Phase-transition induced X-ray features in sGRB observations

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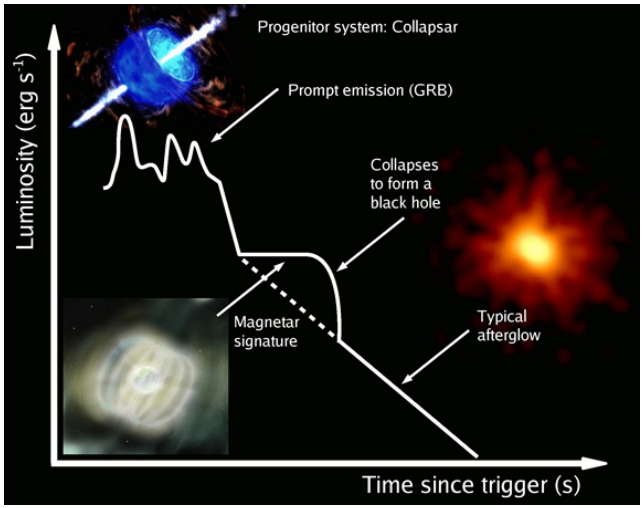
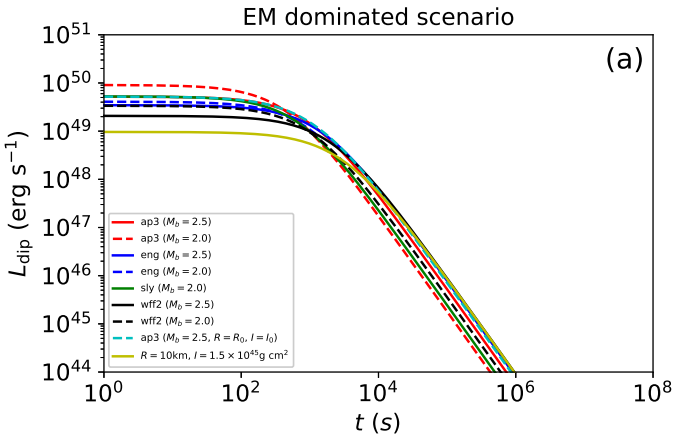
Background: GRB afterglow and rotating star series



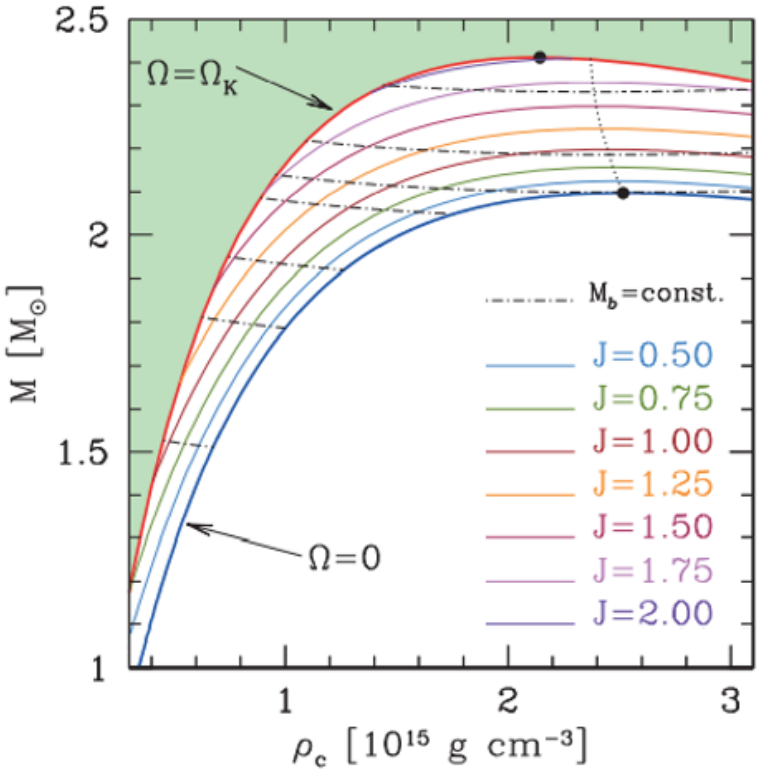
GRB afterglow plateau can be modeled as magnetic dipole radiation. The total energy and angular momentum evolves according to following equations (in geometric units)

$$\frac{dJ}{dt} = \frac{\mu^2\omega^3}{6\pi} \qquad \frac{dM}{dt} = \frac{\mu^2\omega^4}{6\pi}$$



