18 MHz INTERFEROMETRY OF NON–IO–C L–BURSTS

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Abstract

New 18 MHz interferometric observations of Jupiter are reported. During some L–bursts, time–variations in the fringe visibility suggest that the emission region dynamically expands from a "point source" ($< 0.4R_J$ or $10''$) to a substantial fraction of Jupiter's diameter on time scales of a few seconds. Multipath scattering in the interplanetary medium is ruled out as an explanation for the visibility fluctuations. The data also seem inconsistent with simultaneously active, multiple emission regions. We suggest that visibility fluctuations result from the contamination of L–emissions by S–bursts with pulse widths significantly shorter than the integration time of the interferometer. To test this idea, simultaneous observations with an interferometer and a dynamic spectrograph are proposed.

Introduction

The origin of Jupiter's decametric radio emissions (called DAM) is poorly understood despite decades of study. The most serious obstacle to a solution of the problem is that the size and location of DAM emitting regions are not well known. In the past, a number of researchers have used interferometers to measure the source size with baselines as large as 7500 km. One of the most important early studies was conducted by Slee and Higgins (1966) using a 193 km phase switching interferometer at 19.7 MHz. Over a two year period, they measured Gaussian source widths for 39 different storms, 38 of which were associated with either non–Io–A, non–Io–C, Io–A, or Io–C emissions (nomenclature concerning DAM radio sources is reviewed by Carr et al., 1983). Source sizes determined from the Slee and Higgins (1966) experiment usually fell between 10 and 15 arcseconds.

Until recently, the only interferometric studies of A– and C–related emissions were by Slee and Higgins. Although a good deal of Jovian interferometry has been done since the mid–1960's, the only reported results have come from observations made during Io–B storms (May and Carr, 1967; Dulk et al., 1967; Brown et al., 1968; Block et al., 1970; Dulk, 1970; Lynch et al., 1972, 1976). VLBI measurements of the Io–B source size gave upper limits on the order of 0.1 arcseconds, considerably smaller than that determined by Slee and Higgins for A– and C–related sources. To investigate the discrepancy in source size measurements, an 18 MHz interferometer at the University of Florida Radio Observatory has been used to observe Jovian radio emissions during the summer of 1986. Here, we report L–burst data from a non–Io–C storm which indicates that, during some bursts, the source is easily resolved with a 46 km baseline and furthermore, that the apparent source size sometimes varies dramatically on time scales of a few seconds.

Equipment

The 18 MHz interferometer used for this research is located at the University of Florida Radio Observatory (UFRO) near Old Town, Florida. The 2739λ baseline extends from the UFRO to the Rosemary Hill Observatory (RHO), the University of Florida's optical observatory located near Bronson, Florida. As viewed from the UFRO, the Rosemary Hill terminus is at azimuth 108 degrees.

The two stations are connected via a 407 MHz FM radio link. Baseband data with a 6 kHz bandwidth from the RHO are frequency modulated and transmitted to the UFRO where it is demodulated and subsequently correlated with the UFRO data using a one–bit digital correlator. The correlator samples the baseband data at 32 kHz, well above the Nyquist rate for a data bandwidth of 6 kHz. An adjustable bank of digital shift registers within the correlator is used to compensate for the geometrical signal delay between the two stations. The UFRO receiver provides two baseband outputs in phase quadrature so that both sine and cosine fringe components are produced by the correlator. The phase quadrature fringe outputs, as well as the square–law detected power from both ends of the baseline, are integrated with a 150 msec RC time constant and digitized at 10 Hz by a digital microcomputer in real time for later analysis.

The antennas at each end of the baseline are pairs of 5–element crossed yagis sensitive to circularly polarized radiation. Each antenna provides a choice of RH or LH circular polarization. Although only one polarization is transmitted over the FM link at a time, the antenna polarization at both stations may be readily changed to investigate either RH– or LH– polarized Jovian radio emissions.

