Exploring Multi-Messenger Evidences of a Magnetar Birth in GRBs

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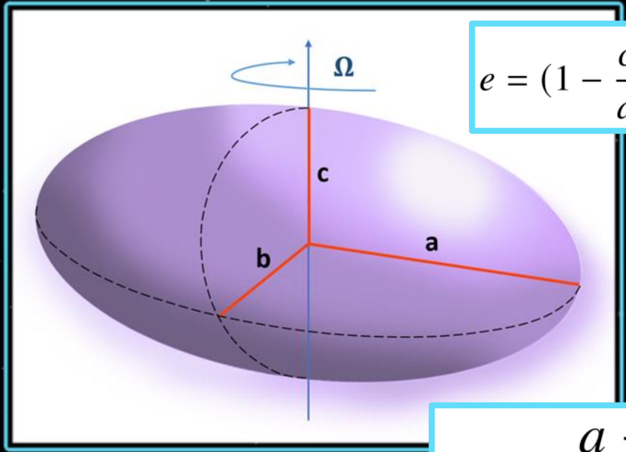
✦ Central Engine Model

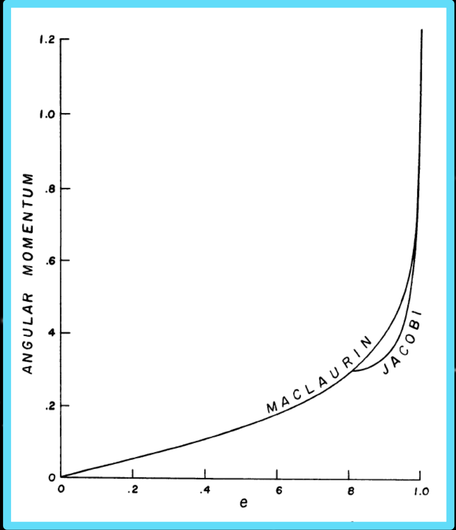
Maclaurin Spheroids

$$\Omega = \frac{2\pi}{P} = (2\pi\rho g(e))^{1/2}$$



$$e = (1 - \frac{c^2}{a^2})^{1/2}$$

$$\epsilon = \frac{a-b}{(a+b)/2}$$



EOS Models

Incompressible Fluid

Constant Density

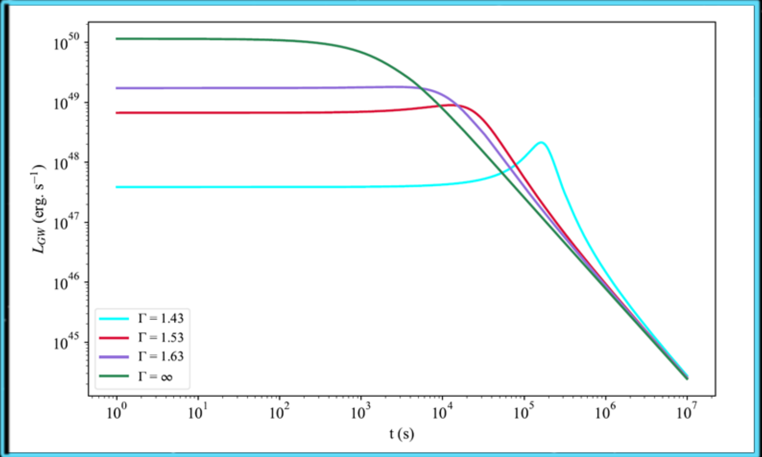
Compressible Fluid

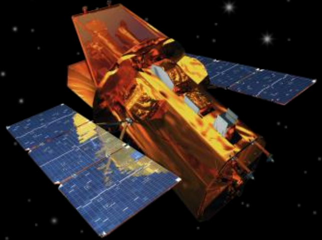
$$\left(\frac{\rho}{\rho_0}\right)^{\Gamma-4/3} = \frac{3}{2}(1-e^2)^{2/3}A_3(e)$$

