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CPCS 2.0 – new automatic tool for time-domain astronomy

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Abstract. The Cambridge Photometric Calibration Server (CPCS) has been designed to respond to the need of automated rapid photometric data calibration and dissemination for transient events, primarily from *Gaia* space mission. The Calibration Server has been in operation since 2013 and has been used to calibrate around 50 000 observations of hundreds of transients. We present the status of the tool and demonstrate improvements made in the newest version, which is enhanced with build-in profile photometric measurement. After tests and implementation on the dedicated website, the new Server will be able to combine imaging data from multiple telescopes and is intended to provide science-ready photometric data within minutes from observations. We also present the OPTICON-supported network of telescopes for *Gaia* alerts follow-up.

Key words: time-domain astronomy – photometry – automatic data reduction and calibration – *Gaia* Science Alerts

1. Introduction

Time-Domain Astronomy (TDA) is a rapidly developing field of observational astronomy, which includes studies of both continuously variable (periodic and non-periodic) sources as well as temporally appearing or changing objects. Transient astrophysical events, e.g., supernovae, gravitational wave optical counterparts, microlenses or tidal disruption events, often require immediate follow-up observations soon after their discovery. In the era of large photometric surveys, for example *Gaia* [1], PTF [2], ASAS-SN [3], OGLE [4] and recently initiated ZTF[5],

[1] http://sci.esa.int/gaia
[2] https://www.ptf.caltech.edu/iptf
[3] http://www.astronomy.ohio-state.edu/ assassin/index.shtml
[4] http://ogle.astrouw.edu.pl
[5] https://www.ztf.caltech.edu

there are thousands of transient phenomena reported every year (about 1000 by *Gaia* alone, currently about 4 per day). Therefore, a careful selection of those which are of the highest scientific interest, or are rare examples of events, play a crucial role. It is essential to observe as many of them as possible in detail from the ground while they are still on-going, in order to understand their nature and discover new types of objects. Early multi-band photometry informs us on how an event develops in brightness and colour, allowing for early characterisation and helping decide on further follow-up observations, both photometric and spectroscopic.

2. OPTICON follow-up network

Coordination of the operation of a network of observatories collecting time-domain data over days-to-years is the main goal of the OPTICON TDA Work Package 13 (H2020 Network Activity 4)[6]. This includes technical support, training, help with the observations and data processing and workshops. Our main product, however, is the automatic software dedicated for TDA, which is a necessity in this field (see Sec. 3.)

Within the OPTICON TDA Work Package we have been coordinating the operation of multiple small- and medium-sized telescopes scattered around Europe and beyond. Many of these telescopes were build in the previous century and now have almost become obsolete due to poor weather conditions in Europe, compared to the best sites, like Chile or Hawaii. However, such telescopes, when gathered into a network, can still provide very useful scientific data, as well as serve as great training facilities for young generations of astronomers. Involvement in a coordinated network is also an opportunity for developing countries to take part in a world-class research.

We have been cooperating with a network of nearly 100 telescopes from around the globe. It is worth noticing that members of the OPTICON follow-up network are volunteers – they are both professional astronomers and amateurs. Some of them were contributing hundreds of observations, while others contributed only a few. Fig. 1 presents the geographical distribution of our partners.

3. Cambridge Photometric Calibration Server

In order to facilitate the homogenous data processing and coordinate the storage of the data, we have been developing and maintaining a unique tool, the Cambridge Photometric Calibration Server. This online tool provides the service to the astronomical community of observers, who are willing to contribute with their observations of objects for which the time-domain aspect is important,

[6]http://astro-opticon.org

Figure 1. The follow-up network of volunteering observers supported by the OPTICON program within TDA Work Package 13.

e.g., variable stars or various transient phenomena (supernovae, microlensing, etc.).

3.1. Current version of CPCS

The CPCS in its current version[7] has been in operation since 2013 and was developed in by Ł. Wyrzykowski and S. Koposov at the Institute of Astronomy, University of Cambridge (UK).

The service is used as a central point of where the data are being stored and calibrated in a homogenous way, so that they can be used in future scientific research. It allows us to combine data collected by different setups and instruments to be standardized in order to provide science-ready photometric light curves. More than 50 000 data points were collected already through our system and several scientific publications have used the data from the CPCS.

