Employing the Technology of Virtual Observatory as the Fundamental Framework for the CCD Photometry Survey.

Petr Škoda[1], Filip Hroch[2], JiříNádvorník[3], Daria Mikhailova[3]

[1]Astronomical Institute, Academy of Sciences, Ondřejov, Czech Republic

[2]Masaryk University, Faculty of Science, Brno, Czech Republic

[3]Faculty of Informatics, Czech Technical University, Prague, Czech Republic

Abstract

The project of Ondřejov Southern Photometry Survey (OSPS) is an attempt to exploit the wealth of temporal information contained in multi-colour CCD photometry obtained with 1.54m Danish telescope at La Silla in remote observing mode by several groups of Czech astronomers working on different scientific programs and various primary targets.
The OSPS realizes the idea of an automatic extraction of multi-colour light curves from every celestial object identified in the frame, thus giving access to 99% of data normally disposed by the PI's, who usually measure only few targets in every CCD frame. The Virtual Observatory (VO) technology is exploited here as an integral part of previewing, data reduction, bookkeeping, method of analysis and publishing.

1 Introduction

The OSPS survey is a collection of CCD frames exposed in the framework of several science programs. We took the opportunity to demonstrate on this survey, reduced anyway by the standard methods (using comparison stars) the power of technology of Virtual Observatory based on standards of IVOA (International Virtual Observatory Alliance).
To facilitate the powerful visualisation of the original and calibrated CCD frames together with easy handling of large amount of measurements as well as the on-the-fly generated light curves, the interoperability between several VO-compatible applications (Aladin, Topcat and SPLAT-VO) are exploited based on Simple Application Message Protocol (SAMP).

2 Observations

In the Autumn 2012 the three independent groups of Czech astronomers started observations with 1.54m Danish telescope at La Silla (Fig. 1 and 2) in remote observing mode sharing part of time with Denmark. The only instrument used is the DFOSC camera with 2kx2k active area of CCD chip and two wheels containing the complete Johnson-Cousins UBVRI and Stromgren filter set. The projects are focused on photometry of individual minor planets, as well as the variability of binary stars and emission line stars, mostly in Magellanic clouds. Due to the small area (13x13 arcmin) of sky covered by the CCD frame, there are always very few targets of interest in the frame. In a classical reduction process would be more than 99% of information contained in the picture disposed, extracting only one or two numbers (magnitudes of target in a given filter), while we are in principle able to measure intensity of tens of thousands objects in every field.

Fig. 1: The dome of the Danish telescope DK154 at La Silla.

Fig. 2: The Danish telescope

3 Data Reduction

The key part of the OSPS project is the robust automatic reduction of CCD frames and automatic astrometry and photometry accomplished by the package MUNIPACK written by F.H.
Munipack is an astronomical software package which implements advanced methods for processing of digital frames. Developed algorithms take care on robustness and can work without any intervention.

3.1 Pipeline

OSPS archive stores observed frames as FITS files which are created by telescope control system in per-night directory structure intended for machine processing.
Data processing is started by classifying types of frames (bias, light, flat). Bias and flat-fields exposures are averaged and applied on scientific images. Next step is the detection of stars and the aperture photometry by slightly modified algorithms of DAOPHOT II. This way processed frames are used for both astrometry and photometry calibration.
As the result of the calibration, frames in photons in a standard filter of Johnson photometric system as well as tables of detected stellar objects are available for import to the Virtual Observatory engine, which provides standard user interface of OSPS.

3.2 Astrometry

The telescope control system includes rough information about position of centres of frames. This position can be used to set centre of cone search in reference catalogue UCAC4 and for the astrometry calibration.
The stars detected on frames are matched to the UCAC4 catalogue. The matching algorithm, which has been developed from scratch, uses the triangle similarity to be invariant against the basic affine transformation. The triangle space is searched by the back-tracking algorithm to get a sequence of stars. The length of the sequence is chosen carefully for highly reliable results which establish a set of stars to determine of a precise transformation.

3.3 Photometry

The estimate of the ratio of expected number of photons derived from a reference magnitude, reference flux density (per wavelength) for zero magnitude star and parameters of a filter is used to convert the image data in counts to photons in given filter (with optional transformation from instrumental to the standard filter). Photons can be easy transformed to another photometry quantity, especially to magnitudes. Moreover, this ratio can be used directly for construction of the multi-wavelength spectral distribution. The principles are similar to the calibration of HST WFPC cameras.

4 Database ingestion

The MUNIPACK-based pipeline writes astrometric positions and photon fluxes and magnitudes of all measured stars in a frame (Fig. 4) into the additional FITS extension containing binary table of measurements (see Fig. 3).

