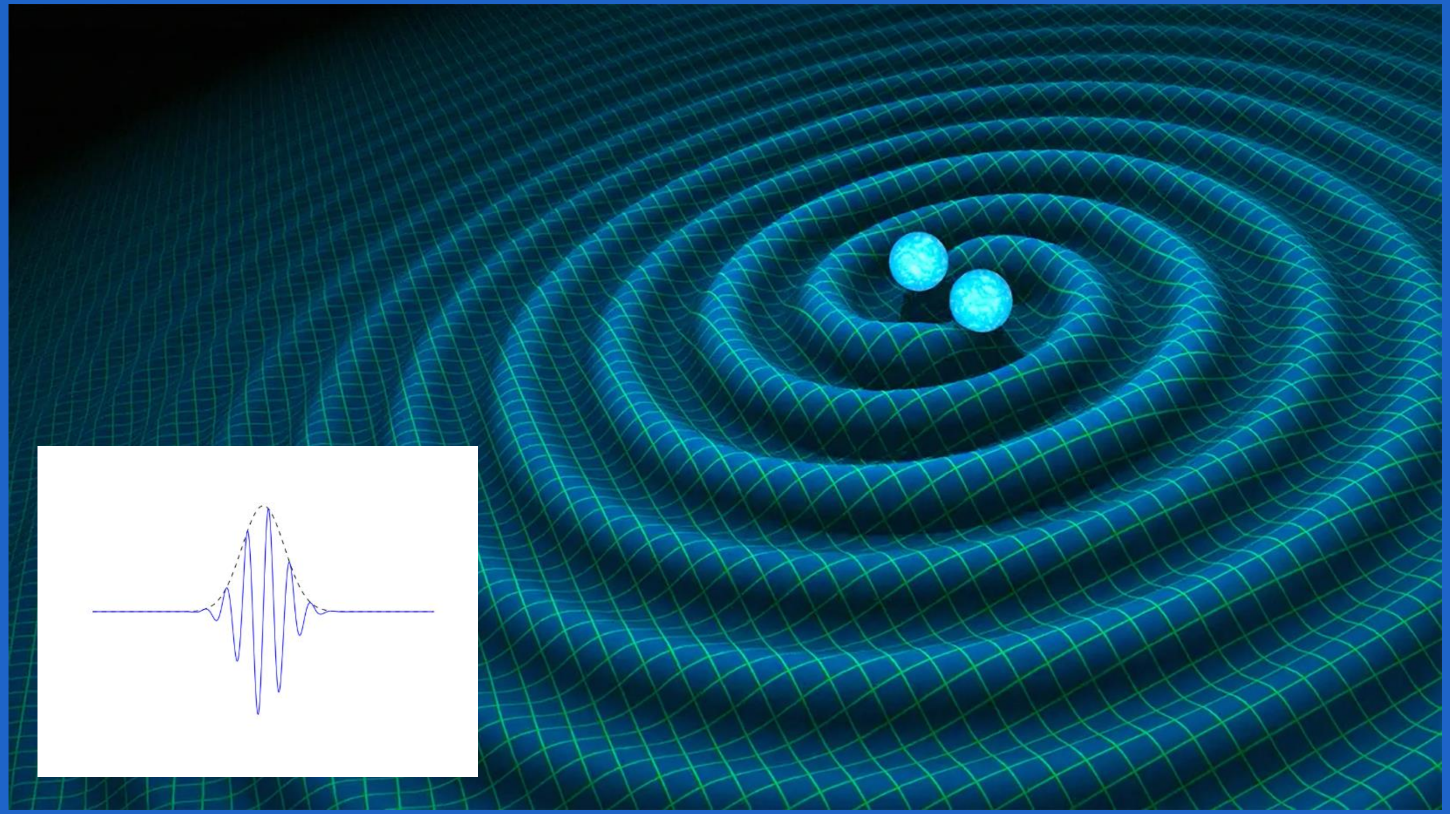
FACULTY
OF SCIENCES

DEPARTMENT OF PHYSICS AND ASTRONOMY
EXPERIMENTAL PARTICLE PHYSICS AND GRAVITY

HUNTING FOR EXOTIC RESONANCES IN COMPACT BINARY MERGERS

Robin Chan
Intermediate thesis presentation



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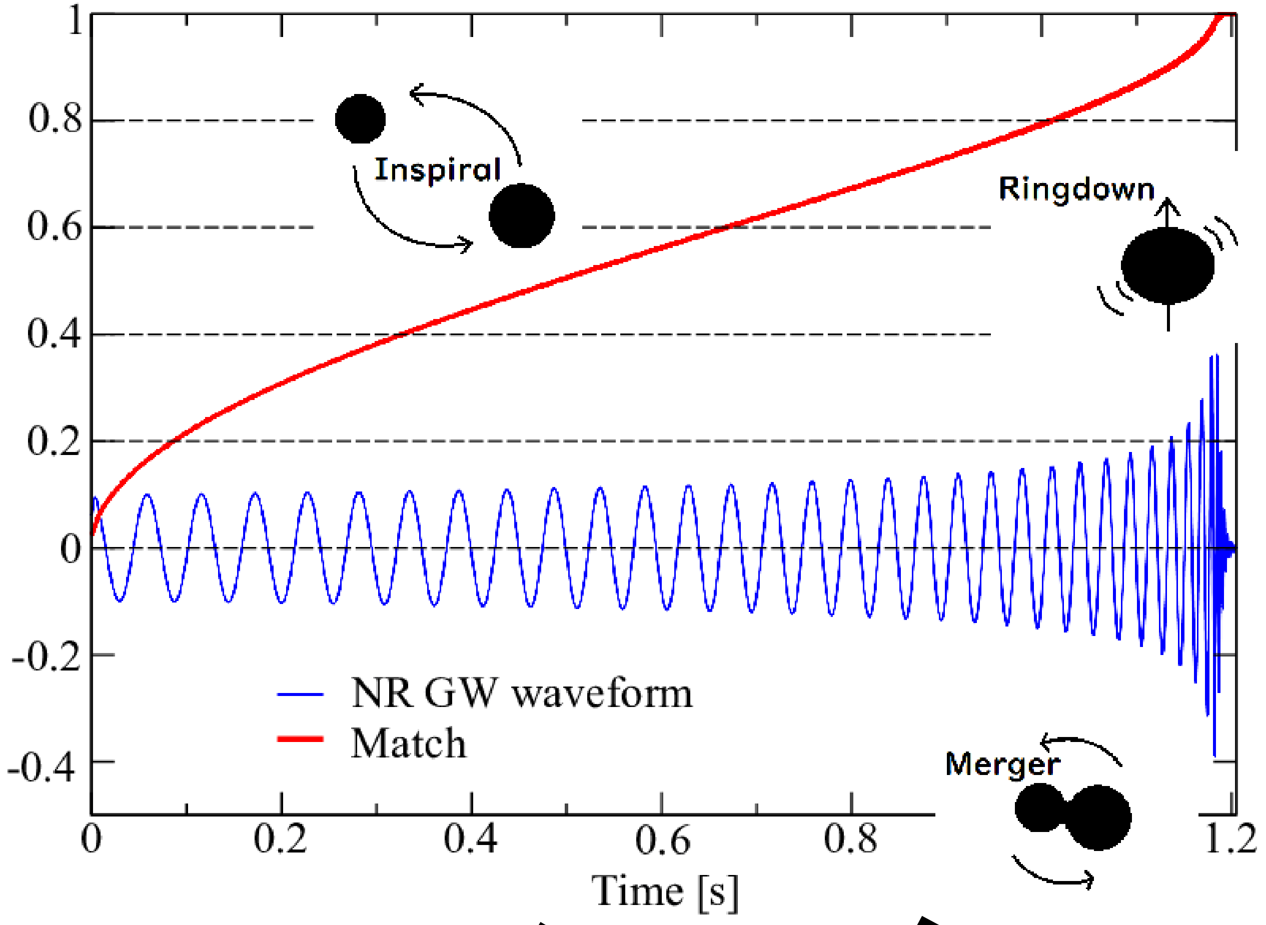
WHAT TO EXPECT?

