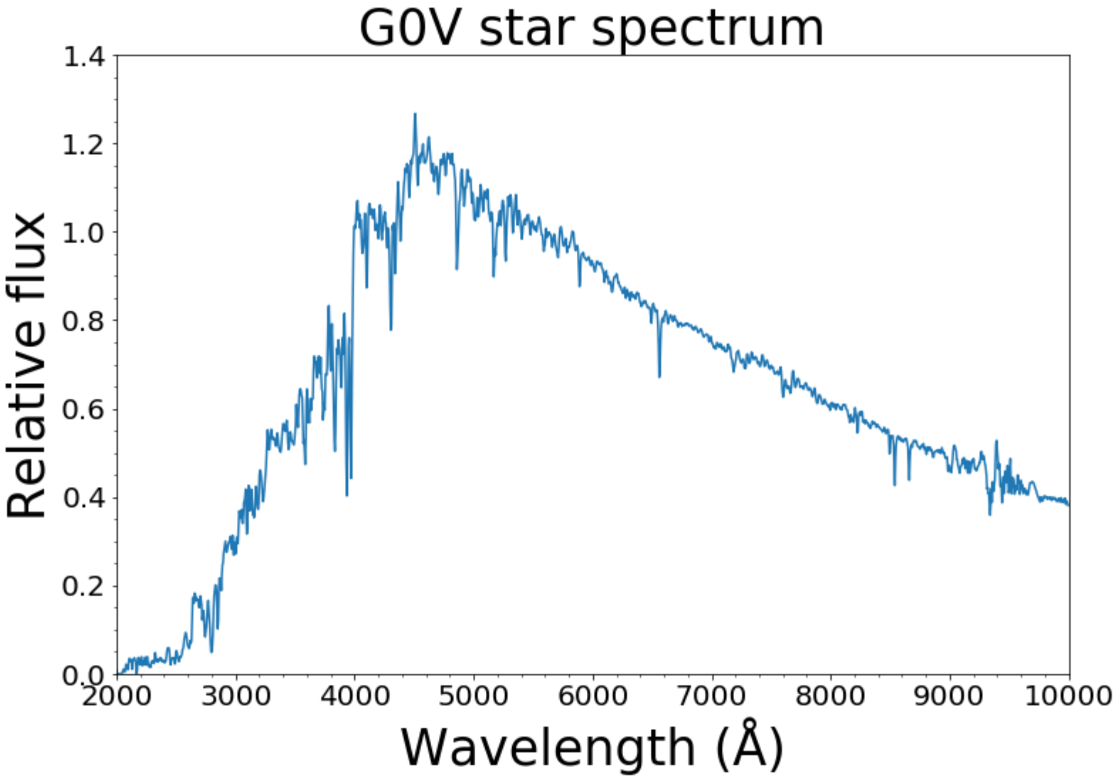
Stars - spectral types

- 1901: Led by Annie Jump Cannon, Harvard astronomers looked at the spectra of >200,000 stars.

- Found that the spectra could be put into relatively few classes (OBAFGKM), based on the relative strengths of the absorption lines of different elements



Mnemonics

Oh Be A Fine Girl Kiss Me

Oh Bother, Another F's Gonna Kill Me

Oh Bother, Astronomers Frequently Give Killer Midterms

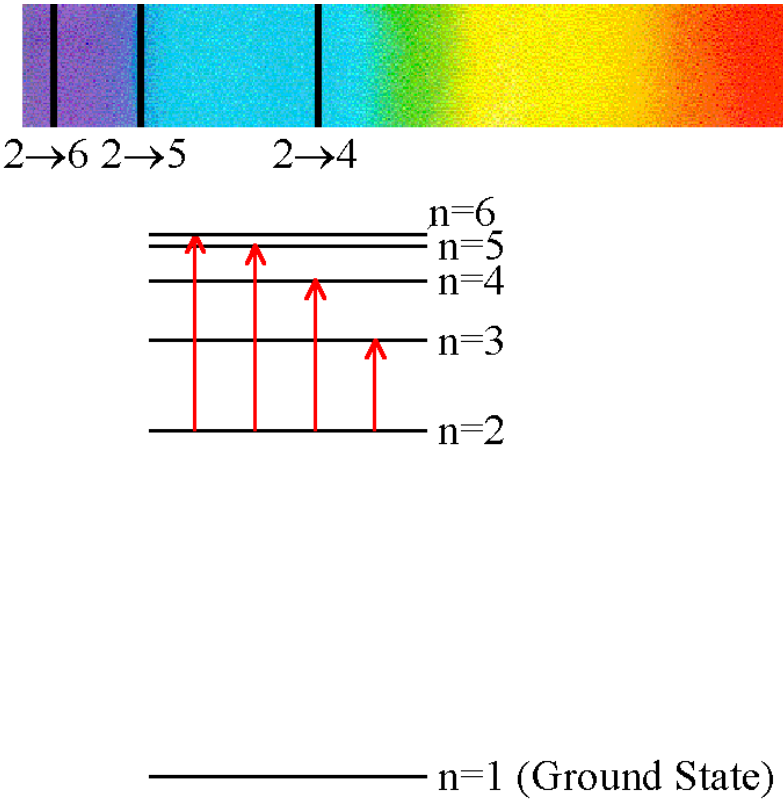
One Bug Ate Five Green Killer Moths

Oven-Baked Ants, Fried Gently, Keeps Moist

Only Boring Astronomers Find Gratification Knowing Mnemonics

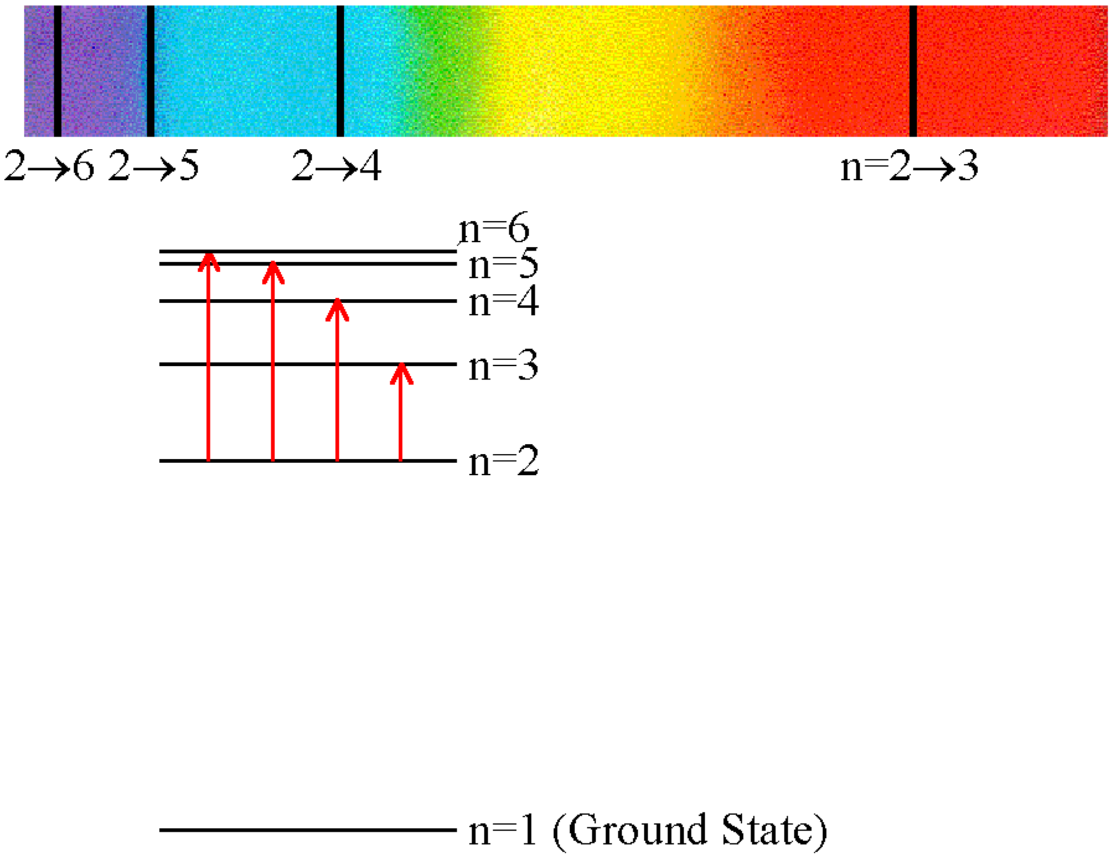
Spectral sequence = temperature sequence

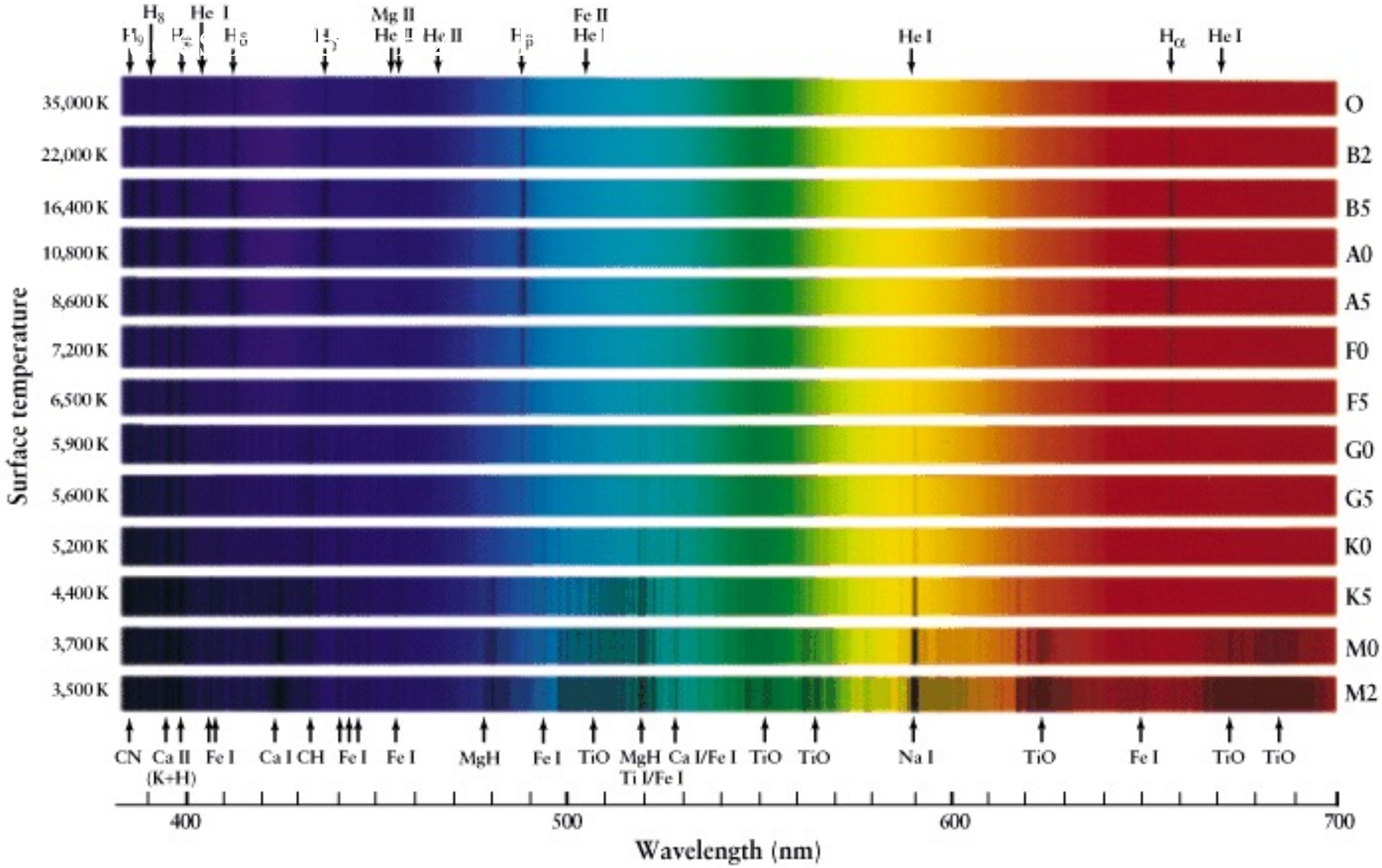
- Stars differ in spectral types due to different temperatures in their photospheres.



