Ulysses Spacecraft Rendezvous with Jupiter

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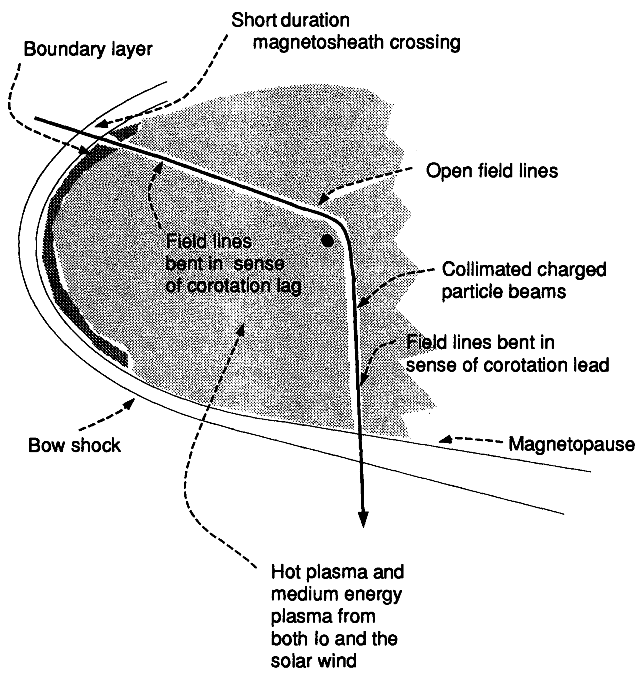
The Ulysses spacecraft was launched in October 1990 on a mission to study the unexplored regions far above the north and south poles of the sun. En route, Ulysses got a gravity assist from Jupiter so as to be hurled into a high-inclination orbit about the sun. The mission, a collaboration between the National Aeronautics and Space Administration and the European Space Agency, took advantage of this interlude to make measurements of charged particles and electromagnetic fields in the Jovian magnetosphere during the 2-week encounter. A number of complementary observations were made from the ground and from the Hubble Space Telescope. As described in this issue (*1*), several new findings came out of the encounter and the mission as a whole has been a boon to planetary scientists.

A description of the spacecraft experiments and trajectory is given by Smith *et al.* (p. 1503) who outline some of the prominent features of Jupiter's magnetosphere investigated by Ulysses. One of the novel aspects of this encounter is that the spacecraft on the outbound leg of the trajectory traversed the outer magnetosphere on the dusk side, a region for which scant information existed previously. A number of interesting and somewhat surprising results were found there as reported below.

The magnetic field experiment (Balogh *et al.*, p. 1515) and the solar wind plasma instrument (Bame *et al.*, p. 1539) found evidence that the magnetosphere was inflated to a size much greater than that detected by previous spacecraft save for Pioneer 10. The simplest explanation is that the solar wind dynamic pressure was a factor of 10 below the usual level and the magnetosphere, with its large reservoir of hot plasma, had expanded to a new equilibrium position. This is confirmed by direct measurements of the solar wind by the plasma probe and indirectly by the fact that the magnetosheath was traversed in a short time, an indication that the magnetopause was moving outward. One of the most interesting findings of the magnetometer team was that the magnetic field was bent tailward in the outer magnetosphere on the dusk side at high latitude. This orientation is opposite to that expected from inertial drag on the field lines from corotating plasma and signifies the possible effect of the solar wind pulling field lines away from the sun to form the magnetic tail of Jupiter.



Passing through. On its way to explore the high polar regions of the sun, the Ulysses spacecraft swung past Jupiter to take advantage of the large planet's gravity. The schematic diagram represents the Ulysses path through the magnetosphere and highlights some of the observations discussed in the text.

Although this result should perhaps not be surprising, it is remarkable that the solar wind influence shows up so deep in the magnetosphere beginning at 30 R_J (Jupiter radii) and extending on out to the magnetopause. The exterior solar wind flow speed is only ~300 km s^{-1} and it is not clear that this exceeds that of the magnetospheric plasma flow which presumably is being sped up by the solar wind. Further work is needed to understand this effect.

The solar wind plasma team (Bame *et al.*, p. 1539) found that the electron population of the magnetosheath persisted through a boundary layer within the magnetic magnetopause boundary where a lower energy magnetospheric electron population was also present. The mixed layer may have been many R_J thick as it was observed for almost half as long as the magnetosheath. Five days later at a position deep within the magnetosphere (15 R_J from Jupiter) on the inbound pass, anomalous plasma properties were observed. The trapped magnetospheric electrons disappeared, as did the penetrating background population. The spacecraft appears to have encountered open flux tubes consistent with having been on polar cap or polar cusp field lines.

