BIBLIOGRAPHY

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

Boslough, M. B., Rigden, S. M. and Ahrens, T. J. (Seismological Lab., California Inst. of Tech., Pasadena, CA 91125): 'Hugoniot Equation of State of Anorthosite Glass and Lunar Anorthosite', *Geophys. J. Roy. Astron. Soc.* **84** (1986), 455–473.

Twenty-one Hugoniot experiments were conducted on an amorphous material of anorthite composition, in the pressure range 8120 GPa, using both routine and new methods. Two Hugoniot measurements at about 120 GPa were made on lunar gabbroic anorthosite (*Apollo 15*, 418). Theoretical Hugoniots are constructed for both materials assuming they are disproportionate to their component oxides. These accurately predict the $P-p$ behaviour of the lunar anorthosite Hugoniot at 12O GPa and the anorthite glass Hugoniot above 50 GPa, but overestimate the shock temperatures of anorthite glass. The mixed oxide model fails to predict the release paths of either material. We conclude that the mixed oxide model is a good description of the bulk properties of the high-pressure phases of anorthite, but does not represent the actual phases. A significant enrichment of calcic refractory material in the Earth's lower mantle is not precluded by the bulk properties of the anorthite high-pressure phases.

Boss, A. P. (Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, Broad Branch Road, NW, Washington, DC 20015): 'The Origin of the Moon', *Science* **231** (1986), 341–345.

The origin of the Moon is considered within the theory of formation of the terrestrial planets by accumulation of planetesimals. The theory predicts the occurrence of giant impacts, suggesting that the Moon formed after a roughly Mars-sized body impacted on the protoearth. The impact blasted portions of the protoearth and the impacting body into geocentric orbit, forming a prelunar disk from which the Moon later accreted. Although other mechanisms for formation of the Moon appear to be dynamically impossible or implausible, fundamental questions must be answered before a giant impact origin can be considered both possible and probable.

Glass, B. P. (Geology Dept. Univ. of Delaware, Newark, DE 19716): 'Lunar Sample 14425: Not a Lunar Tektite', *Geochimica et Cosmochimica Acta* **50** (1986), 111–113.

Energy-dispersive x-ray analysis of a polished section of lunar sample 14425 shows, in contradiction to a previous report, that it has a composition similar to Apollo 14 breccias, but not to high-magnesium

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microtektites. The glass is homogeneous, but the bead contains numerous metallic spherules up to 0.7 mm in diameter. The metal in the spherules is iron with up to 16 wt.% Ni and 9 wt.% P and small amounts of S and Si. The high phosphorus content indicates the presence of a fine-grained phosphide phase in the metal. All of the metallic spherules have an associated sulphide phase. The composition of the glass bead and the presence of numerous Ni-Fe spherules with an associated sulphide phase indicates that the bead was formed by impact melting of surficial deposits at the Apollo-14 site.

Kreutzberger, M. E., Drake, M. J. and Jones, J. H. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Origin of the Earth's Moon: Constraints from Alkali Volatile Trace Elements', *Geochim. Cosmochim. Acta* **50** (1986), 91–98.

Although the Moon is depleted in volatile elements compared to the Earth, these depletions are not in accord with simple volatility. For example, the Cs/Rb ratios of the Earth and Moon inferred from basalts are approximately one seventh and one half of the Cl ratio, respectively. Volatility considerations alone predict that the lunar Cs/Rb ratio should be equal to or lower than the terrestrial ratio if the Moon was derived entirely from Earth mantle material. Thus hypotheses such as rotational fission which invoke derivation of lunar material entirely from the Earth's mantle may be excluded. The collisional ejection hypothesis of lunar origin requires at least 18% of lunar material to be derived from a projectile with dehydrated Cl composition to match the lunar Cs/Rb ratio, and 25%–50% to match both the lunar Cs/Rb ratio and absolute concentrations of Cs and Rb. It remains to be demonstrated that this relatively large contribution of projectile material is consistent with other elemental abundances and element ratios in the Moon.

Nautiyal, C. M., Padia, J. T., Rao, M. N. and Venkatesan, T. R. (Physical Research Lab., Ahmedabad, India): 'Solar Flare Neon Composition and Solar Cosmic-Ray Exposure Ages Based on Lunar Mineral Separates', *Astrophys. J.* **301** (1986), 465–470.

We analyze etched pyroxene grain-size separates from lunar soils 14148 and 24087 and etched feldspar grain-size separates from soil 61221 for neon isotopic and elemental composition and discuss procedures to isolate the implanted solar flare (SF) neon and solar and Galactic cosmic-ray (SCR and GCR)-produced Ne components in these samples. These results indicate that the SF neon composition is $^{20}Ne/^{22}Ne = 11.6 + 0.2$. The surface exposure ages are determined from the resolved SCR-produced Ne contents in the mineral separates from soils 14148, 24087, and 69921 using the appropriate SCR–^{21}Ne production rates for feldspars and pyroxenes, based on the SCR proton flux of $J(\geq 10\,\mathrm{MeV}) = 100$ protons $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ and $R_0 = 100$ MV. These SCR ages agree with those determined by particle track methods within a factor of 2.

Soffel, M., Ruder, H. and Schneider, M. (Lehrstuhl für Theoretische Astrophysik, Auf der Morgenstelle 12, D-7400 Tübingen, FRG): 'The Dominant Relativistic Terms in the Lunar Theory', *Astron. Astrophys.* **157** (1986), 357–364.

In the present paper the transition from the frame induced by the Einstein-Infeld-Hoffmann (EIH) coordinate system to a proper reference frame moving with the Earth-Moon barycenter is discussed in a simplified 3-body (Earth, Moon, Sun) problem. It is explicitly demonstrated how for this case the EIH-equations of motion reduce to the Jacobi-equations (equations of geodesic deviation) after the transformation to the proper reference frame. We then proceed with a Hill-Brown calculation for the dominant relativistic terms in the lunar laser ranging observables in the proper reference frame. For our simplified problem it is shown that in this frame all post-Newtonian terms are proportional to $m = n'/(n - n')[n(n') =$ mean motion of Moon (Sun)] describing the solar influence upon the coupling strength of the Earth-Moon system and consequently all m-independent terms in the lunar EIH-coordinate motion have to be considered as relics from the heliocentric notion of simultaneity used in this coordinate picture.

Shirley, J. H. (Box 169, Canoga Park, CA 91305): 'Shallow Moonquakes and Large Shallow Earthquakes: A Temporal Correlation', *Earth Planet. Sci. Letters* **76** (1986), 241–253.

The structure and seismicity of the Moon is very different from that of the Earth. One point of similarity is that statistics of seismic energy release in both bodies are dominated by the largest shallow-focus events. This study presents evidence of a relationship linking the timing of the 28 known shallow moonquakes with the timing of the 26 largest shallow earthquakes occurring in the same years (1971–1976). Distributions of the geocentric ecliptic longitude of the Moon λ_m for the time of occurrence of the lunar and terrestrial seismic events were analyzed both separately and in combination. for the entire 6-year period and for individual years, with the following results:

(1) Statistically significant clustering is present in the series of λ_m for the times of the earthquakes and moonquakes .for the entire sample period (random probability = 0.0036) and for 2 of the 6 individual years (random probabilities ≤ 0.02).

(2) Phases of the separate lunar and terrestrial seismic event λ_m distributions for the 6-year period differ by less than 7°. Phases of the earthquake and moonquake distributions are found in the same quadrant of the range in 5 of the 6 individual years.

(3) Annual levels of shallow-focus seismic activity in the Earth and Moon vary in concert in the years 1971–1976.

Stothers, R. B. (NASA Goddard Space Flight Center. Inst. for Space Studies. 2880 Broadway. New York, NY 10025): 'Dark Lunar Eclipses in Classical Antiquity', *J. Bri. Astron. Assoc.* **92**(2) (1986). 95–97.

Credible reports of dark lunar eclipses do not appear to exist in surviving ancient European and Near Eastern literature, apart from some undatable allusions in astrological writings.

Valeev, S. G. (Kemerovo State University, USSR): 'Coordinates of the Moon Reverse Side Sector Objects', *Earth, Moon, and Planets* **34** (1986), 251–271.

The coordinates of 171 objects of the reverse side and marginal zone, and 42 objects of the visible side of the Moon's Western hemisphere in survey zone from the automatical interplanet stations of 'Zond 6 and 8' type are presented. While dealing with the measuring information, systematical errors arising from the breakdown of orthogonality in coordinate transformation were taken into account, as well as original geometry of the Moon's limb as measured from the space.

Walker, J. C. G. and Zahnle, K. J. (Dept. of Atmospheric and Oceanic Sciences, Univ. of Michigan, Ann Arbor, MI 48109): 'Lunar Nodal Tide and Distance to the Moon During the Precambrian', *Nature* **320** (1986), 600–602

The pace of tidal evolution for the past ~450 Myr implies an Earth/Moon collision some 1,500–2,000 Myr BP an event for which there is no corroborating evidence. Here we present the first direct determination of the lunar distance in the Precambrian. We interpret a 23.3 ± 0.3-yr periodicity preserved in a 2,500 Myr BP Australian banded iron formation (BIF) as reflecting the climatic influence of the lunar nodal tide, which has been detected with its modern 18.6-yr periodicity in some modern climate records. The lunar distance at 2,500 Myr BP would then have been about 52 Earth radii. The implied history of Precambrian tidal friction is in accord with both the more recent palaeontological evidence and the long-term stability of the lunar orbit. The length of the Milankovich cycles that modulate the ice ages today also evolve with the Earth-Moon system. Their detection in the Precambrian sedimentary record would then permit an independent determination of the lunar distance.

Yabushita, S. (Dept. of Applied Mathematics and Physics, Kyoto Univ., Japan): 'Hypothesis of Variable G and the Secular Accelerations of the Sun and the Moon', *Earth, Moon, and Planets* **34** (1986), 139–148.

It is known that the observed secular accelerations of the Sun and Moon are not consistent with the tidal interactions of the Earth with the Sun and Moon. Following Dicke, the hypothesis of variable constant of gravity is adopted and expressions for the accelerations are derived. It is shown that if the theoretical ratio of the acceleration is equated the observed one, a unique value for $-\dot{G}/G$ can be calculated. Adopting the accelerations Fotheringham, Newton, Muller and Stephenson, found that $-G/G$ ranges from 1.4×10^{11} to $3.3 \times 10^{11}\,\mathrm{yr}^{-1}$. This estimate is consistent with the one based upon the comparison of the lunar accelerations measured with respect to atomic and ephemis times.

2. PLANETS (Articles about More than One Body)

Appleby, J. F. (Earth and Space Sciences Division, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91109): 'Radiative-Convective Equilibrium Models of Uranus and Neptune', *Icarus* **65** (1986), 383–405.

A study of radiative-convective equilibrium models for Uranus and Neptune is presented, with particular emphasis on the stratospheric energy balance. including the influence of aerosol heating and convective penetration. A straightforward numerical method is employed (J. F. Appleby and J. S. Hogan (1984). *Icarus* **59**, 336–366) along with standard opacity formulations and the assumption of local thermodynamic equilibrium. A range of models was considered for Uranus. reflecting uncertainties in observational constraints on the middle stratospheric temperatures. The results indicate that a "continuum absorber" could be significant in the stratosphere, despite Uranus' great distance from the Sun. Also, test runs are presented to illustrate the influence of uncertainties in the gas composition and changes in the effective mean insolation A long-standing theoretical problem for Neptune has been to explain the unexpectedly high stratospheric temperatures without invoking supersaturation of CH_4. The results show that a "continuum absorber" could contribute significantly to the energy balance within a localized stratospheric region; however, it probably cannot provide enough power to explain the observed infrared spectrum, regardless of its vertical distribution. One alternative is "convective penetration" which could arise if, for example, vertical mixing is so rapid that CH_4 condensation cannot occur before the gas is swept upward, above the condensation region. In the example considered here. the CH_4 mixing ratio in the middle and upper stratosphere is equal to that below the condensation region in the troposphere. The infrared emission from this model was found to be in generally good agreement with the observations. Such a model could also apply to Uranus, in lieu of aerosol or other "additional" heating mechanism, to an extent that is commensurate with weaker convective uplifting.

Araki, S. and Tremaine, S. (Dept. of Physics, Center for Theoretical Physics, MIT, Cambridge, MA 02139): 'The Dynamics of Dense Particle Disks', *Icarus* **65** (1986), 83–109.

We investigate the mechanical equilibrium and collisional transport processes in differentially rotating dense particle disks in which the filling factor is not small, so that the ordinary Boltzmann kinetic theory is not accurate. Our treatment is based on the Enskog theory of dense hard sphere gases, except that the spheres are inelastic. We show that the viscous instability which has been suggested as a source of the structure in Saturn's B ring does not arise in our models. However, the ring may be subject to a phase transition similar to the liquid-solid transition seen in molecular dynamics simulations of elastic hard spheres: in this case the ring could have alternating zero-shear ("solid") and high-shear ("liquid") zones.

Bell, E. V. and Armstrong, T. P. (Dept. of Physics and Astronomy, Univ. of Kansas, Lawrence, KS 66045): 'Monte Carlo Simulation of Charged Particle Impact on the Satellites of Jupiter and Saturn', *J. Geophys. Res.* **91** (1986), 1397–1403.

Ensemble-averaged lifetimes of Jovian and Saturnian trapped charged particles against loss by impact on natural satellites are presented. Precise values of these loss rates can be obtained from the known geometry of the satellite orbits, magnetic fields, and particle trajectory. These loss rates are needed as an ingredient of transport theory which is usually formulated in terms of the first and second adiabatic invariants and radial distance. The effects of satellite orbital inclination and eccentricity, ion charge to mass ratio and energy, equatorial pitch, and distance from the planet on the particle lifetime are discussed utilizing a tilted, but not offset, dipolar field geometry resulting in lifetime values expressed as functions of the first two adiabatic invariants and the equatorial radial distance from the planet ($\tau_{\rm life}(\mu, K, L)$).

Bell, E. V. and Armstrong, T. P. (Dept. of Physics and Astronomy, Univ. of Kansas, Lawrence, KS 66045): 'Monte Carlo Simulation of Charged Particle Impact on the Satellites of Jupiter and Saturn', *J. Geophys. Res.* **91**, 1397–1403 (1986).

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Cheng, A. F. (Johns Hopkins Univ. Applied Physics Lab., Laurel, MD 20707): 'Energetic Neutral Particles from Jupiter and Saturn', *J. Geophys. Res.* **91** (1986), 4524–4530.

The Voyager-1 spacecraft has detected energetic neutral particles escaping from the magnetospheres of Jupiter and Saturn. These energetic neutrals are created in charge exchange reactions between radiation belt ions and ambient atoms or molecules in the magnetosphere. If the Io torus is assumed to be the dominant Jovian source region for energetic neutrals, the Voyager observations can be used to infer upper limits to the average ion intensities there below about 200 keV. No readily interpretable in-situ measurements are available in the Io torus at these energies. The middle and outer Jovian magnetospheres may also be a significant source of energetic neutrals. At Saturn, the observed neutral particle count rates are too high to be explained by charge exchange between fast protons and H atoms of the Titan torus. Most of the energetic neutrals may be produced by charge exchanges between heavy ions and a neutral cloud containing H_2O in Saturn's inner magnetosphere. If so, the Voyager measurements of energetic neutral fluxes would be the first detected emissions from this region of Saturn's magnetosphere.

