



Space physics EF2240

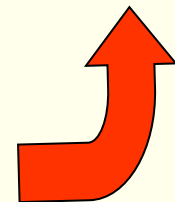
Tomas Karlsson

Space and Plasma
Physics

*School of Electrical
Engineering*



What is this?

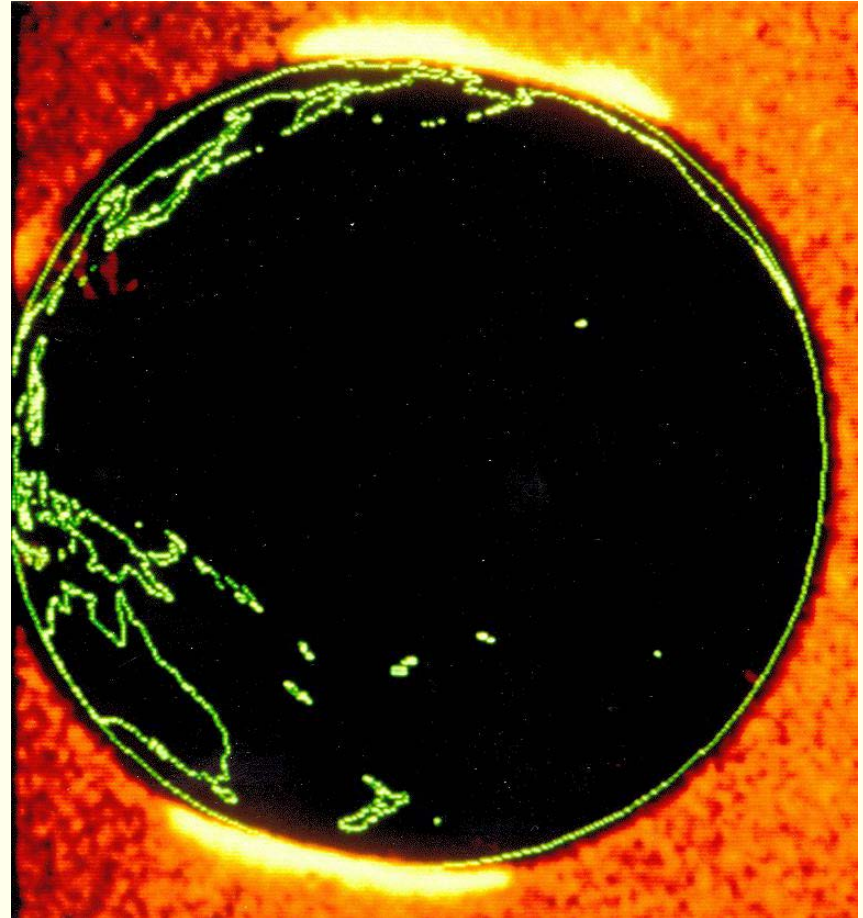
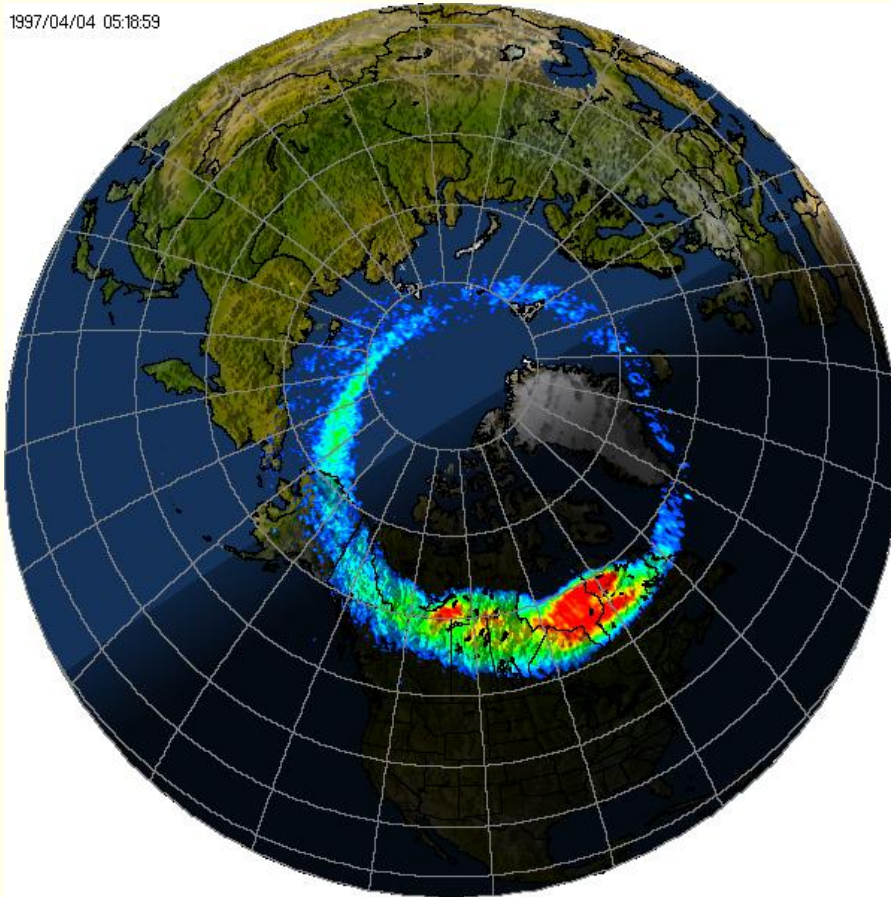


Clue...



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



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	2/9	10-12	Q33	Course description, Introduction, The Sun 1, Plasma physics 1	CGF Ch 1, 5, (p 110-113)
L2	3/9	15-17	Q31	The Sun 2, Plasma physics 2	CGF Ch 5 (p 114-121), 6.3
L3	9/9	10-12	Q33	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	11/9	10-12	Q34	Mini-group work 1	
L4	16/9	15-17	Q33	The ionosphere 2, Plasma physics 4	CGF Ch 3.4, 3.7, 3.8
L5	18/9	15-17	Q21	The Earth's magnetosphere 1, Plasma physics 5	CGF 4.1-4.3, LL Ch I, II, IV.A
T2	23/9	10-12	Q34	Mini-group work 2	
L6	25/9	10-12	M33	The Earth's magnetosphere 2, Other magnetospheres	CGF Ch 4.6-4.9, LL Ch V.
L7	30/9	14-16	L51	Aurora, Measurement methods in space plasmas and data analysis 1	CGF Ch 4.5, 10, LL Ch VI, Extra material
T3	3/10	10-12	V22	Mini-group work 3	
L8	7/10	10-12	V22	Space weather and geomagnetic storms	CGF Ch 4.4, LL Ch IV.B-C, VII.A-C
T4	9/10	15-17	Q31	Mini-group work 4	
L9	11/10	10-12	M33	Interstellar and intergalactic plasma, Cosmic radiation, Swedish and international space physics research.	CGF Ch 7-9
T5	15/10	10-12	L51	Mini-group work 5	
L10	16/10	13-15	Q36	Guest lecture: Swedish astronaut Christer Fuglesang	
T6	17/10	15-17	Q31	Round-up	
Written examination	30/10	14-19	B21-24		

Guest lecturer



Swedish astronaut Christer Fuglesang Lecture 10



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

Grades:

A: 111-125 p

B: 96-110 p

C: 81-95 p

D: 66-80 p

E: 50-65 p

(Fx)



Written examination, 30/10 2013, 14.00-19.00, B21, B22, B23, B24

(*) 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
(5×5 p = 25 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!**

EF22445 Space Physics II

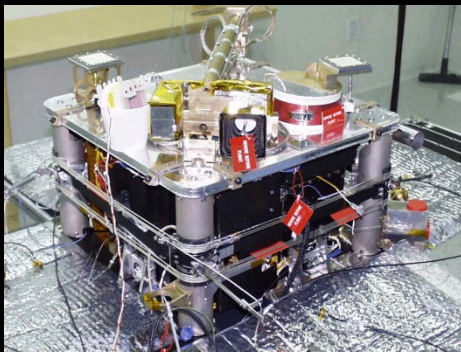
7.5 ECTS credits, P2

- 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

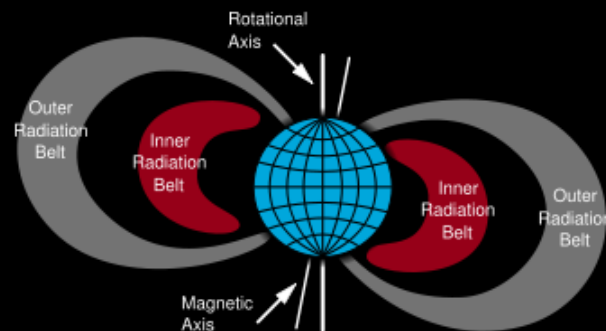
Courses at the Alfvén Laboratory

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:

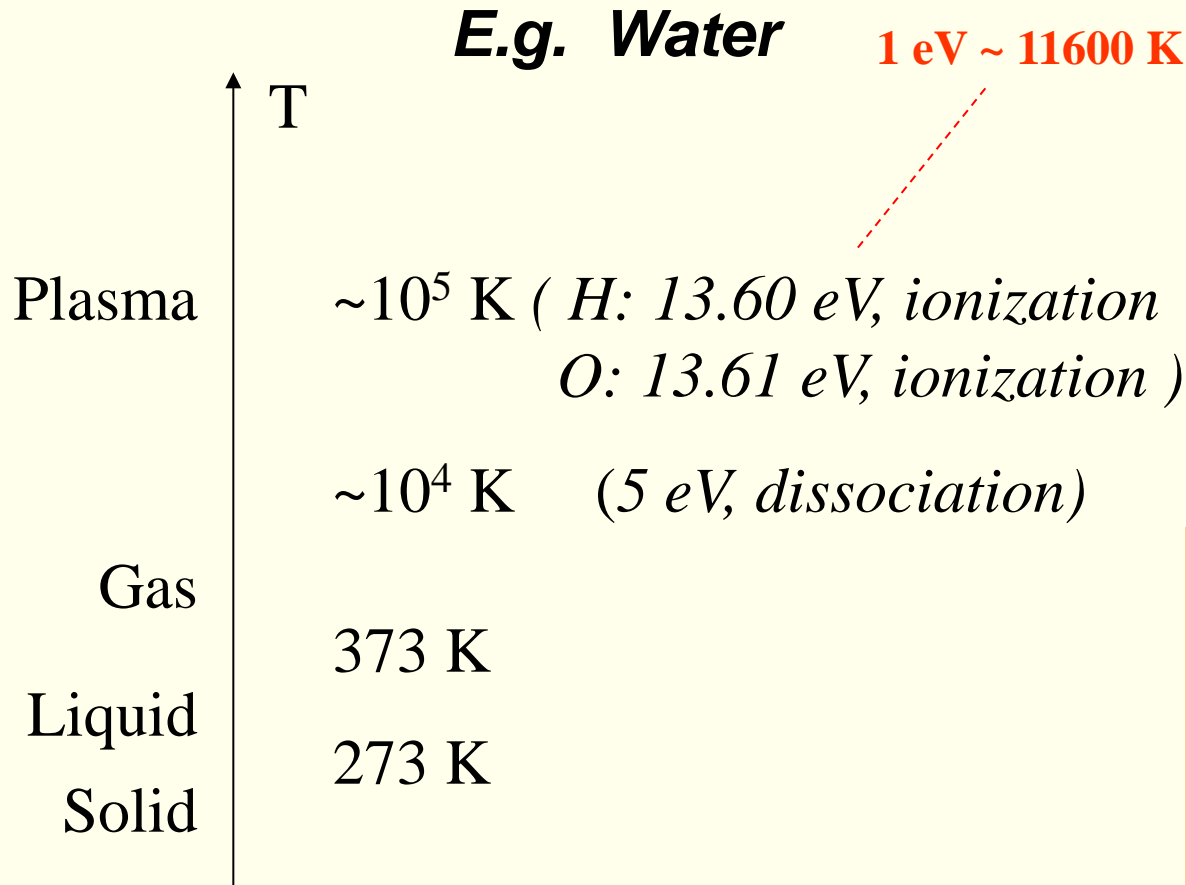
- Design power supply for spacecraft
- Study of radiation effects on electronics



What is a plasma?

Where in the universe can you find it?

Plasma



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!

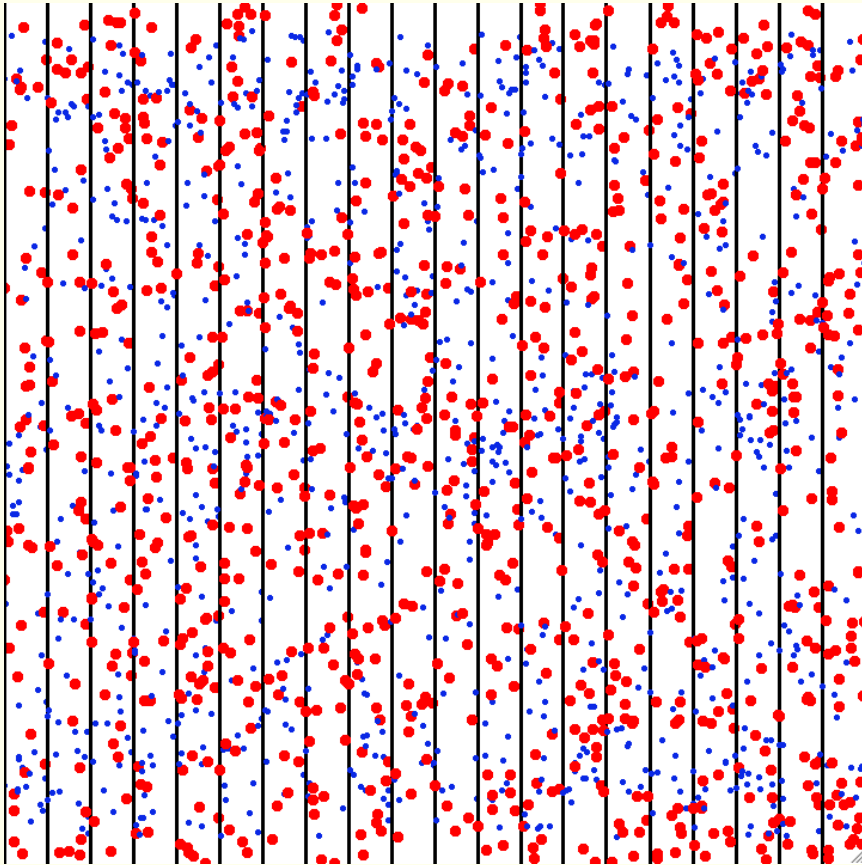
In plasma physics, usually:

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

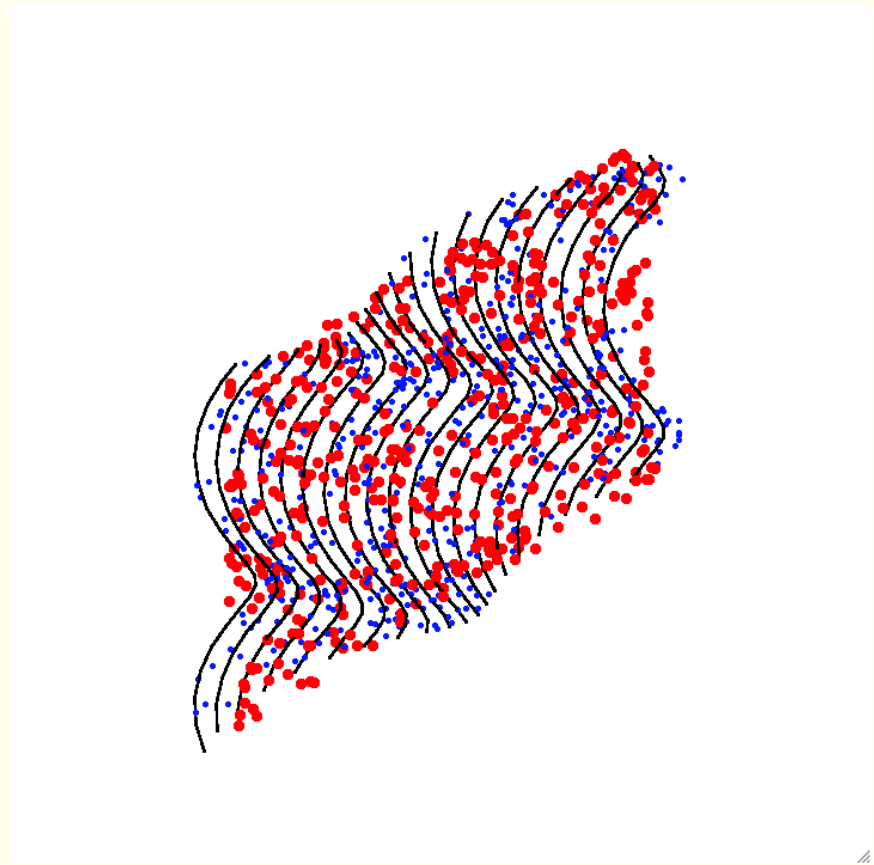
$$1 \text{ eV} = 1.6 \cdot 10^{-19} \text{ J} \Rightarrow$$

