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Periodic radio flaring on the T Tauri star V 773 Tauri

M. Massi, K. Menten, and J. Neidhöfer

Max Planck Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany

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Abstract. We present the results of a monitoring of the binary system V773 with the Effelsberg 100-m telescope extended over 522 days. A clear periodicity present in the flaring activity is confirmed by a dominant peak at 52 ± 5 days in the Fourier power spectrum. Folding the data with the orbital period of 51.075 days the flares cluster at the periastron passage. The detailed monitoring around one periastron passage with the VLA and with the Effelsberg telescope reveals a modulation of the radio emission in agreement with the 3.4 days rotational period of the star spots, observed in the optical range. A possible scenario explains the 52 days periodicity and the 3.4 days modulation with recurrent interactions of giant loops, anchored on the two rotating stars of the system, consecutively colliding for two or three rotations during each periastron passage. Considerations about the large sizes required for the loops caused us to re-examine the generally assumed scale-height and we conclude that such a large size might be possible.

Key words. stars: individual: V773 Tau – radio continuum: stars – stars: flare – sun: oscillations

1. Introduction

X-ray observations of the Sun have shown that almost all the coronal emission comes from plasma confined in closed magnetic structures in the form of arcs (loops). In this sense, instead of saying that loops are in the corona we should rather say that they are the corona (Vaiana & Rosner 1978). The theory of the dynamo developed by Parker (1979) explains how the differential rotation generates a toroidal field in the interior of the star from an initial dipole field and how the convection bringing this field up to the surface gives rise to the emergence of the loops. In its emergence on the surface, one loop may intrude into other already-established loops; this occurrence of two fields of opposite directions pushed one against the other is one of the assumed mechanisms of large flares. The release of energy produces relativistic particles emitting bremsstrahlung in hard X-rays and gyro-synchrotron radiation at radio wavelengths (Parkes 1979; Bastian et al. 1998). Images of the Sun with the Yohkoh telescope and the Nobeyama Radio Interferometer (Nishio et al. 1996) have actually confirmed this scenario of colliding loops.

The RS Canum Venaticorum (RS CVn) stars are close binary systems with flares in radio and X, orders of magnitudes stronger than solar flares. The higher degree of magnetic activity is due to an increased efficiency of the dynamo because of the deeper convective zone of those stars and because of their higher rotational velocity, compared to the Sun. In fact, the more active star of the system is generally a sub-giant of spectral type G or K rotating in less than one month (Owen et al. 1976; Dulk 1985; Elias et al. 1995; Beasley & Güdel 2000).

One of the most active RS CVn stars, UX Arietis, produces strong flares following two clearly alternating "regimes": an active regime (with flares above 250 mJy) and a quiescent one alternating with a period of 158.7 days (Massi et al. 1998). During the active phase the activity does not take place randomly, but shows a period trend of 25.5 days. Moreover the sign of the circular polarization seems to reverse within the cycle of 25 days, returning to its initial value after 56 ± 4 days (Massi et al. 1998). What is the origin of this periodicity? UX Arietis is a binary system with an orbital period of 6.44 days (Carlos & Popper 1971; Elias et al. 1995). Before speculating on possible mechanisms responsible for the periodic emergence of the loops, one must first establish whether the flares could be the result of collisions of loops anchored on the two stars of the system. VLBI observations of UX Arietis have been interpreted by a model of two intruding loops, emerging from the same star and pushed one against the other (Franciosini et al. 1999). However, in close binary systems the magneto-spheres of the two stars may interact, giving rise to a joint magnetosphere (Uchida & Sakurai 1983). In order to study the mechanism of the flares and their relationship with the dynamo we selected a new source (avoiding the complication that may be implied by a modified topology of the magnetic field because of the small distance of the stars). V773 Tau (HD 283447)

