Ligo Gravitational waves: Ripples in Spacetime or Electromagnetic V2

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ABSTRACT

On Feb. 2016 the Ligo team announced the detection of gravitational waves from a collapsing Black Hole that occurred on Sept 14 2015. This definitively answers the question of the existence of gravitational radiation, and confirms the pulsar radiation energy measured by Hulse, & Taylor [1,2]. Although the loss of energy in orbiting binaries is indicative of radiational loss, it does not automatically follow that the energy being radiated is gravitational, there is the possibility proposed by several theorists, that the waves are electromagnetic [3-9]. The Ligo experiment has developed impressive measures to reduce electromagnetic signals, but at the levels of strain being measured, it is not certain that the momentum transfer can be completely avoided. Electromagnetic signals diffracted around the limb of the earth vs. gravitational waves passing freely through, yield timing and attenuation differences that can clearly distinguish between the two, but as of yet that has not happened. There can only be certainty when the three Ligo Virgo observatories simultaneously triangulate signals through the earth with proper timing and attenuation. This paper will explore the aspects of the measurements that will define the difference.

Issues with Curved Spacetime

The nature of gravitational waves has been an issue since the inception of GR, and the Ligo Virgo consortium is on the verge of delivering the definitive answer. Although the loss of energy in orbiting binaries is indicative of radiational loss, and GR's distortion of spacetime is cited as the carrier of the energy it is not yet clear that, that is true. There has been an array of theorists that have proposed that the nature of gravitation and the radiation is electromagnetic.

There are hundreds of, mostly field theories of gravitation that generally break into 2 major groups: Those that involve curved space with non-local conservation of energy, and those that fit within Minkowski 4-space generally having local conservation of energy. There are many theories that mix both, to arrive at a predicted result [10]

The basic problem for GR is that it is a tensor formulation that by Noether theorem cannot have localized energy, whereas the 4space Minkowski theory of QM and electromagnetism has local localized energy conservation as the basic principle. Equations that have mixed elements when subjected to coordinate transforms are mathematically inconsistent. The unresolved issue of the compatibility of Quantum Mechanics and general relativity is the most glaring example of this.

The discovery of orbital energy loss by orbiting stars in 1975 by Hulse, & Taylor [1,2], solidified the fact that there is radiation, and is the best evidence that something can be measured. The detection of waves generated by collapsing black holes in 2015 by Ligo finished that issue.

Dicke in 1957 [3], as well as others[4-9], have speculated on the possibility that gravitation has an electromagnetic origin, and in fact it was only after the Pulsar Hulse, & Taylor [1,2], measurements that there was a serious belief that the carrier of the energy, energy-momentum pseudo-tensor could have or carry any energy at all.

It is notable that Misner, Thorne & Wheeler, Gravitation, 1973, p.467: remarked of the gravitational the energy-momentum pseudo-tensor:

> "It is not localizable. The equivalence principle forbids." "There is no unique formula for it", "it has no weight. It does not curve space. It does not serve as a source term ... It does not produce any relative geodesic deviation of two nearby world lines ... It is not observable." [11]

Belief in this changed after 1975 but, whether the measurements of gravitational radiation by the Ligos-Virgo consortium are inherently gravitational or electromagnetic as still open. If the energy-momentum pseudo-tensor is unable to carry energy then the transfer mechanism could well be electromagnetic.

Why Gravitational Waves could be Electromagnetic

The Larmor radiation dipole radiation for each of a pair of rotating charges is:

$$P_E = \frac{2}{3}\frac{q^2}{c^3}\dot{v}^2 \quad (1)$$

In addition to the dipole radiation there is a quadrupole radiation with a power ratio between the two modes of v^2/c^2, [28]. The quadrupole contribution is then:

$$P_E = \frac{2}{3}\frac{q^2}{c^3}\dot{v}^2\left(\frac{v^2}{c^2}\right) \quad (2)$$

This can be added to the Larmor power for the total radiation of a rotating charge.

