INTRODUCTION TO THE ULYSSES ENCOUNTER WITH JUPITER

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Abstract

The Ulysses spacecraft encountered Jupiter in February, 1992, passing within 6.31 radii of the planet. For approximately 8 days, it was inside the jovian magnetosphere and, for several days before and after that, Ulysses was in the interaction regions formed by the solar wind (the magnetosheath and boundary layer), The inbound trajectory was at a local time of= 10 hours and the outbound trajectory was at 18 hours, i.e., dusk, a unique feature of the flight path. The three regions interior to the magnetosphere were identified as on previous missions both inbound and outbound. In addition, the spacecraft twice penetrated a cusp-like region at high latitude in the inner magnetosphere. Following closest approach, Ulysses traversed the Io Plasma Torus in basically a North-South direction. Although Ulysses is a heliospheric mission, the experiments were well suited to an investigation of Jupiter's magnetosphere and have returned much new and useful information. This introduction to the accompanying articles by the Ulysses investigators provides basic information on the experiments, the spacecraft and the trajectory. In addition, the scientific context of the encounter is reviewed based on the preliminary analyses of the Ulysses observations and a rudimentary comparison with the earlier Pioneer and Voyager results. Some important scientific questions raised by the encounter, along with some tentative answers, are presented.

Introduction

Ulysses is only the fifth spacecraft to encounter Jupiter. Fifteen years had elapsed since the last spacecraft passed through its complex and dynamic magnetosphere. The first four encounters, by Pioneer 10 in 1973, Pioneer 11 in 1974 and Voyagers 1 and 2 in 1977, were designed specifically to study Jupiter and left an impressive legacy of scientific information regarding Jupiter's atmosphere and magnetosphere (JGR Vol. 79, p. 3487-3695, 1974; JGR Vol. 86, p. 8123-8841, 1981; Gehrels, 1976; Dessler, 1983). Ulysses is a heliospheric mission that made use of Jupiter for the purpose of a gravity assist. However, the capabilities of the Ulysses field and particle experiments compare very favorably with those of the earlier missions and, during the long traversal through the magnetosphere, have produced a body of significant new results. In particular, while outbound from Jupiter, Ulysses passed through a previously unexplored sector of the magnetosphere near a local time of 18 hours (dusk).

In keeping with the past practice, which has proven scientifically productive, a preliminary report of the scientific results from Ulysses were published a few months after the encounter in the journal, Science (Vol. 257, p. 1449-1596, 1992), Within the past year, the investigator teams have been extending and refining the analysis of their data. The articles published in this special section of JGR, and in the companion papers to be published in a special issue of the European journal, *Planetary and Space Science*, are an important step in getting the Ulysses results to the scientific community. Theorists will probably have to revise their models in order to accommodate these new results. The results should also be of value to the investigators on Galileo which will arrive at Jupiter in 7 December, 1995 and will begin the next phase of jovian studies.

This article is an introduction to the accompanying scientific publications. It provides general information of interest regarding the investigations, the spacecraft and, especially, the trajectory past Jupiter. It avoids the necessity to have the authors of the articles provide this kind of background information.

This introduction is also intended to provide a broad scientific context in which to view the detailed analyses. At this stage in incorporating the results into a more comprehensive picture of Jupiter's magnetosphere, it is important to identify important questions which have been raised and to suggest some of the answers that Ulysses has provided or may supply. Another important task is to begin comparisons with the earlier Pioneer and Voyager results which will undoubtedly represent a major undertaking but which should prove very fruitful scientifically.

Accordingly, a major portion of the introduction is devoted to summarizing some of the scientific results for Ulysses with an emphasis on magnetospheric structure. In one sense, this attempt is the result of a careful reading and interpretation of the preliminary reports available in *Science*. Pioneer and Voyager results are compared with the Ulysses findings within the limited scope of our discussion and are inevitably qualitative.

The Ulysses Mission

The possibility of sending a spacecraft over the poles of the sun has been contemplated since the dawn of the space age. Several prerequisites delayed the achievement of this goal for many years. Because the earth is moving around the sun at 30 km/see, a large initial velocity essentially in the solar equator is unavoidable. An extremely high speed launch directed poleward from earth at an equivalent speed of 30 km/see (a so-called C3 value of 900 km^2/sec^2!) would achieve an inclination of only

45o. Thus, it was realized early that such a mission is only practical by launching outward toward Jupiter and using its gravitational field to cancel the residual tangential velocity (reduced to 2.1 km/see from the initial 30 km/see at 1 AU) to obtain a high inclination.

First, however, the radiation environment of Jupiter had to be surveyed (by Pioneer 10,11 in 1973-74) and confidence developed that the concomitant long lifetime (a minimum of 5 years) necessary to ensure operation of the spacecraft and experiments was achievable. After the success of the Pioneer spacecraft which survived the hostile Jupiter environment, a cooperative mission was designed and approved by ESA and NASA in 1977. Because of various fiscal upsets in the U.S. and the launch interruption caused by the challenger disaster, Ulysses (originally known as the Out-of-Ecliptic or the International Solar Polar Mission) was not launched until October 6, 1990.

The combination of launch vehicles, the shuttle, Discovery, two Boeing Inertial Upper Stages and a McDonald Douglas Payload Assist Module) provided an extremely high asymptotic speed (after escaping the earth's gravitational field) of 11.3 km/see. The "" spacecraft arrived at Jupiter and passed within 6,3 r_J on 8 February 1992, It left Jupiter traveling southward in an elliptical orbit inclined 80.1° to the solar equator, with an aphelion of 5.4 AU, a perihelion of 1.1 AU and a semilattis rectum of 2,2 AU.

Ulysses will reach 70° latitude south in June 1994, will achieve a maximum south latitude in September and descend to 70° south latitude in December. The next year, in June 1995, it will be at 70° north latitude, will pass above the sun's polar cap and descend to 700 N in September. A total of 240 days will be spent above 700 latitude. The tilt angle between the sun's rotation axis and the axis of its magnetic dipole is expected to be

>10° so that Ulysses should survey all solar-magnetic latitudes. The above aspects of the trajectory with the key dates can be seen in figure 1.

The primary scientific objective of the mission is to characterize the fields and particles in the sun's polar regions and as a function of solar latitude (Smith, et al., 1991; Wenzel et al., 1992). The fields to be measured include the sun's polar cap magnetic fields, hydromagnetic waves, heliospheric plasma waves and solar radio waves. Properties of the solar wind plasma, including the minor heavy ion constituents (H through Fe), will be determined as well as the properties of locally accelerated and solar energetic particles and, at the highest energies, galactic cosmic rays and the anomalous cosmic ray component. Observations are being carried out of two important interstellar constituents, dust and neutral helium. Short wavelength emissions will also be detected, namely, solar x-rays and cosmic gamma rays. Finally, a radio science investigation will probe the solar corona and the spacecraft radio signal will also be used to conduct a search for the gravitational radiation predicted by general relativity.

Table 1 contains a listing of the experiments, their acronyms, the principal investigators, their home institutions and a brief description of their technical capabilities. In keeping with the cooperative nature of the mission, the scientific investigations are equally divided between Europe and the United States. In addition, the teams consist of approximately equal numbers of American and European investigators and a mixture of American and European instrumentation.

The instrumentation is intended to provide comprehensive measurements, without gaps in energy, composition or frequency, that are equal to or better than the measurements now available in or near the ecliptic. Thus far, all the experiments are functioning flawlessly and without any anomalies.

The spacecraft was designed, built and tested in Europe by Dornier Space Systems of Friedrickshafen, Germany under the direction of ESA, specifically the European Space Research and Technology Center (ESTEC) in Noordwijk, the Netherlands. Figure 2 is a three-dimensional drawing of the spacecraft.

It consists of a box-like main body containing the spacecraft subsystems to which a compartment has been added along one side to house the experiments. Power is supplied by a Radioisotope Thermoelectric Generator (RTG) mounted outside the spacecraft body. A parabolic High Gain Telemetry Antenna (HGA) is mounted on top of the main body. A boom extends radially outward opposite the RTG which contains the magnetometer sensors, the x-ray-gamma ray detectors and triaxial magnetic induction search coils. A pair of long monopoles forming a plasma-radio wave antenna 80 meters long from tip-to-tip also extend radially outward. Finally, a single monopole 8 meters long is deployed opposite to the center line of the HGA. The spacecraft spins about the axis coinciding with the HGA at 5 RPM.

As the spacecraft proceeds along its trajectory, the direction of the spin axis must be corrected every few days to keep the HGA pointed to Earth within 0.4°. The telemetry rate near aphelion and throughout the encounter was 1024 bps. The encounter data were transmitted in real time and were received continuously by the NASA Deep Space Network. In normal, non-encounter operations, the scientific and engineering data are stored in an on-board tape recorder for ~16 hours and down-linked once a day along with the remaining 8 hours of real time measurements during a single acquisition sequence by a 34 antenna.

Further details regarding the spacecraft and each of the investigations have been published in a special issue of the journal, Astronomy and Astrophysical Supplements Series (Vol. *92*, p. *207-440, 1992)*,

The Encounter with Jupiter

If the encounter is defined as the interval between the first inbound bow shock crossing to the last outbound crossing, it lasted 13.6 days. The spacecraft was continuously inside the magnetosphere for **7.4** days. Inside of 100 r_J, encounter data were acquired continuous y and, in the absence of an occultation of the spacecraft by the planet, without any gaps in coverage.

The experiments are specifically designed for interplanetary studies and, although their capabilities to study the jovian magnetosphere compare very favorably with those of the Pioneer and Voyager predecessors, many had to be reconfigured in different parts of the magnetosphere. In addition, several of the particle instruments were commanded off, or into a safe state, nearest closest approach to avoid damage to electron channel multipliers and other radiation sensitive detectors. Commanding was carried out without fault by the ESA operations team in residence at JPL.

As with the previous missions, the spacecraft was traveling more slowly around the sun than Jupiter and was basically overtaken by the planet. As a consequence, the inbound leg of the trajectory occurred at a local time of 10 hours similar to the local times inbound of the four previous encounters.

Ulysses, however, passed around Jupiter in a clockwise sense as viewed from above the north pole, as did Pioneer 11. Since the close approach distance of Ul ysses was only 6.3 r_J, as compared to 1.6 r_J for Pioneer 11, the spacecraft was deflected through an angle of approximately 135° whereas the Pioneer 11 deflection angle was approximately 315°. An important consequence is that Ulysses traveled outbound at a local time of approximately 18 hours, i.e., through the previously unexplored dusk sector of the magnetosphere. It will be recalled that Pioneer 11 exited the magnetosphere near noon while Pioneer 10, Voyager 1 and Voyager 2 all traveled outbound at local times between 3.0 and 5.7 hours in the pre-dawn sector.

The inclination of the hyperbolic trajectory of Ulysses relative to Jupiter was 30°. Periapsis (closest approach = 6.3 r_J) occurred at a local time of 1.5 hours and at a jovigraphic latitude of 30°. The spacecraft crossed Jupiter's equator 5.0 hours later at 8.3 r_J and a local time of 22.7 hours.

The following sequence of plots describe the various trajectory parameters as a function of time. An attempt has been made to provide complete and accurate trajectory information for future reference as well as a convenient description accompanying the companion scientific articles. The standard unit of distance of 1 r_J has been defined as 71,398 km. Times are presented in three forms: as day-of-year 1992, as the day of the month and as time from closest approach. All three times appear in the scientific articles and it is convenient to be able to relate one to the other.

Figure 3 is a plot of jovicentric distance versus time. Figure 4 shows jovigraphic latitude as a function of time. The magnetic longitude of the spacecraft appears in figure 5. The longitude system used is Jupiter System 111 (1965) adopted by the International Astronomical Union in 1976. It is based on a sidereal rotation period of 9 hours, 55 minutes and 29.71 seconds. The longitude is measured clockwise from the prime meridian, according to the usual astronomical convention. The prime meridian or zero longitude is defined as coinciding with the Jupiter-Earth direction in 1965,00. The longitude of the north magnetic pole is taken to be 200°.

The instantaneous local time of Ulysses, i.e., the longitude relative to the Jupiter-Sun direction after projection of the spacecraft radius vector into the equatorial plane, appears in figure 6. The magnetic latitude of the spacecraft, with respect to the 04 planetary field model, is given in figure 7.

Two additional figures that are generally useful have also been included. Figure 8 is a representation of the magnetic coordinates of the spacecraft in a system based on distance along, and perpendicular to, the magnetic dipole axis. Information relevant to the traversal of the Io Plasma Torus appears in figure 9. The coordinate system here is based on the centrifugal equator rather than either the rotational or magnetic equator (e.g., see Dessler, 1983). The isodensity contours of an IPT model based on Voyager 1 plasma science observations and the trajectory of Voyager 1 are also shown.

The Solar Wind Interaction

Solar wind conditions just prior to the start of the encounter were established by the solar wind analyzer and magnetometer. These data show that Jupiter was inside a solar wind Rarefaction Region, which regularly follows a Corotating Interaction Region at distances of several AU. As a consequence of the low density within this region, solar wind ram pressure was low compared to the expected average at 5 AU. No doubt, this low pressure accounts for the extension of Jupiter's magnetosphere outward to distances beyond 100 r_J. In this regard, the start of the encounter was similar to that of Pioneer 10 which also arrived at a very inflated magnetosphere and dissimilar to the Voyager encounters when the magnetosphere was found in a more compressed state.

A single bow shock crossing was observed by Ulysses at 113 r_J. The shock structure was quasi-parallel ($\theta_{BN} \approx 30°$) which favored production of upstream waves and particles. Hydromagnetic waves were seen by the magnetometer (Tsurutani et al., 1993) and electron plasma oscillations from the bow shock were detected by URAP upstream of the bow shock (Stone et al., 1992). Upstream electrons and ions were seen by various particle experiments (Lanzerotti et al., 1992; Keppler et al., 1992). Observation of the quasi-parallel shock is the result of the chance radial orientation of the heliospheric magnetic field (not an unusual bow shock orientation).

The magnetopause was crossed soon after the bow shock at a distance of 110 r_J. Taken at face value, the distance between the two crossings suggests a very thin magnetosheath. However, a plausible interpretation is that the apparent thinness is caused by the rapid outward motion of the magnetopause. At a speed of 100 km/see, the delay of four hours would imply a thickness of $\approx 20\ r_J$ which represents a reasonable standoff ratio between the shock and the magnetopause.

Plasma measurements (electrons) did not indicate that the magnetosphere was actually entered at the time of the magnetopause crossing identified in the magnetic field data. The plasma instrument puts the magnetospheric entry at 109 r_J, 1.7 hours following the magnetopause crossing. This difference implies that between these two times, the spacecraft was inside a boundary layer. The existence of the boundary layer had been inferred earlier from Pioneer observations (Sonnerup et al., 1981).

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Subsequent analysis has confirmed that three distinct regions were observed: the magnetosheath, the boundary layer (for which the outer boundary is the magnetopause), and the magnetosphere. Energy-time spectra and moments of the distribution function, i.e., v, n, T, show these different regions clearly and imply 5 intervals when Ulysses was inside the boundary layer and 5 magnetopause crossings (see Phillips et al.., this issue). The low frequency cutoffs of the continuum radiation from Jupiter being received continuously by URAP provides confirmation.

These regions are typically difficult to identify in the Ulysses magnetic field data for the reason that the sheath field (and presumably the interplanetary magnetic field) tended to be southward throughout the inbound crossings. Since B inside the magnetosphere is also characteristically southward, the fields tended to be more or less parallel rather than "sheared", the latter being a circumstance in which the field directions vary through a large angle with a strong sheet current at the interface. Furthermore, the field magnitude tended to be nearly equal (- 5 nT) in the sheath, the boundary layer and the outer magnetosphere also making identification of these regions difficult.

The near, equality of the sheath and magnetospheric fields shows that any pressure balance that obtained during the encounter must have involved a significant contribution from magnetospheric particles. This conclusion was also drawn following the Pioneer encounters, although 'the particles responsible were not observed, and following the Voyager encounters, when it was shown that heavy Iogenic ions were the major contributor (e.g., Krimigis and Roelof, 1983).

The Ulysses observations lead to estimates of the boundary layer thickness and speed of motion. Inbound the average boundary layer thickness is approximately 1 r_J and its speed is approximate y 10 km/see.

Outbound, Ulysses crossed the bow shock three times, the magnetopause five times and spent 9 intervals inside the boundary layer. The nearest and furthest magnetopause crossings from Jupiter were 83 and 124 r_J. The corresponding distances for the bow shock were 109 and 149 r_J. The bow shock was quasi-perpendicular at the time of all three crossings.

