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COORDINATED X-RAY, OPTICAL AND RADIO OBSERVATIONS OF YZ CANIS MINORIS*

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I. INTRODUCTION

UV Ceti flare stars are small, cool variable stars, characterized by remarkable transient releases of energy in the form of flares. The optical flares achieve maximum light in seconds, attaining peak luminosities that often exceed the quiescent stellar luminosity. Both optical and radio bursts from flare stars are typically 10^2 to 10^3 times as energetic as corresponding flare phenomena on the sun (Gershberg 1975). Strong magnetic field ($\gtrsim$ 10 kilogauss) on the surfaces of flare stars have been predicted by both Mullan (1974) and Worden (1974). Recent observations may indicate the presence of such large magnetic fields, perhaps concentrated in localized regions on the stellar surfaces (cf. Bopp and Evans 1973; Mullan and Bell 1976; Koch and Pfeiffer 1976; and Anderson et al. 1976). As these objects are red dwarfs, of spectral classes dKe - dMe, they may well be the most numerous variables in the Galaxy. Thus, their contribution to the galactic emission over the entire electromagnetic spectrum and processes by which this radiation is generated are subjects of considerable astrophysical interest.

Significant information on stellar flares has been obtained in coordinated optical and radio observing programs, such as those reported by Lovell (1964, 1969, 1971), Higgins et al. (1968) and Spangler and Moffett (1976). However, previous x-ray observations have been very limited. The only published detection of x-ray flares (Heise et al. 1975) refer to two flares, one each on YZ CMi and UV Cet, observed with the ANS satellite. No radio coverage was available for either flare, and no optical coverage was available to provide positive identification for the YZ CMi flare. Nevertheless, the observation of an x-ray flare on UV Cet accompanied by an optical flare has stimulated renewed interest in the numerous theoretical papers that have been devoted to the prediction of stellar flare x-ray emission. To test such models, simultaneous x-ray, optical and radio coverage are of prime importance since the distinctions between the various models depend upon the ratios of the luminosities in these respective energy bands. We present here the results of the first flare-star observing program in which triply coincident x-ray, optical and radio monitoring has been achieved.

II. OBSERVATIONS

During the period 1975 November 30, 14^h UT to December 3, 14^h UT, x-ray observations of the flare star YZ CMi were coordinated with ground-based optical and radio coverage. This star is a good candidate for study, as it is one of the most active flare stars known at optical wavelengths. The MIT SAS-3 satellite provided x-ray coverage in the energy range 0.15 - 50 keV; ground-based optical and radio observations were provided by the facilities listed in Tables 1 and 2. A description of the instrumentation on board the SAS-3 observatory is given by Hearn et al. (1976). The energy ranges, bandpasses, and frequencies covered are shown as a function of the times of coverage in Figure 1. In addition to the photometric observations indicated in Figure 1, polarimetric observations in the optical B, V, O, and R bandpasses were made at the Crimean Astrophysical Observatory. The total duration of polarimetric coverage with each filter was 2^h10^m in B, 26^m in V, 17^m in O and 17^m in R; these observations occurred within the timespans of the B-band observations at the same institution (See Figure 1). Due to the occultation of YZ CMi for nearly half of every satellite orbit, x-ray coverage was available about 50% of the time; optical coverage was provided for 63% of the program; and radio coverage with at least one telescope was essentially continuous. Thus, triply-coincident x-ray, optical and radio observations were available for approximately 30% of the three-day program.

The intensities of the smallest flares noted by each of the optical observers were dependent on their respective instrumental sensitivities. Since the relative increase in optical luminosity during a flare is a strong function of wavelength (Kunkel 1970), the filters with which the observations were made significantly influenced the lower limit on flare detectability. The mean photometric sensitivities of each optical facility are listed in Table 1 in terms of I_f, which is defined as follows:

$$I_f = \frac{L_{flare + quiescent\ star}}{L_{quiescent\ star}} - 1.0. \qquad (1)$$

A total of 22 optical flares was observed during the entire period of optical coverage; these events are listed in Table 3. Light curves of four flares with I_f (B)> 1.0 are shown in Figures 2 through 5. For the flare which had coincident polarimetric coverage, the data reveal no linear polarization above the 2σ level. These results are consistent with the most reliable of earlier polarimetric observations (cf. Gershberg 1971). X-ray coverage was available for only 15 of the 22 optical events; no x-ray emission above the 3σ level was found to accompany any of these minor flares.

The radio coverage included 12 frequencies in the range 38 to 6300 MHz. All radio telescopes utilized in this work except those at Clark Lake, Culgoora and Ootacamund (henceforth referred to as Ooty) are single-dish telescopes; the instrumental sensitivities for the frequencies of observation are listed in Table 2. Reduction of optical and radio data was performed independently by the respective observers. The reduced data were then cross-correlated in search of events seen at different radio frequencies or at both optical and radio wavelengths.

Twelve radio bursts were detected during this program; the data for these events are given in Table 3. One burst was recorded at 160 MHz with the Culgoora telescope and at 5000 MHz with the Parkes telescope without coincident optical or x-ray coverage. Another burst, which occurred on December 3 at $7^h05^m.0$ UT, was accompanied by a small optical flare; the

U-band, the 196 MHz and the 318 MHz peaks were simultaneous to within $\pm$ 2 seconds. The upper limit on the x-ray emission during this event is discussed in the following Section. A third radio burst, noted by Ooty at 1975 December 1, $20^h44^m.3$ UT, was followed $1^m.7$ later by a small optical flare, observed at the Crimean Astrophysical Observatory. Unfortunately, no x-ray coverage was available for this event. The remaining 10 bursts may well have been of stellar origin, but we cannot rule out terrestrial causes for a radio event observed at one frequency alone, or without optical verification; this problem is not so serious for the multi-element facilities, but caution must still be exercised in interpreting such data. Thus, only the two above mentioned radio events appear conclusively to have originated on YZ CMi. Seven radio bursts were found to have coincident x-ray coverage, but each of these showed null results for enhanced x-ray emission.

The 3σ upper limits on the x-ray emission in the energy range 0.15 to 0.8 keV, associated with the 3 larges optical flares for which x-ray coverage was available, are given in Table 4. For each flare, upper limits were determined for five contiguous, 83.4-second intervals, centered on the time of flare maximum. The largest upper limit of the five was then adopted as the upper limit for that flare. For comparison with the predictions discussed in the following Section, the ratio of the upper limit on the x-ray flux to the peak B-band flux, L_x/L_B, was determined for each of the three flares, and is listed in Table 4.

