STARS - S11

Wladimir (Wlad) Lyra
Brian Levine

AMNH After-School Program

AMERICAN MUSEUM OF NATURAL HISTORY

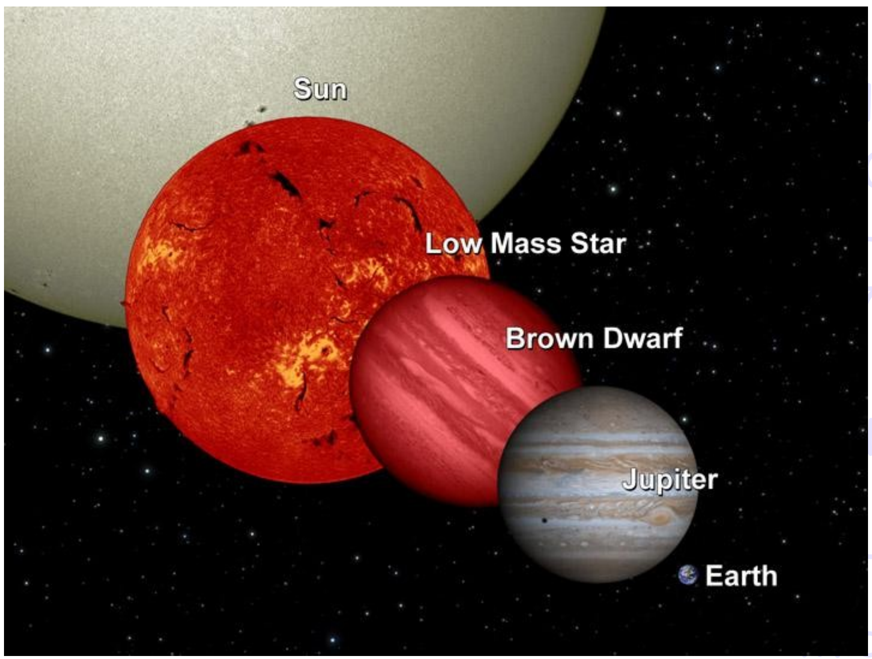
From last class

Brown dwarfs are runt stars, formed by the same way,
but do not have much mass to fuse hydrogen

They fuse deuterium for a little while (10 Myr)

Masses range from the

Hydrogen Burning Limit (80 M_J) to the Deuterium Burning Limit (13 M_J)



are similar to Jupiter's

types – OBAFGKM - LTY

0 K, water and hydrite lines

- 1300 K, methane lines

700 K, ammonia lines

galaxy may also have free floating planets

letection methods

al Velocity

Transit

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Direct imaging

Kepler mission

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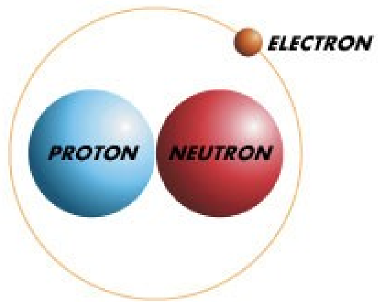

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L dwarfs – 130 … nd hydrite lines

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Y dwarfs - < 700 K, ammonia lines

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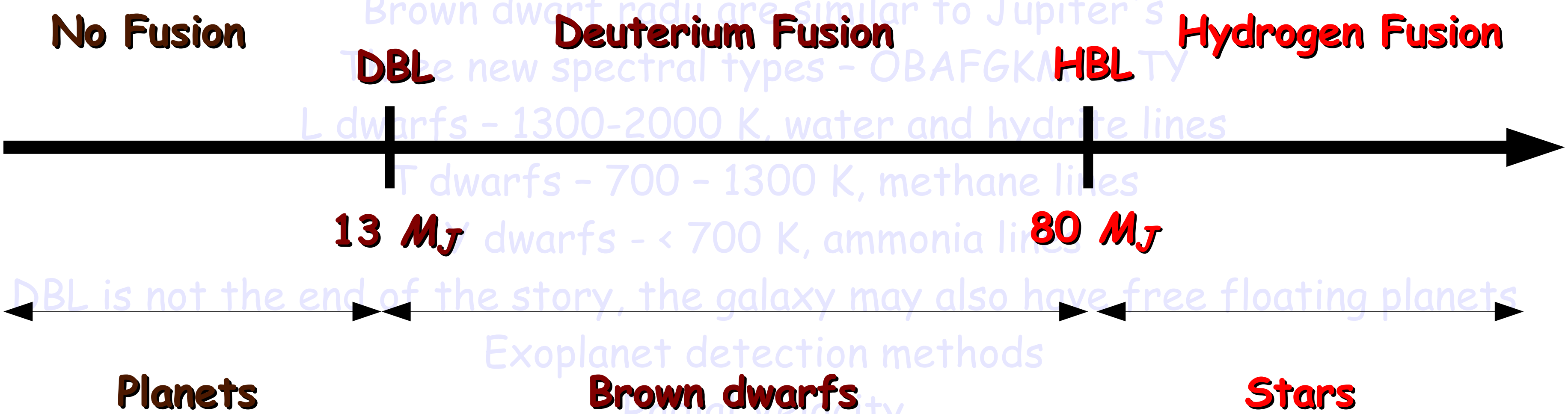

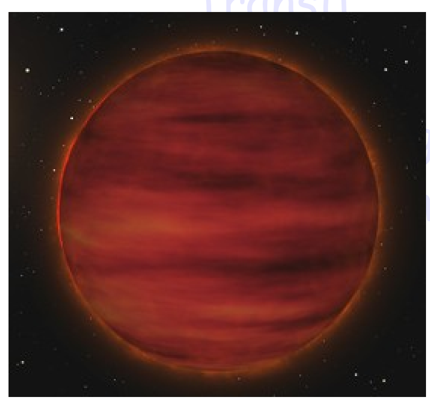

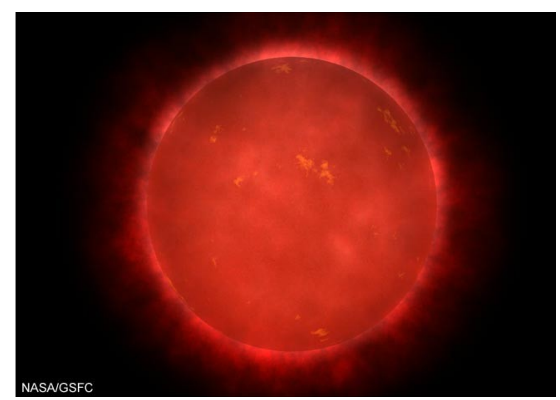

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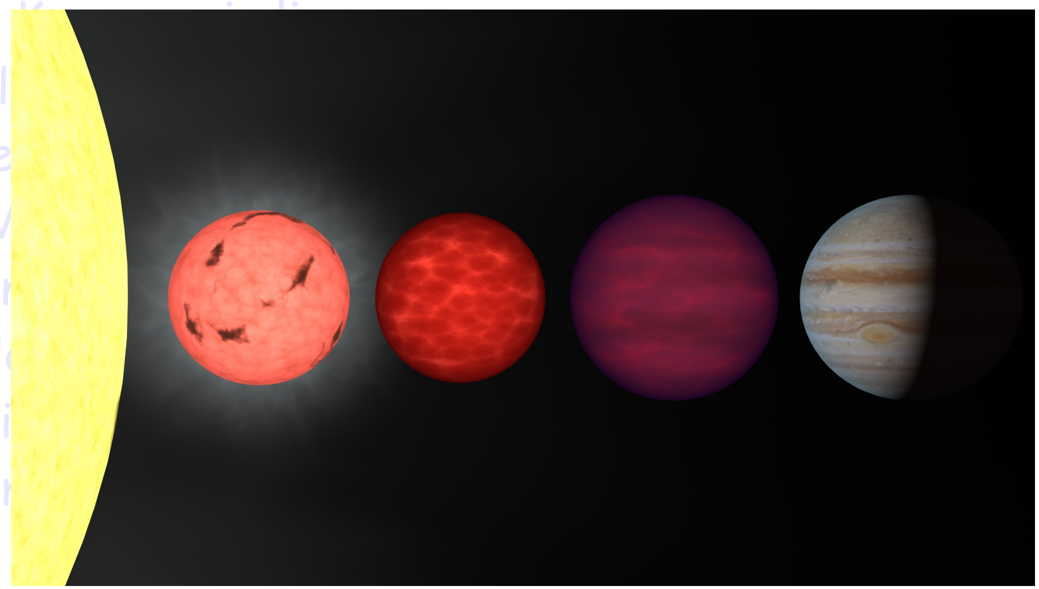
Direct i
Kepler

They are degenerate gas!
In this regime, adding mass
just makes stuff denser.



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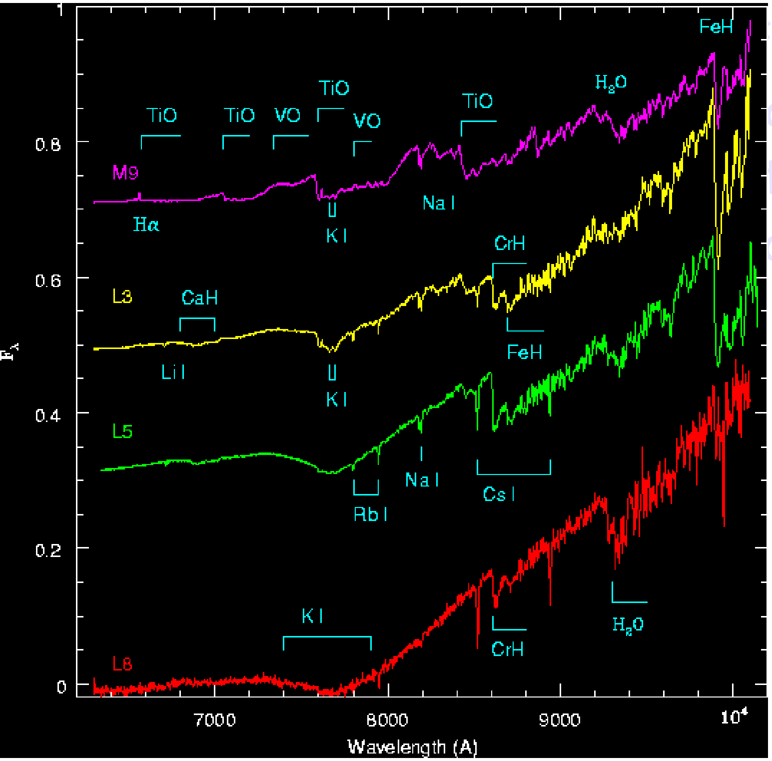

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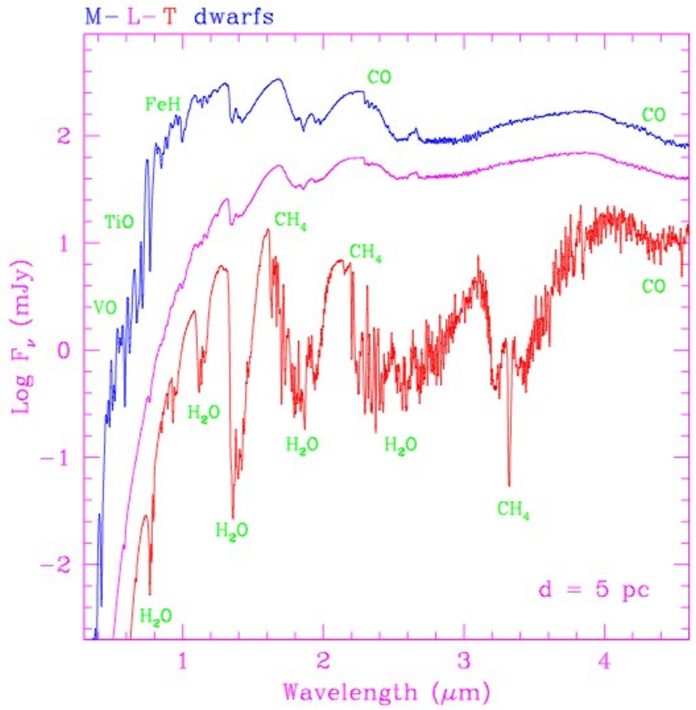

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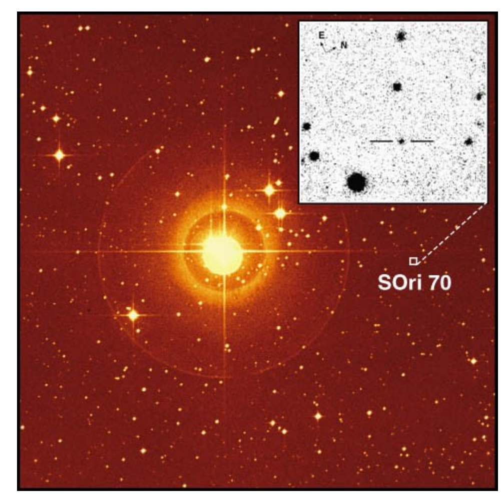

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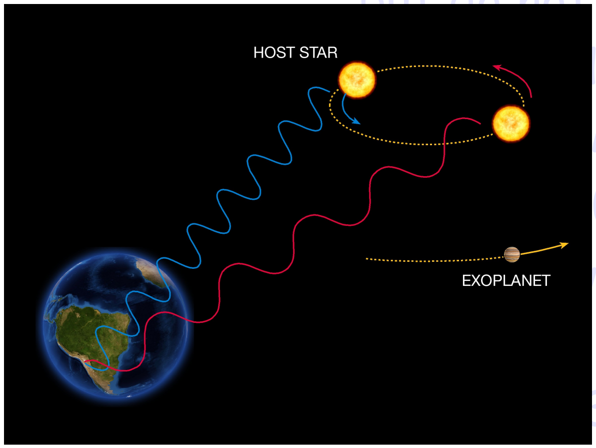
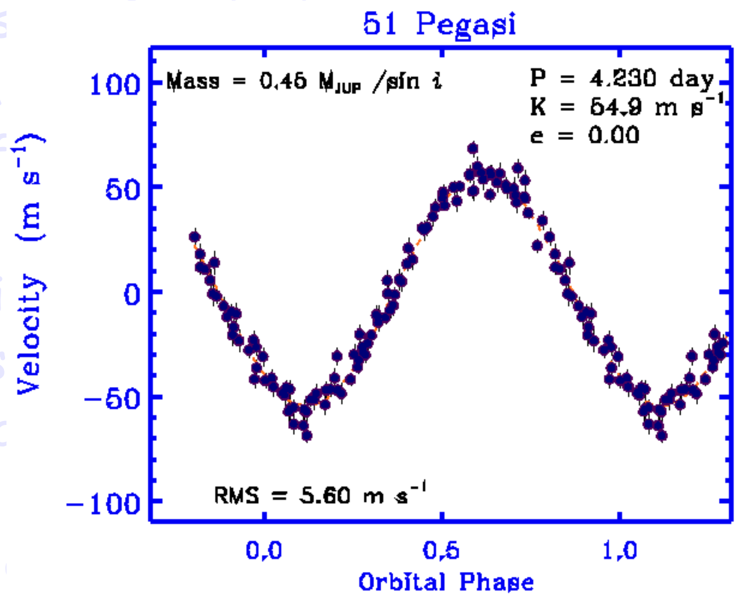


The Radial Velocity Method

ESO Press Photo 22e/07 (25 April 2007)



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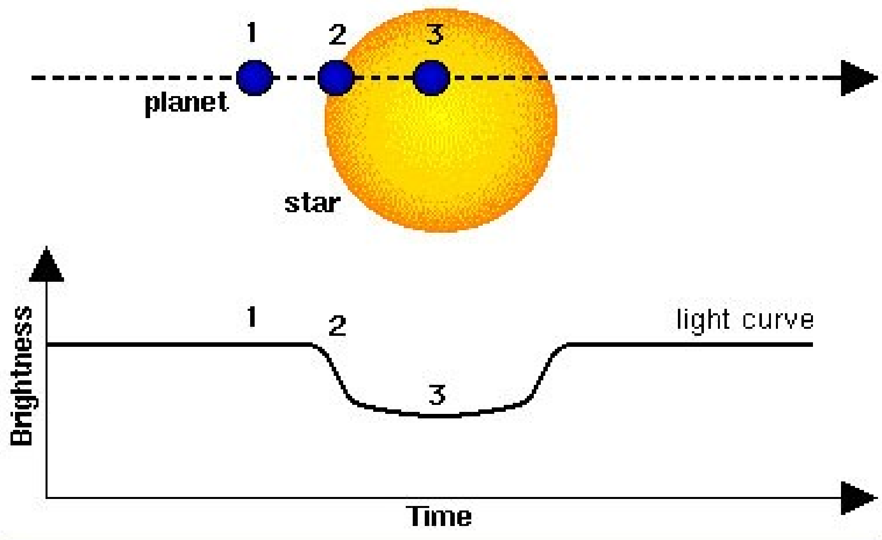

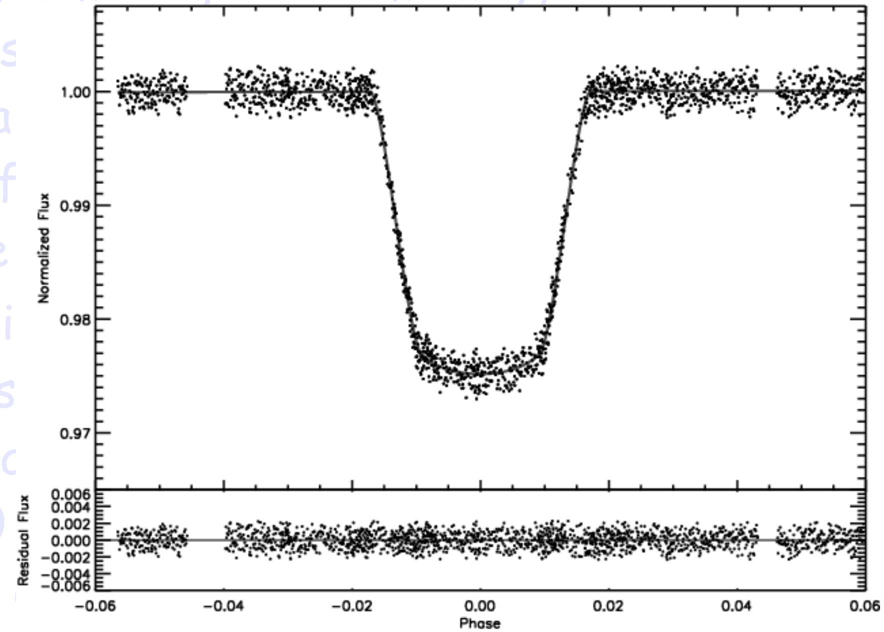

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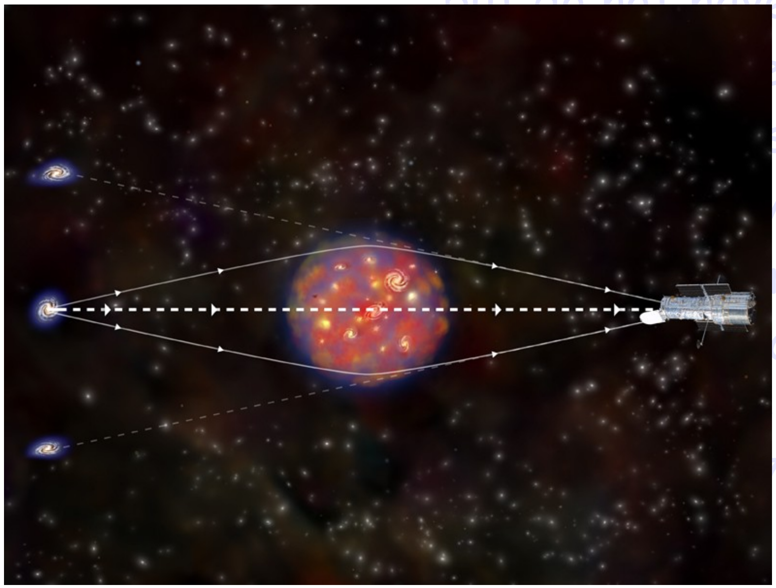

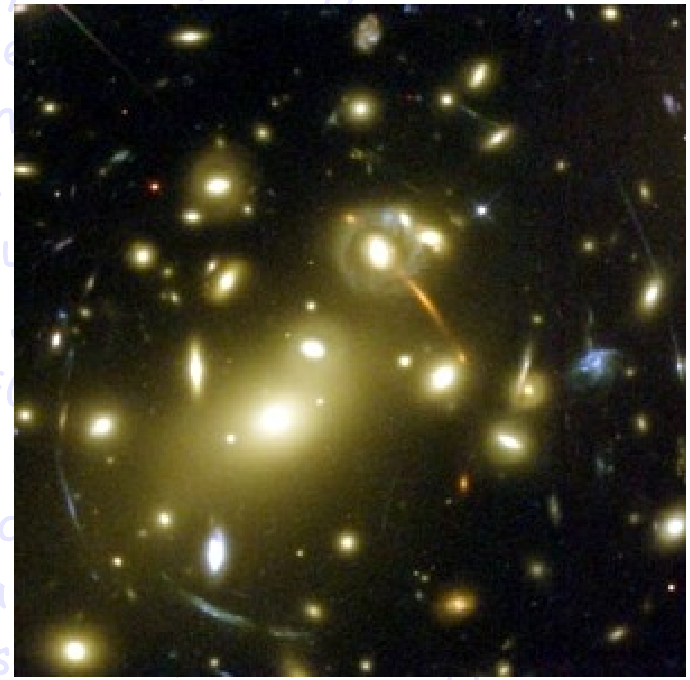

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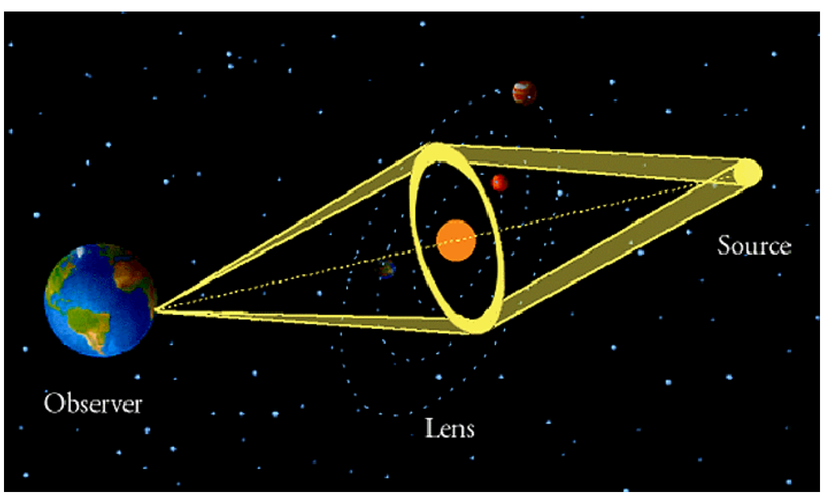

