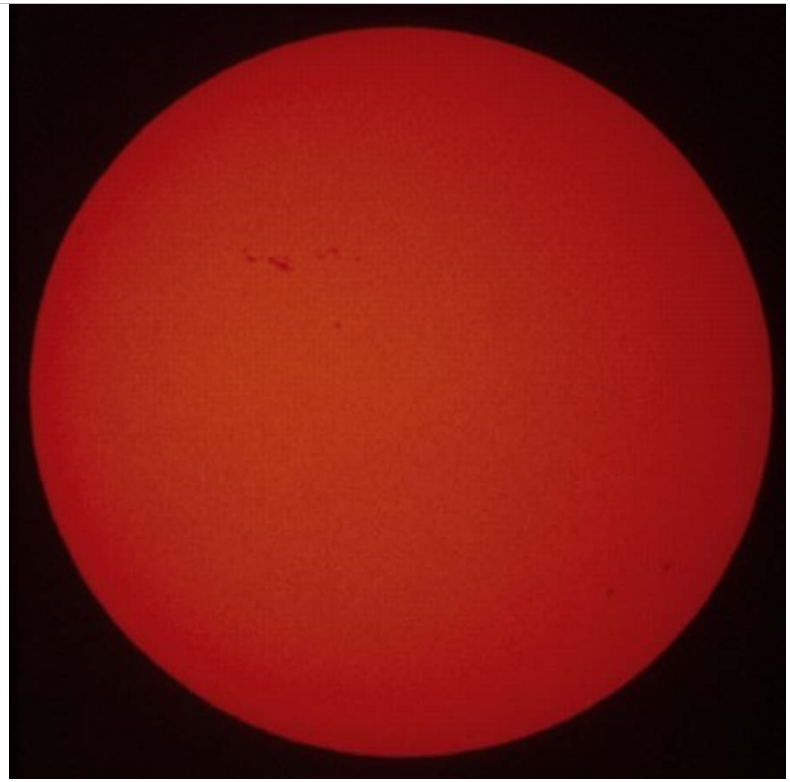
ASTR 1030– October 15

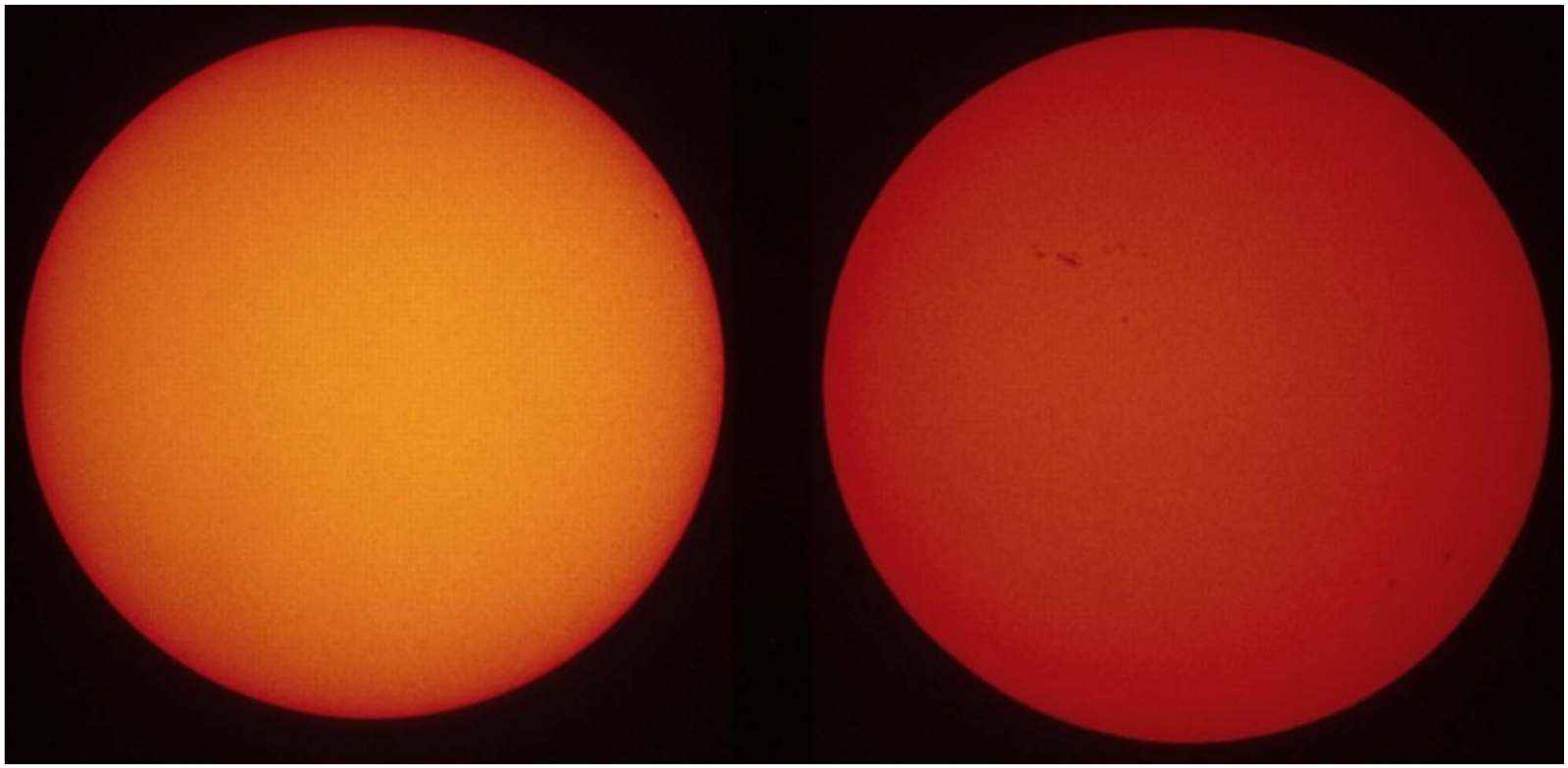
Announcements

Problem Set 4 now posted.
Please turn in on Monday October 18
If that's not enough time we'll take it on the 20th

Second Exam on Monday 25th
Next Observatory also 25th



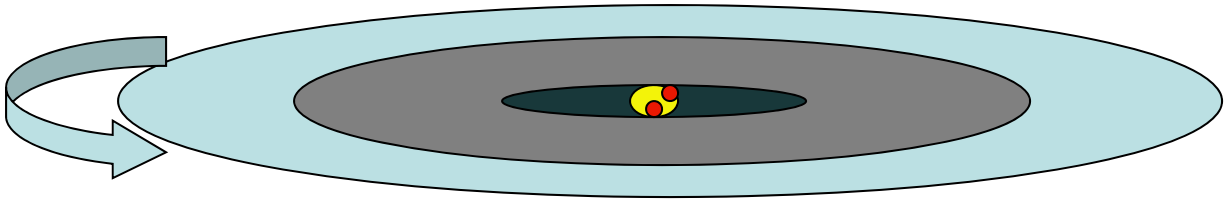
The Sun



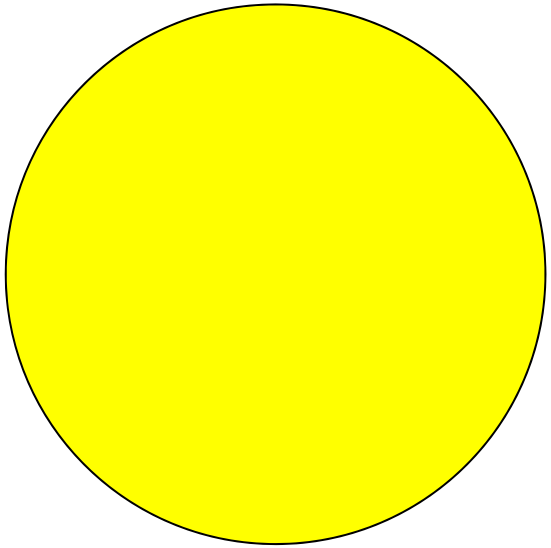
The Sun

Falls into “Disk Stability”
99.9% Ended in Sun (0.1% in Jupiter)
Probably the Same Around All Stars -- Planets are Common

Shoots Planet-Size
Bullets into Space



Most of Mass Forms Ball in Center



One Million Miles

A Star Is a Hot Ball of Hydrogen (plus 11% Helium)

What Stops the Fall?

Gravity Gets Stronger As Material Gets More Dense

$$F_g = \frac{GMm}{R^2}$$

R smaller implies F greater

The smaller it gets, the faster it falls in!

Why doesn't it just become a black hole?

Or worse yet, a point-like singularity of mass?

Temperature

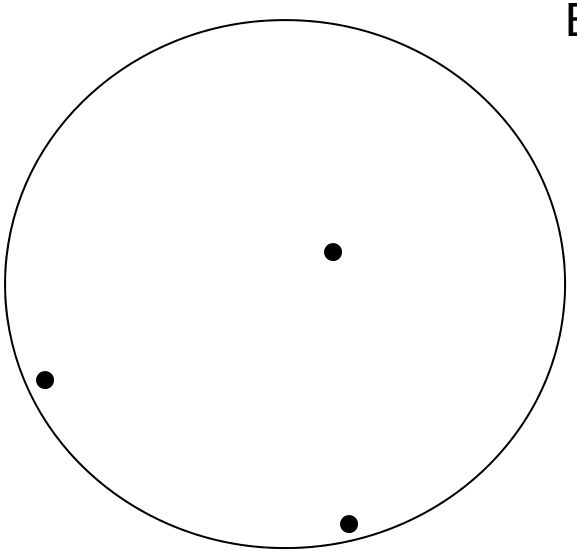
Temperature is a Measure of the
Random Kinetic Energy per Particle

The faster the atoms move, the higher the temperature.

But we're talking about *random* motion.
If they all move together, then the object moves.

