STARS - S09

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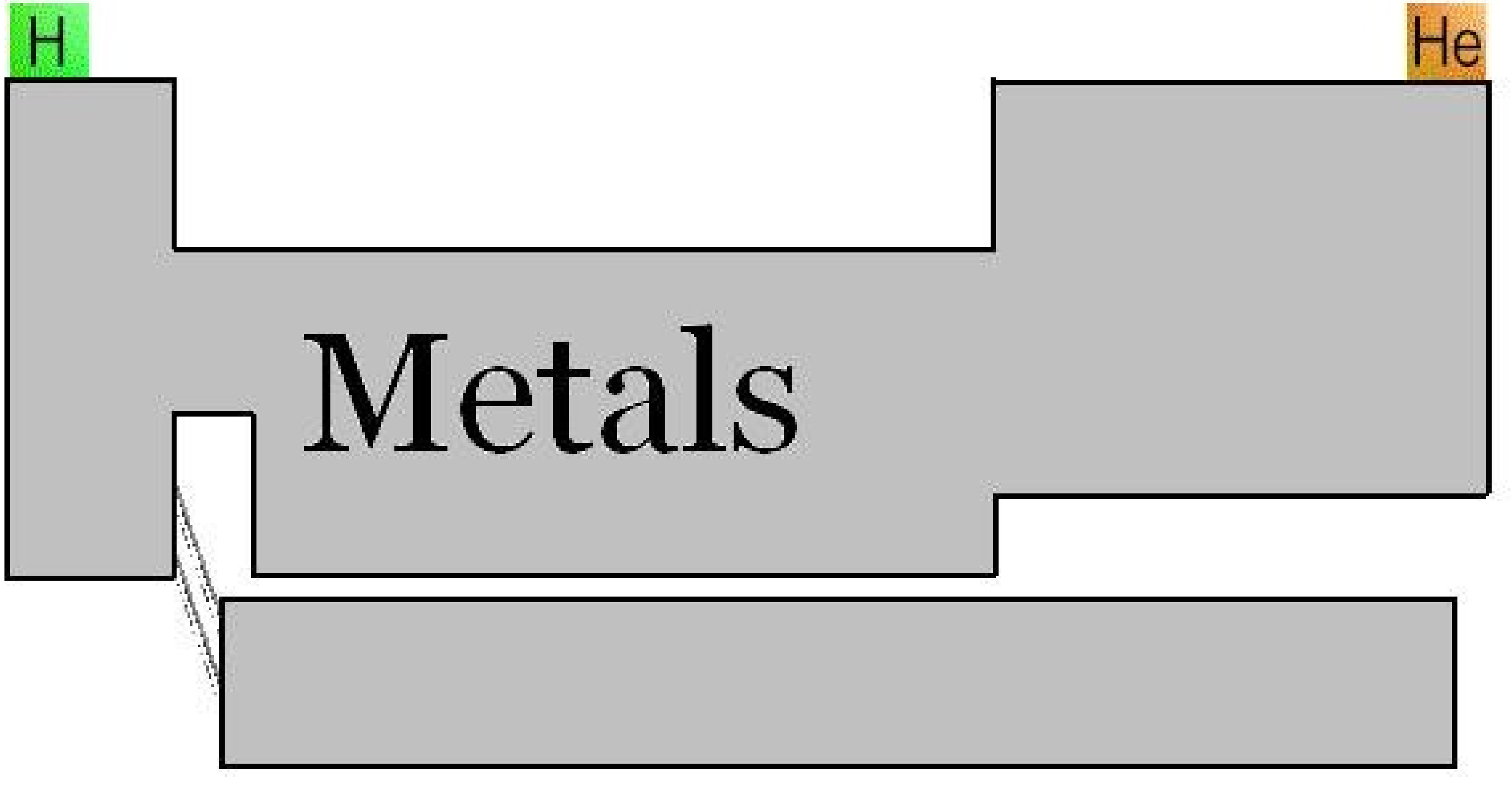
From last class

Some astrochemistry jargon

Metal: anything that is not Hydrogen or Helium

The Astronomer's Periodic Table



From last class

Some astrochemistry jargon

Metal: anything that is not Hydrogen or Helium

X: Hydrogen abundance
Y: Helium abundance
Z: All the rest (i.e., abundance of metals)

X+Y+Z=1

Sun: X=0.749, Y=0.238, Z=0.013

Metallicity
Iron abundance (normalized to solar)

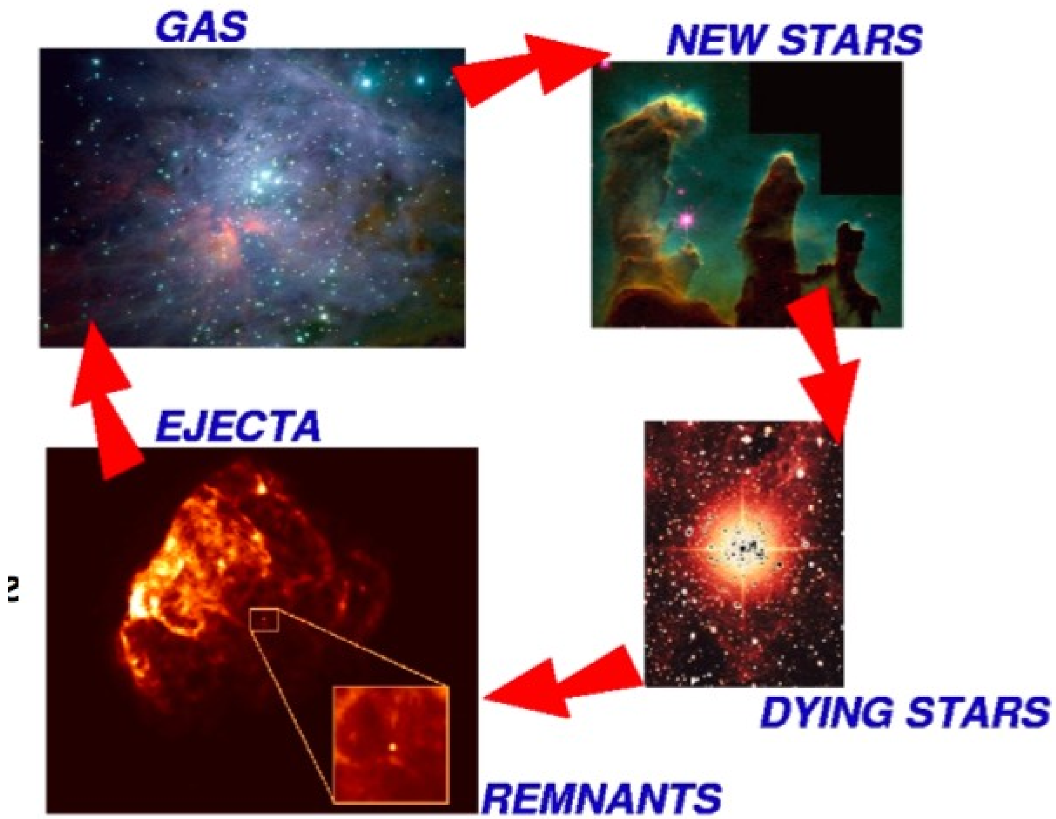
$$[Fe/H] = \log\left(\frac{N_{Fe}}{N_H}\right)_{\star} - \log\left(\frac{N_{Fe}}{N_H}\right)_{\odot}$$

Sun: [Fe/H] = 0.0

From last class

Some astrochemistry jargon

Successive generations of stars enrich the Galaxy in metals



From last class

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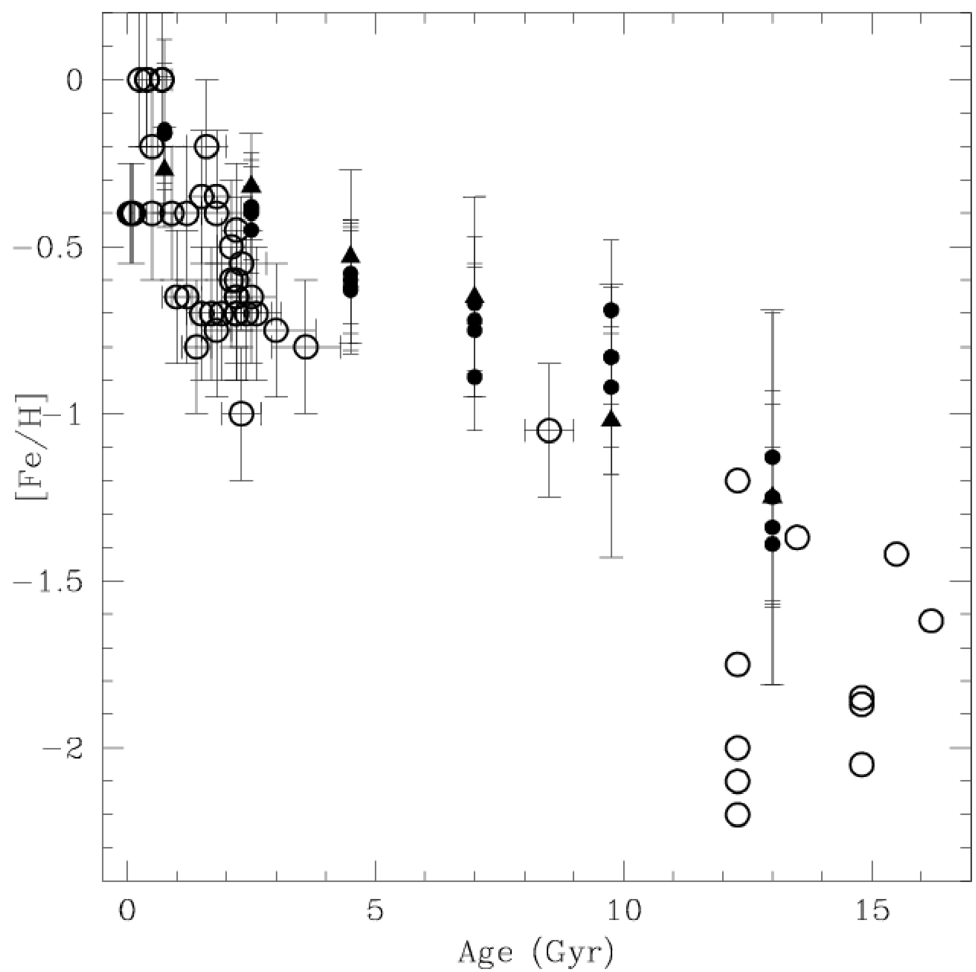
Some astrochemistry jargon

Successive generations of stars enrich the Galaxy in metals

An age-metallicity relation can be traced



Age of the stars

From last class

Some astrochemistry jargon

Successive generations of stars enrich the Galaxy in metals

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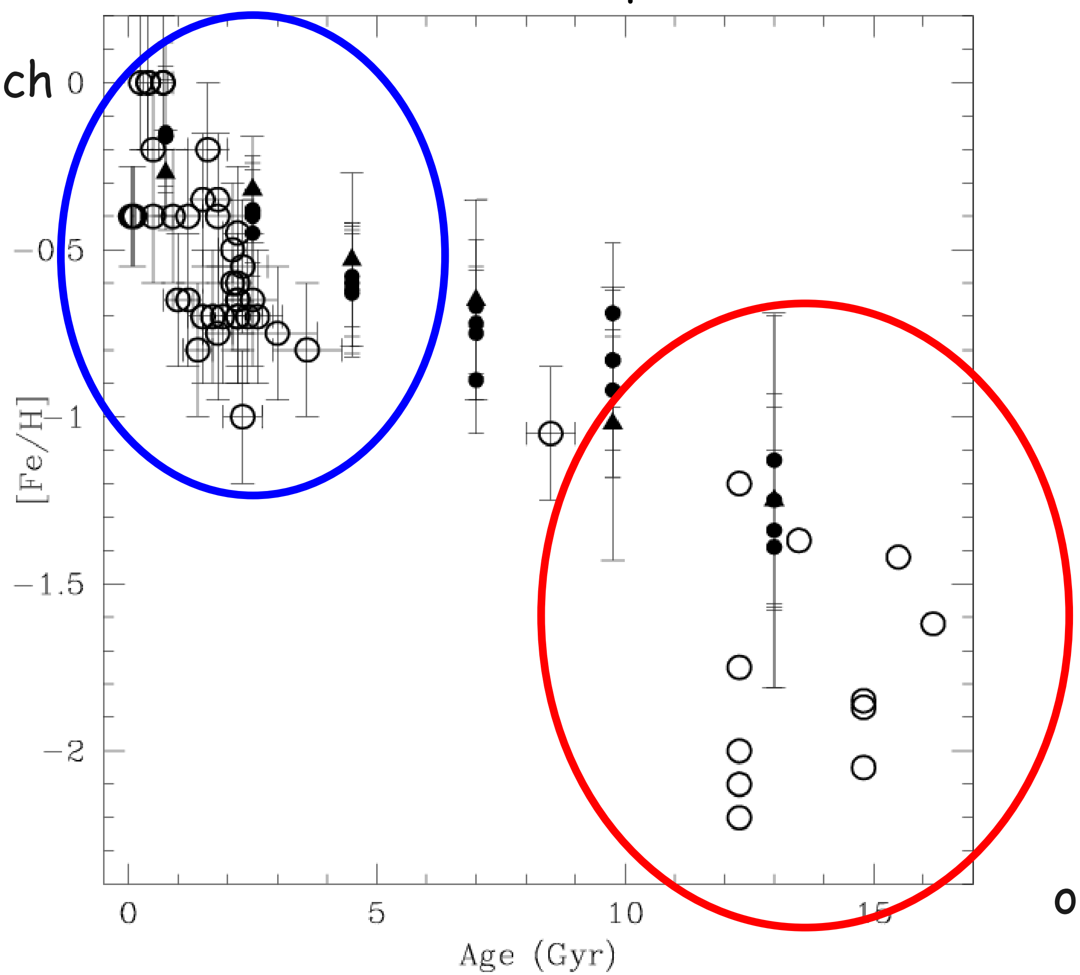
Stellar Populations

Population I

young and metal-rich



Population II

old and metal-poor

Age of the stars

From last class

Some astrochemistry jargon

Successive generations of stars enrich the Galaxy in metals

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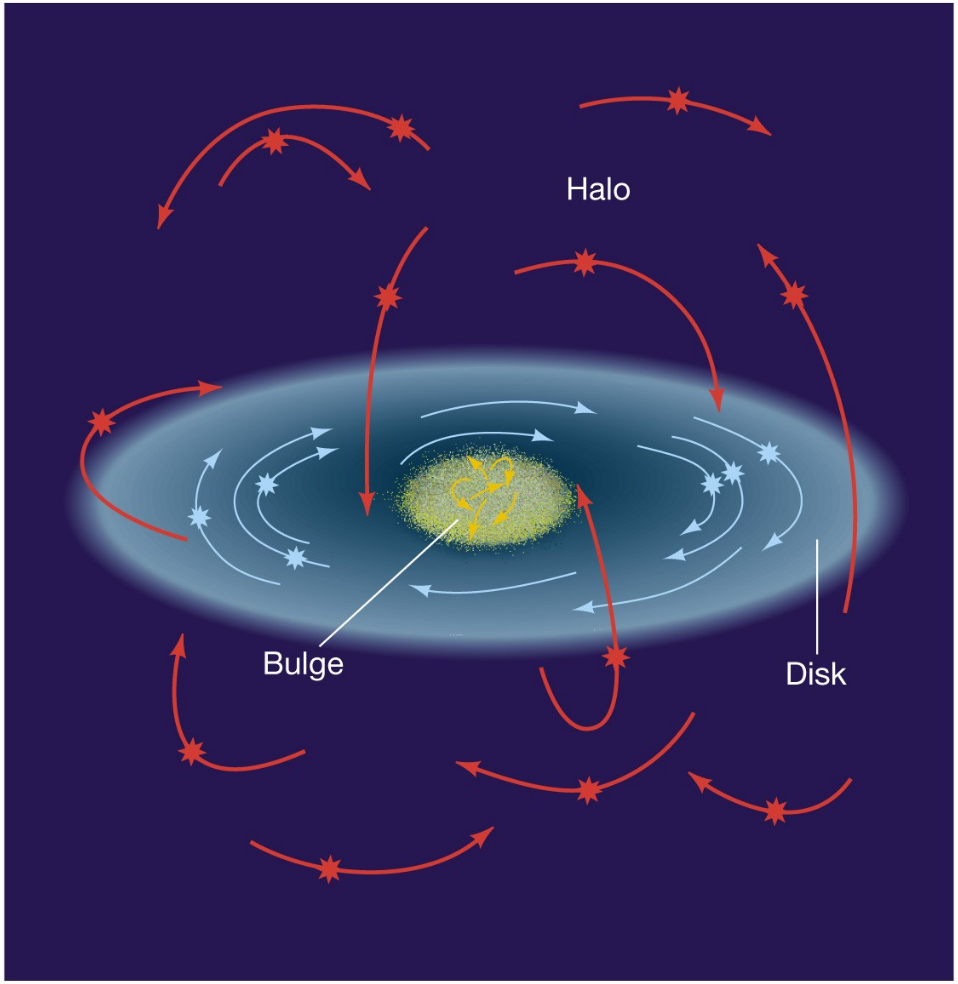
Stellar Populations

Pop I – Disk stars ; Pop II – Halo stars

Population II
old and metal-poor
Halo Stars

Star formation ceased long ago



Population I
young and metal-rich

Disk Stars

Star formation is ongoing

From last class

Some astrochemistry jargon

Successive generations of stars enrich the Galaxy in metals

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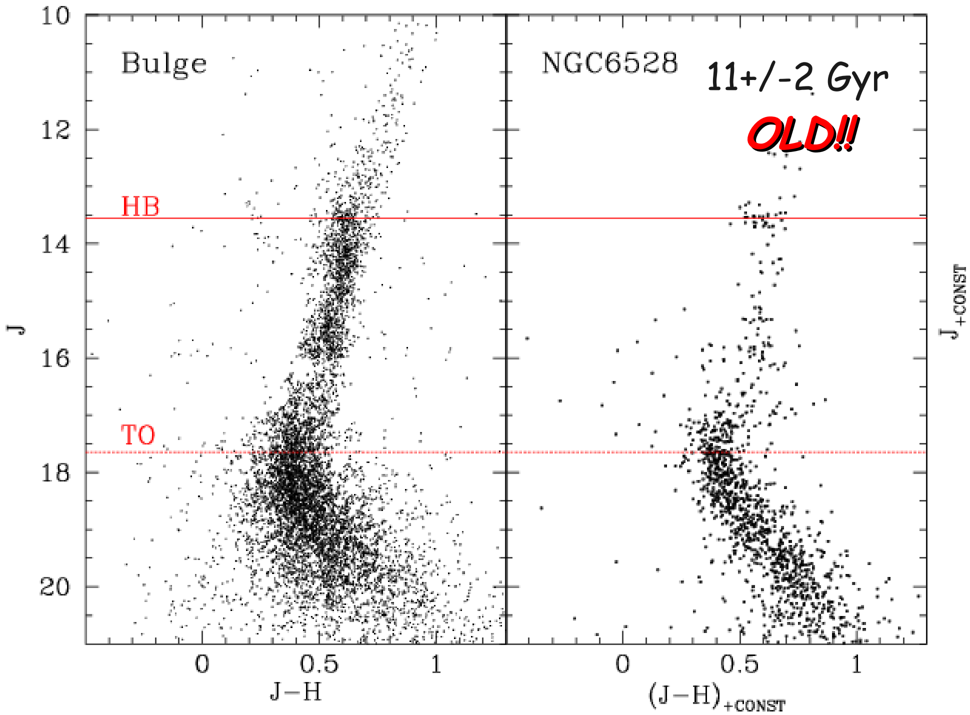
Stellar Populations

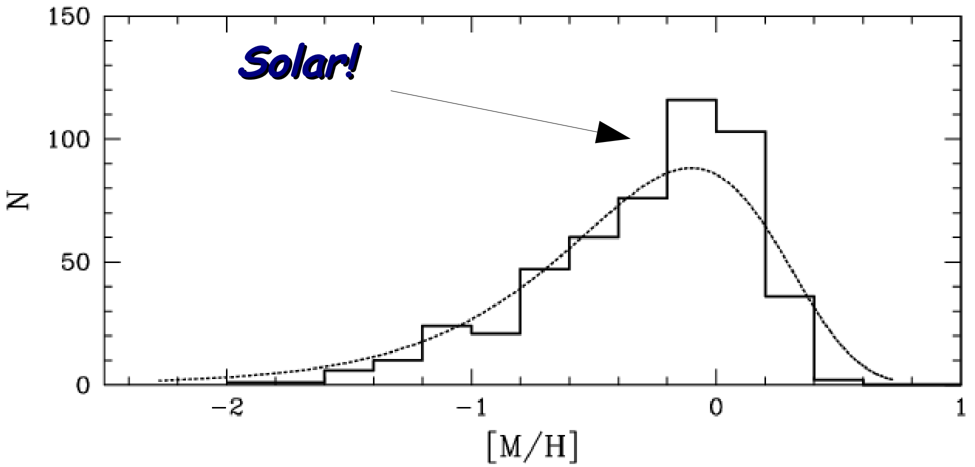
Pop I - Disk stars ; Pop II - Halo stars

Bulge stars break the classification. They are old and metal rich.

