MODIFICATIONS OF THE SYNCHROTRON RADIATION BELTS OF JUPITER TWO YEARS AFTER THE COLLISION WITH COMET SL9

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Abstract

The existence of short term variations of the nonthermal Jovian radio emission has been suspected for many years, but not proved [Gerard, 1976]. The collision of comet Shoemaker-Levy 9 with Jupiter offered a chance to readdress this question. The planet was observed regularly with the Nançay Radio Telescope at 21.3, 18.0 and 9.1 cm between 1 April 1994 and 11 April 1996. The comet impacts produced a large increase of the nonthermal flux density with a hardening of its spectrum. Furthermore, the east-west size of the emission region broadened in late 1994. In April 1995, the radiation belts were not yet back to normal and a new surge occurred in October 1995, also characterized by a hardening of the flux and a broadening of the east-west size. Our observations strongly suggest that both natural and comet induced variations happened during our two years monitoring.

1 Introduction

The Nançay Radio Telescope (NRT) took part in the worldwide effort to detect possible changes of the Jovian radio emission induced by the comet impacts [de Pater et al., 1995]. The first merit of this campaign (hereafter JSL9) was to prove that the Jovian synchrotron flux can increase over time scales of days [Galopeau et al., 1996]. The second merit is to suggest that natural variations added to the JSL9 effects. A second year of observations April 1995 – April 1996 was decided in order to confirm the existence of such natural variations once the JSL9 effects had subsided.

The nature of the Jovian nonthermal emission is explained in great detail by Carr et al. [1983] and only a few major points are recalled here. The emission is due to the synchrotron emission of relativistic electrons trapped in the planetary magnetic field. Most of the radiation is emitted when the electrons are close to their mirror points, strongly

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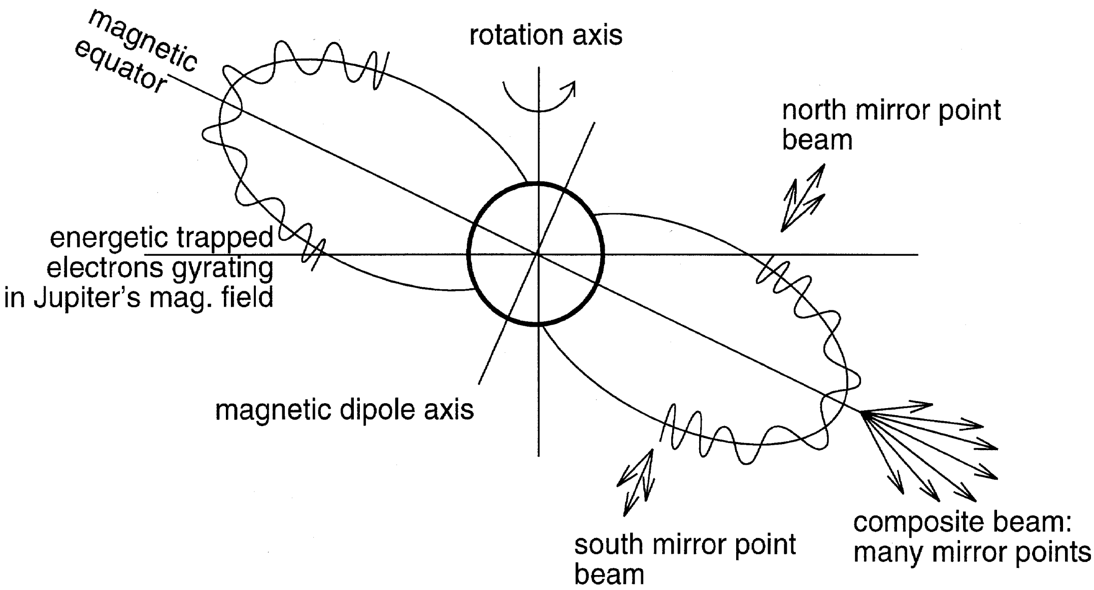

Figure 1: Beaming geometry of the Jovian synchrotron radiation. Adapted from Fig. 7.8a of Carr et al., [1983].