The x-ray records for fourteen optical flares were superposed, providing a 3σ upper limit on the x=ray emission per flare, $\langle L_x \rangle$, averaged over these fourteen events. The average peak B-band luminosity of these flares, $\langle L_B \rangle$, was calculated, thereby enabling the determination of the ratio $\langle L_x \rangle / \langle L_B \rangle$ for this group of optical events; this ratio is given in Table 4. Superpositions also were performed with the x-ray data for a sample of five radio bursts, and for the entire set of nineteen optical and radio events. The 3σ upper limits on the x-ray emission per flare for the three sets of superposed flares are listed in Table 4.

III. MODELS FOR FLARE STAR X-RAY EMISSION AND COMPARISON WITH THE DATA

Gurzadyan (1966) originally suggested the inverse Compton effect as a possible source of x-ray emission from flare stars. Grindlay (1970) proposed nonthermal bremsstrahlung from fast electrons accelerated in the flares as a more efficient mechanism. He did not take into account synchrotron self-absorption of the radio emission, as pointed out by Gurzadyan (1971) who predicted a higher x-ray flux from nonthermal bremsstrahlung. Kahler and Shulman (1972) and Crannell, McClintock and Moffett (1974) made estimates of the x-ray emission in stellar flares based on scaling of observed solar flare events. Mullan (1976) invoked a purely thermal mechanism through which conductive cooling dominates the initial phase of the flare decay.

Predictions of stellar-flare x-ray emission based on these models are presented in Tables 4 and 5. In Table 4 the predicted values are expressed in the common form, L_x/L_B, for comparison with each other and with the observations. The estimate published by Kahler and Shulman (1972) has been modified in two ways: (1) the x-ray luminosity has been extrapolated to the energy range 0.15 - 0.8 keV using a spectral index of 2.0 for the photon number spectrum, and (2) the white-light luminosity has been reduced to the B-band luminosity using the empirical relation due to Lacy, Moffett and Evans (1976):

$$\begin{aligned} L_W &= L_U + L_B + L_V \\ &= 1.2\ L_B + L_B + 0.7\ L_B \qquad (2) \\ &= 2.9\ L_B \end{aligned}$$

The estimates based on Models 1 and 2 of Grindlay (1970) were obtained in the following manner. At such low x-ray energies, the effects of self-absorption on the predicted spectra are undoubtedly significant, although they were not included in Grindlay's analysis. According to Grindlay (private communication), it is reasonable to postulate that the total x-ray luminosity in the energy range 0.15 to 0.8 keV is approximately equal to the total luminosity at photon energies greater than 10 keV. Grindlay (1970) estimated L_x(>10 keV) for Models 1 and 2 to be 2.8×10^{31} erg s^{-1} and 2.6×10^{28} erg s^{-1} respectively, for an optical flare of white-light luminosity $L_w = 8 \times 10^{28}$ erg s^{-1}. L_w has been changed to L_B, for purposes of this analysis, by means of the relation $L_w = 2.9L_B$ (Lacy, Moffett and Evans 1976). The resultant estimates should be regarded with caution, as the models were developed expressly to predict the hard x-ray flux (>10 keV) only; furthermore, the effects of self-absorption have been included in a very approximate manner. The predictions based on Mullan (1976) have been scaled from L_x/L_w to L_x/L_B by means of the relation stated above. Mullan, however, does not specify the x-ray range of his model, other than to say he is dealing with "thermal" x-rays. Thus, his predictions should be considered only as order-of-magnitude values when they are compared to the present observations. The estimate from Gurzadyan (1971) has been extrapolated to the 0.15 to 0.8 keV energy range using a spectral index of 2.0 for the photon number spectrum, and has been adjusted from L_x/L_U to L_x/L_B by means of the relation $L_U = 1.2L_B$ (Lacy, Moffett and Evans 1976).

From inspection of Table 4, it is immediately obvious that the estimates due to Gurzadyan and Grindlay are in excess of the observations. These predictions are also considerably greater than the x-ray to optical luminosity ratio for a flare recently observed on UV Cet (Heise et al. 1975). The reported ratio of x-ray to U-band luminosity at maximum light is

$$L_x(0.2 - 0.28\ \mathrm{keV})/L_U = 0.03 \tag{3}$$

which is equivalent to

$$L_x\ (0.15 - 0.8\ \mathrm{keV})/L_B = 0.24 \tag{4}$$

The x-ray luminosity was extrapolated from the published 0.2 to 0.28 keV data using an x-ray spectral index of 2 for the photon number spectrum, and the B-band luminosity was assumed to be 0.83 times that observed in the U-band. This ratio is consistent with the upper limits given in Table 4 for the three optical flares observed in this program and is in disagreement with the predictions based on the models of both Grindlay and Gurzadyan. For two of these three optical flares, the ratios L_x/L_B are less than that determined for the UV Cet flare seen by Heise et al. (1975), which is also given in Table 4. This discrepancy could be due to the assumption of a perfect linear relation between the U-band and B-band flare luminosities, used in determining B-band luminosities for those flares observed only in the U-bandpass. The general uncertainties resulting from the x-ray data analysis may also contribute to this discrepancy. On the other hand, this may indicate that x-ray emission only occurs during large optical flares, larger than any seen during the coincident x-ray and optical observations reported in this paper. It would be of interest to establish the existence and properties of such a "threshold effect", as this would provide valuable information on the physical conditions in stellar flares.

The 3σ upper limit on the x-ray flux associated with the optical and radio event for which coincident x-ray coverage was available is given in Table 5, along with the upper limit on the ratios of the soft x-ray flux to the 196 MHz and 318 MHz fluxes. An interpolation of these ratios gives the ratio of soft x-ray flux to the 210 MHz flux, which is presented in Table 5 together with the ratio inferred from the estimate of Crannell et al. (1974). The estimate due to Crannell et al. (1974) has been extrapolated to the relevant energy range using an x-ray spectral index of 2 for the photon number spectrum. That prediction is too optimistic by approximately four orders of magnitude.

Three of the five predictions under consideration in the present analysis are significantly at variance with the observations. The discrepancy between the predictions of Grindley and Gurzadyan and the observations is not surprising, however, since both models already have been criticized in the literature (cf. Kahler and Shulman 1972). Crannell et al. computed the ratio of x-ray flux to the radio flux at 210 MHz for only one specific solar flare. Solar flare soft x-ray fluxes, however, correlate very poorly, both temporally and energetically, with meter-wave fluxes (cf. Kundu 1965). On a more fundamental level, the soft x-ray emission during flares is generally believed to be thermal in nature, while the radio emission is certainly non-thermal. Although this does not preclude some relationship between flare-induced soft x-ray and radio emission, the basic differences in the physics of these emission mechanisms would naturally lead to poor correlations in the resultant luminosities. As for the two estimates which are apparently in accord with the x-ray observations, neither has been demonstrated to be thoroughly successful. More coincident x-ray, optical, and radio observations must be made to find out whether these remaining models are consistent with a larger sample of major flares. It is interesting to note that Mullan's model predicts a larger x-ray-to-optical ratio for solar flares as compared to stellar flares. Again, more observations are needed to test this hypothesis.

