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SEARCH FOR AN OPTICAL COUNTERPART OF THE SOURCE OF GRB 911001

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ABSTRACT

The positional error box of GRB 911001 is centered in the north ecliptic pole field (Fishman et al. 1994) which was extensively observed with the Tautenburg Schmidt telescope between 1990 and 1992 (more than 100 Schmidt plates). The plate taken nearest to the time after the occurrence of the burst is from 1991 October 2. We report here on the results of a search for variable objects within the error box of GRB 911001. We detected four objects, among them a possibly so far unknown cataclysmic variable. At the time of the occurrence of the GRB this object was presumably in a maximum state.

Subject headings: gamma rays: bursts — novae, cataclysmic variables — stars: individual (X Draconis) — stars: variables: other

1. INTRODUCTION

Since the early attempts of Grindlay, Wright, & McCrosky (1974) and later on Schaefer (1981) to detect optical counterparts of gamma-ray bursts (GRBs), more than 20 years after their discovery by Klebesadel, Strong, & Olson (1973) there is still no conclusive observational evidence whether any burst and/or burster has really been detected in the optical waveband (e.g., Greiner 1992). Most papers dealing with this subject concentrated so far on the search for optical transients on archival plates taken from regions of the sky which contain the positional error box of a GRB (for a recent review, see Hudec 1993). The background behind this strategy is that the burster might repeat within a time of the order of years. Only recently the attention has also drawn to the search for optical counterparts of the bursters itself by means of plates taken a short time *after* the occurrence of a GRB (Boer et al. 1991; Borovička, Hudec, & Dědoch 1992; Schaefer et al. 1994; Vrba et al. 1994). The basic idea is that any source which has emitted a GRB might show anything like an afterglow because of various reasons (e.g., Hartmann, Woosley, & Arons 1988) or simply represent an unusual variable object. Finally, the third observing strategy represents the BACODINE network which can provide optical observations when a burster is still bursting (Barthelmy et al. 1994), but no optical counterpart of any GRB has been detected so far (Greiner 1994).

Among the four popular models discussed in the literature concerning the spatial origin of the GRBs (in the Oort cloud, in the local solar neighborhood, in an extended Galactic halo, at cosmological distances; for a recent review see Hartmann 1995) no model is definitely ruled out by the observations, although the solar system model seems to have the greatest difficulties to be compatible with the observations (Maoz 1993; Clarke, Blaes, & Tremaine 1994; Horack et al. 1994). It has been suggested by Lingenfelter & Higdon (1992) and others (Atteia & Dezalay 1993; Smith & Lamb 1993; but see also Paczyński 1992) that the observed GRBs could be due to different populations of bursters. In particular, although there seems to be growing evidence that the bursters are at cosmological distances (Mao & Paczyński 1992; Fishman 1994; Norris et al. 1994; but see also Brainerd 1994; Band 1994), it cannot be definitely ruled out that the observational data are contaminated by GRBs coming from nearby Galactic sources (Liang & Li 1993). If some GRBs have their origin in single (e.g., Liang & Li 1993) or binary (e.g., Anzer, Börner, & Mészáros 1976) stars located in the Galaxy, then the corresponding bursters could be the members of a class of optically variable stars.

We have cross-correlated the BATSE 2-catalog which is available via e-mail (Meegan 1994) with the catalog of the Tautenburg plate archive. The far most interesting coincidence found concerns GRB 911001 which was a typical standard burst with a fluence (>20 keV) of about 1×10^{-6} ergs cm^{-2} (Fishman et al. 1994). Its positional error box has a 1 σ radius of 6°.7 and is centered at $\alpha_{2000}, \delta_{2000} = 270°, 66°.7$, a field which has been extensively observed with the Tautenburg Schmidt telescope since 1990.

2. ANALYSIS OF THE PLATE MATERIAL

The north ecliptic pole (NEP) field is one of the fields most frequently observed with the Tautenburg 1.34 m Schmidt telescope in the recent years as part of project to optically identify *ROSAT* sources (Simon et al. 1995). For this reason plates from five overlapping areas around the NEP (see Table 1) have been taken between 1990 January and 1992 September, on average twice a week per moonless observing period. A plate covers a 3°.3 × 3°.3 vignetting-free field (51.41 arcsec mm^{-1}), the limiting *B*-magnitude is about 20 mag after 30 minutes exposure. The Tautenburg *B*-system well approximates the Johnson *B*-system (van den Bergh 1964). All plates from the NEP field are *B*-plates.

