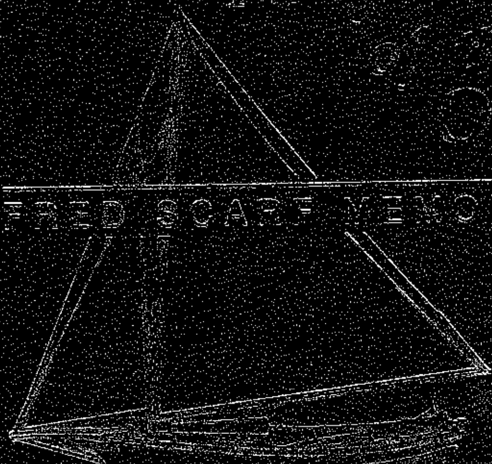
Magnetospheres of the Outer Planets



FRED SCARF MEMORIAL SYMPOSIUM

Annapolis, Maryland
August 20-24, 1990

Magnetospheres of the Outer Planets

FRED SCARF MEMORIAL SYMPOSIUM

Annapolis, Maryland
August 20-24, 1990

Sponsored by:

The Laboratory for Extraterrestrial Physics

Goddard Space Flight Center

Solar System Exploration Division

&

Space Physics Division

National Aeronautics and Space Administration

Program Committee

Dr Alex J. Dessler
Dept Space Physics & Astronomy
Rice University
Houston, TX 77251

Dr Ralph L. McNutt
Center for Space Research
Massachusetts Institute of Technology
Cambridge, MA 02139

Dr William P. Kurth
Department of Physics and Astronomy
University of Iowa
Iowa City, IA 52242

Dr Richard M. Thorne
Dept Atmospheric Sciences
UCLA
Los Angeles, CA 90024

Dr Barry H. Mauk
Johns Hopkins University
Applied Physics Lab
Laurel, MD 20707

Dr Vytenis M. Vasyliunas
Max Planck Institut fur Aeronomie
Postfach 20
D-3411 Katlenburg-Lindau 3, FRG

Local Organizing Committee

NASA/Goddard Space Flight Center
Greenbelt, MD 20771

Dr John E. P. Connerney

Dr Michael D. Desch

Mr Michael L. Kaiser

Dr William M. Farrell

Ms. Stephanie A. Myers

Meta Hutchison-Frost, Conference Coordinator, Westover Consultants Inc.

Magnetospheres of the Outer Planets
Fred Scarf Memorial Symposium
Annapolis, MD August 20–24, 1990
PRELIMINARY PROGRAM

time	Monday	Tuesday	Wednesday	Thursday	Friday
09:00	Intro	*Sat Int. &*	*Radio &*	*Neptune*	*Auroral*
	Scarf	*Io Torus*	*Plasma Wave*		*Emissions*
09:30	Kurth	Neubauer	Gurnett	McNutt	Prange
	Global Models	SI-2	RPW-2	N-2	A-2
10:00	*Transport*	SI-3	RPW-3	N-3	A-3
	Birmingham	SI-4	RPW-4	N-4	A-4
10:30	BREAK	BREAK	BREAK	BREAK	BREAK
11:00	GT -2	SI-5	RPW-5	N-5	A-5
	GT -3	SI-6	RPW-6	N-6	A-6
11:30	GT -4	SI-7	RPW-7	N-7	A-7
	GT -5	SI-8	RPW-8	N-8	A-8
12:00		SI-9	RPW-9	N-9	
12:30	LUNCH	LUNCH	LUNCH	LUNCH	LUNCH
01:00					
					Galileo
01:30	GT-6	SI-10	RPW-10	N-10	Johnson
	GT-7	SI-11	RPW-11	N-11	*Ulysses*
02:00	GT-8	SI-12	RPW-12	N-12	Wenzel
	GT-9	SI-13	*Comparative*	N-13	*Cassini*
02:30	GT-10	SI-14	*Magnetosph.*	N-14	Ip
	BREAK	SI-15	Williams	BREAK	F-4
03:00		*BREAK*	BREAK		F-5
	Satellite			N-15	Discussion
03:30	*Interactions*	*Rings &*	CM-2	N-16	Next Meeting
	Cheng	*Dusty Plasmas*	CM-3	N-17	
04:00	S-2	Goertz	CM-4	N-18	
	S-3	R-2	CM-5	N-19	
04:30	S-4	R-3	CM-6	N-20	
		R-4	CM-7		
05:00		R-5	CM-8		
		R-6	CM-9		

MONDAY, August 20, 1990

09:15 **Fred Scarf** by Kurth

09:45 *GLOBAL MODELS AND TRANSPORT MECHANISMS – A.J. Dessler, chair*

GT-1 **Global Models** by Birmingham [INVITED]

10:30 BREAK

GT-2 **Thermodynamic Conditions in Neptune's Rotating Magnetosphere** by Voigt

GT-3 **Field aligned currents and twisted magnetic fields in rapidly rotating planetary magnetospheres** by Kivelson and Walker

GT-4 **Collisionless Reconnection in Jupiter's Nightside Magnetosphere** by Zimbardo

GT-5 **Ionospheric Conductivity Effects: Implications for the "Plasma Edge" at Uranus** by Hammond and Kivelson

12:00 LUNCH

GT-6 **Jovian Plasma Transport via Transient Flux Tubes** by Pontius and Hill

GT-7 **Interchange Motions and Plasma Transport in the Jovian Magnetosphere** by Fazakerley and Southwood

GT-8 **High Resolution Measurements of Density Structures in the Jovian Plasma Sheet** by Ansher, Kurth, Gurnett and Goertz

GT-9 **Radial Diffusion in Outer Planet Radiation Belts: Evidence for the Ionospheric Dynamo Mechanism** by Hood

GT-10 **Drift-wave Instability in the Io Plasma Torus** by Hill and Huang

02:45 BREAK

03:15 SATELLITE INTERACTIONS – J.F. Cooper, chair

S-1 **Satellite Interactions: Charged Particle Absorption** by Cheng [INVITED]

S-2 **Satellite and Ring Sweeping in Magnetospheres of the Outer Planets** by Paranicas and Cheng

S-3 **Energetic Electrons at Uranus: Simultaneous Radial and Pitch-Angle Diffusion in a Satellite Limited Radiation Belt** by Selesnick and Stone

S-4 **Applications of Energetic Particle Spectroscopy to the Investigation of Ring and Satellite Systems in the Outer Planet Magnetospheres** by Cooper

05:00 SOCIAL HOUR AT CALVERT HOUSE INN

TUESDAY, August 21, 1990

09:00 SATELLITE INTERACTIONS AND *IO* TORUS – F. Bagenal, chair

SI-1 **Satellite Interactions** by Neubauer [INVITED]
SI-2 **Slow Mode 'Wings' of a Moving Conductor in a Magnetized Plasma** by Krisko and Hill
SI-3 **A Model for the Magnetic Field Distribution Near the Ionopauses of Titan and of Triton** by Ip and Axford
SI-4 **The Io Plasma Torus Dawn-dusk Brightness Asymmetry** by McGrath, Moos, Strobel and Ballester

10:30 BREAK

SI-5 **Fabry-Perot Observations of the Jupiter Plasma Torus in Nov-Dec, 1988** by Scherb, Roesler, Woodward and Oliversen
SI-6 **Chaotic Dynamics of the Io Torus** by Matheson
SI-7 **Probable Detection of [OI] 6300 Emission from Io** by Scherb and Roesler
SI-8 **Split Personality for Io's Sodium Cloud?** by Schneider, Trauger and Brown
SI-9 **Io Plasma Torus Characteristics Derived from Optical Imaging of Jupiter's Neutral Sodium Magneto-Nebula** by Flynn, Hughes, Mendillo and Baumgardner

12:15 LUNCH

SI-10 **A Jovian Magnetic Octopole Model Constrained by the Cold Plasma Torus** by Trauger, Schneider, Garrett, Evans and Brown
SI-11 **The Source Position of Jovian 'Auroral' Hiss** by Morgan, Gurnett, Kurth and Bagenal
SI-12 **Flow Near Io and Generation of Plasma Perturbations** by Kivelson, Linker and Walker
SI-13 **Escape of Gases from Io and their Impact on the Planetary Magnetosphere** by Smyth
SI-14 **Empirical and Theoretical Models of the Io Plasma Torus** by Bagenal and Richardson
SI-15 **Modeling the Io Plasma Torus: A Progress Report** by Smith and Bagenal

03:00 BREAK

03:30 *R*INGS AND DUSTY PLASMAS – T.G. Northrop, chair

R-1 **Rings and Dusty Plasmas** by Goertz [INVITED]
R-2 **The Saturnian Ring-Ionosphere Plasma Environment** by Wilson
R-3 **Dynamics and Origin of Saturn's E Ring** by Horanyi, Burns, Hood and Larson
R-4 **Shadow Resonance for Circumplanetary Dust** by Horanyi and Burns
R-5 **Grain Impacts During Ring Plane Crossings at Neptune** by Pedersen, Meyer-Vernet, Aubier and Zarka
R-6 **Water Group Plasma in the Magnetosphere of Saturn** by Eviatar and Richardson

WEDNESDAY, August 22, 1990

09:00 RADIO & PLASMA WAVE – A. Roux, chair

RPW-1 **Radio and Plasma Waves** by Gurnett [INVITED]

RPW-2 **A Search for Short-Term Variations in the Synchrotron Emission from Jupiter** by Bolton, Gulkis, Klein, de Pater and Heiles

RPW-3 **Source Structure of Jovian Decametric Radiation and Interplanetary Scintillation** by Maeda

RPW-4 **A Three-Dimensional Ray Tracing Study of the Jovian Hectometric Radiation** by Ladreiter and Leblanc

10:30 BREAK

RPW-5 **Emission Cones in Jupiter's Hectometric Radiation** by Barrow

RPW-6 **Ray Tracing of Jovian Kilometric Radiation — Revisited** by Green, Aist, Thieman, Fung and Candey

RPW-7 **New Results on the Source Locations, Beaming, and Spectrum of SKR** by Galopeau and Zarka

RPW-8 **Evidence for Saturn's Magnetic Field Anomaly from SKR Observations** by Galopeau, Ortega-Molina and Zarka

RPW-9 **An Analysis of the Source Location of Broadband Smooth Radio Emission at Uranus** by Gulkis, Menietti and Curran

12:15 LUNCH

RPW-10 **Possible 2nd Harmonic Emission at Uranus and Jupiter** by Menietti and Curran

RPW-11 **Generation Mechanisms of Smooth and Bursty Radio Emissions in Planetary Magnetospheres** by Wong

RPW-12 **Bursty Radio Emissions at Uranus and Neptune: The Possible Role of Surface MHD Waves as a Free Energy Source** by Farrell, Curtis and Lepping

RPW-13 **The University of Florida Jovian S Burst Catalog** by Reyes, Flagg, Greenman and Carr [POSTER]

RPW-14 **Monitoring and Modeling Jupiter's Hectometric Radiation** by Wang and Carr [POSTER]

02:15 BREAK

02:45 COMPARATIVE MAGNETOSPHERES – B. Mauk, chair

CM-1 **Energetic Particles in Planetary Magnetospheres** by Williams [INVITED]

CM-2 **A Comparison of the Energetic Particle Composition in the Magnetospheres of the Outer Planets and Earth** by Hamilton

CM-3 **Plasma Sources in Planetary Magnetospheres** by Krimigis

CM-4 **Planetary Magnetospheric Substorms** by Williams

CM-5 **Improved Estimates of High Energy Particle Number Density and Pressure in the Jovian Plasma Sheet from Comparison Between Particle and Magnetic Data** by Khurana and Kivelson

CM-6 **Spectrum of Planetary Radio Emissions** by Zarka

CM-7 **A Comparison of the Fine Structure in the earth's AKR Emission to SSA Emission of the Outer Planets** by Thieman, Green, Aist, Fung, and Candey

CM-8 **Shocklets Upstream of Saturn** by Orlowski and Russell

CM-9 **Upstream Waves at the Outer Planets** by Smith, Wong, Goldstein and Zhang

06:30 CHESAPEAKE BAY CRUISE – CITY DOCK

THURSDAY, August 23, 1990

09:00 NEPTUNE – R. Selesnick, chair

N-1 **The Magnetosphere of Neptune: An Overview** by McNutt [INVITED]
N-2 **Energetic Protons in the Magnetosphere of Neptune** by Looper, Selesnick and Stone
N-3 **Hot Plasma Parameters in Neptune's Magnetosphere** by Krimigis, Mauk, Keath, Kane, Cheng, Armstrong, Gloeckler and Lanzerotti
N-4 **Low-energy Plasma in Neptune's Magnetosphere** by Richardson, Belcher and McNutt

10:30 BREAK

N-5 **Magnetic Field of Neptune** by Connerney, Acuna and Ness
N-6 **The Magnetic Field of Neptune: Field-geometric invariants controlling particle absorption by rings and moons** by Acuna, Ness and Connerney
N-7 **Energetic Charged Particle Angular Distributions Near ($r<2\ R_N$) and over the Pole of Neptune** by Mauk, Kane, Keath, Cheng, Krimigis, Armstrong and Ness
N-8 **Voyager-2 Plasma Electron Observations at Neptune** by Sittler, Huang and Belcher
N-9 **Evidence for Large Plasma Densities Within 3 R_N of Neptune** by Kurth, Gurnett, Granroth, Barbosa and Moses

12:15 LUNCH

N-10 **Neptune's Polar Cusp Region: Observations and Magnetic Field Analysis** by Lepping, Burlaga, Lazarus, Siscoe, Vasyliunas, Szabo, Steinberg, Ness and Krimigis
N-11 **A Search for Magnetic Signatures of Triton's Interaction with the Neptunian Magnetosphere** by Neubauer and Ness
~~N-12~~ **Voyager-2 at Neptune: Phenomenology of Radio Emissions** by Pedersen, Aubier, Boischot, Lecacheux and Zarka
N-13 **Source Location of Neptune's Kilometric Radio Emission** by Rabl, Rucker and Kaiser
N-14 **Source Location of Smooth Neptunian Kilometric Radiation** by Ladreiter and Leblanc

02:45 BREAK

N-15 **Localization of the Source of the Neptunian Auroral Emission** by Lecacheux and Boischot
N-16 **Neptunian Bursty Radio Emission** by Boischot, Genova and Zarka
N-17 **Field-independent Source Localization of Neptune's Radio Bursts** by Farrell, Desch and Kaiser
N-18 **Identification and Localization of Anomalous Neptune Radio Emission** by Desch, Farrell and Kaiser
N-19 **What is Driving the Bursty Neptune Radio Emission?** by Desch, Farrell and Kaiser
N-20 **The Sidereal Rotation Period of Neptune** by Lecacheux, Zarka, Desch and Evans

06:30 BUSES FOR BAY RIDGE INN CRAB FEAST

FRIDAY, August 24, 1990

09:00 AURORAL EMISSIONS [T. Kostiuk, chair]

A-1 **Auroral Emissions from the Outer Planets: Their Relationship to Magnetospheric Processes** by Prange [INVITED]

A-2 **Longitudinal Modulation of Jovian Auroral Activity Modeled from IUE Observations of H_2 Emission** by Livengood and Moos

A-3 **Jupiter's Doppler-shifted Auroral Emissions** by Clarke and Waite

A-4 **Jovian HUV H_2 Aurora: Correlations** by Peterson, Harris and Clarke

10:30 BREAK

A-5 **Time Variability in the Jovian Magnetosphere as Evidenced by Variations in Jupiter's Two-micron Aurorae** by Trafton

A-6 **Thermal Infrared Emissions from Jupiter's Polar Regions** by Kostiuk, Bjoraker, Espenak and Goldstein

A-7 **A Magnetospheric Model of the Jovian North and South Polar Infrared Hot Spots** by Zhan and Dessler

A-8 **The Uranian Aurora** by Herbert and Sandel

12:00 LUNCH

01:15 FUTURE MISSIONS – J.E.P. Connerney, chair

F-1 **Galileo** by Johnson and Yeates [INVITED]

F-2 **The Ulysses Mission — Its Contribution to Studies of the Jovian Magnetosphere** by Wenzel [INVITED]

F-3 **Cassini** by Ip [INVITED]

F-4 **Imaging Saturn and its Moons using Energetic Neutral Atoms** by Roelof

F-5 **Determination of the Surface Composition of Volatiles for Saturn's Icy Satellites and Rings Using Cassini In Situ Plasma Observations** by Johnson, Pospieszalska and Sittler

F-6 **The Planetary Plasma Interactions Node of the Planetary Data System** by Walker, Joy, King, Cline, McPherron, Russell, Kurth and Kaiser **[POSTER]**

03:15 DISCUSSION OF NEXT MEETING [J.E.P. Connerney, chair]

Fred Scarf

William S. Kurth

Department of Physics and Astronomy, University of Iowa, Iowa City, IA 52242

Two years ago, this community decided that this meeting held to discuss the magnetospheres of the outer planets should be named in honor of our friend, Fred Scarf. Let us use this week to celebrate Fred's enthusiasm, curiosity, contributions, and companionship as we carry on the exploration of the solar system, an activity of which Fred had become so much a part. Many of the symposium attendees might not be here without Fred's untiring efforts over the past two or three decades. He has truly been a force in opening the exploration of the solar system to those of us who study not only plasma waves, but basic plasma physics and magnetospheric physics, in general. Many words have been written, and many more have been spoken of Fred's legacy to our community and our field. One cannot hope to say all and do justice to such a man in a few brief pages. But, perhaps a few observations about Fred from the perspective of a colleague, a (once) young scientist, and a friend would set the tone for this symposium in Fred's memory.

