of each mechanism as a seasonal reservoir. Discussion is also included of the behaviour of water on longer timescales, driven by the variations in solar forcing due to the quasi-periodic variations of the orbital obliquity. Finally, specific suggestions are made for future observations from spacecraft which would further define or constrain the seasonal cycle of water.

Jakosky, B. M. and Carr, M. H. (Lab. for Atmospheric and Space Physics, Univ. of Colorado, Boulder, CO 80309): 'Possible Precipitation of Ice at Low Latitudes of Mars During Periods of High Obliquity', *Nature* **315** (1985), 559–561.

Most of the old cratered highlands of Mars are dissected by branching river valleys that appear to have been cut by running water yet liquid water is unstable everywhere on the martian surface. In the equatorial region, where most of the valleys are observed, even ice is unstable. It has been suggested, therefore, that Mars had an early denser atmosphere with sufficient greenhouse warming to allow the existence of liquid water. Here, we suggest instead that during periods of very high obliquities, ice could accumulate at low latitudes as a result of sustained sublimation of ice from the poles and transport of the water vapour equatorwards. At low latitudes, the water vapour would saturate the atmosphere and condense onto the surface where it would accumulate until lower obliquities prevailed. The mechanism is efficient only at the very high obliquities that occurred before formation of Tharsis very early in the planet's history, but limited equatorial ice accumulation could also have occurred at the highest obliquities during the rest of the planet's history. Partial melting of the ice could have provided runoff to form the channels or replenish the groundwater system.

Kahn, R. (Center for Radiophysics and Space Research, Cornell Univ., Ithaca, N.Y. 14853): 'The Evolution of CO_2 on Mars', *Icarus* **62** (1985), 175–190.

At an average location on the surface of Mars, the pressure of CO_2 (P_{CO_2}) varies seasonally between about 6 and 8 mbar. Outgassing models suggest that at least 140 mbar, and possibly as much as 3000 mbar, of CO_2 have been placed in the atmosphere over geologic time. Neither the polar caps nor the regolith alone appears to be an adequate repository for the CO_2. The north polar cap does not contain a permanent store of CO_2 ice, while the south polar cap is unlikely to hold in excess of a few millibars. The regolith can adsorb no more, and probably much less, than 280 mbar of CO_2. Mechanisms associated with storing carbon in these reservoirs do not account for the particular range and stability of P_{CO_2} found on Mars today. It is argued that carbonate rock is the most reasonable reservoir for the excess CO_2 and that the rock formation process can explain the current CO_2 pressure.

To effect carbonate formation at a rate rapid enough to produce significant deposits over geologic time, liquid water, at least in transitory pockets, is apparently required. Solid–solid and solid–gas reactions are probably orders of magnitude too slow; however, even intermittent aqueous chemistry may be sufficient. Cations are also needed, and the existing constraints on the chemical state of the Martian soil do not preclude their occurrence in usable forms and adequate supply.

A feedback mechanism that links the evolution of R_{CO_2} directly to the occurrence of liquid water is postulated. According to the scenario, the evolution of P_{CO_2} is controlled largely by aqueous chemistry forming carbon-containing sedimentary rocks as on Earth, perhaps during early history in open water, but more recently in transitory pockets of moisture in the soil. Once the total atmospheric pressure is reduced to near a limiting value (P^*), below which liquid water can not form in the Mars environment, the occurrence of transitory pockets is inhibited, and atmospheric CO_2 is no longer depleted by an efficient mechanism.

While present conditions on Mars preclude the existence of open bodies of liquid water, the formation of moisture in disequilibrium is not excluded by any known constraints. To a first approximation, the water evaporation rate is inversely proportional to P_{CO_2}, which suggests the existence of a minimum overburden pressure P^*. Calculations showing that it is difficult but not impossible to form liquid water in disequilibrium on Mars today support the argument that a limiting value of P_{CO_2} has been approached. P_{CO_2} is currently quite close to the triple-point pressure of water,

which is the minimum equilibrium vapor pressure of water above the pure liquid. This too is in accord with the hypothesis, given existing constraints on current Martian conditions, since the minimum disequilibrium overburden pressure is unlikely to be lower, but need not be much higher, than the triple-point pressure of water if a feedback mechanism of the type proposed is operating. To form transitory pockets of pure liquid water, the smallest possible value of P^* is loosly constrained to 6.1 mbar by the minimum criterion, in a space- and time-averaged sense, for which very rapid evaporation of ice would occur until open liquid water could be maintained in equilibrium on the surface. From a consideration of available insolation at Mars, a very crude upper bound on P^* of around 30 mbar is obtained.

The hypothesis has profound implications for the history of the Mars surface and atmosphere. It suggests that unless rapid outgassing events occurred subsequent to early Mars times, the climate of the planet has, to first order, evolved linearly, rather than in the cyclic manner allowed by polar cap storage or some models of regolith absorption in reservoirs.

Substantial carbonate deposits are predicted, though they may be mixed in the soil or covered by eolian debris. If these deposits can be mapped on a global scale, their spatial distribution should contain clues about the way heat and water needed for sedimentation are supplied.

Komitov, B. (Central Lab. for Space Research, Bulgarian Academy of Science, Astronomical Observatory, 6000 Stara Zagora, Bulgaria): 'Ozone Vertical Distribution in Mars Polar Atmosphere', *Adv. Space Res.* **5**(8) (1985), 101–104.

On the basis of an ultraviolet spectrum obtained over the north polar region of Mars on board the space sound Mariner-9, the vertical profile of the ozone density is calculated. A density maximum is found at about 25 km height over the surface of the planet. Its value is about 1.10 molecules cm. The obtained result is compared to the results obtained by other authors.

Masson, Ph. (Université Paris-Sud, Laboratoire de Géologie Dynamique Interne (BAT. 509), ERA. 804 du C.N.R.S., F-91405 Orsay Cedex, France): 'Origin and Evolution of the Valles Marineris Region of Mars', *Adv. Space Res.* **5**(8) (1985), 83–92.

The Valles Marineris Region of Mars is located on the eastern flank of the Tharsis bulge which exhibits dramatic landforms that relate in origin to tectonic, volcanic, and geomorphic processes. Tectonic activity due to crustal extension related to the Tharsis–Syria rise (regional doming or lithospheric response to volcanic loading) appears to be the fundamental influence on the canyon formation and evolution. Tectonic activity contributed to deepen the canyon system and competed with erosional and depositional processes that caused canyon to broaden and fill. The primary tectonic processes appear to have been vertical adjustments of crustal blocks under the influence of N–S and E–W extensional stresses. Canyon wall erosional features and landslide morphologies indicate that materials have been transported from the walls to the floor essentially by mass wasting and downfaulting. However, seepage of liquid water or sublimation of ground ice could have contributed to the liquid water or sublimation of ground ice could have contributed to the enlargement of the tributary canyons, thus suggesting that variations in climatic conditions could have accounted for the morphologic evolution of the canyon system.

Paige, D. A. and Ingersoll, A. P. (Div. of Geological and Planetary Sciences, California Inst. of Tech., Pasadena, CA 91125): 'Annual Heat Balance of Martian Polar Caps: Viking Observations', *Science* **228** (1985), 1160–1168.

The Infrared Thermal Mappers aboard the two Viking orbiters obtained solar reflectance and infrared emission measurements of the Martian north and south polar regions during an entire Mars year. The observations were used to determine annual radiation budgets, infer annual carbon dioide frost budgets, and constrain spring season surface and atmospheric properties with the aid of a polar radiative model. The results provide further confirmation of the presence of permanent CO_2 frost

deposits near the south pole and show that the stability of these deposits can be explained by their high reflectivities. In the north, the observed absence of solid CO_2 during summer was primarily the result of enhanced CO_2 sublimation rates due to lower frost reflectivities during spring. The results suggest that the present asymmetric behavior of CO_2 frost at the Martian poles is caused by preferential contamination of the north seasonal polar cap by atmospheric dust.

Ryan, J. A. (Dept. of Geological Sciences, California State Univ., Fullerton, CA 92634): 'Mars Atmospheric Circulation: Aspects from Viking Landers', *J. Geophys. Res.* **90** (1985), 6319–6325.

Winds measured by the two Viking landers have been filtered and then compared with predictions from the general circulation model and to orbiter observations of clouds and surface phenomena that indicate wind direction. This was done to determine the degree to which filtered winds may represent aspects of the general circulation. Excellent agreement was found between wind direction data from Lander 1 and the model predictions and orbiter observations. For Lander 2, agreement was generally good, but there were periods of disagreement which indicate that the filtering did not remove other extraneous effects. It is concluded that Lander 1 gives a good representation of the general circulation at 22.5°N latitude but that Lander 2 is suspect. Most wind data from Lander 1 have yet to be analyzed. It appears that when analyzed these Lander 1 data (covering 3.5 Mars years) can provide information about interannual variations in the general circulation at the lander latitude.

Schultz, R. A. (Dept. of Geosciences, Purdue Univ., West Lafayette, Indiana 47907): 'Assessment of Global and Regional Tectonic Models for Faulting in the Ancient Terrains of Mars', *J. Geophys. Res.* **90** (1985), 7849–7860.

Structural landforms within parts of the heavily cratered terrain of Mars were studied in order to test various models of global fracturing. Landforms analyzed were scarps, grabens, simple ridges, and channel wall scarps. Many of these landforms predate graben formation in Tharsis. Very few structural landforms were found to be either radial to Tharsis or normal to principal stress trajectories calculated for Tharsis isostacy or flexural loading. These results suggest either that the structures are locally derived or, if they were produced by Tharsis activity, that the state of stress in Tharsis was different from that which produced the classic graben systems. Association of narrow valley networks with subdued grabens in one portion of Margaritifer Sinus suggests that one episode of narrow valley formation coincided with flexural loading in Tharsis. Crustal fracturing in Oxia Palus that predates outflow channel formation does not correlate with Tharsis tectonism and may reflect fracturing by the proposed Chryse multiring basin to the north. In contrast to previous studies, no evidence was found for either an orthogonal Martian grid or conjugate sets of shear fractures. It is concluded that Mars probably did not experience significant tidal despinning. Calculations of thermal stress within a cooling early lithosphere performed for varying lithospheric thicknesses predict large-scale tensile near-surface failure. Many of the large ridges in Memnonia that predate classical Tharsis-centered tectonism may reflect normal faulting generated in part by thermal stress.

Scott, D. H. (U.S. Geological Survey, Branch of Astrogeology, 2255 North Gemini Drive, Flagstaff, AZ 86001): 'Global Geologic Mapping of Mars: The Western Equatorial Region', *Adv. Space Res.* **5**(8) (1985), 71–82.

Global geologic mapping of Mars was originally accomplished following acquisition of orbital spacecraft images from the Mariner-9 mission. The mapping program represented a joint enterprise by the U.S. Geological Survey and other planetary scientists from universities in the United States and Europe. Many of the Mariner photographs had low resolution or poor albedo contrast caused by atmospheric haze and high-sun angles. Some of the early geologic maps reflect these deficiencies in their poor discrimination and subdivision of rock units. New geologic maps made from higher resolution and better quality Viking images also represent a cooperative effort, by geologists from the U.S. Geological Survey, Arizona State University, and the University of London. This second series

of global maps consists of three parts: 1) western equatorial region, 2) eastern equatorial region, and 3) north and south polar regions. These maps, at 1:15 million scale, show more than 60 individual rock-stratigraphic units assigned to three Martian time-stratigraphic systems. The first completed map of the series covers the western equatorial region of Mars. Accompanying the map is a description of the sequence and distribution of major tectonic, volcanic, and fluvial episodes as recorded in the stratigraphic record.

Singer, R. B. (Planetary Geosciences Div., Hawaii Inst. of Geophysics, Univ. of Hawaii, Honolulu, HI 96822): 'Spectroscopic Observation of Mars', *Adv. Space Res.* **5**(8) (1985), 59–68.

Visible and near-infrared reflectance spectroscopy has proven a powerful tool for exploring the geology of Mars. Most of this data has been obtained from Earth, but the technique is ideally suited to orbital application, as proposed for the U.S. Mars Geoscience/Climatology Orbiter mission. Spectral reflectance in the near-UV and visible is highly diagnostic of ferric-iron mineralogy, and has shown that Fe^{3+} in the ubiquitous bright dust and soil is amorphous or poorly-crystalline. Other iron-oxide minerals, indicative of other modes or episodes of crustal alteration, may be found in spatially localized deposits. Clay minerals (hydroxylated silicates) have diagnostic vibrational absorptions throughout the near-infrared. While some form of bound water and/or OH has been known on Mars for many years, a new result presented here is the identification of structural OH in a dilute or poorly crystalline magnesian clay. Salts such as carbonates, sulfates, and nitrates have not yet been detected in Martian soils but have diagnostic spectral features in the 3- to 4-μm region, best suited to Mars-orbital observation. Analysis of reflectance spectra of low-albedo regions is a primary source of evidence for a basaltic or ultramafic crust, with identification of abundant clinopyroxene and possible detection of other mafic minerals. The distinctive near-infrared spectral shape of dark regions indicates that the dark materials commonly consist of relatively unaltered rocks or rock fragments very thinly coated by (or mixed with) bright oxidized material similar to the global dust. Visible and near-infrared reflectance spectroscopy is also a sensitive technique for detecting and analyzing water ice, as has been demonstrated on Mars by observations of the north polar cap.

Steel, D. I. (Dept. of Physics, Univ. of Canterbury, Christchurch, New Zealand): 'Collisions in the Solar System – II. Asteroid Impacts upon Mars', *R. Astr. Soc. Mon. Not.* **215** (1985), 369–381.

Using a sample of 284 asteroids whose orbital elements indicate them to cross at least part of the present orbit of Mars, a mean collision probability with that planet of $3.5 \times 10^{-10}\,\mathrm{yr}^{-1}$ is calculated. If there are $\sim 10^4$ Mars-crossers larger than ~ 1 km, then one impact by such a body every 300 000 yr is to be expected. This is close to the impact rates previously calculated for the Earth and Venus, but much higher than that for Mercury (Steel & Baggaley). Due to the possibility of bias in the sample, and the effect of resonances which cause many asteroids to avoid Mars-encounters, these figures should be viewed with caution.

Tanaka, K. L. (U.S. Geological Survey, 2255 North Gemini Drive, Flagstaff, AZ 86001): 'Ice-Lubricated Gravity Spreading of the Olympus Mons Auerole Deposits', *Icarus* **62** (1985), 191–206.

Gravity sliding and spreading at low strain rates can account for the general morphology and structure of the aureoles and basal scarp of Olympus Mons. Detachment sliding could have occurred around the volcano if either pore-fluid pressures were exceptionally high (greater than 90%) or the rocks had very low resistance to shear (about 1×10^5 Pa or 1 bar). Because of the vast areal extent and probable shallow depth of the detachment zone, development of ubiquitous, high pore-fluid pressures beneath aureole-forming material was unlikely. However, a zone of sufficiently weak material consisting of about 10% interstitial or interbedded ice could have been present. If so, a simple rheologic model for the aureole deposits can be applied that consists of a thin ductile layer overlain by a thicker brittle layer. According to this model, extensional deformation would have occurred near the shield and compressional deformation in its distal parts. Proximal grabens and distal

corrugations on aureole surfaces support this model. A submarine slide at Kitimat Arm, British Columbia, is a valid quantitative analogy for the observed features and inferred emplacement style of the aureole deposits. Ground-ice processes have been considered the cause of many geologic features on Mars; a 3% average concentration of ground ice in the regolith is predicted by theoretical models for the ice budget and cryosphere. Ice may have been deposited in higher concentrations below the aureole-forming material; the source of the ice could have been juvenile water circulated hydrothermally by Olympus Mons volcanism. The basal scarp of Olympus Mons apparently demarcates the transition between the upper, stable part of the shield and its lower part that decoupled and formed the aureole deposits. This transition may reflect a change in the bulk shear strength of the shield, caused either by a radial dependence in the abundance of ice or fluid in the shield materials or by the concentration of intrusive dikes within the volcano. Other Martian volcanoes exhibit virtually no evidence of similar large-scale gravity spreading and basal scarps. Perhaps such evidence, if it existed, has been buried by lava flows, or perhaps the smaller size of other volcanoes did not permit the development of these features.

Trego, K. D. (Planetology Research Inst., Phoenix, AZ 85020): 'Hoyle's Ice Age Origin: Application to Mars', *Earth, Moon, and Planets* **33** (1985), 103–104.

If we assume that the Martian outflow channels are results of sporadic melting of ground ice, their planet-wide distribution could imply that a sheet of ice once covered Mars. This ice sheet could have acted, in a similar manner as Hoyle's oceanic meteoric dust suspension layer model as an initiator of a Martian ice age which would be responsible for the decline of valley network formation at the end of the heavy bombardment period.

Van Hemelrijck, E. (Belgian Institute for Space Aeronomy, Brussels, Belgium): 'The Influence of Global Dust Storms on the Mean Seasonal Daily Insolations at the Martian Surface', *Earth, Moon, and Planets* **33** (1985), 157–162.

In this paper, we compare changes in the mean seasonal daily insolations at the Martian surface caused by global dust storms characterized by various atmospheric optical thickness (τ). The calculations, made for optical depths equal to 0, 0.1, 0.5, 1.0, 2.0, and 3.0, are based on the assumption of planet encircling storms lasting one season or one year. The variations in the latitudinal and seasonal surface insolation distributions are important, mainly at the poles where e.g. the mean annual and summer daily insolations decrease by nearly a factor of 3000 as τ goes from 0 to 3.0. At equatorial latitudes the corresponding loss is much smaller, reaching a value of approximately 40. Concerning the mean wintertime solar radiations it is found that the decrease is even more spectacular, especially at high latitudes.

Wright, I. P. and Grady, M. M. (Dept. of Earth Sciences, The Open Univ., Walton Hall, Milton Keynes MK7 6AA, UK): 'More News from Mars', *Nature* **315** (1985), 367–368.

The results obtained from studies of SNC meteorites have widespread implications for theories of Solar System formation, planetary accretion, thermal histories of planets and petrogenesis on planetary bodies. Chemical and isotope analyses of SNC meteorites have given a clearer appreciation of the composition of the martian surface and atmosphere. There is a strong feeling in the community of lunar and planetary investigators that a Mars sample-return mission should be given high priority in space exploration programmes in the years ahead.

7. MERCURY

Epstein, E. E. and Andrew, B. H. (Electronics Research Lab., Aerospace Corp., Box 92957, Los Angeles, CA 90009): 'Mercury: Thermal Emission at Radio Wavelengths I. 3.3- and 28-mm Observed Brightness Temperature and Periodicities therein', *Icarus* **62** (1985), 448–457.

Measurements of the thermal radio emission from Mercury at 3.3 mm were made on 103 days and at 28 mm on 113 days over a several-year interval. The data can be represented by

$$T_B(3.3\text{ mm}) = \underset{\pm 4}{359} + \underset{\pm 6}{147}\cos(\phi + \underset{\pm 2}{17})^\circ\text{K}, \qquad SD = 42^\circ\text{K}.$$

$$T_B(28\text{ mm}) = \underset{\pm 4}{374} + \underset{\pm 5}{42}\cos(\phi + \underset{\pm 7}{36})^\circ\text{K}, \qquad SD = 34^\circ\text{K},$$

where the statistical standard errors and deviations are indicated. T_B is the brightness temperature, and ϕ is the planetocentric phase angle. The estimated absolute calibration uncertainties are 7% (3.3 mm) and 5% (28 mm). Fitting with higher order harmonics of ϕ or including the hermocentric longitude of the sub-Earth point does not improve the goodness of fit. Of the fits considered, the two data sets are best represented by multiterm harmonics as a function of time which include terms corresponding to several physically significant periods in the Earth–Mercury relationship. Summaries of measurements at 2.1, 3.1, 13.5, and 37.5 mm by other observers are included.

Potter, A. and Morgan, T. (Space Science Branch, NASA Johnson Space Center, Houston, TX 77058): 'Discovery of Sodium in the Atmosphere of Mercury', *Science* **229** (1985), 651–653.

The spectrum of Mercury at the Fraunhofer sodium D lines shows strong emission features that are attributed to resonant scattering of sunlight from sodium vapor in the atmosphere of the planet. The total column abundance of sodium was estimated to be 8.1×10^{11} atoms cm^{-2}, which corresponds to a surface density at the subsolar point of about 1.5×10^5 atoms cm^{-3}. The most abundant atmospheric species found by the Mariner 10 mission to Mercury was helium, with a surface density of 4.5×10^3 atoms cm^{-3}. It now appears that sodium vapor is a major constituent of Mercury's atmosphere.

8. NEPTUNE

Taylor, G. E. (Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, East Sussex, BN27 1RP, UK): 'The Observations of Neptune by Galileo', *Brit. Astron. Assoc. J.* **95** (1985), 116–117

Suggestions have been made that Galileo's observations of Naptune in 1612–13 indicate that it was as much as 1 arcminute from its predicted position. The author of this paper argues that Galileo's drawing has been misinterpreted and that there is no justification for the adoption of a 1 arcminute error.

9. SATELLITES OF NEPTUNE

Lunine, J. I. and Stevenson, D. J.(Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Physical State of Volatiles on the Surface of Triton', *Nature* **317** (1985), 238–240.

The most recent analyses of infrared spectrophotometric studies of Neptune's satellite Triton concluded that both condensed methane and nitrogen are present. It was also concluded that the most likely surface configuration is a liquid nitrogen (N_2) 'ocean' with dry areas of solid methane (CH_4), and perhaps some exposed fine-grained water frost (H_2O). However, this model runs into some difficulties, especially when requirements of phase equilibrium between the solid and liquid components are imposed. Because an understanding of the distribution and state of volatiles is crucial in interpreting secular changes in Triton's appearance due to seasonal effects, and in planning observing strategies for the Voyager–Neptune/Triton encounter, we assess here several possible configurations for these volatiles on Triton. We conclude that the simplest volatile configuration which best satisfies the constraints which the least number of *ad hoc* assumptions is N_2 and CH_4 both in solid forms, perhaps partly as a microscopic mixture, but more probably as a disequilibrium assemblage, non-

uniformly distributed. Thermodynamic equilibrium is then limited by seasonal transport and the finite diffusion time of CH_4 in crystalline N_2. Although a nitrogen ocean cannot be excluded, it requires very restrictive assumptions.

10. PLUTO

Binzel, R. P., Tholen, D. J., Tedesco, E. F., Buratti, B. J. and Nelson, R. M. (Dept. of Astronomy, Univ. of Texas at Austin, TX 78712): 'The Detection of Eclipses in the Pluto-Charon System', *Science* **228** (1985), 1193–1195.

The first eclipses between Pluto and its satellite ('Charon') were detected in January and February 1985, confirming the satellite's existence, Eclipses lasting a few hours will now occur at 3.2-day intervals for the next 5 to 6 yr and then will cease for about 120 yr. Careful observations of these eclipses will allow greatly improved determinations to be made of several physical parameters for the Pluto-Charon system: the diameters of the planet and satellite, the surface albedo distribution on one hemisphere of the planet, the orbit of the satellite, and the mass of the planet and hence its density. Knowledge of the density will provide a constraint on models of Pluto's bulk composition.

Van Hemelrijck, E. (Belgian Institute for Space Aeronomy, Brussels, Belgium): 'Insolation Changes on Pluto Caused by Orbital Element Variations', *Earth, Moon, and Planets* **33** (1985), 163–177.

