SEARCH FOR ECLIPSING Binary Stars In The Direction Of Galaxy Bulge With Data Of OGLE-II And MACHO Catalogues

E. Urday E.1, J. Tello G.2
Faculty of Science, National University of Engineering, Av.T´upac Amaru 210, Lima, Perú
E-mail: lllue130@hotmail.com1, jtelllog@uni.edu.pe2

Abstract. It is known that the parameters of a simple star (radii, temperatures, masses) are obtained from the study of eclipsing binary systems. With the eclipsing binaries of the OGLE catalogue, we look for their counterparts in the MACHO catalogue, that is, the same binaries that are contained in the second catalog. As a result, we will generate our own catalogue of eclipsing binaries with photometric information in three filters I, R and V.

1. Introduction
The Optical Gravitational Lensing Experiment (OGLE) is an astronomical project created to discover dark matter using the gravitational microlensing technique[1]. This technique consists of observing continuously and systematically different regions of the sky where the microlenses could be produced. The microlenses have a high probability of occurring in the galaxies Large and Small Magellanic Clouds and in the bulge of our Galaxy, due to the large number of stars in those regions. As a result of using this technique, in addition to observing the microlenses, data were obtained on the variation of the luminous flux of variable stars (pulsating stars and eclipsing binary systems). The OGLE project, in its second stage of operation (called OGLE-II), made measurements in the direction Galactic bulge, and as a result, data of 200000 variable stars were obtained[2]. The sky region measured by OGLE was divided into 49 fields and their results are contained in a catalogue with information about each field of the sky, position of the stars in that field, observation time and variation of stellar magnitude in filter I.

On the other hand, the collaboration of Massive Compact Objects of the Halo (collaboration MACHO) is a project made to prove that a significant fraction of dark matter in the halo of the Milky Way is composed of brown dwarfs or planets [3]. For this reason, they observed for several years in the direction of the galaxy Greater Cloud of Magellan and the bulge of our Galaxy. Like the OGLE catalogue, the results of their observations consist of information on the position of the measured stars and variation of the luminous flux, but in two filters R and V. The observed region was divided into 94 fields and the measured objects contain the stars variables.

2. Methodology
An eclipsing binary system is a system composed of 2 stars gravitationally linked and whose orbital plane is close to the observer’s visual line, so, in each orbital cycle, 2 eclipses occur: first
when one of the components is interposed between the observer and the second star and then, at another time, when the second component eclipses the first.

The variation of the light flux in a given filter is called the light curve. In the case of an eclipsing binary system, the more light curve are measured in different filters, the more system parameters can be determined.

The OGLE catalogue presents light curves of variable stars measured with a single filter. Our work consists of using the OGLE-II data of variable stars in the direction of the bulge of our Galaxy with the purpose of separating from them a type of variable stars: the eclipsing binary stars. We finely seek to identify these systems in the MACHO catalogue to obtain their counterparts. As a result, we generated our own catalogue of eclipsing binaries with light curves in three I, R and V filters.

As a first step we must select the eclipsing binaries from the OGLE catalogue. Next, we will look for these same objects in the MACHO catalogue (that is, we will find the counterparts of the eclipsing binaries of the OGLE catalogue in the MACHO catalogue).

In Figure 1 we present a scheme of the procedure followed to obtain the MACHO counterparts of an OGLE binary star.

![Figure 1](image)

**Figure 1.** Scheme that describes the steps to follow to obtain the MACHO counterpart of an OGLE binary star.

The procedure applied consists of the following steps:
2.1. Compare the OGLE-II and MACHO fields.

The OGLE II and MACHO catalogues are examined to determine which fields of a catalogue are closest to each other. For example, we find that the center of the field 10 of OGLE called BUL-SC10 has equatorial coordinates close to field 309 of MACHO. Table 1 shows the equatorial celestial coordinates Right Ascension (R.A.) and Declination (Dec.) of both fields.

| Catalogue Field | R.A.  |
|----------------|-------|
|                | Dec.  |
| OGLE II BUL-SC10 | 18:20:06.6 | -22:23:03.0 |
| MACHO 309       | 18:19:01.19 | -22:23:43.5 |

Figure 2 shows a graph of the areas occupied by each of these fields, the center of the field is marked by a (+) (field 10 of OGLE) or a (×) (field 309 of MACHO). We see that a large part of the BUL-SC10 field is contained in field 309. The OGLE field is of the shape of a rectangle of 14′′ × 57′′ in the sky and the MACHO field is a square of 43′′ × 43′′.

2.2. We calculate the period and separate the eclipsing binaries.

We identify the periodic variable stars and separate the eclipsing binary systems from them. For each variable star of the OGLE II catalogue, we calculate the period of variation of the light curve using the String-Length method [4]. After obtaining the light curves of the OGLE variable stars that are periodic, we separate those that are eclipsing binaries, according to the shape of the light curve. For example, figures 3a and 3b show some light curves of eclipsing binaries from the BUL-SC10 field with their orbital periods (in days) and the time of their main eclipse. Of all the light curves that we have obtained for the field 10 of OGLE, we select those that correspond
to eclipsing binary systems, which are the objects of study of this work. Note in these graphs that the vertical axis is called the I band and the horizontal axis is called the phase and, by convention, in eclipsing binary systems the phase is zero in the deepest eclipse; when the phase is 1 the system has given one complete orbit. The eclipse in phase zero is called the primary eclipse and the other less deep eclipse, in phase 0.5, is called the secondary eclipse. The different depth of these minima indicates that both stellar components have different surface temperatures. For example, in figure 4a the binary 1082 of field 10 of OGLE (named BUL-SC10-1082) its calculated orbital period was approximately 4.30 days.

