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Semiannual Technical Progress Report

1.0 General

1.1	Date of Report :	28 October 1983
1.2	Period Covered :	15 April 1983 through 14 October 1983
1.3	Title of Grant :	Jupiter Data Analysis Program: Analysis of Voyager Wideband Plasma Wave Observations
1.4	Principal Investigator :	W. S. Kurth
1.5	Grant Number :	NAGW-337
1.6	Grantee's Institution :	The University of Iowa Dept. of Physics & Astronomy Iowa City, IA 52242
1.7	Signature :	Submitted by:

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Principal Investigator

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2.0 Summary of Progress During Reporting Period

One of the primary goals of the Jupiter Data Analysis Program at the University of Iowa is to analyze Voyager plasma wave wideband frames from the Jovian encounters. During the reporting period 511 frames were reduced and analyzed. The frames which have been analyzed were chosen on the basis of low-rate spectrum analyzer data from the plasma wave receiver. These frames were obtained in regions and during times of various types of plasma or radio wave activity as determined by the low-rate, low-resolution data and were processed in order to provide high resolution measurements of the plasma wave spectrum for use in the study of a number of outstanding problems.

A number of papers were presented during the reporting period at various meetings, but primarily at the "Physics of the Jovian and Saturnian Magnetospheres Conference" held at MIT in June. These and other presentations as well as publications to date are listed in Section 4 and abstracts of the most recent contributions are attached to the end of this report.

The most significant accomplishment of the reporting period was the submission of a paper analyzing chorus emissions at Jupiter by a group led by F. V. Coroniti of TRW/UCLA. This study compared the detailed temporal and spectral form of the very complex chorus emissions near L = 8 on the Voyager 1 inbound passage to both terrestrial chorus emissions as well as to the theory which has been developed to explain the terrestrial waves. The conclusions, among others, are that the chorus at Jupiter exhibits extremely complex spectral forms, including a persistent double banded structure with a gap at half the electron gyrofrequency. Further, the morphology of the Jovian chorus is similar to terrestrial chorus in most respects. A review of the theories devoted to explaining the chorus leads to the conclusion that none are completely successful in describing either terrestrial or Jovian chorus emissions.

A considerable amount of work continues to be carried out in the study of the Jovian bow shock and associated wave phenomena. An ongoing study is being led by a graduate student at TRW, S. Moses, who is studying the quasi-parallel shock observed by Voyager 2 at extremely high temporal resolution. This work involves correlating the plasma wave observations with plasma measurements and high temporal resolution magnetic field data. Another graduate student, S. Fuselier of the University of Iowa is studying wave phenomena upstream of the shock in an attempt to identify the various wave modes present and to explain some especially complex spectra in terms of the resistive medium instability in particular.

A review paper is presently being prepared by W. Kurth of the University of Iowa which describes the plasma wave spectra at Jupiter and Saturn and compares them to terrestrial plasma waves. One unique portion of that comparison is to describe the gross characteristics of the spectrum at low temporal resolution as a function of magnetospheric region such as outer, middle, or inner magnetosphere and show that the plasma waves actually provide clear indications of major magnetospheric boundaries.

A continuation of a study begun during the last reporting period is being carried out by J. Seery, a graduate student at Iowa. This study involves analyzing the plasma wave spectrum in the Io plasma torus for evidence of ion cyclotron waves on field lines threading the torus. Ion cyclotron waves are thought to be required in order to pitch angle scatter energetic heavy ions to produce the Io torus aurora observed by UVS on Voyager. Because a polarization reversal takes place at latitudes not reached by Voyager, the ion cyclotron waves cannot be detected directly and their presence must be inferred. One question which remains is whether the ion cyclotron waves are generated directly at relatively high latitudes, or whether the wave energy is derived from whistler mode waves generated near the equator.

3.0 Projected Activities for the Next Reporting Period

Analysis of several hundred additional wideband frames will be carried out in support of ongoing research topics as well as new ones. Progress should be made in the continuing studies mentioned in the previous section. In particular, it is hoped that the review paper and an initial report on the bow shock studies can be submitted.

