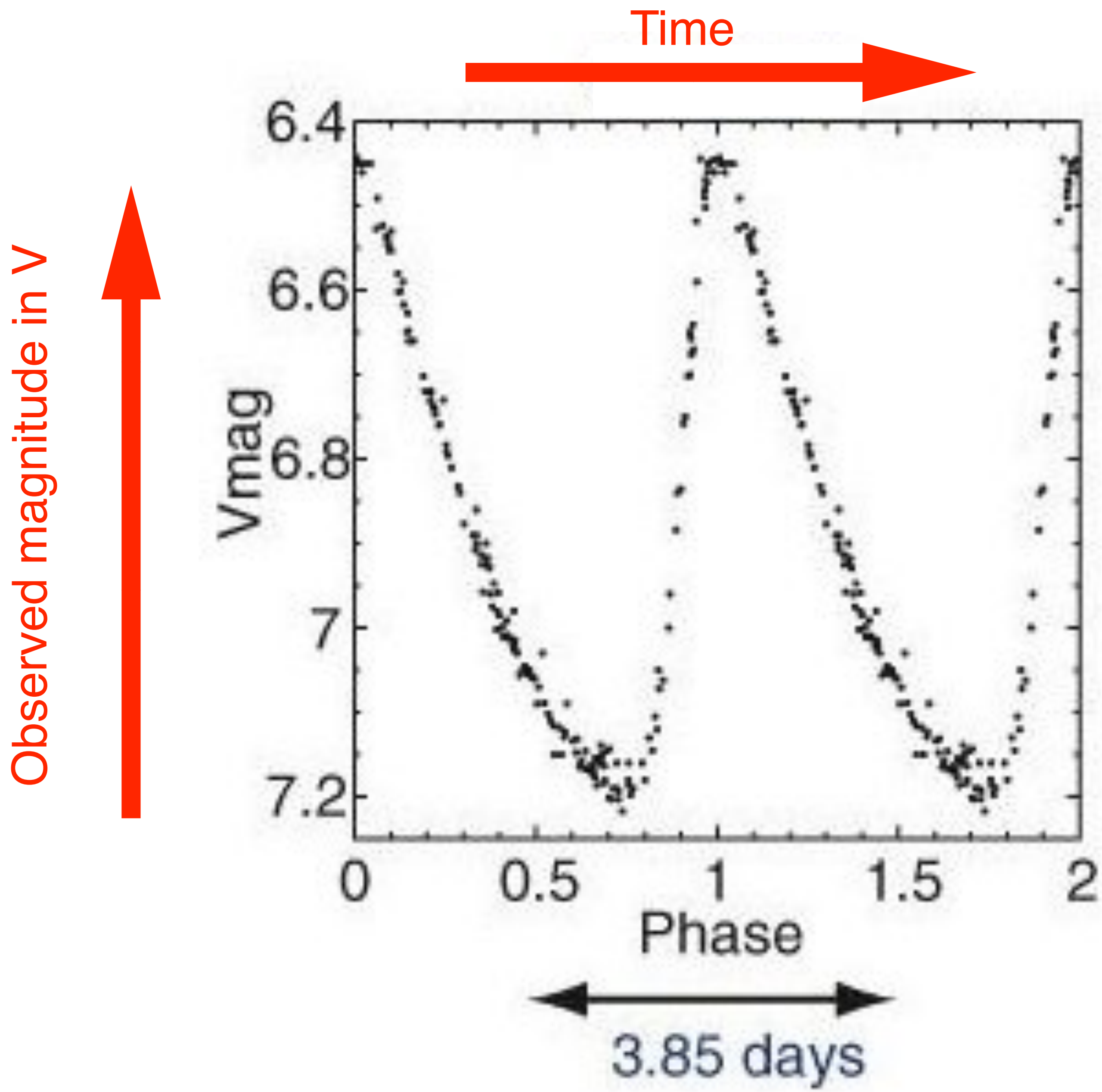
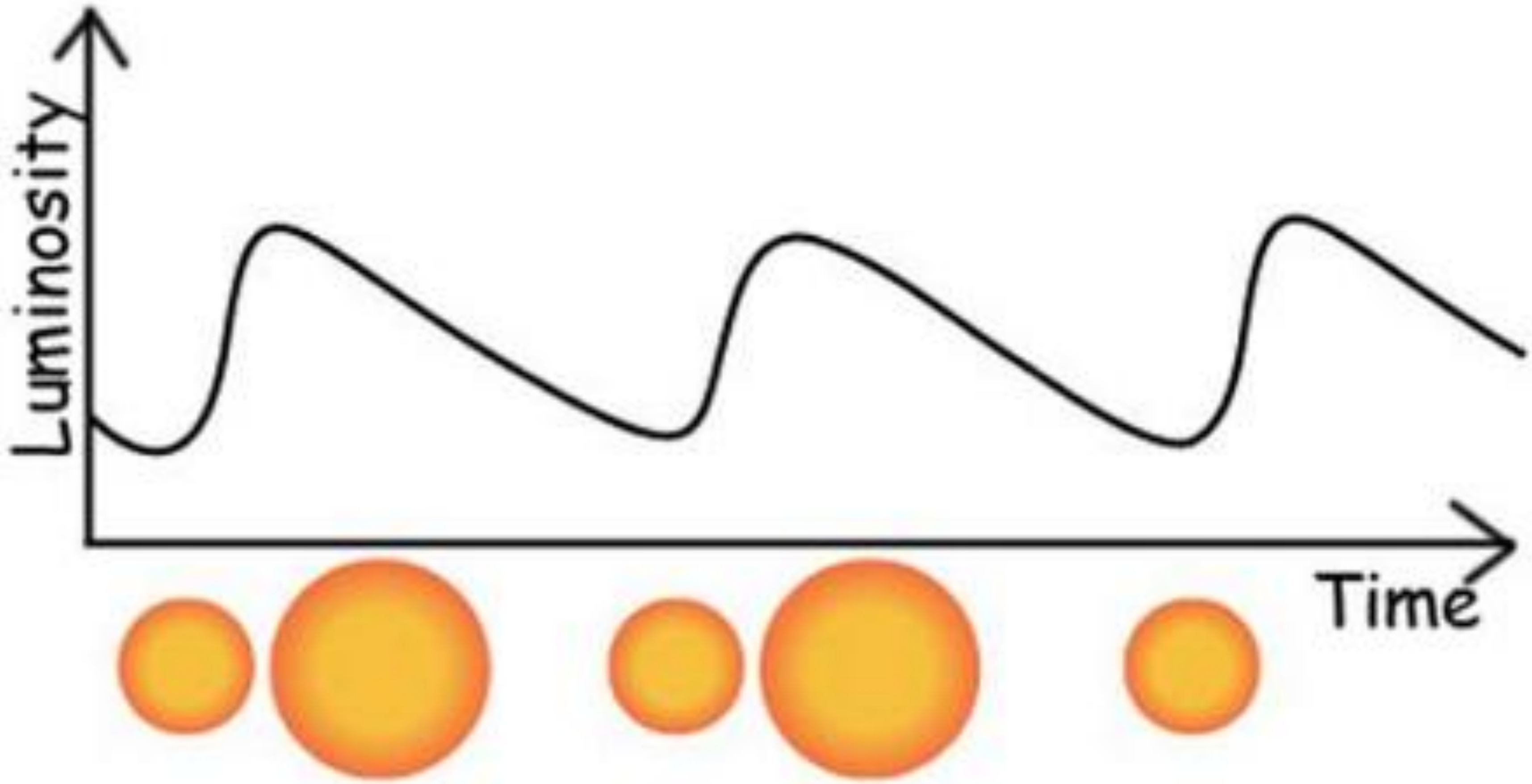
Variable stars

Variable stars: **Cepheids**

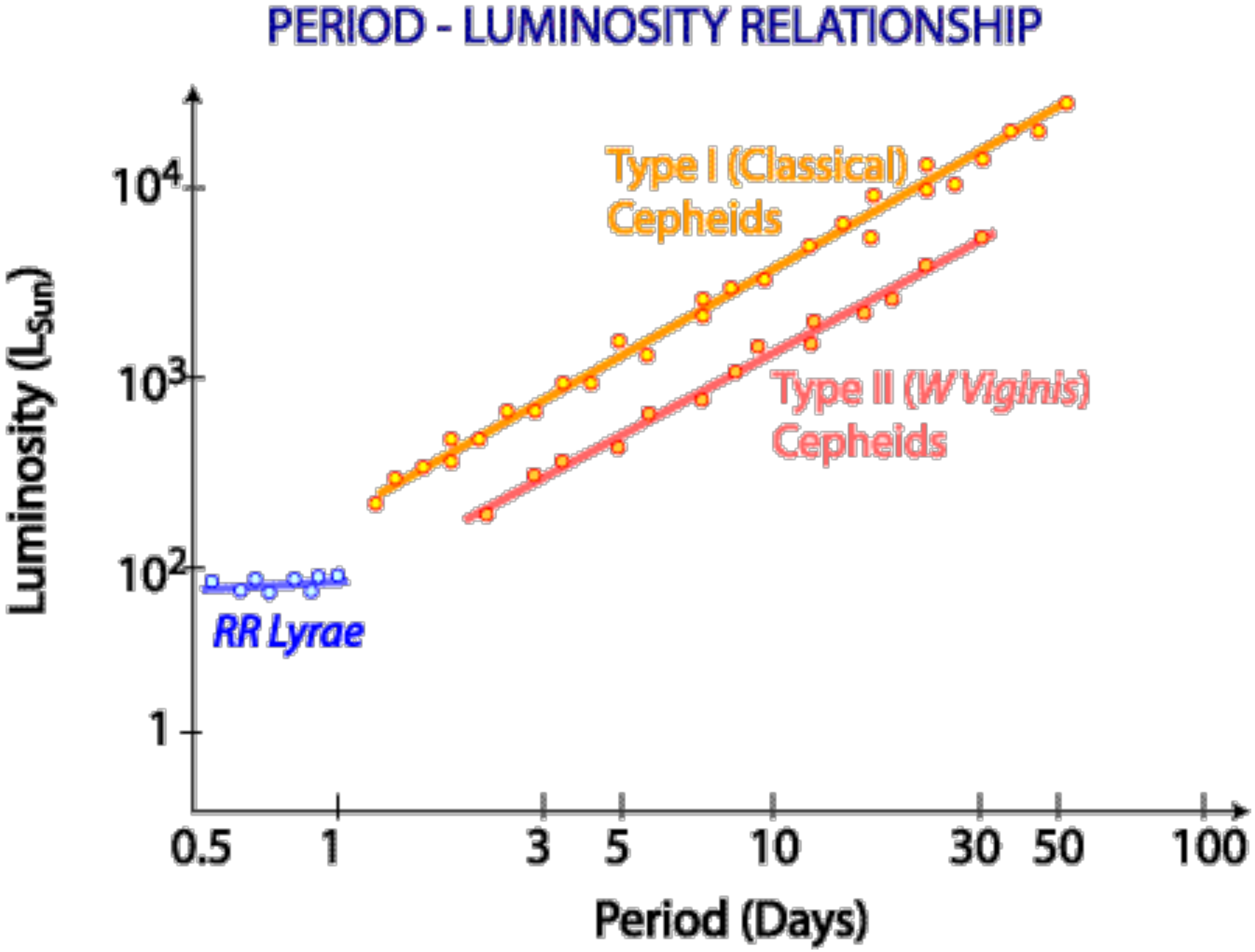


Variable stars: **Cepheids**



Star’s luminosity changes because its size changes

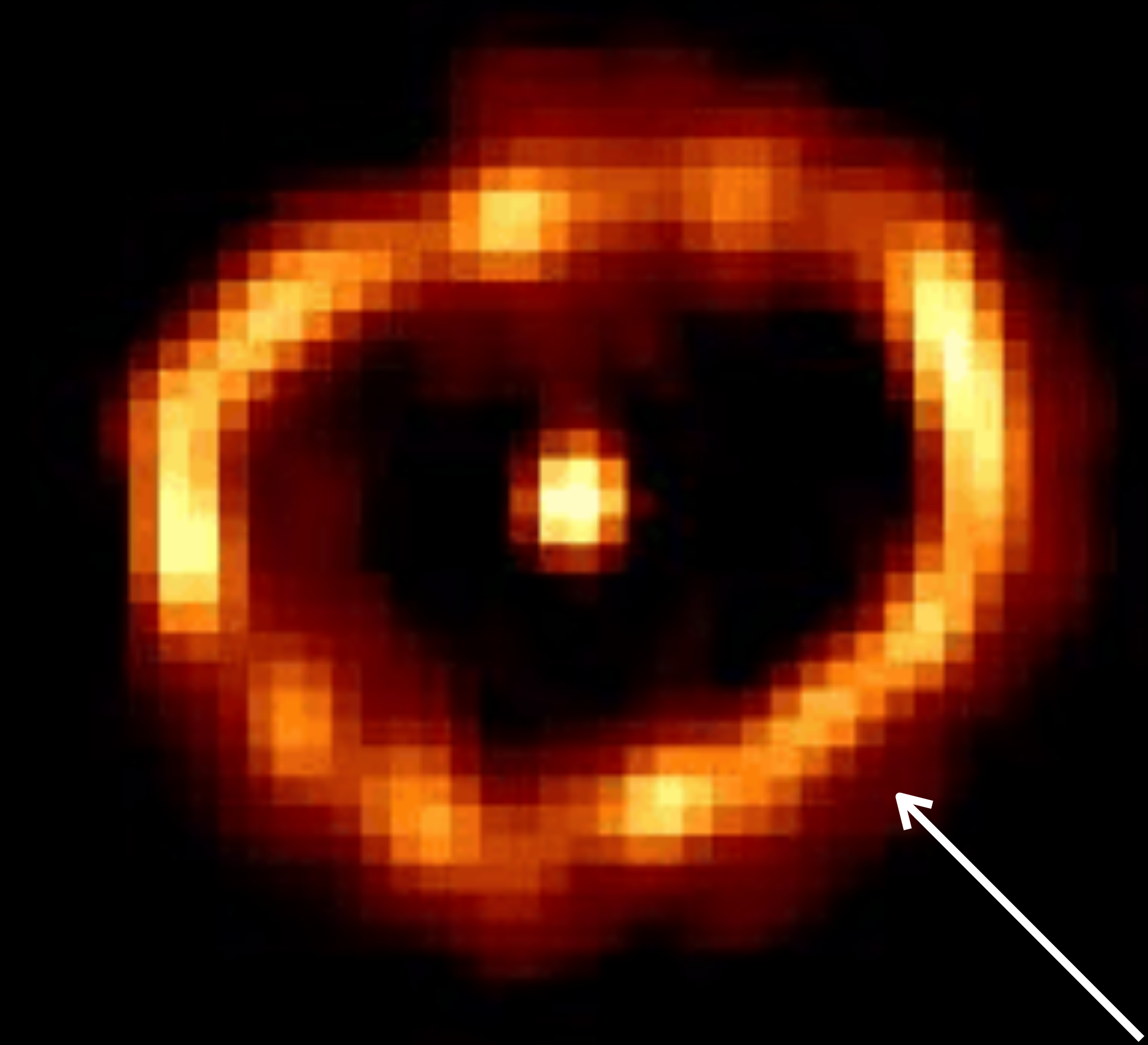
Variable stars: **Cepheids**



Type I Cepheids are younger, chemically more evolved & more massive than Type II Cepheids

Variable stars: **Novae**

(8–15 magnitudes variation)



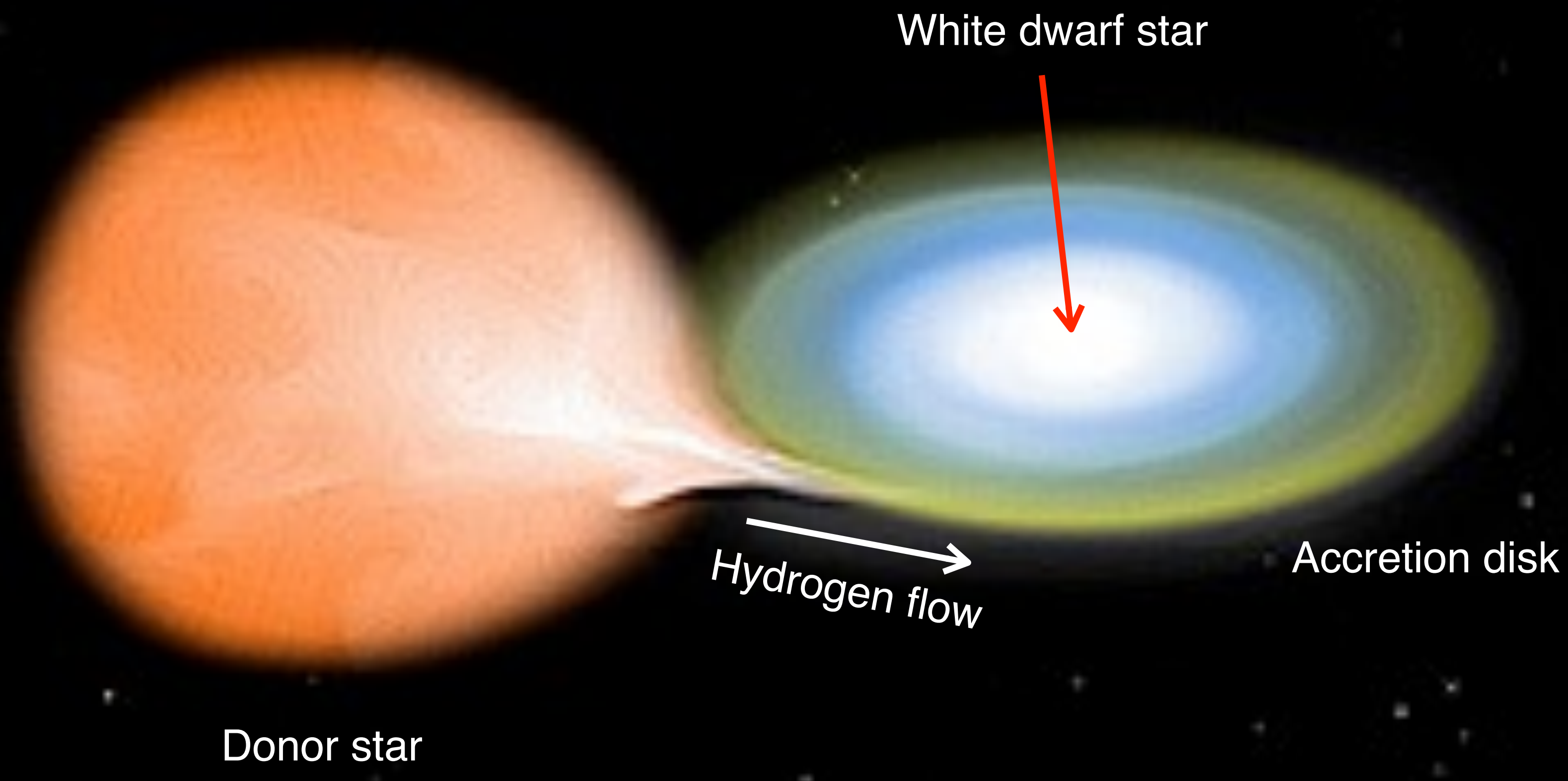
Gas expulsion from outer shell
of a primary star after outburst

