BIBLIOGRAPHY

Edited by

E. B. CARLING

Department of Astronomy, University of Manchester, England

Z. KOPAL

Department of Astronomy, University of Manchester, England

and

F. B. WARANIUS

Lunar and Planetary Institute, Houston, Texas, U.S.A.

(July–September 1989)

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

Benz, W., Cameron A. G. W. and Melosh, H. J. (Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138): 'The Origin of the Moon and the Single-Impact Hypothesis III, *Icarus* **81** (1989), 113–131.

In previous papers in this series the smoothed particle hydrodynamics method (SPH) has been used to explore the conditions in which a major planetary collision may have been responsible for the formation of the Moon. In Paper II (W. Benz, W. L. Slattery, and A. G. W. Cameron 1987, *Icarus* **71**, 30–45) it was found that the optimum conditions were obtained when the mass ratio of the impactor to the protoearth was 0.136. In the present paper we investigate the importance of the equation of state by running this optimum case several times and varying the equation of state and other related parameters. The two equations of state compared are the Tillotson (used in the previous papers) and the CHART D/CSQ ANEOS. Because of differences in these equations of state, including the fact that different types of rocks were used in association with each, it was not possible to prepare initial planetary models that were comparable in every respect, so several different simulations were necessary in which different planetary parameters were matched between the equations of state. We also used a new version of the SPH code.

The results reaffirmed the previous principal conclusions: the collisions produced a disk of rocky material in orbit, with most of the material derived from the impacting object. These results indicate that the equation of state is not a critical factor in determining the amount of material thrown into orbit. This confirms the conclusions of Paper II that gravitational torques, and not pressure gradients, inject the orbiting mass. However, the way this mass is distributed in orbit is affected by the equation of state and the choice of rock material, the Tillotson equation for granite giving a slightly larger mean orbital radius for the particles left in orbit than the ANEOS dunite for the same impact parameter. We also find, compared to Paper II, that in all subsequent cases the new SPH code leads to a slightly less extended prelunar accretion disk. We think this is due to the new shape adopted for the kernel.

A few additional calculations were made to test the effects of increasing the impact parameter on the calculations, other parameters remaining unchanged. The motivation for this was that solar tides will have reduced the Earth–Moon angular momentum somewhat over the course of time. An increment of 6% in the angular momentum of the collision increases the amount of iron-free material in orbit and its mean orbital radius, but more than that leaves increasing amounts of iron in orbit (the iron has a small mean orbital radius). The debris from the destroyed impacting object tends to form a straight rotating bar which is very effective in transferring angular momentum. If the material near the end of the bar extends well beyond the Roche lobe, it may become unstable against gravitational clumping.

Berger, A., Loutre, M. F., and Dehant, V. (Institut d'Astronomie et de Géophysique G. Lemaître, Université Catholique de Louvain, Louvain-la-Neuve, Belgium): 'Influence of the Changing Lunar Orbit on the Astronomical Frequencies of Pre-Quaternary Insolation Patterns', *Paleoceanography*, **4** (1989), 555–564.

The sensitivity of the frequencies of the Earth's orbital elements, involved in the astronomical theory of paleoclimates (obliquity and climatic precession), to the Earth-Moon distance and consequently to the length of the day and to the dynamical ellipticity of the Earth is investigated for the last billions of years. But the new frequencies have been computed for the last 440 million years only, a time interval over which data and a model of the Earth were available. Moreover, we consider only the impact of the changing precessional parameter, assuming that the fundamental frequencies of the planetary motion are steady at the geological time scale. Under such hypotheses, the shortening of the Earth-Moon distance and of the length of the day back in time induces a shortening of the fundamental astronomical periods for obliquity and precession, a shortening that is larger for longer periods.

Brown, G. M. (Wheatley, Oxford OX9 1YN, U.K.): 'The Evolution of the Moon', *Modern Geology* **13** (1989), 217–23.

The Moon provides observable evidence, absent from the more evolved Earth, of a sequence of events that were influential during the early evolutionary stages of a planetary body. About 50 million years after formation of the Solar System, the Moon was formed in a near-liquid state. In the next 1,500 million years shortly after crust-mantle-core formation, intensive cratering and volcanism shaped the lunar surface in a series of dated events. Better understanding of those events and processes awaits a new phase of Moon exploration.

Busarev, V. V. and Shevchenko, V. V.: 'Ilmenite Forecast on the Lunar Surface from the Colour and Spectrometric Characteristics' (in Russian), *Astronomicheskii Zhournal* **66** (1989), 596–603.

The four lunar mare reflectance spectra of the plots with higher concentration of titanium are obtained. The interpretation of the characteristic spectral features as given rise to by titanium and mineral ilmenite is made from the spectra. Basing on the photometric processing of the 'Zond-6' photographs with the effective wavelength $\lambda = 0.65\ \mu m$ and colour characteristics of the lunar surface in Oceanus Procellarum, the areas with higher content of ilmenite are forecasted.

Di Cicco, D.: 'August's Eclipsed Moon', *Sky and Telescope* **78** (1989), 548–553.

Dickey, J. O., Newhall, X. X., and Williams, J. G. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109): 'Investigating Relativity Using Lunar Laser Ranging: Geodetic Precession and the Nordtvedt Effect', *Adv. Space Res.* **9**(9) (1989), 75–78.

The emplacement of retroreflectors on the Moon by Apollo astronauts and the Russian Lunakhod spacecraft marked the inception of lunar laser ranging (LLR) and provided a natural laboratory for the study of general relativity. Continuing acquisition of increasingly accurate LLR data has provided enhanced sensitivity to general relativity parameters. Two relativistic effects are investigated in this paper: (1) The Nordtvedt effect, yielding a test of the strong equivalence principle, would appear as a distortion of the geocentric lunar orbit in the direction of the Sun. The inclusion of recent LLR data limits the size of any snch effect to 3 ± 4 cm. The sensitivities to the various PPN quantities are also highlighted. (2) The geodetic precession of the lunar perigee is predicted by general relativity as a consequence of the motion of the Earth-Moon system about the Sun; its theoretical magnitude is 19.2 mas/yr. Analysis presented here confirms this value and determines this quantity to a 2% level.

Dolginov, A. Z. (Ioffe Physics and Technology Institute, USSR Academy of Sciences, Leningrad, USSR): 'Lunar Magnetic Fields', *Sov. Astron. Lett.* **15** (1989), 39–41.

The local ($\sim$100 km) magnetic fields of $\sim 10^{-4}$ gauss observed on the moon and the comparatively strong ($\sim$1 gauss) field early in the moon's evolution may derive from inhomogeneities in the temperature and composition of the lunar interior. Similar irregularities at the core-mantle interface may have played a significant role in generating the magnetic field of the earth.

Khramov, D. A., Zemchik, T., and Cymbalník, A. (V. I. Vernadskii Geochemistry and Analytical Chemistry Institute, Moscow, USSR): 'Iron Distribution in Lunar Olivines Based on Mossbauer-Spectroscopy' (RS), *Geokhimiya* (1989), No. 8, 1164–1169.

Kirk, R . L. and Stevenson, D. J. (Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125): 'The Competition Between Thermal Contraction and Differentiation in the Stress History of the Moon', *Journ. Geophys. Res.* **94** (1989), 12133–12144.

The scarcity of both extension and compression features on the Moon strongly constrains the history of the lunar radius – to variations of less than ± 1 km over the past 3.8 Gyr. This limit has traditionally been interpreted as requiring a delicate balance between thermal contraction of the near-surface and expansion of a substantial cold interior region. Recent theories of lunar origin (e.g., giant impact), in contrast, favor a "hot" initial state. We propose that a reconcilliation may be possible by taking account of the volume change $\Delta V/V|_d$ due to differentiation. We calculate STP densities based on simplified normative mineralogies for a suite of estimates of the bulk lunar composition, of primary lunar basalt, and of the residuum left when the maximum amount of the latter is extracted from the former. Typically $\Delta V/V|_d \simeq 2$ to 5% – an expansion equivalent to heating by $\sim 10^3$ K. Provided the timing of differentiation is correct, one might offset the cooling of a magma ocean as much as 630 km deep by differentiation of the remainder of the Moon (which need not start much below the solidus temperature). A large but not impossible amount of gabbroic melt production is implied: $\sim$100 times the volume of mare basalts known to have been extruded. We do not address the detailed genetic relationship of this melt to the basalts observed on the lunar surface but point out that it need not have reached the surface directly or even have entered the crust in order for the expansion to have occurred. To assess the timing of melt formation, we investigate a simple conductive lunar thermal model which takes account of both $\Delta V/V|_d$ and thermal contraction. Our initial state is characterized by a central temperature T_c and a depth Z_0 above which the material (derived from the magma ocean) is already at the solidus and is not suceptible to volume changes upon further differentiation. We find a range of models satisfying the limits on radius increase and decrease. The hottest has $T_c = 1210$ K, $Z_0 = 500$ km; without $\Delta V/V|_d$, we would need a larger or colder (or both) core, e.g., $T_c \lesssim 700$ K for $Z_0 = 200$–400 km, in agreement with previous investigators. Our modeling thus lends credence to the idea that the Moon could have been initially $\lesssim$50% molten (with the remainder relatively close to the solidus) and yet experienced little volume change over the last 3.8 Gyr.

Koziel, K. (Jagellonian University Observatory, Cracow, Poland): 'Constants of the Moon's Free Libration on the Basis of Heliometric Observations from the Years 1841–1945', *Earth, Moon and Planets* **45** (1989), 153–159.

The results of simultaneous and homogeneous reduction of 8 libration series are presented On this basis all 6 free libration constants have been estimated using some new formulae.

Kunetsov, R. A. and Styf, V. I. (A. A. Zhdanov State University, Leningrad B-164, USSR): 'Radiochemical Multielement Neutron Activation Phase Analysis of Agglutinates from Luna-16 Regolith' (RS), *Geokhimiya* (1989) No. 7, 1005–1010.