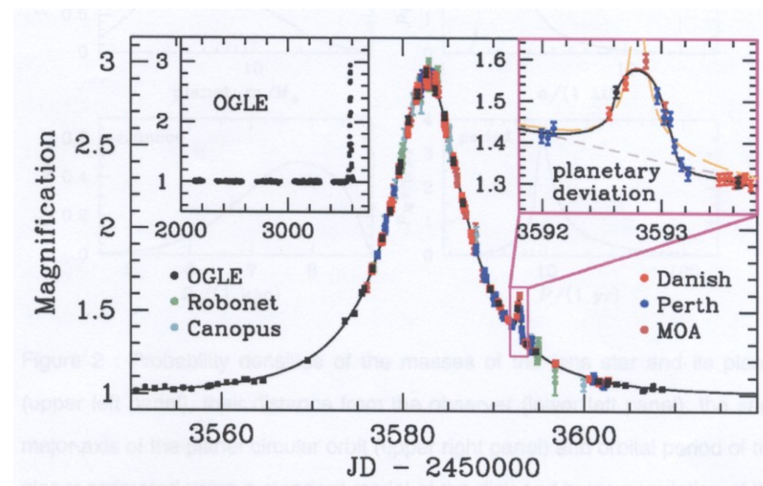

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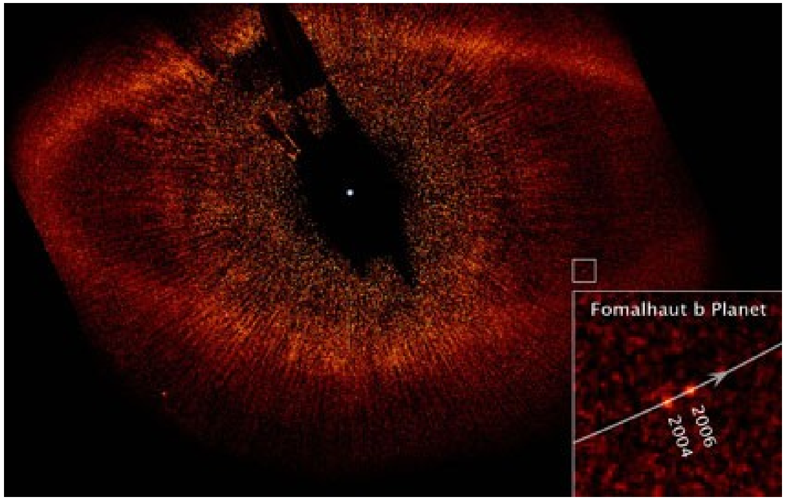
Extrasolar planets – Direct Imaging

Fomalhaut
A3V star, V=1.2
8 parsecs away

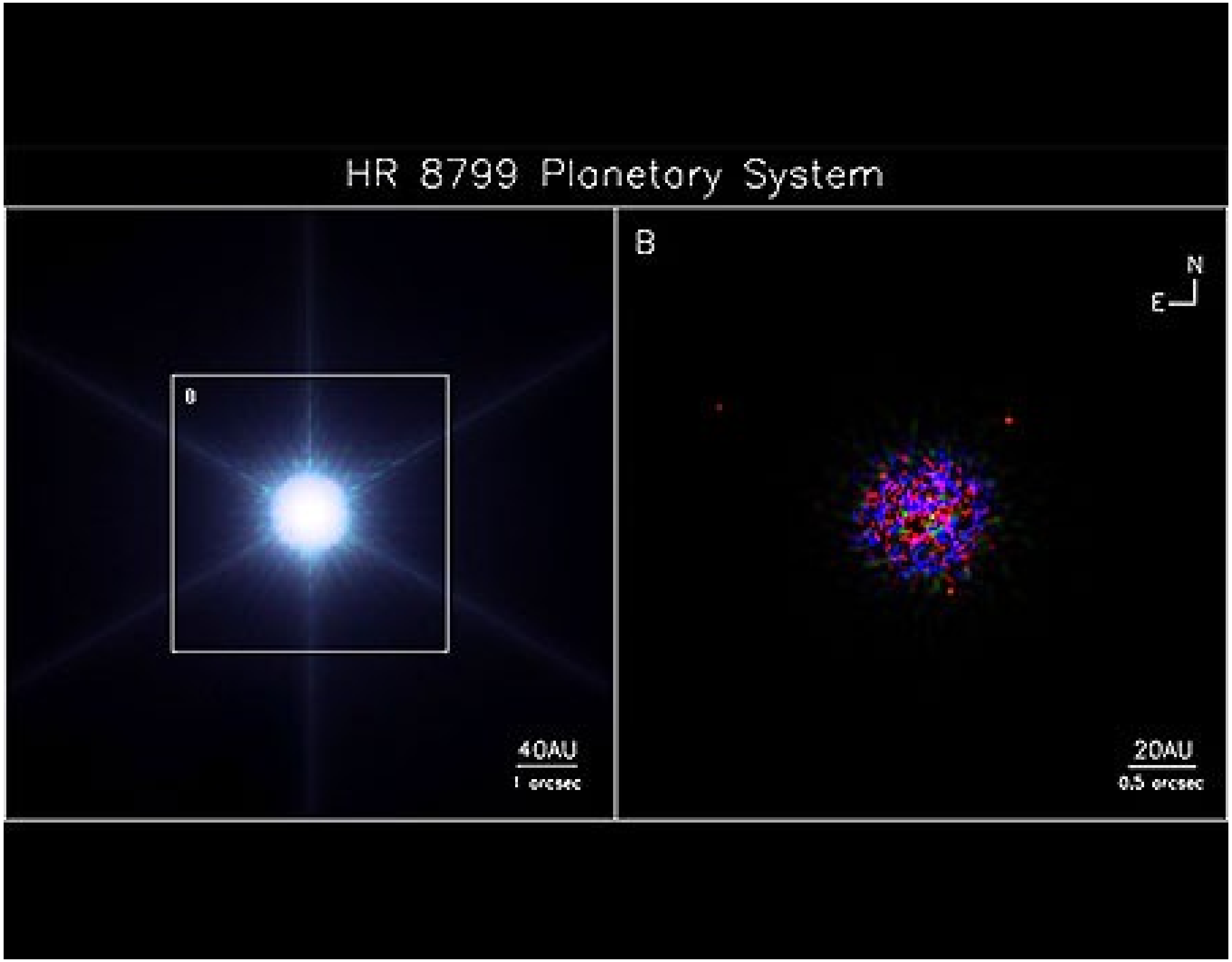
A firefly next to a lighthouse

Block the starlight
and check the surroundings

**"Block-image" thousands of stars
and hope for the best**



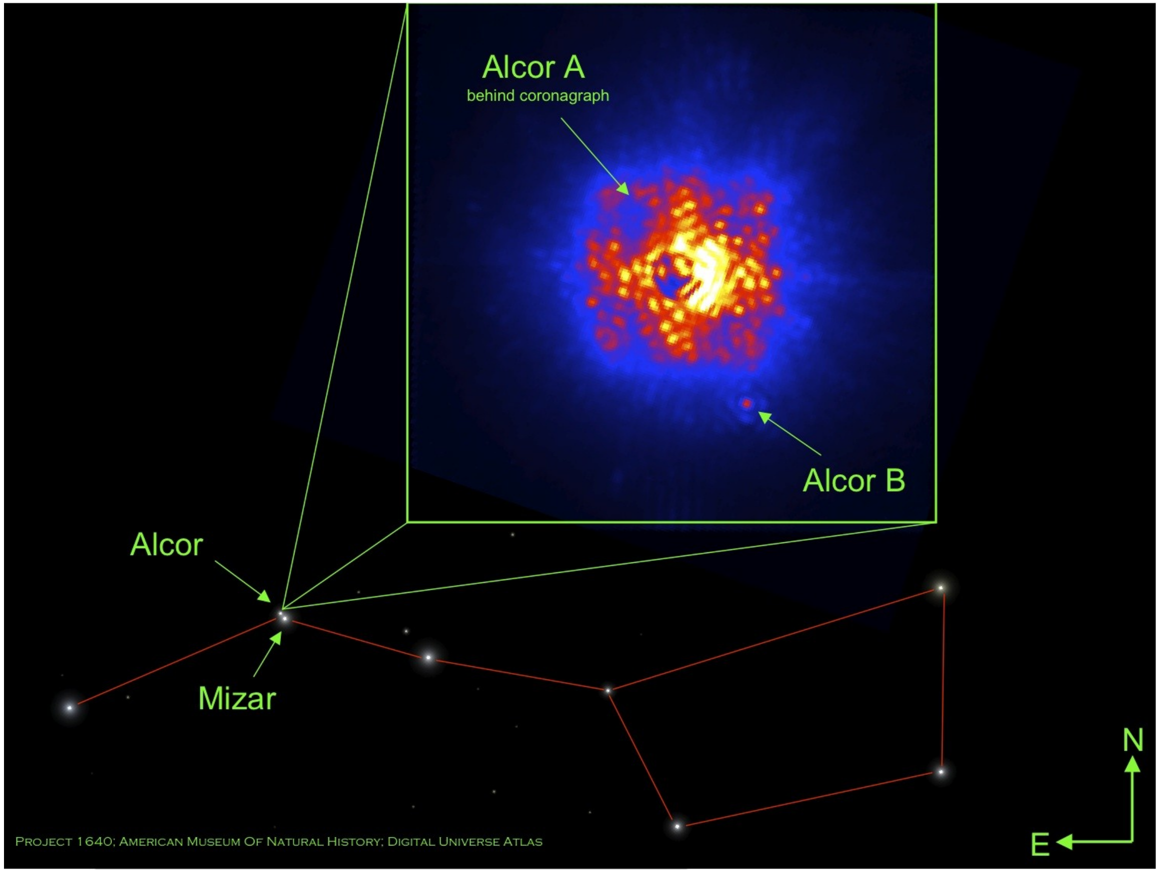
Extrasolar planets – Direct Imaging



3 planets around HR 8799

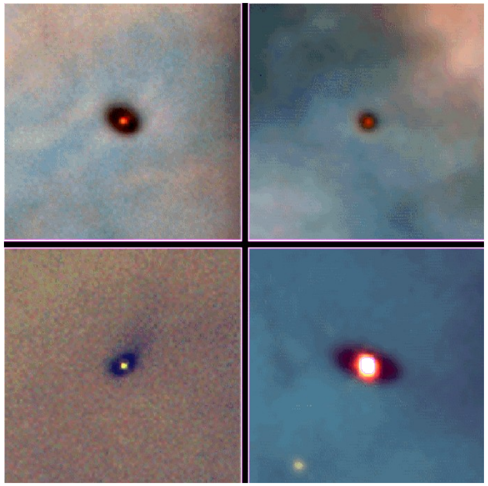
Extrasolar planets – Direct Imaging

Sometimes you find things you were not looking for...

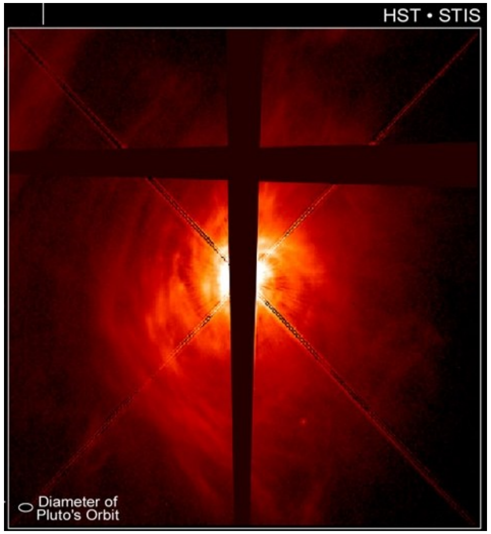


A previously unknown **red dwarf** around Alcor

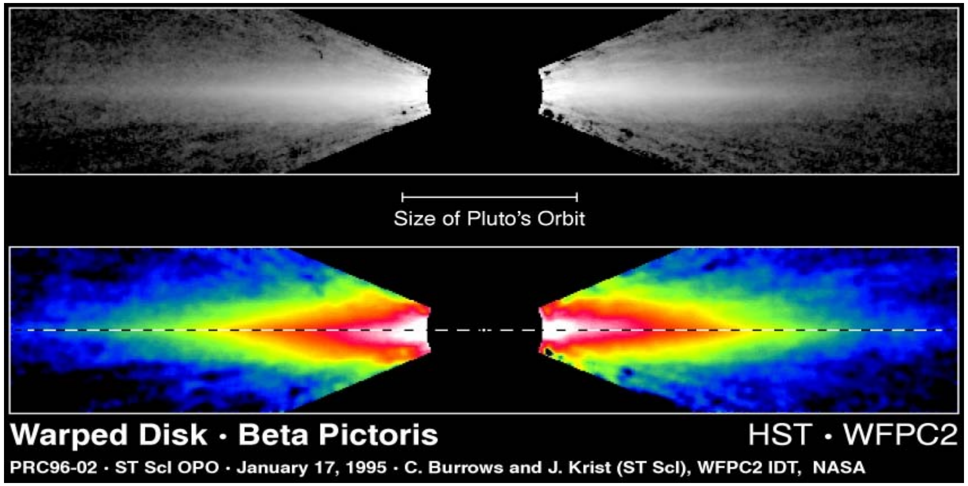
Planetary Cradles – Circumstellar Disks



Disks in the Orion Nebula
Dark against a bright background



Disk around AB Aurigae
Warm dust shines in Infrared

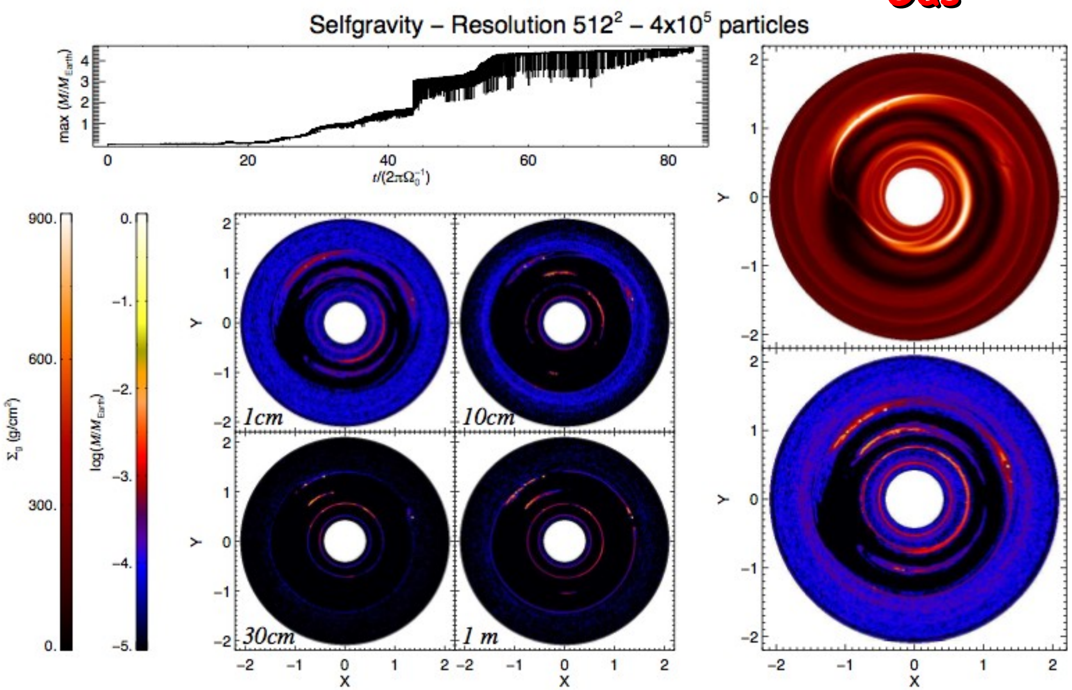


Massive disk around Beta Pictoris

The wake of a planet in the AB Aurigae disk

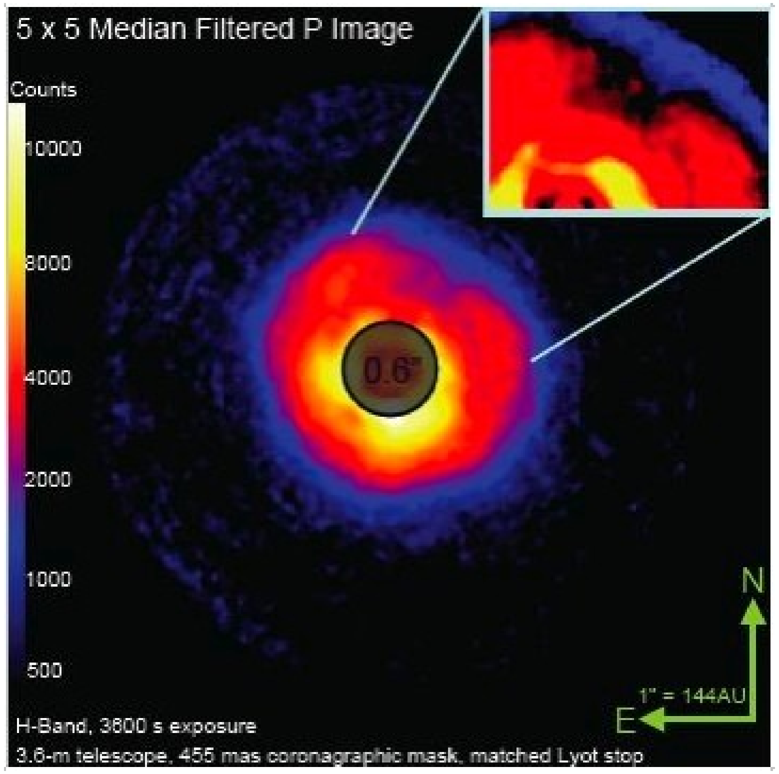
Theoretical prediction

Gas



Dust

Observation



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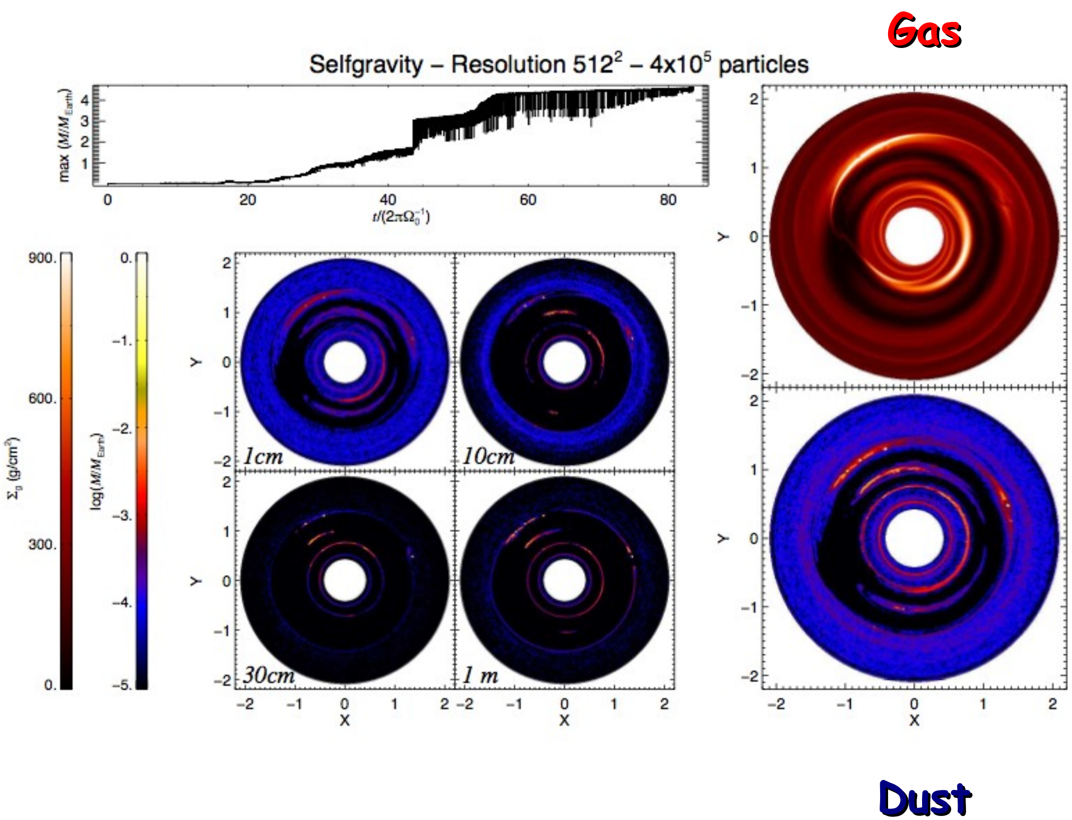
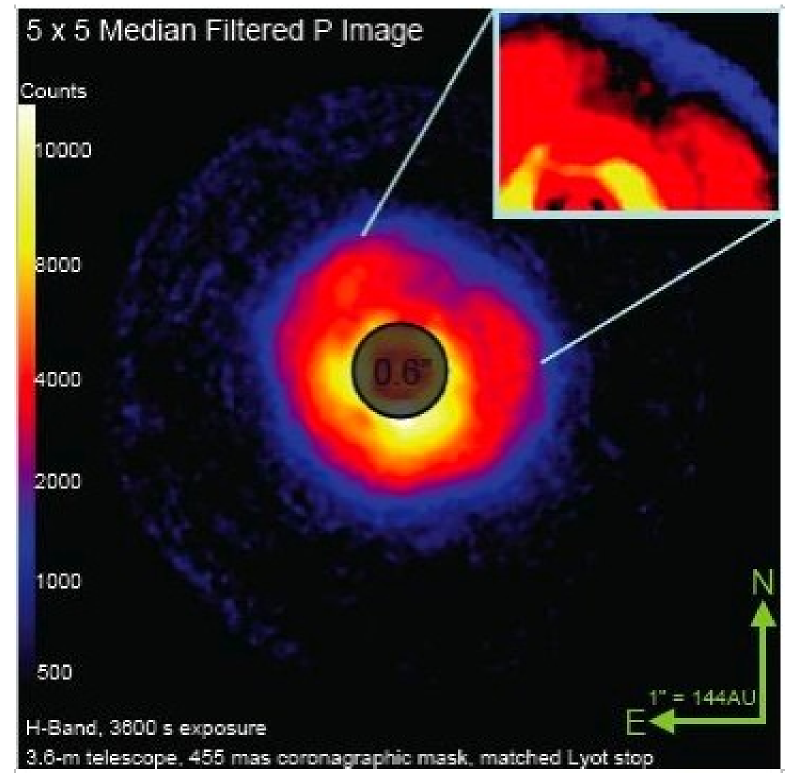


Lyra et al. (2009)

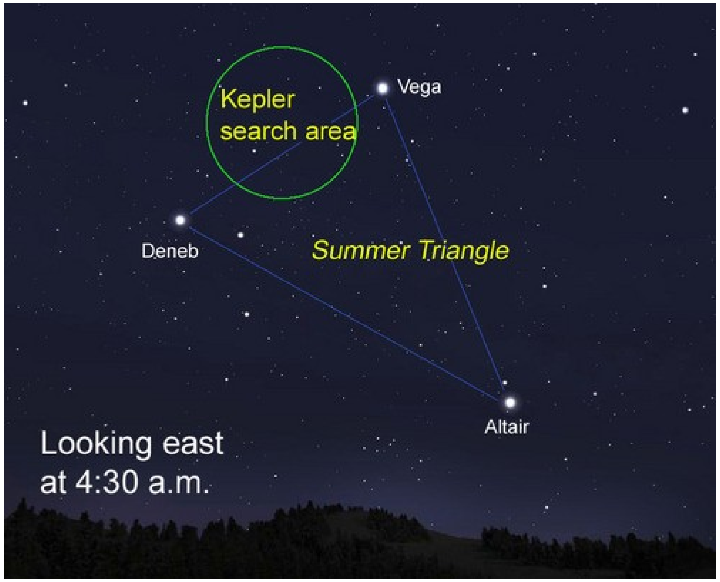
Observation



Oppenheimer et al. (2009)

Go AMNH !!