Conway, R. G., Davis, R. J. and Padin, S. (Radioastronomy Labs., Univ. of Manchester, Jodrell Bank, Macclesfield, Chesire SK119DL, UK): 'Microwave Measurements of the Outer Planets', *R. Astr. Soc. Mon. Not.* **219** (1986), 31P–33P.

In 1985 February the flux densities at $\lambda 6$ cm of Uranus and Neptune were measured to be 45.9 ± 2.2 and 14.7 ± 1.4 mJy, corresponding to disc temperatures of 251 and 225K respectively. No emission (<0.8 mJy) was detected from Pluto.

The microwave emission from Uranus varies with time, possibly as a seasonal effect. Since 1970 there has been an increase in disc temperature at $\lambda 6$ cm, as at other wavelengths, but between 1978 and 1985 the increase at $\lambda 6$ cm appears to have stopped.

Drobyshevski, E. M. (A.F. Physical-Technical Institute, USSR Academy of Sciences, Leningrad, USSR): 'The Structure of Phaethon and Detonation of its Icy Envelope', *Earth, Moon, and Planets* **34** (1986), 213–222.

It is suggested that Phaethon – a hypothetical planet whose breakup gave rise to the asteroid belt – has a structure similar to that of Callisto, and thus consisted of a rocky core (40% in mass) and an ice envelope (60%). Total breakup of the planet becomes possible in an explosion of the electrolysis products accumulated in the ice in the form of a solid solution if the planet mass $M \leqslant 0.5\ M_C$. Assuming $M = 0.5\ M_C$ we obtain 1750 km for the planet's radius with the envelope's thickness of 750 km. Application of the hydrodynamic theory of detonation to the $(2H_2 + 0_2)$ solution in ice reveals that depending on the actual critical temperature which for conventional explosives lies in the range 700–900 K the minimum $(2H_2 + O_2)$ concentration in ice required for its explosion is 13–18%.

Geake, J. E. and Dollfus, A. (Dept. of Pure and Applied Physics, UMIST, PO Box 88, Manchester M60 1QD, UK): 'Planetary Surface Texture and Albedo from Parameter Plots of Optical Polarization Data', *R. Astr. Soc. Mon. Not.* **218** (1986), 75–91.

Optical reflectance polarization measurements obtained with the Meudon Observatory polarimeter, in the laboratory and on the telescope. are collected together for the first time; surfaces investigated include rock and powder samples, meteorites. Iunar samples and atmosphereless planetary bodies. Interpretation of the data involves plotting polarization curve parameters and albedo, two or three at a time; all the types of plot that have been found useful are reviewed, including a new three-dimensional model. The empirical relationships found from these plots, calibrated by using data for known surfaces, are then of use for the remote determination of planetary surface properties, such as surface texture and albedo; a new method of estimating grain size is described.

Gomez, R. D. S. (Departamento de Astronomia, CNPQ-Observatorio Nacional, Rio de Janeiro, Brasil): 'Validation of Sagnier's Theory by its Application to the Major Planets', *Earth, Moon, and Planets* **34** (1986), 103–116.

In this paper, the theory of Sagnier was applied to the major planets, in order to have a first evaluation of this theory which was built, primarily, to study the galilean satellites of Jupiter. In this application we included the first order of the intermediary solution and the solution of the linear variational equations. Results from other theories, mainly those of Simon and Bretagnon, have been used as basis for comparisons. The results and their comparisons are shown by means of tables of coefficients and proper frequencies and graphs of variations of the orbital elements.

Grimm, R. E. and Solomon, S. C. (Dept. of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA 02139): 'Tectonic Tests of Proposed Polar wander Paths for Mars and the Moon', *Icarus* **65** (1986), 110–121.

We have tested the polar wander paths recently proposed for Mars by Schultz and Lutz-Garihan and for the Moon by Runcorn through a comparison of the lithospheric stress field predicted for rapid global reorientations against observed tectonic features. We have employed the theory of Vening Meinesz and of Melosh to calculate the reorientation stresses, and we argue that the formation of normal faults or graben in broad regions surrounding the former rotation poles should be the minimum tectonic signature of a reorientation that generates lithospheric stresses in excess of the extensional strength of near-surface material. Such regions of normal faults are not present in the vicinity of the most recent proposed paleopoles for Mars. despite the large magnitude of the predicted shear stress (1–2 kbar). The minimum tectonic criterion would not be relaxed by invoking gradual polar wander or by considering the superposition of stresses associated with the global lithospheric response to the Tharsis rise. We conclude that polar wander of the magnitude and timing proposed by Schultz and Lutz-Garihan did not occur. It follows either that Tharsis has always been located near the Martian equator or that Tharsis began to dominate the nonhydrostatic figure prior to the end of heavy bombardment so that any tectonic signature of reorientation has since been obliterated by cratering. The predicted directions of stresses that would result from the most recent episode of proposed polar wander on the Moon, including stresses produced by reorientation of both the rotational and tidal figures, show little or no correspondence to observed tectonic features in the vicinity of the postulated nearside paleopole. The magnitude of the predicted reorientation stress is at most a few tens of bars, however, so that the tectonic test of polar wander on the Moon is inconclusive

Ingersoll, A. P. and Miller, R. L. (Division of geological and Planetary Sciences, California Institute of Technology, Pasadena, of Jupiter and Saturn; 2. Barotropic Instabilities and Normal Modes of an Adiabatic Planet', *Icarus* **65** (1986), 370–382.

The low-frequency motions in a rotating, adiabatic, inviscid fluid planet are barotropic. quasi-geostrophic, and quasi-columnar. The only steady motions are differentially rotating cylinders in which zonal velocity $\bar{u}$ is a function of cylindrical radius r. Projected onto the planetary surface the limiting curvature at which the flow becomes unstable is negative: its amplitude is three to four times the amplitude for thin atmospheres. for planets in which density decreases linearly to zero at the surface. This result, derived first by A. P. Ingersoll and D. Pollard (1982, *Icarus* **52**, 62–80) for low zonal wavenumber perturbations, is shown to hold for all quasi-columnar perturbations. When $\bar{u} = 0$ the small amplitude motions are oscillatory. The lowest mode, as regards structure parallel to the axis, propagates eastward with a speed proportional to $(\text{wavelength})^2$. Both the barotropic stability criterion and the phase speed of the normal mode oscillations have features in common with Jupiter and Saturn observations, although the test is inconclusive with current data and theory.

Kohlhase, C. E. (Jet Propulsion lab., California Inst. of Tech., Pasadena, CA 91109): 'Voyager's Path of discovery', *Astronomy* **14**(2) (1986), 15–19, 22.

The mission of Voyager 2 to Uranus and Neptune is described.

Lambeck, K. (Dept. of Geophysics, Research School of Earth Sciences, Australian National Univ., Canberra 2600, Australia): 'Banded Iron Formations', *Nature* **320** (1986), 574.

The problem of the timescale of the dynamical evolution of the [2]Earth-Moon system is discussed.

Lange, M. A. and Ahrens, T. J. (Seismological Lab., 252–21, California Inst. of Tech., Pasadena, CA 91125): 'Shock-induced CO_2 Loss from $CaCo_3$; Implications for Early Planetary Atmospheres', *Earth Plan. Sci. Letters* **77** (1986), 409–418.

We report new results of shock recovery experiments on single crystal calcite. Recovered samples are subjected to thermogravimetric analysis. This yields the maximum amount of post-shock CO_2, the decarbonization interval, ΔT, and the energy of association (or vaporization), ΔEV, for the removal of remaining CO_2 in shock-loaded calcite. Comparison of post-shock CO_2 with that initially present determines shock-induced CO2 loss as a function of shock pressure. Incipient to complete CO_2 loss occurs over a pressure range of ~10 to ~70 GPa. The latter pressure should be considered a lower bound. Comparable to results on hydrous minerals, ΔT and ΔEV decrease systematically with increasing shock pressure. This indicates that shock loading leads to both the removal of structural volatiles and weakening of bonds between the volatile species and remainder of the crystal lattice.

Optical and scanning electron microscopy (SEM) reveal structural changes, which are related to the shock-loading. Comparable to previous findings on shocked antigonte is the occurrence of dark, diffuse areas, which can be resolved as highly vesicular areas as observed with a scanning electron microscope. These areas are interpreted as representing quenched partial melts, into which shock-released CO_2 has been injected.

The experimental results are used to place bonds on models of impact production of CO_2 during accretion of the terrestrial planets.

Matsui, T. and Abe, Y. (Geophysical Institute, Faculty of Science, University of Tokyo, Tokyo, Japan): 'Formation of a 'Magma Ocean' on the Terrestrial Planets due to the Blanketing Effect of an Impact-Induced Atmosphere', *Earth, Moon, and Planets* **34** (1986), 223–230.

We show that the surface of a planet growing by planetesimal impact is heated over the melting temperature of the surface materials due to the blanketing effect of an impact induced H_2O atmosphere with the present H_2O abundance of the Earth even when the accretion time is as long as $1O^8$ years. Hence, a magma ocean' covering the entire surface was formed on the Earth and Moon and other terrestrial planets during their formations.

Milani, A., Nobili, A. M., Fox, K. and Carpino, M. (Theoretical Astronomy unit, School of Mathematical Sciences, Queen Mary College Mile End Road, London E1 4NS, UK): 'Long-term Changes in the Semimajor Axes of the Outer Planets', *Nature* **319** (1986), 386–388.

One of the oldest problems of celestial mechanics is that of the long-term behaviour of the semimajor axes a of the planetary orbits. Analytical theories predict periodic variations in a, some of which may have very long periods, but these terms have never been computed. We have now performed a 9.3-Myr numerical integration of the orbits of the outer planets, using a pure newtonian point mass model. An accurate integrator and an effective low-pass filtering of the output allow us to detect high-order variations in the energies, and hence also in a, with periods ranging from tens of thousand to millions of years. The most interesting feature is an energy exchange between Uranus and Neptune with a period of 1,119,000 years, the same as the period of the libration between the perihelia of Jupiter and Uranus. The mechanism involves Jupiter and also Saturn; moreover, their energy shows puzzling longer-term trends. The energy of Pluto changes mostly with periods close to that of the 3:2 libration in mean motion with Neptune. Its spectrum in this region shows a very complicated structure; however, we have found no indication of chaotic behaviour.

Noll, K. S., Knacke, R. F., Tokunaga, A. T., Lacy, J. H., Beck, S. and Serabyn, E. (Dept. of Earth and Space Sciences, State University of New York, Stony Brook, NY 11794): 'The Abundances of Ethane and Acetylene in the Atmospheres of Jupiter and Saturn', *Icarus* **65** (1986), 257–263.

Infrared spectra near 780 cm^{-1} of Jupiter and Saturn have been obtained to determine the stratospheric abundances of ethane (C_2H_6) and acetylene (C_2H_2.). Atmospheric models using Voyager thermal profiles and density profiles with constant mixing ratios result in the mixing ratios, $X(C_2H_2) = 1.0(\pm 0.3) \times 10^{-7}$ and $X(C_2H_6)=5.5(\pm 1.5) \times 10^{-6}$ for Jupiter. The results for Saturn are $X(C_2H_2) = 3.0(+1.0) \times 10^{-7}andX(C_2H_6) = 7.0(+1.5) \times 10_{-6}$. The ratio of ethane to acetylene $n[C_2H_6]/n[C_2H_2]$, is found to be insensitive to model atmosphere assumptions. The ratio is 55 ± 31 for Jupiter and 23 ± 12 for Saturn from models with uniform mixing ratios. Atmospheric models with density profiles adapted from theoretical photochemical models also result in a higher ratio of ethane to acetylene (by a factor of 2 at the 1-mbar level) on Jupiter. The lower abundance of acetylene on Jupiter suggests that the rate of vertical transport in the stratosphere may be more rapid on Saturn than on Jupiter.

Owen, T., Lutz, B. L. and de Bergh, C. (Dept. of Earth and Space Sciences, Suny at Stony Brook, NY 11794): 'Deuterium in the Outer Solar System: Evidence for Two Distinct Reservoirs', *Nature* **320** (1986), 244–246.

We have just completed a series of determinations of the CH_3D/CH_4 ratio in the atmospheres of Saturn, Titan and Uranus. These results, coupled with the work of other investigators, suggest that the Solar System contains at least two distinctly different primordial reservoirs of deuterium: that contained in gaseous hydrogen and that contained in the volatiles which have been maintained at low temperatures or isolated from hydrogen; for example, trapped in cold, solid material. Both of these reservoirs were established before the formation of the Solar System.

Pollack, J. B., Rages, K., Baines, K. H., Bergstralh, J. T., Wenkert, D. and Danielson, G. E. (Space Sciences Division, NASA Ames Research Center, Moffett Field, California 94035): 'Estimates of the Bolometric Albedos and Radiation Balance of Uranus and Neptune', *Icarus* **65** (1986), 442–466.

We have attempted to bound the wavelength-averaged phase integrals and bolometric albedos of Uranus and Neptune by fitting a wide range of aerosol model atmospheres to their observed geometric albedo spectra. These models are characterized by an upper haze layer of finite optical depth and a lower cloud layer of infinite optical depth at discrete altitudes. Alternative models differ in the assumed value of the particles' single scattering phase function and the wavelength dependence of the haze optical depth. Phase functions ranging from isotropic to those characteristic of particles in the atmospheres of Titan. Jupiter, and Saturn are considered. We have partially tested the models of Uranus by comparing the dependence of their disk-integrated brightness on phase angle with that derived from a combination of ground-based and Voyager I data that span phase angles from 0 to 85° and by comparing their predicted shapes of several H_2 quadrupole lines with observed shapes. Predictions of the Neptune models were compared with determinations of the planet s disk-integrated brightness from 0 to 48° phase angle. The derived model parameters lie within useful bounds. In the case of Uranus. the cloud pressure for all seven models considered falls between 2.2 and 2.5 bars. implying methane mixing ratios in the deeper portion of the atmosphere that are at least 30 times higher than expected from solar elemental abundances if the cloud is interpreted as being a methane condensation cloud. The range of haze pressure ($\leqslant 0.5$ bars) and optical depth (0.06 to 0.6 at a wavelength of 0.6435 μm) imply that haze aerosols are a significant absorber of sunlight and hence constitute a significant heating source in Uranus's upper troposphere and stratosphere. The haze aerosols absorb strongly at both short and long visible wavelengths, unlike the aerosols in Titan's atmosphere. Qualitatively similar conclusions apply to our model atmospheres of Neptune. with the cloud pressure being somewhat higher than for Uranus (2.7–3.2 bars) and the methane abundance being at least 60 times higher than expected from solar elemental abundances. At the current epoch. the wavelength-averaged phase integrals of Uranus and Neptune equal 1.26 ± 0.11 and 1.25 ± 0.1. respectively. The corresponding bolometric albedos are 0.343 ± 0.055 and 0.282 ± 0.044. respectively. When averaged over an orbital period. these albedos may be 7% lower for Uranus and altered little for Neptune. based on measurements of their secular brightness variability. Comparison of these results with thermal observations implies that the internal heat source for Uranus is less than 0.27 times the solar input (specific luminosity $\leqslant 1.6 \times 10^{-7}$ erg/g/sec), while this value for Neptune is (1.85 ± 0.56) times its solar input (specific luminosity $= 3.4 \pm 1.1) \times 10_{-7}$ erg/g/sec). These results imply that the meteorological regimes in the observable atmospheres of Uranus and Neptune may be very different. with internal heat flux playing a much more important role for Neptune than for Uranus.