Reese, R. L., Chang, G. Y., and Dupuy, D. L. (Department of Physics, Washington and Lee University, Lexington, VA 24450): 'The Oscillation of the Synodic Period of the Moon: a "Beat" Phenomenon', *Amer. Journ. Physics* **57** (1989), 802–807.

The synodic period of the Moon (the period of the phases or the time from, say, full moon to full moon) exhibits oscillations about its mean value of 29.530 59 days which immediately suggest a "beating" between at least two frequencies. A Fourier analysis can provide some insight into the causes of the oscillation without the complexity of rigorous lunar theories. Such a Fourier approach is quite appropriate for undergraduate students of physics and astronomy, but, of course, is no substitute for more rigorous lunar theory. Fourier analysis suggests the periods of the beating frequencies to be 411 and 366 days. The 411-day period arises since this is the time it takes the Sun to return to a similar orientation along the line of apsides (the major axis) of the lunar orbit. The 366-day period is about a year or the time it takes the Earth to orbit the Sun. Since the lunar phases occur because of the relative orientation of the Earth, Moon, and Sun, an annual period might also be anticipated. The beat period of 3293 days is half the saros eclipse cycle period of 6585.3 days. Alternating lunar and solar eclipses are separated by the beat period. Higher frequency effects are apparent from the data, but not from the elementary Fourier approach. Thus this procedure must be used with caution in analyzing complex periodic data in astronomy.

Reinold W. U. (Schonland Research Centre, University of Witwatersrand, P.O. Wits, 2050 South Africa): 'What Have We Learnt about the Origin of the Moon?', *South African Journ. Science* **85** (1989), 365–356.

The Twentieth Lunar and Planetary Science Conference which was held in Houston Texas in March 1989.

Ringwood, A . E., Seifert, S., and Wänke, H. (Research School of Earth Sciences, Australian National University, Canberra, A.C.T. 2601, Australia): 'Comments on "Lunar Meteorites: Siderophile Element Contents, and Implications for the Composition and Origin of the Moon" by P. H. Warren, E. A. Jerde and G. W. Kallemeyn', *Earth and Planetary Science Letters* **94** (1989), 165–166.

Shukloyukov, Yu, A., Minh, D. V. and Tarasov, L. S. (Vernadskiy Institute of Geochemistry and Analytical Chemistry, USSR Academy of Sciences, USSR): 'Xenon Concentration and Isotope Composition in Luna 24 Agglutinates, Breccias, and Regolith', *Geochemistry International* **26** (1989), 1–12.

Xe isotope compositions have been examined in secondary-rock particles (agglutinates and regolith breccias) provided by Luna 24, as well as in the regolith, in order to evaluate the effects of shock evaporation and melting on the concentration and isotope composition of Xe. The Xe levels range from 1.6×10^{-8} to 2.3×10^{-7} cm^3/g and are dependent on the rock type, not the depth of the sample. The regolith Xe levels are less by factors of 2–4 than those in the agglutinates and of 2–14 than those in the regolith breccias. There are indications of trapped cosmogenic ^{126}Xe (not formed *in situ*), so there may have been Xe redistribution and absorption during meteorite impacts. The cosmogenic Xe consists of spallation products formed from BA by protons in the galactic and solar cosmic radiation as well as spallation products from the REE produced by solar cosmic-ray protons, The trapped Xe includes not only SUCOR-type solar Xe but also anomalous Xe enriched in ^{136,134,132,} and ^{130}Xe.

Shukolyukov, Yu. A., Minh, D. V., and Tarasov, L. S. (Vernadskiy Institute of Geochemistry and Analytical Chemistry, USSR Academy of Sciences, USSR): 'Xe Isotope Compositions and Concentrations in Luna 16, 20, and 24 Samples', *Geochemistry International* **26** (1989), 64–71.

The Xe isotope compositions and concentrations of soil specimens from the Sea of Abundance and a continental region have been compared with Xe from the Sea of Crises, where previously unknown isotope anomalies were identified earlier. The Sea of Abundance specimens (Luna 16) and the continental ones (Luna 20) show several Xe components of differing origins, including anomalous ones similar to those found in the Sea of Crises (Luna 24): spallogenic Xe from galactic and solar cosmic rays, trapped surface-correlated xenon of SUCOR type, and Xe from the Moon's transient atmosphere trapped by condensing material and released at 400–600 °C, together with a special type of primary solar Xe (1100–1200 °C). The results make it very likely that the SUCOR type is derived not from the Sun's exosphere but instead is a mixture of several of the above components arising from volatile redistribution during meteorite bombardment.

Varnek, V. A., Mazlov, L. N., Dikov, Y. P., and Ivanov, A. V. (Academy of Sciences of the USSR, Institute of Inorganic Chemistry, Novosibirsk, USSR): 'New Data on the Forms of Occurrence of Iron in Luna-16 Regolith' (RS), *Geokhimiya* (1989), No. 8, 1170–1175.

Warren, P. H., Jerde, E. A., and Kallemeyn, G. W. (Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024): 'A Reply to "Comments by A. E. Ringwood, S. Seifert and H Wänke on 'Lunar Meteorites: Siderophile Element Contents, and Implications for the Composition and Origin of the Moon'"', *Earth and Planetary Science Letters* **94** (1989), 167–169.

2. PLANETS (Articles about more than one body)

Asimov, I.: 'The Unknown Solar System', *Discovery* **10**(10) (1989), 38–43.

For millenia we have wondered about our planetary neighbors. In the past decade we have finally gotten some answers.

Bishop, J. and Chamberlain, J. W. (Department of Space Physics and Astronomy, Rice University, Houston, TX 77251): 'Radiation Pressure Dynamics in Planetary Exospheres: A "Natural' Framework', *Icarus* **81** (1989), 145–163.

Constituent atoms of a planetary exosphere are subject to an effective radiation pressure resulting from resonant scattering of solar photons. When this is taken into account, particle trajectories can depart significantly from Keplerian counterparts, with consequent effects on exospheric structure. This paper introduces and explores a reformulation of exospheric mechanics with radiation pressure based on parabolic-cylindrical coordinates. With the aid of a previously unutilized constant of motion, considerable insight into trajectory behavior is gained without explicit integration of the equations of motion; this new constant is identified as a remnant of the Laplace–Runge–Lenz vector invariant of the Keplerian problem. The existence of this constant permits the derivation of analytic expressions for exospheric quantities along the subsolar and antisolar axes when the exobase is uniform and collisions are neglected. To illustrate the usefulness of this formalism, "tail" ratios (i.e., ratios of bound component densities along the midnight axis to those along the noon axis) are presented for the H exospheres of Venus, Earth, and Mars, and for the Na exosphere of Mercury.

Borderies, N., Goldreich, P., and Tremaine, S. (Observatoire du Pic-du-Midi et du Toulouse, Toulouse, France): 'The Formation of Sharp Edges in Planetary Rings by Nearby Satellites', *Icarus* **80** (1989), 344–360.

Sharp edges, boundaries between regions of high and low optical depth in planetary rings, are maintained by shepherd satellites which transfer angular momentum to and from the ring particles. We derive equations that govern the shapes of the perturbed streamlines near such a boundary. These equations are solved for a simple numerical model whose parameters are chosen to resemble those of the Encke division and its associated satellite. The results of our calculation faithfully reproduce the sharp edges which bound the division and imply that the ring thickness in the unperturbed regions far from the edges is of order 10 m. In particular. the angle-averaged surface density is found to vary on a much shorter radial length scale than that over which the satellite torque is applied. We demonstrate that this striking feature is related to the local reversal of the viscous transport of angular momentum in the most strongly perturbed regions.

Campins, H. and Krider, E. P. (Planetary Science Institute, SAIC, Tucson, AZ 85719): 'Surface Discharges on Natural Dielectrics in the Solar System', *Science* **245** (1989), 622–624.

When Earth-orbiting spacecraft are exposed to large fluxes of energetic charged particles, electric discharges occur on circuit boards, solar panels, and other dielectric surfaces. Large fluxes of energetic particles can produce such discharges on natural materials in the solar system. Surface discharges will occur under a variety of conditions, but particularly favorable environments are expected to occur within the magnetospheres of the giant planets; an example is the surface of Io.

Drake, M. J., Newson, H. E., and Capobianco, C. J. (Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721): 'V, Cr, and Mn in the Earth, Moon, EPB, and SPB and the Origin of the Moon: Experimental Studies', *Geochimica et Cosmochimica Acta* **53** (1989), 101–2111.

The abundances of V, Cr, and Mn inferred for the mantles of the Earth and Moon decrease in that order and are similar, but are distinct from those inferred for the mantles of the Eucrite Parent Body (EPB) and Shergottite Parent Body (SPB). This similarity between Earth and Moon has been used lo suggest that the Moon is derived substantially or entirely from Earth mantle material following terrestrial core formation. To test this hypothesis, we have determined the partitioning of V, Cr, and Mn between solid iron metal, S-rich metallic liquid, and synthetic basaltic silicate liquid at 1260 °C and one bar pressure. The sequence of compatibility in the metallic phases is Cr $>$ V $>$ Mn at "high" oxygen fugacity (just below the iron-wüstite buffer) and V $>$ Cr $>$ Mn at low oxygen fugacities. Solubilities in liquid metal always exceed solubilities in solid metal. These partition coefficients suggest that the abundances of V, Cr, and Mn do not reflect core formation in the Earth. Rather, they are consistent with the relative volatilities of these elements. The similarity in the depletion patterns of V, Cr, and Mn inferred for the mantles of the Earth and Moon is a necessary, but not sufficient, condition for the Moon to have been derived wholly or in part from the Earth's mantle.

Durham, R., Schmunk, R. B., and Chamberlain, J. W. (Department of Physics, United States Air Force Academy, Colorado Springs, CO 80840): 'Comparative Analysis of the Atmospheres of Early Earth and Early Mars', *Adv. Space Res.* **9** (1989), (6)139–(6)142.

