

Cambridge Photometric Calibration Server (CPCS)

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There is large number of medium and small telescopes (diameter 0.5–2m) scattered around Europe and the world. Some of them are already quite historical and have taken part in important discoveries in astronomy in the twentieth century. However, today the requirements for very good image quality, clear skies, many cloudless nights, have forced astronomers to install observatories in places like Canary Islands, Chile or Hawaii. The old telescopes, if not closed down, has been used primarily for training of new generations of astronomers at the universities.

However, the development of large scale time-domain surveys, e.g. PTF, OGLE, ASAS-SN or Gaia, has shown that the astronomical resources available at the best observing sites are simply not sufficient to fully exploit the scientific potential of discoveries. Moreover, the discoveries has transitioned to time-domain – the Universe has been turned into motion and change! This applies in particular to transient objects, e.g., supernovae, novae, microlensing events and other more exotic and rare events, e.g., tidal disruption events. Such events, once discovered by surveys, require rapid reaction and continued photometric and spectroscopic follow-up in order to understand their nature. The best example is Gaia16aye (Ayers Rock), a spectacular binary microlensing event, discovered by Gaia in July 2016, for which only the extensive coordinated ground-based follow-up provided enough information to explain the details of the event.

Here we present the Cambridge Photometric Calibration Server (CPCS), a system designed and developed by Sergey Koposov and Łukasz Wyrzykowski. The Server is the central point where the photometric data from various telescopes for multiple targets are being stored. The system performs a homogenous zero-point calibrations for heterogenous data sets, using stars found in the field around the target of interest. The zero-point is derived by comparison between the measured magnitudes of many stars with these in the archival catalogue. The linear relation between the magnitudes is assumed and the relation with the lowest scatter is selected (when in automatic mode). Once the transformation is known, the magnitude of the target of interest is computed. Below we first describe how to prepare the data for the input, then present the manual of the web-based interface and conclude with the description on how to automatise/script the calibration.

PREPARING THE DATA

The Calibration Server required as input a catalogue of positions, magnitudes and their errors of ALL stars detected on the image. The catalog should also contain the target we would like to obtain the magnitude for, however, if the target is not detected (e.g. was too faint), the system will derive the upper limit, given the faintest stars present in the catalog.

Astrometry of the image can be performed, for example, by using astrometry.net service. Photometric measurements of brightness of the stars in the field can be obtained by using any standard or non-standard tools, e.g., Daophot, Dophot, IRAF or SourceExtractor (SExtractor). Since SExtractor is widely spread and probably the easiest to use, we suggest it for less experienced users. However, please note that it is clear that in most applications the quality of the photometry from SExtractor is not optimal and we advise to use more advanced tools for best results.

If using SExtractor for deriving the photometry, one should configure the output to ASCII format by setting in SExtractor's *default.sex* configuration file:

```
CATALOG_TYPE  ASCII_HEAD
```

and in *default.params* request the following columns in the output file:

```
MAG_AUTO  
MAGERR_AUTO  
ALPHA_J2000  
DELTA_J2000
```

If not using SExtractor one should make sure the columns in the catalogue file keep the following header:

```
# 1 MAG_AUTO    Kron-like elliptical aperture magnitude    [mag]  
# 2 MAGERR_AUTO  RMS error for AUTO magnitude             [mag]  
# 3 ALPHA_J2000  Right ascension of barycenter (J2000)     [deg]  
# 4 DELTA_J2000  Declination of barycenter (J2000)         [deg]
```

The system will then look for magnitudes in the first column, errors in the second, etc. In principle, one can use any number of columns, as long as the above-mentioned four columns are present in any order.

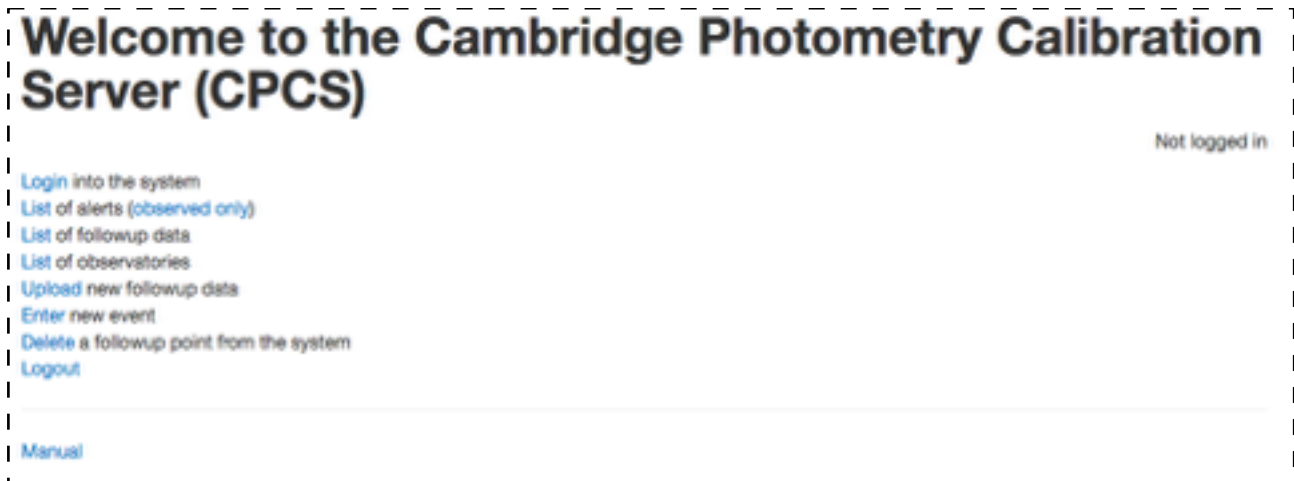
Note: the white space separator in the ASCII output should be space not tab.

