GRAVITATIONAL MICROLENSING AND EXTENDED SOURCE MODELS

V.M. Sliusar, V.I. Zhdanov

Astronomical Observatory, Taras Shevchenko National University of Kyiv
Observatorna str., 3, Kyiv, Ukraine
vitaliy.slyusar@gmail.com; valeryzhdanov@gmail.com

ABSTRACT. We perform statistical simulations of light curves of extended microlensed sources having different brightness distribution in the source plane. We generated a set of realizations of lensing point mass system that takes into account an external shear; these include 12000 point masses which are uniformly distributed in the lens plane. The list of the circular symmetric source models used includes gaussian, limb-darkening, power law and Shakura-Sunyaev accretion disk models observed face-on. We estimated difference η between the amplification curves (an analog of the light curves) for these different source models. This difference appears to be considerable, in some cases it amounts up to $\sim 10\%$. However, the effect of the shear within limits $\gamma = 0 \div 0.5$ is not considerable, though it leads to some diminishing of η.

Keywords: galaxies, quasars, gravitational lensing

PACS 98.62.Sb

1. Introduction

In this paper we study the light curves of an extended microlensed source in extragalactic gravitational lens systems (GLSs). Microlensing processes induce a considerable brightness variations of the source images; this is observed in a number of real extragalactic GLSs (Schneider et al., 1992), which have several macro-images of one quasar.

Sometimes a considerable brightness enhancement in some micro-image occurs which is referred to as a high amplification event (HAE); it is associated with an intersection of the GLS caustic by the source. One of important applications of HAE deals with a possibility to study a light distribution over the source. Since a pioneering paper by Grieger, Kayser and Refsdal (1988) this question has been analyzed in a number of papers, as theoretically and observationally (for a review see, e.g., Mortonson, 2005; Zhdanov et al, 2012; Alexandrov & Zhdanov, 2011). The determination of the source profile from observational data is an incorrect mathematical problem and to solve it one needs some additional assumptions about this profile and, possibly, about the mass distribution in the gravitational lens system. Anyway, it is often claimed (see, e.g., Mortonson, 2005) that under some general conditions the only characteristic, that can be presently derived from typical light curve measurements in GLS, is the source size. This question needs further statistical studies with various assumptions about the source model.

In particular, one of the questions concerns the accuracy that is needed in order to distinguish different fiducial source models in GLS using the light curves. These questions were discussed by Alexandrov et al, 2011; Sliusar et al, 2009; Sliusar et al, 2013. However the consideration of these papers has been limited mainly to the shearless distributions of masses. The present paper continues this line taking into account the effect of non-zero external shear γ.

2. The model

We use the same source models as Sliusar et al, 2009; Sliusar et al, 2013; these models can be uniquely characterized by the half-brightness radius $R_{1/2}$, which is different from the size parameter R below. The simplest and most widely used is Gaussian model (GS):

$$I_G(r) = \pi^{-1} R^{-2} \exp\left[-(r/R)^2\right].$$

Limb-darkening (LD) model is:

$$I_{LD}(r) = (q+1)\pi^{-1} R^{-2}\, \Xi(r/R; q),$$

where $\Xi(\xi; q) = \Theta(1-\xi^2)(1-\xi^2)^q, \quad q \geq 0.$

The power-law (PL) models ($p > 1$):

$$I_{PL}(r) = (p-1)\pi^{-1} R^{-2} \left[1 + r^2/R^2\right]^{-p}.$$

The accretion disk (AD) of Shakura-Sunyaev (1973) has the (normalized) brightness distribution $I_{AD}(r) = 3R\theta(r-R)(2\pi r^3)^{-1}[1-\sqrt{R/r}]$, R being the radius of the inner edge of the accretion disk.

Here we assume zero optical depth of a continuous matter. In this case the lens equation is as follows:

$$\mathbf{y} = \mathbf{A}\mathbf{x} - \sum_{i=1}^{N} R_i^2 \frac{\mathbf{x} - \mathbf{x}_i}{|\mathbf{x} - \mathbf{x}_i|^2} \quad (1)$$

where $\mathbf{x}_i$ is the angular position of the i-th microlens on the sky, R_i is its angular Einstein ring radius; $\mathbf{A} = diag\{1-\gamma, 1+\gamma\}$ is the 2-dimensional external shear matrix.

