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GRB INVESTIGATIONS BY ESA GAIA AND LOFT

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Abstract. The possibility of studying GRBs with the ESA Gaia and LOFT missions is briefly addressed. The ESA Gaia satellite to be launched in November 2013 will focus on high precision astrometry of stars and all objects down to limiting magnitude 20. The satellite will also provide photometric and spectral information and hence important inputs for various branches of astrophysics, including the study of GRBs and related optical afterglows (OAs) and optical transients (OTs). The strength of Gaia in GRB analyses will be the fine spectral resolution (spectro-photometry and ultra-low dispersion spectroscopy), which will allow the correct classication of related triggers. An interesting feature of Gaia BP and RP instruments will be the study of highly redshifted triggers. Similarly, the low dispersion spectroscopy provided by various plate surveys can also supply valuable data for investigations of high-energy sources. The ESA LOFT candidate mission, now in the assessment study phase, will also be able to detect and be used in the study of GRBs, with emphasis on low-energy (X-ray) emission.

Keywords: gamma ray bursts, satellites: Gaia, spectroscopy: low-dispersion spectra, LOFT.

1. Introduction

This paper briefly discusses the potential of the ESA Gaia and LOFT missions for studying gamma-ray Bursts (GRBs). The Gaia mission will chart a three-dimensional map of our Galaxy, the Milky Way, in the process revealing its composition, formation and evolution. The satellite is expected to provide unprecedented positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars in our Galaxy and throughout the Local Group. Combined with astrophysical information for each star, provided by on-board multi-color photometry/low-dispersion spectroscopy, these data will have the precision necessary to quantify the early formation, and the subsequent dynamical, chemical and star formation evolution of the Galaxy [6].

Gaia will provide several advantages for studies of the optical counterparts of gamma-ray bursts (GRBs). First, it will have a deep limiting magnitude of 20 mag [5], much deeper than most previous studies and global surveys. Secondly, the time period covered by Gaia observations, i.e. 5 years, will also allow some studies requiring long-term monitoring, recently provided mostly by astronomical plate archives and by small or magnitude-limited sky CCD surveys. But perhaps the most important benefit of Gaia for these studies will be the color (spectral) resolution thanks to the low-resolution (prism) Gaia photometer. This will allow some detailed studies involving analyses of the color and spectral changes that were not possible before. The studies of the optical counterparts of high-energy sources are described in detail in the dedicated sub-workpackages within the Specific objects studies workpackage within Gaia CU7 [3, 4]. The main objective is to investigate the optical counterparts of high-energy astrophysical sources including high-mass X-ray binaries, low-mass X-ray binaries, X-ray transients, X-ray novae, microquasars, optical transients (OTs) and optical afterglows (OAs) related to X-ray flashes and GRBs, etc.

We put emphasis on the photometric mode RP/BP, and its potential use for analyses of optical counterparts of GRBs. The use of the dispersive element (prism) generates ultra-low dispersion spectra. One disperser called BP (Blue Photometer), operates in the wavelength range of $330 \div 660$ nm; the other disperser called RP (Red Photometer), covers the wavelength range of $650 \div 1000$ 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.

The ESA LOFT satellite, now in the assessment phase, will also have a potential for GRB investigations, with emphasis on their X-ray emission, as briefly discussed below.

2. Gaia and GRBs: Photometry

OTs and OAs of GRBs display characteristic light curves. These events usually reach their peak optical luminosity in the initial phase, shortly (several minutes) after the gamma-ray emission, which typically lasts from a fraction of the second to several minutes. In the later, much longer phase, which can last for several (even more than 10) days, OAs usually display a characteristic power-law fading profile. A sequence of observations mapping this OA light curve is therefore necessary. According to Zhang [13], most OAs are fainter than about 18 mag already about 1 day after the GRB, although some of them can even be brighter than 14 mag in the early phase. Gaia is therefore definitely able to detect these OAs in their early phase. However, the sampling provided by Gaia is not optimal, so we can only rarely expect OA of GRB to be detected only on the basis of this type of data. Additional data can be provided by ground-based robotic telescopes (Supplementary SOS Observations WP in Gaia CU7). We will show that the low-dispersion spectroscopy provided by Gaia will be very helpful in identifying of new sources as OAs, even without available GRB detection.

3. Gaia and GRBs: spectrophotometry/low-dispersion spectroscopy

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. All BP and RP CCDs are operated in TDI (time-delayed integration) mode. 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 the BP and RP spectra have similar sizes (of the order of 30 pixels along the scan). BP and RP spectra will be binned on-chip in the across-scan direction; no along-scan binning is foreseen. RP and BP will be able to reach object densities in the sky of at least 750 000 objects deg^{-2}. The obtained images can be simulated by the GIBIS simulator (Fig. 1).