beamed and linearly polarized in the gyration plane (see Figure 1). The electron distribution in space, energy and pitch angle determines the brightness distribution and Stokes parameters of the radio source. The Jovian synchrotron emission is strongly polarized ($P_l \sim 0.20$) and exhibits negligible circular polarization ($P_c \sim 0.01$). The width and height of the total radio source are $\sim$ 6 and 2 R_J, respectively. The total flux density S and the degrees of polarization P_l and P_c of the nonthermal decimetric emission are periodically modulated by the rotation of Jupiter since the axis of the magnetic dipole is tilted with respect to the rotation axis ($\sim 10°$) of the planet. As a consequence, S exhibits two maxima per rotation of Jupiter.

The next section is devoted to the description of our observations carried out at Nançay. The data analysis is detailed in Section 3; then we explain how we determine the nonthermal flux density and the east-west diameter. Our results are discussed in the fourth section.

2 Observations with the NRT

The NRT is a large multifrequency radio telescope with 7000 m^2 geometrical area, providing a good signal to noise ratio on Jupiter. It is a meridian instrument which allows to track a given radio source $\sim$ 1 hour a day centered on transit time. We observed Jupiter at three pairs of frequencies in protected radioastronomy bands with linear horizontal (H) and vertical (V) polarization: 1.404 and 1.416 GHz (21.3 cm, 6.4 MHz bandwidth), 1.664 and 1.668 GHz (18.0 cm, 3.2 MHz bandwidth), 3.263 and 3.335 GHz (9.1 cm, 6.4 MHz bandwidth). The point source efficiency is 1.2, 1.0 and 0.5 K/Jy at 21.3, 18.0 and 9.1 cm. The system noise temperature is 45 K at 21.3 and 18.0 cm and 65 K at 9.1 cm.

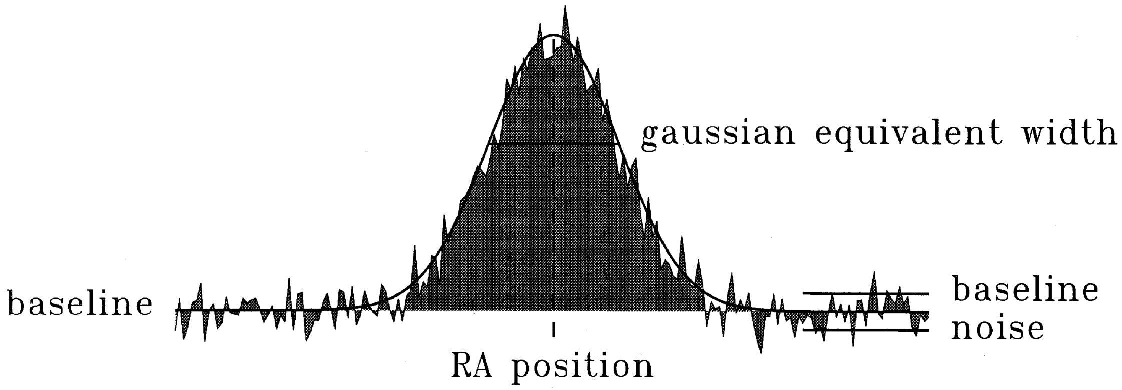

Figure 2: Gaussian fit of an individual drift scan across a radio source. The flux density corresponds to the grey shaded area.

Each daily Jupiter run lasts one hour and involves the following sequence of right ascension (RA) drift scans: 3 scans at 21.3 cm, 3 scans at 18.0 cm, 3 scans at 9.1 cm and finally 3 scans at 21.3 cm. The scan duration is 3 min at 21.3 and 18.0 cm and 1.5 min at 9.1 cm, which we deem appropriate to keep track of background sources. Each scan has four channels: one pair of frequencies in the H and V polarization. The confusion limit with the NRT is 0.02 Jy at 21 and 18 cm and 0.005 Jy at 9 cm, negligible compared to the Jovian flux density. For each daily Jupiter run, we observe two calibrators on the same day with the same time sequence as Jupiter; they are chosen amongst 3C48, 3C123, 3C286, 3C348, 3C433, P0023−26, P2203−18 according to the NRT schedule. The observing sessions of Jupiter are given in Table 1 and represent 236 hours between April 1994 and April 1996.

