On the LIGO GW150914 event induced by sudden change of gravity forces of ocean tidal bulges acting on the LIGO test masses

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Abstract

We argue that the sudden change of the sign of the difference between the gravity forces of ocean tidal bulges on the test masses of two orthogonal arms of LIGO interferometers could be responsible for the LIGO GW150914 event at the time when the relative strain was measured. The time coincidence of the events at Hanford and Livingston (USA) interferometers is explained by the moving ocean bulge crossing the critical point in the southern part of the Indian Ocean where the forces change the sign. The precise position of the critical point is defined by positions and orientations of the two LIGO interferometers. During the LIGO GW150914 event, the Moon and the Sun were in very close zenith positions in East Africa. The approximate alignment of the Moon and the Sun with the Earth is present also at the time of the LIGO GW151226 and LVT151012 events. The local maxima of tidal forces exerted on the Indian Ocean appear once in a month. The future inclusion of the third Virgo interferometer in Cascina (Italy) proves to be decisive because it cannot produce the time coincident event with the two LIGO interferometers within the described scenario.

I. INTRODUCTION AND MOTIVATION

In analogy with electrodynamics, there is a common belief that gravity waves are an inevitable consequence of Einstein's general theory of relativity (GR). However, electrodynamics is the intrinsic gauge force where the vector radiative field propagates in spacetime with the velocity of light, according to the derived corresponding exact wave equation. The GR is a theory of spacetime itself. There is no wave equation derived from exact GR equations. The exact equation for the metric can be put into the form of a nonlinear integral equation [1] and this is not a wave equation. Propagation wave equations can be derived only by linearization of GR equations. The approximate linear theory is no more invariant under the general coordinate transformations of the GR. Therefore, this procedure cannot be considered as a proof of the existence of gravity waves (tensor radiative fields).

The excellent matching of the kinetic energy loss measured in the binary systems with a derived quadrupole GR formula is the standard argument as an indirect proof of the existence of gravity waves. The exact local conservation equation for GR derived by Landau and Lifshitz [2] represents the correct way to treat the problem of kinetic energy loss in binary systems:

$$
\begin{aligned}
& \frac{\partial}{\partial x^k}[(-g)(T^{ik}+t^{ik})] = 0, \qquad (1)\\
g &= det(g_{ij}),\\
t^{ik} &= \frac{1}{2\kappa}\{(2\Gamma^n_{lm}\Gamma^p_{np} - \Gamma^n_{lp}\Gamma^p_{mn} - \Gamma^n_{ln}\Gamma^p_{mp})(g^{il}g^{km} - g^{ik}g^{lm})\\
& + g^{il}g^{mn}(\Gamma^k_{lp}\Gamma^p_{mn} + \Gamma^k_{mn}\Gamma^p_{lp} - \Gamma^k_{np}\Gamma^p_{lm} - \Gamma^k_{lm}\Gamma^p_{np})\\
& + g^{kl}g^{mn}(\Gamma^i_{lp}\Gamma^p_{mn} + \Gamma^i_{mn}\Gamma^p_{lp} - \Gamma^i_{np}\Gamma^p_{lm} - \Gamma^i_{lm}\Gamma^p_{np})\\
& + g^{lm}g^{np}(\Gamma^i_{ln}\Gamma^k_{mp} - \Gamma^i_{lm}\Gamma^k_{np})\}.
\end{aligned}
$$

It was shown [3] that even for the quadrupole parts of the kinetic and potential energies of binary systems, the local conservation equation implies that any loss in kinetic energy is compensated by a gain in potential energy (not with the emission of gravity waves):

$$\delta E(T^{ik}\ quadrupole; kinetic\ energy) + \delta E(t^{ik}\ quadrupole; potential\ energy) = 0.$$

The author of ref. [4] came to the same conclusion on the absence of gravity waves.

The existence of electromagnetic radiation has been proved by Hertz in experiments where one can control and measure physical parameters of both the source and the antenna. Recently, the LIGO collaboration announced the discovery of gravity waves found and measured by two interferometers in Hanford and Livingston (USA) [5]. They interpreted the strong signal as a coalescing event of two black holes. No electromagnetic or neutrino counterparts of the process were observed, therefore there was no information from the source.

Every scientist has to be very suspicious and sceptic when the theoretical and observational explanations are controversial. In this paper, we decided to present an alternative explanation of the LIGO event. The next chapter is devoted to the description and quantification of our scenario, while the last chapter offers some conclusions.

