Magnetars, Electromagnetic Pulses and Fast Radio Bursts

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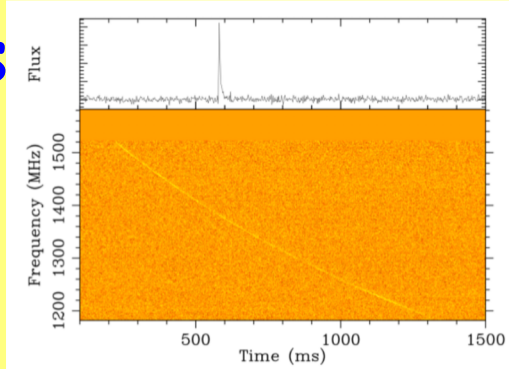
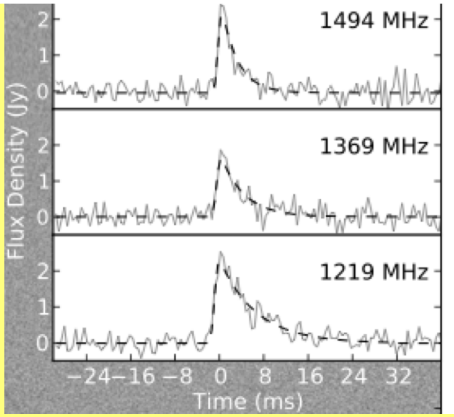
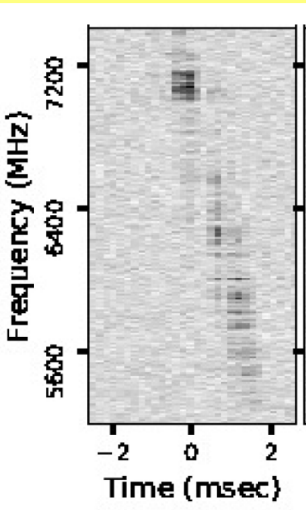
Fast Radio Bursts

- 2007 Lorimer (2001) burst/perytons
- ~GHz (only?) ~1ms? radio bursts
  - Dispersed and broadened; =>d<~2 Gpc?
  - $E_{FRB} \sim 10^{33} f_{beam}$ J? <<SNR, GRB
  - $\delta t >\sim 30\mu s$, spectrally complex
  - $T_B \sim 10^{30\text{-}40}$K?cf giant pulses
  - Can be highly linear (and circular) polarized
  - ~ 50 FRB; all sky frequency ~100 mHz?
- FRB 121102 - repeater
  - z~ 0.2 dwarf galaxy; steady source
  - Large, variable RM





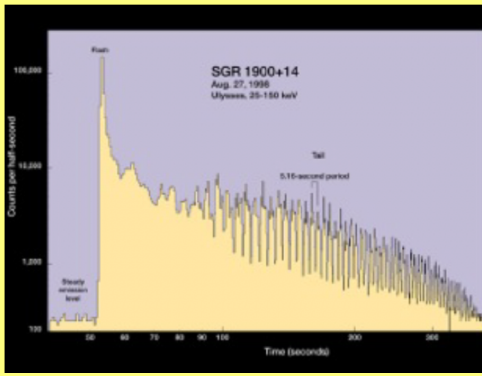


Many models: ET, DM, SGR/SN, AGN, PSR…
Should learn much, soon, CHIME, DSA, ASKAP…

Magnetars?

(Popov, Postnov…)

- B <~ 10^3 B_{Crab} ~100 GT; P~ 3-10 s *(Thompson, Duncan; Kouveliotou; Kaspi, Beloborodov)*
  - SGR, AXP
  - MSM could be endpoint of stellar evolution
- Birthrate >~10^{-4} yr^{-1} $Galaxy^{-1}$
  - Repeat activity - 1-10 per magnetar
- Magnetic energy > 10^{40}J; elastic energy ~10^{39}J
  - Rotational energy ~ 10^{45} J but soon lost; P~5s
- Magnetars flare
  - $E_{X\gamma}$ ~$10^{37\text{-}39}$ J; magnetic? rotation
  - Radio sometimes but



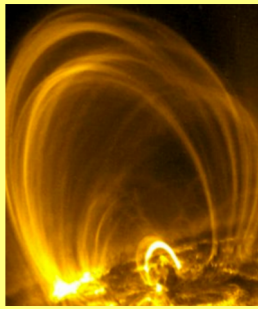
Relativistic, spinning SF+SC nuclear matter with B~30 B_{crit}
The boring and conservative explanation!

Why Magnetars?

