Modelling crustal mountains in accreting systems

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Low Mass X-ray Binaries

- Mass is stripped from the donor
- Forms a disc and spirals in
- Interacts with the magnetic field
- Transfers angular momentum to the central NS, spinning it up
- Weak B fields \( B \approx 10^8 \text{G} \)
GWs from Low Mass X-ray Binaries

Spin up halted well before breakup frequency
(Theoretical lower limit on max breakup f \( \sim 1200 \) Hz - BH et al. in preparation)

Disk/magnetosphere interaction?

GWs!: “mountains”, unstable modes, magnetic deformations

Cutoff of distribution at \( \sim 730 \) Hz
Fastest Neutron Star: 719 Hz

epsilon \( \approx 10^{-7} \)

(Bildsten 1998, Andersson 1998, Cutler 2002, BH et al. 06, BH et al. 08, Payne & Melatos 05)
Thermal mountains

Mountains from ‘wavy’ capture layers in crust

Deep crustal heating ‘consistent’ with cooling observations from X-ray transients.

(Ushomirsky, Cutler, Bildsten 2000)

Magnetic mountains

- In accreting systems, magnetic field distorted by the accretion flow

- Possibility of confining a ‘mountain’


Chuck’s talk! (Fattoyev et al. 2018)

r-modes: Ben’s talk, Kai’s talk
Spin distribution is bimodal, with a cutoff around 540 Hz

Slow population widely distributed around 300 Hz

Ms Radio Pulsar distribution is NOT bimodal, but consistent with the slow population

(Patruno, BH & Andersson 2017)
The spin of Low Mass X-ray Binaries

Spin distribution is bimodal, with a cutoff around 540 Hz. Slow population widely distributed around 300 Hz.

Ms Radio Pulsar distribution is NOT bimodal, but consistent with the slow population.

(Patruno, BH & Andersson 2017)
Which are the fast pulsars?

- 6 NXPs, 4 AMXPs (30 in the full sample)
- Two ‘transitional’ pulsars
- one is J1023+0038: well monitored in radio and X-ray

\[
\dot{\nu}_{\text{radio}} = -2.3985 \times 10^{-15} \text{ Hz/s}
\]
\[
\dot{\nu}_{\text{xray}} = -3.0413 \times 10^{-15} \text{ Hz/s} \quad \text{27% faster!}
\]

- Problem for accretion torque models....
So what about GWs?

- Can GWs explain the additional spin-down?

\[ \dot{\nu}_{\text{diff}} = -6.428 \times 10^{-16} \text{ Hz/s} \]  

(BH & Patruno 2017)

- Mountain:

\[ Q_{22} \approx 4.4 \times 10^{35} \text{ g cm}^2 \]
\[ \varepsilon \approx 5 \times 10^{-10} \quad h \approx 6 \times 10^{-28} \]

- r-mode

\[ \alpha \approx 5 \times 10^{-8} \]
So what about GWs?

Thermal Mountain:

\[ Q_{22} \approx 3 \times 10^{35} \left( \frac{\delta T_q}{10^5 \text{K}} \right) \left( \frac{E_{th}}{30 \text{ MeV}} \right)^3 \text{ g cm}^2 \]

(Ushomirsky, Cutler & Bildsten 2000)

\[ \delta T \approx 5 \times 10^6 \text{K after 1 month of accretion} \]

\[ \frac{\delta T_q}{\delta T} \approx 0.03 \]

(BH & Patruno 2017)
Crustal (thermal and magnetic) mountains

- Mountain accumulates during outbursts
- Does it dissipate between outbursts?

(BH, Priymak, Patruno, Oppenooorth, Melatos & Lasky 2015)
Thermal mountains

If deformations of J1023+0038 are typical, persistent sources promising

Still Tricky! (Watts et al. 2008)

(BH, Priymak, Melatos, Lasky, Patruno & Oppenooirth, 2015)
Magnetic mountains

- Only systems with strong buried fields detectable

- Possible cyclotron features

  (BH, Priymak, Patruno, Oppenoorth, Melatos & Lasky 2015)
Magnetic mountains

- Only systems with strong fields detectable
- Possible cyclotron features

(BH, Priymak, Patruno, Oppenooirth, Melatos & Lasky 2015, Mukherjee et al. 2012)
what is $\frac{\delta T_q}{\delta T}$?

Solve for equilibria of accreted matter on a magnetised star (work by Neha Singh, Grad Shafranov code by Dipanjan Mukherjee)

Assume capture layers are perturbed

$$\delta T_q = -10^2 C_k^{-1} p_{30}^{-1} \Gamma \left(\frac{\delta \rho_2}{\rho_0}\right) Q_M \Delta M_{21}$$

$$\frac{\delta T_q}{\delta T} = -\Gamma \frac{\delta \rho_2}{\rho_0}$$
Extrapolate linearly to neutron drip

For accretion on full 70 degree cap \( \frac{\delta T_q}{\delta T_0} \approx 0.001 \)

For accretion on a 10 degree cap \( \frac{\delta T_q}{\delta T_0} \approx 0.1 \)

work by **Neha Singh** (University of Warsaw)
Conclusions

- There is a ‘fast’ and a ‘slow’ population of LMXBs
- In the ‘fast’ population GW emission may be efficient
- PSR J1023 may be building a mountain and emitting GWs during accretion...the next transition to radio will help constrain the model
- If deformations persist at this level some of these systems may be interesting sources of GWs...especially those with long outbursts.
- Accretion geometry fundamental to determine quadrupolar deformations