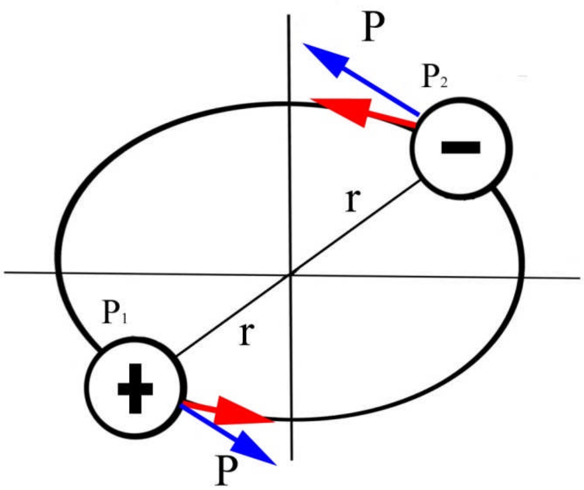
The value of the power radiated from the linearized GR equation which only has quadrupole components is [27]:

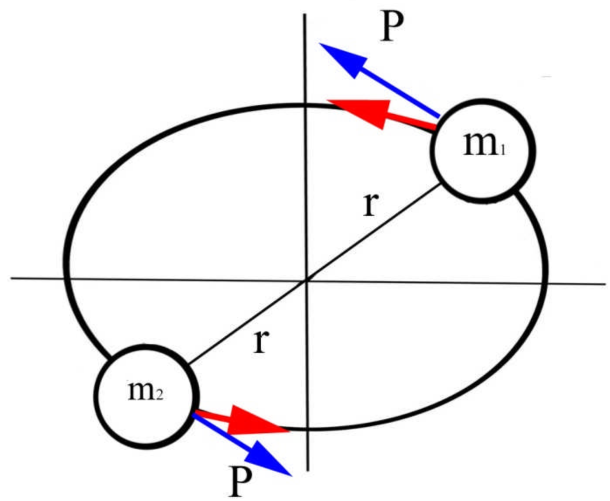
$$P_G = \frac{2}{3}\frac{Gm^2}{c^3}\dot{v}^2\left(\frac{v^2}{c^2}\right) \quad (3)$$

Keeping to a simple concept, consider two equal masses, or two equal charges placed in a circular orbit with the centrifugal forces balancing the attraction. The power radiated by each is defined by Eq.(1), Eq.(2), and Eq.(3), and by Feynman's analysis the radiation reaction force is proportional to and opposite the third derivative (jerk).

The configuration of this is illustrated in Fig. 1.

Fig 1





$$P_E = \frac{2}{3}\dot{v}^2\frac{q^2}{c^3} + \frac{2}{3}\dot{v}^2\frac{q^2}{c^3}\left(\frac{v^2}{c^2}\right)$$

$$P_G = \frac{2}{3}\frac{Gm^2}{c^3}\dot{v}^2\left(\frac{v^2}{c^2}\right)$$

The force holding one of the charges P_1, in orbit is just the centrifugal force, thus the coupling constant can be replaced with:

$$f_E = \frac{kq^2}{(2r)^2} = k\,m\frac{v^2}{r} \quad \rightarrow \quad q^2 = mv^2r = Lv \quad (4)$$

The force holding one of the masses M_1 in orbit is just the centrifugal force, thus the coupling constant can be replaced with:

$$f_G = \frac{Gmm}{(2r)^2} = m\frac{v^2}{r} \rightarrow = Gmm = mv^2r = Lv \quad (6)$$

And noting for a centrifugal force $\dot{v} = v^2 / r$, results in the power radiated:

$$P_Q = \frac{8}{3}(m\dot{v})v\left(\frac{v^3}{c^3}\right) + \frac{8}{3}(m\dot{v})v\left(\frac{v^5}{c^5}\right) \quad (5)$$

And noting for a centrifugal force $\dot{v} = v^2 / r$, results in the power radiated:

$$P_G = \frac{8}{3}(m\dot{v})v\left(\frac{v^5}{c^5}\right) \quad (7)$$

Or in terms of the third derivative (jerk), this is: (See appendix II for parameter substitutes)

