Observations of Gamma-ray Bursts in Abastumani Observatory

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ABSTRACT

Phenomenological properties of gamma-ray bursts (GRB) are briefly reviewed and observations of GRB optical afterglow and other transients in Abastumani astrophysical observatory are discussed. In particular, the catalog of observations in 2012-2015, and some results including the final photometry of the optical afterglow of GRB 140801A are presented.

Keywords: gamma-ray bursts, transients, afterglow, cosmology

1. Basic GRB Properties

Gamma-ray bursts (GRB) are among the most energetic events in the Universe and brightest on the gamma-sky and yet among the most enigmatic phenomena. GRBs are commonly defined as cosmological nonrepetitive violent flashes of gamma-rays with photon energy about several tens of keV registering from un-predictable directions in the sky. Duration of GRB active phase (prompt emission) in gamma-rays are ranging from $\sim$0.01 s to $\sim$1000 s. They were discovered for the first time in 1969 (but published only in 1973, Klebesadel 1973). Gamma-ray spec-trum of these events is mostly non-thermal, with the bulk energy emitted in 0.1 to 1 MeV range. Light curves of GRBs are highly variable, with significant variability down to a few mil-liseconds, consisting of non-symmetrical mostly overlapping pulses with Fast Rise and Exponential Decay (FRED pulse type).

1.1. Results ofBATSE/CGRO

An important result obtained by Burst and Transient Experiment (BATSE)on-board the *Compton GammaRay Observatory* (operated in 1991-2000) which recorded over 2700 GRBs, is an isotropy of the error box localization across the sky (Fishman 1995). The absence of concentration of the events to the Galactic plane suggested a cosmological origin of the GRB sources, but the distance to the sources were still undefined.

Another result from *BATSE* was a confirmation of two classes of bursts initially pointed out by (Mazetz 1981). The parameter of T_{90}, which is defined as the duration of the time interval comprising 90% of GRB flux, showed a bimodal distribution for all GRBs detected by *BATSE* with separation point between two modes at 2 seconds. All GRBs with T_{90} <2 s were referred as short duration and with T_{90} >2 as long duration gamma-ray bursts (Kouveliotou 1993). Now it became clear that most of long GRBs are associated with the core collapse of massive stars and a progenitor of short GRBs are likely merging compact binaries, e.g. neutron star - neutron star or neutron star - black hole (e.g., Zhang 2012).

1.2. GRB Afterglow

In 1997 the era of BATSE changed into the era of the afterglow starting with the BeppoSAX space observatory, equipped with X-ray detectors (Boella 1997). It is supposed that the after-glow is a passive phase of GRB phenomenon when relativistic jet accelerated in the active phase expanding in circumburst media. In 1997 the first X-ray and optical transient accompanying the GRB was discovered (e.g., ?) GRB 970228,][see e.g.,]970228xray,970228opt, and after the afterglow faded away, the deep follow-up optical observations showed that the after-glow coincided with a distant small galaxy (e.g., Bloom 2001). This galaxy was suggested to be a host galaxy of the GRB and confirmed the extragalactic origin of these events. Today the nearest GRB is GRB 980425 with a red shift z =0.0085.(Fynbo 2000), the most distant is GRB 090429B with z=9.4.(Cucchiara 2011).

Today GRBs are being discovered by several space-born experiments, but only three space observatories can localize GRB in near real-time: Swift (Gehrels 2004), INTEGRAL (Courvoisier 2003), and Fermi (Michelson 2007; Meegan 2007).

Quick broadcast data of triggers from the orbit to a ground-based the Gamma-ray Coordinates Network[1] system and numerous ground based optical and radio telescopes around the world allowed to effectively discover optical and radio afterglow of GRBs. Since the first afterglow detection in 1997 till the end of 2015 the space missions discovered about 1550 well localized GRBs[2] , and 2/3 of them have X-ray afterglow. Optical after-glows are detected for∼60 % of GRBs with X-ray afterglow, and radio transients are discovered for only∼11 % of the bursts from the same sample. Gamma-ray bursts were also detected in high energy domain up to 100 GeV by LAT/Fermi detector (Ackermann 2014). The nature of GeV emission seems to be different from both prompt and afterglow emission.