Once the catalogue (a text file) is ready for a observation it can be uploaded to the Calibration Server. It can be done manually via web interface, or in a script.

1. Web interface

The main welcome page is:

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



1.1. Authorization

Logging into the system is needed in order to be allowed to upload new data, delete data points, and to download the data.

In order to access the server one needs a, so called "hashtag", which is an authorization key. The hashtag can be requested from the administrator of the server (Lukasz Wyrzykowski) after providing the details of the telescope (geographical coordinates and list of available filters). Hashtag is then used to authorise the user on the server and allow extended access to the services. Hashtag is also required for using the Server in scripts in the GET, POST requests.

NOTE: a hashtag is a unique identification *per person* and *per observatory*. If you plan to upload the data from multiple observatories, you will need multiple hashtags. Or if there is more than one observer who will be uploading the data from a single observatory, each observer needs to have their own hashtag. This helps keep track of who did which observations and on which telescope. For example, the name associated with the hashtag will be shown at the light curve display over each datapoint.

1.2. List of observatories

Direct link: <http://gsaweb.ast.cam.ac.uk/followup/observatories>

This link provides the list of all registered observatories/people. The Name is how the observatory/person has been registered in the system. This is also the name which labels each contributed data point. Longitude and Latitude are the geographical coordinates of the observatory and the last column shows the number of contributed observations. The number of observations leads to the a list of all individual data points inserted by that person/observatory (see list of observations).

id	Name	Longitude	Latitude	Observations
110	AAVSO	0.0	0.0	728
18	admin	None	None	6
132	Akeno,Ryosuke Itoh	138.3	35.47	0
49	Aleks Scholtz James Gregory Telescope 0.94 St.Andrews,UK	-2.8	56.3	0
16	Alex Ball-SMARTS1.3	70.815	-30.16527778	145
76	Anna Hourihane	0.0	0.0	898
1	AnonymousFollowUpAccount	0.0	0.0	0
129	Aries1.04,Goran Damjanovic	79.68	29.35	23
96	Aristarchos, Nikos Nanouris	22.1982	37.986	0
9	AshishMahabalEulerLaSillaChile	-70.73	-29.257	28
7	AshishMahabalIGOIndia	73.666667	19.083333	0
10	AshishMahabalP60	-116.863889	33.355833	0
8	AshishMahabalSAAO1.9SA	20.811642	-32.378961	0
15	AshishMahabal-SMARTS1.3	70.815	-30.16527778	0
112	ASV1.4 Goran Damjanovic	21.55	43.15	109
130	AUT25,Volkan Bakis	30.656254	36.89838	354
92	A.Zubareva 0.6m SAI	34.02	44.7	53
27	BAS NAO 2m Rozhen	24.74	41.7	59
28	BAS NAO 60cm Rozhen	24.74	41.7	0
29	BAS NAO Rozhen 50/70cm Schmidt	24.74	41.7	36

1.3. List of alerts

Direct link: http://gsaweb.ast.cam.ac.uk/followup/list_of_alerts

or: http://gsaweb.ast.cam.ac.uk/followup/list_of_alerts?observed_only=1

or: http://gsaweb.ast.cam.ac.uk/followup/list_of_alerts?offset=20&observed_only=1

This page shows all alerts/targets which are stored in the data base (see Add new alert below). The columns are the following:

