The optical gravitational lens experiment

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Abstract: Optical lenses simulating light deflection due to a 'point mass' object and a 'spiral galaxy disk', seen face on, have been manufactured by the authors. Using these lenses, we present here selected results of a well known optical experiment reproducing all types of image configurations presently observed among gravitational lens systems (see examples of real observed systems in the next paper). This contribution is adapted from a general review on 'Gravitational Lenses' by Refsdal and Surdej to be soon published in Reports on Progress in Physics [REF93.2].

1 The experiment

In order to simulate the formation of lensed images by a given mass distribution (point mass, etc.), we have used the optical setup that is shown in Figure 1. A compact light source is located on the left side (not clearly seen), then comes the point mass optical lens (cf. the closer view in Fig. 2) that deflects the light rays very nearly as a black hole having one third of the Earth mass ($R_{sc} \simeq 0.3\ cm$). Behind the lens, we find a white screen with a small hole at the center (pinhole lens). Further behind, there is a large screen on which is projected the lensed image(s) of the source (the Einstein ring, in this case) as it would be seen if our eye were located at the position of the pinhole. In the example illustrated here, the pinhole is set very precisely on the optical axis of the gravitational lens so that the source, the lens and the pinhole (observer) are perfectly aligned. Considering other relative positions between the source, the lens and the observer, and also for the additional case of an asymmetric lens, we have illustrated in Figures 3, 4 and 5 the resulting lensed images as a function of the pinhole position in the observer plane. Note that the bright regions seen on the lens are caused by scattered light.

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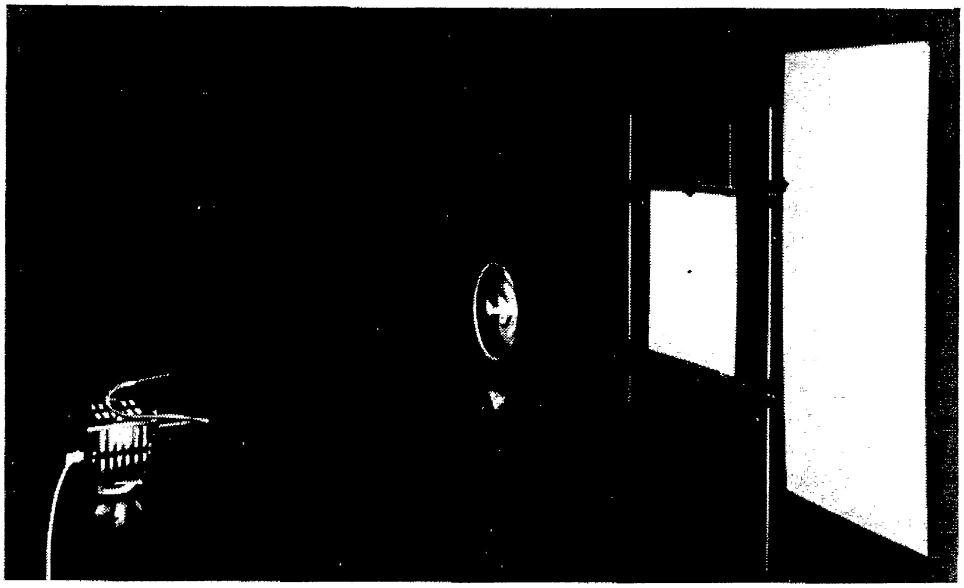

Figure 1: Setup of the optical gravitational lens experiment for the case of a point mass deflector and conditions of a perfect alignment between the observer, the lens and the source.

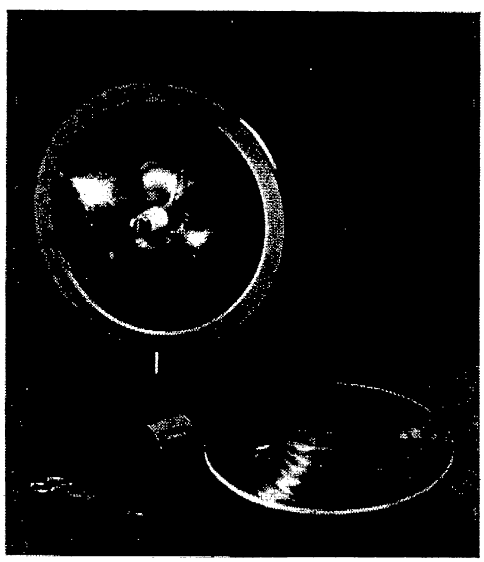

Figure 2: Examples of (left side) a 'point mass' lens (28 cm in diameter) manufactured at the Hamburg Observatory and of (right side) a 'spiral galaxy disk' optical lens (30 cm in diameter) produced by the authors at the European Southern Observatory (Garching bei München). These lenses, made of plexiglas-like material (n = 1.49), reproduce very nicely the formation of multiple images of a distant source due to gravitational lensing by a 'point mass' object and a 'spiral galaxy disk', respectively.

