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A survey for GRB orphan afterglows(*)

A. Rau and J. Greiner
Max-Planck Institut für Extraterrestrische Physik - 85741 Garching, Germany

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Summary. — Gamma-ray bursts are believed to be produced in highly-relativistic collimated outflows. Support for this comes among others from the association of the times of detected breaks in the decay of afterglow light curves with the collimation angle of the jets. An alternative approach to estimate a limit on the collimation angle uses GRB afterglows without detected prompt-emission counterparts. Here we report on the analysis of a dedicated survey for the search of these orphan afterglows using the Wide Field Imager at the 2.2 m telescope at La Silla, Chile.

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PACS 95.85.Kr – Astronomical observations. Visible (390–750 nm).
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1. – Introduction

Soon after the discovery of the first optical transients associated with gamma-ray bursts, identification of afterglows without observed high-energy prompt emission was recognized as a powerful tool to test the collimation of the gamma-ray burst outflow [1]. It is now widely accepted that the enormous apparent energy release and the temporal behavior of GRBs require collimated highly relativistic outflows. This conical geometry manifests itself among others in the break in the power law decay of the afterglow emission. Jet opening angles derived from the break times in radio afterglows vary from 1° to 25° with a strong concentration near 4° [2]. The collimation implies that the GRB rate in the Universe is significantly higher than the actual rate of detections of burst prompt-emissions.

If a GRB is observed far enough from the jet axis, no γ-rays will be visible by the observer. Nevertheless, the afterglow emission, which is thought to be less collimated, as the Lorenz factor of the ejecta decreases with time, can still be detected. The properties of these *orphan afterglows* should be similar to that of on-axis afterglows observed after

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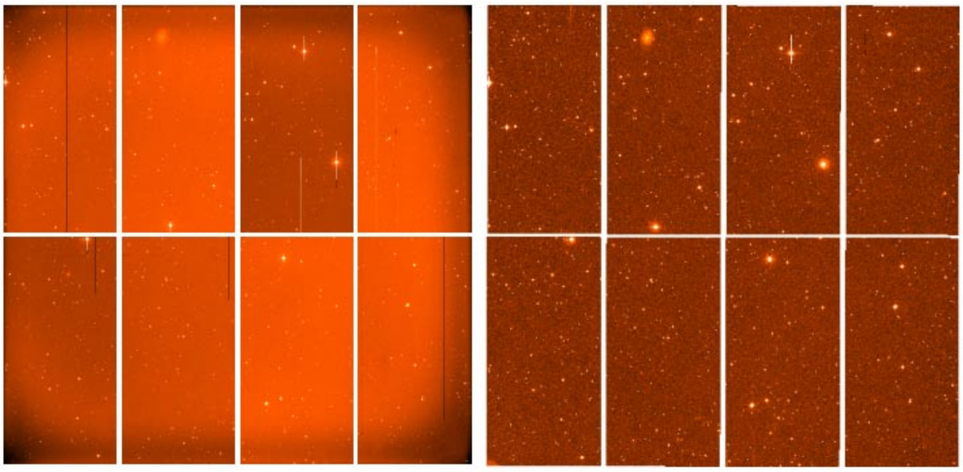

Fig. 1. – *Left:* Raw WFI image of a subset of the MITT field. Each mosaic consists of eight 2142×4128 pixel CCDs with a pixel scale of $0.283''$ giving a total $34' \times 33'$ field of view. *Right:* Reduced image of the same field after pipeline processing

the break in the light curve [3]. Here, we present preliminary results of the analysis of a dedicated R-band survey for such GRB orphan afterglow candidates.

2. – Observations and data reduction

From May to October 1999 an R-band survey for GRB orphan afterglows was performed using the Wide Field Imager (WFI) at the 2.2 m telescope at La Silla, Chile. The WFI consists of a mosaic of 4×2 CCDs with a field of view of $34' \times 33'$ (fig. 1). 10 different fields on the sky, covering a total of ~ 13 square degrees, were monitored in up to 28 nights each (table I). The observations were scheduled in three periods in May-June, August & September-October. In each of these time intervals photometry was taken at least every second night. Unfortunately, weather constraints allowed only a completion of the survey of roughly 75%. The performed observational strategy would have made possible the detection of a typically decaying GRB afterglow candidate in at least two consecutive observations. Images taken at later or earlier periods could be used to identify recurring transient objects. Images were taken in the R-band with some additional observations in V and I for a possible identification of non-GRB related transient sources from their photometric colors. The exposure times were 7 min per pointing.