In this paper, we compare changes in the insolation at Pluto, corresponding to three epochs during the dynamical history of the planet: $t = -1$, 0 and 0.5, where t is the time in millions of years A.D. The two extreme values of t coincide respectively with a maximum (126°) and a minimum (102°) value of the obliquity (ϵ). The other orbital elements i.e. the eccentricity (e) and the longitude of the perihelion (λ_p) which affect solar radiation and which are apt to significant periodic changes are also calculated for the times under consideration. In a series of figures, the combined influence of the evolving dynamic parameters on the daily insolation and on the mean (summer, winter, annual) daily insolation is illustrated.

11. SATELLITES OF PLUTO

Wildey, R. L. (Northern Arizona Univ. Astrophysical Observatory, Flagstaff, AZ 86001): 'The Determination of Physical and Dynamical Parameters of Pluto/Charon and Binary Asteroids by Least-Square Formation of a Matched Filter for a Time Series of Images. I. The Operational Theory', *Astron. J.* **90** (1985), 1883–1893.

A theory is derived for the determination of the masses, radii, and orbital elements of the Pluto/Charon, or similar, system based on the prediction of an image distribution over space and time and its comparison with observation. The comparison may be ultimately through the theory of least squares or the application of a matched filter to the observations as a three-dimensional signal stream at an initial or intermediate state. The theory is an approximation correct to fifth order in the diameters of celestial bodies. The theory of astronomical seeing that is used is based on Kolmogorov turbulence in the long-exposure limit. The images must be photometric. Linear tracking errors that can be removed are preferable to either automatic or manual guiding, in the collection of candidate observations.

12. SATURN

Brahic, A. (Université Paris VII et Observatoire de Paris, 92190 Meudon, France): 'Saturn's Rings – Dynamical Processes', *Adv. Space Res.* **5**(8) (1985), 121–124.

The study of planetary rings, like the rings themselves, is dynamic and evolving. Despite the flood of new information on morphology and optical properties, we have very little direct evidence about what rings are, how they formed, and how they behave. Answers to such questions can only be obtained by building theoretical models and comparing their implications with past and future observations. A number of dynamical problems are briefly presented here, namely the physics of the particle collisions, the role of the resonances, the disc-satellite interactions, and the timescale of evolution. A short list of outstanding problems concludes this short review.

Heath, A. W. (136 Trowell Grove, Long Eaton, Nottingham, NG10 4BB, UK): 'Saturn, 1981–1982', *J. Brit. Astron. Assoc.* **95** (1985), 143–150.

The report covers the period 1981 October to 1982 August during which time 'B' change from +9° · 7 to +12° · 5. Opposition was on 1982 April 9 at which time 'B' was +11° · 0.

Hollis, A. J. ('Ormada', 85 Forest Road, Cuddington, Northwich, Cheshire, CW8 2ED, U.K.): 'A Comparison of the Latitudes of Saturn's Belts Derived from Voyager Imagery and Earth-Based Observations', *Brit. Astron. Assoc. J.* **95** (1985), 110–114.

Mean belt latitudes for Saturn have been derived from measures of *Voyager* photographs and also from drawing of the planet made by members of the BAA Saturn Section. A comparison between the results from each source is made and a possible explanation of the discrepancies is made. In general there is a good agreement.

It is noted that there is some variation in the condition of the North Equatorial Belt. Further study of this belt should continue to confirm this.

Hood, L. L. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Radial Diffusion of Low-Energy Ions in Saturn's Radiation Belts: A Combined Analysis of Phase Space Density and Satellite Microsignature Data', *J. Geophys. Res.* **90** (1985), 6295–6303.

Phase space densities for low-energy (80 MeV/G) ions in Saturn's inner magnetosphere are analyzed using solutions of the time-averaged radial diffusion equation for charged particle transport in a dipolar magnetic field. A series of distributed loss models ranging from satellite absorption only to satellite and maximum estimated Ring E absorption losses plus pitch angle scattering losses occurring at the strong diffusion limit in the inner magnetosphere are assumed. In each case the corresponding form of the magnetospheric radial diffusion coefficient (assumed to be expressible as $D(L) = D_0 L^n$, where D_0 is a constant and n is an integer)which yields a minimum rms residual between model and data is determined. Independent constraints on the diffusion rate at specific L values derivable from satellite microsignatures in low-energy ions and electrons are then considered. Estimates previously derived from the Dione microsignature in Voyager 1 low-energy electrons are supplemented by additional analyses of the Tethys microsignature in Voyage 2 low-energyy ions and the Rhea microsignature in Voyager 1 low-energy electrons. The resulting diffusion rate estimates of $D(4.9) \sim 4 \pm 2 \times 10^{-8}\ R_s^2\,s^{-1}$ and $D(8.7) > 6 \pm 5 \times 10^{-8}\ R_s^2\,s^{-1}$ are consistent with those derived from the Dione microsignature if $D(L)$ increases outward. A comparison with the phase space density modeling results shows that satellite and maximum Ring E absorption losses alone are insufficient to yield diffusion rates at Tethys and Dione that are in agreement with the microsignature estimates. Models containing weak pitch angle scattering losses of low-energy ions in the inner magnetosphere occurring at a rate less than one-tenth that of the strong diffusion limit produce diffusion rates that are compatible with microsignature estimates and additionally result in an improved fit to the radial variation of the experimental phase space densities. The preferred radial diffusion coefficient for these low-energy ions is characterized by a relatively high amplitude and low-order L dependence that is most consistent with Jovian-type diffusion mechanisms including the centrifugal interchange instability and the ionospheric dynamo mechanism.

Kerr, R. A.: 'Making Better Planetary Rings', *Science* **229** (1985), 1376–1377.

Particles colliding in Saturn's rings appear to be ice balls, not snowballs, acting like molecules of a gas, a liquid, and perhaps even a solid.

Lissauer, J. J. (Space Sciences Div., NASA-Ames Research Center, Moffett Field, CA 94035): 'Bending Waves and the Structure of Saturn's Rings', *Icarus* **62** (1985), 433–447.

The surface mass density profiles at four locations within Saturn's rings are calculated using Voyager spacecraft images of spiral bending waves. Bending waves are vertical corrugations in Saturn's rings which are excited at vertical resonances of a moon, e.g., Mimas, whose orbit is inclined with respect to the mean plane of the rings. Bending waves propagate toward Saturn by virtue of the rings' self-gravity; their wavelength depends on the local surface mass density of the rings. Observations of bending waves can thus be used to determine the surface density in regions of Saturn's rings near vertical resonances. The average surface density of the outer B ring near Mimas' 4:2 inner vertical resonance is $54 \pm 10\,\mathrm{g\,cm^{-2}}$. Surface density in this region probably varies by ~30% over radial length scales of tens of kilometers; an irregular radial structure is present on similar length scales in this region. Surface densities ranging from $24\,\mathrm{g\,cm^{-2}}$ to $45\,\mathrm{g\,cm^{-2}}$ consistent with its more uniform optical appearance.

Marouf, E. A. and Tyler, G. L. (Center for Radar Astronomy, Stanford Univ., CA 94305): 'Radio Occultation by Saturn's Rings: Observations of Structure and Particle Size with Voyager 1', *Adv. Space Res.* **5**(8) (1985), 117–120.

Voyager 1 radio occultation study of Saturn's rings gives detailed information regarding the rings' radial structure and particle sizes. Structure within the rings is mapped to a radial resolution of few hundred m in the tenuous parts of ring C and the Cassini Division, and few km over most of ring A. Fine resolution profiles reveal extremely sharp edges, very narrow gaps, and a host of wave phenomena. Particle size distributions obtained from occultation data within several ring regions are roughly consistent with an inverse cube power law with upper size cutoff in the 5 to 10 m radius range.

Salo, H. (Dept. of Astronomy, Univ. of Oulu, Finland): 'Numerical Simulations of Collisions and Gravitational Encounters in Systems of Non-Identical Particles', *Earth, Moon, and Planets* **33** (1985), 189–200.

Numerical simulations of 200 mutually colliding non-identical particles indicate that the equipartition of random kinetic energy is possible only in systems having a narrow distribution of particle masses. Otherwise the random energy is concentrated on heavy particles. The form of the velocity distribution versus particle mass depends also on the elastic properties of the particles, and on the relative importance of the particle size. If the coefficient of restitution is a weakly decreasing function of impact velocity, a large difference in the equilibrium velocities of largest and smallest particles is possible. On the other hand, if the elasticity drops to a low level even in the small velocity regime, the dispersion of velocities is maintained by finite size and differential rotation, and the velocities of smallest particles are, at most, slightly larger than those of the largest ones. The results of simulations are consistent with the predictions of the collisional theory of non-identical particles (Hämeen-Anttila, 1984). The application to Saturn's rings indicates that the geometric thickness of cm-sized particles is of the order of 50 m in the rarefied regions of the rings. Without the gravitational encounters a thickness of about 30 m is derived. These estimations are made by using the latest measurements (Bridges *et al.*, 1984) for the restitution coefficient of icy particles.

Taylor, D. B. and Sinclair, A. T. (Royal Greenwich Observatory, Herstmonceux Castle, Hailsham,

East Sussex BN27 1RP, U.K.): 'Positions of the Satellites of Saturn in 1978, 1982 and 1983 obtained at the Royal Greenwich Observatory', *Astron. Astrophys. Suppl.* **61** (1985), 221–223.

Reduced photographic observations are given for satellites II–VIII of Saturn. These observations were taken with the 26-in refractor at the Royal Greenwich Observatory at Herstmonceux during 1978, 1982 and 1983.

13. SATELLITES OF SATURN

Cerceau, F., Raulin, F., Courtin, R. and Gautier, D. (Laboratoire de Physicochimie de L'Environment, Université Paris Val de Marne, 94010 Creteil Cedex, France): 'Infrared Spectra of Gaseous Mononitriles: Application to the Atmosphere of Titan', *Icarus* **62** (1985), 207–220.

A list of volatile nitriles, not yet detected in the atmosphere of Titan, but likely to be present in this environment, has been selected: acetonitrile, propionitrile, acrylonitrile, crotononitrile, allyl cyanide, methacrylonitrile, and cyanopropyne. The spectra of these compounds in the gas phase have been systematically studied, in the mid- and far-infrared ranges. For each selected nitrile, the most intense vibration bands have been determined. Their strengths have been characterized by estimating the monochromatic absorption coefficient at the maximum(s) of the bands, and the integrated absorbance over the entire band. Then, in order to estimate the detectability of the selected compounds by infrared spectroscopy in the atmosphere of Titan, the data obtained have been extrapolated to the case of Titan.

Chugunov, I. G., Stolyarov, G. V. and Stolyarov, V. V. (Mordovian State University, Saransk, U.S.S.R.): 'Evolution of the Mimas-Tethys Resonance' *Soviet Astron.* **29** (1985), 103.

Taking the classical approach to the problem of resonance in the motion of Saturn's satellites, we investigate the behavior of the solutions to the resonance equation, allowing for long-term variability in the orbital elements. Changes in the inclinations of the satellite orbits to the planet's equatorial plane will dominate the effects upon the resonance coefficients but will not disturb the periodicity of the resonant motion.

Sinclair, A. T. and Taylor, D. B. (Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, East Sussex BN27 1RP, England): 'Analysis of the Orbits of Titan, Hyperion, and Iapetus by Numerical Integration and by Analytical Theories', *Astron. Astrophys.* **147** (1985), 241–246.

The orbits of Titan, and Iapetus have been generated by both numerical integration and analytical theories, and fitted to astrometric observations made in the period 1967–1982. For Titan and Iapetus the two fits to the observations were of similar accuracy, but for Hyperion the numerical integration was significantly better. The numerical integration gave good determinations of the mass ratio Titan/Saturn of $(2.36777 \pm 0.00055)\ 10^{-4}$, the dynamical flattening J_2 of Saturn (0.01675 ± 0.00089) and the mass ratio Saturn/Sun of $(2.85877 \pm 0.00021)\ 10^{-4}$. A direct comparison of the analytical theories with the numerical integrations has been made, and reveals very clearly the inadequacies of the theories.

14. URANUS

Ip, A. K. and Voigt, G.-H. (Dept. of Space Physics and Astronomy, Rice Univ., Houston, TX 77251): 'Plasma-Dominated Magnetic Field Configurations for the Magnetosphere of Uranus', *J. Geophys. Res.* **90** (1985), 6287–6293.

We present hydromagnetic equilibrium configurations for the nonrotating 'pole-on' magnetosphere of

Uranus. According to a plasma supply mechanism proposed by Cheng (1984) we assume that charged particle sputtering of the water-ice covered moons of Uranus provides a continuous internal plasma source to the Uranian magnetosphere. We assume further that (1) dynamical changes of the magnetosphere are quasi-static, (2) the internal plasma source fills the Uranian mangetosphere in a homologous manner, and (3) the plasma residence time within the magnetospheric cavity is long enough to allow the Uranian magnetosphere to evolve from a vacuum configuration toward a plasma-dominated equilibrium. With these assumptions, we calculated configurational changes of Uranus's magnetosphere, given the amount of the thermal plasma pressure as a free parameter. In order to include Uranus's dipole in the equilibrium calculations the homogeneous Grad-Shafranov equation for cylindrically symmetric magnetospheres has been complemented by an inhomogeneous source term. We derived linear analytic solutions to the inhomogeneous problem. We found that a plasma ring forms near the equatorial plane of the planet when the thermal pressure reaches about 75% of the maximum amount that would lead to a Harris sheet magnetotail configuration. The appearance of a plasma ring is due to the particular pole-on orientation of Uranus's dipole; such a ring would not exist in an earth-type equilibrium magnetosphere.

16. VENUS

Bertaux, J. L., Chassefiere, E. and Kurt, V. G. (Service D'Aeronomie du C.N.R.S., B-P, No. 3, 91370 Verrières Le-Buisson, France): 'Venus EUV Measurements of Hydrogen and Helium from Venera-11 and Venera-12', *Adv. Space Res.* **5**(9) (1985), 119–124.

Lyman α and 58.4 nm HeI radiations resonantly scattered was observed with EUV spectrophotometers flown on Venera 11 and Venera 12. The altitude distribution of hydrogen was derived by limb observations from 250 km (exobase level) to 50,000 km. In the inner exosphere (up to $\approx$2000 km of altitude) the distribution can be described by a classical exospheric distribution with $T_c = 275 \pm 25$ K and $n = 4 \pm 3 \times 10^4$ atom $\cdot$ cm^{-3} at 250 km. The integrated number density from 250 to 110 km (the level of CO_2 absorption) is 2.1×10^{12} atom $\cdot$ cm^{-2}, a factor of 3 to 6 lower than that predicted by aeronomical models. This number density decreases from the morning side to the afternoon side, or alternately from equatorial to polar regions. Above 2000 km a 'hot' hydrogen population dominates, which can be simulated by $T = 10^3$ K and $n = 10^3$ atom $\cdot$ cm^{-3} at the exobase level.

The optical thickness of helium above 141 km (the level of CO_2 absorption for 58.4 nm radiation) was determined to be $\tau_0 = 3$, corresponding to a density at 150 km of 1.6×10^6 cm^{-3}. This is about 3 times less than what was obtained with the Bus Neutral Mass Spectrometer of Pioneer Venus, and about twice less than ONMS measurements, but is in agreement with earlier EUV measurement by Mariner 10 ($2 \pm 1 \times 10^6$ cm^{-3}).

Blamont, J. (Service d'Aeronomie du C.N.R.S., B.P. No. 3, 91370 Verrières le-Buisson, France): 'The Exploration of the Atmosphere of Venus by Balloons', *Adv. Space Res.* **5**(9) (1985), 99–106.

Presentation of the scientific objectives of balloon missions to Venus; description of the 1985 VEGA balloons; discussion of possible future missions as a function of technological constraints.

Breus, T. K., Gringauz, K. I. and Verigin, M. I. (Space Research Inst., Academy of Sciences of the USSR, 84/32 Profsoyuznaya, Moscow 117810, USSR): 'On the Properties and Origin of the Venus Ionosphere', *Adv. Space Res.* **5**(9) (1985), 145–156.

The brief review of the properties of dayside and nightside ionosphere of Venus is given, and some possible origins of ionization are discussed. There are arguments in favour of the impact ionization by electrons from magneto-tail as the source of main ionization peak of the nightside ionosphere.

The discrepancies in the results obtained by the different in-situ experimental techniques, as well as the discrepancies between the in-situ experimental results and radio occultation results, do not allow

the Venus ionosphere to be described quantitatively (although the qualitative description seems to be possible).

After Venera-9, -10 and Pioneer–Venus experiments, a great number of publications followed which dealt with experimental data, hypotheses and theoretical models. They described some properties of Venus' ionosphere as well as its origin. Measurements of the same properties made by different methods often gave inconsistent results. Models based on various preconditions had both common and different features. Finally hypotheses of ionization sources, especially in the night ionosphere, are still under discussion.

It is of interest to analyze the available publications about the properties and origin of Venus' ionosphere emphasizing the inconsistent and debatable results in order to argue for the necessity of statistically processing the available information, its averaging and tabulation for VIRA.

Esposito, L. W. (Lab. for Atmospheric and Space Physics, Univ. of Colorado, Boulder, CO 80309): 'Long Term Changes in Venus Sulfur Dioxide', *Adv. Space Res.* **5**(9) (1985), 85–90.

Pioneer Venus data from the first 5 years of operation show a decline by more than a factor of ten in SO_2 at the cloud tops. A consistent decline has also recurred in the amount of sub-micron haze above the clouds. The correlation between these two observables is 0.8 over this period. A plausible explanation is injection of SO_2 from episodic volcanism. The episodic behavior implies that steady state models of the Venus cloud chemistry and dynamics may be of limited use.

Fox, J. L. (Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138): 'The O_2^+ Vibrational Distribution in the Venusian Ionosphere', *Adv. Space Res.* **5**(9) (1985), 165–169.

Calculations are presented of the vibrational distribution of O_2^+ in the Venusian ionosphere for a model atmosphere based on Pioneer Venus data. At 100 km, quenching precludes the survival of vibrationally excited O_2^+. At the exobase, near 200 km, more than half are vibrationally excited. The effects of vibrationally excited O_2^+ on the hot oxygen corona and the airglow are discussed.

Garvin, J. B., Head, J. W., Pettengill, G. H. and Zisk, S. H. (Dept. of Geological Sciences, Brown Univ., Providence, RI 02912); 'Venus Global Radar Reflectivity and Correlations with Elevation', *J. Geophys. Res.* **90** (1985), 6859–6871.

The global distribution of the reflectivity of the surface of Venus as determined by the Pioneer Venus orbital radar instrument has been analuzed in a geological context and statistically correlated with elevation. In addition, a comparison between the reflectivity and rms slope (roughness) correlations with elevation permits radar-geologic topographic zones to be identified. The radar reflectivity ρ at normal incidence and at a wavelength of 17 cm (1.76 GHz) is a model-dependent measure of the bulk dielectric constant κ of surfaces dominated by dry rocks and soils and depends on surface material properties such as porosity and conductivity. Only the quasi-specular component of the radar echo was used in determining the reflectivity values analyzed in this study, and for very rough surfaces the absolute magnitude of ρ may be underestimated by 10–15%. Empirically derived relationships between ρ, κ, and bulk density γ are used to interpret geologically the ρ distribution. The global mean ρ, κ, and bulk density γ are used to interpret geologically the ρ distribution. The global mean ρ of 0.13 is significantly greater than the average lunar and typical martian values of ~0.07, suggesting the absence of a continuous soil mantle on Venus. The ρ distribution is well described by a two-stage Gaussian distribution with modes at 0.11 and 0.14. The close proximity of these modes suggests that there is no fundamental dichotomy of surfaces on Venus insofar as their ρ properties, in contrast with roughness. Less than 15% of Venus has ρ values low enough to indicate a major soil component on the surface. Approximately 27% of the surface is dominated by low-porosity materials such as bedrock, and less than 15% is enriched in high dielectrics. The rest of the surface (43%) is most simply envisioned as partially mantled bedrock, perhaps an extension of the types of terrain viewed by

the Venera 10 and 13 landers. The most plausible model for the highest ρ (and thus highest κ) materials requires enrichment in Ti and Fe (e.g. minerals such as rutile, ilmenite, and magnetite). High-titanium basalts such as those found on the moon would produce the required enrichment, as would pyrites. Since surface geochemical measurements demonstrate that there are basalts in the Venusian plains, a model in which high-titanium basalts are exposed at the highest elevations (Maxwell, Theia, Atla, Ovda) is favored. Possible weathering of ilmenite in such basalts to produce rutile could explain the high-κ materials in less elevated regions. When correlated with elevation, ρ exhibits a complex nonmonotonic trend in which both decreases and increases are observed. A major decrease in ρ of $\sim 0.02\,\mathrm{km}^{-1}$ in the upper plains contrasts with the almost 1° rms km^{-1} increase in surface roughness over the same interval and may be an expression of increased soil production, perhaps due to enhanced breakdown of silicates into carbonates in the lower highlands. Alternately, the decrease could be due to increased centimeter scale roughening, perhaps caused by the increase in regional slope in the highlands. A major increase in ρ ($0.05\,\mathrm{km}^{-1}$) in the middle highlands correlates with a rapid rise in rms slope. Unlike rms slope, however, there is no overall correlation of ρ with either elevation or regional slope, suggesting that it may be a more locally controlled parameter. Hierarchical clustering analysis of the ρ, roughness, and regional slope properties of Venus demonstrates that distinct subregions are best defined on the basis of topographic zones in which the radar parameters follow well-defined trends. The lowland plains are extremely smooth at scales from centimeeters to 100 km. In general, no single radar parameter (e.g., ρ) serves to subdivide the surface into distinct geologic regions, but taken together, the radar parameters can be statistically correlated to define meaningful radar geologic units. Such units appear to correlate with the kinds of surfaces that can be seen on Venus at kilometer resolution.

Gordiets, B. F. and Kulikov, Yu. N. (Lebedev Physical Inst., USSR, Academy of Sciences, Leninsky Prospect 53, Moscow 117901, USSR): 'On the Mechanism of Cooling of the Nightside Thermosphere of Venus', *Adv. Space Res.* **5**(9) (1985), 113–117.

The plausible mechanisms of cooling of the nightside Venus' thermosphere are analyzed with the aid of the model of the atmospheric heat budget that incorporates, in addition to thermal conduction and IR radiation in the 15μ band of CO_2, heating and cooling due to global scale winds, eddy turbulence, and IR radiation in the rotational bands of H_2O and CO, as well as the 63μ line of atomic oxygen. The H_2O mixing ratio and parameters of turbulence required for cooling of the thermosphere down to the observed low temperature are evaluated.

Head, J. W., Peterfreund, A. R. and Garvin, J. B. (Dept. of Geological Sciences, Brown Univ., Providence, RI 02912): 'Surface Characteristics of Venus Derived from Pioneer Venus Altimetry, Roughness, and Reflectivity Measurements', *J. Geophys. Res.* **90** (1985), 6873–6885.

The three primary data sets for the Pioneer Venus orbiter radar experiment (topography, roughness, and reflectivity) contain important information about the geological and textural characteristics of the surface of Venus. We have subdivided the range of roughness and reflectivity values into three categories as follows: roughness, in degrees rms slope: relatively smooth ($1^\circ - 2.5^\circ$), transitional from smooth to rough (2.5°–5°), and relatively rough ($>5^\circ$); and Fresnel reflectivity: surfaces dominated by soil or porous material (<0.1), surfaces dominated by rock material (0.1–0.2), and surfaces with a significant percentage of anomalously high dielectric material (>0.2). We have analyzed each of these data sets and their relationships to each other in order to define areas of the surface that are characterized by distinctive properties (e.g., rough rocky surfaces, smooth soil surfaces). We then describe the abundance and areal distribution of such areas and locally calibrate the geological significance of some of the surface types by examining high-resolution images from spacecraft and earth-based observatories. We find that the majority of Venus is covered by regionally contiguous rock and bedrock surfaces. Many of the smooth surfaces we interpret to be of volcanic origin, most likely lava flows, while rougher surfaces are locally characterized by tectonic deformation of several types. Soil surfaces cover less than about 27% of the planet and are generally patchy in their

distribution. On the basis of the distribution of these surfaces we see no evidence for the extensive preservation of an ancient global regolith or for widespread, topographically controlled erosion, lateral transport, and sedimentation. The small percentage of the surface of Venus characterized by high-dielectric material appears to originate from several processes including primary lava flows probably containing enrichments of high-dielectric materials, such as metal or metal oxides (e.g., Theia Mons in Beta Regio), and the exposure of high-dielectric materials by tectonic deformation (e.g. Maxwell Montes in Ishtar Tegga). These global data set correlations provide a fundamental framwork for understanding the nature of the surface of Venus and will permit extrapolation of local and regional findings from future geochemical and imaging experiments to a global context.

