Magnetar Corona

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Anomalous X-ray Pulsars (AXP)
Soft Gamma Repeaters (SGR)

(Thompson&Dunkan,92;
Kouvelitou et al., 98)

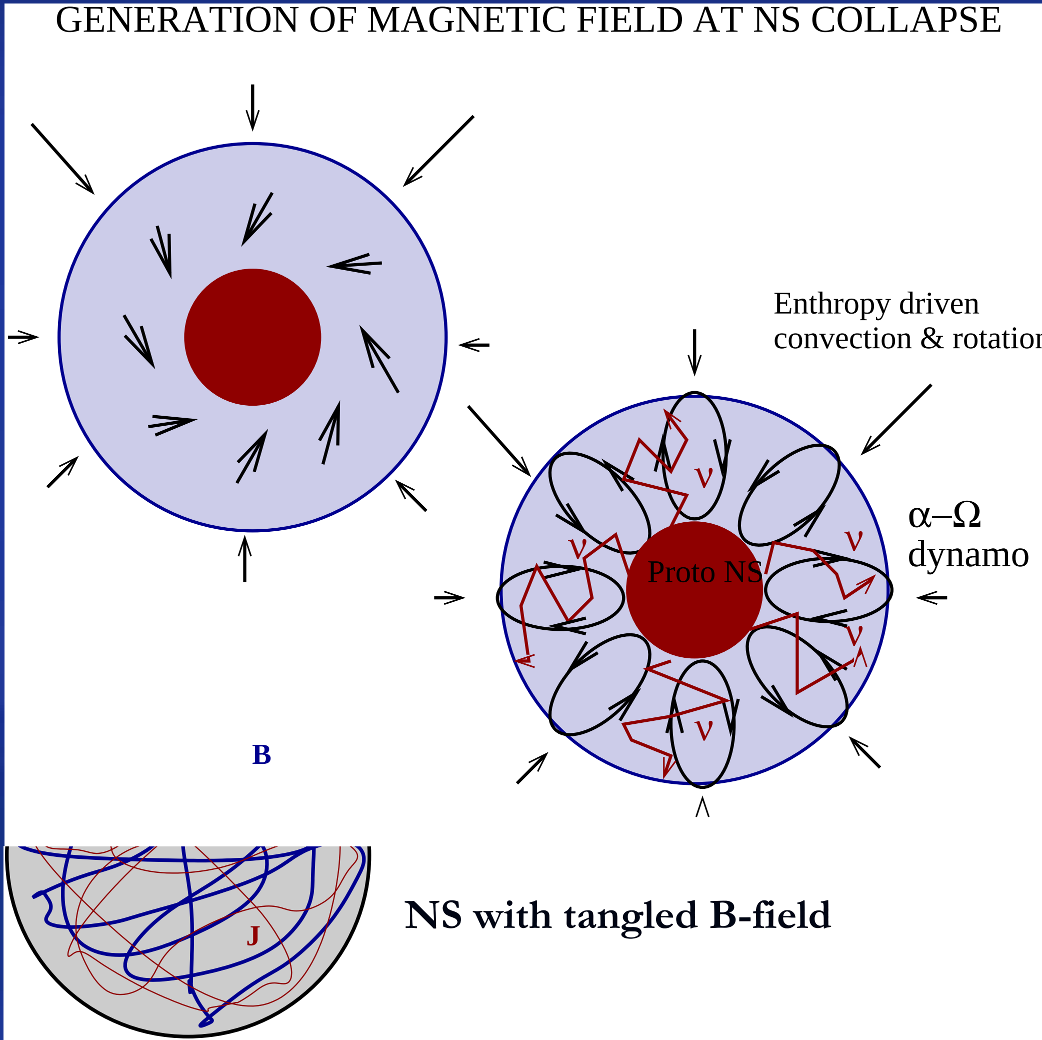
- 5 AXP, 5 SGR
- Neutron stars, $M \sim 1.4\ M_{Sun}$, $P = 5 – 12$ s - slow
- Young $P/P = 3\ 10^{3} - 4\ 10^{5}$ yr
- Isolated (not accretion-powered), associated with SNRs
- X-rays: bursts and persistent:

  $L_X = 3\ 10^{34} - 10^{36}$ erg $s^{-1} > 100\ I\ \Omega\ \overset{\circ}{\Omega}$

  Bursting (SGRs, $L \sim 10^{5}\ L_{Edd}$, AXP – rare and weak)
- L_x comes from decay°of super-strong B-field
- $B \sim 10^{15}$ G – Magnetars