The various crossings were not evenly spaced even approximately. Several magnetopause crossings were seen near 80 r_J, followed by a reasonably prolonged interval (39.3 hours) when the spacecraft was outside the magnetosphere. More multiple crossings then occurred between 109 and 124 r_J including the first two bow shock crossings. Another long interval (of 34.2 hours) followed when the sheath was observed continuously before the final bow shock crossing.

The two long intervals in the boundary layer or sheath promoted certain types of observations. During the first such interval, mirror mode waves were observed essentially continuously. The second interval was characterized by strong (5 nT) fields which were unusually quiet for the magnetosheath. This' behavior may correspond to episodes seen near Earth when the bow shock was found to be laminar, a structure that is particularly favored by solar wind conditions involving low β, low Mach number and large θ_{BN}.

An incidental feature of this long quiet interval is that it permitted the observation of a (10 hour) periodicity in $|B|$. This observation confirms the earlier report of periodic variations in the sheath by Voyager made during its long outbound traversal of the predawn sheath (Lepping et al., 1981).

The Ulysses observations complement those made earlier by Pioneer and Voyager. The unusual aspect of the Ulysses inbound crossings is their large distances from Jupiter. The location of the outbound crossings also indicate that the magnetosphere was inflated as compared to the two Voyager encounters.

It is interesting to list the magnetopause distances for all five encounters in order of increasing distance. For the observations near 9 hours local time, these distances are 47, 57, 65, 80, 87, 95, 98 and 110 r_J for Pioneer-U] ysses and 47-67 and 62-72 for Voyager. The impression is gained of a nearly continuous distribution of distances. The magnetopause location must be highly variable (all the missions observed the magnetopause both far away and significantly closer in during their traversals) and it seems likely that it is continuously in motion. If so, care must be taken in trying to balance pressures inside and outside the magnetopause to include the effect of dynamics which can drastically alter the type of analysis needed (e.g., see Sonnerup et al., 1987).

The Magnetosphere: Inbound Observations

The internal structure of a magnetosphere is governed by the dominant processes occurring in different regions, Extensive studies of the magnetospheres of the Earth and the other planets indicate that these dominant processes are coronation, convection and reconnection. Bearing in mind the peculiarities of Jupiter's magnetosphere (the strength of its planetary field, its rapid rate of rotation and the presence of strong internal sources of plasma, especially Io), it is nevertheless anticipated that these same processes are active (Hill et al., 1983; Vasyliunas, 1983; Cheng and Krimigis, 1989).

Previous missions have led to a classification of Jupiter's magnetosphere into three or four basic regions. They are generally referred to simply as the inner, middle, and outer magnetosphere (figure 10) and, in the case of observations sufficiently downstream, the magnetotail has also been identified (Acuña et al., 1983). The Ulysses mission has once again confirmed the value of identifying the three regions appropriate to the pre-noon magnetosphere. Accordingly, the following description is organized by discussing each of these regions successively. We begin with the inbound observations of the outer magnetosphere and proceed inward, essentially in time sequence.

The Ulysses observations benefited from the state of the magnetosphere at the time of the encounter with the magnetosphere extending sunward to approximate y 100 r_J. *This* outward extension enabled the study of both the outer magnetosphere and the Jovian Current Sheet or magnetodisc which is characteristic of the middle magnetosphere. If the magnetosphere had been compressed, the passage through the outer magnetosphere would have been brief at best and few if any current sheet crossings might have been seen. As Ulysses traveled inward, its latitude gradually increased and the magnetic equator was no longer crossed inside approximately 40 r_J.

The average magnetic field topology of the outer magnetosphere is particularly simple (figure 10). The field is directed southward. However, the outer magnetosphere is extremely dynamic - it has been referred to as a turbulent boundary region - so that relatively large time variations are superposed on the southward field and the field orientation can depart from being southward for many tens of minutes.

Upon crossing the magnetopause/boundary layer into the outer magnetosphere, the lowest energy plasma (electrons) was observed to increase markedly in temperature but decrease significantly in density (figure 11), i.e., it represents a very dilute hot plasma

(Bame et al.., 1992). At the same time, a persistent flux of energetic (0.6 -6 kev) heavy ions (S,0) was present (figure 12, Geiss et al., 1982). The other particle component that changes drastically is the high intensity of trapped radiation, both electrons and ions (figures *13,14,* Lanzerotti et al., 1992; Simpson et al., 1992; Keppler et al., 1992).

A peculiarity of the Ulysses encounter, not seen by either Pioneer or Voyager, was a delay of about one day between the abrupt increases in the high energy electrons, which were seen upon magnetospheric entry, and the high energy ions. This delay was not seen near the magnetopause outbound. What is the explanation? It maybe associated with the rapid expansion of the magnetosphere which was ongoing and the differing rates at which the electrons and ions fill the outer magnetosphere (J.A. Simpson, private communication).

The topology of the field and the intensities of the trapped radiation testify that the magnetic field lines throughout this region are closed. Thus far, measurements of possible convection have proven difficult (in part because the measured anisotropies of the energetic particles have been, confused by spatial gradients). However, the conclusion appears inescapable that convection is dominant. The count rates of the low energy plasma and of the medium and of the high energy trapped particles are essentially the same in the outer magnetosphere as in the middle magnetosphere. The energy densities of the protons and heavy ions seem large enough that, if the region was essentially corotating (not necessarily rigidly), the high speeds (which exceed the solar wind speed at these distances) would stretch out the field lines and maintain a configuration like that of the middle magnetosphere. Furthermore, there is no clear evidence of a 10-hour periodicity in the data from any of the spacecraft. The confirmation of convection and the determination of the average direction and speed await further detailed analysis, Among the many irregularities in the outer magnetosphere, a notable feature is the occurrence of nulls in the magnetic field, at irregular intervals of several minutes during which B decreases monotonically to zero and then recovers. These distinct variations have been suggested to be the result of a mirror instability or possibly to represent a breakup of the outer edge of the magnetodisc (Haynes et al., 1993).

The Middle Magnetosphere

No definite demarcation between the outer and middle magnetosphere has been identified. Over a period of hours, the magnetic field rotates gradually from a southward orientation to being essentially radial. Crossings of the current sheet or magnetodisc become evident as reversals in the polarity of the radial field (in the case of Ulysses, from outward (above) to inward (below)). The first few Ulysses current sheet crossings occurred at irregular intervals but were foil owed by a succession of crossings at 10 hour intervals which persisted until the inner magnetosphere was reached.

The dominance of the magnetodisc throughout this region is also seen in all the particles (figures 11-14). The low energy plasma sheet is characterized by periodic peaks in density which coincide with the current sheet. The intensities of the higher energy trapped particles from 1 kev to tens of MeV also peak at the magnetodisc. The strong dependence of intensity on magnetic latitude (or distance above or below the current sheet) produced a characteristic signature in the Ulysses higher, energy particle data. A "sawtooth-like" variation in intensity can be seen, presumably caused by periodic, nearly constant maxima at the magnetodisc and successively decreasing minima caused by the gradual increase in the maximum magnetic latitude reached by the spacecraft.

Overall, the Ulysses observations are consistent with those of the earlier missions which led to the interpretation that coronation is dominant in the middle magnetosphere. The mass-loaded field lines combined with the rapid rotational speeds lead to an extreme stretching outward of the field lines and to the formation of the magnetodisc.

If, as supposed, the middle magnetosphere is rotating rapidly inside the thick outer magnetospheric shell, where the field lines are convecting more slowly, it seems surprising that the transition between two such different regions is not more evident. Such a model might imply a transition involving high velocity shears and associated turbulence. Is the transition "smeared-out" and is this effect responsible for the irregular nature of the outer magnetosphere?

The radial magnetic field is associated with the azimuthal current encircling Jupiter in the form of the magnetodisc. At the large distances appropriate to the middle magnetosphere, say 30-60 r_J, the field magnitude is principally determined by the properties of the azimuthal currents, the dipole field not only being small but nearly poloidal (southward) near the magnetic equator. Reasonably good agreement with the Voyager observations (out to 30 r_J) was achieved using as a model of the magnetodisc a flat, cylindrical current sheet extending from 5 to 50 AU whose surface current density was assumed to be proportional to r^{-1} (Connerney et al., 1981). The field produced by this model current is proportional to a single parameter, namely, the surface current density at the inner edge, l., or, equivalently, the total current in the disc.

In order to achieve a reasonable correspondence between the Ulysses observations inbound and the model, it was necessary to decrease 1_0 by a factor of 0.55 as compared to the value which gave a reasonable fit to the Voyager data (Balogh et al., 1992). Since the tracks of Ulysses and Voyager through the dayside magnetosphere were at approximately the same local time, a significant time variation is implied, perhaps the consequence of the more extended magnetosphere sampled by Ulysses.

Although the middle magnetosphere is corotating with the planet, there is ample evidence that the coronation is not rigid. Although the magnetodisc crossings occurred at approximately 10 hour intervals, they clearly lagged behind the times at which Ulysses would have been at the magnetic equator assuming a rigid disc. A gradual decrease in the time lag from approximately two hours to nearly zero was seen as the spacecraft traveled inward.

Direct evidence exists in the magnetic field measurements of the spiraling of the field lines out of magnetic meridian planes (defined by the magnetic dipole, M, and the radius vector, $\hat{r}$, from Jupiter to the point of observation). In a spherical coordinate system based on M and $\hat{r}$, the azimuthal field component, B_Φ, has an average negative value indicative of a lag at northern latitudes (see figure 15, Balogh et al., 1992). When the current sheet is crossed, B_Φ changes sign implying that lagging is also present in the southern hemisphere.

The disk model is axi-symmetric so that the observed spiraling of the field lines above and below the disc is not included. Spiraling was also observed by Pioneer and Voyager and the observations led to considerable discussion of the currents responsible and of the magnetospheric consequences (Hill et al., 1983; Vasyliunas, 1983). It was recognized very early that a solar wind-like or planetary wind model would require unrealistically large outflow speeds (~10^3 km/s).

The azimuthal field component associated with the spiral requires the presence of poloidal (j_θ) currents which (for a lag) flow away from the equator toward the north and south polar ionosphere. The circuit must be completed by currents in the ionosphere and a radial outward current at the equator. A torque (jϕ Br) is then exerted on the magnetospheric plasma to produce rotation.

The existence of this torque necessarily implies a transfer of angular momentum which, for this configuration, is radially outward. Models have been developed which relate the rate of rotation of the field and plasma to the angular momentum flux and to the Pederson conductivity in the ionosphere. In principle, the field lines could be tied in the ionosphere and corotate with the planet or slip through the ionosphere at either slower or faster angular velocities. Thus, the observations of a simple spiraling of the field can have profound implications.

The outflow can apparently be accommodated by the transport of Iogenic plasma throughout the magnetosphere. The ten hour periodicity evident in the pre-noon sector shows that coronation is being enforced which implies a very large plasma source strength (10^{29}-10^{30} amu/see, Vasyliunas, 1983). Since this plasma obviously cannot continue to accumulate, an important question is: how, is "this outflow able to escape from the magnetosphere? Does it turn in the outer magnetosphere and flow into the tail or is magnetic reconnection providing a "hole" somewhere through which it can leave?

It should be mentioned that an obvious alternative to the above scenario is a sweeping-back of the field lines due to the influence of the solar wind as it flows around the magnetosphere. In the above context, however, it is unlikely that the solar wind can transfer sufficient angular momentum to the middle magnetosphere to compete effectively with the very powerful effects of coronation in this region.

Observations of the Cusp and Reconnection

We have seen that convection and coronation are responsible for some of the basic structure of the magnetosphere. The Ulysses observations near closest approach also provide evidence for reconnection by disclosing several intervals when the spacecraft 'reached open field lines most likely in the high latitude cusp.

Evidence of this sort was first obtained by the plasma analyzer which recorded sheath-like plasma, i.e., cooler, more dense plasma, within a day of closest approach (Bame et al., 1992). Sheath-like plasma was actually seen twice when the spacecraft was at 15 and 8.7 r_J and, more significantly, was at two successive maximum latitude excursions of 34° and 47°. Confirmation of the cusp was forthcoming from several other investigations and measurements. The high energy particle experiments (COSPIN and EPAC) recorded drops in intensity to interplanetary levels (e.g., see figure 14, events A and B). The URAP investigation detected a plasma wave emission that was identified as a form of auroral hiss characteristically seen in the earth's cusp. The investigation was also making measurements of the steady electric field, E= -VxB, and during penetration of the cusp detected a large departure from coronation to oppositely-directed convection followed by a return to coronation (figure 16, Stone et al., 1992).

The local times at which the cusp was observed are also significant. Neither Pioneer nor Voyager particle experiments detected the cusp near their closest approaches to Jupiter (however, see Thomas and Jones, 1984). However, while Pioneer 10 was outbound at a local time of 5.7 hours, the intensities of the energetic particles dropped to interplanetary levels periodically whenever the spacecraft was off the magnetic equator. At the time, these observations were interpreted as indicating the presence of open field lines and which were incorporated into the magnetic field model of Goertz et al. (1976).

A surprising aspect of this interpretation was that the field lines had to bc open at relatively low latitudes.

The Ulysses spacecraft passed around Jupiter in a clockwise sense as seen from the north pole while Pioneer 10 passed behind the planet in the opposite, counter-clockwise sense, Nevertheless, the local times at which the cusp was detected by Ulysses (between 09 and 00 hours) are in the same local time sector as Pioneer 10 when it was on open field lines. Furthermore, Pioneer 11 reached even higher latitudes than Ulysses near Jupiter but without detecting the cusp, e.g., in the energetic particle data. The combined observations suggest that the field lines are open at relatively low latitudes near dawn but not at local times of 10 or 12 hours. Does this mean the open field lines from the magnetotail are reconnecting near dawn as they return to the inner or middle magnetosphere?

Io Plasma Torus

The Ulysses trajectory provided a second opportunity to sample the density of the Jo Plasma Torus. Some of the particle experiments which might have returned useful information were not operating inside the IPT but were turned off to avoid possible damage to charge multipliers and other sensitive detectors, However, two investigations did return data on the electron density of the torus. Remote sensing was made possible by the occultation of the Ulysses dual frequency (S, X band) radio signals by the torus (Bird et al., 1992). The radio-plasma wave investigation used several techniques to diagnose local electron density (Stone et al., 1992). Naturally-stimulated emissions near the local electron plasma frequency were detected within the torus and, in addition, the swept frequency sounder was operated to provide another accurate measure of the plasma frequency and to infer the corresponding electron density.

The unique aspect of the Ulysses trajectory was its basically North-South traversal of the IPT which complemented the equatorial survey carried out by Voyager 1 (figure 9). One consequence was that the radio ray path penetrated the front and rear of the torus during successive intervals thereby providing density measurements at two widely-separated longitudes or local times. Both remote sensing and in-situ measurements were compared with models of the IPT density based on the Voyager 1 observations developed by Bagenal et al. (1985) and Divine and Garrett (1983).

The direct measurements yielded peak densities of approximately 300 cm^{-3} as expected from the trajectory and the models (figure 17). The sounder was operated further from, and south of, Jupiter and yielded densities of tens of electrons per cm^3 which compared favorably with the Bagenal model and less well with the Divine and Garrett model. Overall, however, the agreement was surprisingly good.

The radio occultation data (figure 18) also agree well with both models where the ray passed through the peak of the plasma distribution, i.e., near the equator. However, the electron densities inferred where the ray passed through the sunward part of the torus showed a systematically lower value than the models, possibly implying an asymmetry in electron density with longitude or local time.

The Inner Magnetosphere

With many of the particle experiments turned off to avoid radiation damage near closest approach, the three investigations that returned information on the inner magnetosphere were the magnetometer, the radio-plasma wave receivers, and the high-energy particle detectors.

The transition from the middle to the inner magnetosphere is also not well defined. In particular, the magnetic field rotates gradually from being radial to a south-north direction characteristic of the dipole field. In the past, the outer edge of the inner magnetosphere has been loosely identified as occurring at 20-30 r_J. How can the transition be reliably identified? Probably the best indicator is the large increase in energetic particle intensity, especially at high latitudes. In the middle magnetosphere, as has been seen, the intensity drops off rapidly with magnetic latitude because of the severe stretching out of the field lines, whereas, in the inner magnetosphere, a more normal distribution of pitch angles is expected because the field is dipolar.

