Mem. S.A.It. Vol. 77, 265

Memorie della

Results of the OGLE-II and OGLE-III surveys

I. Soszyński[1,2]

[1] Warsaw University Observatory, Al. Ujazdowskie 4, 00-478 Warszawa, Poland
[2] Universidad de Concepción, Departamento de Fisica, Casilla 160–C, Concepción, Chile
e-mail: soszynsk@astrouw.edu.pl

Abstract. We present the most important results concerning variable stars obtained during the second and the third stage of the Optical Gravitational Lensing Experiment (OGLE). Since 1997 about 10^{11} photometric points for about 200 million stars in the Galaxy and Magellanic Clouds have been collected. Among them there is a full variety of variable stars of all types: Cepheids, RR Lyrae stars, pulsating Red and Blue Giants, eclipsing and ellipsoidal variables, cataclysmic variables, planetary transits, and many others. The photometric data of all identified variables are available to the astronomical community from the OGLE Internet Archive.

Key words. Surveys – Catalogs – Magellanic Clouds – Galaxy: bulge

1. Introduction

The Optical Gravitational Lensing Experiment (OGLE) began in 1992 and is continuing until now. The original idea of the survey was monitoring millions of stars in the Milky Way and Magellanic Clouds with the aim of detecting the gravitational microlensing events. The idea of employing the microlensing phenomena for the dark matter search was proposed by Paczyński (1986). Collected long-term photometric data of millions of objects are an ideal material for studying a wide variety of variable stars.

The first stage of the survey (OGLE-I) was conducted with the 1-m Swope telescope at the Las Campanas Observatory, Chile, (operated by Carnegie Institution of Washington) with 2048 × 2048 Ford/Loral CCD camera. The most important scientific results of the first phase of the project were: discovery of the first microlensing event toward the Galactic Bulge, discovery of the first binary microlensing event, the first determination of the optical depth for microlensing toward the Galactic center, catalogs of variable stars in the Galactic center, globular clusters and dwarf galaxies.

This paper presents the main results concerning variable stars achieved during the second and the third phases of the OGLE survey, both conducted with the 1.3-m Warsaw Telescope located at the Las Campanas Observatory, Chile. The OGLE-II stage started in January 1997, and continued until 2000. The telescope was equipped with the "first generation" 2048 × 2048 thin CCD camera working in a driftscan mode. In 2001 the camera was replaced with an eight chip 8192 × 8192 mosaic, and the third stage of the survey started. Currently, the OGLE survey monitors in real time the luminosities of about 200 million stars with mmag accuracy. More information about the data analysis systems can be found in Udalski (2003).