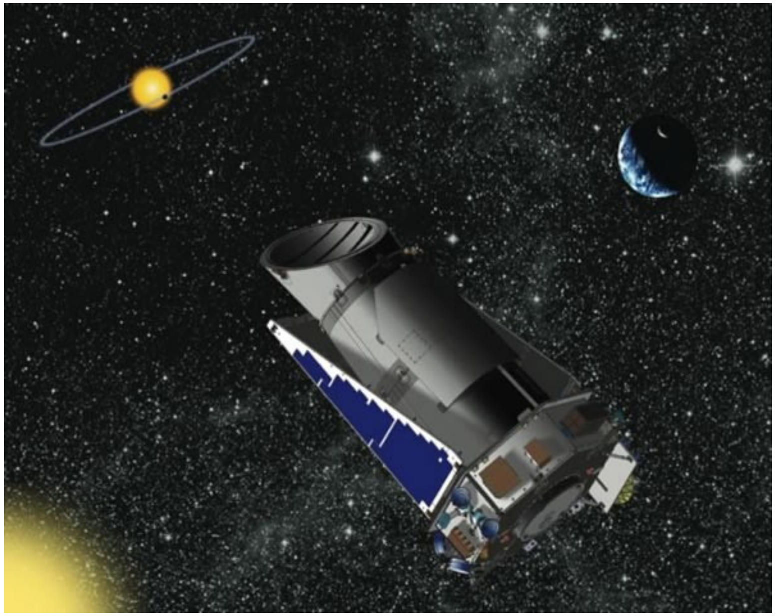
Kepler mission



Goal: Detect transits of Earth-sized exoplanets

Measure light curves
for thousands of stars
and hope for the best

Continuously observe a single area of the sky, monitoring 150,000 stars



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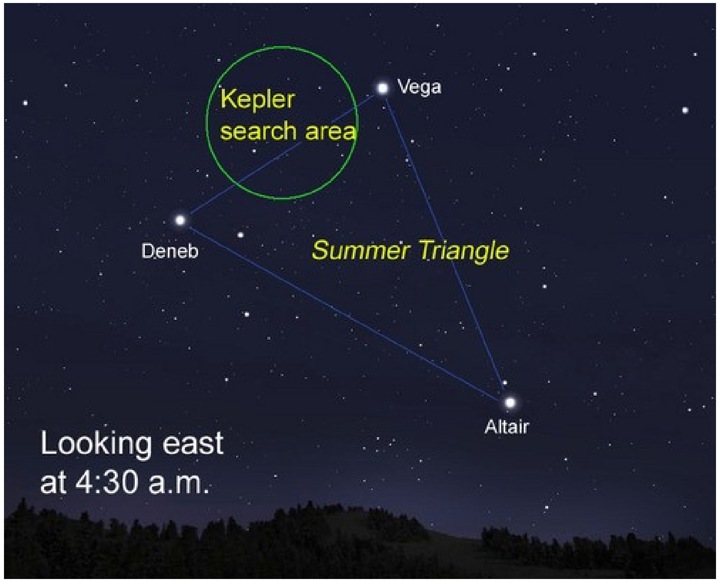

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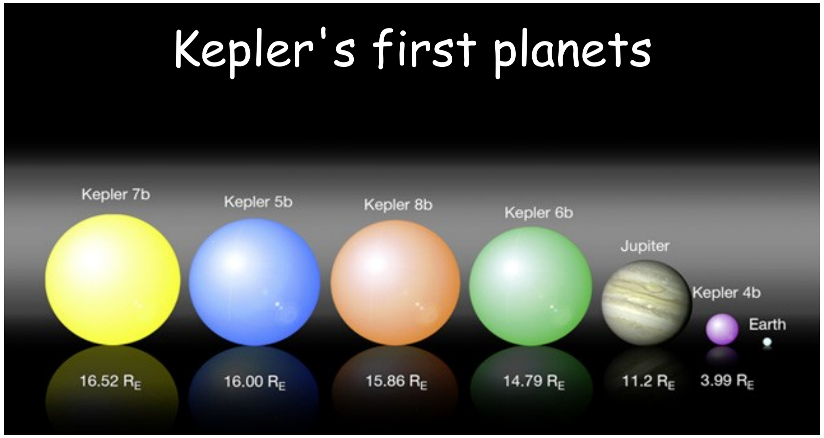
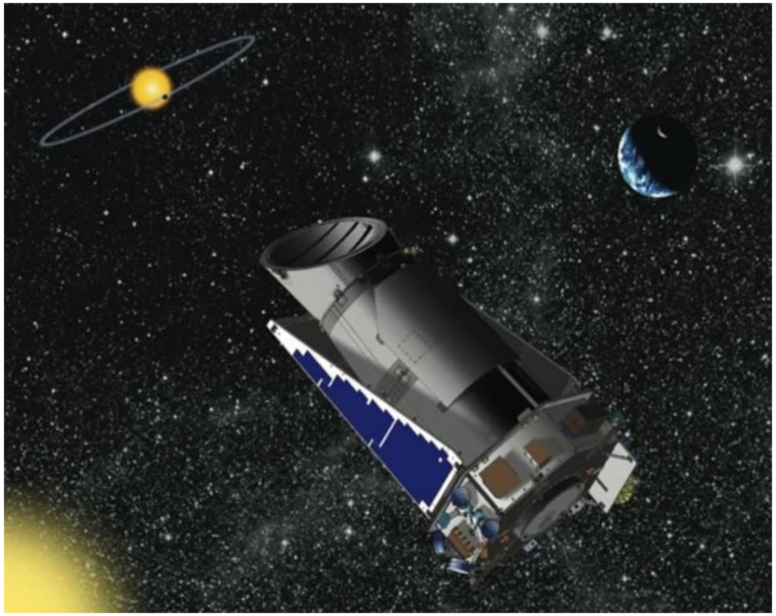


Hot Jupiters. More of the same.
But stay tuned!!



Outline

- Solar Physics
  - Stable vs Unstable Hydrostatic equilibrium
    - Radiative and Convective Zones
  - Magnetic Fields
    - Sunspots
      - The solar cycle
      - The butterfly diagram
    - The solar dynamo
    - Differential Rotation and Meridional Circulation
    - Solar Flares
      - Magnetic Reconnection
    - The Solar Corona
      - Coronal Heating
      - Solar Wind

Stellar Astrophysics vs Solar Physics

Wait a minute, the sun is a star, what is the difference?

Stellar Astrophysics vs Solar Physics

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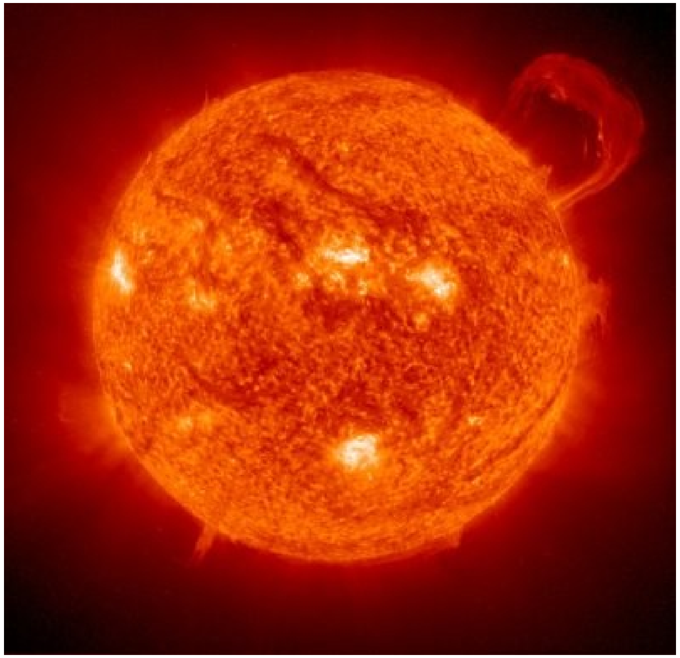
Tiny light dots



An awful lot of details to explain!

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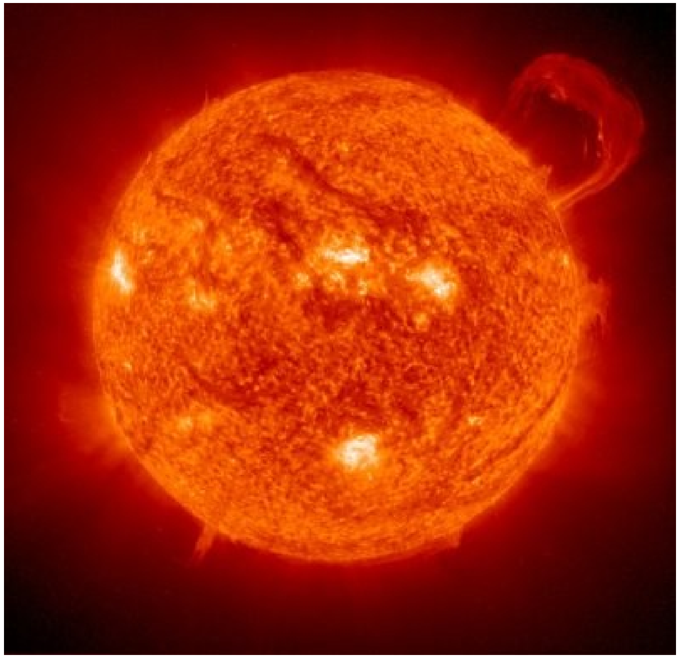


An awful lot of details to explain!

Complementary fields

Studying **stars** helps placing the **Sun** in context.

Studying the **Sun** helps understanding **stars**.

The Sun

Above its surface, the sun appears to have a corona
The corona is measured to be very hot (1,000,000 K)

The solar wind. … f 10^{-14} Msun/yr

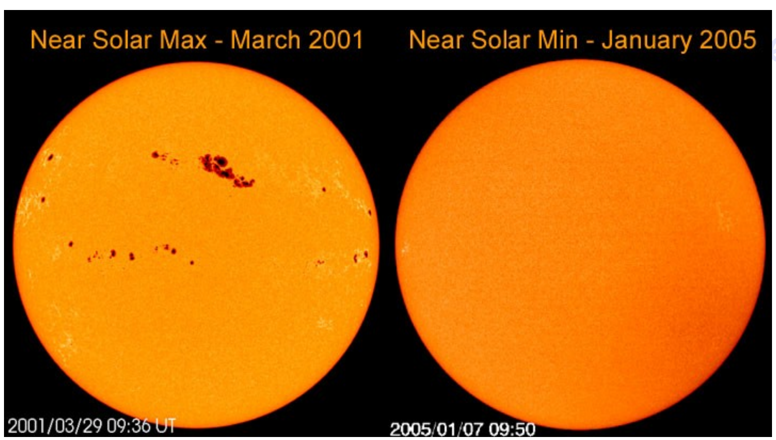
Solar … tions

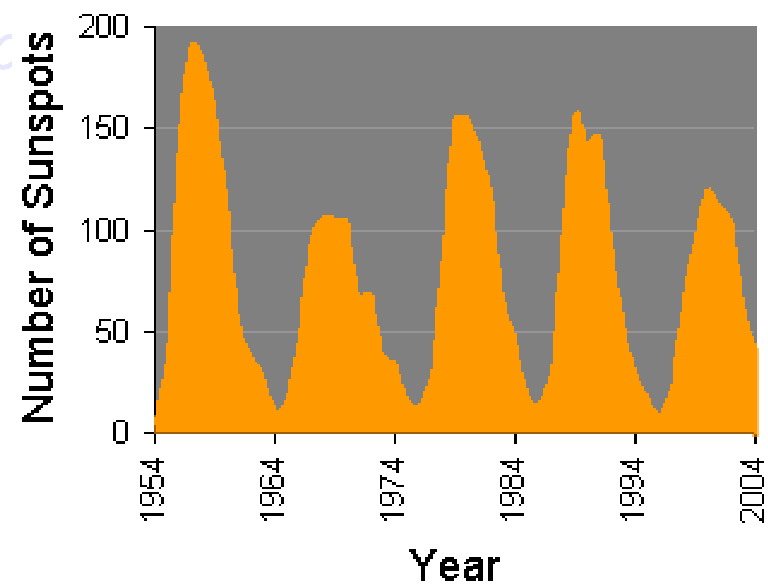
The Sun

Above its surface, the sun appears to have a corona
The corona is measured to be very hot (1,000,000 K)

Sunspots that show a cycle of 11 years

The solar wind. The sun emits charged particles at the rate of 10^{-14} Msun/yr





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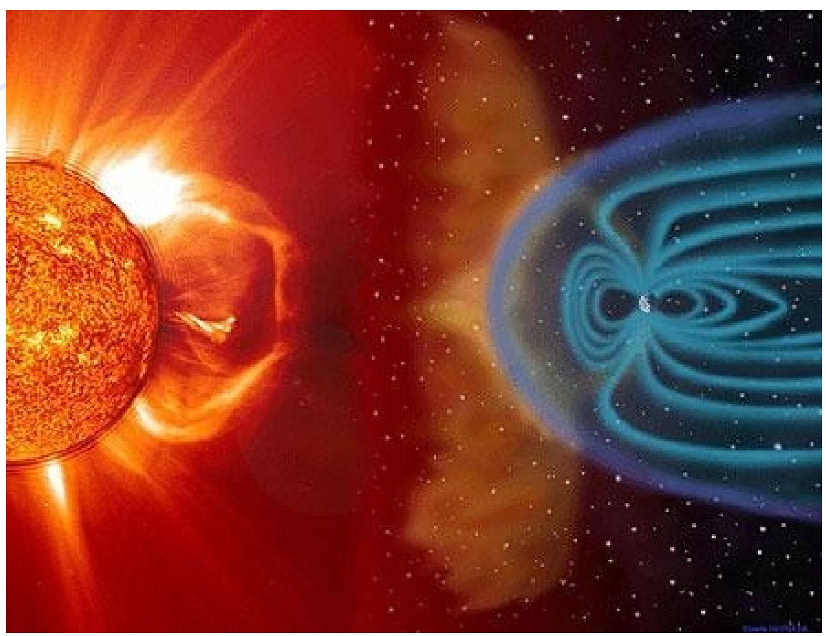
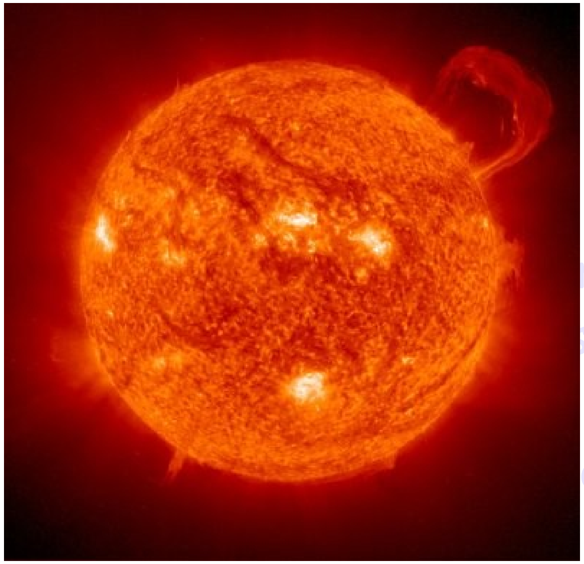
Solar Pror Ejections



The Sun



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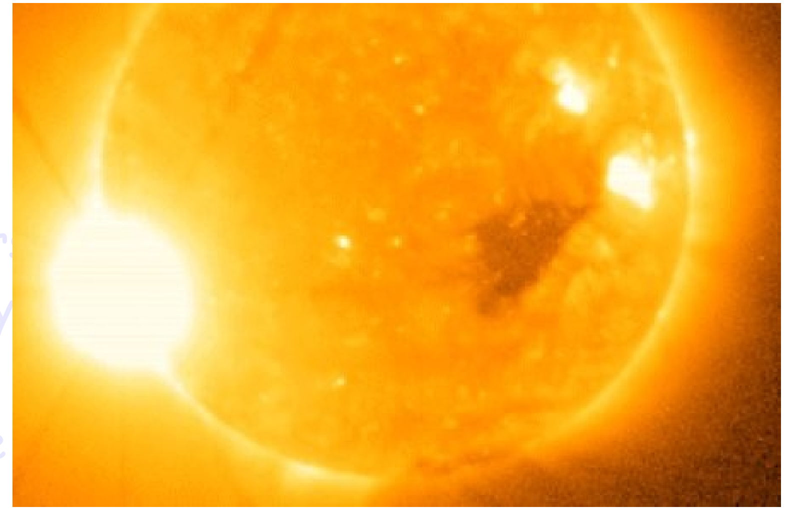


