Solar Physics: Importance, Current Understanding and 'Yet Unanswered' Problems

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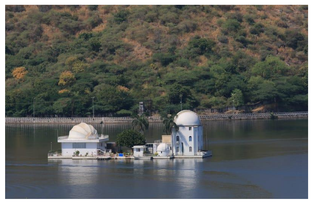


Why do we need the Sun?

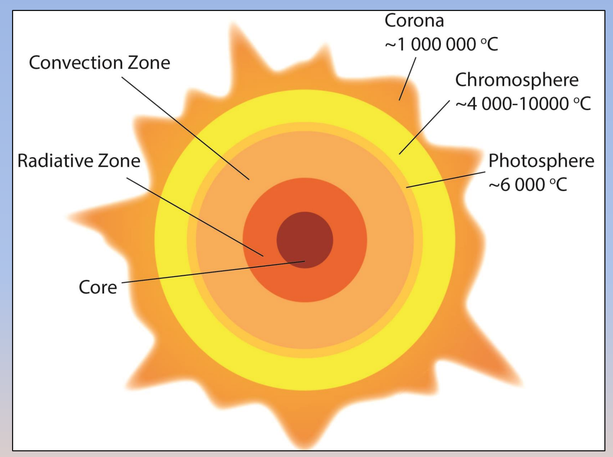
- Provides the most essential ingredient for life: energy (light and heat).
- Being the nearest star to us, it gives us the best opportunities to understand main sequence stars in general.
- It produces a natural laboratory for studying plasma physics.

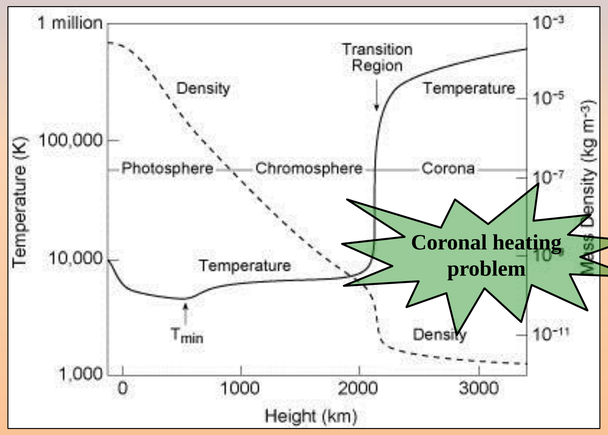
"*We should study the Sun because it is beautiful.*"- Dr. Arvind Bhatnagar

Sun as a star

- G-type main sequence star
- Radius: ~696000 km (~109 R_E)
- Mass: ~2×10^{30}kg (~333000 M_E)
- Age: ~4.6 billion years

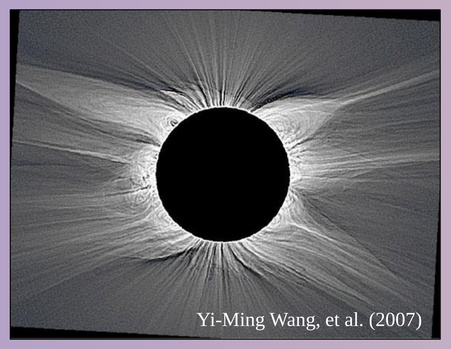
Structure of the Sun

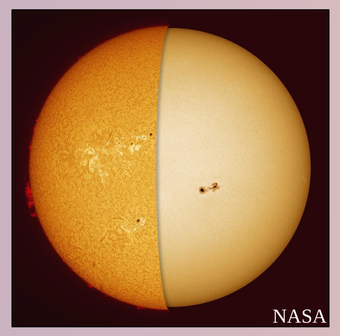


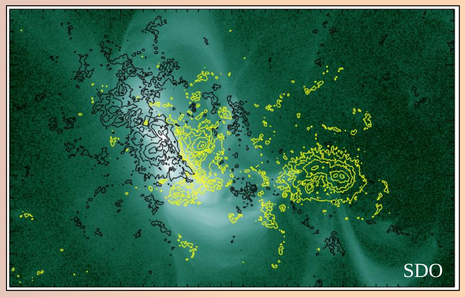


(Eugene Avrett, Smithsonian Astrophysical Observatory)

Different atmospheric layers of the Sun







Corona

- Outermost layer of the solar atmosphere
- Density is very low: ~10^{15} particles/m^3
- Temperature is very high: few million K
- Highly structured magnetic field