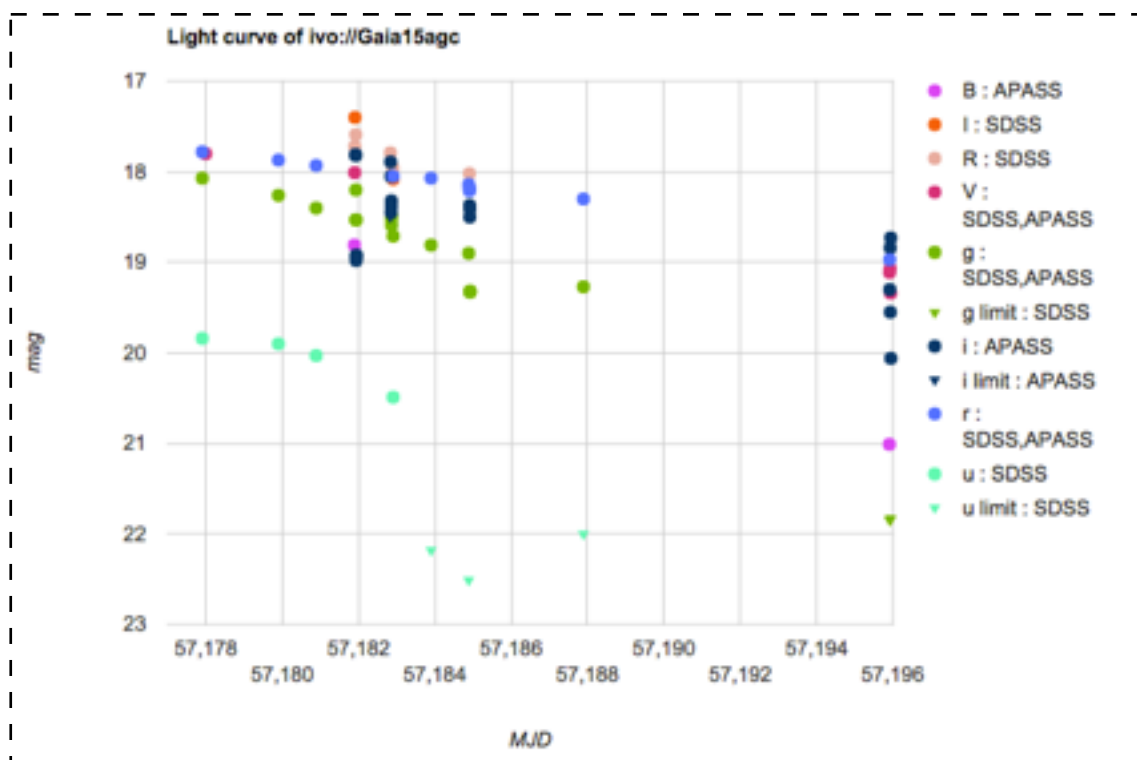
- id – unique number assigned to a given alert. Ivorn is the Virtual Observatory standard for names of alerts, which always begins with *ivo://*
- publication date – date/time when given target was added to the CPCS database
- Ra/Dec – equatorial coordinates in decimal degrees
- nfollowup – number of data points from various telescopes, collected so far for this target
- LC – link to displaying the full light curve of the object
- data – link to the JSON-format file with all data points. Accessing this requires prior authorisation.

id	ivorn	published	ra	dec	nfollowup	LC	data
26319	ivo://Gaia15agt	2016-08-11 00:32:10	308.125	38.4418888889	111	LC	data
26318	ivo://Gaia15agj	2016-08-11 00:07:32	295.961	35.0116111111	9	LC	data
26316	ivo://Gaia15aye	2016-08-09 22:49:33	295.005	30.1315	13603	LC	data
26315	ivo://Gaia15axt	2016-08-09 01:58:45	302.697	58.5296944444	53	LC	data
26314	ivo://Gaia15axq	2016-08-09 01:18:47	298.167	51.6991111111	19	LC	data
26313	ivo://Gaia15axs	2016-08-09 00:39:21	289.67	52.3511111111	12	LC	data
26312	ivo://Gaia15axr	2016-08-08 23:59:48	279.99	33.2666111111	11	LC	data
26311	ivo://Gaia15aui	2016-08-03 05:50:35	44.6220833333	40.0646111111	97	LC	data
26310	ivo://Gaia15atw	2016-08-03 05:11:10	31.4992083333	47.7371944444	68	LC	data

This page displays 20 alerts at a time. Clicking Next page will move to next 20 alerts. Option *offset* given in the address bar can be used to provide arbitrary offset to the list of displayed alerts. Option *observed_only=1* allows to limit the displayed alerts to these with more than 1 observations.

1.4.1. Light curve display

The light curve displays all data points collected for the target. Each catalogue/filter is denoted with a different colour, however, if two surveys use the same filter (e.g., SDSS and APASS), such filter will be marked with the same colour. Upper limits are denoted with triangles. By clicking on a selected filter in the legend, the data points in that filter will be highlighted. Hovering with the pointer above a data point will display the name of the observatory/person who took that data point, as well as the magnitude and matched filter.



1.4.2. Data download

Direct access to the data:

http://gsaweb.ast.cam.ac.uk/followup/get_alert_lc_data?alert_id=25960

or:

http://gsaweb.ast.cam.ac.uk/followup/get_alert_lc_data?alert_name=ivo://Gaia15ael

The data for an object can be downloaded only in JSON format (JavaScript Object Notation). Such format is easily readable by both humans and robots.

