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PROGRESS REPORT

# Analysis of Jovian Decametric Data: Study of Radio Emission Mechanisms

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### I. Introduction

The Voyager 1 and Voyager 2 Planetary Radio Astronomy Experiments (PRA) have produced the finest set of Jovian decametric radio emission data ever obtained; it is unique in its time and frequency coverage, polarization information, and geometric characteristics. The data can be broadly characterized in simple ways, but the more subtle systematic complexities have scarcely been explored.[1-5]

These data are sufficiently extensive and varied that the radio emission mechanism is strongly constrained, and perhaps is even so constrained that, with reasonable assurance, it could finally be deduced uniquely; information available from the various Voyager particles, waves, and ultraviolet investigations will also be very important. Such a successful interpretation would not only provide the key to further interpretation of Voyager data, but could enhance the value of previous and future decades of earth-based radio observations, and perhaps the value of Saturnian, terrestrial, and even pulsar radio burst observations (to the extent that they prove to be similar).

Work at MIT began in September, 1982 under this grant (NAGW-373), and was initially focused on the cataloging and characterization of Jovian decametric L-burst and S-burst "arcs," and the initial reconciliation of these data with models for the radio emission geometry and mechanisms. The first major results involve comparison of the distribution of arc separations with longitudes; in general the arcs are too close together and do not have the proper longitudinal variations[6] to be consistent with conical emission from simple current-carrying Alfvén waves reflected between the northern and southern Jovian ionospheres. Independent theoretical considerations also suggest that the simple Alfvén wave model requires modification, and that the nature of this elaboration could help reconcile theory and experiment. In addition the distribution of certain arc properties such as occurrence probability, width, and curvature have also been studied, but their systematic variations still remain unexplained. Some S-burst statistics have also been examined with interesting results. This work is discussed further here in Section II.

The identification and analysis of systematic variations in the PRA data have yielded very interesting results, but only the most obvious features of the data, such as arc separations, vertex frequencies, occurrences, etc. have been examined; the raw data we have used are crude computer intensity plots of the Jovian emission spectrum with 48-sec resolution. These data have three serious deficiencies -- they are available with only one choice of 1) quantization levels (meaning some features are too faint or too saturated to be seen), 2) noise-suppression filters (bad channels, bad bursts, variable gains, etc. can degrade an image) and 3) integration time (48-sec); this obscures most of the S-burst information and some additional wavelike behavior that is occasionally seen for 6-sec integration, but which requires better display formats.

Therefore the continuation of this effort not only extended these analyses of the PRA Jovian decametric emission, but also used new 6-sec formats that are much more sensitive to S-burst and other short-term phenomena perhaps associated with instabilities which may be anticipated in the Io-Jupiter current system (as discussed further in Section III).

## II. Studies of 48-Second PRA Jovian Spectral Data

Work began in September 1982 under this grant (NAGW-373); a small amount of additional support was also received from the NASA/Goddard Space Flight Center, particularly for catalogue preparation. Three catalogues have been prepared for decametric arcs observed by the PRA experiments on the Voyager 1 and 2 spacecraft. These three catalogues respectively contain descriptions of 1) decametric arcs (∿ 200), 2) gaps between decametric arcs (∿ 200), and 3) arcs below ∿ 1.2 MHz (∿ 60). In addition a catalogue of gaps between decametric S-burst "arcs" was provided by Dr. Y. Leblanc of Meudon as part of a joint effort to understand their nature too. From analyses of these data several very interesting conclusions were reached, as summarized briefly below.

1) Plots of the arc vertex frequency versus Jovian $\lambda_{III}$ longitude (Fig. 1) reinforce the picture of Staelin[5] based on preliminary data, namely that the vertex frequency is approximately a simple function of surface magnetic field strength for the flux tube which contains the radiating particles, and that the resulting emission-directionality pattern is a hollow cone with a half-angle of ∿ 65° when projected on the Jovian equator. The same relation between field strength and vertex frequency is somewhat less successful for the left-circularly polarized (LCP) arcs presumed to originate from the southern hemisphere (Fig. 2); in particular there is one small set of LCP arcs which occur in the vertex-frequency-$\lambda_{III}$ plane exactly where right-circularly polarized (RCP) arcs would be expected (∿ 19 MHz), suggesting some northern hemispheric arcs may be LCP.

