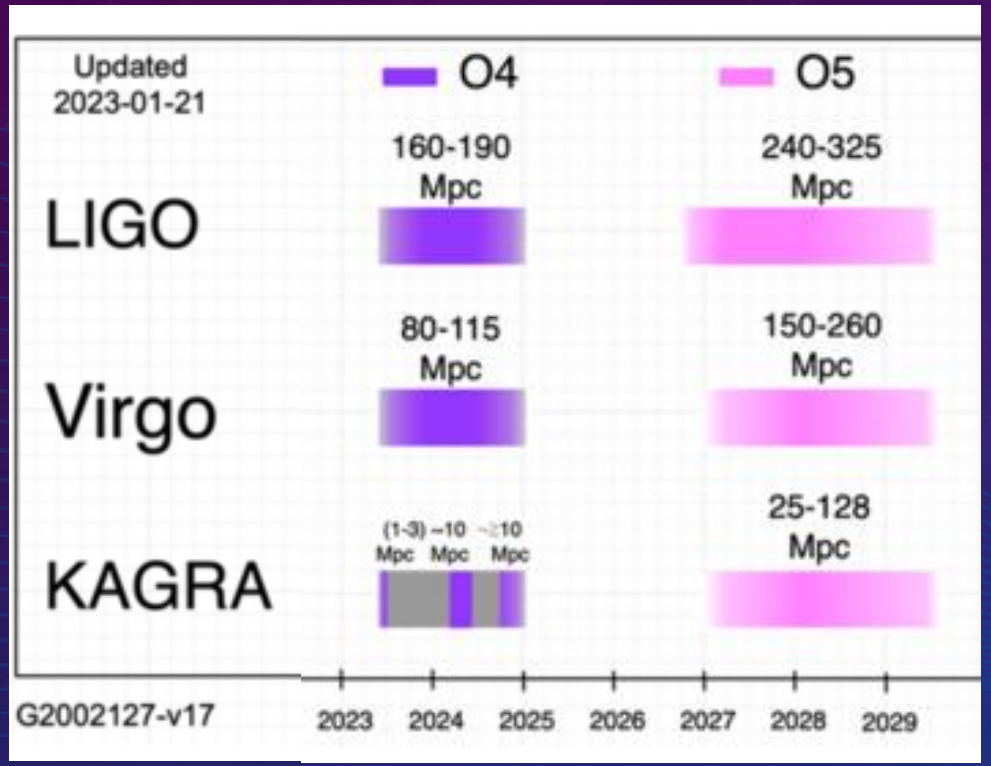
Detecting Explosive New Sources of Gravitational Waves