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

Example of collective behaviour: Plasma waves

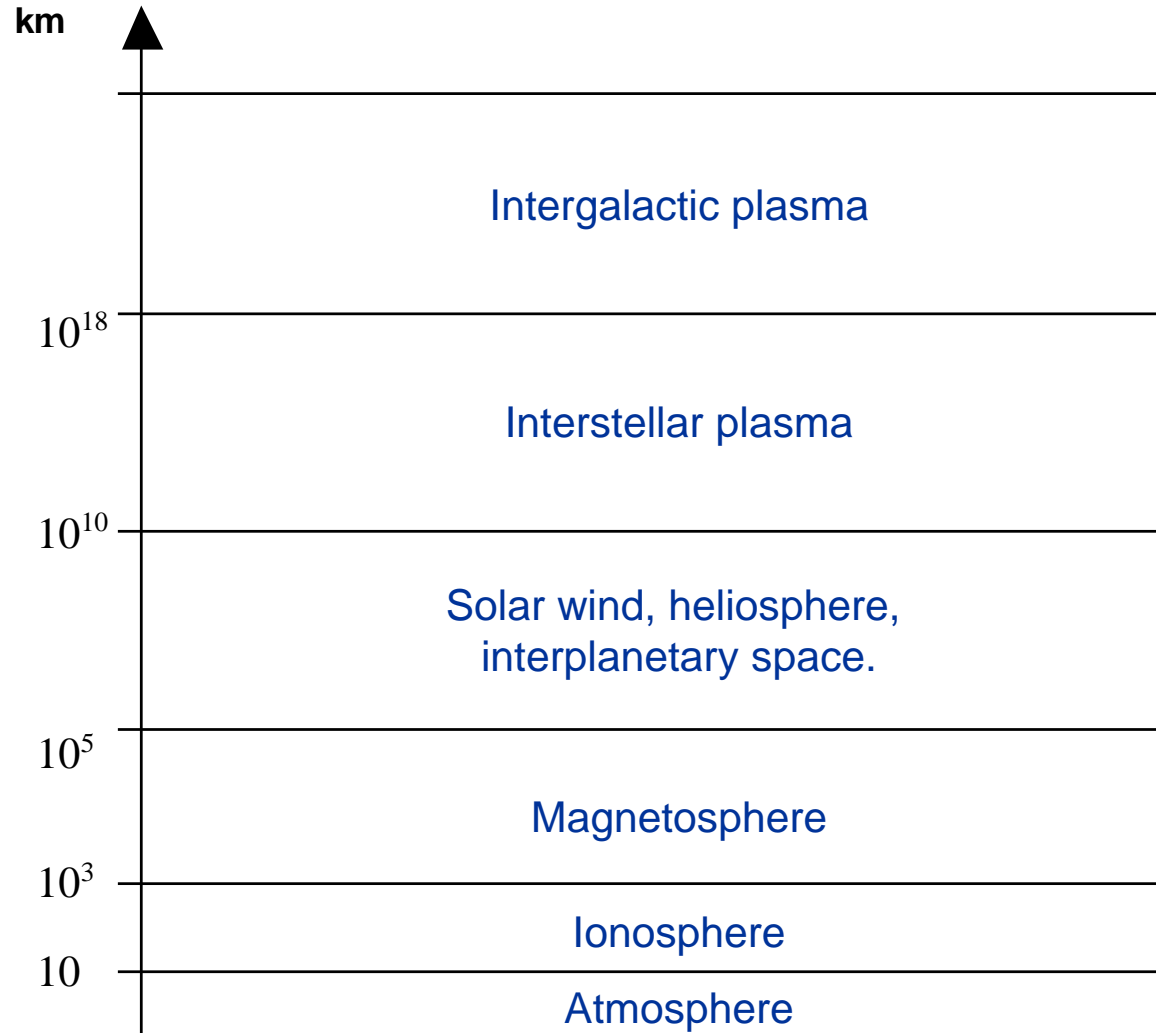


Electron plasma waves



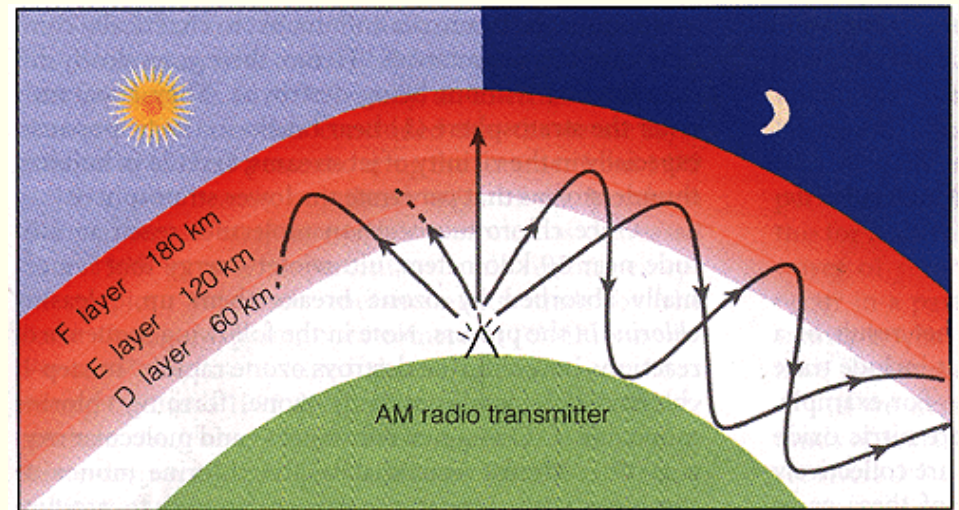
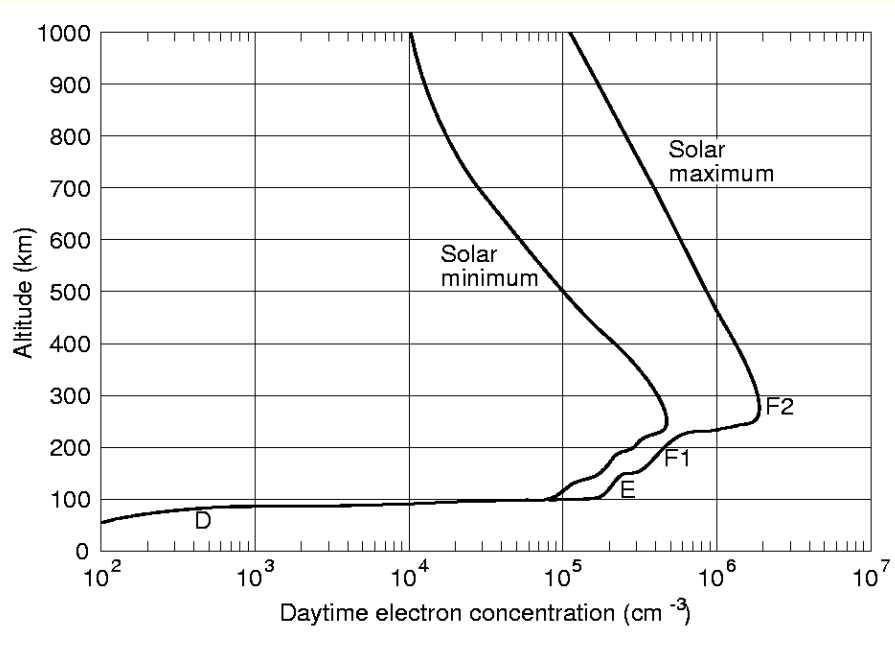
Whistler waves

From atmosphere to intergalactic plasma!

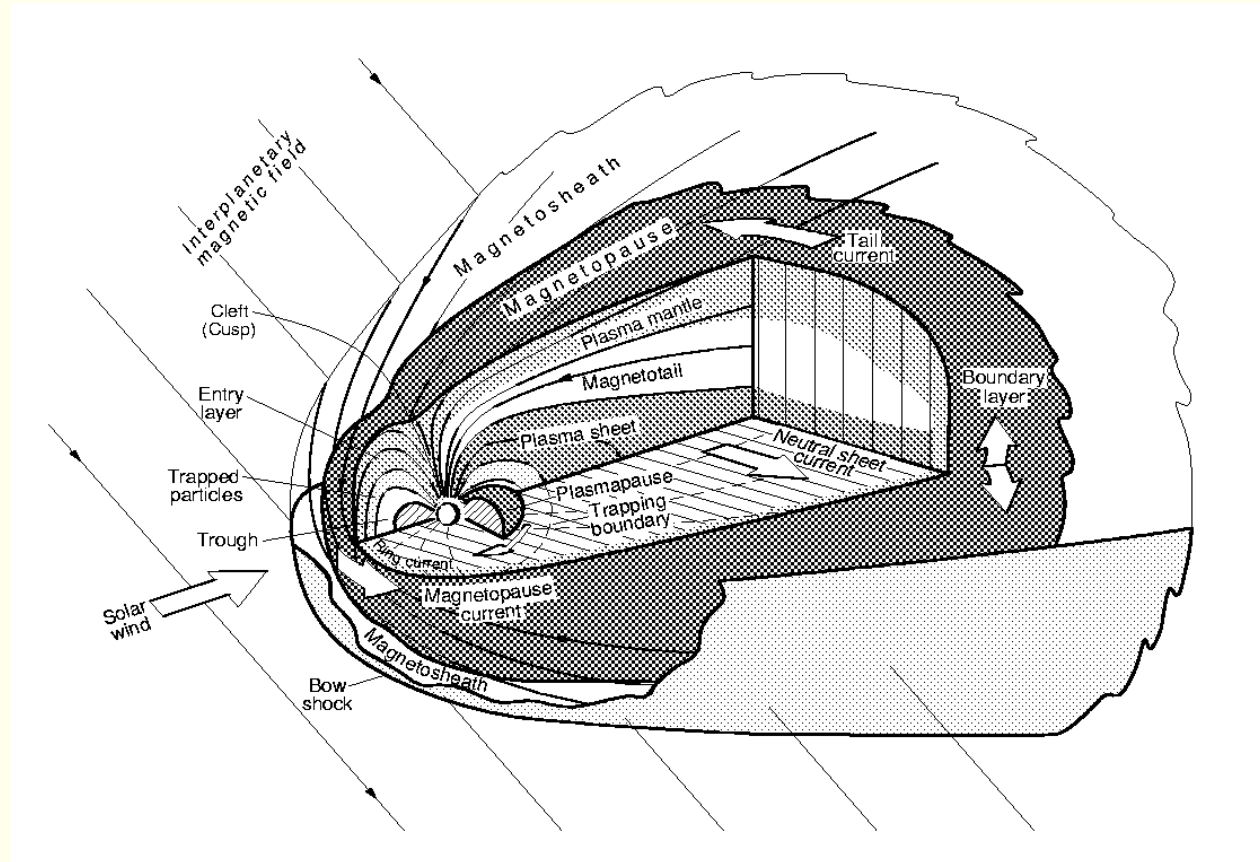


Solar
system

Ionosphere



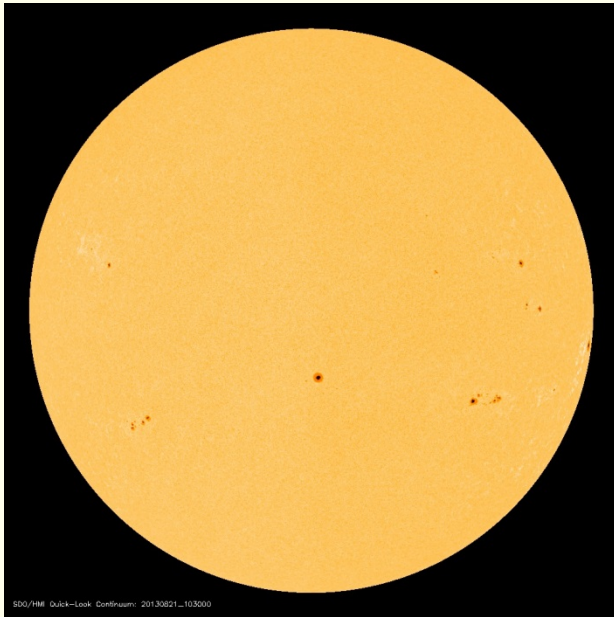
Magnetosphere



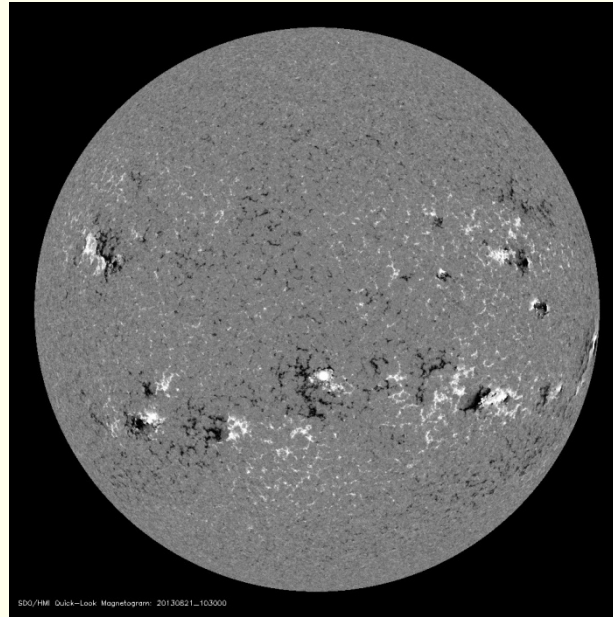
Definition: *That region in space where the geomagnetic field is the dominating magnetic field.*

The sun (2012-08-23)

