THE LOW FREQUENCY VARIABILITY OF EXTRAGALACTIC RADIO SOURCES +

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1. Introduction

The flux variability of extragalactic radio sources at decimetric wavelengths (L.F.V.) is now considered a classical astrophysical subject connected with compact radio sources.

The observational constraints, already shown in several reviews and universally accepted, can be summarized in a few points.

1) There is an association between sources showing L.F.V. and sources with other 'extreme' characteristics: flat spectrum radio sources (50% of them show dS/S>6%), high frequency variables, superluminal expanding sources, optically violent variables and highly polarized quasars.

However there are exceptions, L.F.V. sources not identified with quasars, others with steep radio spectrum and so on.

2) The 'light-curves' of the sources are very complex, as a sequence of maxima and minima where it is very difficult to determine a pre-event stable level. Therefore, it is almost impossible to state whether the variations we observe are emission or absorption events.

3) The average time scale of the L.F.V. is about 2 years (corrected to the proper frame of the source). That means that for the majority of variable quasars, with the usual 'causality arguments', we obtain brightness temperatures in the range 10^{14}-10^{16} K. These values exceed by 2-4 order of magnitude the 10^{12} limit for incoherent synchrotron radiation. The expected inverse Compton X-ray fluxes were not detected for several sources observed during their active phases.

Several groups of researchers are currently working to extend the amount of information available on this subject and to provide new input for theoretical models, focusing the attention on the spectral character of the L.F. variations. It is also very important to search for a possible relationship between high and low frequency enhancements and monitor, with high resolution (milliarcsecond scale) the structures of the sources simultaneously with the L.F.V.

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2. Multifrequency monitoring of L.F.V.

Several programs of multifrequency observations have started during the last few years: H.E. Payne et al.(1982) are monitoring 30 sources at 5 frequencies in the range 300-1400 MHz bandwidth; S.R. Spangler and W. Cotton are observing 10 sources in the frequency range from 1.4 to 89 GHz; H.D. Aller, M.F. Aller, P.E. Hodge and the Bologna group have been observing monthly, since 1980, about 60 sources at 0.4, 4.4, 8.0 and 14.4 GHz; in the last year the frequencies 1.4 and 2.7 were also added; W.B. McAdam is monitoring a big sample of ~180 sources at 0.84 GHz.

We refer to the paper of B. Dennison (this volume) for detailed results of multifrequency observations. We wish only to point out that the L.F. variable sources can show two different spectral behaviours.

1) Some sources follow, at least qualitatively, the expectation of standard models of variability. The bursts are first seen at very high frequency and then they drift towards lower frequencies until they reach decimetric wavelenghts, with reduced amplitude. This is the case of BL Lac.

2) However, the majority of sources show a narrow L.F.V. bandwidth from 300 to 1000 MHz (for example DA 406). Other sources show, together with L.F.V., a high frequency activity that follows more or less the expectations of the standard models, leaving a mid-frequency gap around 1-3 GHz where the source is quite quiescent (3C 454.3).

Spangler and Cotton (1981) noted close coincidences between some decimetric and millimetric events in the last type of sources.

To evaluate the statistical significance of these coincidences we have used the sample of 50 sources simultaneously observed at 408 MHz at Bologna and at 8 GHz at Michigan University during the last 3 years.

For each source, the light-curves at the two frequencies were first interpolated to obtain regular monthly sampled functions and after they were correlated with each other. The distribution of correlation coefficients were compared with a sample obtained correlating the function at 8 GHz of a source with that at 0.4 GHz of an other source, chosen at random. The real distribution of the correlation coefficients shows no excess of high coefficients with respect to the random population. We can put a limit of the order of 5% to the occurrence of sources with simultaneous bursts at 8 GHz and 0.4 GHz. Also introducing a delay in time between the two frequencies we find a small (not significant) excess in the real distribution. This excess is mostly due to sources with a burst spectrum behaviour like BL Lac, and the occurrence of this kind of sources is not greater than 10%.

These data give no evidence for correlated 8 GHz and low frequency activity through the intermediate gap, but the same analysis should be made with data at higher frequency (>30 GHz).

3. The 18 cm VLBI monitoring program

We carried out 18 cm VLBI observations in two epochs of 23 L.F. variable sources to determine their structures, their physical sizes, and to investigate the structural changes connected with the flux variations (Romney et al. 1983).

The first observations were made in February 1980, using 7 telescopes, namely: Simeis USSR, Onsala Sweden, Effelsberg W.Germany, Artebeesthoek South Africa, Green Bank, Fort Davis and Owens Valley USA. The observations were repeated in October 1981 with the addition of the Jodrell Bank station.