The examples of intensive follow-up observations of different types of objects are shown in Fig 2.

[7] http://gsaweb.ast.cam.ac.uk/followup

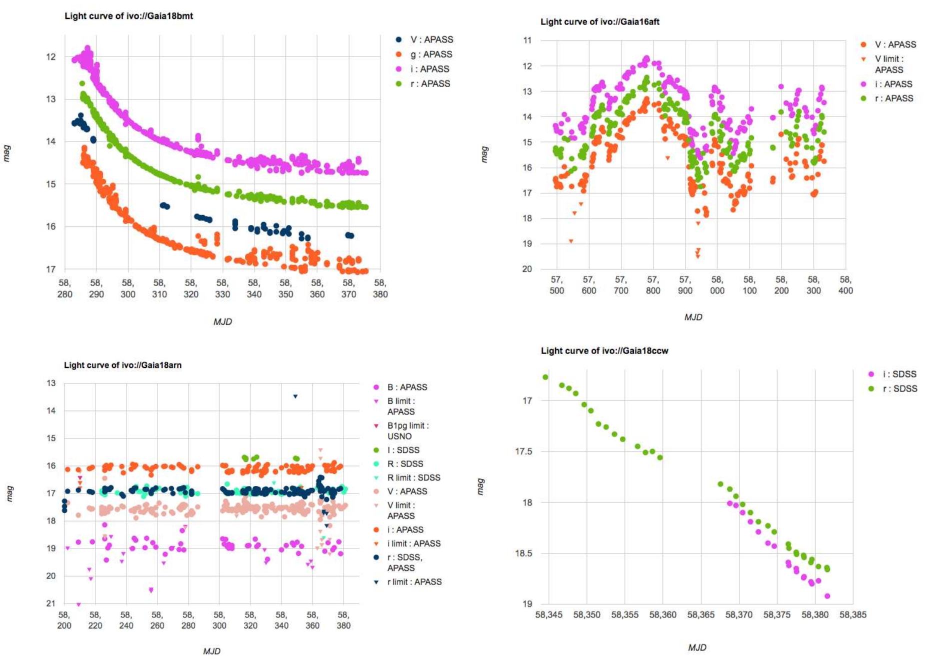

Figure 2. The example light curves of *Gaia* Science Alerts constructed by CPCS. *Top left:* Gaia18bmt – a microlensing event. *Top right:* Gaia16aft – an eruptive star. *Bottom left:* Gaia18arn – unknown nature of the object. *Bottom right:* Gaia18ccw – a supernova of Type Ia.

3.2. Towards CPCS 2.0

Over recent years we have been working on the new version of the automated data processing pipeline, the Calibration Server 2.0 (CPCS 2.0). Fig. 3 presents a schematic diagram of CPCS 2.0. Its main feature is that it accepts images from the observers and performs the measurements of stars' brightness and positions. The input CCD files must be calibrated (bias-, dark-subtracted and normalized by flat-field). This approach allows less experienced observers, including amateurs and even school pupils, to collect scientifically important observations without the need of tedious and difficult data processing.

The new version is currently under tests on data from various observatories, including instruments from LCOGT, REM (Chile), Moletai (Lithuania), Loiano (Italy), OHP (France), Ostrowik, Białków, Borówiec (Poland), SMARTS (Chile), Terskol (Ukraine), Aristarchos (Greece), etc. After appropriate software examination and old website rebuilt, the CPCS 2.0 will be publicly available online for everyone.