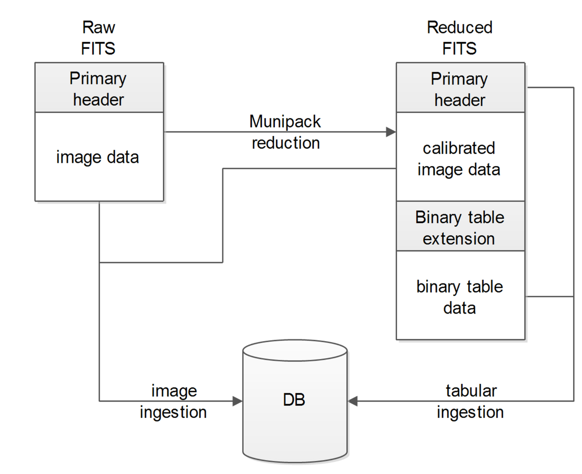

Fig. 3: The structure of the FITS files of CCD frames before and after reduction. Note the attachment of measured data in the binary table extension

It also replaces the raw WCS from telescope control system by new astrometric solution and writes the reduced (flat-fielded, bias-subtracted combined) frames into the primary data unit of FITS (see Fig. 4). The DaCHS VO publishing modules then read the image information and store their metadata in a image database for access by SIAP. The measurements extracted from binary tables are stored in another database (as a number of tables) which is queried by SCS and TAP protocols.

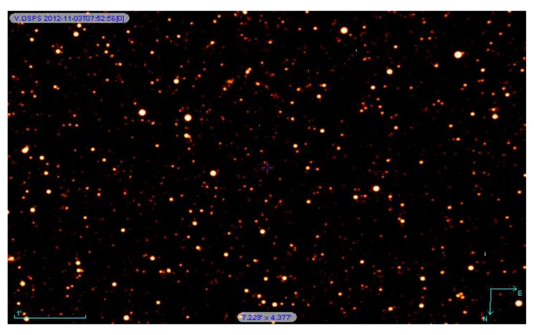

Fig. 4: Reduced image of part of SMC. The bias and flat field correction were applied and WCS corrected according to the astrometry

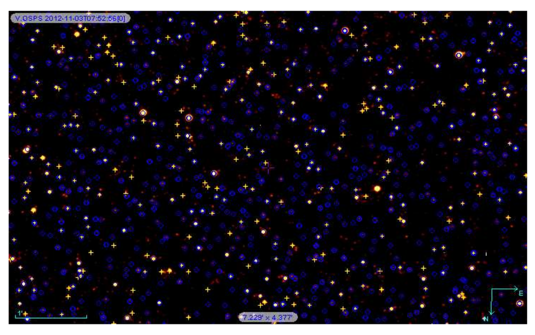

Fig. 5: The same image with marked all identified stars (yellow crosses) and objects cross-matched with ppmxl catalogue (blue circles)

5 Generation of the light curve

The light curve is simply created as a subset of photometric measurements of individual stars limited to given filter and ordered by middle time of exposure in a increasing order. The key problem is to create the cluster of the measurements belonging to exactly the same object. Even if we have the precise astrometric positions (with precision better than arsec), the identification of the same object may be difficult in denser regions and namely the objects with big positional errors may be misidentified. On the Fig. 6 there are shown three clusters of measured points — results of a cone search in a small circle. It is obvious that in each cluster should be the measurements of a one single star. As the precise astrometric positions still have small random error (see the zoomed cluster on Fig. 7), the positions must be limited to a very small circle (about 1 arcsec) to be able to get light curve of particular stars.

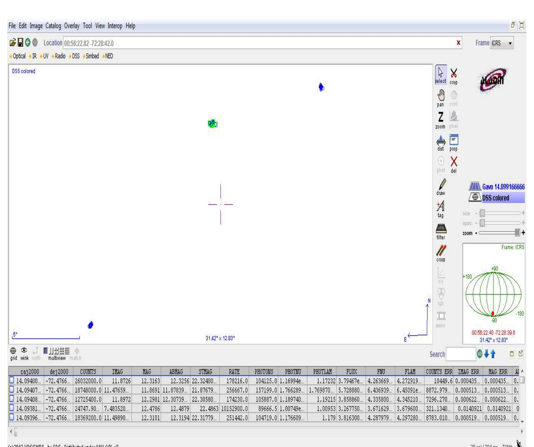

Fig. 6: The three clusters of measured points obtained by Simple Cone Search. Each one represents one stars

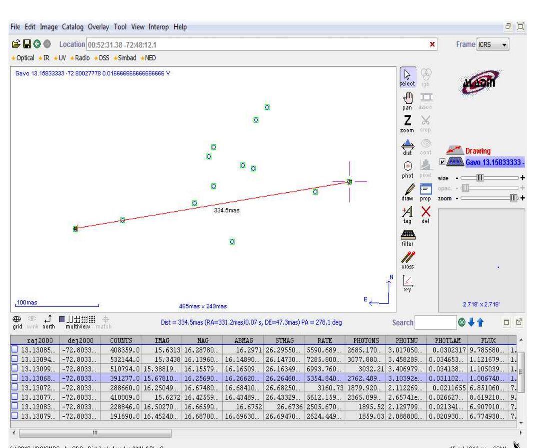

Fig. 7: The detailed zoom of one cluster of positions. The light curve is generated from these measurements