Periods	Days
2 – 17 April 1994	16
30 April – 17 May 1994	17
9 July – 30 Sept. 1994	71
11 – 16 Oct. 1994	6
2 – 6 Nov. 1994	5
14 – 29 Dec. 1994	15
2 – 23 Feb. 1995	15
1 – 17 April 1995	16
2 – 24 July 1995	16
1 – 17 Sept. 1995	16
9 Oct. – 17 Nov. 1995	25
25 March – 11 April 1996	18
	236

Table 1: Observing periods for Jupiter and number of days per period. During one day of observation, Jupiter and two calibrators are tracked for one hour.

3 Results

3.1 Data Analysis

Each individual drift scan of Jupiter and its calibrators is analysed by fitting a gaussian as shown on Figure 2. The NRT has an elliptical beam elongated in the north-south direction. The width of the Jovian radio emission is comparable to the east-west half power beam (HPB) given in Table 2 and a large beam broadening follows. The flux density of the planet is deduced from the areas under the scans of Jupiter and the calibrators. Drift scans are automatically rejected if any of the four following criteria deviates by more than 3 times the rms: baseline noise, gaussian fitting residual, RA position, gaussian equivalent width. This drastic procedure takes into account both instrumental failures and confusion due to background sources. For the total two years observing period, 38 % of the drift scans were rejected.

3.2 Nonthermal Flux Density

The data analysis is described in detail by Galopeau et al. [1997]. The nonthermal flux density is determined by subtracting the thermal contribution of the disk. From de Pater et al. [1982], we find respectively 0.87, 1.15 and 3.55 Jy at 21.3, 18.0 and 9.1 cm.

The modulation effect due to the rotation of Jupiter is removed by using a reference beaming curve. Four separate beaming curves were determined in order to cover our two years observing periods, namely: April – May 1994, August – September 1994, February – July 1995, March – April 1996. Each individual flux corrected for beaming is shown in Figure 3.

3.3 East-West Diameter

We have simply deconvolved the observed drift scans by assuming gaussian profiles for both the beam pattern and the Jovian brightness distribution (see Figure 4). This is clearly not the case for the latter one and caution must be exercized in interpreting the data. Furthermore, the situation is complicated by the fact that the Jovian flux density is the sum of a thermal component confined to the disk and an extended nonthermal component. The actual E-W width of the nonthermal brightness distribution is broader than the observed gaussian width by a correction factor C (see Table 2). The corrected values are shown on Figure 5.

λ	C	θ_B	S_{th}
21.3 cm	1.07	$\sim 240''$	0.87 Jy
18.0 cm	1.11	$\sim 180''$	1.15 Jy
9.1 cm	1.33	$\sim 120''$	3.55 Jy

Table 2: Correction factors used for determining the true nonthermal diameter, half-power widths of the beam profile (in arcsec) and thermal flux densities.