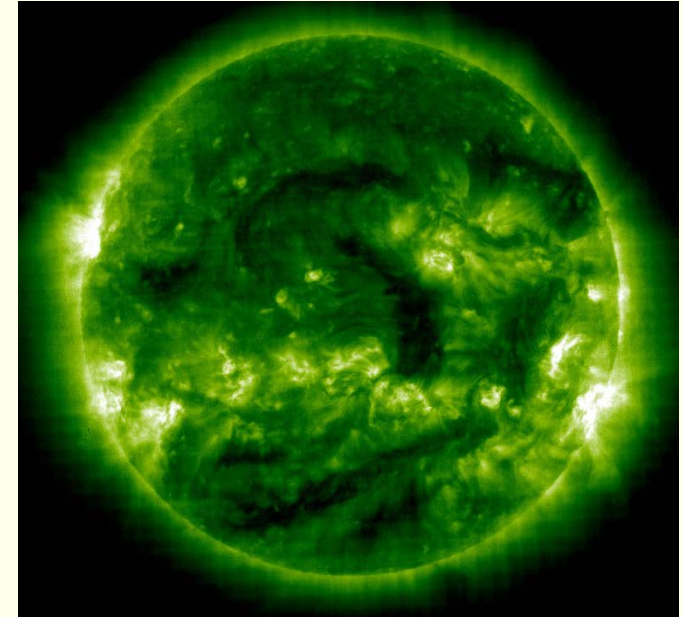
SOHO observations



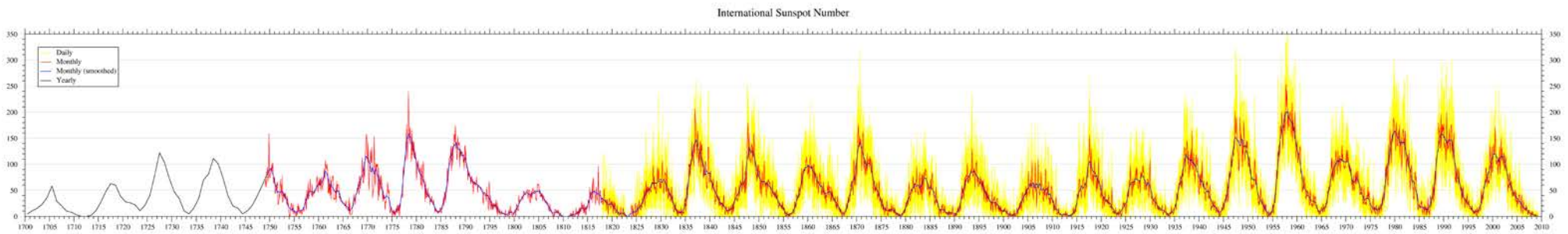
Visible light



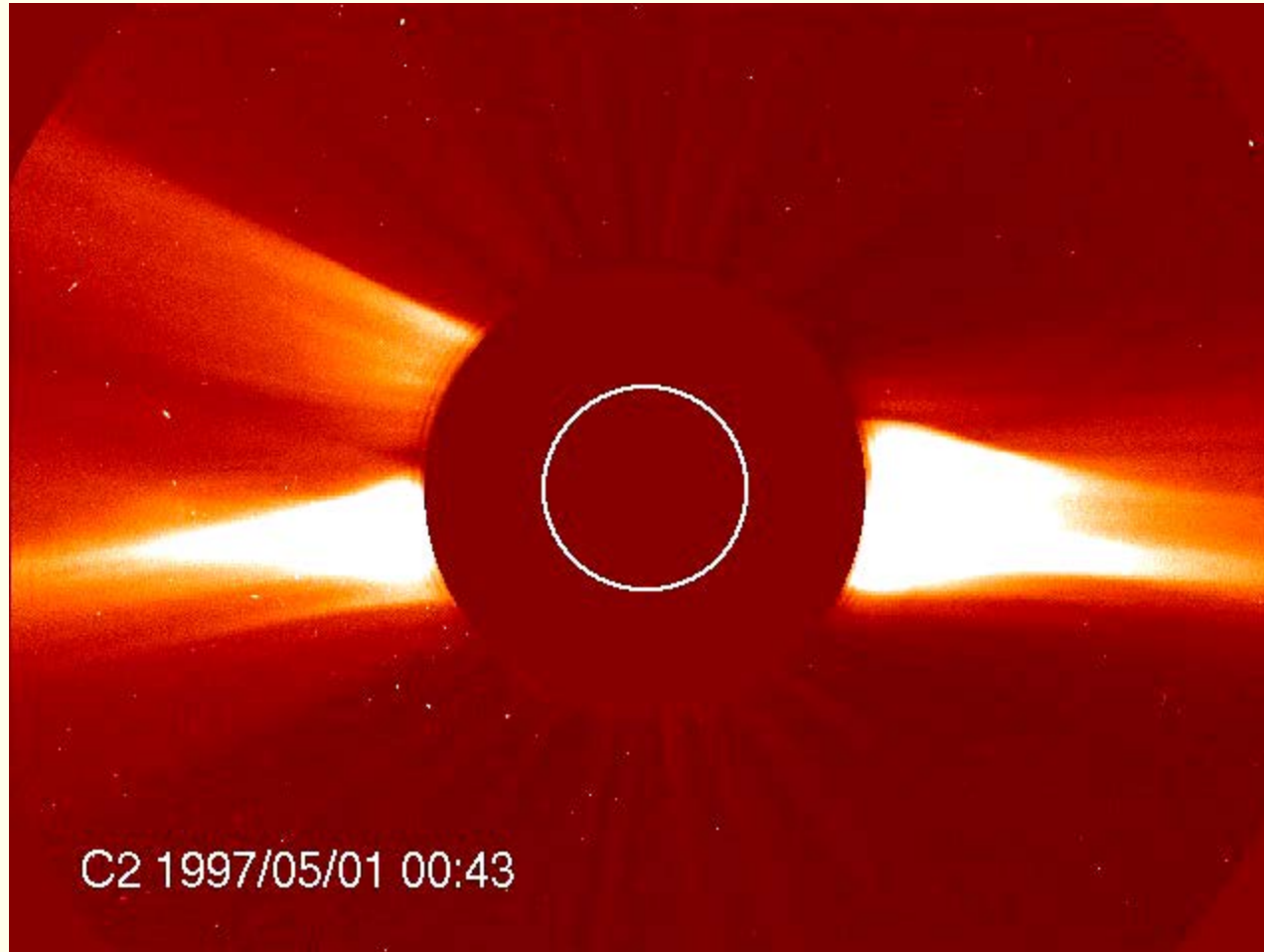
Magnetogram



SOHO EUV (Fe XV)

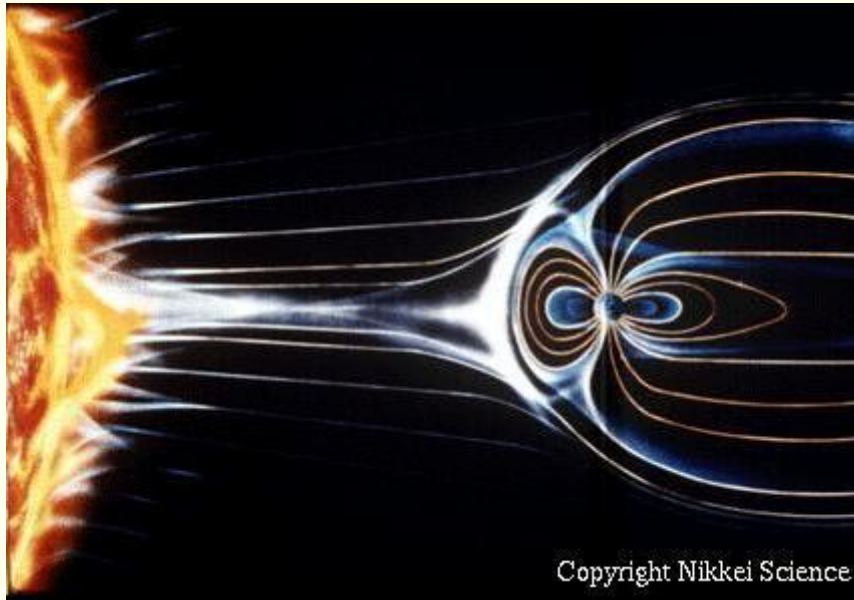


The sun, solar wind

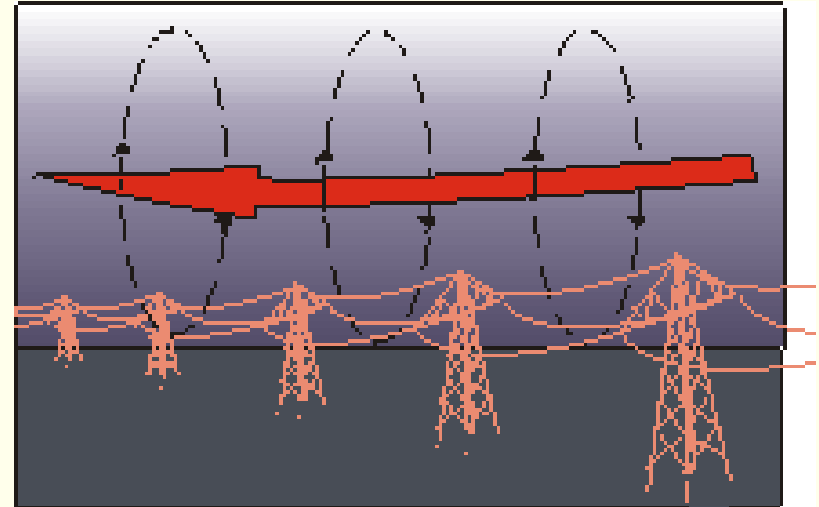


**Solar and Heliospheric Observatory (SOHO),
*LASCO C2 Coronagraph Movie***

Solar-terrestrial interaction

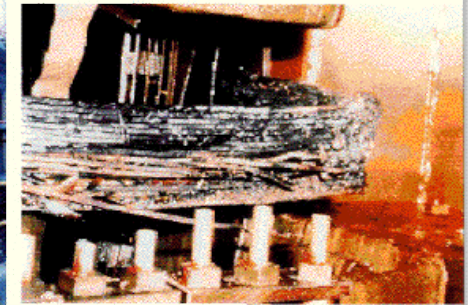


Space weather: Geomagnetically induced currents (GIC)



PJM Public Service
Step Up Transformer

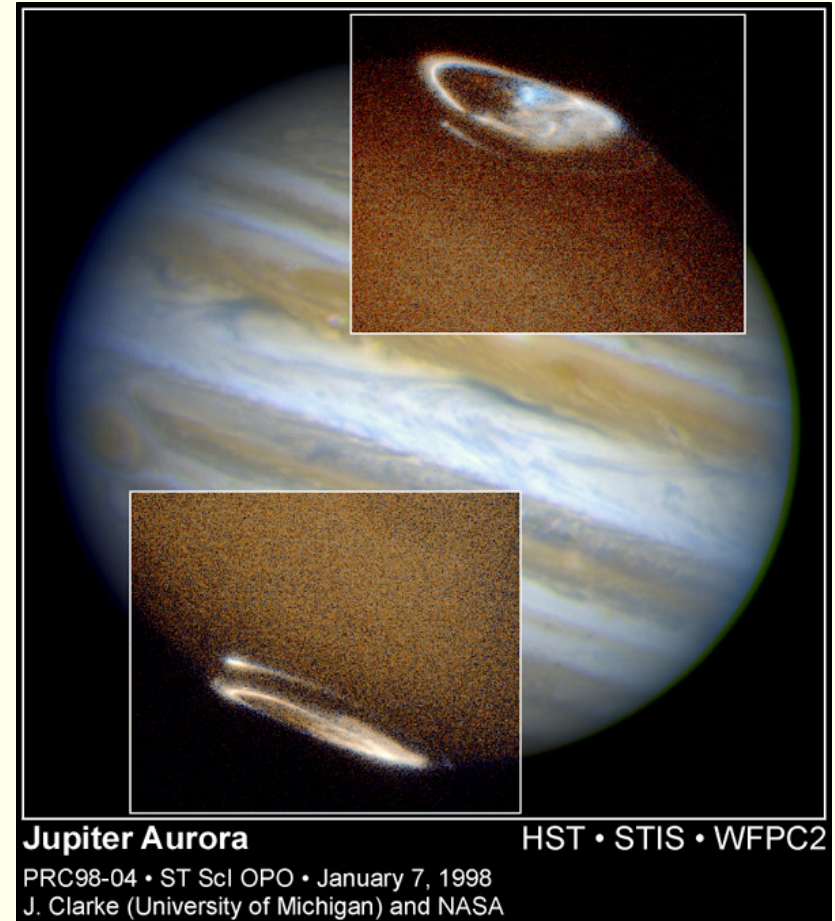
Severe internal damage caused by
the space storm of 13 March, 1989.



Aurora on Earth

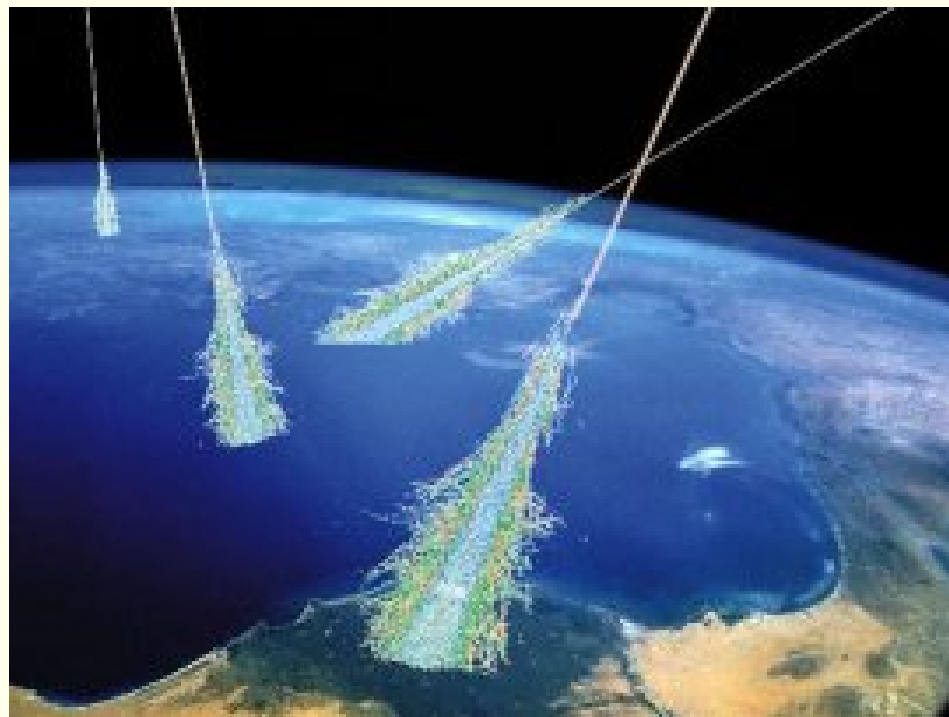
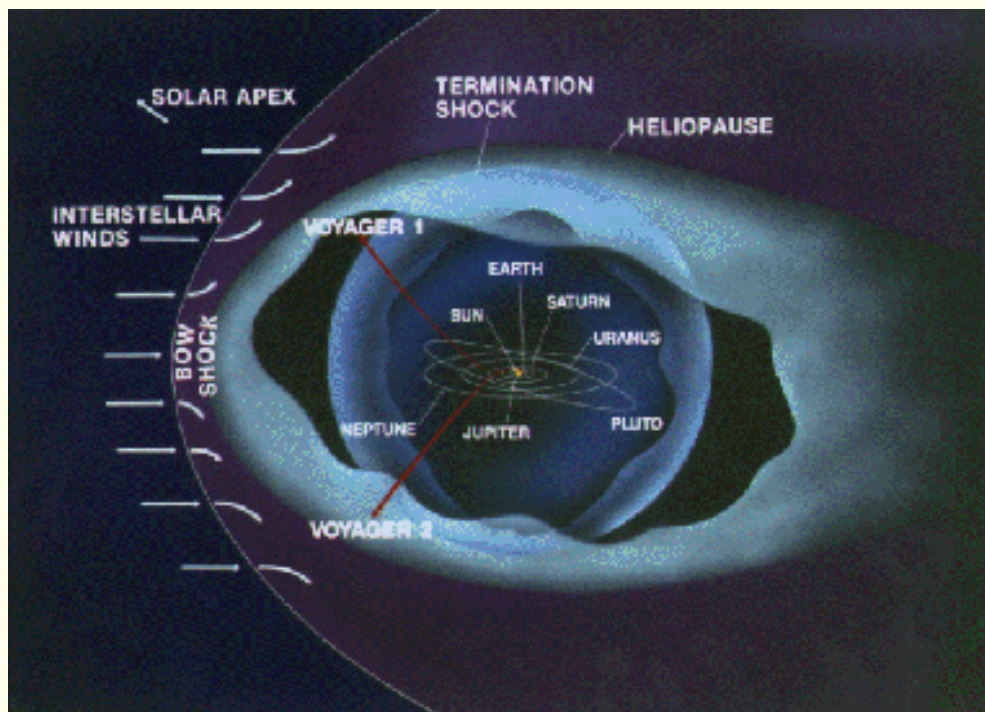