- Known source!
- Birthrate ~10 mHz; FRB ~0.1-100mHz
- Repeat activity
- Magnetic energy > 10^{40}J
- Elastic energy ~10^{39}J
- Magnetars glitch, wander and flare
  - Rotational energy could be much larger
- Active when young <~ 100yr?
- Pulsars produce coherent radio waves

Quakes and Flares

- **Pulsar glitches – $\Delta P/P <\sim 10^{-(6-8)}$ $\Delta E \sim 10^{30-32}$ J**
  - Vortex line unpinning?
  - Magnetars are slow rotators; ρ_{GJ} unimportant
- **Neutron astrology** *(eg Blaes et al 1989, Levin & Lyutikov 2012)*
  - $\mu \sim 0.02$ K in lattice, maximized below neutron N drip?
  - $\rho \sim 4 \times 10^{14}$ kg m^{-3} , $\mu \sim 10^{28}$ Nm^{-2}, B ~ 100 GT
  - Most of crust moves horizontally, incompressibly
  - L ~ 300m, $E_{magnetoelastic} < 10^{34} \varepsilon_{-1}^2$ J; $V_{shear} \sim .01$-1 c, t ~ 3-100μs
  - Good transmission unlike pulsars
- **Magnetic flares** *(Beloborodov)*
  - Most of surface covered with closed field lines
  - Complex, multipolar, potential field has "coronal holes"
  - Invoked for SGR etc

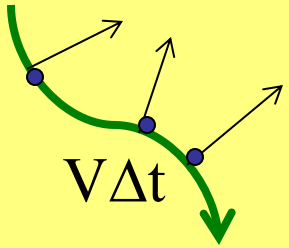


Force-Free Electrodynamics

- Sufficient plasma for currents; insufficient for inertia

  $\mathbf{j} = [\,(\mathbf{B}\cdot\mathrm{curl}\,\mathbf{B} - \mathbf{E}\cdot\mathrm{curl}\,\mathbf{E})\mathbf{B} + \mathrm{div}\,\mathbf{E}\;\mathbf{E}\times\mathbf{B}]/B^2$

- Characteristics for linear waves
  - Fast mode: $\omega = k$, unimportant
  - Intermediate mode: $\omega = k_{\|}$; $V_g = c$ along B; favored?



- Amplitude growth: $\delta B/B \sim B^{-1/2}$ on open field lines
  - Nonlinearity-> steepening when r > ct ~ 100 km
    - Bullwhip, tsunami…
  - Compute using Smooth Particle ElEctroDYnamics?

Pulse of toroidal field propagates into magnetosphere along open field lines?

Pair Production

- T_{ns} ~ 10MK; Compton processes near star
  - E ~ 10 EV/m !
  - E.B?
- R ~ 10-10^3 R_{ns}
  - Curvature γ-rays
  - γ-B pair production
  - Avalanche
- Eventually pair production ceases
  - Mode convert to EM wave

ElectroMagnetic Pulse

- **Linear e-mode launched at R_{ns}**
  - $(\delta B_\phi/B) \sim 0.05$; $\lambda \sim 300$m; $U \sim 10^{33}$J;
  - pair production by inverse Compton, synchrotron processes
- **Wavefront become nonlinear at $R_{nl} \sim 10\ R_{ns}$**
  - $(\delta B_\phi/B) \sim B^{-1/2}$
- **Wave detaches from field, propagates spherically, may steepen**
  - Energy $\sim B_\phi^2 R^2 \Delta \sim$ const; Flux: $B_\phi R \Delta \sim B_{dipole} R^2 \sim R^{-1}$;
  - => $B_\phi \sim$ const, $\Delta \sim R^{-2}$;
- **Pair production too slow when $R \sim 1000\ R_{ns}$??**
  - $\Delta \sim 0.1$ m -> GHz frequencies
  - Linearly polarized
  - Intergalactic propagation disperses and scatters wave.
  - Alternatively an "Anomalous Cyclotron" maser may operate.

Waves are launched and may steepen => ~GHz emission?

Propagation Effects

- **High brightness radio emission subject to:**
  - **Induced Compton Scattering**
  - **Stimulated Raman Scattering**
  - **Same as pulsars**
- **Interstellar and Intergalactic Scintillation**
  - **Powerful probe of plasma turbulence spectra**
    - Many correlations predicted
- **Gravitational Lensing**
  - **Await macrolensing delay in months for ~10^{-3} FRBs**
  - **Microlensing by stars**

FRBs even more interesting as probes than as sources?

Summary

- FRB are <ms radio pulses every minute
- Good for Ap, Cos, plasmas, QED?
- Magnetars (ρ_{nuc}, $10^{15}G$, $0.1c^2$)-HED Heaven!
- Quake/flare create EMP
- Force free electrodynamics with pairs
- e-mode along B - nonlinear,steepen -> EM
- Polarized pulses dispersed and broadened
- Should repeat without observable γ-rays
- Good near-term observational prospects
- Pulsarshine?