Another important issue is the unique object identifier, which is used as a primary key in databases. We tried to solve both problems using the reference catalogue with dense sky coverage. Currently we use the stars in *ppmxl* catalogue as a reference centres with which the cluster s of positions are cross-matched after pre-selection of points in a reasonably small circles around (see Fig. 8 and Fig. 5).

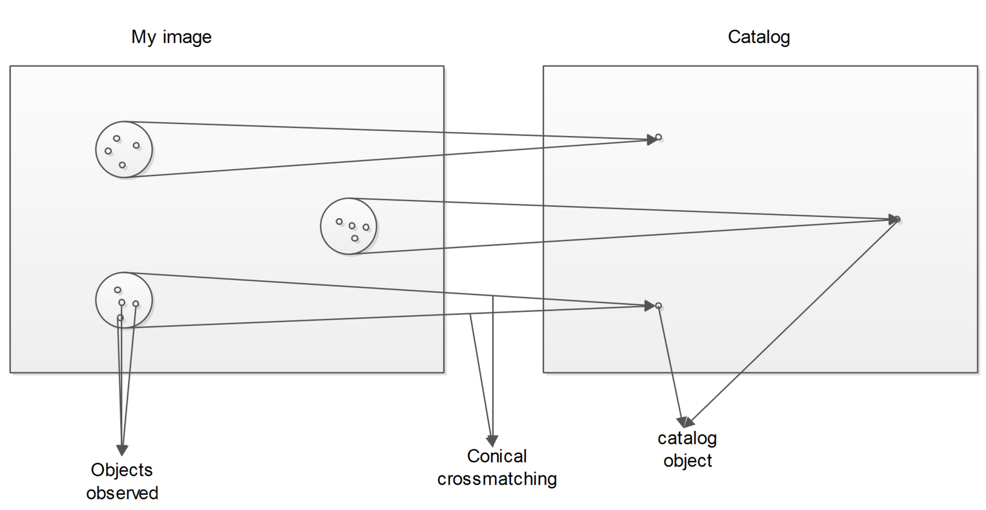

Fig. 8: The schema of cross-matching of clusters of positions with ppmxl catalogue

6 VO Publishing

The OSPS survey is accessible using multiple VO protocols thanks to the complexity and interconnected tables of the DaCHS VO servers suite written by Markus Demleitner. The basic observation (ObsCore) metadata and all the tables of measurements can be accessed with authenticated ADQL queries using Table Access Protocol (TAP). as well as Simple Cone Search (SCS). It may be used either from clients (e.g. Topcat) or directly in web browser using the web query form (Fig. 9) and returning results in HTML Table (see Fig. 10).

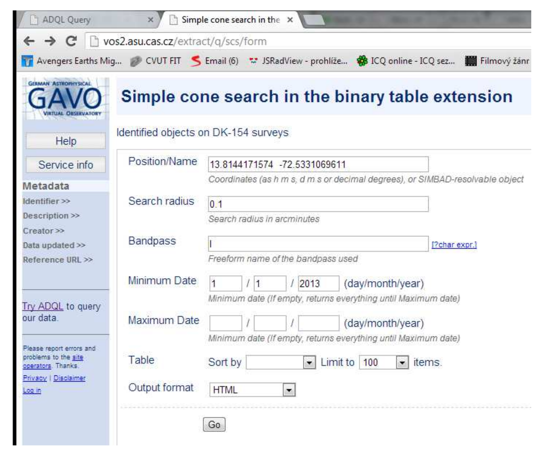

Fig. 9: Simple Cone Search query in web form

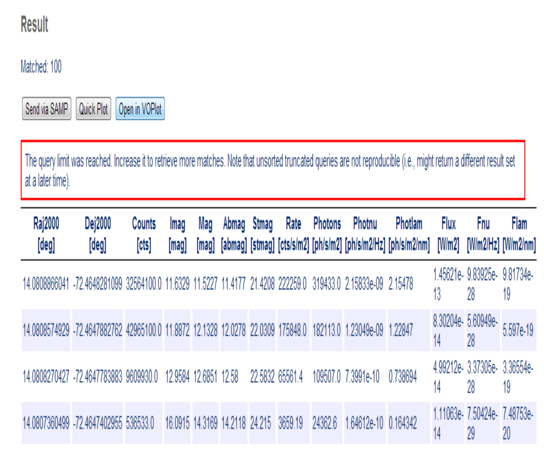

Fig. 10: Result of SCS query as a HTML table (shortened)

