OPTICAL AND RADIO OBSERVATIONS OF THE FLARE STAR UV CETI IN AUSTRALASIA DURING SEPTEMBER–OCTOBER 1967

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Summary

This paper presents the results of a joint radio-optical programme of observations in Australasia on the flare star UV Ceti during an observing period in September–October 1967 organized by Commission 27 of the International Astronomical Union.

Eight of the 21 optical events were recorded by more than one observatory and are regarded as certain flares. Six of the verified flares were also monitored at radio frequencies and 5 of these were accompanied by radio emission. Two bright flares were recorded within a time interval of 2 hr on October 3, 1967.

On existing evidence, it is suggested that if a flare period does exist, it is probably shorter than 0·1821 day (Chugainov, preprint 1967).

Over the range $80 < f < 2650$ MHz, the average spectrum of radio bursts from UV Ceti decreases with increasing frequency. The exponent of an assumed power law variation is less than -1 below 240 MHz and steeper at higher frequencies.

I. Introduction

Commission 27 of the International Astronomical Union has recently formed a working group which has initiated a programme of worldwide observation of certain well-known flare stars. One of the main objects of this investigation is to establish a continuous monitor of these stars over a time interval of the order of a fortnight, using optical and radio observatories in different countries. The present paper describes the optical and radio observations carried out in Australia and New Zealand during the first of these programmes on UV Ceti for the interval September 26 to October 10, 1967.

During the observations 8 flares were certainly detected, and in addition there is less conclusive evidence for the occurrence of another 13 outbursts from this star.

II. Observations

Fortunately, we were able to make use of a reasonably extensive network of optical telescopes which were operated by both professional and amateur organizations; this cooperative effort (Slee, Higgins, and Patston 1963; Slee, Solomon, and Patston 1963) has been fostered over the past eight years primarily for the purpose of providing optical evidence for the occurrence of flares at times corresponding to the reception of bursts of radio emission.

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During the latter half of the programme, from October 2 to October 9, radio observations were also conducted with the 64 m telescope at Parkes, N.S.W., on frequencies of 150 and 2650 MHz, and with the recently commissioned radioheliograph at Culgoora, N.S.W., on a frequency of 80 MHz.

TABLE 1

COOPERATING OBSERVATORIES

Location	Operating Authority	Instrument	Type of Observation
Belfield, N.S.W.	Astronomical Society of New South Wales	25 cm reflector	Visual
Brisbane, Qld.	Page Observatory	30 cm Schmidt camera	Photographic
Brisbane, Qld.	Balmoral Observatory	30 cm reflector	Visual
Brisbane, Qld.	Roscom Astronomical Society	15 cm reflector	Visual
Bundaberg, Qld.	Amateur Astronomical Club of Bundaberg	49 cm reflector	Visual
Lithgow, N.S.W.	Lithgow Observatory	20 cm reflector	Visual
Moe, Vic.	Latrobe Valley Astronomical Society	20 cm reflector	Visual
Yallourn, Vic.	Latrobe Valley Astronomical Society	32 cm reflector	Visual
Auckland, N.Z.	Astronomical Society of Auckland	51 cm reflector	Visual
Nelson, N.Z.	Royal Astronomical Society of New Zealand	32 cm reflector	Visual
Lake Tekapo, N.Z.	Mt. John University Observatory	20 cm refractor	Visual
Lake Tekapo, N.Z.	Mt. John University Observatory	41 cm reflector	Photoelectric
Mt. Stromlo, A.C.T.	University of Uppsala, Sweden	66 cm Schmidt camera	Photographic
Woomera, S.A.	Smithsonian Institution	50 cm Baker–Nunn Schmidt camera	Photographic
Culgoora, N.S.W.	CSIRO	3 km heliograph	Radio (chart recorder)
Parkes, N.S.W.	CSIRO	64 m reflector	Radio (chart and digital recorder)

The observatories that contributed to these observations are listed in Table 1, which also briefly describes the telescopes and the type of observation made with each instrument. The methods used by the various observing groups are described briefly below.

