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Final Technical Report
NASA Grant NAGW-386
for
"A Multidisciplinary Study
of Planetary, Solar and
Astrophysical Radio Emissions"

by

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I. INTRODUCTION

The purpose of this grant was to conduct a multidisciplinary study of planetary, solar and astrophysical radio emissions as part of the NASA innovative research program. The past decade has been a period of very rapid development in the field of planetary, solar and astrophysical radio astronomy. Extensive measurements have been made of the earth as an intense radio emitter. Voyagers 1 and 2 have now provided detailed measurements of radio emissions from Jupiter, Saturn, and Uranus. Spacecraft and ground-based radio receivers have performed detailed measurements of various types of radio emissions from the sun. Finally, rapid advances in very long baseline interferometry (VLBI) techniques and the completion of the very-large-array (VLA) in New Mexico have provided remarkable advances in the sensitivity and angular resolution available for studying astrophysical radio sources. The objective of this grant was to bring together these diverse but nevertheless related fields of planetary, solar and astrophysical radio astronomy by holding special seminars, bringing in invited speakers and visiting faculty, and supporting noteworthy lines of research that would advance the understanding of radio emission processes.

To conduct this research the study team was organized into three groups: (a) Theory, under the leadership of Dr. Spangler, (b) Solar Radio Astronomy, initially under the leadership of Dr. Shawhan, and

later under the leadership of Dr. Kurth, and (c) Astrophysics, under the leadership of Dr. Mutel. Each group met on the average of once per month and arranged seminars and coordinated other research activities.

One research scientist, Dr. Ralph Fiedler, and one visiting scientist, Prof. Bernard Roberts, were hired to work on this grant. Dr. Fiedler was an expert on magnetohydrodynamic aspects of cosmic radio jets and was employed from Dec. 1983 to Sept. 1985. Prof. Roberts was an expert on Solar magnetohydrodynamics with a special interest in solar oscillations and was employed from Aug. 1985 to June 1986.

Overall the research group was quite successful. From the start of the grant on Jan. 1, 1983, to the termination on Jan. 31, 1986, a total of 52 papers were submitted or published with complete or partial support from this grant. Numerous departmental seminars were conducted by members of this group, including a series of lectures by Prof. Roberts giving a short course on solar magnetohydrodynamics. These seminars and lectures were very successful in their basic objective which was to inform the entire group of progress and new developments in different fields.

Some aspects of the grant research did not go exactly as originally planned. The departure of Prof. Shawhan early in the project left us with a gap in the solar physics area. We found that it was quite difficult to find a suitable senior solar physicist who would come to Iowa on a visiting appointment. During the last year of

the grant we were fortunate in getting Prof. Roberts, who has contributed considerably to this project. The departure of Prof. Shawhan also increased the research burden on Prof. Gurnett who took over several of his projects. This sharply reduced the amount of time that Prof. Gurnett had available to work on this project. Finally, our initial hope of finding an astrophysical analog of the intense, strongly polarized radio emissions characteristic of earth, Jupiter, Saturn, and Uranus, has not materialized. Considerable effort was spent by Prof. Mutel's group on studies of stellar binary systems, which were initially regarded as possibly similar to the planetary emission processes. Although very successful, these studies show that the radio emissions probably are not produced by the same mechanism as the planetary emissions.

Detailed reports of the research results from this grant are given in the next three sections.

II. THEORY REPORT (S. Spangler)

The theory group addressed the effect of plasmas on astrophysical radio sources. As part of the rationale for NASA support, we investigated topics in which our understanding would benefit from spacecraft studies of solar system plasmas. This end was achieved by studies of plasma processes or phenomena which occur in the solar wind or magnetosphere, and which might also be important in more remote astrophysical plasmas. However, we also used techniques developed for study of solar system plasmas in our investigation of the interstellar medium and extragalactic plasmas.

A brief description of each of the major areas of investigation is given below.

A. Remote Sensing Studies of Astrophysical Plasma Turbulence

In analogy with the interplanetary medium, we expect that astrophysical plasmas will generally be turbulent. There are many theories which attribute considerable importance to such turbulence, such as those concerned with the acceleration of cosmic rays. However, such speculations are weakened by the paucity of information on turbulence in the interstellar medium and other astronomical plasmas.

Spacecraft studies of solar system plasmas, particularly the interplanetary medium, can assist in two respects. First, we can observationally determine general properties of plasma turbulence,

and then apply these findings to the more remote plasmas. Second, in some limited cases we can use techniques developed for studies of solar system plasmas. Specifically, the same technique used to detect Alfvén waves in the solar corona can be used for the study of magnetic turbulence in the interstellar medium.

The ideas described above were realized in a number of projects undertaken during the grant period. In abstracts 2 and 32, a theory was developed for the transport of polarized synchrotron radiation in a random medium, and the results applied to observations of extragalactic radio sources. In addition to emphasizing the information contained in radio polarization data, these investigations yielded an estimate for the magnetic field scale length, and provided interesting upper limits to the plasma density in the lobes of radio galaxies.

In another investigation [abstract 11] fluctuations in the galactic Faraday Rotation were studied to obtain information on magnetic irregularities in the interstellar medium. Measurements of the Faraday Rotation along the path to a large number of extragalactic radio sources provided the data set. This investigation yielded the interesting result that the net Faraday Rotation is evidently due to a few actively rotating cells, rather than a more uniform, distributed medium.

B. Theoretical Studies of Alfven Waves

Alfvén waves represent one of the most basic plasma wave modes. Observations near the Earth reveal beautiful examples of these waves, reinforcing our belief that they will arise in all natural plasma environments. It is widely believed that they may play a crucial role in the acceleration of the galactic cosmic rays, and it has been frequently suggested that they energize the relativistic electrons responsible for the synchrotron radiation of radio galaxies and quasars.

A major goal of our current research effort has been to obtain a better understanding of the properties of Alfvén waves, particularly their nonlinear development. The reason for this interest in Alfvén wave nonlinearity is that it has been well established that nonlinear processes are extremely important in the evolution of Langmuir waves.

A number of investigations have dealt with the process by which an Alfvén wave packet steepens, termed a "modulational instability." These investigations have shown that a wave packet can develop spatially abrupt structures such as wave pulses or edges to the wave packet. The existence of these structures can result in heavy nonlinear damping of Alfvén waves, which are otherwise relatively free from dissipation, and also lead to enhanced scattering of energetic particles. A result of these studies has been the identification of a general timescale for nonlinear development which can be applied to all astrophysical plasmas. In abstract 31, arguments using this timescale expression are forwarded to suggest that advanced nonlinear

development of Alfvén waves might occur in the region upstream of a supernova remnant shock. It is suggested that such nonlinear processes might account for the acceleration of electrons at these shocks.

C. Observational Study of Alfven Waves in the Interplanetary Medium

In the previous section, we described theoretical work concerned with nonlinear Alfvén waves. Most previous work in this area has been theoretical, with relatively little comparison to observation. Observational study of Alfvén waves in space, on the other hand, has been limited to pointing out the fact that these objects resemble linear or ideal Alfvén waves. Very little effort has gone into extracting results of interest to basic plasma physics from observations of these fine specimens.

Our viewpoint has been that if pronounced nonlinear behavior is a realistic property of Alfvén waves, there should emerge evidence of such properties in observations of interplanetary Alfvén waves. Under the support of this grant, a study was made of the characteristics of Alfvén waves upstream of the Earth's bow shock. The observational material utilized consisted of both published observations and magnetometer data from the ISEE spacecraft.

Our results are presented in Section IV of abstract 44. We have found that the necessary conditions for the development of Alfvén wave nonlinearity, variations in the Alfvén wave energy density and corresponding induced changes in the plasma density, are present in the upstream waves. Furthermore, contracted wave packets, termed

shocklets, which are observed in the upstream region, can be interpreted in terms of Alfvén waves subject to nonlinearity, amplification, and short wavelength dissipation. Briefly stated, these wave packets can be interpreted as solitons which are stifled in the process of formation.

In summary, we feel the spacecraft observations have revealed important nonlinear properties of astrophysical Alfvén waves, and indicate that the interplanetary medium serves as a laboratory for our theories of nonlinear wave behavior.

D. Properties of Astrophysical Shock Waves

One of the main results to come from spacecraft observations of the solar system, particularly in the ISEE program, is the similar character of collisionless plasma shocks, whether associated with the bow shocks of the planets Earth and Venus, traveling interplanetary shocks, or cometary bow shocks. In all cases one observes streaming ion distributions, magnetohydrodynamic waves generated by these ions, and wave-induced density fluctuations. In at least the cases where observations are possible, ion acceleration appears to accompany the other phenomena. This has led to considerable interest in the astrophysical community, as it suggests that the larger and more energetic shock waves associated with supernova remnants might be responsible for accelerating the cosmic rays.

