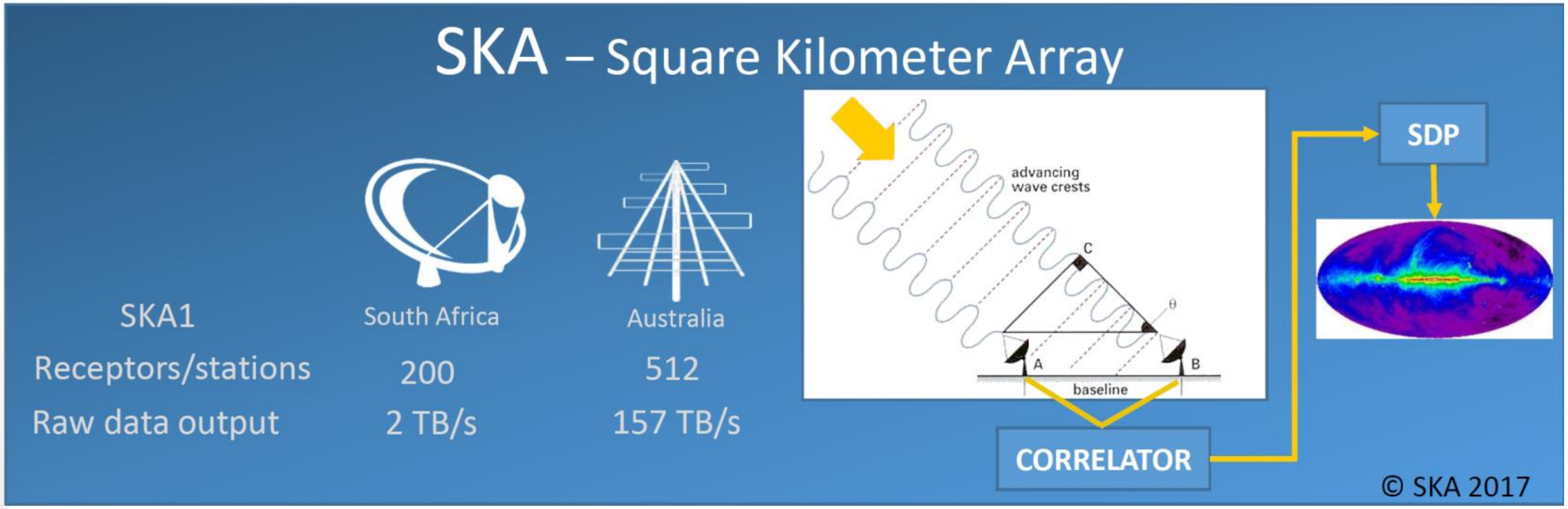
SKA

Evoluzione galattica, materia ed energia oscura.
Relatività generale
Magnetismo galattico ed intergalattico.

Cosmic Dawn
Ricerca della vita.
Sole ed eliosfera.
Transienti radio

Scietific observations from 2025 on



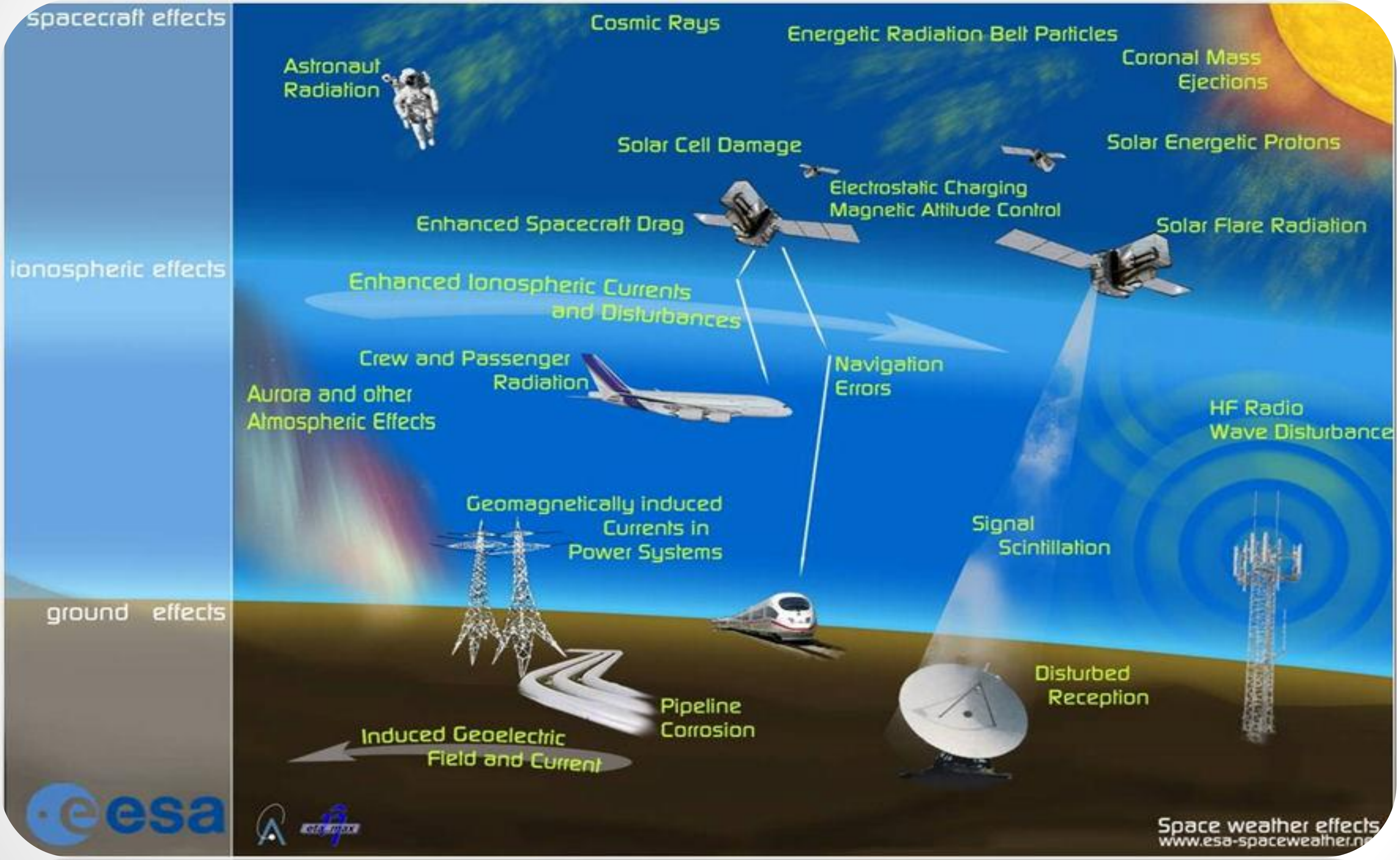
The Sun and the Solar Wind An Introduction

Valentina Alberti

Summary

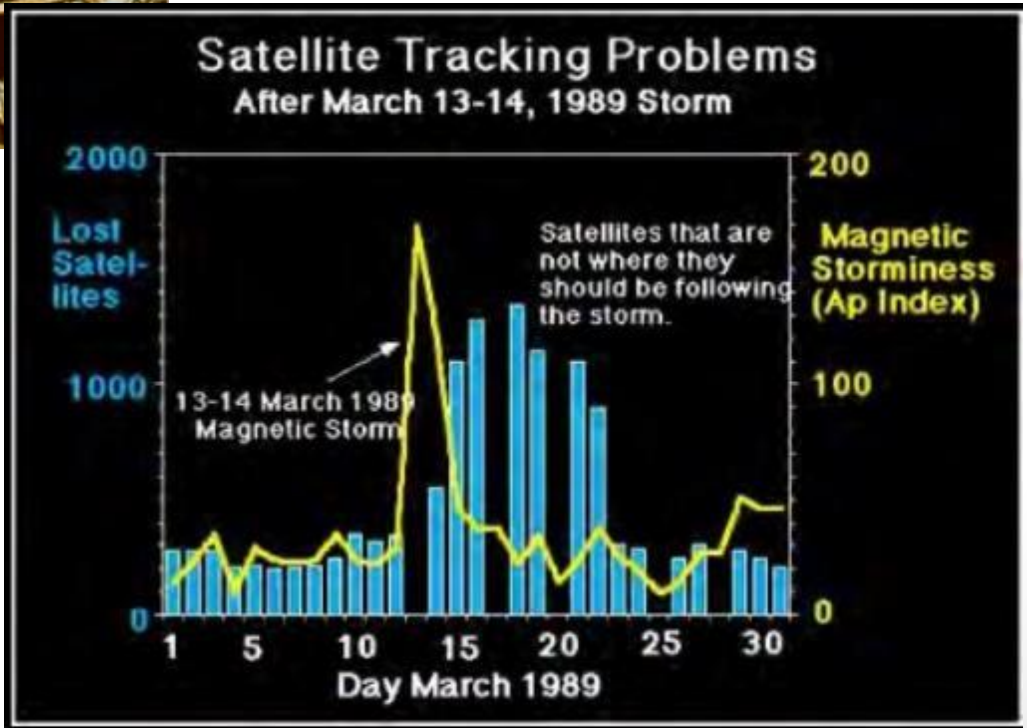
- Context – Space Weather
- THE SUN
  - Sun's facts
  - Solar spectrum
  - Solar structure
  - Solar activity
  - Flare
  - CME
- THE SOLAR WIND

Context – Space Weather



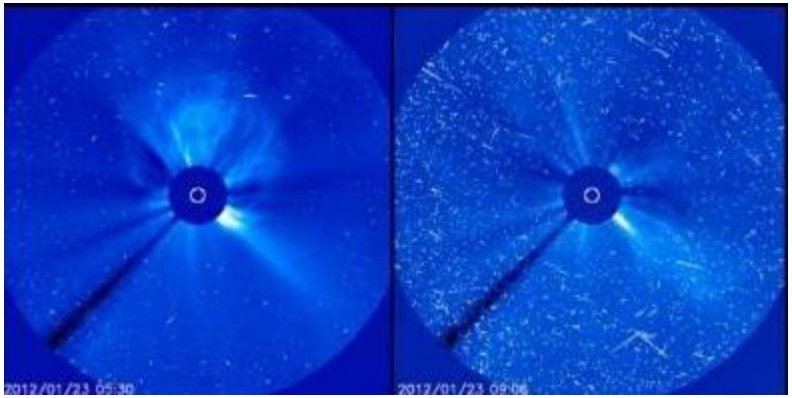
Is it real?

1989. 13-14 March

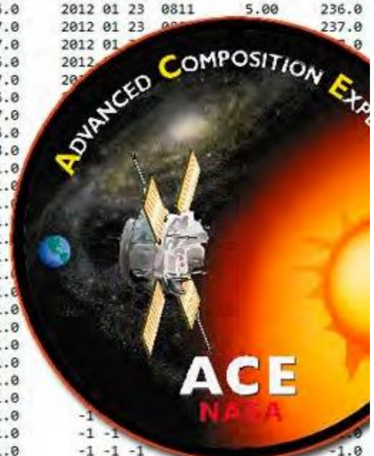


During a solar storm in 1989 one lost 1300 of 8000 objects being tracked.

Is it real?