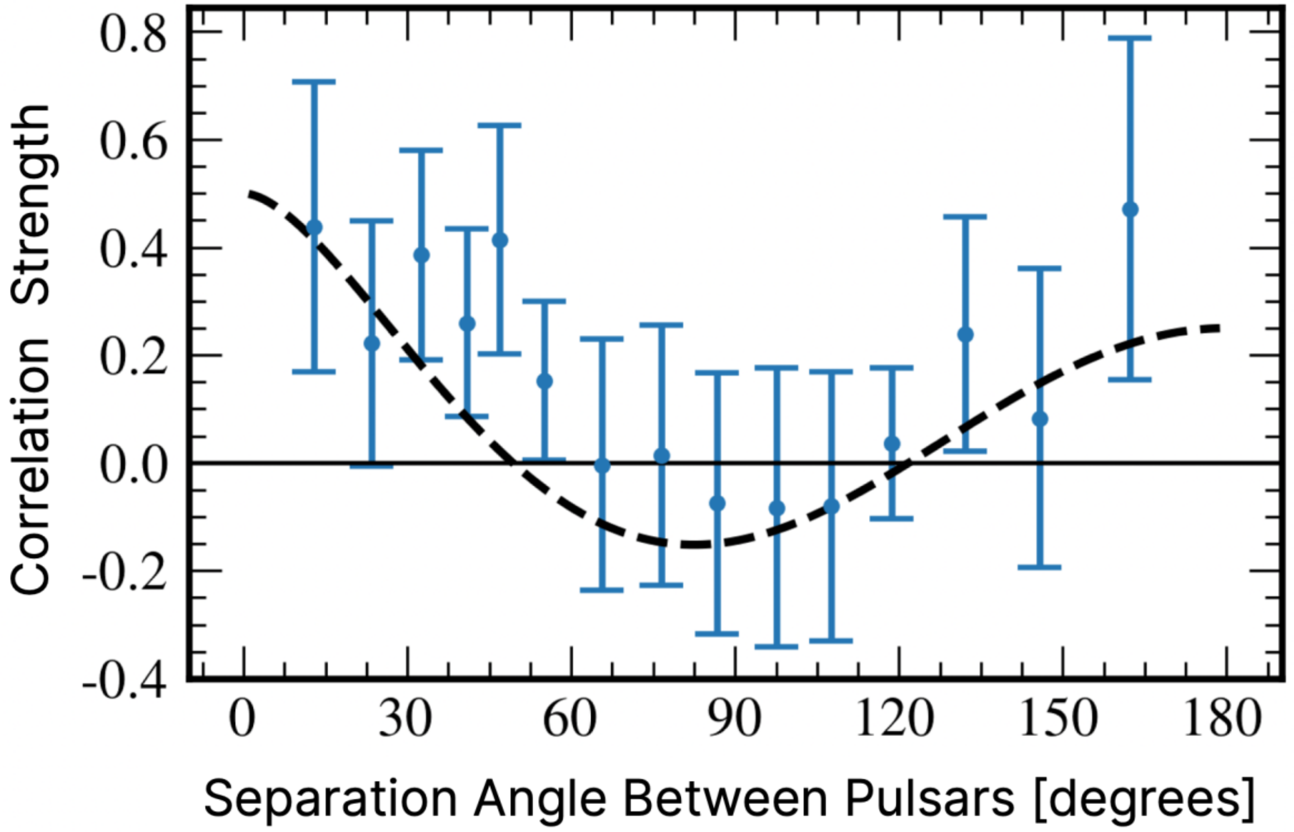
- Current GW observations
- Exotic compact objects
  - What are they?
  - How to find them?
- tBilby
- Results
  - Gaslighting a large collaborative codebase
- Future steps

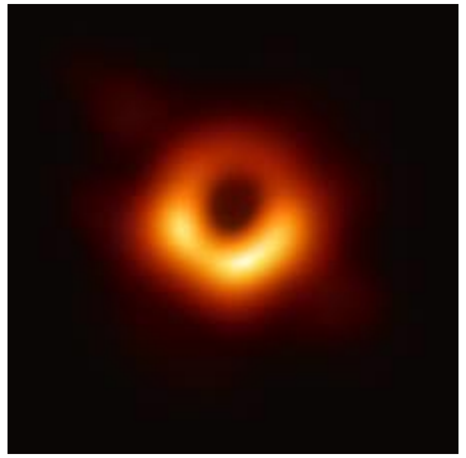
WHAT DO WE CURRENTLY SEE IN THE GW SKY?

