



# Space physics EF2240

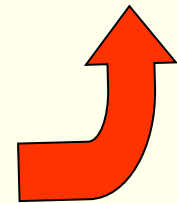
*Tomas Karlsson*

Space and Plasma  
Physics

*School of Electrical  
Engineering*



**What is this?**



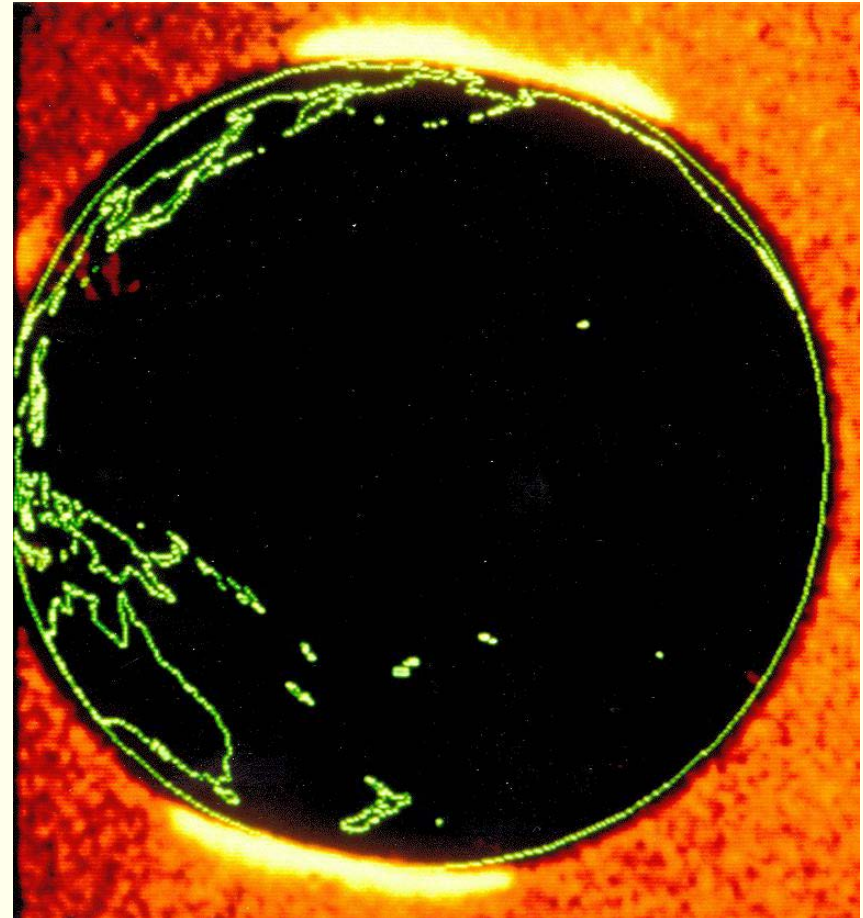
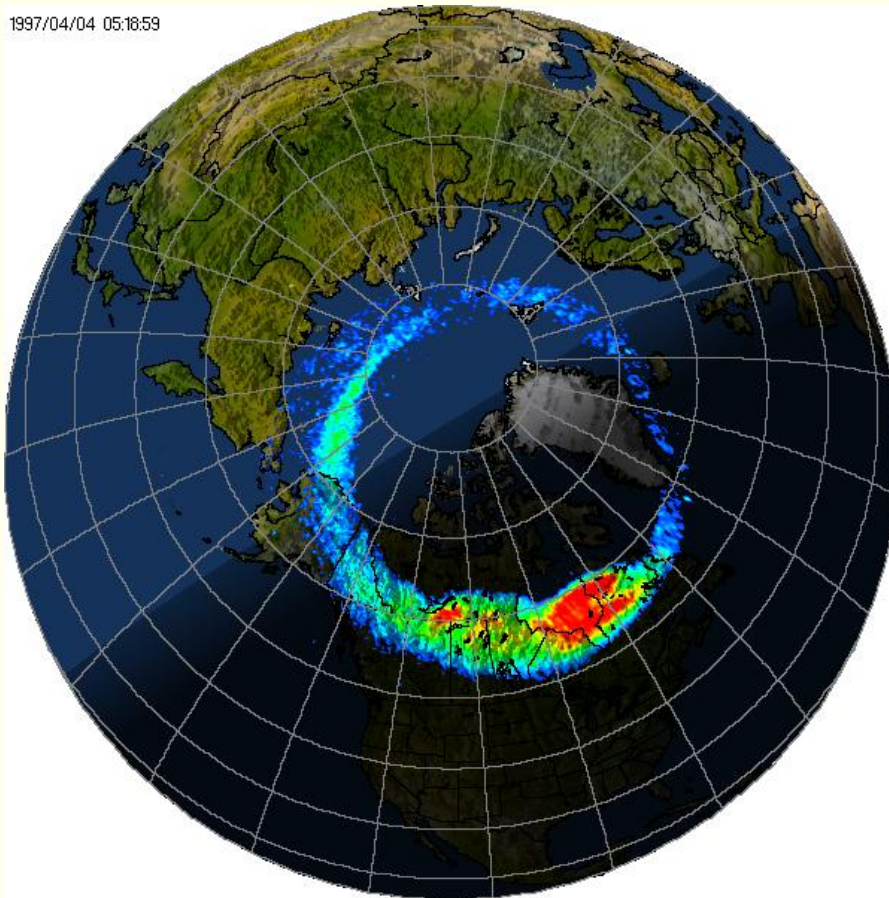
# *Clue...*





# The auroral ovals

1997/04/04 05:18:59





# Today's lecture

- Course info
- Overview of course content
- Definition of plasma
- Solar interior and atmosphere



# Steps to take to take the course

**1) Make sure you have signed up for the course.**

**If you haven't: contact your Masters coordinator or studievägledare**

**2) Register for the course! (My Pages)**

**You have to do this yourself!**



# Definition of Space Physics

- Studies of space in Earth's vicinity with the help of *in situ* measurements (unique for this area, cf. astronomy and astrophysics).
- More than 99% of matter in space is in the *plasma* state.
- Alternative names:
  - *Space plasma physics*
  - *Solar-terrestrial physics (incl. space weather)*



# Schedule

10×2 h Lectures

6×2 h Tutorials

L = Lecture, T = Tutorial

Activity	Date	Time	Room	Subject	Litterature
L1	31/8	13-15	V22	Course description, Introduction, The Sun 1, Plasma physics 1	CGF Ch 1, 5, (p 110-113)
L2	3/9	15-17	Q36	The Sun 2, Plasma physics 2	CGF Ch 5 (p 114-121), 6.3
L3	7/9	13-15	Q36	Solar wind, The ionosphere and atmosphere 1, Plasma physics 3	CGF Ch 6.1, 2.1-2.6, 3.1-3.2, 3.5, LL Ch III, Extra material
T1	10/9	15-17	Q36	Mini-group work 1	
L4	14/9	13-15	E2	The ionosphere 2, Plasma physics 4	CGF Ch 3.4, 3.7, 3.8
T2	17/9	8-10	Q31	Mini-group work 2	
L5	17/9	15-17	L52	The Earth's magnetosphere 1, Plasma physics 5	CGF 4.1-4.3, LL Ch I, II, IV.A
L6	21/9	13-15	L52	The Earth's magnetosphere 2, Other magnetospheres	CGF Ch 4.6-4.9, LL Ch V.
T3	24/9	16-18	Q36	Mini-group work 3	
L7	28/9	13-15	Q36	Aurora, Measurement methods in space plasmas and data analysis 1	CGF Ch 4.5, 10, LL Ch VI, Extra material
T4	1/10	15-17	V22	Mini-group work 4	
L8	5/10	13-15	M33	Space weather and geomagnetic storms	CGF Ch 4.4, LL Ch IV.B-C, VII.A-C
L9	6/10	8-10	Q36	Interstellar and intergalactic plasma, Cosmic radiation,	CGF Ch 7-9
T5	8/10	15-17	Q34	Mini-group work 5	
L10	12/10	13-15	Q36	Swedish and international space physics research.	
T6	15/10	15-17	Q33	Round-up.	
Written examination	28/10	8-13	Q21, Q26		



# Course goals

At the end of the course you should be able to:

- **define** what a plasma is, and classify various types of plasma.
- **describe** the plasma physical properties of various regions of space, with emphasis of the near-earth region.
- **explain** how some important plasma populations in the solar system (e.g. Earth's ionosphere and magnetosphere) get their basic properties and how these properties can vary between the planets.
- **make** order of magnitude estimates of some properties of space plasmas and space physics phenomena, for example the power dissipated in the aurora or the magnitude of electric currents floating from the magnetosphere into the ionosphere.
- **make** simple analyses of measurement data from satellites and ground-based instruments. (E.g. calculate currents in space from magnetometer data.)
- **make** simple models of some space physics phenomena by applying basic physical laws expressed with simple mathematics. (An example would be to model the basic shape of the magnetosphere or estimate the temperature of a sunspot.)
- **describe** to interested laymen or “the man in the street” what we can learn from space physics and how it affects our everyday life (for example by various space weather phenomena.)



# Examination

1. Written examination  
(open book), 30/10

100 p

2. Continuous examination  
(mini-group works)

25 p

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Grades:

A: 111-125 p

B: 96-110 p

C: 81-95 p

D: 66-80 p

E: 50-65 p

(Fx)





# Written examination, 28/10 2015, 08.00-13.00, Q21, Q26

You may bring:

- all the course material
- any notes you have made
- pocket calculator
- mathematics and physics formula books or your favourite physics book
- formula sheet

(No computers are allowed, due to the possibility to communicate with the outside world.)

Approx. 5 different problems (which may contain sub-problems).

The character of the problems is such that to get a high score you will have to show that you have obtained a certain course goal, e.g. to make a reasonable order of magnitude estimate or figure out a simple model for some space physics phenomenon.

# Continuous examination

## Mini-group works

5 mini-group works  
( $5 \times 5 \text{ p} = 25 \text{ p}$ )

*Approx. 1 h during Tutorials 1-5*

- *A problem similar to those on the written examination is given*
- *Groups of 3 (randomized).*
- *Elect a secretary!*
- *Write down a solution!*





# Litterature

- C-G. Fälthammar, "Space Physics" (compendium), 2nd Ed, Third Printing, 2001.
- Larry Lyons, "Space Plasma Physics", from *Encyclopedia of Physical Science and Technology*, 3rd edition, 2002.
- Lecture notes and extra material handed out during lectures.



# Course home page

*KTH Social:*

<https://www.kth.se/social/course/EF2240/>

*At the home page I will post new information continuously.  
Here you can also find lecture notes, exercises (and some solutions), etc.*

# Last Minute!

**What was the most important thing of today's lecture? Why?**

**What was the most unclear or difficult thing of today's lecture, and why?**

**Other comments:**



***Study the Course  
Description carefully!***

# **EF2245 Space Physics II**

## **7.5 ECTS credits, P2**

- shocks and boundaries in space
- solar wind interaction with magnetized and unmagnetized bodies
- reconnection
- sources of magnetospheric plasma
- magnetospheric and ionospheric convection
- auroral physics
- storms and substorms
- global oscillations of the magnetosphere



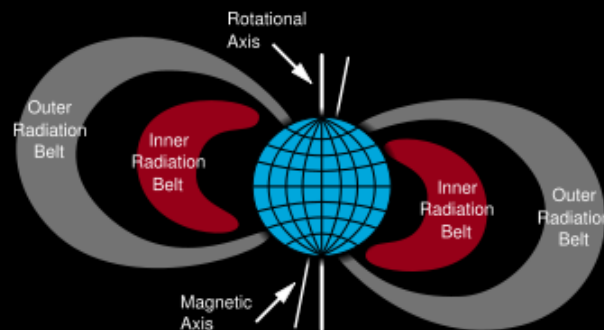
# Courses at the Alfvén Laboratory

## EF2260 SPACE ENVIRONMENT AND SPACECRAFT ENGINEERING , 6 ECTS credits, period 2

- environments spacecraft may encounter in various orbits around the Earth, and the constraints this places on spacecraft design
- basic operation principles underlying the thermal control system and the power systems in spacecraft
- measurements principles in space



*The Astrid-2 satellite*



*Radiation environment in near-earth space*

### Projects:

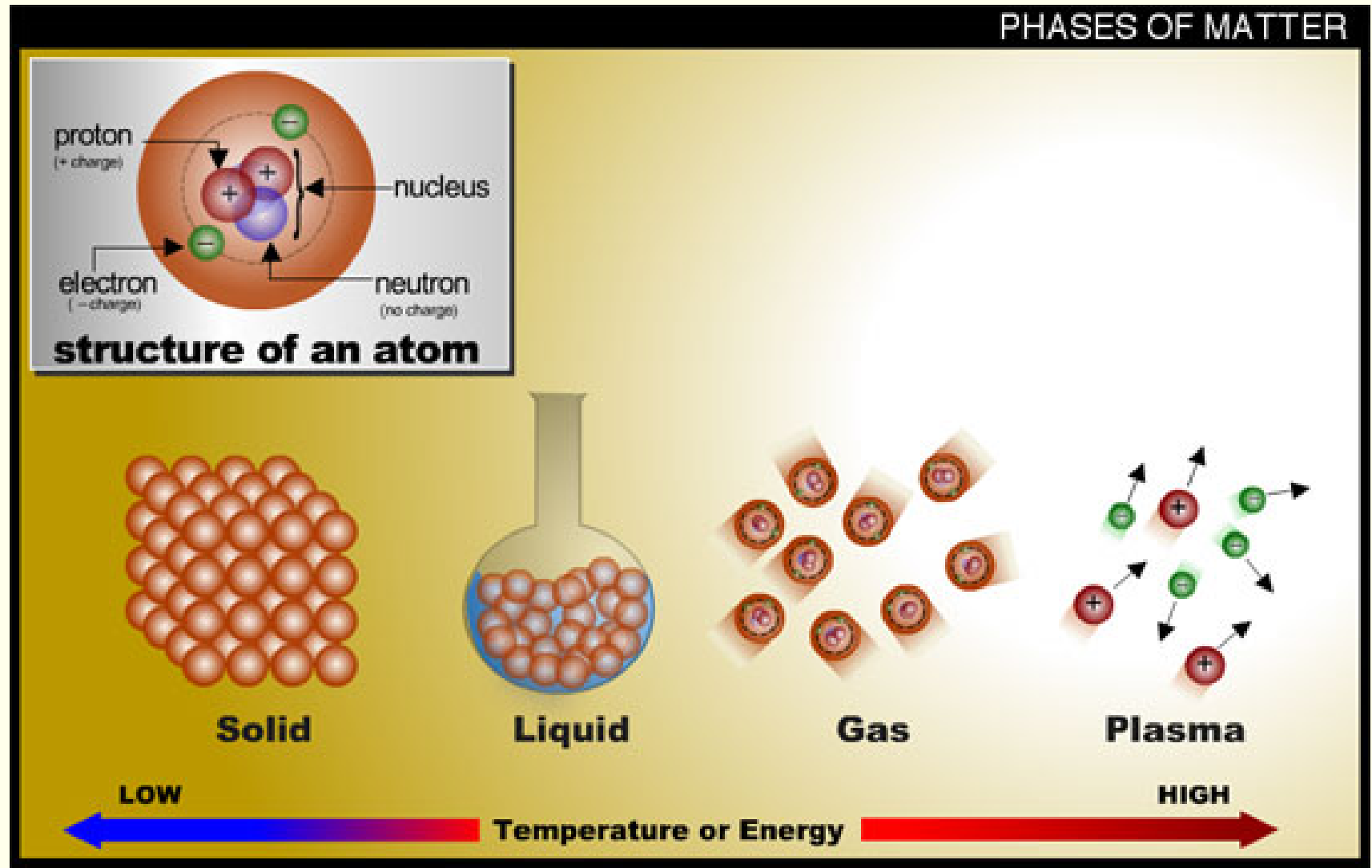
- Design power supply for spacecraft
- Study of radiation effects on electronics



# What is a plasma?

# Where in the universe can you find it?

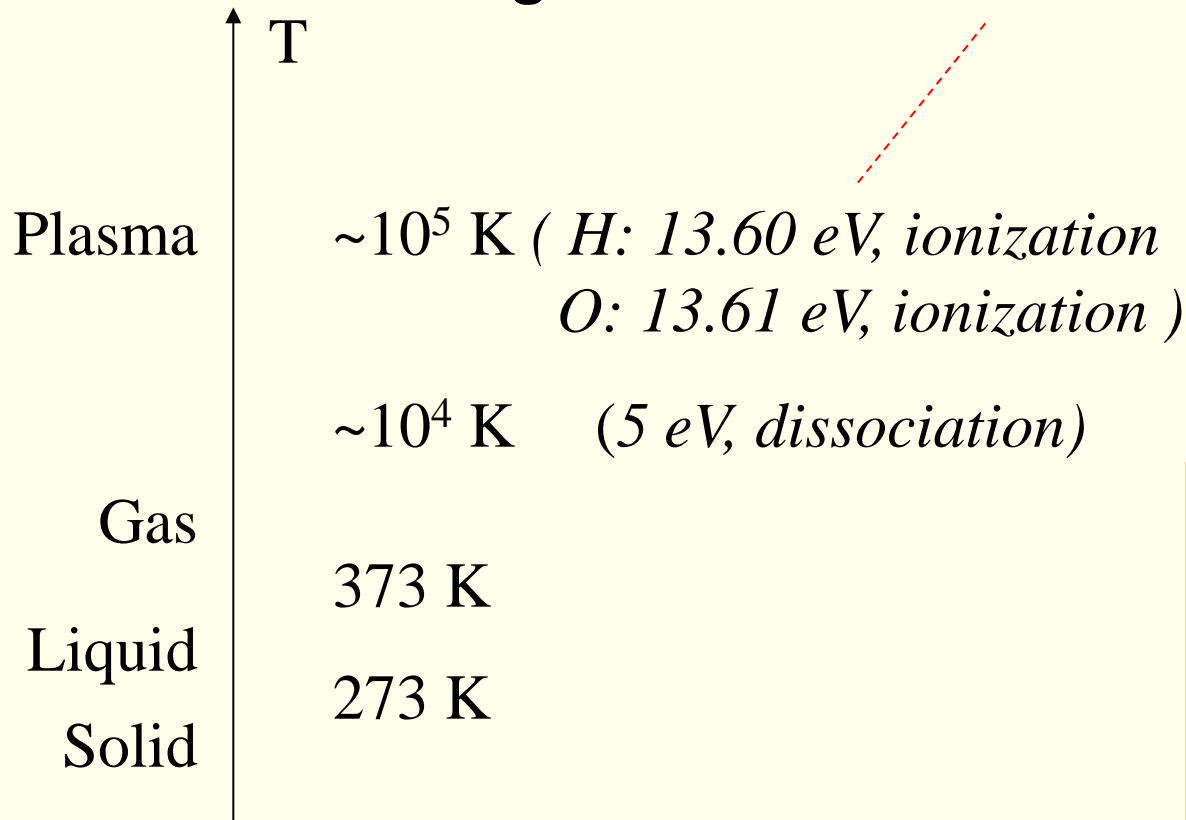
# Plasma



# Plasma

**E.g. Water**

**1 eV ~ 11600 K**



**Definition:** A plasma is an ionized gas, showing collective behaviour.

**"Fourth state of matter"**

Somewhat misleading:

- *No phase transition*
- *Ionization can be caused by other mechanisms than heating, e.g. UV radiation.*

# Energy - temperature

Average energy of molecule/atom:

$$E = \frac{3}{2} k_B T \Rightarrow$$

$$T = \frac{2E}{3k_B}$$

$$1 \text{ eV} = 1.6 \cdot 10^{-19} \text{ J} \Rightarrow$$

$$T = \frac{2E}{3k_B} = \frac{2 \cdot 1.6 \cdot 10^{-19} \text{ J}}{3 \cdot 1.38 \cdot 10^{-23} \frac{\text{J}}{\text{K}}} = 7729 \text{ K}$$