Data reduction

Raw correlation data produced by the interferometer must be carefully processed to arrive at the fringe visibility of the Jovian radio source. Since the digital correlator quantizes the baseband data (preserving only the sign of the digitized signal), a correction must be applied to relate the one–bit correlation, ρ_0, to the true (analog) correlation, ρ. This is accomplished by the Van Vleck equation,

$$\rho = \sin\left(\frac{\pi\rho_0}{2}\right) \tag{1}$$

(Van Vleck and Middleton, 1966). In practice, signals from each end of the baseline are decorrelated slightly because of instrumental effects (unavoidable differences in receiver electronics at each station, etc.). To correct for these effects, the equation

$$\tilde{\rho} = \eta\rho \tag{2}$$

gives the correlation, $\tilde{\rho}$, which would be observed in the absence of equipment–related decorrelation. The instrument–factor, η, is discussed in more detail below. When measured during a Jovian radio storm, $\tilde{\rho}$ represents the analog correlation of Jupiter's radio emission plus the galactic background radiation. To correct for the uncorrelated galactic background, the equation

$$\rho_J = \tilde{\rho}\sqrt{\frac{(P_{J,1}+P_{g,1})(P_{J,2}+P_{g,2})}{P_{J,1}P_{J,2}}} \tag{3}$$

is used to give ρ_J, the correlation due to Jupiter alone; $P_{J,i}$ and $P_{g,i}$ are the powers recorded at station i due to Jupiter and the galactic background, respectively. Finally, the so–called "fringe washing" correction must be applied to ρ_J because of the non–zero bandwidth of the interferometer (6 kHz). The fringe visibility, γ, is related to ρ_J by the expression

$$\gamma = \frac{\rho_J}{G(\tau)} \tag{4}$$

where $G(\tau)$ is the fringe washing function. The temporal variable τ is the difference between the instrumental delay (τ_i) applied to the digitized UFRO baseband data and the geometrical delay (τ_g) between signal arrival times at each end of the baseline ($\tau = \tau_g - \tau_i$); for any given time, τ_g is computed from the celestial coordinates of Jupiter and the known latitude of each antenna. The fringe washing function is the Fourier transform of the receiver passband (Thompson et al., 1986) which, for the UFRO interferometer, is approximately rectangular with a width $\Delta\nu = 6$ kHz. Consequently,

$$G(\tau) = \frac{\sin(\pi\Delta\nu\tau)}{\pi\Delta\nu\tau}\,. \tag{5}$$

Equations (1) through (5) are used to reduce the measured one–bit correlation to the fringe visibility of the Jovian radio source.

As mentioned above, it is important to account for any decorrelation of the Jupiter data which may result from equipment–related considerations. A number of instrumental effects can contribute to the unwanted decorrelation; these include slight differences in the phase behavior of filters and amplifiers used at each end of the baseline, as well as noise added to the RHO data by the upconvertor, modulator, and transmitter which comprise the FM radio link. Correction of the data for instrumental decorrelation is expressed by Equation (2) where η has been determined from a zero–baseline calibration of the interferometer.

For the zero–baseline calibration, the receiver and FM link electronics from the RHO were transported to the UFRO. In order to measure the instrumental decorrelation, a single, broadband Gaussian noise generator was applied to the inputs of both interferometer receivers. The baseband "data" from one receiver was frequency modulated and transmitted at 407 MHz to an FM receiver a few hundred yards away. The transmitted data were then downconverted, demodulated, and one–bit correlated with baseband "data" from the second receiver. Except for the length of the baseline, the signal path followed in the zero–baseline calibration is identical to that encountered by actual data during the normal operation of the interferometer. Since the same noise generator fed both receivers, the one–bit correlator output should (in the absence of equipment–related decorrelation) give $\rho = 1$. In fact, the zero–baseline measurement showed that instrumental effects result in a decrease of the true correlation by 5 percent. Consequently the value $\eta = 1.05$ has been adopted for our L–burst data.

Observations

The non–Io–C data were collected on 30 July 1986 between 10^h15^m and 10^h45^m UT. These times correspond to (CML=308°, $\gamma_{Io} = 219°$) and (CML=327°, $\gamma_{Io} = 223°$), respectively, where CML is Jupiter's Central Meridian Longitude and γ_{Io} is the Io phase (Dessler, 1983). Both antennas were sensitive to LH circular polarization during the storm.

Fourteen L–bursts were strong enough at both ends of the baseline to provide accurate visibility measurements. Approximately half of the L–bursts had a fringe visibility of unity, indicating an unresolved source. Some L–bursts, however, displayed interesting time–variations in the visibility amplitude. Figures 1 and 2 display two such bursts. The top two frames in each figure show the power at each end of the baseline in units of dB above the galactic background; the bottom frame shows the fringe visibility, ρ_J. The integration time was 150 msec and the projected baseline at 10^h15^m UT was 2670λ.