A surface partial pressure of CO_2 of at least 1.3 bars is required in order to sustain liquid water on Mars. We assume that the primitive atmospheres of Mars and Earth were similar and that present differences are a result of their different distances from the Sun and their different masses. We then use a one-dimensional radiative-convective atmospheric model to determine if a 1.3 bar CO_2 partial pressure on Mars is consistent with the climatic conditions thought to have existed on Earth four billion years ago. The Earth atmosphere was evidently then stable against a runaway greenhouse, so that huge amounts of liquid water could accumulate on the surface. We find that these terrestrial conditions are consistent with a high CO_2 partial pressure on Mars, which produces liquid water at perihelion if not during the entire orbit.

El-Shaarawy, M. B. (Helwan Institute of Astronomy and Geophysics, Helwan, Cairo, Egypt): 'Approximate Solution of Third-Order Clairaut Theory of Rotational Sectorial Figures of Jupiter and Saturn', *Earth, Moon and Planets* **45** (1989), 115–126.

The aim of this paper is to investigate numerical solutions of third-order Clairaut theory, under the boundary conditions given in our previous work (El-Shaarawy, 1974). This solution gives an explicit form of the shape and rotational distortion, due to third-order sectorial harmonic terms, of the equipotential surfaces of the two rapidly rotating planets, Jupiter and Saturn at the different levels inside these planets owing to a certain internal density distribution model (Zharkov, 1975). We considered each of them as a heterogeneous self-gravitating fluid mass in hydrostatic equilibrium.

Goertz, C. K. (Department of Physics and Astronomy, University of Iowa, Iowa City, IA 52242): 'Dusty Plasmas in the Solar System', *Reviews of Geophysics* **27** (1989), 271–292.

The processes that lead to charging of dust grains in a plasma are briefly reviewed. Whereas for single grains the results have been long known, the reduction of the average charge on a grain by "Debye screening" has only recently been discovered. This reduction can be important in the Jovian ring and in the rings of Uranus. The emerging field of gravitoelectrodynamics which deals with the motion of charged grains in a planetary magnetosphere is then reviewed. Important mechanisms for distributing grains in radial distance are due to stochastic fluctuations of the grain charge and a systematic variation due to motion through plasma gradients. The electrostatic levitation model for the formation of spokes is discussed, and it is shown that the radial transport of dust contained in the spokes may be responsible for the rich radial structure in Saturn's rings. Finally, collective effects in dusty plasmas are discussed which affect various waves, such as density waves in planetary rings and low-frequency plasma waves. The possibility of charged grains forming a Coulomb lattice is briefly described.

Gomes, R. S. (CNPq-Observatorio Nacional, Rio de Janeiro, RJ, CEP 20921 Brazil): 'On the Problem of the Search for Planet X Based on Its Perturbation on the Outer Planets', *Icarus* **80** (1989), 334–343.

The comparison of Uranus' and Neptune's observations to their theories leads to systematic residuals whose meaning is yet unknown. One of the possible explanations would be systematic errors in the observations. In this paper it is supposed that those discrepancies are due to an unknown planet in the Solar System. Based on this supposition, we look for the best region for a Planet X so as to explain those systematic residuals.

Grabbe, C. L. (Department of Physics, University of Iowa, Iowa City IA 52242): 'Wave Emissions from Planetary Magnetospheres' NASA Contractor Report Series, NASA-CR-185435 (1989), pp. 68.

Gubar, Yu. I. and Mozzhukhina, A. R.: 'The Radial Dependence of the Particle Distribution Function in the Radiation Belts of Earth, Jupiter, and Saturn', *Cosmic Research* **27** (1989), 117–124.

We have studied the radial profiles of the particle distribution functions for specific values of the first and second adiabatic invariants in the radiation belts of Earth, Jupiter, and Saturn. We considered electrons and protons in the inner and outer radiation belts of Earth, respectively, and protons and oxygen ions in the radiation belts around Jupiter and Saturn. We find that for certain and specific values of J the radial dependence of the distribution function can be approximated by an expression that derives from an exponential distribution in Φ in a dipole magnetic field when the range of L is sufficiently wide. When taken with earlier results concerning the Earth's radiation belts, these results point to a similarity in the processes that form the radial profiles of the different radiation belts.

Guberman, S. L. (Institute for Scientific Research, 33 Bedford Street Lexington, MA 02173): 'Theoretical Studies of Important Processes in Planetary and Comet Atmospheres', NASA-CR-184951 (1989), pp. 30.

Kamel, O. M. (Astronomy Department, Faculty of Sciences, Cairo University Giza, Egypt): 'Third-Order Uranus-Neptune Theory by Hori's Method', *Earth, Moon and Planets* **45** (1989), 127–137.

We construct a U–N secular canonical planetary theory of the third order with respect to planetary masses. The Hori-Lie procedure is adopted to solve the problem. Expansions have been carried out by hand, neglecting powers higher than the second with respect to the eccentricity-inclination. We take into account the principal as well as the indirect part of the planetary disturbing function. The theory is expressed in terms of the Poincaré canonical variables, referring to the Jacobi-Radau set of origins. We assume that the 1:2 U–N critical terms and its multiples are the only periodic terms.

Katterfeld, G. N. and Shmouratko, V. I. (All-Union Research Institute for Space and Aerial Geology Methods, Leningrad 199034, U.S.S.R.): 'Planetological Comparison of the Earth and Mars', *Modern Geology* **13** (1989), 209–216.

The comparative analysis of Martian topography and the topography of the Earth's upper mantle leads to the conclusion of their similarity. The principal feature of global morphology, tectonics and petrochemistry of both planets in the North-South antisymmetry that is controlled by the extremal parallels of geoid are areoid (62 °N and 62 °S). Similarity in distribution of three submeridional "planetary waves" of the megatopography of the Earth and Mars is also revealed. The Tharsis tectonic uplife at Mars and its largest volcanic constructions (namely shield volcanoes Olympus, Ascraeus Mons, Pavonis Mons, Arsia Mons) correspond to the uplife beneath the Pacific Ocean in the topography of the Earth's mantle; the Sabaeus-Arabia uplift corresponds to the sub-Atlantic uplift, and the Hesperia Planum with Tyrrhena volcanic shield corresponds to the uplift beneath the Indian Ocean.

The hypothesis is proposed that on the surface of Mars a layer is exposed which is the counterpart of basaltic geophysical layer of the Earth's crust. It has been attempted to explain the absence of a granite type crust on Mars. The authors tend to the sedimentary-metamorphic hypothesis of granite origin since the data of comparative planetology leave no place for other conclusions. The great paleogeological role of Conrad discontinuity plays a very important historical and evolutionary boundary role dividing not only absolutely different pre-geological-basaltic and geological-granitic stages of lithosphere development, but also of the planets themselves.

It is anticipated that the spatial distribution of the primary "continents" and "oceans" of the pregeosynclinal development cycle on our planet was similar to that observed at the surface of Mars. It allows us to consider Mars as an original morphotectonic and petrochemical model of the Earth in its pre-granite stage of evolution. The observed antipodality of recent megatopography of the Earth and Mars owes its development to the different energetic potentials of these planets. It caused finally "inversion" of continents and oceans on the Earth, whereas Mars as a whole preserved the primary morphostructure and petrochemistry.

Lunine, J. I. (Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721): 'The Urey Prize Lecture: Volatile Processes in the Outer Solar System', *Icarus* **81** (1989), 1–13.

The outer Solar System is dominated by the giant planets, but contains also a handful of lunar-sized bodies with surfaces and atmospheres composed of material more volatile than water ice. The best studied of these bodies, Titan, has a surface hidden from view but which may be dominated by a massive ocean of liquid hydrocarbons and nitrogen. The progressive destruction of methane over time by photolysis drives a series of chemical changes in the ocean and atmosphere; some of the evidence for such changes may be detectable in data from Cassini. Much less is known of volatile processes on Triton and Pluto/Charon, but enough can be inferred that a cosmochemistry of the outer Solar System can begin to be assembled. Titan's density and composition and strong indicators of formation in a high pressure disk around Saturn. Pluto/Charon's bulk density and new inferences on the atmospheric composition support an origin in the solar nebula. Triton may be an intriguing hybrid case whose study will really begin in August 1989. Critical to an understanding of outer Solar system chemistry and its relationship to the primordial solar nebula are the composition of comets and molecular abundances on grains in giant molecular clouds. The spacecraft and novel ground-based observations of Halley and other recent comets have provided critical new data, but the level of detail required by most solar nebula models (akin to that derived from meteorites) must await CRAF and sample return missions at the turn of the new millenium.

Maeda, K. and Grebowsky, J. M. (NASA/Goddard Space Flight Center, Greenbelt, MD 20771): 'VLF Emission Bursts in the Terrestrial and Venusian Nightside Troughs', *Nature* **341** (1989), 219–221.

The existence of very-low-frequency (~100 Hz) electric-field bursts in the nightside Venus ionosphere has been commonly assumed to be evidence for lightning, by analogy to the Earth where some of the whistler-mode radiations above the ionosphere originate from lightning. Non-lightning sources for Venus whistler-mode waves have been ignored. VLF emission bursts not associated with lightning are frequently observed over the terrestrial polar ionosphere. One type, saucers, are whistler-mode wave emissions that propagate upwards along magnetic-field lines. Here we show that the 100-Hz emission bursts in the venusian nightside ionosphere are remarkably similar to those of the terrestrial VLF saucer emissions in terms of their spatial and temporal characteristics and the properties of their magnetoplasma environment. We therefore propose that the generation mechanism for such VLF saucers should be considered as a viable alternative to lightning as a source of venusian ionospheric whistler-mode emissions.

Markov, Yu. G. and Minyaev, I. S. (Serge Ordzhonikidze Aviation Institute, Moscow, USSR): 'Evolutionary Equations of Rotational Motion of a Deformable Planet in the Restricted Three-Body Problem', *Soviet Astron.* **33** (1989), 67–71.

Approximate equations describing the evolution of the rotational motion of a viscoelastic planet within the framework of the restricted, circular three-body problem are obtained in this paper by the averaging method. The equations are written in Andover canonical variables, The resulting motion of a deformable planet of the presence of energy dissipation can serve as one model for tidal phenomena in the motion of planets of the solar system.

