Gravitational Waves from Rapidly-Spinning Neutron Stars

1 Neutron Stars

Neutron stars start their lives in an extraordinarily dramatic fashion: they are born from the remnants of massive stars that have ended their lives in a blaze of glory by exploding in a cataclysmic event known as a supernova. They are among the most compact objects in our Universe, with masses comparable to that of the Sun and diameters similar to that of a city. They harbour extremely strong magnetic fields and gravitational fields. These properties make neutron stars excellent astrophysical laboratories for studying extreme areas of physics.

Figure 1. Composite image of the Crab Nebula which hosts a neutron star that was formed in 1054 AD [NASA].

2 Gravitational Waves

Gravitational waves are solutions to the Einstein Equation and are a consequence of the theory of General Relativity. They manifest themselves as miniscule ripples in spacetime.

On 17th August 2017, the Laser Interferometer Gravitational-Wave Observatory (LIGO) detected gravitational waves from the merger of two neutron stars. This marked the beginning of an exciting era of observation for neutron stars as up until that point they had only ever been seen via electromagnetic waves.

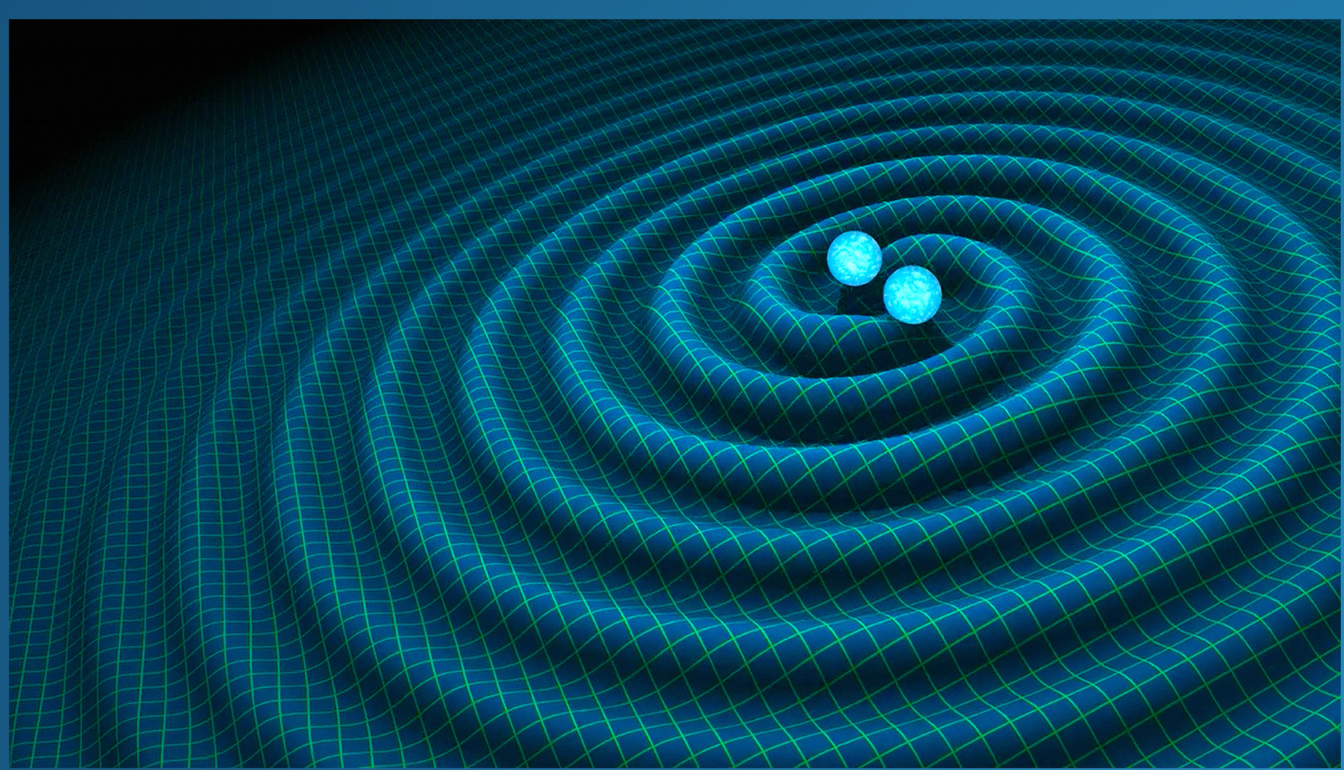

Figure 2. Artist's impression of gravitational waves generated from a binary neutron star inspiralling [R. Hurt/Caltech-JPL].