# But beware!

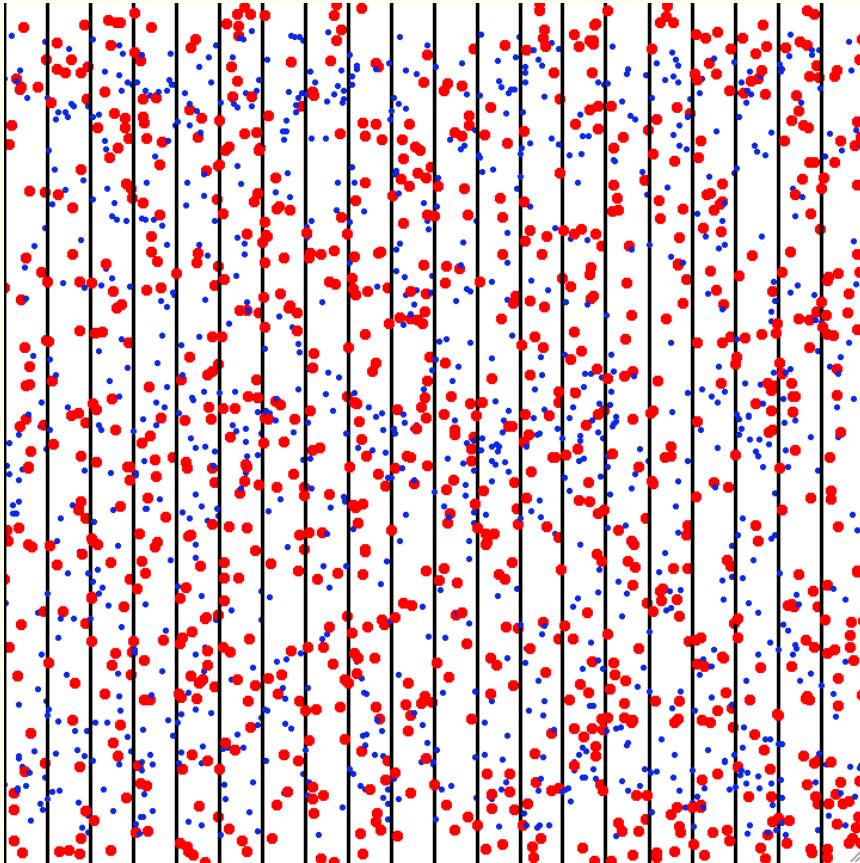
In plasma physics, usually:

$$\cancel{E = \frac{3}{2} k_B T} \Rightarrow$$
$$T = \frac{E}{k_B}$$

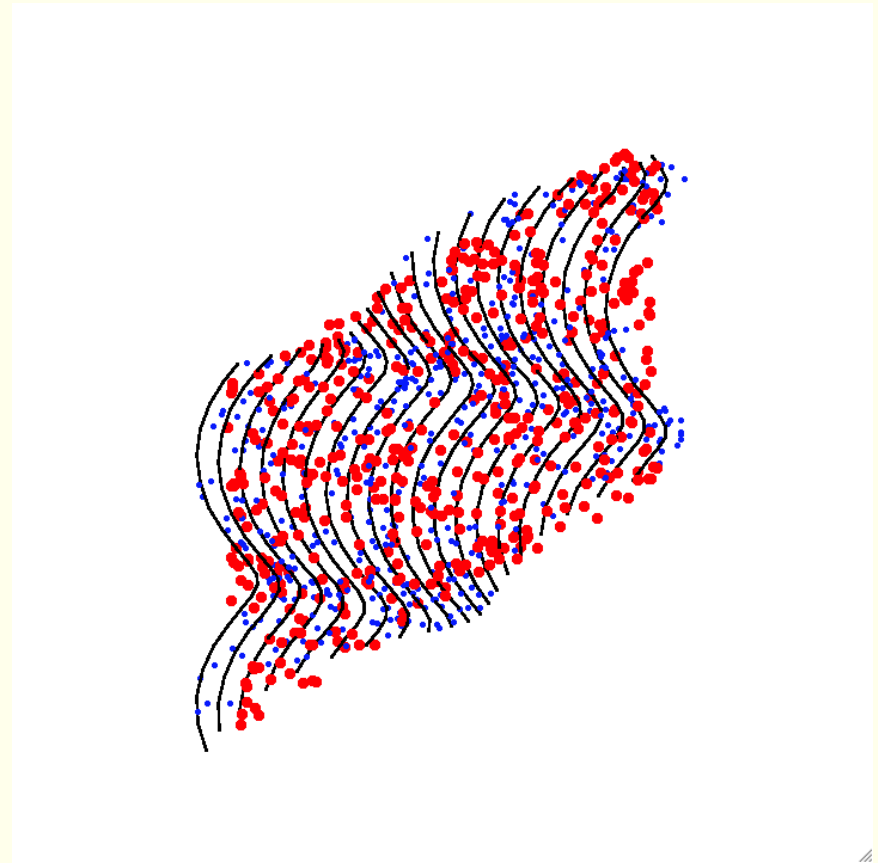
$$1 \text{ eV} = 1.6 \cdot 10^{-19} \text{ J} \Rightarrow$$

$$E = k_B T = \frac{1.6 \cdot 10^{-19} \text{ J}}{1.38 \cdot 10^{-23} \frac{\text{J}}{\text{K}}} = 11594 \text{ K}$$

# Example of collective behaviour: Plasma waves



Electron plasma waves

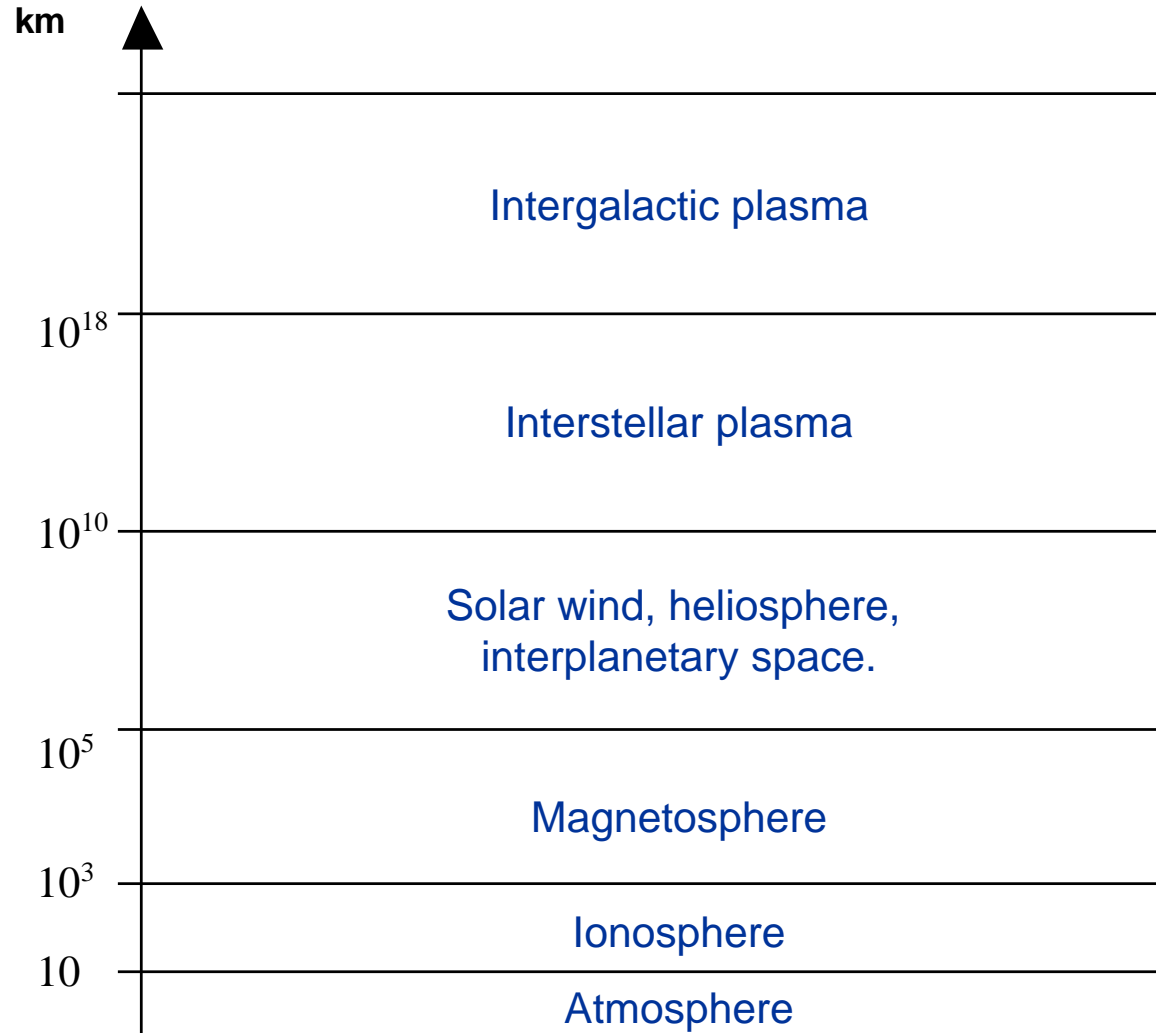


Whistler waves



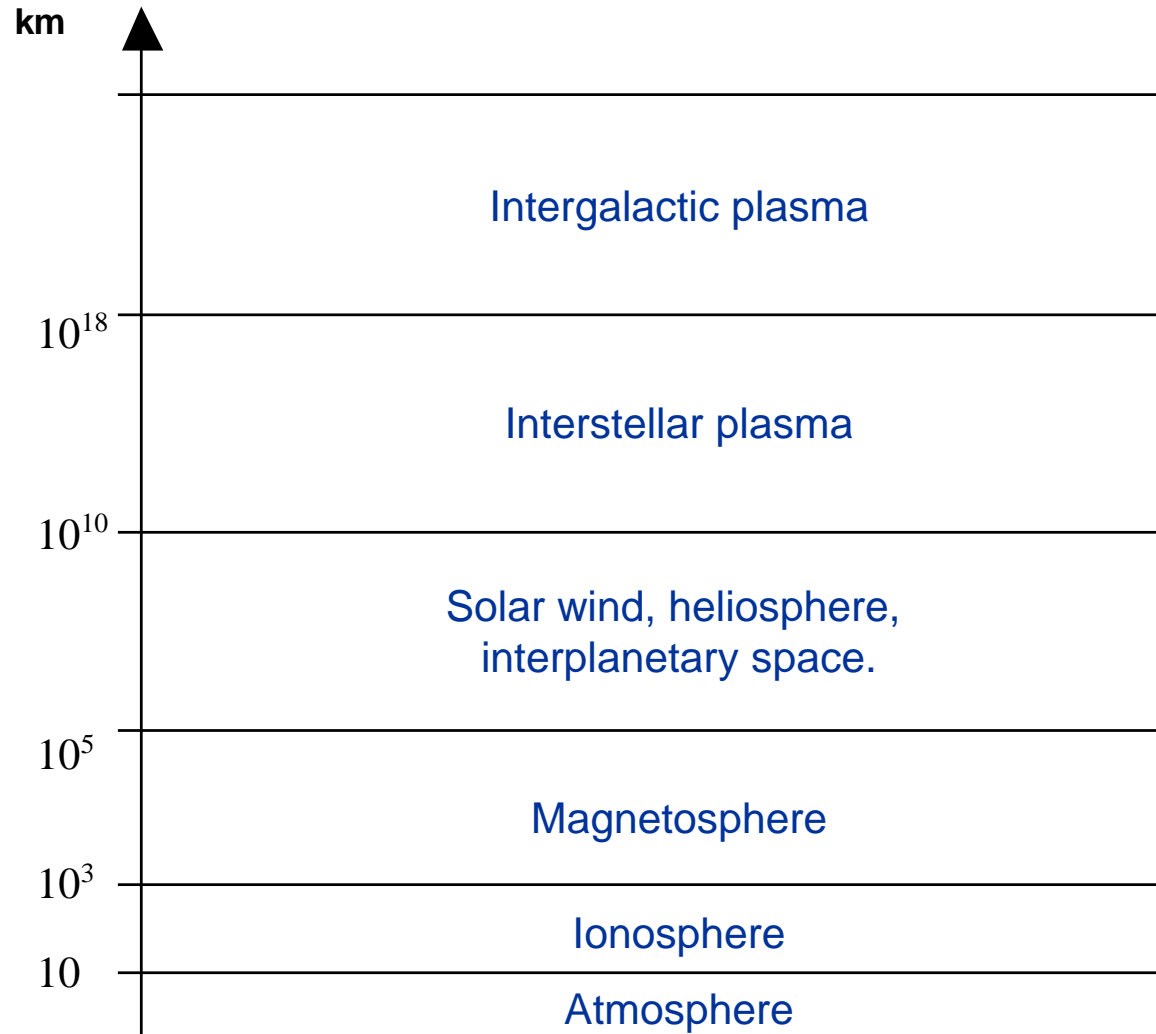
# From atmosphere to intergalactic plasma!

Solar  
system

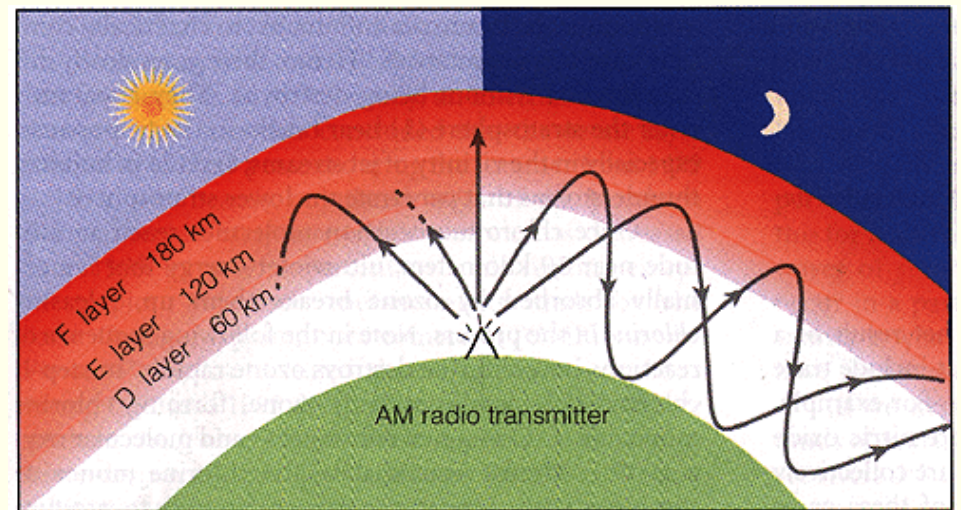
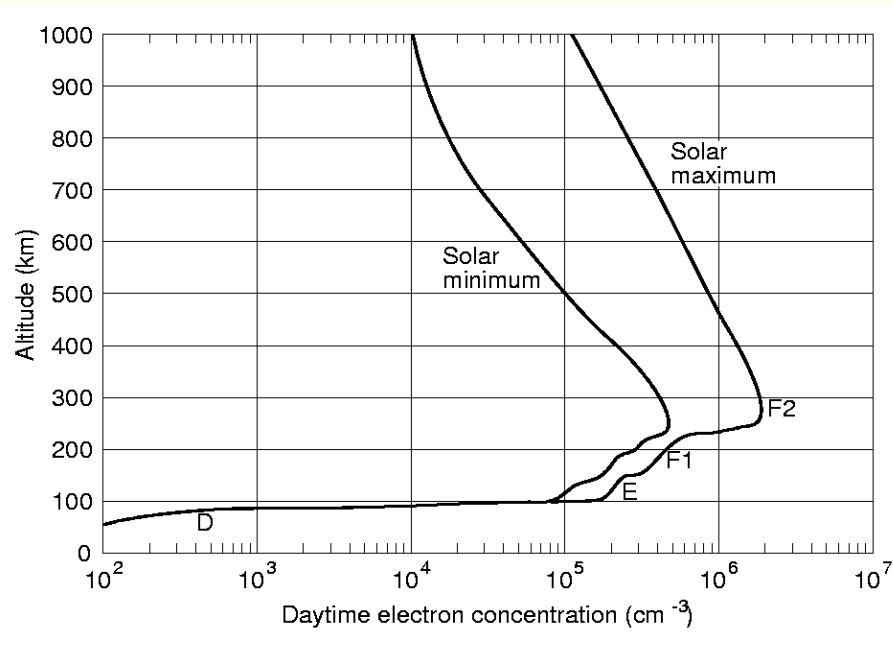


# From atmosphere to intergalactic plasma!

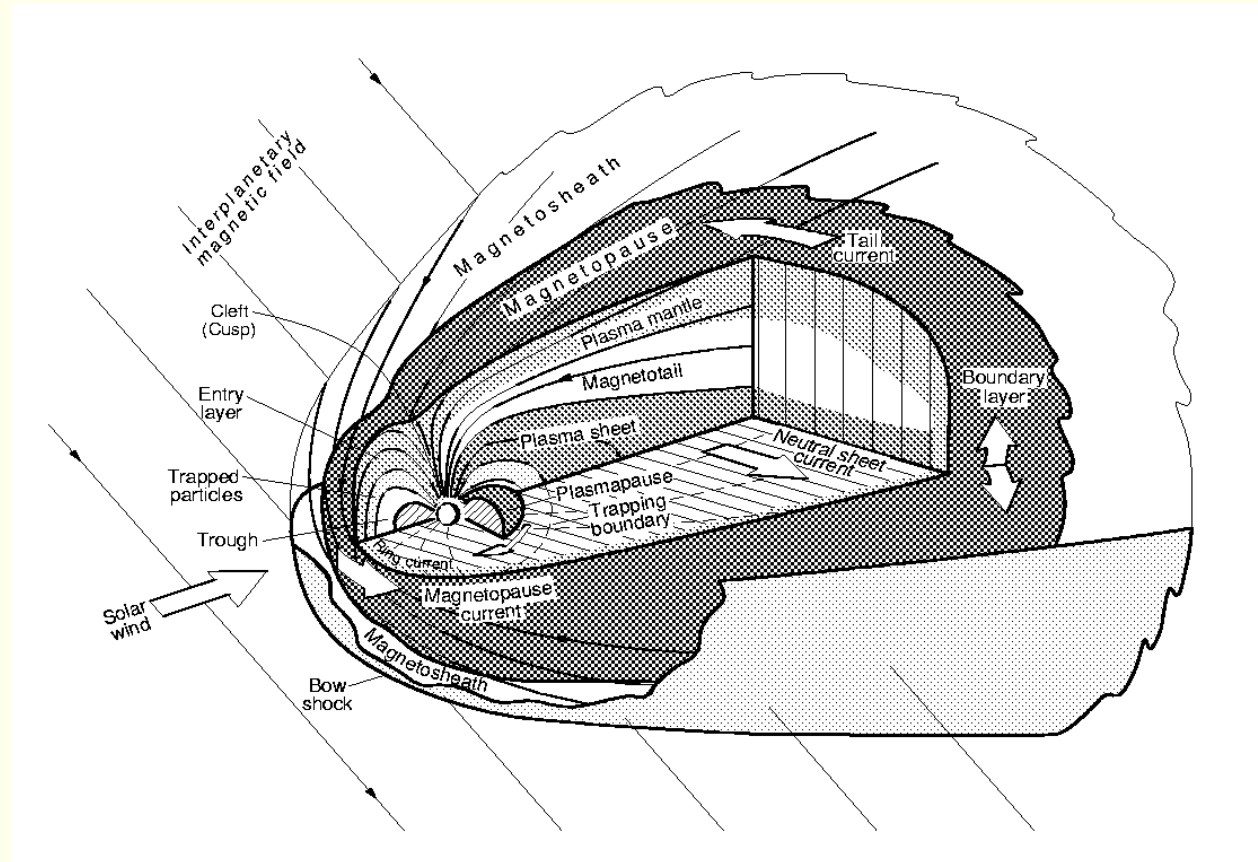
Solar  
system



# Ionosphere



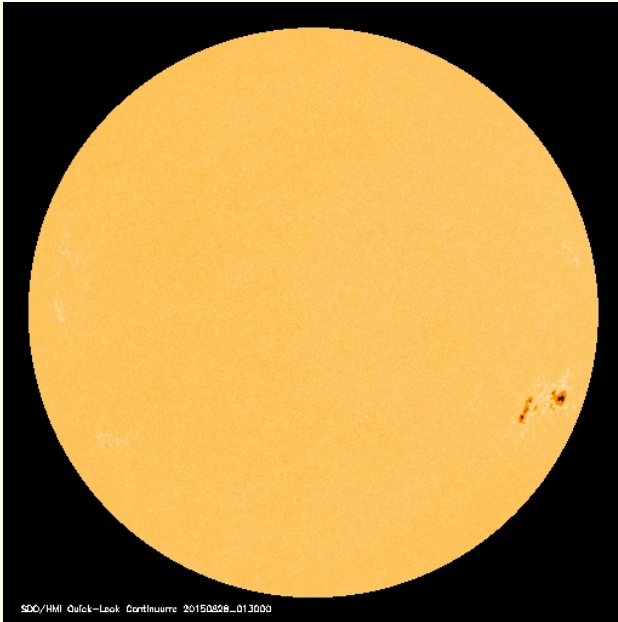
# Magnetosphere



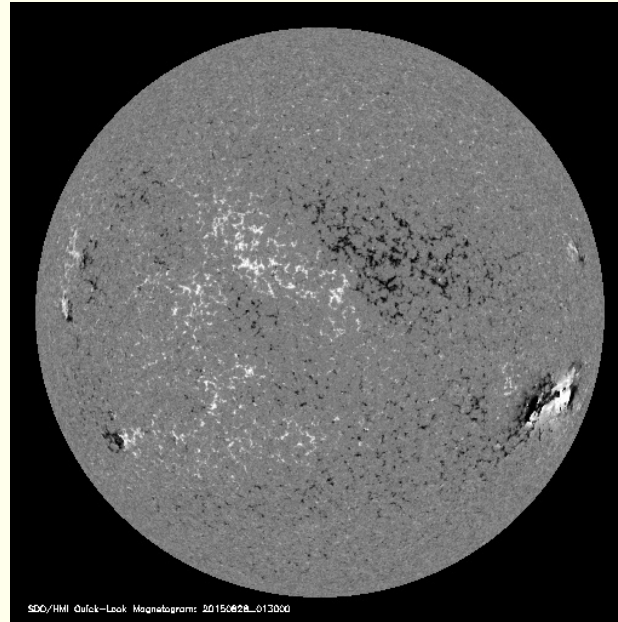
**Definition:** *That region in space where the geomagnetic field is the dominating magnetic field.*

