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POSSIBLE RADIO EMISSION FROM URANUS AT 0.5 MHz

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ABSTRACT

Radio emission from the direction of Uranus has been detected in data from the Goddard radio astronomy experiment on the IMP-6 spacecraft. Previously, emission from the direction of Jupiter and Saturn had been observed by the IMP-6 at a number of frequencies near 1 MHz during the period April 1971 to October 1972. These radio bursts were identified in the IMP-6 data through an analysis of the phase of the observed modulated signal detected from the spinning dipole antenna. This technique was applied to the direction of the planet Uranus with possible positive results. Over the approximately 500 days of data, three to six bursts with unique spectral characteristics have been found. Identification with Uranus is confused by the likely presence of low-level terrestrial and solar emission. The observed events persisted less than three minutes and are strongest in intensity near 0.5 MHz.

Subject headings: Uranus -- radio radiation, planetary

The detection of low-frequency radio emission from the planets Jupiter and Saturn has been reported in recent papers (Brown, 1974a, 1974b, and 1975; hereafter Papers I, II, and III). These sources of emission were identified from data obtained with the Goddard Space Flight Center radio astronomy experiment aboard the Interplanetary Monitoring Platform-6 (IMP-6) spacecraft. The IMP-6 was spin-stabilized about an axis perpendicular to the ecliptic plane with a 100-m dipole antenna situated in the spin plane. The phase of the modulated signal which results from the passage of the gain pattern of the dipole across a radio source is used to determine the direction of the source. Since an analysis of these directions was successful in the detection of Jovian radiation (Paper I) and apparently of the first observed low-frequency radiation from Saturn (Paper III), the technique was eagerly applied to the next logical candidate -- Uranus.

Since the data from the IMP-6 receivers showed the effects of spin modulation at all times, the resulting phase could be converted to an emission direction for all the IMP-6 data. This determination was done for the period April 1971 through October 1972 (orbits 10-136) by a cross-correlation of the observed data with the dipole antenna pattern. For each frequency the directions were sorted to find all the data within $\pm 4^{\circ}$ (probable maximum resolution limitation due to low-level sources) of the ecliptic longitude of Uranus, and then sorted to accept only that part of the data which had at least three contiguous IMP-6 frequency channels showing the direction of radiation to be toward Uranus. Those orbits in which the Uranus-spacecraft direction was within 20° of the Sun-spacecraft direction were eliminated from the analysis. The initial data reduction isolated a large number of events which fitted the above criteria.

The IMP-6 spacecraft was in a highly elliptical orbit (e ~0.94) with the apogee (as seen from Earth) at an ecliptic longitude (ℓ_e) of approximately 10°, which placed the Earth nearly between the IMP-6 spacecraft and Uranus ($\ell_e = 192^{\circ}$ to 196°) so that the line of sight passes through the Earth's magnetosphere for most of an orbit. This resulted in the detection of a large number of events associated with terrestrial radio emission. The terrestrial radiation consists of two components with different spectral characteristics. The first source (designated MF in Brown, 1973) has a low- and high-frequency cutoff; and generally, the peak intensity is in the 150-350 kHz range. Analysis of the direction of arrival has shown that this kilometric radiation probably originates at geocentric distances less than $3R_{\oplus}$ for the higher frequencies (Gurnett, 1974; Kaiser and Stone, 1975). As a result the detection criteria for Uranus were extended to exclude directions which were also within $4R_{\oplus}$ of the Earth-spacecraft direction. The second source (designated LF in Brown, 1973) has a power-law spectrum between the lowest IMP-6 observing frequency of 30 kHz and approximately 300 kHz. Due to this intense continuous low-frequency terrestrial emission at distances greater than $4R_{\oplus}$, observing frequencies below 185 kHz were also excluded. This resulted in a 1000:1 reduction in the number of events which satisfied the detection criteria. All those events eliminated had the spectral characteristics of either the LF or MF kilometric terrestrial source. To further reduce the incidence of false detection, events with intensities greater than twenty times the Galactic radiation were excluded. This deletion eliminated only the occasional data point occurring at the beginning or end of large terrestrial or solar events which altered the phase enough so that the weighed cross-correlation indicated an erroneous direction toward Uranus. Although this level is arbitrary, the probability of emission from Uranus exceeding this value is low since the large distance to the planet would require an emission source ten times stronger than that for Jupiter, Saturn, or Earth. All those events eliminated consisted only of a single data point. Since the direction of the region of maximum emission of the Galactic radiation is also in the general direction of Uranus (Brown, 1973), only those intensities which exceed the maximum Galactic intensity by three times the signal to noise ratio were accepted.