2) The curvature of arcs C [$C \triangleq (f_{max} - f_{vertex})^2 / |t_{max} - t_{vertex}|$, where $f_{max}$, $t_{max}$ are the maximum frequency and time for an arc] is a strong function of the Jovian CML of the associated current; i.e. magnetospheric currents between CML ∿ 130° and ∿ 230° exhibit values of C up to ∿ 10 times greater than for other longitudes. No inferences have yet been drawn from this result.

VERTEX FREQUENCY OF RCP ARCS (NORTH)

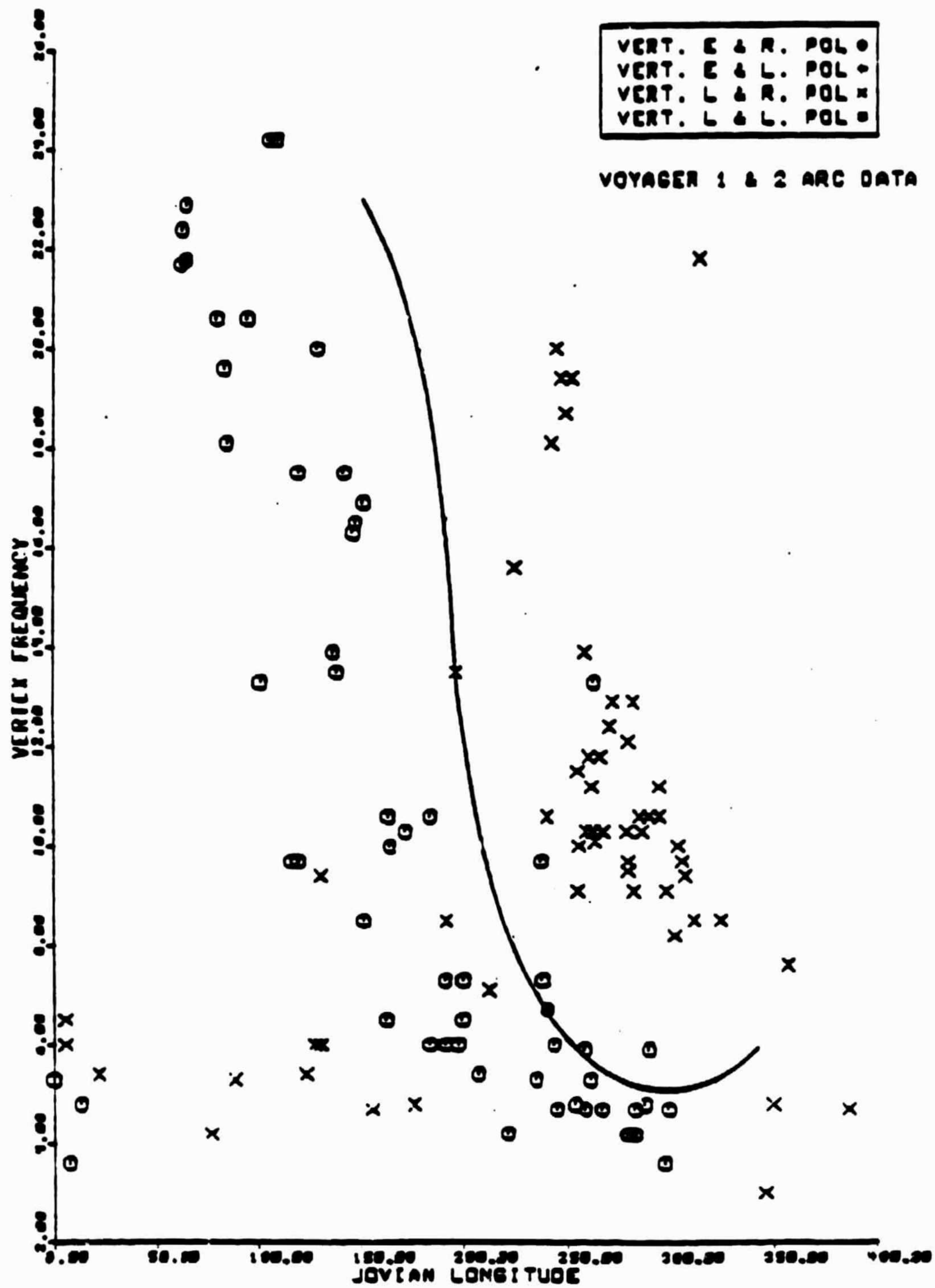


FIGURE 1

The o's and x's correspond respectively to vertex-early and vertex-late right-circularly polarized arcs. The ordinate of the solid line is proportional to the square of the magnetic field strength at the northern foot of the Io-torus flux tubes; the line suggests the vertex frequency of arcs generated by currents at any given longitude (from Garnavich[10]).

