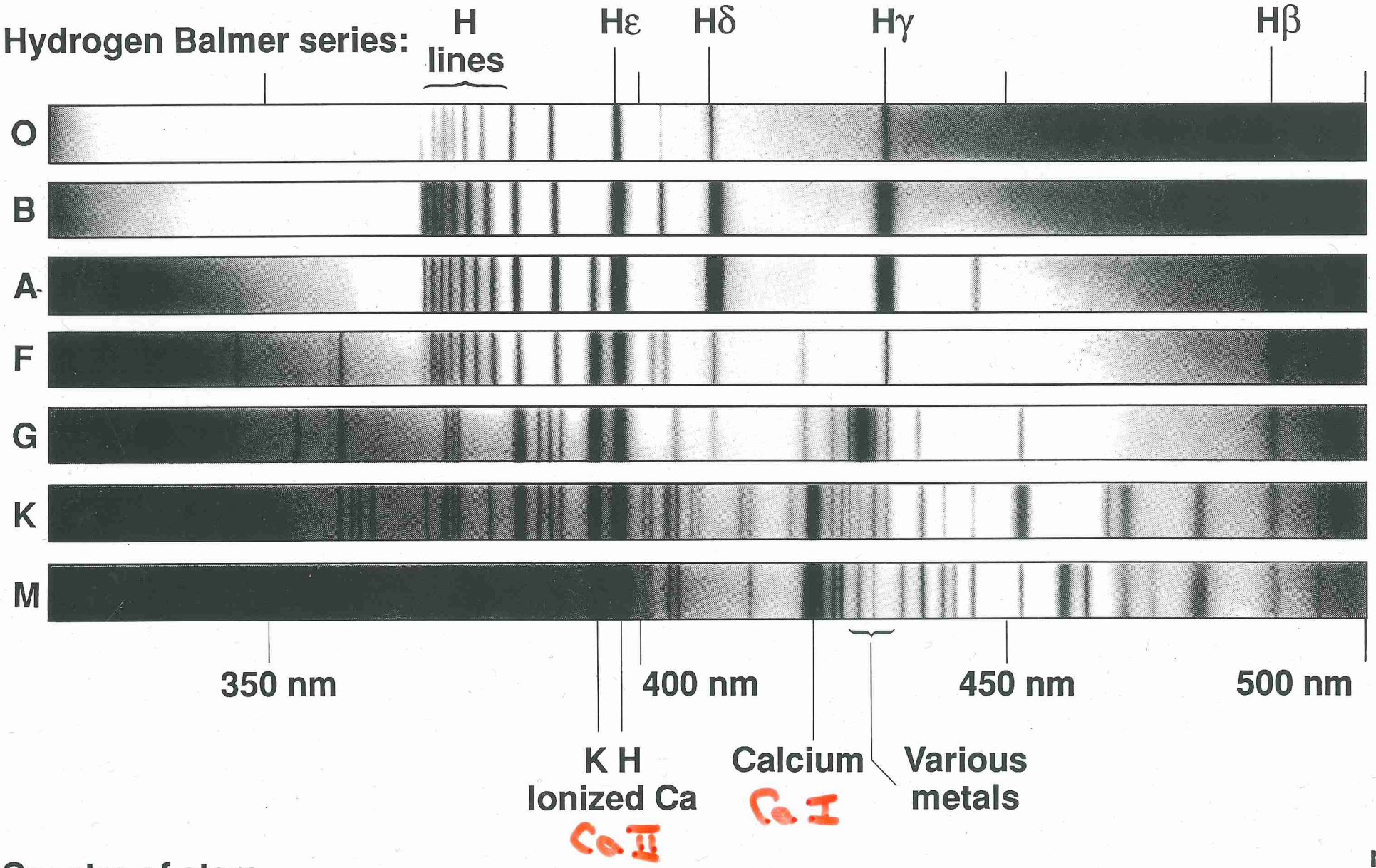
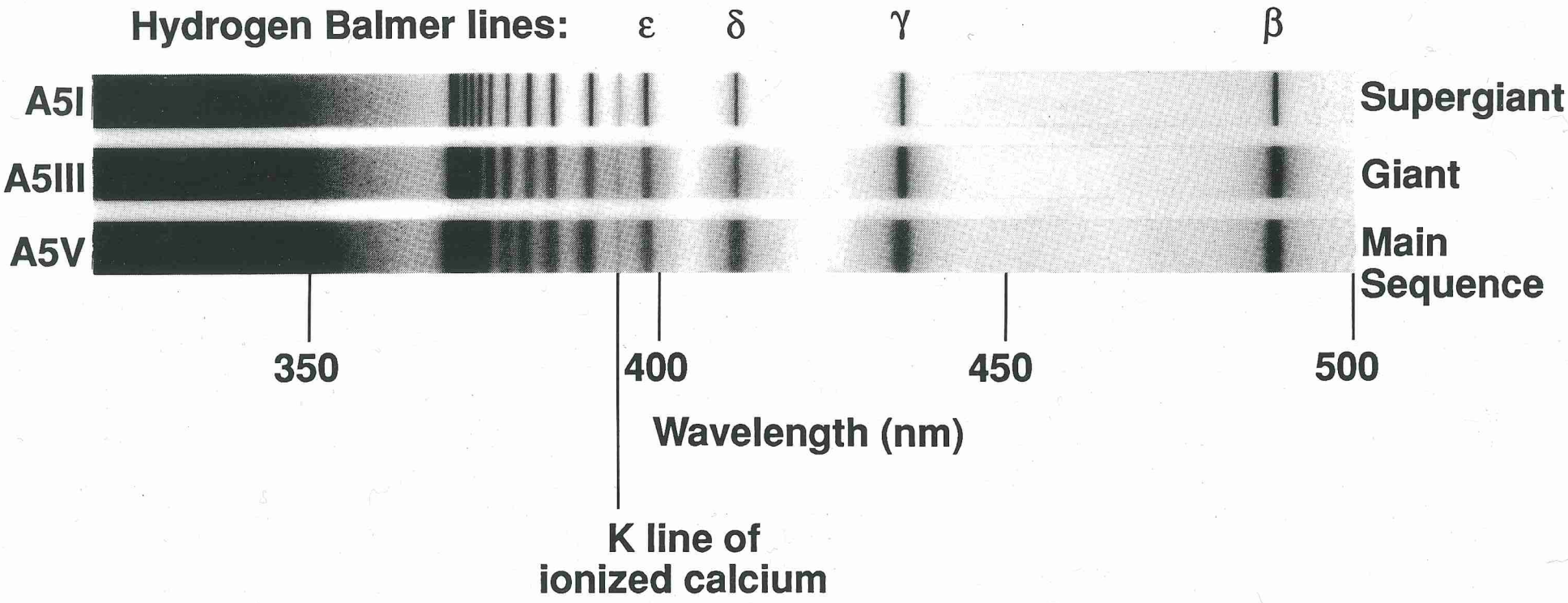