Example json output from the Calibration Server:

```
{ "mjd": [57721.8400664, 57722.90369248, 57722.89987245, 57722.88921215, 57722.89987245],
  "magerr": [0.06199999898672104, 0.01899999938905239, 0.009999999776482582, 0.007000000216066837, 0.007000000216066837],
  "alert_name": "ivo://Gaia16byl",
  "observatory": ["K.Wiersema-Leicester", "OHP Michel Dennefeld", "OHP Michel Dennefeld", "OHP Michel Dennefeld", "OHP Michel Dennefeld"],
  "caliberr": [0.009999999776482582, 0.16327300667762756, 0.08103019744157791, 0.05904430150985718, 0.05904430150985718],
  "mag": [17.39150047302246, 18.37459945678711, 17.71769905090332, 17.343799591064453, 17.343799591064453],
  "catalog": ["APASS", "SDSS", "SDSS", "SDSS", "SDSS"],
  "filter": ["V", "i", "B", "R", "R"],
  "id": [60274, 61395, 61394, 61390, 61391]}
```

The file contains fields (e.g. mjd, mag, magerr), which can be read into an array in Python 3 with:

```
with open('data.json', encoding='utf-8') as data_file:
    data = json.loads(data_file.read())
```

(after StackOverflow).

1.4. List of follow-up data

Direct link: http://gsaweb.ast.cam.ac.uk/followup/list_of_followups

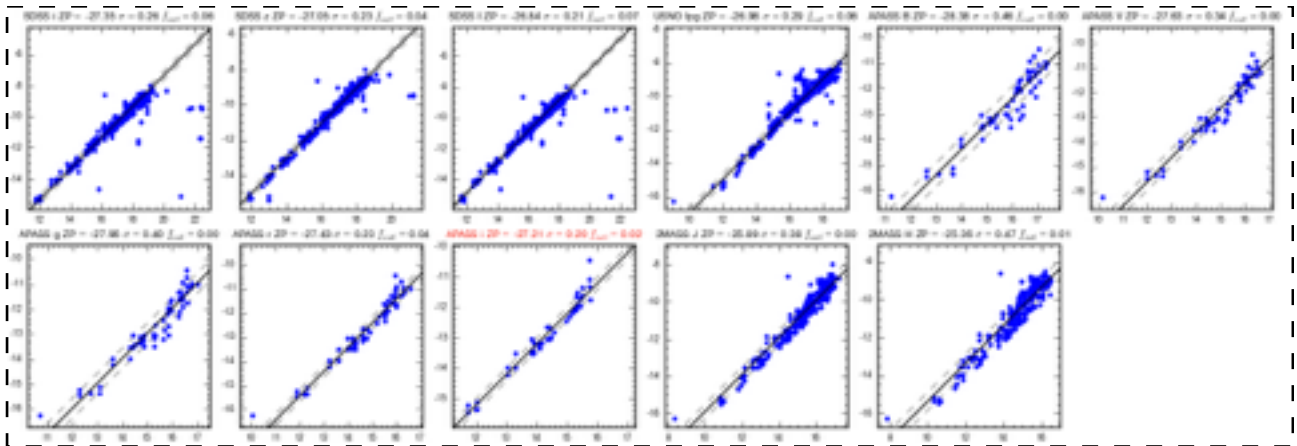
or: http://gsaweb.ast.cam.ac.uk/followup/list_of_followups?offset=20

id	IVORN	Observatory	MJD	mag	mag_err	calib_err	npoints	Catalog	Filter	mode	Calibration date	Image+Data
61379	ivo://PTFS1402ab	Liam Hardy pt5m	57737.81755	17.9315	0.06	0.01	9	APASS	V	FORCED	2016-12-15 19:44:43	ID
61378	ivo://PTFS1200o	Liam Hardy pt5m	57737.24788	19.8331	-1.00	0.12	33	APASS	V	FORCED	2016-12-15 19:38:06	ID
61377	ivo://Gaia16aye	LT- Andreja Gomboc	57737.793844	14.3679	0.00	0.07	29	APASS	i	AUTO	2016-12-15 19:11:09	ID
61376	ivo://Gaia16aye	LT- Andreja Gomboc	57737.793267	15.1565	0.01	0.05	29	APASS	r	AUTO	2016-12-15 19:10:44	ID
61375	ivo://Gaia16aye	LT- Andreja Gomboc	57737.7922	16.5646	0.01	0.07	26	APASS	g	AUTO	2016-12-15 19:10:19	ID
61374	ivo://Gaia16aye	Giuseppe Leto APT2 Catania	57735.7679514	14.2679	0.01	0.09	41	APASS	i	AUTO	2016-12-15 12:41:44	ID
61373	ivo://Gaia16aye	Giuseppe Leto APT2 Catania	57735.7547917	14.2135	0.01	0.09	45	APASS	i	AUTO	2016-12-15 12:41:40	ID

The columns are as follows:

- Id - every observation has a running id number, assigned chronologically (by the date of upload)
- IVORN - unique identification of the object, it always begins with the prefix: [ivo://](#)
- Observatory - name of the telescope and the observer (as coded in hashtag)

- MJD - modified julian date of the observation (mid-exposure)
- mag - brightness of the object calculated by CPCS
- mag_err - magnitude error; *mag_err* = -1 means that the object was not found in the frame and only upper limit for its brightness is derived
- calib_err - calibration error
- npoints - number of stars used to calibrate zero point and choose correct filter/survey
- Catalog and Filter - detected or forced filter band
- mode - can take either FORCED or AUTO value.
- Image+Data - access to calibration images ('I') and the data for given object (download after clicking 'D')