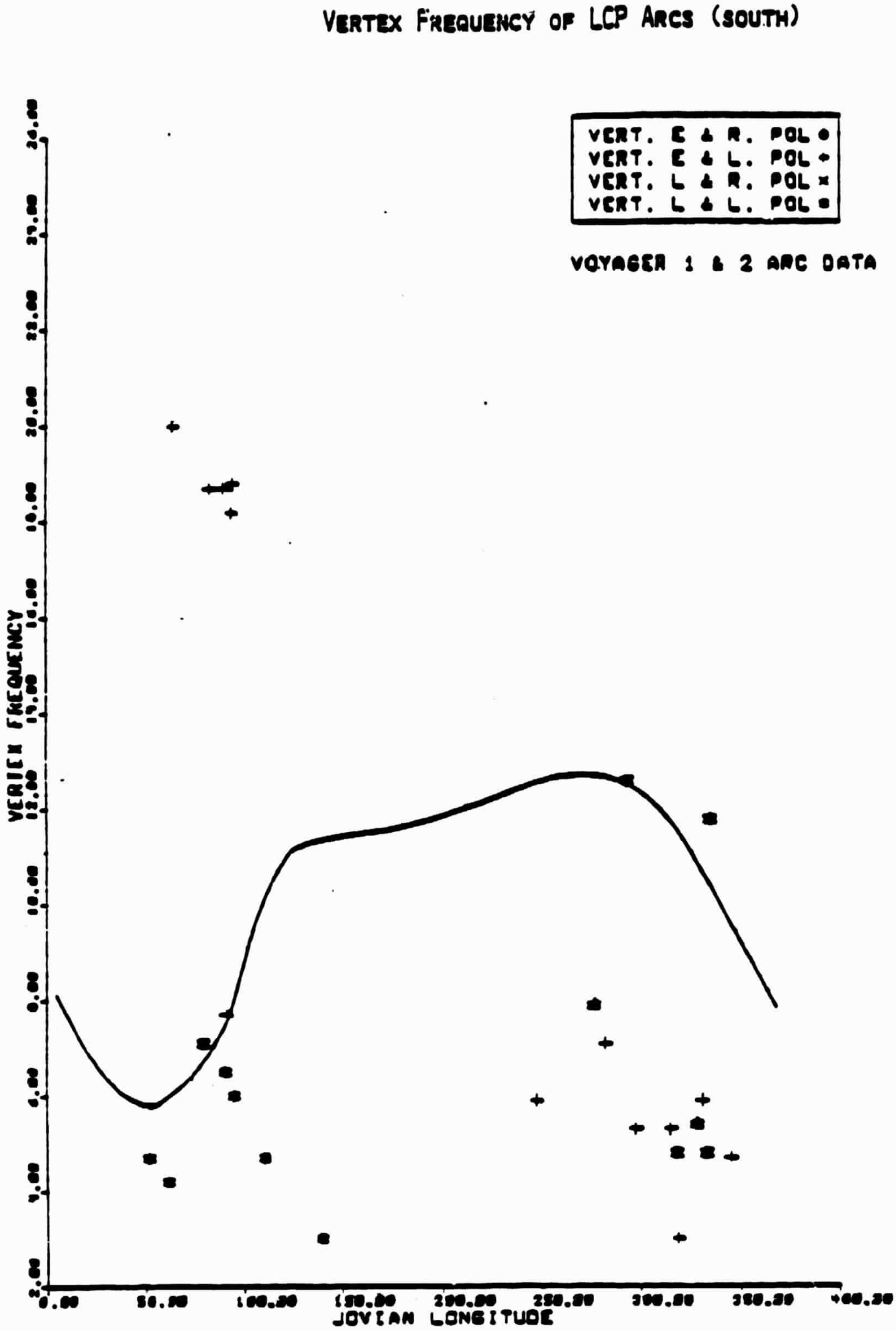


FIGURE 2

The +'s and *'s correspond respectively to vertex-early and vertex-late left-circularly polarized arcs. The ordinate of the solid line is proportional to the square of the magnetic field strength at the southern foot of the Io-torus flux tubes (from Garnavich[10]).

3) The number of arcs observed is nearly independent of the time since Io crossed the longitude of the radiating current; i.e. for up to 360° of revolution there is no noticeable weakening of arc production as a function of the number of Alfvén-wave reflections, which is consistent with the suggestion of Gurnett and Goertz.[7]

4) It was discovered that there is a narrow band of Jovian longitudes (∿ 80-120° CML) where L-burst arc-producing currents almost never flow, and that it is in this band (∿ 80-100° CML) that Io is located when S-burst arcs are seen. There is nothing singular in the 04 model field distributions at this longitude, and thus there are at present no hypotheses for this phenomenon.

5) Most important is the observation that the observed separations between arcs ("gap width") are generally too small (∿ 2-15 min) to be consistent with the Alfvén-wave period (∿ 22-27 min) predicted on the basis of the 04 Jovian magnetic field model and the known plasma density in the Io torus (for example, as observed by the Voyager 1 PRA experiment). Furthermore, as noted by Bagenal,[6] the gap between arcs should increase or decrease for portions of the Io wake pattern well removed from Io. Our calculations, based on the 04 model and classic Alfvén wave propagation, are represented here in Fig. 3 where theory shows a marked increase in expected gap widths whereas the observations show no dependence at all. The gap widths observed for S-burst arcs are similar to those for L-bursts, and thus reinforce the serious discrepancy between the predicted and observed gap widths.

6) On the basis of various data cited in (5) above, it first appeared that if the Jovian decametric arcs were to be associated with currents flowing in multiply-

