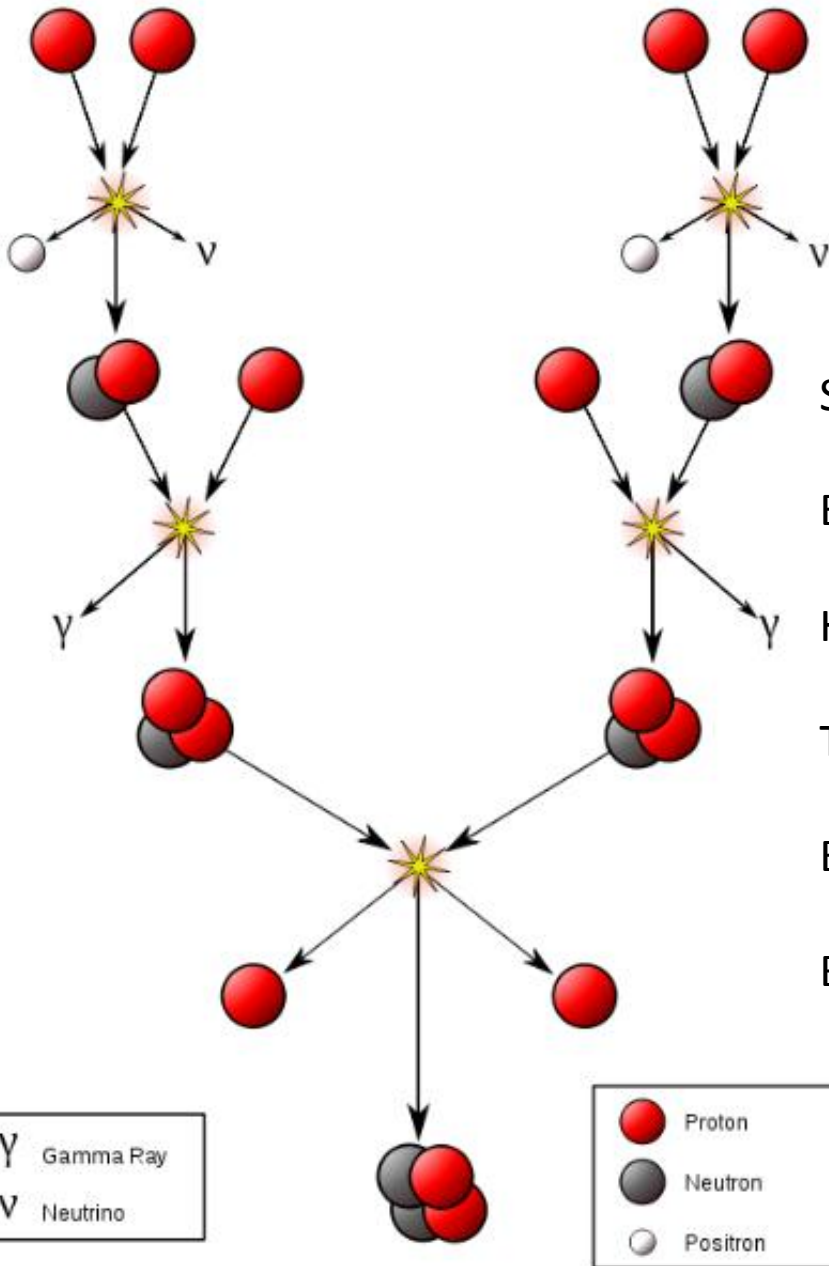


# Introduction: Solar Variability & its Consequences

Nat Gopalswamy  
NASA/GSFC

# Nuclear Fusion Powers the Sun



Start with six protons (Hydrogen nuclei)

