

Deep photometric study of the region of the γ -ray burst localization of June 13, 1979.

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Received April 17, 1997; accepted May 12, 1997.

Abstract. In the framework of the hypothesis on potential sources of some γ -ray bursts being single compact objects of neutron star type with finite surface temperature in the vicinity of the Sun a method of search in the optical range for a corresponding candidate in the region of a powerful short burst localization is considered. The localization region of the GRB790613 event is studied in the B , V and R filters. $B - V$ and $V - R$ colors of 196 objects with a $S/N > 4$ are measured up to the average practical photometric limit $B < 25.7$, $V < 25.7$ and $R < 25.6$ for the whole obtained mosaic of CCD images. No blue objects with $B - V < 0$ and $V - R < 0$ were found up to $B \approx 25.2$, which can be interpreted as the absence of a compact object with a temperature $> 1.5 \cdot 10^5$ K in this direction up to a distance ≈ 40 pc. A probable common upper limit to the temperature of the supposed compact objects in the vicinity of the Sun is indicated based on the accumulated optical and X-ray data. The study of blue ($B - V < 0$) objects in the smallest (in the northern sky) γ -ray box GRB790613, in view of the results of the search for point-like sources in the soft X-ray in the localization regions of bright γ -ray bursts, does not exclude the existence of such "cold" ($\lesssim 10^5$ K) objects, which could give an essential contribution to the observed density of hidden matter close to the Sun and some of them could be related with the closest sources of γ -ray bursts. Several interesting objects were also found in (or near) the localization region of the GRB790613 event.

Key words: gamma rays: bursts — deep optical search

1. Introduction

Here we define the strategy of search for optical candidates for the sources of γ -ray bursts first of all as a direct test of their galactic origin, in particular, allowing for the fact that potential sources of some part of the observed bursts can be objects of hidden mass in the Galaxy. It is evident that deep optical observations with consideration of observations in other wavelength ranges must reduce the number of theoretic variants explaining the bursts, at least for a chosen class of galactic models discussed in the literature (Boer et al., 1993; Greiner et al., 1995; Hartmann, 1994).

Formulating below the statement of an observational problem at the 6 m telescope, we mean single compact objects of neutron star type cooled down to a temperature $\approx 10^5$ K and lower. Analogous considerations have already been used in the literature in interpretation of the results of deep photometric study of several γ -ray boxes (Hartmann et al., 1989; Motch et al., 1990). Ultimately, in any galactic model of the sources of γ -ray bursts, in which at-

tempts of allowing for new data have been made, a problem can be stated of search for *closest* objects in other wavelength ranges. In this case we are concerned with the sources of short γ -ray bursts, that show a $-3/2 \log N - \log P$ power law at high intensities (Kouveliotou et al., 1993). In particular, these can be optical objects of low luminosity related to these bursts and having a density distribution in the B , V , R bands close to that of a black body. With the help of deep CCD photometry of the localization region of the γ -ray burst GRB790613 we will show which distance limitation can be obtained from direct optical observations. In so doing we will use basically only the assumption of compact character of the supposed potential source of a γ -ray burst and the fact that the number of such objects in the vicinity of the Sun can not be greater than it is allowed by the estimates of hidden mass density. Further we use also the results of surveys and point-like observations in the soft X-rays by the ROSAT satellite.

Apparently, similar objects, single pulsars Geminga and PSR 0656+14 with relatively low surface

temperatures and probably situated in the vicinity of the Sun have already been observed in the optical (Halpern & Tytler, 1988; Caraveo et al., 1994) as sources of $25 - 25^m5$. By the example of one of the most powerful γ -ray bursts — the short event GRB 790613 localized with the help of several space detectors with the best (in the northern sky) accuracy (Barat et al., 1984), whose localization error box has already been studied very well in the X-rays (see Greiner et al., 1995; and ROSAT X-ray Images, 1994a) and in the optical range (Ricker et al., 1986; Harrison et al., 1994; Vrba et al., 1995), and supplementing these data with our own deep optical observations of the γ -ray box GRB 790613, we will show here that an object of blue optical candidate type for Geminga can, in principle, be detected in study of such an IPN γ -box in the three standard filters B , V , R .

In Section 2 the statement of a problem of the deep CCD photometric search for weak blue stellar-like objects in relatively small γ -ray boxes at the 6 m telescope is expounded. The obtained photometric data for the GRB 790613 event field are adduced in Section 3.2. The method of photometric search for such objects in the γ -ray box GRB 790613, which are “black body”-like by BVR , and the discussion of the results of deep optical observations of this box are presented in Section 3.3. The estimates of a probable value of proper motions per year for all objects up to $V = 25^m$ are presented in Section 3.4. Section 3.5 is devoted to some other interesting objects found in (or near) the region of localization of the GRB 790613 event.

2. Search strategy

Let us assume that what we are looking for in the γ -ray box under investigation is indeed a single compact object of neutron star type. For example, it could be an object partially or totally consisting of quark matter, which has been a hypothesis so far (Haensel et al., 1986; Overgard & Ostgaard, 1991). But here we try to formulate a possible observational forecast without any theoretical model describing γ -ray burst by itself. We do not assume any particular burst model in advance. The only thing which can be now investigated from observations is the compact character of their sources. Although till now the validity of absorption (cyclotron?) features in redshifted annihilation lines observed in the spectra of “old” γ -ray bursts is disputed and carefully tested, the observational fact of fast temporal flux variations in bursts is not in question (Atteia et al., 1987; Fishman et al., 1994; Ryan et al., 1994). It means that up to now it is sufficiently reasonable to suppose that the source of these mysterious events is a “compact object” with probable strong (not damped) magnetic field.

Table 1: *The log-book of observations*

I	II	III	IV	V	VI
13.04.94					
23:13	I B	600	1.7	22.71	35.1
23:55	II B	600	1.45	22.67	35.5
00:25	III B	600	1.31	22.65	36.0
00:51	IV B	600	1.11	22.58	37.0
23:02	I V	600	1.47	21.83	35.7
23:33	II V	600	1.40	21.82	35.2
00:14	III V	600	1.14	21.79	35.8
00:39	IV V	600	1.08	21.72	36.4
2.06.94					
19:12	I R	600	1.70		36.5
19:32	II R	600	1.63		37.1
19:51	III R	600	1.83		37.5
20:13	IV R	600	2.14		38.0
29.12.94					
02:18	c B	500	1.59	22.70	37.9
02:45	c B	500	1.63	22.66	37.1
03:14	c B	500	1.56	22.11	36.3
02:27	c V	500	1.47	21.81	37.6
02:54	c V	500	1.59	21.71	36.7
03:23	c V	500	1.77	21.10	36.3
02:36	c R	400	1.41	20.54	37.3
03:03	c R	400	1.37	20.38	36.5
03:32	c R	400	1.61	19.52	35.9
24.04.95					
22:03	a B	600	1.40	22.82	35.1
22:14	a V	600	1.29	22.03	35.1
22:36	a V	600	1.12	22.04	35.2
22:24	a R	600	1.24	21.02	35.1
22:47	a R	500	1.20	20.98	35.3
22:56	a R	500	1.26	20.98	35.4
23:21	b B	600	1.18	22.89	35.7
23:32	b V	600	1.28	22.10	36.0
23:52	b V	600	1.14	22.08	36.5
23:42	b R	600	1.25	20.88	36.2
00:04	b R	500	1.14	20.94	36.7
00:13	b R	500	1.05	20.81	37.0
01:14	c B	600	1.30	22.62	39.0
00:30	c V	600	1.20	21.50	38.8
00:55	c R	600	1.18	20.63	38.0
00:41	c R	600	1.14	20.60	38.5

