Not-so-blind searches for young, isolated, nearby gravitars

Rodrigo Tenorio,
Rafel Jaume, Joan-René Mérou, David Keitel, Alicia M. Sintes

Universitat de les Illes Balears

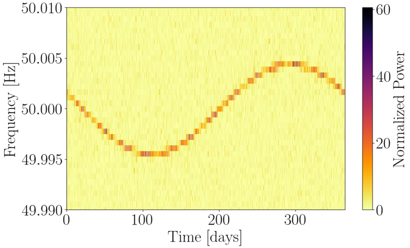
IAC3 Institute of Applied Computing & Community Code.

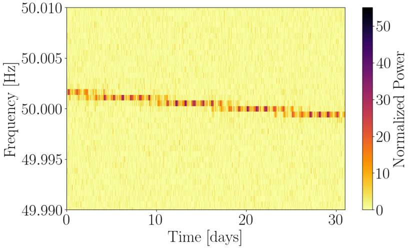
Multi-Messenger Continuous Gravitational Waves Meeting
Nikhef, Netherlands
11th July 2023

Continuous gravitational waves from NS mountains

- Continuous waves (CWs) are long-duration quasi-monochromatic gravitational waves (GWs). No direct detection up to date.
- We'll focus on Neutron Stars (NS) sustaining a "mountain".

$$h_0 = \frac{4\pi^2 G}{c} \frac{I_z \epsilon}{d} [2 f_{\mathrm{rot}}]^2 \simeq 4.2 \cdot 10^{-26} \left(\frac{\epsilon}{10^{-6}}\right) \left(\frac{f_{\mathrm{rot}}}{100\ \mathrm{Hz}}\right)^2 \left(\frac{d}{1\ \mathrm{kpc}}\right)^{-1}$$





CWs from Neutron Stars

NS physics

- Broad uncertainty on ϵ: 10^{-12} to 10^{-5} depending on the model.
- Similar uncertainties for other emission mechanisms.

NS demographics

- Galactic population expected to contain $\mathcal{O}(10^8)$ NSs.
- Only $\mathcal{O}(10^5)$ NSs are expected to be active pulsars.
- Currently only $\mathcal{O}(10^3)$ observed via EM.

- CWs may be required to observe some of the galactic NSs.
- Amplitudes to be expected are a bit "unclear" at the moment.

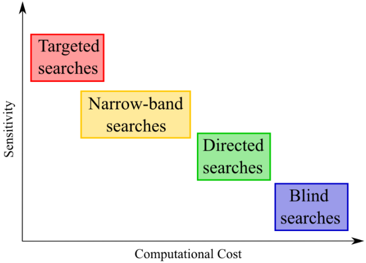
Searching for CW signals

Search types according to available information

The more specific the source, the cheaper the search:

- Targeted searches: Source is known and timed via EM observations.
- Blind searches: "Nothing" is assumed about the source.
  - Most expensive kind of search.
  - No specific assumption on the source.

(Sieniawska & Bejger 2019)

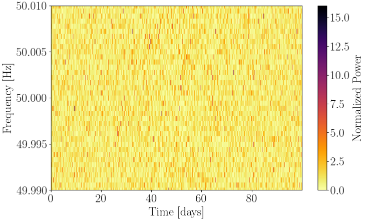


- "Sensitivity" is tied to model accuracy and search method.
- Blind searches use "sub-optimal" search methods to be computationally feasible.
- Incidentally, this makes them more robust to unmodelled physics.

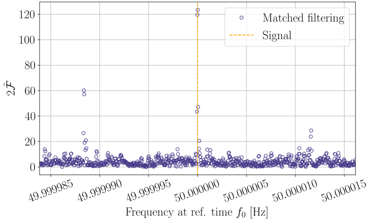
Blind searches for CWs

Simple example of a CW search

- Set up a template bank covering the parameter space of interest.
- Evaluate a statistic (e. g. matched filter) on each template.
- Retrieve outliers for further inspection.



$\xrightarrow{\text{Search } f_0}$



If no detection, constrain the galactic NS population:

$$\text{Upper limits on } h_0(f_{\text{GW}}) \rightarrow \text{ Constraints on } \epsilon/d \text{ (or equivalent)}$$

Constraints from blind CW searches

Constraints on the maximum ϵ of the population

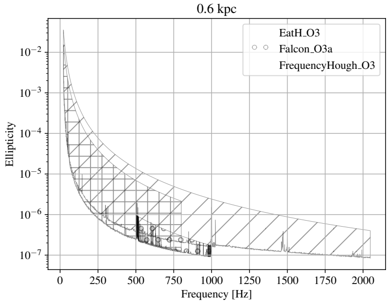
- Upper limits on $h_0(f_{\mathrm{GW}}) \rightarrow$ Constraints on ϵ/d (or equivalent)
- "NS at a distance d have ellipticities lower than ϵ".