4.0 Publications and Oral Presentations

Publications:

1. Observations of Jupiter's Distant Magnetotail and Wake
   W. S. Kurth, J. D. Sullivan, D. A. Gurnett, F. L. Scarf, H. S. Bridge, and E. C. Sittler, Jr.
   J. Geophys. Res., 87, 10,373, 1982.

2. Narrowband Electromagnetic Emissions from Jupiter's Magnetosphere
   D. A. Gurnett, W. S. Kurth, and F. L. Scarf
   Nature, 302, 385, 1983.

3. Observations of Lower Hybrid Noise in the Io Plasma Torus and Anomalous Plasma Heating Rates
   D. D. Barbosa, F. V. Coroniti, W. S. Kurth, and F. L. Scarf
   J. Geophys. Res., submitted, 1983.
   [See attached abstract]

4. Terrestrial vs Jovian VLF Chorus; A Comparative Study
   U. S. Inan, R. A. Helliwell, and W. S. Kurth
   J. Geophys. Res., 88, 6171, 1983.
   [See attached abstract]

5. Ion Cyclotron Waves in the Io Plasma Torus: Polarization Reversal of Whistler Mode Noise
   D. A. Gurnett and C. K. Goertz
   Geophys. Res. Lett., 10, 587, 1983.
   [see attached abstract]

6. Chorus-Related Electrostatic Bursts at Jupiter and Saturn
   L. A. Reinleitner, W. S. Kurth, and D. A. Gurnett
   J. Geophys. Res., in press, 1983.
   [See attached abstract]

7. Structure and Other Properties of Jupiter's Distant Magnetotail
   R. P. Lepping, M. D. Desch, L. W. Klein, E. C. Sittler, Jr., J. D. Sullivan, W. S. Kurth and K. W. Behannon
   J. Geophys. Res., in press, 1983.
   [See attached abstract]

8. Analysis of Chorus Emissions at Jupiter
   F. V. Coroniti, F. L. Scarf, C. F. Kennel, and W. S. Kurth
   J. Geophys. Res., submitted, 1983.
   [see attached abstract]

Oral Presentations:

Presented at the Spring College on Radiation in Plasmas, International Centre for Theoretical Physics, Trieste, Italy, May 24-June 17, 1983:

1. Plasma Waves in Space
   F. L. Scarf
   [See attached abstract]

Presented at the American Geophysical Union Meeting, Baltimore, Maryland, May 30-June 3, 1983:

2. The Shape and Structure of Jupiter's Distant Magnetotail
   R. P. Lepping, M. D. Desch, L. W. Klein, E. C. Sittler, K. W. Behannon, J. D. Sullivan, W. S. Kurth
   [See attached abstract]

Presented at Physics of the Jovian and Saturn Magnetospheres Conference, Massachusetts Inst. of Technology, Cambridge, Massachusetts, June 21-24, 1983:

3. What We Think We Know About Jupiter's Distant Tail
   R. P. Lepping, M. K. Desch, L. W. Klein, E. C. Sittler, Jr., K. W. Behannon, J. D. Sullivan, and W. S. Kurth
   [See attached abstract]

4. Plasma Waves at Jupiter and Saturn
   W. S. Kurth
   [See attached abstract]

5. Ion Cyclotron Waves in the Io Plasma Torus: Polarization Reversal of Whistler Mode Noise
   D. A. Gurnett and C. K. Goertz
   [See attached abstract]

Presented at the International Union of Geodesy and Geophysics Meeting, Hamburg, Germany, August 15-27, 1983:

6. Whistler Mode Induced Electrostatic Bursts in Three Magnetospheres
   L. A. Reinleitner, W. S. Kurth, and D. A. Gurnett
   [see attached abstract]

Observations of Lower Hybrid Noise in the Io Plasma Torus

and Anomalous Plasma Heating Rates

by

D. D. Barbosa, F. V. Coroniti, W. S. Kurth, and F. L. Scarf

A study of Voyager 1 electric field measurements obtained by the plasma wave instrument in the Io plasma torus has been carried out. A survey of the data has revealed the presence of persistent peaks in electric field spectra in the frequency range 100-600 Hz consistent with their identification as lower hybrid noise for a heavy ion plasma of sulfur and oxygen. Typical wave intensities are 0.1 mV/m and the spectra also show significant Doppler broadening $\Delta\omega/\omega \sim 1$. A theoretical analysis of lower hybrid wave generation by a bump-on-tail ring distribution of ions is given. The model is appropriate for plasmas with a superthermal pickup ion population present. A general methodology is used to demonstrate that the maximum plasma heating rate possible through anomalous wave-particle heat exchange is less than approximately 10^{-14} ergs cm^{-3} s^{-1}, insufficient to meet the power requirements of the EUV emitting warm torus. However, the heating rate is large enough to maintain a low density superthermal electron population of keV electrons, which may lead to a small but significant anomalous ionization effect.

