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A tide-induced starquake model for GRB211211A

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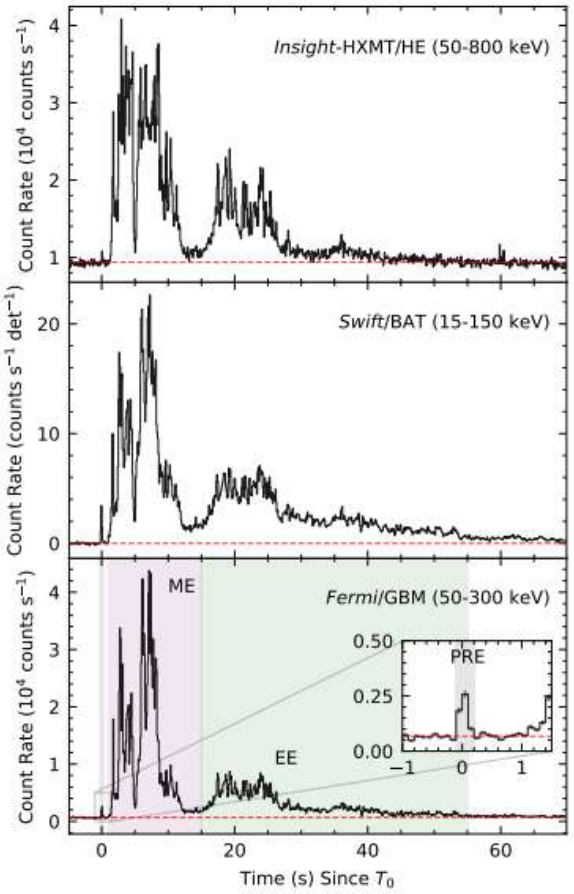
Arxiv:2305.10682