McKellar, A. R. W. (Herzberg Institute of Astrophysics, National Research Council of Canada, Ottawa, Ontario, Canada K1A 0R6): 'Low-Temperature Infrared Absorption of Gaseous N_2 and $N_2 + H_2$ in the 2.0–2.5 μm Region: Application to the Atmospheres of Titan and Triton', *Icarus* **80** (1989), 361–369.

Collision-induced spectra of pure N_2 and $N_2 + H_2$ mixtures in the 2.0–2.5 μm spectral region are observed in the laboratory at low temperatures appropriate to the atmospheres of Titan and Triton. The N_2 first overtone ($v = 2$–0) band near 2.16 μm is studied at 97.5 °K and found to have a peak absorption of $3.2 \times 10\text{–}8\ \mathrm{cm}^{-1}$ amagat^{-2} at $4630\ \mathrm{cm}^{-1}$ and a full width at half-maximum of about $84\ \mathrm{cm}^{-1}$. The N_2 enhancement of the fundamental ($v = 1$–0) band of H_2 in the 2.05–2.45 μm region is studied at 77 °K in both para- and normal H_2. In the case of Titan, it is shown that the pure N_2 and

$N_2 + H_2$ absorptions are likely to be significant and of roughly comparable strength given the accepted H_2 abundance. For Triton, where much less is currently known about the atmosphere it is shown that the observed N_2 absorption feature at 2.16 μm may be due to the gas rather than to liquid nitrogen as previously supposed. These results emphasize the value of longpath low-temperature laboratory data for interpreting spectra of the outer planets and their satellites.

Mennigmann, H. D. (Institute of Microbiology, University, D-6000 Frankfurt/Main, F. R. G.): 'Exobiology: Results of Spaceflight Missions', *Advances in Space Research* **9** (1989), (6)3–(6)12.

Experiments are reviewed which were carried out on a number of balloon, rocket, and spacecraft missions and which have shown that inactivation of bare bacterial spores by solar ultraviolet radiation (UV) is, at most, a matter of a few minutes only. In addition, laboratory experiments have indicated that a temperature close to that of Space together with a protective coating by ice of simple molecules reduces sensitivity considerably. Extrapolation of these data to Space conditions allows the speculation that under these circumstances spores may survive for hundreds of thousands to millions of years: this time is sufficient for spores to travel from one solar system to another. Together with the enormous number of "protected" spores deposited from spacecrafts into Space these numbers allow for "modern panspermia" to work and point to a serious problem in "planetary quarantine". In addition, they reveal constraints for panspermia in its classical sense. Here, however, UV irradiation may not be the limiting factor; but, HZE-particles of the cosmic galactic radiation may well be so.

Nakazawa, K., Ida, S. and Nakagawa, Y. (Department of Applied Physics, Tokyo Institute of Technology, Tokyo 152, Japan): 'Collisional Probability of Planetesimals Revolving in the Solar Gravitational Field', *Astron. Astrophys.* **221** (1989), 342–347.

We have investigated the validity of the two-body (free-space) approximation in the collisional problem between two Keplerian particles, i.e. two particles revolving in the solar gravitational field, by a perturbation method based on Hill's equation.

When the deviation of the nearest distance between two particles from that of the three-body problem is sufficiently small we have found the radius r_{cr} of the sphere of the two-body approximation, within which an orbit can be well described by a solution to the two-body problem. For the encounter between a protoplanet and a planetesimal, this r_{cr}, is given by

$$r_{cr} = 0.03(a_0/1\ \mathrm{AU})^{-1/4}(\varepsilon/0.01)^{1/2}ha_0\,,$$

where a_0 is the heliocentric distance of the protoplanet, ha_0 its Hill radius and ε the degree of deviation of the nearest distance. This result is very useful in numerically evaluating the collisional rate between Keplerian particles, which is essential for the study of the planetary accumulation; it enables us to stop the three-body numerical calculation at $r = r_{cr}$ and reduce the considerable computation time.

Papaloizou, J. C. B. and Lin, D. N. C. (School of Mathematical Sciences, Queen Mary College, London, England): 'Nonaxisymmetric Instabilities in Thin Self-Gravitating Rings and Disks', *Astrophys. J.* **344** (1989), 645–668.

Nonaxisymmetric instabilities may be important in regulating the structure and evolution of planetary rings and poststellar as well as galactic disks. We examine the stability of geometrically thin self-gravitating rings and disks by computing the eigenvalues and eigenfunctions of linearized normal mode oscillations in these systems. For the vertically averaged incompressible models and models of gaseous and stellar disks with softened gravity, analytic treatment is possible. We establish the existence of oscillatory normal modes using a variational principle and infer instability using perturbation theory. Effects due to the Lindblad and corotation resonances are analyzed in detail. The distribution of the ratio of vorticity to surface density is important for determining the stability of the systems. For illustrative purposes, we compute, numerically, the growth rate for some specific ring models with unstable normal modes.

Pepin, M . B.: 'Recording the Sky on Videotape', *Astronomy* **17**(9) (1989), 86–89.

Astronomy video pioneer David Brewer talks about how he creates stunning videos of the Moon and Planets.

Patnaik, A., Roessler, K. and Zádor, E. (Institut für Chemie I (Nuklearchemie) der Kernforschungsanlage Julich GmbH, D-5170 Julich, F. R. G.): 'Modification of Simple Organic Solids in Space: Energetic Carbon Interactions with Solid Methane', *Adv. Space Res.* **9** (1989), (6)49–(6)52.

The formation of complex organic compounds in space by high energy and radiation chemical reactions was simulated in the laboratory using solid methane as a model substance for primordial organic solids. The reactions were induced by energetic carbon atoms formed via the $^{12}C(^{2}He, ^{4}He)^{11}C$ nuclear process (high energy chemistry) and the accompanying radiolysis by the ^{3}He-cyclotron particles (radiation chemistry). Gaschromatographic analysis of the target showed the formation of many new carbon compounds ranging from acetylene and ethylene to molecules containing up to eight carbon atoms including probably cyclic and aromatic compounds. Formation of this kind of products can only be explained by insertion of hot carbon atoms into CH bonds and bridging reactions between CH_4 molecules. The mechanisms can be responsible for the formation of organic polymers, refractories and crusts on objects in space such as interplanetary dust grains, comets and asteroids hit by particle radiation (e.g. solar wind). It may constitute a general pathway for the build-up of compelx moelcules in prebiotic chemical evoltuion.

Prinzhofer, A., Papanastassiou, D. A. and Wasserburg, G. J. (Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125): 'The Presence of ^{146}Sm in the Early Solar System and Implications for Its Nucleosynthesis', *Astrophys. J.* **344** (1989), L81–L84.

The presence of the *p*-process nucleus ^{146}Sm (mean life, $\bar{\tau} = 149 \times 10^6$ yr) in the early solar system and its *in situ* α-decay into ^{142}Nd is demonstrated by the correlation of $^{142}Nd/^{144}Nd$ with $^{144}Sm/^{144}Nd$ in two meteorites which have a large range in $^{144}Sm/^{144}Nd$ in their constituent mineral phases. Clear excesses of $^{142}Nd/^{144}Nd$, relative to the solar system value, are present in high Sm/Nd phases and a clear deficit of $^{142}Nd/^{144}Sm$ is 0.008 at the time of the last equilibration of each meteorite at 4.47 AE ago, which yields $^{146}Sm/^{144}Sm \sim 0.015$ at the time of formation of the solar system, 4.56 AE ago. These results confirm the presence of ^{146}Sm and provide a well-defined initial abundance for ^{146}Sm. The abundance of ^{146}Sm is compatible with the *p*-process production rate estimates but not with the production rate for ^{146}Sm based on a photodisintegration model for the production of *p*-process nuclides.

Scattergood, T. W., McKay, C. P., Borucki, W. J., Gier, L. P., Van Ghyseghem, H., Parris, J. E. and Miller, S. L. (SUNY at Stony Brook, Stony Brook, NY 11794): 'Production of Organic Compound in Plasmas: A Comparison among Electric Sparks, Laser-Induced Plasmas, and UV Light', *Icarus* **81** (1989), 413–428.

The chemistry in planetary atmospheres that is induced by processes associated with high-temperature plasmas is of broad interest because such processes may explain many of the chemical species observed. There are at least two important phenomena that are known to generate plasmas (and shocks) in planetary atmospheres: lightning and meteor impacts. For both phenomena, rapid heating of atmospheric gases leads to formation of a high-temperature plasma which emits radiation and produces shock waves that propagate through the surrounding atmosphere. These processes initiate chemical reactions that can transform simple gases into more complex compounds. In order to study the production of organic compounds in plasmas (shocks) various mixtures or N_2. CH_2, and H_2 modeling the atmosphere of Titan. were exposed to discrete sparks, laser-induced plasmas (LIP, and ultra-violet radiation. Thc yields of HCN and several simple hydrocarbons were measured by gas chromatography and compared to those calculated from a simple quenched thermodynamic equililbrium model. The agreement between experiment and theory was fair for HCN and C_2H_2. However, the agreement for C_2H_6 and the other hydrocarbons was poor, indicating that a more comprehensive theory is needed. Our experiments suggest that photolysis by ultraviolet light from the plasma is an important process in the synthesis. This was confirmed by the photolysis of gas samples exposed to the light but not to the shock waves emitted by the sparks. Hence, the results of these experiments demonstrate that the thermodynamic equilibrium theory does not adequately model lightning and meteor impacts and that photolysis must be included. Finally the similarity in yields between the spark and the LIP experiments suggests that LIP provide valid and clean simulations of lightning in planetary atmospheres.

Stahara, S. S., Rachiele, R. R., Spreiter, J. R. and Slavin, J. A. (RMA Aerospace, Inc., Mountain View, CA 94043): 'A Three-Dimensional Gasdynamic Model for Solar Wind Flow Past Nonaxisymmetric Magnetospheres: Application to Jupiter and Saturn', *Journ. Geophys. Res.* **94** (1989), 13,353–13,365.

