Population Synthesis of Accreting Neutron Stars Emitting Gravitational Waves

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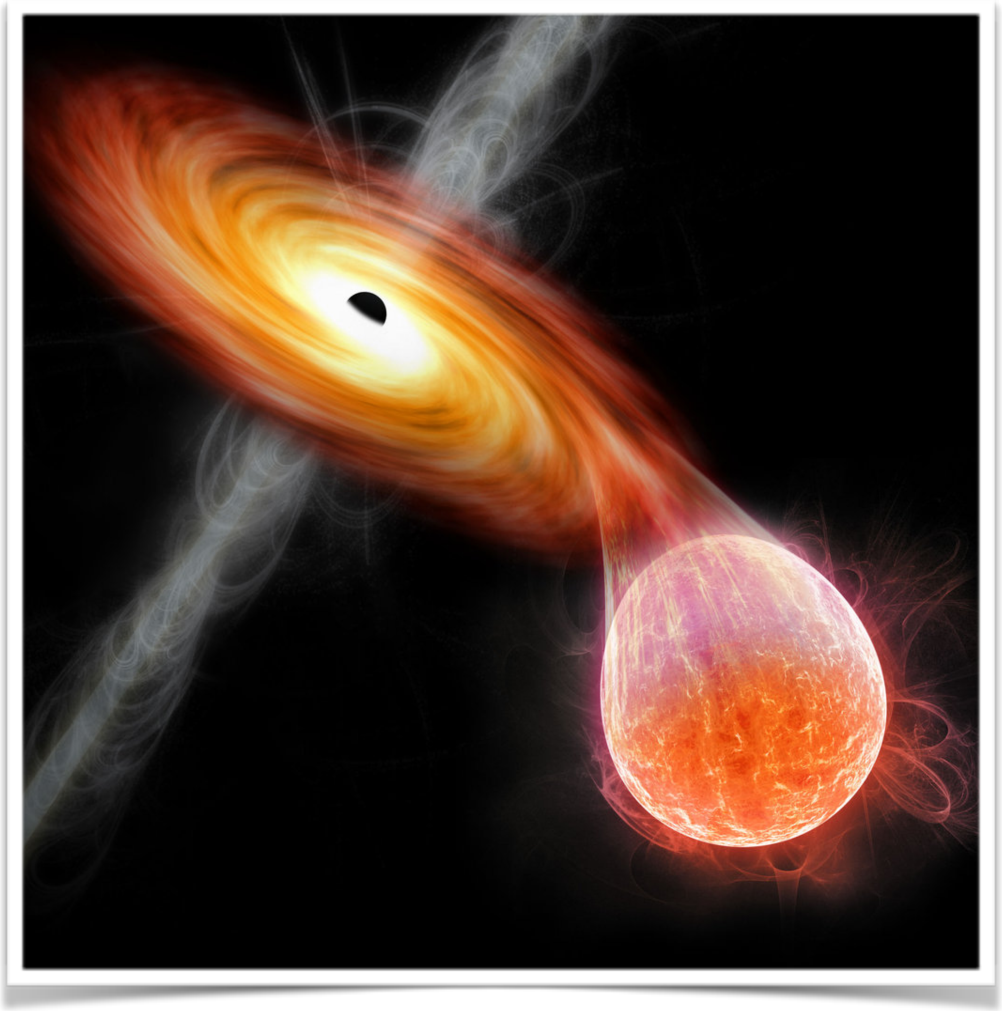
Low-Mass X-ray Binaries