II. NEWTON'S GRAVITY, THE MOON, THE SUN AND THE EARTH

Firstly, let us recapitulate the findings of the two LIGO interferometers. They claim that during the GW150914 event, the separation of test masses is changed by $\Delta s = \Delta s_x - \Delta s_y = 4 \times 10^{-18} m$, the event duration is roughly $\Delta t = 0.2s$, and the time difference between the inceptions of the events at Hanford and Livingston is $7ms$. Using these data one can estimate the difference between the forces exerted on test masses m at the two $4km$ long arms of the interferometer:

$$a(GW150914) = F(GW150914)/m = 2\Delta s/(\Delta t)^2 \simeq 2 \times 10^{-16} ms^{-2}. \tag{2}$$

The event can be interpreted as an action of gravity waves. We try to explain it with Newton's force of gravity.

Let us presuppose the existence of a certain body with mass M, the center of mass at the point x with coordinates $\vec{x}$. We denote the cross point of the interferometer by x_0 and the end points of the two arms by x_1 and x_2, and any distance between two points x_i, x_k by $D(x_i, x_k) = |\vec{x}_i - \vec{x}_k|$. Assuming that the mass M is at a great distance from the interferometer $D(x, x_0) >> D(x_1, x_2)$, one can find the net gravity force at point x_1 with respect to the cross point at x_0 (similarly for point x_2):

$$\vec{a}_1 = -2G_N M \frac{D(x_1, x_M) - D(x_0, x_M)}{D(x_0, x_M)^3} \hat{x}(x_0, x_M), \tag{3}$$

$$\hat{x}(x_0, x_M) = \frac{\vec{x}_M - \vec{x}_0}{|\vec{x}_M - \vec{x}_0|}, \ G_N = 6.6726 \times 10^{-11} m^3 kg^{-1} s^{-2}.$$

What has to be measured is the difference between the two gravity forces exerted on the test masses of the two arms:

$$\vec{a}_1 - \vec{a}_2 = -2G_N M \frac{D(x_1, x_M) - D(x_2, x_M)}{D(x_0, x_M)^3} \hat{x}(x_0, x_M). \tag{4}$$

One can observe immediately that the relative force $\vec{a}_1 - \vec{a}_2$ can change the sign if the factor in the numerator in Eq. (3) (the difference between two distances) changes the sign.

It is clear that the Moon, the Sun or the ISS can act on the interferometers, suddenly changing the sign of the relative gravity force by virtue of relative motions, however the events cannot occur almost concurrently at the two LIGO interferometers that are $3000km$ apart.

The event must be induced by a moving mass somewhere on the surface of the Earth. We remind the reader that the Moon's and the Sun's forces of gravity raise tides on the surface of oceans. The largest tides are at the positions facing the Moon and at their opposite positions, according to the action of gravity tidal forces. Ocean tides move around the Earth with the cycle of two high tides per one lunar day (24 hours 50 minutes).

The precise shape and trajectory of ocean tidal bulges could be calculated numerically, provided that one knows the topology of the oceans and tidal gravity forces. The standard, order of the magnitude estimate of the ocean bulge height can be done assuming the work per unit volume of the static fluid before and after the action of the conservative force of gravity:

$$\rho(g_{Earth} - g_{Moon})(h + \Delta h) = \rho g_{Earth} h,$$

where ρ is the mass density of the fluid, $g_{Earth} = 9.81ms^{-2}$, $g_{Moon} = G_N \frac{M_{Moon}}{d^2}$, where d is the Moon to Earth distance, h is the average depth of the ocean. It follows:

$$\Delta h = h \frac{g_{Moon}}{g_{Earth} - g_{Moon}}.$$

The average depth of the Indian ocean, for example, is $h \simeq 4km$, thus $\Delta h \simeq 1.5cm$. The observations refer up to 30 cm. We use the value of 10 cm in order to estimate the size of the acting bulge mass on the LIGO test masses.

At the time of the GW150914 event UTC=09:50:45, the Moon and the Sun were very close in their zenith positions in East Africa, Moon: lat=1°10′ South, long=42°45′ East, Sun: lat=3°27′ North, long=31°26′ East. Therefore, the dominant Moon's tidal force is amplified by the Sun's tidal force.

The aim is now to find the precise position(s) of the moving mass that changes the sign of the relative forces of Eq. (3) simultaneously at both LIGO interferometers. We describe the Earth as a ball with the radius $R_E = 6371km$ (flattening is only 0.00335). Newton's gravity of a body with a given mass distribution acts with a force proportional to the total mass enclosed within a certain radius. Any mass excess of the ocean bulge above the surface of the sphere gives the additional force. The geoid of the Earth is very complicated, requiring detailed geophysical, astrophysical and fluid-mechanical computations of our scenario, which is beyond the scope of the present paper.