First of all, Fred Scarf was among the first to recognize that what we now call "geospace" (and the similar environments surrounding the sun and the other planets) is a plasma and that plasma physics must be called upon in order to fully understand these environments. There was a time, even recently, when the study of waves in plasmas was a mysterious undertaking, understood by only a very few; the rest of the world sometimes tolerated us and secretly hoped we would soon go away. But Fred, among others, would not allow the world to get off so easy. Over the years he managed to convince many that it *is* important to understand that waves and plasmas interact and can have profound effects. Now, of course, there are still a few out there who need to be converted, but great progress was made by Fred in reducing the numbers of those heretics. Indicative of his success, one can refer to a set of viewgraphs describing a possible Pluto Flyby mission which is being studied by the Solar System Exploration Division of NASA. This is to be a minimal spacecraft to complete the discovery phase of the planets in the solar system. In view of its very limited scope it is quite surprising to find that any fields and particles instruments were included in the payload, at all; there were three. It is even more surprising to discover that in all of their wisdom, the Discovery Program Science Working Group thought that, in addition to a magnetometer and electron spectrometer, a simple plasma wave receiver should be included in the payload in order to study the bow shock of the planet! We can only attribute this inclusion to Fred's diligence, even though he was not a part of this particular group.

While Fred was first a sound theorist and also a foremost experimentalist who contributed greatly to the understanding of space plasmas and their instabilities, much of what we remember Fred for was not his science, but his humanistic approach to all aspects of his life. Not only was Fred a leading scientist, but he was a statesman, a politician, a diplomat, a colleague, a loving husband and father, and perhaps most of all, a friend. Fred and his Soviet colleagues were way ahead of perestroika in terms of opening useful collaborations between the Soviet Union and the United States and other western nations in space exploration. He, likewise, was a principal in promoting joint ventures with the Europeans and the Japanese. While much of this work was exemplified by his participation in the Interagency Consultative Group, his personal efforts predated the IACG significantly. Fred was always known as a fair dealer in building relationships, whether between countries, agencies, and institutions, or simply with other individuals. He was a leader when it came to opening up data sets for distribution; nothing pleased him more than to see someone come up with an innovative way of incorporating his plasma wave data into a new theoretical or experimental framework. He was genuinely interested in his fellow scientists and was the first to express concern at the slightest hint of ill health or misfortune by any of the people he had contact with, even if the relationship was only remote.

While Fred worked outside of a University setting for much of his career, he took a special interest in young scientists and continuously championed the cause for young people to find roles in what often seemed like an ever-narrowing list of prospective new projects. He foresaw the day when the original pioneers, like himself, would need to be followed by a new generation of scientists. He worried about how the new generation would find adequate experience and how they would be groomed to take on the new responsibilities. He was always first to suggest that the young scientist have a chance to prove himself and was always willing to trust in the newcomer to live up to the task at hand. Fred was supportive of the young people around him and never tired of offering encouragement, constructive criticism, or help to them. It was clear that Fred had not lost sight of his own experiences as a young space physicist and could relate to the problems of a person trying to make his mark in a field already crowded with living legends.

Fred was also a great publicist for the field of space plasma physics. By popularizing the use of plasma wave audio tapes at Voyager press briefings, he was able to bring a very complex topic down to reality for millions of laymen throughout the world. His famous recording of the Jovian bow shock washing over Voyager 1 in a reverberating crescendo rapidly changed the media's concept of this structure from an esoteric construct of a clique of seemingly aloof scientists to a very real phenomena which marked the highly dynamic interaction between the supersonic solar wind and the Jovian magnetosphere. Other 'sounds' Fred played for the press may have served more as entertainment than as instructional materials, but even these made those 'other 10' experiments on Voyager seem much more real and an important part of the Voyager mission. Fred liked to pick the most interesting 'sound' from an encounter, especially one which was not understood from a plasma wave mode point of view, and play it for the public. He would then tell of the puzzle which this sound created for the scientists. In one radio program, the interviewer actually solicited suggestions for explanations from the audience; Fred kept a file of the responses which were subsequently sent in and derived a great deal of pleasure in recounting these explanations to his friends. While he understood that most of these suggestions had no physical basis, the very fact that he had elicited enthusiastic, creative thoughts on the subject of plasma waves in space plasmas from laymen made his day, over and over again.

It has been said, recently, by Charlie Kennel, that Fred's two main loves, after his family, were space science and space scientists. And of these two, Fred's love of space scientists was the greatest. Fred was lightning-quick to predict accurately what the reaction of various colleagues would be to different situations which would arise and he was always thinking ahead of how to use such information to obtain a desired effect, steer the colleague into a mutually beneficial course of action, or to avoid difficult situations. Now, such a talent in the wrong hands could have profound negative effects. But Fred was a fair individual and placed the welfare of his fellow colleagues on an even footing with his own. Of course, Fred was competitive, but was so in a good-natured manner and he always sought to compete fairly. On the other hand, Fred often failed to take "No!" for an answer and sometimes found that perseverance paid off, as in the case of the addition of his investigation for Voyager.

Fred had been instrumental in the exploration of space plasma wave phenomena at the Earth, Venus, Jupiter, Saturn, and Uranus. He took great pride in 'stealing' ISEE 3 to study the deep geomagnetic tail and eventually inaugurate *in situ* studies of comets. At the time of his death, he was participating in the initial stages of the Phobos 1 and 2 missions to continue his explorations to Mars and to plan additional investigations of that planet. He was also slated to chair a science working group to finalize plans for a Solar Probe . Of course, Fred had the best seat of all for the Neptune encounter and it is certain that he has had all of the mysteries in the Neptunian wave spectrum figured out for nearly a year now. As we remain behind attempting to catch up to him in understanding the physics of the outer planets' magnetospheres, we should strive to remember and to use his work ethic, enthusiasm, fairness, and friendship. Let us hope that his example will guide us for many years to come.

Global Models and Transport Mechanisms
(GT)

Global Modeling of the Magnetospheres of the Outer Planets

Thomas J. Birmingham

Planetary Magnetospheres Branch, Goddard Space Flight Center, Greenbelt, MD 20771

To many, 'global magnetospheric modeling' connotes the depiction via a large, high speed computer of the evolutionary development of an MHD system consisting of a planetary dipole placed in the flow of a supersonic single fluid (solar wind) plasma. Such modeling has been carried out over the last decade for Earth with interesting results, the physical validity of which, however, has been vigorously debated. Uranus and Neptune are situations where, in contrast with Earth, the dipole can point substantially into the solar wind. Such geometries have been explored to a limited extent by appropriately setting the magnetic obliquity, and the unique results of doing so will be presented and discussed.

More has been done in the area of magnetostatic models. These are more limited in spatial scope, usually depicting in a two-dimensional, time-independent manner the day or night side regions interior to the magnetopause, which is treated as a boundary condition. While some of this work, like the simulations discussed in the previous paragraph, is a direct conversion of terrestrial work, there have been a few efforts wherein the uniqueness of the outer planetary magnetospheres, e.g., observationally based magnetic models, has been incorporated. Jupiter's magnetosphere, with its high beta, centrifugally stressed plasma remains of interest, and recent attempts to understand azimuthal currents in conjunction with its observed multi-ionic composition will be described in this magnetostatic context.

On a less global scale are models of the radial structure of energetic particle fluxes. The physics here dates to the earliest exploration of Earth's Van Allen belts and is basically adiabatic particle motion viewed statistically. Of unique interest in the case of the outer planets are the particle signatures, or absence thereof, of moons, rings, tori, etc. interior to the magnetospheres. Their presence reflects the relative importance of dynamical (electric field) processes, which move the charged particles radially, and the wipe out effect of such magnetospheric 'debris'. Interesting inferences have been drawn, especially about the absorption agents, and recent work will be described.

Finally, as time permits, recent simulations of the bowshock-magnetopause structure of radially extended, high Mach number magnetospheres will be discussed and some interesting and unique ideas about global electrodynamics as well.

My general perspective is that global models are very important for the synthesis of data of quite different types and for inferring the invisible from the observed. This review will be presented from such a viewpoint.

Thermodynamic Conditions in Neptune's Rotating Magnetosphere

G.-H. Voigt, Department of Space Physics and Astronomy, Rice University, Houston, Texas, 77251

The Voyager 2 spacecraft found the Neptunian magnetosphere periodically changing every eight hours between a "pole-on" magnetosphere with only one polar cusp pointing into the solar wind stream and an "Earth-type" magnetosphere with two polar cusps. In the "pole-on" configuration, the tail current sheet has an almost circular shape with plasma currents closing entirely within the magnetospheric cavity. Eight hours later the tail current sheet assumes an almost flat shape with plasma currents touching the magnetotail boundary. Here the plasma currents close over the tail magnetopause.

I have investigated plasma properties and thermodynamic conditions of Neptune's magnetosphere in a simplified two-dimensional MHD equilibrium model. I found that, for $P(A) \propto A^2$, the free energy F in the tail region of the two-dimensional model becomes independent of the dipole tilt angle. It is tempting to conjecture that the Neptunian magnetotail might assume quasi-static equilibrium states that make the free energy of the system independent of its daily rotation. This hypothesis seems to support the Voyager 2 plasma observations which indicate that Neptune, as compared to Earth, has a relatively empty magnetosphere.

Of course, I have no solid proof that the free energy is the only thermodynamic quantity the Neptunian magnetosphere might conserve in the course of its daily rotation. One can formulate other thermodynamic constraints, for example, adiabatic changes during the planet's daily rotation. In that case, the pressure function $P(A)$ has to become a function of the dipole tilt angle ψ, that is $P = P(A[\psi], \psi)$ which leads to $\delta F \neq 0$. What thermodynamic quantitiy the slowly rotating Neptunian magnetosphere would like to conserve in that case remains an open theoretical problem, because we do not even know whether the plasma is transported toward the inner magnetosphere via convection or diffusion.

Field aligned currents and twisted magnetic fields in rapidly rotating planetary magnetospheres

Margaret G. Kivelson and Raymond J. Walker
UCLA Institute of Geophysics and Planetary Physics Los Angeles, CA 90024-1567

Large scale bending and twisting of the magnetic field is an observed feature of the magnetospheres of the outer planets. Such bending and twisting is associated with field aligned currents coupling the magnetosphere and the ionosphere. Here we will use MHD simulation and analytic theory to relate magnetic field observations from the outer magnetospheres of Jupiter and Saturn to the currents flowing in the plasma.

COLLISIONLESS RECONNECTION IN JUPITER'S NIGHTSIDE MAGNETOSPHERE

Gaetano Zimbardo

Dipartimento di Fisica, Universitá della Calabria
87030 Arcavacata di Rende, Italy

Recently [1] it has been shown that an X-type magnetic neutral line may form in Jupiter's nightside magnetosphere as the result of the current flowing in the plasma disc. This fact suggests that a cycle of plasma convection – X line formation – plasma ejection and recovery, that occurs in the Earth's magnetosphere, may be found in Jupiter's magnetosphere as well, although differences may also be present. In this paper we consider the relevant collisionless reconnection mechanism. The magnetic configurations obtained in Ref. 1 correspond to different current disc sizes, and can be interpreted as a time sequence when we consider that the initial disc size r_{co} increases because of the plasma emitted by Io. This means that after some time the conditions for the formation of an X line are met. Still, a dissipative process is required to tear up the magnetic field and to allow reconnection. Recently, Buchner and Zelenyi showed [2,3] that the chaotization of the electron motion, due to the nonconservation of the magnetic moment as the electrons cross the quasineutral sheet, can lead to fast collisionless reconnection in the Earth's magnetotail. In their theory, enhanced pitch angle diffusion is obtained when the curvature parameter $\kappa_e = \sqrt{R_{min}/\rho_{max}} = B_z(L_z/\rho_{e0})^{\frac{1}{2}}/B_0$ decreases to $\kappa_e \simeq 1.6$. Here, R_{min} is the minimum radius of curvature of the field lines, ρ_{max} is the maximum electron Larmor radius, B_z is the magnetic field normal to the current sheet computed at $z = 0$, B_0 the parallel (tailward) field outside of the current sheet, L_z the plasma sheet half-thickness, and ρ_{e0} the thermal electron Larmor radius in the field B_0. We apply Buchner and Zelenyi's theory to Jupiter's magnetotail, using the model of Ref. 1 to compute the magnetic field components. The curvature parameter is readily obtained from the equilibrium magnetic field, and the results for κ_e show that the larger the assumed plasma disc, the larger is the range where κ_e is less than or equal to the stochasticity threshold 1.6. For instance, for $r_{co} = 120\ R_J$, $\kappa_e < 1.6$ in a region from 48 to 58 R_J, which is of the same order of $2\pi L_z \simeq 12\ R_J$. This indicates that fast magnetic field line reconnection occurs in a natural way in Jupiter's magnetosphere. As a consequence, magnetic islands are formed, with starting point in the most unstable region, which is where $|B_z|$ has a minimum. This is consistent with the *in situ* magnetic field observations, that show the signature of magnetic islands and of tearing mode instability at 60–70 R_J [4]. We speculate that these processes, differently from the Earth's case, occur in a semi-steady way.

References

[1] Zimbardo, G., *J. Geophys. Res. 94,* 8707, 1989.
[2] Buchner, J. and L.M. Zelenyi, *J. Geophys. Res. 92,* 13,456, 1987.
[3] Buchner, J. and L.M. Zelenyi, *J. Geophys. Res. 94,* 11,821, 1989.
[4] Behannon, K.W., *J. Geophys. Res. 89,* 57, 1984.

IONOSPHERIC CONDUCTIVITY EFFECTS: IMPLICATIONS FOR THE "PLASMA EDGE" AT URANUS

C. M. Hammond, M. G. Kivelson
Institute of Geophysics and Planetary Physics and Dept. of Earth and Space Sciences, University of California at Los Angeles, Los Angeles, CA 90024
R. J. Walker
Institute of Geophysics and Planetary Physics, University of California at Los Angeles, Los Angeles, CA 90024

During the Voyage 2 flyby of Uranus the PLS instrument reported a plasma edge consisting of a sharp decrease in ion and electron densities near L=5.3 inbound and L=4.8 outbound. *Selesnick* (*J. Geophys. Res.* A9, 1989) has shown that ring current shielding of the cross tail electric field may have formed this edge. As noted by *Selesnick* the location of the edge at these L values is difficult to explain if the bulk of the pressure is carried at energies greater than 500 eV. A possible explanation for the edge L values is that the shielding region is associated with field aligned currents driven by conductivity differences in the ionosphere. The L values of field lines which have both feet in the nightside varies from 2.6 to 7.3 within one uranian day but has an average of L~4.8. In addition the asymmetry in the L values of the edge between the inbound and outbound trajectories can be explained in terms of a diurnal variation changing the L shells which map to the terminator.

Jovian Plasma Transport via Transient Flux Tubes

D. H. Pontius and T. W. Hill

Rice University, Houston, Texas

Various models have been developed to explain the global transport of plasma in the Jovian magnetosphere. It is sometimes presumed that two of these, the corotating- convection and eddy-diffusion models, represent the only viable possibilities, although the transient flux tube model of Pontius and Hill [1990] has been proposed as a serious alternative. In this talk, we reexamine this latest model, in which localized plasma-content enhancements and/or depletions are produced by the interchange instability and travel large distances through the magnetosphere. Newly available data indicate rapid and substantial changes in electron density, as predicted by the model (although there is no direct method to relate density to plasma content from local observations). We argue that some combination of the proposed mechanisms is likely to be responsible for global plasma transport, depending upon the variation of key parameters throughout the Jovian system.

Interchange Motions and Plasma Transport in the Jovian Magnetosphere

A. N. Fazakerley and D. J. Southwood
Blackett Laboratory, Imperial College, London, SW7 2BZ, United Kingdom

It seems likely that centrifugal interchange instability plays a part in driving plasma transport in the Jovian magnetosphere. On a macroscopic level, transport models described in terms of radial diffusion equations give a good description of the observed plasma distribution. Although there have been a number of attempts to describe the transport in terms of interchange motions, difficulties remain. This paper will examine new ideas and discuss their implications.

High Resolution Measurements of Density Structures in the Jovian Plasma Sheet

J. A. Ansher, W. S. Kurth, D. A. Gurnett, and C. K. Goertz
Department of Physics and Astronomy, The University of Iowa, Iowa City, Iowa 52242

A recent effort to digitize the low-frequency cutoff of trapped continuum radiation in the vicinity of the Jovian plasma sheet has revealed the existence of sharply-defined density structures in the plasma sheet. These structures typically show regions where the plasma density is relatively constant, but of order 50% greater or less than the surrounding plasma. The transitions from low to high density at the boundaries of these structures occur on time scales of about 10 seconds, likely corresponding to a few ion Larmor radii. The structures themselves extend over intervals from less than a minute to more than 5 minutes, corresponding to size scales from a fraction of a Jovian radius to more than a Jovian radius, depending on the velocity of the structure relative to the spacecraft. In view of the importance of near corotational plasma flows, these structures are likely to be limited in both the azimuthal and radial dimensions and, therefore, could represent flux tubes with greatly varying plasma content. We present these observations as among the first to directly address the theoretically proposed interchange instability.

RADIAL DIFFUSION IN OUTER PLANET RADIATION BELTS: EVIDENCE FOR THE IONOSPHERIC DYNAMO MECHANISM; L. L. Hood, Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona, 85721.