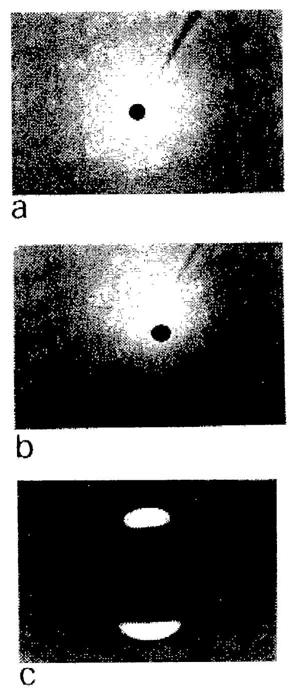

Figure 3: Positions of the pinhole with respect to the optical axis in the conditions of a perfect (a) and non perfect (b) alignment between the observer, the lens and the source and resulting lensed images (c) seen by the observer in the latter case.

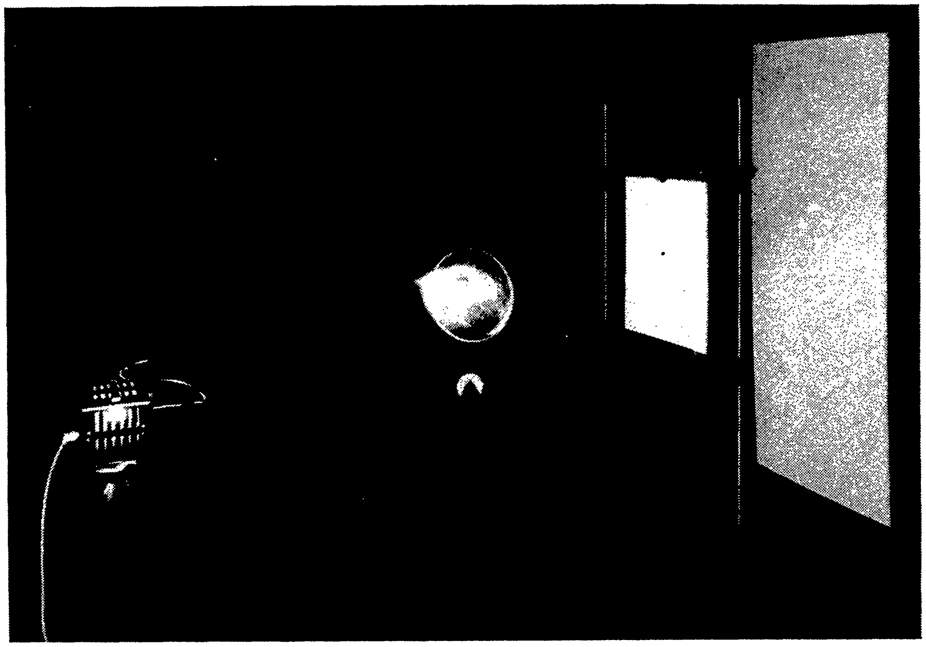

Figure 4: Setup of the optical gravitational lens experiment for the case of a deflector characterized by a non symmetric (but singular) mass distribution and conditions of a nearly perfect alignment between the observer, the lens and the source.

2 The point mass lens model

In the first experiment used to simulate the gravitational deflection of light rays by a point mass lens model, the pinhole (observer) is set very precisely on the optical axis of the gravitational lens so that the source, the lens and the observer are perfectly aligned (Fig. 3a). The resulting image is an Einstein ring (cf. Fig. 1). As the pinhole is moved slightly away from the symmetry axis (Fig. 3b), the Einstein ring breaks up in two images (Fig. 3c).

3 The non symmetric singular lens model

In the second optical gravitational lens experiment, the effects of a typical non symmetric (singular) gravitational lens are simulated by simply tilting the 'point mass' optical lens (cf. Fig. 4). In this case (see also Fig. 5a), the bright (focal) line along the optical axis which existed in the symmetric configuration (cf. Figs. 1 and 3a) has changed into a two dimensional caustic surface, a section of which is seen as a diamond shaped caustic (made of four folds and four cusps) in the pinhole plane. As a result, the Einstein ring that was observed in the symmetric case has now split up into four lensed images (see Figs. 4 and 5b). Such a configuration of four lensed images always arises when the pinhole (observer) lies inside the diamond formed by the caustic. Let us notice that such caustics constitute a generic property of gravitational lensing, the focal line in the symmetric configuration being just a degenerate case.