Further we assume that potential sources of γ -ray bursts can be among objects forming the hidden mass of the Galaxy. For the vicinity of the Sun, which we are basically interested here in, the upper limit to the contribution of unknown objects to the total density of matter (or Oort’s limit deduced from observed star velocities along z coordinate) is determined and is approximately 38% (Lacarrieu, 1971). Thus, we assume that the objects sought may be rather old, in partic-

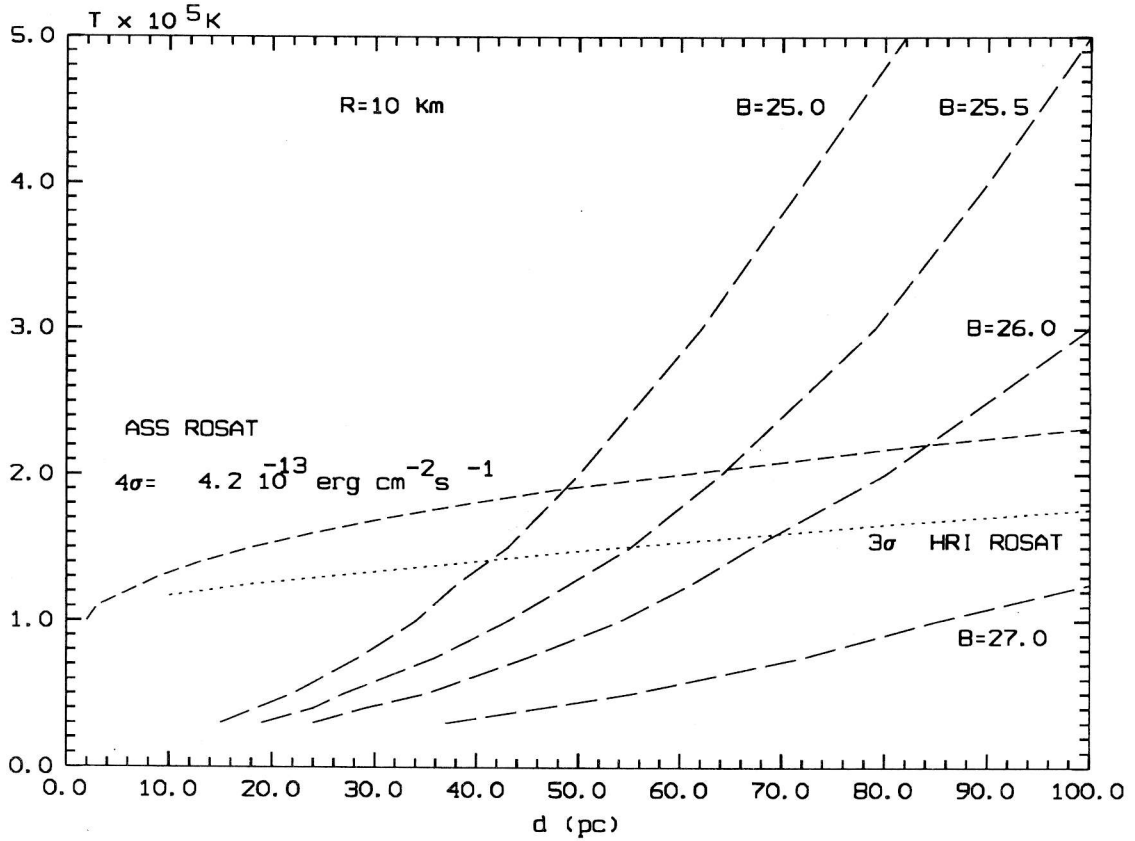


Figure 1: Limits to a black body surface temperature T_{bb} and a distance of neutron star type object with $R = 10 \text{ km}$ as obtained from optical and ROSAT observations are shown. The dashed line corresponds to a black body flux $4.2 \cdot 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$ for the All-Sky Survey ROSAT in the band $0.1 - 2.4 \text{ keV}$ or 4σ (Boer et al. 1993a, ROSAT, 1994b). The dotted line corresponds to 3σ of a limit with the $t_{exp} = 13168 \text{ s}$ exposure for the ROSAT HRI camera for a black body point source ROSAT (1994a). Long dashes denote optical limits of black body source in the B band (see also the text).

ular, their velocities can be close to the velocities of the oldest pulsars. And the total expected number of such objects in the optical and in the soft X-rays is bounded above by the density of hidden mass, which gives the local (in the vicinity of the Sun) numerical density of compact objects with the mass of $1.4 M_{\odot}$ equal to 0.0357 pc^{-3} .

The total number of such objects can be bounded below by the number of all neutron stars, which could be in the vicinity of the Sun (Paczynski, 1990). But, apparently, old neutron stars (ONS) only can not be potential sources of γ -ray bursts, basically because of their small number in the Galaxy, which demands repeated γ -ray bursts at the average rate of events registered per day in the BATSE experiment (Fishman et al., 1994; Hartmann, 1994). Proceeding from the population $N_{tot} \sim 10^9$ of galactic neutron stars born in the Galaxy disk with the velocity distribution observed for radio pulsars (as a result, part of them will leave for the halo), then the spatial den-

sity of our hypothetical objects must not be lower than $n_{ONS} \sim 0.001(N_{tot}/10^9) \text{ pc}^{-3}$, based on the estimates in (Paczynski, 1990) for a probable average density of old neutron stars in the Galaxy plane near the Sun.

We will use $R = 10 \text{ km}$ and $M = 1.4 M_{\odot}$ for the radius and the mass of such an object — a hypothetical potential compact source of γ -ray burst, since we assume a kind of stable object or stable configuration, close to a “standard neutron” star at least by their gravitational properties. Below all estimates concern these parameters namely, though, naturally, the radii and masses of really observed neutron stars (pulsars) are determined with a dispersion of values. To estimate expected optical properties of these objects (in a quiet state — before or after the burst), we should choose also a definite temperature of the thermal emission from the whole surface of such a compact object.

