Magnetars and Giant Flares

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Introduction

- First hypothesized to explain large emissions of energy by unknown stellar objects observed during the 1970's
- These objects were known as Soft Gamma Repeaters (SGR's) as they exhibited irregular bursts of energy in the soft-gamma region of the spectrum
- Magnetar model was proposed in 1993 to explain this behaviour
- Describes neutron stars with very short active lifetimes, which exhibit extremely large magnetic fields
- They occasionally release enormous burst of electromagnetic radiation, known as giant flares

Magnetar Facts

- Location: 10,000 - 50,000 light years away
- Size: 10 - 20 km in diameter, 1.4 - 3.2 solar masses
- Number: currently 20 confirmed magnetars, with 3 proposed candidates, and an estimated 30 million inactive magnetars
- Lifetime: only active for approximately 10,000 years
- The crust consists of a solid Coulomb lattice of ordinary atomic nuclei (suspected to be iron) with electrons flowing freely through the lattice
- The tensile strength is 10^9 times stronger than that of steel

Magnetar Formation

- Magnetars are formed when a supernova collapses into a neutron star
- When a neutron star falls within certain ranges of spin, temperature, and initial magnetic field, dynamo action occurs
- The large magnetic fields of magnetars are thought to result from this dynamo action
- Dynamo action may increase magnetic field from 10^8 to 10^{11} T
- Three conditions are required for dynamo action to occur:
    - The medium must be electrically conductive
    - The body must be rotating in order to provide kinetic energy
    - There must be regions of convection due to some internal source

Magnetohydrodynamics (MHD)

- Some of the central equations of MHD are:

  - Continuity equation
    $$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0$$
  - Induction equation
    $$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B}) - \eta \nabla^2 \mathbf{B}$$
  - Energy equation
    $$\frac{\rho^\gamma}{\gamma - 1} \frac{D}{Dt}\left(\frac{p}{\rho\gamma}\right) = -L$$
  - Momentum equation
    $$\rho \frac{\partial \mathbf{v}}{\partial t} + \rho(\mathbf{v} \cdot \nabla)\mathbf{v} = -\nabla \mathbf{p} + \mathbf{j} \times \mathbf{B}$$

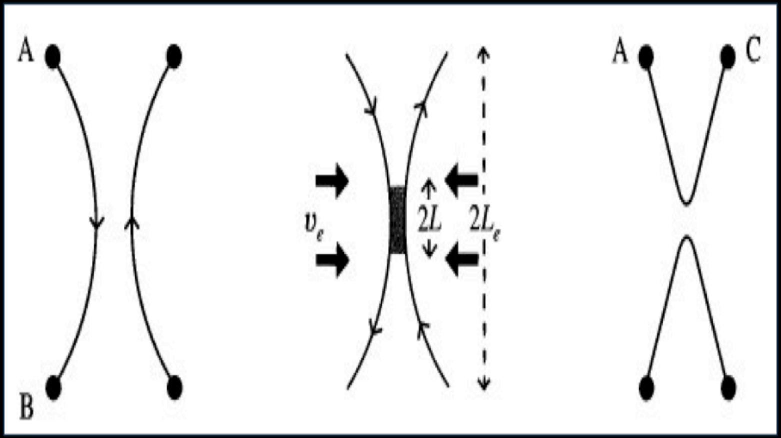
- Magnetic Reynold’s number R_m is the ratio of the advection term to the diffusion term in the induction equation.
- Ideal MHD requires R_m >>1, where the advection term dominates and the diffusion term may be neglected.
- In ideal MHD some interesting phenomena emerge, such as flux “freezing in”

Flux Freezing

- In a perfectly conducting fluid ($R_m \rightarrow \infty$) the magnetic field lines move with material, i.e they are "frozen" into the plasma
- Motions along the field lines do not change the field, but motion transverse to the field lines carry the field with them.
- If field lines in a star pass through the surface, the magnetic field is anchored to it
- For huge magnetic fields, there are huge forces acting on the surface
- Leads to "winding up" of field lines in the interior of a magnetar, ➔ enormous internal magnetic stresses.

Magnetic Reconnection

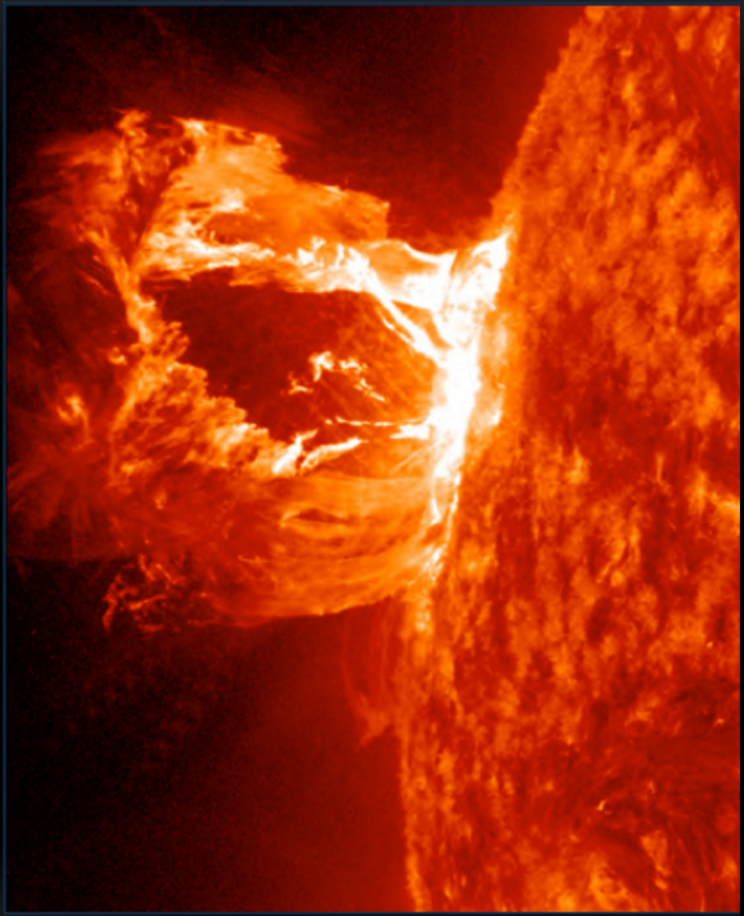
- Reconnection is at the heart of many magnetar phenomena
- Magnetic fields store energy
- When topology of the magnetic field changes, this energy is released (as EM radiation)



