SEARCH FOR EFFECTS OF COMET S–L 9 FRAGMENT IMPACTS ON LOW RADIO FREQUENCY EMISSION FROM JUPITER

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Abstract. Decametric radio observations of Jupiter were made before, during, and after the impacts of the fragments of the comet S-L 9 with the planet, from the University of Florida Radio Observatory, the Maipu Radio Astronomy Observatory of the University of Chile, and the Owens Valley Radio Observatory of the California Institute of Technology. The decametric radiation was monitored at frequencies from 16.7 to 32 MHz. The minimum detectable flux densities were on the order of 30 kJy, except for that of the large 26.3 MHz array in Florida, which was about 1 kJy. There was no significant enhancement or suppression of the decametric L-burst or S-burst emission with respect to normal activity patterns that might be attributed to the fragment entries. However, a burst of left-hand elliptically polarized radiation having a considerably longer duration than an L-burst was observed almost simultaneously with the impact of the large fragment Q2, and another with right-hand elliptical polarization was observed simultaneously with Q1. We consider the possibility that these two bursts were emitted just above the local electron cyclotron frequencies from the southern and northern ends, respectively, of magnetic flux tubes that had been excited in some way by the proximity of fragments Q2 and Q1.

In addition to the monitoring of the decametric radiation, a search was conducted for possible comet-enhanced Jovian synchrotron radiation at 45

MHz using a large dipole antenna array at the observatory in Chile. This frequency is above the cutoff of the decametric radiation, but is considerably below the lowest frequency at which the synchrotron emission has previously been detected. The minimum detectable flux density with the 45 MHz antenna was about 5 Jy. No synchrotron emission at all was found before, during, or after the entry of the comet fragments.

1. Overview of the Project and of the Results

The response by the astronomical world to the prediction of the collisions of the fragments of Comet Shoemaker-Levy 9 with Jupiter was unprecedented. Many types of observations were made during the impacts, spanning as much of the electromagnetic spectrum as possible. As our contribution to this worldwide effort, our group from the University of Florida, the University of Chile, and the California Institute of Technology monitored Jupiter's decametric radiation from three widely separated locations at a number of frequencies between 16.7 and 32 MHz. These frequencies span most of the part of Jupiter's decametric radiation spectrum that is observable from Earth. The observations were made from one, two, or all three of the observatories at the times of predicted impacts of fragments A, B, C, F, H, J, L, Q1, Q2, R, T, U, and V. In addition, observations were made before and after impact week in order to establish normal undisturbed activity levels for comparison with any observed increase or decrease that might have resulted from the impacts. A search was also made for enhanced synchrotron radiation at 45 MHz (which is above the decametric radiation cutoff), using a large radio telescope in Chile. A general description of Jupiter's decametric and synchrotron radiations can be found in Carr *et al.* (1983).

With two possible exceptions, there were no instances of Jovian decametric activity that appeared to have been triggered by the entry of any of the fragments into Jupiter's magnetosphere or ionosphere. There was no evidence that the impacts either increased or decreased the occurrence probability of activity predicted on the basis of central meridian longitude and Io's orbital phase that happened to fall within impact week. Nor was there any evidence that the occurrence probability of unpredicted activity increased during the week of the impacts. The two possible exceptions noted above were two highly atypical polarized bursts having durations of about 1 min each (much longer than L-bursts) that occurred within one standard deviation of the accepted impact times of the large fragments Q2 and Q1. We consider this remarkably close correspondence of decametric burst and fragment impact times to be impressive evidence that the bursts were triggered by the fragment entries.

A preliminary analysis of the data obtained with the large Chilean radio telescope indicates that the observations were not of sufficient sensitivity to reveal either normal or comet-enhanced Jovian synchrotron radiation at the relatively low frequency of 45 MHz. The lowest frequency at which this radiation had previously been detected is 80 MHz. We had hoped that a possible comet-enhancement of the synchrotron radiation at 45 MHz would bring its level above the threshold for detection by the Chilean radio telescope. Although this apparently did not occur, we are able to provide an upper limit on the flux density of any undetected comet-enhanced Jovian synchrotron emission at 45 MHz that may have been present. Such an upper limit may be of value in the interpretation of the substantial enhancements of the synchrotron radiation following the comet impacts which were observed by others at much higher frequencies.

