Gamma-ray bursts: Historical afterglows and early-time observations

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Abstract We discuss two historical afterglows (GRB 920723 and 920925C) prior to the Afterglow Era that started in 1997. We show how the use of both the 6-meter BTA in Zelenchuk (Russia) and 10.4-m GTC in La Palma (Spain) have benefited the study of GRB afterglows and their host galaxies. Moreover, when completed with our BOOTES Global Network of 0.6-meter robotic telescopes, this result had completed studying the early phases starting seconds after the trigger.

Keywords: Gamma-Ray Bursts, Afterglows, Early-Time Observations

1. Introduction

Since the discovery of the afterglows to Gamma-Ray Bursts (GRBs) in 1997, much has been advanced in the field, with several hundreds of counterparts in the last 20 yr in all the electromagnetic range from radio to gamma-rays, ending up with the detection of gravitational waves associated to a short-duration GRB in 2017.

2. Historical GRB afterglows

In 1997 the first counterpart at longer wavelengths was detected thanks to *BSAX* satellite. We always refer to 'the Afterglow era' to the period starting in 1997, following the important *BSAX* discovery of X-ray afterglows [1] followed by counterparts at other wavelengths. But we wonder whether there were other afterglows prior to 1997 serendipitously reported.

2.1. GRB 920723: the first X-ray afterglow?

An X-ray afterglow was pinpointed 5 yr before the *BSAX* detection of GRB 970228, which started the so-called Afterglow Era. This was the cased for GRB 920723, detected by the WATCH all-sky monitor on *Granat* ([2], [3]). See Fig. 1. Indeed Terekhov et al. refer to it as “afterglow” in their above-mentioned work published in 1993 [2].