# The sun (2015-08-28)

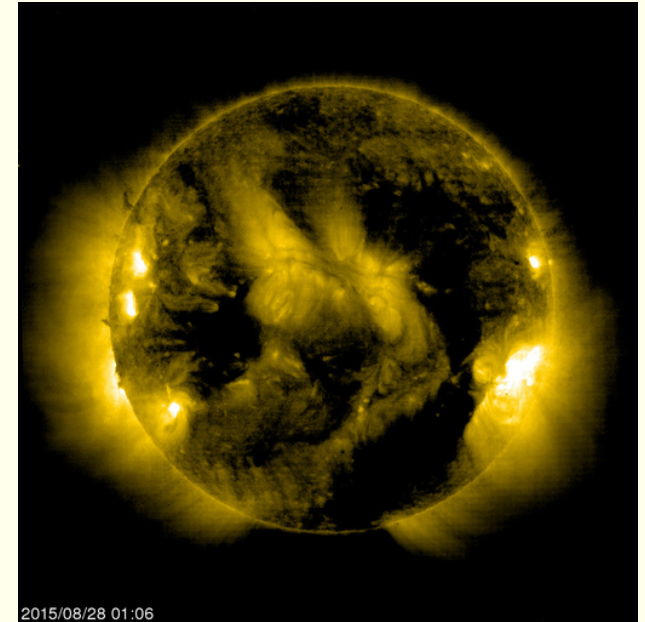
## SOHO observations



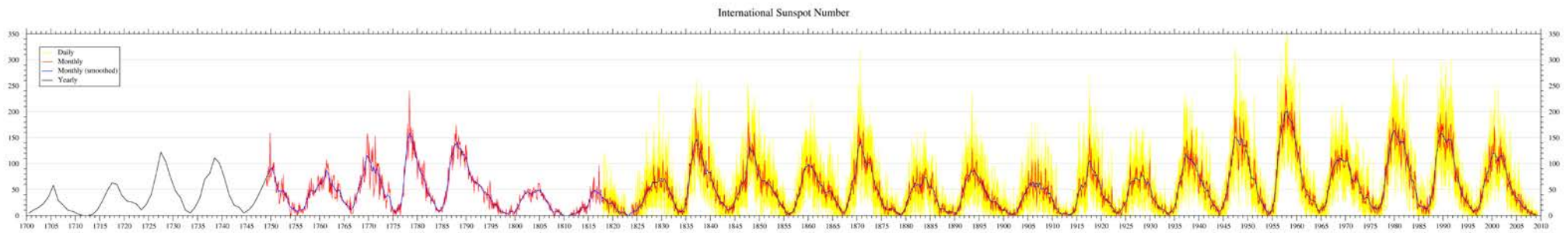
*Visible light*



*Magnetogram*

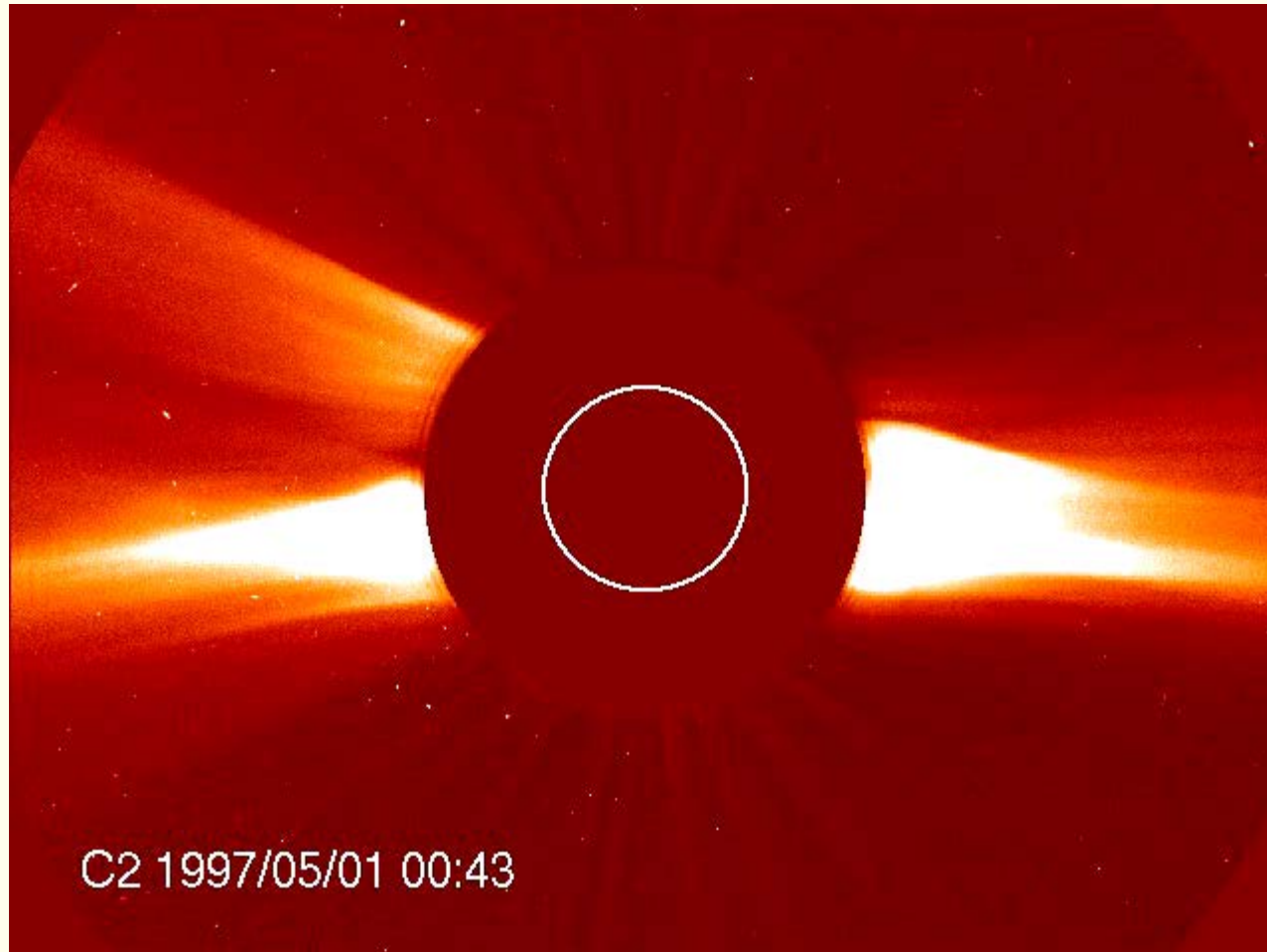


*SOHO EUV (284 Å)*



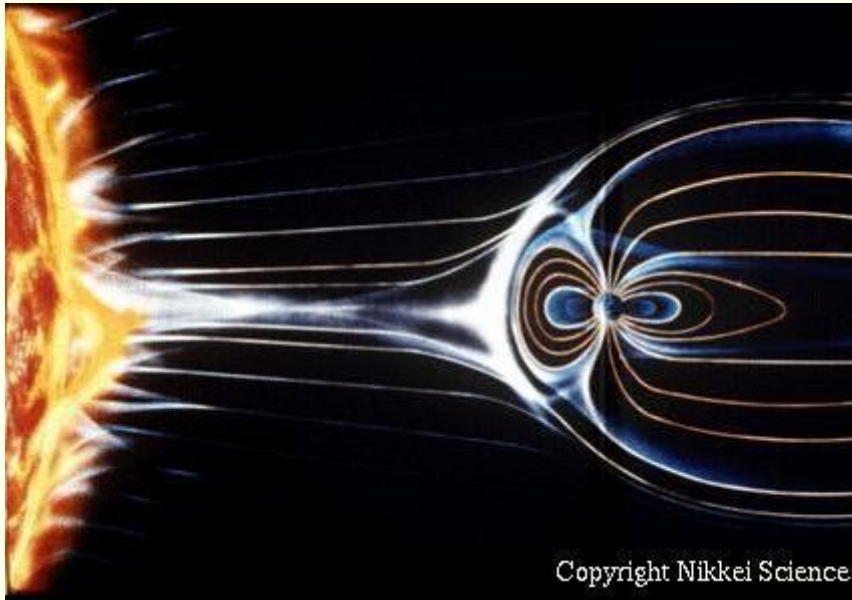


# The sun, solar wind

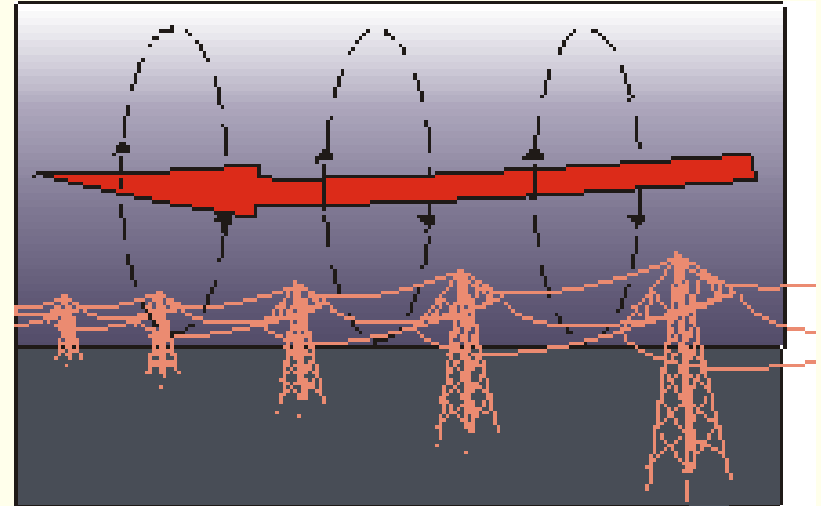


**Solar and Heliospheric Observatory (SOHO),  
*LASCO C2 Coronagraph Movie***

# Solar-terrestrial interaction

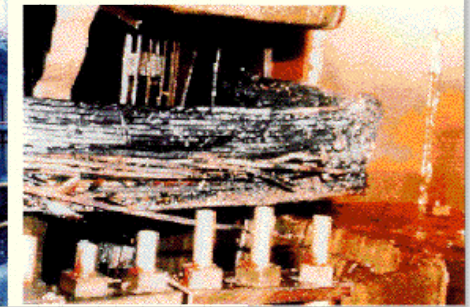


## Space weather: Geomagnetically induced currents (GIC)



PJM Public Service  
Step Up Transformer

Severe internal damage caused by  
the space storm of 13 March, 1989.