Despite the 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. We have shown previously [11, 12] that the individual OAs of GRBs display quite specific and remarkably similar color indices, with negligible changes during the first several days after the GRB (an example of such a color-color diagram is shown in Fig. 2). This feature is important for distinguishing OAs from other types of astrophysical objects. This suggests that although OAs possess a large range of redshifts z, they display very similar spectra in the observer frame for $z < 3.5$. This gives us a chance to resolve whether an optical event is related to a GRB even without available gamma-ray detection. It will be possible to classify optical transients using this method. This also means that it will be possible to classify OAs of GRBs in one photometric shot.

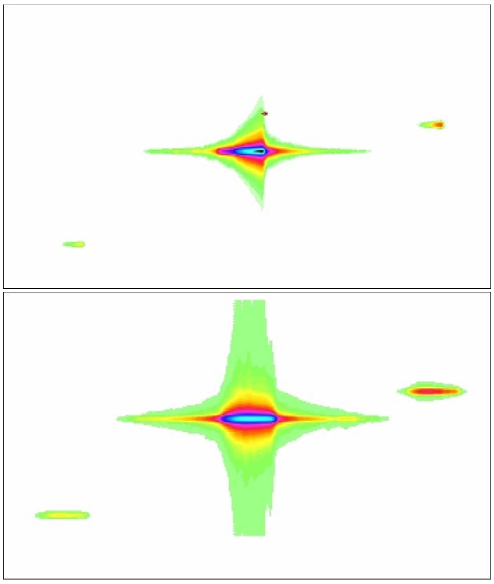

Figure 1. BP (top) and BR (bottom) images simulated by the GIBIS simulator, the same sky field.

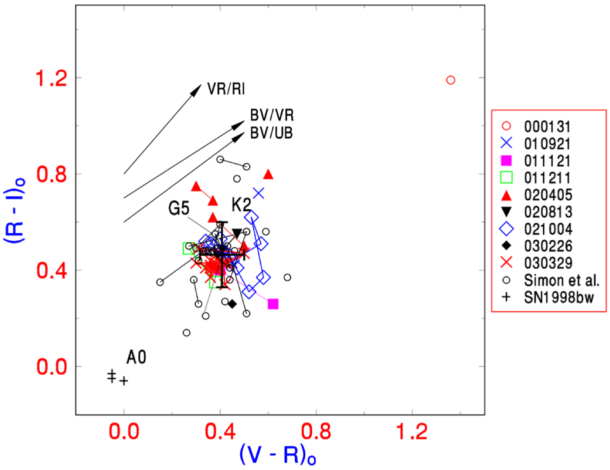

Figure 2. Example of the color–color diagram of OAs of long GRBs. The data for the time interval < 10.2 d after the burst in the observer frame and corrected for the Galactic reddening are displayed. Multiple indices of the same OA are connected by lines for convenience. The mean colors (centroid) of the whole ensemble of OAs (except for GRB 000131 and SN 1998bw) are marked by the large cross. The representative reddening paths for $E_{B-V} = 0.5$ mag and the positions of the main-sequence stars are also shown. Adapted from [11, 12].

4. Low-dispersion spectral databases

Before Gaia, low dispersion spectra were frequently taken in the 20th century by various photographic telescopes with objective prisms. The motivation of plate survey low-dispersion spectral studies is as follows: (1) compare the simulated Gaia BP/RP images with images obtained from digitized Schmidt spectral plates (both using dispersive elements) for selected test fields, and (2) study the feasibility of applying the algorithms developed for the plates for Gaia.

The dispersion is an important parameter: (1) Gaia BP: $4 \div 32$ nm/pixel, i.e. $400 \div 3200$ nm/mm, 9 nm/pixel, i.e. 900 nm/mm at Hγ, RP: $7 \div 15$ nm/pixel, i.e. $700 \div 1500$ nm/mm. PSF FWHM ~ 2 px, i.e. spectral resolution is ~ 18 nm, (2) Schmidt Sonneberg plates (typical mean value): the dispersion for the 7 deg prism 10 nm/mm at Hγ, and 23 nm/mm at Hγ for the 3 deg prism. The scan resolution is 0.02 mm/px, thus about 0.2 and 0.5 nm/px, respectively, (3) Bolivia Expedition plates: 9 nm/mm, with calibration spectrum, (4) Hamburg QSO Survey: 1.7 deg prism, 139 nm/mm at Hγ, spectral resolution of 4.5 nm at Hγ, (5) Byurakan Survey: 1.5 deg prism, 180 nm/mm at Hγ, resolution 5 nm at Hγ.

It emerges that the Gaia BP/RP dispersion is ~ 5 to 10 times less than a typical digitized spectral prism plate, and the spectral resolution ~ 3 to 4 times less. Note that for the plates the spectral resolution is seeing-limited, hence the values represent the best values. It is only ~ 2 times less on the plates affected by bad seeing.