End with Helium and 2 protons

Helium nucleus weighs smaller than 4 protons

The missing mass became energy according to

$$E = mc^2$$

By-products: 2 neutrinos, 2 gamma rays



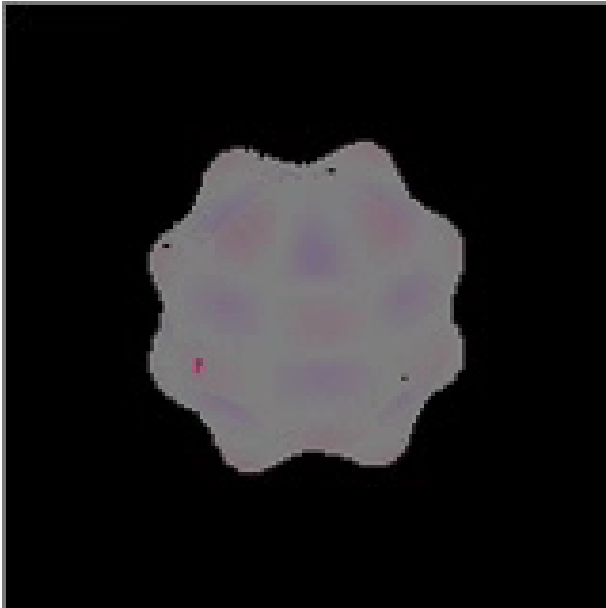
Proof of Fusion



Energy from the Sun

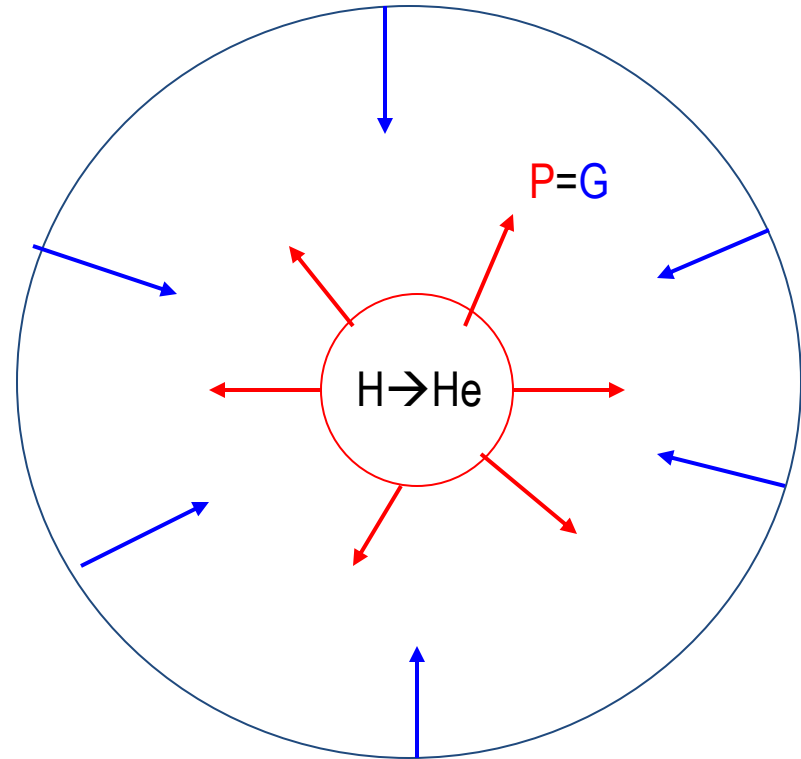
# Solar Oscillations

Helioseismology confirms  
the standard solar model



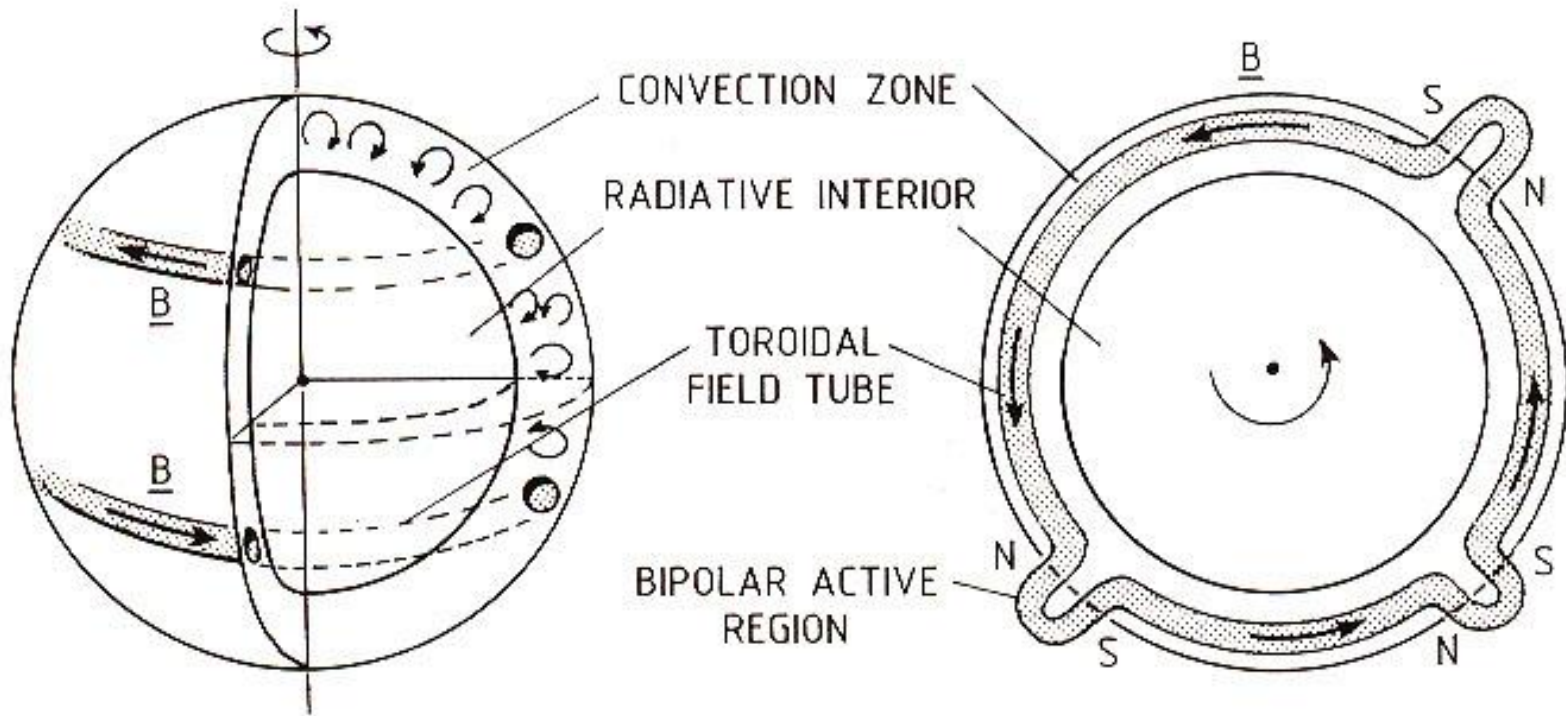
Movie showing oscillations with greatly  
exaggerated amplitudes

Courtesy: D.B. Guenther & P. Demarque 1996



The Sudbury Neutrino Observatory in Canada  
confirmed the correct number of neutrinos  
released from the Sun due to fusion

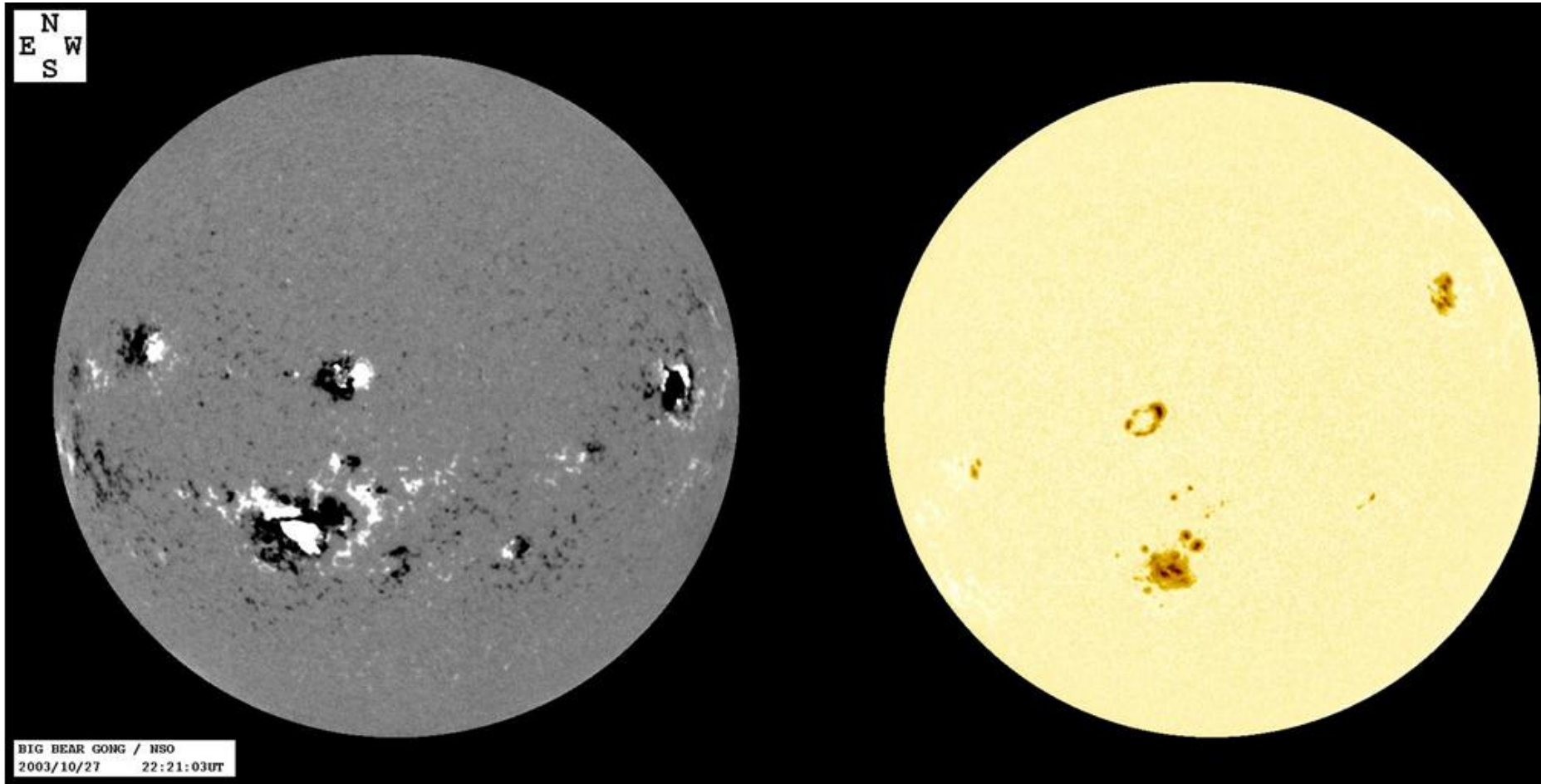
# Trouble in the outer layer: convection



Solar rotation and convection (motion of ionized matter = current) in the outer 1/3 of the Sun results in dynamo action