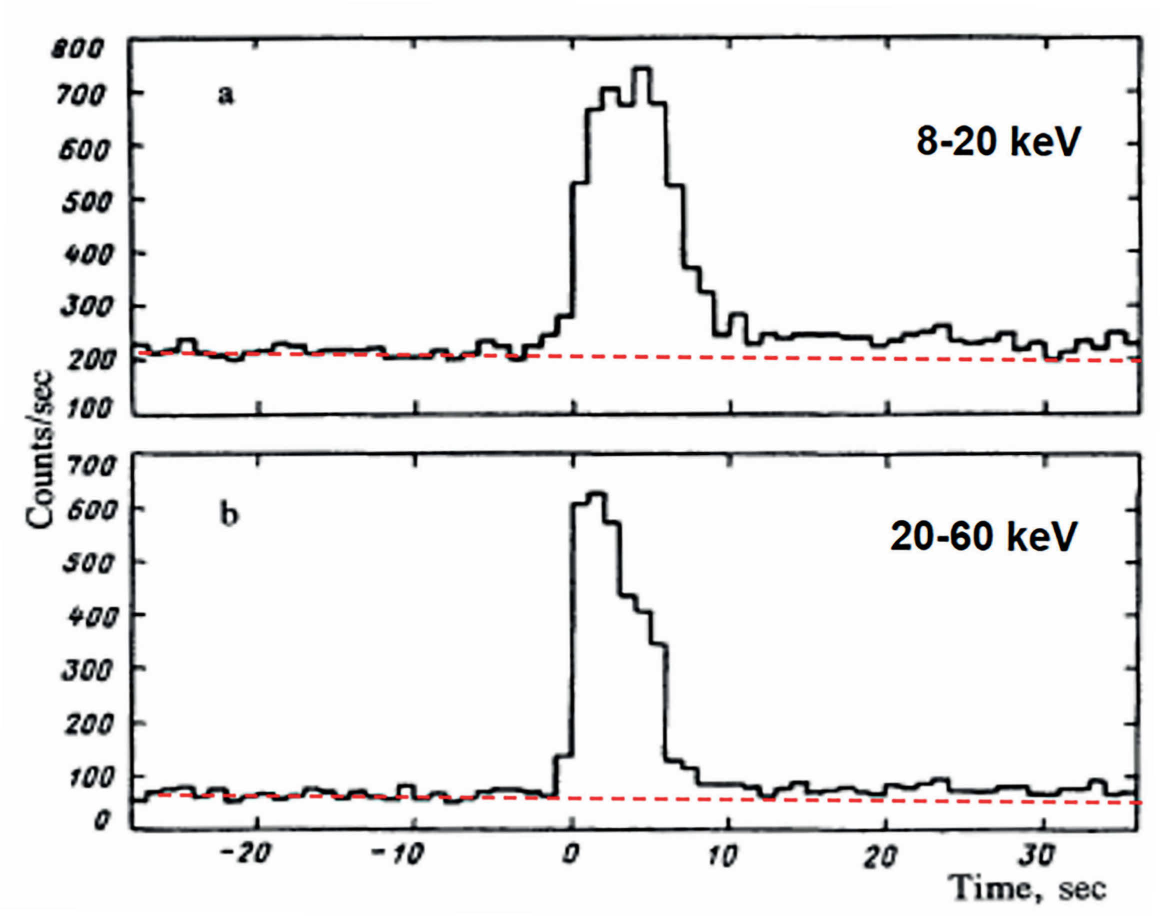

Fig 1. GRB 920723 as detected by WATCH on board Granat in the low energy range (8-15 keV, panel a) and in the high energy range (20-60 keV, panel b). See in a) how the low-energy emission above the background (red dotted line) extends significantly while the high energy emission (in b) has ceased. Adapted from [3].

2.2. GRB 920925C: the first optical afterglow?

GRB 920925C was a 400s long-duration GRB detected by WATCH/ *Granat* [3] and reported 4.5 yr prior to the famous GRB 970228, yet its optical afterglow (OA) needed 10 yr to be discovered once the corresponding POSS-II plates were checked! (and reported in [4]). A 2.6m Shajn initial search at Crimean Astrophysical Observatory was carried [5], reporting an upper limit of 25th mag. Deeper imaging conducted at the OA position revealed in

2013 a GRB 920925C candidate host galaxy and the very deep 10.4m GTC multicolour imaging performed in 2014 and 2017 showed a blue galaxy, as found in many other events. See Fig. 2.

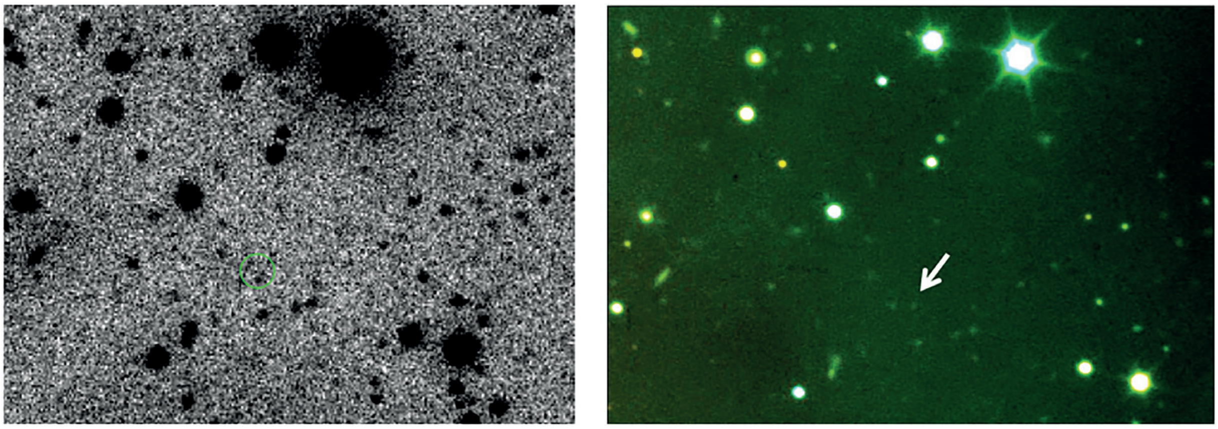

Fig 2. The green circle in the SAO image (left) represents the optical afterglow position found in [4] in the POSS-II plates, superimposed to the BTA deep V-band image, taking under Sokolov's GRB program in 2013. The GTC image (right) shows a color image as a result of combining g'r'i' images taken by the 10.4m GTC under the Castro-Tirado GRB program in 2013 and 2017. The arrow points to the candidate host galaxy. The field of view is 1.8' x 1.3'. North is up and east to the left.

