IS THE CLOSE BINARY XY URSAE MAJORIS A RADIO STAR?

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Abstract: The optical position of the short period eclipsing binary XY UMa, which shows large scale star spot activities, coincides within 2 minutes of arc with a radio source, listed in the 4C-, 4CP-, OK-catalogues, and the position obtained with the Effelsberg radio telescope. A fainter star, centered on the radio source position, is according its U-,B-,V-values a K main sequence star. The radio source is non-thermal, and has a spectral index $\alpha \sim -0.85$. If the radio source is identical with the binary, it would imply important consequences about the extragalactic nature of high latitude 4C-sources, the radio background and the high radio luminosity of the binary.

1. Introduction

XY UMa ($l = 168.^{\circ}6$, $b = +45.^{\circ}9$) is intimately connected with the Remeis Observatory Bamberg: its variability was found by Strohmeier in 1955, the period determined by Kippenhahn, and I carried out the first p.e. observations of this system with the 60 cm Cassegrain reflector. It is a 0.479 day eclipsing binary of unusual nature as far as its photometric behaviour is concerned. The large light curve variations as well as the system brightness changes observed now over 22 years have been interpreted by Geyer (1976a, 1976b) as large scale star spot activity on the hotter primary component (G2-5/V) of the detached system. This star spot model has the following main characteristics: A magnetic activity cycle is present in the primary component. The star spots preferentially form in a limited stellar longitude interval, and which interchanges during the star spot cycle by about 180° in stellar longitude perhaps as a consequence of tidal effects.

In figure 1 are shown three V- and B-light curves of this system obtained in the last two years with a double beam photometer (Geyer and Hoffmann, 1974, 1975) attached at the Nasmyth focus of the 106 cm reflector of the Hohe List Observatory. These observations indicate that the star spot cycle of XY UMa is only about 1/4

https://doi.org/10.1017/S0252921100069463 Published online by Cambridge University Press