Thus, serious difficulties remain in the interpretation of flare activity on UV Ceti stars. It should be noted that many gaps remain also in current understanding of solar flare activity, even though the Sun has been studied much more extensively and accurately than have flare stars. Observations of flare stars simultaneously in appropriate regions of the electromagnetic spectrum can provide significant insights into the physics behind stellar flares, even with the limitations of present-day instrumentation.

IV. THE FLARE-STAR CONTRIBUTION TO THE DIFFUSE X-RAY BACKGROUND

UV Ceti flare stars have been proposed to be the source part, if not all, of the diffuse soft x-ray background in our Galaxy (Hayakawa 1973). These numerous, evenly-distributed stars, each flaring at random, could provide this diffuse radiation if the mean x-ray emission during flares were sufficiently large.

The analysis presented here is similar to that of Edwards (1971). According to Arakelian (1970), the space density of red dwarfs with hydrogen emission in the solar neighborhood is 0.055 pc^{-3}; however, from the analyses by Gershberg and Shakhovskaya (1976) and Coleman and Worden (1976) this value could be considered a lower limit to the mean density of flare stars. Although there is evidence that the local flare stars may comprise an association (Arakelian 1970; Ambartsumian and Mirzoyan 1975), it will be assumed in this analysis that the flare-star space density in the Galaxy as a whole is the same as in the solar neighborhood. According to Kunkel (1970), Cristaldi and Rodono (1975) and Lacy, Moffett and Evans (1976), a flare star expends in the B-band from a fraction of a percent to a few percent of its B-band quiescent luminosity. The time-averaged flare luminosity in the B-band, denote $L_f(B)$, therefore, is approximately equal to 0.01 times the B-band quiescent luminosity. A typical B-band quiescent luminosity of a UV Ceti-type flare star is approximately 2×10^{30} erg s^{-1}; thus $L_f(B) = 2 \times 10^{28}$ erg s^{-1}.

The diffuse soft x-ray background fluctuates only slightly with galactic longitude, as noted by several observers (e.g. Davidsen et al. 1972 and Levine et al. 1976). However, at energies less than 1 keV, this background radiation is observed to be stronger at high northern galactic latitudes than at low latitudes (Bowyer et al. 1968; Davidsen et al. 1972; Levine et al. 1976; Hayakawa et al. 1975). This feature, in conjunction with the observed hardening of the background spectrum with decreasing galactic latitude (Levine et al. 1976), indicates that the effects of x-ray absorption by the interstellar medium are important, particularly at the lowest energies.

Gorenstein and Tucker (1972) considered a model for the diffuse x-ray background wherein the observed flux is provided by a population of point sources. They used then-current observations of the diffuse background in two soft energy ranges to deduce the necessary properties of such a stellar population. The present analysis makes use of their mathematical formulation of the problem and the observed properties of flare stars and stellar flares to deduce the contribution of stellar flares to the diffuse x-ray flux.

In the galactic plane, the diffuse x-ray background intensity at energy E, resulting from point sources with a homogenous number density N(0), can be expressed as follows (Gorenstein and Tucker 1972):

$$I(E) = N(0)\ L(E)\ \ \lambda(E)/4\Pi \quad \text{photons cm}^{-2}(\text{s keV sr})^{-1} \tag{5}$$

where

$N(0) \simeq 0.055\ \text{pc}^{-3}$;

$L(E)$ = the x-ray luminosity of the source at energy E in photons s^{-1} keV^{-1};

$\lambda(E)$ = the mean free path of an x-ray photon of energy E in the interstellar medium,
$= (\sigma(E)\ n_H)^{-1}$;

$\sigma(E)$ = the effective x-ray absorption cross-section per hydrogen atom; and

n_H = the number density of hydrogen atoms in the galactic plane, $\approx 0.5\ cm^{-3}$.

The x-ray luminosity of each source, L(E), is essentially the x-ray emission during flares on a typical flare star, time-averaged to give an equivalent continuous flux. Thus,

$$L(E) = (L_x/L_B)\ L_f(B), \tag{6}$$

where (L_x/L_B) is the ratio of the x-ray to the B-band luminosity of a stellar flare, as originally defined in Section II.

Assuming a photon number spectrum of the form $N(E)\ dE = A\ E^{-2}\ dE$ photons $(s\ keV)^{-1}$ for a stellar flare and using the 3σ upper limit on the ratio L_x/L_B for the largest optical flare in Table 4, the upper limit on the ratio L_x/L_B is found to be:

$$L_x/L_B \leq \frac{3.24 \times 10^{37}\ E^{-2}\ \text{photons}\ (s\ keV)^{-1}}{3.04 \times 10^{30}\ \text{erg}\ s^{-1}} . \tag{7}$$

Thus, $L(E) \leq 1.14 \times 10^{35}\ E^{-2}$ photons $(s\ keV)^{-1}$.

The effective x-ray absorption cross-section per hydrogen atom is not a well-established quantity at present. As pointed out by Cruddace et al. (1974) and Fireman (1974), the effective cross-section is dependent on the sizes and composition of dust grains, the abundances of the intermediate-weight elements, and the amount of interstellar H_2; none of these quantities, however, are well-known. For purposes of the present analysis, the absorption cross-section derived by Brown and Gould (1970), as given by Hayakawa (1973) in the following convenient analytical form, is used:

$$\sigma(E) = \begin{cases} 6 \times 10^{-23}\ E^{-3} & 0.1 < E < 0.53\ \text{keV} \\ 2 \times 10^{-22}\ E^{-2.5} & 0.53 < E < 10\ \text{keV} \end{cases} \text{cm}^2. \quad (8)$$

Substituting the proper values for N(0), L(E) and λ(E) into Equation 5, then multiplying be E and integrating the resultant expression over the energy range 0.15 to 0.8 keV, yields the flare-star contribution to the diffuse soft x-ray continuum in the galactic plane,

$$F_{fx}(0.15\text{-}0.8\ \text{keV}) \leq 2.42 \times 10^{-9}\ \text{erg cm}^{-2}\ (\text{s sr})^{-1}. \quad (9)$$