The diffusive transport of trapped energetic particles across L shells by violation of the third adiabatic invariant is dominantly responsible for supplying and energizing planetary radiation belts. Within the terrestrial magnetosphere, the two major mechanisms that drive radial diffusion are (1) magnetic impulses and associated induced electric fields; and (2) time variations of the magnetospheric convection electric field. Available theoretical models predict relatively high-order L dependences for the resulting diffusion coefficients ($D(L) \sim L^6 - L^{10}$) that are generally consistent with observational constraints. At Jupiter, Saturn, and Uranus, however, modeling analyses of Pioneer and Voyager energetic particle measurements have thus far indicated relatively high amplitudes and low-order L dependences (L^2 to L^5) that are inconsistent with the terrestrially dominant mechanisms listed above. Brice and McDonough proposed in 1973 that dynamo electric field variations produced by neutral winds at ionospheric heights and mapped into the magnetosphere along magnetic field lines would provide an efficient radial diffusion mechanism in the inner Jovian magnetosphere. A theoretically predicted low-order L-dependence for the diffusion coefficient allowed a high amplitude in the inner zone ($L < 3$) as needed to supply the intense radiation belts responsible for decimetric radio emissions. Later work showed that the centrifugal interchange instability operating in the Io plasma torus also is characterized by a low-order L-dependence and probably dominates Jovian radial diffusion outside Io's orbit. At Saturn, modeling studies of Pioneer 11 and Voyager phase space density profiles assuming a range of possible loss models have indicated low-order (L^3 to L^6) L-dependences and a coefficient amplitude of $\sim 10^{-9}$ to 10^{-8} R_S^2 s^{-1} near $L = 4$. Possible diffusion processes include the ionospheric dynamo mechanism supplemented possibly by the centrifugal interchange instability in the Tethys-Dione-Rhea plasma torus. At Uranus, a study of protons and electrons with first invariants $\mu \leq 100$ MeV/G has inferred a low-order ($\sim L^3$ to L^4) L-dependence and a high amplitude in the inner zone similar to that inferred for Saturn. Due to the effective absence of a Uranian plasmasphere in the region sampled by Voyager, the centrifugal interchange instability is less viable leaving the ionospheric dynamo mechanism as the most probable candidate radial diffusion mechanism. Thus ionospheric dynamo electric fields emerge as the most probable dominant driver of radial diffusion in outer planet magnetospheres. Theoretical models for radial diffusion by this mechanism will be reviewed.

Drift-Wave Instability in the Io Plasma Torus

T. W. Hill [1] and T. S. Huang [2]
[1]Center for Space Physics, Rice University

[2]NASA Goddard Space Flight Center

We present a linear normal-mode analysis of low-frequency electrostatic drift waves in the Io plasma torus, providing a kinetic description of the centrifugal interchange instability of the outer boundary of the torus regulated by coupling to Jupiter's ionosphere. We assume a periodic potential perturbation with azimuthal wavenumber m>>1, and solve a boundary-value problem to obtain the wave dispersion relation and radial eigenfunction. For given m, the growing mode is a standing wave in the corotating reference frame. If the outer torus boundary is taken as a discontinuity, the growth rate is proportional to m times the torus flux-tube content times the ion drift frequency, divided by the Pedersen conductivity of Jupiter's ionosphere. The inner torus boundary has a modest stabilizing effect for azimuthal wavelengths greater than the radial thickness of the torus. The finite slope of the outer torus boundary has a more pronounced stabilizing effect, reducing the growth rate by the factor 2b/m where b^{-2} is the exponent of the assumed power-law decline of flux-tube content with distance. Even so, the e-folding time is of order 1 hr, much less than the inferred residence time of torus ions. The growth rate can be further reduced dramatically by the stabilizing effect of an as-yet unobserved ring-current distribution, the "impoundment" effect proposed by Siscoe et al. [1981]. Various theoretical models of global radial transport in Jupiter's magnetosphere, including corotating convection, interchange diffusion, and transient flux-tube convection, can be understood as plausible nonlinear evolutions of electrostatic drift waves. Further observations and/or numerical simulations are needed to ascertain the relative importance of these transport mechanisms.

Satellite Interactions

(S)

Satellite Interactions: Charged Particle Absorption

Andrew Cheng

Applied Physics Laboratory, John-Hopkins University, Laurel, MD 20723

Moons and rings in the magnetospheres of the outer planets absorb energetic charged particles from the radiation belts. The theory for longitudinally averaged particle absorption rates will be reviewed. Important effects arise from particle gyroradii that are not small compared to moon radii and from offset and tilt of the planetary magnetic dipole moment relative to the spin axis. Applications to charged particle absorption by the moons and rings of neptune will be presented.

Satellite and Ring Sweeping in Magnetospheres of Outer Planets

C. P. Paranicas and A. F. Cheng
Applied Physics Lab Johns Hopkins University Laurel, MD 20723

We generalize the sweeping theory of Cheng and Paonessa [1985] to include a full (x,y,z)-offset tilted dipole magnetic field and to compute the sweeping caused by rings as well as satellites of the outer planets. For the moons of Neptune, we see sweeping signatures similar to those predicted for Uranus, namely, peaks in the sweeping rates at the minimum L value of each moon and additional peaks for particles mirroring at the moon's latitude. For the rings, we see absorbtion signatures which we use to explain some features of the particle data measured by the Low Energy Charged Particle Experiment on Voyager 2.

Cheng, A.F. and Paonessa, M.P., J. Geophys. Res., 92, 1160,1987.

Energetic Electrons at Uranus: Simultaneous Radial and Pitch-Angle Diffusion in a Satellite Limited Radiation Belt

R. S. Selesnick and E. C. Stone
(California Institute of Technology, Pasadena, CA 91125)

Absorption by the satellites Miranda, Ariel and Umbriel cause large radial variations of the energetic ($\gtrsim$ 1 MeV) electron flux in the magnetosphere of Uranus. The ~60° tilt of Uranus' magnetic dipole leads to satellite orbits which cover a large range of magnetic L shell. The efficiency of electron absorption by the satellites then has a characteristic L dependence which is strongly peaked near the minimum L values of the satellite orbits. At larger L the satellites move to higher magnetic latitudes and absorb only those electrons with equatorial pitch-angles small enough not to mirror below the satellite orbits.

Radial profiles of electron phase space density, in the energy range from ~1 to ~3 MeV, have deep minima which are clearly associated with satellite absorption. Electrons with mirror points at low magnetic latitudes show minima approximately located at the satellite minimum L values. However, for electrons mirroring at higher magnetic latitudes they are displaced radially outwards. In between the regions of strong satellite absorption there is little radial variation in the electron pitch-angle distribution which is peaked at 90°. The energy spectra in this region are well represented by a power law with spectral indices near 6. Apart from the local minima there is a generally positive radial gradient in the phase space density, consistent with inward radial diffusion and energization by conservation of the first two adiabatic invariants.

If radial diffusion is the dominant mechanism for populating the radiation belt, then a significant source of energetic electrons is required to account for the local minima in the phase space density. However, the latitude variation of the satellite absorption efficiency suggests that pitch-angle diffusion is also occurring in order to maintain similar pitch-angle distributions on each side of a satellite minimum L. We suggest that diffusion due to nearly elastic pitch-angle scattering can also provide a sufficient source of electrons to account for the local phase space density minima. If a small change in energy accompanies each change in pitch-angle, as is required in scattering by resonant wave-particle interactions, then diffusion in energy and pitch-angle must occur simultaneously. The steep energy spectra can provide the source of electrons to higher energies even with a small energy diffusion coefficient. Model solutions of the simultaneous radial and pitch-angle diffusion equation, with a source due to energy diffusion, show that the phase space density minimum at a satellite minimum L can diffuse outwards at high magnetic latitudes. Thus a well-defined and detailed particle sink associated with satellite absorption can provide information on radiation belt diffusion that would otherwise be unavailable.

Applications of Energetic Particle Spectroscopy to the Investigation of Ring and Satellite Systems in the Outer Planet Magnetospheres

John F. Cooper
Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA

A rich variety of interactions exist in the outer planet magnetospheres between energetic trapped radiation and the ring and satellite systems. These interactions can be studied as probes of the material distributions and the dynamics of magnetospheric diffusion. The spatial and spectral characteristics of "macrosignatures' from satellites and diffuse dust rings, and of "microsignatures" from satellites or clumps of co-orbiting material, can be fully analysed in the large database of such signatures to be expected from the four-year Cassini Orbiter tour. Measurements of such signatures should be done with the highest possible resolution in energy and spatial position to resolve the most important characteristics of interest for planetary and magnetospheric science. These characteristics and the relevant capabilities of potential charged particle experiments for Cassini and other planetary missions are compared to determine the prospects for advancements in the field of "charged particle astronomy."

Satellite Interaction and Io Torus (SI)

Satellite Interactions

F. M. Neubauer

Institut für Geophysik and Meteorologie, Universität
Köln, 5000 Köln 41, Federal Republic of Germany

The review will cover work duing the past five years. Emphasis will be on Io. In Io's case the first three-dimensioned MHD-models have appeared which generally treat the ionosphere-atmosphere interaction in a very simple way. In addition some interesting work on the wave generation mechanisms has been published. In this context the work on the electrodynamic tether problem is also relevant. Interesting ground based observations have yielded important results on the atmosphere. The gap between plasma dynamics and classical chemistry oriented, stagnant atmosphere-ionosphere models yet remains to be closed, however. Torus physics will only be considered as far as it is directly relevant to Io. Little has been published on TItan. The Voyager 2 encounter at Triton in August 1989 has initiated some theoretical work before and after the encounter in addition to interesting observational studies which revealed a surprisingly significant ionosphere.

Slow Mode 'Wings' of a Moving Conductor in a Magnetized Plasma

P.H. Krisko and T.W. Hill

Dept. of Space Physics and Astronomy, Rice University, Houston, Tx, 77001

A conductor moving through a magnetized plasma generates a current that must close outside the conductor to maintain a steady state. The accepted mechanism for current closure is a standingAlfven (intermediate MHD mode) wave pattern, similar to the standing wave pattern attached to an obstacle in an ordinary hydrodynamic flow. This mechanism was proposed by Drell et al.(1965) to explain the drag on the Echo satellite, and has since been used to model plasma/conductor interactions of such objects as tethered satellite systems in Earth orbit and the natural satellite Io in Jupiter orbit. We argue that the mechanism for current closure is not a standing Alfven wave, but a thin standing slow mode expansion fan (SMEF). It is the small Alfven Mach number in each case that makes the SMEF steep,thin, and nearly incompressible, thus easily mistaken as an Alfven wave.

A Model for the Magnetic Field Distribution Near the Ionopauses of Titan and of Triton

W.-H. Ip and W.I Axford

Max-Planck-Institut f'ur Aeronomie D-3411 Katlenburg-Lindau FRG

One scenario of the magnetospheric or solar wind interaction with the ionospheres of Titan and Triton is that the external magnetic field lines will be draped around the respective ionospheres just like in the case of comet-solar wind interaction. The convection of the solar wind plasma through the neutral atmospheres of these two planetary satellites is subject to neutral drag effect. A simple model for the diffusion-convection process is used to approximate the locations of the magnetic field free boundaries in Titan's and Triton's ionospheres. It is shown that, for example, such a plasma boundary might form this way at an altitude of about 1200 km on the sunward side.

The Io Plasma Torus Dawn-Dusk Brightness Asymmetry

M. A. McGrath, H. W. Moos, and D. F. Strobel [1] and G. E. Ballester[2]

[1]Johns Hopkins Univ

[2]Oxford Univ

Back-to-back observations of the E (dawn) and W (dusk) ansas of the Io plasma torus at $5.9R_J$ were obtained with the International Ultraviolet Explorer (IUE) satellite for the first time in November 1989. These observations show far-ultraviolet ion emission lines which are approximately 50% brighter for the W ansa than for the E ansa. Reexamination of earlier IUE observations, made on a regular basis since 1979 (Ballester et al., 1988; Moos et al., 1985), has revealed this brightness asymmetry to be a persistent feature of the plasma torus over the duration of the IUE observations. The dawn-dusk brightness asymmetry has been observed previously by the Voyager Ultraviolet Spectrometer (Sandel and Broadfoot 1982) in extreme-ultraviolet ion emissions and by ground-based observers in optical ion emissions (Oliversen 1983; Morgan 1985). Ground-based observations of neutral sodium (Bergstralh et al., 1977) show a brightness asymmetry which is anti-correlated with that of the ion emissions, being brighter E of Jupiter instead of W. The Voyager UVS observations have been interpreted in terms of a variation in electron temperature with no measureable density enhancement (Shemansky and Sandel 1982). The observed brightness asymmetries have been cited as evidence for an E-W convection electric field in the Jovian magnetosphere (Ip and Goertz 1983; Barbosa and Kivelson 1983; Smyth and Combi 1987), and the optical brightness asymmetry has been interpretted in terms of the convective motions suggested by Barbosa and Kivelson and Ip and Goertz (Morgan 1985). Discussion of the IUE observations is presented in light of the earlier observations and their interpretation.

References

Ballester, G. E., et al., 1988. *ESA SP-281*, 79.

Barbosa, D. D., and M. G. Kivelson, 1983. *GRL 10*, 210

Bergstralh, J. T., D. L. Matson, and T. V. Johnson, 1977. *Ap J Lett 211*, L51.

Ip, W.-H., and C. K. Goertz, 1983. *Nature 302*, 232.

Moos, H. W., T. E. Skinner, S. T. Durrance, P. D. Feldman, M. C. Festou, and J.-L. Bertaux, 1985. *Ap J 294*, 369.

Morgan, J. S., 1985. *Icarus 63*, 243.

Oliversen, R. J., 1983. PhD thesis, University of Wisconsin-Madison.

Sandel, B. R., and A. L. Broadfoot, 1982. *JGR 87*, 212.

Shemansky, D. E. and B. R. Sandel, 1982. *JGR 87*, 219.

Shemansky, D. E., and G. R. Smith, 1981. *JGR 86*, 9179.

Smyth, W. H., and M. R. Combi, 1987. *GRL 14*, 973.

Fabry—Perot Observations of the Jupiter Plasma Torus in November-December, 1988

F.Scherb, F.L. Roesler, R.C. Woodward [1] and R.J. Oliversen[2]
[1]Physics Department, University of Wisconsin, Madison, WI 53706

[2]GSFC, Greenbelt, MD 20771

In November-December, 1988, we carried out Fabry-Perot observations of the plasma torus at the McMath solar telescope on Kitt Peak. We obtained a large number of high-spectral- resolution scans of [SII]6717,6731 and [SIII]9531 over a 40° field of view, centered on either the approaching or receding ansa of the torus. We have analyzed part of the data set for periodicity in the intensity variations, using both phase plots and Lomb-Scargle periodograms. Evidence of periodicity is much weaker than it was in our 1982 observations. Detailed results will be presented.

On the last night of our observing run, we took three sequences of fourteen CCD images each through the high-resolution etalons in our instrument. Each image was taken at a slightly different wavelength than the others in a sequence; thus, an image sequence effectively scanned the torus [SII]6731 line. These "datacubes" allow us to examine spectral profiles of individual sections of the torus, although they have relatively coarse spatial and spectral resolution. The results will be presented.

Chaotic Dynamics of the Io Torus

Philip L. Matheson
Lunar and Planetary Lab, University of Arizona

A record of intensity measurements from the Io torus of the *SIII* $685\mathring{A}$ feature is available over several time scales from the Voyager Jupiter encounters. Aside from the time asymmetry, (that the western ansa is regularly brighter than the eastern ansa), the measurements show erratic intensity fluctuations in each region over several time scales. Studies of the time series of these measurements have been performed to investigate the role of chaotic dynamics in the Io torus. The correlation integral method is used to determine the dimension of the attractor in the system. Calculation of this correlation dimension D_2 reveals the nature of the chaotic process. If D_2 is of low dimensionality, then the torus dynamics most likely can be modelled with a set of equations of order $Modulus(D_2 + 1)$. Although this information does not help reveal the actual dynamics involved, it can give a valuable limit on the dimensionality of any dynamic model constructed of the Io torus system. If D_2 is of high or indeterminately high dimensionality, the processes are stochastic. Understanding of the dynamics may be correspondingly difficult.

Probable Detection of [OI]6300 Emission from Io

F.Scherb and F.L. Roesler
Physics Department, University of Wisconsin, Madison, WI 53706

On UT February 17, 1990, observations of Io and Europa were carried out by the National Solar Observatory staff using the solar-stellar spectrograph on the McMath telescope at Kitt Peak. The echelle spectra were obtained at a spectral resolving power of about 120,000. A recent examination of the preliminary spectra indicates that [OI]6300 emission was probably detected from Io, and does not appear to be present in the Europa spectra. Detailed results will be presented.

Split Personality for Io's Sodium Cloud?

N.M. Schneider [1], J.T. Trauger[2], and D.I. Brown[2]

[1]LASP/U. Colorado

[2]JPL

Extensive imaging of the Io sodium cloud in 1988-1990 shows a markedly different appearance from the last large imaging program by Goldberg (*Science 226,* p. 512, 1984). High-quality narrow-band images were taken on about 30 nights with a CCD camera on the Catalina Observatory 1.5m telescope, in many cases recording both sides of Jupiter simultaneously. In general, the part of the cloud leading Io does not lie in the orbital plane, and appears distinctly different from either the "docile banana" model (e.g. Smyth and Combi, *Ap.J. 328,* p.888, 1988) or the directional features observed by Goldberg or Pilcher et al. (*Ap.J. 287,* p.427, 1984). The forward cloud often appears as a well-collimated out-of-plane jet, and is observed to change dramatically on a timescale of a few hours. This variability, plus additional velocity-resolved data, suggests that much of the sodium in the forward cloud is travelling at speeds of tens of km/sec, unlike the slow sodium (~3 km/sec) thought to populate the forward cloud in Goldberg's images. Other spectroscopic and imaging observations revealed a similar preponderance of high-speed sodium in 1984 (Schneider, Ph.D. dissertation, 1988). Implications of this "Jekyll & Hyde" difference, probably related to a change in the interaction between the plasma torus and Io's atmosphere, will be discussed.