3 Low-Mass X-ray Binaries

Rotating neutron stars that are deformed from being perfectly spherical emit gravitational waves. This can be achieved through accretion – when a star receives mass from another. As matter builds up on the surface of a neutron star a **mountain** can form.

For this reason, candidate sources of gravitational-wave emission are **low-mass X-ray binaries**. These systems comprise a neutron star that is accreting gas from a companion star less massive than our Sun.

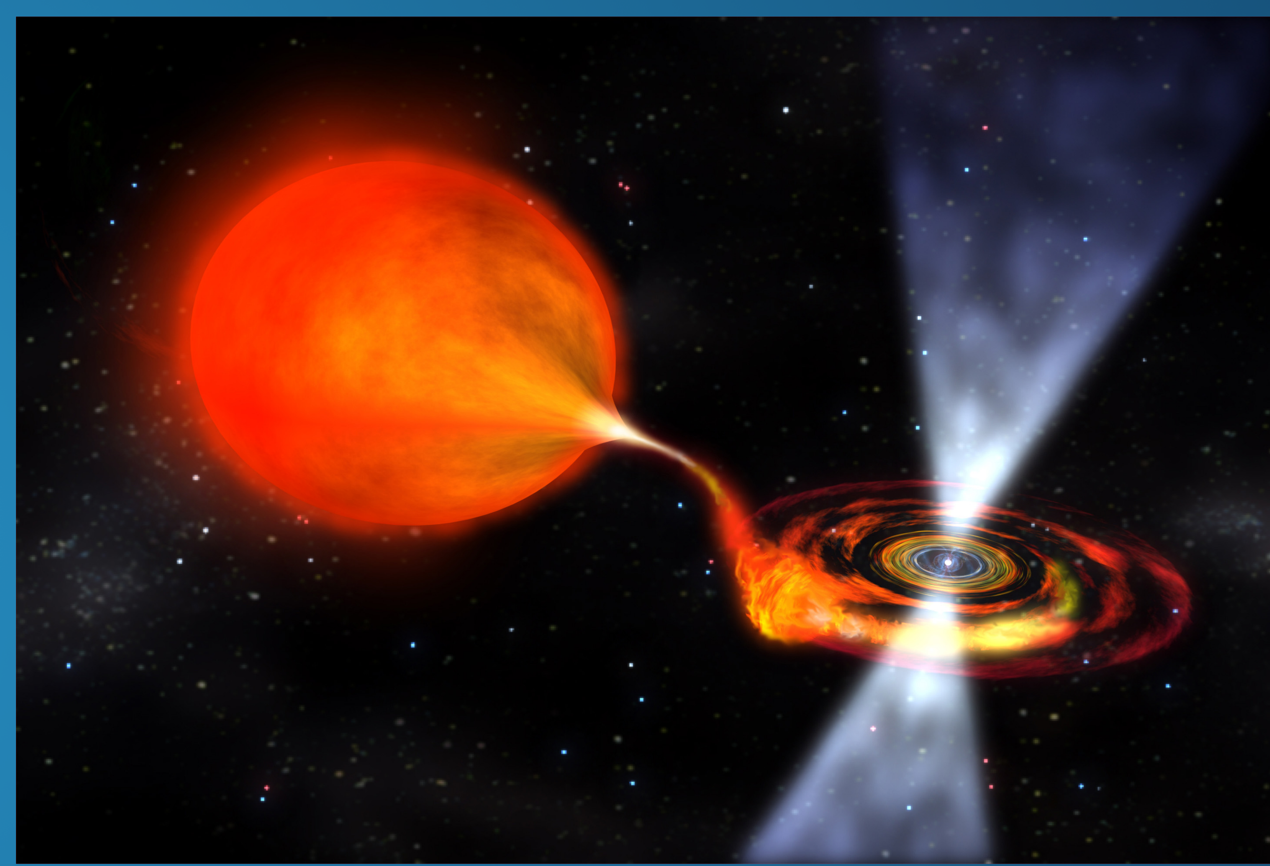

Figure 3. Artist's impression of a low-mass X-ray binary [D. Berry/NASA].

4 Mountains on Neutron Stars

There are two main channels through which a mountain is built on a neutron star.

1) As matter is accreted and buried, it undergoes nuclear reactions such as electron captures, neutron emission and pycnonuclear reactions. This, in turn, produces changes in density and heating in the crust of the neutron star and, providing the accretion flow is asymmetric, then a **crustal mountain** will form.
2) The magnetic field of the neutron star can perturb the structure of the star. As the neutron star accretes matter and the matter spreads towards the equator of the star, the magnetic field is dragged along and compressed producing a locally strong magnetic field that can sustain a **magnetic mountain**.