Read, P. L. (Geophysical Fluid Dynamics Lab., Meteorological Office (21), London Road, Bracknell, Berks., U.K.): 'Stable, Baroclinic Eddies on Jupiter and Saturn: A Laboratory Analog and Some Observational Tests', *Icarus* **65** (1986), 304–334.

Laboratory experiments (and corresponding numerical simulations) on free thermal convection in a rotating fluid, subject to horizontal differential heating and cooling. are examined in the light of recent observations of the longest-lived eddies on Jupiter and Saturn (including Jupiter's Great Red Spot and White Ovals). Both laboratory and atmospheric systems are shown to be capable of satisfying scaling requirements for mutual dynamical similarity, within the uncertainties of the Jovian observations. By employing a suitable distribution of heat sources and sinks in the laboratory, a pattern of zonally averaged flow analogous to a laterally sheared belt or zone on Jupiter can be obtained at upper levels. Baroclinic eddies may develop in such a flow, whose properties are remarkably similar in structure and appearance to the long-lived features on the major planets. Difficulties in determining from global energy budget studies the essential processes maintaining and dissipating stable eddies are discussed with reference to the laboratory and atmospheric systems. Such difficulties do not arise when considering the potential vorticity budget for the flow. Inviscid, unforced "free mode" (i.e., nonadvecting) solutions to a suitable potential vorticity equation are first-order components of most recent models of the Jovian eddies (including the baroclinic eddy analog described herein). Small departures from such a "free mode in a realistic flow arise as a result of the dynamically crucial processes maintaining and dissipating it, with baroclinic eddies in the laboratory corresponding largely to a residual balance between thermal forcing (via internal heating) and viscous dissipation. On Jupiter, diabatically forced and transient eddy-driven flows are shown to differ primarily in the implied role of transient eddies in transporting potential vorticity q across closed geostrophic streamlines in the time mean. The feasibility of using observations of naturally occurring chemical tracers to infer aspects of the transport of q on Jupiter are discussed with a view to testing models of the long-lived eddies using data from the Galileo mission.

Rossbacher, L. A. (Geological Sciences Dept., California State Polytechnic Univ., Pomona, CA 91768): *Planetology Geotimes* **31**(2) (1986), 45–47.

Recent developments in planetology and future plans for planetary exploration are outlined.

Shizgl, B. and Blackmore, R. (Dept. of Geophysics and astronomy, univ. of British columbia, Vancouver, British columbia V6T 1Y6, Canada): 'A Collisional Kinetic Theory of a Plane Parallel Evaporating Planetary Atmosphere', *Planet. Space Sci.* **34** (1986), 279–291.

The departure from equilibrium in the exosphere of a planetary atmosphere owing to the loss of energetic atoms is studied with solutions of the Boltzmann equation. A rigorous collisional solution is obtained for a plane parallel model with a newly developed discrete ordinate method, and the decrease in the escape flux relative to Jeans flux is calculated together with density and temperature profiles. The escape of hydrogen and helium atoms from Earth and the escape Or hydrogen atoms from Mars is considered. The results are compared with previous studies or the same effect. The departures from equilibrium are largest for the escape of a light species from an atmosphere with a heavy background gas such as for the escape of hydrogen atoms from Mars.

Sicardy, B., Roques, F., Brahic, A., Bouchet, P., Maillard, J.P. and Perrier, C. (Observatoire de Paris, Meudon, France): 'More Dark Matter around Uranus and Neptune', *Nature* **320** (1986), 729–731.

In addition to their natural satellites,the giant planets possess a surprisingly rich population of moonlets, rings, arcs and diffuse haloes of dust, the dynamics of which involves gravitational interactions and radiation and magnetic force. Recent analyses (by A.B., W. Hubbard, F.R. and B.S.) of isolated events observed around Neptune indicate the existence of an incomplete or at least 9 highly azimuthally variable ring or 'arc' around Neptune. Similar phenomena may be detectable around Uranus. In order to look for yet undetected dark matter around Uranus and Neptune, the best signal-to-noise ratio stellar occultations have been reanalyzed. To be confirmed, an 'event' should be observed with more than one telescope on the same site since the Fresnel scale (see below) is about 2–3 km at the level of Uranus and Neptune, and it should also be observed from widely separated observatories (100–1,000 km) to have an idea of the spatial extent of the occulting object, and to distinguish between satellites and ring-like structures. Moreover, theoretical models of diffracting bars or circular objects provide useful tests to reject some isolated events as being incompatible with real and celestial events. We report here an investigation of the surroundings of Uranus and Neptune using stellar occulations observed at the European Southern Observatory (ESO) on 22 April 1982 and at the Canada-France Hawaii Telescope (CFHT) on 15 June 1983, respectively. The high signal-to-noise ratio of these observations sets stringent limits on the presence of matter around these planets.

Thomsen, D. E.: 'How to Form Large Planets',*Science News* **129** (1986), 214.

Bodenheimer's theory for the formation of large planets is presented.

3. JUPITER

Barnett, A. (MIT, Cambridge, MA 02139): 'In Situ Measurements of the Plasma Bulk Velocity near the IO Flux Tube, *J. Geophys. Res.* **91** (1986), 3011–3019.

We study the flow around the Io flux tube by analyzing the eleven spectra taken by the Voyager 1 Plasma Science (PLS) experiment in its vicinity. We determine the bulk plasma parameters using a procedure that uses the full response function of the instrument and the data in all four PLS sensors. The mass density of the plasma in the vicinity of Io is found to be $22{,}500 \pm 2500$ amu/cm^3, and its electron density is found to be 1500 ± 200 cm^{-3}. We determine the Alfvén speed using three independent methods, the values obtained are consistent and, taken together, yield $V_A = 300 \pm 50$ km/s, corresponding to an Alvén Mach number of 0.19 ± 0.02. For the flow pattern we find good agreement with the model of Neubauer (1980) and conclude that the plasma flows around the flux tube with a pattern similar to the flow of an incompressible fluid around a long cylindrical obstacle of radius $1.26 \pm 0.1 R_{Io}$.

Carr, M. H. (U.S. Geological Survey, Menlo Park, CA 94025): 'Silicate Volcanism on Io', *J. Geophys. Res.* **91** (1986) 3521–3532.

Io is currently emitting 1–1.5 W m^{-2} of tidal energy as a result of its volcanic activity. If the lithosphere is more than 20 km thick, as appears probable from the surface relief, only a fraction of the tidal energy can be dissipated within the lithosphere, otherwise it will become thinner. The rest of the tidal energy must be dissipated below the lithosphere. Io is likely to be highly differentiated as a result of the volcanic activity, with a low melting temperature fraction. such as basalt, near the surface and a high melting temperature fraction, such as peridotite, at depth. If solidus temperatures are reached at depths shallower than the thickness of the basalt layer, a partial melt zone will separate an all-basalt lithosphere above from a peridotite mantle below, and part of the tidal energy will be dissipated by viscous deformation within the melt zone. Most of the energy dissipated below the lithosphere will be transported upward through the lithosphere as silicate magma, which is generated in quantities sufficient to resurface the satellite at a rate of a few tenths of a centimeter a year, depending on the lithosphere thickness. Many of the characteristics of the lonian surface have been explained in terms of sulfur volcanism. However, most of the features observed can be as readily explained by silicate volcanism, and silicates are more consistent with the apparent strength of the surface as implied by the relief Simulations of basaltic eruptions indicate that the surface temperatures that would result from basaltic eruptions are similar to those measured by the Voyager infrared interferometer spectrometer experiment. The high rates of emission by the lonian hot spots imply eruption rates that are high compared with typical terrestrial eruptions. An eruption rate of 4000 m^3 s$^-$1 may be required to explain Loki which is currently emitting 10^{13} W. Although the near-surface materials are mainly silicate, they may contain several percent of volafile components rich in 5, Na, and K. Remobilization of these components by the ongoing silicate eruptions causes the plumes. provides material to the torus, and gives the satellite its characteristic reflectivity.

Flasar, F. M. (Laboratory for Extraterrestrial Physics, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771): 'Global Dynamics and Thermal Structure of Jupiter's Atmosphere', *Icarus* **65** (1986), 280–303.

Jupiter has an intrinsic luminosity and most if not all of its interior is believed to be fluid and of low viscosity These imply a regime of thermally driven turbulent convection The convection is likely to be strongly constrained by the planet's rotation. and should maintain a nearly adiabatic interior with small horizontal gradients in temperature Observations at visible wavelengths depict a cloudy atmosphere with a system of westerly and easterly jets with peak-to-peak amplitudes of up to ~200 m/sec near the equator Near the equator the specific angular momentum exceeds that corresponding to corotation with the interior How the observed multiple-jet stem is driven is closely related to how deeply it extends into Jupiter: neither is known. A jet system which extends into the adiabatic interior would imply that the convective eddies themselves are an important source of zonal momentum Analyses of Voyager images have suggested that the eddies at the observable cloud level tend to transport net zonal momentum countergradiently into the jets. but this interpretation may suffer from nonuniform and incomplete sampling Moreover the momentum transport by any secondary circulation induced by such eddies has not been addressed. Between the visible cloud layer and adiabatic interior lies a transition zone about which little is known. Latent heat release by condensibles disequilibrium between *ortho-* and *para*-hydrogen, and baroclinic/symmetric instabilities might contribute significantly in maintaining the vertical and horizontal thermal structure of this region Theory and observation suggest that, except for a limited range of altitudes, the mean lapse rate in the transition zone is close to dry adiabatic. Horizontal gradients in temperature are not well constrained. Above the clouds in the upper troposphere and lower stratosphere, the observed temperatures suggest a decay of the zonal winds with altitude This is consistent with a forced mean meridional circulation with frictional and radiative damping, which has upwelling and adiabatic cooling at the latitudes of anticyclonic vorticity In the upper stratosphere. the meridional temperature anomalies tend to reverse sign The cause of this is not known and could have either a radiative or dynamical origin Additionally, there is a global north-south asymmetry in temperature suggestive of a seasonal forcing and implying a cross-equatorial circulation at high altitudes.

Forni, O., Thomas, P. G. and Masson, Ph. (Laboratorie de Géologie Dynamique Interne, Université Paris-Sud, Orsay, France): 'Ganymedean Pedestal Craters Distribution: Implications on Thermal and Tectonic Histories', *Earth, Moon, and Planets* **34** (1986), 177–188.

The distribution analysis of the ganymedean pedestal craters shows a very good correlation between them and the grooved terrains. These craters seem to be the earliest post-grooved impacts. The presence of 'tectonized' pedestal craters is 'also noted. This type of crater is the only one lying on the grooved terrains and being affected by the grooves. Assuming that a lowering of the terrain's viscosity is the determining factor for the presence of pedestal craters, we conclude that at the time of their formation, the grooved terrains have a lower viscosity than the other terrains. Moreover, using the density ratio between non-pedestal craters and pedestal craters, a relative low viscosity state's duration time is calculated. Based on the density ratio between pedestal craters and tectonized pedestal craters, a grooved terrains formation's time is also calculated. These two times are of the order of 10^7 yr and 10^6 yr respectively. This period of low viscosity may be partly due to internal heating.

Froeschlé, C. and Scholl, H. (Observatoire de Nice, France): 'Gravitational Splitting of Quadrantid-like Meteor Streams in Resonance with Jupiter', *Astron. Astrophys.* **158** (1986), 259–265

We investigate numerically the dynamical evolution of meteor streams with the same orbital elements as the Quadrantids except for a slightly different range of semimajor axes ($3.24 < a < 3.36$ AU). This range covers the whole width of the observed 2/l Kirkwood gap in the asteroidal belt. We find a peculiar behaviour for those streams in resonant motion with Jupiter: The streams break up into arcs of different sizes with distinctly different dynamical evolutions due to possible modes for resonant motion. Large, isolated arcs with differing orbital parameters are formed. We conjecture that such a gravitational splitting which causes the formation of isolated stream arcs with slow dispersion rates might occur in various ring systems in mean motion resonance with a perturbing body.

Griffin, M. J., Ade, P. A. R., Orton, G. S., Robson, E. I., Gear, W. K., Nolt, I. G. and Radostitz, J. V. (Dept. of Physics, Queen Mary College, Mile End Road, London, England): 'Submillimeter and Millimeter Observations of Jupiter', *Icarus* **65** (1986), 244–256.

We report narrowband photometry of the Jovian disk in 10 passbands covering the range from 0.35 to 3.3 mm wavelength. Absolute calibration was referenced to Mars. The derived brightness temperature spectrum is analyzed in the context of existing constraints on the atmospheric temperature structure and composition from ground-based studies at shorter wavelengths and from various spacecraft measurements. Our results for wavelengths between 0.35 and 0 15 mm suggest that the radiances can be matched by models which include NH_3 ice particles which are between 30 and 100 μm in size, regardless of the scale height characterizing the cloud. It is difficult however. to model the relatively cool observations longward of 0.7 mm unless additional absorbers are assumed in the atmosphere or a different NH_3 lineshape is assumed. If the absolute calibration scale were increased by 5%, the results would be fit by a clear atmosphere (or a small particle cloud) model. with no need to invoke additional absorption in the Jovian atmosphere.

Hecht, J.: 'Io Spirals Towards Jupiter', *New Scientist* **109**(1492) (1986), 33.

Io, the innermost of Jupiter's four bright satellites discovered by Galileo, is spiralling slowly towards the planet. Io's orbit is shrinking only about 13 cm per year, but such a change was unexpected. The Moon is slowly drifting away from the Earth, with its orbit growing a few centimetres each year, and astronomers had expected similar effects for satellites such as Io.

Inan, U. S. (Star Lab., Stanford Univ., CA 94305): 'Jovian VLF Chorus and Io Torus Aurora', *Geophys. Res.* **91** (1986), 4543–4550.

A test particle model of the cyclotron resonance interaction of waves and trapped radiation belt particles is used to estimate the energetic electron fluxes precipitated by Jovian VLF chorus waves observed on the Voyager 1 and 2 spacecraft near the Io torus. The precipitation fluxes induced by 1-s-long chorus wave packets at $L \simeq 7.6$ and 8.6 are estimated to be bursts of ~5 s duration with a peak of 0.3–3 and 0.7–7 ergs/cm^2 s that consist of electrons of ~5–100 keV energy and that arrives at the ionosphere ~15 s after the generation of the chorus wave at the equatorial plane. The effects in the Jovian ionosphere of the chorus-induced precipitation are estimated using existing ionospheric models. A possible experiment for measuring Jovian chorus-induced aurora is proposed and discussed.

Limaye, S. S. (Space Science and Engineering Center, University of Wisconsin, Madison, Wisconsin 53706): 'Jupiter: New Estimates of the Mean Zonal Flow at the Cloud Level', *Icarus* **65** (1986), 335–352.