[1] http://gcn.gsfc.nasa.gov/

[2] http://www.mpe.mpg.de/~jcg/grbgen.html

1.3. Afterglow and Its Properties

The standard model of GRB afterglow formation states (Sari 1998, 1999), that the afterglow radiation is originated from relativistic bulk motion of electrons in the collimated ejecta (jet) from the dying massive star (long duration GRB) and from merging a compact binary system (short duration GRB). It is supposed that synchrotron radiation is a main origin of the afterglow in different energy bands.

The model of a long GRB states that during the collapse of a massive star the relativistic jet with high gamma-factor **Γ** is formed. It has a narrow opening angle $\theta\sim7$ degrees and is oriented toward the observer. In initial stage of the afterglow **Γ** is high, the cone emission of relativistic electrons is much smaller than the jet opening angle. While expanding the ejecta loses energy and **Γ** decreases. At the moment when the emission cone of relativistic electrons is equal to the opening angle of the ejecta cone, i.e. when**$\sim1/\Gamma$** becomes more than θ, the decay of the afterglow flux becomes steeper, and the observer registers a break in the light curve, which is called a jet-break. The time t_b corresponding to the jet-break allows to estimate the jet opening angle. This phenomenon was predicted theoretically (see, e.g., Rhoads 1997) and is observed for many GRB afterglows. This effect is based only on the outflow geometry and thus is achromatic, i.e. seen in all energy bands at the same time.

The "zoo" of afterglow light curves displays a diversity of forms and flux, but there are common properties (see, e.g., Kann 2010). The light curve of typical optical afterglow of a GRB may be generally approximated by simple power law$\sim t^{\alpha}$, where $t = T-T_0$ is the time from GRB trigger, and $\alpha=-(0.5-2)$. In many cases the light curve has a jet break.

In general case the light curve of an GRB counterpart in optic or X-rays can be divided into phases of different emission origin. The first one is an active phase also called a prompt emission; the emission is generating when central engine of the GRB is still active. Sometimes the prompt optic emission could be registered simultaneously with gamma-radiation (see e.g. Zheng 2012). The prompt emission light curve is complex and highly variable. This phase is rarely observable in optics because of unpredictable location of a GRB source in the sky. The most effective way to register the prompt emission is simultaneous observations of the same field of view in optic and in gamma-rays by space-born telescopes (see e.g. Pozanenko 2013). Sometimes prompt emission in optics can be caught by a chance (see e.g. Racusin 2008) or if the prompt emission is sufficiently long it could be registered with fast slewing robotic telescopes (see e.g. Rykoff 2009).

The second phase is a passive pase, i.e. the afterglow itself with power law decay of a light curve. In case of X-ray after-glow the slope of the light curve decay may become shallower or even temporally come out to a plateau (see e.g. Xin 2012). Typical optical or X-ray afterglow lasts for a few days, but bright one may be observable for months (e.g., GRB 030329, Lipkin 2004., GRB 130427A, Perley 2014). The X-ray afterglows are usually monitored by X-ray Telescope (XRT) on-boardSwift pace observatory, and the light curve may be very detailed. But in most cases the only information obtained about the optical afterglow is a few broad-band photometric observations. Some afterglows may be accompanied with flares and bumps, which are not described by a standard model.

In some cases the GRB afterglow may be accompanied with a supernova feature Hjorth (2012). On the light curve it appears as a significant flux increase in the late phases of the afterglow and a subsequent decay which can not be fitted with a power law model (see Fig.3). Spectroscopic observations made at the time of the brightening maximum and decay demonstrate broad lines which are typical for Ib/c type supernova. But current observations allow to register the supernova feature only for nearby GRBs, with redshift less than ~0.5. Today there are about 30 GRB associated supernovae with spectroscopic confirmation (e.g., Cano 2014) and a few dozens of photo metrically detected supernova.