The choice of the observing frequency of 18 cm represented a compromise between low frequency and high resolution. Unfortunately, this frequency is close to the 'intermediate frequency gap', but the resolution of few mas is good enough for detecting the structural changes expected by the current models based on relativistc motion along the line of sight.

The analysis of the first observations was done independently in different institutions and hybrid maps were obtained for all sources. All sources have been detected in the transatlantic baselines and all the compact features appear resolved in the longest baselines with extension of the order of 2 - 3 mas.

The most common morphology can be described as being a core-jet like structure, with linear sizes ranging from 5 to 50 pc. There are, however, also sources that present elongated emission regions symmetric about the core, that are not expected in these core dominated objects (fig.1). 60% of the sources have 'large' scale structures on a scale of few arcsecond. The comparison between arcsecond and milliarcsecond structures shows a great misalignment. This result is similar to that found by Browne et al. (1982), who studied a sample of core dominated sources.

The reduction of the second run of observations is still in progress and we show here only the preliminary results on the comparison between the two epochs.

The most spectacular variation of total power flux between the two epochs is shown by BL Lac, whose 18 cm total flux increased by a factor 2.3. In fig.2 we show the two epochs VLBI maps and the light-curves of the source at three different frequencies. It is possible to see a strong burst shifting with time toward lower frequencies. The map presents an extended small jet with the same flux density of about 600 mJy at both epochs. The increased central component is resolved in the longest baselines with an extension of 2.4 mas in p.a. 10°. The extension is almost the same in the two epochs.

An other example of structural change in the central component is shown by the source 0607-15 (fig.3). From the light-curves it is not completely clear whether the L.F.variation seen at 408 MHz corresponds to the event seen earlier at high frequency. Also in this case the jet is very similar in the two epochs and the decrease is due to the central component (4 mas extended in p.a. 60°).

Again a similar case: 1730-13 (fig.4), where the flux decreases in a broad frequency band from 0.4 to 8 GHz. The shape of the source is the same in the two epochs and the decrease is mostly due to the central component (2.3 mas). The minor differences of the structures cannot be considered significant, but it is worthwhile noting that this source shows a radio emission rather symmetric about the core.

Fig.5 shows the source DA 406. Its 18 cm total power flux showed a flux increase of ~15% between the two epochs, that corresponds to the strong flare seen at 408 MHz. If we interpret this variation in term of relativistic motion the 408 MHz time scale implies a brightness temperature of $2\text{x}10^{15}$ K with a kinematic factor (δ) ~12 and an apparent expansion of about 0.7 mas between the two epochs*. The two maps are very similar: a single compact source increased ~10% in flux but with the same extension in the two observations (3 mas in p.a. 10-20°). An expansion of only 0.5 mas would cause a decrease of 40% in the fringe visibilities of the baselines with the S.African station.

3C 454.3 (fig.6) is an other interesting case. Unfortunately, 18 cm corresponds to the almost quiescent frequency gap for this source, but nevertheless, after the first VLBI measurement, the source had a strong burst at 408 MHz. The corresponding brightness temperature is of the order of $1.3\text{x}10^{15}$ with $\delta \sim 11$ and an expected apparent expansion of about 1 mas.

The two maps are very similar and the separation between the core (E component) and the jet (W component) is unchanged. From spectral information derived by 2.8 and 6 cm VLBI observations (Pauliny-Toth et al.1981) we expect to see mainly the jet at 408 MHz, and therefore we would expect an increase of 1 mas just in the separation of the two components. This expansion is excluded by the data at the level of 1 sigma. However the data can not exclude an expansion of 1 mas of the central component, that could contribute to the total L.F. flux by not more than a few (2- 3) Jy.

A similar case is NRAO 140 (fig.7). An interpretation of the L.F.V. in term of relativistic motion would predict an expansion of the 408 MHz emitting region of the order 0.7 mas.

The 18 cm map shows a core of about 3 mas that is resolved at 2.8 cm in two superluminal expanding components at a rate of about .10-.14 mas per year (Marscher and Broderick 1982). The second E component is a jet visible also at 2.8 cm. It has a steep spectral index, of the order of one, down to .4 GHz, while the other components are completely self-absorbed at this frequency (Marscher and Broderick,1981). Also in

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* H=100, q_o=1

this case we have no direct evidence of an increase in the angular separation of the two components.