→ generation of magnetic field that emerges into the atmosphere as sunspots

# Sunspots and magnetic Field

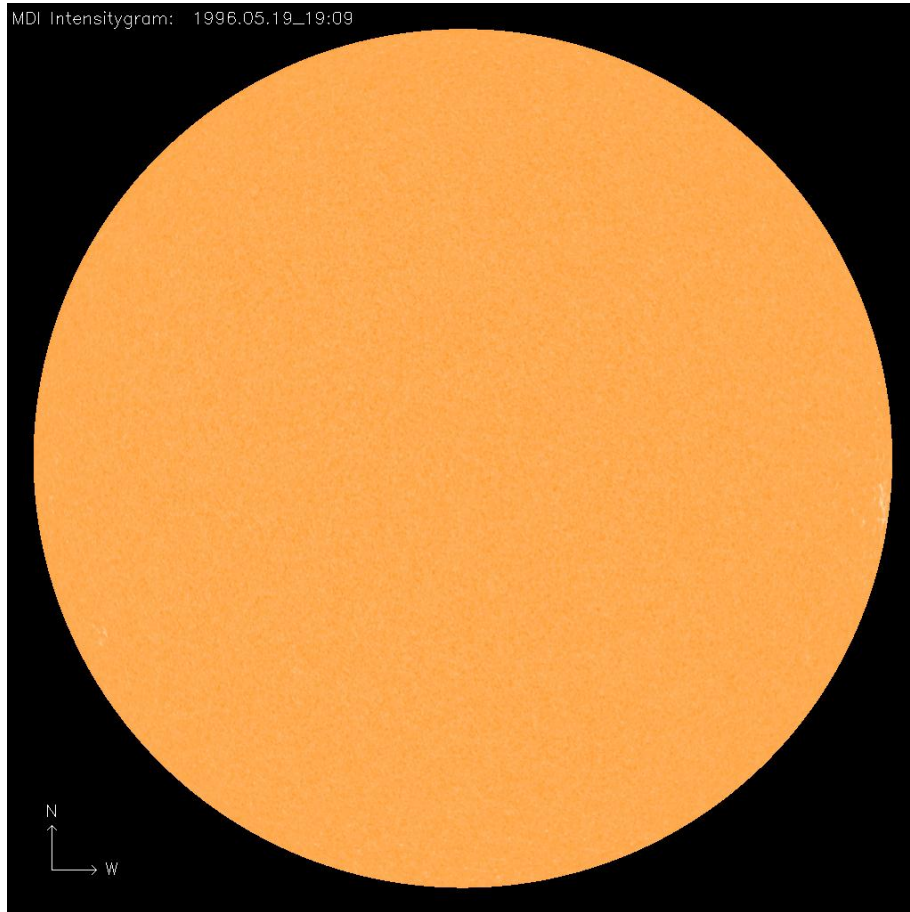


Solar magnetic fields

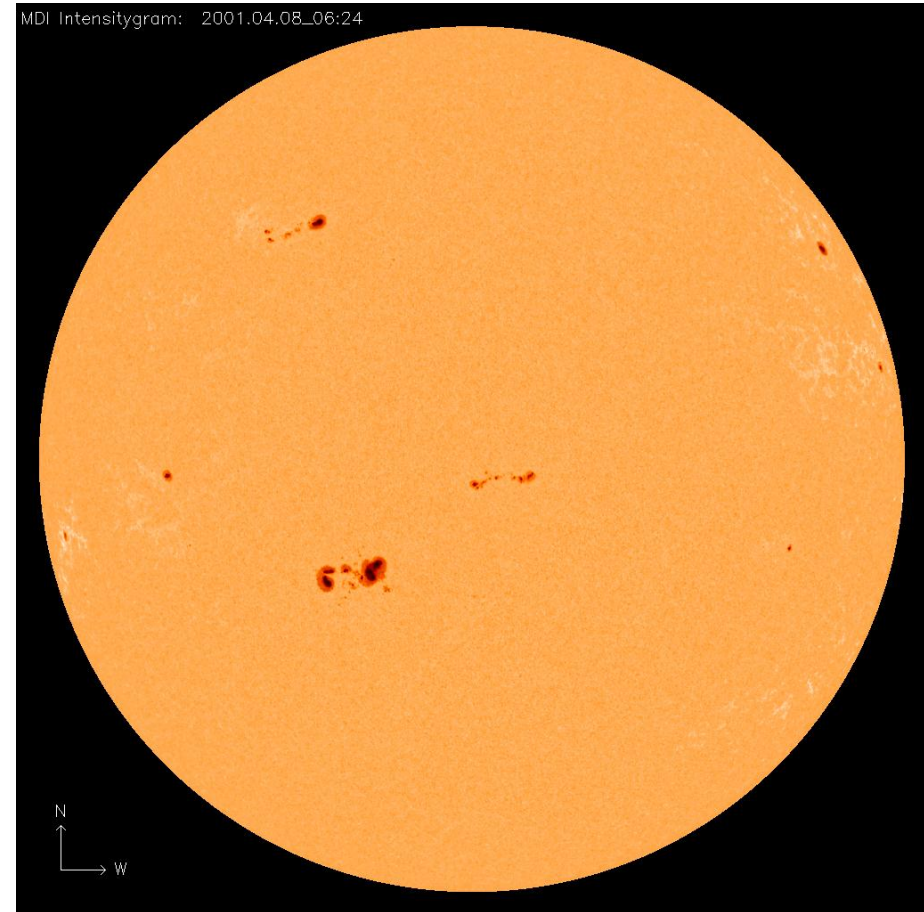
Sunspots = regions of high magnetic field strength

