

The Solar Resource:



The Active Sun as a Source of Energy

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School of Earth and Atmospheric Sciences
January 14, 2010

The Sun: A Source of Energy

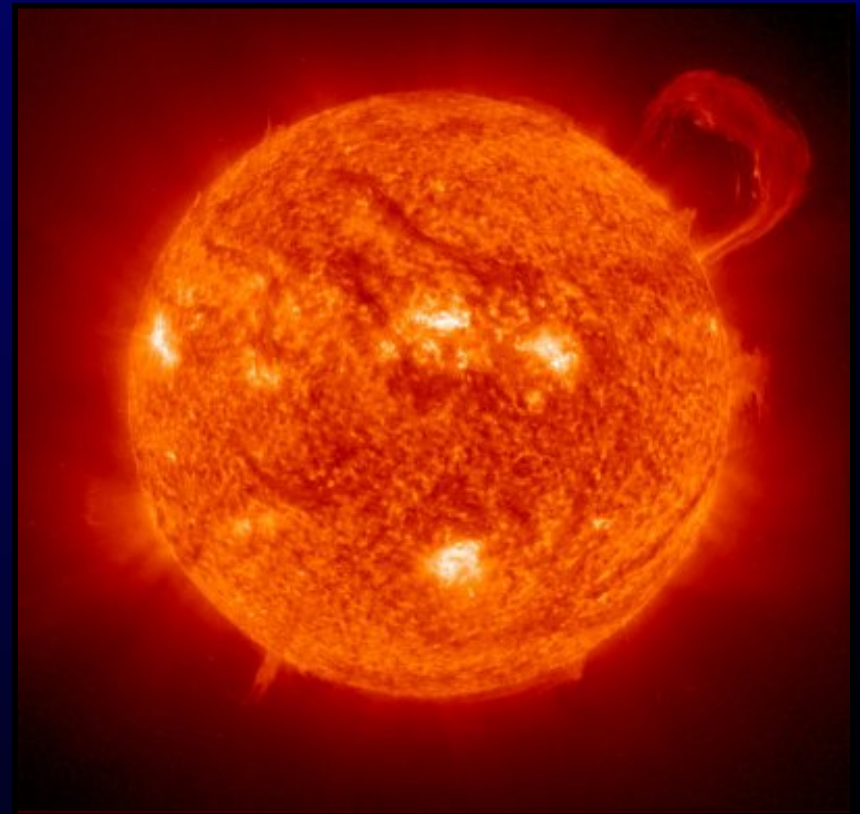
Solar Structure

Solar Wind

Solar Cycle

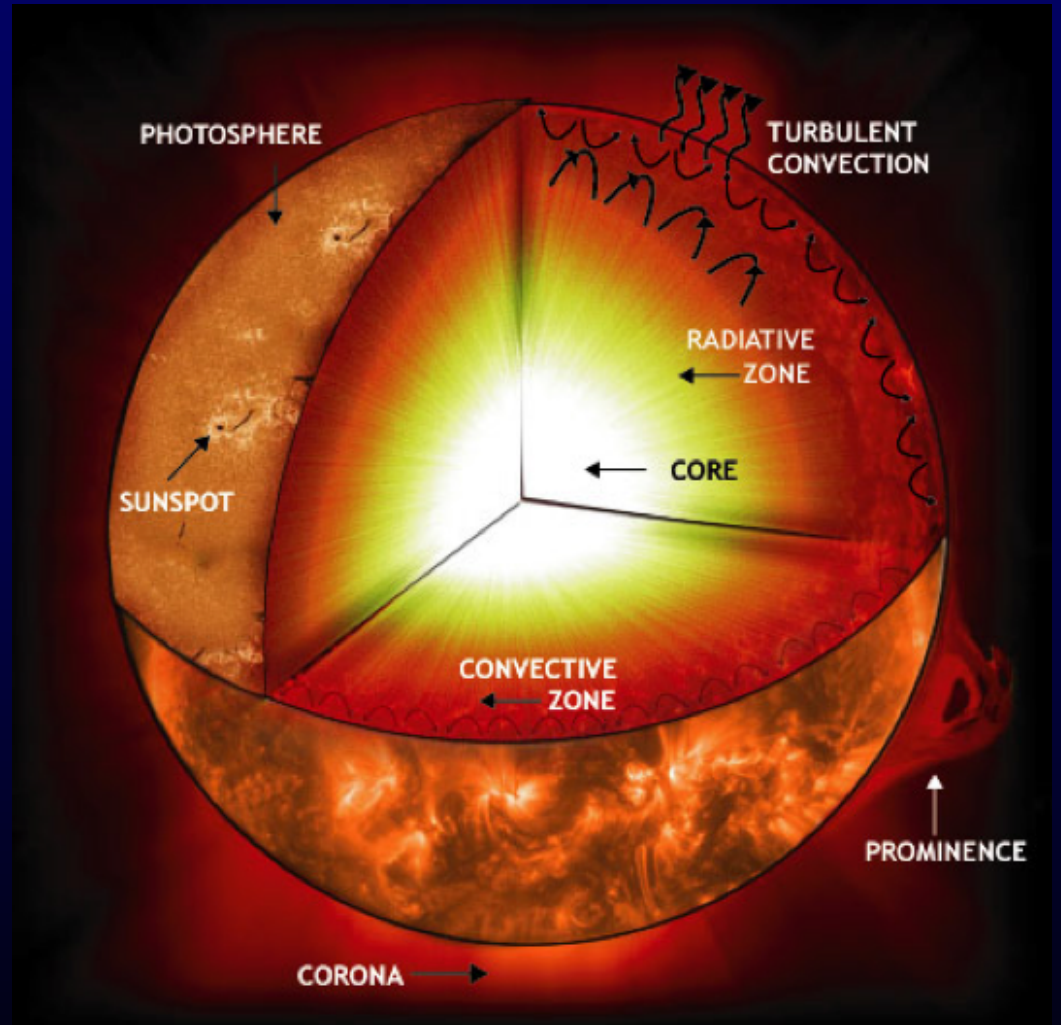
Solar Activity

Sun Earth Connection



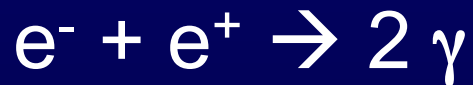
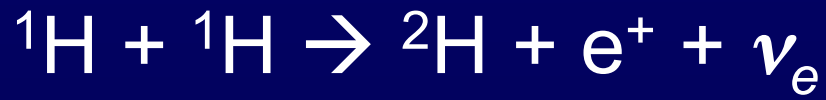
Solar Structure

- Core:
 $r < 0.3 R_S$
- Radiative Zone:
 $0.3 R_S < r < 0.7 R_S$
- Convective Zone:
 $r > 0.7 R_S$
- Photosphere:
‘Surface’ of the sun
- Corona:
Solar Atmosphere

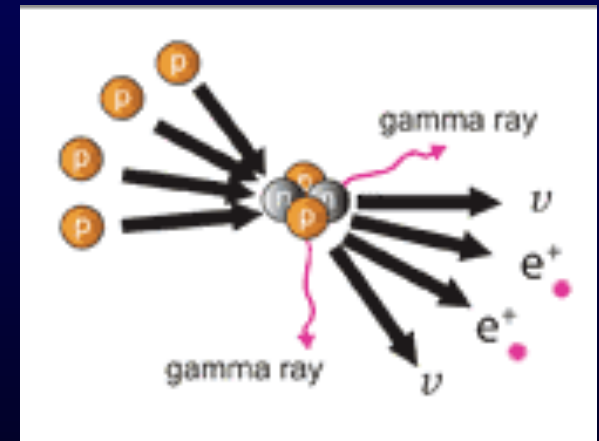


$$R_S \sim 6.96 \times 10^8 \text{ m} \sim 110 \times R_{\text{Earth}}$$

Core: Nuclear Fusion



Proton-Proton
Chain



Overall Reaction:



$$\Delta E = [4(1.007825\text{u}) - 4.002603\text{u}] \cdot [931\text{MeV/u}]$$

$$\Delta E = 26.7\text{ MeV}$$

Solar Structure

The Radiative Zone is a region of highly ionized gas where the energy transport is primarily by photon diffusion where photons are absorbed and re-emitted.

At the base of the Convection Zone, lower efficiency of photon diffusion leads to thermal gradients where convection becomes the dominant mechanism for energy transport.

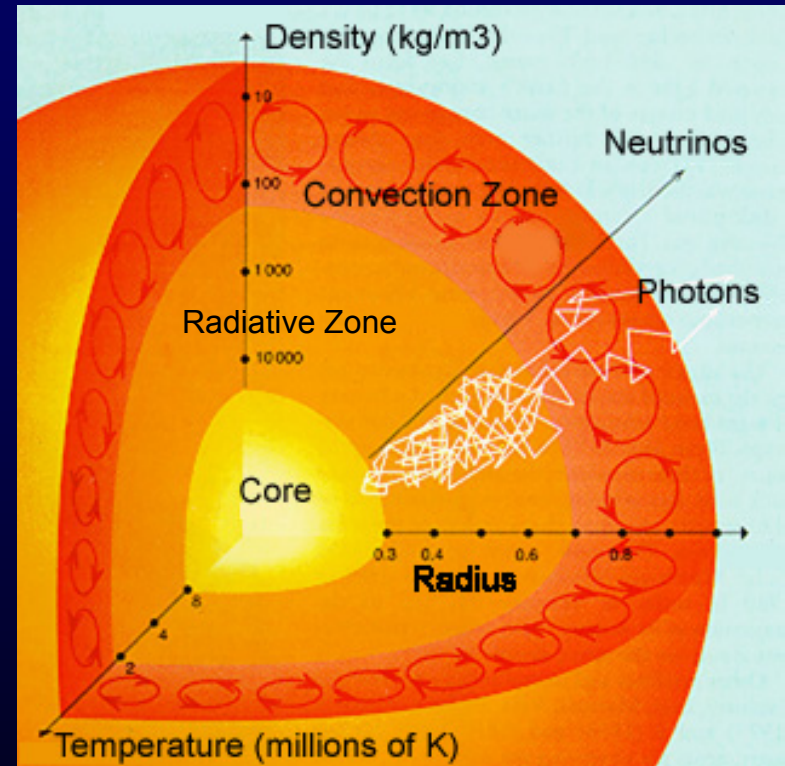
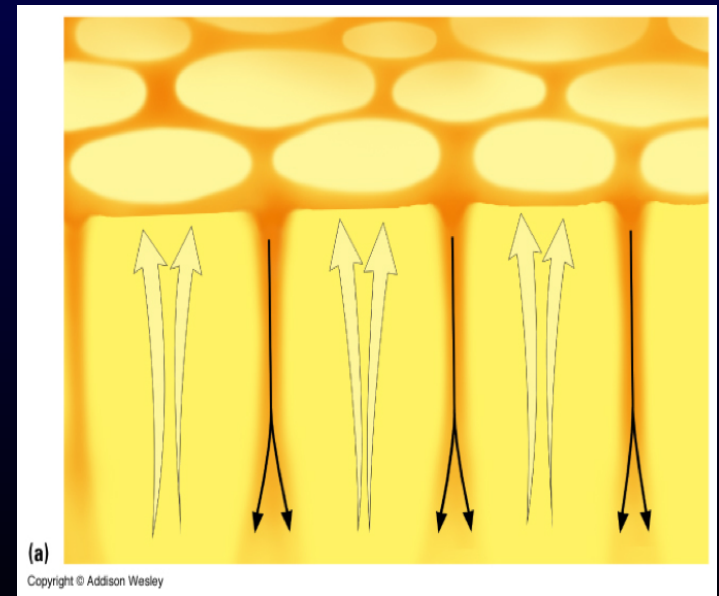
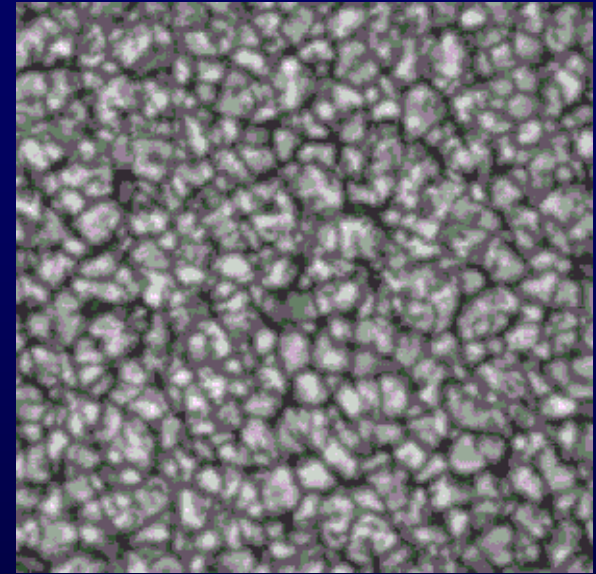