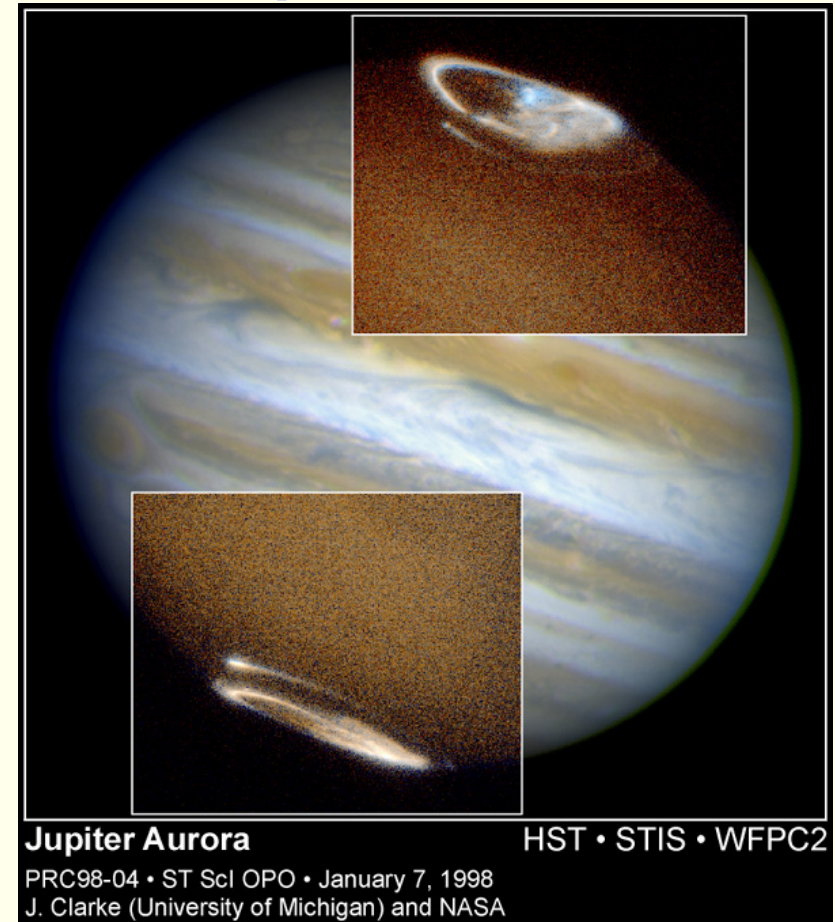




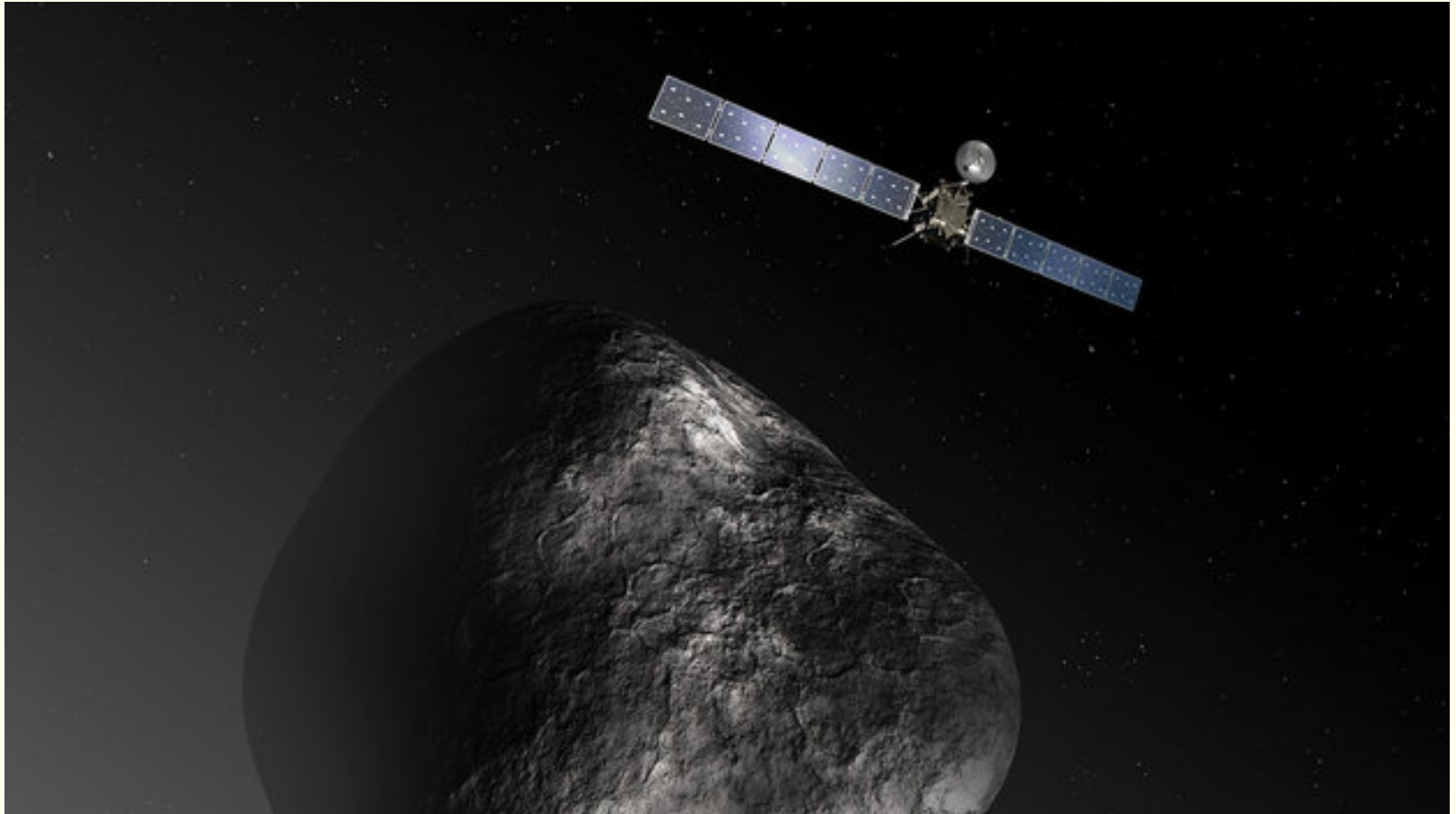
## Aurora on Earth



## Aurora on other planets



# The Rosetta mission to comet 67P/Churiumov-Gerasimenko

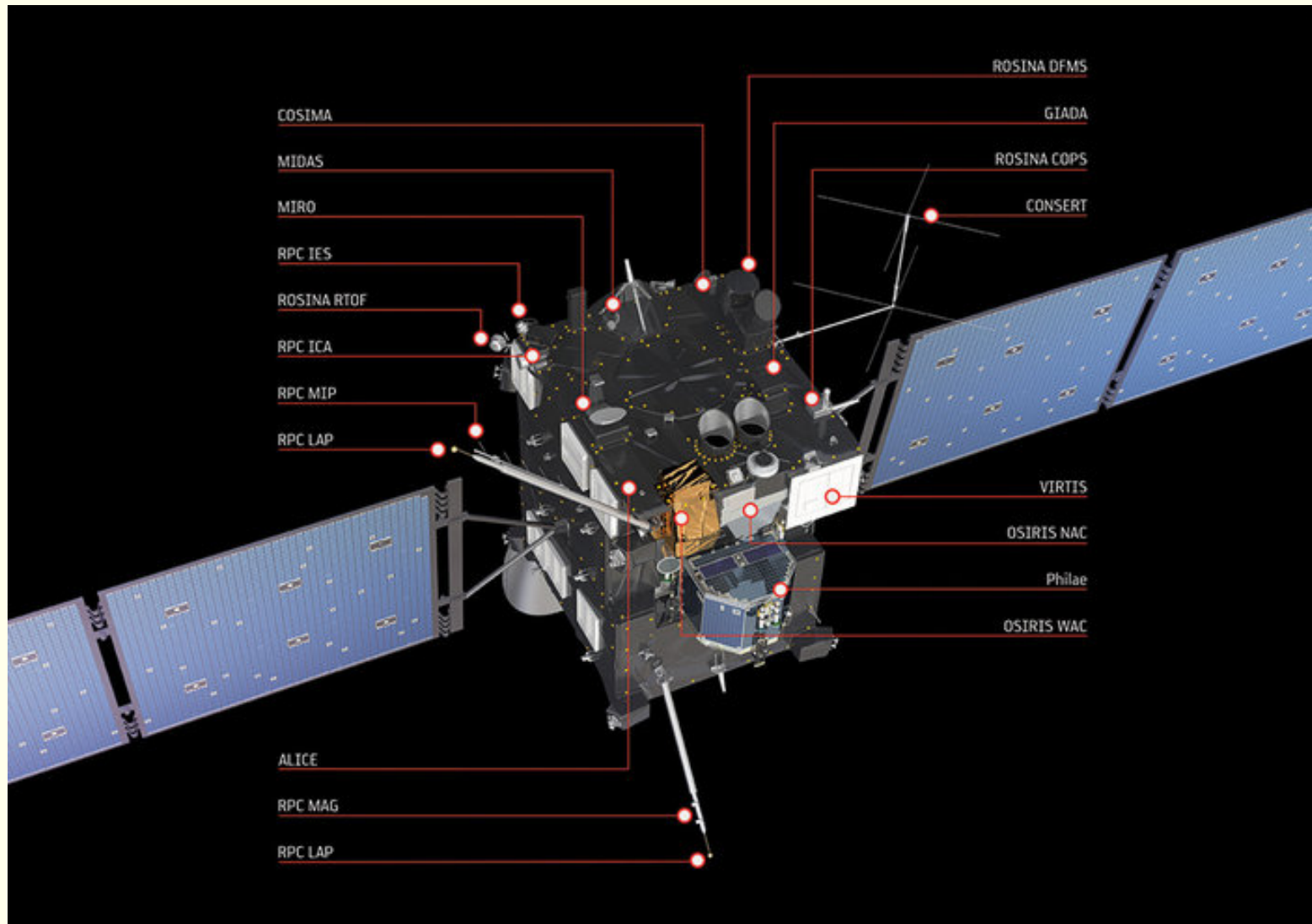




# *The Rosetta mission to comet 67P*



# The Rosetta mission to comet 67P



# The Rosetta mission to comet 67P





# The Rosetta mission to comet 67P



*3 August 2014*



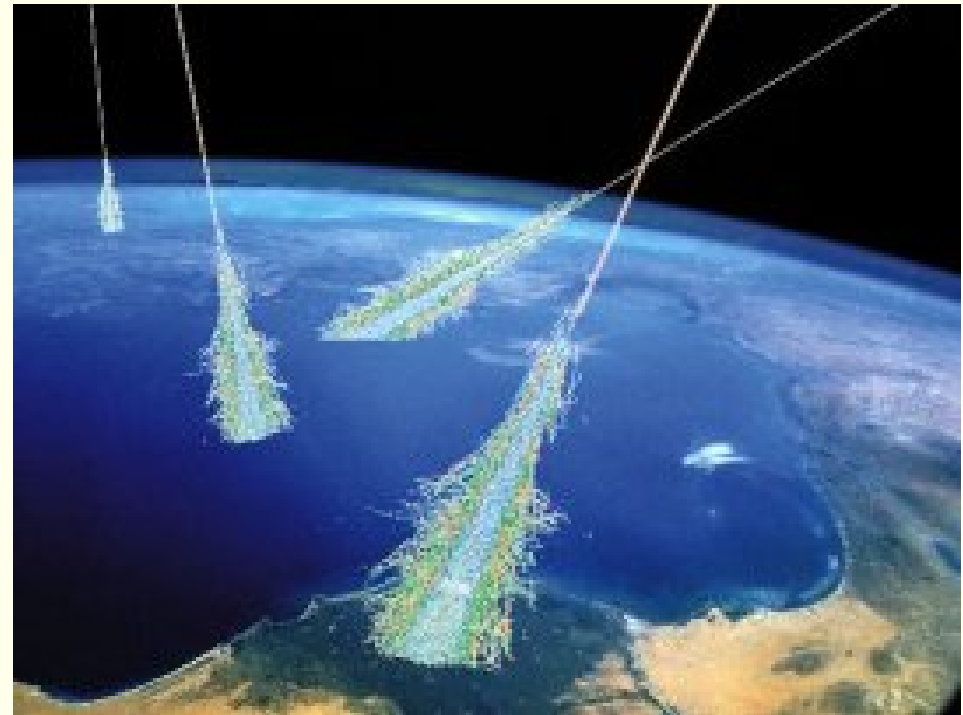
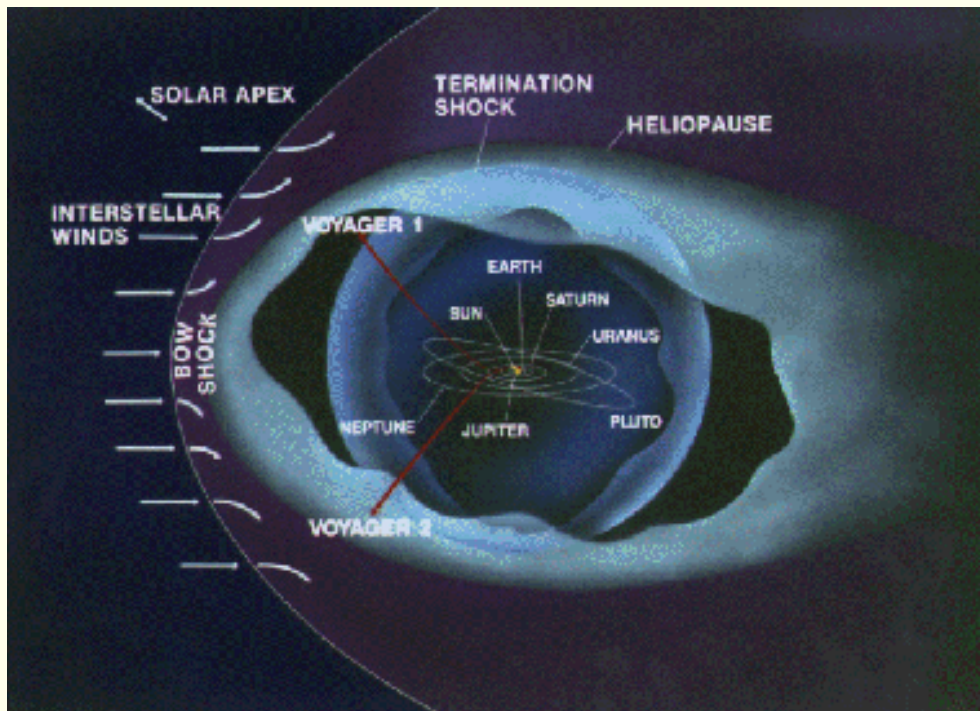
# The Rosetta mission to comet 67P

Landed Nov 12, 2014. In June, sporadic contact.



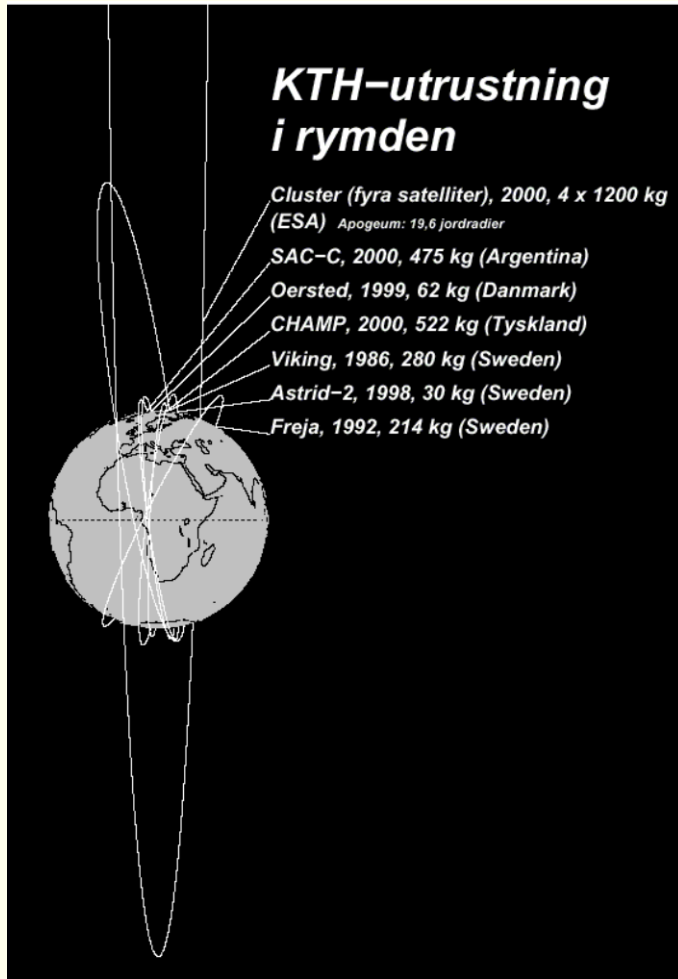
# Interstellar and intergalactic plasma

## Cosmic radiation

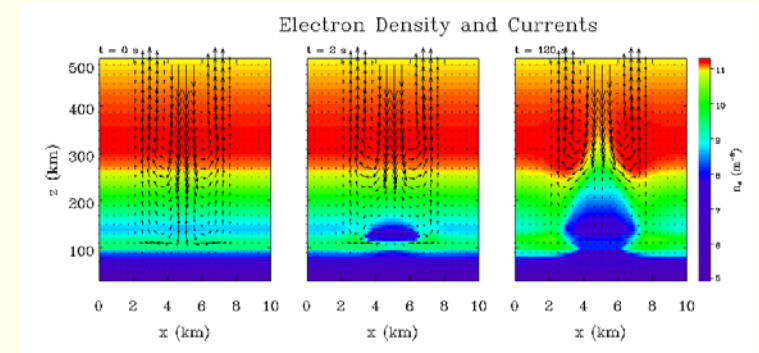




# Swedish and international space physics research



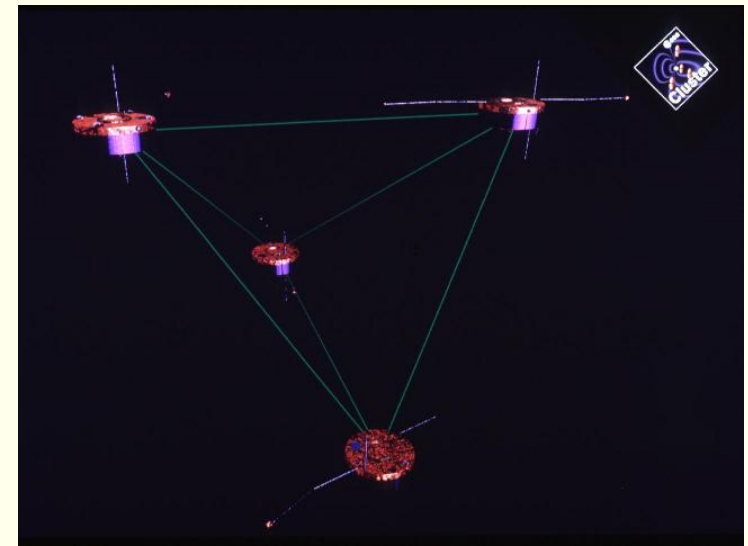
*Micro satellite Astrid-2*



*Simulations*



*Cassini & Huygens at Saturn*



*Cluster satellites*



# Schedule

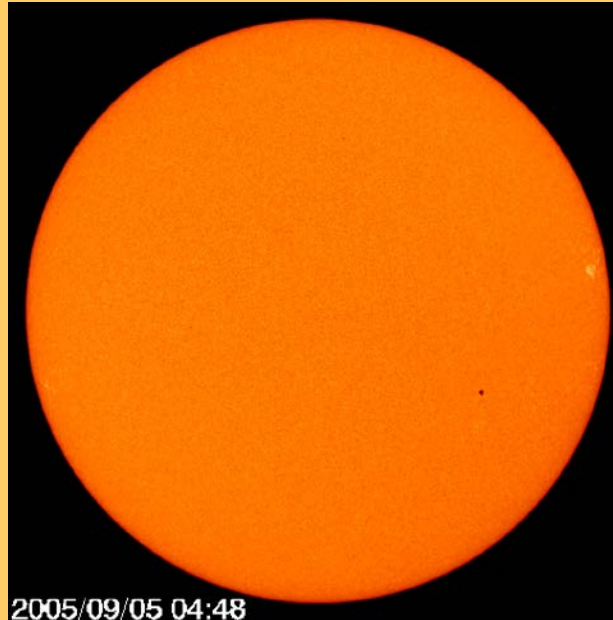
10×2 h Lectures

6×2 h Tutorials

L = Lecture, T = Tutorial

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L2	3/9	15-17	Q36	The Sun 2, Plasma physics 2	CGF Ch 5 (p 114-121), 6.3
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L5	17/9	15-17	L52	The Earth's magnetosphere 1, Plasma physics 5	CGF 4.1-4.3, LL Ch I, II, IV.A
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Written examination	28/10	8-13	Q21, Q26		

# Think about this:



The temperature of the solar surface is approximately 6000 K.

How can we know that ???

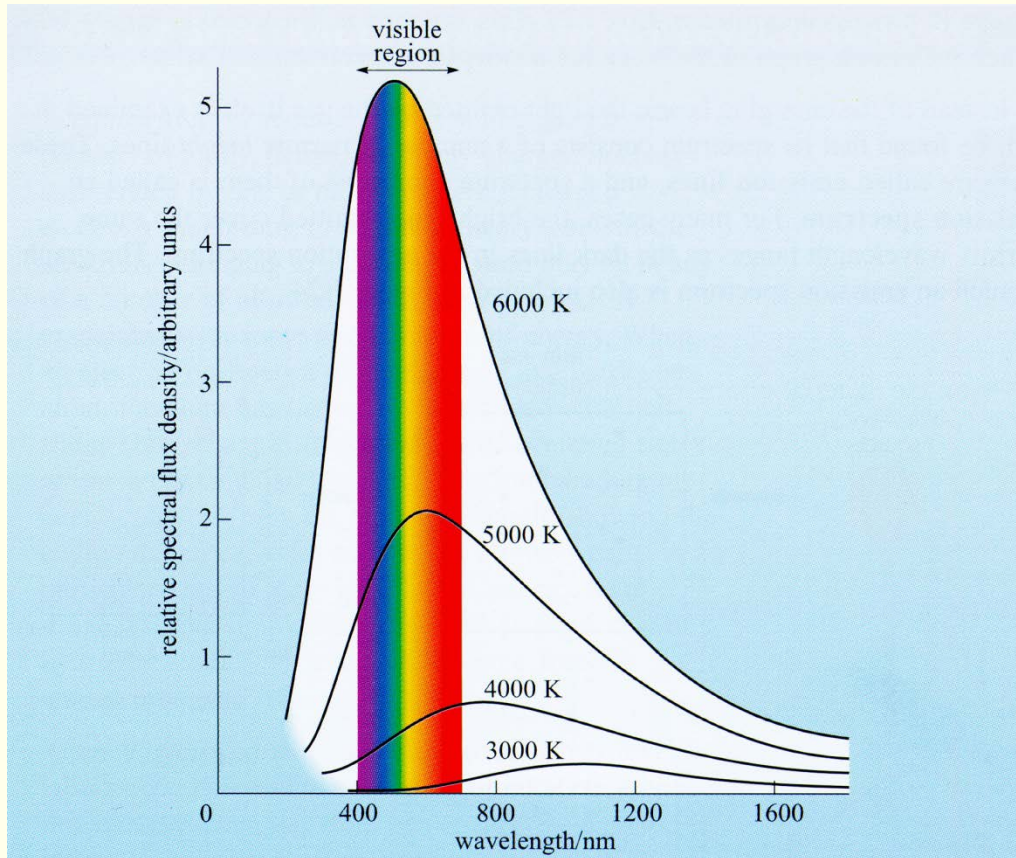


Hot steel emitting red light.



Chart to estimate steel temperature in steelworks.