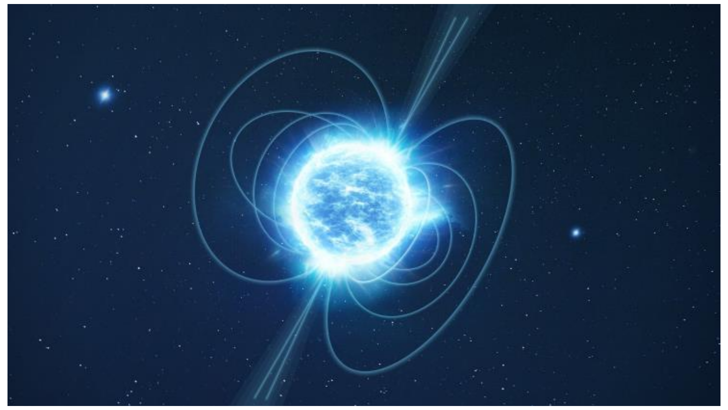
Binary coalescence



Stochastic GW background







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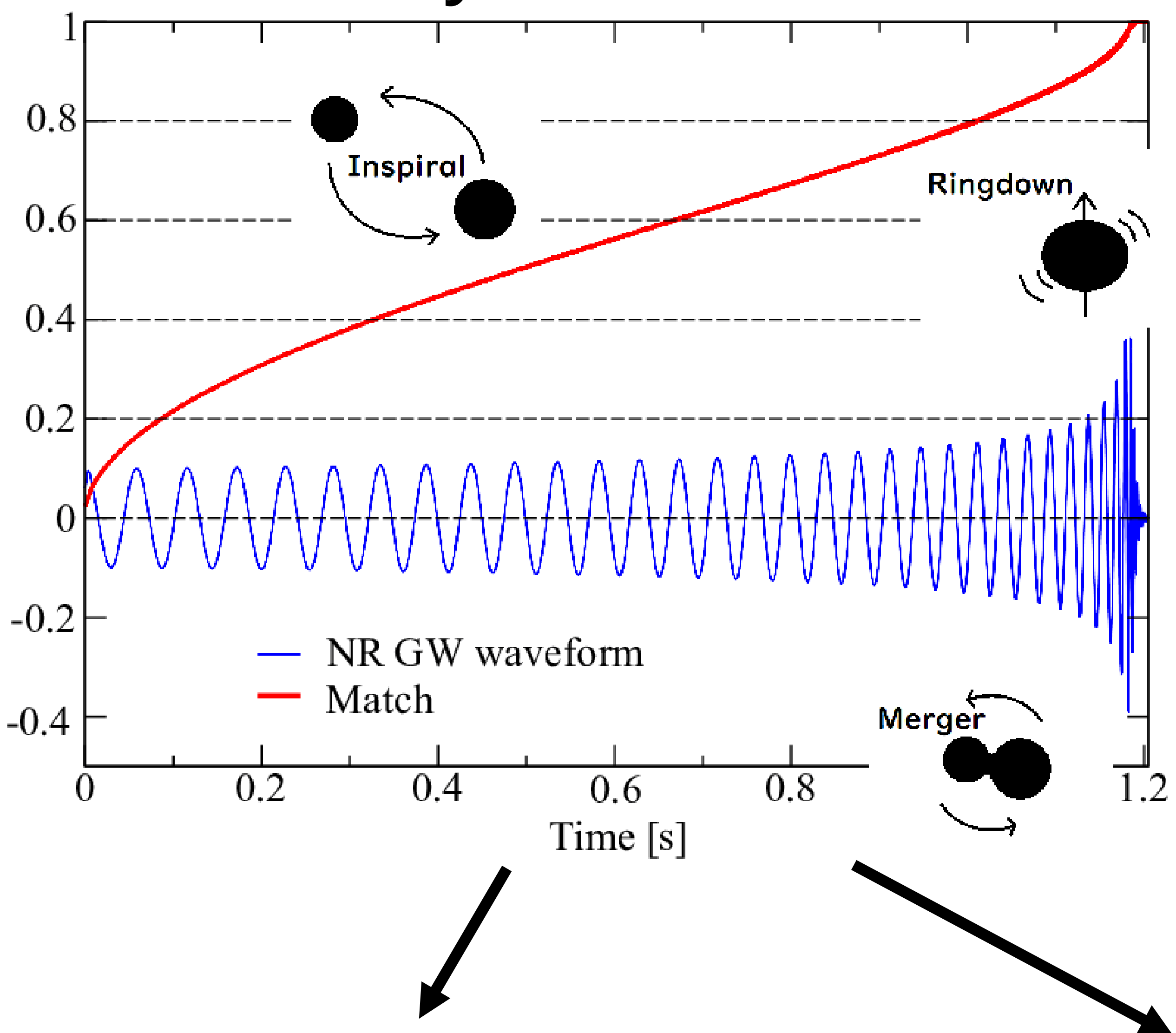

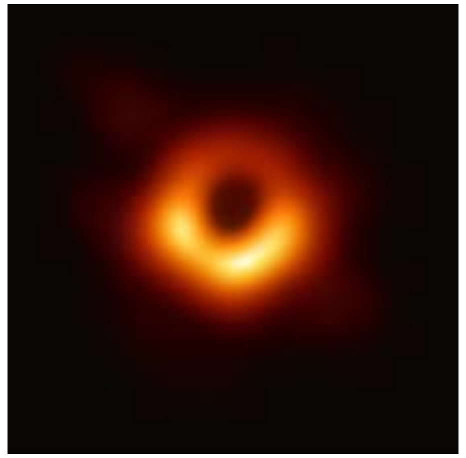

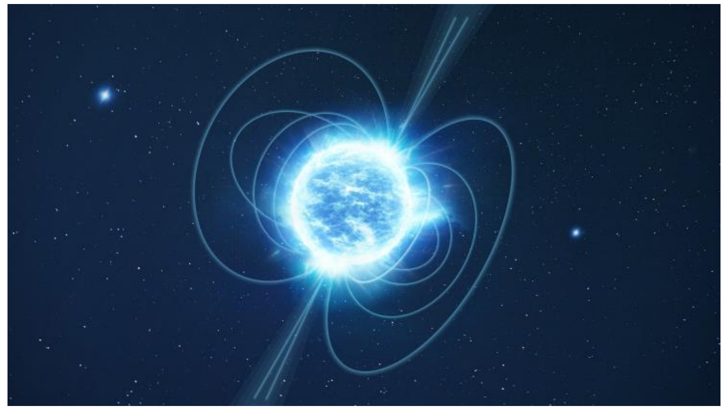

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GRAVITATIONAL WAVES

GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 26 September 2017; revised manuscript received 2 October 2017; published 16 October 2017)

Gravitational-wave observations alone are able to measure the masses of the two objects and set a lower limit on their compactness, but the results presented here do not exclude objects more compact than neutron stars such as quark stars, black holes, or more exotic objects [57–61].

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GW190814: Gravitational Waves from the Coalescence of a 23 Solar Mass Black Hole with a 2.6 Solar Mass Compact Object

Second, our discussion has thus far neglected the possibility that the secondary component is an exotic compact object, such as a boson star (Kaup 1968) or a gravastar (Mazur & Mottola 2004), instead of an NS or a BH. Depending on the model, some exotic compact objects can potentially support masses up to and beyond 2.6 $M_\odot$ (Cardoso & Pani 2019). Our analysis does not exclude this hypothesis for the secondary.

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Observation of Gravitational Waves from Two Neutron Star–Black Hole Coalescences

However, consistency with the maximum NS mass does not exclude the possibility that the secondaries could be BHs or exotic compact objects, if such objects also exist within the NS mass range. For instance, models of primordial BHs predict a peak in the primordial BH mass function at $\sim 1\,M_\odot$ (Carr et al. 2021). These models also predict that primordial BHs may form coalescing binaries at mass ratios comparable to those reported here.