# Sunspot Cycle

1996 May 1 Minimum

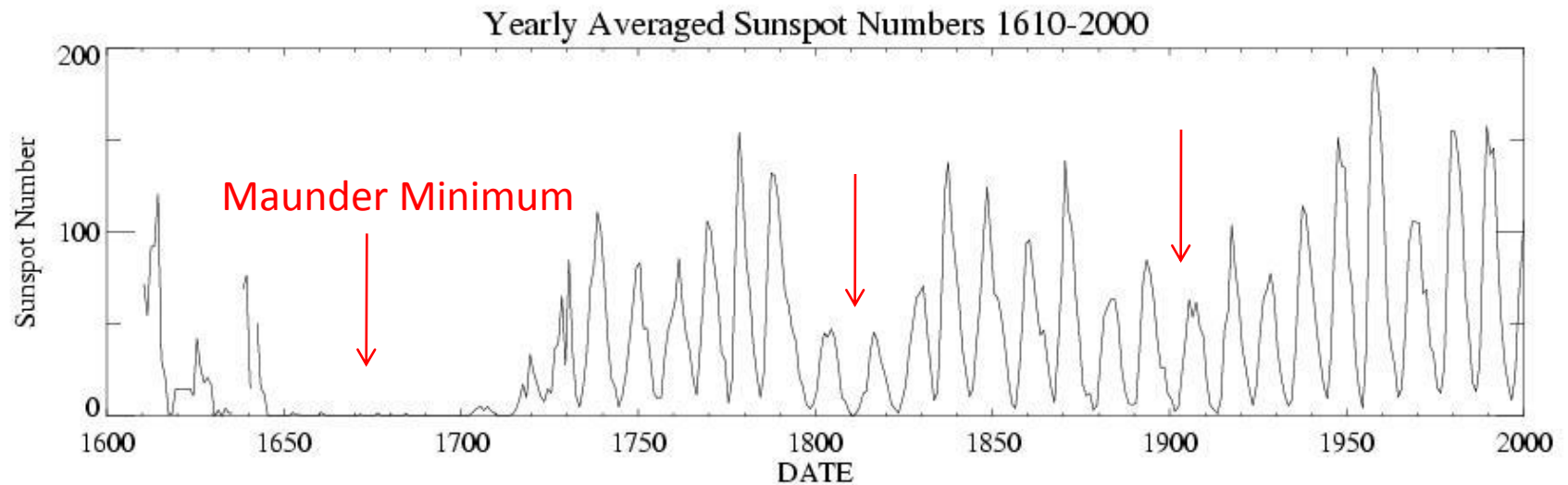


2001 April 8 Maximum



Sunspot cycle discovered by Schwabe 1843, confirmed by Wolf 1856

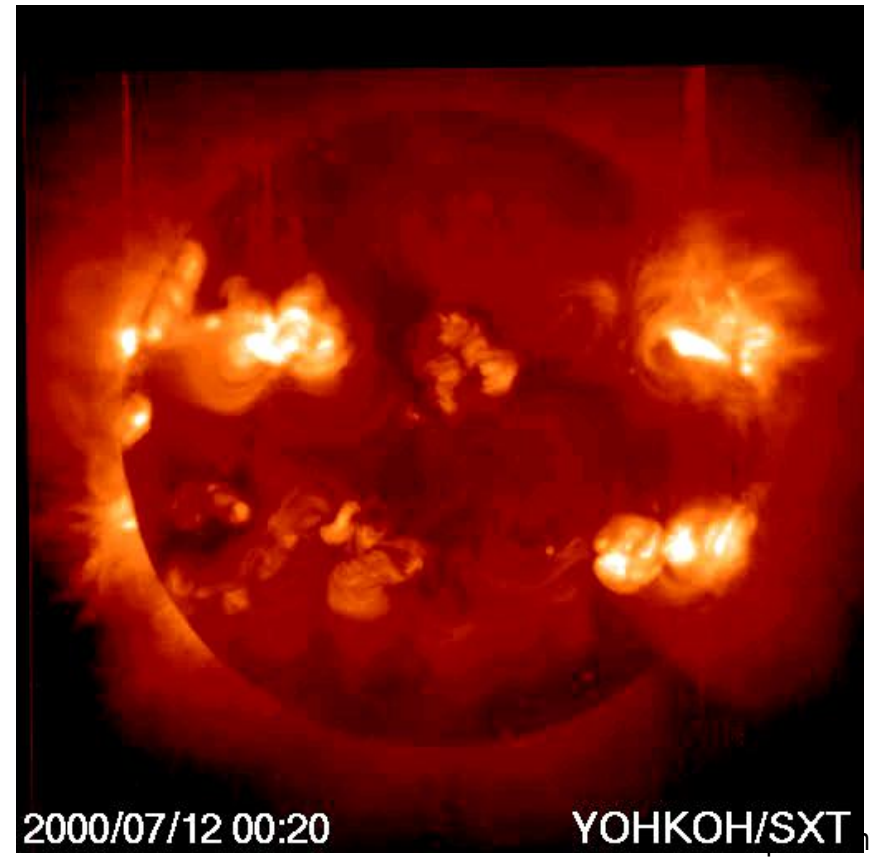
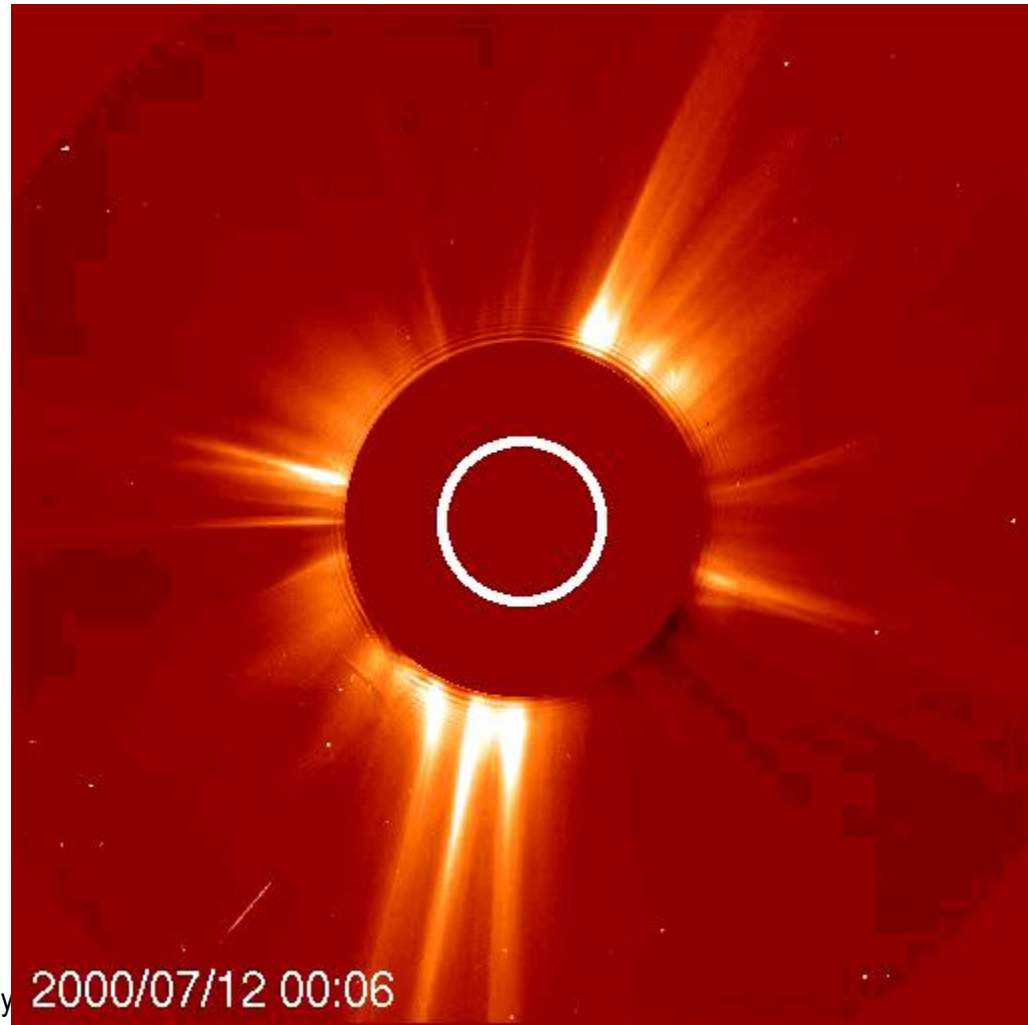
# Solar Cycle



# Solar eruptions

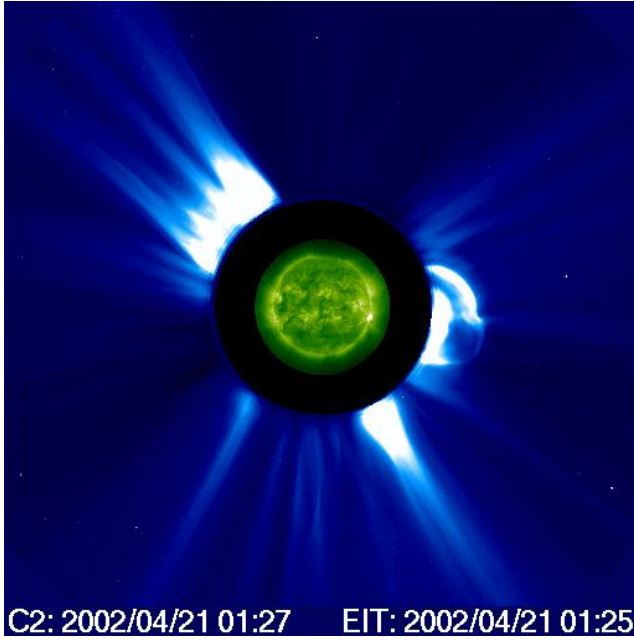
Coronal mass ejections  
particle and magnetic storms

Flares: modify the  
ionosphere





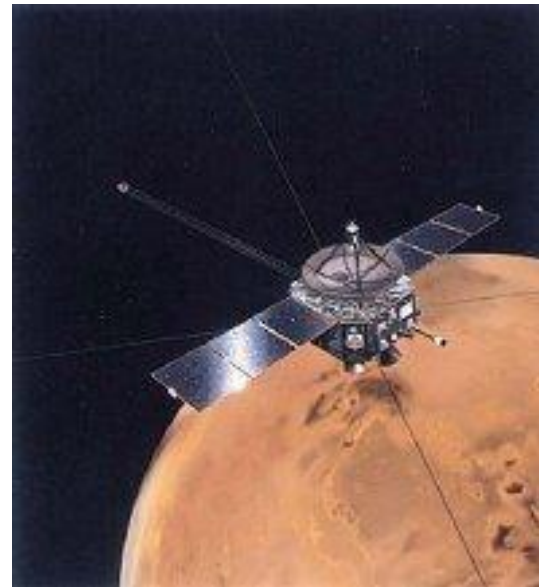
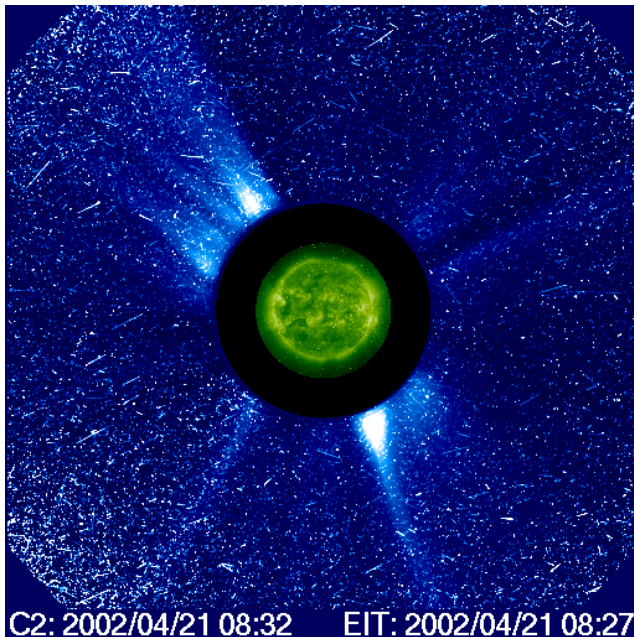
2002 April 21 CME