The solar wind. The sun emits charged particles at the rate of 10^{-14} Msun/yr

Solar Prominences, Solar Flares, Coronal Mass Ejections

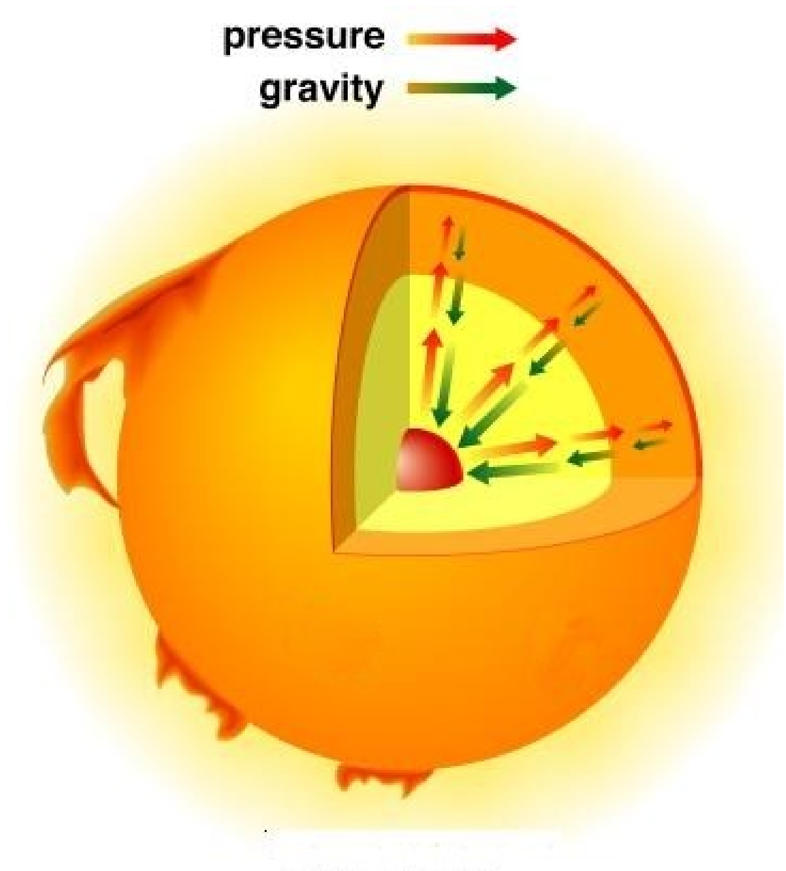
A fusor in hydrostatic equilibrium

<u>Hydrostatic equilibrium</u>

A tug of war between

(outwards) PRESSURE

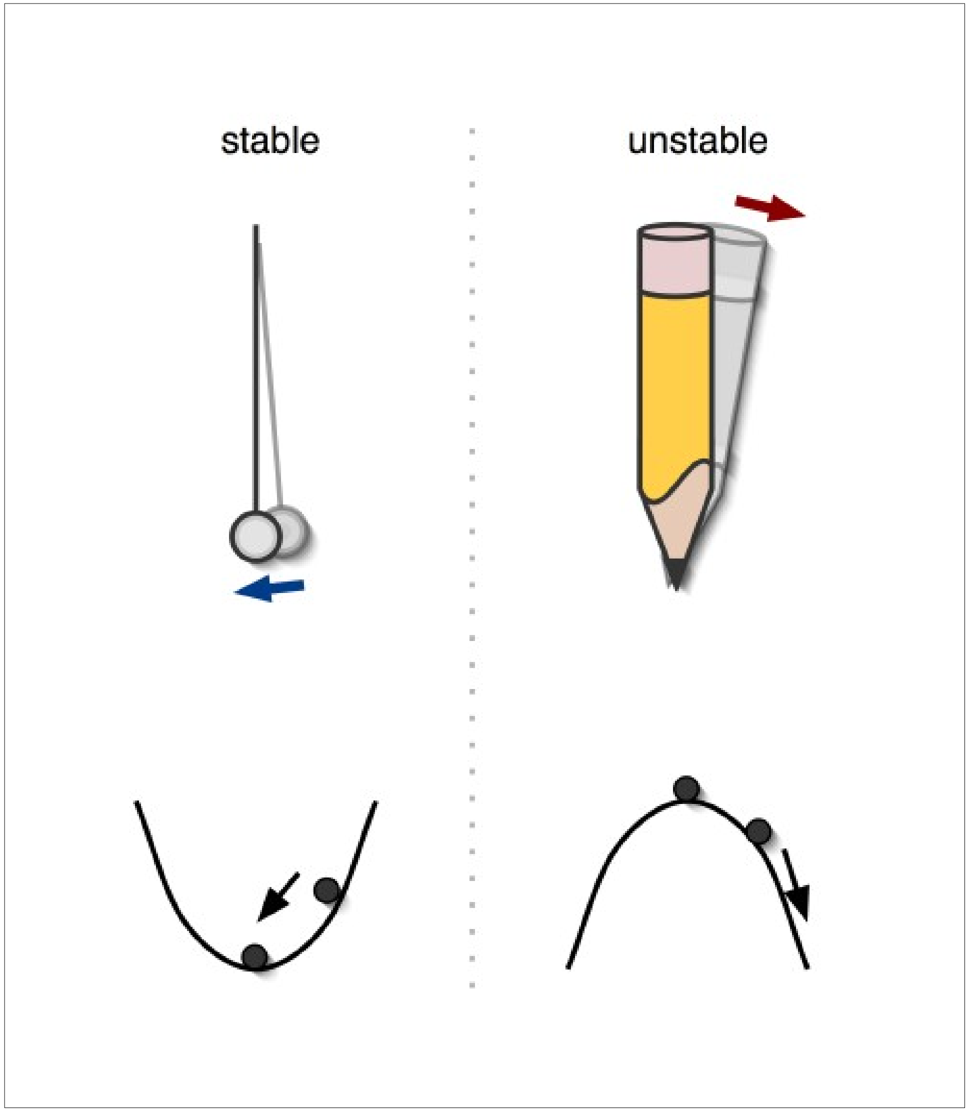
(inwards) GRAVITY



Stable and Unstable Equilibria

Stable Equilibrium

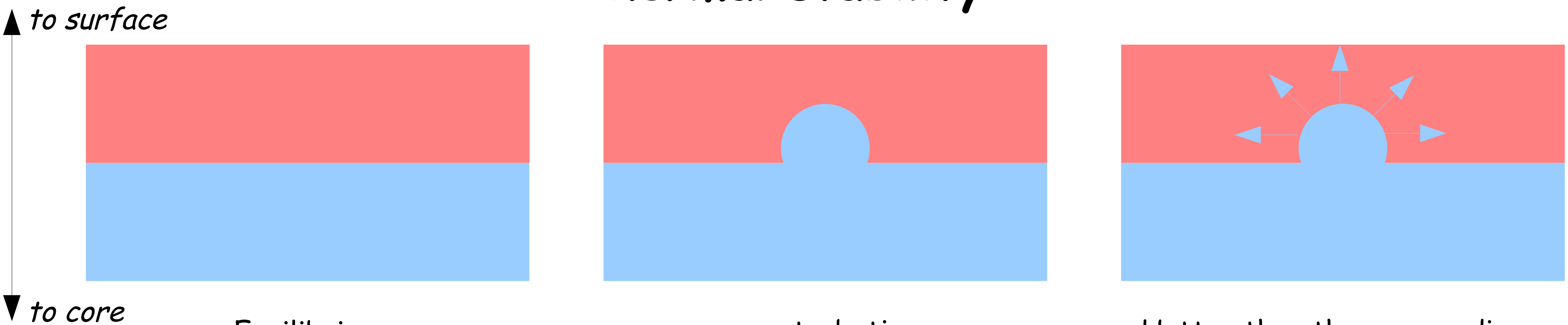
Returns to equilibrium position when disturbed



Unstable Equilibrium

Does not return to equilibrium position when disturbed

Thermal stability



Equilibrium

a perturbation

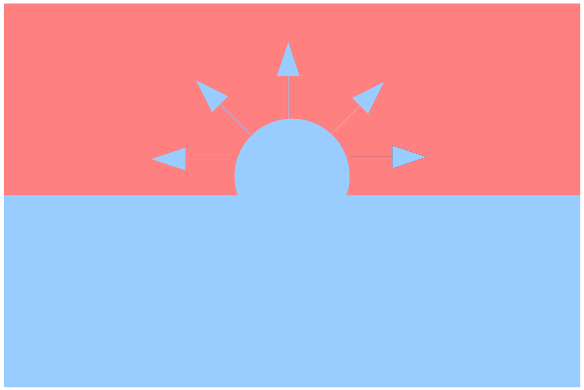
Hotter than the surroundings, it expands and rises

Expansion cools the blob

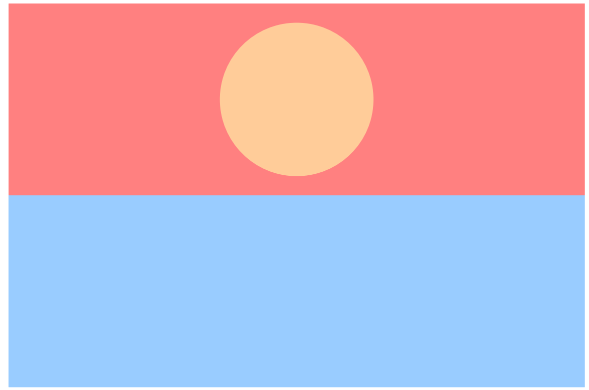
It cools further and sinks

Equilibrium

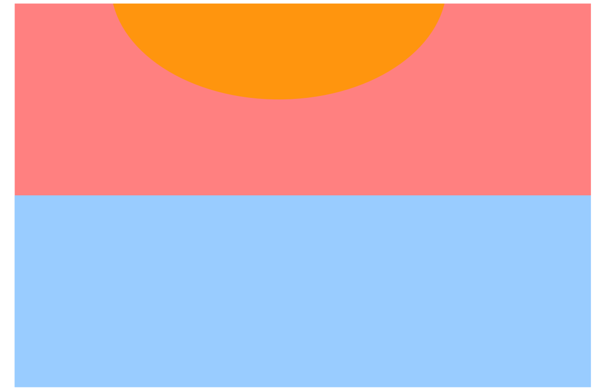
Thermal instability



Hotter than the surroundings
The blob expands and rises

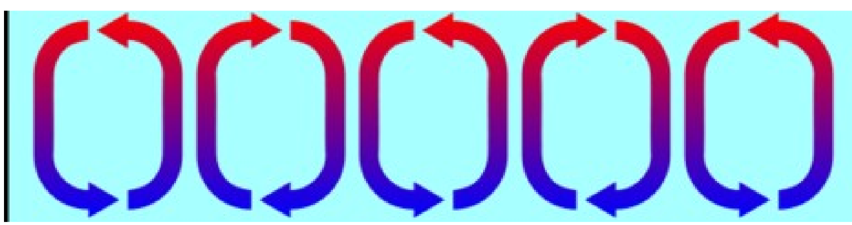


It rises faster than it cools



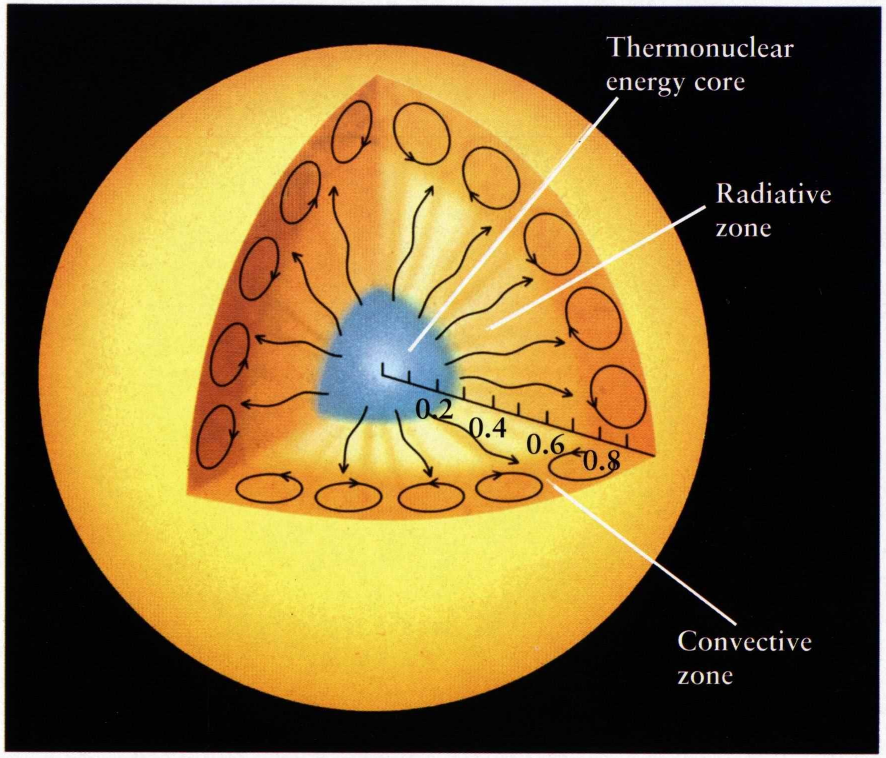
It keeps rising

It travels a great distance
before cooling and sinking



CONVECTION

Solar Structure



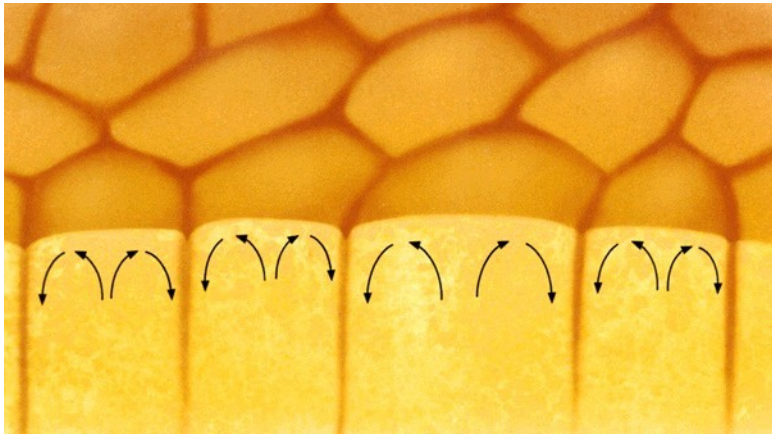
In **stable equilibrium**,
heat is transported by **radiation**
(without transport of mass).

In **unstable equilibrium**,
heat is transported by **convection**
(with transport of mass).

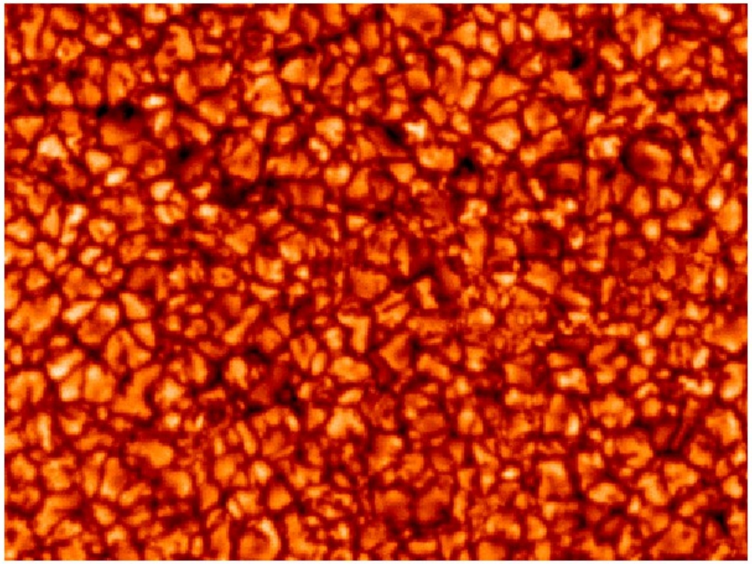
The Sun displays a
radiative zone
in the interior

And a
convective zone
near the surface

Granulation

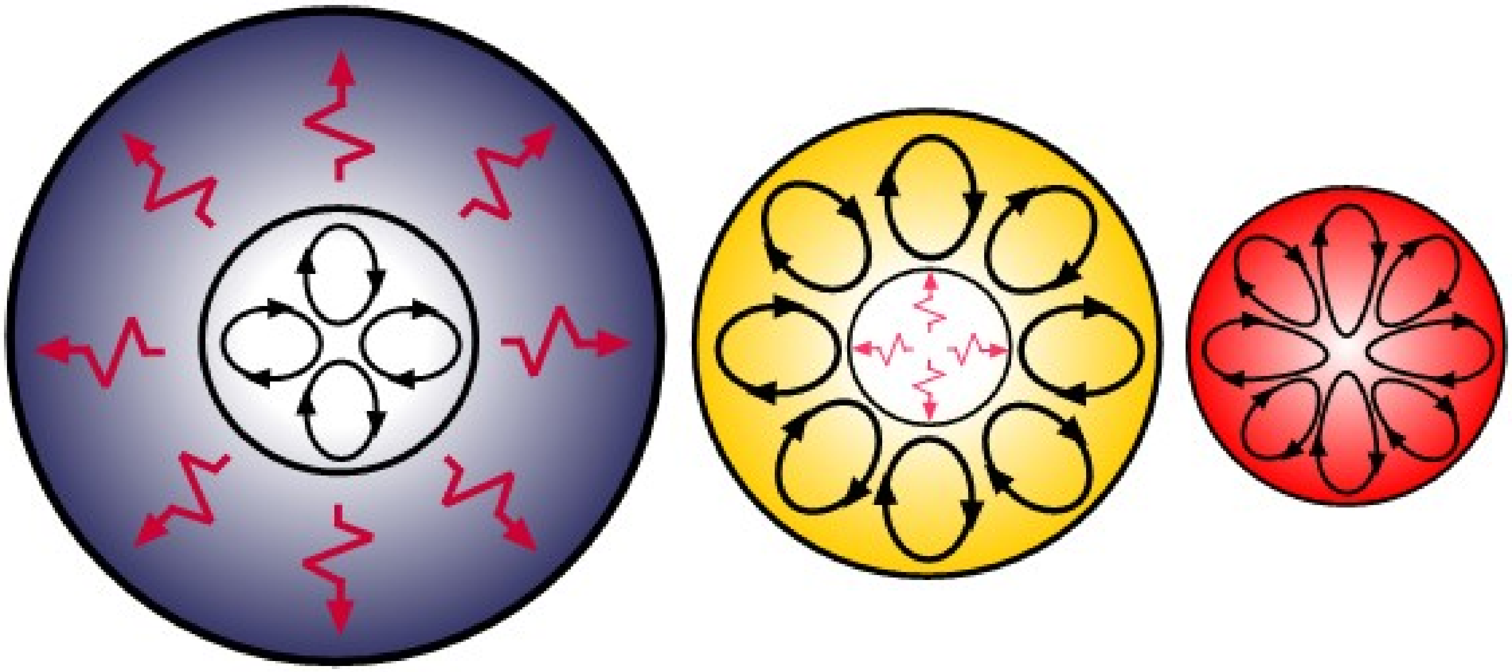


Convective cells



Close-up of the surface of the Sun

Stellar Structure



$M > 1.5$ Convective Core Radiative Envelope

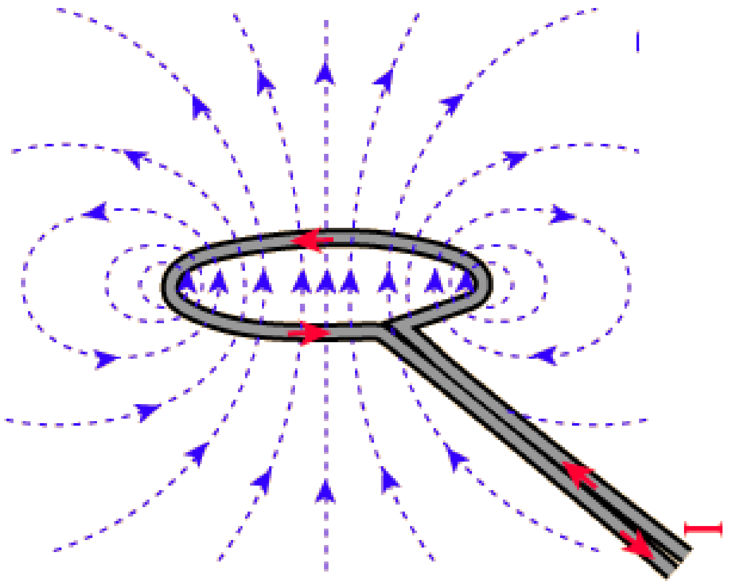
$0.5 < M < 1.5$ Radiative Core Convective Envelope

$M < 0.5$ Fully Convective

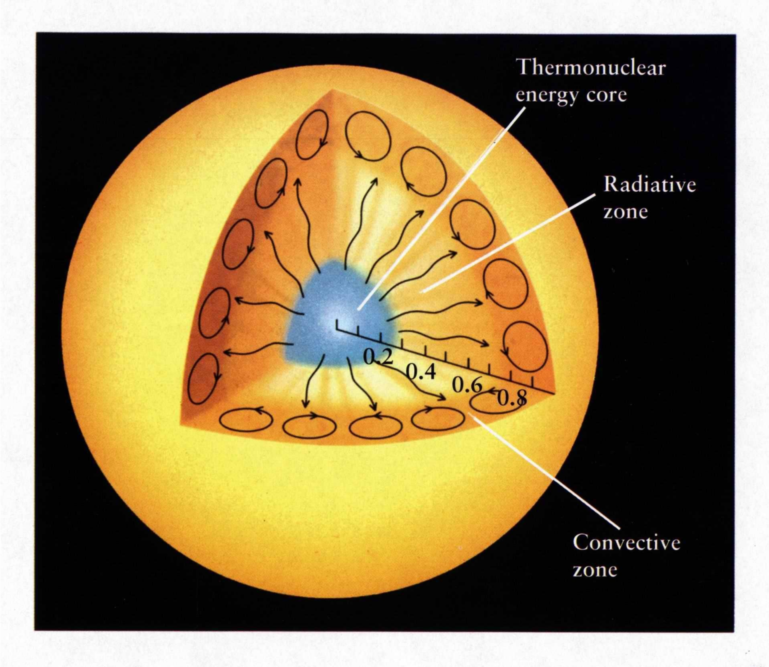
Magnetic Fields

Masses produce gravitational fields
Static charges produce electric fields
Moving charges produce **magnetic fields**