It would be of great interest to detect a "foreshock" of a supernova remnant, similar to those of the smaller solar system shocks. During the grant period, we conceived a method for detecting supernova

remnant foreshocks, and began observational implementation of this method.

Briefly, the method consists of searching for the wave-induced density irregularities in the foreshock. These irregularities should cause angular broadening or "blurring" of extragalactic radio sources viewed through the supernova remnant foreshock. With support from this grant, we were able to investigate the feasibility of this technique, assemble a list of radio sources whose lines of sight pass close to the edge of a supernova remnant, and begin an observational program.

Our first results were presented in abstract 36. Observations of five supernova remnants yielded no cases of unambiguous, remnant-associated scattering. Analysis of the upper limits yielded constraints on foreshock density turbulence which verge on being uncomfortable. We are currently engaged in similar observations of other remnants, as well as more sensitive searches for scattering of our best candidates. Continued negative results might require reconsideration of the idea that quasi-parallel foreshocks exist in front of supernova remnants.

E. Surface Waves in Astrophysics

In recent years, observations have emphasized the segmented, structured nature of solar system plasmas. In such media, surface waves are of importance as well as the more familiar "body waves" of infinite plasmas. These surface waves and waves on plasmas interfaces

are particularly important in the solar atmosphere, and may play an important role in coronal heating.

In view of the above lessons, it seems very probable that surface waves also play an important role in more remote astrophysical plasmas. One very obvious candidate is the extragalactic jet, which represents a cylindrical region of synchrotron-radiation-emitting plasma. There are presumably discontinuities in other quantities as well, such as magnetic field strength, plasma density, etc., so it would seem that surface waves could propagate on these objects. In abstract 42, we investigated the possibility that solitons could exist on these jets. It was found that in certain circumstances, these solitons might be able to account for the radio-bright "knots" seen on these objects.

III. ASTROPHYSICS REPORT (R. Mutel)

Since early 1983, a group headed by R. Mutel and J.-F. Lestrade (Bureau des Longitudes, Paris) has undertaken a series of VLBI and VLA observations designed to investigate the spatial structure and polarization properties of non-thermal radio emission from late-type close binary stars, mainly of the RS CVn class. Observations of x-ray emission, UV and optical line emission and radio emission all indicate that the chromospheres and coronae of these systems are heated and confined by magnetic flux tubes, which transport the mechanical energy of turbulent convection cells at the photosphere to the upper stellar atmosphere by means of MHD waves. The radio emission is the result of enhanced magnetic activity, probably caused by forced rapid rotation (via tidal effects), giving rise to a powerful dynamo originating in the convective envelope. Since the radio emission is strongly dependent on the magnetic field strength and geometry (e.g., for gyro-synchrotron emission, the emissivity scales as B^2), the study of radio properties provides a powerful tool for probing the magnetic properties of these systems.

A. VLBI Results

VLBI observations are particularly useful, since they are the only means available at any wavelength for probing spatial structure on a scale of the binary system itself, which is typically a few milliarcseconds or less. The goals of the VLBI program are two-fold:

- To determine the characteristic spatial scales and brightness temperatures of the radio emission during quiescent and flaring states. From this information, we can infer both the basic physics of the emission mechanism and estimate the magnetic field strength and distribution and electron energies. Such estimates have been published for a few systems (abstracts 6, 9, 7, 16). In addition, the first VLBI map of any close binary stellar system was published (abstract 25, Figure 1 below).

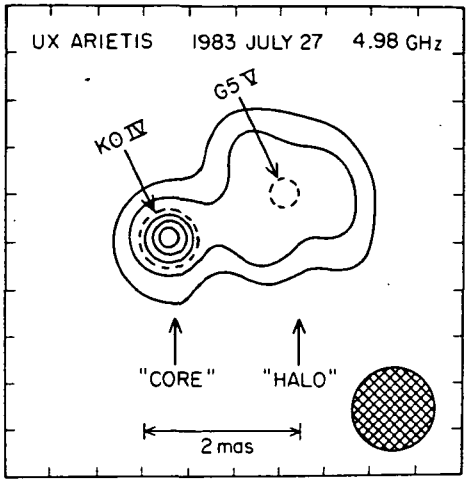

Fig. 1. Hybrid Map of UX Arietis on 26 July 1983 at 5 GHz. The core-halo radio structure is evident (Mutel et al., 1985).

- To use nearby unresolved phase calibrators to determine the position of the binary system (relative to the extragalactic calibrator) to an accuracy of less than 1 mas. This astrometric data can then be used to tie the optical and radio coordinate systems together (abstract 5), and to measure motion of radio emitting plasmoids during flares (abstract 38). The latter effect is measureable on a timescale of one hour if the emission region moves at about the local Alfven velocity (a few hundred km/s).

The astrometic program requires searches of the fields (about 1 deg radius) around the target stars, first by mapping at the VLA and then testing for milliarcsecond structure by observing with VLBI. This procedure has now been completed for 6 of the most active RS CVn systems. Several VLBI array observations have been conducted to make milliarcsecond position measurements and to look for microarcsecond motions within the observing time. The first astrometric results are reported in abstract 46.

A summary of all VLBI observations of RS CVn systems completed during the IRP grant period (1 January 1983 to 31 January 1986) is given in Table 1 below.

Date	Freq.	Stns	Stars	Publication/ Status
Feb. 1983	1.6	GYO	2 stars	Mutel et al., 1984
Mar. 1983	8.4	MSOW	HR1099	Lestrade et al., 1984b
May 1983	2.3/8.4	MSOWF	Algol	Lestrade et al., 1986
July 1983	5.0	BKGFYO	7 Sys.	Mutel et al., 1985b
Oct. 1983	1.6	BGFYO	8 Sys.	Reduced (in prep.)
Mar. 1984	5.0	BKGYO	HR5110	Reduced (astrometry)
July 1984	5.0	KYO	Algol	Reduced (astrometry)
Oct. 1984	5.0	BKGOY	Algol	Lestrade et al., 1986
June 1985	5.0	BKGOY	3 stars	Data reduced

The principal scientific results of the VLBI program so far are:

- A systematic determination of the brightness temperature both during active and quiescent states. The corresponding sizes are a fraction of the stellar disk (active phase) and about overall binary size (quiescent state). This has been confirmed in several systems and appears to be a general property of the radio emission in RS CVns and in Algol.

- The brightness temperatures, sizes, and circular polarization are all consistent with the incoherent gyro-synchrontron emission from mildly relativistic electrons (1-5 MeV) in magnetic fields of 10-30 Gauss. There are a few very rare flares with extremely high degrees of circular polarization and high brightness temperature which could be a coherent process, such as an electron cyclotron maser.
- Evidence of asymmetric core-halo structure in a single system (UX Ari, July 1983). The hybrid map shown in Figure 1 is the first image of a close binary system made at any wavelength and represents a major advance in the study of these systems. The core component (near stellar surface?) had no measured circular polarization, while the halo had about 5% net polarization. We have proposed a model (abstract 25) in which the core is emitting by a synchrotron process, while the halo emits gyro-synchrotron radiation from electrons which have diffused out from the core site while suffering radiation losses. The observed timescales, inferred electron energies and magnetic field strengths are all consistent with the model.
- A single measurement of the angular size of the periodic x-ray binary LSI+61303 (Mutel and Lestrade, in prep.). The size (4 mas or about 1E14 cm at 2 Kpc) is about 100 times the size of the stellar system and seems to indicate that production of energetic electrons takes place well away from the stars, perhaps via Compton scattering from the observed gamma rays. This result

eliminates 'local' models wherein the synchrotron electrons are produced at the interaction zone between the O star wind and the compact object's wind or accretion disk.

B. VLA Observations

The VLA is ideally suited for studies of the polarization and flux behavior of the radio emission, because of its great sensitivity and well-defined polarization characteristics. We have used the VLA to determine the polarization of several active systems over a period of two years (abstract 48) and to search for new radio-active close binaries (abstract 26). In addition, we have studied the eclipsing binary AR Lac over two eclipse periods to search for a radio light curve signature which would be caused by occultation of the radio source by the closer star (abstract 8). The principal scientific results of the VLA program are:

- To establish that there is a high correlation between handedness of circular polarization and frequency, with a reversal typically between 1.6 and 5.0 GHz (abstract 48). This result would be expected if the source is radiated by a gyro-synchrotron process and became optically thick between 1.6 and 6 GHz. Since this behavior has been observed over almost two years for several systems, it implies that the global magnetic fields have a fairly stable orientation.
- The discovery of more than twenty new RS CVn systems with detectable radio emission. This increases the total number of known radio-detected systems to more than 60. The VLA survey and a summary of the properties of all radio detections published to date, is given in abstract 49.