Send offprint requests to: M. Massi,
e-mail: `mmassi@mpifr-bonn.mpg.de`

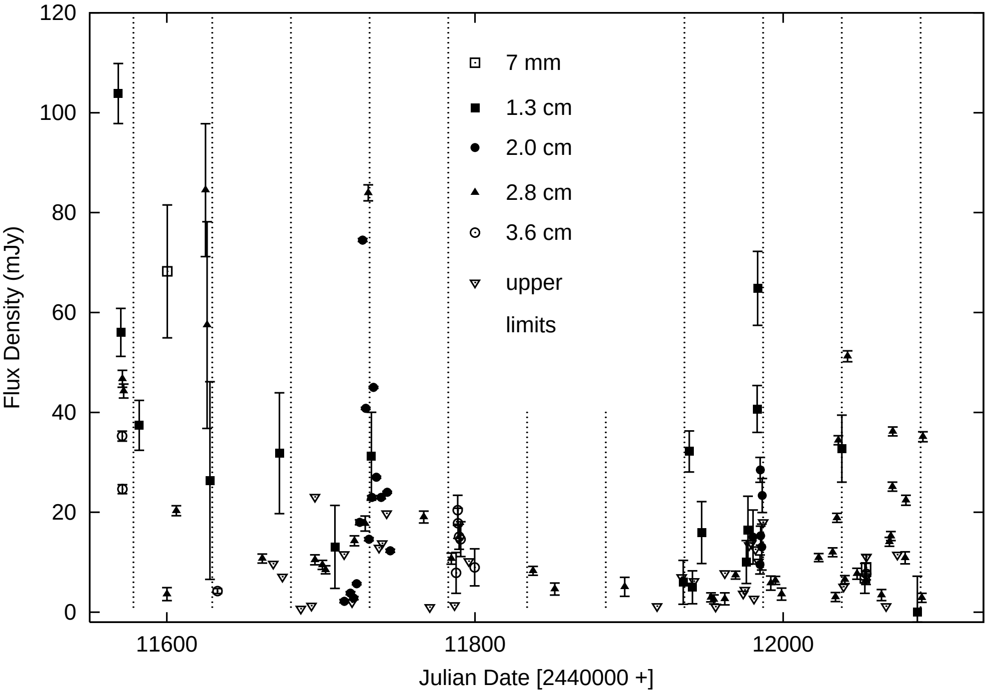

Fig. 1. Observations of V773 Tau with the Effelsberg 100-m telescope and the VLA. The VLA observations are those at 2.0 cm centered at Julian Day 11730. The system V773 Tau is composed of two stars orbiting with a period of 51.075 days; the bars in the figure show the periastron passages assuming as initial epoch t_0 = 2449330.94 JD (Welty 1995).

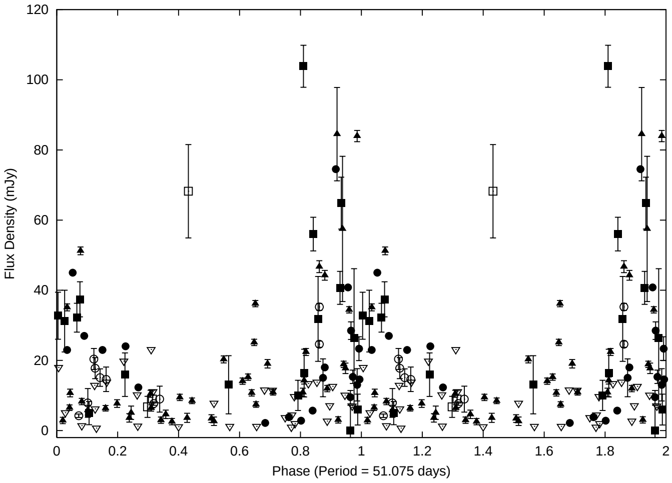

Fig. 2. Radio observations of V773 Tau folded with the orbital period of 51.075 days. Phase 0 (1, 2) refers to the passage at periastron.

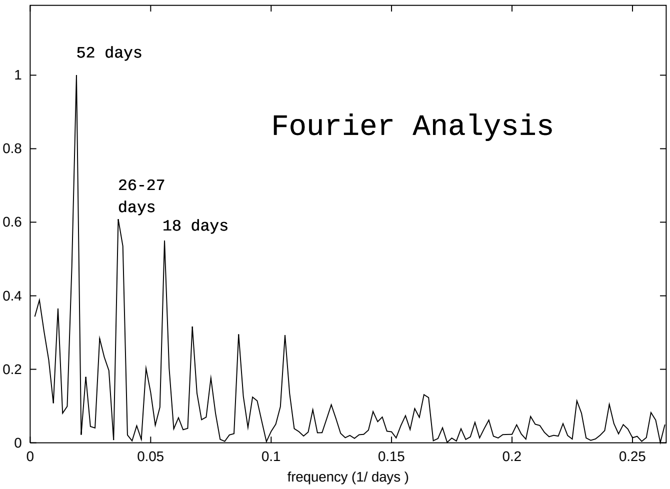

Fig. 3. Fourier power spectrum of the time series shown in Fig. 1. The dominant peak is at 52 ± 5 days. The second peak (corresponding to 27.4 ± 1.4 and 25.9 ± 1.3 days) could be one harmonic of the dominant peak. The third peak at 17.9 ± 0.6 days is a mode interaction feature: $\frac{1}{\frac{1}{52}+\frac{1}{27.4}} = 17.9.$ and disappears when the Phase Dispersion Minimization method (Stellingwerf 1978) is used instead of the Fourier analysis.