# Black-body radiation



*Black-body good approximation for opaque bodies where emitted light is much more likely to interact with the material of the source than to escape.*

Wien's displacement law

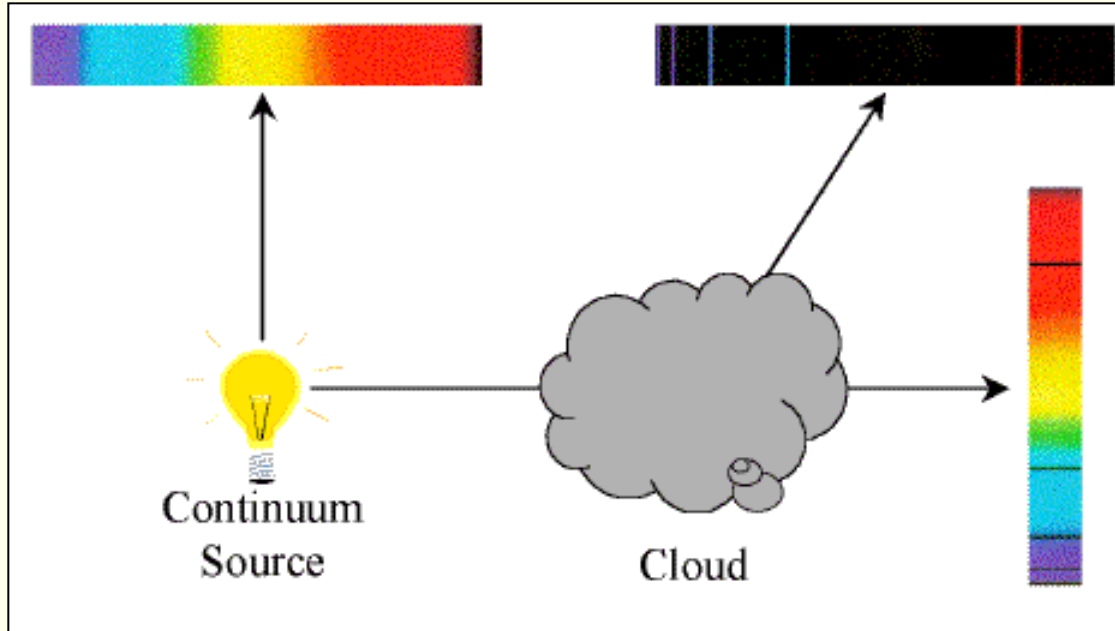
$$\lambda_{peak} = \frac{2.90 \times 10^{-3} \text{ m} \cdot \text{K}}{T}$$

Stefan-Bolzmans law

$$J = \sigma_{SB} T^4$$

(J = total energy radiated per unit area per unit time )

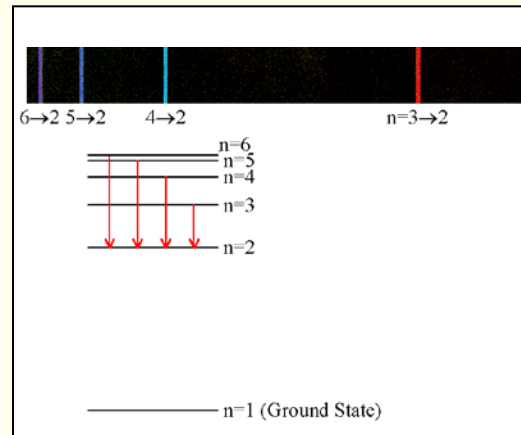




*For non-blackbody thermal light emitter (for example a thin gas) it is more complicated. Spectrum depends on e.g. chemical composition, and how many atoms/molecules happen to be in state with high probability to decay and cause emission.*

## Black-body radiation

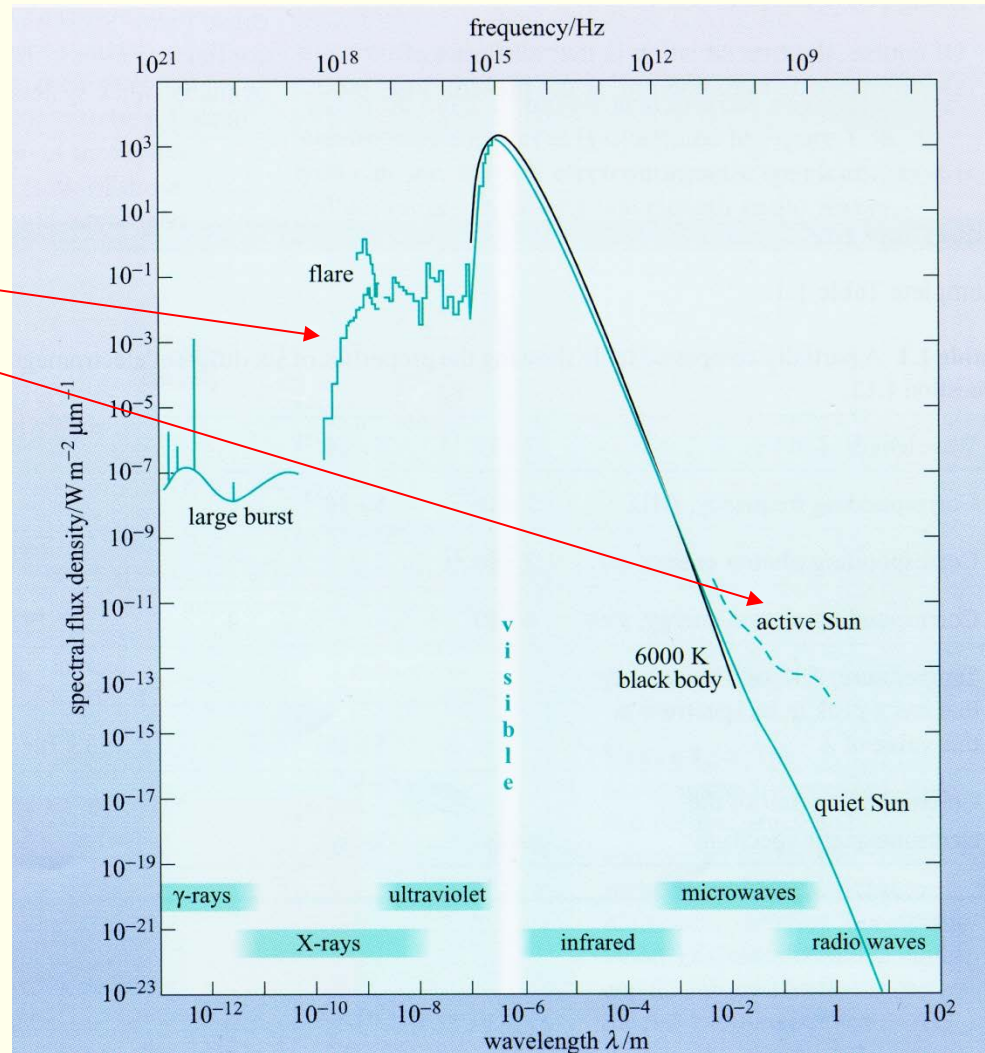
$$\lambda_{peak} = \frac{2.90 \times 10^{-3}}{T}$$

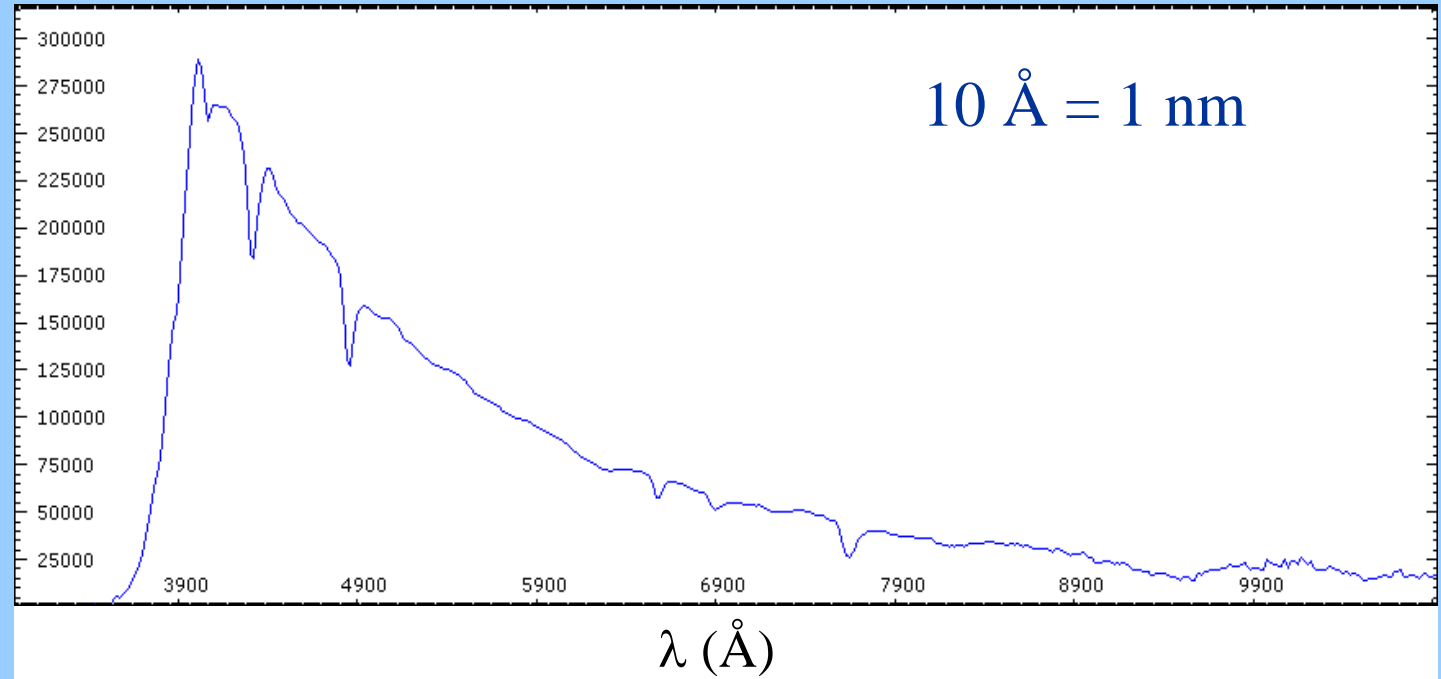


Atomic energy levels

# The solar spectrum

Non-blackbody  
contributions





$T = 9300 \text{ K}$



# Estimate the temperature of the star *Gamma Geminorum A0iv* !

Wien's displacement law

$$\lambda_{peak} = \frac{2.90 \times 10^{-3}}{T}$$

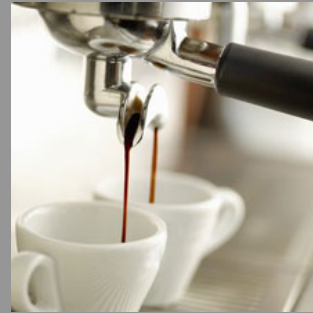


$$T = \frac{2.90 \times 10^{-3}}{\lambda_{peak}} \approx \frac{2.90 \times 10^{-3}}{400 \times 10^{-9}} \text{ K} \approx 7250 \text{ K}$$

Green

T = 7200 K

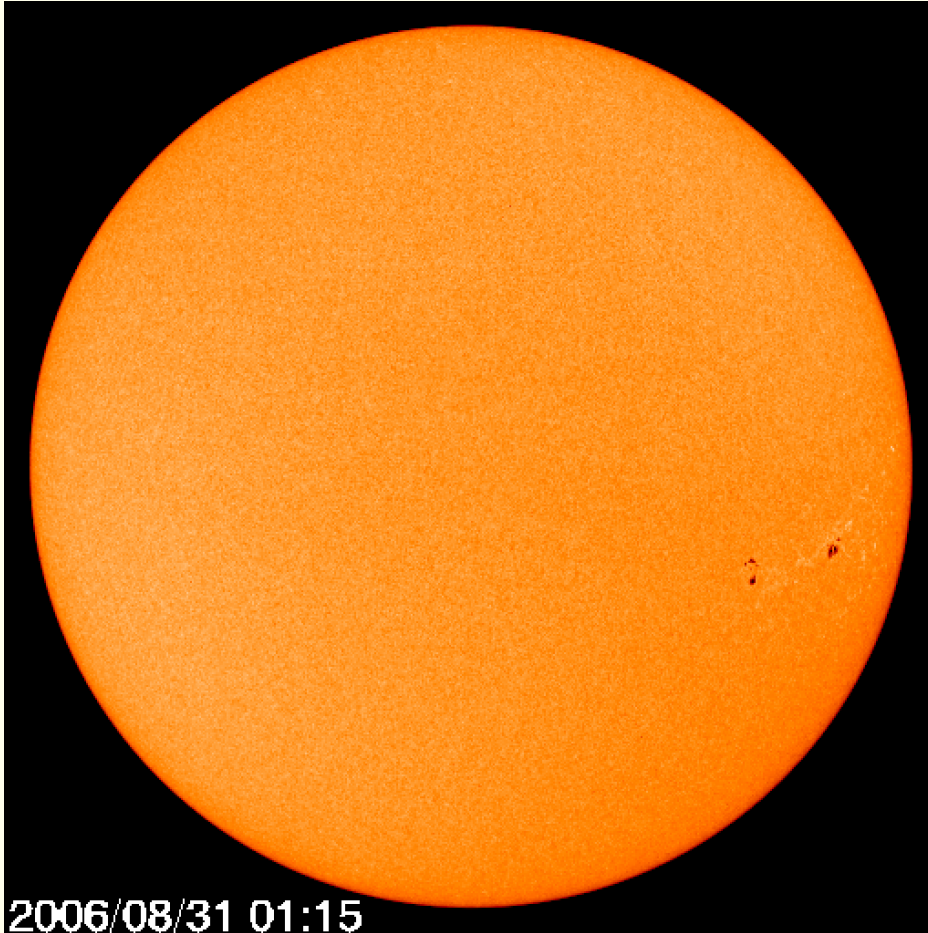
# BREAK!



## But think about this:

How can we know anything about the solar interior?

# The Sun



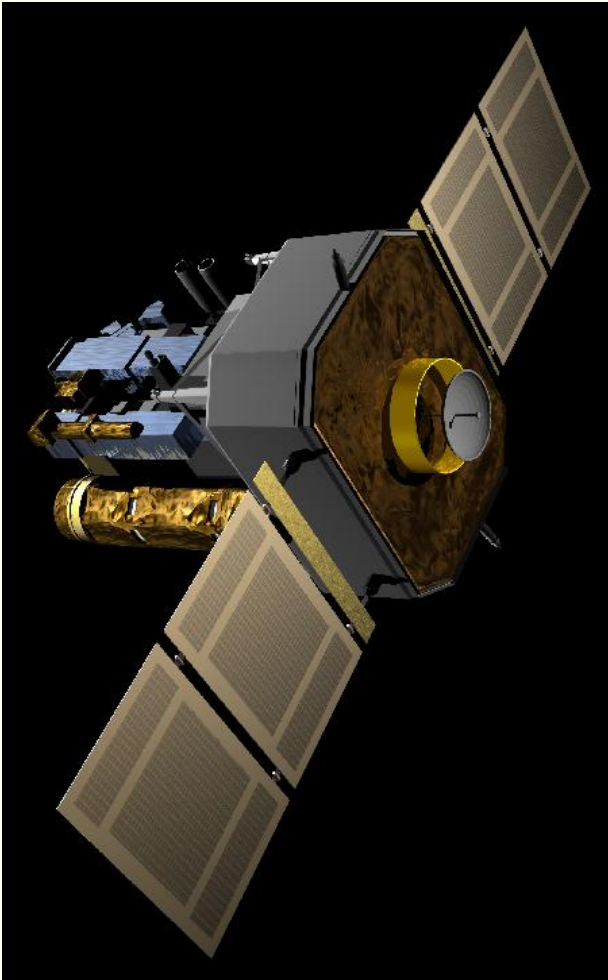
*SOHO Michelson Doppler Imager  
(MDI) 6767 Å continuum images from  
Stanford University*

## Basic facts

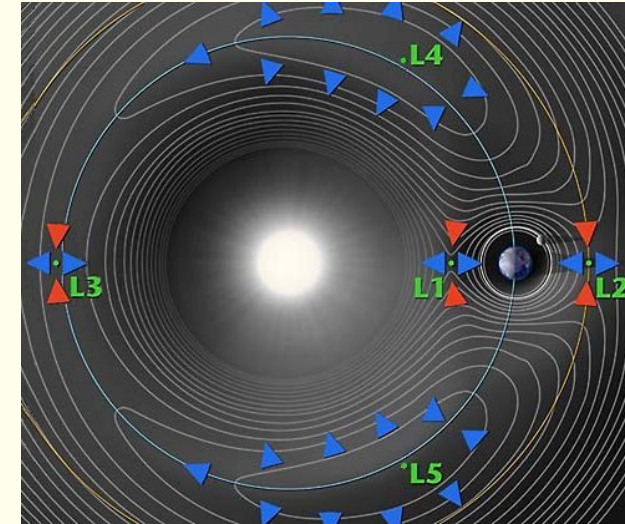
- *diameter:  $1.39 \cdot 10^9 \text{ m} \approx 109 d_E$*
- *mass:  $2 \cdot 10^{30} \text{ kg} \approx 333\,000 m_E$*
- *density:  $1.4 \text{ kg/dm}^3$*
- *radiated effect:  $4 \cdot 10^{26} \text{ W}$*
- *age:  $4.5 \cdot 10^9 \text{ years}$*

# SOHO spacecraft

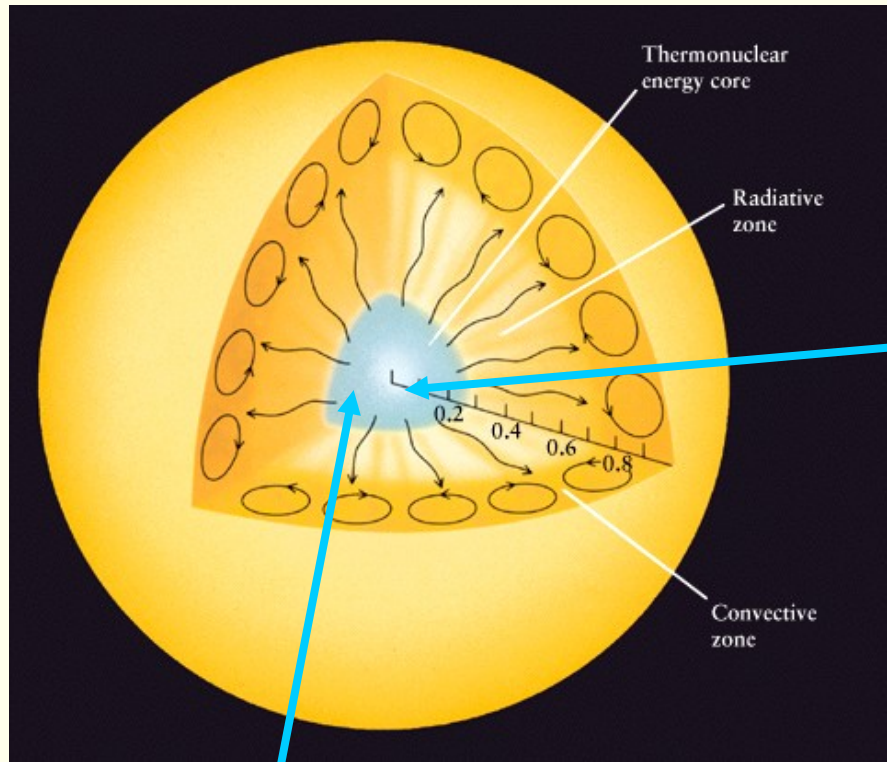
## SOLar and Heliospheric Observatory



- Launched 1995
- Orbiting L1
- Collaboration between ESA and NASA
- 12 instruments, including imagers and particle detectors



# Sun's interior

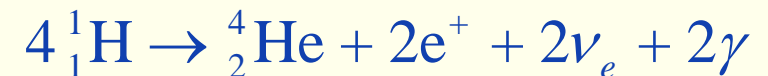
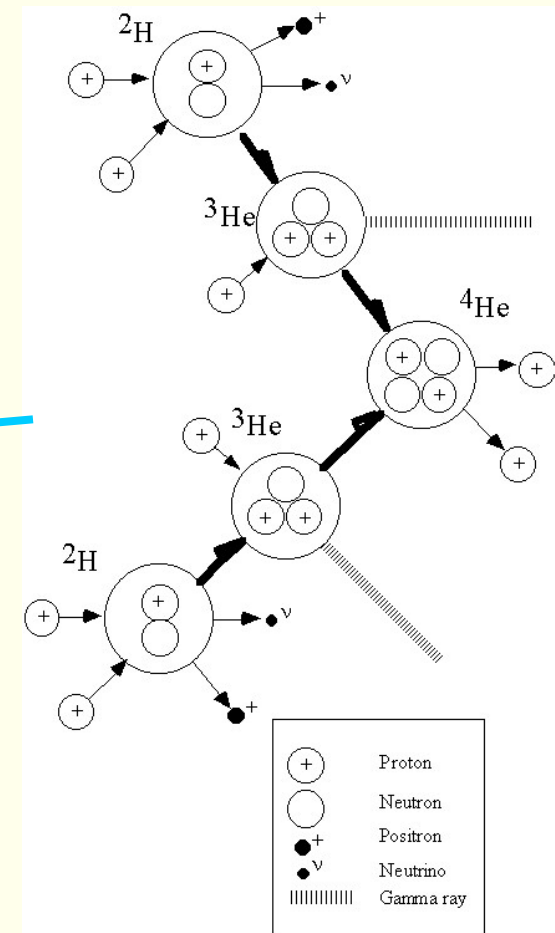


