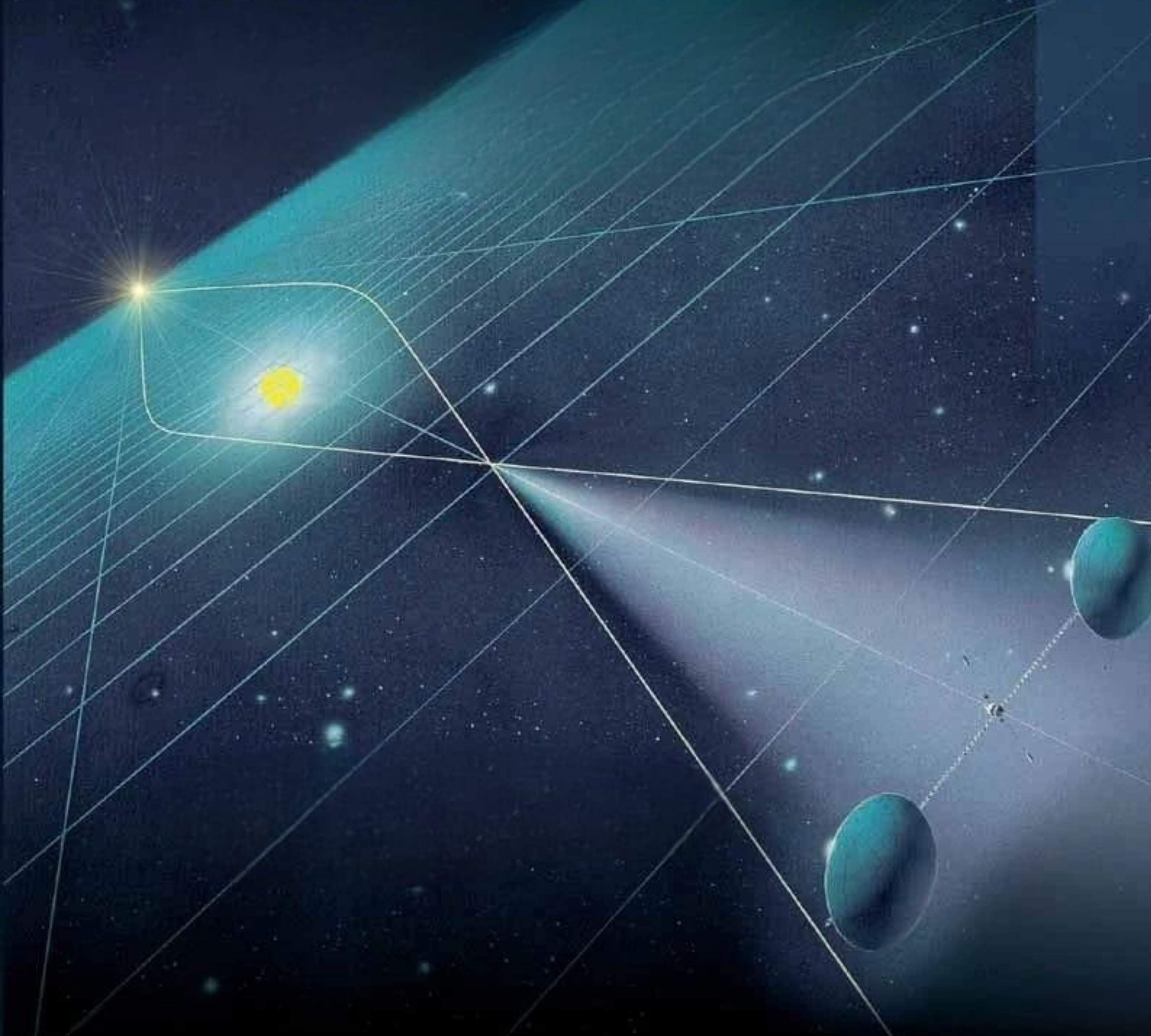
GRAVITAIONAL LENSES:

HOW GRAVITY BENDS LIGHT LIKE A TELESCOPE



Gravitational lenses: How gravity bends light like a telescope

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Abstract

Gravitational lensing was created as a result of Einstein's famous General Relativity theory and was officially proven in 1919. In the decades that followed, some of the brightest minds theoretically explored various facets and characteristics of the gravitational lens effect. Examples include the possibility of numerous or ring-like pictures of background sources, the use of a lens as a gravitational telescope for extremely faint and distant objects, and the possibility of calculating the Hubble constant by lensing. With the finding of the first twice photographed quasar in 1979, the idea was elevated to the status of an observational science. Its other characteristics were found to be pertinent to multiply-imaged quasars. Galactic microlensing event, huge luminous arcs, weak gravitational lensing, and Einstein rings. It is a really helpful astrophysical instrument that has achieved some amazing accomplishments.in this paper we review progress in understanding gravitational lenses and its types.