Recent measurements of the diffuse soft x-ray background in the galactic plane (Hayakawa _et al_. 1975) can be approximated by a spectrum of the following form:

$$I_g(E) = \frac{4.5 \times 10^{-18}}{4\pi E\ \sigma(E)}\ e^{-E/0.18\ \text{keV}} \{1 - \exp(-\sigma(E)\cdot 3 \times 10^{21} \text{cm}^{-2})\} \quad (10)$$

$$\approx 1.07 \times 10^{3}\ E^{-1}\ e^{-E/0.18\ \text{keV}}\ \text{photons cm}^{-2}\ (\text{s keV sr})^{-1}.$$

By multiplying Equation 10 by E, then integrating over the energy range 0.15 to 0.8 keV, one finds the observed flux of the diffuse x-ray background in that energy range, denoted F_x(obs.). Thus,

$$F_x(\text{obs.}) = 1.31 \times 10^{-6}\ \text{erg cm}^{-2}\ (\text{s sr})^{-1}. \quad (11)$$

An estimate of the fraction of the soft x-ray background which could be due to flare stars can now be made. The ratio of the estimated upper limit on the flare-star contribution, F_{fx}, to the observed flux, F_x(obs.), is:

$$F_{fx}/ F_x(\text{obs.}) \leq 1.2 \times 10^{-3}. \quad (12)$$

Thus, UV Ceti flare stars could be responsible for at most 0.2% of the galactic component of the diffuse x-ray continuum in the energy range 0.15 to 0.8 keV. Consequently, other sources for this mysterious background radiation must be sought.

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TABLE 1

Observatory	Bandpass	Minimum Detectable I_f
Catania - 61 cm	U	0.50
	B	0.07
	V	0.05
Crimea - 64 cm	B	0.15
McDonald - 76 cm	U	0.11 - 0.17
	B	0.04 - 0.06
McGraw-Hill - 1.3 m	U	0.16
	B	0.05
		Minimum Detectable Polarization
Crimea - 2.6 m	B	0.8%
	V	0.4%
	O	0.5%
	R	0.5%

TABLE 2

Observatory	Frequency-MHz	Minimum Detectable Signal(3RMS) in Jy	Integration Time
Algonquin - 120'	6300	0.11	35^s
Arecibo - 1000'	196	1.0	1^s
	318	0.15	1^s
Clark Lake	38	20.0	1^s
Culgoora	160	1.0	30^m
NRAO - 140'	1400	0.14	1^s
	1700	0.12	
NRAO - 300'	264	5.7	1^s
	296	1.1	
	340	1.4	
	420	1.0	
	500	0.8	
Ooty	327	0.45-0.75	1^s
Parkes - 210'	5000	0.03	2^m

TABLE 3

Peak Time	Duration	Peak Flux (Jy or I_f)	Bandpass (UBV) or Frequency (MHz)	Institution
1975 Nov 30				
15^h17^m	1^h33^m	1.1	160	Culgoora
1975 Nov 30				
$20^h29^m.0$	1^m	0.5	327	Ooty
		<0.15	B	Crimea
1975 Nov 30				
$23^h02^m.0$	6^m	15.48	U	Catania
		3.20	B	
		0.71	V	
		<0.75	327	Ooty
1975 Nov 30				
$23^h16^m.3$	$>1^m$	7.15	U	Catania
		1.30	B	
		0.50	V	
		<0.75	327	Ooty
1975 Dec 1				
$0^h07^m.15$	2^m	5.42	U	Catania
		0.43	B	
		0.11	V	
		<0.75	327	Ooty

Table 3 - Continued

Peak Time	Duration	Peak Flux (Jy or I_f)	Bandpass (UBV) or Frequency (MHz)	Institution
1975 Dec 1				
$2^h28^m.0$	24^s	0.5	327	Ooty
		<0.50	U	Catania
		<0.07	B	
		<0.05	V	
1975 Dec 1				
$3^h19^m.0$	24^s	0.6	327	Ooty
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 1				
$7^h35^m.1$	$<20^s$	0.29	U	McDonald
		<20.0	38	Clark Lake
		<1.0	196	Arecibo
		<0.15	318	
		<5.7	264	NRAO
		<1.4	340	
		<1.0	420	
		<0.8	500	
		<0.14	1400	
		<0.12	1700	

Table 3 - Continued

Peak Time	Duration	Peak Flux (Jy or I_f)	Bandpass (UBV) or Frequency (MHz)	Institution
1975 Dec 1				
$9^h43^m.6$	2^m37^s	0.10	B	McGraw-Hill
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 1				
$9^h54^m.6$	35^s	0.05	B	McGraw-Hill
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 1				
$10^h53^m.6$	1^m24^s	0.58	U	McDonald
		< 20.0	38	Clark Lake
		<0.14	1400	NRAO
		<0.12	1700	
		<0.11	6300	Algonquin
1975 Dec 1				
$11^h48^m.9$	1^m36^s	0.20	B	McDonald
		<20.0	38	Clark Lake
		<0.14	1400	NRAO
		<0.12	1700	
		<0.11	6300	Algonquin

Table 3 - Continued

Peak Time	Duration	Peak Flux (Jy or I_f)	Bandpass (UBV) or Frequency (MHz)	Institution
1975 Dec 1				
16^h12^m	31^m	1.2	160	Culgoora
	2^m	0.078	5000	Parkes
1975 Dec 1				
$20^h44^m.3$	20^s	0.75	327	Ooty
$20^h46^m.0$	5^s	0.42	B	Crimea
1975 Dec 1				
$22^h21^m.3$	12^m	2.80	B	Crimea
		<0.75	327	Ooty
1975 Dec 2				
$0^h28^m.5$	30^s	0.4	327	Ooty
		<0.15	B	Crimea
1975 Dec 2				
$0^h36^m.5$	15^m	1.11	B	Crimea
		<0.4%	V-polarimetry	Crimea
		<0.75	327	Ooty
1975 Dec 2				
$6^h55^m.75$	15^m	1.25	B	McDonald
		<1.0	196	Arecibo
		<0.15	318	

Table 3 - Continued

Peak Time	Duration	Peak Flux (Jy or I_f)	Bandpass (UBV) or Frequency (MHz)	Institution
1975 Dec 2				
$6^h55^m.75$ (continued)		<1.1	296	NRAO
		<1.4	340	
		<1.0	420	
		<0.8	500	
		<0.14	1400	
		<0.12	1700	
1975 Dec 2				
$9^h15^m.3$	5^m57^s	0.98	U	McGraw-Hill
		<1.1	296	NRAO
		<1.4	340	
		<1.0	420	
		<0.8	500	
		<0.14	1400	
		<0.12	1700	
1975 Dec 2				
$9^h22^m.0$	1^m25^s	0.48	U	McGraw-Hill
		<0.14	1400	NRAO
		<0.12	1700	