5. Gaia and GRBs: proposed strategy and detection rate

As the duration of most OAs is about 10–20 days in the observer frame, they are likely to be detected by Gaia during its scans even without rapid pointing at the GRB position. However, this assumes that they will occur in the FOV of the Gaia telescopes.

As already indicated, the OA can be recognized from several features, even without information on the time profile. The following features appear to be important: (1) unique color indices, (2) rapid rise (a new object appears between two scans), (3) host galaxy of the GRB at the position of OA – this galaxy can be detected later by ground-based observations.

It should be noted that even a search for so-called orphan afterglows will be possible with Gaia. A missing gamma-ray emission, with only an OA remaining, can also suggest this important event. Gamma-ray emission from many GRBs remains unobservable because the jet is not pointing towards the observer, but the late-time OA is less beamed and can reach us [8, 10]. Failed GRBs can also contribute to the population of orphan afterglows [1].

The estimated Gaia detection rate for OAs of GRBs, including orphans, is expected to be up to ~ 100 in the whole lifetime of Gaia (5 years). This low rate is due to the small FOV of the Gaia telescopes ($\sim 0.36\,\mathrm{deg}^2$ each). A higher detection rate is expected in the plate LDS surveys mentioned in this paper (due to a much larger FOV), in which analogous strategies (e.g. high-redshift triggers) can be applied.

6. Gaia LDS and highly redshifted Universe

The redshifted Lyman alpha line/break can be used to measure the value of z. This was e.g. the idea of the proposed JANUS Space Mission with a coverage range of $0.7 \div 1.7$ microns (Gaia RP has a coverage of $0.65 \div 1.0$ microns). GRBs are located at cosmological distances, often with $z > 0.5$ (e.g. [9]), and the Lyman break is shifted to the optical band for objects at z larger than about 3.5. This break manifests itself as a sharp decrease of the flux in the blue part of the spectrum. This feature is prominent in the smooth spectral profile of OA. This OA will therefore appear shifted from its true position because of the lack of its blue part of the spectrum. A comparison of the accurate position of the OA obtained by Gaia in astrometric mode with the blue edge of its spectrum can be used to resolve easily the objects occurring in our Galaxy from those located at cosmological distances. It will also be possible to determine z, and hence the distance necessary for determining its luminosity.

Digitized plate surveys can also be used for discovering and identifying OAs, especially those taken in the red-IR range (numerous surveys in these region have been made in the past for red objects, such as carbon stars).

7. ESA LOFT

The Large Observatory for X-ray Timing (LOFT) is a proposed ESA space mission to be launched around 2022, which will be devoted to the study of neutron stars, black holes and other compact objects by means of their very rapid X-ray variability [14]. The mission was submitted in the ESA Cosmic Vision M3 call for proposals, and was selected, together with three other missions, for the initial Assessment Phase. Two onboard experiments are proposed.

7.1. LOFT LAD and GRBs

The LAD (Large Area Detector) is a collimated pointed experiment, so it is very improbable that it will detect a GRB by chance. However, it can be used for GRB follow-up pointing at the GRB positions. The energy range ($2 \div 60$ keV) is consistent with X-ray afterglows of GRBs, and with X-ray flares. The obvious preference is for fine time resolution (5 µs) together with energy resolution (< 200 eV), expected to provide new insights into GRB physics, including spectroscopy (possible emission lines, etc.).

7.2. LOFT WFM and GRBs

The LOFT WFM (Wide Field Monitor) has a very large instantaneous field of view (> 3 sr), and also an unprecedented capability for detecting rare, short-lived, bright sources. The energy range of $2 \div 50$ keV is consistent with the range in which X-ray afterglows and X-ray prompt emission of GRBs, X-ray rich GRBs and X-ray flashes radiate. This offers a unique possibility to study very soft X-rays from these objects. WFM has moderate sensitivity (0.2 Crab for 1 s and 5σ detection) and energy resolution (< 200 eV). The instrument will localizate triggers (few arcmin accuracy). The soft X-ray coverage (~ 1 keV) will allow GRBs at very high z to be detected and investigated. Preliminary approximate expected rates are 150 GRBs and 30 XRFs/year.

8. Conclusions

The ESA Gaia satellite will contribute to scientific investigations of GRBs not only by providing long-term photometry but also by using the ultra-low dispersion spectra provided by BP and RP photometers. These data will present a new challenge for astrophysicists and for informatics in general. In the field of GRB study, the advantages of Gaia and LOFT can be briefly summarized as follows.

- Gaia: A unique opportunity to provide early or simultaneous LDS for GRBs (so far, LDS is mostly late)
- Gaia: An opportunity to recognize/classify OAs and OTs of GRBs using LDS and/or color information even in their later phases and without known GRB
- Gaia: An opportunity to detect/study orphan OAs of GRBs
- Gaia: An opportunity to estimate redshift up to ~ 7
- LOFT: WFM&LAD: Unique tools for detecting and studying GRBs, XRFs with emphasis on (soft) X-rays

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