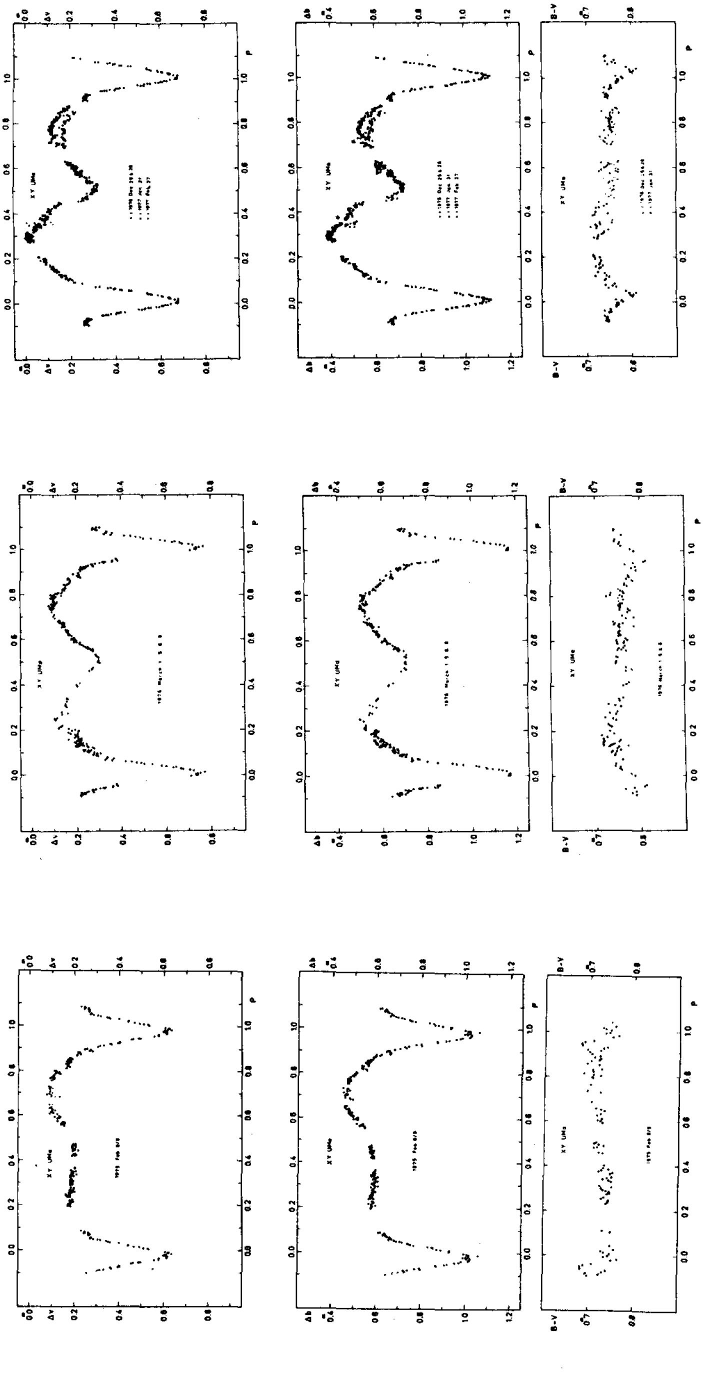

Figure 1: B-,V-light- and colour curves of XY UMa in 1975, 1976 and 1977

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where d = distance in pc; $S_{\lambda\odot}$ = solar flux per 1% spot area ($S_{\lambda\odot} \sim 6\cdot10^2\cdot S_{\lambda\odot}$ (R = 100); R = solar spot number); A = spot area in per cent of the hemisphere; B = magnetic field in kilogauss, we find about $2\cdot10^{-3}$ f.u., which is just detectable with the 100 m Effelsberg radio telescope.

At this instrument 1 1/2 hours of observing time were allocated to me in February 1977. The observations were carried out by my colleague Dr. W. Reich under unfavourable weather conditions at λ 11 cm. He found a 0.3 f.u. - source within 2.5 minutes of arc of the optical position of XY UMa. Immediately it turned out that this source is also listed in the 4C-, 4CP- and Ohio-catalogues. It is non-thermal with a spectral index $\alpha \sim -0.85$. In table 1 the radio positions of the different observations in comparison to the optical position of XY UMa and the neighbouring comparison stars are given. The average radio source position coincides with a fainter star f. This appears already on the POSS charts medium red, and is according to my U-,B-,V-measurements a normal K-V star, as can be seen from the two colour diagrams of figure 2.

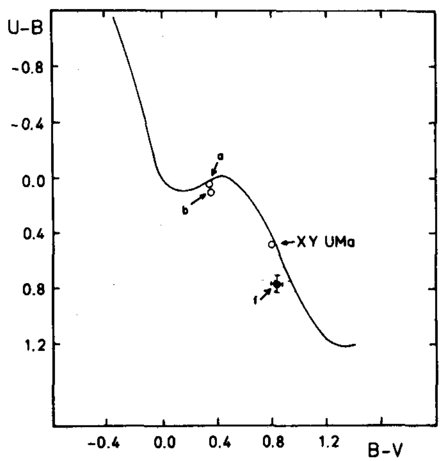

Figure 2: Two colour diagram for XY UMa and neighbouring comparison stars.

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Though it may be quite premature to interpret the differences in the radio fluxes at identical frequencies as a variation of the source, it may be nevertheless indicative that this radio source is identical with the binary. In addition, it should be noted that within 2° there are no other radio sources in the masterlist of Dixon (1970). Also the two faint galaxies appearing on the relevant POSS charts are 7' and 27' respectively north of the radio source.

3. Consequences

If this radio source is really identical with XY UMa, quite a few important consequences could be deduced:

First of all, it would imply that not all high galactic latitude 4C-sources are of extragalactic nature. Quite similar the contribution of ordinary G-type main sequence binaries to the high galactic radio background has to be taken into account.

Further on, since the radio magnitude (Hanbury Brown and Hazard, 1961), as given in Table 2, is nearly as high as the visual magnitude of the binary, the question arises about the additional energy source for the non-thermal radio flux.

Table 2: Radio Magnitude of the Radio Source in the Neighbourhood of XY UMa

λ [cm]	m_{λ}
167.6	$10^{m}.40$
168.5	10.10
21.0	12.55
21.0	11.80
11.0	12.90:

The optical radiation flux blocked off in the spots is quite smaller than the observed radio flux.

4. Rotational Energy Surplus Mechanism

The following proposed mechanism, which makes use of the rotational energy of the primary component of XY UMa could supply the surplus energy for the radio emission:

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of the previous adopted duration of about 15 yrs. This cycle length is now much closer to the expectations of Mullan (1975) for magnetic spots on the primaries of W UMa systems.

