Lightning or Gravitational Waves? The Effects of a Global Lightning Background on LIGO Detectors

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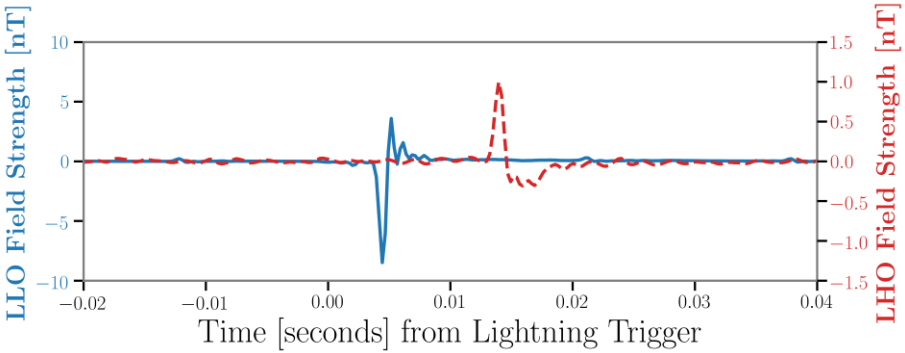
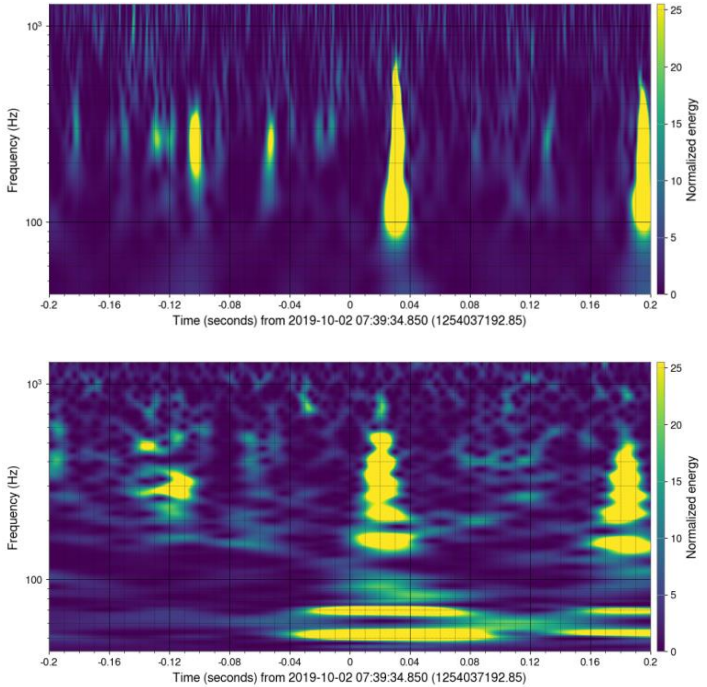
Motivation

- Identifying non-astrophysical signals
  - Relies on inter-site incoherence
  - What if environmental noise is also coherent?
- Magnetic Correlations
  - Schumann Resonances considered below 50 Hz
  - Individual lightning strokes measured at multiple interferometer locations with signals above 50 Hz
  - Post-O3 stochastic investigations found elevated magnetic coherence above 100 Hz

Motivation

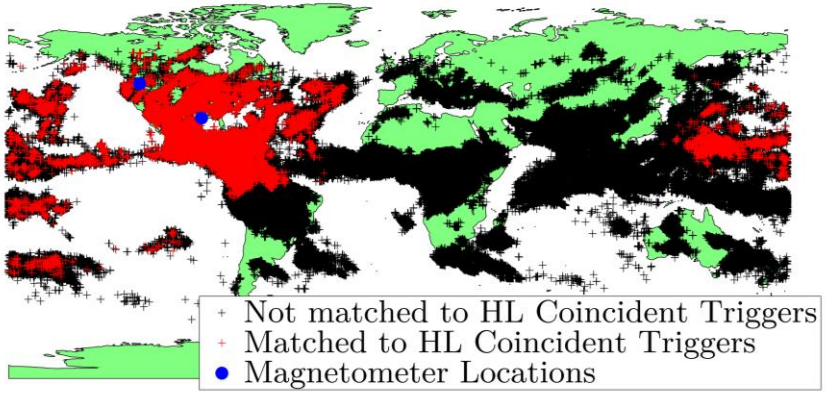
- New, high-sensitivity magnetometers reduce the noise floor
- Individual lightning strokes observed in coincidence at multiple interferometer locations
- Short duration and very broadband

