Coherent Radio Emission from Magnetar Starquakes

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Why Magnetars?

- Known source!
- Birthrate >~10^{-4} yr^{-1} $Galaxy^{-1}$
- Repeat activity
- Magnetic energy > 10^{40}J
- Elastic energy ~10^{39}J
- Magnetars glitch, wander and flare
  - **FRB rotational energy could be much larger**
- Active when young
- Pulsars produce coherent radio waves

Starquakes

- Pulsar glitches – $\Delta P/P$ <~10^{-6} ~ 10^{35}J
  - Vortex line unpinning?
- Shear modulus

eg Blaes et al 1989

  - $\mu \sim 0.02$ K in lattice
  - Surface at N drip: $\rho \sim 4 \times 10^{14}$ kg m^{-3} ; K ~ 10^{29}Nm^{-2}
  - Most of crust moves horizontally, incompressible
- Magnetic stress >~ μ
  - Field lies in fault plane (cf Levin &Lyutikov 2012)
  - Shear speed->c; ν~100kHz; good transmission
- Magnetic failure following slow evolution

Slow variation: Potential Field

$$B = -\nabla\psi$$

- e.g. dipole $\psi \sim \cos\theta/r^2$; field lines: $r \sim \sin^2\theta$
- $ds/d\cos\theta \sim (1+3\cos^2\theta)^{1/2}$
- Slow variation of surface field due to horizontal motion
- Slower magnetospheric current / twist dissipation time (cf Thompson et al 2002)
- Incompressible motion– stream function
- Slowly varying potential fields

Now, consider rapid changes

Force-Free Electrodynamics

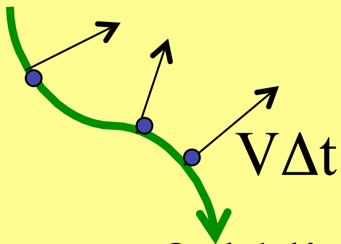
- Sufficient plasma for currents; insufficient for inertia

$$\rho E + j \times B = 0 \Leftrightarrow E + V \times B = 0; V = \frac{E \times B}{B^2}$$

$$\frac{\partial E}{\partial t} = (\nabla \times B)_\perp - (\nabla \cdot E)V$$

- Characteristics
  - Fast mode: $\omega=k$
  - Intermediate: $\omega=k_{||}$; $V_g=1$ along B; favored?

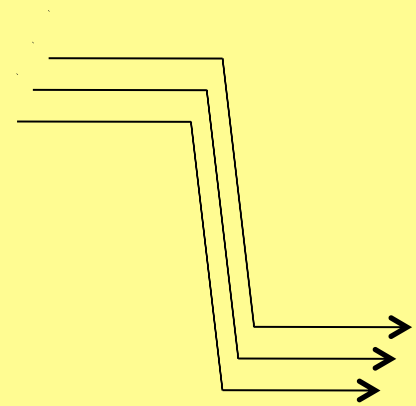
Smooth ParticlE ElectroDYnamics



- Nonlinearity and wave steepening: $\delta B/B \sim B^{-1/2}$ on open field lines
  - Cracking the whip

Perhaps a current front propagates into magnetosphere

Observing a Current Front?



- Pairs freely made
  - $t_{cool} << t_{dyn}$; min ground gyrational state
  - Particles irrelevant; $j^{\mu}_{ret} \rightarrow A^{\mu}$
- Orthogonal polarization – fast mode
  - Mode conversion
- $t_{obs}=s(r)-n.r$
  - Depends on orientation with respect to open field lines
- Doppler beaming
  - Maximum intensity from point of tangency

Coherent Radio Emission??

- **Relativistic pulses are radiatively efficient**
  - **Calculate as near field or far field?**
    - cf EMP
    - cf (not a) PBH search (Rees 1976, Blandford, 1977)
  - **No absorption**
  - **Polarization**
  - **Radiation reaction important for dynamics**
- **~GHz radio emission requires:**
  - **Either $\Gamma \sim 50$**
  - **Or current filamentation?**

Summary+TBD

- Circumstantial evidence -> conviction?
- Free energy in field and stress
- Relativistic environment -> high energy
- Force-Free simulations
  - Steepening of pulse when nonlinear
  - Rotation
  - Caustics?
- Structure of current fronts
  - High energy emission