# Monte Carlo Simulations of Quasars' Brightness Magnification due to Gravitational Lensing: the Highly Luminous Quasar HS 1946+7658

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**Abstract**

In this paper we present Monte Carlo simulations of the gravitational (two-plane) lens magnification of the quasar HS 1946+7658 brightness. Depending on the position of the lenses relative to the quasar the magnification of the quasar brightness varies from $-0.06$ mag to $-2.09$ mag, and the probability that the quasar brightness is magnified less than $-0.50$ mag is 97.607 %.

## 1 Introduction

The radio-quiet flat-spectrum quasar HS 1946+7658 ($z = 3.051$, Hagen et al. 1992; $R = 16.20$, Véron-Cetty & Véron 2000) is one of the most luminous quasars ($L_{\rm tot} = 1.5 \times 10^{15}\,L_{\odot}$, Hagen et al. 1992; absolute $B$ magnitude of $-30.50$, Véron-Cetty & Véron 2000) discovered up to now. Tripp et al. (1996) discovered two Mg II absorbtion line systems in the spectrum of the quasar with $z_1 = 1.11903$ and $z_2 = 1.53448$. We shall assume that these absorbtion line systems are prodused by the gaseous halo of a single galaxy intersected by the quasar line-of-sight (Bergeron & Boissé 1991). The high brightness of the quasar and the presence of at least two intervening galaxies strongly suggest that HS 1946+7658 is possibly magnified by gravitational lensing.

This paper is aimed to investigate numerically the magnification of HS 1946+7658 brightness caused by the gravitational lensing effect of two intervening galaxies through Monte Carlo simulations. We assume that the quasar flux density is magnified without creation of multiple images of the quasar. This is quite common situation because every mass concentration, located near the quasars light-of-sight, will magnify the quasar flux density, i.e. there will be at least one magnified image of a background source (Schneider 1984; Schneider 1985). Throughout the paper we use Einstein-de Sitter cosmology with Hubble parameter $H_0 = 75\,{\rm km\,s^{-1}\,Mpc^{-1}}$.

## 2 Numerical Modelling

Let us define the magnification, $\mu$, of a lensed source to be equal to the ratio of the flux density of the lensed source to that of the unlensed one (Schneider

1985). Gravitational lensing preserves the surface brightness of the source and therefore, the magnification is simply the ratio of the area of the lensed source to that of the unlensed one. In general, knowing the geometry, the distances and the mass distribution of the lens system (a lens system contains the lens(es), the image(s) and the source(s)) we can determine the magnification of the source flux density produced by the gravitational lens and therefore, we can recover the true source luminosity.

In the case of HS 1946+7658 the distances can be determined as well as the position of the quasar. Therefore, we should assume the position and the mass model for each of the two lenses (the galaxies associated with the Mg II absorbtions at $z_1$ and $z_2$). The positions of the lenses are chosen randomly within a $20'' \times 20''$ rectangle centered on the quasar. Those positions of the lenses so that the calculated source position lie within the Einstein radius of at least one of the lenses are rejected in order to avoid the creation of multiple images. For both lenses we assume a singular isothermal spherical mass distribution (SIS) with equal model velocity dispersions $\sigma_1 = \sigma_2 = 200\,\mathrm{km\,s^{-1}}$. The corresponding Einstein radii of the lenses are $0.436''$ and $0.301''$.

The two-plane lens equation is taken from Erdl & Schneider (1993). For a given set of model parameters the magnification is found to be $\mu = J^{-1}$, where $J$ is the Jacobian of the image to source plane mapping (Kayser 1990). For each simulation we choose randomly the positions of the lenses within the specified region and then we calculate the increase of the quasar brightness (in magnitudes) caused by the gravitational lensing as:

$$\Delta m = m - m_0 = -2.5 \times \lg \mu,$$

where $m$ is the quasar magnitude after the lensing, and $m_0$ is the true quasar magnitude. We run a total of 100 000 Monte Carlo cycles and 805 of them were rejected on the base of the above criterion.

