

ASTR 400/700: Stellar Astrophysics

Stephen Kane

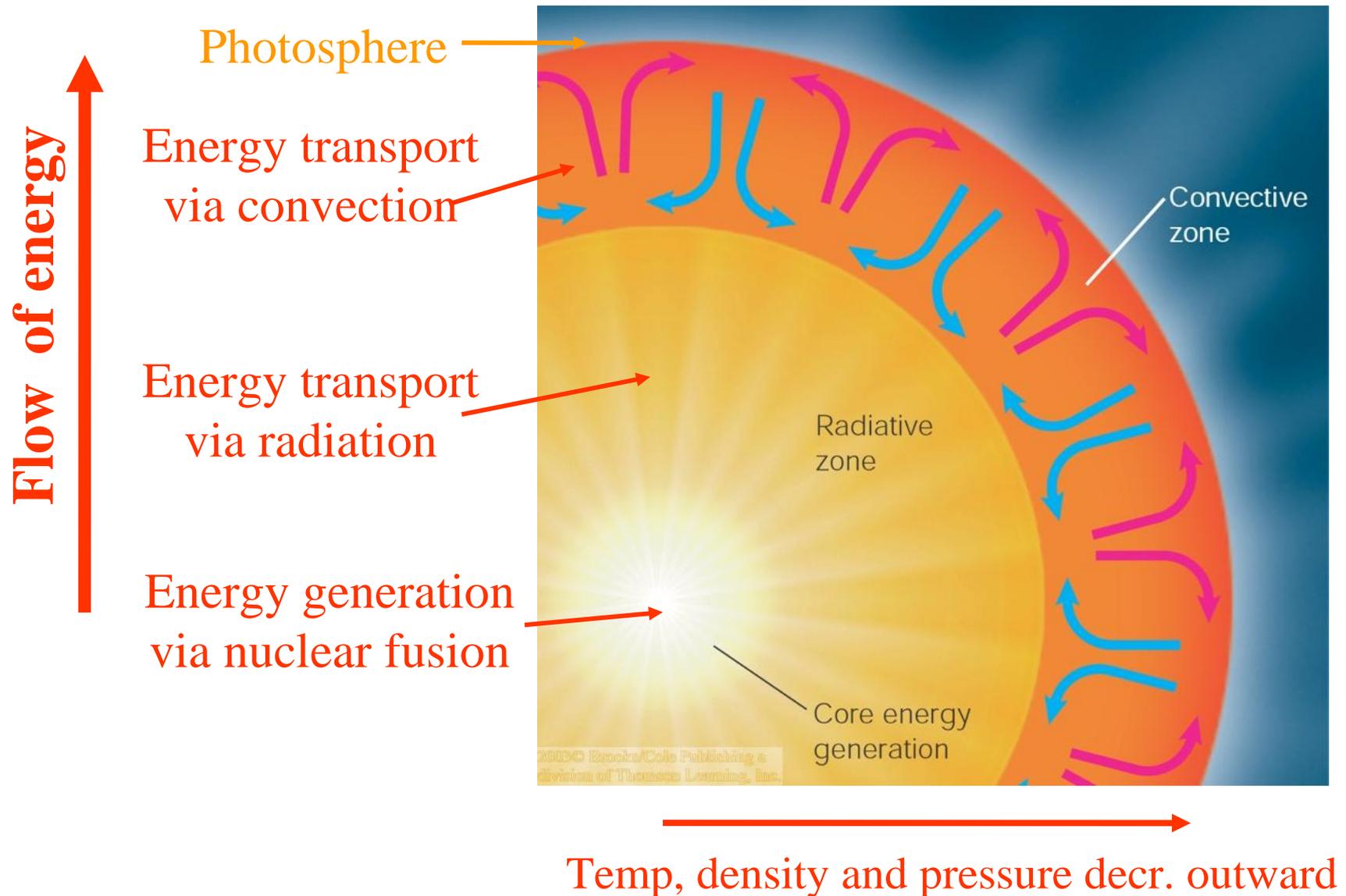


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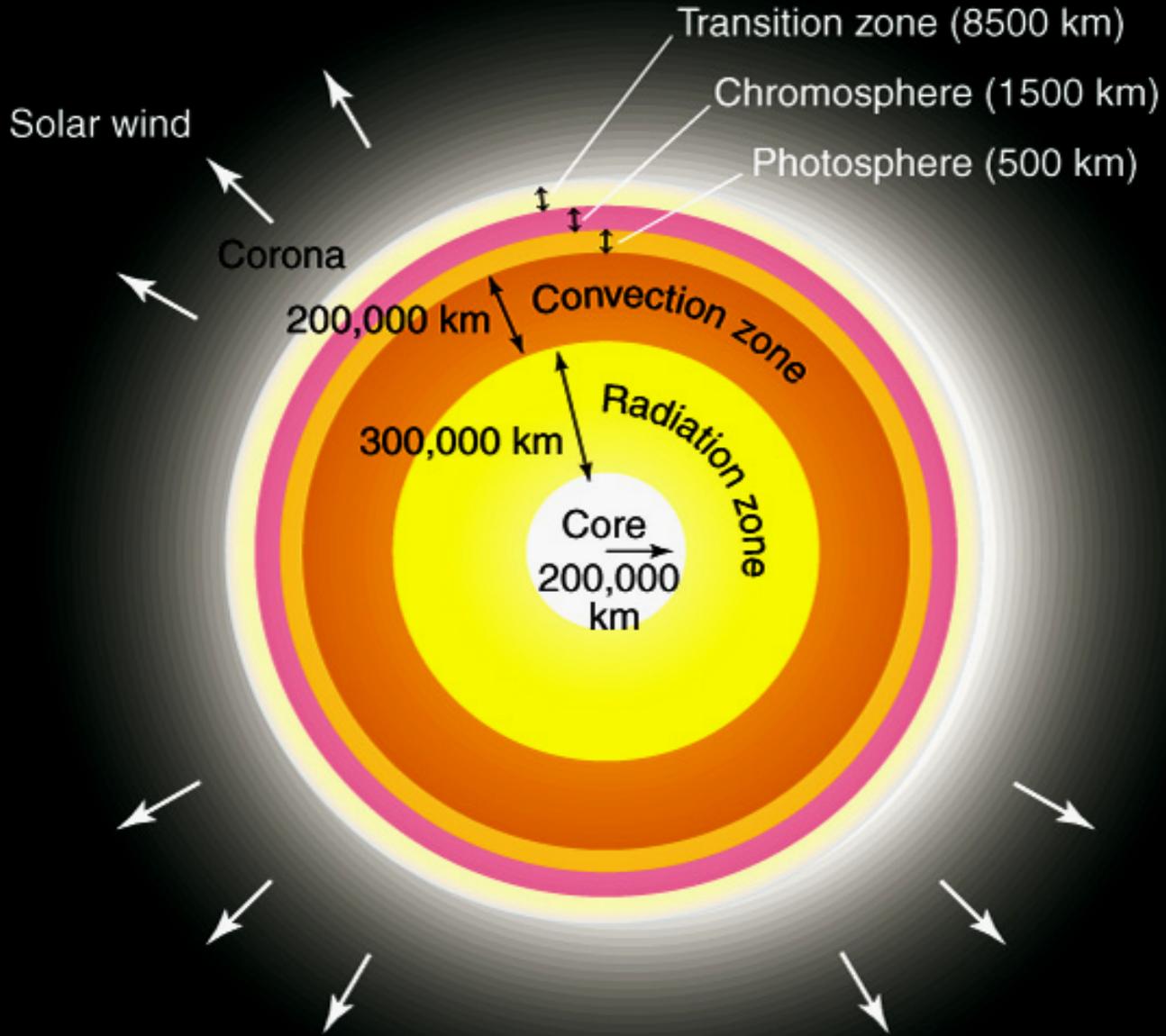
Solar Atmosphere