3. Early observations of optical GRB afterglows

3.1. Reverse shocks

The strength of the reverse shock (RS) depends on magnetization content of the ejecta. See [6]. One such example is GRB 060117 [7]. See Fig.3.

3.2. Forward shocks

From the peak time of the rising OA lightcurves the initial Lorenz factor Γ_0 can be determined [8]. The rising lightcurves are also important to understand the onset of the afterglow [9] : $\alpha\sim2$ ($\nu_c < v_{\mathrm{optical}}$) or $\alpha\sim3$ ($\nu_c > \nu_{\mathrm{optical}}$) in the case of ISM or $\alpha\sim0.5$ for a WIND density profile. And they also help to constrain off-axis and structured jet models [10].

3.3. Automated and Robotic telescopes: advantages for GRB afterglow follow-ups

The automatization and robotizacion of existing telescopes, or the installation of newly developed robotic telescopes is greatly helping the early detection of the GRB afterglows, thus completing the rapid response for the space (e.g. by the *Swift* satellite). A further step is the deployment of networks of robotic telescopes, such as MASTER [11] and BOOTES [12], amongst others.

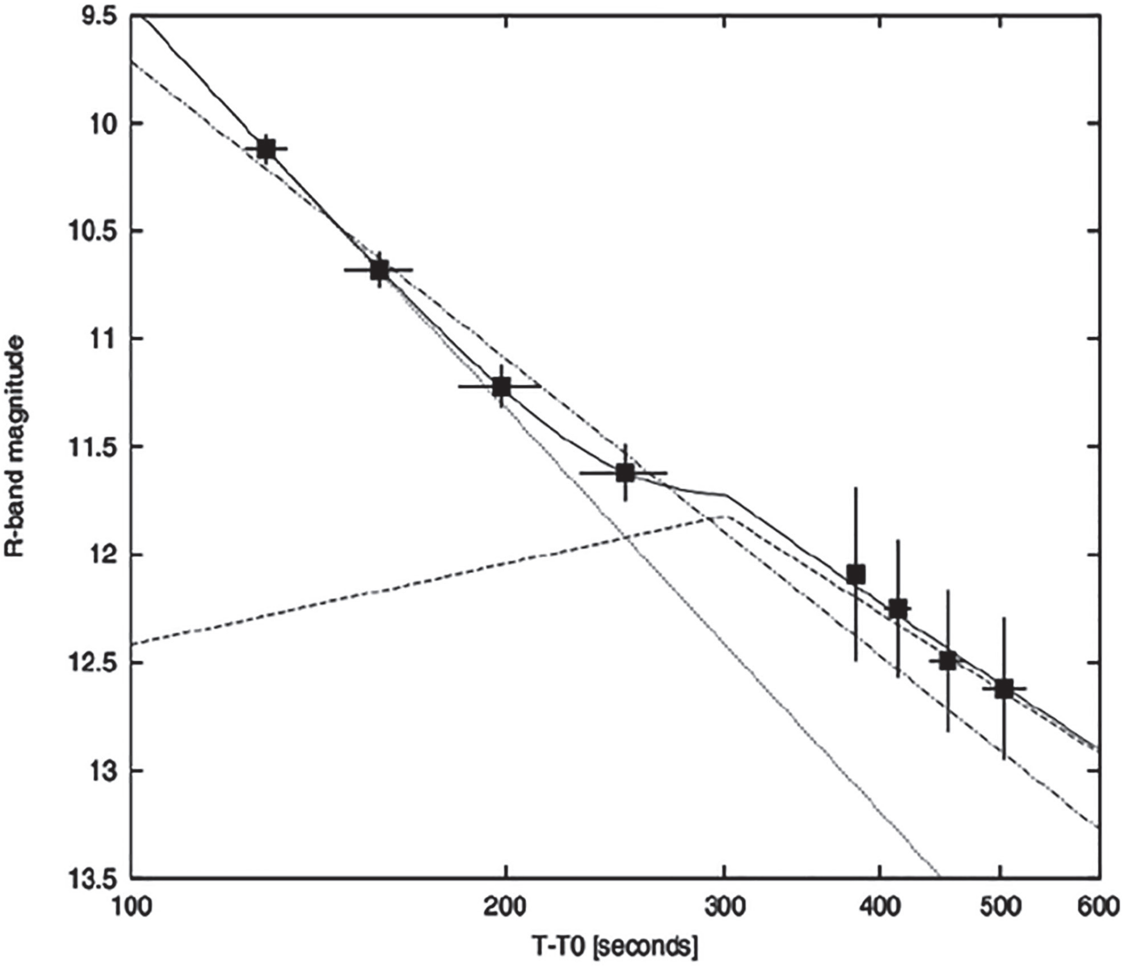

Fig 3. The early optical light curve of GRB 060117 (filled squares), fitted by a rapidly declining reverse shock and a forward shock peaking at about 300s (dotted lines resulting in the continuous line. Adapted from [7].

Fig 4. Some of the BOOTES stations worldwide. Robotic telescopes with a diameter of 60cm attached to EMCCD cameras. See [13] for further details.

