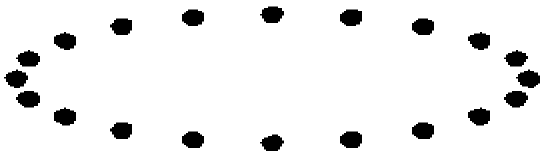
Localizing Gravitational Wave Events for Electromagnetic Followup

Orion Sauter for the Virgo Collaboration at LAPP

Effect of Gravitational Waves

- Alternately stretch and squeeze space
- Change proportional distance between points
- Extremely weak: $O(10^{-22})$ or less
- Created by accelerating masses, e.g. compact binaries, spinning neutron stars



Wikipedia

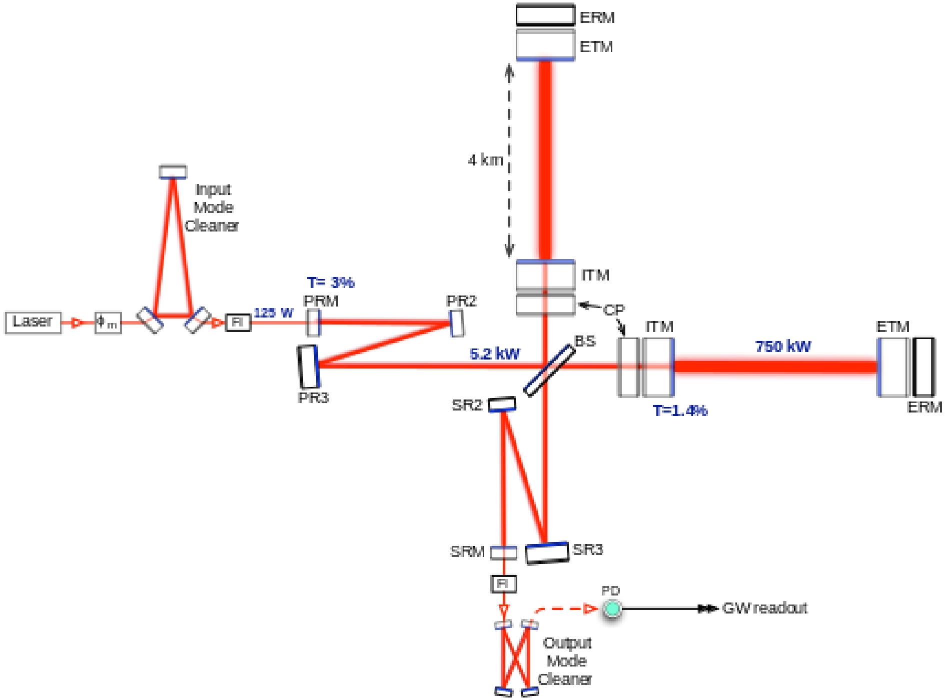
Gravitational Wave Detectors

Virgo Collaboration

Cyril FRESILLON/Virgo/CNRS PHOTOTHEQUE

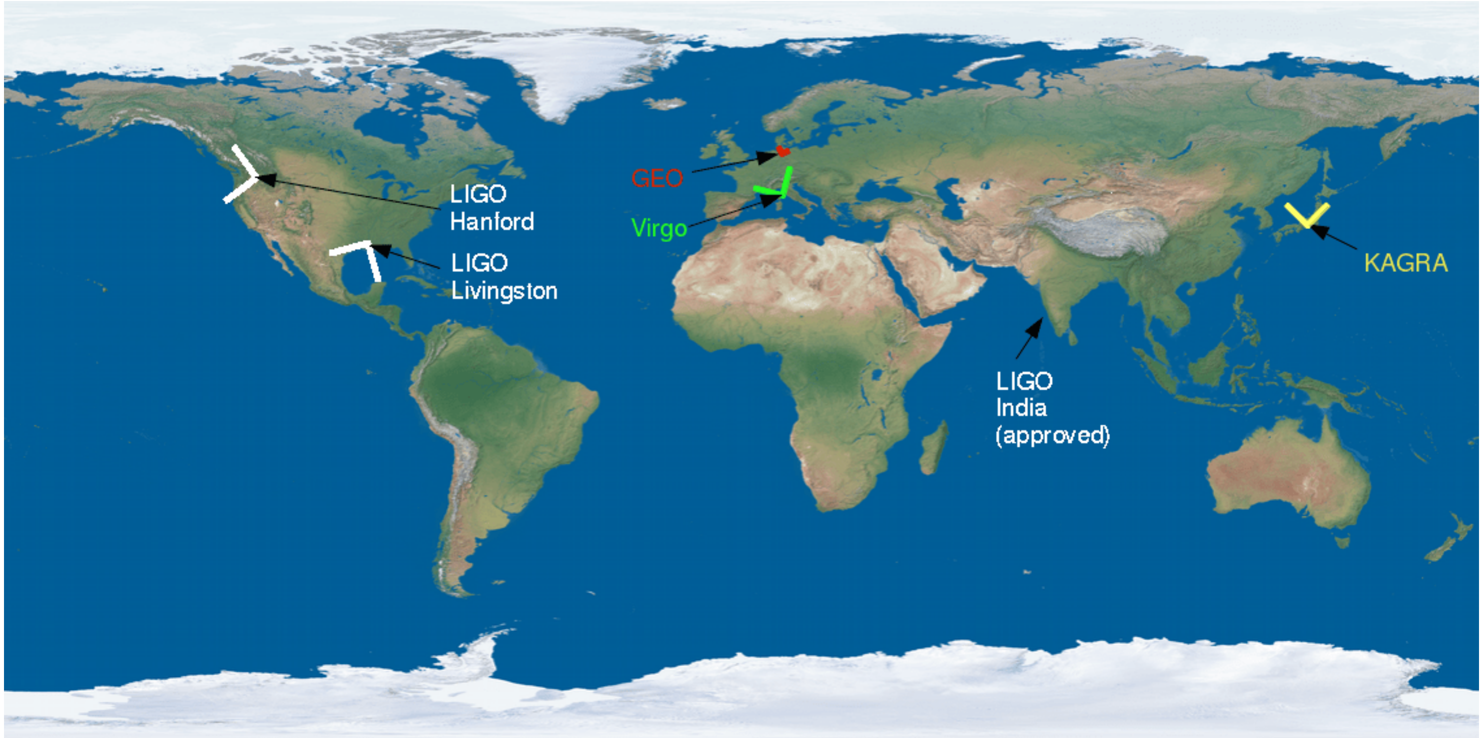
Gravitational Wave Detectors