The observation: GRB211211A



Relatively long main burst ~8s

Precursor 1s prior to the main burst

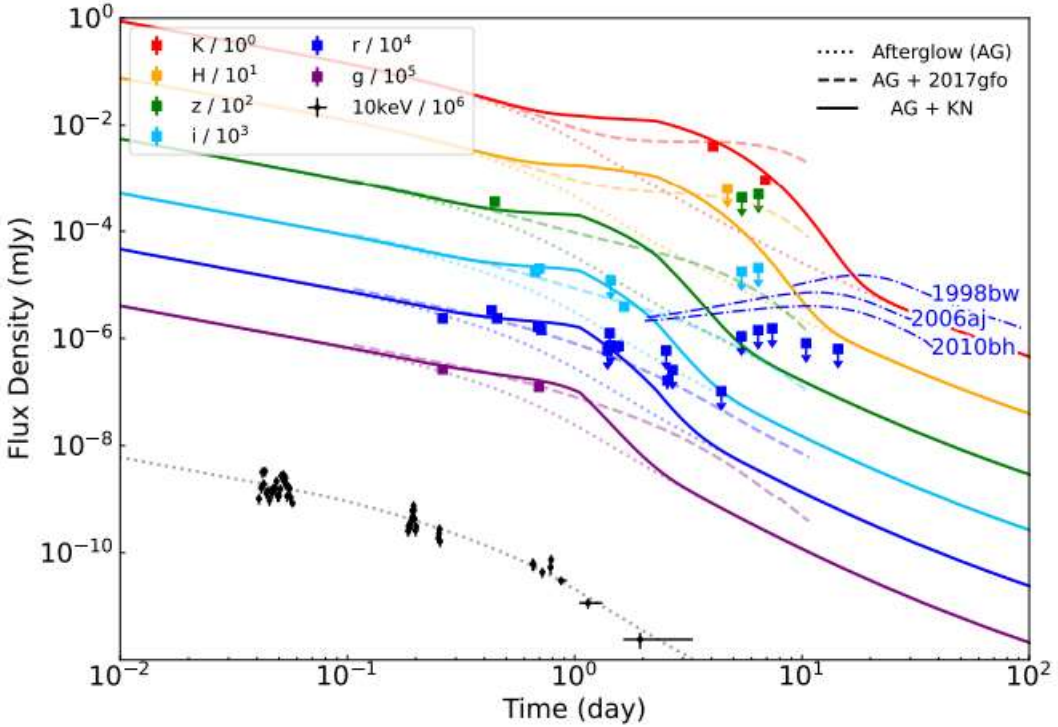
Precursor lasts ~ 0.2 s

Precursor energy 7.7E+48 erg

QPO in precursor ~ 22 Hz

Xiao et al., 2022

The observation



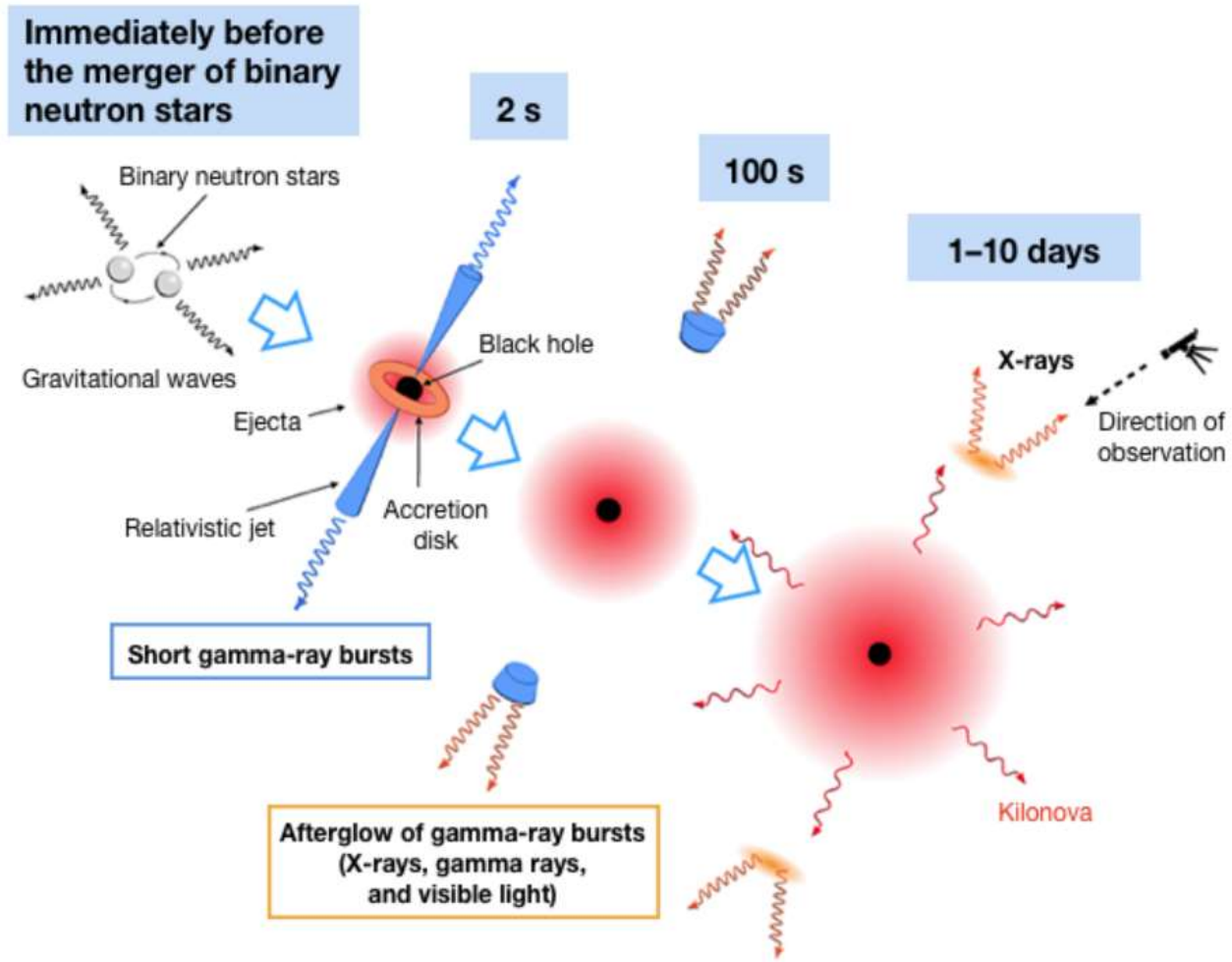
Xiao et al., 2022

Late optical excludes Type Ic SN

Optical excess consistent with KN

Indication:
Merger (involving NS) origin event with precursor

BNS merger scenario for sGRB

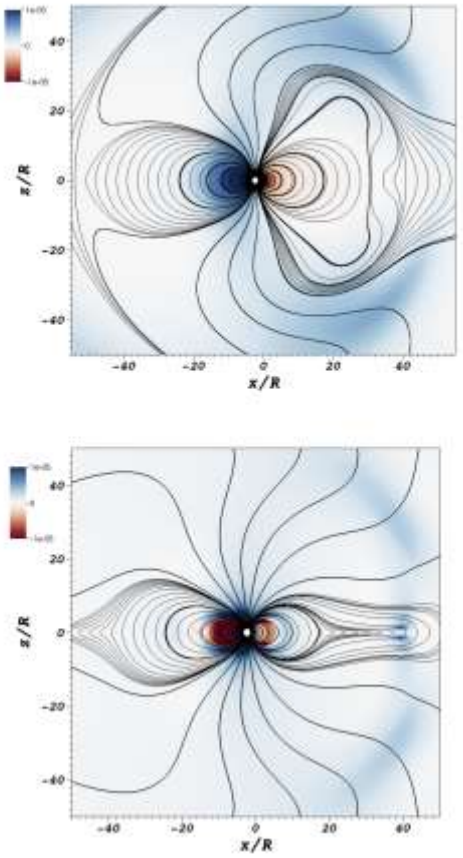


Previous models for the precursor

- Poynting flux of an orbiting magnetized NS

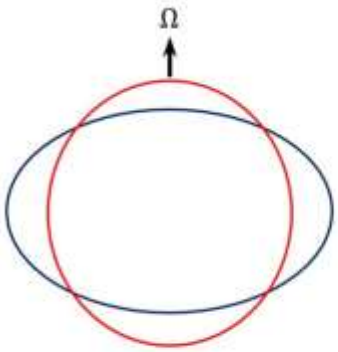
- Flares of magnetars before merger

- Resonant shattering of a spinning NS crust during inspiral

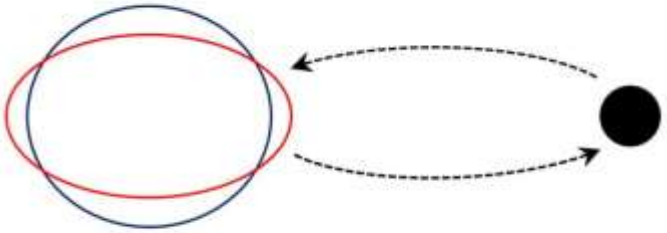


Carrasco & Shibata 2019

Our model



Spindown-induced Quake



Tide-induced Quake

