cial for addressing major problems concerning the internal structure of the major planets. Recent developments in spectroscopic and x-ray diffraction techniques used with the diamond-anvil cell are beginning to provide this information. The pressure of the insulator-metal transition in solid hydrogen is one of the major problems in both planetary and condensed-matter physics. In recent experiments we have contained hydrogen in a diamond-anvil cell to pressures in the 200-250 GPa range using new low-temperature, ultrahigh-pressure techniques. Vibrational Raman spectra of the hydrogen indicate the the solid remains in the molecular state under at these pressures but undergoes an orientational ordering transformation near 150 GPa (and 77 K). Recent developments in single-crystal and polycrystalline x-ray diffraction techniques have provided essential information on the equations of state of condensed planetary gases at high pressure. X-ray diffraction of molecular H_2 and He has been measured to 26 GPa using single-crystal techniques, and diffraction of Ne, Ar, Xe and H_2O has been obtained at pressures in the 100 GPa range have been obtained using polycrystalline methods. In general, the *P-V* relations determined from the diffraction data indicate that the materials are considerably more compressible than the predictions of simple pair-potential and statistical electron models used in planetary models. The development of accurate *P-V-T* equations of state based on static compression data and theoretical calculations for the thermal contribution appropriate for interiors of the large planets is examined, and comparisons with recent compositional models are presented.

Planetary Mineralogy II (P21A)

Exhibit Hall E TUES AM
A V Murali, L.P.I.
Presiding

P21A-01 0830H POSTER

Quantitative Deconvolution of Mineral Absorption Spectra

J M Sunshine and C M Pieters (Brown University, Department of Geological Sciences, Providence, RI 02912; 401-863-2417)

At visible and near-infrared wavelengths, spectra of geologic surfaces are composed of absorption bands from the minerals present in the target surface. While such spectra contain diagnostic information, deconvolving these composite signals to reveal the modal mineralogy is non-trivial. A successful approach, described here, is to represent absorption bands as discrete mathematical distributions and to then deconvolve the composite spectra into its fundamental absorptions bands using a least-squares fitting procedure.

Gaussian distributions of the form $g(x) = s \cdot \exp\{-(x-\mu)^2/2\sigma^2\}$, were first assessed as an analytical model of absorption bands. Although an efficient non-linear least-squares fitting routine was developed, Gaussian distributions proved to be inappropriate descriptions of the absorption bands found in pyroxene spectra. The Gaussian model required two distributions for each of the characteristic 1.0 and 2.0 μm pyroxene absorptions features, despite the fact that these absorptions are each thought to be dominated by single electronic transitions. However, a modified distribution model utilizing distributions of the form $g(x) = s \cdot \exp\{-(x^{-1}-\mu^{-1})^2/2\sigma^2\}$ was developed which precisely describes each electronic transition absorption band in pyroxene spectra with a single distribution, and as such represents a significant improvement over the Gaussian analysis technique.

The extraction of mineralogical information from a spectrum of a mixture is considerably simplified by modeling absorption spectra with these new modified distributions. The two pyroxene components of a pyroxene mixture spectrum have, for example, been readily identifiable using this technique. Based on the success of the modified distribution model of electronic transition (Fe^{+2}) absorption bands in pyroxene spectra, a similar approach was applied to the more complex electronic transitions (Fe^{+2}) in olivine spectra. The systematic behavior of olivine absorption bands, as described by R. G. Burns (*Am. Min*, **55**, p. 1608, 1970) in single crystal transmission spectra, has been quantified for the first time for particulate reflectance spectra. As in Burns' transmission spectra, the modified distribution model of olivine reflectance spectra, shows a monotonic increase in the band centers of each of the three olivine absorption bands as the composition becomes increasingly fayalitic.

Since the band center and strength of the absorption band are highly indicative of the nature of the absorption site, it is of the utmost importance that the correct deconvolution technique be used to describe absorptions in crystals. The ability of the modified distribution model to analytically describe the absorption bands in both pyroxene and olivine spectra suggests that the modified distribution model presented here be the analytical method of choice to characterize electronic transition bands.

P21A-02 0830H POSTER

Thermal Infrared Reflectance Spectroscopy of Impact Related Rocks and Glasses

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J. B. Garvin (NASA/GSFC, Code 622, Greenbelt, MD 20771; JGARVIN/GSFCMAIL; 301-286-6565)

Shock metamorphism of rocks and minerals is a natural consequence of exogenic processes such as hypervelocity impact. Indeed, impact processes have dominated the geologic history of the solar system. We seek to characterize the effects of shock metamorphism on solar system materials using thermal infrared reflectance spectroscopy (TIRS), as this technique is relevant to remotely sensed thermal emission observations of planetary, asteroidal, and cometary surfaces. TIRS differs from traditional thermal IR transmission spectroscopy in that both refractive index and wavelength-dependent absorption properties control the shape of the spectra. In addition, TIRS can be applied to natural, polymineralic rock surfaces unlike single-phase IR absorption. TIRS spectra can be directly related to emission properties as measured with thermal emission spectrometers such as the instrument TES which is to map Mars in the 1990's. In this study, we have carried out a survey of over 70 varieties of shocked materials from terrestrial impact craters and regolith breccia meteorites, in order to explore how TIRS spectra are distorted due to molecular disruptions caused by shock processes; the results are complementary to the database of IR absorption spectra for shocked minerals. Our initial results suggest that there is a minimum peak shock pressure (*Ps*) threshold at 250-300 kbar in crystalline granitic or quartzose rocks at which point TIRS spectra are noticeably and consistently degraded. This concurs with Stöffler's observations that the refractive index of quartz changes at shock levels above 260 kbar. In addition, it appears to be possible to distinguish homogeneous rock melts from heterogeneous (impact glasses) types on the basis of TIRS spectra; two-peaked TIRS spectra of shock-fused rocks from the *Ries* indicate that quartz and feldspar were melted and quenched before they could chemically equilibrate, an effect that is not possible in endogenic processes such as volcanism. A progressive degradation of the quartz doublet in TIRS spectra has been observed as a function of *Ps* for samples from the *Ries* and *Barringer Crater*. Analysis of powdered samples is now underway to explore grain-size effects.

P21A-03 0830H POSTER

Asteroidal H2O and the Hydration State of Terrestrial Planet Raw Materials.

T. Jones, L. Lebofsky[1], and J.S. Lewis[1]
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The low-albedo asteroids in the outer belt (2.5 - 5 AU) are spectrally analagous to chemically primitive, volatile-rich carbonaceous meteorites. While infrared observations show that about 2/3 of the "primitive" C-class asteroids have the 3-μm absorption typical of surface hydrated silicates, the more distant P and D classes appear distinctly anhydrous. This class distinction indicates that outer belt planetesimals accreted as mixtures of anhydrous silicates, water ice, and complex organic kerogens. A belt-wide heating event (that declined in intensity with increasing solar distance) melted ice and transformed the surface layers of many C asteroids to the observed clay mineralogy. The unscathed P and D classes (3.5-5.2 AU) did lose surface ices via sublimation, but retained the original organic/anhydrous silicate mineralogy. Our observations confirm nebular condensation models ruling out hydrated silicates as major water-bearing minerals during terrestrial planet accretion. Ice must have been the dominant form of H_2O.

P21A-04 0830H POSTER

Paragenesis and Metastability of Mg-Carbonates on Weathered Equilibrated Ordinary Chondrites from Antarctica

M A Velbel (Dept. of Geological Sciences, Michigan State University, East Lansing, MI 48824-1115)

White efflorescences of weathering origin occur superposed on fusion crusts, or along fractures in the interiors, of approximately 5% of all meteorites in the U.S. Antarctic collection[1]. All efflorescences from equilibrated ordinary chondrites studied to date (N=4) consist of the hydrous Mg-carbonates nesquehonite (± hydromagnesite)[1]. X-ray diffraction[2] and scanning electron microscope studies of efflorescences from LEW 85320 (H5) show abundant elongate prismatic crystals of nesquehonite (idiomorphic, *not* pseudomorphous after lansfordite), with minor local encrustations of hydromagnesite. Previous studies showed that terrestrial volatiles were involved in the rapid (<40 yr) carbonate-forming reaction[2], and that meteorite interior temperatures occasionally permit liquid water[3]. The Mg probably originated from weathering of meteoritic olivine. Superposition of hydromagnesite on rounded terminations of nesquehonite prisms from LEW 85320 suggests that late-paragenetic hydromagnesite probably formed by heating and/or desiccation of nesquehonite during sample handling.

Nesquehonite is unstable with respect to magnesite under Earth-surface conditions. Thermodynamic analysis of the reaction forsterite+water+carbon dioxide ==> nesquehonite+silica at Antarctic temperatures and pCO_2 indicate a positive affinity for the weathering reaction for all water activities greater than 0.3, compatible with the presence of liquid water as brines and/or thin films. Thus, metastable Mg-carbonate phases accurately record the physical-chemical conditions (e.g., lower limits of water activity) of their formation. Equilibrium assemblages would not; the forsterite-magnesite equilibrium does not involve water, so water activity could not be constrained if metastable precursor phases later converted to thermodynamically stable phases. The possible existance of metastable precursors (e.g., ikaite) should be considered when interpreting the significance of Ca- and Ca-Mg-carbonates and other "evaporite" minerals in carbonaceous chondrites and SNC meteorites, and possible dehydration products formed as a consequence of thermal excursions during future planetary and asteroidal sample-return missions.

[1]Velbel, 1988, Meteoritics, **23**, 151-159.
[2]Jull and others, 1988, Science, **242**, 417-419.
[3]Schultz, 1986, Meteoritics, **21**, 505.

P21A-05 0830H POSTER

Transmission Electron Microscopy of an Allende Refractory Inclusion

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J.P.Poirier (Institut de Physique du Globe de Paris, 4 Place Jussieu, 75252 Paris Cedex 05)

We have studied by transmission electron microscopy a crystal of clinopyroxene (fassaite), from the coarse-grained refractory inclusion Egg 6 of the Allende meteorite (provided by G.J. Wasserburg).

The pyroxene contains euhedral inclusions of pure spinel, devoid of dislocations and without any topotactic relations with their host. Long, clean dislocation walls, characteristic of high-temperature anneal are present in the pyroxene crystal.Some dislocation walls are decorated with bubbles (or voids), often in the shape of tubes about 1000 Å in diameter, along the dislocation lines .The dislocations constituting the decorated walls are identical to those of the walls that do not exhibit bubbles. We believe that these features are not healed fractures, but are due to the precipitation of a fluid migrating along the dislocations, as sometimes observed in olivines from peridotite xenoliths.
This view is comforted by the observation of alteration products at the interface spinel-pyroxene in regions of high dislocation density,where decorated walls are present.

These observations provide good evidence of a metasomatic stage in the evolution of the refractory inclusion supporting the conclusions of Meeker et al.(1983).

P21A-06 0830H POSTER

Geochemical Studies of Libyan Desert Glass

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R. F. Giegengack *(Department of Geology, University of Pennsylvania, Philadelphia, PA 19104)*

Libyan Desert Glass (LDG) represents ~1.4 X 10^9 g of natural glass fragments scattered over ~6500 km^2 of the Western Desert of Egypt. We made a systematic study (employing INAA, microprobe and mass spectrometry techniques) of several varieties of LDG and locally associated sand and sandstone to provide insight into the nature and formation of these enigmatic glass fragments. These studies indicate that:

1) Although the LDG has restricted major element compositions (97-98 wt % SiO_2; 1-2 wt% Al_2O_3) their trace element contents (ppm) (Fe=490-5200; Co=0.2-1.2; Cr=1.2-29 and Sc=0.46-2.5) vary by as much as a factor of 5 to 30.
2) The LDG fragments exhibit a factor of three variation in the REE abundances (La=5.4-15.3 ppm). They all show parallel and steep LREE enriched patterns ($[La/Sm]_N$=3.8-4.2) and flat HREE ($[Tb/Lu]_N$=1.1-1.2) and distinct negative europium anomalies (Eu/Eu^*=~0.5).
3) The gases in the vesicles of LDG (N_2, Ar, O_2, CO_2, H_2O and their dissociation products) are present in proportions consistent with derivation from the terrestrial atmosphere.
4) Dark streaks present in some samples of LDG contain significantly higher siderophile element abundances (Ir=~0.5 ppb), possibly representing a meteoritic residue.