L. S. Finn; S. L. Shapiro, Astrophysical Journal v.359, p.444
S. Chandrasekhar, Ellipsoidal Figures of Equilibrium, 1969

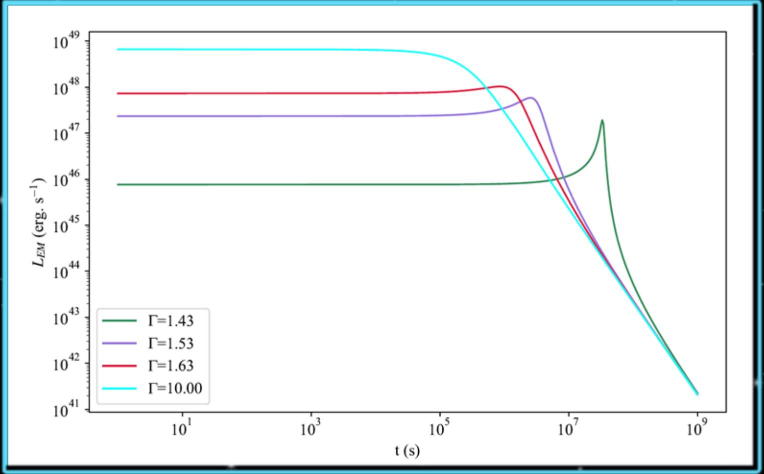
✦ EoS and Flaring Feature

GW Luminosity



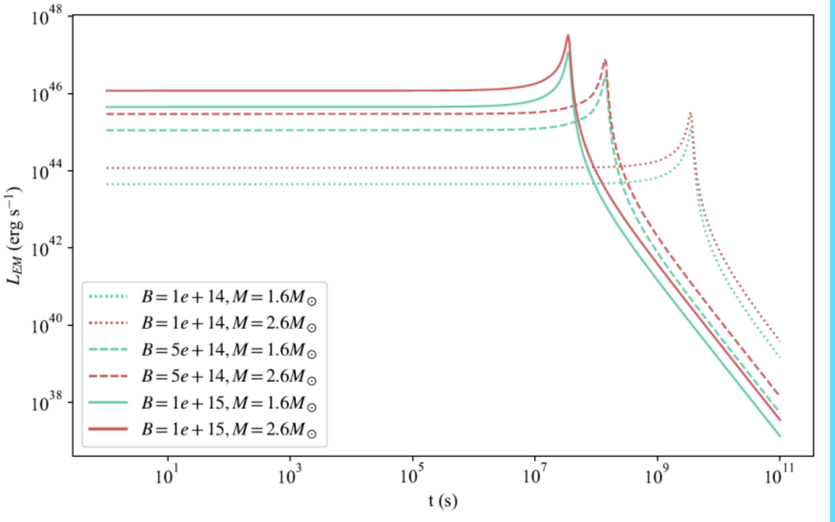


EM Luminosity

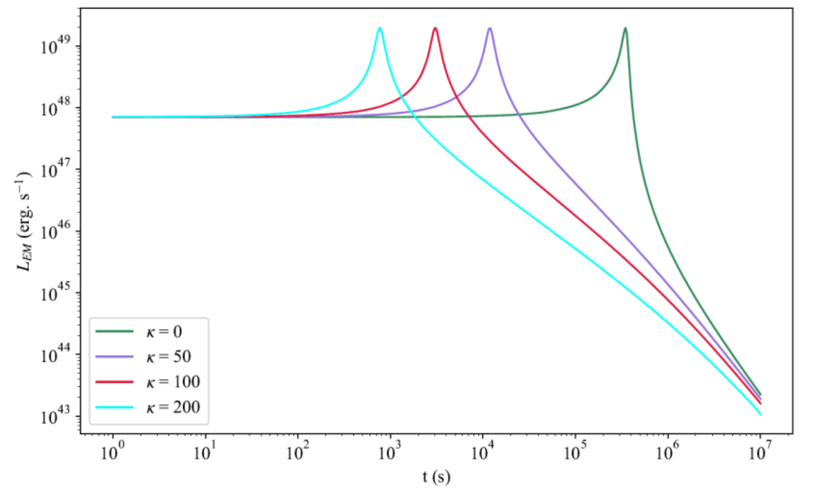