The Solar Wind Ion Composition Spectrometer (SWICS) (Geiss *et al.*, p. 1535) returned some very important results regarding the identity of the various species that comprise the hot plasma population of Jupiter. The dominance of sulfur and oxygen ions confirmed previous findings of the Voyager spacecraft that heavy ions from the satellite Io were a major plasma constituent at medium energies ~10 keV. About a ton of material from the volcanically active moon finds its way into the magnetosphere every second, becomes ionized, and then is accelerated to high energies by a number of plasma processes. The proton population was found to have two sources: solar wind protons gained entry to the magnetosphere and were predominant in the outer magnetosphere whereas protons from the Jovian ionosphere became more prevalent in the middle and inner magnetosphere. What may prove to be a critical point is that on the outbound leg sulfur and oxygen ions were in great abundance which tends to suggest the plasma is on closed field lines; presumably if the magnetic field were open and connected to the solar wind (that is, polar cap field lines), Iogenic heavy ions would have freely escaped and the composition would reflect solar wind conditions.

At somewhat greater energies (≥100 keV) the Heliospheric Instrument for Spectra, Composition, and Anisotropy at Low Energies (HI-SCALE) (Lanzerotti *et al.*, p. 1518) made measurements of ions and electrons and confirmed the presence of a large population of Iogenic sulfur and oxygen ions throughout the magnetosphere. One new result that could have a significant impact on theoretical models was the observation of highly collimated distributions of energetic ions and electrons streaming along the magnetic field on the outbound leg, electrons traveling away from the planet and ions toward the planet. This type of

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particle behavior is not unexpected if these field lines thread what many believe to be a plasma sheet boundary layer separating internal heavy ion–rich plasma from external solar wind–dominated plasma. As noted previously these field lines on the high latitude dusk side are laden with sulfur and oxygen ions. The situation suggests that the field lines are closed but under stress as a transition is made to a dynamically different plasma regime. If in any way a determination of the elemental species that compose the ion beams could be made, it would shed light on a very important aspect of Jovian magnetospheric dynamics. A good possibility is that they are protons from Jupiter's ionosphere which have been reflected back to the planet from an undetected primary beam traveling away from the planet (see below).

The Cosmic Ray and Solar Particle Investigations (COSPIN) experiment (Simpson *et al.*, p. 1543) measures ions and electrons at even higher energies (≥ 1 MeV). They report a number of interesting findings including the possible entry of the spacecraft around the time near closest approach into a polar cap region where fluxes of energetic particles dropped to levels seen in the interplanetary medium and the confirmation of a previously discovered phenomenon involving the temporal variation of the spectral index of relativistic electron spectra with a 10-hour synodic period. The drop in particle fluxes supports the proposal of the solar wind plasma team that Ulysses encountered field lines open to the solar wind at this time. On the outbound leg the instrument also found evidence for short duration bursts of relativistic electrons streaming away from the planet, giving further credence to the plasma sheet boundary layer interpretation of this region.

The Energetic Particle Composition (EPAC) experiment (Keppler *et al.*, p. 1553) also covered the energetic particle range $E \geq 1$ MeV. Their observations added to the store of information on the dusk-side high-latitude magnetosphere. Of particular note is the detection of field-aligned bursts of energetic protons traveling away from Jupiter. Whereas the HI-SCALE experiment reported field-aligned fluxes of unidentified ions streaming toward the planet, the EPAC instrument positively identified protons moving in the opposite direction. This would fit in with the picture that Jovian protons are accelerated out of the ionosphere in an active auroral region where field-aligned potential drops are likely to occur on field lines connected to the plasma sheet boundary layer as experience with Earth's auroral region has shown. The protons form a primary beam of ions that stream out, are scattered in pitch angle, and remain in the outer magnetosphere as a hot proton plasma population. Those protons that avoid being scattered are reflected back to the planet and can be identified as the field-aligned components of ions detected by the HI-SCALE experiment traveling toward Jupiter. Although some of the exact details still have to be verified (such as the HI-SCALE ion species identification), this scenario ties together a large body of diverse phenomena and explains the source of the hot ~10-keV protons and electrons that have been observed for quite some time now by spacecraft but have never really been explained in a convincing manner.