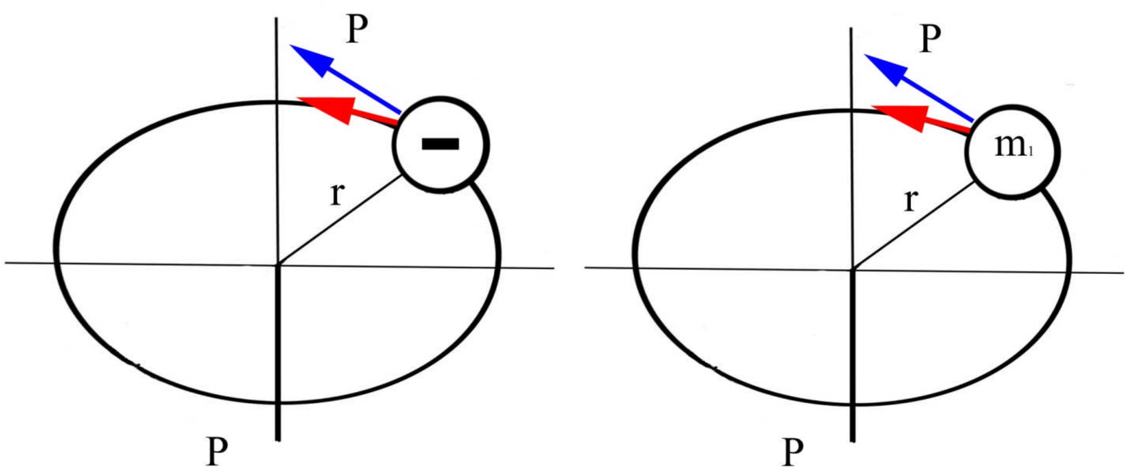
$$P_Q = \frac{8}{3}mr\ddot{v}\left(\frac{v^3}{c^3}\right) + \frac{8}{3}mr\ddot{v}\left(\frac{v^5}{c^5}\right) \qquad P_G = \frac{8}{3}mr\ddot{v}\left(\frac{v^5}{c^5}\right) \quad (8)$$

Note that the dependence is on mass, jerk, and kinematics of a central force, and, not dependent on G or q. The quadrupole power radiated is identical for both charge and gravitation.

Change of Central Force

Now let us presume to replace one of the masses and charges in Fig.1 with a string to provide the exact same central force.

Fig. 2



We know for certain in the case of the charge, the Larmor radiation produces the same radiation, and the radiation originates at the mass not from the system:

With the second charge gone however the electric dipole vanishes for the charge configuration and the radiation for both particles are the same:

$$P_Q = \frac{8}{3} m r \dddot{v} \left(\frac{v^5}{c^5} \right) \qquad P_G = \frac{8}{3} m r \dddot{v} \left(\frac{v^5}{c^5} \right) \qquad (9)$$

The radiation depends completely on the kinematics of mass acceleration and velocity no Q or G dependence. The coupling constants participate only in the binding force, not the radiation. Gravitation does not have a negative equivalent, thus there is no dipolar radiation for it, but the quadrupole radiation is exactly the same as the electric dipole.

Note for the mass on a string is just that, a mass on a string, and now has no reference to gravitation.

Mass undergoing a change in acceleration radiates about the same energy charged or not.

Ligo Detectability of Electromagnetic Signals

If the waves are electromagnetic it is difficult to estimate the magnitude of strain that would be inducted into the LIGO detector. This is primarily due to the fact that every effort has been made to shield the detector from electrical interference, and whatever electromagnetic coupling is present is only that which inadvertently leaks into the system.

There is however coupling not related to electromagnetic effects, and is on the order of magnitude capable of inducing the observed signal. That is the Poynting vector momentum transfer of the electromagnetic signal to the surface at and around the detector. Since the detector is sensitive to seismic signals, this is still a possible source of the measured signal. Known correlations in the detector noise for gravitational events exclusive of the signal could suggest also that there is extraneous induced seismic activity associated with the event. [12]

The energy per unit area calculated from the stellar merger is the same for both electromagnetic and a gravitational signals and the impact of the electromagnetic waves onto the earth can be estimated and seems sufficient to induce seismic displacements on the order of the sensitivity of the detectors.