✦ Exploring The Effect of Free Parameters On The Light Curve

Magnetic Field & Mass



Quadrupole to Dipole Ratio



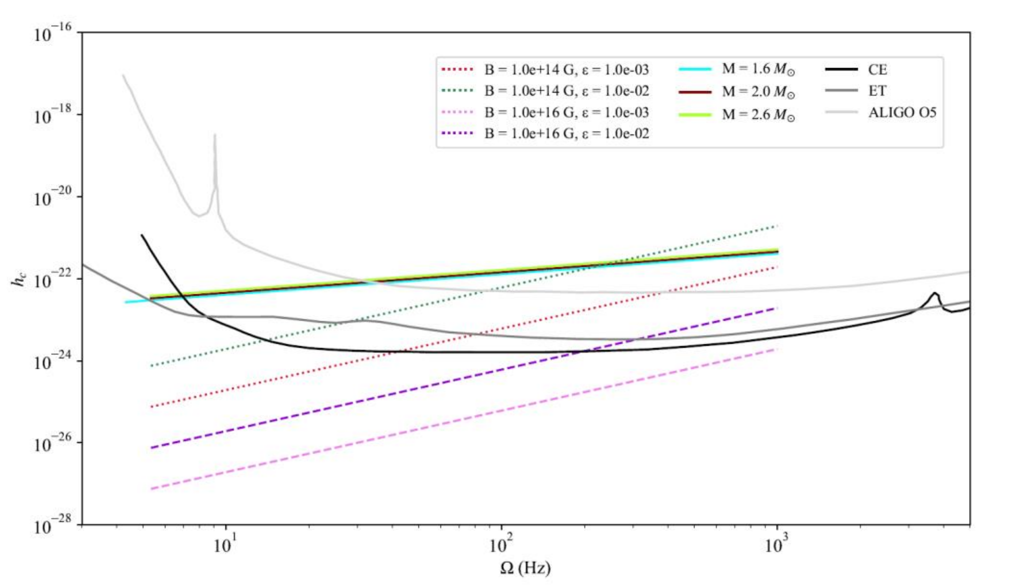
✦The Multi-Messenger Nature of Magnetars

GW radiation dominant

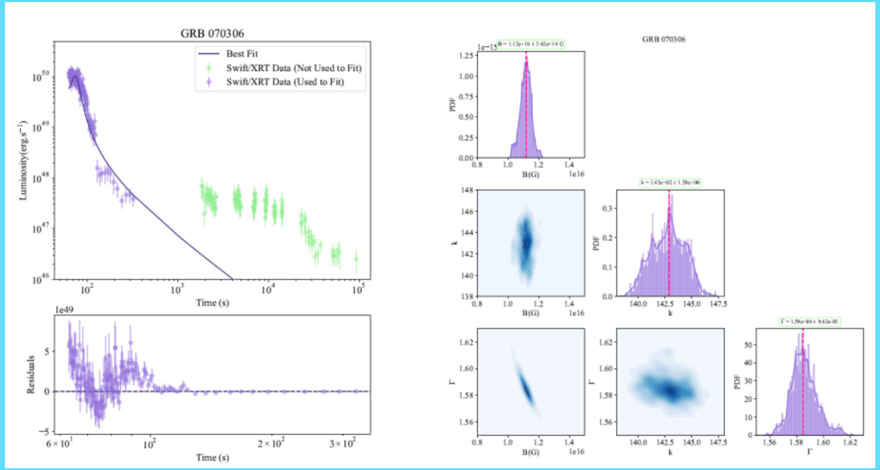
$$h_c(t) = \frac{1}{d}\sqrt{\frac{5If}{2}} = \frac{1}{d}\sqrt{\frac{5I\Omega(t)}{2\pi}}$$