$$T = 15 \cdot 10^6 \text{ K}$$

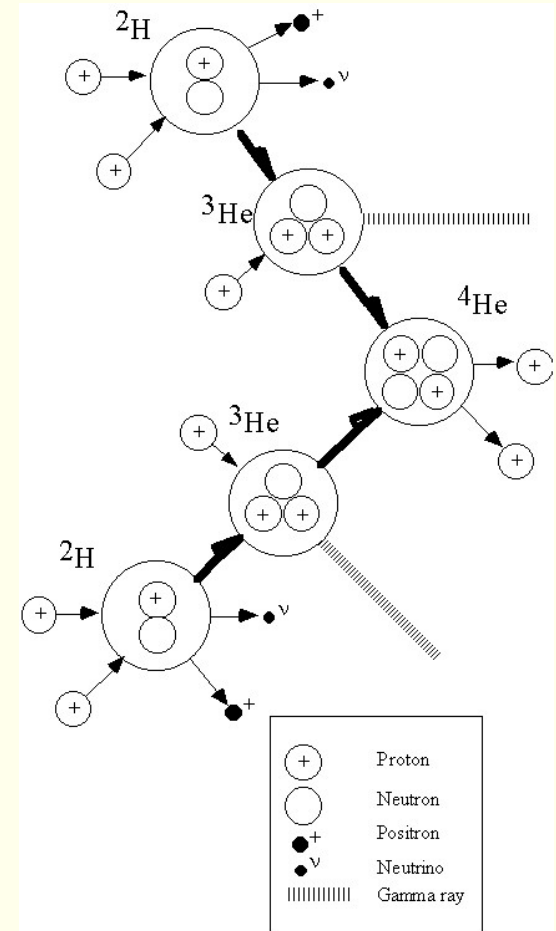
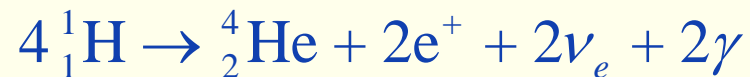
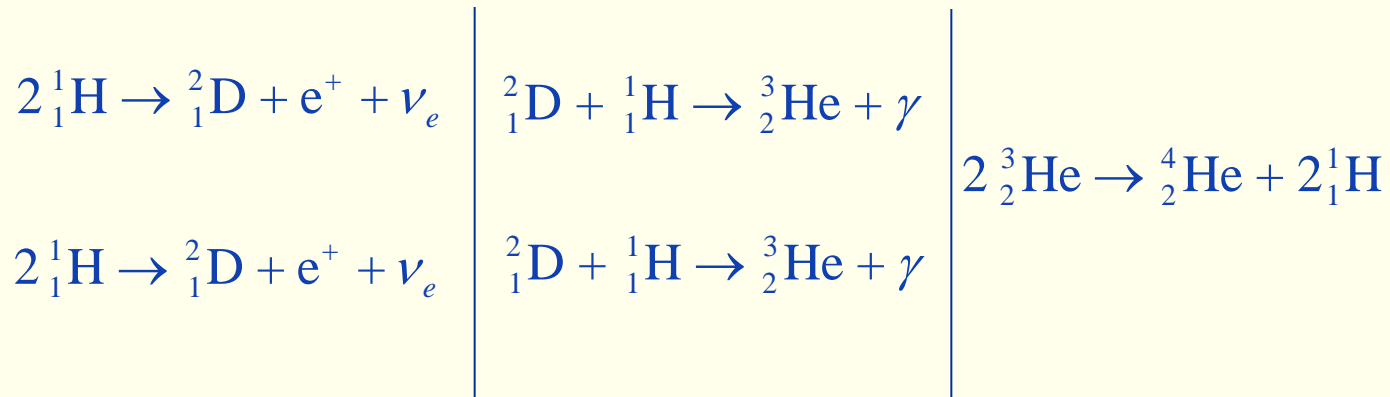
$$P = 4 \cdot 10^{26} \text{ W}$$

$$(P/m \sim 1 \text{ mW/kg})$$

## The proton cycle

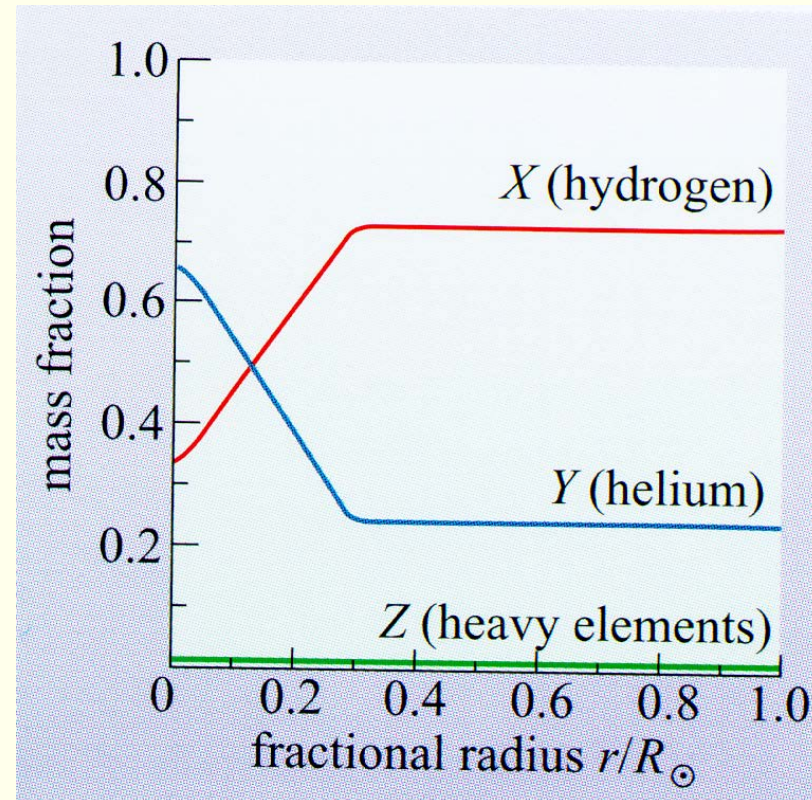
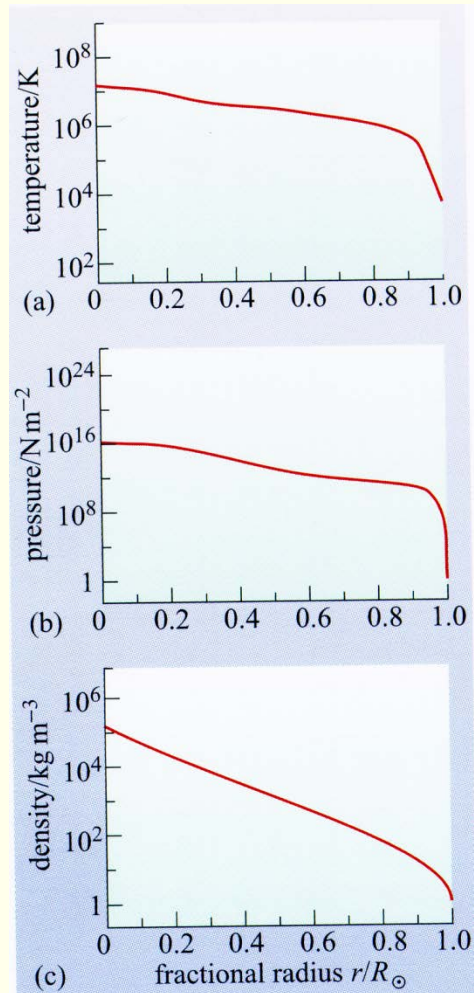


# Proton cycle

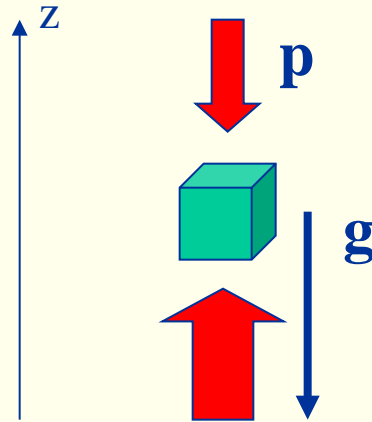




# Sun's interior



# Atmospheric scale height



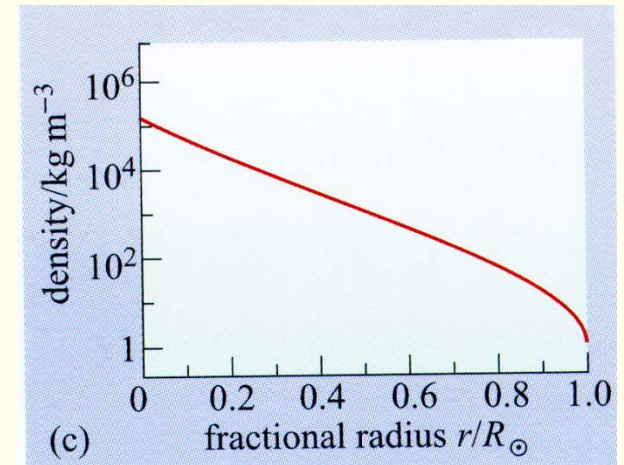
$$-\frac{dp}{dz} = g\rho \quad \text{hydrostatic equilibrium for a volume element}$$

$$p = nk_B T = \frac{\rho k_B T}{m} \quad \text{ideal gas law}$$

$$-\frac{k_B T}{m} \frac{d\rho}{dz} = g\rho \quad \text{if } T \text{ is constant}$$

$$\rho = \text{const} \cdot e^{-z/(k_B T / gm)} = \text{const} \cdot e^{-z/H}$$

$$\log \rho = \text{const} - \frac{z}{H}$$

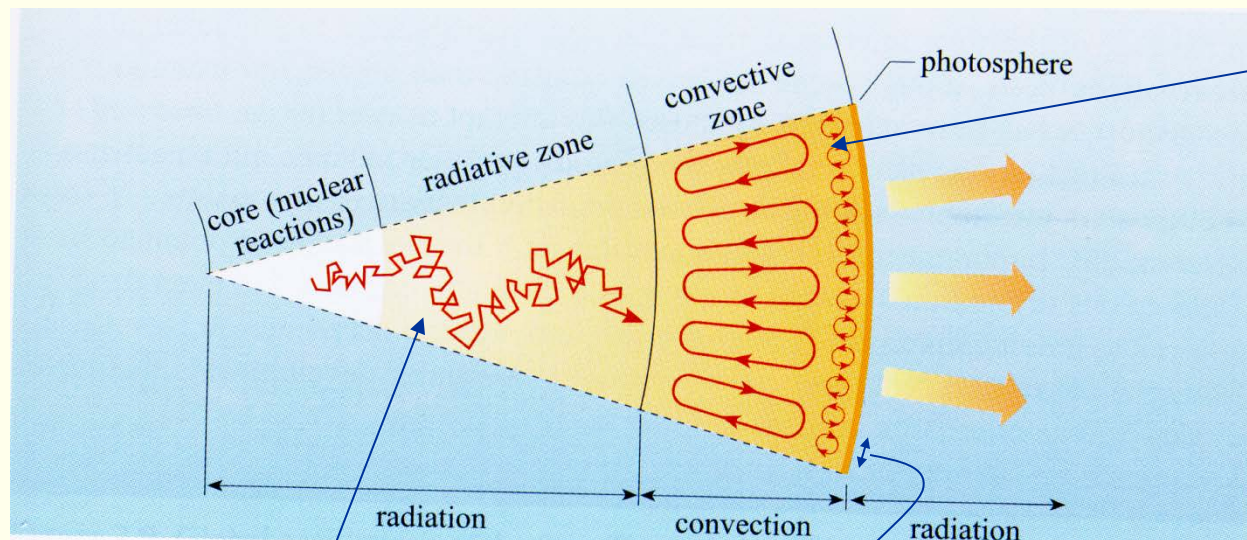


**Scale height**

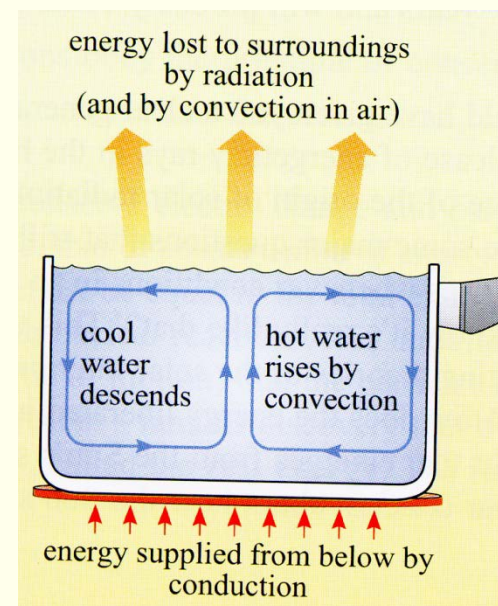
$$H = k_B T / gm$$



# Energy transport in the sun



Transport by convection



Transport by radiation, which interacts with the dense solar matter (scattering and absorption/re-emission).

**It takes on average 200 000 years for a photon to reach the photosphere!**

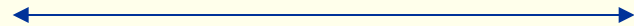
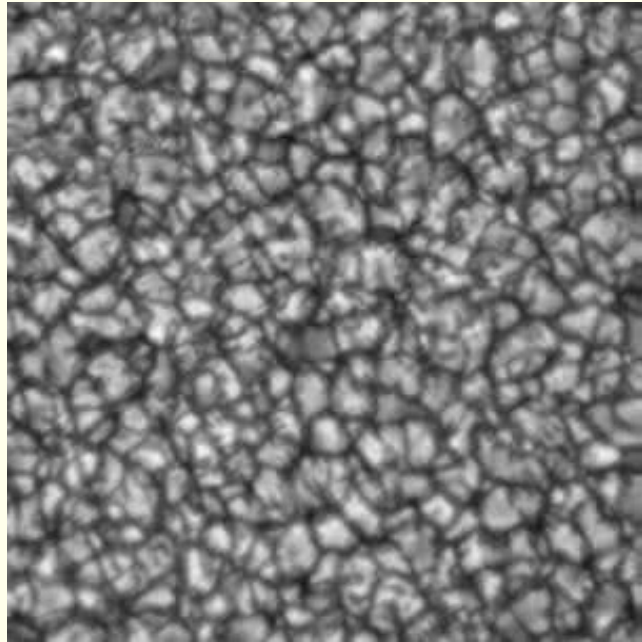
~1000 km

These convection cells are called *granulation*.

At the photosphere the mean free path of the photons becomes so large that they can reach directly out into space.

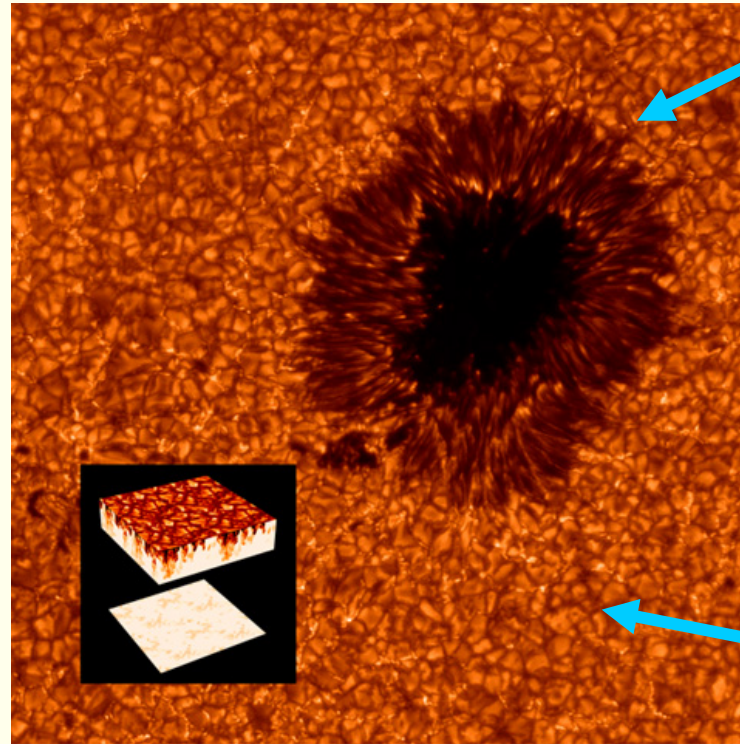
# Granulation in photosphere

$t = 35 \text{ min}$



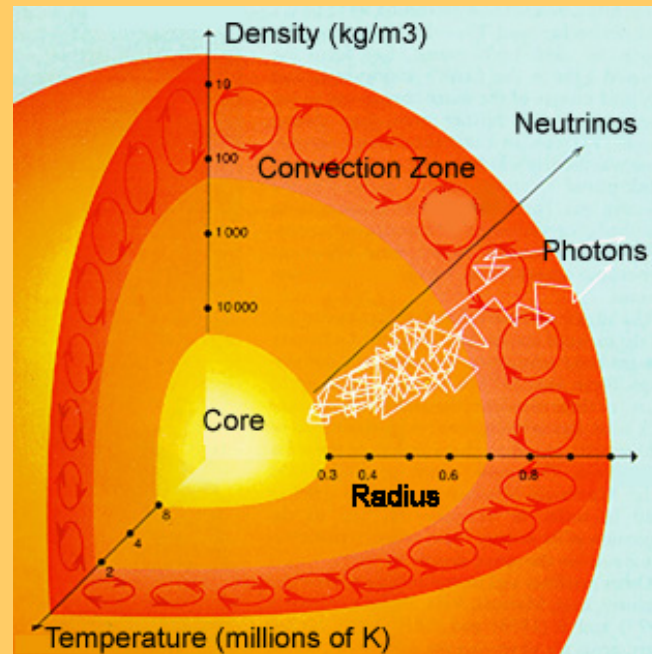
$\sim 27\,000 \text{ km}$

Life time  $\sim 10 \text{ min}$



$1000 - 50\,000 \text{ km}$

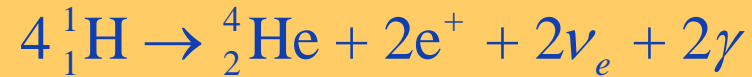
$300 - 2000 \text{ km}$



**So how can we know all these details about the solar interior?**



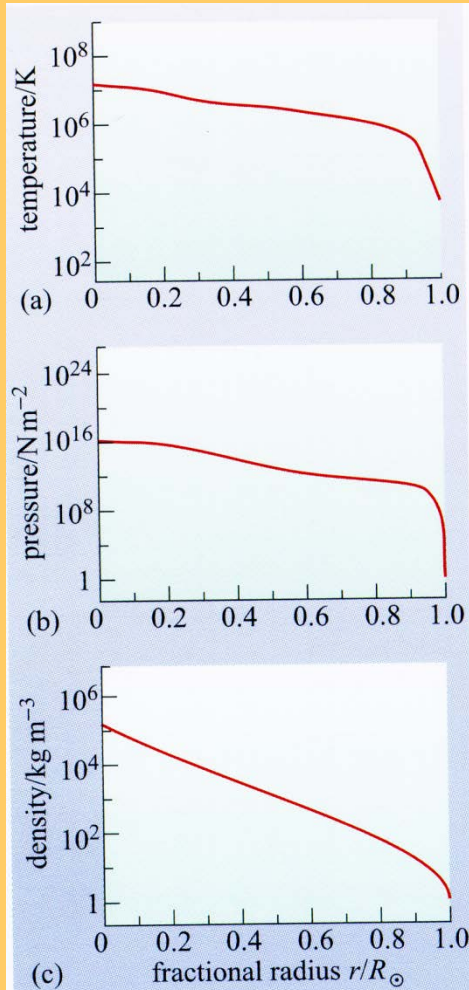
# 1. Solar models



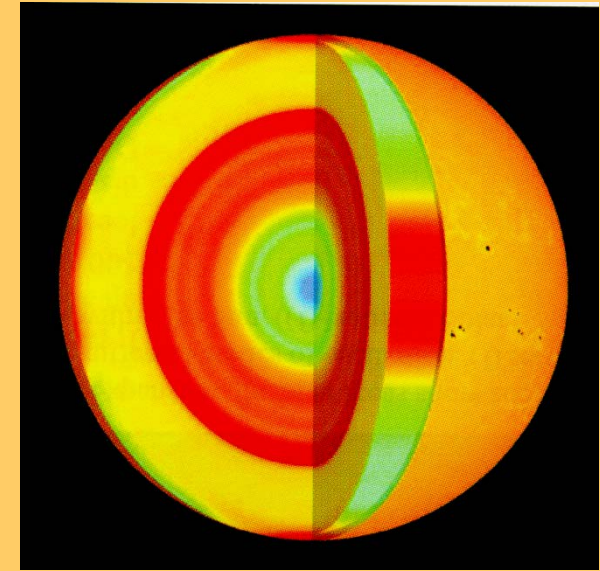
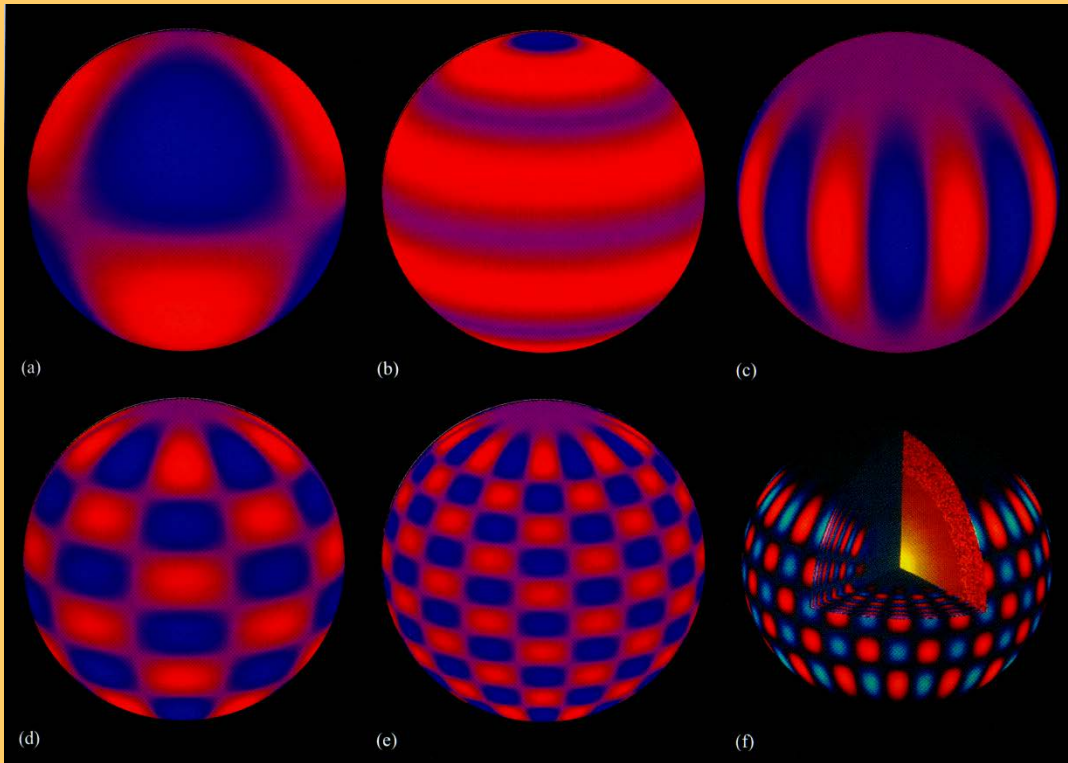
Models of nuclear reactions etc are tuned to *boundary conditions*.