The Ligo team estimated energy flux from event GW150914 to be 1.e5 ergs/meter^2 [13], and if this is electromagnetic energy is absorbed in about a meter of soil the displacement at 100 Hz would be about 1.1e-16 cm [14], on the same order of the displacement sensitivity of for the advanced Ligo detectors. (4e-17cm [15],)

If the entire Ligo assembly and surrounding surface is thus impacted with a plane wave displacement in phase with the gravitational radiation it is reasonable to assume that it could couple into the detectors

Measurements that will distinguish E&M from G Waves

The two distinct effects that the Ligo Virgo detectors will be able to measure that will be differ significantly between E&M and GR waves: “Time of arrival”, and: “Attenuation” of signal around the earth. Specifically:

Do the waves pass “through” the earth without delay or attenuation, as specified by GR or are they diffracted, refracted and attenuated in the trajectory “around” the earth?

Timing

The properties of Gravitational waves as predicted by General relativity asserts that GR waves pass through matter with very little hindrance, thus the detectors are “all sky”, line of sight between the event and the detector no matter where on the earths location. For electromagnetic waves the route is around the limb of the earth and there are considerable delays and attenuation mechanisms that will affect the signal.

For a plane wave impacting the earth, the time directly through to an opposite point would be a minimum of about 12 ms faster than one that goes around the limb. Fig.3. There is some uncertainty in the travel time since the refraction and diffraction for a 3000-6000 Km wavelength electromagnetic is not well known.

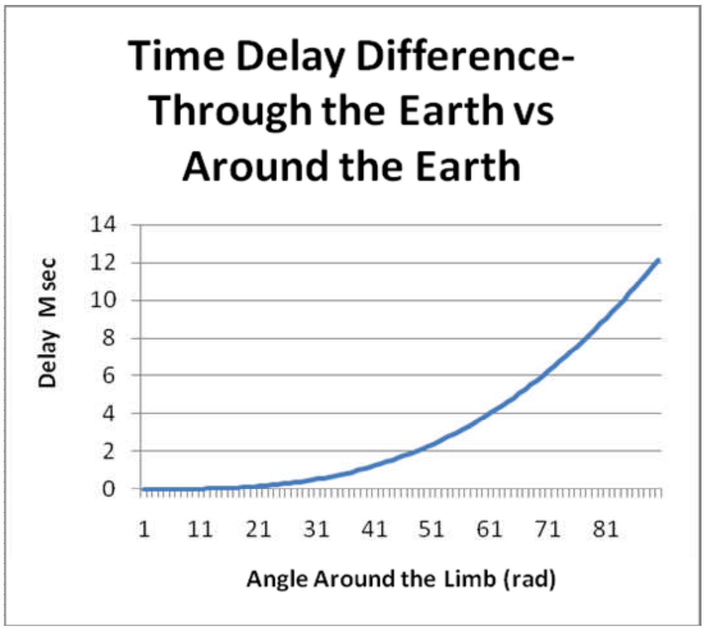


Fig.3 Plot of the minimum delay of electromagnetic signals around the surface of the earth vs. signal coming directly through.

An evaluation of the currently detected events [13-21], shows:

> None of the detected events have route timing difference sufficient to distinguish E&M form GR waves.

Only one detected event has signal measurements from all three detectors (GW170104), and for that event, and the Pisa detector is too faint to arrive at distinguishable timing accuracy. In this case the difference of around vs. through the earth would be only about 1 ms. (See appendix I)

Attenuation

General Relativity allows for almost no attenuation of gravitational on passing through a mass such as the earth, whereas an electromagnetic signal must travel around the surface. The electromagnetic wave will also be attenuated by a combination of diffraction, refraction, and the distance around the limb from one detector to the other.

The attenuation mechanisms for low frequency electromagnetic radiation around the earth are not well known and not easily evaluated, but nevertheless will be appreciable. Detectors located such that the event is above the horizon should have signals larger than those observing the event below the horizon. For an electromagnetic signal the signal to noise ratio should drop proportionally to the angular distance around the earth.