The limitation on the temperature T_{bb} on the

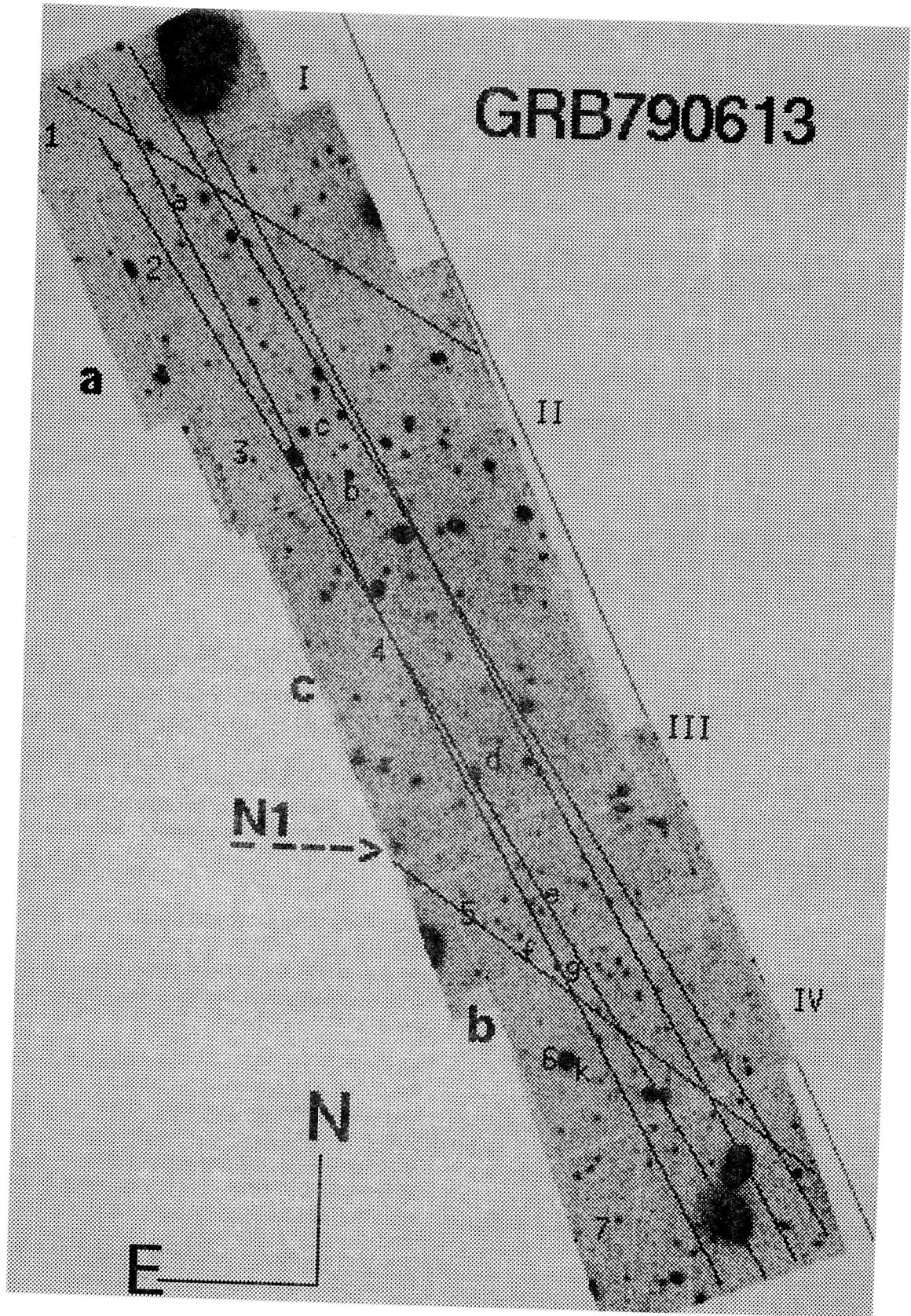


Figure 2: The CCD mosaic of the GRB 790613 error box. The error box was taken from Barat et al. (1984). Rome numbers and bold letters correspond to numbers and letters in column III of the Journal of observations. Small letters correspond to secondary photometric standard stars inside the CCD mosaic. Numbers correspond to areas with homogeneous photometric limits. Number 1 marks the star-like object with $B = 23.03$, $B - V = 0.03$, $V - R = 0.1$.

whole surface of the compact object for an analogous model (a "cold" single neutron star as a potential source of γ -ray burst) in connection with deep X-ray EXOSAT observations of γ -ray boxes has been already used in the interpretation of optical observations of the supposed candidates near the γ -ray box GRB 790325b (Hartmann et al., 1989; Motch et al., 1990). There is already quite a number of papers limiting the neutron star surface temperature by observations not only with the EINSTEIN and EXOSAT satellites (Pizzichini et al., 1986; Boer et al., 1988; Boer et al., 1991), but also by later ROSAT data in the soft X-rays (Boer et al., 1993b) (see also references in Boer et al., 1993a; Greiner et al., 1995). Here we use the results of ROSAT observations in the soft X-ray range (0.1 - 2.4 keV) for the same purpose — to set an upper limit to the value T_{bb} , to set later, using our own optical observations of the GRB 790613 γ -ray box, a limit on T_{bb} and a lower limit on the distance to the supposed potential candidates. Thus, that is a kind of development of the method of Pizzichini et al. (1986) for single objects, which has already become almost standard.

In Fig.1 are presented corresponding bounds on T_{bb} temperature of emission from the surface of the compact object with $R = 10$ km as a function of distance to it. The source of black body emission with $R = 10$ km can be detected in the X-rays or/and in the optical if at a given temperature and distance it is found to the left or/and above the corresponding curve in Fig.1.

For the all-sky survey in the energy range of 0.1 - 2.4 keV with the help of the ROSAT satellite (ROSAT All-Sky Survey = ROSAT ASS) we will use the flux $F_x \approx 4.2 \cdot 10^{-13} \text{ erg} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$, averaged over the whole survey (with an average exposure time of 500 s), which corresponds approximately to a level of 4σ . (5 X-ray sources found near or inside small γ -ray boxes were studied at this level of signal detection in ROSAT ASS (Boer et al., 1993a)). If based on this flux value, then at $T_{bb} > 200000$ K, even for a spatial density (lower estimate) of 0.001 pc^{-3} in ROSAT ASS, there must be a considerable number (about 30 sources up to 20 pc) of bright ($\sim 4 \cdot 10^{-12} \text{ erg} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$) X-ray sources, which could be identified long ago if they existed indeed. So far there are no unidentified *bright* X-ray sources (J. Greiner, private communication), and from the absence of large number of coincidences of weak X-ray sources with small γ -ray boxes (Greiner et al., 1995) it should be expected that even if such objects do exist in Nature, then their temperature is lower than $1 - 2 \cdot 10^5$ K, according to Fig.1.

At $T_{bb} \lesssim 10^5$ K even at a maximum allowable density of such objects in the vicinity of the Sun (0.0357 pc^{-3}) in ROSAT ASS a very small number should be expected of corresponding X-ray sources

with a typical flux of $\gtrsim 5 \cdot 10^{-13} \text{ erg} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$. At the same time, as is seen from Fig.1, corresponding compact objects with temperatures from 50000 K to 150000 K will be seen as objects stronger than 25.5^m in the B band, from 30 to 50 pc respectively.

Consequently, in the vicinity of the Sun we are concerned with the search in the optical for weak blue objects with colors: $U - B \approx -1.0$, $B - V \leq -0.3$, and $V - R \approx -0.1$. On the whole sky sphere they can be met with a frequency up to $\approx 0.5/\text{degree}^2$, if their temperatures are $\approx 10^5$ K. At the same time in the all-sky survey in the soft X-ray range such sources will be either weak (if $T_{bb} \approx 2 \cdot 10^5$ K) or so weak (at $T_{bb} \approx 10^5$ K) that they can be detected only at observations with long exposures in the same frequency band (see Fig.1). The fact that some source was found nevertheless in ROSAT ASS studying 40 small γ -ray boxes of a total area of $\approx 3.1 \text{ degree}^2$ (Greiner et al., 1995) does not contradict the above said and this implies that the temperature of such objects is $\lesssim 2 \cdot 10^5$ K.