Kaufl, H. U., Rothermel, H. and Drapatz, S. (Max-Planck-Institut für Physik und Astrophysik, Forschungsgelande, 8046 Garching bei München, F.R.G.): 'Investigation of the Thermal Structure of the upper Atmosphere of Venus by 10 micron Heterodyne Spectroscopy', *Infrared Phys.* **25** (1985), 505–512.

The Venusian atmosphere has been investigated using a 10 μm heterodyne spectrometer (spectral resolution $\lambda/\Delta\lambda = 3 \times 10^6$) during upper conjunction and during elongation in 1983. In both cases a variety of spectra from the subsolar region were taken with high spatial resolution showing fully-resolved lines of the 10 μm laser transition of CO_2. From these measurements kinetic and rotational temperatures are derived ($T \sim 200$ K). These spectroscopically-derived temperatures represent the atmospheric temperature for extended areas (1000–6000 km dia) at an altitude of 100–120 km. They are in agreement with on-the spot temperature measurements indirectly obtained by space probes during descent. Multiple-line structures have been observed in the 10 μm spectra, which indicate a wave-like perturbation of the vertical temperature profile about a cloud layer at ~20 mb atmospheric pressure.

Kliore, A. J. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'Recent Results on the Venus Atmosphere from Pioneer Venus Radio Occultations', *Adv. Space Res.* **5**(9) (1985), 41–49.

Radio occultation measurements of the temperature structure of the Venus atmosphere have been obtained during seven occultation 'seasons' extending from December 1978 to December 1983. Approximately 123 vertical profiles of temperature from about 40 km to about 85 km altitudes have been derived. Since these measurements cover latitudes from both poles to the equator, they have shown the latitudinal dependence of thermal structure. There is a smooth transition from the troposphere to the mesosphere at latitudes below about 45°, with the tropopause at about 56 km. The troposphere then rises to about 62 km in the 'collar cloud' region between about 60° and 80° latitude, where a strong temperature inversion (up to 30 K) is present. In the polar areas, 80°–90°, the mesosphere becomes isothermal and there is no inversion. This latitudinal behavior is related to the persistent circulation pattern, in which a predominantly zonal retrograde motion at latitudes below 45° gradually changes to a circumpolar vortex at the "collar cloud" latitudes. Indeed, the radio occultation data have been used in a cyclostrophic balance model to derive zonal winds in the Venus atmosphere, which showed a mid-latitude (50°–55°) jet with a speed of about 120–140 ms^{-1} at about 70 km altitude. The observations obtained in 1983 and 1984 have shown that above the tropopause there is considerable temporal variability in the detailed thermal structure, suggesting that the persistent circulation pattern is subject to weather-like variability.

Kotelnikov, V. A., Bogomolov, A. F. and Rzhiga, O. N. (Inst. of Radio Engineering and Electronics, Academy of Sciences of the U.S.S.R., Prospekt K. Marxa 18, 103907, Moscow, U.S.S.R.): 'Radar Study of Venus Surface by Venera-15 and -16 Spacecraft', *Adv. Space Res.* **5**(8) (1985), 5–16.

Description is given of the first results of radar study of Venus surface by Venera 15 and 16

spacecraft. Unique images of the Venus surface were obtained on which mountain ridges, craters, plateau, folds and breaks of the Venus crust are seen. Indications of tectonic activity of Venus were discovered. Areas with anomalous character of radio waves reflection were found.

Krasnopolsky, V. A. (Space Research Inst., Profsojuznaja 84/32, 117810 Moscow, U.S.S.R.): 'Total Injection of water vapour into the Venus atmosphere', *Icarus* **62** (1985), 221–229.

The atomic hydrogen mixing ratio at the homopause and the deuterium fractionation factor equal 0.5 ppm and 2.2%, respectively. The function which defines hydrogen amounts in the lower thermosphere relative to the lower atmospheric water vapor mixing ratio has been calculated for the sulfuric acid trap. We consider the effects of the enhanced solar EUV radiation in the past as well as the supersaturation of water vapor at the cold trap on the nonthermal hydrogen escape. If the present amount of carbon dioxide on Venus were present in the atmosphere throughout the entire history of the planet, then an initial water amount equal to a full terrestrial ocean (fto) is consistent with the present deuterium-to-hydrogen ratio if the water vapor outgassing was $\sim 10\,cm^{-2}\,sec^{-1}$ up to $t \sim 2$, with a subsequent steep increase to $\sim 10^{10}\,cm^{-2}\,sec^{-1}$ and a gradual falloff to the present value of $2 \times 10^7\,cm^{-2}\,sec^{-1}$. However, it should be noted that much lower water amounts, ~1% fto, seem more probable.

Ksanfomaliti, L. V. (Academy of Sciences of the U.S.S.R., Space Research Inst., Profsoyuznaya 88, Moscow V-485, U.S.S.R.): 'Volcanism on Venus: Connecting Link?', *Adv. Space Res.* **5**(9) (1985), 91–98.

New observational data obtained from Venera-11 through Venera-14 and Pioneer-Venus data (1979–1982) call for searching for the interdependences of the phenomena occurring on this planet. It is proposed that the presence of electrical discharges in the near-surface layers of the atmosphere, the variable density of the above-cloud submicron haze, and the peculiarities of the cloud microphysics can be tied by a hypothesis that volcanic eruptions occur on Venus.

Kumar, S. and Taylor, H. A. Jr. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Deuterium on Venus: Model Comparisons with Pioneer Venus Observations of the Predawn Bulge Ionosphere', *Icarus* **62** (1985), 494–504.

A model of the predawn bulge ionosphere composition and structure is constructed and compared with the ion mass spectrometer measurements from the Pioneer Venus Orbiter during orbits 117 and 120. Particular emphasis is given to the identification of the mass-2 ion which we find unequivocally due to D^+ (and not H_2^+). The atmospheric D/H ratio of 1.4% and 2.5% is obtained at the homopause (~130 km) for the two orbits. The H_2^+ contribution to the mass-2 ion density is less than 10%, and the H_2 mixing ratio must be <0.1 ppm at 130 km altitude. The He^+ data require a downward He^+ flux of $\sim 2 \times 10^7\,cm^{-2}\,sec^{-1}$ in the predawn region which suggests that the light ions also flow across the terminator from day to night along with the observed O^+ ion flow.

Limaye, S. S. (Space Science and Engineering Center, Univ. of Wisconsin-Madison, Madison, WI 53706): 'Venus Atmospheric Circulation: Observations and Implications of the Thermal Structure', *Adv. Space Res.* **5**(9) (1985), 51–62.

Continued analysis of Pioneer Venus imaging and polarimetry data indicates that the average cloud-top level circulation is mainly zonal (east to west) with a small meridional component. Presence of planetary scale waves and possible sun-related component are evident in the data. If the tracked features refer to the same vertical level, then some variability of the circulation would have to be present to account for the Pioneer and Mariner-10 cloud-tracking results. However, the implied

balanced flow from the observed thermal structure analysis strongly suggests that at least some of the variations in these observations is due to apparent cloud-top variations and that the circulation itself is relatively stable.

Direct cyclostrophic calculations based on the observed thermal structure of the atmosphere yield a balanced zonal circulation with distinct mid-latitude jets (peak velocities about 110–120 ms^{-1}) located between 50 and 40 mb in each hemisphere of the planet near 45° latitude. The calculations which extend to about 40 km altitude from 80 km above the surface agree well with the observed entry probe zonal components and indicate breakdown of the balance condition near the upper and lower boundaries at low latitudes.

The balanced flow results are consistent with the Mariner-10 and Pioneer cloud tracked estimates of the zonal circulation provided the effective altitude of the tracked features is slightly different at different observation periods. The features in the Pioneer Venus data would then lie on a sloping surface that extends from about 68 km (40 mb) at low latitudes to about 75 km (10 mb) in mid-latitudes. The polarization features would occur on a roughly parallel surface that is 1–2 km above the effective cloud-height surface, and Mariner 10 features would have effective altitudes somewhat lower than the Pioneer ultraviolet features. A slightly asymmetry is evident in the balanced zonal circulation arising out of an asymmetry in the thermal field.

Finally, the solenoids formed by interesecting isobaric and isosteric (constant specific volume) surfaces deduced from the Pioneer Venus radio occultation data show distinct evidence of a direct meridional circulation that may be important in sustaining the Venus atmospheric circulation.

Mayr, H. G., Harris, I., Stevens-Rayburn, D. R., Niemann, H. B., Taylor, H. A. Jr. and Hartle, R. E. (Goddard Space Flight Center, Greenbelt, MD 20771): 'On the Diurnal Variations in the Temperature and Composition: A Three-Dimensional Model with Superrotation', *Adv. Space Res.* **5**(9) (1985), 109–112.

Based on a simplified theoretical interpretation of the composition measurements with the ONMS and OIMS experiments on Pioneer Venus, the conclusion was drawn that the rotation rate of the thermosphere should be close (within a factor of two) to that of the lower atmosphere. A more realistic three-dimensional model of the thermosphere dynamics is now being developed, considering non-linear processes, higher order modes and collisional momentum exchange between the major species CO_2, CO and O, which describes the diurnal variations in temperature and composition (Niemann et al., *JGR*, 1980). The computed horizontal winds are about 300 $m\,sec^{-1}$ near the terminators and poles. Results are also presented from a two-dimensional (quasi-axisymmetric) spectral model which describes the four day superrotation in the lower atmosphere of Venus.

McQue, J. and Nichol, J. (69 Keithlands Avenue, Norton, Stockton-on-Tees, Cleveland, TS20 2QR, UK): 'Venus: Eastern Elongation 1979–1980', *J. Brit. Astron. Assoc.* **95** (1985), 157–161.

Visual and photographic studies of Venus during its eastern elongation 1979–80 are described and analyzed.

Nagy, A. F. and Cravens, T. E. (Space Physics Research Lab., Dept. of Atmospheric and Oceanic Science, Univ. of Michigan, Ann Arbor, MI 48109): 'Recent Advances in Model Calculations of the Venus Ionosphere', *Adv. Space Res.* **5**(9) (1985), 135–143.

Our understanding of the physical and chemical processes which control the behavior of the Venus ionosphere has advanced significantly during the last few years. These advances are the result of a still growing data base and a variety of evolving theoretical models. This review summarizes some of these recent studies, especially those concerning the dynamics of the ionosphere, the maintenance of the nightside ionosphere, the energetics of the nightside ionosphere, and the time evolution of magnetic fields in the dayside ionosphere.

No Author Cited: 'Investigating Venus: Arecibo Radar Maps the Planet', *The Planetary Report* **5**(3) (1985), 10–12.

Here we present a few examples of radar images taken by the Arecibo Observatory in Puerto Rico, operated by Cornell University. These images are the work of Donald B. Campbell, Director of the Observatory, and Ellen R. Stofan and James W. Head of Brown University. Dr. Head wrote the captions for these images.

Oertel, D., Spänkuch, D., Jahn, H., Becker-Ross, H., Stadthaus, W., Nopirakowski, J., Döhler, W., Schäfer, K., Güldner, J., Dubois, R., Moroz, V. I., Linkin, V. M., Kerzhanovich, V. V., Matsgorin, I. A., Lipatov, A. N., Shurupov, A. A., Zasova, L. V. and Ustinov, E. A. (Academy of Sciences and Meteorological Service of the G.D.R., G.D.R.): 'Infrared Spectrometry of Venus from "Venera-15" and "Venera-16"', *Adv. Space Res.* **5**(9) (1985), 25–36.

Fourier spectrometers for the investigation of infrared spectra of Venus were installed on the recent Soviet orbiters "Venera-15' and 'Venera-16'. Many spectra with reliable absolute calibration were obtained in the 280–1500 cm^{-1} region with a spectral resolution of 5 cm^{-1} (ground based processing) and about 7 c^{-1} (preprocessed on board) and a spatial resolution of about 100 km at the Venusian cloud top level. Bands of CO_2, H_2O, H_2SO_4 and SO_2 are identified, The 15 μm-CO_2-fundamental band was used for retrieval of altitude dependent temperature profiles. There are significant differences in the cloud structure above 60 km for distinct regions of Venus, demonstrated by differences in the spectra.

Paxton, L. J., Anderson, D. E. Jr. and Stewart, A. I. F. (E. O. Hulburt Center for Space Research, Naval Research Lab., Washington, DC 20375): 'The Pioneer Venus Orbiter Ultraviolet Spectrometer Experiment: Analysis of Hydrogen Lyman Alpha Data'. *Adv. Space Res.* **5**(9) (1985), 129–132.

Pioneer Venus Orbiter Ultraviolet Spectrometer (PVOUVS) H I 1216 Å data from six (6) orbits are analyzed. Analysis of subsolar region periapsis data show that for an exobase temperature of 305 K, the exobase density is $5 \pm 2(4)$ cm^{-3} and the column abundance of atomic hydrogen between 110 and 200 km is $2.4 \pm 0.8(13)$ cm^{-2}. The upward flux through the exobase is determined to be $7.5 \pm 2.5(7)$ cm^{-2} s. Apoapsis data were analyzed for both evening and morning geometries. We conclude: (1) the observed limb profiles show a diurnal variation consistent with Brinton *et al.*; (2) the model temperature field provides a good fit to the morning data, but the morning temperature field must be used to match the evening data; and (3) the theoretical Ly α limb intensity profiles are sensitive to small changes in the shape and magnitude of the variation of exobase hydrogen with solar zenith angle. The solar Ly α flux at line center required to fit the magnitude of the data is 8(11) photons cm^{-2} s Å at Venus.

Pérez-de-Tejada, H. (Inst. de Geofisica, Univ. Nacional Autonoma de Mexico, Ensenada, Baja California, Mexico): 'Plasma Measurements in the Venus Near Wake', *Adv. Space Res.* **5**(9) (1985), 193–199.

A study of the plasma measurements conducted with the Mariner 5, Verera 9 aand 10, and the Pioneer Venus spacecraft in the Venus ionosheath and near wake is presented. The data available indicate that in the inner ionosheath, downstream from the terminator, the density and the velocity of the plasma are significantly smaller than those measured further outside. The slower particle fluxes detected near the ionopause also exhibit higher plasma temperatures and show a tendency to move towards the nightside hemisphere. The observation of high plasma temperatures in the inner ionosheath indicates that the interaction of the solar wind with the Venus ionospheric/exospheric material is dominated by dissipative phenenoma, and that its entry into the wake is due to local thermal expansion processes.

Phillips, J. L., Luhmann, J. G. and Russell, C. T. (Inst. of Geophysics and Planetary Physics, Univ. of California, Los Angeles, CA 90024): 'Dependence of Venus Ionopause Altitude and Ionospheric Magnetic Field on Solar Wind Dynamic Pressure', *Adv. Space Res.* **5**(9) (1985) 173–176.

The shape of the dayside Venus ionopause, and its dependence on solar wind parameters, is examined using Pioneer Venus Orbiter field and particle data. The ionopause is defined here as the altitude of pressure equality between magnetosheath magnetic pressure and ionospheric thermal pressure; its typical altitudes range from ~300 km near the subsolar point to ~900 km near the terminator. A strong correlation between ionopause altitude and magnetosheath magnetic pressure is demonstrated; correlation between magnetic pressure and the normally incident component of solar wind dynamic pressure is also evident. The data support the hypothesis of control of the ionopause altitude by solar wind dynamic pressure, manifested in the sheath as magnetic pressure. The presence of large scale magnetic fields in the ionosphere is observed primarily when dynamic pressure is high and the ionopause is low.

Revercomb, H. E., Sromovsky, L. A., Suomi, V. E. and Boese, R. W. (Space Sciences and Engineering Center, Univ. of Wisconsin-Madison, Madison, WI 53706): 'Thermal Net Flux Measurements on the Pioneer Venus Entry Probes', *Adv. Space Res.* **5**(9) (1985), 81–84.

Corrected thermal net radiation measurements from the four Pioneer Venus entry probes at latitudes of 60° N, 31° S, 27° S, and 4° N are presented. Three main conclusions can be drawn from comparisons of the corrected fluxes with radiative transfer calculations: (1) sounder probe net fluxes are consistent with the number density of large cloud particles (mode 3) measured on the same probe, but the IR measurements as a whole are most consistent with a significantly reduced mode 3 contribution to the cloud opacity; (2) at all probe sites, the fluxes imply that the upper cloud contains a yet undetected source of IR opacity; and (3) beneath the clouds the fluxes at a given altitude increase with latitude, suggesting greater IR cooling below the clouds at high latitudes and water vapor mixing ratios of about $2–5 \times 10^{-5}$ near 60°, $2–5 \times 10^{-4}$ near 30°, and $>5 \times 10^{-4}$ near the equator.

Rich, V.: 'Soviet Probes Make Soft Landing', *Nature* **315** (1985), 708.

The first part of the Soviet VEGA (Venus-Halley) mission, the descent of atmospheric and surface probes to Venus, has been a success, according to Dr Vladimir Kotel'nikov, first vice-president of the Soviet Academy of Sciences. Indeed, in good Soviet style, the VEGA-2 surface probe, which included a rock-gathering minidrill and spectrometer analysis chamber, overfulfilled its norm, working and transmitting data for 22 minutes and 17 seconds rather than for the expected 14 minutes. 'Express analysis' of incoming data, moreover, revealed a number of new results, both confirming previous postulates and producing various surprises.

Russell, C. T., Saunders, M. A. and Luhmann, J. G. (Inst. of Geophysics and Planetary Physics, Univ. of California, Los Angeles, CA 90024): 'Mass-Loading and the Formation of the Venus Tail', *Adv. Space Res.* **5**(9) (1985), 177–184.

Despite its lack of an intrinsic magnetic field Venus has a well defined magnetotail, containing about 3 megawebers of magnetic flux in a tail about $4R_V$ across with perhaps a slightly elliptical cross section. This tail arises through the mass-loading of magnetic flux tubes passing by the planet. Mass-loading can occur due to charge exchange and photoionization as well as from the diffusion of magnetic field into the ionosphere. Various evidence exists for the mass-loading process, including the direct observation of the picked up ions with both the Venera and Pioneer Venus plasma analyzers.

Scarf, F. L. (TRW Space and Technology Group, Redondo Beach CA 90278): 'Lightning of Venus' *Adv. Space Res.* **5**(8) (1985), 31–36.

On the night side of Venus, the plasma wave instrument on the Pioneer-Venus Orbiter frequently detects strong and impulsive low-frequency noise bursts when the local magnetic field is strong and steady and when the field is oriented to point down to the ionosphere. The signals have characteristics of lightning whistlers and we have tried to identify the sources by tracing rays along the B-field from the Orbiter down toward the surface. An extensive data set strongly indicates a clustering of lightning sources near the Beta and Phoebe Regios, with additional significant clustering near the Atla Regio at the eastern edge of Aphrodite Terra. These results suggest that there are localized lightning sources at or near the planetary surface.

Scarf, F. L., Neumann, S., Brace, L. H., Russell, C. T., Luhmann, J. G. and Stewart, A. I. F. (TRW Space and Technology Group, Redondo Beach, CA 90278): 'Current-Driven Plasma Instabilities and Auroral-Type Particle Acceleration at Venus', *Adv. Space Res.* **5**(9) (1985), 185–191.

Above the ionosphere of Venus, several instruments on the Pioneer Orbiter detect correlated wave, field and particle phenomena suggestive of current-driven anomalous resistivity and auroral-type particle acceleration. In localized regions the plasma wave instrument measures intense mid-frequency turbulence levels together with strong field-aligned currents. Here the local parameters indicate that there is marginal stability for ion acoustic waves, and the electron temperature probe finds evidence that energetic primaries are present. This suggests an auroral-type energy deposition into the upper atmosphere of Venus. These results appear to be consistent with the direct measurements of auroral emissions from the Pioneer-Venus ultraviolet imaging spectrometer.

Smith, B. A.: 'Soviets Deploy Instrumented Balloon in Venus Atmosphere', *Aviation Week and Space Technology* **122**(24) (1985), 23–24.

Soviet VEGA 1 spacecraft has deployed an instrumented balloon into the atmosphere of Venus that was tracked for 46 hr by an international network of receiving stations, according to leaders of U.S. and French science teams associated with the progam.

The spacecraft was one of two launched by the Soviet Union last December to study Venus with the scientific balloons and landers and then continue on trajectories for encounters with Halley's Comet during March of 1986.

Sromovsky, L. A., Revercomb, E. and Suomi, V. E. (Space Science and Engineering Center, Univ. of Wisconsin-Madison, Madison, WI 53706): 'New Atmospheric Temperature Results from the Pioneer Venus Entry Probes', *Adv. Space Res.* **5**(9) (1985), 37–40.

The interpretation of unexpected characteristics of Pioneer Venus temperature measurements, and of the large difference between these and the Venera results, is aided by new Venus temperature profiles derived from engineering measurements of the Pioneer Venus Small-Probe Net Flux Radiometer (SNFR) instruments. To facilitate correction of a temperature-dependent radiometric response, these instruments monitored the temperatures of their deployed radiation detectors. The accurate calibration of the temperature sensors, and their strong thermal coupling to the atmosphere, make it possible to deduce atmospheric temperatures within 2° K (at most altitudes) using a simple two-component thermal model to account for lag effects. These independent temperature profiles generally confirm to high accuracy, the small-probe results of A. Seiff, D. B. Kirk, R. E. Young, R. C. Blanchard, J. T. Findlay, G. M. Kelly, and S. C. Sommer (1980a, *J. Geophys. Res.* **85**, pp. 7903–7933) concerning vertical structure and horizontal contrast in the lower atmosphere, although the stable layer below 25 km is found to be slightly more stable (by about 0.4° K km^{-1}) and absolute

temperatures are an average of 2° K higher. The measured Day-Night thermal contrast is compatible with predicted responses to the diurnal variation in solar heating, except near the cloud base, where 3–5° K differences may be due to thermal radiative heating differences associated with different cloud opacities. Temperature contrasts between latitudes 30 and 60° are roughly consistent with cyclostrophic balance. But pressure and temperature measurements by the Pioneer Venus Sounder probe at 4° latitude, when compared to Small-probe results, imply unreasonably large equatorward accelerations of 100 $(m\,sec^{-1})\,day^{-1}$. Poleward accelerations compatiable with cyclostrophic balance can be obtained if Sounder-probe temperatures are increased by a scale-factor correction reaching 6–7° K at 13 km.

Sromovsky, L. A., Revercomb, H. E. and Suomi, V. E. (Space Science and Engineering Center, Univ. of Wisconsin-Madison, Madison, WI 53706): 'Temperature Structure in the Lower Atmosphere of Venus: New Results Derived from Pioneer Venus Entry Probe Measurements', *Icarus* **62** (1985), 458–493.

New Venus temperature profiles, derived from engineering measurements of the Small Probe Net Flux Radiometer (SNFR) instruments generally confirm to high accuracy the vertical structure and horizontal temperature contrast results of Seiff et al.