Aurora on other planets

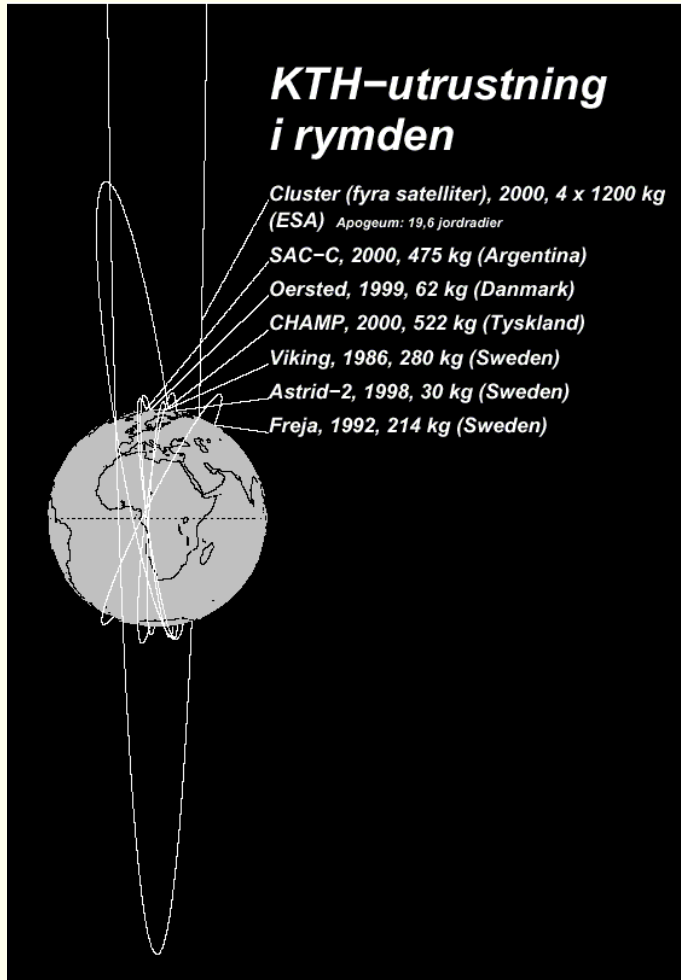


Interstellar and intergalactic plasma

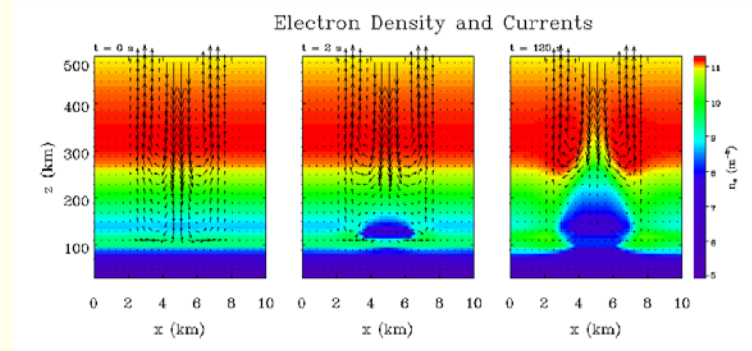
Cosmic radiation



Swedish and international space physics research



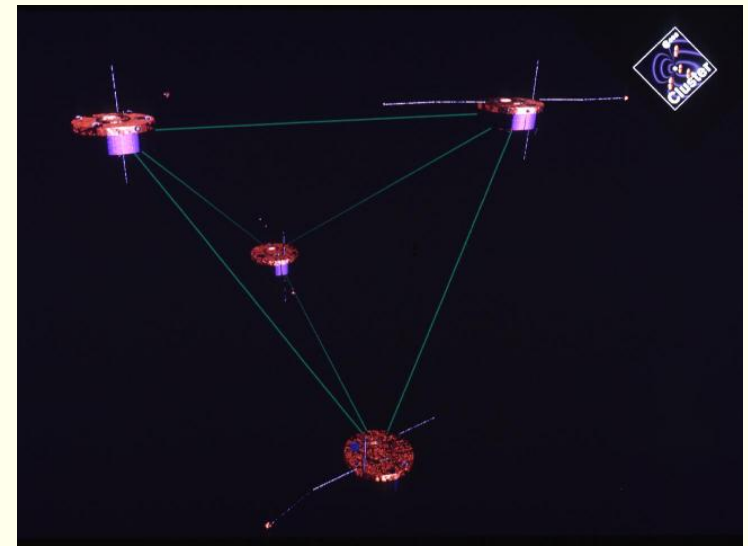
Micro satellite Astrid-2



Simulations



Cassini & Huygens at Saturn



Cluster satellites



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Think about this:



The temperature of the solar surface is approximately 6000 K.

How can we know that ???

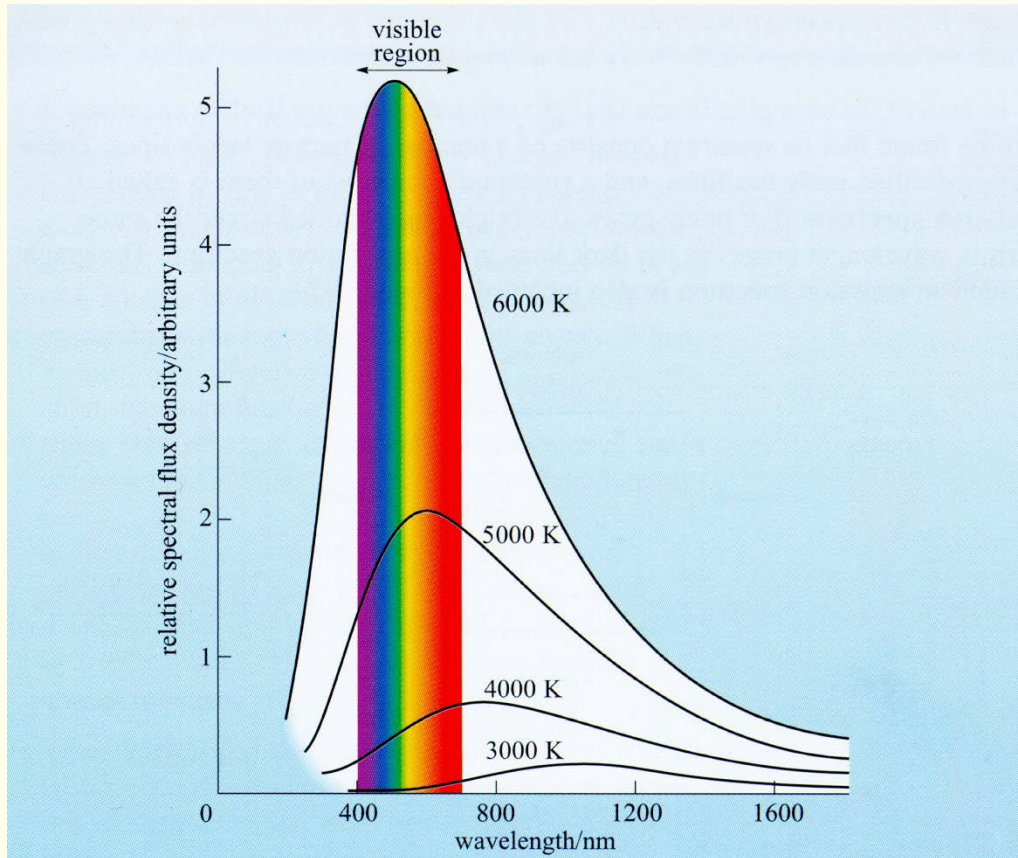


Hot steel emitting red light.



Chart to estimate steel temperature in steelworks.

Black-body radiation



Wien's displacement law

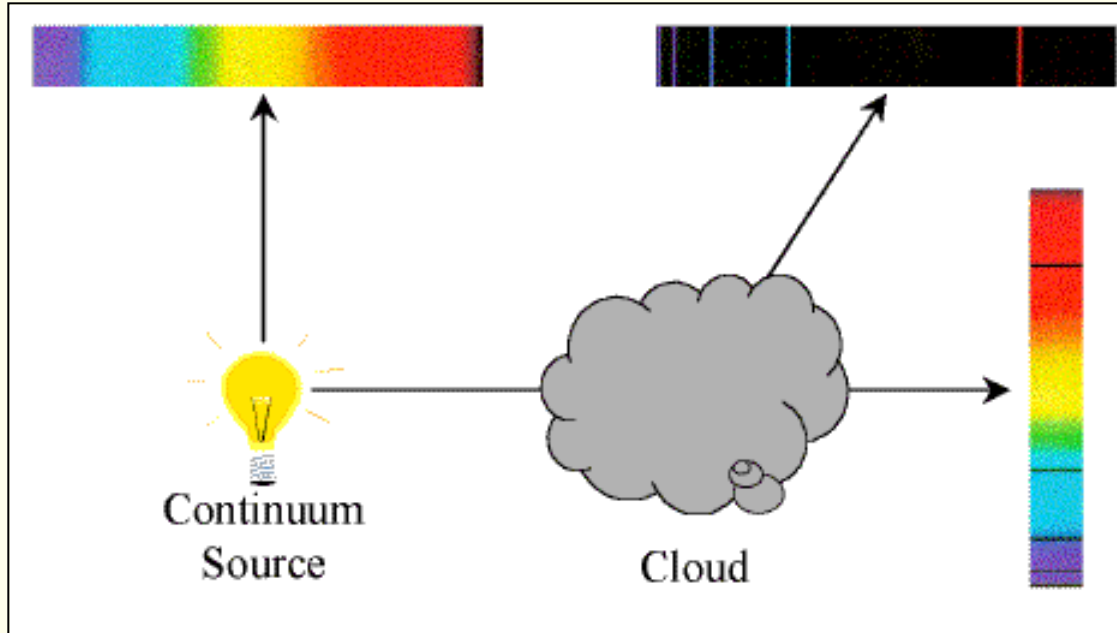
$$\lambda_{peak} = \frac{2.90 \times 10^{-3}}{T}$$

Stefan-Bolzmans law

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

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

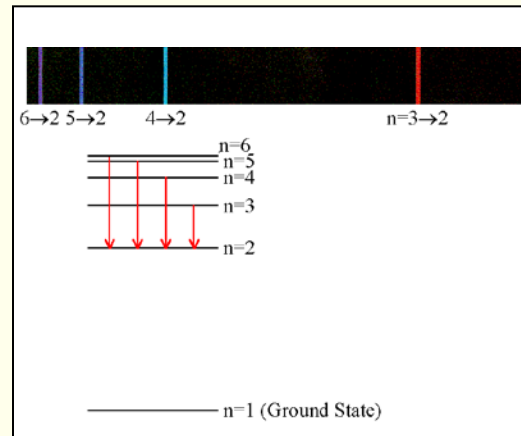
Black-body good approximation for opaque bodies where emitted light is much more likely to interact with the material of the source than to escape.



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

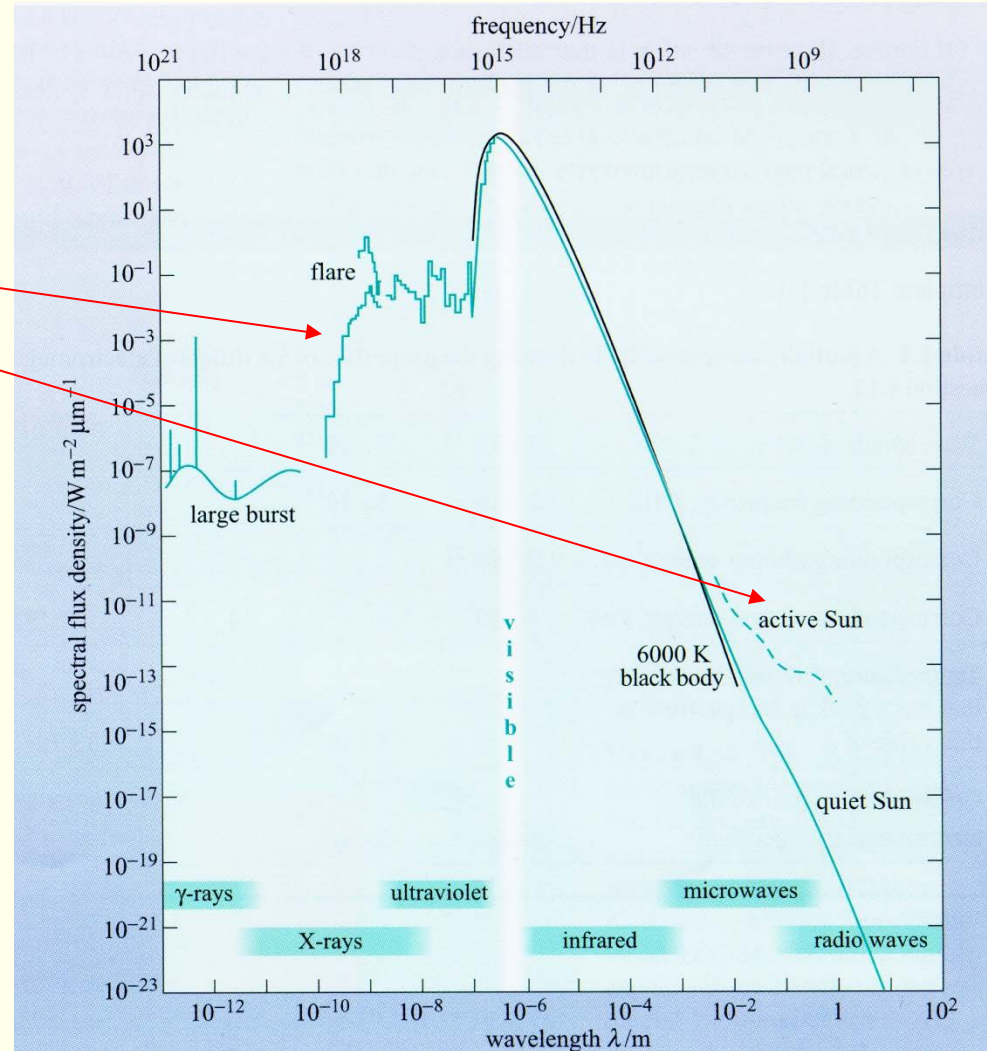
$$\lambda_{peak} = \frac{2.90 \times 10^{-3}}{T}$$



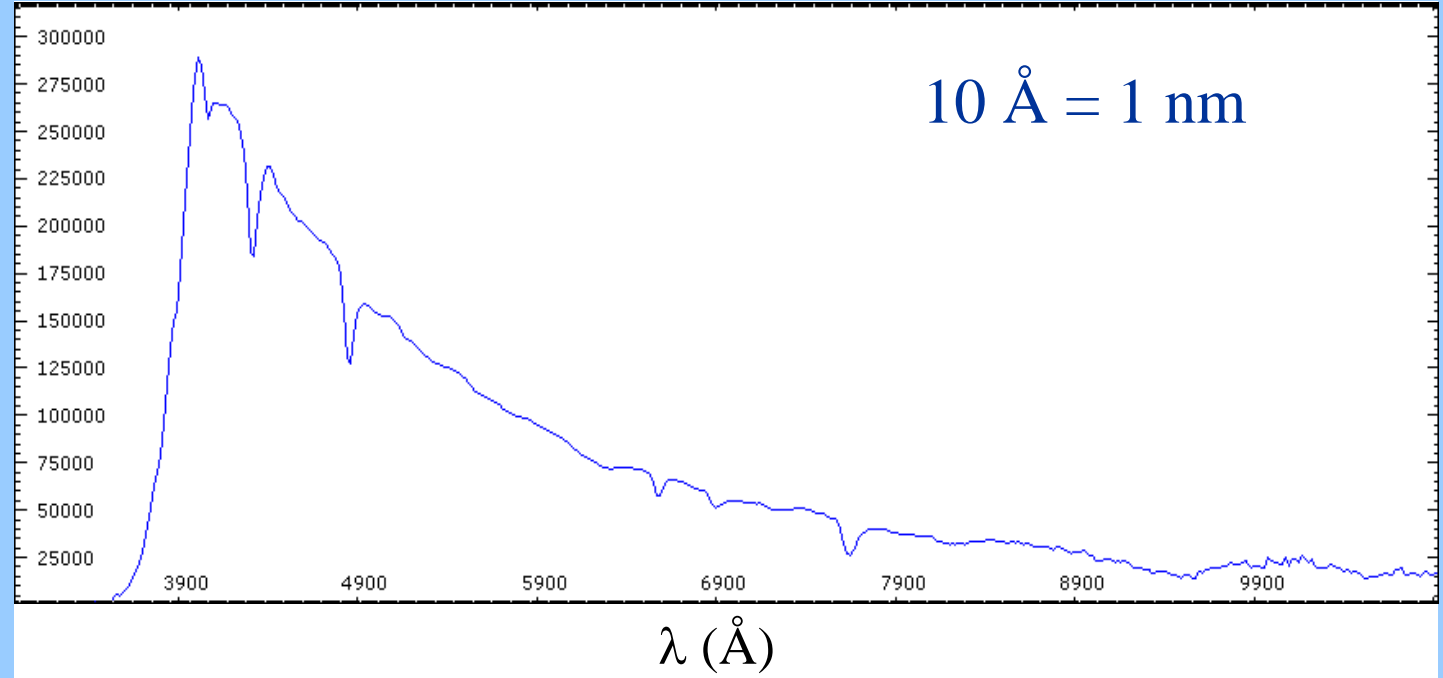
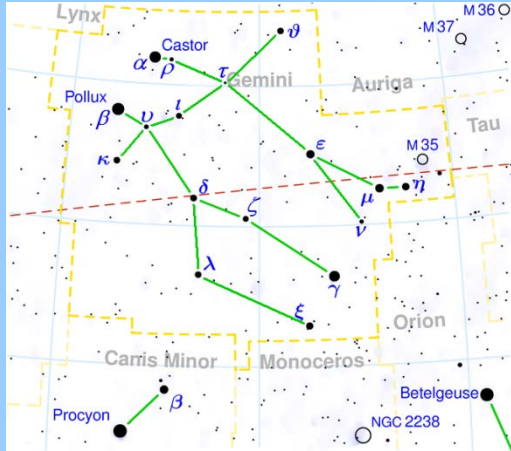
Atomic energy levels

