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OPTICAL STUDIES OF γ-RAY BURST FIELD GRB790418 AT THE 6 M TELESCOPE

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ABSTRACT. *The SAO RAS 6 m telescope was used to obtain deep CCD images o one of the smallest γ-ray burst error boxes derived from multi-satellit wave front triangulation. The "CCD mosaic" for this 10 arcmin^2 field o GRB790418 was made, 3.7 hours of open shutter time were used to obtain and V filter frames covering an area of the localization of this GRB event For 158 objects in this field above the detection threshold of $B \cong 25.5^m$ calibrated photometric measurements were made.*

In the bounds of the program of studying of such smallest GRB erro boxes, the basic aim of which is the search for weak ($V>23^m$) blue stellar like objects, an object was found in the GRB790418 field wit $B=24.40^m \pm 0.20^m$ and $B-V=-0.42^m \pm 0.40^m$. This object, the bluest of our CCD mosaic and the closest (≅30 arcsec) one to the centre of the error box could be a suitable candidate for testing our supposition that γ-ra sources are relatively nearby old isolated compact objects of the type o neutron stars (quark stars, may be).

1. INTRODUCTION

The sources of classical γ-ray bursts (GRB) are still unidentified in optics i spite of efforts undertaken recently by many research groups. The basic difficulty i still poor localizations of the bursts in the sky. Dimensions of overwhelming erro boxes known today are of the order of square degrees. Only a few events have been s localized in the sky with the help of the simultaneous observations by many space crafts, so the possibility emerged to begin a CCD-photometric survey of all the best localized burst error boxes (that have been published) at the 24″ telescope with a 8.7 arcmin CCD image side (Harrison et al., 1994a,b), and at the 1.0 m telescope with a 5.7x5.7 arcmin field (Vrba et al., 1993).

In these photometric surveys of GRB error boxes (see also earlier papers by Motch et al., 1985; 1990; Ricker et al., 1986) one of the basic purposes is the selection of objects which are variable and have peculiar colours for their brightness and apparent galactic location. All objects of non-stellar nature in these fields are also noted. In fact, all stellar and extragalactic contents are investigated in these fields in order to note unusual objects. This is the consequence of a number of different explanations for the phenomenon of GRB which are proposed today. In particular, the isotropy of GRB localization found by BATSE experiment aboard CGRO (Meegan et al., 1992) has brought into question galactic neutron star models (Hartmann et al., 1990; Quashnock & Lamb, 1993; also see Atteia & Dezalay, 1993). Though it should be said that there are still a lot of questions and problems.

If adhering to the idea of galactic origin of GRB which proceeds from the notion of neutron stars in the vicinity of the Sun (Higdon & Lingenfelter, 1990), then such isolated, nearby neutron stars should manifest themselves in optics as relatively blue, very faint ($V > 23\text{-}24^m$) objects with significant proper motions. Here Geminga could be the example (Halpern & Tytler, 1988; Bignami *et al.*, 1993) for which the proper motion was found to be ≅0.2"/yr. The large proper motions of such objects are explained not only by the suggestion that they could be relatively near, but also by their high spatial velocities (more than 100 km/s), which are close to spatial velocities of the nearest pulsars (Lyne & Lorimer, 1994). A part of these objects which could manifestate themselves as soft X-ray sources (Helfand *et al.*, 1980) in turn could be between approximately 50000-60000 sources of All-Sky Survey data of the ROSAT satellite (Voges *et al.*, 1992), which are actively identified now in optics.

Since the search for optical GRB counterparts can be connected with the search for such very weak (weaker than 23^m) stellar-like objects in optics, the observations at large telescopes of the smallest fields connected with GRB can be very actual. Such deep searches can now only be produced for a few (3-4) well-localized GRB events from the list adduced in the report by Vrba et al. (1993). Careful investigations of stellar and extra-galactic contents of these fields up to the limit (approximately) of the Palomar Observatory Sky Survey (Harrison et al., 1994a,b) or about 23^m (Vrba et al., 1993) are already being carried out at the small telescopes.

In principle, to make sure, analogous investigation at a large telescope must also cover all stellar and non-stellar contents in the field under consideration. But, if it is kept in mind that single compact objects of the neutron star type are most probably displayed as very faint blue stellar-like objects, then the search for such candidates, namely in an investigated field, can become a basic task (or a goal) at a large telescope. This task continues and deepens the studies of the same (smallest) GRB error boxes which are already being carried out at small telescopes.

