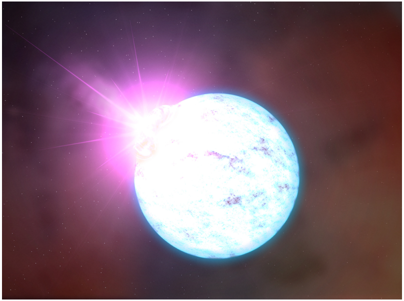
Neutron Star Mountains and Gravitational Waves



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- *Supervisor*: Charles J. Horowitz, Indiana University - Bloomington

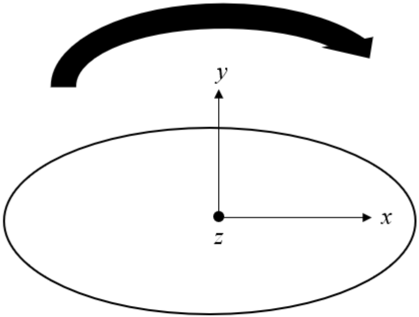
Outline

Structure

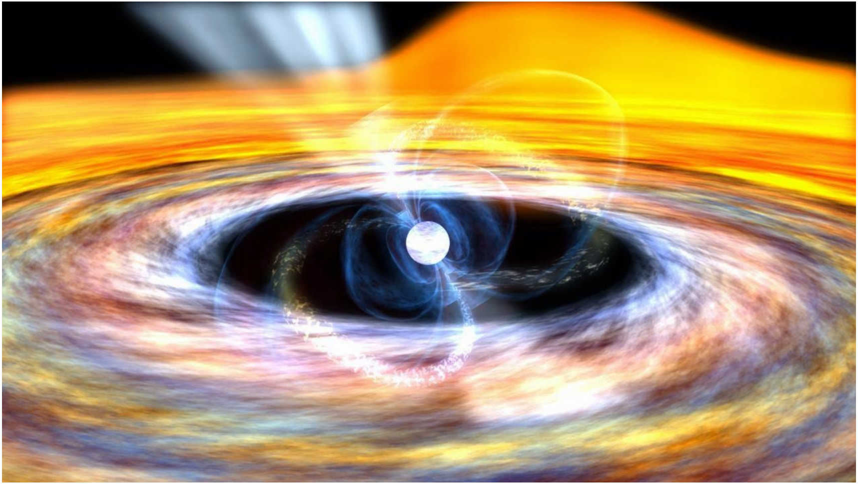
- 'Mountains' are non-axisymmetrical deformations on the neutron star crust.
- When neutron stars spin, mountains can lead to the emission of continuous, almost monochromatic, gravitational waves (CGWs).
- CGWs from neutron star mountains are suited to study the composition of the crust and to test fundamental theories of nature.

Structure

- The mass multipole on a spinning neutron star with a mountain that contributes the most to the emitted gravitational radiation is the mass quadrupole moment $Q_{22} = \int \delta\rho r^4 dr \ Y_{22}$, where $\delta\rho$ is the small change in density that corresponds to the mountain, and Y_{22} is the $l = m - 2$ multiple moment.



Formation: Accretion



Source: *Danna Berry, NASA Goddard Space Flight Center*

Formation: Fallback

The Maximum Ellipticity Quest

- We want to know what are the chances of 'catching' a CGW from a neutron star mountain with second or third generation detectors.
- *Natural question*: What is the maximum deformation that the neutron star crust can support?
- *Note*: Mountain deformations are usually quantified by the ellipticity, or the fractional difference in the moments of inertia, $\epsilon \equiv \sqrt{\frac{8\pi}{15}} \frac{Q_{22}}{I_0}$, where I_0 is the moment of inertia of the background spherical star. The maximum ellipticity provides an important upper limit on the strength of these CGW sources.

Predominant Methods to Calculate the Maximum Ellipticity and Results for Neutron Stars

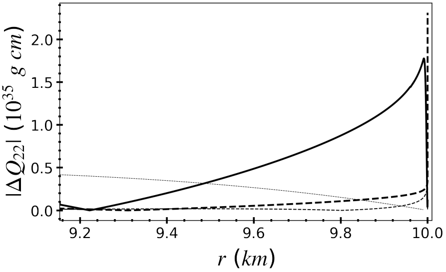
- *Method 1*: Deform maximally all of the points solid crust while leaving fluid region undeformed [1].
- *Method 2*: Fine-tune a force that acts on the whole NS until the crust breaks at *one* point [2].
- *Conundrum:* For a 1.4 $M_{\odot}$, $R = 10\ km$ canonical neutron star with a solid crust with thickness $\sim 0.85\ km$, *Method 1* gives a maximum ellipticity $\epsilon_{max} \sim 10^{-6}$, while *Method 2* gives a maximum ellipticity $\epsilon_{max} \sim 10^{-7}$.