Chapter 11.2, 11.3

The Sun's Interior Structure

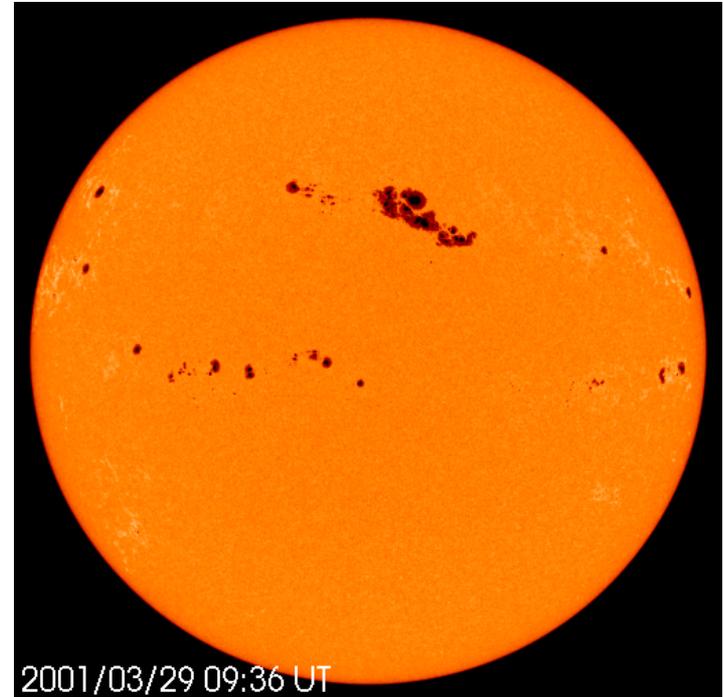


Main Regions of the Sun



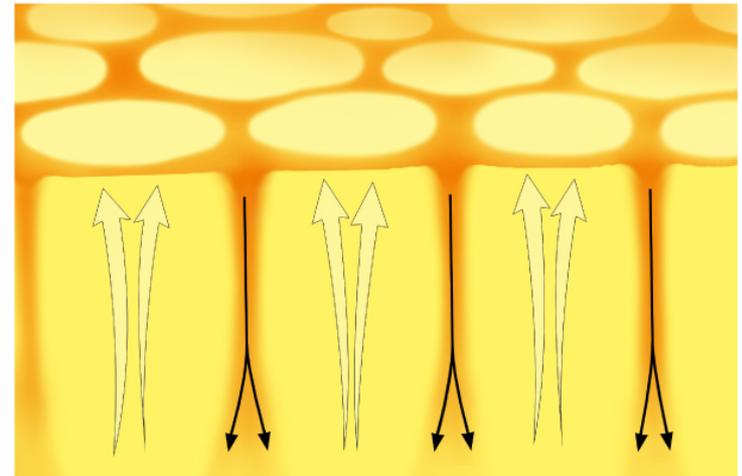
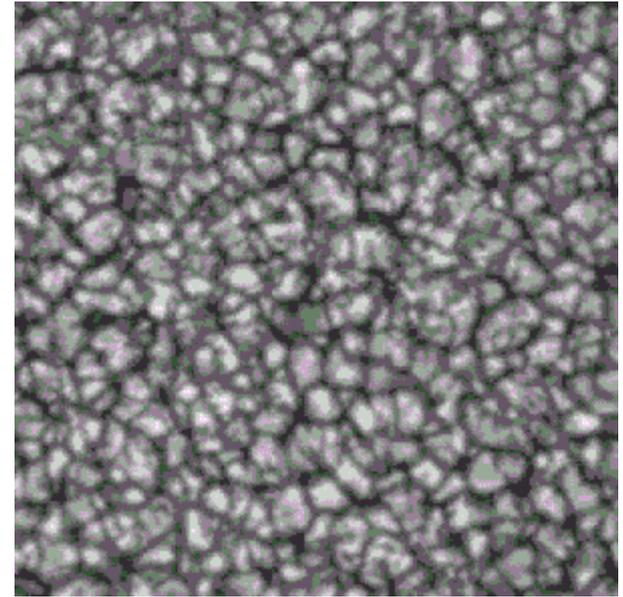
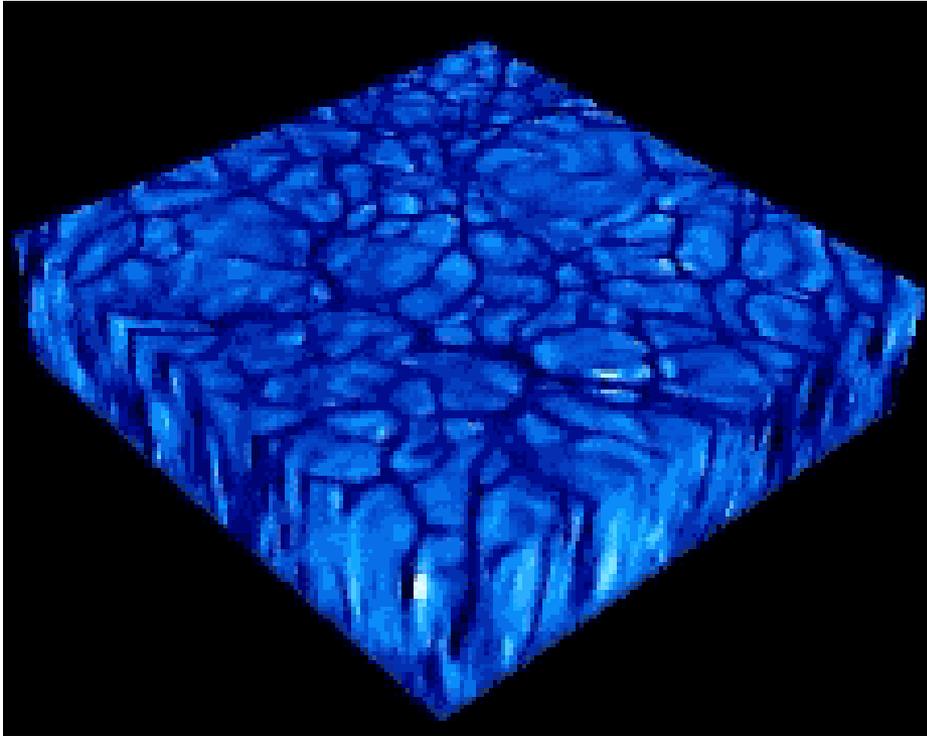
The Photosphere

- $T \sim 5,800 \text{ K}$
- $r \sim R_{Sun}$
- Photosphere is the visible surface of the Sun.
- At the photosphere, the density drops off abruptly, and gas becomes less opaque.
- Energy can again be transported via radiation. Photons can escape from Sun.
- Photosphere contains many features:
 - Sunspots
 - Granules



Granules

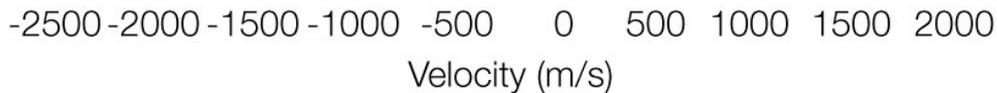
Convection from inside the sun causes the photosphere to be subdivided into 700 km cells. Radial velocities of 0.4 km/s.