Image modified from: UCB's Center for Science Education

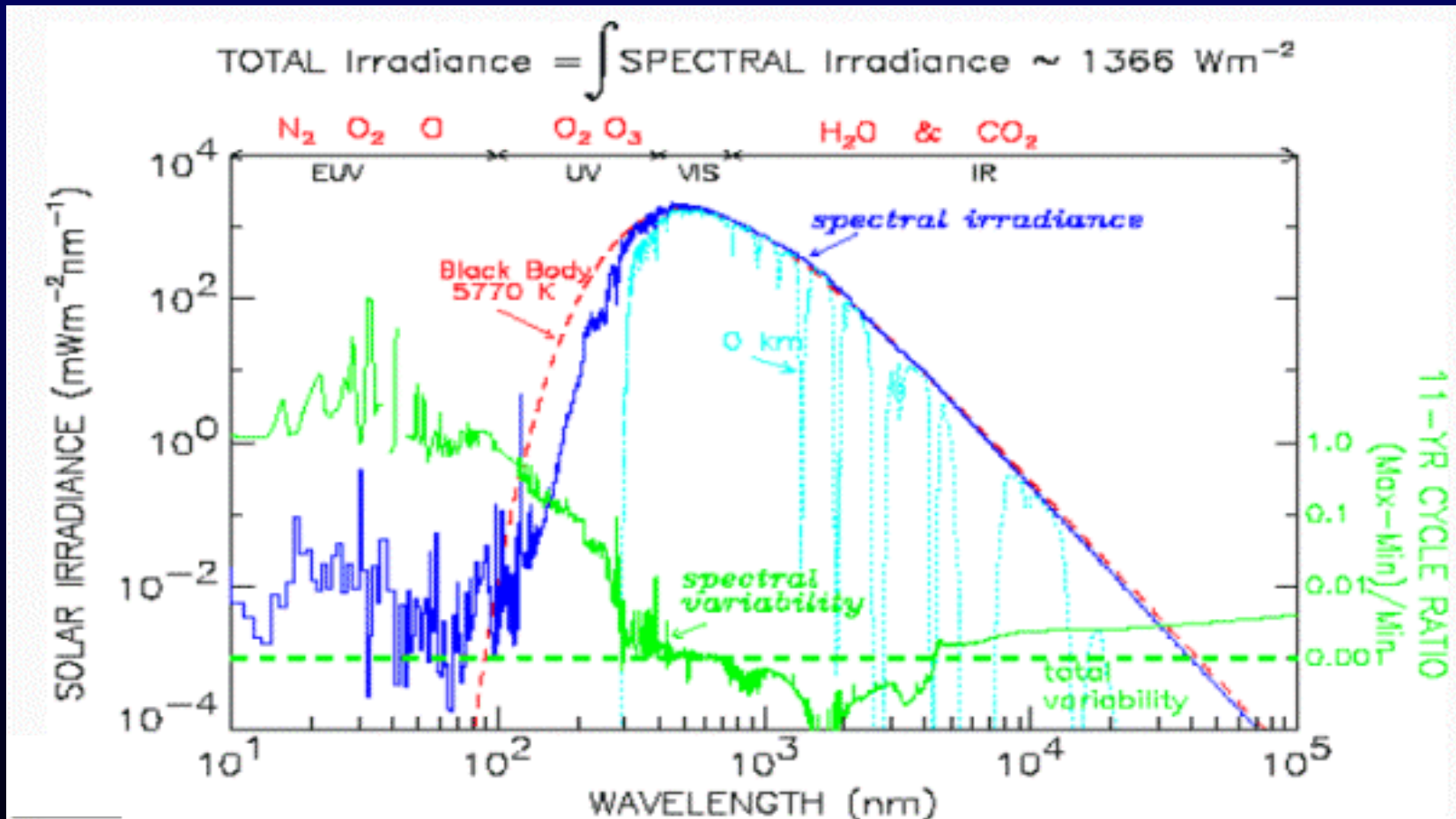
Solar Structure

In the Photosphere the plasma becomes transparent to the optical spectrum, allowing for the escape of most of the electromagnetic energy reaching that layer. Hence, the Photosphere is the visible 'surface' of the sun.

Below the photosphere the plasma is so dense that we can not see through it, but evidence of the convection zone are visible as 'granules'.



Solar Spectrum, Variability, and Atmospheric Absorption



Courtesy of J. Lean, NRL

Solar Structure

The Solar Atmosphere:

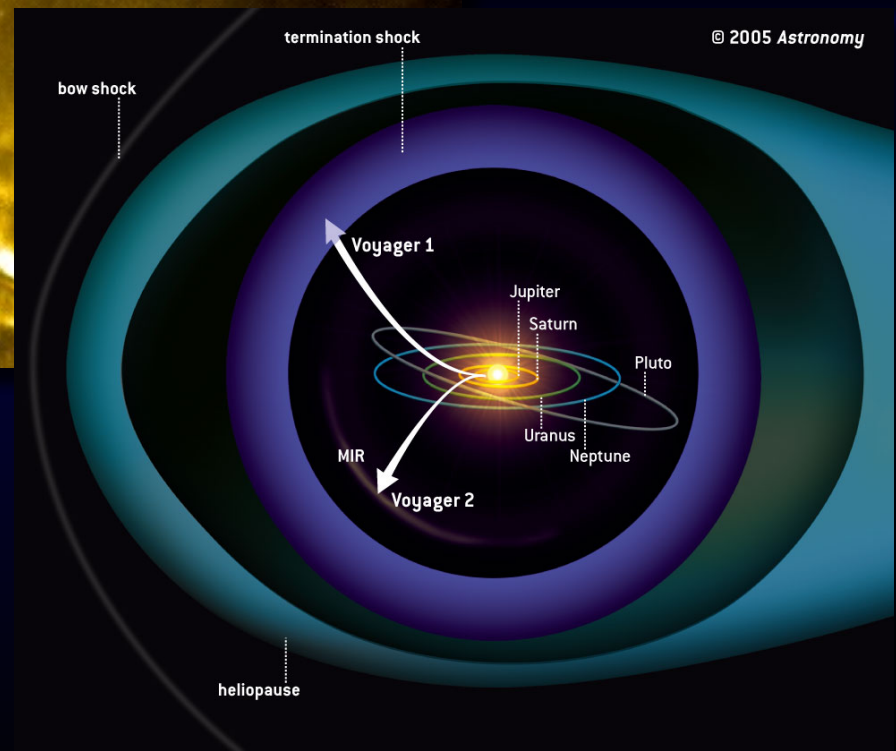
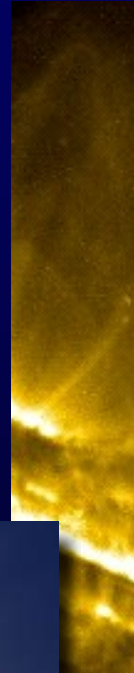
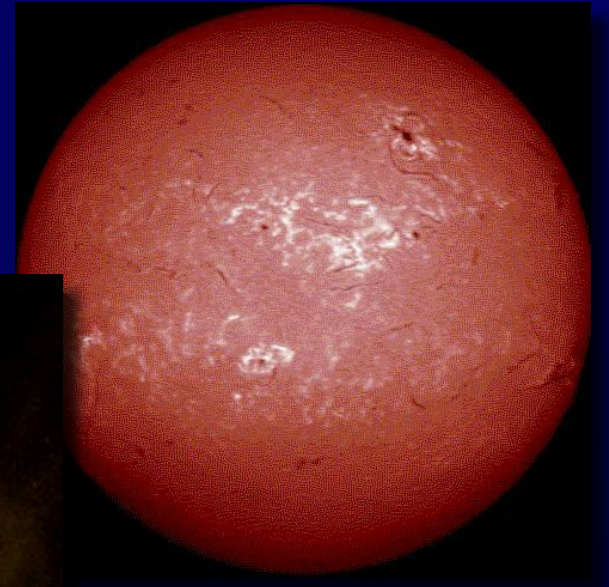
Photosphere