Jade Powell

Swinburne University of Technology

Compact Binary GW Detections



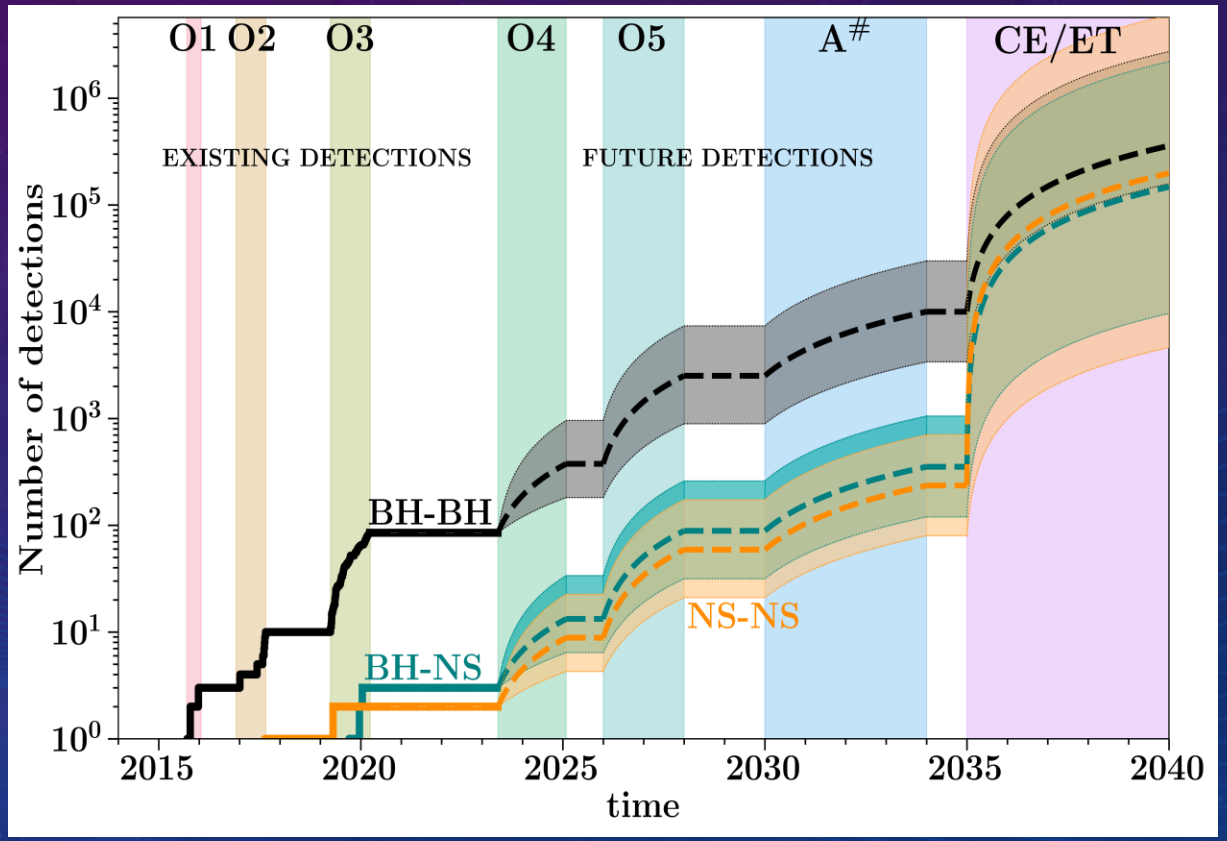


Image Credit: Floor Broekgaarden

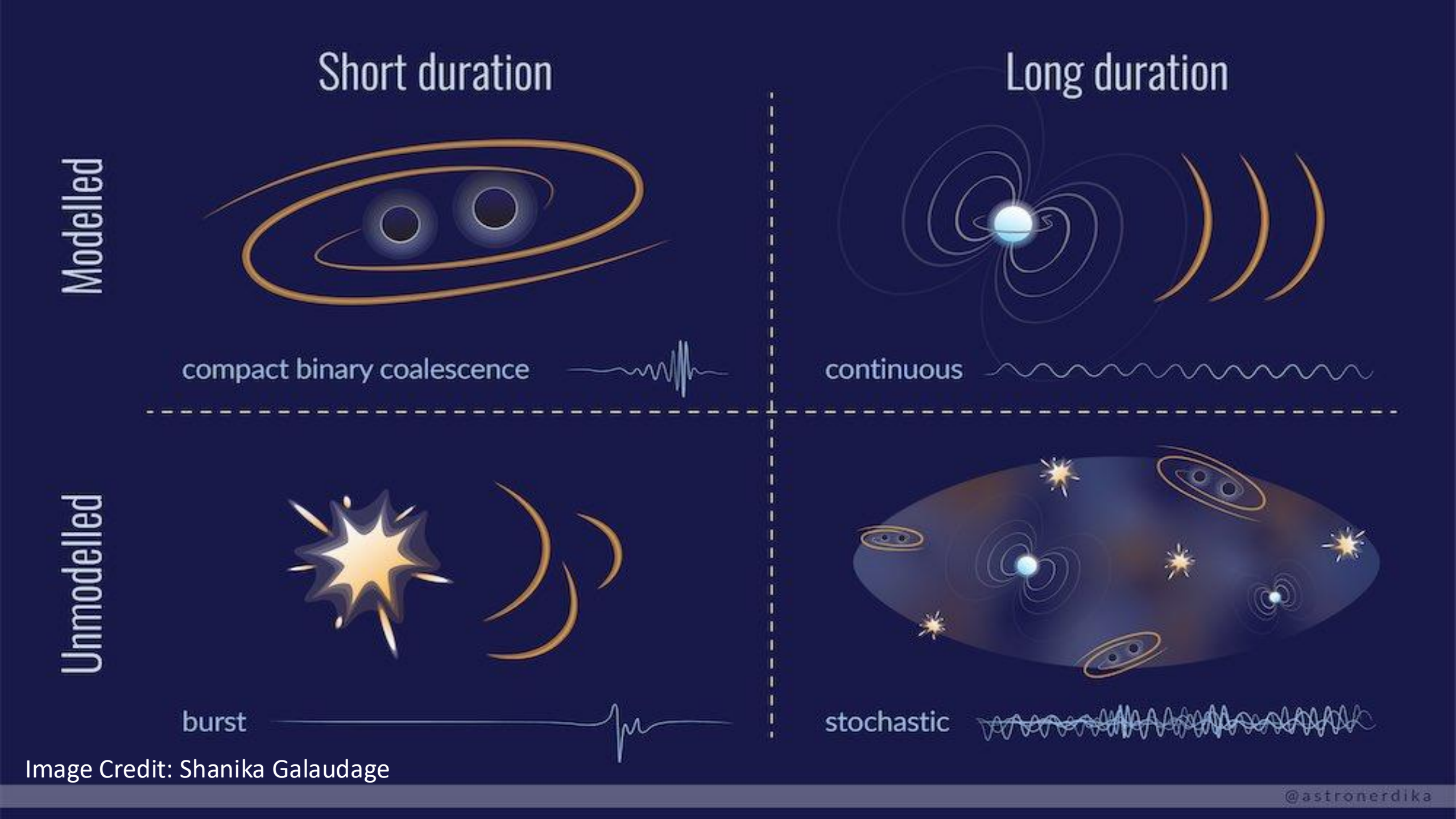
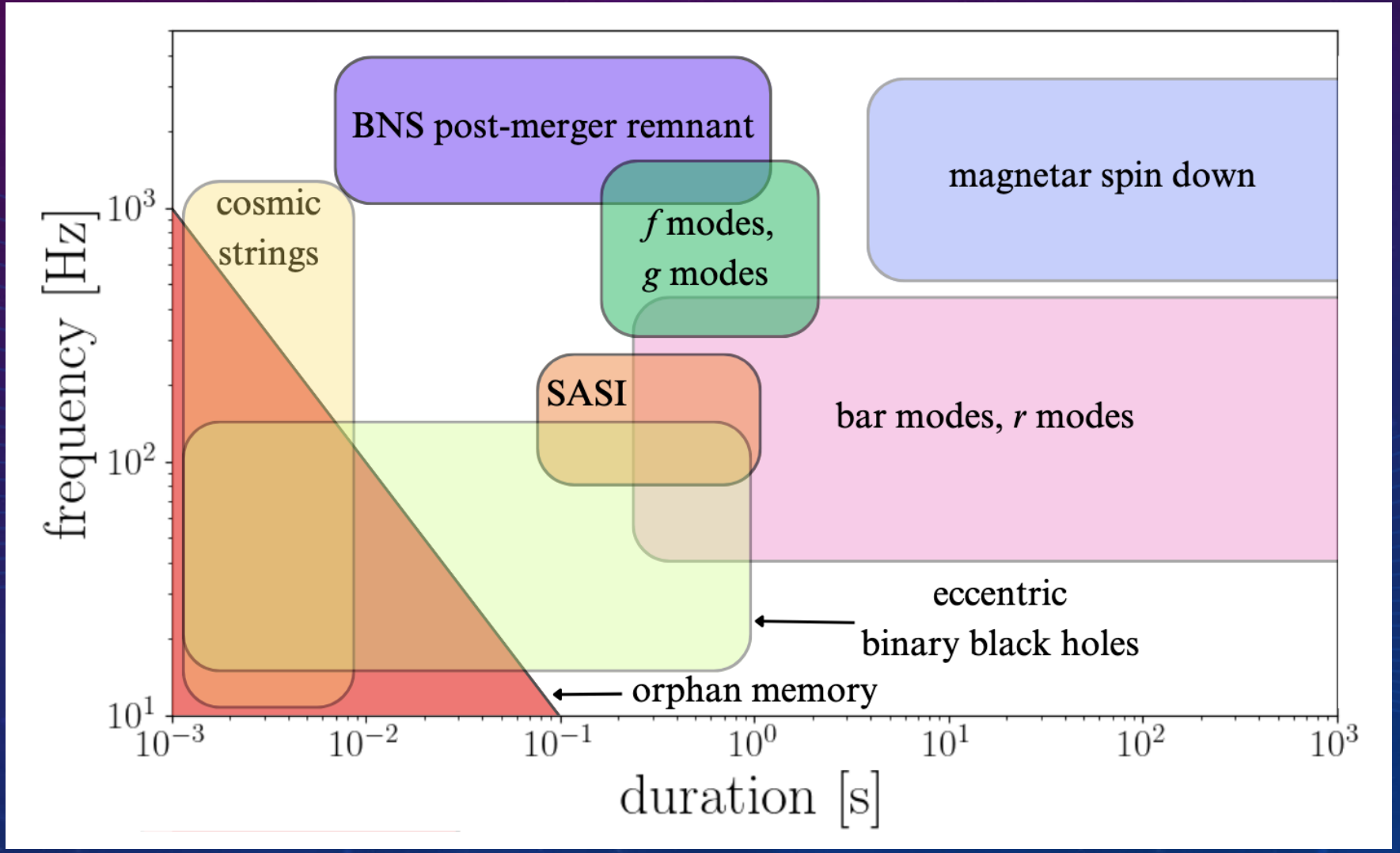


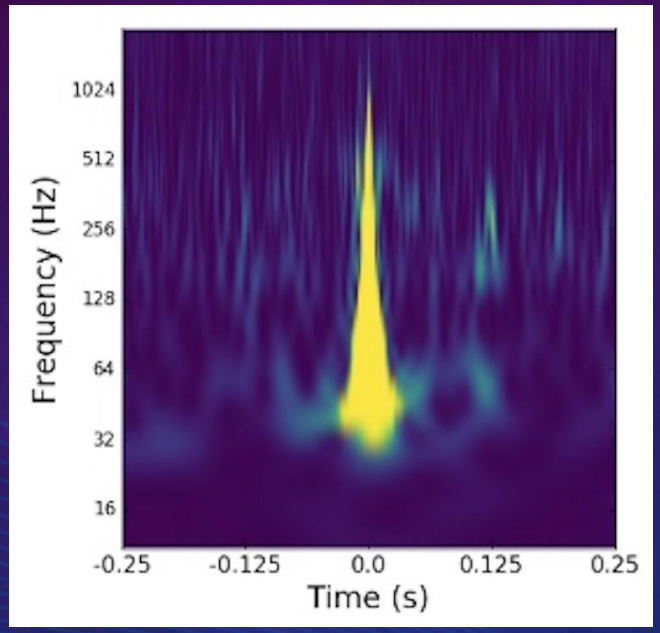
Image Credit: Shanika Galaudage

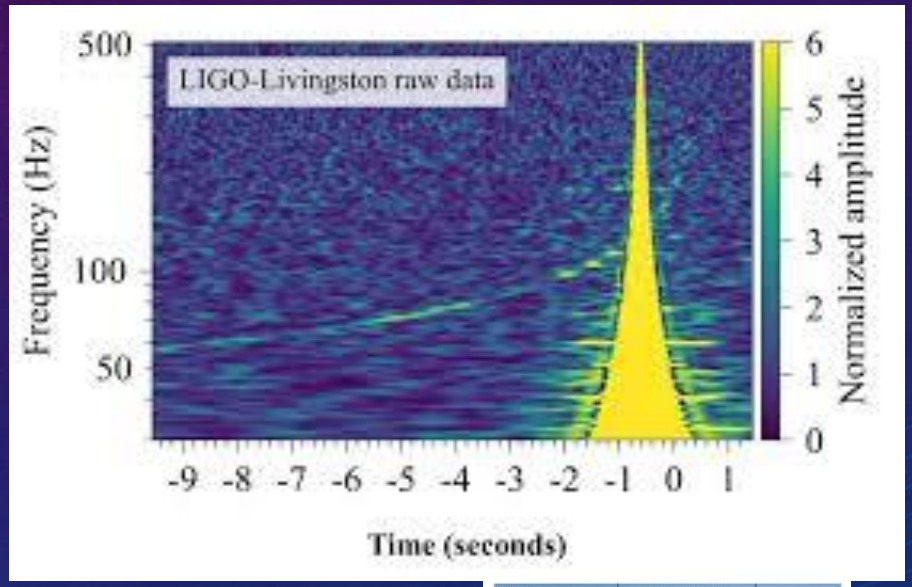
Gravitational Wave Bursts

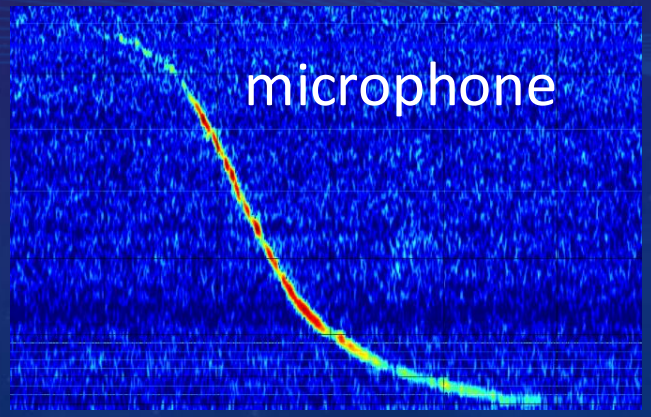


Burst Detection Challenges

- The detector noise is contaminated by glitches.
- They can mimic or contaminate signals.
- They limit the search backgrounds.
- We look for signals that occur in multiple detectors with the same shape.