The three Ulysses particle experiments (HI-SCALE, COSPIN, EPAC) show a large intensity increase at time 038,5, i.e., at 24 r_J (figures 12-14). They also registered a sharp drop outbound at day 040.0 (14 r_J) which can be taken to be the outer edge of the inner magnetosphere. These times also correspond to a broad maximum in plasma wave activity between 10 and 100 kHz as seen by URAP which may be confirmation of this identification.

The magnetic field investigation has provided continuous accurate measurements throughout the inner magnetosphere. The maximum observed field strength was -2400 nT at 6.3 r_J. Because the spacecraft reached to within only 6.3 r_J of Jupiter, it remained in a region in which the' internal field of the planet is significantly perturbed by the magnetodisc current. Careful removal of the effect of this external plasma current is required before anything can be said with confidence either about improved planetary field models or secular changes (temporal variations).

The Magnetosphere: Outbound Observations

In terms of magnetospheric structure, the basic question in the dusk sector is whether or not the middle and outer magnetosphere are seen. The high inclination of the trajectory means that, except for a single crossing shortly after closest approach, all the observations are made well away from the magnetic equator. This complication makes it difficult to compare directly the Ulysses outbound data with the Pioneer, Voyager and Ulysses inbound data.

What is the evidence that the spacecraft passed through the middle magnetosphere? The magnetic field data do not show the radial orientation characteristic of low latitudes. A significant southward component is, however, present.

Indirect evidence of the magnetodisc in the dusk sector is provided by comparing the observations with the model of the planetary field plus magnetodisc. The current sheet field makes a significant contribution to the total field even at high latitudes. It was noted above that, in order to achieve agreement with the measured field magnitude, it was necessary to include the magnetodisc current at double the strength needed to account for the inbound measurements (Balogh et al., 1992).

The particle measurements also support the conclusion that the properties of the middle magnetosphere in the dusk and pre-noon sectors are similar. Following the precipitous drop in the high energy trapped radiation at DOY 40.0, taken above to mark the exit from the inner magnetosphere, the particle measurements show periodic variations of approximately 10 hours (figures 11-14). Although several of the investigator teams refer to “plasma sheet” or “current sheet” crossings in their preliminary reports, it is much more likely that what is being seen are magnetic latitude variations.

Although the magnetodisc is not detected directly, i.e., in the magnetic field observations, the strong dependence of the particle properties on magnetic latitude is a characteristic feature of the middle magnetosphere. Thus, the particle observations also help identify the interval during which the outbound Ulysses traversed the middle magnetosphere. Although no clear demarcation seems possible, a reasonable estimate of this interval based on the presence of the 10 hour period icity is from day 040.0 to 042.0. The corresponding range of radial distances is 14 to 54 r_J which compares reasonably well with the distances corresponding to the middle magnetosphere as observed inbound, especially when allowance is made for the radial distances at which the high latitude fields cross the equator.

It follows that the interval from 042.0 to the first magnetopause crossing at 43.6 corresponds to the outer magnetosphere as observed at high latitude. The magnetic field is not strictly southward on average, nor would that be expected, but exhibits a distinct southward component throughout this region. The plasma properties and energetic particle intensities are nearly the same as were observed inbound. This identification implies that the outer magnetosphere near dusk extended from 54 to 83 r_J at a latitude of -37”.

The high intensities of the particles observed outbound at a local time of 18 hours implies that the field lines are closed. The 10-hour periodicity and the successful identification of the middle magnetosphere show that coronation is dominant in this region. Thus far, no reports have been available that would confirm plasma convection of the outer magnetosphere. However, the same arguments that were presented in the discussion of the day side magnetosphere presumably apply here as well.

The magnetic field has also been found to be spiraled in the dusk magnetosphere, however, in contrast to the pre-noon magnetosphere, the spiral leads rather than lags coronation. The lead is seen most clearly in the B_Φ component (figure 19, Balogh et al., 1992) which has a persistent negative average value beyond 30 r_J . The sense of the spiraling has been confirmed with the COSPIN energetic particle data by comparing the times of successive intensity minima with the times of maxima in magnetic latitude assuming rigid coronation. What is the cause of this phase lead and at what local time does it switch from a phase lag?

One obvious explanation is that the field is being convected tailward, presumably the effect of the solar wind as it flows around the magnetosphere. Since the phase is advanced in the middle magnetosphere as well as the outer magnetosphere, this possibility faces the challenge of how the solar wind effect is able to penetrate so deeply into the middle magnetosphere and to compete so effectively with coronation. An alternative possibility is to reverse the argument above involving magnetic torque and angular momentum flux, i.e., by postulating an inward flow of plasma accompanied by a reversal in the directions of the poloidal and radial currents. Which of these hypotheses is correct, or what the ultimate explanation may be, will have important implications for Jupiter's magnetosphere, An important consideration is how the spiral angle varies with local time. Proceeding from post-midnight around to dusk, the two Voyagers and Pioneer 10, all outbound, exhibited a lagging tailward of the field prior to 0600 hours. Near 09 hours, the Pioneers, Voyagers and Ulysses show that the field was also lagging coronation. When Pioneer 11 was outbound near noon and at high latitude, no obvious spiraling was seen (although periodic 10 hour variations in the azimuth angle were present). Finally, Ulysses showed the field is leading (or tailward) at 18 hours.

Superficially, this local time dependence is what would be expected of the solar wind flow as it stagnates near noon and flows tailward along both flanks of the magnetosphere. However, can the effect of internal processes, or ambiguities associated with comparing observations at widely different latitudes, be dismissed?

Particle Acceleration

"Jupiter's magnetosphere not only has a complicated internal structure but is known to be very dynamic. Striking examples of time-dependent particle phenomena were seen by Ulysses outbound. The possibility that these phenomena are characteristic of 18 hours local time cannot, of course, be excluded by a single set of observations. However, ultraviolet imaging of Jupiter at the time of the Ulysses encounter by instruments on Earth-orbiting satellites showed that the high-latitude aurora (as distinct from the Io-associated aurora) was present (Caldwell et al., 1992). Therefore, there has been a guarded tendency on the part of the investigators to associate these particle events with the ongoing aurora.

At medium energies, very "strong anisotropies were detected by HI-SCALE (Lanzerotti et al., 1992). Both electrons and ions were seen streaming along field lines in opposite directions. The field aligned currents that were inferred were very strong ($8x10^5 A/r_J^2$) and, if they extended over a considerable fraction of the polar cap, imply an extraordinarily large current and associated generation of energy.

At higher energies, relativistic electron bursts were observed by the COSPIN investigation at brief irregular intervals (figure 20, McKibben et al., 1993). A component with a quasi-period of about 40 minutes appears to be present. A correlation was observed between bursts of plasma waves detected by URAP and the subsequent arrival of the relativistic electrons at the spacecraft. A recent, more detailed analysis implies that the electrons are streaming outward from both polar regions.

The relevant questions raised by both sets of observations are where and how these particles are being accelerated. The analysis by Zhang et al. (1993) leads to the conclusion that a mechanism proposed several years ago by Nishida (1976), which postulates the transfer of particles at low altitudes from middle to high latitude field lines, may be operating.

Finally, Ulysses has again found evidence of prodigious particle acceleration in the form of the "clock". The earlier Pioneer 10, 11 observations showed that bursts of relativistic electrons were seen at strict 9 hour 55 minute intervals both well outside and inside the magnetosphere (Chenette et al., 1974; Simpson et al., 1975). The bursts have the property of involving time dependent changes in the energy spectra between softer and harder (referred to as a "rocking" of the spectrum), When Ulysses arrived at Jupiter, the electron bursts were seen right on schedule and persisted throughout the dayside magnetosphere (Simpson et al., 1992). For a while outbound, they were less obvious but re-appeared at large distances and continued as Ulysses left the vicinity of Jupiter. The timing of the. bursts confirmed the clock-like behavior being in-phase both above and below the magnetic equator or magnetodisc. The amount of energy being released is extraordinarily large and jovian electrons are seen throughout the heliosphere from the orbit of Mercury to beyond 50 AU. No explanation as to where and how these electrons are generated and how they are released periodically is yet available.

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Figure Captions

1. Profile of the Ulysses Mission as represented by the Trajectory.

   The trajectory consists basically of two ellipses, one that carried the spacecraft from the Earth to Jupiter and the other highly inclined to the ecliptic plane and passing over the sun's polar regions. The dates of key events are noted.

2. The Ulysses Spacecraft.

3. Radial Distance of Ulysses from Jupiter.

4. Jovigraphic Latitude of Ulysses during the Encounter.

5. Magnetic Longitude of Ulysses for several days near closest approach.

   The longitude system in use is system III (1965.00) described in the text. The north magnetic pole is located at 200° longitude in that system.

6. Local Time of Ulysses throughout the Encounter.

   Local time is based on the angle between the Sun-Jupiter line and the projection of the Ulysses radius vector onto the jovian equatorial plane.

7. Magnetic Latitude of Ulysses.

   The magnetic latitude is obtained from the O_4 model of the planetary field (e.g., see Acuña et al., 1983).

8. Location"of Ulysses Relative to the Magnetic Dipole.

   The radius vector from Jupiter to Ulysses is shown as resolved into two components, one perpendicular to, and the other parallel to, the O_4 magnetic dipole.

9. Ulysses Trajectory during passage through the Io Plasma Torus.

   The trajectories of Ulysses and Voyager are shown along with isodensity contours derived from a model based on the Voyager measurements and assumptions regarding latitude dependence. Note that the coordinate system is based on the centrifugal equator which lies between the magnetic and rotational equators (e.g., see Dessler, 1983).

10. Internal Structure of Jupiter's Dayside Magnetosphere.

Three regions are identified in the upper half figure, a Pioneer schematic. The lower half figure contains magnetic field vectors derived from Voyager measurements showing the qualitative agreement with the schematic.

11. Electron Plasma Density and Temperature: an Overview of the Encounter.

These data were derived from the Ulysses Solar Wind Analyzer (Bame et al., 1992).

12. Overview of Ions with Energies Between 0.6 and 60 keV.

These measurements were made by the Solar Wind Ion Composition Spectrometer (SWICS) which distinguishes ions on the basis of their mass and charge (Geiss et al., 1992). The H+ ions apparently originate both from the solar wind and internal sources possibly including the ionosphere. The He++ ions originate exclusively in the solar wind and are depleted inside the magnetosphere. The oxygen and sulfur ions, which are not discriminated in this presentation, originate at Io.

13. Medium Energy Electrons and Ions: An Overview.

The measurements shown were obtained by the HI-SCALE investigation (Lanzerotti et al., 1992). A third profile showing the count rate of heavy ions has been deleted.

14. An Overview of High Energy Electrons and Ions During the Encounter.

These measurements of trapped radiation were obtained by the COSPIN investigation (Simpson et al., 1992).

15. Magnetospheric Field Longitude Angle.

The difference between the measured azimuthal field component, B_ϕ, and the value of the component predicted by a model of the Planetary Field (O_4) is shown during the inbound part of the trajectory.

16. Plasma Flow Speed in the Vicinity of the Jovian Cusp inferred from Electric Field Measurements.

The electric field from which the flow speed was derived was measured by the radio-plasma wave investigation, URAP (Stone et al., 1992). The flow speed was computed from E=-VXB using knowledge of the spacecraft attitude and the magnetic field strength and direction, The solid *line is* the speed of coronation.

17. Electron Plasma Density within the Io Plasma Torus Inferred from Naturally-Occurring Plasma Wave Emissions.

    The solid line is the prediction of the electron density along the Ulysses trajectory, based on new F. Bagenal model (private communication). The dashed curve is derived from the Divine and Garrett model (1983). The electron densities (bars) are inferred from plasma wave measurements (Stone et al., 1992).

18. Electron Plasma Density derived from the effect of the 10 Plasma Torus on the Dual Frequency Radio Signals from Ulysses.

    The basic measurements of phase delay appear in the upper panel (A). The inferred columnar electron content is shown in the lower panel (B) along with expectations based on the two models identified (Bird et al., 1992).

19. Departure of the Observed Magnetic Field from the Magnetic Meridian as observed while Ulysses was outbound from Jupiter.

    These data were derived by comparing the measured B_ϕ component with the component predicted by the 04 magnetic field model as in figure 15 (Balogh et al., 1992). The azimuthal component shown represents a departure of the field from the magnetic meridian and reveals the spiraling of the field which leads coronation.

20. Bursts of Relativistic Electrons Detected at High Latitude in the Dusk Sector of Jupiter's Magnetosphere.

    High time resolution measurements of relativistic electrons obtained in two energy channels are shown (Simpson et al., 1992). The two lower curves are the ratio of the two electron count rates, representing changes in the energy spectrum, and a comparative proton count rate.

Table I

ULYSSES SCIENTIFIC INVESTIGATIONS

Investigation	Principal Investigator	Measurement	Instrumentation
Magnetic Field	A. Balogh Imperial College London	Spatial and temporal variations of the heliospheric and Jovian magnetic field in the range 0.01 to 44000 nT	Triaxial vector helium and fluxgate magnetometers
Solar-Wind Plasma (SWOOPS)	S.J. Bame Los Alamos Nat. Lab	Solar-wind ions between 260 eV/Q and 35 keV/Q solar-wind electrons between 1 and 900 eV	Two electrostatic analysers with channel electron multipliers
Solar-Wind Ion Composition (SWICS)	G. Gloeckler, U. MD/ J. Geiss, U. Bern	Elemental and ionic-charge composition, temperature and mean velocity of solar-wind ions for speeds from 145 km/s(H^+) to 1350 km/s(Fe^{+8})	Electrostatic analyser with time-of-flight and energy measurement
Low-Energy Ions and Electrons (HI-SCALE)	L. Lanzerotti Bell Laboratories	Energetic ions from 50 keV to 5 MeV Electrons from 30 keV to 300 keV	Two sensor heads with five solid-state detector telescopes
Energetic-Particle Composition and Interstellar Gas (EPAC/GAS)	E. Keppler Max-Planck-Institute Lindau, Germany	Composition of energetic ions from 80 keV to 15 MeV/nuc Interstellar neutral helium atoms	Four solid-state detector telescopes LiF-coated conversion plates with channel electron multipliers
Cosmic Rays and Solar Particles (COSPIN)	J.A. Simpson Univ. Chicago	Cosmic rays and energetic solar particles in the range 0.3-600 MeV/nuc Electrons in the range 4-2000 MeV	Five solid-state detector telescopes, one double Cerenkov and semi-conductor telescope for electrons

Table I (cent'd)

ULYSSES 'SCIENTIFIC INVESTIGATIONS

Investigation	Principal Investigator	Measurement	Instrumentation
Unified Radio and Plasma Waves (uRAP)	R.G. Stone Goddard Space Flight Center	Plasma waves Solar radio bursts Electron density Electric field: Plasma waves: 0-60 kHz Radio receiver: 1-940 kHz Magnetic field: 10-500 Hz	72 m radial dipole antenna 8 m axial monopole antenna Two-axis search coil
Solar X-rays and Cosmic Gamma-Ray Bursts	K. Hurley, U. Cal Berkeley M. Sommer, Max-Planck-Institute Garching	Solar-flare X-rays and cosmic gamma-ray bursts in the energy range 5-150 keV	Two Si solid-state detectors Two CsI scintillation crystals
Cosmic Dust	E. Grün Max-Planck-Institute Heidelberg	Direct measurement of particulate matter in mass range 10^{-16} - 10^{-7}gm	Multi-coincidence impact detector with channeltron
Coronal Sounding	M. Bird Univ. Bonn	Density, Velocity and Turbulence spectra in the solar corona and solar wind	Spacecraft transponder
Gravitational Waves	B. Bertotti Univ. Pavia	Doppler shifts in radio signal received at Earth due to passage of wave	Spacecraft transponder