# The Nozomi Killer?

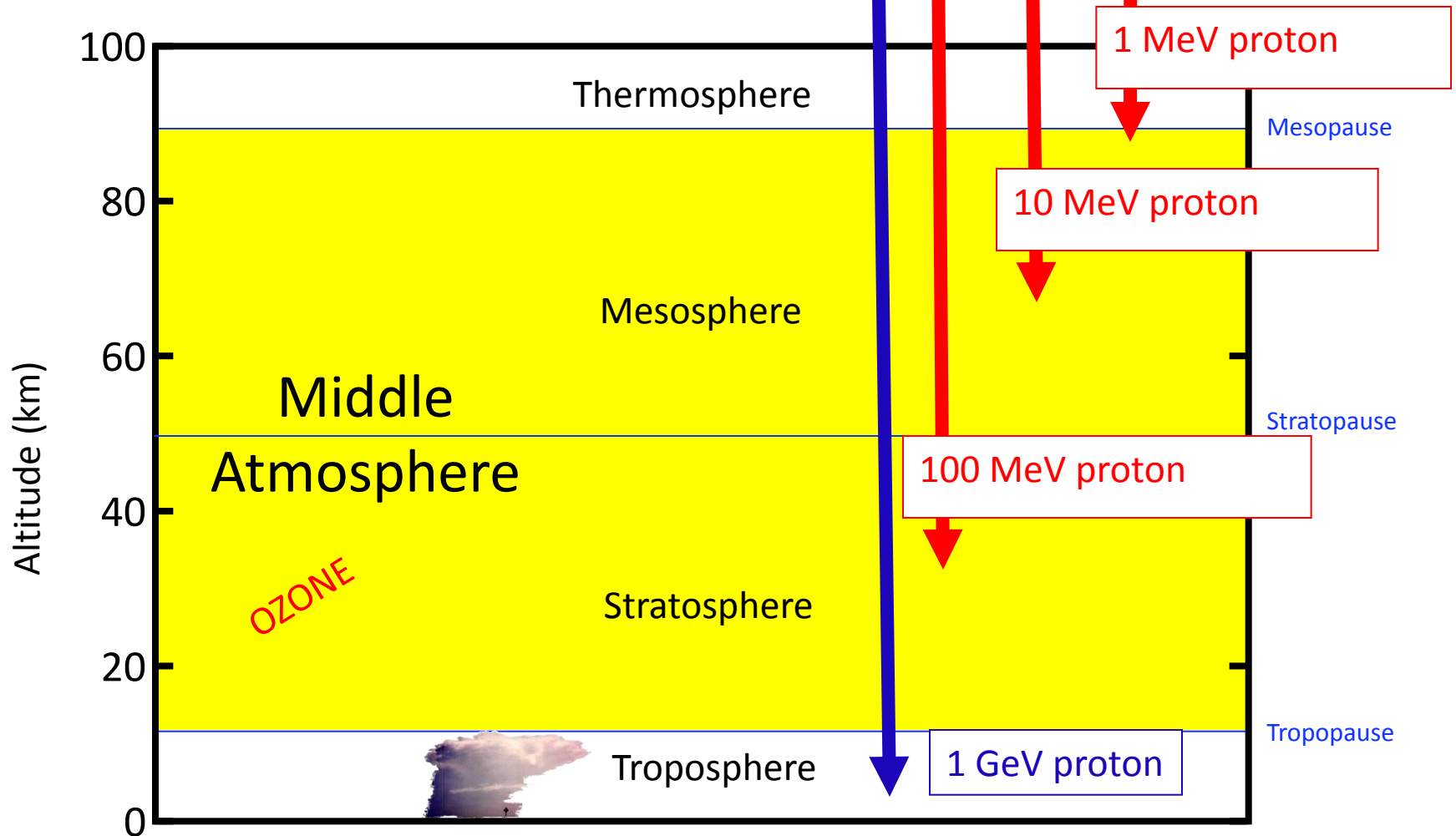
Japan's Mars mission, Nozomi ended six months before insertion into Mars orbit: The April 21 2002 proton storm event seems to be the cause.

SEPs damaged onboard communications and power systems



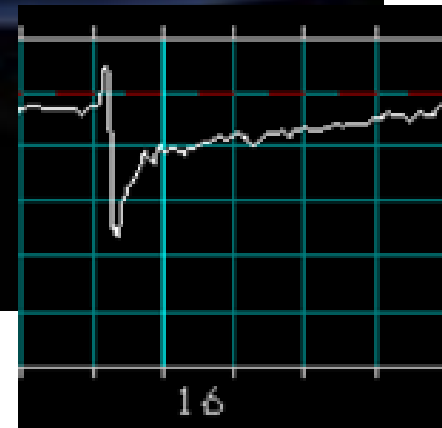
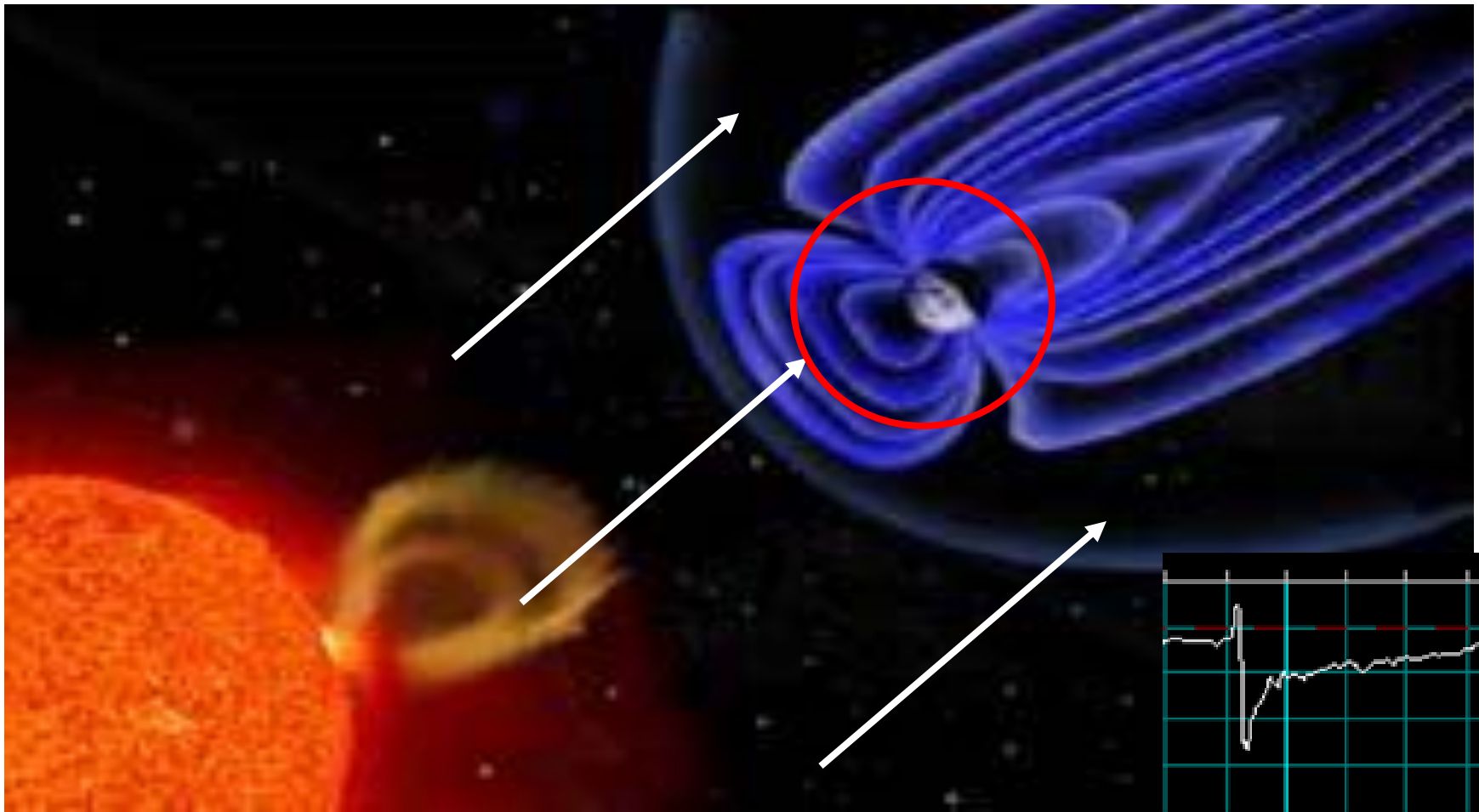
Nozomi = Hope