also is a binary system, but with the two stars separated by tens of stellar radii (Welty 1995). V773 Tau belongs to the class of T Tauri stars (Neuhäuser 1997; Guenther et al. 2000). The fact that they are fully convective objects, together with their fast rotation, makes these objects very similar to the RSCVn-type of stars from the point of view of their magnetic activity with radio flares of three to six orders of magnitude brighter than solar flares (Feigelson & Montmerle 1999).

2. Periodicities in the stellar activity

V773 Tau was observed with the Effelsberg 100-m telescope over a frequency range spanning from 8 GHz (3.6 cm) to 40 GHz (7 mm). The monitoring covers a total time interval of 522 days during which time we collected 110 samples. No simultaneous measurements at different frequencies were performed. The observations have

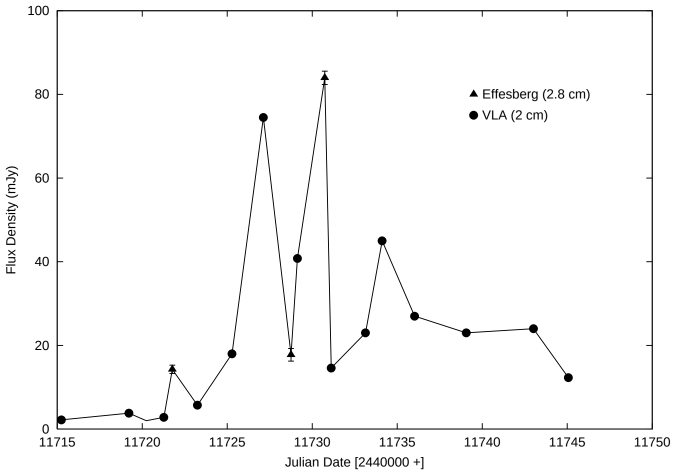

Fig. 4. Details of Fig. 1 around 11730 JD. At that epoch close to the passage at periastron we monitored an activity lasting about a week. The separation between consecutive peaks is 3.6 and 3.4 days.

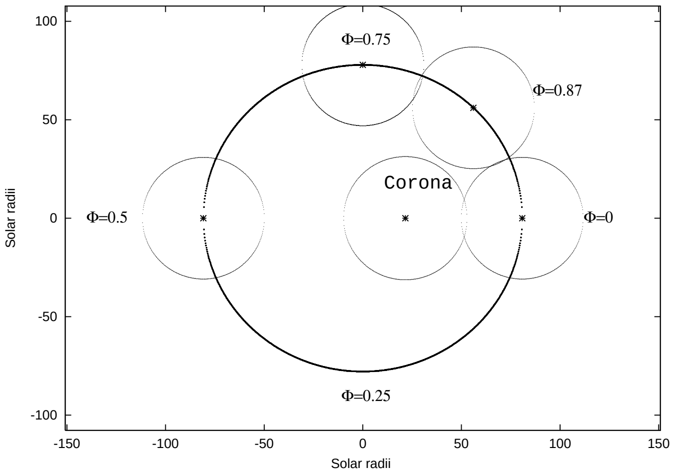

Fig. 5. Sketch of the binary system V773 Tau. The orbit parameters are those of Table 2 by Welty (1995). One star is plotted in the focus of a slightly eccentric orbit, the other star is shown at its four different positions along the orbit. The coronae, here simplified as spheres, may interact and produce flares.

been performed as already described in Neidhöfer et al. (1993). The source was also observed with the VLA for one month centered around JD = 244411730[1] at a frequency of 14.96 GHz (2.0 cm). The sampling rate of two days resulted in 14 samples.