The positional 1 σ error box of GRB 911001 is to ~35% covered by the Tautenburg plates taken from the NEP field during the above mentioned observing campaign. Among them are 100 plates which are centered at $\alpha, \delta = 18^h00^m, 66°34'$, i.e., their central coordinates nearly coincide with the central coordinates of the positional error box of GRB 911001. The plate taken nearest before the occurrence of the GRB (at JD = 2448530.87; Fishman et al. 1994) is from 1991 September 14 (plate 7676), the plate taken nearest to the time after the occurrence of the burst is from 1991 October 2 (plate 7687; see Table 1). At first we used these two plates to search for strongly variable sources. The basic idea (hypothesis) behind this was

TABLE 1

TAUTENBURG PLATES WHICH WERE SEARCHED FOR VARIABLE OBJECTS

α_{2000}, δ_{2000}	Plate	Date	JD −2440000
17.4630, 65.14......	7665	1991 Sep 13	8513.35
	7706	1991 Oct 04	8534.32
17.4630, 67.54......	7636	1991 Sep 09	8509.44
	7695	1991 Oct 03	8533.32
18.0000, 66.34......	7676	1991 Sep 14	8514.35
	7687	1991 Oct 02	8532.31
18.1330, 67.54......	7677	1991 Sep 14	8514.38
	7719	1991 Oct 05	8535.32
18.1330, 65.14......	7653	1991 Sep 12	8512.38
	7688	1991 Oct 02	8532.34

to look for stellar objects which are declining in their apparent magnitude, possibly after having an outburst which was accompanied by the GRB under consideration.

Using a Zeiss blink comparator, we find two sources of about 18.5th and 13th magnitude on plate 7676 which were notably brighter on plate 7687. Object A at α_{2000}, δ_{2000} = $18^h12^m31^s.3$, 67°4′46″(±2″) was about 3.5 mag brighter, object B at α_{2000}, δ_{2000} = $18^h6^m52^s.2$, 67°9′21″ about 1.5 mag. Coordinates were determined using a Zeiss *x*, *y* measuring machine ASCORECORD. Astrometric reference stars were taken from the PPM Star Catalog (Röser & Bastian 1991). Object B was unambiguously identified with the Mira variable X Dra (Kholopov et al. 1985).

Although it is impossible to check all available Tautenburg plates from the NEP field with a Blink comparator within a reasonable time-span, we have at least also checked those eight plates covering the other four fields around the central NEP field and which were taken nearest to the time of the occurrence of GRB 911001 (Table 1). We found two further variable objects (in the following Object C and D, respectively). The first is a recently discovered cataclysmic variable (CV) designated as HS 1804+6753 by Barwig et al. (1994), the other is to our knowledge an anonymous stellar-like object at α_{2000}, δ_{2000} = $17^h45^m32^s.7$, 66°18′24″ (a finding chart is available from the author).

For each object we determined its photographic magnitudes using the Tautenburg semi-automatized iris photometer. In the case of objects A, C, and D at first 13 photometric reference stars in the central NEP field (Cordis et al. 1995) between $B = 14$ and 19 were used to calibrate eight stars in the surroundings of each object on a plate of good photometric quality, assuming that in each case these are nonvariable stars. The brightness of the object of interest was then determined on every plate with respect to its corresponding eight selected photometric reference stars. In the case of object B we used nine stars located in its surroundings and cataloged in The Guide Star Catalog (1989, CD-ROM Version 1.1) as photometric reference stars.

3. RESULTS AND DISCUSSION

In the following we first refer to objects B to D before we concentrate our discussion on object A which turned out to be the most interesting object among the four variable stars found.