1.5. Uploading a new data

Direct link: <http://gsaweb.ast.cam.ac.uk/followup/uploader>

This is the main page of the CPCS, where the individual follow-up data can be uploaded. The fields are as follows:

- **Event ID** – unique identification of the alert, following the convention in the list of alerts, with full ivorn name, e.g. ivo://Gaia16aye
- **MJD OBS** – Modified Julian Date of the observation (in the middle of the exposition). Please remember that MJD is offset from JD by 2450000.5.
- **Exposure time** – exposure time in seconds
- **Comment** – optional comment for a submitted data point, for example: *taken through thin clouds*.
- **SExtractor catalog** – choose the file with the catalog of stars in the field, obtained as described above in *Preparing the data* section.
- **Matching radius** – 1, 2, 4 or 6 arcsec, default 2 arcsec. This is the radius at the match between the uploaded catalogue and archival database of stars.
- **Force filter** – by default the System will attempt to find the best matching archival catalogue to the uploaded data (see Calibration Method). Here one can specify a desired catalogue to match from the list of available filters/catalogues. For example, by selecting SDSS/r the system will forcibly try to match the uploaded catalogue to the stars from SDSS archive in r-band, however, if the object of interest (alert) and its neighbouring stars are not located within the footprint of SDSS, there will be not match and the calibration will fail. An option of any/r allows to force r-band filter, but the best matching archival catalogue will be found automatically, e.g. APASS/r. Also note that we offer some Johnson's (V,R,I) filters for SDSS data, as we created them from the original griz.
- **Dry Run** – if this option should be selected, the uploaded data point will not be stored in the database but the calibration will be performed as normal and its results will be displayed. Please

Follow-up Data Uploading Form

Event ID:

MJD OBS:

Exposure time (sec):

Comment(optional):

SExtractor catalog
(ASCII, FITS, FITS-
LDAC):

Choose File

No file chosen

Matching radius:

Force filter:

Dry Run (no data will be
stored in the database):

☐

Submit

Hi AnonymousFollowUpAccount!

Upload done from IP 131.111.70.231

EventId : lvo/lvo.caltech/voevent/cats#1111171350514156075

Ra : 171.9954

Dec : 36.34131

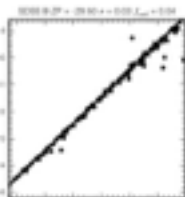
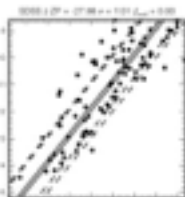
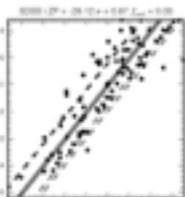
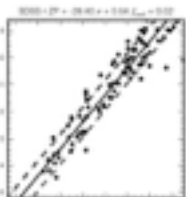
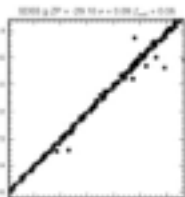
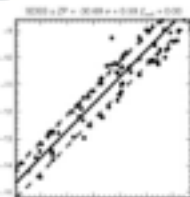
Filter: SDSS / B

Magnitude: 19.4128163479 +/- 0.0033 mag

ZP: -29.50 mag

Scatter: 0.03 mag

Plots:



use this option when not certain about the data, or not yet familiar with the System. A wrongly inserted data point can be removed later (see Deleting Point) if Dry Run was not selected.

Click the **Submit** button to start the calibration process.

The calibration screen will display information about the target (name, coordinates), followed by the name of the best matching (or forced) catalogue/filter. Then the derived magnitude and its error will be given. The error includes the systematic scatter between the uploaded data and matched catalogue with errors of the provided magnitudes added in quadrature. The zero point (ZP) found in the calibration will be printed and the scatter of the linear relation between provided magnitudes and catalogue magnitudes.

The calibration screen will also display the uploaded magnitudes of all matched stars and their catalogue magnitudes for all (if automatic filter determination) or single (if forced filter) catalogue/filter. The best matching catalogue/filter (or forced one) will be marked in red. If the submission was performed not in the Dry Run, the data point should then appear on the light curve display

1.6. Adding new target

Direct link: <http://gsaweb.ast.cam.ac.uk/followup/newevent>

If the object has no previous observations, it must be added through *Enter new event* option. After clicking the link, the page **Creating New Event Form**.



Fields here are as follows:

- IVORN - in this field user assigns the unique name to the object. As previously mentioned, it must be in a format `ivo://alert_name`
- RA - right ascension of the object; it is important to note that decimal format must be used here
- Dec - declination of an object in the decimal format
- URL - link to the event page on the Gaia Alerts site; it should be address http://gsaweb.ast.cam.ac.uk/alerts/alert_name/ although usually users mistakenly type here the alerts index page <http://gsaweb.ast.cam.ac.uk/alerts/alertsindex>

After correctly filling those fields click the submit button to add a new event to the database. After that it is possible to upload new points following steps described in the previous sections.