Further evidence for the star spot activities on the primary component of XY UMa have been obtained by spectroscopic and polarimetric observations. On slit spectrograms of 86 Å/mm appear certain iron lines like λλ 4045.8, 4063.6, 4071.7 which are typical for sunspot lines, when the star spots according to the model are facing the observer. The polarimetric observations made by Geyer and Metz (1977) show that XY UMa is on the average unpolarized, thus excluding the existence of detectable circumstellar matter which could account for the system brightness- and light curve variations. This is also in agreement with the absence of emission lines longward of H & K on the spectrograms.

According to Hall (1976) XY UMa belongs to the short period group of RS CVn type binaries.

2. XY UMa A Possible Radio Star

Due to the spot activity in XY UMa up to 30% of the optical radiation may be blocked off. Since the energy source in the stellar interior is certainly not affected by the spots, the missing flux has to be re-radiated in other wavelength bands. One can think of about quite a few mechanisms like micro flare activity, conversion into mechanical energy with the result of chromospheric- and prominence activity which interacts with the strong magnetic spot fields of about 10-100 kilogauss (Mullan, 1974), or quite generally as Alfvên waves.

Since the U-light curves of XY UMa show a much larger scatter than to be expected from the observational errors, I was previously thinking of re-radiating the missing flux in the UV-spectral region, and predicted soft X-ray emission from XY UMa. On the other hand, one could also expect radio emission: Under the assumption that the radio flux of the slow variable solar radioemission is proportional the spot area and its magnetic field B, one can roughly extrapolate to the distance of about 100 pc of XY UMa:

$$S_\lambda \approx 2.35 \cdot 10^{-11} \cdot d^{-2} \cdot S_{\lambda\odot} \cdot A \cdot \frac{B}{B_\odot} \quad , \quad \text{f.u.} \; ;$$

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Table 1:

Position of the radio source in the neighbourhood of XY UMa
from different catalogues & observations in comparison to the optical star positions

Catalogue	RA (1950)	Decl. 1950	Frequency (MHz)	Flux (f.u.)	V	B-V	U-B	Remarks
4C 54.18	$9^h06^m35\overset{s}{.}7$ ±16.5	$+54^\circ38'48''$ $\pm$ 2 12	179	2.9	-	-	-	
4CP 54.18	9 06 35	+54 39 48	178	3.8	-	-	-	
OK +511	9 06 45	+54 42 00	1412	0.4	-	-	-	
Effelsberg 1977	(9 06 32	+54 39 10)	1428	0.8	-	-	-	
Effelsberg 1977	9 06 32	+54 39 10	2727	0.3:	-	-	-	
Mean of radio pos.	9 06 37	+54 39 57	-	-	-	-	-	
XY UMa = AGK3+54°702	9 06 18.4	+54 41 38.4	-	-	9.8 var.	0.75 var.	0.45 var.	G2-5
A = AGK3+54°703	9 06 36.3	+54 40 23.5	-	-	-	-	-	duplex,F8
a = AGK3+54°701	9 05 53.2	+54 35 58.2	-	-	9.55	0.34	0.04	F5
b = anonymous	9 06 03.8	+54 31 53.5	-	-	10.66	0.35	0.10	-
f = anonymous	9 06 21	+54 40 01	-	-	12.72	0.84:	0.77:	-

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Magnetic spot activity is in analogy to the sun always connected by some kind of prominence activity where only ver few matter is involved. An electromagnetic coupling mechanism similar to that proposed by Schatzman (1959, 1962) could tap the rotational energy: Let us suppose that matter is ejected in form of prominences (Van't Veer, 1976) from the surface close to the spots. Their magnetic field forces the ejected material to turn up along the field lines to a critical distance beyond which it is no longer dragged by the magnetic field. Since this distance is much larger than the stellar radius, the loss of angular momentum by a small mass loss can be very large. Of course, in a binary system the velocity of escape from the primary mass is lowest in the neighbourhood of the Lagrangian points L_1 and L_3. In the case of XY UMa in about this stellar longitude range the stellar spots predominantly occur. On the other hand, in a close binary the rotation of the components is nearly synchronized with the orbital period due to tidal effects. Yet differential rotation must be present if a stellar dynamo is the cause for the star spot activity (Deinzer and Stix, 1971; Mullan, 1975). Due to this synchronization, the loss of rotational angular momentum is fed into the orbital momentum completely.