If $J = I\omega$ and the rotation inertia I is constant, we find $\omega = \left(\frac{\mu^2 t}{3\pi I}\right)^{-\frac{1}{2}}$

Rotating Star Series



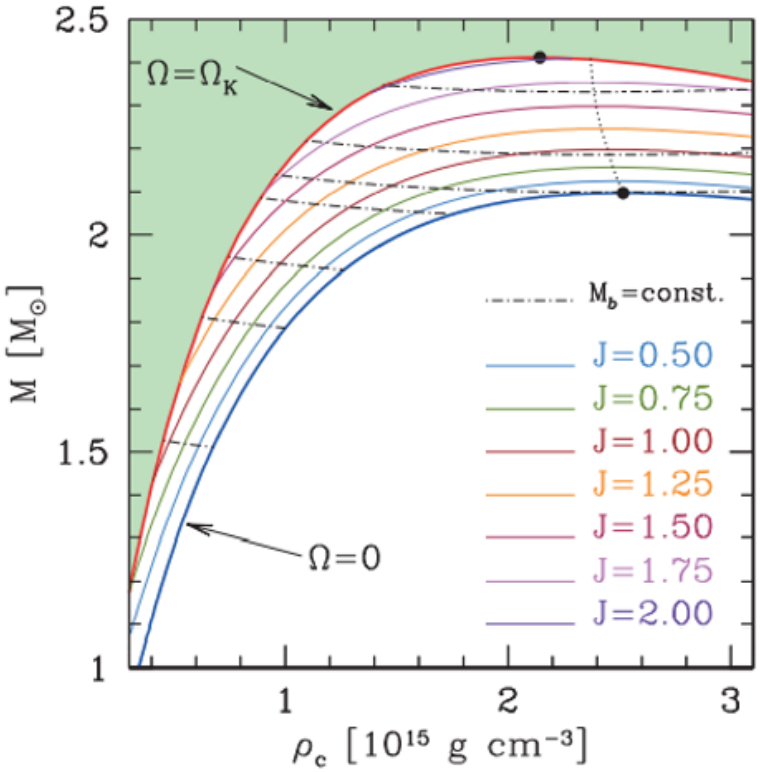
Uniformly rotating stars at equilibrium has 2 degrees of freedom.

$M_0 = const.$

1. $J_{t_0} \rightarrow \omega_{t_0} \rightarrow \frac{dJ}{dt}\Big|_{t_0} \rightarrow J_{t_1}$

2. $M_{t_0} \rightarrow \omega_{t_0} \rightarrow \frac{dM}{dt}\Big|_{t_0} \rightarrow M_{t_1}$

Rotating Star Series



Uniformly rotating stars at equilibrium has 2 degrees of freedom.

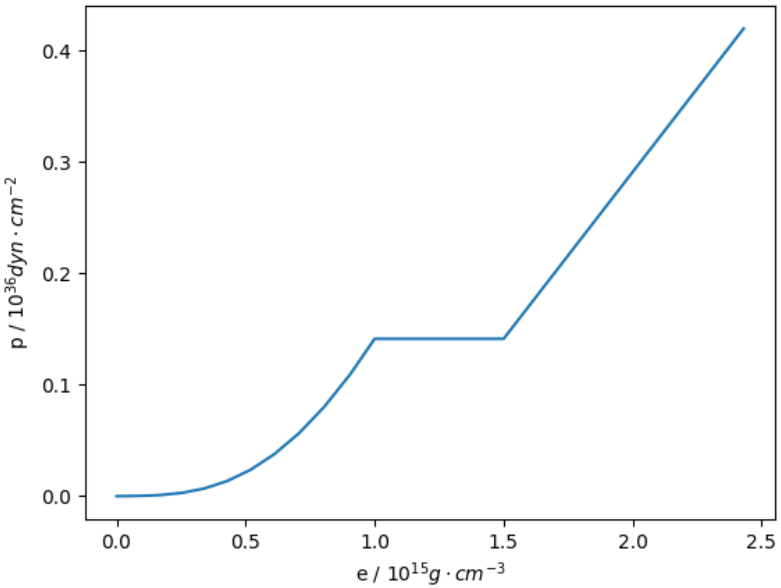
$dM = \omega dJ + \mu_c dM_0$ (Bardeen 1972)

