Trinity College Dublin
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Defence from Solar Flares

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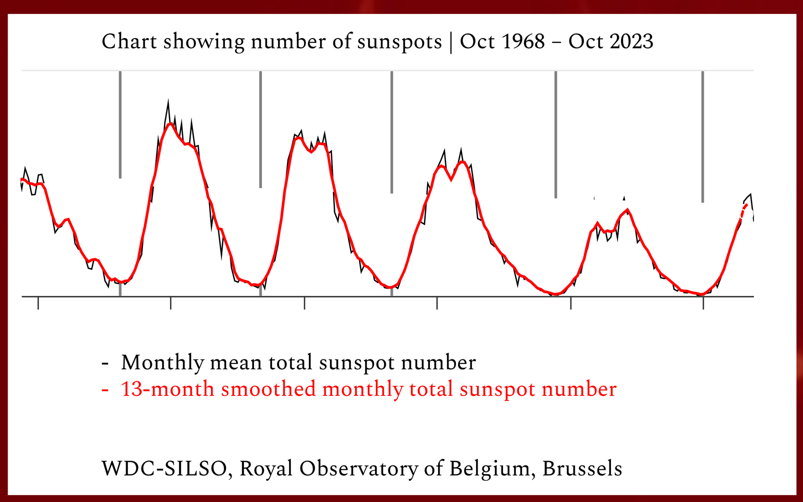
Introduction to Solar Flares

Solar flares are massive localized eruptions of electromagnetic radiation from the Sun. These flares last from several minutes to hours[1.1] and emit a wide range of electromagnetic radiation.

- The power of these flares is given by the equation $P = \frac{E}{t}$, where P is power, E is energy, and t is the duration.
- Flares are classified A, B, C, M, X based on peak flux, with each category having a scale from 1 to 10 indicating strength[1.1].



- They follow an 11-year solar cycle and primarily affect radio communication by increasing ionization in the upper atmosphere[1.2].

Sunspots and Solar Activity

Sunspots are dark, highly magnetized areas on the Sun's photosphere, appearing darker due to inhibited convection.
These sunspots exhibit an 11-year cycle, known as the solar cycle, peaking in number halfway through[4.1].

- Sunspots, sometimes visible to the naked eye, can be vast, with the largest recorded over 4 billion square kilometers[4.1].

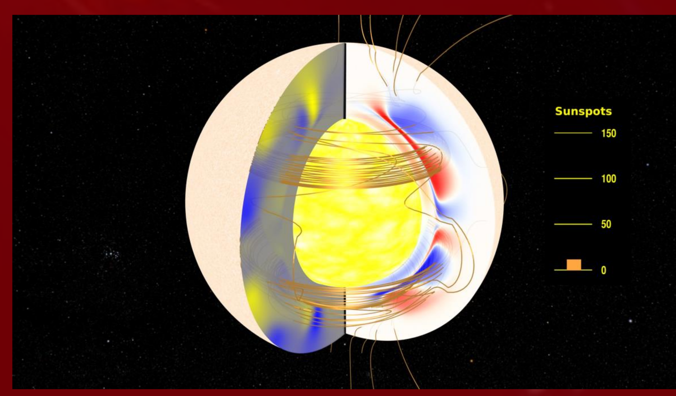
Image of sun with sunspots visible
NASA/Goddard Space Flight Center Scientific Visualization Studio

The intense magnetic fields near active sunspots, over 1,200 times stronger than the Sun's average, interact with solar plasma to trigger solar flares and CMEs[4.2].
This cycle influences Earth, evident in phenomena like enhanced Northern Lights at cycle peaks [4.2].

Solar Dynamo Mechanism

The solar dynamo, responsible for the Sun's magnetic field, transforms the Sun's plasma movements into electromagnetic energy[3.1].

- Key Equation: $\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) + \eta \nabla^2 \boldsymbol{B}$, which describes how the Sun's magnetic field changes over time.
- The tachocline, between the radiation and convection zones, significantly influences magnetic field production[3.2].