(a)
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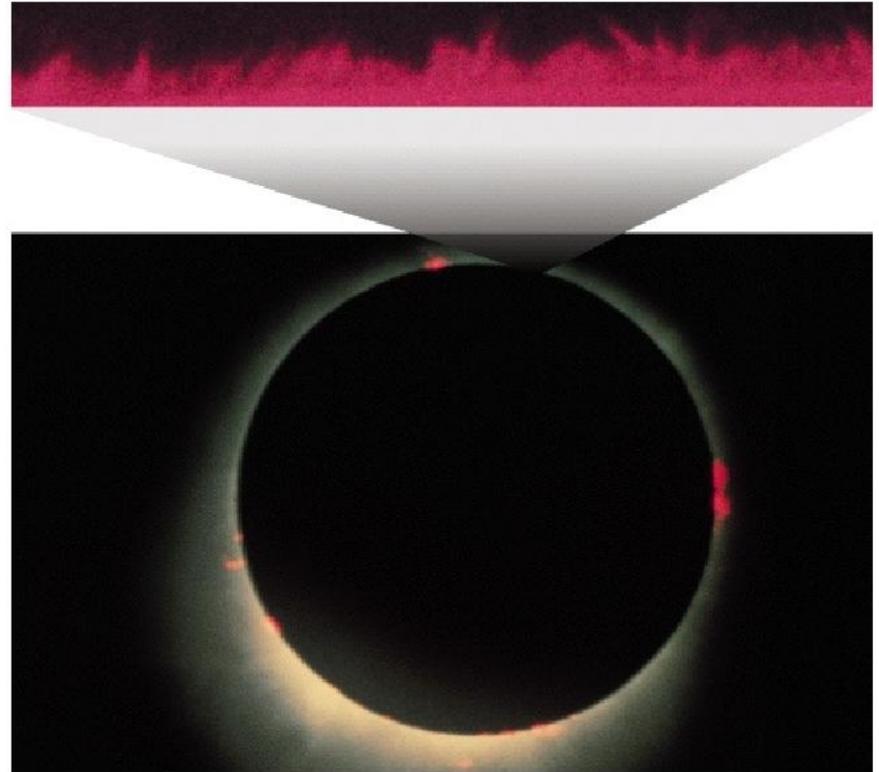
Energy rises to the surface as gas wells up in the cores of the granules, and cool gas sinks around their edges.

Doppler map of
the Sun's
surface tells us
about
vibrations,
granulation, and
differential
rotation.



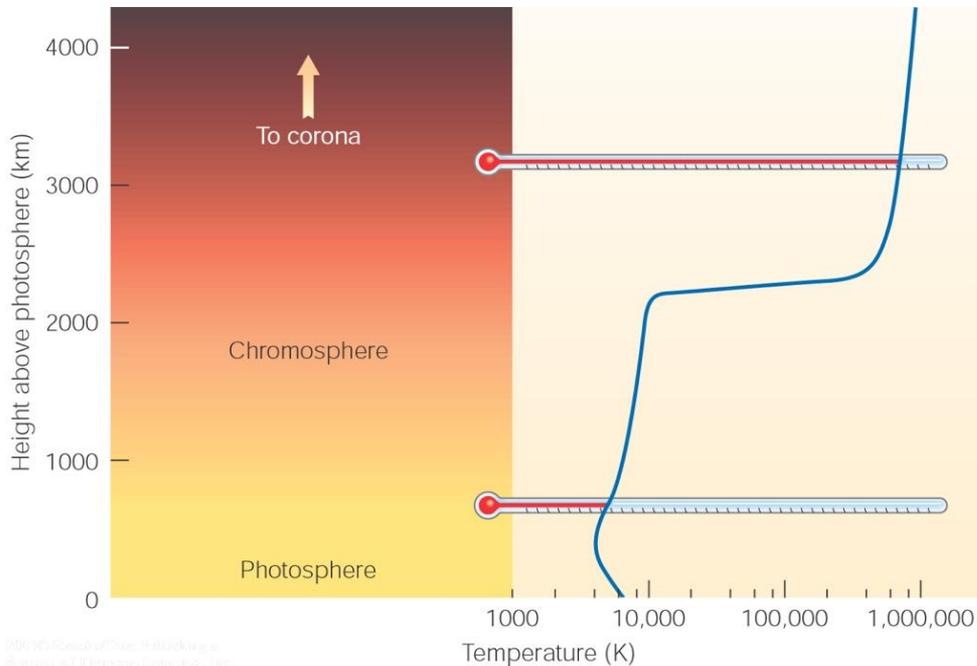
The chromosphere

- Above the photosphere is a layer of less dense but higher temperature gases called the chromosphere.
- First observed at the edge of the Moon during solar eclipses.
- Characterised by “spicules”, “plage”, “filaments”, etc.
- Spicules extend upward from the photosphere into the chromosphere.



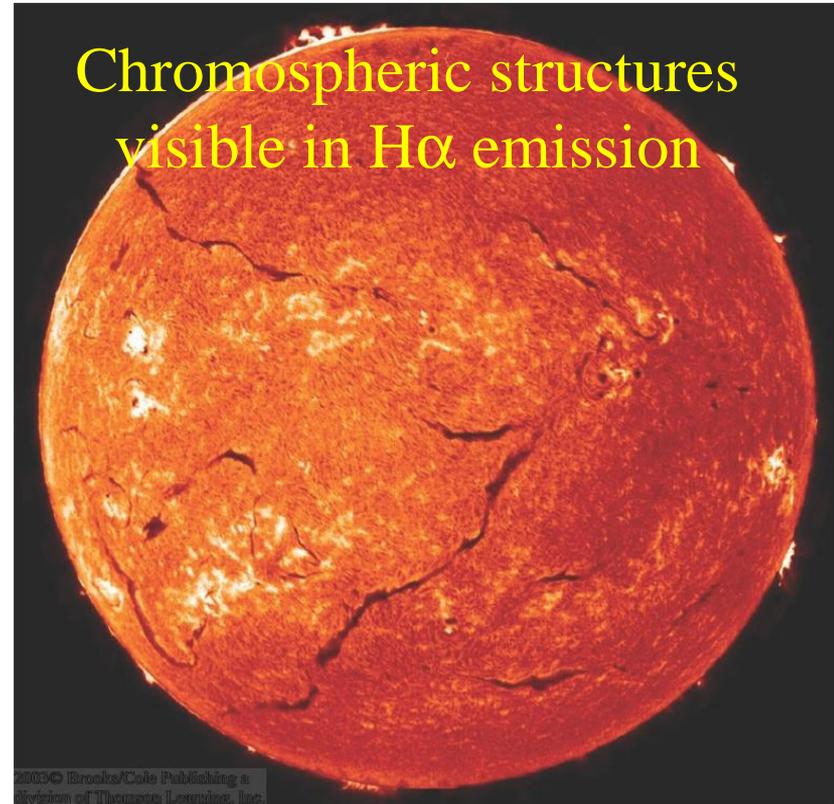
The Chromosphere

Region of sun's atmosphere just above the photosphere.