These are e.g.

- *sun's radius  $R$*
- *total mass  $M$*
- *luminosity,  $L$ ,*
- *surface temperature  $T$ ,*
- *chemical composition etc.*



## 2. Helioseismology

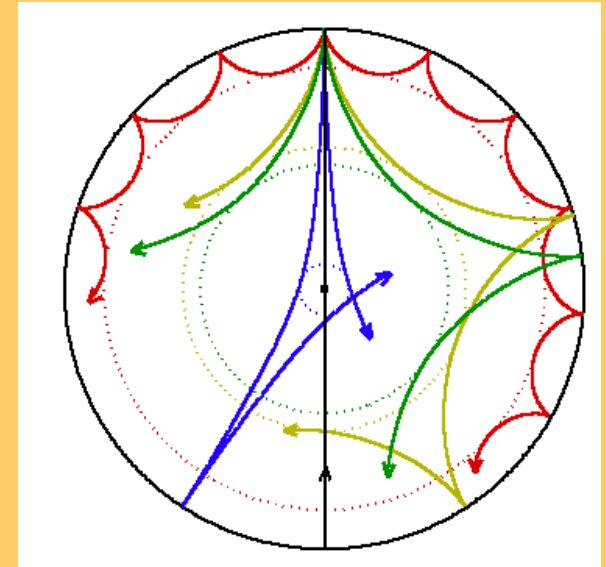
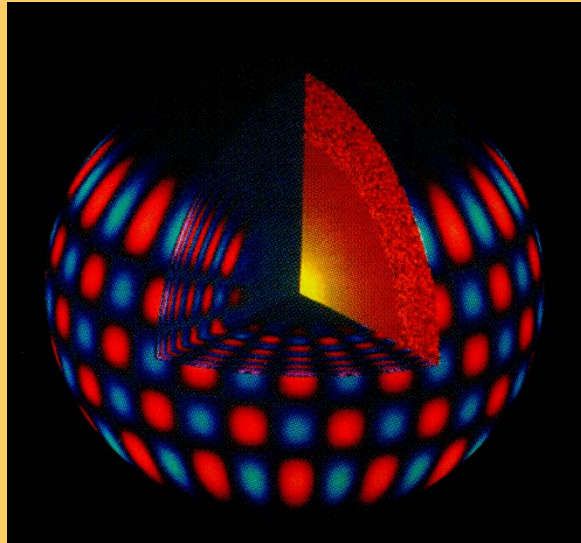
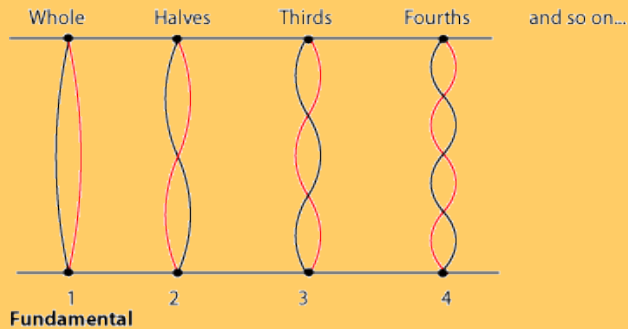


*Sound speed.*

Pressure waves ("sound waves") on the solar surface can give information of e.g. sound speed in solar interior, which depends on temperature and density.

# Helioseismology

## String



Fundamental:  $\lambda = 2L$

$$\lambda f = c_s$$

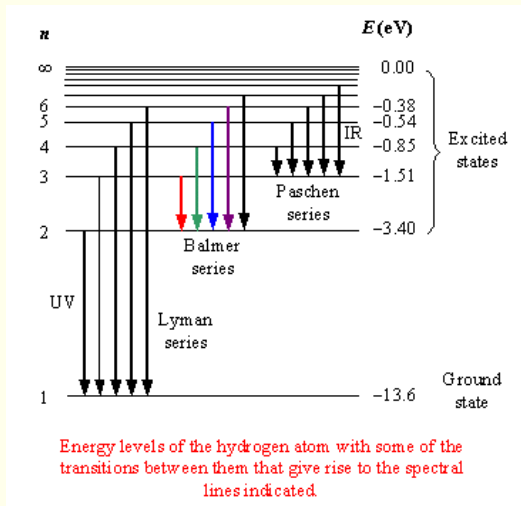
$$c_s = 2fL$$

$$c_s = \sqrt{\frac{5p}{3\rho}}$$

# Solar atmosphere

## Chromosphere

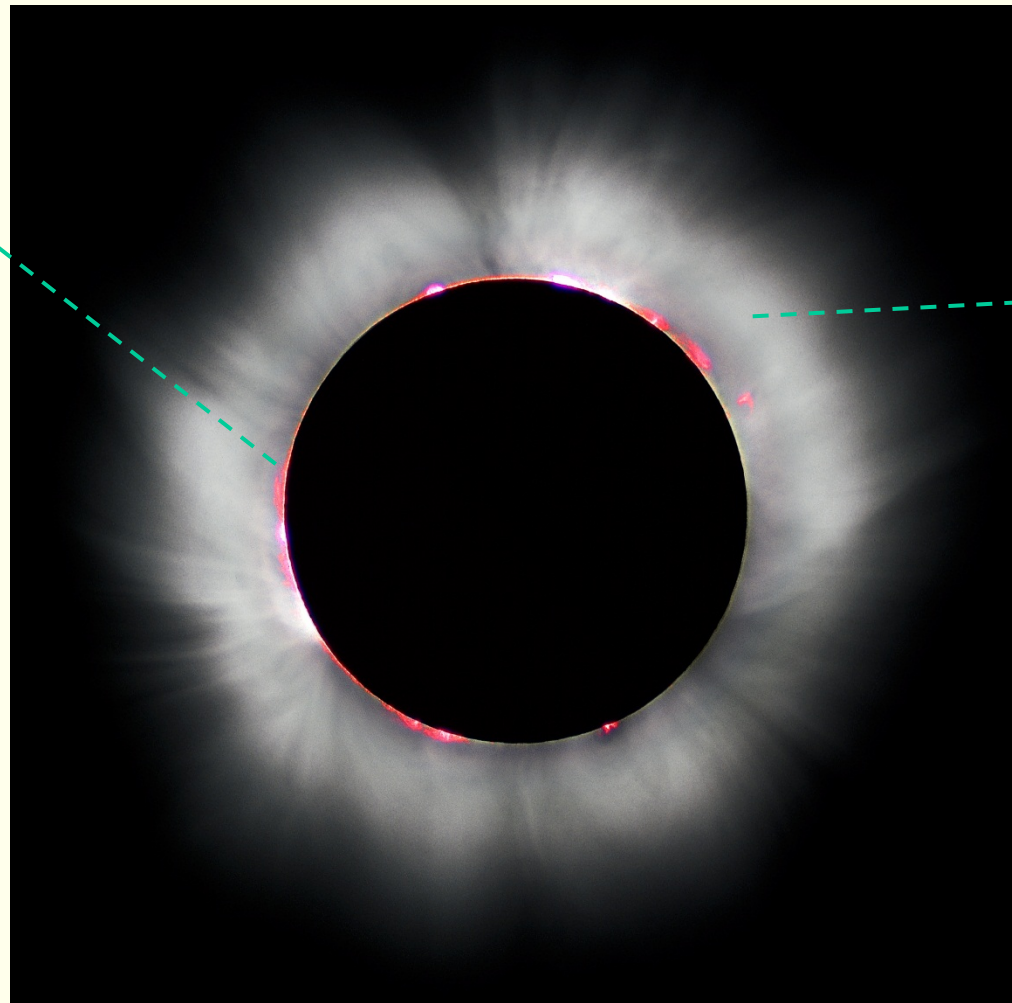
*Reddish colour due to  $H\alpha$  emissions.*



$H\gamma$  434 nm  $H\beta$  486 nm

$H\alpha$  656 nm

*Balmer series*

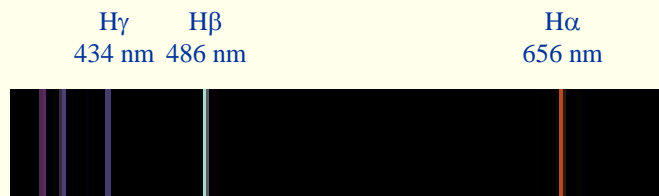
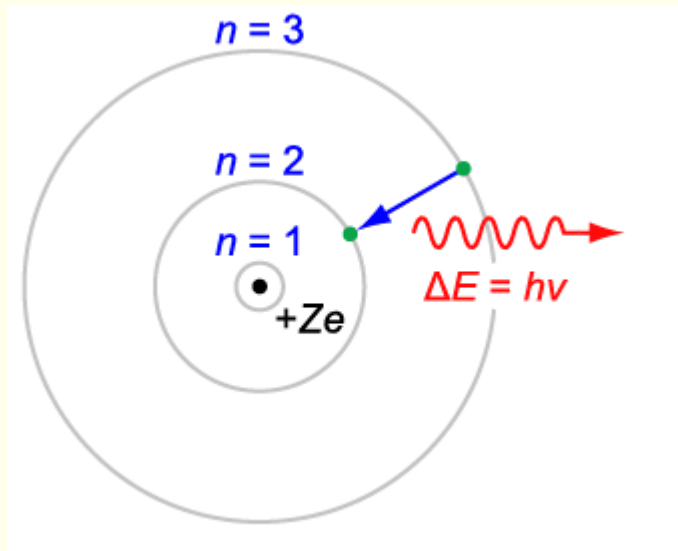


## Corona

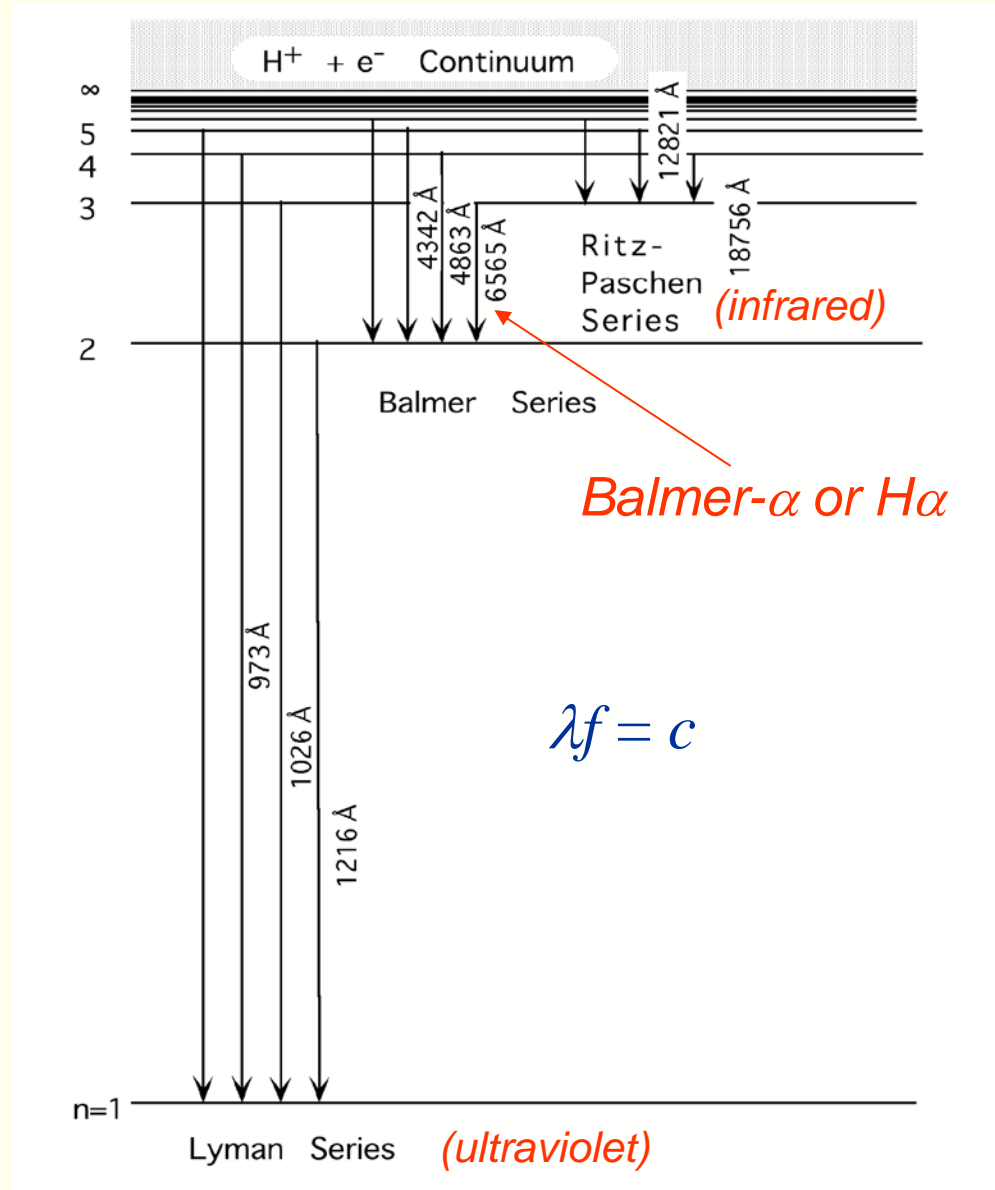
*White light scattered from photosphere*

*Total solar eclips*

# Hydrogen atom



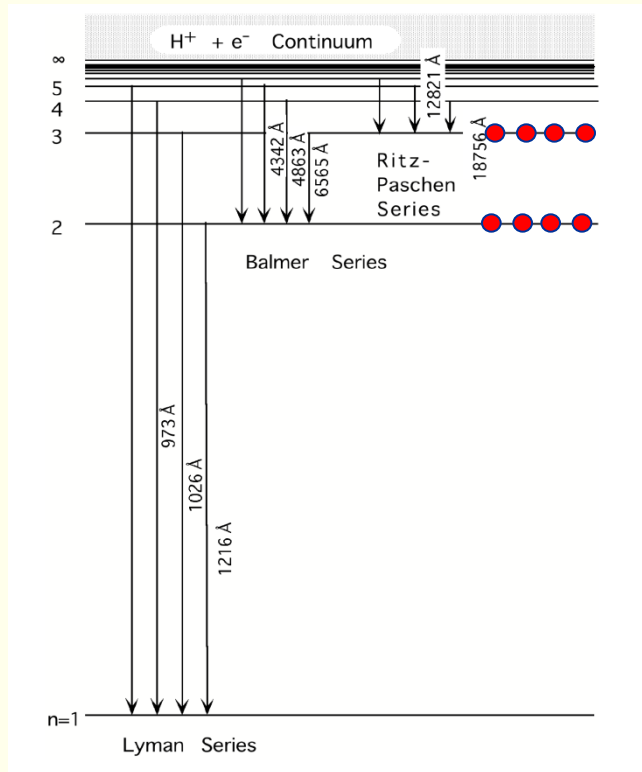
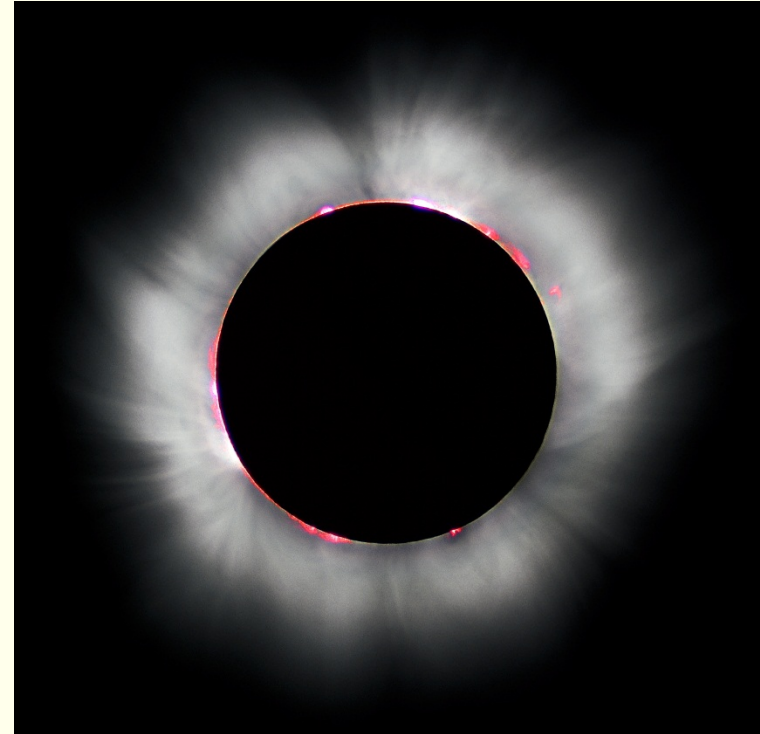
*Balmer series*





# Why is the chromosphere red?

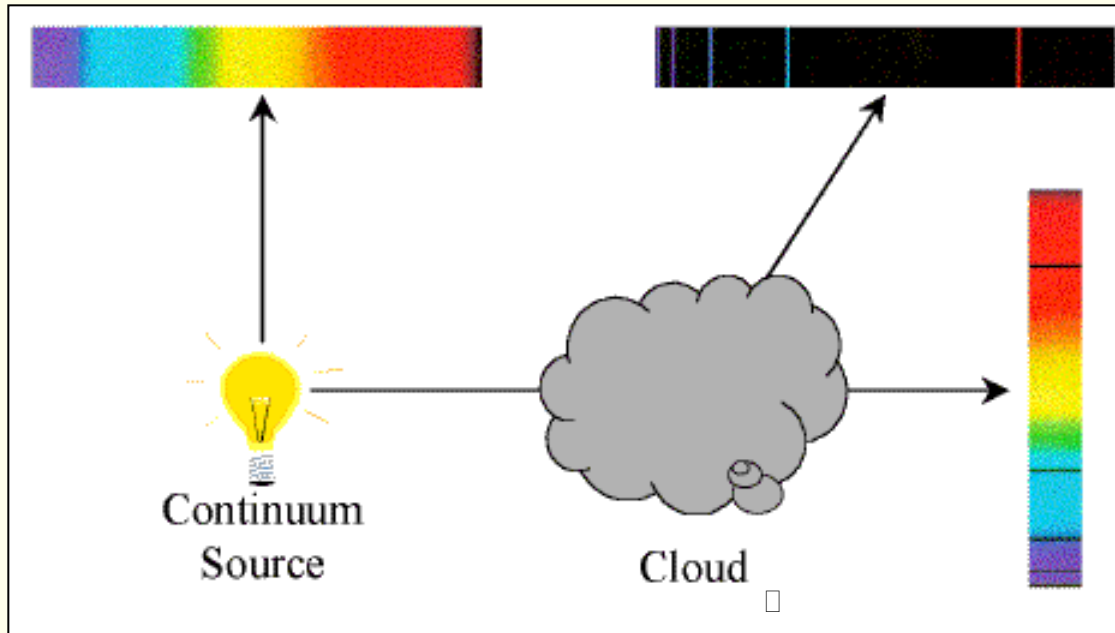
# Hydrogen spectrum


$$\begin{matrix} T_2 \\ T_1 \end{matrix}$$


H $\gamma$	H $\beta$
434 nm	486 nm

H $\alpha$   
656 nm



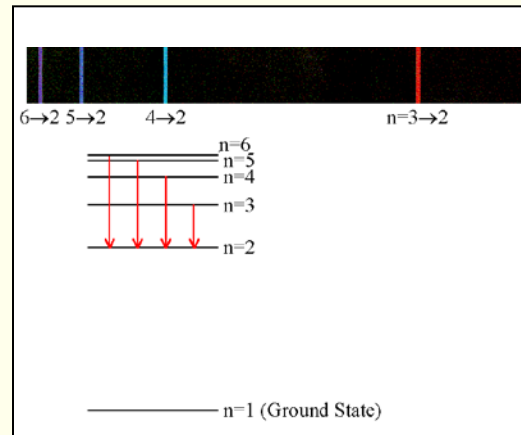


For non-blackbody thermal light emitter (for example a thin gas) it is more complicated. Spectrum depends e.g. chemical composition, and how many atoms/molecules happen to be in state with high probability to decay and cause emission.