Io Plasma Torus Characteristics Derived From Optical Imaging of Jupiter's Neutral Sodium Magneto-Nebula

Brian Flynn, Jeffrey Hughes, Michael Mendillo and Jeffrey Baumgardner
Center for Space Physics
Boston University
Boston, MA 02215

ABSTRACT

Ground based optical observations of the Jovian environment, made in December, 1989, and January, 1990, have revealed a faint cloud of neutral sodium extending from Jupiter out to at least 400 R_J and confined mainly to the Jovian rotational equatorial plane. The emission region is seen to flare out at an angle of $\sim \pm 22°$ with intensities of $\sim$ 275 R at 30 R_J and $\sim$ 10R at 400 R_J. The morphology and intensity gradient of the nebula indicate a source region close to Jupiter, presumably the smaller brighter cloud of neutral sodium known to envelope the satellite Io. The observed emission is well modelled by a resonant scattering of solar radiation by neutral sodium atoms on hyperbolic escape trajectories resulting from charge exchange reactions between co-rotating Na^+ and orbiting Na near Io. The observed flare angle ($\pm$ 22°) is consistent with the fast neutrals having a velocity distribution at their source near Io that is spherical, centered on the corotation speed of $\sim$ 74 km/sec and with a radius of $\sim$ 25 km/sec. Assuming the neutral sodium is accelerated by charge exchange leads to an ion temperature in the Io torus of $\sim$ 94 eV. This fast neutral sodium source velocity distribution results in a spiral particle distribution out to a radius of about 200 R_J, beyond which the spiral arms merge. This leaves large parts of the region within 200R_J periodically void of sodium.

Submitted to the Fred Scarf Memorial Symposium on "Magnetospheres of the Outer Planets" 20-24 August 1990.

A Jovian Magnetic Octopole Model constrained by the Cold Plasma Torus

J.T. Trauger [1], N.M. Schneider[2], H.B. Garrett[1], R.W. Evans[1], and D.I. Brown[1]

[1]JPL / Caltech

[2]LASP / U.Colorado

Ground-based images of the cold S^+ torus, covering the torus both east and west of Jupiter simultaneously, are compared with predictions for the equilbrium distribution of a cold plasma torus derived from the OTD, O4, and P11 models of the Jovian magnetic field between 5 and 6 R_J. The offset tilted dipole model is clearly inadequate, since the torus is warped significantly from the tilted plane, indicating that higher order terms are required. An octopole model of the inner Jovian magnetic field is developed for optimal fit to both the cold plasma observations and standard models. These data were obtained in January and February 1990 with a narrowband coronagraphic CCD camera at the Catalina Observatory 1.5 meter telescope.

The Source Position of Jovian 'Auroral' Hiss

D. D. Morgan[1], D. A. Gurnett[1], W. S. Kurth [1], and F. Bagenal[2]

[1]Dept. of Physics and Astronomy, The University of Iowa, Iowa City, Iowa 52242

[2]Dept. of Astrophysical, Planetary, and Atmospheric Sciences,
University of Colorado, Boulder, Colorado 80309-0391

Wideband data from the Voyager 1 encounter with Jupiter contains evidence of whistler-mode emissions similar in structure to terrestrial VLF saucers and auroral hiss. Whistler-mode emissions have a well-defined and easily observed cutoff frequency that can be expressed as a function of angle of propagation from the magnetic field. With reasonable assumptions ray-tracing techniques can then be used to locate the source of the noise. Earlier analyses of the Jovian auroral hiss assumed straight magnetic field lines and a symmetry surface for the Io torus based on the magnetic equator. Two possible source locations, one centered on the torus and the other at the northern edge of the torus, were consistent with the earlier analyses. Since that work was done, a second cutoff has been found, implying that there are two sources. Using the centrifugal symmetry surface, we now find sources about 0.6 R_J north and south of the centrifugal equator on the L = 5.58 R_J field line. When these source locations are plotted onto a contour map of the Io plasma torus, it is found that the points are symmetrically located toward the north and south edges of the torus and on the boundary between the hot and cold torus. The positions of the sources and spacecraft imply the existence of a field-aligned electron beam moving toward the Io plasma torus. Analogy with the corresponding emissions at Earth suggests that the sources may be associated with plasma double layers.

Escape of Gases from Io and Their Impact on the Planetary Magnetosphere

William H. Smyth

Atmospheric and Environmental Research, Inc.,
840 Memorial Drive, Cambridge, MA 02139

The escape of gases from Io and the manner in which these gases interact and supply plasma and energy to the planetary magnetosphere have been investigated at AER over the last several years. Highly-developed models for the neutral clouds of sodium, potassium, oxygen and sulfur have been used to analyze and simulate cloud brightness morphology data acquired by ground-based facilities. The studies of space-time dependent features of the bright sodium cloud provide a central tool for understanding the gas-plasma interactions in the Io plasma torus for the dominant (but very dim) neutral clouds of oxygen and sulfur. From analysis of the neutral-plasma interactions and the cloud brightness data, estimates have been made and will be presented for (1) the total source rates of neutrals escaping the satellite, (2) the ion loading rate, plasma mass loading rate and ion pick-up energy input rate to the plasma torus, and (3) the source rates of very fast neutrals which permeate and extend far beyond the boundary of the planetary magnetosphere.

Flow Near Io and Generation of Plasma Perturbations

M. G. Kivelson[1,2], J. Linker[3], and R. Walker[1]

[1]Institute of Geophysics and Planetary Physics,
University of California, Los Angeles, CA 90024

[2]Department of Earth and Space Sciences, University of California, Los Angeles, CA 90024

[3]Department of Physics, University of California, Irvine, CA 92717

Computer simulations of the flow of jovian plasma past Io, represented as a conducting sphere, reveal the strong non-linearities that develop when mass loading becomes important. Even without mass loading, the thermal pressure is low in the slow mode wings where the diversion of flow affects the particle density. Pick up ions heat the plasma in regions where the flow is supersonic, but elsewhere the inertia of newly formed ions can slow the flow below the sound of speed and, in such a case, further ion pick up cools the plasma. The low pressure regions serve as sources from which slow mode waves propagate into the torus plasma. Southwood (1990) has suggested that the compressional waves present through a large part of the Io plasma torus may be related to the slow mode waves generated in this way. If so, the amplitude of the waves can depend strongly on the mass loading rate in the immediate vicinity of Io.

Empirical and Theoretical Models of the Io Plasma Torus

Fran Bagenal [1] and John D. Richardson [2]
[1]University of Colorado, Boulder, CO 80309-0391

[2]Center for Space Research , M.I.T., Cambridge MA 02139

We present an empirical model of the Io plasma torus for the Voyager epoch that is based on a combination of in situ and remote sensing measurements. This is compared with the plasma properties derived from a theoretical 2-dimensional model of the torus that includes distributed neutral clouds, radial transport, radiative and collisional processes.

Modeling the Io Plasma Torus: A Progress Report

Robert A. Smith [1] and Fran Bagenal[2]

[1]Department of Physics and Astronomy U. of Iowa

[2]Department of Astrophysical, Planetary and Atmospheric Sciences U. of Colorado

Detailed numerical modeling of the energy balance in the Io plasma torus indicates that local ion pick-up can provide only 10-20% of the energy needed to account for the observed electron temperature and EUV luminosity: the remaining energy must enter the torus from an external source. Observations indicate that the required external energy flux may be supplied by inward diffusion of energetic (>1 keV) heavy ions with energies below the threashold for strong precipitation by Alfven-ion-cyclotron resonance. The numerical model of Smith and Strobel (J. Geophys. Res., v.90. p.9469, 1985) has been generalized to include radial dependence, through diffusive transport, of the flux tube mass and energy content of both the thermal and energetic ion populations, as well as the associated atomic processes of collisional heat transfer, ionization, charge exchange, and EUV emission. Current progress on the model will be discussed.

Rings and Dusty Plasmas

(R)

Rings and Dusty Plasmas

C. K. Goertz

Department of Physics and Astronomy, University of Iowa, Iowa City, IA 52242–1479

Because dust grains are immersed in the convecting plasmas of the magnetospheres, they are charged and subject to electromagnetic forces. These can lead to significant deviations from Kepler motion of small (μm radius and less) dust grains. This motion is the subject of gravitoelectrodynamics which will be briefly reviewed. Small grains in a plasma can also act as plasma sources through sputtering which may be the most important source of plasma in Saturn's magnetosphere outside the orbit of Enceladus. Recent calculations show that dust ejected from Enceladus is transported outwards into the E ring and can maintain the warm plasma torus observed outside the orbit of Enceladus. We will also discuss the evolution of Saturn's main rings caused by electromagnetically induced radial transport of small dust in these rings. We find that the B ring of Saturn cannot be much older than about 50 – 100 million years. This agrees with other independent estimates based on the ionospheric effects of small grains or molecular cluster ions precipitating into Saturn's atmosphere.

The Saturnian Ring-Ionosphere Plasma Environment

G. R. Wilson

Center for Space Plasma and Aeronomic Research
The University of Alabama in Huntsville
Huntsville, AL 35899

The rings of Saturn and the ionosphere of Saturn form a coupled system. Plasma can flow along magnetic field lines from the ionosphere to the rings and water, in the form of either ions (or small charged ice grains), can flow from the rings to the ionosphere and drastically alter the chemistry occurring there. As a result the outflow of plasma from the ionosphere may be greatly reduced in the nightside equatorial region and at high latitudes. The ionosphere and ring plasmas will interact and give rise to compositional variations as one moves radially outward in the rings. Being exposed to these plasmas and a radiation environment the rings will charge up to some potential and, because of azimuthal variations in that potential, drive field-aligned currents through the ionosphere.

This talk will focus on several aspects of the coupled ring ionosphere system. The first is the interaction of a warm ring plasma with the cold ionospheric plasma which could lead to a shutoff of the outflow of ionospheric plasma to the A and B rings. Second is the variation in plasma density and temperature in the vicinity of the C and D rings resulting from the large diurnal variation in the plasma content of the equatorial ionosphere. Third is the charge state of the ring dust cloud and the resulting field-aligned currents driven by azimuthal variation in the ring surface charge density. Lastly, some aspects of microphysical plasma processes occurring within the rings, which could lead to large internal electric fields and the generation of electrostatic waves, will be discussed.

Dynamics and Origin of Saturn's E ring

M. Horanyi[1], J.A. Burns[1,2], L.L. Hood[1], S.M. Larson[1]

[1] Lunar and Planetary Laboratory, U. of Arizona, Tucson, AZ 85721, USA
[2] Theoretical and Applied Mechanics, and Astronomy, Cornell U., Ithaca, NY 14853, USA

The E ring of Saturn extends from $\simeq 3R_S$ to $\simeq 8R_S$ and consists mainly of particles somewhat less than a micron in radius. The ring's observed optical depth peaks sharply at $\simeq 4R_S$, near the orbit of Enceladus, making this satellite the suspected source of these particles. Here we reexamine the effects of various orbital perturbations; in particular we test the idea that the observed optical depth profile may be caused by dust ejected from Enceladus that evolves toward highly elliptical orbits ($e \simeq 0.4$), meanwhile a fraction of the particles shifting their semimajor axes from $\simeq 4R_S$ to $\simeq 5.5R_S$. These particles will be then lost via collision with the dense inner rings.

The solar radiation pressure force will induce periodic changes in the orbital eccentricities and inclinations of ring particles. The amplitude and the frequency of these oscillations are determined by particle properties, the orbital parameters and the oblateness of Saturn. These small grains also experience perturbations due to Lorentz forces since they move in a magnetized plasma. The electromagnetic perturbations oscillate because the particle's charge varies due to the coupling between the particle's velocity and charge; due to the various gradients in plasma temperature, density and composition; and finally due to the charge's periodic modulation when the photoelectron current turns off and on as the particle enters and leaves the planetary shadow.

These perturbations can distribute small dust grains on a much shorter time scale than orbital evolutions caused by plasma or Poynting-Robertson drag or the time required for significant erosion due to sputtering, micrometeoroid impact and/or sublimation. We are now investigating to what extent the radiation pressure and Lorentz force perturbations alone produce the observed density distribution in Saturn's E-ring.

Shadow Resonance for Circumplanetary Dust

M. Horanyi[1], J.A. Burns[1,2]

[1] Lunar and Planetary Laboratory, U. of Arizona, Tucson, AZ 85721, USA
[2] Theoretical and Applied Mechanics, and Astronomy, Cornell U., Ithaca, NY 14853, USA

Orbital perturbations that both i.) oscillate with frequencies that are commensurate with the orbital frequency and ii.) lag the orbital motion can induce secular orbital evolutions. The electrostatic charge on an isolated dust grain that moves through the corotating magnetosphere of an outer planet is determined in part by the ambient plasma, and the grain's velocity through it, as well as by the grain's material parameters (photoelectron yield, secondary electron yield, etc.). The grain's charge will therefore vary over the orbital cycle as the grain periodically samples the various plasma regimes (due to the orbit's eccentricity) and moves through these regimes with periodically varying velocity. The resulting charge variations, which resonate with the orbit and are delayed, have been demonstrated to cause swift orbital evolution until stable positions are reached.

We now investigate a similar effect that is caused by periodic variations in the grain charge due to the modulation of the photoelectron current as the particle enters and leaves the planetary shadow. We demonstrate this effect both numerically and analytically for small grains comprising the Jovian ring. We show that the resulting periodic changes are much faster and more dramatic than any of the orbital drifts due to the standard perturbations. This proposed mechanism may leave its mark on the ring's optical depth profile, producing a dip at the source of these grains. Possible observational constraints will be discussed.

Grain Impacts during Ring Plane Crossings at Neptune

B. M. Pedersen, N. Meyer-Vernet, M.G.Aubier, P. Zarka
Observatoire de Paris/Meudon - CNRS URA 324, France

At the time of the flyby of Neptune on August 25 (DOY 237) 1989, VOYAGER 2 passed through the ring plane of the planet twice. During inbound pass, the ring plane was crossed at about 02:53 UT spacecraft event time (SCET: Universal Time at the spacecraft) at the distance of ~3.42 Neptunian radii (R_N) from the center of the planet. The outbound crossing, downwards towards Triton, took place at around 05:16 SCET at a distance of ~4.27 R_N. During both crossings, the Planetary Radio Astronomy instrument detected an intense, unpolarized, broadband noise (Warwick et al., 1989). As for the previous ring plane crossings at Saturn (Aubier et al., 1983) and at Uranus (Meyer-Vernet et al., 1986), we interpret this noise as due to ring plane dust grains impacting the spacecraft, then being vaporized and ionized, and finally recollected by the spacecraft structures. This causes a frequency-dependant variation of the potential of the spacecraft, giving rise to the observed noise. A quantitative evaluation of this process gives an estimation of the density of the dust grains and their size distribution during both ring plane passages. These results are compared with previous measurements at Uranus.

Water Group Plasma in the Magnetosphere of Saturn

Aharon Eviatar [1] and John D. Richardson[2]
[1] Department of Atmospheric Sciences, UCLA, Los Angeles, CA 90024 and The Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, 69 978 Ramat Aviv, Israel

[2] Center for Space Research, Massachusetts Institute of Technology, Cambridge, MA 02139

We address the question of the composition and spatial distribution of water group plasma in the magnetosphere of Saturn. We suggest that the problem of the coexistence of neutral atomic hydrogen and such a plasma can be resolved if the dominant ion is taken to be H_2O^+ or H_3O^+. We also suggest that this ion may provide a means of radiative cooling of the inner magnetosphere plasma which is possibly easier to realize than transport of nitrogen from Titan. As a source for this plasma in the region inward of the icy satellites, we suggest the ring atmosphere. The depleted plasma density in the domain between the Dione-Tethys torus and the ring plane crossing of Voyager may provide an explanation for the survival of the E- ring. Data are presented which indicate that H_2O^+/H_3O^+ is also a favored candidate in the outer magnetosphere and that it can diffuse with negligible loss through the dense atomic hydrogen cloud and the hot electron gas.

Radio and Plasma Waves
(RPW)

Radio and Plasma Waves

Donald A. Gurnett

Department of Physics and Astronomy, University of Iowa, Iowa City, IA 52242

This paper reviews the advances that have been made in the investigation of radio and plasma waves during the period since the last Symposium on the Magnetospheres of the Outer Planets. The primary new advance has been the Voyager II flyby of Neptune. Neptune is now known to have many of the same radio and plasma wave emissions as Jupiter, Saturn, and Uranus. However, the intensities are generally lower. Particularly notable is the extremely low level of whistler-mode noise in the magnetosphere of Neptune. The absence of intense whistler-mode noise is most likely related to the generally low intensities of energetic electrons in the magnetosphere of Neptune.

Other notable advances that have occurred include the discovery of lightning at Uranus based on the detection of impulsive high frequency radio signals. Whistler-like signals, almost certainly produced by lightning, have also been observed at Neptune. Steady progress has also been made on the analysis of radio emissions from the magnetospheres Jupiter, Saturn, and Uranus, leading to improved knowledge of the frequency spectrum, polarization, source locations, and fine structure. One puzzling feature is the occurrence of intense, narrow-band bursty radio emissions from the magnetospheres of Uranus and Neptune. These emissions are most likely produced by a cyclotron maser mechanism. However, the processes responsible for the fine structure are poorly understood.

A Search for Short Term Variations in the Synchrotron Emission From Jupiter

S. Bolton [1,2], S. Gulkis[1], M. Klein[1], I. de Pater[2] and C. Heiles [2]

[1]Jet Propulsion Laboratory

[2]University of California, Berkeley

An observational program to monitor the short term variations of the microwave radio emission from Jupiter has been under development since 1988. The most recent set of observations began in December 1989, three weeks before Jovian opposition, and continued through March 1990. During that interval 26 days of calibrated measurements were obtained. The measurements are ten hour duration observations made using the University of California Hat Creek 85 foot radio antenna operating at 1400 MHz (21 cm). The objective of the observations are to provide information on the dynamics of the relativistic electron population of the inner Jovian magnetosphere. The observations will be used to establish the presence (or absence) of short term variations (days - weeks) in the Jovian synchrotron emission. In addition, the total intensity vs Jovian longitude data (beaming curve) will be used to further refine the models of the relativistic electron distribution in the Jovian magnetosphere. Preliminary results will be presented and a comparison of beaming curve data from this set of observations will be made with data from previous sets of observations.