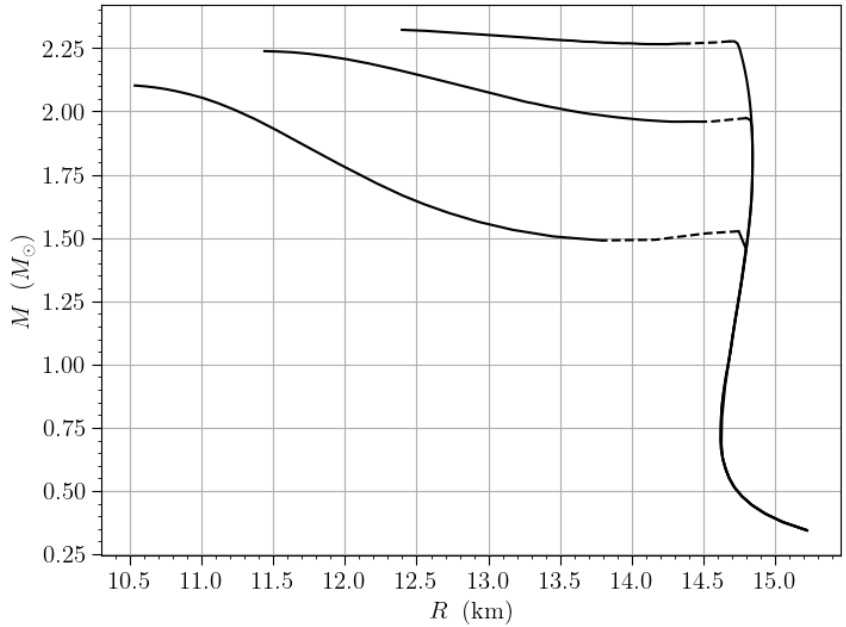
ρ_c can increase by a factor of two during spin down → What if phase transition happens during spin down?