At first it seems worth mentioning (Irwin & Żytkow 1993) that we, like Laros et al. (1985; see also Hartmann & Pogge 1987), found a (already known) Mira variable within the positional error box of a classical GRB. Given the large error box

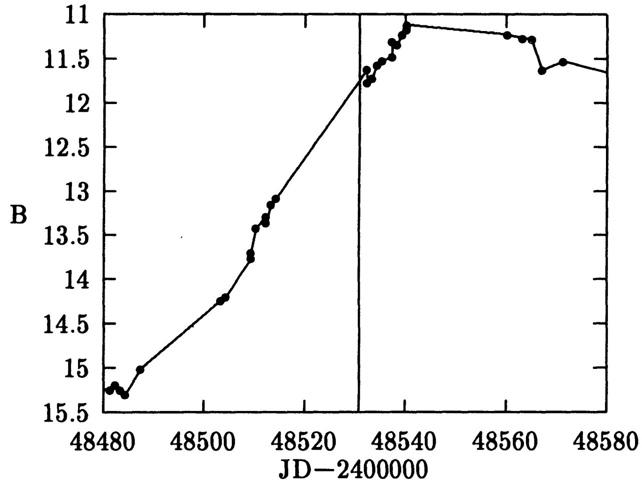

FIG. 1.—Light curve of the Mira variable X Dra for a timespan of 100 days around 1991 October 1. The ordinate gives the *B*-magnitude. Neighboring data points are connected with a straight line. The vertical line indicates the time of the occurrence of GRB 911001 in the NEP field.

of GRB 911001 of about 150 deg^2 this seems to be, however, not a unique detection. One might instead ask whether the candidate object found shows evidence for any anomalous behavior at the time of the occurrence of the GRB. In this respect we note that Schaefer (1991) reported on possible observations of optical flashes from some Mira stars. The only information we can deduce from our data is the light-curve of X Dra (Fig. 1) which, however, shows no sign for any stellar activity around 1991 October 1. One cannot suspect, therefore, that X Dra has anything to do with the occurrence of GRB 911001.

Object C was reported by Noguchi, Yutani, & Maehara (1982) as an UV-excess object and was in detail investigated by Barwig et al. (1994) who found that it is an eclipsing dwarf nova. Its light curve based on our data gives no hint for an unusual behavior at the time of the occurrence of the GRB in the NEP field (Fig. 2). Object D is, unfortunately, too weak ($B \gtrsim 18$) to permit a good photometric study of its whole light-

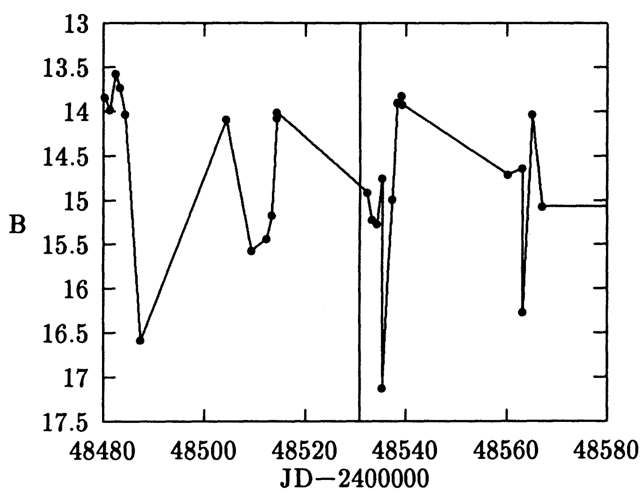

FIG. 2.—Light curve of the recently discovered (Barwig et al. 1994) eclipsing dwarf nova HS 1804+6753 for a timespan of 100 days around 1991 October 1.