Change in spin (B dipole)	Change in tidal field (GW quad)
Ellipticity decreases	Ellipticity increases
Elastic energy accumulated	Elastic energy accumulated
Starquake	Starquake
Glitch	Precursor
Baym & Pines 1971	Zhou et al., 2023

Our model

$$E_{\text{total}} = E_k + E_g + E_t + E_{\text{ela}}$$

E_k negligible before merger (Bildsten & Cutler 1992)

$$E_g + E_t = E_0 + A_g\epsilon^2 - \frac{M_c}{M}A_t(\frac{R}{D})^3\epsilon \qquad \epsilon = \frac{I - I_0}{I_0}$$

$$E_{\text{ela}} = B(\epsilon - \epsilon_0)^2 \qquad B = \tfrac{1}{2}\mu V$$

$$E_{\text{total}} = E_0 + \frac{3}{25}A\epsilon^2 - A\frac{M_c}{M}(\frac{R}{D})^3\epsilon + B(\epsilon - \epsilon_0)^2$$

Minimizing E_total w.r.t. ellipticity:

$$\epsilon = \frac{25A}{6A + 50B}\frac{M_c}{M}(\frac{R}{D})^3 + \frac{50B}{6A + 50B}\epsilon_0 \qquad \epsilon_{\text{eq,fl}} = \frac{25}{6}\frac{M_c}{M}(\frac{R}{D})^3$$