Nova Cygni 1992

HST image 2 years after outburst

Variable stars: **Novae**

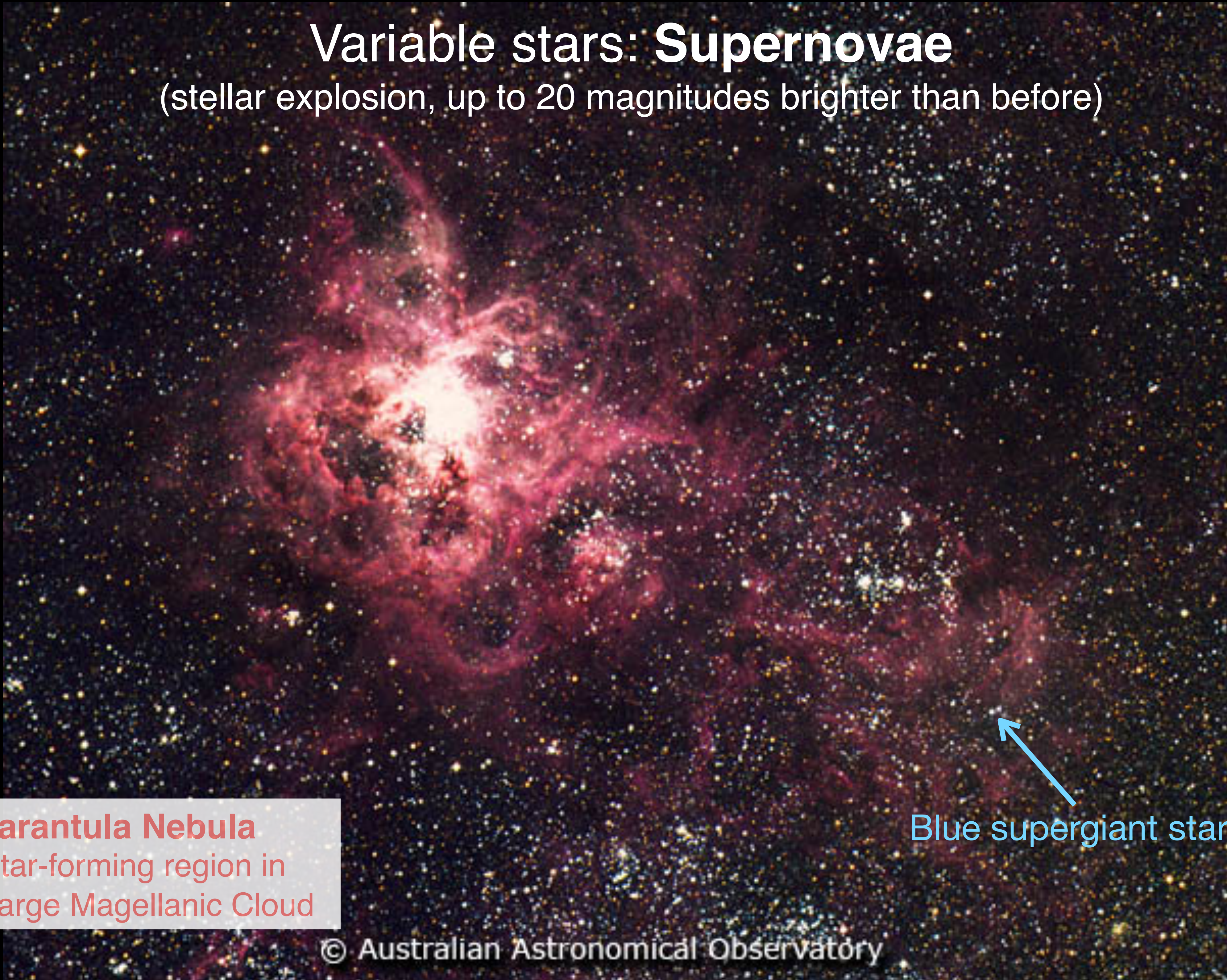
Thermonuclear explosive event on surface of white dwarf in a binary system



Nova mechanism
(artist's impression)

Variable stars: **Supernovae**

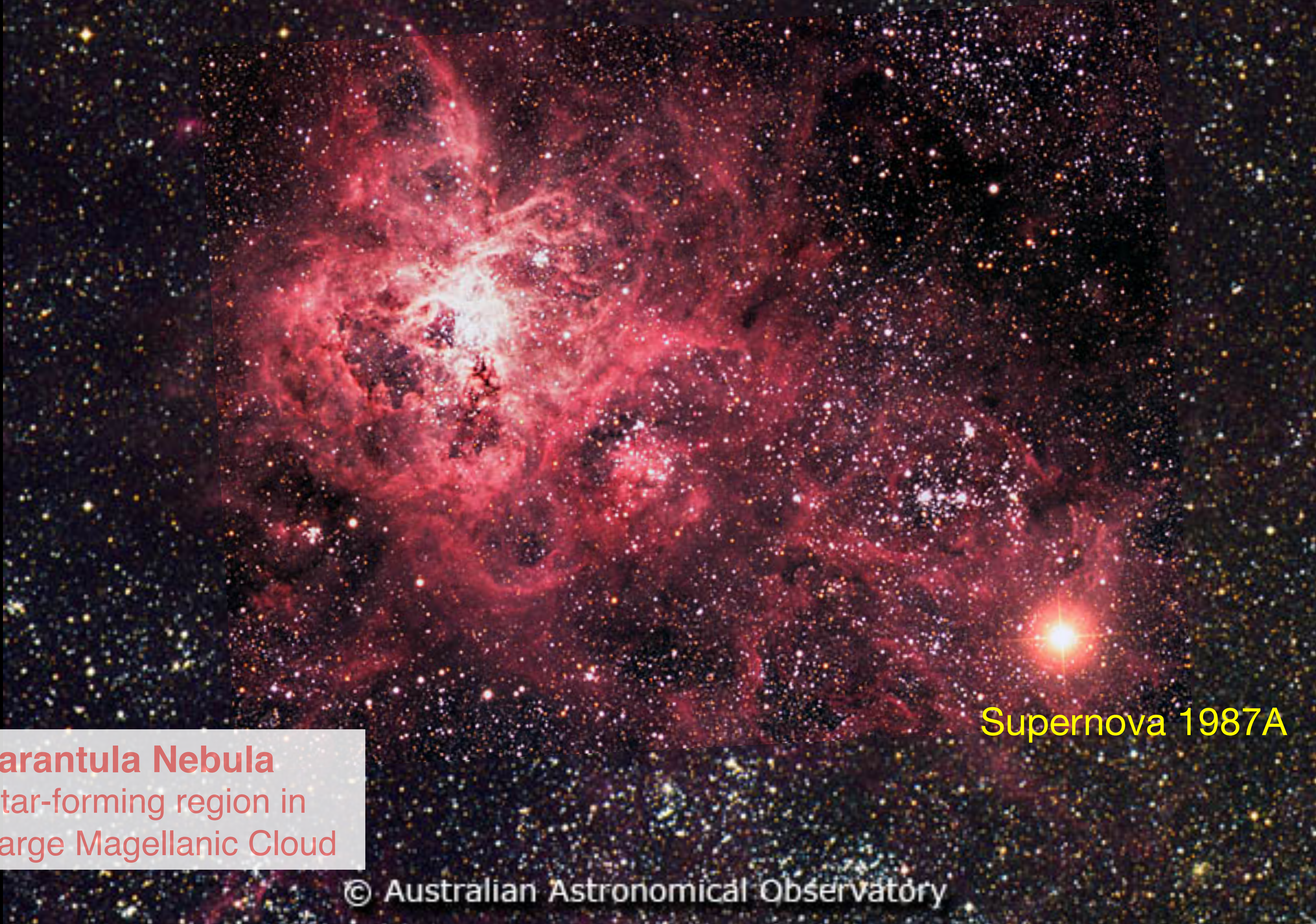
(stellar explosion, up to 20 magnitudes brighter than before)



Tarantula Nebula
Star-forming region in
Large Magellanic Cloud

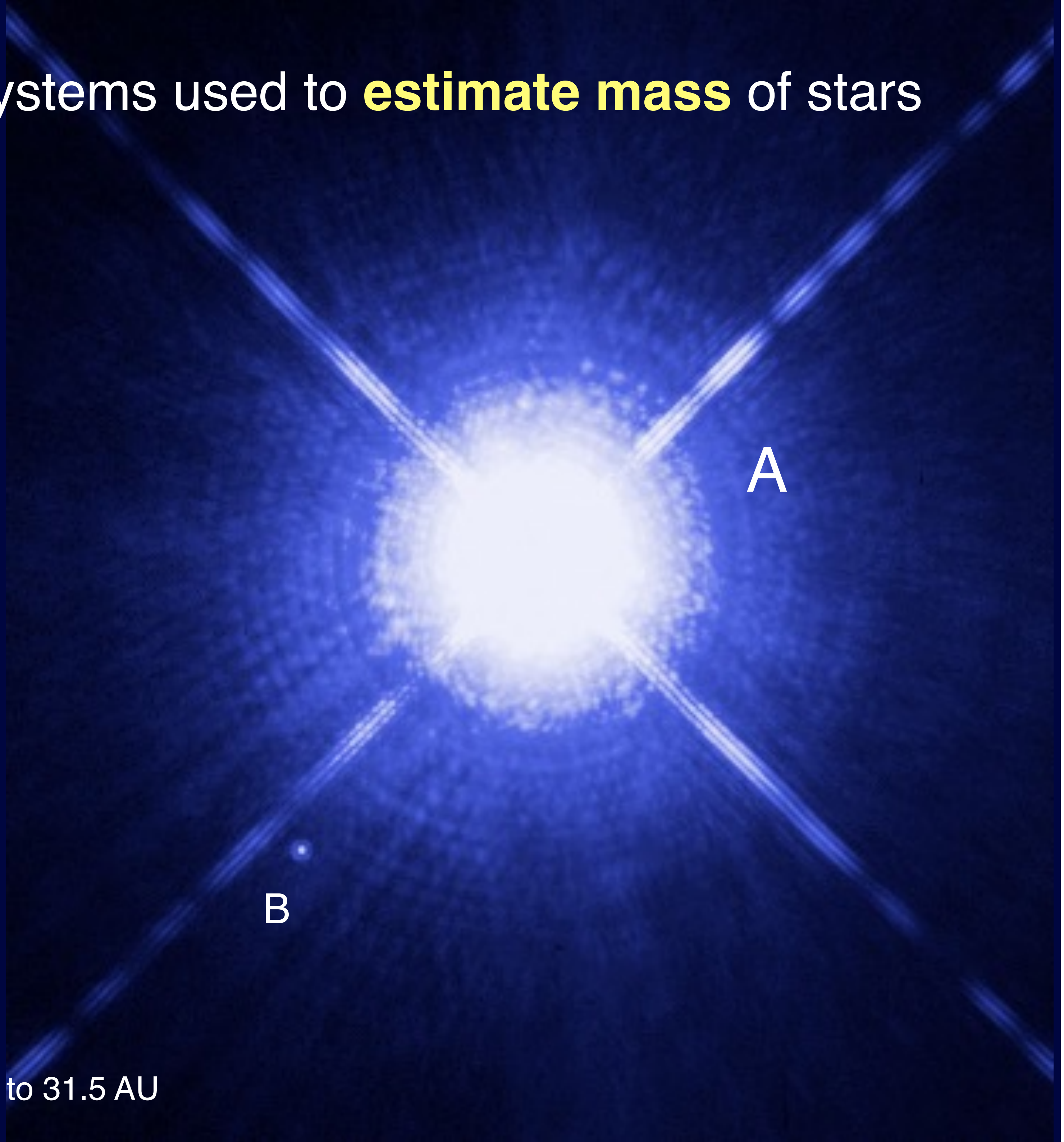
Variable stars: **Supernovae**

(stellar explosion, up to 20 magnitudes brighter than before)



Mass of stars

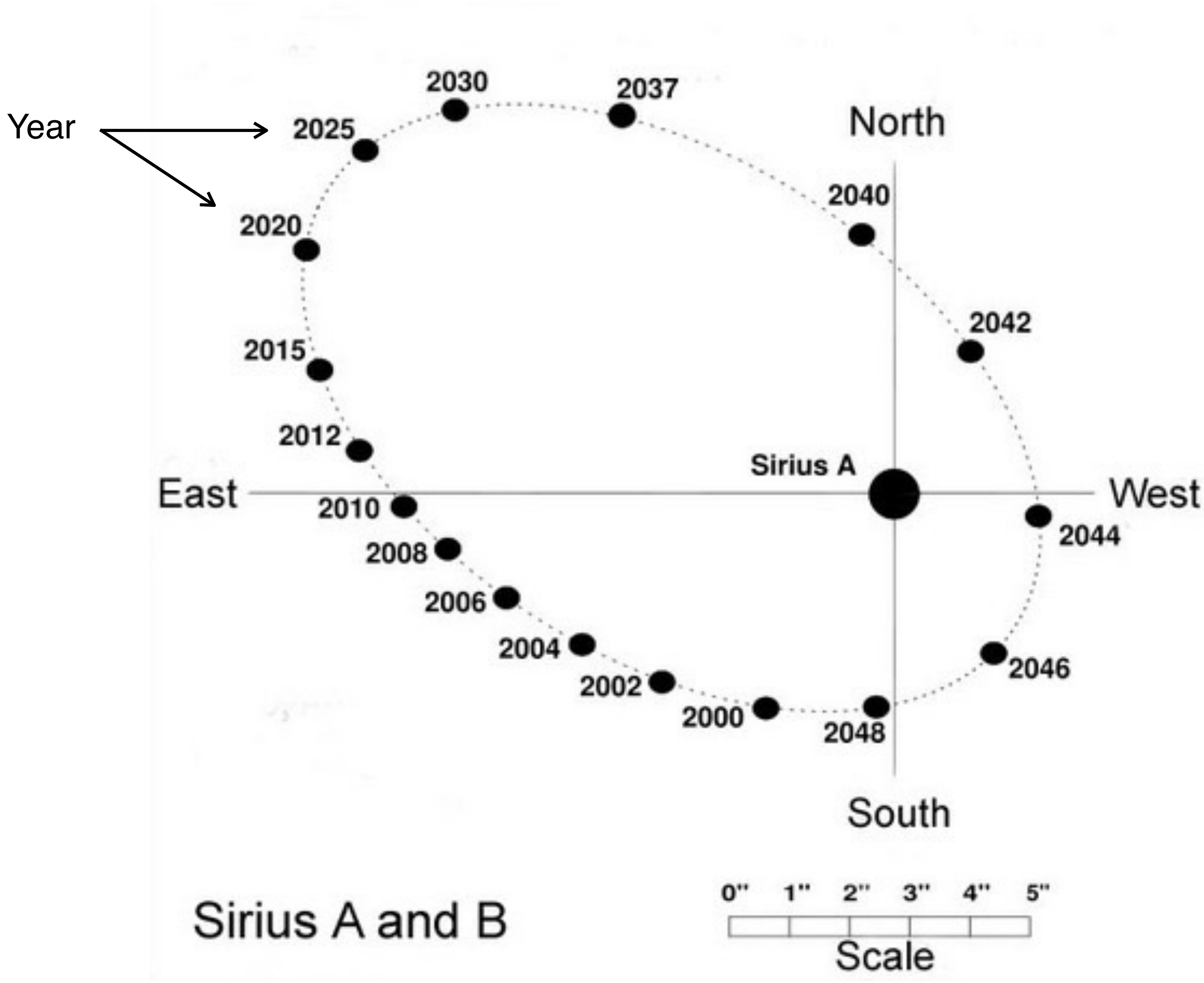
Close binary systems used to **estimate mass** of stars



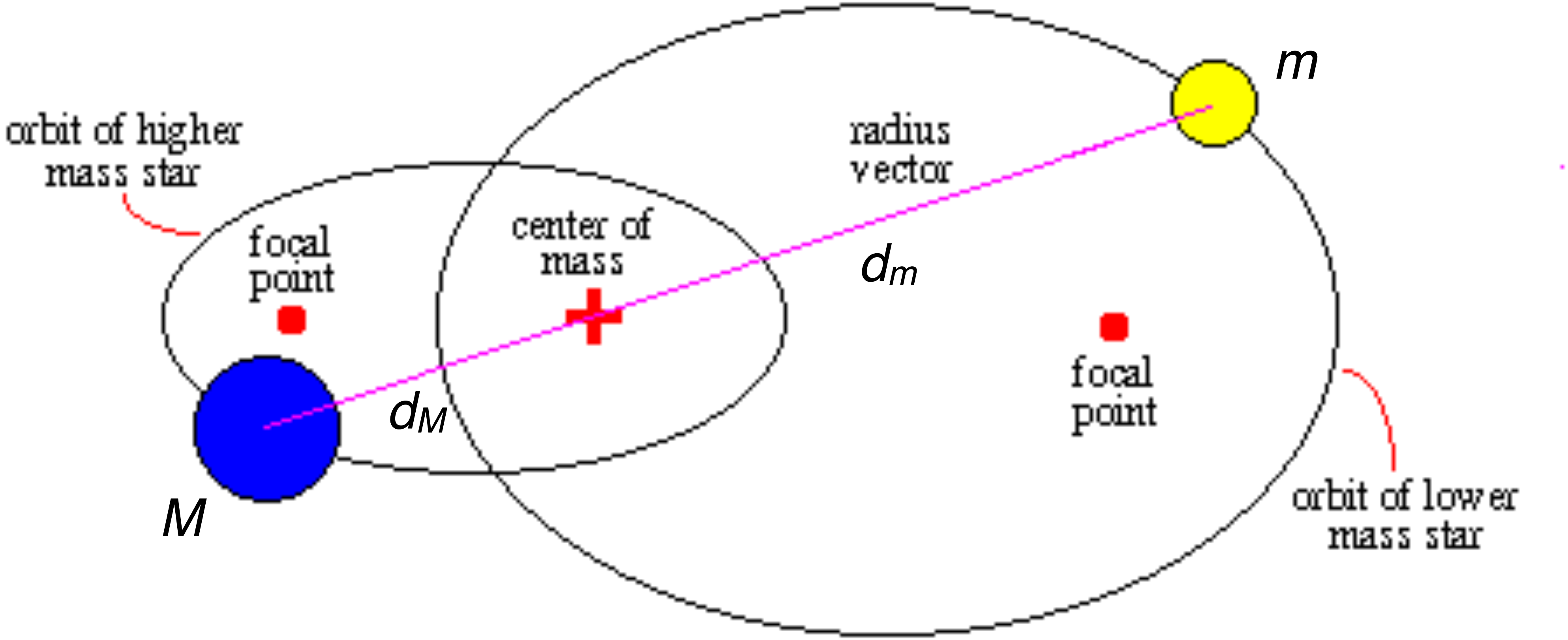
Sirius

Distance from Earth: 2.64 pc
Binary system *A & B*
Rotation period: 50 years
Separation between stars: 8.2 to 31.5 AU