We do not wish to draw general conclusions from this comparison, because the data of only a few sources of the second run are completely reduced and the program could produce some surprises. However, the first impression is that the L.F.variations are not always accompanied by superluminal expansions. We would like merely to point out that the experimental landscape of the L.F.V. is quite complex. The models that invoke synchrotron electrons and magnetic fields relativistically ejected along the line of sight, fit many observational behaviours but surely they can not explain all the observed properties of these sources.

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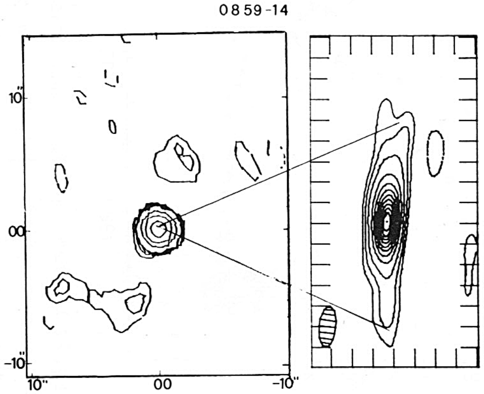

Fig. 1 20 cm VLA map (left) and 18 cm VLBI map (right) of the source 0859-14. In the VLBI map the first contour level corresponds to 5% of the peak flux, the distance between ticks corresponds to 5 mas.