Surkov, Yu. A. and Barsukov, V. L. (Inst. of Geochemistry and Analytical Chemistry of the U.S.S.R. Academy of Sciences, Moscow V-334, U.S.S.R.): 'Composition, Structure and Properties of Venus Rocks', *Adv. Space Res.* **5**(8) (1985), 17–29.

Physical and mechanical properties as well as chemical and mineral composition of Venus rocks are discussed on the basis of the data obtained by ground-based radar observations and the experiments in situ.

Taylor, F. W., Schofield, J. T. and Valdes, P. J. (Dept. of Atmospheric Physics, Clarendon Lab., Oxford Univ., OX1 3PU, England): 'Temperature Structure and Dynamics of the Middle Atmosphere of Venus', *Adv. Space Res.* **5**(9) (1985), 5–23.

The concentrations of neutral hydrogen within the atmosphere of Venus and investigated for the period 1979–1980. During this period, the planet made nearly three orbits about the Sun, so that nearly three complete diurnal cycles were observed from the Pioneer Venus Orbiter (PVO). Values of n(H) are derived from in-situ ion and neutral composition measurements from the Orbiter Ion Mass Spectrometer (OIMS) and the Orbiter Neutral Mass Spectrometer (ONMS) using a charge exchange relationship involving O^+, H^+, O and CO_2. The dawn bulge in the diurnal distribution of n(H), reported from the first diurnal cycle by Brinton *et al.*, is found to persist with n(H) peaking at levels near $2-5\times10^7\,cm^{-3}$ at altitudes below 165 km. At peak levels, the bulge exhibits a concentration ratio up to 400/1 relative to dayside values. Large day to day variations of up to a factor of five in n(H) are frequently encountered, and are attributed to perturbations induced by the solar wind interaction. These short term variations, plus a suggestion of some local time variation in the bulge location, make precise assessment of interannual variations in the n(H) difficult. Between the first diurnal cycle in early 1979 and the tird in the mid 1980, the decline in solar euv flux was of the order of 10% or less. Allowing for uncertainties due to short term variations, no clear evidence is found for an interannual variation in the hydrogen concentrations.

Taylor, H. A., Jr. and Grebowsky, J. M. (Lab. for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, MD 20771): 'Venus Nightside Ionospheric Troughs: Implications for Evidence of Lightning and Volcanism', *J. Geophys. Res.* **90** (1985), 7415–7426.

Ionization troughs are frequently observed in the Venus nightside ionosphere by the orbiter ion mass spectrometer (OIMS) on the Pioneer Venus Orbiter (PVO). These events typically exhibit density depletions which may range from a factor of 2 to an order of magnitude or more, often feature sharp density gradients, and frequently are associated with superthermal ion fluxes. Although their full spatial extent cannot be determined, the ion trough dimensions as perceived along the PVO orbit track extend from 1 to more than 10° in latitude and longitude. Troughs have been encountered as altitudes ranging from more than 1000 to less than 250 kilometers. The nightside trough boundaries are similar to both the ionization gradients which mark the Venus dayside ionopause and the ionization gradients which define the high-latitude ionization trough in the earth ionosphere. In each of these Venus and earth phenomena there is a close association between sharp gradients in thermal ion distribution and energetic and dynamic processes stimulated by the interaction between the solar wind/interplanetary magnetic field (IMF) and the thermal ionosphere. A close correlation is identified between ion trough events and prominent published examples of 100-Hz plasma waves detected by the orbiter electric field detector (QEFD), which have been interpreted by Scarf and Russell (1983) and by Ksanfomaliti *et al.* (1983) as whistler mode propagation stimulated by lightning in the lower atmosphere and frequently occurring over mountains. While the occasional coincidence between the detection of whistler waves and the overflight of Venus mountain ranges is also observed for the ion troughs, neither phenomenon is seen to exhibit convincing evidence of an association with the mountains. Overall, these findings lead us to believe that many of the 100-Hz noise bursts previously attributed to lightning are, like the ion troughs, actually the result of the interaction between the ionosphere and the combined effects of the solar wind and the draped IMF. If this interpretation is correct, there may be little evidence for lightning from the PVO measurements. Similarly, a supporting argument for active volcanism as a possible source for the deduced lightning events would also be discounted.

Taylor, H. A. Jr., Mayr, H. G., Niemann, H. B. and Larson, J. (NASA/Goddard Space Flight Center, Lab. for Planetary Atmospheres, Greenbelt, MD 20771): 'Empirical Model of the Composition of the Venus Ionosphere: Repeatable Characteristics and Key Features not Modeled', *Adv. Space Res.* **5**(9) (1985), 157–163.

In-situ measurements of positive ion composition of the ionosphere of Venus are combined in an empirical model which is a key element for the Venus International Reference Atmosphere (VIRA) model. The ion data are obtained from the Pioneer Venus Orbiter Ion Mass Spectrometer (OIMS) which obtained daily measurements beginning in December 1978 and extending to July 1980 when the uncontrolled rise of satellite periapsis height precluded further measurements in the main body of the ionosphere. For this period, measurements of 12 ion species are sorted into altitude and local time bins with altitude extending from 150 to 1000 km. The model results exhibit the appreciable nightside ionosphere found at Venus, the dominance of atomic oxygen ions in the dayside upper ionosphere and the increase in prominence of atomic oxygen and deuterium ions on the nightside. Short term variations, such as the abrupt changes observed in the ionopause, cannot be represented in the model.

Taylor, H. A. Jr., Brinton, H., Niemann, H. B., Mayr, H. G., Hartle, R. E., Barnes, A. and Larson, J. (NASA/Goddard Space Flight Center, Lab. for Planetary Atmospheres, Greenbelt, MD 20771): 'In Situ Results on the Variation of Neutral Atmospheric Hydrogen at Venus', *Adv. Space Res.* **5**(9) (1985), 125–128.

The definitive data set for the mean thermal structure of the Venusian middle atmosphere is published for the first time. Some recent interim results on a modelling study to interpret the measured thermal field in terms of the global dynamics are also presented. These indicate that (a) the zonal winds on Venus fall to very low values above about 90 km, (b) there is a strong mid-latitude jet which circles the planet approximately every two days, (c) the observed solar tides are dominated by the semi-diurnal component, in agreement with theory.

Tomasko, M. G., Doose, L. R. and Smith, P. H. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'The Absorption of Solar Energy and the Heating Rate in the Atmosphere of Venus', *Adv. Space Res.* **5**(9) (1985), 71–79.

The Solar Flux Radiometer (LSFR) experiment on the large probe of the Pioneer Venus (PV) mission made detailed measurements of the vertical profile of the upward and downward broadband flux of sunlight at a solar zenith angle of 65.7°. These data have been combined with cloud particle size distribution measurements on the PV mission to produce a forward-scattering model of the Venus clouds. The distribution of clouds at high altitudes is considered by measurements from the PV orbiter. Below the clouds the visible spectrum and flux levels are consistent with Venera measurements at other solar zenith angles. The variations in the optical parameters with height and with wavelength are summarized in several figures. The model is used to evaluate the solar heating rate at cloud levels as a function of altitude, solar longitude, and latitude for use in dynamical studies.

18. SPACE UTILIZATION (COLONIZATION, ETC.)

Brookman, D. C.: 'Colonizing the Moon and Mars in the 21st Century', *Design News* **41**(7) (1985), 86–87, 90–92, 94, 96.

Columbus, Magellan, Lewis and Clark, Amundsen, and Cousteau are examples of an inherent human urge to explore the uncharted. Now we are going to open up the last frontier – space.

Harris, P. R. (Harris International, 2702 Costebelle Drive, La Jolla, CA 92037): 'Living on the Moon: Will Humans Develop an Unearthly Culture?', *Futurist* **19**(2) (1985), 30–35.

When a large lunar base is established, possibly by the year 2010, a new space culture will begin to develop. In adapting to their new environment, lunar settlers will develop new lifestyles, new values, and a new vocabulary.

Stephenson, D. G.: 'Commercializing Space' *Spaceflight* **27** (1985), 30–33.

Space technology has progressed to the point where it will soon be possible to use space vehicles to advertise commercial products to millions on Earth. Here the author expresses his personal conception of one way in which this could occur.

Von Puttkamer, J. (Office of Space Flight, NASA Headquarters, Washington, DC 20546): 'Space. The Long-Range Future', *Spaceflight* **27**, (1985), 348–352.

The next major US space programme is the permanent Space Station, due to begin operations in the early 1990's. As the author points out, it is really just the beginning of a breathtaking array of possibilities for future space ventures.

19. ASTEROIDS

Binzel, R. P. (Dept. of Astronomy, Univ. of Texas at Austin, TX 78712): 'Is 1220 Crocus a Precessing, Binary Asteroid?', *Icarus* **63** (1985), 99–108.

Photoelectric observations of asteroid 1220 Crocus (an Eos family member) show evidence for two distinct periods in its light variation: 30.7 days and 7.90 hr. The lightcurve amplitudes are 0.87 and 0.15 mag, respectively. The shorter period variation appears to be modulated over the longer period. Two periods are possible for a rigid body only if it is in a state of precession. The observations are shown to be compatible with a body in a forced precession state. This result leads us to hypothesize the existence of a satellite of Crocus as the source of the external torque. Calculations are presented which show that there are in fact dynamically possible 'binary asteroid' solutions consistent with the observations. More photoelectric and perhaps direct (space telescope) observations are needed to resolve the true nature of this asteroid.

Brahic, A. (Université Paris VII et Observatoire de Paris, 92190 Meudon, France): 'The J.W.G. Asteroid Mission', *Adv. Space Res.* **5**(2) (1985), 97–106.

By the early 1990's, asteroids will be the only major class of objects in the Solar System still awaiting the visit of a spaceprobe. Asteroids are thought to be closely related to the very early stages of the Solar System. They are also of interest because of their relationship with meteorites and their collisional history, and as potential sources of raw materials. After several studies of space missions towards the asteroids over the past few years both in the U.S. and Europe, the N.A.S. and the E.S.F. have formed a Joint Working Group to undertake a study for a joint U.S.-European space mission programme for the exploration of the planets. Following the advice of the Primitive Bodies Study Team, a multiple asteroid orbiter with fly-bys has been recommended with a Saturn-Titan and a Mars mission. The main conclusions of the Study Team final report are presented here.

Butterworth, P. S. and Meadows, A. J. (Observatoire de Paris, 92190 Meudon, France): 'Ultraviolet Reflectance Properties of Asteroids', *Icarus* **62** (1985), 305–318.

An analysis of the UV spectra of 28 asteroids obtained with the Internal Ultraviolet Explorer (IUE) satellite is presented. The spectra lie within the range 2100–3200 Å. Our results are examined in terms of both asteroid classification and of current ideas concerning the surface mineralogy of asteroids. For all the asteroids examined, UV reflectivity declines approximately linearly toward shorter wavelengths. In general, the same taxonomic groups are seen in the UV as in the visible and IR, although there is some evidence for asteroids with anomalous UV properties and for UV subclasses within the S class. No mineral absorption features are reported of strength similar to the strongest features in the visible and IR regions, but a number of shallow absorptions do occur and may provide valuable information on the surface composition of many asteroids.

Chapman, C. R. (Planetary Science Inst., Suite 201, 2030 E. Speedway, Tucson, AZ 85719): 'The Asteroids: The Major Scientific Issues' *Adv. Space Res.* **5**(2) (1985), 121–122.

The asteroids are a collisionally and dynamically evolved population of small bodies in the inner solar system. During the past decade and a half, ground-based astronomical data have yielded much new insight concerning their physical nature. Meteoritical studies and theoretical research programs have also augmented our understanding of these important objects, which are presumably the remnants of

the planetesimal populations from which the terrestrial planets accreted. The time is ripe for applying the scientific capabilities of spacecraft missions in order to address fundamental questions concerning the composition and geological structure of representative asteroids.

Debehogne, H., Netto, E. R., Caldeira, J. F., Machado, L. E. and Vieira, G. G. (Observatoire Royal de Belgique, 3 Ave. Circulaire, Uccle-Brussels 18, Belgium): 'Observed Asteroids at the GPO, La Silla, Chile September 1983', *Rev. Mexicana Astron. Astrof.* **11** (1985), 43–47.

Continuing the observational program which was started in 1978 at the ESO, La Silla, Chile, E.R. Netto, from the Valongo Observatory (UFRJ) and H. Debehogne (O.R.B.), during August 25 to September 20, 1983, have obtained photographic plates for the determination of the positions of asteroids selected by Ephemeridy Malych Planet-1983, and for the possible discovery of new celestial bodies, and also for possible reidentification of lost asteroids, or badly observed ones during the last years. Avaliation of the Valongo plates have revealed 12 asteroids from the Russian ephemeris, and 9 which were not mentioned in this source. The G.P.O. telescope (D = 40 cm; F = 4 m) was used.

Dermott, S. F., Gradie, J. and Murray, C. D. (Center for Radiophysics and Space Research, Space Sciences Building, Cornell Univ., Ithaca, NY 14853-0355): 'Variation of the UBV Colors of S-Class Asteroids with Semimajor Axis and Diameter', *Ithacus* **62** (1985), 289–297.

The mean UBV color of S-class asteroids varies markedly with distance from the Sun and may also vary with diameter, implying either that the surface properties of the asteroids have been modified by space weathering or, as suggested here, that there are least two major subclasses of S-class asteroids with different mean locations.

Garfinkel, B. (Dept. of Astronomy, Yale Univ., New Haven, CT 06511): 'The Theory of the Trojan Asteroids, Part V', *Celestial Mechanics* **36** (1985), 19–45.

E. W. Brown conjectured (1911) that the family of the long-periodic orbits in the Trojan case of the restricted problem of three bodies terminates in an asymptotic orbit passing through the Lagrangian point L_3 at $t = \pm\infty$. In 1977 the author showed that such an orbit deviates from L_3 by the epicyclic term $mq(\pm\infty)$. It is shown here that

$$q(\pm\infty) = 0,$$

so that the Brown conjecture regarding L_3 is false.

Contrary to what Brown believed, there is an entire family of *homoclinic* orbits, doubly asymptotic to short-periodic orbits around L_3. In the complex z-plane of the Poincaré eccentric variables, the latter orbits are circles of radius mR, with R bounded away from zero. The kinematics of the homoglinic family is investigated here in some detail.

Gehrels, T. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Fundamental Studies of Asteroids', *Bull. Astr. Soc. India* **12** (1985), 16–39.

Planetesimals are intermediate stages, in the kilometer size range, between interstellar matter and large bodies such as planets and stars. Planetesimals can still be studied in the form of asteroids although they have been modified by mutual collisions since their formation. The collisional fragments are gravitationally perturbed by Jupiter into the inner part of the solar system where they are observed as near-earth asteroids.

Green, S. F., Eaton, N., Aitken, D. K., Roche, P. F. and Meadows, A. J. (Astronomy Dept., Univ. of Leicester, LE1 7RH, U.K.): '8- to 13-Micron Spectral of Asteroids', *Icarus* **62** (1985), 282–288.

We present 8- to 13-μm spectra of the main-belt asteroids 1, 2, 6, 7, 10, 16, 45, 51, 56, 65, 78 and 451. None of these exhibit pronounced emission features, and all can be fitted reasonably well using a standard thermal model. We also present wide- and narrowband photometery of 19 Fortuna, which has previously been reported to show an emission feature in this region.

Hartke, D. and Möhlmann, D. (Institut für Kosmoforschung der Akademie der Wissenschaften der D.D.R., Rudower Chaussee 5, 1199 Berlin, D.D.R.): 'Fly-By Missions to Near-Earth Asteroids', *Adv. Space Res.* **5**(2) (1985), 107–110.

Based on the TRIAD-catalogue and the Ephemerides of the Leningrad Institute for Theoretical Astronomy, orbits of 26 asteroids with small inclinations and one (or both) nodal points inside 1.5 AU are investigated to find objects appropriated for a near – asteroid fly-by in course of a Hohmann – transfer to Venus or Mars. Up to 1998 especially 2340 Hathor, 2062 Aten and 1982 XB could be visited on this way. Furthermore, the near-Earth positions of seven asteroids could be a cause for direct missions to these objects while a near – Mercury fly-by of 2340 Hathor in April 1991 has been found to be appropriated for a direct Hathor-Mercury mission.

Kozai, Y. (National Astronomical Observatory, Mitaka, Tokyo 181, Japan): 'Secular Perturbations of Resonant Asteroids', *Celestial Mechanics* **36** (1985), 47–69.

Secular perturbations of asteroids are derived for mean motion resonance cases under the assumptions that the disturbing planets are moving along circular orbits on the same plane and that critical arguments are fixed at stable equilibrium points. Under these assumptions the equations of motion are reduced to those of one degree of freedom with the energy integral. The equi-energy-curves on $(2g - X)$ plane (g and X being, respectively, the argument of perihelion and $(1 - e^2)^{1/2}$) are derived for given values of the two constant parameters, the semi-major axis and $\theta = (1 - e^2)^{1/2} \cos i$, and the variations of the eccentricity and the inclination as functions of the argument of perihelion are graphically estimated. In fact this method is applied to numbered asteroids with commensurable mean motions to estimate the ranges of the variations of orbital elements.

The same method is also applied to the Pluto-Neptune system and the results are found to agree with those of numerical integrations and show that the argument of perihelion of Pluto librates around 90°.

Liu, L. and Innanen, K. A. (Physics Dept., York Univ., Toronto M3JIP3, Canada): 'Studies on Orbital Resonance. III', *Astron. J.* **90** (1985), 1906–1909.

Numerically derived data from the orbits of 70 asteroids with orbital commensurabilities with Jupiter's orbit are used to check the accuracy and limitations of theory discussed in Papers I and II. It is confirmed that the dominant effect of the perturber (Jupiter) is its orbital eccentricity. The major features of the computed orbits are outlined.

McFadden, L. A., Gaffey, M. J. and McCord, T. B. (Astronomy Program, Univ. of Maryland, College Park, MD 20742): 'Near-Earth Asteroids: Possible Sources from Reflectance Spectroscopy', *Science* **229** (1985), 160–163.

Spectra of near-Earth asteroids were compared to spectra of selected asteroids, planets, and satellites to determine possible source regions. The diversity of reflectance spectra of the near-Earth asteroids implies different mineralogical compositions and hence more than one source region. The presence of near-Earth asteroid spectral signatures similar to those of certain main-belt asteroids supports models that derive some of these asteroids from the 5:2 Kirkwood gap and the Flora family by gravitational perturbations. Planetary and satellite surfaces are different in composition than the near-Earth asteroids, which is in agreement with theoretical arguments that such bodies should not be sources.

Some near-Earth asteroids supply portions of Earth's meteorite flux, but other sources must also contribute.

Ostro, S. J., Campbell, D. B. and Shapiro, I. I. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'Mainbelt Asteroids: Dual-Polarization Radar Observations', *Science* **229** (1985), 442–446.

Observations of 20 asteroids in the main belt between Mars and Jupiter provide information about the nature of these objects' surfaces at centimeter-to-kilometer scales. Each asteroid appears mcuh rougher than the Moon at some scale between several meters and many kilometers. The range of asteroid radar albedos is very broad and implies substantial variations in porosity of metal concentration (or both). The highest albedo estimate, for the asteroid Psyche, is consistent with a surface having porosities typical of lunar soil and a composition nearly entirely metallic.

Piironen, J. O., Poutanen, M., Di Martino, M. and Zappala, V. (Univ. of Helsinki, Observatory and Astrophysics Lab., 00130 Helsinki 13, Finland): 'UBV Observations and Pole Determinations of Asteroids 15 Eunomia', *Astron. Astrophys. Suppl.* **61** (1985), 299–302.

Photometric observations of asteroids 15 Eunomia and 354 Eleonora are presented. Pole positions are determined for both asteroids using the Amplitude-Magnitude method (Zappalà *et al.*, in *Asteroids, Comets, Meteors*, pp. 73–76). Assuming a biaxial ellipsoid model, the resulting pole positions are ($\lambda_0 = 164° \pm 5°$, $\beta_0 = 52° \pm 5°$) for Eunomia, and ($\lambda_0 = 355° \pm 7°$, $\beta_0 = 36° \pm 8°$) for Eleonora. For 15 Eunomia a triaxial equilibrium shape with $b/c = 1.4$ gave essentially the same result ($\lambda_0 = 170° \pm$, $\beta_0 = 57° \pm 5°$).

Pospieszalska-Surdej, A. and Surdej, J. (European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-8046 Garching bei München, F.R.G.): 'Determination of the Pole Orientation of an Asteroid. The Amplitude-Aspect Relation Revisited', *Astron. Astrophys.* **149** (1985), 186–194.

Near the opposition of a minor planet the geometrical approximation essentially constitutes a good representation of the Hapke-Irvine relation for describing the scattering properties of a surface layer, and we show that the normalized light curve – i.e. I_r^2 versus $\cos^2(\psi)$, where I_r is the relative intensity of a measurement observed at phase ψ – of a three-axes ellipsoid model reduces to a straight line whose slope depends only on the aspect angle A and on the semi-axes ratios a/b, b/c of the ellipsoid. A set of nonlinear equations – including at least one equation per opposition – is then solved by a least squares method in order to derive the four unknown parameters λ_0, β_0 (ecliptic coordinates of the pole) and a/b, b/c. The use of realistic standard deviations as well as of a covariance matrix allows one to fully estimate the degree of accuracy, correlation, etc. affecting the derivation of these parameters. Among several other advantages offered by the present technique, let us mention that: (i) it allows one to test meaningfully the applicability of the amplitude-aspect relation for a given asteroid; (ii) it does not make use of additional and *uncertain* magnitude-aspect relations; (iii) every single photometric measurement within a light curve is taken into account, rather than just the amplitude. Furthermore, it is found that the occultation effect can always be neglected as long as the phase angle $\alpha \leqslant 15°$. As a practical example, we have applied this technique to published observations of two asteroids. For 624 Hektor, two possible solutions are found:

$\lambda = 314°.6 \pm 2°.0$, $\beta_0 = 15°.9 \pm 4°.1$, $a/b = 2.27 \pm 0.03$ and
$b/c = 1.41 \pm 0.16$ for the first pole (P_1), and
$\lambda_0 = 151°.5 \pm 2°.1$, $\beta_0 = 27°.0 \pm 4°.2$, $a/b = 2.26 \pm 0.03$ and
$b/c = 1.29 \pm 0.12$ for the second one (P_2).

For the case of 44 Nysa, we show that additional observations are needed in order to derive a self-consistent pole orientation.

Poutanen, M., Bowell, E., Martin, L. J. and Thompson, D. T. (Univ. of Helsinki, Observatory and Astrophysics Lab., Tahtitorninmaki, SF-00130 Helsinki, Finland): 'Photoelectric Photometry of Asteroid 69 Hesperia', *Astron. Astrophys. Suppl.* **61** (1985), 291–297.

UBV observations on 21 nights in 1977 have been used to establish the rotational lightcurve and the shape of the phase curve of the M asteroid Hesperia for phase angles ranging from 0.13° to 16°. Temporal or phase angle related changes in the lightcurve shape were small. There is evidence for large-scale albedo variegation of a few percent over Hesperia's surface. The synodic rotation period is 5.65537 ± 0.00064 hr; the zero phase color indices are $B - V = 0.68$ mag and $U - B = 0.24$ mag, with phase reddening of 0.003 mag/deg in $B - V$, and the absolute zero phase magnitude at primary maximum is $V = 7.04$.

Sagdeev, R. Z., Managadze, G. G., Shutyaev, I. Yu., Szego, K. and Timofeev, P. P. (Institute for Space Research, Moscow, U.S.S.R.): 'Methods of Remote Surface Chemical Analysis for Asteroid Missions', *Adv. Space Res.* **5**(2) (1985), 111–120.

