Damping of Magnetar Oscillations induced by Giant Flares

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Compact stars and gravitational wave astronomy

第4回DTAシンポジウム@国立天文台

QPOs in Magnetar Giant Flare

Energetic events in our Galaxy

- SGR1806-20(Galactic 6-15kpc) Event in 2004

$$P = 7.5\sec, B_d = 2.1\times 10^{15} G$$

$$\Delta E_{EM} \approx 10^{46} ergs$$

[>>Bursts, Brightening AXP $\Delta E_{EM} \approx 10^{41-42} ergs$]

$$E_G \approx 10^{53}, E_{Rot} \approx 10^{45}, \underline{E_B \approx 10^{48}}, E_T \approx 10^{43}, \ldots ergs$$

✓ Magnetic Energy Source $B \approx 10^{15} G$

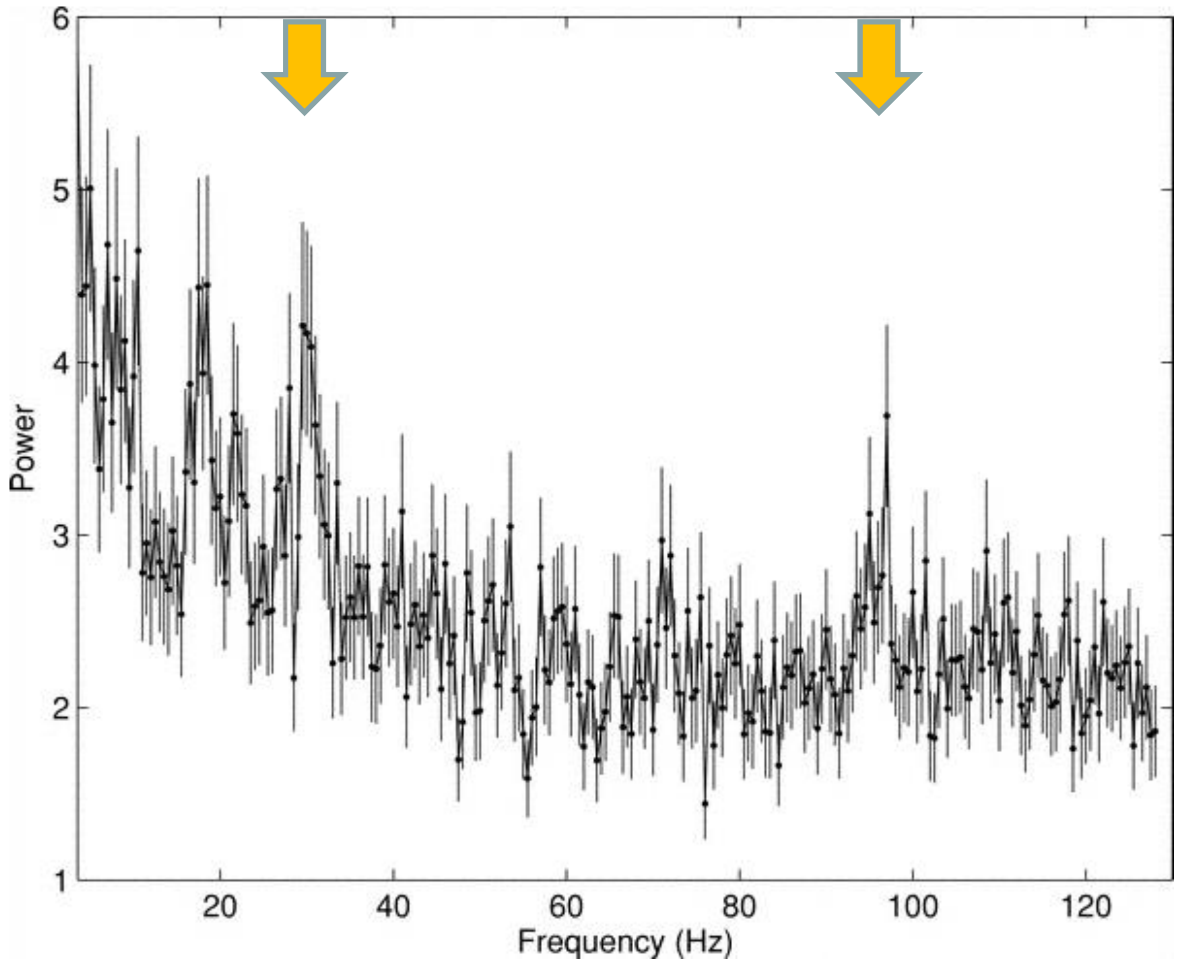
✓ QPO observed in hard X-rays (<200kev)