The first GRB supernova was discovered in 1998 during observations of GRB 980425, which is the closest discovered burst till now. The SN 1998bw associated with this GRB has an extremely low redshift (z =0.0085) and it allows to obtain detailed multicolor light curve, and multiple spectroscopic observations Galama (1998); Iwamoto (1998); Kulkarni (1998). This fact allows to use photometric and spectroscopic data of the SN 1998bw as templates for empirical estimations of main parameters of other GRB connected supernovae (e.g. Cano 2013).

For∼35% of GRBs the optical afterglow is not registered down to a deep limit. These bursts are called optically dark bursts (e.g. Greiner 2011). Dark bursts usually may have bright X-ray afterglow. A model suggests that the absence of an optical counterpart or its unusual faintness result from a high optical extinction in a line of sight to the burst source. However in ∼10% cases the darkness of the optical counterpart is related to a high redshift of GRB sources, because of atz ≥4 flux in optical bandpass ishighly absorbed by Ly_α at the line of sight to the observer. In some cases the optical darkness can be explained by absorption in circumburst medium of d GRB (e.g. Volnova 2014).

Often observations of the GRB host galaxy may be the only way for estimating the distance to the burst source. The host galaxy may be observed at the location of the GRB after the afterglow fading away. The search for GRB host galaxies is an important problem and require deep photometric and spectroscopic observations. Usually long GRBs follow young blue galaxies with a high star formation rate, but there is a less numerous population of GRBs formed in dusty and red galaxies (e.g. Rossi 2012)

2. Abastumani Astrophysical Observatory (AbAO)

Abastumani Astrophysical Observatory (former Georgian National Astrophysical Observatory) was founded in 1932 by Academician Eugene Kharadze on Mount Kanobili (1600 m above sea level), near the resort Abastumani (in Samtskhe-Javakheti,southeastern part of Georgia). Its location is $41^o 45'15''$ N and $42^o 49'10''$ E, i.e. 200 km to the west from Tbilisi. A study of the astroclimate conducted in 1960 – 1980 in the observatory confirmed excellent parameters (Kharadze 1983). Due to difficult access to the original paper about astroclimate investigation we report some parameters from (Kharadze 1983) below.

2.1. Astroclimate

The mean, maximal mean and minimal mean temperature in the Observatory is 6.3,12.6 and 2.2 C., The mean ground wind-speed is 2.1 m/s and mean speed measured only in clear nights is only 0.6 m/s, the number of calm nights is 68 % of the total ones. The mean number of clear night hours is 972, while minimal (maximal) hours measured in 1960 – 1977 is 772 (1153) hours per year. Maximal number of clear nights is in July – October season. It was 220 observational nights (full or partial) in2015. Sky background in filters close to bandpass B and V is 21.82^m and 20.81^m per $arcsec^2$. Seeing was measured by a visual method with two-beams telescope in 1976 – 1977. The mean seeing is 0.63 arcsec.

Our observations in Abastumani observatory (see below) are random in seasons, part of night, elevation etc. The sample of FWHM measurements in the images obtained for GRB observations with AS-32 telescope (Figure 1) may be a good practical estimating for planning observations. Since we have not measured FWHM less than 2 arcsec the distribution is biased by telescope optical system and CCD detector and a dome. The median of the FWHM distribution is 2.7 arcsec. Indeed, the FWHM is an upper limit of the seeing parameter.

