Constraints on the origin of magnetar flares

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Three giant flares from magnetars have been observed, in SGRs 0926, 1900, and 1806.

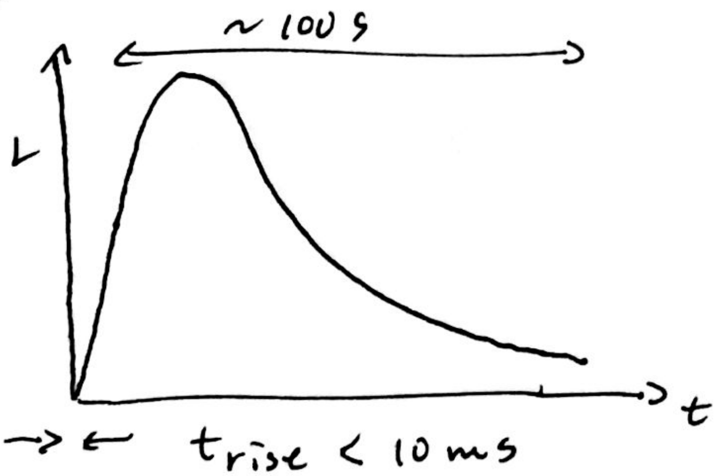
Energy release $E \sim 10^{43} - 10^{44}$ erg
↑ SGR 1806

$\Rightarrow B_{dipole} \sim 10^{15}$ G

<u>Question</u>: Where is the energy stored just before the flare, inside the star or in the magnetosphere?

<u>Answer</u>: In the magnetosphere. (Detailed calculations are given in Link 2014, MNRAS, 441, 2676).

Data...



Energy liberated in the core cannot enter the magnetosphere in < 10 ms – it takes much longer – and so must be stored in the magnetosphere

Two scenarios:

1) core storage (Thompson and Duncan 2001).

The twisted field inside the star <u>suddenly</u> relaxes, e.g.,

2) Magnetospheric storage (Lyutikov 2003).

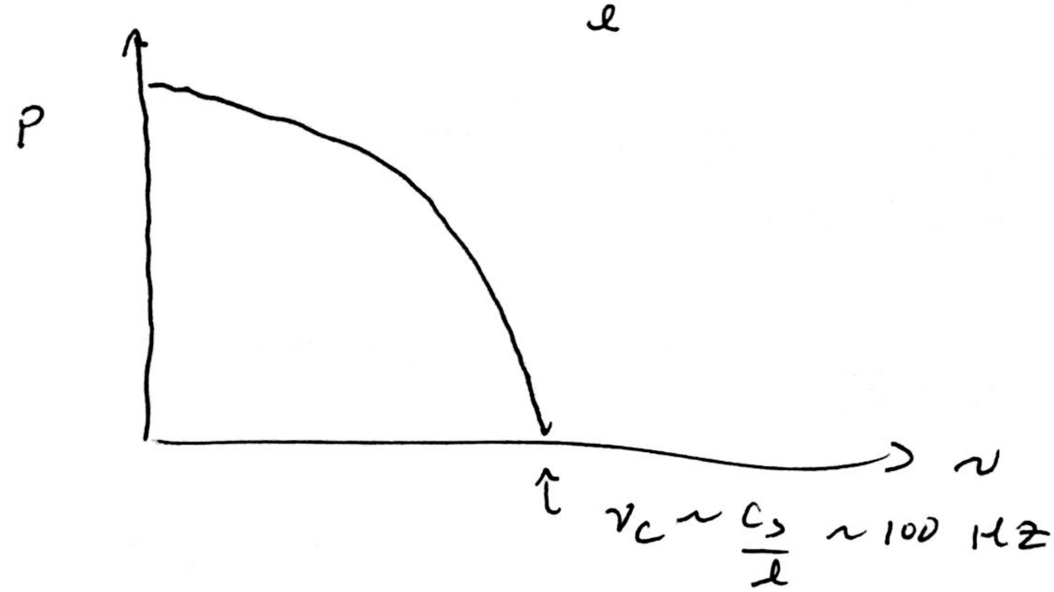
<u>Adiabatic</u> stressing of the magnetosphere leads to an instability, like a coronal mass ejection in the Sun.

