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Co-ordinated Multi-wavelength Observations of the RS CVn System CF Tuc

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Abstract

A 'multi-site, multi-wavelength' campaign on the eclipsing RS CVn binary CF Tuc was carried out in 1996 over both optical (photometry and spectroscopy) and radio (microwave) ranges. The microwave data was taken with the Australia Telescope Compact Array (ATCA). It covered slightly more than one complete orbital cycle at 4.8 and 8.64 GHz in one continuous run. There was also coverage of about 25% of the light curve at 1.38 and 2.38 GHz. High dispersion spectroscopy was obtained using the McLellan 1m telescope and échelle spectrograph at Mt John University Observatory (New Zealand). Supporting photometry came from various smaller-scale facilities in New Zealand.

The data show an anti-correlation between microwave signal enhancement and photometric flux diminution (maculation effect), noted before in such studies. The spectroscopy confirms the effects being related to a very enhanced active region on the secondary star located close to the maculation region.

Cross-correlation of the 4.8 and 8.64 GHz data reveals a tendency for effects at the former frequency to lag those at the higher frequency, typically by about half an hour. This points to travelling wave effects in the corona of the active K4-type component. More observations like these will be required in the future to probe these effects more fully.

1. Introduction

Numerous photometric data sets on CF Tucanae have appeared in recent years from Australia and New Zealand. These show the well-known light curve 'wave distortions' associated with the RS CVn condition. CF Tuc has a standard RS CVn configuration of a G0 type dwarf orbiting in a 2.797672d period with a K4 subgiant showing 'chromospheric' emission lines.

CF Tuc has been observed as a moderately active radio source [1], while Drake et al. [2], reported appreciable X-ray emission as determined from the IPC instrument on the *Einstein* satellite. It is a ROSAT (EUV) bright source [3]. The evidence prompts efforts toward 'multiwavelength' observational studies (e.g.[4]). This poster paper reports a multiwavelength campaign on the star in 1996 consisting of radio observations at the Australia Telescope in June 1996, that covered a complete orbital cycle of the binary, and complementary photometric and spectroscopic data.

2. Data

2.1. Radio

The data were gathered with the 6-km Australia Telescope Compact Array (ATCA) at Narrabri, NSW (for further details cf. e.g. [5]). The main group of observations were over a 72h allocation that started at 06h 28m UT on June 26, 1996 and continued until 06h 00m UT on June 29, i.e. slightly more than one complete orbital cycle of the binary (P = 67h 8.6m). The point source 1934-638 was used to provide a primary calibration of the flux levels. The source 0454-810 was conveniently placed to provide secondary calibrations. The binary has also been occasionally observed during other radio patrols of active stars. On the first day, observations made simultaneously at 4.8 and 8.64-GHz ('C' and 'X-band') were interleaved with observations at 1.38 ('L-band') and 2.38-GHz ('S-band') for a 16.4 hour angle range, but thereafter they were continued at just C and X-bands.

The microwave light curves from the June '96 run are shown in Figure 1a. There is a common quasi-quiescent state of radio emission from CF Tuc, in which the fluxes at all observed GHz frequencies are in the range 1-2 mJy. Occasionally, however, strong flares may be observed (e.g. 02-03 July, 1994).

There is a possibility of quasi-periodicity to the variation (cf. [6]). The main thrust in the present study, however, concerns structure within the orbital period timescale, and any relationships such structure may show across the range of wavelengths. All this is discussed in detail in a fuller version of this article to appear in the near future.

The light curves show a number of appreciably-sized up-down features, generally with timescale of $\sim P/10$. Other main features can be summarized as follows: (1) initial decline starting at orbital phase 0.4, (2) peak at phase 0.70-0.75, (3) sharp peak at 0.9, though this is fairly dependent on one high flux value at 4.8-GHz, (4) peak at 1.05-1.10, (5) trough at 1.2 with a lead up to the broad maximum again towards phase $\sim$1.4. The