In this paper different active remote sensing methods are discussed which can be applied to investigate the composition of minor solar bodies. Methods using ion, laser and electron beams are treated in detail.

Scholl, H. (Observatoire de Nice, B.P. 139, F-06003 Nice Cedex, France): 'Review of Asteroidal Dynamics', *Adv. Space Res.* **5**(2) (1985), 123–132.

It is a major goal of research in the field of asteroidal dynamics to relate the distribution of orbital elements to the evolutionary history of the asteroidal belt The distribution of orbital elements shows characteristics which are presumably of cosmogonic significance. In particular the distribution of the mean eccentricities and inclinations of asteroidal orbits, the gaps and clusterings of asteroidal semi-major axes are related to the dynamical evolution of the asteroidal belt. Gaps are associated with resonance phenomena. The clustering of asteroidal semi-major axes is associated with resonances or like in the case of Hirayama families with an early break-up of a parent body. Another dynamical problem present the planet-crossers, in particular the Earth-crossers since their low collisional lifetimes require a source. Presumably, the Earth-crossers are a mixture of asteroidal collisional fragments and of extinct cometary nuclei. For this reason, Earth-crossers are of high interest as targets for spaceflights.

Taylor, R. C., Tapia, S. and Tedesco, E. F. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'The Rotation Period and Pole Orientation of Asteroid 4 Vesta', *Icarus* **62** (1985), 298–304.

In 1971 asteroid Vesta was observed in a region of the sky in which it had never been observed before. Its photometric lightcurve had two distinct maxima. Those observations have been the only strong evidence to support a rotation period of about 10 hr 41 min. Lightcurves made in 1982, when Vesta was at the same aspect as 1971, do not show two different maxima. It is concluded that there was a systematic error in the 1971 observations. At this time a definitive statement cannot be made about the true period of Vesta, although the 5 hr 20 min period does appear more plausible. Radar echoes in 1988 and 1992 should resolve the problem. The shorter rotation period was assumed and the photometric astrometry method applied. The sidereal period is 5 hr 20 min 31.68 sec (0.2225889 ± 0.0000002 days), the rotation is prograde, and the coordinates of the north pole are 103° longitude and +43° latitude with an uncertainty of about 6°.

Zappala, V., Martino, M. Di., Hanslmeier, A. and Schober, H. J. (Osservatorio Astronomico di

Torino, I-10025 Pino Torinese, Italy): 'New Cases of Ambiguity among Large Asteroids' Spin Rates', *Astron. Astrophys.* **147** (1985), 35–38.

New observational evidence supports the importance of the ambiguity problem about determination of the spin rate of asteroids. In the range of objects larger than about 150 km, where equilibrium figures are thought to exist, and therefore where irregular fragments should be absent, four cases of periods shorter by a factor two than the previously adopted values, believed unambiguous, were recently found. This paper presents results for two of them (409 *Aspasia* and 423 *Diotima*), attempting to give plausible physical interpretations, but admitting that a quantitative explanation cannot be reached with the present knowledge of the asteroids' surface morphology. Still, the discrepancies found in preliminary analyses seem to be satisfactorily overcome.

Zeigler, K. W. and Florence, W. B. (Gila Observatory, P.O. Box 362, Claypool, AZ 85532): 'Photoelectric Photometry of Asteroids 9 Metis, 18 Melpomene, 60 Echo, 116 Sirona, 240 Athamantis, 694 Ekard, and 1984 KD', *Icarus* **62** (1985), 512–517.

Photoelectric observations of seven asteroids were made from Gila Observatory between October 14, 1983, and June 21, 1984. The following synodic rotational periods and amplitudes are reported: 9 Metis, $P = 5.04$ hr, $\Delta M = 0.05$; 18 Melpomene, $P = 11.570$ hr, $\Delta M = 0.22$; 60 Echo, $P = 25.208$ hr, $\Delta M = 0.22$; 116 Sirona, $P = 12.028$ hr, $\Delta M = 0.42$; 230 Athamantis, $P = 23.99$ hr, $\Delta M > 0.20$; 694 Ekard, $P = 5.925$ hr, $\Delta M = 0.50$; 1984 KD, $P = 1.97$ hr, $\Delta M = 0.26$. The rotational periods reported for asteroid 60 Echo, 116 Sirona, 694 Ekard, and 1984 KD represent completely new results. The synodic rotational period reported for asteroid 1985 KD is tentative and is based largely upon the observations of a single night. The reported synodic periods of the remaining six asteroids are based upon a minimum of 3 nights of photometric observations.

Zellner, B., Thirunagari, A. and Bender, D. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'The Large-Scale Structure of the Asteroid Belt', *Icarus* **62** (1985), 505–511.

We examine the distributions of 2888 numbered minor planets over orbital inclination, eccentricity, and semimajor axis, and define 19 zones which we believe adequately to isolate the selection biases in survey programs of the physical properties of minor planets. Six numbered asteroids have exceptional orbits and fall into no zone. We also call attention to rather sharp upper limits, which become increasingly stringent at larger heliocentric distances, on orbital inclinations and eccentricity.

20. COMETS

Arnold, H. J. P.: 'Photographing Halley's Comet', *Spaceflight* **27** (1985), 298–301.

Photographing Halley's comet when it appears in the skies towards the end of this year will not be a simple task. The author provides a guide to help the amateur.

Bortle, J. E. (W. R. Brooks Observatory): 'Comet Halley: A Newsmaker for 2,000 Years', *Sky and Telescope* **70**(2) (1985), 126–127.

The comet's upcoming apparition includes a moderately good post-perihelion encounter with Earth. Next April observers in the Southern Hemisphere could see a display considerably more striking than first anticipated. With the comet's head (perhaps as bright as 1st or 2nd magnitude) nor far from the zenith and unaffected by atmospheric absorption. Halley should appear like a condensed version of the Pleiades with a long tail pointing down toward the horizon.

Bortle, J. E. (W. R. Brooks Observatory): 'A Halley Chronicle', *Astronomy* **13**(10) (1985), 98–110.

I've consolidated a lot of material into 29 'chapters', each briefly detailing one of the comet's returns. I've also included an ephemeris (1950.0 epoch) that will let you plot the comet's paths on a star atlas. Besides right ascension and declination, the ephemerides tell you how far Halley was from the Earth (d) and the Sun (r) in astronomical units, the elongation from the Sun (e) in degrees, and the "retrodicted" total magnitude (mag).

Brown, R. H., Cruikshank, D. P. and Griep, D. (Planetary Geosciences Div., Hawaii Inst. of Geophysics, Univ. of Hawaii, 2525 Correa Road, Honolulu, HI 96822): 'Temperature of Comet IRAS-Araki-Alcock (1983D)', *Icarus* **62** (1985), 273–281.

Infrared (1.5–20 μm) observations of the nuclear condensation of Comet IRAS–Araki–Alcock (1983d) during the interval 5–8 May 1983 (UT) show that the distribution of 3.5- to 20-μm radiation was blackbody in character with no evidence of 10-μm emission from silicate grains in the coma of the comet. The observed color temperature of the nuclear condensation of the comet was $319 \pm 5°$ K on 7 May and $307 \pm 5°$ K on 8 May. Low-resolution spectrophotometry on 5 May in the 1.5- to 2.6-μm region shows no obvious emission or absorption features, but thermal radiation of approximately the same color temperature as the 3.5- to 20-μm radiation was present along with reflected sunlight. Scans of the nuclear region of the comet indicate that most of the thermal radiation observed at 11.6 and 20.0 μm came from an $\leq$ 120-km-diameter, unresolved area centered on the nuclear region. Absolute flux measurements suggest that projected areas (unit emissivity) of 70 and 40 km^2 were responsible for the thermal radiation from the nuclear condensation on 7 and 8 May, respectively. This large change in total surface area suggests that the amount of dust in the nuclear region of Comet 1983d was highly variable and is consistent with the observation by M. A. Feierberg, F. C. Witteborn, J. R. Johnson, and H. Campins (1984, *Icarus* **60**, 449–454) of an outburst on 11 May 1983.

Clube, S. V. M. and Napier, W. M. (Dept. of Astrophysics, South Parks Road, OX1, 3RQ, Oxford, U.K.): 'Comet Formation in Molecular Clouds', *Icarus* **62** (1985), 384–388.

The observed properties of the long-period comet system, and its periodic disturbance by galactic forces manifesting as terrestrial impact episodes, may be indicative of a comet capture/escape cycle as the Solar System orbits the Galaxy. A mean number density of comets in molecular clouds of $\sim 10^{-1 \pm 1}$ AU^{-3} is implied. This is sufficient to deplete metals from the gaseous component of the interstellar medium, as observed, but leads to the problem of how stars are formed nevertheless with solar metal abundances. Formation of comets *prior to* stars in dense systems of near-zero energy may be indicated, and isotope signatures in cometary particles may be diagnostic of conditions in young spiral arm material.

Cook, A. (Griffith Observatory, 1800 East Observatory Road, Los Angeles, CA 90027): 'Comet Halley: the 1985–86 Apparition, an Outline', *Griffith Observer* **49**(9) (1985), 14–16.

Comet season opens on 11 September 1985, with an International Cometary Explorer flyby of Comet Giacobini-Zinner and the premiere performance of Griffith Observatory's homage to Comet Halley in the planetarium theater. Griffith Observatory Telescope Demonstrator Anthony Cook has been keeping us posted on Comet Halley's approach (his last 'Comet Halley Update' – number 4 – appeared in the July, 1985, issue of the (*Griffith Observer*), but here he offers advice on the Comet Halley yet to come.

Covault, C.: 'First Comet Probe Reveals Structure of Great Complexity', *Aviation Week and Space Technology* **123**(11) (1985), 16–18.

The first direct exploration of a comet carried out Sept. 11 by the U. S. International Cometary Explorer (ICE) satellite has shown that the thousands of comets roaming the solar system are likely to be far more complex and dynamic than Earth-based observation and analysis have indicated.

Covault, C.: 'Comet Data Confirm that Ice is the Primary Structural Element', *Aviation Week and Space Technology* **123**(13) (1985), 46–47, 49.

The U. S. International Cometary Explorer (ICE) spacecraft that flew Sept. 11 into the comet Giacobini-Zinner made direct measurements confirming the theory that comets are 'dirty snowballs' composed of ice that erupts into a reverse snowstorm of material lifting off the comet's surface as it approaches the Sun.

De Pater, I., Wade, C. M., Houpis, H. L. F. and Palmer, P. (Astronomy Dept., Univ. of California, Berkeley, CA 94720): 'The Nondetection of Continuum Radiation from Comet IRAS-Araki-Alcock (1983D) at 2- to 6-cm Wavelengths and Its Implication on the Icy-Grain Halo Theory', *Icarus* **62** (1985), 349–359.

Observations of Comet IRAS–Araki–Alcock have been made with the VLA (Very Large Array) at 6 and 2 cm, when the comet was at geocentric distances of 0.08 and 0.035 AU, respectively. The 3σ upper limits are 90 and 750 μJy at 6 and 2 cm, respectively. We show that the 'conventional' icy-grain halo theory is not adequate to explain the data. If there is such a halo, it is either very thin, or does not contain grains with sizes larger than 10–100 μm. Comparison of our limits with a reported detection at 1.3-cm wavelengths shows that if the centimerer-wavelength radiation all arises in the halo, the halo should have an extent of the order of 300–400 km, but an effective area of 100 km^2. If only thermal emission from the nucleus is significant, the temperature decreases from about 200 K at the layers probed at 1.3 cm to about 50 K or less at depths probed at 2 cm (assuming unit emissivity at all wavelengths and depths). This can be due to a combination of a lower emissivity and lower physical temperature at larger depths in the comet; both effects are expected when considering theories on microwave emission from glaciers on Earth.

Eberhart, J.: 'The Ice Plan Cometh', *Science News* **128** (1985), 138–139.

Half a year before an international cluster of spacecraft visits Comet Halley, a little probe borrowed from a totally different kind of mission is about to become the first man-made object ever to visit a comet.

Gombosi, T. I., Cravens, T. E. and Nagy, A. F. (Space Physics Research Lab., Univ. of Michigan, Ann Arbor, MI 48109): 'Time-Dependent Dusty Gasdynamical Flow Near Cometary Nuclei', *Astrophys. J.* **293** (1985), 328–341.

This paper presents time-dependent solutions to the coupled dusty hydrodynamics equations describing the spherically symmetric expansion of cometary neutral gas in the vicinity of a cometary nucleus. The sublimation process is represented by gas outflow from a dust-covered reservoir containing stationary gas whose pressure and density values are determined by the sublimating (T_s) and surface (T_0) temperatures. The model resolves earlier ambiguities in determining gas production rates and provides analytic relations between T_s, T_0, and the gas parameters at the sonic point.

The time evolution of a cometary outburst was modeled. It was found that, as a result of the strong gas-dust interaction in the inner coma region, a 'slow' disturbance in both the dust and gas parameters will be created in addition to the familiar gas blast-wave solution. This new 'slow' disturbance, which propagates with a velocity of about 0.2 km s^{-1}, might be responsible for some of the observed slowly expanding cometary halos, such as the one which was recently identified using 1910 Mount Wilson high-resolution comet Halley photographs.

Horanyi, M. and Mendis, D. A. (Central Research Inst. for Physics, Hungarian Academy of Sciences, Budapest, Hungary): 'Trajectories of Charged Dust Grains in the Cometary Environment', *Astrophys. J.* **294** (1985), 357–368.

Using a simple model of the particles and fields environment of a comet, we have calculated the trajectories of the smallest (micron- and submicron-sized) dust grains that are expected to be released from the cometery nucleus. It is shown that electromagnetic forces play a crucial role in the dynamics of these particles. The present calculations indicate not only the asymmetry of the sunward dust envelopes that have been suggested earlier by other authors, but they also indicate the possible existence of wavy dust features far down the tail, reminiscent of the peculiar wave dust feature observed in the dust tail of Comet Ikeya-Seki 1965f. The importance of these findings in studying the lower end of the cometary dust mass spectrum during the forthcoming fly-by missions to Comet Halley is underscored.

Hoyle, F., Wickramasinghe, N. C. and Wallis, M. K. (University College, Cardiff, Wales, UK): 'The Nature of Dust Grains in the Comae of Comets Cernis and Bowell', *Earth, Moon, and Planets* **33** (1985), 179–187.

The currently available infrared data on scattered light from the dust comae of Černis and Bowell set stringent upper limits to the contribution of icy grains. For Comet Černis the data is consistent with only a 10% mass fraction of water-ice included within silicate-organic-carbon grains of scale radius 15 microns, while for Comet Bowell there is no evidence for any ice component. A coma of small (10–100 μm) organic grains containing a fraction of OH-bearing molecules that evaporate over weeks at 5 AU and leave an absorptive carbonaceous grain residue is the simplest model for Comet Bowell.

Hughes, D. W. (Dept. of Physics, Hicks Building, The University, Sheffield, S3 7RH, UK): 'Year Posts Round the Orbit of Halley's Comet', *Brit. Astron. Assoc.* **95** (1985), 162–163.

A note on plotting to scale the orbit of Halley's comet and its changing velocity.

Hut, P. and Tremaine, S. (Inst. for Advanced Study, Princeton, NJ 08540):'Have Interstellar Clouds disrupted the Oort Comet Cloud?', *Astron. J.* **90** (1985), 1584–1557.

We derive formulas describing the disruption rate of the Oort comet cloud due to encounters with interstellar clouds and field stars. For a comet with semimajor axis $a = 25\,000\ AU$, the half-life due to encounters with stars is 3×10^9 yr, due to encounters with molecular clouds 3×10^9 yr. and due to encounters with atomic clouds 5×10^{10} yr. These results are based on a local density of molecular gas $\rho_0 = 0.024 M_\odot/pc^3$, a mean column density $N_H = 10^{22}\,cm^{-2}$, and a clumpiness factor of 2. We also assume that the mean density of molecular gas averaged over the solar lifetime was a factor of 1.5 higher than the present density. Thus it appears that molecular clouds have had a substantial, but not devastating, effect on the Oort cloud. However, many of the important parameters are rather uncertain, and the best argument that the Oort cloud has survived encounters with interstellar clouds is an observational one: a significant fraction of field stars are found in wide binary systems whose half-life due to encounters with interstellar clouds is within a factor of 2 of the half-life of the comets.

Ip, W.-H., Fink, U. and Johnson, J. R. (Max-Planck-Institut für Aeronomie, D-3411 Katlenburg-Lindau 3, für Aeronomie, D-3411 Katlenburg-Lindau 3, F.R.G.): 'CCD Observations of Comet Tuttle 1980 XIII: The H_2O^+ Ionosphere', *Astrophys. J.* **293** (1985), 609–615.

A CCD spectrum of comet Tuttle 1980h has been analyzed with emphasis on the emission of H_2O^+ ions. The fine angular resolution (1".5) and the capability of absolute brightness calibration of the

CCD instrument allowed us to determine the spatial concentration of the H_2O^+ ions of this faint comet and the total number of these ions confined within a spherical region. Solar photoionization of the H_2O atmosphere can account for the production of the H_2O^+ ions observed in the confined region. The dimension of the H_2O^+ ionosphere at the time of observation was found to be comparatively small, implying the possible existence of an ionopause sharply delineating the extension of the cometary ionosphere.

Jenkins, R. and Simpson, J. (British Aerospace Space and Communication Div. Filton, England): 'GIOTTO and the Journey to Halley's Comet', *New Scientist* **106**(1462) (1985), 50–53.

Astronomers had their first opportunity to photograph Halley's Comet when it last appeared in 1910. This time around, the Giotto spacecraft will probe the comet's heart. How was the spacecraft made ready for its 700-million-kilometre journey?

Kerr, R. A.: 'A Comet's Hearth may be Big But Black', *Science* **229** (1985), 372–373.

Astronomers straining to catch a glimpse of the 'dirty snowball' of Comet Halley are finding that it may be bigger and dirtier than thought.

Kerr, R. A.: 'Heading for a Dusty Death at Comet Halley?', *Science* **229** (1985), 541–542.

Researchers are betting the success of the GIOTTO mission on their understanding of the debris shed by the comet—big uncertainties remain.

Kerr, R. A.: 'New Plasma Physics Lab at Giacobini-Zinner', *Science* **230** (1985), 51–52.

The ICE spacecraft found action aplenty when it passed through a comet last month; plasma physics has a windfall of new natural experiments.

Marsden, B. G. (Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138): 'Comets in 1980', *R. Astr. Soc. Q. J.* **26** (1985), 156–167.

Another record number of comets – 21 – were given provisional designations in 1980, although one of them turned out not to exist. Of the 20 confirmed objects, 10 were new discoveries (three of them new short-period comets) and 10 were recoveries of returning short-period comets. Observations were also made of the four 'annual' comets and five holdovers from 1979, giving a total of 29.

Martys, C. R. (Applecross, Wyedale Crescent, Bakewess, Derbyshire, DE4 IBE, UK): 'Photographic Observations of Comet IRAS-Araki-Alcock, 1983D', *J. Brit. Astron. Assoc.* **95** (1985), 216–219.

A series of photographs on three different emulsions were obtained on the night of 1983 May 9/10 of comet IRAS-Araki-Alcock, Using an Olympus camera with 50 mm lens. The photographs, on Kodak Ektachrome 400 colour transparency film, 103a–F and hypersensitized Technical Pan 2415 film, are compared with respect to their efficiency in recording a diffuse astronomical object. Subsequent darkroom techniques involved copying the images of the comet obtained on 2415 film in order to produce a high contrast photograph showing the maximum extent of the coma of comet 1983d.

Meier, R. R. and Keller, H. U. (E. O. Hulburt Center for Space Research, Naval Research Lab.,

Washington, DC 20375-5000): 'Note Predictions of the Hydrogen Lyman Alpha Coma of Comet Halley', *Icarus* **62**, 521–537 (1985).

Theoretical predictions of the expected Lyman α emission from the hydrogen coma of Comet Halley, as seen from Earth and Venus orbits, are presented for selected dates during 1985–1986 when the comet is within 2 AU of the Sun. Recommendations for scaling to Lyman β and Balmer α are given.

Mignard, F. and Remy, F. (CERGA, Av. Copernic, 06130 Grasse, France): 'Dynamical Evolution of the Oort Cloud: II. A Theoretical Approach', *Icarus* **63** (1985), 20–30.

We investigate the dynamic evolution of a cloud of comets created by stellar perturbations. We first show the respective advantages of numerical simulations and of studies of more theoretical character. Then we investigate the probability distribution of the velocity changes imparted to comets by passing stars. This distribution is shown to be different from a Maxwellian distribution, mainly because of pronounced tails. The number of fairly large impulses is thus more important than it would be in the case of a Maxwellian distribution. Finally we estimate the probability for a comet to be ejected from the Solar system. About 10% of the cloud population is lost through this mechanism over the age of the Solar System. Taking advantage of the velocity change distribution, we study the random walk of semimajor axes of comets as a function of time. We derive the probability that a comet is lost into interstellar space as a function of its initial semimajor axis.

Remy, F. and Mignard, F. (CERGA, Av. Copernic, 06130 GRASSE, France): 'Dynamical Evolution of the Oort Cloud: I. A Monte Carlo Simulation', *Icarus* **63** (1985), 1–19.

We have studied the long-time dynamical evolution of a population of comets surrounding the Solar System at a large distance. Orbital changes are caused by random passing stars. We first emphasize the need for a new simulation because of the lack of completeness of previous analytical and numerical studies. Then the solar neighborhood is modeled by a sphere of 1 pc in radius, which stars cross at random in direction and distance. The geometry of the encounters allows us to compute the impulse gained by the star and the Sun, in the context of an impact approximation. Then we determine the change of orbital elements for a population of comets and follow the evolution of the frequency distribution for the five Keplerian elements. Clouds are selected in such a way that we test the two main hypotheses for the origin of the Oort cloud, and also the regions of stability in an aphelion-eccentricity diagram. We show that stellar perturbations randomize the cloud and prevent one from inferring the initial cloud configuration from the current distribution. Clouds are depleted by the diffusion of comets into the planetary regions, where they become planet-influenced comets or are ejected from the Solar System. The diffusion of aphelion toward interstellar regions proves to be the major source of cometary loss. Direct ejection to hyperbolic orbits amounts to 9% of the original population over the age of the Solar System. Finally the current and original cloud populations are estimated at 1.8×10^{12} and 2×10^{13} comets and we discuss these results.

Russell, C. T., Schwingenschuh, K., Phillips, J.L. and Arghavani, M.R. (Inst. of Geophysics and Planetary Physics, Univ. of California, Los Angeles, CA 90024): 'Three Spacecraft Measurements of an Unusual Disturbance in the Solar Wind: Further Evidence for a Cometary Encounter', *Geophys. Res. Letters* **12** (1985), 476–478.

On February 11, 1982 the Pioneer Venus orbiter detected an unusual disturbance of the interplanetary magnetic field and solar wind plasma. While this disturbance was being detected as Venus, Venera 13 and 14 were making measurements of the interplanetary magnetic field about 6 million km away. These spacecraft observed at most a very weak disturbance several hours after the peak of the event at Pioneer Venus. Had the event been a solar initiated disturbance it should have been seen almost unaltered by the Venara spacecraft. Thus the Venera 13 and 14 data provide further evidence for the cometary nature of this event.

Schmidt, R. and Arends, H. (Space Science Dept. of ESA/ESTEC, Noordwijk, The Netherlands): 'Laboratory Measurement on Impact Ionization by Neutrals and Floating Potential of a Spacecraft during encounter with Halley's Comet', *Planet. Space Sci.* **33** (1985), 667–673.