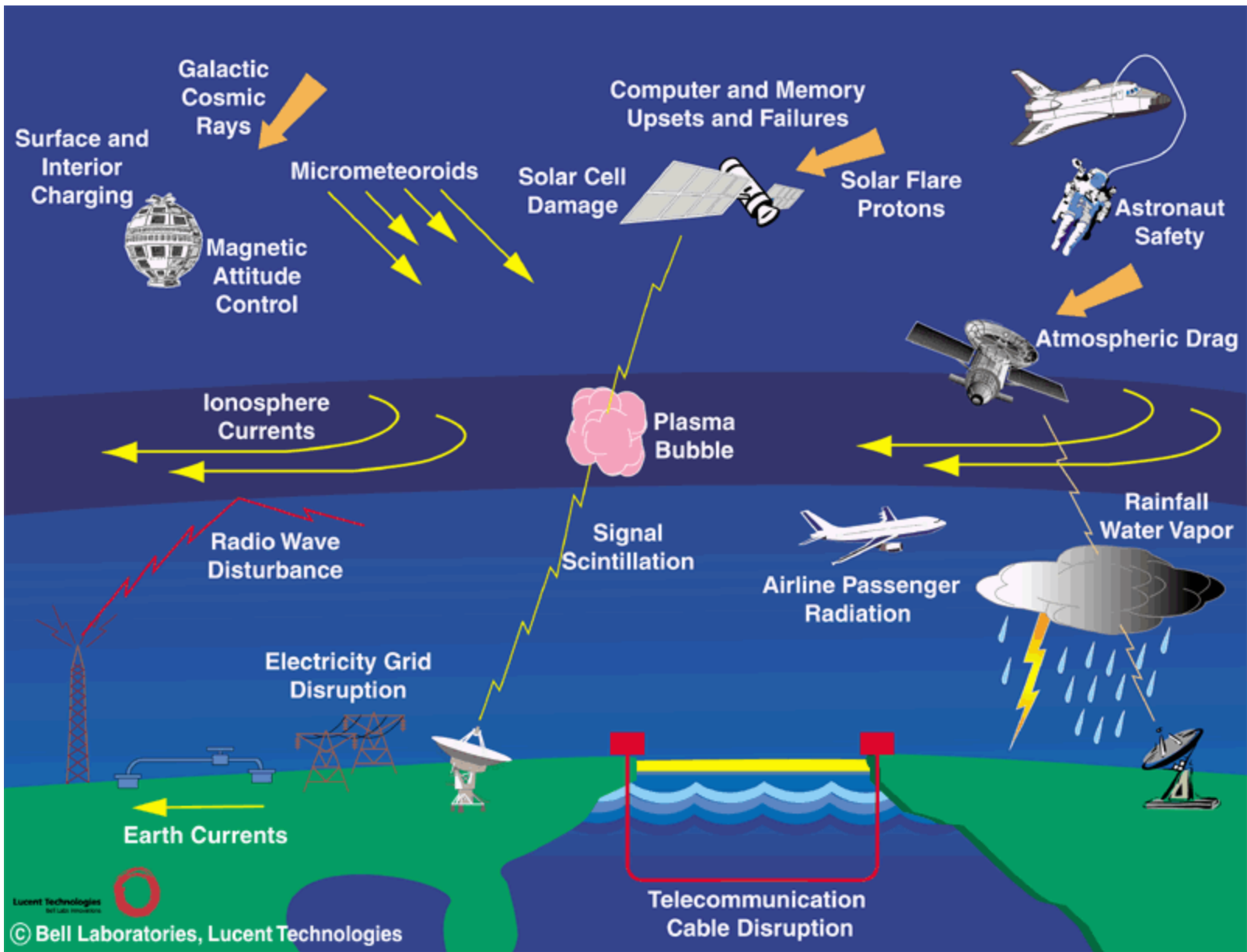
GOES provides Proton flux  
for >1 MeV to >100 MeV



Particle radiation from the Sun can destroy ozone

# Satellites Exposed to Interplanetary Space during Geomagnetic Storms

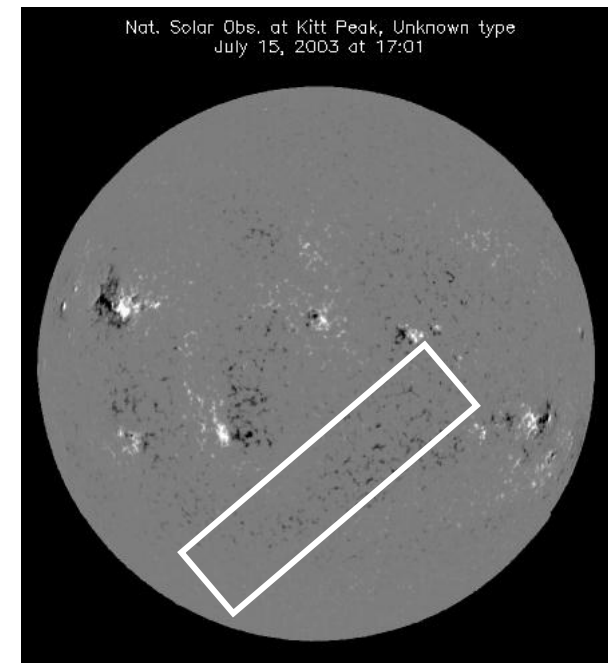
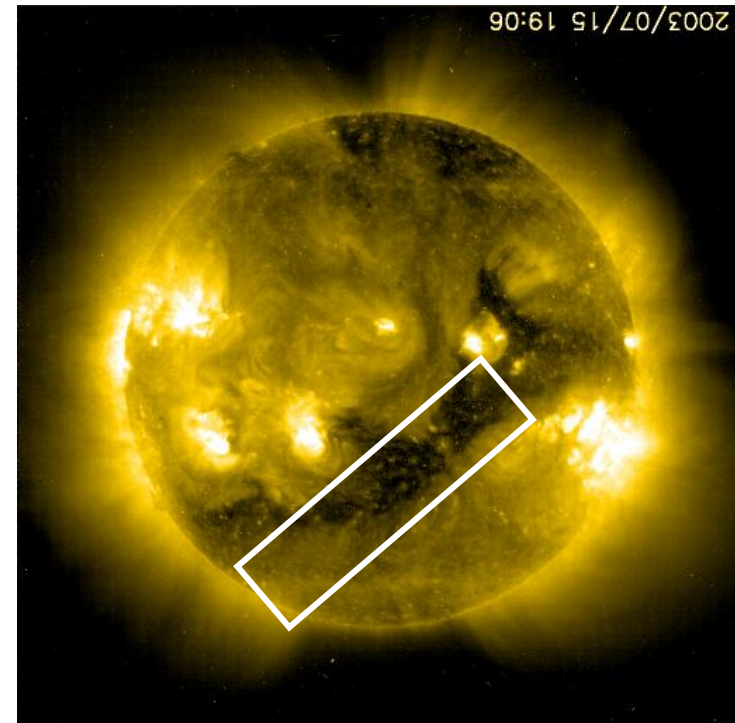