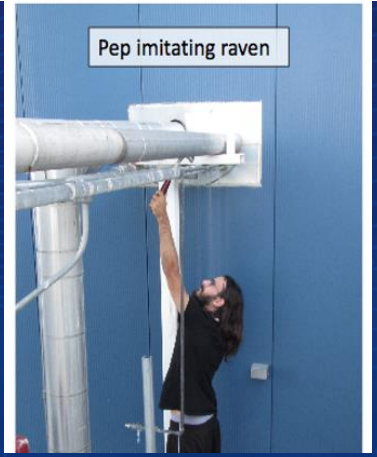
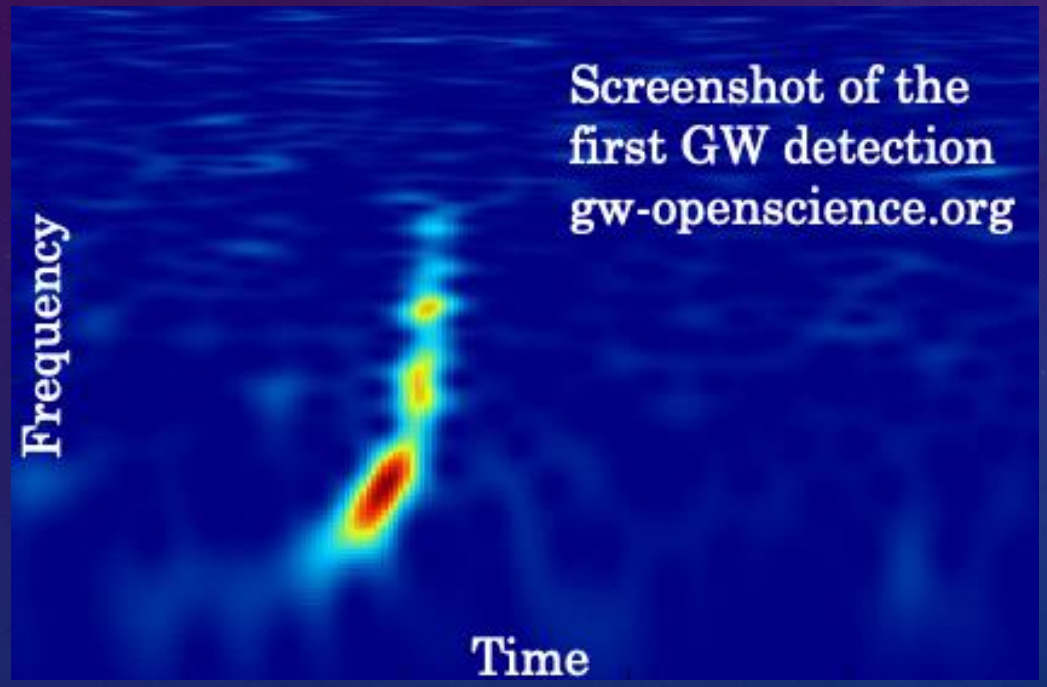
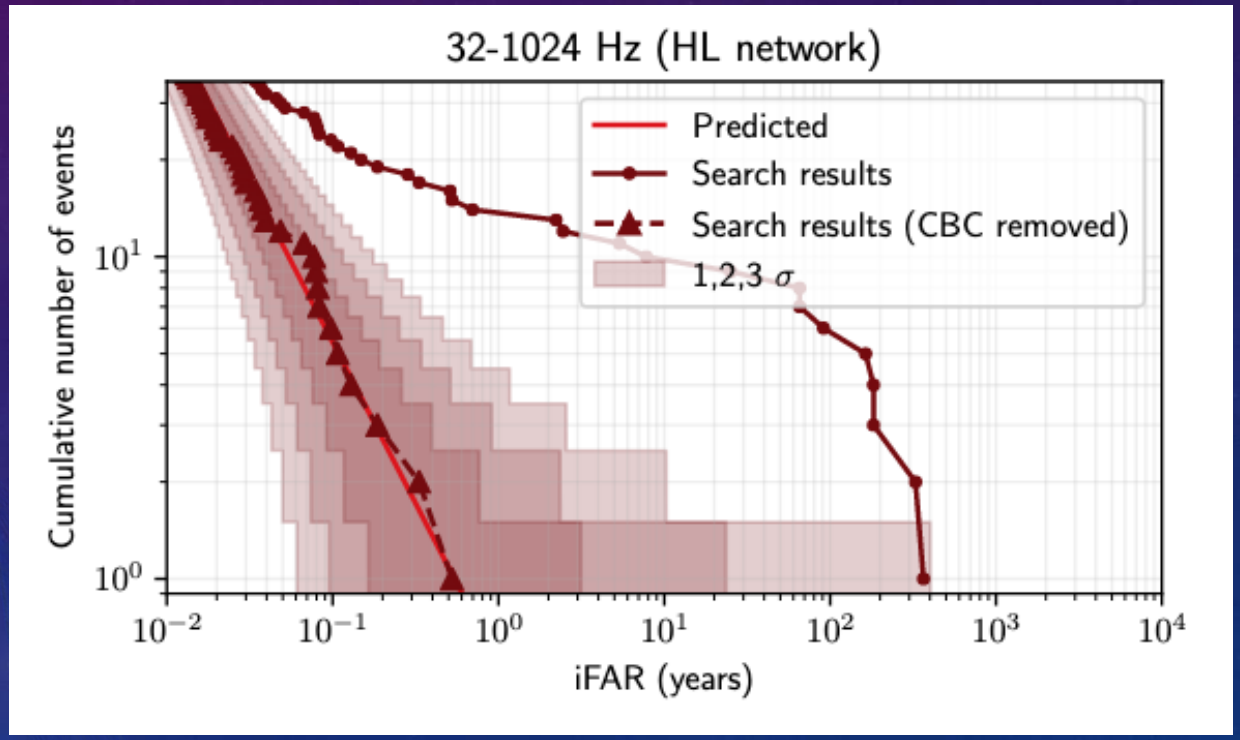


Image Credits: Gravity Spy, LVK Collaborations

Gravitational-Wave Burst Searches

So far, the burst searches have only found GWs from binary black holes.

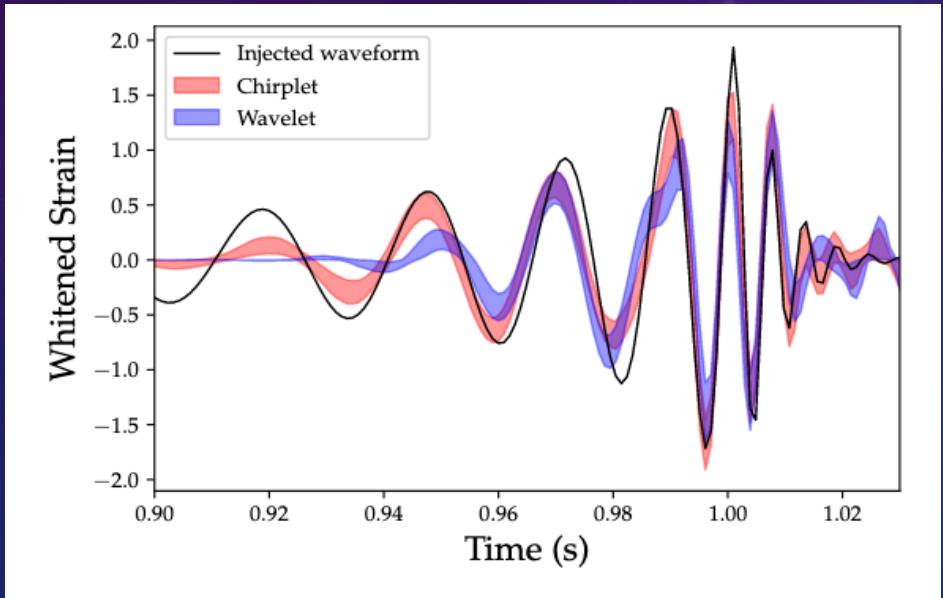




O3 burst search results. Credit: The LIGO, Virgo and KAGRA collaborations. arXiv:2107.03701

Waveform Reconstruction

- Burst searches can also produce model independent reconstructions of GW signals.
- They can also model glitches and subtract them from the data.



Credit: Meg Milhouse, arXiv:1804.03239

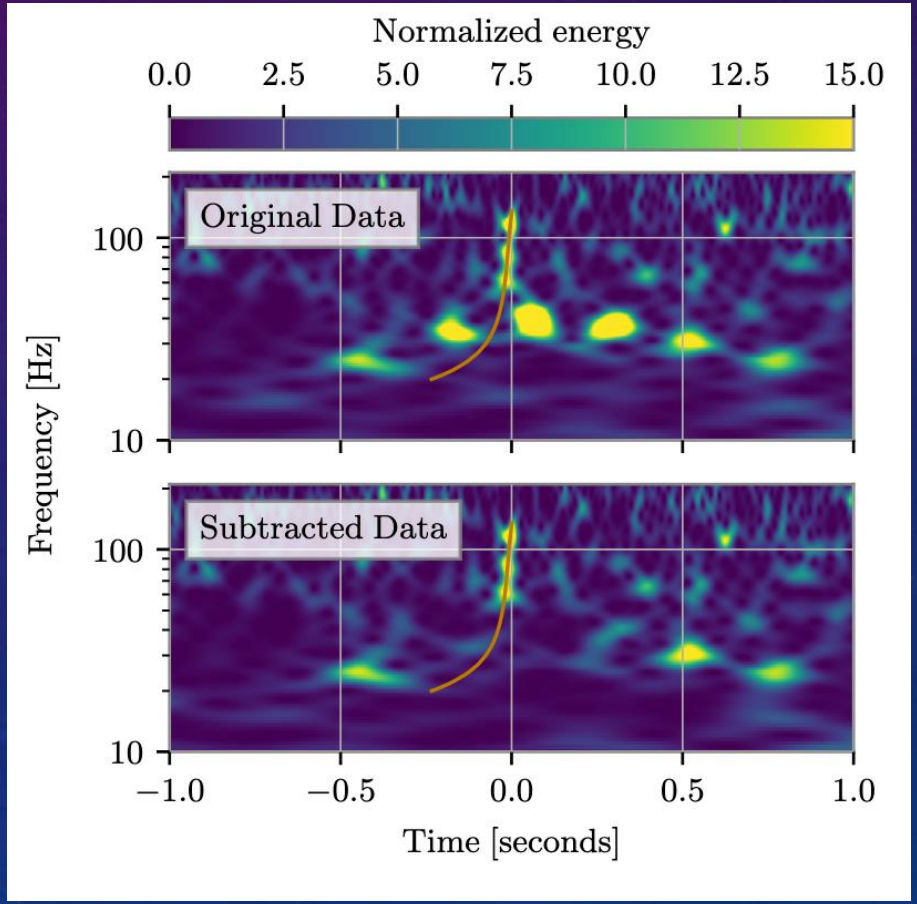


Image Credit: LIGO & Virgo Collaborations. GWTC2 arXiv:2010.14527

Eccentric Binaries

- Binaries normally circularize due to the emission of GWs.
- Eccentric binaries may form dynamically in a dense stellar environment like a globular cluster.
- May form through hierarchical field triples.
- We do not have enough waveforms for these systems for a good templated search.

