"MISSING IMAGE" IN GRAVITATIONAL LENS SYSTEMS

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ABSTRACT. The gravitational lens models involving extended mass distribution generally predict an odd number of images with one of the images close to the centre of the principal lensing galaxy. In all the observed lens systems only an even number of images have been unambigously detected so far. It is demonstrated that the presence of a compact nucleus at the centre of lensing galaxies would dim the "odd" image significantly without affecting the rest of the image configuration.

It is an intriguing fact that in almost all the observed lens systems only an even number of images have been unambigously detected, although an important property of the lensing action of extended smooth distribution of matter is the generation of an odd number of images (Burke, 1981). In fact, the model calculations which invoke a dominant lensing component contributed by a galaxy predict the existence of an image close to the galactic centre. A number of suggestions have been advanced to explain why this "odd" image has not been detected so far, none of which seem compelling enough (Chang and Refsdal, 1984; Subramanian, Chitre and Narasimha, 1985, Narayan, Blandford and Nityananda 1984).

Here we propose a scenario to account for the "missing odd image" phenomenon by making use of a massive compact nucleus that could possibly exist at the cores of giant galaxies. We argue that such a nucleus with even a small fraction ($\lesssim 2\%$) of the total galaxy mass contained within about 50 pc, would have negligible influence on the properties of the images located outside the core of the galaxy. But, the nucleus becomes gravitationally effective in pulling the odd image closer to the galactic centre, at the same time making it significantly dimmer.

Consider a spherically symmetric distribution of matter for the core of the lensing galaxy. Following the notation of Bourassa and Kantowski (1975), the scattering function that represents the bending

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of light rays for an impact parameter distance small compared to the galactic core-radius, may be written as

$$I_G(z_0) = \pi \sigma_G z_0^* \,,$$

where σ_G is the central surface density of the galaxy and z_0 is the complex number giving the image position in the deflector plane. Suppose, in addition we consider the effect of a nucleus of mass, M_N and radius, R_N with a constant surface density. Then, the scattering function of the nucleus is given by

$$I_N(z_0) = \frac{M_N}{R_N^2} z_0^* \,, \qquad |z_0| < R_N$$
$$= \frac{M_N}{z_0} \;; \qquad |z_0| > R_N$$

The image position z_0 is then related to the source position z by the equation

$$z = z_0 - \frac{4GD}{c^2} I_G^* - \frac{4GD}{c^2} I_N^*$$

$$= z_0 (1 - \kappa_G - \kappa_N) \,, \qquad |z| < R_N$$

Here, $\kappa_G = \frac{4GD}{c^2}\pi\sigma_G \,, \; \kappa_N = \frac{4GD}{c^2}\pi\left(\frac{M_N}{\pi R_N^2}\right) \equiv \frac{R_0^2}{R_N^2} \,,$

with $R_0 = \left(\frac{4GD}{c^2}M_N\right)^{1/2}$ being radius of influence of the nucleus and D = (observer-deflector distance) x (deflector-source distance) / (observer-source distance).

For the present problem both κ_G and κ_N exceed unity. In the absence of the nucleus the image would have been located at a position z_0^I given by

$$z = z_0^I (1 - \kappa_G) \,.$$

Writing $r = |z|$, $r_0 = |z_0|$ and $r_0^I = |z_0^I|$, the "odd" image without the nucleus is located at

$$r_0^I = \frac{r}{(\kappa_G - 1)} \,.$$

After inserting the nucleus the image gets shifted to the position

$$r_0 = \frac{r}{(\kappa_G + \kappa_N - 1)} = \frac{(\kappa_G - 1)\, r_0^I}{(\kappa_G + \kappa_N - 1)}$$

The amplification A^I of the image in the absence of the nucleus is obtained as

$$A^I = \frac{r_0^I}{r}\frac{dr_0^I}{dr} = \frac{1}{(\kappa_G - 1)^2} \,,$$

while, with the nucleus, the amplification A is given by

$$A = \frac{r_0}{r}\frac{dr_0}{dr} = \frac{1}{(\kappa_G + \kappa_N - 1)^2} \,.$$

Assume the parent galaxy to have a mass $M \sim 5\times10^{11} M_\odot$ within a core-radius 3 kpc and let us suppose D $\sim$ 600 Mpc. We then have $\kappa_G \sim 6.5$. Consider now a nucleus with mass $M_N \sim 10^{10} M_\odot$ and radius $R_N \sim 50\,pc$ to get $\kappa_N \sim 470$. Clearly $\kappa_N >> \kappa_G$ and we have $$r_0 \simeq \frac{\kappa_G}{\kappa_N} r_0^I = \kappa_G \left(\frac{R_N}{R_0}\right)\left(\frac{r_0^I}{R_0}\right) R_N$$

Thus, for the location, r_0^I of the odd image, without the influence of the nucleus, within a critical radius $\simeq \kappa_G^{1/2} R_0$, the image in the presence of the nucleus is pulled in to the position

$$r_0 \lesssim \kappa_G^{3/2} \left(\frac{R_N}{R_0}\right) R_N \lesssim \frac{3}{4} R_N .$$

The amplifications, before and after the introduction of the nucleus are respectively given by

$$A^I \simeq 3 \times 10^{-2} , \quad A \simeq 4 \times 10^{-6}$$

i.e. the influence of the nucleus becomes effective in further depressing the intensity of the odd image by an order of 10^4 (or, equivalently dimmed by some 10 magnitudes), besides being brought closer to the centre of the galaxy.

We added the gravitational effect of the compact nucleus on the image properties by adopting the realistic lens models which we had previously constructed, without altering any of the parameters of those models (Narasimha, Subramanian and Chitre, 1984; Subramanian and Chitre, 1984). The masses of the parent lens galaxy required to reproduce the observed configuration turn out to be in the range $5 \times 10^{11} - 3 \times 10^{12} M_\odot$, with the mass of the nucleus $\sim 1 - 2 \times 10^{10} M_\odot$ contained within ~ 50 pc. The computations show that in the absence of the nucleus the intensity of the "odd" (third) image is about a few per cent of that of the external bright image. But the introduction of the nucleus depresses the intensity of the image by a factor anywhere from 10^2 to 10^4, i.e., the third image is dimmed by some 6 - 9 magnitudes. The properties of the main images like their positions and intensities are left practically unaltered by the presence of the nucleus.

We should perhaps stress that we do not necessarily invoke any singularities like black holes in the density distribution of matter, although such singularities can also play a similar role in explaining the absence of the "odd" image. Rather we attempt to account for the observed features of the gravitational lens system in the framework of a conventional smooth density distribution before appealing to the presence of any singularities. Young et al (1978) have inferred from photometric and spectroscopic observations that the nucleus of the giant elliptical galaxy M87 contains a compact mass $\sim 5 \times 10^9 M_\odot$ with 100 pc. We have simply demonstrated that the presence of such a compact nucleus in the core of the lens galaxy can lead to a signficant dimming of the third image.

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