A spacecraft penetrating into the dense cloud of ambient gas and dust particles in the coma of Halley's Comet, is exposed to a bombardment by these particles having a high kinetic energy due to the large velocity of the spacecraft relative to the cometary coma. The interaction of the spacecraft and cometary neutral particles was simulated by using neutral beams of different species directed towards various target materials such as aluminium, gold and the white conductive paint PCB-Z. The kinetic energy of the primary beam covered, depending on the species, the range from about 700 eV up to more than 3 keV and contained, except for H_2O, the expected specific ram energy of 24 eV/amu. The highest achievable density corresponded to a distance of slightly less than 10^4 km off the nucleus. Upon impact on the surface of the target, emission of charged as well as neutral secondary particles was initiated. The yields of the charged particles were derived from measurements of the electrical current produced by secondary ions or electrons. The obtained results for the yields complement other measurements performed in parallel to this work. The derived floating potentials show somewhat lower voltages than obtained by model calculations. It was found that for metallic targets, the acquired charging potential due to neutral gas impact lies between 4 and 6 V. In the case of PCB-Z, the averaged floating potential amounts to about 14 V.

Schreur, B. (Dept. of Mathematics, Florida State Univ., Tallahasse, FL 32306): 'Stellar Perturbations of Cometary Orbits and the Production of Long-period Comets', *Texas Journal of Science* **36** (1985), 5–15.

A model of the Oort Comet Cloud containing 10^5 members and with a space density varying roughly as the inverse square of its radius was computed. The effects on the comet orbits due to each of 100 passing stars were construted. The passing stars were chosen to be representative of those which do pass by the sun.

Results indicate that observable comets are produced by small perturbations of large and highly eccentric cometary orbits. It was also found that diffusion from the outer regions limits the cloud radius to 5×10^4 AU.

Sekanina, Z. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'Nucleus Precession of Periodic Comet Comas Solá', *Astron. J.* **90** (1985), 1370–1381.

In a continuing effort to understand the character of the nongravitational acceleration in the motions of comets and the underlying effects of directed outgassing on the stability of the rotation axis, the nucleus properties of periodic comet Comas Solá are studied on the basis of a precession model previously applied by Whipple and Sekanina to P/Encke and by Sekanina to P/Kopff and P/Giacobini-Zinner. The results for P/Comas Solá imply that for a few revolutions about the Sun this comet was precessing more rapidly than any of the other comets studied to date. During each of these revolutions one of the comet's rotation poles is shown to have been essentially fixed on the Sun for about two years about perihelion. When this pattern was upset by a perturbation in the obliquity shortly after the 1952 passage through perihelon, the spin axis rapidly aligned itself with the normal to the orbit plane. This sudden change in precessional behavior brought about a major discontinuity in the parameter A_2 that measures the magnitude of the nongravitational effects in the comet's daily mean motion and it also affected conspicuously the light curve. The derived equatorial radius of P/Comas Solás nucleus is close to 1 km and its rotation periodic is the range between 1.5 and 2.3 days, according to the model. The calculated shape of the comet's nucleus is compared with those of the other comets studied by this technique and with the figure of the nucleus of Comet 1983 VII determined by Goldstein, Jurgens, and Sekanina from spectra of the returned radar signal. Possible evolutionary paths for precessional behavior of comets are briefly discussed.

Sekanina, Z. (MS 183-401, Jet Propulsion Lab., 4800 Oak Grove Dr., Pasadena, CA 91109): 'Light Variations of Periodic Comet Halley beyond 7 AU', *Astron. Astrophys.* **148** (1985), 299–308.

The brightness data on periodic Comet Halley from the period October 1982–February 1984 have been examined for evidence on the nucleus rotation period and projected cross section area. When corrected for heliocentric and geocentric distances and for a phase effect, and reduced to a common photometric system, the data show variations of up to 5:1 in intrinsic brightness, corresponding to a range from 0.48 to 2.40 km^2 in the photometric cross section. If attributed to albedo changes, the brightness amplitude implies an effective nucleus radius of 2.8 km for assumed geometric albedos 6–30% and 4.9 km for albedos 2–10%. The character of the brightness variations does not, however, support this interpretation. Besides, application of a period-finding technique fails to yield a clear choice for the true rotation period among a large number of peaks in the spectrum, some of which virtually coincide with the Sun's rotation period and its submultiples. It is found that rotation periods longer than ~1 day are the most likely ones. Scatter analysis shows that the measurements made with the various color filters do not yield the same results. It is suggested that the observed light curve is a composition of period and erratic variations, of which only the former are rotation related. It is speculated that the erratic changes may be a measure of a variable rate of expulsion, from isolated areas on *P*/Halley's nucleus, of fine dust electrically charged by the impinging solar wind and solar UV radiation, a mechanism proposed by Mendis et al. for comets far from the Sun. The light variations could also be due to specular-type reflection on very thin ice plates, which were observed by Patashnick and Rupprecht to grow from H_2O–CO_2 low-temperature mixtures in the laboratory and which may exist in comets. Other transient surface phenomena can be envisaged. Doubts are being expressed as to whether *P*/Halley's rotation period can at all be determined from photometry.

Stephenson, F. R. and Yau, K. K. C. (Univ. of Durham, England): 'Far Eastern Observations of Halley's Comet: 240 BC to AD 1368', *J. Brit. Interplanetary Soc.* **38** (1985), 195–216.

Halley's comet has been observed at every return since 12 BC and may possibly be traced as far back as 240 BC. The observations by the ancient astronomers of China, Japan and Korea are a valuable contribution to the understanding of the past history of this famous comet. A collection of oriental records of the comet from earliest times down to the period when detailed European observations became available is presented here. Although our main objective has been to assemble a comprehensive catalogue, the reliability and accuracy of each individual observation are also discussed, often in some detail. In addition, a number of comparisons between the dates of perihelion passage derived from observations and those calculated from various theories are made. At most returns, the prominent asterisms through or near which the comet passed were usually recorded by these ancient astronomers. In every case, where the asterisms have been recorded, we have identified and tabulated them along with equivalent Western names of the principal stars. The apparent path of Halley's comet changes considerably from one apparition to the next. Diagrams showing the computed path at all of the returns discussed here are presented.

Stephenson, R. and Yau, K.: 'Halley's Comet and Babylon', *Spaceflight* **27** (1985), 360.

The appearance of Halley's comet in 164 BC was previously thought to have passed unrecorded. Recent work, however, shows that this was not so.

Tsou, P., Brownlee, D. E. and Albee, A. L. (Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'Comet Coma Sample Return via GIOTTO II', *J. Brit. Interplanetary Soc.* **38** (1985), 232–239.

A comet coma sample return is possible with a low-cost flyby mission. Collecting coma materials and returning them to Earth can be accomplished in a free-return trajectory. Intact capture of coma dust, preserving the cometary dust mineralogy, is possible at low encounter speeds. Samples from a known

cometary source can then be compared with the wealth of information on meteorites and interplanetary dust. Sample return *via* GIOTTO II is a unique, low-cost NASA/ESA cooperative opportunity. With ESA providing the GIOTTO spacecraft and payload and NASA the sample return capability, first-class science can be accomplished at a very low cost for both NASA and ESA. This paper focuses on the sample return aspects, including sample return objectives, sample collection techniques, experimental work to verify collection concepts, and some of the characteristics of the cometary targets for sample return.

Von Rosenvinge, T. T. and Brandt, J. C. (International Cometary Explorer Project, NASA/Goddard Space Flight Center, Greenbelt, MD 20771): 'The International Cometary Explorer Mission to Comet Giacobini-Zinner', *EOS; Transactions, American Geophysical Union* **66** (1985), 625, 628–629.

The first in-situ measurements of a comet tail will be made on September 11, 1985, when the International Cometary Explorer (ICE) spacecraft passes through the tail of Comet Giacobini-Zinner. The ICE tailward measurements are complementary to the sunward measurements to be made by the missions to Halley's comet.

Wyckoff, S., Wagner, R. M., Wehinger, P. A., Schleicher, D. G. and Festou, M. C. (Dept. of Physics, Arizona State Univ., Tempe, AZ 85287): 'Onset of Sublimation in Comet P/Halley (1982I)', *Nature* **316** (1985), 241–242.

We report here the first direct evidence for the onset of sublimation of a comet nucleus. Emission due to CN observed in spectra of comet P/Halley (1982i) provides evidence for the development of the gas coma. Broad-band photometric observations of the comet indicate that the dust coma developed near a pre-perihelion heliocentric distance, $r \sim 6$ AU. We have derived rates of gas production and brightening for comet P/Halley at $r \sim 4$–6 AU and use the mean pre-perihelion nuclear magnitude derived for the comet ($r > 8$ AU) to calculate an effective radius of the nucleus (R), which for plausible values of the geometric albedo, $p_v \sim 0.03$–0.6, lies in the range $R = 1$–4 km.

21. METEORITES

Aller, L. H. (Univ. of California at Los Angeles, Los Angeles, CA 90024): 'Solar Abundances and the Role of Nucleogenesis in Low-to-Medium Mass Stars in the Galaxy', *Meteoritics* **20** (1985), 321–330.

The pattern of solar elemental abundances agrees well with that shown by CI chondrites for nonvolatile elements. For metals of the iron peak, the chief source of uncertainty seems to be the structure of the solar atmosphere. Lines of rare elements are frequently masked by atomic and molecular lines of abundant species. The vast majority of stars (including the sun) will do little to change the bulk composition of the interstellar medium from which new stars are formed. He, C, and N in small quantities are supplied by stars from 1 to 8 solar masses as they evolve and produce nebular envelopes that dissipate into the interstellar medium, but as has long been recognized, oxygen, heavier elements, and all r-process and proton-rich nuclides are made in massive stars.

Ehlmann, A. J. and Keil, K. (Dept. of Geology, Univ. of New Mexico, Albuquerque, NM 87131): 'Classification of Eight Ordinary Chondrites from Texas', *Meteoritics* **20** (1985), 219–227.

Based on optical microscopy and electron microprobe analyses, eight previously undescribed or poorly known chondrites were classified into compositional groups, petrologic types, and degree of shock alteration. These chondrities are: Leander, L4b; Nazareth(a), L6d; La Villa, H4b; Mereta, H4c; Gail, H4d; Shafter Lake, H5a; Uvalde, H5b; and Howe, H5d.

Ernston, K., Hammann, W., Fiebag, J. and Graup, G. (Inst. für Geologie der Universität, Pleicherwall 1, D-8700 Würzburg, F.R.G.): 'Evidence of an Impact Origin for the Azuara Structure (Spain)', *Earth Planet. Sci. Letters* **74** (1985), 361–370.

Some 50 km south of Zaragoza (northeast Spain) there is a tectonically peculiar area, which is suspected to be a large impact site. It has a morphologically conspicuous ring structure with a diameter of roughly 30 km and consists mainly of Mesozoic sediments emerging from the Ebro Tertiary Basin, and partly of Palaeozoic rocks from the Iberian System. The strata of the ring, in general, dip to the center and are highly folded and faulted. Intense and unusual deformation is indicated by abundant mixed and monomict breccias. A single poorly exposed outcrop of a mixed breccia with sedimentary fragments exhibits shock-metamorphic effects. Within quartz grains, systems of crystallographically oriented microscopic planar features and planar fractures can be observed, as well as kink bands in micas within the breccia matrix. The age of the impact is estimated to be between Lower Cretaceous and Miocene.

Fahey, A., Goswami, J. N., McKeegan, K. D. and Zinner, E. (McDonnell Center for the Space Sciences, Washington Univ., St. Louis, MO 63130): Evidence for Extreme SOTI Enrichments in Primitive Meteorites', *Astrophys. J.* **296** (1985), L17–L20.

Titanium isotopic compositions in individual refractory oxide and silicate grains from primitive carbonaceous chondrites have been determined by high mass resolution ion probe techniques. Anomalous Ti, and particularly excess ^{50}Ti, was found. One hibonite from the carbonaceous chondrite Murray has a 10% excess of ^{50}Ti, 25 times higher than the maximum value previously reported for bulk samples of refractory inclusions from carbonaceous chondrites. This grain also has a small excess of ^{49}Ti and the ratio of the relative enrichments of ^{50}Ti to ^{49}Ti is 26 ± 10. An admixture of an almost pure ^{50}Ti component to Ti of terrestrial composition is the most plausible explanation for our observations. Hydrostatic silicon burning at the core of massive stars, neutron-rich silicon burning, or neutron-rich nuclear statistical equilibrium processes could be responsible for producing this exotic component.

The variation of the Ti compositions between different hibonite grains, and among pyroxenes from a single Allende refractory inclusion, indicates isotopic inhomogeneities over small scale lengths in the solar nebula and underscores the importance of the analysis of small individual phases. This isotopic heterogeneity makes it likely that the anomalous Ti was carried into the solar system by interstellar dust grains. However, there is no evidence to suggest that either the hibonites are themselves relict interstellar grains, or that individual carrier grains have been preserved as inclusions within them.

Frazier, R. M. and Boynton, W. V. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Rare Earth and Other Elements in Components of the Abee Enstatite Chondrite', *Meteoritics* **20** (1985), 197–218.

Abee clast samples, a matrix sample, a dark inclusion, magnetic and non-magnetic samples, and bulk samples were analyzed by neutron activation analysis (NAA). The REE were determined by radiochemical NAA, Na, K, Sc, Cr, Mn, Fe, Co, Ni, Zn, As, Se, Sm, Ir, Au were determined by instrumental NAA.

High abundances of As, Ir, and Au in the magnetic separate and the correlation of their abundances with the metal content of the clasts indicate that As, Ir, and Au chiefly occur in the metal. Correlations for Zn and Sc indicate that they chiefly occur in niningerite, but a significant amount of Sc may also occur in oldhamite. The dark inclusions do not follow the As and Zn correlations, suggesting that the dark inclusions and clasts are not equilibrated with each other. Correlation of the REE and oldhamite abundances for both the clasts and dark inclusions indicates that the REE chiefly occur in oldhamite.

In view of the INAA and mineralogical evidence for non-equilibration among the clasts and a dark inclusion (Sears *et al.*, 1981), the similar REE patterns for clasts (3, 3) and dark inclusion (5, 1), and

the similar mineral composition of oldhamite in clast (3, 3) and dark inclusion (5, 1), suggest that the oldhamite in the clasts and dark inclusions is of a common origin, which Sears *et al.* (1981) showed could be formed by condensation.

A Tb anomaly of a factor of 2 was found in sample (2, 9 and 9, 2), and a La anomaly of a factor of 2 was found in clast (3, 3). The only other REE anomaly in Abee, a factor of 3.5 for Yb, was found by Nakamura and Masuda (1973). In view of the evidence for equilibration among the clasts, this anomaly must have been introduced shortly before the brecciation processes and indicates that no significant reheating has occurred. This concurs with the findings of Sugiura and Strangeway (1981) and Bogard *et al.* (1982).

Fredriksson, K., Murty, S. V. S. and Marti, K. (Smithsonian Institution, U.S. National Museum, Washington, DC 20560): 'Some Chemical and Isotopic Observations in Chondrules', *Meteoritics* **20** (1985), 347–357.

We report chemical, nitrogen and noble gas isotropic observations in individual chondrules of the Bjurböle (L4) and Dhajala (H3, 4) chondrites. The $\delta^{15}N$ is +9.4 for the Bjurböle 'matrix', ranges from +6.4 to −20.0 in chondrules, and appears to be related to the chemical composition. Nitrogen isotope systematics seem to require the presence of more than one component of distinct signatures. Although we cannot rule out complex processes of chondrule and matrix formation involving element and isotope fractionations, the oxygen isotope systematics also seem to require distinct reservoirs. We discuss the results in terms of the lack of equilibrations among chondrule minerals, as well as with the host meteorite matter, and also the paradox of the constant Fe/Mg ratio of olivines in Bjurböle and of the majority of ordinary chondrites.

Göpel, C., Manhes, G. and Allègre, C. J. (Laboratoire de Géochimie et Cosmochimie, Universités de Paris VI et VII, 4, Place Jussieu, 75230 Paris Cedex 05, France): 'U-PB Systematics in Iron Meteorites: Uniformity of Primordial Lead', *Geochimica et Cosmochimica Acta* **49** (1985), 1681–1695.

Pb isotopic compositions and U-Pb abundances were determined in the metal phase of six iron meteorites: Canyon Diablo IA, Toluca IA, Odessa IA, Youndegin IA, Deport IA and Mundrabilla An. Prior to complete dissolution, samples were subjected to a series of leachings and partial dissolutions. Isotopic compositions and abundances of the etched Pb indicate a contamination by terrestrial Pb which is attributable to previous cutting of the meteorite. Pb isotopic compositions measured in the decontaminated samples are identical within 0.2% and essentially confirm the primordial Pb value defined by Tatsumoto *et al.* (1973). These data invalidate more radiogenic Pb isotopic compositions published for iron meteorites, which are the result of terrestrial Pb contamination introduced mainly by analytical procedure. Our results support the idea of a solar nebula which was isotopically homogeneous for Pb 4.55 Ga ago. The new upper limit for U-abundance in iron meteorites, 0.001 ppb, is in agreement with its expected thermodynamic solubility in the metal phase.

Göpel, C., Manhes, G. and Allègre, C. J. (Laboratoire de Géochimie et Cosmochimie, Universités de Paris VI et VII, 4, Place Jussieu, 75230 Paris Cedex 05, France): 'Concordant 3,676 Myr U–Pb Formation Age for the Kodaikanal Iron Meteorite', *Nature* **317** (1985), 341–344.

The Kodaikanal iron meteorite contains evidence of intensive chemical activity which, according to Rb–Sr studies, occurred ~800 Myr after the formation of the Solar System. Here we report the results of U–Pb isotope analyses on a silicate inclusion from Kodaikanal. Leaching experiments on the two major phases, clinopyroxene (CPX) and alkali-rich glass, indicate a contamination by terrestrial Pb attributable to previous curatorial cutting of this iron meteorite. The leached minerals define concordant U–Pb ages that validate the precise Pb–Pb age of 3676 ± 3 Myr. These data are consistent

with Rb–Sr age determinations. The absence of initial Pb indicates a fast cooling of the silicate material. This has already been established for the metal phase, and a collisional origin for Kodaikanal is favoured.

Grossman, J. N., Rubin, A. E., Rambaldi, E. R., Rajan, R. S. and Wasson, J. T. (Jet Propulsion Lab., California Inst. of Technology, Pasadena, CA 91109): 'Chondrules in the Gingzhen Type-3 Enstatite Chondrite: Possible Precursor Components and Comparison to Ordinary Chondrite Chondrules', *Geochimica et Cosmochimica Acta* **49** (1985), 1781–1795.

The Qingzhen (EH3) fall appears to be the least equilibrated enstatite chondrite; mineral compositions vary widely from chondrule to chondrule, and in some cases, from grain to grain within individual chondrules. As in ordinary chondrite (OC) chondrules, most elements show appreciable ranges in concentration. Porphyritic olivine-pyroxene (POP) chondrules are richer than porphyritic pyroxene (PP) and radial pyroxene (RP) chondrules in refractory lithophiles and siderophiles. Unlike OC chondrules Qingzhen's RP and PP chondrules have similar bulk compositions.

Elements in each of the following sets intercorrelate significantly, probably because these elements were present in the same nebular components: (1) Fe-Co-Ni-Ir-Au, (2) Ca-Eu-Sc, (3) Al-Sc-Hf, (4) Na-REE, (5) Cl-Br. Several additional elements show no correlations. Set (1) elements were probably derived from a metal component, as in OC chondrules. Set (3) elements, which occur in higher concentrations in olivine-bearing (POP) chondrules, suggest the existence of a refractory lithophile-rich, olivine-rich component, similar to the one previously inferred for OC chondrules. Set (2) elements suggest a precursor component rich in oldhamite and set (4) elements suggest another refractory-bearing component. Components (2) and (4) were not precursors of OC chondrules.

For some chondrules, interelement ratios of refractory lithophiles such as Ca, Al, Ti, Sc and REE are similar to CI ratios. This indicates that these elements were probably derived from silicates. We suggest that the earliest solid phases were refractory silicates that were sulfurized before chondrule formation. Some of these sulfurized components (*e.g.*, one rich in oldhamite) were abundant in the region where the Qingzhen chondrules formed.

Grün, E., Zook, H. A., Fechtig, H. and Giese, R. H. (Max-Planck-Institut für Kernphysik, D-6900 Heidelberg, F.R.G.): 'Collisional Balance of the Meteoritic Complex', *Icarus* **62** (1985), 244–272.

Taking into account meteoroid measurements by *in situ* experiments, zodiacal light observations, and oblique angle hypervelocity impact studies, it is found that the observed size distributions of lunar microcraters usually do not represent the interplanetary meteoroid flux for particles with masses $\leqslant 10^{-10}$ g. From the steepest observed lunar crater size distribution a 'lunar flux' is derived which is up to 2 orders of magnitude higher than the interplanetary flux at the smallest particle masses. New models of the 'lunar' and 'interplanetary' meteoroid fluxes are presented. The spatial mass density of interplanetary meteoritic material at 1 AU is $\sim 10^{-16}$ g m^{-3}. A large fraction of this mass is in particles of 10^{-6} to 10^{-4} g. A detailed analysis of the effects of mutual collisions (i.e., destruction of meteoroids and production of fragment particles) and of radiation pressure has been performed which yielded a new picture of the balance of the meteoritic complex. It has been found that the collisional lifetime at 1 AU is shortest ($\sim 10^4$ years) for meteoroids of 10^{-4} to 1 g mass. For particles with masses $m > 10^{-5}$ g, Poynting–Robertson lifetimes are considerably larger than collisional lifetimes. The collisional destruction rate of meteoroids with masses $m \geqslant 10^{-3}$ g is about 10 times larger than the rate of collisional production of fragment particles in the same mass range. About 9 tons sec^{-1} of these 'meteor-sized' ($m > 10^{-5}$ g) particles are lost inside 1 AU due to collisions and have to be replenished by other sources, e.g., comets. Under steady-state conditions, most of these large particles are 'young'; i.e., they have not been fragmented by collisions and their initial orbits are not altered much by radiation pressure drag. Many more micrometeoroids of masses $m \leqslant 10^{-5}$ g are generated by collisions from more massive particles than are destroyed by collisions. The net collisional production rate of intermediate-sized particles 10^{-10} g $\leqslant m \leqslant 10^5$ g is found to be about 16 times larger at 1 AU than the Poynting–Robertson loss rate. The total Poynting–Robertson loss rate inside 1 AU is only

about 0.26 tons/sec. The smallest fragment particles ($m \leqslant 10^{-10}$ g) will be largely injected into hyperbolic trajectories under the influence of radiation pressure (β meteoroids). These particles provide the most efficient loss mechanism from the meteoritic complex. When it is assumed that meteoroids fragment similarly to experimental impact studies with basalt, then it is found that interplanetary meteoroids in the mass range $10^{-10}\,\text{g} \leqslant m \leqslant 10^{-5}\,\text{g}$ cannot be in temporal balance under collisions and Poynting–Robertson drag but their spatial density is presently increasing with time.

Guimon, R. K., Keck, B. D., Weeks, K. S., Dehart, J. and Sears, D. W. G. (Dept. of Chemistry, Univ. of Arkansas, Fayetteville, AR 72701): 'Chemical and Physical Studies of Type 3 Chondrites-IV: Annealing Studies of a Type 3.4 Ordinary Chondrite and the Metamorphic History of Meteorites', *Geochim. Cosmochim. Acta* **49** (1985), 1515–1524.