Age of the Bulge



Metallicity Distribution of the Bulge



From last class

Some astrochemistry jargon

Successive generations of stars enrich the Galaxy in metals

Star formation rate (SFR) is proportional to the density

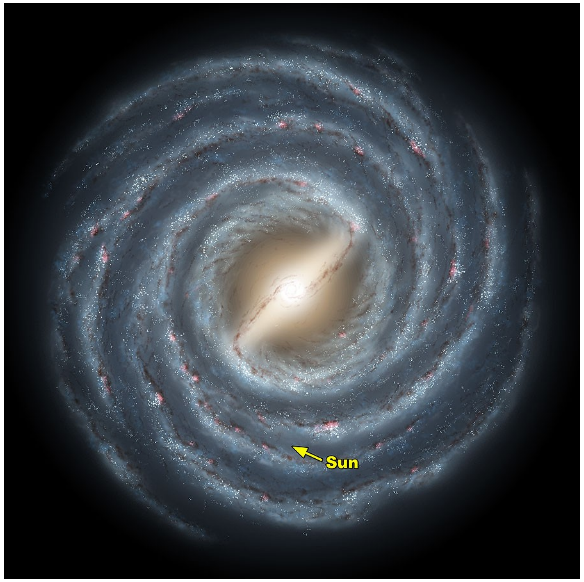
An age-metallicity relation can be traced

Stellar Populations

Pop I – Disk stars ; Pop II – Halo stars

Bulge stars break the classification. They are old and metal rich.

That's because the bulge is dense. More gas, more stars. Fast chemical enrichment.



From last class

Some astrochemistry jargon

Successive generations of stars enrich the Galaxy in metals

Star formation rate (SFR) is proportional to the density

An age-metallicity relation can be traced

Stellar Populations

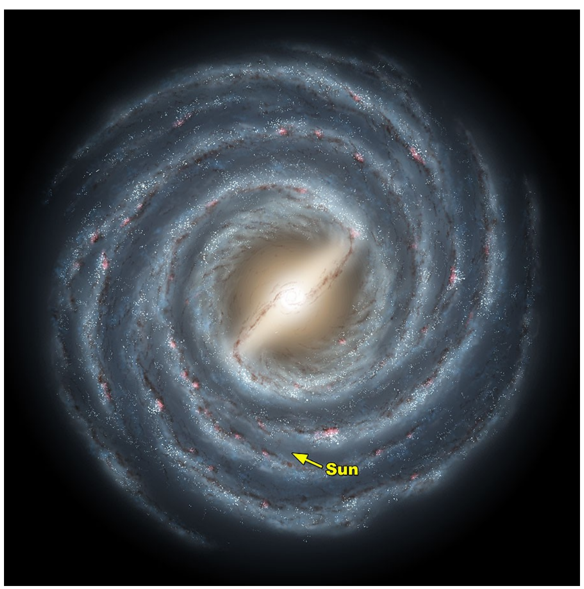
Central part (Bulge)* → *High gas density* → *Fast chemical enrichment

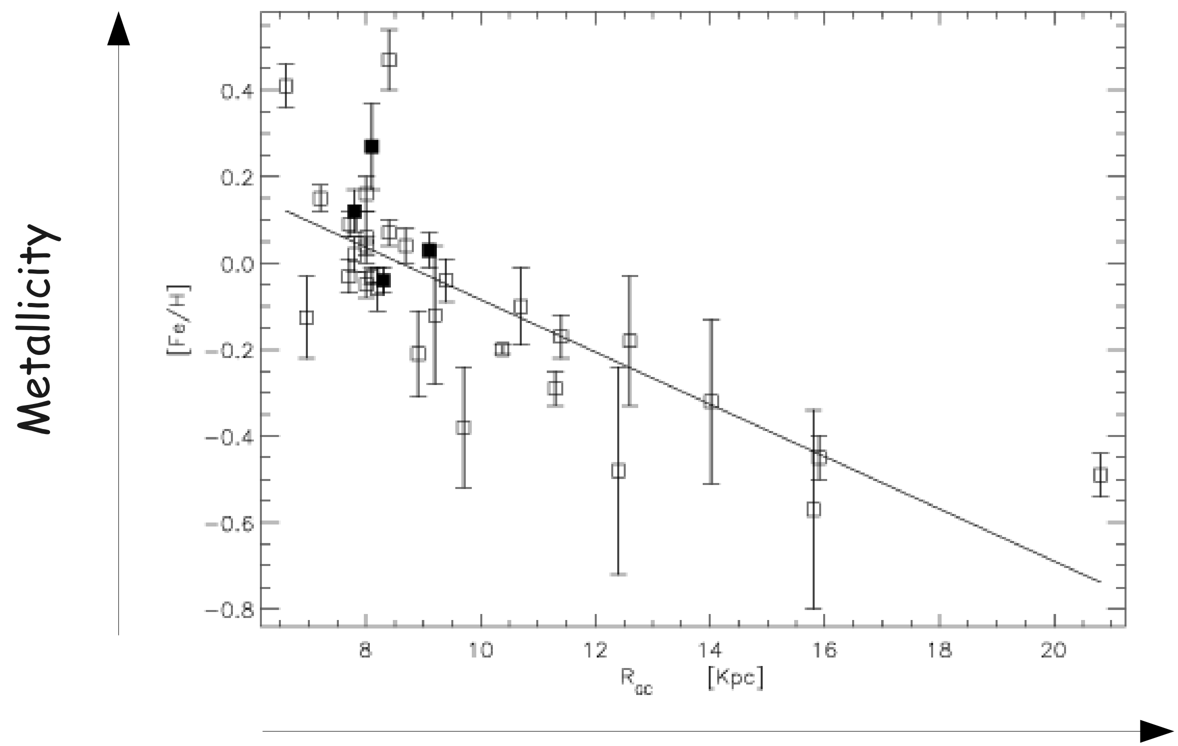
Outer disk* → Low gas density → *Slow chemical enrichment

Bulge stars break the classification. They are old and metal rich.

That's because the bulge is dense. More gas, more stars. Fast chemical enrichment.

The Galaxy has a radial metallicity gradient





Galactocentric distance

From last class

Pop I – metal rich, young

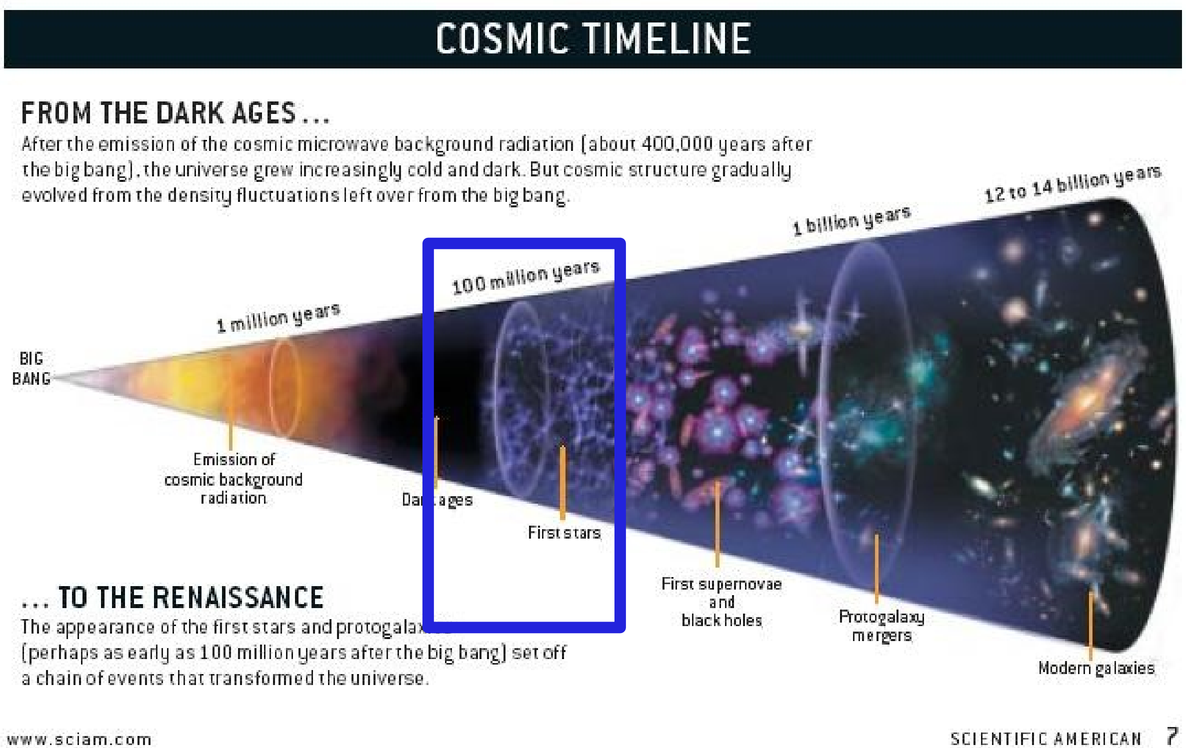
Pop II – metal poor, old

Pop III – metal free, extinct

That's because the bulge is dense. More gas, more stars. Fast chemical enrichment.

The Galaxy has a radial metallicity gradient

Population III stars – Metal free, the first stars



The First Stars

Purely Hydrogen and Helium, nothing else.

We cannot see them since they are gone.

But... the ***second*** generation of stars may still be around

From last class

Some astrochemistry jargon
Successive generations of stars enrich the Galaxy
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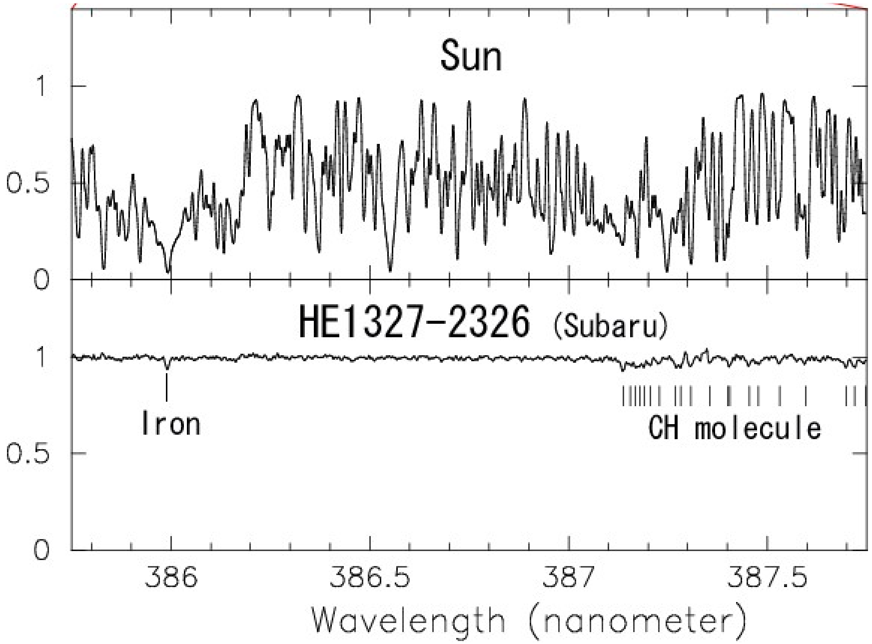
That's because the bulge is dense. More gas, more stars. Fast
The Galaxy has a radial metallicity gradient
Population III stars – Metal free, the first stars

HE 1327-2326: The most metal poor star ever found



[Fe/H] = -5.2

300,000 times less Iron than the Sun

Outline

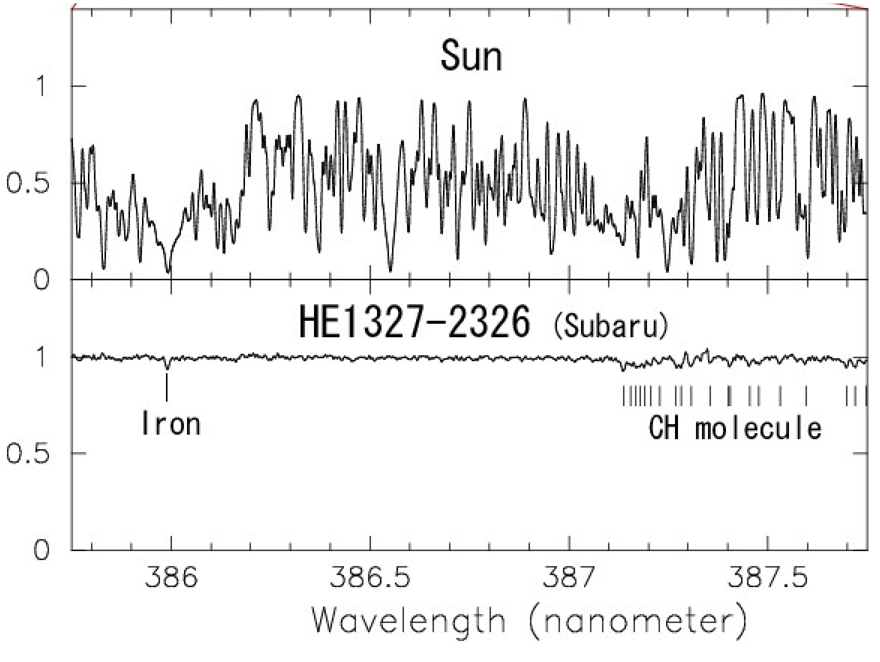
- Supernovae Types Ia and II
- Binaries
  - Types of binaries
    - Visual, astrometric, eclipsing, spectroscopic
    - Detached, semi-detached, contact
  - Mass determination
  - Hidden companions

- The Interstellar Medium
  - Extinction and Reddening
  - The 21cm hydrogen line
  - Interstellar Clouds
    - Absorption Nebulae
    - Reflection Nebulae
    - Emission Nebulae

Very metal poor stars – HE 1327-2326

[Fe/H] = -5.2
300,000 times less Iron than the Sun

Yet, **[C/H] = -1.0**
Only 10 times less Carbon



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Why?

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300,000 times less Iron than the Sun

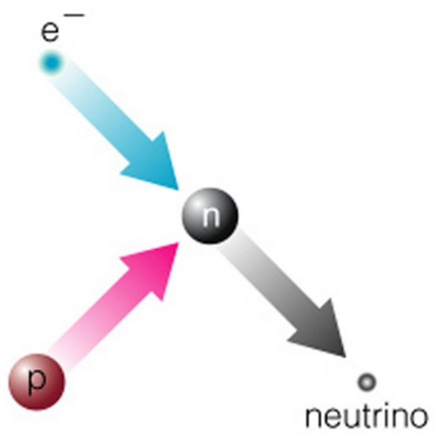
Yet, **[C/H] = -1.0**
Only 10 times less Carbon

Why?

There must be a delay between Carbon production and Iron production in the Galaxy

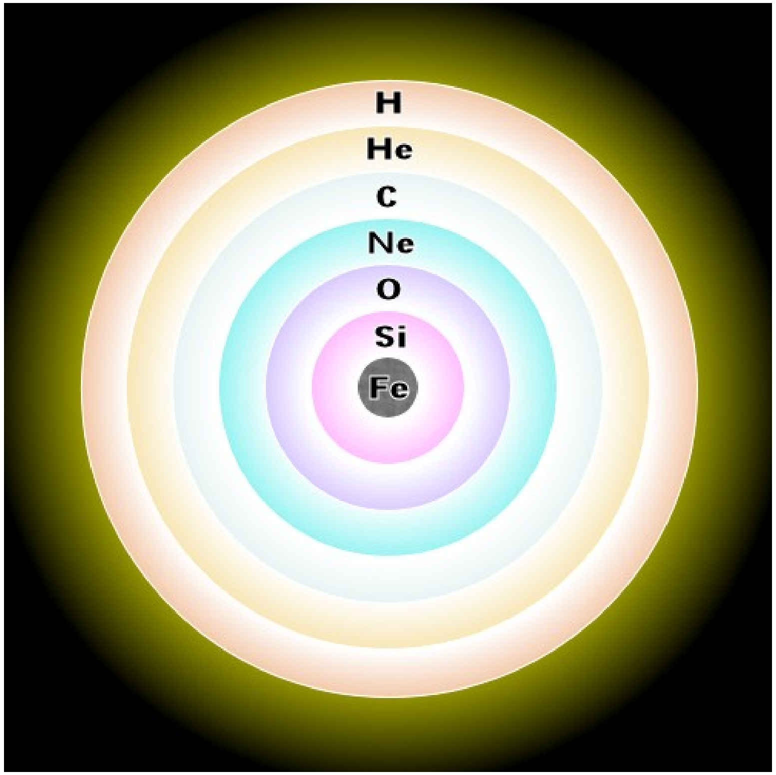
Core-Collapse (Type II) Supernova

The Iron is in the core,
that undergoes neutronization



The iron is (almost) completely lost!!

