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Yu. G. Klimov

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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

Astronomy

Yu. G. Klimov

THE USE IN EXTRAGALACTIC ASTRONOMY OF THE EFFECT OF DEFLECTION OF LIGHT RAYS IN THE GRAVITATIONAL FIELDS OF GALAXIES

(Presented by Academician A. P. Aleksandrov on 11 XII 1962)

The effect of the deflection of light rays in the gravitational field of some body, known from the general theory of relativity, may find a number of practical applications in extragalactic astronomy. In paper ([1]) the possibility was considered of observing the deflection of light rays in the gravitational fields of galaxies. As one of the possible applications of this phenomenon in astronomy, one may point to its use for increasing the penetrating power of a telescope.

Let us agree to call axial screened galaxies the galaxies G_1 that lie on the extension of the ray joining the observation point P with the center of the screening galaxy G_2 (Fig. 1). All screened galaxies that do not lie on the ray SP will be called non-axial.

Fig. 1

The illumination produced by an axial screened galaxy at the observation point exceeds the illumination that the same galaxy would produce in the absence of screening. The illumination from an unscreened galaxy is determined by the expression ([2])

$$E_1 = \pi B \sin^2 \delta_1,$$

where B is the brightness of the surface of the galaxy, and δ_1 is the angular radius of the galaxy. For small δ_1,

$$E_1 = \pi B \delta_1^2.$$

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An axial screened galaxy G_1, from the point P, will be observed in the form of a ring around the screening galaxy G_2 ([1]) (Fig. 1).

Dividing the area of the ring into narrow annular zones with radii x and $x + dx$, and then integrating over the entire area of the ring, we find the total illumination produced by an axial screened galaxy at the point P:

$$E_k = \pi B a^2 \frac{\rho_2^2 - \rho_1^2}{(a^2 + \rho_1^2)(a^2 + \rho_2^2)},$$

where a is the distance from the screened galaxy to the point P; ρ_1 and ρ_2 are the inner and outer radii of the ring.

Since $a \gg \rho_1$ and ρ_2, the formula for E_k may be written as

$$E_k = 2\pi B \delta \delta_k,$$

where δ is the angular width of the ring, and δ_k is the mean angular radius of the ring.

Carrying out the necessary calculations, it can be shown that, for an axial arrangement of the screened galaxy, $\delta = \delta_1$ (δ_1 is the angular radius of the screened galaxy).

The ratio of the illuminances produced at P by the screened and the unscreened galaxies will be equal to

$$\frac{E_k}{E_1} = 2\,\frac{\delta_k}{\delta_1}. \tag{1}$$

Thus, the screening galaxy G_2, by exerting a focusing action on the radiation of the screened galaxy G_1, increases the illuminance per unit area located at P perpendicular to the axis by a factor of $2\delta_k/\delta_1$.

When a screened galaxy is observed through a telescope, its ring-shaped image is formed in the focal plane of the telescope; moreover, rays of only one direction will take part in the construction of each point of the ring-shaped image. As a result, the illuminance produced in the focal plane of the telescope by the galaxy G_1 will be determined, as in the ordinary case, by its stellar magnitude. Therefore, when photographing screened galaxies, the focusing effect of the galaxy G_2 will not appear. To observe distant screened galaxies with a stellar magnitude exceeding the limiting magnitude for a given telescope, one should use radiation receivers that make it possible to sum the light energy falling on some area. Photomultipliers or photoelectric cells may be used as such receivers.

Having determined from (1) the ratio of the illuminances E_k/E_1 and using Pogson' s formula, we find the difference between the apparent magnitudes of the unscreened and the screened galaxy:

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$$\Delta m = 0.75 + 2.5 \lg \frac{\delta_k}{\delta_1}. \quad (2)$$

For the galaxies G_1 and G_2, located respectively at distances $1.9 \cdot 10^9$ and $7 \cdot 10^8$ pc, $\Delta m = 2^m.09$. Thus, screened galaxies whose stellar magnitude exceeds the limiting stellar magnitude of the telescope by 2.09 will be accessible to observation. To obtain the corresponding increase in penetrating power, for example, of a 5-meter telescope, it would be necessary to increase the diameter of its mirror to ~ 13 m.

For practical use of the focusing effect, the following basic scheme for observing very faint screened galaxies may be proposed. A galaxy is selected that satisfies the conditions necessary for observing screened galaxies ([1]), and the total radiation from ring-shaped regions of various radii (smaller than the radius of the avoidance region ([1])) surrounding the galaxy under consideration is measured. In the absence of screened galaxies, the radiation from the ring-shaped regions should decrease as the radius of the region increases. If, on the contrary, an increase is observed in the radiation intensity from some ring-shaped region, then, consequently, an axial or off-axis screened galaxy is located in that region. The deflection of light rays in the gravitational fields of galaxies must be taken into account when estimating the brightness of distant galaxies. As a result of illumination by screened galaxies, the observed brightness of galaxies may exceed their actual brightness. If the angular distance between the ring from the screened galaxy and the screening galaxy is smaller than the minimum angular distance resolved by the given telescope, then both galaxies will be perceived by the observer as merged. Thus, for example, if the absolute integral stellar magnitude of the axial screened galaxy is $-19^m.0$, and that of the screening galaxy is $-18^m.0$, then, taking the distances to the galaxies and their diameters to be the same as in the preceding example, we find that the brightness of the screening galaxy increases

in this case by 0.62 stellar magnitude. The indicated increase in the brightness of galaxies should be taken into account beginning with distances determined by expression (1) $a_2 = r_2^2/4\alpha$, where r_2 is the radius of the screening galaxy; $\alpha = \gamma M/c^2$; γ is the gravitational constant; M is the mass of the screening galaxy; c is the speed of light.

