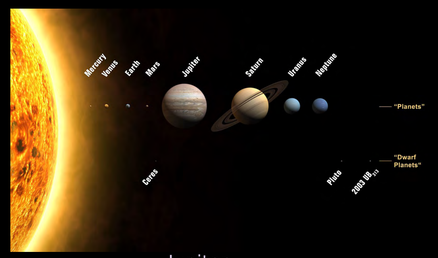
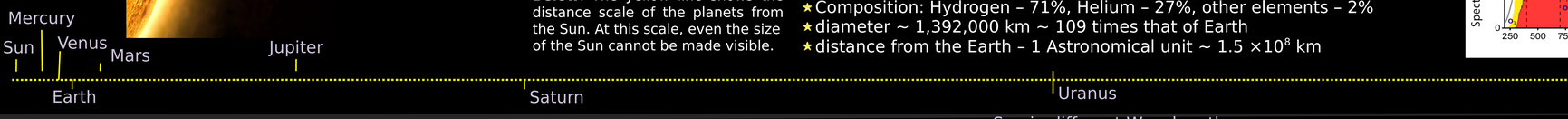
Solar Physics

IUCAA



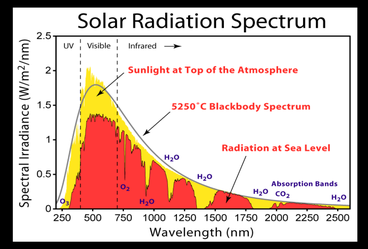


The Sun is the only star at the center of our Solar system

Left: The image shows the Sun and the planets to the same scale as regards size and not their distances.
Below: The yellow line shows the distance scale of the planets from the Sun. At this scale, even the size of the Sun cannot be made visible.

The Sun

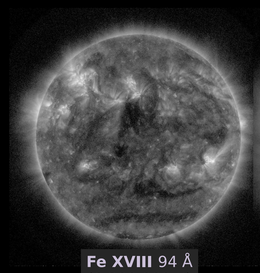
- a main sequence star with a spectral class G2V
- almost perfectly spherical and consists of hot plasma interwoven with magnetic fields
- mass ~ 2×10^{30} kgs ~ 330,000 times that of Earth ~ 99.8% of the total mass of our Solar system
- Composition: Hydrogen – 71%, Helium – 27%, other elements – 2%
- diameter ~ 1,392,000 km ~ 109 times that of Earth
- distance from the Earth – 1 Astronomical unit ~ 1.5 $\times10^{8}$ km

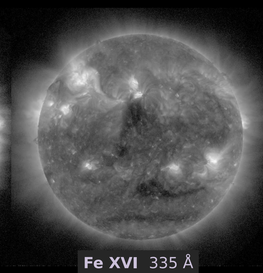


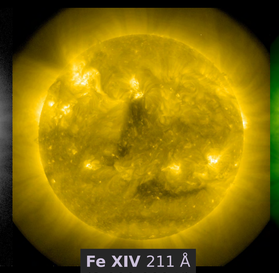
The spectrum of the solar radiation is close to that of a black body with a temperature of about 5,800 K. The Sun emits EM radiation across most of the electromagnetic spectrum. Although the Sun produces Gamma rays as a result of the nuclear fusion process, they are converted to lower energy photons before they reach the Sun's surface and are emitted out into space. As a result, the Sun does not emit gamma rays. The Sun does, however, emit X-rays & ultraviolet (generated in the upper atmosphere), visible light, infrared, and even Radio waves.

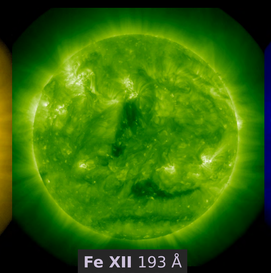
Sun in different Wavelengths

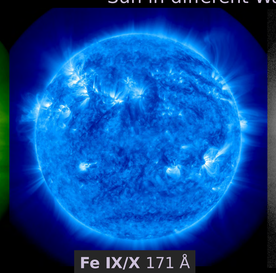
Credits : NASA/SDO AIA

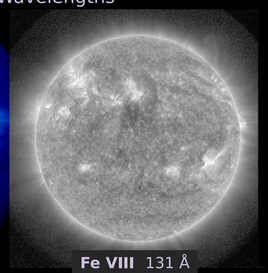

Fe XVIII 94 Å (6,300,000 K)

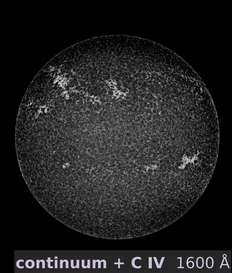

Fe XVI 335 Å (2,500,000 K)