Terrestrial vs Jovian VLF Chorus; A Comparative Study

by

U. S. Inan, R. A. Helliwell, and W. S. Kurth

The relevant parameters of the magnetospheres of Jupiter and Earth are studied from the point of view of wave-particle resonant interactions that are believed to be responsible for the generation of VLF chorus emissions observed on Voyager-1. Using existing models of the cold and energetic plasma distributions in the Jovian magnetosphere, expressions for the wave-particle interaction length (L_I) and the nonlinearity parameter (ρ) are derived. Values of these parameters are compared with those computed for the Earth's magnetosphere. It is found that the typical interaction lengths are at least 2-5 times larger in the Jovian than in the terrestrial magnetosphere. Also, the wave intensity necessary to reach the threshold of nonlinearity in the Jovian magnetosphere was found to be up to 5-100 times lower. The Voyager-1 measurements show, however, that the observed wave magnetic field intensities of the Jovian chorus are in the range of reported intensities for terrestrial chorus. This is attributed to the fact that the fluxes of few keV resonant particles found in the Jovian magnetosphere were typically two orders of magnitude higher. By the same token, it is predicted that the temporal growth rates of Jovian chorus bursts should be typically higher than terrestrial ones. Growth rate measurements on Voyager-1 broadband wave data are used to confirm this hypothesis.

Ion Cyclotron Waves in the Io Plasma Torus: Polarization Reversal of Whistler Mode Noise

by

D. A. Gurnett and C. K. Goertz

Because of the presence of multiple ion species in the Io plasma torus whistler mode noise generated by energetic electrons can be converted to ion cyclotron waves via a polarization reversal process at the local crossover frequency. Whistler mode and ion cyclotron waves in the torus resonate with energetic protons in the energy range from about 10 keV to 10 MeV. Using Voyager 1 electric field intensities measurements the pitch angle diffusion coefficient for the resonant protons is estimated to be about 10^{-6} sec^{-1}. This diffusion coefficient is within a factor of ten of the strong diffusion limit, indicating that the whistler mode noise and associated ion cyclotron waves cause significant pitch angle scattering. This scattering can account for the depletion of energetic protons in the vicinity of the Io torus and the EUV auroral emissions observed at the foot of the torus magnetic field lines.

Chorus-Related Electrostatic Bursts at Jupiter and Saturn

by

L. A. Reinleitner, W. S. Kurth, and D. A. Gurnett

Analyses of the wideband plasma wave data obtained by Voyagers 1 and 2 at Jupiter and Saturn have revealed electrostatic bursts similar to those recently discovered at Earth in association with whistler-mode chorus. In all three magnetospheres the bursts are characterized by sporadic emissions near or slightly below the electron plasma frequency with bandwidths ranging from 10% to more than 50% of the center frequency. The events found at Jupiter occur in the middle magnetosphere during both the dayside as well as the early morning passes. At Saturn, the bursts occurred in the outer regions of the magnetosphere during the dayside pass. In each of the events analyzed, evidence exists for modulation of the electrostatic bursts by a low frequency wave, presumably chorus. One of the observations gained at Jupiter includes the detection of a low-frequency band at the proper frequency for chorus. Detailed waveform analysis confirms that this band does, indeed, modulate the electrostatic bursts. Based on the present understanding of the terrestrial observations it is believed that the electrostatic bursts are generated by an electron beam trapped in Landau resonance with the chorus.