The total data set is presented in Fig. 1. Figure 2 shows the data folded with the orbital period of 51.075 days. Some flares are slightly displaced from the periastron passage (indicated with bars in Fig. 1 and related to phase = 0, 1, 2 in Fig. 2). However, a clustering is evident. The flare at 7mm clearly deviates from this general trend. The spectral analysis (Fig. 3) confirms a main period of 52 ± 5 days.

Figure 4 shows the flares around JD = 244411730 in detail. The peaks are 3.6 days and 3.4 days apart, respectively. Star spots on the surface of V773 Tau produce light variations with a period of 3.4 days as reported by Rydgren & Vrba (1983). Because the star spots are the foot points of the loops confining the radio emitting plasma, the optical and our radio variations can be explained by an active region quite stable in longitude, coming in and out of the line of sight as the star rotates. The energy distribution of the relativistic electrons, responsible for the emission, changes due to losses by synchrotron radiation and by Coulomb collisions over time. The fact that we still see a high density flux after a rotation (see Fig. 4) either implies that the flaring process lasts more than three days or that after one rotation a mechanism (perhaps inter-binary interaction) again activates the flaring process.

3. Inter binary colliding loops

A possible scenario which can explain our result of the 52 ± 5 days periodicity is that the two stars, which have an orbital period of 51.075 days, possess quite large loops which collide at periastron. While for simplicity in the sketch of Fig. 5 we show spherical coronae, in reality the coronae are rather asymmetric. In fact, the observed 3.4 days modulation indicates quite confined loops coming in and out of the line of sight while the stars rotate. The extension of the loops should be large enough to allow at least for two or three collisions to explain the observed consecutive activity of about a week. In Fig. 5 we see that the separation at the periastron is about 56 $R_\odot$, while at the apoastron it is about 95 $R_\odot$. The difference between these two distances is appreciable. The question is: can one star have loops of about 25–30 $R_\odot$?

The pressure scale-height H is normally derived assuming constant gravity, that is $g = G\frac{M}{r^2}$, where r varies from the stellar radius R_* to $R_* + H$, is set equal to $g \simeq G\frac{M}{R_*^2}$. However the resulting value for the pressure scale-height is underestimated for the T Tauri stars: for V773 Tau a value lower than 15 $R_\odot$ results, even for the highest temperatures (Skinner et al. 1997), whereas VLBI measurements indicate $H > 24\ R_\odot$ (Phillips et al. 1996). That is because of the assumption of constant gravity ($r \simeq R_*$) that actually implies $H \ll R_*$ producing as a result low values for H. Assuming the correct value of the gravitational force the pressure scale height becomes:

$$H = \frac{0.072\frac{R_*^2 T}{M}}{1 - 0.072\frac{R_* T}{M}} \qquad (1)$$

with H and R_* in $R_\odot$, M in $M_\odot$ and T in 10^6 K. This general equation for typical values of $M = 1\ M_\odot$, $T = 6.5 \times 10^6$ K and a stellar radius $R_* = 2\ R_\odot$, gives the result $H = 30\ R_\odot$. In conclusion, such a scenario of stars, with giant loops colliding at the periastron, does not contradict the theory.

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[1] VLA is a facility of the USA National Science Foundation operated by the NRAO in support of NASA High Energy Astrophysics programs.