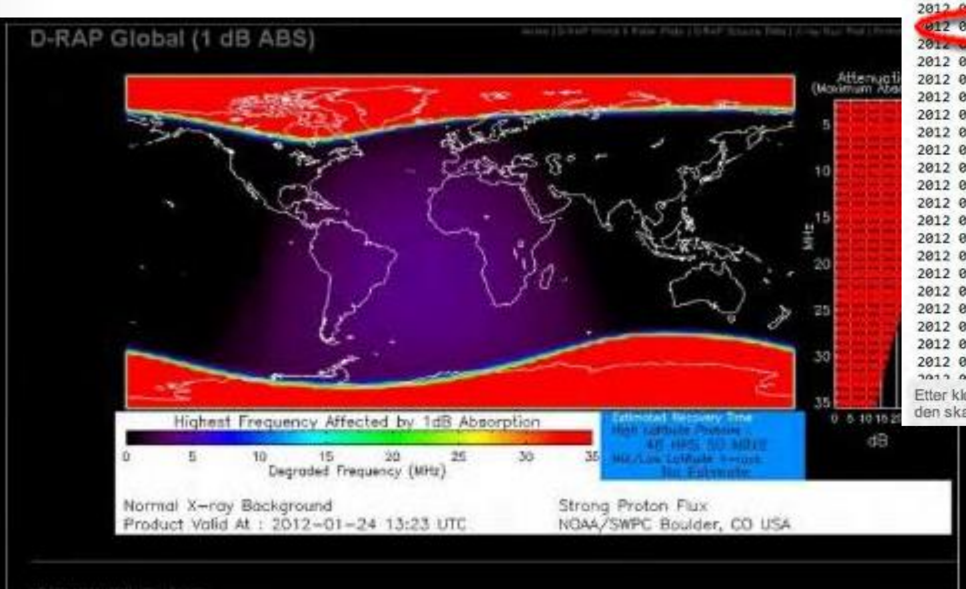


2012, 23-24 April



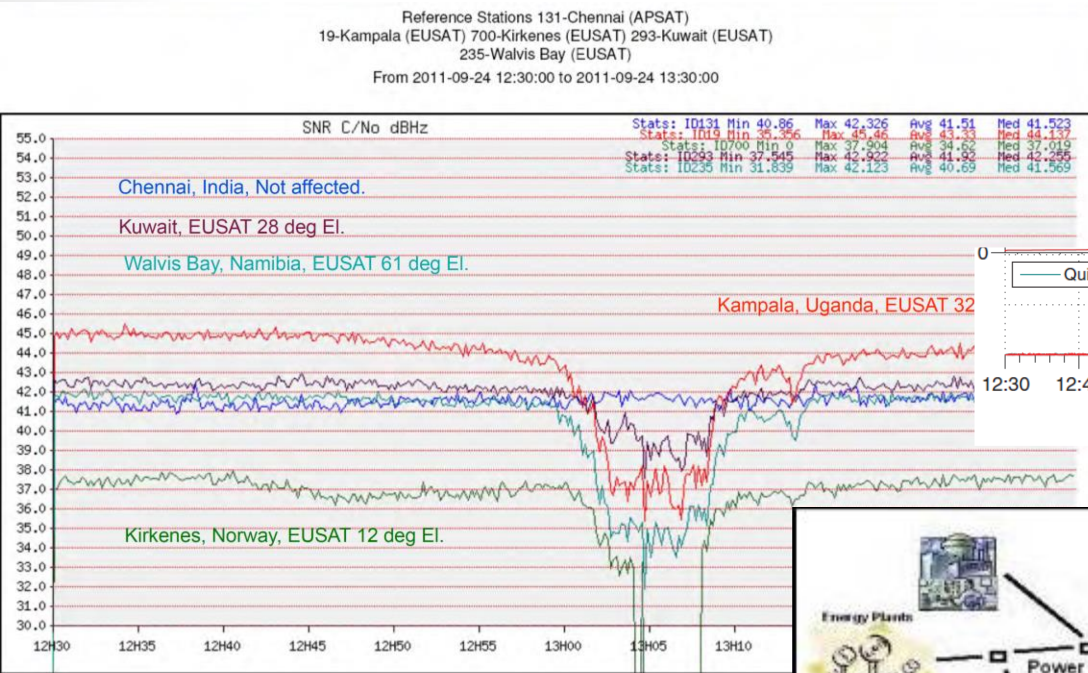
2012 01 23	0345	1	2012 01 23	0442	5.00	57.0	2012 01 23	0742	5.67	237.0
2012 01 23	0400	0	2012 01 23	0456	4.67	56.0	2012 01 23	0756	5.33	236.0
2012 01 23	0415	0	2012 01 23	0511	4.67	56.0	2012 01 23	0811	5.00	236.0
2012 01 23	0430	0	2012 01 23	0527	4.33	57.0	2012 01 23	[illegible]		237.0
2012 01 23	0445	0	2012 01 23	0542	4.33	57.0	2012 01 [illegible]			[illegible]
2012 01 23	0500	0	2012 01 23	0556	4.33	56.0	2012 [illegible]			
2012 01 23	0515	0	2012 01 23	0612	4.00	57.0	[illegible]			
2012 01 23	0530	0	2012 01 23	0626	4.00	56.0				
2012 01 23	0545	0	2012 01 23	0642	3.67	57.0				
[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	56.0				
[illegible]012 01 23	0615	0	2012 01 23	0713	3.67	58.0				
[illegible]	[illegible]	3	-1 -1 -1	-1	[illegible]	-1.0				
2012 01 23	0645	3	-1 -1 -1	-1	-1.00	-1.0				
2012 01 23	0700	3	-1 -1 -1	-1	-1.00	-1.				
2012 01 23	0715	3	-1 -1 -1	-1	-1.00	-1.				
2012 01 23	0730	3	-1 -1 -1	-1	-1.00	-1.				
2012 01 23	0745	3	-1 -1 -1	-1	-1.00	-1.				
2012 01 23	0800	3	-1 -1 -1	-1	-1.00	-1.				
2012 01 23	0815	3	-1 -1 -1	-1	-1.00	-1.0				
2012 01 23	0830	3	-1 -1 -1	-1	-1.00	-1.0				
2012 01 23	0845	3	-1 -1 -1	-1	-1.00	-1.0				
2012 01 23	0900	3	-1 -1 -1	-1	-1.00	-1.0				
2012 01 23	0915	3	-1 -1 -1	-1	-1.00	-1.0				
2012 01 23	0930	3	-1 -1 -1	-1	-1.00	-1.0				
2012 01 23	0945	3	-1 -1 -1	-1	-1.00	-1.0				
2012 01 23	1000	3	-1 -1 -1	-1	-1.00	-1.0	-1			
2012 01 23	1015	3	-1 -1 -1	-1	-1.00	-1.0	-1 -1			[illegible]
2012 01 23	1030	3	-1 -1 -1	-1	-1.00	-1.0	-1 -1 -1			-1.0
2012 01 23	1045	3	-1 -1 -1	-1	-1.00	-1.0	-1 -1 -1	-1	-1.00	-1.0
2012 01 23	1100	3	-1 -1 -1	-1	-1.00	-1.0	-1 -1 -1	-1	-1.00	-1.0

Etter klokken 7.15 norsk tid mandag har det bare lagt -1 i listen med observasjoner fra NOAA. ACE-satellitten fungerer ikke den skal. *Foto: NASA / NOAA*

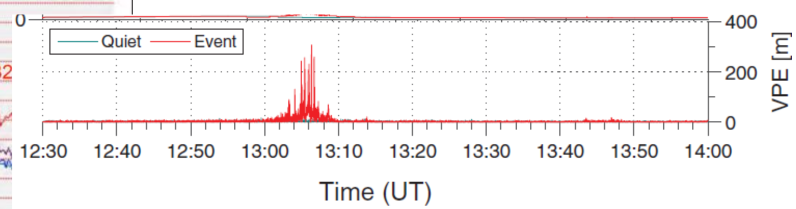


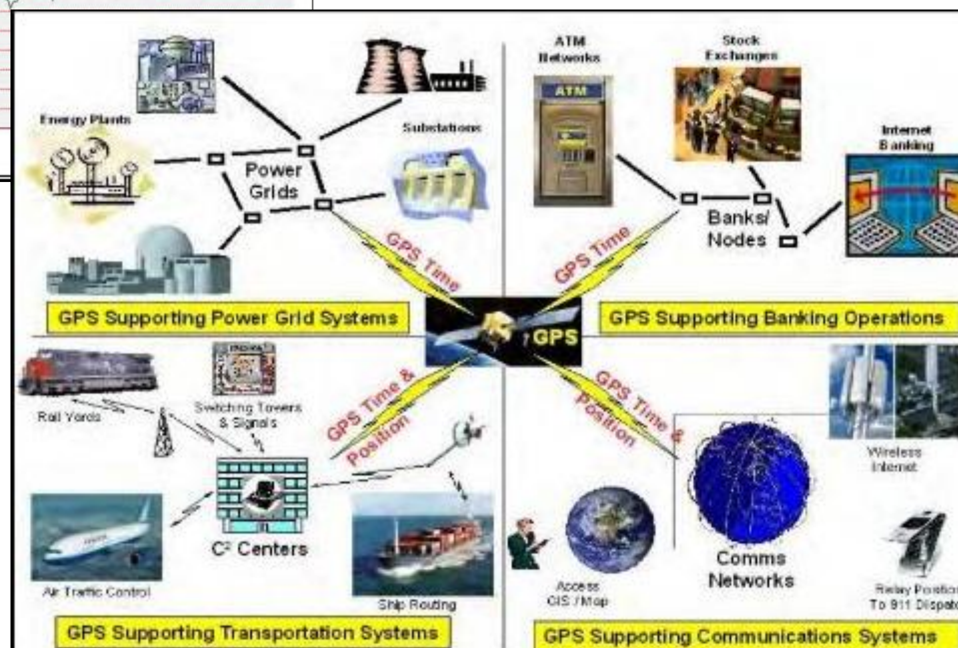
This graphic shows the energetic particles entering the D-region of the ionosphere. SWPC forecasters use this product to show where the energetic particles are entering and to give a visual to what is currently happening here at Earth. The red that can be seen at the poles is where the energetic particles enter and where airliners and spacecraft, should try to avoid.

Is it real?

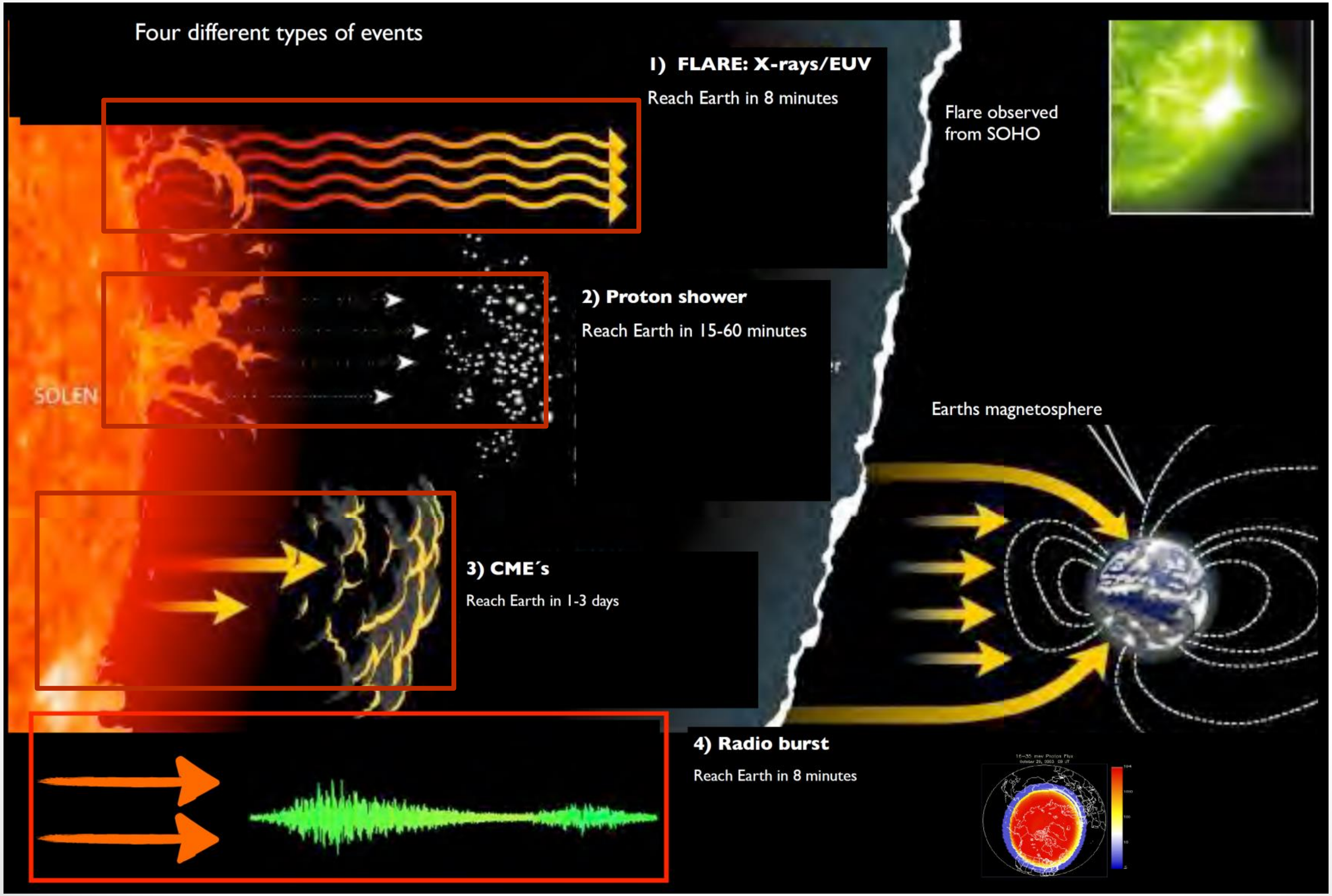


2011, 24 Sept





Connection



Four different types of events
1) FLARE: X-rays/EUV
Reach Earth in 8 minutes
Flare observed from SOHO
SOLEN
2) Proton shower
Reach Earth in 15-60 minutes
Earths magnetosphere
3) CME´s
Reach Earth in 1-3 days
4) Radio burst
Reach Earth in 8 minutes

SUN: data

G2 V, absolute magnitude = 4.8

$r_{Sun\text{-}Earth} = 1.5\times10^{11}$ m = 1 AU

Age = 4.5×10^{9} yr

$R_{\odot} = 6.96\times10^{8}$ m

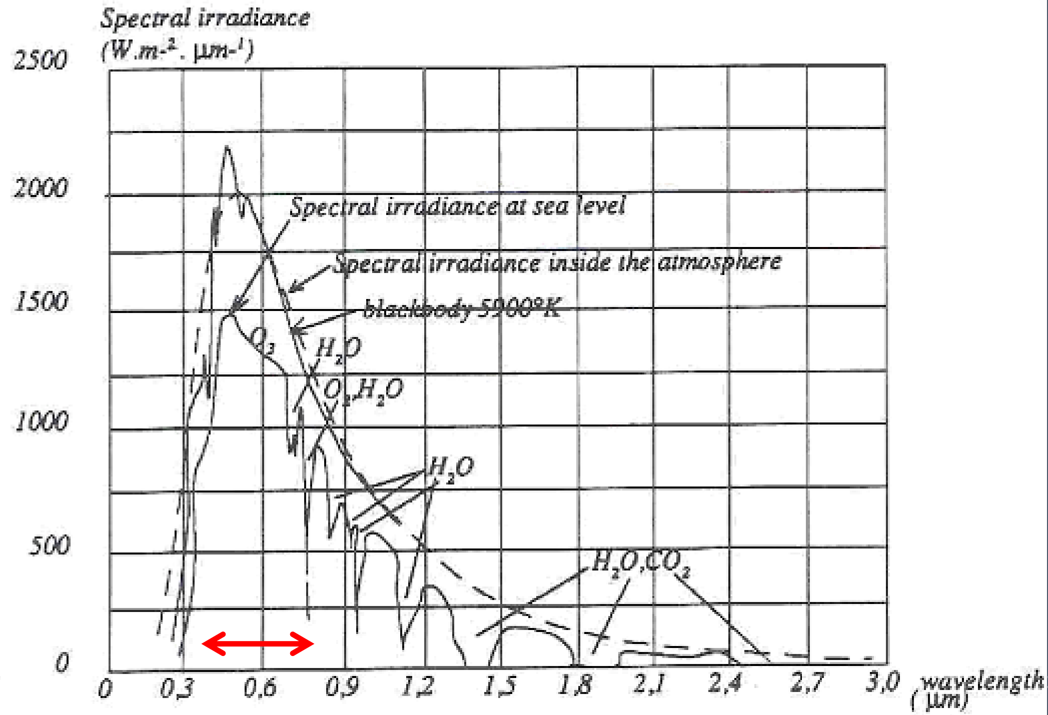
$M_{\odot} = 1.99\times10^{30}$ kg

$L_{\odot} = 3.86 \times 10^{26}$ W

	Temperature (K)	Density (kg m^{-3})	Chemical Composition
Core	1.56×10^{7}	1.5×10^{5}	35% H, 63% He, 2% C, N, O,..
Surface	5770	2.07×10^{-4}	70% H, 28% He, 2% C, N, O,..