- Tentative evidence for a relationship between the radio luminosity and Rossby number (defined as the ratio of the rotational period to the convective turnover time). A preliminary plot of the correlation is shown in Figure 2 below. A luminosity-Rossby number relation might be expected in dynamo models of stellar activity and has already been established for x-ray and UV line emission. The detailed functional form of the radio luminosity-Rossby number relation needs to be established clearly and compared with those for other activity indicators. With well-defined statistics it may be possible to determine if the radio source (at least during flare events) is associated with the chromosphere or corona.

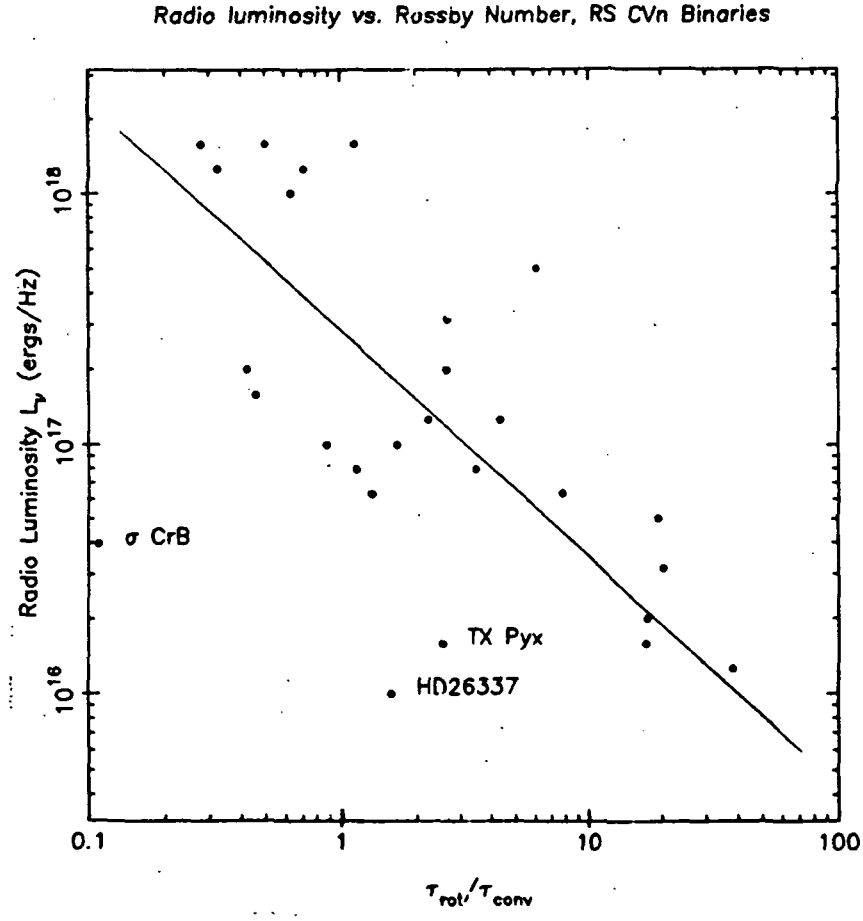

Fig. 2. Radio luminosity versus Rossby Number for RS CVn binary systems (abstract 49).

IV. SOLAR REPORT (D. Gurnett)

Because of the long delay in obtaining a solar physicist to work on the innovative research program, progress in solar physics was mainly limited to Prof. Robert's work during the last year of the grant interval. Prof. Robert's primary interests were in magnetohydrodynamic waves and solar oscillations. During his 9 month stay at Iowa he completed two review papers, one (abstract 52) reviewing dynamical processes in solar magnetic flux tubes for the book, Abhandlungen der Akademic der Wissenschaffen, and the other (abstract 50) reviewing the use of guided MHD waves as a tool for diagnostics of the solar corona in, Proceedings of the Solar Maximum Workshop on "Coronall Prominence-Plasmas". In addition to these review papers, he completed a paper with his Ph.D. student, Mr. W. R. Campbell, on magnetic field corrections to solar oscillation frequencies. This important piece of research (abstract 51) for the first time provides a method of determining the magnetic field strengths deep within the solar interior. The inferred magnetic field strengths are on the order of 5×10^5 G, comparable to what was expected from various theoretical arguments, but never before subject to a direct determination.

V. Abstracts of All Papers Completed From January 1983 to January 1986

1. Nonstationary Coupling Between the Magnetosphere and Ionosphere
C. K. GOERTZ
Proceedings, 6th ESA Symposium on Rockets and Balloons, ESA-SP-183, 221, 1983.

Large-scale MHD perturbations couple to small-scale kinetic Alfven waves which drive field-aligned currents tens of $\mu A/m^2$ into the ionosphere with accelerated electrons of energies a few keV. Bounce resonant interaction with standing kinetic Alfven waves may precipitate higher energy electrons. East-west aligned arcs should be thinnest and move polewards relative to the plasma at the poleward edge. Downward travelling wave packets trap electrons between the wave front and the ionosphere whose energy is below the peak energy and whose phase-space density should be independent of the peak energy.

2. Determination of the Properties of Magnetic Turbulence in Radio Sources
S. SPANGLER
Astrophys. J. Lett., 271, L49, 1983.

We have considered the transport of polarized synchrotron radiation in a source possessing a highly irregular magnetic field, as proposed by Laing. The transport equation has been solved in a special case, relating the observable correlation functions in the Stokes parameters Q and U to the correlation function of magnetic field and plasma density in the source. A rough application of our results to observations of the radio galaxy 3C 166 indicates that the turbulent scale length may be a few percent of the lobe size.

3. Alfven Wave Collapse and the Stability of a Relativistic Electron Beam in a Magnetized Astrophysical Plasma
STEVEN R. SPANGLER and JAMES P. SHEERIN
Astrophys. J., 272, 273, 1983.

The generation of Alfven waves by magnetic field-aligned electron streams, and the evolution of such streams under the action of the self-generated waves, remains an important question in theoretical radio astronomy. In this paper we present a simple derivation of a time scale on which a nonlinear Alfven wave packet collapses. This time scale is compared with the linear growth and quasi-linear relaxation time scales for conditions appropriate to an extragalactic radio source. The nonlinear time scale can be comparable to the linear and quasi-linear time scales, which suggests that nonlinear effects may stabilize this instability and permit the propagation of anisotropic electron streams.

4. The Io Control of Jupiter's Decametric Radiation: The Alfven Wave Model
C. K. GOERTZ
Adv. Space Res., 3, 59, 1983.

Geometrical considerations based on a conical sheet model of the observed DAM sources show that DAM is generated on field lines in the active longitude sector $\phi \sim 200 \pm 90°$. We show how Io excites Alfven waves and calculates the propagation of these waves through the inhomogeneous torus and magnetosphere. The power flux at high latitudes is largest at two longitudes which are seen as the B(1), B(2), A and C sources. We also discuss the parallel electric field accompanying the Alfven wave pulses and show that at high latitudes electrons can be accelerated to energies in excess of 1000 eV. It is suggested that these current carrying electrons excite ion-cyclotron, upper and lower-hybrid electrostatic waves which may all play crucial roles in the generation of DAM.

5. Linking HIPPARCOS Observations to an Extragalactic VLBI Frame by Use of Optically Bright Radio Stars
R. PRESTON, J.-F. LESTRADE, and R. MUTEL
Proceedings, FAST Thinkshop, ed. by P. L. Bernacca, 395-402, 1984.

We are attempting to link the HIPPARCOS stellar reference frame and the JPL VLBI reference frame by means of VLBI measurements of the positions and proper motions of the radio components of some bright stars. We discuss the selection of the candidate stars, our first VLBI observations of some of these candidates, and plans for tying the positions and proper motions of these stars to the VLBI frame. Through VLBI observations of known radio stars, we have identified radio emitting stars that should be appropriate for both VLBI and HIPPARCOS observations. These stars belong mainly to the RS CVn class of close binaries. Our measurements indicate that the angular extent of the radio emission from two of these stars is < 2 milliarcseconds, and this is presumably true for all of them, although further study is needed. This small angular size suggests that the radio and optical emitting regions are coincident at this level.

6. Very Long Baseline Interferometry Observations of the RS Canum Venaticorum System HR 5110 at 8.4 GHz
JEAN-FRANCOIS LESTRADE, ROBERT L. MUTEL, ROBERT A. PRESTON, JOHN A. SCHEID, AND ROBERT B. PHILLIPS
Astrophys. J., 279, 184-187, 1984.