Ejecta of Type II SN is carbon-rich but iron poor.



Onion-layer structure

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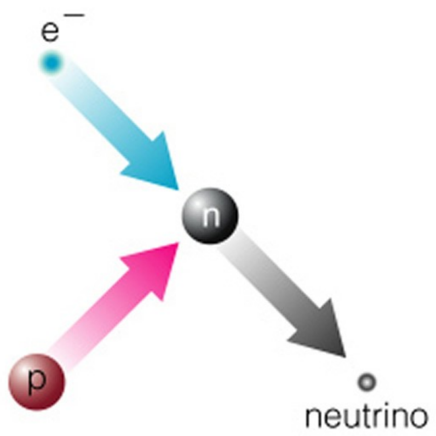

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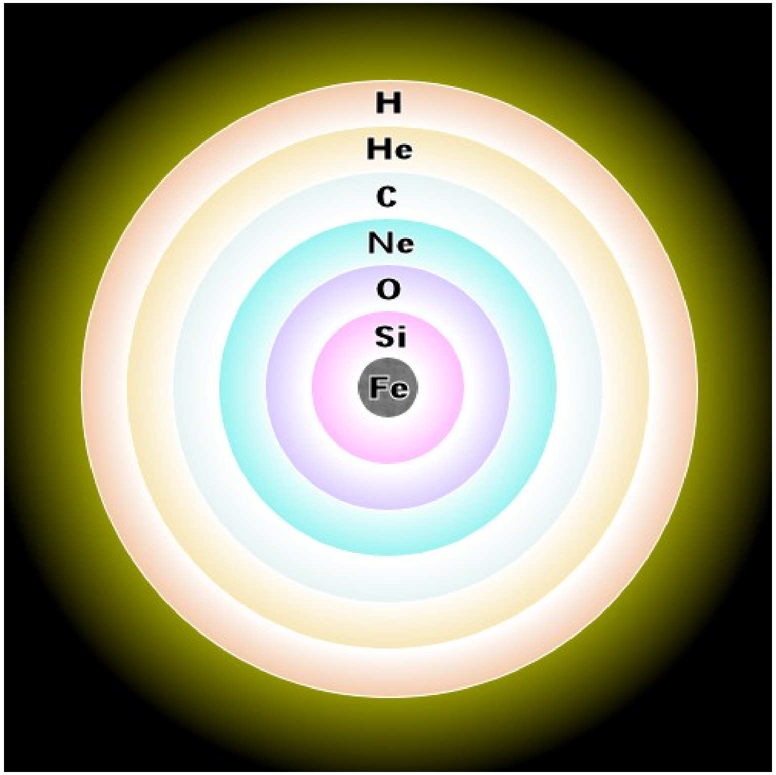
Ejecta of Type II SN is carbon-rich but iron poor.

Most of the iron in the Galaxy comes from ***Type Ia Supernovae***



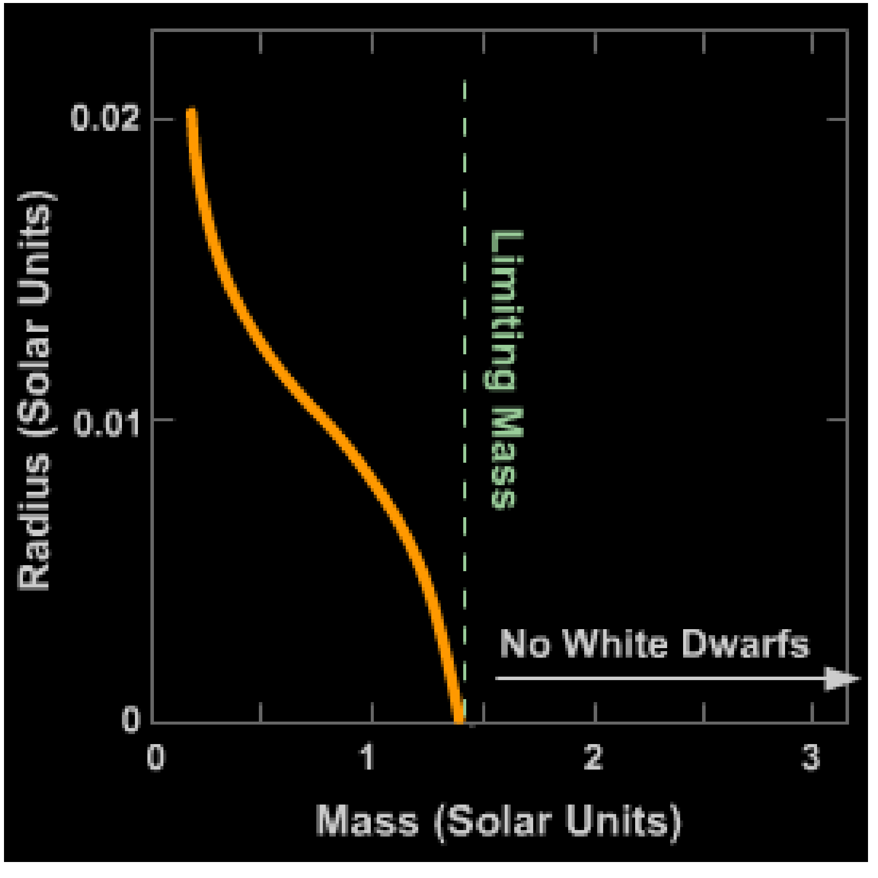
Onion-layer structure

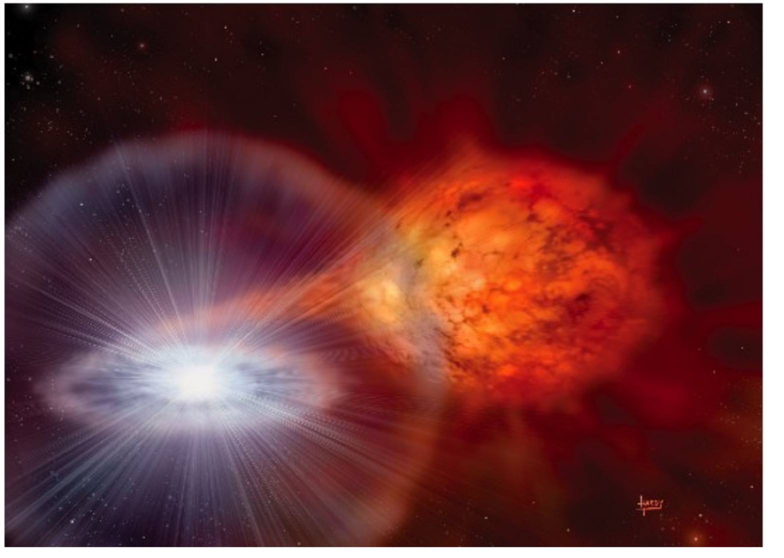
The other Supernovae

Supernovae Type Ia (White dwarf binary Supernovae)

White dwarf + Ordinary star

Steady and slow accretion onto a denegerate C-O white dwarf below the **Chandrasekhar limit**





Mass-Radius relationship for degenerate matter.

Beyond 1.4 $M_{\odot}$, electron degeneracy cannot hold against gravity

The other Supernovae

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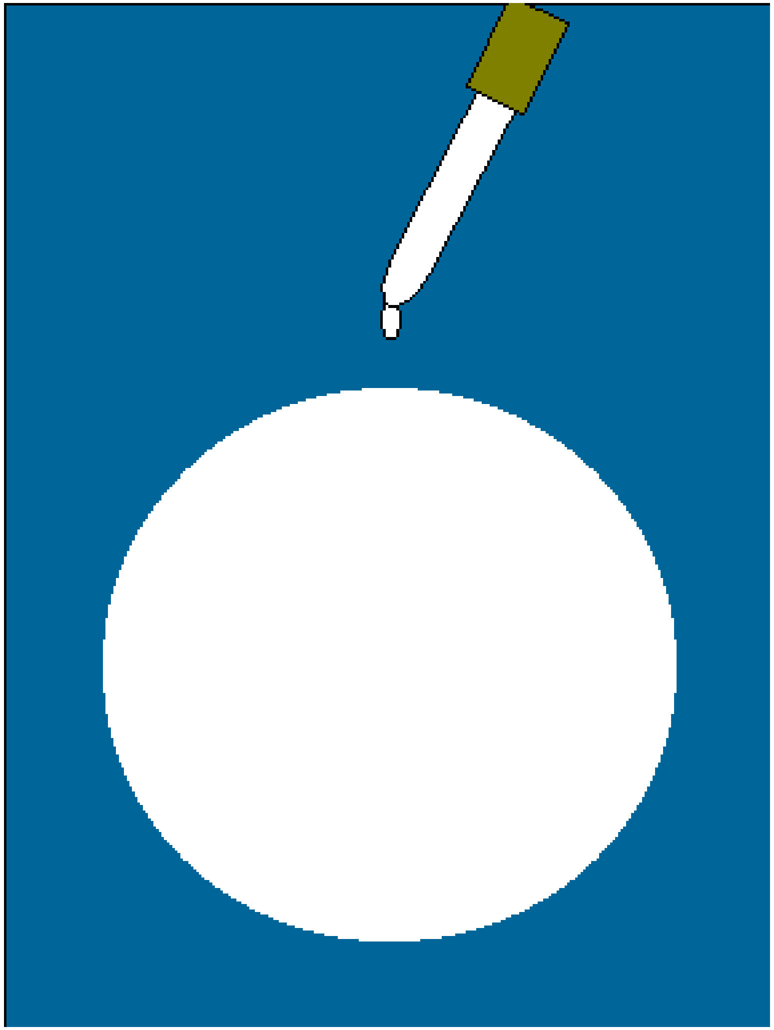
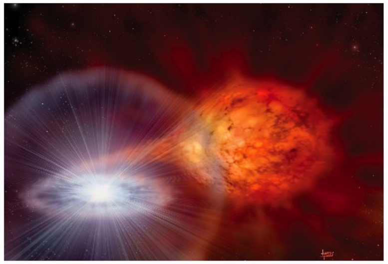
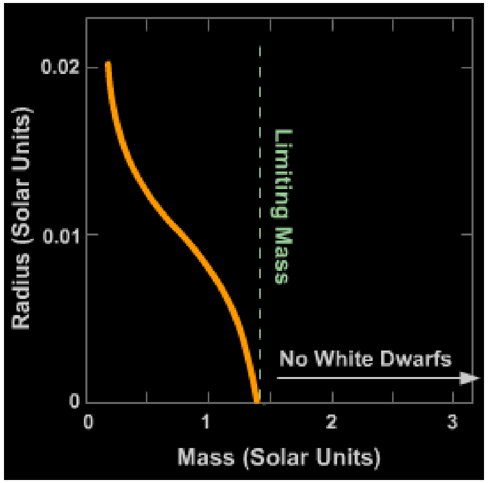




Chandrasekhar limit



The other Supernovae

Supernovae type Ia (White dwarf binary Supernovae)

White dwarf + Ordinary star

When the limit is achieved, the degenerate core implodes and achieves **carbon fusion** temperatures

This deflagrates a thermonuclear flame.

Carbon Detonation

The other Supernovae

Supernovae type Ia (White dwarf binary Supernovae)

White dwarf + Ordinary star

When the limit is achieved, the degenerate core implodes and achieves **carbon fusion** temperatures

This deflagrates a thermonuclear flame.

Carbon Detonation

So powerful that **no remnant** is left.

If the **Black Hole** is **gravity's ultimate victory**,

the **Carbon detonation** is **pressure's ultimate victory**!

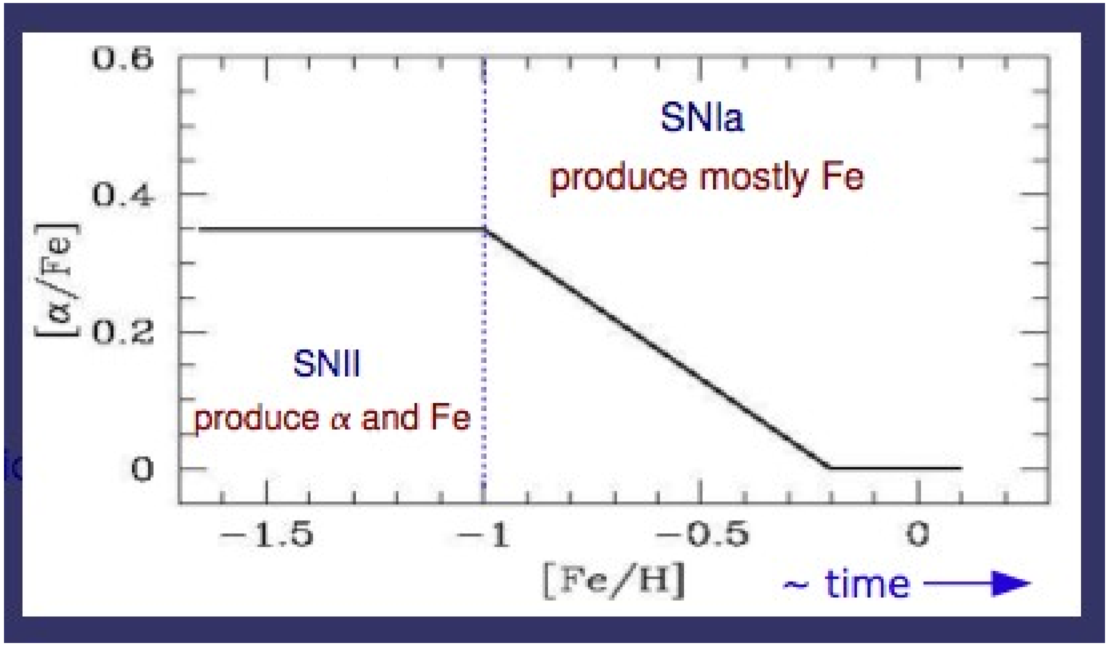
The other Supernovae

Supernovae Type II - **Core collapse of a massive star** **INSTANTANEOUS (10 Myr)**

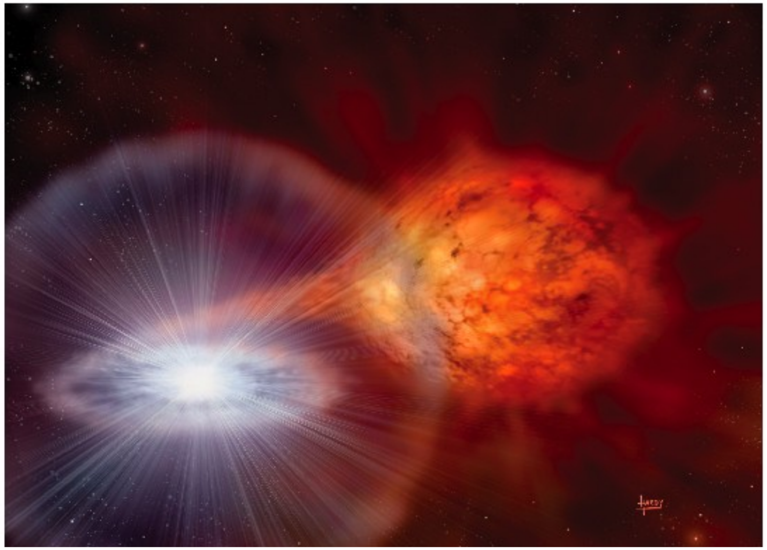
Supernovae Type Ia - **White dwarf binary** **GOTTA WAIT SOME BILLION YRS**

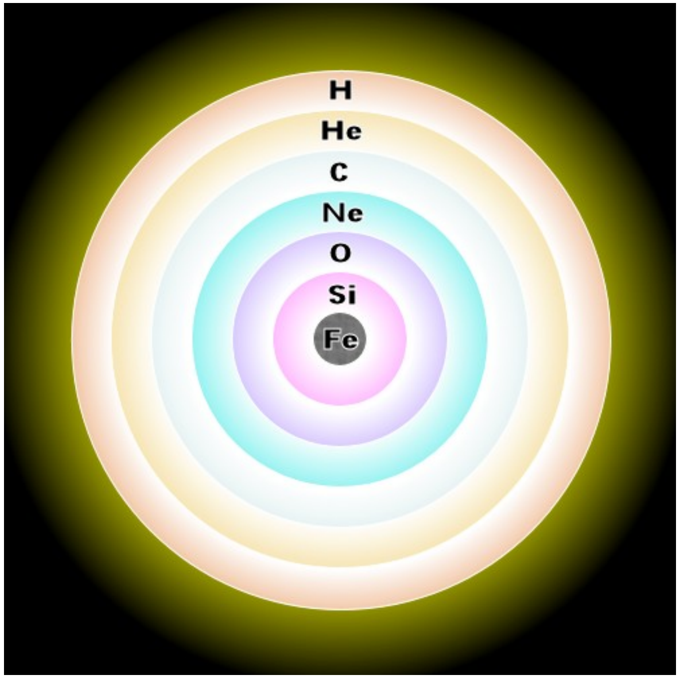
A galaxy is first enriched in alpha elements (from Type II SN)

Iron comes later (from Type Ia SN)



SNIa as standard candles



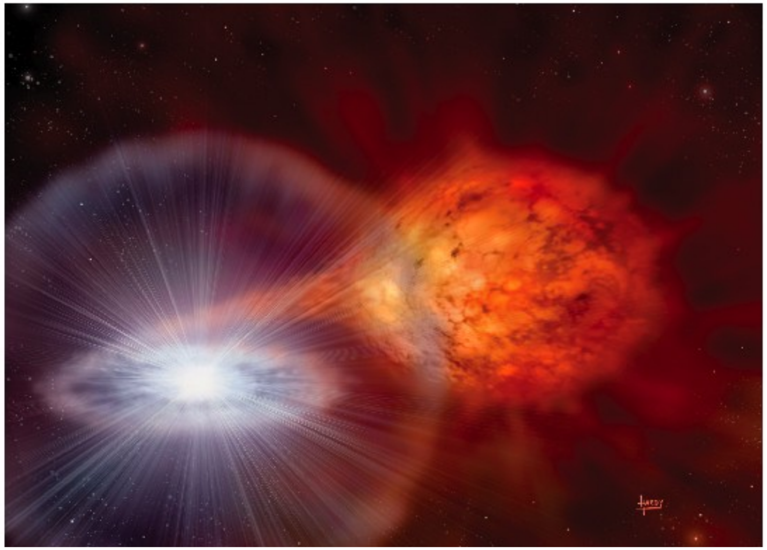


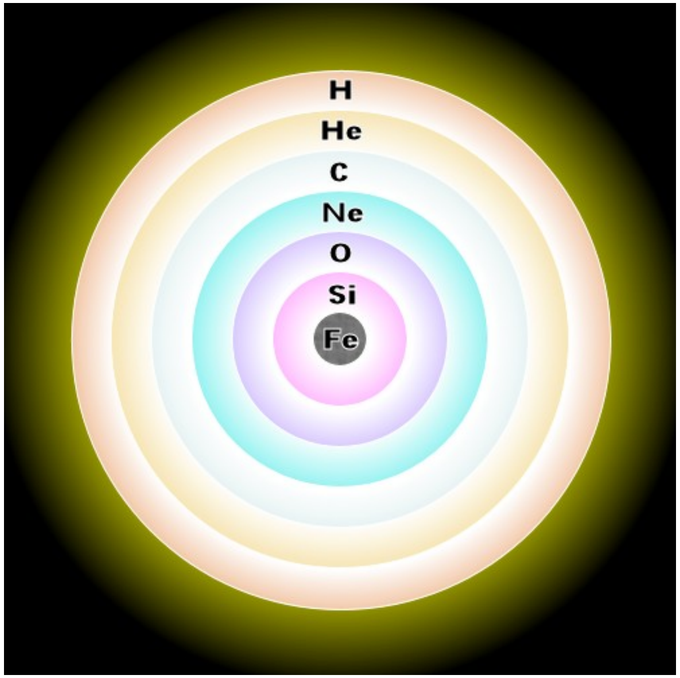
Both SNIa and SNII detonate when the core reaches the Chandrasekhar limit

So they both have the same energy – 10^{51} erg

Why is SNIa a standard candle, and SNII is not?