SUN: spectrum

InfraRed	52 %
Visible	41%
NUV	<7%
EUV	0.1%
Radio	0.1%
X	<0.1%

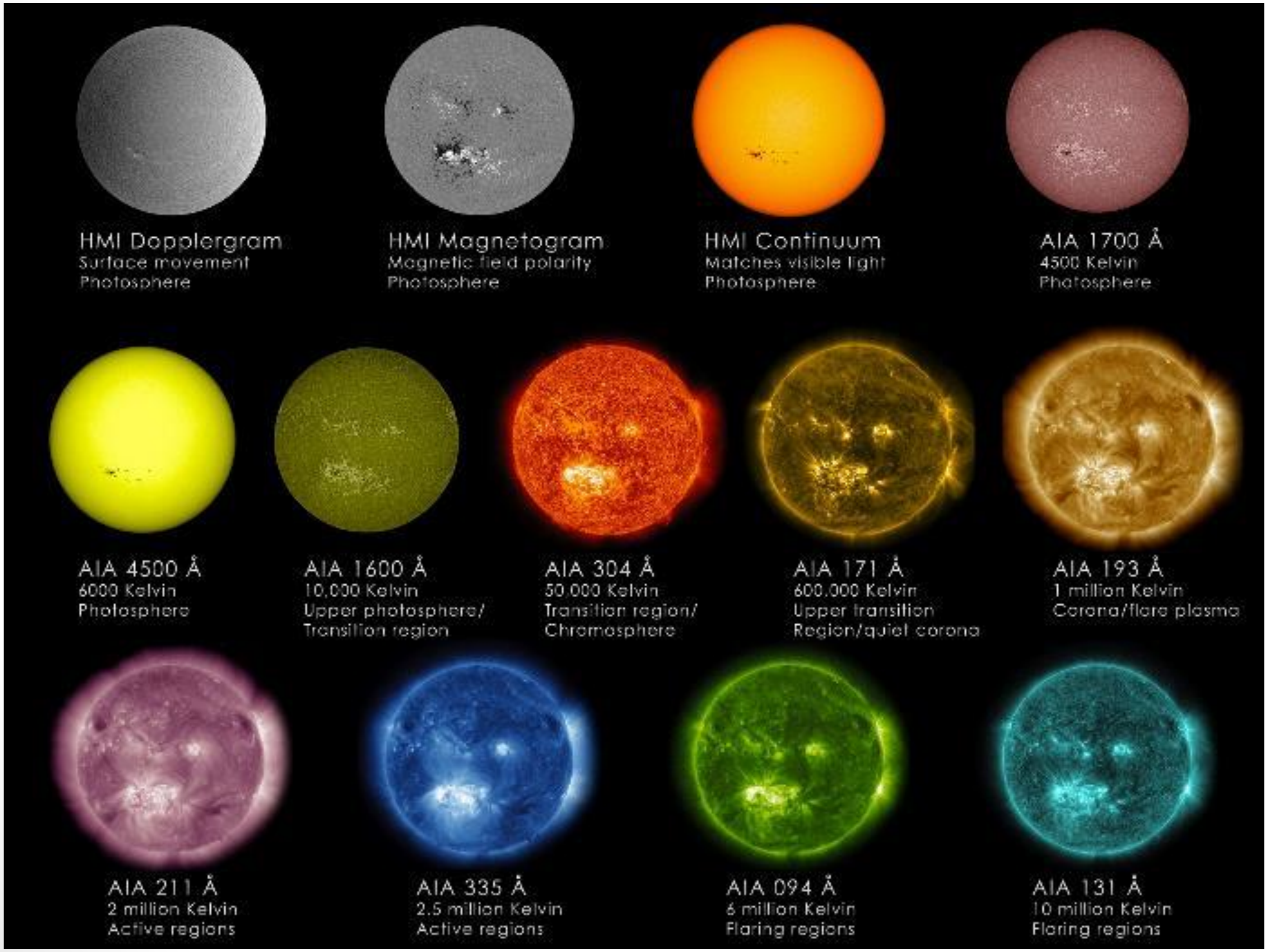


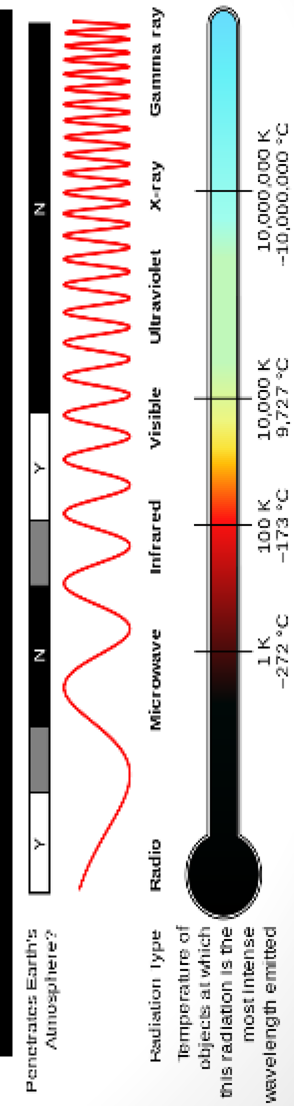
Energy at Earth = 1380 Wm^{-2}

Variations ± 3% (1326 ÷ 1418 Wm^{-2}) → ΔT ~ 1%

Δ/year ~ 0.018%

SUN: Sun Wavelength Chart





NASA SDO Goddard Space Flight Center

SUN: state of the matter

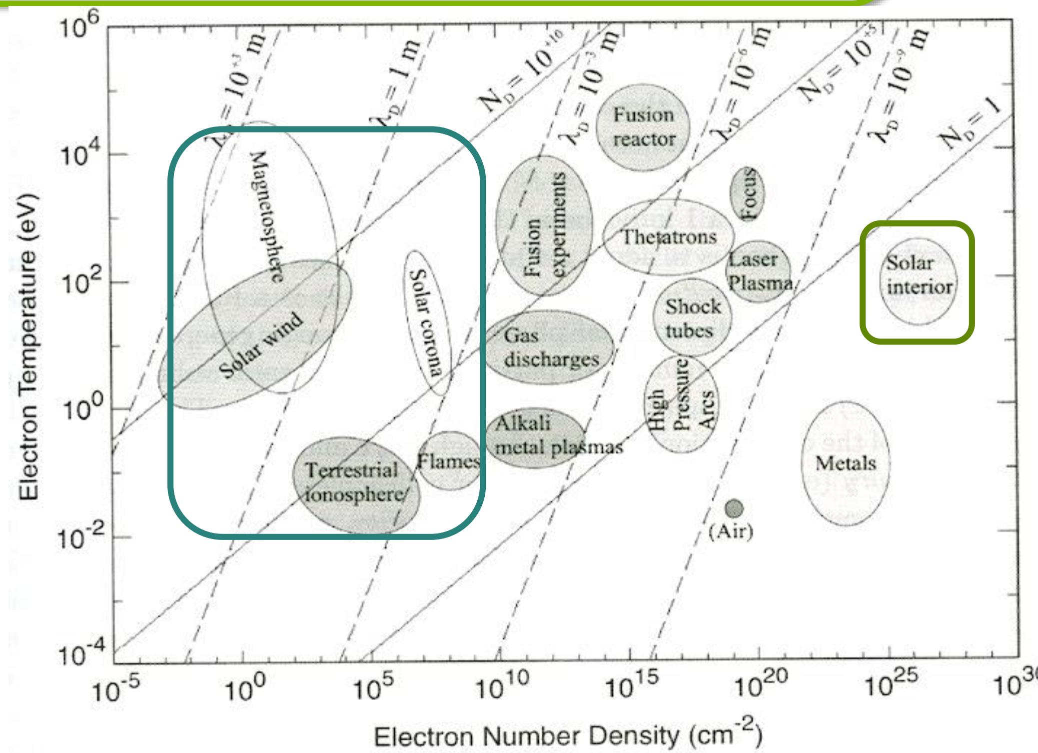
The matter that constitutes the Sun is in the state of PLASMA

PLASMA: quasi-NEUTRAL gas of CHARGED particles that exhibit a COLLECTIVE BEHAVIOUR

Sun-Earth Plasma:

T: 6 orders of magnitude

n: 10 orders of magnitude

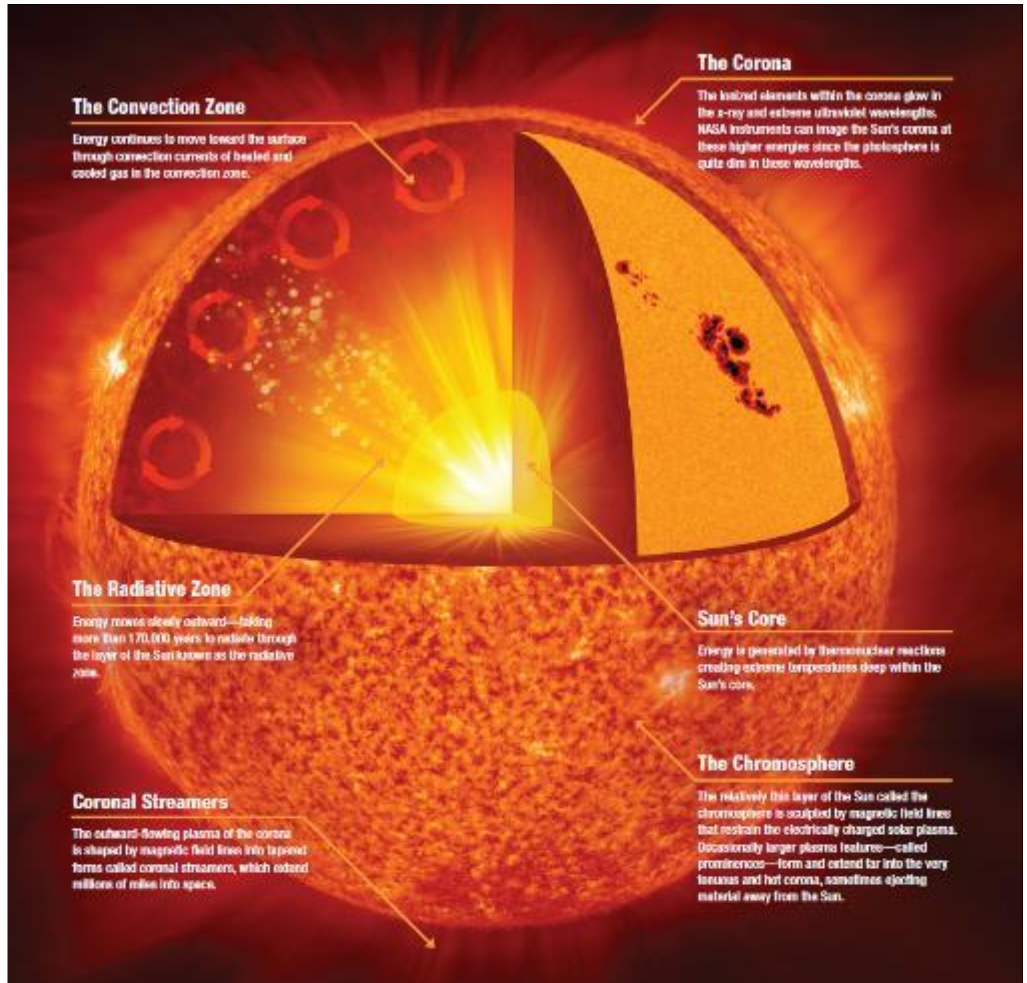


1eV = 11,604.5 K

SUN: structure

- Core
- Radiative zone
- Tachocline
- Convective zone
- **Photosphere**

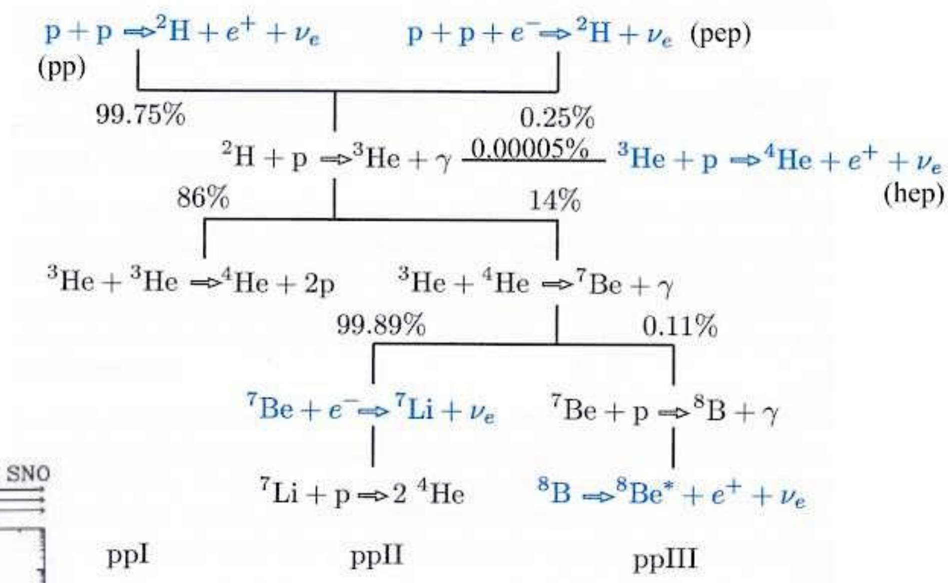
- Cromosphere
- Transition region
- **Corona**

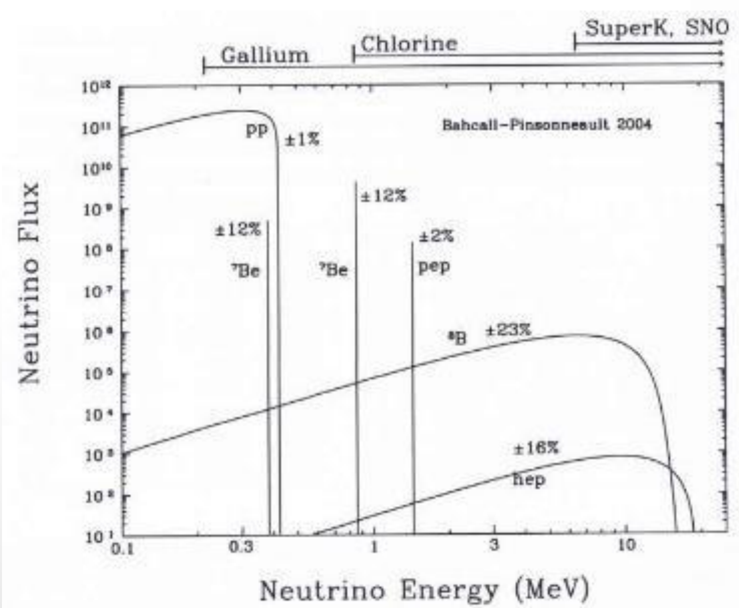


NASA Jenny Mottar

SUN: core

- T ≈ 1×10^7 K
- R ≈ $R_\odot/4$
- M ≈ $M_\odot/2$
- ρ ≈ 1.5×10^5 kg m^{-3}





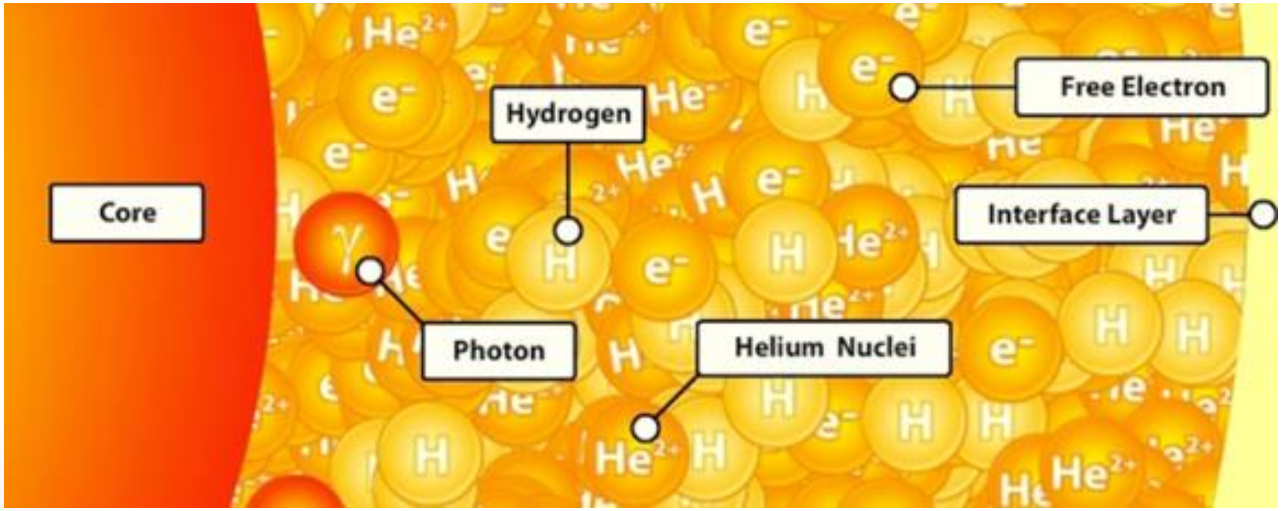
Photons: E of the order of MeV (gamma-rays) transport energy to the outer layers of the star.