The details of the observations and the full presentation of the results that we obtained follow.

2. Observatories, Instrumentation, and Observational Details

The three radio observatories at which the radio observations were made, with the longitude and latitude of each and name of the nearest town or city, are:

1) Maipu Radio Astronomy Observatory (MRAO); 70.9°W; 33.5°S; Santiago, Chile.

2) University of Florida Radio Observatory (UFRO); 83.0°W; 29.5°N; Old Town, Florida.

3) Owens Valley Radio Observatory (OVRO); 118.3°W; 37.2°N; Big Pine, California.

The frequencies monitored at each of the three observatories are listed in Table 1. The effective areas of the principal antennas employed are given in Table 2. For those antennas used to search for the Jovian decametric radiation, which is usually more or less circularly polarized, we define the effective area to be the spectral power density output per unit flux density for incident circularly (RH or LH) polarized radiation. For the large 45 MHz array at MRAO (used to search for synchrotron radiation) we define effective area in the usual way on the basis of unpolarized radiation. The receivers, with the exception of that for 45 MHz, were all of about 6 kHz bandwidth, and their rectified and smoothed outputs (time constant about 1 s) were pen-recorded on strip charts. An observer was always present, and each instance of suspected Jovian activity was audio-monitored as quickly as possible by means of a loudspeaker to aid in its identification. The UFRO receiver outputs were recorded digitally as well as by strip chart.

TABLE 1. Frequencies monitored at the three observatories. Both LH and RH circularly polarized flux density components were measured for those frequencies with asterisks. For those without asterisks, only a linearly polarized component was measured.

Observatory	Frequencies, MHz
MRAO	16.7*,18,22.2*,27.6, and 45
UFRO	18*,20*,22.2*,24.3*,26.3*,28.5*, and 32
OVRO	Various combinations of frequencies between 18 and 28 MHz, usually multiplexed with two receivers.

TABLE 2. Effective areas (A_e) of the principal antennas used. Each value is the ratio of the output power density to the input flux density of completely circular polarized radiation, except for the 45 MHz value. The latter is the ratio of twice the output power density to the input flux density of unpolarized radiation. (Not included here are the 5-element Yagis used to supplement the UFRO log spiral array coverage between the hour angles 4 to 6 h)

Observatory	Antenna System	A_e, m^2
MRAO	16.7 MHz crossed twin 3-element Yagis	220
	18 MHz 5−element Yagi	180
	22.2 MHz crossed twin 5-element Yagis	240
	27.6 MHz 7−element Yagi	100
	45 MHz 528−fullwave dipole array	9600[a]
UFRO	Wideband array of 4 RH log spiral ants.	370[b]
	Wideband array of 4 LH log spiral ants.	370[b]
	26.3 MHz 640−halfwave dipole array	8000
OVRO	Wideband array of two 7−element log periodic ants.	170[b]

[a] for unpolarized radiation
[b] at 18 MHz

The large 26.3 MHz antenna at UFRO is a phased array of 640 parallel horizontal halfwave dipoles located about a quarter wavelength above ground (Desch *et al.*, 1975; Flagg *et al.*, 1991). For a given pointing direction, there are three adjacent simultaneously operated beams at the same hour angle but at slightly different declinations (beam axes are offset by 2.5° north and south). The half–power width of each beam is 2.5° north-south by 6° east-west. The three beams are connected to different receivers and recorder channels. The central beam is kept pointed at Jupiter while the adjacent north and south beams have nulls in the direction of the planet, making possible the recognition of interference arriving from non-Jupiter directions. Jupiter is tracked for a 3.5 h interval centered on transit by automatic rephasing every 26 min. Normally, receivers having bandwidths from 0.26 to 1.0 MHz are used with this array, but 6 kHz bandwidths were used for the comet impact monitoring because of the relatively close spacing of the interfering radio stations that were present during the daylight observing periods. The minimum detectable flux density of circularly polarized Jovian radiation with this radio telescope, as used for the comet impact monitoring, was about 1 kJy (*i.e.*, 1 kilojansky, or 10^{-23} w m^{-2} Hz^{-1}). The minimum detectable flux densities of the Yagi, log spiral, and log periodic decametric radio telescopes employed at MRAO, UFRO, and OVRO were on the order of 30 kJy.