I'll now discuss how the core storage model fails.

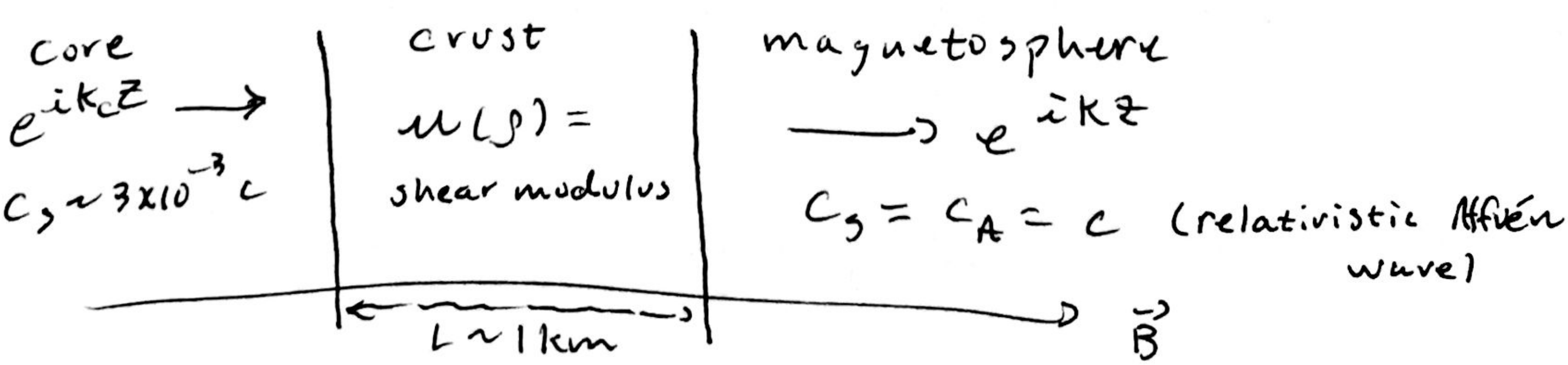
Suppose magnetic energy in the core, stored in volume ℓ^3, is suddenly released. The energy in the flare is bounded by

$$E < \ell^3 \frac{B^2}{8\pi} \Rightarrow \ell > 6\ \mathrm{km} \left(\frac{E}{10^{46}\ \mathrm{erg}} \right)^{1/3} B_{15}^{-2/3}$$

Much of the stellar volume must be involved.
Shear waves will be excited in the core.
Their speed is $c_s \sim 3\times10^{-3}\,c$.
The Fourier power in the excited waves will drop near $\nu_c \sim \frac{c_s}{\ell} \sim 100$ Hz.



How quickly can energy escape? Shear waves escape most efficiently in regions where $\vec{B}$ is perpendicular to the stellar surface, allowing direct conversion to relativistic Alfvén waves. Consider a planar problem



Note that there is a severe impedance mismatch between the core and magnetosphere
$\Longrightarrow$ significant reflection of energy back into

the core.

For $\nu \lesssim 100\ \mathrm{Hz} \Rightarrow k_c l \ll 1$

In this limit, the energy transmission coefficient is

$$T \simeq 4 \frac{c_s}{c} \sim 10^{-2}$$

The energy is trapped in the core for a time

$$t_{trap} = \nu_{esc}^{-1} = \left[\frac{c_s}{2R} T \right]^{-1} \sim 10\ \mathrm{s}$$

$$\gg t_{rise} < 10\ \mathrm{ms}.$$

The core storage scenario is ruled out; the energy cannot escape nearly fast enough.

⇒ Energy must be stored in the magnetosphere just before the flare. One possibility, not the only one, is that the magnetic footprints are moved adiabatically, stressing the magnetosphere until a reconnection instability lowers the magnetic energy. The field could tear very quickly, over a timescale as short as

$$\frac{l}{c} \sim 3\times 10^{-5}\ \mathrm{s} \ll t_{rise}$$

<u>Corollary</u>: The neutron star is highly reflective to Alfvén waves in the magnetosphere

The energy reflection coefficient is

$$R = 1 - T \simeq 0.99$$

QPOs have been observed. Can they be excited by a magnetospheric explosion before the waves damp?