The basic result of such a study is the proper motion of a *weak* (V > 23^m) bl object found inside the GRB error box. If these are galactic objects, then they most probably compact objects of the neutron star type (though other hypotheses also proposed). But if this is not the case, then, according to more than 100 diff rent explanations of GRB phenomenon which can be found in literature now, it can whatever you like, and all CCD mosaic images have to be studied carefully.

Though the deep search at a telescope with small CCD image is more difficult is necessary to do the CCD mosaic images and to spend a lot of telescope time nevertheless, if it is possible, it is more informative and concrete in the sense revealing the nature of GRB sources. Thus, if the increasing degree of isotropy GRB localizations, as found by BATSE experiment, has indeed brought into question lactic neutron star models for GRBs, then to test this suggestion it is necessary search *only* for very weak (up to 25-26^m) objects, and to use a large telescope f this purpose. In this report we state only this (so far) central problem f GRB790418, which can not be solved at small telescopes.

Some preliminary results can now be reported here, although analysis of t database is not completed. The GRB790418 was registered by 7 spacecrafts (Atteia al., 1987). The galactic coordinates of event localization are: l=212°.8; b=-16 (1950). By using the time of burst arrival to each satellite, the error box with di mensions <10 arcmin was obtained by Golenetsky et al.(1986). Here we *only select* t candidates for further study (the photometry and proper motion), leaving more com lete investigation of all stellar and extra-galactic contents of this field for t next paper. It should be emphasized right now that we will look for weak blue ste lar-like objects with large proper motion which can be connected basically with the high spatial velocity. Ultimately, we are interested in the objects with noticeab differential shifts (of the order and more than 0.2″/yr) relative to their positio in two CCD pictures obtained during one or two years.

Thus, we present here an interim report on our study of 1 out of the 3 smalle archive GRB fields (Vrba et al., 1993) observed at the 6 m telescope, and our futu plans. In the range of B=24^m.5 (where errors of colour indices are still not so la for photometric classification) near the centre of GRB790418 error box we managed find a corresponding candidate for our future study.

2. OBSERVATIONS

Some preliminary results of the first (searching) stage of the study of this G field can now be reported, although the analysis of the database is far from com lete.

The CCD mosaic images for the GRB790418 field were employed at the 6 m telesco with 580×530 CCD providing a 120×80 arcsec field. The CCD chip has rectangular pixels 24×18 μm on sides resulting in an image scale at the prime focus of the 6 m telescope of 0.2055″×0.154″/pixel. The B and V Cousins filter set was used for our observations. The first stage was designed to carry out multiple observations with 600 or 400 s exposures in the B and V filter system (see Table 1). Atmospheric conditions were limit-permissible ones for deep CCD images throughout the observing run. Besides, observations of GRB790418 error box at the 6 m telescope are possible for zenith distance $Z>51^{\circ}$ only. Typical seeings were 2″ - 2.5″. The CCD images were corrected for a bias and flat field. All photometry was reduced using the normal reduction in the PC VISTA package (Treffers & Richmond, 1989). The photometric calibration including colour transformation was derived from the measurements of seven standard stars from Landolt (1992).

Table 1. Journal of observations

Start time (UT)	Number of single frame *	Exposure time (s)	Filter	Seeing (″)	zenith distance (Z)
6/7 February 1994					
18:35	1	400	V	2″.16	51
18:42	1	600	B	2.28	51.5
18:56	2	400	V	2.34	52
19:03	2	600	B	2.25	52
19:22	3	400	V	2.37	53
19:30	3	600	B	2.26	54
19:48	4	400	V	2.84	56
19:55	4	600	B	2.85	57
20:21	5	400	V	2.60	59
20:28	5	600	B	2.56	60
10/11 February 1994					
16:40	1	600	V	1.89	52
16:52	1	600	B	1.96	52
17:05	2	600	V	1.85	51
17:17	2	600	B	1.92	51
17:31	3	600	V	1.74	50.6
17:43	3	600	B	1.97	50.5
17:57	4	600	V	2.20	50.6
18:08	4	600	B	2.16	50.9
18:41	5	600	V	2.64	52.2
18:52	5	600	B	2.16	52.9
19:05	6	600	V	3.27	54
19:16	6	600	B	2.45	54
19:31	7	600	V	3.64	56
19:41	7	600	B	3.40	57

* The number of single frames is shown in Fig. 1 in the centre of each frame.