Magnetic Field produced by current

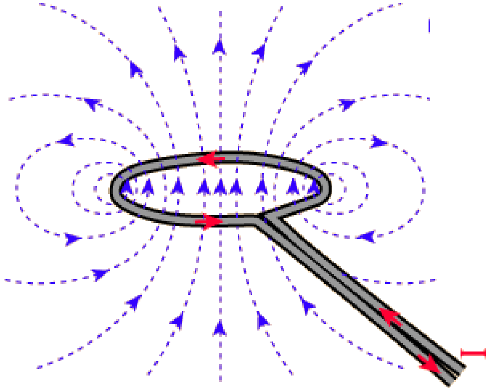


The sun is a ball of ionized gas

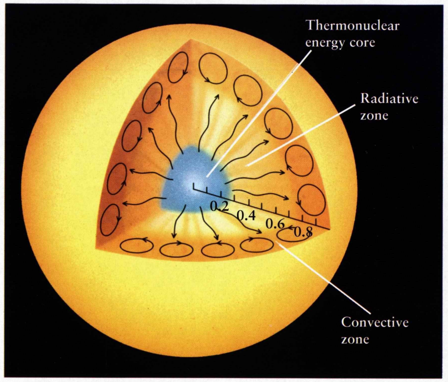


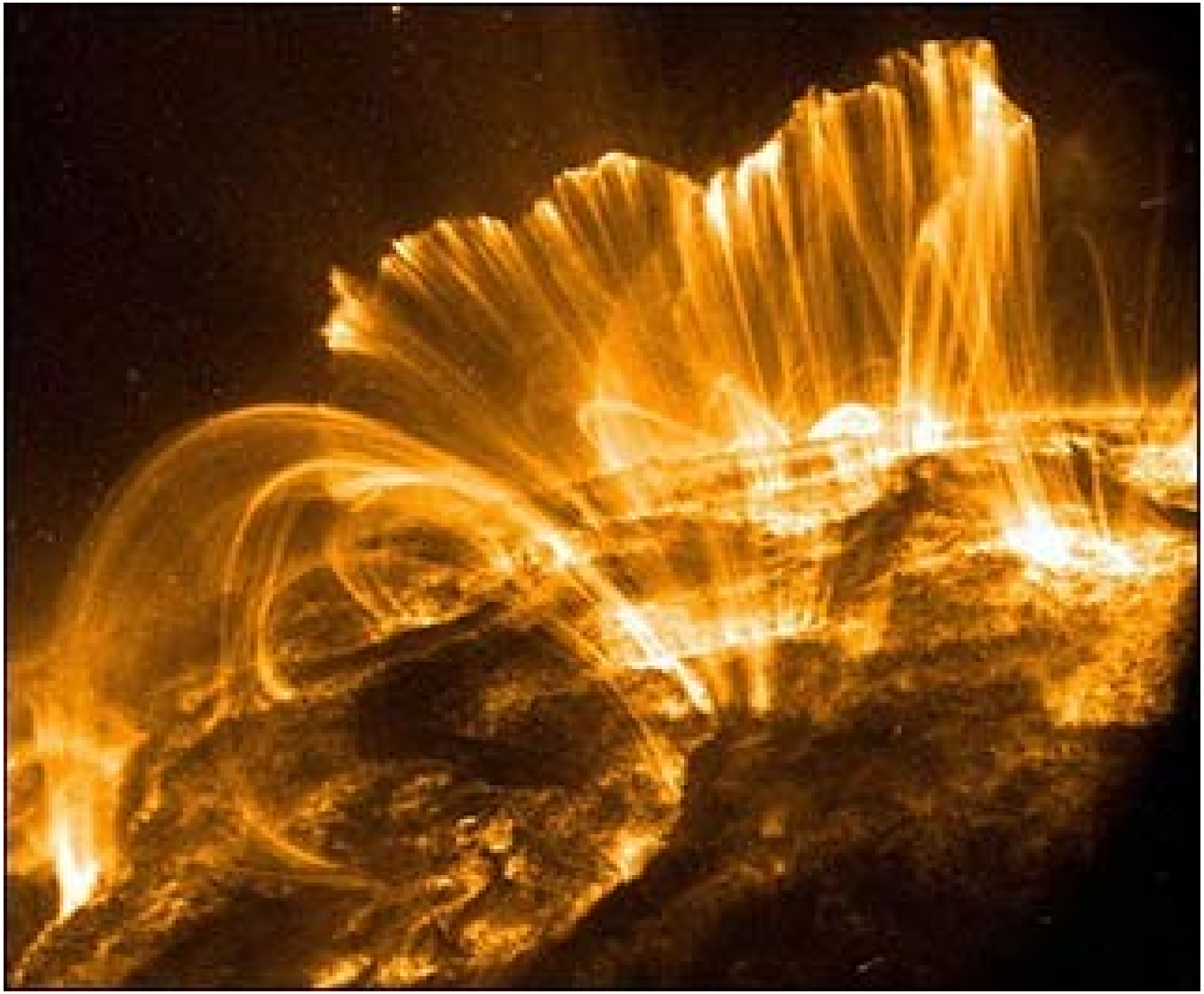
A convective cell is a current loop

We should expect **magnetic fields** associated with **convection**

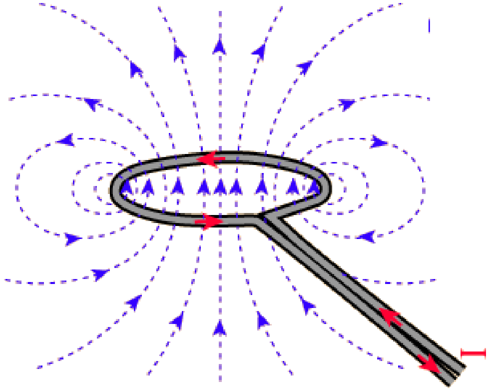


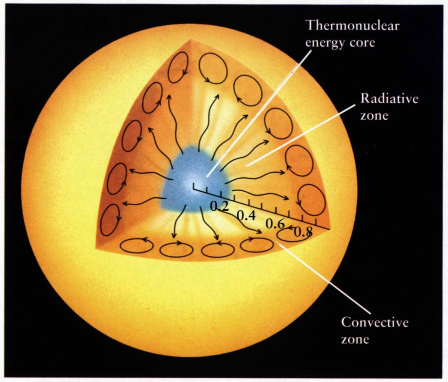
Magnetic Fields

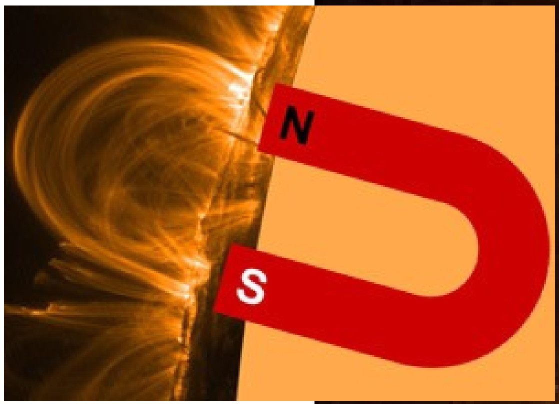




Magnetic Fields

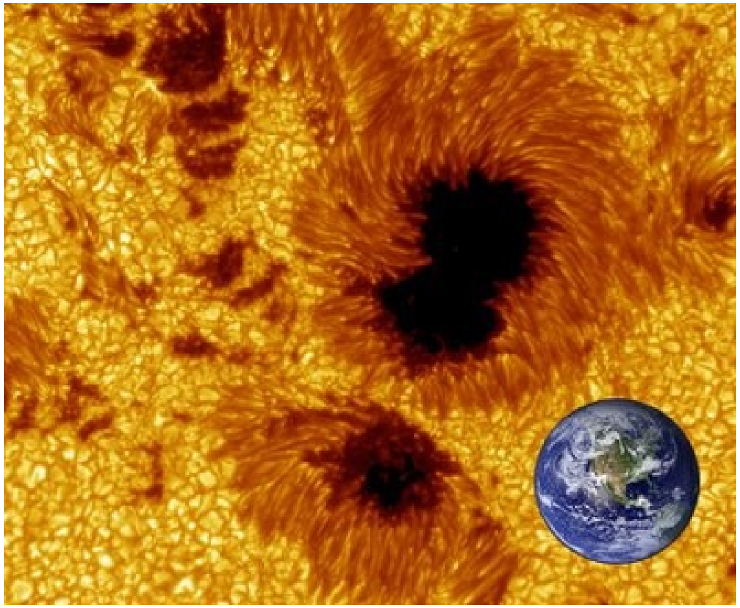


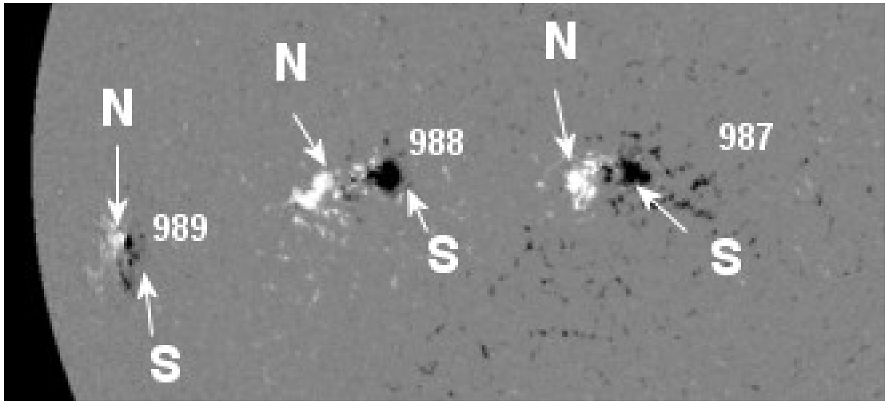




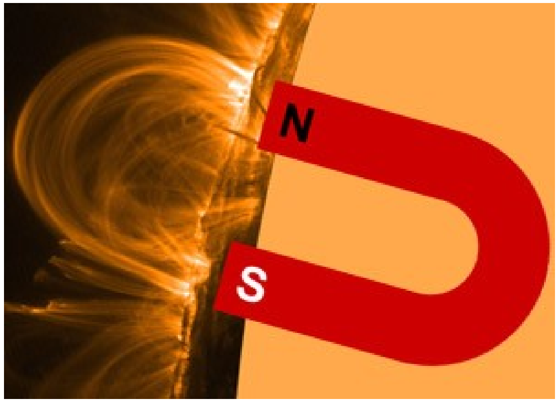
Sunspots

Sunspots are regions of strong magnetic fields





They always appear in
pairs of inverse polarity

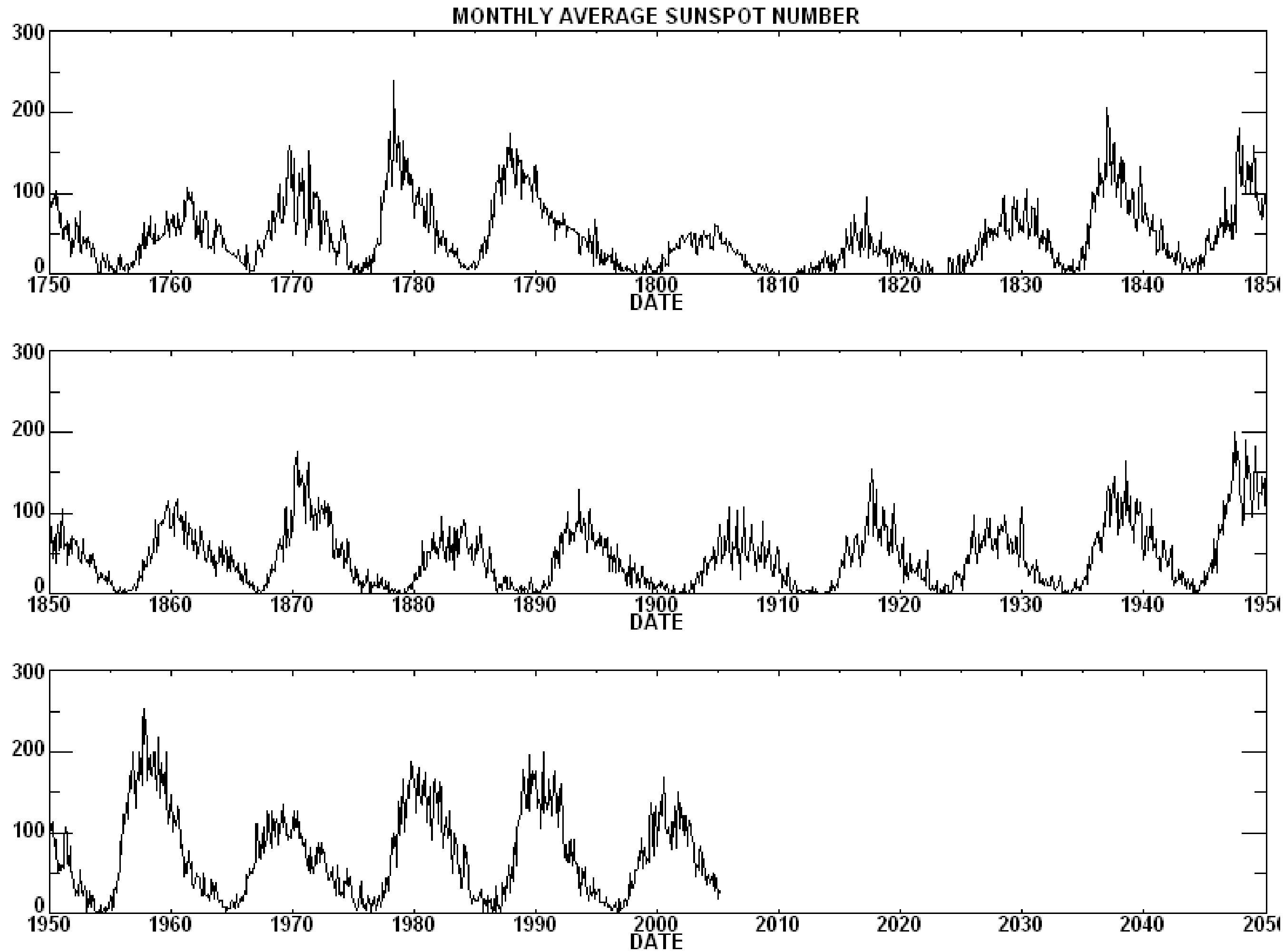


Sunpots are **dark** because they are **colder**
The strong magnetic field inhibits motion

Surrounding temperature ~ 6000 K
Sunspot temperature ~ 4000 K

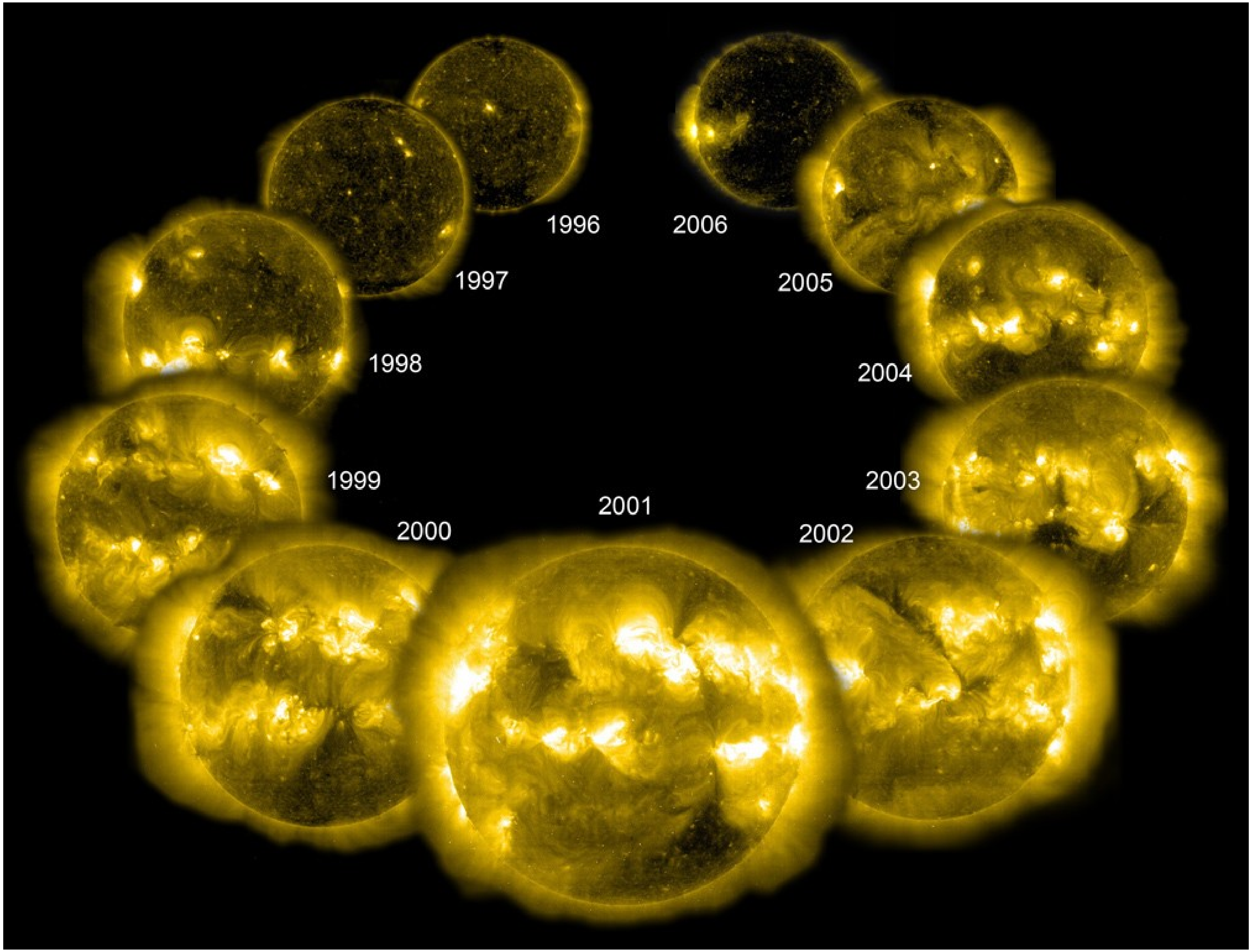
The Solar Cycle

Number of sunspots since 1750
11 year cycle

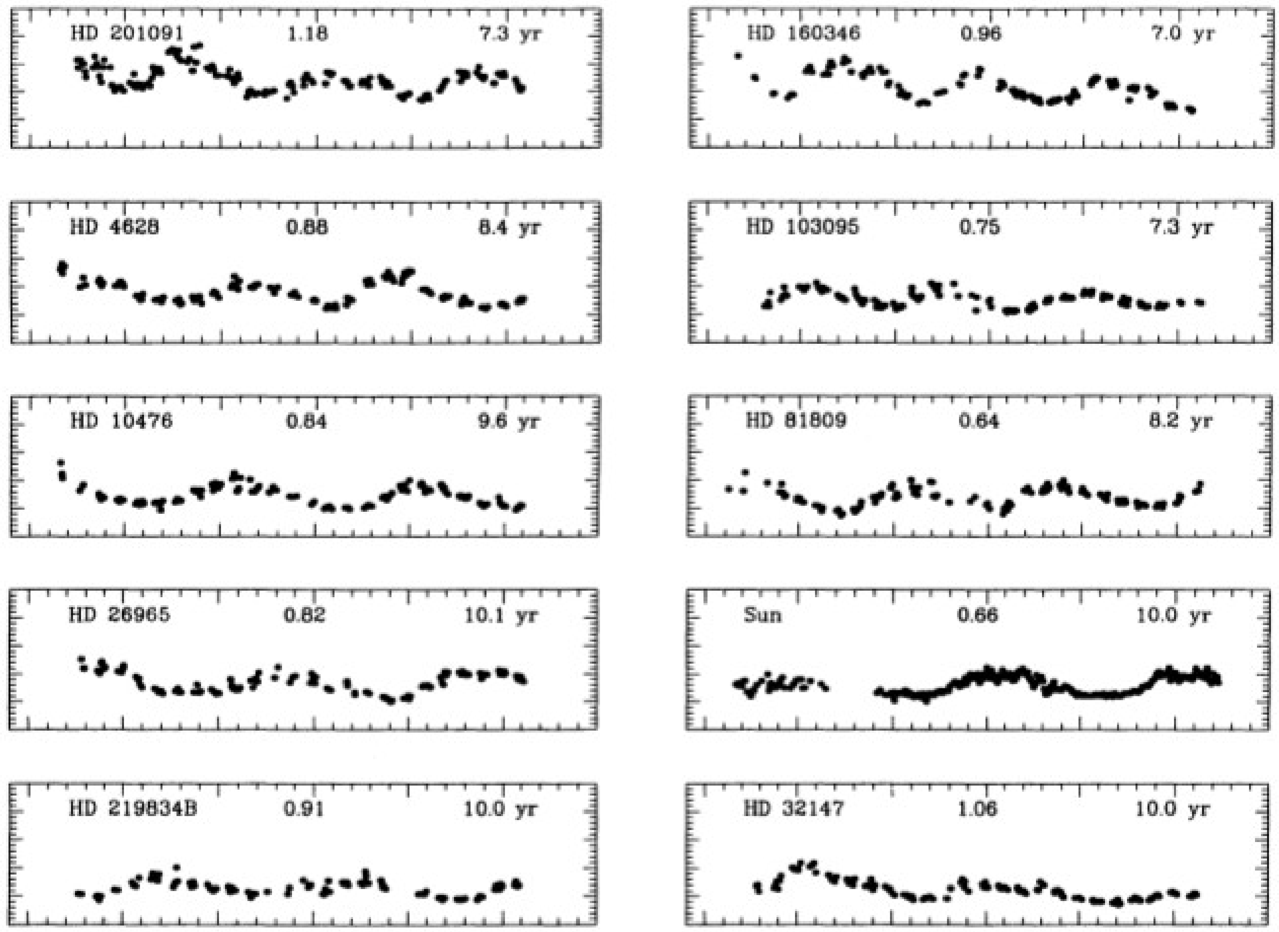


Number of sunspots = Wolf number

The Solar Cycle



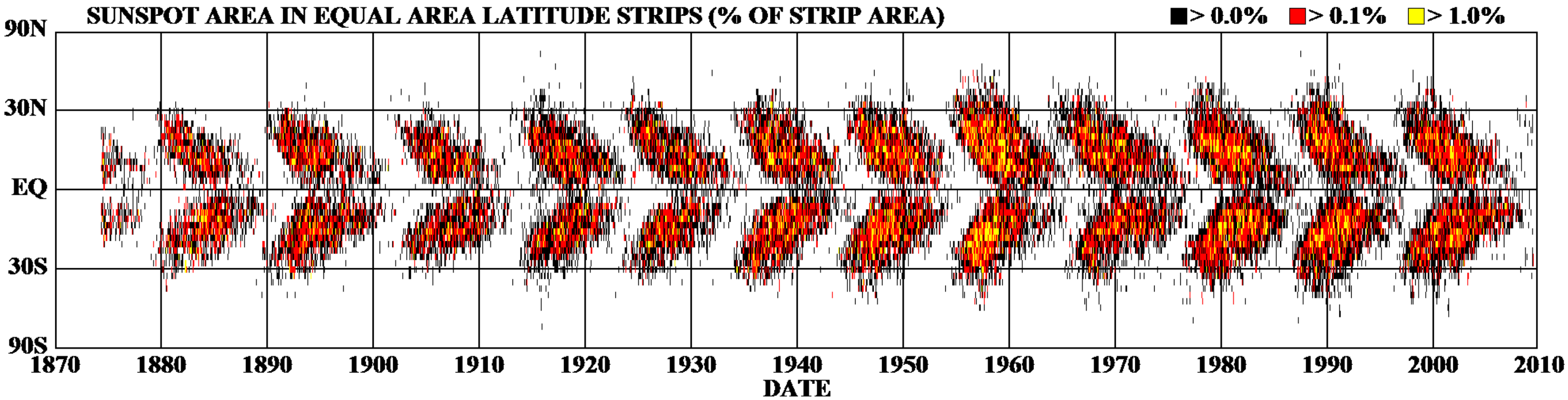
Starspots and Stellar cycles



Other stars also show cycles

The Butterfly Diagram

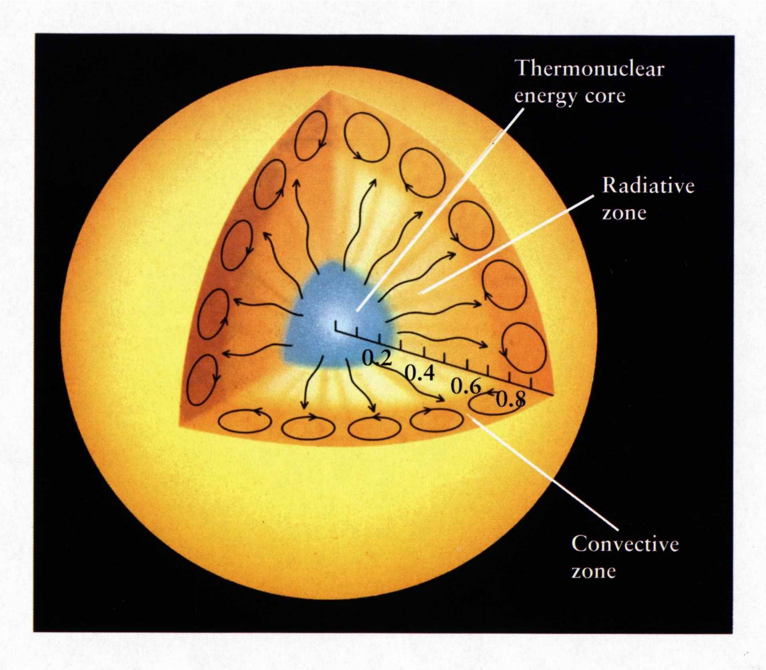
Sunspot latitude *vs* time



Sunspots appear at northern latitudes and travel equator-ward.