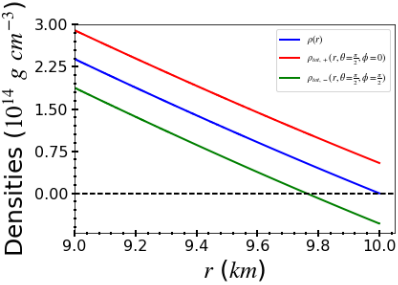
[1] G. Ushomirsky, C. Cutler, and L. Bildsten. Deformations of Accreting Neutron Star Crusts and Gravitational Wave Emission. *Mon. Notices Royal Astron. Soc.*, 319:902–932, Aug 2000

[2] F. Gittins, N. Andersson, and D.I. Jones. Modelling neutron star mountains. *Mon. Notices Royal Astron. Soc.*, 500:5570–5582, Nov 2021

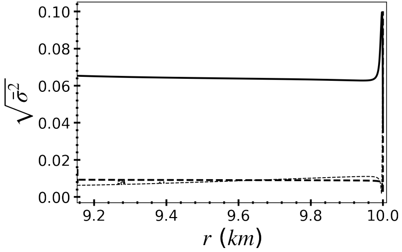
My Preferred Method

- I believe that *Method 1* gives the best estimate. Why? Consider a canonical NS.



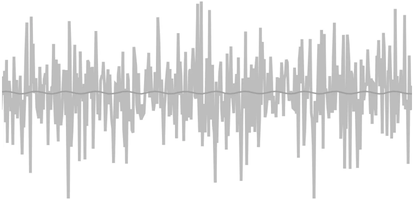


My Preferred Method



- It is possible to obtain a maximum ellipticity $\epsilon_{max} \sim 10^{-6}$ for a canonical neutron star.
- Fiducial deforming force needs to act in the transversal direction to avoid opposition from the large incompressibility of neutron star matter.

Searches



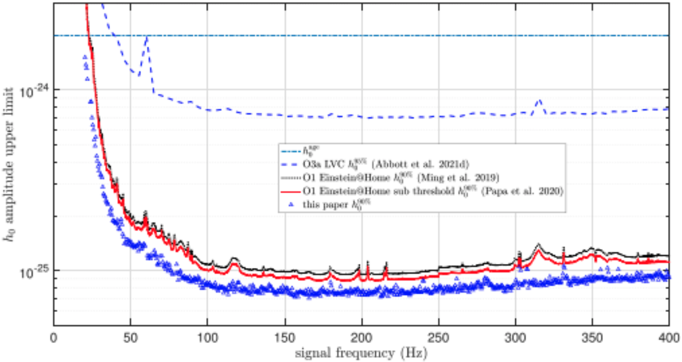
- There are three type of CGW searches: *targeted searches*, *directed searches*, *all-sky searches*.
- The parameter space is *usually* large, so searches are typically limited by computational cost.
- We have no CGW detection yet, but we have obtained constrains for some physical properties of neutron stars *in our galaxy*.

Searches: Example

- Let's see as an example some of the results of a directed search of the SNR G347.3 conducted by J. Ming et. al. (2022) [3].
- The search used Einstein@Home, which uses the idle time of volunteer computers to search for weak electromagnetic and CGW signals from spinning NSs.
- The search used $\sim 5.1 \times 10^{16}$ templates and 2.5 million work units (keeping a CPU busy for 8 hours). It was running on Einstein@Home for roughly a month.

[3] J. Ming et al. Results From an Einstein@Home Search for Continuous Gravitational Waves From G347.3 at Low Frequencies in LIGO O2 Data.
ApJ, 925:1–7, Jan 2022

Searches: Example

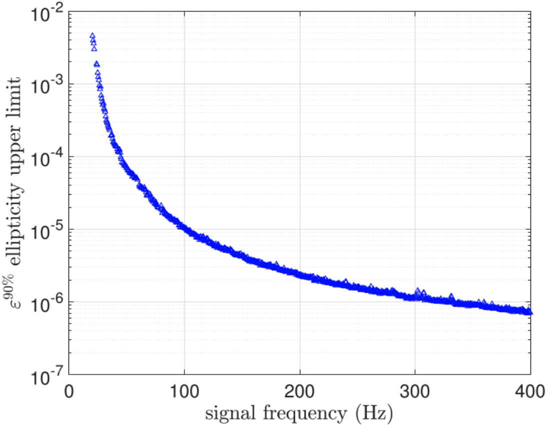


- Constrains on the GW strain from directed search on the SNR G347.3, which might harbor a neutron star.

Searches: Example

- We can constrain the ellipticity.

$$\epsilon = \frac{c^4}{4\pi^2}\frac{h_0 D}{If^2}$$



Conclusions

- A neutron star crust can sustain a maximum ellipticity as big as $\epsilon_{max} \sim 10^{-6}$, and not $\epsilon_{max} \sim 10^{-7}$.
- There have been no CGW detection yet, but searches have been able to place useful upper-limits on the ellipticity of neutron stars in our galaxy.
- Einstein@Home is performing the most sensitive searches to detect a CGW signal for the first time, and the idle time of your computers can be of great help.

Acknowledgements

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- Thanks to the Max Planck Institute for Gravitational Physics - Albert Einstein Institute in Hannover, Germany for hosting me for a year so that I can get involved in the search for a CGW signal from Cas A.

Questions?