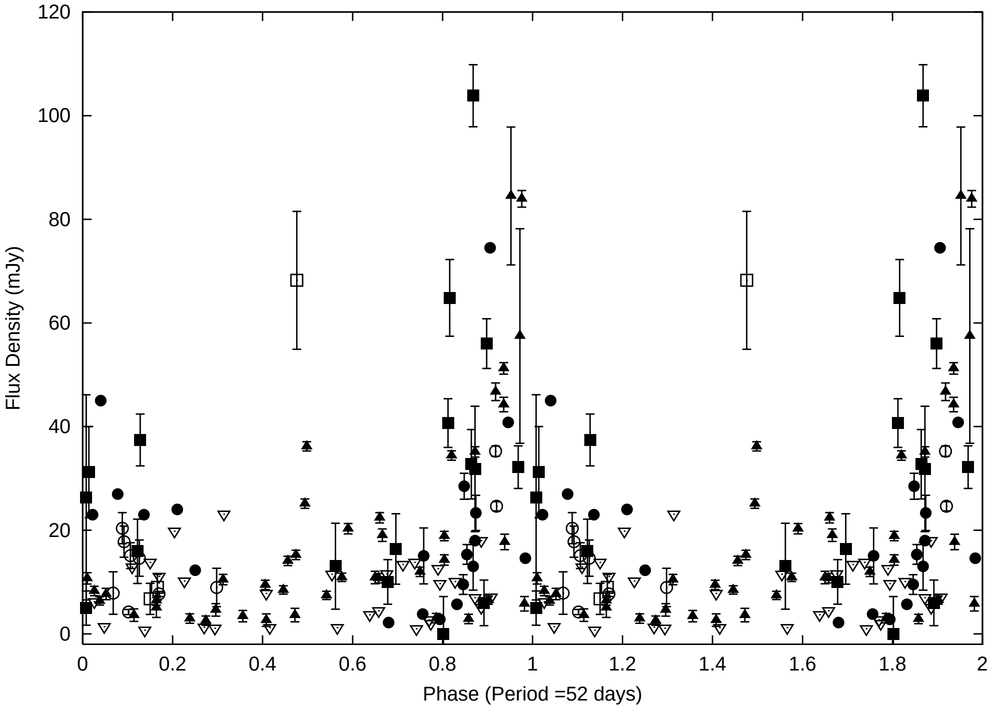

Fig. 6. Radio observations of V773 Tau folded with the period of 52 days found in the spectral analysis.

4. Comparison with other periodicities

The flare at 7 mm is clearly in contrast with the above given scenario of inter-binary collision at periastron. In fact, it occurs almost at the apoastron. Even if one postulates a fundamentally different nature for the millimeter emission (Skinner et al. 1997) the occurrence of another independent process exactly in the middle of the 52 day cycle is rather unlikely. The periodicity of 52 days might only accidentally be coincident with the orbital period. If the data are folded with 52 days (Fig. 6) there is an alignment at phase 0.5 of the flare at 7 mm with one at 2.8 cm. The time between Phase 0 and 0.5 corresponds to a time interval of 26 days.

Looking more deeply into the solar literature we have discovered that Bai (1987) found a periodicity of 51 days in the occurrence rate of flares during the solar cycle 19. Delache & co-authors (1985) found periods at 51 days and 153 days analyzing the Zürich daily sunspot number of a 10 years interval. From solar neutrino flux data again periods of 52 and 157 days have been found (Sturrock et al. 1999). This long period between 152 and 160 days which sometimes appears in the Sun was first discovered by Rieger et al. in γ-ray and X-ray flares (Rieger et al. 1984) and afterwards confirmed also for Hα flares, flares at radio wavelengths and even for variations of the solar diameter (see references in Oliver & Ballester 1995).

Bai & Sturrock (1993) rose the question of a comparison with helioseismological data and suggested the solar periods around 51 and 153 days to be just sub-harmonics of a fundamental period that they found to be 25.5 days. Indeed, analyzing the power spectrum of sunspot area data over more than 110 years Bai (1999) confirms the 25.5 day period as the most persistent period in the Sun.

The similarity with UX Arietis and its periods of 25.5, 56 and 158.7 days discussed in the introduction is very impressive. In conclusion: It appears that there exists an intrinsic mechanism causing the periodic emersion of loops. The periodicity appears to be a multiple of 25.5 days in the Sun. Similar periodicities have been found in the evolved star UX Arietis. Does this picture apply as well for V773 Tau? If that would be the case, this periodicity would be independent of age and rotational period but dependent from the stellar mass, quite similar for all these three stellar systems.

5. Conclusions

The main results of the present paper are the following:

1. The spectral analysis of the data shows a main peak at 52 ± 5 days, in agreement with the orbital period of 51.075 days.
2. The data folded with the orbital period clusters at the periastron passage.
3. A detailed monitoring of an activity period around periastron reveals a regular pattern in agreement with the rotational period of the star spots, inferred from optical observations.

On that basis we conclude that a scenario of flares originating in recurrent collisions of giant loops, anchored on the two stars of the system, during the periastron passage, is the most straightforward interpretation.

The fact that a strong flare at 7 mm and a lower one at 2.8 cm occur outside the periastron passages certainly is not enough to rule out the above scenario or to suggest a new one. However, the similarities with other periodicities discussed in Sect. 4 remain very appealing. We conclude that only future observations will definitely support the choice between the two scenarios of an inter-binary collision (depending on the binary nature) or of an intrinsic mechanism originating in the stellar interior (and therefore also common to other stars).

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