Chromosphere

Transition Zone

Corona

Heliosphere

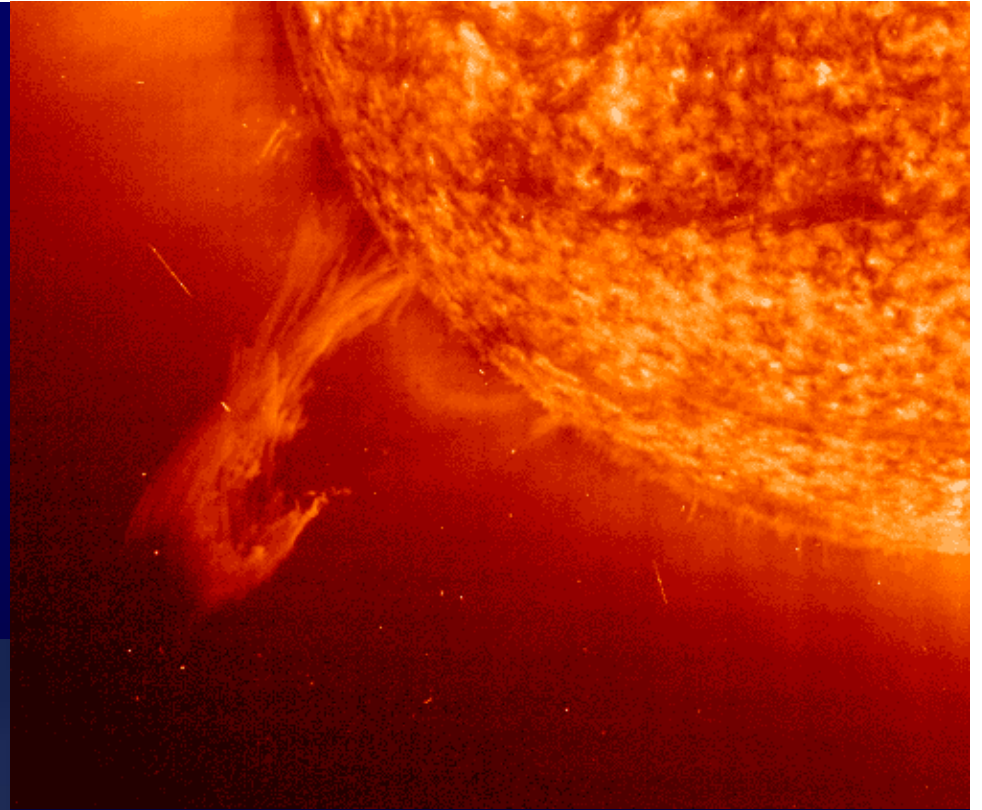


Solar Wind

Density $\sim 5\text{-}10\text{ cm}^{-3}$

Speed $\sim 450\text{ km/s}$

Magnetic field $\sim 6\text{ nT}$



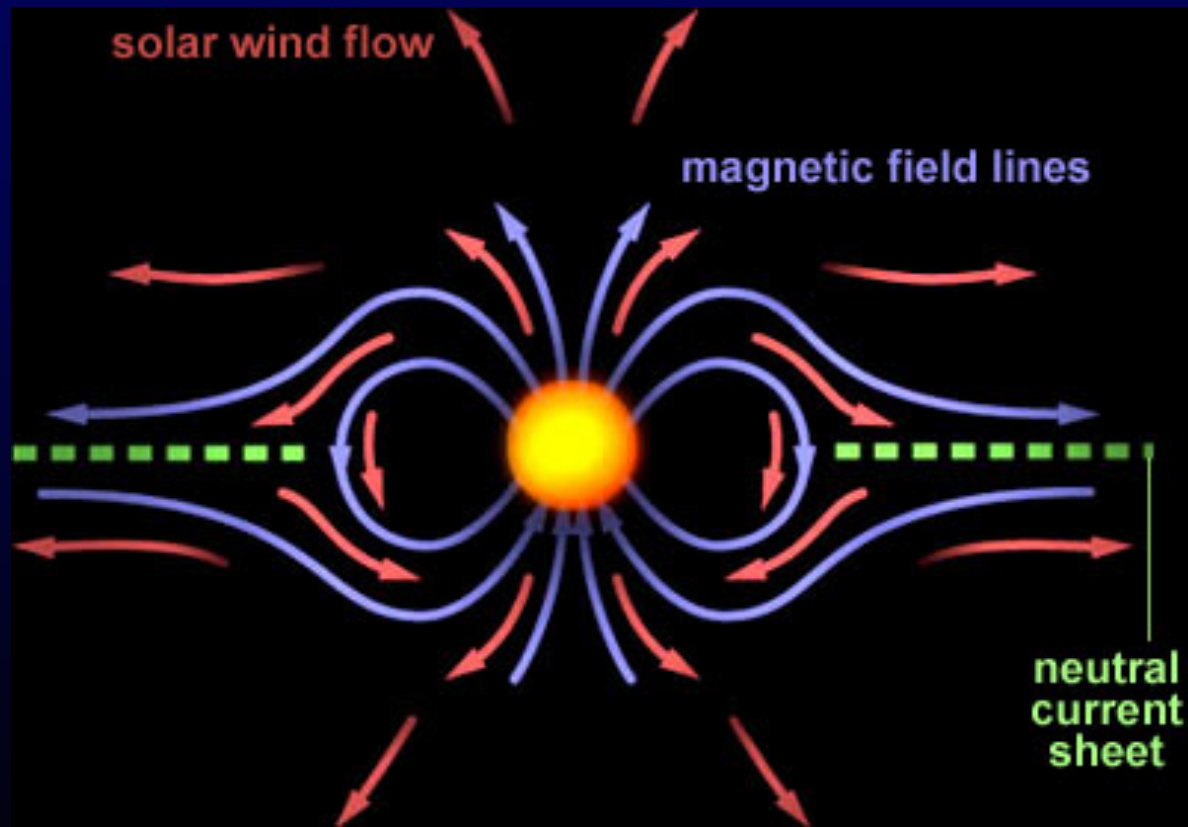
Temperature $\sim 10^5\text{ K}$

Sonic Mach ~ 10

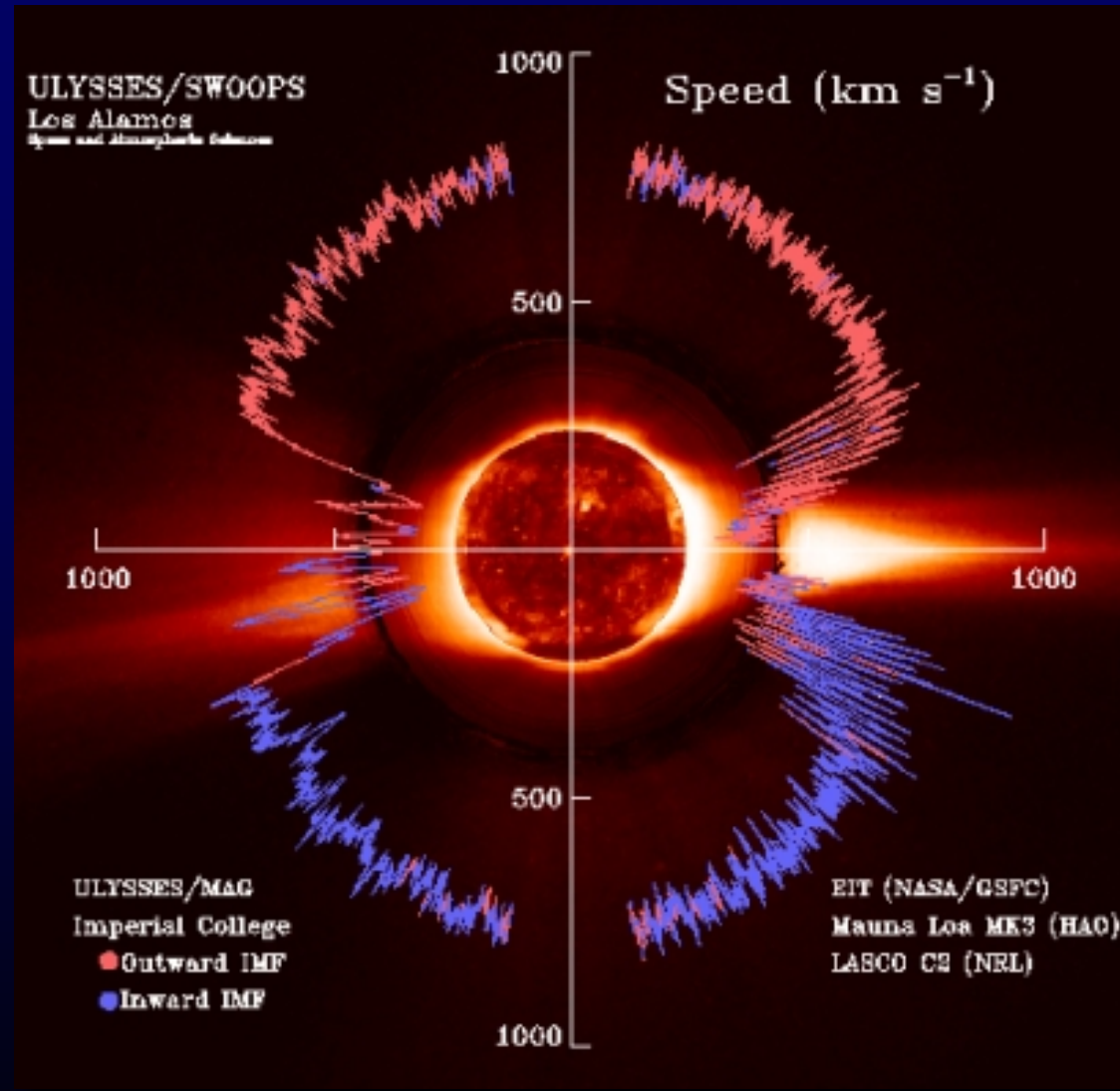
Alfvén Mach ~ 4

Solar Wind Propagation

At Solar Minimum the Sun's magnetic field is very dipolar, and the solar wind carries the magnetic field radially outward, creating a neutral current sheet.



Solar Wind Propagation

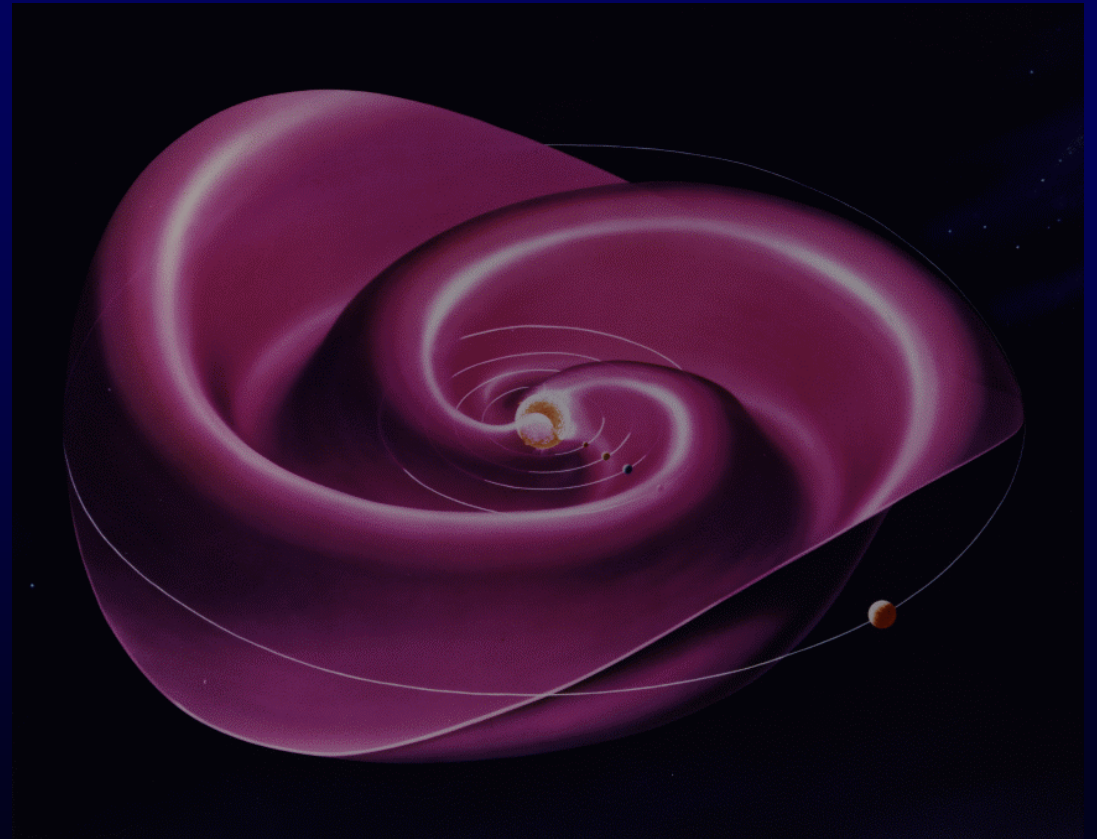


McComas, D. J. et al., GRL, 1998

Solar Wind Propagation

Eugene Parker -- Parker Spiral

However, there are two additional effects, the rotation of the Sun, and the fact that the magnetic moment is not perfectly aligned with the rotation axis. These two effects create a spiral with ripples, or 'ballerina skirt' effect.



