

## The Montsec Observatory and the *Gaia* science alerts

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### Abstract

The continuous and reiterative scan of the whole sky performed by *Gaia* ESA's mission during its (at least) 5 years of mission allows to detect transient events (e.g., supernovae, microlensing events, cataclysmic variables, etc) almost in real time among the daily millions of observations. The pipeline in charge to discover these alerts does a quick look analysis of the daily data stream, identify those sources increasing their brightness with respect to previous *Gaia* observations and also analyse their spectrophotometry to decide if those sources are good candidates to be published as a *Gaia* Photometric Science Alerts. These events are publicly announced for follow-up observations (both photometric and spectroscopic are needed). Observatories around the world confirm, classify and study them in detail. Observations are put in common and analysed together in a common interface in order to get a single analysis as detailed and precise as possible. Our team in Barcelona contributes to this *Gaia* science alerts follow-up programme with the 0.8 m robotic telescope Joan Oró (TJO), at the Montsec Observatory (OAdM), located at Sant Esteve de la Sarga (Lleida, Spain) performing photometric observations to derive the lightcurves of the most interesting alerts accessible from the observatory. Until now we have contributed with about 4500 images in multicolour Johnson-Cousins passbands obtained with TJO for a total of 38 *Gaia* science alerts, becoming the third most contributing observatory in the programme. Here we summarise the procedure to select new targets to be observed by TJO, submit follow-up observations and we explain the analysis we did for some interesting obtained lightcurves.

## 1 *Gaia* photometric alerts

*Gaia* ESA's mission [7] is continuously scanning the sky during its 5 years mission measuring

the positions, proper motions and parallaxes of more than 1 billion stars brighter than  $G = 20.7$  in our Galaxy. In average, every object in the sky is observed about 70 times, which allows to also detect its variability during the mission. Some of these sources are transient sources (supernovae: SNe, microlensing events, cataclysmic variables: CV, tidal disruption events: TDE, ...), suddenly increasing its brightness for a short time interval. To better study the properties of these transients, a follow-up programme was established to collect ground-based observations from many observatories [12].

A public web interface was put in place by the team at the Cambridge Institute of Astronomy<sup>1</sup> within the Photometric Calibration Unit of Data Processing and Analysis Consortium. From that web is in charge of distributing the information of all alerts is distributed to the astronomical community. The first alert was Gaia14aaa<sup>2</sup>, announced on 30 August 2014. Since then, 1268 alerts (up to 10th October 2016) have been arised, including 26 CVs, 167 SNe and 1036 unknown objects.

Science alerts are published together with several information such as the triggering date, coordinates, magnitude, historic magnitude, historic standard deviation, alert type and additional information like ATEL references.

Once every ground-based telescope has perform follow-up observations, their photometric data can be uploaded to the Cambridge Photometry Calibration Server (CPCS<sup>3</sup>, password required) and put in common with those obtained from all other observatories in the world to build a dense lightcurve of the object.

## 2 Joan Oró Telescope (TJO)

Montsec Astronomical Observatory (OAdM<sup>4</sup>), located at Sant Esteve de la Sarga (Lleida, Spain, alt = 1570 m, lat= 42° 03' 05" N, long= 0° 43' 46" E), is contributing to this ground-based effort since 23rd February 2015 with its 0.8 m telescope (Joan Oró Telescope, TJO).

TJO is totally controlled in a robotic way and the observer can program the list of observations though a web interface. Every night, the list of observations is decided depending on the priority of the programme and proposed target. No human intervention is needed during the night: the telescope (Optical Mechanics Inc., F/9.6 Ritchey-Chrétien), the dome (6.15m Baader Planetarium GmbH) and the camera (Back illuminated iKon L, DW936N-BV model, 2048 × 2048 pixels = 12.3 × 12.3 arcmin) are controlled automatically, using TALON software in OpenROCS architecture [5] and the observations are stopped without intervention if rain or storms appear thanks to the use of 2 weather stations installed in the observatory.