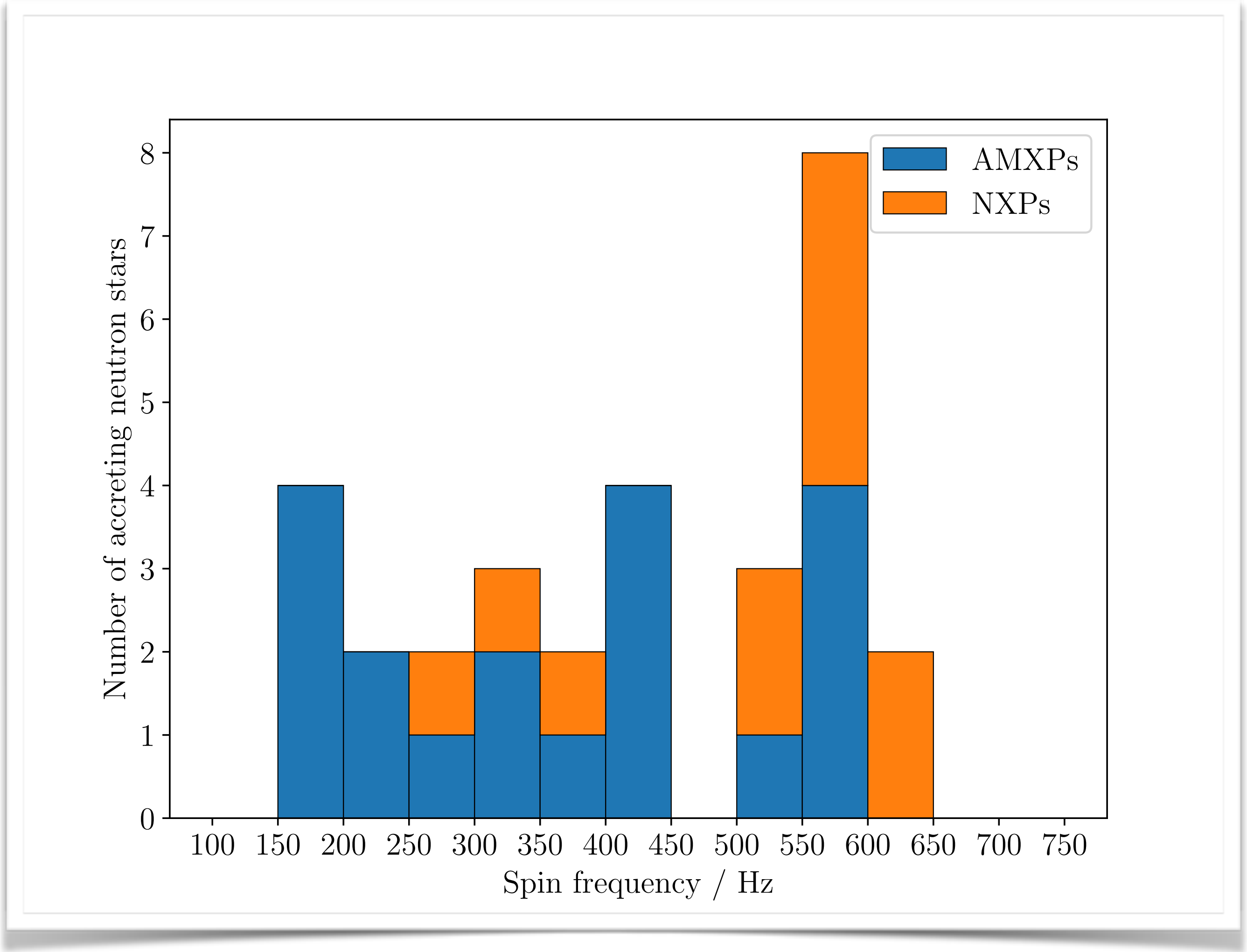
- A low-mass X-ray binary comprises a compact object (in our case, a neutron star) and a low-mass companion star.

- The neutron star accretes gas from the companion which gives rise to the X-ray pulsations and can spin it up.

- There are a number of problems with our understanding of this process:
    1. We don't know *precisely* where the magnetic field starts to dominate interactions.
    2. There exists a coupling between the disc and field lines when the lines are threaded through the disc.



Distribution of Accreting Neutron Stars



- There appears to be an unusual spin distribution for accreting neutron stars…

- The fastest accreting neutron star spins at 619 Hz, but accretion should be able to spin these systems up to ~ 1.5 kHz (Cook, Shapiro & Teukolsky 1994)!