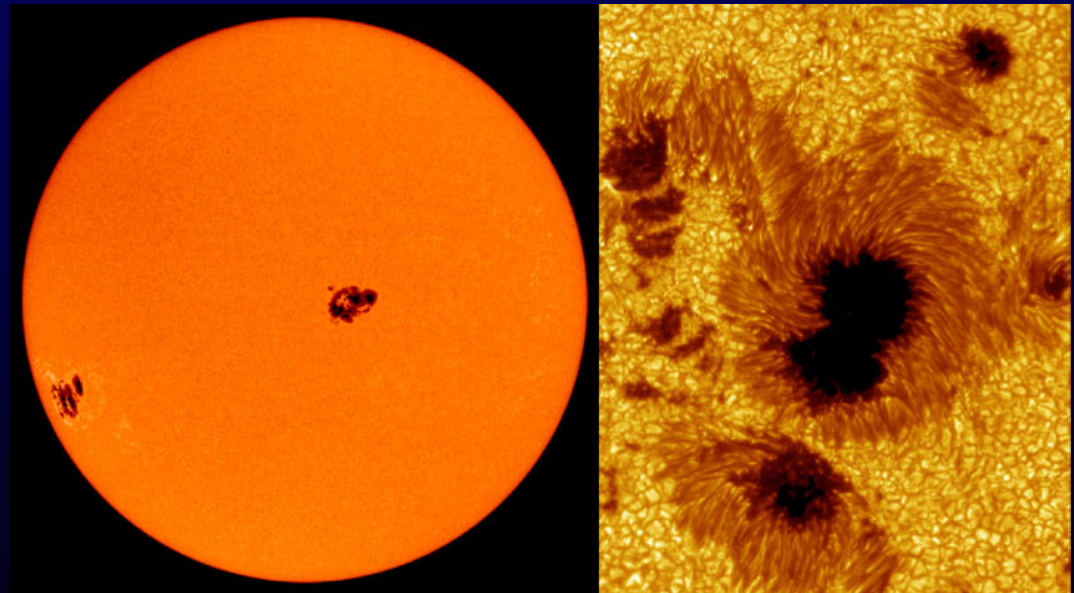
Compliments of the WSO

Solar Cycle

The Sun has an internally generated magnetic field that reverses about every 11 years (~22 years for magnetic cycle)

First noticed through the variation in the number of sunspots

Later recognized by the level of energetic activity on the surface and its impact on the Earth



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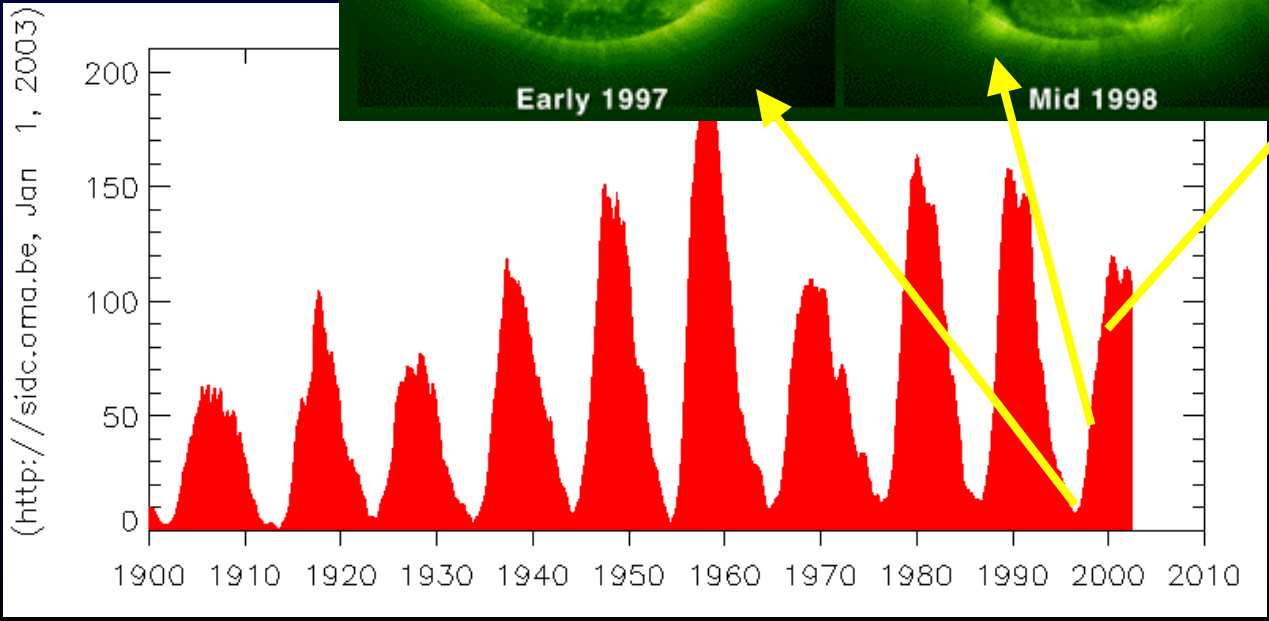
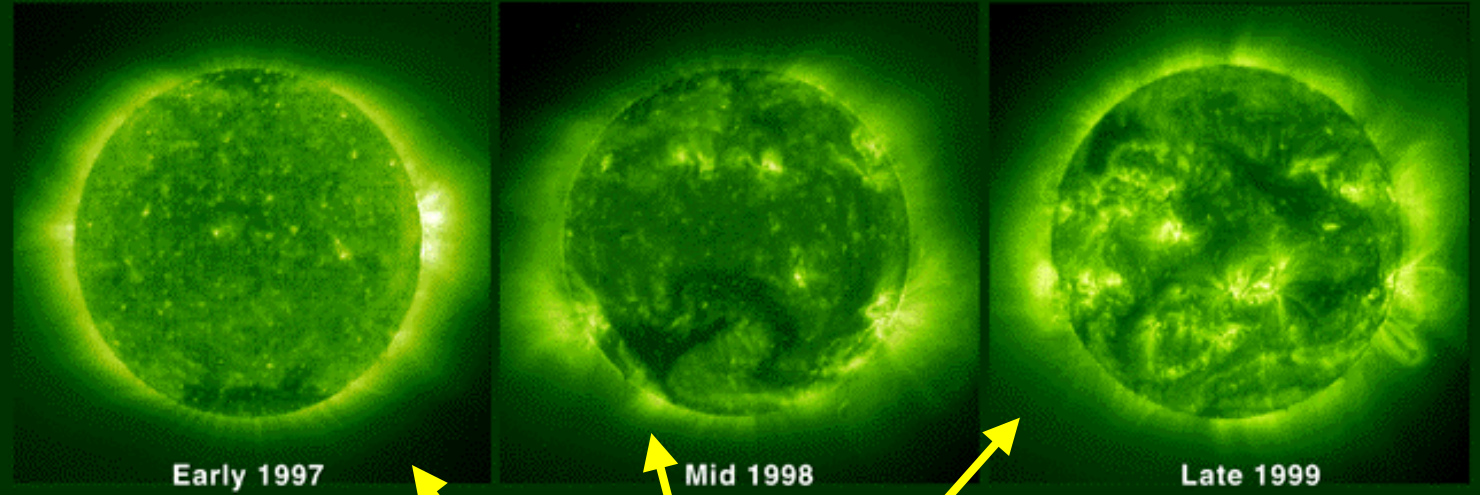


