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FINAL REPORT:

ANALYSIS OF URANIAN RADIO EMISSIONS,

Uranus Data Analysis Program (UDAP) Grant No. NAGW-1206

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SUMMARY

Progress under this grant has included identifying certain new radio emission components and determining the source location of both these and the two major Uranian radio emission (the SHF and b-bursty components) by a unique new statistical minimization technique. This new source location technique has subsequently also been applied at Neptune, with considerable success. New radio spectrograms have been prepared to clarify the behavior of such emissions, using both the usual 48-second, log-averaged data and the original 6-second PRA data, the latter showing a number of interesting new features. Also, a plasmasphere was discovered at Uranus, auroral plasma cavities were discovered at both Uranus and Neptune, and it was found that the currently-accepted rotation period for Uranus is in error by a small amount.

HIGHLIGHTS

- o Spectrograms prepared with signal strengths corrected for distance.
- o Superimposed-epoch spectrograms revealed b-bursty signal pattern.
- o Source locations determined for both SHF and b-bursty emissions.
- o New arc-shaped features identified in the SHF emission component.
- o Analysis of the 6-second PRA data to improve spectrogram quality.
- o Discovery of regular spacings within the B-bursty emission pattern.
- o Discovery of a plasmasphere at Uranus, within approximately L = 3.
- o New determination of planetary rotation rate (17.40 ± 0.06 hr).
- o Discovery of auroral plasma cavities at both Uranus and Neptune.
- o Miscellaneous other related studies (see Publications).

INTRODUCTION

During the Voyager-2 encounter with Uranus, at least six new non-thermal radio components were detected using the Planetary Radio Astronomy (PRA) experiment. The two most prominent of these, the smooth high frequency (SHF) component and the broadband bursty (BB) emissions, had polarization and power fluxes comparable to Earth's auroral kilometric radiation and Saturn's kilometric emissions and they are believed to be the Uranian counterpart of such emissions. In addition to these two electron-cyclotron emissions, a unique O-mode signal, smooth low-frequency emissions, and both hectometric and kilometric arcs have been observed. Clearly, all of these different components will be of interest to radio science for years to come, and the purpose of this project was to clarify the nature of such emissions.

SUMMARY OF PROGRESS

It was originally proposed to study only the occurrence and modulation patterns of the different Uranian radio emissions in order to determine the source location and generation mechanisms. However, having completed much of that work relatively early in the project, additional related studies were also undertaken. Our principal results and progress were as follows:

(a) In order to emphasize certain occurrence and modulation patterns, special spectrograms were created to accentuate specific features. These have included both color spectrograms and new black-and-white presentations (e.g. Plates 1 and 2 of Farrell and Calvert [1989a] and figures 1 and 3 of Farrell and Calvert, [1989b]). In particular, Plate 2 of Farrell and Calvert [1989a] is a special spectrogram in which we have added together, in what we call the "superposed epoch" form, relative intensities from six consecutive planetary rotations after encounter in order to obtain the average emission pattern of the b-bursty component.

(b) A set of support software was developed to interpret and simulate the observed emission patterns. This software includes a three-dimensional emission-cone simulator based on the OTD magnetic model. The emission cone in this simulator can be placed anywhere around the planet, pointing in arbitrary directions, and it can then be extended out to large distances in order to determine where it intercepts Voyager. Based on this program, a second one was then written to find the best-fitting, symmetric emission cone consistent with a given set of observed emission features, to minimize the statistical deviations of the apparent cone angles for all possible source positions near the planet.

(c) This technique was applied first to the broadband bursty emissions detected during and after closest approach. It was found that these emission tended to extend to the highest frequencies twice during each planetary rotation, before and after an apparent emission gap. In order to verify this, the composite, superposed-epoch spectrogram for six consecutive rotations was created to more clearly show its emission pattern, and this revealed the suspected emission gap, which is attributed to Voyager completely exiting the b-bursty emission cone, at the center of a symmetrical pattern which is attributed to Voyager intercepting a thin conical beam from the source. Using the nine high-frequency events which could be found in the data, the source location was determined by our minimization technique and found to occur near the south magnetic pole at 48° S, 234° W, on an L-shell of 64 and in excellent agreement with others studies.