SNIa as standard candles





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So they both have the same energy – 10^{51} erg

Why is SNIa a standard candle, and SNII is not?

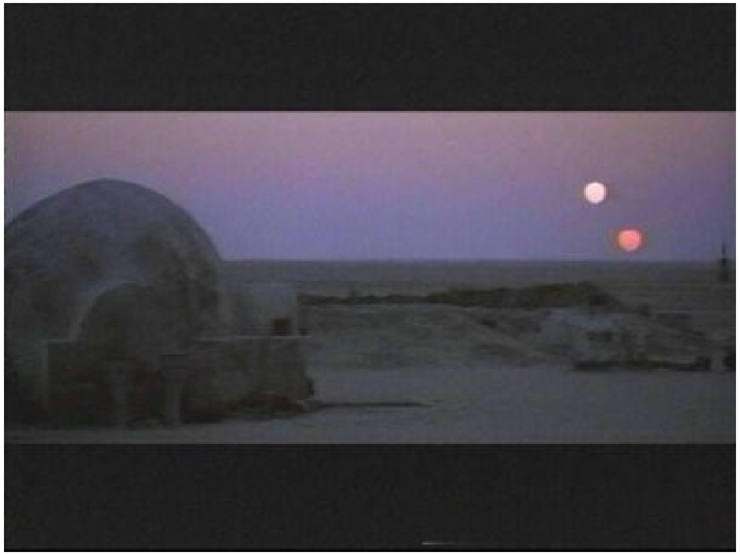
The envelope!!

SNII progenitor has a huge envelope that scatters some of the light

SNIa progenitor is a naked core

Binary and multiple stars

Most stars are found in multiple systems
Isolated (single) stars like the Sun are rare!!



Types of Binary stars

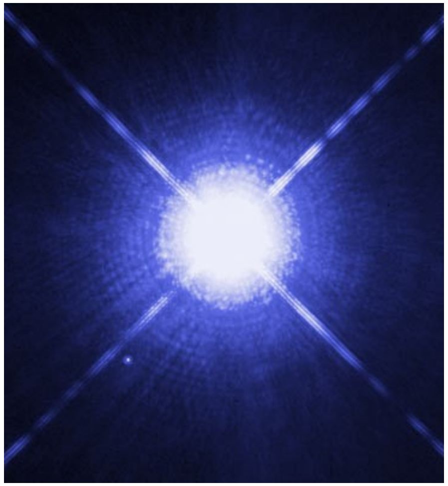
Visual Binaries Astrometric binaries	**WIDE**
Spectroscopic binaries Eclipsing binaries	**CLOSE**

Wide
(long orbital periods – 100-1000 yrs)

Close
(short orbital periods – days)

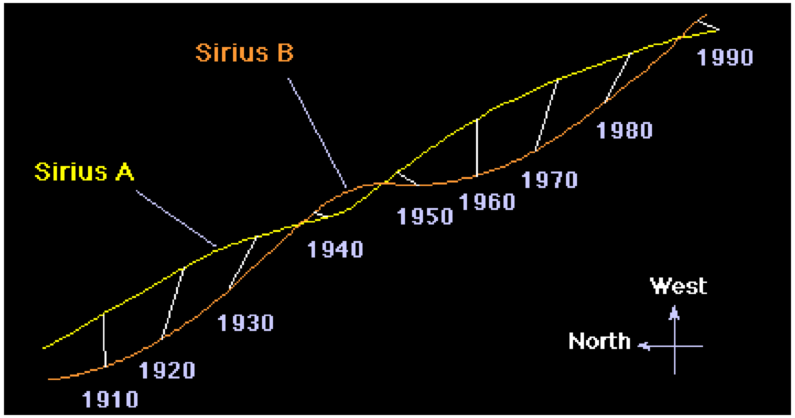
Visual Binary

We see the two stars



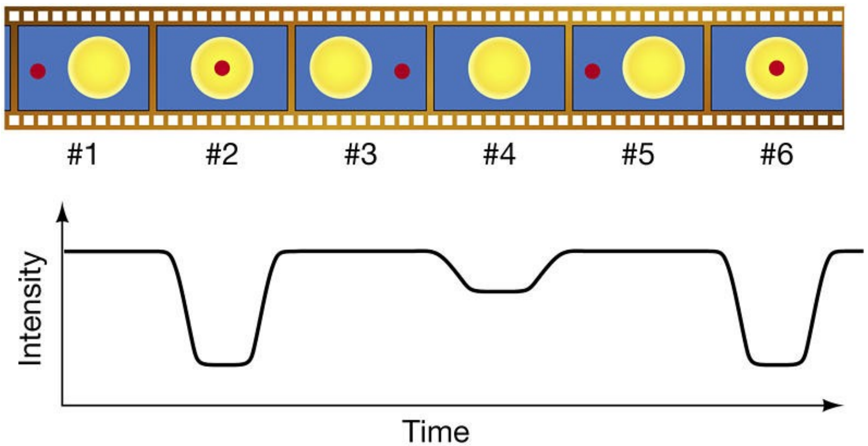
Astrometric Binary

One of the stars is too faint to be seen
But the visible star wobbles



Eclipsing Binary

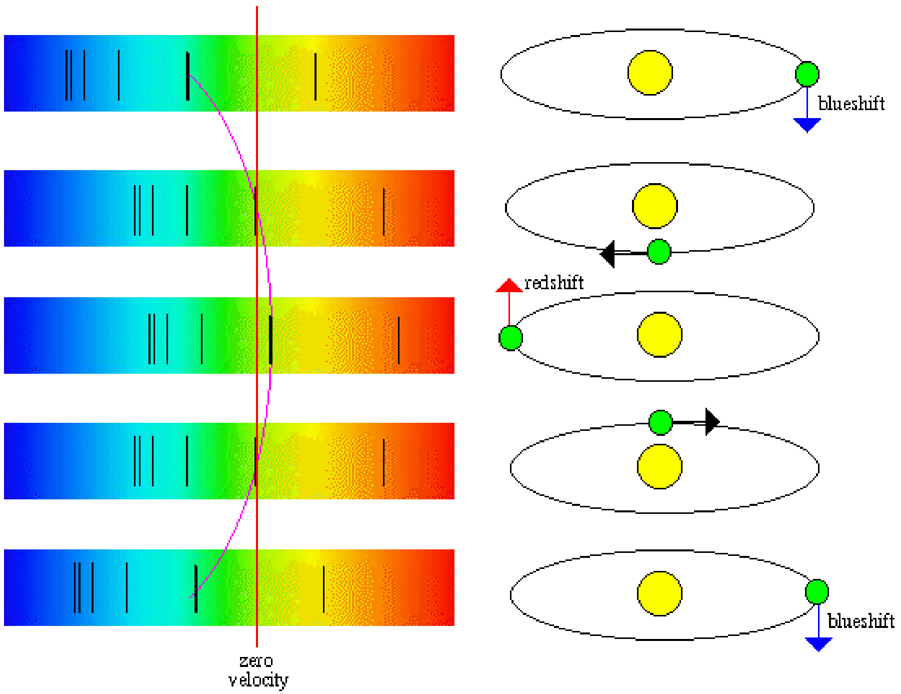
The two stars periodically eclipse each other



Spectroscopic Binary

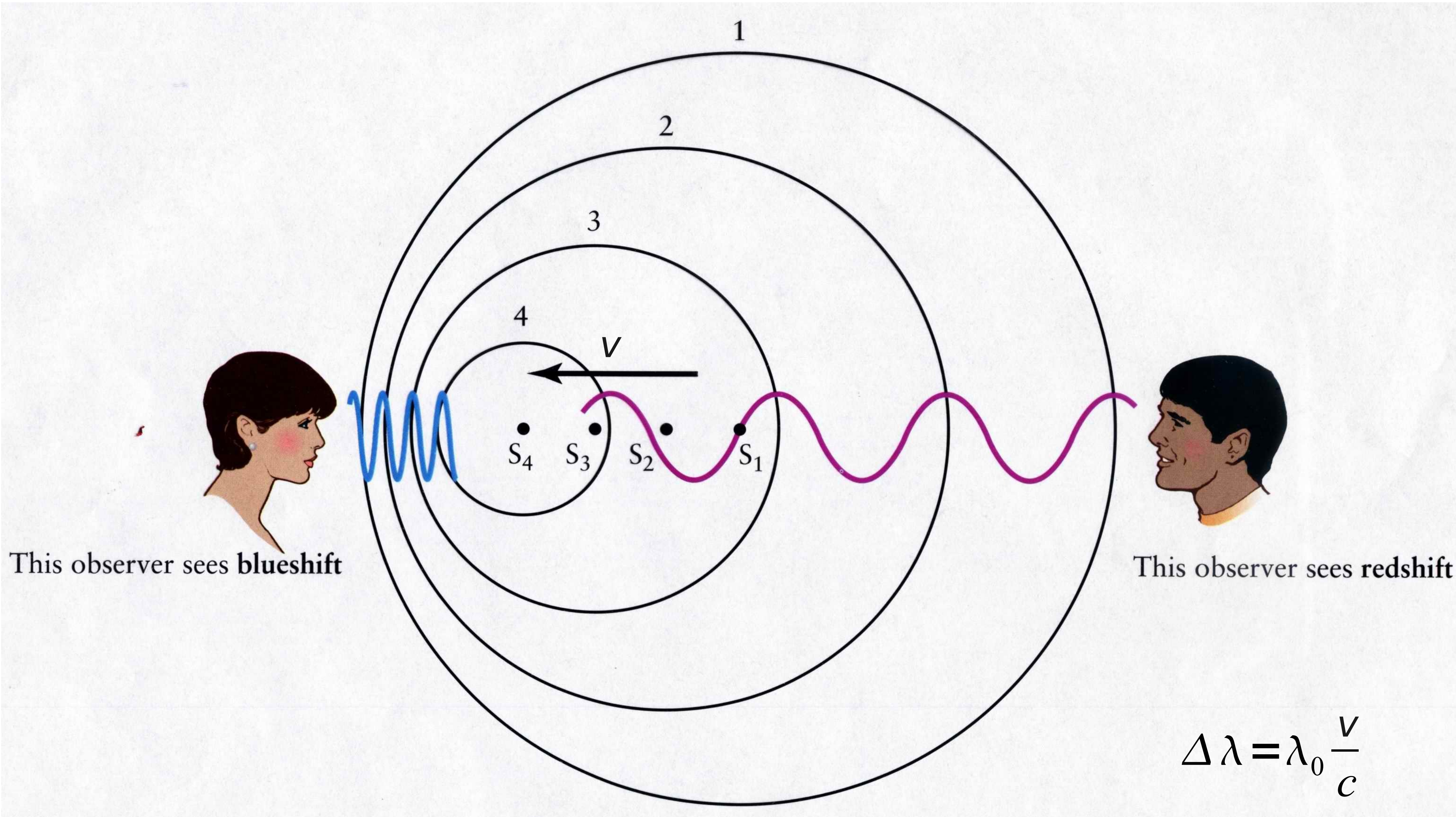
Spectroscopic Binary

A spectroscopic binary is where there is evidence of orbital motion in the spectral features due to the Doppler effect