1.7. Deleting data point



Direct link: <http://gsaweb.ast.cam.ac.uk/followup/delpoint>

It is possible to delete points in CPCS by clicking the link *Delete a followup point from the system*. The procedure is rather straightforward as the only thing to do is to type the ID of the followup in

the form. The point will be removed from the database after clicking the submit button. One can only delete point added by himself, which means that he has to be logged in with exactly the same hashtag as the one used to upload the point.

2. AUTOMATIC ACCESS via scripts

In case of uploading multiple events and/or many points for every object, the automatization of the steps mentioned earlier is necessary. The uploading procedure is described in section 1.5 and this is the one that will benefit the most from the access via scripts. This access is possible through the *curl* command used with <http://gsaweb.ast.cam.ac.uk/followup/cgi/upload> address. the *-F* option allows to specify value for every field mentioned in section 1.5. The translation from actual fields names described in that section to ones understood by curl command is presented below:

- Even ID – EventID
- MJD OBS – MJD
- Exposure time – expTime
- SExtractor catalog – sexCat
- Matching radius – matchDist
- Force filter – forceFilter
- Dry Run – dryRun

The fragment of code presented below is an example of the automatic upload of every *.cat file in a current directory with a bash *for* loop. After the curl command, multiple *-F* options are used to fill fields of the form. Some values can vary for different frames or runs. That's why most of the options in the example are variables. The information about *MJD* and *expTime* are taken from the header (lines 387 and 390) of the image that was used to create a *.cat file. Of course, it requires an original image as *.cat files do not contain header from the original file. Moreover, as only *HJD* keyword is obtainable in this case, it needs to be converted to *MJD* for every frame (line 393). It is also convenient to let *dryRun* be set up from the command line - it allows for a quick inspection of the results. Note, that in this method hashtag has to be included as well, although one can provide it conveniently via the *-F* option, instead of logging in to the CPCS.

```

383     for fil in *.cat
384     do
385         core=`cut -f 1 -d '.' <<< $fil`
386
387         HJD=`gethead HELJD ${core}.fts`
388         fpath=`pwd`
389         id=$object
390         exp=`gethead EXPTIME ${core}.fts | cut -f 1 -d '.'`
391         filename=$fil
392
393         MJD=`echo "$HJD-2400000.5" | bc -l`
394
395         curl -F matchDist=2 \
396             -F MJD=$MJD \
397             -F expTime=$exp \
398             -F EventID="ivo://$id" \
399             -F sexCat="@${fpath}/${filename}" \
400             -F forceFilter=no \
401             -F "hashtag=${XXXXXXXXXXXXXXXXXXXXXXXXXXXX}" \
402             -F outputFormat=json \
403             -F noPlot=1 \
404             -F dryRun=$upload "http://gsaweb.ast.cam.ac.uk/followup/cgi/upload"
405
406         echo ""
407     done
408 
```

Sometimes it might be useful to delete a point in an automatised fashion. Although removing point from the database via webpage is already very simple, doing this 100 times can become a nuisance.