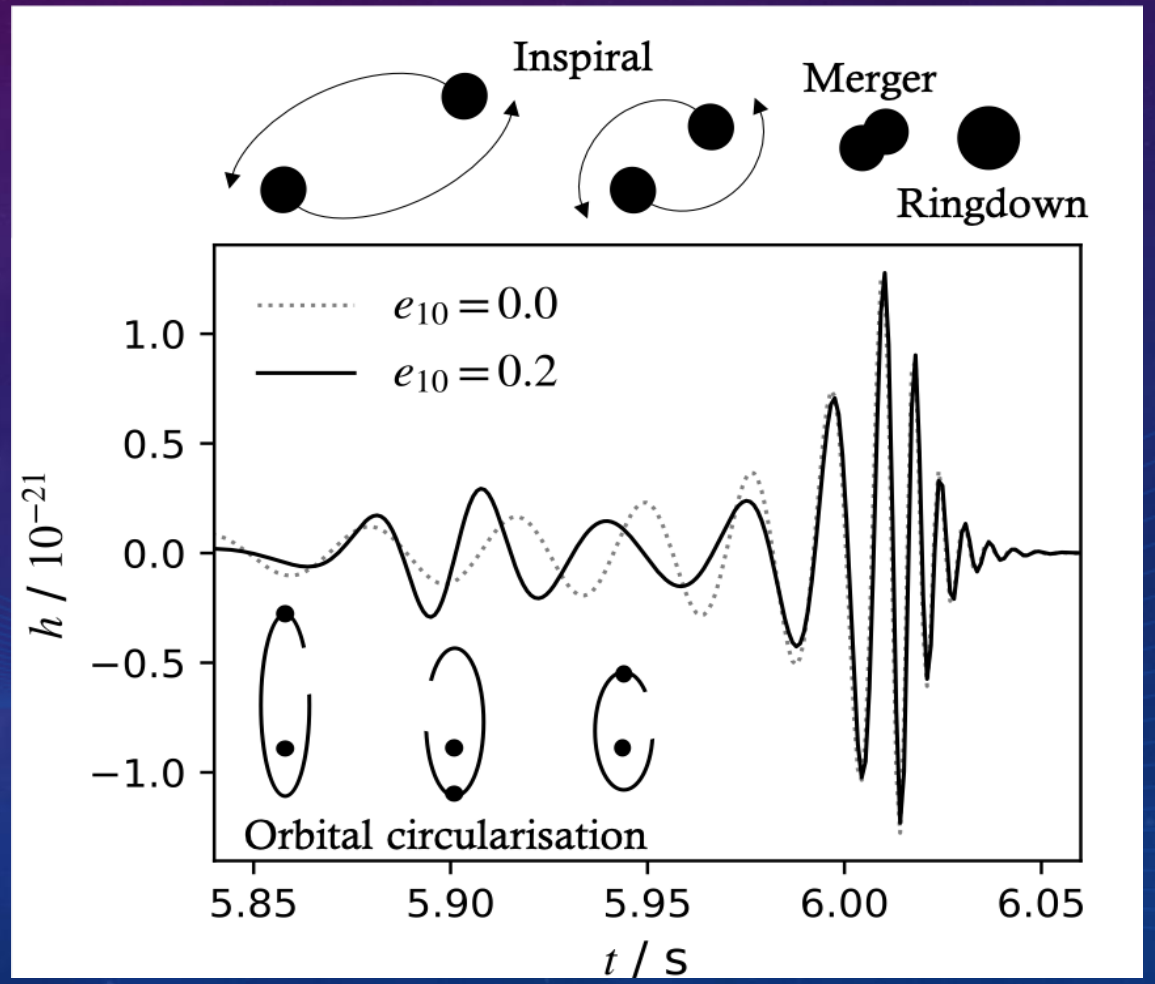


Image Credit: Isobel Romero-Shaw

Intermediate Mass Black Holes

- Only a few cycles of the signal in the LIGO-Virgo-KAGRA frequency band.
- They look similar to common detector noise glitches.
- They look like other kinds of potential astrophysical signals.

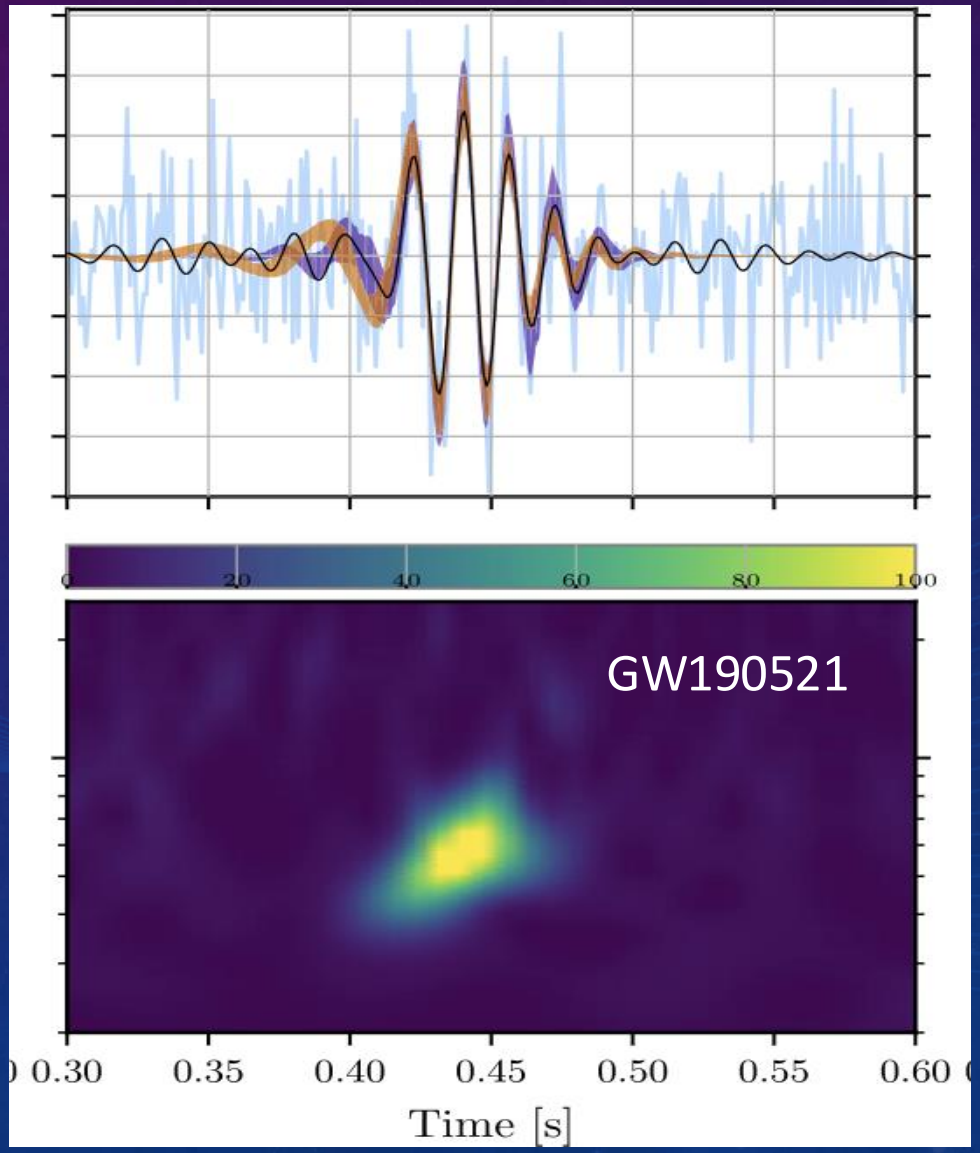
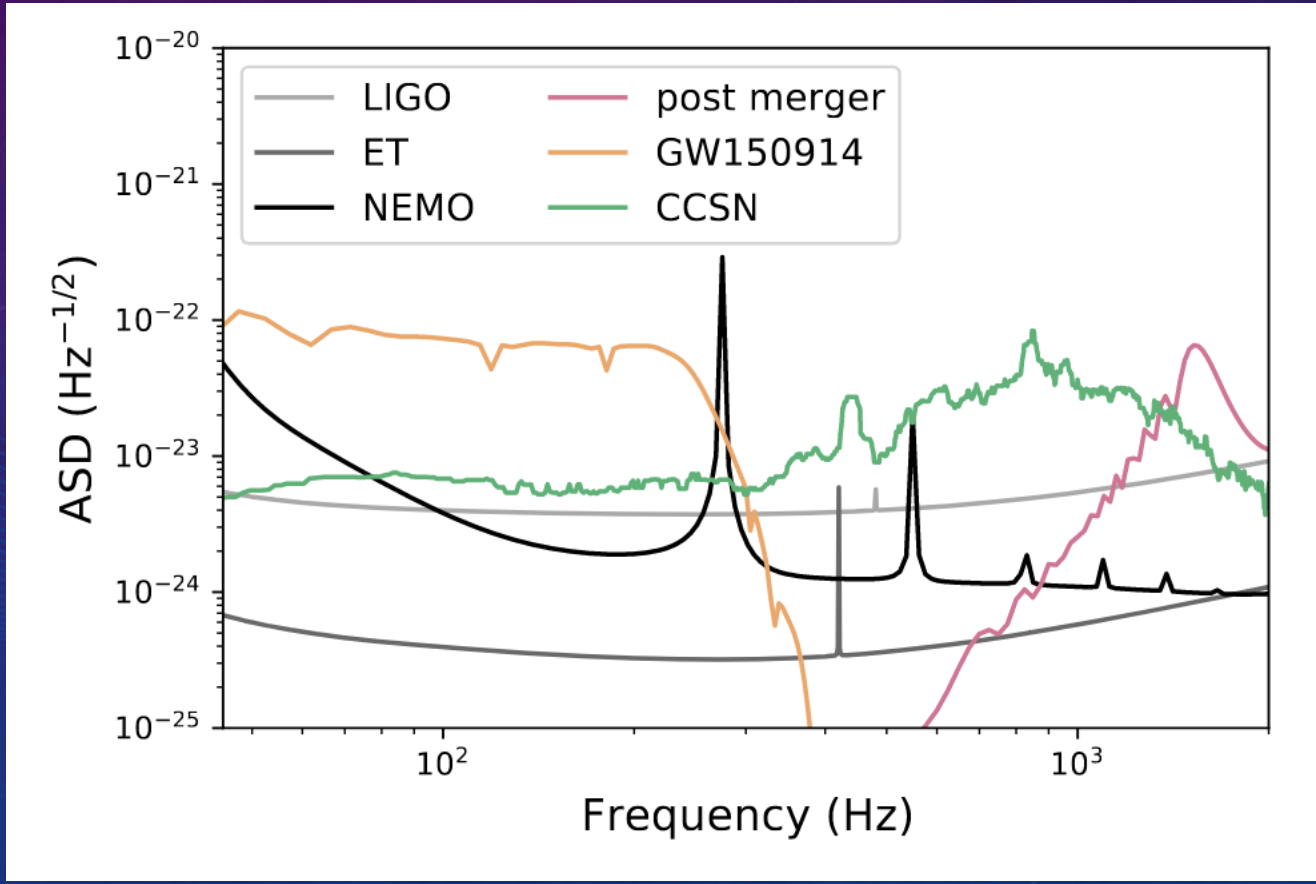