Spectra of stars

Hartmann/Impey: The Cosmic Journey, 5th ed., Fig. 16–7; Hartmann: The Cosmic Voyage, 1992 ed., Fig. 16–4

Luminosity Classes

V	Main Sequence [Dwarfs]
IV	Subgiants
III	Giants
II	
I	Supergiants



Spectra of giant, supergiant, main-sequence stars

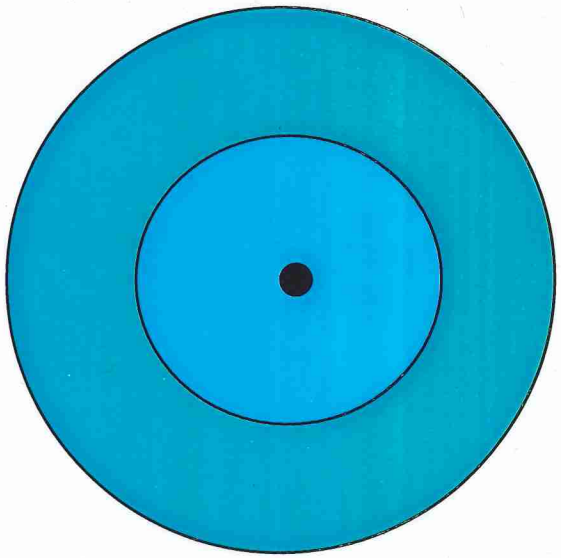
Hartmann/Impey: The Cosmic Journey, 5th ed., Fig. 16–13; Hartmann: The Cosmic Voyage, 1992 ed. Fig. 16–8