SUN: radiative zone

- ΔT: 1×10^7 K ÷ 2×10^6 K
- ΔR: $0.25\ R_\odot$ ÷ $0.7\ R_\odot$
- $\Delta\rho$: 20×10^3 kg m^{-3} ÷ 2×10^2 kg m^{-3}

Mean free path: $\lambda_{ph} \approx 1$ mm

Diffusion timescale (radiative zone): $t_{ph} \approx 10^5$ yr



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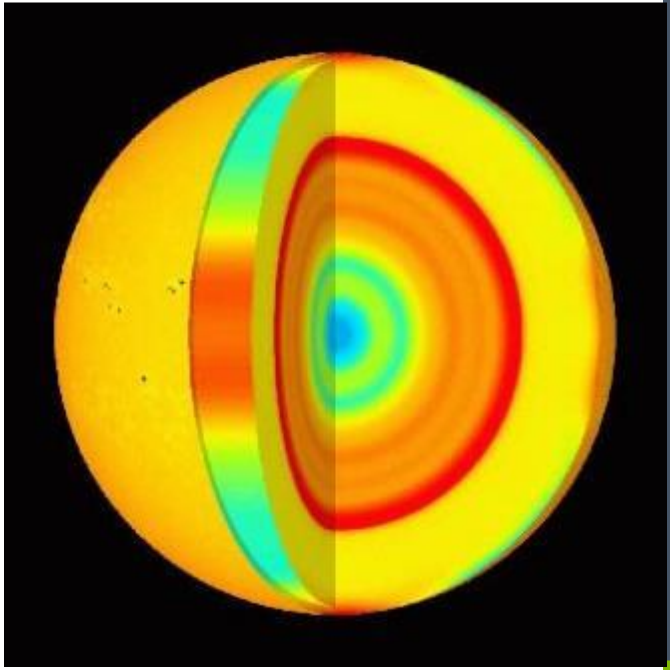
SUN: tachocline

Transition region between the radiative and the convective zone

- $T \approx 2 \times 10^6$ K
- $R \approx 0.69 \div 0.71\ R_\odot$
- Thickness $< 0.05\ R_\odot$
- $R/R_\odot$ varies by 0.02 from 0° to 60° lat
- $\rho \approx 2 \times 10^2$ kg m^{-3}

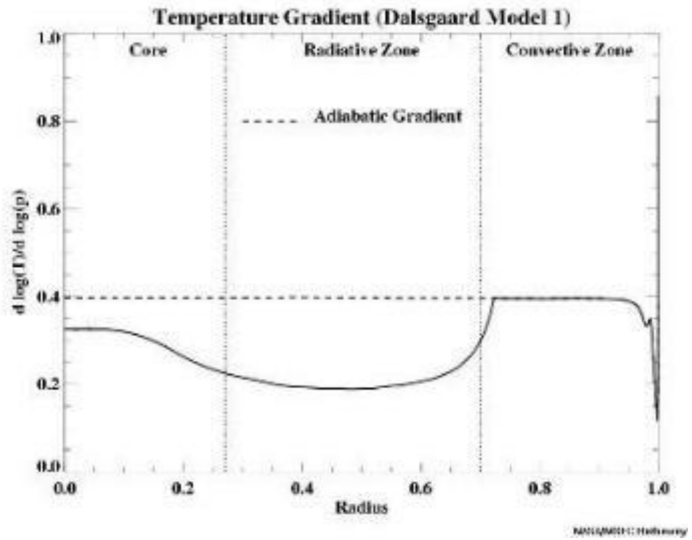
◆ Location of the SOLAR DYNAMO

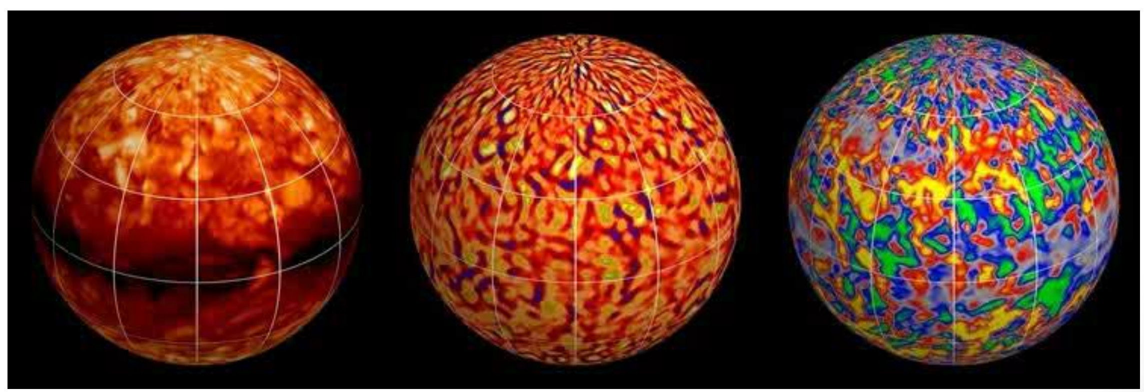


SOHO (ESA/NASA)

SUN: convective zone

- $T \approx 2 \times 10^6$ K
- $\Delta R \approx 200{,}000$ km





Fluid T vertical flow speed magnetic field

http://www.astro.umontreal.ca/~paulchar/grps/mhd_a.html#sec1

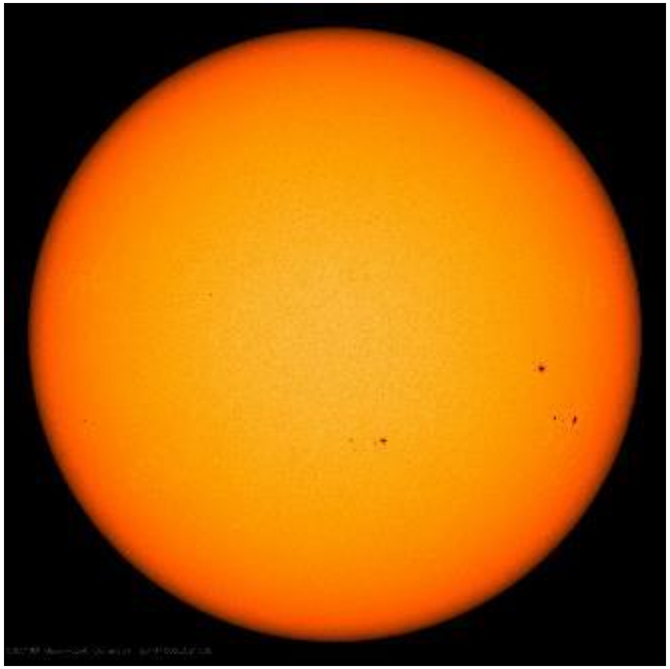
SUN: photosphere

Solar surface visible in the optical band.

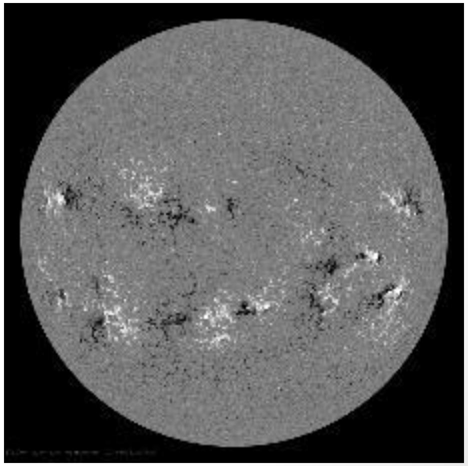
- T ~ 7500 ÷ 4200 K (r >)
- ΔR ~ 600 km
- $\rho \sim 10^{-4}$ kg m^{-3}
- n ~ $10^{23} \div 10^{21}$ m^{-3} (r >)

Solar Activity Manifestations

Sunspots
Faculae
Granules
Supergranules

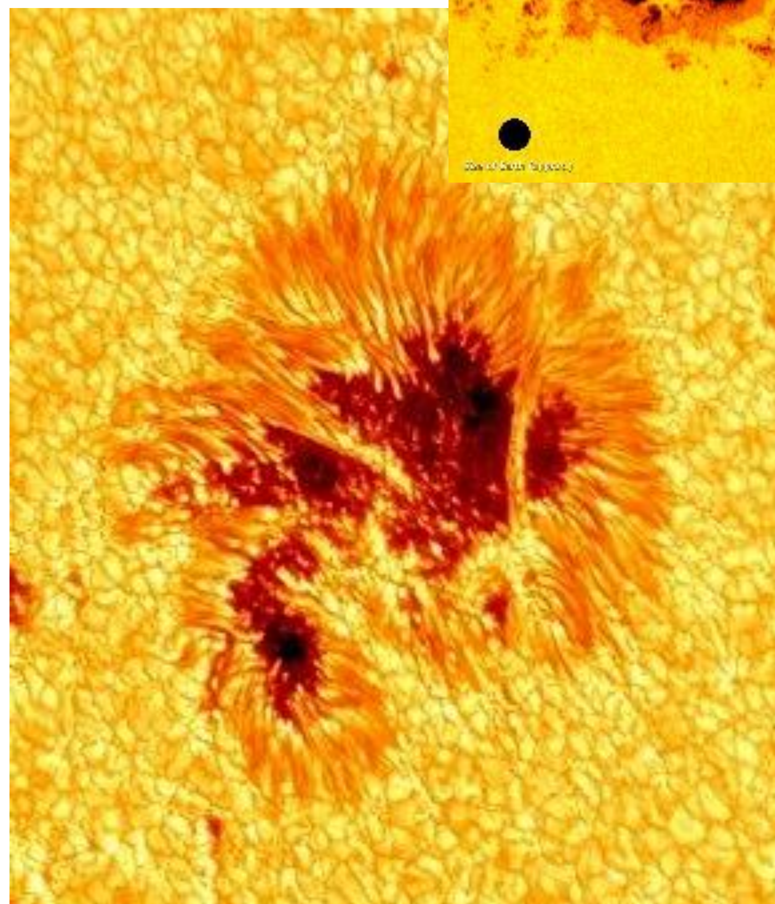


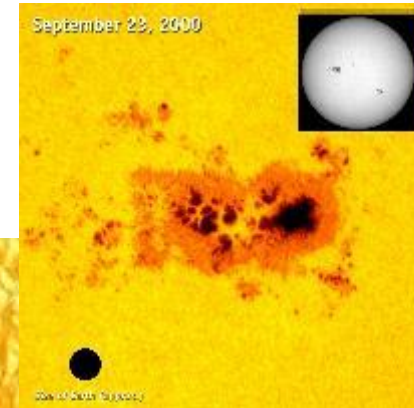
SDO Oct 6, 2014



SUN: photosphere

- Sunspots
- Umbra:
  - B ~ 0.2 ÷ 0.4 T, vertical
  - T ~ 3700 K
  - L ~ 3-5% $L_\odot$ (@500 nm)
- Penumbra:
  - B ~ 0.1 ÷ 0.2 T, horizontal
  - L ~ 80% $L_\odot$ (@500 nm)

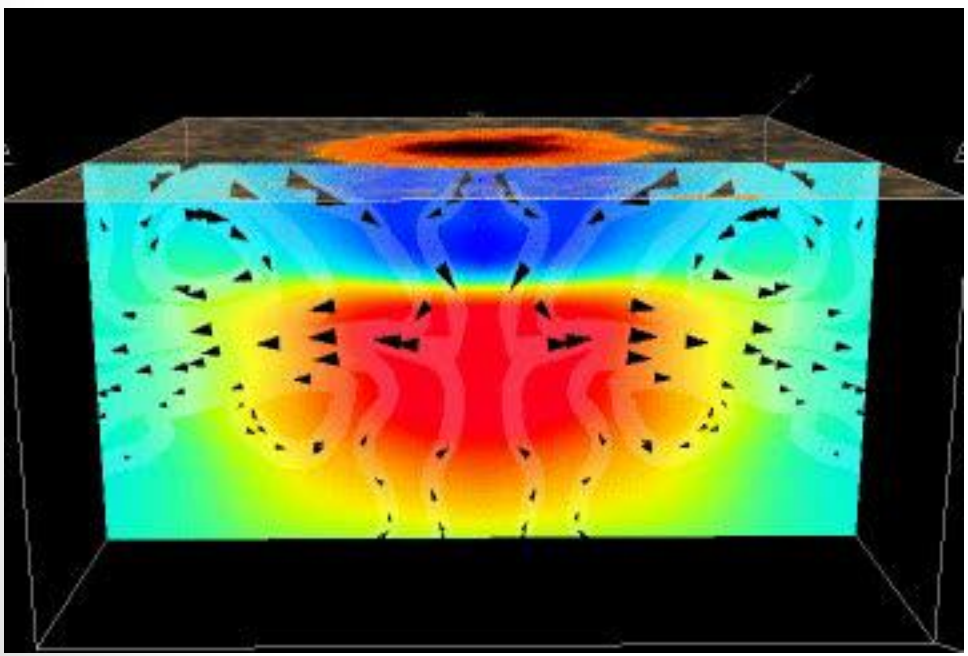


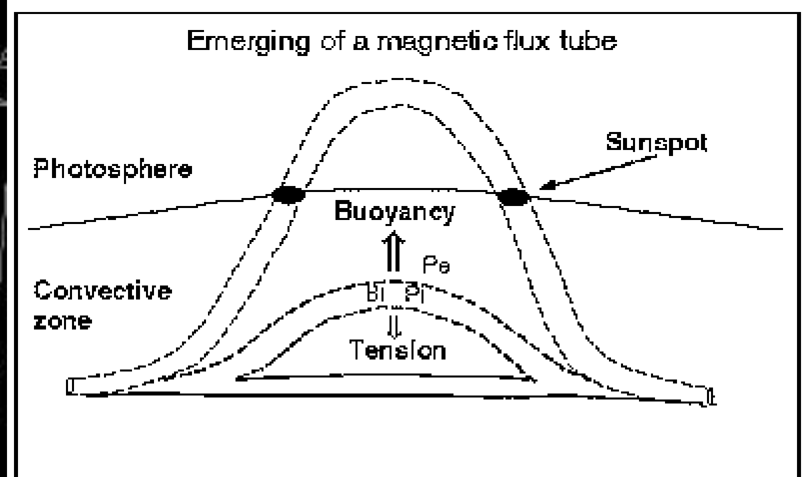


BBSO/NJIT

SUN: photosphere

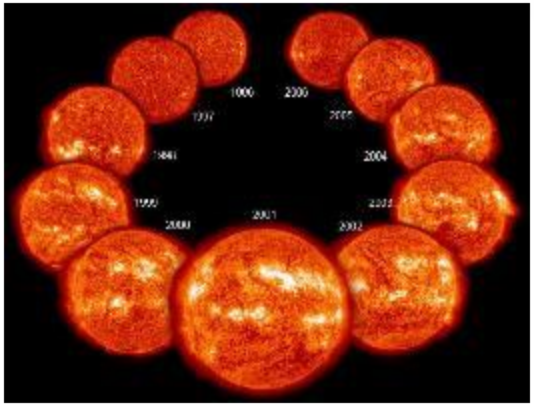
- Sunspots
  - Are originated by the presence of very intense magnetic fields that inhibit upwards motion of hotter plasma from regions at higher depths
  - A flux tube is less dense than the surroundings and rises up

