Lightning, LIGO and GW150914

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Summary:

1) The magnetic fields from the 504 kA Burkina Faso strike, and the 59 other strikes in the second containing GW150914, were at least 3 orders of magnitude too small to produce an event with the amplitude of GW150914. This is demonstrated with injected magnetic chirps.

2) The fields from lightning do not evolve in time and frequency like GW150914. The magnetic fields are broadband, shorter and do not evolve in frequency. Interactions with the magnetosphere may produce electromagnetic signals (tweaks and whistlers) that evolve in frequency, but in the opposite direction of our gravitational wave chirp.

3) There were 11 much closer lightning strikes in Dec. 2015 with larger peak currents that occurred when at least one detector was observing (41 to 1500 km vs. about 10,000 km; 508 kA - 734 kA vs. 504 kA). No events were detected on the gravitational wave channels during these 11 larger and closer strikes.

4) Studies of lightning coupling over the last 15 years have indicated that lightning could produce a DARM event only if the current is extremely high and the strike is within kilometers of a site.

Introduction

GW150914 was coincident with a large lightning strike over Burkina Faso (measured peak current 504 kA, distance about 10000 km). We expect lightning to be coincident with any detection because there are tens of strikes per second globally. In the second of GW150914, there were 60 strikes reported globally and 2 in the United States. But the Burkina Faso strike had an unusually high current and so has raised some concern. We did not detect electromagnetic fields from any of the 60 strikes using sensors that would have detected any fields large enough to affect the GW channel. Nevertheless, because of the concerns, I have attempted to summarize LIGO's experience with lightning and the arguments that G150914 could not have been produced by lightning.

History

Lightning has been a concern for LIGO since the beginning. Multiple studies of lightning during iLIGO found no evidence of coupling, except through power grid glitches. In one such study, operators pressed a button to record the time of flashes that they observed on video monitors. The nearby lightning did not appear to affect the gravitational wave channel, although we did detect magnetic fields from strikes that were within tens of kilometers of one of the sites. Often the studies were made more difficult because the thunder would knock the interferometer out of lock. A student study in 2001 suggested that a strike half way between the sites would have to reach about 500 kA in order to be detected by magnetometers at both sites (LIGO-T010108-00-D) and, of course, it would have to be far louder to affect the interferometer.

Coupling of magnetic chirps

Magnetic coupling in aLIGO is lower than for iLIGO because of the lack of magnets on the masses (Link) We measure this coupling by injecting diagnostic magnetic fields. Figure 1 shows an injected magnetic chirp, similar in time-frequency characteristics to GW150914. While the injected fields are nearly 1000 times the magnetometer background, the chirps do not appear on the GW channel. This suggests that in order to produce an event as strong as GW150914, the fields would need to be several thousand times larger than the minimum fields detected by the magnetometers. We were not able to produce chirps with our equipment that were strong enough to be visible in the GW channel, but continuous line injections do show on the gravitational wave channels and are used to estimate the coupling in meters of test mass motion per Tesla of field (Link). Figure 1 also shows the same magnetometer channel during GW150914; nothing is evident on the magnetometer, though the strong gravitational wave signal is evident in the gravitational wave channel. There was also nothing evident on the radio channels during GW150914.

Magnetic field amplitude produced by lightning strikes

The magnetic fields from lightning are expected to increase roughly linearly with I/R, where I is the peak current and R is the distance from the magnetometer. Figure 2 shows that this is the case for our magnetometer measurements of lightning strikes in O1, at least for those in the I/R range below about 6 A/m, indicated by red points. For the highest I/R strikes (mainly within a few km of the site), there is a broad range of field values. Figure 3 shows locations of the strikes around LLO, with the strikes that have high fields for their I/R values indicated by red points, and those with low fields for their I/R values indicated by blue points. No systematic difference between the red and blue strikes was noticed. It may be that the largest fields come from local ground, beam tube, or power grid currents caused by the close lightning strikes.

Figure 2 shows the predicted field from the Burkina Faso strike, using the linear fit. The fields are predicted to be too low to be detected with our fluxgate magnetometers. The I/R fit is a good predictor for lightning, but not for lightning-related transient luminous events, such as sprites and jets. The plot in Figure 2 has a point for a gigantic jet event near Corsica in 2009 with the I/R value for the largest lightning strike (200 kA) that was associated with the jet (reference at the end). The field measured at LIGO sites was much greater than would be predicted by the I/R value for the lightning strike and was probably produced by the gigantic jet. While the currents in the gigantic jet were though to be on the order of kA, they were observed to last tens of milliseconds rather than microseconds (shorter than a magnetometer sample), and were thought to flow over a much greater fraction of the earth-ionosphere distance than the current in the lightning strike (reference at end). Possibly for these reasons, the field associated with the gigantic jet event was detected on our magnetometer channels at both sites and by magnetometers around the world. The Burkina Faso event was not one of these unusual events: it was not detected by our magnetometers or by magnetometers at several other locations around the globe.

