TIME EVOLUTION OF AN ENSEMBLE OF RELATIVISTIC ELECTRONS IN A NON-HOMOGENEOUS ATMOSPHERE

E.Franciosini

The flaring and quiescent radio emission of RS CVn stars has been interpreted in terms of the time evolution of a population of electrons injected in the source at the beginning of the flare and then undergoing energy losses [1]. A uniform source with a locally constant magnetic field was assumed.

In this paper new calculations of the time evolution of the electron population are presented. A more realistic magnetic field configuration reproducing a bipolar starspot group is considered and the thermal absorption is taken into account. The time evolution of the spectrum and of the brightness distribution, in the extreme configuration of a loop viewed face-on, are shown and compared with available spectral and VLBI observations.

1. INTRODUCTION

RS CVn binary systems present a highly variable radio emission ranging from a few mJy in quiescent periods up to several hundreds of mJy during flares. The spectra of the flaring and quiescent components are very different: the flaring spectrum is optically thick at low frequencies with a peak at about 10 GHz, while the quiescent one is optically thin and has a power-law dependence with a spectral index $\alpha \simeq -0.2$.

Chiuderi Drago and Franciosini [1] have shown that the quiescent spectrum and other observational characteristics are well reproduced in the assumption that both the flaring and quiescent components are due to the time evolution of a population of electrons accelerated during the flare and then undergoing collision and synchrotron energy losses. The assumed initial distribution is a power-law of the form:

$$N(\gamma) \propto (\gamma - 1)^{-\delta} \qquad (1)$$

reproducing, with $\delta = 2$ or $\delta = 3$, the observed flaring spectrum.

As a result of energy losses, the electron population changes with time causing a modification of the spectrum of the emitted radiation. Calculations were performed in the assumption of a locally constant magnetic field and have shown that the lifetime of relativistic electrons is of the order of 5 days in regions where the magnetic field is $B \simeq 5$ G.

In this paper new results obtained in the more realistic assumption of a non-uniform magnetic field are presented. The assumed source structure is described in next section. The time evolution of the spectrum and of the brightness distribution are shown in section 3; a detailed calculation of the time evolution of the electron population can be found in [2].

2. THE SOURCE STRUCTURE

It is assumed that the source is a dipolar magnetic loop reproducing two starspots on the stellar surface, with angular separation $\Theta = 90°$ and radius $R_{spot} = 20°$, in agreement with the values derived from the analysis of the optical light curves [3]. The two spots are generated by a dipole buried under the surface at a certain depth; the depth and strenght of the dipole are chosen in order to give, in the centre of the starspots, a magnetic field $B_{max} = 1000$ G ([4, 5]) perpendicular to the stellar surface.

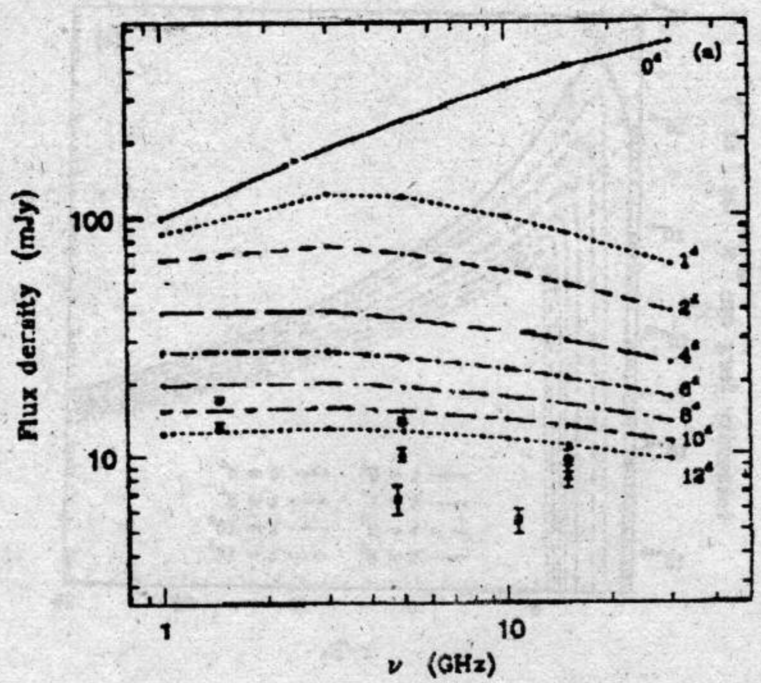
In the plane of the sky the loop is limited by the two lines of force passing through the borders of the spots; for simplicity, along the line of sight the source has been assumed to have a triangular shape and the magnetic field is assumed constant along this direction.