Effects of Atmospheric Pressure on Absorption Lines

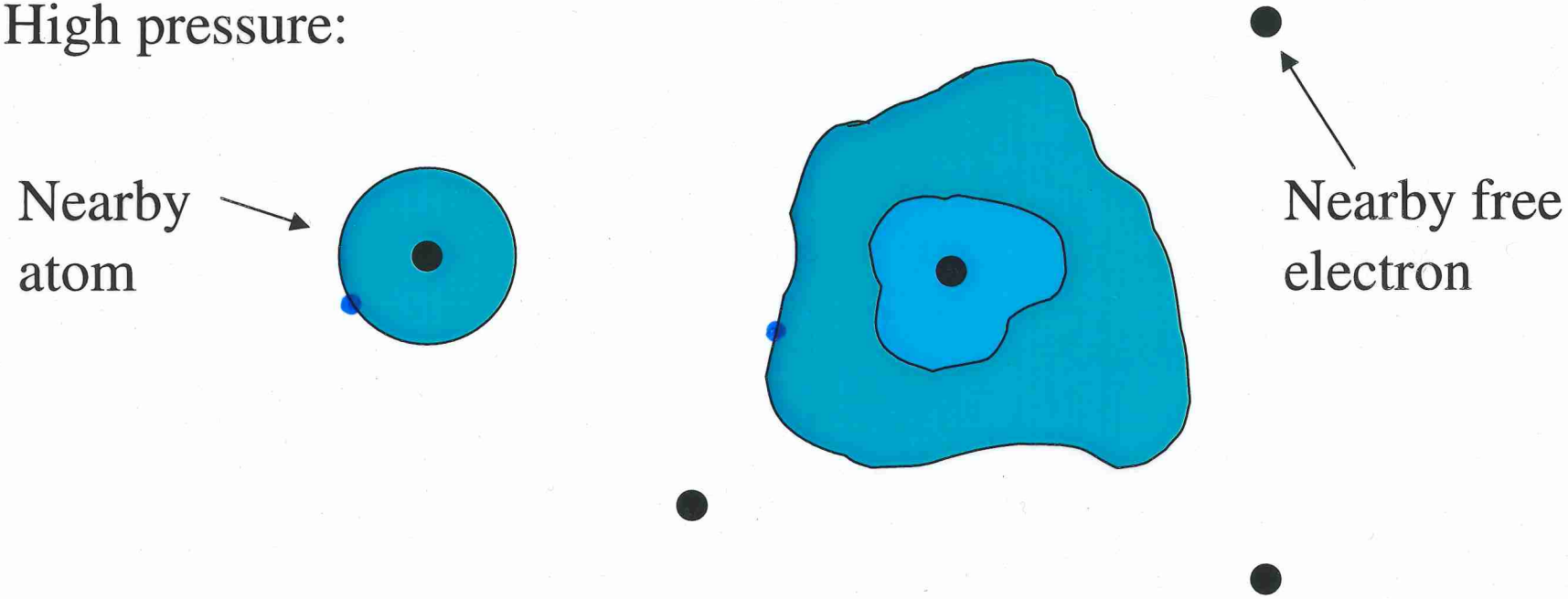
1. Lines may be broadened at high pressure.

Low pressure:

Atoms are well separated, effectively isolated from each other, Bohr orbits are "perfect"



High pressure:



An atom is affected by the presence of free electrons and adjacent atoms, Bohr orbits are distorted, energy differences between orbits are affected.

Photons emitted/absorbed are at somewhat different λ for different atoms.

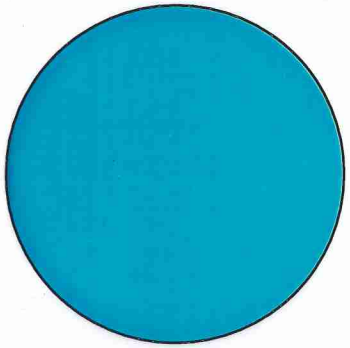
2. Neutrals favored over ions at higher pressures

Cars collide more frequently on city streets than country roads!