Energy (and wavelength) of emitted quantum can still be approximated:

## Black-body radiation

$$\lambda_{peak} = \frac{2.90 \times 10^{-3}}{T}$$



Atomic energy levels

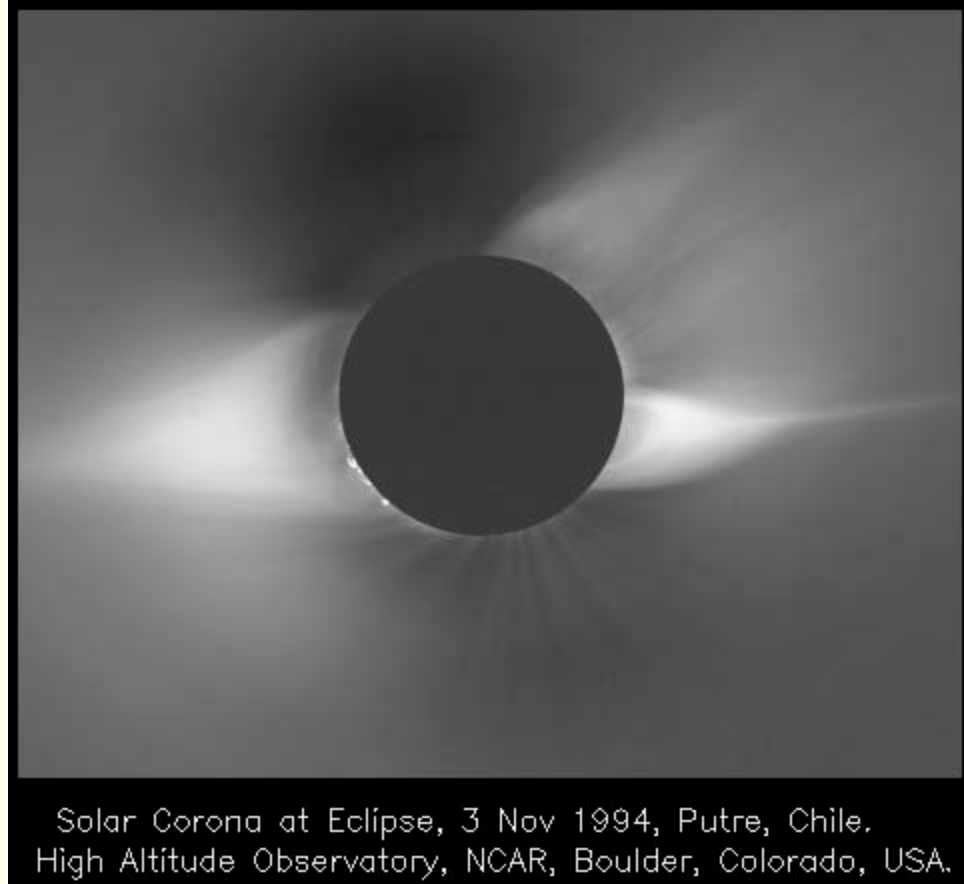
$$E \sim k_B T$$

$$E = hf$$

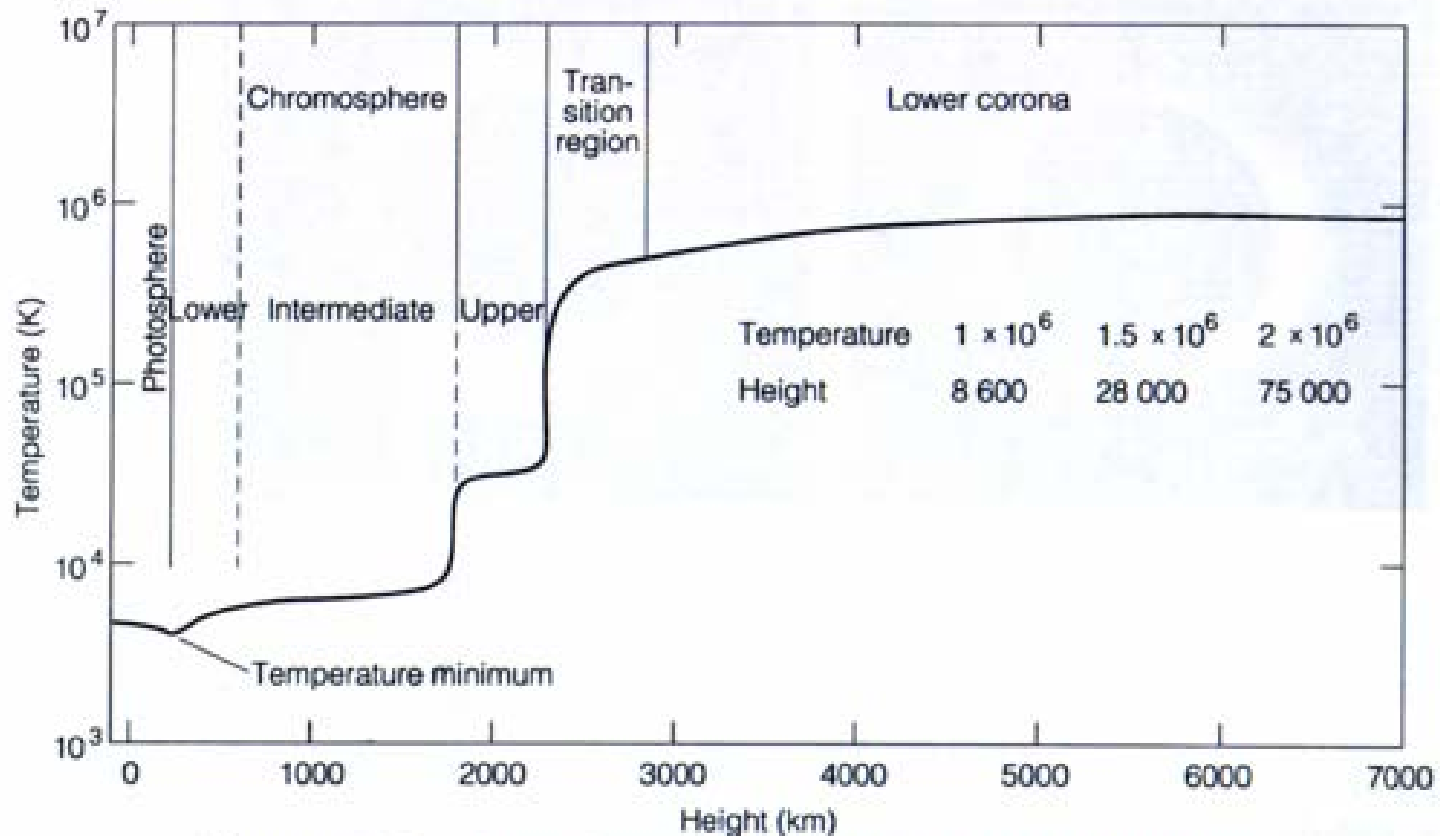
$$\lambda \sim \frac{hc}{k_B T}$$

# Corona

- Temperature: up to 2 MK
- Density:  $10^{-18}$  g/cm<sup>3</sup>  
–  $10^{-24}$  g/cm<sup>3</sup>
- Turns into the solar wind at high altitudes, without a sharp boundary.

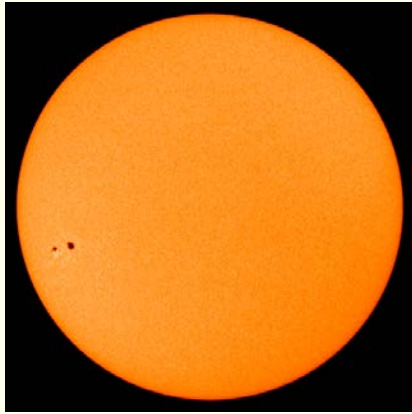


# The layers of the solar atmosphere



**Figure 5.3.** Distribution of average temperature in the solar atmosphere (Athay 1976).

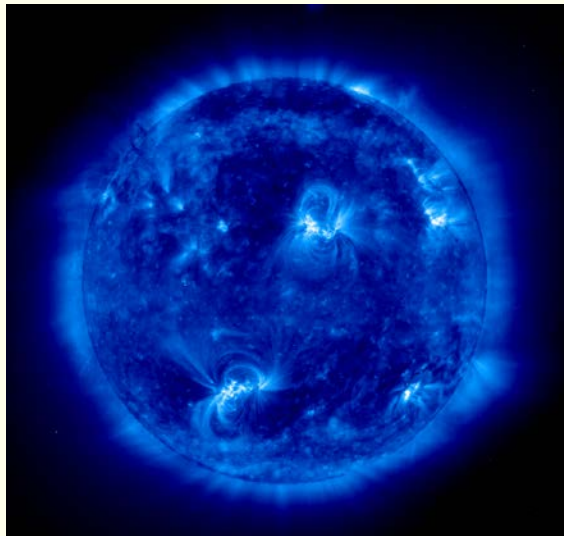
# Using different wavelengths to study atmospheric layers



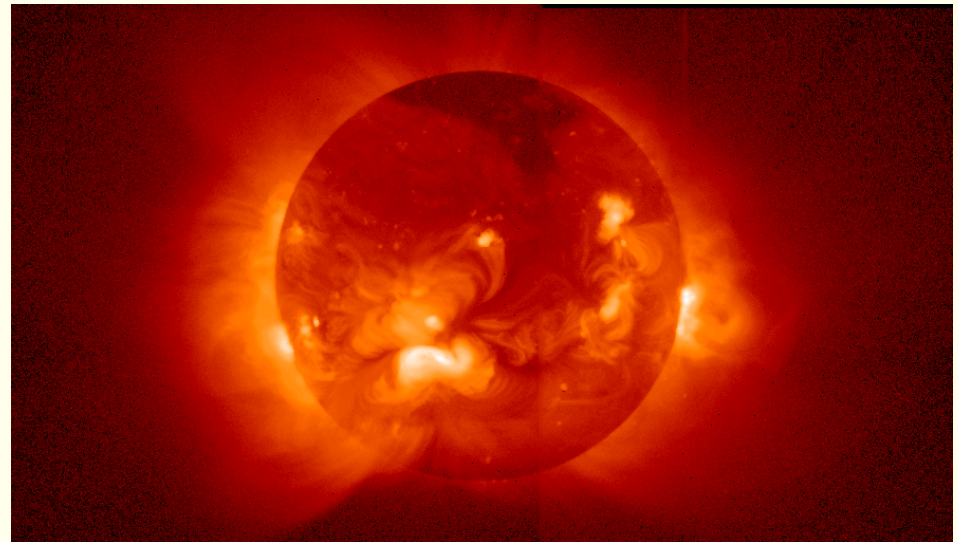
*Visible light  $\sim 6768 \text{ \AA}$*



*He II emission line at  $304 \text{ \AA}$*

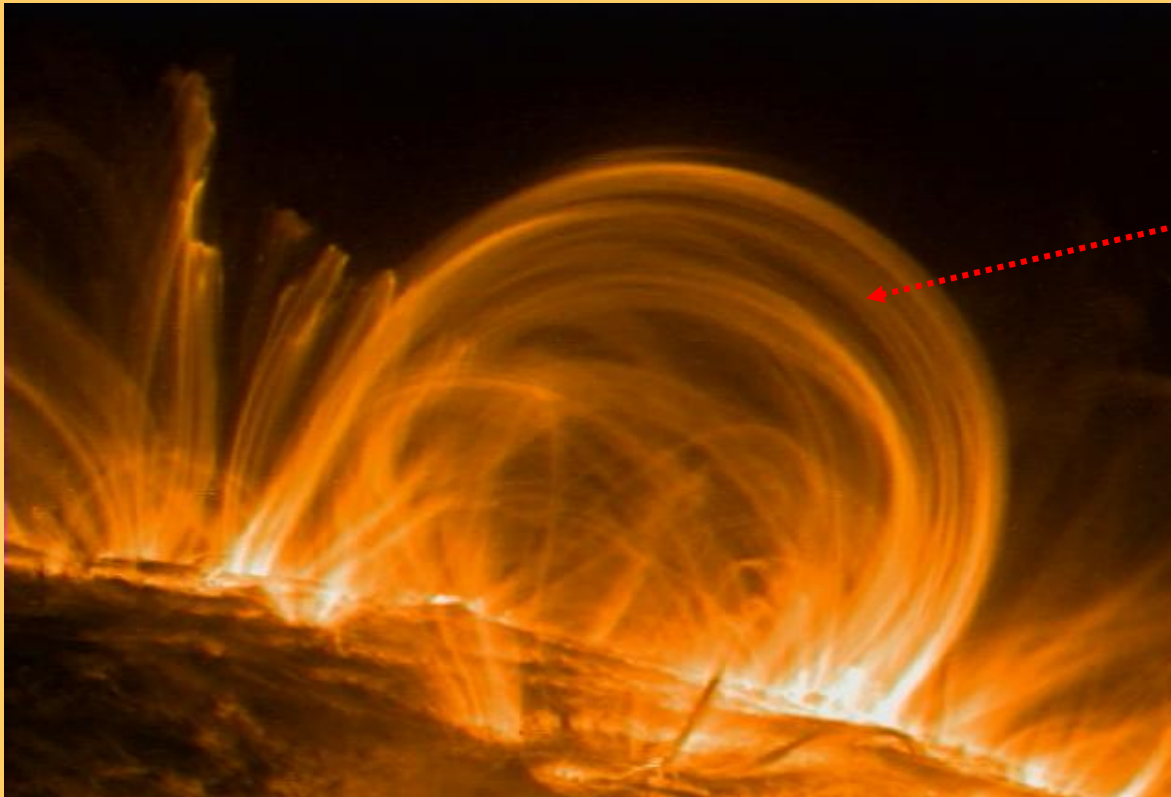


*(Fe IX/X) at  $171 \text{ \AA}$*



*X-ray at  $0.3\text{-}5 \text{ \AA}$*

# Coronal loops



**What gives the loops this structure???**



# Coronal loops



Until next time:

*Why does the plasma follow the magnetic field lines?*





# Last Minute!



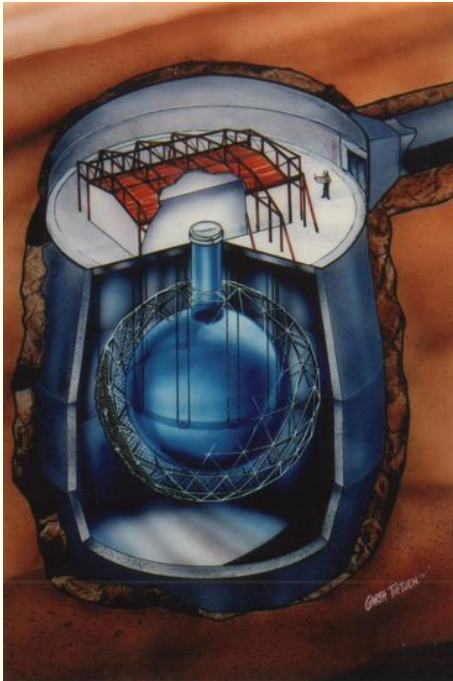
# Last Minute!

- What was the most important thing of today's lecture? Why?
- What was the most unclear or difficult thing of today's lecture, and why?
- Other comments

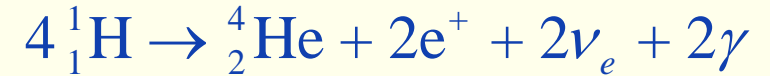
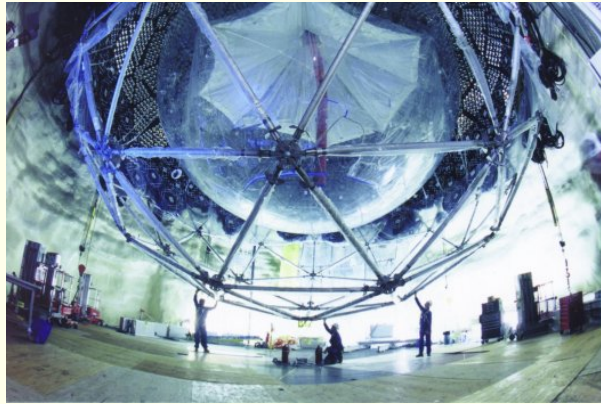




# Solar neutrino problem



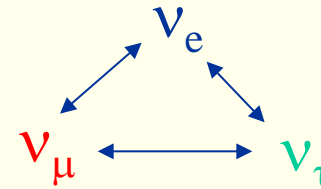
Sudbury Neutrino Detector (Canada)



Neutrino detectors only gave 1/3 of expected neutrino flux.

Explanation:

New theories have shown that different "flavours" of neutrinos can change into each other:



During travel from sun to earth, only 1/3 probability that neutrino is electron neutrino, which was the only one that could be detected by early neutrino detectors.

# EF2230 EXPERIMENTAL METHODS IN SPACE PLASMA PHYSICS , 6 ECTS credits, period 2

- 
- 3944 H $\gamma$   
3970 H $\gamma$   
4026 H $\gamma$   
4721 H $\delta$   
4776 H $\delta$   
4861 H $\beta$   
4861 H $\beta$   
5051 H $\beta$   
5051 H $\beta$   
5570 O I  
6300 O I  
6354 O I  
6553 H $\alpha$
- 4000 Å 5000 Å 6000 Å 6800 Å
- WAVELENGTH
- AIRORAL SPECTRUM  
LINES, BANDS  
SOLAR SPECTRUM  
CONTINUUM



- Critical analysis and oral presentation
- Data acquisition or analysis using commercial software