STRUCTURE AND OTHER PROPERTIES OF JUPITER'S DISTANT MAGNETOTAIL

R. P. Lepping, M. D. Desch, L. W. Klein, E. L. Sittler, Jr., J. D. Sullivan, W. S. Kurth, and K. W. Behannon

Observations from the Plasma Wave, Plasma Science, Planetary Radio Astronomy (PRA) and Magnetometer (MAG) experiments onboard Voyager 2 covering at least the period October 1980 to August 1981 provide compelling evidence for a Jovian magnetotail extending over 9,000 Jovian radii from the planet. During approximately monthly sightings of the tail the magnetic field tended to point radially away from Jupiter (i.e., a 'northern lobe' field) for the first 1/3 of 1981, and radilly toward the planet ('southern lobe') for the second 1/2 of the year. For the angle β defined as the latitude of the magnetic field measured from a plane perpendicular to the Jupiter-spacecraft line, an autocorrelation analysis of $|\beta|$ (for $|\beta| > 45°$) for days 0-240 of 1981 indicates a prominent peak at a quasiperiod of 25 days, which is very close to the sideral rotation period of the sun. This fact, along with characteristics of solar wind features at this time, indicates that the tail is apparently influenced by recurrent solar wind features. Very low frequency (1.2 kHz) continuum radiation detected by the PRA receiver is also an indicator of the presence of Voyager inside Jupiter's tail. A significant peak correlation coefficient is obtained at a field lag of zero days when $|\beta|$ is cross-correlated with PRA data over the 240 days and when MAG is restricted to include only tail-like events. Around all of the tail encounter periods on a broad scale the field magnitude decreases, which is not expected for a static tail structure and probably indicates tail expansion to the position of the spacecraft. On a finer scale the field increases across the inbound boundary as expected for an outward pressure imbalance. It is shown that a possible contributor to the internal pressure of the tail is tailward flowing bulk plasma pressure. Both large scale and "detailed" magnetic field variance analyses were performed, resulting in quantitative evidence for field-line draping around the boundary of the tail as well as providing a characterization of internal tail field transverse variations. One event, that of May 1981, is studied in detail, confirming most of the statistical properties of the overall set of prominent events observed by Voyager 2. Voyager 1 magnetic field and wave data from the same time period indicate that it was very unlikely that the distant Jovian tail was observed at the spacecraft. It is speculated that the Jovian tail has a quasi-periodically variable width on a very long length scale, tens of thousands of Jupiter radii, due to the influence of the radial variation of the solar wind's pressure, and it is probably partly filamentary.

ANALYSIS OF CHORUS EMISSIONS AT JUPITER

F. V. Coroniti, F. L. Scarf, C. F. Kennel, and W. S. Kurth

On the Voyager 1 inbound pass through the Jovian magnetosphere, the frequent acquisition of wideband data from the Plasma Wave Instrument has permitted a quasi-continuous survey of the waves which occur in the frequency band below the electron cyclotron frequency -- the chorus band. Structured, rising frequency chorus was observed just outside the dense Io plasma but inside the low-density middle magnetosphere. A quasi-continuous, very narrowband emission occurred just above one-half the electron cyclotron frequency. Power spectra, which were constructed from the wideband data, showed that the half-cyclotron emissions is unaffected by the simultaneous occurrence of chorus at lower frequencies and is separated from the chorus by a deep spectral gap just below one-half the cyclotron frequency. Within the rising chorus band, a new emission was observed which consisted of two quasi-continuous, very narrowband tones located near the upper and lower frequency limits of the rising chorus band. Sequential power spectra showed that these twin-frequency tones persisted during rising chorus bursts. Chorus occurs in the spatial regions where whistlers have cyclotron resonant interactions with the suprathermal population of ~ keV electrons. A possible interpretation of the twin tones is that these signals are electrostatic or resonance cone whistlers. Growth rate calculations show that the electrostatic whistler is destabilized by a loss-cone distribution with the same pitch-angle anisotropy which is needed to excite the electromagnetic chorus whistlers. A speculative hypothesis is presented to explain the half-cyclotron emission. The Landau absorption of oblique chorus whistlers results in the spectral gap just below one-half the cyclotron frequency and in the formation of a quasi-linear plateau in the parallel velocity distribution of the suprathermal electrons. The plateau alters the Landau and cyclotron resonant interactions and permits the unstable growth of electrostatic and electromagnetic whistlers in a narrow range just above one-half the cyclotron frequency.