Our studies suggest that LDG is the product of meteorite impact into quartz-rich surficial eolion and alluvial sand, and perhaps also into quartz-rich sandstone, of the western Desert of Egypt.

Neptune and Triton: Pre-Voyager Analysis I (P21B)

323 TUES AM
K Baines,
Jet Propulsion Laboratory
Presiding

P21B-01 0830H INVITED

Magnetosphere of Neptune

A F Cheng (The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20707)

As even the existence of a magnetosphere at Neptune has not yet been established, any predictions are necessarily hazardous. Given a magnetic moment expressed in planetary units comparable to those of Saturn and Uranus, the magnetosphere of Neptune should have a magnetopause radius of ~30 planetary radii, large enough to include Triton comfortably but not Nereid. A key issue is whether Triton will prove to be as strong a source of plasma and neutrals as is Titan

P

at Saturn; both moons appear generally comparable, except that Triton has a 21° orbital obliquity to the spin equator. Triton may maintain a nitrogen plasma torus in the magnetosphere. Alternatively, plasma sources at Neptune may be dominated by a planetary non-thermal hydrogen exosphere like that at Uranus. The Voyager Neptune encounter may also include the first low altitude pass through the auroral zone of a planet other than Earth. Auroral precipitating particles may be detected and correlated with remote sensing of the planetary aurora and measurements of field-aligned currents.

P21B-02 0850H

Deuterium on Neptune: Observational Constraints on the Origin and Evolution

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The spectrum of Neptune in the 1.6-micron region is observed to contain spectral signatures of CH_3D in a series of spectral scans made with the Cassegrain Fourier Transform Spectrometer on the 3.6-m Canada-France-Hawaii telescope on Mauna Kea. Analysis of the scans, recorded at a spectral resolution of 4 cm^{-1} and coadded to obtain a total signal-to-noise ratio in excess of 50, yields the first identification of this isotopically substituted molecule in the atmosphere and a measurement of the CH_3D/CH_4 ratio for Neptune. The D/H ratio derived by the methane observations implies a global enrichment of deuterium on Neptune of about a factor of 8 over the protosolar value. The observed enhancement of the CH_3D/CH_4 ratio is shown to favor accretion models for the formation of Neptune over homogeneous collapse models, and it is used to constrain the enrichment that was present in the primitive ices trapped in the core of the planet as it formed.

This research is supported in part by NASA grants NAGW-1505 and NGR-33015141.

P21B-03 0905H

The Structure of the Atmosphere of Neptune Determined from Groundbased and IUE Spectrophotometry: Constraints on Stratospheric and Tropospheric Aerosol Properties, Methane Abundance, and the Ortho/Para Hydrogen Distribution

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(Sponsor: R A West)

Constraints on the global atmospheric structure of Neptune are presented, derived from a broad range of groundbased broadband (10-Å spectral resolution) and high-resolution (0.10-Å resolution) spectra, as well as IUE satellite spectra. The analysis yields a narrow family of models which characterizes a stratospheric haze layer near the 1-mbar level presumably composed of condensed hydrocarbons, an upper tropospheric methane condensate haze near 1 bar, and a deep, optically-infinite cloud near 3.5 bars. The global-mean stratospheric haze column density is found from Mie-scattering theory to be 3.0 - 8.0 10^{-6} gm/cm^2, in agreement with recent calculations of hydrocarbon production and sedimentation rates for sub-micron-sized hydrocarbon condensates in the Neptunian stratosphere. Neptunian stratospheric aerosols are relatively bright, with the global mean imaginary index of refraction for these particles being 0.002 - 0.007 in the uv, compared to 0.005 - 0.020 found for Uranus by the Voyager Science Team (J. B. Pollack et al., 1987, JGR 92, 15037) in the mid-visible. The methane haze optical depth, 0.1 - 0.2 at 0.64 microns for isotropically-scattering particles, is about half of that previously found for Uranus (Baines and Bergstralh, 1986, Icarus 65, 406), and close to that found for stratospheric particles. Given the large methane molar fraction of 0.023 - 0.037 derived in this analysis, representing some 18 - 30 percent of the mass of the troposphere, the low methane cloud opacity indicates that significant vertical transport of methane crystals occurs in the troposphere. Finally, we find at least 85% of hydrogen is in the equilibrium state, in agreement with theory.

P21B-04 0920H

Cloud Structure on Neptune: Ground-based Imaging from 1986-1988

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(Sponsor: Bruce Jakosky)

Recent ground-based CCD images obtained with the University of Hawaii 2.24-m telescope (Mauna Kea Observatory) have provided new information about cloud structure on Neptune. Images were taken in 1986, 1987, and 1988, through filters centered on three methane bands (6190, 7270, and 8900 Å) and three continuum regions (6340, 7490, and 8260 Å).

In all three years, a feature in the southern hemisphere dominated the reflected sunlight at the strongest methane band (8900 Å); no bright features have been detected in the northern hemisphere. The latitude of the 1988 bright feature (-30° ± 2°) differs from the latitude of the brightest feature seen in earlier years (-38° ± 3°). Furthermore, the rotation period of the 1988 feature (17.7±0.5 hrs) is longer than the rotation period of features observed in 1986 and 1987 (17.0±0.05 hrs).

In 1988, the bright feature was also detected at a weaker methane band (6190 Å). These are the first reported images showing discrete cloud structure at this wavelength, although disk-integrated photometry at 6190 Å has indicated structure in the past. Also visible at this wavelength was an apparent polar haze layer centered on the southern pole. The wide-angle camera on the Voyager 2 spacecraft has a filter at this wavelength; the resolution of the wide-angle camera will surpass that of ground-based telescopes in June 1989.

The best images of Neptune have sufficient spatial resolution to allow center-to-limb (CTL) profiles to be extracted. Models of the observed CTL profiles indicate that the atmosphere of Neptune has at least two distinct cloud layers: the 8900-Å CTL profile requires the presence of some material above the 5-mbar level, but such a haze does not provide sufficient reflected flux at the 6340-Å continuum region, indicating another scattering layer is present deeper than 1.5 bars. A bright optically-thick cloud at 2.6 bars provides a good fit to 6340-Å reflectivity.

P21B-05 0935H

The Brightness and Geometric Albedo Variations of Neptune During the Solar Cycle

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The brightness of Neptune, observed at 472 and 551 nm since 1972, continues basically to vary inversely with solar activity, increasing by about 4% from solar maximum to solar minimum. The effect is thought to be caused by a photochemical process in Neptune's atmosphere that varies according to the Sun's ultraviolet output. In 1988, Neptune was brighter by about 1% than any time during the past 17 years. Discrete "clouds," visible only in images recorded through filters centered on the red methane bands, have been reported and may account for the unusual recent visual brightening.

We present the photometric results, including if possible an updated 1989 measurement to be obtained late April. In addition, we will present an improved geometric albedo spectrum from 330 to 890 nm obtained at 0.8-nm resolution annually since 1980.

This work is supported in part by NSF grant ATM-8619590 and NASA grant NAGW- 1505.

P21B-06 0950H

Neptune's Exospheric Temperature: Implications for Electroglow

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If the magnetic field of Neptune does not possess a tilt and offset similar to that of the Uranus magnetic field, then the Neptune magnetosphere will lack what may be a major source of precipitation as compared to Uranus. Limited to auroral energy inputs alone, the Neptune exosphere may be much colder. Specifically, we expect the exospheric temperature at Neptune to be about 200° K as compared to nearly 800° K at Uranus. It is also suggested that the high exospheric temperatures, which also have been observed in association with electroglow on Jupiter, Saturn and Uranus, are a necessary condition for the occurrence of electroglow on Neptune. Implications of this work for the existence of Neptune electroglow are discussed.

P21B-08 1020H

Stratospheric Aerosols From CH_4 Photochemistry on Neptune

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Methane photolysis in the stratosphere of Neptune produces C_2H_6, C_2H_2, and C_4H_2 in abundances greater than those allowed by their saturation mixing ratios over their respective ices. We have used a combined photochemical-condensation model to study this and predict a total stratospheric haze production rate of 4.2 X 10^{-15} grams cm^{-2} sec^{-1} of these hydrocarbon ices (75% ethane, 25% acetylene, trace diacetylene). This total production rate is insensitive to within a factor of two to order of magnitude changes in the eddy diffusion coefficient and methane mixing ratio, which is within our estimate of uncertainty for this number. We have estimated the optical depths of these hazes by balancing the photochemical production rate by loss due to sedimentation. For C_2H_2/C_4H_2 ice to be the source of the high altitude haze layer the lifetime for the haze particles must be longer than the sedimentation time. Observed variations in this haze layer are likely due to dynamics, not photochemistry. Since C_4H_2 ice haze production is confined to within its condensation level and where C_2H_2 freezes out, it may form a detached haze layer.

Since the mixing ratio profiles of C_2H_6 and C_2H_2 are controlled by eddy mixing in the lower stratosphere, the effects of the condensation sink propagate several scale heights above the condensation level. This reduces their mixing ratios below a mixing ratio profile based upon a photochemical model and saturation alone. How far above the condensation level this reduction propagates is dependent upon the strength of eddy mixing in the lower stratosphere. This feedback on the photochemistry lowered the total haze production by about half from our previous estimates.

P21B-09 1035H

Ethane Abundance on Neptune

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P Romani (SSAI, 7375 Executive Place, Suite 300, Seabrook, MD 20706; 301-286-4859; SPAN VIRIS::YS2PR)
D Zipoy (Astronomy Program, University of Maryland, College Park, MD 20742; 301-454-7189)

Upper limits to the mole fraction of C_2H_6 on Neptune where determined from infrared heterodyne spectroscopic measurements near 12μm. Observations were made at the NASA Infrared Telescope Facility on Mauna Kea, Hawaii in June, 1988 with a resolving power $\lambda/\Delta\lambda \sim 10^{-6}$. This resolution permitted the measurement of individual emission line profiles of ethane (RR[1,7]; 835.5217 cm^{-1}). Iterative fitting of spectra calculated from existing atmospheric models to the measured spectra permitted the extraction of ethane mole fractions on Neptune. Measured data did not show significant emission profiles, but the signal-to-noise ratio was sufficient to extract meaningful upper limits on the C_2H_6 mole fraction and to constrain existing atmospheric and photochemical models of Neptune. An upper limit to ethane mole fraction $\leq 2 \times 10^{-6}$ was derived. This value will be compared to existing data and the implications on atmospheric and photochemical models will be discussed.

P21B-10 1050H INVITED

Neptune's Arc Rings.

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(Sponsor: B. Jakosky)

In July 1984 Neptune joined the family of 'ringed' planets, with the discovery during a stellar occultation of a narrow, asimuthally extended, partially transparent structure orbiting the planet at a distance of ~ 67000 km, or 2.68 R_N. The most puzzling aspect of this observation was lack of any detectable feature in the data at the point where the star again crossed this orbital radius, which led Hubbard et al. (Nature 319 636, (1986)) to dub the feature an 'arc', rather than a ring. Since 1984, data from ~ 20 stellar occultations by Neptune have been examined, at least 6 of which have yielded additional evidence for incomplete rings, or arcs. In only 3 cases, however, was the putative arc occultation observed at more than one telescope, and for 2 of these the data are of relatively poor photometric quality. The sole

remaining unambiguous arc observation occurred on 20 August 1985. In no experiment has a complete ring been observed.

The picture which emerges from these observations is fragmentary, and almost certainly very incomplete. A major source of uncertainty is our currently poor knowledge of the orientation of Neptune's equatorial plane (linked to the unknown mass of Triton), which translates into substantial uncertainties in the calculated arc radii. Arcs exist at radii of ~ 2.3 and ~ 2.6 R_N, and probably also near 2.15 R_N and perhaps also at 1.65 and 1.41 R_N. Typical widths are 10 – 20 km, with normal optical depths of 0.08 – 0.30. The arcs are thus similar in width to the Uranian rings, but more similar in optical depth to Saturn's C Ring. Information on arc lengths comes from a statistical comparison of occultation observations at widely-separated sites; typical lengths of ~ 1000 km are indicated, but with an uncertainty of at least a factor of 3. Combined with a fractional longitudinal coverage of 10 – 20%, this leads to an estimate for the total arc population of 30 – 60.