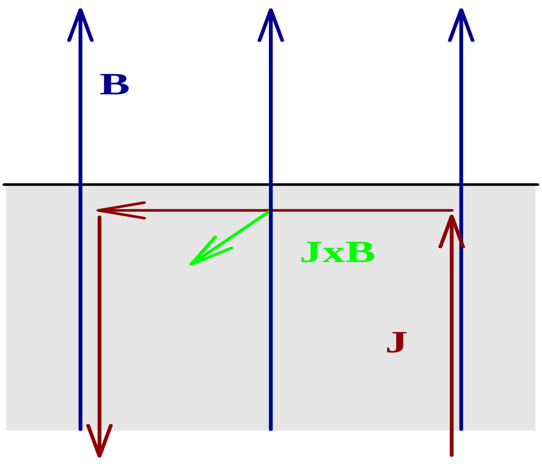
How is B-field generated? Dynamo

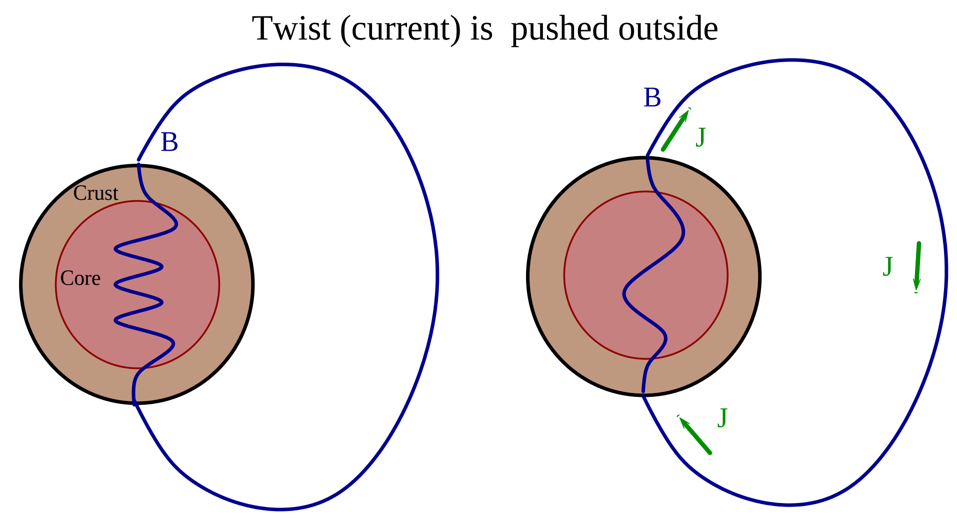
- Collapsing Fe core of a SN progenitor
- Conservation of angular momentum → rotation
- Optically thick ν-emsn
- Convection
- Shear stretches B_φ, convection and Coriolis force makes $B_p \to \alpha$-ω dynamo
- Exponential growth on $\tau_{convection} \sim 1$ msec
- $B \sim 10^{15}$ G



How is B-field dissipated?

- Conductivity inside NS is very large ($\tau_D >> 10^4$ yrs)
- Vacuum has LOW conductivity R ~4π/c ~377Ω
- Currents inside == twisted fields
- B > 10^{14} G can deform crust
- Current is pushed out

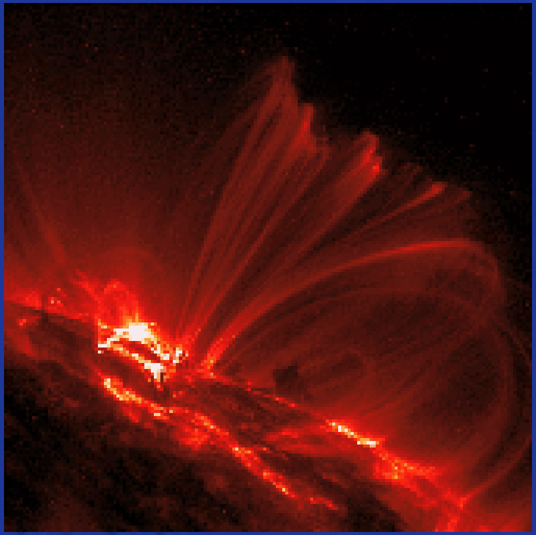



Twist (current) is pushed outside

(Thompson, ML& Kulkarni 2002)

“Solar Flares” paradigm

- B-fields generated inside, pushed outside, dissipated outside, convert magnetic energy to X-rays through reconnection



- Similar statistical properties of SGR and Solar flares
  - Waiting time distribution – lognormal ($\tau \sim 50$ sec)
  - $dN/dE \sim E^{\alpha}$, $\alpha = 1.66$ for SGRs, $\alpha = 1.5\text{-}1.8$ for Sun

How reconnection proceeds in $B \sim 10^{15}$ G ?