Results: GRB afterglow light curves for hybrid stars

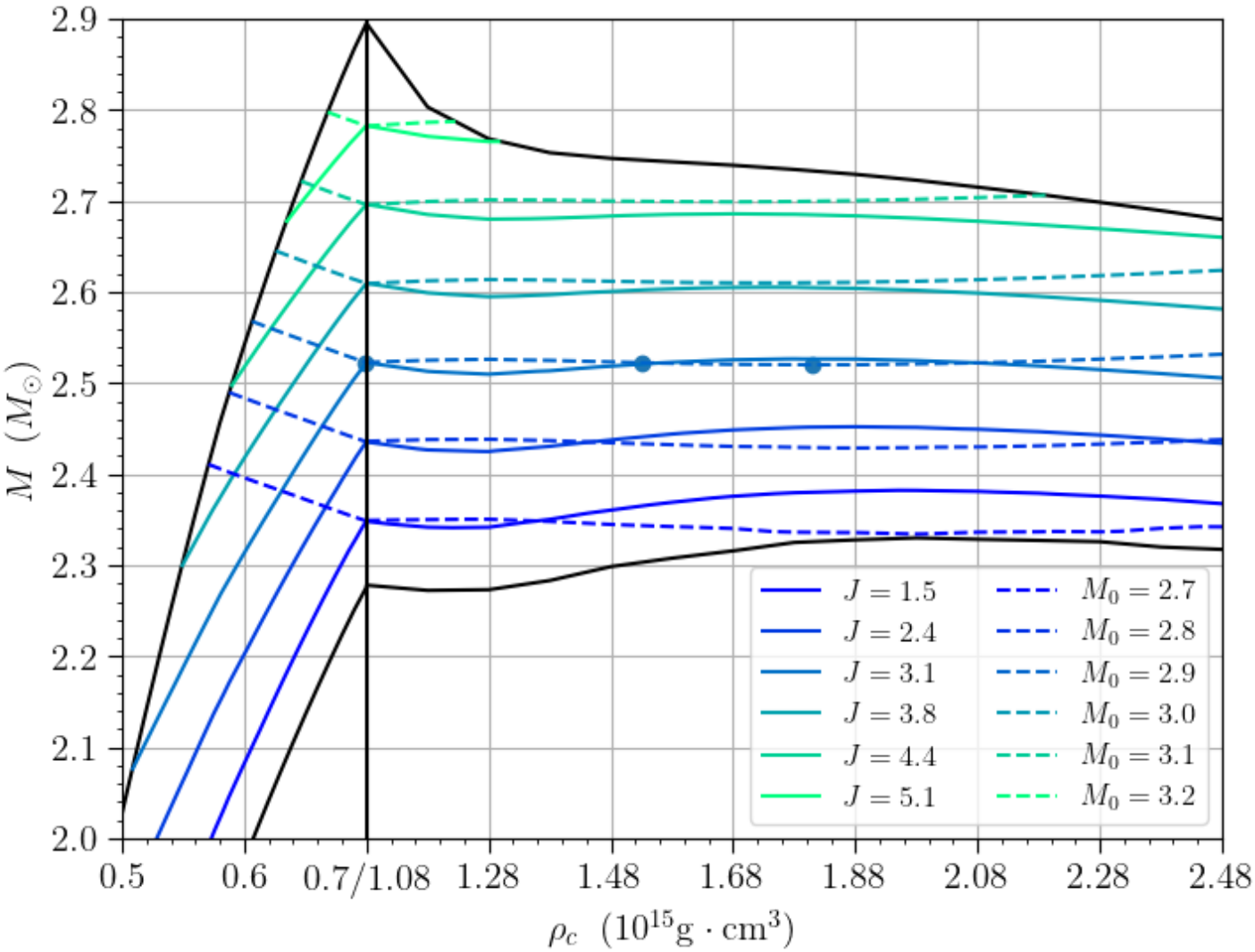
The EoS of hybrid star is as follows

$$e(p) = \begin{cases} e_{\text{hadronic}}(p) & p \leq p_{\text{tr}} \\ e_{\text{hadronic}}(p_{\text{tr}}) + \Delta e + c_s^{-2}(p - p_{\text{tr}}) & p \geq p_{\text{tr}} \end{cases}$$





Results: GRB afterglow light curves for hybrid stars



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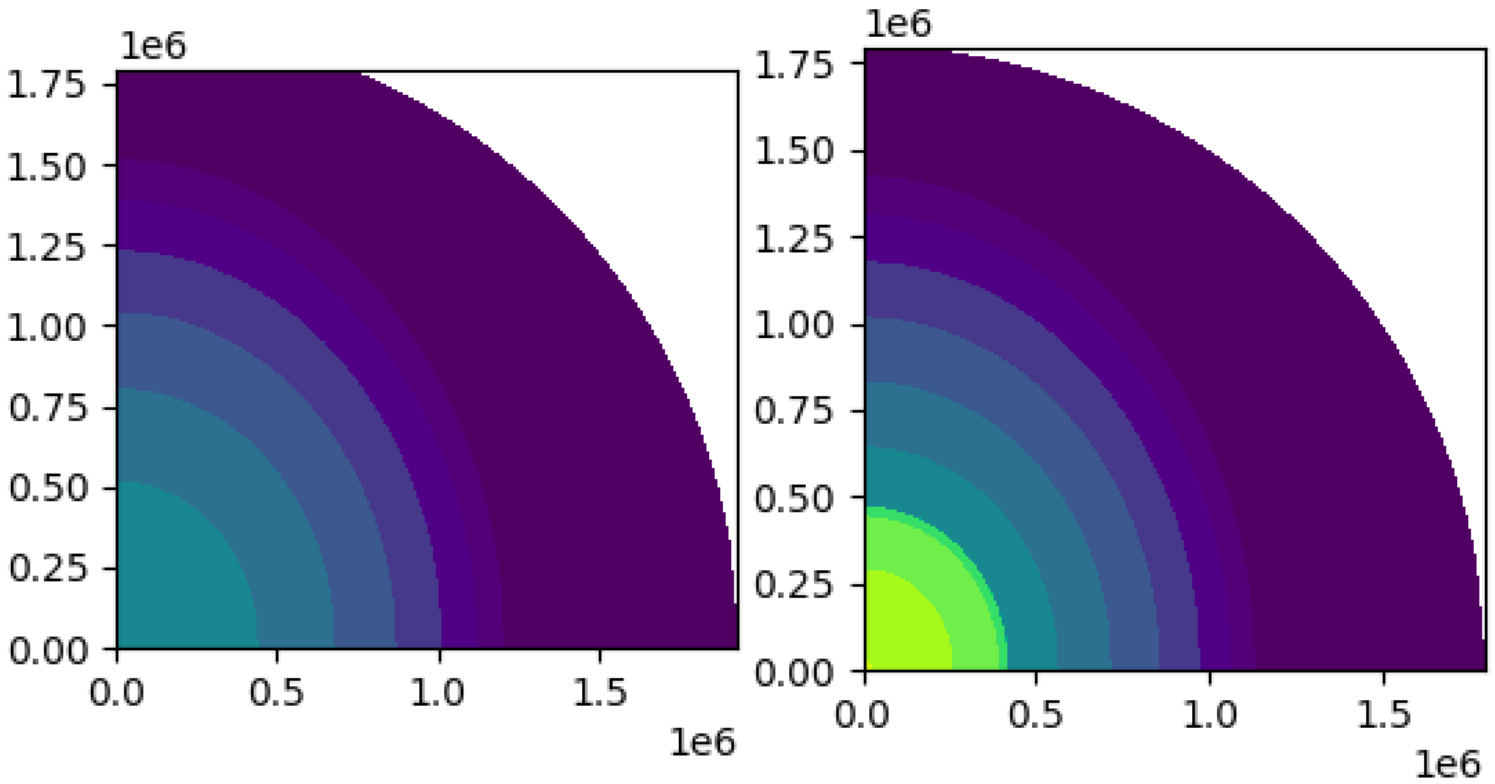