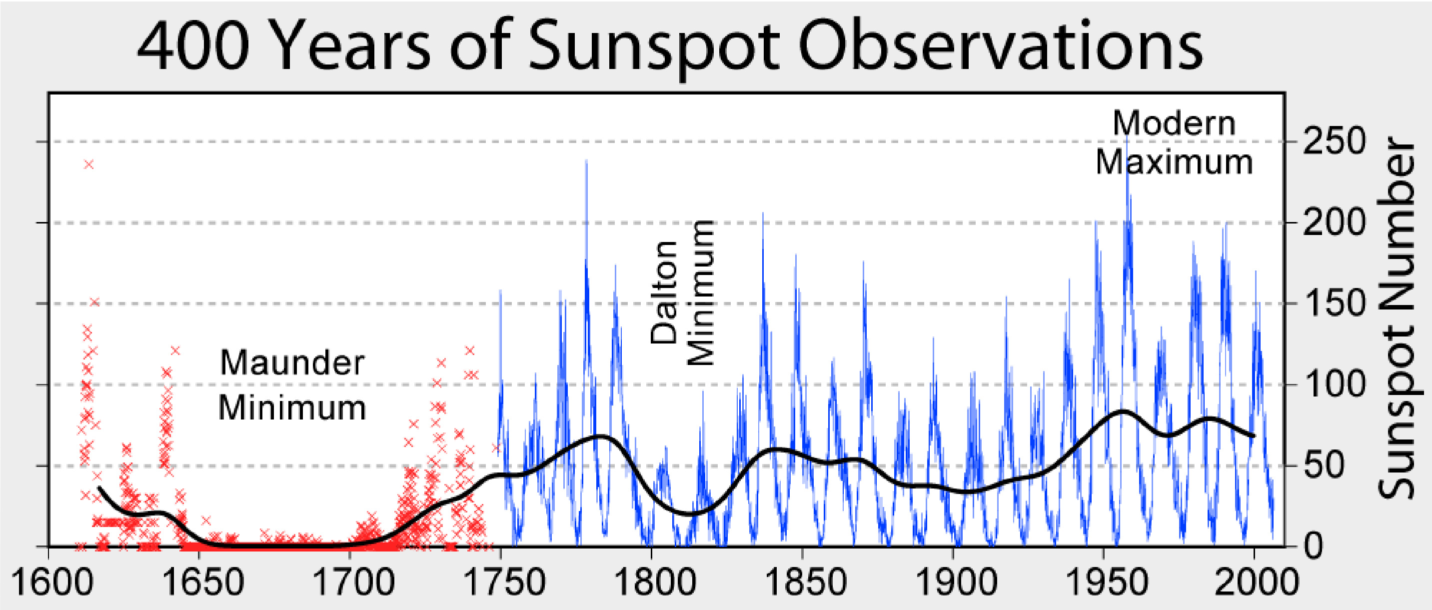




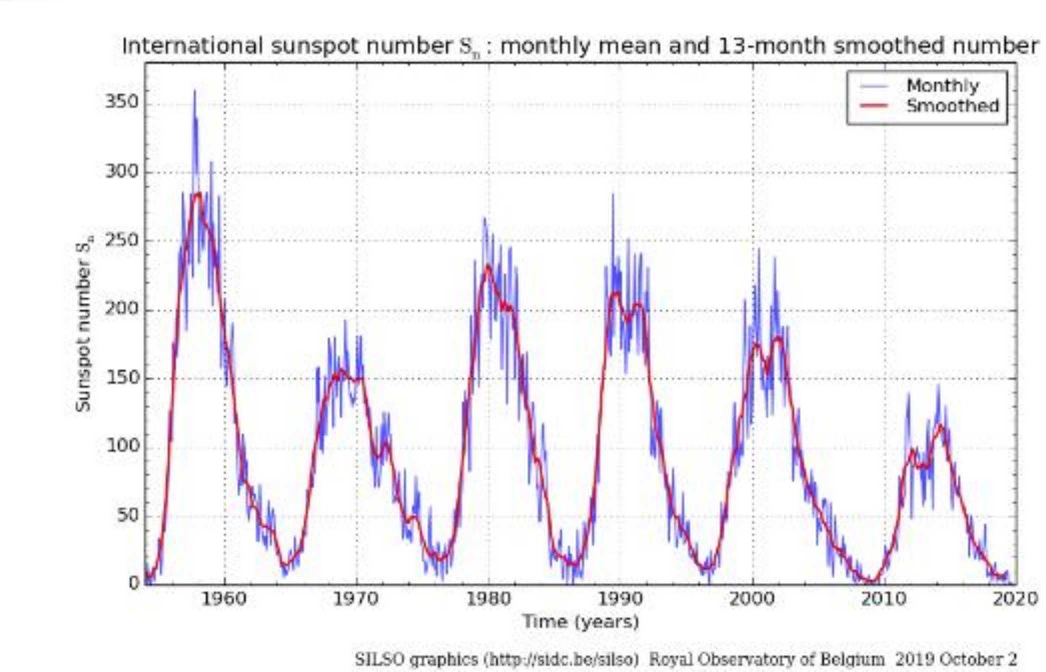
SUN: Sunspots

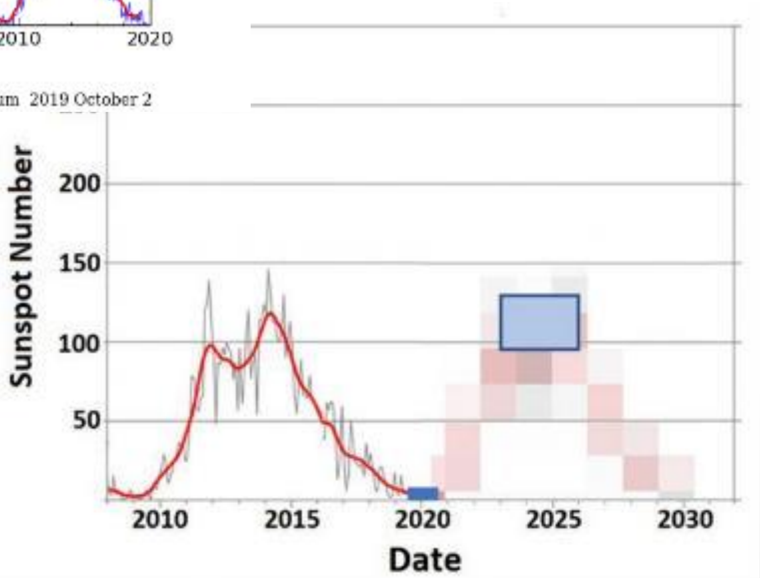
- **Sunspot cycle**: periodicity ~ 11 years
- Equatorward drift of activity latitude (butterfly diagram)
- Hale’s law for sunspot polarity, **magnetic cycle** of 22 years
- Sunspot groups tilt (Joy’s law)
- Polarity inversion at maximum of solar cycle





SUN: solar activity

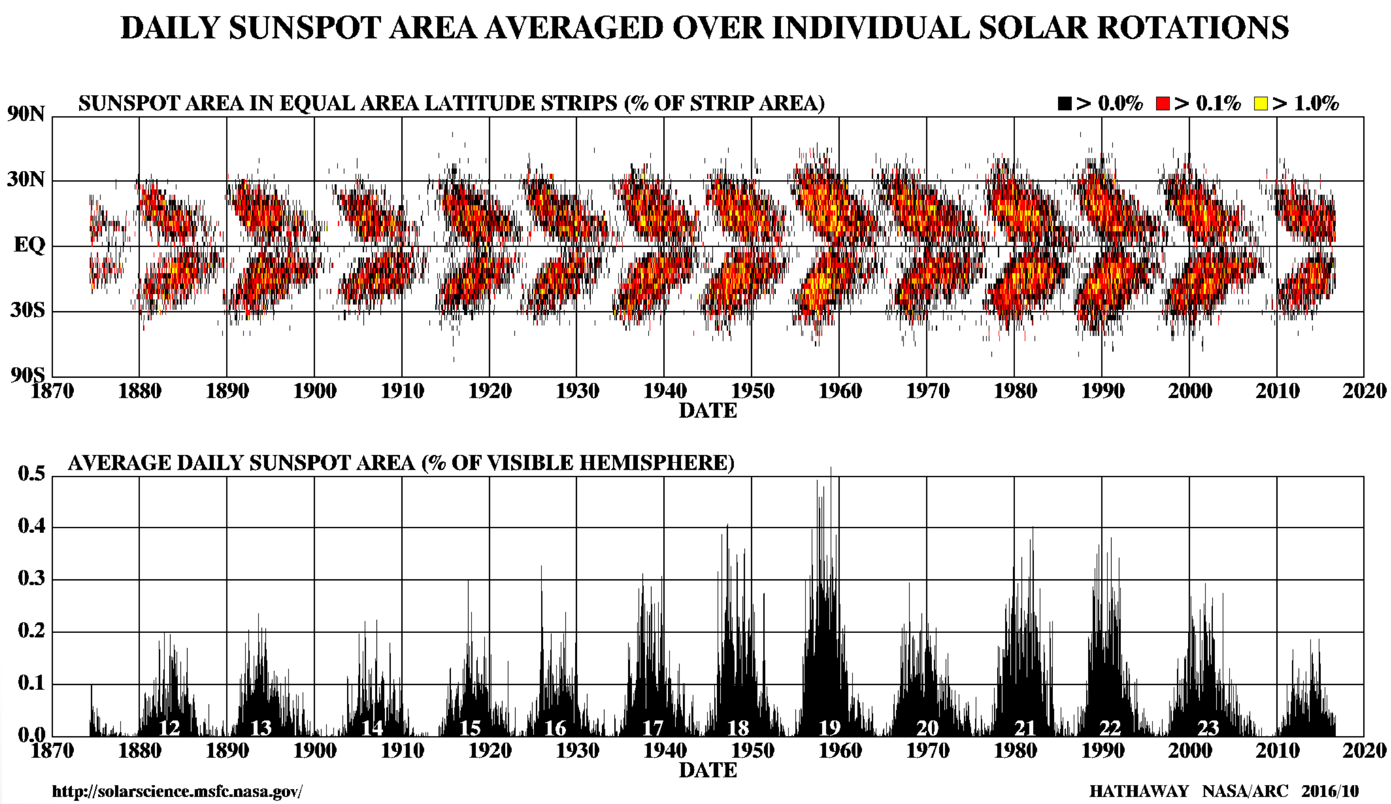




http://sidc.be/silso/home

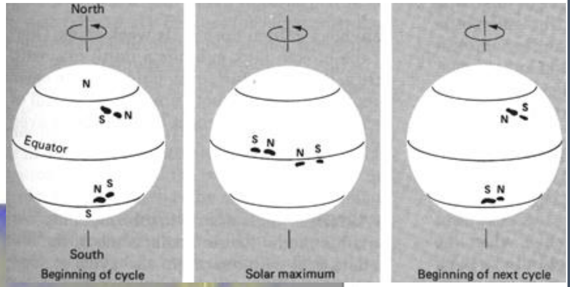
SUN: Batterfly diagram

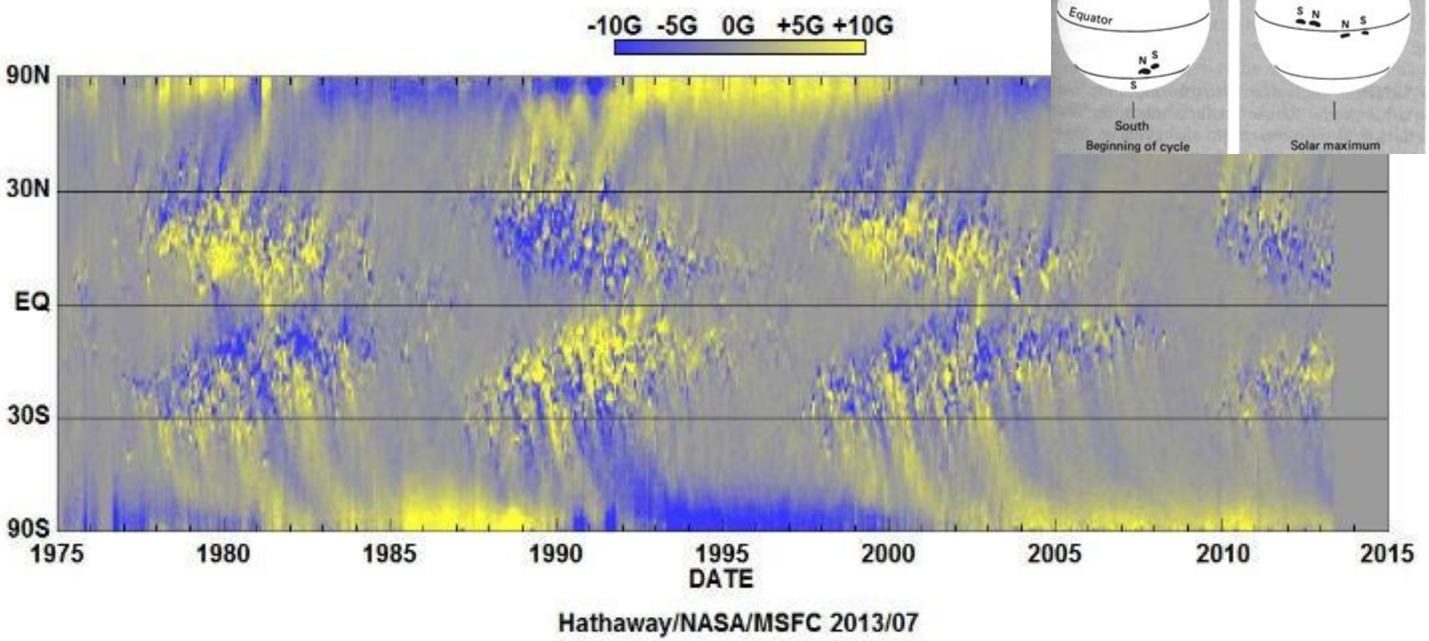
- Equatorward drift of activity latitude during the cycle