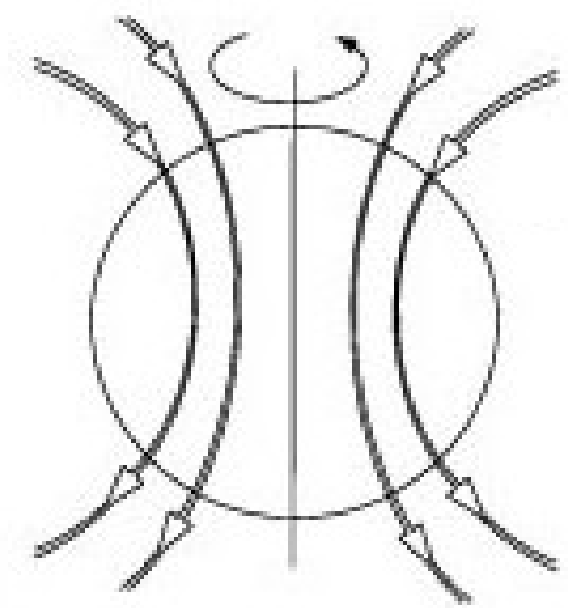
The Solar Dynamo

Dynamo: something that generates
electromagnetic energy from mechanical energy

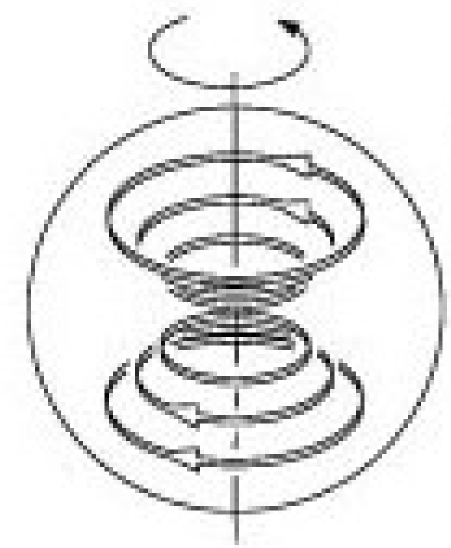


A magnetic field decays in time,
so a dynamo is needed to maintain the field.

Magnetic field configurations



Poloidal Field

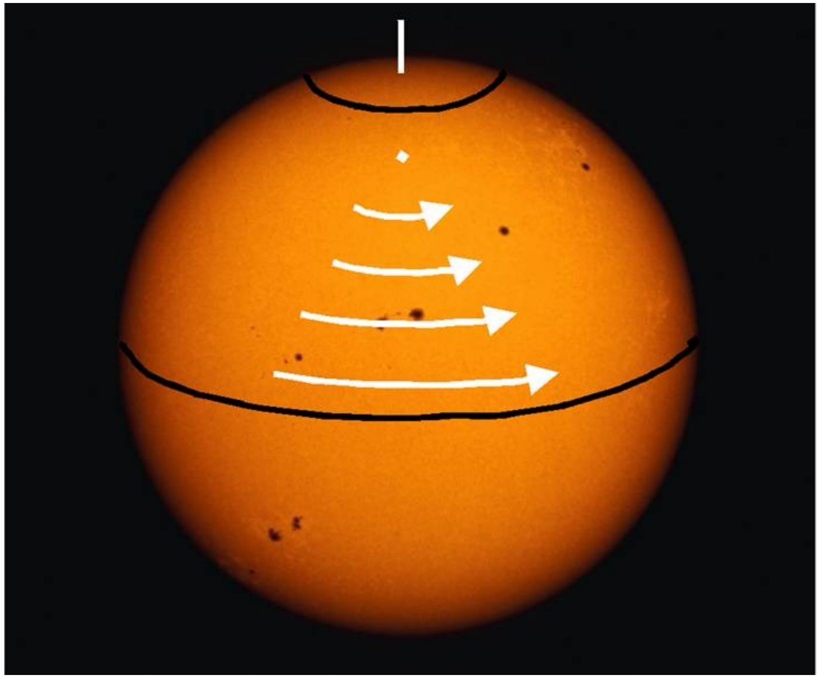


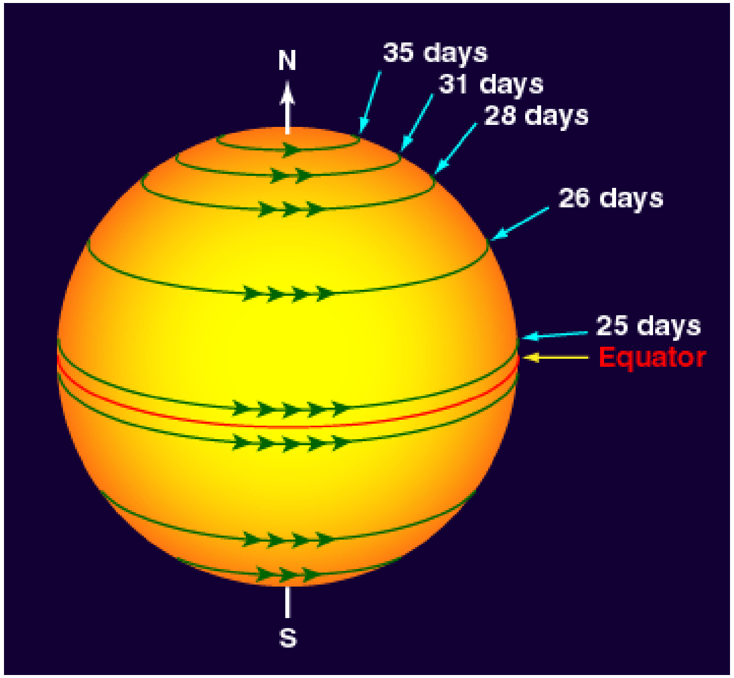
Toroidal Field

The solar cycle consists of the dynamo periodically flipping the field between the poloidal and toroidal field configurations.

Differential Rotation

The equator spins faster than the poles

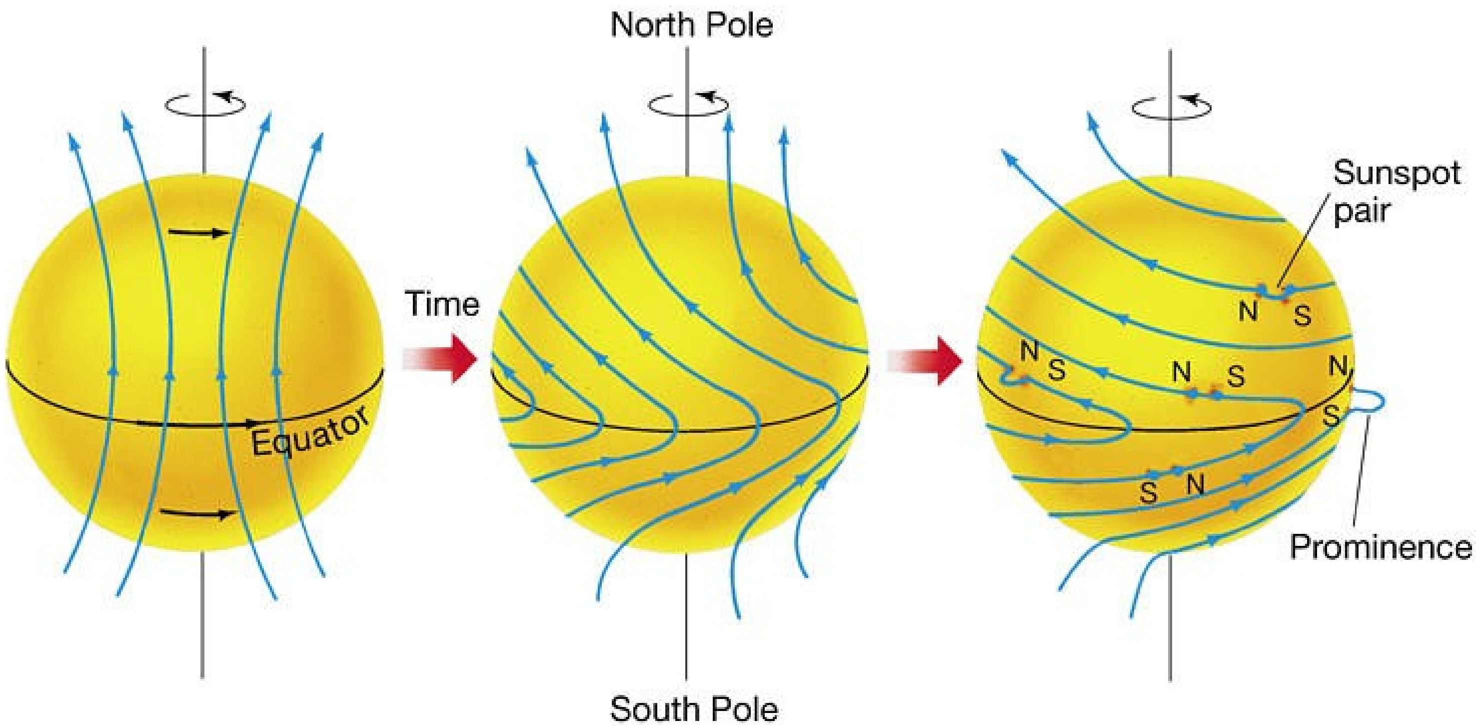




As any gaseous body, the Sun displays differential rotation.

25 days at the equator
35 days at the poles

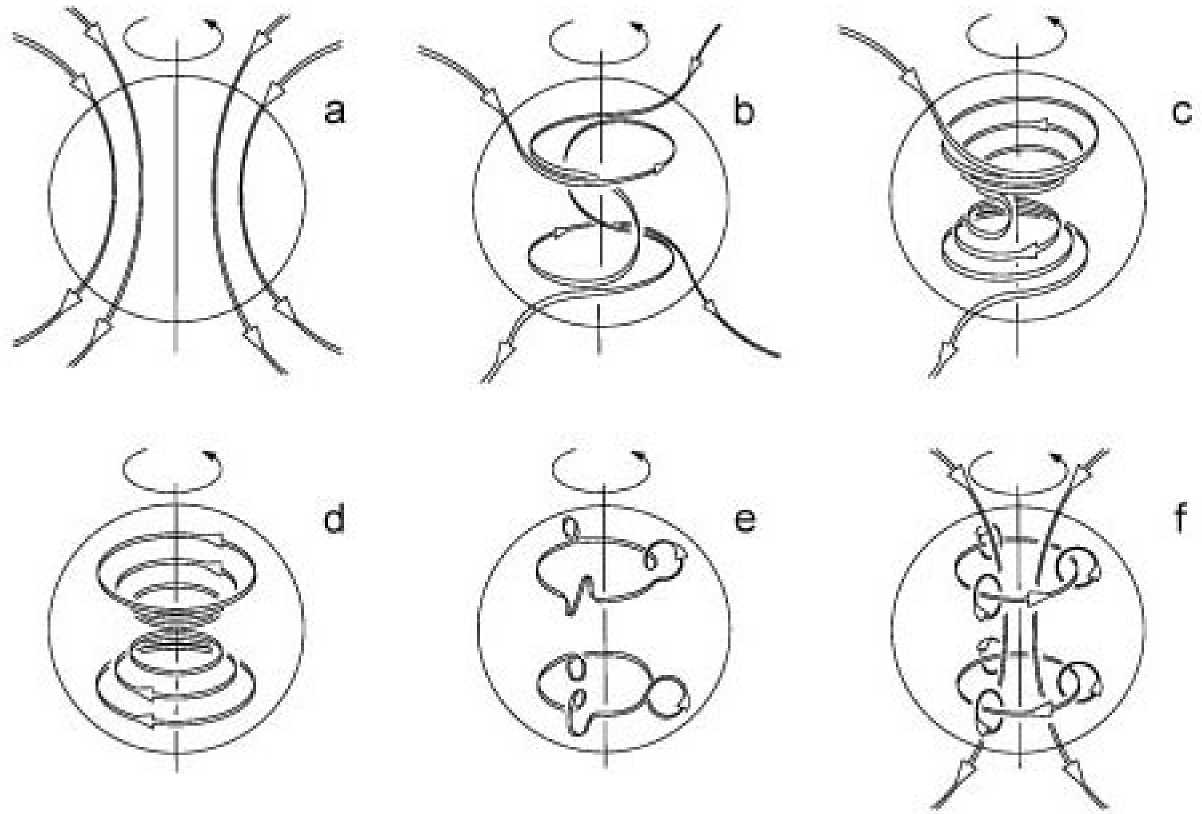
The Omega effect



Differential rotation drags the field lines, turning a poloidal field into a toroidal one.

Sunspots and the maximum of activity appear in the toroidal phase

The solar dynamo cycle



Omega effect

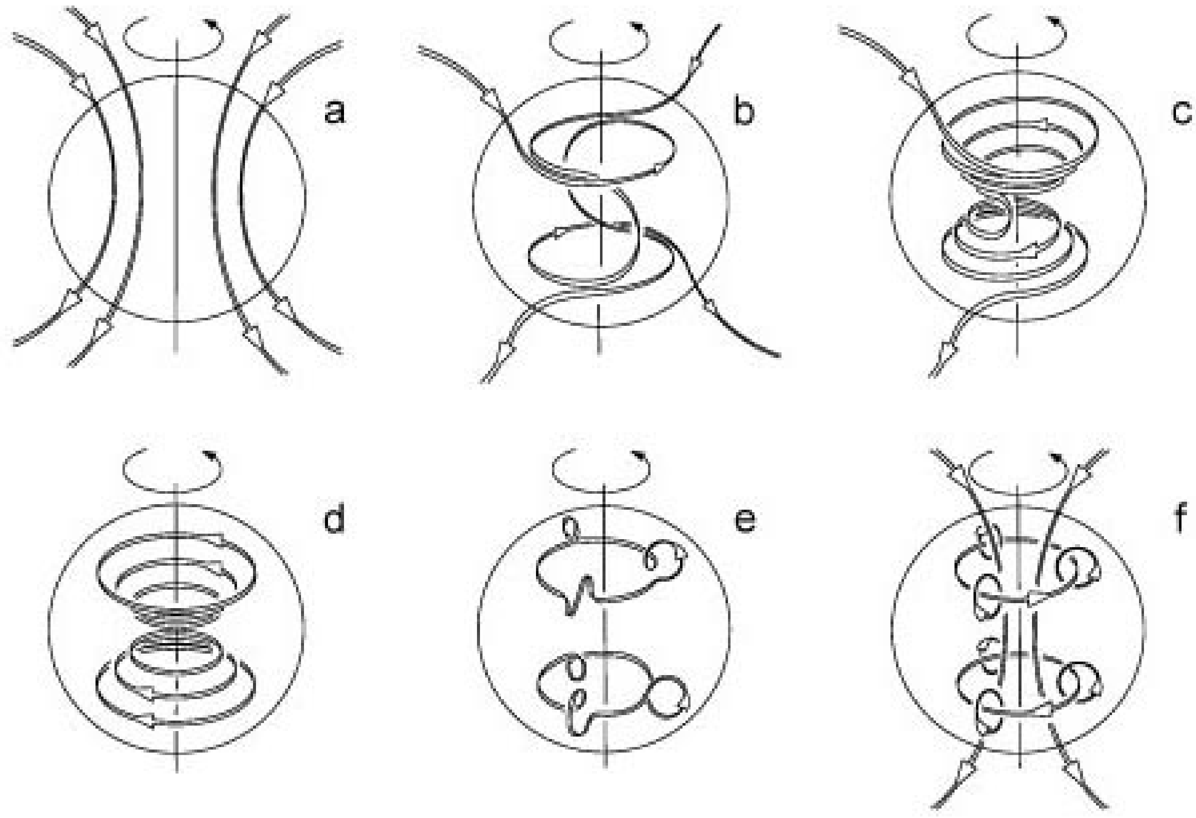
Poloidal → Toroidal

Alpha effect

Toroidal → Poloidal

$\alpha-\Omega$ dynamo

The solar dynamo cycle



Omega effect

Poloidal → Toroidal

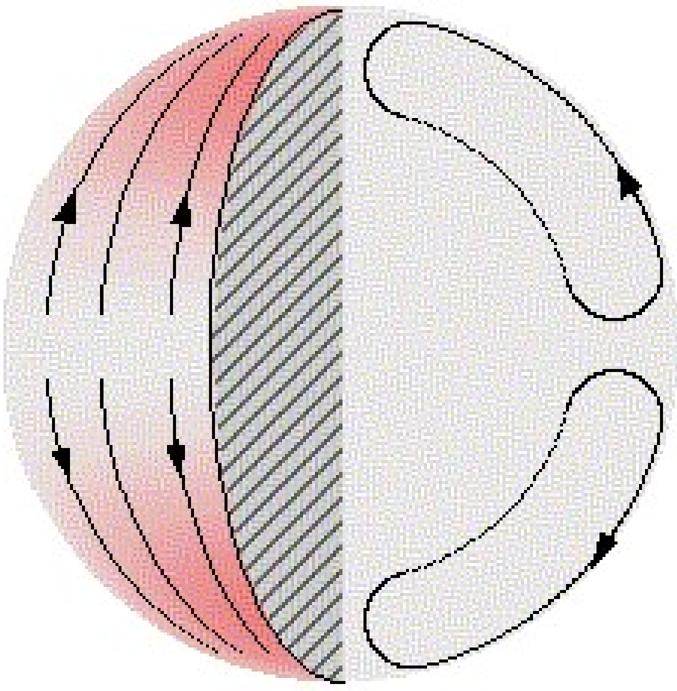
Alpha effect

Toroidal → Poloidal

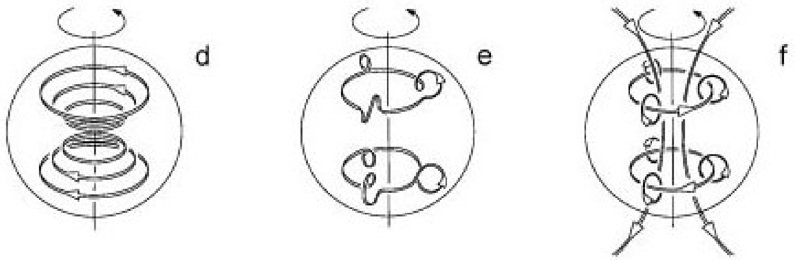
$\alpha - \Omega$ dynamo

We don't understand the precise mechanism behind the alpha effect

Meridional Circulation

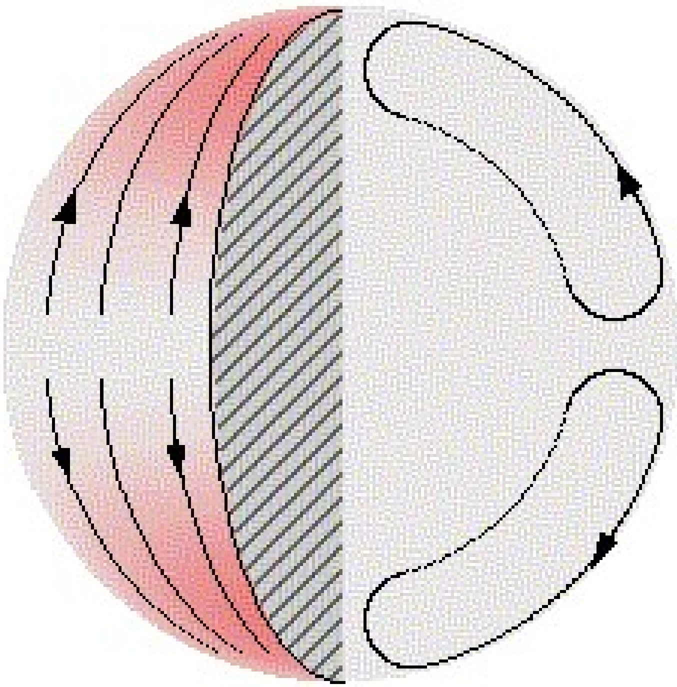


The sun presents a pole-ward motion at the surface, with speeds of 20 m/s.



