Mem. S.A.It. Vol. 83, 342

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ESA Gaia & the multifrequency behavior of high-energy sources with ultra-low dispersion spectroscopy

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Abstract. We present and discuss the project related to the ESA satellite Gaia to be launched in 2013 with focus on the 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 study of high-energy sources. The strength of Gaia in such analyzes is the fine spectral resolution (spectro-photometry and ultra-low dispersion spectroscopy) which will allow the correct classication of related triggers. The low dispersion spectroscopy provided by various plate surveys can also provide valuable data for investigation of high-energy sources.

Key words. High-energy sources – Satellites: Gaia – Spectroscopy: low-dispersion spectra

1. Introduction

Gaia is an ambitious mission of European Space Agency (ESA) to chart a three-dimensional map of our Galaxy, the Milky Way, in the process revealing the composition, formation and evolution of the Galaxy. Gaia will 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. This amounts to about 1 per cent of the Galactic stellar population. 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 subsequent dynamical, chemical and star formation evolution of the Galaxy (Perryman 2005).

To study the optical counterparts of celestial high-energy sources, 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 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 small or magnitude-limited sky CCD surveys. But perhaps the most important benefit of

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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 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 astrophysical sources (including high-mass X-ray binaries, low-mass X-ray binaries, X-ray transients, X-ray novae, optical transients and optical afterglows (OAs) related to X-ray flashes and gamma-ray bursts, microquasars etc.).

In this paper we focus on the photometric mode RP/BP, and its use for analyzes of high-energy sources. The use of the dispersive element (prism) 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).

2. High-energy sources with Gaia

In addition to the long-term photometry, the most important benefit of Gaia for the studies of high-energy (HE) sources will be the fine color resolution. Most high-energy sources have also an optical emission, mostly variable and accessible by Gaia. The monitoring of this variable optical emission provides important input to understanding of the physics of the source. The investigations and analyzes of optical counterparts of high-energy sources based on the Gaia data also require complex analyzes with additional data. Specifically, for selected targets, multispectral analyzes using Gaia and other databases (such as the satellite X-ray and gamma-ray data, optical ground-based data etc.) may be feasible. They will deal with the long-term light changes and their evolution, especially active states, outbursts, and flares.

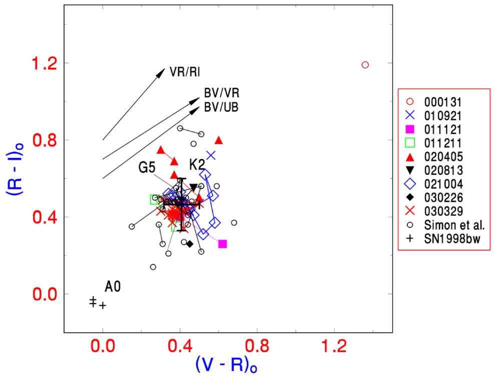

Fig. 1. Examples of the color diagrams of OAs of long GRBs. The data for the time interval < 10.2 d after the burst in the observer frame and corrected for the Galactic reddening are displayed. Multiple indices of the same OA are connected by lines for convenience. The mean colors (centroid) of the whole ensemble of OAs (except for GRB000131 and SN 1998bw) are marked by the large cross. The representative reddening paths for E_{B-V} = 0.5 mag and positions of the main-sequence stars are also shown. Adapted from Šimon et al. (2001, 2004a).

For the selected sources, dedicated complex analyzes will be undertaken, including spectrophotometry and investigation of the relation between the brightness and spectral/color index. This will enable a study and understanding of related physical processes. Also a statistics of the whole sample of objects will be made.

Examples of the color diagrams of OAs of GRBs are shown in Fig. 1, of microquasars in Fig. 2, and of supersoft X-ray binaries in Figs. 4 and 5.

