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A novel method for identifying Fast Optical Transients on astronomical archival plates(*)

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Summary. — We report on a novel method to identify brief optical transients (OTs) on astronomical archival photographic plates. This method does not require identification of all objects and their comparison with the catalogue, but rely solely on the information included in the particular plate itself.

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1. – Introduction

Independent optical searches for prompt and afterglow emission of Gamma-Ray Bursts (GRBs) do not require newly taken data—there is no reason to expect that these phenomena were absent or less frequent in the past. There are nearly 3 millions astronomical archival plates located at different observatories [1]. Some of the archives have very high-quality plates achieving limiting magnitudes of up to 20–23 (direct imaging) and/or 17–19 (spectral with objective prism). These plates represent a unique database for various scientific projects including GRB analyses.

2. – Orphan afterglows and optical surveys

Orphan afterglow is an optical afterglow of a GRB without detectable gamma ray emission (due to different beaming). The orphan afterglows are predicted by theory (*e.g.* [9, 10]). The rate of Orphan Optical Afterglows (OOAs) may exceeds the GRB rate, hence the improved GRB statistics is expected with numerous consequences such

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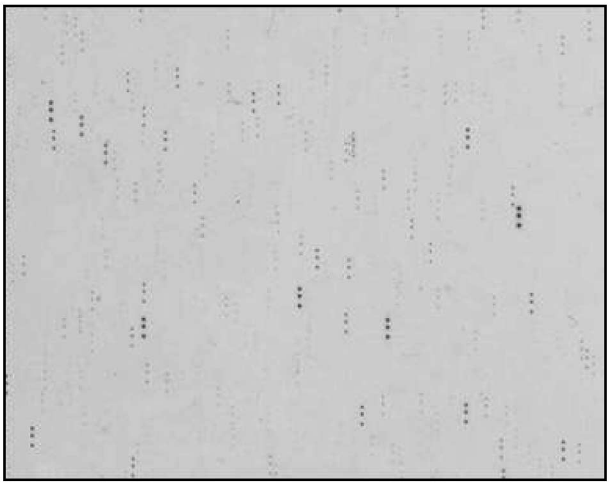

Fig. 1. – The digitised plate (small part) with multiple star images used to test the algorithms described in this paper. ROB astronomical plate collection, binned data.

as improved statistics of host galaxies, redshift distribution, cosmological conclusions, etc. So far, no optical orphan afterglow has been confirmed, despite of dedicated efforts (*e.g.* [7, 8]). However, this does not necessarily mean that such triggers do not exist, since there are severe technical problems related to the searches for brief OTs. Moreover, a non-negligible background of various phenomena imitating the genuine astrophysical OTs exists [2-4]. We need novel, effective, and reliable methods to identify and to verify these objects.

The optical surveys may provide a larger sample (due to different beaming) and better localization accuracy (1 arcmin or better) than gamma ray satellite detectors provide. The larger sample of OAs and, consequently, their host galaxies may be crucial for understanding the nature of GRBs as well as for related cosmological implications. The actual rate of OAs can place constraints on the afterglow appearance fraction and, perhaps, the initial beaming angle of GRB sources. The optical flashes preceding GRB expected by theory [6] can be detected and analysed. And moreover, the optical surveys are cost-effective, if compared with satellite-based methods.

3. – The application of multiple-exposure plates in OT searches

If we search for optical prompt emission (including orphans) from GRBs, we need to look for short-living transient phenomena lasting minutes or less, analogous to the event observed for the GRB990123 [5]. However, on long-exposed deep images and plates, it is very difficult to look for brief transients, since the OT image is hidden by typically tens to hundreds of thousands stellar images with similar appearance. The methods of comparing plates and/or comparison with catalogues is still not very effective and reliable. Here we propose a novel method using multiply exposed astronomical plates and based solely on the information recorded in the plate itself. Such plates are available and are relatively numerous in various sky plate archives, *e.g.* at the Royal Observatory Brussels. These plates contain several (typically 2 to 10) identical star field images on the same plate. This means, each star inside the FOV of the telescope, is represented