Some contribution to the total bolometric luminosity can be made by accretion from interstellar medium onto a single compact object moving at a velocity of v (Bondi & Hoyle, 1944). In the computation of the accretion rate $\dot{M} \sim n_{ISM} \cdot v^{-3}$ for a given interstellar medium density n_{ISM} (for the number of hydrogen atom in a cm^3) we will assume that the velocity of our hypothetical objects is close to the velocity, which was really observed for radio pulsars, or, at least is close to spatial velocities observed for the oldest of them (Lyne & Lorimer, 1994). Assuming that in the vicinity of the Sun n_{ISM} is on average $\approx 0.07 \text{ H cm}^{-3}$, then at $T_{bb} \approx 10^5$ K the corresponding contribution ($G \cdot \dot{M} \cdot M/R$) to the total bolometric luminosity is only several percent for $v \gtrsim 200 \text{ km} \cdot \text{s}^{-1}$.

It is evident that because of their assumed low luminosity we can try to look for such objects only in the closest vicinity of the Sun. It refers not only to the optical, but also to the soft X-rays, which are strongly sensitive to inhomogeneities in the interstellar medium distribution (Paresce, 1984). So, keeping in mind the data on interstellar medium close ($\lesssim 250$ pc) to the Sun and also the absorption not only in the soft X-rays, but also in the far ultraviolet ranges (Welsh et al., 1994), we have to do in the *optical* only with corresponding objects (observed both in the ultra-violet and in the soft X-rays), which are situated very close to us. These may be only the objects which are in the bounds of the Local Bubble. Hence our model estimates refer also only to the nearest space, where, in particular, the distances to the supposed sources are determined only by their average spatial density ($\approx 0.001 - 0.036/\text{pc}^3$), if it is assumed to be approximately constant in a sphere of radius 100 pc. Thus, first of all from the observational

point of view, we are interested in the local situation with the sources of γ -ray bursts of the bright (short and powerful) events for which the law of $-3/2$ in the distribution LogN/LogS is still valid (Kouveliotou et al., 1993; Fishman et al., 1994). Here we try to use a minimum of model assumptions referring to "Big Galactic models" (Hartmann, 1994) and, so, we are dealing here only with the nearest objects — potential sources of γ -ray bursts.

GRB790613 is just one of the most powerful short (≈ 0.1 s) events which was simultaneously observed with the help of V-12 SIGNE, V-11 KONUS and PVO at photon energies exceeding 100 keV (≈ 0.1 photons \cdot cm $^{-2}$ \cdot s $^{-1}$ \cdot keV), when the greater part of γ -ray burst energy was released at the annihilation emission frequency during a time of ≈ 0.1 s (Atteia et al., 1987; Vrba et al., 1995). It could be expected that a supposed compact object, which was connected with this γ -ray burst, is one of such nearest objects, that has probably undergone a kind of explosion on its surface. In next Sections, with the use of the above mentioned, by the example of GRB790613 event it will be shown how an observational problem of search for such "cold" compact objects can be stated under the conditions, when we have to conduct optical search for weak sources by studying very big areas in the sky.

3. Observations

The observational data were obtained with the CCD camera of 580×520 pixels placed at the prime focus of the 6 m telescope of SAO RAS. The CCD chip has rectangular pixels of 24×18 μm , resulting in an image scale of $0''.205 \times 0''.154$ per pixel. We obtained the data with Cousins *BVR* filters. Normal program exposures were 600 s, 500 s or 400 s for the *BVR* filters. Longer exposures are not reasonable because of increasing number of space particles, since about 30 particles on the average are registered during a 10 minutes' exposure. A total of ≈ 5.7 hours of open shutter time was eventually obtained for the observation of the GRB790613 error box. Atmospheric conditions were stable throughout the observational runs with a seeing of 1.1 – 1.7 arcseconds. The first observation of this box was carried out on 13/14 April, 1994 in the *B* and *V* filters (Sokolov et al., 1994), where blue "candidates" were selected by the criterion $B - V < 0$. An additional observation in *R* filter was made on 2/3 June, 1994, but the CCD was not in the standard mode, and we used these data only as a photometric reference of relatively bright stars in the *R* filter over the whole mosaic obtained later. A subsequent observation in the three (*BVR*) filters of the central part of the GRB790613 error box, where several blue ($B - V < 0$) objects were found, was carried out on 29/30 December, 1994, and for the whole

Table 2: *The photometric limits.*

Number of area (Fig.2)	B	V	R
1,7	24.7	24.7	—
2.,3,5,6	25.7	25.7	25.6
4	26.2	25.8	25.6

field — on 24/25 April, 1995.

The coordinates of the center of the studied field are $\alpha(1950) = 14^{\text{h}}12^{\text{m}}12^{\text{s}}.8$; $\delta(1950) = +78^{\circ}54'13''.8$. Unlike other observers, we deliberately choose a symmetric γ -ray box obtained as a result of intersection of three stripes, and not only its northern part, which is a common part for all four triangulation stripes, since the symmetry of the error box evidences in favor of a correct burst localization. The total area of the symmetric box is ≈ 1.5 arcmin 2 .

The log-book is adduced in Table 1. For the GRB790613 field there are: I – the date and UT of observations, II – the area number and the filter, III – the exposure time, IV – the seeing, V – the night sky brightness per one square arcsec, VI – the zenith distance.

The procedure of construction of the GRB790613 field mosaic we obtained is shown in Fig.2. The roman numerals and bold letters correspond to the numbers and letters in column III of the log-book. Small letters indicate seven secondary photometric standards. The numbers correspond to areas with homogeneous photometric limits (see Table 2).

3.1. Data reduction and calibration

Standard data processing involves bias removing, flat fielding and removing of space particles and bad chip pixels. Bias-images were obtained during the night at regular intervals. Flat-field frames were obtained at twilight along with bias frames at the end of each night of observation. By shifts and turns all images were reduced to a unified internal frame of reference. Cosmic particles were selected by subtraction of median smoothing over several images from one image and were removed individually. The whole processing was carried out with the use of the ESO-MIDAS software package.

The photometric standard star MS 1443+63 B was observed every observational night before and after observation of the GRB790613 error box. We used the star MS 1443+63 B to calibrate secondary standard stars inside the CCD mosaic. We used seven secondary standard stars for calibration of different frames for one night and for different nights. The total number of the objects registered up to 27^{m} in the *B* filter is 426.