An inspection of the data reveals that the fringe visibility can vary substantially during an L–burst. In Figure 1, the visibility decreases from $\rho_J = 1$ (an unresolved source) to $\rho_J \approx 0.8$ at $10^h16^m34.6^s$ and from $\rho_J = 1$ to $\rho_J \approx 0.6$ at $10^h16^m36^s$. Similarly, in Figure 2 the visibility decreases from 1 to ~ 0 between $10^h16^m58.3^s$ and $10^h17^m00.3^s$. in each example, the visibility varies on a second time scale and always *decreases* from $\rho_J = 1$ to some smaller value. The variations in ρ_J are clearly not a consequence of noisy data. In Figure 2, for example, the power was at least 2.5 dB above the galactic background at both ends of the baseline during the precipitous decrease in visibility. The data indicate a genuine dynamic increase in apparent source size.

Discussion

These L–bursts apparently belong to a class of Jovian radio emissions called "flaring bursts" reported by Phillips (1986). Phillips observed 12 L–bursts during three A–related storms in which the fringe visibility was observed to decrease on time scales of 1 to a few seconds. Roughly 30% of the L–bursts observed from the A–related sources were of the flaring variety. Unlike the earlier data reported by Phillips (1986), the non–Io–C visibility data are calibrated accurately enough to compute the change in apparent source size. Figure 3 shows the relationship between fringe visibility and source size for the bursts in Figures 1 and 2. The source size, θ, is the full width between half brightness points assuming a Gaussian brightness distribution. From Figure 3 it is evident that any source smaller than $10''$ will be unresolved with a 2670λ baseline. The visibility fluctuations in Figure 1 indicate that the source size changes from $\theta < 10''$ to $\theta \approx 20''$ at $16^m34.6^s$ and from $\theta < 10''$ to $\theta \approx 30''$ at $16^m36.0^s$. In Figure 2 the source size increases even more dramatically, from $\theta < 10''$ to $\theta > 60''$. On 30 July 1986, Jupiter's diameter subtended $46''$ on the sky. The maximum size of each flaring event we have discussed was therefore 0.88 R_J, 1.31 R_J, and 2.63 R_J, respectively.