Source Structure of Jovian Decametric Radiation and Interplanetary Scintillation

Koitiro Maeda
Department of Physics, Hyogo College of Medicine, Nishinomiya, Hyogo 663, Japan

It is well known that when the Jovian decametric radiation is received on Earth, it exhibits, in addition to a relatively slow intrinsic structure, strong and more rapid intensity fluctuations of the order of seconds. Such intensity fluctuations are caused by diffraction due to electron density irregularities in the solar wind, i.e., interplanetary scintillation (IPS).

Genova and Boischot (1981) proposed to use IPS to test a source model. It is believed that the emission frequency of the Jovian decametric radiation is close to the electron gyrofrequency at the emission point, and that the sources at various frequencies are excited along an activated flux tube. If such a source structure is true, the higher-frequency source lies closer to the planet than the lower-frequency one. The difference in the source positions causes a shift of the IPS diffraction pattern on the ground at one frequency with respect to that at another frequency. Such a positional difference in the IPS diffraction patterns at the two frequencies in turn causes a time delay between the intensity fluctuations at the two frequencies. Genova and Boischot (1981), and Boischot et al. (1987) found such an effect as a frequency drift pattern consisting of tilted lanes in the Nancay dynamic spectra. Their analyses, however, were qualitative. It is therefore necessary to make more accurate measurements of the frequency-drift rate to confirm the phenomenon.

We have made simultaneous observations at two frequencies in a frequency range from 21.86 to 23.30 MHz over two apparitions of Jupiter (1988–1990). A cross correlation analysis between the intensity fluctuations at the two frequencies was made to measure the time delay due to IPS. We present a preliminary result from the analysis of Io-related components (so-called Sources Io-A and Io-B). It is shown that there is a time delay between the intensity fluctuations at the two frequencies, and that the frequency-drift rate changes as a function of Jupiter's elongation from the sun.

A Three-Dimensional Ray-Tracing Study of the Jovian Hectometric Radiation

H. P. Ladreiter [1] and Yolande Leblanc [2]

April 19, 1990

[1] Space Science Institute of the Austrian Academy of Sciences, A-8010 Graz, Austria

[2] Observatoire de Paris, F-92195 Meudon, France

Abstract

Considering source locations of the Jovian hectometric radiation (HOM) at high magnetic latitude auroral zones, and the characteristics of the maser cyclotron mechanism which put severe constraints on the emission beaming, we are able to explain the main properties of the hectometric radiation as observed by both Voyagers during their Jupiter flyby. In particular the results of a three-dimensional ray-tracing study (Ladreiter and Leblanc, 1990) account for the latitudinal beaming of HOM, the overall change in the HOM occurrence near the Voyager 1 encounter, and the complicated polarization pattern. The modeled intensity profiles, compared with observations in the vicinity of Jupiter, as well as far from the planet show a remarkable agreement. This study establishes that the HOM sources are located along open magnetic field lines with footprints in the tail-field auroral ovals in both hemispheres. We further explain why HOM is very likely the low-frequency extension of non-Io DAM.

Emission Cones in Jupiter's Hectometric Radiation

C. H. Barrow
Max-Planck-Institut fuer Aeronomie, D-3411 Katlenburg-Lindau, FRG

The jovian hectometric radio emission (HOM) is believed to be generated at frequencies close to the gyrofrequency and beamed into a radiation pattern having the form of a hollow cone. Solar wind control of the HOM supports the idea that the radio emission may influenced by conditions affecting auroral activity on Jupiter. A qualitative model is proposed which invokes the observed HOM polarization characteristics and continuous radiation into emission cones from field lines having footprints in the auroral zones. As Jupiter rotates, left- or right-handed HOM, from the southern or the northern hemisphere respectively, is received by an observer when the emission cone orientation is correct. It is possible that the Non-Io dependant decametric radio emission (Non-Io DAM) could also be explained in similar terms in which case the HOM may be a low frequency extension of the Non-Io dependent DAM.

Ray Tracing of Jovian Kilometric Radiation - Revisited

J. L. Green[1], L. Aist[1], J. R. Thieman, [1] S. F. Fung[2], and R. M. Candey[2]

[1]NASA/GSFC Code 930 Greenbelt, MD 20771

[2]Atlantic Research Corporation 8201 Corporate Drive Landover, MD 20785

One of the outstanding problems in advancing an understanding of the emission mechanism for the broad-band Jovian Kilometric Radiation (bKOM) is the determination of the location of the source region. Computer ray tracing calculations in a realistic Jovian magnetosphere provide a mechanism to predict where potential source regions would exist. In addition, when coupled with observations, ray tracing calculations can also be used to investigate the validity of certain characteristics of proposed generation mechanisms such as any preferred wave normal angles.

There have been several attempts to determine possible source region locations from ray tracing calculations. Green and Gurnett, [1980] and Lecacheux, [1980] presented two dimensional ray tracing results which favored L-O mode sources on field lines between the moon Io and the planet. Another effort by Jones [1980] suggested that the source is located on the outer flanks of the Io torus generating the radiation with preferred wave normal angles.

Since Leblanc and Daigne (1985) corrected the previously reported observed polarization of bKOM as being right-handed in the northern hemisphere there has not been an attempt to perform ray tracing. In the light of these new data analysis results of bKOM we will utilize a fully three dimensional ray tracing code using the latest models of the Jovian magnetosphere which were not available at the time of the previous ray tracing calculations. The new ray tracing results will be used to better define possible source regions for Jovian Kilometric Radiation.

Green and Gurnett, Geophys. Res. Lett., 7, 65, 1980.

Jones, Nature, 288, 225, 1980.

Leblanc and Daigne, J. Geophysics Res., 90, 12073, 1985.

Lecacheux, J. Geophys. Res., 86, 8523.

New Results on the Source Locations, Beaming, and Spectrum of SKR

P. Galopeau and Ph. Zarka

Observatoire de Paris/Meudon, CNRS URA 324, France

The method of Zarka and Lecacheux [1987], used for deriving the source location and beaming of Uranus' kilometric radiation, is applied here to Voyager's near encounter observations of SKR. Very precise northern and southern source locations are found and compared with previous determinations done by other authors. It is concluded that the SKR is generated along planetary, open magnetic field lines. The SKR beaming and its variations with the frequency are presented.

Evidence for Saturn's Magnetic Field Anomaly from SKR Observations

P. Galopeau, A. Ortega-Molina and Ph Zarka

Observatoire de Paris/Meudon, CNRS URA 324, France

A detailed study of the variation of the high frequency limit of the Saturnian Kilometric Radiation (SKR) allowed us to prove unambiguously the existence of a magnetic field "anomaly" near the planetary surface, at auroral latitudes. This was obtained through the theoretical results of a model of SKR spectrum inspired by the cyclotron maser instability mechanism. We estimate its location and its amplitude. This existence of this anomaly had been already postulated in order to explain the observed modulation of SKR at saturnian rotation period but it could not be detected by the spacecraft-embarked magnetometers which passed too far from the planetary surface. This result makes planetary radio emissions a very pertinent tool for the fine study of planetary magnetic fields.

An Analysis of the Source Location of Broadband Smooth Radio Emission at Uranus

S. Gulkis [1], J. D. Menietti, and D. B. Curran[2]
[1] JPL, Pasadena, CA

[2] SWRI, San Antonio, TX

Our knowledge of the source location(s) of the nightside Uranian kilometric radiation (UKR) remains uncertain despite attempts to determine it by a number of investigators using a variety of techniques. In a further attempt to determine source location(s), we have begun a ray tracing study in a model magnetosphere of Uranus in which we assume that the emission mechanism is due to the cyclotron maser instability. We have compared calculated radio intensity profiles to radio data observed by the Planetary Radio Astronomy (PRA) instrument on board Voyager 2 as it flew past Uranus. By varying the source region and emission lobe profiles we are able to test a variety of different models. This technique appears to offer a powerful means to discriminate between various possible source locations. This paper will present a status report of our studies.

Possible 2nd Harmonic Emission at Uranus and Jupiter

J. D. Menietti and D. B. Curran
SWRI, San Antonio, TX

URANUS: During the inbound trajectory toward Uranus the Planetary Radio Astronomy Instrument (PRA) on board the Voyager 2 spacecraft observed narrowband smooth (n-smooth) emission at frequencies centered near 60 kHz. By assuming models of the plasma density for the dayside magnetosphere of Uranus, and using cold plasma theory together with strigent observational constraints we have performed ray tracing calculations to determine the source location and mode of the n-smooth emission. Ray tracing calculations suggest that the emission with sources near the magnetic equator may be fundamental X-mode for certain conditions or second harmonic gyroemission. If the emission is second harmonic gyroemission, the fundamental emission at 30 kHz is expected but apparently not observed.

JUPITER: To determine if the source of the Jovian Io- dependent DAM emission is along the instantaneous Io flux tube (IIFT), we have compared the results of ray tracing calculations to radio emission data obtained by the PRA instrument on board Voyager 1 and 2. We assumed RX mode gyroemission at frequencies near the local gyrofrequency. Our results indicate good agreement with the observations if we assume the source is within 20@ of the IIFT, but the maximum gyrofrequency of the model magnetic field is larger than the observed maximum frequency of the DAM for the assumed "active" field line. While errors in the magnetic field model coupled with emission at large Doppler shift might explain this discrepancy, a more natural explanation is that the higher frequency component of the DAM is due to 2nd harmonic gyroemission.

Generation Mechanisms of Smooth and Bursty Radio Emissions in Planetary Magnetospheres

H. K. Wong
Department of Space Sciences, Southwest Research Institute, San Antonio, TX 78228-0510

Smooth and bursty radio emissions have commonly been observed in planetary magnetospheres. These emissions have very different characteristics and are believed to be generated by different source mechanisms. It is shown that both smooth and bursty emissions can be generated by cyclotron resonance interaction between the waves and the energetic electrons. The nature of the emissions: the frequency, polarization, angular structure, and duration of the emissions, depend on the form of the free energy sources, plasma and field parameters, and the energy of the energetic electrons.

Bursty Radio Emissions at Uranus and Neptune: The Possible Role of Surfaces MHD Waves as a Free Energy Source

W. M. Farrell, S. A. Curtis, and R. P. Lepping

Laboratory for Extraterrestrial Physics, NASA/Goddard Space Flight Center, Greenbelt, MD 20771

The radio source locations of the bursty kilometric radio emissions at Uranus and Neptune are known, but the free energy source operating in the regions is still unidentified. We shall examine the magnetic field data at the boundary layer crossings that map near the radio source location for evidence of large-scale MHD waves and instabilities that might create a transient or "bursty" free energy source in the radio wave generation region. Surface waves, possibly associated with a Kelvin-Helmholtz instability, were observed at the magnetopause crossings at Uranus, and MHD turbulence was observed in the south polar cusp region at Neptune. Both observations lend some support for a free energy source driven by large-scale MHD waves.

THE UNIVERSITY OF FLORIDA JOVIAN S BURST CATALOG

F. Reyes, R. S. Flagg, W. B. Greenman, and T. D. Carr
Dept. of Astronomy, University of Florida, Gainesville, FL

The University of Florida Jovian S Burst Catalog is based on 22 Io-related decametric storms observed at the University of Florida Radio Observatory between 1972 and 1989. All of the storms were observed with a radio telescope in which the receiver baseband output was analog magnetic tape recorded. Tapes were subsequently played back at a 128:1 slowdown ratio into a spectrum analyzer and the resulting dynamic spectrum was recorded on photographic film. The resolution of these spectra is very high (3.3 kHz in frequency and 0.3 millisecond in time). For 13 of the storms the radio telescope utilized a 640-dipole antenna array, providing a very high sensitivity. The receiver bandwidth ranged from 0.5 to 1.35 MHz. The remaining 9 of the storms were observed with relatively low sensitivity antennas (e.g., a 5-element yagi) at center frequencies of about 18, 23, or 26 MHz, and a receiver bandwidth of 0.5 MHz. Some storms were also observed with an acousto-optic radio spectrograph having a separate antenna (an array of 4 conical spiral antennas) of wide bandwidth (24-39 MHz) but relatively low sensitivity; in this case the dynamic spectrum was recorded on film directly.

Because of the practical impossibility of analyzing all of the many thousands of S bursts occurring during one storm, we limited the data reduction to 10 selected intervals of 10 sec each within each storm. The photographic films were used for the production of the many illustrations of S burst dynamic spectra (approximately 250) contained in the catalog and also for the measurement of S burst drift rate and separation data to be included in the catalog. For these (and other) measurements, the time and frequency at the beginning and at the end of each S burst were obtained with a digitizing tablet interfaced to an Apple computer, and a burst-type classification code was entered. The computer then calculated the corresponding frequency drift rate (df/dt), which was stored on disk together with the classification code and a time tag for that S burst. A total of 26,000 code-classified and time-tagged bursts were digitized in this way for use in preparing the catalog (and also for subsequent study). Plots contained in the catalog include distributions of burst drift rate and interburst time separations, and mean drift rate and mean interburst time separation as a function of central meridian longitude and Io phase.

It is expected that the catalog will be available by November, 1990. During the process of inspecting and analyzing the data for the catalog we have found many unusual S bursts, a few examples of which will be presented in this talk. In addition to the catalog itself, the data set of 26,000 code-classified time-tagged S burst drift rate values stored on computer disk and the large amount of filmed spectra from which the illustrations were selected will remain a valuable resource for continuing investigation.

MONITORING AND MODELING JUPITER'S HECTOMETRIC RADIATION

Liyun Wang and Thomas D. Carr
Dept. of Astronomy, University of Florida, Gainesville, FL

Jupiter's hectometric emission was observed from both Voyager spacecraft on every rotation of the planet for a relatively long time. The observed deep modulation of the radiation with respect to the central meridian longitude (CML) of the spacecraft was undoubtedly due to a thin-sheet beam pattern that alternately illuminated and avoided the spacecraft with each rotation. Cyclotron resonant auroral zone sources producing such thin-sheet beams have been proposed by Carr and Wang and by Ladreiter and Leblanc. When the intensity vs time data from any fixed-frequency channel between about 0.5 and 1.5 MHz are suitably smoothed, this beam modulation is manifested as a bilobed or monolobed pattern that tends to be repeated on subsequent rotations. In a repeating bilobed pattern, successive intensity peaks are separated alternately by a narrow gap and a wide gap. In the monolobed pattern the two intensity peaks on either side of the narrow gap have merged into one. Both types of pattern can be explained by the thin-sheet beam models. We have measured the CML values at the midpoints of the wide gaps for 180 rotations. The mean was 202.2°, with a standard deviation of the mean of 0.9°. This is essentially the same as the mean of the north magnetic pole CML values, 202.5°, for the four most widely used offset tilted dipole models derived from magnetometer data.

The CML of the wide gap midpoint can be used as a fiducial point for the precise measurement of the mean Jovian magnetospheric rotation period. We predict that the Jovian hectometric observations to be made from Galileo, when used in conjunction with those of the Voyagers some 16 years earlier, will provide a mean rotation period measurement with an accuracy of 0.01 sec. This is about an order of magnitude better accuracy than could be obtained from terrestrial observations of the Jovian synchrotron or decametric radiation over a similar span of years. By comparing the Voyager-Galileo rotation period measurement (mean epoch about 1987) with the best presently available synchrotron-decametric average (mean epoch about 1967), we will have a good opportunity to look for a secular change in the Jovian magnetic field as revealed by a change in rotation period. The continued monitoring of Jupiter's rotation by means of occasional measurements at about 1 MHz from high earth orbit may also become feasible in the not too distant future. This is above the frequency of nearly all of the terrestrial AKR, and yet it is low enough that the opaque ionosphere will shield the spacecraft from manmade and thunderstorm interference coming from below.

We are making a comparison of the original Carr-Wang model, the Ladreiter-Leblanc model, and other possible beam models. In making this comparison, we consider both the plausibility of the assumptions required by the model and the closeness of the fit to the observed data that can be achieved with it. A 3-dimensional ray-tracing program is being used in this study. Some results of this comparison that have been obtained to date will be shown.

Comparative Magnetospheres

(CM)

Energetic Particles in Planetary Magnetospheres

D. J. Williams
Johns Hopkins University, Applied Physics Laboratory, Laurel, MD 20723

Energetic particles ($\geq$ 20 keV) represent an important segment of the particle populations observed in planetary magnetospheres. They are important both as diagnostics of the magnetospheric configuration and its processes, and as determinants of that configuration and its dynamics. They have been observed at all planets where the intrinsic planetary magnetic field provides sufficient solar-wind standoff to form a planetary magnetosphere. In this talk we present synthesis of energetic particle observations in planetary magnetospheres and describe their role in determining the observed magnetospheric configuration and resulting dynamics. We further summarize, with examples if time permits, various transport/loss mechanisms and sources inferred for the observed planetary magnetospheric energetic particle populations.

A Comparison of the Energetic Particle Composition in the Magnetospheres of the Outer Planets and Earth

Douglas C. Hamilton
Department of Physics and Astronomy, University of Maryland, College Park, MD 20742 (SPAN UMDSP::hamilton)

Measurement of the composition of energetic particles in a planet's magnetosphere provides information on plasma sources and their relative strengths as well as on energization and transport processes. At the Earth, the solar wind and the ionosphere are the two possible sources. At all the outer planets imbedded natural satellites and rings are additional potential plasma sources. We will review the composition results above ~200 keV/nucleon from the Low Energy Charged Particle (LECP) experiments on Voyager 1 and 2 at Jupiter, Saturn, Uranus, and Neptune and compare them with recent Earth results, particularly from the AMPTE/CCE spacecraft. Typically, the composition varies with energy and location in the magnetosphere. At Earth, Jupiter, and Saturn low charge state ions of local origin tend to dominate at low energies with the importance of the higher charge state ions from the solar wind increasing at high energies. At Uranus and Neptune, however, little evidence was seen of the very weak solar wind source. We find that the composition results are generally best ordered by energy per charge rather than by energy per nucleon or total energy.