Thermal Pressure

Thermal Gas Pressure Balances Gravitational Pressure



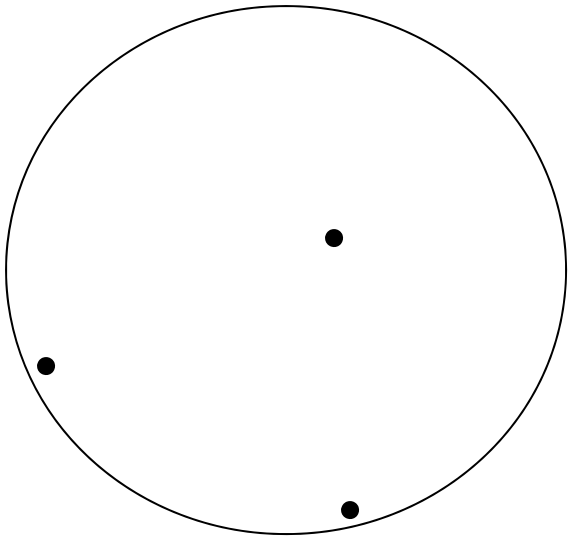
Balloon

Every Time An Bounces Off Edge of Balloon It Keeps It From Collapsing

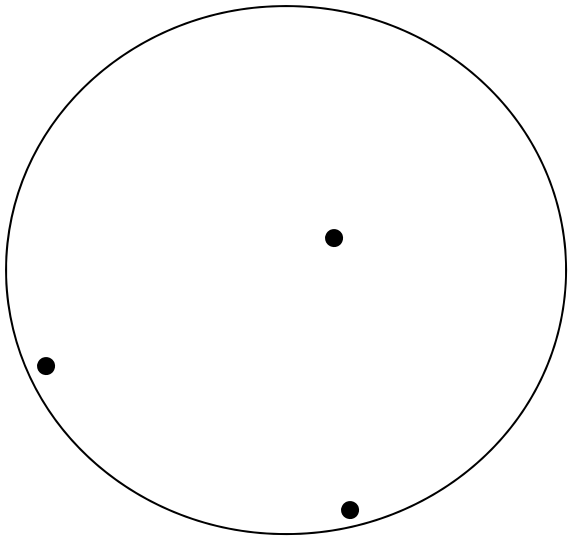
That's Pressure

Pressure is Force per Unit Area

Pressure is Proportional to Temperature

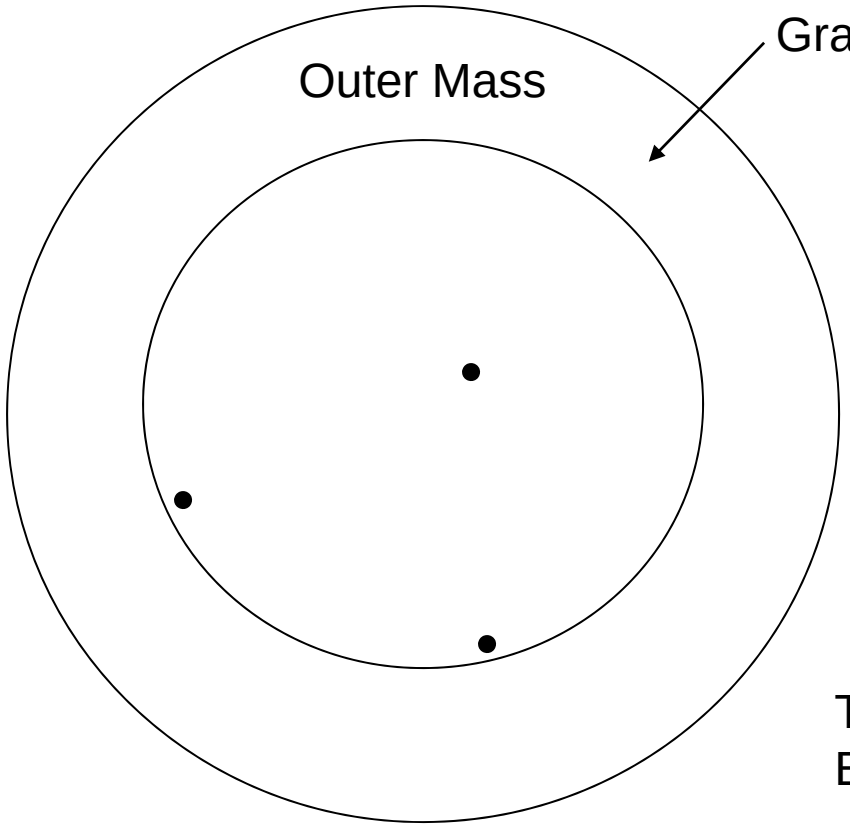


Low Temperature
Atoms Move Slowly



High Temperature
Atoms Move Fast

A Star Is Held Up By Thermal Pressure From Below



Individual Atoms Don't Orbit Entire Inside of Star Like This

They Jostle Each Other But Effect Is The Same

Temperature Scales

- Fahrenheit –
  - 0=salt water freeze 100=human body
- Celsius
  - 0=pure water freeze 100=water boil (sea level)
  - C=(F-32)x5/9
- Kelvin
  - 0=absolute zero 100 degrees between freeze and boil
  - K=C+273
  - -273C = 0K = Absolute Zero

At Absolute Zero Atoms Stop Moving

Thermal Pressure

$$PV = nRT$$

Ideal Gas Law
Chemistry Style

P Pressure
V Volume
n # moles
R Constant
T Temperature (K)

$$PV = NkT$$

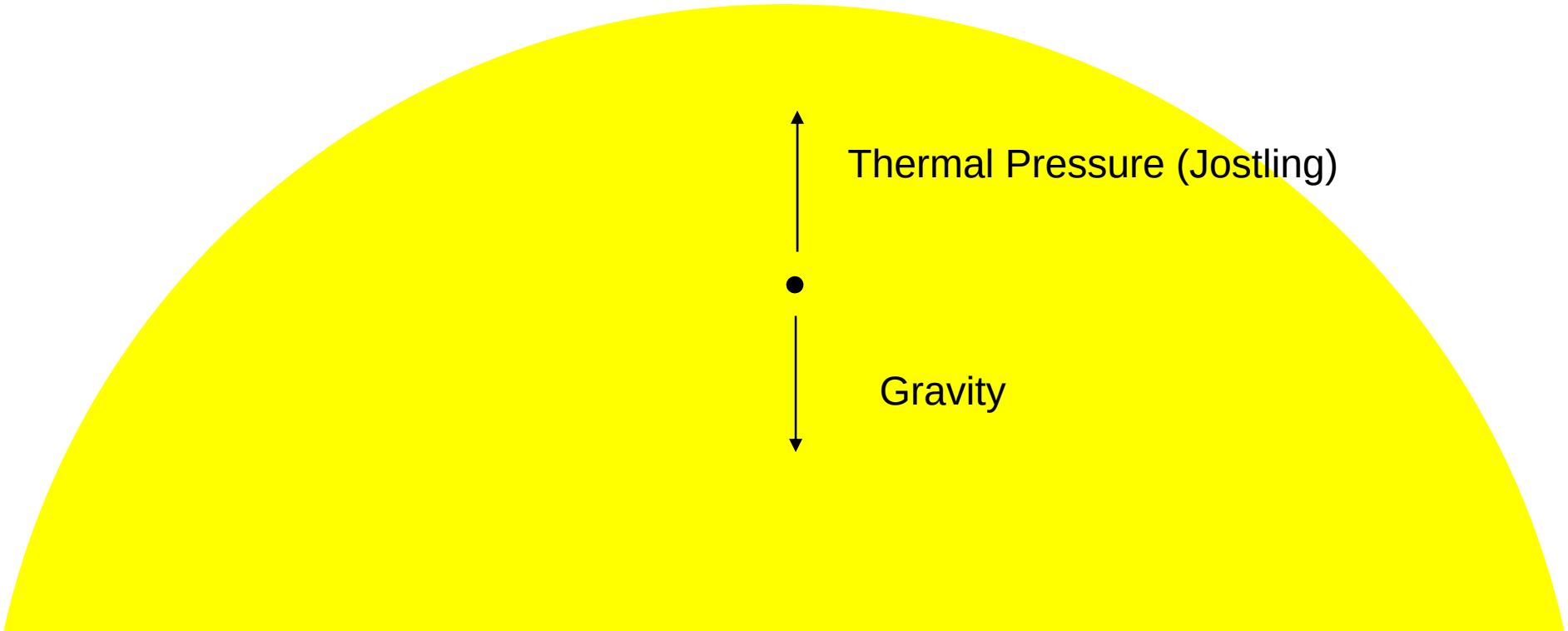
Ideal Gas Law
Physics Style

P Pressure
V Volume
N # atoms
k Constant
T Temperature (K)

Pressure Is Proportional to Temperature x Density

Pressure Balance

A Star Always Balances Gravitational Pressure with Thermal Pressure
At Each Point Inside



But We Have a Problem

The Sun is Luminous

Radiates Energy Into Space

Luminosity is Power Radiated -- ergs/second

The Energy Comes From Motion of the Atoms
Temperature Drops

What Happens When T Drops?

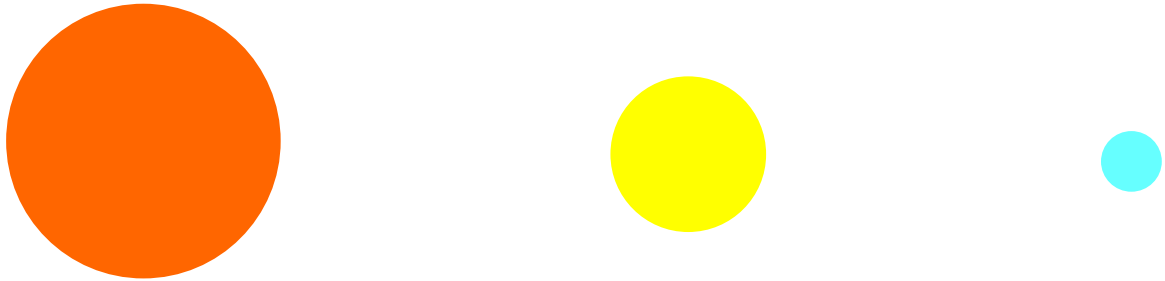
Luminosity Effect

When T Drops Thermal Pressure Can't Hold Off Gravity

The Sun Shrinks -- Radius Drops

Energy is Released as Gas Falls Deeper Into Gravity Field

Temperature Rises



Note – Loss of Energy Results in
a) Temperature Rise
b) Radius Decrease

But Wait A Minute…
Isn't the Sun Stable?

The Sun has been remarkably stable for 4 billion years as evidenced by geological records.

This collapse is the process by which the Sun coalesced.
But then it stopped. Why?

The Sun collapsed until a new source of energy offset the losses to radiation.

NUCLEAR FUSION --- IT'S BURNING HYDROGEN

As long as it burns H at this rate, it will be stable.