Table 3 - Continued

Peak Time	Duration	Peak Flux (Jy or I_f)	Bandpass (UBV) or Frequency (MHz)	Institution
1975 Dec 2				
$9^h28^m.7$	27^s	0.45	U	McGraw-Hill
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 2				
$9^h52^m.1$	1^m39^s	0.42	U	McGraw-Hill
		<0.06	B	McDonald
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 2				
$10^h02^m.0$	3^m15^s	0.13	B	McDonald
	3^m34^s	1.04	U	McGraw-Hill
		<20.0	38	Clark Lake
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 2				
$10^h10^m.4$	6^m57^s	0.42	U	McGraw-Hill
		<0.06	B	McDonald
		<0.14	1400	NRAO
		<0.12	1700	

Table 3 - Continued

Peak Time	Duration	Peak Flux (Jy or I_f)	Bandpass (UBV) or Frequency (MHz)	Institution
1975 Dec 2				
$11^h36\overset{m}{.}0$	1^m06^s	0.11	B	McDonald
		<20.0	38	Clark Lake
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 2				
$12^h12\overset{m}{.}9$	$<2^m$	0.16	B	McDonald
		<20.0	38	Clark Lake
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 2				
15^h09^m	31^m	1.1	160	Culgoora
		<0.03	5000	Parkes
1975 Dec 2				
$20^h14\overset{m}{.}2$	1^m	0.32	B	Crimea
		<0.45	327	Ooty
1975 Dec 2				
$20^h59\overset{m}{.}4$	30^s	0.29	B	Crimea
		<0.45	327	Ooty

Table 3 - Continued

Peak Time	Duration	Peak Flux (Jy or I_f)	Bandpass (UBV) or Frequency (MHz)	Institution
1975 Dec 2				
$21^h09^m.25$	45^s	0.4	327	Ooty
		<0.15	B	Crimea
1975 Dec 2				
$21^h23^m.8$	24^s	0.5	327	Ooty
		<0.15	B	Crimea
1975 Dec 2				
$22^h11^m.8$	4^m	0.15	B	Crimea
		<0.45	327	Ooty
1975 Dec 3				
$0^h21^m.1$	3^m30^s	0.57	B	Crimea
		<0.45	327	Ooty
1975 Dec 3				
$1^h53^m.6$	8^m	0.39	B	Crimea
		<0.45	327	Ooty
1975 Dec 3				
$7^h05^m.0$	$<15^s$	"very small"	U	McDonald
	10^s	2.0	196	Arecibo
	$7^s.5$	0.25	318	
		<0.14	1400	NRAO
		<0.12	1700	

Table 3 - Continued

Peak Time	Duration	Peak Flux (Jy or I_f)	Bandpass (UBV) or Frequency (MHz)	Institution
1975 Dec 3				
$9^h43^m.4$	6^m40^s	0.31	U	McDonald
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 3				
$9^h49^m.8$	3^m40^s	0.33	U	McDonald
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 3				
$11^h11^m.0$	1^m20^s	0.30	U	McDonald
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 3				
$11^h39^m.9$	6^m40^s	0.49	U	McDonald
		<0.14	1400	NRAO
		<0.12	1700	

Table 3 - Continued

Peak Time	Duration	Peak Flux (Jy or I_f)	Bandpass (UBV) or Frequency (MHz)	Institution
1975 Dec 3				
$11^h48^m.2$	1^m	1.28	U	McDonald
		<0.14	1400	NRAO
		<0.12	1700	
1975 Dec 3				
$11^h51^m.0$	9^m30^s	1.46	U	McDonald
		<0.14	1400	NRAO
		<0.12	1700	

TABLE 4

3σ X-Ray Upper Limits
0.15-0.8 keV

Time of Flare	I_f(B)	(photons $cm^{-2}s^{-1}$)	L_x(0.15-0.8 keV)/L_B
30 November 1975			
$23^h16^m.3$	1.31	0.04	≤0.28
2 December 1975			
$00^h36^m.5$	1.1	0.029	≤0.24
2 December 1975			
$6^h55^m.8$	1.25	0.025	≤0.19
Solar x-ray/optical (Kahler and Shulman 1972)			0.43
Grindlay (1970): Model 1			10^3
Grindlay (1970): Model 2			1
Gurzadyan (1971)			≥2.6
Mullan (1976)			0.003 - 0.02
Observed Flare on UV Cet (Heise *et al*. 1975)			0.24
Superpositions:			
14 optical events		0.0084	0.32
5 radio events		0.017	----
All 19 events		0.0076	----

TABLE 5

Time of Flare	F(196 MHz)	F(318 MHz)	3σ X-ray Upper Limits 0.15 – 0.8 keV (Photons $cm^{-2}s^{-1}$)	L_X(0.15-0.8 keV)/ L_R(210 MHz)
3 December 1975				
$7^h05^m.0$	2.0 Jy	0.25 Jy	0.02	$\leq 7 \times 10^5$
Solar X-ray/Radio (Crannell *et al*. 1974)				8.5×10^9

FIGURE CAPTIONS

Figure 1: X-ray, Optical and Radio Coverage during Coordinated Observations.

Figure 2: Flare Light Curve.

Figure 3: Flare Light Curve. Note that this event is a secondary maximum of the flare depicted in Figure 2.

Figure 4: Flare Light Curve.

Figure 5: Light Curve of a "Spike"-type Flare.