The solar spectrum

Non-blackbody contributions



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



Red

$T = 2100 \text{ K}$

Green

$T = 7200 \text{ K}$

Blue

$T = 4700 \text{ K}$

Yellow

$T = 9300 \text{ K}$

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

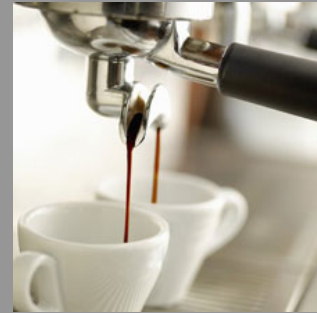
Wien's displacement law

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

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

Green $T = 7200 \text{ K}$

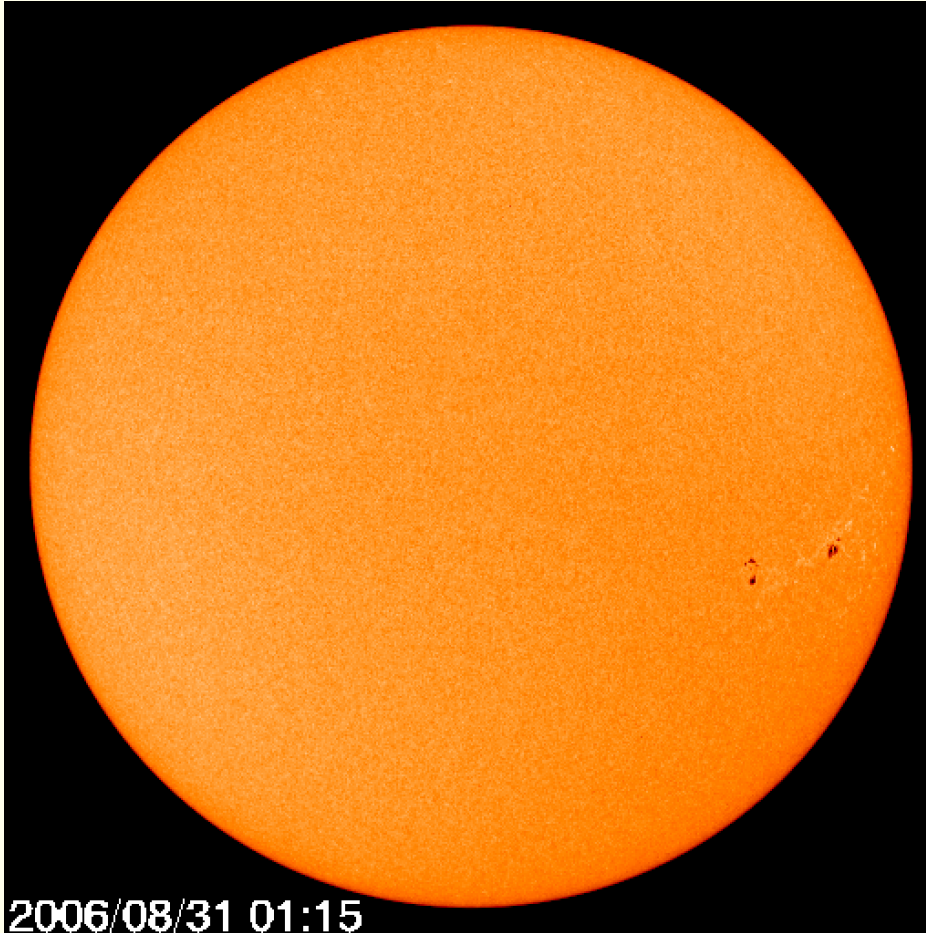
BREAK!



But think about this:

How can we know anything about the solar interior?

The Sun



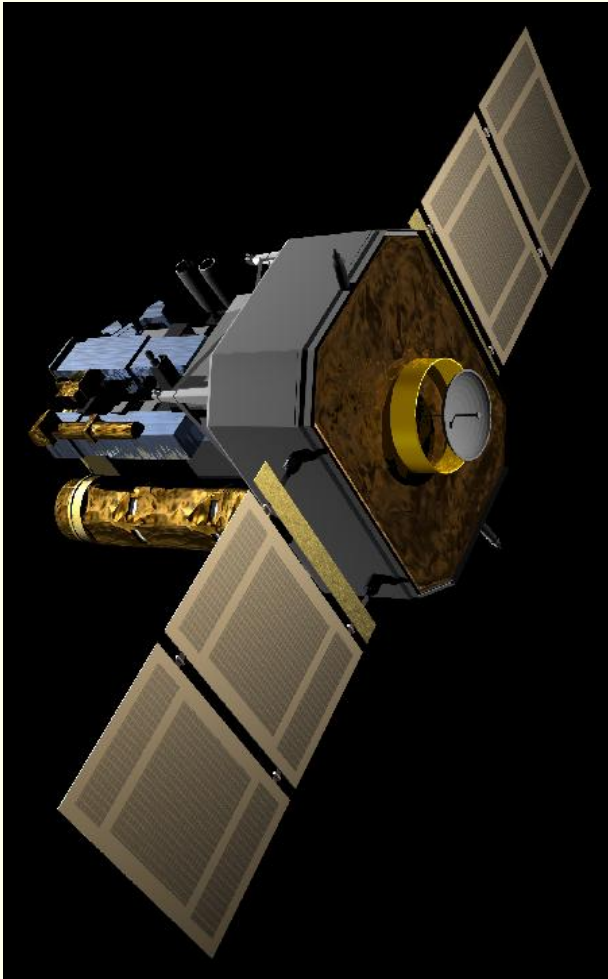
*SOHO Michelson Doppler Imager
(MDI) 6767 Å continuum images from
Stanford University*

Basic facts

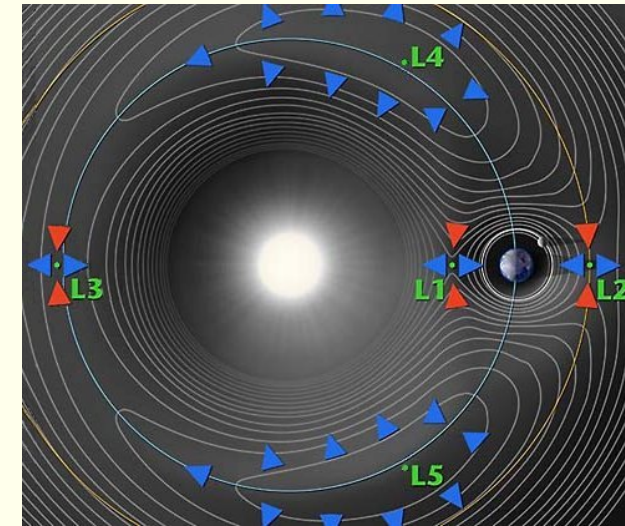
- *diameter: $1.39 \cdot 10^9 \text{ m} \approx 109 d_E$*
- *mass: $2 \cdot 10^{30} \text{ kg} \approx 333\,000 m_E$*
- *density: 1.4 kg/dm^3*
- *radiated effect: $4 \cdot 10^{26} \text{ W}$*
- *age: $4.5 \cdot 10^9 \text{ years}$*

SOHO spacecraft

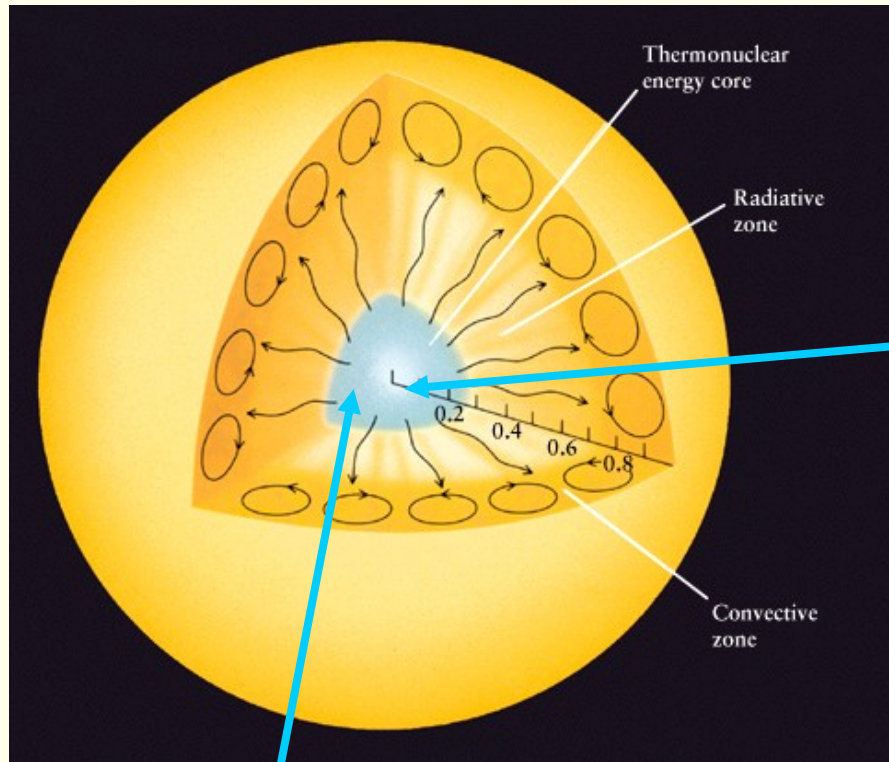
SOLar and Heliospheric Observatory



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

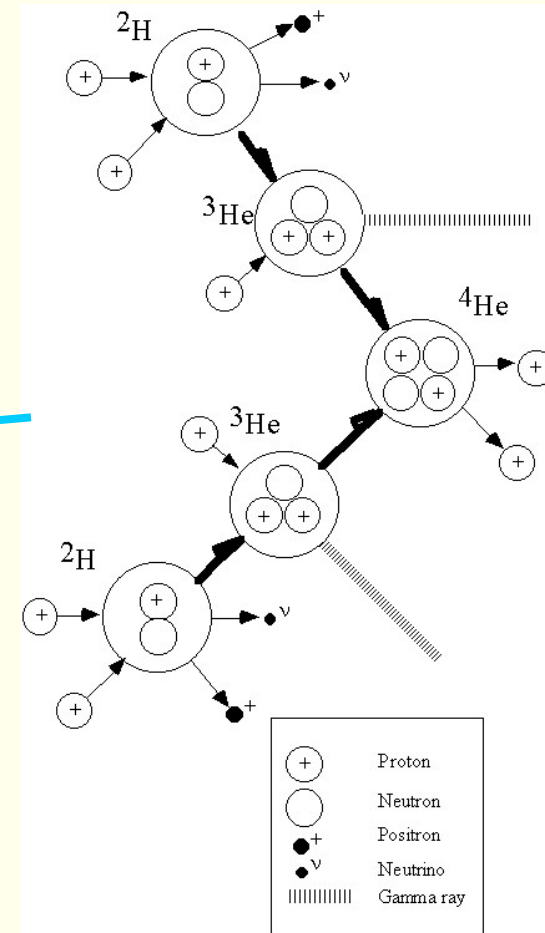


Sun's interior

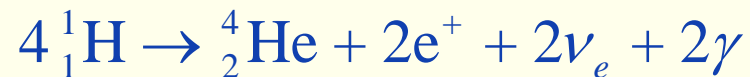
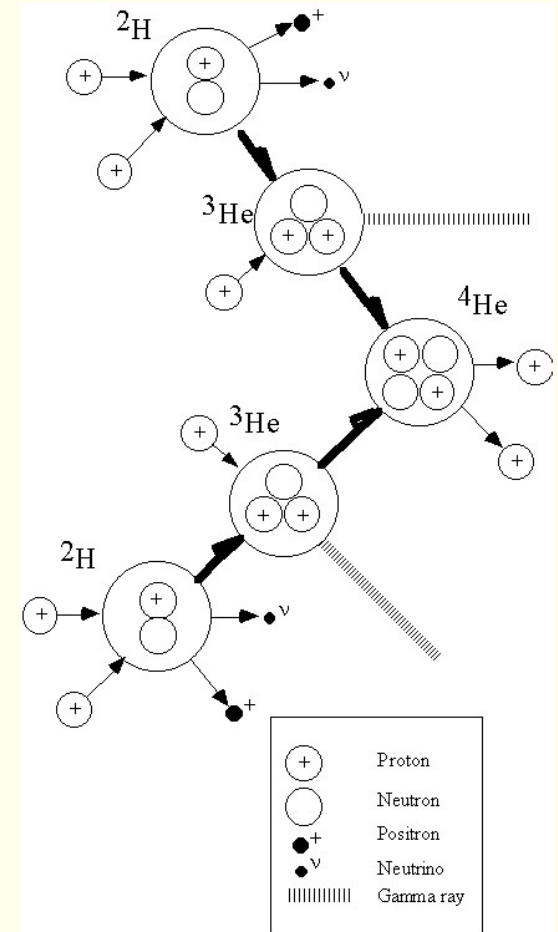
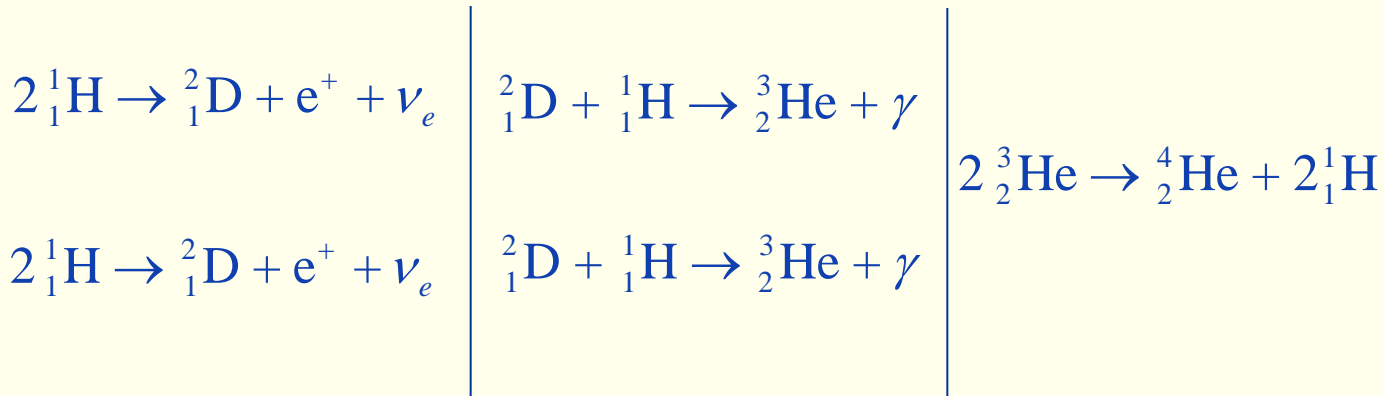


$T = 15 \cdot 10^6 \text{ K}$
 $P = 4 \cdot 10^{26} \text{ W}$
($P/m \sim 1 \text{ mW/kg}$)