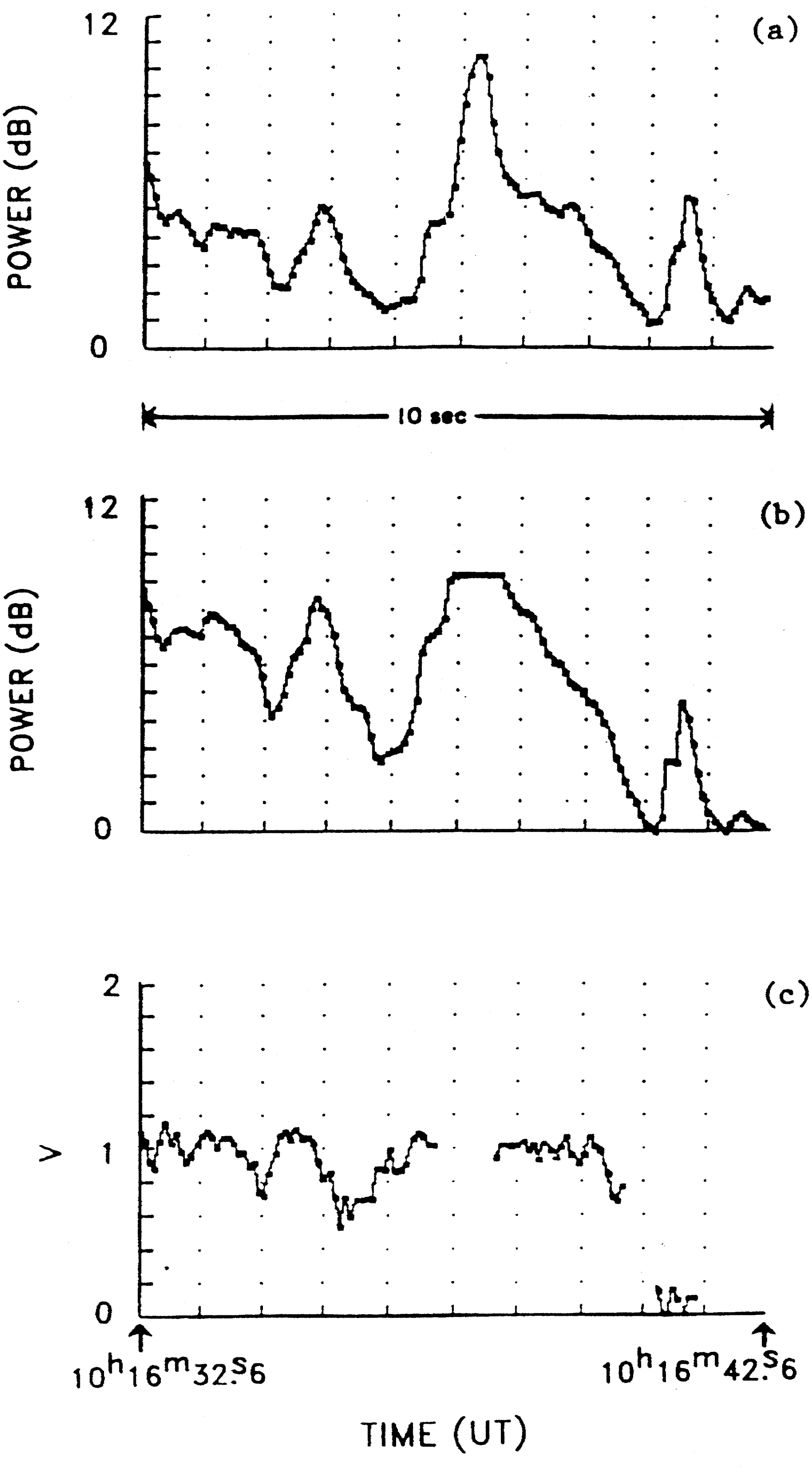

Fig. 1: Non–Io–C interferometer data. a) The square–law detected power in dB above the galactic background at the UFRO end of the baseline. b) The power at the Rosemary Hill station. c) The fringe visibility.