The Solar Cycle



The Sun Approaching Solar Maximum

Solar and Heliospheric Observatory, Extreme ultraviolet Imaging Telescope



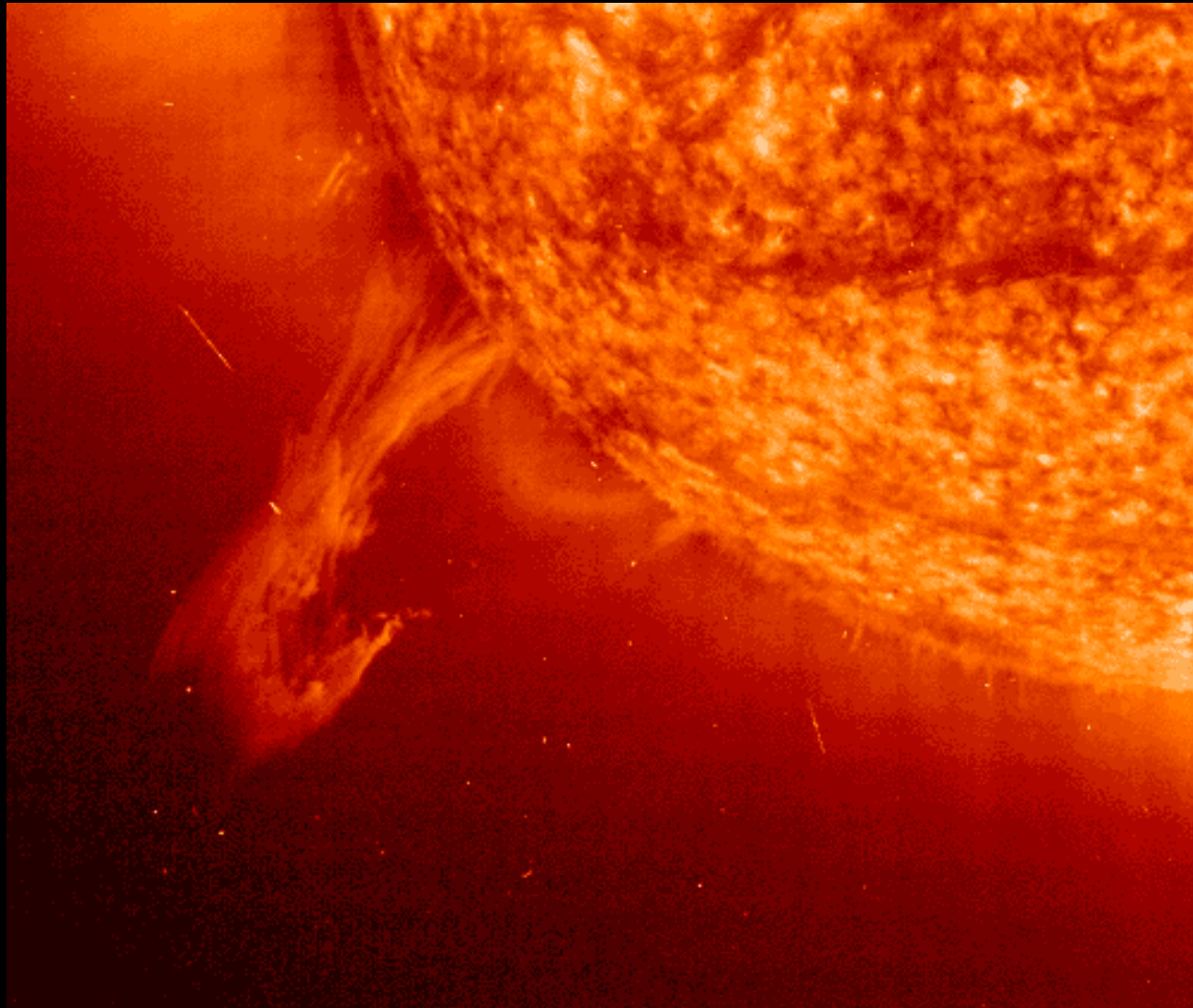
Solar Activity

① Solar Flares

- Large release of energy:
 - Generate X-rays and sometimes even gamma rays
 - Magnetic loops colliding together
 - 10,000-100,000 km in size

Solar Activity

① Solar Flares



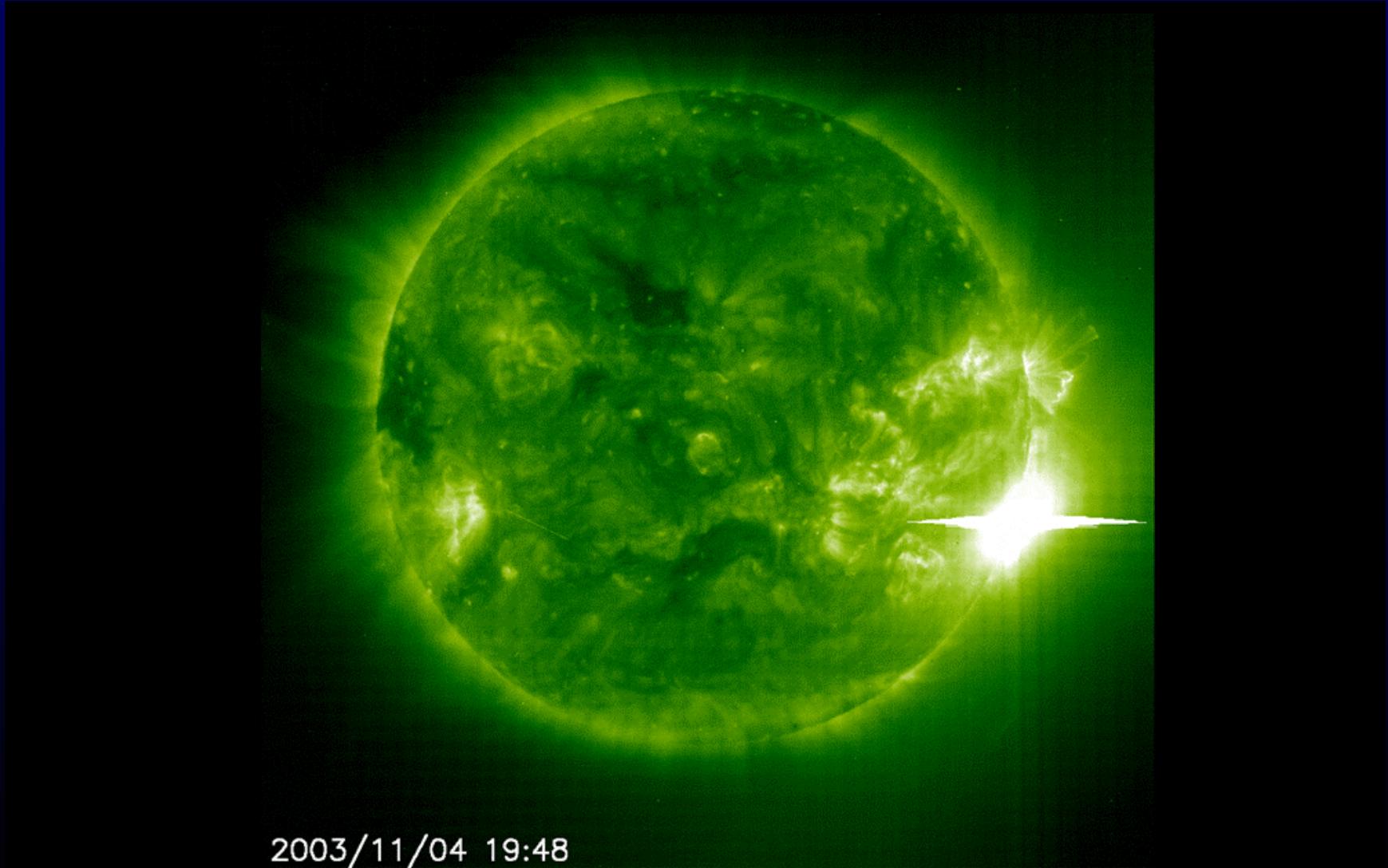
Solar Activity

② Coronal Holes

- Release fast moving plasma continuously into space:
 - No magnetic confinement
 - Dark Areas in X-ray images
 - Large during solar minimum, smaller closer to solar max

Solar Activity

② Coronal Holes



2003/11/04 19:48

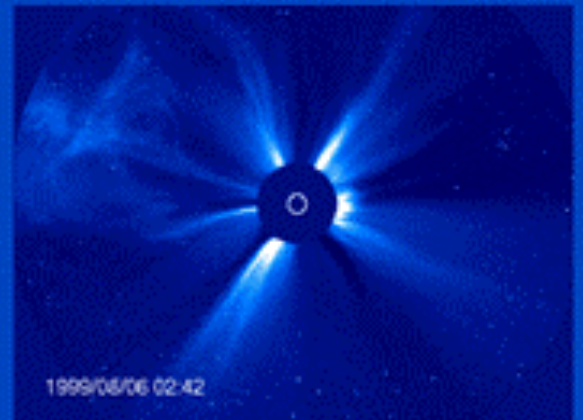
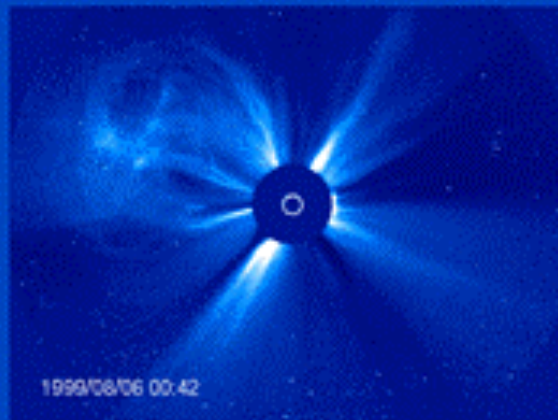
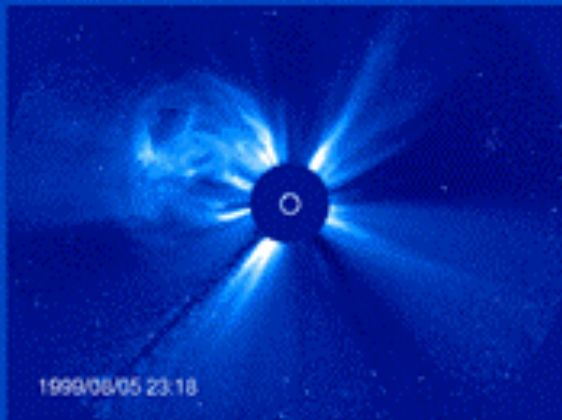
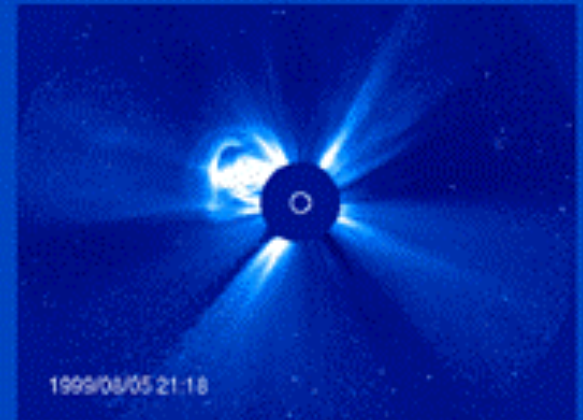
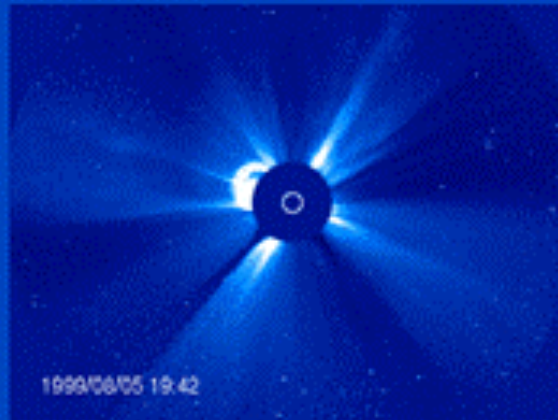
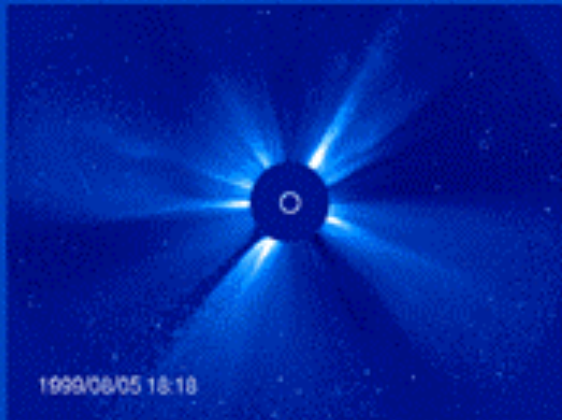
Solar Activity

③ Coronal Mass Ejections

- Very large release of energy and energetic particles:
 - Generates X-rays
 - Releases very energetic ions
 - Larger than the Sun