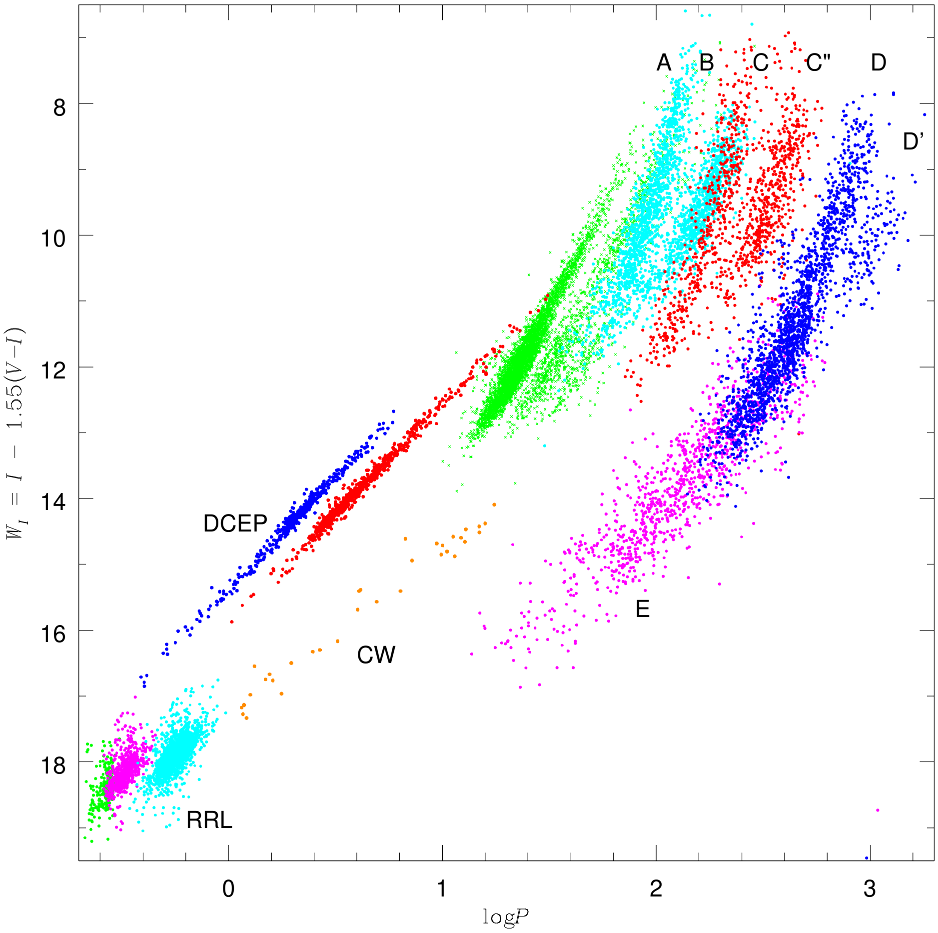

Fig. 1. Period–luminosity diagram for some types of variable stars discovered by OGLE in the LMC. Different colors indicate different types of variables: RR Lyr stars (RRab, RRc, RRe), Classical Cepheids (FU, FO), Population II Cepheids, OGLE Small Amplitude Red Giants, Semi-Regular Variables, Miras, Long Secondary Periods and Ellipsoidal Variables.

2. Variable stars

The OGLE survey has yielded a particularly rich harvest of variable stars. Fig. 1 presents the period-luminosity (*PL*) diagram of some types of variables in the LMC classified and published by the OGLE group. One can see here RR Lyrae stars, classical Cepheids, population-II Cepheids, and a variety of types of red giants.

2.1. RR Lyrae stars

The OGLE team published catalogs of 7600 RR Lyr stars in the LMC (Soszyński et al. 2003) and 570 objects in the SMC (Soszyński et al. 2002). 2600 RR Lyrae variables were found by Mizerski (2003) in the OGLE fields in the Galactic Bulge. The largest (so far) samples of double-mode RR Lyr stars were also found in the Magellanic Clouds: 230 objects

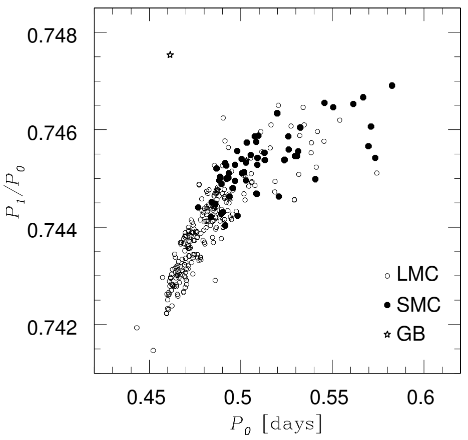

Fig. 2. Petersen diagram for double-mode RR Lyr stars in the LMC, SMC and the Galactic Bulge.

in the LMC and 57 in the SMC (Fig. 2). In the LMC three RR Lyr stars which simultaneously show an eclipsing binary variability were found. Two of them have a chance to be binary systems with RR Lyrae star as one of the components. If confirmed, the empirical determination of parameters of RR Lyr stars will be possible for the first time.

2.2. Cepheids

The catalogs of Classical Cepheids in the Magellanic Clouds were published by Udalski et al. (1999acd) and Soszyński et al. (2000). One of the most important results was the discovery of 13 single-mode second-overtone Cepheids in the SMC (Udalski et al. 1999b). Besides, about 50 Population II Cepheids were published in the Magellanic Clouds (Udalski et al. 1999cd), and the same number of these variables were discovered by Kubiak & Udalski (2003) in the Galactic Bulge.