Even before all the detection criteria were applied to the data it was evident that a small set of events existed with spectral characteristics different from the previous sources identified in the IMP-6 data. The complete application of the detection criteria reinforced this uniqueness. The set consisted of six independent events occurring during times when the apparent competing source was probably the low-level and slightly spin-modulated Galactic radiation. The peak intensity for each event occurs at 475 kHz with a rapid decrease in intensity at adjacent frequency channels to levels below the detection limit of the receiving system. The frequency range extends over 4 IMP-6 frequency channels from 375 to 600 kHz. The observed events were found to last less than three minutes (3x the basic beat period between the spacecraft spin period and the data rate, Paper I). All the events were detected as the spacecraft was receding from the Earth at distances between 15 and 25 $R_{\oplus}$. In this segment of the IMP-6 orbit the Earth-Uranus angular separation was the greatest, and the spacecraft-Uranus line of sight traversed little of the Earth's magnetosphere. The non-detection of any similar events during other portions of the orbit supports the uniqueness of this set of events and their identification with Uranus.

A test of the uniqueness of the spectral behavior of these events was made by applying the detection techniques to other sources. Since the search for emission from Jupiter and Saturn was successful, the data was reexamined for events with spectral characteristics similar to those attributed to Uranus. There was no evidence that similiar events existed whose intensities were greater than three times the signal to noise ratio. Again only the spectral characteristics found in the data other than the LF and MF terrestrial noise, were that of Saturn whose intensity peaks near 1100 kHz and Jupiter which possibly has two sources whose intensities peak near 900 and 8000 kHz. As in the Jupiter and Saturn searches, the planet Mars was used as a control source. When the detection techniques were applied to the IMP-6 data for the direction of Mars the only emission found was that from the LF and MF terrestrial sources. No evidence of any events with unique spectral characteristics were found with the complete application of the detection criteria for Uranus.

Figure 1 displays one of the possible events at an observing frequency of 475 kHz for $3^{h}.2$ U.T. May 3, 1971. The top panel shows the actual observed antenna temperature with its basic modulated pattern. The bottom panel is a plot of the directions relative to the solar direction indicated by the phase analysis of this data. At the beginning there appears to be very weak solar activity as the intensity is slightly higher than the normal Galactic background and the indicated direction deviates from the area of the Galactic maximum toward the Sun. At $3^{h}\ 13^{m}$ U.T. where the first obvious intensity increase occurs, the phase locks on to the direction of Uranus. This is enhanced further as the intensity reaches its maximum one minute later.

One of the difficulties of this method of detection is that two sources may combine in such a manner as to produce an erroneous direction. The observed phase of the modulated signal will then give a direction that is an intensity-weighted mean of the sources. Such a problem could readily happen in the preceeding case if radiation was being observed both from the Sun and the Earth.

However, calculations show that the observed intensity is probably too high for either the Earth or the Sun to have produced the indicated direction. Under the possible error conditions of the cross-correlation technique the direction could be no closer than 4^o to the direction of Uranus for this event assuming only radiation from the Sun, Earth and Galactic background. Similar results were obtained for two of the other events, lending support for the detection of emission from Uranus. Even with this optimism, the fact that all six possible events occurred under conditions where low-level solar and terrestrial radiation could combine to produce an erroneous direction toward Uranus may possibly argue against the detection.

The most favorable time for observing is near opposition when the Earth-Uranus distance is at a minimum. During the 500 days of observation, one pre- and two post-opposition periods occurred. Five of the six possible events (as well as the three strongest possibilities discussed above) were detected during the first post-opposition period (after April 1, 1971) with the other event occurring during the second post-opposition period (after April 6, 1972). All six events were found within 70 days of opposition. The lack of events found during pre-opposition (before April 6, 1972) could have resulted from the orientation of the IMP-6 orbit in that the Uranus-spacecraft direction traverses a large portion of the Earth's magnetospheric tail. The smaller occurrence probability for the second post-opposition period is surprising since the spacecraft had a more unobstructed view as the angular separation of Earth and Uranus had increased by 4^{o}. However, as in the case of Jovian radiation this could be a geometric (beaming) effect caused by a change in orientation of the magnetic field of Uranus as viewed from Earth. The rotational pole of Uranus lies very nearly in the ecliptic plane so that one might assume that the dipole might also lie at a small angle to the ecliptic (although there is no a priori reason to assume magnetic poles are nearly parallel to rotational poles). The line of sight for the 1972 opposition should then be about 4^{o} closer to this polar area (latitude changes from $\sim 24^{o}$ to $\sim 28^{o}$). Similar effects might occur from the existence of higher-order magnetic poles.