The error box for the GRB790419 localization and the part of the sky actually covered by our CCD mosaics are presented in Fig.1. The GRB error box observed here was taken from GRB catalogue (Atteia et al., 1987) and discussed with G.G. Petrov a S.V. Golenetsky (Private communication, see also Golenetsky et al., 1986). The coordinates of corners A,B,C,D of GRB790418 error box are listed in Table 2, and its position in the sky is in Fig.1. The triangulation circle error (or the distance fro the diamond centre to any of its sides in Fig.1) is about 72 arcsec.

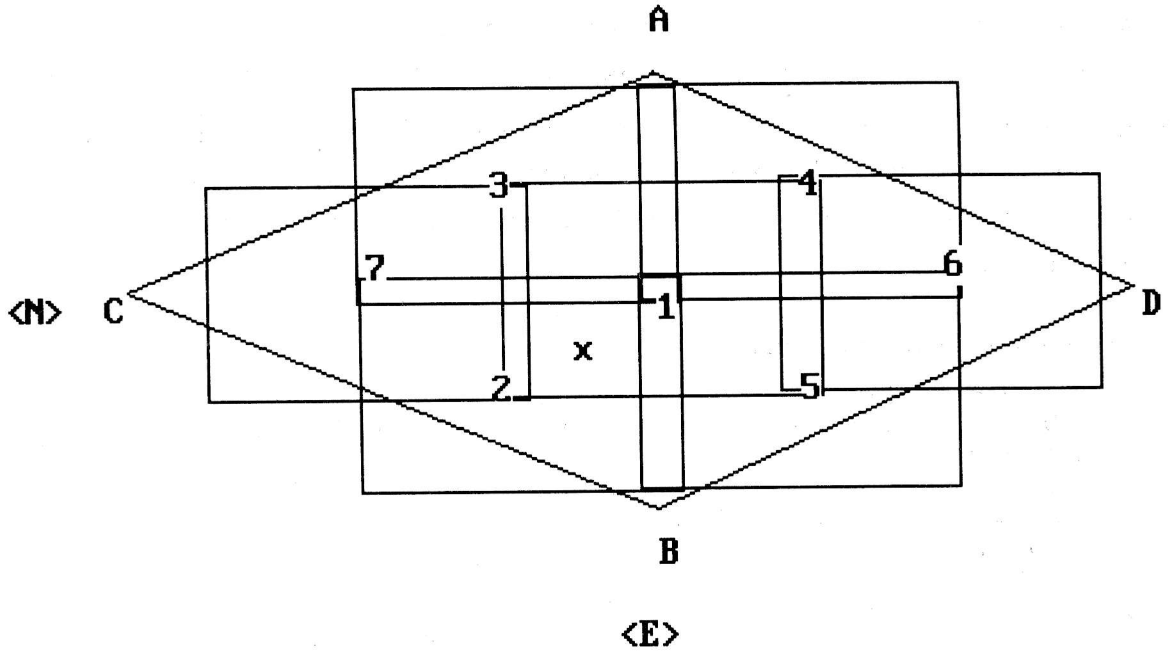


Fig. 1. *GRB790418 error box according to the data of Golenetsky et al. (1986 (see Table 2). The error of triangulation circle is 72 arcsec. The numbers show th sequence of CCD frames. The cross indicates the place where the bluest object in th field is situated.*

Table 2. The coordinates of the centre and corners of GRB790418 error box

R.A. (1950)	Decl. (1950)	
$05^h\ 51^m\ 51^s.84$	$-06^\circ\ 57'\ 10''.80$	
05 51 51.60	-07 00 07.20	D
05 51 46.56	-06 57 10.80	A
05 51 57.12	-06 57 10.80	B
05 51 52.08	-06 54 14.40	C

Our telescope and CCD combination required 7 pointings to cover almost the entire error box. The algorithm of covering GRB790418 error box is shown in Fig.1. In the centre of every frame its number from Table 1 is shown. To be more precise, two frames (the areas of 120×80 arcsec), obtained in the B and V filters, correspond to every number. Any next frame was made by counting the minimum total number of frames for covering the entire error box with maximum possible intersections. In sum, the last point allows us to increase the stellar magnitude limit for intersected parts of different frames and to evaluate by common stars in different CCD frames the accuracy of photometric measurements in the entire error box.