SUN: Hale’s law

- Hale’s law
  - “…the preceding and following spots … are of opposite polarity, and that the corresponding spots of such groups in the Northern and Southern hemispheres are also opposite in sign. Furthermore, the spots of the present cycle are opposite in polarity to those of the last cycle” Hale et al. (1919).
- Polarity inversion in proximity of solar maximum





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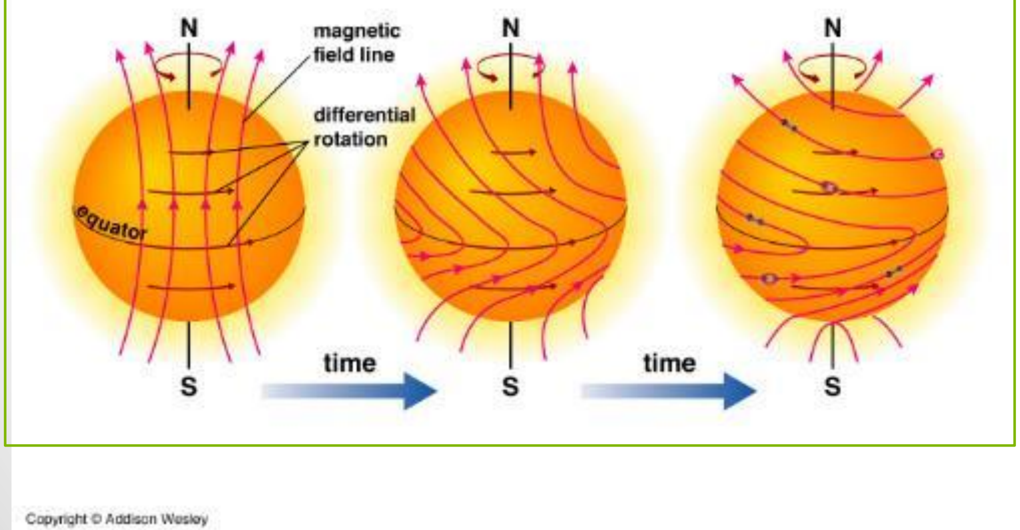
SUN: α-Ω effect

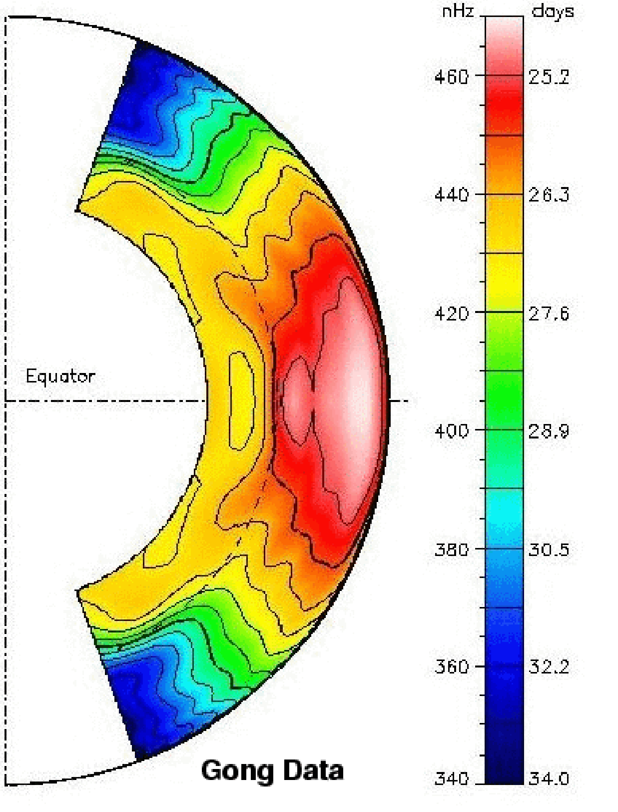
- Kinetic dynamo related to the α-Ω effect

  ω_{eq} ~ 2.9 ×10^{-6} rad/s (T ~ 24.9 days)

  ω_{poli} ~ 2.0 ×10^{-6} rad/s (T ~ 31.5 days)

Poloidal -> Toroidal -> Poloidal->…



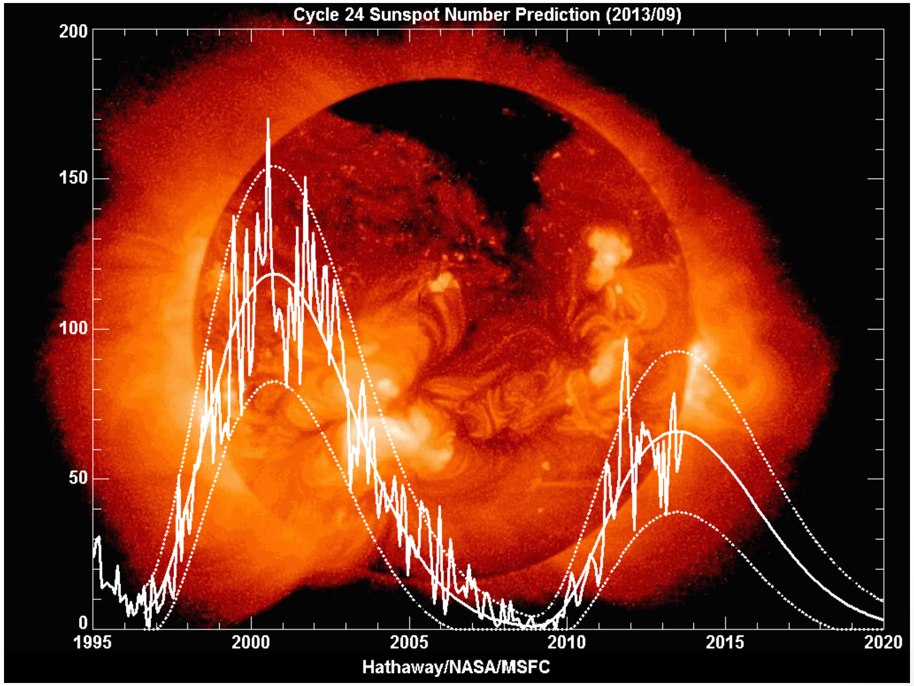


SUN: solar activity

◆ ACTIVITY CYCLE Period range: 7÷13 years

- Shapes the coronal structure and modulates the solar wind
- Modulates the occurrence of eruptive phenomena (flares, CMEs, etc.)
- Modulates solar irradiance
- Modulates UV, X radiation
- CME → Space Weather
- Modulates GCR flux

The previous solar cycle is the weakest (smoothed sunspot number for Cycle 24 = 70) since 1906 (smoothed sunspot number for Cycle 14 = 64,2)



http://solarscience.msfc.nasa.gov/predict.shtml

SUN: corona

- In white light it can be observed only during total eclipses.
- Its structure varies with solar activity

CORONA AT SOLAR ACTIVITY **MAXIMUM**

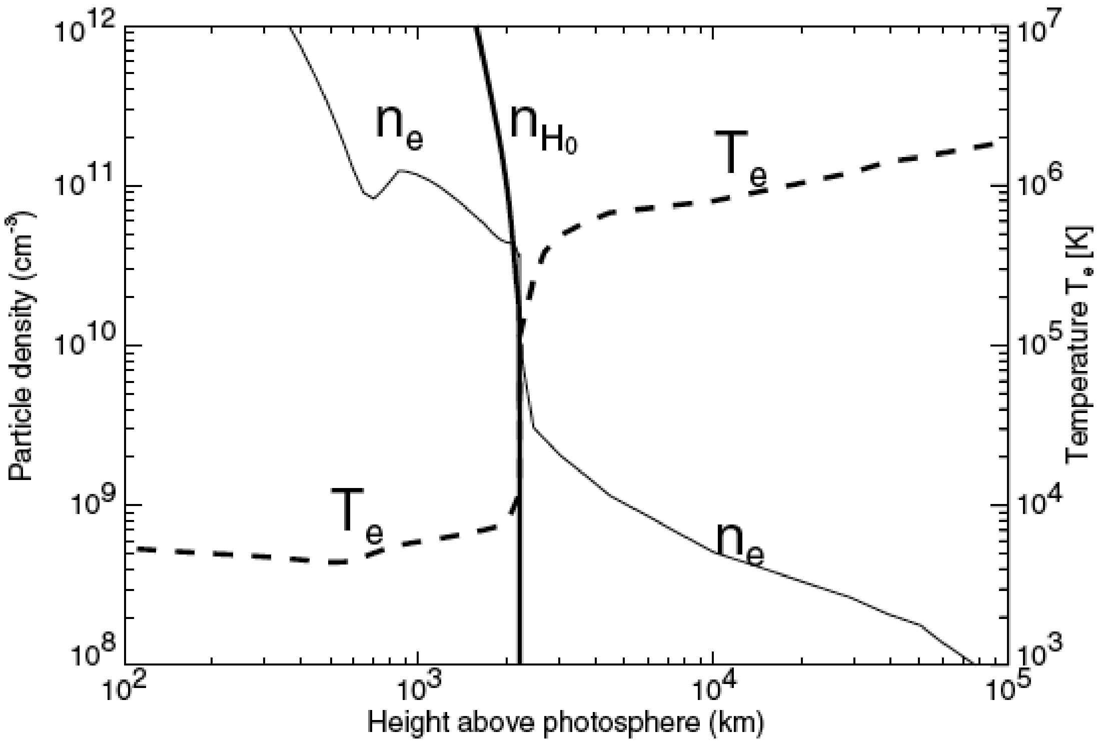
CORONA AT SOLAR ACTIVITY **MINIMUM**

SUN: corona

$T \sim 2 \times 10^6$ K → X, EUV, UV

$n \sim 10^{15} \div 10^{16}$ m^{-3}

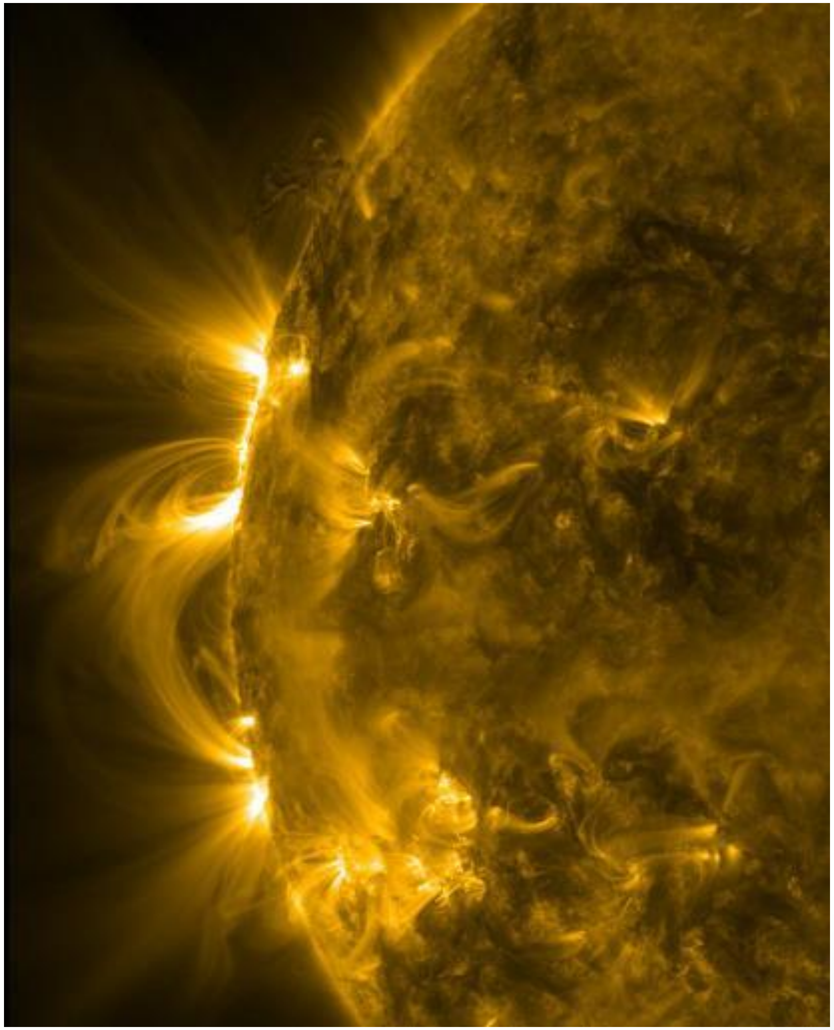
Helmet Streamers
Polar Plumes
Coronal Loops
Coronal Holes



Fontela et al.1990

SUN: corona

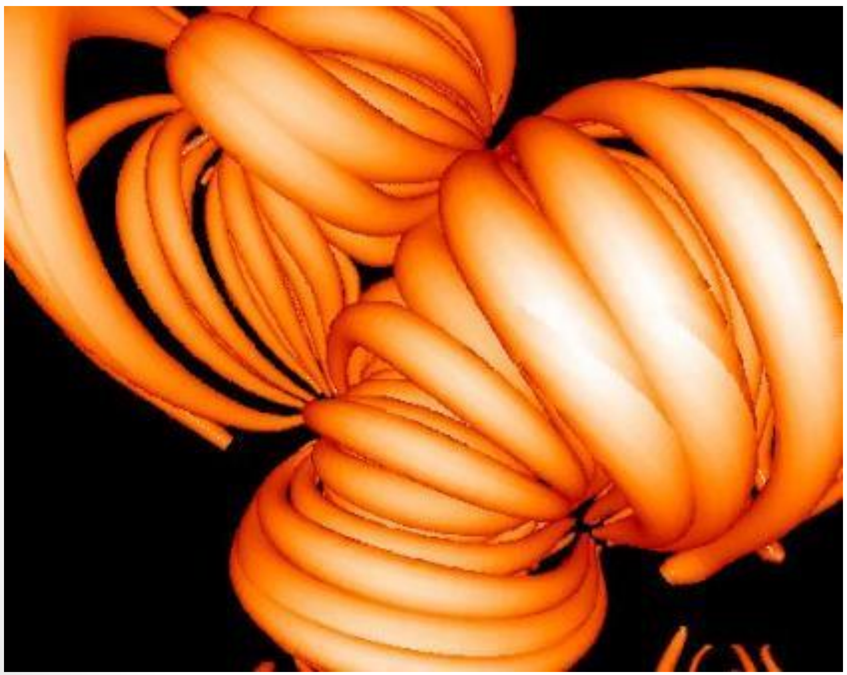
- Coronal Loops
  - Associated with closed magnetic field lines
  - Plasma is injected into the corona from underlying layers
  - Can persist for days even if the structure is changeable
  - Are associated with solar flares
  - Exhibit a 3D structure