Figure 3a. Light curve of the eclipsing binary OGLE BUL-SC10-1082.

Figure 3b. Light curve of the eclipsing binary OGLE BUL-SC10-1006.
The light curve of the eclipsing binary OGLE BUL-SC10-1006 in the figure 3b shows that the difference between the eclipses is not so pronounced, which indicates that the temperature of the components is not very different.

2.3. For each OGLE star we look for the possible counterparts of the eclipsing binary stars in the MACHO field.

With information from the OGLE catalog of the positions of each eclipsing binary we look for the counterparts in the MACHO catalog. For example, for the binary BUL-SC10-1743 with orbital period 0.380 d its coordinates are:

R.A.: 18h19m45.55s
Dec: -22°12′44.4″

In the MACHO catalogue we search for objects with coordinates close to the OGLE binary with the condition:

\[ r = \sqrt{(\text{RA}_{\text{OGLE}} - \text{RA}_{\text{MACHO}})^2 \cos \text{DEC}_{\text{OGLE}}^2 + (\text{DEC}_{\text{OGLE}} - \text{DEC}_{\text{MACHO}})^2} \]

Where \( r \) is a value that indicates the proximity of one object to another in the sky and that we choose to obtain the closest counterparts to the OGLE binary. For that we write a script so that for the position of an OGLE object it looks for all the objects of the MACHO catalogue of the nearest region and only takes into account those possible counterparts with the condition \( r < 4″ \).

As an example on the counterparts, object BUL-SC10-1743 is in field 10 of OGLE and 7 possible counterparts were found (as seen in the table 2) in field 309 of the MACHO catalog with a value of \( r \) comprised between: \( 4.85 \times 10^{-5} \) ″ \( \leq r \leq 0.001″ \).

Since the fields scanned in the MACHO catalogue can overlap, the regions in which the sky was divided and which never overlap were called TILES. Therefore, to describe the position of a star in the MACHO catalogue, 3 parameters are needed: the field, the tile and the star number in this tile [5]. Figure 4 shows how the fields and tiles of the MACHO catalogue are distributed.

![Figure 4. Distribution of FIELDS and TILES of the MACHO catalogue.](image-url)
Table 2. 7 possible counterparts of BUL-SC10-1743 found in the MACHO catalogue ordered according to their proximity in the sky.

| OGLE      | FIELD | TILE | STAR | \( \times 10^{-4} \) |
|-----------|-------|------|------|----------------------|
| bul-sc10-1743 | 309   | 38255 | 169  | 8.88E^{-04}          |
| bul-sc10-1743 | 309   | 38255 | 500  | 4.82E^{-04}          |
| bul-sc10-1743 | 309   | 38255 | 747  | 4.85E^{-05}          |
| bul-sc10-1743 | 309   | 38255 | 789  | 5.36E^{-04}          |
| bul-sc10-1743 | 309   | 38255 | 1382 | 6.62E^{-04}          |
| bul-sc10-1743 | 309   | 38255 | 1612 | 1.00E^{-03}          |
| bul-sc10-1743 | 309   | 38255 | 1681 | 7.99E^{-04}          |

field number of the MACHO counterpart, the third column is the TILE or region of the observed field, the fourth column is the STAR number within the tile, the last column is the parameter r.

2.4. We identify MACHO counterparty, corresponding to the object OGLE.

The period found of the OGLE binary in step 2 will serve to identify the MACHO counterpart among the 7 possible candidates and select it. We make the light curve of each possible candidates with the period of the eclipsing OGLE. The light curve of the candidate with similar shape of the eclipsing OGLE which is the counterpart (figure 5a). In figs. 5b and 5c the light curves of the object 309-38255-747 of the MACHO catalogue are shown in filters V and R, respectively and that turned out to be the counterpart of OGLE BUL-SC10-1743. Note the similarity of light curves.

![Figure 5a. Light curve OGLE BUL-SC10-1743 with period 0.380264269d.](image-url)
3. Results
As a result of using this method, it was found that of the 49 OGLE-II fields, only 22 fields contain counterparts in the MACHO fields. In turn, the light curves were obtained in filters I, R and V. For example, for field 10 of OGLE-II, the eclipsante 1743 has its counterpart, which is object 747 of field 309 of MACHO (figure 6).

Figure 5b. Light curve of the MACHO object 309-38255-747 in filter R.

Figure 5c. Light curve of the MACHO object 309-38255-747 in filter V.
Figure 6. Shows the light curves of this object on three different filters.

4. Conclusions
Our method was successful in selecting the eclipsing binaries, obtaining the counterparts and finding the light curves in different filters. These results may be useful, in a later study, to determine some parameters of the eclipsing binaries such as the inclination angle of the orbital plane, the relative radii of the components and their mass ratio. Additionally with additional spectroscopy information it is possible to obtain parameters such as the temperatures of the system components. Finally this method can be used in other catalogs of variable stars, such as pulsating stars, to find their corresponding counterparts.

5. References
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