T: 4400 K \rightarrow 10,000 K

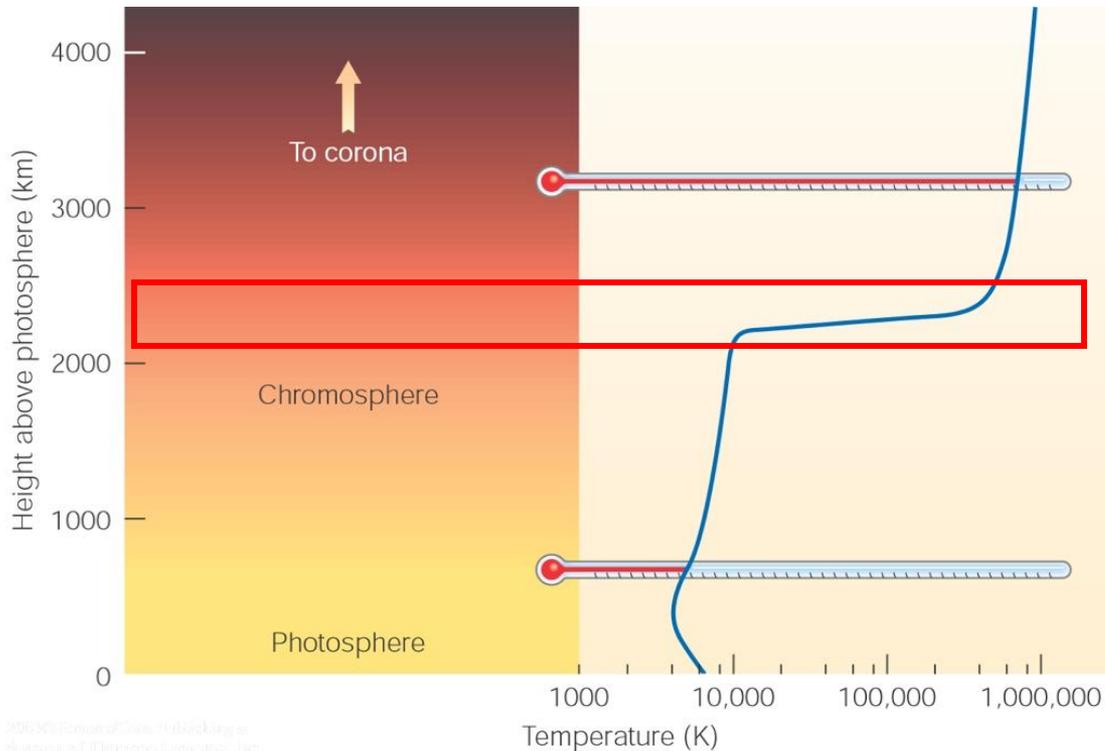
n: $10^{11} \text{ cm}^{-3} \rightarrow 10^7 \text{ cm}^{-3}$



Absorption and emission lines from singly ionized metals (He II, Fe II, Si II, Cr II, Ca II)

The Transition Zone

Transition from moderate to high ionization



$h \sim 2300 - 2600$ km above photosphere

$T \sim 10,000 \rightarrow 10^6$ K

$n \sim 10^7 \rightarrow 10^5$ cm⁻³

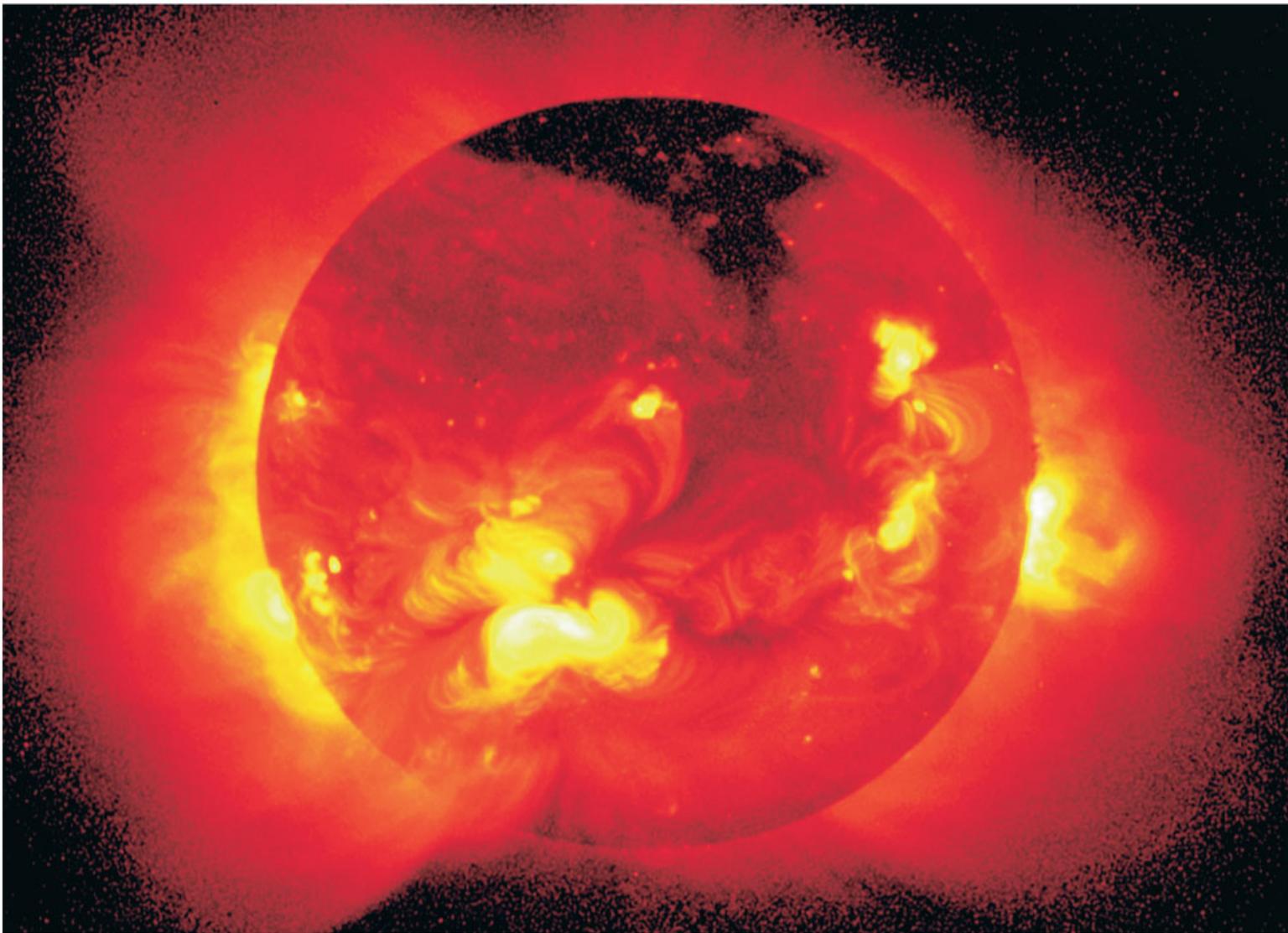
Observe selective heights in (UV) emission lines of ionized metals