Previous estimates of the mean zonal flow on Jupiter from Voyager images by Ingersoll *et al.* (A. P. Ingersoll, R. Beebe, J. L. Mitchell, G. W. Carneau, G. M. Yagi, and J. P. Mueller (1981). *J. Geophys. Res.*, **86**, 8733–8743) and by Limaye *et al.* (S. S. Limaye, H. E. Revercomb, L. A. Sromovsky, R. J. Krauss, V. E. Suomi, S. A. Collins, and C. C, Avis (1982) *J. Atmos Sci* **39**, 413–1432) showed good agreement in the locations of the easterly and westerly jets but differed somewhat in magnitude. Recent measurements of the high-speed jet located near 24° north (planetographic) latitude by T. Maxworthy ((1984) *Planet, Space Sci.* **32**, 1053–1058) from high spatial and temporal resolution Voyager images indicate that both Ingersoll *et al.*, and Limaye *et al.*, underestimated the magnitude of the jet by more than 30–40 msec^{-1}. In an attempt to examine the differences in the magnitude of the Jovian jets determined from Voyager 1 and 2 images a new approach to determine the zonal mean east–west component of motion was investigated The new technique, based on simple, digital pattern matching approach and applied on pairs of mapped images (cylindrical mosaics) yields a profile of the mean zonal component that reproduces the exact locations of the easterly and westerly jets between ±60° latitude. Not only do the jet magnitudes but also the wings of the jets agree remarkably well from mosaic pair to pair. Further. the latitudinal resolution is five (midlatitudes) to eight times (equatorial) greater than previous results Results have been obtained for all of the Voyager 1 and 2 cylindrical mosaics The correlation coefficient between Voyager 1 and Voyager 2 average mean zonal flow between ±60° latitude determined from violet filter mosaics is 0 998 A slight latitude offset, possibly due to navigation errors, is detectable (+0 2 latitude average) in the Voyager 1 data Independent cloud motion measurements in two high-resolution image pairs (orange and violet) acquired from Voyager 1 cameras agree well with the average mean zonal flow for the fastest Jovian jet at 23.8°N latitude. Comparison with Maxworthy's (1984) results suggests longitudinal variations in cloud motions approaching about 20 $msec^{-1}$. In particular, the jet magnitude is about 163 ± 7 (RMS) $msec^{-1}$, which compares well with 182 ± 10 $msec^{-1}$ reported by Maxworthy. There is excellent agreement in the location of the peak magnitude as well as its shape The time average Voyager 2 mean zonal flow profile with latitude is presented in a table.

Lieske, J. H. (Jet Propulsion Lab., California Inst. of Tech., Mail Stop 264/664, 4800 Oak Grove Drive, Pasadena, CA 91109): 'A Collection of Galilean Satellite Eclipse Observations, 1652–1983: Part I', *Astron. Astrophys.* **154** (1986), 61–76.

The most complete collection of extant Galilean satellite eclipse observations since 1652 has been assembled. Since many of the old data exist only in manuscript form or in archaic forms (e.g., apparent time, local time, sidereal time, Julian calendar, etc.), they have been reduced to a modern proleptic Universal Time (UT) system (where the day begins at midnight) on the Gregorian calendar. Many of the data had been presumed to be lost for more than a century and since they are very valuable for discussion of long-term effects on the satellites, I present them here for present as well as future generations of astronomers. The data are invaluable for long-term studies of Galilean satellite motion and for the determination of physical parameters.

Lieske, J. H. (Jet Propulsion Lab., California Inst. of Tech., Mail Stop 264/664, 4800 Oak Grove Drive, Pasadena, CA 91109): 'A Collection of Galilean Satellite Eclipse Observations, 1652–1983: II', *Astron. Astrophys. Suppl. Ser.* **63** (1986), 143–202.

The largest collection of Galilean satellite eclipse observations extent has been gathered from the published literature and from manuscript collections from 1652 to 1983. Many of the observations were thought to have been irretrievably lost for more than a century. The collection will be of great value in evaluating long-term effects on the Galilean satellites such as the possible existence of tidal dissipation on their periods.

McEwen, A. S., Soderblom, L. A., Matson, D. L., Johnson, T. V. and Lunine, J. I. (Dept. of Geology, Arizona State Univ., Tempe, AZ 85287): 'Calculated Occultation Profiles of Io and the Hot Spots', *Geophys. Res. Letters* **13** (1986), 201–204.

Occultations of Io by other Galilean satellites in 1985 provide a means to locate volcanic hot spots and to model their temperatures. We have computed the expected time variations in the integral reflected and emitted radiation of the occultations as a function of wavelength (visual to 8.7 μm). The best current ephemerides were used to calculate the geometry of each event as viewed from Earth. Visual reflectances were modeled from global mosaics of Io. Thermal emission from the hot spots was calculated from Voyager 1 IRIS observations and, for regions unobserved by IRIS, from a model based on the distribution of low-albedo features. The occultations may help determine (1) the location and temperature distribution of Loki; (2) the source(s) of excess emission in the region from long 50 to 200°; and (3) the distribution of small, high-temperature sources.

MacLow, M.-M. and Ingersoll, A. P. (Joint Institute for Laboratory Astrophysics, University of Colorado and National Bureau of Standards, Boulder, Colorado 80309): 'Merging of Vortices in the Atmosphere of Jupiter: An Analysis of Voyager Images', *Icarus* **65** (1986), 353–369.

We have studied interactions between stable oval structures (spots) using the Voyager2 cylindrical projection mosaics In contrast with the solitary wave type of interaction collisions between spots are irreversible. Most interactions (23 out of 27 cases) lead t.o merging of the two original spots. The other type of interaction (4 out of 77 cases) is simply a near miss – the spots pass around each other Interactions of spots with filamentary regions which are actively changing and mole amorphous than spots, usually lead to the disappearance of the spot. Filamentary regions are also the major source of spots. Stable spots do not produce other spots Instead spots destroy each other by merging. Most spots are anticyclonic and sit in anticyclonic shear zones. Filamentary regions are cyclonic and sit in cyclonic shear zones. Larger spots are more elliptical than smaller ones. The most common spots have major diameters of 2000 km and minor diameters of 1500 km.

Murchie, S. L. and Head, J. W. (Dept. of Geological Sciences, Brown Univ., Providence, RI 02912): 'Global Reorientation and Its Effect on Tectonic Patterns on Ganymede', *Geophys. Res. Letters* **13** (1986), 345–348.

The perturbation to the momental figure of Ganymede by the impact basin Gilgamesh was modelled, and it was found that the formation of the basin could have significantly reoriented the satellite. Global trends of groove orientation suggest that groove sets formed in reactivated zones of weakness, which were created by tidal despinning and furrow formation. The paleopole on which despinning occurred was shifted about 15° after the emplacement of most grooved terrain. The youngest grooves have orientations consistent with those expected for fractures caused by their reorientation.

Murray, C. D. (Theoretical Astronomy Unit, School of Mathematical Sciences, Queen Mary College Univ. of London, Mile End Road, London E1 4NS, UK): 'Structure of the 2:1 and 3:2 Jovian Resonances', *Icarus* **65** (1986), 70–82.

The chaotic regions of the phase space in the vicinity of the 2:1 and 3:2 jovian resonances are identified by using a mapping technique derived from a second-order expansion of the disturbing function for the planar elliptical restricted three-body problem. It is shown that both resonances have extensive chaotic regions which in some cases can lead to large changes in the eccentricity of asteroid orbits. Although the 3:2 resonance is shown to be more chaotic than the 2:1 resonance. the existence of the Hilda group of asteroids and the Hecuba gap may be explained by distinct differences in the location of the high-eccentricity regions at each resonance. The problem of the convergence of the expansion of the disturbing function in the outer asteroid belt is also discussed.

Nagy, A. F., Barakat, A. R. and Schunk, R. W. (Space Physics Research Lab., Univ. of Michigan, Ann Arbor, MI 48109): 'Is Jupiter's Ionosphere a Significant Plasma Source for Its Magnetosphere?', *J. Geophys. Res.* **91** (1986), 351–354.

A semikinetic model was used to study the steady state, collisionless, polar wind outflow from the Jovian polar caps. H^+ escape fluxes and energies were calculated for a range of conditions, including several values of the ambient electron temperature, different hot electron populations, and both with and without the effects of the centrifugal force. The calculations indicate that if hot electron populations exist over the Jovian polar caps, as they do on earth, polar wind escape fluxes of the order of $10^8\,cm^{-2}\,s^{-1}$ are possible. When integrated over the polar cap area, escape fluxes of this order of magnitude imply an ionospheric source strength of 2×10^{28} ions/s, which is comparable to the present estimate of the total magnetospheric plasma source population. Therefore, the ionosphere may play an important role in populating the Jovian magnetosphere, specifically the "hidden", low energy, light ion component of the population.

Nelson, M. L., McCord, T. B., Clark, R. N., Johnson, T. V., Matson, D. L., Mosher, J. A. and Soderblom, L. A. (Planetary Geosciences Div., Hawaii Inst. of Geophysics, Univ. of Hawaii, Honolulu, HI 96822): 'Europa: Characterization and Interpretation of Global Spectral Surface Units', *Icarus* **65** (1986), 129–151.

The Voyager global multispectral mosaic of the Galilean satellite Europa (T. V. Johnson, L. A. Soderblom, J. A. Mosher, G. E. Danielson, A. F. Cook, and P. Kupferman, 1983, *J. Geophys. Res.* **88**, 5789–5805) was analyzed to map surface units with similar optical properties (T. B. McCord, M. L. Nelson, R. N. Clark, A. Meloy, W. Harrison, T. V. Johnson, D. L. Matson, J. A. Mosher, and L. Soderblom, 1982, *Bull Amer. Astron. Soc.* **14**, 737). Color assignments in the unit map are indicative of the spectral nature of the unit. The unit maps make it possible to infer extensions of the geologic units mapped by B. K. Lucchitta and L. A. Soderblom (1982, in S*Satellites of Jupiter*, pp. 521–555, University of Arizona Press, Tucson) beyond the region covered in the high-resolution imagery. The most striking feature in the unit maps is a strong hemispheric asymmetry. It is seen most clearly in the ultraviolet/violet albedo ratio image, because the asymmetry becomes more intense as the wavelength decreases. It appears as if the surface has been darkened, most intensely in the center of the trailing hemisphere and decreasing gradually, essentially as the cosine of the angle from the antapex of motion, to a minimum in the center of the leading hemisphere. The cosine pattern suggests that the darkening is exogenic in origin and is interpreted as evidence of alteration of the surface by ion bombardment from the Jovian magnetosphere.

Riihimaa, J. J. (Aarne Karjalainen Observatory, University of Oulu, Finland): 'Beaming of Jupiter's Decametric Emission', *Earth, Moon, and Planets* **34** (1986), 133–138.

Dynamic spectra of a Jovian non-Io-A storm recorded simultaneously by the Voyager 1 spacecraft and by the Kiiminki radio spectrograph are compared. It seems that the emission beam of the storm co-rotates with the planet and has a sloped leading edge, in accordance with the result of Maeda and Carr (1984).

Smith, C. W. and Lee, M. A. (Space Science Center, Dept. of Physics, Univ. of New Hampshire, Durham, NH 0382): 'Coupled Hydromagnetic Wave Excitation and Ion Acceleration Upstream of the Jovian Bow Shock', *J. Geophys. Res.* **91** (1986), 81–90.

We extend the Lee (1982) self-consistent theory of upstream wave excitation and particle energization to address observations by Voyager 2 of sunward propagating MHD waves and diffuse suprathermal particle populations upstream of the Jovian bow shock. Two new ideas are incorporated into the theory. First, the interplanetary seed wave population is taken to be an equal admixture of waves propagating both toward and away from the shock parallel to the interplanetary magnetic field. Second, finite connection times are incorporated approximately into the theory in an effort to understand whether the particle spectra at high energy are limited by particle escape or finite connection time. It is found that finite connection times dominate the particle distribution at energies above 40 keV. In this manner the suprathermal proton distributions can be accounted for by a multiple reflection, shock acceleration theory. We find that the theory can also account for the low-frequency waves observed upstream of the shock in conjunction with the suprathermal ions.

Smith, P. H. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, Arizona 85721): 'The Vertical Structure of the Jovian Atmosphere', *Icarus* **65** (1986), 264–279.

An inhomogeneous atmospheric model. which includes both polarizing aerosols and methane gas has been developed for the equatorial and tropical regions of Jupiter consistent with the Pioneer polarimetry and photometry data as well as the methane-band data of West (1979a, *Icarus* **38**, 12–33). A two-cloud model with an overlying stratosperic haze has been used to explain the relative strengths of weak and strong methane bands. The upper cloud. assumed to be composed primarily of ammonia crystals is denser in the zones (5–8 optical depths) than the belts (3–4 optical depths) when viewed in red light. There is also a compositional difference; an increase in the concentration of the unknown chromophore lowers the blue albedo in the belts. Otherwise. bells and zones are remarkably similar. The cloudtops are found between 700 and 230 mbar and the cloud extends down to the saturated vapor pressure of ammonia at 700 mbar: a haze of 0 3 ± 0 1 optical depths overlies all regions. For all the regions studied. the polarization measurements are best fit with a negatively polarizing ammonia cloud (−20%) beneath a positively polarizing haze (40–50%). Unlike the nearby features the Equatorial Region and the Great Red Spot have a negative polarization at 80° phase angle implying less gas above the clouds in these regions a conclusion supported by the increased brightness al 8900 Å. Tables are presented giving the preferred model parameters for each region studied.

Steudel, R., Holdt, G. and Young, A. T. (Institut für Anorganische und Analytische Chemie, Technische Universität Berlin 1000 Berlin 12, Strasse des 17 Juni 135, Berlin, FRG): 'On the Colors of Jupiter's Satellite Io: Irradiation of Solid Sulfur at 77 K', *J. Geophys. Res.* **91** (1986), 5971–5977.

The colors of seven sulfur allotropes al 77 K have been investigated both before and after irradiation by a high-pressure mercury lamp. S_8 is white at 77 K but turns intense yellow within a few minutes on irradiation through quartz or DURAN. On warming, the yellow species (presumably chain-like sulfur diradicals characterized by an absorption al 430 nm) decomposes near 260 K and polymeric sulfur (S_∞) is formed; the sample color changes gradually to the very similar color of an S_8–S_∞ mixture, resulting in no visually detectable color change with temperature from 77 to 260 K. This is consistent with the lack of posteclipse brightening on Io. Other sulfur forms also turn intense yellow (S_7, S_{10}) greyish yellow (S_{12}, S_{20}, S_∞) or brownish yellow (S_6) on irradiation at 77 K, and these colors also change to the normal colors of the starting materials on warming to 298 K. We suggest that the yellowish features on Io are caused by the effect of solar radiation on elemental sulfur. The yellow color thus produced may subsequently be modified by deposits of SO_2 frosts and volcanic ash.

Tan, A. (Dept. of Physics, Alabama A and M Univ., Normal, AL 35762): 'Spatial and Diurnal Features of the Jovian Equatorial Anomaly', *Planet. Space Sci.* **34** (1986), 117–124.