Meridional circulation drags the field vertically, potentially turning the toroidal field poloidal.

Meridional Circulation



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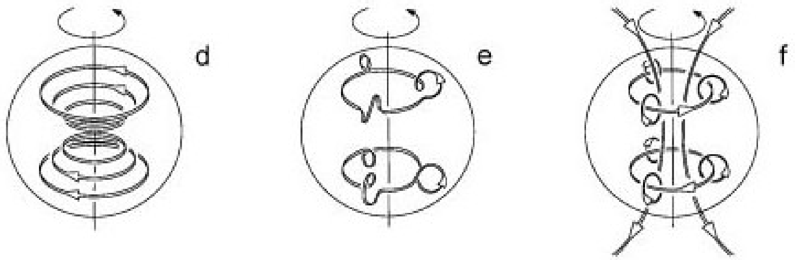

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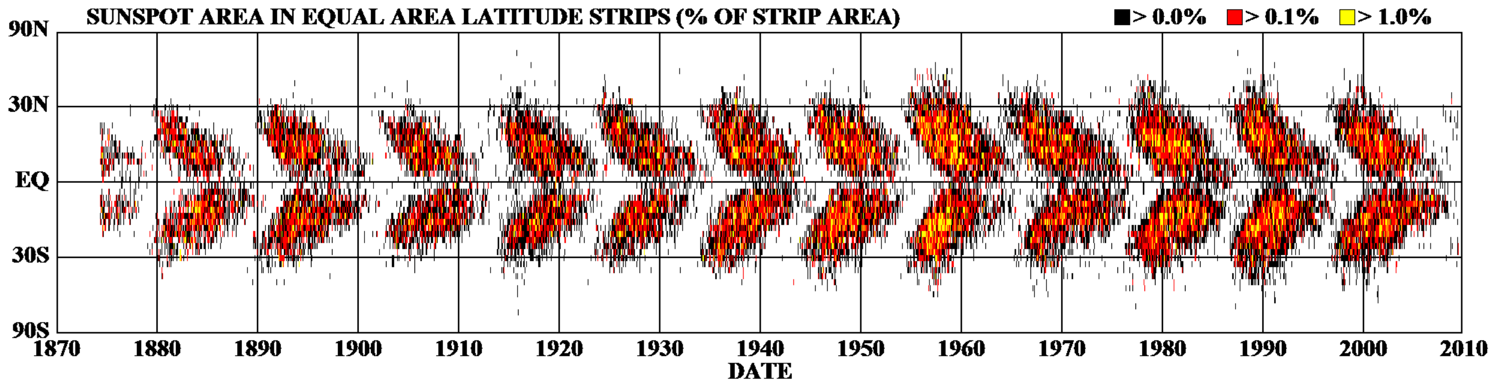
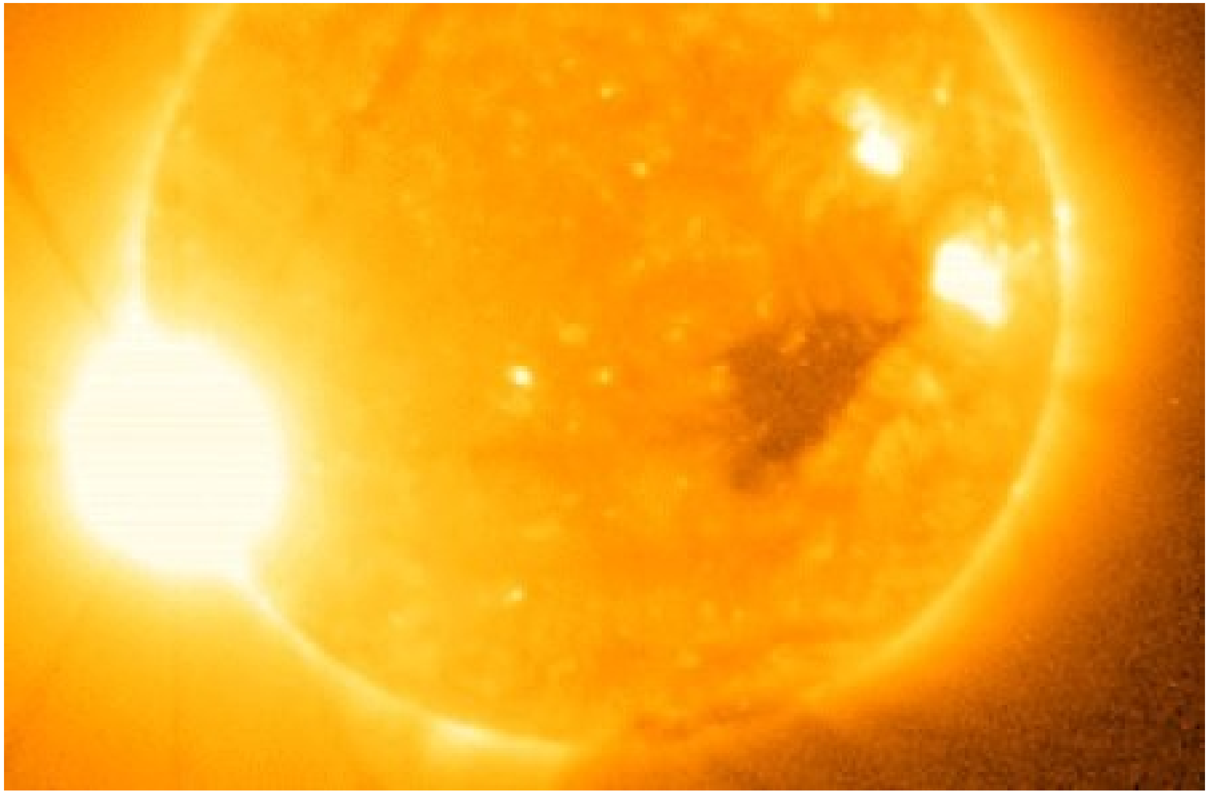


Also potentially explaining the butterfly diagram!

Solar Flares

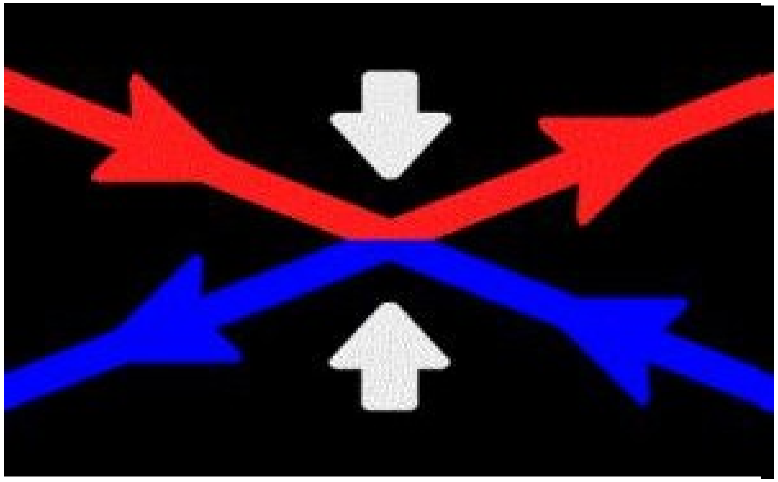
The most powerful explosions in the solar system (~10^{32} ergs)



Flares are **explosions** on the surface of the Sun
powered by **magnetic reconnection**

Magnetic Reconnection

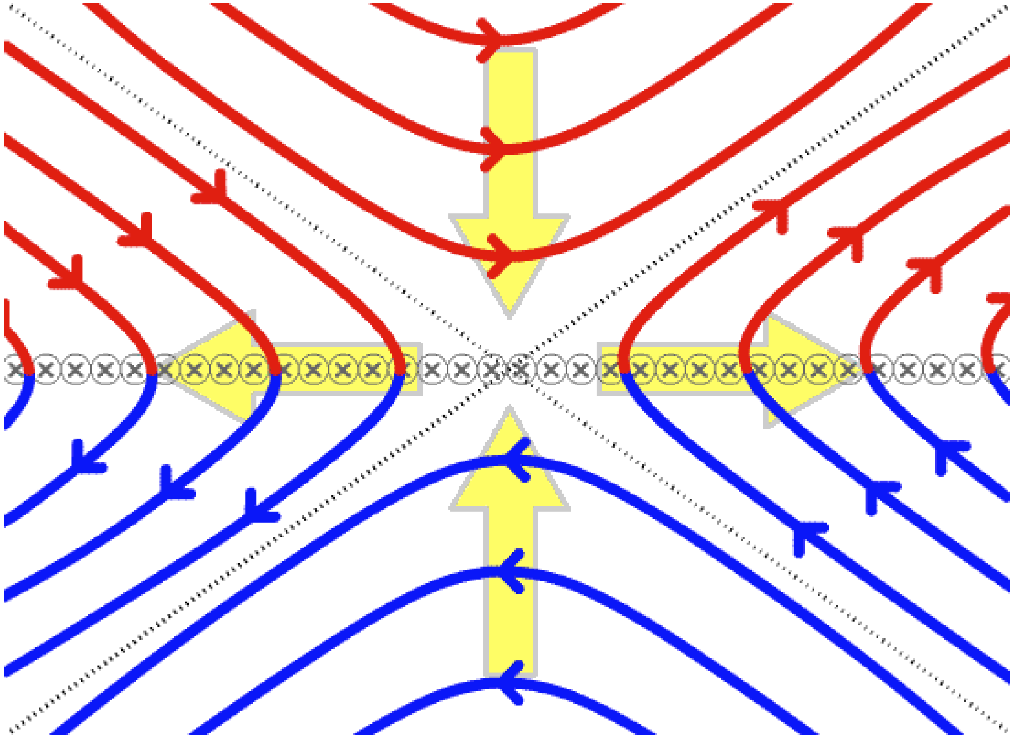
Get two field lines of opposite polarity together...



… and you have the magnetic equivalent of a short circuit

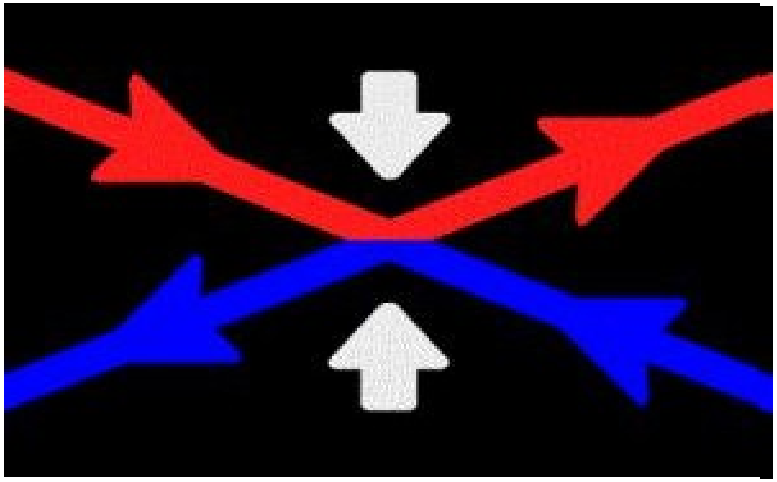
Magnetic Reconnection

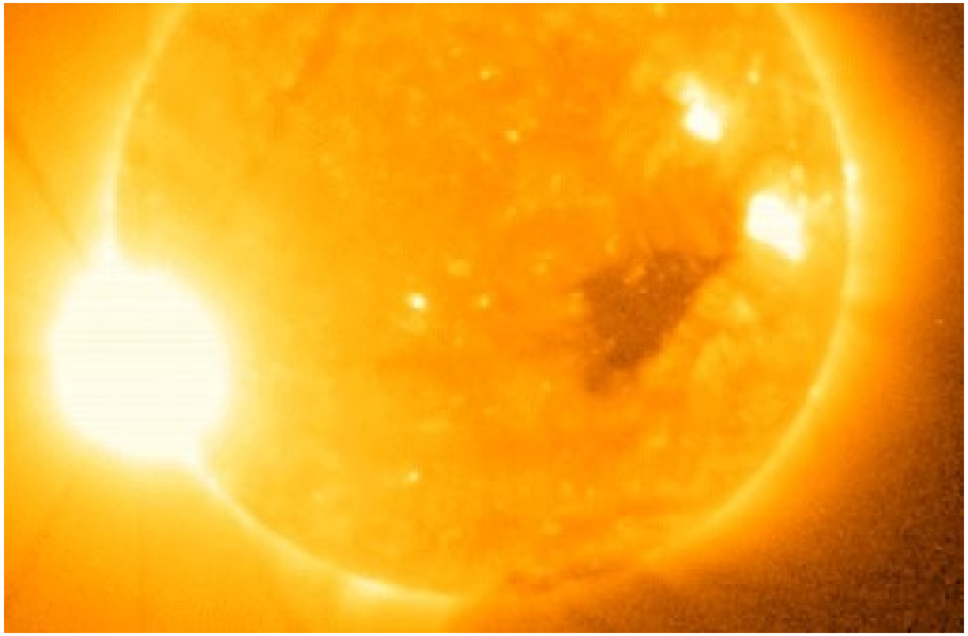
The field lines cancel and reconnect



Magnetic Reconnection

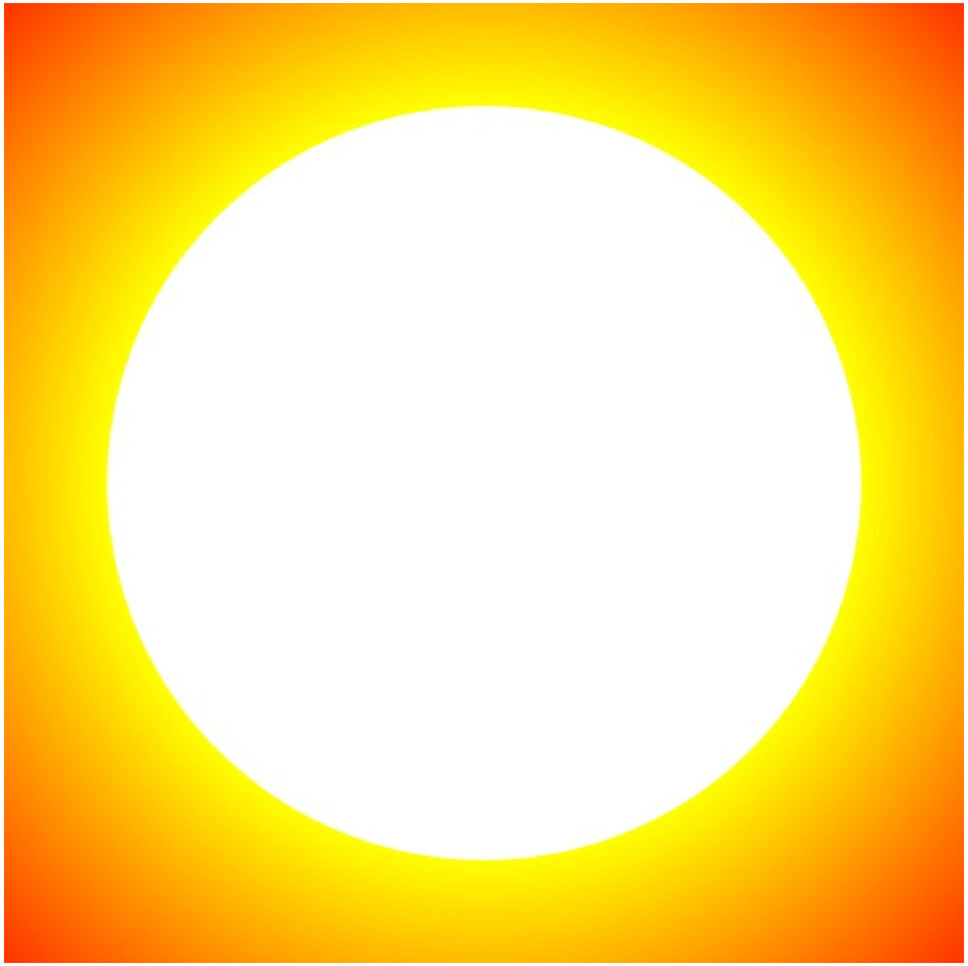
Magnetic Field lines store energy





Upon cancellation, the energy is explosively released

The Solar Atmosphere
Photosphere, Chromosphere, and Corona



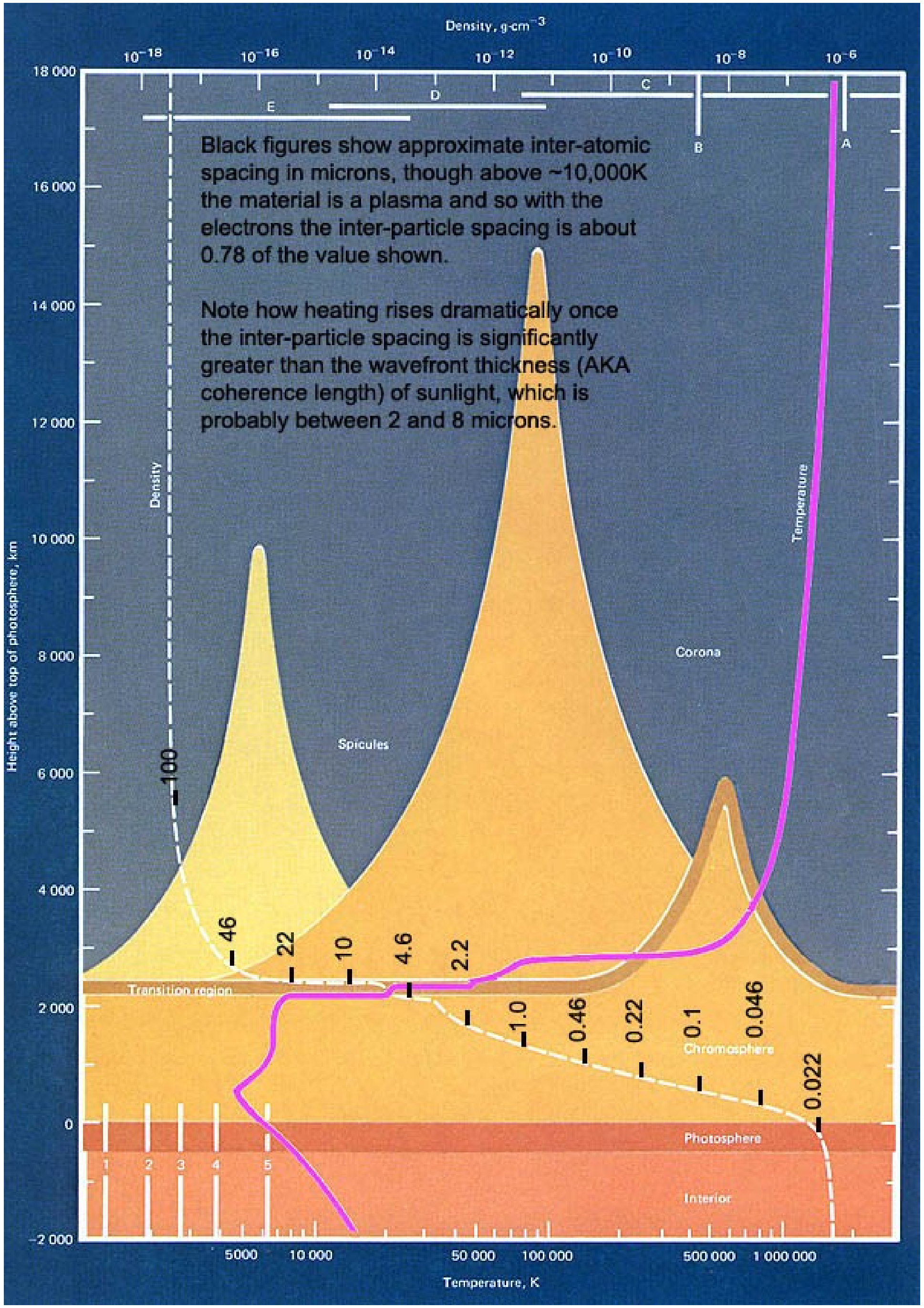
The photosphere is what we see
The surface layers whence photons escape
(max depth 400 km)

The Solar Atmosphere
Photosphere, Chromosphere, and Corona

The Chromosphere

The Corona

The Coronal Heating Problem

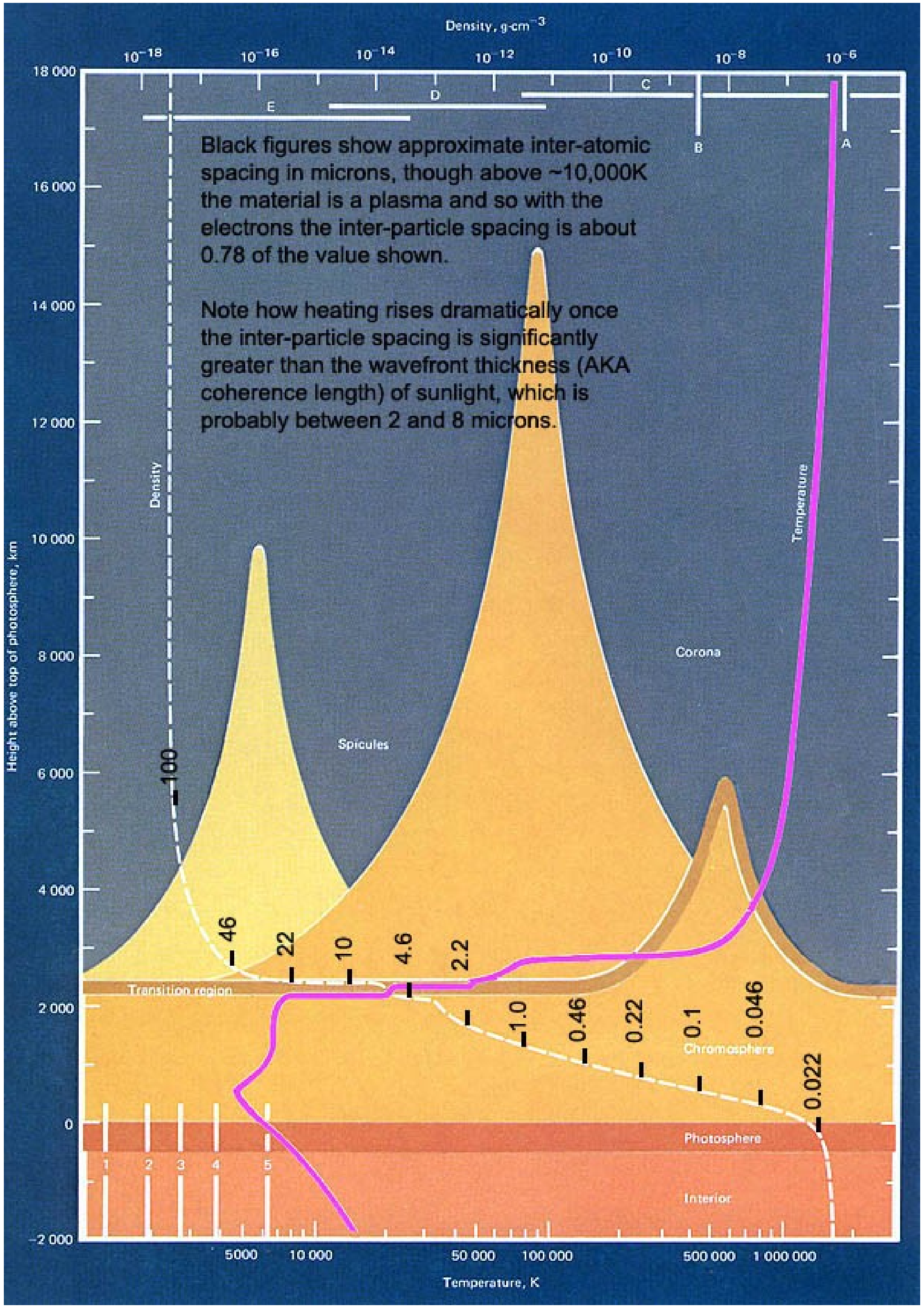


The temperature of the photosphere is ~6000 K

The chromosphere reaches 10,000 K

The corona is 2,000,000 K hot !!