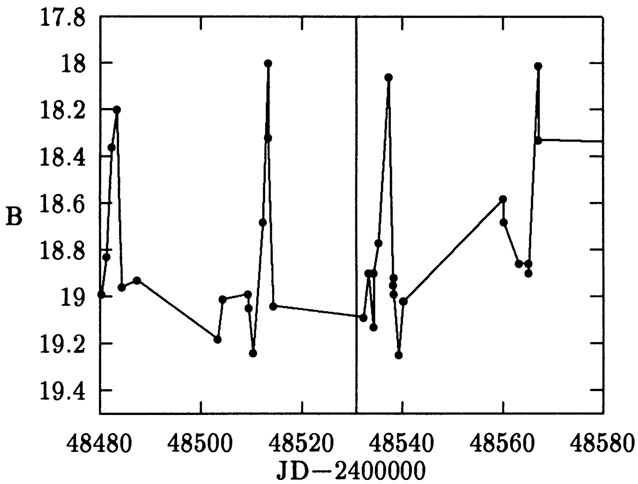

FIG. 3.—Light curve of object D for a timespan of 100 days around 1991 October 1. Note that above $B \approx 19$ the data become worse (see Fig. 1 in Meusinger et al. 1994). In general, in these cases the B-magnitude of the object is higher (the object is weaker) than given here.

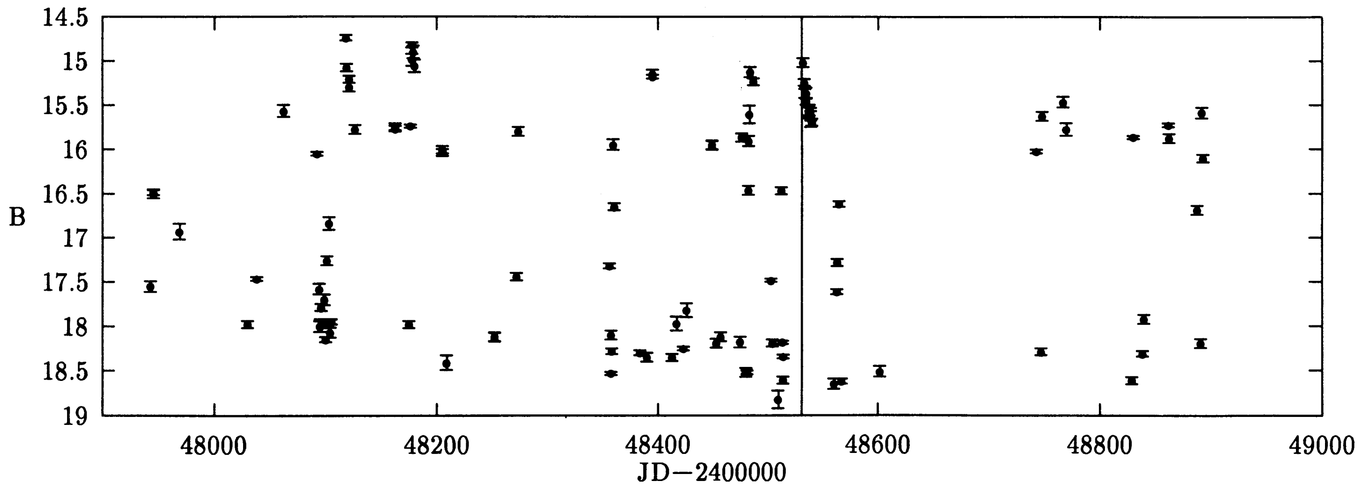

FIG. 5a

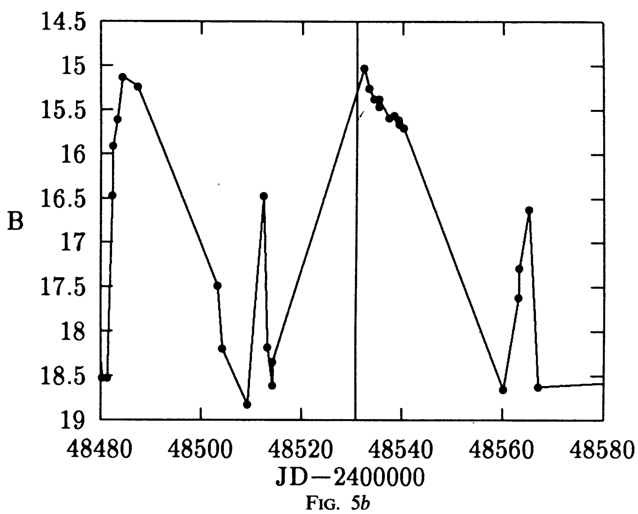

FIG. 5b

FIG. 5.—(a) Light curve of object A between 1990 and 1992 Only those measurements are shown here where the rms scatter of the eight comparison stars around the calibration curve (parabolic fit) was ≤ 0.1 mag. (b) The same as (a) but shown are only the data for a timespan of 100 days around 1991 October 1.

curve (Fig. 3). Based on our data there is no evidence that the object was in an active state on 1991 October 1.