GW190814: Grav... of a ... lar Mass Black Hole

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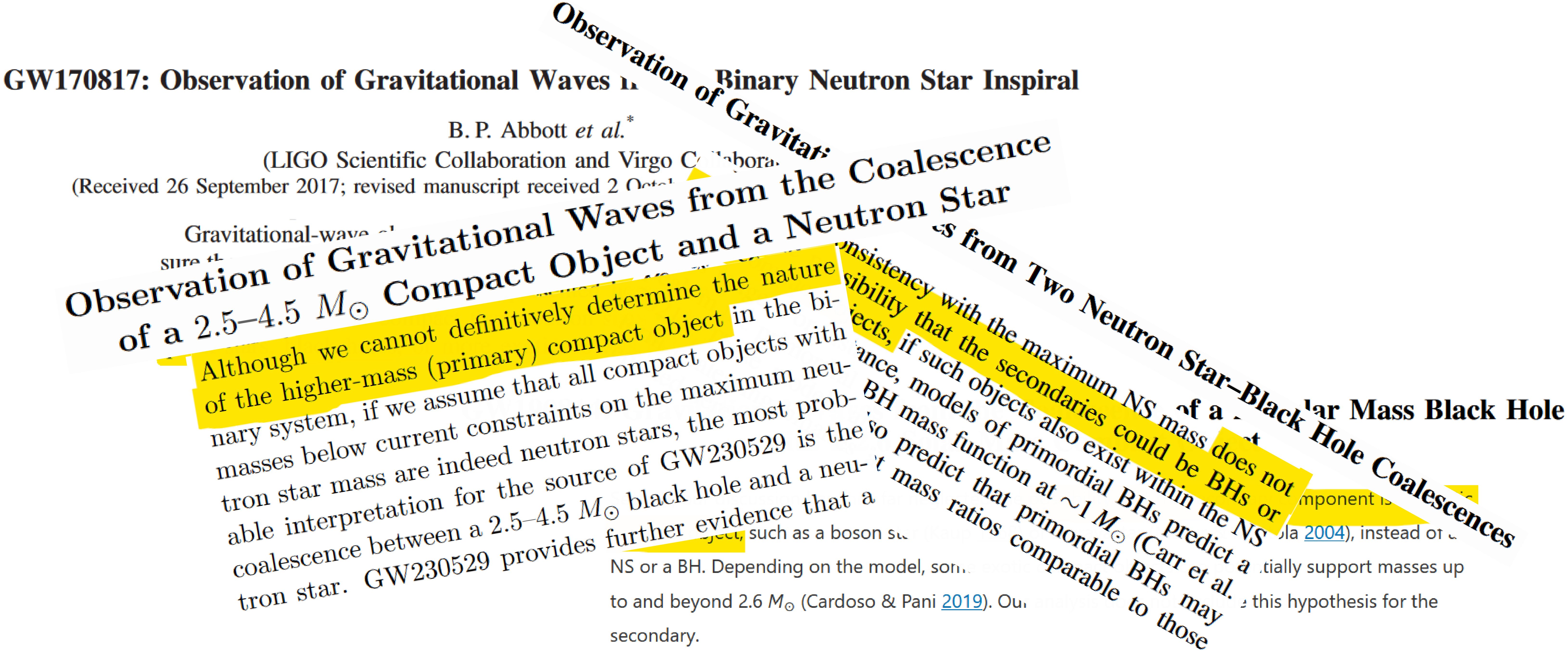

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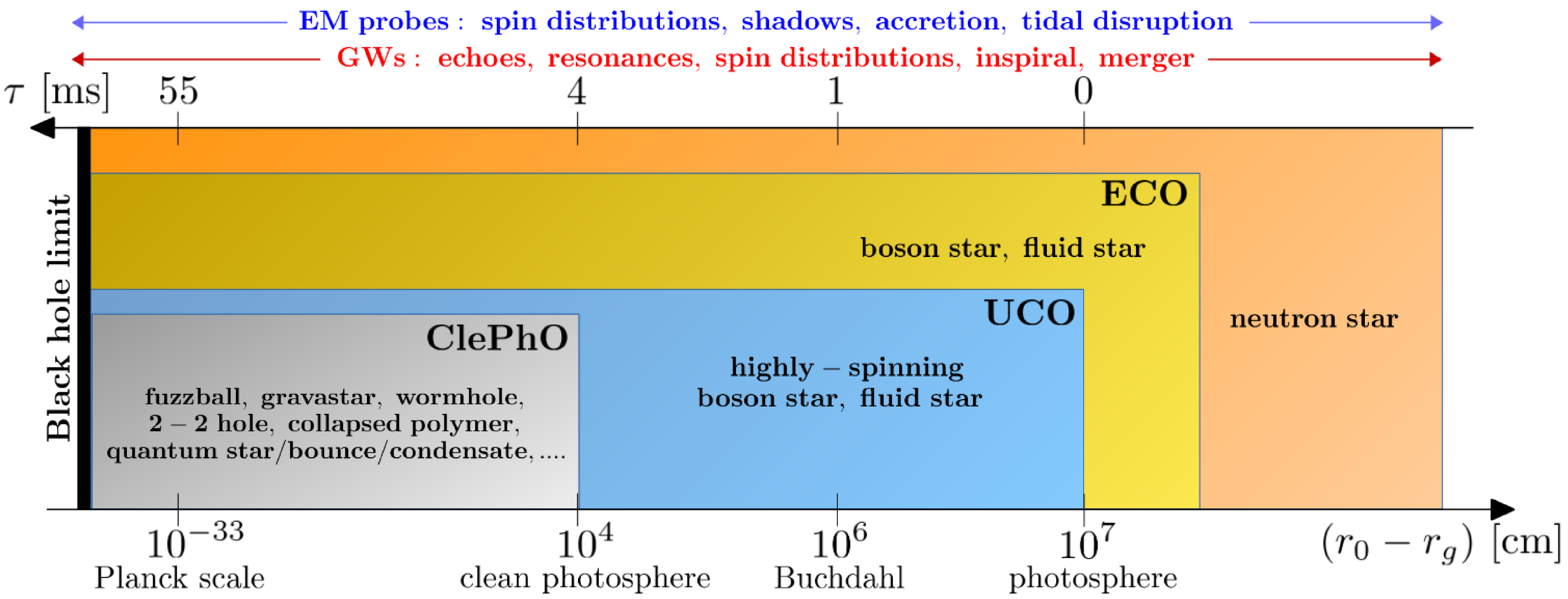
EXOTIC COMPACT OBJECTS

– Hypothetical objects between neutron stars (NSs) and black holes (BHs) in compactness
– Hard to distinguish with EM observations



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EXOTIC COMPACT OBJECTS

– Why are they interesting?