Solar Activity

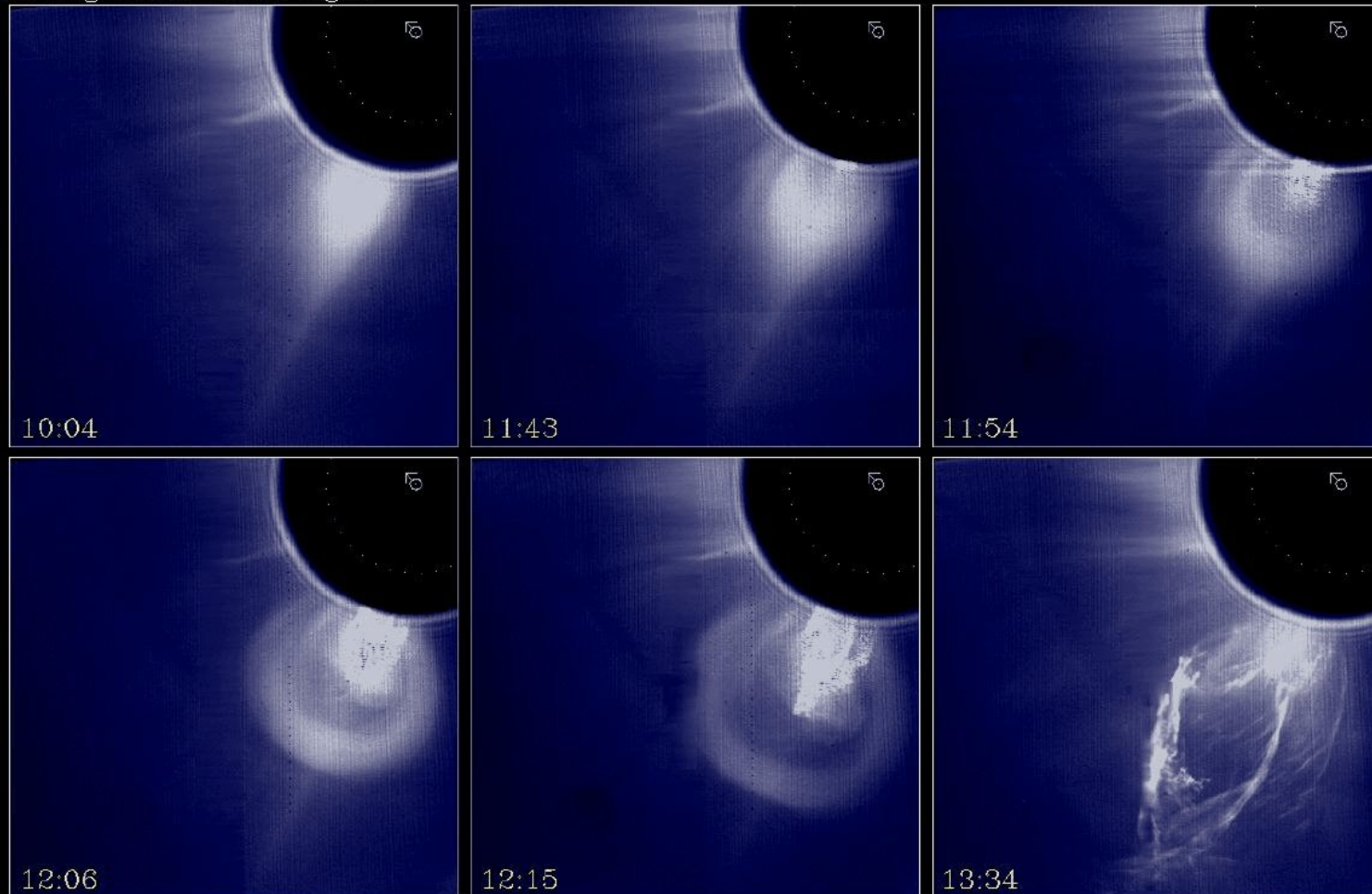
③ Coronal Mass Ejections



Solar Activity

③ Coronal Mass Ejections

18 Aug 1980: White Light

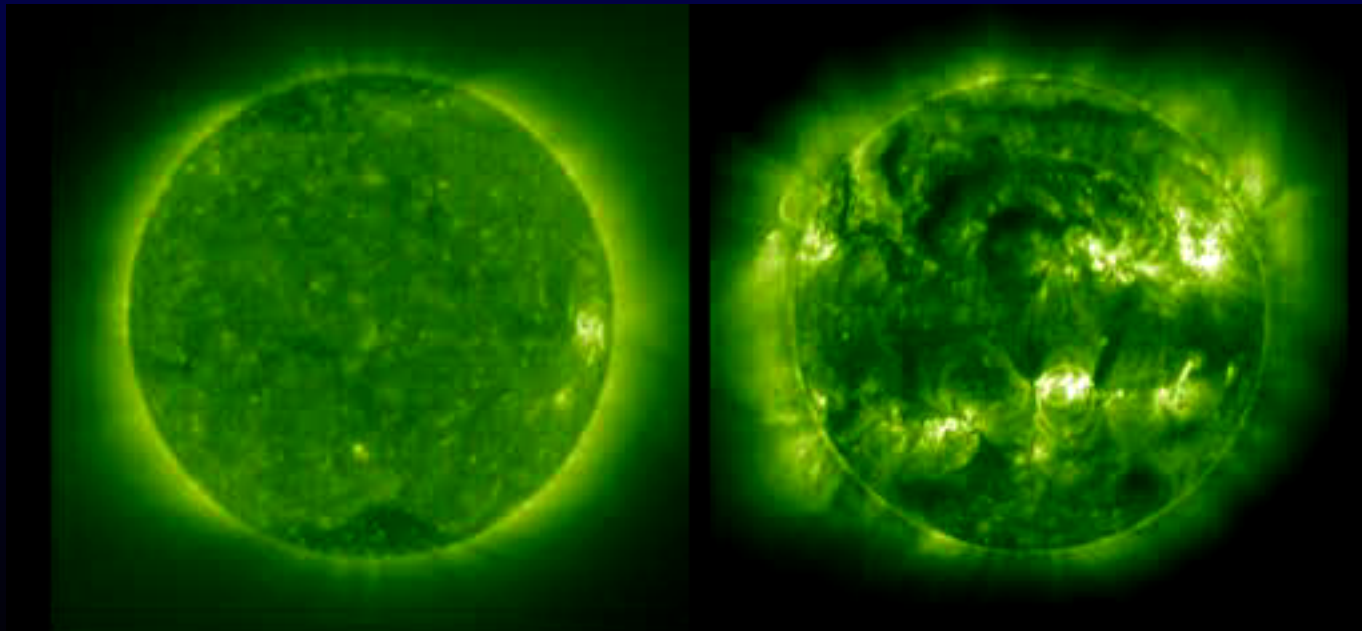
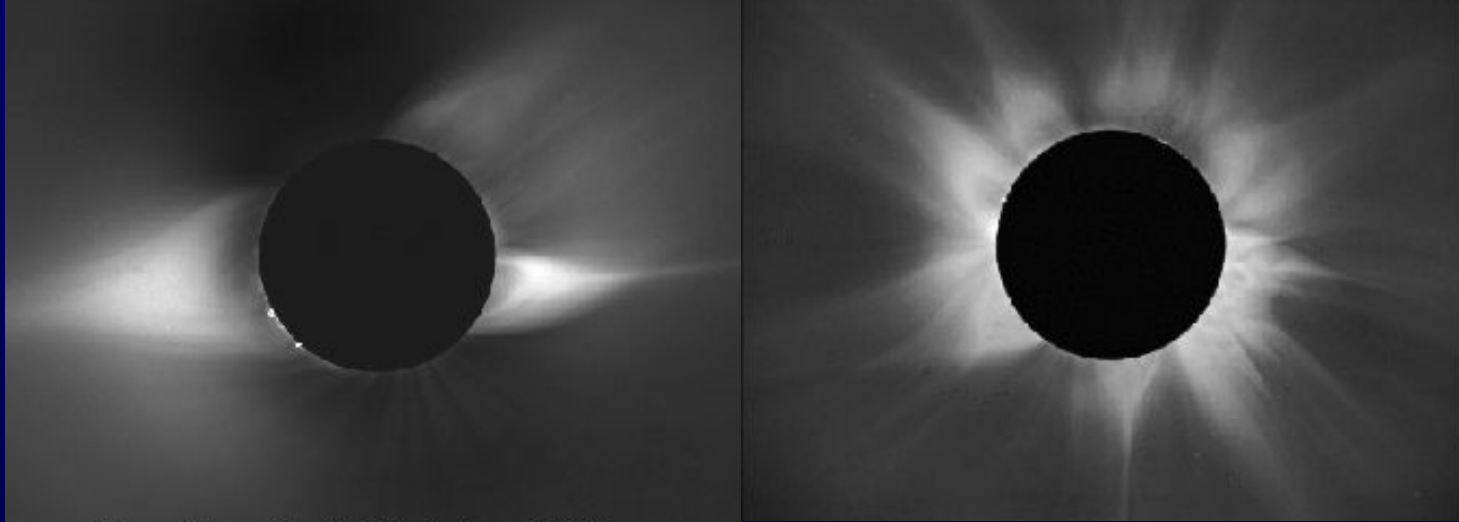