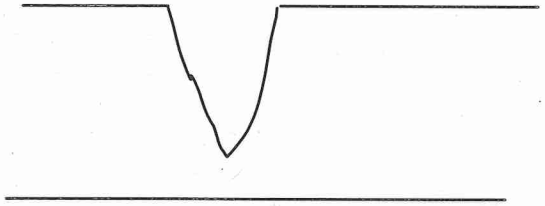
3. Luminous stars of low surface gravity and low atmospheric pressure tend to have more turbulent atmospheres.

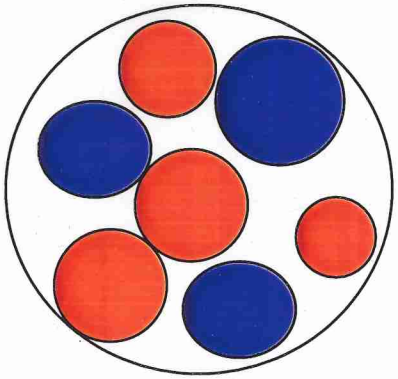
Doppler effect broadens lines from turbulent atmosphere

Non-turbulent

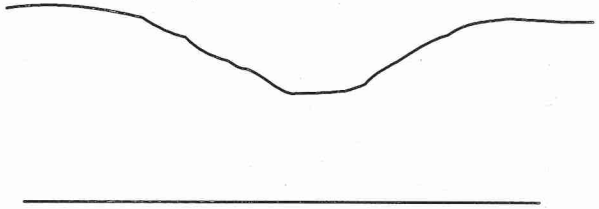


Sharp line





Broad line



- Rising gas gives lines shifted to blue
- Sinking gas gives lines shifted to red
- Net effect is a broadening of the line

SUMMARY

•A normal star has an absorption line spectrum.

•Analysis of spectrum provides a wealth of information about the stellar atmosphere.

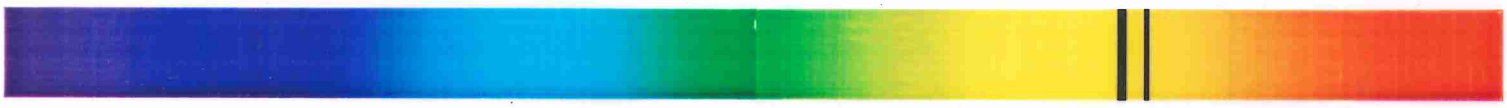
- Temperatures
- Pressures (Gravity)
- Composition
- Turbulence
- Wind
- Radial Velocity
- Rotation Rate
- Magnetic Field
- Companion Stars and planets

The Sun

Read Ch. 9!

Sun ≡ 'Typical' Star

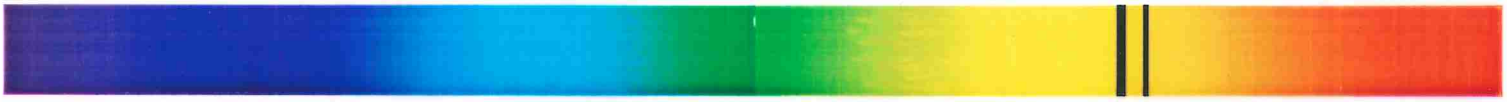
- G2V
- Rotates – differentially
  25 days at equator
- Average density ~
  1.4 × density of water
- Temperature
  6,000 K at 'surface'
  15×10^6 K at centre
- Chemical Composition
  90% H, 10% He, 0.1% all else by no. of atoms



The Sun

Not a Dead Subject!