BOOTES (Burst Observer and Optical Transient Exploring System), is becoming a worldwide network (with 4 units so far) of 0.6-meter ∅ identical robotic telescopes, attached to electro multiplying charged couple device cameras (EMCCD) cameras and filters (clear and g'r'i'ZY) which should help rapidly pointing to GRBs as soon as they go off. The next station (BOO-6) is opened in 2018 at the Boyden Observatory (South Africa). See Fig. 4.

A compilation of several early-time optical light curves provided by BOOTES-1 and -2 is shown in Fig. 5. 71 follow-ups in the period 2004-2013 resulted in 21 detections.

In some cases, the prompt discovery by one of the BOOTES telescope has led to trigger the 10.4-m GTC telescope, confirming the suspected high-redshift for the GRB itself. See Fig. 6.

4. 6.0-meter BTA & 10.4-meter GTC complementary observations

Following the 6.0-meter BTA, the largest telescope in the world in 1976, the 10.4-meter GTC is now the largest diameter optical telescope so far. See Fig. 7.

Some highlights follow:

a) Redshifts determination for about 20 GRBs (the first one: GRB 100316A, the last one: GRB 170626A). Redshift confirmation for another dozen of them. For instance, for GRB 100316A: the redshift was determined by GTC (z = 3.20). For GRB 140629A, the redshift was determined by BTA (z = 2.27, Hu et al. 2018). See Fig.8.

b)The extraordinarily bright and nearby (z = 0.340) GRB 130427A at the BTA & GTC, which was associated to a highly energetic supernova (SM2013cq). Spectroscopy was obtained at 6 different epochs. Work in progress. See Fig. 9. See also [17].

c) Searches for medium size GRB (few arcmin diameter) error boxes: discovery of a quasar in the short-duration GRB 140606A error box [18]. See Fig. 10.

