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The role of Robotic telescopes in space astronomy

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Abstract. We present and discuss the role of robotic telescopes in satellite projects, as well as related strategies. Numerous satellite projects in space astrophysics focus on high energy astrophysics from X-rays to gamma-rays. However, a large fraction of objects of high-energy astrophysics emit also optical light, which in many cases, are variables. The observation of these sources at optical wavelengths can provide valuable inputs for multispectral analysis of various categories of celestial high-energy (HE) sources. There are also satellite projects outside the high–energy astronomy, in which the robotic telescopes can also play an important role, e.g. the ESA satellite Gaia. In Gaia, robotic telescopes are expected to verify the triggers detected by satellite (such as transients and flares) but also to provide additional (mostly photometric) data for better scientific cases.

Keywords : space astronomy: satellites – robotic telescopes – Gaia

1. Introduction

In this paper we focus on interface between network of robotic telescopes and satellite projects in space astronomy, with emphasis on astrophysical issues. This is important not only for satellite projects focussing on visible (optical) light (such as ESA Gaia satellite) but also for satellites observing in high–energy i.e. X–rays and gamma–rays. We have to take into account that an essential fraction of objects of high–energy astrophysics emits also optical light, which is, in many cases, variable. For example, most of optically identified INTEGRAL gamma-ray sources are brighter than mag 20, and more than half are brighter than mag 15. The observation of these sources at optical wavelengths can provide valuable inputs for multispectral analysis of various

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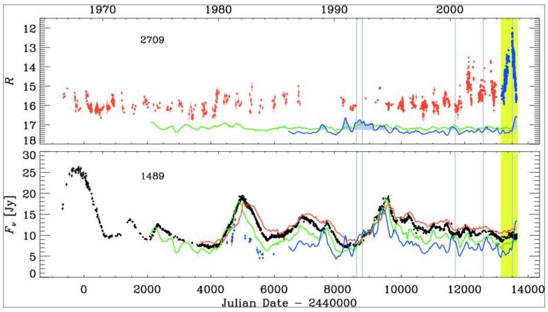

Figure 1. The long–term optical light curve of blazar 3C454.3 with large outbursts which triggered the satellite HE observation by INTEGRAL. As the number of objects to be monitored is large, the network of RTs can provide important contribution. Source: Villata et al. (2006).

categories of celestial high-energy (HE) sources. However, either dense, or dedicated observations at given times in optical light are necessary, which can be effectively provided by automated observatories.

Some other types of astrophysical objects (e.g. blazars, cataclysmic variables, gamma-ray bursters, flare stars, etc) exhibit rare flares for which satellite observations are important. These events cannot be monitored by satellites itself in most cases but cab be effectively monitored by robotic telescopes (RT) generating ToO (Target of Opportunity) triggers for satellites with ToO regime (Fig. 1).

These monitors, in contrast to alert telescopes, can deliver optical photometric data for objects prior and during the active/flaring states. Wide-field (WF) coverage is important to cover as many sources as possible. There is a scientifically justified need to have this mode in robotic (i.e. autonomous remotely controlled) telescopes(RT). RT with reasonably large field of view (FOV), performing regular sky surveys, or with an attached WF camera, can serve as a monitoring device. In some cases, even post-flare monitoring is important as shown by magnetar candidate GRB070610 optical flares (Castro-Tirado et al. 2008) in order to (1) detect the optical flares (see Fig. 2), (2) detect possible recurrence (this is a very difficult task, but important one, which can be performed only by robotic instruments as the recurrence cannot be predicted).