- Fabry-Perot interferometer
- Heavy mirrors with pendulum suspension for seismic isolation
- Intensity of light at output depends on difference in arm length
- Gravitational wave changes differential arm length, resulting in interference



J. Aasi et al. 2015

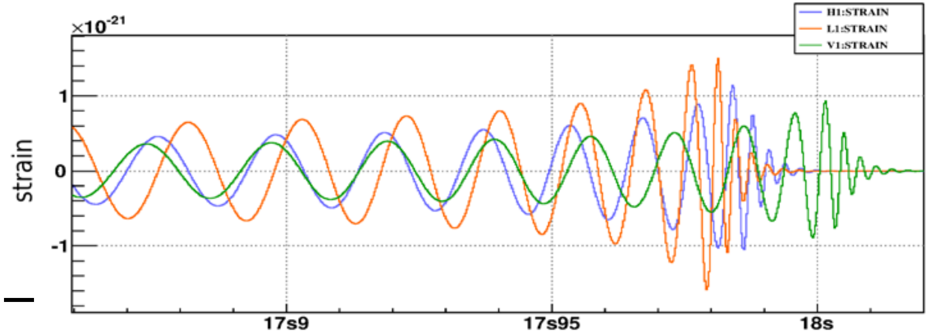
Detector Network



The Virgo Collaboration/LAPP and Tom Patterson

Sky-Localization

- Arrival times at each detector compared
- Phase-shift required to bring signals into alignment informs direction
- Detection template includes masses/spins – Distance based on expected magnitude