Object A is visible on about 140 (partly overlapping) Tautenburg plates taken since 1962. It can undergo brightness changes of about 2.5 mag within 24 hours. Its amplitude can reach about 3.5 mag within 2 weeks. A periodicity analysis of the photometric data using the Deeming/Scargle analysis (see Horne & Baliunas 1986, and references therein), which is appropriate for unevenly sampled data, revealed evidence for a period of ~45.7 days in the power spectrum (the window function of our data does not peak there). This period does, however, not match all data.

Object A (Figs. 4a and 4b [Pl. 10 and 11]) is not contained in the General Catalogue of Variable stars (Kholopov et al. 1985). It is not contained in the *IRAS* Catalog of Infrared Observations (Gezari, Schmitz, & Mead 1987) and is not seen by *Einstein* (Harris et al. 1990). It has been detected in the Kiso Schmidt UV-excess survey (Noguchi, Maehara, & Kondo 1980; Kondo, Noguchi, & Maehara 1984) and is described by Noguchi et al. (1982) as a variable UV-excess object with a proper motion of 0.016 arcsec yr^{-1}. The object has been classified as a B-type subdwarf by Wegner & McMahan (1988). It is

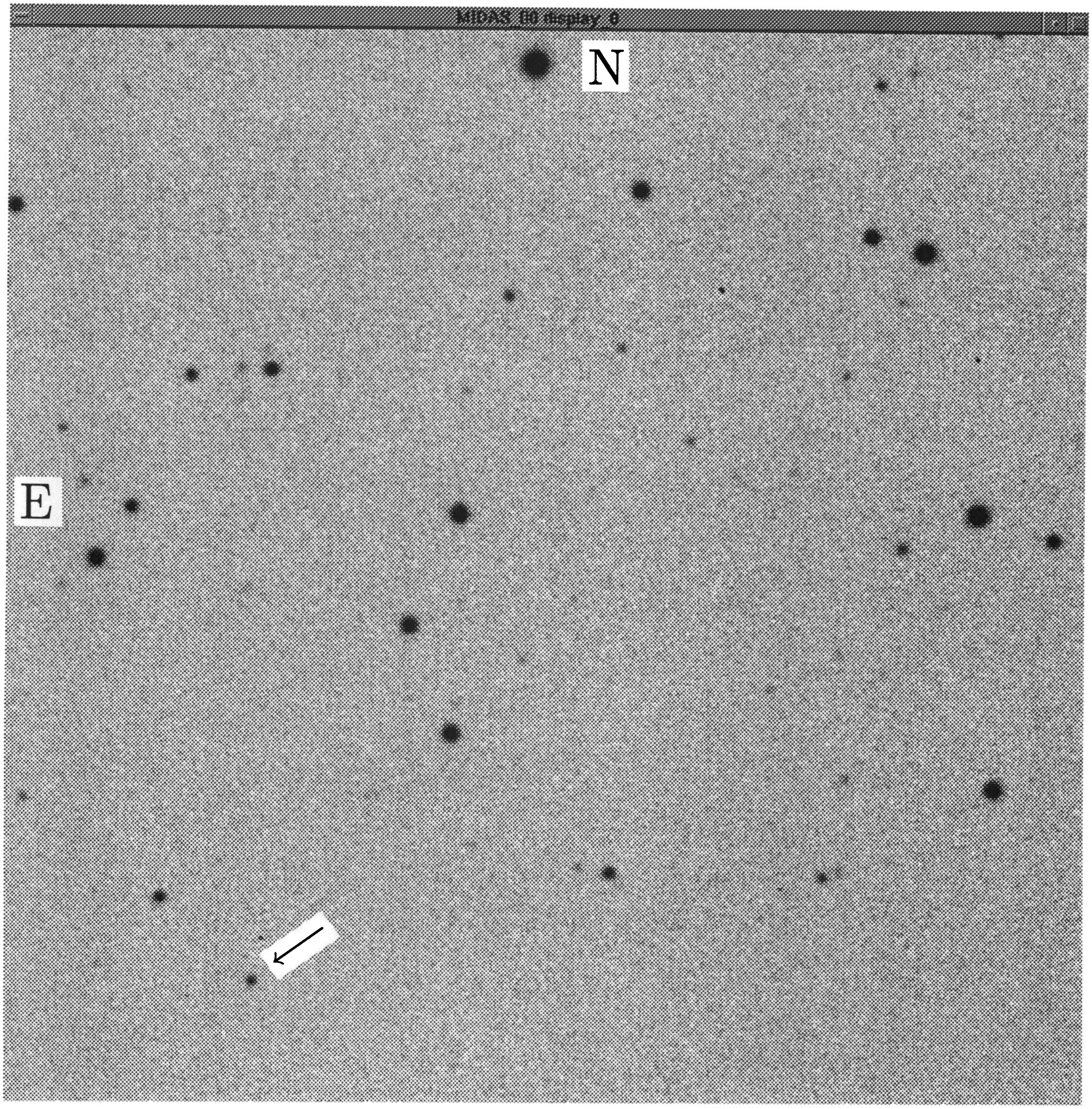

FIG. 4*a*

FIG. 4.—Finding chart for object A. (*a*) The object on 1991 September 14 (plate 7676), (*b*) the object on 1991 October 2 (plate 7687; in detail see text). The size of the figures is approximately 6 × 6 arcmin.

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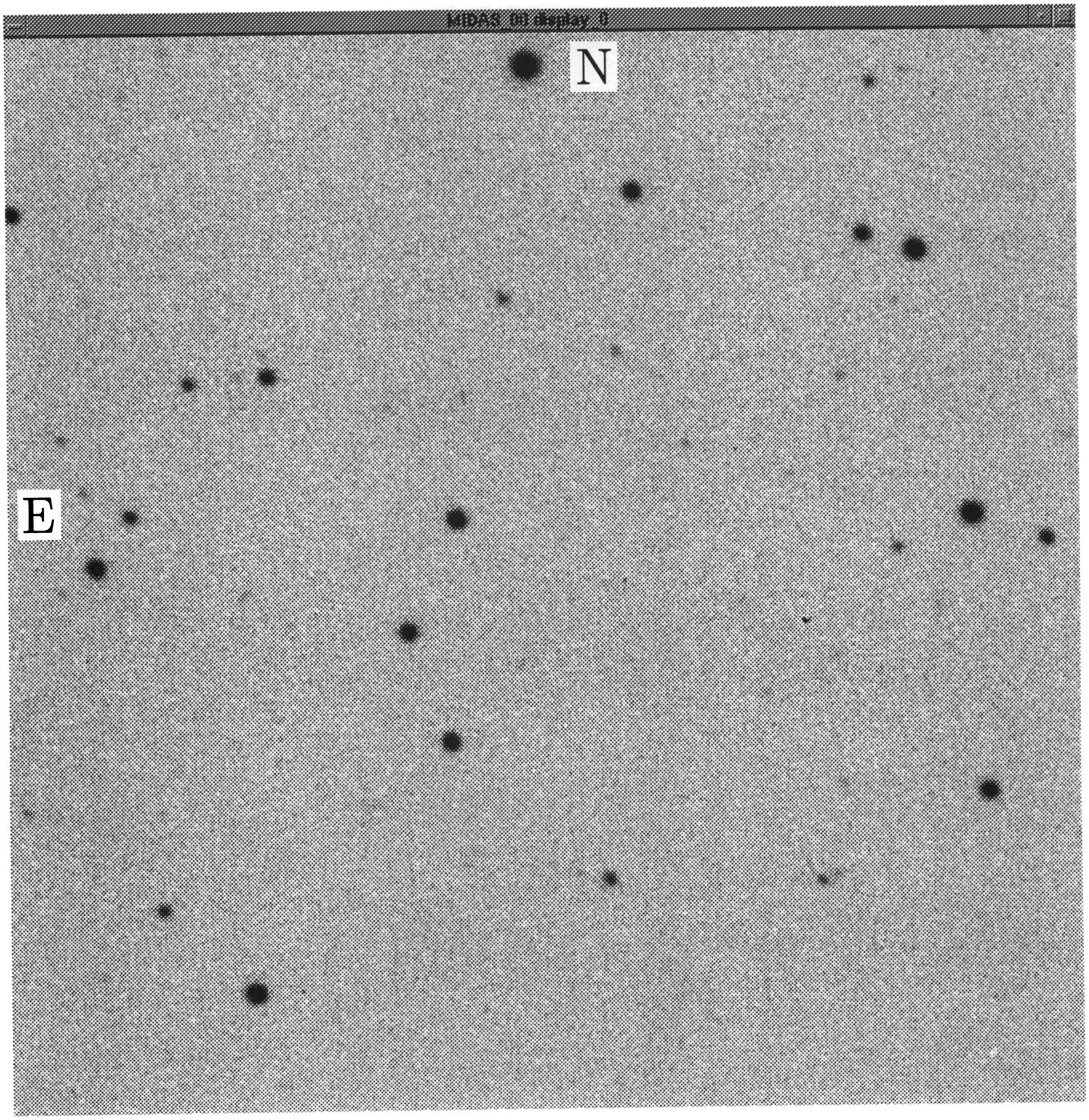