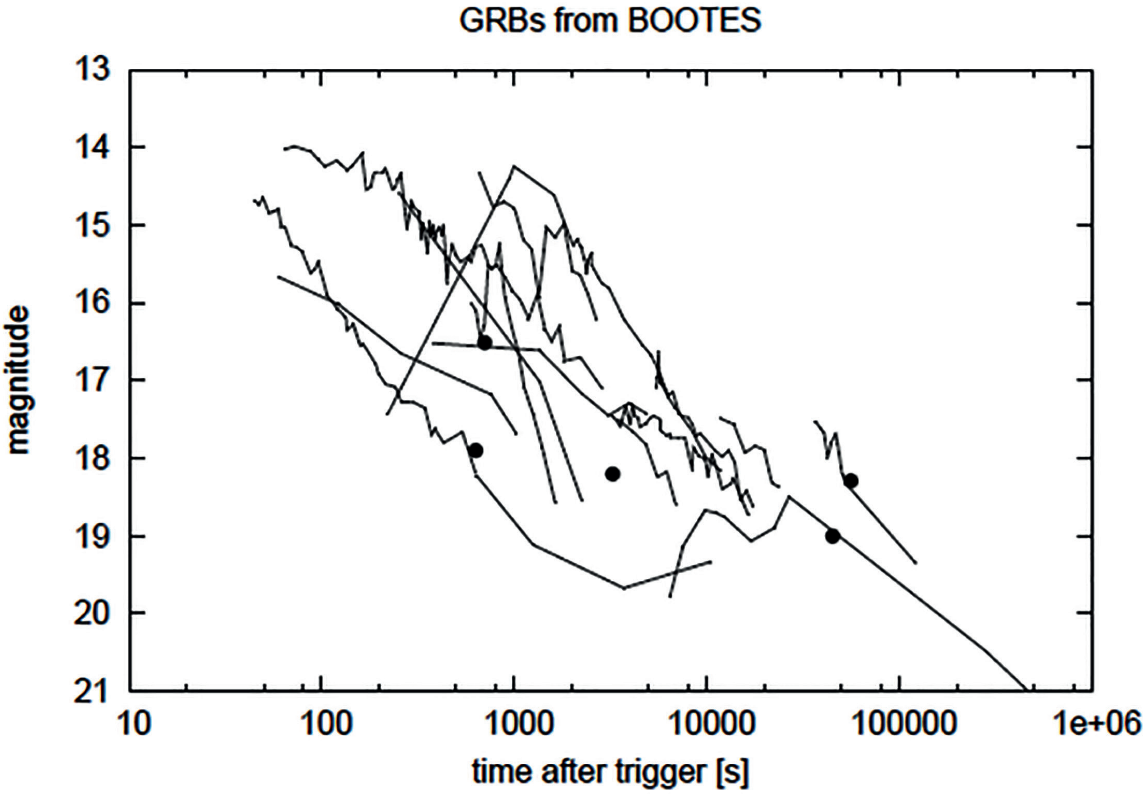

Fig 5. Some early light curves obtained by BOOTES-1 and -2 stations in South Spain. Adapted from [14].