The gasdynamic convected magnetic field model for predicting solar wind flow past a planetary magnetoionopause obstacle has been extended to three dimensions to apply to obstacles of nonaxisymmetric shape. Thc need for such an extension is of first-order importance for Jupiter and Saturn because the effects of rapid spin, large size, and substantial ring current phenomena are believed to cause the magnetospheres of these planets to be significantly broader near the planetary equatorial plane than near the noon-midnight polar meridian plane. Direct observational determination of such asymmetrics for Jupiter and Saturn has not been possible, however, because only limited amount of data are available from four spacecraft at Jupiter and three at Saturn, all of which followed flyby trajectories at fairly low latitudes. With the aid of the new three-dimensional model, it is now possible to infer the degree of flattening of the magnetospheric cross sections from a knowledge of the locations of the low-latitude magnetopause and bow shock crossings. In this paper, the computational procedures of the new model are described, and calculated results are presented for a number of magnetospheres of elliptic cross sections with values ranging from 1 to 2 for the ratio a/b of major (equatorial) to minor (polar) axes. This range is sufficient to include values appropriate to both Jupiter and Saturn. Comparisons of the model results with the locations of observed crossings of the magnetopause and bow shock directly provide an estimate of the degree of equatorial broadening of the magnetospheric cross section for each of these planets. For Jupiter, the results indicate a broadening to $a/b \sim 1.75$, a value consistent with previous estimates determined from independent calculations of the three dimensional magnetosphere shape formed by adding to the planetary dipole field the magnetic field of an equatorial current sheet selected so as to match the observed Jovian magnetic field near the equatorial plane. For Saturn, a similar comparison indicates a smaller broadening to $a/b \sim 1.25$. The determination is less certain than for Jupiter, however, because of the smaller amount and greater scatter of the available data.

Stothers, R. B. (NASA/Goddard Space Flight Center, Institute for Space Studies, New York, NY 10025): 'Turbulent Atmospheric Plumes above Line Sources with an Application to Volcanic Fissure Eruptions on the Terrestrial Planets', *Journ. Atmospheric Sciences* **46** (1989), 2662–2670.

The theory of turbulent plumes maintained above steady line sources of buoyancy is worked out in detail within the limitations of Taylor's entrainment assumption. It is applied to the structure of a pure plume injected into a stably stratified atmosphere. Volcanic basalt eruptions that develop from long, narrow vents create line source plumes. which rise well above the magmatic fire fountains playing near the ground level. The eruption of Laki 1783 may provide an example of this style of eruption. Flood basalts are more ancient examples. Evidence of enormous fissure eruptions that occurred in the past on Mars and Venus also exists. Owing to the different properties of the atmospheres on these two planets from those on the Earth, heights of line source plumes are expected to vary in the ratios 1:6:0.6 (Earth:Mars:Venus). It is very unlikely that the observed increase of sulfur dioxide above the Venusian cloud deck in 1978 could have been due to a line source volcanic eruption, even if it had been a flood basalt eruption.

Ward, W. R. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91102): 'On the Rapid Formation of Giant Planet Cores', *Astrophys. J.* **345** (1989), L99–L102.

The formation of the ice-rock cores of the giant planets by density wave-assisted accretion is outlined. The process could be rapid (10^5–10^6 yr) and completed within the probable lifetime of the solar nebula. The mechanism works for both Jupiter and Saturn and does not require a large excess of mass over that believed present in their cores.

Zuber, M., James, O., MacPherson, G. and Plescia, J. (Goddard Space Flight Center, Greenbelt, MD 20771): 'Planetary Geosciences 1988', NASA Special Publ. Series, NASA-SP-498 (1989), pp. 108.

3. JUPITER

Bagenal, F. (Masachusetts Institute of Technology, Cambridge, MA 02193); 'Torus-Magnetosphere Coupling', NASA Special Publication Series, NASA-SP-494 (1989), 196–210.

To understand temporal variability of the jovian magnetosphere, it is necessary to study the coupled system of the Io plasma torus, the magnetosphere, and Jupiter's ionosphere. At present, efforts have been concentrated on separate elements of the system.

Progress has been made in both measuring and modeling the plasma conditions in the cold and warm regions of the torus. Models of the warm torus developed by Shemansky (1987b) show that the observed plasma conditions require an additional source of energy in the torus, comparable to that picked up by the ions in plasma production (3×10^{13} W). Estimates of mass-loading on the ionosphere and the concomitant perturbation in the plasma flow suggest it may not be possible to produce this much power in a small region such as Io's atmosphere, as Shemansky proposes. A fully self-consistent, three-dimensional plasma model of the magnetosphere-atmosphere interaction is urgently required. A recent analysis of the Voyager plasma science data in the region between the warm torus and the plasma sheet ($L = 6$ to 12) indicates that there is an additional source of plasma between 9 and 11 R_J, possibly the ionization of neutral material from Europa or recycling of material from the Io torus. In addition to a thermalized ion population with $T_i \sim 50$ eV there is a hot population with temperatures >1 keV that comprises up to 35 percent of the total charge density. To ascertain if this hot population could be acting as an intermediary and transferring energy from the inwardly diffusing energetic particles to provide the 10^{13} W to the torus, we need a comprehensive model of the region between the torus and the plasma sheet, including ionosphere-magnetosphere coupling.

Baines, K. H., Smith, W. H. and Alexander, C. (Jet Propulsion Laboratory, Pasadena, CA 91103): 'Spatial and Temporal Variations of NH_3 Abundance and Cloud Structure in the Jovian Troposphere Derived from CCD/Coude Observations', NASA Special Publication Series, NASA-SP-494 (1989), 363–370.

Beebe, R. F., Orton, G. S. and West, R. A. (New Mexico State University, Las Cruces, NM 88003): 'Time-Variable Nature of the Jovian Clou Properties and Thermal Structure. An Observational Perspective', NASA Special Publication Series, NASA-SP-494 (1989), 245–288.

This chapter reviews observations of the temporal behavior of jovian cloud properties and thermal structure of the upper troposphere and stratosphere. Changes in the albedo and color of belt and zones have been reported in the literature for well over a century. We discuss the north-south asymmetry of the equatorial zone, contrast between the north and south equatorial belts and the role of south equatorial belt disturbances.

Belton, M. J. S., West, R. A. and Rahe, J.: (National Optical Astronomy Observatories, Tucson, AZ 85721), 'Time-Variable Phenomena in the Jovian System', NASA Special Publication Series, NASA-SP-494 (1989), pp.403.

Carlson, B. E. and Lutz, B. L. (NASA/Goddard Space Flight Center, Greenbelt, MD 20771): 'Spatial and Temporal Variations in the Atmosphere of Jupiter: Polarimetric and Photometric Constraints', NASA Special Publication Series, NASA-SP-494 (1989), 289–298.

New spatially resolved narrow-band charge-coupled device (CCD) polarimetric and photometric images of Jupiter in the methane absorption band at 7270 Å and continuum light near 7500 Å were obtained at the Lowell Observatory in the fall of 1986. Images were recorded at three phase angles from 0°.3 to 11°.1. The CCD images reveal an asymmetric increase in the degree of linear polarization toward the poles. These images confirm that there is a significant enhancement in the degree of linear polarization from the disk center toward the limbs, as was observed in the early measurements made by Lyot. Also shown by the images is a variation in the degree of linear polarization measured at the east (sunrise) limb and west (sunset) limb, with larger polarizations associated with the west limb.

Cheng, A. F. and Krimigis, S. M. (Applied Physics Laboratory, The Johns Hopkins University, Laurel, MD 20707): 'A Model of Global Convection in Jupiter's Magnetosphere', *Journ. Geophys. Res.* **94** (1989), 12003–12008.

The "planetary wind" model, which holds that corotation must break down outside some Alfvén critical radius and that a centrifugally driven wind outflow must then develop, does not agree with Voyager observations at Jupiter. The discrepancies are most evident in the distant compositional signatures observed by Voyager that showed the plasma to be mostly of indigenous (i.e., Io) composition to $\sim 60\, R_J$, solar wind-like to $\sim 150\, R_J$, and again mostly indigenous at $\gtrsim 150\, R_J$. Throughout most of the Jovian magnetodisk plasma sheet, the corotational energy density exceeds the magnetic energy density, but corotation-dominated flow is maintained. Furthermore, the composition of the energetic particles observed by Voyager changed significantly when the spacecraft left the rotating plasma sheet and entered the outflowing magnetospheric wind, contrary to the prediction of the planetary wind model. A new global convection model for the Jovian magnetosphere is proposed to explain these observations, drawing upon models of quasi-stationary plasma convection in Earth's magnetosphere. The model predicts a substantial dawn-dusk asymmetry in the structure, dynamics, and plasma composition of the magnetopause and magnetosheath, as well as a region of cross-tail now (dusk-to-dawn) in the nightside plasma sheet extending from ~ 60–$150\, R_J$ and containing a substantial admixture of solar wind plasma.

Christon, S. P., Chenette, D. L., Baker, D. N. and Moses, D. (Applied Physics Laboratory, The Johns Hopkins University, Laurel, MD 20707): 'Relativistic Electrons at Geosynchronous Orbit, Interplanetary Electron Flux, and the 13-Month Jovian Synodic Year', *Geophys. Res. Letters* **16** (1989), 1129–1132.

We report the results of a search to determine the correlation, if any, between the temporal behaviors of $\gtrsim 0.2$–7 MeV electrons at geosynchronous orbit ($\sim 6.6\, R_e$) and 6–10 MeV electrons in the interplanetary region near Earth at the period of the jovian synodic year (~ 13 months). The ~ 13-month intensity variation results from the synodic interplanetary magnetic field connection of Earth to Jupiter. Direct comparison of intensity-time flux profiles for the years 1976–1984, ~7 synodic jovian electron seasons, shows that the intensity envelope of peak electron flux at ~6.6 R_e does not appear to be correlated to the observed 13-month intensity envelope of relativistic electron flux in the interplanetary region near Earth. A persistent 13-month variation of geosynchronous orbit flux is not obvious, thus indicating that the intensity of electron flux at ~6.6 R_e is not directly and solely related to the intensity of jovian electron flux near Earth. We conclude that dynamic energization and redistribution processes in Earth's magnetosphere must be invoked to produce the intensity variations of relativistic electron flux at ~6.6 R_e and not interplanetary magnetic field connection to Jupiter.