(a) *Amateur Visual Observations*

These were carried out by nine groups of amateurs, each group consisting of two or three observers, who took turns to man the telescope. During each observer's turn at the telescope, estimates were made at intervals of 30 sec of the flare star's brightness relative to preselected comparison stars in the same field; these results were recorded by one of the members of the group. The accuracy of such visual determinations is hard to assess and obviously varies with the competence and experience of the particular observer and the seeing conditions. However, even experienced observers record a peak-to-peak fluctuation level of about $0^m{\cdot}5$ over an observing interval of 1 hr, so that it does not appear legitimate to attach much significance to brightness increases of $< 0^m{\cdot}5$ unless there is some independent confirmatory observation.

(b) *Amateur Photographic Measurements*

The Schmidt camera located at Brisbane made use of plates, with a fast panchromatic emulsion, which were exposed for intervals of 4–6 min. Up to four or five exposures were made on each plate by laterally shifting the plate holder so that the stellar images were displaced a few seconds of arc. The time interval between the end of one exposure and the start of the next was only a few seconds, except when the plate was changed, when a break of about 5 min occurred. The smallest detectable brightness increase appears to be about $0^m{\cdot}2$.

(c) *Baker–Nunn Schmidt Camera*

The observations conducted at Woomera also made use of multiple displaced images, each exposure being of a few seconds duration with an interruption of about 20 sec between exposures. The 55 mm Extended-Red Royal-X Pan Recording film can be quickly transported through the camera, so that no appreciable interruption occurs between exposures on different frames. The minimum detectable brightness increase is about $0^m{\cdot}3$.

(d) *Uppsala Schmidt Camera*

This equipment made use of the displaced-image technique, exposure times being 3·5 min on Kodak I-N emulsion through a Schott RG2 filter. Observations were conducted on one night only for $1^h\,14^m$, during which a brightness increase of $\sim 0^m{\cdot}2$ would have been detected.