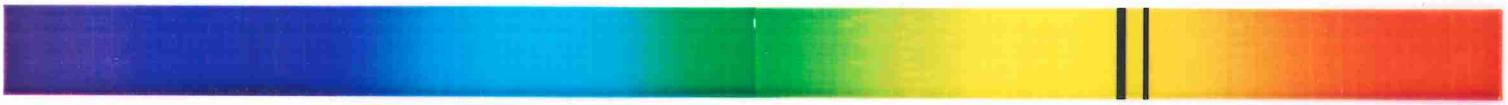
- Solar Seismology
- Solar Neutrinos (later)
- Solar Wind/Corona
- Sunspot Cycle



Solar Atmosphere

- Sun is gas therefore there is NO sharp boundary
  - — Sun extends out into interstellar space
  - —Earth orbits in solar wind

- Major Regions (Fig. 8–3)
  - — Photosphere
  - — Chromosphere
  - — Corona/Solar Wind



The Photosphere

- ~ 500 Km thick
- ~ 4,500 K at top
- ~ 8,000 K in deepest visible layer
- Granulation, spots
- Source of sunlight

Why is there a sharp edge (apparently) to Photosphere?

Height ~ 100Km but viewed from *large distance* (1 AU) so is seen as a very small angle ($\approx 1/10''$)

Then, appears sharp

The Solar Corona

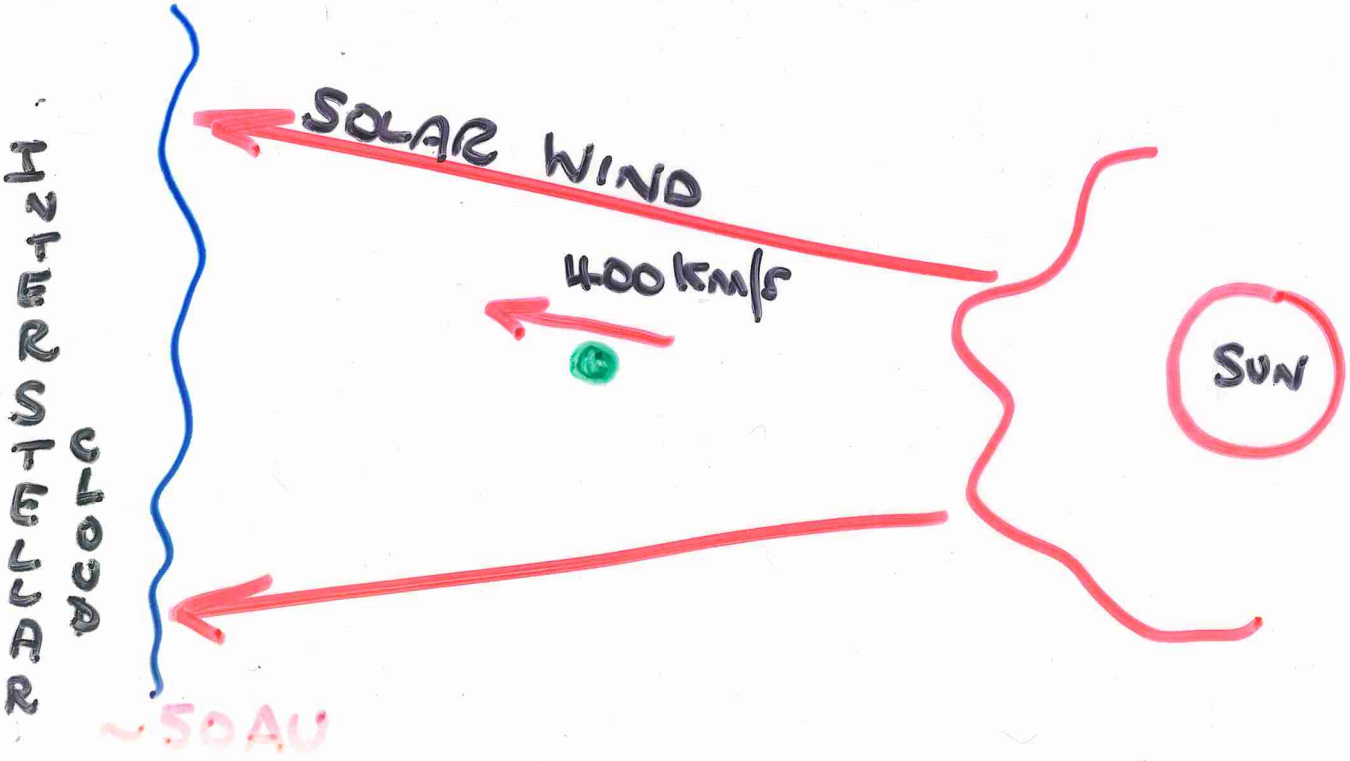
- Hot (T ~ 2 million K)
- Tenuous
- Expands into solar wind
- First observed at solar eclipses (visible light)
- Now, radio emission, UV and X-rays (out of eclipse)