The RS Canum Venaticorum (RS CV_n) binary system HR 5110 was observed with a well calibrated four-element VLBI array at a frequency of 8.4 GHz. The total flux density, which was nearly constant at 32 ± 2 millijansky, was monitored throughout the experiment with a 20 km baseline interferometer allowing accurate visibilities to be calculated. The observed visibilities are consistent with a source unresolved on all the baselines. The maximum size of the equivalent

Gaussian source is 1.4 milliarcsecond (FWHM) corresponding to a linear size of 1.1 10^{12} cm at 52 parsecs. This maximum size is comparable with the overall size of the binary system. The inferred lower limit of the brightness temperature is 4 10^{8} K which is higher than the coronal temperature of 10^{7} K measured in a soft X-ray survey. This is consistent with a nonthermal mechanism for the radiation process of the quiescent state observed.

7. VLBI Observations of the RS Canum Venaticorum Binary Systems UX Arietis and HR 1099 at 1.65 GHz
R. L. MUTEL, D. J. DOIRON, J. F. LESTRADE, and R. B. PHILLIPS
Astrophys. J., 279, 220, 1984.

VLBI observations of the RS CVn binaries UX Arietis and HR 1099 have been made at 1.65 GHz using a three-element array with a minimum fringe spacing of 11.5 mas. Both sources were found to be unresolved within measurement uncertainties. The derived upper limit to the source sizes in both cases were comparable to the overall size of each binary system. The lower limit to the brightness temperature was $T_B \gtrsim 1 \times 10^{10}$ K. Simultaneous polarization measurements at the VLA showed 4-8% circular polarization and less than 2% linear polarization. It is found that the data are consistent with gyro-synchrotron emission from a power-law energy distribution of electrons in a magnetic field $B \lesssim 6$ Gauss.

8. VLA Observations of the Eclipsing Binary System AR Lacertae
D. J. DOIRON and R. L. MUTEL
Astron. J., 89, 430, 1984.

Dual-frequency radio observations of the RS CVn binary system AR Lacertae are reported during two secondary eclipses. No clearly defined eclipse signature was observed during either eclipse at either 1.5 or 4.9 GHz. This implies a lower limit of 5×10^{11} cm for the source diameter if the source is located in the orbital plane. Significant circular polarization (2% - 8%) was observed on both days, with a helicity reversal between 1.5 and 4.9 GHz. This polarization signature is consistent with a gyro-synchrotron emission mechanism if the source becomes optically thick between 1.5 and 4.9 GHz. Using this emission model, the derived range of magnetic field strength is $5 \lesssim B \lesssim 80$ G.

9. Detection of a Submilliarcsecond Radio Component in the RS CVn System HR1099
J.-F. LESTRADE, R. MUTEL, R. PHILLIPS, J. WEBBER, A. NEILL, and R. PRESTON
Astrophys. J. Lett., 282, L23-L26, 1984.

The RS CVn system HR 1099 was observed with a five station VLBI array at a frequency of 8.4 GHz during a strong radio outburst of approximately 400 mJy. The data are consistent with a circular Gaussian source of 0.8 ± 0.12 milli-arcsec (FWHM), corresponding to a linear size of $4 \pm 0.6 \times 10^{11}$ cm. This is comparable to the distance between the surfaces of the two stars, or to 75% of the diameter of the chromospherically active K star. Extrapolation of published photometric data shows that the starspot formation of HR 1099 was facing toward us at the times of observations. The high equivalent brightness temperature, approximately 10^{10}K, is consistent with gyro-synchrotron emission from a power-law energy distribution of electrons in a magnetic field of strength B ~ 30 gauss.

10. Kinetic Alfven Waves on Auroral Field Lines
C. K. GOERTZ
Planet. Space Sci., 32, 1387-1392, 1984.

Several observations near moving arcs require particle acceleration in nonstationary electric fields. We suggest that kinetic Alfven waves play a significant role in the acceleration process. The characteristic properties of kinetic Alfven waves are summarized and the Hasegawa and Mima (1976) solitary kinetic Alfven waves are described. The resonant coupling of large-scale surface waves to the kinetic Alfven wave is discussed. Finally, we show that kinetic Alfven waves can reasonably well explain the observations of what has hence been called "electrostatic" shocks.

11. Small Scale Variations in the Galactic Magnetic Field: The Rotation Measure Structure Function and Birefringence in Interstellar Scintillations
J. H. SIMONETTI, J. M. CORDES, and S. R. SPANGLER
Astrophys. J., 284, 126, 1984.

The structure function of rotation measures of extragalactic sources and birefringence in interstellar scintillations are used to investigate variations in the interstellar magnetic field on length scales of ≈ 0.01 - 100 pc and ≈ 10^{11} cm, respectively. Model structure functions are derived for the case of a power-law power spectrum of irregularities in the quantity (n_eB), and an estimate for the structure function is computed for several regions of the sky using data on extragalactic sources. The results indicate an outer

angular scale for RM variations of $\lesssim 5°$ (a linear scale of ~ 9 to 90 PC at a distance of ~ 0.1 to 1 kpc). There is also evidence for RM variations on angular scales as small as 1 arcmin, but we cannot determine whether these are intrinsic to the source or caused by the interstellar medium. The effect of a random, Faraday-active medium on the diffraction of radio waves is derived and an upper limit to the variations in $n_e\ell$ on a length of ~ 10^{11} cm is obtained from available observations.

12. Detection of a Radio Emission at 3 kHz in the Outer Heliosphere
W. S. KURTH, D. A. GURNETT, F. L. SCARF, and R. L. POYNTER
Nature, 312, 27-31, 1984.

Evidence of a radio source in the outer heliosphere is given based on observations made by the plasma wave receivers on Voyagers 1 and 2 at heliocentric radial distances ranging from 13 to 19 AU. The radio emission is observed in the frequency range of 2 to 3 kHz, and is above the local solar wind electron plasma frequency whenever supporting plasma density data are available. The maximum spectral density of the emission recorded to date is about 10^{-14} $V^2m^{-2}Hz^{-1}$. The bandwidth of the radio noise is about 1 kHz. Several possible sources for the radio emission are discussed, including continuum radiation escaping from Jupiter's distant magnetotail and radiation at the second harmonic of the plasma frequency at the heliopause. If the latter interpretation is correct, these data represent the first remote observations of the heliopause.

13. Modulational Instability and Soliton Formation During Ionospheric Heating
G. L. PAYNE, D. R. NICHOLSON, R. M. DOWNIE and J. P. SHEERIN
J. Geophys. Res., 89, 10,921-10,928, 1984.

The most intense electric fields during ionospheric heating occur a fraction of a kilometer below the classical reflection point. At this location, the nonlinear evolution of Langmuir waves is studied within the context of the modified Zakharov equations. It is found that the modulational instability (oscillating two-stream instability) is more important than the three-wave parametric decay instability, leading to the rapid formation of solitons.

14. Nonlinear Effects and the Limitation of Electron Streaming Instabilities in Astrophysics
S. R. SPANGLER and J. P. SHEERIN
Proceedings, IAU Symp. 107, "Unstable Current System and Plasma Instabilities in Astrophysics," Reidel, 1984.

Nonlinear effects, such as soliton collapse, will result in evolution of hydromagnetic waves excited by a field-aligned charged

particle beam. If the time scale for such evolution is comparable to, or shorter than, linear time scales such as those for wave growth or pitch angle isotropization, then nonlinear effects may limit the instability. For conditions appropriate to relativistic electron streaming in a radio galaxy, the nonlinear time scale may be comparable to the linear time scales.

15. Results of VLBI Observations of Radio Stars and Their Potential for Linking the HIPPARCOS and Extragalactic Reference Frames
J.-F. LESTRADE, R. PRESTON, A. NIELL, R. MUTEL, and R. PHILLIPS
Proceedings, IAU Symposium 109, D. Reidel, 1984.

VLBI observations of bright radio stars have been initiated in an attempt to measure the positions and proper motions of their radio components in order to tie the future HIPPARCOS stellar frame to a VLBI extragalactic reference frame. Through observations of a sample of 20 known radio stars we have identified 11 stars that should be appropriate for both VLBI and HIPPARCOS observations. Our measurements indicate that the angular extent of their radio emitting regions is small, i.e., < 3 milliarcseconds for 7 of them. Most of these radio stars belong to the RS Canium Venaticorum class of binary systems.