Plasma Sources in Planetary Magnetospheres

S. M. Krimigis
Applied Physics Laboratory, The Johns Hopkins University Laurel, MD 20723-6099

Measurement of the H/He ratio for energetic (n 0.5 MeV/nucleon) ions during the Voyager 2 encounter with Neptune revealed a value larger (13000:1, Krimigis et al., 1989) than any observed in planetary magnetospheres. This ratio is smallest for Earth (70:1, Gloeckler and Hamilton, 1987) and becomes progressively larger as the heliocentric radial distance of successive magnetospheres increases. This fact, together with "tracer" ions measured at each planet (O^+, He^+ at Earth; O, S, H_2, H_3 at Jupiter; O, H_2, H_3 at Saturn; H_2 at Uranus, Neptune) suggests that the respective planetary ionospheres and/or satellites are the major contributors to the energetic particle populations in magnetospheres and, by inference, the sources of the low energy thermal plasmas as well. Thus the standard diffusion-convection model, whereby solar wind plasma enters the magnetosphere and becomes accelerated to higher energies through magnetic pumping as it propagates inward by violation of the third adiabatic invariant, is in dire need of revision. Alternate suggestions will be presented and discussed.

Krimigis, S. M., et al., *Science*, **246**, 1483-1488, 1989.

Gloeckler, G., and D. C. Hamilton, *Physica Scripta*, **T18**, 73-84, 1987.

Planetary Magnetospheric Substorms

D.J.Williams
Johns Hopkins University, Applied Physics Laboratory

Of the six planets possessing intrinsic magnetospheres, three show the presence of substorm activity and three do not. Using simple scaling laws we show that this is a normal result to be obtained from the available data base. A more general look at the observation or non-observation of planetary substorms based on measured particle distributions shows substorm presence or absence to be correlated with the magnetospheric particle distribution existing at the time.

IMPROVED ESTIMATES OF HIGH ENERGY PARTICLE NUMBER DENSITY AND PRESSURE IN THE JOVIAN PLASMA SHEET FROM A COMPARISON BETWEEN PARTICLE AND MAGNETIC DATA

K. K. Khurana and M. G. Kivelson

Institute of Geophysics and Planetary Physics, University of California at Los Angeles, Los Angeles, CA 90024

T. P. Armstrong

Department of Physics and Astronomy, University of Kansas, Lawrence. KS 66045. Also at Space Physics Division, NASA Headquarters, Washington D. C. 20546.

The hot particle density and pressure measurements from the Voyager 1 and 2 LECP (Low Energy Charged Particle Experiment) instruments are uncertain by factors of ≈ 6 and 10 respectively because the LECP does not have a mass/charge ratio discrimination capability. In the past we have shown [*Khurana and Kivelson*, 1988] that improved bounds on the particle pressure can be obtained by studying the total pressure (particle + magnetic) in compressional ULF waves. However, the LECP instrument on the Voyager 2 spacecraft was operated in a partial exposure mode to avoid detector saturation and damage from the intense radiation. This procedure provided a high time resolution data set ($\Delta t = 24$ s) making it possible to study ULF waves (periods between 2 and 10 minutes) in Jupiter's magnetosphere but information on the background count rate was lacking. In the past our data analysis assumed zero background counts but now we have derived estimates of the background counts for all of the channels from correlative studies with data obtained from the regular mode.

The waves studied have $k_\perp \gg k_\parallel$ [*Khurana and Kivelson*, 1989]. It can be shown that for such waves, for large plasma β (which holds in most of the Jovian magnetosphere), the total pressure remains constant. This fact allows us to obtain an independent inference of the particle pressure in the waves. If it is assumed that all incoming particles were protons then the particle pressure variations are too small to balance the magnetic pressure variations. The missing pressure cannot be accounted for by the hidden particle distribution below the threshold of the LECP instrument. However, a fractional contribution of O^+ component in the plasma reproduces pressure derived from pressure balance constraints and explains the observed particle fluxes.

REFERENCES:

Khurana K. K., and M. G. Kivelson, Bounds on the LECP particle pressures in the middle Jovian magnetosphere from a ULF wave study, *EOS: Trans. A.G.U.*, *69*, 433, 1988.

Khurana K. K., and M. G. Kivelson, Ultralow frequency MHD waves in Jupiter's middle magnetosphere, *J. Geophys. Res.*, *94*, 5241, 1989.

10 keV 30 R_J
40 17

Spectrum of Planetary Radio Emissions

Ph. Zarka

Observatoire de Paris/Meudon, CNRS URA 324, France

The average spectrum of the five known planetary radio emissions (including in particular the recently observed Neptunian one) are presented. Their shapes and relative intensities are commented in the frame of the cyclotron maser instability (CMI) theory plus simple physical considerations. The consistency of the results deduced from the above comparisons strongly milits in favor of their generation through the CMI.

A Comparison of the Fine Structure in the Earth's AKR Emission to SSA Emission of the Outer Planets

J. R. Thieman[1], J. L. Green[1], L. Aist [1], S. F. Fung[2], and R. M. Candey[2]

[1]Code 930 NASA/GSFC Greenbelt, MD 20771

[2]Atlantic Research Corporation 8201 Corporate Drive Suite 350 Landover, MD 20785

Studies of wideband analog dynamic spectra from the Dynamics Explorer Plasma Wave Instrument (PWI) reveal a multiplicity of fine structure often present in the auroral kilometric radiation (AKR). These phenomena are reminiscent of the Striated Spectral Activity (SSA) [Thieman, et al., 1988] seen in the high resolution 6-second frequency-time spectrograms of the outer planets measured by the Voyager Planetary Radio Astronomy (PRA) instrument. Both AKR and SSA contain non-harmonically-spaced bands or striations of emission that stand out clearly or are separated from a more pervasive diffuse or amorphous radiation. Both also have occasional episodes of chaotic short duration bursts. The main question is whether all of these phenomena (bands, chaotic bursts, and amorphous radiation) can be produced by the same source mechanism.

Kaiser [1990] has shown the overall planetary radiation intensity to be strongly correlated channel-to-channel in the 48-second average PRA data over the frequency band encompassing these phenomena. The fine structure, however, exhibits semi-correlated and uncorrelated behavior in spectral appearance. Is the fine structure just a randomly-fluctuating "tip of the iceberg" of the more diffuse radiation or does it represent separate phenomena and a separate source mechanism? SSA phenomena at Jupiter usually occur in the absence of an amorphous background, but background subtraction algorithms are in effect.

In this paper we compare observed properties of the planets' fine structure as measured by the PRA instrument to the AKR properties observed by the PWI instrument. Constraints implied by three- dimensional ray tracing in model magnetospheres are also presented.

Thieman, J. R., J. K. Alexander, T. A. Arias, and D. H. Staelin, Striated Spectral Activity in Jovian and Saturnian Radio Emission, *J. Geophys. Res., 93*, 9597-9605, 1988.

Kaiser, M. L., Fine Structure in Planetary Radio Emissions, *EOS, 71*, 596-597, 1990.

Shocklets Upstream of Saturn

D.S.Orlowski and C.T.Russell
Institute of Geophysics and Planetary Physics UCLA,Los Angeles,CA 90024-1567

Within several Saturn radii from the shock ,on the outbound leg of the Voyager 1 trajectory we observe shocklets associated with the intense low-frequency upstream waves very similar to those observed at the earth.The shocklets are observed at the frequencies about 0.15 Hz with well distinguished narrow peak in the spectral density at 0.1 nT/Hz.They are right-hand elliptically polarized propagating obliquely to the both magnetic field and solar wind flow.

Upstream Waves at the Outer Planets

C. W. Smith [1], H. K. Wong[2], M. L. Goldstein[3], and M. Zhang[4]

[1] Bartol Research Institute, University of Delaware, Newark, DE 19711

[2] Department of Space Sciences, Southwest Research Institute, San Antonio, TX 78228

[3]Laboratory for Extraterrestrial Physics, Goddard Space Flight Center, Greenbelt, MD 20771

[4]Center for Space Research, Massachusetts Institute of Technology, Cambridge, MA 02139

We review the observations and supporting theory of magnetic waves upstream of the bow shocks of the outer planets. In the first half of the presentation low frequency Alfvenic fluctuations at Jupiter, Saturn, Uranus, and Neptune will be discussed and compared. A critical evaluation of the various instability sources will be presented with comparison made between these observations and upstream waves and particles at other heliospheric shocks. The second half of the presentation will discuss the recent analysis of whistler waves upstream of Uranus (both intense bursts as well as extended wave trains) that result from two distinct populations of upstream particles. The unifying theme of the discussion will be the diversity of observations and sources responsible for the waves.

Neptune

(N)

The Magnetosphere of Neptune: An Overview

Ralph L McNutt, Jr.
Department of Physics and Center for Space Research, MIT, Cambridge, MA 02139; 617-253-7396

On August 24, 1989 Voyager 2 encountered the last planetary magnetosphere on its journey to near-interstellar space. Far from the planet ($> 4\ R_N$), the large tilt of the dipole moment of Neptune's internal magnetic field produces a magnetosphere which oscillates between a pole-on and an Earth-like configuration every 16.1 hours. Serendipitous phasing of the dipole resulted in the only in situ measurements in the cusp/plasma mantle of a giant planet magnetosphere. This large tilt angle and the geometry of Triton's orbit results in a large region of space over which plasma is injected into the magnetosphere and decreases the time during which new plasma is injected on closed field lines. A longitudinally asymmetric plasma sheet/torus is expected due to the complex geometry produced by Neptune's spin and magnetic axes combined with the inclination of Triton's orbital plane. Plasma observed within Triton's orbital distance is consistent with such a model; the presence of heavy ions (possibly N^+), as well as the profile of total flux shell content, suggests Triton's upper atmosphere is the source. There is some evidence that this plasma plays a key role in exciting an aurora at Neptune. Comparison of electron densities with those derived from upper hybrid resonance emissions indicates that there is no cold, "hidden" population of plasma in the vicinity of $\sim 10\ R_N$. Radiation belts of hot ($T_i \sim 55$ keV) protons are observed within Triton's minimum L shell, as are features suggesting sweeping of radiation belt particles by the inner moons discovered by Voyager. Composition measurements suggest these particles ultimately derive from Neptune's atmosphere rather than Triton's. Plasma stresses are negligible, with $\beta < 0.2$, and energetic (> 1 MeV) electron phase space densities are consistent with inward diffusion. Low intensities of energetic particles near closest approach, the locally non-dipolar magnetic field, and a complex thermal plasma structure, suggest that the spacecraft may have passed under the radiation belts. Also near closest approach, "whistlers" were apparently detected, but with dispersions so large as not easily to be reconciled with locally measured electron densities and ionospheric electron densities inferred from occultation measurements. Detailed intercomparison of the various Voyager-derived data sets will be required to provide answers to questions on the physics of this region as well as to understand the implications of the magnetic field structure, never before sampled so near one of the giant outer planets.

Supported by NASA under contract 957781 from the Jet Propulsion Laboratory to the Massachusetts Institute of Technology.

Energetic Protons in the Magnetosphere of Neptune

M. D. Looper, R. S. Selesnick, and E. C. Stone

California Institute of Technology, Pasadena, CA 91125

Analysis of Voyager 2 Cosmic Ray Subsystem (CRS) observations of 1 to 5 MeV protons at Neptune is presented. Trapped protons are observed inside the orbit of Triton; fluxes are low near the planet due to absorption by inner satellites and rings. Differential energy spectra above ~2 MeV have power law indices of ~6. Correction of spectral data for gradient anisotropies allows pitch angle distributions and phase space densities to be calculated. These are compared with CRS electron data at similar energies, and implications for sources, sinks, and transport are discussed.

Hot Plasma Parameters in Neptune's Magnetosphere

S. M. Krimigis[1], B. H. Mauk[1], E. P. Keath[1], M. Kane[1], A. F. Cheng[1], T. P. Armstrong[2], G. Gloeckler[3], and L. J. Lanzerotti[4]

[1]Applied Physics Laboratory, The Johns Hopkins University, Laurel, MD 20723–6099

[2]Department of Physics, University of Kansas, Lawrence, KS 66044

[3]Department of Physics and Astronomy, University of Maryland, College Park, MD 20742

[4]AT&T Bell Laboratories, 600 Mountain Avenue, Murray Hill, NJ 07974

Energy spectra of energetic protons and electrons (Ep ≥ 28 keV, Ee ≥ 22 keV, respectively) obtained with the Low Energy Charged Particle (LECP) instrument during the Voyager 2 encounter with Neptune on August 24–25, 1989 are presented. The proton spectral form was a power lay ($dj/dE = KE^{-y})^{\lambda}$, outside the orbit of Triton, but changed to a hot (kT ~ 20 to 100 keV) Maxwellian distribution inside that distance. Similarly, the electron spectral form changed from a simple power law outside Triton to a two-slope power law with a high energy tail inside. Intensity and spectral features in both protons and electrons were observed in association with the crossing of the Triton and 1989 N1 L-shells, but not simultaneously in both species. Such signatures were manifested by relative peaks in the spectral indices in both kT and γ. Peak proton pressures of ~2 x 10^{-9} dynes cm^{-2}, and $\beta \sim 0.2$ were measured at successive magnetic equatorial crossings, bot inbound and outbound. These parameters show Neptune's magnetosphere to be relatively undistorted by plasma loading, similar to that of Uranus and unlike those of Saturn and Jupiter.

Low-Energy Plasma in Neptune's Magnetosphere

John D. Richardson, Ralph L. McNutt, and John W. Belcher

MIT Center for Space Research

Plasma data from the region of Neptune's magnetosphere between L=6.5 and L=13.5 are analyzed. Selecting only spectra where both light and heavy ions are present, we derive density and temperature profiles under the assumption that the ions are H^+ and N^+. These results are used to calculate the total flux shell content (for a shell of unit width in L), N, of each ion in this region. Values of N derived from inbound and outbound data are similar, indicating the plasma distribution functions are isotropic. Average values of NL^2 are 3×10^{32} for H^+ and 10^{32} for N^+. Profiles of NL^2 for both H^+ and N^+ increase outwards, suggesting that Triton is the probable source of both these plasma components. Evidence is presented for significant inbound-outbound asymmetries in the plasma morphology.

Magnetic Field of Neptune

J. E. P. Connerney[1], M. H. Acuña[1], and N. F. Ness[2]

[1]NASA Goddard Space Flight Center, Greenbelt, Md., 20771
[2]Bartol Research Institute, University of Delaware, Newark, DE, 19716

The planetary magnetic field of Neptune, with its large dipole tilt and complex structure, is very similar to that of Uranus. Since Voyager's flyby trajectory brought the spacecraft much closer to this planet (Close approach=1.18 R_n) than its predecessors, and Uranus in particular, the rich complexity of the field is evidenced in the close-approach data as never before. The magnetic field data obtained near closest approach evidences contributions from spherical harmonics up to (approximately) degree and order 8. The combination of a close flyby trajectory and a very complex field presents a formidable challenge to unique interpretation of the magnetic field observations. A spherical harmonic model is obtained by partial solution to the underdetermined inverse problem (8'th order spherical harmonic model) using generalized inverse techniques. In this solution, dipole and quadrupole Schmidt-normalized spherical harmonic coefficients are determined, or resolved, independently of the higher-order terms; some with relatively large uncertainties. The model yields a dipole of magnitude 0.14 G R_n^3, tilted by 48° towards 70° W Longitude. Neptune's quadrupole is relatively large, equal to or exceeding in magnitude the (surface) dipole field. Much additional information is also obtained regarding higher order components of the field, but this information is more difficult to make use of. We present a model of this extraordinary field and discuss the limitations/uniqueness of our result, particularly as regards the expected accuracy of the model near the planet's surface.

The Magnetic Field of Neptune: Field-geometric invariants controlling particle absorption by rings and moons

M. H. Acuña[1] , N. F. Ness[2], and J. E. P. Connerney[1]

[1] Laboratory for Extraterrestrial Physics, Goddard Space Flight Center, Greenbelt, MD 20771

[2]Bartol Research Institute, Newark, DE 19716

Spherical harmonic models of the Neptunian field derived from Voyager 2 measurements have been used to compute field-geometric invariants that control the motion of energetic trapped particles in the magnetosphere. The models can be used to predict regions where trapped particle absorption effects should be observable with special emphasis on signatures observed by particle experiments aboard Voyager 2. The derived models reflect the high complexity of the Neptunian field and provide significant insight into the understanding of the charged particle observations.

Energetic Charged Particle Angular Distributions Near (r< 2 R_N) and over the Pole of Neptune

B.H.Mauk[1], M.Kane[1], E.P.Keath[1], A.F. Cheng[1],
S.M. Krimigis, T.P.Armstrong[2], and N.F.Ness[3]

[1]The Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723

[2]The University of Kansas, Lawrence, KS 66044

[3]Bartol Research Institute, University of Delaware, Newark, DE, 19716

Energetic ion (> 28 keV) and electron (> 22 keV) angular distributions very close to (r < 2 R_N) and over the north planetary pole of Neptune are presented as sampled by the Low Energy Charged Particle (LECP) experiment of the Voayager 2 spacecraft. Pitch angle distributions are generated by combining the angular scanning of the LECP instrument with the magnetic field data obtained by the MAG experiment. High-time resolution displays show that the particle data are tempoally structured and spectrally soft; a similarity with Earth-like auroral signatures has previously been noted. However, the pitch angle distributions (showing trapped distributions at high magnetic latitudes) do not support an Earth-like auroral interpretation, and alternative explanations for the temporal dynamics must be sought. Between r = 1.6 and 2.0 R_N and in the vicinity of the magnetic equator, the higher energy ion and electron pitch angle distributions (E > 80 keV) display dramatic "bite-outs" at about 90°. This bite-out feature could be caused by interactions with the newly discovered ring 1989N3R with a radial extent of about 1.5 to 2.0 R_N

Voyager 2 Plasma Electron Observations at Neptune

E.C.Sittler Jr.[1], T.S.Huang , T.S.Huang [1] and J.W.Belcher[2]

[1]Goddard Space Flight Center, Greenbelt, MD

[2]MIT, Cambridge, MA

We present preliminary results of an analysis of the plasma electron measurements made by the Voyager 2 Plasma Science Experiment (PLS) during the Neptune encounter. These observations cover the electron energy range from 10 eV to 5950 eV. The electron observations have revealed Neptune's magnetosphere to be of little plasma content with maximum observed thermal electron density n_c less than 0.3 cm^{-3} and thermal electron temperature T_c less than 50 eV. Typical plasma sheet n_c and T_c are 0.01 cm^{-3} and 10 eV, respectively. Detectable electron fluxes were generally confined below a few hundred electron volts, but suprathermal electron fluxes were at times observed in excess of 1 keV. We will comment about some of the interesting features in the data and discuss the implications of the PLS electron observations upon observations made by some of the other Voyager 2 experiments.