Fusion Increases with T

As T in core of Sun increases so does energy production

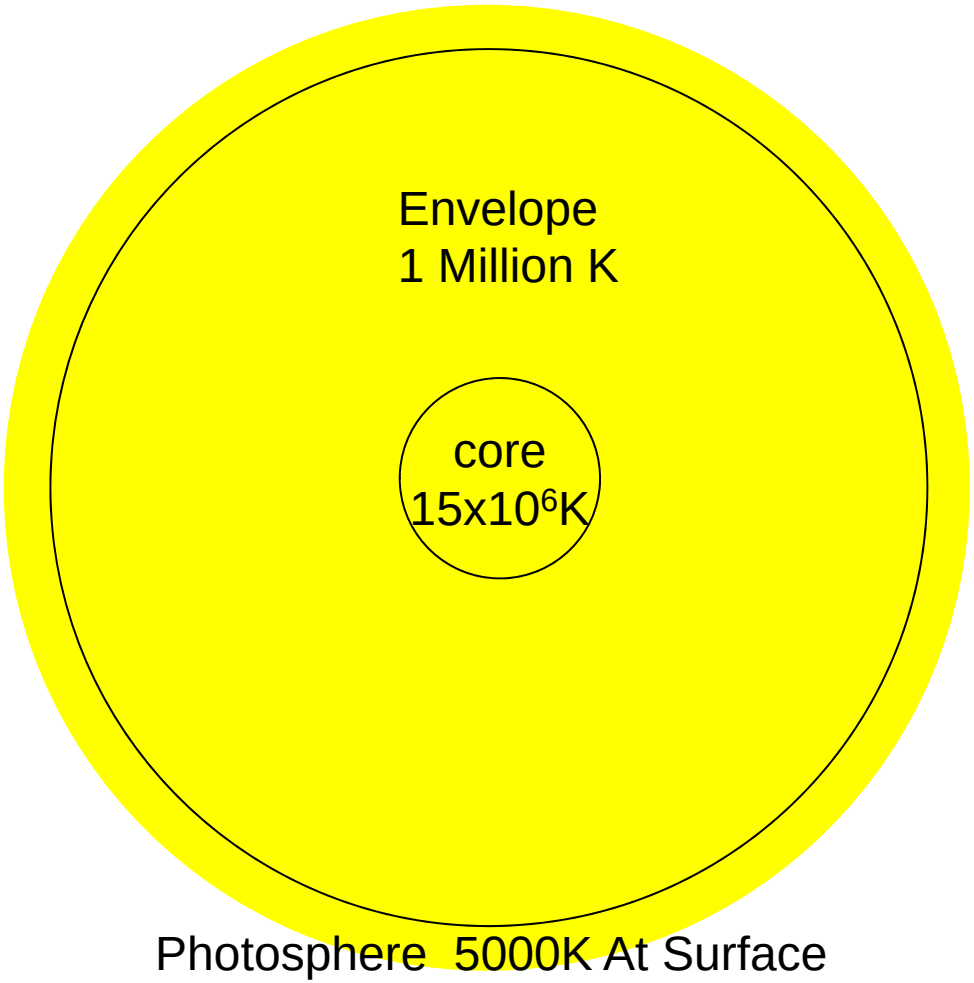
Sun shrank steadily, with T rising until, about 10 million years after it started to form, it reached its current size

There is a VERY fast increase in nuclear energy production above 1,000,000K.

At 15,000,000K in the core nuclear power generated finally balanced the luminosity from the surface.

That’s the equilibrium we are still in.

The Nuclear Core



Cosmic Composition

- H hydrogen 89% by number
- He helium 11%
- O oxygen 0.1%
- C carbon 0.06%
- N nitrogen 0.015%

Pretty much the composition of the entire universe.
Sun and Jupiter have this composition
Earth does not.

Fusion vs. Fission

Fusion: Atoms unite and release energy (Fuse)
New atom must be no heavier than iron z=26

Fission: Heavy atoms split to release energy
Initial atom must be heavier than iron

WWII Nukes were fission bombs made of U and Pu

Sun works on FUSION of H into He

Proton-Proton Chain

Bottom Line: $H+H+H+H \rightarrow He$

$$_1H^1 + {}_1H^1 \rightarrow {}_1H^2 + e^+ + \nu$$

$$_1H^2 + {}_1H^1 \rightarrow {}_2He^3 + \gamma$$

$$_2He^3 + {}_2He^3 \rightarrow {}_2He^4 + {}_1H^1 + {}_1H^1$$

$5 \times 10^6 < T < 2 \times 10^7 K$

CNO Cycle

$$_{6}C^{12} + _{1}H^{1} \rightarrow _{7}N^{13} + \gamma$$

$$_{7}N^{13} \rightarrow _{6}C^{13} + e^{+} + \nu$$

$$_{6}C^{13} + _{1}H^{1} \rightarrow _{7}N^{14} + \gamma$$

$$_{7}N^{14} + _{1}H^{1} \rightarrow _{8}O^{15} + \gamma$$

$$_{8}O^{15} \rightarrow _{7}N^{15} + e^{+} + \nu$$

$$_{7}N^{15} + _{1}H^{1} \rightarrow _{6}C^{12} + _{2}He^{4}$$

$2x10^{7} < T < 10^{8}K$

Net: $_{1}H^{1} + _{1}H^{1} + _{1}H^{1} + _{1}H^{1} \rightarrow _{2}He^{4} + 2e+ + 4\gamma + 2\nu$

hydrogen -> helium + energy

Triple-α Reaction

$$ {}_2He^4 + {}_2He^4 \Leftrightarrow {}_4Be^8 + \gamma $$

$$ {}_4Be^8 + {}_2He^4 \rightarrow {}_6C^{12} + \gamma $$

$T < 10^8 K$

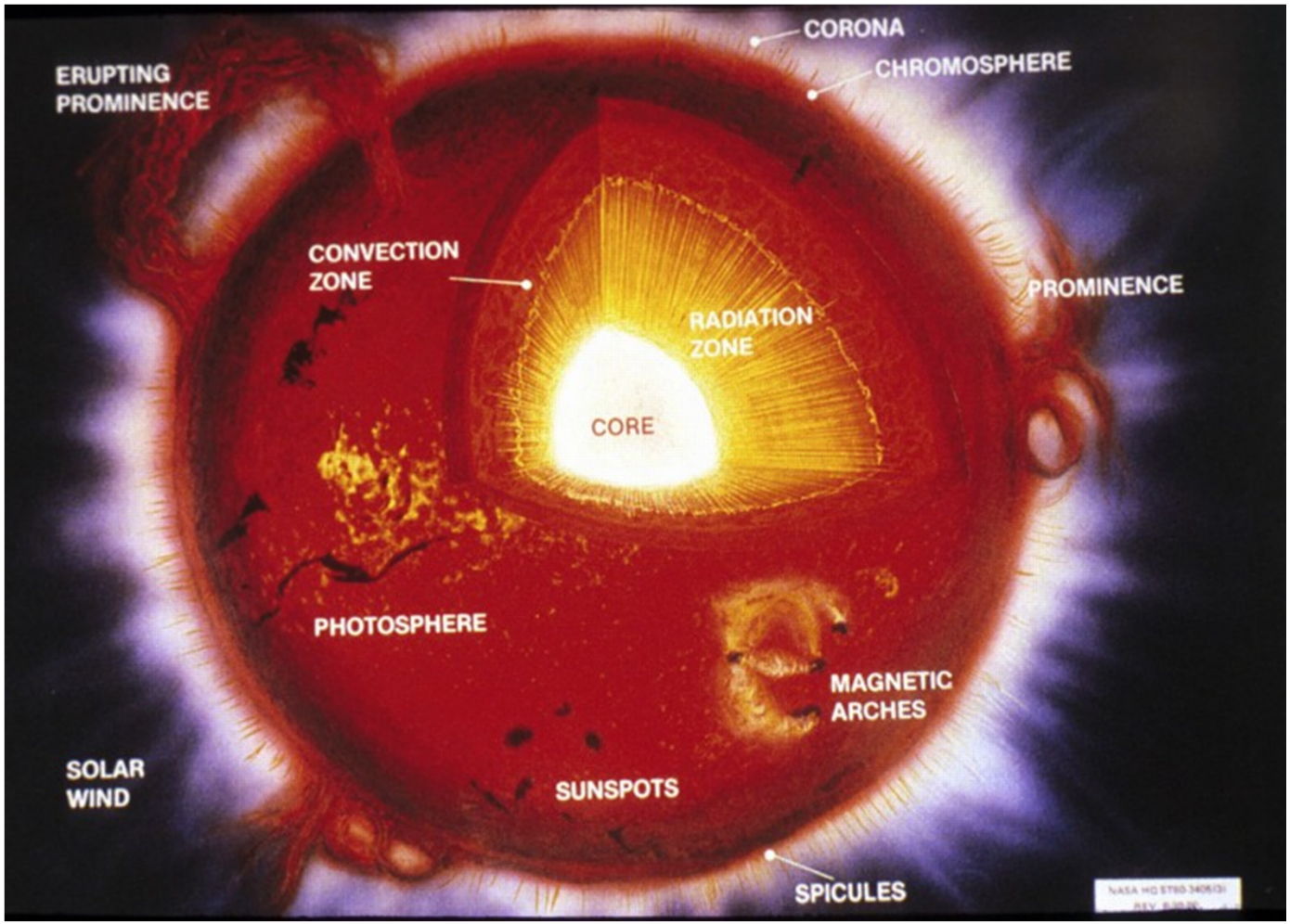
Must be very dense for this to work
Be^8 decays back into helium very quickly unless struck by another He^4