ULYSSES

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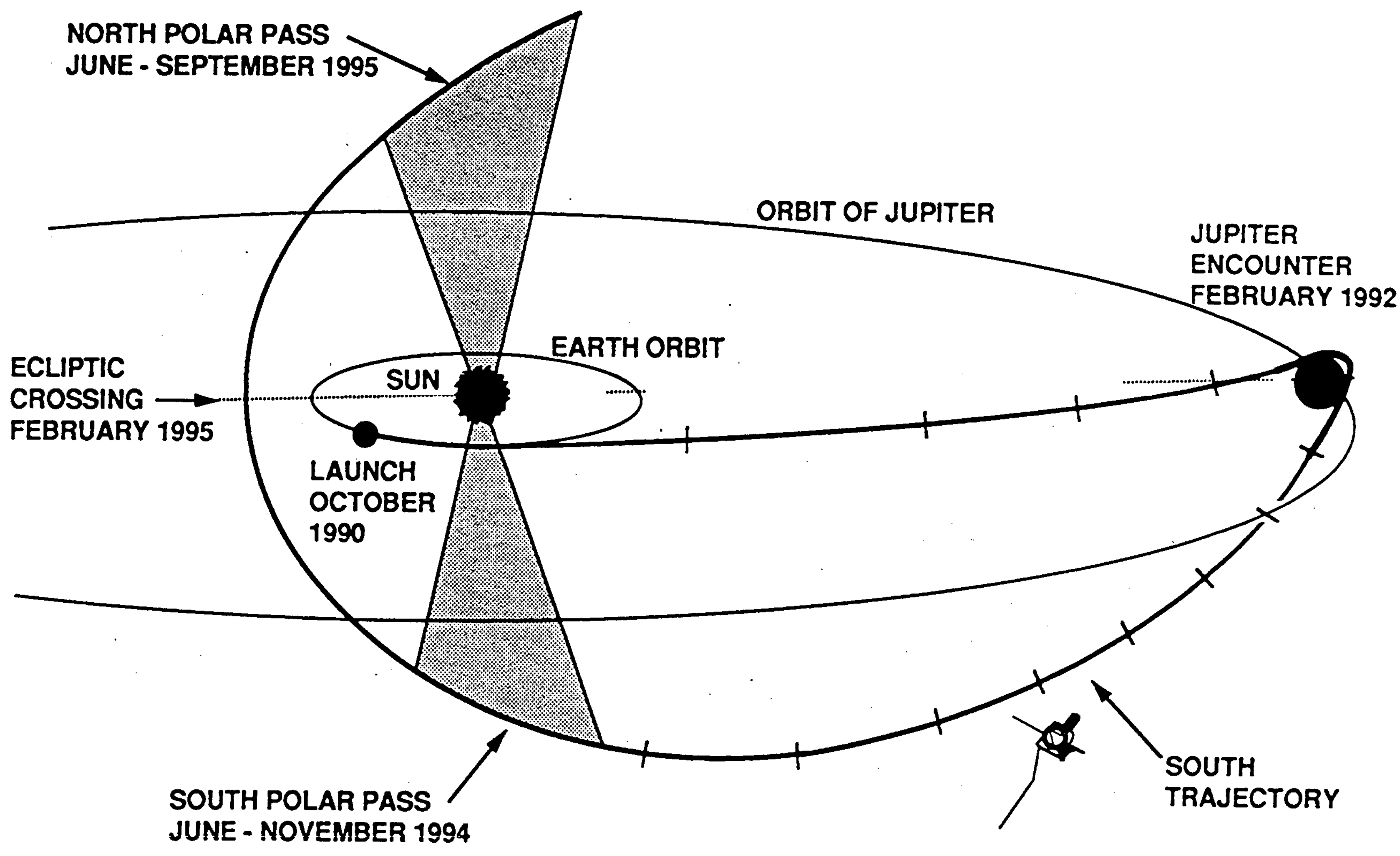

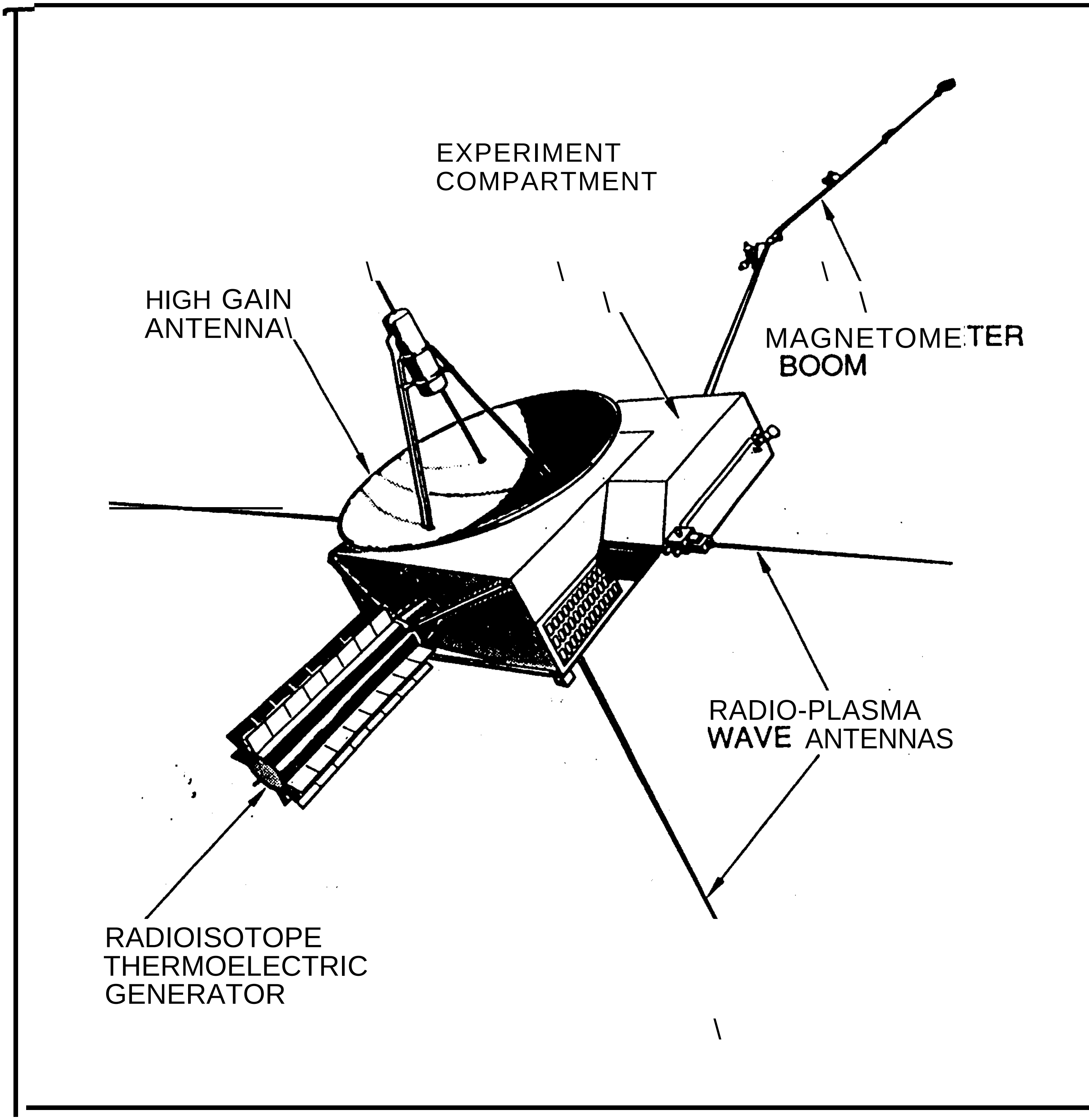
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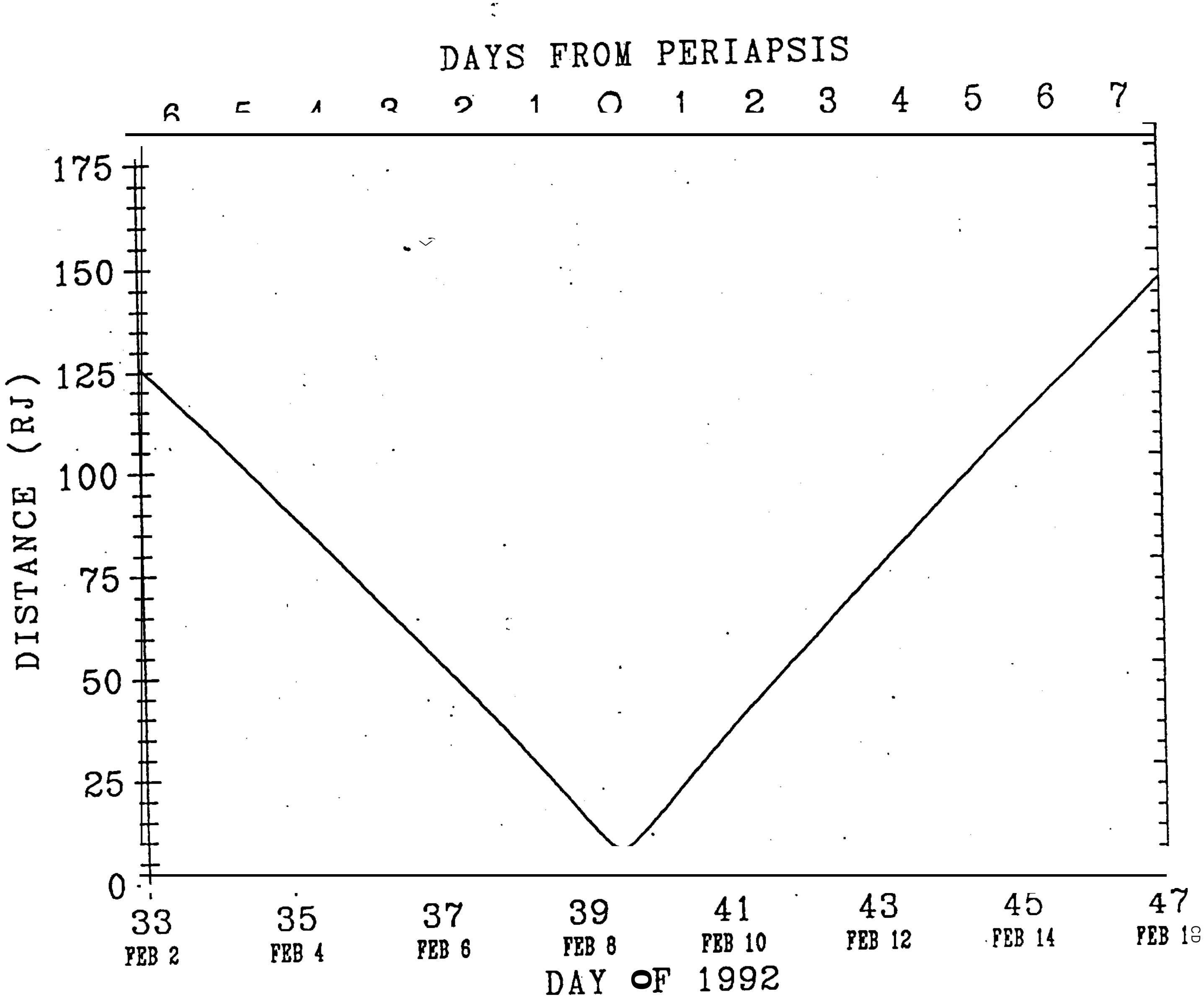
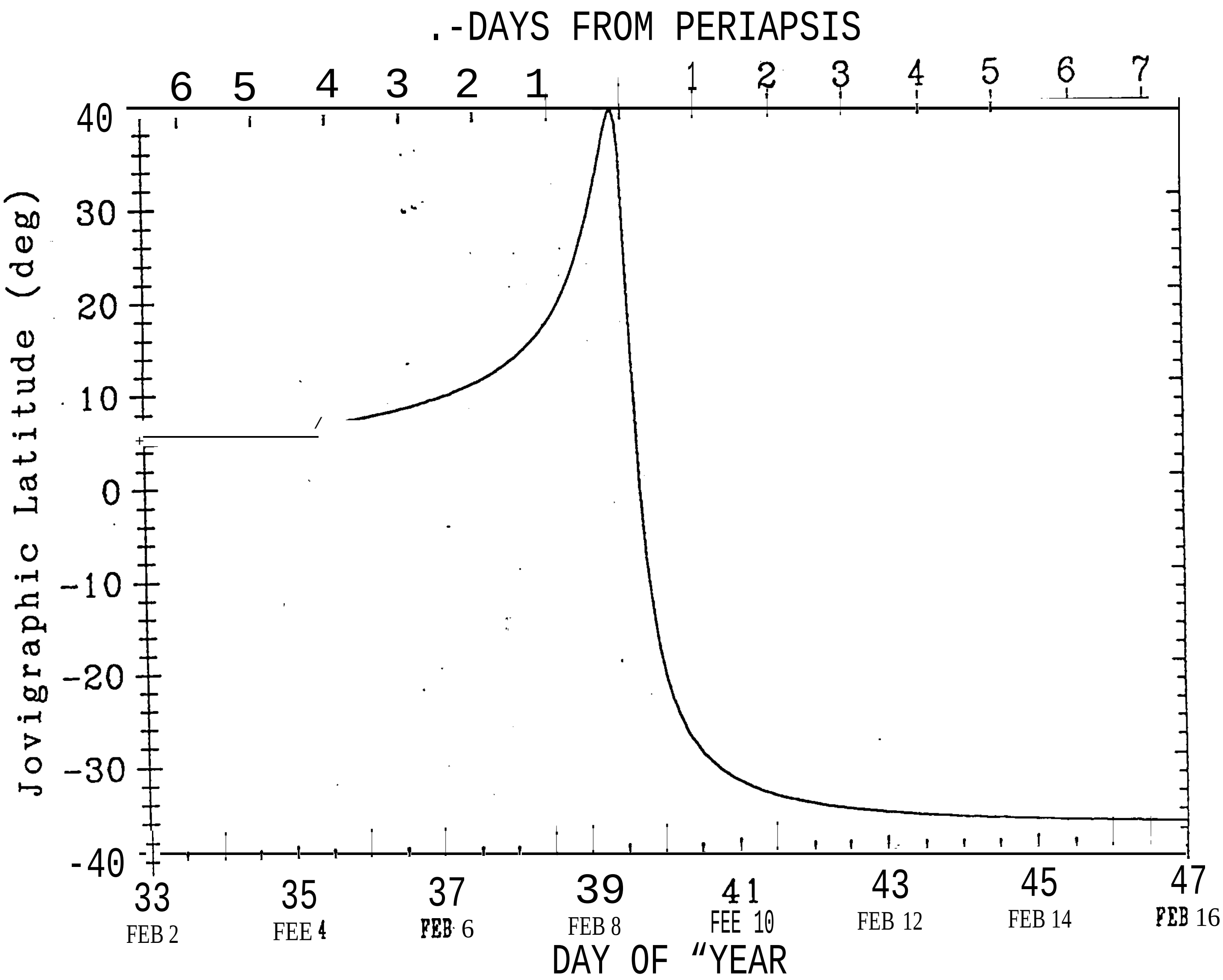

DAYS FROM PERIAPSIS
1 0 1 2 3 4 5 6 7
DISTANCE (RJ)
0 25 50 75 100 125 150 175
33 FEB 2
35 FEB 4
37 FEB 6
39 FEB 8
41 FEB 10
43 FEB 12
45 FEB 14
47
DAY OF 1992