This paper outlines a lime-dependent model of the Jovian ionosphere with electrodynamic drift to study the spatial and temporal features of the Jovian equatorial anomaly.Two sinusoidal drift velocity, models are considered - Model 1, akin to that in the terrestrial ionosphere and Model 2, having opposite phase. The drift velocity amplitude is taken to be $100\,\mathrm{m\,s^{-1}}$. In either model, we obtain an equatorial anomaly which persists throughout the day unlike its terrestrial counterpart, which disappears after midnight. The crest of ionization is centered around 7–8 degrees latitude in either model as compared with about 15 degrees for the terrestrial anomaly The R_m index attains a maximum value of 2.6 in the afternoon in Model 2. The peak electron density at the equator minimizes before midnight in Model 1, but after sunrise in Model 2.There is no "noon biteout" like that found in the terrestrial equatorial ionosphere. The height of the peak electron density roughly) follows the drift velocity pattern. Comparison with experimental data indicates that drift velocity amplitudes far exceeding $100\,\mathrm{m\,s^{-1}}$ would be required to produce the observed Jovian equatorial anomaly.

Thomas, P. G., Forni, O. P. and Masson, P. L. (Laboratoire de Geologie Dynamique Interne, Universif de Paris XI, Orsay, France): 'Geology of Large Impact Craters on Ganymede: Implications on Thermal and Tectonic Histories', *Earth, Moon, and Planets* **344** (1986), 35–53.

The geometry of the furrows of Galileo Regio indicates that they are not of impact origin, and irrelevant to discussion about large impact effects. The detailed study of three large impact basins indicates that their transient cavity radii are different from previously reported values. Because of the relations between crater's size and lithospheric thickness, these new values of basins radii would constrain further models of Ganymede's thermal evolution. The geometry of lineaments around these three basins, which occurred on grooved terrains, indicates that these impacts induced tectonic motions along a preexisting planetary wide grid pattern. This pattern influenced also the formation of the furrows on Galileo Regio. That would indicate that the grooved terrains are only superficial layers and that they were formed without destruction or rotation of their basement.

Tomasko, M. G., Karkoschka, E. and Martinek, S. (Pacific-Sierra Research Corporation, 12340 Santa Monica Boulevard, Los Angeles, CA 90025): 'Observations of the Limb Darkening of Jupiter at Ultraviolet Wavelengths and Constraints on the Properties and Distribution of Stratospheric Aerosols', *Icarus* **65** (1986), 218–243.

Three series of spectra of Jupiter covering the spectral range from 0.22 to 0.33 μm were obtained with the International Ultraviolet Explorer (IUE) satellite in November 1979. The absolute reflectivity of Jupiter was obtained in 50-Å-wide regions centered at 0.221, 0.233, 0.252, and 0.330 μm from these observations. One of the three spectral series includes 7 spectra at various latitudes along Jupiter's central meridian. These data show a strong decrease in reflectivity for latitudes greater than about 30°, in agreement with measurements made by Voyager (C. W. Hord, R. A. West, K. E. Simmons, D. L. Coffeen, M. Sato, A. L. Lane, and J. T. Bergstrahl. 1979, *Science* (*Washington, D.C.*) **206**, 956–959). A total of 24 spectra were also obtained in a west-east series along the equator and another near 40°N latitude. Both west-east series of spectra were obtained by using the motion of a Galilean satellite to pull the 3-arcsec-diameter IUE aperture across the disk of Jupiter. Spectra which straddled the edge of the disk were used to determine the locations of all the spectra in both west-east series to high accuracy. The west-east series show limb darkening at high latitudes and brightening toward the illuminated limb at low latitudes. Comparisons of model calculations with the data obtained near 40°N indicate a significant absorption optical depth (increasing from ~0.3 at 0.25 μm to nearly 0.6 at 0.22 μm) centered near pressure levels of 20 to 30 mbar. Models in which the haze particles have effective radii within a factor of about 2 of 0.2 μm are favored. Smaller particles have difficulty fitting the variation with wavelength in our data (even with rapidly varying amounts of absorption with wavelength) and larger particles rapidly fall out of the high atmospheric layers. The aerosol mass loading of the atmosphere at high latitudes is estimated at 20 $\mu g/cm^2$ above the 50-mbar level. The required variation of the imaginary index of refraction of the aerosol material with wavelength is derived for several possible aerosol distributions. The variation measured by M. Podolak, N. Noy, and A. Bar-Nun (1979, *Icarus* **40**, 193–198) for polyacetylene photochemical products is in reasonable agreement with the IUE observations for one of the vertical haze distributions presented, although mixtures of materials produced by irradiating various combinations of methane. hydrogen, and some nitrogen-bearing compounds with energetic particles may also be able to reproduce the observations. Near the equator, the haze aerosols produce much less absorption than near 40°N, and the derived aerosol distributions and optical properties are more dependent on the assumed location and reflectivity of the top of the tropospheric cloud. The equatorial haze aerosols can be as optically thick as the high-latitude aerosols only if they are concentrated much deeper in the atmosphere (near 150 mbar). However. if the haze aerosols extend up to pressures as low as 50 mbar or less at low latitudes as suggested by the eclipse studies of D. W. Smith (1980, *Icarus* **44**, 116–133), then they have 5 to 10 times less absorption optical depth near the equator than at 4O°N. Comparisons with the satellite eclipse studies and analyses of polarimetry near the limb at large phase (P. H. Smith and M. G. Tomasko, 1984, *Icarus* **58**, 35–73) indicate that the haze aerosols at low latitudes can have sizes in the same range as found near 40=N. A radius estimate of 0.2 μm yields a mass loading of some 4 $\mu g/cm^2$ for the haze aerosols near the equator above the 150-mbar pressure level. Assuming that the haze aerosols have the same composition at high and low latitudes implies that the single-scattering albedo of the tropospheric cloud particles at low latitudes decreases strongly from 0.33 to 0.22 μm.

West, R. A., Strobel, D. F. and Tomaski, M. G. (Earth and Space Sciences Division, J.P.L., California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109): 'Clouds, Aerosols and Photochemistry in the Jovian Atmosphere', *Icarus* **65**(1986), 161–217.

In this paper we review current ideas about the composition. horizontal and vertical distribution, and microphysical properties of clouds and aerosols in Jupiter's upper troposphere and stratosphere. We also discuss several key photochemical species, their relation to aerosol formation, and their implications for transport processes. We treat photochemistry in the context of comparative planetology and point out important similarities and differences among the outer planet atmospheres. Our approach emphasizes observational data of relevance to cloud properties and to this end we assemble a wide assortment of ground-based and spacecraft observations. We challenge some widely held views about the distribution of clouds in the troposphere and present a rationale for alternative interpretations.

Winglee, R. M. (Dept. of Astrophysical, Planetary and Atmospheric Sciences, Univ. of Colorado, Boulder, CO 80309): 'On Io's Control of Jovian Decametric Radio Emissions', *J. Geophys. Res.* **91** (1986), 1405–1416.

Io's control of Jovian decametric radio emission (DM) has been attributed to Io distorting the electron distribution in the inner Jovian magnetosphere. Observations of Faraday rotation in DAM are used to determine the properties of the electron distribution before and after its interaction with Io. It is shown that there is an enhancement in the density of the energetic component in the Io plasma torus correlated with certain Jovian longitude. Io's interaction with this energetic component can produce heating of this component. The Io-controlled emission is attributed to enhanced emission from the heated electrons moving down the field lines to Jupiter.

5. MARS

Baker, V. R. and Partridge, J. B. (Dept. of Geosciences, Univ. of Arizona, Tucson, AZ 85721): 'Small Martian Valleys: Pristine and Degraded Morphology', *J. Geophys. Res.* **91** (1986), 3561–3572.

The equatorial heavily cratered uplands of Mars are dissected by two classes of small valleys that are intimately associated in compound networks. Pristine valleys with steep valley walls preferentially occupy downstream portions of compound basins. Degraded valleys with eroded walls are laterally more extensive and have higher drainage densities than pristine valleys. Morphometric and crater-counting studies indicate that relatively dense drainage networks were emplaced on Mars during the heavy bombardment about 4.0 b.y ago. Over a period of approximately 10^8 years, these networks were degraded and subsequently invaded by headwardly extending pristine valleys. The pristine valleys locally reactivated the compound networks, probably through sapping processes dependent upon high water tables. Fluvial activity in the heavily cratered uplands generally ceased approximately 3 8–3 9 b y ago, coincident with the rapid decline in cratering rates. The relict compound valleys on Mars are morphometrically distinct from most terrestrial drainage systems. The differences might be caused by a Martian valley formation episode characterized by hyperaridity, by inadequate time for network growth, by very permeable rock types, or by a combination of factors.

Burns, R. G. (Dept. of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA 02139): 'Terrestrial Analogues of the Surface Rocks of Mars?', *Nature* **320** (1986), 55–56.

The pathways of chemical weathering processes on Earth, and the virtual absence of them on the Moon, are well characterized because we have direct access to samples of primary igneous rocks. their upper mantle sources and derivative sedimentary rocks and soil forming the regolith. Tracing chemical changes on the surface of Mars, however, is more difficult because of limited access to samples from Mars. Terrestrial rocks and minerals are continually being sought which might serve as analogues for martian materials. Evidence presented here suggests that hisingerite, iddingsite and several ferric sulphate minerals derived from deuteric alteration of iron-rich basalts may provide clues to the evolutionary history of the surface of Mars.

Christensen, P. R. (Dept. of Geology, Arizona State Univ., Tempe, AZ 85287): 'Regional Dust Deposits on Mars: Physical Properties, Age, and History', *J. Geophys. Res.* **91** (1986), 3533–3545.

Major dust storms on Mars play an important role in the deposition and removal of fine dust material. Thermal, radar, and visual remote sensing observations provide important constraints on the Martian regolith which have been used to determine the location and physical properties of regional dust deposits. These deposits are located in three northern equatorial regions, Tharsis (−20°S to 50°N, 60 to 190°W), Arabia (−5°S to 30°N, 300 to 360°W), and Elysium (10 to 30°N, 210 to 225°W). They are covered by fine (~2–40 μm), bright (albedo > 0.27) particles, with fewer exposed rocks and coarse deposits than round elsewhere. Dust is currently deposited uniformly throughout the equatorial region at a rate of ~40 μm/global storm. Over geologic time the rate of accumulation may vary from 0 to 250 μm/yr due to changes in atmospheric conditions produced by orbital variations. Dust deposited during global storms is subsequently removed only from dark regions, resulting in a net accumulation in the low-inertia, bright regions. The thickness of these current dust deposits is 0.1–2 m. The thermal inertia places a lower limit of ~0.1 m on the thickness of these deposits, while the sparse but ubiquitous presence of exposed rocks and the degree of visible mantling indicate that the thickness is less than 5 m. Dual-polarization radar observations of a very rough texture in Tharsis are consistent with this model, with a ~2-m-thick dust layer burying most of the surface rocks but permitting radar sampling of the rough subsurface. Based on their thickness and rate of accumulation, the age of these deposits is 10^5–10^6 years, suggesting a cyclic process of deposition and removal. One possible cause may be cyclic variations in the magnitude and location of maximum wind velocities related to variations in Mars' orbit. At present, perihelion and maximum wind velocities occur in the south, whereas regional dust deposits occur in the north, suggesting net transport from south to north. Orbital parameters oscillate with periods ranging from 5×10^4 to 10^6 years. The agreement between these periods and the dust deposit age suggests a possible link. At different stages in orbit evolution, maximum wind velocities will occur in the north, with subsequent erosion and redistribution of the accumulated fines. Based on this model, much of the uppermost Martian surface is very young and is being continually reworked.

Clark, P. S.: 'The Soviet Mars Programme', *J. Brit. Interplanet. Soc.* **39** (1986), 3–18.

Beginning in 1960, the Soviet Union launched a number of probes to explore the planet Mars. While the contemporary Venus venture met with many successes, the Mars programme, using the same spacecraft technology, met with failure. Only one mission was a total success (Mars 5). This paper reviews the Mars programme, looking at the launch and arrival conditions that have applied and how the spacecraft have performed. Details will be given of future launch opportunities and a possible sample return mission will be examined. A companion paper covers the Venus programme.

Harvey, B.: 'Phobos Lander Mars Project', *Spaceflight* **28** (1986), 113–114.

A 460 day unmanned mission to Mars and its moon Phobos during 1988/89 is now in the final stages of design. Landers will be deployed on the Phobos surface and scientists in the Soviet Union hope to receive signals from these and spacecraft left in orbit for up to 12 months.

Henderson-Sellers, A. (Dept. of Geography, Univ. of Liverpool, P.O. Box 147, Liverpool, L69 3BX, UK): 'Are Martian Clouds Fractals?', *R. Astr. Soc. Q. J.* **27** (1986), 90–93.

It has been proposed by Lovejoy that terrestrial clouds and rain areas are fractals: shapes with structure at all scales and no characteristic length. If this feature is the result of the physical and chemical controls upon atmospheric dynamics, then it should also occur on other planets. Examinations of *Viking* images of Mars lend some support to the theory that all clouds are fractals.

Jakosky, B. M. and Christensen, P.E.R.: (Lab. for Atmospheric and Space Physics, Univ. of Colorado, Boulder, CO 80309): 'Global Duricrust on Mars: Analysis of Remote-Sensing Data', *J. Geophys. Res.* **91** (1986), 3547–3559.

Global remote-sensing data for Mars are analyzed to obtain a simple, self-consistent model for the surface layer. The data sets discussed include radar cross-section measurements at several wavelengths, radio whole-disk thermal emission observations at two wavelengths, the global distribution of thermal inertia, deviations of diurnal temperatures from those of a homogeneous model, and thermal spectral estimates of surface rock abundance and of the thermal inertia of the nonrocky component of the surface. The data sets which most constrain the interpretation are the rock abundance map and the correlation of thermal inertia with radar cross section; these require the rock abundance to not vary significantly from place to place and simultaneously require the density and thermal inertia of the fines to vary in a consistent manner. The simplest model which can explain all of the data involves a global case-hardened crust ("duricrust") which varies spatially in its degree of formation. In general, low-thermal-inertia regions have a poorly-developed crust and high-inertia regions have a well-developed crust there are, however, regions that consist of coarse particles and which do not fit this model (e.g., Chryse). This model is consistent with the ages of low-inertia regions and with aeolian mechanisms for their development. The duricrust is thought to form via the mobilization of salt ions within a layer of water adsorbed within the regolith, and its formation may be associated with the exchange of water between the regolith and atmosphere which occurs on the 10^5- and 10^6-year time scale.

Lenorovitz, J. M.: 'Soviets Urge International Effort Leading to a Manned Mars Mission', *Aviation Week and Space Technology* **124**(12) (1986), 76–77.

Soviet Union is suggesting that a cooperative Mars sample return mission be organized which could serve as a precursor to an international manned mission to the planet.

Manent, L. S. and El-Baz, F. (National Air and Space Museum, Smithsonian Institution, Washington, DC 20560): 'Comparison of Knobs on Mars to Isolated Hills in Eolian, Fluvial and Glacial Environments', *Earth, Moon, and Planets* **34** (1986), 149–167.