Key words: Gravitational lenses, General theory of relativity, Light bending, Lens equation

I. Introduction

Gravitational lensing has evolved over the past 20 years from being viewed as a geometric oddity to a useful and in some ways distinctive technique of contemporary astrophysics. The first experiment to correctly verify a prediction of Einstein's theory of general relativity was the deflection of light near the solar limb in 1919, it took more than half a century to establish this phenomenon observationally in some other environment, but nearly a dozen different lensing realizations have already been identified and seen, and more are undoubtedly on the way. As a field of study, gravitational lensing—the attraction of light by matter—displays a number of appealing qualities. Due to the fact that it is a geometrical phenomenon, its concepts are fairly simple to comprehend and describe. Both scientists and laypeople find its capacity to create optical illusions fascinating. Additionally, and most crucially, it is a valuable tool in many areas of astronomy due to its applicability to a variety of astrophysical issues. In this paper we will be discussing newton's theory, gravitational lenses types and applications.

II. Newton's theory

In 1915, Einstein published a theory of relativity that showed how the laws of physics work when comparing frames of reference that are not necessarily inertial in other words, incorporating those which are experiencing acceleration as well as those in the 'special' situation of uniform motion). According to Einstein's general theory of relativity, time and space are fused together in a quantity known as spacetime. Within this theory, massive objects cause spacetime to curve, and gravity is simply the curvature of spacetime. As light travels through spacetime, the theory predicts that the path taken by the light will also be curved by an object's mass. Gravitational lensing is a dramatic and observable example of the Einstein's theory in action. Extremely massive celestial bodies such as galaxy clusters cause spacetime to be significantly curved. In other words, they act as gravitational lenses. When light from a more distant light source passes by a gravitational lens, the path of the light is curved, and a distorted image of the distant object — maybe a ring or halo of light around the gravitational lens — can be observed.

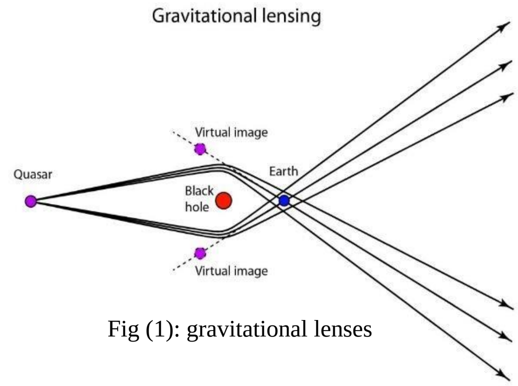

Fig (1): gravitational lenses

III. Lenses equation

The basic setup for such a simplified gravitational lens scenario involving a point source and a point lens is displayed in Figure 2. The three ingredients in such a lensing situation are the source S, the lens L, and the observer O. Light rays emitted from the source are deflected by the lens. For a point-like lens, there will always be (at least) two images S1 and S2 of the source. With external shear – due to the tidal field of objects outside but near the light bundles – there can be more images. The observer sees the images in directions corresponding to the tangents to the real incoming light paths. In Figure 3 the corresponding angles and angular diameter distances DL, DS, DLS are indicated. In the thin-lens approximation, the hyperbolic paths are approximated by their asymptotes. In the circular-symmetric case the deflection angle is given as:

$$\alpha = 4GM/c*2\ \xi$$

where M(ξ) is the mass inside a radius ξ. In this depiction the origin is chosen at the observer. From the diagram it can be seen that the following relation holds:

$$\theta DS = \beta DS + \tilde{}\alpha DLS$$

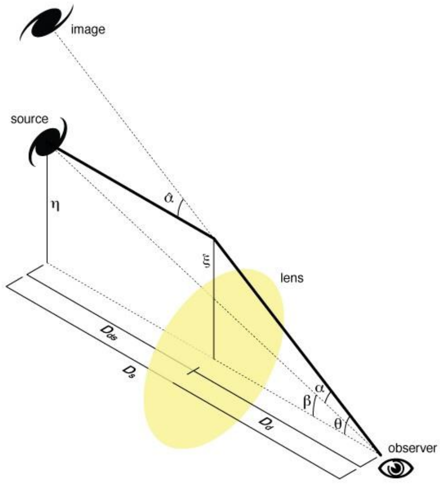

Figure 2: Setup of a gravitational lens situation: The lens L located between source S and observer O.

(for θ, β, ˜α 1; this condition is fulfilled in practically all astrophysical relevant situations). With the definition of the reduced deflection angle as α(θ) = (DLS/DS)˜α(θ), this can be expressed as: $\beta = \theta - \alpha(\theta)$

This relation between the positions of images and source can easily be derived for a nonsymmetric mass distribution as well. In that case, all angles are vector-valued. The two-dimensional lens equation then reads:

$$\beta\sim = \sim\theta - \sim\alpha(\sim\theta)\ [1].$$

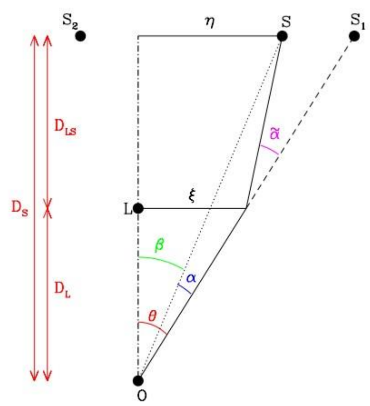

Figure 3: The relation between the various angles and distances involved in the lensing setup can be derived for the case ˜α 1 and formulated in the lens equation.