.-DAYS FROM PERIAPSIS
6 5 4 3 2 1 1 2 3 4 5 6 7
Jovigraphic Latitude (deg)
40
30
20
10
0
-10
-20
-30
-40
33
FEB 2
35
FEE 4
37
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41
FEE 10
43
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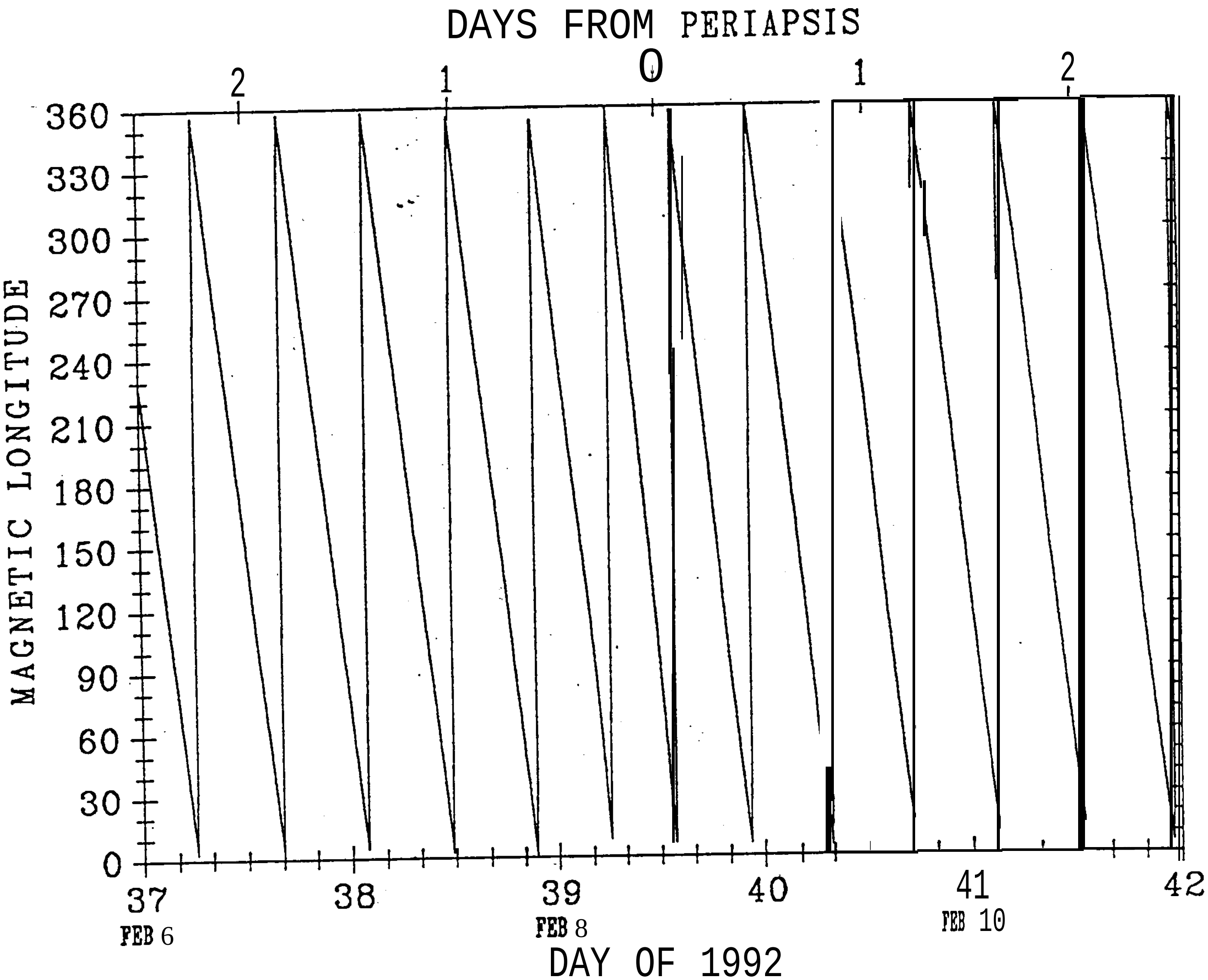
45
FEB 14
47
FEB 16
DAY OF "YEAR

4


DAYS FROM PERIAPSIS
2
1
0
1
2
MAGNETIC LONGITUDE
360
330
300
270
240
210
180
150
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90
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30
0
37
FEB 6
38
39
FEB 8
40
41
FEB 10
42
DAY OF 1992

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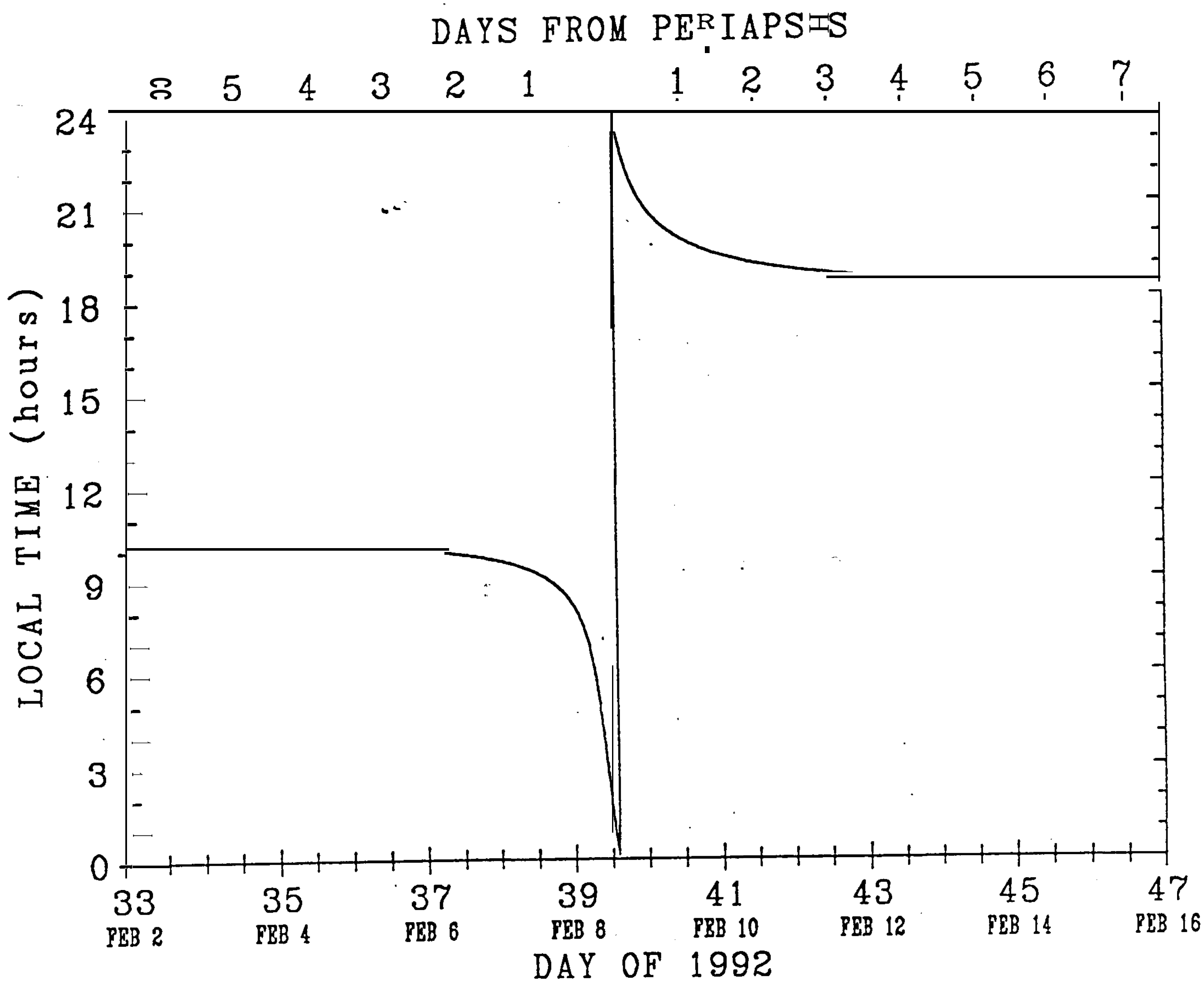
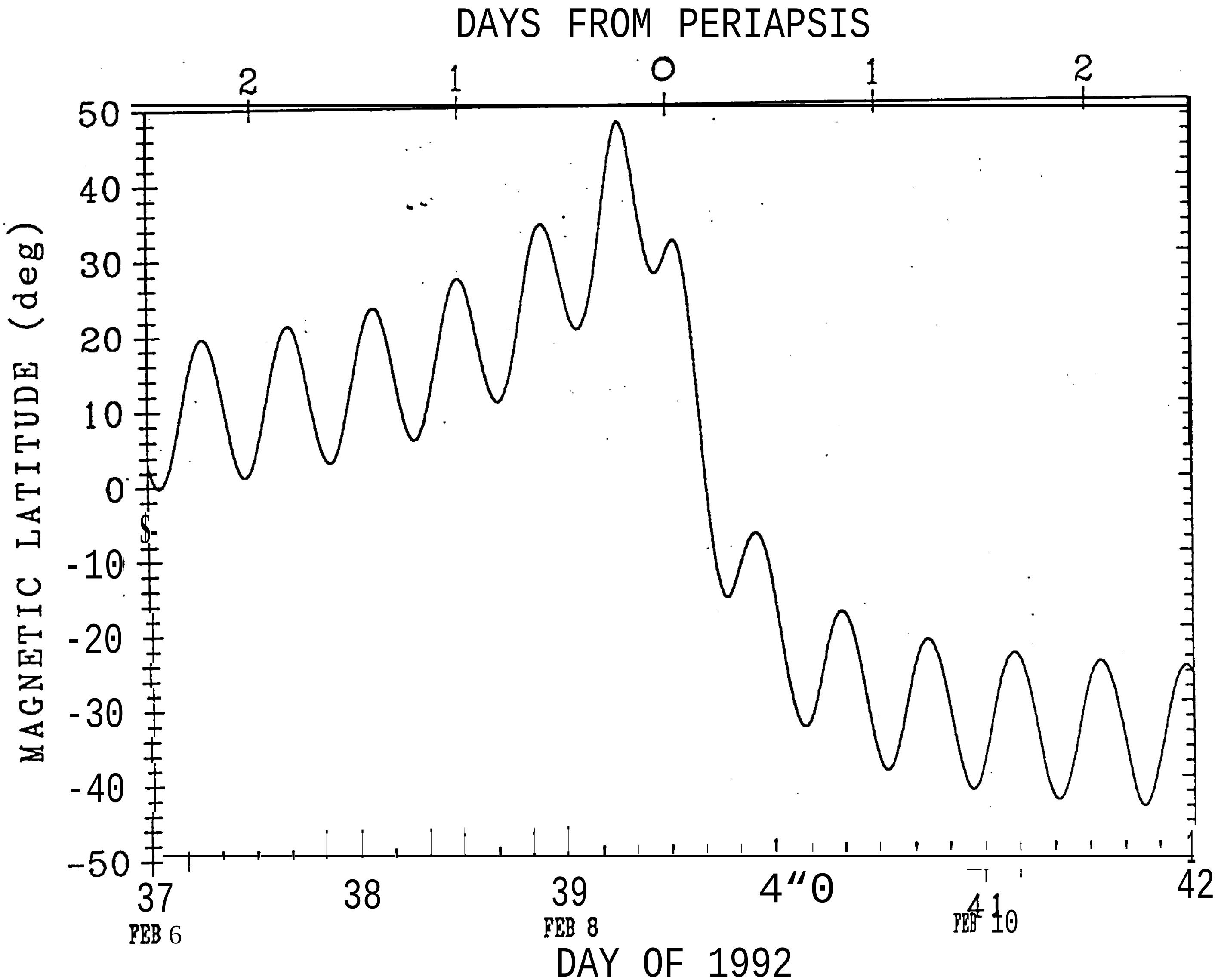
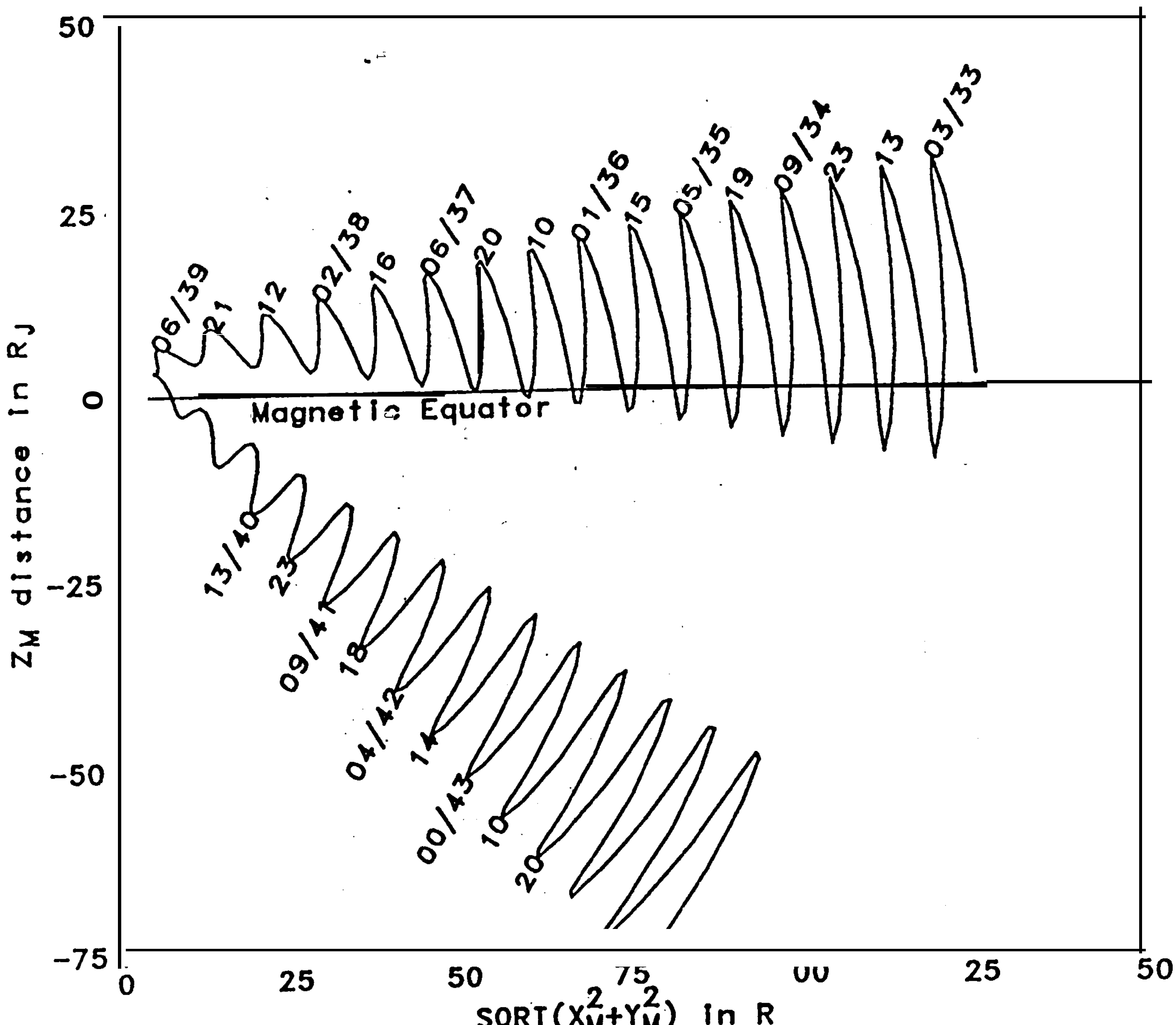

DAYS FROM PERIAPSIS
LOCAL TIME (hours)
DAY OF 1992
33 FEB 2
35 FEB 4
37 FEB 6
39 FEB 8
41 FEB 10
43 FEB 12
45 FEB 14
47 FEB 16

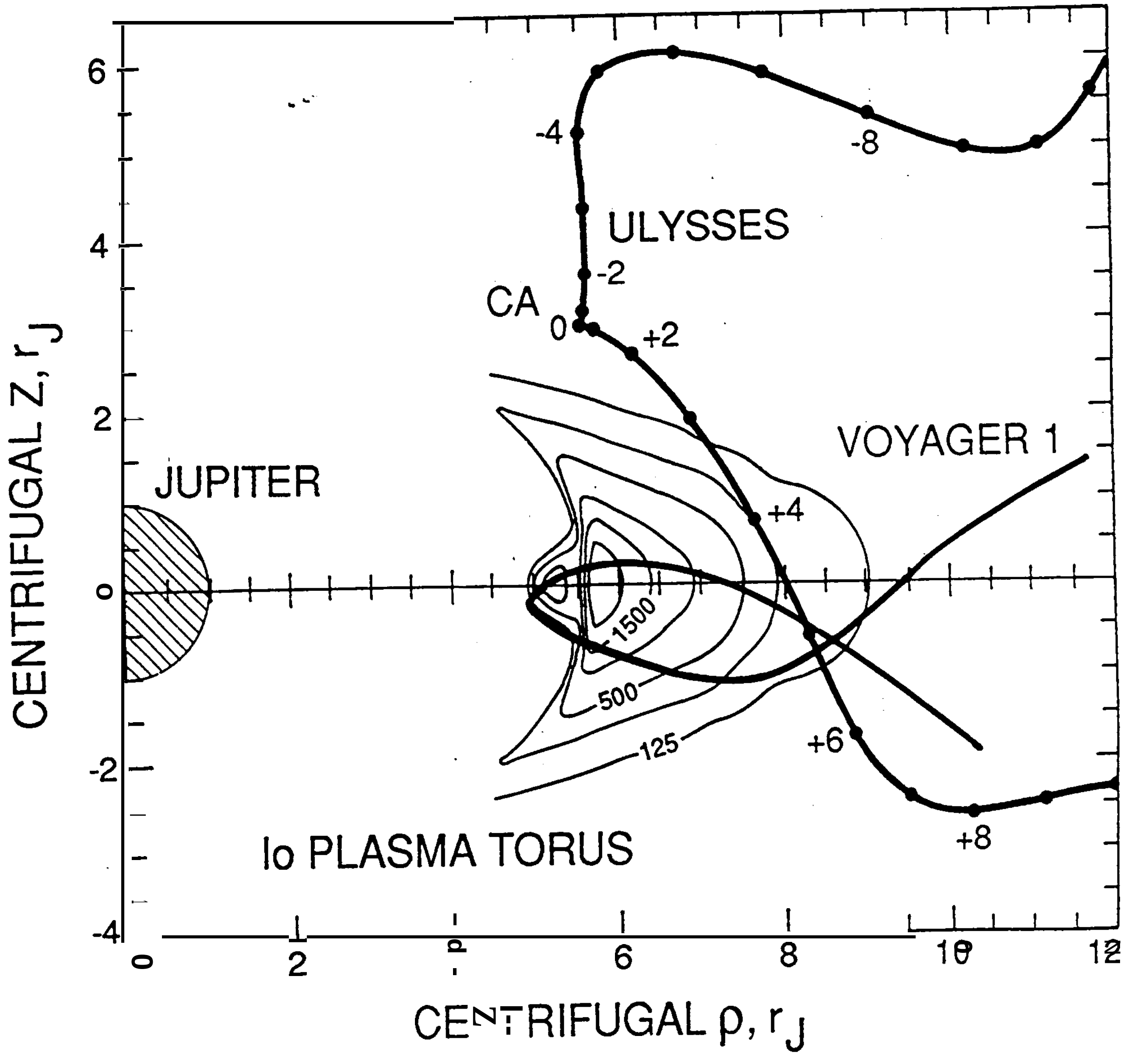

DAYS FROM PERIAPSIS
2
1
0
1
2
MAGNETIC LATITUDE (deg)
50
40
30
20
10
0
-10
-20
-30
-40
-50
37
38
39
4"0
41
42
FEB 6
FEB 8
FEB 10
DAY OF 1992

7.