- There are two competing explanations for this behaviour:
  1. An interaction between the accreting gas and the magnetic-field lines (Ghosh & Lamb 1978).
  2. Gravitational-wave emission.

How about gravitational waves?

- It was suggested by Bildsten (1998) and Andersson (1998) that the distribution of spins could be explained through gravitational-wave emission.

$$N_{\mathrm{GW}} = -\frac{256\pi}{75}\frac{G\Omega^5 Q_{22}^2}{c^5}$$

- Gravitational waves would provide a physical explanation for the two key features of the distribution (Patruno, Haskell & Andersson 2017):
  1. They become relevant at ~ 500 Hz.
  2. They stop neutron stars spinning faster than ~ 650 Hz.

Simulating the Spin Evolution

- We performed a population synthesis study by simulating the spin evolution of accreting neutron stars.

- We modelled both persistent and transient accretion.

- For our treatment of accretion we used the phenomenological model from Ho et al. (2014):

$$N_{\mathrm{acc}} = \dot{M} r_{\mathrm{m}}^2 [\Omega_{\mathrm{K}}(r_{\mathrm{m}}) - \Omega]$$

- And included gravitational waves to obtain:

$$N = \dot{M} r_{\mathrm{m}}^2 [\Omega_{\mathrm{K}}(r_{\mathrm{m}}) - \Omega] - \frac{256\pi}{75} \frac{G\Omega^5 Q_{22}^2}{c^5}$$

What produces the gravitational waves?

- There are three candidate mechanisms for producing gravitational radiation from accreting neutron stars:
  (1) Thermal mountains.
  (2) Mountains sustained by magnetic stresses.
  (3) Unstable r-modes.

- We explored mechanisms (1) and (3) and also considered the case of a permanent crustal mountain.

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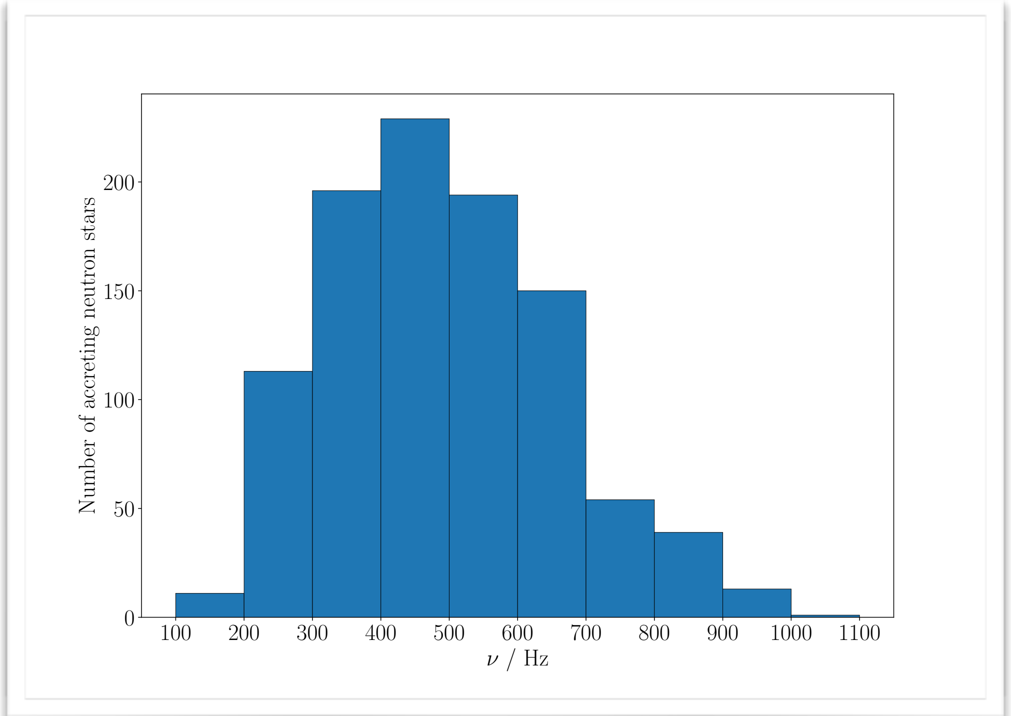
Simulated Populations