Chromosphere

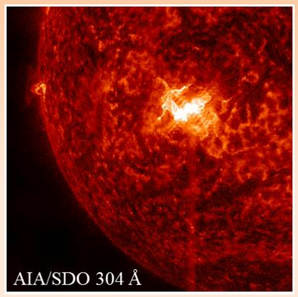
- Second layer of the solar atmosphere
- Observed in reddish color during the solar eclipse
- Filaments are observed in chromospheric images

Photosphere

- So called "surface" of the Sun.
- Most of the intense light from the Sun comes from this region
- Sunspots are observed in photospheric images

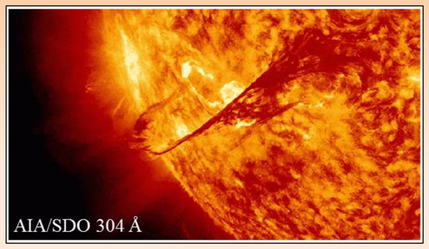
Sunspots are connected by magnetic loops that extend up to the corona. In corona, because of 'Alfvén's frozen in condition', magnetic field gets embedded into the plasma body. Emission from these trapped plasma makes coronal loops visible.

Active Sun



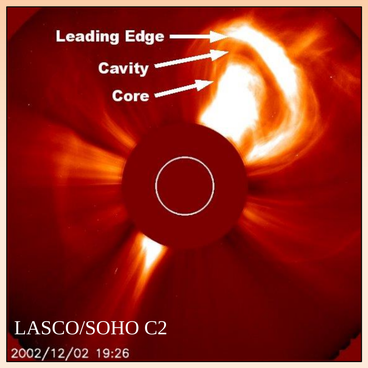
Flare

- Sudden, localized enhanced brightness observed in the solar atmosphere
- Energy released during a flare: 10^{27} to 10^{32} erg: most energetic in the solar system
- Magnetic reconnection is believed to be the source of the energy released during a flare.
- During a flare, electro-magnetic radiation is observed across the entire e-m spectrum.
- Lifetime of a flare: few minutes to several hours.



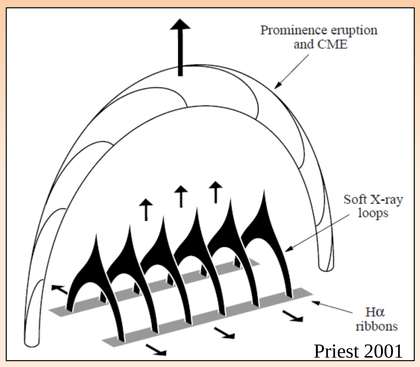
Filament/Prominence eruption

- Filaments are dark, thread-like structures observed in the chromospheric images of the Sun.
- These are structures composed of relatively cool, dense plasma in association with magnetic field.
- Successful eruption of a filament leads to the formation of 'coronal mass ejections' (CMEs).



Coronal Mass Ejection (CME)

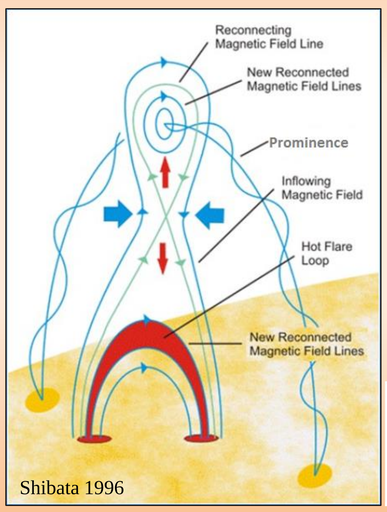
- Release of huge amount of plasma and magnetic field in the interplanetary medium from the solar corona.
- When CMEs interact with the Earth's magnetosphere, the effects are called 'space weather'.
- Filament eruptions, flares, and CMEs are observed to be intrinsically related and believed to be different manifestations of same physical mechanism: magnetic reconnection.

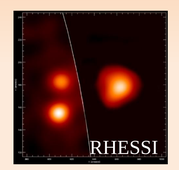


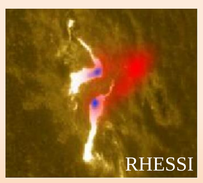
When a filament achieves eruptive motion, it induces inflow of surrounding magnetic field causing reconnection between them. As a result, flare happens. Erupting filament constitutes a CME.

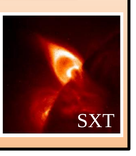
Standard Flare Model

Based on the pioneering works of ***Carmichael 1964, Sturrock 1966, Hirayama 1974, Kopp & Pneuman 1976.*** Therefore, this model is also called 'CSHKP model'.

