Massive Variability Search and Monitoring by OGLE and ASAS

Bohdan Paczyński
Princeton University, Princeton NJ 08544, USA

Abstract. OGLE and ASAS are long term observing projects operated by the Warsaw University Observatory at the Las Campanas site in Chile. OGLE is currently monitoring almost 200 million stars in the Galactic Bulge and the Magellanic Clouds, and has detected so far almost 1,000 events of gravitational microlensing with the dedicated 1.3-meter telescope. ASAS uses several very small instruments to monitor all southern sky for variability down to approximately 14 magnitude. A total of almost 300 thousand variable stars were discovered so far by the two projects, and all photometric data is available on the WWW. Both projects aim at real time recognition and verification of all new phenomena in the sky. OGLE is likely to discover planets by 2003 and stellar mass black holes by 2004-2005. All OGLE and ASAS data is made public domain as soon as possible, and may be used by a Virtual Observatory.

1 OGLE - Past and Present

OGLE (Optical Gravitational Lensing Experiment, the leader: Andrzej Udalski) is a long term project, with a gradual expansion of its capability. The dedicated 1.3 meter telescope is located at the Las Campanas Observatory in Chile, a site owned and operated by the Carnegie Institution of Washington. OGLE is operated by the Warsaw University Observatory. Information about it may be found at:

OGLE: http://sirius.astrouw.edu.pl/~ogle/
OGLE: http://bulge.princeton.edu/~ogle/

OGLE-III is the current, third stage of the project. The observations are done with a mosaic 8K × 8K CCD camera built by A. Udalski. OGLE-III began in May 2001. In the 2002 Galactic Bulge season almost 400 candidate microlensing events were discovered:

OGLE-EWS: http://sirius.astrouw.edu.pl/~ogle/ogle3/ews/ews.html

A search for planetary transits was conducted on 32 nights during a 45 day interval in 2001. A total of 59 stars were identified, for which low depth flat bottom transits with orbital periods shorter than 10 days were found (Udalski et al. 2002a,b). Some of these are likely caused by 'hot Jupiters', others by brown and red dwarfs.

The analysis of OGLE-II stage (Udalski, Kubiak & Szymański 1997), which covered years 1997-2000, is advanced, and almost all data is in public domain. This includes catalogs of I, V, B magnitudes and positions for a total of almost 40 million stars in the Galactic Bulge, and in the Magellanic Clouds (Udalski
et al. 2002c, 2000b, 1998a), catalogs of over 500 microlensing events (Udalski et al. 2000a, Woźniak et al. 2001), catalogs of over 270 thousand variable stars (Zebruń et al. 2001, Woźniak et al. 2002), and in particular thousands of eclipsing binaries in the SMC (Udalski et al. 1998a) and Cepheids in the LMC and SMC (Udalski et al. 1999a,b). In addition OGLE astrometry provided proper motion measurements of thousands of stars (Soszyński et al. 2002, Sumi et al. 2002), leading to the discovery of streaming motion (rotation) in the Galactic Bar.

Of particular interest are special microlensing events. OGLE-2000-BUL-43 was found to have a spectacular parallax effect (Soszyński et al. 2001). Even more dramatic was OGLE-1999-BUL-19, the first event with multiple peaks in its apparent brightness caused by the Earth’s orbital motion and a very long time scale: \( t_E = R_E/V = 372 \) days (Smith et al. 2002). Even longer time scales were found for OGLE-1999-BUL-32 (Mao et al. 2002, \( t_E = 641 \) days and OGLE SC 5 2859 (Smith 2002, \( t_E = 551 \) days). The last two events are likely caused by massive lenses, probably stellar mass black holes.