To simulate the light curves we have used the "ray-shooting" method with direct calculation of each deflection angles. The parameters of numerical simulations along with are as follows. The total number of point masses is about 12000. The masses of the point lenses were distributed according to the Salpeter law in the interval $0.2 \sim 10\, M_{Sun}$ with index -2.35. The microlens positions were chosen in a random way with uniform distribution over the lens plane. The length of source trajectory has been chosen long enough to have enough the caustic crossings events (far from the boundaries of the field), and the size of the microlensing field was chosen large enough to avoid boundary effects. As a rule we generated hundred realisations of the microlensing field and, correspondingly, 100 light curves. To compare the light curves for different source models we used the relative difference

$$\eta = 2 \max_t \left(\frac{|K_i(t) - K_j(t)|}{K_i(t) + K_j(t)} \right) \quad (2)$$

where $K_i(t)$ and $K_j(t)$ is amplification for i-th and j-th model respectively along the trajectory of source, which moves uniformly.

3. Results

We present the results of simulations for source models with the same half-brightness radius $R_{1/2} = 0.21$. The index for the "long range" PL model was $p = 3/2$; Shakura-Sunyaev (1973) accretion disk also corresponds to this class of the power-law asymptotic dependence for large distances from the center. For LD model we have chosen $q = 1$.

The results are mainly analogous to that of Alexandrov et al, 2011; Sliusar et al, 2009; Sliusar et al, 2013; see also Zhdanov et al (2012). We do not see a considerable changes of η for different value of the shear from the interval $\gamma = 0 \div 0.5$. However, there is a tendency of diminishing η with γ, which is slightly different for different directions of the source motion. We expect that this tendency will be even larger for larger values of γ.

We note that the maximum difference between the light curves corresponding to different models is within the reach of the photometrical measurements. However it must be taken into account that (i) this is a statistical result "in principle", which appeals to a long-term observations, and (ii) we used simplified source models that can differ greatly from the real source picture. For more detailed information the probability distributions of η must be added; this requires additional and longer statistical simulations.

Table 1: Relative difference η between the light curves for different source models. Motion of the source is orthogonal to the direction of the shear. The accuracy of statistical simulation for η is < 0.002.

Models	$\gamma = 0.1$	$\gamma = 0.3$	$\gamma = 0.5$
GS-PL	0.101	0.095	0.059
GS-LD	0.089	0.078	0.033
GS-AD	0.097	0.088	0.049
PL-LD	0.117	0.103	0.059
PL-AD	0.041	0.042	0.040
LD-AD	0.120	0.105	0.056

Table 2: Relative difference η between light curves with different source models. Motion of the source is directed along the direction of the shear. The accuracy of statistical simulation for η is < 0.002.

Models	$\gamma = 0.1$	$\gamma = 0.3$	$\gamma = 0.5$
GS-PL	0.103	0.089	0.052
GS-LD	0.083	0.069	0.028
GS-AD	0.098	0.082	0.040
PL-LD	0.115	0.098	0.050
PL-AD	0.044	0.042	0.038
LD-AD	0.117	0.099	0.044

The above results concern a comparison of different models with the same $R_{1/2}$. However, in reality we do not know what radius should be used and one may ask why not to fit a light curve with a different size parameters of different models. Therefore, we must check whether we can replace one model with a different one with some other source parameters to get better fitting. This check has been carried out by Sliusar (2013); it has been shown that, at least for the involved values of the parameters, the results are almost the same as for the models with equal $R_{1/2}$.

References

Alexandrov A.N., Sliusar V.M., Zhdanov V.I.: 2011, *Ukrainian Journ. Phys.*, **56**, 389.

Alexandrov A.N., Zhdanov V.I.: 2011, *MNRAS*, **417**, 541.

Grieger B., Kayser R., Refsdal S.: 1988, *Astron. Astrophys.*, **194**, 54.

Mortonson M.J., Schechter P.L., Wambsganss J.: 2005, *ApJ* , **628**, 594.

Schneider P., Ehlers J., Falko E.E.: 1992, *Gravitational Lenses* (New York, Springer).

Shakura N.I., Sunyaev R.A.: 1973, *Astron. Astrophys.*, **24**, 337.

Sliusar V.M., Alexandrov A.N., Zhdanov V.I.: 2009, *Visnyk KNU (Astronomy)*, No. **45**, 29.

Sliusar V.M., Zhdanov V.I., Alexandrov A.N.: 2013, *Journ. Phys. Stud.*, **16**, No. **3**, 3904.

Zhdanov V., Alexandrov A., Fedorova E., Sliusar V.: 2012, *ISRN Astron. Astrophys.*, **2012**, ID 906951.