Too low density in Big Bang

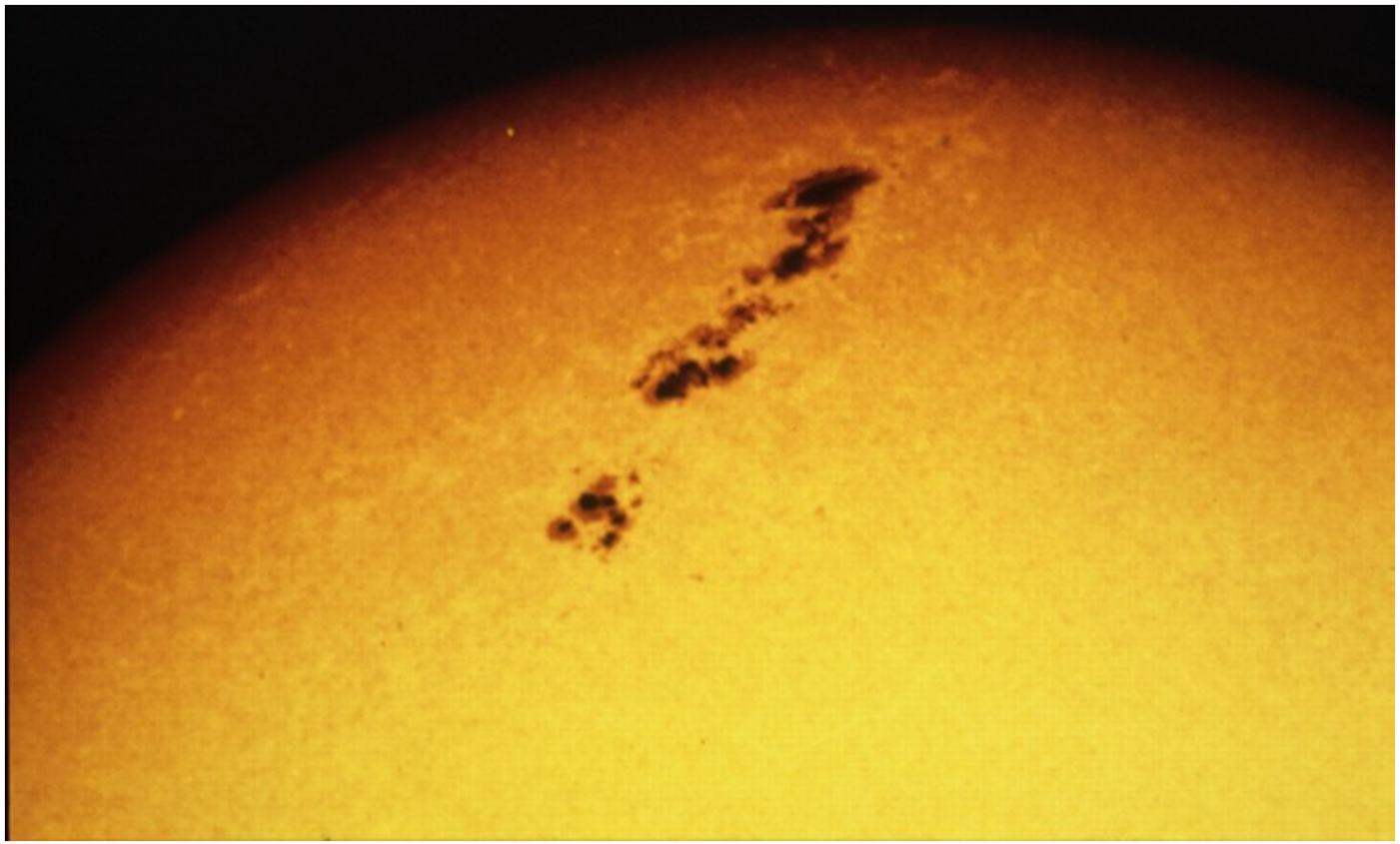
Net: $ {}_2He^4 + {}_2He^4 + {}_2He^4 + {}_2He^4 \rightarrow {}_6C^{12} + 2\gamma $