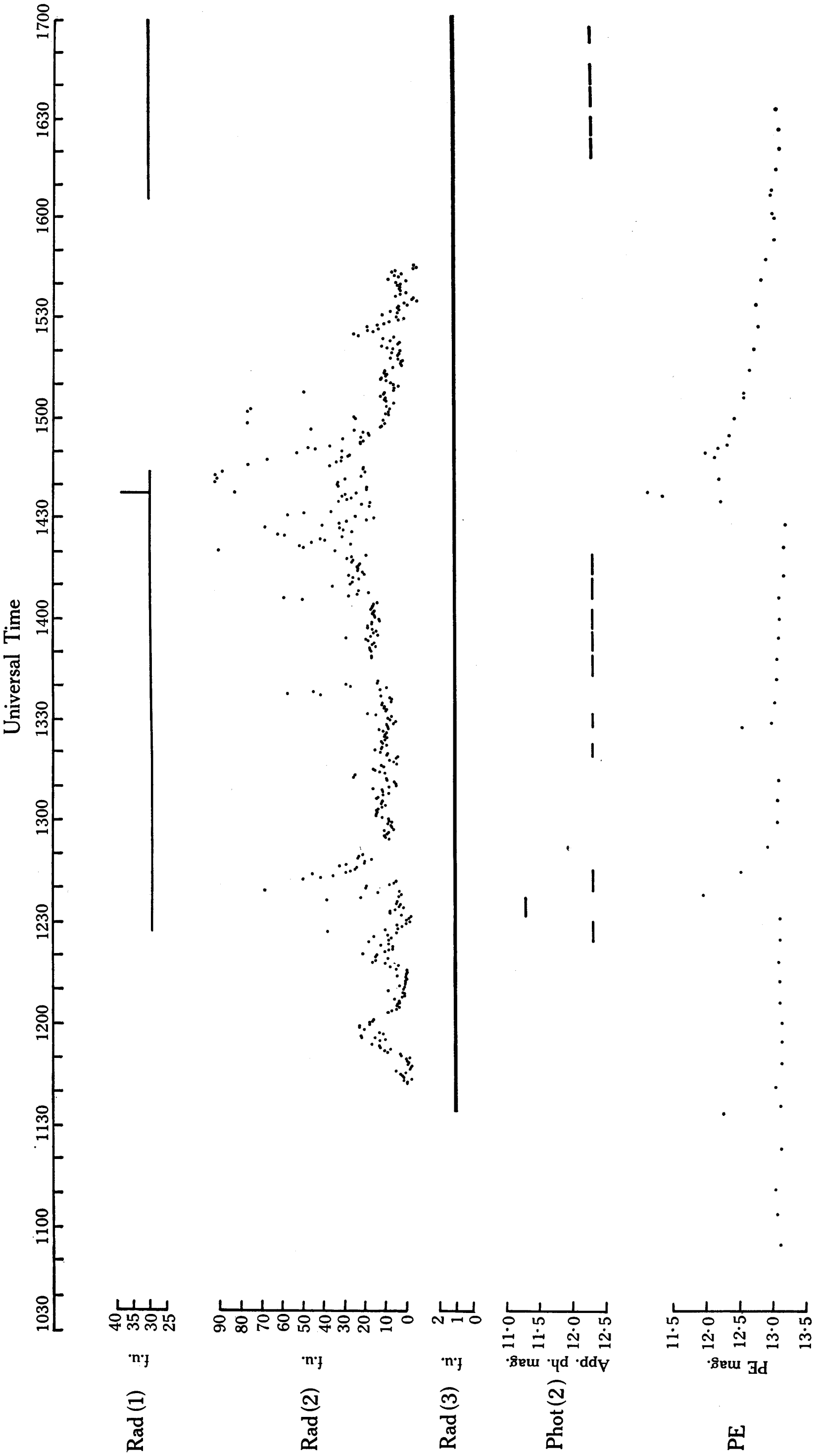
(e) *Lake Tekapo, Visual Observations*

These observations have been described in some detail elsewhere (Bateson and Kohler 1968) and it is not proposed to repeat the description here. An inspection of the variability of the brightness estimates suggests that it would be difficult to detect a flare of magnitude $< 0^m{\cdot}5$ unless there is independent confirmatory evidence.

Bateson and Kohler suggest that some of the fast brightness fluctuations may be intrinsic in the star, although their conclusions are yet to be confirmed.

(f) *Lake Tekapo, Photoelectric Observations*

The 41 cm reflector at the Mt. John University Observatory was used with a photomultiplier RCA 1P21, observations being made in integrated light without a filter. In addition to the normal pen-recorder, a General Electric integrating voltmeter, with an integration time of 1 min, was used. This gave an accuracy approaching $0^m{\cdot}01$.


Universal Time
1030
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Rad (1)
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Rad (2)
f.u.
90 80 70 60 50 40 30 20 10 0
Rad (3)
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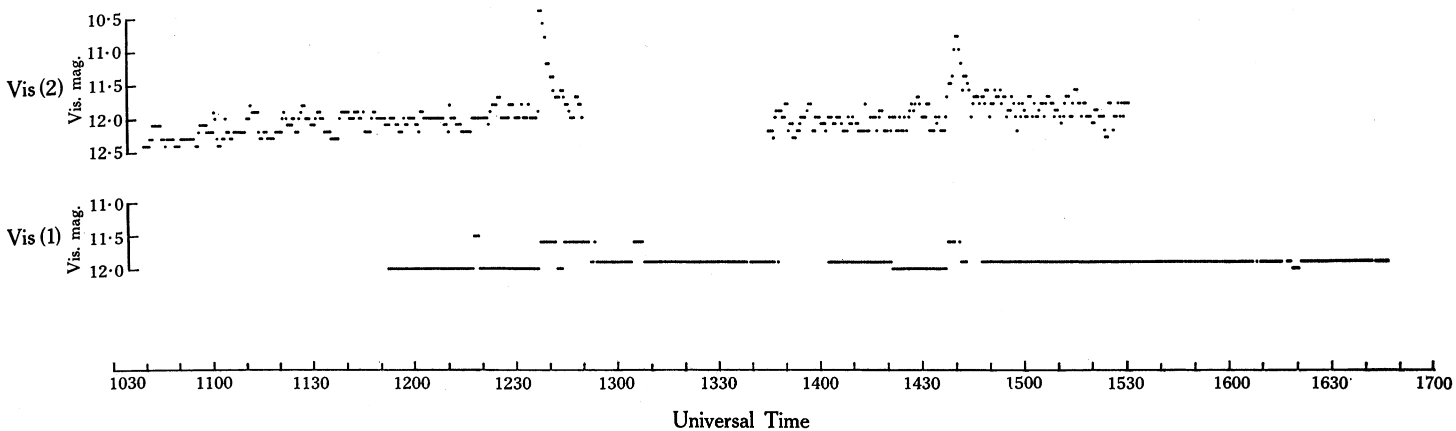