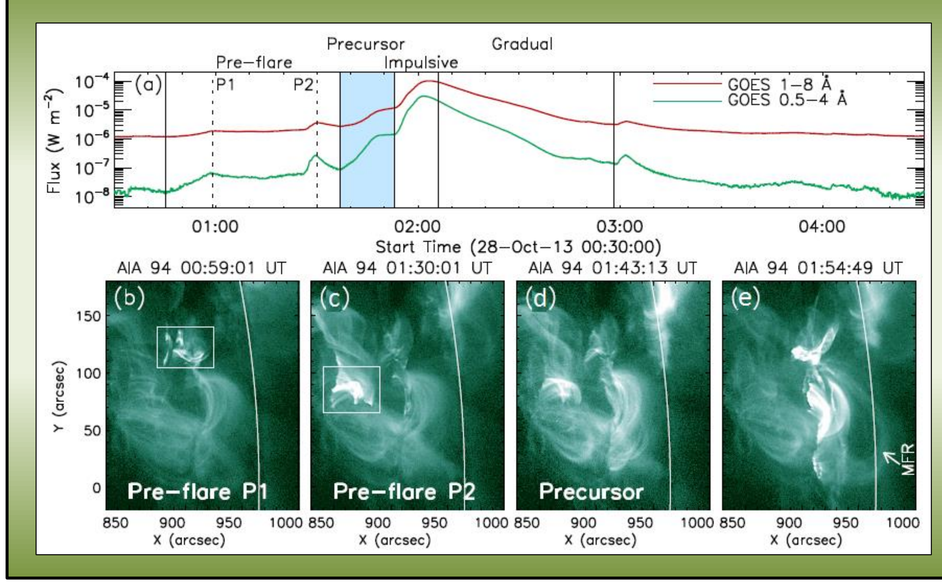


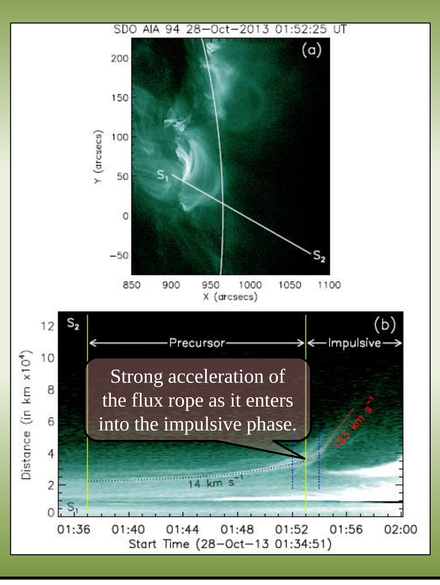


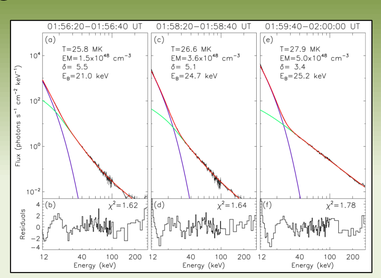




Pre-flare processes, Activation and Eruption of Flux Rope and Associated Flare







- Consistent small-scale reconnection at one of legs of the flux rope slowly destabilizes it toward eruption.
- As the flux rope becomes activated (destabilized) it slowly elevates with less speed (precursor phase). It attains fast eruptive motion in the impulsive phase. Eruption of this flux rope resulted into a halo-CME.
- Strong acceleration of the flux rope during the impulsive phase suggests a feedback relation between erupting speed of the flux rope and reconnection rate beneath it.

Publication: Mitra & Joshi, ApJ, 2019, 884, 46

Open Questions

- What causes coronal temperature to be so high? How is it sustained?
- What are the exact formation mechanisms of sunspots and active regions?
- What is the exact morphology of filaments/prominences?
- How a flux rope eruption is triggered?
- Not all flares are eruptive. What are the factors that determine whether a flare will be eruptive or confined?
- Circular ribbon flares usually contain a pre-existing coronal null point. How null points evolve during a circular ribbon flare is still not known.
- There is no theoretical model that can explain magnetic reconnection properly.
- Magnetic energy is released in the form of heat and particle acceleration during magnetic reconnection. The exact partition between thermal and non-thermal energy is not yet formulated.
- etc.

Future Solar Missions

- Aditya L1 / *ISRO, India*
- Solar Orbiter/ *ESA, Europe*
- SMILE / *China, ESA coll.*

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