helium -> carbon + energy

Solar Schematic

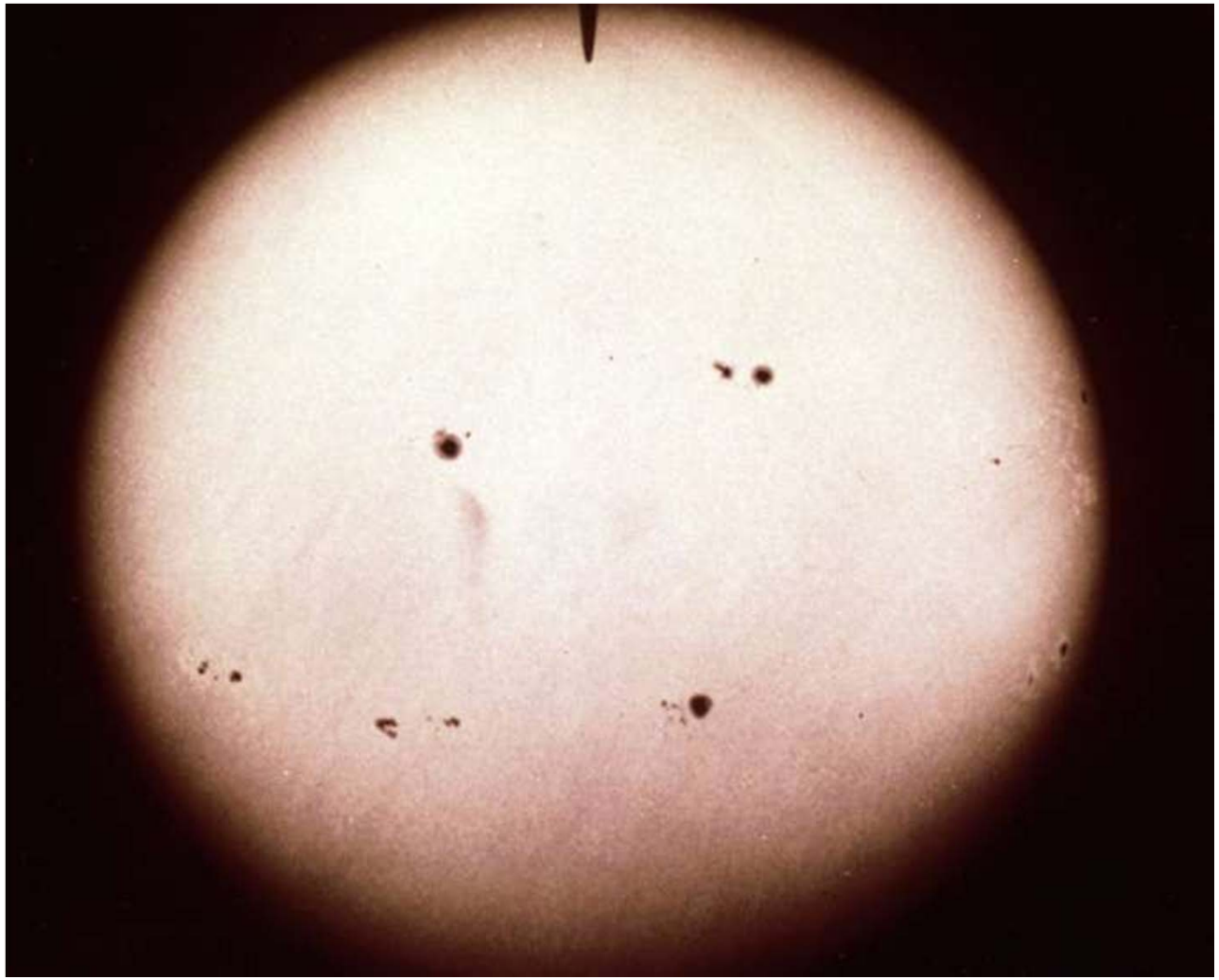


Sunspots

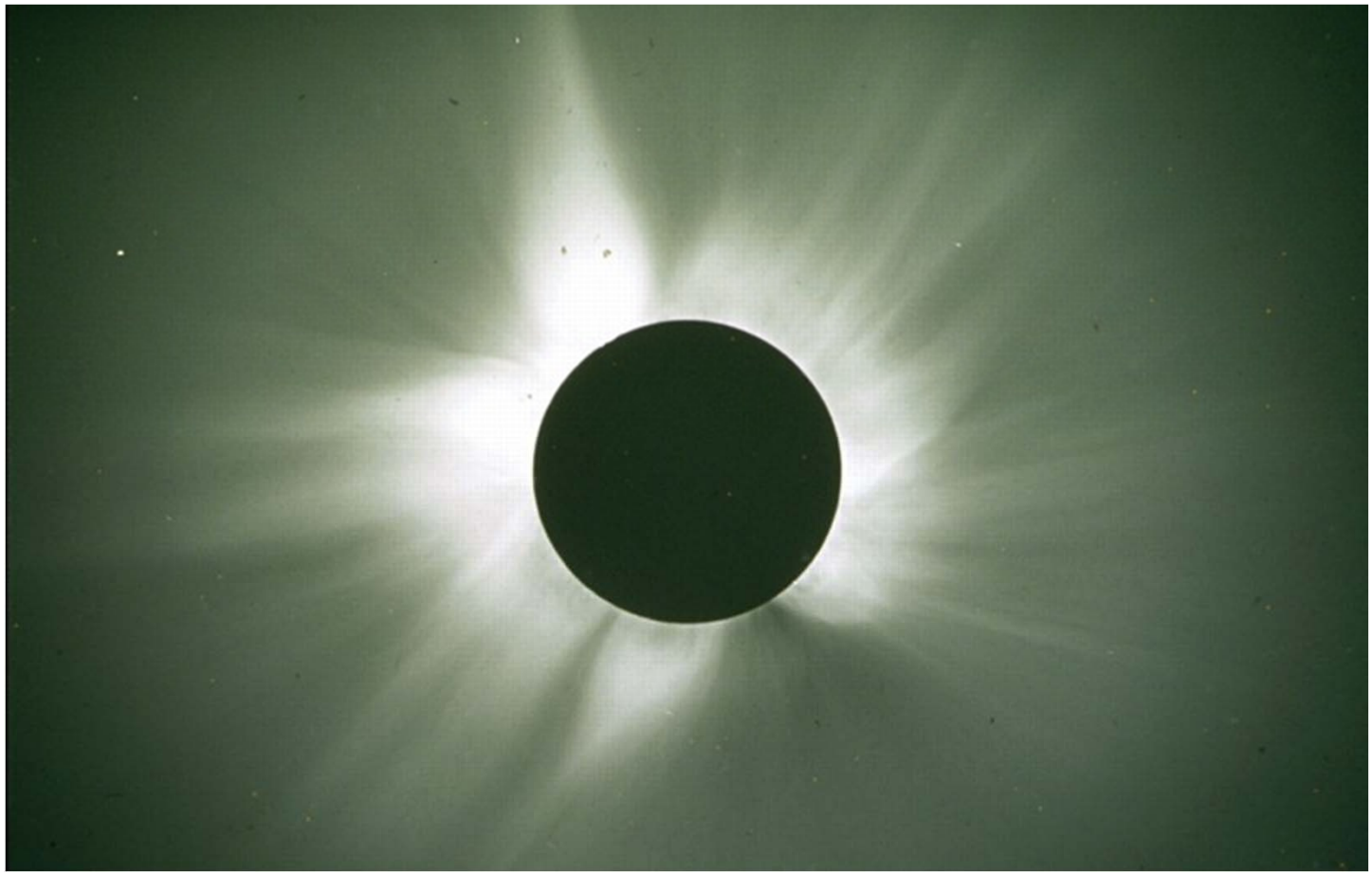


Seen by Ancient Persians

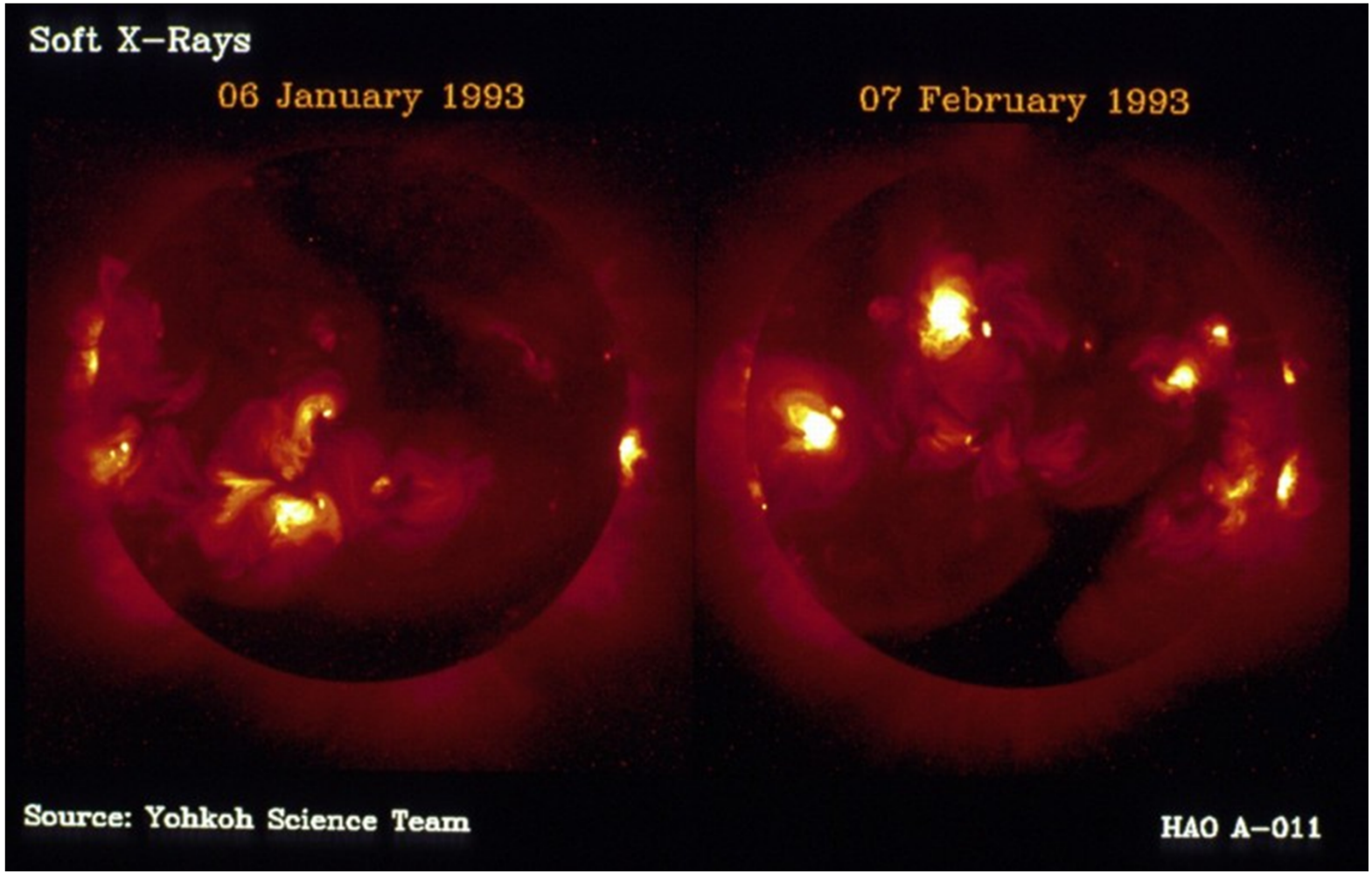
Groups of Sunspots



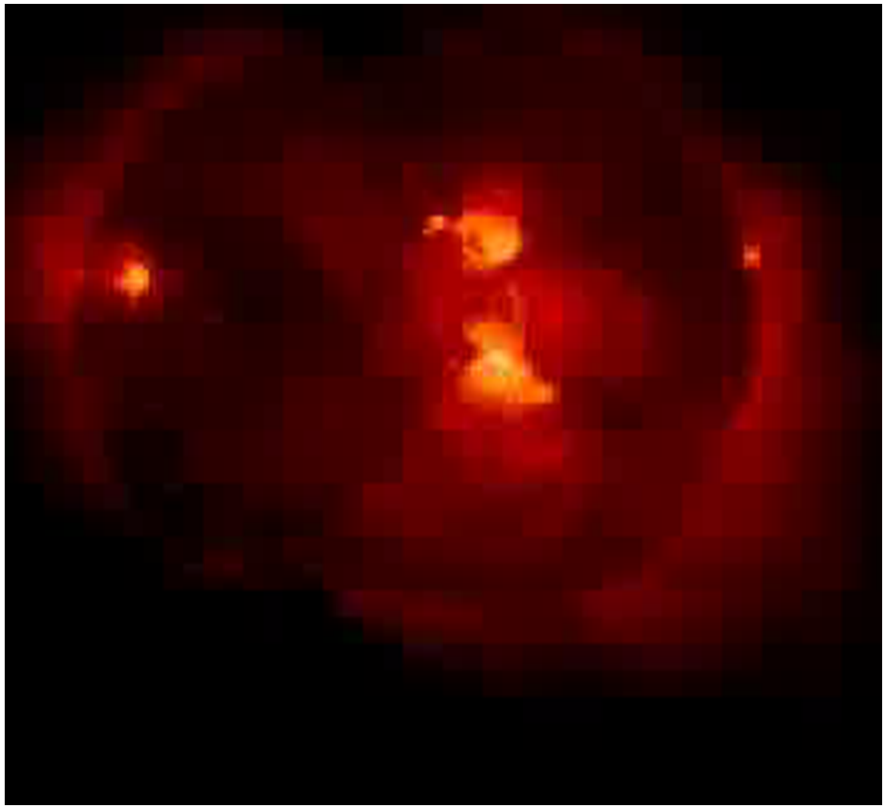
Solar Corona Visible in Eclipse



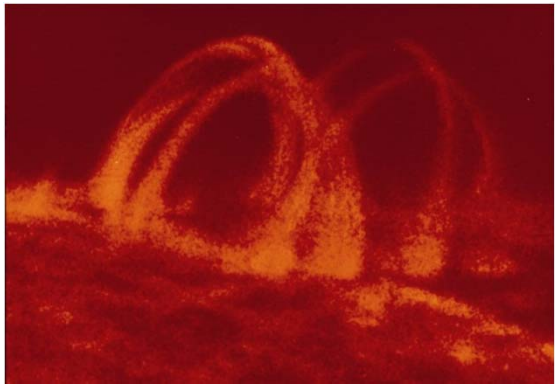
The Sun Viewed in X-rays

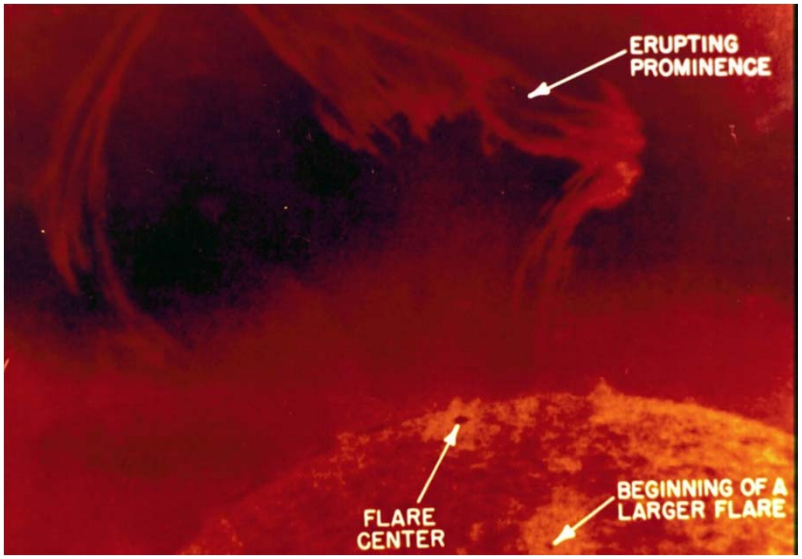


X-ray Movie

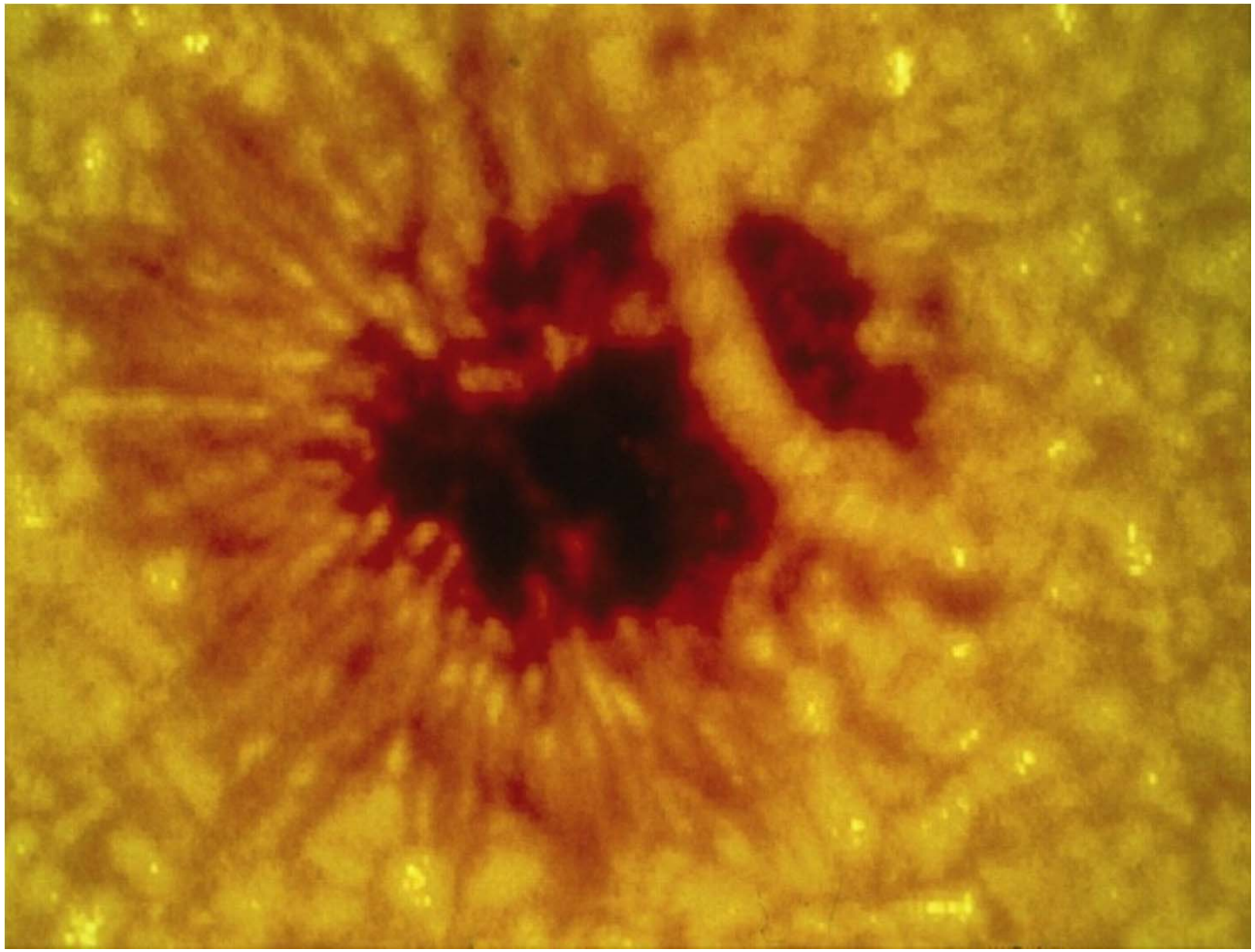


X-ray Loops

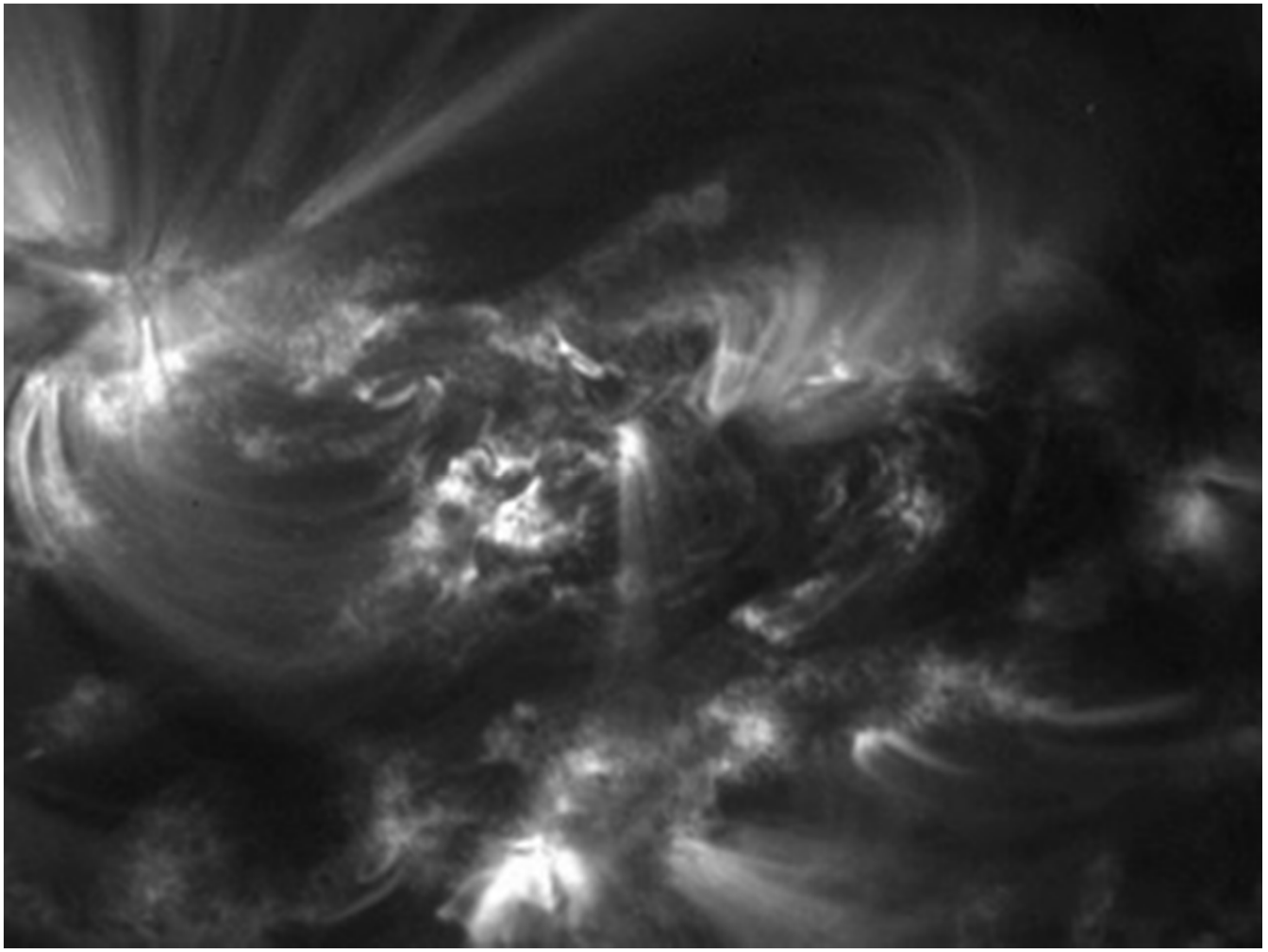