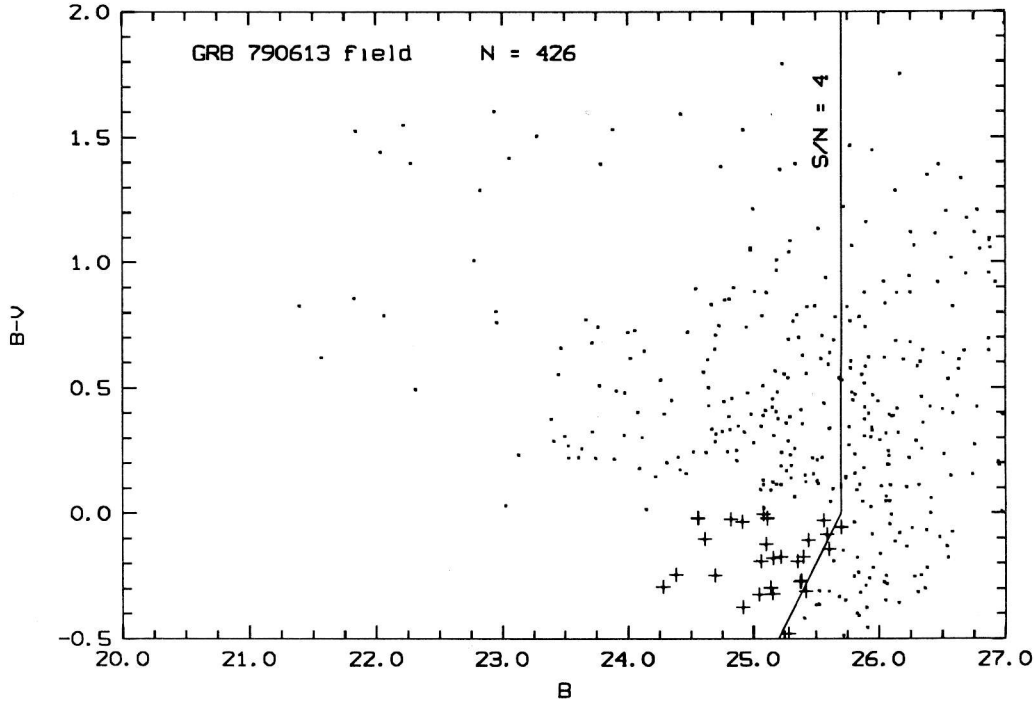


Figure 3: $B - V$ vs. B is shown for all detected objects ($N = 426, B \leq 27$) of the GRB 790613 field. Crosses mark all objects with $B - V < 0$ and $S/N \geq 4$. The line corresponds to the "practical photometric limit" ($S/N \approx 4$).

3.2. Photometry

The images obtained and reduced to a unified frame of reference were summed up in each filter. Photometry was obtained for all objects inside the whole CCD mosaic. But for further analysis we used only the objects with a $S/N \geq 4$. The $S/N = 4$ corresponds to the error of 0.25^m and for an object with magnitude determined with such an error the color error is 0.35.

The photometric procedure consisted of the following stages:

1. Since we were interested first of all in blue ($B - V < 0$) objects, then by the images obtained in the B filter using MIDAS context INVENTORY and smoothed with a gaussian we obtained coordinates for all detected objects of the whole mosaic.

2. By the coordinates obtained at the first stage the aperture photometry was done in all three BVR filters.

3. The obtained values were corrected for the finite radius of the aperture and atmospheric extinction at the given zenith distance, and were reduced to the standard Cousins system.

The results of the photometry are shown in Figs. 3,4,5. The crosses denote 31 objects in Figs. 3,4 with $B - V < 0$ and $S/N > 4$. Photometric limits (defined as $S/N = 4$) for the CCD mosaic are given in

Table 2.

The S/N was calculated for every object by the formula:

$$\frac{S}{N} = \frac{F_{star}}{\sqrt{F_{star} + F_{sky}}},$$

where F_{star} is the flux from a star in the given aperture, F_{sky} is the sky background in the same aperture.

Photometric errors were determined as follows:

1. If we had one measurement only, then the error was calculated using Poisson distribution of accumulated quanta:

$$\sigma_{mag} = \sqrt{\sigma_{star}^2 + \sigma_{sky}^2},$$

where

$$\sigma_{star} = \sqrt{F_{star}}, \quad \sigma_{sky} = \sqrt{F_{sky}}.$$

2. If we have several measurements, then in addition to 1)

$$\sigma_{mag} = \sqrt{\frac{\sum_i^n (mag_{sr} - mag_i)^2}{n - 1}}.$$

And correspondingly, the color errors are obtained as follows:

$$\sigma_{(B-V)} = \sqrt{\sigma_B^2 + \sigma_V^2}, \quad \sigma_{(V-R)} = \sqrt{\sigma_V^2 + \sigma_R^2}.$$

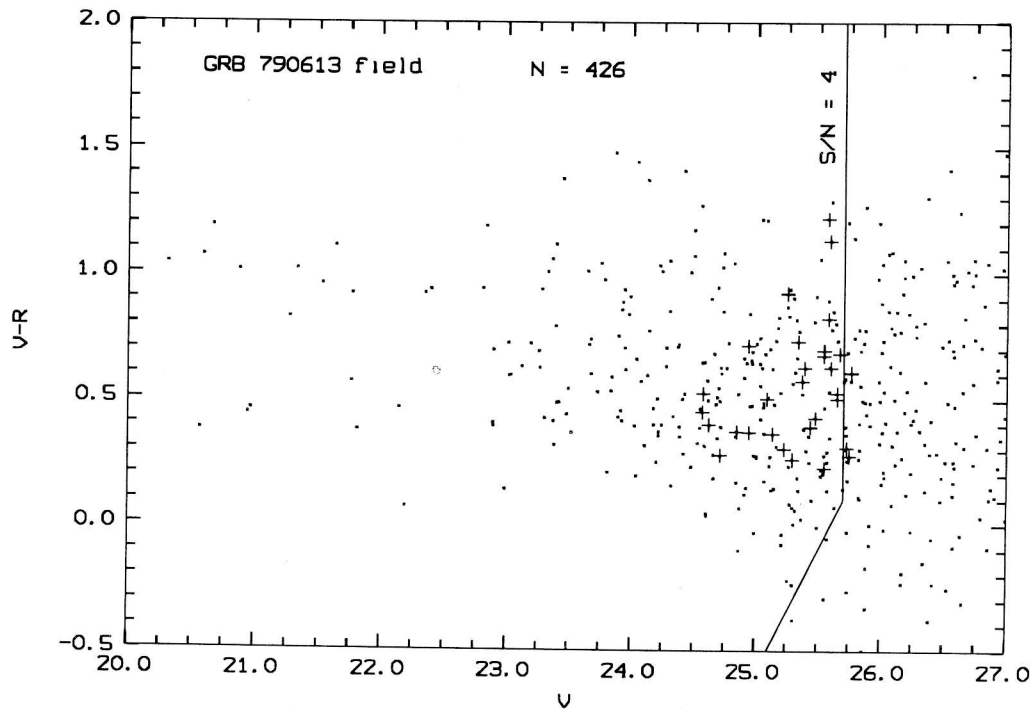


Figure 4: $V - R$ vs. V is shown for all detected objects ($N = 426, B \leq 27$) of the GRB 790613 field. Crosses mark 31 objects with $B - V < 0$ and $S/N > 4$.

The color errors for several objects with color indices closest to those of probable black-body objects are shown in Fig.5.

3.3. The search for blue stellar-like objects

The search for a neutron star type object with a black-body surface temperature $T_{bb} \approx 10^5$ K, as a possible potential source of a γ -ray burst, in the case γ -ray bursters are of local Galactic origin, was the main purpose of our observations. These sources must be observed as faint ($V > 23^m$) blue stellar-like objects of $B - V \approx -0.37$ and $V - R \lesssim -0.1$ and may be soft X-ray sources.

That is why our first step in selection of probable "candidates" was selection of objects with color indices $B - V < 0$ (see Fig.3). Observations in the R filter (the second approximation) allow us to select among such blue "candidates" only the ones, which must be below the line $V - R = 0$. In Fig.4 it is well seen how the objects with $B - V \leq 0$ (crosses) "scatter" over the diagram $(V - R)/V$. A subsequent test of blue in $B - V$ objects with the help of the criterion $V - R < 0$ reduces sharply large number of such "candidates" with the expected black body ("stellar") distribution over the B, V, R fluxes even without a careful analysis of their profiles for the purpose of revealing stellar likeness or extended character

of an object.