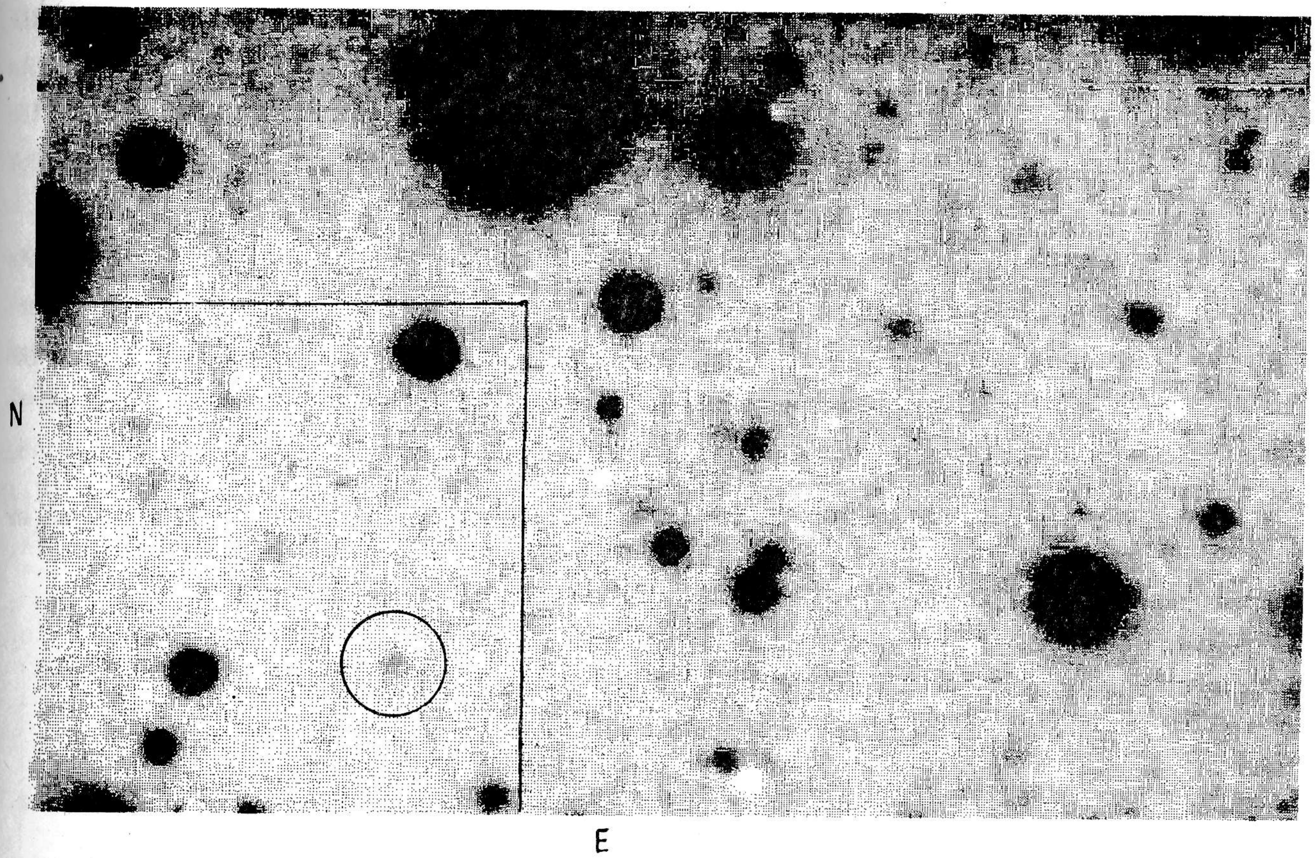
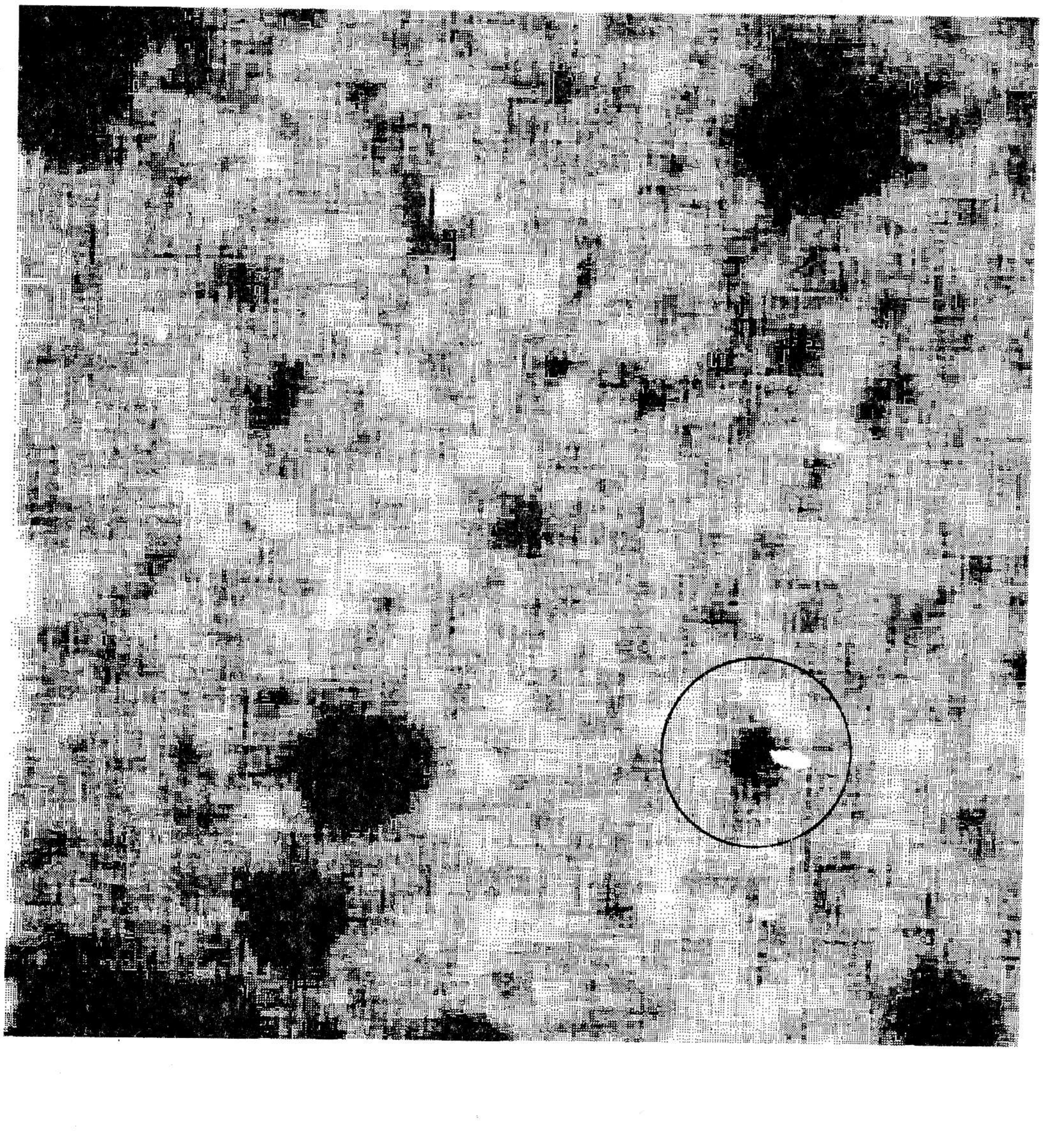