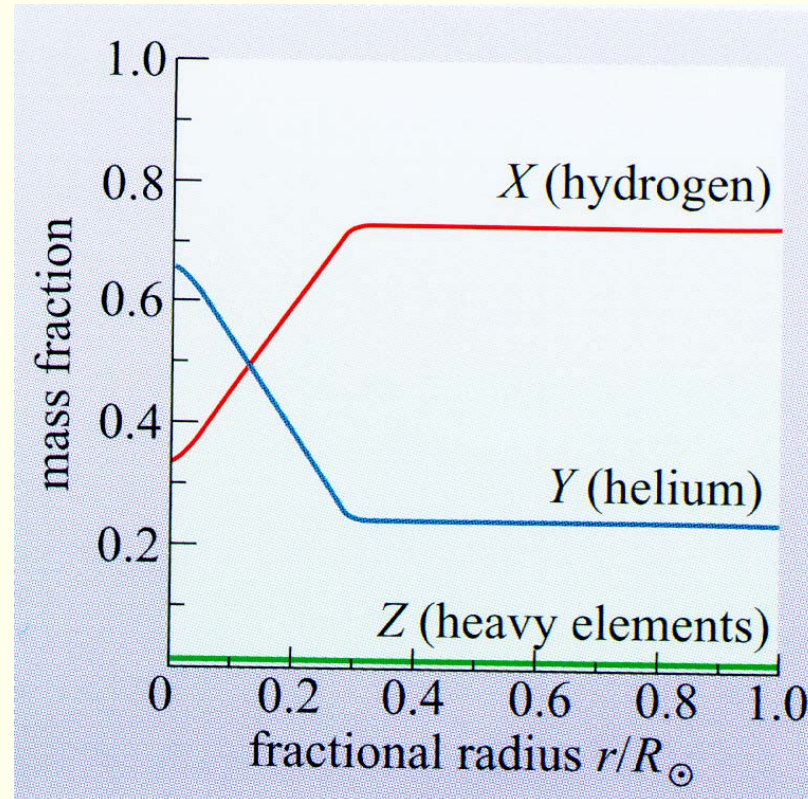
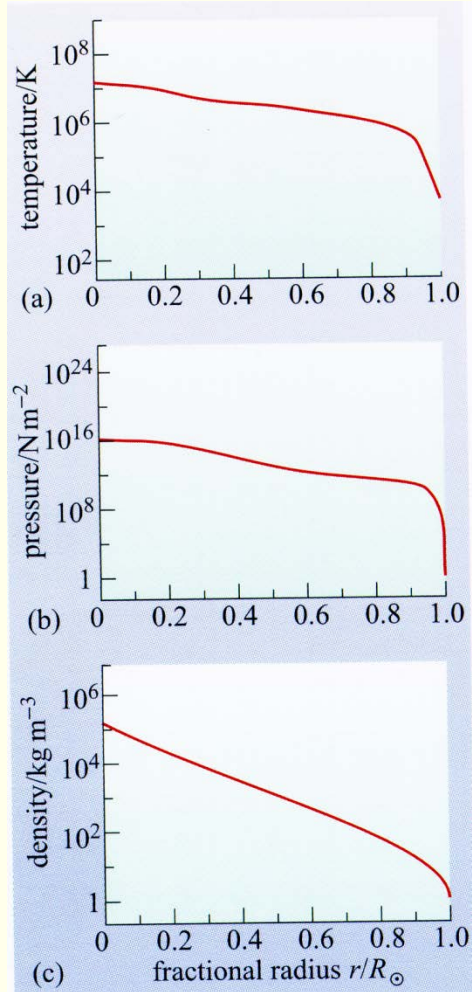
The proton cycle



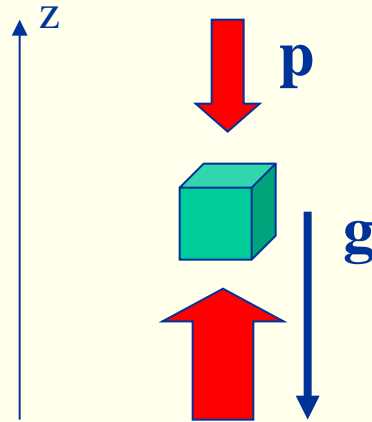
Proton cycle



Sun's interior



Atmospheric scale height



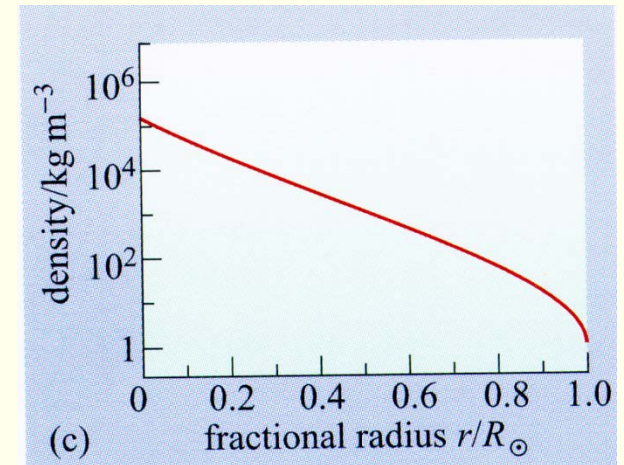
$$-\frac{dp}{dz} = g\rho \quad \text{hydrostatic equilibrium for a volume element}$$

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

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

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

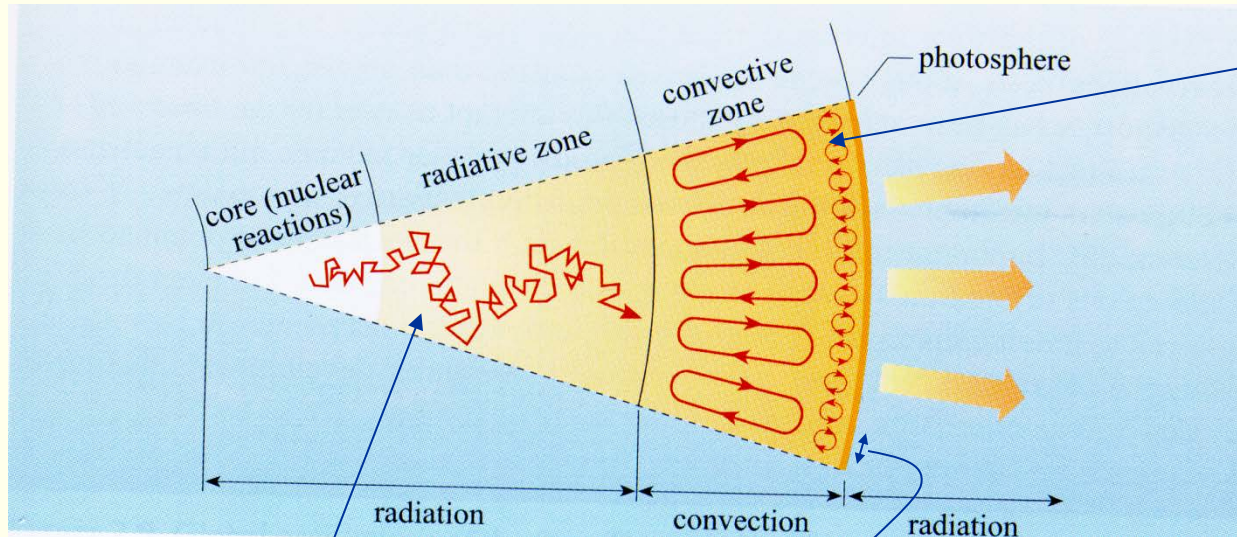
$$\log \rho = \text{const} - \frac{z}{H}$$



Scale height

$$H = k_B T / gm$$

Energy transport in the sun



Transport by convection

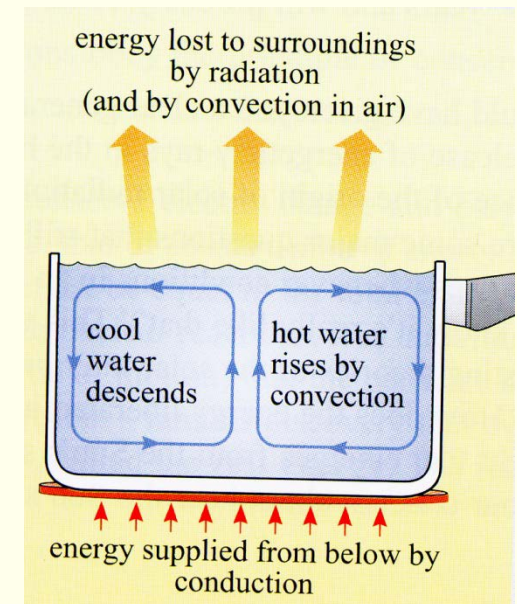
Transport by radiation, which interacts with the dense solar matter (scattering and absorption/re-emission).

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

~1000 km

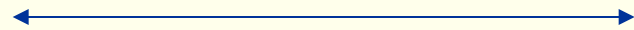
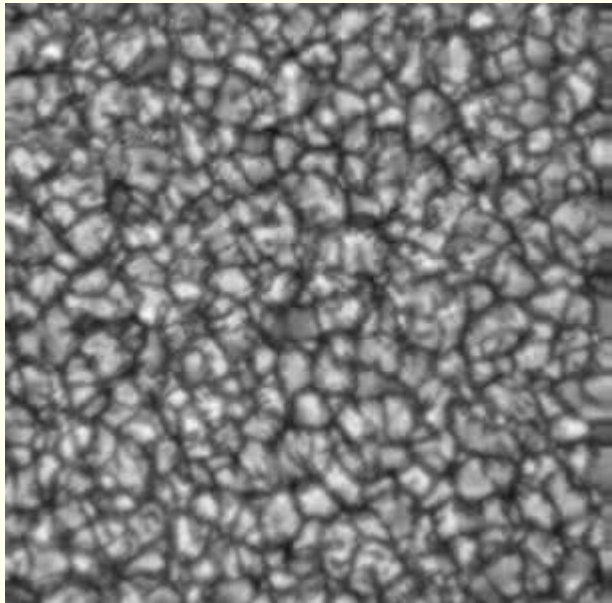
These convection cells are called *granulation*.

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

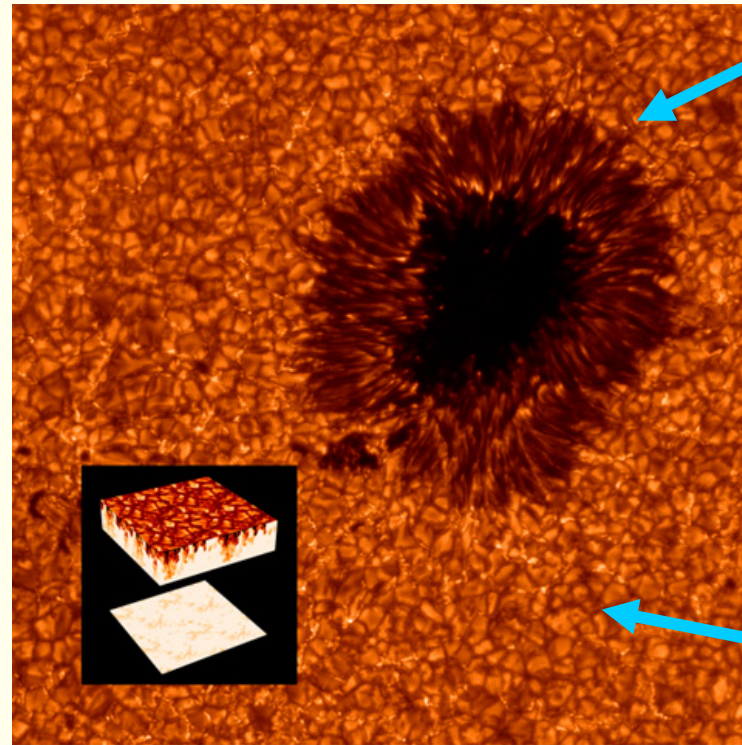


Granulation in photosphere

$T = 35 \text{ min}$



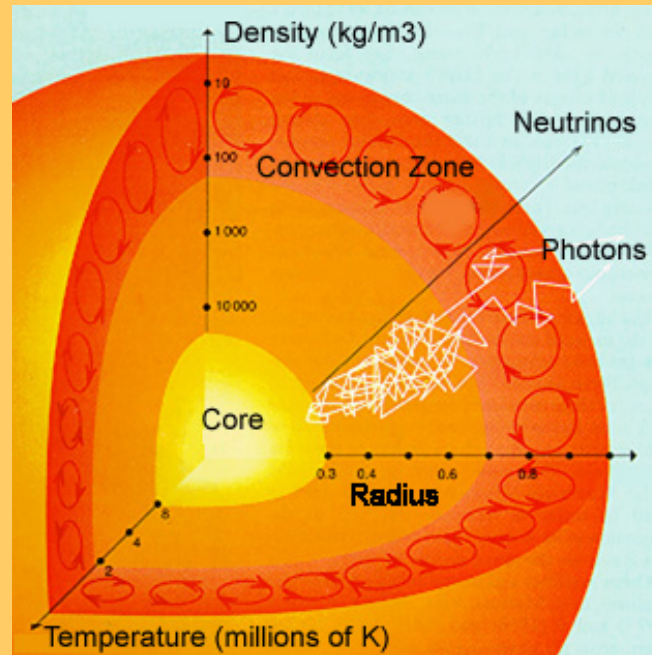
$\sim 27\,000 \text{ km}$



1000 - 50 000 km

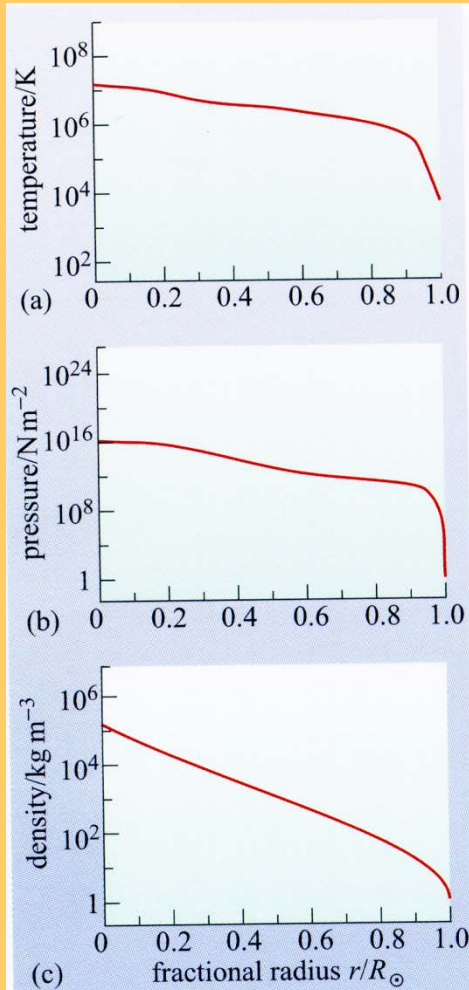
300 - 2000 km

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



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

1. Solar models

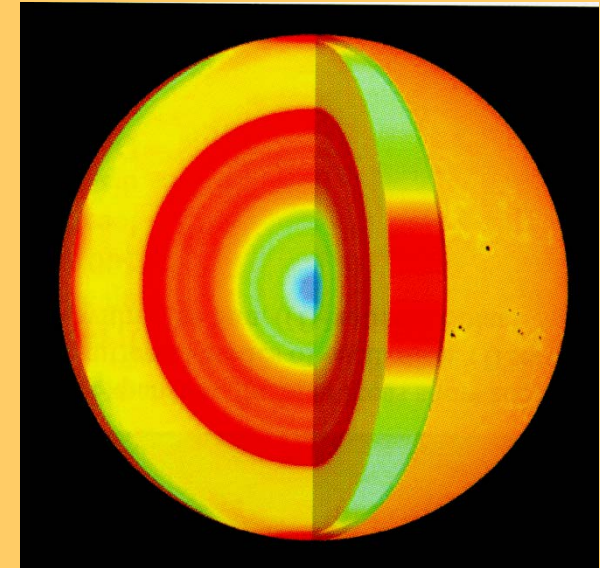
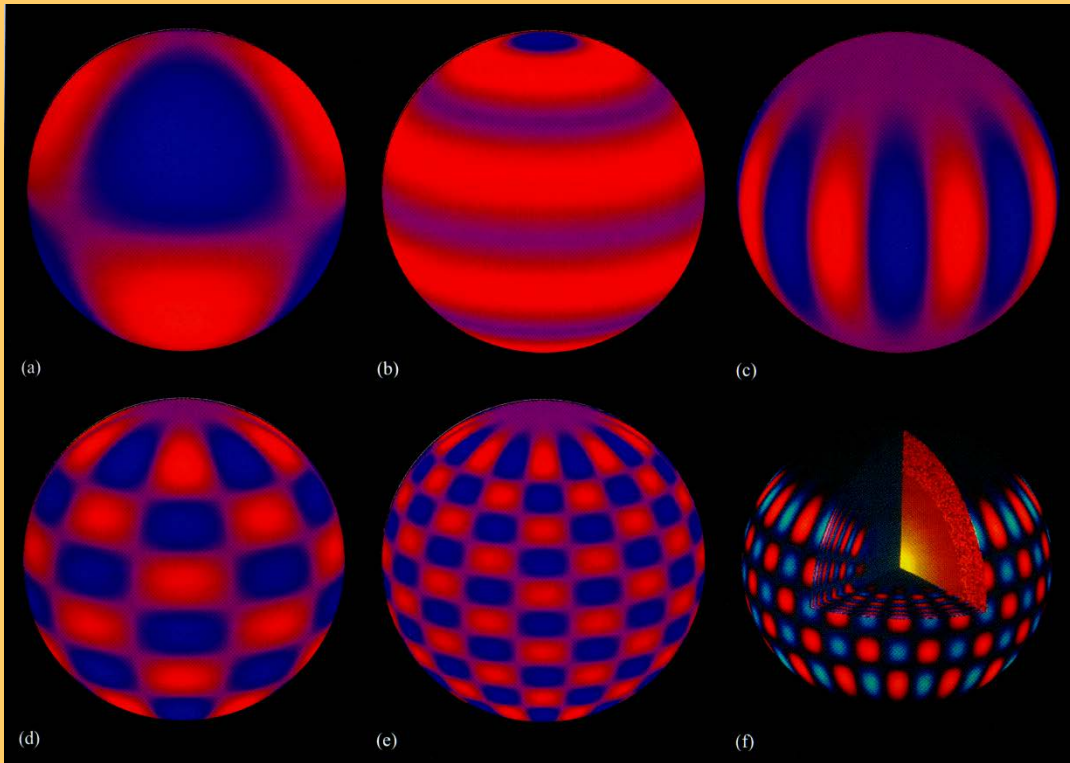


Models of nuclear reactions etc are tuned to *boundary conditions*.