## 3 Results

The results from the simulations are presented in Figure 1 where the histogram of the magnifications is given. The fluctuations of the histogram are due to the relatively small number of Monte Carlo cycles used. The maximal magnification achieved is $\Delta m_{\max} = -2.09$ mag (the quasar is close to the Einstein radius of the second lens). This means that the observed quasar flux density is magnified 6.87 times relative to the true flux density. The minimal magnification achieved is $\Delta m_{\min} = -0.06$ mag. In Table 1 we list the probability, $P\,(\Delta m_1 \geq \Delta m > \Delta m_2)$, the quasar magnification to be in the interval $(\Delta m_1, \Delta m_2)$. One can see that magnifications equal to or larger than $-0.50$ mag should occur very seldom.

## 4 Discussion

In this paper we have presented the results from Monte Carlo simulations of HS 1946+7658 brightness magnification due to gravitational lensing. We have assumed a SIS mass profile with a model velocity dispersion equal to $200\,\mathrm{km\,s^{-1}}$

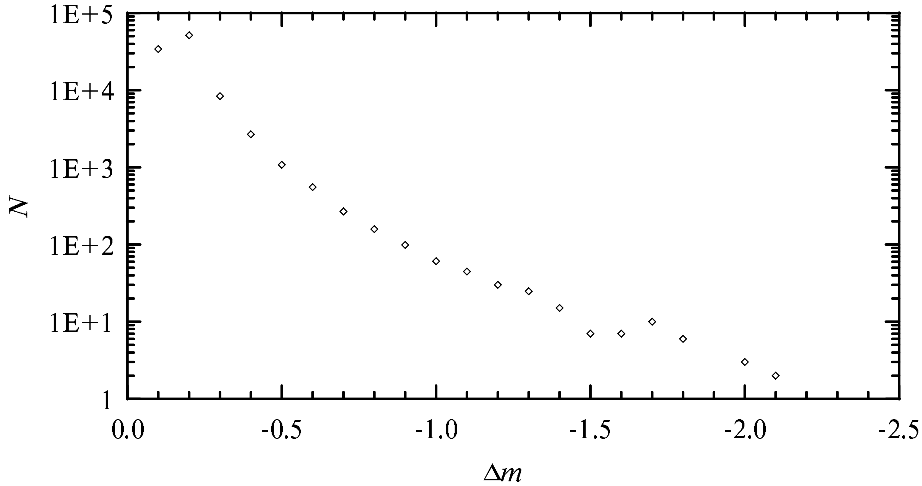


Figure 1: Histogram of the magnifications. The number, $N$, of cycles having magnification $\Delta m$ is plotted (the bin size of the histogram is 0.1 mag).

Table 1: The probability, $P$, the magnification of the quasar brightness (in magnitudes) to be in the interval ($\Delta m_1$, $\Delta m_2$).

| $\Delta m_1$, $\Delta m_2$ | $P$ [%] |
|---|---|
| 0.0, $-0.5$ | 97.607 |
| $-0.5$, $-1.0$ | 2.181 |
| $-1.0$, $-2.0$ | 0.208 |
| $-2.0$, $-3.0$ | 0.005 |

for both lenses. If the galaxies causing the Mg II absorbtion in the quasar spectrum are within $10''$ from the quasar the magnification lies in the range from$-0.06$ mag to $-2.09$ mag, and the probability that the quasar brightness is magnified less than $-0.50$ mag is 97.607 %. Our computations shows that part of the high luminosity of the quasar HS 1947+7658 could be attributed to the double gravitational lens magnification.

Our simple model could be improved in two ways. Firstly, we should vary the model velocity dispersions of the lenses (also allowing the velocity dispersions not to be equal). Secondly, we should run a larger number of cycles than used in this paper. The great advantage will be the detection of at least one of the intervening galaxies; this will decrease the number of the model free parameters. First attempt for this detection was made and we were able to set a lower limit of the magnitude of the intervening galaxies of about 23 $R_C$ mag (Mihov, in preparation).

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