16. VLBI Observations of Stellar Binary Systems
R. L. MUTEL, J.-F. LESTRADE, R. A. PRESTON, A. E. NIELL, R. B. PHILLIPS and J. WEBBER
VLBI and Compact Radio Sources, IAU Symposium #110, ed. by Fanti, Kellermann, and Setti, D. Reidel Publishing Co., pp. 277-279, 1984.

We summarize the results of an on-going program of multi-station VLBI observations of radio active RS CVn and related binary stellar systems at centimeter wavelengths. During the course of four experiments, the following sources were detected: UX Arietis (2), HR 1099 (2), II Peg, HR 5110 (2), σ Crb, Algol, and LSI 61°303. The measured sources' sizes were generally comparable to the overall size of the binary system and the brightness temperatures were usually $T_B \gtrsim 10^{10}$ K. The data, along with simultaneous polarization data obtained from the VLA for some observations, were found to be consistent with gyro-synchrotron emission from a power-law distribution of electrons with $\langle E \rangle \sim 1$ MeV in a magnetic field of $B \sim 5 - 10$ gauss.

17. Soliton Collapse During Ionospheric Heating
J. P. SHEERIN, D. R. NICHOLSON, G. L. PAYNE, and L. M. DUNCAN
Proceedings, 1984 International Conference on Plasma Physics, Lausanne, Switzerland, June, 1984.

Analytical and numerical work indicate that during ionospheric heating with high-powered HF radio waves, the oscillating two-stream instability may dominate the parametric decay instability. The

oscillating two-stream instability leads to the formation of a set of collapsing, collisionally damped solitons. The collapsing solitons may be detected using incoherent scatter radar. Using the heater and radar facilities at Arecibo Observatory, we have investigated this phenomenon experimentally. Recent results from theoretical and experimental investigations will be reported.

18. Generation of Broadband Electrostatic Noise in the Tail for Two-Component Electron Populations
CROCKETT L. GRABBE
Proceedings, 1984 International Conference on Plasma Physics, Lausanne, Switzerland, June, 1984.

ISEE-1 data shows a close correlation between the occurrence of broadband electrostatic bursts and ion beams. A recent theory for the generation can explain the essential features of the spectrum for the hot electrons observed in the source region. The theory is further developed here for the presence of a second population of cold electrons. It is seen that both two-stream or resistive medium instabilities may occur depending on the relative density of the cold electrons. The consequences for the broadband noise spectrum are discussed.

19. A New Radio Emission at 3 kHz in the Outer Heliosphere
W. S. KURTH, D. A. GURNETT, F. L. SCARF and R. L. POYNTER
Proceedings, Course and Workshop on Plasma Astrophysics, Varenna, Italy, ESA SP-207, ESA Scient./Tech. Publ. Branch, pp. 285, 1984.

Evidence of a radio source in the outer heliosphere is given based on observations made by the plasma wave receivers on Voyagers 1 and 2 at heliocentric radial distances ranging from 13 to 20 AU. The radio emission is observed in the frequency range of 2 to 3 kHz, and is above the local electron plasma frequency whenever supporting plasma density data are available. The maximum spectral density of the emission recorded to date is about 10^{-14} $V^2m^{-2}Hz^{-1}$. The bandwidth of the radio noise is about 1 kHz. One of several possible sources considered for the emission is radiation at the second harmonic of the plasma frequency at the heliopause. Should this interpretation be correct, the data reported represent the first remote observations of the heliopause.

20. Nonlinear Evolution of Astrophysical Alfven Waves
S. R. SPANGLER
Proceedings, Course and Workshop on Plasma Astrophysics, Varenna, Italy, ESA SP207, p. 197, 1984.

We report numerical studies of nonlinear Alfven waves, using the Derivative Nonlinear Schrodinger Equation as a model. We have studied the evolution of a variety of initial conditions, such as envelope solitons, amplitude-modulated waves, and band-limited noise. The last two furnish models for naturally occurring Alfven waves in an

astrophysical plasma. We have studied a collapse instability in which a wave packet becomes more intense and of smaller spatial extent. We conjecture that this instability will lead to enhanced plasma heating. We have begun studies in which the waves are amplified by an electron beam. The aforementioned instability tends to modestly inhibit the growth of the waves.

21. Fundamental Emission by the Parametric Process $L \rightarrow T + S$ in Interplanetary Type III Bursts
IVER H. CAIRNS
Proceedings, Course and Workshop on Plasma Astrophysics, Varenna, Italy, p. 281, 1984.

Recent observations of low frequency ion acoustic-like waves associated with Langmuir waves present during interplanetary Type III bursts lead us to consider plasma emission mechanisms and wave processes involving ion acoustic waves. We show: (1) the observed wave frequency characteristics are consistent with the processes $L \rightarrow T + S$ and $L \rightarrow L' + S$ proceeding, (2) the usual incoherent (random phase) version of the process $L \rightarrow T + S$ cannot explain the observed wave production time scale, (3) the clumpy nature of the observed Langmuir waves is vital to the theory of IP Type III bursts, and (4) the incoherent process $L \rightarrow T + S$ may encounter difficulties explaining the observed Type III brightness temperatures when Langmuir wave clumps are incorporated into the theory. We conclude that the parametric process $L \rightarrow T + S$ may be the important emission process for the fundamental radiation of interplanetary Type III bursts.

22. Planetary Radio Waves
C. K. GOERTZ
Proceedings, Magnetospheric Phenomena in Astrophysics Workshop, Taos, New Mexico, August, 1984.

Three planets, the earth, Jupiter and Saturn are known to emit non-thermal radio waves which require coherent radiation processes. The characteristic features (frequency spectrum, polarization, occurrence probability, radiation pattern) are discussed. We distinguish between radiation which is externally controlled by the solar wind and internally controlled radiation which only originates from Jupiter. The efficiency of the externally controlled radiation is roughly the same at all three planets (5×10^{-6}) suggesting that similar processes are active there. We discuss briefly the maser radiation mechanism for the generation of the radio waves and general requirements for the mechanism which couples the power generator to the region where the radio waves are generated.

23. Jovian Magnetospheric Processes
C. K. GOERTZ
Proceedings, Magnetospheric Phenomena in Astrophysics Workshop, Taos, New Mexico, August, 1984.

Jupiter's rotational energy (6×10^{34} J) powers a large number of processes such as auroral UV emission, radio waves, and charged particle energization. We describe how the rotational energy may be dissipated by injection of plasma, magnetic pumping and field aligned electric fields. In addition, we describe energization by radial diffusion and plasma wave absorption. We also describe the generation of Alfven waves by the moon Io and their relation to the emission of the Jovian DAM radio waves.

24. Resource Letter: PWI-1 Plasma Waves and Instabilities
CROCKETT L. GRABBE
Am. J. Phys., 52, 970, 1984.

This Resource Letter provides a guide to the literature on plasma waves and instabilities. Approximately 50% of the references are on linear waves, 25% on nonlinear waves, and 25% on applications. After each reference is a two-letter code. The first letter indicates the level of the material. The letter E after an item indicates elementary level or material of general interest to persons becoming informed in the field; the letter I, for intermediate level, indicates material of a somewhat more specialized nature; and the letter A indicates rather specialized or advanced material. The second letter indicates the type of material, and is either T (tutorial), R (review), B (benchmark), or H (historical). An asterick (*) in front of an item indicates those articles to be included in an accompanying reprint book. These are primarily benchmark papers. Material from in-print books and review series, as well as most review articles, have been excluded because of page limitations.

25. Dual Polarization VLBI Observation of Stellar Binary Systems at 5 GHz
R. L. MUTEL, J.-F. LESTRADE, R. A. PRESTON, and R. B. PHILLIPS
Astrophys. J., 289, 262-268, 1985.

The milliarcsecond radio structure of seven binary stellar systems (σ CrB, UV Psc, HR 1099, UX Arietis, HR 5110, Algol, and Cyg X-1) were determined using an intercontinental VLBI array at 5 GHz. Two sources (HR 5110 and UX Arietis) were undergoing intense radio outbursts during the observations. Four of the seven sources were fit with single Gaussian brightness distributions with θ(FWHM) ranging from 0.5 mas to 2.0 mas, corresponding to brightness temperatures $2 \times 10^8 K < T_B < 2 \times 10^{10}$ K. Cygnus X-1 was unresolved, corresponding to a linear size less than 1.4 a.u. The sources UX Arietis and Algol had a core-halo structure. In each case the core size was smaller than an individual stellar diameter and the halo was

comparable in size to the binary system. There was a clear offset of $\sim$ 1.8 mas between the centroid of the halo and core in UX Arietis. For all sources, an upper limit to the angular separation between left and right hand circular emission regions was $\theta < 0.05$ mas.

