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25 Years of the Southern Skies Monitoring by OGLE

Workshop 4

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Abstract. The Optical Gravitational Lensing Experiment (OGLE) started at Las Campanas Observatory in 1992 with a pilot monitoring programme of two million stars in the Galactic Bulge. It is still operating today, collecting time-domain photometric data of a billion stars from the densest regions in the southern sky. Among its main achievements are discoveries of thousands of microlensing events, a few dozen extrasolar planets and candidates for black holes, a million variable stars, and thousands of quasars and supernovæ. It has made a major contribution to the studies of the dark-matter content of the Milky Way halo, the structure of the Galactic Bulge, the Magellanic Clouds, and new classes of variable stars. In this its 25$^{\rm th}$ anniversary year, we presented a selection of the major scientific highlights of OGLE.

Keywords. Surveys

OGLE is one of the longest-running large-scale observational surveys. It uses a dedicated 1.3-m telescope built in 1996, located at Chile's Las Campanas Observatory (which is operated by the Carnegie Institution for Science). Currently in its fourth phase (OGLE-IV), since 2010 OGLE has employed a 32-chip CCD mosaic camera with a total field of view of 1.4 sq. deg (Udalski *et al.* 2015). The total sky area covered is about 3500 sq. deg, and includes about 1.3 billion sources located in the densest stellar regions of the southern sky, namely the Galactic Bulge, the Galactic Disk and the Magellanic Clouds. Some areas of the sky have been monitored continuously since 1992; an example is given in Fig. 1.

During this workshop we presented a selection of important highlights of OGLE's science output achieved over the last 2.5 decades.

1. Dark Matter and Dark Lenses

The main founding scientific motivation for OGLE was to detect microlensing events due to massive dark-matter objects in Milky Way's halo (e.g., in the form of primordial black holes), following Paczynski's suggestion (Paczynski 1986). However, 13 years of monitoring of the Large and Small Magellanic Clouds (LMC, SMC) yielded only 8 microlensing candidates instead of the many dozens expected in a dark-matter halo filled with dark compact objects with masses of about 0.4 $M_{\odot}$. The optical depth derived for the LMC was $\tau_{LMC} = 0.43 \pm 0.33$ and 0.16 ± 0.12, which is in a good agreement with expectations of self-lensing (Sahu 1994), where all the events can be explained by stars of the LMC lensing more distant stars of the LMC (Wyrzykowski *et al.* 2009, Wyrzykowski *et al.* 2010, Wyrzykowski *et al.* 2011a, Wyrzykowski *et al.* 2011b). OGLE continues its monitoring

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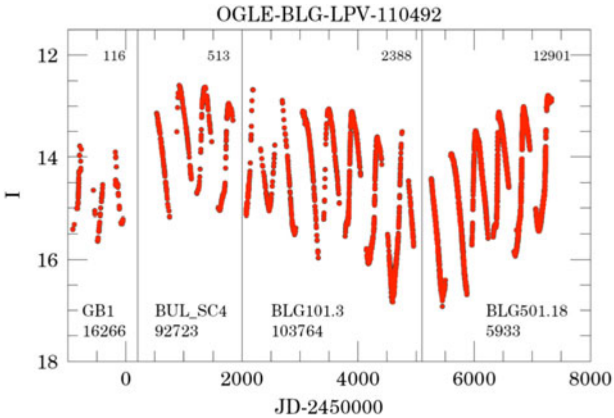

Figure 1. An example of 25 years of photometric data of a Long-Period Variable in the Bulge, covered by all phases of the OGLE project (separated by vertical lines). The numbers at the top indicate the number of I-band data points collected in each phase. The internal field and the star ID are given at the foot.

of the Magellanic Clouds, and now with more than 20 years of data a much tighter constraint on the lack of compact dark-matter halo objects can be derived.

Nearly 20,000 microlensing events have been discovered towards the Galactic Centre (Udalski *et al.* 1993). Among them were four candidates for lensing black holes (Mao *et al.* 2002; Wyrzykowski *et al.* 2016). A preliminary distribution of the masses of dark lenses hints that there is no mass gap between Galactic neutron stars and black holes.

2. Planets

With its high-cadence observations of the Bulge, OGLE discovers and characterises at least a few microlensing planets every year (e.g., Bond *et al.* 2004, Udalski *et al.* 2005, Udalski *et al.* 2015). Moreover, the OGLE-IV survey is sensitive to planets at very wide orbits or even planets with no host stars. Recently re-analysed microlensing data for free-floating planets have shown that there is no excess of such planets in the Jupiter-mass range. However, there might be an additional population of Earth-like planets (Mróz *et al.* 2017).

OGLE has also pioneered the technique of discovering planets via their transits across their host stars. Even by 2001, OGLE had monitored millions of stars, and could recognise a planetary transit if a star's brightness dimmed briefly (Udalski *et al.* 2002).

3. Variable Stars

The largest natural yield from a long-term, wide-scale survey like OGLE is the discovery of a great many new variable stars. OGLE has revolutionised this field, recognising more than a million new variables, thereby increasing the previous records by orders of magnitude and also providing cases of rare (e.g., Rattenbury *et al.* 2015) and new types of variable stars. For example, completing the cataloguing of classical Cepheids in the Magellanic Clouds has concluded the work of Henrietta Leavitt, which was started a century ago (Soszyński *et al.* 2017). These types of variable stars can help us understand the structure of the Clouds (e.g., see Jacyszyn-Dobrzeniecka *et al.* 2016). Tens of thousands of RR Lyrae-type stars have been found in the Galactic Bulge (Soszyński *et al.* 2014); they have then been used to decipher the structure of the old bar and to measure the distance to the centre of the Galaxy (Pietrukowicz *et al.* 2015). Blue Large-Amplitude Pulsators

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(BLAPs) is a newly-recognised class of hot stars; with periods of 20–40 min and amplitudes of 0.2–0.4 mag, they are thought to be low-mass evolved stars (Pietrukowicz *et al.* 2017).

4. Transients and Extragalactic Science

Long-term time-domain data are excellent for detecting short-lived phenomena like microlensing events. OGLE is also finding many other types of transients, such as the spectacular stellar merger V1309 Sco (Tylenda *et al.* 2011), numerous dwarf and classical novæ (Mróz *et al.* 2015) and novæ switching types (Mróz *et al.* 2017). Known transients and unusual variables, including X-ray binaries, R Coronae Borealis-type stars or dwarf novæ that are within the OGLE footprint, are monitored; the data are available within a day, on the OGLE website (Udalski 2008).

Since 2012 OGLE has been conducting a regular search for extragalactic transients (Wyrzykowski *et al.* 2014), and has discovered more than 1000 supernovæ, including cases of rare types (Inserra *et al.* 2015) and candidates for tidal disruption events (Wyrzykowski *et al.* 2017). Hundreds of new quasars have been detected by virtue of their long-term photometric variability (Kozłowski *et al.* 2013), and one strongly lensed one (Kostrzewa-Rutkowska *et al.* 2018). The Einstein Cross lensed quasar (Q2237+0305) has been monitored continuously since 1997 (Woźniak *et al.* 2000; Udalski *et al.* 2006).

5. Conclusions

OGLE is continuing its service of monitoring the densest stellar areas of the southern sky. Its data gradually become accessible by the community after careful cleaning and analysis. The source of the OGLE data, and updates on the survey and its discoveries, are available at the OGLE website: http://ogle.astrouw.edu.pl.

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