On Gravitational Waves and Black Holes

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Abstract

A simple estimate is presented that raises doubts whether the new and spectacular observations of gravitational waves by the LIGO collaboration can be attributed unambiguously to black-hole mergers. In addition, with the advent of the VIRGO detector running, a test of the polarization character of gravitational waves has become possible and a corresponding analysis of the data should be envisaged.

Remark

The LIGO collaboration [1] has has opened a new and exciting era in cosmology by the observation of gravitational waves (GW) from the merger of objects of extreme mass density. The first few events could be attributed to the merger of black holes (BH) [2-5]. Recently, by the concurrent observation of optical phenomena (a gamma-ray flash with a subsequent kilonova eruption) a merger of two neutron stars could be identified [6]. We present here a few back-of-an-envelope type considerations in connection with these events.

A short consideration of Newtonian mechanics of two identical stars in a circular orbit yields for the frequency of revolution, ν

$$\nu^2 = \frac{G \rho \alpha^3}{12 \pi} \quad , \tag{1}$$

where G is the gravitational constant, ρ the mass-density of the stars (assumed constant), and α the ratio between the radius of the stars and their distance from the center of mass. This ratio is smaller then one and approaches a value of one in the (idealized) merger situation. Evaluating (1) for the case of neutron stars with a density of $5 \cdot 10^{17}$ kg/m^3, we obtain an upper limit of 900 Hz for the frequency of revolution at merging time. To estimate the order of magnitude of relativistic corrections, we calculate from this frequency and a typical radius of a neutron star of 10 to 20 km a speed of 0.2 to 0.4 times the speed of light. Corrections would be of the order of the square of these numbers, i.e. an irrelevant 4 to 16%. Thus, considering the coarseness of argument we expect a limiting frequency in the range of a couple of hundred Hertz. This is also the range in which the observations fall, which have been classified as BH mergers.

Stressing approximations a bit further we may introduce in (1) the “density” of a black hole

$$\rho_{BH} = \frac{3}{8 \pi} \frac{c^2}{G r_s^2} \quad , \tag{2}$$

where c is the speed of light and r_s the Schwartzschild radius. Clearly, this density can assume arbitrary values. Consequently, any merger frequency can be attributed to a BH merger.

Thus, to be sure that one has observed black holes, the merger frequency has to lie above the one of a merger of neutron stars, or one has to be a hundred percent (not less!) sure that one has not missed an optical effect associated with the merger. In my opinion, both criteria are not met in the LIGO events, attributed to BH mergers.

In addition, the BH masses derived from the GW experiments lie in a range that was previously considered above the values one used to expect from star formation theories. Furthermore, lower-mass (regular) BH mergers appear to be rare events.

One can elaborate a bit further and acknowledge that speculative higher-density stars above the Tollman-Oppenheimer-Volkoff limit may exist which would would raise the merging-frequency limit of non-BH events even further. The concept of black holes has freed us from having to speculate on even higher-density states of matter, but one may ask, whether this is really justified by experimental evidence (see also [7]).

Polarization

In General Relativity gravitational waves have tensorial character and the LIGO interferometers are attributed corresponding antenna beams. Because of the practically parallel orientation of the Hanford- and Livingston interferometers they do not provide the possibility to test this prediction. With the VIRGO detector operating the situation has become more amenable to such a test, and it should be envisaged. This particularly, because it has been proposed that gravitational waves may have longitudinal polarization character [8].

References

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