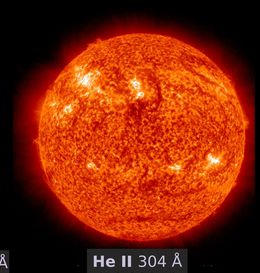

Fe XIV 211 Å (2,000,000 K)

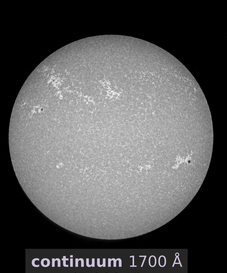

Fe XII 193 Å (1,600,000)

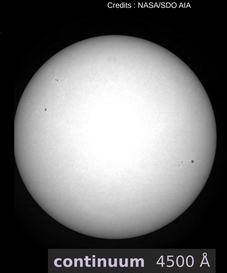

Fe IX/X 171 Å (630,000 K)


Fe VIII 131 Å (400,000 K)

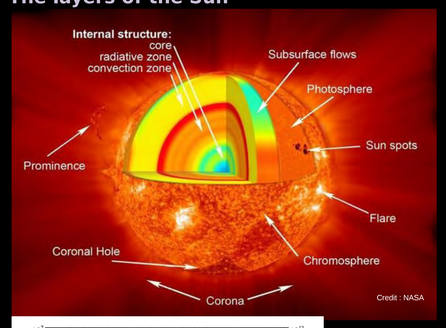

continuum + C IV 1600 Å (100,000 K)

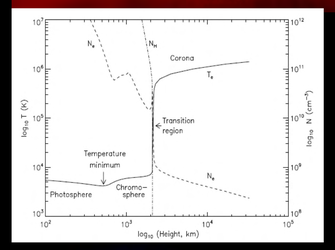

He II 304 Å (50,000 K)


continuum 1700 Å (5,000 K)


continuum 4500 Å (5,000 K)

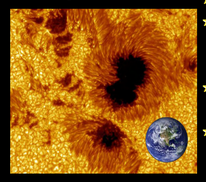
The layers of the Sun





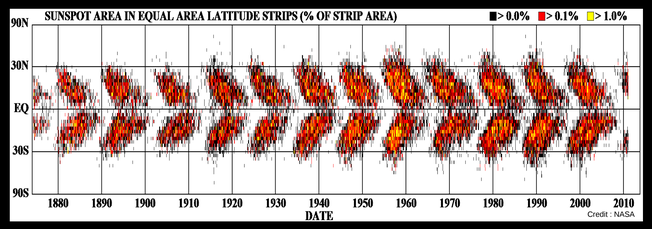
Left: Temperature and density profile in the solar atmosphere
Below: Composite image of the Sun from SDO

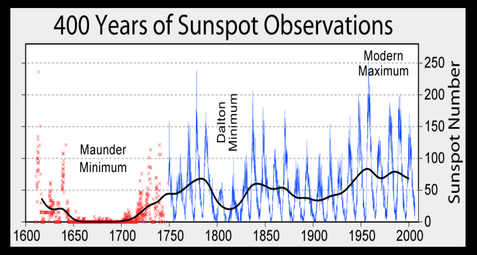
Sunspots



- dark spots observed at the photosphere
- the temparature is of the order of 4500 K in contrast with the photospheric material at 5800 K, hence they appear dark
- associated with intense magnetic field of the order of few thousand gauss
- associated with bright loop structures at coronal temperatures, called as **active regions**
- they do not appear randomly on the surface of the Sun, but they are concentrated in a belt between -35 deg south and +35 deg north of the equator

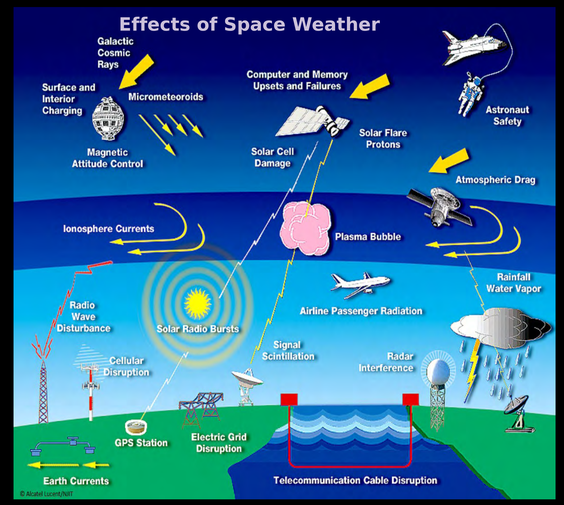
Below: Maunder's butterfly diagram – the plot shows the lattitude of the sunspot occurence versus time





The **solar activity** periodically varies over a span of

- 11 years – the sunspot cycle or Schwabe cycle, where the Sun's magnetic poles flip. The number of sunspots that appear on the Sun goes from low-high-low. The period of low activity/fewer sunspots is called the solar minimum and the period of high activity/large number of sunspots is called the solar maximum
- 22 years – the solar cycle or Hale cycle, where the Sun's magnetic poles return to the same state after two Schwabe reversals.