Ly α $\rightarrow \sim 20,000$ K

O VI 1032 $\rightarrow \sim 300,000$ K

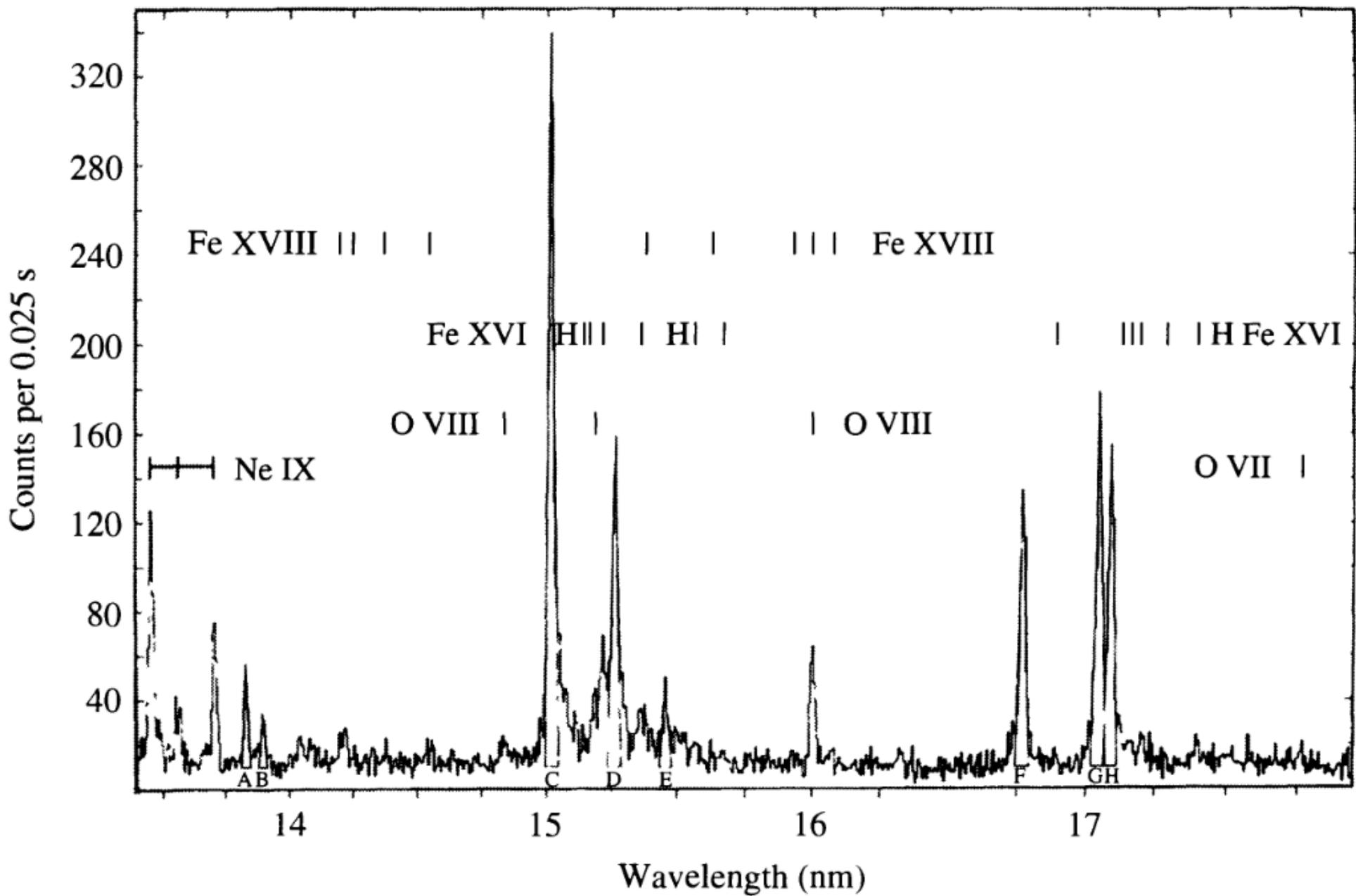
CIII 977 $\rightarrow \sim 90,000$ K

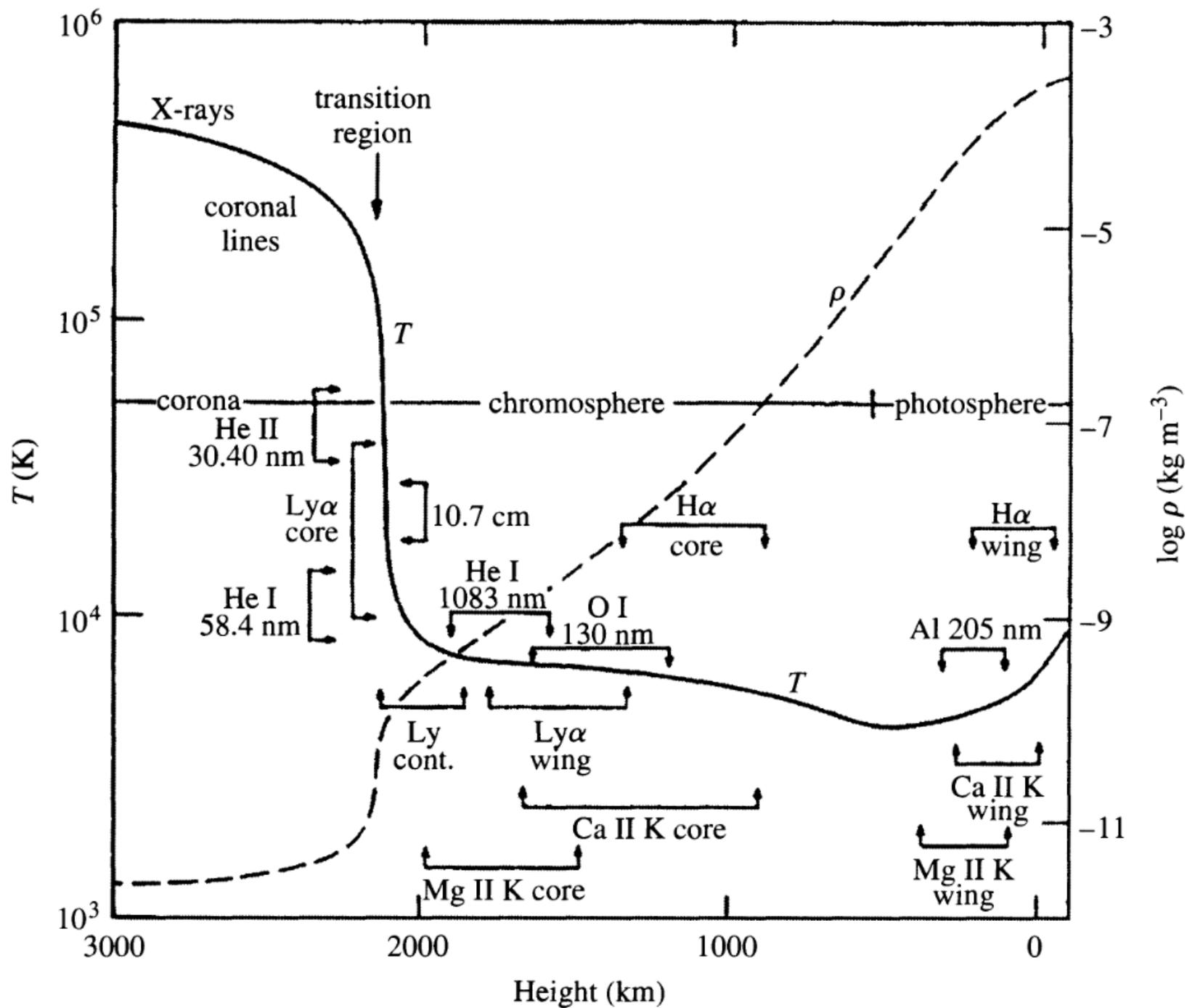
Mg X 625 $\rightarrow \sim 1,400,000$ K



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The corona appears bright in X-ray photos in places where magnetic fields trap hot gas.





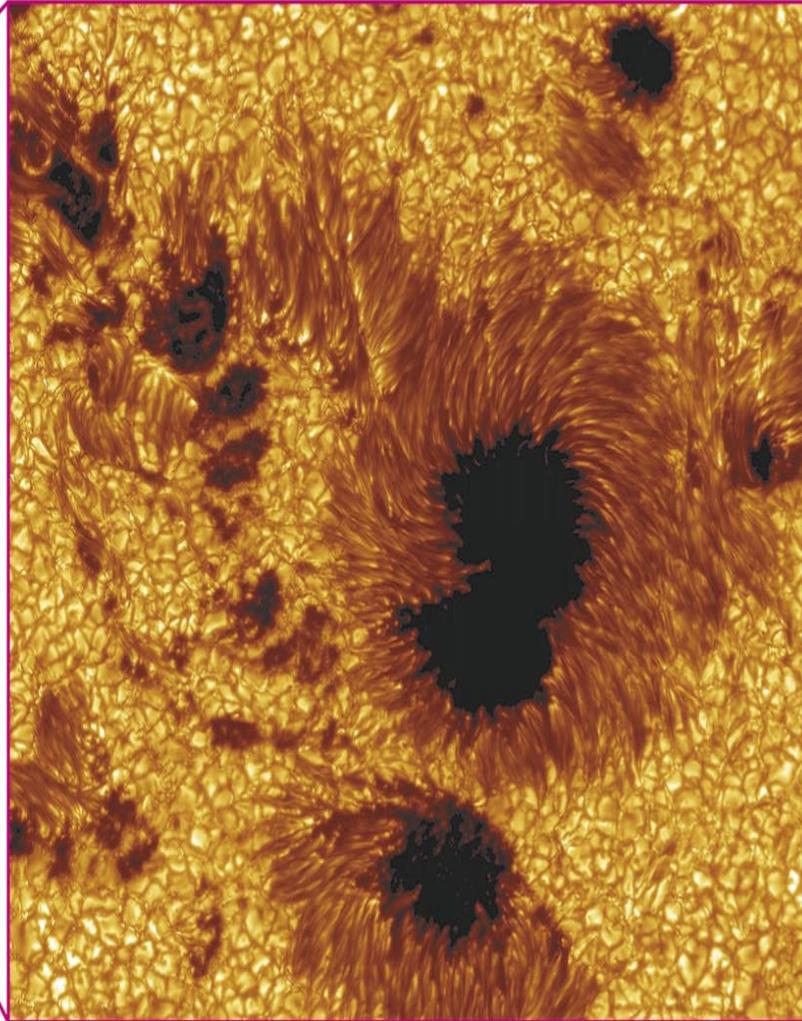
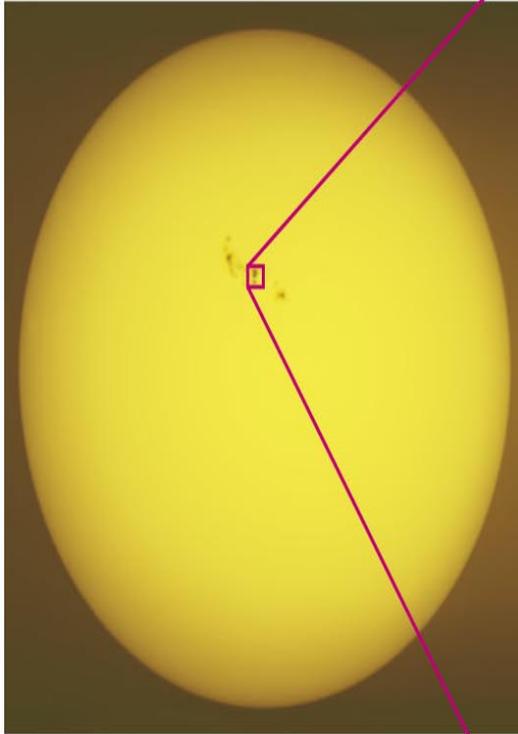
Corona and Solar Wind