As is seen from Figs. 3,4 and Table 2, the limits, from which the level of S/N is greater than 4 for each of the B, V, R filters in the average for the whole mosaic, are equal correspondingly to $B = 25.7, V = 25.7$ (and $R = 25.6$). Thus, from the aforesaid it might be assumed that almost all obviously blue in $B - V$ objects studied up to $B \approx 25.2$ (see Fig.3) are too red in color index $V - R$ to attribute them confidently (with $S/N > 4$) to objects with the black-body distribution in the B, V, R fluxes. That is no blue optical counterparts by $B - V$ and $V - R$ (for $S/N > 4$) were found.

The ROSAT HRI observation of the GRB 790613 field with a 13168 s exposure did not detect any objects in this error box and showed that the black body temperature must be less than 150000 K for the objects of the neutron star type at a distance less than 100 pc (ROSAT X-ray Images, 1994a; ROSAT Guest Observer Program, 1994b). Our observation with ROSAT data can be interpreted as the absence of a single compact object with $R = 10$ km and $T_{bb} \approx 10^5$ K up to a distance of ≈ 40 pc (Fig.1) and accordingly, the energy of GRB 790613 event is higher than $(4 - 9.5) \cdot 10^{35}$ erg. Nevertheless, if the value $B \approx 25.2$ is assumed to be the photometric limit, at which the blue object with $B - V \approx -0.3, V - R \gtrsim -0.1$ can yet be classified (by two color indices at once!) by our

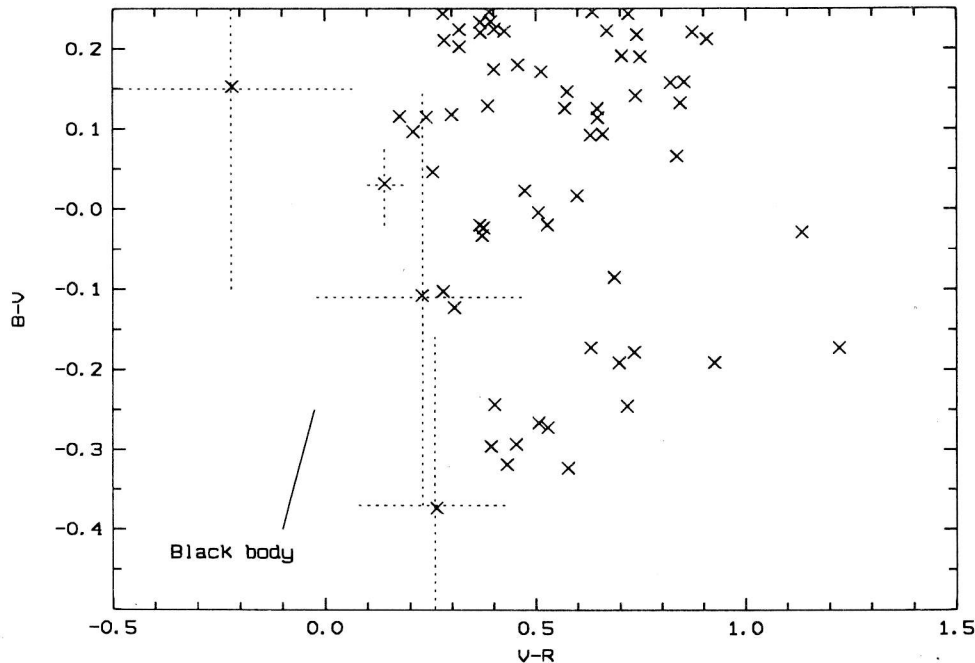


Figure 5: $(B - V)/(V - R)$ diagram for relatively blue ($B - V < 0.25$) objects with the ratio $S/N > 4$. A place is marked by a solid line where black body objects with $100000 \text{ K} > T_{bb} > 30000 \text{ K}$ could be situated. For several objects being near this place corresponding rms for their colors are indicated.

data (bearing in mind an object analogous in brightness and color to Geminga optical candidate). Then from the X-ray 3σ -limit for deep observations of the same box with HRI ROSAT (ROSAT X-ray Images, 1994a; ROSAT Guest Observer Program, 1994b) it is seen (Fig.1) that in this case a single object, which could be connected with this brightness, can be situated very close to us, if its temperature is $T_{bb} \lesssim 10^5 \text{ K}$.

3.4. Estimations of proper motions

Close objects (of NS type) can have considerable proper motions. For example, at a velocity of $\approx 200 \text{ km/s}$ and a distance of 100 pc the proper motion up to 0.4 arcsec/year can be expected from such an object. But if the object has a non-thermal spectrum, it may be photometrically lost among the great number of other objects. That is why the proper motion measurement is of special importance as an opportunity to select *all* close objects with high spatial velocities. The proper motion measurement procedure was as follows.

All images were reduced to one frame of reference with the help of bright stellar-like objects with normal stellar color indices. Since these objects lie in the range of $20\text{-}21^m$, they are the most probable stars at the distance of several kiloparsecs and, correspondingly, are good reference points for construction of motionless frame of reference. Since all objects, which are the nearest to us, must have stellar profiles, to de-

termine the position of all objects we used the approximation of their profiles by the Gauss function, and, correspondingly, defined the position of the object as the Gauss function center of mass. After making such measurements for two epochs: April 1994 and April 1995, we estimated the proper motion of objects per year as the difference between the coordinates for the two epochs. For galactic objects this difference would be just the proper motion, for extragalactic ones it corresponds to the accuracy of the object profile approximation by the Gauss function. To determine the standard error of the object position, analogous measurements were made for the same objects in different images obtained during one night. The results of our measurements are presented in Fig.6.

The proper motion of objects with $V \leq 25$ was measured. Down to $V \approx 25$ objects with the proper motion larger than 3σ of average position were not found. Objects with cosmic particles or closely spaced objects have a position error between 2σ and 3σ of the average position error.

3.5. Some interesting objects

Some interesting objects were found near and inside the error box. The first (Number 1 in Fig.2) of them is a stellar-like object with $B = 23.03$, $B - V = 0.05$ and $V - R = 0.1$. It is situated outside the error box at a distance of about $30''$ from its boundary. The object has color indices close to those of black body with