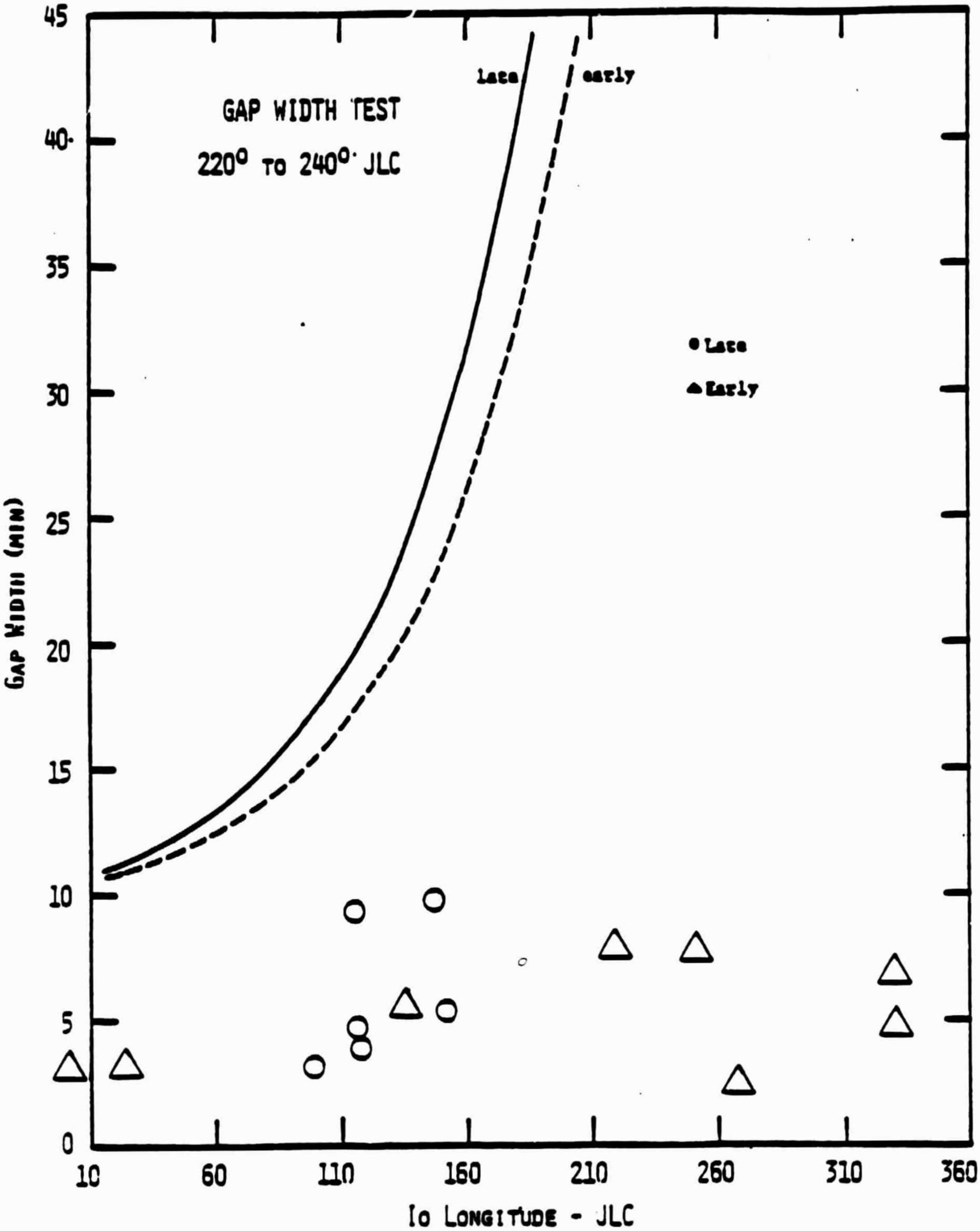


FIGURE 3

Gap (minutes of time) between adjacent arcs as a function of time (degrees longitude) since Io passage at the longitude of the presumed radiating current (JLC), where only currents at 220° to 240° longitude are considered. The solid and dashed lines represent theoretical gap widths calculated by Garnavich[10] following Bagenal.[6]

reflected Alfvén waves, as proposed by Gurnett and Goertz,[7] then the classic Alfvén wave velocity cannot be used; a velocity a few times greater must be assumed.

7) A study of decametric burst emission times, where the longitude of the radiating current is assumed to be uniquely related to the vertex frequency as proposed by Staelin[5] and Garnavich[10] suggests that the cone angle of the emission can have values ranging most typically from ∿ 40° to ∿ 90°; in this case the unexpectedly high rate of arc occurrence could be due to this effect and to single Alfvén waves producing multiple arcs.

In addition to the work on L-bursts some effort was devoted to S-burst data (in collaboration with Y. Leblanc of Meudon) and models. These models are based on the fact that the peculiar properties of Jovian decametric V-bursts can be nicely explained by ballistic electron bunching induced by longitudinal energy modulation in the region of beam acceleration; beam densities, energies, and coherences can be estimated from these data (Staelin and Rosenkranz).[8]

## III. Study of 6-second PRA Jovian Spectral Data

The primary observing mode of the PRA experiment was "POLLO" for which the full spectrum (∿ 1 kHz to ∿ 40 MHz) was scanned at 6-second intervals. The data we initially examined consist of computer-generated intensity plots of 48-second average spectra. This time resolution is sufficient to define wider arcs but not to resolve much structure within single arcs or to resolve S-bursts or other fast phenomena. The group at Goddard Space Flight Center (J. Alexander)[9] subsequently printed much of the POLLO data with 6-second resolution on a computer graphic device with limited gray-level resolution. This was a major undertaking because of the large amount of paper involved, and is therefore not likely to be repeated.