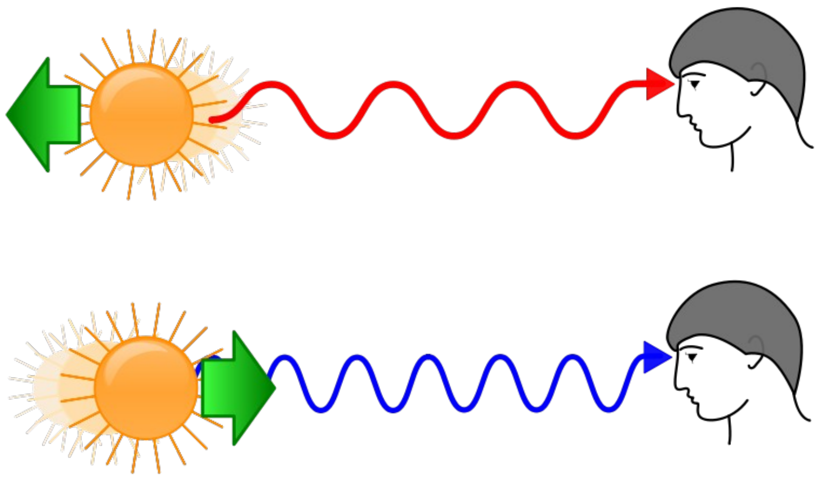


The Doppler effect

Change in wavelength caused by the motion of the source



$$\Delta \lambda = \lambda_0 \frac{v}{c}$$



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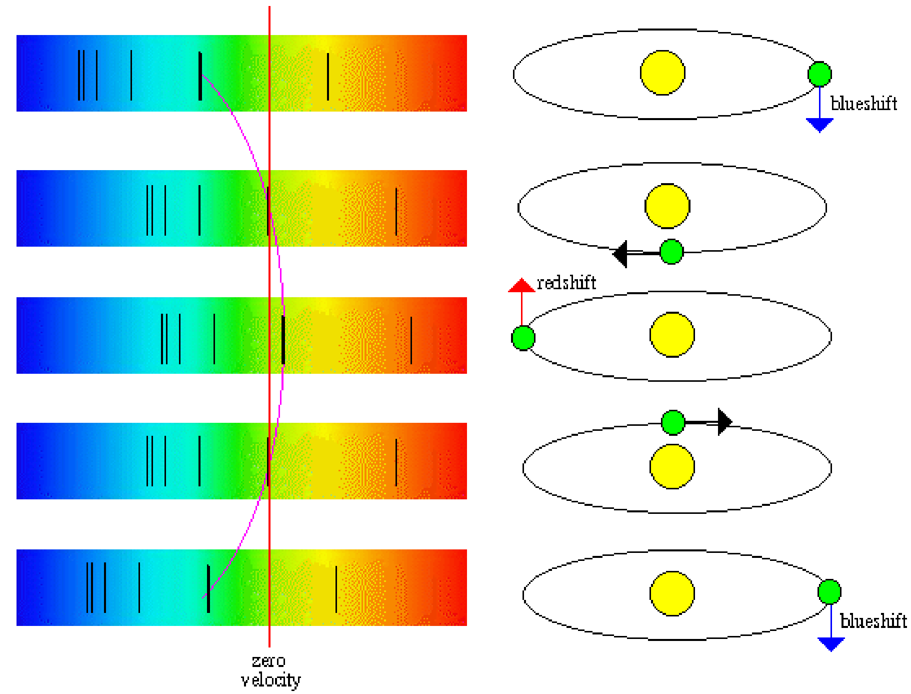
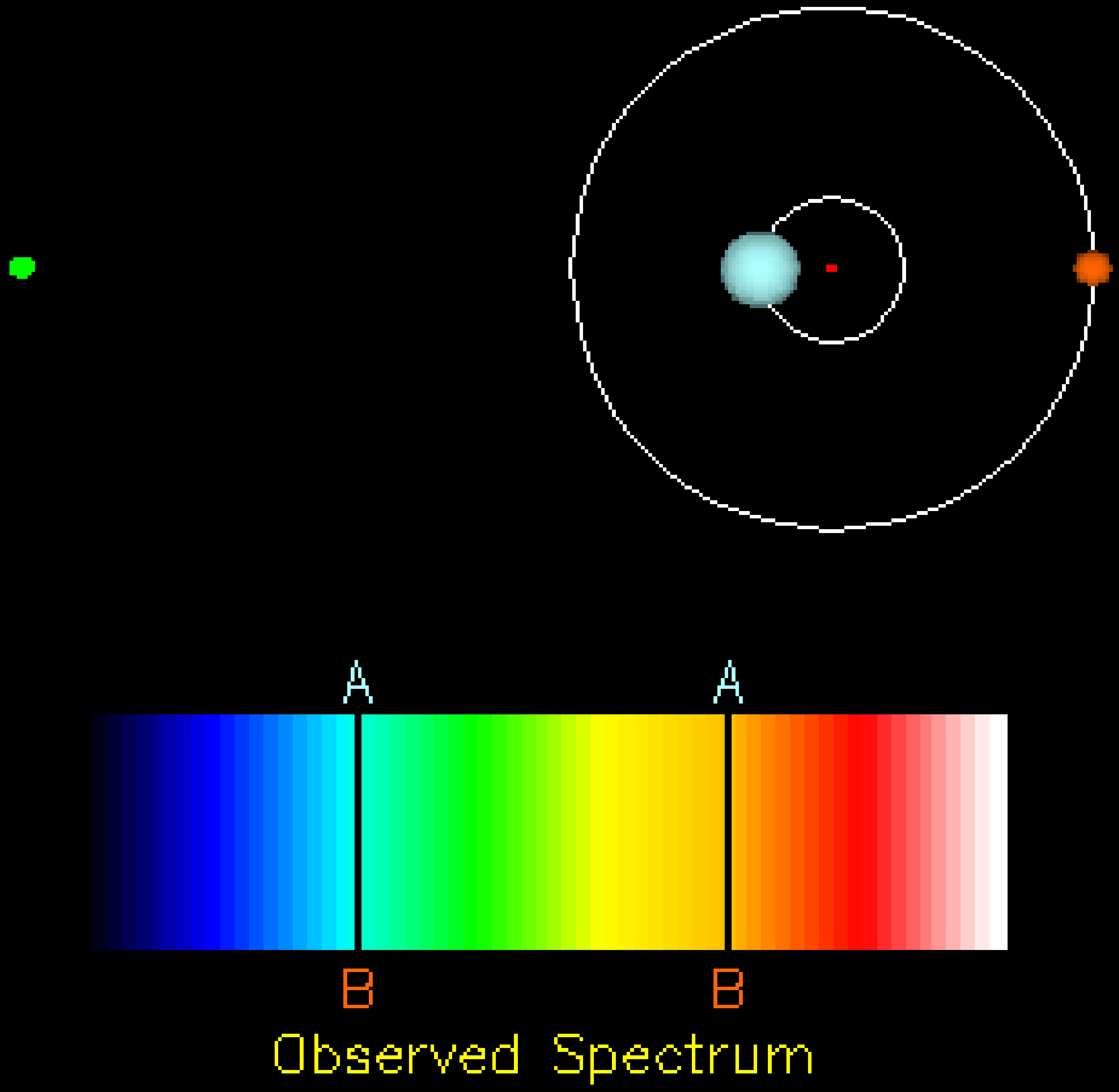
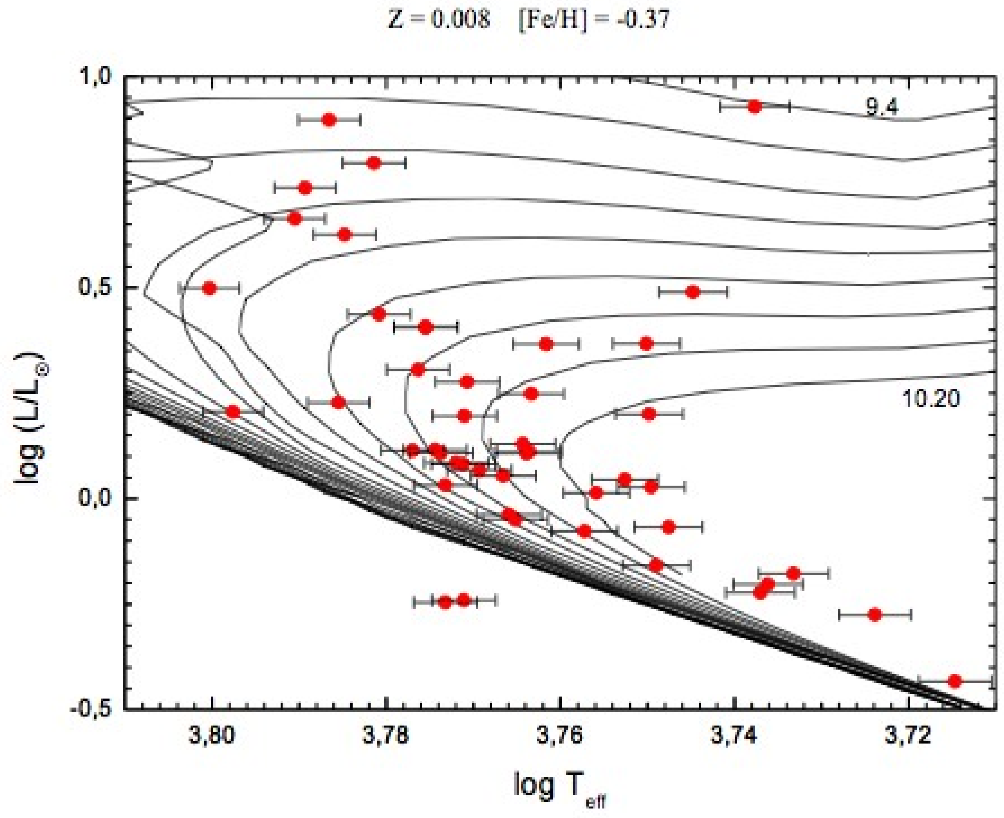



A
A
B
B
Observed Spectrum

Mass determination by evolutionary tracks



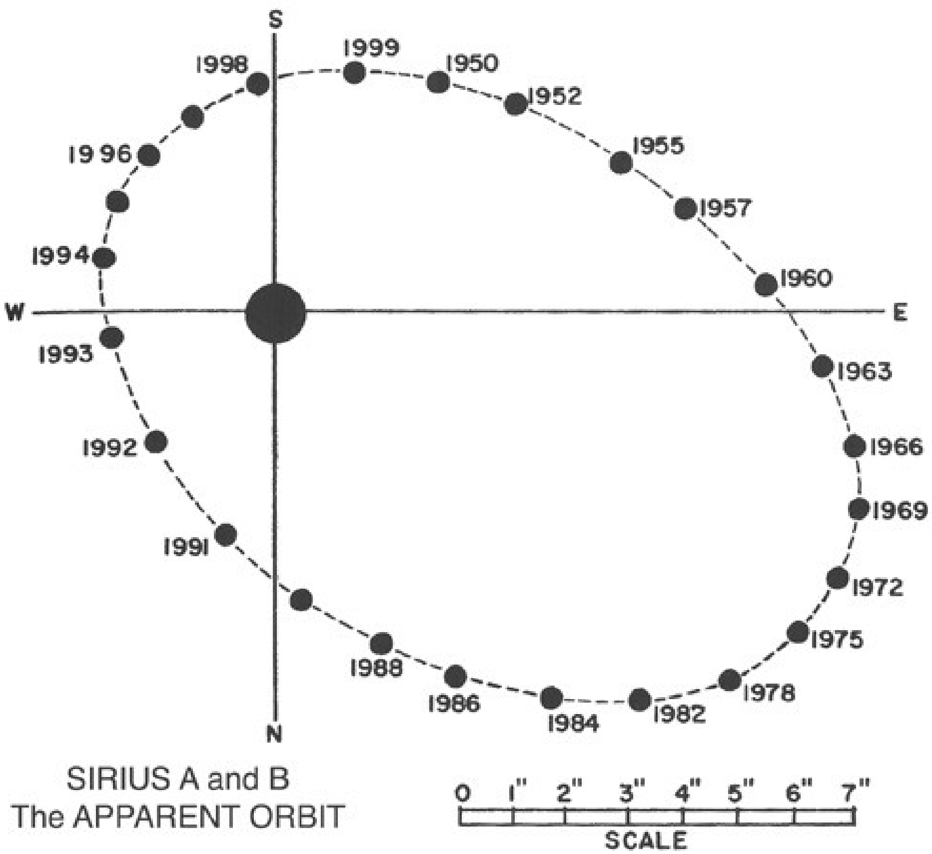
Measure a star's
luminosity and temperature,
compare with
model evolutionary tracks

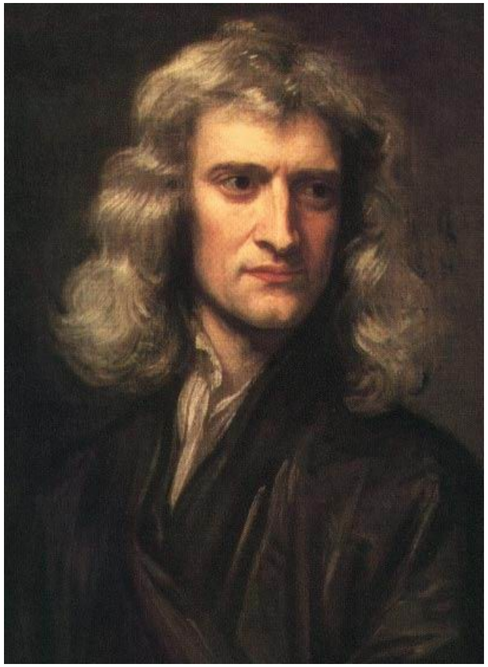
Errors in luminosity, temperature

Plus, models are ***not*** perfect

Can easily add up to a large error in mass

Mass determination by orbits



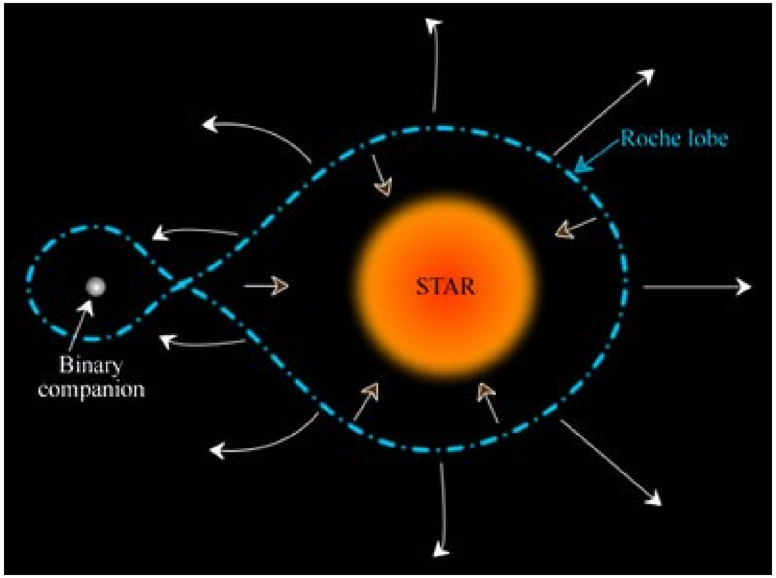


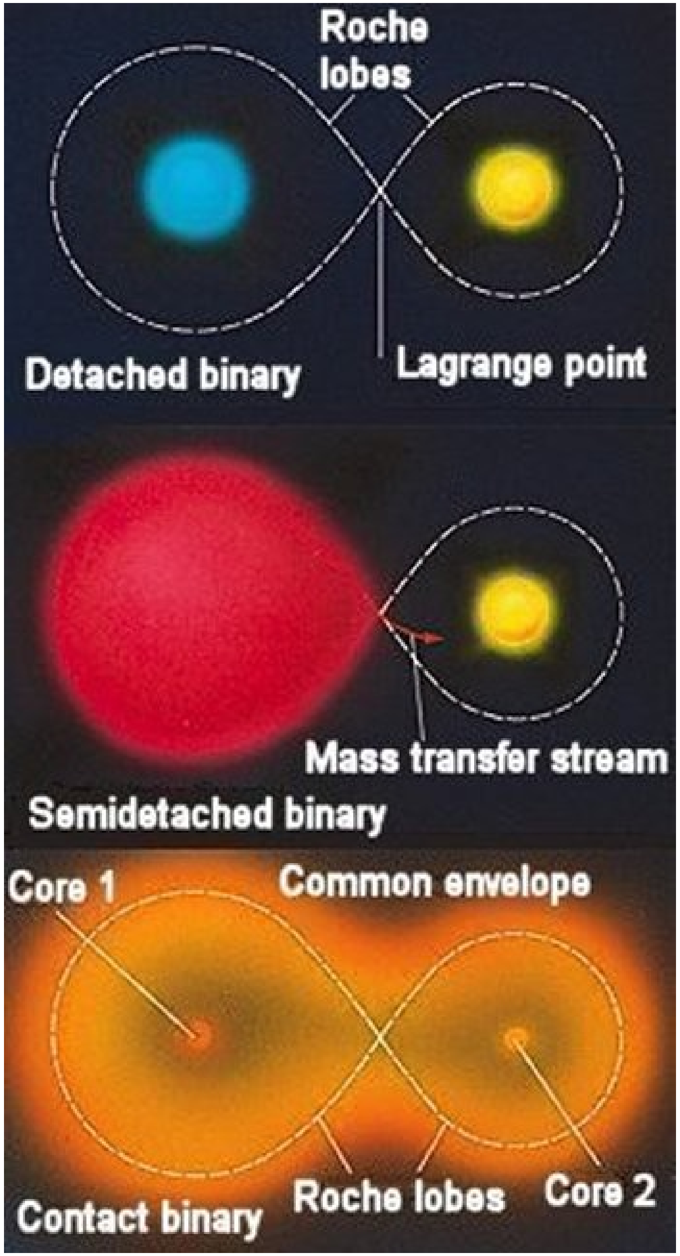
$$F = -\frac{G\,M\,m}{r^2}$$

Alpha Centauri Masses	
By orbital solution	1.105 +/- 0.007, 0.934+/-0.006
By evolutionary tracks	1.13 +/ 0.01, 0.89 +/- 0.05

← *10x more accurate*

Classification by interaction



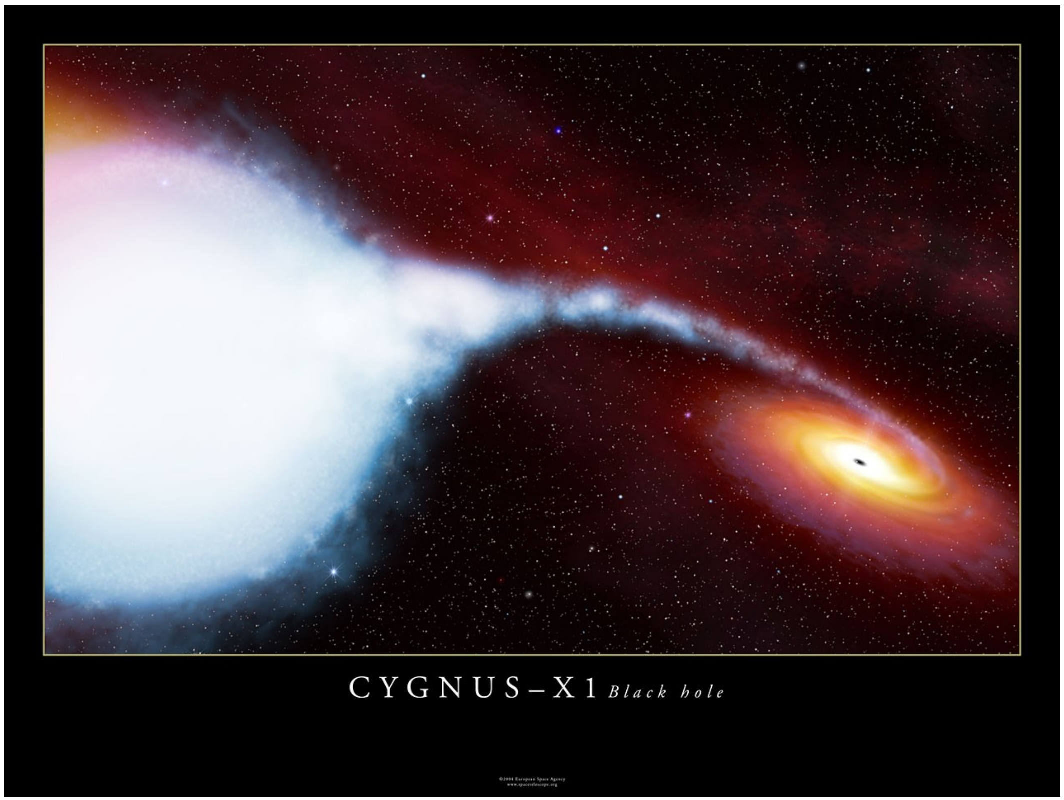


Roche Lobe
Gravitational region of influence

Lagrange Point
Equilibrium point where the
gravity from both stars cancel each other

Hidden Companions

Hidden = Low Luminosity



Cygnus X1

Blue star orbiting an unseen object

From the orbit, the compact object must have a mass of **8 Msun**

Too massive to be a white dwarf or neutron star.

It's a Black Hole!!

The compact object emits ***X-rays*** from a region smaller than 0.1AU

Accretion disk around the black hole!!

Friction heats up the gas to ***1 million K***
Very hot stuff emits X-rays

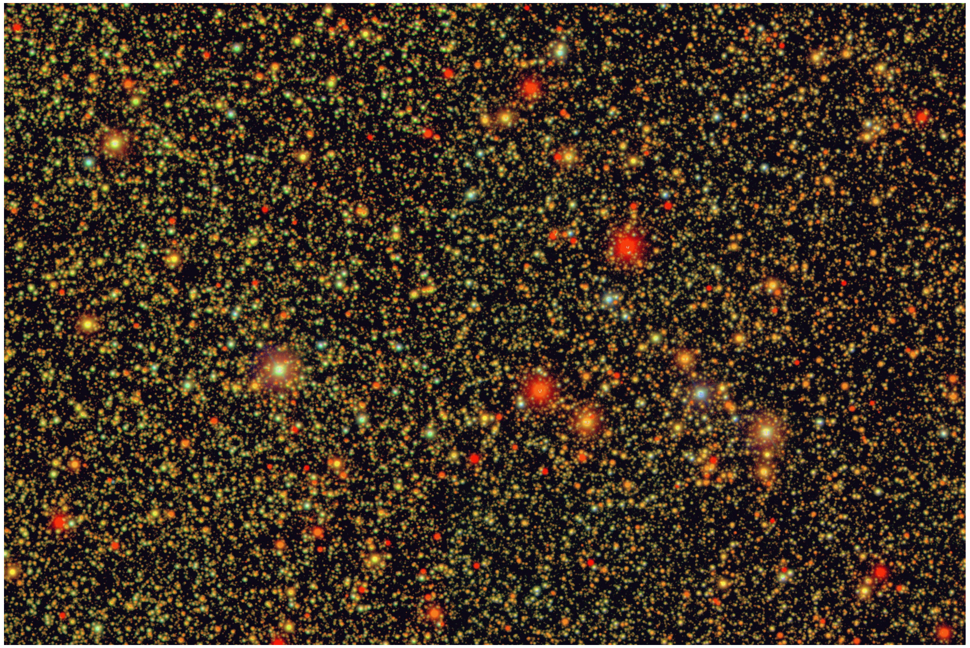
Stellar Extinction

A foggy day

Stellar Extinction

A foggy day

A foggy place

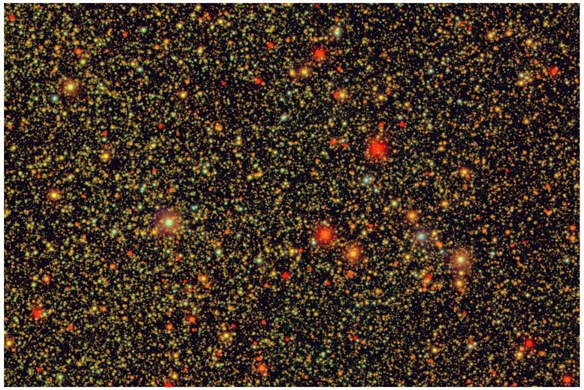


Starlight is extincted by dust in the Interstellar Medium

Stellar Extinction

Starlight is extincted by dust in the interstellar medium

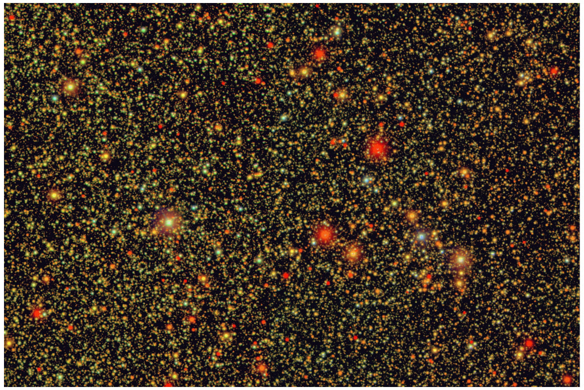
$$V - M_V = -5 + 5\log d$$



Stellar Extinction

Starlight is extincted by dust in the interstellar medium

$$V - M_V = -5 + 5\log d + A_V$$



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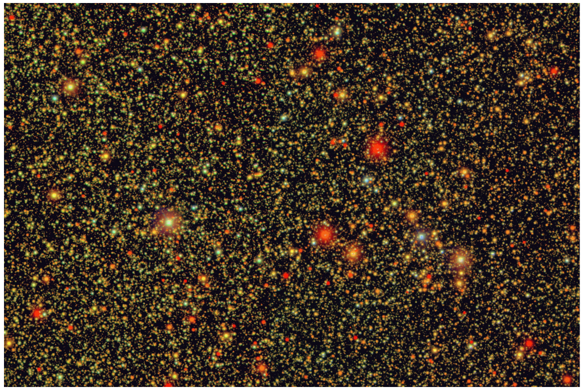
Extinction!!



