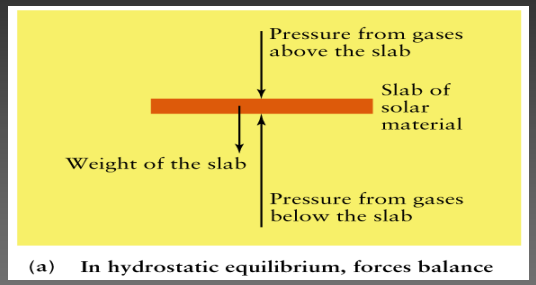
Models of the Sun's interior

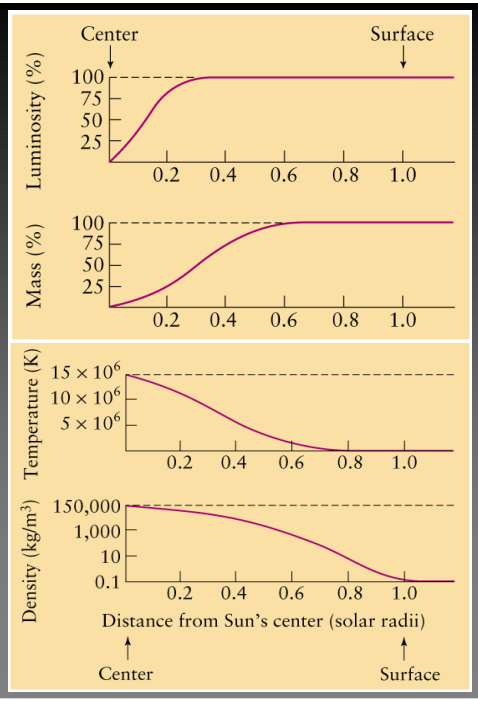
- The Sun's interior is an ionized gas
- Hydrostatic equilibrium keeps it stable



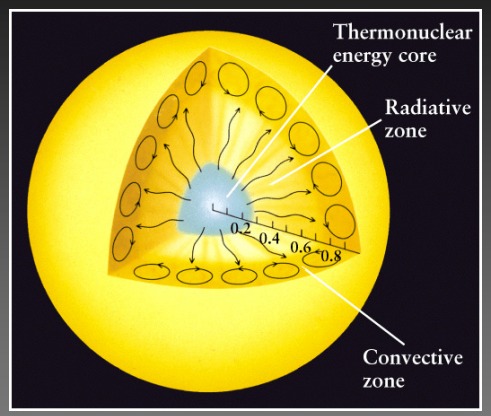
(a) In hydrostatic equilibrium, forces balance

- Upward pressure is caused by the nuclear reactions and upward flow of energy
- Using ideas of hydrostatic equilibrium, thermal equilibrium (all energy generated by fusion in core must be eventually radiated into space), fusion rates, energy transport, and the ideal gas law, we can create models of the Sun's interior. Info also from "solar oscillations".

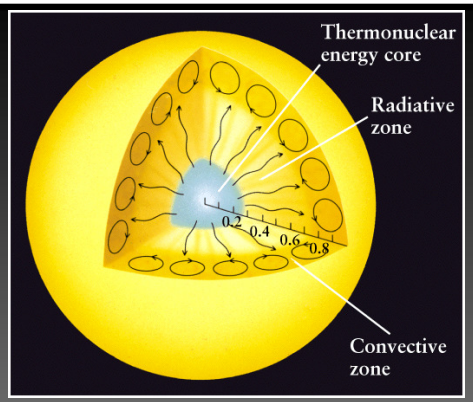
i.e. energy generated per sec, all in core



How does energy get to the surface?



- Radiation, or "radiative diffusion"
  - Photons created in core diffuse outward toward surface. Radiative zone is essentially fully ionized. Individual photons are frequently scattered by electrons (every cm!). Nevertheless, the radiation can effectively diffuse away from core.



Convection

Atoms and ions with bound electrons form in outer layer. Much harder for radiation to get through as photons too frequently absorbed and re-emitted (in random directions). Hot gas starts to rise, releases energy near surface, falls back down.