We know the position of the x_0 point of the interferometer on the sphere. The tangential plane T of the sphere S is defined by three points x_0, x_1, x_2. We choose the center of the ball as the origin of the coordinate system. While the positions x_0 of the two LIGO and one Virgo interferometers can be read from the official web sites, the orientation angles of the interferometers are from ref. [6]:

$$
\begin{aligned}
& LIGO(Hanford): \\
\vec{m} &= (-\sin\alpha\cos\beta, \sin\alpha\sin\beta, \cos\alpha),\ \vec{v} = (\sin\beta, \cos\beta, 0), \\
\vec{\xi}_1 &= -\sin\delta\vec{v} + \cos\delta\vec{m},\ \vec{\xi}_2 = -\cos\delta\vec{v} - \sin\delta\vec{m}, \\
\alpha &= latitude = 46°27'18.52''North,\ \beta = longitude = 119°24'27.56''West, \\
\vec{x}_0 &= R_E(\cos\alpha\cos\beta, -\cos\alpha\sin\beta, \sin\alpha),\ l_4 = 4\ km,\ \delta = 36.8°, \\
\vec{x}_1 &= \vec{x}_0 + l_4\vec{\xi}_1,\ \vec{x}_2 = \vec{x}_0 + l_4\vec{\xi}_2,
\end{aligned}
$$

$$
\begin{aligned}
& LIGO(Livingston): \\
\vec{m} &= (-\sin\alpha\cos\beta, \sin\alpha\sin\beta, \cos\alpha),\ \vec{v} = (\sin\beta, \cos\beta, 0), \\
\vec{\xi}_1 &= -\cos\delta\vec{v} - \sin\delta\vec{m},\ \vec{\xi}_2 = \sin\delta\vec{v} - \cos\delta\vec{m},
\end{aligned}
$$

$$
\begin{aligned}
\alpha &= latitude = 30^\circ 33' 46.42'' North,\ \beta = longitude = 90^\circ 46' 27.27'' West, \\
\vec{x}_0 &= R_E(\cos\alpha\cos\beta, -\cos\alpha\sin\beta, \sin\alpha),\ l_4 = 4\ km,\ \delta = 18.0^\circ, \\
\vec{x}_1 &= \vec{x}_0 + l_4\vec{\xi}_1,\ \vec{x}_2 = \vec{x}_0 + l_4\vec{\xi}_2,
\end{aligned}
$$

$$
\begin{aligned}
&Virgo(Cascina): \\
\vec{m} &= (-\sin\alpha\cos\beta, -\sin\alpha\sin\beta, \cos\alpha),\ \vec{v} = (-\sin\beta, \cos\beta, 0), \\
\vec{\xi}_1 &= \sin\delta\vec{v} + \cos\delta\vec{m},\ \vec{\xi}_2 = -\cos\delta\vec{v} + \sin\delta\vec{m}, \\
\alpha &= latitude = 46.6305^\circ North,\ \beta = longitude = 10.5021^\circ East, \\
\vec{x}_0 &= R_E(\cos\alpha\cos\beta, \cos\alpha\sin\beta, \sin\alpha),\ l_3 = 3\ km,\ \delta = 18.5^\circ, \\
\vec{x}_1 &= \vec{x}_0 + l_3\vec{\xi}_1,\ \vec{x}_2 = \vec{x}_0 + l_3\vec{\xi}_2.
\end{aligned}
$$