2.2. Telescopes

Abastumani observatory has a dozen of optical telescopes and a few solar instruments. The main instrument used for GRB afterglow observations is the Maksutov telescope AS-32 equipped with CCD-camera. It was constructed in 1955, the meniscus diameter is 0.7 meter, the main mirror is 975 mm in diameter, the focal length is 210 mm, so the whole system has a field of view about 5 degrees in diameter. Since 2005 Abastumani observatory collaborates with the ISON project (Molotov 2008) for space debris observations. In 2007 a new telescope ORI-22 was installed in the framework of the collaboration. Space debris observations were stopped in 2009. Since 2011 observation of potentially hazardous near-Earth asteroids started with AS-32 telescope, and in 2014 the asteroid survey started with ORI-22 telescope. AZT-11 (1.25m) the telescope is not operational since 2011 due to failure of telescope control system.

3. GRB Observations

The first observations of a GRB afterglow was carried out at the end of 2012. Since then Abastumani observatory provides without filter observations for GRBs operating in an alert mode (Pozanenko 2013). The results of quick data reduction are published via GCN: The Gamma-ray Coordinates Network in the form of Circulars[3].

3.1. Catalog of GRB Observations

Table 1 contains the information about all GRB fields observed in Abastumani till the end of 2015. In the first column there is a name of the GRB, the second one is a time delay between the GRB trigger onboard a space observatory and the start of observations, the third column contains the brightest magnitude observed during the set, and the last one contains references for the publications.
Some of the bursts observed are of a particular interest. GRB 130427A (redshift z=0.34) is one of the brightest GRBs in optics (Perley 2014) was observed in AbAO in the first 3 days (April 27-29) and in May 1-4.2014. In all observations the optical afterglow of GRB 130427A is detected. The image of fading afterglow of GRB 130427A observed in AbAO is presented in Figure 2.
GRB 130702A was detected initially by GBM/Fermi experiment with a poor localization error box. However optical scanning of the error box of 71 square degrees with Palomar Transient Factory discovered the bright optical afterglow candidate (iPTF13bxl, see also (Singer 2013)) which was observed in AbAO observatory within three days. A light curve of GRB 130702A afterglow reconstructed from observations in AbAO and IKI follow up network is presented in Figure 3. The light curve clearly exhibits the initial afterglow phase, supernova bump at∼12 days and the host galaxy with brightness of about 22.5m. A redshift of the burst source is confirmed as z=0.145
Also in 2015 Abastumani observatory participated in a worldwide observational campaign of the V404 Cyg flash activity – the black hole binary the last activity of which was detected in 1989 (Kimura 2015). The log of V404 Cyg observations is presented in Table 2.

[3] http://gcn.gsfc.nasa.gov/gcn3_archive.html

3.2. GRB 140801A

GRB 1400801A was detected by GBM/Fermi with poor localization error-box of about 1.2 degrees (radius, statistical only) on August, 1, 2014 (UT) 18:59:53. MASTER robotic telescope in Tunka valley discovered a bright optical source 98 seconds after GBM/Fermi trigger (Lipunov 2016). Our observations started on the same day at (UT) 22:13:30 in Maidanak observatory with AZT-22 telescope and continued up to 23rd days after GRB trigger with AbAO AS-32 telescope, Tien Shan Zeiss-1000 (East), and Crimean Astrophysical Observatory ZTSh (2.6m) telescopes. A log of our observations as well as the photometry of the afterglow of GRB 140801A are pre-sented in Table 3. For calibration we use following stars of USNO-B1.0 catalog (USNO-B1.0 id, R2): 1209-0038209, 18.02; 1209-0038197, 17.35; 1209-0038227, 15.88. The calibration stars were chosen with automatic pipeline for identification candidates into secondary photometric standards in the field of GRB (Skvortsov 2016). Using our data from Table 3 and data from the paper (Lipunov 2016) we constructed the light curve (Fig. 4). The light curve consists of afterglow phase, and a host galaxy with brightness of about 24.6^{m}. It is evident that the light curve is non-monotonous, and at least three bumpy episodes are evident, on∼0.1 days,∼1 days, and∼6 days after trigger. The last bump on ∼6 days cannot be a supernova feature since it is too early in comparison with known GRB supernova (see section above), especially taking into account the redshift of the GRB 1400801A source of z =1.32. The bumpy light curve is not a rare event in GRB afterglows, see e.g. well sampled GRB 030329, GRB 100901A, GRB 151027A etc. A nature of bumpy (non-monotonous) behavior of afterglow light curvesis not yet established.