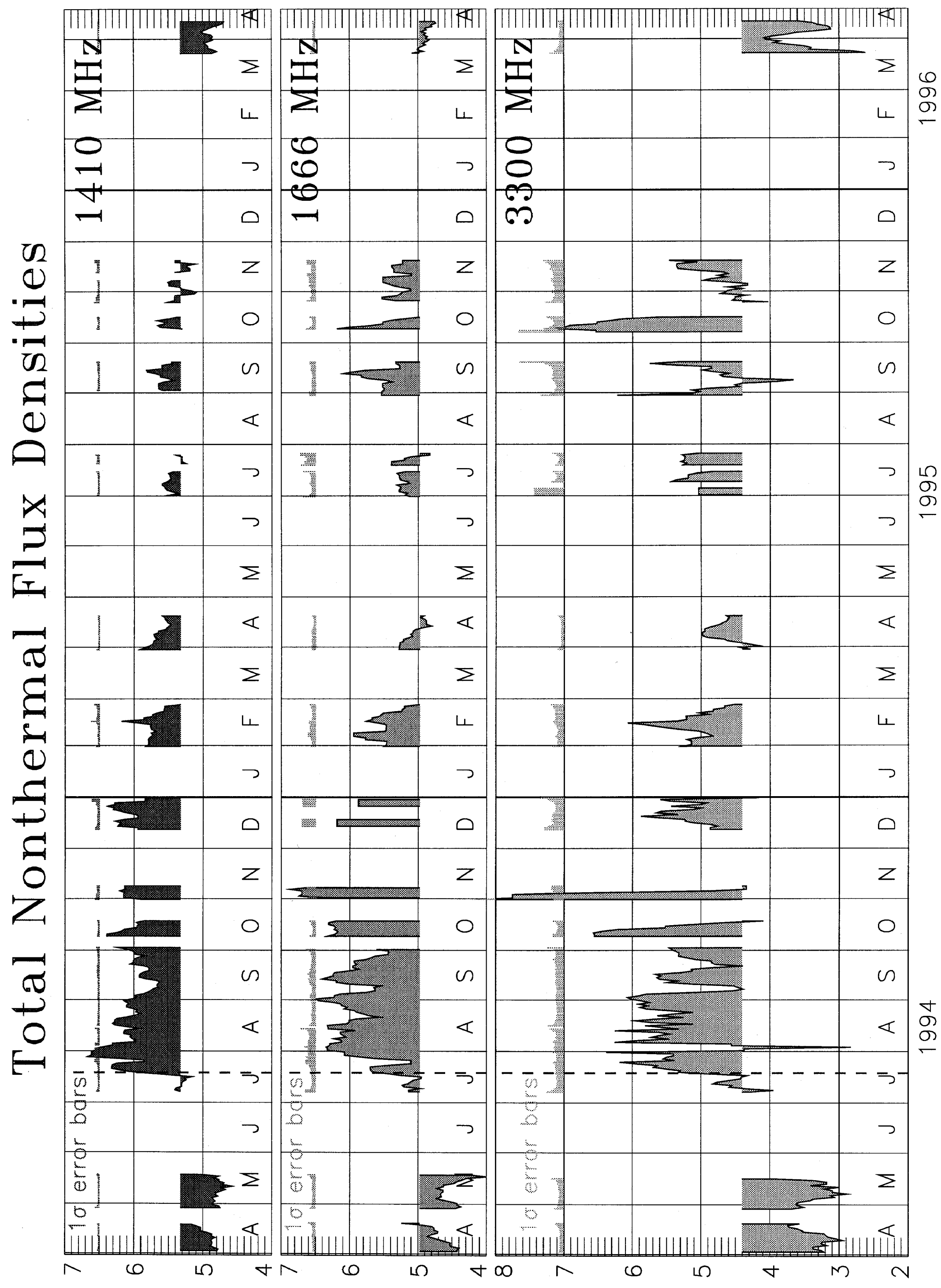

Figure 3: Total nonthermal flux densities observed with the NRT between April 1994 and April 1996. The fluxes are given at 1410, 1666 and 3300 MHz, normalized to 4.04 AU, corrected for Jupiter rotation and smoothed with a boxcar average of 5 days. The shaded areas show the difference between the actual flux and a reference level taken as the average preimpact flux in early July 1994. The dashed line indicates the time of SL9 impacts. The 1 σ error bars are displayed above the flux density curves.

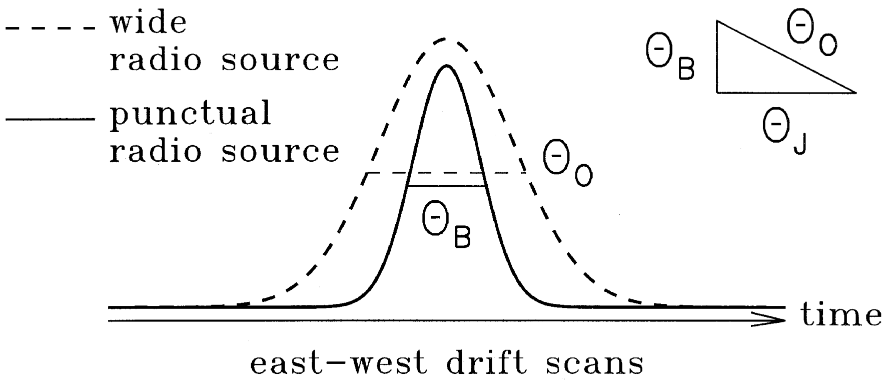

Figure 4: Gaussian profile fitted for wide and punctual radio sources. The east-west diameter corresponds to the half-power width of the Jovian brightness distribution. $\theta_{\rm O}$, $\theta_{\rm B}$ and $\theta_{\rm J}$ are respectively the half-power width of the observed drift scan, the beam profile and the Jovian E-W brightness distribution.

