Search for memory from subsolar mass compact binary mergers

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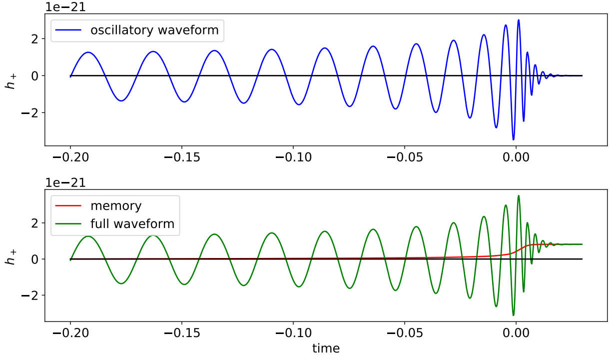
based on the paper: `https://arxiv.org/abs/2005.03306`

Subsolar mass compact objects

- Compact objects of $< 1M_{\odot}$ have never been observed
- No known mechanism in stellar evolution models to form them
- Proposed as relics of the early universe ("Primordial black holes")
- Such objects could contribute to the cold dark matter density
- Could form binaries and emit gravitational waves

What is gravitational wave memory?

Gravitational wave (GW) signal from a binary black hole merger:



$$\Delta h_{\mathrm{mem}} = \lim_{t \to +\infty} h(t) - \lim_{t \to -\infty} h(t)$$ where h is strain

An "ideal" (freely-falling) GW detector would experience a permanent displacement after the GW has passed – leaving a "memory" of the signal

Non-linear memory waveform

- Gravitational wave emission itself contributes to the source → (non-linear) memory
- State-of-the-art waveform models usually do not contain memory
  → Compute it separately:
- Oscillatory waveform decomposed into spherical harmonic modes:

$$h_+ - ih_\times = \sum_{\ell=2}^{\infty} \sum_{m=-\ell}^{\ell} h^{\ell m}\, Y_{-2}^{\ell m}(\Theta, \Phi)\,,$$

- Can compute non-linear memory contribution (Favata 2009, Ebersold 2019)

$$h_{\ell m}^{\mathrm{mem}} \sim \int_{-\infty}^{T_R} \mathrm{d}t \sum_{\ell_1 \ell_2 m_1 m_2} G_{m m_1 m_2}^{\ell \ell_1 \ell_2}\, \dot{h}_{\ell_1 m_1}(t)\, \dot{\bar{h}}_{\ell_2 m_2}(t)$$

- Hereditary effect, depends on entire dynamical past evolution
  → Here we consider only memory from the last few cycles and the merger, neglect inspiral

Memory in GW detectors

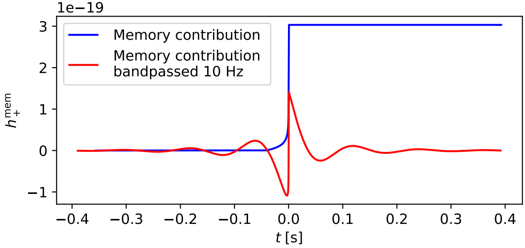


Fig 1: *Memory waveform of a non-spinning* $1-1M_\odot$ *BBH at 10 kpc*

- GW detectors are only sensitive in a certain frequency range (LIGO: $\sim$ 10-2000 Hz)
- Band-passed memory is a short duration burst
- GWs of arbitrary high frequencies also contain a memory component saturating towards the low-frequency limit of the detector (see e.g. McNeill et al. 2017, arXiv:1702.01759)

Search Idea

Why the memory from subsolar mass compact object mergers?

Going to low masses:

- Oscillatory chirp signal rises in frequency and eventually moves outside LIGO's sensitive band
- Spectral content of the memory signal stays where it is

→ **Search for the memory only signal of subsolar mass BBH**

- Search for memory only signal
- Memory is about an order of magnitude weaker as compared to the oscillatory signal

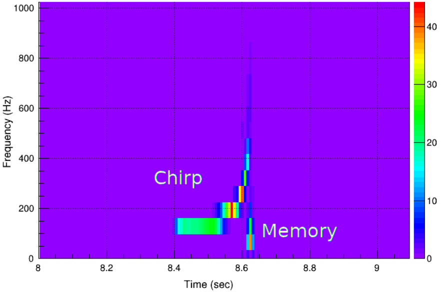


Fig 2: *Whitened spectrogram with O2 noise PSD of a GW signal from a* $5 - 5M_\odot$ *BBH at SNR* ≈ 100 *with enhanced memory signal*

Search sensitivity

- Here we employ the same LIGO-Virgo all-sky search for short-duration bursts in the second observing run (Abbott et al. 2019, arXiv:1905.03457)
- We find the range (iFAR $\geq$ 1yr) by injecting 6 different memory signals in O2 data (equal masses, 3 non-spinning, 3 with 0.8 aligned spins)
- Range scales linearly with total mass of the system, can be extrapolated to arbitrarily low masses

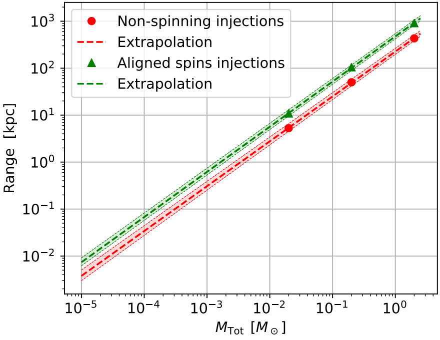


Fig 3: *Visible Range of the search*

Constraints on the rate of subsolar mass mergers

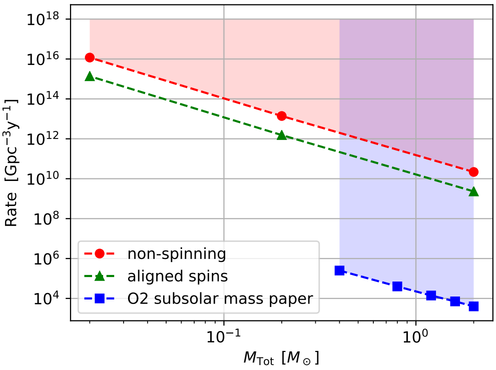


Fig 4: *Upper limit on binary merger rate*

- Constraints from memory are not competitive with matched-filter searches for the corresponding oscillatory signal (reported e.g. in LIGO O2 subsolar mass paper, arXiv:1904.08976)
- However, memory only search expands the parameter space to masses below $M_{\mathrm{Tot}} \leq 0.4 M_\odot$

Conclusion

- Memory signal enables search for very low mass BBH systems
- Morphology of memory signal is similar for different source properties
- Blip glitches is the limiting factor
  $\rightarrow$ A better classifier will help the search
- Future Work: - Search for stochastic background from subsolar mass memory signal
  - Conduct the same search for LIGO-Virgo's third observing run

Thanks for your attention!