Fig. 5d shows the merging of two of the four images into one, single, bright image when the pinhole approaches one of the fold caustics (Fig. 5c). Just after the pinhole has passed the fold caustic (see Fig. 5e), the two merging images have totally disappeared (Fig. 5f).

A particularly interesting case occurs when the pinhole (observer) is located very close to one of the cusps (cf. Fig. 5g). Three of the four previous images have then merged into one

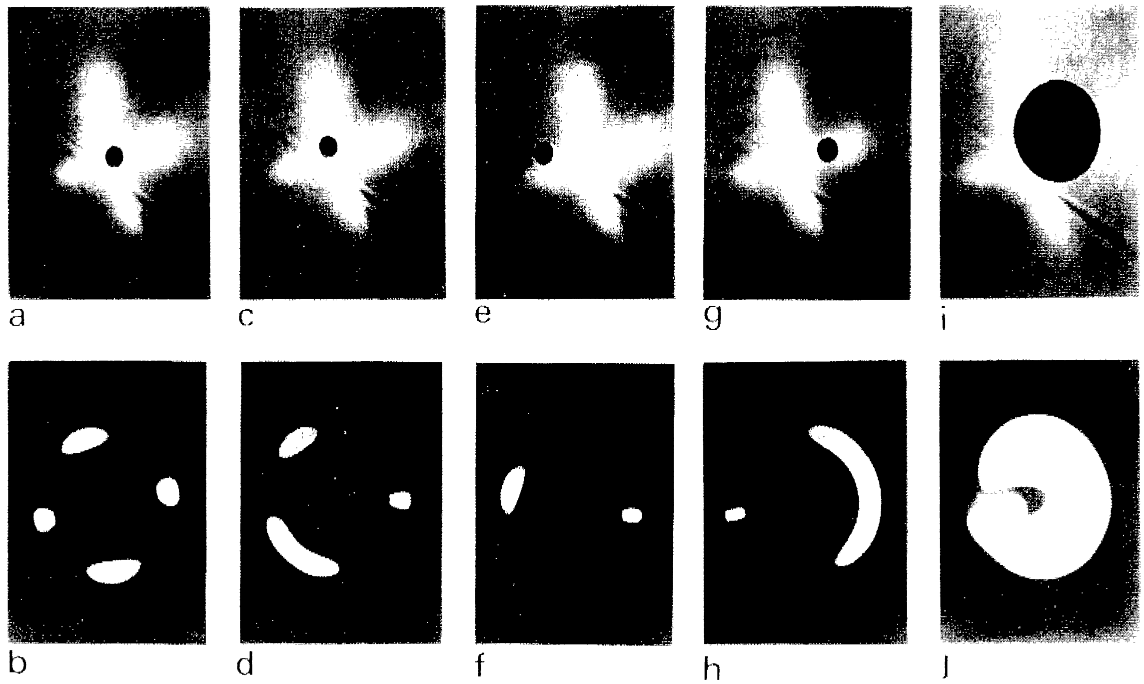

Figure 5: The upper row of pictures illustrates various positions of the pinhole (observer) with respect to the diamond shaped caustic caused by a deflector that is non symmetric but singular in its center. The resulting lensed images are illustrated in the lower row of pictures.

luminous arc, whereas the fourth one appears as a faint counterimage (Fig. 5h).

For large sources that cover most of the diamond shaped caustic (Fig. 5i), an almost complete Einstein ring is observed (Fig. 5j), although the source, lens and observer are not perfectly aligned and the lens is still being tilted. In this last experiment, the increase of the source size has been simulated by enlarging the pinhole radius by a factor $\simeq 4$. In order to show that this is a correct simulation, one may consider the pinhole and the screen behind it as a camera. It is then clear that an increase in the size of the pinhole leads to a larger and less well focused image of the compact source, corresponding indeed to an increase in the source size. A more detailed and rigorous analysis does confirm this result.

4 Conclusions

The image configurations illustrated in Figs. 3c, 4 and 5b, d, f, h, j are all found among the observed gravitational lens systems (see the next paper in these proceedings). It is of course obvious that if our optical lens would have been constructed non-singular in the center (cf. the 'spiral galaxy disk' optical lens shown in Fig. 2), we would have seen an additional image formed in the central part of the lens. For the known lenses with an even number of observed images, it may well be that a black hole resides in the center of the lens. The presence of a compact core could also account for the "missing" image since then the very faint image expected to be seen close to, or through the core, would be well below the detection limits that are presently achievable.

A more detailed account on these optical gravitational lens simulations and on the shapes and manufacturing of the optical lenses is given in [REF93.2].

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