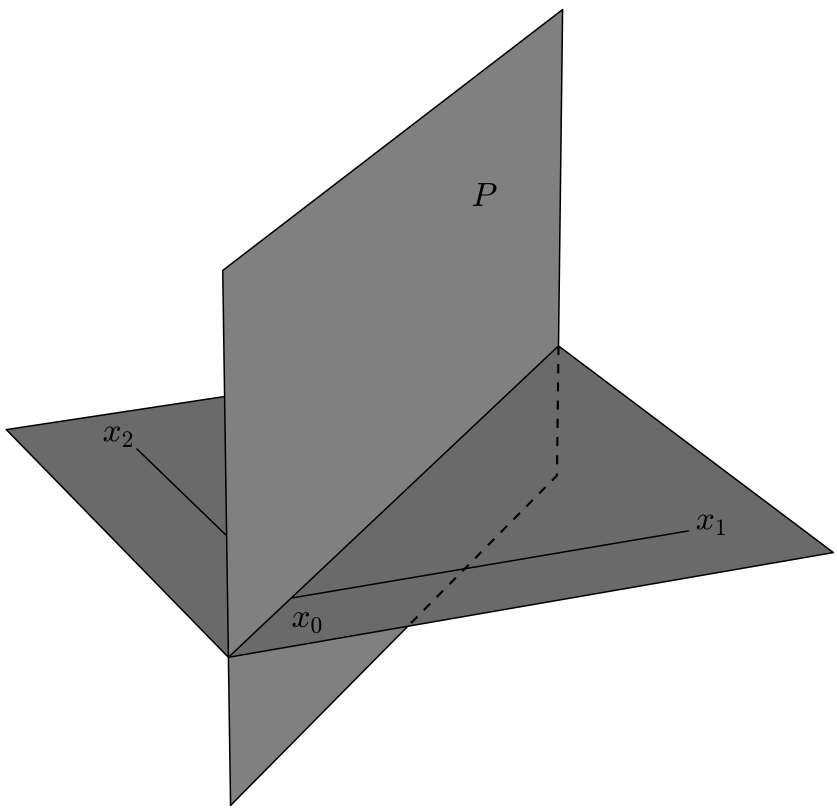

Fig. 1: Plane P orthogonal to the plane T and bisecting the interferometer.

The plane P, orthogonal to the tangential plane T, bisecting the interferometer in point x_0, and crossing the center of the ball, can now be defined by two ort vectors $\vec{c}$ and $\vec{d}$ (see Fig. 1):

$$\vec{c} = \frac{1}{\sqrt{2}}(\vec{\xi}_1 + \vec{\xi}_2),\ \vec{d} = \vec{\xi}_1 \times \vec{\xi}_2.$$

The plane P consists of the points where the distances between any point $p \epsilon P$ and x_1 and x_2 are equal $D(p, x_1) = D(p, x_2)$. The intersection of the plane P with the sphere S is the circle C of the radius R_E. Clearly, the intersection of two circles of the LIGO interferometers at Hanford C_1 and at Livingston C_2 consists of two critical points (see Fig. 2): x and its mirror point x_M. The above definitions of x_0, x_1, x_2 and P permit us to find the circles C_1 and C_2 and the coordinates of the critical points $x, x_M(\vec{x}_M = -\vec{x})$:

$$x : latitude = \alpha = 37.485^\circ South,\ longitude = \beta = 93.712^\circ East,$$

$$D(x, x_0\ at\ Hanford) = 12415.9\ km,\ D(x, x_0\ at\ Livingston) = 12712.0\ km,$$

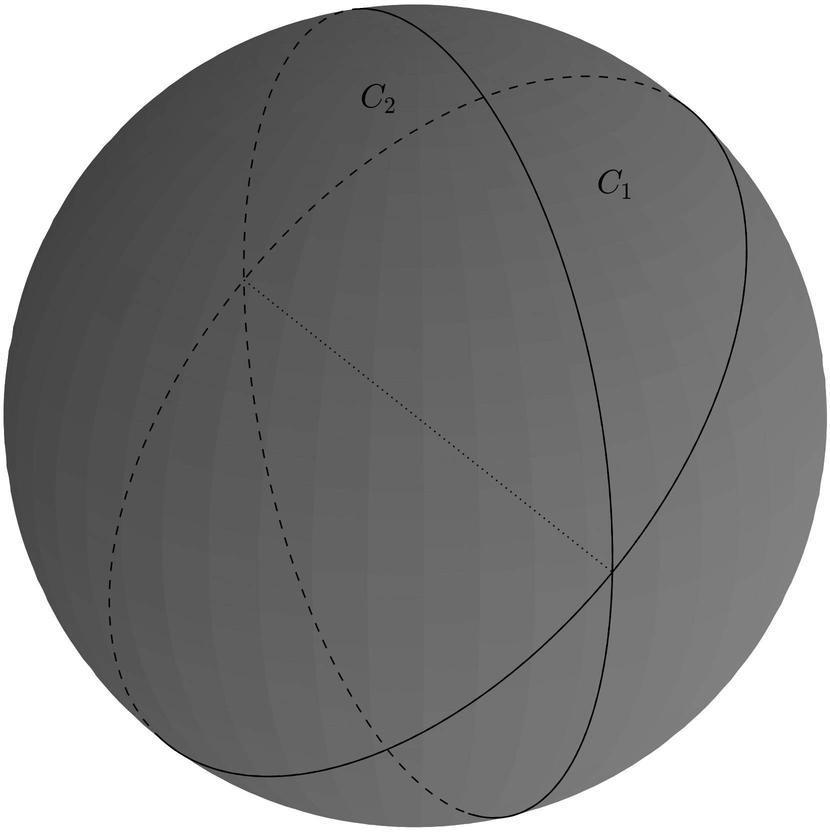

Fig. 2: Crossing of two circles C_1 and C_2 on the sphere at two mirror points.