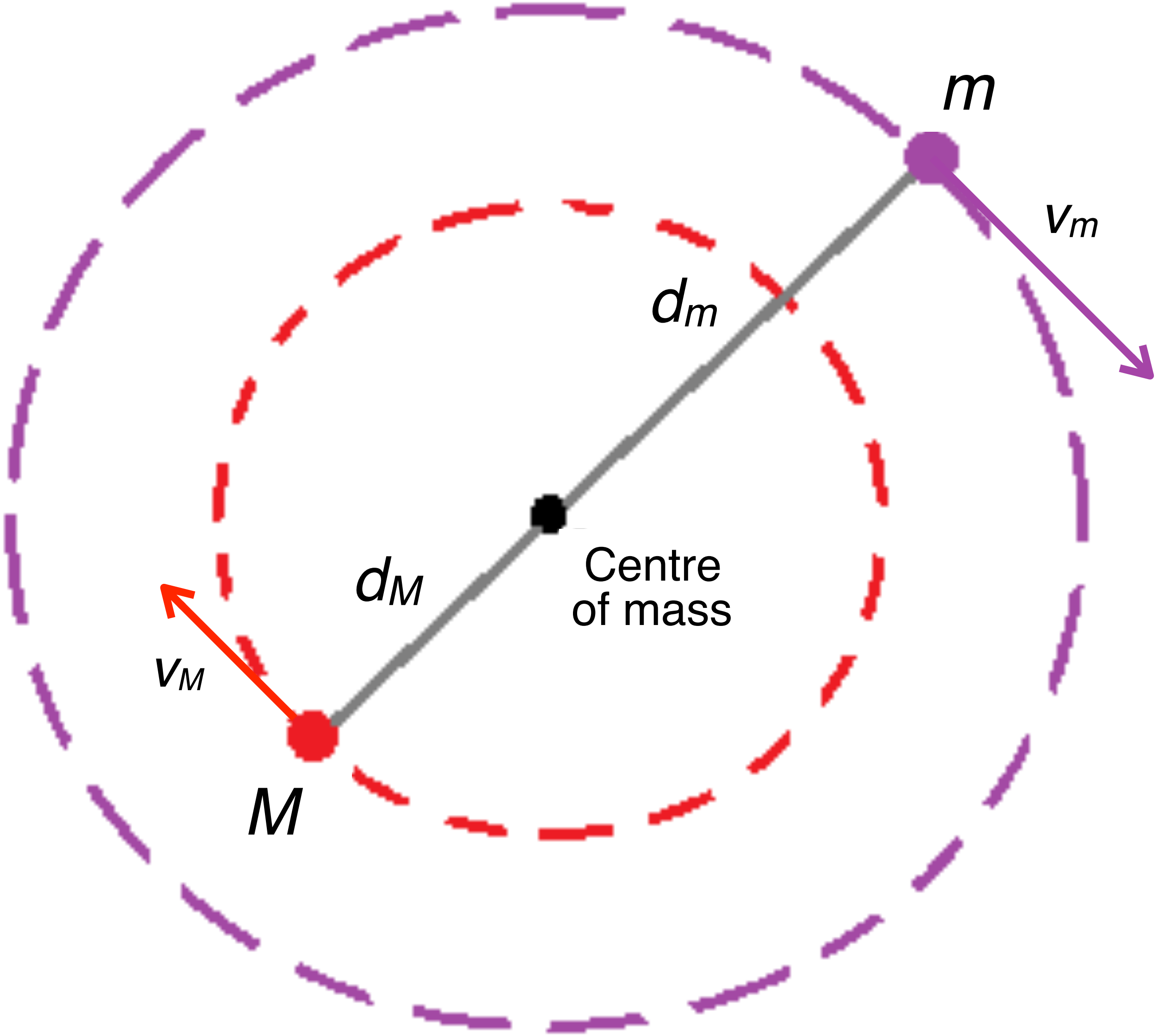
Rotation of *Sirius B* around *Sirius A* over time



Rotation of two stars around the center of mass



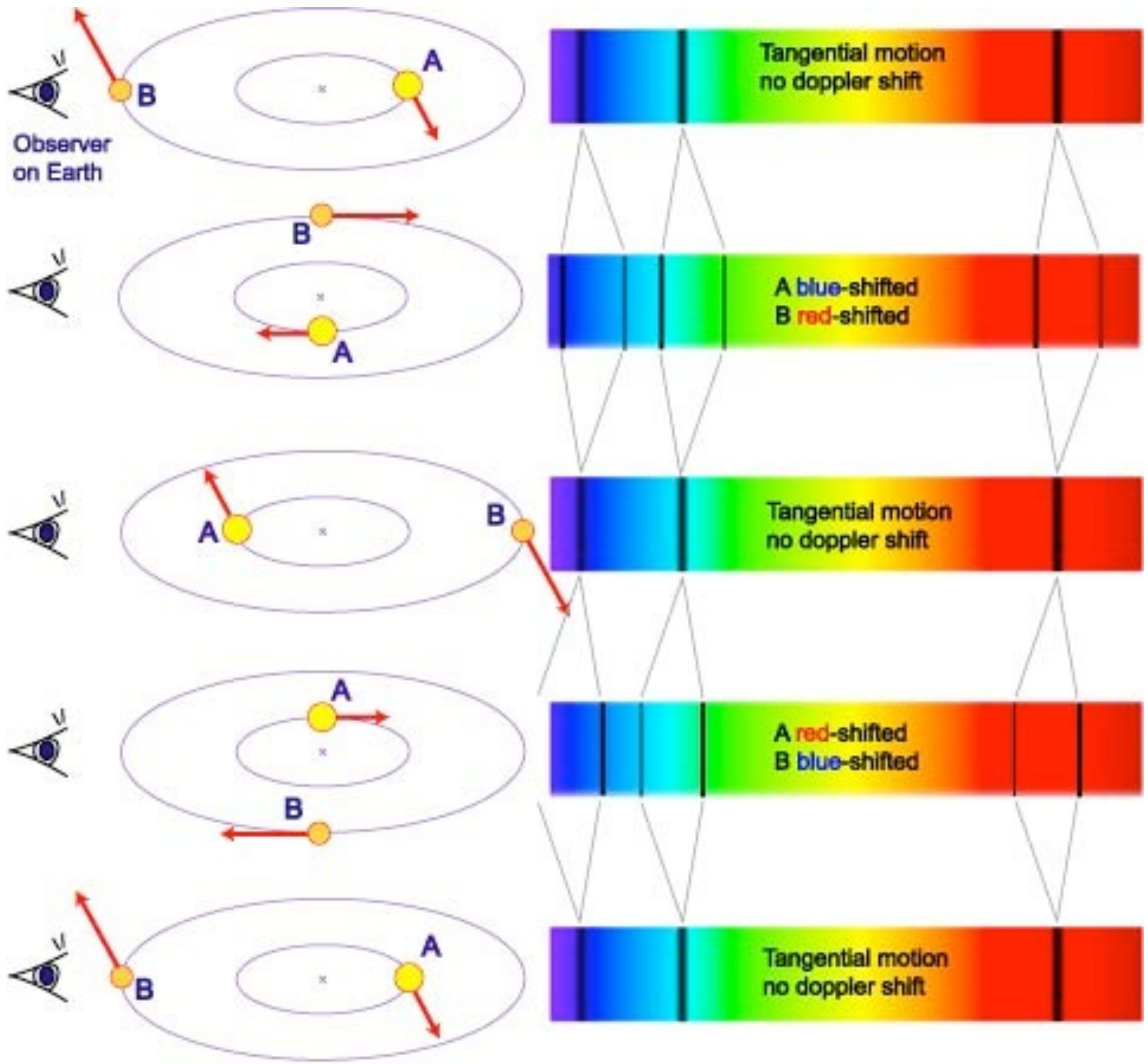
Binary stars in circular orbits



$$M/m = d_m/d_M = v_m/v_M$$

If stars are not seen individually

Absorption lines & Doppler effect used to measure **radial velocity**



A Spectroscopic Binary System

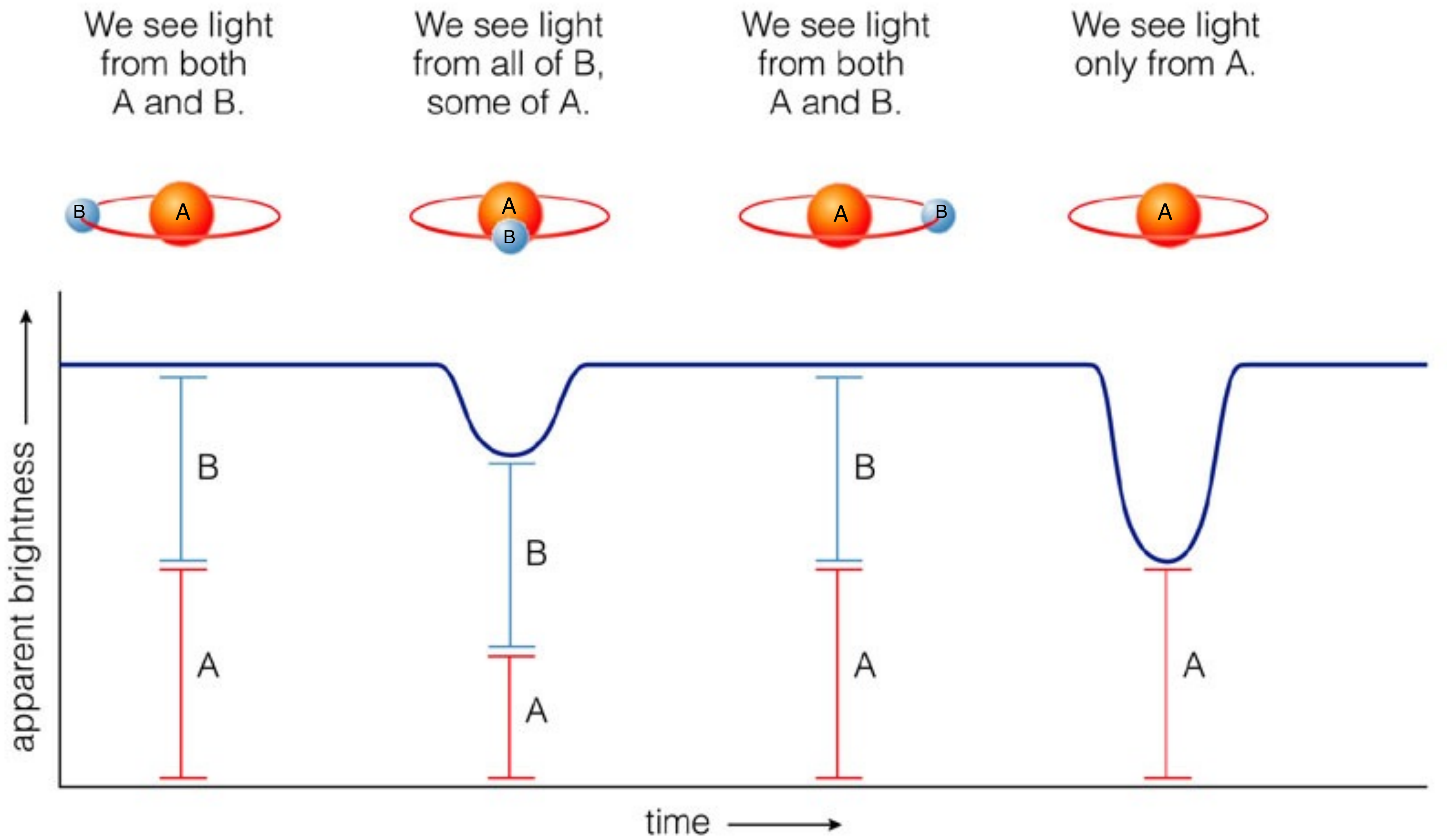
High-mass star A and lower-mass B orbit around a common centre of mass. The observed combined spectrum shows periodic splitting and shifting of spectral lines. The amount of shift is a function of the alignment of the system relative to us and the orbital speed of the stars.

Radial velocity: velocity of stars along the line of sight

Eclipsing binary system to obtain radius of largest star

(valid if one star is much larger than the other)

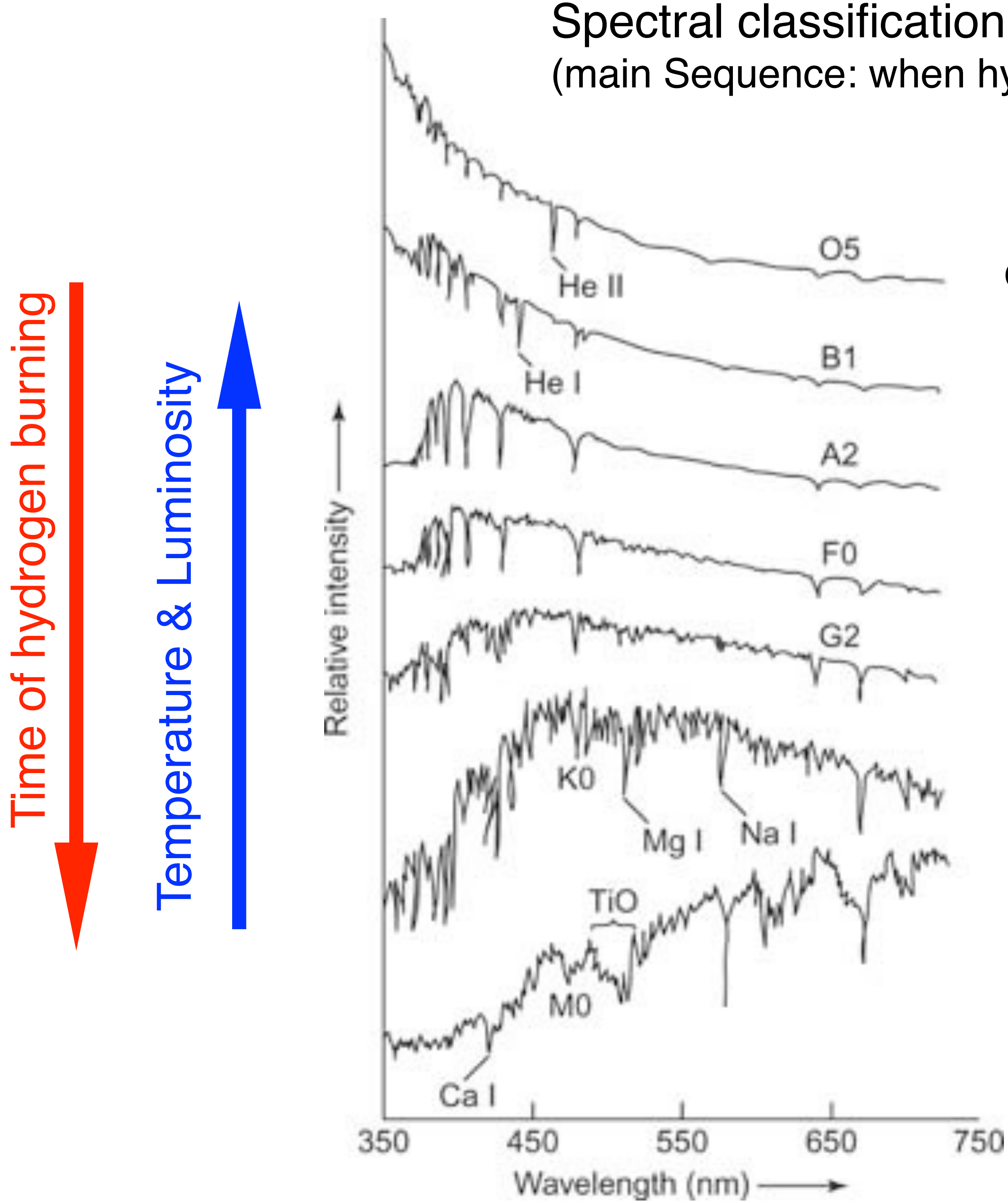
Using **Doppler shift** to derive **radial velocity** of small star & duration (time) of eclipse



Hertzsprung-Russel (HR) diagram

Spectral classification of stars in *Main Sequence*

(main Sequence: when hydrogen is burned in core)



O5 star (40,000 K)

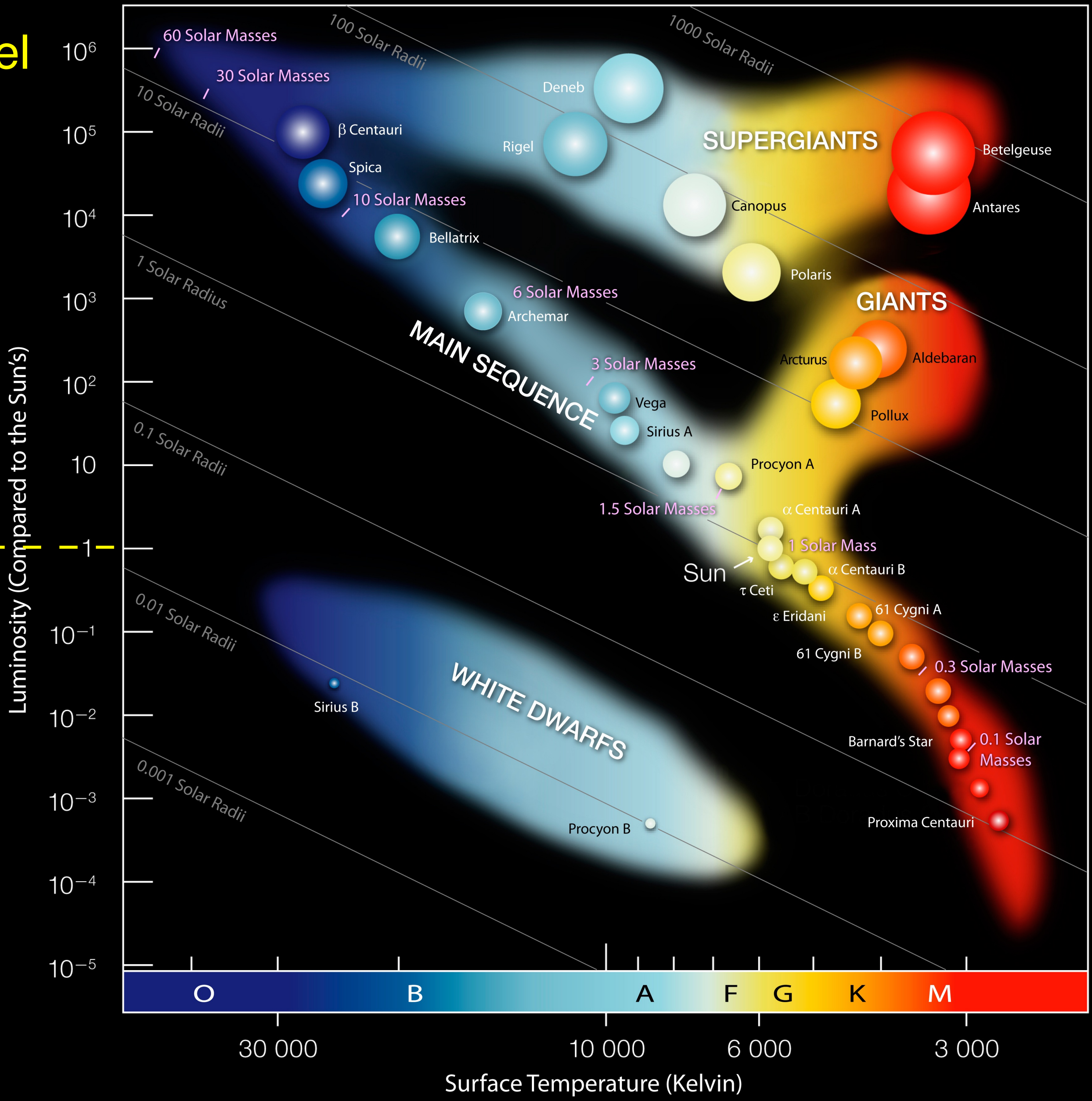
M0 star (3500 K).