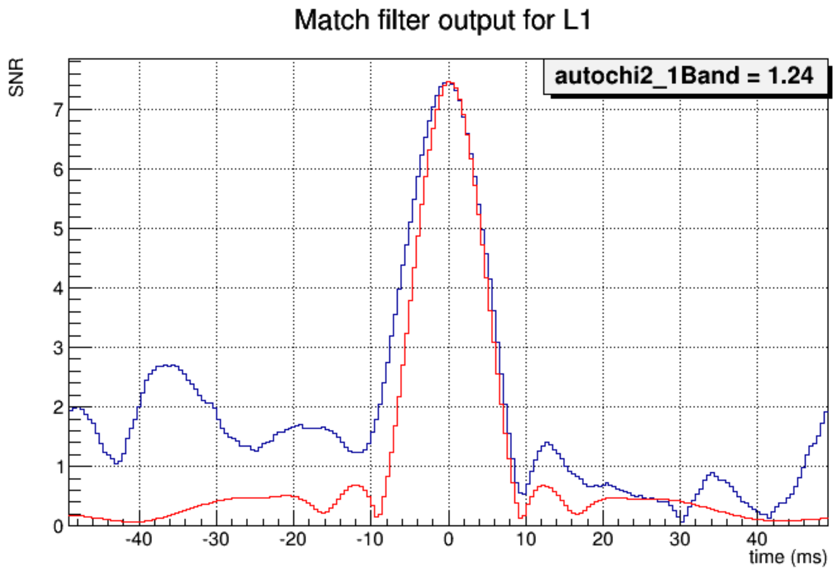


Search Templates

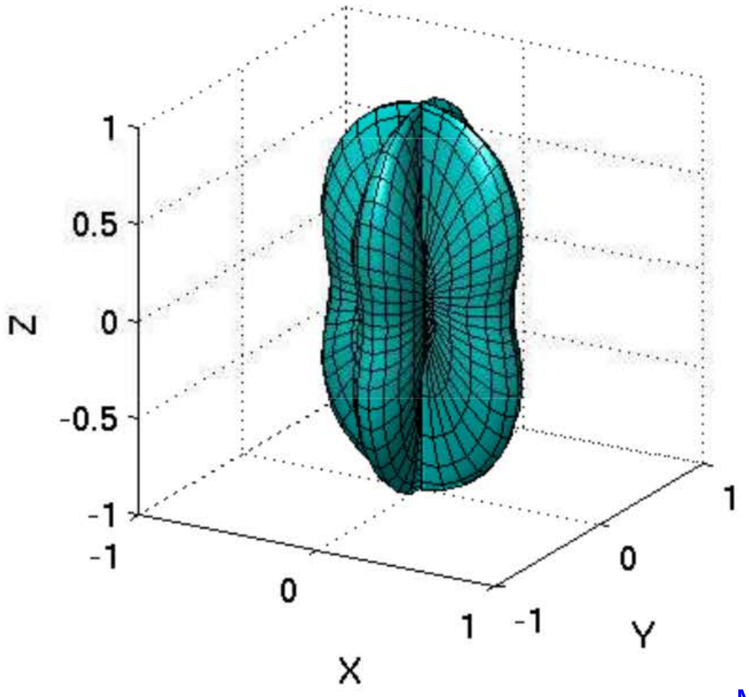
- Calculate expected gravitational waveforms, then search for correlation with detector output