These are e.g.

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

2. Helioseismology

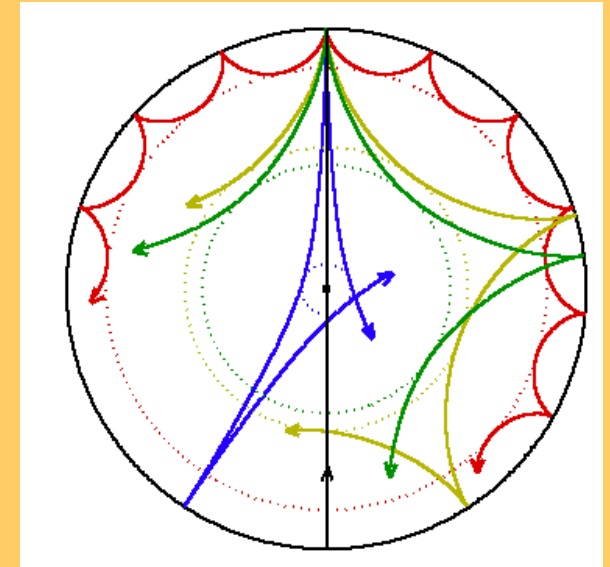
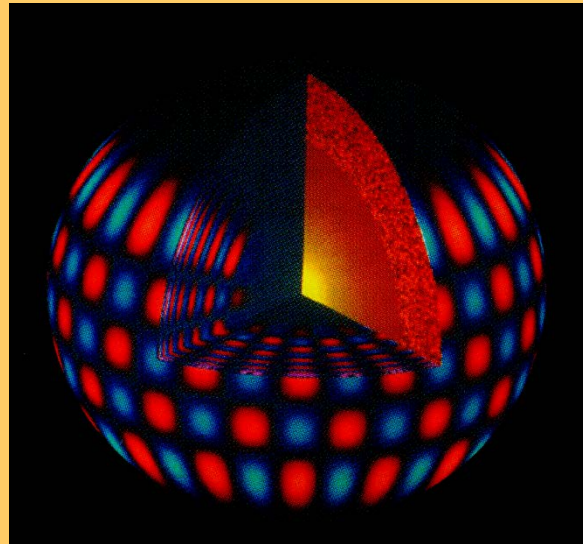
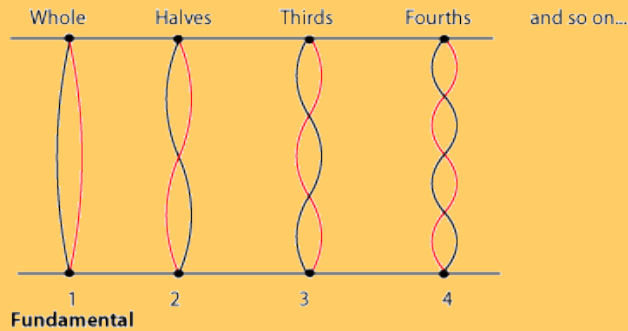


Sound speed.

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: $\lambda = 2L$

$$\lambda f = c_s$$

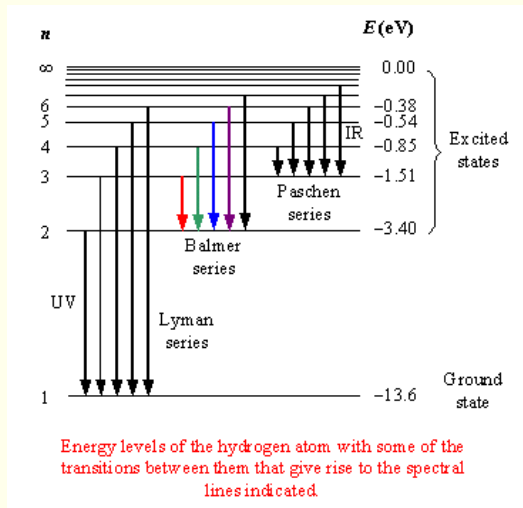
$$c_s = 2fL$$

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

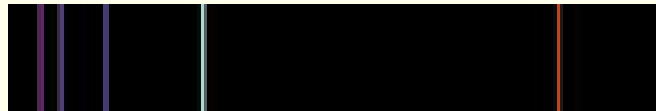
Solar atmosphere

Chromosphere

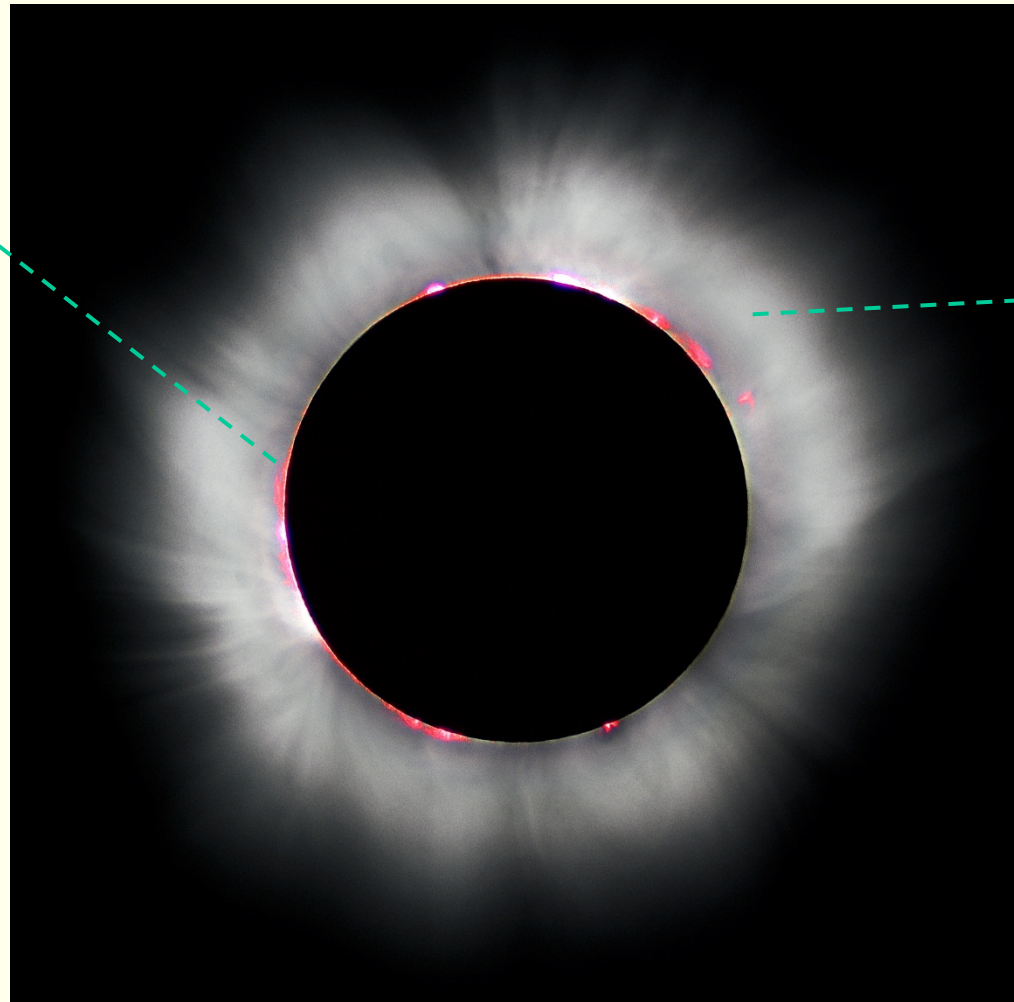
Reddish colour due to $H\alpha$ emissions.



$H\gamma$ 434 nm $H\beta$ 486 nm $H\alpha$ 656 nm



Balmer series

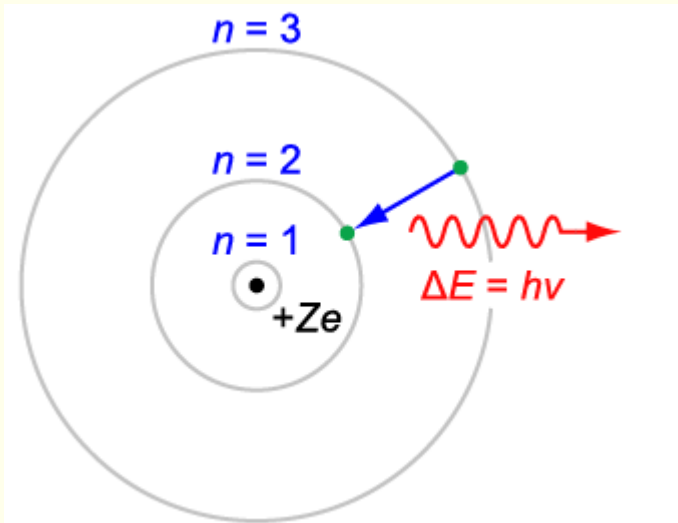


Corona

White light scattered from photosphere

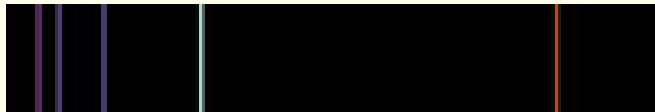
Total solar eclips

Hydrogen atom

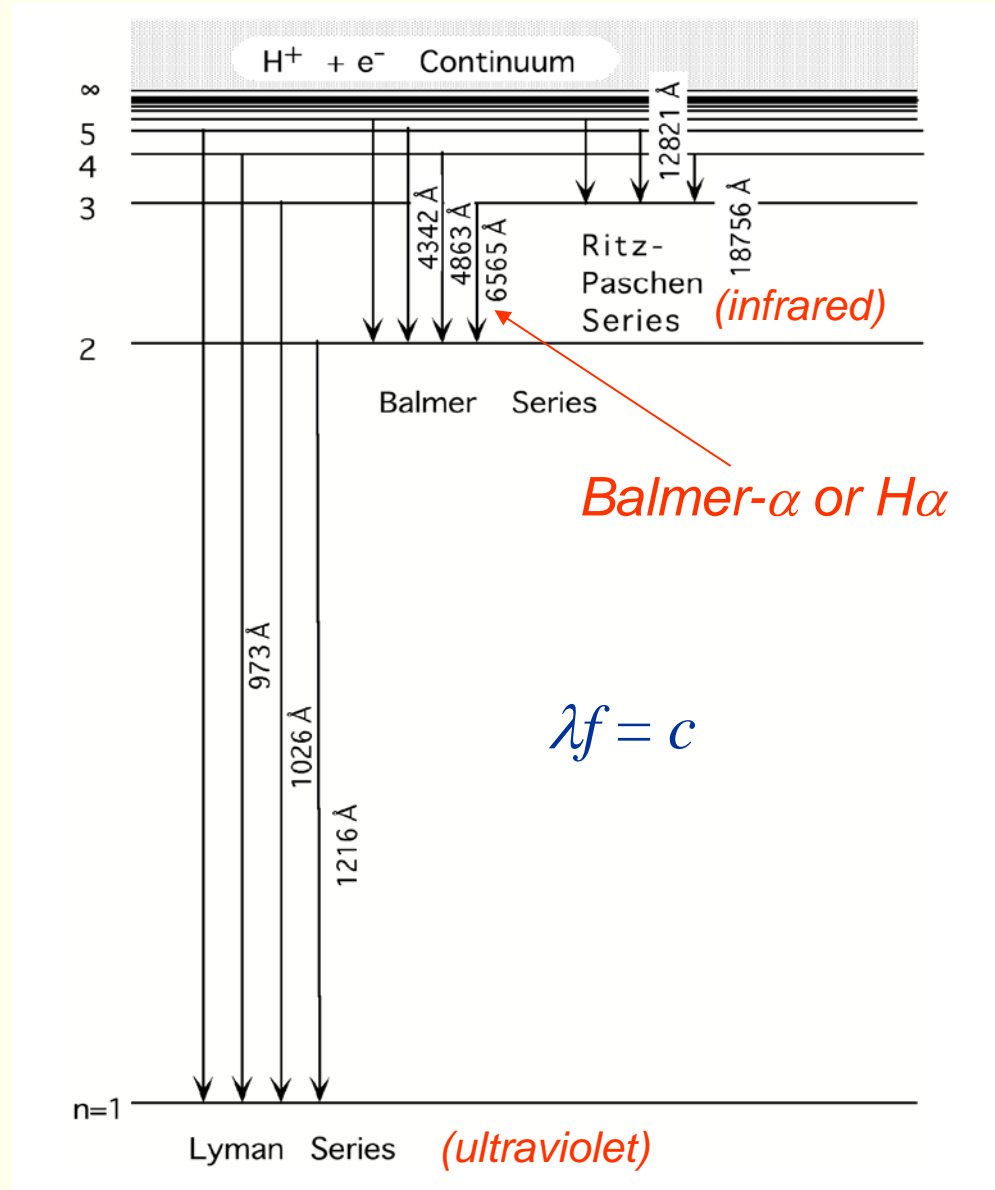


$H\gamma$ 434 nm $H\beta$ 486 nm

$H\alpha$ 656 nm

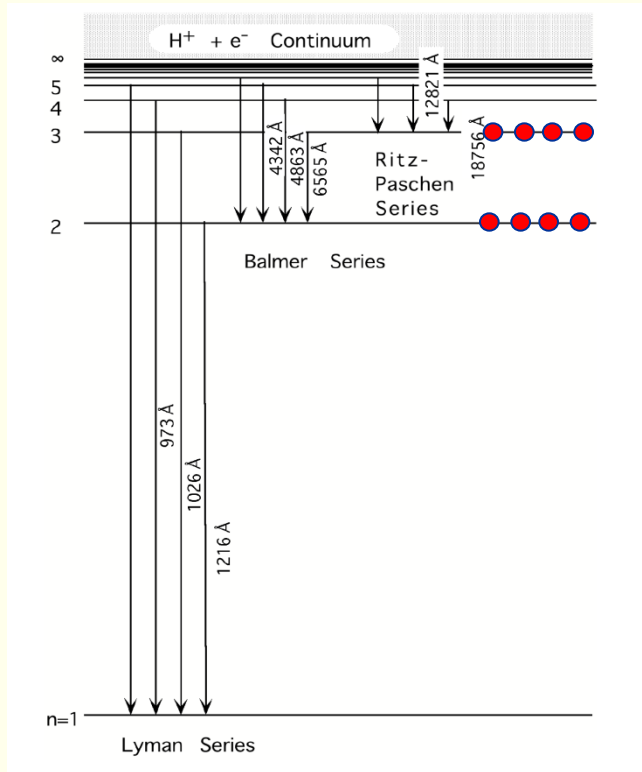


Balmer series

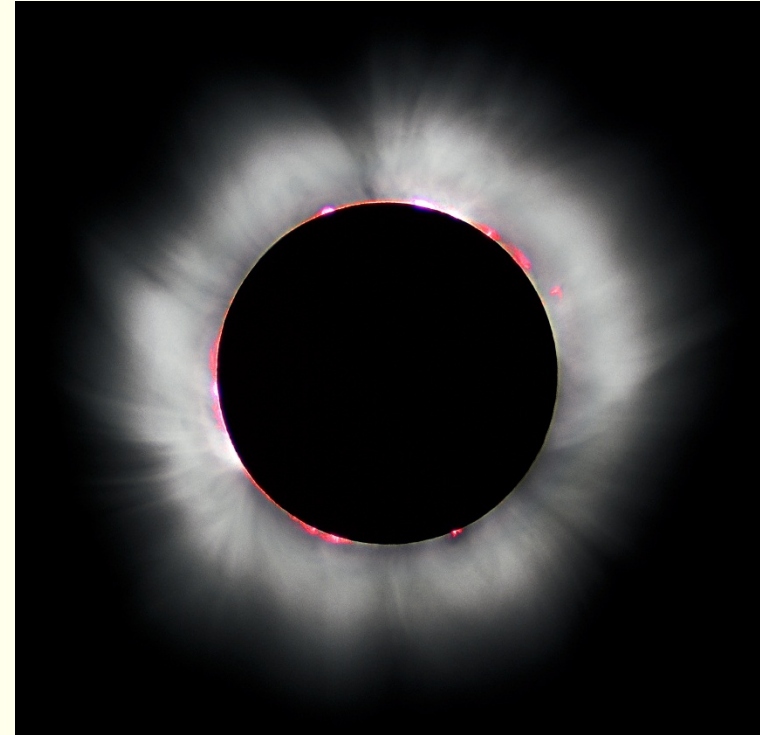


Why is the chromosphere red?