## 2 ASAS - Past and Present

ASAS (All Sky Automated Survey, the leader: Grzegorz Pojmański) is a long term project, with gradual expansion of its capabilities. Currently it has 4 small instruments, with apertures of 2 cm, 7 cm, 7 cm, and 20 cm, all located at the Las Campanas Observatory in Chile, at a site owned and operated by the Carnegie Institution of Washington. ASAS is operated by the Warsaw University Observatory. Information about it may be found at:

ASAS: [http://www.astrouw.edu.pl/~gp/asas/asas.html](http://www.astrouw.edu.pl/~gp/asas/asas.html)

All four instruments use as detectors Apogee 2K×2K CCD cameras. The two instruments with 7 cm aperture cover all sky every two nights in standard V and I filters down to about 14 magnitude. A total of over 6 thousand variables was discovered so far by ASAS (Pojmański 1998, 2000, 2002), and all photometric data are on the WWW.

All instruments are fully robotic, with some support provided by the OGLE observers.

## 3 Future of OGLE and ASAS

Both projects aim at real time data processing, and in particular at real time recognition and verification of any new events in the sky, among them microlensing events, supernovae, novae, dwarf novae, stellar flares, GRB afterglows, etc.

Two specific goals of OGLE are: a firm detection of microlensing by planets, and by stellar mass black holes. So far stellar mass black holes were suggested as lensing masses for several long microlensing events (Bennett et al. 2002, Mao et al. 2002, Smith 2002), but evidence is not conclusive. No definite planetary
microlensing event has been discovered so far (cf. Bennett et al. 1999, Albrow et al. 2000, Gaudi et al. 2002).

Inspecting almost 400 microlensing events reported by OGLE-III EWS (Early Warning System) in 2002 Jaroszyński & Paczyński (2002) noticed that the event OGLE-2002-BLG-055 has a single data point deviating from otherwise smooth microlensing light curve by 0.6 magnitudes, while the photometric errors were about 0.01 magnitude. Dr. Udalski kindly examined the CCD image and found that there was nothing wrong with it, i.e. the bright point appears to be real. As nearby data points show no obvious departure from a smooth light curve a plausible interpretation of the phenomenon is in terms of a binary lens with a very extreme mass ratio. While a unique value of the mass ratio cannot be determined from so sparse time coverage, a good fit to all data was obtained for the mass ratio of 0.01 and 0.001, indicating a planetary mass companion to a stellar mass lens. Obviously, it is not possible to make a strong claim based on a single data point, but a modest modification of the future OGLE observing procedure will provide a far better coverage of future planetary events. There are typically only several hundred stellar microlensing events unfolding at any given time, compared to over 150 million stars monitored on a given night. Small CCD sub-frames covering known events can be processed within minutes of data acquisition. When an anomalous data point is noticed the observation of the field will be repeated. If the anomaly is confirmed the field will be observed every 30 or 60 minutes, to provide a good coverage of the rapidly changing brightness, and allowing a unique determination of the mass ratio. We expect that OGLE-III EWS system will have this capability by the spring of 2003 (A. Udalski, private communication), and it is likely that the first definite planetary microlensing event will be detected in 2003.

At the opposite end of the lens mass spectrum are the very long duration events, which are plausible candidates for stellar mass black holes. Currently two independent lens parameters can be determined for long events with the OGLE-III photometry: the event time scale $t_E$ and the magnitude of the parallax effect. One additional parameter: the angular separation between the two images, or the astrometric shift in the combined light centroid is needed to determine uniquely the lens mass. It will be possible to make such measurements with the future VLT Interferometer (Delplancke et al. 2001, Segransan et al. 2002), or with the existing HST. A massive lens like the one associated with OGLE-1999-BUL-32 had the two images separated by several milli arc seconds (Mao et al. 2002, eq. 9), leading to the centroid motion of a comparable amount. This astrometric effect is within easy reach of the HST (e.g. Benedict et al. 2002). The long events last several years, and with the OGLE-III data rate there will be several of them unfolding at any given time within several degrees of the Galactic center. Very likely the VLTI and/or HST observations may be scheduled in advanced, with no need for the TOO (Target of Opportunity) mode of operation. Little is known about the number and the distribution of stellar mass black holes in the Galaxy, and the range of their masses. OGLE is likely to lead to the first definite mass determination in 2004 - 2005.
We expect that OGLE as well as ASAS will expand their capability in the future. There are no definite and specific plans for the expansion, but there is a general idea how to proceed. A natural step to OGLE-IV would be another 1.3 - 1.8 meter telescope with a CCD camera with a total of \( \sim 1 \) giga pixels, i.e. an instrument with the data rate 16 times higher than current OGLE-III. The data rate is the single most important parameter for the search and/or monitoring projects like OGLE and ASAS. For ASAS we expect more frequent all sky coverage, with a more gradual increase in its depth. A virtue of bright transients is that they may be followed up for a longer time, in greater detail and with more instruments than faint transients can. Obviously, bright transients are rare, hence the need for all sky coverage and a frequent time sampling.