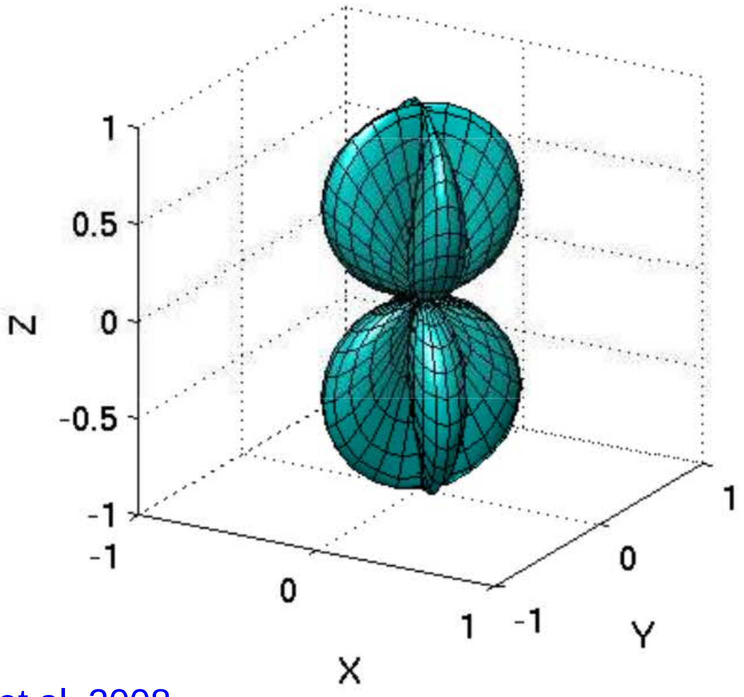
- When looking for detector coincidence, must use same template across detectors