Example hydrogen: if $T<10^4$ K, most electrons are in the n=1 orbital state => cannot absorb visible light (Balmer photons).

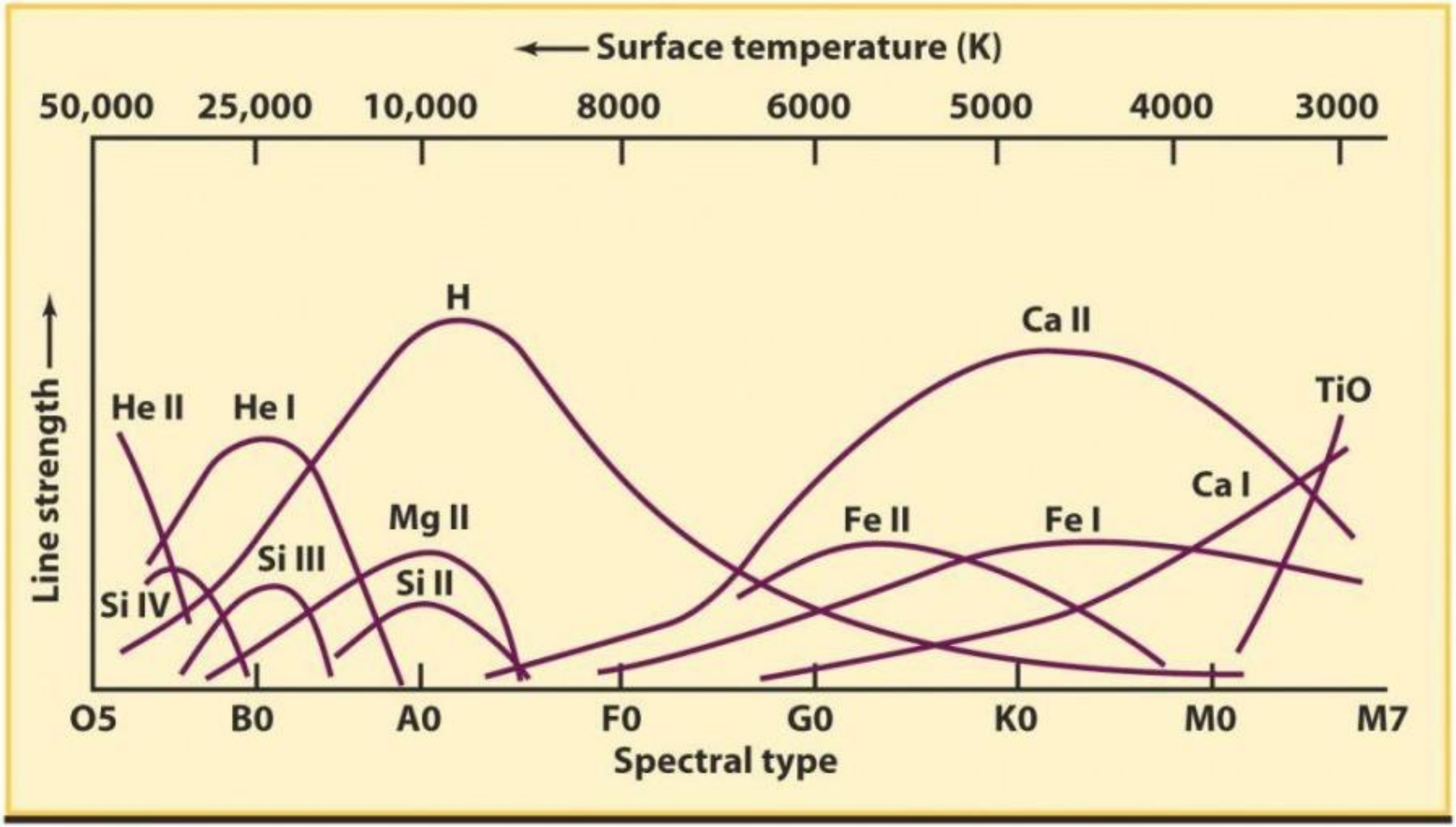
- If T~10^4 K, most electrons are in the n=2 orbital state => can absorb visible light => Balmer absorption lines.
- If T>>10^4 K, most electrons are in level 3 or higher, and cannot absorb visible light.





H_8
He I
H_9
H_ϵ
H_δ
H_γ
Mg II
He II
He II
H_β
Fe II
He I
He I
H_α
He I
Surface temperature
35,000 K
22,000 K
16,400 K
10,800 K
8,600 K
7,200 K
6,500 K
5,900 K
5,600 K
5,200 K
4,400 K
3,700 K
3,500 K
O
B2
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M2
CN
Ca II (K+H)
Fe I
Ca I
CH
Fe I
Fe I
MgH
Fe I
TiO
MgH
Ti I/Fe I
Ca I/Fe I
TiO
TiO
Na I
TiO
Fe I
TiO
TiO
400
500
600
700
Wavelength (nm)

Balmer lines of hydrogen are most prominent about 10,000 K, peaking around A0. Other lines peak at different temperatures.



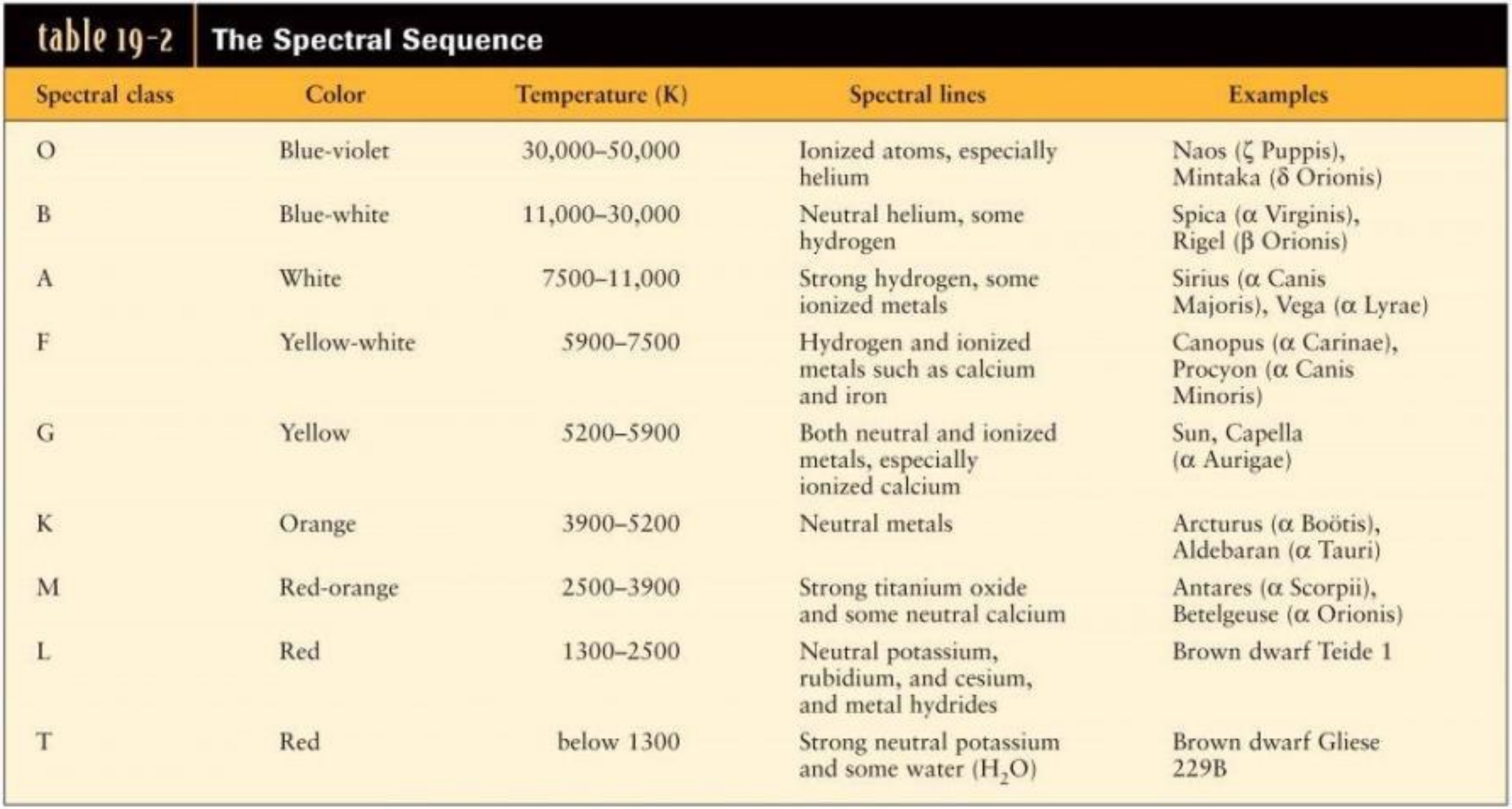


table 19-2 The Spectral Sequence

Spectral class	Color	Temperature (K)	Spectral lines	Examples
O	Blue-violet	30,000–50,000	Ionized atoms, especially helium	Naos (ζ Puppis), Mintaka (δ Orionis)
B	Blue-white	11,000–30,000	Neutral helium, some hydrogen	Spica (α Virginis), Rigel (β Orionis)
A	White	7500–11,000	Strong hydrogen, some ionized metals	Sirius (α Canis Majoris), Vega (α Lyrae)
F	Yellow-white	5900–7500	Hydrogen and ionized metals such as calcium and iron	Canopus (α Carinae), Procyon (α Canis Minoris)
G	Yellow	5200–5900	Both neutral and ionized metals, especially ionized calcium	Sun, Capella (α Aurigae)
K	Orange	3900–5200	Neutral metals	Arcturus (α Boötis), Aldebaran (α Tauri)
M	Red-orange	2500–3900	Strong titanium oxide and some neutral calcium	Antares (α Scorpii), Betelgeuse (α Orionis)
L	Red	1300–2500	Neutral potassium, rubidium, and cesium, and metal hydrides	Brown dwarf Teide 1
T	Red	below 1300	Strong neutral potassium and some water (H_2O)	Brown dwarf Gliese 229B

Stellar classification provides a mean to estimate physical characteristics of stars!

Method established by Annie Jump Cannon in 1901

Announcements

- VLA Tour Saturday Sept. 28
- Depart UNM at 8:00am from RH parking lot; 10am VLA+LWA1 tour Noon: lunch at picnic tables; return UNM
- Extra Credit will be assigned for attending tour