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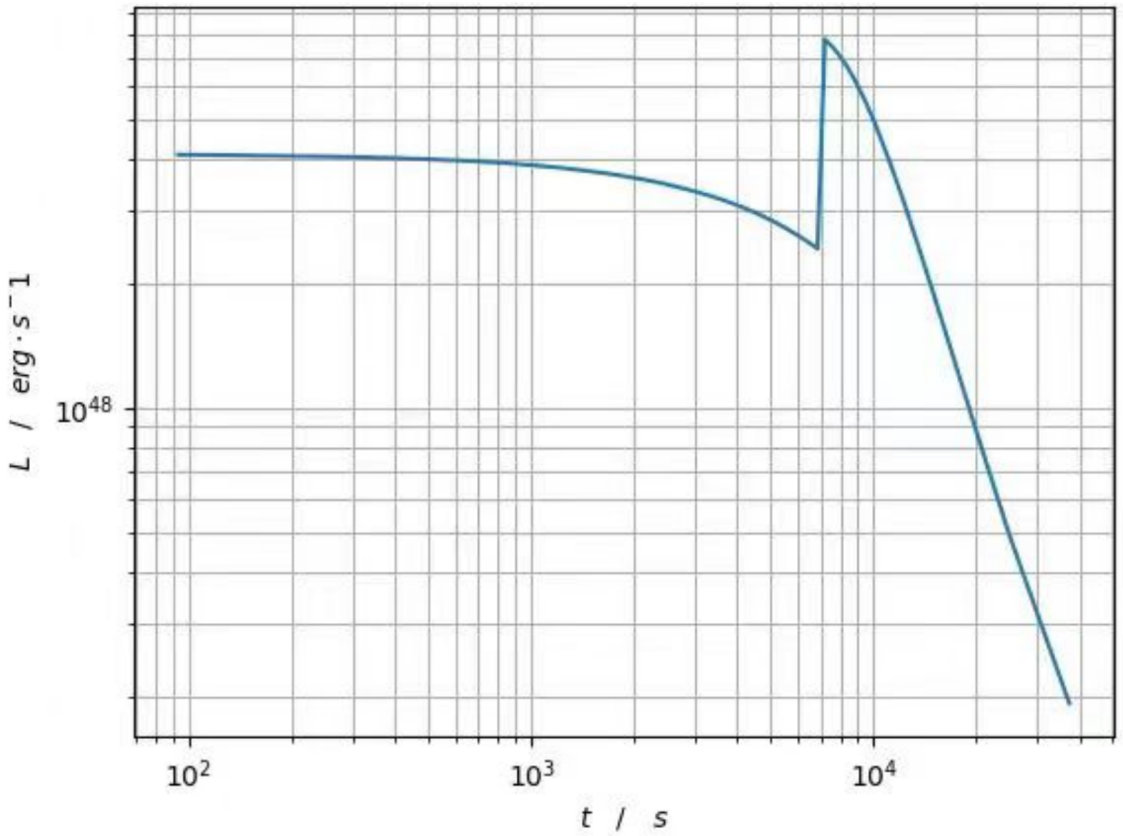