4. Conclusions

Fast and world wide observations of GRB optical counterparts are crucial for a detailed light curve construction. Well sampled multicolor light curves provide experimental support for modeling of GRB physics including central engine activity, afterglow emission mechanism and its evolution, properties of the medium around the burst source. Abastumani observatory provides fast observational data of a good quality and successfully participates in the world wide GRB follow-up campaign.

Table 1.GRBs observed in Abastumani astrophysical observatory
[1]- of the first observation
[2]- of the set
[3]- in the first frame or stacked frames

GRB name	Date & time	Delay	Exposure, s[2]	FWHM, ¨	Mag.[3]	Reference
121123A	2012-11-23 15:18:28	5.3 h	180×24	2.5	19.0	GCN #14200
121128A	2012-11-28 15:27:50	10.7 h	300×42	2.9	20.2	GCN #14201
130427A	2014-04-27 17:00:56	9.2 h	180×71	2.7	16.4	-
130603BS	2013-06-03 22:19:06	44 m	300×22	3.2	18.8	GCN #14806, Pandey (2016)
130606A	2013-06-06 21:47:43	16.2 h	180×8	3.4	20.3	GCN #14813
130702A	2013-07-03 17:40:00	1.7 d	120×34	2.7	18.7	Volnova (2016)
130822A	2013-08-22 20:56:42	8.8 h	30×144	3.2	>21.9	GCN #15137
130829A	2013-08-29 18:55:48	13.2 h	120×9	2.7	>20.6	GCN #15136
130912A	2013-09-13 00:18:46	15.7 h	120×31	2.6	>22.3	GCN #15239
131011A	2013-10-11 22:32:33	5.3 h	120×26	2.8	21.3	GCN #15341
131024B	2013-10-25 00:26:12	3.9 h	120×46	2.9	>22.6	GCN #15392
131026A	2013-10-26 21:06:35	14.5 h	180×32	3.2	>22.6	GCN #15394
131108A	2013-11-11 00:44:00	2.2 d	120×36	2.9	21.2	GCN #15484
131231A	2014-01-03 17:08:16	3.5 d	120×33	2.7	20.3	GCN #15711
140102A	2014-01-05 00:48:24	2.1 d	120×38	2.6	>22.5	GCN #15730
140103A	2014-01-03 01:21:18	0.9 h	120×15	2.7	21.1	GCN #15735
140114A	2014-01-15 00:07:23	0.5 d	120×40	2.6	>20.6	GCN #15756
140129B	2014-01-29 12:23:49	2.6 h	120×4	3.2	>18.7	GCN #16055
140423A	2014-04-24 00:29:23	16.4 h	120×16	2.9	.20.3	GCN #16264
140521A	2014-05-21 18:12:00	1.4 h	120×28	2.7	>21.2	GCN #16317,16372
140606AS	2014-06-06 18:16:50	7.9 h	120×30	2.7	>21.7	GCN #16371, Pandey (2016)

