# PROBLEMS OF DELAY AND MICROLENIZATION TIME

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**Abstract -**This article presents a representation of the probability of gravitational lensing and summarizes the latest achievements in the field of GLS research.
**Index terms** - Gravitational lensing, gravitationally lensing systems, quasars, delay time, theory, observation, researched objects.

## INTRODUCTION

Gravitational lensing (GL), associated with the refraction of light rays in the gravitational field of the intermediate body, was one of the first confirmations of the general theory of relativity. Gravitationally lensing is interesting in that it allows solving many astronomical problems of cosmology that have not yet been solved: to observe quasars - the most distant objects of the universe, to determine the mass distribution in lensing galaxies, to study the nature of dark matter, to obtain independent values of the Hubble constant, other cosmological parameters.However, to obtain an answer to these questions, a comprehensive study of each of the known GLS is necessary. One of the known and widely researched objects of gravitationally lensable systems (GLS) is UM673, also called Q0142-100.

The delay time is because light from the source to each component comes in different ways. In addition, this means that any event that occurred in the source will first appear in the leading component, only after some time, equal to $\Delta t$, in the other component.

The analysis of observational data of the SFS makes it possible to obtain a number of important results concerning the nature of objects involved in lensing and the universe as a whole. Therefore, gravitational lenses, figuratively speaking, are cosmic telescopes. Due to the effect of amplification, we can observe the most distant objects of the universe, which in other cases it would not be possible to see - quasars. The most distant of the known quasars ($z_q = 10.2$) was found precisely due to gravitational lensing in the cluster of galaxies [1]. Quasars, as is known, are galaxies that are at an early stage of their evolution. This means that what studied in the main theoretically can confirm by observations.

This can also helped by the known value of the delay time. The fact is that because of the location of observatories it is impossible to observe continuously many quasars. The light curves suffer from seasonal breaks in observations. However, if the value of $\Delta t$ is known for some FP, then with its consideration it is possible to obtain a full-fledged quasar luminosity curve.

On the other hand, the GL allows directly, regardless of the intermediate distance indicators, to determine the Hubble constant Ho. This method was proposed by S. Refsdal in 1964 [2,3] for the case when the source is a supernova lying behind and close to the line of sight of the lens-galaxy. The spread of the values of the Hubble constant, calculated from known GLS, is approximately ~ 20%, from 52 to 69 with errors, of the order of ± 20 days. These differences are due to a number of factors: the uncertainty of the parameters in modeling the mass distribution in the lens galaxy, the influence of the unevenness of the light curves in determining $\Delta t$, etc. However, in general, we can assume that the obtained Ho values are in good agreement.

In general, the delay time is related to the geometric and relativistic properties of the universe, so the function $\Delta t$ is the sum of these two parts:

$$\Delta t(\vec{\theta},\vec{\beta}) = t_{geom} + t_{grav} = \frac{1+Z_L}{c}\frac{D_L D_S}{D_{LS}}\left(\frac{1}{2}(\vec{\theta}-\vec{\beta})^2 - \psi(\vec{\theta})\right)$$

(1)

Where, $\psi(\vec{\theta})$ - two-dimensional potential.

As can be seen, the delay time is the main parameter of the SFS, which makes it possible to judge the properties of the Universe and the structure of the lens. Despite the fact that the values of Δt for some systems (PKS1830-211, Q0957 + 561, B0218 + 357, B1600 + 435, B1422 + 231, B1608 + 656) have been measured using light radios or X-ray observations, yet the most significant the share in the determination of the delay time gives optical monitoring. Currently, according to the catalog, the values of the delay time are very likely known for 12 GLS.