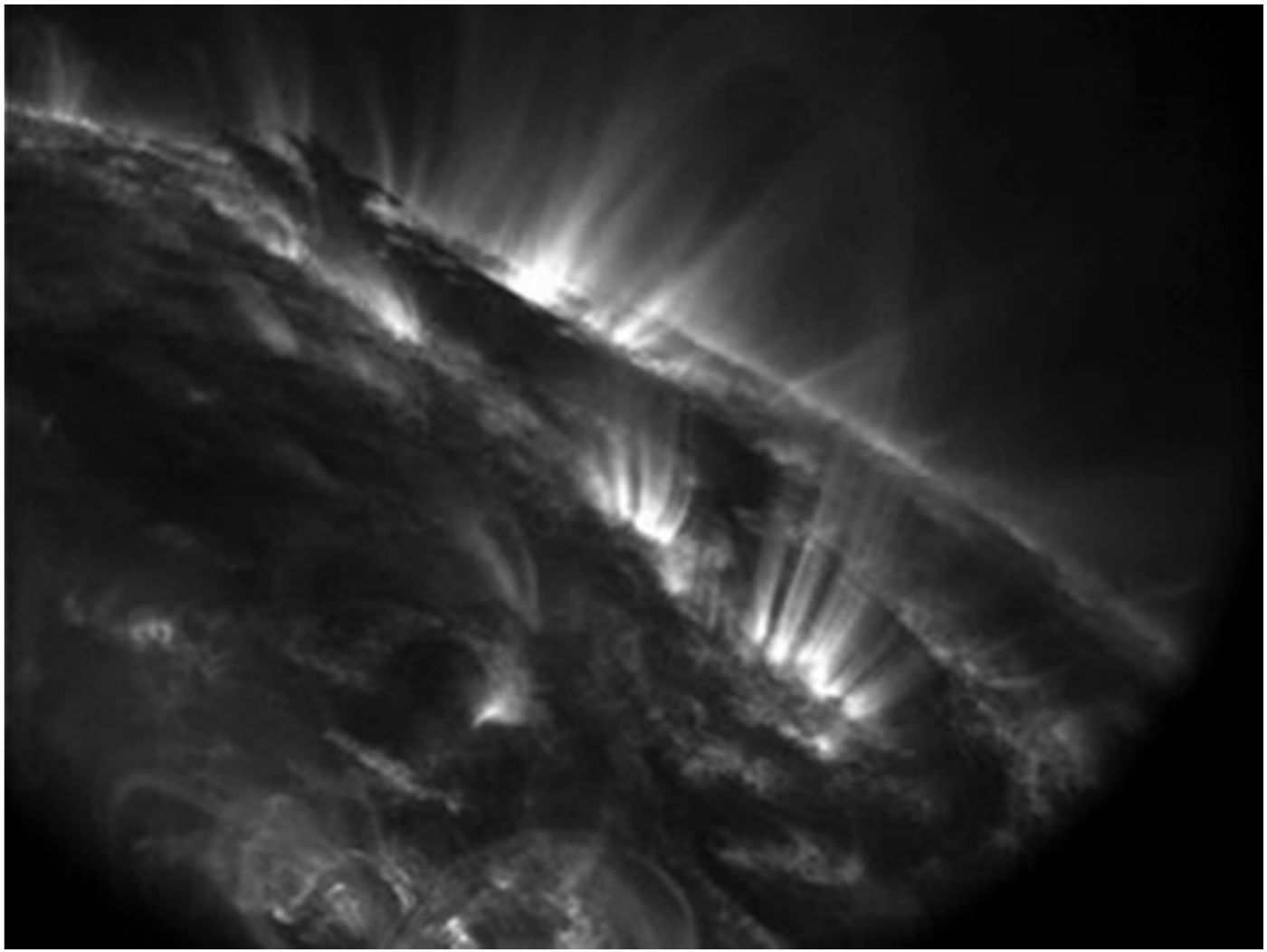

ERUPTING
PROMINENCE
FLARE
CENTER
BEGINNING OF A
LARGER FLARE

Magnetic Structure

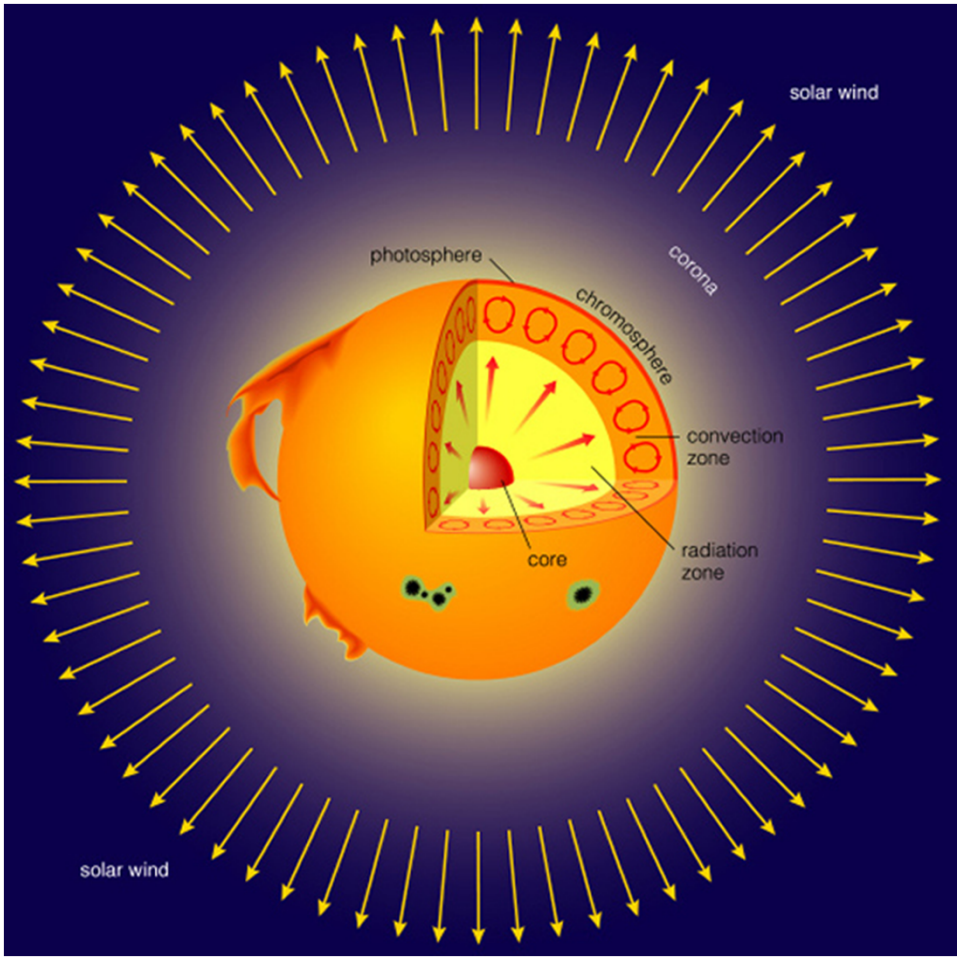


Dynamic Structure



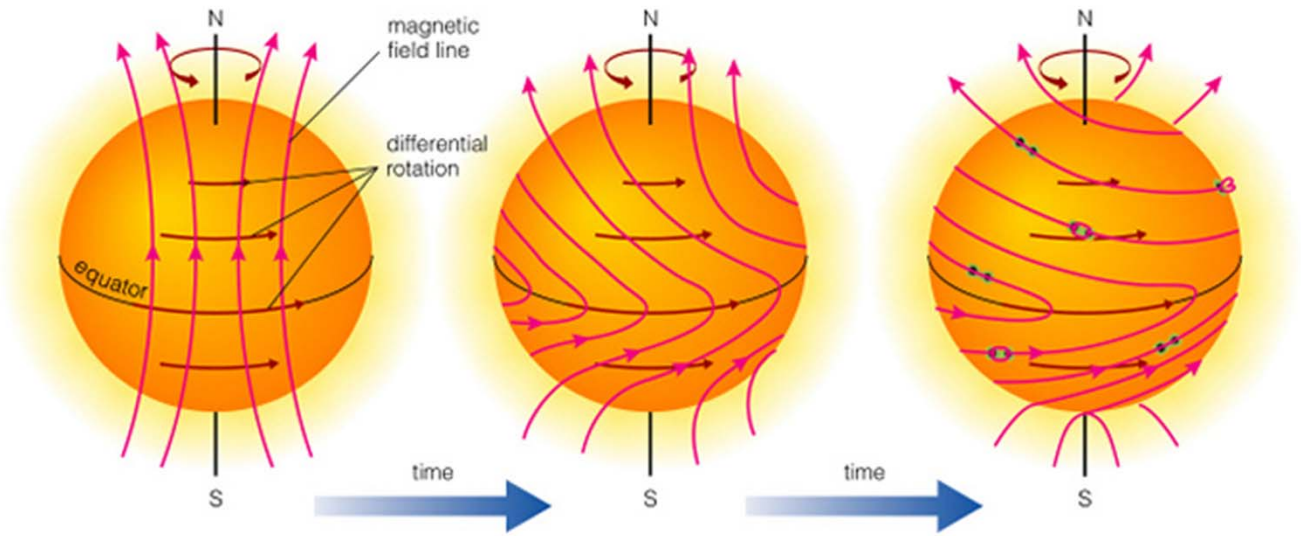


Solar Turbulence

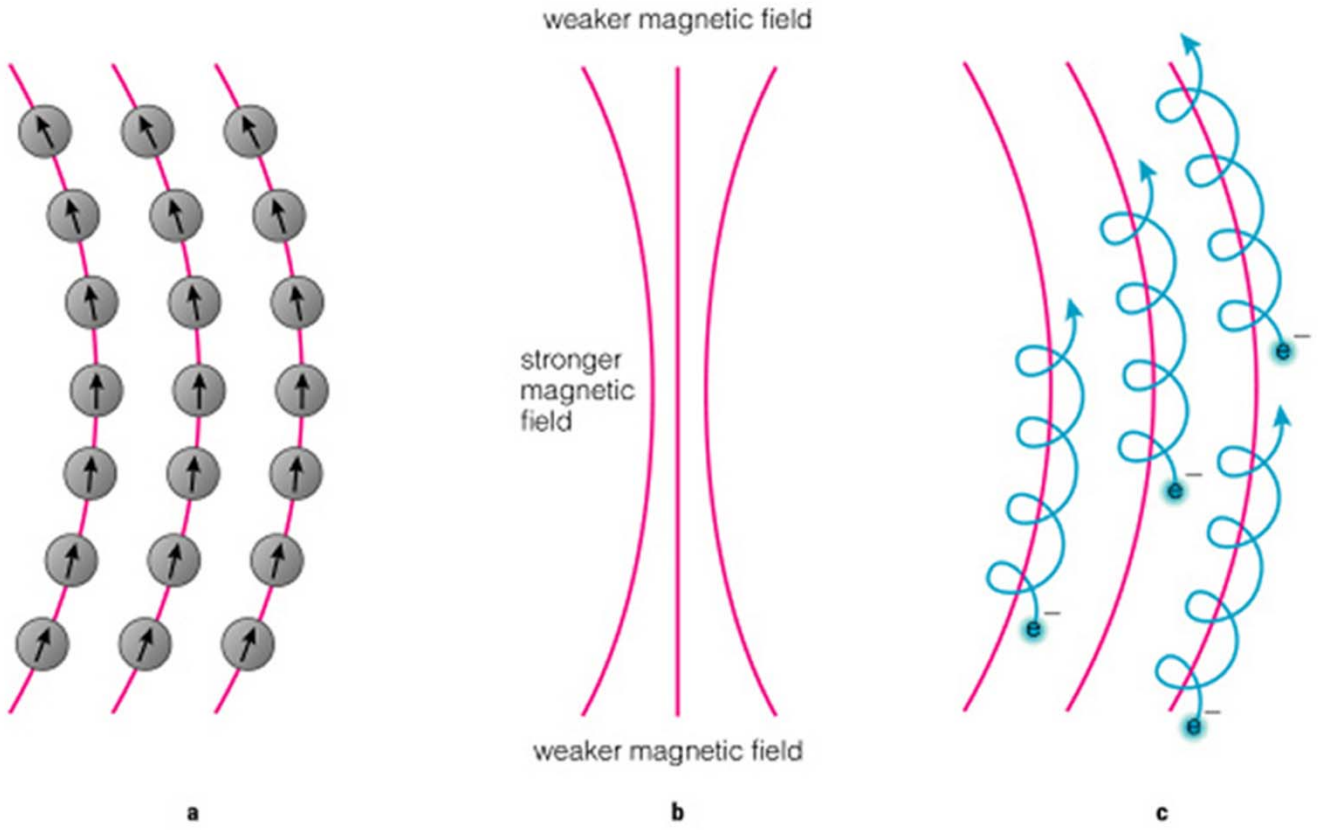


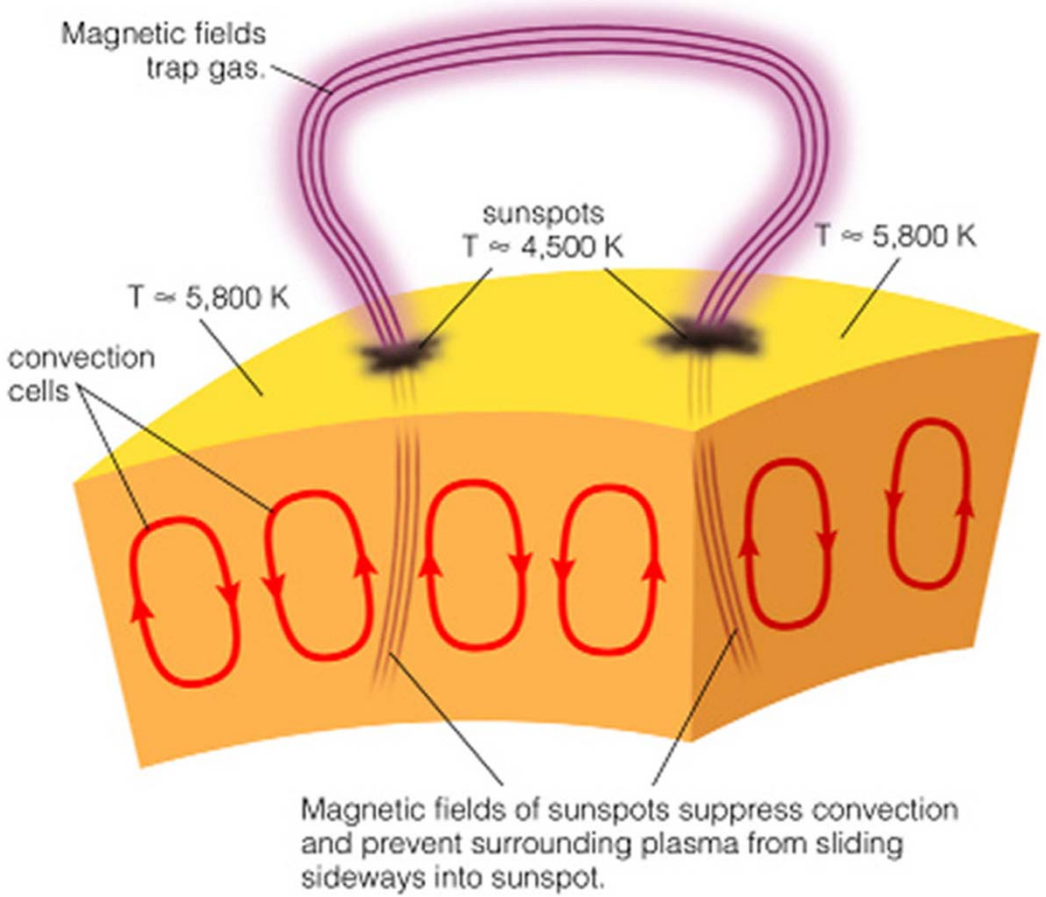
Differential Rotation

Rotates in 25 days at Equator
28 days Mid Latitude
30 days Poles

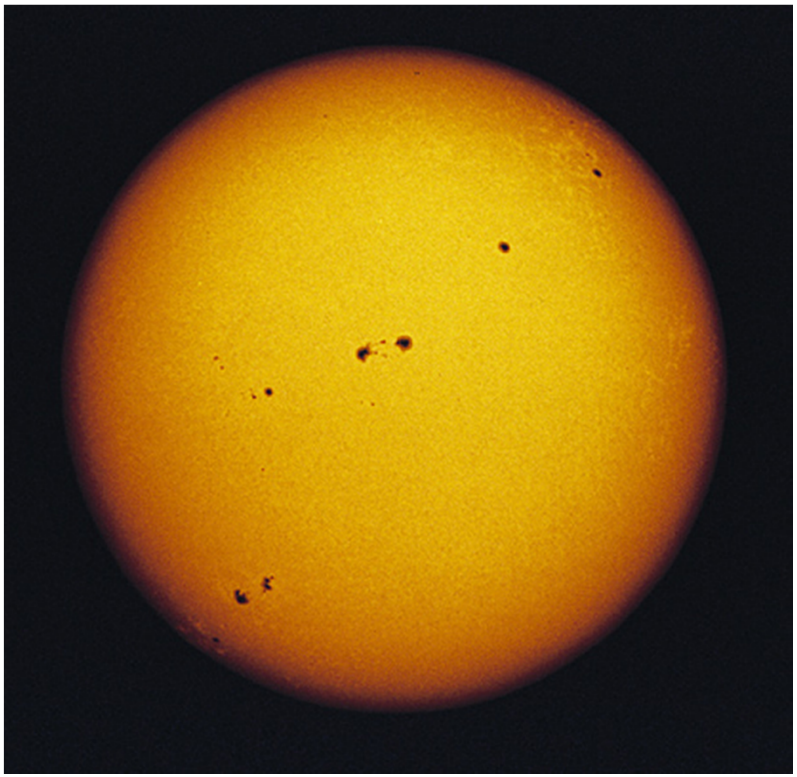


Rapidly Twists Up