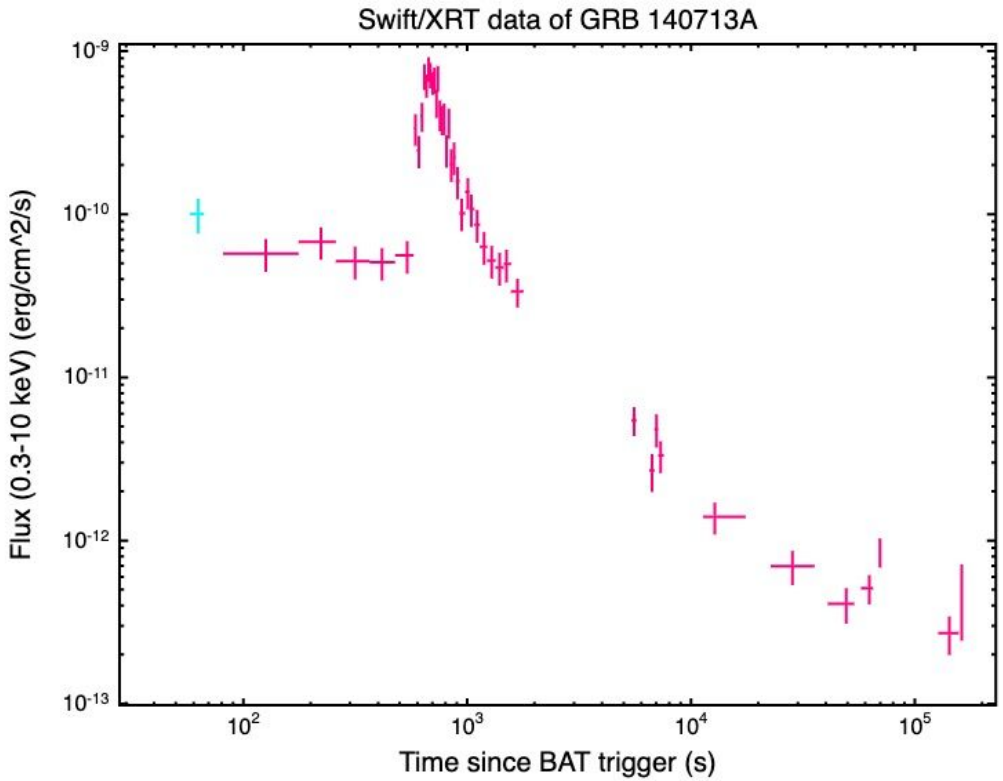
$M_0 = 1.8 M_\odot$
$e_{tr} = 5 \times 10^{14} g \cdot cm^{-3}$
$\Delta e = 5 \times 10^{14} g \cdot cm^{-3}$
Two features

- L increase by a factor of 3 5
- slope deeper after phase transition

Parameters

- $\Delta\epsilon : \Delta L$
- ϵ_{tr}, ω_0: t_{burst}

Results: GRB afterglow light curves for hybrid stars



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Results: GRB afterglow light curves for hybrid stars

hadronic eos	e_{tr}	Δe	M_0	ω_1/ω_0	R_1/R_0	ΔM
NL3	5	5	1.8	1.41	0.884	0.0018
NL3	5	5	1.97	1.36	0.905	0.0023
NL3	6	4	2.65	1.19	0.94	0.0017
SK272	6	5.5	1.485	1.27	0.99	0.0016

* densities in $10^{14} g \cdot cm^{-3}$, masses in solar mass

Conclusion

- New born magnetars will experience large change in central density during spin down.
- The increase of central density could cause strong interactiong phase transition.
- Phase transition could induce a shrink in the magnetar and a giant glitch in the angular velocity.
- The phase transition is potentially detectable in X ray light curve.