The Sun's Corona is forever expanding into interplanetary space filling the solar system with a constant flow of solar wind.



Solar wind is the continuous flow of charged particles (ions, electrons, and neutrons) that comes from the Sun in every direction.

Solar wind consists of slow and fast components. Slow solar wind is a consequence of the corona's high temperature. The speed of the solar wind varies from less than 300 km/s (about half a million miles per hour) to over 800 km/s.



Sunspots...

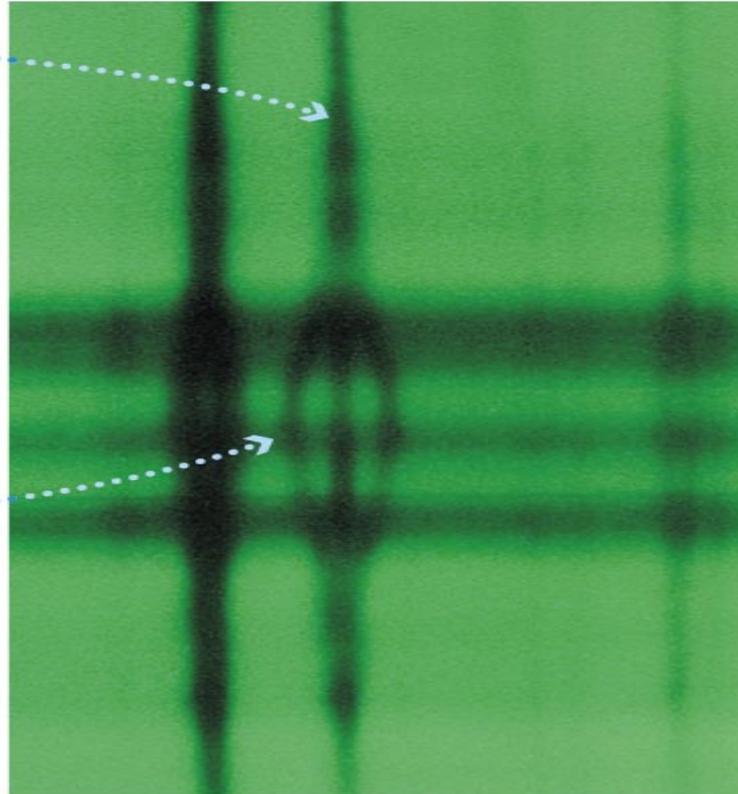
Are cooler than other parts of the Sun's surface (4000 K).