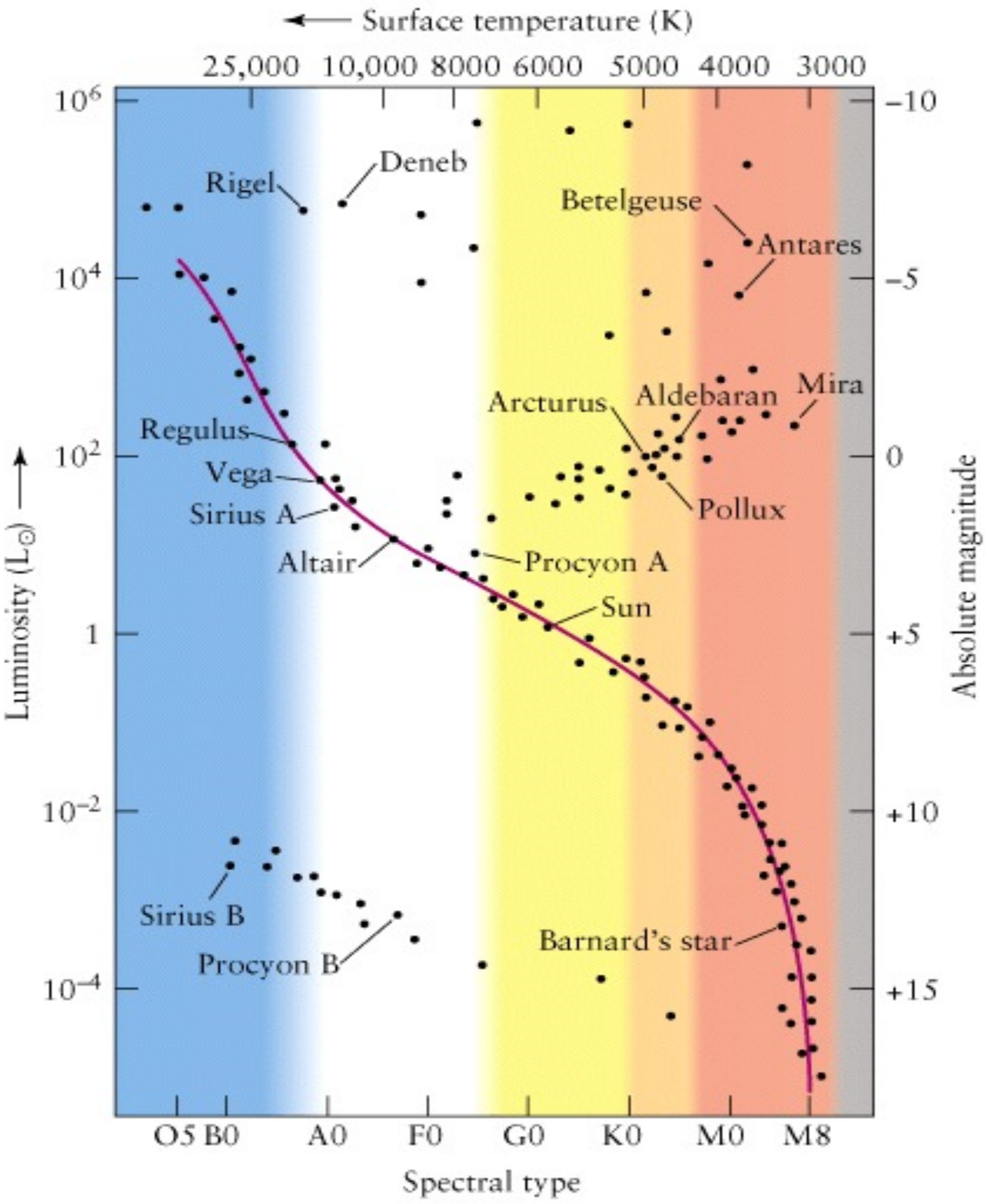
The H-R diagram

- Simple in concept, but a VERY powerful tool to examine stellar evolution

- Hertzsprung and Russell independently asked themselves: "What are the two basic things we know about stars"?

1. Luminosity (or mass)
2. Temperature (or color or spectral type)

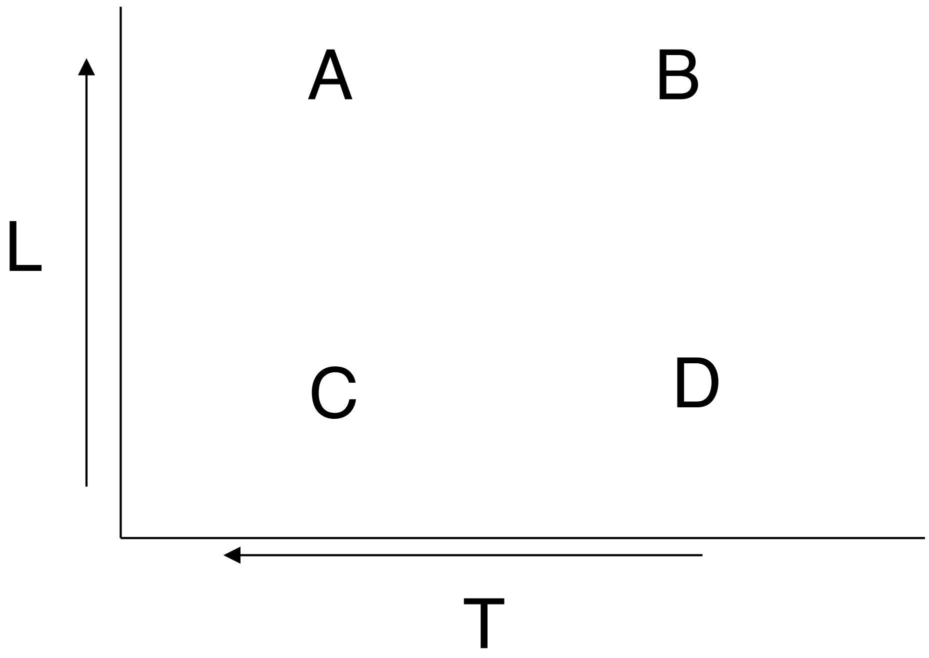
H-R diagram is a plot of L (or M) vs. T (or color/B-V/spectral type) for stars.



← Surface temperature (K)
25,000
10,000
8000
6000
5000
4000
3000
10^6
10^4
10^2
1
10^{-2}
10^{-4}
Luminosity ($L_\odot$) →
−10
−5
0
+5
+10
+15
Absolute magnitude
Rigel
Deneb
Betelgeuse
Antares
Mira
Arcturus
Aldebaran
Regulus
Vega
Sirius A
Pollux
Altair
Procyon A
Sun
Sirius B
Procyon B
Barnard's star
O5
B0
A0
F0
G0
K0
M0
M8
Spectral type

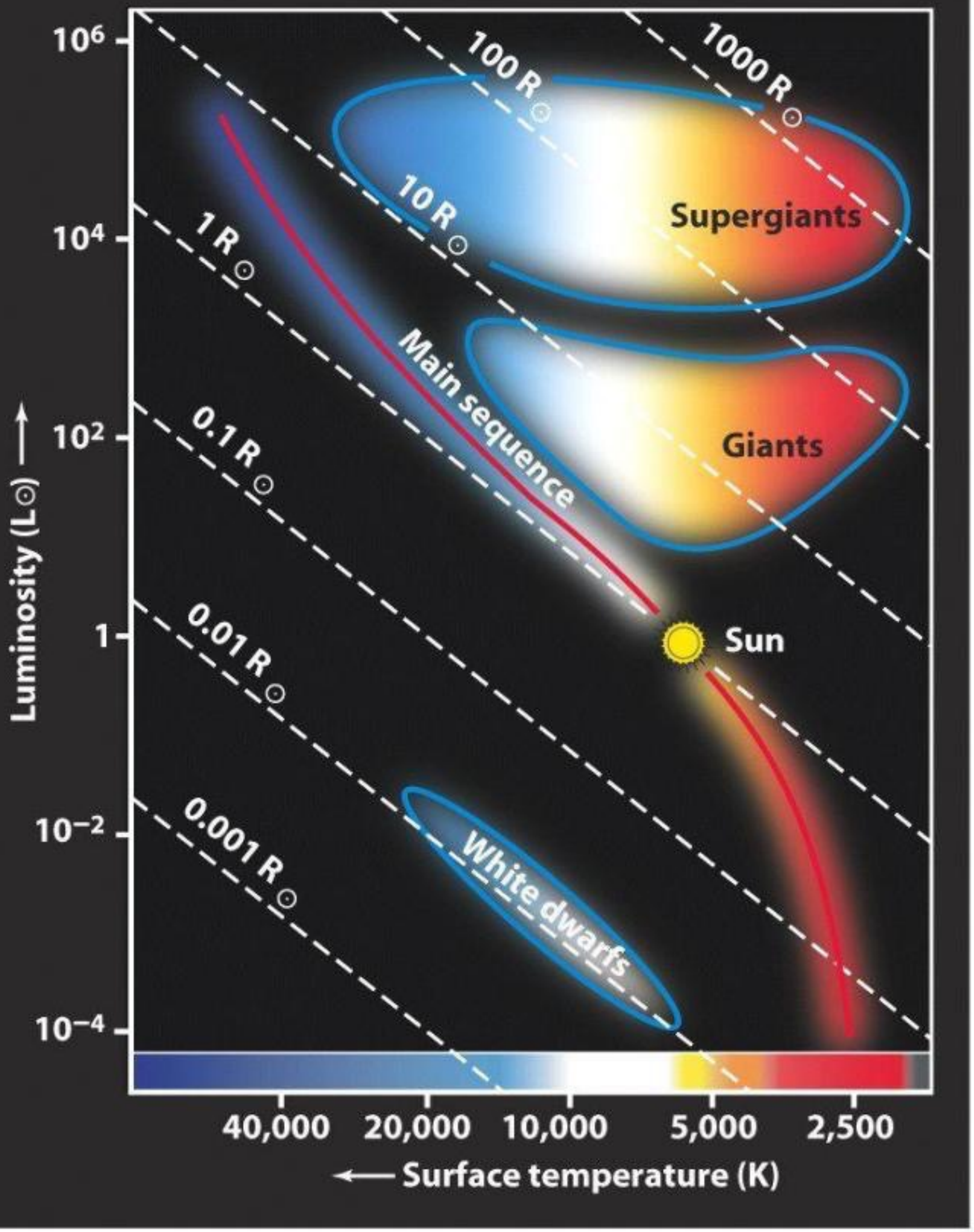
Giants and dwarfs

$L = 4\pi R^2 \sigma T^4$



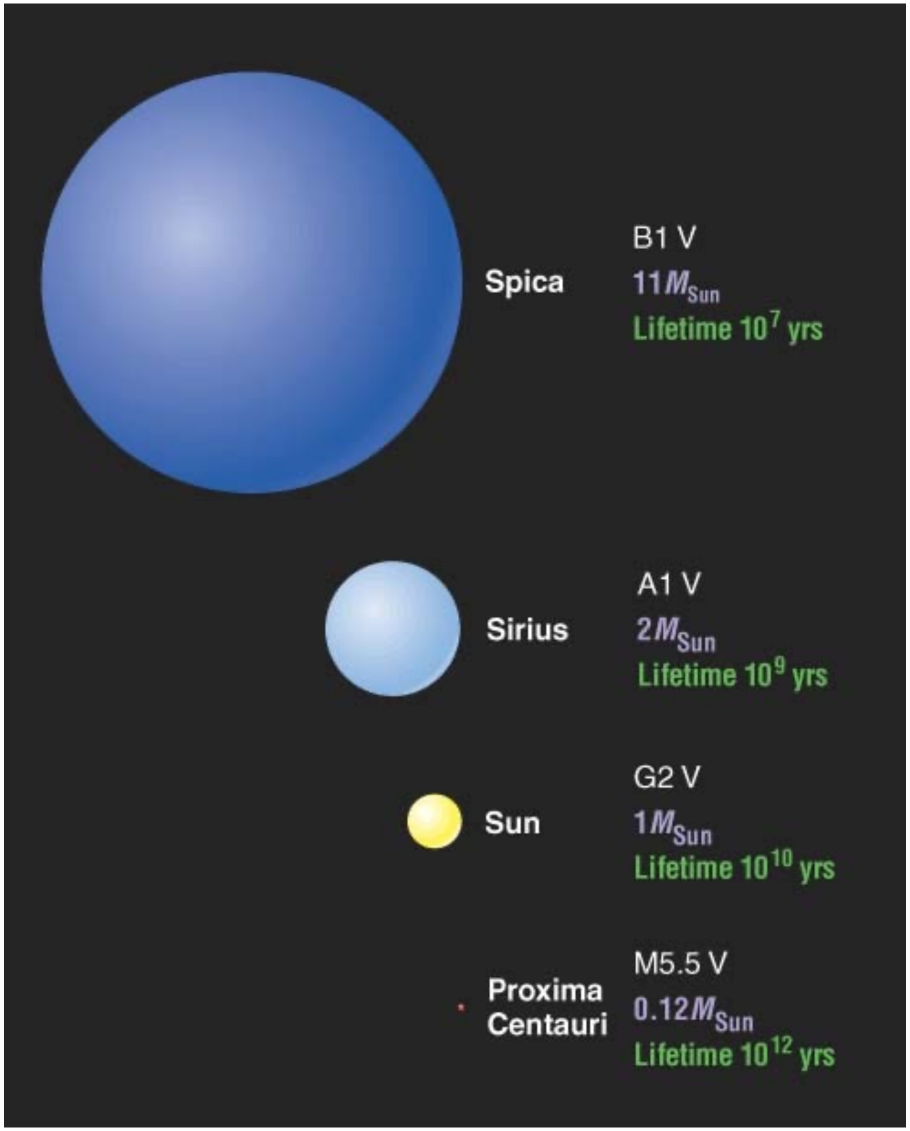
Where are the largest stars? Smallest stars?