A simple model describing all of the observations is given in which a flare event originates on the surface of the spotted star and radiates by synchrotron radiation. The flare evolves on a time scale of hours, and the electrons diffuse into an extended magnetosphere approximately the size of the stellar system. The particles lose energy and gradually emit gyro-synchrotron emission, which increases the degree of circular polarization.

26. Radio Emission from RS CVn Binaries I: VLA Survey and Period-Radio Luminosity Relationship
R. L. MUTEL and J.-F. LESTRADE
Astron. J., 90, 493-498, 1985.

A VLA survey of radio emission from 36 close binary stellar systems with RS CVn properties is reported. Eight new sources were detected. A summary of all published reports of radio emission from RS CVn systems is presented. There appears to be a correlation between maximum radio luminosity and rotational period, with a tentative functional form $L_R \propto P^{-0.7}$. Rapid rotators (periods $\simeq$ 2 days) may be underluminous compared with the extrapolated trend from longer-period systems. The luminosity-period correlation probably results from a dynamo mechanism which produces strong magnetic fields and, in turn, enhances the nonthermal radio emission. The decrease in radio luminosity at short periods may be caused by a saturation of energy deposition in the chromosphere, possibly because the surface of the active star has become covered with spotted regions.

27. A Theory for the $2f_p$ Radiation Upstream of the Earth's Bow Shock
I. H. CAIRNS and D. B. MELROSE
J. Geophys. Res., in press, 1984.

A theory for the radiation at the second harmonic of the plasma frequency f_p observed near the Earth's bow shock is advanced in which the dominant plasma emission mechanism is the process $L + L \pm S \rightarrow t$, proceeding in two 3-wave steps, $L \pm S \rightarrow L'$ and $L + L' \rightarrow t$, where L, S, and t denote Langmuir, ion sound, and electromagnetic waves, respectively. This theory receives strong observational support from the correct prediction of the existence and frequencies of a class of low frequency ion sound-like waves associated with Langmuir waves in the Earth's foreshock. Three predictions of the theory which may be suitable for observational testing are stated. The observed brightness temperature of the $2f_p$ source is calculated to be of order 10^{11}K. It is shown that Fung et al.'s [1982] theory cannot explain the $2f_p$ radiation due to an intrinsic brightness temperature limit of 6×10^9K for their model.

28. A Numerical Study of Nonlinear Alfven Waves and Solitons
STEVEN R. SPANGLER, JAMES P. SHEERIN, and GERALD L. PAYNE
Phys. Fluids, in press, 1985.

Finite amplitude Alfven waves can be modeled by a nonlinear wave equation termed the derivative nonlinear Schrodinger equation. A computer program has been developed which solves the derivative nonlinear Schrodinger equation via the "split-step" Fourier method. This program has been used to investigate a number of topics in the area of nonlinear Alfven waves. When analytic envelope solitons are used as initial conditions, the wave packets propagate stably and with the expected speed-amplitude relation. These results confirm the existence and stability of the analytic solitons. When an arbitrary, amplitude-modulated wave is used as an initial condition, the results depend strongly on the β of the plasma and the polarization of the wave. For a left circularly polarized wave in a $\beta < 1$ plasma, or a right circularly polarized wave with $\beta > 1$, a collapse instability has been observed in which the wave amplitude increases, and modulation scale decreases. For other combinations of polarization and value of β, the wave packet tends to broaden, eliminating the initial modulation.

29. High Resolution Studies of the HF Ionospheric Modification Interaction Region
L. M. DUNCAN and J. P. SHEERIN
J. Geophys. Res., submitted, 1984.

Incoherent backscatter radar studies were conducted of the HF ionospheric modification interaction region using the facilities of the Arecibo Observatory. Very high relative spatial and temporal resolutions were achieved. These measurements resolve the mini-overshoot (2-10 ms after HF on) and main overshoot (20-40 ms after HF on) plasma wave excitation features. The main overshoot phenomenon is observed to develop very reproducibly with enhancements of a factor of ten greater than the steady-state HF-enhanced plasma-line intensity. However, this main overshoot effect is strongly suppressed for HF off times of less than 100 ms. The mini-overshoot excitation is found to occur 800-1000 m below the main overshoot excitation height. In addition, a small plasma-line enhancement is detected at very early times (<1 ms) distinct from the mini-overshoot and originating at a greater height. The main overshoot and the steady-state enhanced plasma-line both develop at essentially the same altitude. However, the interaction layer is observed to broaden by several hundred meters during the main overshoot relaxation. Possible explanations for these effects are proposed using a combination of the theories of soliton formation and collapse, profile modification, parametric instabilities, and other interactive processes.

30. Linking the Hipparcos Catalog to the VLBI Inertial Reference System: High Angular Resolution Structures and VLBI Positions of 10 Radio Stars
J.-F. LESTRADE, R. A. PRESTON, R. L. MUTEL, A. E. NIELL and R. B. PHILLIPS
Proceedings, Second FAST Thinkshop, Marseille, France, 21-25 January 1985, ed. by J. Kovalevsky, Laboratoire d'Astronomie Spatiale Publisher, 1985.

VLBI observations of bright radio stars have been initiated in an attempt to measure the positions and proper motions of their radio components in order to tie the future HIPPARCOS stellar frame to the VLBI extragalactic reference frame. Through observations of a sample of 22 known radio stars, we have identified 11 stars that should be appropriate for both VLBI and HIPPARCOS observations. Our measurements indicate that the angular extent of their radio emitting region is < 2 milliarcseconds. Most of them belong to the RS Canum Venaticorum class of binary systems.

31. Nonlinear Astrophysical Alfven Waves: Onset and Outcome of the Modulational Instability
STEVEN R. SPANGLER
Astrophys. J., submitted, 1985.

A numerical study has been made of the nonlinear development of Alfven waves with application to Alfven waves in astrophysical plasmas. The waves are modeled by the Derivative Nonlinear Schrodinger Equation. We have studied the evolution of initial conditions consisting of (a) amplitude-modulated wave packets and (b) broadband Alfvenic noise. The results of this study are as follows. (1) Dependent on the polarization of the Alfven wave, a strong modulation instability results in which a wave packet becomes more intense and of smaller spatial extent. (2) The numerical runs indicate that a timescale, obtainable from simple analytic arguments, accurately represents the time for nonlinear development of wave packets possessing a large range of amplitude, wavelength, and modulation scale. (3) The collapse instability causes a broadening of the wave power spectrum on the aforementioned timescale, specifically producing power at high wavenumbers. (4) The intensification of the wave packet is halted by the formation of solitons, so the asymptotic state of the instability consists of propagating soliton-like pulses. We discuss application to several astrophysical settings in which Alfven waves play a major role, such as the Earth's bowshock region, the interstellar medium adjacent to a supernova remnant, and extragalactic radio sources. Our results suggest the possibility of a major difference in the properties of waves in the upstream wave layers of the Earth's bowshock and supernova remnant shocks, which might result in energetic electron acceleration.

32. Limits on Thermal Plasma in the Lobes of the Radio Galaxies 3C 79 and 3C 379.1
STEVEN R. SPANGLER and TAKAYUKI SAKURAI
Astrophys. J. Lett., submitted, 1985.

Dual frequency VLA polarimetric observations of the radio galaxies 3C 79 and 3C 379.1 show remarkably small Faraday rotation gradients across most or all of both sources. The measured rms difference between the 6 and 20 cm polarization position angles is as low as 2° for portions of 3C 379.1. These measurements are used to place limits on internal Faraday rotation, and thus on the thermal plasma density in the radio-emitting lobes. We use formulas which are derived assuming that the magnetic field is random and disordered on scales smaller than the lobes. The upper limits to the thermal plasma density are $\sim 4 \times 10^{-5}$ cm^{-3} for both 3C 79 and 3C 379.1.

33. High-Angular Resolution Observations of Stellar Binary Systems
JEAN-FRANCOIS LESTRADE, ROBERT L. MUTEL, ROBERT A. PRESTON and ROBERT B. PHILLIPS
Radio Stars, ed. by R. M. Hjellming and D. M. Gibson, D. Reidel Publishing Co., Proceedings of Workshop on Stellar Continuum Radio Astronomy, August 8-10, Boulder, Colorado, 116, 275, 1985.

We report on a long-term program designed to investigate the spatial structure of centimeteric radio emission from close binary systems using multi-station VLBI arrays. We have detected eleven binaries, including eight RS CVn systems, Algol, LSI 61°303, and Cyg X-1. The measured brightness temperatures vary from $T_B \sim 10^{8.5}$ K during periods of low activity to $T_B \sim 10^{10.5}$ K during flares. Extensive observation of a few sources has shown that the spatial structure is 'core-halo' with linear dimensions of about a stellar radius and the binary system, respectively. The observations are consistent with gyrosynchrotron emission of mildly relativistic electrons ($\langle E \rangle \sim 1 - 5$ MeV) in magnetic fields of $B \sim 10^{1.5 \pm 0.5}$ gauss. The core sources appear to be optically thick, while the halo component is optically thin.