The antenna of the 45 MHz radio telescope at MRAO is a filled rectangular array of 528 horizontal full-wave dipoles located a quarter wavelength above a reflecting plane (May *et al.*, 1984). It is a transit instrument. Two beams, connected to different receivers, were used simultaneously. One was at the declination of Jupiter and the other, the comparison beam, was offset in declination by one beamwidth. The east-west half-power beamwidths are 4.6°, providing about 20 min of Jupiter observing time during each daily drift scan. The receiver bandwidths are 1 MHz, and the receiver outputs are digitally recorded. Changes of declination are made by rephasing the array. The minimum flux density that is detectable with this radio telescope is about 5 Jy (Alvarez *et al.*, 1992). A new calibration will be performed in order to determine this value more accurately.

The most serious forms of interference affecting decametric observations at well-located isolated observatories are 1) skywave-propagated signals from distant radio stations (*i.e.*, those from beyond the horizon that are refracted downward toward the receiving antenna by the ionosphere), 2) skywave-propagated interference from lightning discharges in distant thunderstorms, 3) groundwave-propagated interference from local thunderstorm lightning, and 4) interference in the form of high harmonics of 120 Hz generated by corona discharges across one or more defective insulators of a nearby high voltage transmission line (usually the one supplying power to the observatory, since a well-chosen site must be far from all other high voltage lines). Of the above, 1) and 2) tend to disappear late at night as the ionosphere becomes less dense, 2) and 3) are usually a problem only in summertime, and 4) can be corrected by the power company if the offending member is identified and shown to them by the radio astronomer (but such identification may be difficult). At times when none of these forms of interference is present, it is then only the galactic background that competes with the Jovian signal for detectability (receiver noise being negligible).

We were fortunate that the prevailing sunspot number is relatively low at this time. If the encounter of the comet with Jupiter had occurred during an active part of the solar cycle, observations at frequencies below about 24 MHz would most often have been impossible from Chile, Florida, and California during hours of daylight because of the increased ionospheric plasma density; skywave-propagated interference from distant radio stations would have been prohibitive.

Observing conditions were considerably better at MRAO than at either OVRO or UFRO, because it was winter in Chile. Interference at MRAO from lightning was at a minimum due to the rarity of local thunderstorms at that season and because the distant tropical thunderstorm centers had moved northward to their maximum distance from Chile. Furthermore, sunrise was later and sunset earlier in Chile than in California or Florida, reducing the density of the morning and afternoon ionosphere and thereby reducing the skywave interference from distant radio stations. In addition, Jupiter was above the horizon for a longer time at MRAO than it was at the Northern Hemisphere observatories. OVRO, on the other hand, had an advantage that it is located between two mountain ranges running north and south that blocked out most of the radio station interference. However, these mountains did not block out the interference arriving from the tropical thunderstorms far to the south, nor that from local thunderstorms on the mountainsides visible from the observatory. Locally generated power line interference, referred to as "buzz", was also a problem at OVRO but was reduced to an acceptable level by means of filters (but there was still some loss in detection sensitivity due to the residual buzz). The intense static crashes from lightning discharges in local thunderstorms were much more severe at UFRO than at the other two observatories because the comet impacts occurred at the peak of Florida's summer thunderstorm season. We were agreeably surprised to find that despite the presence of this seasonal heavy local interference, the UFRO observations appear to be almost as effective as those of the other two stations.

3. Results and Discussion

Daily observations began at all three observatories about a month before the impact of the first fragment of the comet, which was on July 16, 1994. The UFRO and MRAO stations continued observing every day for a week after the last impact, which occurred on July 22. The OVRO station continued monitoring until September 9, but because manpower was short these observations were not conducted every day. (We decided to concentrate the post-impact OVRO observations on the CML range from 0° to 180° because we believed, mistakenly as it later turned out, that there had been a possible enhancement of Non-Io-B activity during impact week.) Figure 1b is a histogram indicating the number of hours per 24–hour day that observations were made from one, two, or all three of the stations.