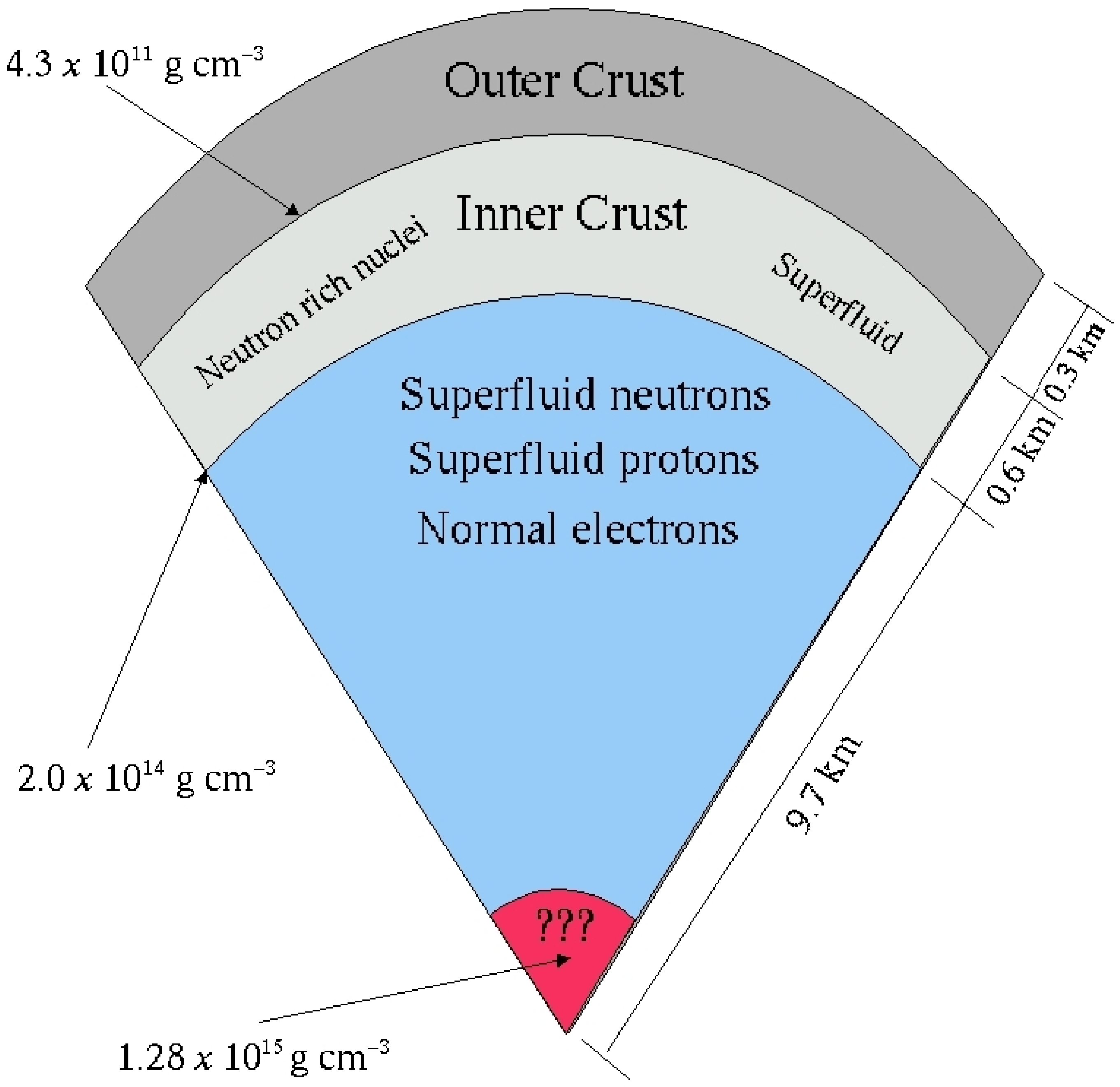
EXOTIC COMPACT OBJECTS

- Why are they interesting?
  - New states of matter
  - Beyond the Standard Model physics
  - Extensions of GR
  - Quantum gravity

GRAVITATIONAL WAVES

- EM observations probe surface

  (NS glitches are an exception)
- GWs probe mass-distribution dynamics
  - Inner structure



Neutron Star Pizza

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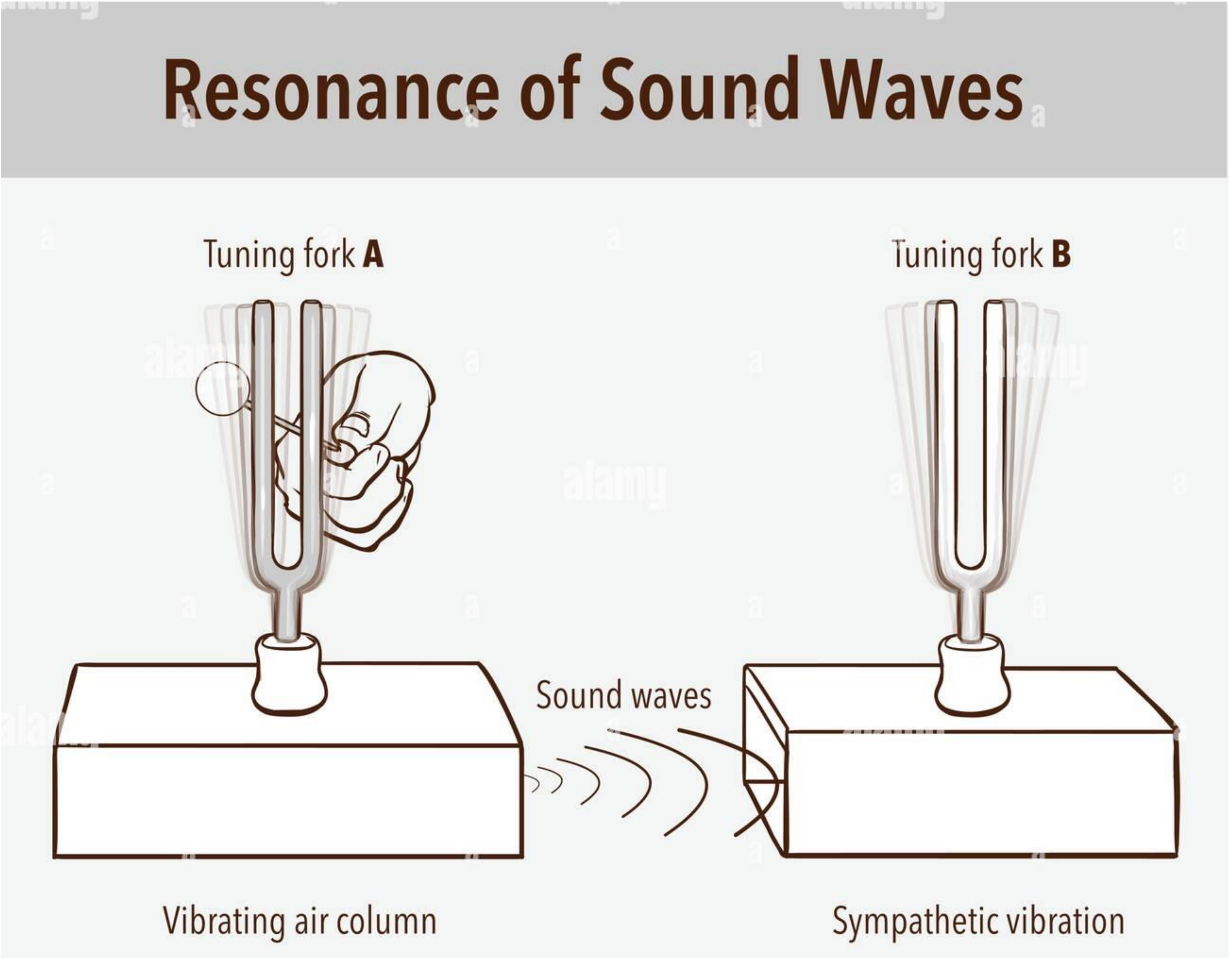
ECOS AND HOW FIND THEM