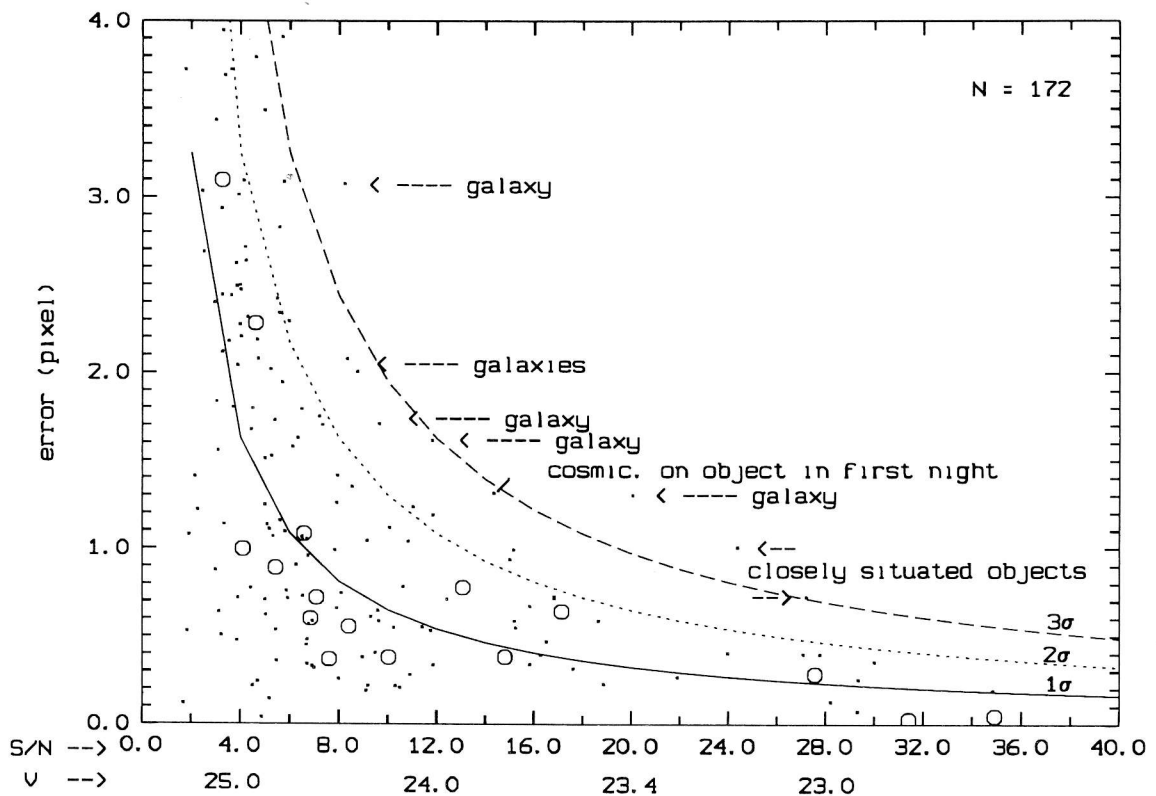


Figure 6: The objects position error (point) was measured as a difference of positions of the Gauss sum of B and V images for 13/14 April 1994 and 24/25 April 1995. Circles are the measurements of an object positions during one night. Lines correspond to 1σ , 2σ , 3σ of an average position error, $1\text{pixel} = 0''.205$. The axis with S/N corresponds to S/N for Gauss sum of B and V images for April 1994.

Table 3: The photometry of bright galaxies of the group.

Number of galaxy (Fig.8)	B	V	R	B-V	V-R
1.	21.39	20.42	19.65	0.97	0.76
2.	21.44	20.35	20.03	1.08	0.32
3.	20.84	19.86	19.54	0.97	0.32
4.	22.03	21.00	20.53	1.02	0.47
5.	22.13	20.82	20.27	1.31	0.55
6.	22.60	21.64	21.23	0.96	0.40

the temperature $T_{bb} \approx 17000$ K. Assuming that this object is the object of neutron star type, then it might be situated at a distance less than 10 pc from the Sun and, accordingly, it has to have a noticeable proper motion (> 1 arcsec/year). But the proper motion of this object is less than $0''.1$ per year. It may be a QSO or a halo object: a subdwarf or a white dwarf at about 3 kpc distance.

A group of galaxies was found in a projection on

the northern part of the error box using the galaxy counts. Fig.9 displays the excess of bright galaxies when counting them in two adjacent frames of our mosaic (II and III of our log-book and see also Fig.2). The size of the group of galaxies is about $120''$. It is obtained on the basis of counting the number of galaxies up to $\approx 24.5^m$ in the stripes of $80'' \times 10''$ in size along the whole mosaic (Fig.8). Assuming the masses of galaxies to be proportional to their magnitudes, the determined coordinates of the center of mass for the group are $\alpha(1950) = 14^h 12^m 16^s.7$, $\delta(1950) = 78^\circ 55' 02''.0$. The center of mass is denoted by the cross in Fig.7. The redshift of the group $z \approx 0.3$ is estimated from magnitudes and colors of galaxies with the use of K-correction taken from the paper (Frei & Gunn, 1994). The numbers in Table 3 correspond to the numbers in Fig.7.

4. Summary and discussion

From the mentioned in Section 3.3 it follows that today's X-ray and optical observations do not exclude at all a cooled compact object as a candidate for the sources of γ -ray burst in this concrete case of the γ -

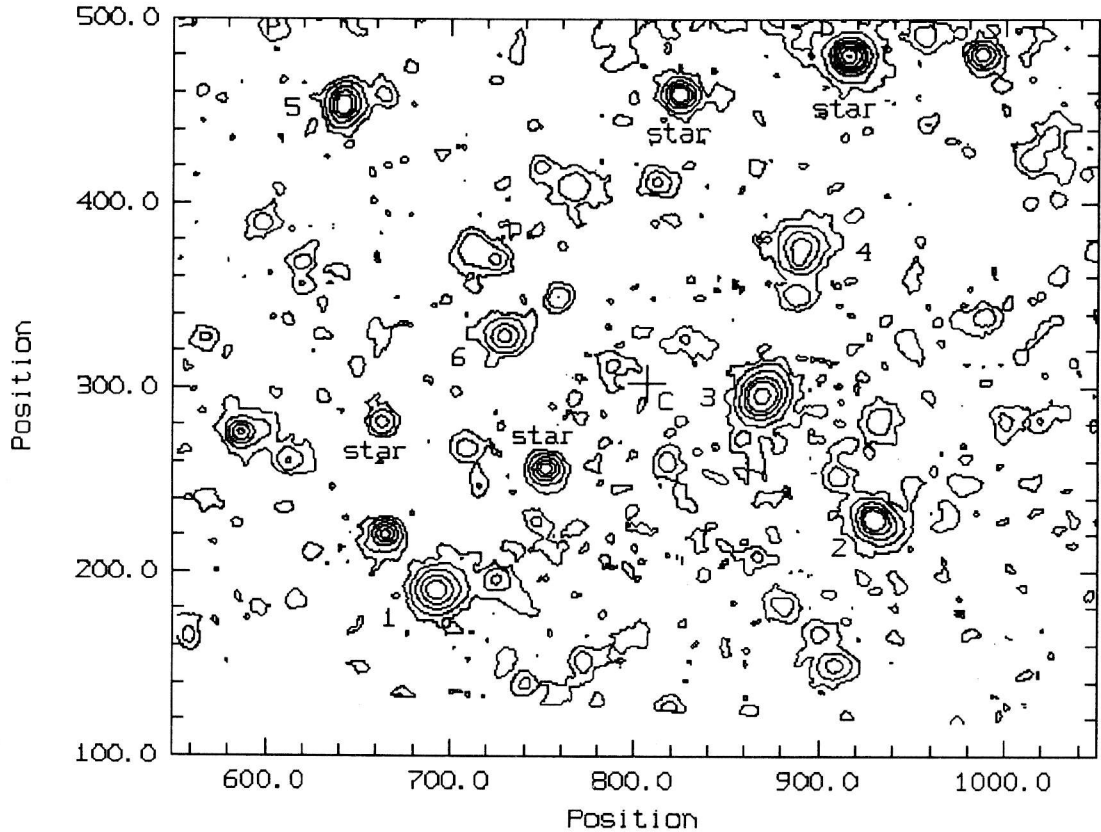


Figure 7: The isophote map of the group of galaxies is shown. Numbers correspond to numbers in the Table 3 with the photometric data for these galaxies. The cross marks the center of mass for this group.