Several theoretical models of arc confinement have been proposed, each of which invokes the presence of at least one rather large (~ 200 km diameter) satellite orbiting near Neptune's Roche limit. It is possible that such a satellite has already been detected in a chance occultation in May 1981 (Reitsema, *et al. Science* **215** 289 (1982)). *Voyager* imaging observations should identify any satellites, and, with luck, provide us with a complete map of the spatial distribution of arcs.

P21B-11 1110H INVITED

The Thermal Structure of Triton's Atmosphere: Pre-Voyager Models

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We have investigated the thermal state of a N_2–CH_4 atmosphere on Triton. We have adapted a non-grey radiative-convective model developed for Titan. As on Titan, we find that the organic haze that would be produced by photochemical reactions is the most significant factor affecting solar energy deposition. The production of haze material (~ 10^{-15} g cm^{-2} s^{-1}) is obtained by scaling from the Titan value. Pressure induced absorption, primarily N_2-N_2, is the dominant source of infrared opacity. In all model runs the tropospheric temperature lapse rate is determined by the saturation of N_2. By varying the surface albedo and emissivity we have considered a range of consistent surface temperatures. For example a cold surface temperature of about 46 K, which corresponds to surface albedo of 0.6 and emissivity of 0.6, has negligible atmosphere (~ 2 mb) with virtually no insulating or reflecting effects. For higher albedo or emissivity the atmosphere has even smaller effects. In the other extreme (albedo = 0.05, emissivity = 0.3) we find a relatively warm surface temperature, ~ 59 K with a corresponding pressure of 54 mb. In all model runs there is a hot stratosphere ($T \simeq 120$ K) due to absorption by tholin-like haze similar to that on Titan. The implications of these results for the Voyager flybys will be discussed.

P21B-12 1130H

Triton's Ionosphere

S K Atreya (Atmospheric, Oceanic and Space Science Department, University of Michigan, Ann Arbor, MI 48109-2143; 313-764-3335)

Ground-based observations at 2.3 μm and 0.89 microns yield a CH_4 abundance of between 7 and 50 m-atm at the surface of Triton (corresponding surface pressure of 0.1-1 mb). On the other hand, should a feature at 2.16 micron indeed be due to liquid N_2, a surface pressure of 130-300 mb of N_2 would be expected. In either case, the 'atmospheric' thermal structure would determine the location of unit optical depth for ionization (as the saturated vapor abundances of CH_4 and N_2 are expected to drop rapidly with height). It is expected to be a few scale heights above the surface. A peak electron concentration of a maximum 1000 electrons cm^{-3} is expected, with the solar EUV as the ionization source. Should Neptune possess a magnetosphere similar to Uranus, the charged particle ionization of N_2 would dominate; the peak ion concentration, however would be similar to that due to the EUV. Unlike Titan, however, there is little likelihood of the formation of the ions of H-C-N type, as the vapor mixing ratio of CH_4 relative to N_2 would be small, $\lesssim 10^{-6}$, if N_2 were present.

P21B-13 1145H

Is There a Detectable Aurora on Triton?

A J Dessler, F C Michel, and T W Hill (Space Physics and Astronomy Department, Rice University, Houston, TX 77251; 713-527-4045)

With even a modest magnetic moment, Neptune will have a magnetosphere of impressive size. For example, if the equatorial magnetic field at cloud-top level is 0.3 Gauss, the nose of the magnetosphere will project nearly 8 x 10^5 km (31 R_N) into the solar wind. Even with an improbably weak cloud-top field of just 0.01 G, the nose magnetopause distance is still 2.5 x 10^5 km (10 R_N). The magnetosphere promises to be rotationally dominated so that the plasmapause extends to the magnetopause. Neptune's satellite Triton, which is in an inclined, retrograde orbit at 14 R_N, will, except under the most extraordinary of circumstances, move through this plasmasphere with a relative speed of about 40 km/sec. Triton has an atmosphere, and it ought to have a significant ionosphere. Plasma flow past Triton should induce a potential of the order of 3 kV across the ionosphere. We scale from Saturn's satellite Titan and conclude that Triton's atmosphere is subject to sporadic bombardment by a flux of about 2 x 10^{24} electron/sec with energies of about 3 keV. If such fluxes are present, they could produce a detectable aurora. The Voyager viewing geometry at Triton seems well-suited to discover such an aurora.

The Pluto-Charon System I (P22A)

323 TUES PM

S A Stern, Univ of Colorado Presiding

P22A-01 1330H INVITED

Pluto-Charon Mutual Events: Overview and Preliminary Results

R P Binzel (Department of Earth, Atmospheric, and Planetary Science, MIT, Cambridge, MA 02139)

(Sponsor: T. Jordan)

Once every 124 years, Pluto's heliocentric motion causes the orbital plane of its satellite (Charon) to sweep through the inner solar system, thereby allowing *transits* of Charon in front of Pluto and *occultations* of Charon behind Pluto to be observed. The current series of mutual events began in 1985 (Binzel et al. 1985, *Science* 228, 1193) with partial transits and occultations. During 1987 and 1988, total transits and occultations were observed. The last partial events will be observable in 1990.

Photometric observations of the times, durations and depths of the mutual events have constrained Charon's orbital parameters and have yielded new estimates for the diameters and albedos of Pluto and Charon as well as estimates for the mass and density of the system. Thus mutual event observations are able to constrain physical and dynamical models. Spectroscopic and spectrophotometric observations during periods (lasting about an hour) when Charon is totally occulted behind Pluto, have allowed the compositions of their individual surfaces to be discerned.

Deconvolution of mutual event photometry will also allow surface maps to be derived for one hemisphere of each body. (Charon is in a synchronous 6.4 day orbit.) The changing impact parameter over 1985 through 1989 has caused Charon to perform a "raster scan" in front of Pluto's surface. (Similar "scans" have occurred for Charon's surface.) In addition to a discussion of the new physical parameteres gained from Pluto-Charon mutual event observations, preliminary results for the surface albedo distribution of Pluto's Charon-facing hemisphere, including evidence for polar caps, will be presented.

P22A-02 1350H INVITED

The Interiors of Pluto and Charon: Composition, Structure, and Implications

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Pluto is in a size class all its own, intermediate between the Galilean satellites and the medium-sized satellites of Saturn and Uranus; and it forms a unique "double planet" with its satellite Charon. Further, the Pluto/Charon system may have had a more direct association with the solar nebula than (for example) giant planet satellites that formed from circumplanetary disks. For all these reasons, the internal structure and evolution of these two bodies is especially intriguing. Determination of the mean density of the Pluto/Charon system from ongoing "mutual events" has made accurate internal modeling possible for the first time—but it has also complicated the process, by way of continuing changes in the best-fit density and the inability to separate out the individual densities of the two bodies. To these complications must be added the usual modeling uncertainties—have differentiation or solid-state convection occured, what is the density and hydration state of the rock component, are there contributions from non-water ices, etc. Despite these difficulties, however, a coherent picture is emerging of two bodies that are significantly denser and rockier than anticipated. The mean system density of roughly 2 g cm^{-3} severely limits the amount of light non-water ices that can be present in the Pluto and Charon interiors; and the density translates into a rock/(rock + H_2O) mass ratio of at least ≈ 0.7, making Pluto/Charon rockier than any of the giant planet satellites with the exception of the inner Galileans. This unexpected rockiness may be indicative of Pluto/Charon's formation from a CO-rich outer solar nebula—and may also bear witness to volatile loss that occured during a Charon-forming impact event. We look forward to the approaching completion of the mutual event cycle, which should finally stabilize the best-fit system density—and also anticipate future improvements in astrometric techniques aimed at constraining the relative masses of Pluto and its satellite.

P22A-03 1410H INVITED

Pluto's Atmosphere Near Perihelion

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(Sponsor: S A Stern)

I review the evidence for Pluto's extended atmosphere and discuss model-dependent predictions for Pluto's seasonal changes with emphasis on the impending changes expected as a result of Pluto's imminent perihelion passage.

A recent stellar occultation has confirmed predictions that Pluto has an atmosphere which is sufficiently thick to globally envelope the planet and to extend far above the surface. Because Pluto's atmosphere consists of methane and perhaps other volatiles at temperatures below their freezing points, the atmospheric bulk is a strong function of the temperature of the surface ices. Pluto's volatile atmosphere is sufficiently thick to regulate the surface temperature of its volatile ices to a common value. As Pluto approaches perihelion in its markedly elliptic orbit, these ices will heat up and tend to sublimate into the atmosphere. This is expected to cause a seasonal maximum in the atmospheric bulk and a corresponding minimum in the exposed volatile ices shortly after perihelion. This lag will be diagnostic of the thermal properties of the surface. Because the atmosphere is also escaping, the ices freshly deposited during the last winter should sublimate before this atmospheric maximum is achieved, exposing darker material progressively more rapidly. Observations of this effect may constrain Pluto's total atmospheric bulk.

P22A-04 1430H INVITED

Dynamics of Pluto

Anthony R Dobrovolskis (245-3 NASA/Ames Research Center, Moffett Field, CA; 415-694-4194; Span 24609::DOBRO)

A historical perspective is given on Pluto's orbit, mass, density, and rotation, tidal evolution of Charon's orbit, origin of the system, and prospects for future advances.

Because of its high eccentricity (e ≈ 0.25), Pluto's orbit crosses the orbit of Neptune. Nevertheless, their orbits are separated by ~7 AU by virtue of Pluto's high inclination (I ≈ 16°) to the invariable plane of the Solar System. Furthermore, a 3:2 commensurability between their orbital periods keeps Pluto at least 17 AU away from Neptune. Another resonance keeps Pluto's perihelion out of the plane of Neptune's orbit. Long-term numerical integrations have also revealed additional cycles as well as chaotic behavior.

Before Charon was discovered, estimates of Pluto's mass from its perturbations on Neptune ranged from ~0.1 to ~1.0 Earth masses. An upper limit of ~6000 km for Pluto's diameter then led to unrealistic densities of ~5—50 g/cm^3. The modern values of ~0.002 Earth masses, ~2300 km, and ~2.1 g/cm^3 have been determined from Charon's orbital radius and period.

Pluto's brightness varies by ~13% over a 6.39-day cycle, identified as the period of Pluto's rotation. This equals Charon's orbital period to within the uncertainty of only a few minutes. Pluto's obliquity varies between ~ 88° (prograde) and ~ 112° (retrograde) with a period of ~3 Myr. Like Uranus, Pluto receives more heat at its poles than at its equator (averaged over all seasons).

The time required for tidal friction to establish Charon's synchronous orbit is on the order of 50 million years, while the time to despin Charon to synchronous rotation is only a few million years. Tides also damp Charon's orbital eccentricity over a timescale of ~50 Myr. A detectable eccentricity would be evidence for recent impacts.

If the resonances between Neptune and Pluto ever broke down, close encounters with Neptune could not eject Pluto from the Solar System. Conversely, Pluto is not likely to be a captured extrasolar wanderer, but might have originated in the inner Oort cloud. Chiron may have split off from Pluto, since the net angular momentum of the system is close to the critical threshold for binary fission. However, Pluto cannot be an escaped satellite of Neptune because tidal friction would have despun Pluto and fused it to Chiron in under a million years.

The Voyager 2 encounter with Neptune offers the best chance for clarifying the history of the Neptunian system and its relationship with Pluto. Analysis of the final Pluto/Charon mutual events will better constrain the parameters of that system. The coming generation of visible and infrared telescopes will provide still more information, and may discover other satellites (or rings) of Pluto or Charon.

P22A-05 1450H

The Mass Ratio of the Pluto/Charon System

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In an effort to predict the the ground track location of the June 9, 1988 occultation by Pluto, 55 plates containing Pluto and the target star were taken with the 61-inch Astrometric Reflector at the U.S. Naval Observatory's Flagstaff Station. The resulting predictions provided the basis for deployment of the Kuiper Airborne Observatory and a portable groundbased station from Lowell Observatory, both of which succeeded in observing the occultation. In this paper we discuss the

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use of these same astrometric observations to constrain the mass ratio of the Pluto/Charon system. A total of 73 exposures were obtained on 14 nights between May 26 and June 11, 1988. All plates were measured with respect to a common set of standard stars. The plates were initially measured with the PDS microdensitometer at Lowell and subsequently with the more sophisticated version of this machine at the Yale University Astronomy Department. Both sets of measurements show a well-defined, cyclic variation in the position of the blended Pluto/Charon image with respect to Pluto's ephemeris. The observed motion of the center-of-light no doubt results from the motion of Pluto and Charon about their common barycenter. However, the amplitude and shape of the motion as a function of the satellite's orbital position also depends on the relative brightness of the various faces of the two bodies. The combined brightness of Pluto and Charon is accurately known as a function of orbital phase, but the relative brightness of the two objects has been measured at only one or two points in Charon's orbit. We have attempted to model the variation in the position of the center-of-light on the commonly adopted assumption that Charon is constant in brightness. It is possible with this model to set useful limits on the ratio of the masses of Pluto and Charon. However, we are unable to match exactly the observed motion of the center-of-light with our model. In our opinion, significant variation of albedo across the surface of Charon is implied.