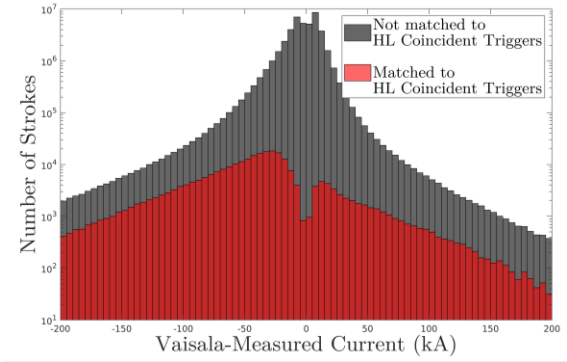




Identifying Magnetic Transients associated with Lightning

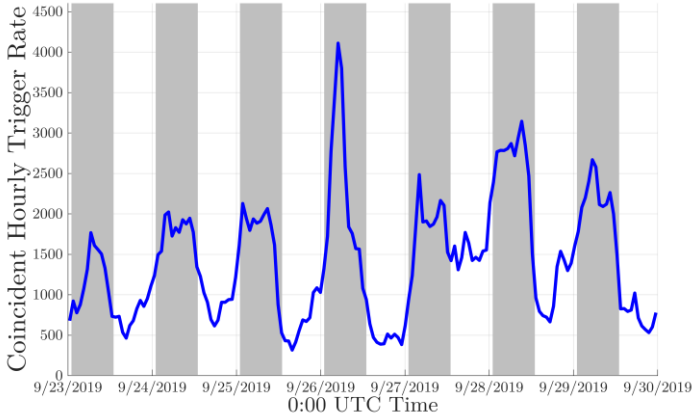
- Use DetChar's Omicron algorithm to identify magnetic transients in LEMI magnetometers at each site for 1 week
- Require LHO & LLO transient times to be consistent with signal travel time from a GLD360 source
- 268971 total magnetic transients coincident with lightning