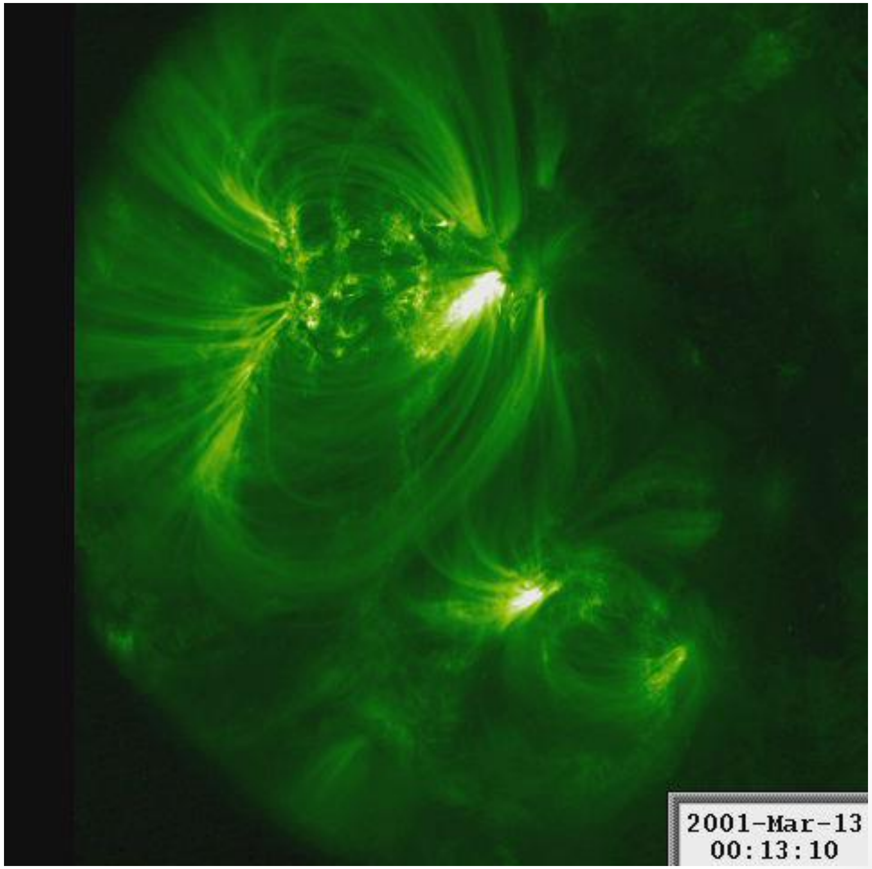


Solar Dynamics Observatory/NASA

SUN: corona

- Coronal Loops

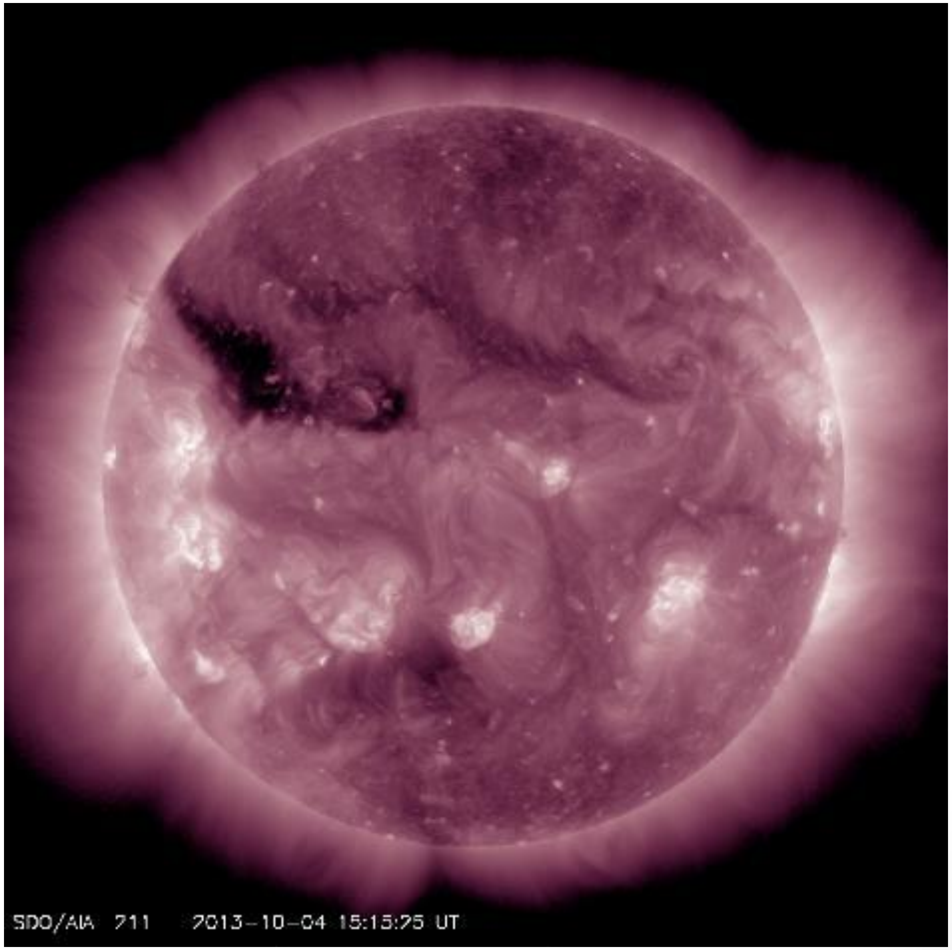

Dr. Allen Gray



TRACE

SUN: corona

- Coronal Holes
  - Low-emissivity regions in the solar corona
  - Associated with open magnetic field lines
  - high speed solar wind
  - Polar regions



SUN: flare

- A solar flare is a rapid energy release in solar corona triggered by an instability in the magnetic configuration. (Magnetic reconnection)
- Flares release $10^{16} \div 10^{25}$ J ($10^{23} – 10^{32}$ erg) energy in tens of minutes (Note: one H-bomb: 10 million TNT = 5.0×10^{23} erg)
- Emission almost at all wavelength + energetic particles

	Peak in 0.1 to 0.8 nm band
Class	[$W \cdot m^{-2}$]
B	$I < 10^{-6}$
C	$10^{-6} \leq I < 10^{-5}$
M	$10^{-5} \leq I < 10^{-4}$
X	$I \geq 10^{-4}$

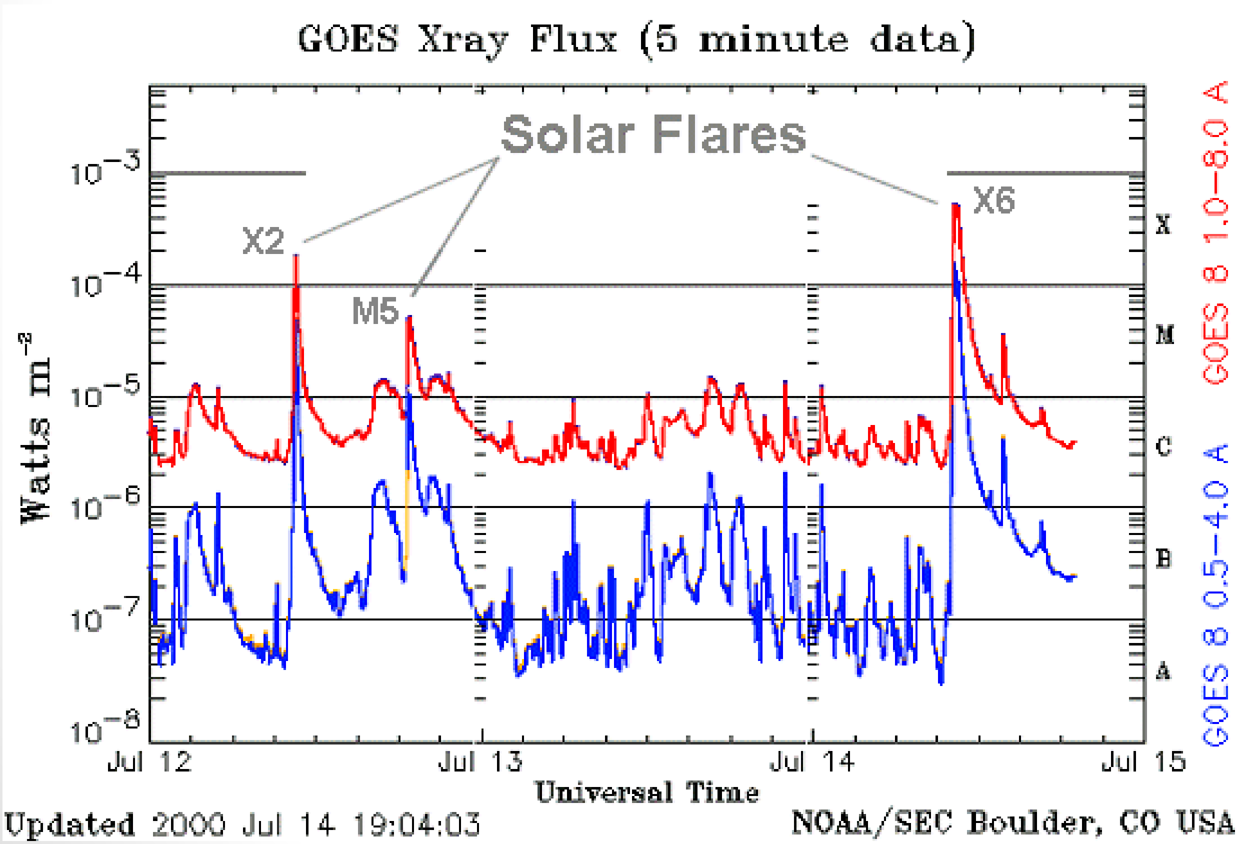
Each category for x-ray flares has nine subdivisions ranging from, *e.g.*, C1 to C9

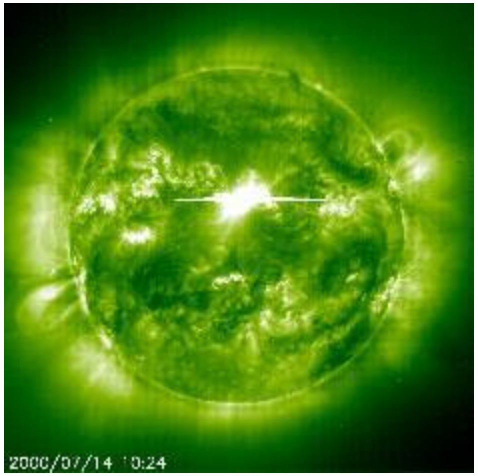
A multiplier is used to indicate the level within each class. For example:
$M6 = 6 \times 10^{-5}\ W \cdot m^{-2}$

I = burst peak intensity

SUN: flare

- The X6 flare triggered a radiation storm around Earth nicknamed the Bastille Day event.





SUN: flare

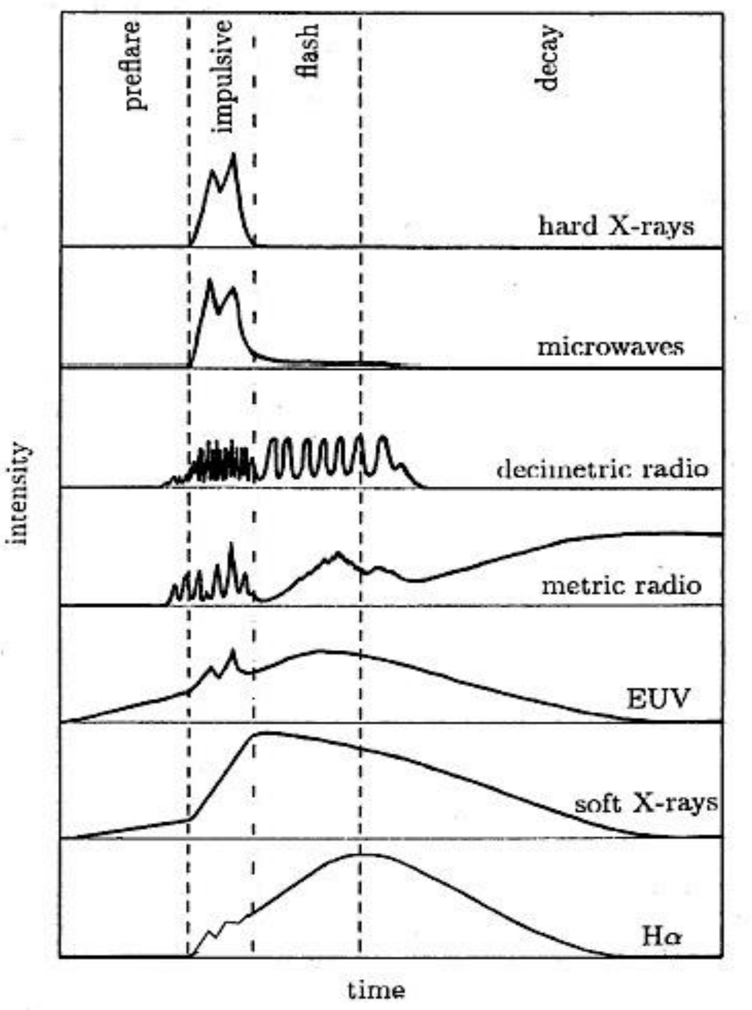
- The temporal evolution of a flare may consist of *three phases*:

Preflare phase: lasts a few minutes, coronal plasma heats up, soft x-rays and H_α brightening

Impulsive phase: ~ 3 ÷ 10 min, energetic particles acceleration, hard x-rays emission

(flash phase: rapid increase in H_α, 5 ÷ 10 min)

Gradual phase: coronal plasma gradually returns to its original state



October 21, 2019

SUN: flare

Flare evolution by TRACE (19.5 nm)