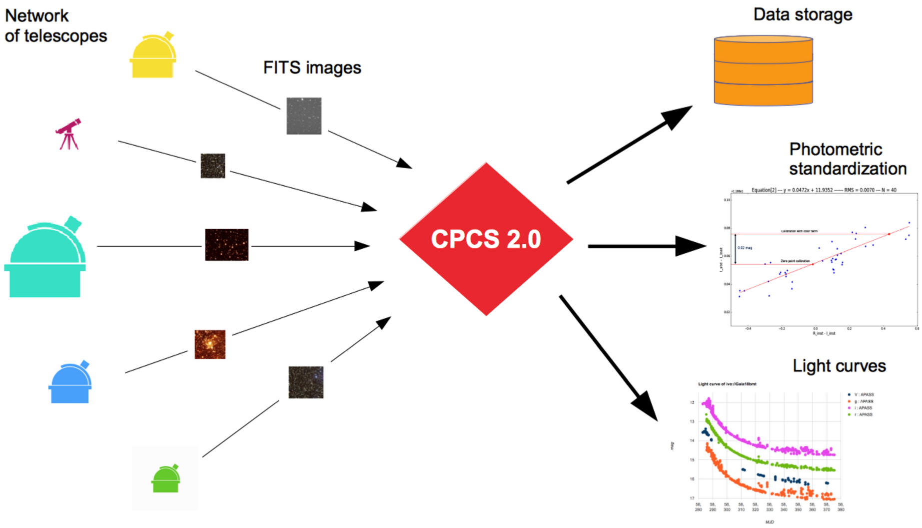

Figure 3. The schematic diagram of the Cambridge Photometric Calibration Server 2.0. On the left hand side, the input data are shown – calibrated FITS files, while on the right hand side are the CPCS 2.0 outputs.

The main improvements comparing to the current version of CPCS include the following issues:

– automatic photometric and astrometric reduction of CCD images by using CCDphot software as a kernel of the new Calibration Server. CCDphot is based on bash shell and Python tasks and scripts and uses several well-known packages and programs such as IRAF/PyRAF[8], SExtractor (Bertin & Arnouts, 1996), SCAMP (Bertin, 2006), DAOphot[9] and WCStools[10],

– transition from ASCI data files to CCD FITS images as input data for the Calibration Server,

– the selection of reference astrometric and photometric catalogues for a specific field-of-view includes (at this moment): URAT-1 (Zacharias et al., 2015), UCAC-4 (Zacharias et al., 2013), USNOB1 (Monet et al., 2003) and *Gaia*-DR2 (Gaia Collaboration et al., 2016, 2018) for astrometric solutions, as

[8]IRAF is written and supported by the National Optical Astronomy Observatories (NOAO) in Tucson, Arizona. NOAO is operated by the Association of Universities for Research in Astronomy (AURA), Inc. under cooperative agreement with the National Science Foundation. PyRAF is a product of the Space Telescope Science Institute, which is operated by AURA for NASA.

[9]http://www.star.bris.ac.uk/ mbt/daophot

[10]http://tdc-www.harvard.edu/wcstools

well as ASAS (Pojmanski, 1997), SDSS (Gunn et al., 1998), PS1 (Chambers et al., 2016), DES (Abbott et al., 2018) and 2MASS (Skrutskie et al., 2006) catalogues for photometric references,

– standardization of CCD file headers originating from different observatories (telescopes, instruments) according to the FITS[11] standard,

– automatic procedure for selection of stars to construct the Point Spread Function (PSF) model of the whole CCD image,

– both aperture and PSF photometry based on DAOphot calculation procedure obtained with precision ∼0.01 mag,

– final astrometric solution based on *Gaia*-DR2 coordinates and proper motions obtained with precision ∼0.01 arcsec,

– transformation of instrumental magnitudes to the standard ones by zero-point calibration and colour term application.

In addition, an important feature available in both versions of CPCS is the possibility of uploading or deleting the data in an automatic manner (e.g. by using shell scripting).

4. Summary

Our ultimate goal is to facilitate the data flow from an astrophysical trigger (alert) to a science-ready observational data point. This will allow us to gather time-domain data produced by a network of heterogenous instruments and telescopes. By inclusion of robotic telescopes and homogeneous protocols, it will become possible to avoid (or at least minimize) human intervention in generating science-ready data.

We demonstrate here the status and recent work on the Calibration Server which helps in the automatisation process of data reduction and constitutes a step forward towards the above mentioned goal. The current version of CPCS has been publicly available since 2013. The work under the second version is in progress now, but it should be available via the dedicated website soon. Finally, we emphasize that everyone can use this tool for own research independently. Everyone interested please contact Ł. Wyrzykowski via e-mail: `lw@astrouw.edu.pl`.

Please feel invited to cooperate within the OPTICON follow-up network and use the Calibration Server!

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[11]Flexible Image Transport System, https://fits.gsfc.nasa.gov

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