Most of the *Gaia* alerts observations have been performed using MEIA2 CCD camera and  $B$ ,  $V$ ,  $R_C$  and  $I_C$  Johnson-Cousins photometric filters. This multiwavelength information is crucial and helps to better characterise and classify the observed alerts. Although  $U$

<sup>1</sup><http://gsaweb.ast.cam.ac.uk/alerts/>

<sup>2</sup>The number (14) stands for the year of the discovery and the three letters ('aaa') indicates the order of discovery in that year ('aaa' is the first of the year, 'aab' the second and so on).

<sup>3</sup><http://gsaweb.ast.cam.ac.uk/followup/>.

<sup>4</sup><http://www.oadm.cat>

passband is also available, we decided to not use it because of the low response of the detector in that spectral range.

The list of targets can be changed daily by the user and this makes very easy to incorporate recent alerts to the system. The day after the observation, the observer receives the acquired raw images and also their reduced catalogues derived by the reduction pipeline of the observatory. This procedure ease the work of the astronomer and does not prevent to re-reduce the raw observations if a more sophisticated reduction process is needed.

### 3 Alerts followed from TJO

Our observational strategy is to get 3 images of a maximum of 300 seconds for each target every night. This maximum exposure time restricts our targets to have  $G \leq 17$ – $17.5$  when alerted and started to be observed. The follow-up observations can continue until its brightness has decreased to  $V \sim 19$ , depending on the passband. All our observations are done with airmasses  $< 1.55$  (altitude  $\geq 40^\circ$ ) in order to prevent the effects of the strong atmospheric turbulence. Each target was observed once every one to two hours per night, depending on the observing conditions specified. In some cases, the alerted object was found to be a short-period variable star. In this case, we got a denser lightcurve by obtaining many observational points in a single passband ( $V$ ) for an hour.

Our procedure to reduce the images (when no automatic reduction by OAdM is provided) consists in cleaning the obtained data from the effects of bias, dark and flat using Astropy CCDproc package [6]. Extraction of the sources with the instrumental magnitudes to a catalog file is done using SExtractor [2]. Astrometry.net is used in order to give coordinates (WCS, [9]). This process compares the photometric data with previously obtained 2MASS fields providing the matched sources in a radius of an arcsecond. The output catalogues are uploaded to the CPCS to derive their apparent magnitudes using differential photometry and making them accessible to all observers of the net.

In total 38 targets (see Table 1) have been observed with TJO (4583 images obtained and analyzed during 20 months of observations). This number of images uploaded to CPCS make us the 3rd most contributing observer of a total of 109 other registered <sup>5</sup>. Among all the targets observed we mention few of them in the following lines.

**Microlensing events:** The lightcurve of Gaia16aye microlensing event [1, 13] produced by a binary system can be seen in Fig. 1. This figure was built with more than 6000 datapoints collected from 26 different observatories (ours included). This event is the second of its type observed by the *Gaia* alerts network and the first binary microlensing ever observed in the Galactic spiral arms. Most of the previous microlensing events were found in the bulge of the Milky Way.

**Supernovae:** Several supernovae discovered by *Gaia* photometric alerts were also observed from OAdM (see Table 1). Among them, one of most interesting is the case of Gaia16apd

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<sup>5</sup>Check the complete list of observatories in <http://gsaweb.ast.cam.ac.uk/followup/observatories>.

Table 1: *Gaia* alerts observed from OAdM. Magnitude in the table is the  $G$  magnitude when the alert was triggered.  $N_{\text{obs}}$  is the number of nights dedicated to the target at TJO.