SUN: coronal mass ejection

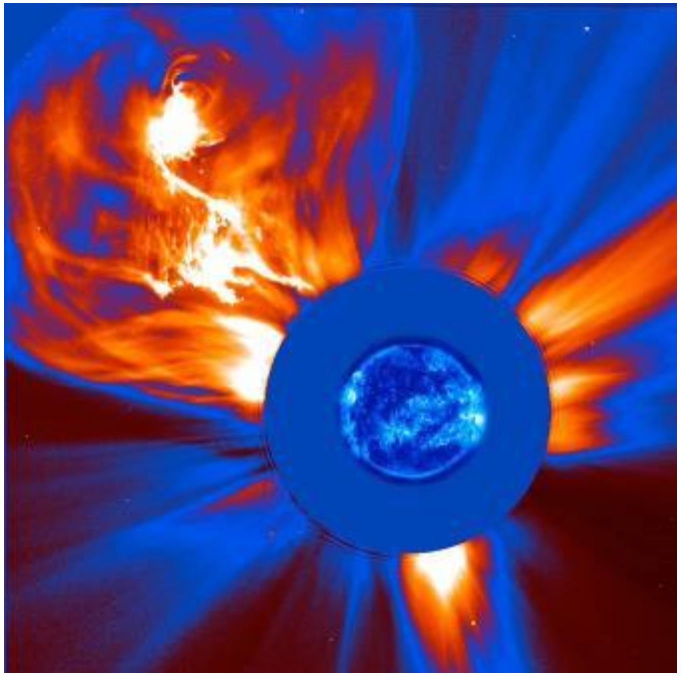
- A CME is a huge cloud of magnetized plasma ejected from the Sun's corona into space at high speeds
  - Sometimes, but not always associated with flare and prominence eruption

Apparent angular width:

few ÷ 120° (normal CME)

120° ÷ 360° (partial halo CME)

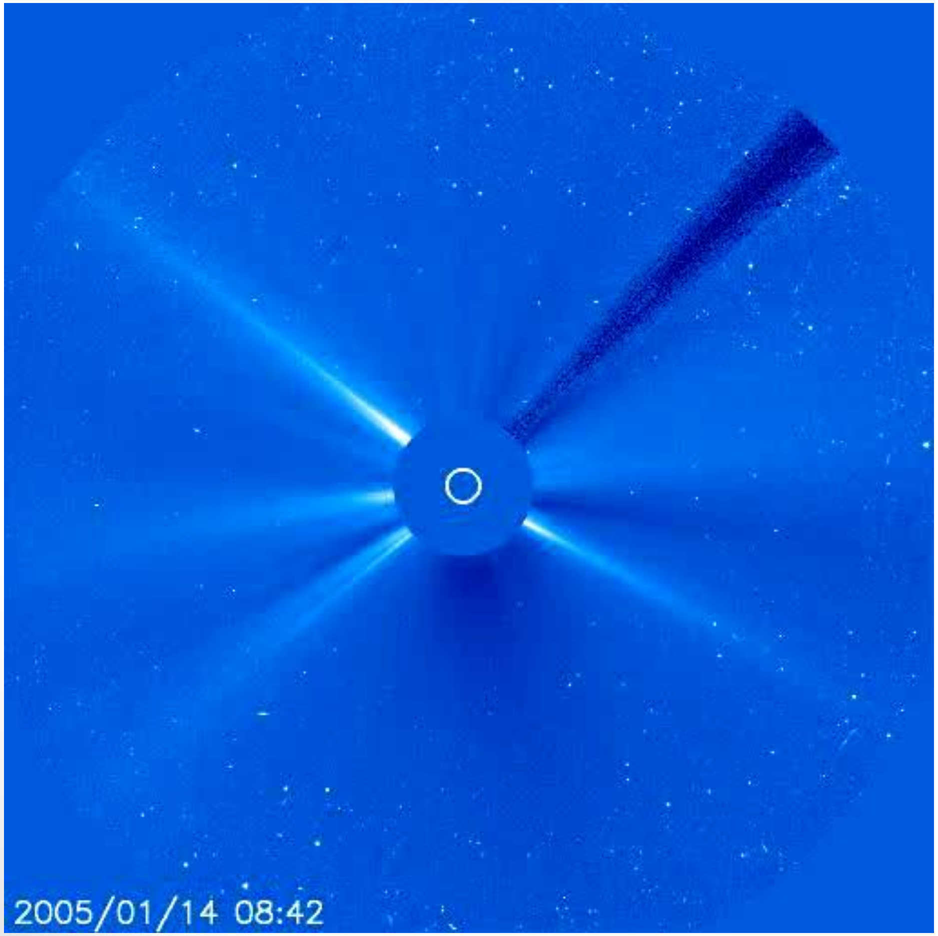
Front (Earth) or back side directed CMEs are referred to as halo CMEs

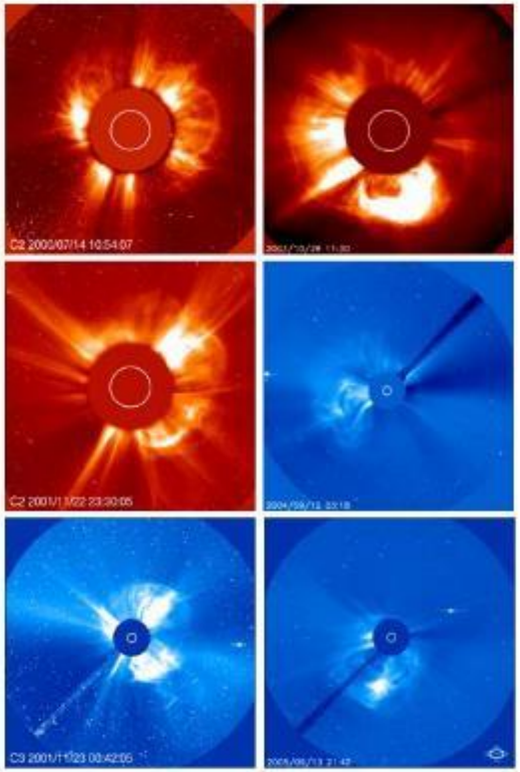


SOHO/LASCO

SUN: coronal mass ejection

- Halo CME are Earth-directed CMEs





SOHO/LASCO

SUN: coronal mass ejection

- $M_{ej} = 10^{10} \div 10^{13}$ kg
- $E_{tot} = E_{cin} + E_{potential} = 10^{20} \div 10^{26}$ J
- $V = 300 \div 2000$ kms^{-1}

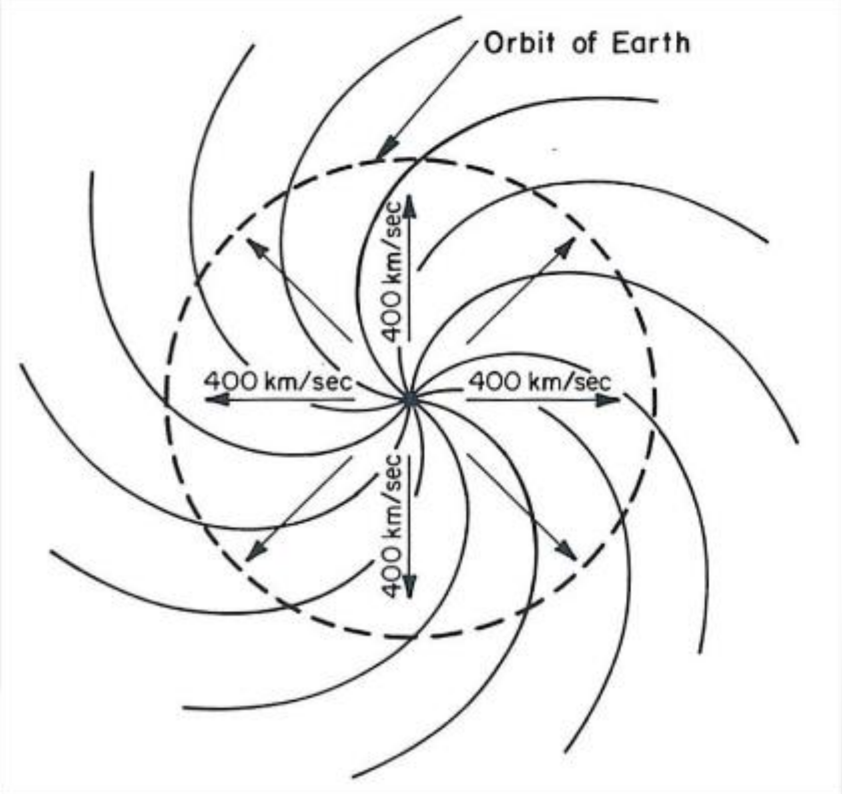
- Interfere with solar wind for example by the creation of a shock wave that moves ahead the CME, accelerating solar wind particles to high energies

SOLAR WIND

- It is a stream of charged particles (mostly e^- and p) released from the Sun's corona in radial direction

The solar magnetic field is frozen in to the radial outflowing solar wind. Thus, due to the Sun's rotation, the magnetic field lines exhibit an Archimedean spiral configuration.

The angle to the radial direction of the magnetic field depends on distance, latitude and the local solar wind velocity.



SOLAR WIND

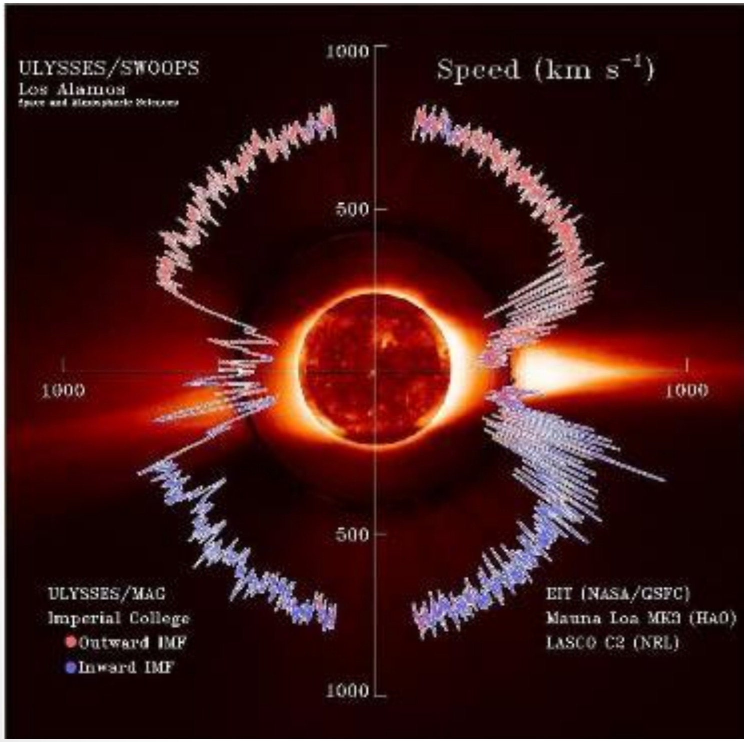
- Typical values of several solar wind parameters as measured by Helios 2 at 1AU

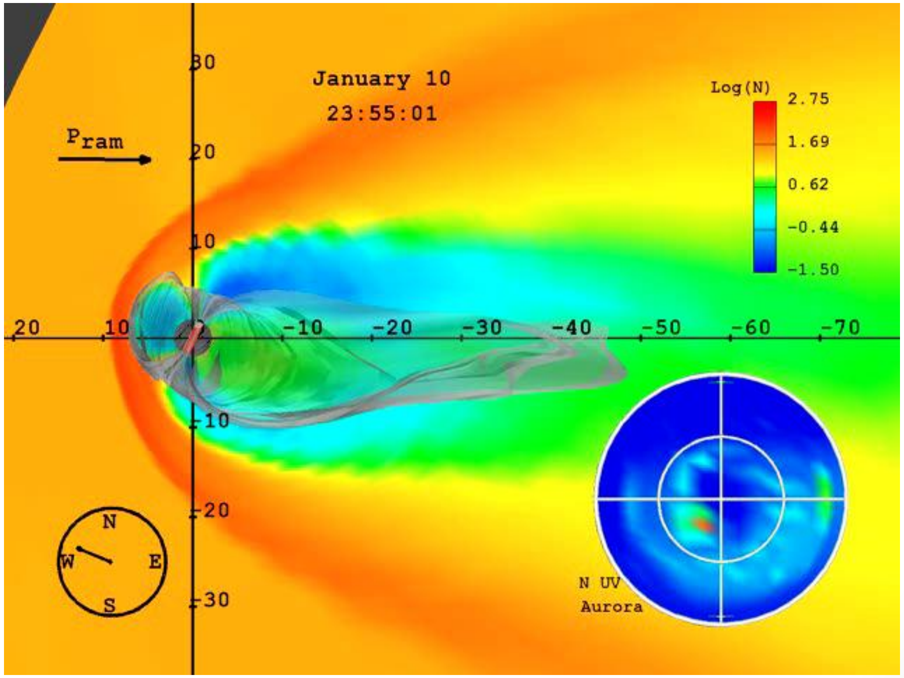
Wind Parameter	Slow wind	Fast wind
number density	~ 15 cm^{-3}	~ 4 cm^{-3}
bulk velocity	~ 350 km s^{-1}	~ 600 km s^{-1}
proton temperature	~ 5 x 10^4 K	~ 2 x 10^5 K
electron temperature	~ 2 x 10^5 K	~ 1x 10^5 K
α-particles temperature	~ 2 x 10^5 K	~ 8 x 10^5 K
magnetic field	~ 6 nT	~ 6 nT

http://solarphysics.livingreviews.org/open?pubNo=lrsp-2005-4&page=articlese12.html

SOLAR WIND

- Solar wind velocity and interaction with the magnetosphere





Space Weather Missions

- Ulysses https://solarsystem.nasa.gov/missions/ulysses/in-depth/
- SOHO http://www.esa.int/Science_Exploration/Space_Science/SOHO_overview2
- Double star (magnetotail and solar cups – follower of CLUSTER) http://www.esa.int/Science_Exploration/Space_Science/Double_Star_overview2
- ACE https://solarsystem.nasa.gov/missions/ace/in-depth/
- TRACE http://www.lmsal.com/TRACE/
- STEREO https://www.nasa.gov/mission_pages/stereo/main/index.html
- SDO https://sdo.gsfc.nasa.gov/mission/
- SMILE https://www.cosmos.esa.int/web/smile
- Solar Orbiter https://sci.esa.int/web/solar-orbiter

SW Models and Real Time Data

MODELS

- SPENVIS https://www.spenvis.oma.be/
- CCMC https://ccmc.gsfc.nasa.gov/

Space weather Real Time

- https://sohowww.nascom.nasa.gov/sunspots/
- https://www.swpc.noaa.gov/
- http://sidc.be/