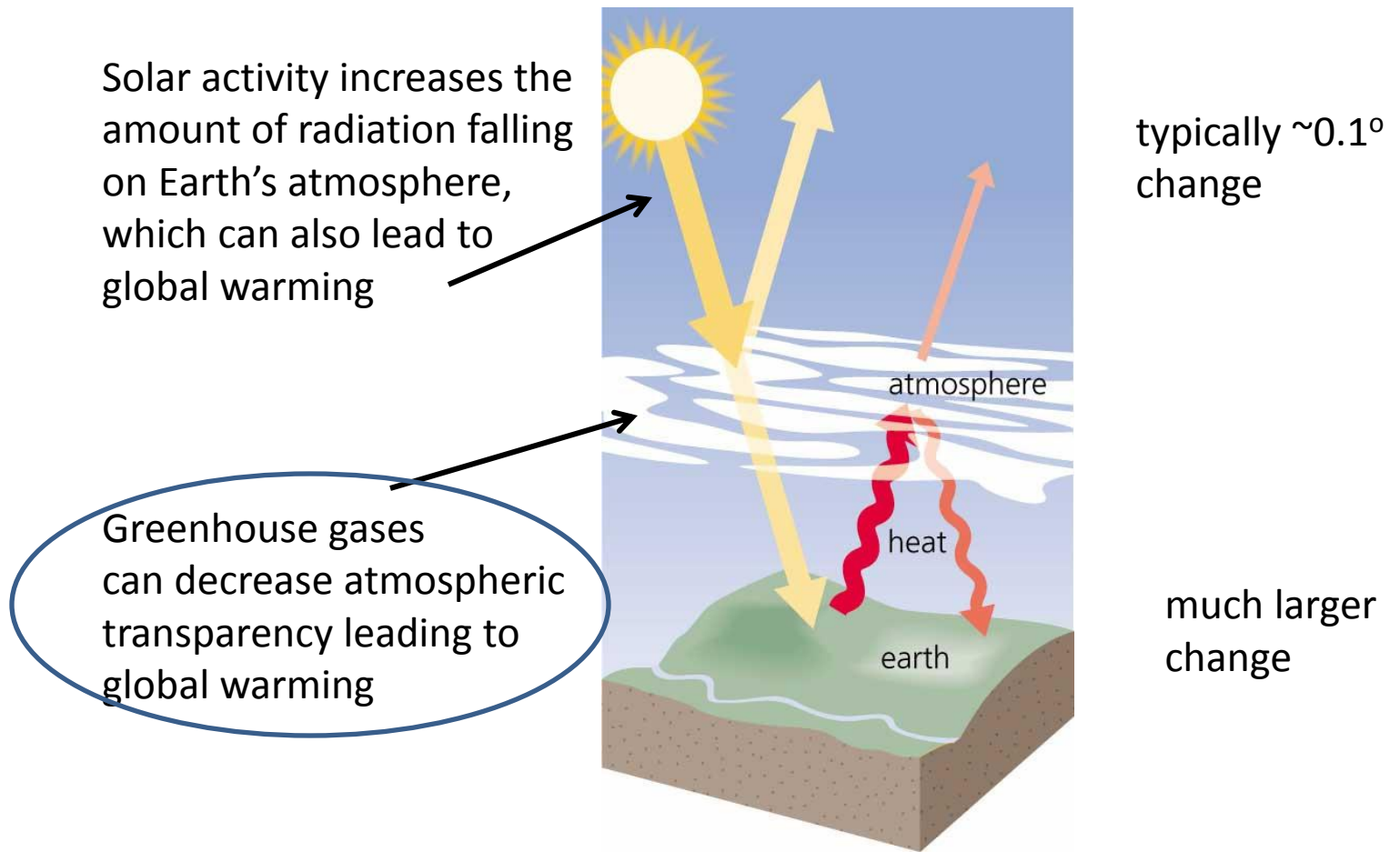
Various facets of space weather

# Coronal Holes

- Coronal holes regions of enhanced unipolar magnetic field
- High Speed winds up to 800 km/s compared to 400 km/s for ordinary solar wind
- Form interaction regions (CIRs)
- When CIRs impact Earth, they can cause geomagnetic storms ( Dst down to  $\sim -150$  nT)



# Sun-Climate Connection



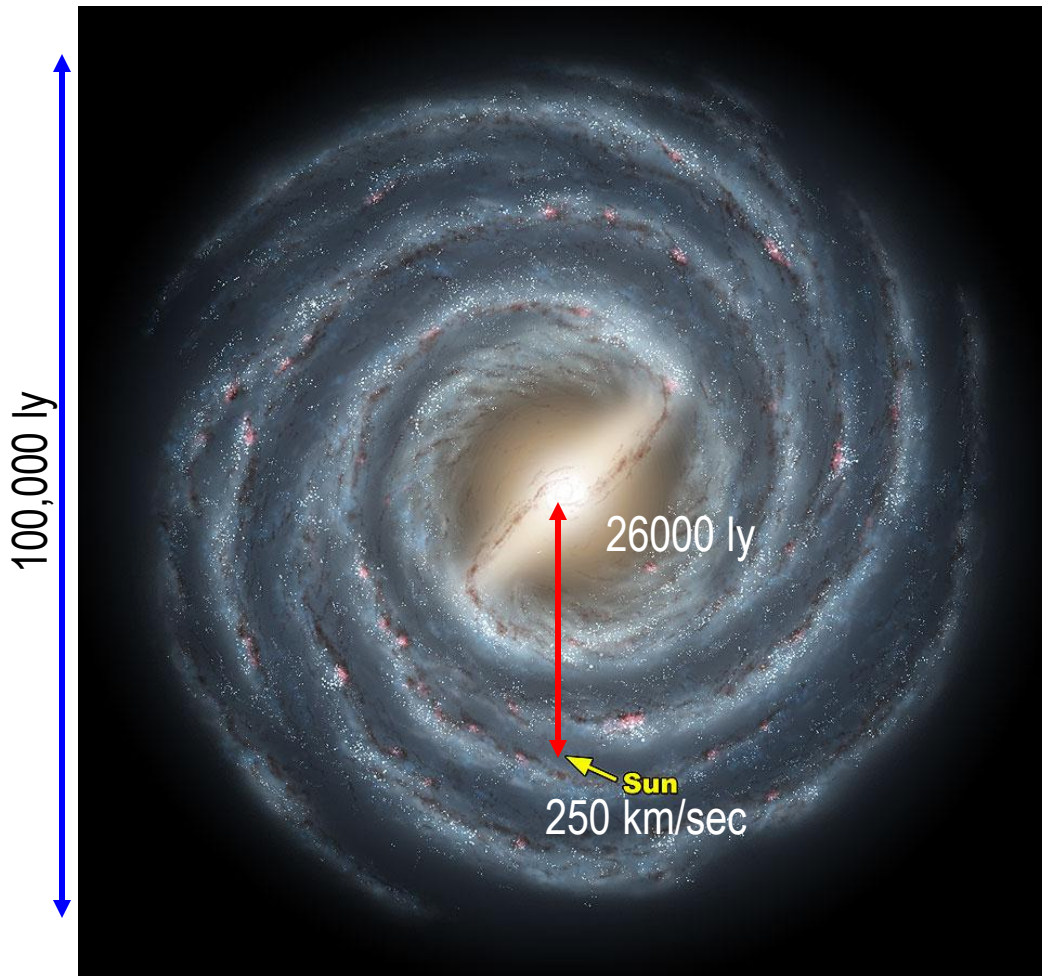
Volcanic eruptions, El nino, change in greenhouse gases, ocean-atmosphere interaction...