2. Observations of high-energy sources by Robotic telescopes

2.1 Organization of robotic observations

To contribute to astrophysical satellite projects effectively, the automated optical observations must be prepared and planned carefully. The nature of the various types of astrophysical sources (observation targets) must be respected. This is not easy task as for some object categories, their nature and also their behaviour in optical light can

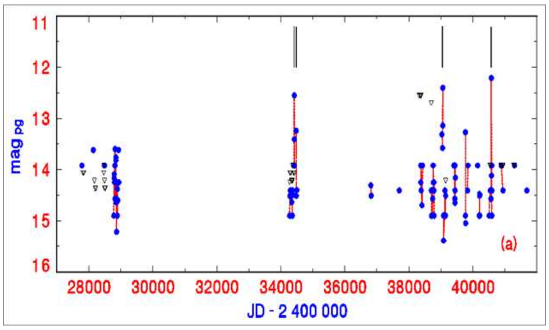

Figure 2. Optical flares in cataclysmic variable TV Col, as detected on Bamberg Observatory archival plates. Monitoring of these flares, which might be observable also in X–rays (by analogy to other objects), by RTs, is scientifically important.

be very complex. Most of recent RTs perform photometric observations, however, also low-dispersion spectral (LDS) devices are able to deliver valuable data for certain astrophysical objects with prominent, strong, and/or variable spectral features, as required newly by the ESA Gaia mission (Fig.5).

Satellite observing campaigns. One of the most important modes of supporting optical ground-based observations is the response to satellite observing campaigns. While the satellite observation itself usually lasts for several days, the whole observing campaign lasts typically for weeks, as also the time interval before and after the satellite observation needs to be covered. Dense coverage during the satellite observation is required, with less dense coverage before and after. Magnitudes of the targets are typically 12-18 mag but occasionally can go deeper. In addition to that, planned observations (mostly known in advance) of optically variable sources by satellites can be supplemented by optical ground based observations, with similar requirements as described above.

Monitoring for triggering satellite (ToO Target of Opportunity) observations belong to another important type of optical observations of HE sources. In most cases, moderate sampling of about 1 point/day is enough. Magnitudes are typically 12–18 mag. For example, ToO proposal on blazars within INTEGRAL project (see Fig.1). Here, the blazars included in the approved list are to be optically monitored for possible brightening. Again, about 1 photometric point/day is acceptable for most of the sources.

Providing optical data for non-triggered satellite observations represents another category (e.g. providing optical monitoring data for the time span of INTEGRAL operation, i.e. 2002–2012). Typically 1 point/day (or even less) is enough. Magnitudes of most of the objects are typically within the range 10 – 18 mag. This type of observations allows to compare behavior of gamma-ray sources at various energies and is hence physically important as from such comparison physical interpretations and conclusions may be drawn.

Alert follow-up observations represent another important type. They need fast response, better (but not necessarily) automated. However, even a site with non automated instrumentation has chance due to observational/weather constraints. Mostly Gamma-Ray Bursts (GRBs) belong to the object observed this way, but occasionally various types of other flaring and transient targets may be added. Expected magnitudes are 6 – 22 mag except in some cases (optically dim GRBs even fainter). With the ESA Gaia satellite, we expect another (Gaia project related) type of alerts, which will point on suspicious (mostly flaring) objects detected within Gaia. As the Gaia itself will have limited ability to confirm the reality of these objects, in most cases the final confirmation and further analyses of Gaia alert triggers will rely on ground-based (preferably robotic) observers.

Verifying suggested identifications represent another type of job where robotic observatories may contribute. Typical magnitudes for these kind of objects are 10 – 20 mag. The preferred response is within days or a week. Photometry both with good sampling as well as moderate sampling, photometry with filters, spectroscopy (including low dispersion), are required.

Optical supplementary analyses of HE sources (for complex multispectral analyses) may also add valuable optical data for understanding the physics of the sources. The typical magnitudes of these objects are 10 – 20 mag. Again, photometry both with good sampling as well as moderate sampling, photometry with filters, and spectroscopy (including low dispersion) are required.

2.2 New discoveries and new types of optically variable objects

In addition to the main types of HE objects described above, occasionally also objects worth study of another (and sometimes even new) category appear. The variable objects at positions of Ultra High–Energy (UHE) sources can serve as an example: Puzzling poorly investigated variable star at position of UHE source, namely the variable M6 star V347 Aql,with coordinates J2000.0 ICRS position of RA=19h08m01.3s, DEC=+06d18'27, and magnitude B= 11.5 mag. The star is within the error box of the new VHE (very high energy) source HESS J1908+063. The nature of this star is unknown, T Tauri star? Oxygen rich irregular variable? The star is an IRAS source. The light curve is poorly investigated albeit object magnitude is at B~11, i.e. good target for small robotic observatories.