- Look for tidal resonances during inspiral
- Leave imprint on phase evolution
- Not detected thus far



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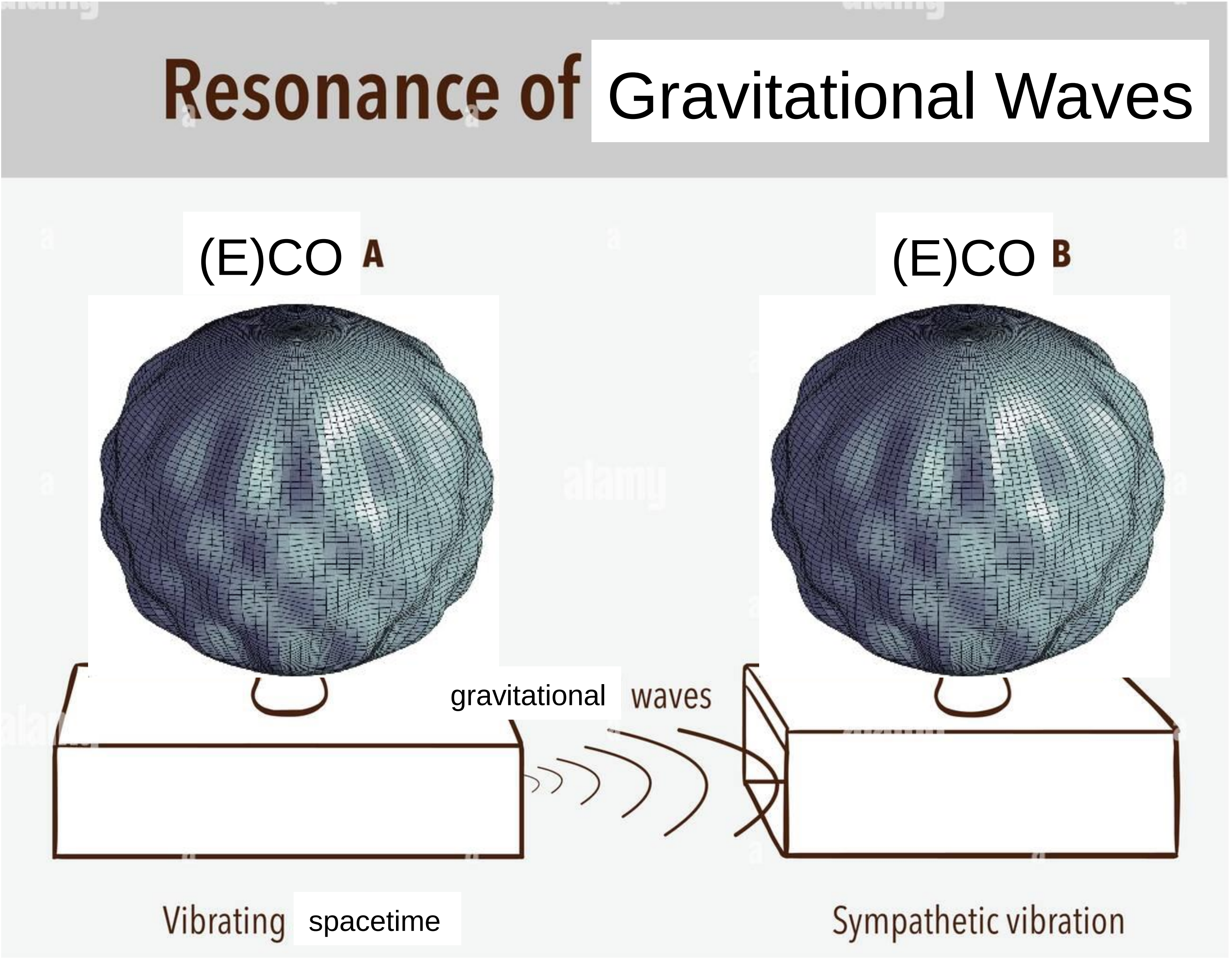

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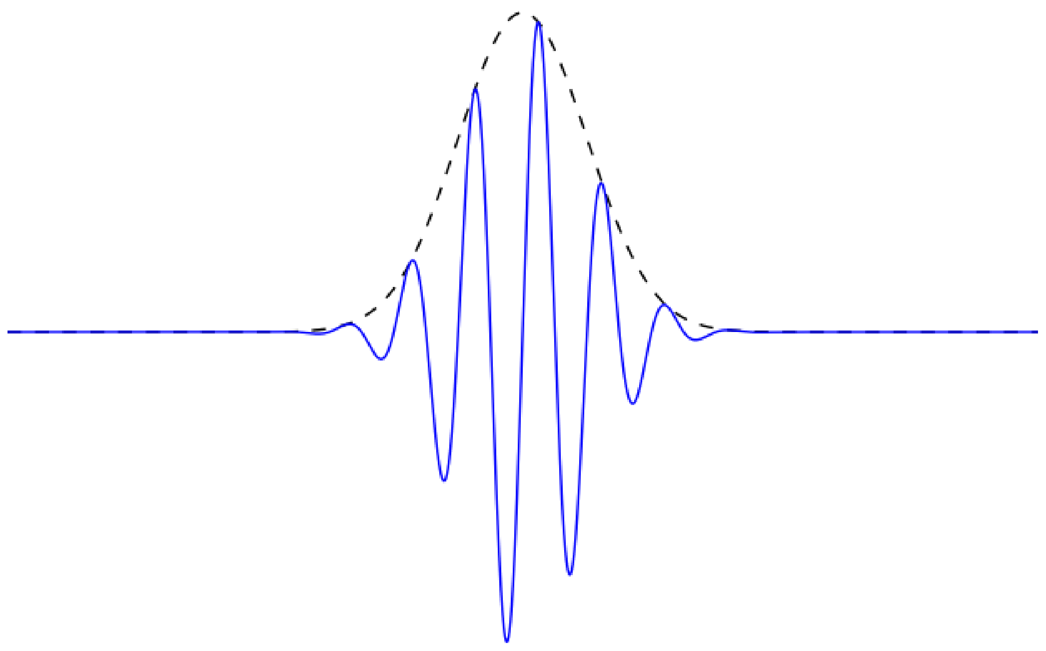
ECOS AND HOW FIND THEM