Stronger, closer strikes did not produce events in the gravitational wave channel

The 500 kA Burkina Faso strike had a very high peak current, but, in the investigated month of Dec. 2015, there were at least 20 strikes that were stronger, ranging as high as 734 kA, and within the United States, much closer than the Burkina Faso event. Both interferometers were locked for the 734 kA strike and Figure 4 shows that no signal was detected by the magnetometers or by the gravitational wave channel during this extremely large strike. There were a total of 11 strikes in the US during the investigated month of December 2015 that had higher peak currents than the Burkina Faso strike, and for which at least one interferometer was observing. No events were detected on the gravitational wave channels for any of these much stronger and closer events (41 to 1500 km vs. about 10,000 km; 508 kA to 734 kA vs. 504 kA).

The Excel files that I used are attached; one for the time period before Dec. 1, and the second for December strikes. Most of the strongest strikes are on the December Excel sheet. I only checked the ones that were stronger than 504 kA; the smaller strikes could also be checked.

Power grid and RF

Lightning might also affect LIGO through the power grid, but power grid glitches are also monitored by our magnetometers. In iLIGO, we used our magnetometers to veto trips, faults, and capacitor insertions (for frequency control) in the power grid. We also have power grid voltage monitors (though they were not working at LLO during GW150914). In addition, intersite coupling through the grid is unlikely because the two sites are on different power grids connected only by AC-DC-AC interconnects.

Finally, lightning could affect DARM through demodulation of electromagnetic fields that are higher frequency than the detection band. But our radio receivers and those from external observatories showed no signals large enough to influence the gravitational wave channel.

The argument from time frequency path

An event produced by electromagnetic fields from lightning would differ from GW150914 in time-frequency path. Typical lightning produces multiple short (microsecond scale) field bursts (made longer by the FFT band width in Figure 4), often in groups that last about a second. The 2009 Corsica gigantic jet event produced a single burst of peaks on our magnetometer channels at roughly 8 Hz and higher Schumann resonance frequencies (Figure 5). Interactions with the magnetosphere may produce electromagnetic signals (tweaks and whistlers) that evolve in frequency, but in the opposite direction of our chirp.

Reference: O van der Velde, J Bór, J. Li, S. Cummer, E. Arnone, F. Zanotti, M. Fullekrug, C. Haldoupis, S. NaitAmor, T. Farges (2010) Multi-instrumental observations of a positive gigantic jet produced by a winter thunderstorm in Europe. J. Geophysical Research, 115, D24301.