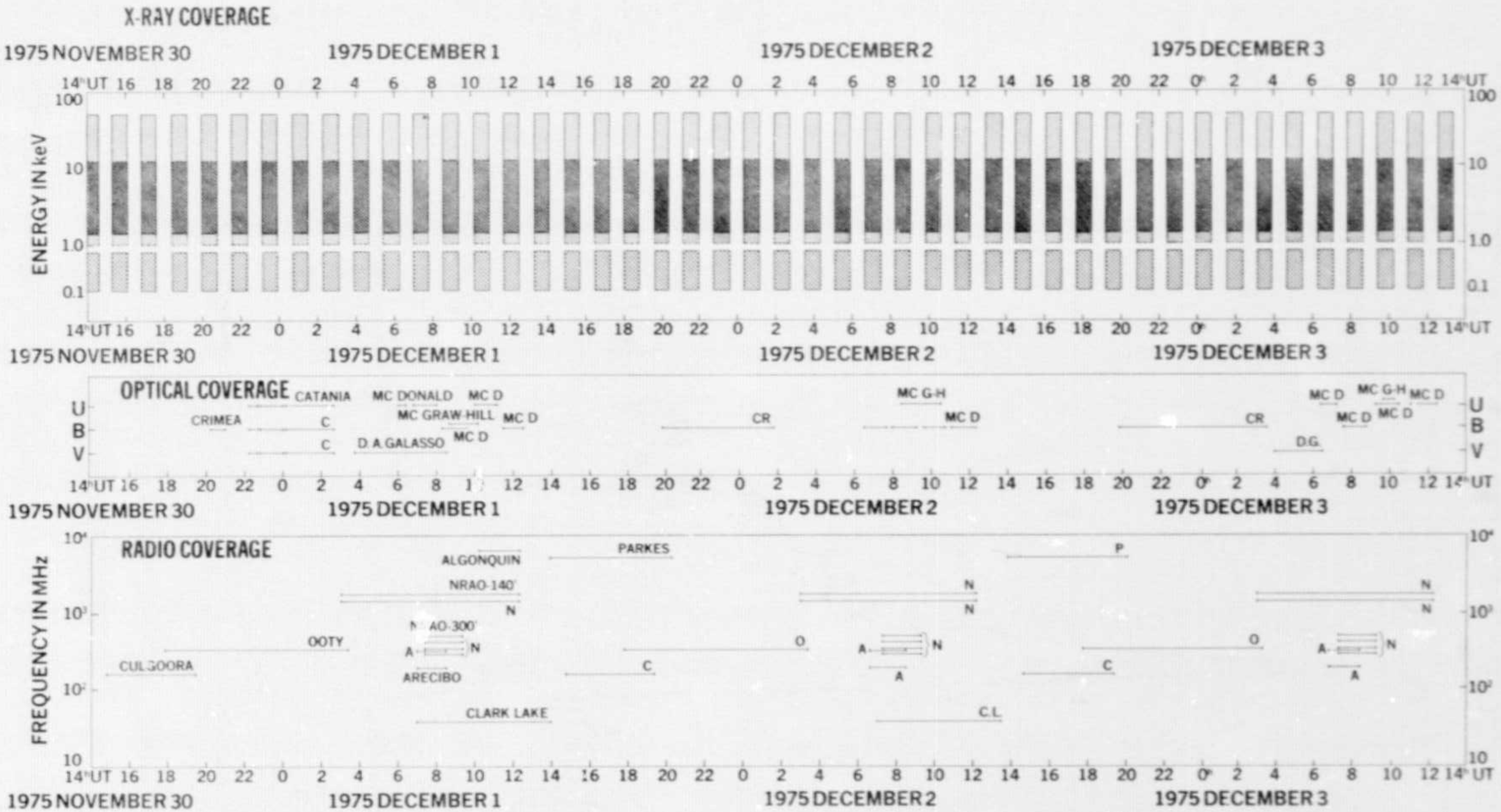
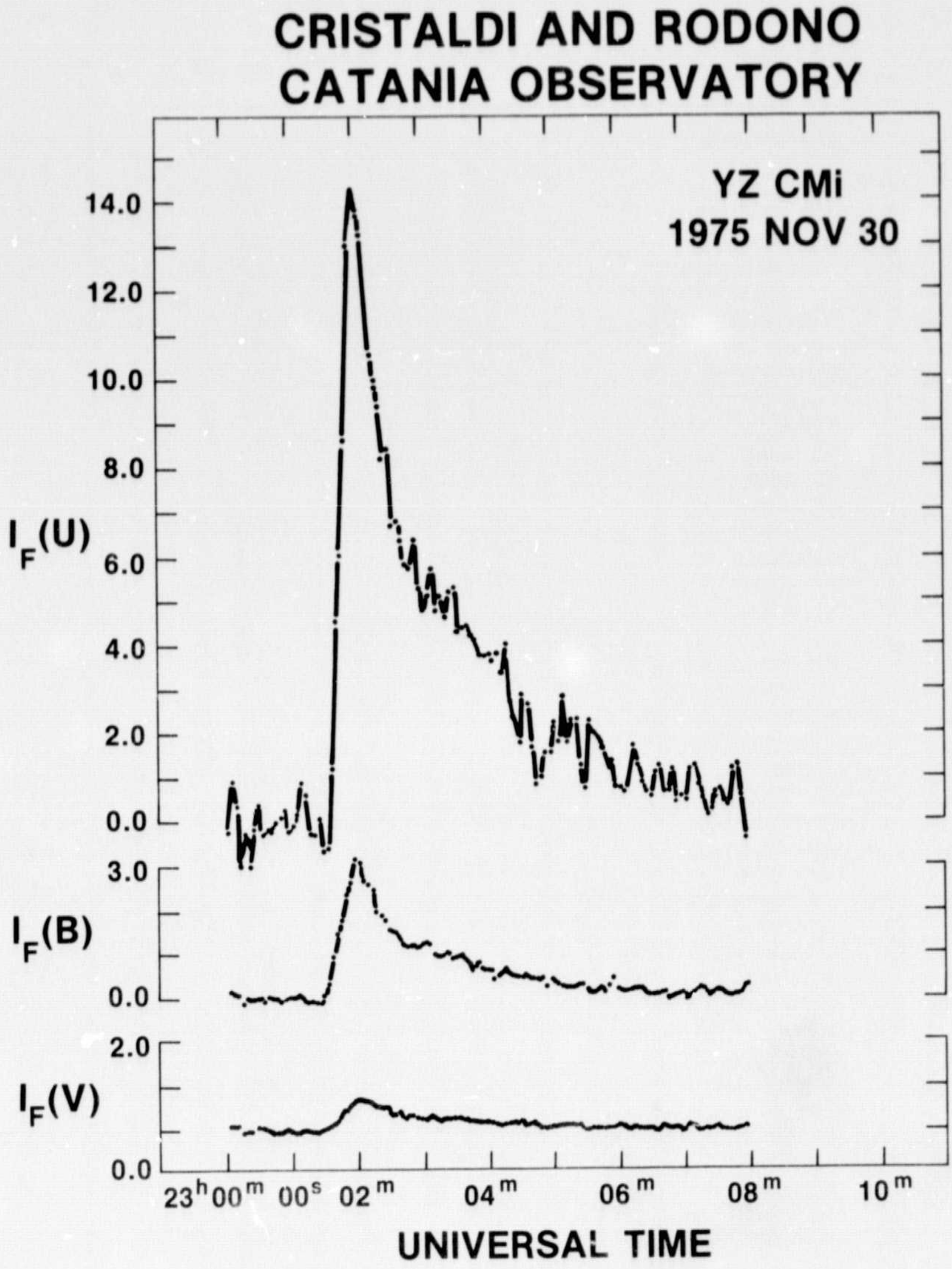

X-RAY COVERAGE
1975 NOVEMBER 30
1975 DECEMBER 1
1975 DECEMBER 2
1975 DECEMBER 3
ENERGY IN keV
OPTICAL COVERAGE
CATANIA
MC DONALD
MC D
CRIMEA
MC GRAW-HILL
D.A.GALASSO
CR
MC G-H
D.G.
RADIO COVERAGE
FREQUENCY IN MHz
PARKES
ALGONQUIN
NRAO-140'
OOTY
CULGOORA
ARECIBO
CLARK LAKE
C.L.

