CONSTRAINING THE P-MODE G-MODE TIDAL INSTABILITY WITH GW170817

With the first detection of gravitational waves from the merger of two neutron stars by LIGO and Virgo (GW170817) and the detection of the merger's electromagnetic counterpart, we have entered a very exciting era in gravitational wave astronomy and neutron star astrophysics. Among the rich array of science that the detection of neutron star mergers will deliver is the exciting prospect of constraining the properties of matter in the neutron star core, where the densities are several times greater than that of an atomic nucleus. Constraining this enigmatic supranuclear "equation of state" has been a goal of astrophysicists and nuclear physicists for many decades. GW170817 was such a strong signal that it already places interesting bounds on the neutron star equation of state.

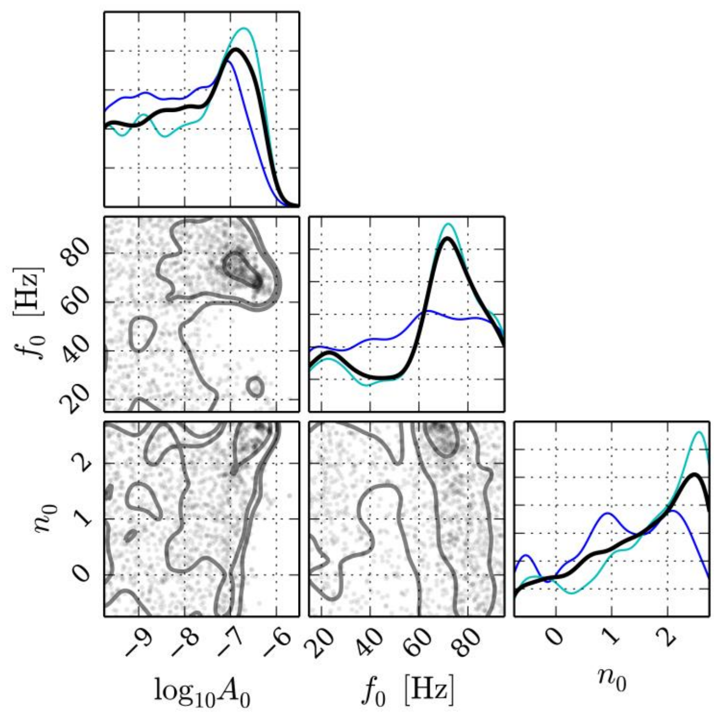
Gravitational wave measurements are sensitive to the equation of state due to tidal effects. The two stars in the binary induce a tide on each other due to differential gravitational fields, and these tides distort the shape of both stars and modify the rate at which the two stars spiral in. The strength of this effect depends on the properties of the core and the equation of state. By precisely measuring the rate of inspiral, gravitational wave observations can constrain the equation of state.

There are many potentially unstable p-g pairs, each becoming unstable at a different frequency and growing at a different rate. Although there is considerable uncertainty about the number of unstable pairs, their exact growth rates and how they saturate (i.e. reach a limiting value), estimates suggest that the impact could be measurable with current gravitational-wave detectors. Such a measurement would provide a new way of probing the neutron star interior, distinct from measurements of the neutron star tidal deformability.

Using a phenomenological model, we analyzed the instability's impact on the way the phase of the gravitational wave signal changes over time, using three parameters per star: an overall p-g amplitude, a saturation frequency, and a spectral index. We computed the Bayes factor — which provides a measure of how probable one model is relative to another, for a given set of data — comparing our p-g model to a standard model without this instability.

FIGURES FROM THE PUBLICATION

For more information on this figure, see the freely accessible arXiv preprint at https://arxiv.org/abs/1808.08676 which contains the full analysis and results.



This figure shows the relative degrees of belief between different possible nonlinear tide behaviors. While there is a peak in the amplitude parameter, $\log_{10}A_0$, it is completely consistent with what noise alone might accidentally do about 50% of the time. f_0 is a saturation frequency (in Hertz), and n_0 is a spectral index.

Our analysis found Bayes factors close to one, which indicates that the observed signal is consistent with waveform models that neglect p-g effects. On the other hand, it also implies that the p-g model is equally good at fitting the data. By injecting simulated signals that do not include p-g effects and recovering them with the p-g model, we showed that there is currently about a 50% probability of obtaining similar Bayes factors even when p-g effects are absent.

We find that the p-g amplitude for neutron stars with masses of 1.4 times that of the sun is constrained to less than a few tenths of the theoretical maximum. This suggests that there are less than a few hundred excited modes, assuming they all saturate through a process known as wave breaking. For comparison, theoretical upper bounds suggest less than 1000 modes saturate by wave breaking. Thus, the measured constraints only rule out extreme values of the p-g parameters. They also imply that the instability dissipates an energy of less than 10^{51} ergs over the entire inspiral, corresponding to less than a few percent of the energy radiated as gravitational waves.

In the future, with several more signals comparable to GW170817, it should be possible to improve the constraints on the p-g amplitude by a factor of a few. Obtaining even tighter constraints will likely require many more detections. Future measurements will also benefit from a better understanding of how the instability saturates. To date, there have only been detailed theoretical studies of the instability's threshold and growth rate, not its saturation. As a result, we cannot be certain of the fidelity of our phenomenological model. Nonetheless, with the LIGO and Virgo detectors becoming increasingly sensitive, the future for p-g studies promises to be very exciting. Stay tuned for updates as more detections pour in!

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Visit our websites: www.ligo.org, www.virgo-gw.eu
Freely available arXiv preprint of the scientific paper: https://arxiv.org/abs/1808.08676
Final journal article published in Physical Review Letters: https://doi.org/10.1103/PhysRevLett.122.061104

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GLOSSARY

Neutron star: Extremely dense object composed predominantly of neutrons, which remains after the supernova explosion of a massive star.

Equation of state: In the context of neutron stars, this is the relation between the density and pressure of nuclear matter.

Instability: A state that is not stable to slight changes, like a pin balanced on its head.

Stratification: The formation of distinct layers in parts of a neutron star, e.g. an outer crust.

Phenomenological model: A model which has parameters are that not necessarily directly derived from first physical principles.

Spectral index: A model parameter that describes how the saturation energy of the modes evolves with frequency.

Bayes Factor: The ratio of likelihoods of two different hypotheses. It can be used to determine if the data favor one hypothesis over another.

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