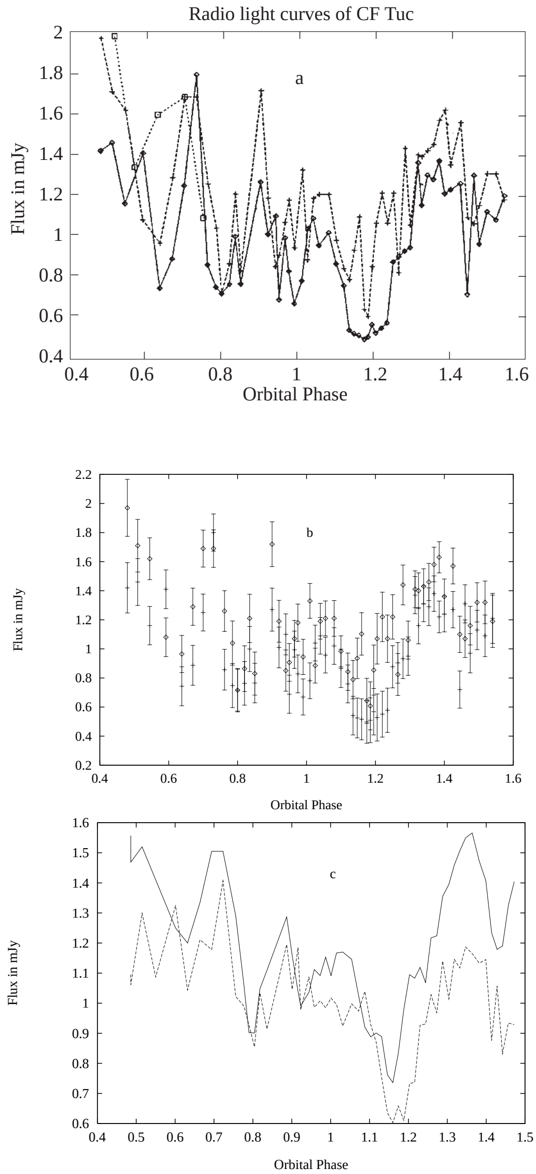

Figure 1. Microwave radiometry of CF Tuc between 1996, Jun 26 06h 28m and Jun 29 05h 08m. *MIRIAD* [9] analysis of this ATCA data indicates data precision of about 0.12 mJy at 8.64 and 4.8-GHz and about 0.20 mJy at 2.38-GHz. (a) 2.38 (squares), 4.8 (crosses) & 8.64-GHz (diamonds) fluxes vs CF Tuc orbital phase, (b) 4.8 (diamonds) & 8.64-GHz (bars) fluxes vs time with $\pm 3\sigma$ error bars, (c) smoothed (running mean over 5 points) 4.8 (continuous) & 8.64-GHz (dashed) fluxes vs orbital phase.