Positive isolated features or knobs have been observed on Mars since Mariner 9 first photographed the planet in 1972. More recently, the Viking Orbiters photographed the surface at increased resolution. With the use of Viking photomosaics, a systematic search for knobs was completed. The knobs were characterized by length, width, geographic location, proximity to streaks and geologic surroundings. Similar isolated features on Earth eroded by fluvial, glacial, and eolian processes were studied and measured. Comparison of length-to-width ratios of Martian knobs to isolated hills on Earth indicate that the Martian knobs are most similar to the isolated hills formed in a hyper-arid environment. The terrestrial features were probably formed initially when solid rock was fractured, then wind erosion, starting at the fractures, continued to sweep away sediments leaving isolated hills. Such hills in fluvial and glacial environments have length-to-width ratios significantly higher than those of the Martian knobs. Other diagnostic features associated with such environments are absent in the case of the Martian knobs. Moreover, streaks, splotches, dunes and pitted and fluted rocks, all indicative of a eolian regime, are associated with the Martian knobs.

No author cited: 'Soviet Union's 1988 Mars Flight to Return Wide Range of Data', *Aviation Week and Space Technology* **124**(12) (1986), 80–81.

Soviet Union's 1988 flight to Mars arid Phobos is designed to return a broad base of data on the planet, its moon, the solar wind, cosmic rays, interplanetary shock formations and cosmic/solar gamma bursts during the mission's 460-day duration.

Two sets of spacecraft will be launched to provide redundancy and to expand upon the volume of data that could be returned by a single spacecraft mission. Each set will consist of a main spacecraft and a small lander to be deployed to the surface of the Martian moon Phobos.

Santer, R., Deschamps, M., Ksanfomaliti, L. V. and Dollfus, A. (Universite des Sciences et Techniques, Lille, France): 'Photopolarimetry of Martian Aerosols', *Astron. Astrophys.* **158** (1986), 297–258.

The two photopolarimeters VPM placed on board the soviet spaceprobe MARS-5 which orbited planet Mars in February 1974 recorded a number of intensity and polarization scans from limb to terminator over the planet. Ground properties of the planetary surface and scans analysis over scarce clouds and dust raised features have already been published. Here we analyse the permanent aerosols in the free atmosphere. They appear to be mostly concentrated at high altitude between 40 to 60 km above the surface. Polarization indicates sub-micron sizes and a refraction index around 1.55 reminiscent of the terrestrial troposphenic aerosols above continents. The optical depth did not exceed much $\tau = 0.1$ at 592 nm during the measurements which corresponded to an overall period of particularly clean atmosphere.

Schrey, U., Rothermel, H., Kaufl, H. U. and Drapatz, S. (Max-Planck-Institut für Physik und Astrophysik, Institut für Extraterrestrische Physik, 8046 Garching, FRG): 'Determination of the $^{12}C/^{13}C$ and $^{16}O/^{18}O$ Ratio in the Martian Atmosphere by 10 Micron Heterodyne Spectroscopy', *Astron. Astrophys.* **155** (1986), 200–2204.

During the opposition of Mars in May, 1984, the planetary atmosphere was studied using a $10\,\mu m$ heterodyne receiver mounted at the Cassegrain focus of the 3 m IRTF telescope on Mauna Kea/Hawaii. Fully resolved absorption spectra of different transitions in the 00°1–(10°0, 02°0), band of $^{12}C^{16}O_2$, $^{13}C^{16}O_2$ and $^{16}O^{12}C^{18}O$ have been observed.

Using a model for the Martian atmosphere, the following isotopic ratios have been obtained: $^{12}C/^{13}C = 96 \pm 6$ and $^{16}O/^{18}O = 518 \pm 64$. They are compared with the results of the in situ measurements made by the Viking spaceprobes and terrestrial values and agree within the statistical errors. It is shown that highly resolving spectroscopy allows for a determination of isotopic ratios in remote sensing with a precision competitive to m situ mass spectroscopy.

Schumm, S. A. and Phillips, L. (Dept. of Earth Resources, Colorado State Univ., Fort Collins, CO 80523): 'Composite Channels of the Canterbury Plain, New Zealand: A Martian Analogy?', *Geology* **14** (1986), 326–329.

Channels eroded into the sea cliff at the distal margin of the Canterbury Plain have a composite origin. Large- and medium-size composite channels formed initially by overland flow from a swamp. Subsequent seepage through outwash gravels enlarged them to produce wide, flat-floored valleys with irregular margins. Smaller channels have been and are being formed by seepage and mass movement, but they stagnate when an armor is formed that cannot be breached by seepage now. All the channels show characteristics that have been described as criteria of channels formed by ground-water sapping, but the large channels were eroded predominantly by surface runoff and subsequently modified by ground-water sapping. The New Zealand composite channels resemble some small Martian valleys that are incised into cliffs and valley walls on that planet.

Spangenburg, R. and Moser, D.: 'The Secret Ice of Mars', *Space World* **W-1**(266) (1986), 14–19.

The history of Martian water is discussed.

Squyres, S. W. and Carr, M. H. (Theoretical Studies Branch, NASA Ames Research Cente, Moffett Field, CA 94305): 'Geomorphic Evidence for the Distribution of Ground Ice on Mars', *Science* **231** (1986), 249–252.

High-resolution Viking orbiter images show evidence for quasi-viscous relaxation of topography. The relaxation is believed to be due to creep deformation of ice in near-surface materials. The global distribution of the inferred gound ice shows a pronounced latitudinal dependence. The equatorial regions of Mars appear to be ice-poor, while the heavily cratered terrain poleward of $\pm 30°$ latitude appears to be ice-rich. The style of creep poleward of ±30° varies with latitude, possibly due to variations in ice rheology with temperature. The distribution suggests that ice at low latitudes, which is not in equilibrium with the present atmosphere, has been lost via sublimation and diffusion through the regolith, thereby causing a net poleward transport of ice over martian history.

Thomas, P. G. and Masson, P. L. (Laboratoire de Géologie Dynamique Interne, Université Paris XI, France): 'Martian Fluidized Crater Distribution: Tectonic Implications', *Earth, Moon, and Planets* **34** (1986), 169–176.

Little scaled studies on the entire planet Mars, and large scale studies of a local area (3600 km in diameter) seem to indicate geographic relations between martian fluidized craters and ridges: all the intensely ridged areas exhibit a lot of fluidized craters. Because the presence of fluidized craters indicates low viscosity states of the martial surface, this relation would indicate that the compressive stresses only induced ridges when they occurred at times and places of low viscosity states of the martian surface.

Weijermars, R. (Hans Ramberg Tectonic Lab., Geological Inst., Univ. of Uppsala, Box 555, S-751 22 Uppsala, Sweden): 'The Polar Spirals of Mars may be due to Glacier Surges Deflected by Coriolis Forces', *Earth Planet. Sci. Letters* **76** (1986), 227–240.

All previous accounts of the spiral patterns at the Martian poles emphasize that the north polar spiral is centered about the geographic pole. whereas that of the south polar region is off-set by about 4°. This paper demonstrates that the patterns near both poles are centered on topographic highs rather than the spin poles themselves. This is circumstantial evidence in favour of the relatively unexplored mechanism of radial outflow of viscous rock by gravity spreading.

The hypothesis developed here is that the spiral patterns are essentially due to crevasse patterns formed perpendicular to flow lines which are perturbed by Coriolis forces. In order to account for a crevasse pattern that has a form concave to the east the angular deflection of an hypothetical ice flow emanating from the topographic high centered about the geographical north pole. must he about 40° or 0.7 radians in a westward direction at 85°N latitude.

The polar cap rock has previously been assumed to consist mainly of either frozen carbondioxide or water ice. Corresponding viscosities (at 190 K) allow for the occurrence of radial outflow or gravity driven tectonics at a maximum rate of 1 cm a^{-1}, but the flow pattern remains unaffected by Coriolis forces.

The spiral patterns of the Martian poles can be explained if the flowing mass has an occasional effective kinematic viscosity as low as about 7×10^6 $m^2 s^{-1}$, because gravity tectonics will then be deflected by Coriolis forces resulting in appropriately curved flowlines. A tensile fracture pattern. resembling an anticlockwise spiral pattern perpendicular to the clockwise deflected flowlines may subsequently form by local brittle failure.

The occasional kinematic viscosity 7×10^6 m^2s^{-1} would cause flow rates of 0.2 m s^{-1} along the slopes of the topographic highs. This velocity and the corresponding viscosity is tentatively thought to he possible when thermal and pressure runaway occurs in the polar layered deposits. This would mean glacier surges on the Martian poles are two orders of magnitude faster than those hitherto observed on Earth.

7. MERCURY

Harmon, J. K., Campbell, D. B., Bindschadler, D. L., Head, J. W. and Shapiro, I. I. (National Astronomy and Ionosphere Center, Arecibo, Puerto Rico): 'Radar Altimetry of Mercury: A Preliminary Analysis', *J. Geophys. Res.* **91** (1986), 385–401.

Measurements of Mercurian topography based on Arecibo radar observations are presented. The data which were obtained from 1978 to 1984, cover much of the equatorial zone of Mercury between 12°N and 5°S latitude. Over thirty continuous altitude profiles were obtained. each spanning from 20 to 90 degrees of longitude at a resolution of 0.15° (longitude) by 2.5° (latitude). Radar depths for large craters support previous indications from imagery that Mercurian craters are shallower than lunar craters of the same size. One very large (800 km) impact basin shows some distinct topographic structure, although its relative shallowness suggests postimpact modification by isostatic relaxation or volcanic filling. The plains of Tir Planitia appear topographically smooth to the radar. These plains extend well into the hemisphere not imaged by Mariner 10, possibly forming part of a large annulus of smooth plains around Caloris Basin. The circum-Caloris smooth plains are strongly down-bowed, indicating subsidence under a load. This and other similarities to lunar maria suggest a volcanic origin for these plains. Additional areas of topographically smooth terrain have been found in both the imaged and unimaged hemispheres. Several ridges. scarps, and fault zones have been identified in the altimetry. Three mapped arcuate scarps show heights of about 700 m and cross-sectional widths of about 70 km. One of these features is clearly a ridge, while the other two scarps have a more ridge-like appearance than is suggested by images. One large-scale topographic drop of 3 km correlates well with a mapped system of faults and intracrater scarps. The equatorial zone of Mercury shows 7 km of maximum relief, although the typical elevation difference between highlands and lowlands is closer to 3 km. Three major highland areas are found, the largest two of which are roughly antipodal and aligned within about 10° of the "hot poles" of Mercury. The unimaged hemisphere, possessing both large craters and topographically smooth areas, does not appear to he markedly different in its topography from the imaged hemisphere. No evidence has been found for another Caloris-type impact structure in the unimaged hemisphere.

Nobili, A. M. and Will, C. M. (School of Mathematical Sciences, Theoretical Astronomy Unit, Queen Mary College, London E1 4NS, UK): 'The Real Value of Mercury's Perihelion Advance', *Nature* **320** (1986), 39–41.

The perihelion advance of the orbit of Mercury has long been one of the observational cornerstones of general relativity. After the effects of the gravitational perturbations of the other planets have been accounted for, the remaining advance fits accurately to predictions according to the theory of general relativity, that is, 43 arc s per 100 yr. In fact, radar determinations of Mercury's motion since the mid-1960s have produced agreement with general relativity at the level of 0.5%, or to ±0.2 arcs per 100 yr. We have recently been puzzled by an apparent uncertainty in the value of the theoretical prediction for the advance within general relativity, as cited in various sources. The origin of this discrepancy is a 1947 article by Clemence, who used unconventional values for the astronomical unit (A) and the speed of light (c) in his calculation of the predicted advance. Since that time, virtually everyone has followed suit. Although the current value of the prediction, using the best accepted values for the astronomical constants and for the orbital elements of Mercury, is 42.98 arc s per 100 yr, there is a preponderance of citations over the past 25 years of Clemence's value 43.03 arc s per 100 yr. Here we derive the accurate value and uncover the source of Clemence's value.

8. NEPTUNE

Čelebonovič, V. (Marodna Opservatorija, Kalemegdan, Beograd, Yugoslavia): 'On the Origin of Triton', *Earth, Moon, and Planets* **34** (1986), 59–63.

On dynamical grounds Neptune's satellite Triton is believed to be a captured body. We present nondynamical arguments in favour of this idea.

Hubbard, W. B. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): '1981N1: A Neptune Arc?', *Science* **231** (1986), 1276–1278.

An object in the vicinity of Neptune detected in 1981 by simultaneous stellar occultation measurements at observatories near Tucson, Arizona, was interpreted as a new Neptune satellite. A reinterpretation suggests that it may have instead been a Neptune arc similar to one observed in 1984. The 1981 object, however, did not occult the star during simultaneous observations at Flagstaff, Arizona. This result constrains possible arc geometries.

Kohlhase, C. E., Frampton, R. V. and Gerschultz, J. W.: 'Towards Neptune', *Spaceflight* **28** (1986), 10–15.

A new chapter in the remarkable journey of Voyager 2 is about to be written during the forthcoming flyby of Uranus and in three years' time with an encounter of Neptune.

Manfroid, J., Haefner, R. and Bouchet, P. (Institut d'Astrophysique de Liège, Belgium): 'New Evidence for a Ring Around Neptune', *Asltron. Astrophys.* **157** (1986), L3–L5.

This paper presents an account of observations of the 1984 July 22 appulse of Neptune to SAO 186001. An occultation of 0.8 s duration (FWHM) was detected from La Silla at 05:40:08.6 UTC by two telescopes operating in I and K bands. This, combined with earlier observations led to the recognition of the existence of an irregular ring around Neptune.

10. PLUTO

Goffin, E., Meeus, J. and Steyaert, C. (Vereniging voor Sterrenkunde, Ringlaan 3, B-1180 Brussels, Belgium): 'An Accurate Representation of the Motion of Pluto', *Astron. Astrophys.* **155** (1986), 323–325.

We present three series of periodic terms, which allow to calculate the heliocentric coordinates of Pluto (longitude, latitude, radius vector) during a time interval of more than two centuries. The terms and coefficients have been derived indirectly by least-square approximation of a numerical integration of the motion of Pluto. For the years 1885 to 2099, the maximum error is 0″.5 in longitude, 0″.1 in latitude, and 0.00002 a.u. in radius vector as compared to the numerical integration.

12. SATURN

Alfvén, H., Axnäs, I., Brenning, N. and Lindqvist, P.-A. (Royal Inst. of Tech., Dept. of Plasma Physics, S-100 44 Stockholm, Sweden): 'Voyager Saturnian Ring Measurements and the Early History of the Solar System', *Planet. Space Sci.* **34** (1986), 145–154.

The mass distribution in the Saturnian ring system is investigated and compared with predictions from the plasma cosmogony. According to this theory, the matter in the rings has once been in the form of a magnetized plasma, in which the gravitation is balanced partly by the centrifugal force and partly by the electromagnetic forces. As the plasma is neutralized, the electromagnetic forces disappear and the matter can be shown to fall in to 2/3 of the original saturnocentric distance. This causes the so called "cosmogonic shadow effect", which has been demonstrated earlier for the asteroidal belt and in the large scale structure of the Saturnian ring system.