Image Credit: LIGO-Virgo

Post Merger Remnants

- May be detectable for a short time after the merger.
- Frequency in the kHz band.
- If detected, we may learn about the neutron star equation of state.



Gamma-Ray Bursts (GRBs)

- At least some short GRBs are neutron star mergers.
- Long GRBs are thought to be from extreme supernovae.
- Burst searches target data from 600s before to 60s after Fermi & Swift events.
- Previously only looked in the frequency band of 20-500 Hz.

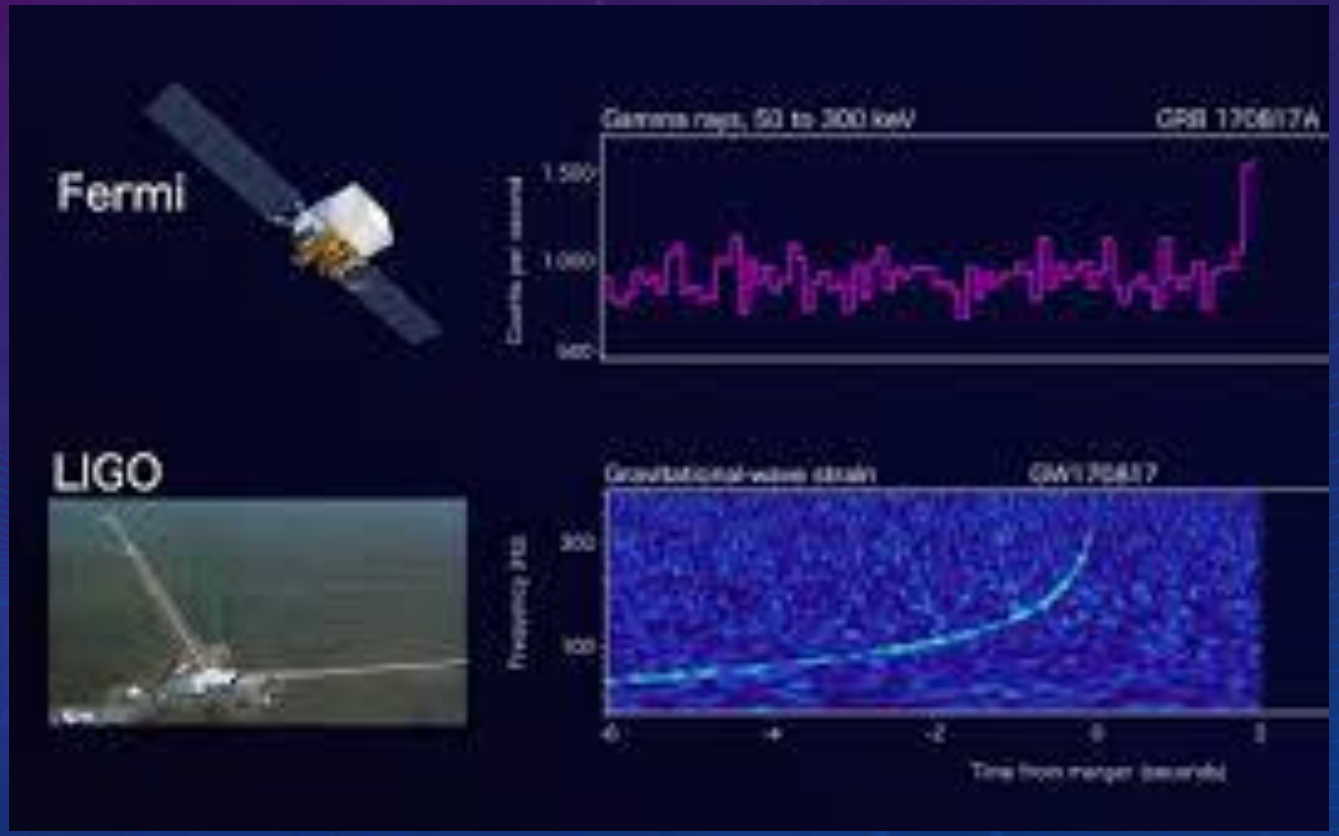


Image Credit: LIGO-Virgo-KAGRA

Fast Radio Bursts

- What are they?
- We search for GWs from FRBs with both compact binary searches and burst searches.
- During the fifth observing run (05) 2027-29 we expect several CHIME FRBs within the BNS detection range.

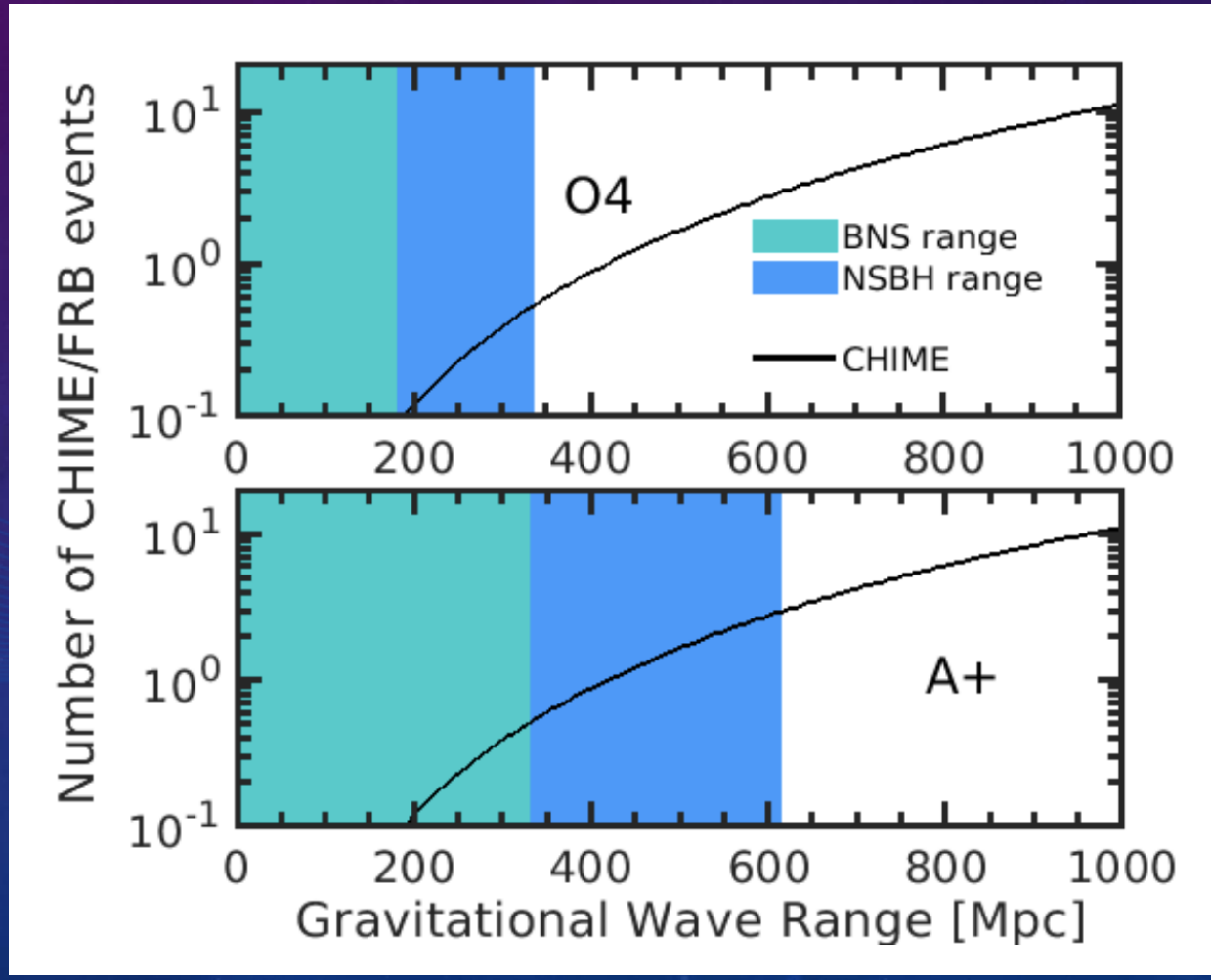
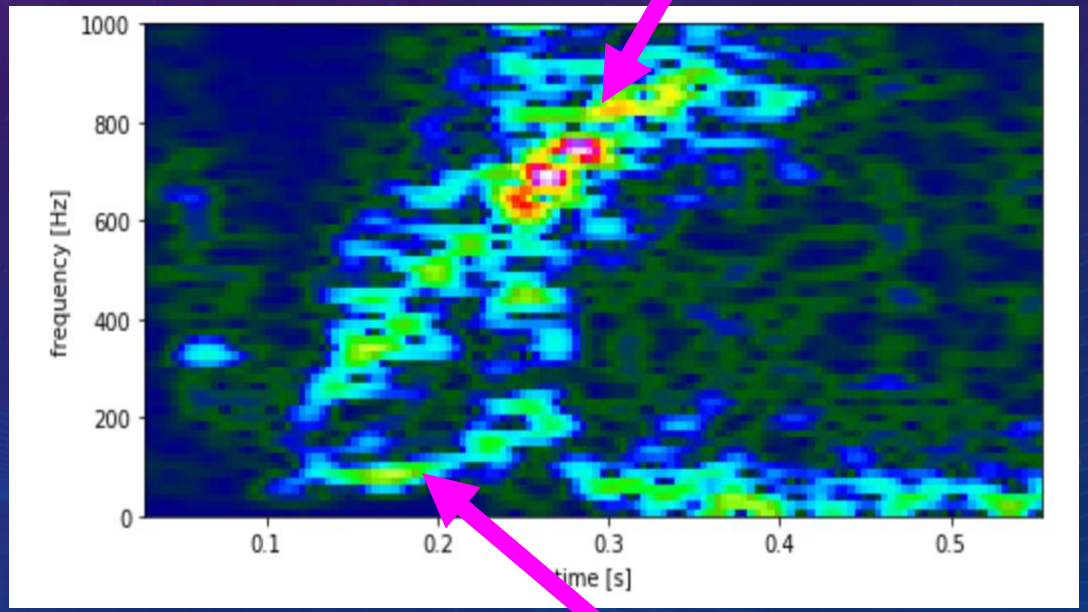