There are definite suggestions in these data of one or more phenomena with short time constants and/or periodic fine structure in the frequency domain. Unfortunately such tentative phenomena are difficult to detect in these printouts because often the signals either fade below the minimum intensity level displayed, or saturate the scale. Setting the scale was difficult because different frequency channels have different baselines, gains, and interference levels; the choice made in the computer printouts was necessarily a compromise and therefore a large part of all such events was probably missed.

We have begun to read the appropriate PRA data tapes; we have 6250 BPI tapes for most of the Voyager 1 and 2 data within a few months of encounter. These tapes are being copied to 1600 BPI so that they can be read by our group's Data General Nova-4 computer. These data can then be displayed with our high-quality video monitor which is capable of displaying up to 256 × 240 4-bit pixel images at full video rates; this image can be fully changed several times per second so that display of large amounts of data is feasible. Visual detectability of features is improved by real-time bilinear interpolation circuits to 512 × 480 resolution.

With such a high quality flexible display facility we were able to extract much more information from the PRA data.

We have 1) completed conversion programs which enable the 6250 BPI POLLO data to be displayed on the Nova-4 video monitor, 2) developed a set of filtering algorithms that normalize the baselines and gains of the various channels while still rejecting most interference; these algorithms are adjustable depending on the character of the data and the phenomena sought, 3) displayed in various ways Voyager 1 and 2 POLLO data near encounter in an effort to identify interesting new phenomena and S-burst activity. At this stage there is no need to sequence the data into long consecutive segments, and therefore the data are simply displayed (if near encounter) in the random order they were (unfortunately) archived. This is a major simplification, and 4) just begun interpretation of these new data in light of previous results and new theoretical considerations.

Figure 4 presents two samples of 6-second data which clearly exhibit the most prevalent of these new phenomena -- parallel striations which drift back and forth in frequency on a time scale of seconds while maintaining the differences in frequency among themselves. Although this Modulated Striation Activity (MSA) resembles other known modulations of Jovian decametric emission, it clearly is different due to its very low frequency and its lack of a systematic direction of frequency drift.

Portions of these results were reported to NASA in July 1983 in an unsolicited proposal.