Following Brosche (1962) and Ureche (1976) we make a rough estimate about the orbital-and rotational momentum N_o and N_r respectively, and for the rotational energy T_r of the system XY UMa with the realistic assumption for system parameters:

$P_o = 0\overset{d}{.}479 = 1.311.10^{-3}$ yr; $\omega_o = \omega_r = 1.518 \cdot 10^{-4}$ rad s^{-1}; G5-component: $M_1 = 0.95\ M_{\odot}$; K5(?)-component: $M_2 = 0.7\ M_{\odot}$

$a = 1.415.10^{-2}$ a.u.; $i \sim 85^{o}$

$R_1/a \sim 0.32$; $R_2/a \sim 0.24$.

From these data we obtain:

$N_o = 5.45 \cdot 10^{51}$ g cm^{2}s^{-1}; $N_{r1} = 9.4 \cdot 10^{49}$ g cm^2 s^{-1};

$$N_o/N_{r1} \sim 60$$

The rotational energy related to the sun is now given by:

$$\frac{T_{r1}}{T_{r\odot}} = \frac{I_{\omega 1}}{I_{\omega\odot}} \cdot \left(\frac{\omega}{\omega_\odot} \right)^2 \text{ ; since } I_{\omega 1}/I_{\omega\odot} \sim 1 \text{ ; } I_\omega = \text{moment of inertia;}$$

$$\frac{T_{r1}}{T_{r\odot}} = 4 \cdot 10^3 \text{; } T_{r1} \sim 9.6 \cdot 10^{45} \text{erg.}$$

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These figures give a lower limit about the time how long the rotational energy source could support the total stellar radiation:

$$\left(\frac{T_{rl}}{L_1}\right)_{XY} \gtrsim 4\cdot 10^3 \left(\frac{T_{r\odot}}{L_\odot}\right) = 8\cdot 10^4 \text{yrs.}$$

Finally, we roughly can estimate the future orbital period P_{of} if we assume that the total rotational angular momentum is transformed into orbital angular momentum:

$$\frac{P_{of}}{P_o} = \left(\frac{N_o(1+1/60)}{N_o}\right)^{3/4} = 1.012$$

The resulting period change $\Delta P/\Delta t < 7.5\cdot 10^{-8}$ days per yr; this agrees with the observation that the orbital period of XY UMa was constant within $5\cdot 10^{-7}$ day in the last 50 yrs (Geyer, 1977).

Acknowledgements

The author is very much obliged to Drs. K.H. Gebler and W. Reich from the Astronomical Institutes of University Bonn for their assistance in the radio observations. He also gratefully acknowledges the allocation of observing time at the 100 m radio telescope at Effelsberg by the Max Planck Institut für Radioastronomie at Bonn.

Note added in proof:

After this investigation has been completed, a paper by A.M. Cohen, R.W. Porcas, I.W.A. Browne, E.J. Daintree and D. Walsh, on accurate position measurements and optical identifications for radio sources at 966 MHz was published (Mem. R. Astr. Soc. 1977, 84, 1). Their list also contains the position of the radio source in the vicinity of XY UMa, and is given to

RA (1950) : $09^h06^m34^s.2$; Decl. (1950) : + $54^o39'34''.6$

with an accuracy of better than two arcsec. It coincides with a very faint stellar object 2^s west and $49''$ south of star A. XY UMa is therefore not identical with the radio source, though the a priori probability to find a radio source within 2.5 arcmin of a given position is about 10^{-4} in this field!

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D I S C U S S I O N of paper by GEYER:

BIERMANN: What is the accuracy of your Effelsberg radio position? The pointing error of Effelsberg is usually much better than 2 arc minutes at 11 cm.

GEYER: Yes, the pointing accuracy is much better than the quoted 2'. But what happens if the measurements are carried out under rainy variable weather conditions?

VAN'T VEER: Do you obtain sufficient radio emission when you extrapolate both a sun-spot and the associated radio activity to the dimensions of large magnetic star spots?

GEYER: I have made only a very rough estimation and extrapolation in this paper for the slowly variable radio emission, which is believed to be connected with the solar spots. This extrapolation yields about 2.10^{-3} f.u. at λ 6 cm at a distance of 100 pc for XY UMa and a spot area of 30% of the stellar hemisphere with a magnetic field of $B \sim 40$ kilogauss.

BOOTH: 4C is a low frequency radio survey. Would not the stellar plasma be optically thick making it difficult to observe a radio source? I would think your positional coincidence is a chance coincidence with an extragalactic radio source.

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