P22A-07 1530H

Origin of the Pluto–Charon Binary

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The normalized angular momentum density H of Pluto–Charon, assuming equal densities for both components and that Pluto's mutual occultation radius is close to correct, is 0.45. This exceeds the critical H, 0.39, above which no stably rotating single object exists. A collisional origin for the binary is strongly implied. H exceeds 0.39 for Charon densities ρ_C exceeding 1.77 g cm^{-3}. Even for ρ_C = 1.0 g cm^{-3}, H = 0.23, significantly greater than that of the Earth–Moon system. Moreover, for ρ_C = 2.3 g cm^{-3}, a tidally evolved Charon starting at the appropriate Roche limit implies a Pluto with $H \geq 0.39$ alone. This is not a possible initial configuration, so *2.3 g cm^{-3} is the dynamical upper limit to Charon's density.* The dynamical lower limit (after Lin) is too low to be meaningful, so a plausible cosmochemical lower limit of 1.0 g cm^{-3} is assumed. These density limits hint at but do not prove a Charon less dense than Pluto; such would be consistent with a collisional origin if one or both proto-objects were differentiated. A density upper limit closer to the system mean is possible if the rapidly rotating Pluto, as a Jacobi ellipsoid, is not allowed to contact Charon at the Roche limit. Viscosity will more likely constrain Pluto to a more biaxial figure, however. The angular momentum of the system requires that the proto-objects be comparably (if not equally) sized, if off-center impact velocities vary between escape (~1.3 km/s) and somewhat greater values (~2.5 km/s) appropriate to the outer solar system. The average temperature increase, post-Charon formation, could be as great as 100 K (for a 3/1 rock/ice mass ratio), triggering differentiation. This formation scenario differs from that of the Moon in that the comparable mass ratios of the impactors allow non-Keplerian gravitation and viscous coupling to move Charon's mass to Roche altitude. The impact velocities are too low for vaporization of water ice except during jetting. Loss of material during the jetting phase may be substantial, though, affecting the final system ice/rock ratio in the case of differentiated proto-objects.

P22A-08 1545H INVITED

Effects of Irradiation on the Surface of Pluto

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A number of experiments on charged particle and photon irradiations of methane ice and mixtures of methane with other ices have been carried out over the last few years. This data will be used, along with recent atmospheric information to describe the effects of solar irradiation on the surface of Pluto and its satellite Charon.

P22A-09 1600H

Composition and Thermal Structure of Pluto's Atmosphere

R V Yelle and J I Lunine (Both at: Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721; 602-521-4652)

We propose that the dominant constituent in the atmosphere of Pluto is a molecular species with a mass greater than or equal to 28, rather than methane as customarily assumed. This conclusion is based on the recently measured scale height of the atmosphere and on thermal structure calculations. Simple 1-D models incorporating absorption and emission of infrared radiation, thermal conduction, and NLTE effects predict a temperature profile with a strong gradient near the surface rising asymptotically to a temperature of 106 K at a few microbars. This temperature along with the measured scale height constrains the mean mass of the atmosphere to 25 ±3. Candidates for the heavier species are CO, N_2, and Ar.

P22A-10 1615H

Cosmochemical Inferences Concerning the Identity of the Heavier Gas in Pluto's Atmosphere

J.I. Lunine and R. V. Yelle (Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721; 602-621-2789)

Recent analysis of the thermal structure of Pluto's atmosphere yields a mean molecular weight of 22 to 28 a.m.u. (Yelle and Lunine, Nature, submitted), well above that of methane, the only spectroscopically identified gas in Pluto's atmosphere. The derived thermal structure reproduces certain features of the stellar occultation data (Hubbard, this session), so the presence of a gas heavier than methane appears to be a robust conclusion. Candidate gases which are plausible from the standpoint of solar nebula models are carbon monoxide, molecular nitrogen and argon. Cosmochemical models predict argon to be at least two orders of magnitude less abundant than the carbon-bearing species, and roughly an order of magnitude less abundant than nitrogen. Molecular nitrogen is a potentially attractive candidate as the heavier gas, insofar as it dominates the atmosphere of Titan and may be present on Triton. However, its presence on Titan is most readily explained as the product of photolysis and shock chemistry of ammonia early in that satellite's history. If Pluto formed in a gaseous nebula dominated by water, methane and ammonia (as predicted for Titan), it would have a bulk density of 1.5 to 1.6 g/cm^3, well below the system value of roughly 2.0 g/cm^3. The most likely heavy gas for Pluto is carbon monoxide, predicted to have been an abundant carbon-bearing gas in the outer solar nebula. The bulk density of Pluto is consistent with a solar nebula dominated by carbon monoxide as the major carbon-bearing molecule. Small amounts of methane in the nebula would have been preferentially trapped in water ice which accreted to form Pluto, consistent with a mixed methane-carbon monoxide atmosphere at present (and consistent with the methane and carbon monoxide abundances in Comet Hally). Lesser amounts of nitrogen and argon in Pluto's atmosphere are predicted by this model.

P22A-11 1630H

Pluto Occultations: Effect of a Large Near-Surface Temperature Gradient

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Light curves from the June 1988 occultation of a star by Pluto show a smooth behavior characteristic of an isothermal atmosphere, for normalized stellar fluxes ϕ > 0.45 (Hubbard, et al., *Nature*, 336, pp. 452-454, 1988). At about $\phi \lesssim 0.45$, observations show an abrupt "knee" in the lightcurve, with a rapid but smooth decline to $\phi \approx 0$ (Elliot, et al., *Icarus*, 1989, in press). The "knee" has been interpreted as the result of the submergence of the stellar image in a near-surface haze layer.

Yelle and Lunine (*Nature*, 1989, in press) point out that the Pluto atmosphere is not likely to be isothermal, but should instead undergo a rapid temperature change with a gradient on the order of 5 K/km above the planet's surface, such that the high atmosphere (corresponding to $\phi \approx 1$) is at a temperature in excess of 100 K, while the near-surface temperature drops to about 50 K. In this paper, we show that the calculated occultation lightcurve by such a Pluto atmosphere has characteristics which agree with those reported by Elliot, et al. In particular, the stellar flux ϕ is rapidly and smoothly quenched to a value very close to zero as soon as the stellar image enters the part of the atmosphere where the strong temperature gradient prevails. It seems possible that such a model could explain all of the data without the need for a near- surface haze layer. If the model is correct, the temperature gradient should start at a pressure on the order of one microbar and the solid surface of the planet should lie some 5–10 km deeper.

P22A-12 1645H

The solar wind interaction with Pluto's atmosphere

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Ralph McNutt, Jr (MIT Center for Space Research, Cambridge, MA 02139)

The low dynamic pressure of the solar wind in the outer heliosphere suggests that Pluto's atmosphere should stand off the solar wind at a large distance from the planet. Simple pressure balance calculations are meaningless, however, since they would put the stand off distance at >23 atmospheric scale heights, well above Pluto's exobase and into a highly-collisionless regime. It therefore seems more appropriate to apply the cometary stand off distance $R_s = Qm\nu/(4\pi V_{esc}\rho_{sw}V_{sw})$. Since both the ionization rate ν and the solar wind density ρ_{sw} scale with the square of the heliocentric distance we only need to know the exospheric escape rate Q ~ 10^{28} molecules s^{-1} and the escape speed V_{esc}. Taking the thermal speed appropriate for CH_4 (m=16) at a temperature of 60 K gives an escape speed of ~1 km s^{-1}, (comparable to the cometary expansion speed) and we obtain a stand off distance of ~6700 km or 6 R_{Pluto}. This is the critical distance where the pick-up of newly-ionized material mass-loads the solar wind to stagnation. If one continues scaling from comets one finds a 'contact distance' for Pluto that is less than the size of the planet. Thus it remains an issue whether there is sufficient ionization inside R_s to provide an electrically-conducting barrier around which the magnetic field is draped and deflected, to form a tail downstream (as is generally the case for Venus and comets). If Pluto has a weak ionosphere then the interplanetary magnetic field will penetrate Pluto's atmosphere, analogous to the situation at Venus for high solar wind dynamic pressures and low solar activity. Note that to stand off the solar wind to 6 R_{Pluto} with an internally-generated magnetic field Pluto would require a dipole moment of >1.3 x 10^{22} G cm^3, greater than 15 times that of Mercury.

Planetary Physics (P31A)
Exhibit Hall E WED AM
B Chao,
NASA/Goddard Space Flight Center
Presiding

P31A-01 0830H POSTER

Galileo: The Earth and Moon Encounters

Theodore C. Clarke (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91009)
Fraser P. Fanale (Institute of Geophysics, University of Hawaii, Honolulu, HI 96822)

The voyage of the Galileo spacecraft, scheduled to be launched October 12, 1989 on a Venus-Earth-Earth-gravity-assist (VEEGA) trajectory to Jupiter, includes two encounters with the planet Earth and the Earth-Moon system, the first in December 1990 and the second in December 1992. These fortuitous encounters provide unique Earth and Moon scientific observing opportunities.

This paper reviews the conditions and constraints of the Earth and Moon encounters (observing geometry, lighting, temperature, telemetry, safety) which define the observing opportunity and bound the science objectives, reviews Galileo's Earth and Moon science objectives, and reviews a preliminary timeline of events developed for the first Earth encounter.

High priority lunar science objectives include composition and multispectral characterization of Mare Orientale, the lunar farside, the lunar north pole, and unmapped portions of the lunar south polar region. High priority Earth science objectives include global mapping of methane, other "greenhouse" gases, and mesospheric water, and hydrogen geotail and geocorona observations. Calibrations and measurements for comparison with observations at Jupiter are an important objective for both the Earth and the Moon. A 5 day Earth rotation movie, as well as searches for evidence of postulated cometesimals raining down on the Earth and for evidence of an Earth shepherded dust ring, are also planned.

P31A-02 0830H POSTER

Numerical Simulation of Satellite Capture for Planets Venus and Earth

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R R Winters (Dept. of Physics and Astronomy, Denison Univ., Granville, OH 43023)

A three-body (sun, planet, planetoid) numerical integration code with an energy-dissipation subroutine is used to assess the possibilities of satellite capture by way of radial tidal energy dissipation within the interacting bodies. This study is restricted to venus-like and earth-like planets in appropriate heliocentric orbits interacting with lunar-like (lunar mass and density) planetoids in coplanar orbits with geometries similar to the respective planetary orbits. The major variables are: (1) the pericenter distance (r_p) of close encounters, (2) the displacement Love number (h) for each body, (3) the effective tidal dissipation factor (Q) for each body, (4) the planet anomaly (the position of the planet relative to the sun at the beginning of the calculation), and (5) the planetoid anomaly (the position of the planetoid at the beginning of the calculation). The results of the simulations can be placed into five categories: (1) close noncapture encounters in which the planetoid is deflected into a near parabolic course by the planet and then continues on a heliocentric orbit; (2) noncapture scenarios in which the planet goes into a planetocentric orbit for a few orbits and then returns to a heliocentric orbit; (3) stable capture scenarios; and (4) collision scenarios in which the distance of closest approach is less than the sum of the planet-planetoid radii. From our limited set of calculations we find that stable prograde capture for an earth-like planet

P31B-15 0830H POSTER

Pickup of Newborn Ions with an Initial Ring Distribution Function

M E Mandt and C S Wu (Both at: Institute for Physical Science and Technology, University of Maryland, College Park, MD 20742)

The pickup processes of newborn ions by the solar wind have been studied theoretically by many authors. It is known that when the intrinsic turbulence in the solar wind is moderate the pickup process may be described by a quasilinear theory which stresses the resonance condition $\omega \pm \Omega_i - k_{||}v_{||} = 0$ and applies very well to the case in which the distribution function of the newborn ions exhibits a beam along the ambient magnetic field. However, when the solar wind velocity V_s and the interplanetary magnetic field are perpendicular, the initial newborn ion distribution function is expected to be a ring in velocity space. In this case the aforementioned resonance condition is not satisfied. However, a mirror like instability can take place [Wu et al., 1988]. As a result, the pickup process no longer follows the usual quasilinear theory. To investigate the pickup of newborn ions with an initial ring distribution we have used a hybrid code to perform numerical simulations. In this paper we present the results of our study. It is shown that the pickup of ring ions can be speedy and efficient. The results are also compared with those obtained with an initial ring-beam distribution.