34. Auroral Arc Formation: Kinetic and MHD Effects
C. K. GOERTZ
Space Plasma Simulations, Proceedings of the Second International School for Space Simulation, ed. M. Ashour-Abdalla and D. A. Dutton, D. Reidel, Dordrecht, Holland, in press, 1985.

Recent observations by the Dynamics Explorer satellites indicate that auroral field lines are not equipotentials. The field-aligned "conductivity" is the same for up and downgoing currents and of the order of several 10^{-8} to several 10^{-9} $\Omega^{-1}m^{-2}$. This is not in agreement with models based on the resistance provided by the magnetic mirror force alone. It is suggested that the resistivity is due to damping of

kinetic shear-Alfven wave packets. This damping may be nonlinear in nature or Landau damping. We briefly review the properties of kinetic Alfven waves.

35. Auroral Arc Formation: Kinetic and MHD Effects
C. K. GOERTZ
Space Sci. Rev., 42, 499, 1985.

Recent observations by the Dynamics Explorer satellites indicate that auroral field lines are not equipotentials. The field-aligned "conductivity" is the same for up and downgoing currents and of the order of several 10^{-8} to several 10^{-9} $\Omega^{-1}m^{-2}$. This is not in agreement with models based on the resistance provided by the magnetic mirror force alone. It is suggested that the resistivity is due to damping of kinetic shear-Alfven wave packets. This damping may be nonlinear in nature or Landau damping. We briefly review the properties of kinetic Alfven waves.

36. Interstellar Scattering of Compact Radio Sources Near Supernova Remnants
S. R. SPANGLER, R. L. MUTEL, J. M. BENSON, J. M. CORDES
Astrophy. J., 301, 312, 1986.

We report a multifrequency, VLBI search for interstellar scattering of extragalactic radio sources near supernova remnants. VLBI observations at 610, 1663, and 4911 MHz were made of compact radio sources near the supernova remnants CTA 1, G33.6 + 0.1, G74.9 + 1.2, and HB 9. These observations were motivated by the possibility of enhanced cosmic-ray-induced turbulence in front of supernova remnants, as expected in "diffusive" theories of shock wave acceleration. Angular broadening is definitely seen in the case of the source 2013 + 370, which lies within 4" of the supernova remnant G74.9 + 1.2. Our present observations cannot unambiguously attribute the scattering material to the supernova remnant, as the line of sight also passes through the Cygnus OBI association. The source 1849 + 005 appears to be highly scattered, as we did not detect fringes, even on short baselines at 5 GHz. This result may be due to the low galactic longitude of this source rather than its proximity to the supernova remnant G33.6 + 0.1. Broadening was not detected for sources whose lines of sight pass close to the supernova remnants HB 9, HB 21, and CTA 1.

37. Polar Cap Photoionization and the Ten-Hour Clock at Jupiter
C. K. GOERTZ, D. N. BAKER
J. Geophys. Res., 90, 6304, 1985.

We show that the clocklike modulation of the spectral index of energetic electrons (>2 MeV) in the outer Jovian magnetosphere is due to a periodic shift of the particle energy spectrum toward higher and

lower energies. This shift results in a modulation of the spectral index when the spectrum is not a pure power law in energy. We suggest that the periodic energization is due to a periodic modulation of the magnetic field in the outer magnetosphere. This modulation is caused by a variation of the longitudinally averaged Pedersen conductivity due to the asymmetric solar illumination of the trace of the magnetodisc in the high-latitude ionospheres. Such a modulation requires the presence of a surface magnetic anomaly.

38. High-Angular Resolution Studies of Stellar Radio Sources
ROBERT L. MUTEL
Radio Stars, ed. by R. M. Hjellming and D. M. Gibson, D. Reidel Publishing Co., Proceedings of Workshop on Stellar Continuum Radio Astronomy, August 8-10, Boulder, Colorado, 116, 359, 1985.

Scientific goals and instrumentation for high-angular resolution studies of stellar radio sources are discussed. By plotting the sampling range of various instruments in luminosity-brightness temperature coordinates, an appropriate instrument can be selected for the study of a given emission process independent of observing wavelength.

39. Radio Polarization Characteristics of Two RS CVn Binaries
ROBERT L. MUTEL, JEAN-FRANCOIS LESTRADE and D. J. DOIRON
Radio Stars, ed. by R. M. Hjellming, D. M. Gibson, D. Reidel Publishing Co., Proceedings of Workshop on Stellar Continuum Radio Astronomy, August 8-10, 1984, Boulder, Colorado, 116, 259, 1985.

We report the results of multifrequency epoch VLA observations of polarized radio emission from the nearby active RS CVn binaries UX Arietis and HR 1099. For both systems, there is an excellent correlation between handedness of circular polarization and frequency. Helicity reversal is almost always seen between 1.4 and 5.0 GHz, possibly due to optical depth effects. There may also be an anticorrelation between total intensity and fractional circular polarization, especially at 5 GHz. This is consistent with models in which intense flares are associated with compact self-absorbed synchrotron sources, while the quiescent emission arises from larger gyrosynchrotron-emitting plasma.

40. Properties of Stellar Magnetic Fields in Close Binaries Deduced from Nonthermal Radio Observations
R. L. MUTEL
Highlights of Astronomy, I.A.U. Symposium on "Joint Discussion on Stellar Activity," New Delhi, Reidel Publishing Company, in press, 1985.

Analysis of VLA and VLBI observations of non-thermal radio emission from close binary stellar systems can produce reliable estimates of magnetic field strength and geometry in the source emission region.

Assuming a gyrosynchrotron emission model for the non-flare emission, one can model the magnetic field as a relatively small number of stable magnetic loops of overall size $R \approx (1\text{-}3)\times10^{12}$ cm. with an average field strength of $10^1 < B < 10^2$ gauss. A correlation of mean fractional circular polarization with inclination angle along with an absence of any clear phase dependence, indicates that the loops are azimuthally symmetric with poles nearly orthogonal to the orbital plane, i.e. axisymmetric dipolar. The loops are probably the same as the loops derived from observations of x-ray emission of 'hot' ($T \approx 10^7$K) coronal gas.

41. Milliarcsecond Structures, VLBI and Optical Positions of 8 HIPPARCOS Radio Stars
J.-F. LESTRADE, R. A. PRESTON, M. REQUIEME, M. RAPAPORT, R. L. MUTEL
Proceedings, Scientific Aspects of HIPPARCOS Catalog, E.S.A. Publication, in press, 1985.

No abstract.

42. Magnetohydrodynamic Solitons and Radio Knots in Jets
RALPH FIEDLER
Astrophys. J., 305, 100, 1986.

Weakly nonlinear surface waves are examined in the context of the beam model for jet-like radio sources. Through the introduction of a finite scale length, the beam radius, geometrical dispersion can act to balance nonlinearity and thereby produce solitons, localized wave packets of stable waveform. A method for obtaining a soliton bearing ODE from the MHD equations is presented and then applied to radio hot spots in jets.

43. Dispersive Ducting of MHD Waves in the Plasma Sheet: A Source of Pi2 Wave Bursts
P. M. EDWIN, B. ROBERTS, W. J. HUGHES
Geophys. Res. Lett., 13, 373, 1986.

Fast magnetoacoustic waves can be ducted by plasma inhomogeneities such as the plasma sheet. As this ducting is dispersive, an impulsive source will give rise to a well-defined, quasi-periodic wave packet with time-scales determined by the width of the inhomogeneity and characteristic speeds in the wave duct and surrounding medium. The duration of the wave packet depends upon the distance from the source. We argue that an impulsive source in the plasma sheet at substorm onset will produce a wave packet near earth with characteristics similar to Pi2 wave bursts and put this idea forward as a mechanism for the generation of Pi2 pulsations.

