Research is being done into 3D magnetic reconnection, as proposed by S. M. (1992) and C. Thompson and R. C. Duncan (1992) to explain these large emissions of energy. These proposed magnetars were neutron stars with extraordinarily large magnetic fields and a short but active lifetime. Along with the repeated smaller bursts, occasional magnetars have been observed to release enormous bursts of electromagnetic radiation, known as giant flares.

**Magnetohydrodynamics**

Here are some of the central equations describing MHD:

- **Continuity equation**: \( \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \)
- **Induction equation**: \( \frac{\partial \mathbf{B}}{\partial t} = \nabla \times \mathbf{E} \times \mathbf{B} + \mathbf{V} \times \mathbf{B} \)
- **Momentum equation**: \( \frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot (\rho \mathbf{v} \mathbf{v}) = -\nabla P + \nabla \cdot \mathbf{T} + \mathbf{F} \)
- **Energy equation**: \( \frac{\partial \rho E}{\partial t} + \nabla \cdot (\rho E \mathbf{v}) = \mathbf{V} \cdot (\rho \mathbf{v} \mathbf{v} - \mathbf{T}) + \mathbf{V} \cdot \mathbf{F} \)

An important quantity is the magnetic Reynold’s number \( R_m \) which is the ratio of the advection term to the diffusion term in the induction equation. Ideal MHD is the case in the limit where \( R_m >> 1 \), here many interesting phenomena emerge, such as flux “freezing”.

**Flux Freezing**

In a perfectly conducting fluid, a phenomenon occurs whereby the magnetic field lines move with the 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 field is anchored to the surface. This means that for huge magnetic fields, there are huge forces acting on the surface. This leads to “winding up” of the field lines in the interior of a magnetar, giving rise to enormous internal magnetic stresses.

**Magnetic Reconnection**

Magnetic reconnection is at the heart of many magnetar phenomena. The magnetic field stores energy, and when the topology of the magnetic field changes, this energy is released as EM radiation. There are various models describing magnetic reconnection in two dimensions, such as the Sweet-Parker, Petschek, and almost uniform models. Meanwhile, 3D reconnection is still a very new field where progress is driven by computational models.

**Giant Flares**

Giant flares are enormous emissions of electromagnetic energy, far larger than ordinary observed bursts. These events are extremely rare, but also spectacular. The three largest were observed in 1979[9], 1998[7] and 2004[7]. These events are powerful enough to saturate every gamma radiation detector in space. Existing theoretical models had difficulty explaining the magnitudes of some of these outbursts. Currently there are several competing models explaining the mechanism behind giant flares.

**Magnetar Formation**

Magnetars are hypothesised to be a type of neutron star, and like other neutron stars, are believed to be the result of supernova collapse. They are thought to have diameters in the range of 10 - 20 km and masses greater than that of the Sun. The large magnetic fields of magnetars are thought to result from dynamo action during their formation. In magnetars, dynamo action increases their magnetic field from \( 10^9 \) to \( 10^{13} \) T[6]. There are currently 20 confirmed magnetars[4], along with 3 proposed candidates. They are located between 10,000 - 50,000 light years away, and are only active for approximately 10,000 years. There are an estimated 30 million inactive magnetars[6] in the Milky Way, however these are almost impossible to detect.

**Comparison of Two Giant Flare Models**

- **Crust Failure Model**
  - Thompson, Duncan (2001)[6]
  - Magnetic stresses in core become too great, exceeding the elastic stresses in the crust
  - Quick and brittle fracture of the crust occurs, i.e. starquake
  - Due to the relaxation of internal magnetic stresses, energy is released via giant flares
  - Energy limited by tensile strength of crust
  - Created after the 1998 event, which reached a peak luminosity of \( 10^{51} \) ergs[6]

- **Magnetospheric Model**
  - Lyutikov (2006)[6]
  - Slow untwisting of the internal magnetic field leads to twisting of magnetospheric field lines
  - Flux injection leads to increase in magnetospheric energy held in flux ropes
  - Unstable flux ropes rupture and release energy via giant flares
  - Energy limited by total external magnetic field
  - Created to explain magnitude of 2004 event which reached a peak luminosity of \( 10^{51} \) ergs[6]

**SGR 1806-20**

The event in 2004[7] was the largest ever observed, it saturated satellite instruments for up to 0.5 s[8]. This magnetar is the most highly magnetized object ever observed[7], with magnetic field of over \( 10^{15} \) T. It unleashed energy at a rate of about \( 10^{44} \) watts for 0.2s. The total energy produced was more than the Sun emits in 150,000 years[7]. Thankfully it is located approximately 40,000 light years away[7] and so did not pose a significant danger. The magnitude of the flare observed led to the development of the Lyutikov model to allow for the larger flare energies.

**Open Questions**

- Research is being done into 3D magnetic reconnection, and relativistic models for reconnection.
- Theoretical models for giant flare mechanisms need to be improved upon, as none of the current proposed models are entirely satisfactory.
- Can a method be developed to detect inactive magnetars?
- Can magnetars be used to detect gravitational wavebursts?

**References**

4. McGill Online SGR/AXP Catalogue
5. R.C. Duncan, 2003