- Various 2D models, e.g. Sweet-Parker, Petschek
- 3D reconnection still a very new field (driven by computational models)

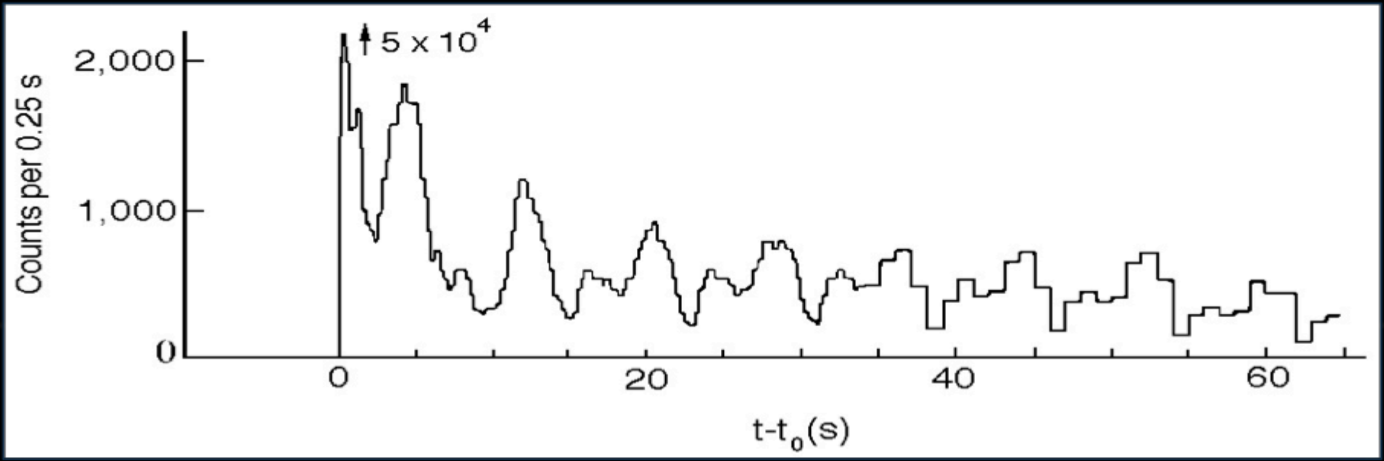
Giant Flares

- Enormous emissions of electromagnetic energy, far larger than the ordinary bursts observed from magnetars.
- Events this large extremely rare, only three have been observed so far in 1979, 1998 and 2004.
- Size of flares made it necessary to create new models to explain such extreme behaviour.
- At present, many models exist to explain the mechanism by which giant flares occur
- We examined two models; the crustal failure model, and the magnetospheric model



SGR 1806-20

- Event in 2004 was the largest ever observed, saturated instruments for 0.5 s
- Most highly magnetized object ever observed, magnetic field of over 10^{11} T, over 10^{15} times stronger than that of Earth
- For 0.2 s, energy was unleashed at a rate of 10^{40} watts.
- Total energy produced more than the Sun emits in 150,000 years.
- Theoretical model of the time struggled to explain the magnitude of the flare
- This lead to new models being developed to allow for the larger flare energies



Mechanisms for Giant Flares: Comparison of Two Models

Crust failure model

- Thompson, Duncan (2001)
- Quick and brittle fracture of the crust, i.e. starquake
- Energy limited by tensile strength of crust
- Magnetic stress → elastic stress ➔ fracture occurs

Magnetospheric model

- Lyutikov (2003, 2006)
- Magnetic energy limited by total external magnetic field, not by tensile strength of crust
- Flux injection leads to flux ropes

Open Questions

- The magnetic reconnection is not very well understood so research is being done into 3D magnetic reconnection.
- Theoretical models need to be improved upon as none of the current proposed models are entirely satisfactory
- Waiting for another event to occur to provide more data to improve on current theories.
- Can magnetars be used to detect gravitational wavebursts?

Conclusion

- We have seen what magnetars are and how they are thought to form.
- We discussed some of the basic equations of MHD which govern the behaviour of magnetars
- We looked at an important feature of magnetars, i.e. the giant flares
- We looked briefly at two competing models for the mechanism behind giant flares
- We considered the future of research into magnetars

References

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