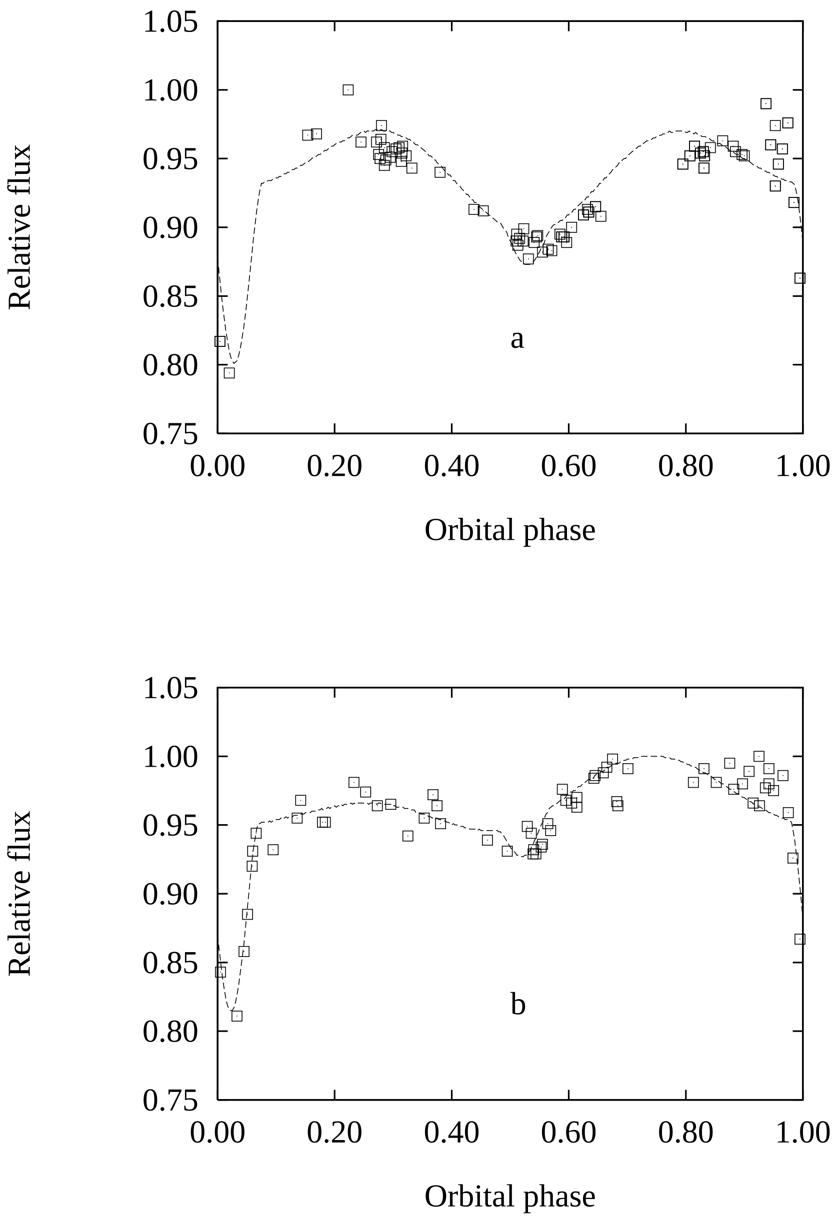

Figure 2. CF Tuc: (a) V light curves for July, 1995 until Jan 1996 and (b) V light curves for Aug-Dec, 1996.

Table 1. Radio sources in the CF Tuc field. Source 2 is CF Tuc as measured on June 26, 1996.

Source no	Position (1996.48)						Flux density (mJy)				Spectral Index
	RA			Dec			1.376 GHz	2.382 GHz	4.800 GHz	8.640 GHz	α
	h	m	s	°	′	″					
1	00	52	30.01	–74	37	47.7	5.0	3.3	1.5	0.6	–1.15
2	00	53	07.55	–74	39	05.8	1.0	1.6	1.3	1.0	+0.10
3	00	53	15.42	–74	42	35.3	2.3	1.9	1.2		–0.55

position of the peak at phase ~0.4 is of particular present interest, because the longitude of an optical maculation wave on CF Tuc corresponds to this phase.

2.2. Optical photometry

The automatic photometric telescope (APT) at the Kotipu Place Observatory near Wellington (NZ) has made observations of RS CVn stars, carrying out near contemporaneous optical photometry during multi-wavelength observational campaigns. Members of the RASNZ's Photometric Section and other potentially interested parties, have been similarly involved, particularly T Rounthwaite, who has provided a long record of data on CF Tuc over the last decade.

The net photometric data show reasonably coherent maculation waves. The starspot parameterization of these effects is summarized in Table 3. These maculation effects were analysed after confirming the system parameters as in Table 2. The maculation wave drifts down in longitude. This effect is frequently observed for RS CVn stars showing spot-waves, and the rate of this drift for CF Tuc was found to be typically of order 50° per year [7]. If the drift was uniform over the photometry period, the phase of the spot minimum should have been about 0.41 at the time of the radio observations in Australia. The spectroscopic evidence, however, points to some non-uniformity of this derived drift, so that the activity centre may have been somewhat higher in longitude than 150 deg at the time of the ATCA observations.

2.3. Spectroscopy

Hα spectra of CF Tuc were obtained on three consecutive nights, 1996 July 29, 30 and 31, at the Mount John University Observatory (MJUO), using the McLellan 1-metre telescope and MJUO échelle spectrograph. Figure 3 shows the wavelength regions about the Hα line for all three observations. All three spectra show numerous cosmic ray strikes. None of the apparent sharp emission features is real.

