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ESA Gaia, ultra-low dispersion spectroscopy and GRBs

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Abstract. The ESA satellite Gaia to be launched in 2013 will focus on precise astrometry of stars down to magnitude 20. The satellite will also provide photometric and spectral information for various branches of astrophysics including GRB science. The strength of Gaia in such analyzes is the fine spectral resolution (spectro-photometry and ultra-low dispersion spectroscopy) The possibilities to detect and to analyze optical transients and optical afterglows of GRBs by Gaia, both based on photometry as well as spectrophotometry and low-dispersion spectroscopy, are discussed.

Key words. Gamma-Ray Bursts – Satellites: Gaia – Low-dispersion spectra

1. Introduction

Gaia is a global space astrometry mission. Its goal is to make the largest, most precise three-dimensional map of our Galaxy by surveying an unprecedented number of stars – more than a thousand million. Gaia will monitor each of its target stars about 70 times over a five-year period. It will precisely chart their positions, distances, movements, and changes in brightness.

To study the optical counterparts of gamma-ray bursts (GRBs), there will be several advantages provided by Gaia. First, this will be a deep limiting magnitude of 20 mag (Jordi & Carrasco 2007), much deeper than most of the previous global surveys. The most important benefit of Gaia for these studies will be the color (spectral) resolution thanks to the low-resolution (prism) Gaia photometer. The use of the dispersive element (prism) in Gaia BP/RP photometers generates ultra-low dispersion spectra. One disperser called BP for Blue Photometer operates in the wavelength range of 330–660 nm; the other one called RP for Red Photometer covers the wavelength range of 650–1000 nm. The dispersion is higher at short wavelengths, and ranges from 4 to 32 nm/pixel for BP and from 7 to 15 nm/pixel for RP (Perryman et al. 2006). This will allow some detailed studies involving analysis of the color and spectral changes not possible before. The details of studies of the optical counterparts of high-energy sources are described in detail in the dedicated sub-workpackages within the workpackage Specific objects studies within the Gaia CU7 (Hudec & Šimon 2007a,b). The main objective is the investigation of optical counterparts of high-energy

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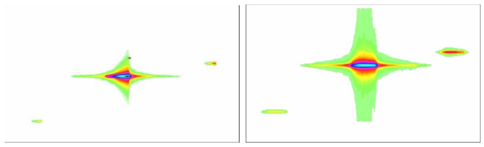

Fig. 1. BP (left) and BR (right) images simulated by the GIBIS simulator, the same sky field.

astrophysical sources (including optical transients (OTs) and optical afterglows (OAs) related to X-ray flashes and GRBs).

2. Ultra-low dispersion spectroscopy with Gaia

The Gaia instrument consists of two low-resolution fused-silica prisms dispersing all the light entering the field of view (FOV). Two CCD strips are dedicated to photometry, one for BP and one for RP. Both strips cover the full astrometric FOV in the across-scan direction. CCDs have 4500 (for BP) or 2900 (for RP) TDI lines and 1966 pixel columns (10×30 micron pixels). The spectral resolution is a function of wavelength as a result of the natural dispersion curve of fused silica. The BP and RP dispersers have been designed in such a way that BP and RP spectra have similar sizes (on the order of 30 pixels along scan) (Perryman et al. 2006). The obtained images can be simulated by the GIBIS simulator (see Fig. 1).

The algorithms for automated analyzes of digitized spectral plates are developed by informatics students (Hudec 2007). The main goals are as follows: an automated classification of spectral types, searches for the spectral variability (both the continuum and lines), searches for the objects with specific spectra, correlation of the spectral and light changes, searches for transients, and application to Gaia. The archival spectral plates taken with the objective prism offer the possibility to simulate the Gaia low-dispersion spectra and related procedures.

3. GRBs with Gaia

In addition to the long-term photometry, the most important benefit of Gaia for the studies of GRB sources will be the fine color resolution. This means that the optical counterparts of GRBs, namely OTs and OAs, can be detected and analyzed by the Gaia instruments.

3.1. GRB photometry with Gaia

There will be a variety of OTs of various origin which might be detected by Gaia. The real OTs and OAs of GRBs can be, among these, recognized according to their characteristic power-law fading profile. However, the sampling provided by Gaia is not optimal, hence only rarely we can expect detection (and reliable conformation) of OT of GRB based only on this type of data.

3.2. GRB spectrophotometry with Gaia

Despite a low dispersion, the major strength of Gaia for many scientific fields will be the fine spectrophotometry, as the low-dispersion spectra may be transferred to numerous well-defined color filters. As an example, OAs of GRBs are known to exhibit quite specific color indices, distinguishing them from other types of astrophysical objects (Šimon et al. 2001, 2004a,b), hence a reliable classification of OTs will be possible using this method (see also Fig. 2).

3.3. Proposed strategy for observing of OAs with Gaia

Most OAs form an ensemble with very similar color indices, largely independent of the phase of the decaying brightness in the curve for the initial 10 days after GRB and for redshift $z < 3.5$. OAs with duration about 10–20 days are likely to be detected by Gaia during its scans even without rapid pointing at the GRB position. OA can be recognized according to several features even without information on the time profile: unique color indices, rapid rise (new object between two scans), and host galaxy at the position of OA detected by ground-based observations later. Even search for orphan afterglows will be possible (they are objects predicted by theory, due to the jet orientation only the optical emission is observed (gamma-rays are not observable)). Colors of the ensemble of OAs vs. redshift are shown in Fig. 3.