- Choose density of templates for some maximum mismatch



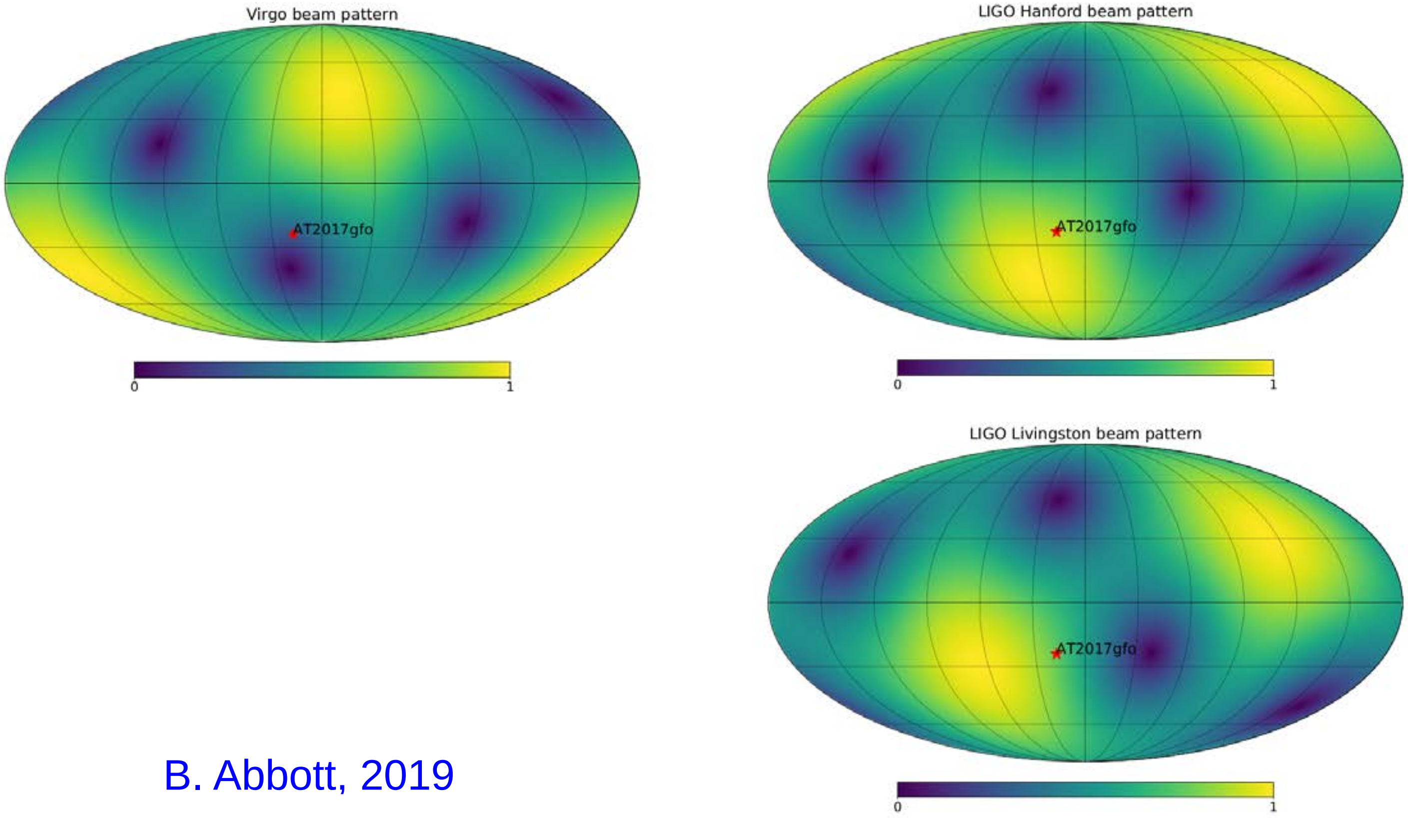
Antenna Pattern





M. Rakhmanov et al. 2008

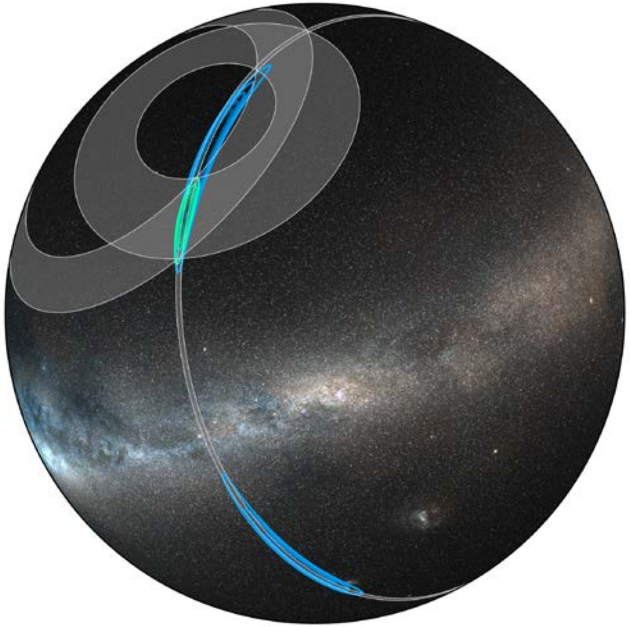
Antenna Pattern



B. Abbott, 2019

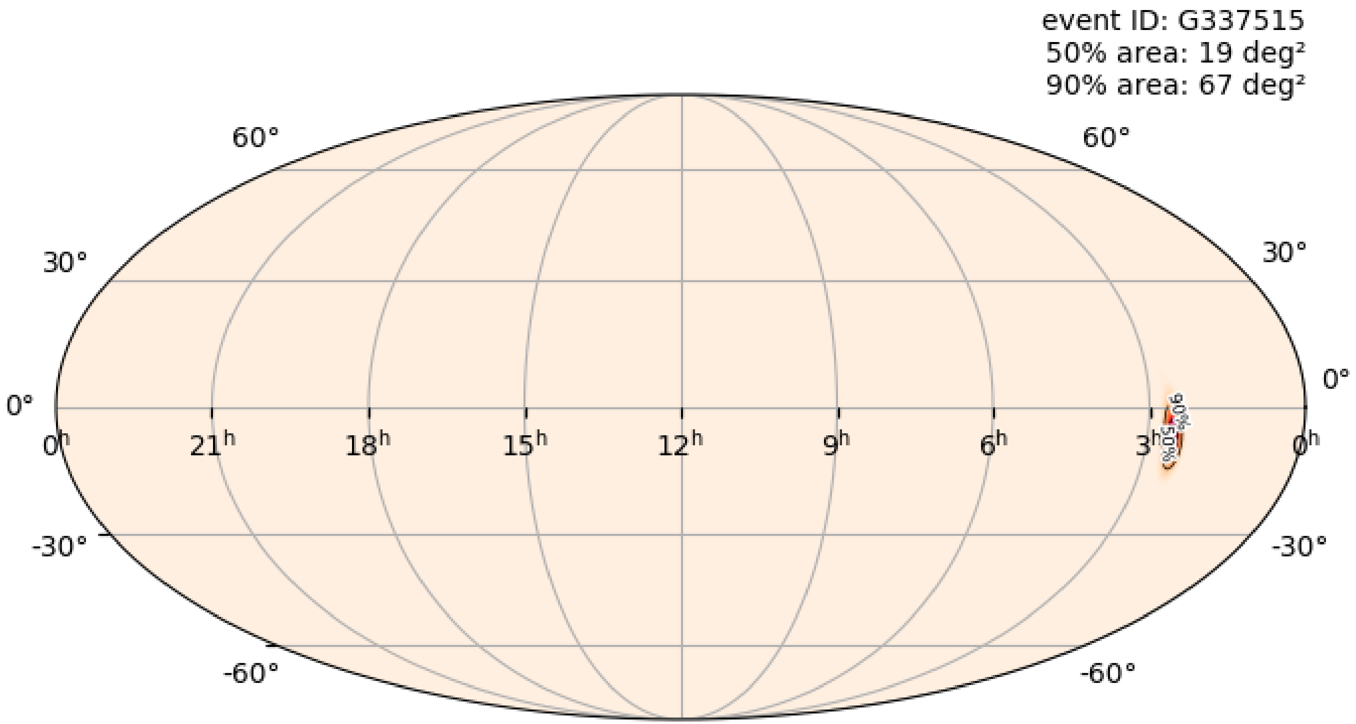
First BNS: GW170817

- Despite being online, Virgo did not detect
- Suggested source was in a blind-spot
- Using antenna pattern, able to narrow region enough to allow fast EM detection



Credit: LIGO/Virgo/NASA/Leo Singer (Milky Way image: Axel Mellinger)