(d) Using this same minimization technique, the source location of the smooth high frequency (SHF) component was also determined. In this case, the pertinent emission feature was the beginnings and endings of the SHF emission dropouts at 616 kHz. In this case, ten events were available, counting both the beginnings and endings of the five available dropouts, and we thus determined the source location indirectly, from the best-fitting hollow-cone portion of the emission pattern. Having a source footprint on the surface at 57°S, 222°W and a dipole L-value of 10.9, the resulting source location was almost identical to that of most other investigators.

(e) In the SHF emissions at intermediate frequencies (250 to 450 kHz) a new kind of kilometric arc, centered near 300 kHz with a bandwidth of roughly 200 kHz, was found in about half of the SHF occurrences. These arcs are quite distinct from the hectometric arcs previously discussed by others. Again using the same minimization technique, the source location of these arcs was determined to lie approximately at the equatorial edge of that previously determined from SHF dropouts. The radiation was also found to be beamed only toward the equator.

(f) The above studies were carried out using the 48-second, log averaged data of M. L. Kaiser at GSFC. However, this was considered inadequate for a number of reasons, including the fact that the log-averaging severely de-emphasizes bursty signals. The original, high-resolution 6-second, PRA data from Radiophysics Inc. were therefore analyzed, using a special non-random dithering algorithm and interactive cleaning, in order to produce spectrograms of exceptional quality, and these spectrograms have revealed a number of interesting new features.

(g) It was found from the b-bursty emissions that the rotation period of Uranus is slightly longer than that previously measured, it being 17.40 ± 0.06 hours rather than 17.24 ± 0.01 hours. This error is attributed to the original investigators not distinguishing different radio components having different temporal characteristics.

(h) A uranian plasmasphere was discovered at approximately L = 3 which casts a detectable shadow in the radio emissions observed shortly after closest approach. This is particularly significant, since theory predicts that no plasmasphere should occur at this planet.

(i) Sloping striations occur on the smooth emissions of Uranus which may indicate a non-circular limit polarization, but funds ran out before this could be verified.

(j) The data set for Neptune were also cleaned and processed, using the same procedure. Since initially none of the other investigators were able to produce usable amplitude spectrograms, we thought this might be of some use to the entire PRA team. However, it was later found that NASA had subsequently funded others to perform this task, essentially copying our technique and duplicating our efforts without giving us credit, so work on this was terminated and the excellent spectrograms already produced have been discarded.

(k) Using the previous observations at Uranus and similar recent observations at Neptune of the double, thin, conical emission patterns of the bursty emissions, plus a new relativistic cyclotron emission theory, it was found that both planets exhibit an auroral plasma cavity like that which exists at the Earth and controls the AKR emission spectrum, with a plasma-to-cyclotron frequency ratio perhaps as low as 0.02. This indicates local plasma densities as low as 0.01 to 0.05 cm^{-3} at the source, and constitutes one of the first remote determinations of source plasma density at the outer planets.

A great deal was therefore accomplished under this project, including also other investigations of radio lasing at the outer planets and studies of other wave emissions at the earth, and it is indeed a pity that this kind of innovative research cannot be continued at Neptune.

PUBLICATIONS

The following publications were supported all or in part under this grant:

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M. G. Aubier, W. Calvert, and F. Genova, Source location of Jupiter's Io-dependent radio emissions, *Planetary Radio Emissions II*, H. O. Rucker, S. J. Bauer, and B. M. Petersen, eds., Verlag der Osterreichischen Akademie der Wissenschaften (Graz, Austria), 113-126, 1988.

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