Standard image reduction (bias subtraction, flatfielding) was done using a pipeline based on IRAF/MSDEX. Flatfields were constructed from sky observations of the individual nights. Instrumental point-spread-function photometry was performed within IRAF/DAOPHOT and for the astrometric solutions WIFIX/ASTROMETRIX [4] was implemented in the reduction pipeline. At average seeing ($1.4''$) all sources brighter than $R \sim 15$ are saturated in the images and a limiting magnitude of $R \sim 22.5$ is reached. This allows to catch a typical GRB afterglow which fades below this limiting magnitude after 2 to 10 days [5] corresponding to typical 2–3 observations.

In order to obtain variability information for all objects detected in the data we applied the differential photometry technique. For this an ensemble of at least 20 local, non-saturated, non-variable reference stars was selected for each individual field. From these stars the average offset of the instrumental magnitude of each pointing was calcu-

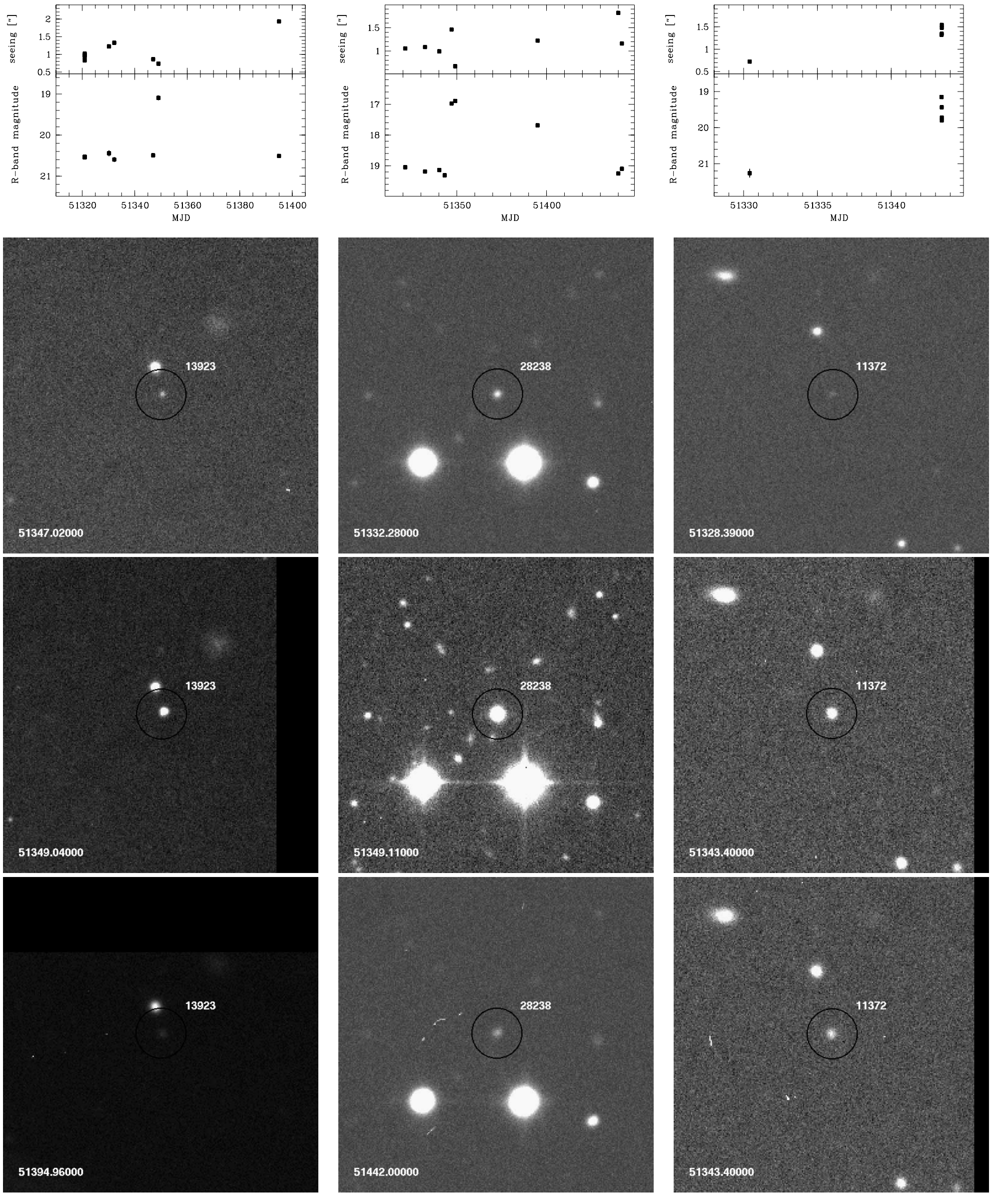

Fig. 2. – Light curve and seeing evolution together with images for three transient source candidates (not included in the SIMBAD database). *Left:* The magnitude of the object (RA = 13:28:13.7, DEC = − 21:42:37) increased by ∼ 1.5 mag within 2 days. Observations ∼ 50 days later showed that the source had decayed again to its former brightness. This is typical for a flare star. *Middle:* The source (RA = 16:19:53.3, DEC = + 3:19:09) exhibits a rapid brightening by > 2 mag followed by a shallow decay over ∼ 100 days typically for a dwarf nova. *Right:* At the position of the candidate (RA = 21:54:06.6, DEC = − 27:42:26) a faint, possibly extended, object is detected at early epochs. This source has brightened at MJD = 51343.41 by ∼ 2 mag and exhibited a rapid decay (∼ 1 mag in 30 min). Lacking a later observation a distinction between *e.g.* a possible orphan afterglow or a flare star remains difficult.

TABLE I. – *Observation log.*

Field	RA(2000)	DEC(2000)	Size (RA × DEC)	# of nights
1	01 32 31.2	−43 11 42	$68' \times 66'$	16
2	03 33 40.2	−27 37 30	$68' \times 66'$	12
3	13 28 00.0	−21 40 00	136'$\times 66'$	11
4	14 29 42.9	−62 40 46	$68' \times 33'$	14
5	16 20 00.0	+04 00 00	$68' \times 132'$	16
6	18 49 07.5	−03 20 30	$68' \times 99'$	23