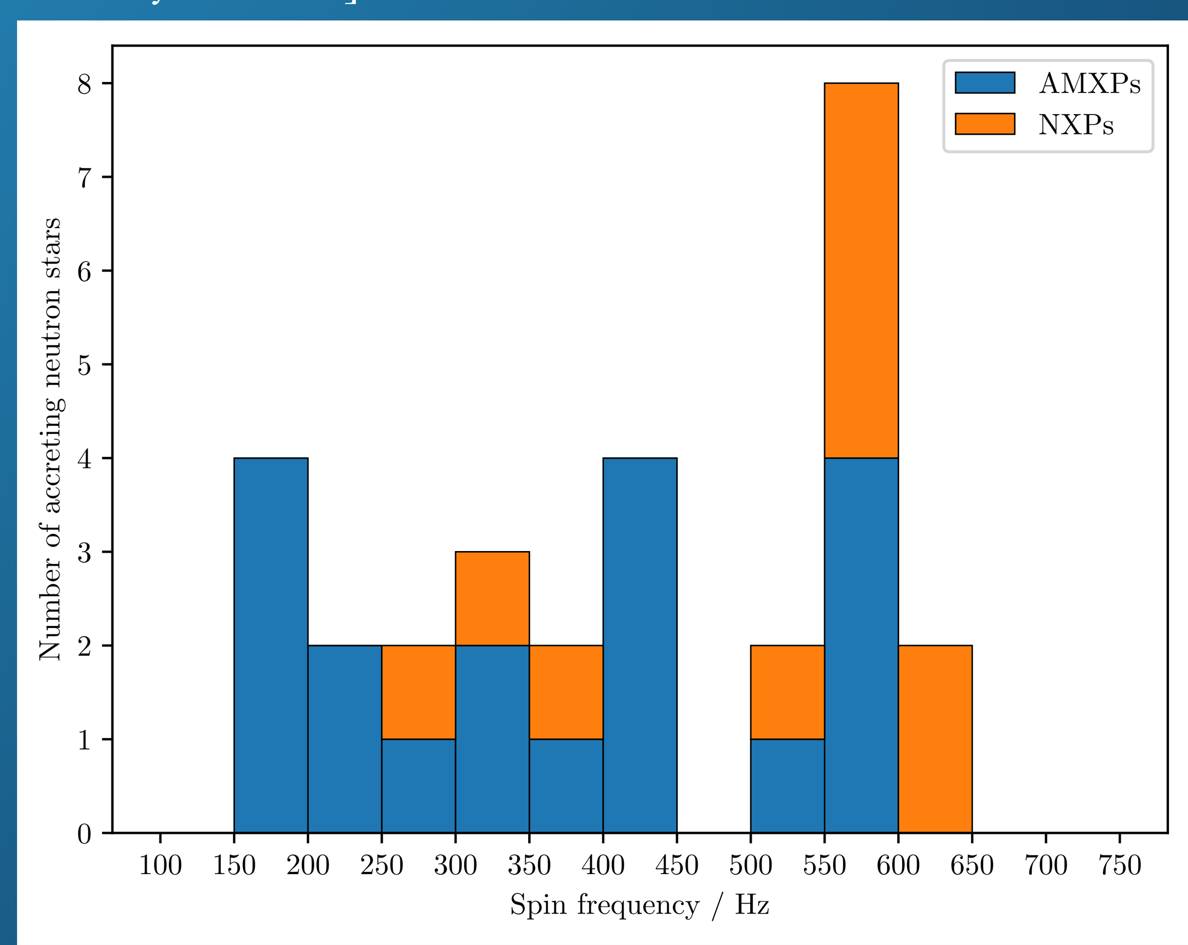

Figure 4. Distribution of spin frequencies for accreting neutron stars.

5 The Spin Distribution of Neutron Stars

One of the current puzzles in understanding accreting neutron stars is the way in which they spin. Accretion should, in theory, have no difficulty in spinning these systems up to kHz frequencies. However, the fastest-spinning observed neutron star (PSR J1748-2446ad) spins only at 716 Hz. This indicates that there must be some mechanism inherent in low-mass X-ray binaries that is acting as a brake to slow down their spins.

There are two competing mechanisms to explain this effect. An explanation could lie in the interaction between the accreting gas and the magnetic field. However, in order for this to be correct, there would need to be an unexpected coupling between the field strength and the accretion rate. Another possible explanation comes from gravitational waves. Gravitational waves take energy and angular momentum away from the system from which they are radiated. Therefore, they could impose a spin-frequency limit on accreting neutron stars which could be detected by LIGO.

Currently, I am investigating whether gravitational waves can indeed give us this observed distribution and which model of gravitational-wave production is the most promising. I do this by modelling the different mechanisms that can alter the spins of accreting neutron stars.

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