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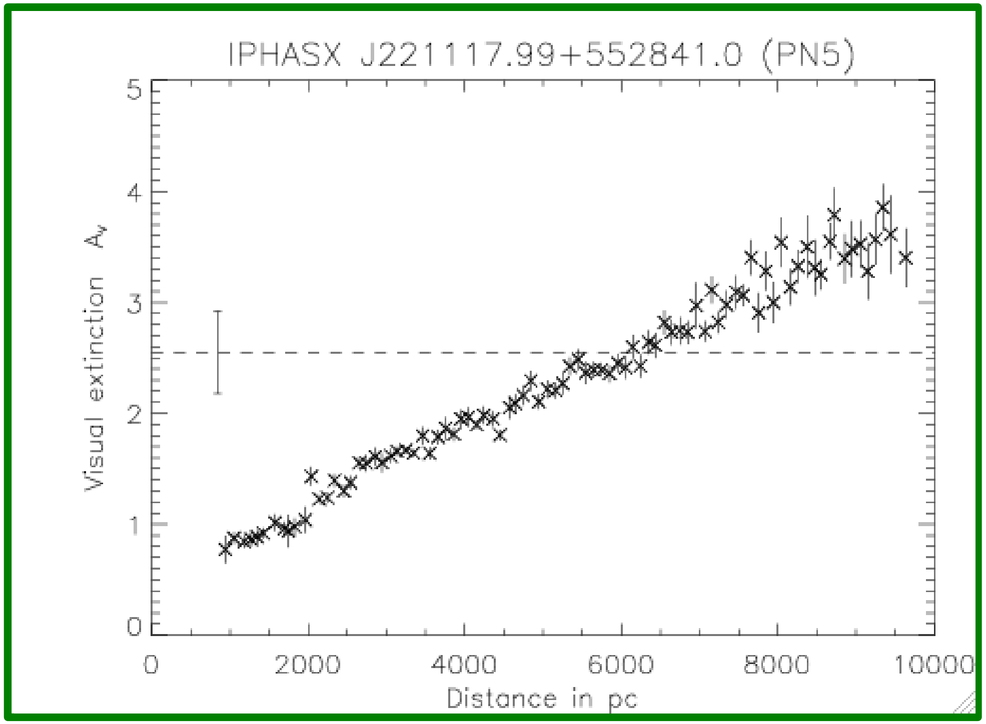
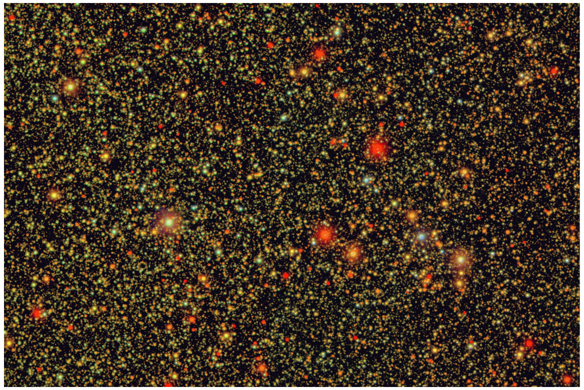
Extinction!!

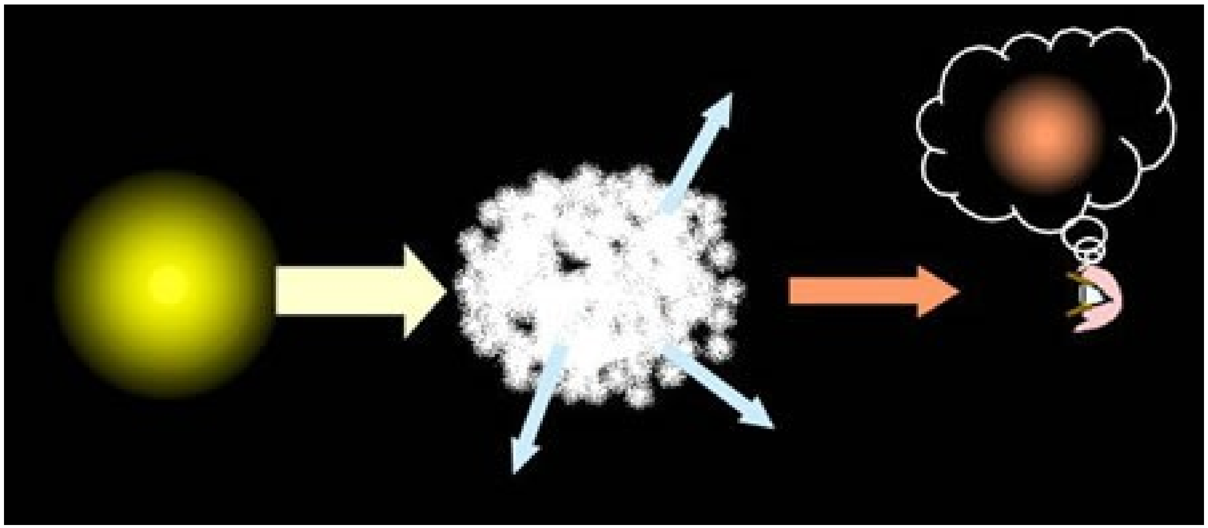




Just as in a foggy day, the amount of ***extinction*** depends on the ***distance***

Reddening

The extinction depends on wavelength
Dust absorbs and scatters more blue light than red light



Starlight is "de-blued"

When not totally extincted, the star will look ***reddened***

B, V, I

We speak of a ***color excess, E(B-V)***

$$B-V = (B-V)_0 + E(B-V)$$

$$A_V = R_V\, E(B-V)$$

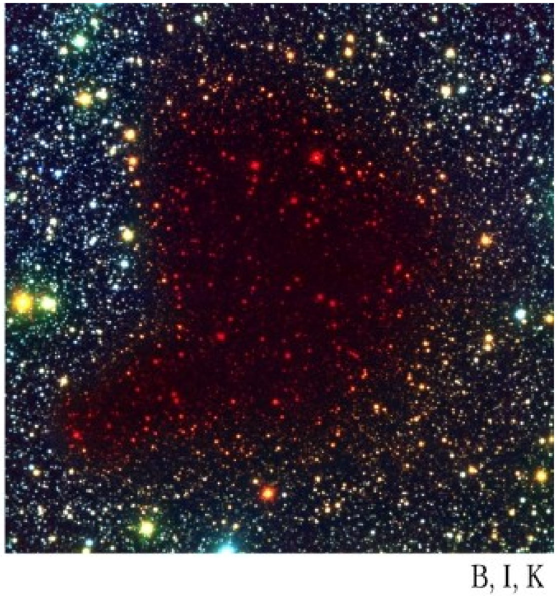
$$R_V \sim 3.1$$

Avoid extinction. Go infrared.

Dust more efficiently absorbs and scatters bluer wavelengths

A lot of extinction in ultraviolet and optical
Little extinction in infrared

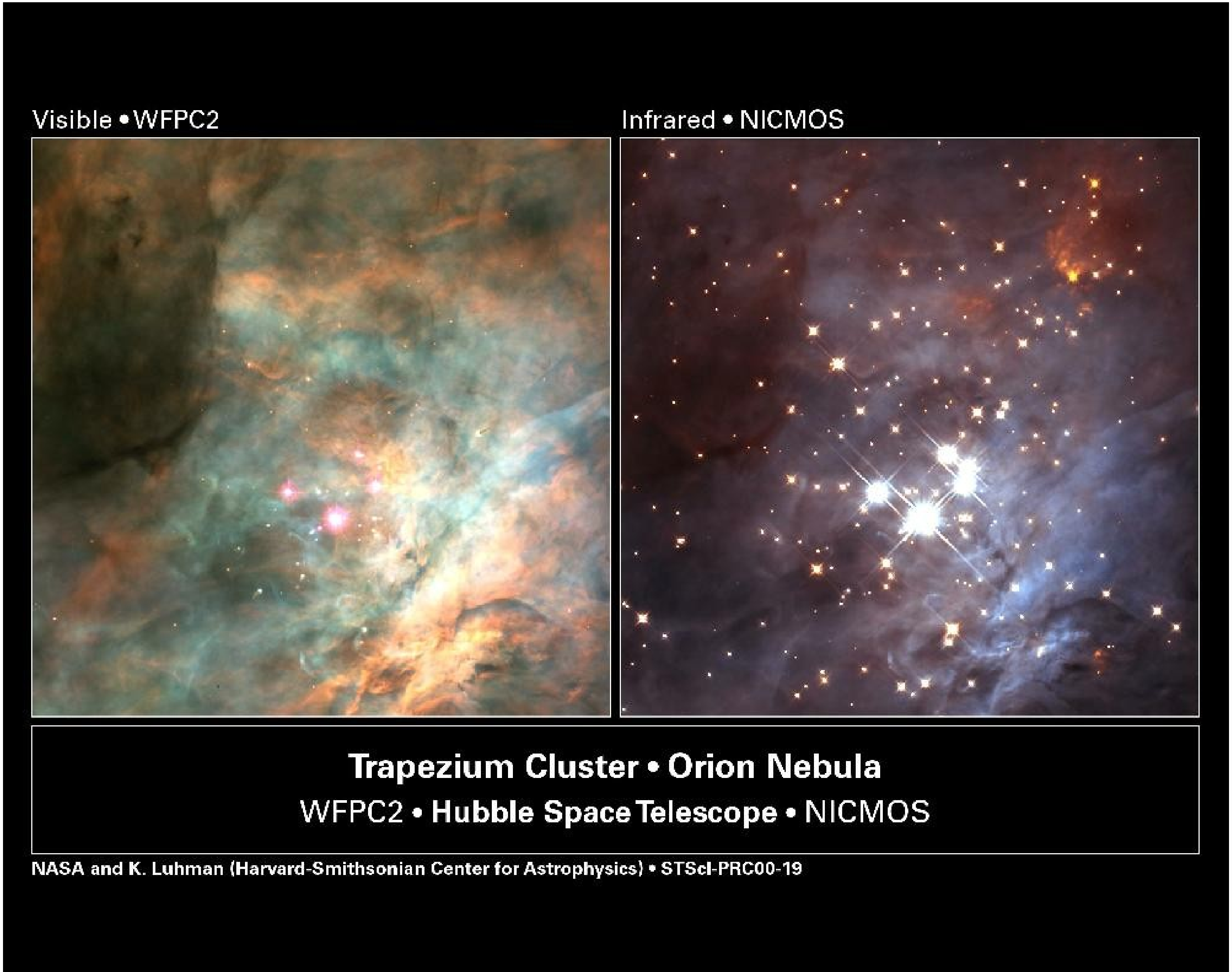
Go to infrared to see through the dust!!



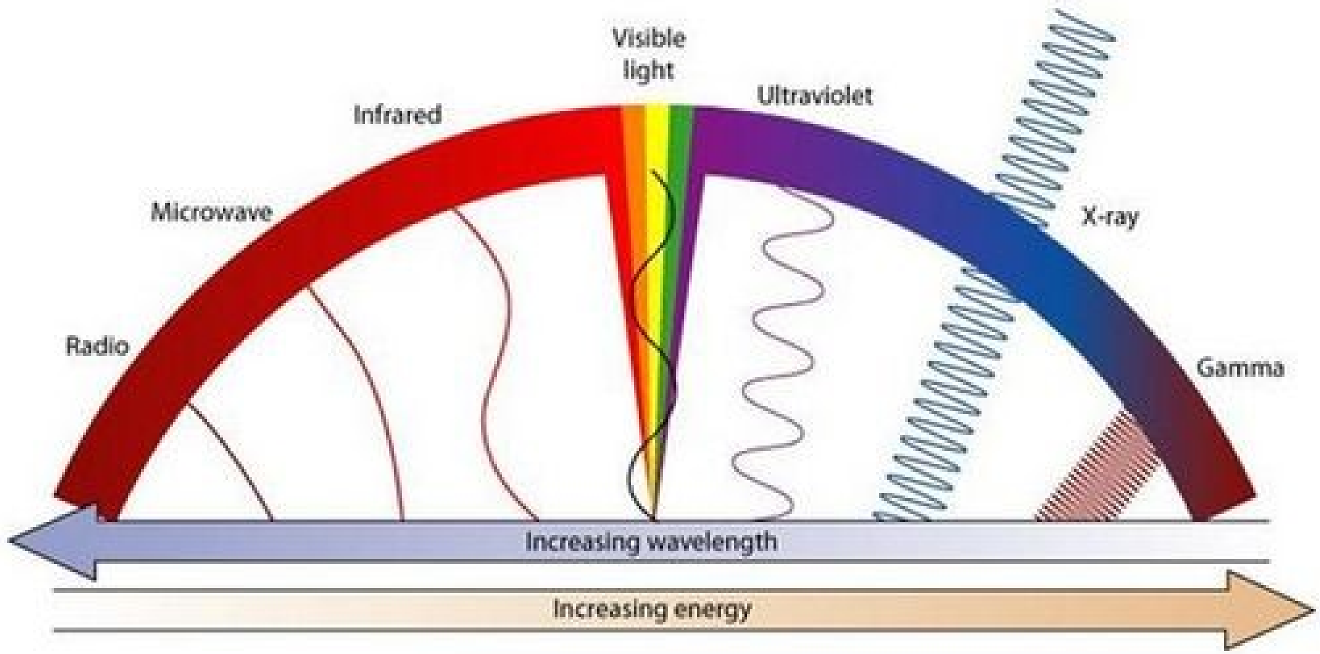
B V I
image

B I K
image

Avoid extinction. Go infrared.



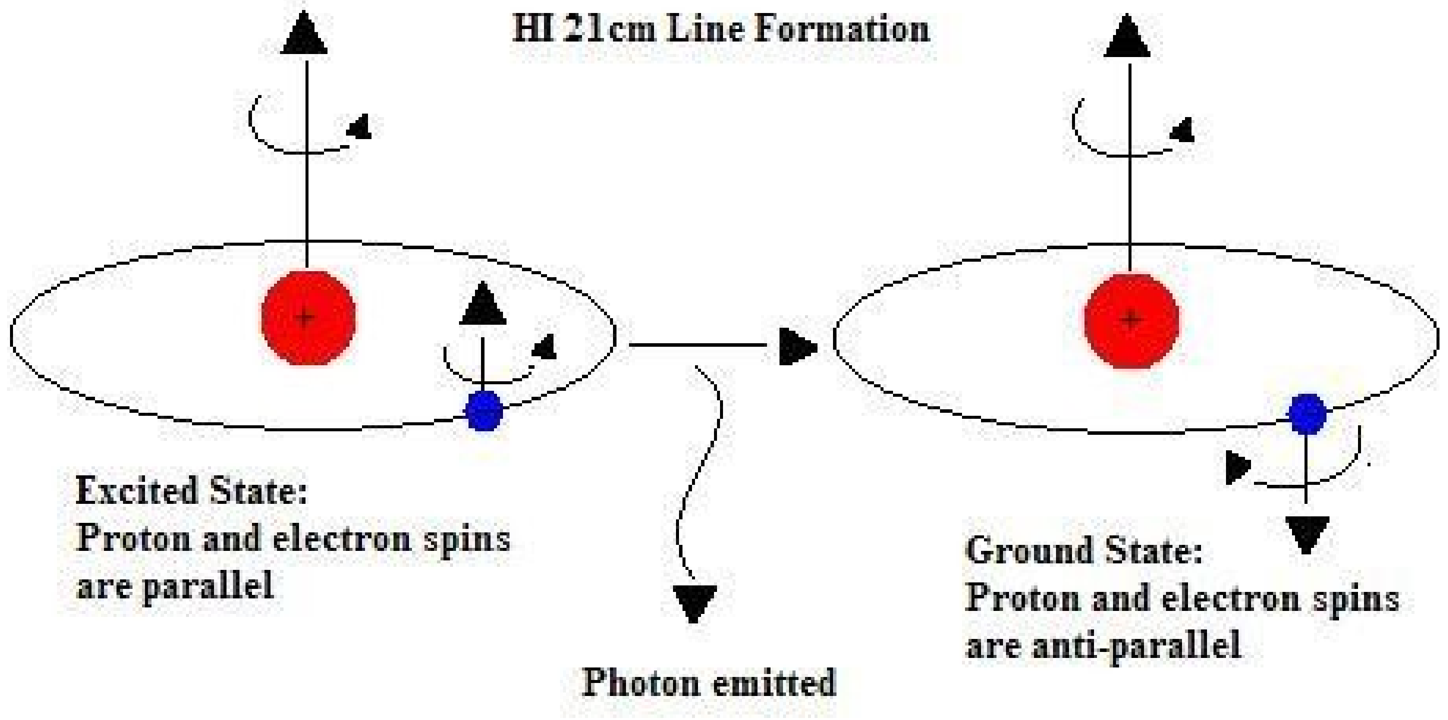
Wow, infrared is great!
What if we used even longer wavelengths?