FIGURE 1



CRISTALDI AND RODONO
CATANIA OBSERVATORY
YZ CMi
1975 NOV 30
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
3.0
0.0
2.0
0.0
$I_F(U)$
$I_F(B)$
$I_F(V)$
$23^h00^m00^s$
02^m
04^m
06^m
08^m
10^m
UNIVERSAL TIME

FIGURE 2

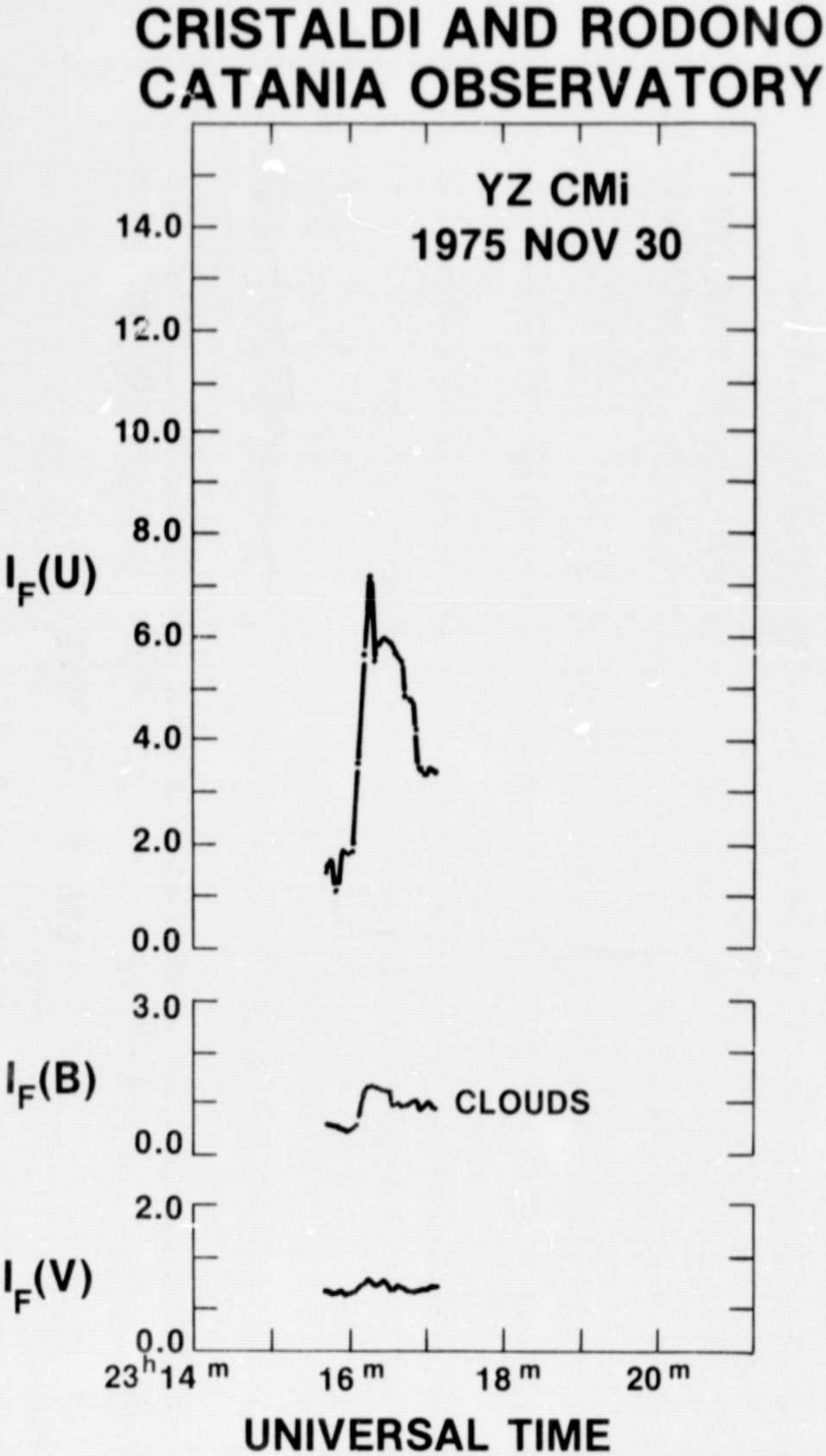

CRISTALDI AND RODONO
CATANIA OBSERVATORY
YZ CMi
1975 NOV 30
14.0
12.0
10.0
8.0
$I_F(U)$
6.0
4.0
2.0
0.0
3.0
$I_F(B)$
CLOUDS
0.0
2.0
$I_F(V)$
0.0
23^h14^m
16^m
18^m
20^m
UNIVERSAL TIME