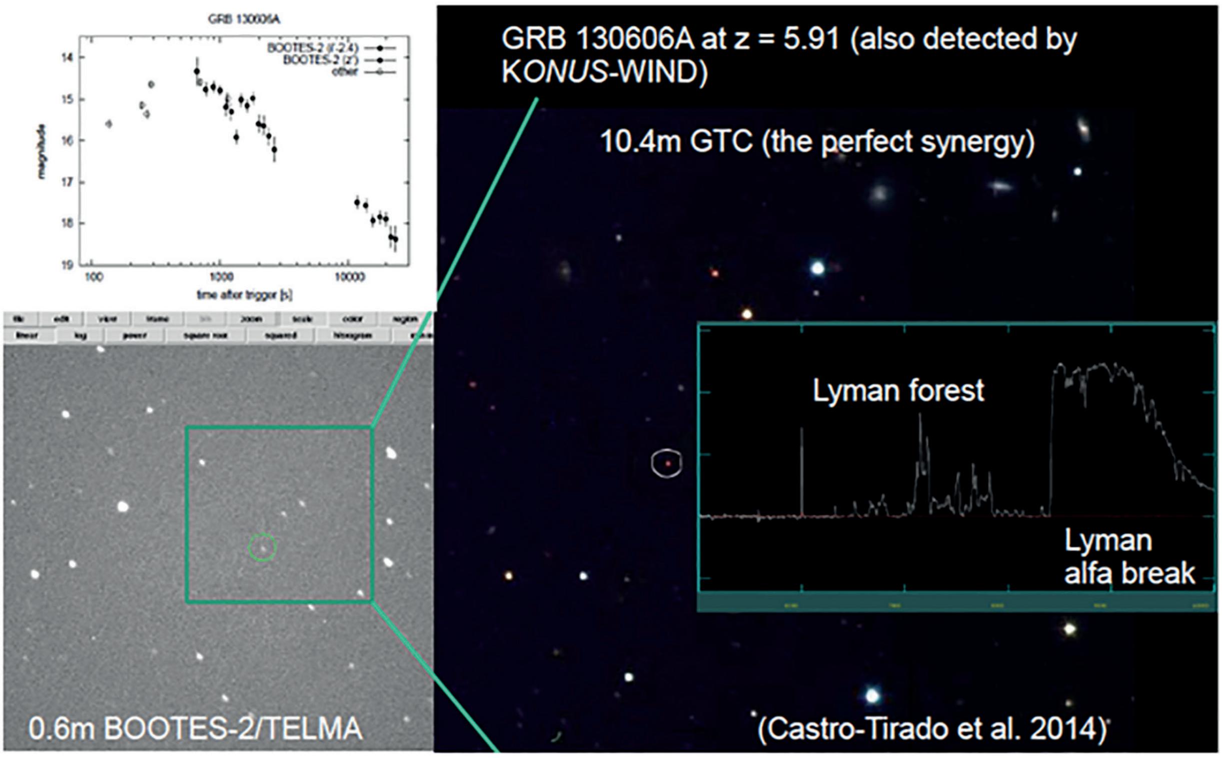

Fig 6. GRB 130606A at z = 5.91, first discovered by BOOTES-2 (lower left image), sampling the optical afterglow lightcurve (upper left) with the GTC showing the very highly reddened afterglow (right) at the z = 5.91 redshift determined by the GTC (insert). Adapted from [15].

Fig 7. Left: The dome of the 6-meter BTA telescope of SAO RAS. Right: The dome of the 10.4-meter Gran Canarias Telescope (GTC) (top) and the telescope itself (bottom).