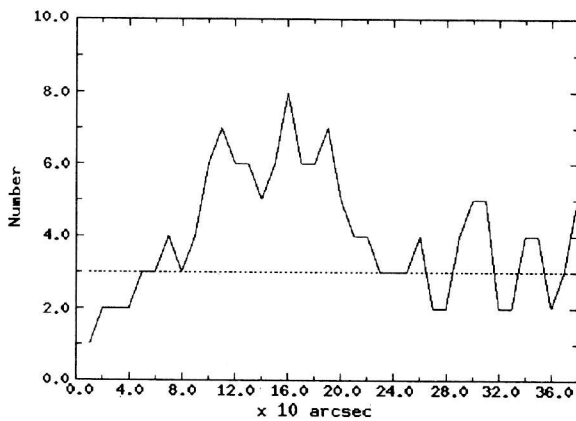


Figure 8: The size of the group is $120''$. The size was obtained using counts of galaxies up to $V \approx 24.5$ in 80×10 arcsecond strips along the CCD mosaic.

ray box, which has already been well studied in the X-rays (see also in Greiner et al., 1995). In general, based on the average limit of ROSAT ASS (dashed line in Fig.1), all such sources or at least the closest of them could be located at a distances of ≈ 50 pc or more by varying the spatial density of corresponding hypothetical cold ($T_{bb} \leq 1.5 \cdot 10^5$ K) compact ob-

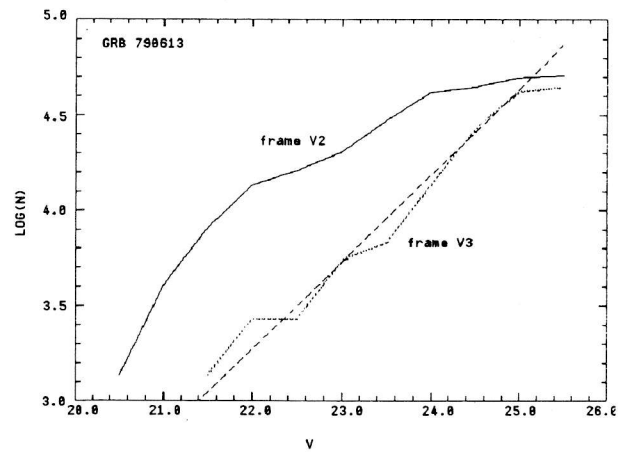


Figure 9: The counts of galaxies in two neighbouring frames. The frame N2 corresponds to II V in the Journal of observation. The frame N3 corresponds to III V. $\text{Log}(N)$ is logarithm of number of galaxies per a square degree and per a magnitude.

jects from a maximum density of $0.0357/\text{pc}^3$ (bearing in mind the objects with the mass of $1.4 M_{\odot}$ as unknown objects of (Lacarrieu, 1971) and up to a

minimum spatial density close to the density of old neutron stars in the vicinity of the Sun.

It means that we can construct any "global" galactic models for γ -ray bursters, beginning with the well studied situation in the vicinity of the Sun. And from Fig.1 it is well seen that if it is difficult to observe such single objects in the soft X-rays (because of absorption also), then nevertheless at big telescopes they could be detected in optics in small γ -ray boxes ($\approx 1' \times 1'$) up to a distances of ~ 100 pc (up to $m \sim 27^m$).

The emission of these cold compact objects can be weakened in the soft X-rays because of the fact that for the X-rays the walls of so called "Local Bubble", which are situated close to the Sun, become opaque (Paresce, 1984). (See the calculation of soft X-ray absorption for the thermal emission of single neutron stars in Helfand et al. (1980), analogous calculation for the band of 0.1 – 2.4 keV is in Boer, et al., (1993a).) For the same reason there must be few such objects in EUVE and ROSAT WFC sky surveys (Welsh et al., 1994), and the objects which can still be seen in the far ultra-violet (the closest ones) may be potential sources, which have not yet manifested themselves as the sources of γ -ray bursts — the sources "in a quiet state".

To emphasize here the fact that study of blue ($B - V < 0$) objects with $B \approx 25.5$ in the whole field is not a limiting problem for the 6 m telescope at all, we refer to analogous observations in February 1987 of the Geminga object (Halpern & Tytler, 1988) at the 5 m telescope. The corresponding exposures in the g and r bands were 7200 s and 5500 s, which allowed only a rough color estimate ($g - r = -0.3$) to be obtained for the expected optical candidate with $g = 25.1$, i.e. this was limiting problem indeed. Even in the case of observation at NTT of an optical candidate for PSR 0656+14 in January 1991 (Caraveo et al., 1994), when an object with $V \approx 25$ was found at the level of 3σ , the total exposure in the V filter was 4200 s. In the B, V and R frames obtained at the 6 m telescope (during an exposure time of ≈ 25 min in each filter, as was mentioned above) all these objects were not only detected at the level higher than 3σ but their colors were also measurable. In particular, the object analogous to the optical candidate for Geminga should be registered in B and V with a good S/N.

Certainly, in principle, the situation is possible when a probable source of the γ -ray burst is on the same line of sight as a brighter object. The probability of such a projection of the GRB 790613 event source on one of the relatively bright objects inside the mosaic is $\approx 6\%$. This is the ratio of the area covered by all objects to the total area of the mosaic for the GRB 790613 error box. Thus, the observation of the GRB 790613 γ -ray box in three filters allows us

to hope for a 94% "cleaning" of the whole investigated field for such objects as optical candidates for the identification of the Geminga object (Halpern & Tytler, 1988) or PSR 0656+14 (Caraveo et al., 1994).

Thus, the results of the study of the localization region of the GRB 790613 event up to the magnitudes $B = 25.7$, $V = 25.7$ and $R = 25.6$ permits the following conclusions to be drawn:

1. The absence of blue (by $B - V$ and $V - R$ color indices) objects up to $B = 25.2$ near the box center can be interpreted as the absence of a compact object with a "naked" surface (without any dense envelope in the optical) hotter than ≈ 150000 K, at least up to ≈ 40 pc in this direction. So, optical observations add new details to the estimate of temperature of the supposed single compact objects in the vicinity of the Sun, which can be made in interpretation of results of the search for point-like X-ray sources in the range of 0.1 – 2.4 keV.

2. The observational data available do not reject the existence of "cold" ($T_{bb} \lesssim 10^5$ K) compact objects up to $\approx 2 \cdot 10^4$, some of which could be related with the closest sources of γ -ray bursts in the vicinity of the Sun (in a sphere of radius $\lesssim 50$ pc). Accordingly, lower values of the supposed spatial density ($\lesssim 0.001/\text{pc}^3$) at a given observed average frequency of γ -ray events "remove" the closest source of the burst to a distance greater than 50 pc. For a given rate of γ -ray bursts, $< 0.8/\text{day}$ (Fishman et al., 1994) it turns out automatically that old neutron stars born in accordance with the "standard" scenario (Paczynski, 1990) can not be sources of γ -ray events at least near the Sun).

Since here we mean only the most powerful and the closest to us sources of γ -ray bursts and, correspondingly, the closest compact objects probably related to them, then the global spatial distribution of sources is open to question and it becomes essential for weak sources (Fishman et al., 1994). The question is also open of recurrent events, short and long flashes and, in general, the mechanism of γ -ray burst remains incomprehensible.

The work was carried out with the support of ESO C&EE Programme (grant A-02-023), and also with the support of Russian Foundation for Basic Research (grant 94-02-04871a).

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