P31B-16 0830H POSTER

The Stability of the Distribution of Continuously Created Newborn Comet Ions*

J D Gaffey, Jr and C S Wu (Both at: Institute for Physical Science and Technology, University of Maryland, College Park, MD 20742)

In the literature numerous authors have discussed the amplification of waves by newborn ions in the solar wind. However, all of the investigations in the past have used model distribution functions, which primarily describe newborn ions. In the present discussion we make use of a distribution function derived from a quasilinear theory. Particular attention is placed on the long time asymptotic distribution, which describes recently created newborn ions and pickup ions generated throughout the entire process. The results of the stability analysis based on this distribution function are reported. Emphasis is placed on the low-frequency hydromagnetic modes.

*This research was supported by NASA.

P31B-17 0830H POSTER

Electron Heating at the Comet - Solar Wind Interaction Regions

A S Sharma and K Papadopoulos (Both at: Department of Physics and Astronomy, University of Maryland, College Park, MD 20742)

The transition regions at the comet-solar wind interactions at both the comets Halley and Giacobini-Zinner have been found to be dominated by strong low-frequency hydromagnetic turbulence. These large amplitude waves can heat the solar wind plasma by different wave-particle interaction processes. These fluctuations can become kinetic Alfven waves in the presence of gradients or shear. The observed heating of the solar wind protons may be attributed to the Landau damping of these modes[1]. Another mechanism for heating by low-frequency waves is the transit time damping and this accounts for the observed alpha particle heating at comet Halley. The electron heating by the low frequency turbulence through different processes is studied in this paper. The heating rate of the electrons by the kinetic Alfven wave is smaller than that of the protons. Similarly the transit time damping is more efficient for ion heating than for electron heating. However the combined effect of these processes on the electron heating is found to be significantly large. The recent data[2] from the comet Halley show that the ratio of the solar to the anti-solar components of the electron heat flux vary over the interaction region[2]. These observations are related to the above electron heating processes.

1. A.S. Sharma, P.J. Cargill and K. Papadopoulos, Geophys Res. Lett., 15, 740, 1988.

2. K.H. Glassmeier et al., J. Geophys. Res., 94, 37, 1989.

Neptune, Triton; Pluto II (P31C)

Exhibit Hall E WED AM
M D Desch,
NASA/Goddard Space Flight Center
Presiding

P31C-01 0830H POSTER

The Neptune Ionosphere: Comparison with the Ionospheres of Jupiter, Saturn, and Uranus

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J. H. WAITE, Jr. (Southwest Research Institute, San Antonio, TX 78284)

The Neptune ionosphere has been studied using a one-dimensional ionospheric/thermospheric model based on the current best estimates of the Neptune atmosphere, and knowledge obtained from the studies of the ionospheres of the other outer planets (Jupiter, Saturn, and Uranus). Previous studies suggested that there must be significant ion loss mechanisms in the ionospheres of the outer planets in order to explain the observed electron densities.

If similar ion losses are present in the Neptune ionosphere, the peak electron density would be on the order of 10^3 cm^{-3} instead of 6×10^4 cm^{-3} which is expected from a "standard" ionospheric theory. In the auroral region, however, the peak electron density might reach 10^6 cm^{-3}. It is likely that multi-layer structure observed in the lower ionospheres of Jupiter, Saturn, and Uranus will also be observed in the Neptune ionosphere.

P31C-02 0830H POSTER

Neptune Radio Emission: Progress and Predictions

M D Desch and M L Kaiser (both at Laboratory for Extraterrestrial Physics, NASA/Goddard Space Flight Center, Greenbelt, MD 20771)

We will present a progress report on the search for low-frequency Neptune radio emission using the radio astronomy experiment onboard the Voyager spacecraft. Detection of radio signals from Neptune would provide the first direct evidence of a magnetosphere surrounding the planet. Based on magnetic dynamo[1] and radiometric scaling laws[2], we expect first detection of Neptune approximately 45 - 90 days before encounter, or late May 1989 at the earliest. Voyager is thus entering the detection window near the time of the Spring AGU meeting. Using an equatorial field strength of 0.5 Gauss and typical solar wind conditions, we expect the radio source to have a spectral peak near 400 kHz and emit slightly more than 10^7W total power.

[1]Curtis and Ness, JGR, 91, 11003, 1986.
[2]Desch, GRL, 15, 114, 1988.

P31C-03 0830H POSTER

Solar Wind Parameters Upstream of Neptune

Louis A Villanueva, John T Steinberg, Ralph L McNutt, Jr, Alan J Lazarus, and John W Belcher, (Department of Physics and Center for Space Research, M.I.T., Cambridge, MA 02139)

Recent measurements of the solar wind density and velocity made with the Voyager 2 Plasma Science instrument (PLS) have been extrapolated from the location of Voyager 2 to the location of Neptune, in order to determine the solar wind ram pressure upstream of Neptune, and to predict the location of the Neptunian magnetopause. Using measurements made during the period in late 1988 from day 172 hour 19 UT to day 308 hour 15 UT, when Voyager 2 was between 3.9 AU and 2.7 AU away from Neptune, we obtained a mean ram pressure at Neptune of 2.1×10^{-12} Pascal with with a standarad deviation of 1.6×10^{-12} Pascal. The highest and lowest values of ram pressure during this period were 1.1×10^{-11} Pascal and 2.6×10^{-13} Pascal. Assuming a magnetic dipole moment of ~1 G R_N^3 (dePater and Goertz, 1989*) and using pressure balance, we determine the mean magnetopause standoff disstance to be $46.9R_N$, with a standard deviation of $5.8R_N$. The largest and smallest values of the standoff distance determined during this period were $62.8R_N$ and $33.5R_N$. The typical solar wind particle density at Neptune is on the order of 9.5×10^{-3} cm^{-3}. We will continue to update this study using the most recent Voyager 2 measurements from now until the time of the Voyager 2 Neptune encounter.

*dePater, Imke and Christoph K. Goertz, Synchrotron radiation from Neptune: Neptune's magnetic field and electron population, Geophys. Res. Lett. 16, 97-100, 1989.

This work supported in part by NASA contract 957781 and NASA Grant NGL 22-009-015.

P31C-04 0830H POSTER

Photochemical Haze on Triton

J A Stansberry, M G Tomasko and J I Lunine (Department of Planetary Sciences, University of Arizona, Tucson, AZ 85721; 602-621-2272)

As the Voyager flyby of Neptune's moon Triton approaches, speculation focuses on the ability of Voyager's cameras to image the surface. We model photochemical hazes in Triton's atmosphere in order to address this question. Adapting Trafton's (Icarus 58) model of an atmosphere in thermal equilibrium with volatile ice polar caps, we calculate Triton's surface pressure and temperature. We include the possibility that nitrogen, as well as methane, is present on the basis of accumulating observational evidence (Cruikshank et al., Icarus 74). Radiative equilibrium calculations indicate that such an atmosphere will probably be nearly isothermal. Parameters implicit in our Triton model are R_T=1600 km, p=2 g/cm^3, g=90 cm/s^2, albedo=0.3, cap albedo=0.6, cap extent=35 degrees in colatitude.

The photochemical production altitude is taken to be the level in the model atmosphere where the UV optical depth due to methane photolysis is unity. We use an average photolysis cross section of 1.5×10^{-17} cm^2, and an aerosol mass production rate, scaled from Titan, of 3×10^{-15} g/cm^2/s. An aerosol growth and transport code incorporating coagulation, condensation, sedimentation and eddy diffusion uses these inputs and the T-P structure to calculate the vertical distribution of aerosol particles in the atmosphere as well as their size distribution. The vertical optical depth to the surface due to scattering and absorption by the haze particles is calculated from these distributions. The initial results presented here exclude condensation and eddy diffusion.

For plausible polar cap temperatures of 50K and 62K we obtain visible optical depths at Triton's surface of 0.03 and 0.3 respectively, assuming that N_2 is present, and 0.001 and 0.01 assuming the atmosphere is CH_4 only.

P31C-05 0830H POSTER

Radiative Timescales on Triton and Their Implications

S. A. Stern (LASP/University of Colorado, Boulder, CO 80309; 303-492-7669; SPAN ORION::ASTERN

We consider the radiative timescale for Triton's atmosphere. The radiative timescale τ_r is the characteristic time for the atmosphere to respond to radiative balance changes:

$$\tau_{RAD} = \frac{m(T)C_p(T)}{\sigma T_e^3}$$

This approximation assumes the atmospheric temperature is near the effective temperature, which is not unreasonable in the absence of a strong greenhouse. Here *m* is the atmospheric mass per unit area, σ is the Stefan-Boltzmann constant, and C_p is the mole fraction weighted-average constant-pressure specific heat of an atmospheric parcel. We take *m(T)=P(T)/g* where *P(T)* is the strongly temperature dependent saturation vapor pressure and *g* is the surface gravity. Specific heat data for cryogenic N_2 and CH_4 gases were taken from the International Critical Tables (1933); vapor pressure relations for CH_4 and N_2 were taken from Brown and Ziegler (1980). The model was run for two bounding cases of the surface gravity: 60 and 135 cm/sec^2.

The following results were obtained. If Triton possesses an N_2 atmosphere near saturation vapor pressure equilibrium, then diurnal variations should be inconsequential for any surface temperature consistent with the available albedo constraints (0.2<A<0.8). If the surface temperature exceeds ~65K, then the orbital/obliquity variations predicted to occur on 50-100 year timescales (Trafton 1984) will be highly damped. However, T>65K requires greenhouse warming (Nolan and Lunine 1988). To prevent this result from contradicting the apparent evidence for the onset of a major summer towards the end of the century, it would seem that no significant greenhouse is operating. If CH_4 is the only atmospheric constituent, the radiative timescale will be substantially shorter, permitting diurnal variations if T≤60K (hence less than a few torr atmospheric pressure). For a CH_4-only atmosphere, seasonal variations will be permitted unless T>90K, which cannot obtain without a substantial greenhouse.

P31C-06 0830H POSTER

Results From Five Years of Pluto-Charon Mutual Event Observations

D J Tholen (Institute for Astronomy, 2680 Woodlawn Drive, University of Hawaii, Honolulu, HI 96822)
(Sponsor: A. Stern)

High-precision photometric observations of over fifty Pluto-Charon mutual events have been obtained at Mauna Kea Observatory between 1985 and 1989. Only one year, 1990, remains in the mutual event season, thus the five years of observations represent nearly complete sampling of the entire range of viewing geometries the system can produce during the season. Model fits to the observations have produced a very reliable orbit for Charon around Pluto. To this point, the orbital eccentricity has remained undetectable, with a 2σ upper limit of 0.0009, and the orbital period of 6.387230 ± 0.000021 days has been shown to be indistinguishable from the rotational period of Pluto, both results suggesting that the system has completely tidally evolved. The obliquity is approximately 118 degrees, and coupled with Pluto's orbital eccentricity of 0.25, demonstrates that Pluto and Charon experience rather extreme seasonal effects.

The diameters of both bodies have also been determined to high accuracy, Pluto being 2285 ± 40 km and Charon being 1190 ± 40 km in diameter. Kepler's Third Law can be employed to compute a system mass of only 0.0026 Earth masses. This result, combined with the volumes of Pluto and Charon computed from their diameters (assuming spherical shapes for both objects), yields a mean density for the system of 2.065 ± 0.047 gm cm^{-3}, which indicates that Pluto is substantially rockier than the icy satellites of the other outer planets. The rock component represents about 70 percent of the system by mass, and about 50 percent by volume.