Hertzsprung-Russel diagram

Information on:

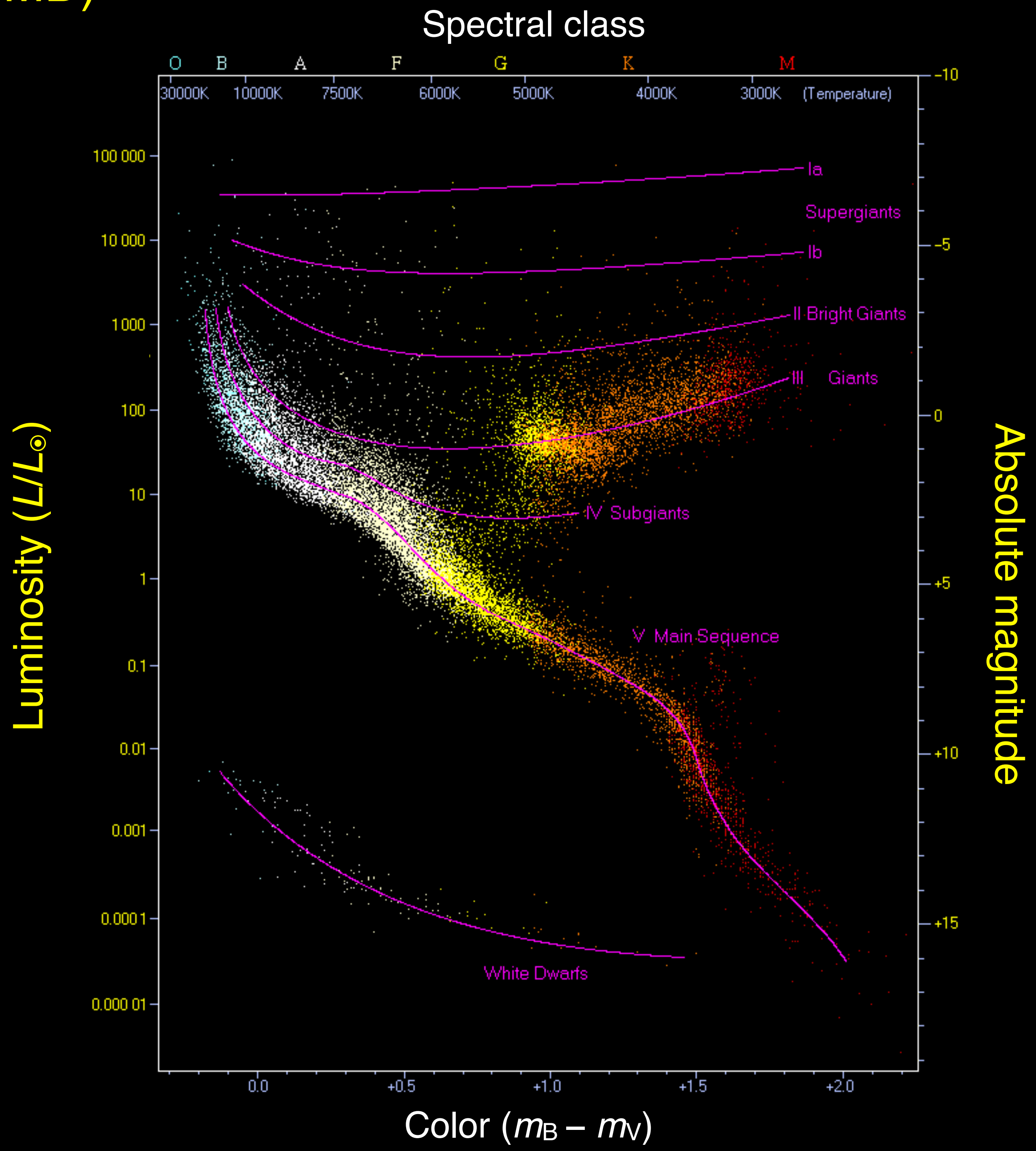
- Luminosity ***L***
- Temperature ***T***
- Radius ***R***

Solar luminosity:
$L_\odot$ = 3.846×10^{26} W =
= 3.846×10^{33} erg/s



Color of stars as substitute for temperature:
Color Magnitude Diagram (CMD)

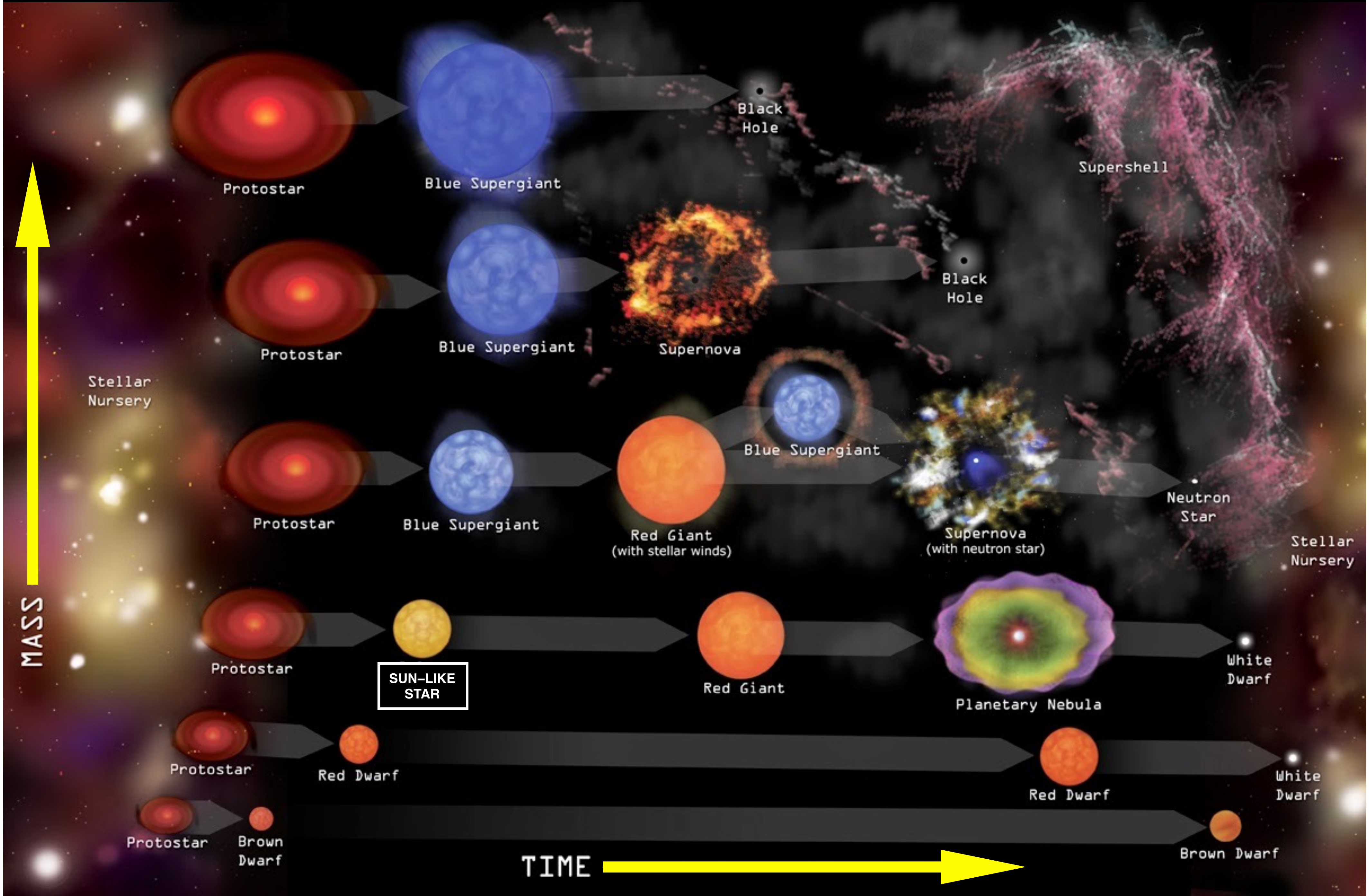
CMD of 23000 nearby stars



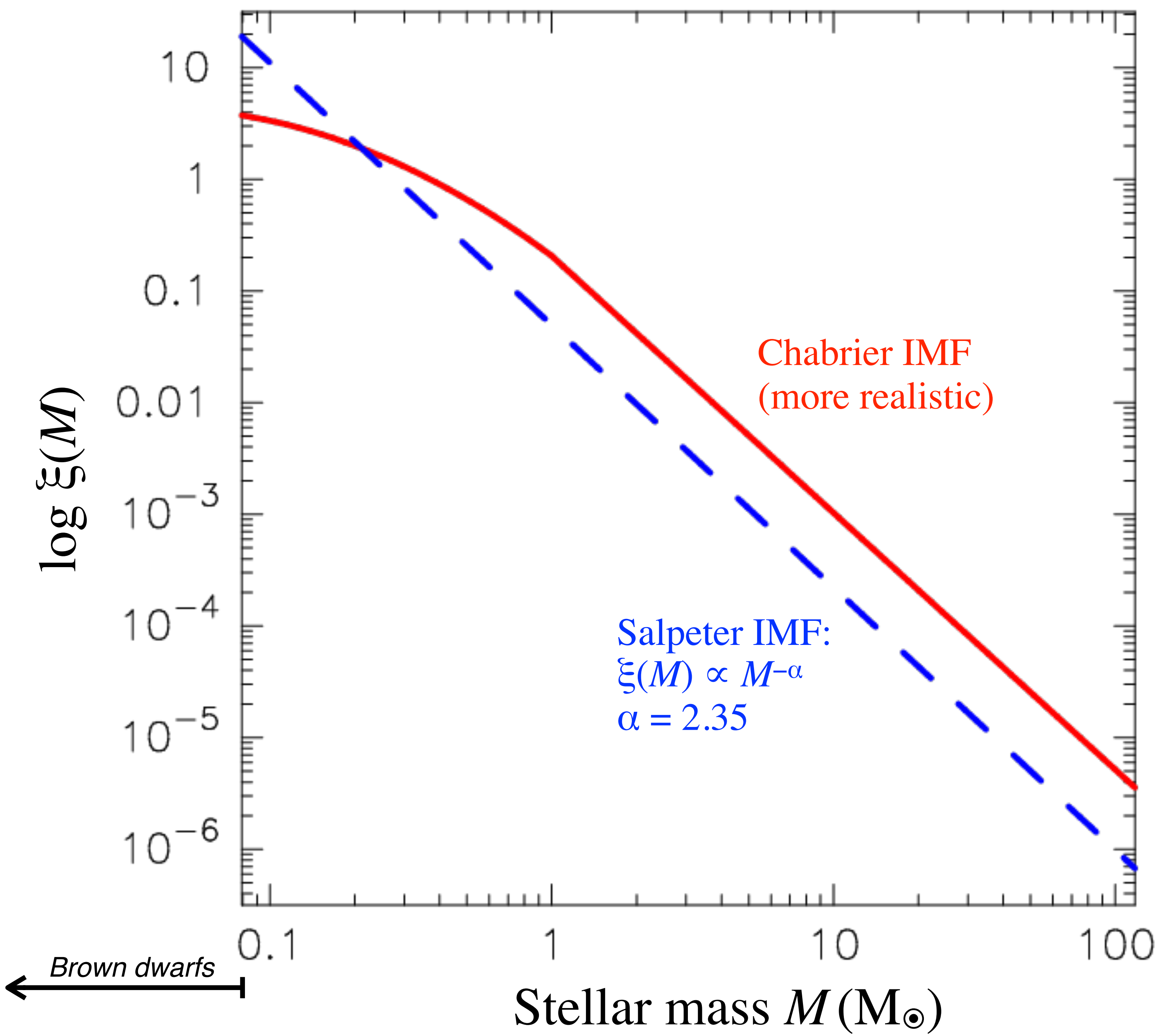
B band magnitude, $\lambda_c = 440$ nm

V band magnitude, $\lambda_c = 550$ nm

Evolution of stars with different mass



Stellar initial mass function (IMF): number of stars per mass interval



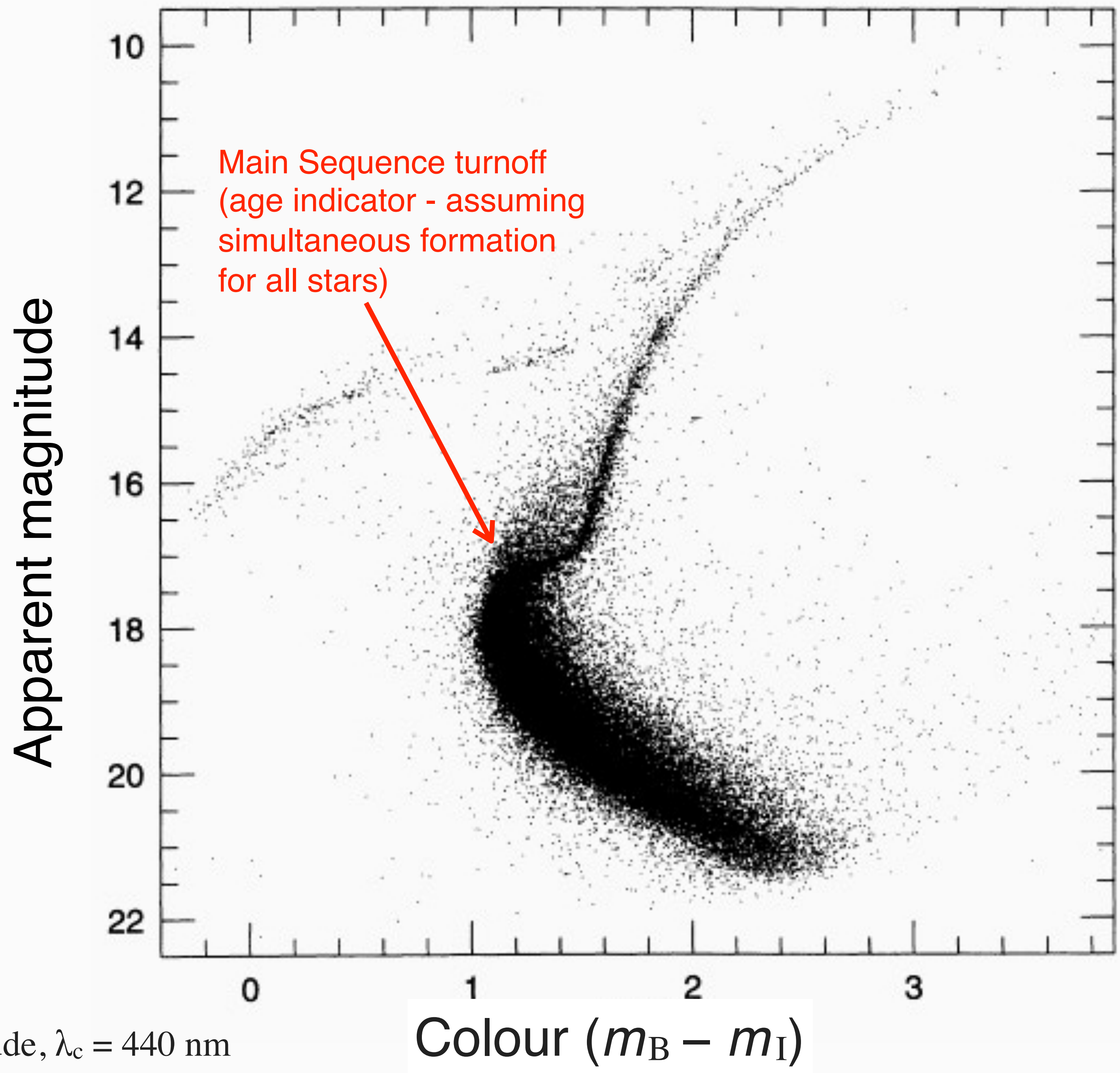
Stellar population with similar age

Stars formed almost simultaneously

NGC 6093
Globular cluster
Distance: 10 kpc
Size: 29 pc

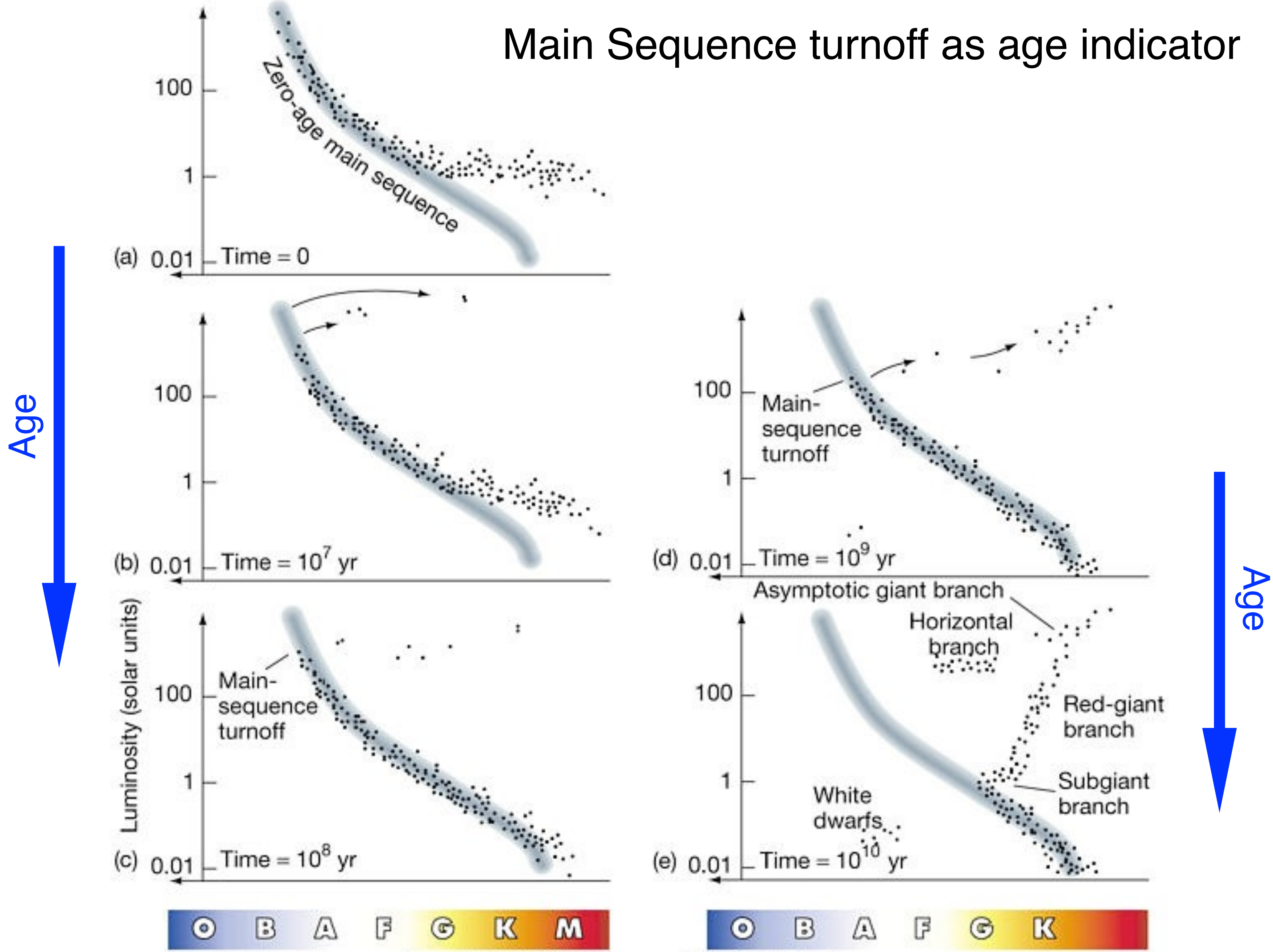
Hubble Space Telescope (HST) image

Typical colour–magnitude diagram for a globular cluster



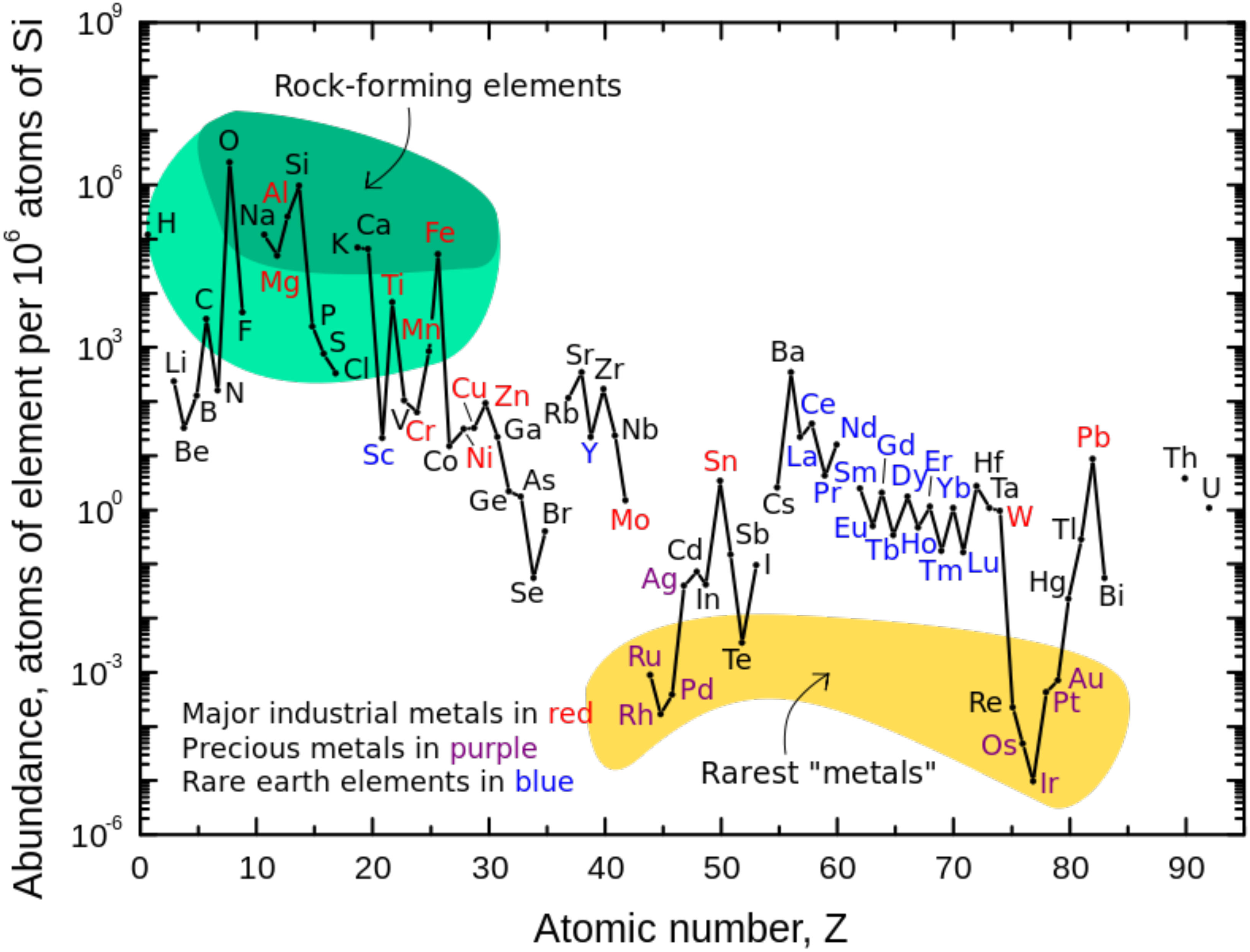
B band magnitude, $\lambda_c = 440$ nm
I band magnitude, $\lambda_c = 660$ nm