Clarke, J., Caldwell, J., Skinner, T. and Yelle, R. (NASA/Goddard Space Flight Center, Greenbelt, MD 20771): 'The Aurora and Airglow of Jupiter', NASA Special Publication Series, NASA-SP-494 (1989), 211–220.

We define the aurora as atmospheric emission induced by precipitating magnetospheric particles (or secondary electrons), and airglow as scattered solar radiation and/or emissions from the polar regions of Jupiter, which include extreme ultraviolet (EJV) and far ultraviolet (FW) emissions of H and H, soft X rays most likely produced by sulfur and oxygen K-shell excitation, and localized stratospheric infrared (IR) emissions. Outstanding questions about the aurora include the composition and energies of the precipitating particles (i.e., electrons, protons, and O and S ions), the source regions and energization mechanism within the magnetosphere, contributions by ionospheric electric fields to particle acceleration, and the effects of the deposited energy in heating and ionizing the upper atmosphere. Airflow processes include resonant scattering of incident solar H L_α direct photoelectron excitation of H and H_2, a potentially significant level of H_2 fluorescence, and the phenomenon of electroglow. Electroglow has been defined as soft charged particle excitation of atmospheric gas in the presence of sunlight, although ideas about the electroglow process are rapidly evolving beyond the initial definition. Important questions include the nature of the additional energy source beyond direct photoelectron and ion excitation, the role of sunlight in producing electroglow, and the associated contributions to heating and ionization of the upper atmosphere.

de Pater, I. and Klein, M. J. (University of California, Berkeley, CA 94720), 'Time Variability in Jupiter's Synchrotron Radiation', NASA Special Publicatlon Series, NASA-SP-494 (1989), 139–150.

This chapter presents an overview of possible time variability in the decimetric radio emission from Jupiter. It investigates the presence or absence of fluctuations with time in different synchrotron radiation characteristics: the total intensity, the position angle of the electric vector, the degree of linear and circular polarization, the angular separation of the radiation peaks projected on the sky, and the longitudinal asymmetry of the radiation peaks. Variations in time, other than those caused by the changing viewing aspect of the planet, are only apparent in the total flux density and the angular separation of the radiation peaks. The longitudinal asymmetry of the radiation peaks changed once between 1967 and 1973. In the same period a large decrease was detected in the total flux density, and the centroid of the radiation peaks (the standoff distance) moved closer to the planet. The spectrum of the synchrotron radiation hardened slightly.

Doyle, L. R. and Borucki, W. J. (S.E.T.I. Institute, Los Altos, California): 'Jupiter Lightning Locations', NASA Special Publication Series, NASA-SP-494 (1989), 384–390.

A redetermination of the location of lightning events gave substantial differences with those determined by Cook *et al.* (1979), which were based on preliminary navigation data, and systematic differences with those determined by Williams (1986). The lightning events shown in the two discovery images are found near 50° and 57° N latitude. A search for lightning events in 13 previously unexamined images showed no events. These, however, were much shorter exposures of less than 1 s each. This result implies that the lightning event rate at other latitudes is not likely to be much larger than that determined from the high-latitude discovery images. The mean and median values of the optical energy radiated per flash are found to be 1.08×10^9 and 6.65×10^8 J, respectively; somewhat higher than the values previously derived, implying that lightning activity on Jupiter is more energetic than previously estimated.

Drossart, P., Courtin, R., Atreya, S. and Tokunaga, A. (Observatoire de Paris, Meudon, France): 'Variations in the Jovian Atmospheric Composition and Chemistry', NASA Special Publication Series, NASA-SP-494 (1989), 344–362.

After the Voyager observations, a mean atmospheric composition model has become available from a combination of spacecraft and ground-based measurements, and this model can be used as a reference for future studies on the spatial and temporal variations of atmospheric composition. A further step for understanding the jovian atmospheric structure is therefore the study of departures from this "standard atmosphere."

Drossart, P., Maillard, J.-P., Caldwell, J., Kim, S. J., Watson, J. K. G., Majewski, W. A., Tennyson, J., Millar, C, Atreya, S. K., Clarke, J. T., Waite, J. H., Jr. and Wagoner, R. (Laboratoire Spatial (CNRS-URA264), Observatoire de Paris-Meudon, 92190 Meudon, France): 'Detection of H_3^+ on Jupiter', *Nature* **340** (1989), 539–541.

Since their detection in the high latitudes of Jupiter, first by the Voyager Ultraviolet Spectrometer (UVS) experiment, then by the International Ultraviolet Explorer (IUE) satellite, the auroral particle precipitations have been associated with various phenomena in the jovian environment. In the magnetosphere, the H_3^+ ion, probably of ionospheric origin, was detected *in situ* by the Voyagers. Infrared emissions were observed in spectral bands characteristic of CH_4 and of other hydrocarbons, localized in two auroral spots. Here we present high-resolution spectra at a wavelength of 2 μm, in the southern auroral region of Jupiter, recorded at the Canada–France–Hawaii Telescope (CFHT), which we believe to be the first astronomical spectroscopic detection of H_3^+. The derived rotational temperature of H_3^+ is in the range 1,000–1,200 K. Such strong H_3^+ lines could be used in future round-based monitoring of the jovian auroral activity and to search for this molecular ion in the interstellar medium.

Flasar, F . M. (NASA/Goddard Space Flight Center, Greenbelt, MD 20771): 'Temporal Behavior of Jupiter's Meteorology', NASA Special Publication Series, NASA-SP-494 (1989), 324–343.

This chapter reviews radiative, chemical, and dynamic time scales pertinent to Jupiter's meteorology. The radiative relaxation time of the atmosphere is so large that diurnal variations attributable to purely radiative effects are precluded. The radiative time is comparable to Jupiter's orbital time scale consistent with the observed seasonal variation in stratospheric temperature. The small seasonal variation in the upper troposphere probably results from the short time required for convective redistribution of heat in the deeper atmosphere and interior. Rapid convective turnover also plausibly explains the presence of disequilibrium minor constituents spectroscopically observed in Jupiter's troposphere. The observation of *para*-hydrogen disequilibrium on Jupiter but not on Saturn or Uranus can also be explained in terms of dynamic overturning, in the context of the relative magnitudes of the radiative relaxation time and the *para*-hydrogen equilibration time in the upper tropospheres of these planets. Jupiter's mean zonal winds appear to be remarkably stable: They exhibited virtually no change in the time (four months) between the two Voyagers, and ground-based observations have indicated little change during at least the previous five years, and perhaps longer. This apparent stability could result from the inertia associated with a differential rotation that extends far into Jupiter's interior but it also could result, at least in part, from a delicate balance between eddy forcing and induced mean meridional flows in an atmosphere with weak friction and radiative damping. Changes in the zonal mean temperatures or winds would then be indicative of changes in the level of eddy activity. In contrast to the winds, the visual appearance in Jupiter's banded structure typically changes significantly over the course of a few years and is not always well correlated with the zonal wind structure. The utility of waves, themselves temporally varying phenomena, in sounding Jupiter's atmosphere is discussed.

Genova, F., Zarka, P. and Lecacheux, A. (Observatoire de Paris, Meudon, France): 'Jupiter Decametric Radiation', NASA Special Publication Series, NASA-SP-494 (1989), 156–174.

The ground-based and Voyager radio observations of Jupiter show that the emission in the decametric and hectometric frequency ranges is extremely variable. Many kinds of fluctuations are seen, on time scales of milliseconds to days or longer, and the spectrum of the emission is also very fluctuating. After a brief review of the general characteristics of the emission, this chapter describes first its dominant periodicities – the planetary rotation and the control by Io – then, the short-term modulations – the S-bursts, with durations of some tens of milliseconds, and other fluctuations with time scales shorter than several minutes, in particular the arcs, the effects of propagation close to the source, and, in the case of ground-based observations, those between Jupiter and the radiotelescope. Finally, the search for long-term fluctuations of the emission, and the difficulties found in correlating them with the variations of other parameters of the jovian environment, the solar wind, the auroras, and the like are discussed. As a conclusion, the perspectives and needs for observational as well as theoretical work are discussed, especially for long-term observations and correlations with observations at other wavelengths.

Gladstone, G. R. and Skinner, T. E. (University of Colorado, Boulder CO 80309): 'Spectral Analysis of Jovian Auroral Emissions', NASA Special Publication Series, NASA-SP-494 (1989), 221–228.

Beginning in early 1981, a comprehensive set of 14 International Ultraviolet Explorer (IUE) observations of the jovian aurora, each comprised of ~10 spectra, has been devoted to mapping the north and south pole emissions over complete rotations of the planet. The long-term nature of this study makes the IUE data set especially valuable, since they augment and extend our knowledge of the jovian aurora derived from the Voyager "snapshot." In addition, the resolution of the IUE shortwavelength spectrograph is ~3 times better than that of the Voyager ultraviolet spectrometer (UVS). Using a detailed model for electron-impact excitation of H_2 together with an up-to-date model jovian atmosphere and an accurate radiative transfer code, we are able to determine the column density of CH_4 above the auroral emission layer to very high precision. This provides an important constraint on the structure of the auroral atmosphere and the energy spectrum of the precipitating particles. Preliminary results determined from applying the model to two spectra representing the brightest and the weakest auroral emissions observed with IUE are presented. The sensitivity of the model to changes in the auroral particle energies and the composition of the atmosphere is also examined.