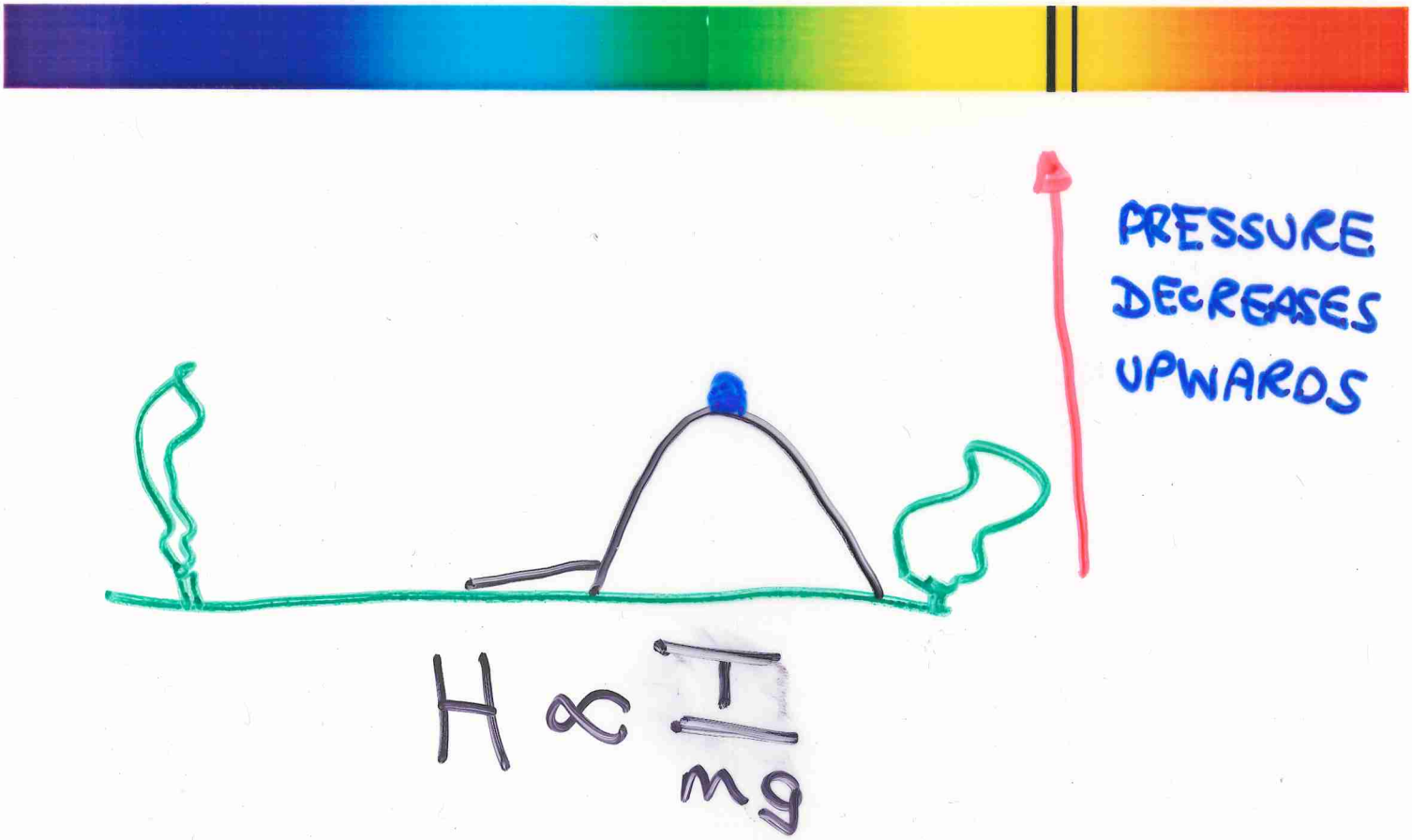
The Solar Corona

Why is Corona Very Hot?