Recent Public Alert: S190701ah



Alerts

- For events with sufficiently low false-alarm rate, GCN notice is sent
- Includes localization skymap
- P_{astro}: Probability that trigger is astrophysical (not terrestrial)
- EMBright: Probability that event is visible in EM spectrum (NS component)

TITLE: GCN CIRCULAR
NUMBER: 21505
SUBJECT: LIGO/Virgo G298048: Fermi GBM trigger 524666471/170817529: LIGO/Virgo Identification of a possible gravitational-wave counterpart
DATE: 17/08/17 13:21:42 GMT
FROM: Reed Clasey Essick at MIT <ressick@mit.edu>

The LIGO Scientific Collaboration and the Virgo Collaboration report:

The online CBC pipeline (gstlal) has made a preliminary identification of a GW candidate associated with the time of Fermi GBM trigger 524666471/170817529 at gps time 1187008884.47 (Thu Aug 17 12:41:06 GMT 2017) with RA=186.62deg Dec=-48.84deg and an error radius of 17.45deg.

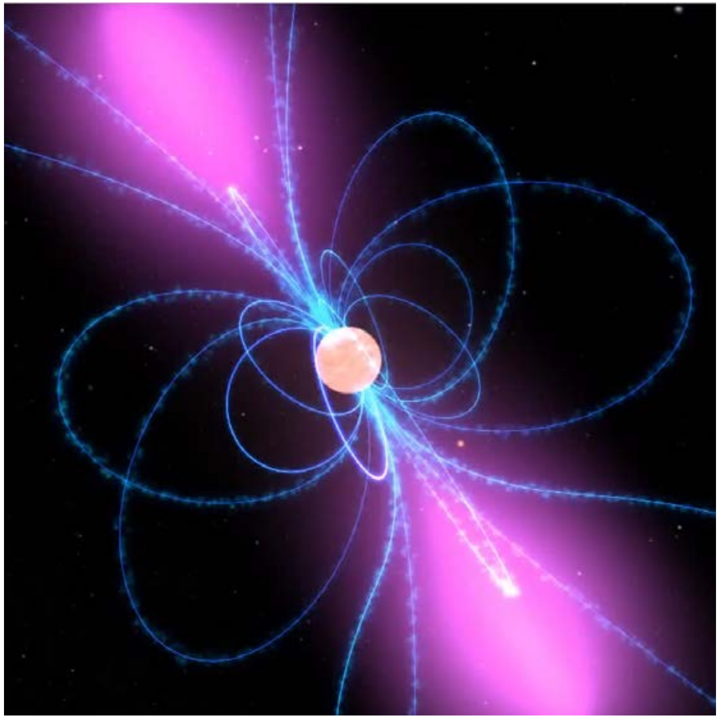
The candidate is consistent with a neutron star binary coalescence with False Alarm Rate of ~1/10,000 years.