The Coronal Heating Problem



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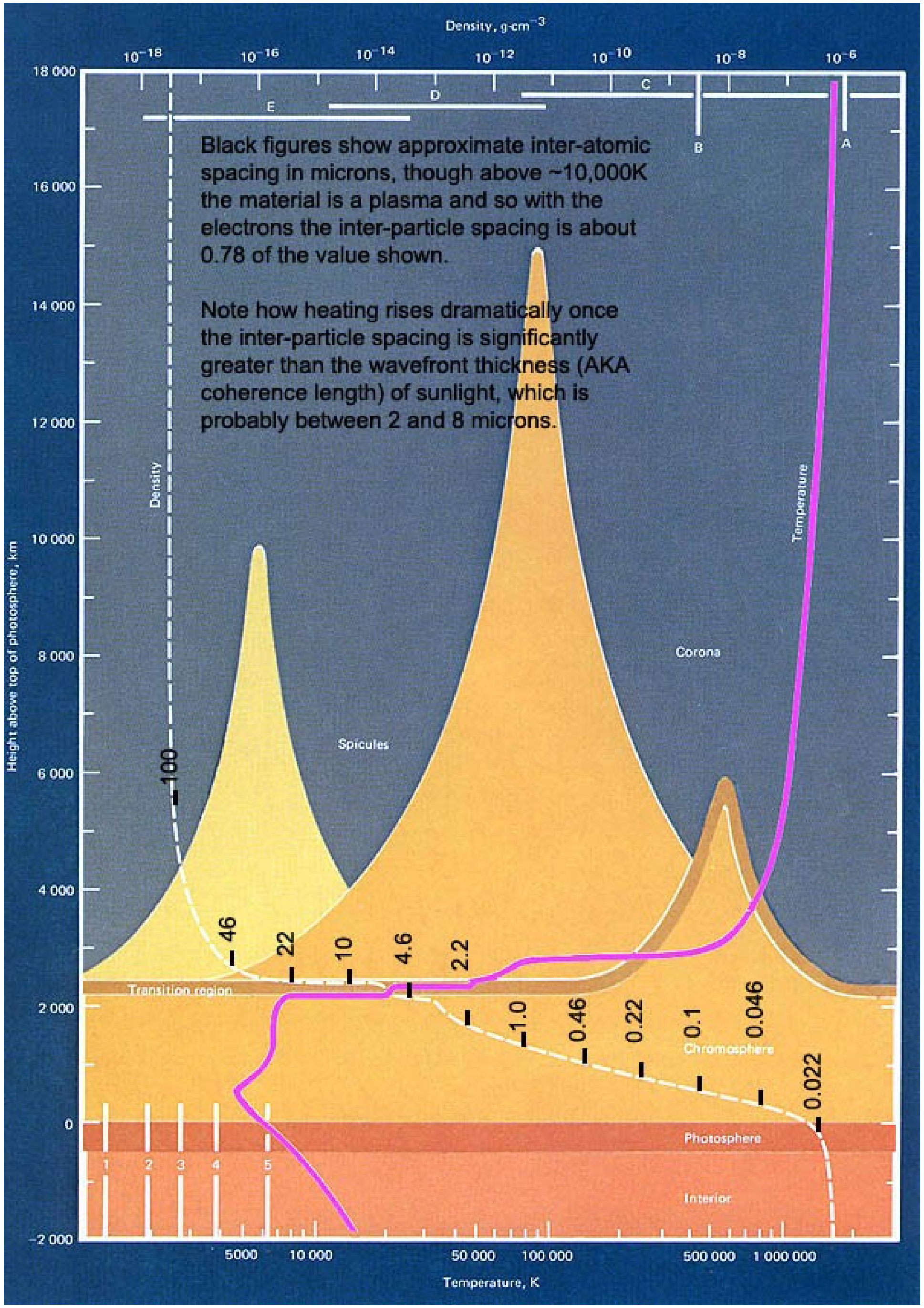
How does this temperature inversion occur?

The Coronal Heating Problem



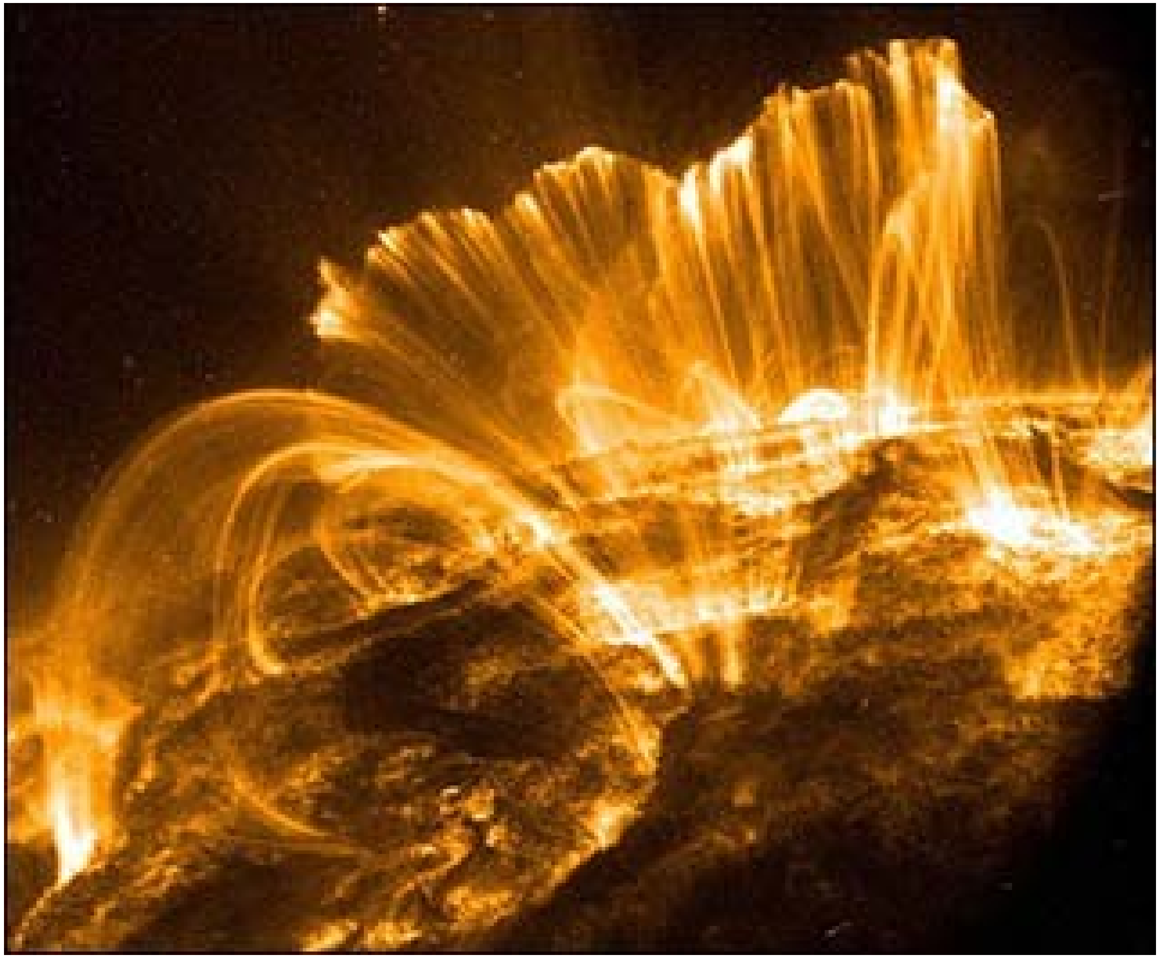
The temperature of the photosphere is ~6000 K

The chromosphere reaches 10,000 K

The corona is 2,000,000 K hot !!

How does this temperature inversion occur?
We don't know!

The Coronal Heating Problem



Microflares?

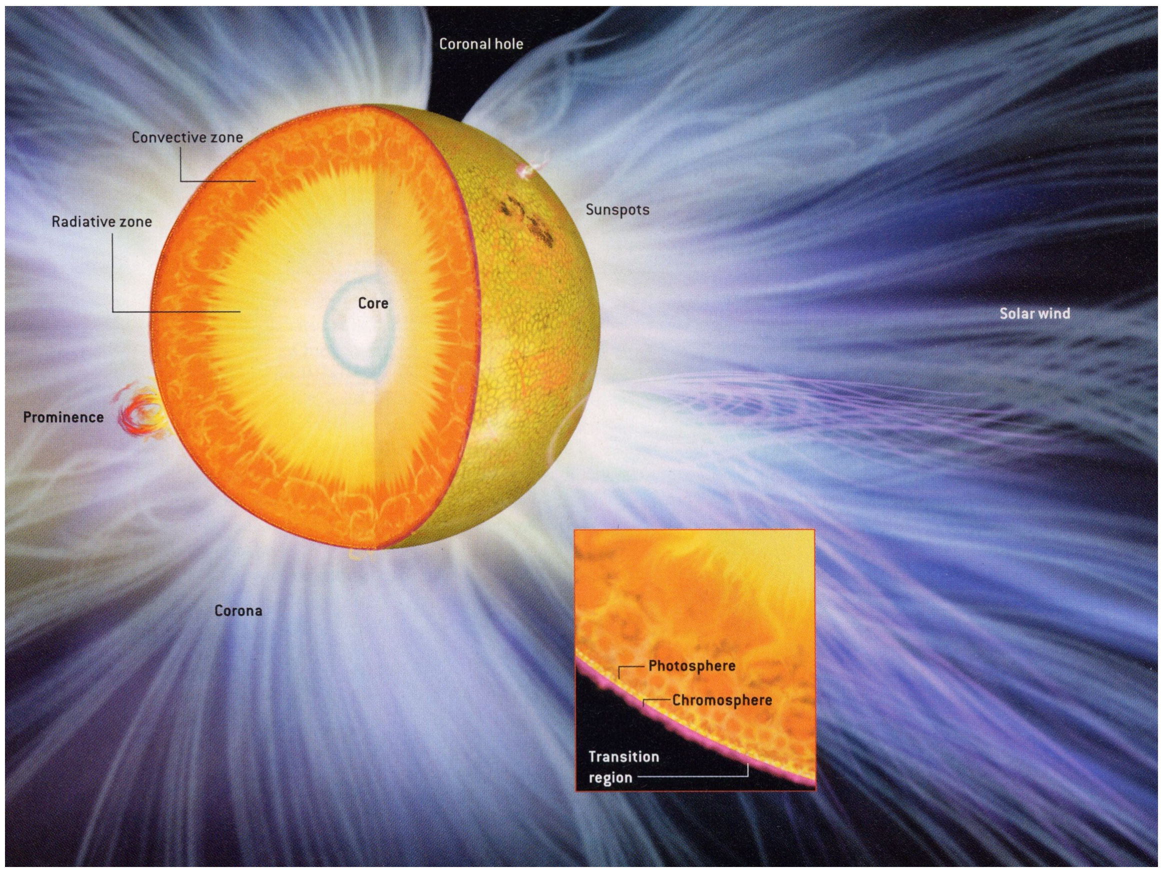
The Solar Wind

Whatever causes the heating, the corona is VERY HOT

So hot it cannot maintain hydrostatic equilibrium

It must be escaping from the Sun as **a stream of ionized particles**

(**aka Solar Wind**)

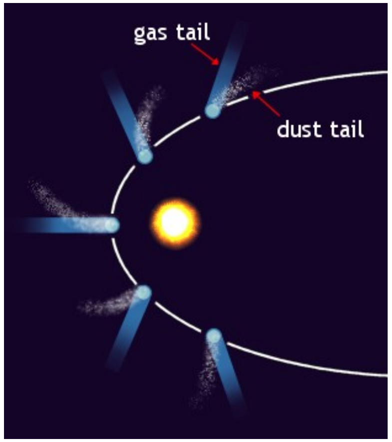


The outflow is measured in 10^{-14} Msun/yr

The Solar Wind

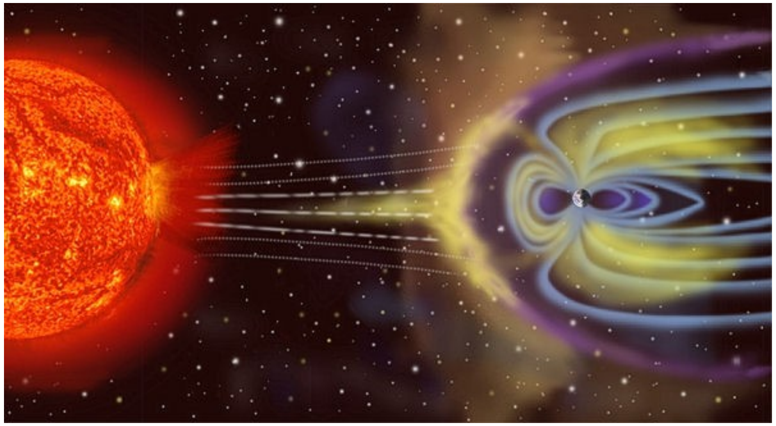
Effects of the solar wind in the solar system

Cometary tails



The ion tail is shaped by the solar wind and always points away from sun

Magnetospheres

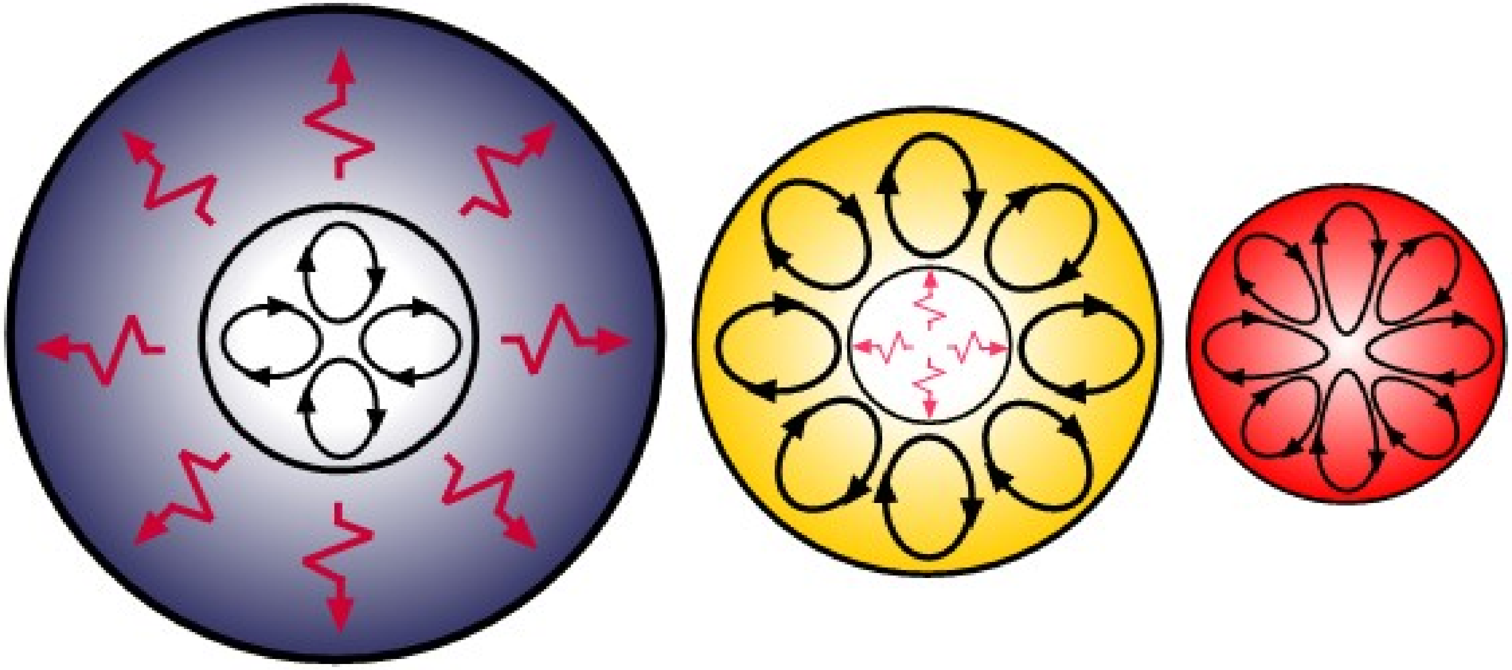


Planetary magnetic fields deflect the solar wind

Interaction with the wind changes the magnetic field topography

Stellar Structure

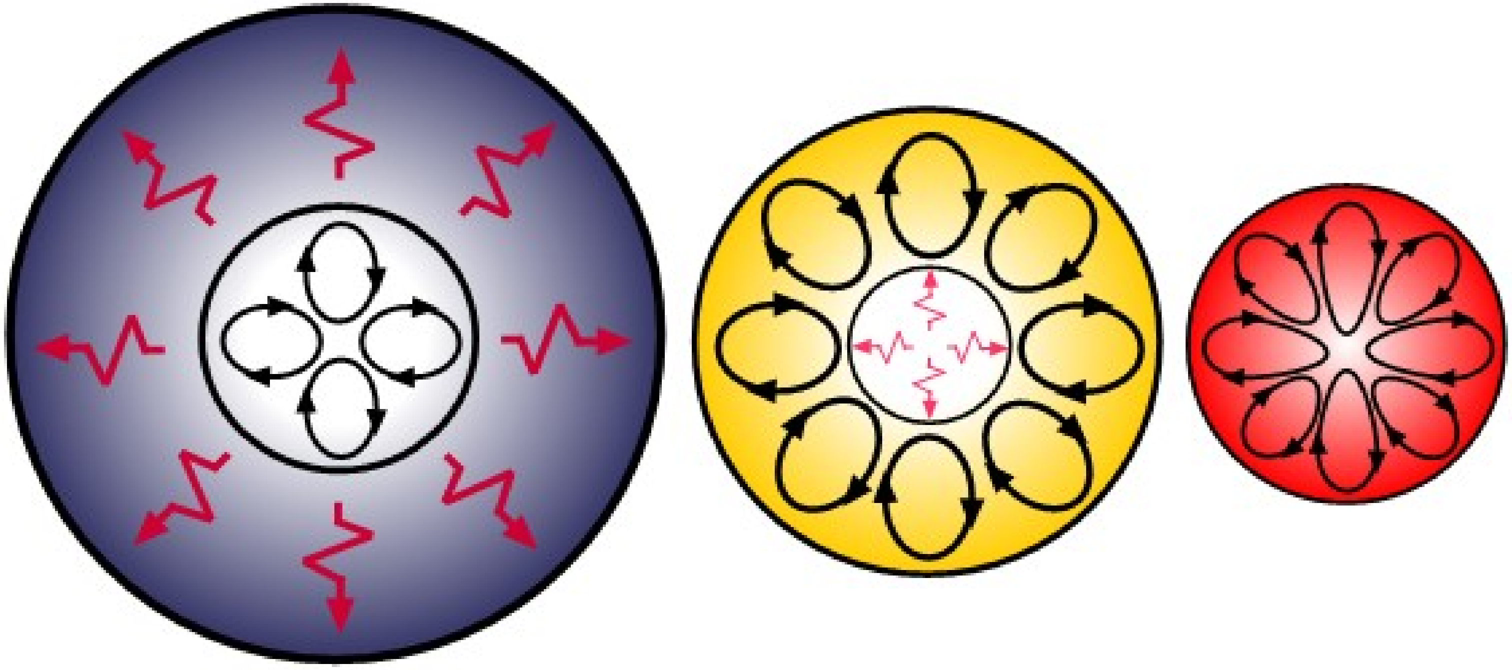
Magnetic activity is associated with convection



$M > 1.5$	$0.5 < M < 1.5$	$M < 0.5$
Convective Core Radiative Envelope	Radiative Core Convective Envelope	Fully Convective

Stellar Structure

Magnetic activity is associated with convection



$M > 1.5$	$0.5 < M < 1.5$	$M < 0.5$
Convective Core Radiative Envelope	Radiative Core Convective Envelope	Fully Convective
Non-magnetic	**Magnetic**	**Very magnetic**