Supplementary material A

# The optical effect on the image and time delay of gravitational lensing

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**Abstract**: The size of image and time delay in a gravitational lensing is related with the wavelength of the light. It indicates that, the optical effect is important to calculate the accurate size of a galaxy from the gravitational lensing. Some of new discoveries about light should be obtained from the new observational results about the gravitational lensing.

**Keywords**: Gravitational lensing; Wavelength; Size of image; Optical effect

It was observed: "Significant time delays are detected between the far-UV, near-UV, and optical broadband light curves.."[14] "Under the condition that the disk size is larger at longer wavelength, the time delays between the light curves in different bands provide a measurement of the size: the larger the disk, the longer the delay."[15] Therefore, a method is presented that the distance of extragalactic can be measured with "the time lag between variations in the short wavelength and long wavelength light from an active galactic nucleus".[16]

There are two points in the above observations: 1) the size of the image is a function of wavelength. 2) light curves measured in different bands will give different time delays.

In optics, for a given general lens and an object at the same positions, the size of the image of an object is determined with the index of refraction: The wavelength is longer, the index is less, the image is larger, the distance between the image and object is larger.

In a gravitational field, the degree of curve of a light line is analogous to the index of refraction. Therefore, for a given gravitational lens, the wavelength is longer, the degree of curve is less, the image is larger, the distance between the image and object is larger which results in that the time delay is larger.

Therefore, the current observations about the image and time delay of gravitational lensing could be better understood with optics.

The observations in [14,15] shows that the degree of curve of a light line in a gravitational field is related with the wavelength of the light.

The speed of light is a function of the index of refraction, $c' = \frac{c}{n}$, where n is a function of wavelength. There is a difference of the time delays between the light with different wavelengths. It means that the speeds for the light with different wavelengths are different. For a double-image gravitational lensing system, as the two images of a star are formed at the same time, it is clear, two light curves with different wavelengths are needed. The image with larger distance from the object is formed by the light curve with longer wavelength while the another one is with shorter wavelength. Therefore, the speed of the light with longer wavelength is larger.

**Conclusions**

Currently, the gravitational effect in the gravitational lensing was focused on. However, even in the gravitational lensing system, the formation of image is still according to the law of optics. Therefore, the optical effect need be further studied to better understand the image and time delay of gravitational lensing. In optics, for a given lens, the size of the image can be larger, less than or equal to the object as the positions between the object and the lens are different. Therefore, the law of optics is needed to calculate the accurate size of the galaxy from the positions among the gravitational lens, the galaxy and the image to know the reason why “the disk size is larger at longer wavelength”.

On another hand, the new observations in [14,15] could be a line to have some of new discoveries about light. In the little distance for a usual camera, the image affected by the index of refraction of light is negligible. But, in the astronomical scale, a little difference between the degrees of the curve of two light lines can produce a significant effect. For example, in the double-image gravitational lensing, two images with a very big distance can be produced by the difference.

The degree of the light curve, $\theta_\lambda$, is related with wavelength, λ, for that $\theta_\lambda$ is varied with the index of refraction, $n_\lambda$, with different wavelength . The speed of light with different wavelength could be expressed as $c_\lambda = \frac{c}{n_\lambda}$. It could be observed through the double-image gravitational lensing system or through “the time delays between the light curves in different bands”.[15]

Supplementary material B

## The enlarged effect of the dispersion of light in a strong gravitational field

Under the condition that dispersion of light, as a light ray with two (or more) wavelengths is running through a gravitational field as shown in Figure 1s, because the speed of light is

$$c_\lambda = c/n_\lambda$$

As $n_{\lambda 1} < n_{\lambda 2}$, there is $c_{\lambda 1} > c_{\lambda 2}$. In this case, as the light with the wavelength of $\lambda_1$ has arrived at point $P_1$ where the field strength is $g_1 = G\frac{M}{R^2}$, the light with the wavelength of $\lambda_2$ only arrived at point $P_2$ where the field strength is $g_2 = G\frac{M}{(R+r)^2}$. In a super strong field, $(g_1 - g_2)$ is very large. Under the condition that the light can be bent with $\varphi = 2G\frac{M}{rc^2}$, the line that the light with $\lambda_1$ running is greatly different from that with $\lambda_2$.

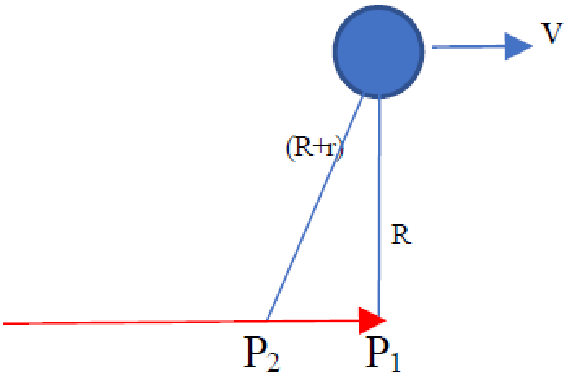


**Figure 1s. The enlarged effect of dispersion of light in strong gravitational field.** The star is moving along v. The light with two wavelengths is running along the red arrow. At point $P_1$ the field strength is $g_1 = G\frac{M}{R^2}$ while at point $P_2$ the field strength is $g_2 = G\frac{M}{(R+r)^2}$. As the time that the light with the wavelength of $\lambda_1$ arrived at point $P_1$ and the light with $\lambda_2$ arrived at $P_2$ is same and the light is bent by gravity at $P_1$ and at $P_2$, there shall be a difference between the bent angle of the light with $\lambda_1$ and that of the light with $\lambda_2$. In a super strong field, $(g_1 - g_2)$ is a very large value. This difference is also very large. For the moving of the star, this difference shall be enlarged with time. In the field with proper strength, a spectrogram by gravity should be observed.