The spectral characteristics of the May 3 event appear in Figure 2. The uncertainty in the data results from the errors in calibrating the IMP-6 radio astronomy experiment and from separating the Uranus emission from the background radiation. The total error ranges from 56% at 475 kHz to over 100% for the remaining frequencies (approximately 4x the total error for the galactic spectrum given in Brown, 1973 for 475 MHz and 8x for the remaining frequencies). Apparently the emission is not observed at 292 and 737 kHz because the emission levels fall below the detection limit of the receiving system.

The spectral behavior seems similar to Jupiter and Saturn with the exception of a smaller bandwidth. This bandwidth difference could be due to a smaller emission region and/or a different viewing geometry since the rotational pole of Uranus lies in the ecliptic plane. The peak flux density (0.5 MHz) is nearly equal to that found for Jupiter (8 MHz, Paper II) and Saturn (1 MHz, Paper III) when the distance from Earth of the planets is considered. The difference in the frequency of the emission peak might be related to the difference in magnetic field strengths. If linear scaling is appropriate as it would be for cyclotron emission, this would suggest that the dipole moment of Uranus is lower than Saturn's by a factor of 2 and lower than Jupiter's by a factor of 16. Extrapolating from the Jovian polar field intensities of 10-14 Gauss as measured by Pioneer 11 (Acuña and Ness, 1975; Smith et. al., 1975) yields values of 1-2 Gauss for the Saturnian field and 0.6 - 0.9 Gauss for the polar field intensity of the magnetic field of Uranus.

In summary, three to six individual emission events have been observed which apparently originate from the direction of Uranus. Positive identification is confused by the likely presence of terrestrial and solar emission, although the uniqueness of the set of events indicates the possibility of detection of radiation from Uranus.