Our model

- After the starquake, elastic energy will be released

$$E_{\rm ela} \sim B[\frac{25}{6}\frac{M_c}{M}(\frac{R}{D})^3]^2$$

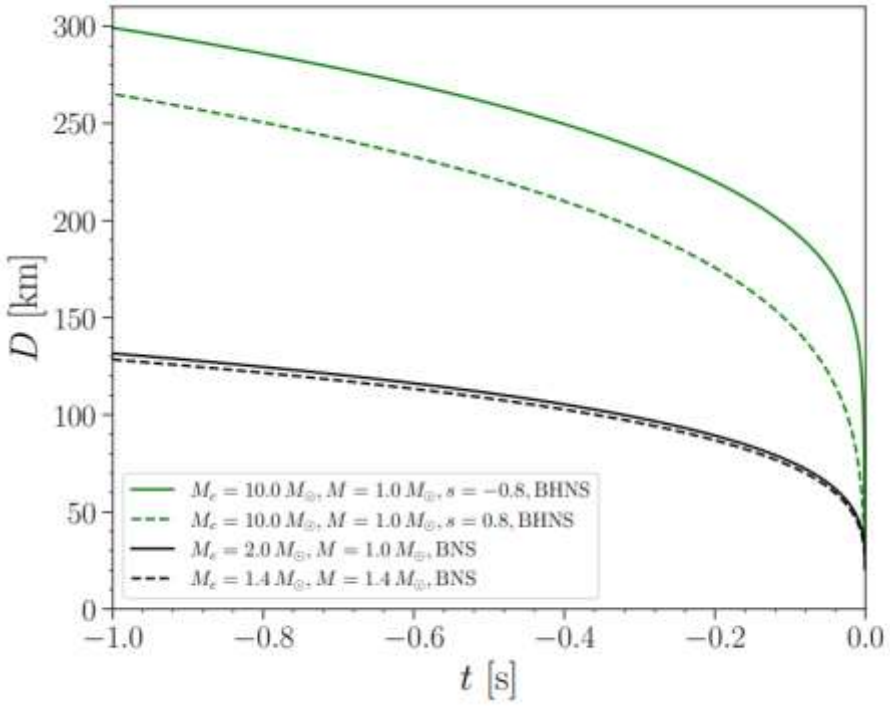
- In addition, gravitational energy will change as ellipticity changes during the starquake

$$\delta\epsilon = \epsilon_{\rm eq,fl} - \epsilon_{\rm eq,so} = \frac{50B}{6A+50B}\frac{25}{6}\frac{M_c}{M}(\frac{R}{D})^3$$

$$\delta(E_g + E_t) \sim \frac{\partial(E_g+E_t)}{\partial\epsilon}|_{\epsilon_{\rm eq,fl}}\delta\epsilon$$

Our model

$$E_{\rm ela} = 2.3\times10^{49}\,{\rm erg}\left(\frac{\mu}{10^{34}\,{\rm erg\,cm^{-3}}}\right)\left(\frac{M_c/M}{1.0}\right)^2\left(\frac{D}{50\,{\rm km}}\right)^{-6}$$