Source: High Altitude Observatory/Solar Maximum Mission Archives

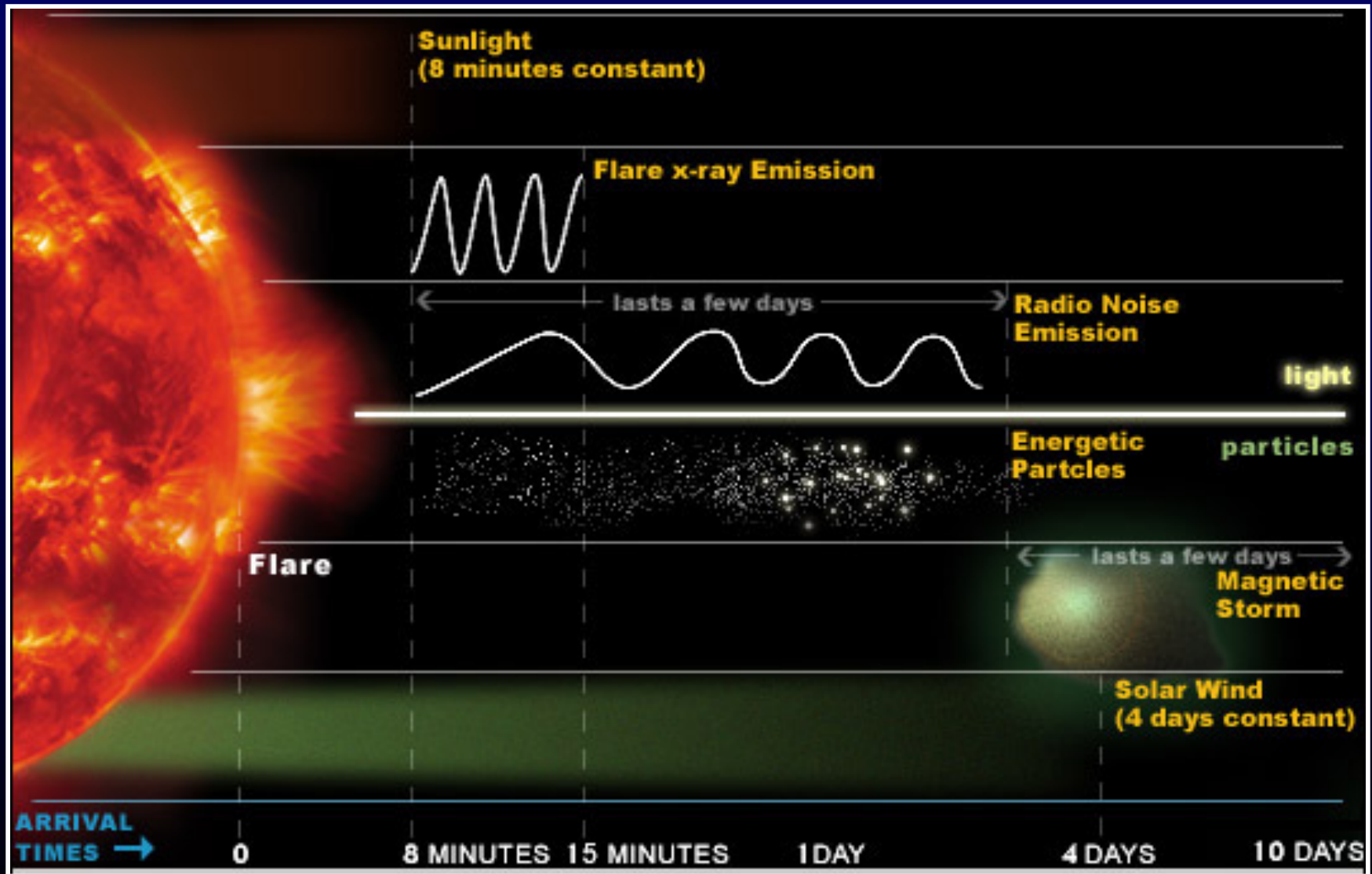
HAO A-013

Solar Wind at Solar Minimum and Max

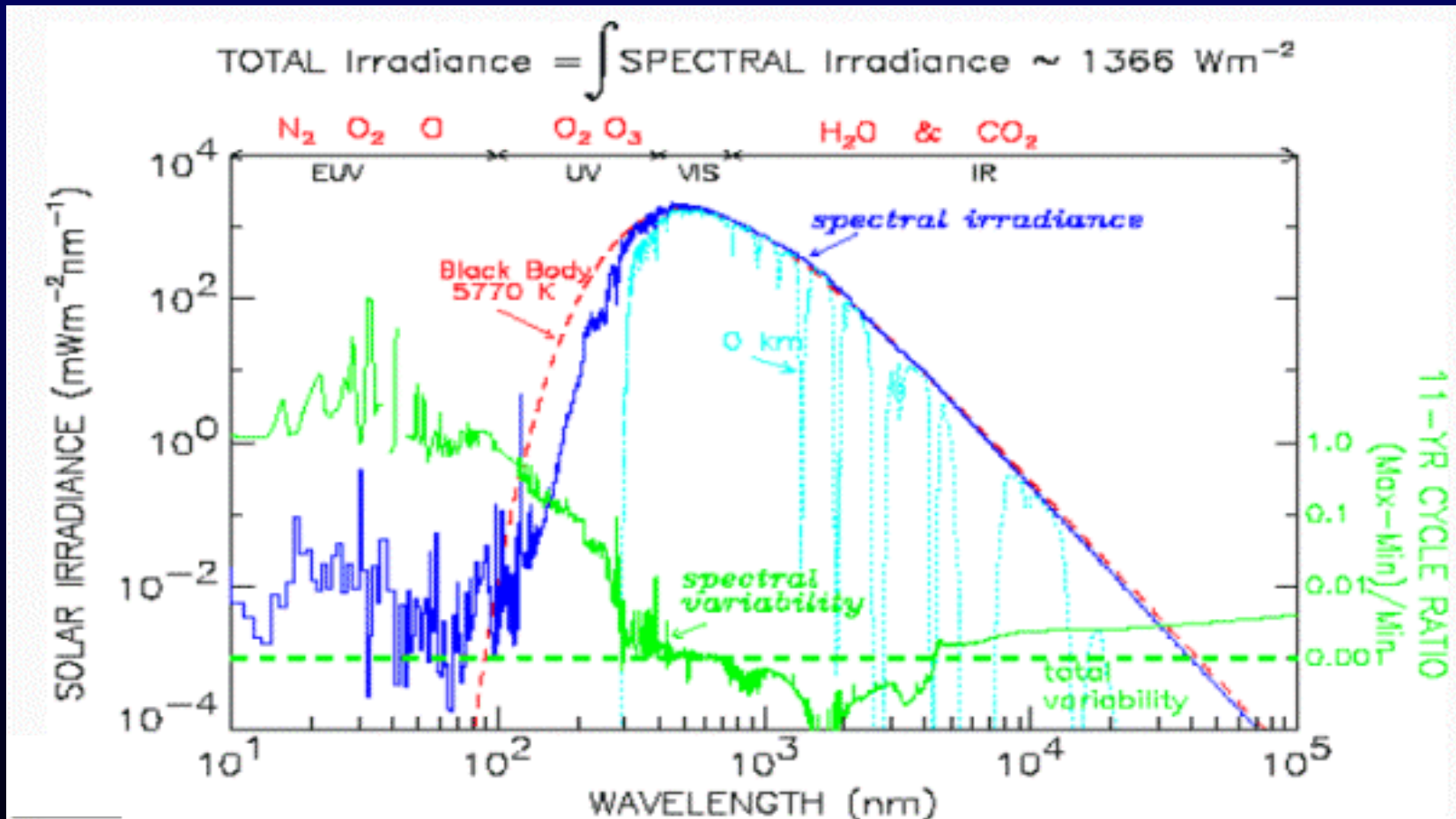
(White Light Eclipse Images from the High Altitude Observatory)