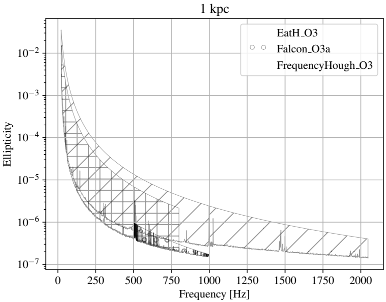
Maximum ellipticity probed by the search

- Searches probe a maximum spindown $|f_1^{\mathrm{max}}|$.
- ϵ implies spindown $|f_1(\epsilon)|$.
- If $|f_1(\epsilon)| > |f_1^{\mathrm{max}}|$, the signal is not covered by the search.
- (This also limits the astrophysical reach of a search.)

Brief summary of latest (isolated) blind search results

Abbott+ PRD 106, 102008 (2022), Steltner+ 2303.04109, Dergachev & Papa 2202.10598





f_0 selected following instrumental or astrophysical leads.

Origin of sensitivity difference

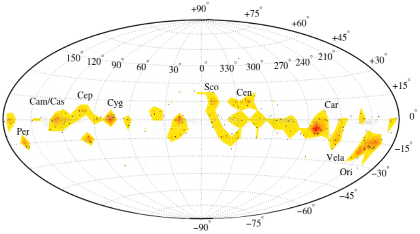
- Parameter-space breadth (related to computing cost).
- False alarm probability (related to the follow-up).

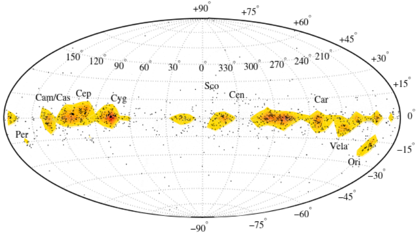
How to improve blind searches

- Sensitivity depends on search method and parameter space.
- Getting closer to a fully-coherent matched filter folds in stricter priors on the signal evolution → Likely detrimental for unknown sources.
- Reducing the parameter space risks missing a signal
  - but also increases the fraction of candidates to follow-up!

→ Potential improvement on search sensitivity if done appropriatelly.

Supernova (SN) progenitors to map young NS





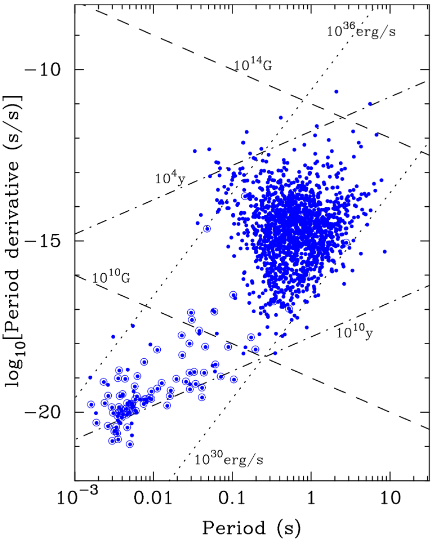
Schmidt+ [Astron. Nachrichten 335 (2014)]

- "Young" SN (last few Myr) are correlated to future supernova.
- SN progenitors are within 10% of the sky for the first (0.6 – 1) kpc.
- Similar to "spot-light searches"

Aasi+ PRD 93, 042006 (2016), Dergachev+ PRD 99, 084048 (2019) .

The (f_0, f_1) space: pulsar population

- Majority of the observed NS galactic population.
- Dominated by EM emission.
- CW search results suggest a fairly small ellipticity
  $\rightarrow$ high f_0 is desirable.
  $\rightarrow$ higher computing cost.
- Age tends to be incompatible with Schmidt+.



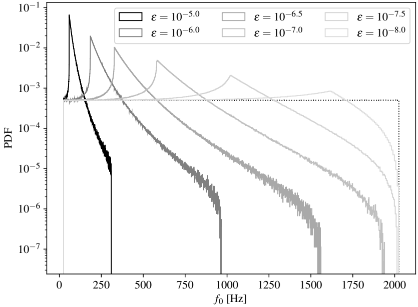
Lorimer+ LRR

An alternative choice for (f_0, f_1): gravitars

Palomba MNRAS 359 (2005), Knispel & Allen PRD 78 (2008)

- Gravitars: CW-driven NSs (ellipticity "dominates" over magnetic field).
- If older than 5 kyr $\rightarrow$ linear spindown model.
- For the first few Myr tend to cluster at $\lesssim 1000\mathrm{Hz}$ depending on ϵ.

- The more "detectable", the lower the frequency.
- Gravitars tends to have smaller spindowns than pulsars'.



Potential impact on blind searches

Assume a gravitar population, then...

- 10-fold reduction in sky area (~ 10 times lower computing cost).
- Relevant population tends towards lower frequencies (less sky templates required).
- Spindowns tend to be 10 times lower than traditionally considered.

Lower computing cost to run a search without any special requirements.

Conclusion

- Blind searches are a promising avenue to detect CW signals.
- Lack of specific astrophysical priors tends to produce prohibitely expensive searches.
- We propose to guide these searches using a population compatible with gravitars.
- The result is a search setup one to two orders of magnitude cheaper than current blind searches.