Albedo mapping efforts have shown Charon to be noticeably less reflective and more neutral in color than Pluto, while Pluto shows a high contrast surface with bright, neutrally colored polar caps and a much darker and redder equatorial region. Substantial variegation in longitude must also be present to account for the rotational lightcurve variation of over 0.3 magnitude.

P31C-07 0830H POSTER

Topographic Relaxation on Ice-Covered Worlds: Application to Pluto II.

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(Sponsor: Larry A. Lebofsky)

The subject of topographic relaxation on Pluto was addressed by Marcialis (1985). Recently, more realistic models of Pluto's interior have appeared as a result of the mutual event analysis, allowing the question to be readdressed. Since Pluto's bulk density is around 2 gm cm^{-3}, the methane lithosphere probably is much thinner than initially assumed. This drastically alters the conclusions of our earlier study.

An empirical temperature-viscosity law for water ice is restated in terms of melting temperature and has been assumed to hold for methane. Using the approach of Parmentier and Head (1979) and the interior models of McKinnon & Mueller (1988) and Simonelli *et al.* (1989), we now find that not only can significant lateral topography persist on Pluto, but the wavelength scale of such features is extremely sensitive to the actual thickness of the methane layer. This result therefore leads us to call for experimental data on the rheology of methane ice in the relevant temperature range of 50–60°K.

On a global scale, Pluto's figure is still found to be essentially hydrostatic, which implies that only 2 millimag of its (~300 millimag) lightcurve may be attributed to shape. This result is independent of rheology and interior model assumed, for all but the most pathological cases.

References:

Marcialis, R.L. (1985) *Bull. Amer. Astron. Soc.* **17**, 715.
Parmentier, E.M. and Head, J.W. (1981) *Icarus* **47**, 100–111.
Simonelli, D.P., *et al.* (1989) *Icarus*, in press.

P31C-08 0830H POSTER

Reflectance Spectroscopy of the Surface and Atmosphere of Pluto-Charon

S R Sawyer (Astronomy Department, University of Texas, Austin, TX 78712; 512-471-3466)
(Sponsor: Alan Stern)

Reflectance spectra of Pluto-Charon in the 0.5 to 1.0 μm range have been obtained spanning 1983 to 1988. The spectra cover the full 6.4 day rotational period. Mutual event spectra were obtained in 1987 and 1988. Further observations are scheduled for 1989. There is no evidence for significant variation of the CH_4 band strengths with rotational phase. This implies that the CH_4 bands arise from Pluto's atmosphere and not a surface frost. Recent results on the surface albedo distribution in the Pluto-Charon system derived from mutual event observations are being used to model the contributions of frost and gas to the observed spectra. Mutual event spectra are being used to produce separate spectra of Charon and portions of the surface of Pluto. In particular, polar region spectra may reveal the composition of Pluto's polar caps. If Pluto's atmospheric bulk is increasing as the system approaches perihelion, changes in the CH_4 band strengths with time may be measurable.

Mars-Venus Comparisons: Atmospheres, Ionospheres, and Solar-Wind Interactions I (P32A)

323 WED PM
J A Slavin,
NASA/Goddard Space Flight Center
Presiding

P32A-01 1330H INVITED

The Solar Wind Interaction with Venus and Mars

C T Russell and J G Luhmann (both at: Institute of Geophysics and Planetary Physics, Los Angeles, CA 90024-1567)

W Riedler and K Schwingenschuh (Space Research Institute, Graz, Austria)

Both Venus and Mars deflect almost completely the supersonic solar wind generating strong magnetosonic bow shocks in front of these planets. In the case of Venus, the magnetized solar wind plasma is convected against the planetary ionosphere creating a magnetic barrier which both puts a lid on the ionosphere and shields the ionosphere from the solar wind flow. At Mars an analogous region is found which has been called the ion cushion by O. Vaisberg and co-workers. Venus has a magnetic tail formed from the interplanetary magnetic field draped around the planet. Mars too has a magnetic tail but there is much debate as to whether the field is induced or intrinsic to the planet. The Phobos spacecraft should be able to answer this question. In its initial 77 hour orbit on February 1, 1989 the spacecraft came as close as 860 km to the surface of Mars. As it crossed the subsolar region, it saw a 30 nT steady field but near periapsis (1713 UT) the field was less than half this size and turbulent. Above the nightside of the planet reversals of the direction of the magnetic field are observed. While these initial results alone are not sufficient to settle the debate, we expect that the measurements from the 4 more highly-elliptical-phase orbits and those in the more nearly circular Phobos phase orbits will be able to settle many of the controversies surrounding the solar wind interaction with Mars.

P32A-02 1400H

First Results of the Ion Composition in the Martian Magnetosphere

R. Lundin, H. Borg, B. Hultqvist (Swedish Institute of Space Physics)
Zakharov, A., N. Pissarenko, E.M. Dubinin (Space Research Institute, USSR Academy of Sciences, Moscow, USSR)
R. Pellinen, I. Liede, H. Koskinen (Finnish Meteorological Institute, Helsinki, Finland)

This report will review the first results in the Martian magnetosphere from the three-dimensional ion composition experiment ASPERA on the Soviet Phobos-2 spacecraft. Of particular interest is the solar wind interaction with the upper ionosphere at Mars and the subsequent escape of ionospheric plasma.
Preliminary results on the solar wind interaction with the Martian moon Phobos will also be discussed.

P32A-03 1415H

Dayside Pickup Ion Precipitation at Venus and Mars: Spatial Distributions and Energy Deposition

J G Luhmann (IGPP, University of California, Los Angeles, CA 90024)
J U Kozyra (Space Physical Research Laboratory, University of Michigan, Ann Arbor, MI 48109)

The fluxes and energy spectra of picked-up planetary O^+ ions incident on the dayside atmospheres of Venus and Mars are calculated using the neutral exosphere models of Nagy and Cravens (1988) and the Spreiter and Stahara (1980) gasdynamic model of the magnetosheath electric and magnetic field. Cold (~10 eV) O^+ ions are launched from hemispherical grids of starting points covering the daysides of the planets and their trajectories are followed until they either impact the dayside "obstacle" or cross the terminator plane. The impacting, or precipitating, ion fluxes are weighted according to the altitude of the hemispherical starting point grid in a manner consistent with the exosphere density models and the local photoion production rate. "Maps" of precipitating ion number flux and energy flux show the asymmetrical distribution of dayside heating expected from this source which is unique to the weakly magnetized planets.

P32A-04 1430H INVITED

Solar Wind Interaction with Mars

F S Johnson and W B Hanson (University of Texas at Dallas, Richardson TX 75083–0688; 214–690–2820)

Retarding Potential Analyzers carried on the Viking Landers have provided data that show that the ionospheric plasma pressure and solar wind plasma pressure above the ionopause are insufficient to balance the impact pressure of the solar wind. This indicates the presence of magnetic field, which might be either intrinsic or induced. The principal evidence that the magnetic field is intrinsic comes from the position of the shock front, which implies the existence of a relatively larger obstacle to the solar wind flow than exists in the case of Venus. The only altitude in the Viking data on electrons that appears suitable for identification as a magnetopause is the ionopause near 300 km, which is too low to provide the larger obstacle size needed to account for the observed location of the shock front. The observed location of the shock front should therefore be regarded as equally anomalous for the two hypotheses for the magnetic field, induced and intrinsic. The Viking 1 data indicate that the shock front was quasi parallel. There is also evidence in the Viking 1 data that the extreme ultraviolet airglow produced observable effects and corresponded to an albedo of the order of 1%. Below 10,000 km, light from the planet could enter the RPA and cause photo currents; sunlight could not enter the instrument. Part of the evidence for the photocurrents is that the collector current changed when the potential on one of the internal grids of the RPA was changed under conditions where this could only influence electrons of internal origin. The remainder of the evidence comes in the retarding potential scans when the negative retarding potential barrier fell below about 10V; the profile of the observed curve indicates that electrons of internal origin with energies up to 10 eV escaped during this part of the sweep.

P32A-06 1515H INVITED

Comparison of the Ionospheric Response to the Solar Wind at Venus and Mars

T. E. Cravens (Dept. of Physics and Astronomy, The University of Kansas, Lawrence, KS 66045; 913-864-3610; SPAN KUPHSX::CRAVENS)

The solar wind interacts almost directly with the upper atmospheres and ionospheres of planets such as Venus and Mars, which possess only weak, or nonexistent, intrinsic magnetic fields. The upper atmospheres and ionospheres of Venus and Mars are known from *in situ* measurements to be very similar in their neutral and ion compositions. For example, the major neutral species on both planets is CO_2 and the major ion species is O_2^+. However, there are also significant differences between the two planets relevant to the solar wind interaction, such as differences in the gravitational acceleration, in the heliocentric distance (i.e., solar flux differences), and possibly in the presence of an intrinsic magnetic field. Observational data and theoretical models will be reviewed and used to examine the behavior of the ionospheric densities, ion velocities, and magnetic fields at Venus and Mars as they respond to varying solar wind conditions. For example, the ionosphere of Venus is known to be permeated by large-scale magnetic fields when the solar wind dynamic pressure is high, whereas it is free of such fields for conditions of low solar wind dynamic pressure On the other hand, it is likely that large-scale magnetic fields are almost always present in the ionosphere of Mars. The average ionospheric plasma velocity is downward on both planets for magnetized conditions, although it is somewhat larger at Venus than at Mars. The plasma carries magnetic flux from the magnetosheath down into the ionosphere. Ohmic dissipation of the currents responsible for the magnetic field takes place deep in the ionospheres of both planets.

P32A-07 1545H

MHD Models of the Ionospheres of Venus and Mars

H. Shinagawa (NASA/MSFC, Huntsville, AL 35812)

The ionospheres of Venus and Mars are discussed based on ionospheric MHD models developed by Shinagawa and Cravens (1988) for Venus, and by Shinagawa and Cravens (1989) for Mars. The models are currently being improved in order to study various processes in more detail. Some new results are presented and discussed.

P32A-08 1600H

The Transonic Nightward Flow in the Venus Ionosphere and Implications for Mars

L Fu and K L Miller (Both at CASS, Utah State University, Logan, UT 84322-4405; 801-750-3437)

The nightward flow of ions in the Venus ionosphere has been shown by measurements of the Pioneer Venus Retarding Potential Analyzer (RPA) to be supersonic with respect to the neutral atmosphere in the vicinity of the terminator. The axially-symmetric flow of ions at high velocities is possible on Venus, and presumably on other unmagnetized planets. We discuss characteristics of the ion flow in the Venus ionosphere, as well as the possibility of similar ion velocities in the Martian environment. Ion velocity at Venus has been modelled by Elphic et al. (1984) using the momentum equation, giving results that were consistent with measurements. If the continuity equation is included in a one-dimensional calculation, it can be shown that neglecting collisions and gradients in temperature results in a maximum velocity equal to the thermal velocity. We have extended the calculations of Elphic et al. to include continuity as well as momentum. Either a gradient in temperature, collisions, or both are required in our calculations for the ion velocity to accelerate through the critical point to velocities greater than the thermal velocity. Results of our calculation using Pioneer Venus measurements compare favorably with measurements by the RPA. We will discuss differences between measured and modelled ion velocities in terms of the limitations of a one-dimensional calculation. We will also discuss our calculations of ion velocities using current knowledge of the Martian ionosphere.

Elphic, R. C., Mayr, H. G., Theis, R. F., Brace, L. H., Miller, K. L., Knudsen, W. C., Nightward ion flow in the Venus ionosphere: implications of momentum balance. Geophys. Res. Lett. 11:1007-1010. 1984

P32A-09 1615H

Response of the Venus Ionotail to Changes in the Solar EUV Flux, Solar Wind Pressure and the IMF: Implications for Mars

L H Brace and R F Theis (Both at: NASA/Goddard Space Flight Center, Laboratory for Atmospheres, Greenbelt, MD 20771; 301-286-8575)
J G Luhmann (IGPP/UCLA, Los Angeles, CA 90024; 213-825-1245)
J D Mihalov (NASA/Ames Research Center, Moffett Field, CA 94035; 415-694-5516)

Ionosphere instruments on the Pioneer Venus Orbiter (PVO) have shown that the nightside ionosphere of Venus extends several thousand km downstream from the planet, often exhibiting comet-like tail rays, streamers, and filaments. This region, known as the Venus ionotail, is highly dynamic. Previous work has shown that the ionotail plasma originates in the ionosphere. Most of the ionotail electrons are cool, but the ions have been accelerated to velocities somewhat greater than the planetary escape velocity by solar wind interaction processes not currently understood. We have investigated the response of the ionotail electron density to solar variations that might be expected to influence it; specifically the solar wind dynamic pressure, solar extreme ultraviolet (euv) flux, and the amplitude and orientation of the interplanetary magnetic field at Venus. All of these parameters are measured by PVO instruments. We find that the euv (primarily solar cycle variations) exerts primary control over the ionotail causing its density to be larger at solar maximum. The solar wind dynamic pressure causes major orbit to orbit variations in the ionotail density, with the tail nearly disappearing at high pressures and nearly filling up with plasma at lower pressures. The interplanetary magnetic field exerts a much smaller influence on the ionotail, if any. The implications of this behavior for solar wind-ionosphere interactions at Mars will be discussed.