Fig.2.

a) *The CCD frame No.1 (the smoothed sum of the B and V frames) in the center of the GRB error box, where a weak blue object with* $B\text{-}V = -0.42^{m}$ *and* $B=24.4^{m}$ *was found. The object situated approximately at the distance of 30 arcsec from the center of the box is marked with a circle.*

b) *A part of the frame No.1, in which the same candidate is distinguished with better contrast.*



The central part of CCD field for GRB790418 error box (Gauss smoothed sum for th B and V frames No. 1), in which the bluest object of the box is situated, is given i Fig.2. It is at the distance of approximately 30 arcsec from the box center to th north-east. In Fig.2 a fragment of frame No.1 is shown in which the same obje is seen with better contrast.

Accurate colour information is obtained here only for relatively bright object in GRB790418 error box. Fig.3 shows the B/B-V diagram for all objects ($B>16^{m}$) dete ted in the B images (without separation into stars and galaxies). Dispersion of th instrumental V and B magnitude of these objects is shown in Fig.4. The error esti mation of the brightness determination in both filters ("theoretical" error) i made with the use of Poisson distribution $\sigma = \pm\sqrt{F_{star} + \sigma^{2}_{sky}}$, F_{star} is an in tegral count for a star, σ_{sky} is the measured sky noise around the star.