An offline analysis is ongoing. Any significant updates will be provided by a new Circular.

[GCN OPS NOTE(17aug17): Per author's request, the LIGO/VIRGO ID was added to the beginning of the Subject-line.]

Continuous Waves

- Also expect to find waves from isolated spinning neutron stars
- Signals are much weaker, but last many years
- Can sum signal coherently to detect through noise
- Targeted searches for known pulsars (e.g. Scorpius X1)

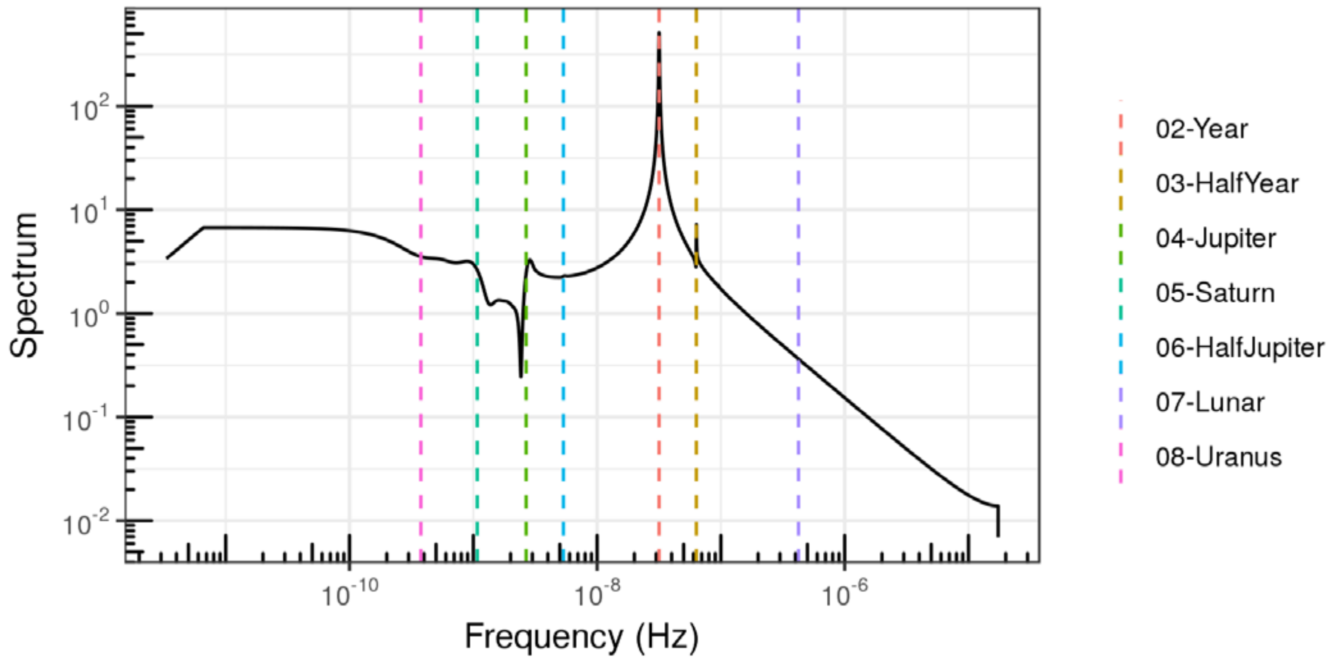


NASA/Goddard/CI Lab

“Pointing” the Detector

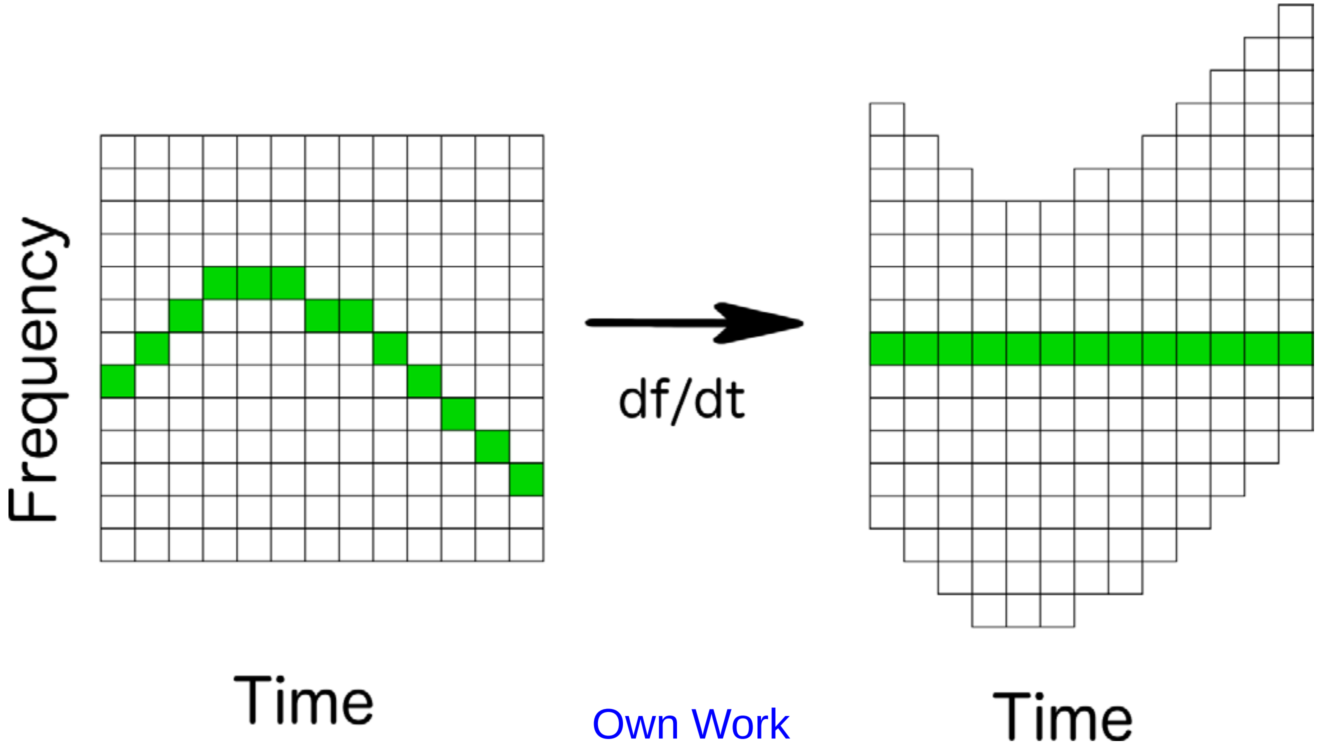
- For long-lasting signals, localization is possible even with a single detector
- At different points in Earth’s orbit, signal travel time will be different
- GR effects if signal passes through massive objects (Sun, Jupiter)
- Want to convert between detector reference frame and source frame
- Precision provided by TEMPO2 radio astronomy package is
  1 ns ~ 30 cm

Earth Position in ICRF



Own Work

Doppler Shift



Own Work

Multi-Messenger Astronomy

- With a growing network of interferometers, localization will improve
- By collaborating with EM partners, we can pool our findings to learn more about the universe
- Many opportunities to confirm or rewrite physical laws (speed of gravity, black hole/neutron star populations, etc.)