The relevance of the cosmogonic shadow effect is investigated for parts of the fine structures of the Saturnian ring system. It is shown that many structures or the present ring system can be understood as shadows and antishadows of cosmogonic origin. These appear in the form of double rings centered around a position a factor 0.64 (slightly less than 2/3) closer to Saturn than the causing feature. *Voyager* data agree with an accuracy better than 1%.

Borysow, A. and Frommhold, L. (Dept. of Physics, Univ. of Texas at Austin, TX 78712): 'Theoretical Collision-Induced Rototranslational Absorption Spectra for Modeling Titan's Atmosphere: H_2–N_2 Pairs', *Astrophys. J.* **303** (1986), 495–510.

We compute from theory the collision-induced rototranslational absorption coefficient of the H_2–N_2 molecular complex at frequencies from 0 to beyond 1000 cm^{-1}, and at temperatures from 50 to 300 K, for which no laboratory measurements exist. We account for quadrupolar and hexadecapolar induction of both species, H_2 and N_2. and use a rigorous quantum line shape formalism combined with numerical procedures. The present uncertainties of computed intensities arise mainly from the uncertainties of the H_2–N_2 interaction potential. For the first time a theoretical description of the spectral features of H_2–N_2 dimers in the isotropic potential approximation is given. The work is of interest for a detailed analysis of the *Voyager* IRIS spectra of Titan's atmosphere, especially in the regions of the rotational S_0(O) and S_0(1) lines of hydrogen, from ~200 to 700 cm^{-1}.

Exact line shape calculations are complex and expensive. Therefore, we define simple, six parameter model line shape functions which allow us to reproduce the results of our quantum calculations in seconds on computers of small capacity with a numerical accuracy of better than 2%.

Clarke, T. L. (NOAA, Atlantic Oceanographic and Meteorological Lab., 4301 Rickenbacker Causeway Miami, FL 33149): 'Radiation Pressure Induced Instability in Saturn's Rings', *Astrophys. Letters* **25** (1986), 51–56.

A mechanism for producing density dependent diffusive instability as a result of radiation pressure in a planetary ring is proposed. This instability is operative particles ≲1 cm, and may explain the initial formation of the fine radial structure in Saturn's B-ring.

Davis, L. Jr. and Smith, E. J. (Physics Dept., California Inst. of Tech., Pasadena, CA 91109): 'New Models of Saturn's Magnetic Field using Pioneer 11 Vector Helium Magnetometer Data', *j. Geophys. Res.* **91** (1986), 1373–1380.

In a reanalysis of the Vector Helium Magnetometer data taken by Pioneer 11 during its Saturn encounter in 1979, using improvements in the data set and in the procedures, studies are made of a variety of models. The best is the $P_{11}84$ model, an axisymmetric spherical harmonic model of Saturn's magnetic field within 8 Saturn radii of the planet. Its coefficients for the internal sources are $g_1^0 = 0.2114$, $g_2^0 = 0.016O$, $g_3^0 = 0.0226$ gauss and for the external sources $G_1^0 = -7.1$ nT while Pioneer 11 was approaching Saturn and -12.6 nT while it was leaving. The appropriately weighted root mean square average of the difference between the observed and the modeled field is 1.13%. For the Voyager-based Z_3 model of Connerney, Acuna, and Ness, this average difference from the Pioneer 11 data is 1.81%. The external source currents in the magnetopause, tail, bow shock, and perhaps ring currents vary with time and can only be crudely modeled. An algebraic formula is derived for calculating the L shells on which energetic charged particles drift in axisymmetric fields.

Eviatar, A. and Richardson, J. D. (Dept. of Amospheric Sciences, Univ. of California, Los Angeles, CA 90024): 'Corporation of the Kronian Magnetosphere', *J. Geophys. Res.* **91** (1986), 3299–3303.

Observations of the radial variation of azimuthal plasma velocity in the inner part of the magnetosphere of Saturn show deviations from corotation occur as far in as $L = 4$. Major deviations from rigid corotation occur near the orbits of Rhea and Dione. We use Voyager-derived neutral and plasma density and temperature vs. altitude profiles in the upper atmosphere to verify that the atmospheric torque needed to drive corotation through neutral-ion coupling is available. We find that the observed azimuthal velocities and calculated Pedersen conductance are consistent with one another, but that the conductance is much less than previous values estimated for Saturn and Jupiter. We attribute the lower than anticipated conductivity to the large heliocentric distance, to the absence of an active satellite (such as Jonan Io) and to a possible role of ring material in depleting the ionosphere.

Gilman, D. A., Hurley, K. C., Seward, F. D., Schnopper, H. W., Sullivan, J. D. and Metzger, A. E.: 'An Upper Limit to X-ray Emission from Saturn', *Astrophys. J.* **300** (1986), 453–455-

X-rays are produced in auroral discharges. and their measurement can serve to characterize the interaction processes responsible for the aurora itself. The existence of auroral activity on Saturn was suggested by the observation of a magnetosphere by *Pioneer 11* and confirmed by UV measurements during the *Voyager* encounters. The detection of X-rays from Jupiter with the *Einstein Observatory* (*HEAO 2*) satellite provided the impetus for a subsequent observation of Saturn. No emission was detected. This article presents the upper limit established by the observation and derives an expected emission level assuming X-ray production to bc the result of bremsstrahlung from keV electrons precipitating into Saturn's atmosphere. The difference is a factor of 100.

Goertz, C. K., Morfill, G. E., Ip, W.-H., Grun, E. and Havnes, O. (Dept. of Physics and Asronomy, Univ. of Iowa, Iowa City, IA 52242): 'Electromagnetic Angular Momentum Transport in Saturn's Rings', *Nature* **320** (1986), 141–143.

The observed 'spokes' in Saturn's rings have been interpreted as consisting of elevated, sub-micrometre sized dust particles[1]. Arguments in favour of this interpretation are, for example, the photometric properties (spokes are dark in backscattered, bright in forward scattered light), the dynamics (approximate keplerian rotation) and lifetime (less than half an orbital period). We show here that submicrometre dust particles sporadically elevated above the ring are subject to electromagnetic forces which will reduce their angular momentum inside synchronous orbit and increase it outside. When the dust is reabsorbed by the ring the angular momentum of the ring is decreased (increased). inside (outside) of synchronous orbit. For the case of the spokes in Saturn's B-ring we estimate that the timescale for transporting ring material due to this angular momentum coupling effect is comparable to the viscous transport time or even smaller. We suggest that the minimum in the optical depth of the B-ring at synchronous orbit is due to this effect.

Ip, W.-H. (Max-Planck-Institut für Aeronomie, D-3411 Katlenburg-Landau, FRG): 'Plasmatization and Recondensation of the Saturnian Rings', *Nature* **320** (1986), 143–145.

One major puzzle from the ground-based and Voyager observations of the saturnian system concerns the presence of the E ring and its possible relationship to the icy satellite, Enceladus. Several issues concerning the surface property and interior condition of Enceladus remain unresolved if it is the main supplier of the E-ring particulate matter. Here we explore the intriguing alternative that the mass supply and orbital configuration of the E ring may be derived from a mass and momentum coupling between the A ring and the tenuous E ring a process of plasmatization and recondensation of the A-ring icy material. In the same way, the C ring could be replenished by the B ring. In this new view, plasma transport has a very important role in the dynamical evolution of the saturnian ring system.

Lockwood, G. W., Lutz, B. L., Thompson, D. T. and Bus, E. S. (Planetary Research Center, Lowell Observatory, Flagstaff, AZ 860): 'The Albedo of Titan', *Astrophys. J.* **303** (1986), 511–520.

Photometric observations of Titan since 1972 show a cyclical variation of ~10%. A minimum value of brightness and albedo apparently occurred in 1984. Spectrophotometric observations, made annually since 1980 at 8 Å resolution, 3295–8880Å, were used to derive the value $p^* = 0.156 \pm 0.010$ for the integrated geometric albedo in 1984. Variations of the equivalent widths of spectral features were not seen.

Nava, D. F., Mitchell, M. B. and Stief, L. J. (Astrochemistry Branch, Lab. for Extraterrestrial Physics, NASA Goddard Space Flight Center, Greenbelt, MD 20771): 'The Reaction $H + C_4H_2$: Absolute Rate Constant Measurement and Implication for Atmospheric Modeling of Titan', *J. Geophys. Res.* **91** (1986), 4585–4589.

Diacetylene (C_4H_2). an intermediary product in the photodecomposition of Titan's methane, has been suggested to be the catalyst in processes converting H atoms into molecular hydrogen for subsequent escape from Titan's atmosphere. This role for C_4H_2 has importance concerning formation and survival of the unsaturated species in the atmosphere of Titan. The reaction kinetics of $H + C_4H_2$ are also of significance in incomplete combustion processes forming higher unsaturated hydrocarbons from acetylene and its radicals in the $C_2H_2/O/H$ system. The absolute rate constant for the reaction $H + C_4H_2$ has been measured over the temperature interval 210–423 K, using the technique of flash photolysis-resonance fluorescence. At each of the five temperatures employed in this study the results were independent of variations in $[C_4H_2]$, total pressure (Argon or Nitrogen), and flash intensity (i.e., initial [H]). The rate constant results for $210 \leqslant T \leqslant 423$ K are $k = (1.39 \pm 0.25) \times 10^{-1} \exp(-1184 \pm 44/T)$ $cm^3 s^{-1}$, where the error quoted is one standard deviation. This represents the first temperature study of this reaction. The Arrhenius parameters at the high pressure limit determined here for $H + C_4H_2$ are contrasted with those for the corresponding reactions of H with C_2H_2 and C_3H_4. Implications of the kinetic results, particularly those at low temperatures, are considered for models of the atmospheric hydrocarbon chemistry of Titan. The rate of this reaction, relative to that of the analogous, but slower, reaction of $H + C_2H_2$, appears to make $H + C_4H_2$ a very feasible reaction pathway for effective conversion of H atoms to molecular hydrogen in the stratosphere of Titan.

Paonessa, M. and Cfiheng, A. F. (Applied Physics Lab., Johns Hopkins Univ., Laurel, MD 20707): 'Limits on Ion Radial Diffusion Coefficients in Saturn's Inner Magnetosphere', *J. Geophys. Res.* **91** (1986), 1391–1396.

Voyager low energy charged particle (LECP) ion phase space densities at constant first and second adiabatic invariants have been used to place limits on the rate of radial diffusion of energetic ions (30 keV to 1 MeV) in Saturn's inner magnetosphere. Upper and lower limits to the radial diffusion coefficient, D_{LL}. are deduced from physical requirements on the rates of diffusion and loss. Lower limits to D_{LL} are obtained between $L = 4$ and $L = 9$ by requiring the rate of inward diffusion to be just large enough to balance satellite sweeping losses. An approximate upper limit on D_{LL} is obtained by requiring the rate of inward diffusion not to be so large as to predict observable ultraviolet aurora on plasma torus L shells. Both methods make no assumption about the functional form of D_{LL}. An independent upper limit to D_{LL} is obtained by assuming various functional forms for D_{LL} and requiring the inferred loss rate of energetic ions to be less than the strong diffusion rate. If D_{LL} is near the lower limit found in this work, then satellite sweeping accounts for a large fraction of the total ion losses. If D_{LL} is near the upper limit, then ion losses can approach 10% of the strong diffusion rate. In this case, ion losses are dominated by wave-particle interactions, and sweeping losses are relatively unimportant.

Pinto, J. P., Lunine, J. I., Kim, S.-J. and Yung, Y. L. (Hoffman Lab., Dept. of Geological Sciences, Harvard Univ., Cambridge, MA 02138): 'D to H Ratio and the Origin and Evolution of Titan's Atmosphere', *Nature* **319** (1986), 388–390.

A value of 1.7×10^{-3} has been reported for the ratio of CH_3D to CH_4 in the stratosphere of the saturnian moon Titan. A lower value of 6×10^{-4} for this ratio in the deeper part of Titan's atmosphere was reported by de Bergh *et al.* For comparison we note that the CH_3D to CH_4 ratio on Saturn and Jupiter is 8.7×10^{-5} and 6.7×10^{-5}, respectively (see Table 1). We estimate the uncertainties in all these observations and data reduction to be about a factor of 2. Despite these uncertainties it appears that Titan's atmosphere is enriched in deuterium by a factor of $\geqslant 3$ relative to Jupiter and Saturn. Potential causative factors examined here for this enrichment are condensation to form tropospheric methane clouds, fractionation occurring over a hypothetical CH_4–C_2H_6 ocean and between the ocean and the clathrate crust beneath, fractionation which occurred during the formation of Titan and fractionation occurring as a result of the evolution of Titan's atmosphere. We conclude that the greater part of the observed fractionation is probably derived from the formation of Titan and the subsequent evolution of Titan's atmosphere driven by photochemistry.

Richardson, J. D. (Center for Space Research, MIT, Cambridge, MA 02139): 'Thermal Ions at Saturn: Plasma Parameters and Implications', *J. Geophys. Res.* **91** (1986), 1381–1389.

Plasma data from the PLS experiment on Voyagers 1 and 2 are analyzed at the Saturn encounters Measured ion currents are simulated using the full response function or the PLS instrument assuming plasma distributions are isotropic Maxwellians The plasma velocity, densities, and temperatures which best simulate the observations are determined. Saturn's magnetosphere is found to subcorotate outside of $L = 5.5$ for Voyager 1 and $L = 7$ for Voyager 2. Large radial and vertical flows are observed, especially in the outer magnetosphere and on the nightside. Ion temperatures increase with L to a maximum at $L = 10$, outside of which they vary rapidly. A temperature anisotropy with $T_\perp > T_\parallel$ is necessary to account for the observed temperatures and densities. The ions present are H^+ and O^+, there is no evidence of heavier ions or higher charge states. Calculations of NL^2 show an O^+ peak at $L = 10$ for both encounters, indicating the major O^+ source is at $L = 10$.

Stevenson, D. J. and Potter, B. E. (Div. of Geological and Planetary Sciences, California Inst. of Tech., Pasadena, CA 91109): 'Titan's Latitudinal Temperature Distribution and Seasonal Cycle', *Geophys. Res. Letters* **13** (1986), 93–96.

Voyager IRIS brightness temperature measurements of Titan at a wavelength of $530\,cm^{-1}$ are crudely indicative of ground or lower tropospheric temperatures and indicate 93 K for the equator and 91 K for both northern and southern high latitudes. The symmetry between north and south is unexpected for the time of Voyager encounter (Northern Titan spring). We show that this near-symmetry can arise naturally in a model where the poles are "pinned" year-round at the dew point of CH_4–N_2 lakes or, more probably, a CH_4–N_2 rich surface layer on a deep ethane-rich ocean. For a polar temperature of 91 K, the model implies that the atmosphere contains somewhat less than 8% mole fraction of CH_4.

14. URANUS

Anderson, I.: 'Moons of Uranus Force Cosmic Rethink', *New Scientist* **109**(1491) (1986), 15.

A radical theory explaining the formation and composition of the Solar System is supported by data sent back from the Voyager 2 spacecraft. The theory suggests the planets and their satellites were formed from condensing gas rings shed by the Sun as it contracted.

Anderson, I.: 'Voyager will Fly Past Uranus Tomorrow', *New Scientist* **109**(1492) (1986), 25.