Name	Magnitude	$N_{\text{obs}}$	Type	Name	Magnitude	$N_{\text{obs}}$	Type
Gaia14aan	15.75	6	Unknown	Gaia14aav	16.06	2	Unknown
Gaia14adn	15.95	1	CV	Gaia14adr	16.68	9	RR Lyrae
Gaia15aab	17.89	13	RR Lyrae	Gaia15aai	17.00	5	AGN
Gaia15aal	17.13	1	SN	Gaia15aan	13.03	1	CV
Gaia15acx	17.28	4	SNIa	Gaia15acz	17.99	4	SN
Gaia15adb	17.22	32	SNIa	Gaia15adf	16.20	4	CV
Gaia15aea	17.46	3	AGN	Gaia15aek	17.73	7	SNIIP
Gaia15ael	17.27	10	SNIa	Gaia15aff	17.19	23	SN
Gaia15afd	16.37	22	SNIa	Gaia16aac	17.32	8	SN
Gaia16aaf	17.66	17	SN	Gaia16aam	17.54	17	SN
Gaia16aap	17.98	5	Blue transient	Gaia16abc	17.42	8	SNIIP
Gaia16abk	16.92	23	SNIa	Gaia16abg	17.37	4	SN
Gaia16acf	16.70	5	SN	Gaia16ael	16.91	35	SN
Gaia16ahp	17.23	4	SNIa	Gaia16aiz	17.46	21	SNIa
Gaia16ajm	17.59	10	SN	Gaia16ajh	17.54	11	SNI
Gaia16ajq	19.01	5	SN	Gaia16aik	17.04	2	Outburst
Gaia16alq	17.01	26	SNIa	Gaia16alo	17.73	4	SN
Gaia16alz	17.62	7	Microlens	Gaia16apd	17.35	7	SL SN
Gaia16aze	16.71	2	CV	Gaia16aye	14.27	38	Microlens

[3, 8, 11]. This is a superluminous SN (25 times brighter than regular SNe with only few tens of them observed until now).

Another SN case is Gaia16alq [4]. We could start the observations of this target before it reached its maximum brightness and well beyond the light curve peak (Fig. 2). The obtained data could be used to estimate the absolute magnitudes at the peak for this event using the SNooPy code<sup>6</sup>. The derived absolute magnitudes for this supernovae at  $z = 0.020\text{--}0.027$  [10] are:  $M_B = -18.58$ ,  $M_V = -18.87$ ,  $M_I = -18.17$ ,  $M_R = -18.58$ .

**Variable stars:** Some of the targets observed have a more rapid variation while observing with a variability period smaller than an hour. To better understand these targets we obtained a denser lightcurve in a single passband ( $V$ ). Fig. 3 shows one example of an unknown RR Lyrae (Gaia14adr) folded lightcurve derived.

<sup>6</sup><http://csp.obs.carnegiescience.edu/news-items/snoopy-released>

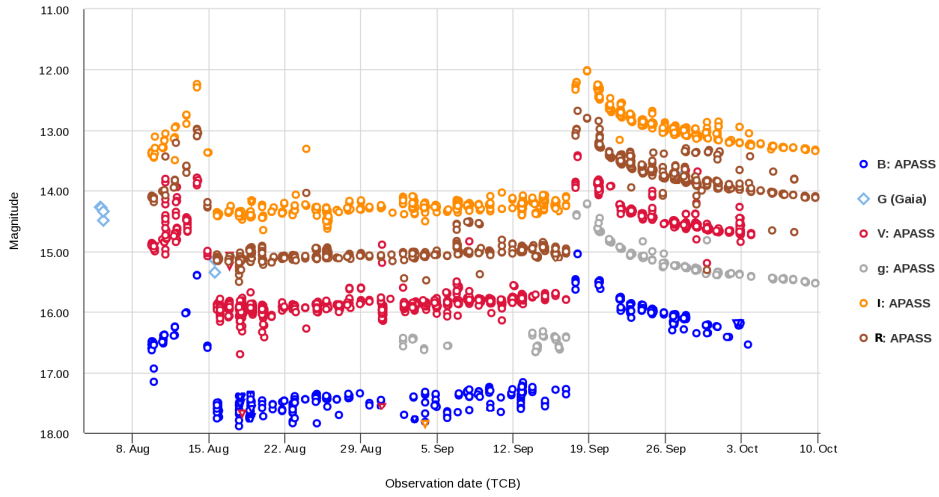


Figure 1: Lightcurve obtained by many observers (also us) and made accessible through the *Gaia* Alerts webpage<sup>1</sup>. This lightcurve in several passbands corresponds to a microlensing event with a binary system, Gaia16aye [1, 13], where a double peak can be seen (a third one is expected to be observed in December 2016, according with the current models).