Main Sequence turnoff as age indicator

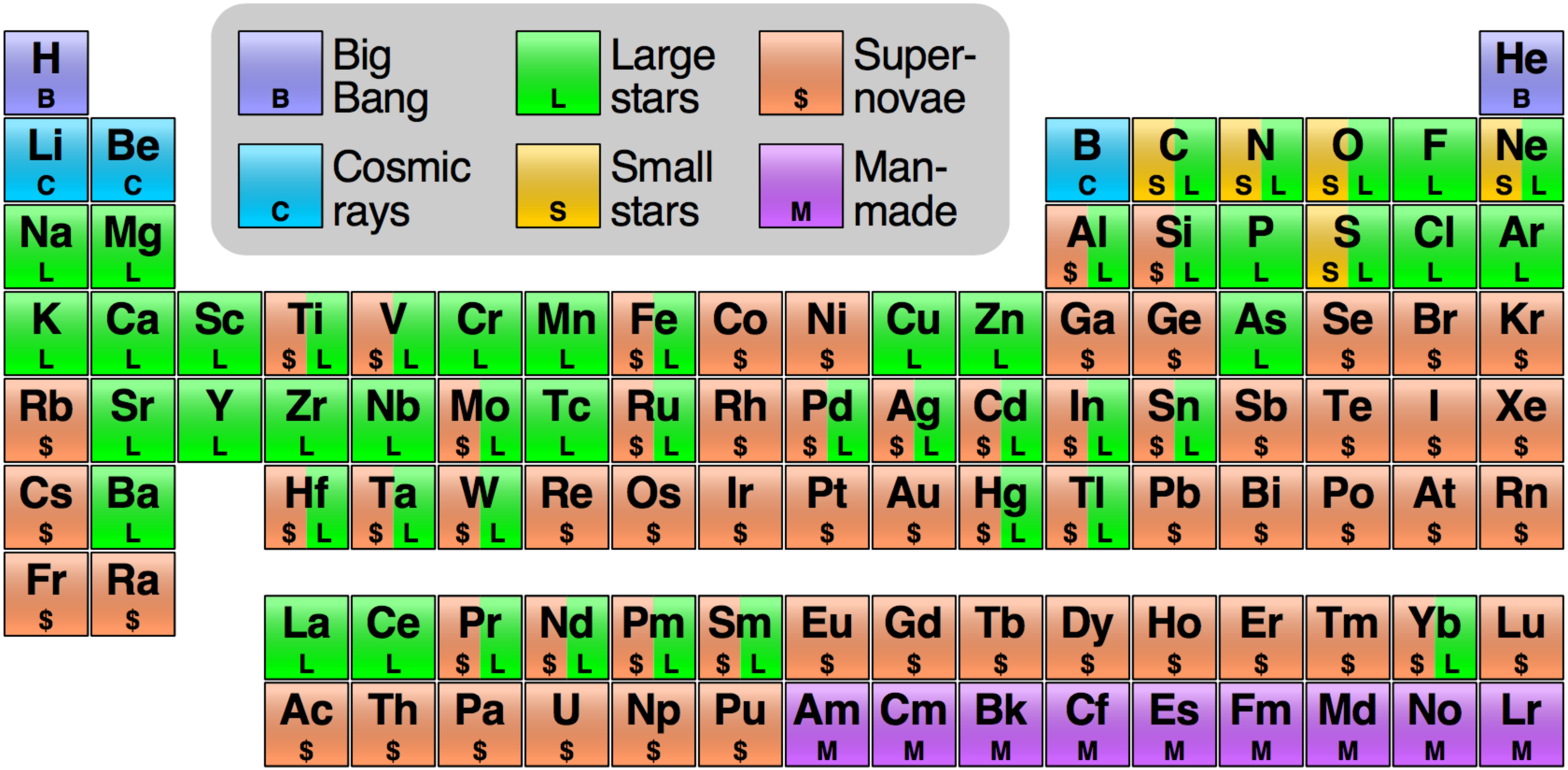


Stars: what are the made of?

Abundance of chemical elements in Earth's crust

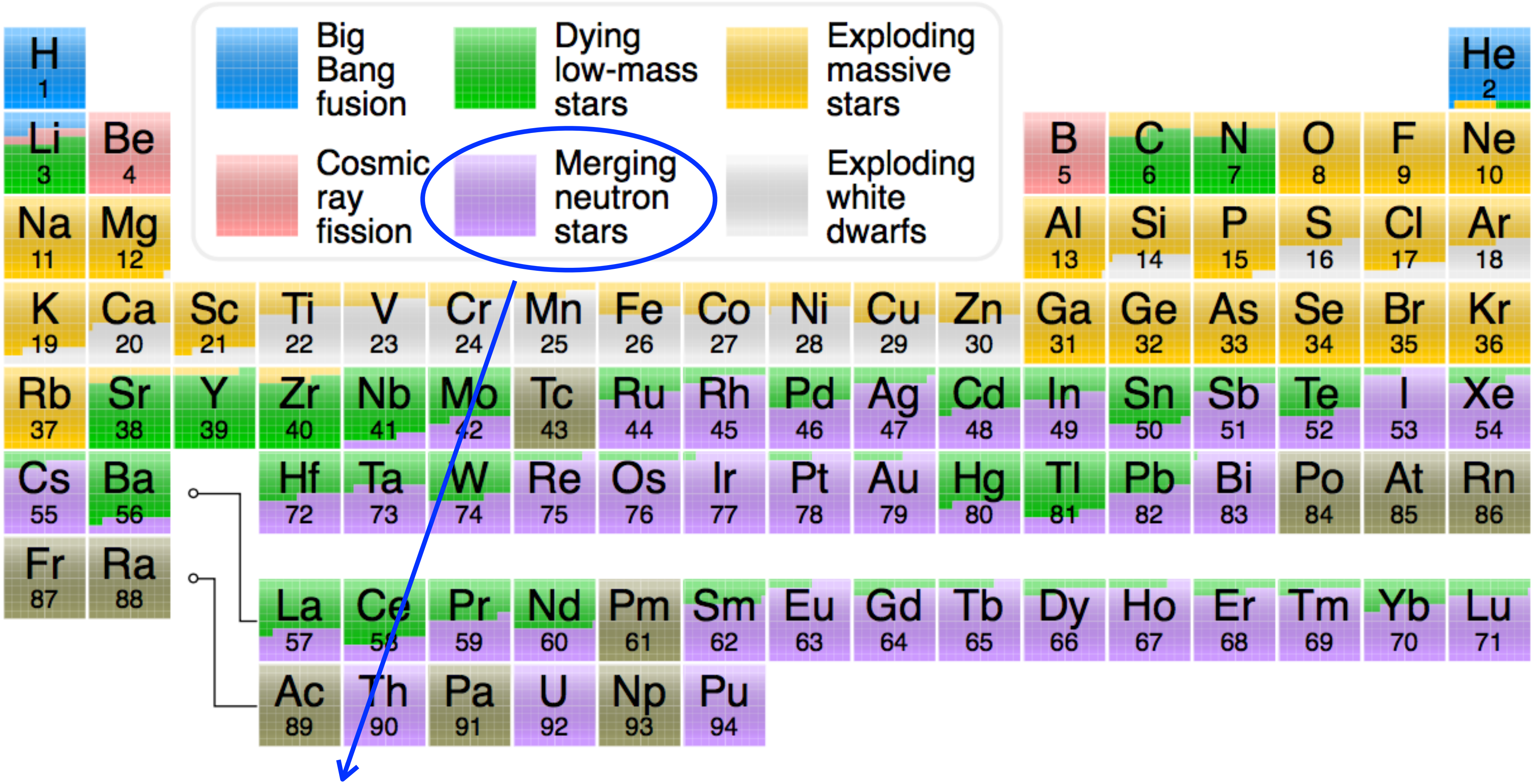


The periodic table of chemical elements (old!)

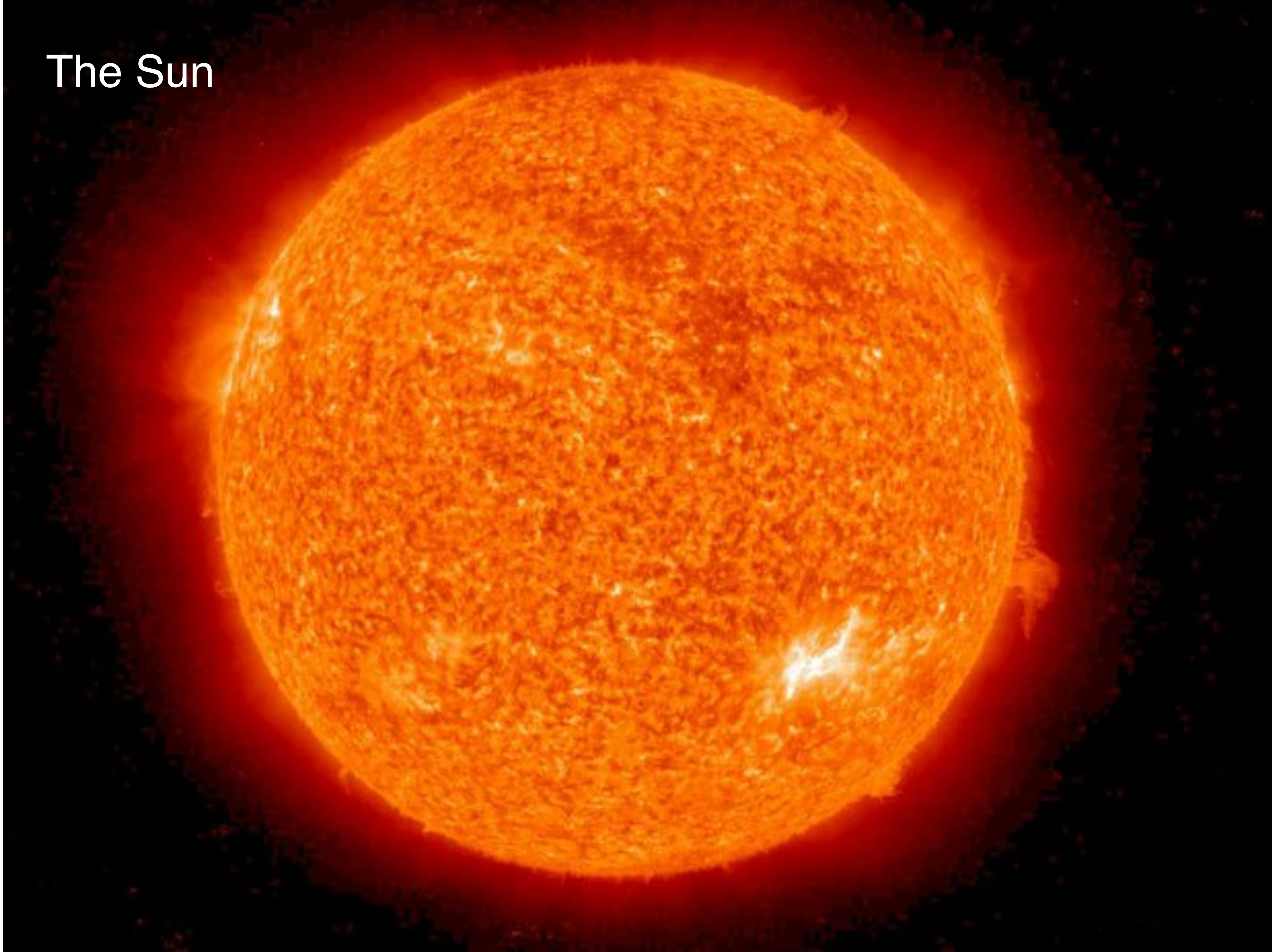


The periodic table of chemical elements today

(reviewed after gravitational-wave event detected in August 2017)

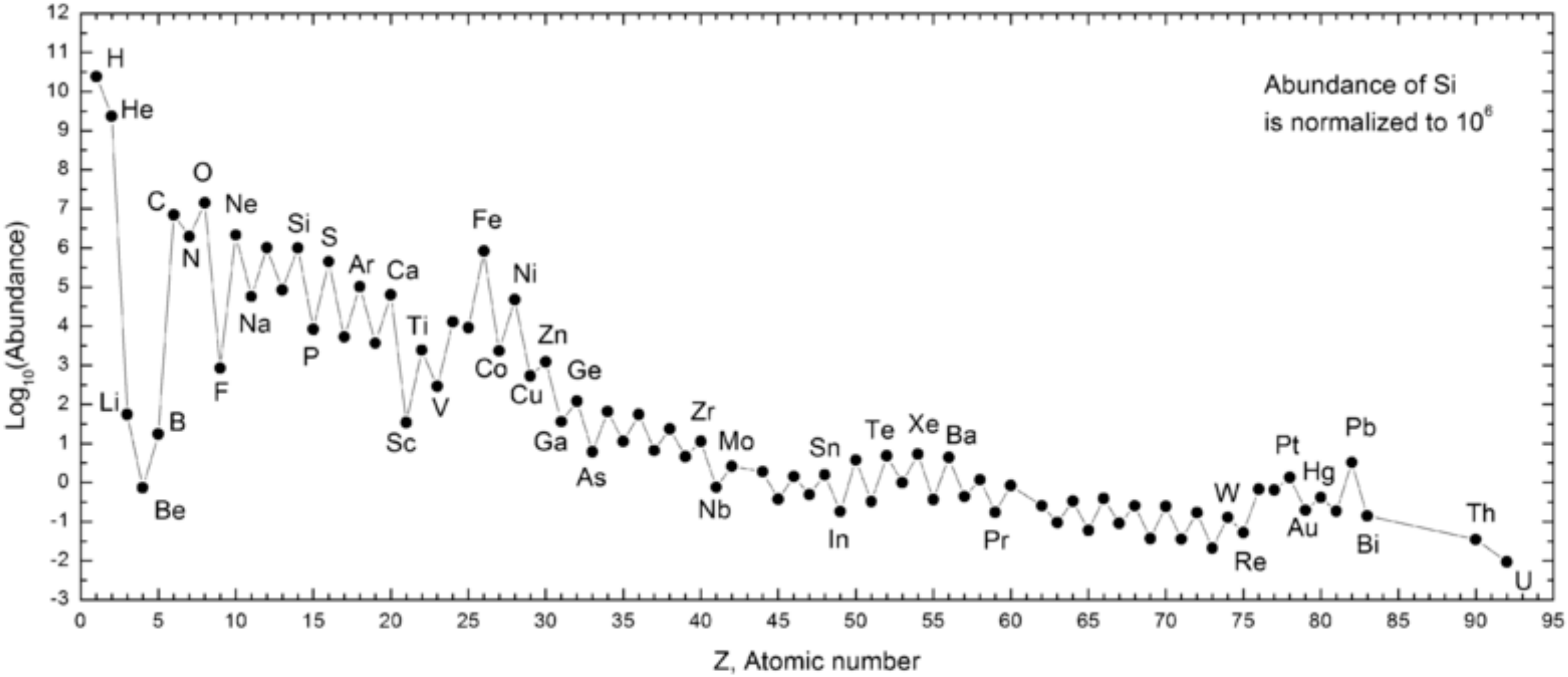


Explosion called *Kilonova* and discovered thanks to simultaneous detection of GW and EM emission for same event


The Sun

Abundances of chemical elements in the Solar system

Peaks are α elements, particularly stable because multiple of alpha particle



α elements: multiple of alpha particle

(alpha particle is made of 2 protons & 2 neutrons ⟾ He nucleus)

Chemical composition after primordial nucleosynthesis (20 minutes after Big Bang)

Element	**Mass(X) / Mass(total)**
H	0.78
He	0.22
Z	$< 10^{-9}$

Z: all elements heavier than helium (called metals)

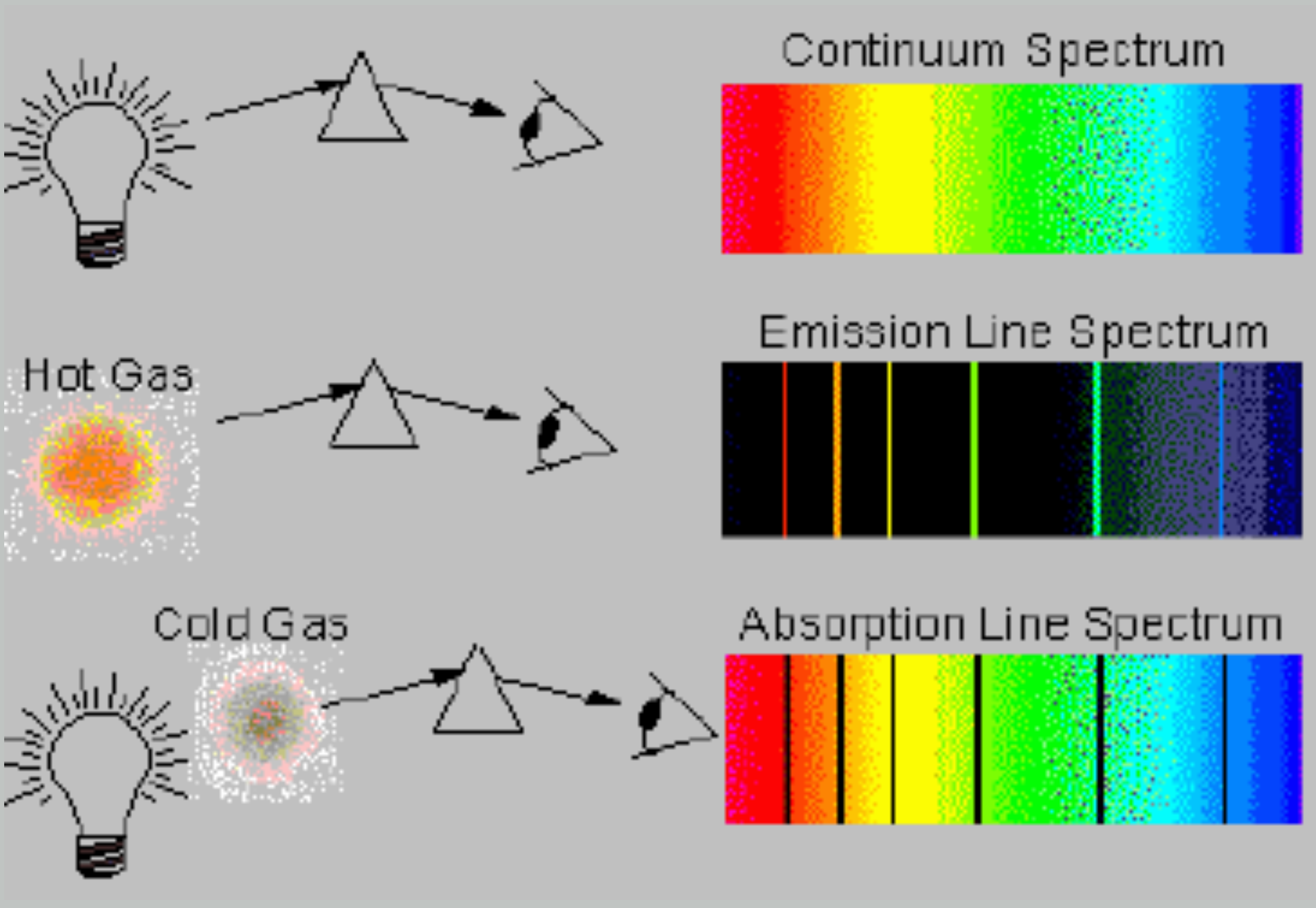
Cosmic cycling of matter (and chemical enrichment)
happened 3 times in the universe
The Sun is a 3rd generation star (**Population I**)