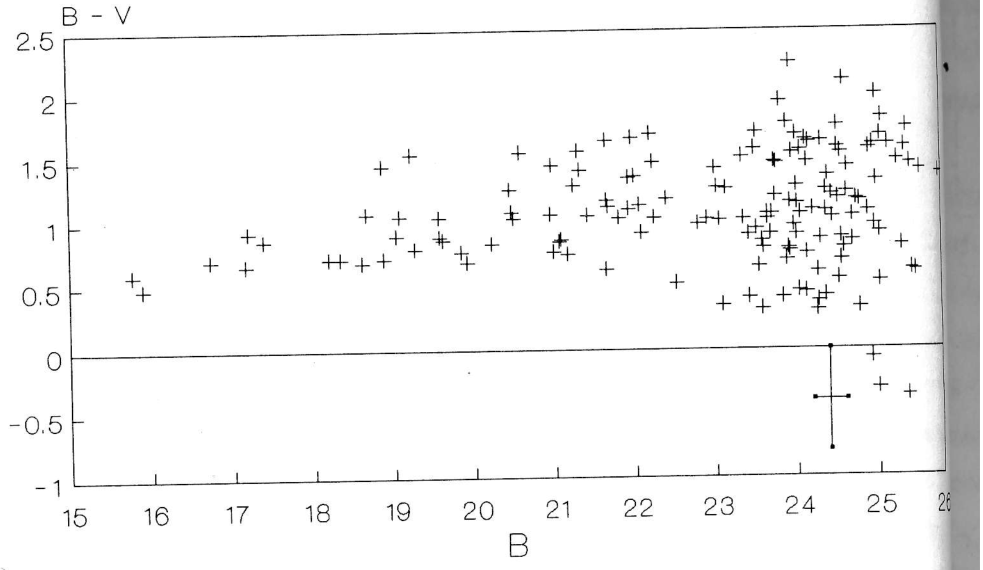


Fig. 3. *The B-V colour index versus B magnitude for all 158 objects detected in the B frames of GRB790418 CCD field. The errors are only indicated for the one brightest blue object (see the text).*

Photometric accuracy of measurements was also estimated from the objects situ ated in the intersecting parts of CCD mosaic frames. We twice managed to make suc estimates, and in several cases three times for 29 common objects. The results ar shown in Fig.4. Among them the weakest object has the magnitude V=23.95. Satisfactor accordance of the error of repeated measurements of these 29 relatively bright ob jects with the corresponding "theoretical" error allows us to use the last one in th case of weaker objects (though, of course, the real errors may be larger). In Fig. the solid lines show the way of theoretical error up to $25\overset{m}{.}0$ in the V and B. In par ticular, for stellar magnitude V=24.7 the error is $\pm0\overset{m}{.}35$.

Table 3 is constructed from the data of Fig.4, including brightness estimate for stellar-like objects.

The weakest stars registered in these CCD images were of $V\approx25\overset{m}{.}5$, when it wa still possible to notice the presence of an object in B and V frames, but measuremen errors do not allow us to speak already about the colour classification of these ob jects. Only four weak blue objects can be interesting from the point of view of ou program of γ-bursters identification in a quiet state. But, three of them lie in the region of such large measurement errors (behind "photometric limit") so without additional observations it is hard to say confidently something about their colours. One brightest blue object near the center of γ-error box has the magnitude B=24.40 and B-V = -0.42 with errors ± 0.20 and ± 0.40, respectively.

Table 3. Photometric errors

V	1σ error in V	1σ error in B-V (for B-V=0)
17.5	0.001	0.001
18.5	0.002	0.003
19.5	0.004	0.006
20.5	0.007	0.01
21.5	0.02	0.03
22.5	0.04	0.05
23.5	0.10	0.14
24.5	0.26	0.32
25.0	0.45	0.54