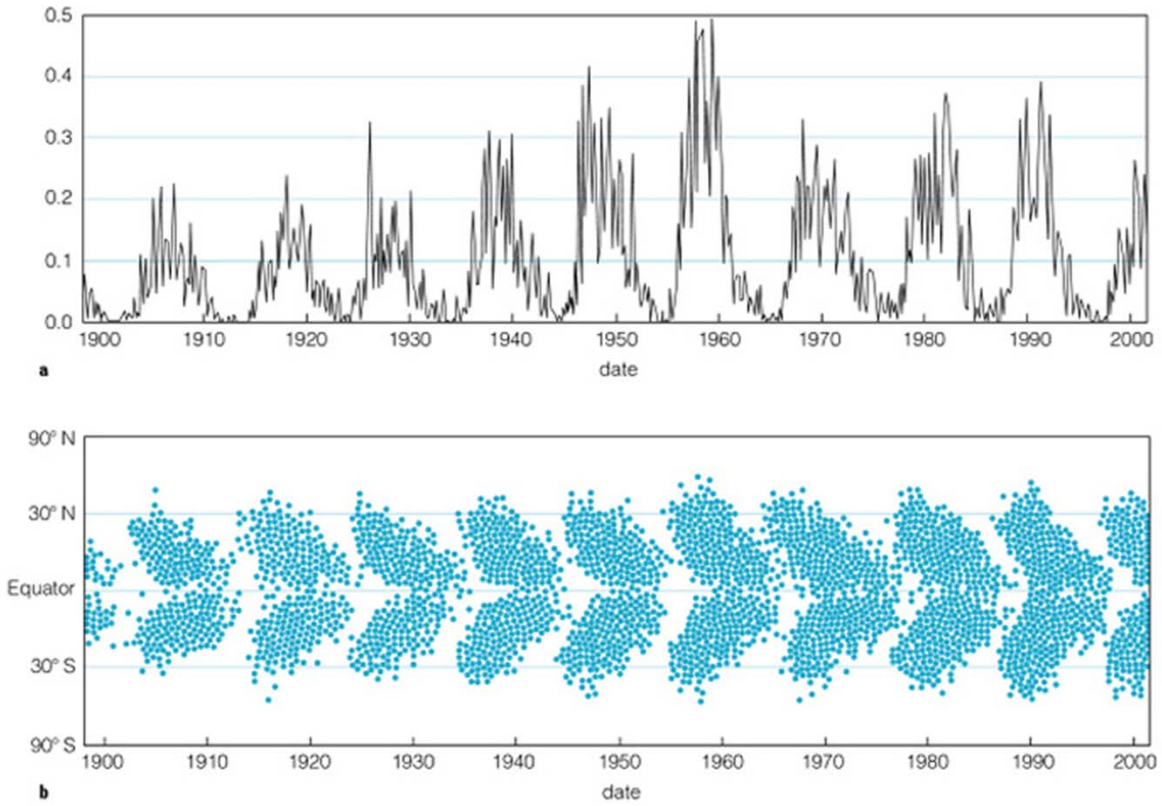

weaker magnetic field
stronger
magnetic
field
weaker magnetic field
e⁻
e⁻
e⁻
e⁻
e⁻
a
b
c


Magnetic fields
trap gas.
sunspots
T ≈ 4,500 K
T ≈ 5,800 K
T ≈ 5,800 K
convection
cells
Magnetic fields of sunspots suppress convection
and prevent surrounding plasma from sliding
sideways into sunspot.

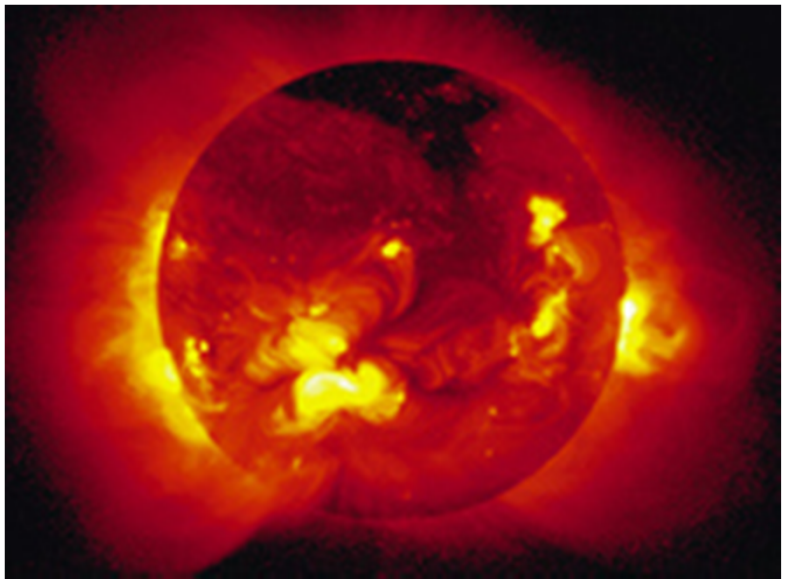
Sunspots Erupt in Groups



Sunspot Cycle



During mid 1600's sunspots became non-existent
Maunder Minimum



Solar Wind 5×10^5K