Takes about 170,000 years for energy created in the core to get out, but only about 8 minutes for light to travel from the photosphere to us.

The Sun's Atmosphere

- Layers are photosphere, “transition zone”, chromosphere, and corona

The Photosphere

- What we see as “surface” (below which atmosphere becomes opaque). Defines diameter
- Peak emission 500 nm (greenish) => T=5800 K in photosphere

Solar photosphere as a function of depth

Depth (km)	% Direct Light	Temp (K)
0	99.5	4465
100	97	4780
200	89	5180
250	80	5455
300	64	5840
350	37	6420
375	18	6910
400	4	7610

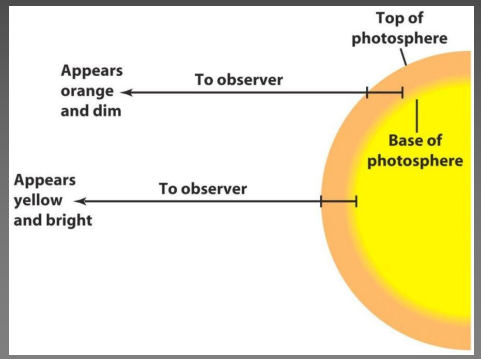
- Why does surface look sharp? 400 km is a tiny fraction (0.06%) of radius (696,000 km).

Limb darkening

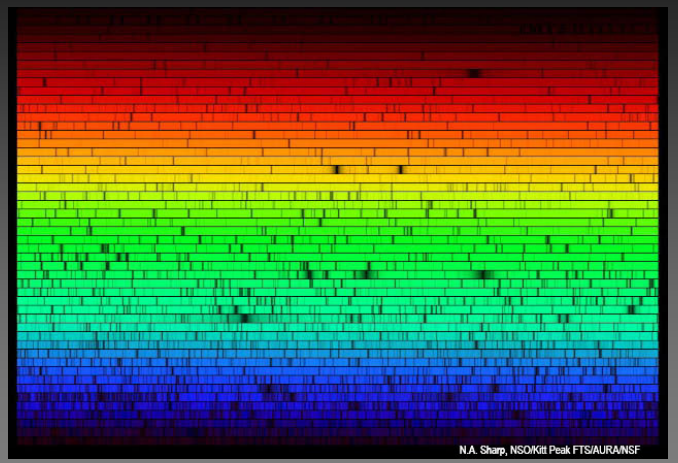
- Edge of Sun looks dimmer
- Reason: we look to nearly the same physical depth at center and edge

Dimmer light comes from higher, relatively cool layer within the photosphere

Bright light comes from low-lying, hot layer within the photosphere



The Solar (absorption line) spectrum is from gas in photosphere only

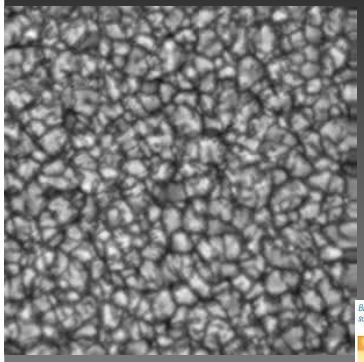


10,000's of lines from 67 elements, in various excited or ionized states.

Elements weren't made in Sun, but in previous stellar generations.

Granulation

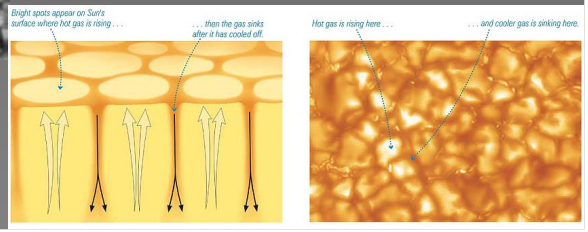
- Due to convection. Each cell lasts a few minutes



~1000 km or 1”