30Hz(2,0) 92Hz(6,0) 150Hz(10,0),… Magneto-shear oscillation

Important timescale puzzle <-> GW emission

SGR1806-20 Israel+ 2005

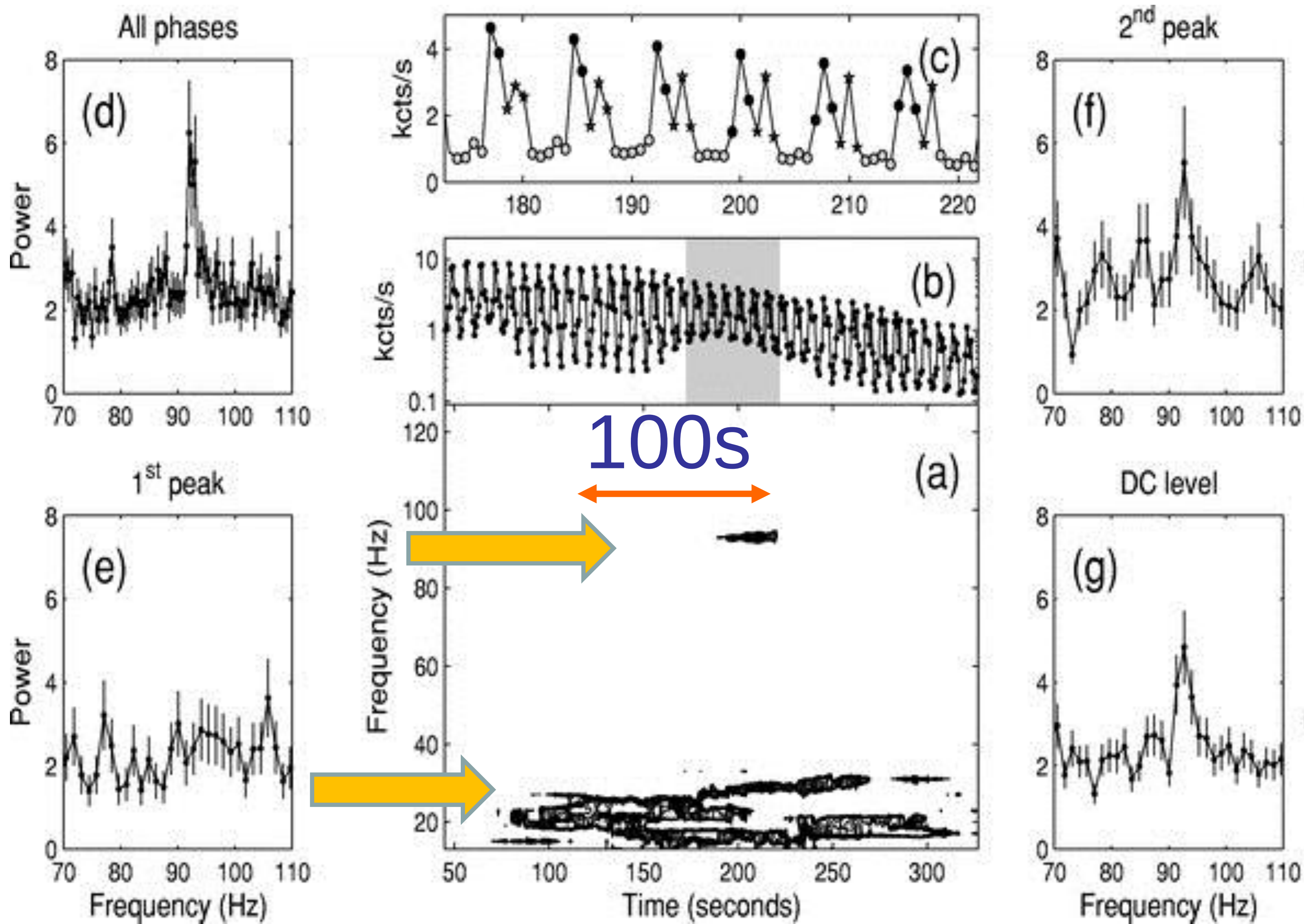
$P(\nu)$



$\nu[Hz]$

Peaks at 20, 30, 95Hz during 200-300s

SGR1806-20 Israel+ 2005



Timescale Puzzle

QPO observed in a specific time ~1000 s

- Long timescale >> dynamical one

$$R/c \approx 10^{-3}, R/c_s \approx R/c_A \approx 0.1\mathrm{sec}$$

- Short compared with damping timescales discussed later

->Theoretical task to identify the mechanism

Numerical simulation < 10 sec

(Gabler +, Sotani, Lasky, Zink, Kokkotas+ …..)

->It is necessary to follow thousands of oscillations

Site of energy deposit

$$\Delta E_{EM} \approx 10^{46} ergs$$

Energy associated with mag. configuration change

Order-of-magnitude estimate in magnetars

$$E_{EM} \approx 2\times 10^{48} B_{15.5}^2 R_6^3 ergs$$

$$\varepsilon_{mag} \approx 1(B_{15.5})^2 [kev/fm^3]$$

- Core

$$\varepsilon_g \approx 200 Mev/fm^3$$

Strong force allows 'small' deviations

- Crust