The sizes of stars on an H-R diagram

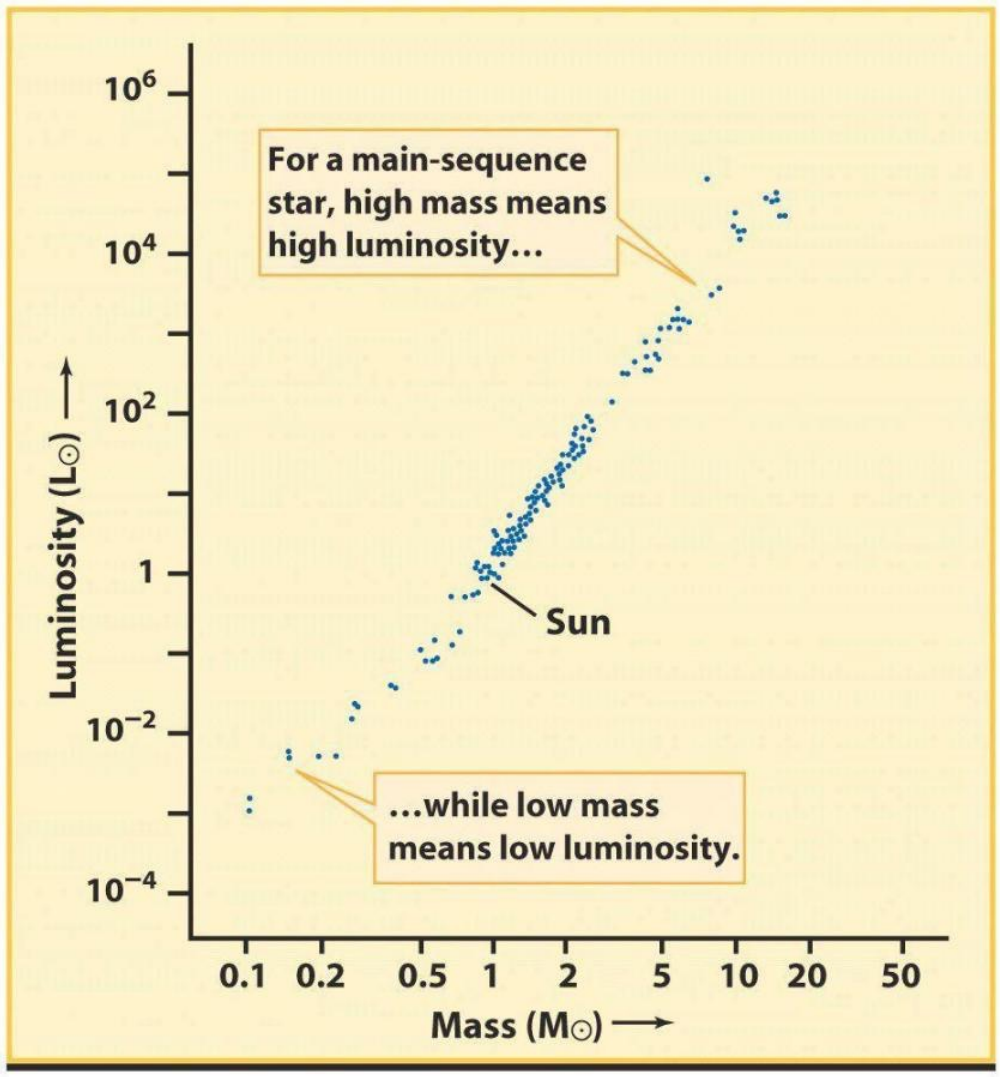


- $L=4\pi\sigma R^2 T^4$
  $\Rightarrow L \propto R^2 T^4$

- Four main sequence stars to scale



Mass-luminosity relation



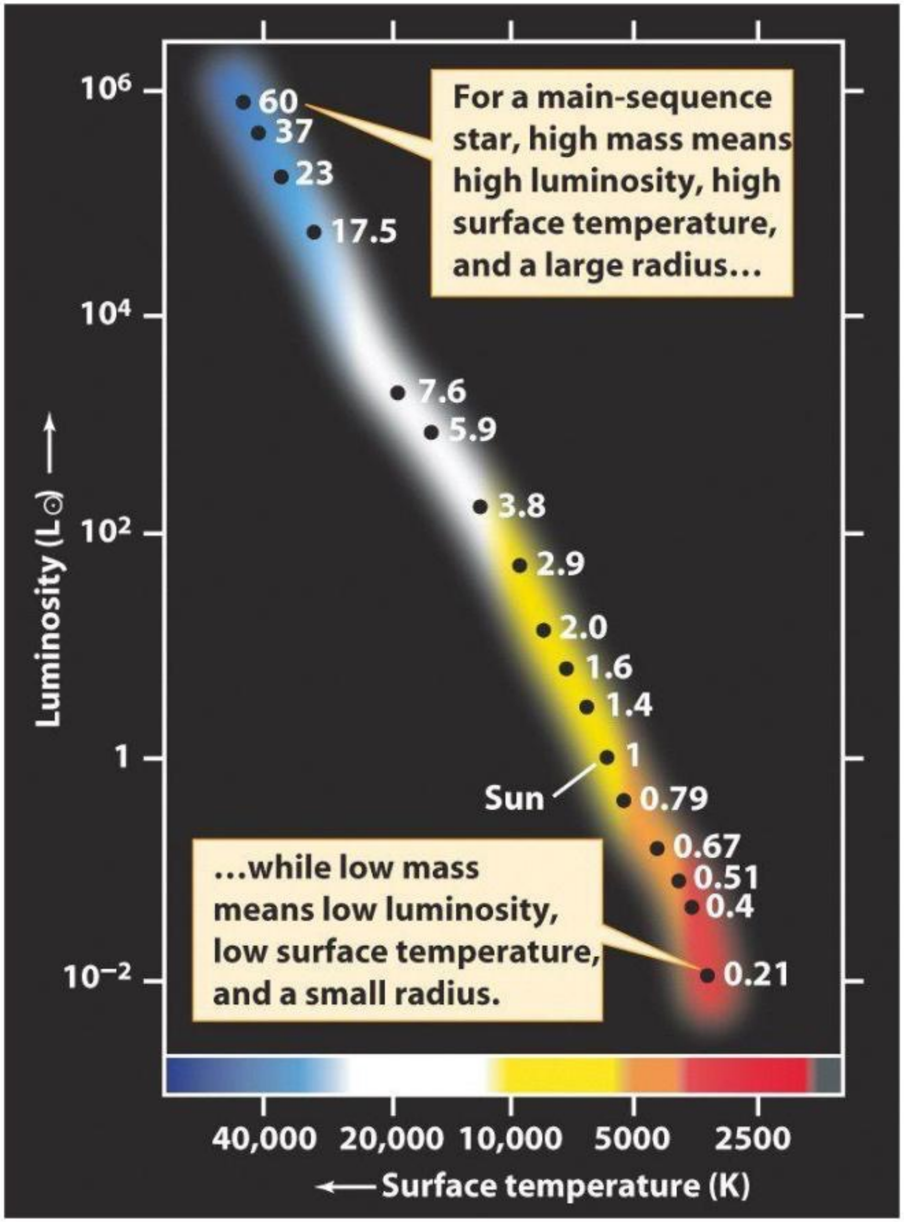
$L \sim M^{3.5}$

Only valid for main sequence stars.

Order implies mass is an important property of an H-burning star.

Why? Because the weight of the outer layers in a star determines the nuclear fusion rate in the core.

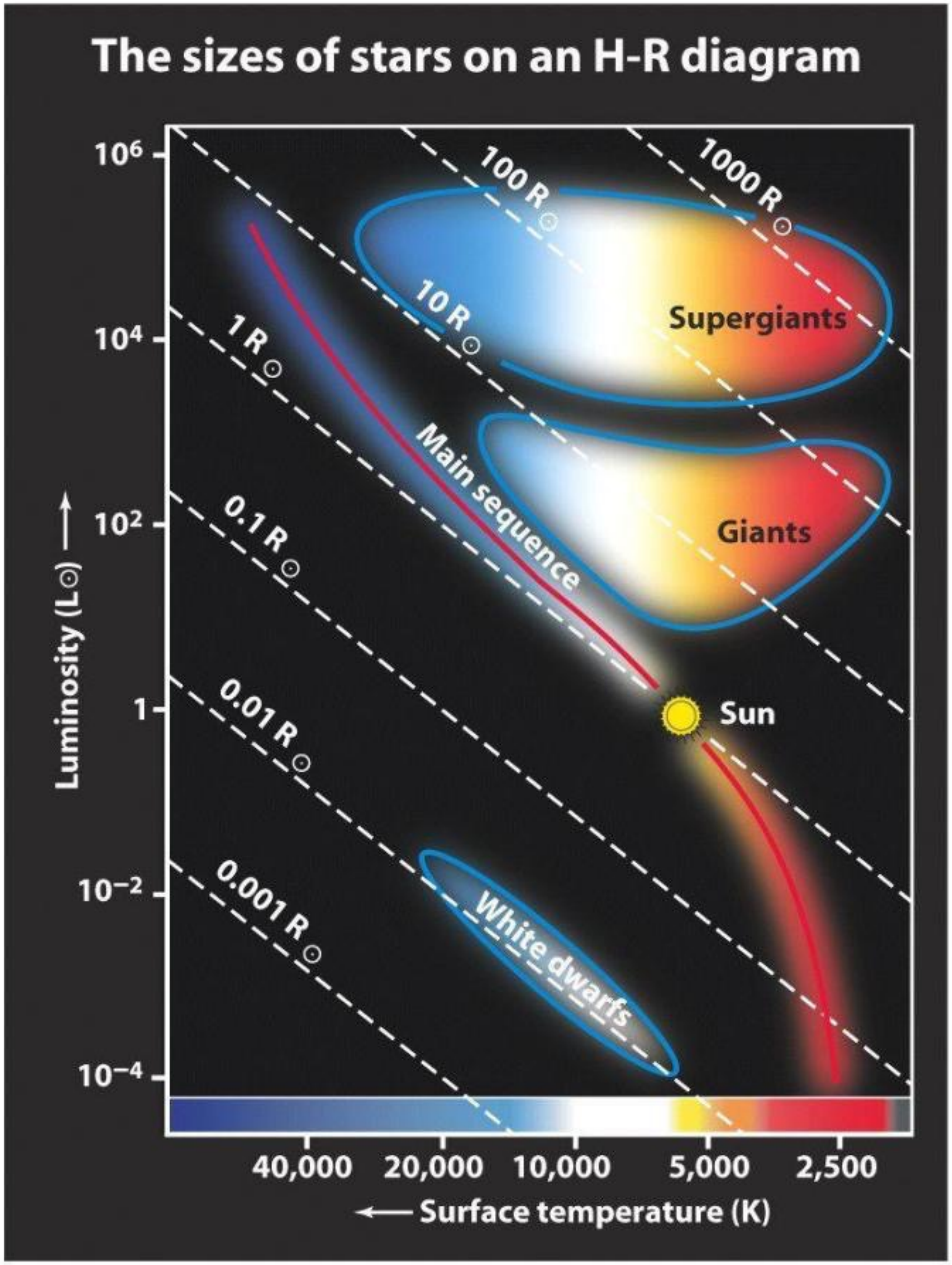
Thus, the main sequence on the H-R diagram is also a sequence of mass:



What if we don't know the distance to the star?

We have the temp from B-V measurements, 5000K, but only an apparent brightness.

This could be on the main sequence, a giant or a supergiant?