PLASMA WAVES IN SPACE

F. L. Scarf

During the first ten years of space exploration, spacecraft were generally instrumented to measure properties of the local magnetic field and characteristics of energetic particles, but during the last fifteen years, plasma physics investigations have assumed dominant roles in many space programs. Sensitive, high-resolution plasma probes for analysis of the distribution functions and plasma wave instruments for measurements of electromagnetic and electrostatic wave modes are commonly flown together to provide information on plasma instabilities and wave-particle interactions. Spacecraft with plasma physics payloads have not explored the magnetospheres of Earth, Jupiter and Saturn; the plasma environment of Venus; and the very-low density interplanetary medium from within the orbit of Mercury to well beyond Saturn's orbit. During the next few years, it will also be possible to study at close range plasma waves and wave-particle interactions that develop near Uranus, Neptune, Comet Giacobini-Zinner, and Comet Halley.

These measurements of solar system plasma processes are of great importance because they provide the only opportunity to acquire in situ data that can be used to test theories developed to explain astrophysical observations. The measurements generally involve parameter ranges that are not accessible in laboratory experiments, and so the space plasma physics programs also serve to extend and validate concepts developed in the laboratory. However, the discipline of space plasma has some unique problems. For instance, when local measurements are made from a small platform that moves within the plasma, it is sometimes difficult to separate space and time variations, it is sometimes difficult to distinguish spacecraft interference tones from ambient plasma waves, and it is generally difficult to estimate the wavelengths of the plasma oscillations with certainty. In some areas, however, space plasma physics measurements have natural advantages. For instance, wall effects are not important except at the surfaces of the spacecraft. Plasma physics measurements in space are also unique because, here the plasma probes are able to measure fine details of the distribution function that are needed to understand how the observed waves are generated. Finally, since many plasma waves in space have characteristic frequencies that occur in the audio range, it is possible to listen directly to the measurements of wave activity in space plasmas.

The Shape and Structure of Jupiter's Distant Magnetotail

by

R. P. Lepping, M. D. Desch, L. W. Klein, E. C. Sittler,
K. W. Behannon, J. D. Sullivan, and W. S. Kurth

A collaborative study of the distant Jovian magnetotail using Voyager 2 magnetic field, plasma, plasma wave, and radio astronomy data has revealed that the dynamics of the tail is dominated by quasi-periodic (~ 25 days) expansions and contractions, and only secondarily by a flapping motion. These cross-sectional changes result from the quasi-periodically varying external pressure of the solar wind, which beyond 5 AU from the sun is characterized more by alternating compressions and rarefactions in density and magnetic field magnitude and less by velocity variations. Hence, on a length scale of 10 or more AU the tail should have the appearance of a string of sausages to a first approximation, where the wider cross-sections appear to have diameters on the order of 1 1/2 AU. Furthermore, the cross-sectional shape should be typically oval at all distances from Jupiter with the north-south dimension smaller than the east-west dimension due to the contribution of an anisotropic magnetic field pressure to the total external pressure acting on the tail boundary, since the external field is predominantly azimuthal at these distances. It has also been determined that a considerable amount of plasma flows (in the anti-solarward direction) within the tail adding to the internal pressure, which is primarily due to the tail magnetic field as in the Earth's case. It also appears that the tail field often assumes directions which are far (i.e., > 30°) from being parallel to the average tail axis, suggesting field complexity.

What We Think We Know About Jupiter's Distant Tail

by

R. P. Lepping, M. K. Desch, L. W. Klein, E. C. Sittler, Jr., K. W. Behannon, J. D. Sullivan, and W. S. Kurth

We will delineate and discuss what has been discovered about Jupiter's distant tail based on Voyager 2 PWS, PLS, PRA and MAG data. This includes: the observations upon which comprehensive identifications have been made, the apparent width and sausage-string shape, the role of pressure waves in the solar wind, questions of the internal plasma properties, filamentary structure, pressure balance, and internal/external magnetic field complexity. We will present evidence for the possibility of Saturn being in Jupiter's tail during the Voyager 2-Saturn encounter. There exists a central region of the distant tail, referred to as the core, in which ion densities usually drop to values lower than $\sim 10^{-2}\ cm^{-3}$, the speed is inferred to be very low, and the magnetic field magnitude is usually at or near a local minimum. This core region was seen at every prominent tail encounter and is not well understood; this too will be discussed.