Can we try radio?

The 21cm (1420 MHz) line of neutral hydrogen (HI)

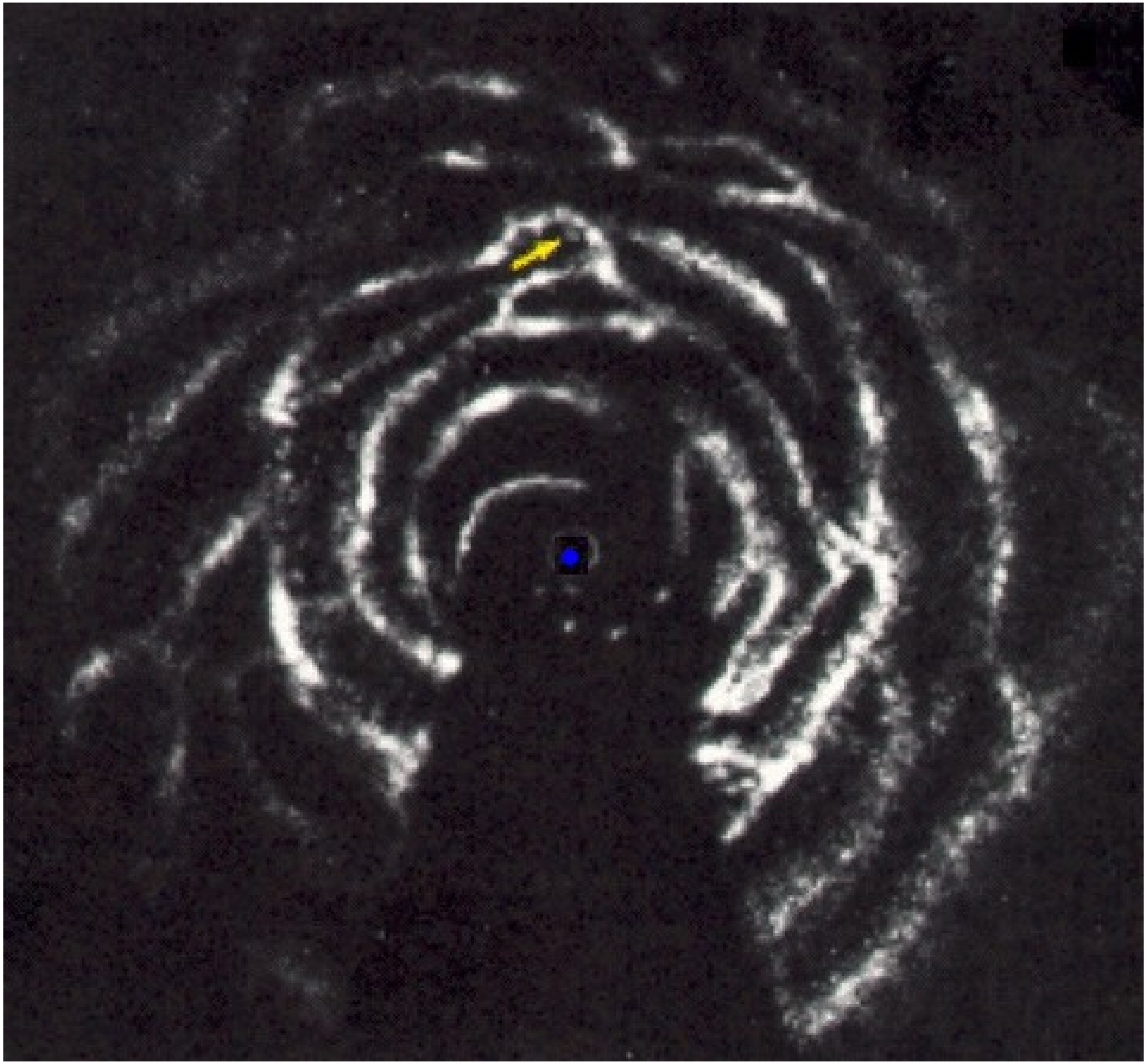
Spin transition



Nothing is more abundant than neutral hydrogen
Plus, it's RADIO! Unstoppable!

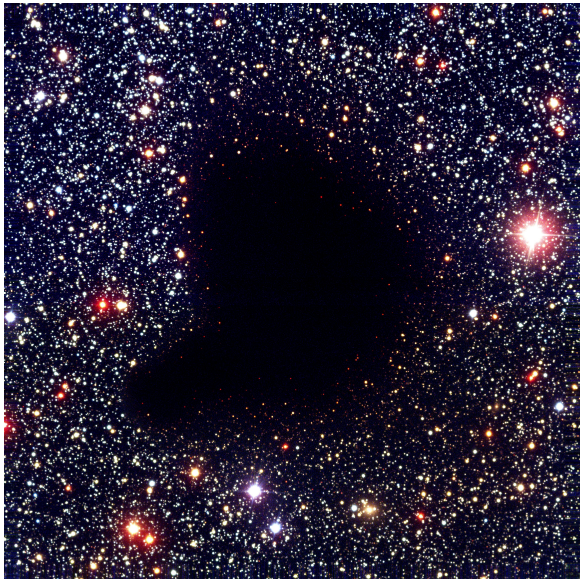
This 21cm radiation should be pervading the Galaxy

A map of the Galaxy in the 21cm HI line



Interstellar Nebulae

Interstellar clouds can be referred to as absorption (dark), reflection or emission nebulae



Absorption Nebula

Reflection Nebula

Emission Nebula

Interstellar Nebulae

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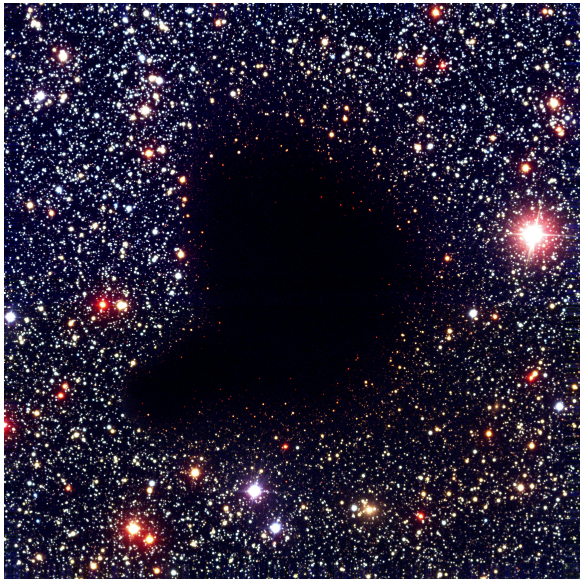

Absorption Nebula

Absorption Nebulae

A lot of gas and dust simply blocking light

Interstellar Nebulae

Reflection Nebulae

Physically the same as dark nebulae, but ***illuminated*** by nearby stars.

The dust shines by reflected light

Usually blue (why?)

Interstellar Nebulae

Reflection Nebulae

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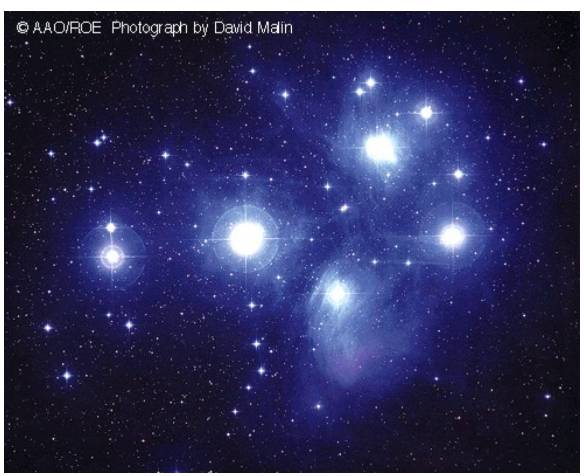


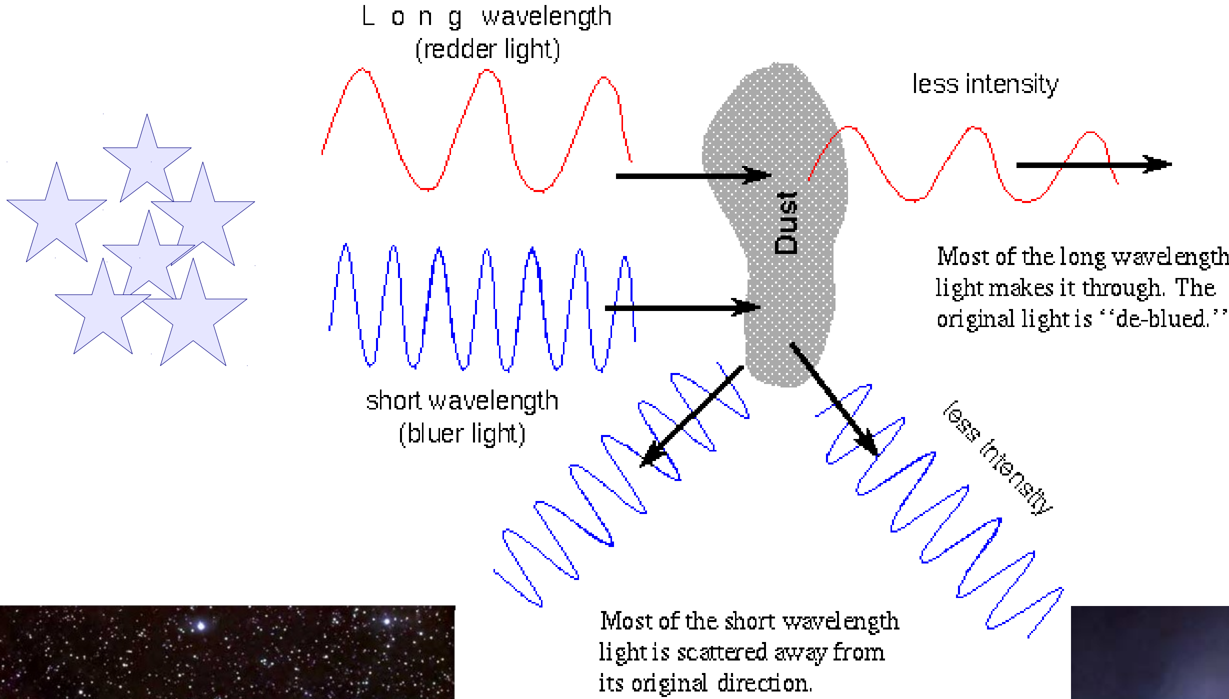
1. **Illuminated by blue/white stars**

2. Same reason why the sky is blue
Blue is better scattered than red

Interstellar Nebulae

Absorption and reflection nebulae are the same object

Reddening and Extinction



Absorption

Reflection

Reflection + Absorption

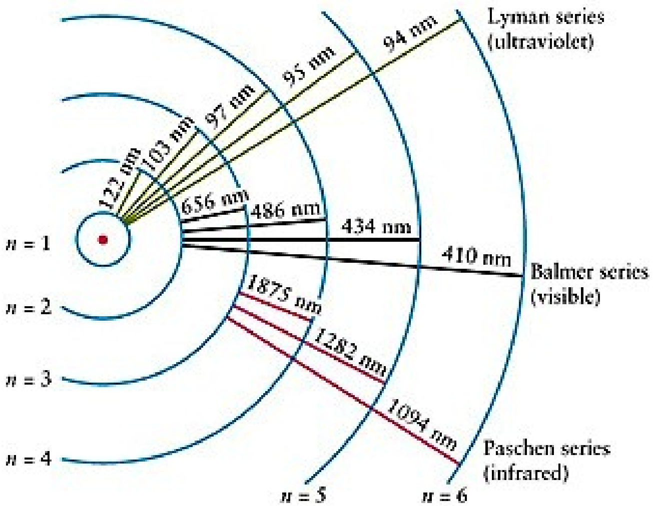
Interstellar Nebulae

Emission Nebulae

Glow by their own light

Illuminated by nearby OB stars,
very hot stars that emit ionizing radiation

When the electrons recombine, they cascade emitting light in all the atom's discrete set of wavelengths



Interstellar Nebulae

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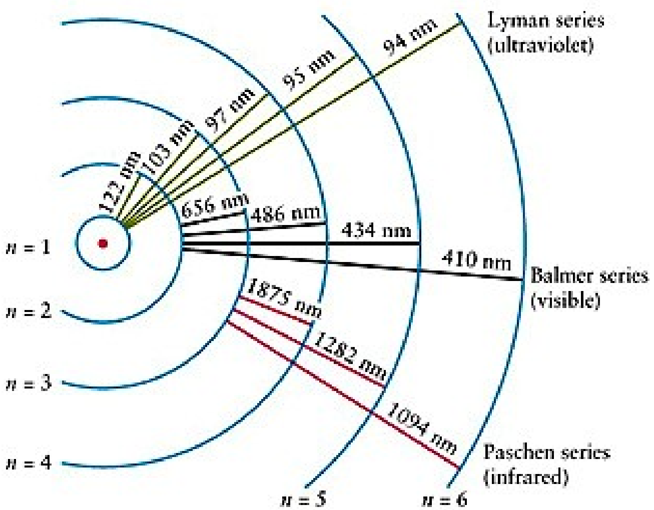

Interstellar Nebulae

Emission Nebulae

Hydrogen emission in the **6563 Å** line ($H\alpha$)

Glow by their own light
Usually red (why?)

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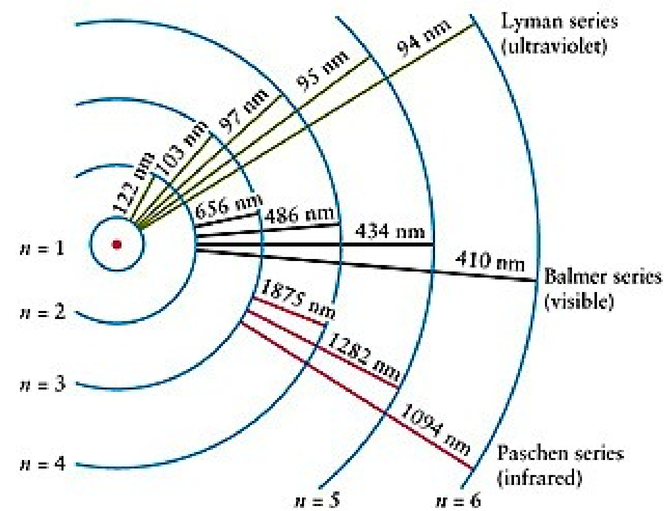
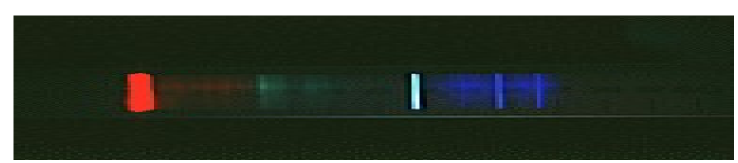
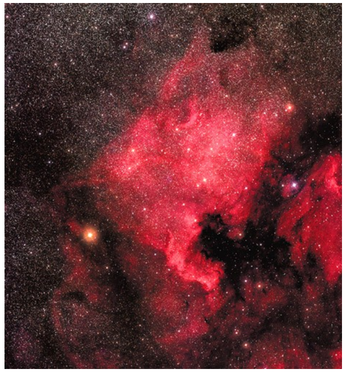
When the electrons recombine, they cascade emitting light in all the atom's discrete set of wavelengths



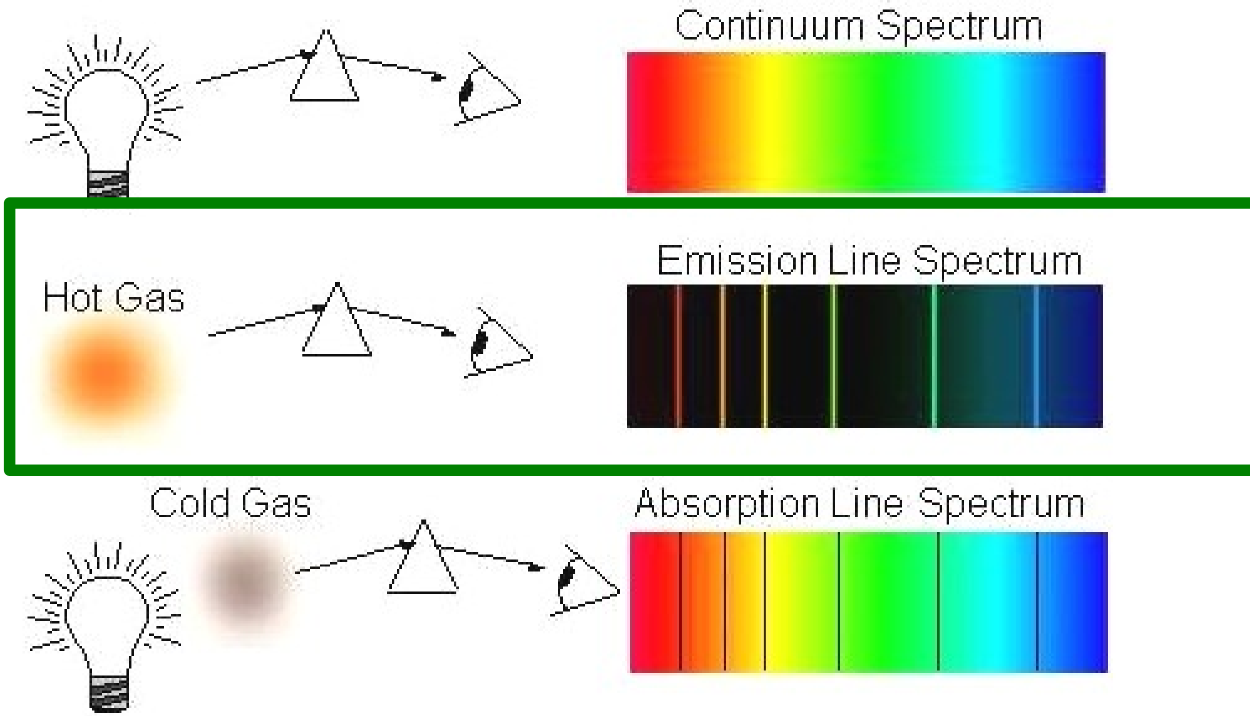


Interstellar Nebulae

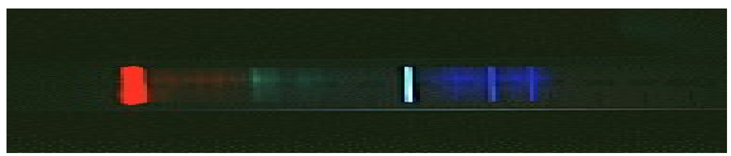
Emission Nebulae



Kirchhoff's laws



Hydrogen emission in the **6563 Å** line ($H\alpha$)