The critical point lies in the southern part of the Indian Ocean, while its mirror is on the North American continent. The mirror point is obviously ruled out as a position of the ocean bulge. We confirmed that in the vicinity of the critical point, the relative distance in Eq. (3) changes the sign ($\Delta D \to -\Delta D$), producing a sudden change in the relative forces on the two interferometers almost concurrently. It is possible now to estimate the mass of the ocean bulge M_B responsible for the GW150914 event by Eq. (3):

$$\begin{aligned} M_B &= \frac{1}{4} a(GW150914) D^3(x, x_0 \; at \; Hanford)[G_N \Delta D]^{-1}, \\ D(x, x_0 \; at \; Hanford) &= 1.24 \times 10^4 \; km, \; \Delta D \simeq 0.15 \; km \Rightarrow M_B \simeq 9.52 \times 10^{12} kg. \end{aligned}$$

Assuming that the height of the bulge is $10cm$, (with the mass density of water $\rho(water) = 10^3 kgm^{-3}$) the resulting diameter of the bulge's cylinder is roughly $350km$.

Moreover, we can also find the velocity of the ocean bulge v_{bulge} at the cross point of two critical curves in the Indian Ocean:

$$v_{bulge} = \frac{2\pi \cos(37.485^\circ) R_{Earth}}{24h50min}, \; R_{Earth} = 6371km$$
$$\Rightarrow v_{bulge} = 0.355kms^{-1}.$$

Let us denote with C_3 the corresponding circle of the third interferometer in Cascina in Italy. We found that the minimal distance of the critical point x derived for LIGO from the circle C_3 is $minD(x, y\epsilon C_3) = 3154.6\ km$. It follows that the time coincidence of the event at all three interferometers is impossible.

We investigated tidal forces at the critical cross point in the Indian Ocean with NOVAS ephemeris code (Naval Observatory Vector Astrometry Software) [7] including the Moon's and the Sun's gravity forces. The forces are calculated with a time step of one hour from September 1, 2015, 0 hours until January 31, 2016, 23 hours, accounting also for the corrections from IERS Bulletin tables at 0 hours every day (every one hour time step is evaluated by linear interpolation).

The dependence of the magnitude of the tidal force at the critical point can be seen in Fig. 3. Periodicity is expected and we specify the time and magnitude of the local maxima: (a) September 25, 2015, 15h; $a = 1.224 \times 10^{-6} ms^{-2}$, (b) October 28, 2015, 6h; $a = 1.208 \times 10^{-6} ms^{-2}$, (c) November 25, 2015, 5h; $a = 1.188 \times 10^{-6} ms^{-2}$, (d) December 23, 2015, 4h; $a = 1.141 \times 10^{-6} ms^{-2}$.