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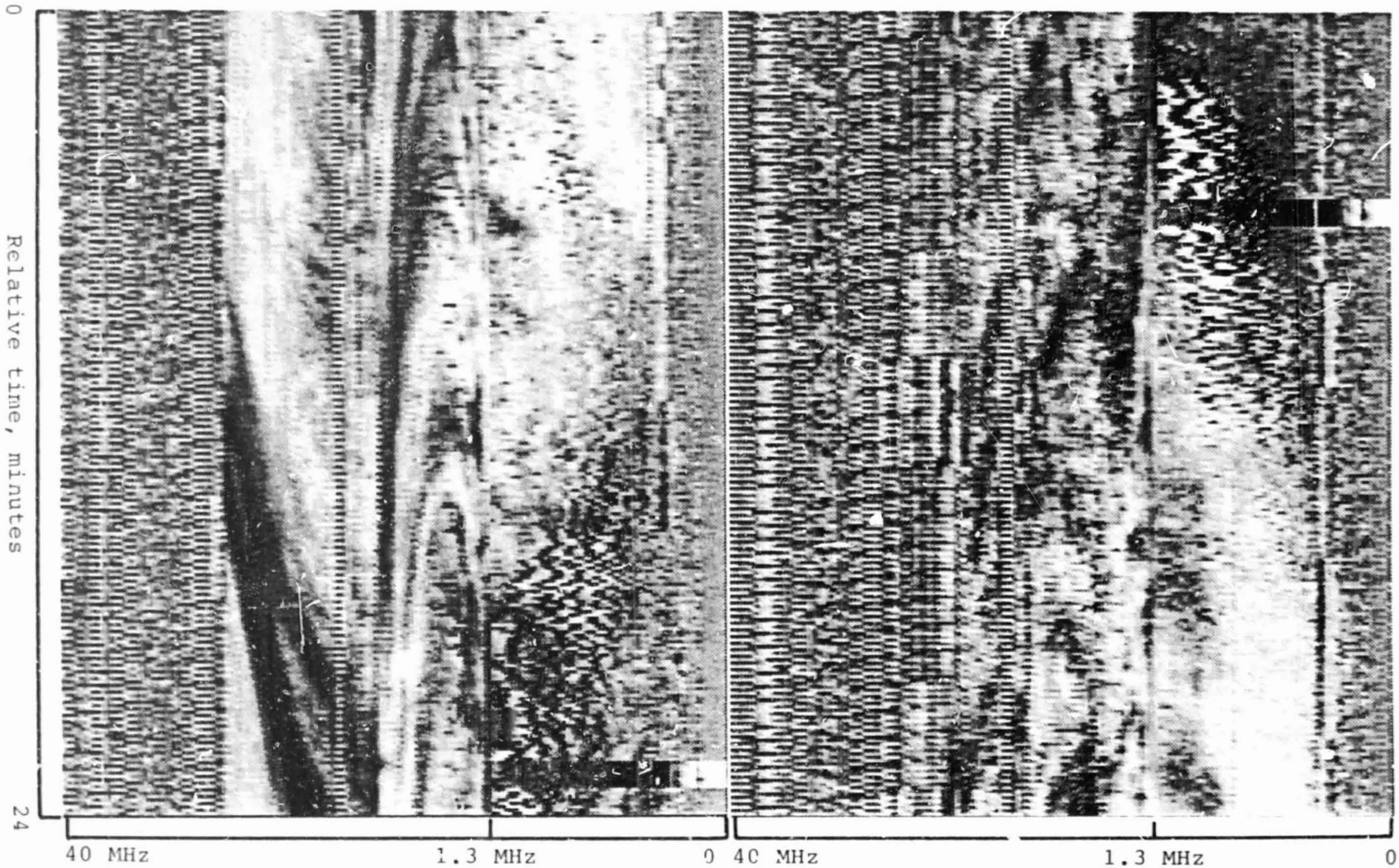


Figure 4. Normalized 6-sec Voyager-1 PRA POLLO data exhibiting modulated striation activity in the 0.3-1.3 MHz band; near 1900 h on day 59 and 1324 h on day 57. Frequency scales are piece-wise linear. Much spacecraft interference is visible.

## References


1. J. W. Warwick et al., "Voyager 1 Planetary Radio Astronomy Observations near Jupiter," Science, 204, 995 (1 June 1979).

2. J. W. Warwick et al., "Planetary Radio Astronomy Observations from Voyager 2 Near Jupiter," Science, 206, No. 4421, 991 (23 November 1979).

3. Y. Leblanc, "On the arc structure of the DAM Jupiter emission," Journ. Geophys. Res., 86, A10, 8546-8560 (1981).

4. A. Boischot et al., "Radio Jupiter after Voyager: an overview of the planetary radio astronomy observations," Journ. Geophys. Res., 86, A10, 8213-8226 (1981).

5. D. H. Staelin, "Character of the Jovian decametric arcs," Journ. Geophys. Res., 86, A10, 8581-8584 (1981).

6. F. Bagenal, "Alfvén wave propagation in the Io plasma torus," Journ. Geophys. Res., 88, A4, 3013-3025 (1983).

7. D. A. Gurnett and C. K. Goertz, "Multiple Alfvén wave reflections excited by Io: origin of the Jovian decametric arcs," Journ. Geophys. Res., 86, 717-722 (1981).

8. D. H. Staelin and P. W. Rosenkranz, "Formation of Jovian decametric S bursts by modulated electron streams," Journ. Geophys. Res., 87, A12, 10,401-10,406 (1982).

9. J. K. Alexander, personal communication (1982).

10. P. M. Garnavich, Jovian Decametric Radiation: A Test of the Multiple-Reflection Alfvén Wave Model, S.M. thesis, Dept. of Physics, Mass. Inst. of Tech., June, 1983.