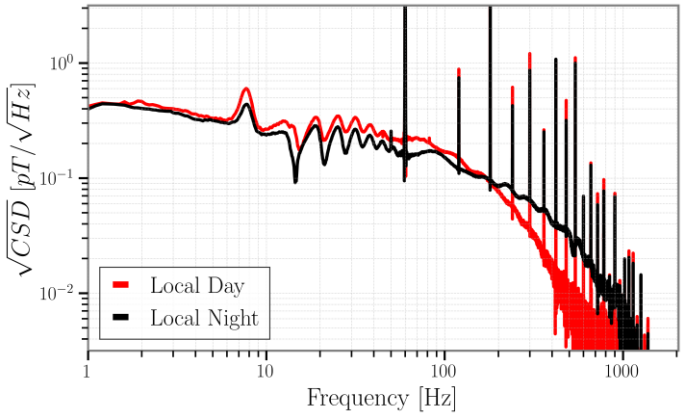




Diurnal Behavior of Lightning

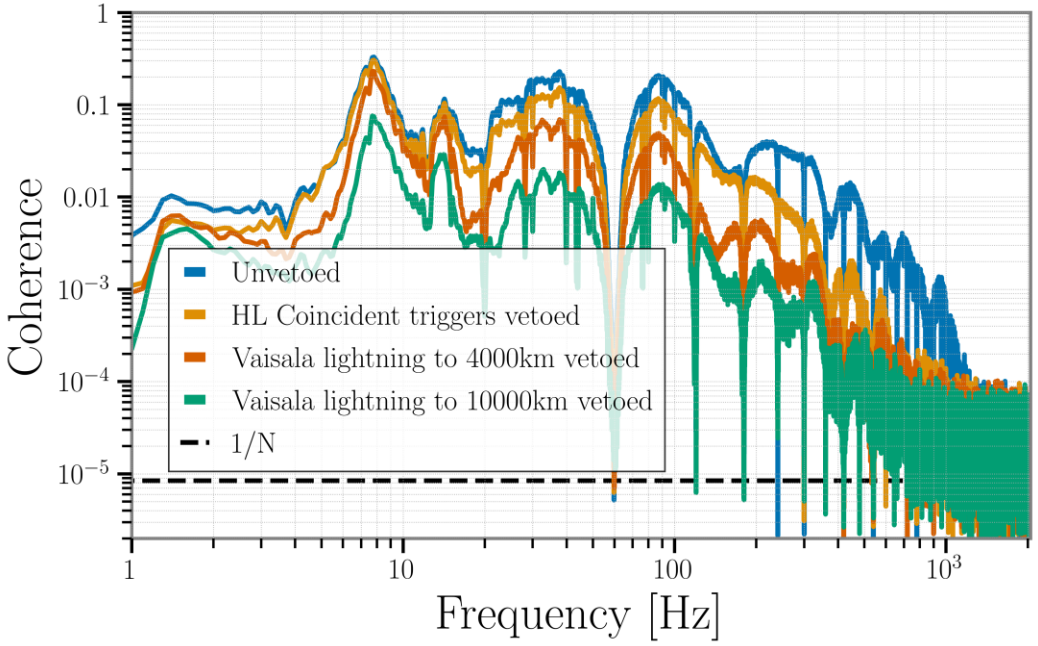
- Rate of coincident lightning events and cross-correlation spectra are highly diurnal
  - Time-dependent source lightning rate
  - Variations in ionosphere conductivity due to solar radiation
- Separate day/night samples could provide a check of a potential stochastic signal





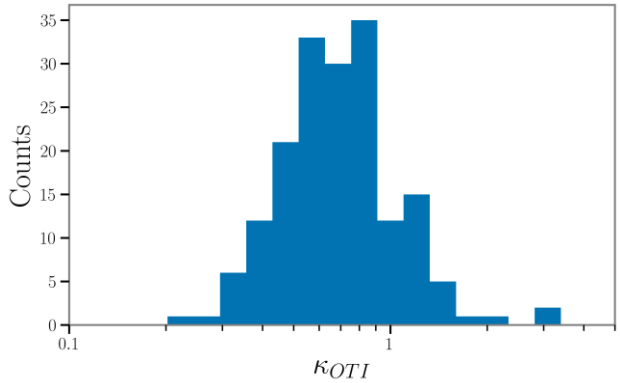
Magnetic Coherence

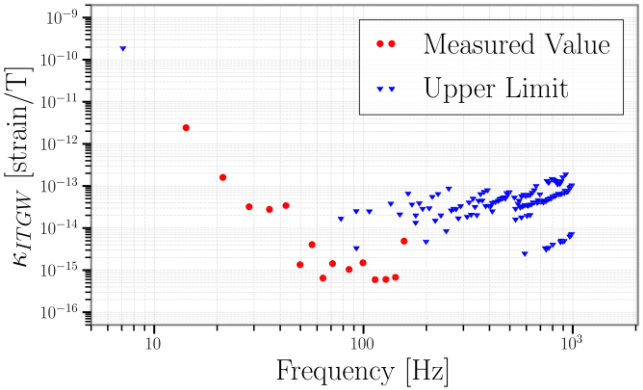
- Veto individual lightning strokes to quantify effect on coherence
- Removed in 3 stages:
  - Only HL-GLD360-coincident triggers
  - All GLD360 lightning strokes within the sensitivity range
  - All GLD360 lightning strokes within 2.5x the sensitivity range