4 Discussion

When the twenty fragments of comet Shoemaker-Levy 9 collided with Jupiter in July 1994, unexpected changes occured in the Jovian radiation belts [de Pater et al., 1995]. First, a rapid increase of the flux density started during the week of impacts [Bird et al., 1996]. By late July, the flux density had reached its maximum. The exact percentage increase depends on the preencounter level. If one adopts the mean flux measured between 1 April and 16 July 1994 [Galopeau et al., 1996], the percentage increase reached 20 %, 25 % and 55 % at 21.3, 18.0 and 9.1 cm. In contrary, if one suspects natural variations over a 3 months period it is safer to take the mean flux of the early July data. In that case, the percentage increase becomes respectively 19 %, 22 % and 30 % [Galopeau et al., 1997]. In any case, the nonthermal Jovian spectrum becomes harder and this fact undoubtedly constitutes a signature of the mechanism responsible for the energization of the radiation belts. A second and new effect appeared several weeks after the collision: the size of the emitting region broadened at all wavelengths but mostly in the V polarization.

Contrary to expectations, the flux density did not decrease monotonically after April 1995. Our subsequent year of monitoring (April 1995 – April 1996) clearly shows that "natural" variations of the Jovian synchrotron emission are also present in addition to the modifications induced by the SL9 event. Indeed such natural changes were already suspected between April and July 1994 as well as between September and December 1994 [Galopeau et al., 1996]. Such a natural flux variation is particularly obvious during the second half of 1995. The flux starts to increase in July 1995 especially at 9.1 cm, suggesting a hardening of the nonthermal spectrum. The flux peaks in September – October and subsides in November. In April 1996, the Jovian flux density is back to the April – May 1994 levels at all wavelengths. The V diameter starts to rise in late October 1995, roughly one month later than the flux surge. But, again, the H diameter does not show any significant change. Contrary to the flux, the V diameter is not back to the preencounter value in April 1996.