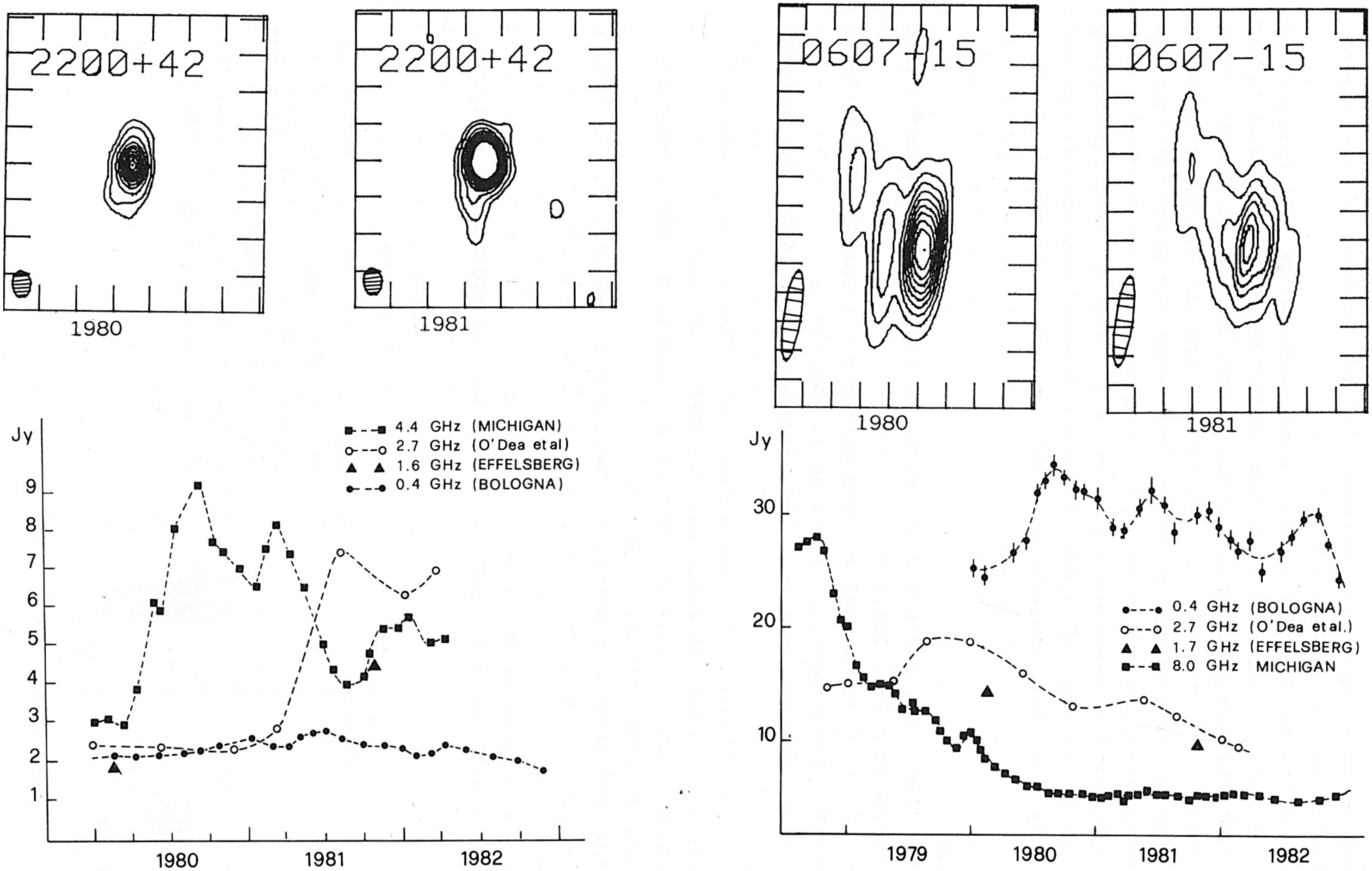

Fig.2-3 Two epochs VLBI maps of Bl Lac (2200+42) and 0607-15. The distance between ticks corresponds to 5 mas. The contours are plotted at the same flux levels for both epochs. The light-curves at different frequencies are shown for each source.

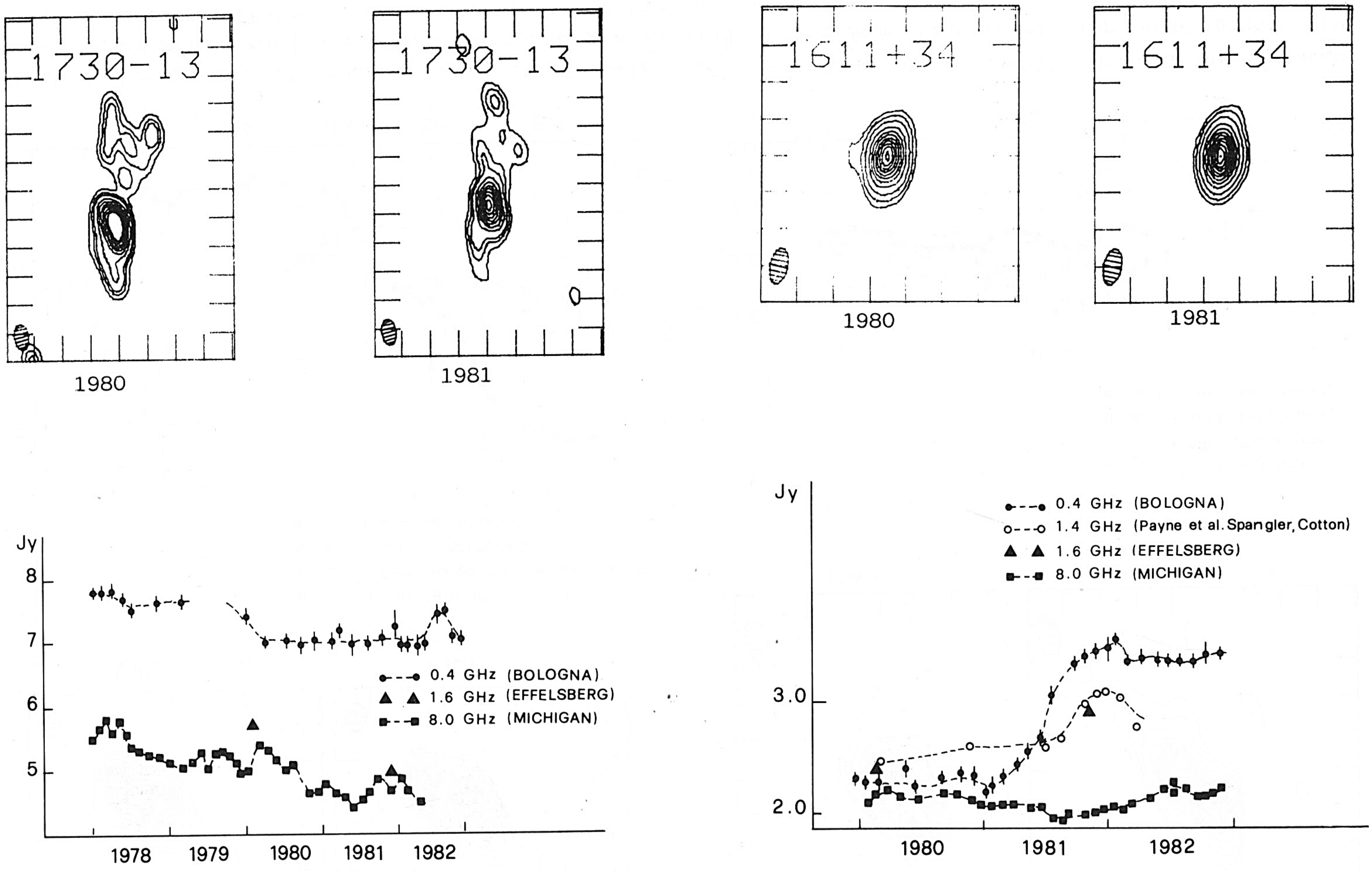

Fig.4-5 Two epochs VLBI maps of 1730-13 and DA 406 (1611+34). The distance between ticks corresponds to 5 mas. The contours are plotted at the same flux levels for both epochs. The light-curves at different frequencies are shown for each source.