FIGURE 3

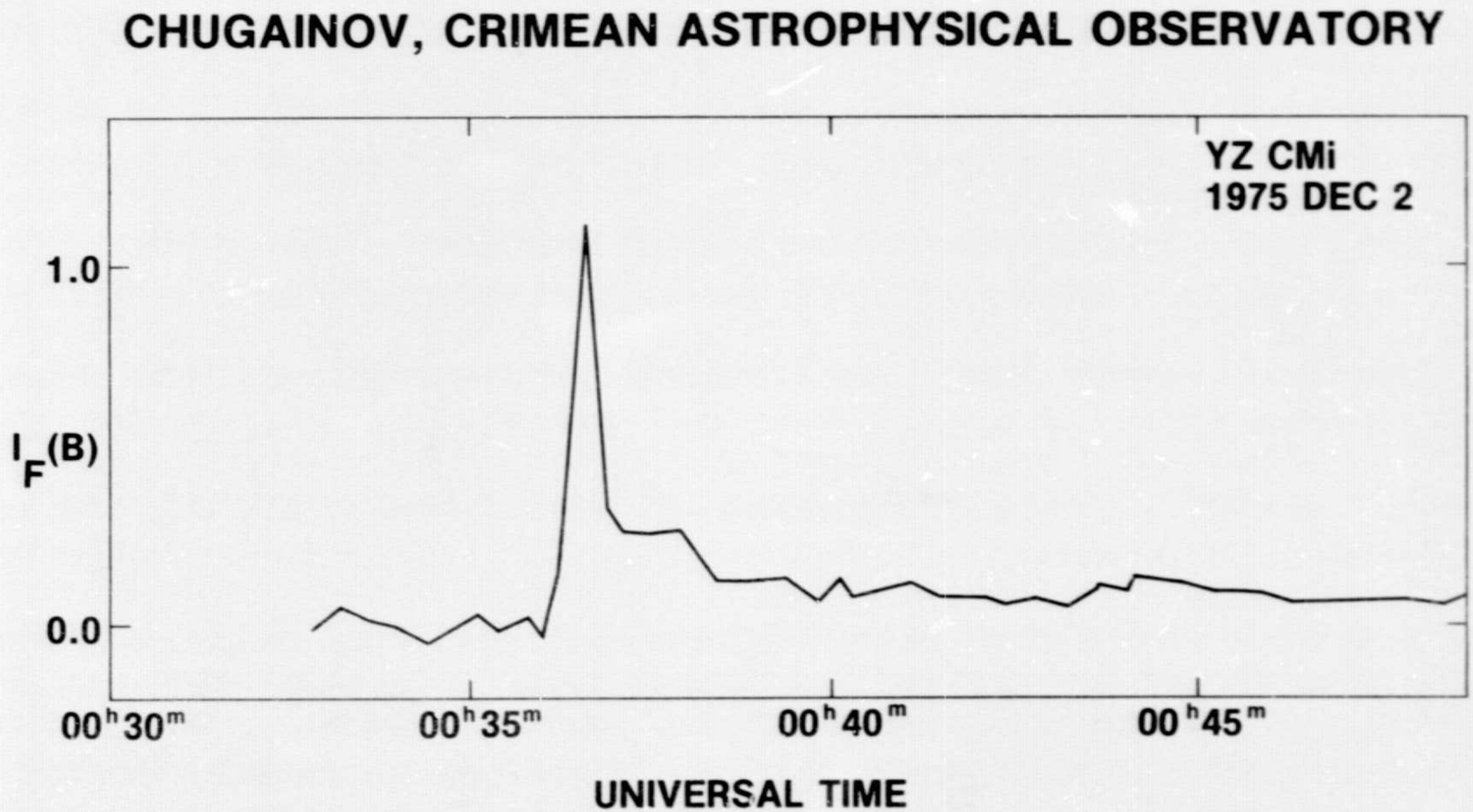

CHUGAINOV, CRIMEAN ASTROPHYSICAL OBSERVATORY
YZ CMi
1975 DEC 2
1.0
0.0
I_F(B)
00^h30^m
00^h35^m
00^h40^m
00^h45^m
UNIVERSAL TIME

FIGURE 4

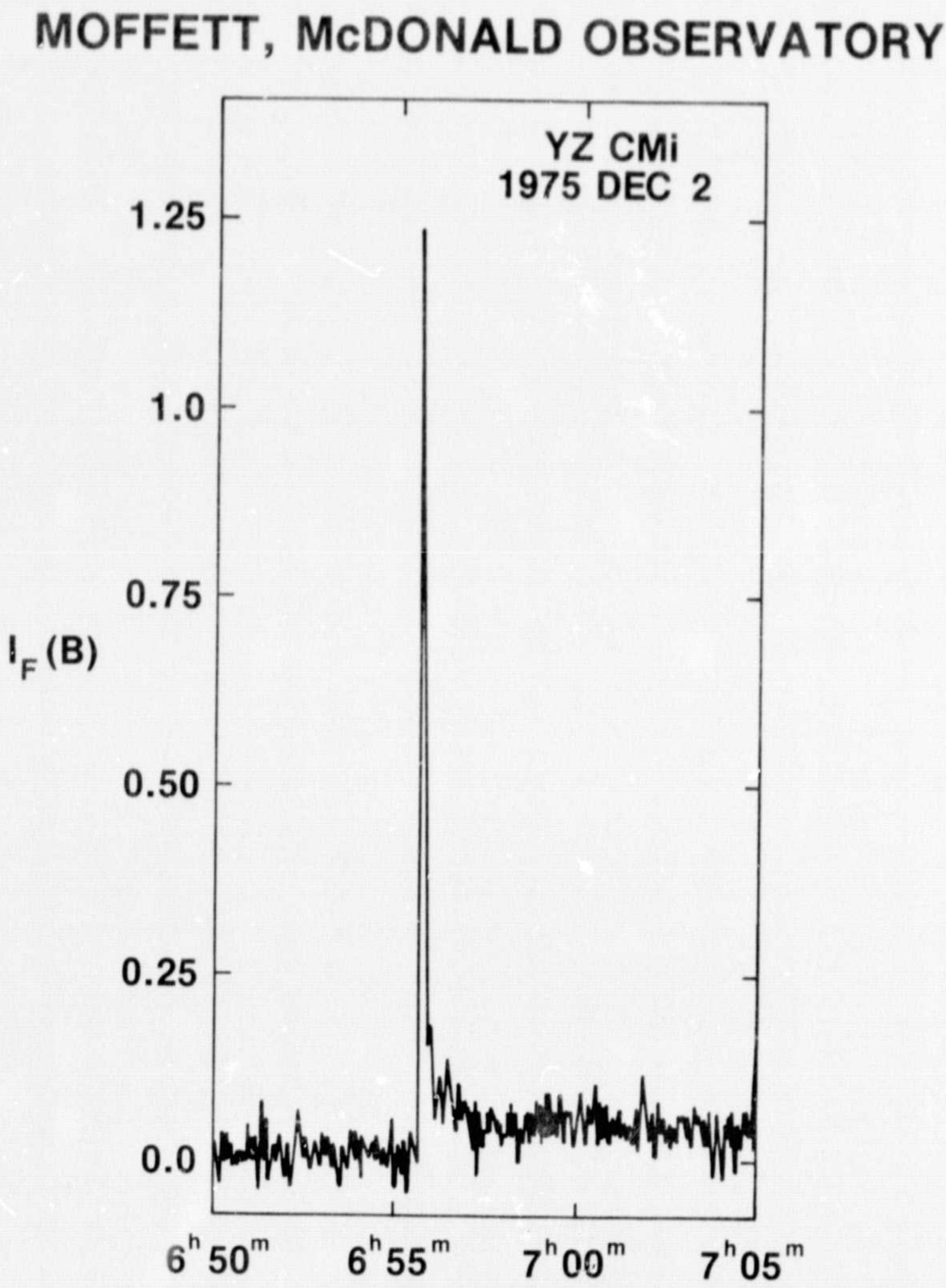

MOFFETT, McDONALD OBSERVATORY
YZ CMi
1975 DEC 2
1.25
1.0
0.75
0.50
0.25
0.0
I_F (B)
6^h50^m
6^h55^m
7^h00^m
7^h05^m
UNIVERSAL TIME

FIGURE 5

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