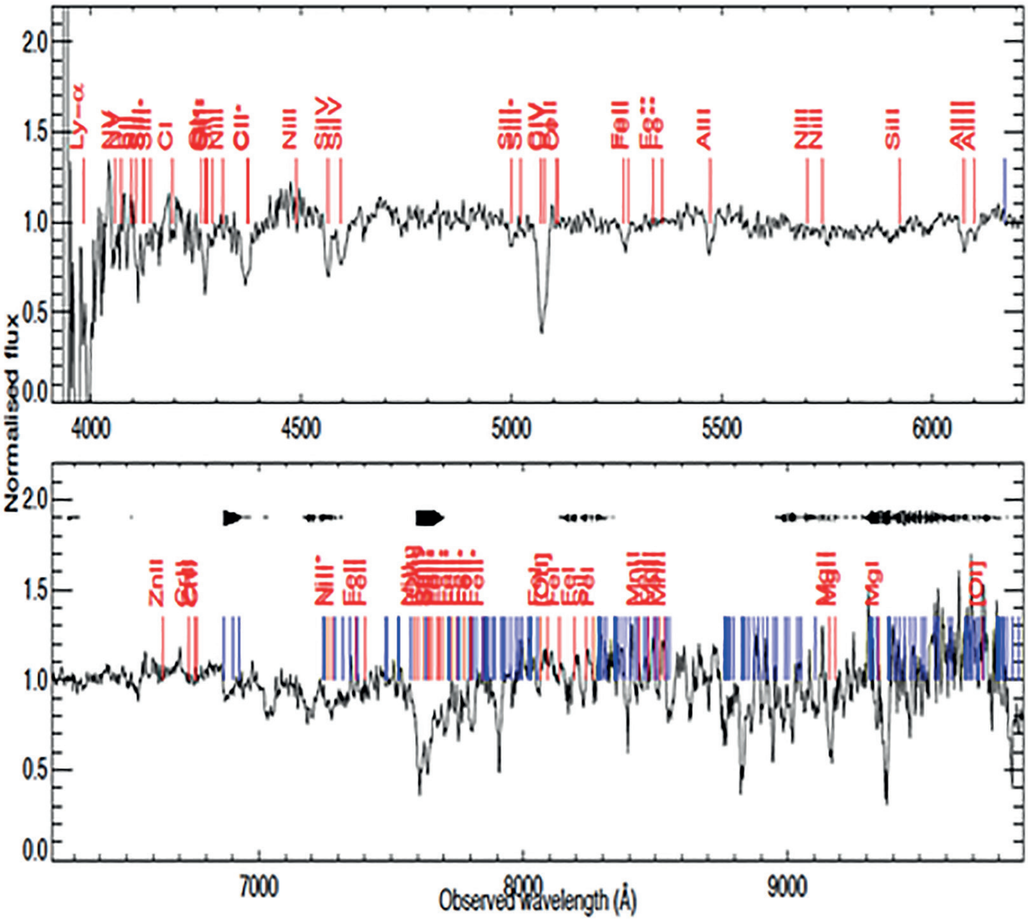

Fig 8. BTA optical spectrum of GRB 140629A obtained only 4.1-h after the detection of the GRB. It shows the Lyman-alpha emission line arising from the host galaxy plus some of the most prominent absorption line systems at the host galaxy redshift (in red). For completeness, the foreground system at z = 2.275 is also shown (in blue). Adapted from [16].

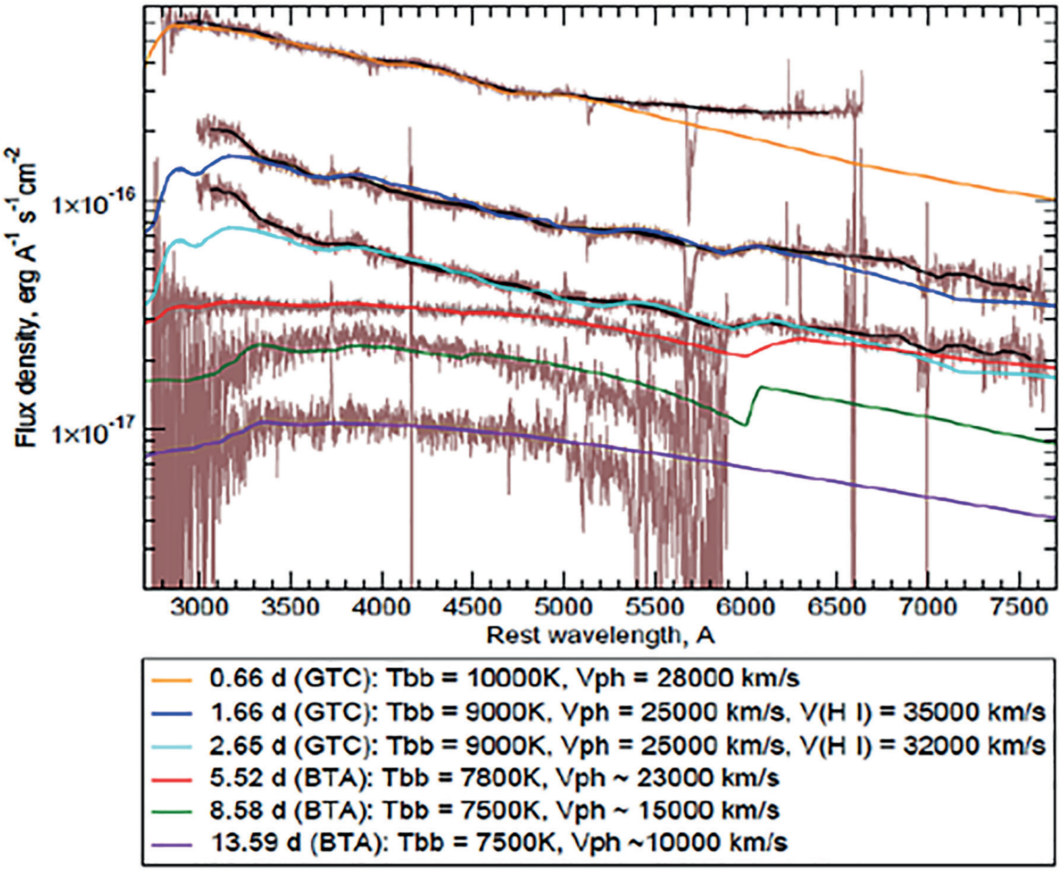

Fig 9. Multiepoch optical spectroscopy for GRB 130427A (z = 0.340) obtained at both the BTA and GTC, showing the velocity of the ejecta as a function of time.