Abundances of chemical elements in the Solar system (13.7 Gyr later)

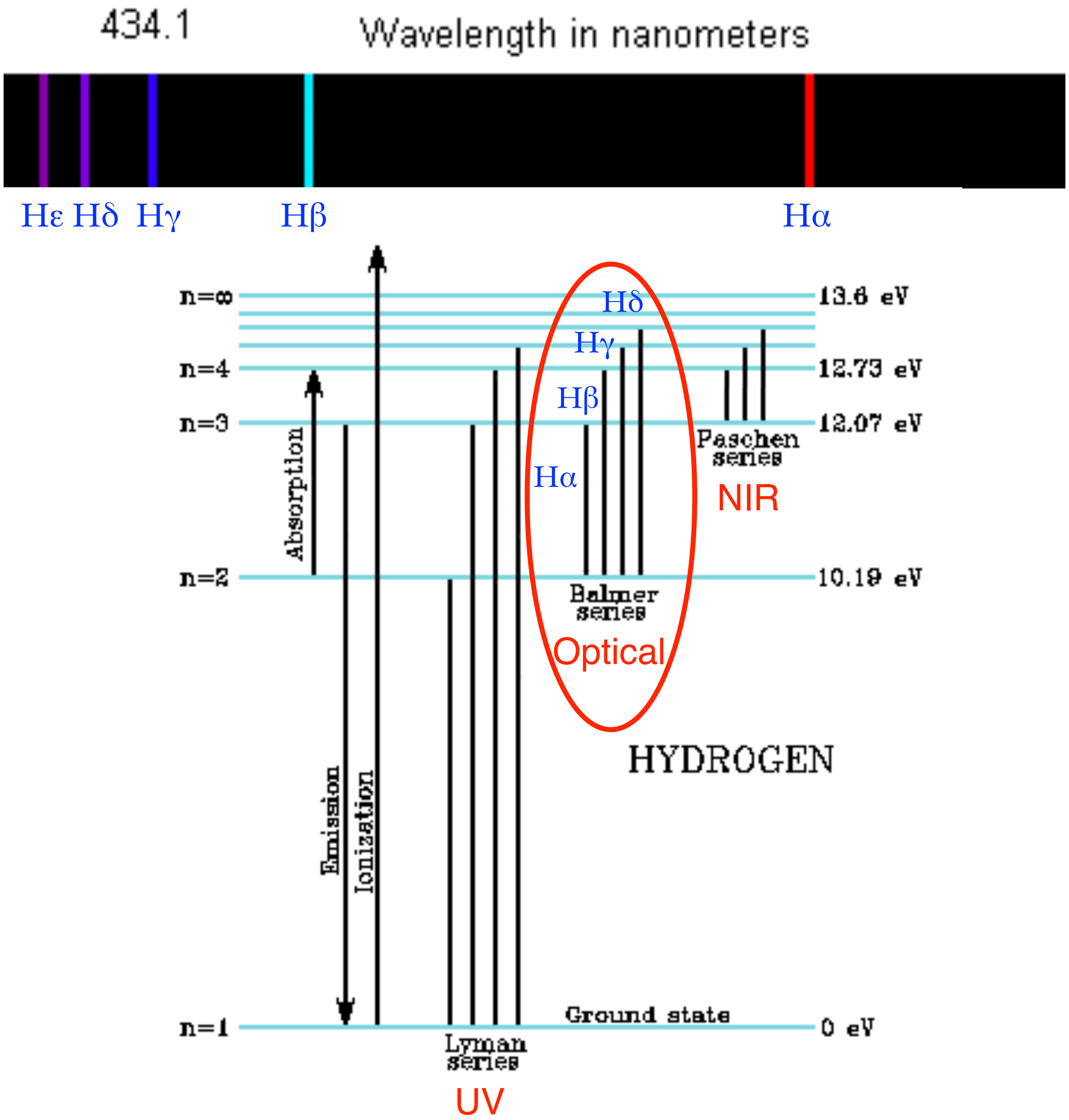
Element	**#particles**	**Mass(X) / Mass(total)**
H	92.1%	0.74
He	7.8%	0.25
Z	0.1%	0.014

Chemical composition of solar system from meteorites

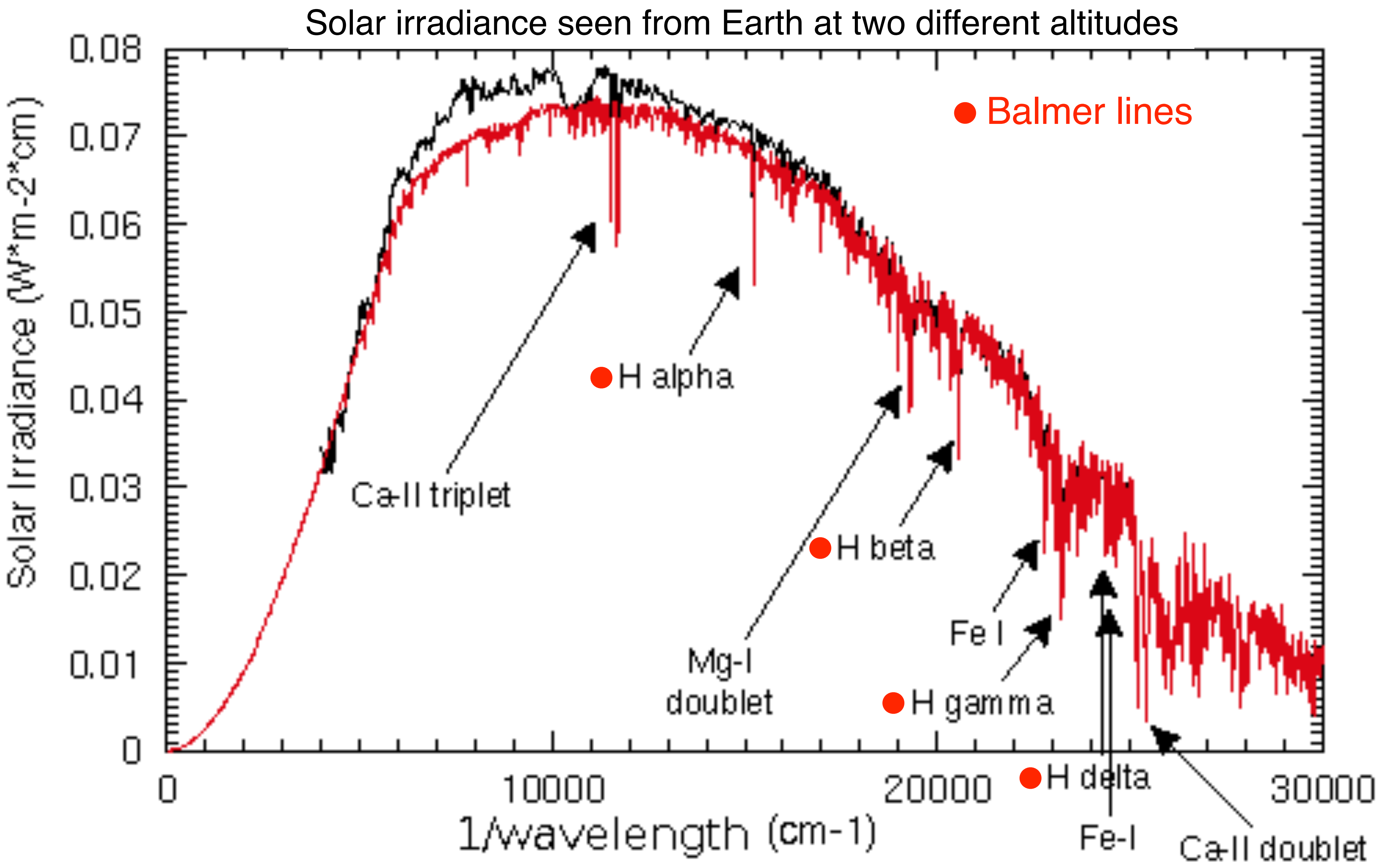
Chemical composition of gas using emission and absorption lines



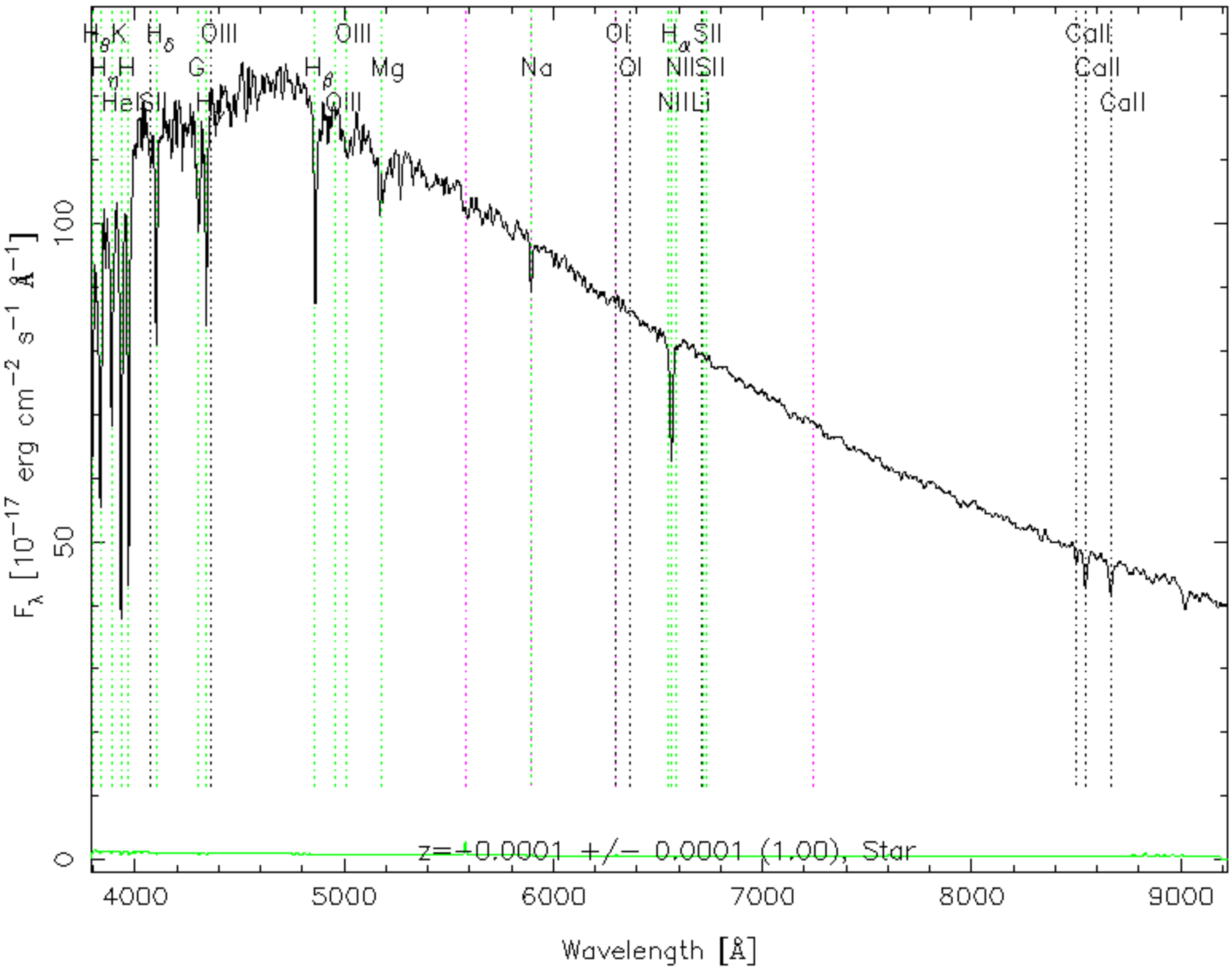
Energy levels and Balmer lines in hydrogen atom



The spectrum of the Sun to study the chemical composition



Chemical composition of stellar atmosphere



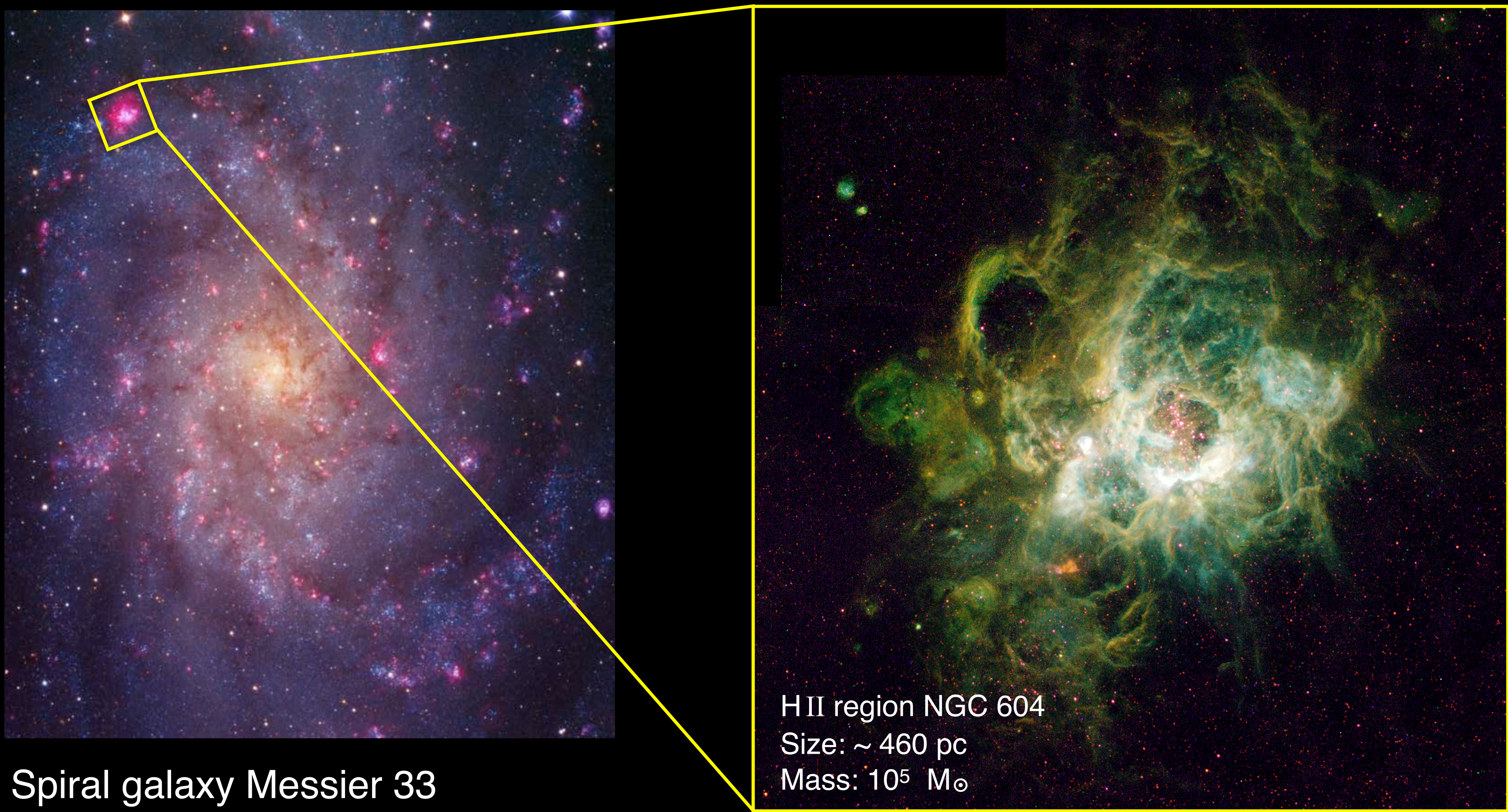
Interstellar medium: gas present between stars

Signature: atomic & molecular features in spectra,
reddening due to dust

Ionised gas in regions of star formation

H II is indicating ionised hydrogen H^+

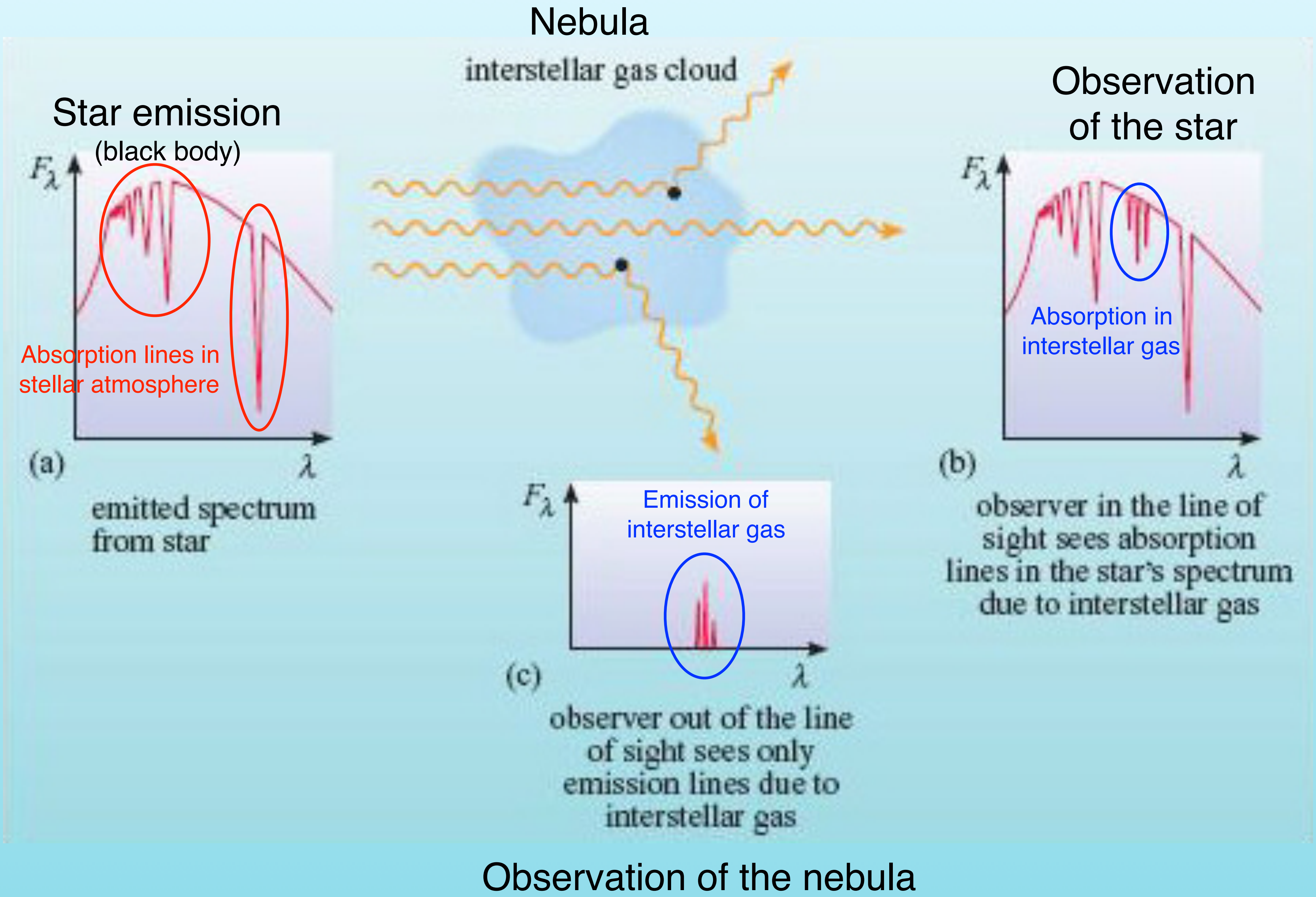
Ionised hydrogen in a star-forming region
(called H II region)