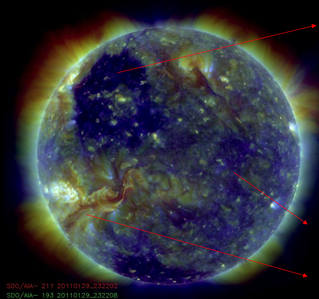


Solar wind

- continuous evaporation of streams of ionized magnetized solar plasma into the interplanetary space
- mainly consists of electrons and protons
- the flow is not steady, because of huge solar activities like flare, CMEs, etc.
- is what blows the tails of comets back away from the bodies of comets, as they go through the solar system
- causes Aurora Borealis and Aurora Australis and responsible for the space weather in the near Earth space

Left: A simple illustration of technological systems affected by Space Weather. **Copyright:** Bell Laboratories, Lucent Technologies)

Coronal hole

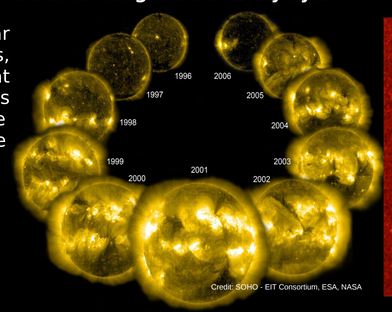


predominantly unipolar magnetic field regions, which appear dark at coronal temperatures and are indistinguishable at chromosphere and the photosphere

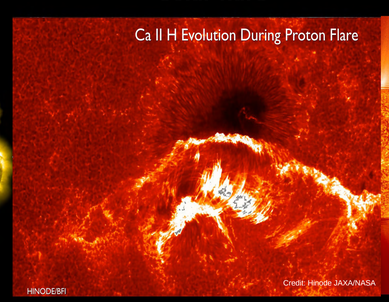
Quiet Sun region

Active region

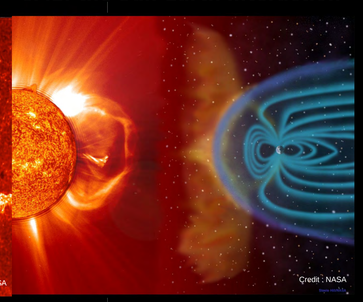
The solar magnetic activity cycle



Solar flare

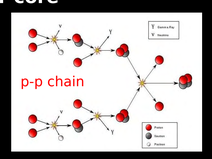


CME: the Sun-Earth interaction



The Sun's energy source – the solar core

* extends upto 25% of the solar radius
* density is about 150 g/cm^3
* temperature is ~ 15.7 MK
* energy generation mechanism - nuclear fusion



Around 99% of the Sun's energy is produced through the proton-proton chain cycle and the rest from CNO cycle

Solar flare

- a sudden, rapid and intense brightening observed over the Sun surface
- associated with complex magnetic field configurations
- release huge amount of energy, upto 10^{33} ergs
- accelerate electrons, protons and ions to near the speed of light and induce EM radiation across the entire EM spectrum

Coronal mass ejection (CME)

- massive bubbles of plasma, threaded with magnetic field, that are ejected from the Sun
- casued by the disruption of huge coronal magnetic structures
- often associated with solar flares and prominences
- can cause geomagnetic disturbances

Outstanding problems in Solar physics

- **The coronal heating problem :** Why the corona is at million degrees K while the photosphere below is merely 6000 K ?
- **The solar wind acceleration problem :** How the charged particles are accelerated to few hundred kms/sec ?
- **Coupling of the Solar atmosphere :** How the layers of the solar atmosphere interact with each other? – important in understanding the mass and energy tranfer needed for the coronal heating
- **CME :** What are the pre-eruption signatures? How the magnetic complexity in the source region relates to CME productivity? - crucial to predict the onsets of CMEs and there by space weather
- **Coronal loop dynamics :** The solar corona is composed by a complex superposition of loops, which populate both active and quiet solar corona. How the individual loops are heated and maintained? What is the thermal structure of the confined plasma?
- **Active region heating :** How the different structures in the active regions - the core (> 2 MK), warm loops (~ 1 MK), cool fan loops (< 1 MK), are heated? What evolution precedes the solar flares and CMEs?
- and many more ...

The **first Indian space based Solar mission** to address some of the above mentioned problems like



the coronal heating
the formation and dynamics of coronal loops
the origin, cause and acceleration of CMEs
the topology of coronal magnetic fields

Aditya -1 will be built and launched by the Indian Space Research Organization (ISRO)