The authors of [3] determined Δt between the components of the GLS HE1104-1805. Schechter et al. [4] obtained a delay time for 2 pairs of components of the PG1115 + 080 SFS. At the Scandinavian optical telescope, during recent years, some SFS intensively observed. Several observation projects were carried out there and delay times were measured for a number of B1600 + 434, HE2149-2745, RXJ0911 + 0551, SBS1520 + 530, FBQ0951 + 2635 [3,4]. The formal error value of these measurements is in the range from 5 to 25%, which corresponds to values from 4 to 24 days. [5] Also reported the measurement of Δt between four components of the lensed quasar HE0435-1223.

Determining the delay time is a very difficult problem. A typical example is SFS Q0957, to the measurements of which began immediately after its discovery. The various groups [3,4] who carried out observations both in the optical and in the radio bands gave results that differed greatly from each other (from 410 days to 540 days). This problem was resolved in [4,5], when a relatively sharp variability of the components in 1994-1996 was discovered with a difference Δt = 417 ± 3 days.

Difficulties in determining the exact value of the delay time is due, first, to the presence of seasonal interruptions in observations and a limited set of data, as well as the possible influence of microlenses in the lensing galaxy. To take into account these effects, a number of methods have been developed that can be conditionally divided into discrete (using directly observational data) and those that use various kinds of analytical functions for data interpolation. Common to all methods is the following approach, namely, the light curve of a component with a constant step shifted backward (forward), depending on whether it is driven or leading. For each shift, the degree of correspondence (eg correlation or minimization) between the two curves is calculated. In the end, the amount of shift corresponding to the maximum match taken as the most probable value of the delay time.

One of the first methods of disperse spectra was proposed. With its help, Δt was calculated in the FPG Q0957. Other methods based on the use of a discrete cross-correlation function (DCF) in the form:

$$DCF(t) = \frac{1}{M}\sum_{i,j}\frac{(a_i - \bar{a})(b_i - \bar{b})}{\sqrt{(\sigma_a^2 - \varepsilon_a^2)(\sigma_b^2 - \varepsilon_b^2)}}$$

(2)

where, M is the number of data pairs (ai, bi), taking into account the displacement t, εx are measurement errors, σx is the standard deviation, and is the average value of the corresponding components. Various authors used modified versions of the function (1), for example, a locally normalized DCF, continuously defined by DCF, a combination of the latter two. As a measure of the correspondence between the data, one can also use the minimization of χ2, for example, in the following form:

$$\chi^2 = \frac{1}{N-2}\sum_{i=1}^{N}\frac{(A(t_i) - B(t_i + \Delta t) - \Delta m)^2}{\sigma_A^2 - \sigma_B^2}$$

(3)

Here N is also the number of data pairs,Δm is the weighted average difference between the two data of the two components. In this way, we succeeded in obtaining the most probable value of the delay time Δt = 130 ± 3 days in the SBS1520 SFS.

Analysis of discrete methods has shown that they work well in the case. When there is many data corresponding to a long period of observations, and the intervals between the seasons should be less or of the order of the expected value of Δt. Otherwise, especially when there is little data, it makes sense to interpolate the data and thus obtain full-fledged light curves. Interpolation can be carried out in various ways, for example, by Fourier series expansion, linear interpolation, approximations by polynomials of different degrees, and other functions. However, the main drawback of this approach is that it is necessary to make some assumptions, for example, about the slowly changing variability or the absence of microlensing, etc. At the same time, one can get false information about variability or, on the contrary, miss some features. This method used with great care.

The type of lensing considered above caused by the field of massive galaxies, in which the distance between images is of the order of ~ 1″ and more. This type of lensing also called macrolensing. Now imagine that at least one of the rays refracted by the galaxy passes through it and / or its halo. In this case, the beam will be affect by the gravitational fields of compact objects that make up the galaxy - planets, stars, black holes, etc., called microlenses. They will give at least one more image of the source. Accordingly, this very phenomenon called microlensing. Since the angle of splitting during microlensing is very small (of the order of 10-5 arc seconds), with the help of modern instruments it is not yet possible to see such microimages, since micro-magnitudes are beyond their sensitivity. It turned out that despite the large difference in the mass of the galaxy as a whole and of a single star, such small objects can significantly affect the brightness of one of the observed macroimages of the object. These changes caused by changes in the time of the spatial configuration of the "source-quasar" - "galaxy-lens" - "microlens" - "observer". Later, many analytical and numerical studies of the microlensing phenomenon were carried out.