- Not heated by absorbing sunlight
- Heated by 'Sonic Booms'
- Generated by convection currents in and below photosphere

Corona Feeds a Wind





- **Higher temperature → faster moving atoms/molecules → greater heights**
- **Higher gravity slows atoms/molecules at lower heights**
- **More massive atoms/molecules move more slowly → stopped at lower heights.**

Earth:

T ~ 300 K

m ≈ mass of N_2 or O_2

g ≈ 1,000 cm/sec2

Height ~ 10Km

$H \propto \frac{T}{mg}$

Sun-Photosphere:

T ~ 20 × Earth's

m ~ 1/15 × Earth's (H atoms)

g ~ 25 × Earth's

Height ~ (10–20) × Earth's

The Corona

- Very extended – Figures 3–15 and 7–14: Observed height ~ Radius of Sun
- Extension implies high temperature

$H \propto T/mg$

$T \propto mgH$

$$T_{Corona} = \frac{H_{Corona}}{100Km} T_{Photo}$$

$H_{Corona} \sim R_{Sun} \sim 700{,}000$ Km

$$\therefore T_{Corona} \sim \frac{700{,}000}{100} T_{Photo}$$

$$\sim 7{,}000\ T_{Photo}$$

~ few million K

SUN'S ENERGY SOURCE?

$$\text{LIFETIME} = \frac{\left(\begin{matrix}\text{FUEL}\\ \text{SUPPLY}\end{matrix}\right) \times \left(\frac{\text{ENERGY}}{\text{GM}}\right)}{\text{ENERGY/SEC}}$$

1. FOSSIL/CHEMICAL FUEL?

   LIFETIME ~ 1000 YEARS!

2. GRAVITATION (KELVIN + HELMHOLTZ)

   SLOW CONTRACTION → HEATING

   $\frac{1}{10}$ MILE/YR BUT RADIUS NOW ~ 430,000 MILES!

   BUT 10-20 MILLION YRS AGO SUN'S RADIUS ≈ EARTH'S ORBIT IF LUMINOSITY ≈ CONSTANT

WHAT IS EARTH'S AGE?

KELVIN ASSUMED EARTH BEGAN MOLTEN. HE ESTIMATED IT TOOK 10-20 MILL. YRS TO COOL. PROVIDED THAT NO ADDITIONAL HEAT ADDED.

OH DEAR

THEN, RADIOACTIVITY WAS DISCOVERED:

- HEAT SOURCE
- ACCURATE AGE OF EARTH → 4.5 BILL YRS

Lord Kelvin said

1900 "X-rays are a hoax"

1897 "Radio has no future"

1895 "Heavier-than-air machines, flying machines, are impossible!"

3. NUCLEAR ENERGY

EINSTEIN'S $E = mc^2$

ENERGY CONSERVATION replaced

by

ENERGY + MASS IS CONSERVED

IF SUN TURNED MASS → ENERGY,
IT COULD SHINE AT PRESENT
LUMINOSITY FOR 15 TRILLION YRS

- BUT NEED CONVERSION PROCESS.

IT IS $4H \rightarrow He + ENERGY$

LEADING TO LIFETIME OF ABOUT

10 BILLION YRS

~HALF SPENT!

"IT IS HELD THAT THE FORMATION OF HELIUM FROM HYDROGEN WOULD NOT BE APPRECIABLY ACCELERATED AT STELLAR TEMPERATURES, AND MUST THEREFORE BE RULED OUT AS A SOURCE OF STELLAR ENERGY. BUT THE HELIUM WHICH WE HANDLE MUST HAVE BEEN PUT TOGETHER AT SOME TIME AND SOME PLACE. WE DO NOT ARGUE WITH THE CRITIC WHO URGES THAT THE STARS ARE NOT HOT ENOUGH FOR THIS PROCESS; WE TELL HIM TO GO AND FIND A HOTTER PLACE.

A. S. EDDINGTON

1926