Joiner, J., Steffes, P. G. and Jenkins, J. M. (School of Electrical Engineering, Georgia Institute of Technology, Atlanta, GA 30332): 'Laboratory Measurements of the 7.5–9.38-mm Absorption of Gaseous Ammonia (NH_3) under Simulated Jovian Conditions', *Icarus* **81** (1989), 386–395.

Previous laboratory results have verified that to within experimental limits, the modified Ben-Reuven lineshape correctly describes the opacity of gaseous ammonia (NH_3) in an H_2/He atmosphere from 1.38 to 18.5 cm (1.62–21.7 GHz) (P. G. Steffes and J. M. Jenkins 1987, *Icarus* **72**, 35–47). However, at wavelengths shortward of 1 cm, significant uncertainties exist as to the actual absorption spectrum of gaseous ammonia under simulated planetary conditions. We have made laboratory measurements of the millimeter-wave opacity from gaseous ammonia under simulated conditions for the Jovian atmosphere so that the abundance and distribution of ammonia can be more accurately inferred from radio emission measurements. The measurements were made at several frequencies between 32 and 40 GHz (7.5–9.38 mm), at a temperature of 203° K, and at a total pressure of 2 atm in a mixture consisting of 88.34% hydrogen, 9.81% helium, and 1.85% ammonia. The results of these measurements are significant in that the experimental data can be modeled quite well by using the lineshape factor given by E. P. Gross (1955, Phys. Rev. **97**, 395–403) in place of that given by J. H. Van Vleck and V. F. Weisskopf (1945, Rev. Mod. Phys. **17**, 433–443) as applied to the given conditions. Various parameters in the nen-Reuven lineshape can also be modified to give a good fit to the laboratory results. More laboratory results at shorter wavelengths will be needed before it is clear which theory will be able to best describe the opacity of ammonia over the entire inversion spectrum.

Khurana, K. K. and Kivelson, M. G. (Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024). 'On Jovian Plasma Sheet Structure', *Journ. Geophys. Res.* **94** (1989), 11791–11803.

We evaluate several models of Jovian plasma sheet structure by determining how well they organize several aspects of the observed Voyager 2 magnetic field characteristics as a function of Jovicentric radial distance. The present study focuses exclusively on the data from the Voyager 2 spacecraft because the magnetosphere was more stable during the flyby than it was during the Pioneer 10 and Voyager 1 flybys. It is shown that in the local time sector of the Voyager 2 outbound pass (near 0300 LT) the published hinged-magnetodisc models with wave (i.e., models corrected for finite wave velocity effects) are more successful than the published magnetic anomaly model in predicting locations of current sheet crossings. We also consider the boundary between the plasma sheet and the magnetotail lobe which is expected to vary slowly with radial distance. We use this boundary location as a further test of the models of the magnetotail. The plasma-sheet-lobe boundary is often identified from the observed field gradients, the gradients in the lobes being much smaller than those in the plasma sheet. We show that the compressional MHD waves have much smaller amplitude in the lobes than in the plasma sheet and use this criterion to refine the identification of the plasma-sheet-lobe boundary. When the locations of crossings into and out of the lobes are examined, it becomes evident that the magnetic-anomaly model yields a flaring plasma sheet with a halfwidth of $\sim 3\ R_J$ at a radial distance of 20 R_J and $\sim 12\ R_J$ at a radial distance of 100 R_J. The hinged-magnetodisc models with wave, on the other hand, predict a halfwidth of $\sim 3.5\ R_J$ independent of distance beyond 20 R_J. New optimized versions of the two models locate both the current sheet crossings and lobe encounters equally successfully. The optimized hinged-magnetodisc model suggests that the wave velocity decreases with increasing radial distance. The optimized magnetic anomaly model yields lower velocity contrast than the model of Vasyliunas and Dessler (1981). The hinged-magnetodisc models are shown to satisfy the constraints on the plasma sheet thickness imposed by MHD theory. The magnetic anomaly model can be made consistent with the expectations from MHD theory only by assuming plasma anisotropy so large that the plasma would be unstable to mirror mode instability. We recognize that the magnetic anomaly model is a comprehensive model designed to account for many features of the Jovian system as observed in multiple flyby missions. The plasma sheet structure for the Voyager 2 epoch is only one aspect of the model's predictions. Nonetheless, we believe that the model's failure to satisfy constraints on plasma sheet structure imposed by MHD equilibrium theory presents a challenge to the magnetic anomaly model as it is currently described.

Klein, M. J., Thompson, T. J. and Bolton, S. (Jet Propulsion Laboratory, Pasadena, CA 91109): 'Systematic Observations and Correlation Studies of Variations in the Synchrotron Radio Emission from Jupiter', NASA Special Publication Series, NASA-SP-494 (1989), 151–155.

A long-term observational program to monitor the time variations of the microwave radio emission from Jupiter has been in progress since April 1971. The measurements are made several times each month with the NASA Deep Space Network (DSN) antennas operating at 2295 Mz (13.1 cm). The data set, when combined with measurements by other observers, provides a record that extends over two 11-year solar cycles. The combined data set shows considerable variability that may be directly related to high-energy electron population of the inner magnetosphere. Preliminary results of a study to search for plausible correlations between the jovian synchrotron emission and solar related phenomena reveal that a positive correlation may exist with the ion number density in the solar wind.

Kostiuk, T., Espenak, F. and Mumma, M. J. (NASA/Goddard Space Flight Center, Greenbelt, MD 20771): 'Is Ethane Varying in the Jovian North Polar "Hot Spot"?' NASA Special Publication Series, NASA-SP-494 (1989), 234–241.

Several ground-based observations have revealed increased emission intensity in the spectra from methane and acetylene in the jovian polar stratosphere near 180° longitude and 60° latitude. Increased stratospheric temperature was suggested as at least partly responsible for the observed methane and acetylene enhancements. Observations (in 1982, 1983, and 1986) of individual lines of ethane using Doppler-limited spectral resolution showed no increase in emission and on one occasion a decrease in the observed line intensities.

We modeled the behavior of ethane emission as a function of jovian temperature profile and stratospheric ethane abundance. Our results suggest that ethane emission in the north polar "hot spot" cannot be explained by reasonable temperature changes alone, and thus, hydrocarbon density (and therefore chemistry) must be altered in this region.

Krisher, T. P. (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109); 'Possible Test at Jupiter of the Nonsymmetric Gravitational Theory', *Physical Review D* **40** (1989), 1372–1373.

Radiometric data generated during spacecraft flybys of Jupiter have the capability to provide an Interesting constraint on the coupling of cosmions in the nonsymmetric gravitational theory (NGT) of Moffat. It is shown that the close flyby of Jupiter by Pioneer 11 could imply a possibly limit on the NGT l parameter of the Sun of $l_{\odot} < 2800$ km, a limit which could affect the ability of the NGT to account for the procession of the perihelion of Mercury with a large solar quadrupole moment.

Lanzerotti, L. J., Rinnert, K., Krider, E. P. and Uman, M. A. (AT&T Bell Laboratories, Murray Hill, NJ 07974): 'Jovian Lightning', NASA Special Publication Series, NASA-SP-494 (1989), 374–383.

This chapter reviews the present status of knowledge of lightning in Jupiter's atmosphere. The chapter summarizes some current ideas of the atmospheric structure that is likely important for the generation of jovian lightning, reviews measurements made by Voyager 1 of jovian lightning, outlines the objectives of the Galileo probe (RF) lightning experiment, and descrlbes the differences in RF radiation between cloud-to-ground and intra-cloud discharges as observed on Earth. The RF lightning instrument on the Galileo probe will provide important new information on jovian lightning.

Lellouch, E., Drossart, P., Encrenaz, T., Guelachvili, G., Lacome, N. and Tarrago, G. (Observatoire de Paris, Meudon, France): 'A New Analysis of the Jovian 5-μm IRIS Spectra', NASA Special Publication Series, NASA-SP-494 (1989), 371–373.

Previous analysis of the Jupiter infrared interferometric spectrometer (IRIS) data in the 1800–2200 cm^{-1} range have given estimates of PH_3, GeH_4, CH_3D, and H_2O abundances in the deep regions of the jovian atmosphere (Kunde *et al.*, 1982; Drossart *et al.*, 1982; Drossart and Encrenaz, 1982; Bjoraker, 1984). However, in the case of NH_3, the fit was not fully satisfactory in this window, due to the lack of accurate NH_3 laboratory data for the ν_4 and $2\nu_2$ bands. In order to improve this analysis, low-temperature laboratory data of NH_3 have been recorded at high-spectral resolution in the 1800–2100 cm^{-1} range (Lellouch *et al.*, 1987).

With these data, it has been possible to obtain a good fit of the jovian spectrum for various locations on the jovian disk (north equatorial belt [NEB], north tropical zone [NTZ], equatorial zone [EQZ], south equatorial belt [SEB], and south tropical zone [STZ]). The abundance of NH_3 is found to be varying between zone and belts, and is smaller by a factor of two in the hot spectra of north and south equatorial belts, in agreement with observations in the centimetric range, which sound even deeper atmospheric levels (de Pater, 1986). The abundances of some minor atmospheric constituents are reestimated and discussed.

Levy, E. H. (University of Arizona, Tucson, AZ 8721, 'Possible Time Variations of Jupiter's Magnetic Field', NASA Special Publication Series, NASA-SP-494 (1989), 129–138.

Planetary magnetic fields are apparently generated by magnetohydrodynamic dynamos in the highly electrically conducting fluid interiors of the planets. Temporal variations in such dynamo magnetic fields occur directly as a result of the motions of the electrically conducting fluid in which the field lines are embedded and as a result of the overall temporal behavior of the dynamo's regenerative modes. Thus, the observed variations, of internal origin, in a planetary magnetic field yield clues about the characteristics and motions of the planet's interior. This chapter briefly reviews the basic physical processes leading to magnetic field variations of internal origin in planets and surveys the implications of such variations as may be observed at Jupiter for our understanding of that planet.