P32A-10 1630H

Plasma Temperatures in the Dayside Ionospheres of Mars and Venus and Their Response to the Solar Cycle

A. J. Kliore, G. Lindal, L. F. Mullen, and D. N. Sweetnam (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109)

Radio occultation measurements of the electron density vertical profiles on the dayside of Venus have been performed with the Pioneer Venus orbiter from 1979 to the present. This has allowed the effects of varying solar input on the structure of the topside ionosphere to be observed from the maximum to the minimum of Solar Cycle 21. In 1971, near solar maximum, a substantial number of radio occultation measurements of the dayside ionosphere of Mars were obtained with the Mariner 9 orbiter, and later, from 1976 to 1978, near solar minimum, measurements were again made with the Viking 1 and 2 orbiters. From each measurement, a vertical profile of the plasma scale height can be obtained, and by assuming that the topside ionosphere is in diffusive equilibrium, the ion and electron temperatures can be estimated. It is found that on Venus the plasma scale height decreases by about a factor of 2 from solar maximum to minimum, indicating a threefold reduction in the electron temperature. On Mars, approximately the same percentage decrease in the plasma scale height is observed from solar maximum to minimum.

Mars-Venus Comparisons: Atmospheres, Ionospheres, and Solar-Wind Interactions II (P41A)

310 THURS AM
A Nagy, Univ of Michigan
Presiding

P41A-01 0830H

A Post-Pioneer Venus Reassessment of the Dayside Ionosphere of Mars as Observed by Radio Occultation Methods

M Hantsch (University of Graz, Graz, Austria)
J G Luhmann (IGPP, University of California, Los Angeles, CA 90024)
A J Kliore (Jet Propulsion Laboratory, Pasadena, CA 90011)

The dayside altitude profiles of the electron density in the Martian ionosphere obtained over a decade ago with the radio occultation experiments on the Mariner 9 and Viking 1 and 2 spacecraft* are collectively reanalyzed to determine the global characteristics of the daytime ionosphere of Mars. The present study focuses on the comparison with analogous profiles obtained at Venus during solar minimum conditions when the solar wind interaction effects on the ionosphere should be most like those at Mars. Contrasts between the profiles at the two planets include an almost constant peak altitude at Venus relative to that at Mars, which moves upward as the solar zenith angle increases, and a topside scale height at Mars which increases with solar zenith angle at solar zenith angles near 45° while that at Venus consistently decreases with increasing solar zenith angle. These differences in the ionospheres reflect differences in the neutral atmospheres of the two planets, but they may also reflect differences in their solar wind interactions. For example, the rotation of Mars could produce a more substantial ionosphere near the terminator and thus explain the peak altitude behavior, but either the presence of dust in the Martian atmosphere during the Mariner 9 main mission or different solar wind interactions are required to produce the distinctive topside characteristics observed in the subsolar region.

(* Viking data were provided courtesy of D. Sweetnam and G. Lindal, JPL.)

P41A-02 0845H

Radio Scintillation Measurements of the Solar Wind Interaction With the Ionospheres of Venus and Mars

R. Woo, A.J. Kliore and L. Mullen (All at: Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109)
J. G. Luhmann (Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024)

In situ measurements of the ionosphere of Venus by Pioneer Venus Orbiter (PVO) have revealed the presence of large-scale magnetic fields when the solar wind dynamic pressure exceeds the ionospheric plasma pressure. These fields occur most frequently in the subsolar region. It has recently been found that these large-scale magnetic fields are accompanied by disturbed plasma representing electron density irregularities in the topside ionosphere (JGR, 94, 1473, 1989). Furthermore, these irregularities cause radio scintillations which can be remotely detected during radio occultaion measurements. Like large-scale magnetic fields, radio scintillations are, therefore, another manifestation of high-dynamic solar wind interaction with the ionosphere.

We have initiated a radio scintillation investigation of the ionosphere of Venus based on PVO radio occultation measurements that have been conducted since 1979. Results pertaining to the variation of high-dynamic solar wind interaction with solar zenith angle and solar cycle will be presented. The radio occultation results complement the PVO *in situ* measurements because the latter are only available for a period of two years during solar maximum. Measurements during solar cycle minimum are especially interesting because conditions at Venus during this time are thought to be similar to those at Mars.

The results of a similar investigation based on radio occcultation measurements of Mars will be presented and compared with those of Venus.

P41A-03 0900H INVITED

Mars and Venus Compared : The Neutral Thermospheres and Exospheres.

A I F Stewart (Laboratory for Atmospheric and Space Physics,University of Colorado, Boulder, CO 80309-0392; (303)-492-8689)

The most striking difference between the thermospheres of Mars and Venus is the much smaller abundance of O and CO relative to CO_2 on Mars (1-2% on Mars, 10-15% on Venus, near the ionospheric peak). Other major properties such as the exospheric temperature and the theoretical wind speeds are more remarkable for their similarities than their differences. Given the comparable wind speeds, the depletion of the dissociation products of CO_2 on Mars appears to derive partly from the reduced solar fluxes and partly from the increased flux divergences (estimated by the ratio of scale height to planetary radius). Details of the circulation differ; on Venus the subsolar upwelling is balanced by a downflow localized near 2 a.m. whereas on Mars the upwelling is predicted to occur at 3 p.m., the downflow at 9 p.m., and a peculiarly violent overturning is predicted just after sunrise. The case for vigorous vertical eddy mixing on both planets to explain the scarcity of O and CO is less compelling in light of the strong general circulations. On the other hand, there is clear evidence of gravity-wave activity in the Viking entry science data on Mars and in mass spectrometer data on Venus.

The difference in the O and CO abundances does not greatly affect the major ion composition, but it may have an important affect on the odd nitrogen chemistry. On Venus, N dominates NO because $N(^2D)$ (which forms NO upon reaction with CO_2) is rapidly quenched by O and by CO. The detection of NO by Viking suggests that Mars is NO-dominated, implying that the relative lack of O and CO critically reduces the quenching of $N(^2D)$. One consequence of this might be that on Mars the radiative recombination of NO may not provide the admirable tracer of nightside thermospheric winds that it does on Venus.

The neutral exospheres of the two planets should differ greatly in density. On Venus the dissociative recombination of O_2^+ near the exobase provides a substantial population of hot oxygen atoms extending up to about 4300 km, and lesser coronae of C and N also exist. The hot O atoms promote the escape of H, although most of the escape flux of H originates on the night side where abundant cold-trapped H atoms charge exchange with hot plasmaspheric protons. On Mars the source of hot atoms is weaker, and most of them escape from Mars' weaker gravitational field, leaving a much reduced corona. The reduced gravity on Mars also allows thermal Jeans escape of H from the dayside; this is the dominant H escape mechanism.

P41A-04 0930H INVITED

The Neutral Thermospheres of Mars & Venus

J. L. FOX (Institute for Atmospheric Sciences and Department of Mechanical Engineering, SUNY-Stony Brook, Stony Brook, NY 11794)

Similarities and differences in the chemical and thermal structures of the thermosphere of Mars and Venus are discussed. Both atmospheres are composed predominantly of CO_2 with a small admixture of the dissociation products CO, O and O_2. The most outstanding difference is the greater density of atomic-oxygen in the thermosphere of Venus, which has important implications for the thermal structure. Both atmospheres contain a small amount of N_2. The odd nitrogen chemistry on both planets is compared and potential for contributions to our understanding of terrestrial odd-nitrogen chemistry is discussed.

P41A-05 1000H

The Thermospheres of Venus and Mars: A Comparison

S W BOUGHER (Lunar and Planetary Lab., U. of Arizona, Tucson, AZ 85721), and R G ROBLE (National Center for Atmospheric Research, Boulder, CO 80307-3000)

The NCAR terrestrial one-dimensional NLTE radiative transfer model and the Thermospheric General Circulation Model (TGCM) have been recently adapted to the thermospheres of Venus and Mars for solar minimum (F10.7-67) and maximum (F10.7-200) conditions. The former global mean heat balance code provides inputs and initializations for its corresponding circulation model. Self-consistently calculated TGCM neutral composition, temperatures, and winds are given for each planet on 24 constant pressure levels above 100 km on a 5 x 5 degree latitude-longitude grid. Inputs include internally calculated solar EUV, UV, and IR heating, and net CO_2 photodissociation over the globe. Global mean CO_2 cooling is used to drive a 3-D parameterization for total cooling. We present calculations using the above standard fluxes for both planets enabling a comparison of thermospheric structure and circulation at Equinox. Results indicate that planetary rotation significantly modifies thermospheric winds, giving strong differences between Venus and Mars. Adiabatic heating and cooling are also more effective on Mars where the planetary radius is smaller. No nightside "cryosphere", of the type observed on Venus, is predicted for Mars. Model and observed atomic-O are greatly depleted on Mars compared to Venus. The importance of fundamental planetary parameters (e.g. gravity, sun-planet distance, rotation, magnetic field, etc.) in affecting vertical structure and diurnal density, temperature and wind distributions will also be discussed. Finally, the TGCM model heat balances maintain a modest Mars solar activity variation in exospheric temperatures (310-190 K), while that for Venus is a factor of two smaller (300-235 K). This response is somewhat different than that predicted assuming radiative equilibrium, yet it is consistent with observations.

P41A-07 1030H INVITED

Mars and Venus Atmospheric Evolution

T Owen (Department of Earth and Space Sciences, State University of New York, Stony Brook, NY 11794-2100; 516-632-8188)

It is not yet possible to present a single model that will explain the volatile abundances on the three inner planets with substantial atmospheres. Instead we are faced with the uneasy feeling that each body has suffered a unique formation history whose details are still unclear. It remains attractive to try to account for the total volatile inventory on each planet as an outcome of the late accretion of volatile-rich meteorites and comets, in different proportions and sequences. A large, low-temperature icy planetesimal could be responsible for the peculiar heavy noble gas abundance pattern on Venus, while large impacts have apparently dramatically reduced the mass of the Martian atmosphere and probably eliminated the initial inventory on the Earth. Venus seems to show the effect of an additional contribution from the solar wind. Subsequent evolution has been dominated by solar distance and planetary mass, but within these two major constraints, numerous puzzles remain to be solved. Among these is the question of how much CO_2 remains on Mars, in what form, deposited by what processes? An especially intriguing problem for exobiologists is the quantity and lifetime of liquid water on the early Martian surface. New studies of the abundance of deuterium on Mars provide additional support for geomorphological evidence suggesting a warm, wet early climate that could have allowed the presence of open bodies of water.

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P41A-08 1100H INVITED

Atmosphere-surface interactions on Venus and Mars

Ronald Prinn (MIT 54-1824, Cambridge, MA)
Bruce Fegley (MIT 54-1822, Cambridge, MA)

Atmosphere-surface interactions on Venus and Mars are important determinants of their atmospheric composition. These interactions on the present-day planets have some obvious similarities and some equally obvious differences. On both planets photochemical reactions tend to produce species (e.g., SO_2 and H_2SO_4 on Venus, O_3 and H_2O_2 on Mars) which are distinctly non-equilibrium with respect to surface minerals and can therefore potentially react with and/or be incorporated into the regolith. The high pressures and temperatures at the surface of Venus allow purely thermochemical reactions to proceed much faster in general than on Mars. These reactions allow near-thermochemical equilibrum concentrations of HCl and HF to be attained in the atmosphere. They also act as a net sink for photochemically produced SO_2 and atmospheric sulfur on Venus must therefore be replenished at least episodically by volcanism. The much lower surface temperatures on Mars make thermochemical atmosphere-surface reactions improbable for all but very reactive species (O_3, H_2O_2) but the low temperatures do facilitate simple condensation-sublimation processes with important implications for atmospheric CO_2 and H_2O. The rates of many potentially important gas-mineral reactions on Venus and Mars are poorly quantified and laboratory studies of these reactions are needed so crucial parameters such as atmospheric residence times (and thus replenishment times) for trace gases can be determined.