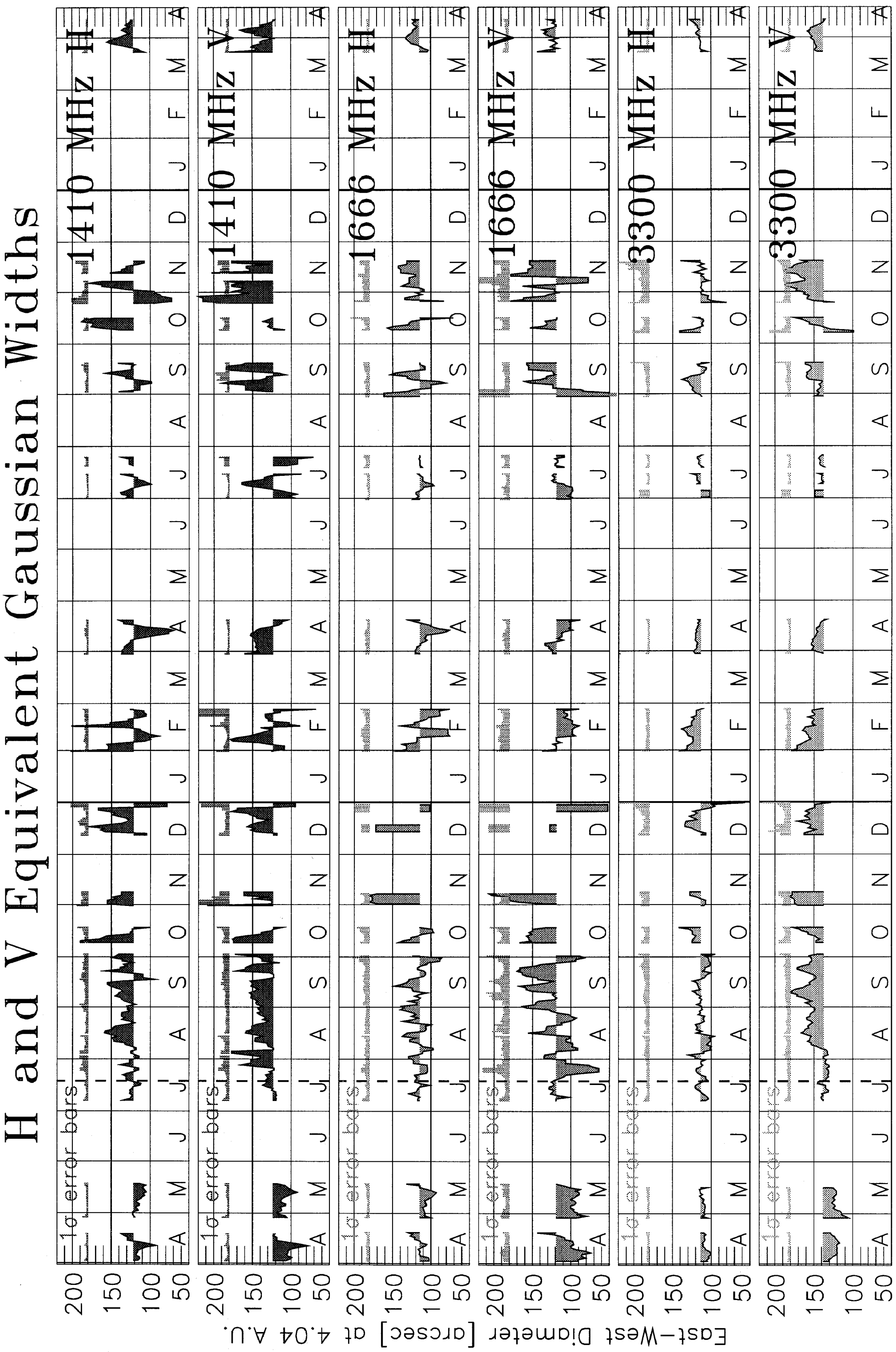

Figure 5: H and V equivalent gaussian widths of Jupiter in arcsec deduced at 1410, 1666 and 3300 MHz, normalized to 4.04 AU and smoothed with a boxcar average of 5 days. The shaded areas show the difference between the actual width and a reference level taken as the average preimpact width during the period 9 – 16 July 1994. The dashed line indicates the time of SL9 impacts. The 1 σ error bars are displayed above the diameter curves.

If one compares the “1995 event” with the “SL9 event”, it appears that the former is harder than the latter, i.e. the flux increase is less pronounced at 21.3 cm than at 9.1 cm. Finally, Figures 3 and 5 suggest that another natural effect may have occured in October 1994 superimposed on the “SL9 event” during its decay phase, with an amplitude comparable to the “1995 event”.

Gerard [1970a] had already reported relatively rapid fluctuations of the total flux density of Jupiter at 2695 MHz (11.1 cm) on time scales of days or weeks from December 1967 to August 1968; in addition a correlation was suggested with the 10.7 cm solar flux. Further observations at 21 cm between September 1974 and January 1975 [Gerard, 1976] revealed significant short term variations of the order of 10 % amplitude with duration of about one week.

5 Conclusions

Our two years monitoring of the Jovian radio emission strongly suggests that there are natural variations of the synchrotron radiation belts in addition to those induced by the SL9 impacts. The most remarkable one occurred in September – October 1995: the flux increased most noticeably at 9.1 cm and was followed by a broadening of the E-W diameter in the V polarization. The Nançay data also suggest that a similar event may have occurred in October 1994, during the descending phase following the SL9 collision.

Finally, one cannot exclude another natural variation between April – May and early July 1994 but of smaller amplitude than the other two. The natural surge of the Jovian synchrotron emission appears to be characterized both by a hardening of the flux and a broadening of the radiation belts in the V polarization.