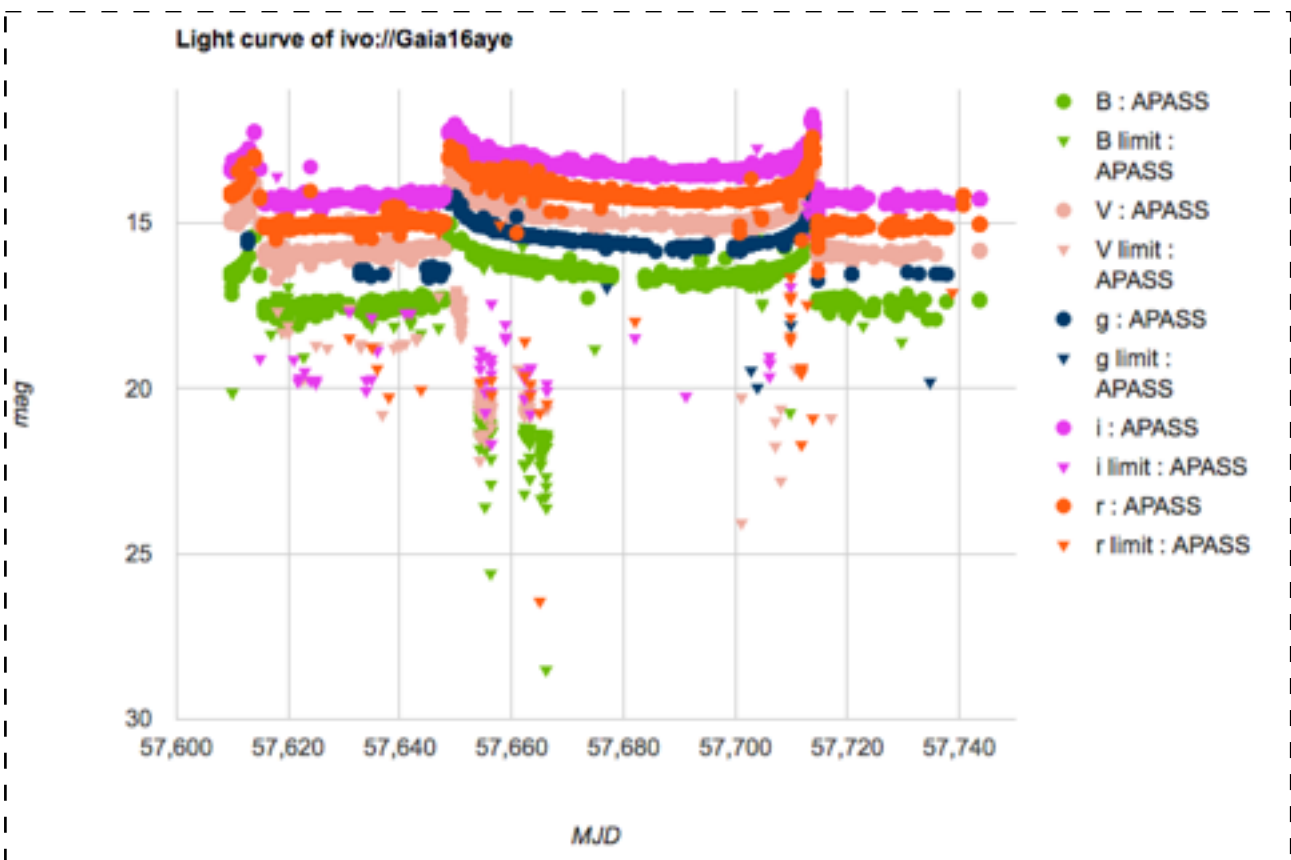
To delete the point the *curl* command will be useful again. As it was mentioned already, there are two requirements here: ID of an observation has to be specified and one has to be logged in with the same hashtag as was used for the upload. So the hashtag will be needed here as well. The example of the command allowing to delete point using the terminal is shown below.