FIG. 4*b*

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not contained in the Bright Source Catalogue of the *ROSAT* Wide Field Camera all-sky survey of extreme-UV sources (Pounds et al. 1993) and not in the First *Ultraviolet Explorer* Source Catalog (Bowyer et al. 1994).

The photometric data together with the reported UV-excess (Noguchi et al. 1982; Wegner & McMahan 1988) indicate that object A could be a CV (it is not contained in the catalog of CVs of Downes & Shara 1993). If it is a CV of U Gem type, i.e., a dwarf nova, which at maximum reach $M_V = 2 \ldots 4^m$ (Hoffmeister, Richter, & Wenzel 1985) and assuming $|B-V| \lesssim 0.5$, then it would be at a distance of $\gtrsim 1$ kpc and located $\gtrsim 500$ pc above the Galactic plane ($b \approx 30°$), which is not unusual for CVs (e.g., Hawkins & Véron 1987; Howell & Szkody 1990; Drissen et al. 1994) and would roughly agree with its reported proper motion (Noguchi et al. 1982). The occurrence of a CV in a GRB error box would, however, not be a unique detection. With respect to other GRBs this has already been noted by others. Vidal & Wickramasinghe (1974) and Vahia & Rao (1988) list 9 and 15 cases, respectively, where a CV is found in the positional error box of a GRB.

Our photometric data seem to indicate that at the time of the occurrence of the GRB in the NEP field object A was in a maximum state. We cannot exclude, however, that this observational evidence is (a) simply due to an observational bias caused by the available plate material and/or (b) due to the fact that it is a short-period variable with a period of about 1 day, or less. One cannot claim, therefore, that the object is physically related to GRB 911001. Furthermore, as pointed out by many authors (e.g., Liang & Li 1993; Schaefer et al. 1994) finding a variable object in an area as large as the error box of GRB 911001 down to about $B = 20$, although at $b \approx 30°$, is not very unlikely. For instance, Hawkins & Véron (1987) reported on the detection of two dwarf novae in a 16 $\deg^2$ field centered at $b = -47°$. The catalog of Downes & Shara (1993) contains 224 CVs lying at a Galactic latitude $|b| \geq 30°$. We also note that Harrison, McNamara, & Klemola (1994) made an optical and proper motion survey complete to about $V = 19.5$ and 17.5, respectively, in a ≈ 160 arcmin^2 region centered on the 41 arcmin^2 error box of GRB 790329 and find no candidate source. All this can be an indication that Figures 5*a* and 5*b* only show a random coincidence between the time of the occurrence of the GRB and the time at which object A possibly was in a maximum state. In any case, the object should be further investigated.

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