3. Ultra-low dispersion spectroscopy with Gaia

Despite the low dispersion discussed above, 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

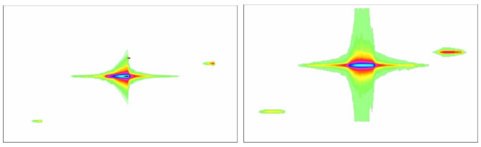

Fig. 2. BP (left) and BR (right) images simulated by the GIBIS simulator, the same sky field.

a reliable classification of optical transients will be possible using this method (see also Fig. 1). Colors of microquasars may serve as another example. The color-color diagram in Fig. 3 contains microquasars of various types: (1) system with the optical emission dominated by the high-mass donor – Cyg X-1, (2) persistent systems with the optical emission dominated by the steady-state accretion disk – SS433, Sco X-1, (3) transient low-mass systems in outburst with the optical emission dominated by the accretion disk – GRO J1655–40, XTE J1118+480 (the disk is close to steady-state in outburst), and (3) the high-mass system CI Cam on the decline from its 1999 outburst to quiescence. The systems plotted, irrespective of their types, display blue colors, with a trend of a diagonal formed by the individual objects. This method can be used even for the optically faint, and hence distant objects. The color-color diagrams of supersoft X-ray binaries are shown in Fig. 4 and 5.

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 BP and RP spectra have similar sizes (on the order of 30 pixels along scan) (Perryman et al. 2006). 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

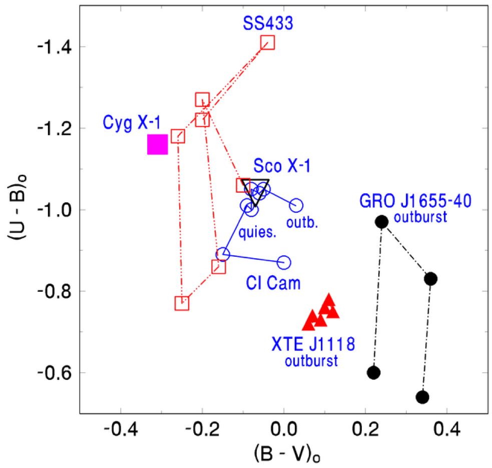

Fig. 3. The color-color diagram for microquasars.

to reach the object densities in the sky of at least 750 000 objects deg^{-2}. The obtained images can be simulated by the GIBIS simulator (see Fig. 2).

The algorithms for automated analyzes of digitized spectral plates are developed by informatics students (Hudec 2007). The main goals are as follows: the 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. We focus on the sets of spectral plates of the same sky region covering long time intervals with good sampling; this enables a simulation of the Gaia BP/RP outputs. The main task is the automatic classification of the stellar objective prism spectra on digitized plates, a simulation and a feasibility study for the low-dispersion Gaia spectra.

4. Low-dispersion spectral databases

Before Gaia, low dispersion spectra were frequently taken in the last century by various photographic telescopes with the objective prisms.

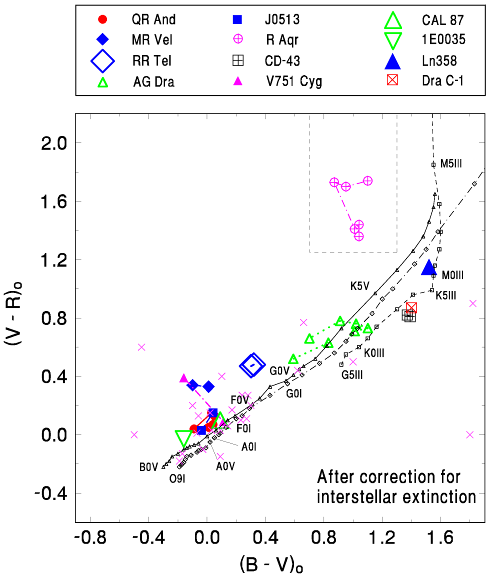

Fig. 4. $(B-V)_0$ vs. $(V-R)_0$ diagram of supersoft X-ray binaries. In the red spectral region, giant donors in symbiotics have the colors expected for isolated stars. The colors of R Aqr are diminished by 3 mag in this diagram. For comparison, the x symbols denote the colors of old novae from Szkody (1994).