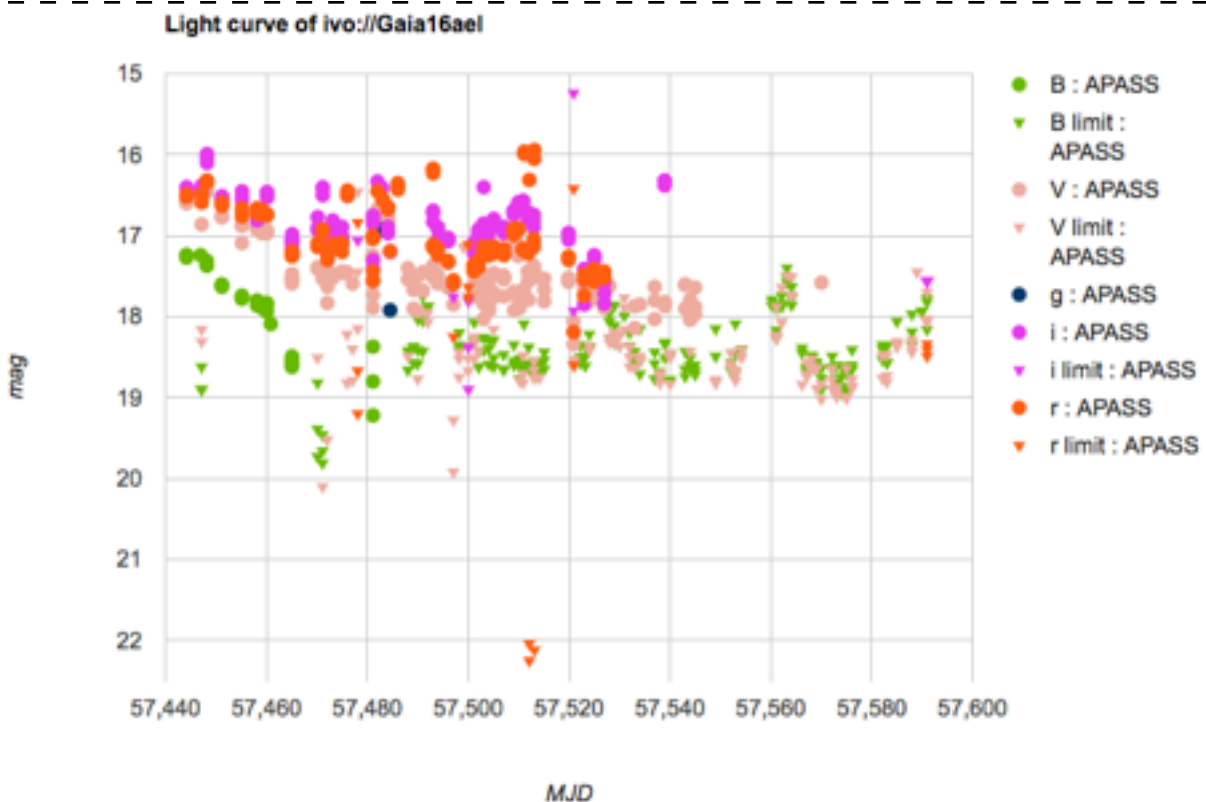
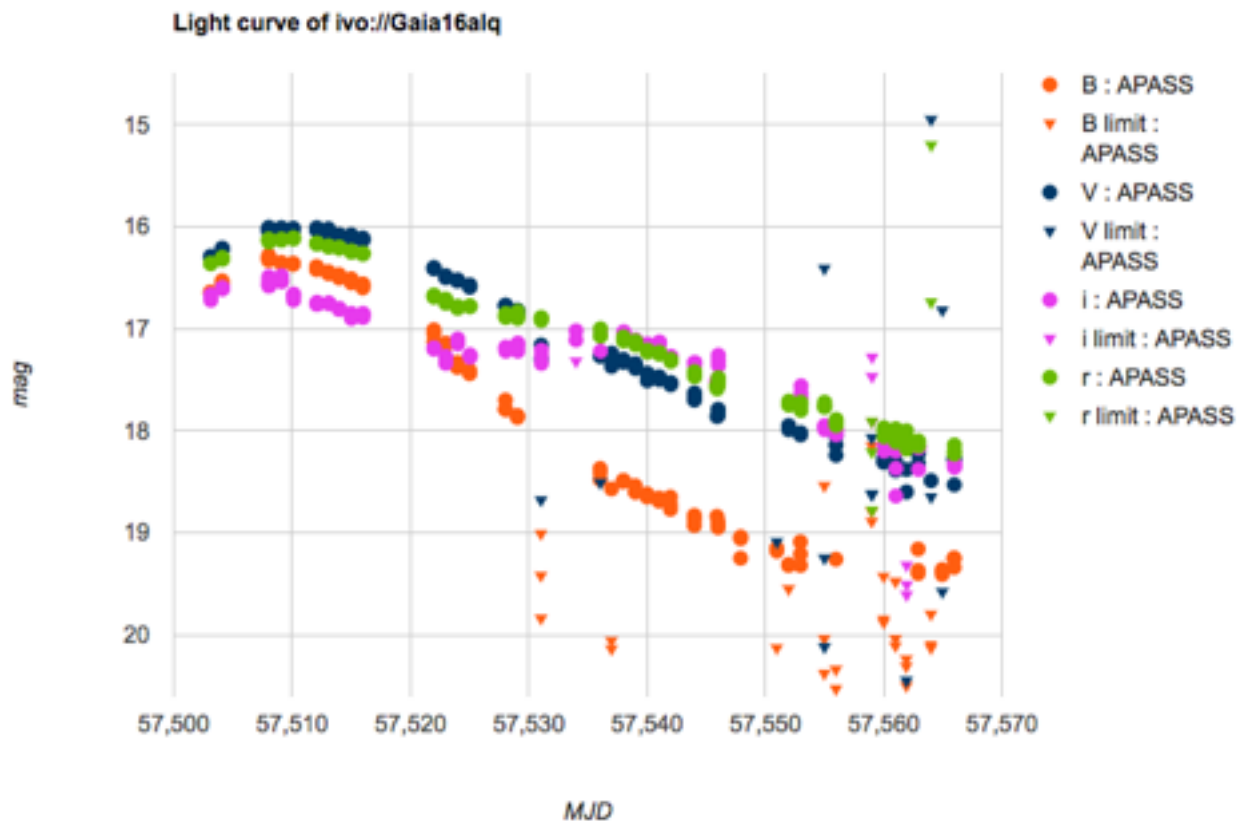
```
curl -F followupid=$id -F hashtag="..." http://gsaweb.ast.cam.ac.uk/followup/cgi/delpoint
```

TROUBLESHOOTING (selected problems):

1. Failed to match catalogues to data: increase the matching radius, or re-do your astrometry
2. Calibration not possible: double check if your catalogue file contains at least 5 stars for calibration and if the astrometry is ok; another possibility is that in the Force Filter mode you have selected a survey/filter which is not covering the part of the sky your target is located at.
3. The derived magnitude of the target is very low and the uncertainty is -1: it means that either your target has faded below your detection limit, then the magnitude is your image's upper limit; or your astrometry is wrong and the system failed to find your target in your catalogue file.

EXAMPLES





FUTURE PLANS

Calibration Server has been continuously upgraded, with new features being added (for example, deleting the data point was added after a request from some users). However, in near future we plan to develop a more advanced tool for photometric calibrations. Among the major planned improvements is the possibility to upload a fits file with the image, instead of the catalogue. It

means that the Server will be performing the astrometric solution and photometric measurements for objects on the image. We do not plan to reduce the images (bias,dark,flats) and we will expect the images to be already past that stage.

Another necessary improvement is inclusion of the colour-term in the calibration solution. The relation between observed instrumental magnitudes and these in the archival catalogue is not linear and depends on the colour of a star, with the reddest stars being most affected by this effect. The new steps will improve the quality of the photometry and will further reduce the offsets between observatories, present in the current version.