P41A-09 1130H INVITED

Water on Venus

T M Donahue (Department of Atmospheric, Oceanic and Space Sciences, The University of Michigan, Ann Arbor, MI 48109; 313-763-2390)

The data concerning water vapor altitude and latitudinal profiles in the Venus atmosphere and the hydrogen budget will be reviewed. This will be discussed in the context of the implications of the deuterium "enrichment" for the history of Venus water. It will be argued that Venus probably had an early ocean. A similar exercise in the case of Mars leads to the conclusion that while Mars has lost a significant fraction of its original endowment of water, it has retained a larger fraction than has Venus.

The CRAF/Cassini Initiative (P42A)

303 THURS PM
T Owen, SUNY Stony Brook
Presiding

P42A-01 1330H INVITED

The Mariner Mark II Project

R. F. Draper (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; 818-354-5684; NASAMAIL CRAF)
(Sponsor: M. Neugebauer)

The Mariner Mark II (MMII) Project is NASA's new initiative for the exploration of the solar system's primitive bodies and outer planets. The first two uses of the new MMII multimission spacecraft, which will be described in this talk, will used be for the Comet Rendezvous Asteroid Flyby (CRAF) and the Cassini missions. CRAF will fly by the asteroid Hamburga, rendezvous with (i.e., match the solar orbit of) the short-period comet Kopff, orbit its nucleus, send an instrumented penetrator/lander into the comet's surface, and then study the properties of the coma and tail as the comet becomes active. The Federal Republic of Germany is a partner in the CRAF mission. Cassini will fly by the asteroid Maja, fly by Jupiter, and then go into orbit about Saturn for a four-year study of the planet, its satellites, its magnetosphere and its ring system. Cassini will also deliver a probe, provided by the European Space Agency, into the atmosphere of Saturn's moon Titan.

P42A-02 1400H INVITED

The Comet Rendezvous Asteroid Flyby Mission

M. Neugebauer (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; 818-354-2005; SPAN JPLSP::MNEUGEB)

The science payload tentatively selected for flight on the Comet Rendezvous Asteroid Flyby mission (CRAF) includes instruments for remote sensing of the asteroid and comet target, an instrumented penetrator to be fired into the surface of the comet's nucleus, instruments for the collection and on-board analysis of cometary grains, a mass spectrometer for studying gas in the comet's coma, and an array of plasma instruments. The capabilities of these instruments and the strategy for using them to address fundamental questions concerning the origin and evolution of the solar system, chemical evolution in space, and several poorly understood astrophysical plasma processes will be described.

P42A-03 1430H

The CRAF-Cassini Initiative

T Owen (Department of Earth and Space Sciences, State University of New York, Stony Brook, NY 11794-2100; 516-632-8188)

In collaboration with the European Space Agency (ESA), NASA is proposing a joint mission to Saturn with a launch in 1996. ESA would build a probe to descend through Titan's atmosphere to the satellite's surface, while NASA would build the Saturn orbiter, to spend four years making observations of the magnetosphere, satellites, rings, and the planet itself. Scientists from Europe and the United States will be able to propose experiments on both probe and orbiter. A strawman payload for both components has been studied and promises a rich yield of new scientific discoveries.

Mars (P42B)

303 THURS PM
B Bills,
Lunar and Planetary Institute
Presiding

P42B-01 1530H

The Behavior of Volatiles on Mars During Periods of Low Obliquity

B. M. Jakosky (Dept. of Geological Sciences and Laboratory for Atmospheric and Space Physics, U. of Colorado, Boulder, CO 80309-0392)

The Mars orbital obliquity oscillates with periods of 10^5 and 10^6 years, with values reaching as low as about 15°. At such values, the polar caps receive much less insolation, and a year-round covering of CO_2 frost is expected. Contrary to past predictions, however, it would be expected only on one cap rather than both. The annual energy budget represents a balance between wintertime condensation and summertime sublimation. It is extremely unlikely that both poles would independently prefer the exact same atmospheric pressure, especially given differences in topography, surface physical properties, and frost albedo; all of the annual frost would eventually migrate to one polar cap. With the other cap losing its CO_2-frost cover during summer, an underlying water-ice cap can heat up and sublimate water into the atmosphere. Based on peak summertime temperatures and water-vapor equilibrium, assuming a water-frost albedo like that of the current northern residual cap, the peak atmospheric column water-vapor abundance would be about 3 pr µm; it may not drop below 50 pr µm, depending on whether the perihelion or aphelion summer cap is exposed. These values imply significant exchange of water between poles even at low obliquity, and have implications for the atmospheric chemistry at such times.

P42B-02 1545H

A Numerical Simulation of Climate Changes During the Obliquity Cycle on Mars

L M Francois, J C G Walker and W R Kuhn (All at: Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI 48109)

A one-dimensional seasonal energy balance climate model has been developed for the Martian surface. This model takes into account the greenhouse warming of carbon dioxide, the meridional transport of heat, the CO_2 condensation and sublimation cycle, and its adsorption in the regolith. It reproduces quite well the observed seasonal change of the atmospheric CO_2 pressure on present-day Mars.

The yearly-averaged temperatures calculated from this climate model at different obliquities are used to estimate the importance of CO_2 exchanges between the regolith and atmosphere-cap systems during the obliquity cycle. The role of meridional heat transport and greenhouse warming is analyzed and shown to be important.

The model is also used to describe the climatic effects of the obliquity cycle in the remote past of the planet, when the solar luminosity was lower and the atmospheric CO_2 pressure was higher. the possible presence of liquid water at some point on the planetary surface in the Martian history is discussed.

P42B-03 1600H

Vertical Distribution of Martian Atmospheric Water Vapor

H M Hart (Dept. of Astrophysical, Planetary and Atmospheric Sciences, U. of Colorado, Boulder, CO 80309-0391)
B M Jakosky (Dept. of Geological Sciences and Laboratory for Atmospheric and Space Physics, U. of Colorado, Boulder, CO 80309-0392)

The Viking Orbiter Mars Atmospheric Water Detector measured reflected solar radiance in three absorption regions and two continuum regions within the 1.4-μm band of water vapor. The three atmospheric transmittances obtained from the measurements are compared with the computation of transmittance for a model atmosphere to determine water vapor column abundance (W), effective pressure (P), and effective temperature (T). We have used a multi-layered single-scattering model to demonstrate that, for cases where the atmosphere is relatively clear ($\tau_{visible} \leq 0.5$), scattering plays a minor role in the atmospheric transmittance. The measured 1.4-μm absorptions exhibit only a weak dependence on temperature; we have therefore used an atmospheric model consisting of a single absorbing layer over a reflecting surface, and constrained the temperature to the most likely value. We solve for the parameters W and P, where P is the average pressure of the water vapor and thereby represents a measure of the vertical distribution of water vapor. Observations were binned temporally to obtain seasonal information, and spatially to decrease noise errors. The temporal bins extend from L_s=0° through L_s=180°. The results indicate that in northern equatorial regions in early spring (L_s=0°) atmospheric water is distributed nearly uniformly with altitude; as spring progresses (L_s=90°) the water vapor becomes concentrated towards the surface. Results for the zonal averages, and interpretation of the seasonal changes in vertical distribution will be presented.

P42B-04 1615H

A Revised Estimate of the Mean Moment of Inertia of Mars: Compositional and Paleoclimatic Implications

Bruce G. Bills (Lunar and Planetary Institute, Houston TX 77058)

The mean moment of inertia of Mars is an important, but poorly known parameter. In the absence of direct observations of the axial precession rate, present estimates are based on an assumed partitioning of the observed second degree gravity field into hydrostatic and nonhydrostatic components, and then using the Darwin-Radau relation to estimate the mean moment from the hydrostatic component. The only legitimate constraint on the decomposition is that the hydrostatic component is an oblate spheroid. If the observed oblateness were entirely hydrostatic, the resulting mean moment estimate would be 0.377 MR^2. The generally accepted value of 0.365 MR^2 is obtained by assuming that the nonhydrostatic component is a prolate spheroid with an equatorial axis of symmetry. Both statistical arguments and a comparison with the Earth, Moon and Venus suggest that a more plausible configuration for the nonhydrostatic component is a maximally triaxial ellipsoid (intermediate principal moment exactly midway between greatest and least). If that were the case for Mars, the remaining hydrostatic component would be consistent with a mean moment of 0.345 MR^2. While a 5% change may not seem especially significant, a downward revision in the moment of inertia by this amount would have major implications for the composition and obliquity history of Mars.

Virtually all of the models for the composition of Mars which have been published in the last decade have used a moment value of 0.365 MR^2 as a constraint on the radial density profile. This, in conjunction with a mean density of 3933 kg m^{-3} suggests (but does not demand) an STP mantle density of 3500-3600 kg m^{-3}. This particular moment value has thus contributed to the consensus view that the mantle of Mars is enriched in iron, relative to the Earth's mantle. If the actual moment value is as low as 0.345 MR^2, a rather different picture emerges. In that case, the mantle density must be quite close to 3200 kg m^{-3}. A density that low would require the mantle composition to be essentially devoid of iron. Clearly, intermediate values of the moment would allow intermediate compositions. The main point is that the range of plausible values for the mean moment of inertia is large enough that no useful compositional inferences may be drawn from it.

It has been suggested that, prior to formation of Tharsis, the obliquity of Mars may have undergone very large periodic variations due to a resonance between the axial and orbital precession rates. This mechanism has been invoked as a major factor in the climatic evolution of Mars. The primary basis for this secular spin-orbit resonance hypothesis consists of two simple observations. The first is that an estimate of the present axial precession rate (7.47 arcsec/yr) lies between two of the eigenfrequencies for orbital precession (6.77 and 7.75 arcsec/yr). The second observation is that estimates of the contribution Tharsis makes to the gravitational oblateness of Mars, taken at face value, suggest that prior to the formation of Tharsis the axial precession rate might have been in exact resonance with the slower of the two orbital terms. While such a resonance may have taken place, direct observational support for it is lacking. The main point here is that uncertainty in the present value of the axial precession rate (due to uncertainty in the mean moment of inertia) is nearly as large as the putative effect of the formation of Tharsis via a change in gravitational oblateness.

P42B-05 1630H

Tectonic Influences on the Development of Mangala Valles, Mars

J R Zimbelman (CEPS, NASM, Smithsonian Institution, Washington, DC 20560)

The orientation of channels and deposits within Mangala Valles, Mars, is strongly controlled by tectonic modification of the materials over which the Mangala flood events moved. Geologic mapping of the southern reaches of Mangala Valles (-7.5° to -22.5°, 145° to 150°W) at a scale of 1:500,000 reveals the close association between channel deposits and several prominent scarps within the ancient materials that separate the Mangala Valles deposits from the younger lava flows of Daedalia Planum. Between latitudes -18° and -10° the scarps have a dominant north-south orientation and the Mangala Valles deposits rest against the eastern margin of the Noachian materials in which the scarps are located. Between latitudes -10° and -8° some scarps follow arcuate paths with an eastward facing concavity while other scarps maintain the dominant north-south trend. Mangala Valles makes a bend to the northwest near the location where the arcuate scarps become prevalent. Both the north-south oriented scarps and the arcuate scarps seem to be related to a proposed ancient impact basin centered in Daedalia Planum (Craddock et al., LPS XIX, pp. 213-214, 1988), an event that established the major structural trends within the oldest materials exposed in the region. The Mangala Valles flood events followed the minimum topographic gradient around the topography associated with the basin event.

P42B-06 1645H

The Dust Environment of Mars

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A meteorite impact on any of the Martian satellites can eject large amounts of micron and submicron sized dust grains, which begin orbiting around Mars. In the present study, the lifetime of these particles will be studied due to the solar radiation pressure. However, we will point out that as the small grains move in a radiative and plasma environment they will collect surface charge and they will respond to the polarized electric field generated by the solar wind flow around Mars. Using a simple plasma and field environment model, we will determine the spatial and charge distribution of the small dust grains.