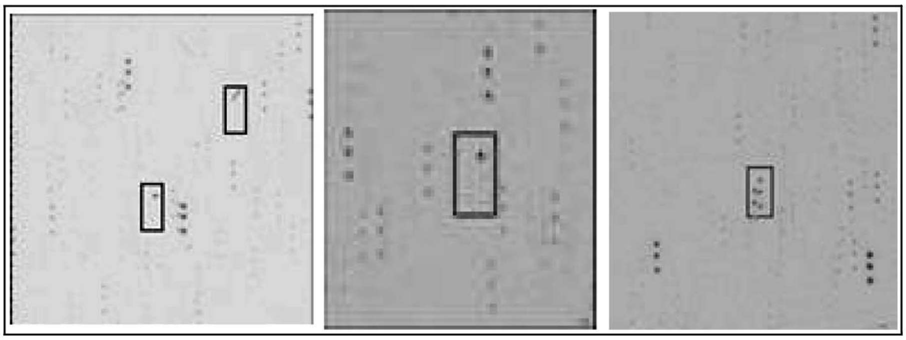

Fig. 2. – *Left:* Examples of fast optical transient with duration less or equal to the first exposure on the plate (left), and of moving object (right, probably asteroid) detected by the algorithms described in this paper. *Middle:* Example of fast transient with duration less or equal to the first exposure on the plate detected by the algorithms described in this paper. *Right:* Example of fast transient with duration more than the first exposure on the plate but less than the total exposure of the plate detected by the algorithms described in this paper. While this OT as well as those indicated in the left and middle image are easily detectable on multiply exposed plates, their identification on normal direct images is much more difficult since the objects appearance is analogous to those of tens of thousands of normal star images on the plates. ROB astronomical plate collection, binned data.

several times. Such plates have been obtained by multiple exposures on the same plate with tiny shifts between the exposures. It is difficult to find transient objects on these plates by classical methods. However, using digitisation, dedicated novel algorithms and software programs, and powerful computers, it is relatively easy, effective and reliable to identify the OT candidates.

4. – The algorithm and software development

So far, the data recorded on archival plates were accessible only by special, and mostly time-consuming and laborious, procedures. The recent wide digitisation of plate collections offers significantly easier access by computers. However, there is still a gap between the digitised archive and the scientific use and application. Special software is required to fill this gap. We have developed new algorithms to access data on digitised plates and we have tested these techniques in trial sets of digitised plates taken by the ESO 50 cm Schmidt GPO camera ($f = 4\,\mathrm{m}$, size $16 \times 16\,\mathrm{cm}$, $1\,\mathrm{mm} = 51.070\,\mathrm{arcs}$) from the Royal Brussels Observatory (ROB) astronomical plate archive. The novel program is able to detect astrophysical transients on digitised photographic plates. Here we present and discuss few examples. Figure 1 shows a small part of the digitised plate with multiple star exposures used to test the novel approach (ROB plate collection). In fig. 2, two typical examples of optical transients found are indicated. The first one (left object on the left image) is a typical example of fast transient with duration less or equal to the duration of the first star field image (*i.e.* typically few minutes). Such short events are expected for prompt optical emission of GRBs, in analogy to the OT of GRB990123 [5]. The second one (right object on the left image) is a moving object, probably an asteroid. Another fast OT of analogous duration category is the object indicated in the middle image, while the object indicated on the right image represents a transient of slightly (by a few minutes) longer duration (more than the first exposure on the plate but less than the total exposure of the plate). The tiny differences between the image centers of images representing the same star can be used to constrain the time of the OT occurrence as well as to identify the right object position. The PSF can be used to confirm the OTs represented by only one image, *i.e.* comparing profiles of object and other normal star images. However, our experience from extended analyses on astronomical emulsions shows that, although a majority of plate faults can be eliminated this way, there is still a small fraction of emulsion defects which are star-like and other additional procedures such as transmitted light microscopy analysis (on original plate) must be applied in order to confirm the object as of genuine astrophysical origin [2-4]. For the OTs represented by 2 or more images, one can be sure that they cannot be caused by plate faults, albeit some probability still remains that the objects may belong to some sort of background phenomena [2].

5. – Discussion

The first results of the application of the novel algorithm and corresponding software program on multiply exposed plates are promising. Recently, the program identifies objects showing deviations with respect to normal (constant) star images, with emphasis on deviations in duration. Then the human inspection is required to discard the obvious defects among the objects indicated. This is however easy and fast, nevertheless we plan further improvements allowing more complex automated analyses. Typically, only 1 OT candidate remains after the procedure for 1 plate. The examples shown are for binned plates (1 from 4 pixels read out) to accelerate the computing process. The final program will use non-binned data. Recently, we focussed on fields outside the galactic plane to avoid crowded fields. This is not in contrast with the uniform distribution of GRBs since the galactic region represents only $\sim 20\,\%$ of the sky.

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