Magnetic Field Structure at Mid-Latitudes During Solar Minimum
NASA/Goddard Space Flight Center Scientific Visualization Studio

The Impact of Solar Storms on Technology

Solar flares and coronal mass ejections (CMEs), linked to solar flares, significantly harm Earth's technology.

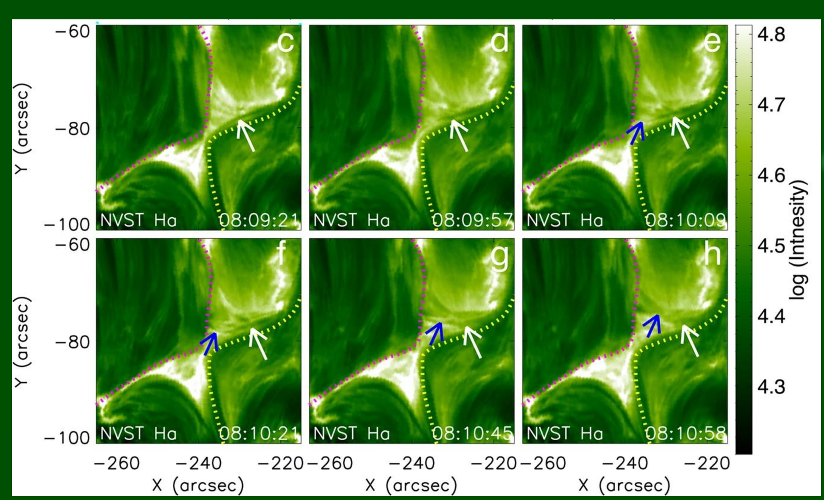
- Our society's reliance on electronics with printed circuit boards (PCBs) and power infrastructure heightens this vulnerability[5.1].
- The impact of a CME on Earth can disturb the geomagnetic field, causing geomagnetic storms.
- These storms affect high-orbit satellites used for communication and navigation, impacting everyday technologies such as mobile phones and computers.

Notable examples include the March 13, 1989, CME that caused widespread blackouts in Québec and parts of northern America, demonstrating the potential severity of these events.

Additionally, the August 28, 1859, solar flare, the most significant observed, caused global telegraph system failures, further highlighting the risks posed by solar activity [5.1].

Geomagnetic Storms and Auroras

Geomagnetic storms are a disturbance in the Earth's magnetosphere. These disturbances happen because of the energy exchange from solar winds. However, they are more noticeable during events like Coronal Mass Ejections (CMEs)[6.1].



Plot showing Dynamic Interactions in a Confined Solar Flare - Filament Involvement in Magnetic Reconnection

Image from article:
Yan, X., Xue, Z., Jiang, C. et al. Fast plasmoid-mediated reconnection in a solar flare. Nat Commun 13, 640 (2022). https://doi.org/10.1038/s41467-022-28269-w

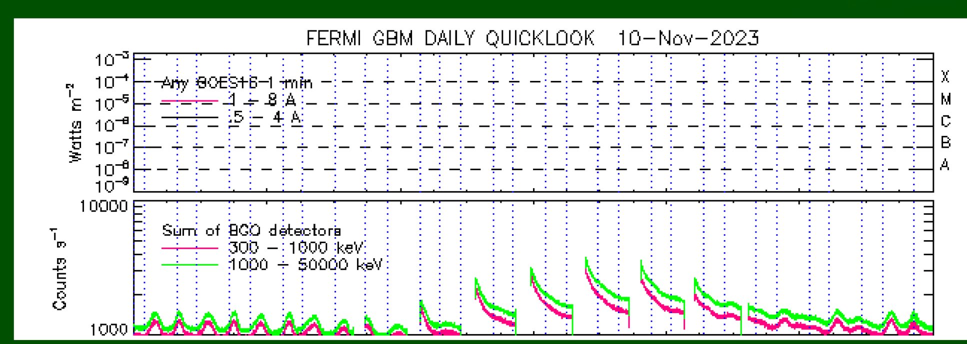
This results in what we know as the northern lights. The auroral displays have different colours and patterns that depend on the specific energized particles[6.1].