However, this topic is far from being closed yet, as shown in papers by Moskalik, Kołaczkowski & Mizerski (2004), who found in the OGLE data triple mode Cepheids in the LMC, or the recent discovery of Buchler et. al (2005), who used MACHO and OGLE data to select eight ultra-low amplitude Cepheids which are supposed to be entering or exiting the instability strip.

2.3. Long Period Variables

Huge samples of OGLE Small Amplitude Red Giants, Semi-Regular Variables, Miras, stars with Long Secondary Periods (LSP) and Ellipsoidal Red Giants were selected using the OGLE databases. These objects follow a series of sequences in the *PL* diagram (Fig 1).

In both Magellanic Clouds about 18000 small amplitude pulsating red giants were discovered (Soszyński et al. 2004a). A similar number of these objects was found by Wray, Eyer & Paczyński (2004) in the Galactic Bulge. We analyzed secondary periodicities of these poorly known pulsators, and showed that they constitute a separate type of variable stars, different than “classic” Semi-Regular Variables. Moreover, it was shown that red giants below the tip of the Red Giant Branch can be empirically divided into RGB and AGB stars, because both groups follow different *PL* relationships.

The second group analyzed in detail were ellipsoidal red giants in the LMC (Soszyński et al. 2004b). For the first time such a large group (1500 objects) of long period ellipsoidal variables was selected (only a few such objects were known before). These stars follow a *PL* relationship, which is the projection of the radius–luminosity relation for red giants. The scatter of the *PL* relation is correlated with the amplitude of variability – the larger the amplitude, the smaller the scatter.

It was shown that the *PL* sequence of ellipsoidal giants is a direct continuation of the Long Secondary Periods (LSP) sequence – a still unexplained phenomenon observed for at least 30% of Semi-Regular and Small Amplitude Red Giants. It may suggest that the LSP phenomenon is related to binarity. Besides it was found that some of the ellipsoidal variables exhibit simultaneously small amplitude pulsations. Thus, in some cases, the LSP phenomenon can be explained by ellipsoidal variability. About 10% of ellipsoidal red giants reveal clear deformation by the eccentricity of the orbits (Fig. 3). This sample may become an important test of tidal circularization theories.

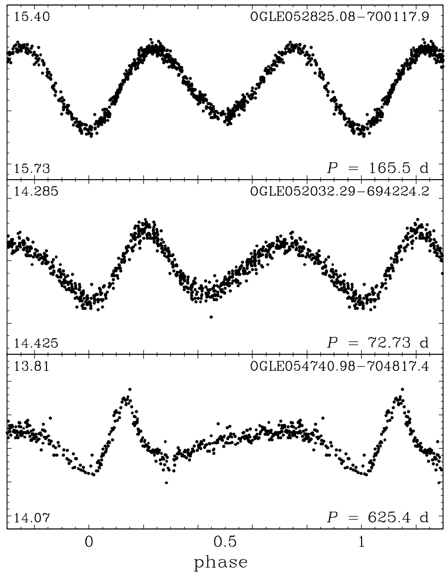

Fig. 3. Light curves of three ellipsoidal red giants in the LMC. The light curves are ordered according to the increasing eccentricity of the orbits.

3. Data availability

The data collected by the OGLE survey constitute a very accurate, long baseline, standard photometry suitable for many astronomical projects. Hundreds of papers which used the OGLE data were published. The policy of the OGLE group is to make the data available to the wide astronomical community. Till now, the general catalogs of variable stars in the Magellanic Clouds (Żebruń et al. 2001) and Galactic Bulge (Woźniak et al. 2002), and photometry maps of the OGLE-II fields (Udalski et al. 1998, 2000, 2002) were published. These data are available to the astronomical community from the OGLE Internet archive:

http://ogle.astrouw.edu.pl/
ftp://ftp.astrouw.edu.pl/ogle/

or its US mirror:

http://bulge.princeton.edu/~ogle/
ftp://bulge.princeton.edu/ogle/

However, the whole photometric data set collected by OGLE-II will be available publicly soon. The total of over 10 billion measurements of about 40 million objects in the Galactic Bulge and the Magellanic Clouds will be available from the WWW page:

http://transit.astrouw.edu.pl/~ogle/photdb/

A very "user friendly" interface allows to select stars fulfilling any set of criteria, e.g. coordinates, mean brightness, errors, etc. The details of the system with the service manual are described by Szymański (2005).