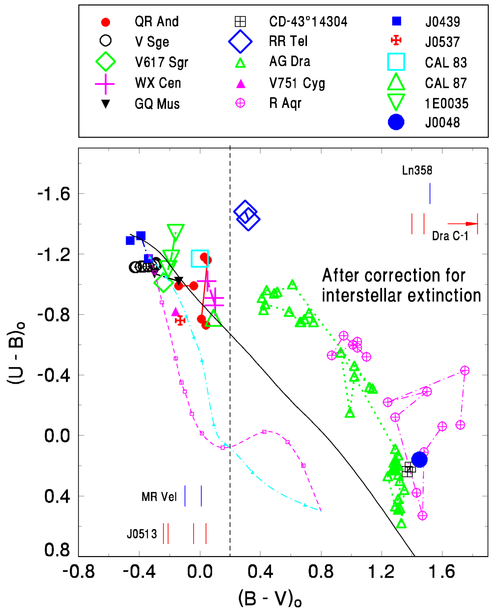

Fig. 5. $(U-B)_0$ vs. $(B-V)_0$ diagram of supersoft X-ray binaries. Notice that some objects lie above the curve of black bodies; this fact is not affected by the possible errors in reddening, i.e. in E_{B-V}. The short vertical lines denote the $B-V$ indices of the objects for which no $U-B$ colors are available. The vertical dashed line separates the region of the short-period systems (with the orbital period $P_{\rm orb} \leq 4$ days) from the long-period ones (mostly symbiotic systems). Short-period supersoft X-ray binaries form a more closed group than symbiotics. This suggests that hot continuum (accretion disk?) with very similar properties dominates in these short-period systems.

The motivation of plate survey low-dispersion spectral studies is as follows: (1) comparison of the simulated Gaia BP/RP images with those obtained from digitized Schmidt spectral plates (both using dispersive elements) for selected test fields, and (2) feasibility study for application of the algorithms developed for the plates for Gaia.

The dispersion represents an important parameter: (1) Gaia BP: 4–32 nm/pixel, i.e. 400–3200 nm/mm, 9 nm/pixel, i.e. 900 nm/mm at Hγ, RP: 7–15 nm/pixel, i.e. 700–1500 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. Hence Gaia BP/RP dispersion ~5 to 10 times less than 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. Gaia BP/RP dispersion is ~5 to 10 times less than typical digitized spectral prism plate, and the spectral resolution ~3 to 4 times less, but on the plates affected by bad seeing only ~2 times less.

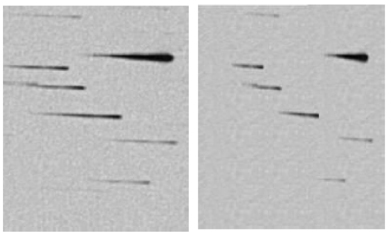

Fig. 6. Left: Part of digitized Byurakan Sky Survey plate (spectral resolution 10 nm/mm at Hγ), Right: Re-scaling to simulate the Gaia BR/RP resolution (18 nm/mm at Hγ). This is part of the efforts to develop an alternative and real Gaia BP/RP simulator.

5. Conclusions

The ESA Gaia satellite will contribute to scientific investigations of high–energy sources not only by providing long–term photometry with but also by use of ultra–low dispersion spectra provided by BP and RP photometers. These data will represent a new challenge for astrophysicists and informatics. The nearest analogy is represented by the digitized prism spectral plate surveys. These digitized surveys can be used for a simulation and tests of the Gaia algorithms and Gaia data. Some types of variable stars are known to exhibit large spectral type changes, however, this field is little exploited and more discoveries can be expected with the Gaia data, as Gaia will allows us to investigate the spectral behavior of huge amounts of objects over 5 years with good sampling for low–dispersion spectroscopy.

6. Discussion

MARIO MACRI: Can you comment on the contribution of Antimatter search in space experiments to the understanding of cosmological evolution?
FRANCO GIOVANNELLI: The detection of exotic cosmic rays due to pair annihilation of dark matter particles in the Milky Way halo is a viable techniques to search for supersymmetric dark matter candidates. The study of the spectrum of gamma-rays, antiprotons and positrons offers good possibilities to perform this search in a significant portion of the Minimal Supersymmetric Standard Model parameter space.

Acknowledgements. The Czech participation in the ESA Gaia project is supported by the PECS project 98058. The scientific part of the study is related to the grants 205/08/1207 and 102/09/0997 provided by the Grant Agency of Czech Republic. Some aspects described here represent a continuation of ESA PECS Project 98023 (Czech Participation in INTEGRAL). The analyzes of spectral plates are supported by MŠMT KONTAKT Project ME09027.

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