This effect should be quite discernible as more measurements become available. There is however already some indication that there is such attenuation of the signal in events GW170814 and GW170817 [13],[21]. It will take many more measurements to determine if this is real or just random coincidence. The SNR are plotted for these events, (Fig.1).

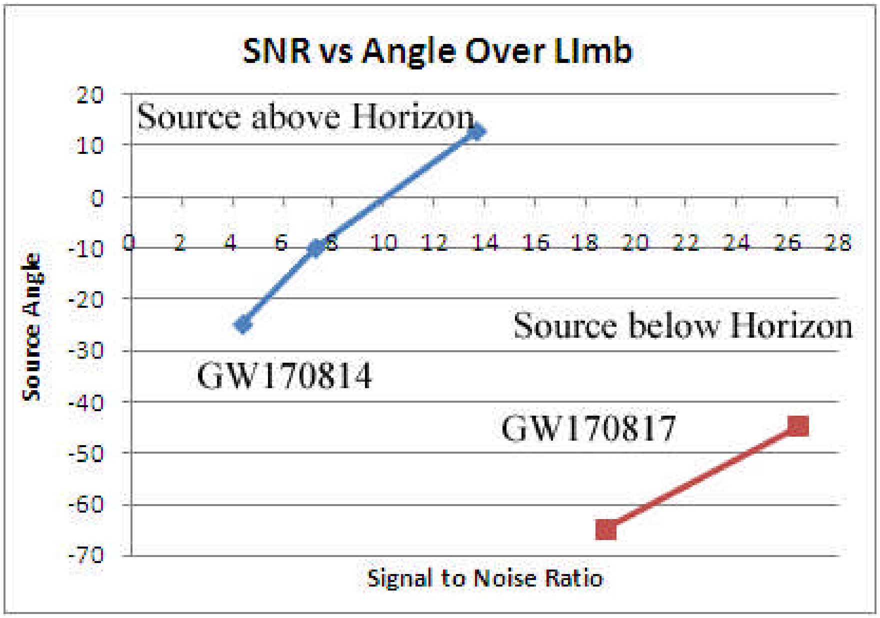


Fig. 2
This is a plot of the SNR for GW170817 and GW170814 in which the event location is known to be below the detector horizon. Both events are detected by all three detectors [13]. For GW170814,[17], but the Virgo signal is too low to get a usable SNR reading. These plots of course could have to do with other factors including sensitivity of the detectors, thus this not definitive but it is an indicator. If the waves are gravitational, there should not be a correlation of SNR with distance through the earth.

The QFT Basic of Electromagnetic Radiation

It is known that the interaction of charged particles is the result of the exchange or interaction of a probability cloud of virtual photons surrounding the particles, the cloud being concentric and decreasing with distance from the particle.

The propinquity of two opposite charged particles, cancels the distant electric vectors surrounding charges, but the virtual photon cloud probabilities are a conserved quantity, and there is no reason to believe the virtual photon probability cloud is annihilated [26]. The total probability and probability amplitude of a cloud of virtual photons is not canceled by the existence, of the probability amplitude of another particle.

This is consistent with the fact that the reaction radiation is proportional to the square of the charge, not the electric vector. When a real particle accelerates, some of its "virtual cloud" is sufficiently accelerated such that $\Delta x \, \Delta p > \hbar$ and so the photons "become" real. All that is required from energy conservation is that a pair of opposite charged particles, undergoing the same acceleration, generates a net radiation that is in phase.

It is conjectured that: Jerk distorts the extended virtual photon cloud surrounding mass, and increases the energy of that mass. The energy is then dissipated by electromagnetic radiation.

Conclusion

The question as to whether the radiation is a ripple in spacetime, or an electromagnetic wave, is clearly an important issue since the theory's origination in 1915, and most current GR theorists would consider the question already answered, but at this point it does appear that the question is still open.. The upcoming Ligo-Virgo 03 run should settle it.

It is ironic that the Michelson Morley experiment that started relativity, is about to examine that last point.

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Appendix I

Gw150914.