140606B	2014-06-07 21:40:06	1.8 d	120×46	2.7	21.9	GCN #16398
140703A	2014-07-03 23:27:06	1.0 d	120×23	2.1	21.3	GCN #16536
140801A	2014-08-02 21:54:52	1.1 d	60×26	2.2	22.1	GCN #16667
141020A	2014-10-20 15:41:01	8.7 h	120×38		>21.4	GCN #16948
141109A	2014-11-10 01:05:04	20.0 h	120×37	2.4	21.7	GCN #17062
141109B	2014-11-09 15:26:30	9.2 h	120×71	2.3	>22.0	GCN #17067
141121A	2014-11-21 20:01:35	17.6 h	120×54	3.6	20.1	GCN #17089
Swift #625898 (SZ Psc)	2015-01-18 15:31:24	3.3 d	2×30	3.8	7.2	-
150213B	2015-02-13 23:22:23	0.9 h	120×39	2.5	19.0	GCN #17468,17478
150222A	2015-02-23 01:21:55	4.6 h	120×37	3.2	>22.9	-
150309A	2015-03-10 01:40:55	3.0 h	120×19	3.1	>21.2	GCN #17570
150314A	2015-03-14 22:06:54	18.2 h	120×24	2.7	>19.8	-
150323A	2015-03-23 22:47:06	20.4 h	180×15	2.4	>21.2	GCN #17647
150407A	2015-04-07 22:11:07	22.1 h	120×20	3.5	>21.1	-
150428A	2015-04-28 17:33:59	16.8 h	120×31	2.2	>21.9	-
150428B	2015-04-28 23:39:49	21.2 h	120×31	2.2	>21.3	-
150607A	2015-06-07 17:54:22	11.0 h	120×44	2.1	21.2	GCN #17915
150728A	2015-07-28 19:32:14	7.3 h	120×28	2.1	20.6	GCN #18094
150811A	2015-08-11 19:07:37	15.7 h	120×31	2.2	19.8	-
150817A	2015-08-17 17:00:31	15.5 h	120×24	2.2	21.6	GCN #18160
150910A	2015-09-10 18:53:55	11.0 h	120×52	2.0	20.2	GCN #18289,18327
150911A	2015-09-12 00:04:59	-	120×31	-	-	-
151022A	2015-10-22 15:59:07	-	120×42	-	-	-

SGR1819-1600	2015-11-22 14:54:30	-	60×18	-	-	-
151118A	2015-11-18 18:08:10	15.8 h	120×35	2.1	>22.1	GCN #18627
151215A	2015-12-15 20:08:51	18.6 h	120×35	2.4	>21.8	-
151228B	2015-12-29 14:38:28	16.6 h	120×34	2.1	>22.1	GCN #18891

Table 2.Observations of V404 Cyg outburst of 2015 in Abastumani

Date & time, UT	Exposure, s	FWHM, "	Mag.	Reference
2015-06-15 22:44:54	120×1 (25)	2.3	14.9	Kimura (2015)
2015-06-17 22:21:54	60×1 (74)	2.2	13.0	"–"
2015-07-18 21:44:14	20×1 (160)	2.2	16.6	"–"
2015-07-01 19:09:26	30×1 (100)	2.3	15.9	"–"
2015-12-29 16:34:45	60×8	-	-	-
2015-12-28 16:19:10	60×1 (39)	2.7	15.5	GCN #18767

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Fig. 1.FWHM distribution of point-like objects in a combined images of GRB afterglow observations presented in Table 1.