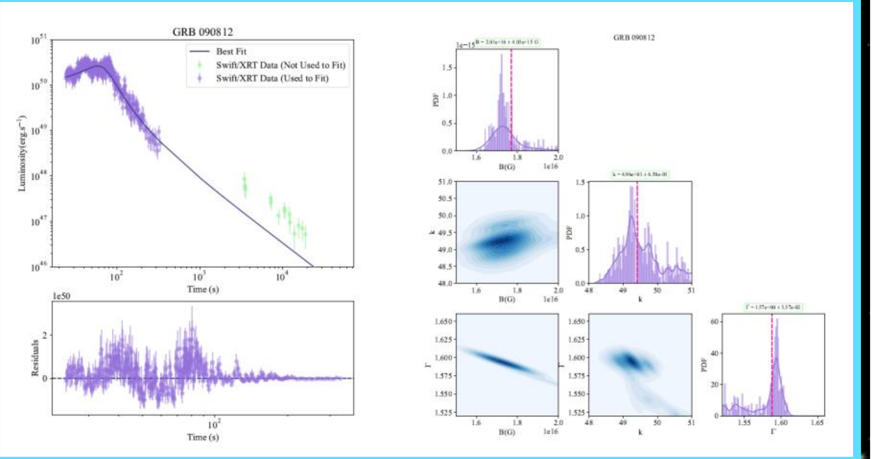
EM radiation dominant

$$h_c(t) = \frac{1}{d}\left(1 + \frac{16}{45}\pi^2 a^2 \kappa \Omega(t)^2\right)^{-1/2} \sqrt{\frac{24 I^3 \epsilon^2 \Omega(t)^3}{\pi B_{dip}^2 a^6}}$$



✦ Fitting Model to Swift/XRT Flare Data





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Multi-messenger signatures of a deformed magnetar in gamma-ray bursts

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ABSTRACT

We study the evolution of a newly formed magnetized neutron-star (NS) as a power source of gamma-ray bursts (GRBs) in the light of both gravitational wave (GW) and electromagnetic (EM) radiations. The compressible and incompressible fluids are employed in order to model the secular evolution of Maclaurian spheroids. It is shown that the GW and EM light curves evolve as a function of eccentricity and rotational frequency with time. We find that the light curve characteristics crucially depend on NS parameters such as magnitude and structure of magnetic field, ellipticity and the equation of state (EOS) of the fluid. The presence of X-ray flares, whose origins are not yet well understood, can be captured in our model regarding some specific nuclear EOSs. Our model allowing us to explain flares that occur within the wide range of 10 to 10^4 seconds and the peak luminosity in the order of 10^{46} - 10^{51} erg/s by using a reasonable set of parameters such as magnetic field strength around $10^{14} - 10^{16}$ Gauss, the quadrupole to dipole ratio of magnetic field up to 500. By applying our model to a sample of GRB X-ray flares observed by Swift/XRT, we try to constraint the crucial parameters of a deformed magnetar via MCMC fitting method. Our analysis shows that ongoing and upcoming joint multi-messenger detections can be used to understand the nature of GRB's central engine and its evolution at the early times of the burst formation.

Keywords: Multi-messenger–Magnetar – Gamma-ray bursts – Gravitational Wave–High-Energy Emission

1. INTRODUCTION

The physics behind GRB's central engine is still among astrophysics open questions, while many scenarios have been introduced to explain it (e.g., Li et al. 2018). The collapse of a massive compact star is a candidate for long duration GRB's central engine **?** and compact binary mergers can be served as a source of short duration GRBs Song & Liu (2023). There are several evidences that the GRB and its afterglow may be powered by a rapidly rotating highly-magnetised NS in which lose of angular momentum is a result of EM and GW emissions or is due to the accretion processes Rowlinson et al. (2013); Mösta et al. (2020); Bucciantini (2012); Bianco et al. (2024). The plateau phase in X-ray afterglow emission is observed in many GRBs (e.g., Liang et al. 2007; Li et al. 2012, 2015; Dainotti et al. 2020, 2022, and references therein) and can be explained by the spin-down of an ultra-magnetized millisecond NS Stratta et al. (2018); Gompertz et al. (2013); Wang et al. (2024). It has been demonstrated that the spin-down luminosity from multipolar EM emission can effectively account for the plateau phase in the majority of GRBs afterglows offering the complex magnetic field structure of magnetars as one of the candidates for GRB's central engine Wang et al. (2024).

X-ray flares are also frequent events occurring in about 33 percent of GRBs within a time interval ranging from 30 to

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Thanks!