If the exact value of the delay time between the components of the investigated SFS known, then the problem of detecting microlensing is much simplified. Indeed, if a noncorrelated light variation detected in a shear on the value of the light curve of the slave component relative to the leading component in one of them, then one can speak with more confidence about microlensing. So we detected changes in the light curves of the SBS1520 components, caused by microlensing. But this cannot always be done. Changes due to microlensing may be very weak. In this case it is necessary to use indirect methods, for example, chromatic microlensing.

The time of variation in the brightness of the components caused by microlensing depends on the transversal velocity of the source relative to the caustic. This speed consists of three parts: the movement of the quasar, the motion of the lensing galaxy as a whole, and the motion of the observer:

$$\vec{V} = \frac{\vec{v}_s}{1+z_s} - \frac{\vec{v}_d}{1+z_d}\frac{D_s}{D_d} + \frac{\vec{v}_o}{1+z_d}\frac{D_{ds}}{D_d} \tag{3}$$

where - speed perpendicular to the line of sight, z - redshift, D - distance, and indices d, s, o - as usual lens, source and observer, respectively. In this expression, the movements of individual microlenses in the lensing galaxy relative to the galaxy itself can neglected.

If there is a well-established microlensing event, then one can draw conclusions about nature as a source-size and radial distribution of brightness, and microlenses-mass, density, transverse velocities. A simple two-component model of a quasar source in the Einstein Cross considered, consisting of a bright and compact nucleus surrounded by a cold, extended shell. Analysis of the light curves of this SFS allowed making restrictions on the angular size and mass of the source - 0.01 ÷ 0.1 pc and 0.01 ÷ 1 Ms, respectively. A long-term monitoring of the SFS Q0957 + 561 revealed events of microlensing by bodies with a planetary mass of 10-5 Ms.

Thus, it is possible to obtain information about the nature of dark matter. For example, in the study of the ring-shaped GL165 + 561 it was found out that the radial distribution of the surface mass density is well described by the dependence in the form. Comparison of the observed mass distribution with the empirical showed the presence of a hidden mass in the lens galaxy.

A lot of work has been devoted to the theoretical and observational study of microlensing. Continuing this topic, let us say that the surface density of masses in the direction of multiple images of a lensed quasar is of the order of the critical. Therefore, microlensing should occur quite often, and if the images are located sufficiently symmetrically, then continuously. This can be shown as follows. If we represent each microlens in the form of a small disk with a radius equal to the radius of its Einstein Ring, then the ratio of the area covered by such disks to the area of the selected section will correspond to the surface mass density expressed in units of critical density. This value also called optical depth. At = 1 Einstein's rings of microlenses overlap and cover the entire observable plane.

Microlenses give a complex two-dimensional picture of the distribution of the gain factors in the source plane, i.e. it consists of a set of caustics, which, as stated, correspond to an infinitely large gain. Calculation of the amplification of an arbitrary source for microlensing is a difficult task, the poet here uses numerical calculations of equation (1), in particular, by the method of reverse ray tracing. The method consists in calculating the path of the rays defined in a square grid in the opposite direction, i.e. from the observer to the plane of the source through the gravitational lens. When the ray system intersects the source plane, a gain distribution is obtained, which is proportional to the density of points. Due to the mutual transverse movements of the observer, GL and source, the apparent brightness of the lensed quasar can vary with time. In this case, it assumed that the positions of the microlensesare fixed and the amount of amplification of the source and the change in its position is expressed by the displacement of the source relative to the calculated picture of the caustic. Examples of numerical calculations of the caustic pattern of the microlens system are shown in Fig. 1. The gray tone expresses the gain as a function of the position of the quasar - the sequence of colors black-gray-white corresponds to an increase in the gain. The corresponding light curve is shown in Fig. They are drawn in the case when the source moves along light, i.e. different implementations of microlens positions (Fig. 1). The figure shows that the larger the source size, the smoother the light curve.