- Resonance and phase shift are linked to “rigidity” (composition) of objects
- Constrains EOS
- Basis of sine-gaussian wavelets to model resonance



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TBILBY

- Each wavelet adds 5 DOF => computational cost!
- Use tBilby
- *Transdimensional* Bilby

t 

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TRANSDIMENSIONAL SAMPLING

- Dimensionality N = sampling parameter
  - Reversible Jump MCMC
- Posterior penalised by Occam factor (weighs model complexity)

$$P(A|B) = P(A) \times \frac{P(B|A)}{P(B)}$$

posterior, prior, likelihood, marginal

TBILBY

- Extension to Bilby for transdimensional inference
- tBilby samples in full N, but evaluates likelihood over $\leq N$
- Likelihood evaluation is the most expensive step, according to the tBilby authors

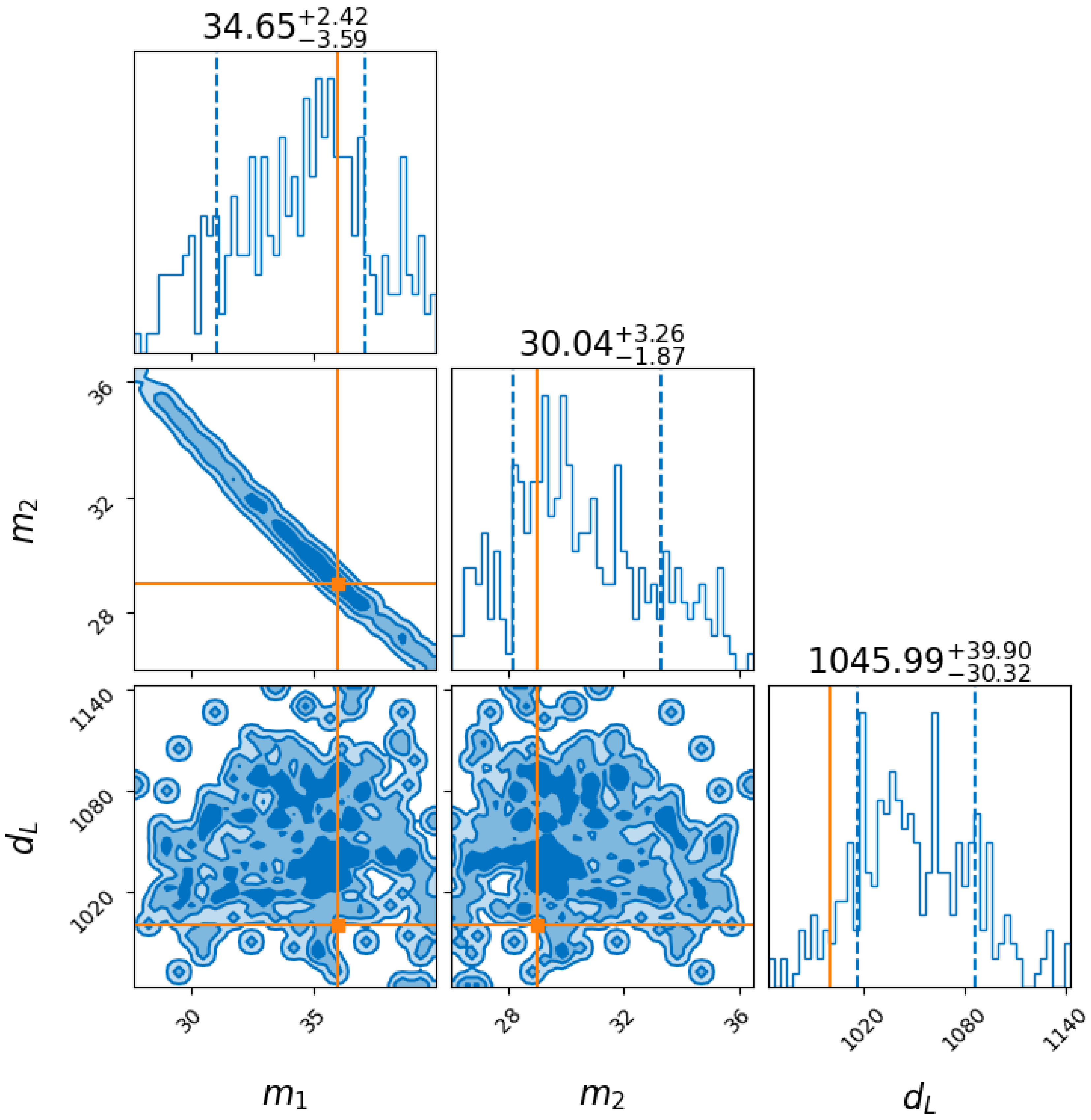
WHERE ARE WE NOW?

– Extended Bilby to use multiple wavelets Gaslight ✓
– Allow for superposition of IMR* signal and wavelet ✓
– Recover injected wavelet ✗

*Inspiral - Merger - Ringdown

CORNER PLOTS

- Visualise multi-dimensional data
- On-diagonal: parameter distributions
- Off-diagonal: parameter correlations