There are also completely newly detected types of optically variable HE sources. The optical counterpart of GRB070610/SWIFT J195509+261406 may serve as an example (De Ugarte Postigo et al. 2007; Castro-Tirado et al. 2008). The This GRB was detected on 10 June 2007 20:52:26 UT by Swift/BAT as a normal burst (Pagani

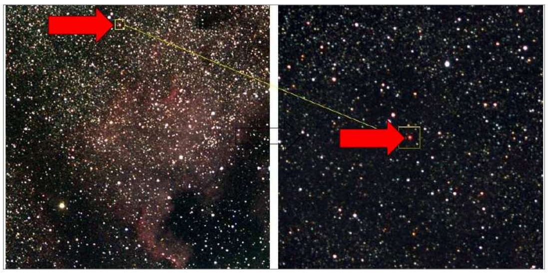

Figure 3. Very bright outburst of symbiotic star V407 Cyg. Nishiyama & Kabashima (2010) observed the star at magnitude of 6.8 on 2010 March 10. Kojima observed the star at around magnitude 7 on two images taken using a Canon EOS 40D (CBET 2199). The object exhibited also gamma-ray flare.

et al. 2007), with T90 = 4.6 s, photon index 1.76 ± 0.25, and fluency (2.4 ± 0.4)10^{-7} erg/cm^2 (Tueller et al. 2007). XRT detected an X-ray counterpart 3100s later (Pagani & Kennea 2007) with a column density consistent with the Galactic. Stefanescu et al. (2007) reported the detection of a variable optical counterpart, De Ugarte Postigo et al. (2007) confirmed the detection with observations from the 1.5m OSN. Kann (2007) suggested a Galactic origin, based on unusual flaring activity and location near the galactic plane: l=63.3 deg, b=-1 deg. About 40 optical flares peaking at up to I mag 14 as shown in Fig.2. The emission between flares slowly decreased until it disappeared with no detectable quiescent source.

V407 Cyg represents another new type of hard-gamma ray eruptive variable (Hudec 2011; Munari et al. 2011). V407 Cyg is a symbiotic binary harboring a Mira variable, of 745 day pulsation and a possible orbital period of 43 years, at a distance of 2.5/3.0 kpc In addition to a possible previous one in 1936 (when the object was noted for the first time by (Hoffmeister 1949), V407 Cyg has been discovered in large outburst by Nishiyama & Kabashima (2010) on 2010 Mar 10.8 UT (Fig.3). Such a scenario was highly reminiscent of the recurrent nova RS Oph. The outburst of V407 Cyg has since then been detected also in gamma-rays (Cheung et al. 2010) and in radio (Nestoras et al. 2010) and observed in the infrared (Munari et al. (2011) and references therein).

Optical Transient (OT) in Pegasus (OT J213806.6+261957) represents a rare type of dwarf nova (DN) with very long recurrence times (67 years) but very large amplitudes (Hudec 2010). The optical transient/cataclysmic variable in Pegasus, reported in CBET 2273 and CBET 2275 (designated VSX J213806.5+261957 or OT J213806.6+261957) was detected in the extended study of Sonneberg Observarory Archival Sky Patrol Plates (more than 3000 plates analyzed, taken during the years 1928 to 2004) in another (historical) large optical outburst (peak on 1942 Nov 30) at mag(B)=9.8 (+-0.5), illustrated in Fig.4. The star was found in a superoutburst from 1942 Nov 30 till 1942 Dec 11, being fainter than mag(B) 13 on 1942 Nov 10 (and before this date) and on 1942 Dec 28 (and after this date). Only 2 outburst are known

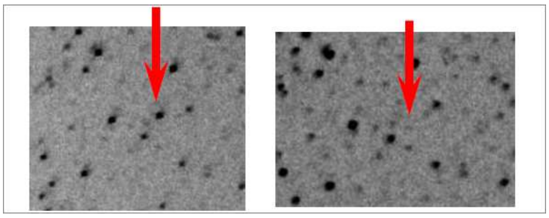

Figure 4. The historical 1942 optical flare of OT in Pegasus as detected on the Sonneberg Observatory Sky Patrol Plates. Left: 1942 flare, Right: comparison plate.