Hydrogen spectrum



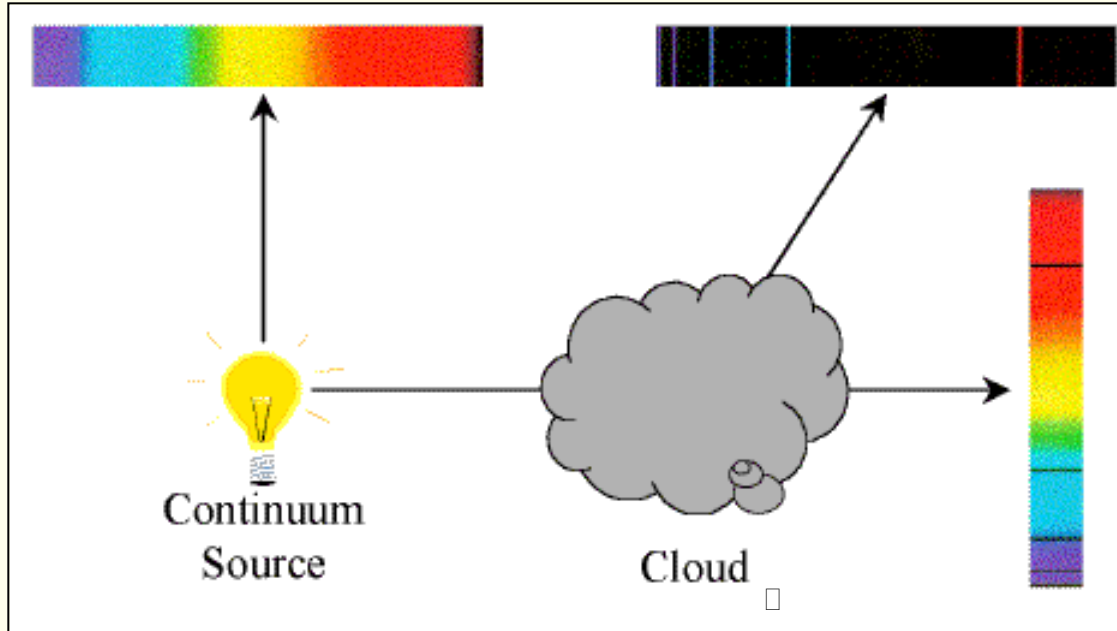
T_2
 T_1



H γ 434 nm H β 486 nm

H α 656 nm



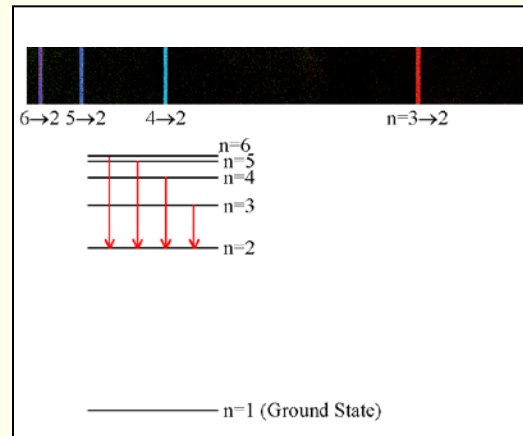


For non-blackbody thermal light emitter (for example a thin gas) it is more complicated. Spectrum depends e.g. chemical composition, and how many atoms/molecules happen to be in state with high probability to decay and cause emission.

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

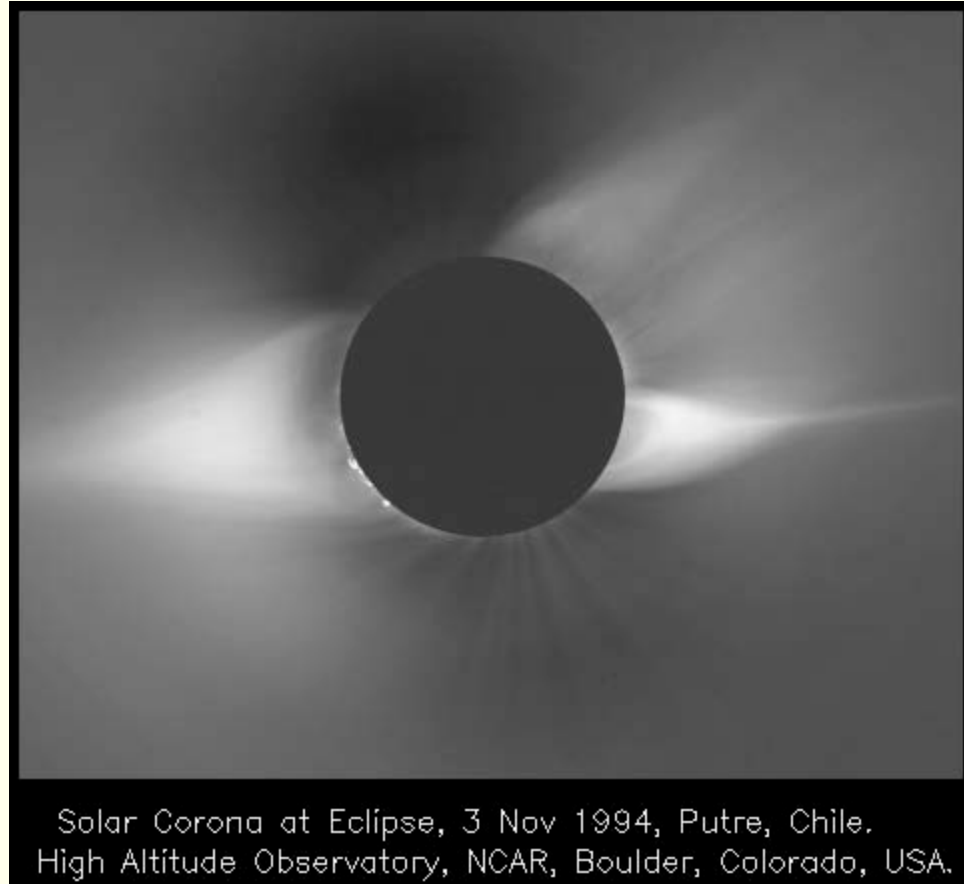
$$E \sim k_B T$$

$$E = hf$$

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

Corona

- Temperature: up to 2 MK
- Density: 10^{-18} g/cm³
– 10^{-24} g/cm³
- Turns into the solar wind at high altitudes, without a sharp boundary.



The layers of the solar atmosphere

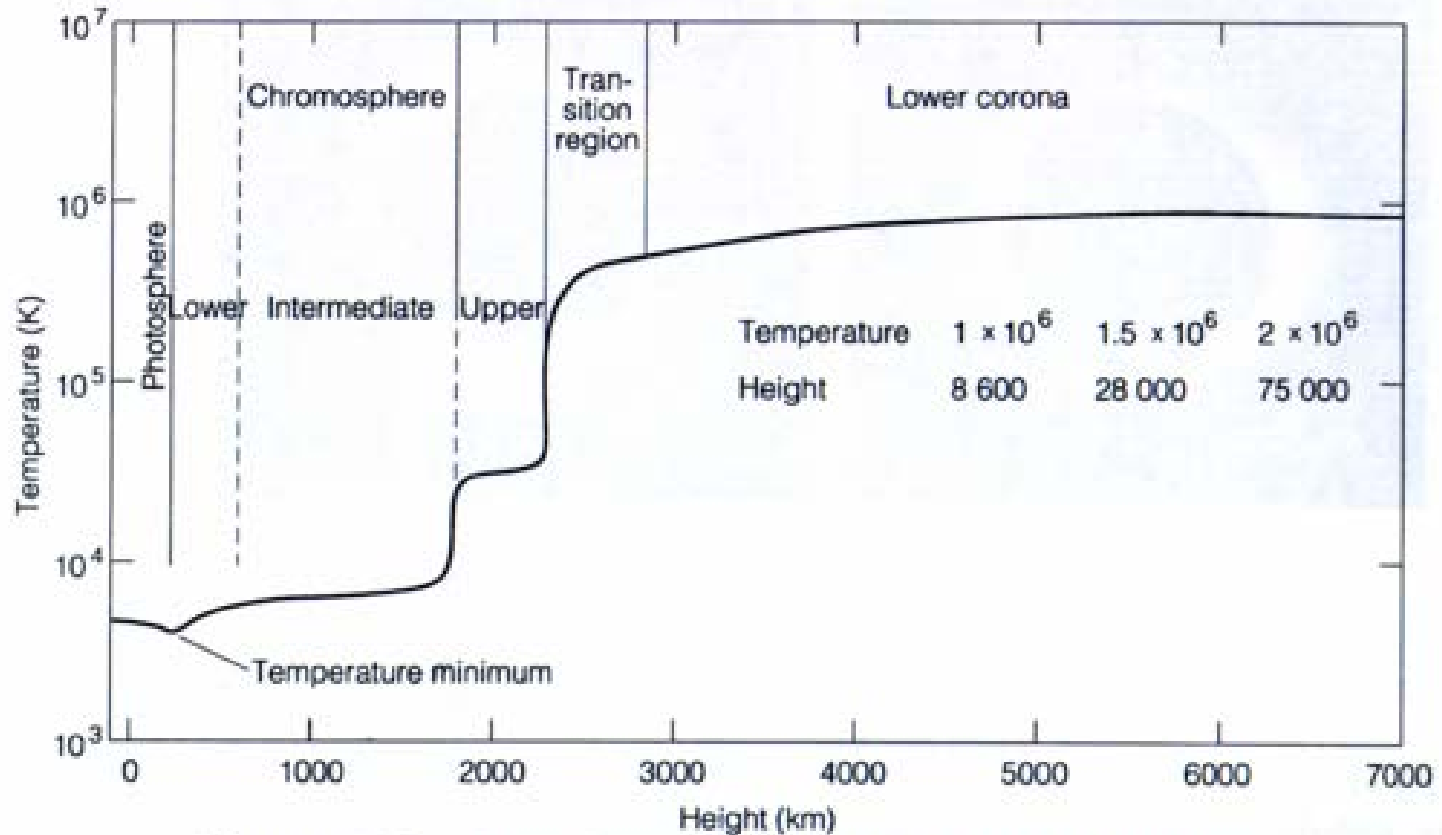


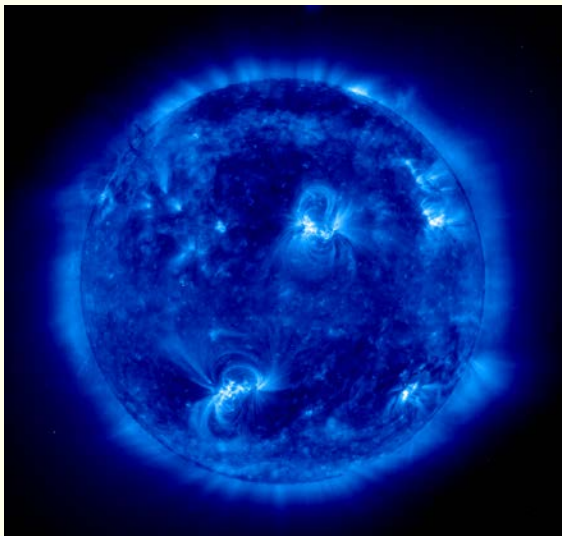
Figure 5.3. Distribution of average temperature in the solar atmosphere (Athay 1976).



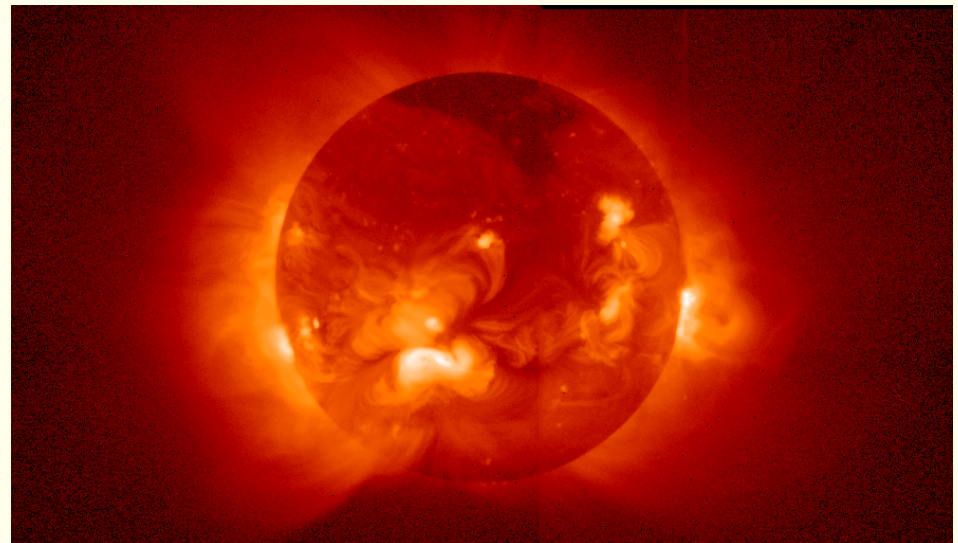
Visible light ~ 6768 Å



He II emission line at 304 Å

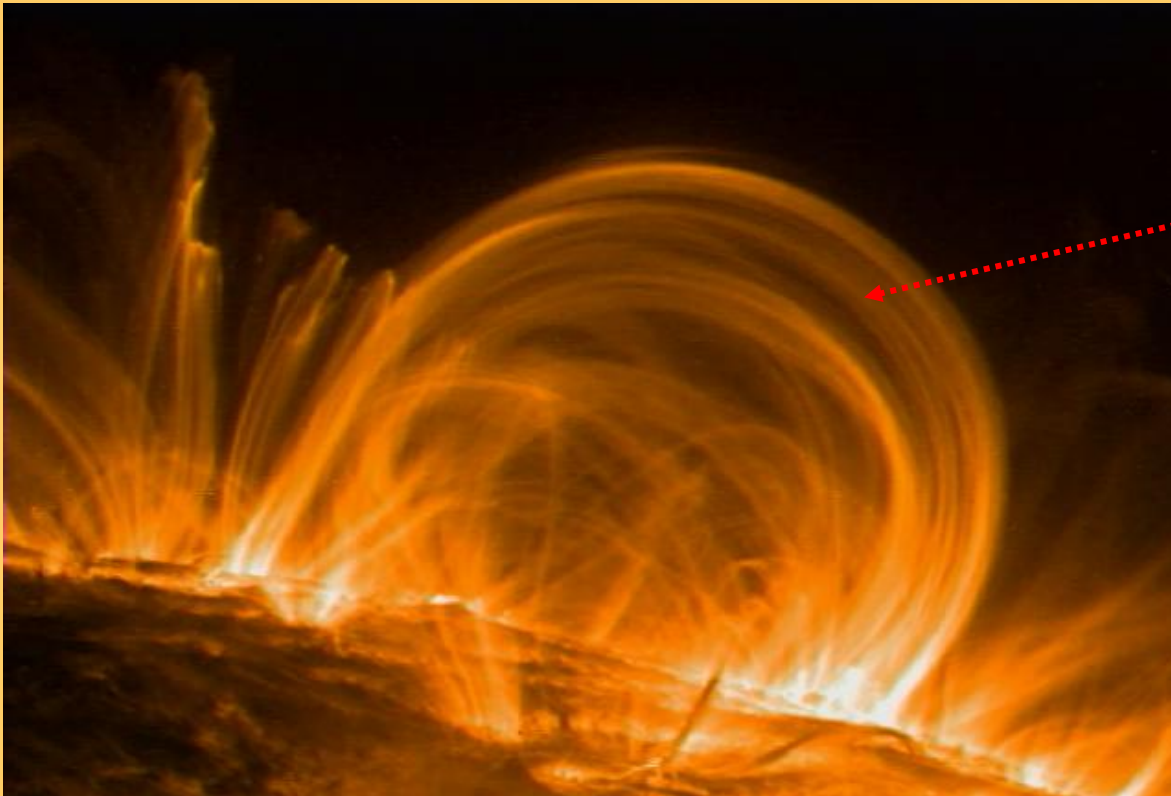


(Fe IX/X) at 171 Å



X-ray at 0.3-5 Å

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