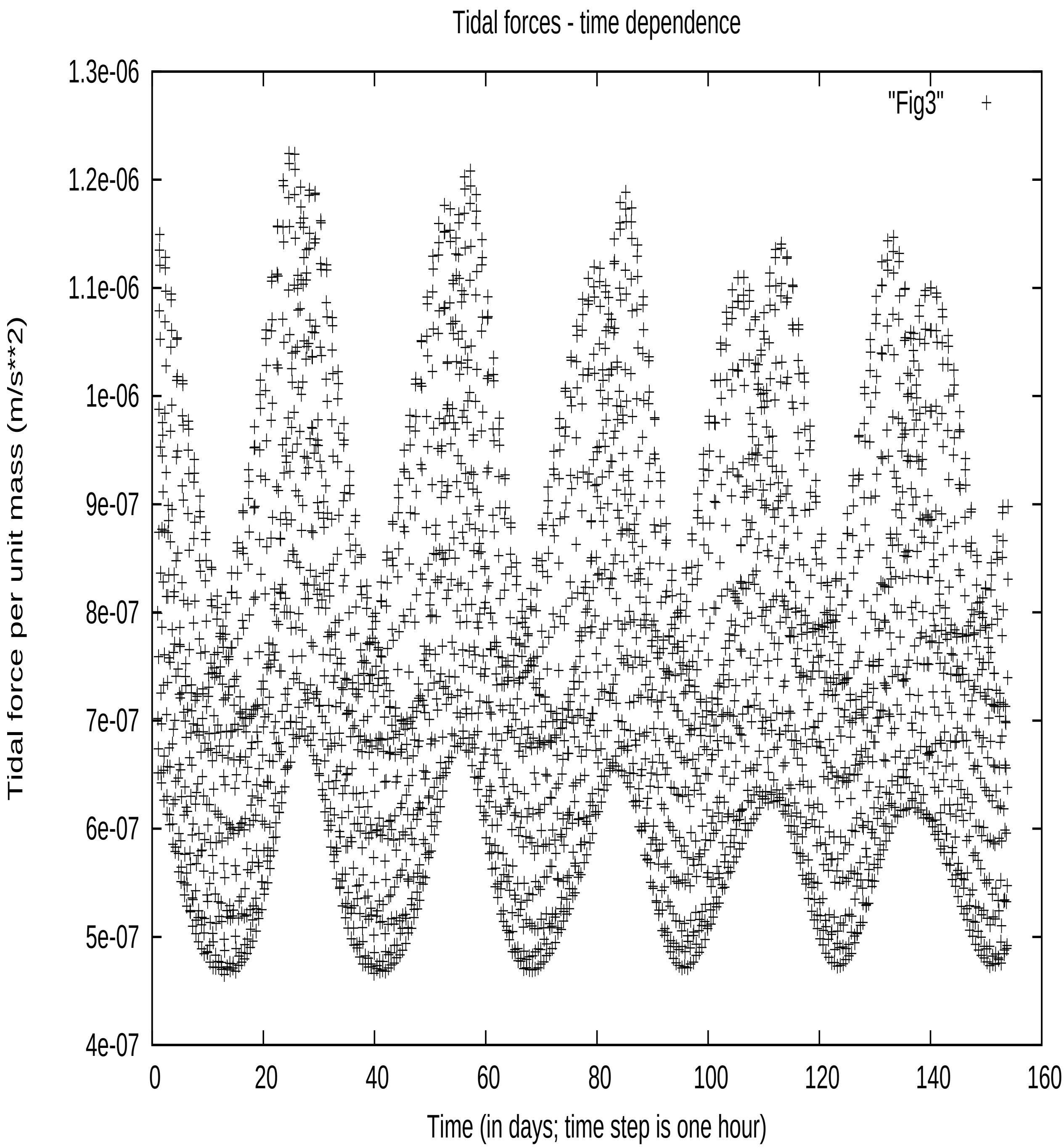

Fig. 3: Magnitude of the tidal force per unit mass as a function of time in one hour step from September 1, 2015, 0 hours until January 31, 2016, 23 hours.

The time dependence of the component of the tidal force orthogonal to the tangential surface of the Earth's sphere at the critical point can be seen in Fig. 4. The time and magnitude of the local maxima for the orthogonal component are: (a) September 21, 2015, 12h; $a = 9.249 \times 10^{-7} ms^{-2}$, (b) October 20, 2015, 11h; $a = 9.421 \times 10^{-7} ms^{-2}$, (c) November

18, 2015, 10h; $a = 9.048 \times 10^{-7} ms^{-2}$, (d) January 18, 2016, 2h; $a = 8.713 \times 10^{-7} ms^{-2}$.