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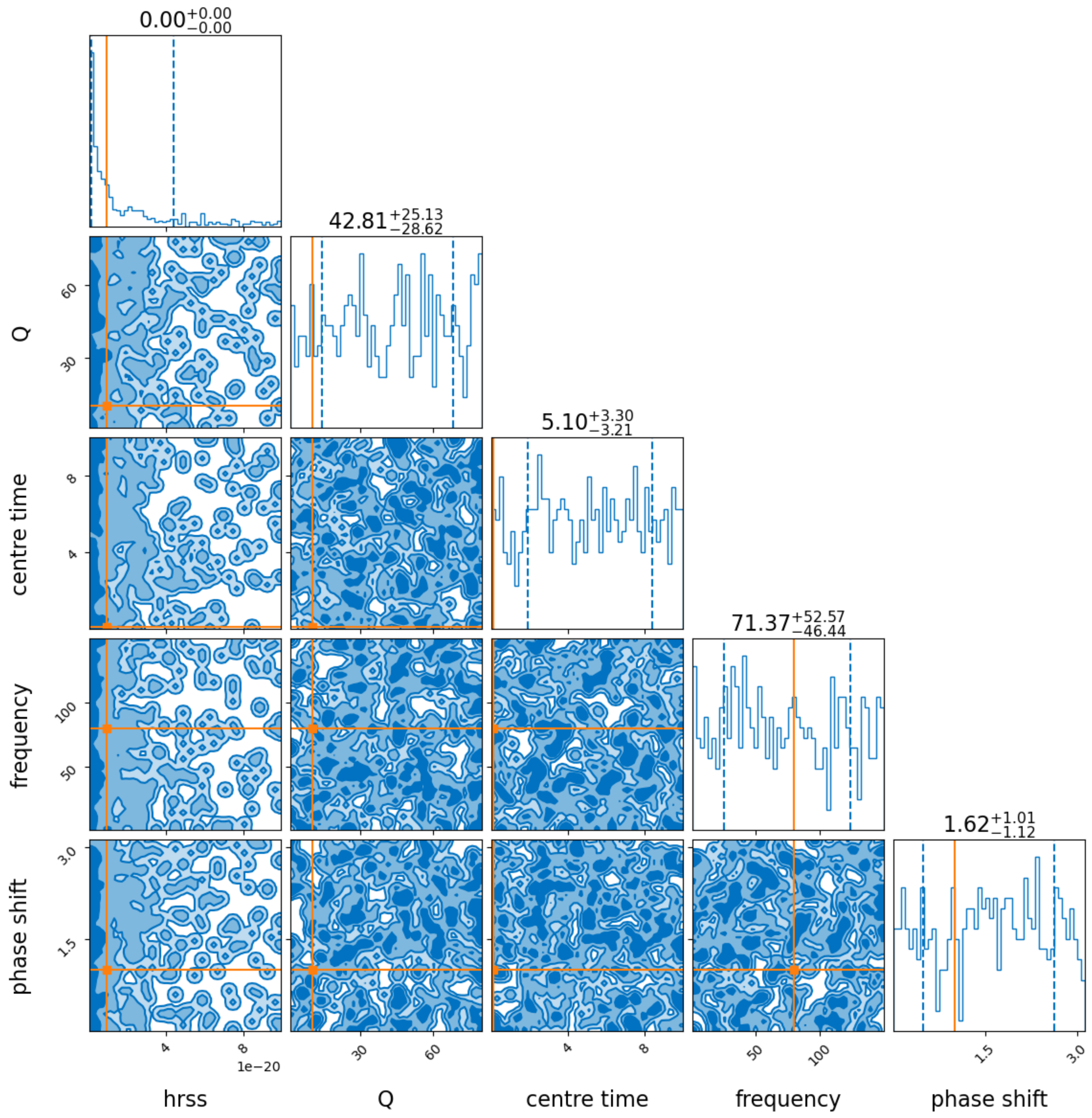
RECOVERY RESULTS



- Sampler seems to sample prior. Issue occurs for different samplers
- Possibly too high SNR
  - Pipeline is designed for relatively low SNRs, here SNR = 1000+
- Possibly bug in code
  - Bilby still works on other inference jobs, so hard to find what it is

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NEXT STEPS

- Recover wavelet(s) with Bilby
- Recover wavelet + IMR with Bilby
- Implement wavelets in tBilby
- Check computational limits

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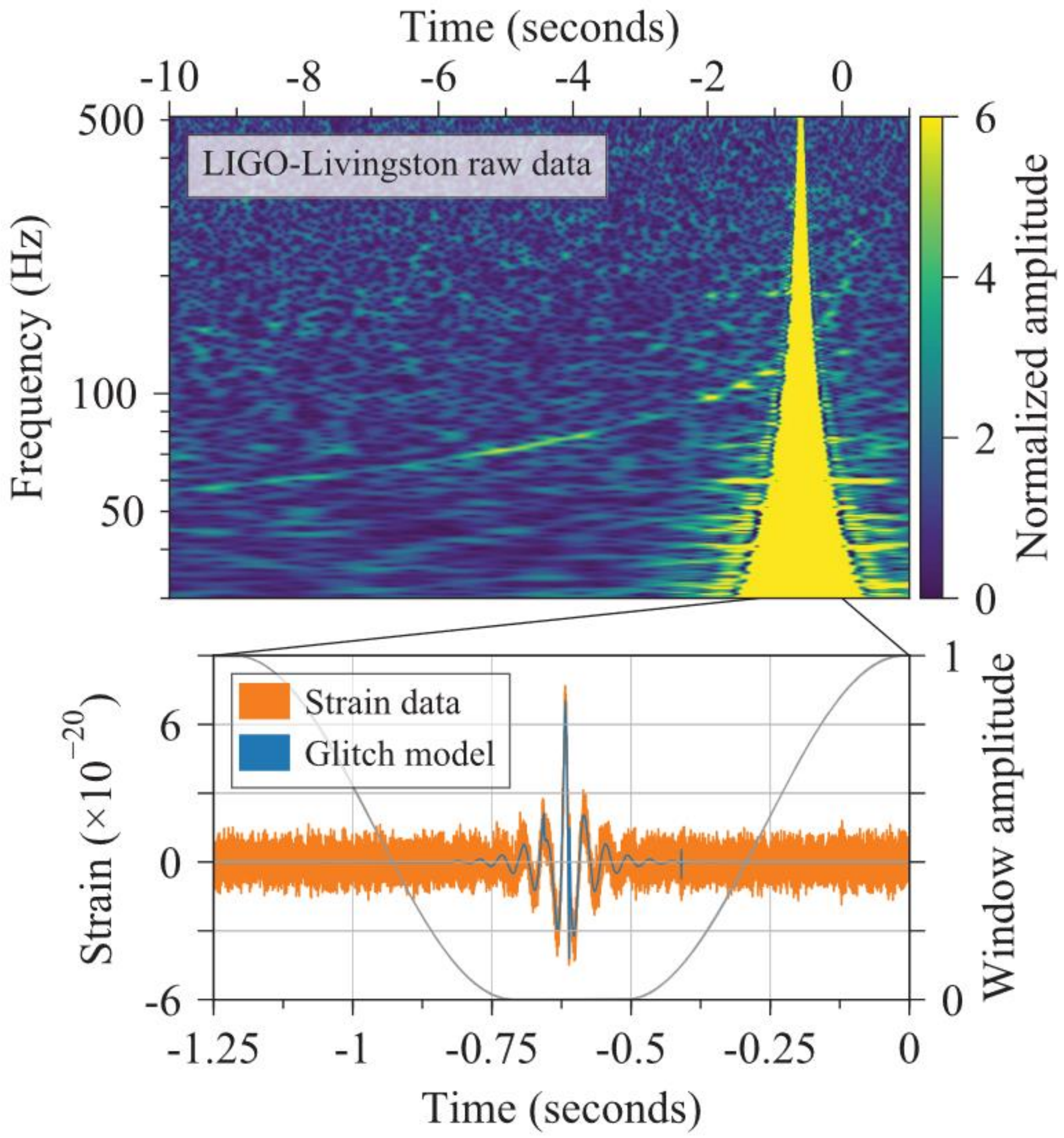
FUTURE PLANS: TBILBY RUNS WELL

- Recovery on more complex waveforms
  - + Artificially added phase shift
  - + Ringdown modes of resonance during inspiral
  - + Full NR-simulated waveform (if they exist)

FUTURE PLANS: TBILBY RUNS POORLY

- RJMCMC probably needed, not in Bilby currently
- Try using wavelets to model simpler signals (e.g. detector glitches)



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Robin Chan

Experimental Particle Physics and Gravity

E robin.chan@ugent.be

www.ugent.be

Universiteit Gent
@ugent
@ugent
Ghent University

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