$$\varepsilon_{str} \approx 0.1[kev/fm^3]$$

NS with mountain

(Horowitz & Kadau 2009)

$$\varepsilon \approx E_{str}/E_{gr} < 4\times 10^{-6}$$

- Magnetosphere

Change between twisted magnetic configurations

1 Triggered in Core

If (hypothetical) phase transition is a trigger,

$$\Delta E_{Flare} \sim \Delta E_{Osc} >> \Delta E_{EM} \approx 10^{46} ergs$$

magneto-shear oscillation in crust may be induced.

GW burst is expected before initial EM spike.

Otherwise, it is difficult to excite core vibration except for extreme field $B > 10^{18} G$

Observational upper bound in GW is important

Upper limit of GW (LIGO S5 PR07)

$$h_{rms} \leq 4.5 \times 10^{-22} Hz^{-1/2}, \Delta E \leq 7.7 \times 10^{46} erg$$

$$\Delta E \approx (c^5 / G)(\nu h d / c)^2 \Delta t$$

-> Hope for upper limit by aLIGO, KAGRA

2 Triggered in Crust

Strongly coupled with exterior

$$\Delta E = \Delta E_{cr} + \Delta E_{ex}$$

$$\Delta E_{cr} \approx 10^{41} R_6^2 \Delta R_1, \underline{\Delta E_{ex} \approx 10^{47} B_{15}^2 R_6^3 ergs}$$