Magnetic Coupling

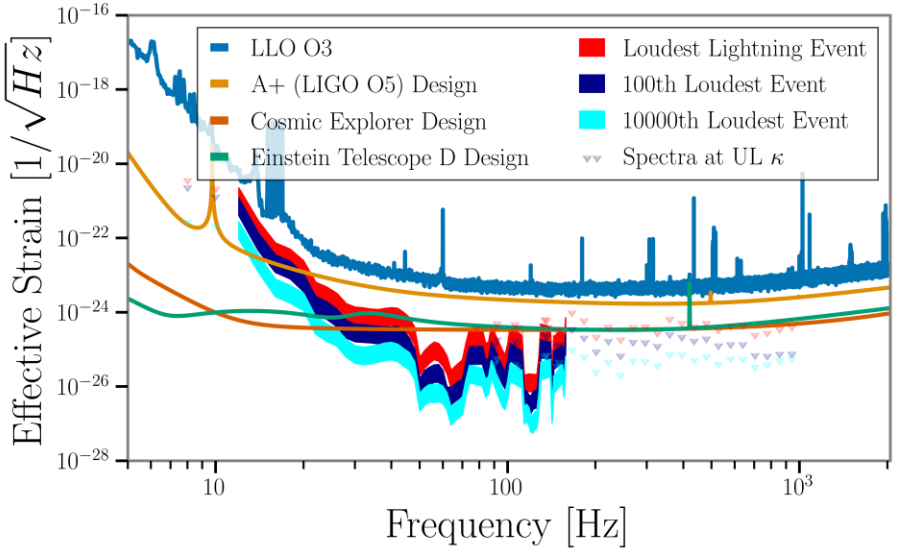
- Divided into outside-to-inside and inside-to-GW coupling
- Outside-to-inside:
  - Use nearby lightning strikes as injections – measured both outside and inside the facility buildings
  - Take ratio of field amplitudes
- Inside-to-GW:
  - Pre- and post- observing run injections using magnetic coils
  - Generate field strong enough to couple to GW channel





Effects on GW Science

- Individual lightning strike signals can be projected into the GW readout and compared to various sensitivity thresholds
- Future detectors assume that the coupling is the same as the current situation
- No risk of magnetic contamination during O3
- A+ and 3rd generation detectors will likely be susceptible to individual lightning strokes
- Any lightning-induced signal in the GW channel will be identifiable with the magnetometers, and should be removable from an overlapping GW signal
  - At least for longer duration signals like BNS or low-mass BBH



Summary

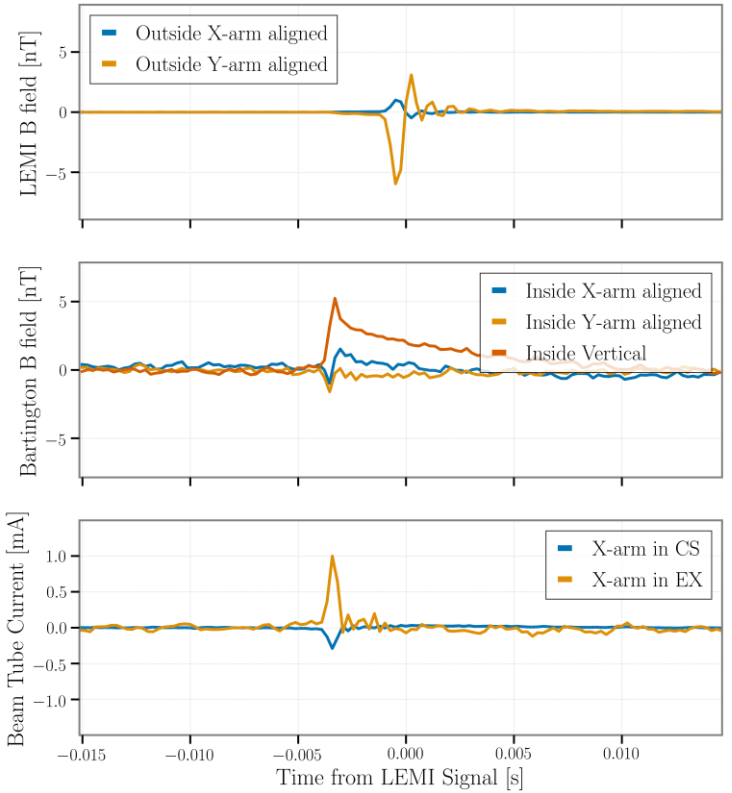
- Magnetic fields from individual lightning strikes are coherent across global distances
  - This will affect all future (ground-based) detectors
- Both the rate of coherent lightning events and the background coherence is highly diurnal
  - Possible way to vet a potential stochastic detection
- Individual lightning strokes did not affect O3 and will likely not affect O4
  - We have some breathing room
- Individual lightning strokes will likely affect A+ and 3rd generation detectors
  - If the coupling effects/mechanisms remain the same
  - We likely want to identify the coupling mechanisms in detail before finalizing construction plans
- If the coupling cannot be physically prevented, there is little risk of mistaking lightning for an astrophysical event
  - Coupling functions need to be up-to-date and comprehensive
- Lightning will likely overlap with real long-duration astrophysical events
  - Not clear for shorter, broadband burst signals like high-mass BBH or cosmic strings
  - Investigation into subtraction or filtering techniques for data cleaning