As in the previous calculations the thermal plasma density is considered uniform within the source, with $N_e = 2 \times 10^8 \text{cm}^{-3}$. Moreover, the thermal plasma is assumed to affect the emitted radiation only by free–free emission and absorption. The work on the inclusion of the Razin effect in the model is now in progress and the results will be published in a future paper.

3. TIME EVOLUTION OF THE SPECTRUM AND OF THE BRIGHTNESS DISTRIBUTION

The spectrum of the radiation emitted from the loop has been computed at different times for an initial distribution with $\delta = 2$ and $\delta = 3$ (Fig.1). The initial total number density of relativistic particles N_0 has been adjusted in order to reproduce the observed flaring flux. The trend of the spectrum is very similar to the one obtained in the assumption of a uniform magnetic field: the initially optically thick spectrum, characteristic of flares, rapidly flattens out, becoming optically thin in the frequency range of interest in one or two days; the shape then remains nearly constant for several days as the flux density decreases. The longer lifetime of the emission with respect to the previous calculations is due to the contribution of regions of very low magnetic field, where the energy losses are less efficient.

It can be seen that the spectral index α between 1 and 5 GHz decreases with time from positive to negative values: this trend agrees very well with the relationship between spectral index and radio luminosity, observed in some objects of this class [6], showing a decrease of α with decreasing luminosity.



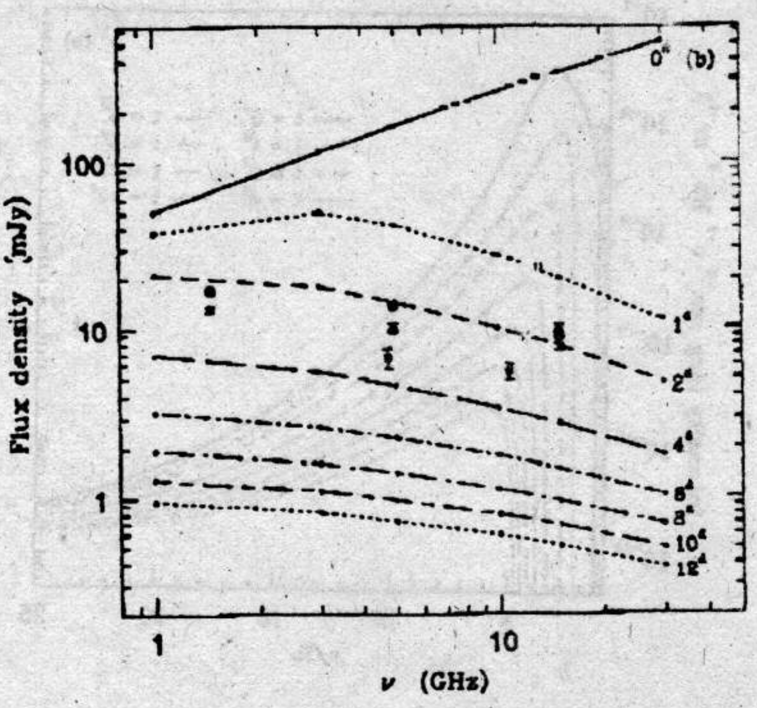


Fig.1. Time evolution of the computed radio spectrum using an initial population of electrons with $\delta = 2$ and $N_o = 5 \times 10^4$ cm^{-3} (a) and with $\delta = 3$ and $N_o = 4 \times 10^6$ cm^{-3} (b). Observations of the system UX Ari are plotted for comparison.