The Ulysses spacecraft also made measurements of plasma waves and radio emissions from the Jovian magnetosphere by means of the Unified Radio and Plasma Wave (URAP) experiment (Stone *et al.*, p. 1524). A wide variety of wave modes was detected in agreement with previous spacecraft observations. Some new findings included the detection at high magnetic latitudes of a very low-frequency hiss that resembled a wave emission seen at Earth on auroral field lines, the implication being that an electron beam was present stimulating the emission, and the observation of a narrowband kilometer radio emission from the Io plasma torus originating in five discrete source longitudes, giving evidence for the inhomogeneous structure of the torus. Another noteworthy result was the discovery of bursts of radio noise that are apparently associated with the short duration electron beams found by the COSPIN experiment. The emission characteristics suggest that energetic electrons may generate radio waves through a beam-plasma interaction as they travel to the outer magnetosphere from an acceleration region located close (a few R_J) to the planet.

The measurements described by Bird *et al.* (p. 1531) made use of the communications radio signal of the spacecraft to probe the properties of the Io torus. The technique allows the determination of the electron column density along the line of sight to Earth for two cuts, one behind and one in front of Jupiter, through the annular plasma structure. The surprising conclusion of their analysis is that the Io torus shows strong inhomogeneity as evidenced by the large differences between the two sectors with one denser and hotter than the other. Some longitudinal inhomogeneity in torus structure can be expected, but the large variations suggested by the authors' preliminary model calculations to reproduce the data are cause for concern. In any case, these observations are sure to stimulate further analysis leading to a refinement of the models.

The report by Grün *et al.* (p. 1550) presents measurements by the Ulysses dust detector of submicrometer- to micrometer-sized particles in the vicinity of Jupiter. The experiment recorded a total of nine dust impacts during the spacecraft's passage through the magnetosphere, confirming the fact that Jupiter is relatively dust-free compared to the other outer planets. An important factor contributing to this situation is Jupiter's intense charged particle environment which is very effective in removing any particulate matter that might escape from Io.

Finally, three papers dealing with complementary observations of the Jovian system made during the time of the Ulysses encounter are included. Spencer *et al.* (p. 1507) report on infrared observations of thermal emission from the satellite Io. The observational program has monitored a number of persistent hot spots which are known to be associated with active volcanoes. The data indicate that Io's dominant volcano Loki was quiescent as measured by its infrared brightness level for a 3-month period preceding the Ulysses encounter. The inference drawn from the study is that lower overall volcanic activity would lead to a smaller source rate of matter injected into the magnetosphere and subsequently ionized to produce the Io plasma torus. However, because matter does not ballistically escape from the volcano into the magnetosphere but is sputtered from Io's atmosphere or surface by magnetospheric ions impacting the satellite, a direct linear relationship between volcanic activity and magnetospheric phenomena is not expected although some soft dependence may be present.

The report by Caldwell *et al.* (p. 1512) presents new ultraviolet images of the Jovian north polar aurora obtained by the Hubble Space Telescope. The results are remarkable inasmuch as they differ from all previous reports on the morphology of the ultraviolet aurora. The principal finding is that the aurora is brightest on that part which astronomically is farthest west corresponding to dusk hours in the Jovian day. This result emphasizes a local time influence on the structure and excitation of the aurora whereas most previous studies have found that magnetic longitude is the controlling factor not only at ultraviolet but also infrared wavelengths. There is little doubt that this recent result from the Hubble Space Telescope will evoke much discussion and debate.

Mendillo *et al.* (p. 1510) present images of Jupiter's far-flung neutral sodium cloud which scatters solar light very efficiently and is easily observed. The cloud is formed through the chemistry of the Io plasma torus where ion recombination processes produce fast moving neutral sodium atoms at the corotation speed near Io's orbit (74 km s^{-1})

which greatly exceeds the escape velocity from Jupiter. Sodium is present only at the 1% trace level; however, it provides a compelling model for atomic processes that can be inferred to exist also for the dominant species oxygen and sulfur which, although more abundant by a factor of 100 than sodium, are not as readily detectable. Observations of the neutral sodium cloud thus give information on temporal changes in the Io torus as described by Mendillo *et al.* One of the more significant conclusions that can be drawn from the study is the source rate for ions that are created out of the magnetonebula (primarily by solar photoionization) and form a population of hot ions in the outer magnetosphere after acceleration to local corotation speed by the planet's magnetic field (*2*). This process is thought to be a principal source of the hot heavy ion (S^+ and O^+) plasma that the SWICS and HI-SCALE instruments on Ulysses were able to measure directly. In all it would seem that Ulysses was very successful in returning a valuable data set that illuminates the workings of Jupiter's magnetosphere in great detail.

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Exons as Microgenes?

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Most eukaryotic genes consist of coding sequences (exons) interrupted by noncoding sequences (introns). After transcription into RNA, the introns are removed by splicing to generate the mature messenger RNA that carries a continuous coding sequence. The splice points are marked by consensus sequences that act as signals for the splicing process. Although much is known about the role of these consensus sequences, there has been little speculation about their evolutionary origin (*1*). Some recent findings now encourage musing on these matters.