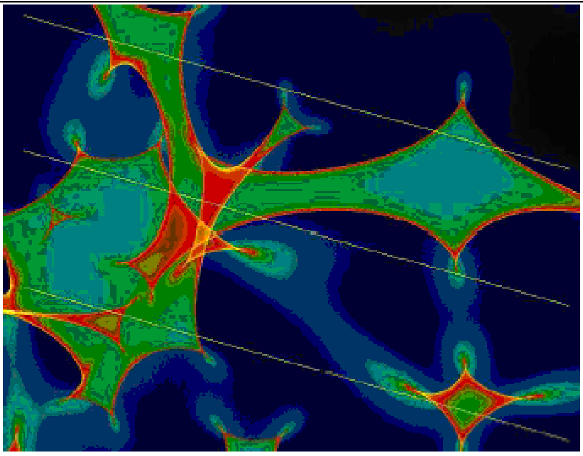

**Fig.1.** A picture of the gain distribution in the source plane, given by a dense star field in a lensing galaxy. The microlens parameters were chosen in accordance with the model of component A of the GLP Q2237 + 0305 - the surface mass density k = 0.36.

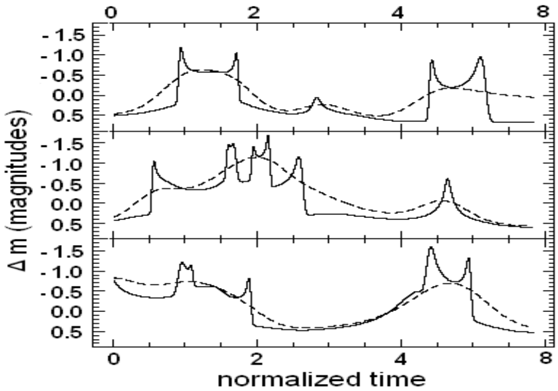


**Fig.2.**The model light curve corresponding to the light lines in Fig. 1 .. Solid and dashed lines - small and large angular size of the source. Each pair corresponds to three realizations of a random distribution of microlens positions.

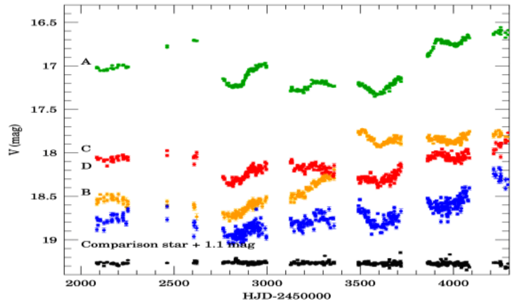


**Fig.3.**The light curves of the four components of the FP Q2237 + 0305 according to the results of the OGLE monitoring program for 7 years

**CONCLUSIONS**

From the point of view of observations and the study of microlensing in real GLS, the ideal object, among known objects, is Q2237. This system represents four images of the lenses quasar, which are located against a background of a relatively close spiral galaxy-lens. Due to the sufficiently high symmetry of the components location relative to the center of the lens, the delay time between the components amounts to hours or tens of hours. Therefore, it is assumed that any uncorrelated variations in the brightness of the components on longer time series are caused by the microlensing effect. Changes in the gloss of the components of GL Q2237 proceed almost continuously from the moment of its discovery. Thus, the light curves of all 4 components of the system over a nearly 6-year observation period by the OGLE program. These changes are caused, in all probability, mainly by microlensing as the rays pass through the dense regions of the lens galaxy.

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