4. Future prospects

All the catalogs presented before were originated in the OGLE-II projects or in the OGLE-II supplemented by the OGLE-III data. It means that the catalogs covered only central parts of the Magellanic Clouds and selected regions of the Galactic Bulge. The OGLE-III survey monitors an order of magnitude larger area: about 85 square degrees in the Galactic Bulge, 38 square degrees in the LMC and 13 square degrees in the SMC. In the time scale of one year or two the new catalogs of variable stars, complete down to $I = 19$ mag, will be prepared and published.

Acknowledgements. The paper was partly supported by the Polish KBN grant 2P03D02124 to A. Udalski. Partial support to the OGLE project was provided with the NSF grant AST-0204908 and NASA grant NAG5-12212 to B. Paczyński.

References

Buchler, J.R, Wood, P.R., Keller, S., & Soszyński, I. 2005, *astro-ph/0506114*
Kubiak, M. & Udalski, A. 2003, Acta Astronomica, 53, 117
Mizerski, T. 2003, Acta Astronomica, 53, 307
Moskalik, P., Kołaczkowski, Z., & Mizerski, T. 2004, ASP Conf. Ser. 310: IAU Colloq. 193: Variable Stars in the Local Group, 310, 498
Paczyński, B. 1986, ApJ, 304, 1
Soszyński, I., Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., & Żebruń, K. 2000, Acta Astronomica, 50, 451

Soszyński, I., Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., Żebruń, K., Szewczyk, O., & Wyrzykowski, Ł. 2002, Acta Astronomica, 52, 369
Soszyński, I., Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., Żebruń, K., Szewczyk, O., & Wyrzykowski, Ł. 2003, Acta Astronomica, 53, 93
Soszyński, I., Udalski, A., Kubiak, M., Szymański, M., Pietrzyński, G., Żebruń, K., Szewczyk, O., & Wyrzykowski, Ł. 2004a, Acta Astronomica, 54, 129
Soszyński, I., Udalski, A., Kubiak, M., Szymański, M. K., Pietrzyński, G., Żebruń, K., Szewczyk, O., Wyrzykowski, Ł., & Dziembowski, W.A. 2004b, Acta Astronomica, 54, 347
Szymański, M.K. 2005, Acta Astronomica, 55, 43
Udalski, A. 2003, Acta Astronomica, 53, 291
Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., & Żebruń, K. 1998, Acta Astronomica, 48, 147
Udalski, A., Soszyński, I., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., & Żebruń, K. 1999a, Acta Astronomica, 49, 1
Udalski, A., Soszyński, I., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., & Żebruń, K. 1999b, Acta Astronomica, 49, 45
Udalski, A., Soszyński, I., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., & Żebruń, K. 1999c, Acta Astronomica, 49, 223
Udalski, A., Soszyński, I., Szymański, M., Kubiak, M., Pietrzyński, G., Woźniak, P., & Żebruń, K. 1999d, Acta Astronomica, 49, 437
Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Soszyński, I., Woźniak, P., & Żebruń, K. 2000, Acta Astronomica, 50, 307
Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Soszyński, I., Woźniak, P., Żebruń, K. Szewczyk, O., & Wyrzykowski, Ł. 2002, Acta Astronomica, 52, 217
Woźniak, P. R., Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Soszyński, I., & Żebruń, K. 2002, Acta Astronomica, 52, 129
Wray, J.J., Eyer, L., & Paczyński, B. 2004, MNRAS, 349, 1059
Żebruń, K., Soszyński, I., Woźniak, P., Udalski, A., Kubiak, M., Szymański, M., Pietrzyński, G., Szewczyk, O., & Wyrzykowski, Ł. 2001, Acta Astronomica, 51, 317