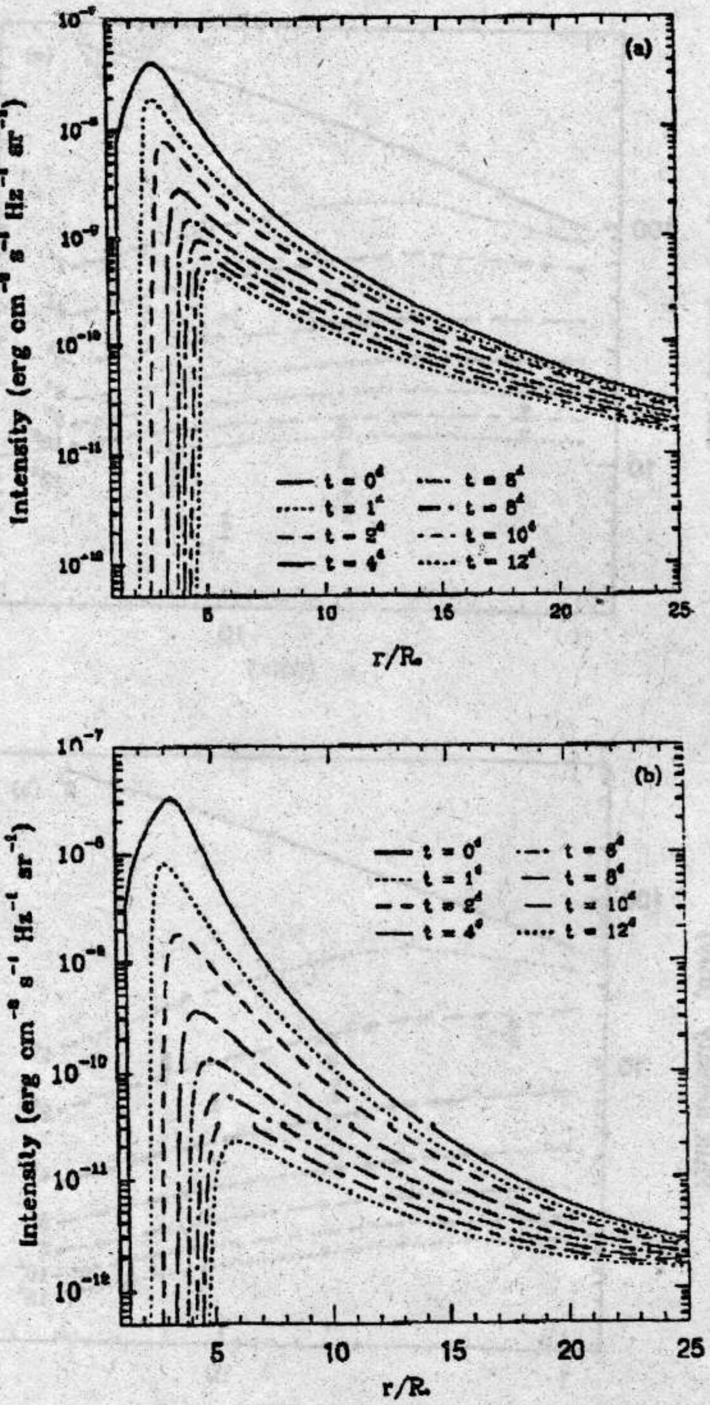


Fig.2. Time evolution of the brightness distribution at $\nu = 5$ GHz, using an initial population of electrons with $\delta = 2$ and $N_0 = 5 \times 10^4$ cm^{-3} (a) and with $\delta = 3$ and $N_0 = 4 \times 10^6$ cm^{-3} (b).

It is to be noted also that the exponent δ of the initial distribution determines not only the slope of the spectrum, but also the velocity of decrease of the flux density and consequently the lifetime of the quiescent component. Continuous observations of the time evolution of the spectrum for some consecutive days after a flaring event could therefore provide a precise indication on the value of δ, which cannot be univocally determined from the flaring spectrum alone.

Fig.2 shows the time evolution of the brightness distribution, at $\nu = 5$ GHz, on the equatorial plane of the dipole, in the two cases $\delta = 2$ and $\delta = 3$. For $t = 0$ the intensity has a maximum near the star, and then decreases with the distance, more rapidly for $\delta = 3$. In both cases the peak brightness is about one order of magnitude greater than the brightness at a distance of six stellar radii, which is of the order of the binary separation in the case of the system UX Ari. The source has therefore a core–halo structure similar to the one observed during a flare with VLBI tecniques [7]. At successively later times the intensity decreases, expecially near the star, in regions of high magnetic field where energy losses are more efficient. This explains also the shift of the maximum with time towards higher values of r/R_*. After a few days the maximum is less pronounced: in this phase only a weak halo emission remains, in agreement with other VLBI observations [8].

REFERENCES

1. Chiuderi D.F., & Franciosini E. //ApJ. 1993. V.410. P.301.
2. Franciosini E., & Chiuderi D.F. — This issue. 1995.
3. Rodonò M., et al. //A&A. 1986. V.165. P.135.
4. Giampapa M.S., Golub L., & Worden S.P. //ApJ. 1983. V.268. L121.
5. Gondoin P., Giampapa M.S., & Bookbinder J.A. //ApJ. 1985. V.297. P.710.
6. Mutel R.L., Morris D.H., Doiron D.J., & Lestrade J.-F. //AJ. 1987. V.93. P.1220.
7. Mutel R.L., Lestrade J.-F., Preston R.A., & Phillips R.B. //ApJ. 1985. V.289. P.262.
8. Massi M., Felli M., Pallavicini R., Tofani G., Palagi F., & Catarzi M. //A&A. 1988. V.197. P.200.

Department of Astronomy and
Space Science, University of
Florence, Italy

Поступила в редакцию
10 ноября 1993 г.