Figure 1a gives the numbers of hours per day that decametric activity was actually observed. The daily activity durations are indicated separately for Io-related and Io-unrelated activity. As is usual for Jupiter's decametric emission, the activity was in the form of bursts. With the exception of the previously mentioned atypical bursts that occurred at fragment Q2 and Q1 impact times, these bursts were individually of durations less than 4 s. In computing activity hours we counted each isolated burst arbitrarily as 60 s of activity (the justification being that each isolated burst is an unusually high scintillation peak that is the only part of a much wider burst that could be observed, *i.e.*, it is the "tip of the iceberg", the remainder of which was too weak to be seen). Figure 1a shows no enhancement of the daily duration of activity during impact week—in fact, there is a suggestion of a reduction in activity times. This apparent reduction, however, is certainly not statistically significant.

The observed Jovian activity from the three stations is shown as a joint function of Io's orbital phase and the central meridian longitude (CML) of the planet for the seven days of the impacts in Figure 2a, and for the other days of our observations in Figure 2b. The extent to which the Io phase vs. CML plots were covered by these observations is indicated in Figures 2c and 2d. The letters A through W on Figure 2c indicate the approximate value of Io phase and CML at the time of each of the impacts during which we were observing. The three rectangular boxes on each of the four plots identify the principal parts of the Io-related source B, A, and C regions, which are customarily referred to as *Io-B, Io-A,* and *Io-C* (see Carr *et al.*, 1983). The other one of the four most prominent of the terrestrially observed Jovian decametric source regions is *Non-Io-A*. It is not indicated on these plots; however, it spans about the same CML interval as does *Io-A* but does not depend on Io. It may have any value of Io phase that is well outside the range for *Io-A*. A comparison of the impact-week activity as presented in Figure 2a with the non-impact-week activity in Figure 2b does not reveal any significant difference in the occurrence probability of Jovian activity during impact week.

Despite the general decline in activity from June 20 through the month of July that is suggested by Figure 1a, the results from the OVRO station alone indicate an increase in Jovian activity during impact week. Very little activity was observed at OVRO during the four week period preceding impact week. We now believe, however, that this pre-encounter period of OVRO–observed Jovian activity deficiency can be largely discounted, because it was mainly a shakedown period for both equipment and observers.

Figure 1. **a)** Histogram showing duration of Jovian decametric burst activity observed on each day of an 80-day period including the week of impacts. **b)** Coverage histogram for above, giving the observing time each day.

Our observing procedures were still being developed at that time. Not as much care was exercised in checking each observed event aurally as well as visually in order to separate the interference from Jovian activity as was

Figure 2. **a)** Activity during impact week displayed on Io phase vs. CML plot, the data from the 3 observatories having been merged. Boxes indicate very approximately the boundaries for the *Io-B, Io-A*, and *Io-C* sources. **b)** Same for the days outside impact week. **c)** Coverage lines for **a** above. The letters indicate the approximate values of Io phase and CML at the times of the fragment impacts. **d)** Coverage lines for **b** above.

employed during and after impact week. Following this initial sharpening of observing skills, however, we have full confidence in the validity of the OVRO impact week and post-impact observations. We believe that there are two reasons for the extreme deficiency in activity indicated in Figure 1a during the post-impact period, neither of which is related to the comet. After July 29, the only observations made were those at OVRO, and they were not made every day. One reason for the reduction in observed activity is that of the 30 post-impact observing hours at OVRO, 23 hours were at

CML values between 0° and 180°, cutting out the *Io-A*, *Non-Io-A*, and *Io-C* activity. The only post-impact activity observed at this station was three predicted Io-related storms on July 23, August 17, and August 18. The other reason for the low post-encounter activity, and perhaps for the general decline in activity from July 20 to September 8 in Figure 1a, is the decline in Jovian decametric activity with decreasing solar elongation that has long been known. It is probably due to some solar-related propagation effect in the interplanetary medium or the terrestrial ionosphere. In our case, the solar elongation decreased from 90° to about 30° between July and September.