Samples of a type 3.4 chondrite have been annealed at 400–1000 °C for 1–200 hr, their thermoluminescence properties determined and analyzed for K, Na, Mn, Sc and Ca by instrumental neutron activation analysis. After annealing at ≤900 °C, the samples showed a 50% decrease in TL sensitivity, while after annealing at 1000 °C it fell to 0.1–0.01 times its unannealed value and loss of Na and K occurred. The TL and compositional changes resemble those observed for the equilibrated Kernouve chondrite after similar annealing treatments, except that the sharp TL decrease, and element loss, occurred at ~1100 °C; this difference is presumably due to petrographic differences in the feldspar of the two meteorites. The temperature and the width of the TL peak showed a discontinuous increase after annealing at 800 °C; peak temperature jumped from 130 to 200 °C and peak width increased from 90 to 150 °C. The activation energies for these TL changes are 7–10 kcal/mole. Similar increases in the TL peak temperature have been reported in TL studies of Amelia, VA, albite, where they were associated with the low to high-temperature transformation. However, the activation energy for the transformation is ~80 kcal/mole. These changes in TL emission characteristics resemble trends observed in type 3 ordinary chondrites and it is suggested that type 3.3–3.5 chondrites have a low-feldspar as TL phosphor and >3.5 have high-feldspar as the phosphor. Thermoluminescence therefore provides a means of palaeothermometry for type 3 ordinary chondrites.

Hanan, B. B. and Tilton, G. R. (Dept. of Geological Sciences, Univ. of California, Santa Barbara, CA 93106): 'Early Planetary Metamorphism in Chondritic Meteorites', *Earth Planet. Sci. Letters* **74** (1985), 209–219.

Lead isotope relations were studied in whole rock and separated phases of Mezö-Madaras (L3) and Sharps (H3) chondrites in order to study the record of early events in the solar system and to seek further information on the isotopic composition of primordial lead. The internal $^{207}Pb/^{206}Pb$ ages are 4.480 ± 0.011 AE (1 AE = 10^9 years) for Mezö-Madaras and 4.472 ± 0.005 AE for Sharps. The ages are not significantly changed when Canyon Diablo troilite lead is included in the data sets, suggesting that the initial Pb isotopic composition in both meteorites was the same as that in the troilite. U-Pb data from both meteorites plot along chords in concordia diagrams that indicate recent disturbances in U/Pb ratios. The chords are poorly defined owing to the relatively non-radiogenic character of the lead isotopes. Rb-Sr measurements on Sharps likewise fail to yield an isochron, in agreement with the U-Pb data. Data from the literature indicate a similar disturbance in the Rb-Sr system for Mezö-Madaras. The 4.48 AE ages could be caused by pre-analysis contamination with terrestrial lead, however statistical comparison of isotope correlations between the acid-washes of analyzed samples and the residual washed samples suggests that the ages are real and not due to terrestrial contamination. The 4.48 AE age, which is distinctly younger than the well-established ages of 4.54–4.56 AE for the Allende chondrite and Angra dos Reis achondrite, appears to date an early metamorphic event rather than the formation of the chondrites. Rb-Sr, Sm-Nd and K-Ar ages in support of the 4.48 AE metamorphic event are reviewed. Such a metamorphic age is not necessarily in conflict with $^{129}I/^{129}Xe$ data which indicate that the parent material of most chondrites, including

those of type 3, cooled through temperatures sufficient to retain radiogenic Xe within a time interval of ca. 0.02 AE.

Hasan, F. and Axon, H. J. (Dept. of Metallurgy and Materials Science, Univ. of Manchester/UMIST, Manchester, U.K.): 'A Transmission Electron Microscopic Study of the Bethany Iron Meteorite', *J. Mater. Sci.* **20** (1985), 590–596.

The Bethany iron meteorite which is a part of the Gibeon shower is a fine octahedrite with zoned plessite fields of various sizes. The optically irresolvable microstructural details inside the plessitic fields have been studied by transmission electron microscopy, and the crystallographic relationships between the primary kamacite (α) and the parent taenite (γ), and between the α and γ particles in the coarse plessite, have been examined using electron diffraction. In the case of primary kamacite the orientation-relationship with γ was close to the Nishiyama–Wasserman relationship, whereas, for the plessitic α, the orientation-relationship with γ was close to Kurdjumov–Sachs. It was also found that the $(111)_\gamma$ and $(110)_\alpha$ planes were not strictly parallel. Additionally, measurements of the composition profile through the zoned plessite have been made using STEM microanalysis technique, and related to microstructure.

Honda, M. (Dept. of Chemistry, College of Humanities and Sciences, Nihon University, Setegaya-Ku, Tokyo, 156, Japan): 'Production Rates of Cosmogenic Helium Isotopes in Iron Meteorites', *Earth Planet. Sci. Letters* **75** (1985), 77–80.

The production rates, P, of cosmogenic ^{3}He and ^{4}He in iron meteorites can be described by introducing empirically determined effective mass difference, ΔA, terms in the general formula for the total isobaric yield of cosmogenic nuclides of mass A:

$$P(A) = k_1' \cdot (\Delta A + 4)^{-k_2'}, \; \Delta A = 56 - A,$$

covering $A = 54 - 20$. It is found that:

$$P(^3\text{He}) = 16.7 \cdot k_1' \cdot (22)^{-k_2'} \text{ and } P(^4\text{He}) = 18.3 \cdot k_1' \cdot (14)^{-k_2'}.$$

Ireland, T. R., Compston, W. and Heydegger, H. R. (Research School of Earth Sciences, Australian National Univ., Canberra Act 2601, Australia): 'Titanium Isotopic Anomalies in Hibonites from the Murchison Carbonaceous Chondrite', *Geochim. Cosmochim. Acta* **49** (1985), 1989–1993.

The isotopic compositions of titanium in eight grains of hibonite ($CaAl_{12}O_{19}$) from the carbonaceous chondrite Murchison have been determined by high precision secondary ion mass spectrometry using an ion microprobe. The titanium in the hibonites varies greatly in ^{50}Ti, from about −42 to +8 permil (relative to terrestrial) with smaller (up to 4 permil), but clearly resolvable, effects in ^{46}Ti and ^{48}Ti. These results complement ion probe measurements by Fahey *et al.* (1985) of a 100 permil excess of ^{50}Ti in a hibonite grain from the carbonaceous chondrite Murray, and confirm the presence of widespread negative anomalies suggested by the rules of Hutcheon *et al.* (1983) on hibonites from Murchison. The magnitude of these variations seems explicable only in terms of nucleogenic processes which produced extremely variable titanium isotopic abundances in the hibonite source materials. The hibonites evidently did not participate to the same extent as most material in the mixing and homogenisation processes that accompanied the formation and later evolution of the solar system. Thus, significant source materials of the hibonites may be the supernova condensates of Clayton (1978) and may support the concept of 'chemical memory' (Clayton, 1978; Nemeyer and Lugmair, 1984).

Ivanov, Ch. P. and Stoyanova, R. Zh. (Institute of Organic Chemistry, Bulgarian Academy of Sciences, Sofia 1040, Bulgaria): 'Composition and Content of Normal and Isoprenoid Hydrocarbons in the Goumoshnik Meteorite', *Doklady Bolgarskoi Akademii Nauk* **37** (1985), 1513–1516.

In the present paper we set ourselves the task to determine the content of individual hydrocarbons in the Goumoshnic meteorite and to find out if there is any considerable difference between the qualitative and quantitative compositions of hydrocarbons in the Pavel and Goumoshnik meteorites, having in mind the different conditions and duration of their storage.

Jovanovic, S. and Reed, G. W., Jr. (Chemistry Div., Argonne National Lab., 9700 South Cass Ave., Argonne, IL 60439): 'The Thermal Release of Hg from Chondrites and their Thermal Histories', *Geochim. Cosmochim. Acta* **49** (1985), 1743–1751.

A quantitative treatment and implications of isothermal and linear heating data on Hg in meteorites are given as a sequelto a more qualitative analysis of meteorite thermal histories (Reed and Jovanovic, 1968). Studies of Hg in terrestrial metamorphic rocks establish that thermal events to which meteorites were subjected fall in the same temperature range, ~400–900 °C, as exists during terrestrial metamorphism. Hg diffusion parameters based on data from the linear and isothermal heating experiments are calculated. The conclusions are: (1) Meteorites experienced thermal events of the same magnitude as those measured by primarily mineralogical metamorphic indicators reviewed by Dodd (1969). (2) No correspondence with mineralogical-petrological metamorphic grade is evident. (3) Hg data for some chondrites correlate with shock facies (non-thermal) indicators (Dodd and Jarosewich, 1979). (4) Small Hg activation energies (6–14 kcal/mole) require that the meteorites much have been stored in closed systems until low temperatures were attained. Hg must be present as an involatile mineral(s) or as a substituent in a host phase at temperatures below ~100 °C. Consistent with this interpretation is the fact that despite diffusion times of 10^2–10^6 years at 200 K, Hg was retained in small objects over cosmic ray exposure periods of 10^7 years.

Kerr, R. A.: 'Chaotic Zone Yields Meteorites', *Science* **228** (1985), 1186.

Jack Wisdom of the Massachusetts Institute of Technology recently found that chaos can quickly transport material from 3:1 gap to Earth without help from Mars. Asteroid behavior would be chaotic if an eventual orbit depends sensitively on initial conditions. Under chaotic conditions, two asteroids starting out in nearly identical orbits can end up in wildly different orbits. They obey Newton's laws of motion, but their sensitivity to initial conditions is so great that prediction is impractical.

Kerridge, J. F. (Inst. of Geophysics, Univ. of California, Los Angeles, CA 90024): 'Carbon, Hydrogen and Nitrogen in Carbonaceous Chondrites: Abundances and Isotopic Compositions in Bulk Samples', *Geochim. Cosmochim. Acta* **49** (1985), 1707–1714.

Whole-rock samples of 25 carbonaceous chondrites were analysed for contents of C, H and N and $\delta^{13}C$, δD and $\delta^{15}N$. Inhomogeneous distribution of these isotopes within individual meteorites is pronounced in several cases. Few systematic intermeteorite trends were observed; N data are suggestive of isotopic inhomogeneity in the early solar system. Several chondrites revealed unusual compositions which would repay further, more detailed study. The data are also useful for classification of carbonaceous chondrites: N abundance and isotopic compositions can differenitiate existing taxonomic groups with close to 100% reliability; Al Rais and Renazzo clearly constitute a discrete 'grouplet'; and there are hints that both CI and CM groups may each be divisible into two subgroups.

Lange, M. A., Lambert, P. and Ahrens, T. J. (Div. of Geological and Planetary Sciences, California Inst. of Tech., Pasadena CA 91125): 'Shock Effects on Hydrous Minerals and Implications for Carbonaceous Meteorites', *Geochim. Cosmochim. Acta* **49** (1985), 1715–1726.

New infrared absorption spectra, thermo-gravimetric analyses and optical-and scanning electron

microscopy of shock-recovered specimens of antigorite serpentine ($Mg_3Si_2O_5(OH)_4$) from the pressure range between 25 to 59 GPa are reported. The infrared spectra show systematic changes in absorption peaks related to structural and molecular surface absorbed water. H_2O absorption peaks increase at the expense of OH peaks with increasing shock pressure. Changes in SiO bond vibrational modes with increasing shock pressure parallel those seen for other, non-hydrous minerals. Thermogravimetric analyses of shock-recovered samples determine the amount of shock-induced water loss. For samples shocked in vented ssemblies, the data define a relation between shock-induced water loss *versus* shock pressure. Results for samples shocked in sealed assemblies demonstrate a dependence of water loss on shock pressure and target confinement. For the vented assembly samples, a linear relation between shock pressure and both the length of dehydration interval and the effective activation energy for releasing post-shock structural water in antigorite is found. Optical and scanning electron miscroscopy of shocked antigorite reveal a number of textures thought to be unique to shock loading of volatile-bearing minerals. Gas bubbles, which probably are the result of shock-released H_2O appear to be injected into zones of partial melting. This process may produce the vesicular dark veins which are distributed throughout heavily shocked samples. The present observations suggest several criteria which may constrain possible shock histories of the hydrous matrix phases of carbonaceous chondrites. A model is proposed for explaining hydrous alteration processes occurring on carbonaceous chondrite parent bodies in the course of their accretion. We speculate that shock loading of hydrous minerals would release and redistribute free water in the regoliths of carbonaceous chondrite parent bodies giving rise to the observed hydrous alterations.

Lavrukhina, A. K., Alekseev, V. A. and Ivliev, A. I. (V. I. Vernadsky Inst. of Geochemistry and Analytical Chemistry, U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.): 'Determination of Nitrogen by Neutron Activation in Meteorites and Rocks', *J. Radioanal Nucl. Chem.* **88** (1985), 145–152.

The results of determination of nitrogen content in meteorites by neutron activation are reported. The method is based on the $^{14}N(n, p)^{14}C$ reaction, which occurs upon irradiation of the samples by neutrons. The use of proportional gas-filled counters for the recording of ^{14}C made it possible to obtain the low nitrogen detection limit of 0.001 μg.

Lund, T., Tress, G., Khan, E. U., Molzahn, D., Vaper, P. and Brandt, R. (Kernchemie, FB 14, Philipps-Universität, 3550 Marburg, F.R.G.): 'Further Attempts to Isolate Superheavy Elements in the Meteorite Allende', *J. Radioanal. Nucl. Chem.* **93** (1985), 363–370.

The search for superheavy elements /SHE/ in the carbonaceous chondrite Allende was continued. This time we carried out a thermochromatographic separation at 1050 °C in O_2-, resp., H_2-gas flow. The volatile fraction (mostly Pb) was collected on a Pt-foil or trapped in KOH-solution. The heavy element probes were investigated for spontaneous fission activities. We observed zero spontaneous fission decays during 421 days. This yielded an upper limit of ≤ 2.9 fission $\times$ kg^{-1} $\times$ yr^{-1} (95% confidence limit). We were unable to confirm the existence of a spontaneous fission activity in the meteorite Allende.

Malvin, D. J., Wasson, J. T., Clayton, R. N., Mayeda, T. K. and Curvello, W. D. S. (Inst. of Geophysics and Planetary Physics, Univ. of California, Los Angeles, CA 90024): 'Bocaiuva – A Silicate-Inclusion Bearing Iron Meteorite Related to the Eagle-Station Pallasites Meteoritics **20** (1985), 259–273.

Bocaiuva is a unique meteorite consisting of major metal having a high Ge/Ga ratio and minor (~50 mg s^{-1}/g) silicates. The silicates are generally chondritic and consist of major olivine (Fa7.7) and orthpyroxene (Fs7.6) and minor plagioclase (Ab49, An49) and clinopyroxene (Fs4.5, Wo42). The low alkali content of the silicates is the only property inconsistent with a chondritic composition. Based on metal composition Bocaiuva seems distantly related to certain iron meteorites having similar Ge contents and similar Ge/Ga ratios, but detailed comparison with six such irons shows none

to be closely related to Bocaiuva. Perhaps most closely related in Cold Bay, a member of the Eagle-Station trio of pallasites, but its composition is too different to suggest formation on the same parent body. Oxygen-isotope data show that Bocaiuva silicates are closely related to those in the Eagle-Station pallasites and to the CO and CV chondrites. The composition and texture of the Bocaiuva metal-silicate assembly indicate mixing in an impact event. We suggest that the Eagle-Station pallasites were also formed by impact heating rather than by a long-lived internal heat source.

Nakamura, N. and Okano, O. (Dept. of Earth Sciences, Kobe Univ., Nada, Kobe 657, Japan): '1,200-Myr Impact-Melting Age and Trace-Element Chemical Features of the Yamato-790964 Chondrite', *Nature* **315** (1985), 563–566.

Age determinations of impact-produced materials in brecciated meteorites are particularly important for understanding the evolutionary history of meteorites. The age characteristics of these meteorites have been examined mostly by the K–Ar method or, in a few cases, by the Rb–Sr method. However, age data are still rare and, except for a few cases, the large-ion lithophile (LIL) trace-element chemical features have not been studied in detail. In this respect, the Yamato-79 shocked meteorites are the best specimens for investigation. We report here results of Rb–Sr systematics and trace-element analyses for an almost wholly impact-melted LL-chondrite, Y-790964, one of the Yamato-79 unusual chondrites. The analyses yield an internal isochron age of 1200 ± 50 (2σ) Myr. The isotopic and trace-element data obtained represent the first clear evidence of the youngest impact melting and LIL-element fractionations for a complete LL-chondrite, and suggest that the 1200-Myr-age is a non-trivial marker in the evolution of meteorites.

Rubin, A. E., James, J. A., Keck, B. D., Weeks, K. S., Sears, D. W. G. and Jarosewich, E. (Inst. of Geophysics and Planetary Physics, Univ. of California, Los Angeles, CA 90024): 'The Colony Meteorite and Variations in CO3 Chondrite Properties', *Meteoritics* **20** (1985), 175–196.

The Colony meteorite is an accretionary breccia containing several millimeter- to centimeter-size chondritic clasts embedded in a chondritic host. Colony is one of the least equilibrated CO3 chondrites; it has an unrecrystallized texture and contains compositionally heterogeneous olivine and low-Ca pyroxene, kamacite with low Ni and Co and high Cr, amoeboid inclusions with low FeO and MnO, a fine-grained silicate matrix with very high FeO, and numerous small chondrules with clear pink glass. However, Colony differs from normal CO chondrites in several respects: Although Al, Sc, V, Cr, Ir, Fe, Au and Ga abundances are consistent with a CO chondrite classification, certain lithophiles (Mg and Mn), siderophiles (Ni and Co) and chalcophiles (Se and Zn) are depleted by factors of 10–40%. The shape of Colony's thermoluminescence (TL) glow curve is similar to that of Allan Hills A77307 (another unequilibrated chondrite with CO3 petrological characteristics) and different from those of normal CO chondrites. [ALHA77307 also resembles Colony in having low Mg, Mn, Ni and Co, compared to normal CO chondrites, but it possesses CO-CV levels of Se and Zn and nearly CV levels of Cd.]

Colony is badly weathered; it contains 22.7 wt.% Fe_2O_3 and 5.7 wt.% H_2O. Recalculating the analysis on an H_2O-free basis with all Fe_2O_3, NiO and CoO converted to metal, yields an inferred original metallic Fe, Ni abundance of ~19 wt.%. This is similar to that of Kainsaz (an unweathered CO3 fall), but much higher than that of all other CO3 chondrites ($\leq$6.3 wt.%). Although it is possible that Colony and either ALHA77307 or Kainsaz constitute distinct CO3 chemical subgroups, the weathered nature of Colony and ALHA77307 preclude the drawing of firm conclusions. Nevertheless, it is clear that CO3 chondrites vary more in compositional and petrological properties than was previously recognized.

Sarafin, R., Bourot-Denise, M., Crozaz, G., Herpers, U., Pellas, P., Schultz, L. and Weber, H. W. (Institut für Kernchemie der Universität zu Köln, D-5000 Köln 1, F.R.G.): 'Cosmic Ray Effects in the Antarctic Meteorite Allan Hills A78084', *Earth Planet. Sci. Letters* **73** (1985), 171–182.

In the Antarctic H4 chondrite ALHA 78084 measurements of ^{26}Al, ^{53}Mn, noble gases and cosmic ray tracks have been performed on documented samples to investigate depth dependences of cosmic-ray-induced effects. ^{26}Al activities vary between 224 and 246 dpm/kg Si_{equ}. ^{53}Mn activities range from 299 to 359 dpm/kg Fe in agreement with the Kohman and Bender model $^{22}Ne/^{21}Ne$ ratios between 1.145 and 1.176 are observed. The $^{3}He/^{21}Ne$ vs. $^{22}Ne/^{21}Ne$ correlation shows a trend line similar to those found for St. Severin and Keyes. Track data indicate ablation depths between 1.3 and 6.5 cm with a mean ablation of 3.8 cm. This leads to a preatmospheric mass of about 40 kg and an ablation loss of about 66% by mass. Preatmospheric size and shielding calculated from measured $^{22}Ne/^{21}Ne$ ratios using the semi-empirical curves of Bhandari and Potdar [2] agree with those derived from track measurements. The combined data of spallation nuclides and cosmic ray tracks indicate a simple one-stage irradiation as a small object with a preatmospheric radius of (14 ± 1) cm for about 32 m.y. and a terrestrial age of less than 170 000 yr.

Sarafin, R., Herpers, U., Signer, P., Wieler, R., Bonani, G., Hofmann, H. J., Morenzoni, E., Nessi, M., Suter, M. and Wolfli, W. (Abteilung Nuklearchemie der Universität zu Köln, D-5000 Köln 1, F.R.G.): ^{10}Be, ^{26}Al, ^{53}Mn, and Light Noble Gases in the Antarctic Shergottite Eeta 79001 (A)', *Earth Planet. Sci. Letters* **75** (1985), 72–76.

The radionuclides ^{10}Be, ^{26}Al, and ^{53}Mn as well as the noble gases He, Ne, and Ar were measured on aliquots of a sample of lithology A from the shergottite EETA 79001. The radionuclide data yield an exposure age of 0.78 ± 0.14 Ma and a terrestrial residence time of 0.32 ± 0.17 Ma. The exposure ages derived from ^{3}He, ^{21}Ne, and ^{38}Ar all range between 0.4 and 0.6 Ma. These data rule out a common ejection of all known shergottites from their parent body as small objects in a single event about 2.5 Ma ago.

Sutton, S. R. (McDonnell Center for the Space Sciences, Washington Univ., St. Louis, MO 63130): 'Thermoluminescence Measurements on Shock-Metamorphosed Sandstone and Dolomite from Meteor Crater, Arizona 1. Shock Dependence of Thermoluminescence Properties', *J. Geophys. Res.* **90** (1985), 3683–3689.

The thermoluminescence (TL) properties of shocked Coconino sandstone and Kaibab dolomite from Meteor Crater, Arizona, have been studied. Equivalent dose (ED), a measure of stored TL, decreases with increasing shock (decreasing TL sensitivity) but becomes shock independent at high shock grades. The minimum shock grade at which ED becomes shock independent, the shock threshold for resetting preimpact TL to a negligible level, falls within petrographic shock class 2 as defined by Kieffer and corresponds to an equilibrated state at about 10 GPa and 700 °C. Shocked Coconino fragments suitable for evaluation of the formation age of the crater using TL are those shocked in excess of the resetting threshold. The average postimpact temperature of the crater floor, about 190 °C based on the TL of samples heated during burial, is consistent with impact energy estimates for the crater.

Sutton, S. R. (McDonnell Center for the Space Sciences, Washington Univ., St. Louis, MO 63130): 'Thermoluminescence Measurements on Shock-Metamorphosed Sandstone and Dolomite from Meteor Crater, Arizona 2. Thermoluminescence Age of Meteor Crater', *J. Geophys. Res.* **90** (1985), 3690–3700.

Thermoluminescence (TL) dating measurements were performed on shock metamorphosed rocks from Meteor Crater, Arizona. TL ages were obtained for eight specimens, four Coconino sandstone and four Kaibab dolomite, which experienced sufficient shock heating during the impact to reset their preimpact TL. Postimpact radiation doses were determined for each shocked fragment from thermoluminescence measurements on quartz mineral separates. Effective radiation dose rates were calculated from concentrations of uranium, thorium, potassium, and rubidium in the rocks and their burial environment and the distributions of these elements are determined by fission track and

microprobe analyses. Cosmic radiation dose rates were estimated by altitude scaling of sea level data and were corroborated by TL dosimeter measurements at the crater. The mean TL ages for the two rock types were reasonably concordant, $50\,400 \pm 2900$ and $46\,000 \pm 3100$ yr for sandstones and dolomites, respectively. The overall mean age, $49\,000 \pm 3000$ yr, is significantly older than the 25 000-yr age estimate based on the inferred correlation of the oldest pluvial episode at the crater with radiometrically dated $\delta^{18}0$ maxima.