Image Credit: Eric Howell

Core-Collapse Supernovae

- Amplitude uncertain, but signal features well understood.
- Might be the first joint GW, EM and neutrino detection.
- We can measure the mechanism that powers the explosion, the rotation and magnetic fields, the equation of state, the neutron star parameters and properties of the shock wave.

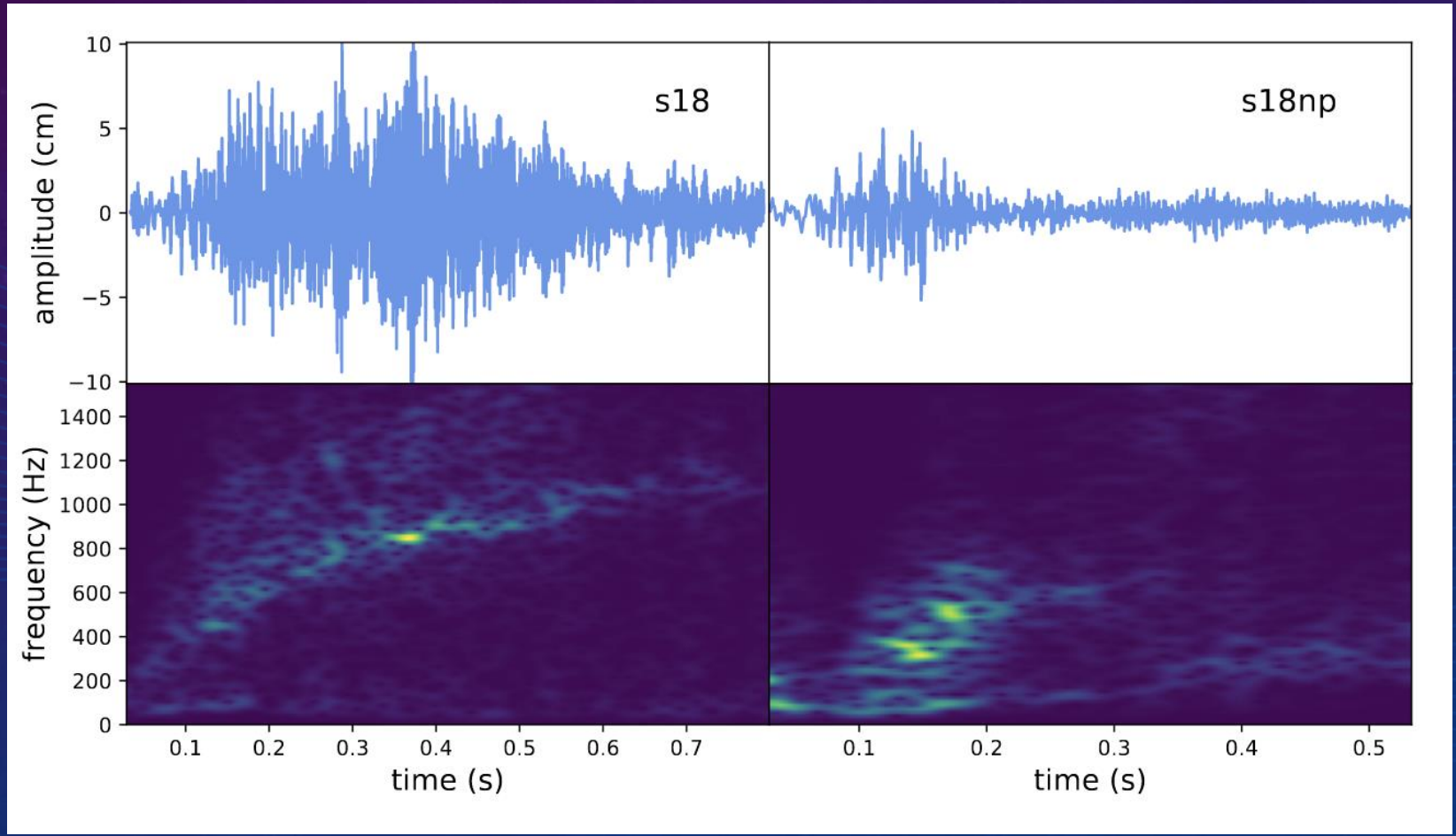
g/f-modes f $\propto \frac{M_{PNS}}{R_{PNS}^2}$



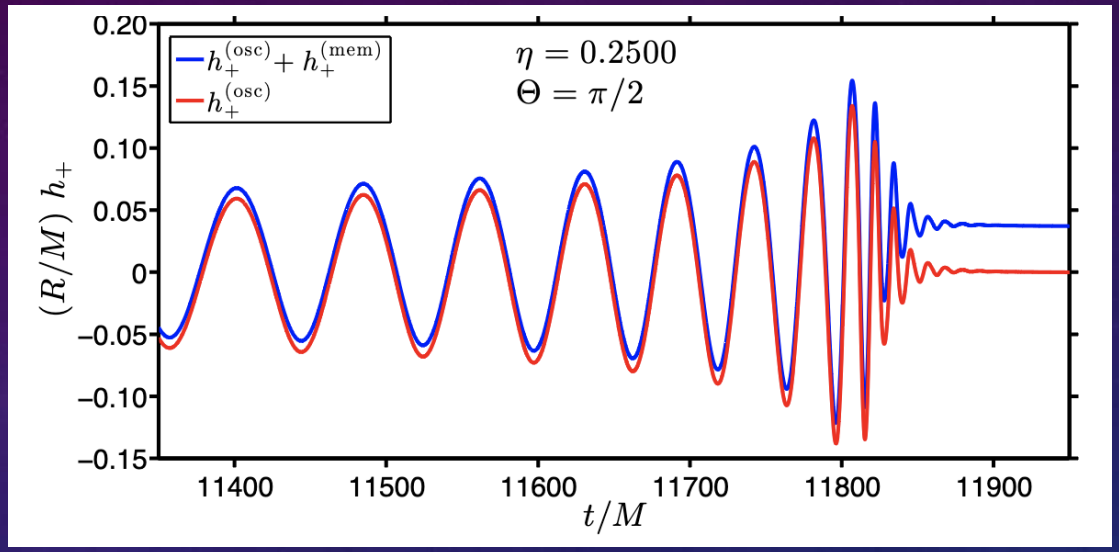
SASI f $\propto \frac{M_{shock}}{R_{shock}^3}$