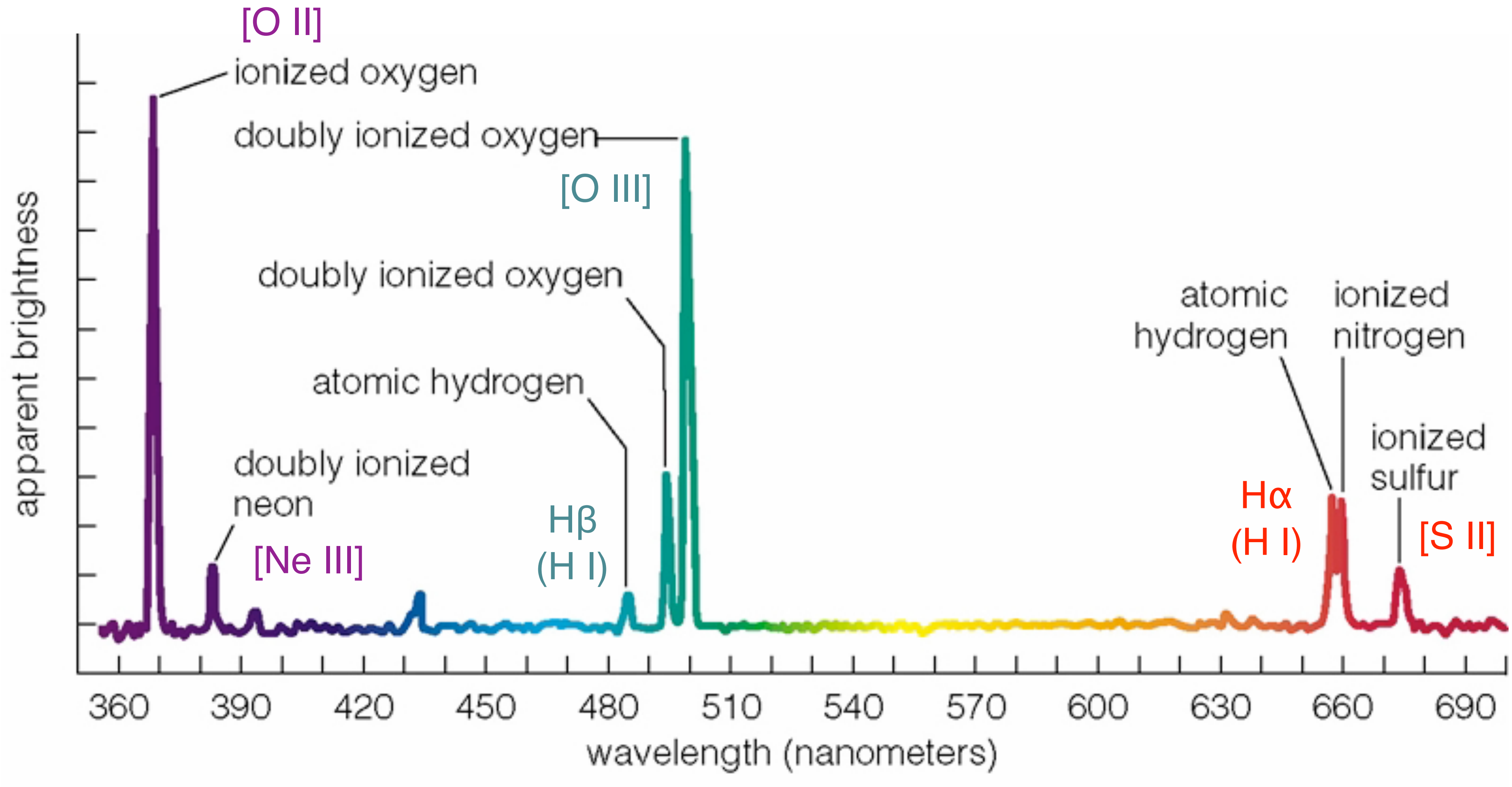
H II region NGC 604
Size: ~ 460 pc
Mass: 10^5 $M_\odot$

Spiral galaxy Messier 33
Distance: 840 kpc

Emission lines in a gas nebula



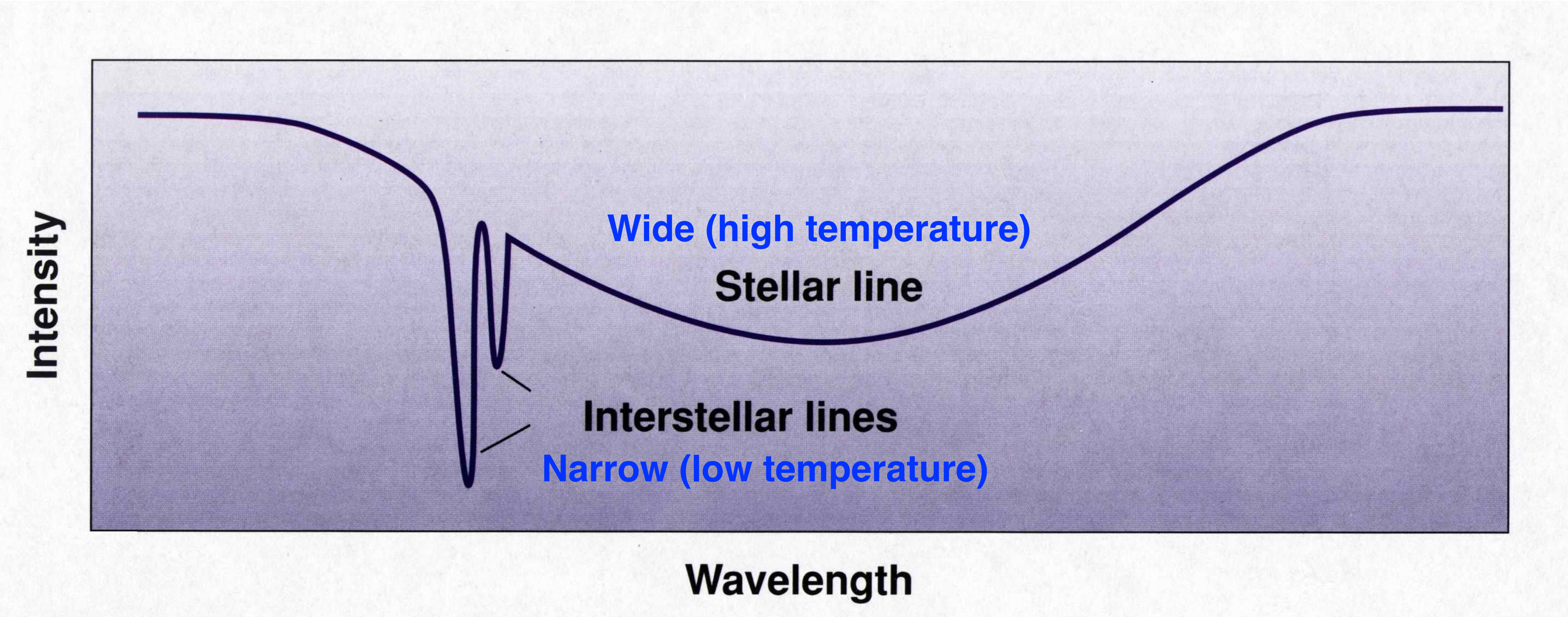
Emission lines in the optical band observed in H II regions



Emission lines are from hydrogen, oxygen, neon & sulfur

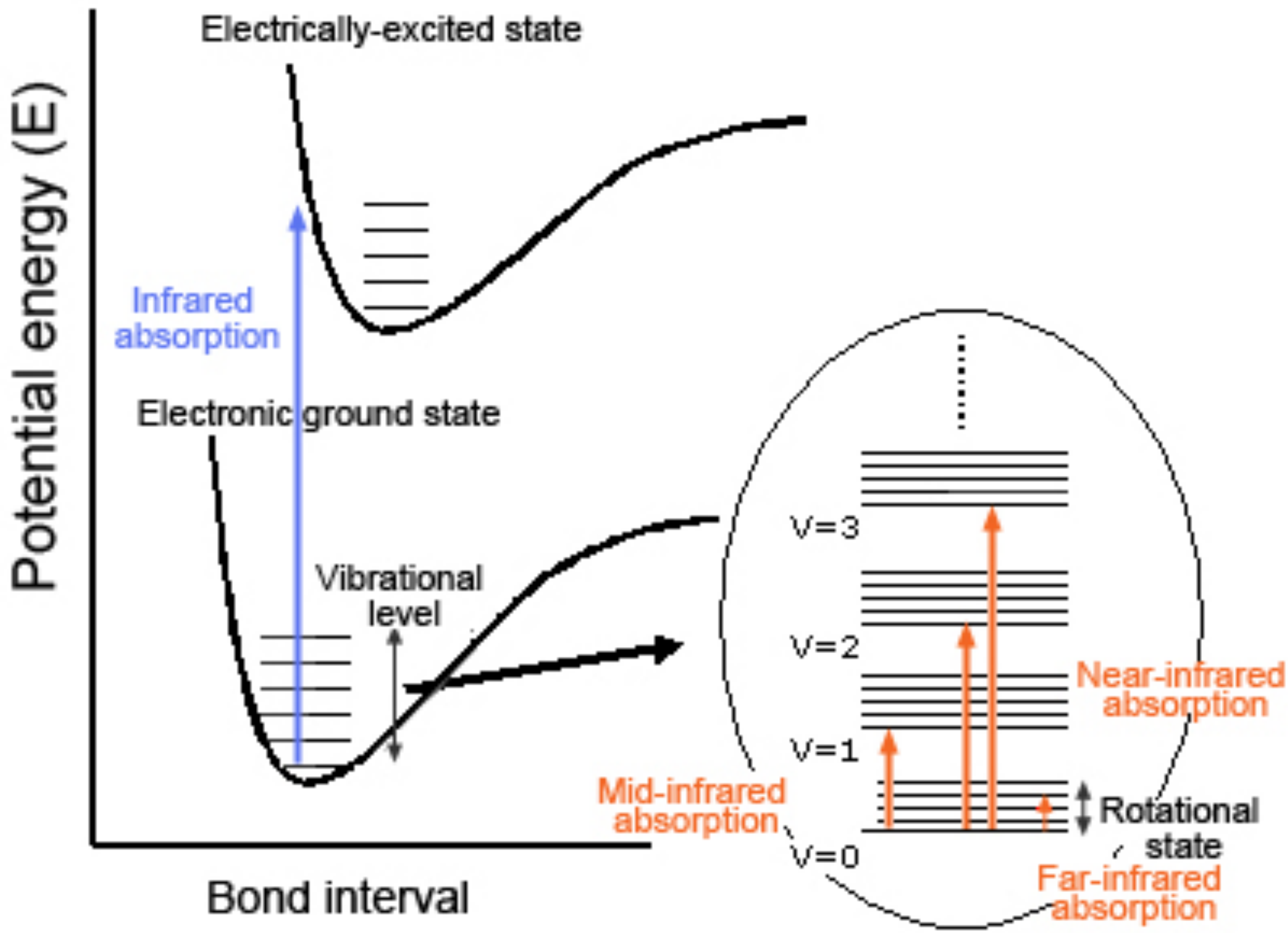

Absorption in dense gas clouds
Dense cloud
“Black Cloud” B68
Distance: 160 pc
Diameter: ~ 0.2 pc

Absorption lines in the interstellar medium & stellar atmosphere



Spectral lines due to molecules in gas clouds

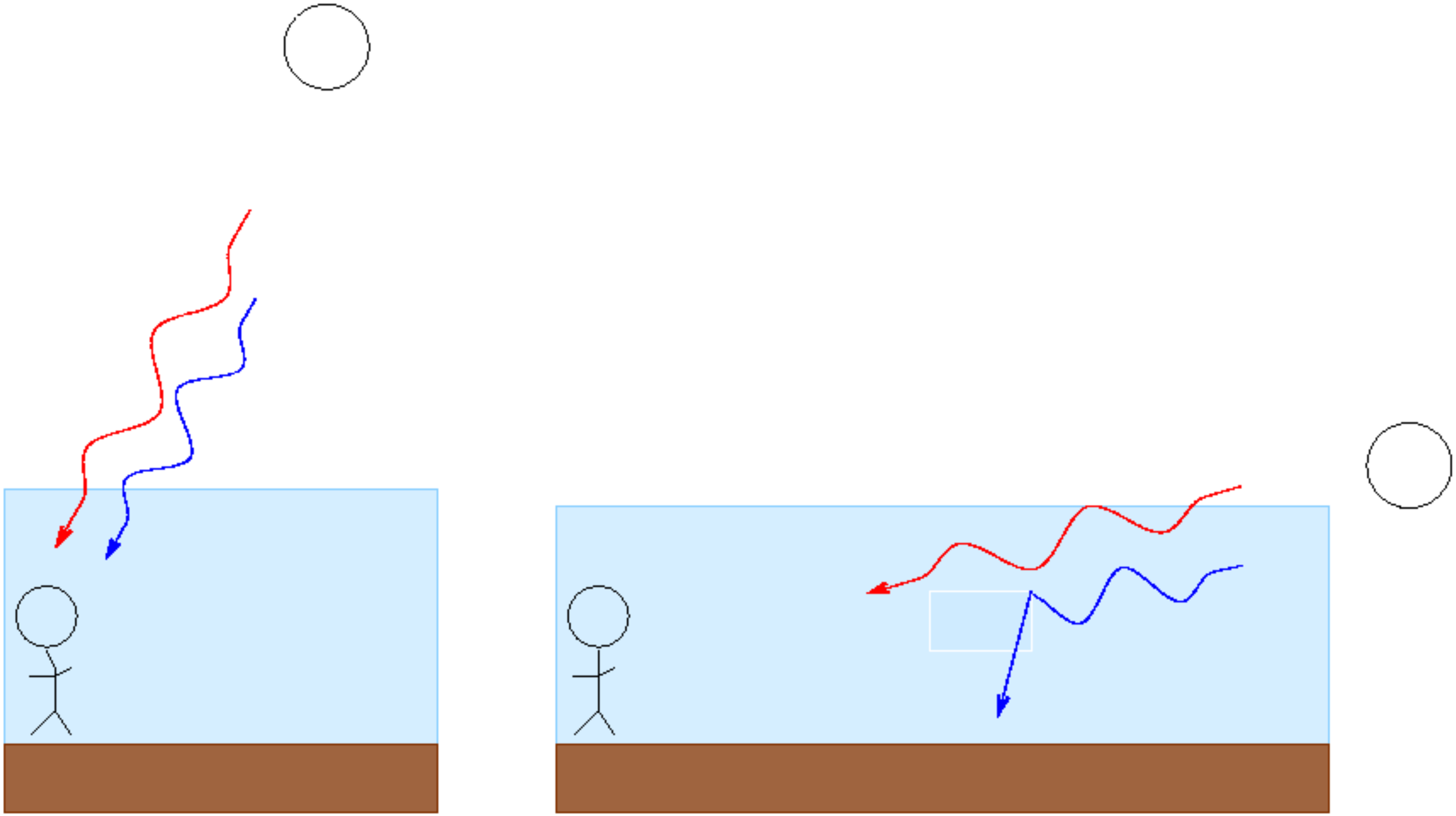
vibrational transitions (periodic motion of atoms in molecule): $E = 10^{-1}$ eV (IR)
rotational transitions (change of angular momentum in molecule): $E = 10^{-3}$ eV (microwave)



(Internuclear separation)

The presence of dust and its effects

Radiation of Sun far and near horizon

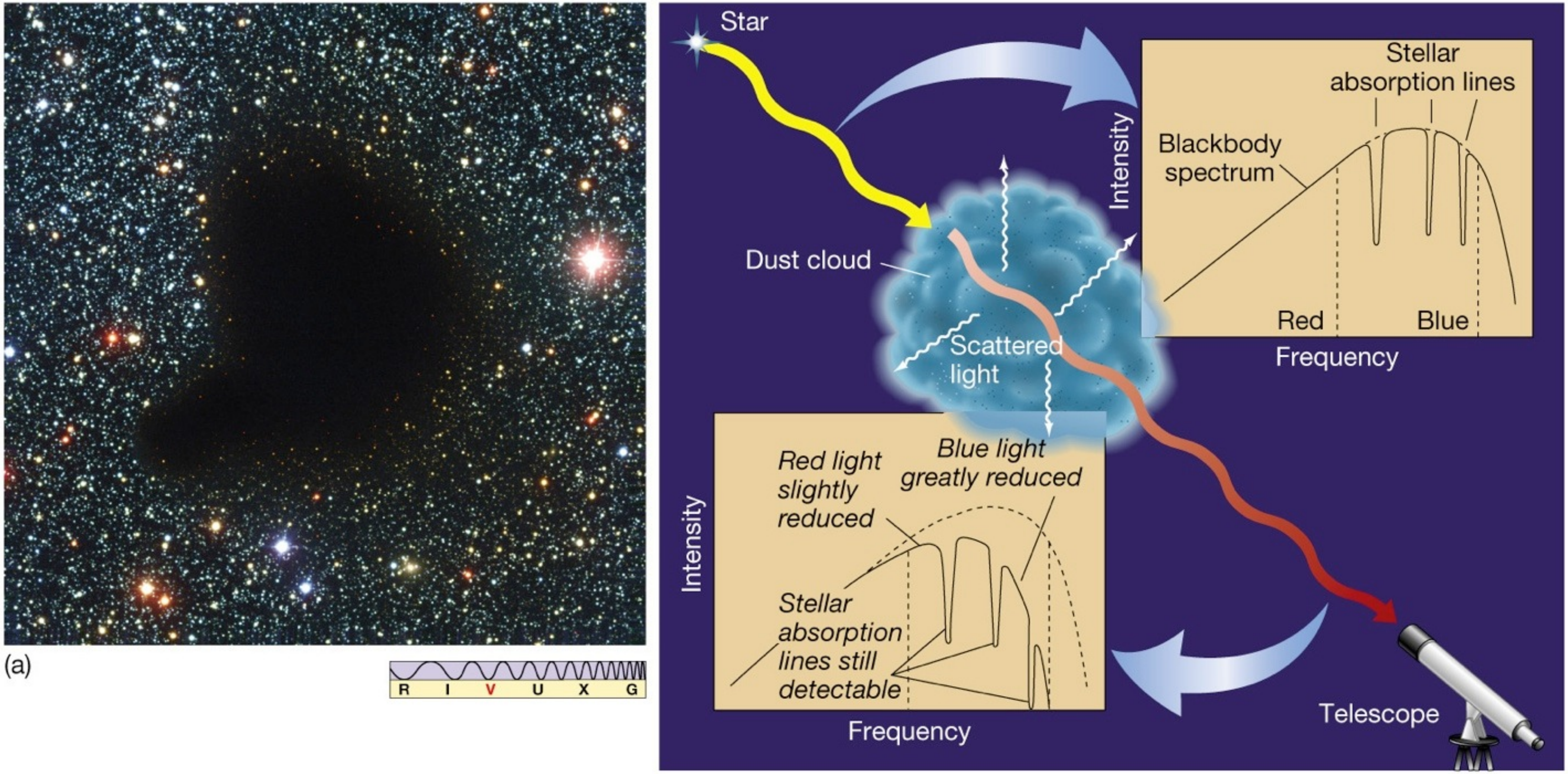


Photons scattered by molecules in atmosphere

Dust in the universe, why it is important:

- It causes extinction (absorption and reddening)
- It is important for the formation of stars
- It absorbs half of radiation emitted in the universe
- This is re-emitted in the far infrared
- In mass, it is 1% of the interstellar medium

Absorption lines in the interstellar medium



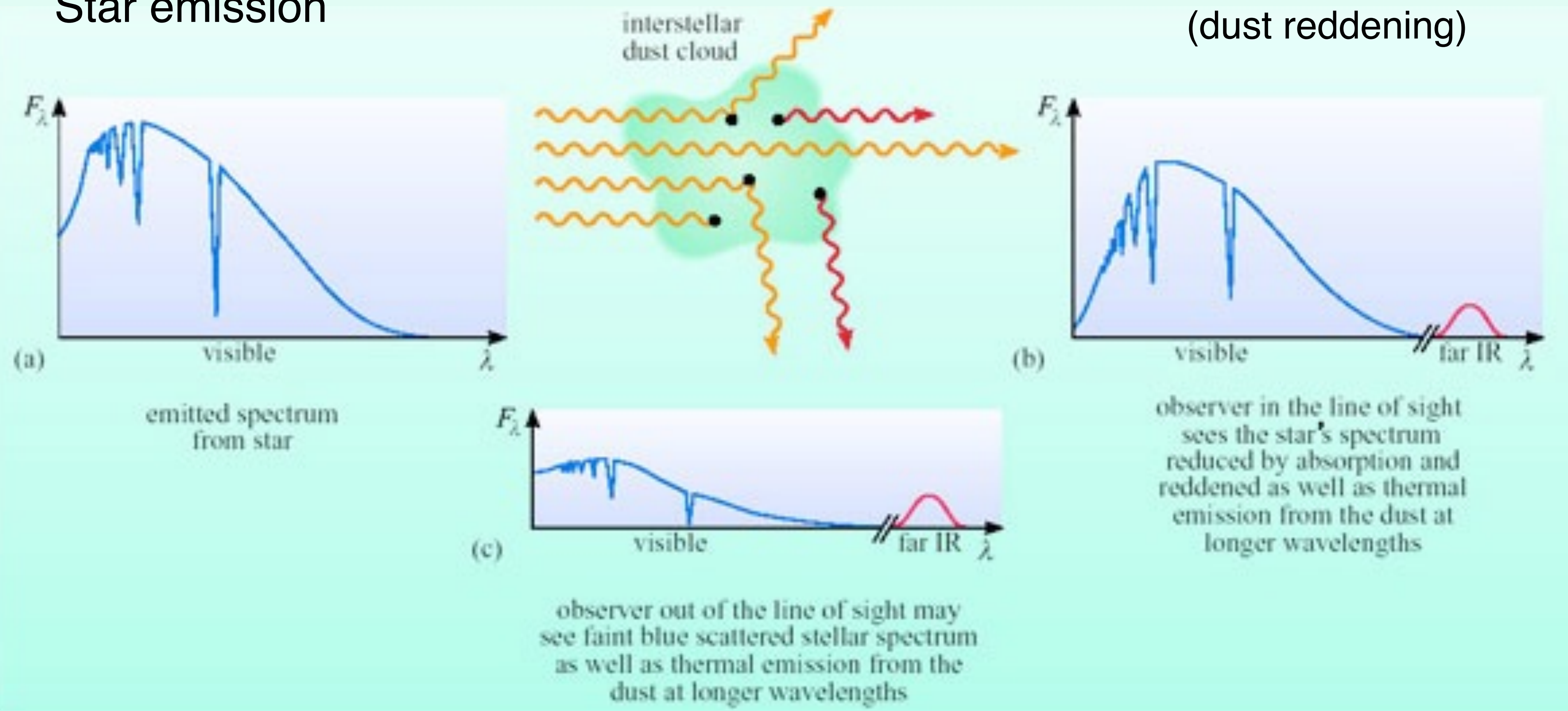
(a) (b)

Scattering of radiation by gas in a nebula

Nebula
(dust scatters & absorbs radiation)

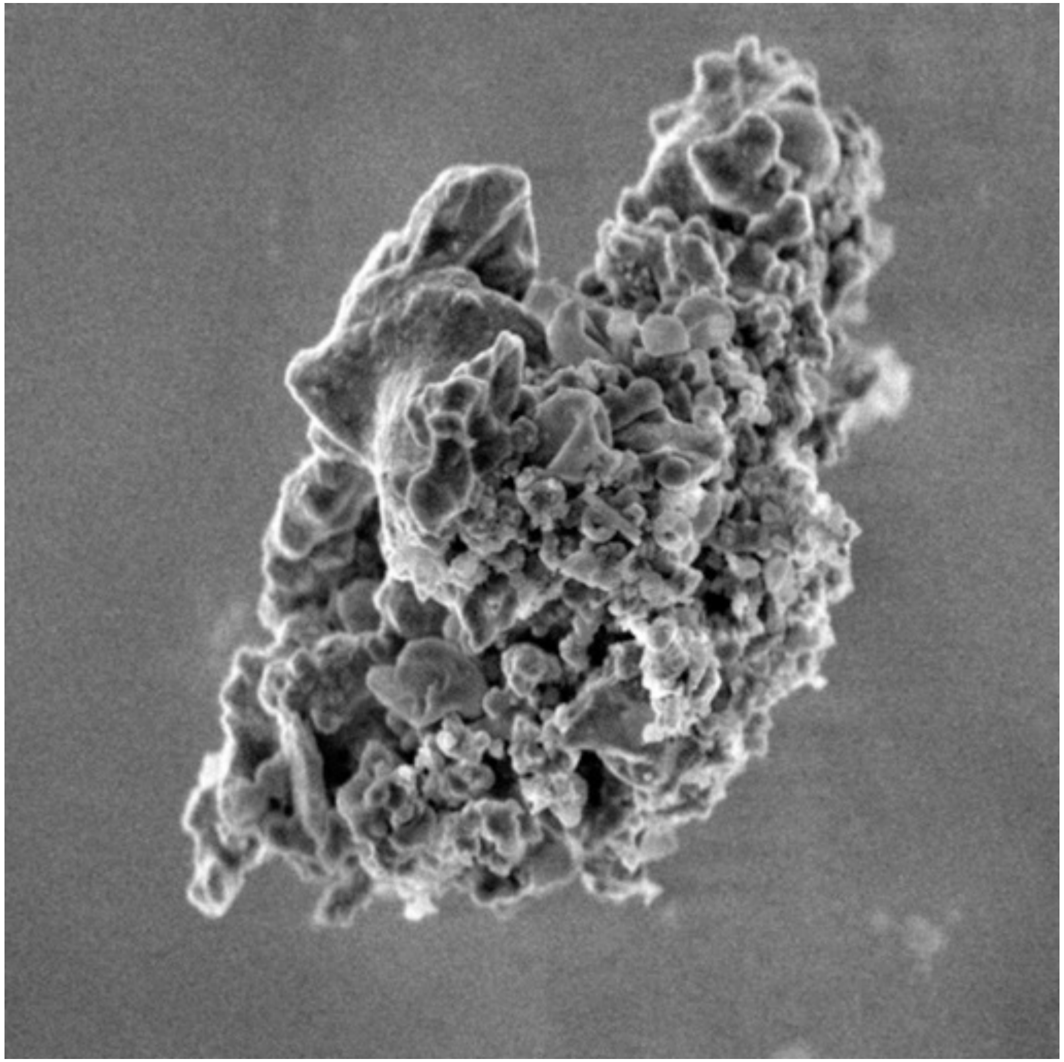
Star emission

Observation of the star
(dust reddening)



Observation of the nebula
dust emission in all directions from far IR to microwave (T a few tens K)

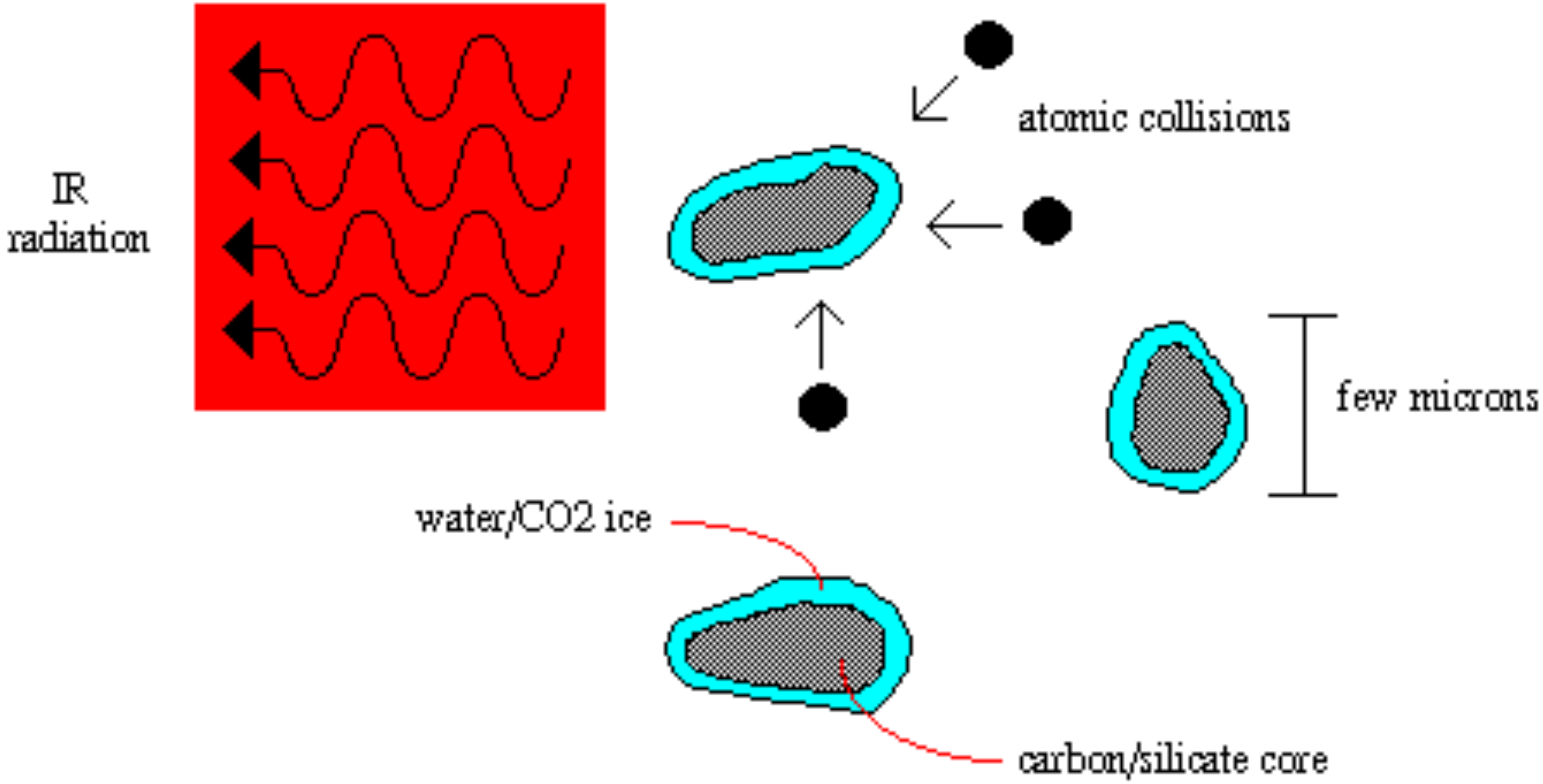
Dust made of silicate and carbon grains



Dust grain size in wide range (mainly in 0.1 – 1 μm)
Small grains much more numerous than large grains (power-law distribution)

Interstellar dust

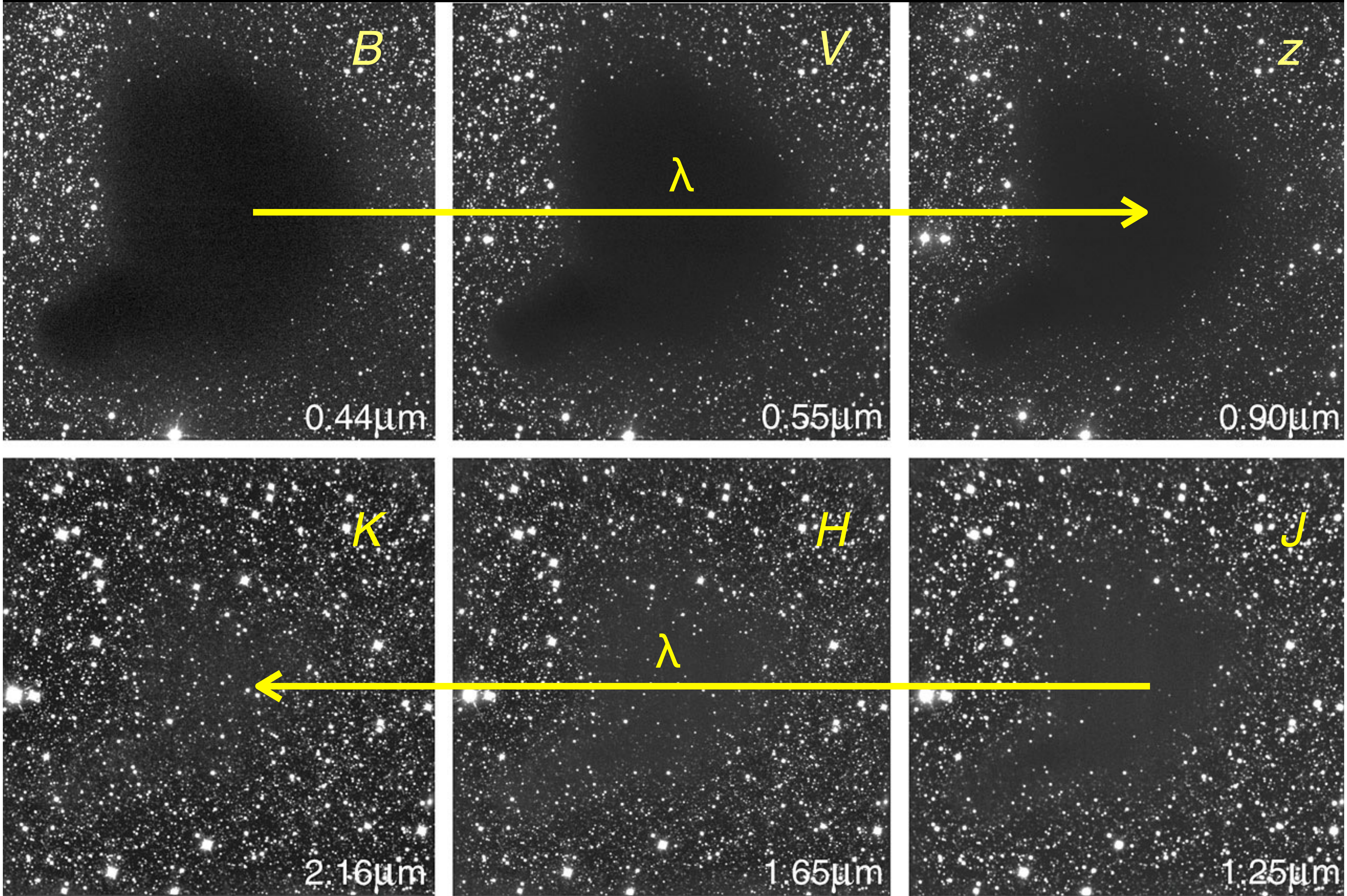
Interstellar dust forms in the envelopes around red supergiants. Their structure is a carbon/silicate core often surrounded by water or carbon dioxide ice. Collisions with atoms causes the dust to emit a thermal spectrum in the IR.



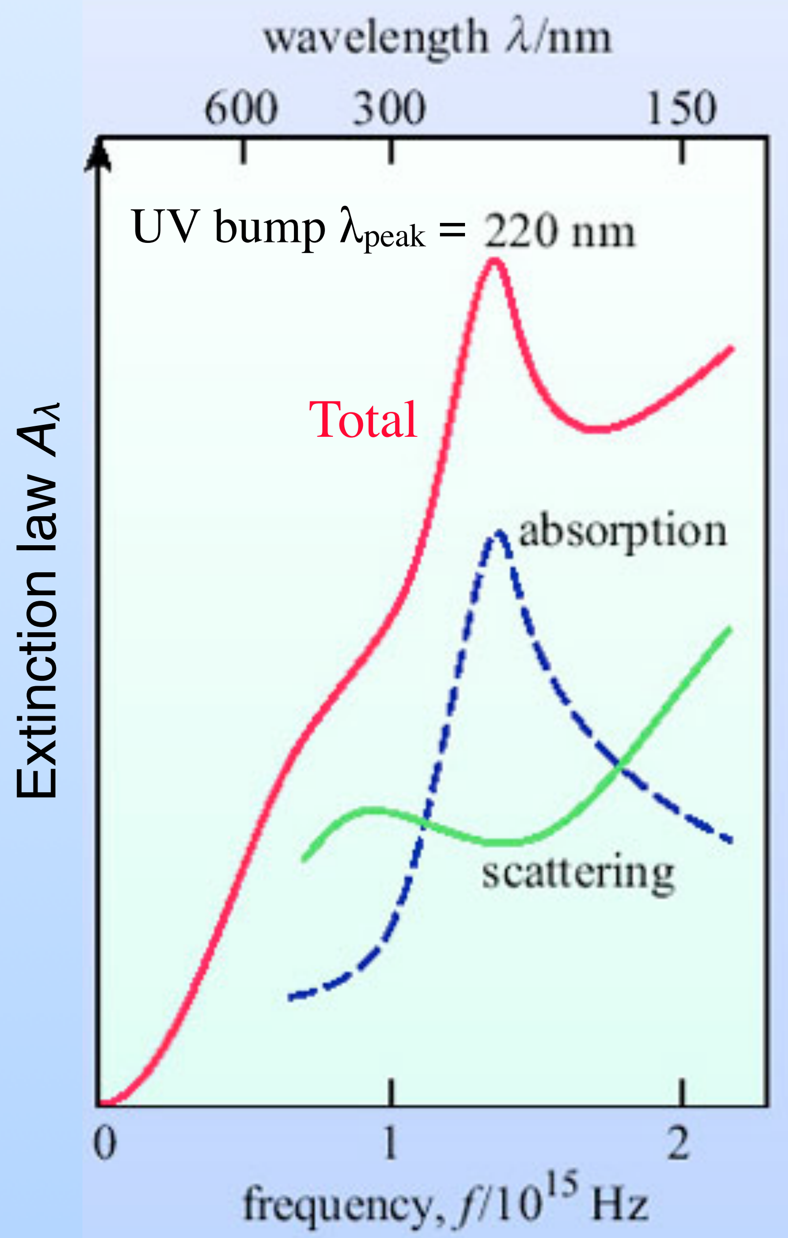
Wavelength dependence of dust extinction


Dust in gas clouds and effects
Dense cloud
“Black Cloud” B68
Distance: 160 pc
Diameter: ~ 0.2 pc

Dense cloud
"Black Cloud" B68



Dust effect as a function of wavelength or frequency: ***extinction law***



A_λ : extinction in magnitudes as a function of wavelength λ

Correcting the observed flux for dust effects:

$F_{\lambda,int} = F_{\lambda,obs} \times 10^{0.4A_\lambda}$

$F_{\lambda,obs}$: observed flux as a function of wavelength

$F_{\lambda,int}$: emitted flux at source (intrinsic)