The stellar lines show Doppler-effects, due primarily to the orbital motion, but combined, in the case of the emission source, with the subgiant's rotation. The geometry can be understood with the aid of Bradstreet's [8] *Binary Maker*. Associating the required

Table 2. Basic parameters of CF Tuc

Parameter		value
Primary (G0V) Luminosity	L_1	2.8 ($\odot$)
Secondary (K4IV) Luminosity	L_2	3.2 ($\odot$)
Primary mass	M_1	1.2 ($\odot$)
Secondary mass	M_2	1.3 ($\odot$)
Primary radius	R_1	1.60($\odot$)
Secondary radius	R_2	3.09 ($\odot$)
Orbital inclination	i	71.6°
Primary temperature	T_1	6000 K
Secondary temperature	T_2	4500 K

Table 3. Starspot effects for CF Tuc 1995-96

Parameter		value
JD of Epoch		2449982.4755
Longitude	λ	212° ± 5°
Latitude	β	45°
Angular radius	γ	17.1° ± 0.1°
JD of Epoch		2450348.9705
Longitude	λ	126° ±11°
Latitude	β	45°
Angular radius	γ	15.3° ±0.2°
JD of Epoch (ACTA obs'ns.)		2450262.2427
Longitude	λ	147°
Latitude	β	45°
Angular radius	γ	15.9°
JD of Epoch (spectroscopy)		2450295.9076
Longitude	λ	139°
Latitude	β	45°
Angular radius	γ	15.6°

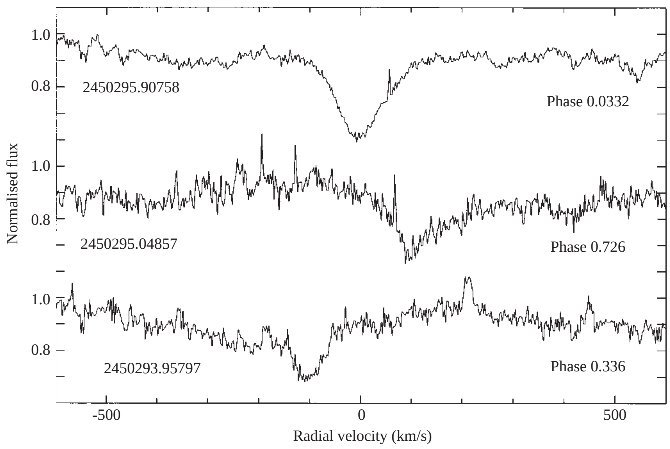

Figure 3. Hα spectra of CF Tuc, obtained on three consecutive nights, 1996 July 29, 30 and 31 NZST. Radial velocities are those of the Hα line relative to the centre of mass of the solar system. All the apparent sharp and narrow emission-like count rises should be disregarded.

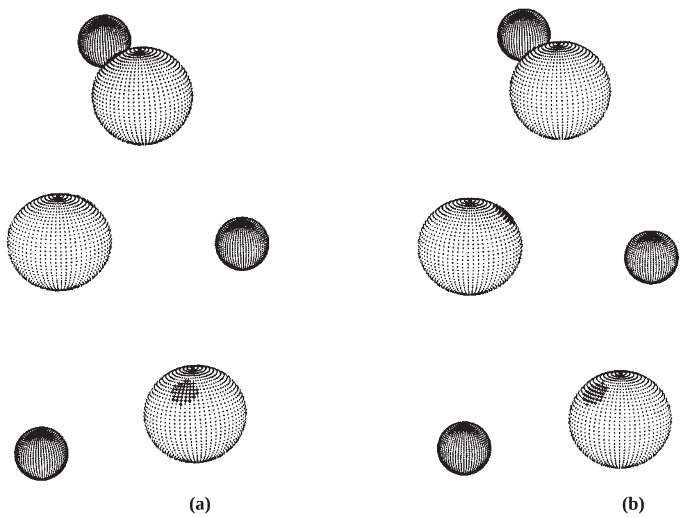

Figure 4. *Binary-Maker* representations of CF Tuc at the phases corresponding to the spectra of Figure 3: (a) with the active region located according to Table 3, (b) with the active region set back in longitude to 160°.