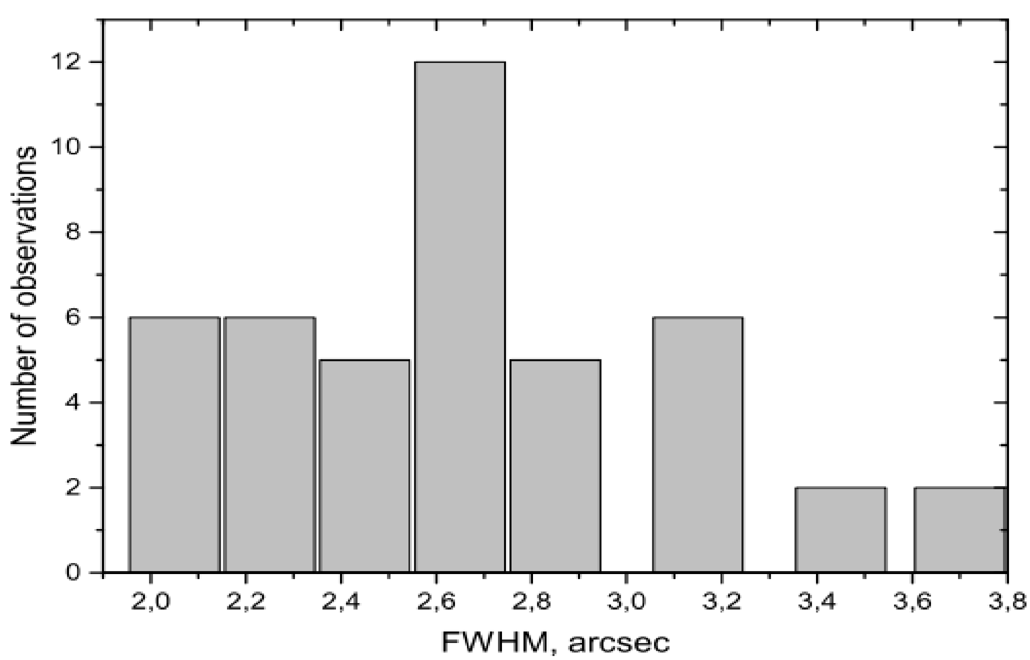

Fig. 2. Observation of the GRB 130427A afterglow with AS-32 telescope on the first day starting 2013-04-27T17:00:57 (left) and on the 3rd days
(2013-04-29T16:59:56) after GRB trigger

Table 3. Observations of GRB 140801A. Photometric magnitudes are not corrected for Galactic extinction in the direction of GRB.Abbreviations:
MAO is a Maidanak astrophysical observatory, TSHAO is Tien Shan astrophysical observatory.

Date	Time UT	t-T0, days	Filte	Exposure, s	Mag & err	Observatory/telesco
2014-08-01	22:13:30	0.13550	R	180	20.14 0.06	MAO/AZT-22
2014-08-01	22:16:55	0.13787	R	180	20.24 0.04	MAO/AZT-22
2014-08-01	22:20:20	0.14024	R	180	20.13 0.04	MAO/AZT-22
2014-08-01	22:23:46	0.14263	R	180	20.17 0.04	MAO/AZT-22
2014-08-01	22:27:12	0.14501	R	180	20.22 0.04	MAO/AZT-22
2014-08-01	22:30:38	0.14739	R	180	20.24 0.05	MAO/AZT-22
2014-08-01	22:34:04	0.14978	R	180	20.23 0.04	MAO/AZT-22
2014-08-01	22:37:29	0.15215	R	180	20.17 0.04	MAO/AZT-22
2014-08-01	22:40:55	0.15454	R	180	20.09 0.03	MAO/AZT-22
2014-08-01	22:44:21	0.15692	R	180	20.19 0.04	MAO/AZT-22
2014-08-02	21:54:52	1.14962	Non	26×60	22.13 0.18	AbAO/AS-32
2014-08-02	22:02:04	1.14422	R	15×180	21.96 0.05	MAO/AZT-22
2014-08-04	20:44:49	3.11106	R	11×600	>22.9	TSHAO/Z-1000
2014-08-07	22:48:48	6.17073	R	10×180	23.40 0.20	MAO/AZT-22
2014-08-24	00:31:46	23.0511	R	39×120	>24.3	CrAO/ZTSh