Are regions with strong magnetic fields.

a This close-up view of the Sun's surface shows two large sunspots and several smaller ones. Each of the big sunspots is roughly as large as Earth.

*Outside a sunspot
we see a single
spectral line . . .*

*. . . but the strong
magnetic field
inside a sunspot
splits that line
into three lines.*



Zeeman Effect

We can
measure
magnetic
fields in
sunspots by
observing the
splitting of
spectral lines.

b Very strong magnetic fields split the absorption lines in spectra of sunspot regions. The dark vertical bands are absorption lines in a spectrum of the Sun. Notice that these lines split where they cross the dark horizontal bands corresponding to sunspots.

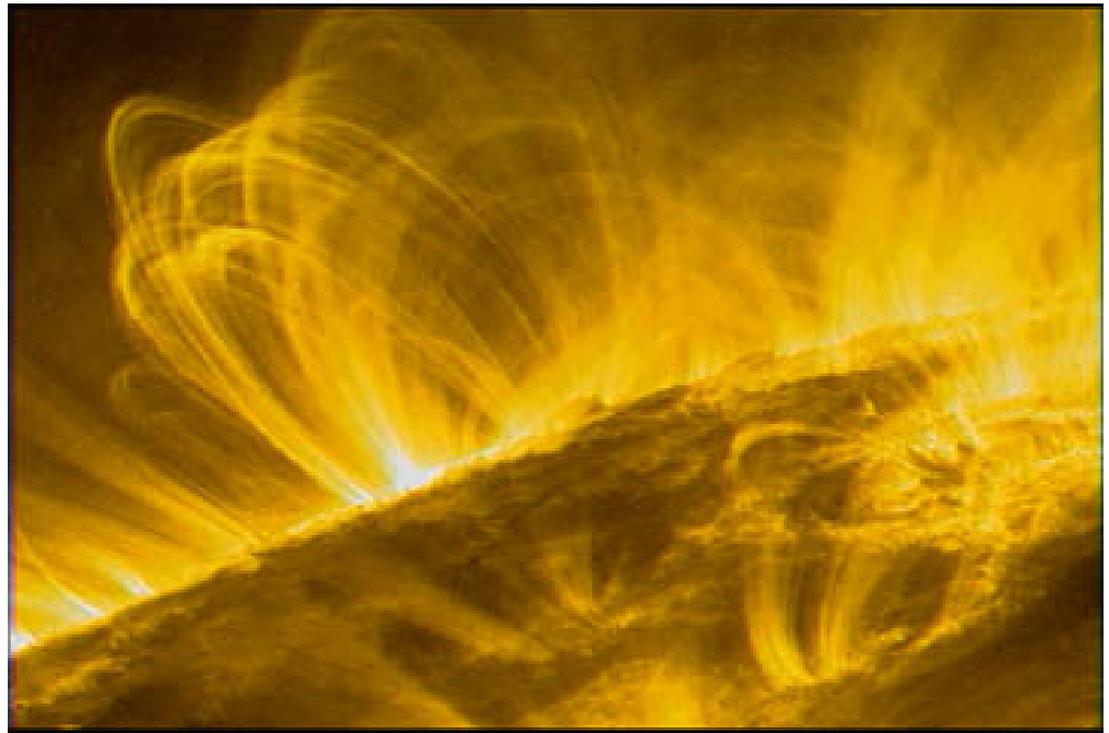
Solar Prominences



Magnetic fields trap gas.
 $T \approx 5800\text{ K}$
convection cells
sunspots
 $T \approx 4500\text{ K}$
 $T \approx 5800\text{ K}$
Magnetic fields of sunspots suppress convection and prevent surrounding plasma from sliding sideways into sunspot.

a Pairs of sunspots are connected by tightly wound magnetic field lines.

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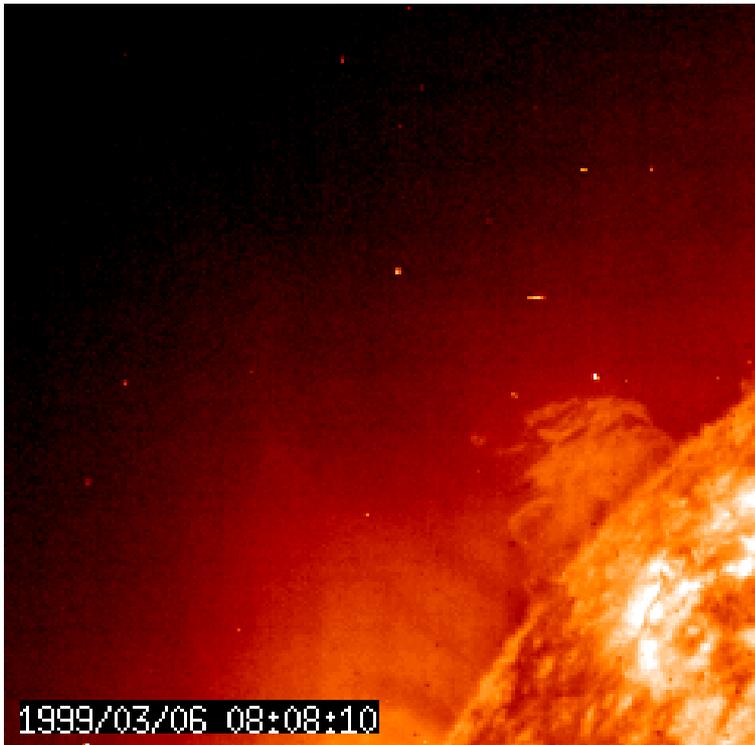


b This X-ray photo (from NASA's TRACE mission) shows hot gas trapped within looped magnetic field lines.