Fig. 1.—The two major flares of October 3, 1967 recorded by radio, photographic, photoelectric, and visual observers. Gaps in the plots denote the absence of good records.

Rad(1), Culgoora (radio, 80 MHz): the horizontal line denotes the upper limit of flux density detected. The minimum detectable peak flux density was 28 f.u. A single burst of a few seconds duration, recorded during the second major flare, is shown as a vertical line.

Rad(2), Parkes (radio, 150 MHz): values of flux density are plotted at intervals of 30 sec.

Rad(3), Parkes (radio, 2650 MHz): the upper limit of flux density is plotted as a horizontal line.

Phot(2), Brisbane (photographic): each exposure is shown as a short horizontal line.

PE, Lake Tekapo (photoelectric): readings are plotted at intervals of several minutes.

Vis(2) and Vis(1), Lake Tekapo and Bundaberg respectively (visual): observations are shown at intervals of 30 sec.

(*g*) *Radio Observations*

The 64 m reflector at Parkes, N.S.W., was equipped with feeds and receivers for frequencies of 150 and 2650 MHz. With the telescope tracking the flare star, continuous chart readings (time constant ~ 2 sec) were obtained at both frequencies; in addition, during possible flare-star activity the output of the 150 MHz receiver was digitized, a facility which is useful for plotting out the recorded radio amplitude to the same time scale as any possible optical activity. The limiting detectable peak flux densities were 3 and 0·4 f.u. at 150 and 2650 MHz respectively (1 flux unit $= 10^{-26}\,\mathrm{W\,m^{-2}\,Hz^{-1}}$).

At Culgoora, N.S.W., the radioheliograph operates at 80 MHz and has a diameter of 3 km. By means of the appropriate interconnection between the 96 aerials forming the heliograph, the equipment produces 48 circular beams with half-power widths of ~ 4 min of arc, the beams being spaced at intervals of 2·1 min of arc along the north–south direction. In this experiment, the radiation received in the six central beams, one of which was placed on the flare star, was recorded on a six-channel chart recorder. The flare star was tracked for an interval of 4·5 hr centred on upper transit. The full sensitivity of the equipment had not been realized at the time of these observations and the minimum detectable peak flux density was 28 f.u.

III. Results

The detailed results of the optical and radio observations have been plotted in the form of curves of light intensity and radio flux density. All known observations have been included in the plots, a set of curves being constructed for each night of the programme. An example is shown in Figure 1, which depicts the behaviour of UV Ceti on the most active night (October 3, 1967) when two major flares were observed within an interval of 2 hr.

Table 2 lists most of the important information which we believe is contained in the light curves. It is apparent that 8 flares were almost certainly recorded, as shown in section (*a*) of the table. The 13 possible flares listed in section (*b*) should be regarded with some caution, since they were recorded by only one optical observatory.

Six of the verified flares were monitored at radio frequencies, and for five of these optical–radio correlations were obtained. Two major flares were observed, both on October 3 and only 2 hr apart. In both cases there is strong evidence that radiation was received at 150 MHz, although care must be exercised in accepting this conclusion without reservation because of the occasionally high level of interference at this frequency. Figure 1 shows that the radio result is more convincing for the flare which commenced at 1237 U.T.; some interference may have been present before the second optical flare, which commenced at 1436. At 80 MHz no radiation was detected during the first flare (peak flux density < 28 f.u.) and a single burst of a few seconds duration (peak flux density ~ 37 f.u.) occurred near the start of the second flare. No emission was detected at 2650 MHz during either event.