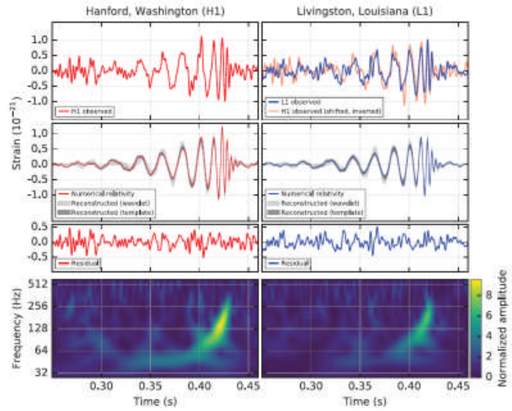

FIG. 1. The gravitational-wave event GW150914 observed by the LIGO Hanford (H1, left column panels) and Livingston (L1, right column panels) detectors. Times are shown relative to September 14, 2015 at 09:50:45 UTC. For visualization, all time series are filtered

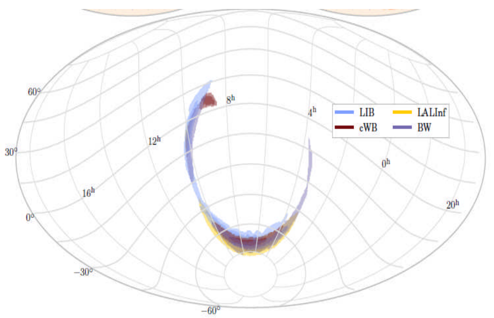

FIG. 7. All-sky projections of several skymaps produced for GW150914. Above, each map is shown by itself in celestial coordinates. Below, a rotated coordinate system shows contours defining the 50% and 90% confidence regions for four reconstructions.

Gw150914. This is the first two detector event with the location probability both above and below the horizon calculated by Waveburst algorithm, BayesWave, & LALInference for both detectors. No triangulation or earth attenuation is possible.

GW151226

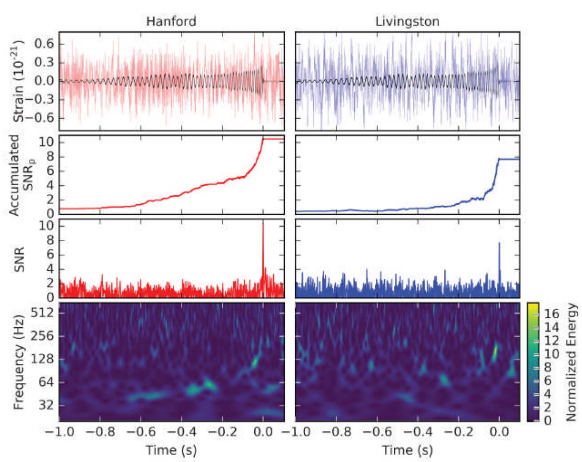

FIG. 1. GW151226 observed by the LIGO Hanford (left column) and Livingston (right column) detectors, where times ar December 26, 2015 at 03:38:53.648 UTC. *First row:* Strain data from the two detectors, where the data are filtered with a

GW151226 Two detector event. No triangulation possible

GW170104

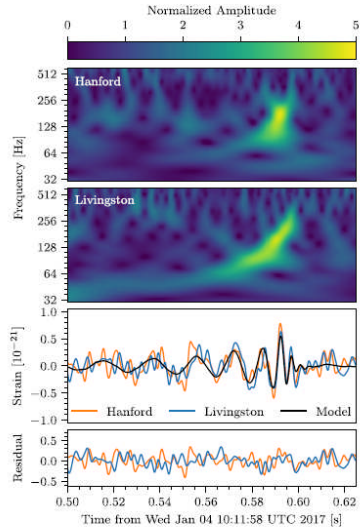

FIG. 1. Time–frequency representation [9] of strain data from Hanford and Livingston detectors (top two panels) at the time of GW170104. The data begin at 1167559936.5 GPS time. The