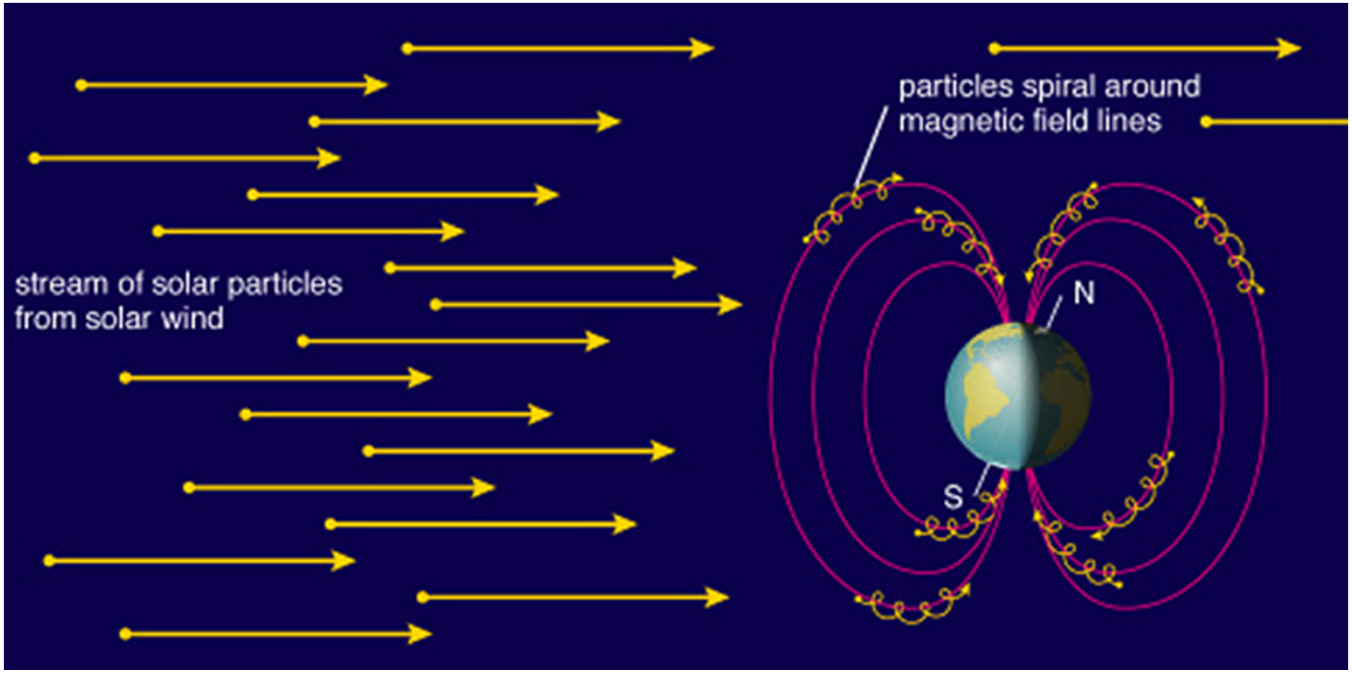
Corona 2×10^6K

Transition Region 10^5K

Chromosphere 10^4K

Photosphere 5500K

Solar Wind Passes Earth



Summary: Sun as a Star

- Formed from cloud 4.6×10^9 years ago
- Collapsed to present size
  - stabilized by nuclear reactions
- Emits 4×10^{26}W
- Runs on proton-proton chain and CNO cycle
- Now 20% brighter than when first formed
- Turbulent upper envelope
- Magnetic Fields from Differential Rotation
- Sunspots, Corona, Solar Wind
- Activity Cycle 11 years