PLASMA WAVES AT JUPITER AND SATURN

W. S. Kurth

Consideration of the plasma wave spectrum is important in the study of any planetary magnetosphere since those waves often play an important role in the mass and energy budget of the magnetosphere. Further, some plasma waves are extremely useful in providing diagnostic information on the state of the local plasma such as the density, temperature, and even magnetic field strength. Our current knowledge of the various plasma instabilities present at Jupiter and Saturn is deeply couched in our understanding of the same or similar phenomena found in the Earth's magnetosphere. Hence, the study of plasma waves in planetary magnetospheres is largely a comparative one in which variations in the occurrence or characteristics of the waves lead to unique views of the differences in the gross morphology of the magnetospheres themselves.

In this review of plasma waves in the magnetospheres of Jupiter and Saturn, we will provide a road map in which various regions of the magnetospheres will stand out simply in terms of the spectrum of plasma waves present. We will show by the use of current theories how the presence of certain instabilities label that region as being a cohesive volume in which one or more particular wave modes dominate because the plasma parameters remain favorable to the modes throughout the region. For example, the inner magnetospheres of both Jupiter and Saturn are characterized by large amplitude whistler mode waves which interact with energetic electrons and quite likely play a role in generating aurora.

ION CYCLOTRON WAVES IN THE IO PLASMA TORUS:
POLARIZATION REVERSAL OF WHISTLER MODE NOISE

D. A. Gurnett, C. K. Goertz and J. R. Seery

Because of the presence of multiple ion species in the Io plasma torus whistler mode noise can be converted to ion cyclotron waves via a polarization reversal process at the local crossover frequency. These ion cyclotron waves resonate with energetic protons and heavy ions in the energy range from about 10 keV to greater than 10 MeV. Using low frequency electric field measurements from Voyager 1, believed to be due to whistler mode noise, we have estimated the pitch-angle diffusion rates that would occur if this noise is converted to ion cyclotron waves. All waves are assumed to propagate along the magnetic field line with no attenuation. Typical pitch-angle diffusion coefficients range from $D_{\alpha\alpha} \approx 10^{-6}$ sec^{-1} for protons resonating near the equator to $D_{\alpha\alpha} \approx 10^{-4}$ sec^{-1} for 10 keV O^+ ions resonating at high latitudes. These diffusion coefficients indicate that the low frequency whistler mode noise and associated ion cyclotron waves cause significant pitch-angle scattering for energetic protons and ions trapped on the torus L-shells. Our preliminary estimates indicate that these waves may be able to account for the EUV auroral emissions at the foot of the torus field lines.

Whistler Mode Induced Electrostatic Bursts in Three Magnetospheres

by

L. A. Reinleitner and W. S. Kurth

Recent studies of data from the Plasma Wave Instruments on board the Voyager 1 and 2 spacecraft have demonstrated that broadband electrostatic emissions can occur in the magnetospheres of both Jupiter and Saturn. These emissions display a strong similarity to whistler mode (chorus) related electrostatic bursts in the Earth's outer magnetosphere. In all three magnetospheres, these bursts are characterized by a fairly large bandwidth, and by being very sporadic. They have some harmonic structures present, and all cases are found to have very similar local plasma parameters. The evidence at Jupiter is strengthened by a case where whistler mode waves are observed to occur simultaneously with electrostatic bursts, and waveform studies show a clear modulation of the bursts at the whistler mode frequency, similar to such modulation in the terrestrial case. Extensive analysis of the phenomenon in the terrestrial case has shown that such broadband electrostatic bursts are produced by electrons trapped in Landau resonance with oblique whistler mode chorus waves in the dayside outer magnetosphere. Furthermore, these electrons produce the broadband electrostatic bursts with a center frequency reduced below the local plasma frequency by anywhere from 5% to 60%. The virtually conclusive evidence at Jupiter and the strong evidence at Saturn renders it probable that all three magnetospheres share this interesting phenomenon.