Limaye, S. S. (University of Wisconsin, Madison, WI 53706): 'Jupiter: Short-Term Variations of the Mean Zonal Flow at the Cloud Level', NASA Special Publication Series, NASA-SP-494 (1989), 311–323.

A latitudinal profile of time-averaged mean zonal (east-west) flow at the cloud level on Jupiter has been previously presented (Limaye, 1986). The technique used to determine the zonal mean flow allowed the profile to be determined for every jovian rotation over the duration of the available image data (111 rotations from Voyager 1, and 134 rotations from Voyager 2) with high-latitudinal resolution. The individual latitudinal profiles of zonal mean zonal flow for each rotation have now been analyzed to reveal temporal changes over the violet filter mosaics from Voyager I (rotations 71–111) and Voyager 2 (rotations 266–407) observations.

Changes of $+10\,\mathrm{ms}^{-1}$ are seen between Voyager 1 and Voyager 2 average zonal flow profiles. Comparable changes are also seen in average flow determined over about 50 rotations of Voyager 2 observations. Changes in the average zonal flow predicted from meridional eddy and mean circulation momentum transports from published results are much larger, indicating either that the vertical transport of momentum cannot be ignored and/or that the horizontal momentum transports are not accurate enough.

Further, changes are also observed in the 150 and 270 mbar thermal structure determined from Voyager 1 and 2 infrared interferometer spectrometer (IRIS) observations, implying changes in the vertical shear of the zonal flow. Thus, real changes in the processes controlling the zonal flow and the thermal structure are plausible as are small changes in the level of the sensed cloud level circulation.

Meyers, S. D., Sommeria, J. and Swinney, H. L. (Department of Physics and the Center for Nonlinear Dynamics, University of Texas, Austin, TX 18712): 'Laboratory Study of the Dynamics of Jovian-Type Vortices', *Physica D* **37** (1989), 515–530.

A laboratory experiment on a turbulent shear flow in a rapidly rotating annulus yields vortices with many properties of jovian vortices, including their spontaneous formation and persistence, the merger of vortices of like sign, and particle trapping. When the fluid is strongly forced (Reynolds number $\geqslant 10^4$), a wide zone or nearly uniform potential vorticity forms, and vortices successively merge until only a single dominate vortex remains. In the less turbulent now or a weakly forced fluid, the zone or uniform potential vorticity is narrower and multiple vortex state are round. These observations are compared to numerical simulations and to related experiments as well as to jovian vortices.

Sanchez-La Vega, A. (48080 Bilbao, Spain): 'Great-Scale Changes in the Belts and Zones of Jupiter: The Outbursts of Activity and Disturbances in the SEB and NTrZ-NTBs Regions', NASA Special Publication Series, NASA-SP-494 (1989), 306–310.

Great-scale changes in the belts and zones of Jupiter can be of two types: (1) gradual, with time scales of several months, (2) cataclysmic and sporadic, with short time scales of several days. This work presents a study about this second type, characteristic of two regions of the planet, the south equatorial belt (SEB) between latitudes 10° S and 20° S, and the north tropical zone-south component of the north temperate belt (NTrZ-NTBs) between latitudes 20° N and 25° N. Both types of disturbances started with the emergence of a bright, high-albedo spot (scale ~6000 km) at 15°.5 S (SEBD) and at 23°.5 N (NTrZ-NTBsD). These spots, of probable convective origin, expanded in area during the first week, and they are followed by the subsequent development of rows of dark and elongated spots (east-west scale ~10,000 km) at nearby latitudes.

Sandel B. R. and Dessler, A. J. (University of Arizona, Tucson, AZ 85721): 'New Longitude System for the Jovian Magnetosphere', NASA Special Publication Series, NASA-SP-494 (1989), 179–182.

Showalter, M. R. (NASA/Ames Research Center, Moffett Field, CA 94035): 'Anticipated Time Variations in (Our Understanding of) Jupiter's Ring System', NASA Special Publication Series, NASA-SP-494 (1989), 116–125.

Jupiter's ring system comprises three rather distinct components, identified as the main ring, halo, and exterior "gossamer" ring. The Voyager data set places significant constraints on each of these components, but leaves many questions unanswered. The system appears to interact in a complex, dynamic manner with the planet's magnetic field, and also with several embedded satellites. Many subtleties of these interactions will require higher-quality data, such as the Galileo orbiter can provide, in order to be understood fully. Some analogous processes are undoubtedly at work in the ring systems of Saturn, Uranus, and Neptune as well.

Smith, W. H., Conner, C. P., Simon, J. and Schempp, W. V. (Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130): 'The H_2 4–0 S(0, 1, and 2) Quadrupole Features in Jupiter', *Icarus* **81** (1989), 429–440.

We have detected the H_2 $S_4(2)$ feature in Jupiter. Using new low-temperature laboratory measurements for NH_3, we have conducted a detailed analysis to determine an improved equivalent width for the Jovian H_2 $S_4(0)$ line. We have found good agreement of the equivalent widths computed from published models with the observed H_2 4–0 line equivalent widths for Jupiter. The effective line formation temperature of ~150 °K at the averaged disk center of Jupiter found from the nominal $S_4(2)/S_4(0)$ ratio is consistent with an H_2 *ortho–para* ratio for equilibrium tropospheric H_2 in Jupiter.

Thompson, W. R. and Sagan, C. (Cornell University, Ithaca, NY 14853): 'Photometric Properties and Classification of Small Jovian Cloud Features', NASA Special Publication Series, NASA-SP-494 (1989), 297–305.

We use a triplet of images taken through the violet, green, and orange filters of the Voyager 2 wide-angle camera to derive photometry for most of the disk of Jupiter visible at a subspacecraft longitude near 100° W. Global photometric gradients in each filter are removed by fitting a least squares Minnaert function to the photometrically and geometrically corrected I/F data, then dividing the original data by that function. The Minnaert-divided green intensity $I/F_{R,GR}$ and the Minnaert-divided color ratios $I/F_{R,VI/GR} \equiv I/F_{R,VI}/I/F_{R/GR}$ and $I/F_{R,OR/GR} \equiv I/F_{R,OR}/I/F_{R,GR}$ are used as the classification variables for cluster analysis. The 18 clusters found identify regions in the jovian clouds with similar photometric properties. Cluster mean values for $I/F_{R,VI/GR}$ vary from 0.76 to 1.32, for $I/F_{R,OR/GR}$ from 0.84 to 1.18, and $I/F_{R,GR}$ from 0.82 to 1.14. Classification serves to group the global data for further study, to quantify the photometric variety seen across the disk in these filters, and to suggest possible similarities in composition and vertical structure between clouds that classify together but are morphologically distinct.

Trafton, L., Carr, J., Lester, D. and Harvey, P. (University of Texas, Austin, TX 78712): 'Jupiter's Aurora: Detection of Quadrupole H_2 Emission', NASA Special Publication Series, NASA-SP-494, (1989), 229–233.

We apparently have detected a weak emission feature in Jupiter's northern and southern aurora at 2.12 μm, the wavelength of the $^1S(1)$ H_2 quadrupole line. We observed an intensity varying with position from 0.5×10^{-3} to 1.9×10^{-3} erg cms^{-2} s^{-1} averaged over 3.8–arcsec diameter beam. This may be the auroral H_2 emission predicted by Kim and Maguire (1986) but it is only 3 to 12 percent of the predicted value.

Trafton, L., Lester, D. F. and Thompson, K. L. (McDonald Observatory and Astronomy Department, University of Texas at Austin, Austin, TX 71782): 'Unidentified Emission Lines In Jupiter's Northern and Southern 2 Micron Aurorae', *Astrophys. J.* **343** (1989), L73–L76.

We have detected emission features in Jupiter's 2 μm spectral region for both the northern and southern aurorae. Several of these can be identified with H_2, while the identification of the others is more problematical. Spectra we have taken as far back as 1987 September show that at least some of these features are long-lived. While some emission features are present in both Jupiter's northern and southern aurorae, others appear to reside in only one or the other aurora. Either the two aurorae contain different emitting molecules or they possess some very different excitation regimes, or both. We have detected certain emission lines only at low latitudes; e.g., the center of the disk and the equatorial limbs, even at longitudes relatively protected from the magnetospherically trapped radiation. Altogether, two or more species besides H_2 are inferred.

Wilkinson, M. H. (72 Raleigh Street, Forest Hill, Victoria 3131, Australia): 'Io-Related Jovian Decametric Arcs', *Journ. Geophysical Res.* **94** (1989), 11777–11790.

In this work an empirical modeling technique is used to analyze certain Io-caused emission (ICE) structures in the Jovian decametric radio spectrographic data. Taking into account that some of these ICE structures have the appearance of great arcs with internal arclike fine structure, a geometrical model is developed in which the observed emission is seen to result from conical emission beams emanating from source regions carried on corotating field lines which are excited only as they cross an excitation zone centered on the Io flux tube. The model is also applied to the analysis of a limited set of spectrograms of the traditional Io-related sources Io A, Io B, and Io D. In some of these spectra it was possible to identify multiple-ICE structures. The model results for these spectra are consistent with a physical model in which emission is occurring from multiple spaced flux tubes positioned ahead of and moving with Io, and lend credence to the multiple Alfvén wave reflection hypothesis.

Zarka, P. and Genova, F. (Observatoire de Paris, Meudon, France): 'Solar Wind Effect on Jovian Low-Frequency Magnetospheric Radio Emissions from Ground-Based and Spacecraft Observations', NASA Special Publication Series, NASA-SP-494 (1989), 175–178.

The Fourier analysis of the intensity fluctuations of jovian radio emission at hectometer wavelengths, observed by the Voyager spacecraft, has allowed a demonstration of the influence of the solar wind, particularly of its magnetic sector structure, on this emission. On the other hand, the jovian decametric emission observed by Voyager appears to be well correlated with the hectometer emission. Finally, the probability of observing Io-independent decameter emission from the ground (with the decameter array in Nançay. France) presents strong time variations that correspond well to the fluctuations of hectometer activity, influenced by the solar wind. This suggests that the hectometer and Io-independent decameter events originate from the same source.