Energy Transport

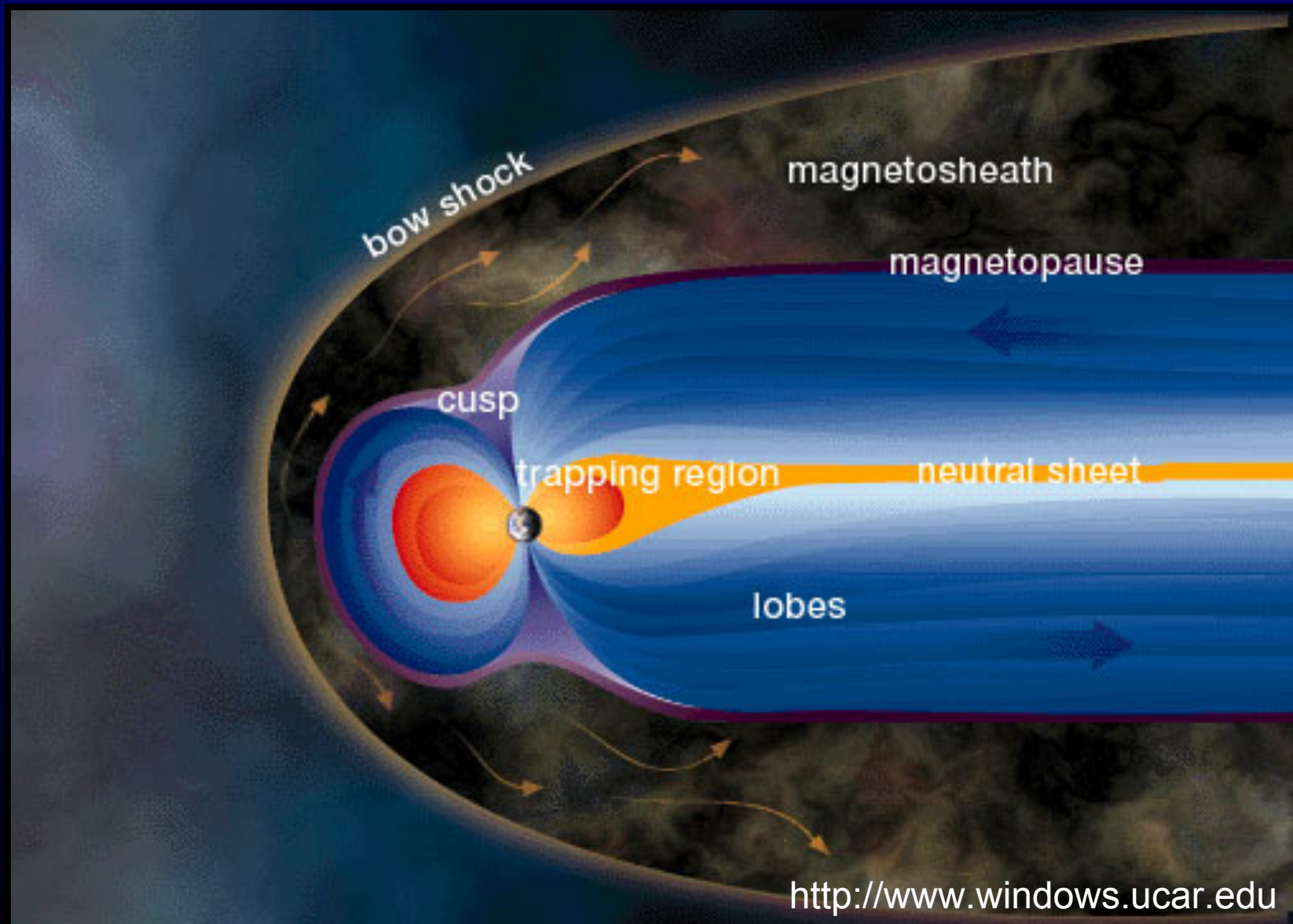


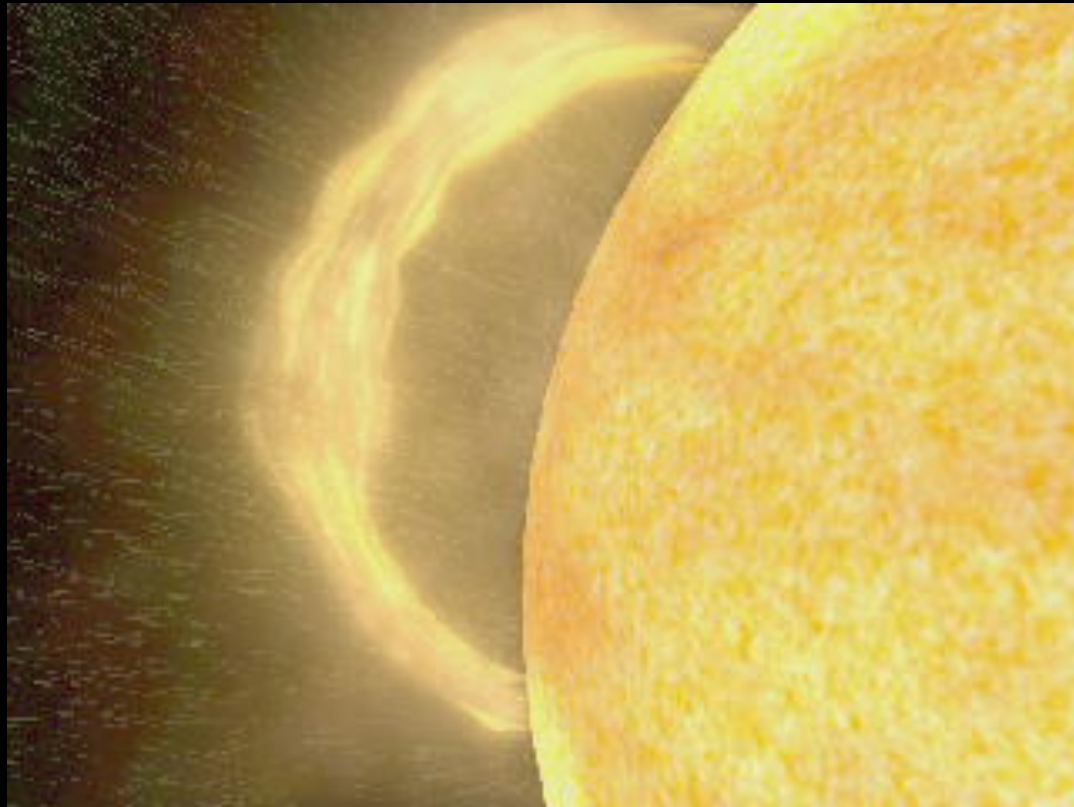
Solar Spectrum, Variability, and Atmospheric Absorption



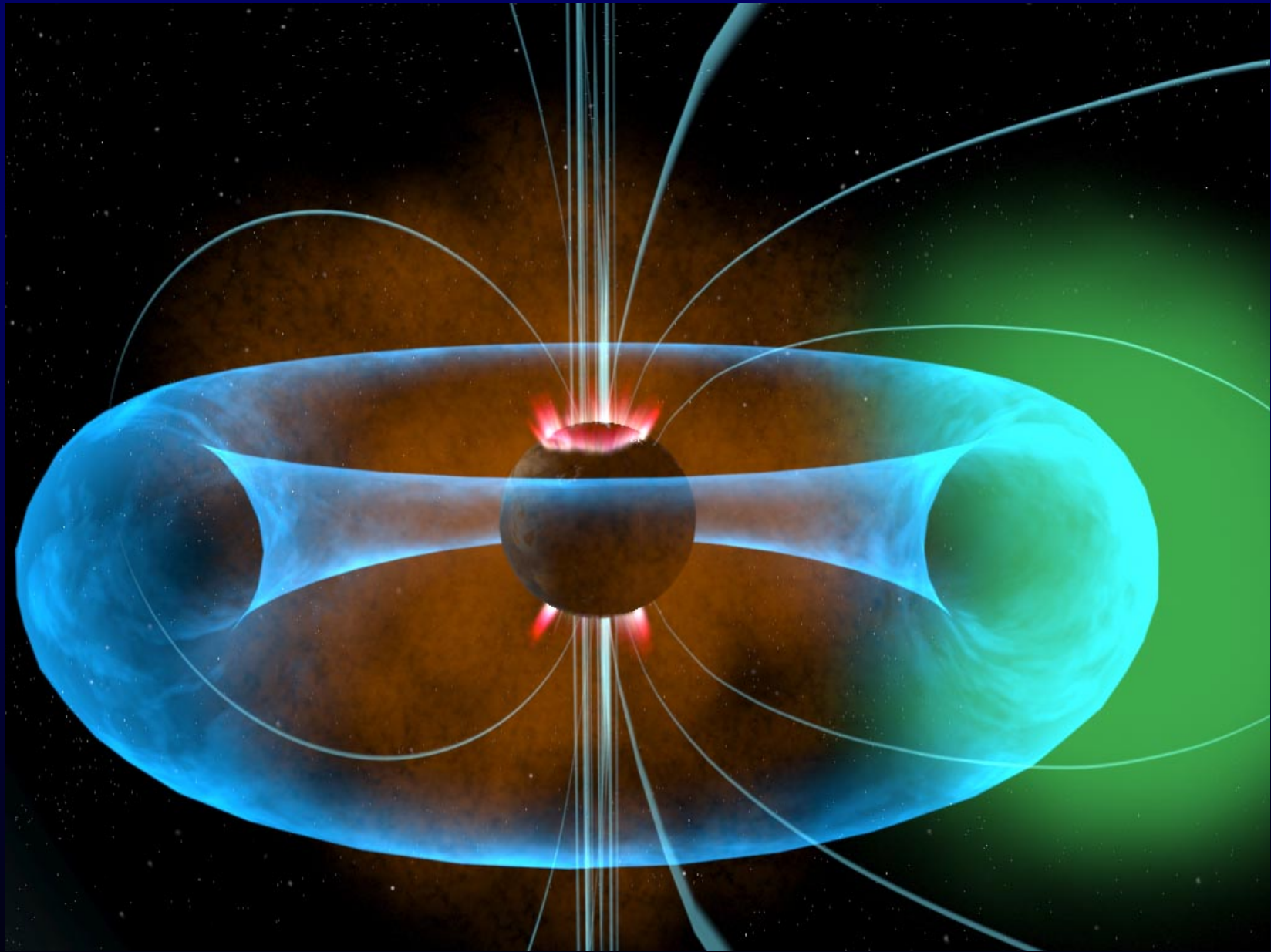
Courtesy of J. Lean, NRL

Planetary Magnetic Fields





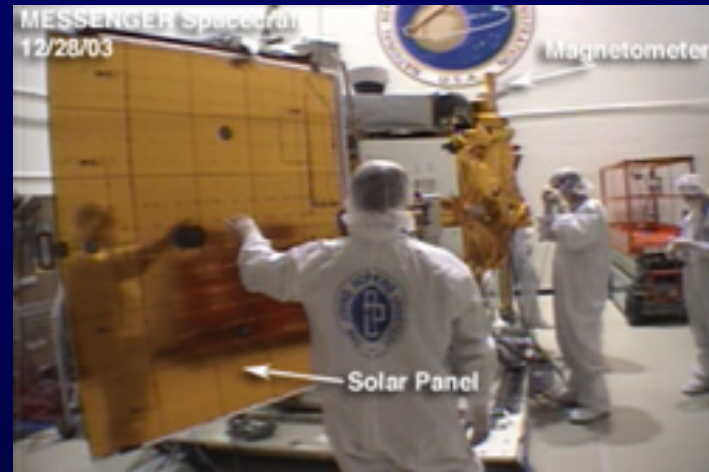
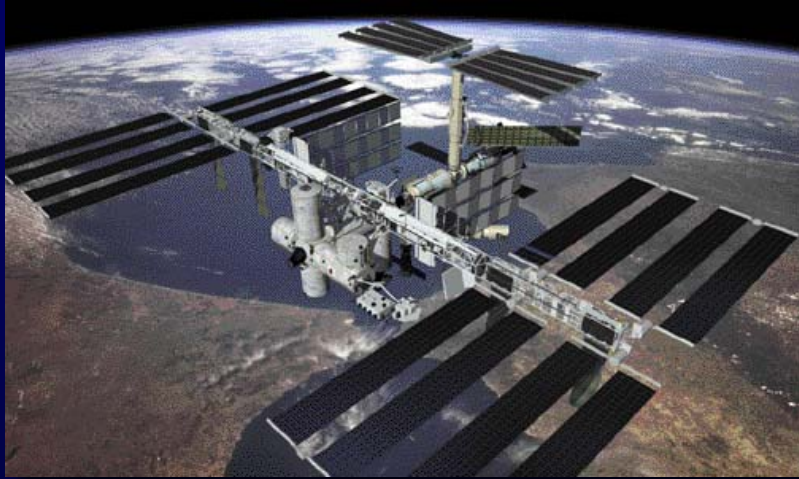
NASA/Goddard Space Flight Center Conceptual Image Lab



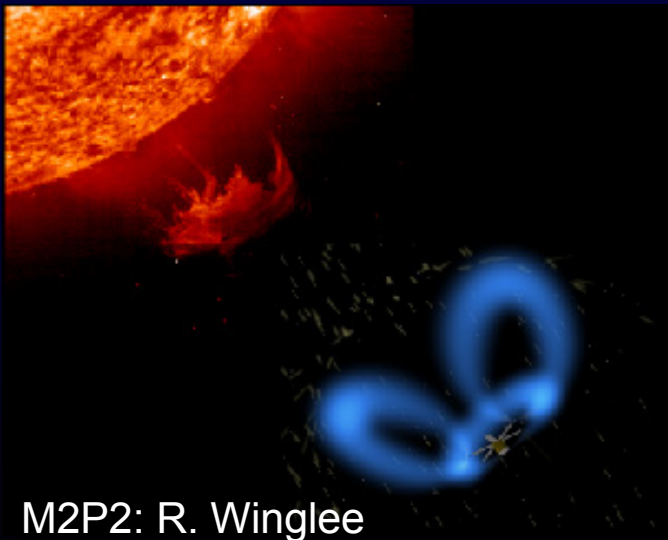
NASA/Goddard Space Flight Center Conceptual Image Lab

The Sun: A Source of Energy in Space

Solar Energy for Power: Earth orbit and robotic exploration



Solar Energy for Propulsion



M2P2: R. Winglee



Star Wars Episode II

Solar Image & Educational Resources

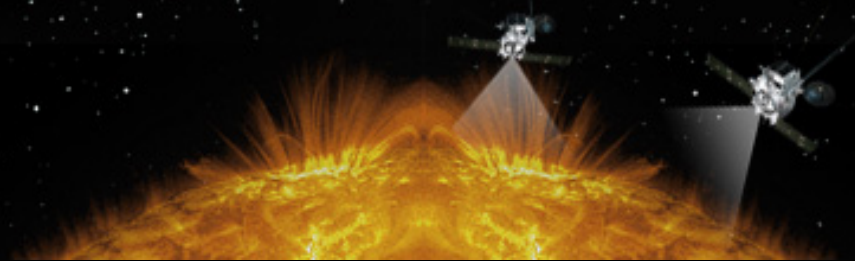


<http://sohowww.nascom.nasa.gov/>

STEREO

Solar **TE**rrestrial **RE**lations **O**bservatory

Capturing the Sun in 3-D



<http://stereo.jhuapl.edu/>