Orbital separation
D < ~100 km for
t-t_merger < -1 s

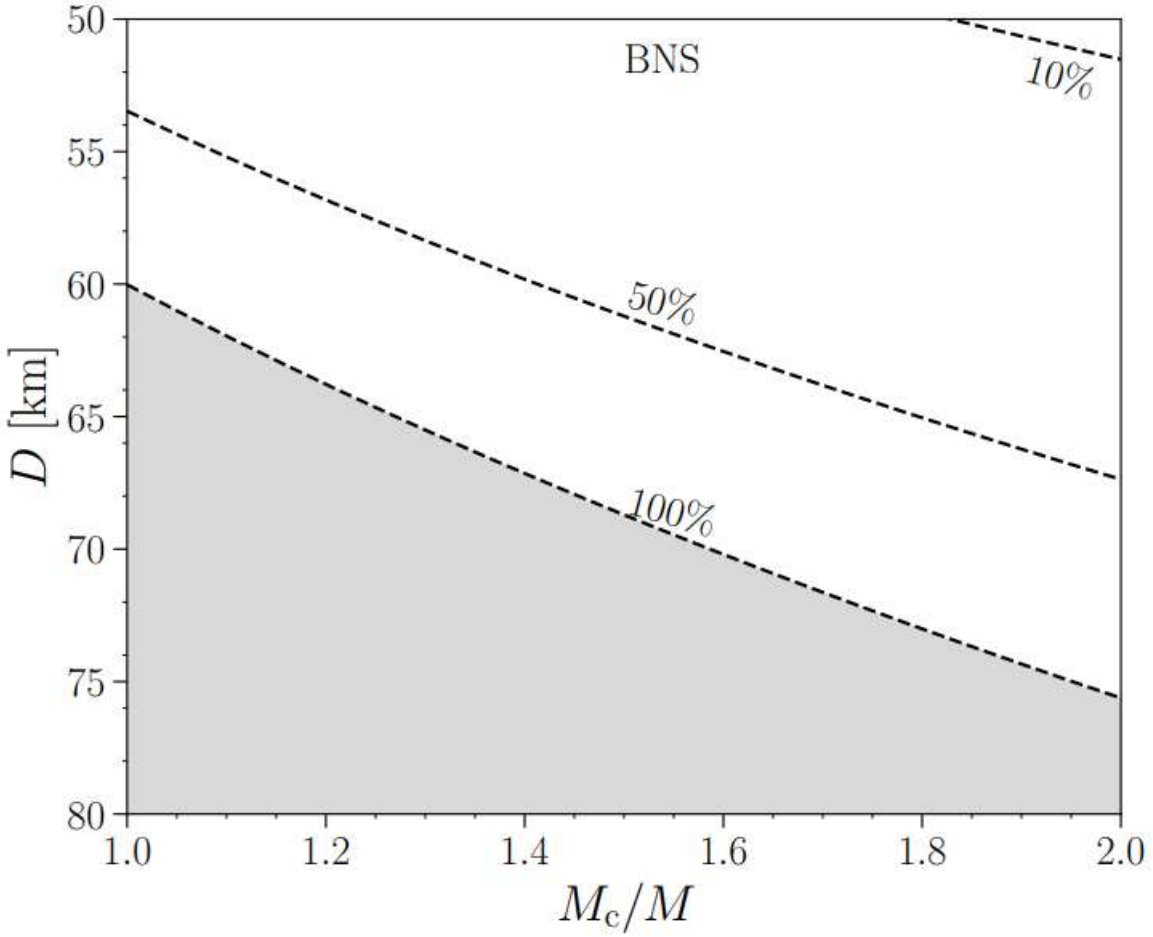
Results of EOB calculation

Our model

- BNS

Tense parameter space

Requires major elastic energy release & conversion



Our model

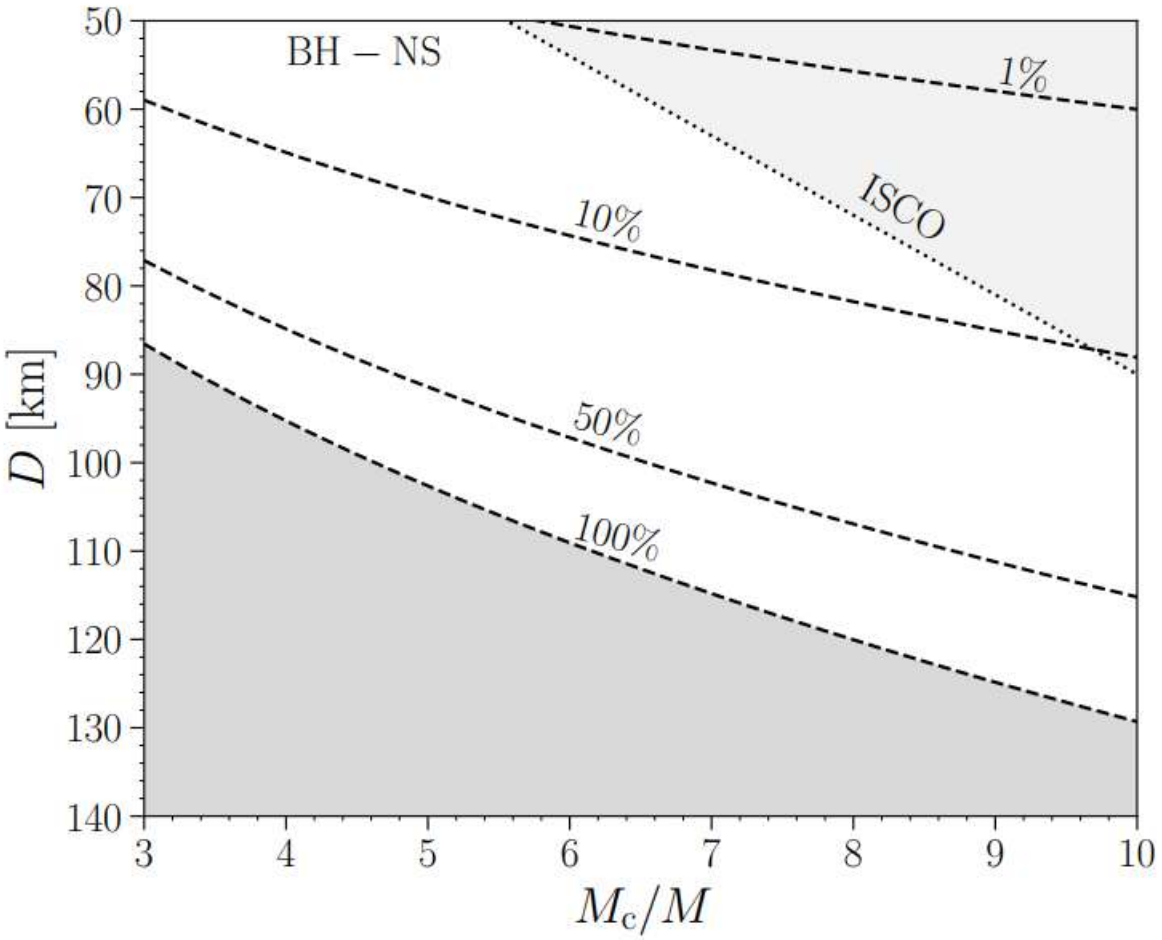
- BH-NS

Larger parameter space

