A diffraction phenomenon of gravitational waves: Poisson-Arago spot for gravitational waves

The gravitational wave, a new observational tool first observed in 2015 [1], offers a great opportunity to explore the nature of the universe. It is very closely relevant to some important issues in astrophysics, cosmology and fundamental physics [2].

The properties of the gravitational wave, especially its wave nature, have long been researched [3] through quasi-normal modes of stars and black holes [4], as well as the lensing [5-7] and scattering [8,9] phenomena. The diffraction effect, Poisson-Arago spot, is considered the “experimental crux” in proving the wave nature of light. However, as the fundamental properties of waves, the diffraction and interference effects can be hardly clarified for gravitational waves, because matter is almost transparent to gravitational waves, and circular aperture and double slits are not easily manufactured.

Recently, Zhang and Fan [10] reported the diffraction phenomenon of gravitational waves. They proposed that black holes could block gravitational waves and act as an optically opaque disk. By relating the well-known Regge-Wheeler equation to a confluent Heun equation, they found an exact diffraction solution for an ingoing (quasi-)plane gravitational wave through a Schwarzschild black hole. With the eikonal approximation, they found that, for the continuous gravitational waves of about 100 Hz detected by ground-based detectors, such as LIGO and Virgo, the diffraction phenomenon of gravitational waves can be perfectly displayed through the supermassive black hole at the center of our galaxy.

They named this effect “Poisson-Arago spot of gravitational waves”. That is, when an observer, the source of a gravitational wave, and a diffractive body black hole are collinear, the observer will just see a bright spot of the gravitational wave. Because of gravitational convergence, the gravitational-wave Poisson-Arago spot is stronger than the corresponding optical one. If some detectors can observe a gravitational wave source for a long time in the future, the earth would be found “moving” between the bright and dark stripes of gravitational waves. For the supermassive black hole in our galaxy, the authors estimate the time scale of moving to be about several days. It would be quite interesting to see such a phenomenon in the future. Another contribution of this article is to deal with the divergence problem of on-axis scattering with the Fresnel half-wave zone method.

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