Evidence for Large Plasma Densities Within $3R_N$ of Neptune

W. S. Kurth[1], D. A. Gurnett[1], L. J. Granroth [1], D. D. Barbosa[2] and S. L. Moses[3]

[1]Dept. of Physics and Astronomy, The University of Iowa, Iowa City, Iowa 52242

[2] Institute of Geophysics and Planetary Physics,
University of California, Los Angeles, California 90024

[3]TRW Space and Technology Group, Redondo Beach, California 90278

Initial reports [Belcher et al., 1989] indicate that Voyager encountered rather small $n_e < 2$ cm^{-3} plasma densities during its closest approach to Neptune in August 1989. Now, an increasing array of direct and indirect evidence is available which supports much larger $10 < n_e < 100$ cm^{-3} densities along the encounter trajectory. The evidence includes the radio occultation observations of the ionosphere [Tyler et al., 1989], the existence of whistlers inside of 2 R_N, implications of a magnetic equatorial density profile based on the escaping continuum radiation spectrum, the identification of Z-mode radiation and the tentative identification of the low-frequency cutoff of the Z-mode spectrum as the L=0 cutoff, and the tentative identification of the lower hybrid resonance frequency in the spectrum of electrostatic ion cyclotron waves. We place limits on a density profile for the Voyager trajectory within about 3 R_N which addresses each of these pieces of evidence in a self-consistent manner. The resulting knowledge of the plasma density should lead to a better model of the Neptune magnetosphere.

Belcher et al., *Science, 246*, 1478, 1989.
Tyler et al., *Science, 246*, 1466, 1989.

Neptune's Polar Cusp Region: Observations and Magnetic Field Analysis

R. P. Lepping [1], L. F. Burlaga [1], A. J. Lazarus[2], G. L. Siscoe[2], V. M. Vasyliunas[2], A. Szabo[2], J. Steinberg[2], N. F. Ness[3], and S. M. Krimigis[4]

[1]Laboratory for Extraterrestrial Physics, NASA Goddard Space Flight Center, Greenbelt, MD 20771

[2]Center for Space Research, MIT, Cambridge, MA 02139

[3]Bartol Research Institute, University of Delaware, Newark, D 19716

[4]Applied Physics Laboratory, The Johns Hopkins University, Laurel, MD 20707

Just before entering Neptune's magnetosphere Voyager 2 penetrated its distant polar cusp on August 24, 1989. At that time the planet's magnetic dipole axis was approximately parallel to the sun-planet line. Broadly speaking, the spacecraft on the day before closest approach traversed four plasma regions. These (and the 'boundaries' separating them) are: 1. solar wind (bow shock at 1438 UT), 2. magnetosheath (inner boundary of the magnetosheath, the magnetopause [MP], at 1800 UT), 3. cusp region (outer boundary of magnetosphere at 1930 UT), and 4. the magnetosphere. The MP is identified by a 45° directional discontinuity in the field (accompanied by a local magnitude depression), a decrease in the flux of anti-sunward flowing plasma, and a change in flow direction toward the corotation direction; it is where the global MP would be expected based on upstream conditions. Energetic (≥28 keV) ion intensities peaked at ≈1800 UT and decreased prior to a second onset at ≈2000 UT, while the electrons (≥22 keV) showed only a marginal increase. The field in the cusp changed direction slowly and smoothly, approaching the magnetospheric field direction at its inner boundary. The plasma flux in the cusp region fluctuated moderately. Hence, the only marked directional discontinuity in the field along this path (after the expected bow shock related changes) occurred at the MP. Similar magnetic field and plasma profiles in the vicinity of the Earth's distant polar cusp have been observed by Earth's orbiting spacecraft.

A Search for Magnetic Signatures of Triton's Interaction with the Neptunian Magnetosphere

F. M. Neubauer [1], N. F. Ness[2], A. Lüttgen [1], and K.-H. Glassmeier [1]

[1]Institut für Geophysik und Meteorologie, Universität Köln, 5000 Köln 41, Federal Republic of Germany

[2]Bartol Research Institute, University of Delaware, Newark, DE 19716

We have analyzed the Voyager 2 magnetic field data obtained on August 24 and 25, 1989, in a search for a magnetic signature of the interaction between Triton and the magnetosphere of Neptune. This also involves considerations of the spacecraft position relative to the instantaneous Triton field line and a search for magnetic fluctuations produced in the Triton torus.

VOYAGER 2 at Neptune: Phenomenology of Radio Emissions, Observed by the Planetary Radio Astronomy (PRA) Experiment

B.M. Pedersen, M. G. Aubier, A. Boischot, A. Lecacheux, P. Zarka
Observatoire de Paris/Meudon - CNRS URA 324, France

The VOYAGER mission around Neptune added a new planet to the four hitherto known planets, generating non-thermal radio emissions. We over- view Neptune's radio emission morphology as observed by the Planetary Radio Astronomy (PRA) experiment on board the spacecraft during a span of a few weeks. We present the characteristics of the observed recurrent "bursty" and "smooth" components of the Neptunian Kilometric Radiation, as observed alternately before and after closest approach and within the context of the various emission features, detected during the closest flyby. In addition, we review the different emission features of the detected radio spectrum during closest approach: an unusual high frequency component; typical cut-offs, due to occultations by the ionosphere of the planet; emissions, related to ring plane- and plasma sheet crossings; VLF components. For most of the observed phenomena, we shall briefly introduce detailed studies in progress which will be presented in other conbribu- tions during this conference. Finally, we compare the observed characte- ristics for the two recurrent NKR components with the smooth and bursty components, observed close to Uranus.

SOURCE LOCATION OF NEPTUNE'S KILOMETRIC RADIO EMISSION

Gerald K.F. Rabl[1], Helmut O. Rucker[1], Michael L. Kaiser[2]

[1] *Space Research Institute, Austrian Academy of Sciences, Graz, Austria*

[2] *Laboratory for Extraterrestrial Physics, NASA-GSFC, Greenbelt, MD, U.S.A.*

Abstract

During the inbound and the outbound leg of Voyager 2's encounter with Neptune, the Planetary Radio Astronomy (PRA) experiment aboard the spacecraft detected two smoothly varying radio emission patterns: one within the frequency range from ~ 40 – 600 kHz, the second one, only observed closer to the planet, extended in frequency from ~ 600 – 800 kHz. Using an offset tilted dipole (OTD 2) model for Neptune's magnetic field, the source locations of Neptune's smooth emission components are determined at the planet's northern and southern hemispheres. Assuming that the emission originates near the electron gyrofrequency a geometrical beaming model is developed in order to fit the observed emission episodes.

Source Location of the Smooth Neptunian Kilometric Radiation

H. P. Ladreiter [1] and Y. Leblanc [2]

April 19, 1990

[1] Space Research Institute of the Austrian Academy of Sciences, A-8010 Graz, Austria

[2] Observatoire de Paris, F-92195 Meudon, France

Abstract

Observations of the smooth kilometric radiation of Neptune are interpreted in terms of source locations in Neptune's auroral zones at both hemispheres. Thereby a geometrical beaming model has been used in order to fit the modeled emission profiles to the observed ones. Because of the Voyager closest approach distance of less than 5000 km from the Neptunian surface, many source candidates in the northern hemisphere can be ruled out solely because of occultation by the planet. We further used the large excursions of Voyager 2 to high southern magnetic latitudes as a critical test for sources in the southern hemisphere. Nevertheless, the limited knowledge of the magnetic field close to the planet translates into a notable uncertainty for the source locations.

Localization of the Source of the Neptunian Auroral Radio Emission

A. Lecacheux and A. Boischot

Observatoire de Paris-Meudon, CNRS URA 324, France

The Planetary Radio Experiment onboard Voyager 2 spacecraft detected an emission from Neptune with a smooth dynamic spectrum similar to the auroral emissions of the other planets. The very close encounter (< 1.2 R_N) allows an accurate localization of the emission source by two independent methods: - the study of the setting and rising of the source above the horizon as seen from the spacecraft. - the study of the variation of the emission intensity when the spacecraft approached the planet ($1/R^2$ law). The two methods agree with a source lying in the northern hemisphere at a position which cannot be reconciled with the available magnetic field models (OTD or OTD2). This confirms the existence of strong magnetic anomalies close to the surface of the planet.

Neptunian Bursty Radio Emission

A. Boischot, F. Genova and Ph. Zarka

Observatoire de Paris-Meudon, CNRS URA 324, France

Neptune is the source of one of the most intriguing radioemissions among the outer planets. This emission is made of very narrow band (< 20 kHz) and fast (<30 ms.) isolated bursts which appear in a relatively narrow frequency range (about 200 kHz) between 200 kHz and at least 1300 kHz. Its occurrence is strongly modulated at the planetary rotation period. The bursts intensity is highly variable and can reach orders of magnitude above the intensity of the smooth auroral emission. We shall present the main characteristics of the Neptunian bursty emission, attempt to localize its source and discuss the constrains on the emission mechanism, which must be very different from that of the smooth emission.

Field-independent Source Localization of Neptune's Radio Bursts

W. M. Farrell, M. D. Desch and M. L. Kaiser

Laboratory for Extraterrestrial Physics, NASA/Goddard
Space Flight Center, Greenbelt, MD 20771

During the Voyager-2 encounter with Neptune, a narrowbanded bursty radio component was observed between 500 and 1326 kHz by the Planetary Radio Astronomy (PRA) instrument. Based on the emission occurrence pattern, the radio source has been localized without the explicit use of the Neptunian offset-tilted dipole (OTD) magnetic field model, which is accurate only at distances greater than 4 R_N from the planet. We used only assumptions based upon the general nature of radio wave propagation in planetary magnetospheres. A number of different candidate radial positions were sampled. At 1.5 R_N, the source location derived was positioned only about 10° from the south magnetic pole. The radiation from the source was beamed into a cone of 77.5°± 6.3° half-angle that was tilted about 10° from the radial direction to the north-northeast. At other sampled radial positions, similar source locations were obtained. We conclude that the radiation originates from an active auroral region located near the south magnetic pole.

Identification and Localization of Anomalous Neptune Radio Emission

M. D. Desch, W. M. Farrell, M. L. Kaiser

NASA/ Goddard Space Flight Center

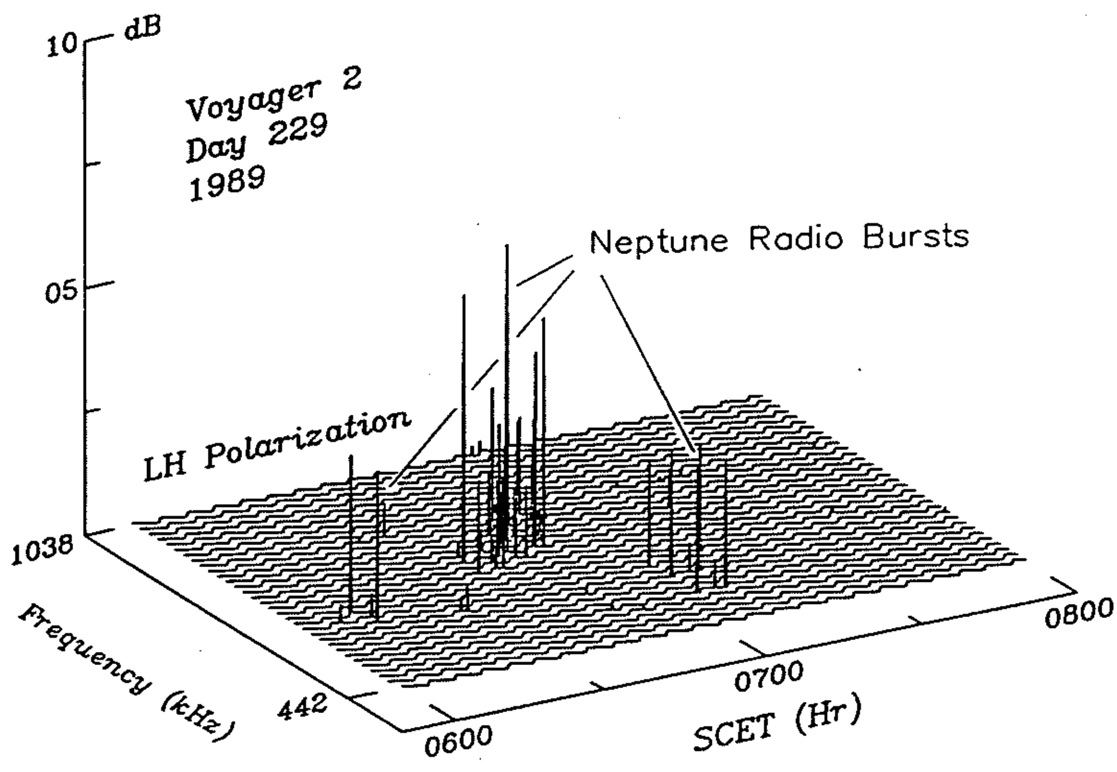
We have identified several episodes of bursty radio emission that do not fit the normal pattern in frequency or phase for the main component of the Neptune bursts. Previously, Farrell et al. showed with a minimum of assumptions that the time of occurrence of the normal burst events can be accounted for by a source on field lines that maps down to a location to the east of the south magnetic pole near what is probably one arc segment of the planet's auroral oval. Although the modeling was done without any reference to the planet's magnetic field, when compared with the OTD the derived source location lies comfortably on field lines that support the very high cyclotron frequency of the bursts.

We show that the rarely-seen anomalous episodes are consistent with a source of emission diametrically to the west of the OTD pole and at somewhat higher altitudes. Therefore, at least from the standpoint of the radio emission the picture that emerges is of an auroral oval with two emission hot spots approximately to the east and west of the south magnetic pole. The possibility of a complete radio-active oval is discussed.

What is Driving the Bursty Neptune Radio Emission?

M. D. Desch, W. M. Farrell, M. L. Kaiser
NASA/ Goddard Space Flight Center

The impulsive component of the Neptune radio emission manifests major intensity fluctuations on a time scale of days that must be indicative of an important magnetospheric interaction with the source of the emission near the planet. Typically, intensity fluctuations of this type are due either to satellite or to solar wind interactions with the magnetosphere. Using Voyager radio astronomy, plasma, and magnetometer data, we show that the usual drivers responsible for radio frequency fluctuations, such as solar wind pressure or speed variations, cannot account for the observations. Instead, the solar wind merging electric field strength seems to be an excellent predictor of emitted radio power, provided the source is active to begin with. At present we have no explanation for those episodes during which the radio source appears to be completely shut off.



The Sidereal Rotation Period of Neptune

A. Lecacheux[1], Ph. Zarka[1], M. D. Desch [2], and D. R. Evans[3]

[1]Observatoire de Paris/Meudon, France

[2] Goddard Space Flight Center, Greenbelt, Md, USA

[3]Radiophysics Inc., Boulder, Co, USA

The two main radio components discovered at Neptune by the PRA experiment aboard Voyager 2, have a well defined periodicity at about 16 hour. By analyzing all the available data, i.e. about 60 days around the closest approach for the "bursts" emission and only 15 days for the "smooth" component, we determine for every component the best estimate of the radio period. We conclude that the two estimates are not statistically different. While the two kinds of radio emissions have very different characteristics (in particular in frequency range and beaming properties), and probably correspond to different emission processes, their modulation is very likely due to the rotation of the planetary magnetic field, as it has been already assumed in the case of the other planets. The deduced value for the sidereal rotation period of Neptune is 16.105 ± 0.006 (or 16h06.7m ± 00.4m).

Auroral Emissions

(A)

Auroral Emissions from the Outer Planets, Their Relationship to Magnetospheric Processes

Renee Prange

Institut d'Astrophysique Spatiale, BP 10, 91371 Verrieres Cedex, France

A review will be presented of the observations of auroral emissions from the outer planets. Emphasis will be put on the diagnostic capabilities of the various observational techniques and wavelength ranges concerning the identification of the primary exciting magnetospheric particles, including some recent modeling efforts. The question of the sensitivity of the auroral patterns to the surface magnetic field structure will also be considered.