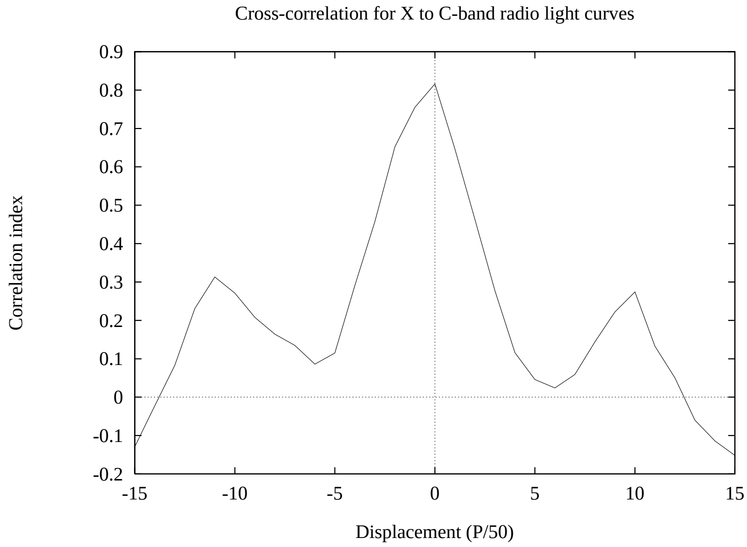

Figure 5. X to C band cross-correlation curve for the CF Tuc data-sets. The asymmetry indicates that the C effects tends to lag X effects, on average.

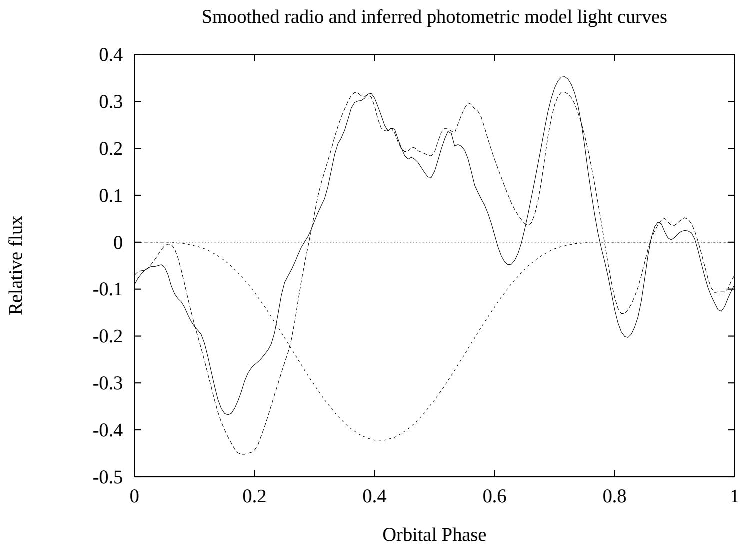

Figure 6. The X and C band light curves of CF Tuc have been smoothed by progressive averaging over 0.2 $\times P$ intervals. They have been shifted in the ordinate scale so that their means are zero. The broad-band V optical model light curve, interpolated to the date of the radio observations, shifted and rescaled (the amplitude of the dip is 0.045 mag), is presented on the same graph for comparison.

large plage-like formations with the maculation regions and substituting this data into *Binary Maker*, we can produce the representations shown in Figure 4a, which has some accord with the effects shown in Figure 3. There is a better agreement by placing the activity centre not at the longitude given by exact linear interpolation between the two photometric analyses. In Figure 4b we place the activity centre at longitude 160°. There is now better visibility of the receding spot at phase 0.73, while it is still invisible at phase 0.03.

The evidence of the spectroscopy, while thus generally supports the photometry on the broad location of the centre of activity in CF Tuc. It points, however, to the phase of the activity centre being closer to 0.5 than the deduced value of 0.41. Further spectroscopic observations of CF Tuc at MJUO are planned for the future.

3. Brief discussion

One interesting effect discovered from the present data by cross-correlating the X and C-band microwave light curves is that effects in the latter tend to be systematically delayed behind those at the higher frequency (cf. Figure 5). The mean value of this delay is close to half an hour. Modelling of the appropriate gyro-synchrotron emitting regions points to the variations resulting from the transmission of radiation-producing effects at the local electron speed of sound in the active star's corona. This parallels effects known in the solar atmosphere, though the scale of the emission in CF Tuc is typically one or two orders of magnitude higher than what is observed during solar noise storms.

In Figure 6 we put the optical and appropriately smoothed and re-averaged (to zero mean) radio variations on the same axes. The anti-correlation is reasonably clear to the eye; though numerical analysis confirms this. CF Tuc shares properties which have been observed on other RS CVn stars in this respect (e.g. UX Ari, AB Dor). The combined evidence of photometry, spectroscopy and radiometry in this campaign on CF Tuc thus points to the system exhibiting properties which are phenomenologically broadly similar to those of solar 'activity', though on an appreciably larger scale.

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