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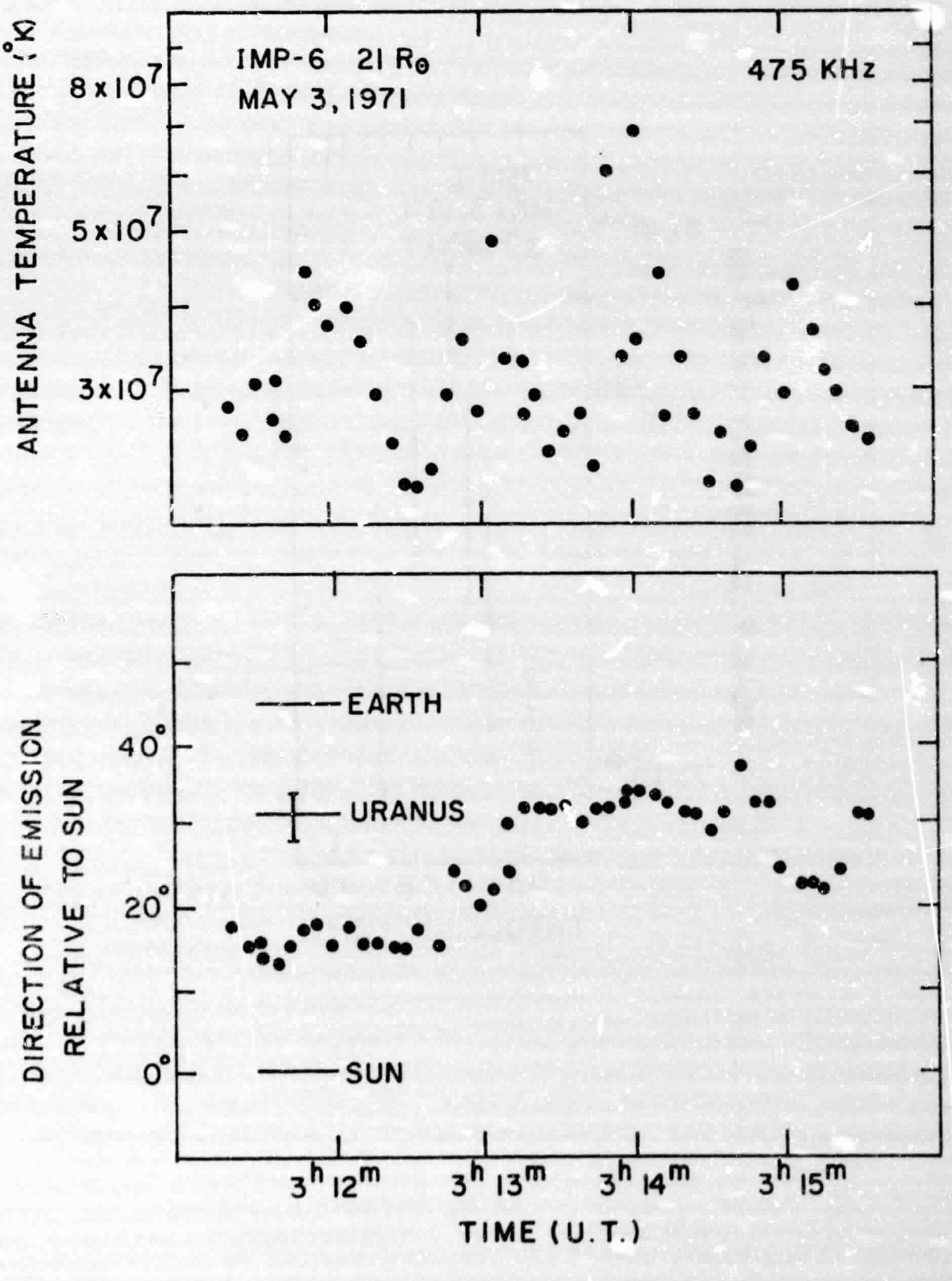
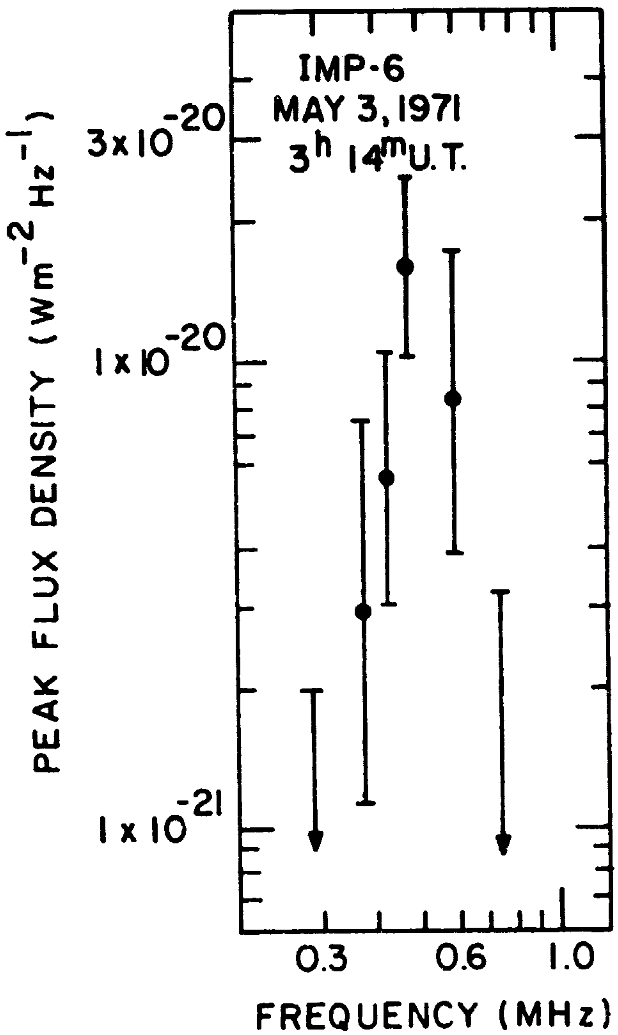
FIGURE CAPTIONS

Figure 1 ______(top) Observed antenna temperature during the period of possible emission from Uranus on May 3, 1971 at $3^{h}.2$ U.T. The observing frequency was 475 kHz with the IMP-6 at a distance of 21 Earth radii.

______(bottom) Direction of emission in degrees relative to the solar direction determined from the phase of the modulated signal in the top panel.

Figure 2 ______Spectrum of the emission from Uranus for the period May 3, 1971 at $3^{h}.2$ U.T. for an Earth-Uranus distance of 17.5 A.U.


ANTENNA TEMPERATURE (°K)
IMP-6 21 R⊙
MAY 3, 1971
475 KHz
8x10^7
5x10^7
3x10^7
DIRECTION OF EMISSION RELATIVE TO SUN
EARTH
URANUS
SUN
40°
20°
0°
3h 12m
3h 13m
3h 14m
3h 15m
TIME (U.T.)


IMP-6
MAY 3, 1971
3h 14m U.T.
PEAK FLUX DENSITY (Wm-2 Hz-1)
3 x 10-20
1 x 10-20
1 x 10-21
0.3
0.6
1.0
FREQUENCY (MHz)