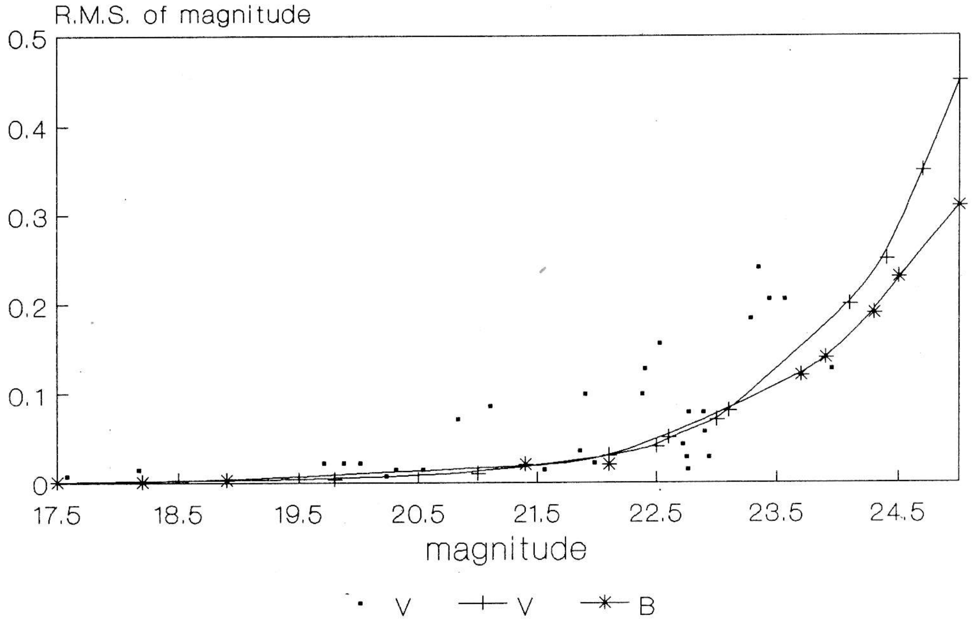


Fig. 4. *The crosses and asterisks show the instrumental errors versus brightness determination in the V and B filters, respectively, calculated with the help of Poisson distribution up to V=25.0. The points show the dispersion estimates of the instrumental V magnitude of all common 29 objects in intersecting parts of the frames from CCD mosaic (see Fig. 1) versus the object brightness.*

If we exclude three of the weakest objects lying below the line B-V=0 in Fig. 3, then it will be the bluest object for our CCD field of GRB780418 error box, at least in comparison with all brighter (B<24.5) objects of the field. In spite of a rather large colour error, it seems to deserve further efforts to elucidate its nature. Its colour and position in γ-error box (other "candidates" are even further from the box center) allow us to consider it to be the first and the most acceptable candidate for measurements of its proper motion in future.

As seen from Fig. 5, the majority of objects in GRB780418 CCD field are of red colour and are roughly separated into the objects of disk and halo. This can be one more, additional (though indirect) test of our photometry quality and objects sam completeness observed in the box. But it should be said that in the conditions which we observed this box, we did not manage to separate stellar-like objects fr galaxies. That is why all objects with V < 24.65 including galaxies entered the histogram. Thus, in Fig.5 all objects are presented for which the colour is dete mined with sufficient (for the purposes of the first stage of our program) accurac

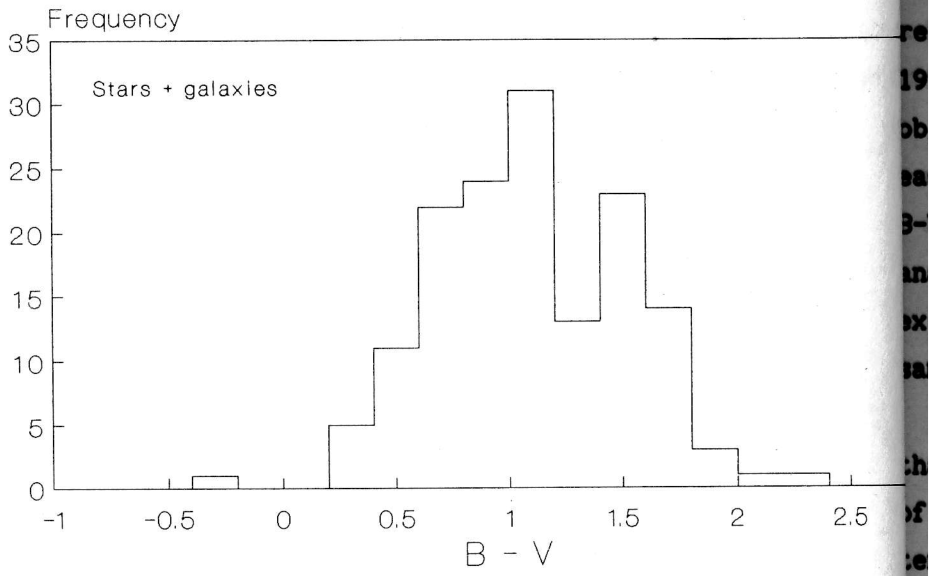


Fig. 5. *B-V histogram of all objects brighter than V=24.65, showing the separation of disk (B-V)~1.2-2.0 and halo (B-V)~0.2-1.2 stellar population. The contribution of extragalactic objects is not excluded. The frequency is given in units of the number of objects/ 0.0033deg*^{2}*/0.2 B-V colour interval.*