Both raw and reduced images are obtained (after authentication) with Simple Image Access Protocol (SIAP v.1) augmented by addition of selection according to the photometric filter name and date/time of observation. In addition to allow the public access to the images the degraded small pictures in png format are prepared during image ingestion. They have three times less pixel resolution and non-linear intensity quantisation applied in order to decrease their size from original 17MB to hundreds of KB and to increase the contrast and visibility of faint stars, while still preserving the coordinate system (WCS) implemented by the embedding of original FITS file header in a png comment space. Such images can be quickly loaded even over the slow internet connection and moreover the recovery of photometric measurements on such data is almost impossible. So the proprietary data are protected for the project consortium, still allowing the qualitative investigation of CCD frames (e.g. verification of transients) by the wide astronomical community.
The most straightforward visualisation of light curves is accomplished with a modified Simple Spectra Access Protocol (SSAP), where the spectral axis is replaced by time axis and the filter names (U,B,V,R,I) used in BAND parameter. See the Fig. 11 for an example query in SPLAT-VO and Fig. 12 as the output light curve.

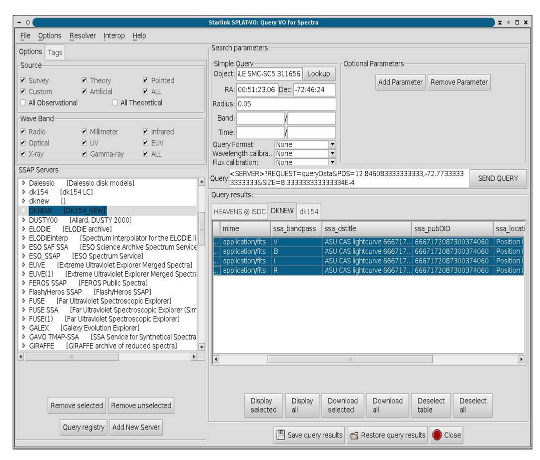

Fig. 11: The SSA query in SPLAT-VO returning BVRI light curves of SMC cepheid. Part of metadata of each light curve

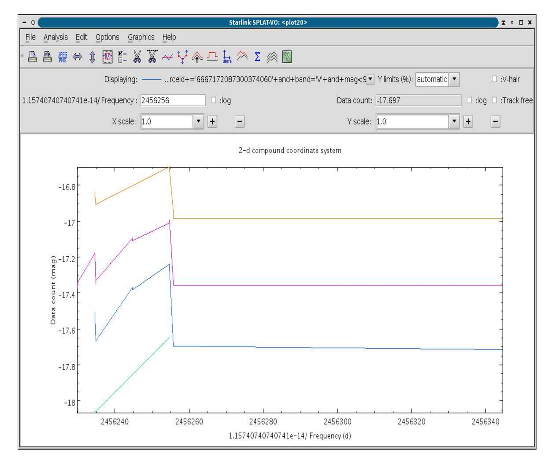

Fig. 12: The resulting BVRI light curves of SMC cepheid. The negative magnitudes are used for flipping the vertical axis

As the light curves need to be dynamically updated after the new observation point is added, the curves are not saved in file but created on-the-fly during the every query using the unique OSPS ID (currently equivalent to *ppmxl* ID). The query is sent as a SQL command as a part of the *accref* of a SSAP protocol.
The VO technology is used here as a principal framework having the standard data format and metadata description as well as powerful query interface and data access protocol. The really powerful engine for light curve analysis and visualisation then results as a aggregation of several VO services sharing their data using the SAMP standard. Thus we can achieve easily the otherwise very complex tasks like seeing the measured data, catalogue information and visualise the multicolour light curves of stars selected manually by multiple clicks in image of stellar cluster. We can as well display the raw image, processed image and all measurements in Aladin or e.g. study the light curves of objects selected after processing the table of catalogue or survey information. The capabilities of such VO-supported applications are almost unlimited.

Conclusions

Using the VO technology as the principal framework for the whole software project is very convenient for SW development, eliminating the need of delivering the visualisation and analysis tools and considerably reducing the amount of necessary custom code programing. It is also very convenient for users providing them with powerful tools, like Aladin, Topcat, SPLAT-VO and many others. This allows, for example, together with interoperability assured by Simple Application Message Protocol (SAMP), to display the light curve of any object randomly pointed at in Aladin, or massive processing of light curves of objects from selected region on the sky in SPLAT-VO, including the cutouts on time axis.

Acknowledgements

This work was supported by grants 13-08195S of Czech Science Foundation and LG12001 of Czech Ministry of Education, Youth and Sports as well as the project RVO:67985815.

Poster presented at ADASS 2013, 29th Sep. – 3th Oct, Waikoloa, Hawaii, USA