In determining distances to remote galaxies from the integral brightness of galaxies, the possible illumination by screened galaxies should be taken into account.

The curvature of the trajectory of light rays in the gravitational fields of galaxies can be used to determine the masses of galaxies. It is known ([1]) that the observation of screened galaxies is possible in the case when the distance to the galaxies, the mass of the screening galaxy, and the angles of observation δ are related by

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$$\frac{4\alpha a_1}{a a_2} = (\delta - \theta)\,\delta\,, \tag{3}$$

where θ is the angle at which the galaxy G_1 would be seen in the absence of screening; a_2 is the distance from the observer to the screening galaxy; a_1 is the distance between the screening and the screened galaxies; $a = a_1 + a_2$.

If the screened galaxy is an axial galaxy, then from expression (3) it is easy to find the mass of the screening galaxy

$$M = \frac{a_2 c^2 \delta^2}{4\gamma a_1}.$$

When observing an off-axis screened galaxy,

$$M = \frac{a a_2 c^2 \delta\, \delta'}{4\gamma a_1},$$

where δ and δ' are the angles at which the images of the off-axis screened galaxy will be observed.

The distances to galaxies may be determined from radial velocity or by some other method. δ and δ' are found directly from observations.

The observation of screened galaxies will give astronomers a new method for measuring distances to remote (screened) galaxies. Suppose that the space surrounding us is homogeneous (Galilean) space. A violation of the homogeneity of space will occur only in regions in which gravitational masses are located. Since the path traversed by a ray of light from the screened galaxy to the observer is large in comparison with the region in which the homogeneity of space is violated, we may consider that the change in the direction of the light ray occurs at one point. In this case the distance between the screened and screening galaxies is written as

$$a_1 = \frac{a_2}{\dfrac{4\alpha}{a_2 \delta\, \delta'} - 1}.$$

Thus, in order to determine the distance to remote screened galaxies it is sufficient to know the mass and the distance of the screening galaxy from the observer.

The existing method for determining distances to remote galaxies from the integral brightness of galaxies requires knowledge of the absolute stellar magnitude of the galaxies. Estimating the absolute magnitude of galaxies presents considerable difficulties. These difficulties are due to the dispersion of the absolute magnitudes of galaxies and to photometric "distance effects," such as···

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···such as redshift and metagalactic absorption of light. Therefore, a large element of uncertainty arises in estimating the absolute magnitude of galaxies, which is one of the sources of errors in determining distances to remote galaxies.

The proposed method of measuring distances is free from the indicated difficulties, since in this case determining distances does not require knowledge of the absolute magnitude of galaxies. This circumstance may be used to measure the metagalactic absorption of light, to refine the form of the dependence of the redshift on distance, and also to determine the luminosity function of galaxies.

To determine the metagalactic absorption of light, let us find from expression (2) the "apparent" stellar magnitude of the screened galaxy m. Then we determine the radius of the screened galaxy and its stellar surface-brightness magnitude

$$m_\sigma = m + 2{,}5 \lg S,$$

where S is the area of the screened galaxy. It is known that m_σ is constant for structurally similar galaxies. Comparing the values of m_σ for nearby galaxies with the values of m_σ found for remote screened galaxies and studying the correlation between the distance to galaxies and the surface brightness of galaxies, one can estimate the magnitude of the metagalactic absorption of light.

In conclusion it should be noted that even qualitative observation of screened galaxies will make it possible to obtain much new data on the structure of the metagalaxy and its dimensions. Thus, for example, observation of axial screened galaxies will make it possible to refine the scale of extragalactic distances. At present three scales of extragalactic distances have been proposed: Hubble' s scale, the doubled Lundmark—Mineur—Baade scale, and Sandage' s scale, which exceeds Hubble' s scale by a factor of 4–5.

Carrying out the calculations, one can show that the minimum distance from which observation of axial screened galaxies is possible (without using the focusing effect discussed above) is equal to $1{,}9 \cdot 10^9$ pc when observations are made outside the Earth' s atmosphere and $5{,}4 \cdot 10^9$ pc when observing under terrestrial conditions ([1]).

If Hubble' s distance scale is valid, the maximum distance accessible to a 5-meter telescope, taking into account observational selection, is $1 \cdot 10^9$ pc. Consequently, if Hubble's scale is valid, axial screened galaxies should not be observed. When axial screened galaxies are observed in telescopes installed on the Earth, Sandage' s scale must be valid; when observing only outside the Earth' s atmosphere, Baade' s scale must be valid.

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CITED LITERATURE

1. Yu. G. Klimov, DAN, **148**, No. 4 (1963).

2. N. A. Sytinskaya, *Absolute Photometry of Extended Celestial Objects*, L., 1948.

Note: Figure translations are in progress. See original paper for figures.

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