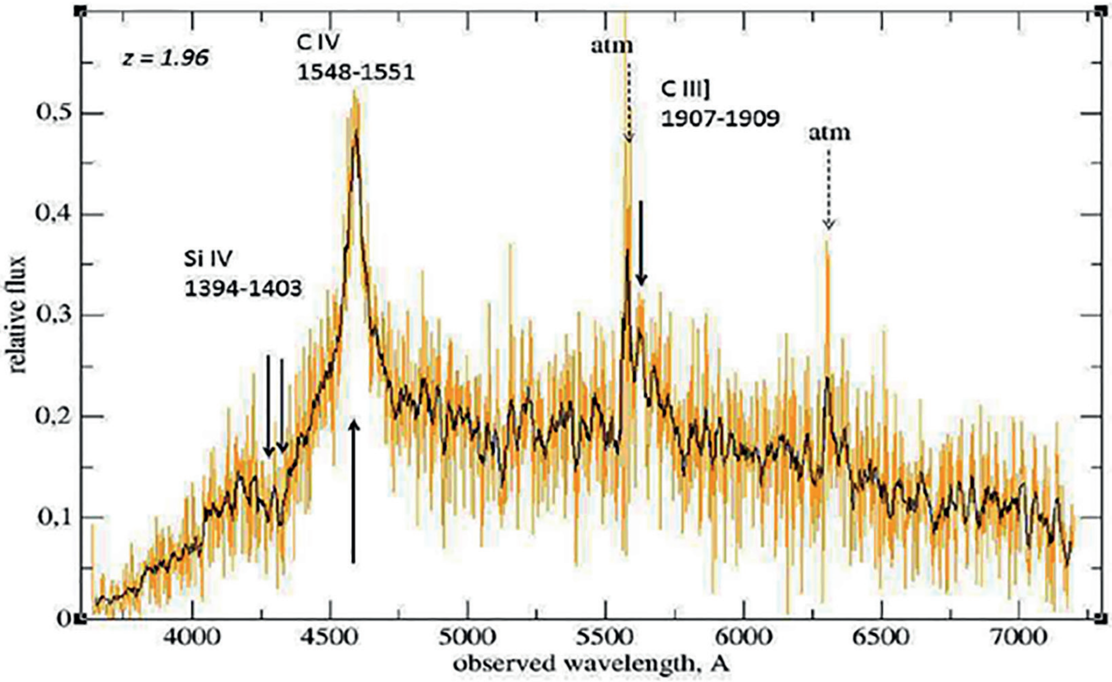

Fig 10. The BTA spectrum of the new quasar discovered in the GRB 140606A error box showing the typical emission lines at a redshift z = 1.96. Adapted from [18].

5. Conclusion

We discuss two historical afterglows (GRB 920723 and 920925C) prior to the Afterglow Era that started in 1997.

Afterglow emission can be detected in all the electromagnetic range (especially for long-duration events), in all timescales from seconds to months (the later in some cases). A variety of features can be studied by different techniques (photometry, spectroscopy, polarimetry) to gain insight into the progenitors, environments, abundances, metallicities, host galaxies... Multi-messenger information is also highly valuable, in the light of the recent detections of gravitational waves associated with the short-duration GRB 170817 (see [19] and references therein).

Automated and Robotic telescopes (such as the BOOTES Global Network) are very useful to study the early phases starting seconds after the trigger. This can be later completed by large diameter telescopes in the optical (e.g. 6.0-meter BTA, 10.4-meter GTC).

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