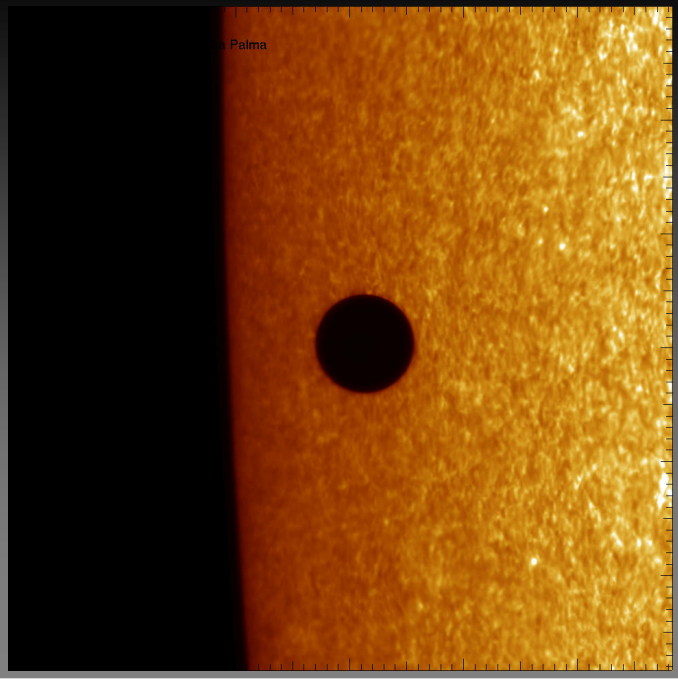
Link if video doesn’t work

Doppler shifts reveal vertical motions



Cooler regions darker

(Stefan's Law: flux α T^4)



Above photosphere is chromosphere. Please read.

The Corona

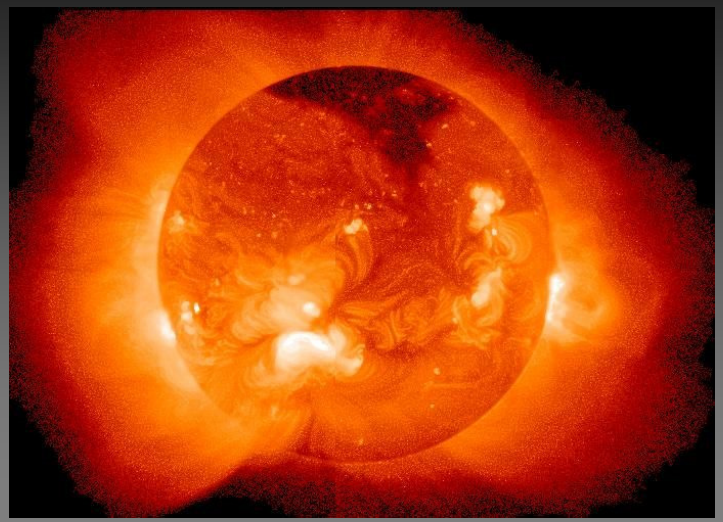
Best viewed during eclipses.

T = 10^6 K

Density = 10^{-12} kg/m^3

Highly ionized, e.g. Fe XI – XIV

We expect X-rays from gas at this temperature.

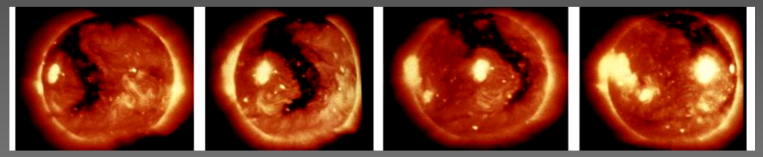


Yohkoh X-ray satellite

The Solar Wind

At top of corona, typical gas speeds are close to escape speed => Sun losing gas in a solar wind.

Fast (700 km/s) wind observed to escape through "coronal holes", seen in X-ray images. Steadier (350 km/s) wind is more widespread. Holes last about 6 months.



Particles take a few days to reach Earth.

10^6 tons/s lost. But Sun has lost only 0.1% of its mass from solar wind.

Sunspots, Solar Cycle – Please Read

About Earth-sized.

Darker because cooler (4300 K vs. 5800 K).

Related to loops of the Sun's magnetic field. Numbers vary on 11-year Solar Cycle of activity.