Many of the mysteries surrounding Uranus, the seventh planet from the Sun should be answered in the next few days. The spacecraft Voyager 2, with 11 experiments on board, is nearing Uranus after almost nine years in space. Early tomorrow morning (Friday), the spacecraft will pass within 81200 kilometres of the cloudtops of Uranus.

Anderson, I.: 'Uranus Stays Shrouded in Mystery', *New Scientist* **109**(1493) (1986), 21–22.

The mysteries of Uranus, the seventh planet from the Sun, remain. "We are happily bewildered", said Ed Stone, project scientist for the Voyager mission to Uranus. "The planet is totally different from anything seen before", he said this week. Scientists have gleaned more about Uranus in the past week than they have been able to accumulate in Earthbound observations in the 200 years since William Herschel, the British amateur astronomer, discovered the planet.

Anderson, I.: 'The Pock-marked Face of Miranda', *New Scientist* 109(1494) (1986), 24.

Miranda, one of the moons of Uranus, may have been repeatedly split apart and reassembled. Geologists believe that such a chaotic history is the best way to account for the bizzare geological formations that have been found on Miranda by Voyager 2.

Axford, W. I. and Vasyliunas, V. M. (Max-Planck-Institut für Aeronomie, D-3411 Katlenburg-Lindau, FRG): 'The Magnetic Field of Uranus', *Nature* **319** (1986), 267.

We believe that the absence of radio emissions in the early records of the PRA experiment does not imply that Uranus does not have a significant magnetic dipole moment and a magnetosphere of considerable extent.

Baines, K. H. and Bergstralh, J. T. (JPL, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109): 'The Structure of the Uranian Atmosphere: Constraints from the Geometric Albedo Spectrum and H_2 and CH_4 Line Profiles' *Icarus* **65** (1986), 408–441.

Constraints on the atmospheric structure of Uranus are derived from recently acquired, high-quality spectral observations [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: J. T. Trauger and J. T. Bergstralh (1981) *Bull. Amer. Astron. Soc.* **13**, 732: K. H. Baines, W. V. Schempp, and W. H. Smith (1983) *Icarus* **56**, 534–542]. The analysis, based on detailed modeling of a broadband (7 Å) geometric albedo spectrum from 3500 to 10,500 Å, and high-resolution (30 and 100 mA, respectively) observations of H_2 4–0 quadrupole and 6818.9-Å CH_4 features, yields a family of models which parameterizes an upper tropospheric haze layer, a lower optically infinite cloud at a pressure level P_{Cld}, the cloud-level methane molar fraction, f_{CH4}, and the mean *ortho/para* ratio in the visible atmosphere. Limits include $2.40 < P_{Cld} < 3.2$ bars, $0.020 < f_{CH4} < 0.046$. and $0.63 < f_{eH2} < 0.95$, where f_{eH2} denotes the fraction of H_2 in the equilibrium state. The haze optical depth at 6435 Å is found to be $0.4 < \tau_H$ (6135 Å) < 1.0, in reasonable agreement with L. M. Trahon's [(1976) *Astrophys. J.* **207**, 007–1024] determination but significantly less than that reported by K. H. Baines [(1983) *Icarus* **56**, 543–5S9]. The single-scattering albedo of atmospheric aerosols exhibits a steep darkening between 5890 and 6040 Å. reminiscent of UV-irradiated H_2S ice crystals. These constraints are consistent with recent infrared and submillimeter and millimeter analyses. The analysis also agrees with the theoretical H_2 quadrupole line strengths but conflicts with a number of reported laboratory measurements.

Baum, R. M. and Hollis, A. J. (25 Whitechurch Road, Chester, CH3 5QA, UK): 'Uranus: The View from Earth', *J. Brit. Astr. Assoc.* **92**(2) (1986), 65–67.

Uranus has received an enormous amount of attention in recent weeks, with the fly past of Voyager 2 providing many times more information about the planet than had been gained in the previous two hundred years of observation. It is appropriate at this time to consider the role of visual observations from the Earth, both the pre-Voyager observations and the ways in which members of the Association can help contribute to future studies of this distant planet.

Beardsley, T.: 'Uranus is Something Else Again', *Nature* **319** (1986), 439.

A new kind of atmospheric emission that has been called "electroglow" was one of the most striking results of the Voyager 2 flyby of Uranus.

Beatty, J. K.: 'Uranus' Last Stand', *Sky and Telescope* **71** (1986), 11–12.

Presentations concerning Uranus, made during a Meeting of the American Astronomical Society's Division for Planetary Sciences one week before the Voyager-2 encounter with the planet are reported.

Beatty, J. K.: 'A Place Called Uranus', *Sky and Telescope* **71** (1986), 333–337.

Preliminary results of the Voyager-2 mission to Uranus are presented.

Chandler, M. O. and Waite, J. H. Jr. (Dept. of Physics, Univ. of Alabama in Huntsville, AL 355899): 'The Ionosphere fiof Uranus: A Myriad of Possibilities', *Geophys. Res. Letters* **13** (1986), 6–9.

A one-dimensional model has been used to study the effects of exospheric temperature, methane and water influx, ionospheric outflow, and electron precipitation on the composition and structure of the ionosphere of Uranus. Peak ion concentrations range from 10^3 to $10^6\,cm^{-3}$ with a wide variation in peak altitude, which depends strongly on the exospheric temperature. In all the cases we considered, H^+ is the major ion in the topside ionosphere. At altitudes near or below the peak, H_3^+ and CH_3^+ can dominate, depending on the magnitude of CH_4 and H_2O influx. Atomic hydrogen column depths above the methane absorbing layer exceed $10^{17}\,cm^{-2}$ and Can produce large (400 R) emissions of resonantly scattered Lyman-alpha. In the sunlit polar cap, electron precipitation with energy fluxes of 0.6 to 1.0 $erg\,cm^{-2}\,s^{-1}$ results ln direct production of Lyman-alpha emissions that exceed 1 kR.

Davies, J. (Dept. of Space Research, Univ. of Birmingham, POB 363, Birmingham D15 1TT, UK): 'Voyage to the Tilted Planet', *New Scientist* **109**(1492) (1986), 39–42.

Uranus is so far away that we know little about it. Tomorrow the spaceprobe Voyager 2 will sweep past the planet, after a journey lasting more than cight years. What is it likely to find?

Dermott, S. F. and Nicholson, P. D. (Center for Radiophysics and Space Research, Space Sciences Building, Cornell Univ., Ithaca, NY 14853): 'Masses of the Satellites of Uranus', *Nature* **319** (1986), 115–120.

The dynamical theory used to obtain the masses of the uranian satellites from their orbital precession rates contains a fundamental error. The masses can be derived from the precession rates, but a correct analysis of the available data must allow for the fact that the eccentricities, inclinations and precession rates all vary considerably with time, due to mutual secular perturbations.

Dessler, A. J. (Space Science Lab. (ESOI), NASA Marshall Space Flight Center, Huntsville, AL 35812): 'Does Uranus have a Magnetic Field?' *Nature* **319** (1986), 174–175.

In just a matter of days, Voyager 2, now nearly 8.4 years into its grand tour of the Solar System, will sweep past Uranus. The prospect has inspired discussion of the strength of the planet's magnetic field, published estimates of which at cloudtop level range from tens of gauss down to zero. This fascinating state of confusion is the result of recent data from Voyager which do not confirm past observations of Uranus from Earth orbit.

Eberhart, J. Uranus: 'Testing Voyager 2's IQ', *Science News* **129** (1986), 8–10.

On January 24, the Voyager 2 spacecraft will pass about 50,600 miles from Uranus's cloud tops and directly through the planet's ring and moon systems. The long-awaited encounter is expected to provide more information in one day than has been gathered about the distant planet since it was discovered more than two centuries ago.

Eberhart, J.: 'Voyager 2's Uranus: 'Totally Different'', *Science News* **129** (1986), 72–73.

An account of the Voyager-2 findings during the Uranus encounter is presented.

Eviatar, A. and Richardson, J. D. (Dept. of Atmospheric Sciences, Univ. of California, Los Angeles, CA 90024): 'Predicted Satellite Plasma Tori in the Magnetosphere of Uranus', *Astrophys. J.* **300** (1986), L99–L102.

We have formulated the rate equations for twelve species: water, hydroxyl, molecular and atomic oxygen, molecular and atomic hydrogen, and their respective first ions for conditions expected to hold in the magnetosphere of Uranus. We have solved these equations numerically for maximal and minimal source strengths of the five known satellites and have calculated the expected neutral and plasma number densities in the tori predicted to be associated with them. We find that under most conditions, there should he a sensible plasma torus associated with each satellite whose orbit is enclosed within the assumed magnetosphere.

French, R. G., Kangas, J. A. and Elliot, J. L. (Dept. of Earth, Atmospheric and planetary Sciences, MIT, Cambridge, MA 02139): 'What Perturbs the Gamma and Delta Rings of Uranus?', *Science* **231** (1986), 480–483.

The γ and δ rings have by far the largest radial perturbations of any of the nine known Uranian rings. These two rings deviate from Keplerian orbits, having typical root-mean-square residuals of about 3 k (compared to a few hundred meters for the other seven known rings). Possible causes for the perturbations include nearby shepherd satellites and Lindblad resonances. If shepherd satellites are responsible, they could be as large as several tens of kilometers in diameter. The perturbation patterns of the γ and δ rings have been examined for evidence of Lindblad resonances of azimuthal wave number $m = 0$, 1, 2, 3, and 4. The δ ring radial residuals are well matched by a 2:1 Lindblad resonance. If this represents a real physical phenomenon and is not an artifact of undersampling, then the most plausible interpretation is that there is an undiscovered satellite orbiting $76{,}522 \pm 8$ k from Uranus, with an orbital period of 15.3595 ± 0.0001 hr and a radius of 75 to 100 k. Such a satellite would be easily detected by the Voyager spacecraft when it encounters Uranus. The 2:1 resonance location is 41 ± 9 k inside the δ ring, which makes it unlikely that the resonance is due to a viscous instability within the ring. In contrast, no low-order Lindblad resonance matches the γ ring perturbations, which arc probably caused by one or more shepherd satellites large enough to be clearly visible in Voyager images.

Ip, W.-H. (Max-Planck-Institute für Aeronomie, D-3411 Katlenburg-Lindau, FRG): 'Solar Wind Interation with Uranus' Atmosphere', *Nature* **319** (1986), 268.

The failure of Voyager 2 to detect radio emission from Uranus even from within I astronomical unit may be explained along the lines suggested by Axford and Vasyliunas (preceding letter) by supposing that the surface magnetic field is approximately 0.01 to 0.1 gauss, but it is also possible that Uranus simply has no intrinsic magnetic field. In that case, the solar wind may impinge directly on the neutral upper atmosphere, as it does on Venus. I shall explore briefly the consequences of this assumption for the forthcoming encounter between Voyager 2 and Uranus.

Maddox, J.: 'Voyager 2 Swings by Uranus', *Nature* **319** (1986), 95.

The US spacecraft launched towards Jupiter 8.5 years ago is about to encounter Uranus, a planet that has completed only two of its orbits since it was first discovered. The event could be exciting.

McLaughlin, W. I.: 'A Voyage of Discovery', *Spaceflight* **28** (1986), 120–126.

A preliminary summary of some of the more important findings of Voyager-2 spacecraft during its closest approach to Uranus are given.

Orton, G. S. (Earth and Space Sciences Div., Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109): 'Thermal Spectrum of Uranus: Implications for Large Helium Abundance', *Science* **231** (1986), 836–840.

An analysis of the infrared spectrum of Uranus' disk between 7 νm and 3 mm suggests a volume mixing ratio for helium in the atmosphere of $40 \pm 20\%$, more than for the sun, Jupiter, or Saturn. Alternative explanations require even more extreme assumptions regarding gas abundances or aerosol vertical distribution and spectral properties. The most serious difficulty with a model containing large amounts of helium is devising a credible evolutionary or chemical model explaining the absence or segregation of so much hydrogen.

Schefter, J.: 'After 3 Billion Miles, Can Voyager Solve the Mysteries of Uranus?'. *Popular Science* **228**(2) (1986), 66–69.

Uranus is an enigma. The planet's composition, rotation, moons, and newly discovered rings leave scientists puzzled. But Voyager 2's slingshot journey to the edge of our solar system may provide some answers – and a clue to how the galaxy was formed.

Shemansky, D. E. and Smith, G. R. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'The Implication for the Presence of a Magnetosphere on Uranus in the Relationship of EUV and Radio emission', *Geophys. Res. Lett.* **13** (1986), 2–5.

Two apparent contradictory sets of facts exist concerning the presence of a magnetosphere at Uranus. The Voyager planetary radio astronomy experiment has not detected a Uranus signal at a range <0.7 AU, whereas IUE satellite observations show relatively strong emission indicating the presence of substantial particle excitation of the atmosphere. The character of the EUV omission implies the presence of an ionosphere, and mass-loading of the extended system comparable to that of Saturn. If the ingredient for production of an active magnetosphere is present, the non detection of radio emission then suggests that Uranus has a very weak or non existent magnetosphere. The apparent paradox of an excited atmosphere in the absence of an active magnetosphere may possibly be explained in terms of the peculiar characteristics of the excited sunlit equatorial exospheres of Jupiter and Saturn. We suggest that (1) the observed Uranus EW emission may be a similar phenomenon to these observed in the sub-solar equatorial regions of Jupiter and Saturn, which appear to be disconnected from auroral or magnetospheric activity, and (2) the Uranus intrinsic magnetic field is probably weak or nonexistent because of the availability of substantial mass for producing an active magnetosphere as derived from the nature of the EUV emission. We predict a substantial escape rate of atomic hydrogen ($\sim 2 \times 10^{28}\, s^{-1}$).

Smith, B. A.: 'Scientists Gain New Insights on Uranus from Voyager 2 Data', *Aviation Week and Space Technology* **124**(6) (1986), 66–67.

Voyager 2 project scientists are continuing to analyze data that have been returned from the Uranus encounter in an attempt to learn more about the planet's magnetosphere, atmosphere, rings and moons.

Yelle, R. V. and Sandel, B. R. (Lunar and Planetary Lab., Univ. of Arizona, Tucson, AZ 85721): 'Uranian H Ly-alpha Emission: The Interstellar Wind Source', *Geophys. Res. Lett.* **13** (1986), 89–92.

IUE observation of Uranian emissions in hydrogen Lyman alpha (H Ly-α over, the past four years have recently been summarized by Clarke *et al.* [1985]. Over this time period they find an average H Ly-α brightness of 1260 R which they estinmate is composed of 200 R of solar scattered radiation and 1060 R from a collisional source. A third component, not considered by previous authors, is the reflections of H Ly-α emissions from the interstellar wind. Hydrogen in the interstellar wind forms an extended source of H Ly-α whose importance relative to the solar flux increases with distance from the sun. We demonstrate that scattering of interstellar H Ly-α is more important than scattering of solar H Ly-α for reasonable values of H column abundance and, in fact, may make up 10–40% of the observed signal. Large H column abundances are still required to explain the H Ly-α brightness solely on the basis of resonant scattering; therefore it is likely that the emissions are due in part to collisional sources and in part to the scattering of interstellar H Ly-α with solar scattering playing a minor role.