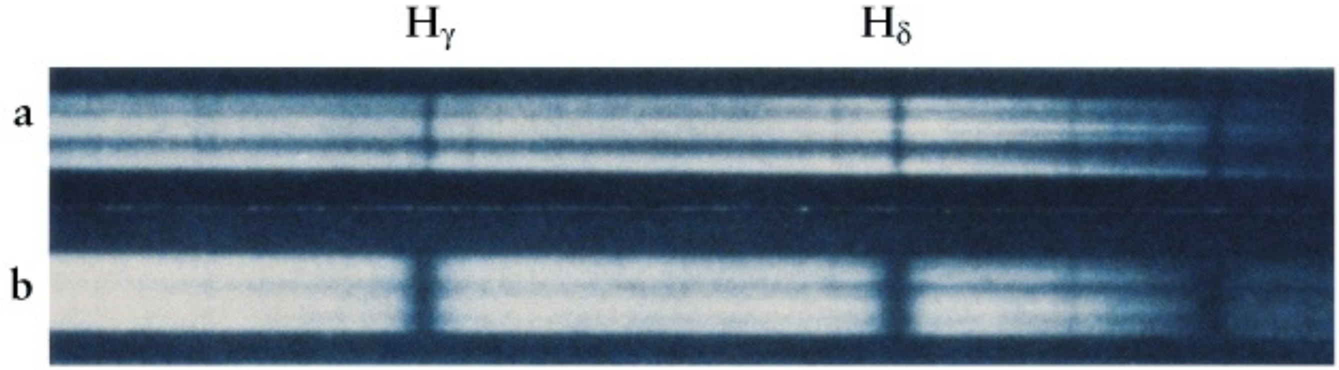


Line width and stellar size

- Atmospheric pressure affects width of absorption lines:
  - Lower pressure => decreased line width
  - Higher pressure => increased line width

- The atmospheric pressure is lower in the photosphere of an extremely large red giant, than in a main sequence star of similar temperature

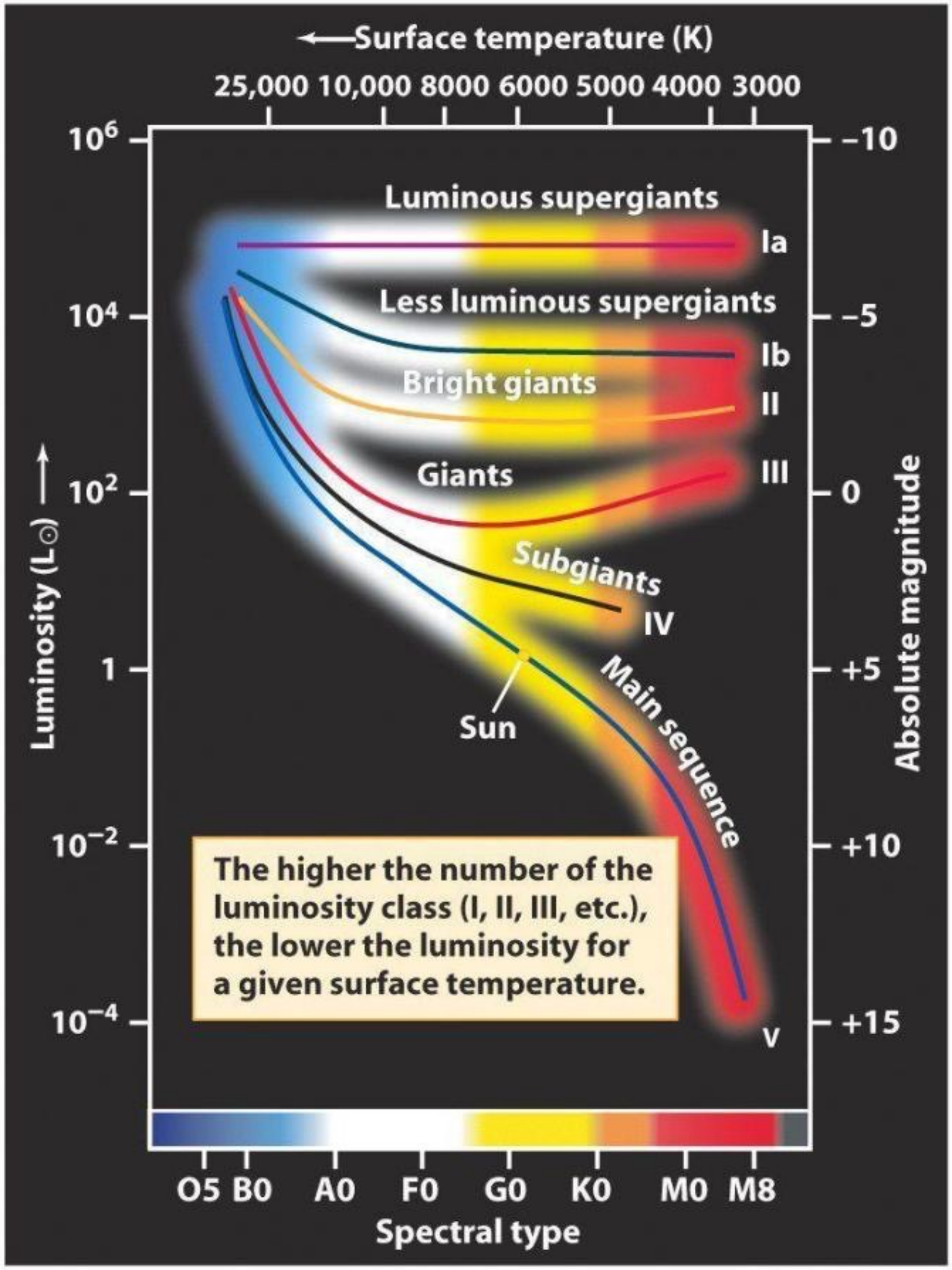
  => giant's spectral lines are *narrower*



Two B8 stars: top is a supergiant, the bottom one is a main sequence.

Luminosity classes

- We classify stars in luminosity classes; I, II, III, IV and V (from narrow to wide, which also is from very luminous to less luminous)
- Two ways to classify stars: via the spectral type, and via the luminosity class.
- The full description of the Sun is G2 V.



The higher the number of the luminosity class (I, II, III, etc.), the lower the luminosity for a given surface temperature.

Spectroscopic parallax

- Without knowing a star's distance, we can place it on the H-R diagram (spectral type and width of lines).
- This yields a luminosity, to be compared to the star's apparent magnitude.
- => distance can be estimated (to about ±10%).

This is how we used to get distances to most stars!

Worksheet – Stellar Lifetimes

Given that $L \sim M^{3.5}$ for stars on the Main Sequence, and the fact that our sun has an expected lifetime of 10 billion years, derive a relation for the lifetime of stars on the Main Sequence.

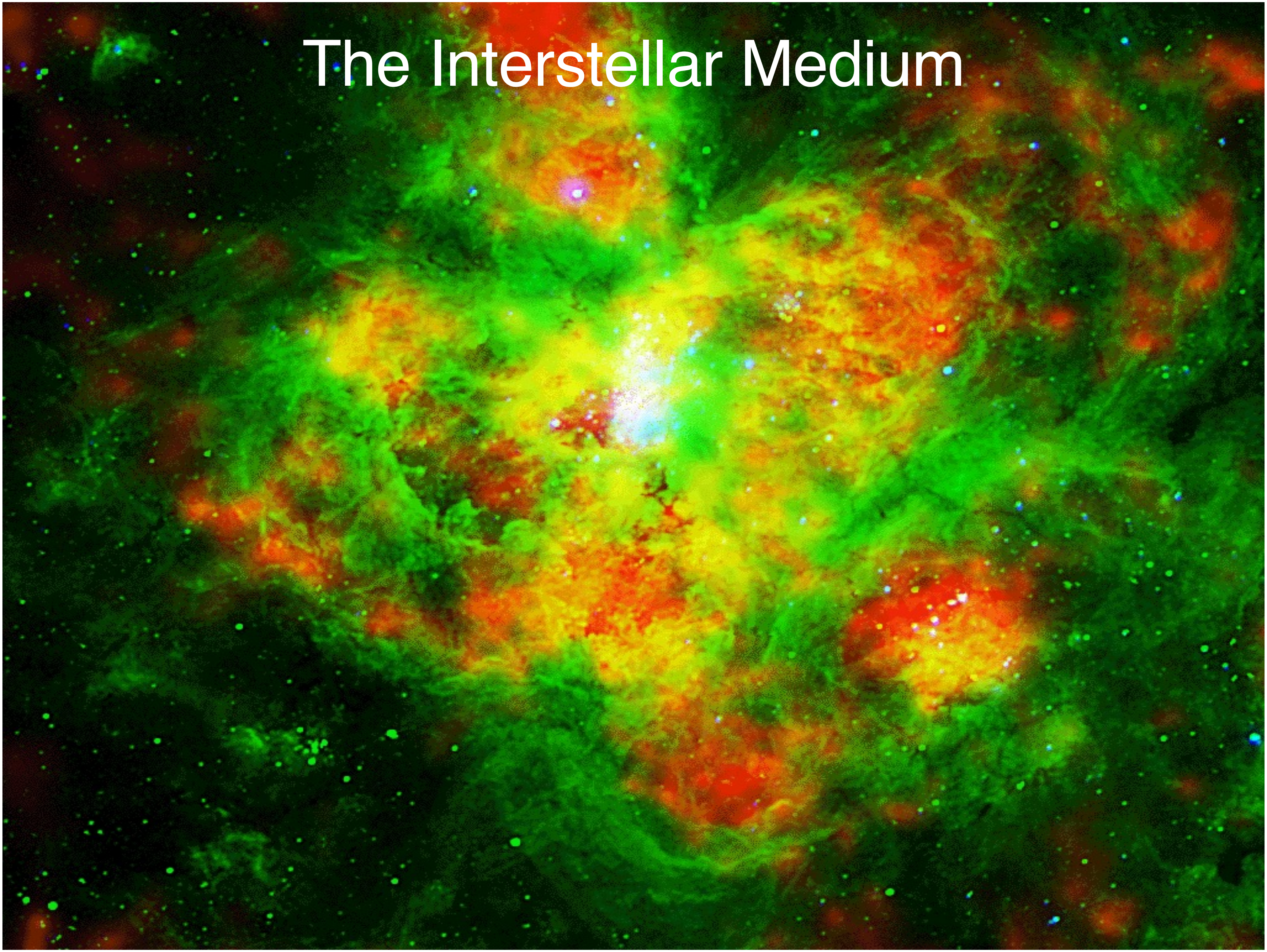
Lifetime = $X M^z$ years

Use your new relation to answer the questions:

What is the expected lifetime for proxima centauri with 0.1 M_sun?

Mintaka in Orion is an O9II star believed to have a mass of 20 solar masses. What is its lifetime?

The Interstellar Medium



The interstellar medium (ISM)

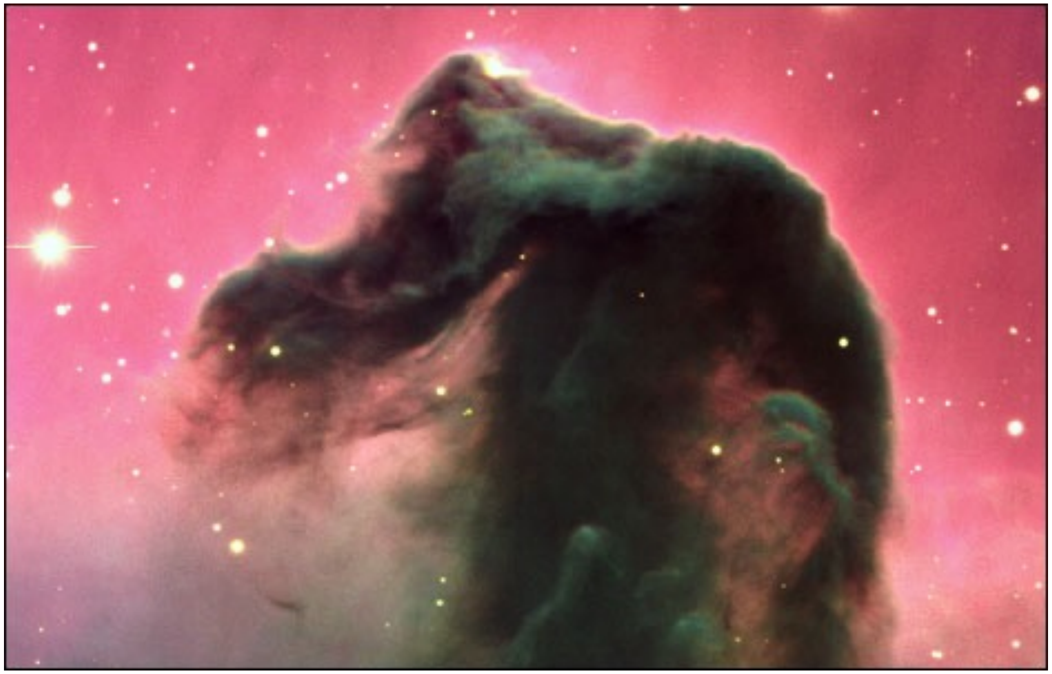
- Space between stars is not a complete vacuum.