Our large 26.3 MHz radio telescope at UFRO has a larger effective area than any other decametric instrument currently in use for observing Jupiter except for the Ukrainian UTR-2 telescope. At the time of the comet encounter with Jupiter, however, the detection sensitivity of the large UFRO telescope was less than normal for two reasons, as has already been stated. These reasons were that the bandwidth had to be reduced to 6 kHz because of the high density of interfering radio stations in the daytime, and that much of the time there were repeated static crashes from lightning from thunderstorms, most of which were local. The large array was useless when the static crashes were so close together that they overlapped. During a considerable amount of the time that Jupiter was in a beam of the large array on the days of comet impacts, however, the static crashes were spaced widely enough apart, on the average, that relatively weak Jovian bursts could have been detected in the quiet periods between them provided the burst durations considerably exceeded that of the individual crash. Examples of periods of lightning interference during which the static crashes were very frequent but clearly separated can be seen in Figures 3 and 4 (although these particular observations were made with the UFRO log spiral array rather than with the large 26.3 MHz dipole array). We therefore believe that in the presence of such separated-crash lightning interference the minimum detectable flux density of possible Jovian continuum emission, or of very long bursts (durations > 4 s), was almost as low as the value for interference-free conditions, which is about 1 kJy. Bursts that were much shorter than 4 s, however, might not have been distinguishable from the static-crash bursts (L bursts observed far from Jovian opposition, as in our case, have durations less than 4 s). We confirmed this estimate of the detection sensitivity by means of a drift-scan of Hydra A, a radio galaxy having a flux density of 1.6 kJy at 26.3 MHz, that we made with the large array during a period of very frequent but sufficiently well separated static crashes.

Table 3 lists the observing periods with the 26.3 MHz array that were closest to the times of eleven of the fragment impacts. The only Jovian activity that was detected during these observing intervals was one 5–min group of ordinary L-bursts that occurred more than two hours from the nearest impact time, and two other events that were probably Jovian L bursts but had not been verified aurally by the observer on duty. There is little reason to believe that these L bursts were related in any way to the impacts. No very long Jovian bursts or possible continuum radiation at all were observed, despite the 1 kJy minimum detectable flux density for such emissions. This result will be important in evaluating the reports from various parts of the world that episodes of intense Jovian decametric long-burst or continuum activity were observed during, before, or after entry of several of the fragments into Jupiter's magnetosphere. Our negative result at 26.3 MHz was obtained with an antenna having at least 30 times the effective area of any of those used to observe the reported intense comet-related Jovian emissions.

TABLE 3. Observing periods with the large UFRO 26.3 MHz radio telescope on comet impact days. Asterisks indicate the impacts which occurred while the observations were in progress. The minimum detectable flux density for very long Jovian bursts (> 4 s duration), or for continuum emission, was about 1 kJy. No such activity was observed in any of the periods listed. Small amounts of ordinary L burst activity were observed as indicated.

Fragment	Impact Date UT	Observing Period UT	Observing Period Relative to Impact	L-Burst Activity Rel. to Impact
A	7/16 20 : 11	22 : 25 to 01 : 49	$+2^h15^m$ to $+5^h38^m$	none
B	7/17 02 : 50	22 : 25 to 01 : 49	-4^h25^m to -1^h01^m	-2^h35^m to -2^h30^m
F*	7/18 00 : 33	22 : 31 to 01 : 45	-2^h02^m to $+1^h12^m$	-0^h50^m to -0^h10^m
H	7/18 19 : 32	22 : 18 to 01 : 42	$+2^h26^m$ to $+6^h10^m$	$+4^h14^m$ to $+4^h25^m$
L*	7/19 22 : 17	22 : 14 to 01 : 38	-0^h03^m to $+3^h21^m$	none
Q2	7/20 19 : 44	22 : 10 to 01 : 34	$+2^h26^m$ to $+5^h50^m$	none
Q1	7/20 20 : 12	22 : 10 to 01 : 34	$+1^h58^m$ to $+5^h22^m$	none
R	7/21 05 : 33	22 : 10 to 01 : 34	-7^h21^m to -3^h59^m	none
T	7/21 18 : 10	23 : 45 to 01 : 31	$+5^h35^m$ to $+7^h21^m$	none
U	7/21 21 : 55	23 : 45 to 01 : 31	$+1^h50^m$ to $+3^h36^m$	none
V	7/22 04 : 22	23 : 45 to 01 : 31	-4^h37^m to -2^h51^m	none