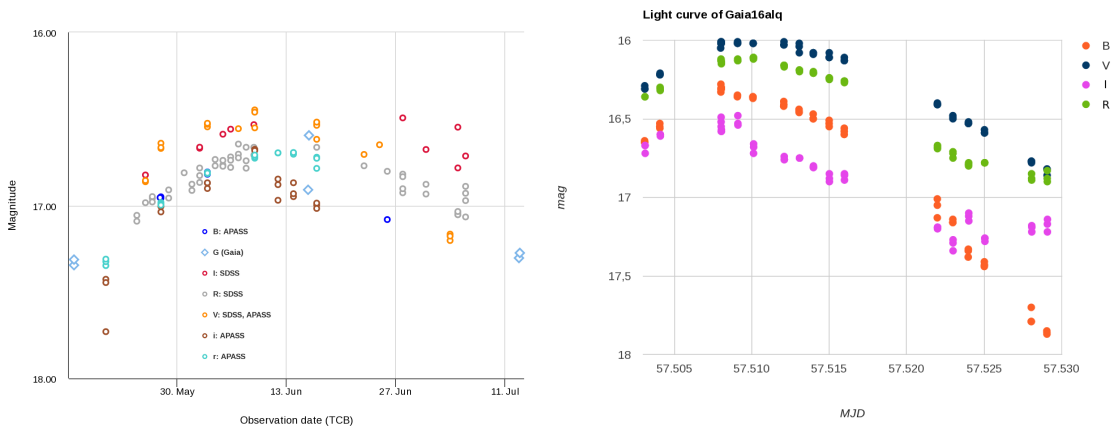


Figure 2: *Left*: Gaia16apd superluminous SN lightcurve. *Right*: Lightcurve of the SN Gaia16alq [4] obtained from OAdM and Bialkow Observatory (Polland).

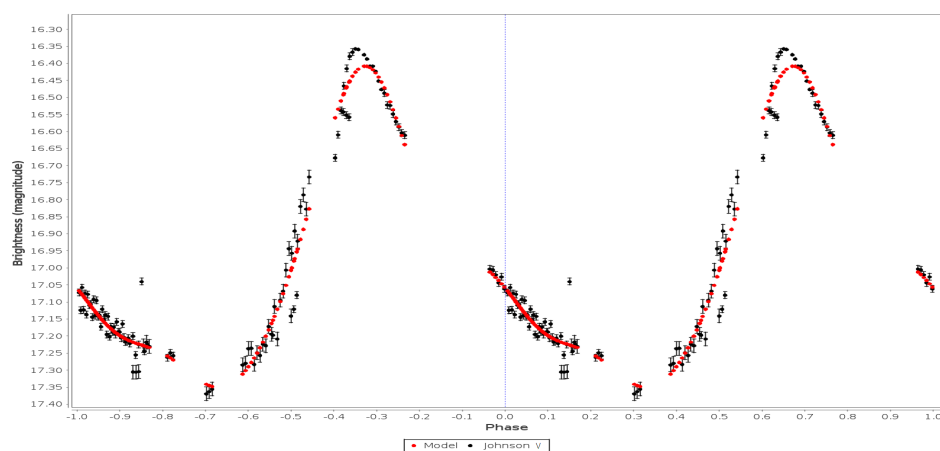


Figure 3: Gaia14adr RR Lyrae  $V$  lightcurve. Black points represent the TJO data. Red points are the fitted model (period= 0.5712 hours,  $V_{\text{average}} = 16.85$  mag).

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