- Why is the ISM important?
  - Stars form out of it
  - Stars end their lives by returning gas to it

- The ISM has
  - a wide range of structures
  - a wide range of densities (10^{-3}-10^{7} atoms/cm^{3})
  - a wide range of temperatures (10 K - 10^{7} K)

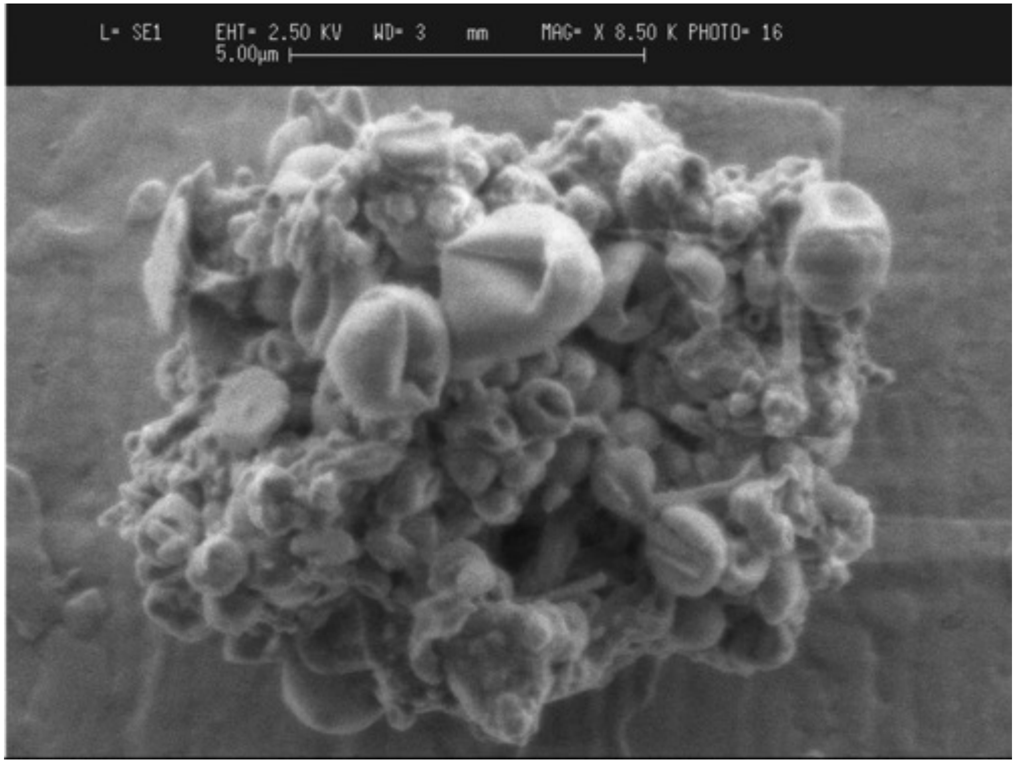
Overview of the ISM

- The ISM is a multi-component, multi phase medium
- The *components* are gas and dust, with dust comprising 1-2% of the ISM mass.
- The *phases*, meaning different kinds of clouds of gas and dust – hot, warm, cold, dense, rarefied.

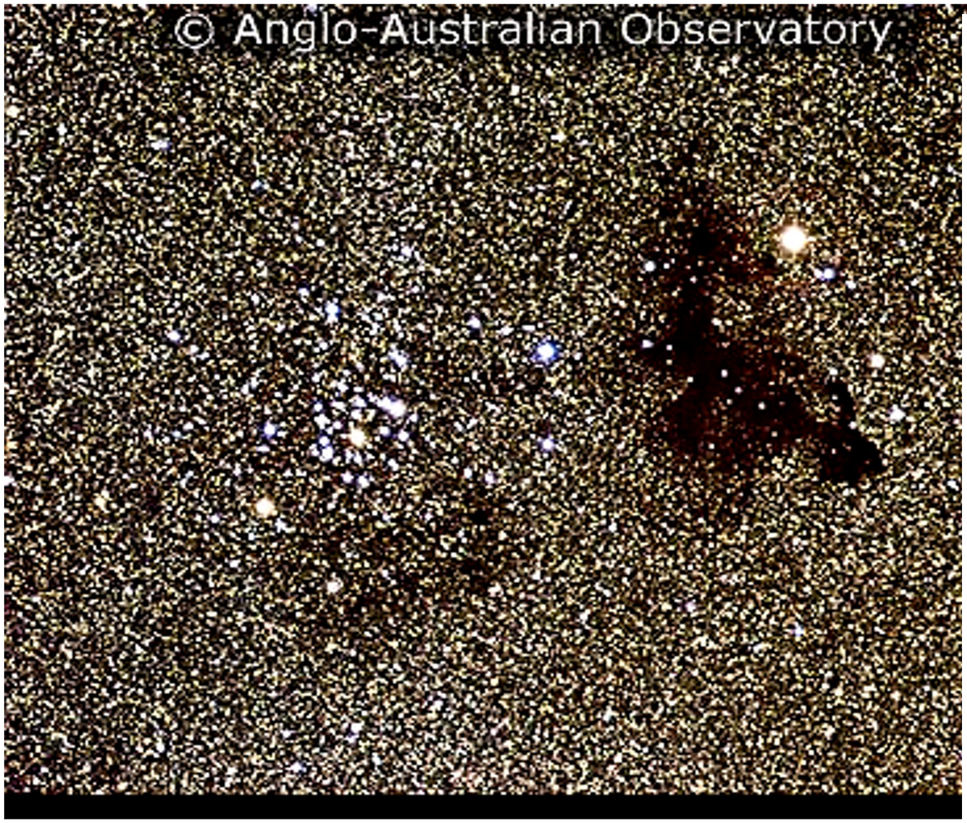


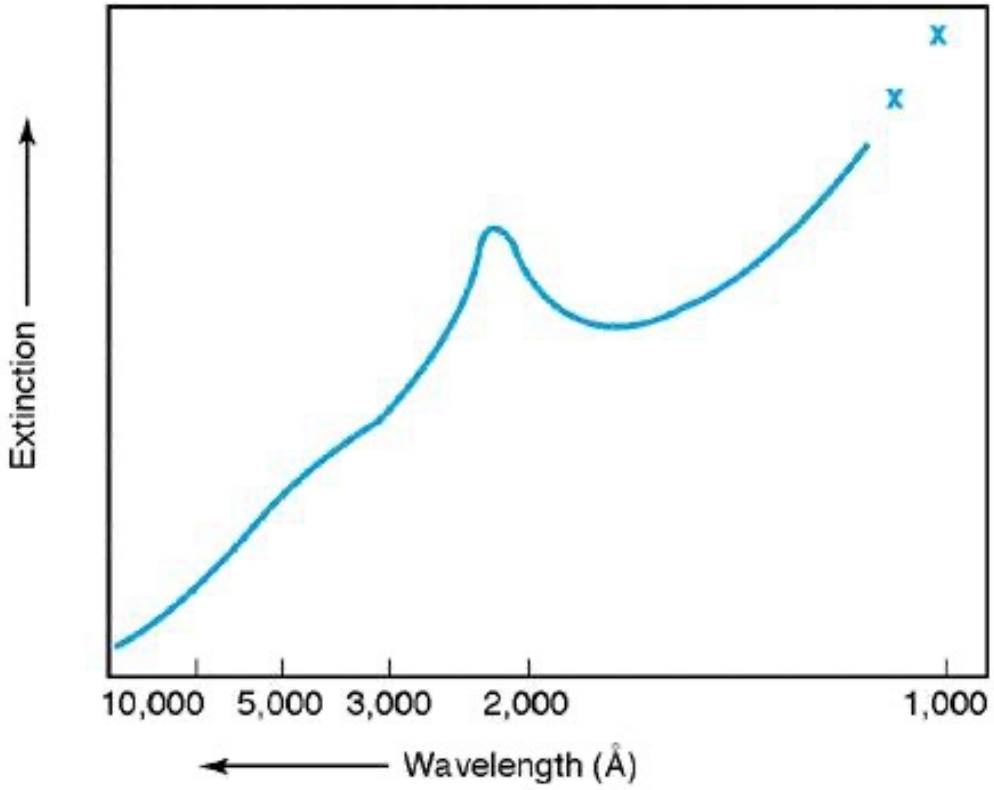
Dust particles

- Grains with carbon, graphite, silicates
- Particles of ~10^3 atoms, physical size d~10^{-7} m (range nm to μm)
- Cause interstellar extinction
- Cause reddening



- Extinction is reduction in optical brightness
- Strong λ dependence on absorption and scattering
- Measure in magnitudes, A_V, at visible light

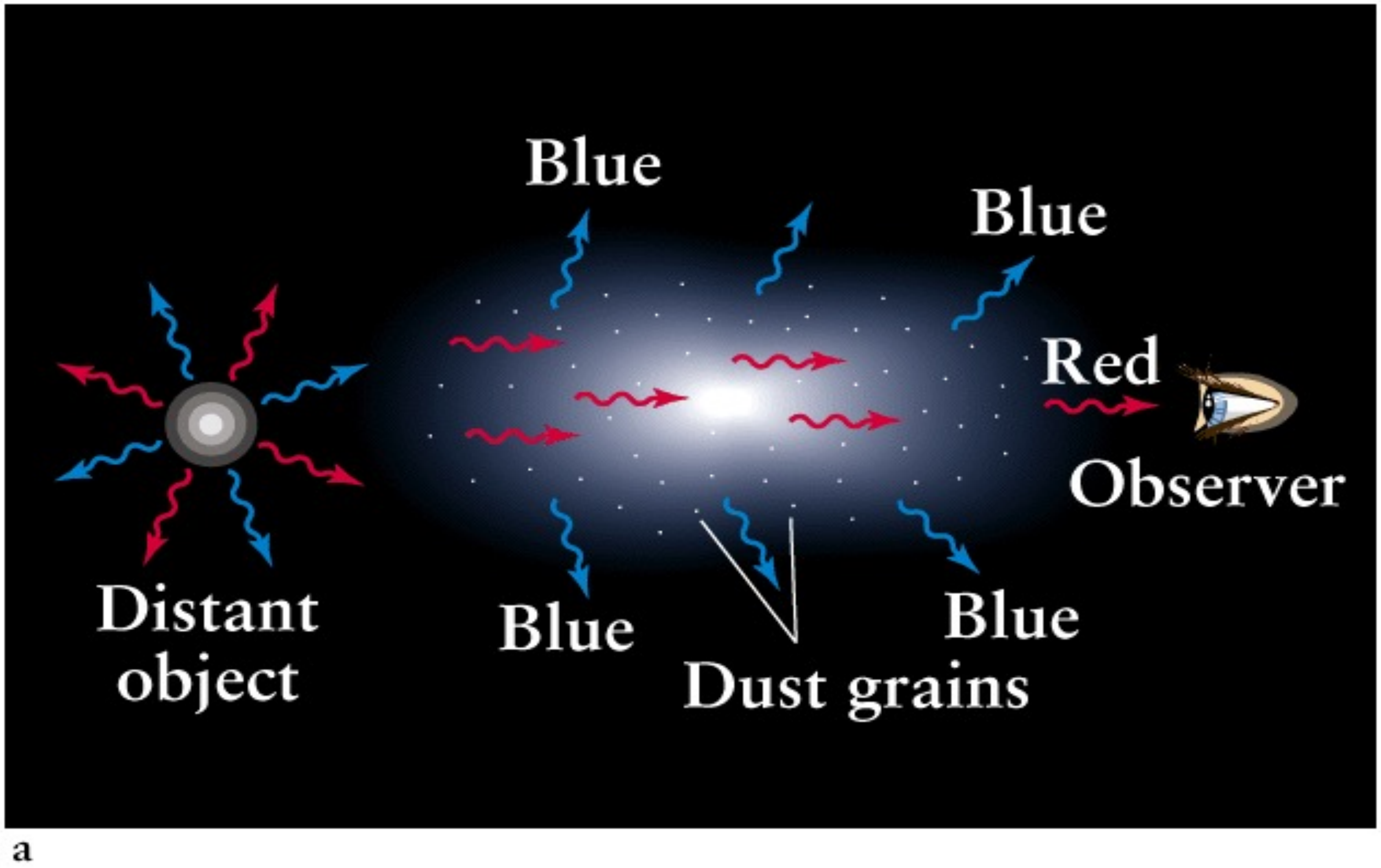




Orion at visible wavelengths

Orion at IR wavelengths (100μm): dust grains absorbs UV light and re-radiates in the IR!