Thompson, W. B. (Physics Dept. B-019, Univ. of California at San Diego, La Jolla, CA 92093): 'Shock Heating of Chondrules', *Meteoritics* **20** (1985), 359–365.

The possibility that chondrules have been heated by shock waves in the early solar nebula is explored. Suitable heating cycles would be produced in the wakes of cometary bodies in eccentric orbits: however, since these are brought to rest with respect to the nebula in a fairly short time, the total mass of the exciting solid bodies would have to have been about 10% of that of the heated gas.

Töpel-Schadt, J. and Müller, W. F. (Institut für Kristallographie und Mineralogie, Universität Frankfurt, D-6000, F.R.G.): 'The Sub-Microscopic Structure of the Unequilibrated Ordinary Chondrites Chainpur, Mezo-Madaras and Tieschitz: A Transmission Electron-Microscopic Study', *Earth Planet. Sci. Letters* **74** (1985), 1–12.

Mineral constituents of chondrules and matrices of the unequilibrated ordinary chondrites Chainpur (LL3), Mezö-Madaras (L3) and Tieschitz (H3) have been studied by means of transmission electron microscopy and attached energy-dispersive X-ray microanalysis. As is typical for petrologic type 3, clinopyroxene is the dominant pyroxene, orthopyroxene is very rare. While in Chainpur orthopyroxene occurs only a few unit cells in width intercalated with Ca-poor clinopyroxene, some chondrules of Mezö-Madaras contain intimately intergrown ortho- and clinopyroxenes (Ca-poor) of about the same amount. In a Tieschitz chondrule pure orthopyroxene crystals without planar defects parallel (100) were observed. The Ca-poor clinopyroxenes of all three meteorites are polysynthetically twinned on (100). In clinopyroxenes of intermediate composition, exsolution in augite and pigeonite is observed on a very fine scale of a few hundred angstroms on (001) and (100) or modulated structures are seen, both due to rapid cooling. Dislocations in olivine with Burgers vector [001], which indicate plastic deformation by shock waves, have been found in the matrices of all three meteorites. However, only chondrule olivines of Mezö-Madaras appear to be affected by shock waves. Chondrule olivines of Chainpur are free of dislocations. Those of Tieschitz contain only few dislocations, among them dislocation loops which are characteristic of recovery.

Troilite of all three meteorites shows antiphase domain boundaries with the displacement vector $1/3\langle\bar{1}10\rangle$. Dislocations with Burgers vector $1/3\langle\bar{1}10\rangle$, probably induced by shock, were observed in Mezö-Madaras and Tieschitz. In Mezö-Madaras taenite polysynthetically twinned on $\{111\}$ which indicates shock deformation was found.

The dark matrix of Chainpur and Tieschitz contains a mixture of kamacite (4–10 mol.% Ni) and probably magnetite according to energy-dispersive microanalysis and electron diffraction. In the case of Chainpur the crystallinity appears to be extremely poor whereas in Tieschitz the crystal size is 120–200 Å. In the matrix of Chainpur vesicular glass with a normative composition of pyroxene has been observed.

Treiman, A. H. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Amphibole and Hercynite Spinel in Shergotty and Zagami: Magmatic Water, Depth of Crystallization, and Metasomatism', *Meteoritics* **20** (1985), 229–243.

Amphibole and spinel occur in the Shergotty and Zagami meteorites only in magnetic inclusions in pigeonite. The trapped magma is essentially identical to the parental magmas for Shergotty and Zagami. The amphibole is a kaersutite with minimal halogen content; by inference, it must have been hydrous. If so, the Shergotty and Zagami melts contained at least 0.2 wt% H_2O and were probably

H_2O-undersaturated. Pressures in excess of 1 kilobar seem necessary for the formation of amphibole. Spinel replaces magnetite in the inclusions, and olivine replaces magnetite elsewhere in the meteorites. To stabilize spinel, the melt in the inclusions must have been enriched in Al during fractionation, possibly because the small volume of the inclusions made nucleation of plagioclase unlikely. Pervasive replacement of magnetite through reduction reactions suggests that Shergotty and Zagami interacted with hydrogen-rich fluids during their cooling.

Vieira, V. W. A., Costa, T. V. V. and Knudsen, J. M. (Physics Lab. I, H. C. Ørsted Inst., Univ. of Copenhagen, Universitetsparken 5, DK-2100, Denmark): 'Rare Earth Oxides and the Contamination Problem in Meteorite Research', *Phys. Scr.* **31** (1985), 303–304.

We have reported the finding of nearly perfect spheres (diameter $\approx 50\ \mu m$) in the meteorites Zagami and Murchison. The spheres, which contain mainly rare earth oxides and iron, are not of meteoritic origin. We have – unfortunately a little too late – established that similar spheres can originate in profusion from the use of common cigarette and gas lighters. Our conclusion is that the meteoritic samples investigated, at some point in their terrestrial history, have been contaminated by spheres from cigarette lighters.

Wang, Y. L., Crow, G. and Levi-Setti, R. (Enrico Fermi Inst., Univ. of Chicago, Il 60637): 'High Lateral Resolution Sims Mapping of Meteorite Chondrule', *Nuclear Instruments and Methods in Physics Research* **B10/11** (1985), 716–718.

Mass spectra for positive and negative secondary ions and elemental maps for O, Na, Mg, Al and Fe at 40 nm lateral resolution are shown of a chondrule rim in the Mezo-Madaras meteorite. The chondrule appears as an aggregate of olivine grains, rimmed by a thin Fe-rich layer, cemented in glass. A wide Fe-rich unlayered rim coats the examined chondrule region.

Wasserburg, G. J. (The Lunatic Asylum of the Charles Arms Lab., Div. of Geological and Planetary Sciences, California Inst. of Tech., Pasadena, CA 91125): 'Extinct Nuclides – 'Much Ado About Nothing'', *Meteoritics* **20** (1985), 295–310.

A concise review of the status of research on short-lived nuclei is presented. The importance of these nuclei is very great in spite of the fact that they are essentially absent today (except for cosmic ray products). The significance of these nuclei for understanding broader cosmic problems is outlined and it is shown that they are a key to the earliest processes in solar system formation and possibly provide a link with presolar processes in the interstellar medium or of intense activity of the early sun.

A few reminiscences about some random interactions with Hans Suess are given illustrating different ways of doing and thinking science.

Weeks, K. S. and Sears, D. W. G. (Dept. of Chemistry, Univ. of Arkansas, Fayetteville, AR 72701): 'Chemical and Physical Studies of Type 3 Chondrites-V: The Enstatite Chondrites', *Geochim. Cosmochim. Acta* **49** (1985), 1525–1536.

We report instrumental neutron activation analysis determinations of 19 major, minor and trace elements in three enstatite chondrites. Based on these, and literature data on the bulk and mineral composition of enstatite chondrites, we discuss the history of the type 3 or unequilibrated enstatite chondrites, and their relationship with the other enstatite chondrites. The type 3 enstatite chondrites have E chondrite lithophile element abundances and their siderophile element abundances place them with the EH chondrites, well resolved from the EL chondrites. Moderately volatile chalcophile elements are at the low end of the EH range and Cr appears to be intermediate between EH and EL. We suggest that the type 3 enstatite chondrites are EH chondrites which have suffered small depletions of certain chalcophile elements through the loss of shock-produced sulfurous liquids. The

oxygen isotope differences between type 3 and other enstatite chondrites is consistent with equilibration with the nebula gas ~30° higher than the others, or with the loss of a plagioclase-rich liquid. The mineral chemistry of the type 3 chondrites is consistent with either low temperature equilibrium, or, in some instances, with shock effects.

Williams, C. V., Rubin, A. E., Keil, K. and San Miguel, A. (Dept. of Geology, Univ. of New Mexico, Albuquerque, NM 87131): 'Petrology of the Cangas de Onis and Nulles Regolith Breccias: Implications for Parent Body History', *Meteoritics* **20** (1985), 331–345.

Cangas de Onis and Nulles are H chondrite regolith breccias from northern Spain. Cangas de Onis consists of 60 ± 5 vol.% H6 clasts and 40 ± 5 vol.% clastic matrix. Olivine (Fa_{19}) and low-Ca pyroxene ($Fs_{17}Wo_{1.4}$) in the clasts and matrix are homogeneous and have the same composition. However, the matrix has well-preserved chondrules and is less recrystallized than the clasts; it resembles the texture of H5 chondrites. Nulles consists of 60 ± 5 vol.% H4 clasts, about 1 vol.% melt-rock clasts, 1 vol.% shocked H chondrite clasts, and 40 ± 5 vol.% clastic matrix. The H4 and shocked clasts and the matrix have uniform olivine (Fa_{19}) and low-Ca pyroxenes ($Fs_{17}Wo_{1.5}$). Although the melt-rock clast has similar MgO/FeO to H chondrites, melt-rock olivine is heterogeneous (Fa_{7-23}) and more magnesian (avg. Fa_{13}). Uniform mineral compositions in both Cangas de Onis and Nulles indicate that their matrices consist almost entirely of comminuted equilibrated clasts. If these meteorites are representative samples of the regoliths in which they resided, the regoliths were compositionally homogeneous at the time of breccia consolidation. Zoned taenites within the clastic matrix of Cagnas de Onis scatter widely on composition-dimension plots, indicating that these taenites cooled at different rates (about 1-1000 K/m · y.) at various depths (1–150 km). This suggests that the H chondrite parent body was disrupted and reassembled. The diverse metallographic cooling rates of H6 clasts in Cangas de Onis of about 8–80 K/m · y. indicate that material of similar metamorphic grade was buried at a variety of depths. The local regolith from which Cangas de Onis formed must have been enriched in H6 material, possibly having been supplied by successive impacts into near-surface H6 boulders or outcrops with diverse cooling rates.

Wisdom, J. (Dept. of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA 02139): 'Meteorites may Follow a Chaotic Route to Earth', *Nature* **315** (1985), 731–733.

It is widely believed that meteorites originate in the asteroid belt, but the precise dynamical mechanism whereby material is transported to Earth has eluded discovery. The observational data for the ordinary chondrites, the most common meteorites, impose severe constraints on any proposed mechanism. The ordinary chondrites are not strongly shocked, their cosmic ray exposure ages are typically <20 Myr, their radiants are concentrated near the antapex of Earth's motion and they show a pronounced 'afternoon excess' (for every meteorite which falls in the morning two fall in the afternoon). Wetherill concluded that these data could only be explained by an "unobserved source" of material with perihelia near 1.0 AU and aphelia near Jupiter. His subsequent, more sophisticated investigations have not changed this basic conclusion. Recently I have shown that there is a large chaotic zone in the phase space near the 3/1 mean motion commensurability with Jupiter and that the chaotic trajectories within this zone have particularly large variations in orbital eccentricity. Since asteroidal debris is quite easily injected into this chaotic zone, it could provide Wetherill's 'unobserved source' if chaotic trajectories which begin at asteroidal eccentricities ($e < 0.2$) reach such large eccentricities that Earth's orbit is crossed ($e > 0.57$). In this report I present a numerical integration which demonstrates that at least some of these chaotic trajectories do have the properties required to transport meteoritic material from the asteroid belt to Earth. Combined with the Monte Carlo calculations which show that the resulting meteorites are consistent with all the observational constraints, the case for this chaotic route to Earth is fairly strong.

Zadnik, M. G. (Enrico Fermi Inst., Univ. of Chicago, Chicago, IL 60637): 'Noble Gases in the Bells (C2) and Sharps (H3) Chondrites', *Meteoritics* **20** (1985), 245–257.

Bells and Sharps have some mineralogical and chemical peculiarities that make their classification uncertain. For Bells, the ^{40}Ar content at 890×10^{-8} cm^{3}STP/g is greater than the highest C1 chondrite value (Ivuna; 640), but close to the mean value for C2's (880). The ^{21}Ne-exposure age of 0.38 ± 0.07 Ma is very short, and coincides with the distinctive cluster of five C2's (0.17 to 0.76 Ma). Very likely Bells belongs to the same cluster, in which case it comes from the C2 parent body. Hence the C2 parent body seems to contain transitional C1–C2 material, like Bells, within a few km of the region of C2 chondrites proper. Thus the radiogenic and especially the cosmogenic gases link Bells to the C2 group. For Sharps, the elemental concentrations of primordial Ar, Kr and Xe (127, 0.76 and 0.59, all 10^{-8} cc/g) are $\sim 3 \times$ higher than for any other H3 chondrite. While Sharps is classified as 3.4 based on five indicators of metamorphism, the very high concentration of remaining two parameters of the Sears *et al.* (1980) scheme – C and primordial ^{36}Ar – (together with the high concentration of the volatile trace elements Bi, In and Tl) implies a classification of 3.0 for its volatile element content. The ^{21}Ne exposure age is 25.5 ± 2.5 Ma, placing Sharps in the second largest peak of the H-chondrite distribution. The nominal K-Ar and U, Th-He ages are 4.6 ± 0.2 and 4.2 ± 1.5 Ga, suggesting that Sharps has remained at low temperature since its beginnings.

22. MISCELLANEOUS (Interplanetary Dust, Tektites, Tunguska, Cretaceous Tertiary Events, etc.)

Brownlee, D. E. (Dept. of Astronomy, Univ. of Washington, Seattle, WA 98195): 'Cosmic Dust: Collection and Research', *Ann. Rev. Earth Planet. Sci.* **13** (1985), 147–173.

This paper reviews the aspects of cosmic dust that are important to its collection and utilization as a resource of extraterrestrial material. Most of the collected dust particles appear to be primitive and sometimes unique solar system materials that contain important clues to early solar system processes and environments. Collected dust can also be studied to investigate selected properties of the interplanetary medium and the terrestrial environment. The treatment of the origin and evolution of dust in the solar system is focused here on aspects important to the interpretation of sample results. The bulk of the paper reviews the reviews the results of laboratory studies of dust samples collected in the stratosphere and deep-sea sediments.

Duke, M. B., Mendell, W. W. and Roberts, B. B. (NASA Johnson Space Center, Houston, TX 77058): 'Towards a Lunar Base Programme', *Space Policy* **1**(1) (1985), 49–61.

When the requisite technology exists, the US political process will inevitably include lunar surface activities as a major space objective. This article examines a manned lunar base in terms of three distinct functions: the scientific investigation of the Moon and its environment; development of the capability to use lunar resources for beneficial purposes throughout the Earth–Moon system; and conduct of R&D leading to a self-sufficient and self-supporting manned lunar base. Three scenarios are outlined with respect to each possible function.

Fisher, A.: 'Death Star', *Popular Science* **226**(6) (1985), 72–75, 99.

At various times in the remote past many forms of life on Earth perished relatively suddenly. The extinction of the dinosaurs 65 million years ago is the most notorious of these events. Why did it happen? A bold and highly controversial new theory holds that our Sun is not a solitary wanderer in the galaxy but has a companion star, dubbed Nemesis, that visits the solar system every 26 million years and unleashes a deadily fusillade of comets. The result: the periodic mass extinction of life on Earth.

Hoyle, F., Wickramasinghe, N. C. and Pflug, H. D. (University College, Cardiff, U.K.): 'An Object

Within a Particle of Extraterrestrial Origin Compared with an Object of Presumed Terrestrial Origin', *Astrophys. Space Sci.* **113** (1985), 209–210.

Filamentary objects of submicron size isolated from an extraterrestrial particle and from the Gunflint cherts are compared and shown to have similarities of size, shape and interior structure.

McKeegan, K. D., Walker, R. M. and Zinner, E. (McDonnell Center for the Space Sciences, Washington Univ., St. Louis, MO 63130): 'Ion Microprobe Isotropic Measurements of Individual Interplanetary Dust Particles', *Geochim. Cosmochim. Acta* **49** (1985), 1971–1987.

Ion microprobe measurements of D/H ratios in individual fragments of eight stratospheric dust particles give δD values ranging from −386 to +2534‰ relative to SMOW. The δD values in five particles far exceed those in terrestrial samples and prove that the samples are interplanetary dust particles (IDPs). The hydrogen isotropic composition is heterogeneous on a scale of a few microns demonstrating that the dust is unequilibrated. Measurements of D/H ratios in conjunction with elemental and molecular ion signals in different fragments of individual IDPs show that a carbonaceous phase, not water, is the carrier of the D enrichments. Previous infrared transmission measurements have shown that IDPs fall into three main spectral classes. Particles from two of those three IR classes show large D/H ratios. Two particles studied from the third class do not. However, one of these contains solar flare tracks and is extraterrestrial. Thus, most, but not all, IDPs contain hydrogen with a non-terrestrial isotopic composition.

Carbon isotopic measurements on fragments of three IDPs give ratios similar to terrestrial values and show a largely uniform isotropic composition for a given particle. Small, but significant, differences in δ^{13}C of ~40‰ between particles are seen. No correlations between the hydrogen and carbon isotopic compositions are observed.

The magnesium and silicon isotopic compositions of fragments of three IDPs are found to be normal within measurement errors.

Mulholland, D.: 'Zodiacal Dust', *Mosaic* **16**(2) (1985), 18–25.

The dust that permeates the solar system contains considerably more information than it has yielded – so far.

Rietmeijer, F. J. M. and Mackinnon, I. D. R. (Solar System Exploration Div., Mail Code SN4, NASA Johnson Space Center, Houston, TX 77058): 'Poorly Graphitized Carbon as a New Cosmothermometer for Primitive Extraterrestrial Materials', *Nature* **315** (1985), 733–736.

The presence of carbon in primitive extraterrestrial materials has long been considered a useful indicator of prevailing geochemical conditions early in the formation of the Solar System. A recent addition to the suite of primitive materials available for study by cosmochemists includes particles collected from the stratosphere called chondritic porous (CP) aggregates. Carbon-rich CP aggregates are less abundant in stratospheric collections and contain many low-temperature phases (such as layer silicates) as minor components. We describe here the nature of the most abundant carbon phase in a carbon-rich CP aggregate (sample no. W7029* A) collected from the stratosphere as part of the Johnson Space Center (JSC) Cosmic Dust Program. By comparison with experimental and terrestrial studies of poorly graphitized carbon (PGC), we show that the graphitization temperature, or the degree of ordering in the PGC, may provide a useful cosmothermometer for primitive extraterrestrial materials.

Shu, F. H. and Stewart, G. R. (Astronomy Dept., Univ. of California, Berkeley, CA 94720): 'The Collisional Dynamics of Particulate Disks', *Icarus* **62** (1985), 360–383.

We use a Krook equation, modified to allow collisions to be inelastic, to describe the dynamics of a particulate disk. By a simple heuristic argument, we compute the effective collision rate in a disk of spherical particles with a power-law distribution of sizes. For Saturn's rings, the effective collision rate for momentum transport is substantially lower than that conventionally estimated on the basis of an observed optical depth at visual wavelengths. We then discuss how the vertically integrated set of momentum equations may be closed without the need to discard the third-order moments at the outset; our formulation allows for the possibility of a bent disk. In the limit that the collision frequency is much larger than the orbit frequency, we recover the usual Navier–Stokes equations of viscous hydrodynamics for a thin disk, with an explicit expression for the shear viscosity. For an unperturbed disk, we can solve the Krook equation directly, without any assumptions about the magnitude of the collision frequency. Our analytical results, for an unperturbed disk, are in good agreement with the treatments of Hämeen-Anttila, of Goldreich and Tremaine, and of Borderies, Goldreich, and Tremaine, using a Boltzmann description for a collection of identical spheres (assumed to be smooth so that the rotational and translation degrees of freedom do not couple). As a final application of the method, we generalize the formation to include the effects of gravitational scattering. This generalization is not crucial for many applications in planetary rings, but it may be important for the discussion of gas clouds in the disk of a spiral galaxy, and it is probably central to the accumulation of plants from smaller bodies in the primitive solar nebula.

Simpson, J. A. and Tuzzolino, A. J. (Lab. for Astrophysics and Space Research, Enrico Fermi Inst., Univ. of Chicago, Chicago, IL 60637): 'Polarized Polymer Films as Electronic Pulse Detectors of Cosmic Dust Particles', *Nuclear Instruments and Methods in Physics Research* **A236** (1985, 187–202.

A dust particle detector based on a new physical principle of detection is described. The basic detecting element requires no bias voltage and consists of a thin film of the polarized polymer polyvinylidene fluoride (PVDF) having conducting electrodes on each of its surfaces. A high velocity (~10 km/s range) dust particle entering the detector removes dipoles along its trajectory. This produces a local depolarization, which results in a fast (ns range) charge pulse signal in the external circuit which is detected using pulse electronics. A theory has been developed for this new mechanism of pulse detection. The dependence of signal amplitude on particle mass and velocity has been measured for several PVDF detectors having thickness in the range 2–28 μm and area in the range 4–150 cm^2 using iron particles with velocity in the range ~1–12 km/s and mass in the range $\sim 10^{-13}$–10^{-10} g. In addition, measurements carried out using a two-detector arrangement show that time of flight information may be obtained. Experimental results are presented which show, for example, the PVDF detectors have mass detection thresholds in the range $\sim 10^{-14}$–10^{-12} g, at an impact velocity of 10 km/s, which compare favorably with mass thresholds reported for current dust detectors based on other physical principles. PVDF detectors have the advantages of being inexpensively and easily fabricated, though, flexible and radiation resistant (to at least 10^7 rad). They exhibit long term stability, and may be operated for extended periods of time over the temperature range −50°C to +50°C. In addition, their fast response permits a detector-pulse electronics system to count dust impacts at event rates up to $10^4\ s^{-1}$ with no corrections required, and they have a response to dust particle impacts which is unaffected by high background fluxes of charged particles. As an example of the application of PVDF dust detectors, a detector is described which is being carried on space probes to measure the mass and flux of dust particles from Halley's Comet in March 1986. Other important applications for experiments in space are discussed.

Whipple, E. C., Northrop, T. G. and Mendis, D. A. (Center for Astrophysics and Space Science, Univ. of California at San Diego, La Jolla, CA 92093): 'The Electrostatics of a Dusty Plasma', *J. Geophys. Res.* **90** (1985), 7405–7413.

We derive the potential distribution in a plasma containing dust grains where the Debye length can be larger or smaller than the average intergrain spacing. We treat three models for the grain-plasma

system, with the assumption that the system of dust and plasma is charge-neutral: the permeable grain model of Goertz and Ip (1984), an impermeable grain model, and a capacitor model that does not require the nearest neighbor approximation of the other two models. We use a gauge-invariant form of Poisson's equation which is linearized about the average potential in the system. The charging currents to a grain are functions of the difference between the grain potential and this average potential. We obtain expressions for the equilibrium potential of the grain and for the gauge-invariant capacitance between the grain and the plasma. The charge of the grain is determined by the product of this capacitance and the grain-plasma potential difference. The three models give similar but not identical results. The results depend primarily on the parameter $Z = 4\pi\lambda^2 NC$, where λ is the Debye length, N is the grain concentration, and C is the grain to plasma capacitance. When $Z \gg 1$, the number of charges on a grain that is only charged by plasma currents is given by $(-Q/e) \cong [(\mu - 1)/(\mu + 1)][\bar{n}_i + \bar{n}_e)/N]$ where μ is the square root of the ion to electron mass ratio, and $\bar{n}_i$ and $\bar{n}_e$ are the average ion and electron densities. We confirm the result of Goertz and Ip (1984) that the charge on a grain in regions such as Saturn's F ring and spokes can be severely decreased from its free space value. The charge reduction occurs because the plasma electrons are depleted so that the grain does not need to be as negatively charged to equalize the ion and electron fluxes to its surface, despite the increased grain to plasma capacitance.