Despite the foregoing negative result, we did observe the two previously mentioned very long bursts that must be considered as strong candidates for comet-induced Jovian radiation. These bursts were obtained using a much smaller antenna than the 26.3 MHz array. They did not occur during any of the observing periods listed in Table 3. Each was of about one minute duration, was identified on more than one of our frequency channels, and occurred very close to one of the fragment impact times. The burst waveform was quite different from that of ordinary Jovian L-bursts. Normally, Jovian radiation that persisted for as long as 1 min would be broken up into many adjacent but irregular L-bursts due to interplanetary scintillation (or into the even shorter S-bursts, which are not due to scintillation). The two bursts under discussion, however, resembled solar bursts of a type emitted from source regions of such size that extreme scintillation of the L-burst type does not occur (*i.e.*, unlike the case for normal Jovian decametric radiation, the source is not small compared with the scale size of the solar wind irregularities). It is possible, in fact, that the two bursts *were* of solar origin, but we think not. Our initial reasons for believing that they were Jovian rather than solar are that a) their times of peak intensity were within one standard deviation of the accepted impact times of two of the largest fragments, Q2 and Q1; b) they were polarized; c) the sun was well outside the main beam of the antenna array; and d) no similar bursts were observed in more than 12 weeks of observing. We will refer to the burst that occurred first, nearly simultaneously with Q2 impact, as burst A, and to the second one, which was at Q1 impact time, as burst B.

Bursts A and B were each observed at UFRO with the LH-polarized and RH-polarized log spiral antenna arrays. The observations were made during a period of repeated intense but well separated static crashes from local thunderstorms. Several of the static crashes occurred during each of the bursts. Fortunately, the intervals between the crashes were sufficiently quiet that most of the burst profile was revealed, as was the normal galactic background level before and after it. Burst A was LH elliptically polarized, and the frequency of its highest intensity was 22 MHz. It was observed at 5 frequencies. Figures 3a and 3b show burst A at 22 MHz as received separately with the LH and RH circularly polarized log spiral arrays. Burst B, on the other hand, was strongest at 32 MHz. Its polarization, as measured at 28 MHz, was RH elliptical. Figures 4a and 4b show burst B at 28 MHz, observed separately with the LH and RH log spiral arrays. Although we could not measure the polarization sense at 32 MHz because had no receiver for the LH channel, there is no doubt that the sense was RH at 32 MHz as well as at 28 MHz.

Burst A appeared to reach its peak simultaneously at all the frequencies at which it was observed, as did burst B. Table 4 gives a comparison of the time of peak intensity of burst A and the accepted impact time of fragment Q2 (Yeomans and Chodas, 1994), and a similar comparison of the times of burst B peak and fragment Q1 impact. The standard deviation of each of the accepted impact times is also given. It is apparent that in both cases the burst peak times and impact times agree to within one standard deviation of the latter. We consider this remarkably close agreement to be the strongest evidence we have that bursts A and B were produced by impacts Q2 and Q1.

Figure 3. **a)** Burst A as observed on the 22 MHz left-hand circularly polarized channel at UFRO on July 20, 1994. All of the large spikes are static crashes from local thunderstorm lightning; most of the smaller ones are from more distant lightning. The burst A profile and the galactic background level before and after the burst are traced out by the segments between static crashes. The vertical scale is for the burst A flux density after the static crash and galactic background intensity components have been subtracted out. **b)** Burst A as observed on the 22 MHz right-hand circularly polarized channel at UFRO.

Figure 4. **a)** Burst B, as observed on the 28 MHz left-hand circularly polarized channel at UFRO on July 20, 1994. **b)** Burst B as observed on the 28 MHz right-hand circularly polarized channel at UFRO.

This close agreement would be a remarkable coincidence indeed if it turned out that the bursts and impacts were really unrelated, particularly so when no bursts at all that were similar to these were observed in many weeks of observations. The characteristics of bursts A and B are summarized in Table 5.

TABLE 4. Comparison of occurence times of the very long bursts A and B that were observed at UFRO on July 20, 1994 with the accepted impact times of fragments Q2 and Q1.

Burst	Time of Peak, UT	Fragment	Accepted Impact Time, UT	Std. Dev. min
A	19:50	Q2	19:44	6
B	20:13	Q1	20:12	4

TABLE 5. Characteristics of bursts A and B. The peak flux density is S. AR is the polarization axial ratio, *(minor axis length)/(major axis length)*.