3.4. Effect of the Lyman break

There is a possible use of the color information provided by the Gaia BP/RP photometers to derive "photometric redshifts" of GRBs. The effect of the Lyman break for GRBs at large redshifts on colors of OAs of GRBs is displayed in Fig. 3.

3.5. Low-dispersion spectra and redshift estimation

Part of Gaia data will be delivered as ultra-low dispersion spectra (BP/RP). The most important application of these Gaia spectra for GRB science is the possibility of the redshift estimation for distant objects. We propose the Lyman break to be used to measure the redshift, analogously to GRB 090423. The Italian 3.5 m TNG Telescope Amici Prism low-dispersion spectrum of the near-infrared GRB afterglow (Salvaterra et al. 2009) confirmed that even very low-resolution spectrum can provide valuable results for GRB science. This is the idea of the proposed JANUS satellite, covering the spectral range of 0.7–1.7 microns (Gaia RP covers 0.65–1.0 microns). Digitized plate surveys can be used, too, as some were taken in the red and near-IR regions.

Prospects of low-dispersion spectra with Gaia RP/BP for GRBs are as follows:

- Unique chance to provide early or simultaneous spectra for GRBs (so far spectra mostly late)
- Unique chance to provide spectra of OTs (prompt emission) of GRBs, not only OAs
- Chance to recognize/classify OAs and OTs of GRBs using the spectral and/or color information
- Chance to detect/study orphan OAs of GRBs
- Study of possible spectral time changes/evolution
- Chance of a redshift estimation up to $z \sim 7$ by the method of the Lyman break.

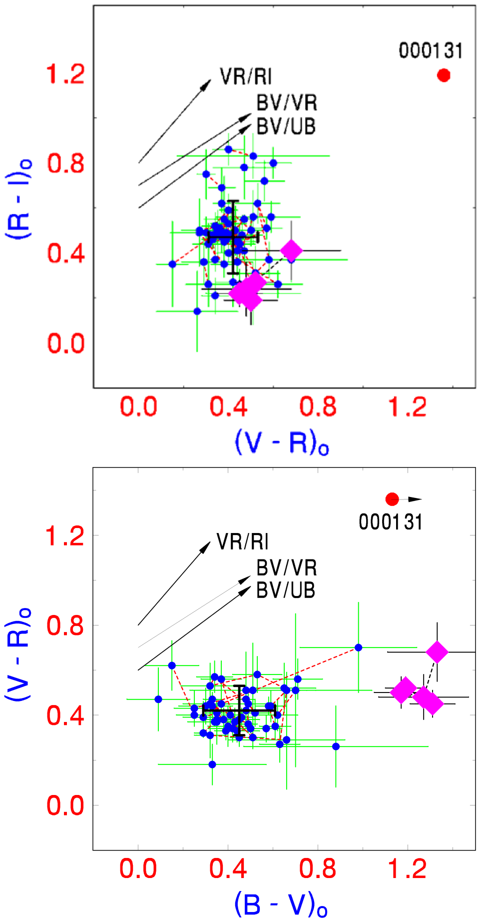

Fig. 2. Color-color diagrams of OAs ($0.17 < z < 3.5$) ($t - T_0 < 10.2$ days), corrected for the Galactic reddening. The large cross represents the mean colors (centroid) of the ensemble with $z < 3.5$. An increasing effect of the Lyman break is observed for $z > 3.5$ (GRB 050502A (pink diamonds, $z = 3.793$) and GRB 000131 ($z = 4.5$)). The shifts of GRB 050502A caused by the Lyman break are different from those expected for the case of interstellar reddening (compare with the vectors).

4. Conclusions

The ESA Gaia satellite will contribute to scientific investigations of GRBs not only by pro-

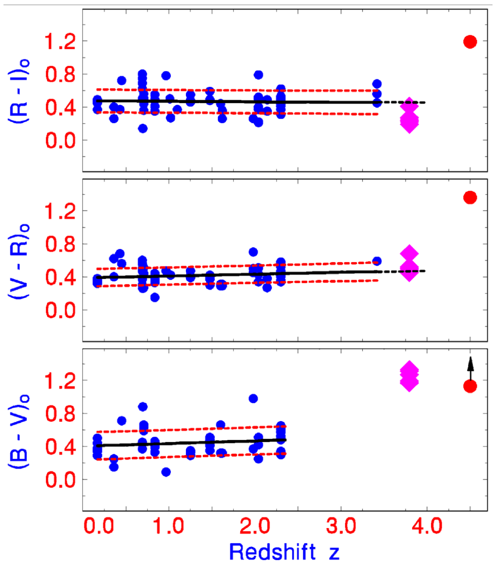

Fig. 3. Colors of the ensemble of OAs vs. redshift z ($t - T_0 < 10.2$ days). Notice the increasing effect of the Lyman break for $z > 3.5$.

viding long-term photometry but also by use of ultra-low dispersion spectra provided by BP and RP photometers. Gaia will give us unique chance to obtain early or simultaneous low-dispersion spectra for GRBs (so far these spectra were mostly for the late epochs), and, in particular, chance to provide low-dispersion spectra of OTs (prompt emission) of GRBs, not only OAs. Gaia will give a chance to recognize/classify OAs and OTs of GRBs using low-dispersion spectra and/or color information including a chance to detect/study orphan OAs of GRBs. Study of possible spectral time changes/evolution will be also possible with Gaia BP/RP data. Gaia RP can yield redshift estimation up to $z \sim 7$.

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