3. DISCUSSION

In 1994 we initiated a long term program to undertake a deep search survey the smallest GRB localizations observable at the 6 m telescope of SAO RAS. Besid GRB790418 error box we have obtained deep BV-imaging for one more (the smallest fr the archive ones) GRB error box, GRB790613, for which we are going to do the sa work as for GRB790418. Both these boxes have already been studied in analogous pr rams at the 24″ and 1.0 m telescopes (Harrison et al., 1994a,b; Vrba et al., 199 As a matter of fact, our study of weaker objects in these fields is simply a mo thorough continuation of these works. We intend to continue observations in UB filter system over a time baseline of 1-3 years for weak blue objects selected at t first stage. It will give us an opportunity to explore their light and colour vari bility. But, as was mentioned above, we consider the obtaining of proper motions the same objects to be the main purpose, since in that case the solution of the bas problem (if we see a stellar or a non-stellar object?) can be guaranteed at a suff ciently large time baseline.

In particular, due to the large zenith distance for GRB790418 and poor seein what we made at the BTA may be the limit for this GRB error box. As shown in Fig. the minimum rms variance of bright stars (V < 20.5) is ~ 0.02, which shows the hi photometry quality and stability of the acquisition system during observations. Many faint objects are detected in intersecting individual frames, that also helps to estimate observation errors.

But unfortunately, the seeings are so poor that they do not allow us to confidently distinguish between stars and galaxies (for $B>23^m$). However, it is seen from Fig.5 that up to "extragalactic background" we can set galactic objects in two distinct branches ($B-V\cong0.2-1.2$; and $B-V\cong1.2-2.0$). These two stellar populations have been observed in many deep surveys at high galactic latitude and are believed to represent halo and late type disk stars, respectively (see, for instance, Motch et al., 1990). The relatively wider and higher peak in our B-V histogram connected with halo objects when compared to the analogous histogram from the paper by Motch et al. is easily explained by the large contribution of galaxies just into the region of $B-V<1.2$ colour. The last point is clearly noted for objects weaker than $B=25^m$ in the analogous B-V/B diagram adduced in this paper, in which the authors select more extended sources from the stellar ones for the area situated approximately at the same distance from the Milky Way.

A candidate which we selected for further investigation is significantly bluer than the bulk population objects, even with a rather large error in the measurement of its B-V. If it is a compact object of the type of neutron star with the surface temperature ≅180000 K at a distance of about 40 pc from us and moving with a spatial velocity of 150 km/s, then its proper motion can be about 0.8″/yr. In any case, the B-V parameter and the brightness of the selected candidate in the limits of measurement errors can be close to the colour and brightness of such a compact object. The corresponding expected X-ray flux from such an object in the band 0.1-2.4 keV is $3.76\cdot10^{-13}$ $erg\cdot s^{-1}\cdot cm^{-2}$. This seems to be lower than 2σ-level for ROSAT All-Sky Survey data (Voges et al., 1992).

One way or another, since the differential colour refraction errors are large, we can not guarantee formal absolute proper motion solutions by this database. In the case of GRB790418 field, for weak stellar-like objects with $B=23-25^m$ we hope to measure proper motions >0.2 arcsec/yr. Thus, here the question is on significant proper motions at these brightness levels. But even if proper motion turns out to be less than the value which we can measure at short timebase, the possibility to elucidate the nature of objects selected by us in this box by measuring for several years at other telescopes always remains.

On the other hand, as is seen from the above mentioned, we intend to energetically pursue only those weak stellar-like objects which could be old isolated compact objects of the neutron star type whose radiation can be connected with thermal emission from their surface - like the case of the Geminga. In the bounds of this hypothesis such studies allow us to pose limitations (together with measurements of soft X-ray emission) for the value of γ-burster brightness in the quiet state, i.e. between two GRBs generated by the same object. If these sources really are very weak in optical region, then only further and more careful observations of the same sm γ-ray boxes at large telescopes can shed light on this problem.

One of the consequences of the CGRO-BATSE experiment is the fact that the sources are commonly believed to be situated in an extended halo around the Gal (at distances D ~100 kpc) or at cosmological distances (D ~ 1 Gpc). An alternati rarely discussed in the literature but generally acknowledged as a possibility that the GRB sources are much closer, at distances comparable with the thickness the Galactic disk (D ~ 100-200 pc). That is just the hypothesis which, while commo acknowledged as the most natural but nevertheless hardly grounded now, we want test by our observations at the 6 m telescope. Objects of the neutron star type whi are in question above could be quark (or strange) stars (Alcock et al., 1986).

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