Allow for 10% (even 1%) energy release

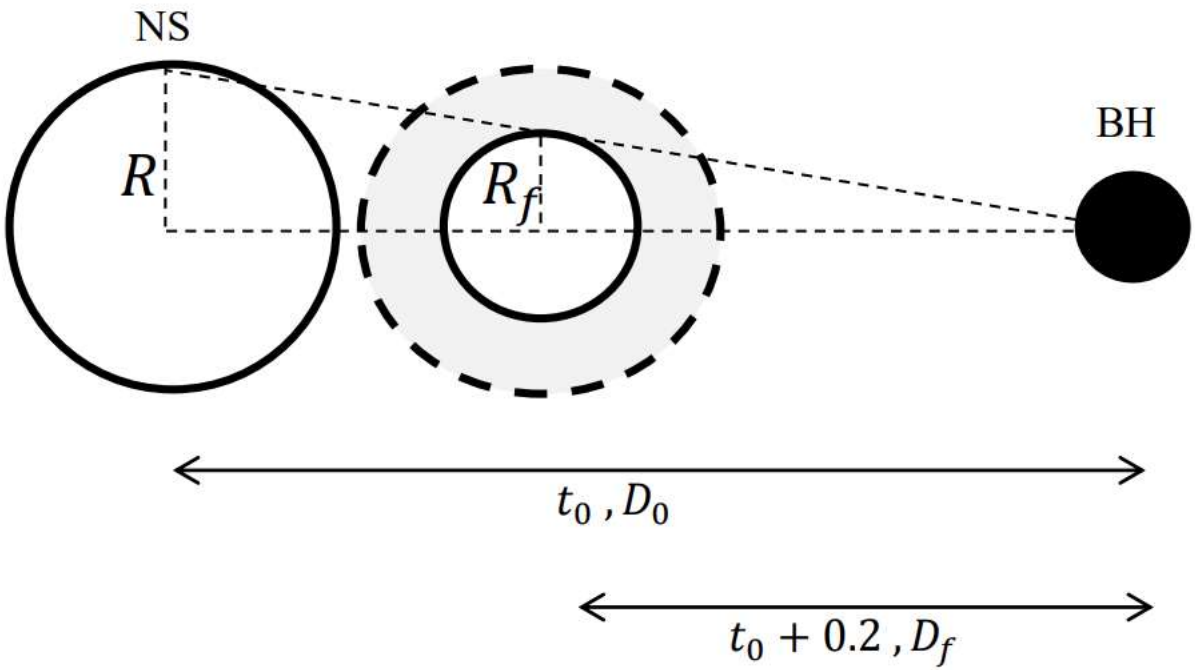
More consistent with event rates (future study)

Consistent with KN observation as well

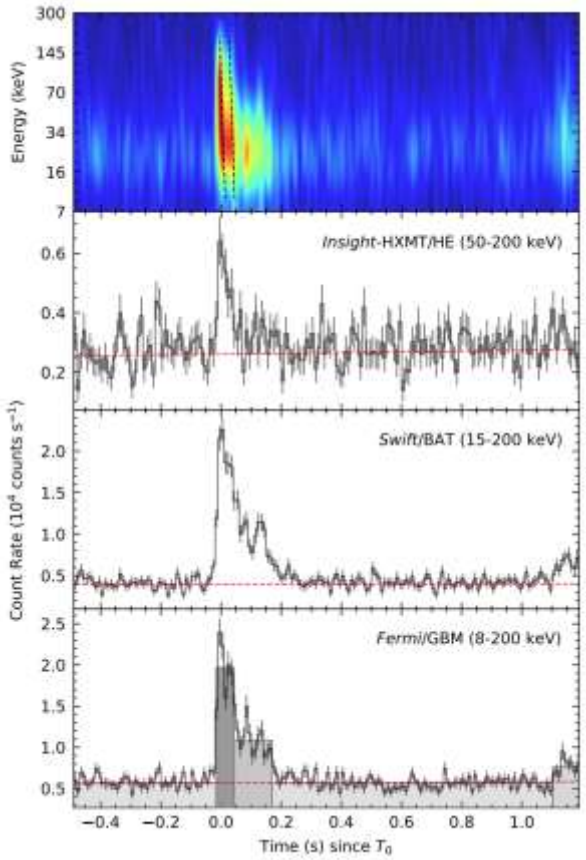


Our model

- In reality, the elastic energy could be released in a sequence of starquakes.