- Interstellar reddening: Scattering will both dim and redden the starlight.
- This is Rayleigh-scattering, which is proportional to $1/\lambda^4$



Thus, we need to be careful calculating distances to stars using the distance modulus:

$$m - M = 5\log d - 5$$

If there is dust (and there will be) this becomes:

$$m - M = 5\log d - 5 + A$$

where *A* is the amount of light absorption in magnitudes at the wavelength you are measuring brightness of star.

- Dust is seen as winding bands, or spherical clouds (Bok globules)
- Can also be detected via polarization

Rosette Nebula

- Dust is formed in low T regions (~<100K), since high T will cause collisions and sputtering of the grains => destruction of the grains.

- The surfaces of dust grains can act as a matrix to hold molecules close together, and allow chemistry to occur.

- These molecules are mostly hydrocarbon chains and other organic molecules (claims of protein, like DNA, seen in molecular cloud). This is the field of *cosmochemistry.*

The main ISM component: gas

- Interstellar gas is either neutral or ionized

- Ionized:
  - WIM, Warm Ionized Medium
  - HIM, Hot Ionized Medium

- Neutral:
  - WNM, Warm Neutral Medium
  - Cool NM
  - Cold NM

Component	**Phase**	**T(K)**	**n(cm^{-3})**
Neutral	Cold (molecular)	10-50	10^3-10^7
	Cool (atomic)	100	1
	Warm	$8x10^3$	10^{-1}
Ionized	Warm	10^4	10^0-10^4
	Hot	$5x10^5$	10^{-3}

Molecular clouds

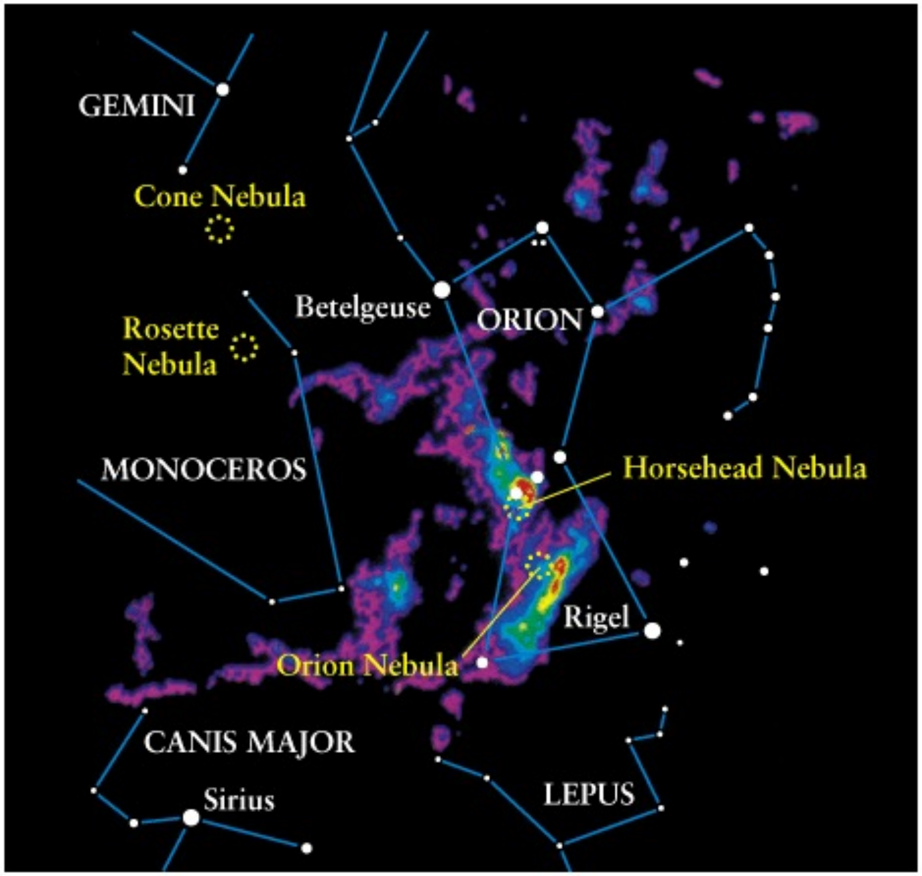
- Cold (~10 K), dense (10^3–10^7 molecules/cm3)
- Cloud masses: 10^3 - 10^6 $M_\odot$ (plenty of stars can form of this)
- Cloud sizes: a few to 100 pc
- In the Galaxy: ~5,000 molecular clouds
- Often buried deep within neutral atomic clouds

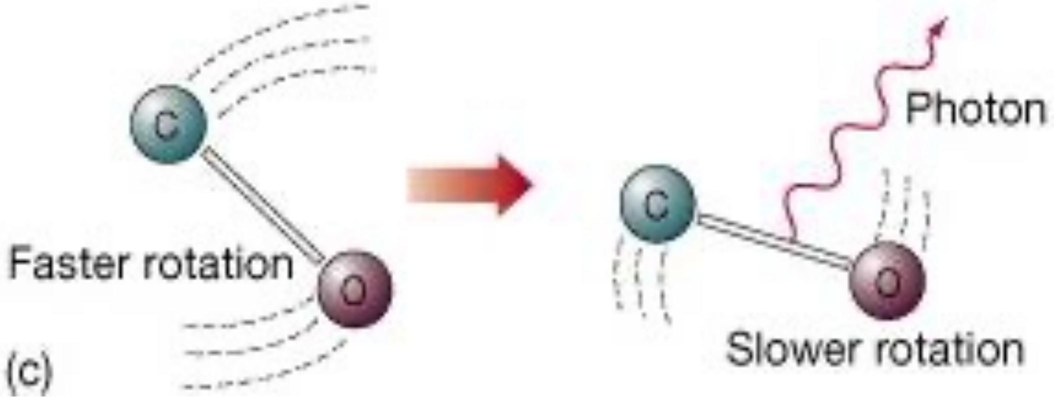
Molecular cloud seen as dark clouds in the optical


© Anglo-Australian Observatory

- Most abundant is H_2, but it has no allowed mm emission, so other "trace" molecules observed: CO, H_2O, NH_3, HCN etc.

- These molecules undergo rotational energy level transitions, emitting photons at mm λ





False color radio observations of CO in the Orion molecular cloud complex.

H_2 is symmetric - need to atoms of different mass to produce rotational transitions.

Molecules in space

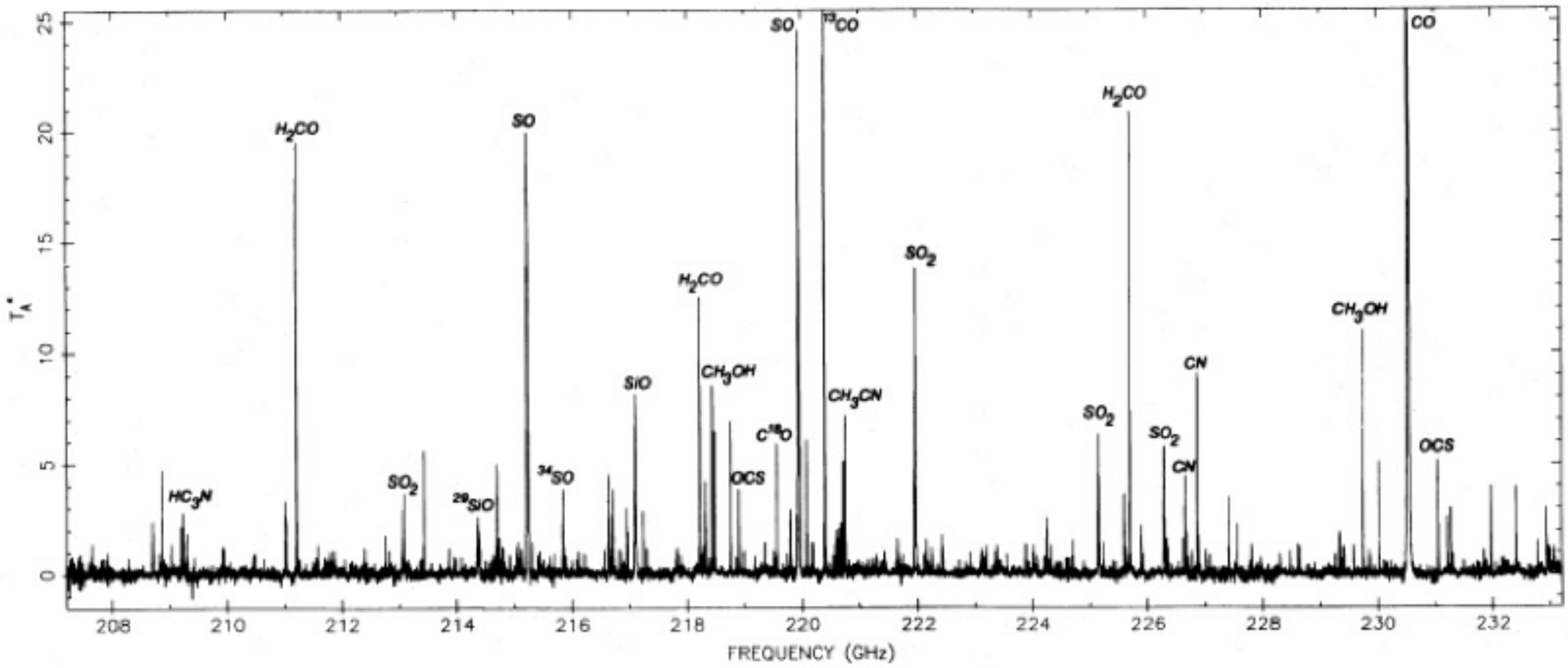
Over 140 molecules detected in space so far.

Examples:

- 2 atoms: H_2, CO, OH, CN
- 3 atoms: H_2O
- 6 atoms: CH_3OH
- 9 atoms C_2H_5OH
- 13 atoms: $HC_{10}CN$ (cyanodecapentayne)

Acetamide in SgrB2 (9 atoms) contains a bond that link amino acids together (building bocks of proteins).