It is a pleasure to acknowledge the support by NSF grants AST 9820314 and AST 0204908, and NASA grant NAG5-12212.

To appear in: “Towards an International Virtual Observatory”, June 2002, Garching bei München (Germany), eds. Górski K. M. et al, ESO conference series.

References

1. Albrow, M. D. et al. (PLANET) ApJ, 534, 894 (2000)
2. Bennett, D. P. et al. Nature, 402, 57 (1999)
3. Bennett, D. P. et al. (MACHO) ApJ, 579, 639 (2002)
4. Benedict, G. et al. (HST) AJ, 124, 1695 (2002)
5. Delplancke, F., Górski, K. M., & Richichi, A. (VLTI) A&A, 375, 701 (2001)
6. Gaudi, B. S. et al. (PLANET) ApJ, 566, 463 (2002)
7. Jaroszyński, J., & Paczyński, B. astro-ph/0212022 (2002)
8. Mao, S. et al. (OGLE) MNRAS, 329, 349 = astro-ph/0108312 (2002)
9. Pojmanski, G. (ASAS) AcA, 48, 35 = astro-ph/9802339 (1998)
10. Pojmanski, G. (ASAS) AcA, 50, 177 = astro-ph/0005236 (2000)
11. Pojmanski, G. (ASAS) astro-ph/0210283 (2002)
12. Segransan, D. et al. (VLTI) astro-ph/0211647 (2002)
13. Smith, M. C. submitted to MNRAS (2002)
14. Smith, M. C. et al. (OGLE) MNRAS 336, 670 = astro-ph/0206503 (2002)
15. Soszyński, I. et al. (OGLE) ApJ, 552, 731 = astro-ph/0102114 (2001)
16. Soszyński, I. et al. (OGLE) AcA 52, 143 = astro-ph/0201281 (2002)
17. Sumi, T., Eyer, L., & Woźniak, P. R.: astro-ph/0210831 (2002)
18. Udalski, A., Kubik, M., & Szymański, M.: AcA 47, 319 = astro-ph/9710001 (1997)
19. Udalski, A. et al. (OGLE): AcA 48, 147 = astro-ph/9806313 (1998a)
20. Udalski, A. et al. (OGLE): AcA 48, 563 = astro-ph/9812558 (1998b)
21. Udalski, A. et al. (OGLE): AcA 49, 223 = astro-ph/9908317 (1999a)
22. Udalski, A. et al. (OGLE): AcA 49, 437 = astro-ph/9912096 (1999b)
23. Udalski, A. et al. (OGLE): AcA 50, 1 = astro-ph/0002415 (2000a)
24. Udalski, A. et al. (OGLE): AcA 50, 307 = astro-ph/0010150 (2000b)
25. Udalski, A. et al. (OGLE): AcA 52, 1 = astro-ph/0201377 (2002a)
26. Udalski, A. et al. (OGLE): AcA 52, 115 = astro-ph/0207133 (2002b)
27. Udalski, A. et al. (OGLE): AcA 52, 217 = astro-ph/0210275 (2002c)
28. Woźniak, P. R. et al. (OGLE): AcA 51, 175 = astro-ph/0106474 (2001)
29. Woźniak, P. R. et al. (OGLE): AcA 52, 129 = astro-ph/0201377 (2002)
30. Zebruń, K. et al. (OGLE): AcA 51, 317 = astro-ph/0110023 (2001)