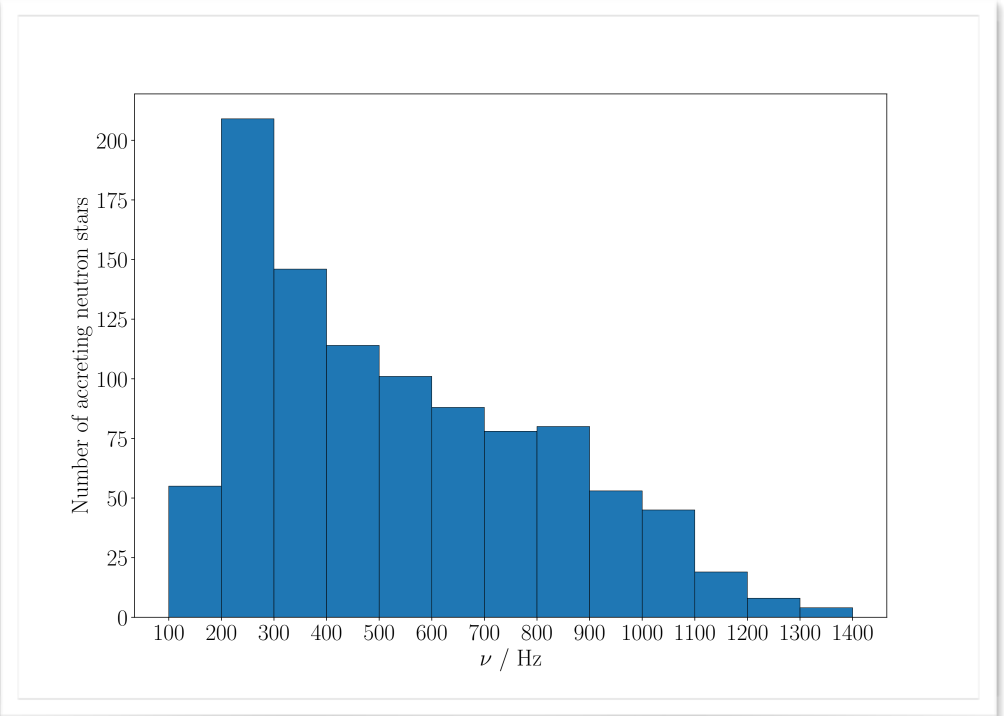
- Initial distributions:

Parameter	Distribution	Values
Mass / $M_\odot$	Single-value	1.4
Radius / km	Single-value	10
$\log_{10}(B\,/\,\mathrm{G})$	Gaussian	$\mu = 8.0,\ \sigma = 0.1$
Initial spin period / s	Flat	$0.01 - 0.1$
ξ	Single-value	0.5
$\log_{10}(\langle \dot{M} \rangle\,/\,M_\odot\,\mathrm{yr}^{-1})$	Gaussian	$\mu = -11.0 + \log_{10}(5),\ \sigma = 0.1$
Q_{22} / $\mathrm{g\,cm}^2$	Single-value	0
Evolution time / yr	Flat-in-the-log	$10^9 - 10^{10}$

- We considered the case of no gravitational-wave emission and found it did not match the observed distribution.



Persistent accretion.



Transient accretion.