IV. Types of gravitational lenses

1. Strong lensing

The region surrounding a dense mass concentration, such as the center of a galaxy or galaxy cluster, is where gravitational lensing is most readily visible. Nearby space-time is so twisted in the "strong lensing" regime that light can travel in several directions around the lens and still be redirected back in the direction of the observer [2]. The light can flow around any side of a circular lens when a distant source is right in front of it, creating the appearance of an "Einstein ring." The square root of the predicted mass inside this ring determines its Einstein radius or size. The backdrop source can nevertheless appear in various locations when viewed from very slightly different angles, even if it is slightly offset or the lens has a complex shape. Each of these many images can be made brighter (magnified) or fainter (damaged), depending on how the light path is focused. The magnification is highest close to the "critical curve" (the asymmetric equivalent of an
Einstein ring).

2. Microlensing

The term “gravitational microlensing” was coined by Refsdal , from the characteristic ∼ 1 microarc second size of a star’s Einstein radius. Only physically small sources will be significantly affected by microlensing; extended background sources like galaxies are effectively immune because only a tiny fraction of their light is strongly magnified, with the rest propagating unaffected. More massive lenses, with milliarcsecond Einstein radii, produce “gravitational milli lensing” that affects slightly larger background sources on a timescale of months (and the statistical long tail is strong lensing around massive clusters, with arcsecond Einstein radii) [3]. This distinction has been most useful when looking at the lensed images of Active Galactic Nuclei (a galaxy’s central, supermassive black hole and surrounding accretion disc), because these really do have different physical sizes when viewed at different wavelengths. As matter gradually falls into the black hole, it emits a warm glow of infra-red light from the large and outer narrow-line region, then optical light from the smaller broad-line region and finally ultraviolet light from the accretion disc itself. The behavior of the source can be modelled from long wavelength observations, which are relatively unaffected by gravitational lensing, then the lens object and even its substructure probed at progressively shorter wavelengths.

3. weak lensing

Most lines of sight through the Universe do not pass near a strong gravitational lens. Far from the core of a galaxy or cluster of galaxies, the light deflection is very slight. In this “weak lensing” regime. As a locally linear transformation of the sky, which is represented as a 2×2 matrix and includes magnification, shear, and (possibly, but not frequently in practice) rotation, the distortion of resolved sources can be estimated to first order. The theory was developed during the 1990s, including some practical methods to accurately measure galaxy positions and shapes in the new pixelated CCD images. Either the magnification or the shear distortion can be measured, but the shear tends to have higher signal to noise, because competing effects of magnification (the brightening of faint galaxies, but the dilution of the surveyed volume in a fixed angle on the sky) act against each other and partially cancel. The shear distortion changes the shapes of distant galaxies, adjusting their major to-minor axis ratio by ∼ 2%. This cannot be seen in an individual object, since it is far smaller than the range of intrinsic shape variation in galaxies.

V. Gravitational lenses and dark matter

Astronomers can gain more insight into the mass and dark matter content of the foreground galaxies according to the gravitational lensing theory. As implied by the name, dark matter is dark. Astronomers can only study it by seeing how its gravity affects things that are visible to us. Dark matter is a mystery to astronomers at the moment. They believe that up to 85% of the universe's entire mass may be made up of dark matter, which poses a significant problem. Therefore, gravitational lensing gives astronomers a tool to determine where the dark matter must lie based on its effects on the background galaxies and delivers more information about foreground objects [4].

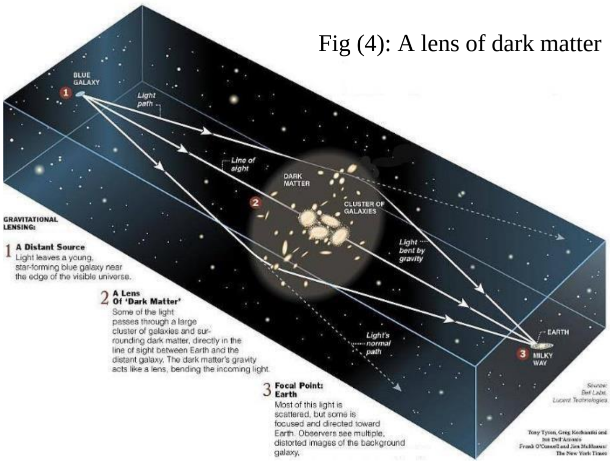

Fig (4): A lens of dark matter

VI. Conclusion

In conclusion, to sum up everything that has been started so far, Gravitational lensing has gained increasing importance in the last decades, although it was considered as a mere theoretical curiosity until the late 1970s. Several recent breakthroughs in cosmology can be attributed to gravitational lensing. Indeed, gravitational lensing and in particular gravitationally lensed quasars offer numerous applications to address fundamental subjects of modern cosmology such as the Hubble constantH0, dark matter or dark energy to name a few.

VII. References

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