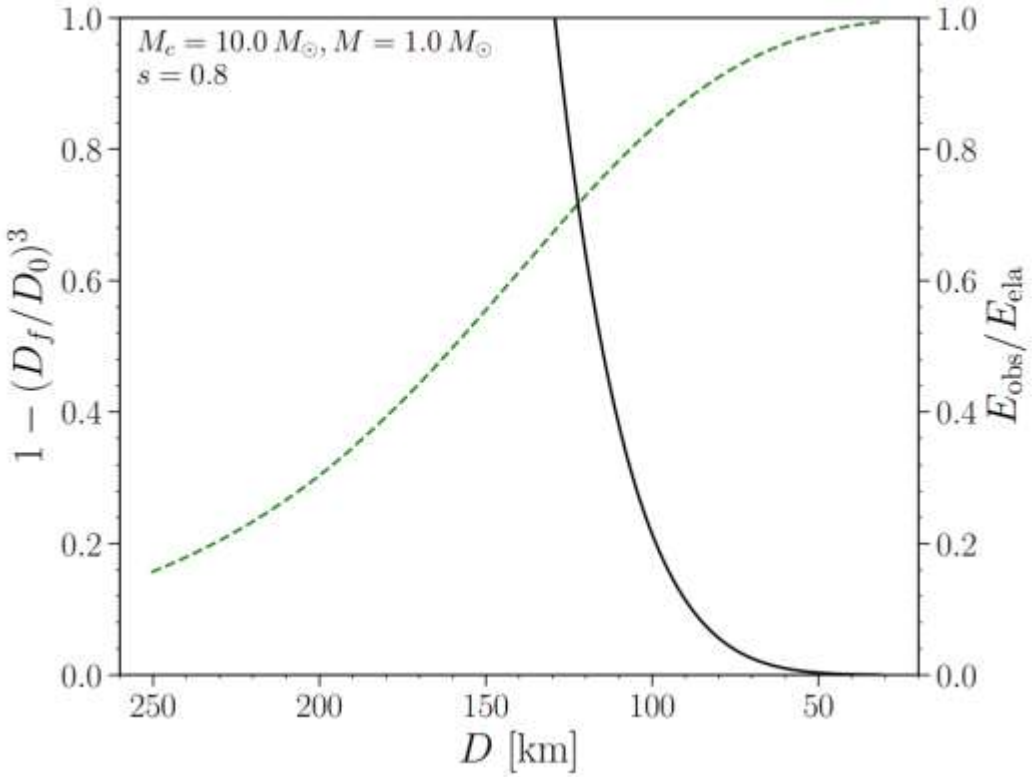
Hints of a sequential starquake model



Hints:
Time-sequential components with declining amplitudes

Tidal force is stronger on the surface and weaker in the center, at a given binary separation.