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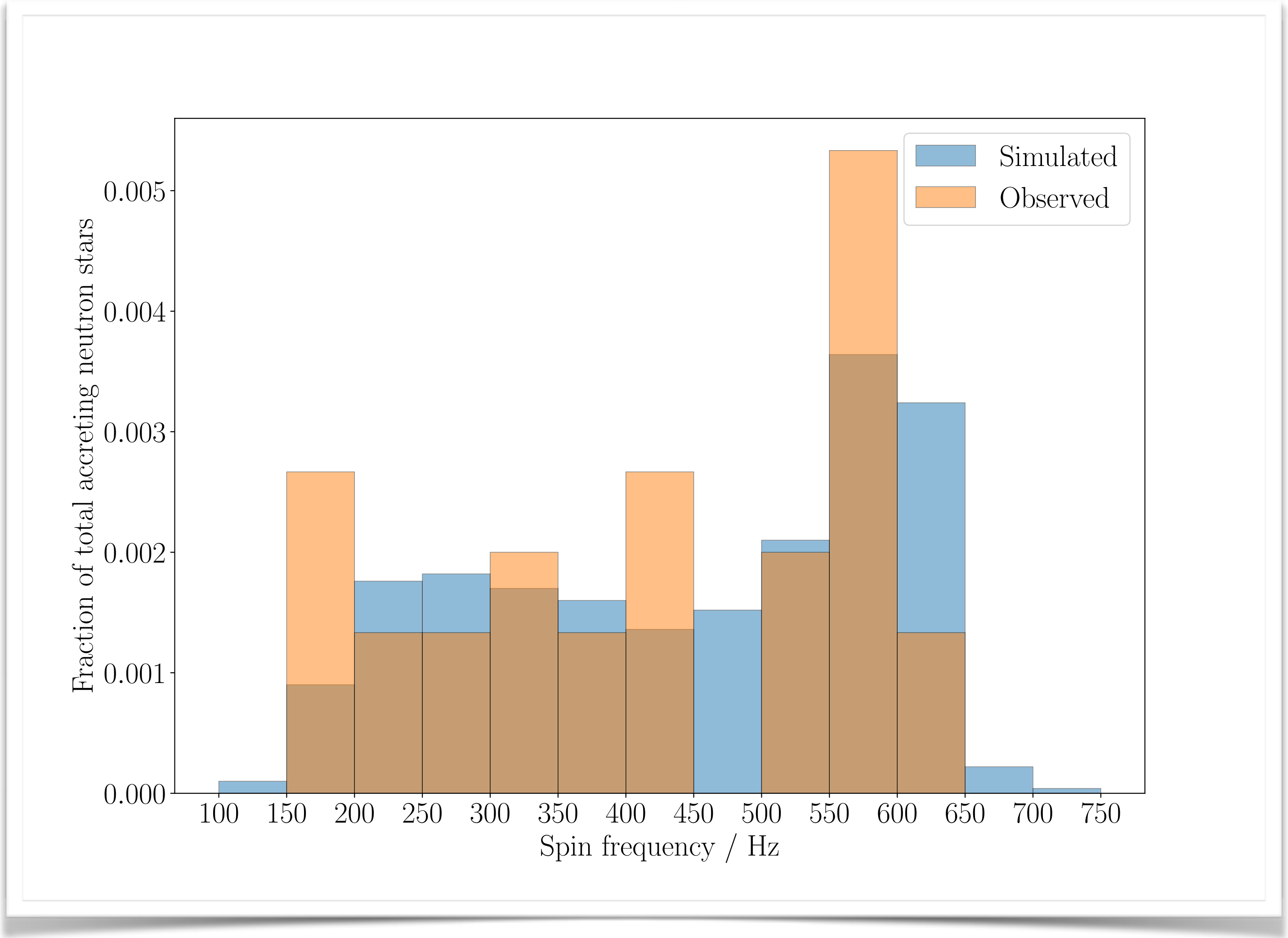
Simulated Populations



Fixed crustal mountains with transient accretion.

- We obtained qualitatively similar distributions for the fixed crustal mountains, thermal mountains and unstable r-modes.

Conclusions

- We have simulated the spin evolution of accreting neutron stars and considered persistent and transient accretion.

- With accretion alone we did not obtain a distribution that matched what is observed. But, including a gravitational-wave component gave qualitatively a similar distribution.

- Based on the resultant distributions alone, one cannot distinguish between the mechanisms. However, the emitted gravitational waves would tell us whether unstable r-modes or mountains are responsible.

- Preprint found at arXiv:1811.00550.

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