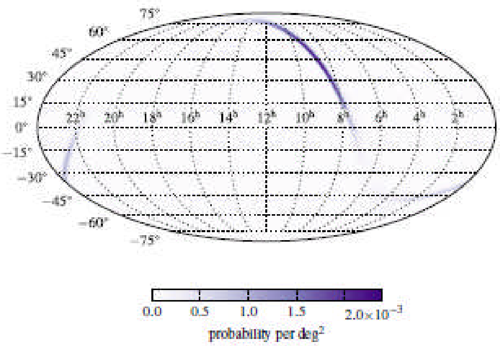

FIG. 3. A Mollweide projection of the posterior probability density for the location of the source in equatorial coordinates (right ascension is measured in hours and declination is measured in degrees). The location broadly follows an annulus corresponding to a time delay of $\sim 3.0^{+0.4}_{-0.5}$ ms between the Hanford and Livingston observatories. We estimate that the area of the 90% credible region is ~ 1200 deg^2.

GW170104 Two detector event no triangulation or attenuation estimates possible

GW170814

Below horizon -10^0 SNR=7.3 | Above horizon +13^0 SNR=13.7 | Below horizon -25^0 SNR=4.4

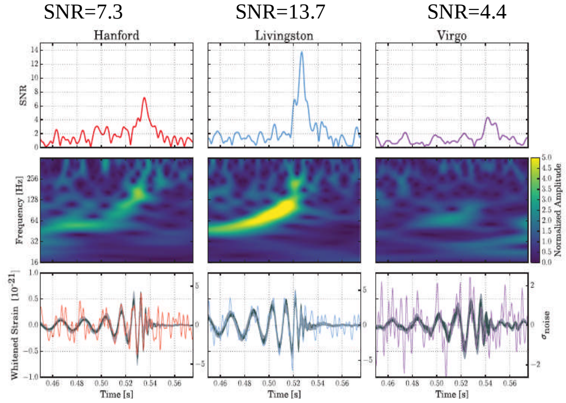

FIG. 1. The GW event GW170814 observed by LIGO Hanford, LIGO Livingston, and Virgo. Times are shown from August 14, 201 10:30:43 UTC. *Top row*: SNR time series produced in low latency and used by the low-latency localization pipeline on August 14, 201

Earth localization point GW70814 45° S, 73° W

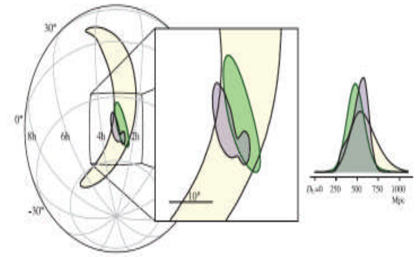

FIG. 3. Localization of GW170814. The rapid localization using data from the two LIGO sites is shown in yellow, with the inclusion of data from Virgo shown in green. The full Bayesian localization is shown in purple. The contours represent the 90% credible regions. The left panel is an orthographic projection and the inset in the center is a gnomonic projection; both are in equatorial coordinates. The inset on the right shows the posterior probability distribution for the luminosity distance, marginalized over the whole sky.

GW170814 First three detector event signal. Insufficient to triangulate with enough accuracy to distinguish whether signals through the earth or around the limb.

SNR attenuation proportionately to the distance around the limb is indicated.

GW170817

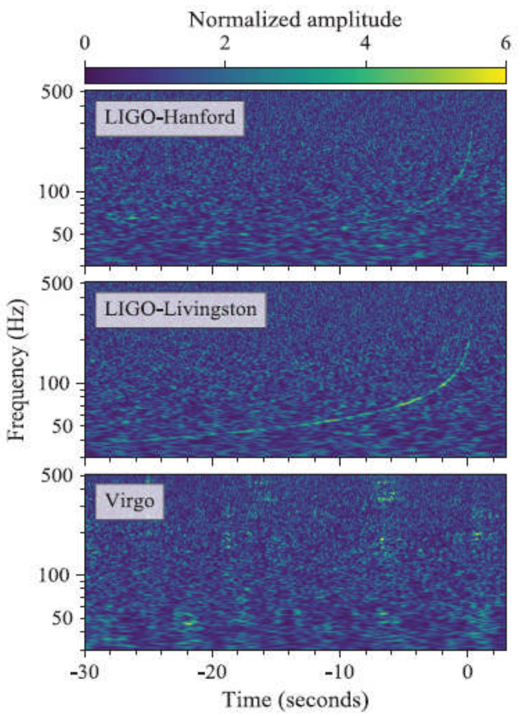

FIG. 1. Time-frequency representations [65] of data containing the gravitational-wave event GW170817, observed by the LIGO-