LONGITUDINAL MODULATION OF JOVIAN AURORAL ACTIVITY MODELED FROM *IUE* OBSERVATIONS OF H_2 EMISSION

T.A. Livengood and H.W. Moos
Dept. of Physics and Astronomy, The Johns Hopkins University
Baltimore, MD 21218
(301) 338-8503, SPAN→ ARGO::CASA::LIVENGOOD

Molecular hydrogen Lyman-band emission in the band 1557–1619Å is an excellent indicator of the level of Jovian auroral activity, as this band spans two strong peaks in the H_2 emission spectrum, the photon energy is such that the emission can only be due to non-thermal excitation, and there is no atmospheric opacity to introduce trade-offs between intensity, emission altitude, and viewing angle. These emissions have been regularly observed with the short-wavelength spectrograph of the *IUE* spacecraft from 1978 to the present. The observations consist of sequences of consecutive exposures measuring the auroral brightness as a function of planetary central meridian longitude (System III, 1965). By reconstructing the observational geometry using models of the locus of the auroral emission on Jupiter, the distribution of auroral intensity as a function of magnetic longitude can be modeled. The auroral intensity must be directly related to the instantaneous rate of energy deposition by particle precipitation from the magnetosphere; however, it is not clear to what extent variations in the deposition rate depend on variations in the precipitation flux of particles, as opposed to variations in the particle energy. As possible models of the auroral locus, we use mappings onto the atmosphere of the GSFC O_4+current sheet magnetic field model for several L-shells, at both poles. In addition, for the north pole, we also try the locus defined by *Voyager* UVS observations. As a model of the intensity distribution on the auroral arc, we employ a gaussian peak in emission centered at some magnetic longitude plus a longitude-independent constant background emission level. In a few cases, we also attempt to determine if the auroral intensity can more accurately be represented by a pair of gaussian peaks, corresponding to more than one longitude of enhanced energy deposition. Variation in the model parameters over the timespan of the observations is also considered.

This work is supported by NASA grant NSG-5393.

Jupiter's Doppler-shifted Auroral Emissions

John T. Clarke [1] and J. Hunter Waite [2]
[1]University of Michigan

[2]Southwest Research Institute

Observations of the H Ly alpha line profile in Jupiter's aurora have not shown any detectable Earth-like proton precipitation, but have shown low-energy Doppler-shifted emissions. These emissions appear mainly to the blue, representing motion of 20-30 km/sec up out of Jupiter's auroral atmosphere, and the presence of Doppler-shifted emission is now well tied to the presence of bright aurora. These velocities correspond to energies of 10-20 eV for fast protons or H atoms, and we interpret these motions as ionospheric plasma accelerated by local fields. The several-kR brightness of the Doppler-shifted emission suggests a substantial upward flux of neutrals and ions at roughly 1/2 of the escape speed, and this could indicate a large source of plasma into the magnetosphere. We will present the evidence for this process, and discuss further the implications for the auroral excitation and magnetospheric plasma supply.

Jovian FUV H_2 Aurora: Correlations

M. C. Peterson[1], W. M. Harris[2], [1] and J. T. Clarke[2]
[1]Univ. Michigan. / U.S.A.F.

[2]Univ. Michigan

Jupiter's FUV aurora exhibits "bright spots" near 185 North, and 10 South in lambda III coordinates. The bright spots are not uniformly bright in time, indicating variability of particle flux or energy. We are using the IUE data base from 1981 - 1989 to look for correlations between FUV H_2 auroral brightness and: H_2 color ratio, Ly alpha / H_2 ratio, Ly alpha doppler shifts, hydrocarbon abundance, and Io position. The dim and bright auroral cases can be compared to see if atmospheric composition, derived from IUE spectra, changes with auroral intensity. Several hypotheses have been presented which indicate auroral particles either vary in penetration depth, or that Jupiter's atmospheric composition changes with longitude due to the unique energy injection region of the auroral bright spots. We will present results of our analysis with the intent of resolving these questions.

Time Variability in the Jovian Magnetosphere as Evidenced by Variations in Jupiter's Two-Micron Aurorae

L. Trafton

Astronomy Department, University of Texas at Austin, Austin, TX 78712

Observations of H_2 and H_3+ auroral emissions in Jupiter's K band since 1987 indicate a long-term variability in their exciting source. This source is believed to be precipitating charged particles trapped in Jupiter's magnetic field. Hence, the observed variability is attributed to changes in the Jovian magnetosphere. The time scale for these changes appears to be on the order of one month. The observed changes include changes in emission strength, variations in the latitudinal extent of the aurorae, changes in the rotational temperature of H_2 and H_3+, and the occasional appearance of unidentified emission lines.

Thermal Infrared Emissions from Jupiter's Polar Regions

T. Kostiuk[1], G. Bjoraker[1], F. Espenak[1] and J. Goldstein[2]

[1]Code 693, NASA/GSFC, Greenbelt, MD 20771

[2]NASM/LA, Washington, DC

The polar regions of Jupiter exhibit enhanced emission in the molecular bands of stratospheric hydrocarbons. In the north polar region a 'hot spot' exists which remains fixed in Jovian magnetic coordinates (System III, 1965) at 180° longitude, 60° N latitude. The character of the emissions from CH_4, C_2H_2, C_2H_4, and C_2H_6 will be illustrated using high spectral resolution ground based and Voyager IRIS observations. From single line emission measurements the differences in the morphology and degree of enhancement between C_2H_6 and C_2H_4 will be investigated. Ethane was found to exhibit little intensity increase within the northern auroral zone, while C_2H_4 line emission increased by at least a factor of 10 at the north polar 'hot spot'. The longitudinal variability near the north polar region of the band emissions from all the hydrocarbons, retrieved from Voyager IRIS results, will be presented and discussed. Evidence for temperature increase and changes in molecular abundances near the polar 'hot spot' will be given. Possible sources of this infrared 'hot spot' will be discussed.

A MAGNETOSPHERIC MODEL OF THE JOVIAN NORTH AND SOUTH POLAR INFRARED HOT SPOTS

Jie Zhan and A. J. Dessler
Department of Space Physics and Astronomy, Rice University, Houston, TX 77251

IR hot spots (infrared emissions coming from somewhere within the 1μb to 1mb level of the atmosphere) in the polar regions of Jupiter exhibit different behavior with regard to longitudinal drift in the two hemispheres: the northern polar hot spot (hereafter, NPHS) is fixed in System III longitude while the southern polar hot spot (SPHS) is not [Caldwell et al.,1988]. We have investigated two possible sources of power and reasons for the difference in drift motion of these hot spots. One possibility is that power for the hot spots comes from energetic particle deposition. However, we find that the flux of particles capable of penetrating to the low altitudes required to produce the hot-spot emission is too small to account for the IR power radiated. Also, it is hard to see how particle precipitation could produce the observed differences in drift motion (Voyager measurement of Jovian UV aurora, which is produced mainly by direct particle impact, does not show any significant drift motion of the aurora in either hemisphere). We propose that Joule heating associated with Pedersen currents in the lower ionosphere is a more successful hypothesis. (The Pedersen currents are generated by the spinning magnetized ionosphere, which acts as a Faraday Disc Dynamo. The currents close through the Birkeland currents in the magnetotail that cause field lines in the tail to twist.) The altitude of maximum Pedersen conductivity falls within the range of inferred hot-spot altitudes. We suggest that Joule heating from dissipation of electrical currents in the ionosphere near auroral latitudes may play a fundamental role in producing the north and south polar hot spots. We propose a quantitative perturbation model to account for the localization of the NPHS. The model shows the NPHS is confined by a steep longitudinal magnetic-field gradient to a System III longitude of approximately 180°, in agreement with observations. Using this model, we derive a Joule heating power of about 10^{16} Watts, which matches the power requirements for the hot spots. We explain the motion of the SPHS in terms of atmospheric gravity waves, which move the longitudes of both peak ionospheric conductivity and enhanced methane concentration. (The IR is emitted by the ν_4 bands of methane.) Because the surface magnetic field in the polar region of the southern hemisphere has less longitudinal variability than that of the northern hemisphere, we find that these atmospheric gravity waves are capable of overcoming the confining force of the smaller magnetic field asymmetries in the southern polar region. We have derived a gravity-wave model for the Jovian atmosphere, and we find the group velocity of the wave can reach as high as several km/sec, which matches the drift speed of the SPHS. The current-driven joule heating thus accounts for the primary features of the Jovian polar hot spots: their power output, the fixed location of the NPHS, and the drift speed of the SPHS.

Caldwell, J. et al., Infrared polar brightenings on Jupiter IV. Spatial properties of methane emission, Icarus 74, 331-339, 1988.

The Uranian Aurora

Floyd Herbert and B. R. Sandel
Lunar and Planetary Lab, U. of Arizona

Voyager 2 UVS observations of the Uranian aurora have been combined into a synthesized image. Bright spots have been observed at both magnetic poles. The southern (spin-axis definition, = dark side) aurora is compact and weak. The northern aurora is (in spots) brighter and more spread out. These characteristics are just what would be expected given the large offset of the dipolar component of the magnetic field towards the south.

However the geometry of the intensity distribution differs in detail from that expected from the GSFC Q3 model (Connerney et al., JGR 92:15329). Preliminary work suggests that the octupole moments, omitted from the GSFC model because an unfavorable flyby geometry made them unresolvable, may be adjusted to improve the agreement between auroral geometry and magnetic field model. The values required lie within the general size range of the GSFC best octupole partial solution. The large extent of the northern aurora suggests that the exciting particles may be precipitating at low to medium L values. If true, this scenario may be related to the interaction between the extensive H corona and the magnetospheric plasma populations, by analogy with the precipitation of the Jovian aurora near the Io L shell.

Future Missions

(F)

The Galileo Mission to Jupiter

Torrance Johnson and Clayne Yeates

JPL, Pasadena, CA 91109

The Ulysses Mission — Its Contribution to Studies of the Jovian Magnetosphere

K.-P. Wenzel

Space Science Department of ESA, ESTEC, Noordwijk, The Netherlands

Ulysses will be fifth and next spacecraft to pass through the Jupiter magnetosphere. This will occur in February 1992 when the Jovian gravitational field will be used to deflect the space probe onto its high-inclination, elliptical orbit designed so that Ulysses can explore the inner heliosphere over the full range of heliographic latitudes, including the solar polar regions. Investigations in the Jupiter magnetosphere are a secondary objective of the Ulysses mission. The fields-and-particles instrumentation of Ulysses designed for interplanetary studies, is expected to be operated throughout most of the Jovian flyby without taking any risk for the health of the spacecraft and its payload. Ulysses will enter the magnetosphere on the dayside at moderate magnetic latitudes, approach the planet to 6 R_j and exit the magnetosphere on its unexplored dusk side. On the outbound pass it will reach magnetic latitudes of up to 45°, i.e., higher latitudes than previously achieved. Areas of study to which Ulysses will contribute include: the solar wind/magnetopshere interaction, observations of magnetospheric boundaries and major plasma/structures, the composition of Jovian plasmas and energetic particles, the planetary magnetic field, Jovian radio emission and plasma waves, the study of Jovian X-rays, and the dust environment. Radio occultation measurements may permit the measurement of the electron content of the Io plasma torus.

The paper will describe the science objectives and capabilities of Ulysses during its Jupiter passage.

The Cassini/Huygens Mission to Saturn and Titan

W.-H. Ip

Max-Planck-Institut f'ur Aeronomie D-3411 Katlenburg-Lindau FRG

The Cassini/Huygens Mission is the first cooperative project between ESA and NASA in the field of planetary research. While the Cassini Orbiter spacecraft will be provided by NASA in the framework of the CRAF-Cassini program, the ESA share is the Huygens Probe for atmospheric measurements at Titan. This mission with a launch date in 1996 will carry out a number of novel observations during the flybys of an asteroid (in 1997) and the Jovian system (in 2000); the final arrival at Saturn in 2002 will be highlighted by the release of the Huygens Probe towards Titan after SOI and then the commencement of the Saturnian system tour by the Cassini Orbiter. Within a time interval of four years the orbital inclination of the Oribter spacecraft will be gradually increased to reach the polar region via repeated close encounters with Titan. Such a tour scenario is to optimize the coverage of different scientific observations. The combination of the Probe and Oribter measurements in the remote-sensing area is expected to produce fundamental, new information on the atmospheres of Titan and Saturn and the physico-chemical properties of the icy satellites and the rings. The in-situ plasma measurements by a suite of advanced instruments should be even more important in the understanding of the dynamics and composition of the Saturnian magnetosphere, the plasma interaction and ionosphere of Titan, and the new phenomena of dusty plasma which could play a key role in the formation and evolution of the planetary and satellite systems. The particles-and-fields observations by the Cassini Orbiter spacecraft are thus unique for the study in cosmical electrodynamics.

Imaging Saturn and Its Moons using Energetic Neutral Atoms

Edmond C. Roelof
Johns Hopkins University Applied Physics Laboratory
Laurel, Maryland 20723-6099

Energetic neutral atom (ENA) imaging of the Saturn system is made possible by the cold neutral atoms and molécules that pervade the portions of the magnetosphere containing energetic ions (>10keV). ENA fluxes (integrated over the entire Kronian system) were detected upstream of Saturn's magnetosphere using the LECP detectors on both Voyager spacecraft by Kirsch et al. [Nature, 298, 718, 1981]. Actual ENA images of the terrestrial storm-time ring current have been obtained from a particle telescope on the ISEE-1 spacecraft [Roelof, GRL, 14, 652, 1987]. ENA can produce an image because there is negligible momentum transfer when a singly-charged energetic ion is converted into a fast neutral by a charge-exchange collision with a cold neutral. Thus the intensity of an ENA image is simply the charge- exchange cross-section multiplied by the line-of-sight integral of the product of the cold neutral density and the energetic ion intensity (evaluated at the pitch-angle corresponding to the direction towards the particle detector). Hsieh and Curtis [GRL, 15, 772, 1988] computed a model ENA image of Saturn using theoretical models of the planetary exosphere [Shemansky and Hall, JGR, in press] and of the Titan hydrogen torus [Hilton and Hunten, Icarus, 73, 248, 1988]. This work adds the molecular exospheres of Titan itself [Bertaux and Kockerts, JGR, 88, 8716, 1983] and of the icy moons [Johnson et al., Icarus, 77, 311, 1989], as well as a more detailed model of the energetic ion fluxes based on the Voyager LECP measurements [Krimigis et al., JGR, 88, 8871, 1983]. Computer-generated ENA images, based on these models, indicate that Titan's extended exosphere may be imaged at large distances (>20 R_s) from the moon. Such images could be formed on time scales of 20 minutes using an ENA camera with a geometric factor of 1 cm^2-sr. This means that Titan could serve as an ENA "remote probe" of variations in the Kronian magnetospheric energetic ions fluxes. For example, the dayside magnetopause is sometimes inside Titan's orbit (Voyager 1) and sometimes outside (Voyager 2). Titan would be detected in ENA images only if the magnetopause were beyond its orbit, thus serving as a remote monitor of magnetopause excursions. If there were to be an ENA camera on the Cassini orbiter, the multiple Titan fly-bys would offer repeated opportunities to measure the Titan exosphere, both in EUV and ENA. Computer simulations of fly-bys of Titan yield ENA images with 20,000 counts accumulated in 20 minutes about an hour before closest approach. The icy moons are a much weaker source of ENA emission. None-the-less, computer- generated images of a Dione fly-by indicate that 2-minute exposures with 10,000 counts might be obtained within minutes of closest approach. The above-mentioned computer-generated images will be presented, along with a simulated Cassini-Orbiter high inclination "tour" of ENA views of the Saturn/Titan system.

Determination of the Surface Composition of Volatiles for Saturn's Icy Satellites and Rings Using Cassini *In Situ* Plasma Observations

R.E.Johnson[1], M.K.Pospieszalska [1] and E.C.Sittler Jr.[2]

[1]University of Virginia

[2]NASA/Goddard Space Flight Center

Charged particle and meteoritic bombardment of the surfaces of Saturn's icy satellites and rings provides a natural process for the formation of neutral clouds within Saturn's magnetosphere where they become ionized by collisions with electrons and solar UV to produce plasma tori which can be measured by the very sensitive plasma instrumentation on the Cassini orbiter. If the plasma instrumentation has the capability to distinguish between atomic and molecular ions of similar mass-per-charge then it will be possible to measure the surface composition of volatiles (i.e., water vapor, ammonia clathrates, and methane clathrates) for the icy satellites and rings. Because the velocity distributions of the pickup ions are expected to be highly anisotropic and transonic in the spacecraft frame, 3-D plasma instrumentation with mass analysis capability will be required to make these observations. Coincidence detection techniques are desireable (i.e.,time-of-flight mass spectrometry) in order to reduce background from penetrating radiation within Saturn's inner magnetosphere. Remote sensing techniques, which have the advantage of providing global information about the surface composition, are hampered by being unable to uniquely identify the surface composition of volatiles from the reflectance spaectra. In situ plasma observations will provide a means by which the remote sensing observations can be calibrated. In situ neutral mass spectrometry measurements using present technological capabilities are not expected to have the sensitivity to measure these neutral clouds except for measurements very near the satellites. These and other issues will be discussed in our talk.

The Planetary Plasma Interactions Node of the Planetary Data System

R. J. Walker, S. P. Joy, T. A. King, N. E. Cline, R. L. McPherron, C. T. Russell [1], W. S. Kurth[2], and M. L. Kaiser[3]

[1]Institute of Geophysics and Planetary Physics, University of California at Los Angeles, Los Angeles, CA 90024

[2]Dept. of Physics and Astronomy, University of Iowa, Iowa City, IA 52242

[3]Laboratory for Extraterrestrial Physics, Goddard Space Flight Center, Greenbelt, MD 20771

The Planetary Data System (PDS) was established by NASA to make high quality planetary data readily accessible to the planetary science community. The Planetary Plasma Interactions (PPI) Node of PDS was established to help planetary scientists solve problems associated with locating and acquiring data for planetary plasma investigations. PPI provides the science community with access to catalog and inventory information about fields and particles data as well as a system with which to browse the data and carry out preliminary scientific investigations. There is a system for researchers to order the data and ship it to their home institutions. We also provide users with access to data analysis tools and access to empirical and theoretical models. The PPI Node adheres to PDS standards for data quality and labeling and all of the data available through PPI has been peer reviewed by members of scientific community. The PPI Node has a distributed architecture with subnodes at the University of Iowa and the Goddard Space Flight Center as well as at UCLA. To access the PPI Node from the SPAN network set host to UCLASP and sign on as PDSGUEST. From the Internet the address is uclasp.igpp.ucla.edu (or 128.97.64.220).