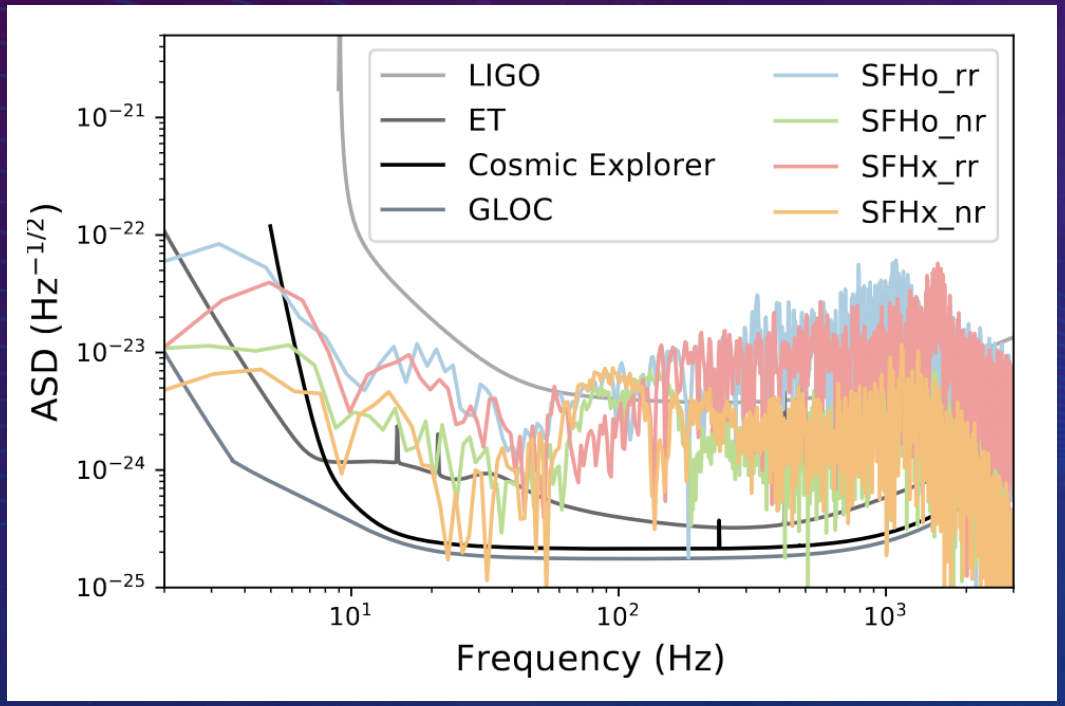
Core-Collapse Supernovae

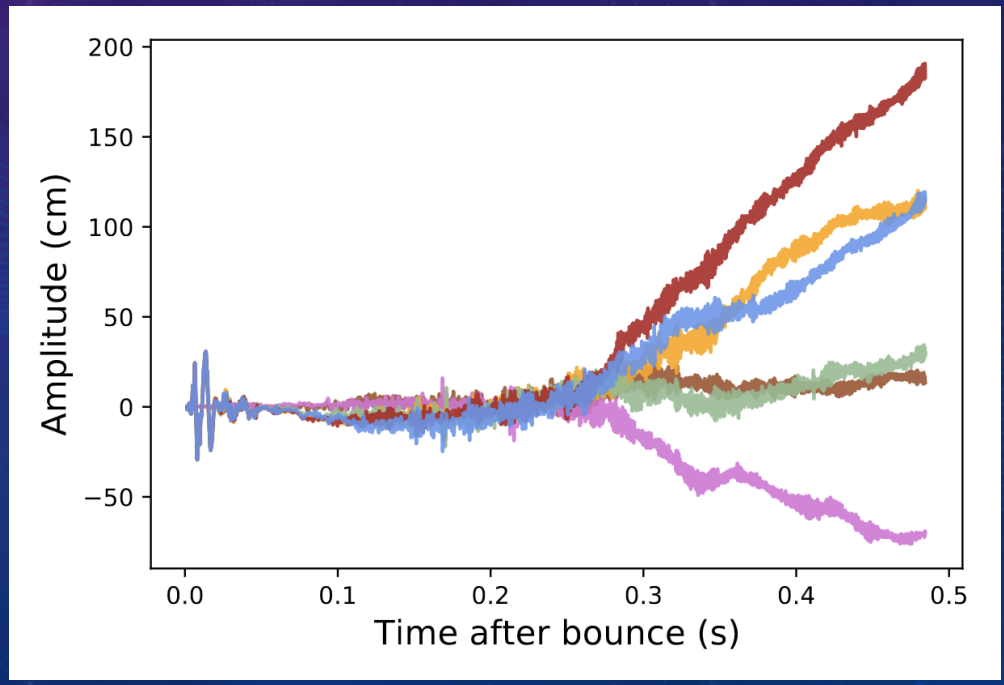
Gravitational waves are still emitted even when the star quickly forms a BH and there is no EM supernova.



GW Memory







Figures: Powell & Mueller 2024

Pulsar Glitches & Magnetars

- Pulsar glitches are sudden increases in the spin angular momentum of the crust of a neutron star causing an inferred increase in the spin frequency.
- Vela pulsar recently glitched and the GW search is ongoing.
- Magnetars – highly magnetized NSs emit regular powerful EM bursts that may be associated with GWs.
- Last brightest giant flare was 2004. None since.
- Galactic magnetar associated with an FRB occurred between the third and fourth observing runs.

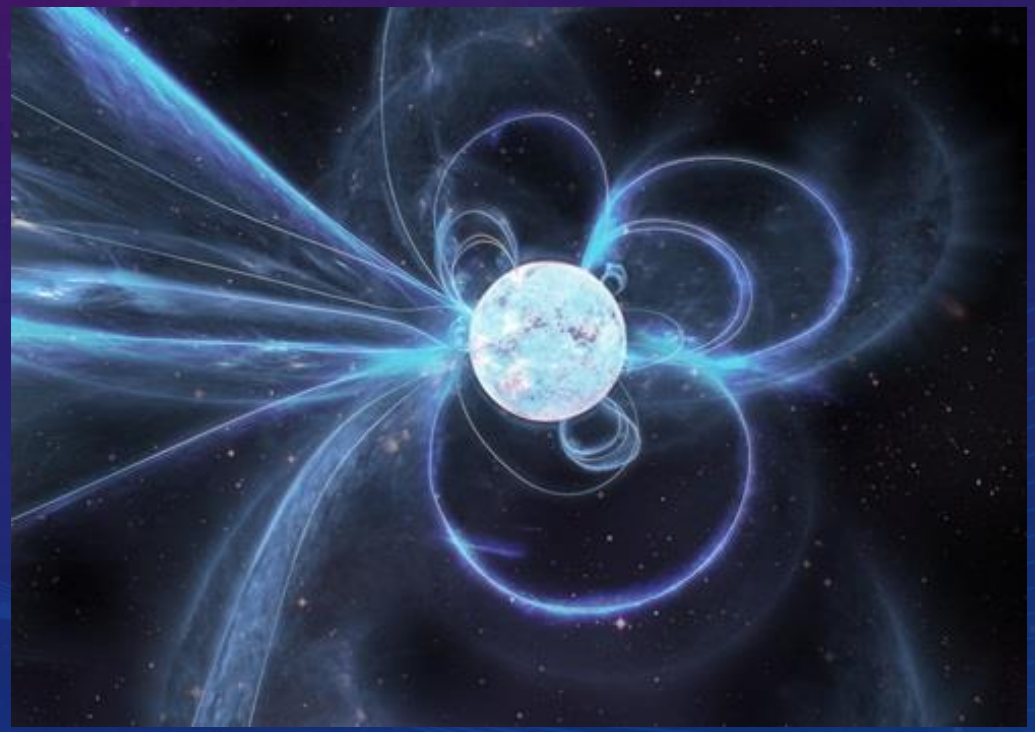


Image Credit: Carl Knox

Topological Defects

- We search for gravitational waves from cosmic string cusps and kinks.
- They look very similar to intermediate mass black holes.
- They look very similar to detector noise glitches.