(1942 outburst found by Hudec (2010), based on analyses of 2000 Sky patrol plates). Only very few such objects are known so far. There is a good chance for such targets to be detected by Gaia (Alert System). Dramatic spectral changes detectable by Gaia BP/RP are also expected.

3. Robotic telescope support for satellites outside High-Energy Astronomy

Only a fraction of recent and planned astrophysical satellites perform observations in X–rays and gamma–rays. Numerous important satellite projects both in operation as well as in development and/or study focus on visible (optical) light, or, alternatively, other low–energy spectral regions such as infrared, near-infrared, microwave, or radio. The ESA missions Planck, Herschel, and Gaia may serve as examples.

The ESA Gaia project is extremely well suited to be supported by network of RTs to achieve valuable scientific results. Albeit its main goal is the ultra precise astrometry, Gaia will monitor all celestial objects down to magnitude 20 over a 5 years time period. However, the photometric sampling will not be optimal; hence the supplementary observations provided by ground-based robotic telescopes are expected to provide a valuable contribution. The main goal of these supplementary observations are as follows: (1) confirm triggers (e.g. optical transients, flares, brightenings, etc.) detected by Gaia satellite (2) provide additional photometric data with more dense sampling than provided by the satellite. The HE objects such as LMXRB, HMXRB, and Optical Afterglows and Optical Transients of GRBs can serve here as an example, together with various types of cataclysmic variables including SNe.

However, the Gaia satellite will address not only astrometry and photometry but also spectroscopy, both high–dispersion as well as low–dispersion. The peculiarity of ESA Gaia, where a substantial fraction of data will be as ultra–low dispersion spectra, raises a question about the role of focal devices with dispersive elements, i.e. on a spectral alternative. This is fully scientifically justified, as the spectral type of Cepheids, Miras and Peculiar Stars is known to change significantly with time. For example, all classical Cepheids definitely vary their spectral types. At maximum,

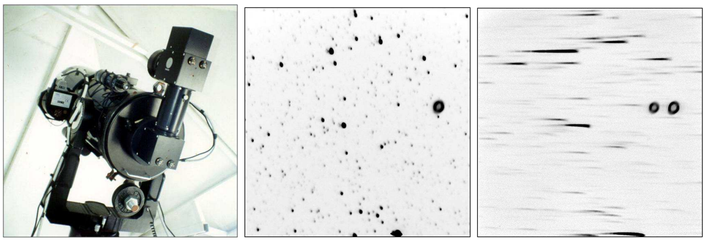

Figure 5. The BOOTES low dispersion prism spectrograph constructed at the Astronomical Institute of the Academy of Sciences of the Czech Republic in Ondrejov (left), and a CCD image without (middle) and with (right) prism. This type of devices greatly extends the possibilities of RT in astrophysical analyses, especially in investigation of strong and prominent emission features by Low dispersion spectroscopy (LDS).

they all have types around F5–F8. At minimum, the longer the period, the later is the spectral type (to K2) (Samus 2008). The long–term behavior of spectral types of various variable celestial objects (so far only poorly investigated) may be a significant goal not only for ESA Gaia, but also for robotic ground–based optical telescopes equipped with corresponding dispersive elements. Especially RT equipped with LDS focal devices (Fig.5) can provide valuable contribution to Gaia spectral alerts.

Hence, at lest two features of Gaia, namely spectroscopic alerts and investigation of spectral type changes, represent innovative approaches in astronomy and astrophysics. In both of them, the RTs (with spectral devices in focal planes) may effectively contribute.

4. Robotic telescope support for Cerenkov telescopes

Another scientifically important application of RTs in high–energy astronomy and astrophysics is the support for (ground–based) Cerenkov telescopes. The CTA (Cerenkov Telescope Array), albeit not being a satellite, is in many aspects similar to satellite projects (see also the CTA effort at ISDC). The CTA project is an initiative to build the next generation ground-based very high energy gamma-ray instrument. It will serve as an open observatory to a wide astrophysics community and will provide a deep insight into the non-thermal high-energy universe.