Radio observations were also conducted during six of the unconfirmed optical events listed in Table 2(*b*). None of these were accompanied by detectable radio emission except that of October 8 at 1341 U.T., when a pulse of radio emission lasting about

3 sec was recorded at 2650 MHz. Some significance should be attached to this apparent correlation, because the remainder of the 2650 MHz record was singularly free of similar deflections.

TABLE 2

OPTICAL AND RADIO EVENTS

October 2, 4, 5, 9, and 10 were days of no flare activity

Date (1967)	Time* (U.T.)	Equipment†	Maximum Brightness Change‡ Δm	Peak Radio Flux Density (f.u.) 80	150	2650 MHz
			(*a*) Confirmed Flares			
Sept. 29	1409–1417	Phot(2), Vis(4)	0·3, 0·7	—	—	—
30	1604–1610	Phot(1), Phot(2)	0·5, ?	—	—	—
Oct. 3	1237–1250	PE, Phot(2) Vis(1), Vis(2)	2·0, 1·0 0·4, 1·6	<28·0	20·0	<1·0
3	1436–1455	PE, Vis(1), Vis(2)	2·0, 1·0 2·0	37·0	25·0	<1·0
6	1612	Phot(1), Vis(4)	0·4, 0·3	—	7·0	—
6	1622	Phot(1), Vis(4)	0·4, 0·4	—	4·5	—
8	1230–1234	PE, Vis(2)	0·6, 0·4	<28·0	<3·0	<0·4
8	1433–1450	PE, Vis(2)	0·4, 0·4	<28·0	4·0	<0·4
			(*b*) Unconfirmed Flares			
Sept. 26	1539–1543	Phot(2)	0·2	—	—	—
27	1131	Phot(1)	0·4	—	—	—
28	1523	Phot(1)	0·3	—	—	—
29	1433	Phot(1)	0·3	—	—	—
Oct. 1	1151–?	Vis(3)	1·0	—	—	—
1	1403	Phot(1)	0·4	—	—	—
3	1134	PE	0·8	<28·0	—	—
3	1330	PE	0·6	<28·0	<3·5	<1·0
3	1601	PE	0·5	—	—	<1·0
4	1008	Vis(2)	0·5	—	—	—
8	1341	Vis(2)	0·5	<28·0	—	1·2 (short pulse)
8	1344·5	Vis(2)	0·6	<28·0	—	<0·5
9	1356·0	Vis(2)	0·5	<28·0	—	<0·4

* Where a single time is given for Baker–Nunn Schmidt observations it refers to the time of maximum brightness; for the photoelectric observations it denotes a short outburst lasting only a few seconds.

† Phot(1) = Baker–Nunn Schmidt, Woomera; Phot(2) = Page Schmidt, Brisbane; Vis(1) = Bundaberg; Vis(2) = Lake Tekapo; Vis(3) = Belfield; Vis(4) = Auckland; PE = photoelectric, Lake Tekapo.

‡ For the photographic observations Phot(2) this value is averaged over the exposure time of 4–6 min.

IV. Discussion

The extensive monitoring of UV Ceti described here was initiated mainly to check a possible periodic tendency for the flares to erupt. It has been suggested by Andrews (1966*a*, 1966*b*) that the flares on YZ Canis Minoris and V1216 Sagittarii tend to recur at 2-day intervals; recently Chugainov (preprint 1967) has proposed that the flares on UV Ceti may follow a similar tendency, but interprets this behaviour in terms of a much shorter basic period of occurrence of 0·1821 day. On this interpretation, the apparent 2-day recurrence cycle is brought about by the limited observing time at any one site.

The optical events outlined in Table 2 are not sufficiently numerous to enable us to search for periodicities; this must await an assessment of the worldwide results by the Working Committee of Commission 27 of the International Astronomical Union. However, the limited results published here permit us to question seriously the period of 0·1821 day proposed by Chugainov. For example, it appears unlikely that the two major flares of October 3, 1967 would occur within 2 hr if a regular period of this order existed.