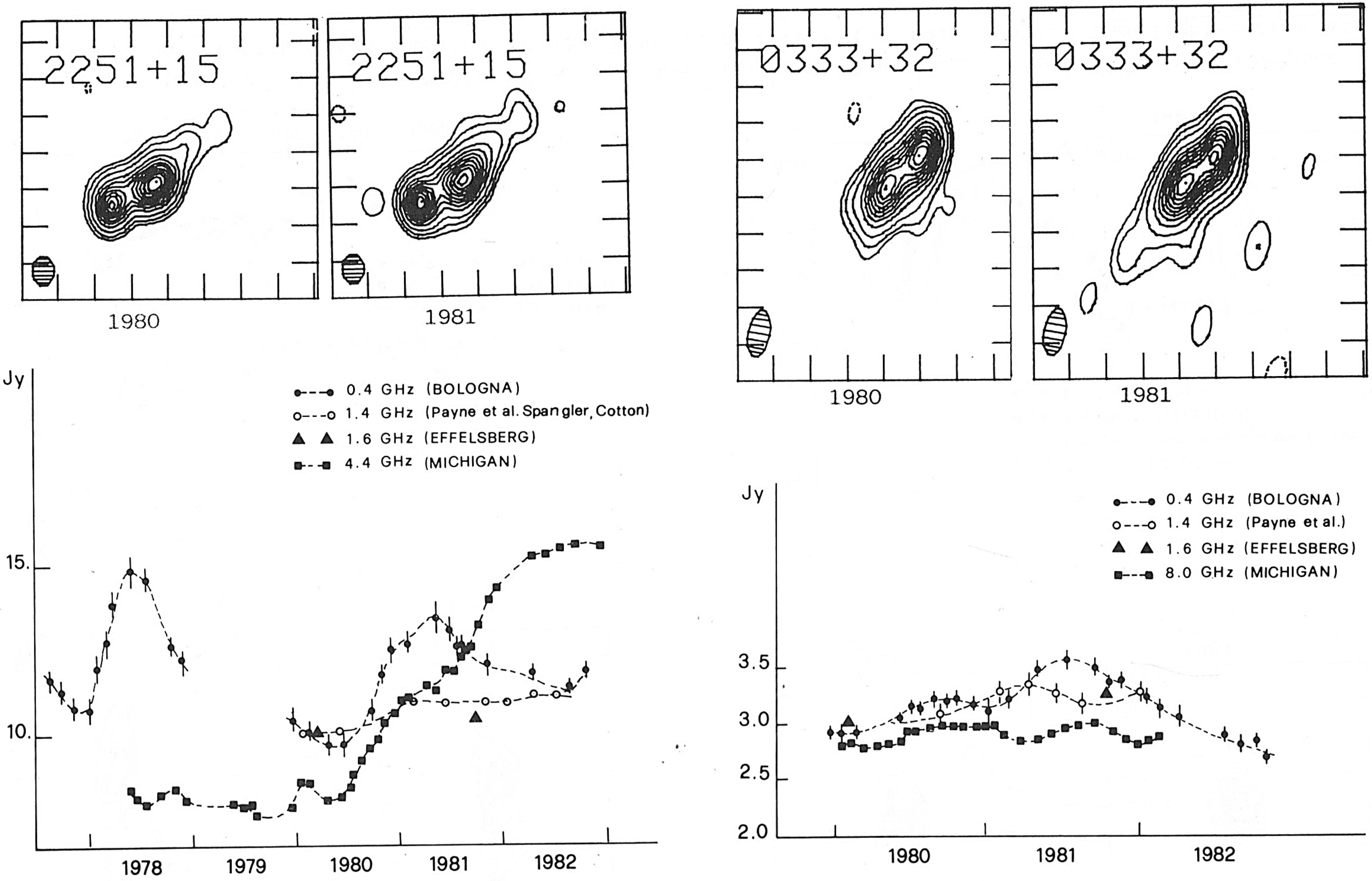

Fig.6-7 Two epochs VLBI maps of 3C 454.3 (2251+15) and NRAO 140 (0333+32). The distance between ticks corresponds to 5 mas. The contours are plotted at the same flux levels for both epochs. The light-curves at different frequencies are shown for each source.