ULYSSES TRAJECTORY RELATIVE TO MAGNETIC EQUATOR



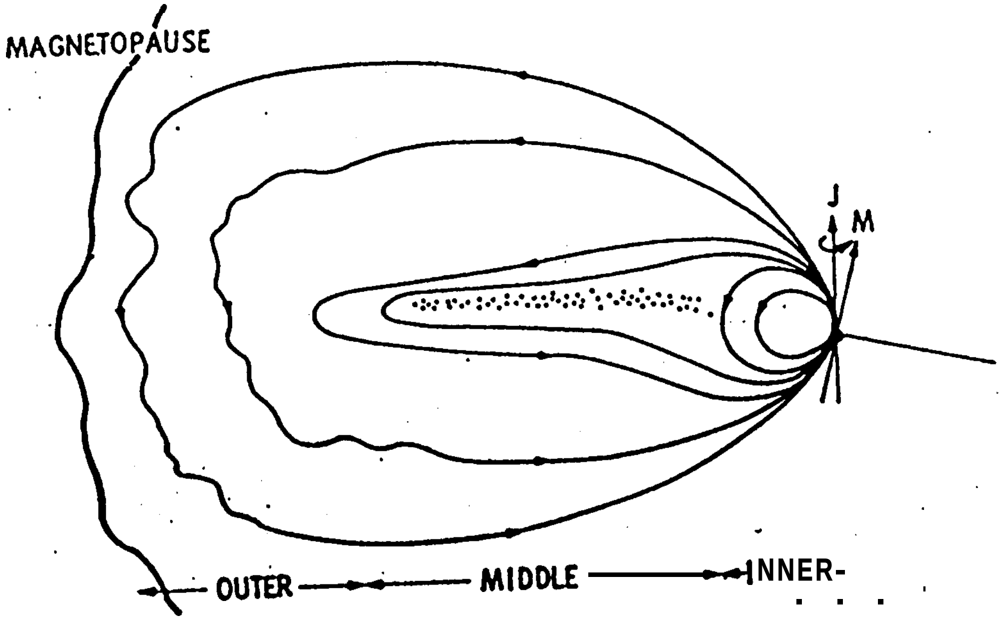
8.



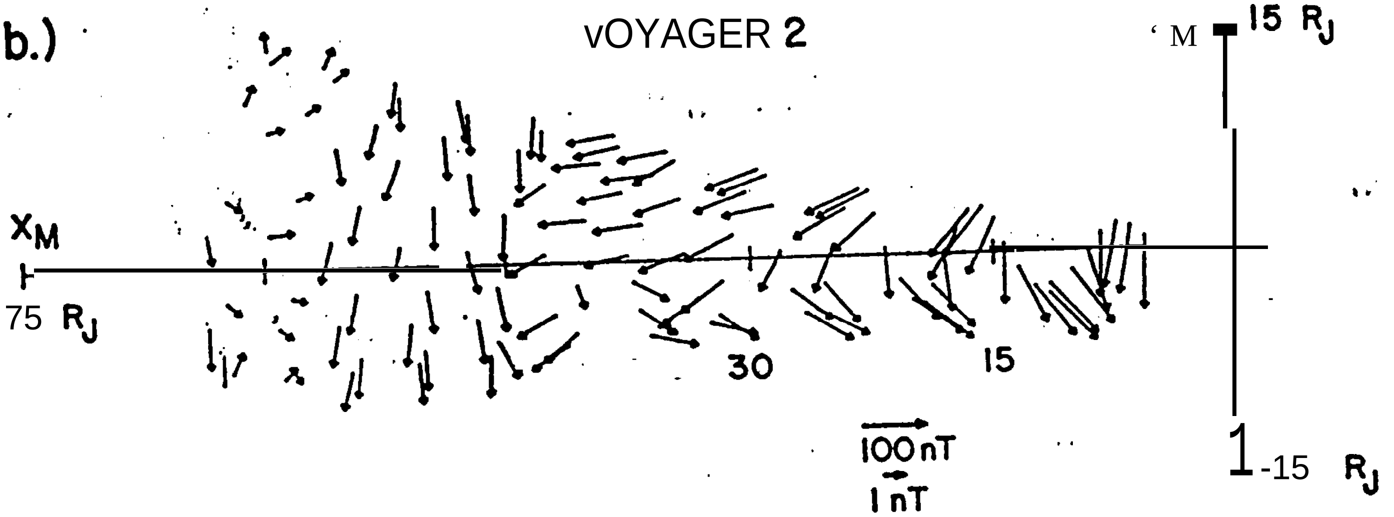
ULYSSES
VOYAGER 1
JUPITER
Io PLASMA TORUS
CA
1500
500
125
CENTRIFUGAL Z, r_J
CENTRIFUGAL ρ, r_J

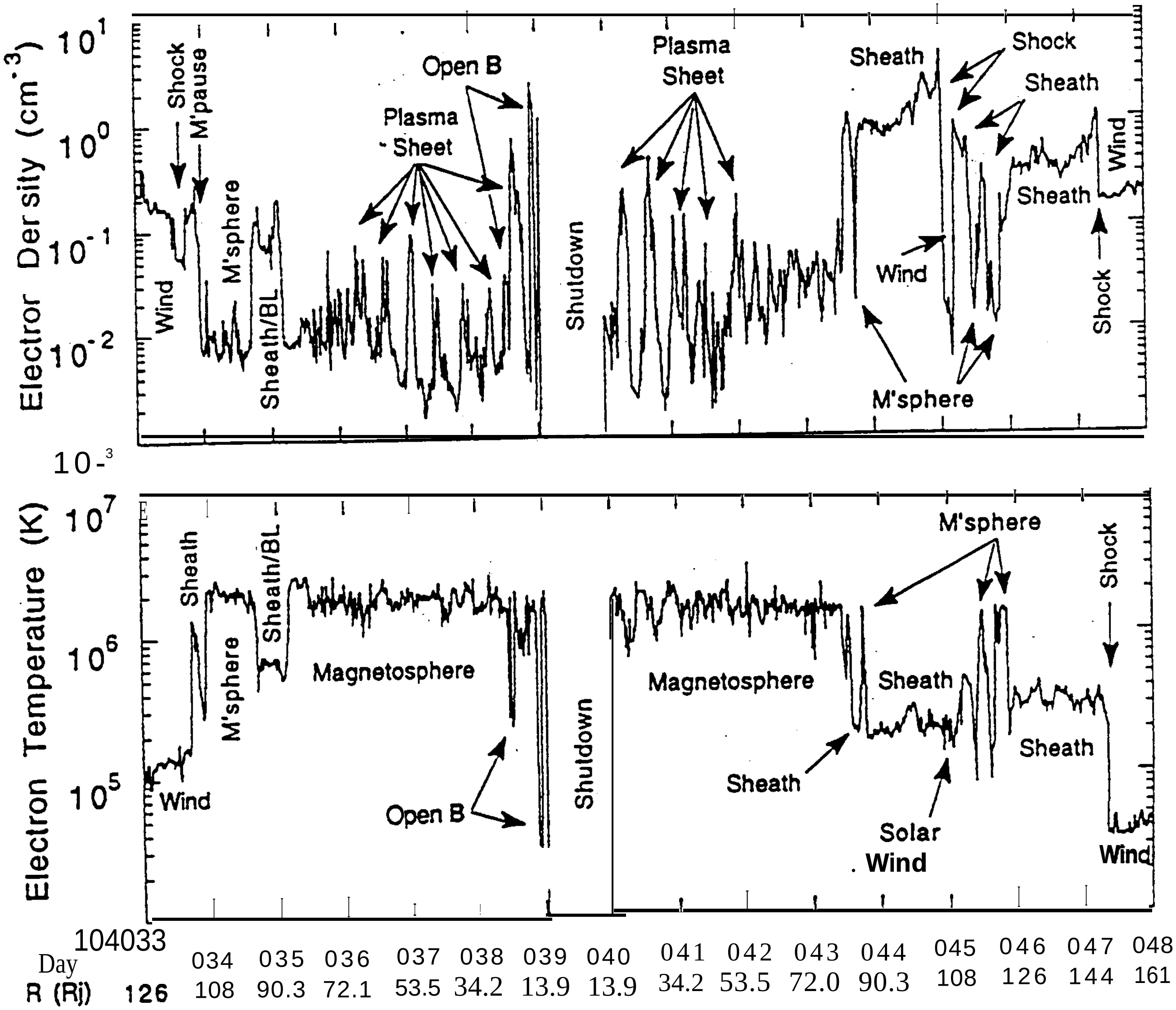
9.

a.)

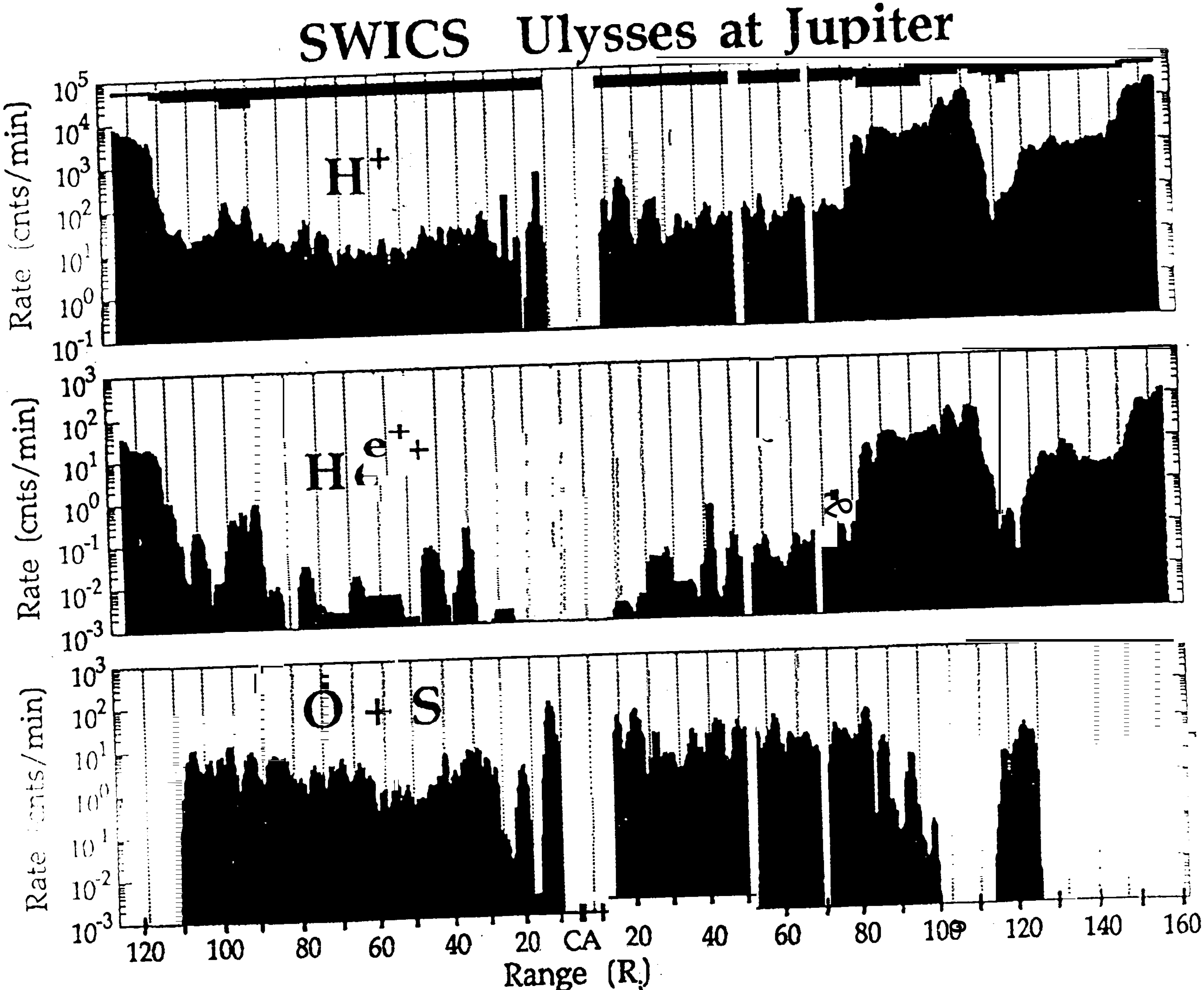

MAGNETOPAUSE
J
M
OUTER
MIDDLE
INNER-

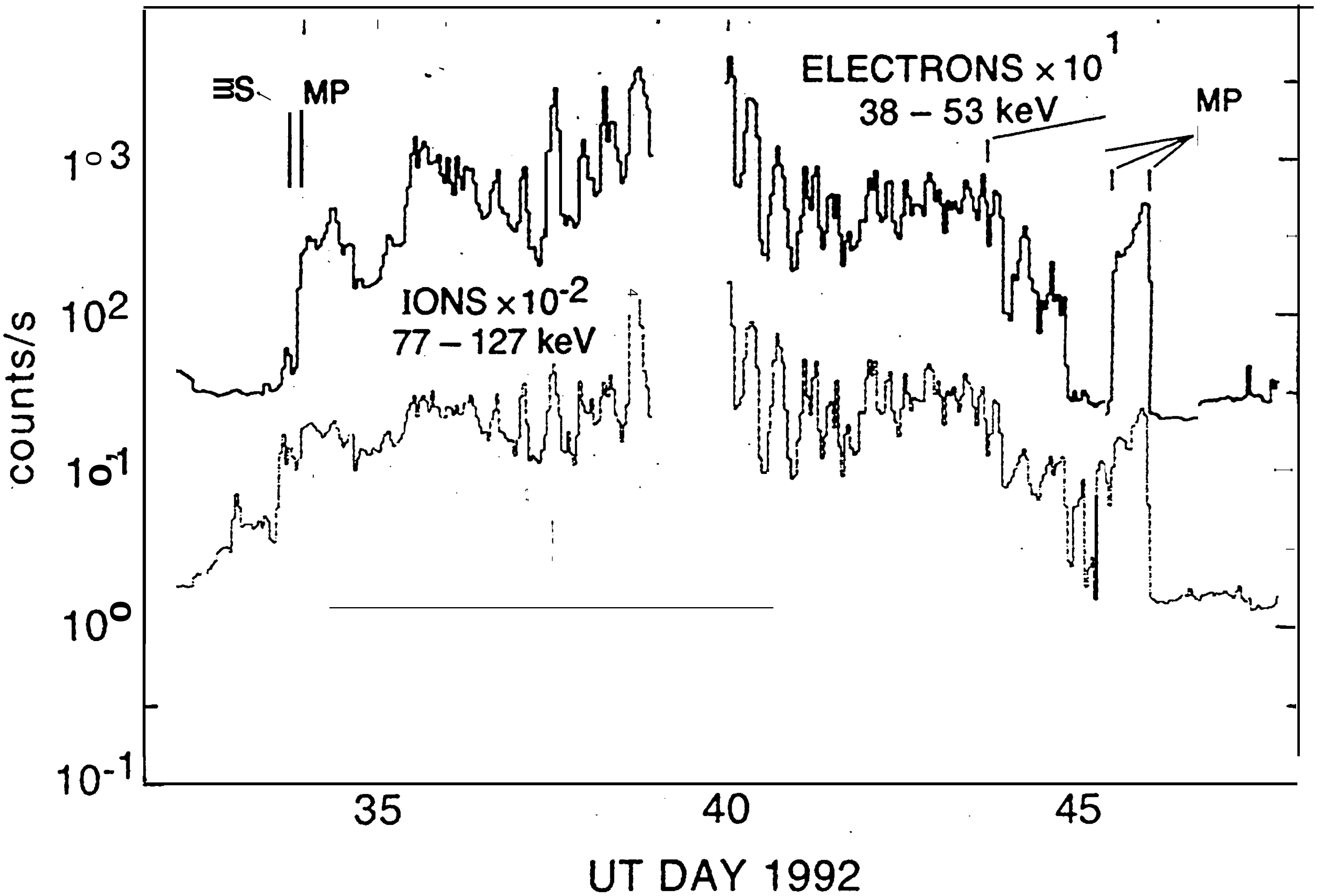
b.)