7	19 25 31.8	+02 47 40	$68' \times 33'$	21
8	21 26 20.4	−43 22 15	$68' \times 132'$	26
9	21 41 30.0	+00 30 00	$68' \times 33'$	28
10	21 52 07.4	−27 31 50	$68' \times 66'$	22

lated in respect to a reference image (normally the one with the best seeing) of the same field. In that way, all pointings of all individual fields were normalized to one instrumental magnitude system. Then, candidate transient objects were selected based on the deviation of their differential light curve from their mean differential light curve. The absolute photometric zero-point was estimated based on observations of the standard star field SA113 in nearly every night.

3. – Candidate transient objects

By now three fields ($\sim$ 6 square degrees) have been processed and for each field a catalogue with all detected sources and differential light curves was compiled. A transient search revealed several promising sources of which three examples are shown in fig. 2. The identification of the nature of these sources appears difficult at this stage of the analysis but two of the shown candidate transients are certainly not of an orphan afterglow nature and may be connected with a flare star (left panel) and a nova (middle panel). The third (right panel) candidate exhibits a rapid decay of $\sim 1\,\mathrm{mag}$ over 30 min. This is similar to an early afterglow phase but also consistent with a flare star.

Applying the typical observed GRB rate of 1 per day and the range for collimation angles given above we expect the number of detectable orphan afterglows in our survey will be of order 1. Thus, it is not at all surprising that no clear candidate has been detected at this early stage of the analysis. Nevertheless, there exists evidence that the burst energy is approximately independent of the collimation [2]. In that case, even if no orphan afterglow will be detected at the end of the survey, a limit on the collimation angle of the outflow can be estimated. However, orphan afterglows may also resemble failed burst, whose ejecta have a baryon loading which is too high to produce a GRB. Nevertheless, [6] showed that both phenomena should exhibit light curve shapes which should be distinguishable in our survey.

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