GW190521

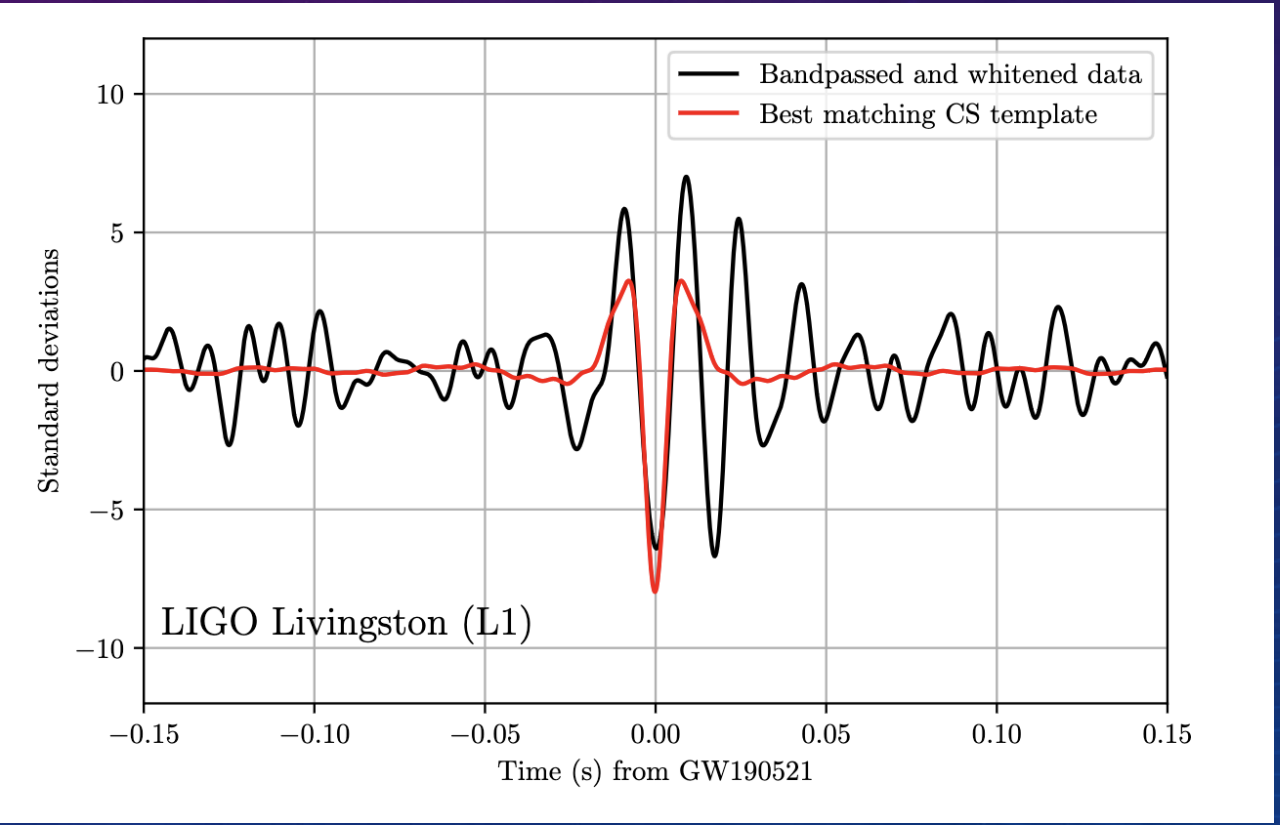
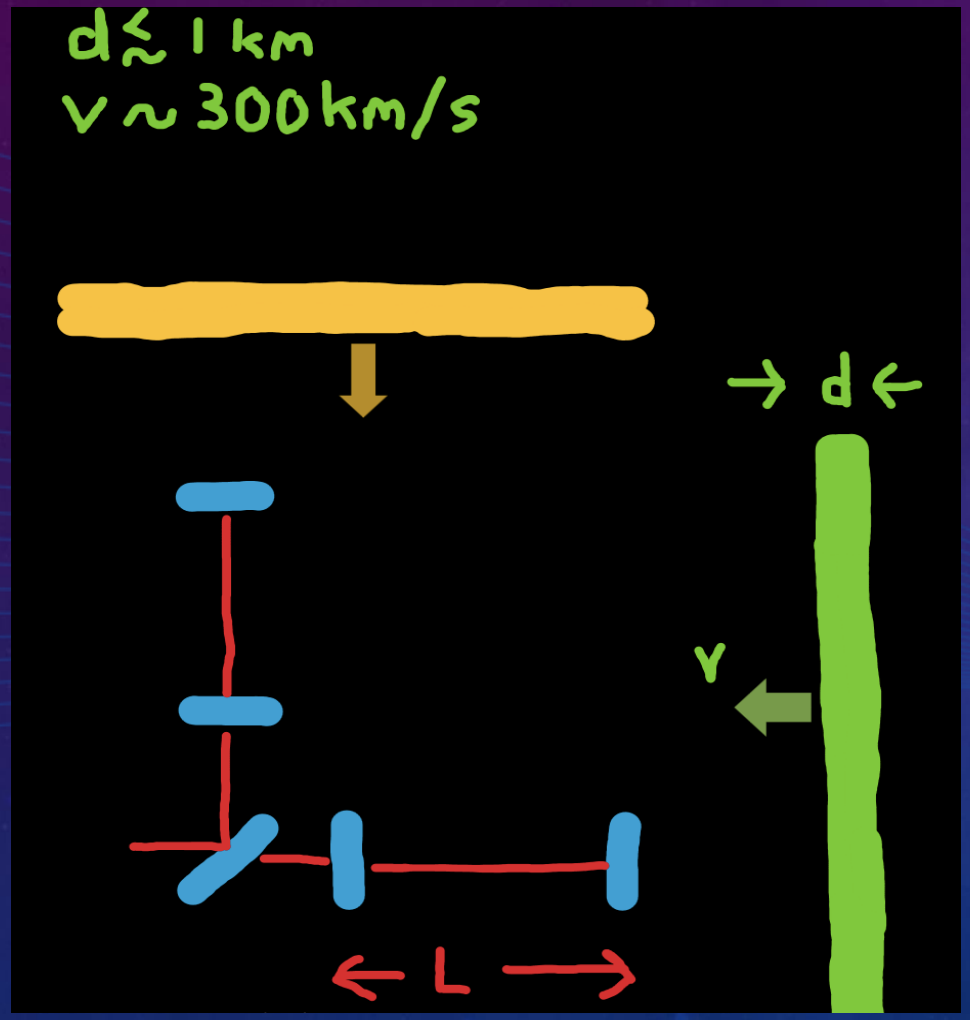


Image Credit: LIGO-Virgo

Domain Walls



Signal strength and morphology both depend on incident direction.

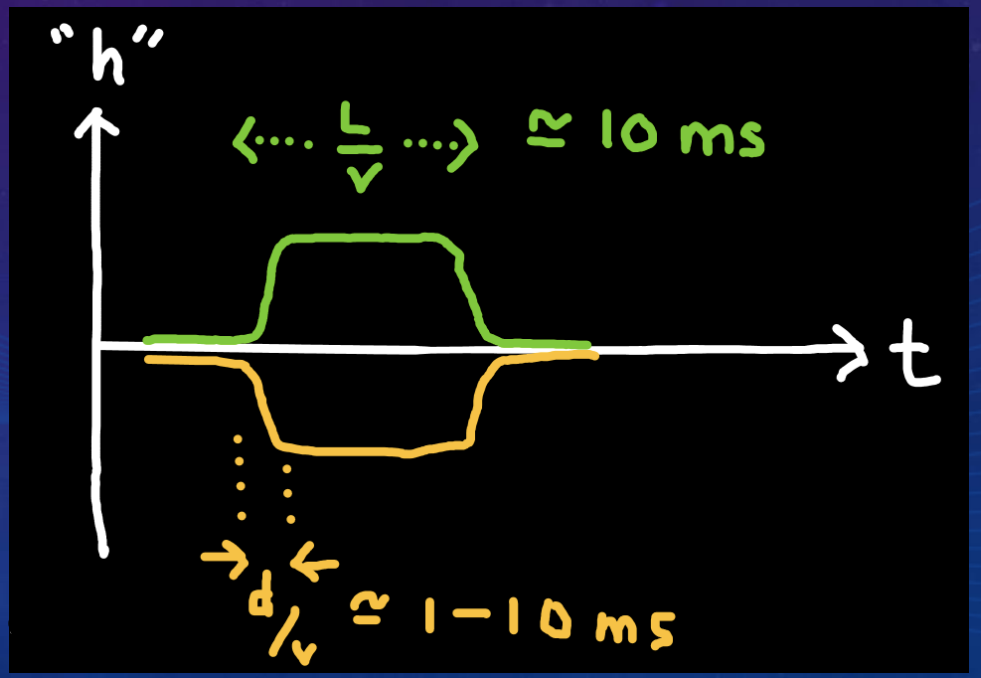


Image Credit: Patrick Sutton

Unknown Unknowns

- One of the most exciting possible sources!
- We currently need multiple detectors to be sure the signal is astrophysical and not a detector noise glitch.
- LVK search the entire sky 30 – 2000 Hz.
- We can measure the signal morphology, amplitude, duration and frequency.

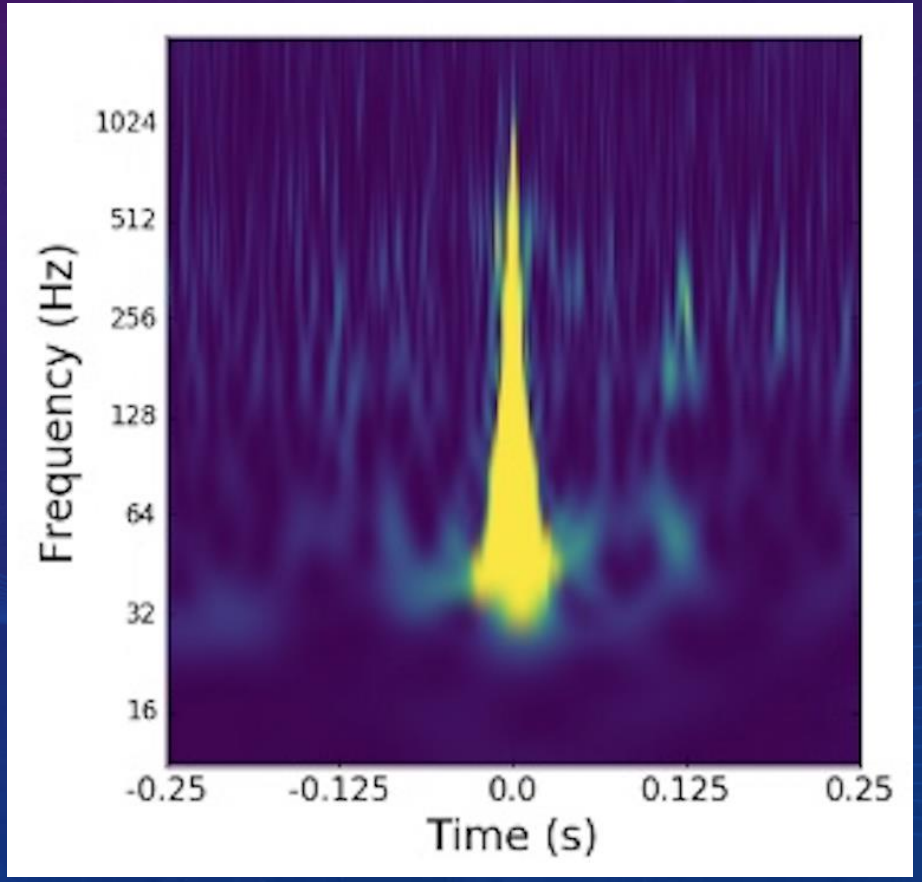


Image Credit: Gravity Spy

Conclusions

- A lot of astrophysical objects emit gravitational waves.
- The first detection of a new gravitational-wave source will have huge scientific impact.
- See Powell & Lasky new PASA review paper for more details on gravitational-wave burst astrophysics.