vOYAGER 2
M
15 RJ
XM
75 RJ
30
15
100nT
1nT
-15 RJ

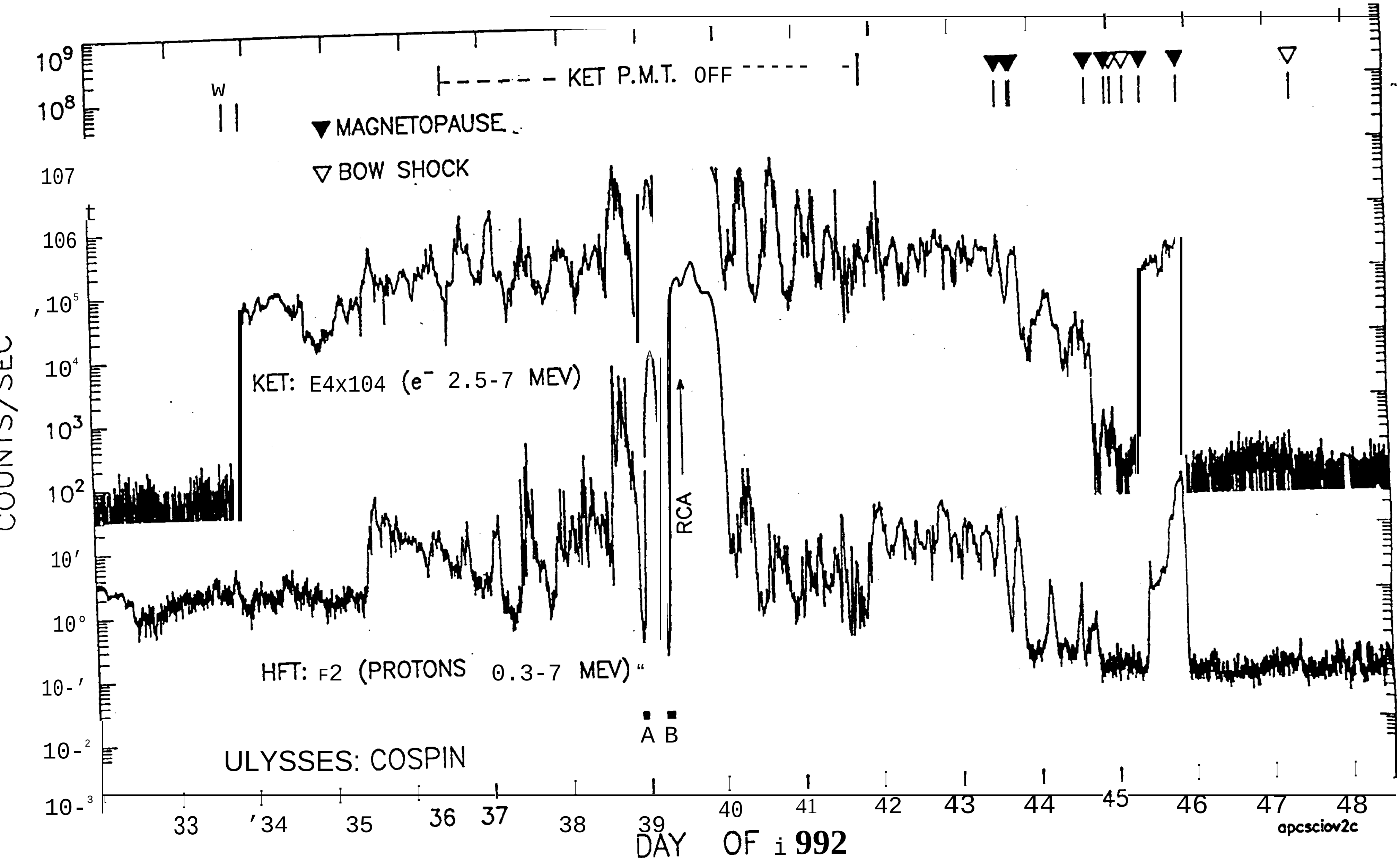


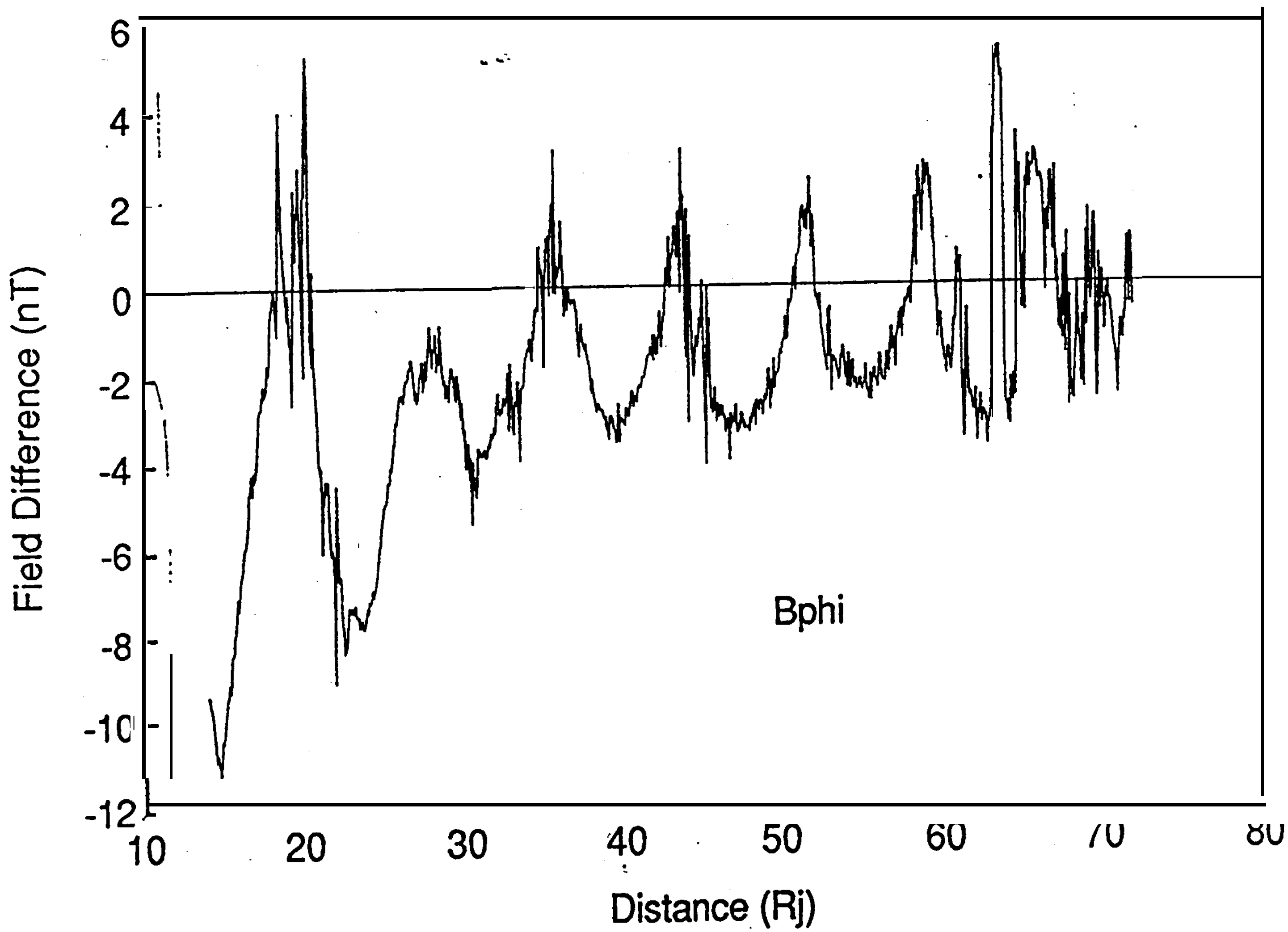
Electron Density (cm^-3)
10^1
10^0
10^-1
10^-2
10^-3
Shock
M'pause
Wind
M'sphere
Sheath/BL
Plasma
Sheet
Open B
Shutdown
Plasma
Sheet
Sheath
Shock
Sheath
Wind
Sheath
Wind
M'sphere
Shock
Electron Temperature (K)
10^7
10^6
10^5
Sheath
Sheath/BL
M'sphere
Magnetosphere
Wind
Open B
Shutdown
Magnetosphere
M'sphere
Sheath
Sheath
Solar
Wind
Sheath
Shock
Wind
Day
104033
034
035
036
037
038
039
040
041
042
043
044
045
046
047
048
R (Rj)
126
108
90.3
72.1
53.5
34.2
13.9
13.9
34.2
53.5
72.0
90.3
108
126
144
161


SWICS Ulysses at Jupiter
H+
He++
O + S
Rate (cnts/min)
Range (Rj)
CA
120
100
80
60
40
20
140
160



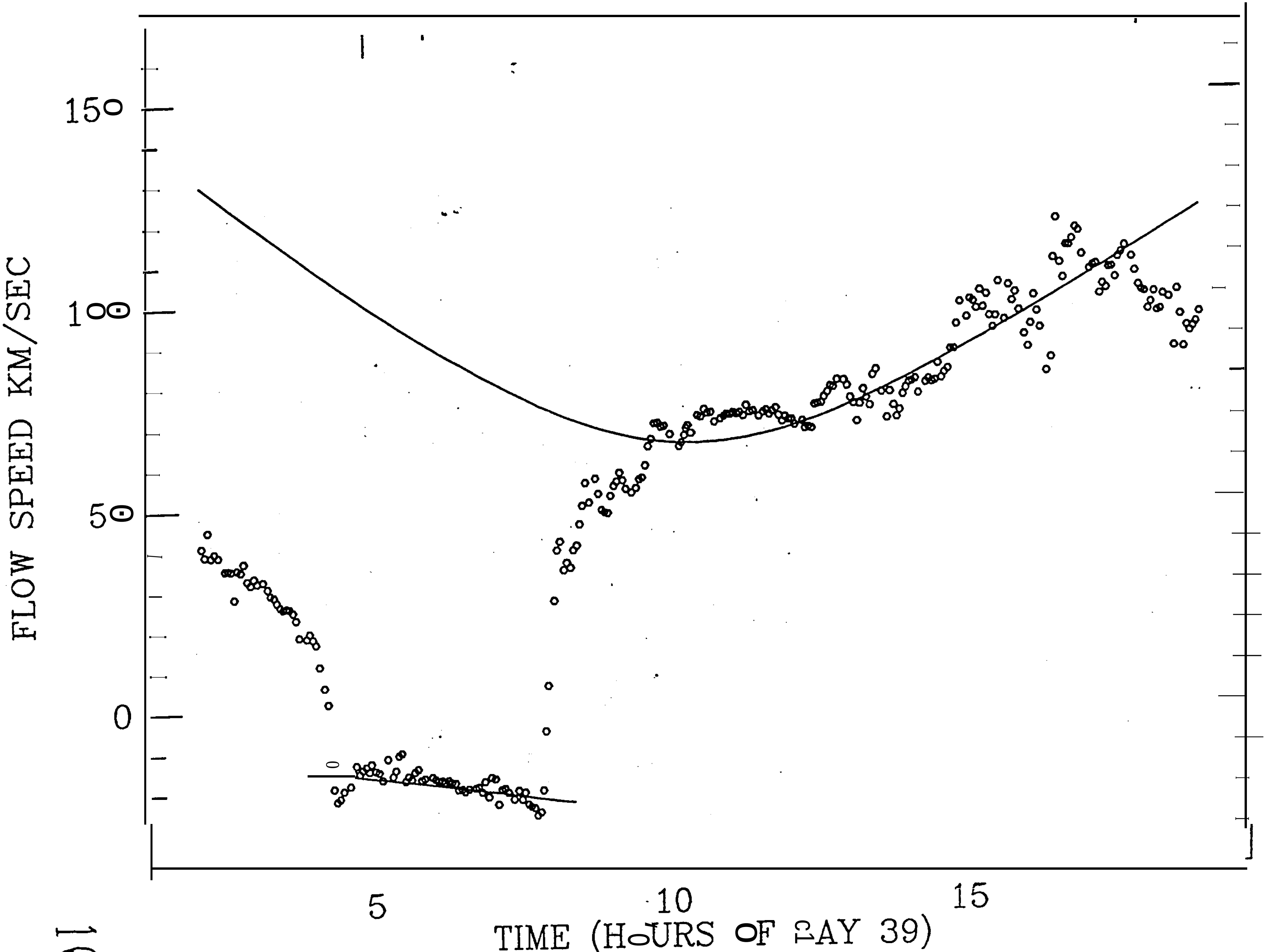
BS
MP
ELECTRONS × 10^1
38 – 53 keV
MP
IONS × 10^-2
77 – 127 keV
counts/s
10^3
10^2
10^1
10^0
10^-1
35
40
45
UT DAY 1992


KET P.M.T. OFF
W
MAGNETOPAUSE
BOW SHOCK
KET: E4x104 (e⁻ 2.5-7 MEV)
RCA
HFT: F2 (PROTONS 0.3-7 MEV)
A B
ULYSSES: COSPIN
COUNTS/SEC
DAY OF 1992
apcsciov2c