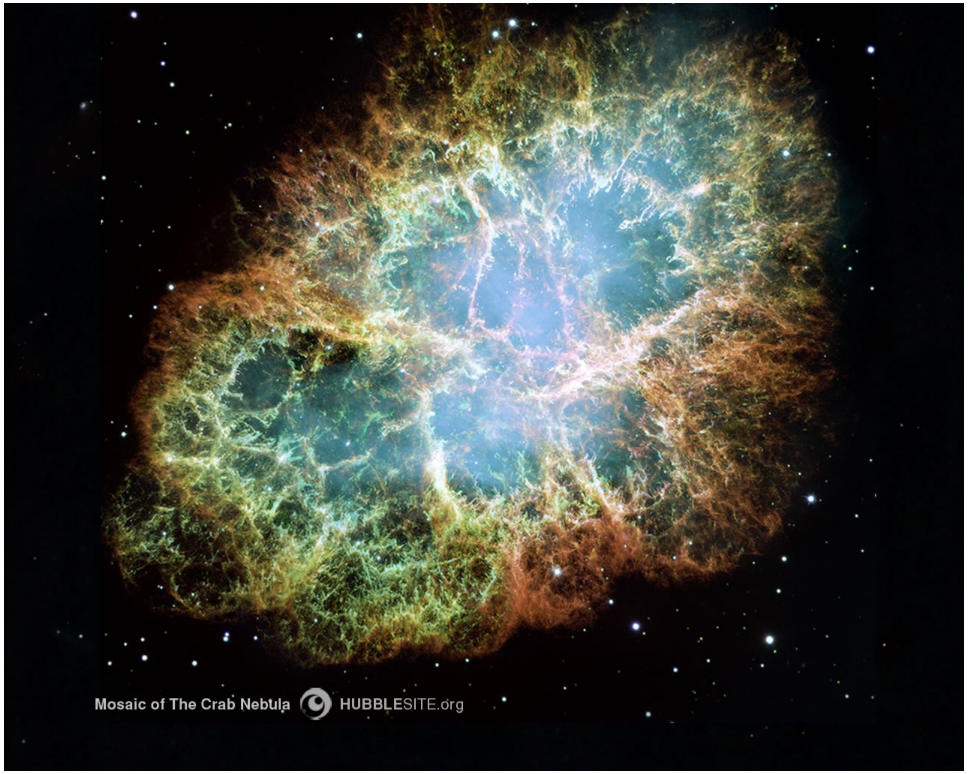


HII Regions

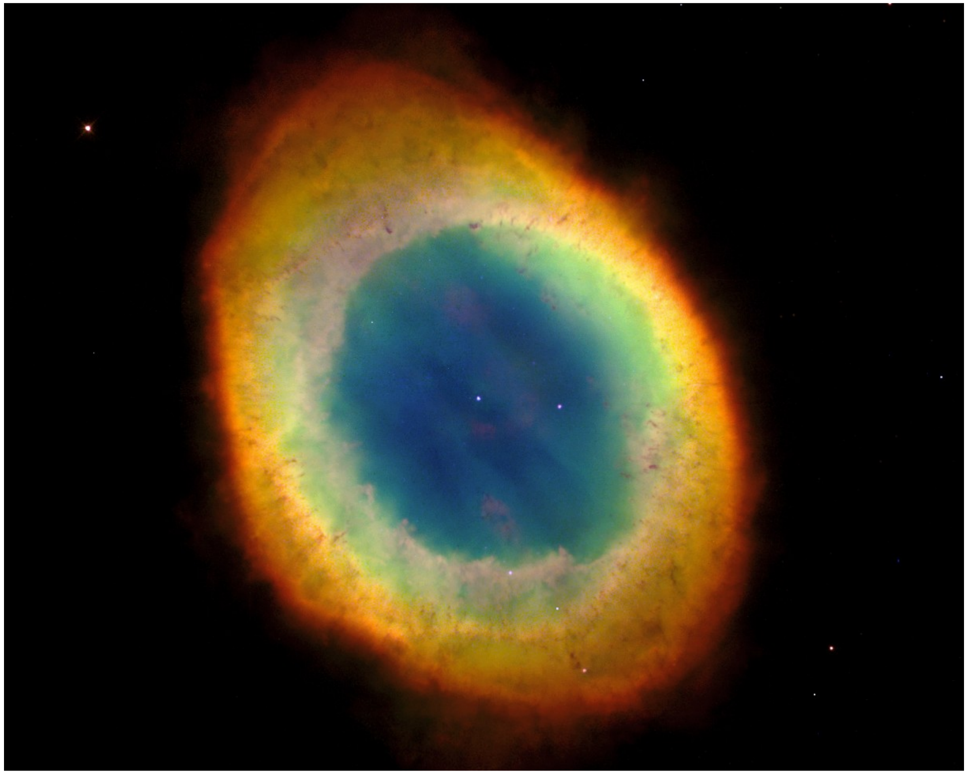
Emission Nebulae are also called HII Regions
HII for Ionized Hydrogen
(Neutral Hydrogen is HI)

Emission nebulae

Emission Nebulae are red because of hydrogen emission in H-alpha
Can you tell then why are Supernovae Remnants and Planetary Nebulae so colorful?



Crab Nebula
Supernova Remnant



Ring Nebula
Planetary Nebula

Emission nebulae

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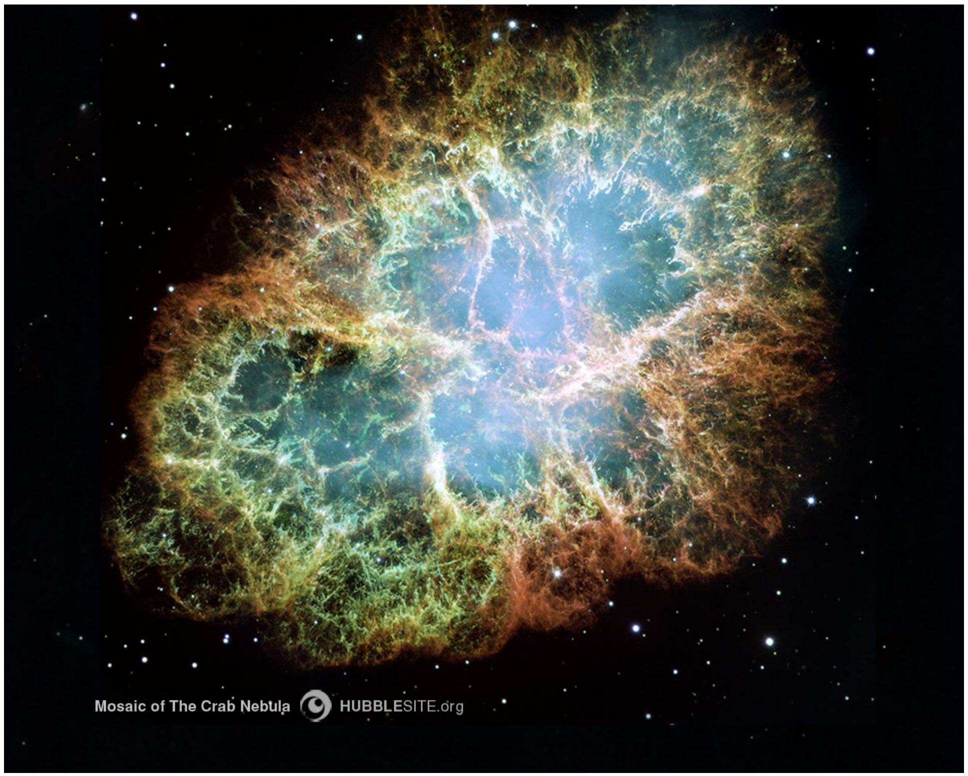
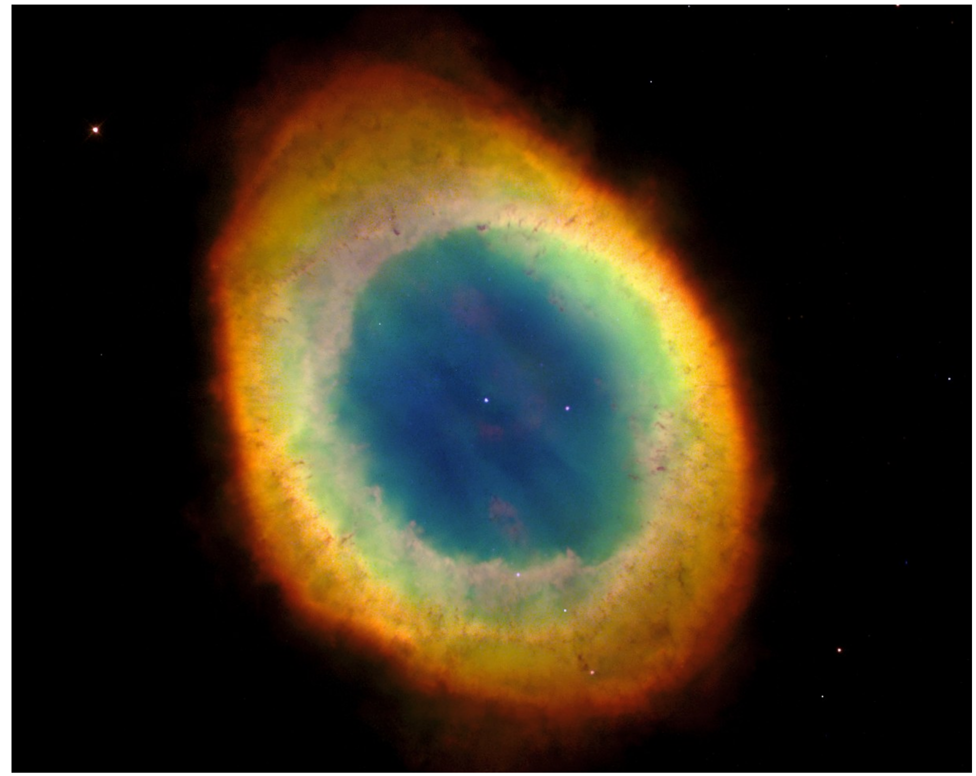
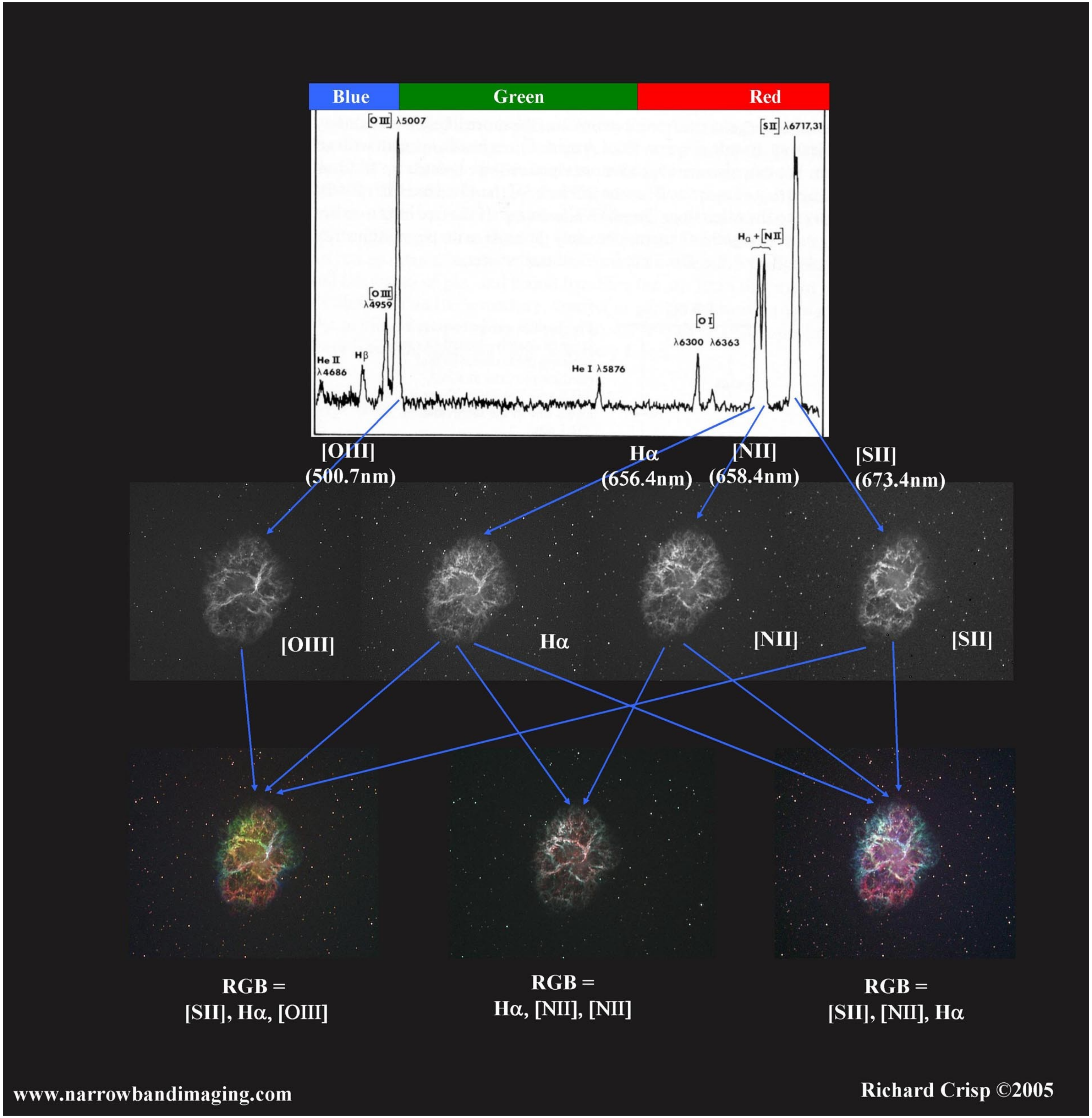


Crab Nebula
Supernova Remnant



Ring Nebula
Planetary Nebula

Chemically enriched !!
Not just hydrogen...



Spectrum of the Crab Nebula

Prominent
Silicon line
(redder than **H-alpha**)
and **Oxygen line**
(green)

Emission, Reflection, and Absorption in the same nebula

Trifid Nebula

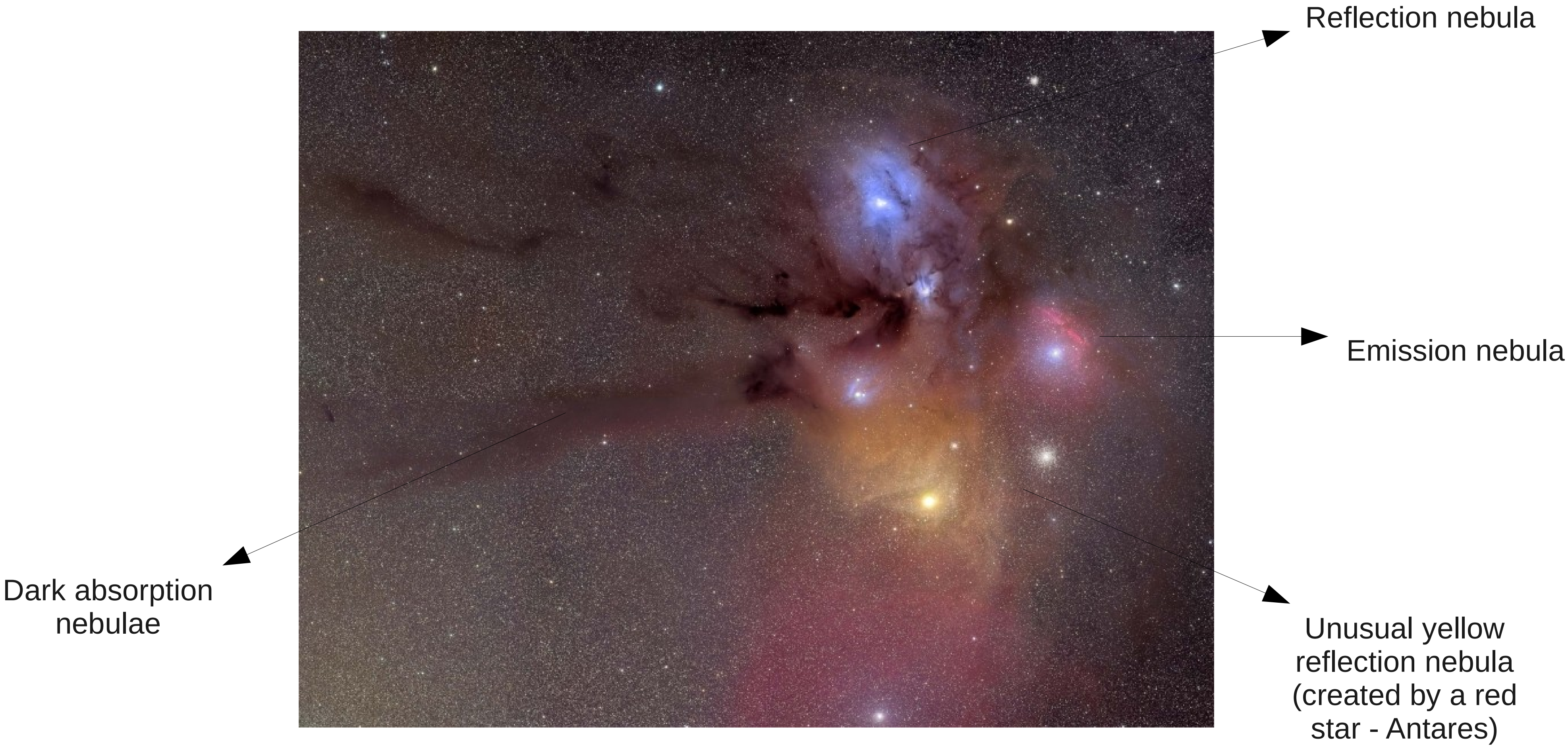
An entanglement of nebulae...

The Antares-Rho Ophiuchi Region

Can you sort what you see?

An entanglement of nebulae...

The Antares-Rho Ophiuchi Region



Can you sort what you see?