Figures

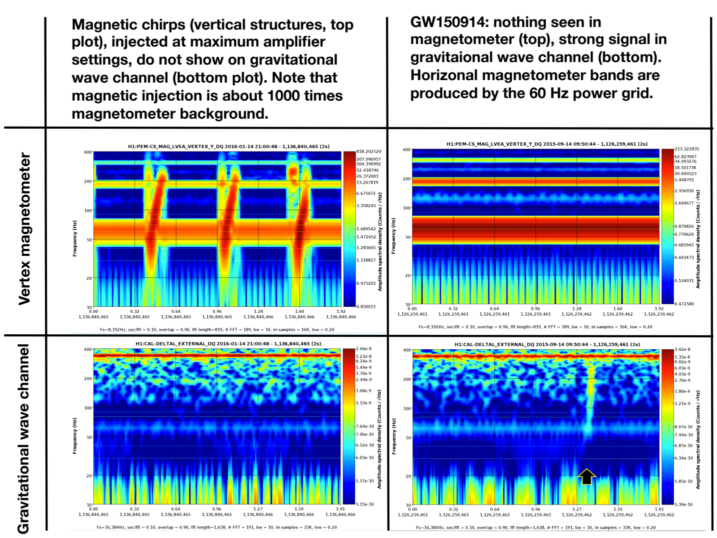

Figure 1. Huge magnetic chirp does not show on gravitational wave channel

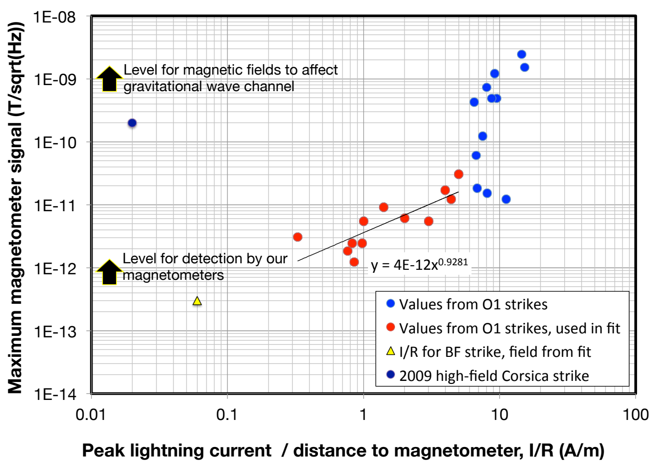

Figure 2. Magnetic fields from lightning.

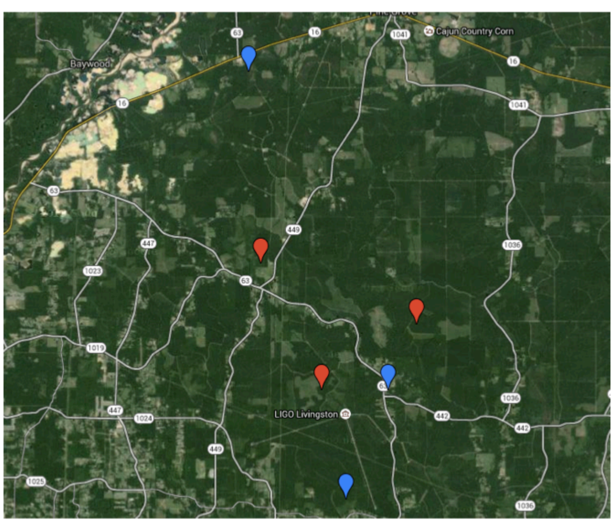

Figure 3. Lightning strike map around Livingston, Blue: low field, Red: high field.

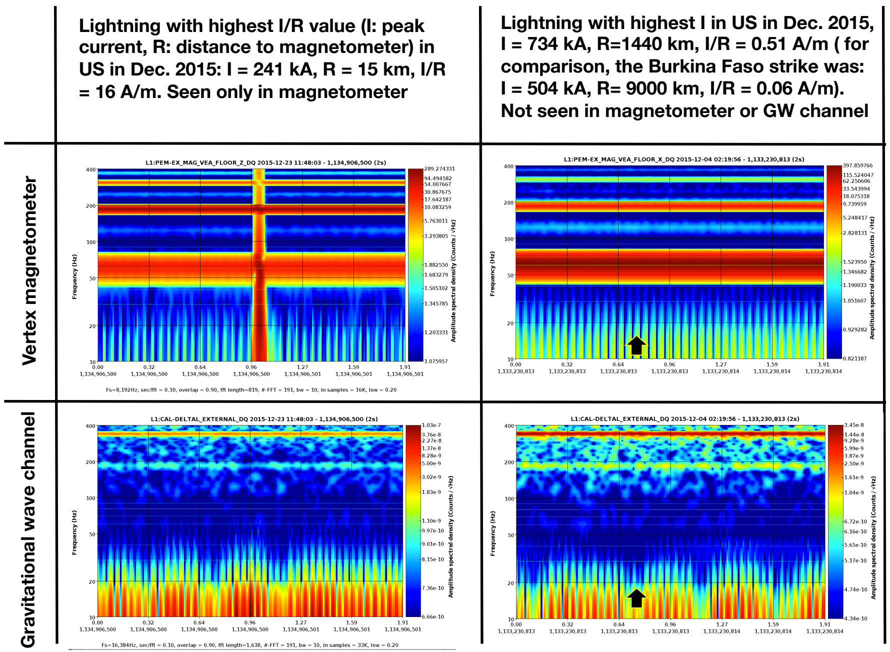

Figure 4. Highest current lightning strikes in US during December 2015.

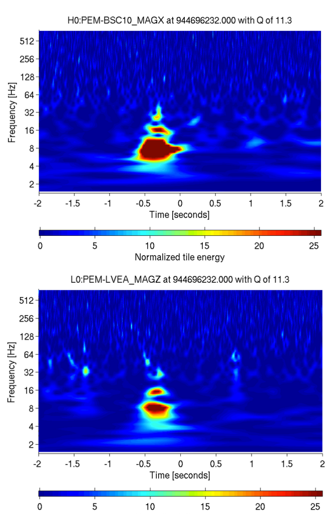

Figure 5. Corsica gigantic jet magnetic field at each site.