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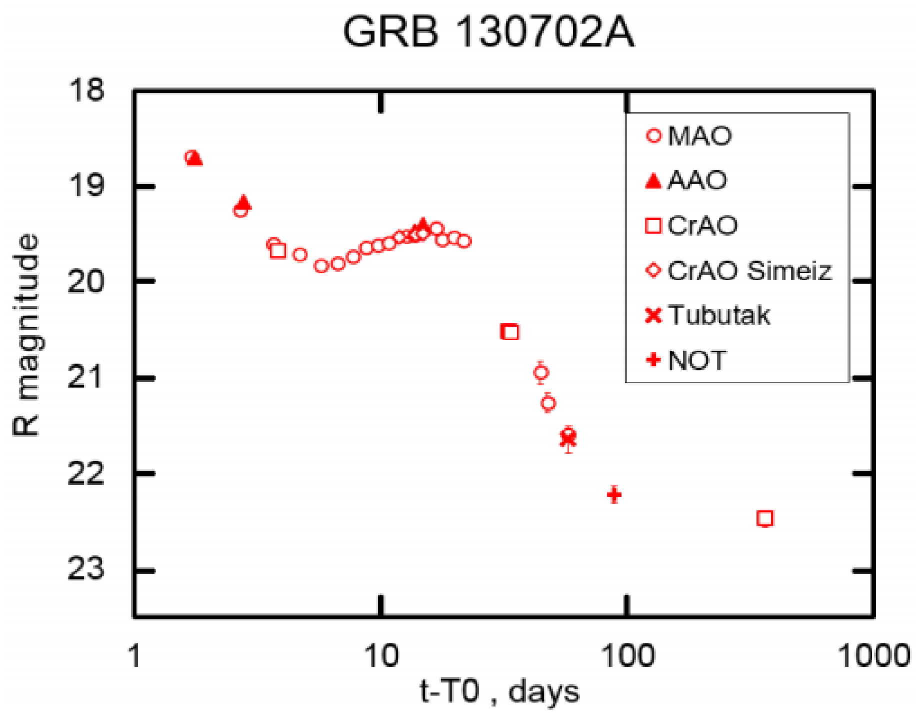

Fig. 3. The optical light curve of the GRB 130702A. After the opticalafterglow with power law decay the supernova feature is observed(SN 2013dx). The observations of Abastumani observatory are shown with filled triangles.

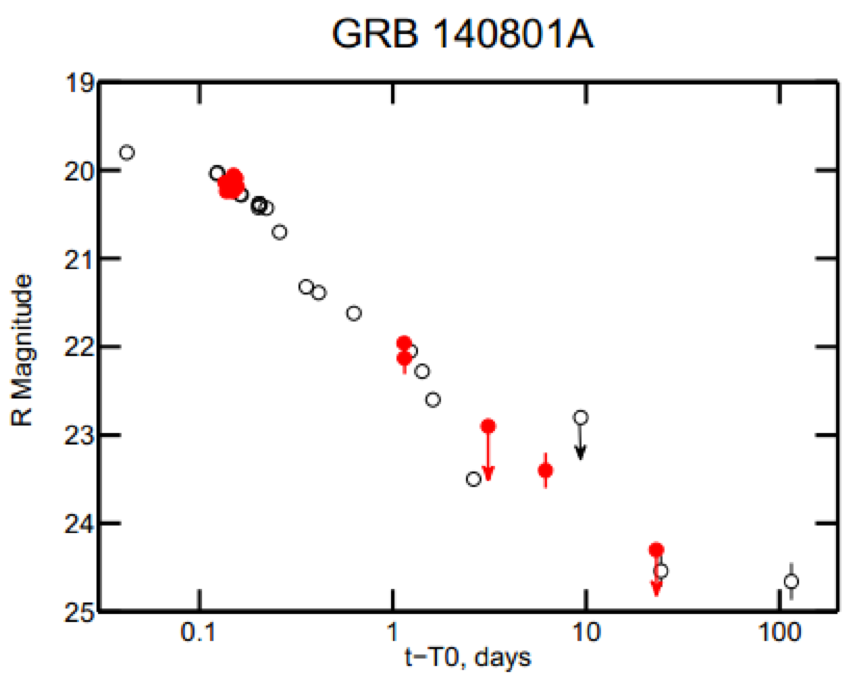

Fig. 4.The optical light curve of the GRB 140801A. Filled red circles depict the observations presented in the Table 3, open circles are the data taken from Lipunov (2016). The photometry of the first observation from Lipunov (2016) is not shown.

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