Hanford over the limb 65^0
SNR=18.8

Livingston over he limb 45^0
SNR=26.4

Virgo over the limb 15^0
SNR~2

Glich at Livingston

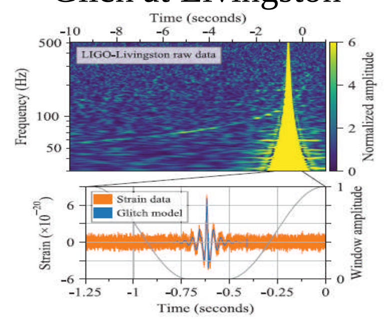

FIG. 2. Mitigation of the glitch in LIGO-Livingston data. Times are shown relative to August 17, 2017 12:41:04 UTC. *Top panel*: A time-frequency representation [65] of the raw LIGO-Livingston data used in the initial identification of GW170817 [76]. The

GW170817

Three detector neutron star merger Virgo didn't detect the signal, and thus no accurate triangulation is possible.

SNR attenuation around the limb is indicated

GW170608

Signal insufficient t
triangulate.

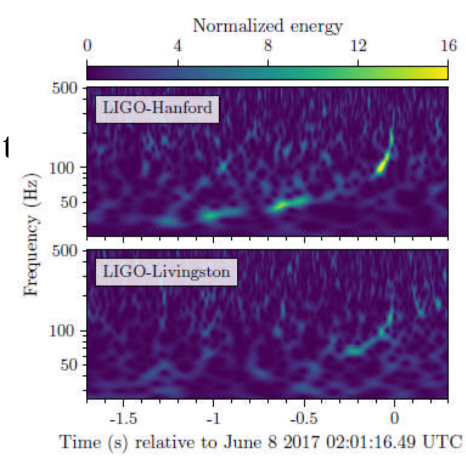

Figure 1. Time-frequency power maps of LIGO strain data at the time of GW170608. The characteristic upwards-

Appendix II

Parameter Substitutions
For equal masses in central attractive orbit

$$P_E = \frac{8}{3}\frac{q^2}{c^3}\dot{v}^2 \rightarrow \frac{8}{3}\frac{mv^2 r}{c^3}\dot{v}^2 \rightarrow \frac{8}{3}\frac{mv^2 r}{c^3}\frac{v^4}{r^2} \rightarrow \frac{8}{3}\frac{mv^2 r}{c^3}\frac{v^4}{r^2} \rightarrow \frac{8}{3}\frac{mv^3 r}{c^3}\frac{v^3}{r^2} \rightarrow \frac{8}{3}mr\ddot{v}\left(\frac{v^3}{c^3}\right)$$

$$P_G = \frac{2}{3}\frac{Gmm}{c^3}\dot{v}^2\left(\frac{v^2}{c^2}\right) \rightarrow \frac{2}{3}\frac{Gmm}{c^3}\frac{v^4}{r^2}\left(\frac{v^2}{c^2}\right) \rightarrow \frac{8}{3}(mr)\frac{v^2 v}{r^2}\left(\frac{v^3}{c^3}\right)\left(\frac{v^2}{c^2}\right) \rightarrow \frac{8}{3}mr\ddot{v}\left(\frac{v^5}{c^5}\right)$$

1 $\quad f_E = \frac{q^2}{(2r)^2} = m\frac{v^2}{r} \rightarrow q^2 = 4mv^2 r$ electric centrifugal force

2 $\quad \dot{v} = \frac{v^2}{r} \qquad m\dot{v} = \frac{mv^2}{r}$ centrifugal force

3 $\quad \ddot{v} = \frac{v^3}{r^2}$ central force orbital jerk[24]

4 $\quad f_G = \frac{Gmm}{(2r)^2} = m\frac{v^2}{r} \rightarrow Gmm = 4mv^2 r$ gravitational centrifugal force