Current systems of Cherenkov telescopes use at most four telescopes, providing best stereo imaging of particle cascades over a very limited area, with most cascades viewed by only two or three telescopes. An array of many tens of telescopes will allow the detection of gamma-ray induced cascades over a large area on the ground, increasing the number of detected gamma rays dramatically, while at the same time providing a much larger number of views of each cascade. This would result in both improved angular resolution and better suppression of cosmic-ray background events.

In a possible design scenario, the southern hemisphere array of CTA will consist of three types of telescopes with different mirror sizes in order to cover the full energy range. The northern hemisphere array would consist of the two larger telescope types (http://www.cta-observatory.org/).

Nowadays, the modern and advanced Cerenkov telescopes are able to deliver data similar to those from other astrophysical facilities, namely images, light curves, and spectra. The number of TeV sources increased essentially, including TeV targets which also emits optical (visible) light. Fraction of these sources exhibit violent variability. As a consequence, there is a need for robotic monitoring of VHE (TeV) sources, but also for an alert system for TeV flaring triggers, e.g. the source 1ES1959+650 (TeV blazar at z=0.047). There was an essential progress in Cerenkov telescopes over past years, and nowadays these deliver data analogous to what is known from other energy pass bands (i.e. images and light curves). We propose to implement in Cerenkov systems analogous alert system as used already on satellites (i.e. rapid alerts sent to optical and radio observers). Also the opposite way may be essential, as the optical robotic telescopes can monitor TeV sources and report detected flares and active periods to Cerenkov teams.

Another alternative is to attach RT directly to the particular Cerenkov telescope. The RT ATOM may serve as an example (http://www.lsw.uni-heidelberg.de/projects/hess/ATOM/).

ATOM (Automatic Telescope for Optical Monitoring) is a 75-cm telescope currently being upgraded to work in a fully robotic way, i.e. do its complete work without human attendance. ATOM is part of the H.E.S.S.-project and will serve as:

(i) an automatic optical monitor of variable gamma-ray sources, (ii) an automatic optical monitor of potential H.E.S.S. targets, and (iii) a transmission monitor to help calibrate the Cherenkov shower image analysis.

The ATOM robotic telescope was build by Zeiss as a prototype for computer controlled azimuthal mounting. It was operated for a decade at LSW and used for many astronomical projects. In preparing for the start of the H.E.S.S.-project, it became apparent that multifrequency observations would best be conducted on-site, resulting in a project to robotize and relocate the telescope. While the mechanical components did only require a modest redesign for automatic operations, the control electronics were replaced completely, following the strategies used for automatisation of the Oskar-Lhning-Teleskop (OLT, see http://www.hs.uni-hamburg.de/EN/Ins/Olt/). In particular, all ATOM motors are operated using industrial approved programmable logic controllers (PLCs), resulting in a very stable system.

The ATOM telescope has already delivered important simultaneous optical data for several flaring TeV sources, e.g. detection of an optical flare from blazar PKS 1424-41 (Hauser et al. 2010a), detection of an optical flare from PKS 1222+216

(4C 21.35) (Hauser et al. 2010b), detection of an optical flare from PKS 2052-474 (Hauser et al. 2009a), and detection of an optical flare from 3EG J1429-4217 (Hauser et al. 2009b)

In addition to RTs directky attached to Cerenkov telescope, alternative approach can be represented by prividing RT alert system, as suggested and described above.

5. Conclusions

The HE objects exhibit optical emission (and mostly variable emission) accessible by robotic observatories. For many of these sources there is a lack of optical data. The optical data provided by automated ground-based optical telescopes are important for multispectral analyses of the sources, contributing to better understanding of related physical processes. Even small apertures may contribute as some sources are brighter than magnitude 12. In addition to that, robotic telescopes may play an important role also in satellite projects outside HE astrophysics, as shown on the example of the ESA Gaia, namely as devices confirming the satellite triggers, as well as delivering additional well sampled photometric data for particular objects.

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