Dipole almost unchanged

Toroidal, higher multipoles

Reflection/transmission is important

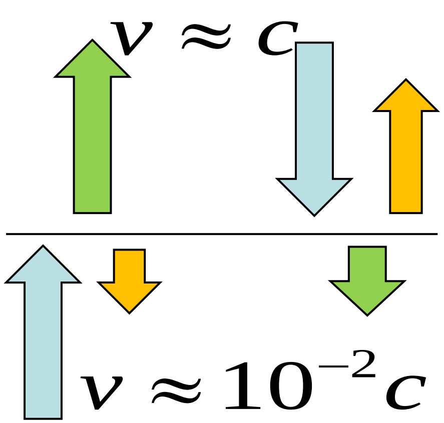
Initial spike by Alfven wave collision at top of flux tube (Takamoto+ 2014)

Transmission & Reflection of Alfven waves at surface

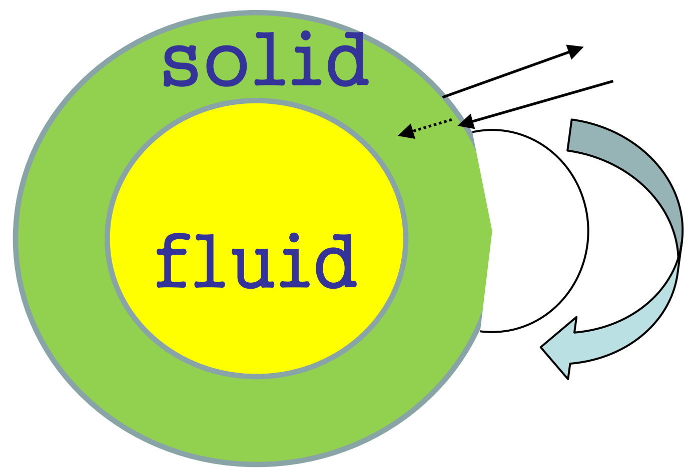
Propagation from interior to exterior

at $(R/c_A)r_{tr} \approx 1\text{sec}$

In the evolution after 1sec., global structure is important.



$$r_{tr} \approx 0.1 B_{15}^2 \nu_3^7 \cos\alpha$$
$$@\nu = kHz, B = 10^{15}G$$



$$\Delta R / R \approx 0.1$$

Melting crust by incoming Alfven wave
> 1sec (Li & Beloborodov 2015)

Damping of mechanisms for oscillations

- EM radiation approximated by Poynting flux

  No wave propagation with low freq.

  Actual mechanism : pair creation, current,…

outward energy flows ⇒ $P_{EM} \approx P_{Poyn}$

By analogy with pulsars

$\tau \approx E / P \approx 10^7 \sec(l = 2);$ $P_{Poyn} = a(\omega R / c)^6 B^2$

Too long

Differences

Pulsar (stationary) $\dot{E}_{Rot} >> \dot{E}_{EM}$

Magnetar $\Delta E_{EM}\ ? < or > \Delta E_{Osc}\ ?$ strong B

cont. 2

- Joul loss

- Power $P \approx \int \sigma^{-1} j^2 dV \approx 10^{33} \sigma_{22}^{-1} B_{15}^2 R_6 [erg/s]$

- Damping timescale > $10^5\ years$
- Conductivity $\sigma = e^2 n_e \tau_c / m_e$

core surface atmosphere(fully ionized gas)

$\sigma \approx 10^{29}, 10^{22}, 10^{18} [s^{-1}]$

- Or anomalous resistivity required

$\sigma \approx 10^{14} [s^{-1}]$

cont. 3

- Damping by neutrino viscosity

Unkown, but expected to be small.

$$\delta\rho \approx 0 \approx \delta T \Rightarrow L \approx 0$$

Estimate by energy

Emissivity by plasmon, brem, pair

$\varepsilon \approx 10^{20} erg/s/cm^3$ @crust is small

Except for dir. Urca $\varepsilon \approx 10^{26} erg/s/cm^3$ @core

Cooling ~1 year

Summary

Giant flare is attractive to GW astronomy, but involves many uncertainties.

Timescale puzzle is briefly discussed, but the relevant mechanism is unknown.