The data which Chugainov has gathered from various observations and which he uses to deduce the proposed period may indicate shorter intervals between flares. On five nights during August–October 1965 pairs of flares were recorded within time intervals ranging from 34^{m} to $1^{h}\,57^{m}$. Hence we conclude that if a basic flare period does exist, it is much shorter than 0·1821 day and, on the existing evidence, probably shorter than 1 hr.

One of the more interesting features of the optical results is the realization that two catastrophic releases of energy, each of $\sim 10^{25}$ J, can occur from the same star within a time interval of 2 hr. The rate at which the flare energy is released is approximately equal to the rate of total energy radiation by the quiescent star, yet the star appears to suffer no permanent alteration to its brightness.

The present observations can be used to deduce some rather limited, but nevertheless useful, information on the radio spectra of the flares from UV Ceti. Lovell, Whipple, and Solomon (1963) and Lovell and Solomon (1966) have given average values of peak flux density at 240 MHz, resulting from flares with a maximum brightness increase of one magnitude in the photographic region of the spectrum. These values range from 4·6 to 7·1 f.u. For the five cases in Table 2(*a*) for which radio emission appears to have been detected at 150 MHz the average peak radio flux density is 9·1 f.u. for a brightness change of one magnitude; the individual flares give values varying between 7·0 and 12·9 f.u. Hence, if it is a valid procedure to compare average values of this quantity recorded in different intervals of time, it appears that the average radio flux density in the range 150–240 MHz is falling at a rate which is not as steep as a $(\text{frequency})^{-1}$ law.

The one positive result recorded at 80 MHz, during one of the more intense flares on October 3, indicates a spectrum of $(\text{frequency})^{-0\cdot 6}$; the negative result obtained during the second bright flare on the same date places an upper limit of $-0\cdot 5$ on the exponent. It thus appears that the 150 and 80 MHz results during the present programme are consistent with the spectrum deduced from a comparison of the average results at 240 and 150 MHz as described in the preceding paragraph.

At the high frequency end of the radio spectrum, the lack of detectable radio emission at 2650 MHz during any of the confirmed flares shows conclusively that the flux density continues to fall at frequencies above 240 MHz. In the case of the two bright flares on October 3, 1967 the average exponent of an assumed power law variation between frequencies of 150 and 2650 MHz is greater than -1. Hence, the average spectrum of radio bursts from UV Ceti appears to decrease with increasing frequency over the range $80 < f < 2650$ MHz, with the exponent of an assumed power law variation being less than -1 below 240 MHz and steeper at higher frequencies.

From the existing meagre information on the radio spectra of UV Ceti flares, it appears that the most profitable range of frequencies for flare-star work, especially for detailed spectral observations, is 150–250 MHz. At the low frequency end of this band the receiver sensitivity is limited by the cosmic background temperature, which is increasing as $\sim \lambda^{2 \cdot 5}$. On the high frequency side of this band, the combination of a flare spectrum that decreases as $(\text{frequency})^{-1}$ or steeper, and a receiver noise temperature that is not easily reduced below 300°K, will ensure a progressively decreasing signal-to-noise ratio as the frequency is increased.

It appears to be of some importance in future radio observations of flare stars to determine the state of polarization of the emission so that the characteristics of these eruptions can be compared with solar flares. There is now reasonable spectroscopic evidence (Gershberg 1967) that the UV Ceti type flare is, like its solar counterpart, restricted to a small volume in the well-developed chromosphere or corona of a red dwarf star. If this is so, it may be possible to observe the types of polarization seen in radio bursts associated with solar flares. A first attempt should be made to record the dynamic spectra of some of these bursts, although a fast sweeping spectrograph of the type used for solar observations would not possess the required sensitivity. It appears that the best that can be achieved in this important field in the immediate future is to obtain recordings of the outputs of several receivers each of bandwidth, say, 1 MHz and separated in centre frequency by several MHz. The observation of time delays between the arrival of bursts in the separated channels would be rather conclusive evidence for the existence of solar-type flare phenomena. In addition, if plasma oscillations are shown to be responsible for the production of the radio emission, some useful information on electron densities in the atmospheres of these stars may be obtained.

V. Acknowledgments

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