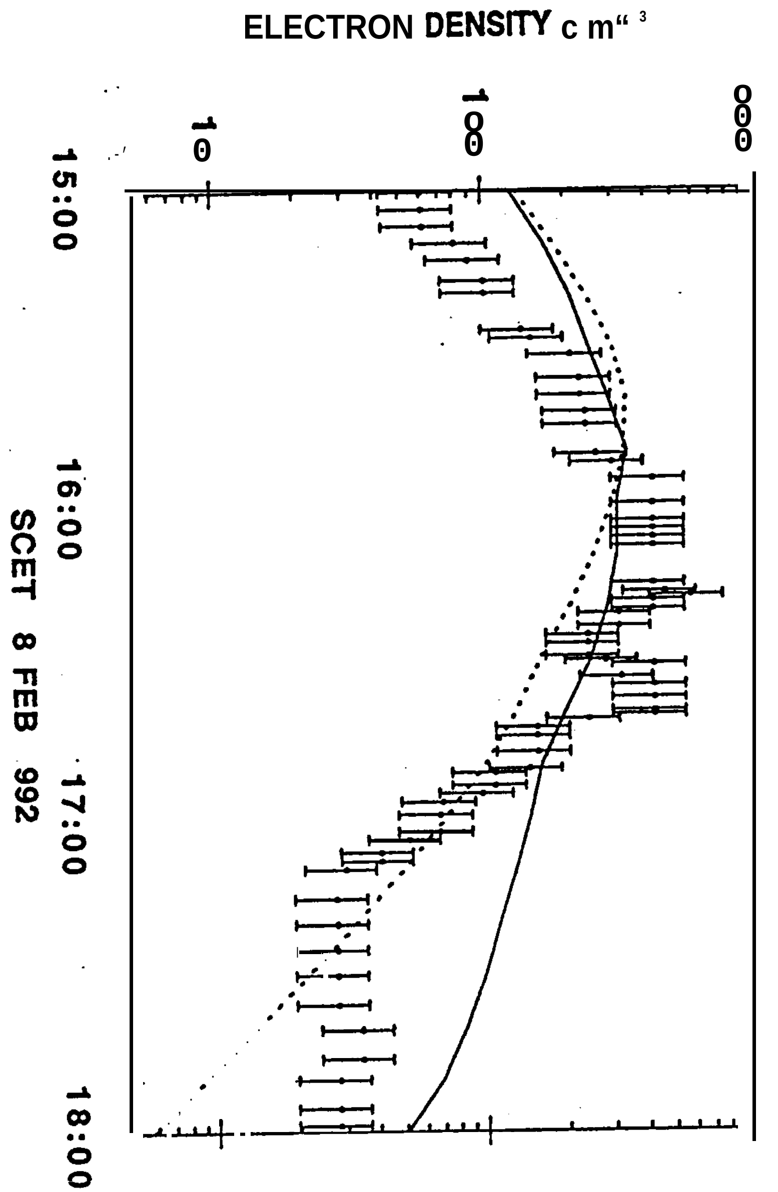


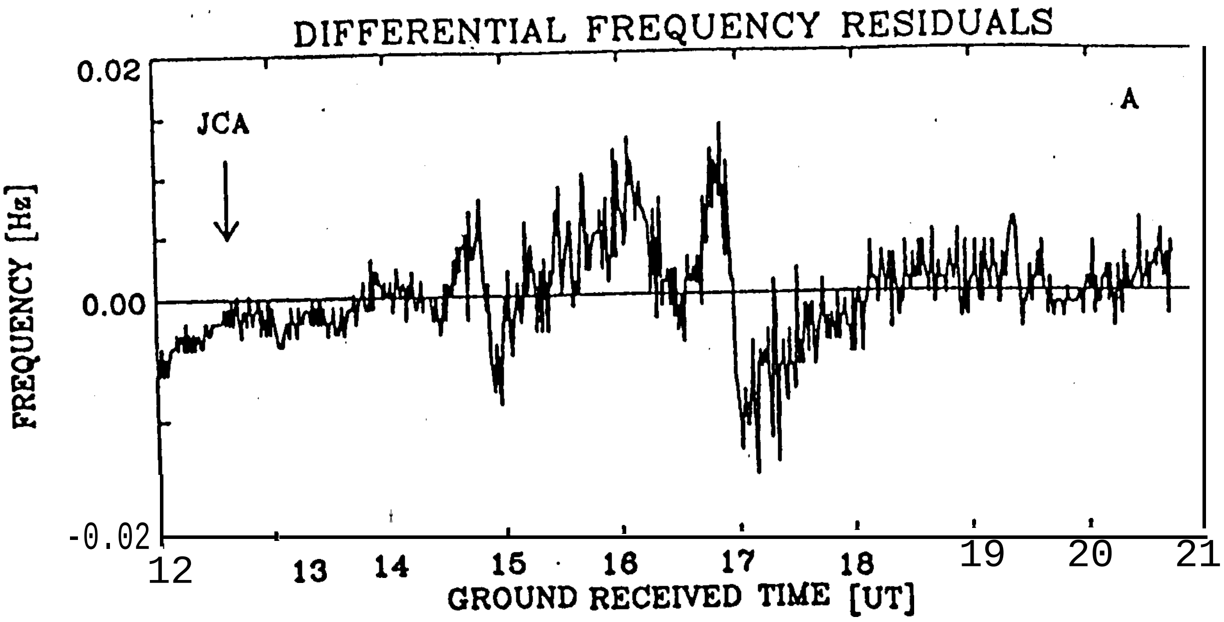
6
4
2
0
-2
-4
-6
-8
-10
-12
Field Difference (nT)
Bphi
10
20
30
40
50
60
70
80
Distance (Rj)

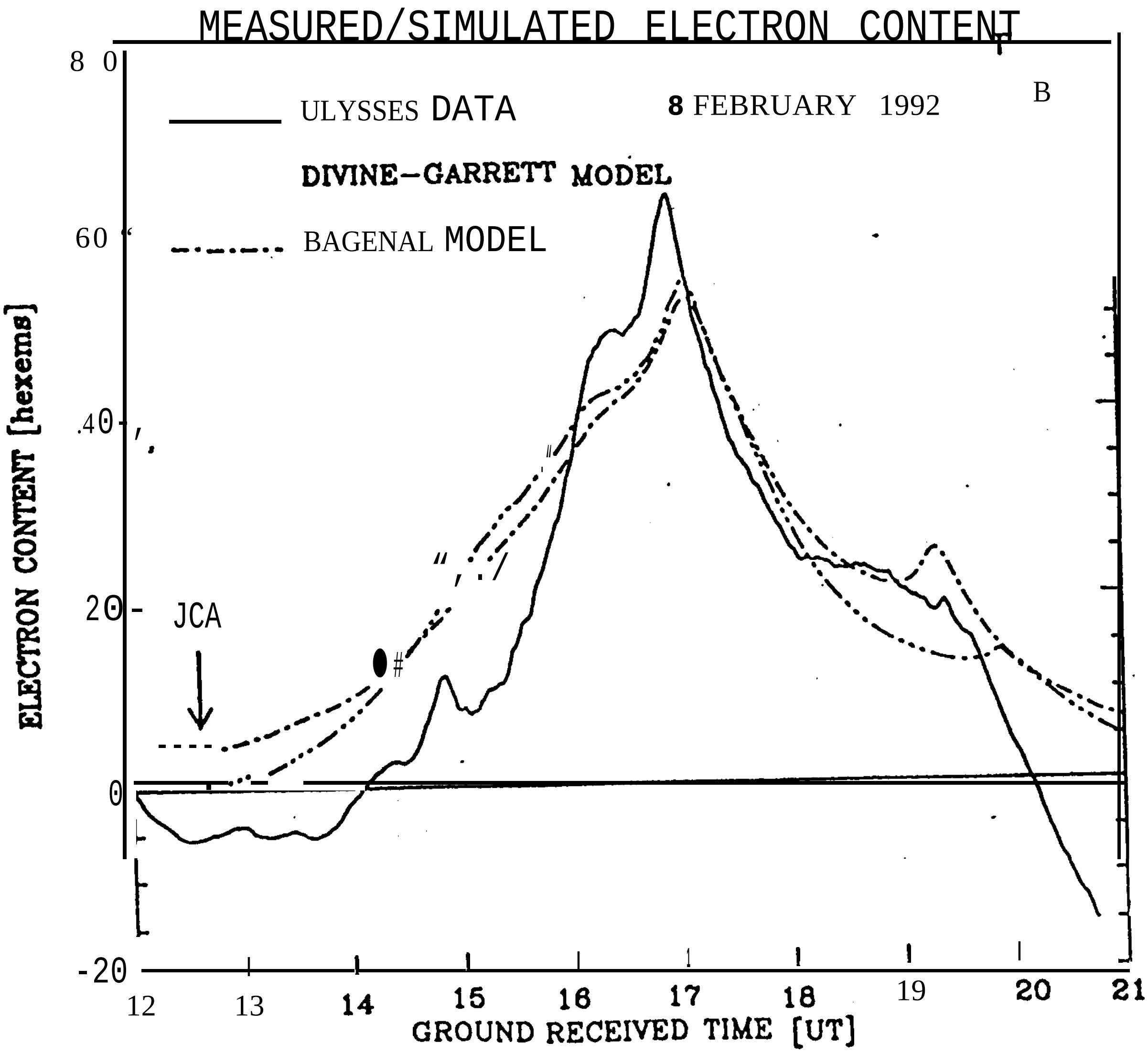
15.

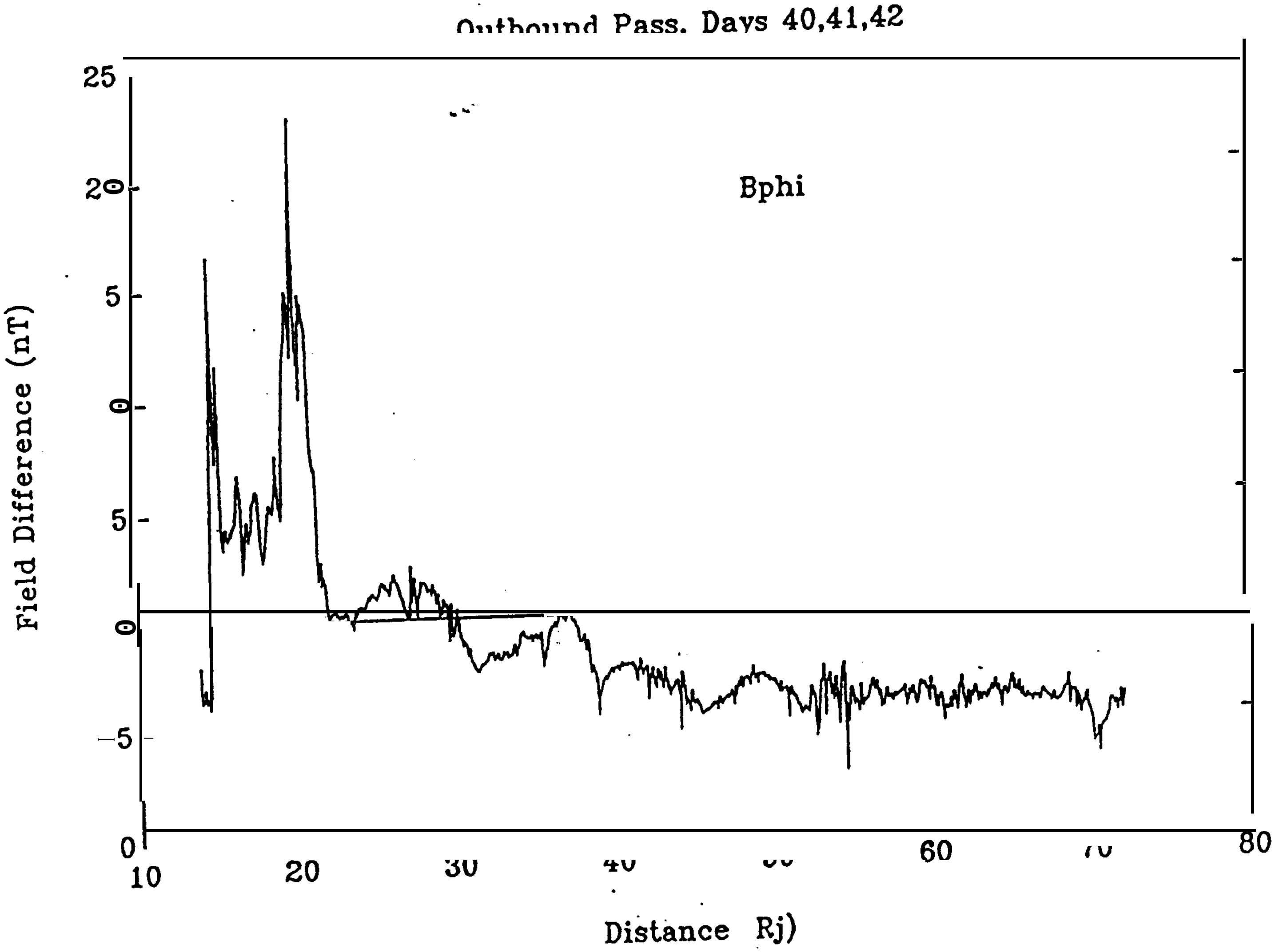


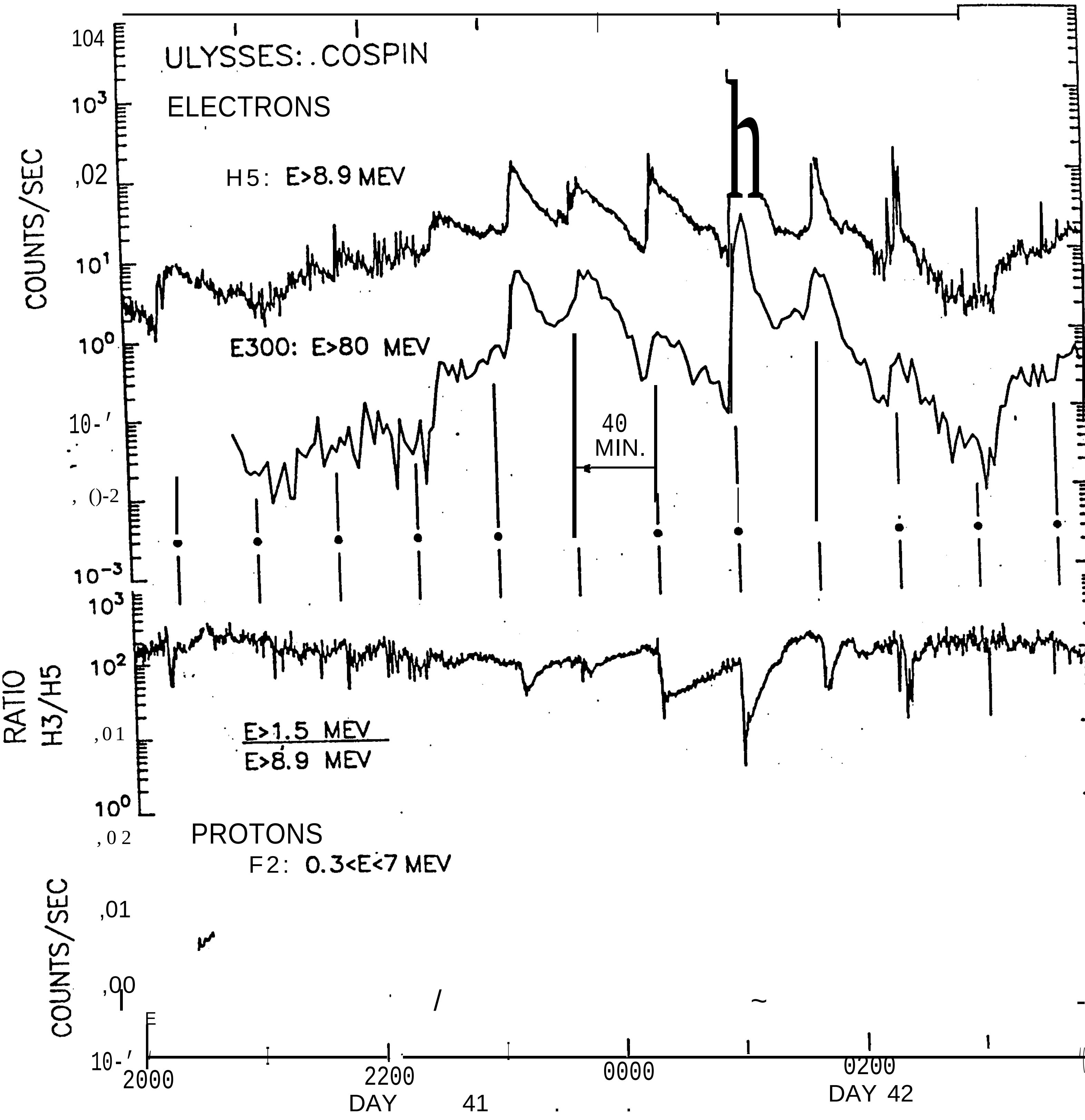
16.


ELECTRON DENSITY c m“ 3
000
100
10
15:00
16:00
17:00
18:00
SCET 8 FEB 992


DIFFERENTIAL FREQUENCY RESIDUALS
0.02
0.00
-0.02
FREQUENCY [Hz]
JCA
A
12
13
14
15
16
17
18
19
20
21
GROUND RECEIVED TIME [UT]


MEASURED/SIMULATED ELECTRON CONTENT
8 0
60
40
20
0
-20
ELECTRON CONTENT [hexems]
ULYSSES DATA
DIVINE-GARRETT MODEL
BAGENAL MODEL
8 FEBRUARY 1992
B
JCA
12
13
14
15
16
17
18
19
20
21
GROUND RECEIVED TIME [UT]


Outbound Pass. Days 40,41,42
Bphi
Field Difference (nT)
25
20
5
0
5
0
-5
0
10
20
30
60
80
Distance Rj)



ULYSSES: COSPIN
ELECTRONS
H5: E>8.9 MEV
E300: E>80 MEV
40 MIN.
COUNTS/SEC
RATIO H3/H5
E>1.5 MEV / E>8.9 MEV
PROTONS
F2: 0.3<E<7 MEV
COUNTS/SEC
2000
2200
0000
0200
DAY 41
DAY 42

20.