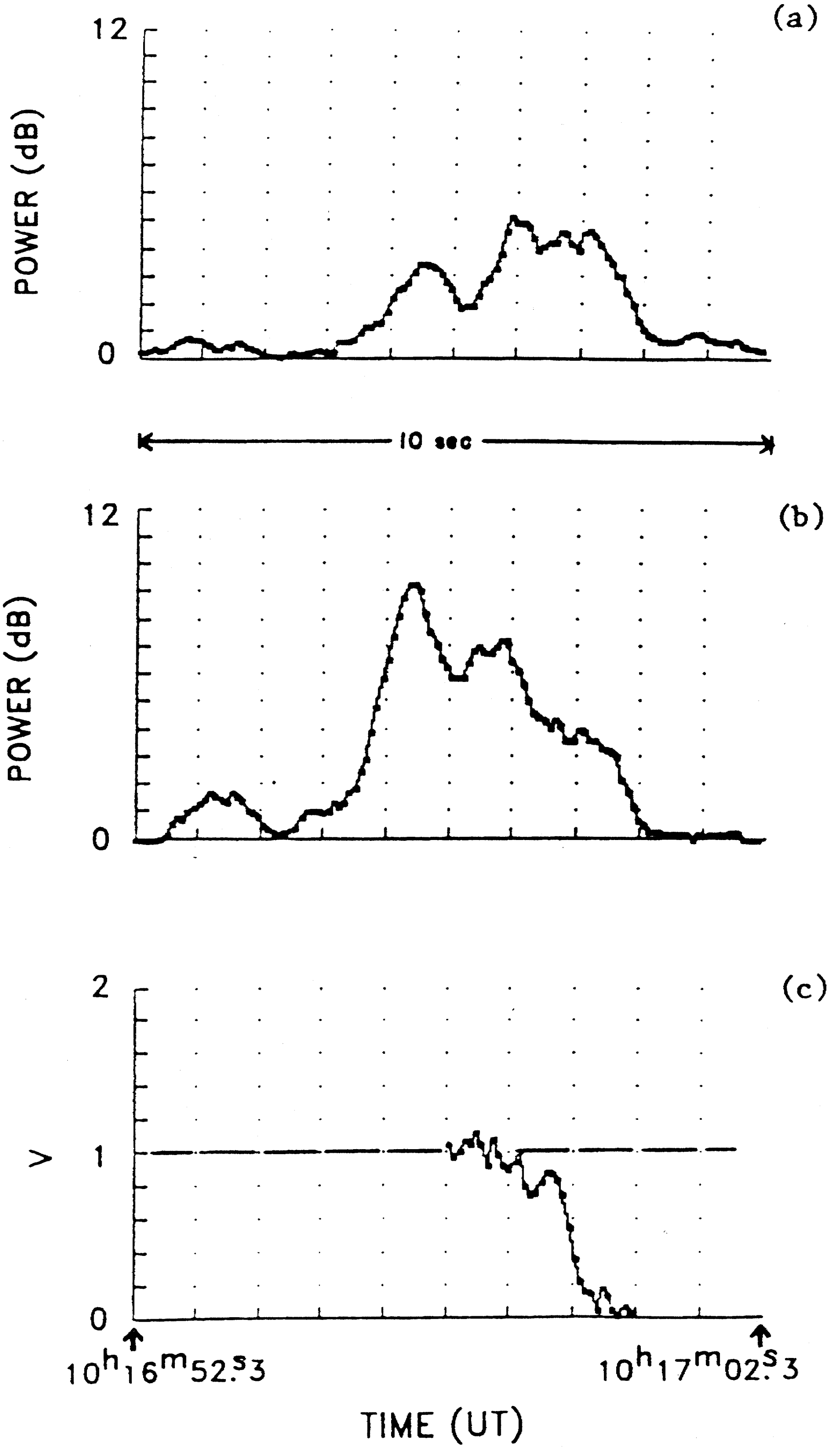

Fig. 2: Non–Io–C interferometer data. a) The square–law detected power in dB above the galactic background at the UFRO end of the baseline. b) The power at the Rosemary Hill station. c) The fringe visibility.

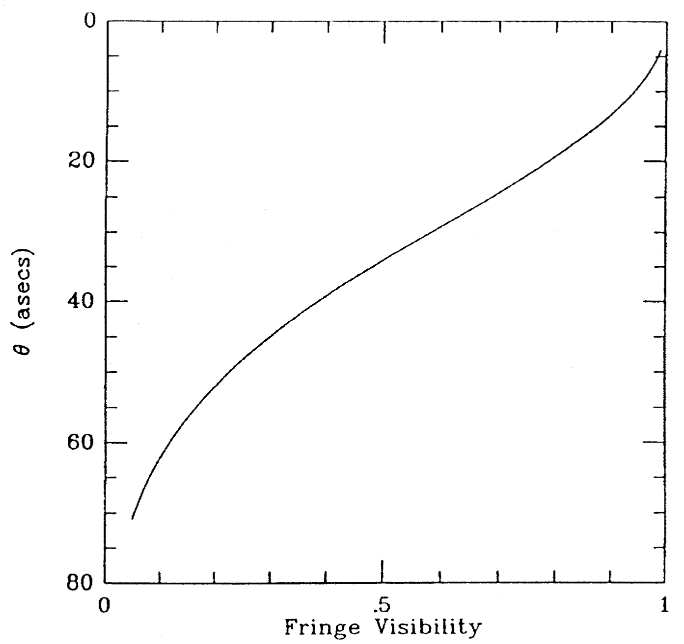

Fig. 3: Fringe visibility versus apparent source size for a 2670λ projected baseline. A Gaussian brightness distribution is assumed. θ is the full width between half brightness points.

What is the cause of the time–dependent fringe visibility? Before the possibility of a true source expansion of such proportions is seriously considered, other possible explanations must be ruled out. One phenomenon which can cause anomalous drops in the fringe visibility amplitude but which has no relation to an expanding source is the presence of S–bursts in the data. Typical S–bursts are narrowband ($\sim$ 50 kHz) and drift through frequency space about 20 MHz/sec. Such an S–burst would occupy the 6 kHz passband of our interferometer for 3 msec, 50 times less than the 150 msec integration time. The Van Vleck relation is nonlinear; consequently, Equation (1) is strictly accurate only when the flux from Jupiter, and thus the correlation ρ_0, is nearly constant throughout the 150 msec integration period. This is simply because $< \sin[(\pi\rho_0)/2] > \neq \sin[(\pi < \rho_0 >)/2]$ where the brackets $<>$ denote time averages. Numerical modeling by the authors shows that if a substantial portion of the flux is contributed by S–emissions then the visibility can be underestimated by a factor of 2 or more. In such a case, the fringe visibility would be a function of time and would depend on the ratio of L–burst flux (slowly varying) to S–burst flux (rapidly varying). Without dynamic spectra we cannot rule out the possibility that the changes in fringe visibility are a consequence of burst structure on times scale significantly shorter than the integration time.