Magnetic energy density $u_B = B^2/(8\pi) >>$

Plasma internal energy $u_p = P/(\Gamma - 1) + \varrho c^2$

Currents flow only along the field

Electro-magnetic field controls dynamics –
relativistic force-free plasma

$$\partial_t B = -\nabla x E, \quad \partial_t E = \nabla x B - j$$

Dynamic eqns

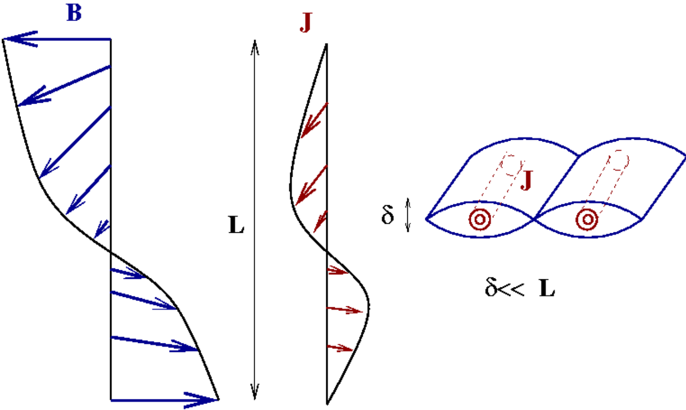
$$\left(j - (\nabla E)\frac{(ExB)}{B^2}\right)\eta = \frac{(E \bullet B)B}{\sqrt{B^4 - (ExB)^2}}$$

Ohm's law ($j_{II}\ \eta = e$)

(ML in prep)

Reconnection in force-free plasma

- Resistivity is usually very small ($\tau_R \sim L^2/\eta >> \tau$)
- Current sheets are unstable – formation of small scale sub-sheets



- Tearing mode $\tau \sim (\tau_A\ \tau_R)^{1/2}$
- $\tau_A \sim L/v_A \sim L/c, \quad \tau_R \sim L^2/\eta$
- Growth rate is intermediate

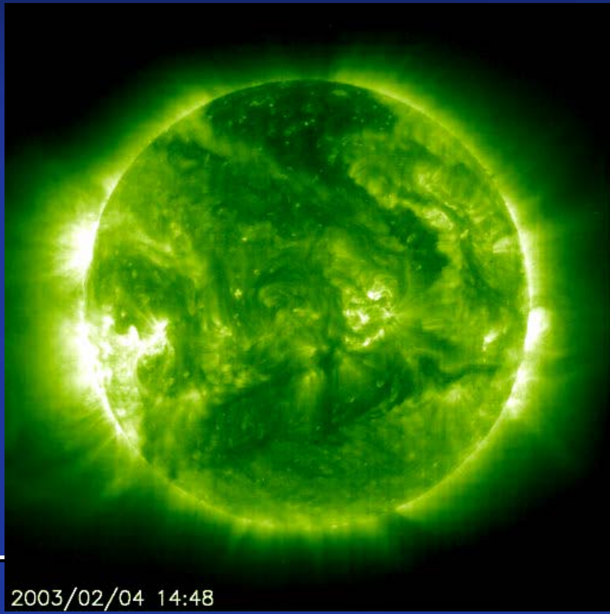
between Alfven (μsec) and diffusion time scale – secs

- For η due to Langmuir turbulence, $\eta \sim c^2\ \omega_p$,

  $\tau \sim 10$msec - typical flare rise-time

(ML, in prep)

Reconnection in magnetars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- Statistics SGR ~ Solar flares

  Persistent emission – small flares?
- Flare rise time ~ growth

  of tearing mode (ML 2003).
- B-field is rearranged by reconnection – softer spectra, simplified profiles (Woods,2000).
- Prediction: contemporaneous coherent radio burst (type-III, l+l->t emission), $\omega_P^2 \sim \omega_B \, c/r \sim 10$ GHz (ML 2002). TOO programs are under way (RXTE+GBT, Arecibo; PI Kaspi)

Conclusion

- Relativistic plasmas that show in X- and γ-ray
- Our theoretical understanding is lacking behind observations – need to explore new regions of "phase space"
- There is an interesting regime of electro-magnetically dominated plasmas –basic plasma physics questions
- Application to pulsars, BHs corona & jets , AGNs, GRBs