The enzyme phosphoenolpyruvate mutase is an unusual enzyme that is responsible for catalyzing the formation of the carbon-phosphorus bonds of phosphonate metabolites. The few organisms that are known to make phosphonates are spread across the evolutionary spectrum, and this biosynthetic activity is believed to be an ancient one (*2*). In the sequence of the messenger RNA for the mutase from the protozoan *Tetrahymena*, there are two in-frame amber codons (*3*). In most organisms, amber (TAG) is one of the three "stop" signals in the genetic code, but *Tetrahymena* reads amber (and ochre) codons as glutamine at these loci (*4*).

In the mutase gene (sequenced from the genome of *Tetrahymena*) there are three introns, two of which start precisely after the amber codons (TAG) and one that begins after a lysine codon (AAG). Moreover, two of the introns also terminate with amber. The base sequences around the three pairs of junctions are

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  exon          intron          exon
--ACTTAGgtactt......aaatagGTTTTG--
--TTCTAGgtaagc......caatagGTCGTC--
--ATGAAGgtaaag......ataaagGAATGG--
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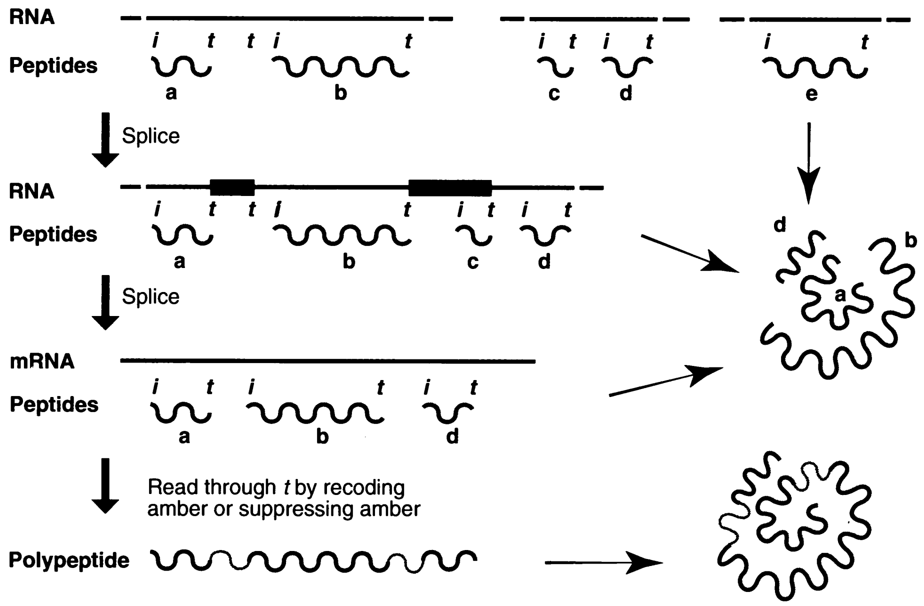
In all, 12 of the 17 known *Tetrahymena* introns end with TAG, 4 with AAG, and 1 with CAG. These junctions all conform to the global consensus sequences for exon-intron junctions (of ..AG|gta..) and intron-exon junctions of (..ag|G..) found in all eukaryotes (*5*). These consensus splice-junction sequences do not occur in the non–protein-encoding ribosomal RNA and transfer RNA genes, which have quite different splicing mechanisms.

What is the origin of the splice-site consensus sequences in protein-encoding genes? The trivial explanation is that the sequence consensus is simply a historical accident and carries no information about its evolutionary origin. Given the existence of ancient RNA splicing mechanisms, however, the evolution of a splicing consensus sequence peculiar to protein-encoding genes seems unlikely to have been accidental and more likely reflects an early functional role of these sequences.

The location of the introns in the *Tetrahymena* mutase gene both explains the origin of the 3′-termini of eukaryotic exons and introns and suggests the possibility that exons were once "microgenes," originally terminating with amber and encoding relatively short oligopeptides that assembled spontaneously into active protein. The argument runs as follows: from various segments of primordial RNA, initiation of protein synthesis (at *i*) and termination (at *t*) would produce a library of oligopeptides (**a**, **b**, **c**, and so forth), some combinations of which would spontaneously combine to form multichain protein assemblies having catalytic activity (see figure). Such assemblies, in which protein fragments come together to generate a catalytically active unit, are well known (*6*). Splicing of these microgenes by using their common amber termini (*t*) as a recognition element for splicing (*7*) could then bring the appropriate microgenes closer together, thereby improving the chances for the linked inheritance of all the fragments that contribute to a particular catalytic activity. This notion is



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