		S		Polarization	
Burst	MHz	kJy	Duration	Sense	AR
A	18	330		LH	
	20	240		LH	
	22	390	54^s	LH	0.3
	24	370		LH	
	26	200		LH	
B	28	210	1^m15^s	RH	0.3
	32	310		(RH)	

Assuming acceptance of the fact that the impacts did cause the bursts, one's first thought in attempting to explain the process is that the fragment acts somewhat like Io in exciting decametric radiation while it traverses the Jovian magnetosphere or ionosphere. Perhaps the entering fragment, like Io, produces a moving source of ionization of sufficiently high conductance and size that it excites the magnetic flux tubes through which it passes. This causes hollow-cone beams of decametric radiation to be emitted by the cyclotron maser instability mechanism at frequencies slightly above the local electron cyclotron frequencies, from places near the northern and southern feet of each excited flux tube. Or perhaps it is the rising fireball following the impact that energizes the process, again stimulating radio emission from conjugate ends of excited flux tubes. A number of papers predicting possible comet-stimulated decametric emission that are based on such effects, and on others as well, have already been published. Of these papers, the one by (Kellogg, 1994) appears to be the most applicable to our results. In this paper, the moving conductor that is analogous to Io is assumed to be a highly ionizing shock wave travelling with the incoming fragment into the top of the Jovian ionosphere.

Regardless of the details of the transfer of energy from the fragment to the flux tubes, however, we will assume the existence of comet-excited flux tubes that emit hollow-cone cyclotron-frequency radio beams from near their two feet. Since all the impacts occurred in the southern Jovian hemisphere, the radio emission arriving from each flux-tube foot nearest the fragment trajectory would be expected to be LH elliptically or circularly polarized, and that from the more distant conjugate foot to be polarized in the RH sense. This provides a natural explanation for the opposite polarization senses of our bursts A and B. The highest frequencies at which burst A emission was detected was 26 MHz, and the highest for burst B was 32 MHz. Assuming emission at frequencies just above the local cyclotron frequency, the magnetic field strength at the source of burst A, in the southern hemisphere, must have been somewhat less than 9.3 gauss, and that at the northern hemisphere source of burst B must have been less than 11.4 gauss. These limits on the field strengths at the radio sources are not inconsistent with the fact that the field strength in the Jovian ionosphere above the south magnetic pole is 10.4 gauss and that above the north magnetic pole is 14 gauss.

Now, playing the devil's advocate, we consider possible evidence that impacts Q2 and Q1 did *not* cause bursts A and B. We start with the fact already mentioned that deep scintillation of the L-burst type was not present, indicating a source size much greater than that of the normal Jovian decametric sources. This might be considered to indicate that they were not Jovian. On the other hand, this contrary evidence can be countered with the argument that the incoming comet fragments were changing L shells and magnetic longitude at a greater rate than does Io, possibly causing the radio emitting regions to be more spread out than in the case of normal decametric emission. Such an enlargement of the sources would tend to reduce scintillation. Another contrary argument is that burst A, which was observed at UFRO, was not detected at the MRAO station despite the fact that 18 and 22 MHz observations were in progress there. Although there was unusually heavy interference at MRAO at the time (probably skywave-propagated thunderstorm interference from the tropics), the burst A deflection would have been visible if the flux density had been the same as it was at UFRO. This fact, however, is not the death knell to the idea that bursts A and B were caused by the comet fragment impacts. Twice during periods of interference-clear observations from UFRO and MRAO on other days, parts of the same storm were observed from the two stations. In neither case, however, was the Jovian activity observed simultaneously at the two. After several minutes the activity that was occuring at one station would disappear, only to reappear at the other station. There were also six cases, on other days, of simultaneous interference-clear observation at the two stations during which a storm appeared at MRAO without any activity at all being observed at UFRO. All these effects were undoubtedly manifestations of focussing or cancellation of the incoming Jovian radiation by spatially and temporally varying horizontal gradients in the terrestrial ionosphere. Horizontal gradients were probably accentuated by the considerable differences in the solar illumination of the ionosphere over the two stations, which are in opposite hemispheres. While it would have been reassuring if bursts A and B had been observed at MRAO as well as at UFRO, the failure to detect them at MRAO does not necessarily mean that they were not Jovian.

We conclude with a statement of what we believe to be our two most important results:

1. There was no increase in the occurrence probability of Jovian decametric radiation during the week of collision of the comet fragments with Jupiter. There is thus no evidence that the lower Jovian magnetosphere became “charged up” over the weeklong period of repeated collisions sufficiently to affect these radiations.

2. Two isolated abnormally long decametric bursts were observed at the Florida observatory that appear to be related to the impacts of two of the fragments of the comet.

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