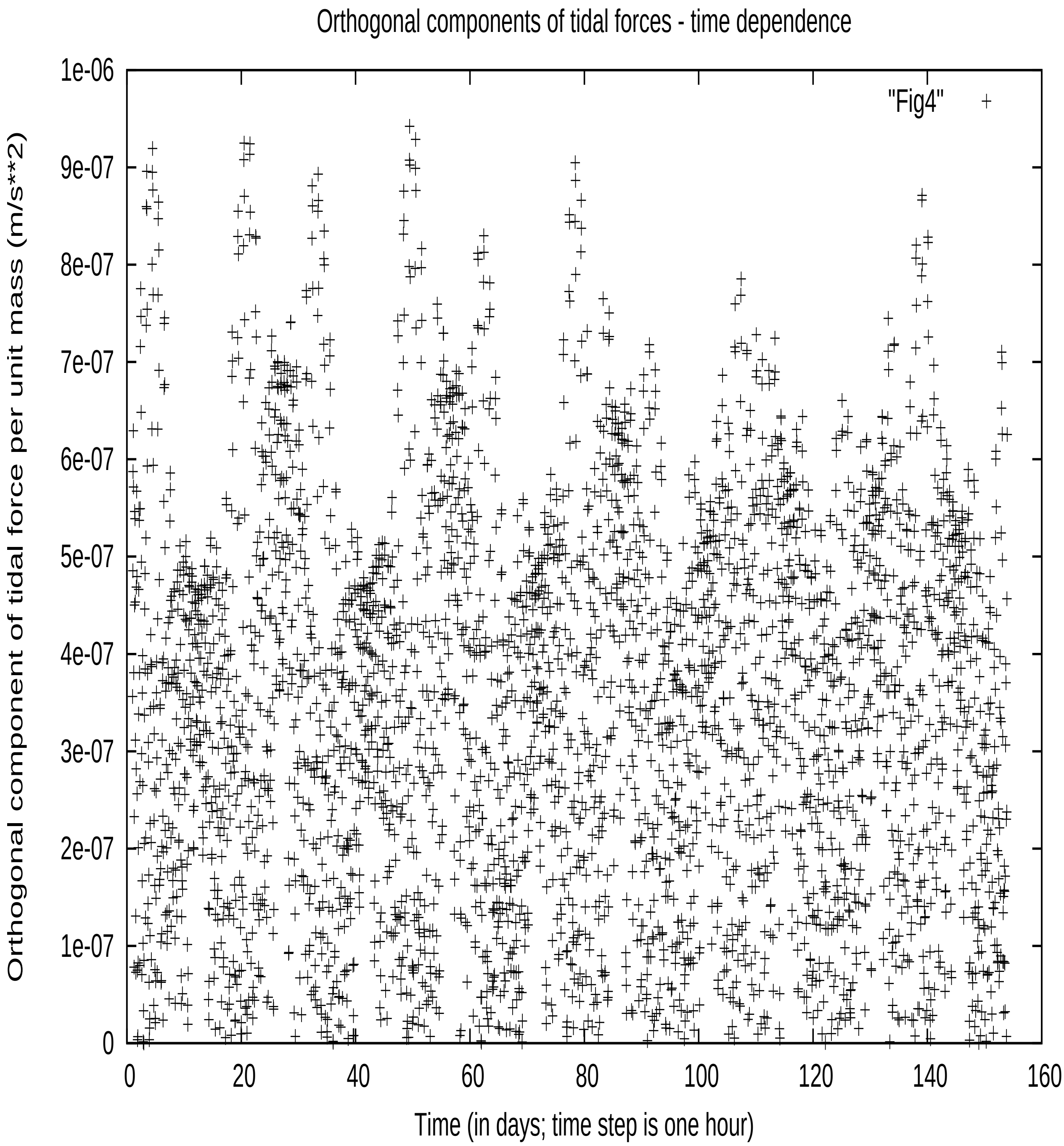

Fig. 4: Magnitude of the orthogonal component of the tidal force per unit mass as a function of time in one hour step from September 1, 2015, 0 hours until January 31, 2016, 23 hours.

As stated previously, it is necessary to perform detailed numerical simulations of the action of tidal forces on the whole Indian Ocean in order to get reliable information on the periodic formations of tidal bulges that could be responsible for LIGO events.

III. CONCLUSIONS AND SUGGESTIONS

We suggest an alternative explanation of the LIGO GW150914 event with the moving ocean tides acting on the test masses of the interferometers. The scenario is decribed only within the simple model of the Earth's surface as a sphere, therefore very precise calculations with geoid are necessary. The gravity force of the Moon is amplified by the coherent gravity force of the Sun, not only during the GW150914 event, but also during the LVT151012 event, when their zenith positions are close in the region of East Africa. We should also mention the third event, GW151226 [8], when the Moon's zenith position was lat=18°04′ North, long=45°28′ West and the Sun's antipodal zenith position lat=23°22′ North, long=54°26′ West on December 26, 2015, UTC=03:38.

One can observe that the strains of the three events (GW150914, LVT151012 and GW151226) are inversely proportional to the durations of the events. A stronger force disturbs the test masses more easily.

It is shown that a sudden change of the relative force can be observed at two, but very unlikely at all three interferometers simultaneously (two LIGO and Virgo) with respect to one particular ocean tide. It would be useful if the LIGO Collab. published all events, i.e. including the events detected by only one interferometer, which are expected to happen more frequently than the coincident events at two interferometers.

It seems that the sudden change of the force of a moving ocean bulge is not covered by extensive environmental noise studies for LIGO [9].