Molecules in space

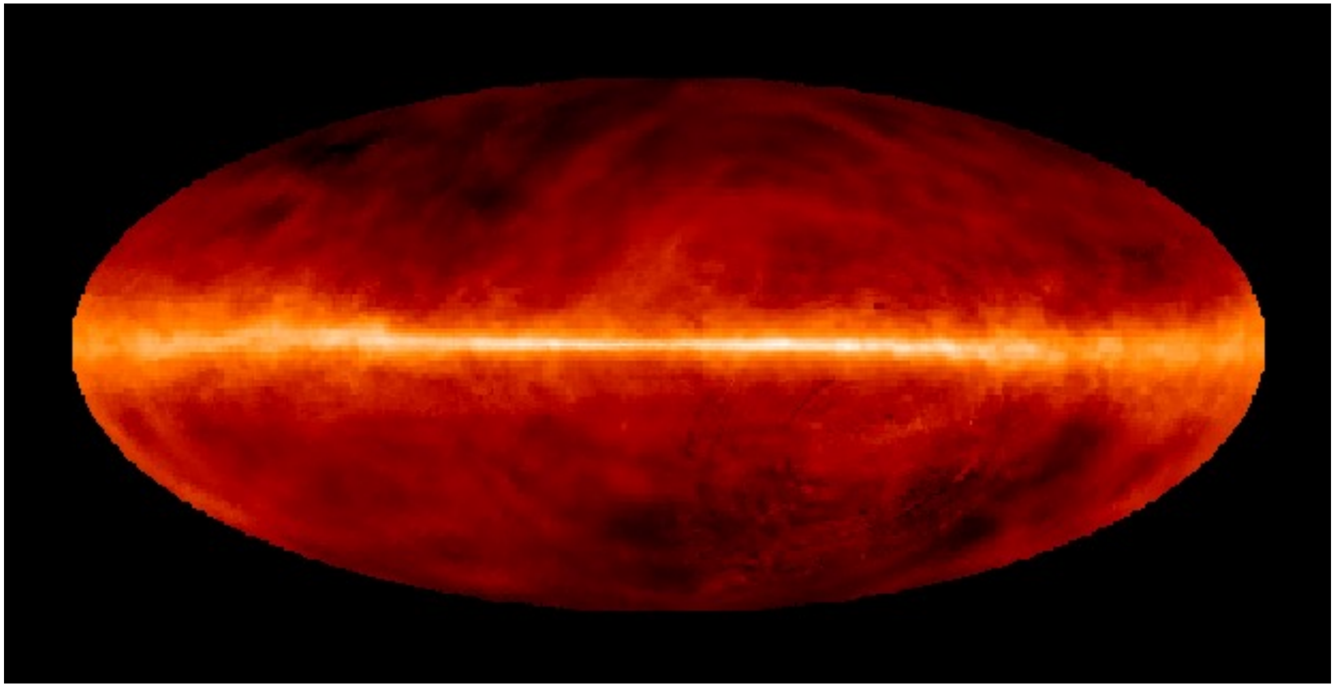


Spectrum of Orion Molecular Cloud 1 (OMC1) from Blake et al. 1987

Component	**Phase**	**T(K)**	**n(cm^{-3})**
Neutral	Cold (molecular)	10-50	10^3-10^7
	Cool (atomic)	100	1
	Warm	8×10^3	10^{-1}
Ionized	Warm	10^4	10^0-10^4
	Hot	5×10^5	10^{-3}

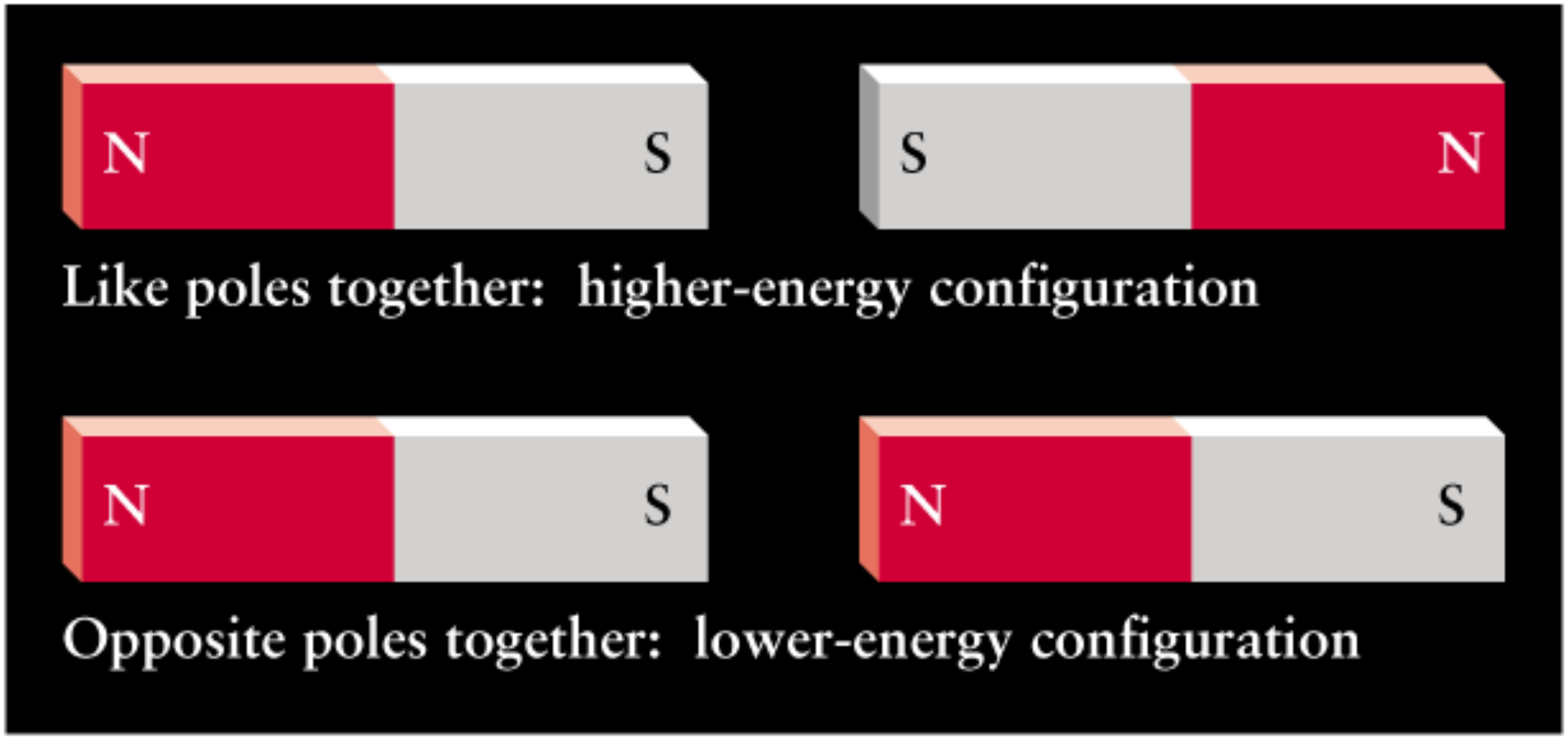
Atomic gas - HI

- Cool (and warm) atomic gas: T~100K (8000K), making up ~22% of the ISM
- 1-10 atoms/cm^3 (diffuse)
- Tenuous clouds filling a large part of the interstellar space
- No optical emission - WHY?
- 2×10^9 M$_\odot$ in the Galaxy



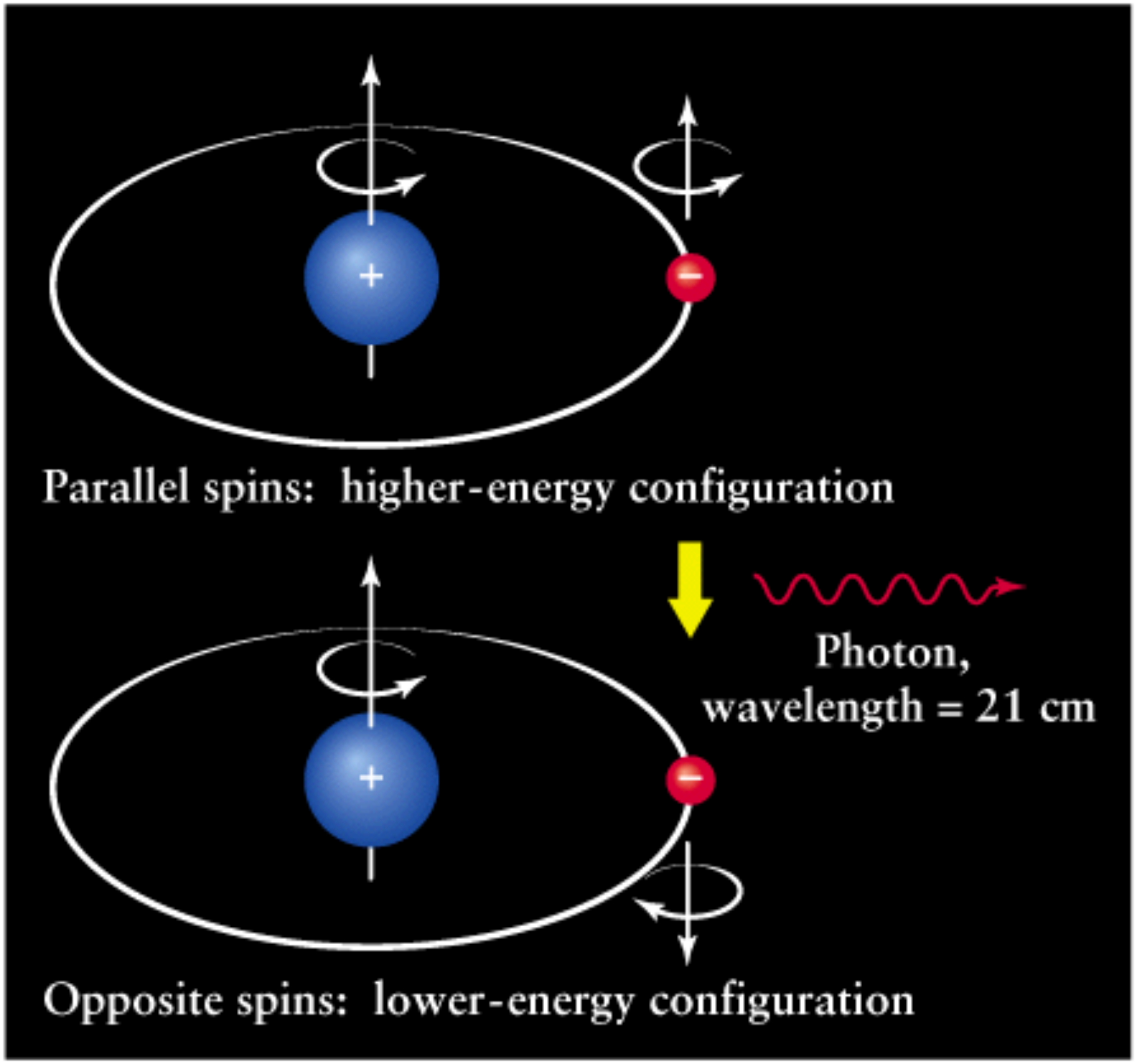
Cold, neutral hydrogen with electrons in n=1 level still emits energy through the “spin-flip transition”.

How? Spinning electrons and protons are charged and act like magnets:



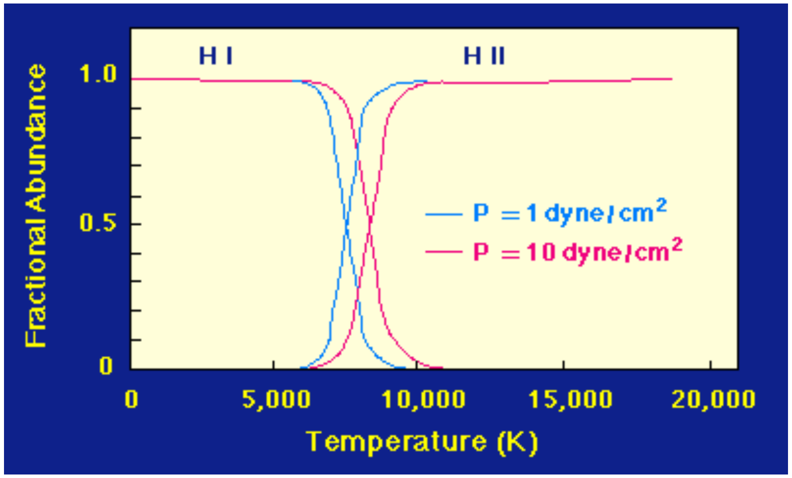
a

The spin-flip transition produces a 21-cm photon (1420 MHz).



b

Component	**Phase**	**T(K)**	**n(cm^{-3})**
Neutral	Cold (molecular)	10-50	10^3-10^7
	Cool (atomic)	100	1
	Warm	$8x10^3$	10^{-1}
Ionized	Warm	10^4	10^0-10^4
	Hot	$5x10^5$	10^{-3}



Emission nebulae - HII regions

- *nebula* = cloud (plural nebulae)
- ~5000/cm^3 (diffuse)
- T≅10^4 K (H essentially completely ionized)
- Sizes 1-20pc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Rosette Nebula

Hot, tenuous gas => emission lines (Kirchoff's laws)

In the Orion Nebula, the Trapezium stars provide energy for the whole nebula.

- UV energies are required to ionize the atoms
- Provided by hot and massive O, B stars
- e^- quickly recombine with the p
- Dominant emission Hα, at λ = 656 nm. Color?