Image of the aurora borealis
Photograph by Sherwin Calaluan

Predicting and Monitoring Solar Activity

Due to the impact of flares and other solar activity on Earth, space stations, and satellites, predicting when and where they can occur is vital. Scientists continuously analyze the Earth's atmosphere and the Sun's surface for this purpose.

- Data from NASA's Heliophysics Systems Observatory fleet and historical data are utilized for predictions, similar to meteorological methods[7.1].
- Recently, scientists at NWRA discovered a new method for predicting solar flares. They noted that smaller flashes in the Sun's upper atmosphere precede giant flares. These brightening events in the corona above active sunspot regions indicate potential flare zones[7.2].



Section of Fermi GBM Daily Solar Flare Activity for November 10, 2023
NASA's Heliophysics Science Division - Fermi GBM Daily Rates

Electromagnetic and Plasma Dynamics

Particle Alignment in Solar Flares & CMEs:
- Charged particles align along Radiation-Free Direction (RFD) in strong fields[2.1].
- Lorentz Force:

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}),$$

where $\vec{F}$ is force, q is the charge, $\vec{E}$ is the electric field, $\vec{v}$ is velocity, and $\vec{B}$ is the magnetic field.

Energy Buildup and Release:
- Buildup occurs due to this alignment, altering magnetic fields.
- Magnetic reconnection transforms magnetic energy into kinetic energy, heat, and light[2.1].

- Energy Conversion:

$$\textit{Magnetic energy} \rightarrow \textit{Kinetic energy} + \textit{Heat} + \textit{Light}.$$

Defensive Strategies

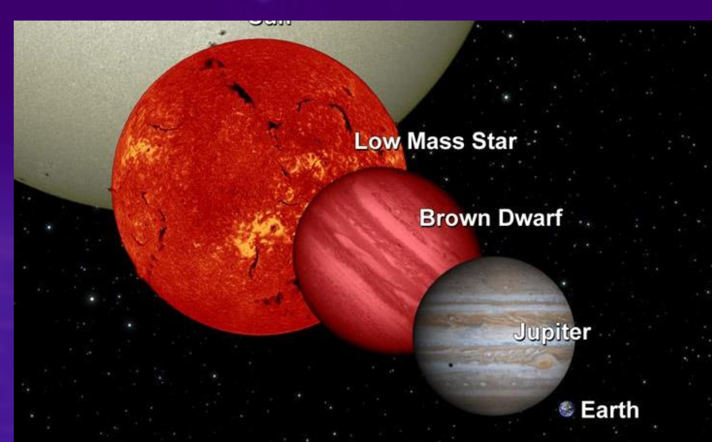
Solar flares and coronal mass ejections (CMEs) pose a significant threat to electrical circuits and power infrastructure, with their impact varying based on whether they strike Earth directly or indirectly[8.1].

- Forecasting Solar Activity: Anticipating solar flare events is crucial. Accurate forecasting helps in preparing and implementing protective measures.
- Recovery Plans for Infrastructure: Establishing robust recovery plans for affected technology and power infrastructure, such as power grids, is essential to mitigate damage[8.1].

Implementing these strategies can greatly reduce the adverse effects of solar storms on technological systems and society.

Future Challenges and Research Directions

- Understanding the Tachocline: Future challenges include understanding the tachocline of stars and how strong magnetic fields occur within stars [9.1].
- Magnetic Fields in Low-Mass Stars: Stars under the solar mass threshold of 0.3 solar masses such as brown dwarfs do not have a tachocline but produce powerful magnetic fields [9.1].
- Research Focus: Investigating how these stars generate strong magnetic fields without a tachocline is essential.



Brown Dwarf Comparison
NASA/JPL-Caltech/UCB

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* Poster background features assets created with DALL-E 3, modified using Adobe Photoshop, and compiled in Inkscape.

The Sun's Phenomena and Mechanisms (Sections 1, 3, 4)
Scientific Theories and Dynamics (Section 2)
Impact and Interaction with Earth (Sections 5, 6, 7)
Defensive Strategies and Future Research (Sections 8, 9)

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