# Our place in the Milky Way

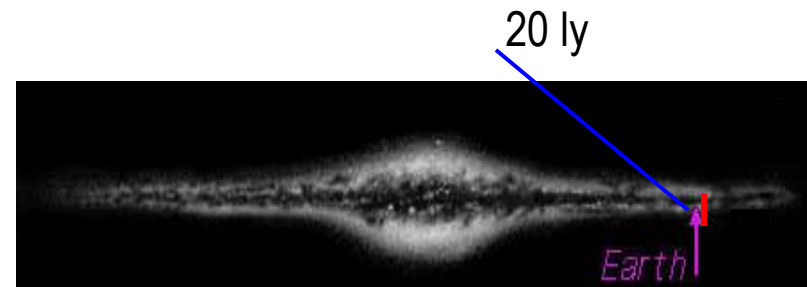
sun is located at a distance of 26000 ly from the galactic center & slightly displaced from the galactic plane (by 20 ly)

## Galaxies:

- Basic units of larger, organized structures
- Sites of star formation from raw gas
- Factories synthesizing heavy elements from Hydrogen & Helium



Orbital period (Galactic year) 220 million years



26000 ly

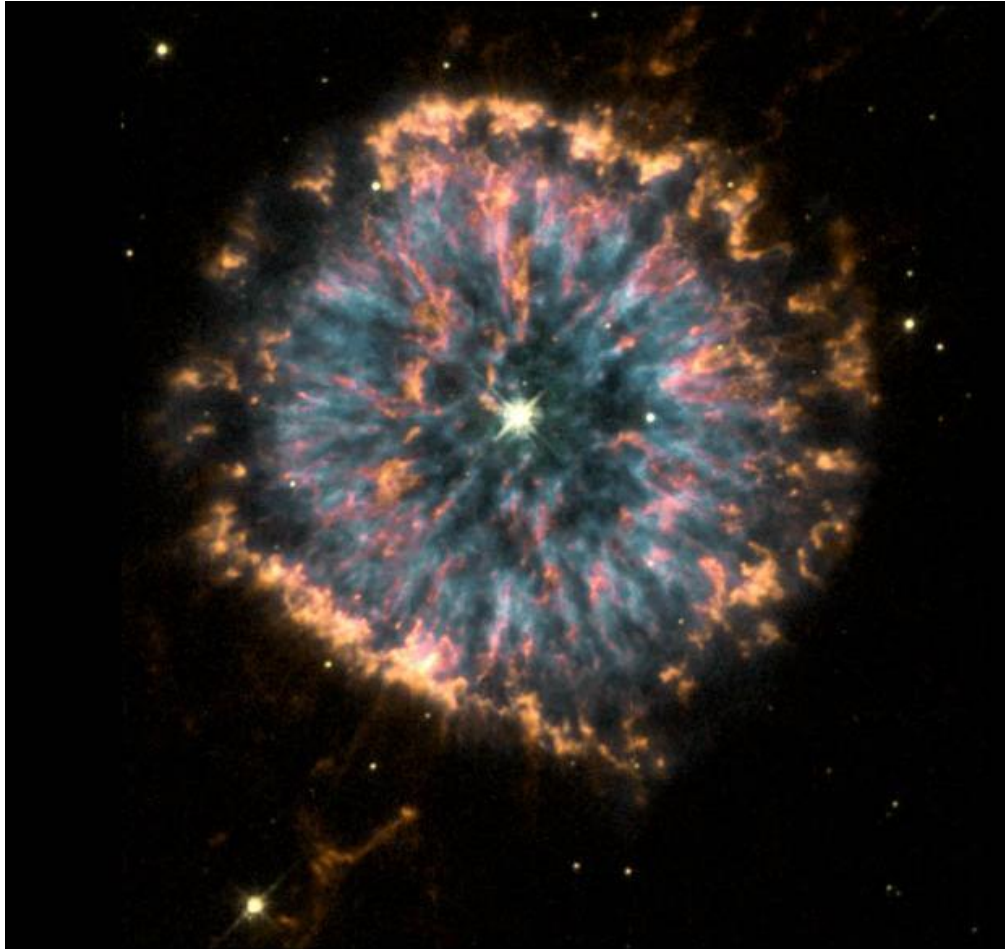
Mass of our galaxy  $\sim 10^{12} M_{\odot}$

stars ( $\sim 400$  billion) and their planets, and thousands of clusters and nebulae, gas, dust

1 ly =  $10^{13}$  km, distance traveled by light in one year

# Last “days” of the Sun

Planetary Nebula NGC 6751



- End of Hydrogen burning
- Further contraction and heating ignites H around core
- Outer layers expand to form red giant (up to Earth’s orbit)
- He fusion → core temperature ~100 MK
- He fusion stops (100 MY)
- Star becomes unstable and the outer envelope is blown off as a planetary nebula (0.5 MY)
- The inner core becomes white dwarf (Earth-size)
- Finally a black dwarf or a giant diamond
- 50,000 in our galaxy



matahari

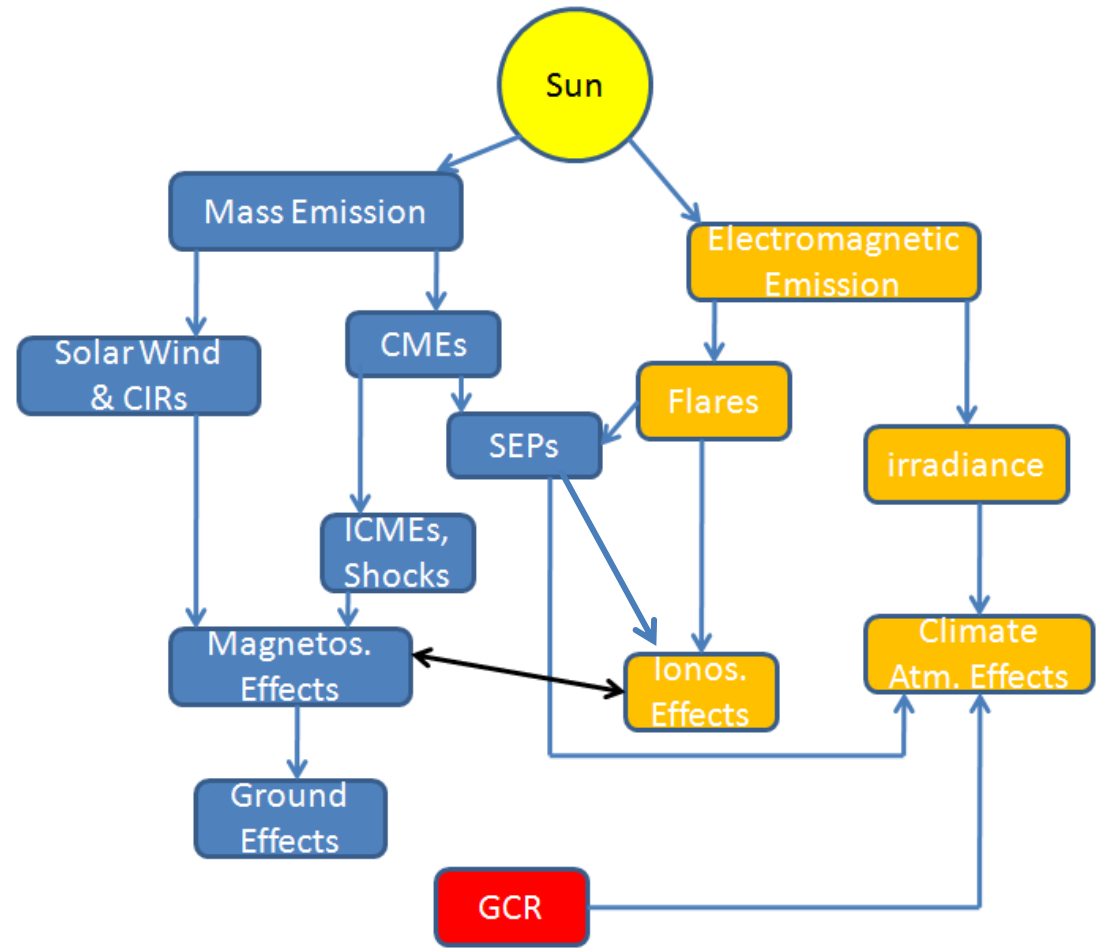


# The Sun-Earth System

Flare photons affect equatorial ionosphere  
All others affect high & mid latitudes

Convection  
+ Rotation

B



Also Earth to space coupling

Terima Kasih !

- The Aeronautics and Space Institute of Indonesia (Lembaga Penerbangan dan Antariksa Nasional = LAPAN)