44. The Evolution of Nonlinear Alfven Waves Subject to Growth and Damping
S. R. SPANGLER
Phys. Fluids, in press, 1986.

We present results of a numerical study of Alfven waves subject to nonlinearity, dispersion, growth, and damping. Our model is the derivative nonlinear Schrödinger equation, modified to include linear growth and damping processes. The processes which are considered are wave amplification by streaming particle distributions, and damping due to ion-cyclotron resonance absorption. These growth and damping mechanisms are dominant in different portions of wave number space. The primary role of nonlinearity is the transfer of wave energy from growing or amplified wave numbers to those which are damped. A nonlinear saturation mechanism thereby results, in which instability of low wave number modes may be quenched. A simple phenomenological model is developed, which accounts for many of the salient features of the numerical calculations. We briefly consider the application of our results to observations of Alfven waves upstream of the Earth's bow shock. We suggest that the short wavelength "shocklet" structures resemble the soliton-like pulses which emerge from the driven derivative nonlinear Schrödinger equation. However, the nonlinear effects discussed in this paper do not seem responsible for limiting the amplitude of the "low frequency" waves in the foreshock region.

45. Dynamical Processes in Magnetic Flux Tubes
B. Roberts
Proceedings, from Workshop on Small Magnetic Flux Concentrations in the Solar Photosphere, in press, 1986.

The concept of an isolated flux tube has proved to be extremely fruitful as a means of investigating the theoretical behavior of concentrated magnetic field in the solar photosphere. By considering the extreme of a slender (or thin) flux tube it is possible to investigate the dynamical behavior of the tube, accounting for a variety of physical effects including stratification and compressibility.

46. MKIII VLBI Observations of the Stellar-System Algol: Evidence for Gyro-Synchrotron Coherent Emissions
J.-F. LESTRADE, R. L. MUTEL, R. A. PRESTON, R. B. PHILLIPS
Astrophys. J., submitted, 1986.

Results of multi-epoch VLBI observations of the stellar system Algol is presented including dual polarization and dual frequency techniques at 2.3 and 8.4 GHz. In general, the brightness

temperatures and degrees of circular polarization of the radio source in Algol is consistent with gyrosynchrotron emission from energetic electrons with mean energy of 50 keV to about 5 MeV in an active coronal region. The size of this region is about 3 times the radius of the K-subgiant and the magnetic field strength is between a few tens to a few hundreds Gauss. However, two exceptional events occurred during our observations. First, an intense outburst at 23 and 8.4 GHz with a measured brightness temperature of 3×10^{10} K is consistent with synchrotron emission from electrons with energy of a few MeV. The emitting region has a size comparable with the radius of the K-star of the Algol system and the magnetic field strength is 1-2 Gauss. This region is thought to be located high above the photosphere where the magnetic field falling with height is low enough. Second, an event observed at 1.7 GHz for 15 minutes exhibited a high degree of circular polarization (50%) and, simultaneously, a high brightness temperature ($T_B > 5 \times 10^9$ K). This combination of high degree of circular polarization and high brightness temperature is consistent with an electron-cyclotron maser driven by a loss-cone in the leg of a coronal loop with a magnetic field strength of 300 Gauss. A displacement of 3×10^{10} cm between the left and right circular polarization components of the source has been measured by VLBI and is consistent with this mechanism.

47. On Similarity Solutions for Langmuir Collapse
J. P. SHEERIN
Phys. Lett. A, submitted, 1984.

A generalized self-similar solution for the problem of Langmuir collapse in an unmagnetized plasma is developed. Comparisons of these results with previous work on restricted classes of solutions are made. The utility of the generalized self-similar solution in the analysis of data from experimental and numerical investigations of this problem is established. Application is made to a number of outstanding problems in strong Langmuir turbulence.

48. Radio Emission from RS CVn Binaries II: Polarization and Spectral Properties
R. L. MUTEL, D. H. MORRIS, D. J. DOIRON, J.-F. LESTRADE
Astrophy. J., submitted, 1986.

Multi-epoch radio observations of circular polarization and spectral characteristics of several close, late-type stellar binaries (mainly of the RS CVn class) are reported. The median luminosity of four well-studied systems ranged from $16.2 < \log(L_R) < 17.1$ ergs sec^{-1} Hz^{-1}. The fractional circular polarization decreases with increasing luminosity, particularly at frequencies $f > 5$ GHz. Eclipsing binaries have significantly lower average circular polarization compared with noneclipsing systems. Helicity reversal is almost always observed

between 1.4 GHz and 4.9 GHz for systems with high-orbital inclination. Comparison with previously published polarization observations for two RS CVn stellar systems for approximately the past ten years shows that the same helicity occurs at a given frequency, indicating a very stable, large-scale magnetic field geometry.

These spectral and polarization characteristics, combined by direct measurements of the brightness temperature using previously published VLBI observations, strongly support a model of inhomogeneous gyrosynchrotron emission from power-law electrons with large-scale magnetic field gradients. The source emission region is probably cospatial with the large coronal loops deduced from x-ray observations.

49. Radio Emission From RS CVn Binaries III: A Complete Radio Survey
D. H. MORRIS, R. L. MUTEL
Astronomical J., submitted, 1986.

A 5 GHz radio survey of 93 close, late-type stellar binaries is presented. The source list was obtained from the recent catalog of RS CVn systems of Hall et al. (1985). The survey comprises a complete sample of all catalogued sources north of -45 degrees declination. Of the 93 candidate stars, 52 (56%) were detected above the 0.4 mJy detection threshold. A comparison of observed radio luminosity with either rotational period or color (B-V) does not show any obvious correlation. Likewise, correlations between radio luminosity and dimensionless activity indices such as Rossby number are also weak or absent.

50. Guided MHD Waves as a Coronal Diagnostic Tool
B. ROBERTS
Proceedings, Solar Maximum Mission Workshop on 'Coronal and Prominence Plasmas,' ed. by A. I. Poland, NASA, in press, 1986.

The coronal atmosphere is observed to be highly inhomogeneous with marked density and temperature variations; coronal loops abound. Magnetic forces dominate the atmosphere providing thermal insulation across field lines and almost rigid wave guides for the propagation of MHD waves. In a homogeneous low β plasma, the slow magnetoacoustic wave gives one-dimensional propagation of sound whereas the fast magnetoacoustic wave gives isotropic propagation at the Alfven speed. (See Weitzner (1983) and Roberts (1984, 1985) for the recent discussions of the properties of MHD waves.) If, however, the low β plasma is inhomogeneous in density, as with the corona, then fast magnetoacoustic waves are guided by regions of low Alfven speed (Habbal, Leer, Leer, and Holzer, 1979; Edwin and Roberts, 1982, 1983; Roberts, Edwin, and Benz, 1983, 1984; see also Newcomb, 1957). For a general overview see Edwin and Roberts (1986a). Regions of low Alfven speed occur in both coronal loops and in open field regions (coronal field reversal occurs) provide wave guides for fast magnetoacoustic waves (Edwin, Roberts, and Hughes, 1986). An important thing about

such wave guides is that they preferentially select certain ranges of frequency and wave number for guided propagation. If a fast mode is generated impulsively, such as by a flare, it is guided along a region of low Alfven speed and will exhibit frequencies of the order of the Alfven speed divided by the width of the inhomogenity. For typical coronal conditions, this will also give rise to frequencies of about 1 Hz or higher.

The occurrence of preferred frequencies in an impulsively generated fast magnetoacoustic wave raises the interesting possibility that such distinctive signatures could be used as a seismological probe of the coronal atmosphere, allowing us to determine magnetic field strengths and/or spatial extents of density inhomogenities. We discuss this possibility here (see also Edwin and Roberts, 1986b).

51. Magnetic Field Corrections to Solar Oscillation Frequencies
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The presence of magnetic field both deep within the Sun and in its atmosphere raises the question of the field's influence on the p- and g-modes of oscillation and the implications for helioseismology. Observations of the p-modes, in particular, have permitted a theoretical determination of the run of sound speed within the solar interior, thus providing a seismological probe of the Sun's depths. Magnetic fields within the Sun are likely to be too weak to significantly affect this determination of the sound speed. Nonetheless, magnetic fields may modify the oscillation frequencies in a distinctive fashion, thereby raising the possibility of placing limits on interior field strengths through frequency measurements. Recently, Woodard and Noyes have reported a slight but systematic decrease in frequencies of low degree p-modes from 1980 to 1984. Here we argue that the frequencies of both p- and g-modes are modified by a magnetic field. In particular, we attribute the decrease in p-mode frequencies to a magnetic field within the solar interior evolving over the solar cycle. Field strengths at the base of the convection zone of at least 5×10^5 G are required.

52. Dynamical Processes in Magnetic Flux Tubes
B. ROBERTS
Abhandlungen der Akademic der Wissenschaften, in press, 1986.

The concept of an isolated flux tube has proved to be extremely fruitful as a means of investigating the theoretical behavior of concentrated magnetic field in the solar photosphere. By considering the extreme of a slender (or thin) flux tube it is possible to investigate the dynamical behavior of the tube, accounting for a variety of physical effects including stratification and compressibility.