An alternative explanation for flaring may involve the interplanetary medium (IPM). As Douglas and Smith (1967) have shown, the modulation of Jovian radio emissions on L–burst time scales can be explained by diffractive scintillation in the IPM. Since source flaring occurs on L–burst time scales, one might wonder whether or not the IPM also plays some role in the flaring phenomenon. One way that the IPM might produce flaring involves multipath scattering effects. Modeling the IPM as a thin screen scatterer, direct rays from Jupiter arrive at Earth T_0 seconds before scattering rays. The equation

$$T_0 = \frac{\theta_S^2 R R'}{8c(R + R')} \tag{6}$$

comes from simple thin screen scattering geometry. R is the screen–observer distance, R' is the screen–Jupiter distance, c is the speed of light, and θ_S is the scattering angle.

Scattered rays arrive from a spectrum of angles whose width is characterized by θ_S. Consequently, an impulsive Jupiter burst from a point–like emission region will appear to grow in size from a point source when the direct ray arrives to a source with width θ_S, T_0 seconds later. Unfortunately, this scenario can not be reconciled with the UFRO visibility measurements. For decameter wavelength Jovian radio emissions $\theta_S \approx 1''$, far too small to account for the flaring source sizes. Also, with $R = 1$ AU and $R' = 3.2$ AU, $T_0 = 1 \cdot 10^{-9}$ seconds, nine orders of magnitude faster than the observed flaring. Clearly, multipath scattering in the IPM does not offer a ready explanation for source flaring.

Finally, we consider two distinct, simultaneously active emission regions which are individually unresolved (consistent with earlier VLBI results) but which are situated sufficiently far apart that they can produce the low fringe visibilities we have observed. In this model, the fringe visibility is a function of the separation of the two sources as well as their relative brightness. The observed visibility amplitude will vary as the brightness ratio of the two emission regions varies. Consequently, we should observe L–bursts in which ρ_J is initially small and increases towards $\rho_J = 1$ just as often as the opposite case. In fact, we have only observed $\rho_J = 1 \rightarrow \rho_J < 1$. This seems inconsistent with the multiple source hypothesis. Clearly, however, more observations are needed to establish the statistical properties of the flaring events.

Conclusions

We have observed variations in the fringe visibility of Jovian L–bursts which indicate that the source size changes in time and that the emission region can sometimes be resolved with a relatively modest baseline. We rule out multipath scattering in the IPM as a valid explanation for our observations based on the size of the scattering angle and the arrival–time delay between scattered and direct rays. Explanations involving multiple, simultaneously active sources also seem unlikely. Instead, we believe that a self–consistent understanding of the data is possible if the following postulates are adopted:

1. All Jovian source sizes are smaller than $10''$ and perhaps smaller than $0.1'$ as previous VLBI work suggests.

2. Apparent L–burst source sizes larger than $10''$, observed interferometrically by Slee and Higgins (1966) and in the present paper, are entirely due to contamination by S–bursts when the integration time is long compared to an individual S–burst pulse width.

3. Although it is commonly stated that only Io–related sources are S–burst emitters, this is not strictly true. (In fact, the authors are aware of S–bursts observed during non–Io–related storms [Carr et al., 1987]). Consequently, S–bursts may be present in our non–Io–C data.

4. It is much more probable that, during a Jovian storm, L–burst emission will evolve into S–bursts (over an interval of a few seconds) than that S–bursts will become L–bursts.

The fourth hypothesis would explain why the visibility is observed always to decrease with time. No statistical studies are available in the literature to substantiate hypothesis # 4. In the observing experience of the authors, however, there is a decided tendency for occasional transitions from L– to S–burst activity, more often than the reverse. In the radio telescope loudspeaker during a strong L–burst storm, one can "hear the S–bursts coming". At first the observer detects a faint S–burst background which becomes rapidly stronger, overwhelming the L–bursts. Such an occurrence would probably register as an interferometric flaring event. The proposal that S–burst contamination is entirely responsible for the large apparent source sizes can and will be tested by operating a dynamic spectrograph simultaneously with future interferometer observations. In conclusion, the data are intriguing but more observations are needed to confirm the existence and establish the regular properties of flaring events.

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