Prominences are dense clouds of material suspended above the surface of the Sun by loops of magnetic field. Prominences can remain in a quiet or quiescent state for days or weeks. However, as the magnetic loops that support them slowly change, prominences can erupt and rise off of the Sun over the course of a few minutes or hours

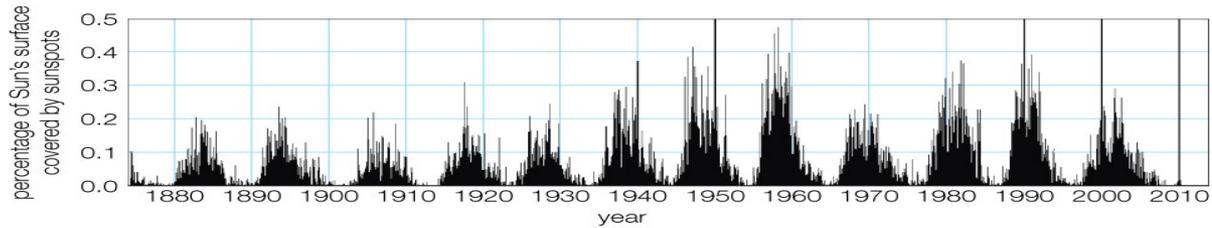
Solar Flares

Solar flares are tremendous explosions on the surface of the Sun. In a matter of just a few minutes they heat material to many millions of degrees and release as much energy as a billion megatons of TNT. They occur near sunspots, usually along the dividing line (neutral line) between areas of oppositely directed magnetic fields.

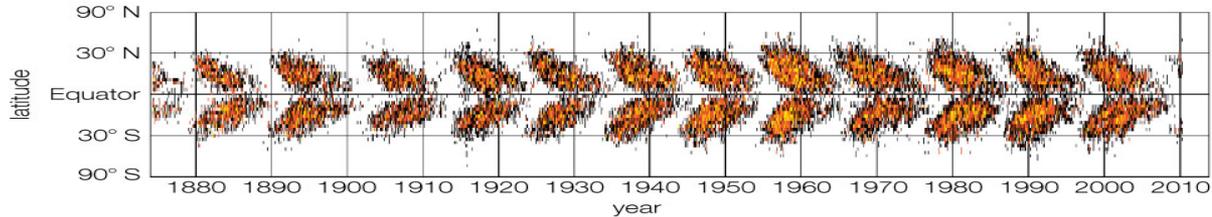


Images from SOHO*

*NASA/ESA Solar and Heliospheric Observatory spacecraft

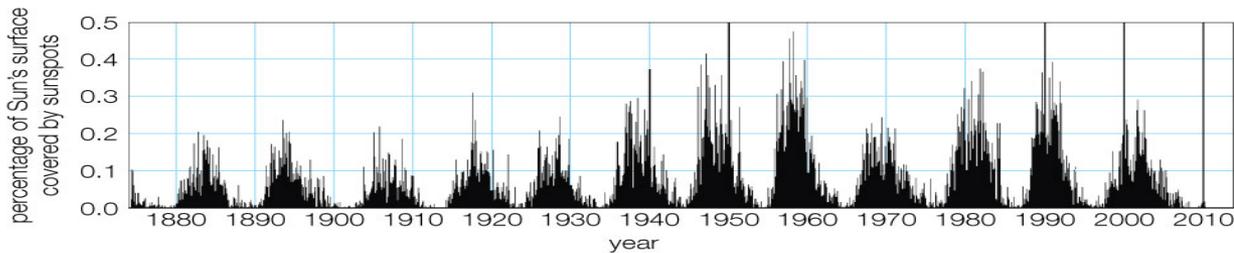


a This graph shows how the number of sunspots on the Sun changes with time. The vertical axis shows the percentage of the Sun's surface covered by sunspots. The cycle has a period of approximately 11 years.

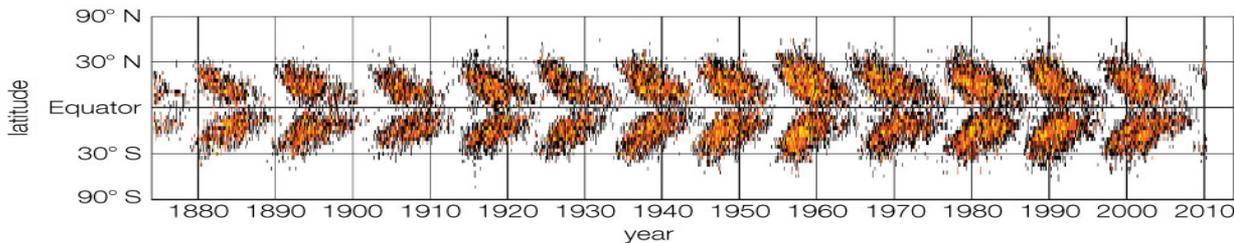


b This graph shows how the latitudes at which sunspot groups appear tend to shift during a single sunspot cycle. The color coding indicates whether the sunspot group is small (black), medium (red), or large (yellow).

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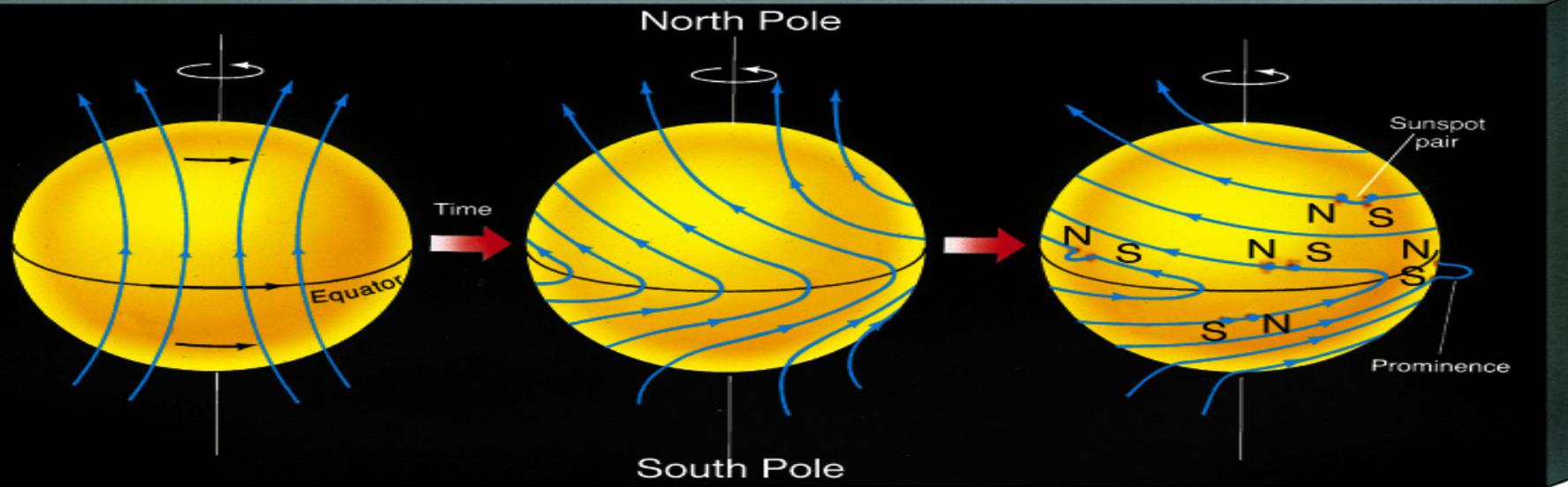


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The number of sunspots rises and falls in 11-year cycles.

The Sun's *differential rotation* distorts the magnetic field lines



The twisted and tangled field lines occasionally get kinked, causing the field strength to increase

“tube” of lines bursts through atmosphere creating sunspot pair