Full paper with extra details

Janssens, K., Ball, M., Schofield, R. M. S., Christensen, N., Frey, et al. (2023). Correlated 1--1000 Hz magnetic field fluctuations from lightning over Earth-scale distances and their impact on gravitational wave searches. *Phys. Rev. D*, *107*, 022004. doi:10.1103/PhysRevD.107.022004

Coupling Mechanism

- Anamaria Effler at LLO installed current clamps on the beam tube grounding spikes which can measure current
- Lightning events witnessed by external LEMIs and internal Bartingtons also appear as currents along the beam tube
- Currents roughly consistent with induction in the loop consisting of:
  - Beam tube – grounding spike – ground under beam tube – ground spike



Another project: Parameter Estimation of Neutron Star f-modes Associated with Magnetar Flares

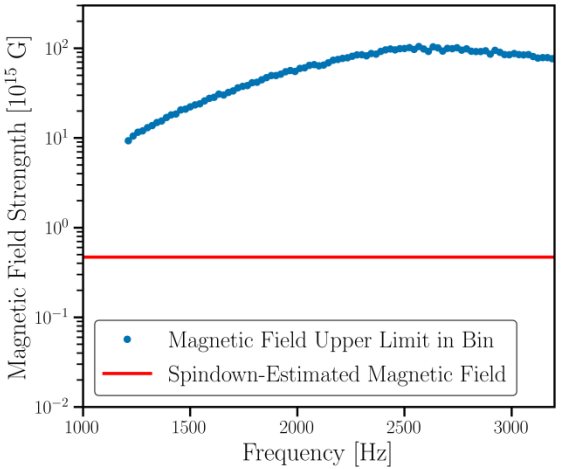
I am limited by time, so this is just an overview

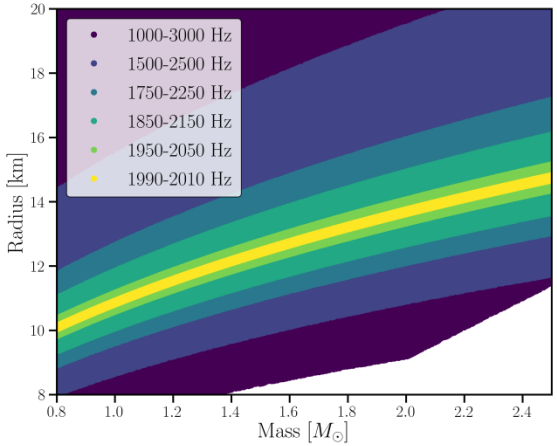
What is an f-mode?

- Fundamental, non-radial oscillatory vibrational mode of a neutron star
- Believed to be excited from catastrophic events like a magnetar flare
- Monochromatic, expected to occur between 1 and 3 kHz
- Expected to be a damped sinusoid, with damping time below 1 second
- Frequency and damping time related to astrophysical parameters of the neutron star and the equation of state
- Equation of state independent fitting functions (Anderson & Kokkotas, 1998) relate damping time and frequency to mass and radius
- Additional fitting function (from P. Lasky, B. Zink, et al. 2012) connects magnetic field strength to amplitude

What could you get from a detection (or non-detection)?

Place upper limits on the magnetic field of the source magnetar





Estimate source mass and radius in the event of a marginal candidate, constraining the equation of state

Predict sensitivities of future detectors