The possible discovery of the associated signal with GW150914 in the LIGO data [10] is very difficult to explain by the binary black hole merger because of the correlated long duration activity present not only before, but also after the hypothetical merger event. This phenomenon, if it proves to be real, could be more naturally incorporated within our scenario by the geometry and physics of tidal bulges that cross critical curves before and after the cross point (see Fig. 2).

We should mention also the paper of ref. [11], which argues that the propagation of gravity waves in the cavity can completely cancel the signal of GW151226.

If the hypothesis of fundamental length fixed by weak interactions [12, 13] and the

Einstein-Cartan cosmology [14]proves to be correct, $d_{min} \simeq 0.6 \times 10^{-18}m$, it could substantially affect the shape and the error budget of the LIGO and Virgo events, because the time measurements of the multiply bouncing photons of the interferometers have an absolute lower bound $\Delta t \geq d_{min}/c$. Let us note that the measured change of the separation between the test masses during the GW150914 event is very close to d_{min}. A similar range of frequencies of the three observed events is probably defined by the intrinsic mechanical and optoelectronical design of the LIGO interferometers. From Figs. 3 and 4, the moving ocean bulge scenario predicts an increase in the number of events with higher sensitivity of the interferometers.

Acknowledgments

I would like to thank my son Grgur for drawing Fig. 1 and Fig. 2.

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[1] D. W. Sciama, P. C. Waylen and R. C. Gilman, Phys. Rev. **187**, 1762 (1969).

[2] L. D. Landau and E. M. Lifshitz, *Teorija polja*, Nauka, Moskva (1973).

[3] D. Palle, *"On binary pulsars and the force of gravity"*, astro-ph/0211481; Acta Phys. Slov. **55**, 549 (2005) [astro-ph/0503366].

[4] F. I. Cooperstock, Ann. Phys. (NY) **282**, 115 (2000) [gr-qc/9904046].

[5] The LIGO Collab., Phys. Rev. Lett. **116**, 061102 (2016); arXiv:1602.03838; arXiv:1602.03839; arXiv:1602.03840.

[6] B. Allen, *"Gravitational Wave Detector Sites"*, gr-qc/9607075.

[7] *aa.usno.navy.mil/software/novas*

[8] The LIGO Collab., Phys. Rev. Lett. **116**, 241103 (2016).

[9] J. C. Driggers et al., Phys. Rev. D **86**, 102001 (2012) [arXiv:1207.0275]; S. M. Aston et al., Class. Quant. Grav. **29**, 235004 (2012); A. Effler et al., Class. Quant. Grav. **32**, 035017 (2015).

[10] Hao Liu and A. D. Jackson, JCAP **10**, 014 (2016) [arXiv:1609.08346]; J. Creswell, S. von Hausegger, A. D. Jackson, Hao Liu and P. Naselsky, *"On the time lags of the LIGO signals"*, arXiv: 1706.04191.

[11] Zhe Chang, Chao-Guang Huang and Zhi-Chao Zhao, *"Is GW151226 a really signal of gravi-*

tational wave?", arXiv:1612.01615.

[12] D. Palle, Nuovo Cim. A **109**, 1535 (1996) [hep-ph/9706266]; Nuovo Cim. B **115**, 445 (2000) [hep-ph/9910512]; Hadronic J. **24**, 87 (2001) [hep-ph/9804326]; hep-ph/0703203; arXiv:1111.1638; arXiv:1210.4404; Acta Phys. Pol. B **43**, 1723 (2012) [arXiv:1111.1638]; Acta Phys. Pol. B **43**, 2055 (2012) [arXiv:1204.1171]; D. Palle, *"On the possible new 750 GeV heavy boson resonance at the LHC"*, arXiv:1601.00618.

[13] A. Heister, *"Observation of an excess at 30 GeV in the opposite sign di-muon spectra of* $Z \to b\bar{b} + X$ *events recorded by the ALEPH experiment at LEP"*, arXiv:1610.06536.

[14] D. Palle, Nuovo Cim. B **111**, 671 (1996) [astro-ph/9706012]; Nuovo Cim. B **114**, 853 (1999) [astro-ph/9811408]; Nuovo Cim. B **122**, 67 (2007) [astro-ph/0604287]; Eur. Phys. J. C **69**, 581 (2010) [arXiv:0902.1852]; Entropy **14**, 958 (2012) [arXiv:0802.2060]; ZhETF **145**, 671 (2014) [arXiv:1405.3435].