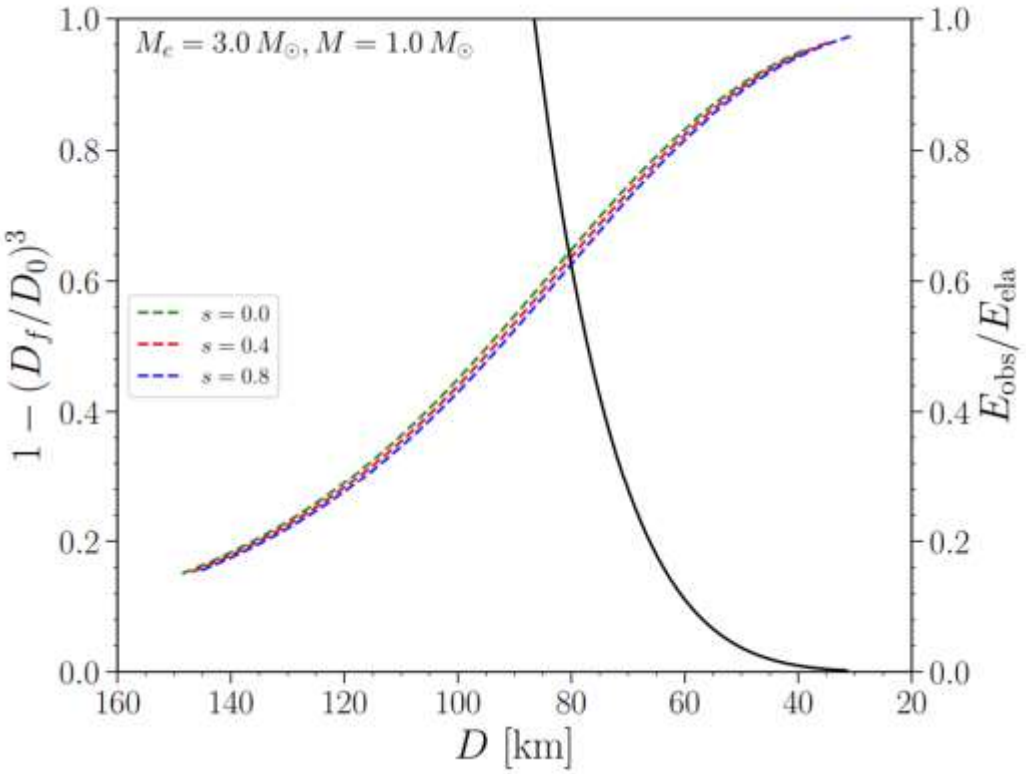
Our model



Black: Fraction of elastic energy released according to observation

Green: Fraction of elastic energy released during the sequential quakes.

Our model



Black: Fraction of elastic energy released according to observation

Colored: Fraction of elastic energy released during the sequential quakes by assuming different BH spin.

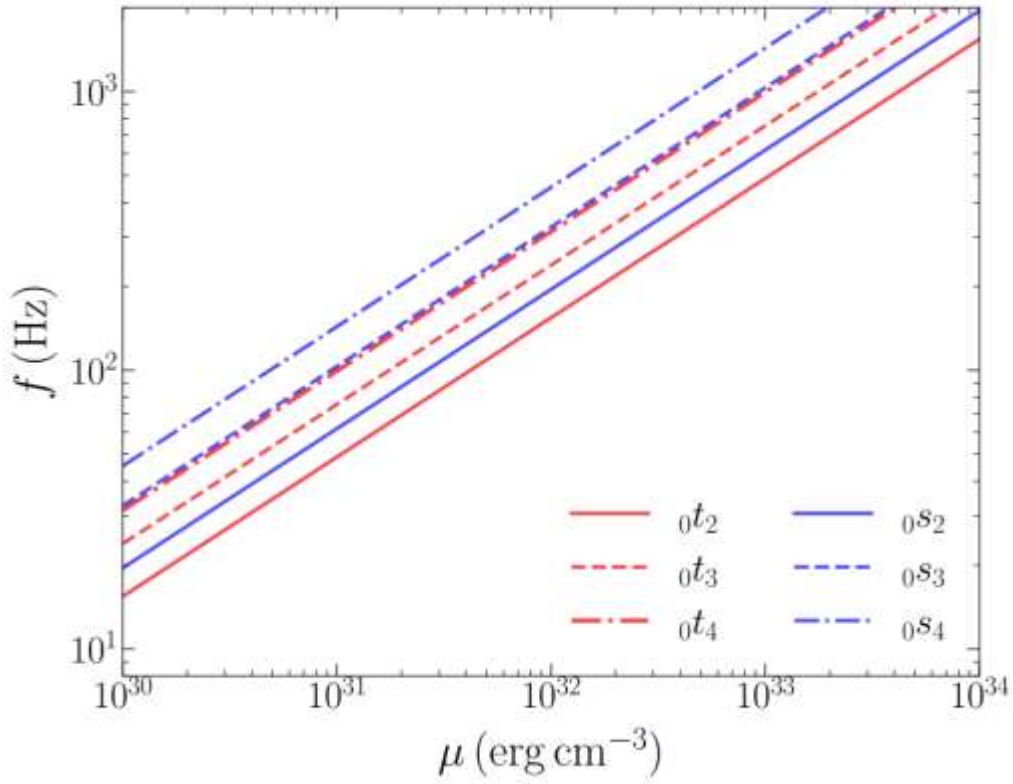
Our model

- Other origin of QPOs?

$$f({}_0t_2) = 48.8\,\mathrm{Hz}\left(\frac{\mu}{10^{31}\,\mathrm{erg\,cm^{-3}}}\right)^{\frac{1}{2}}$$

$$f({}_0s_2) = 61.7\,\mathrm{Hz}\left(\frac{\mu}{10^{31}\,\mathrm{erg\,cm^{-3}}}\right)^{\frac{1}{2}}$$

$$f_{\mathrm{obs}} \sim \left(1-\frac{2GM_c}{Dc^2}\right)^{\frac{1}{2}}\left(1-\frac{2GM}{Rc^2}\right)^{\frac{1}{2}} f$$



Future prospects

- Event rates
- Number of quakes in a sequence?
- Moment tensor analysis for sequential quake model?