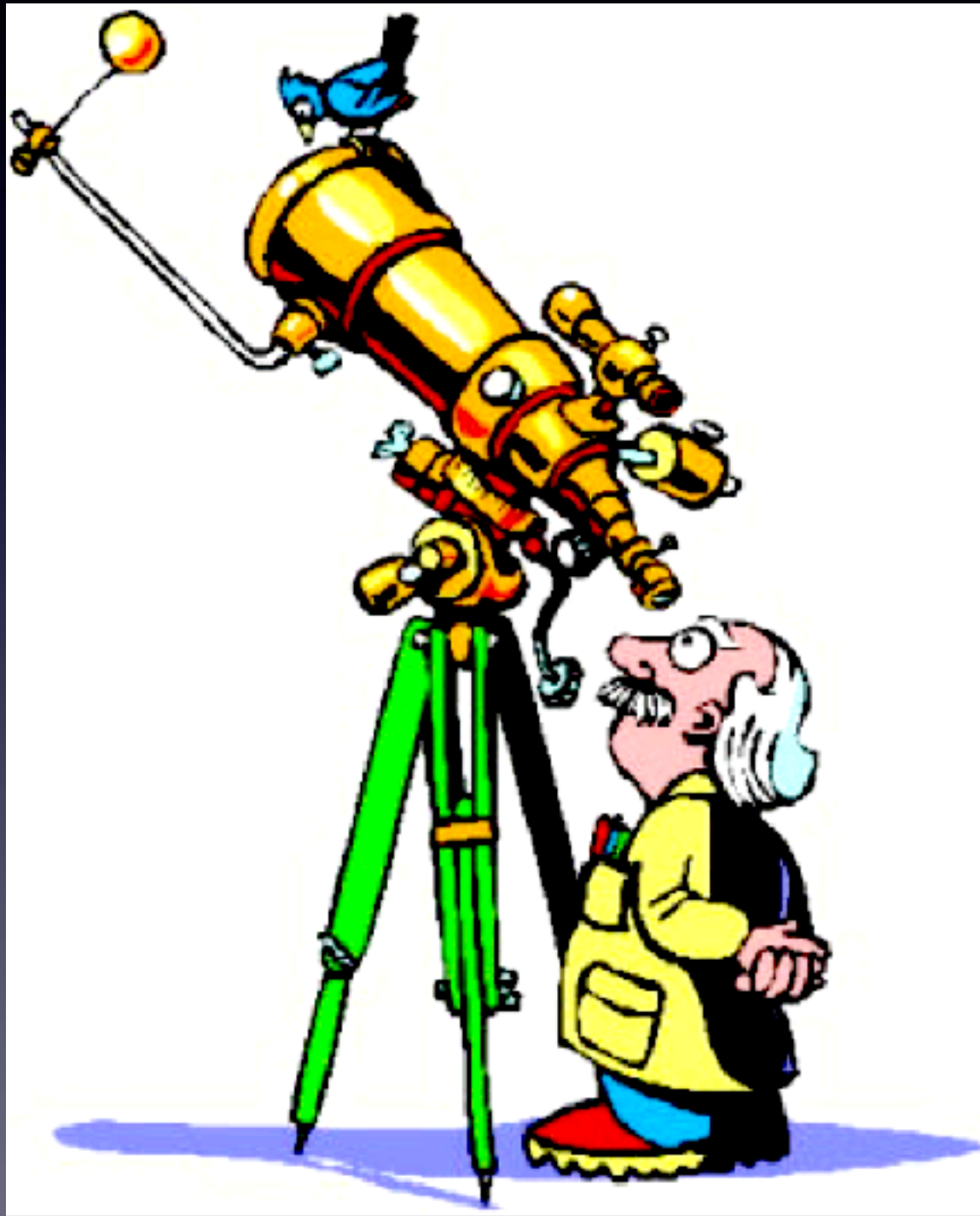


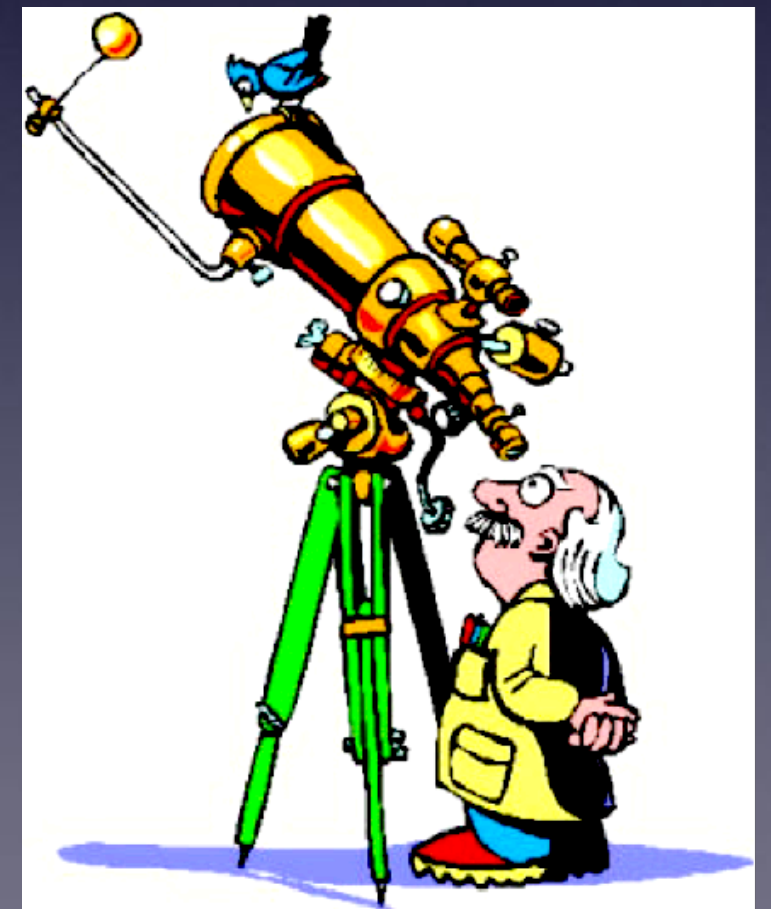
6/30/2026 ASIAA Summer Program



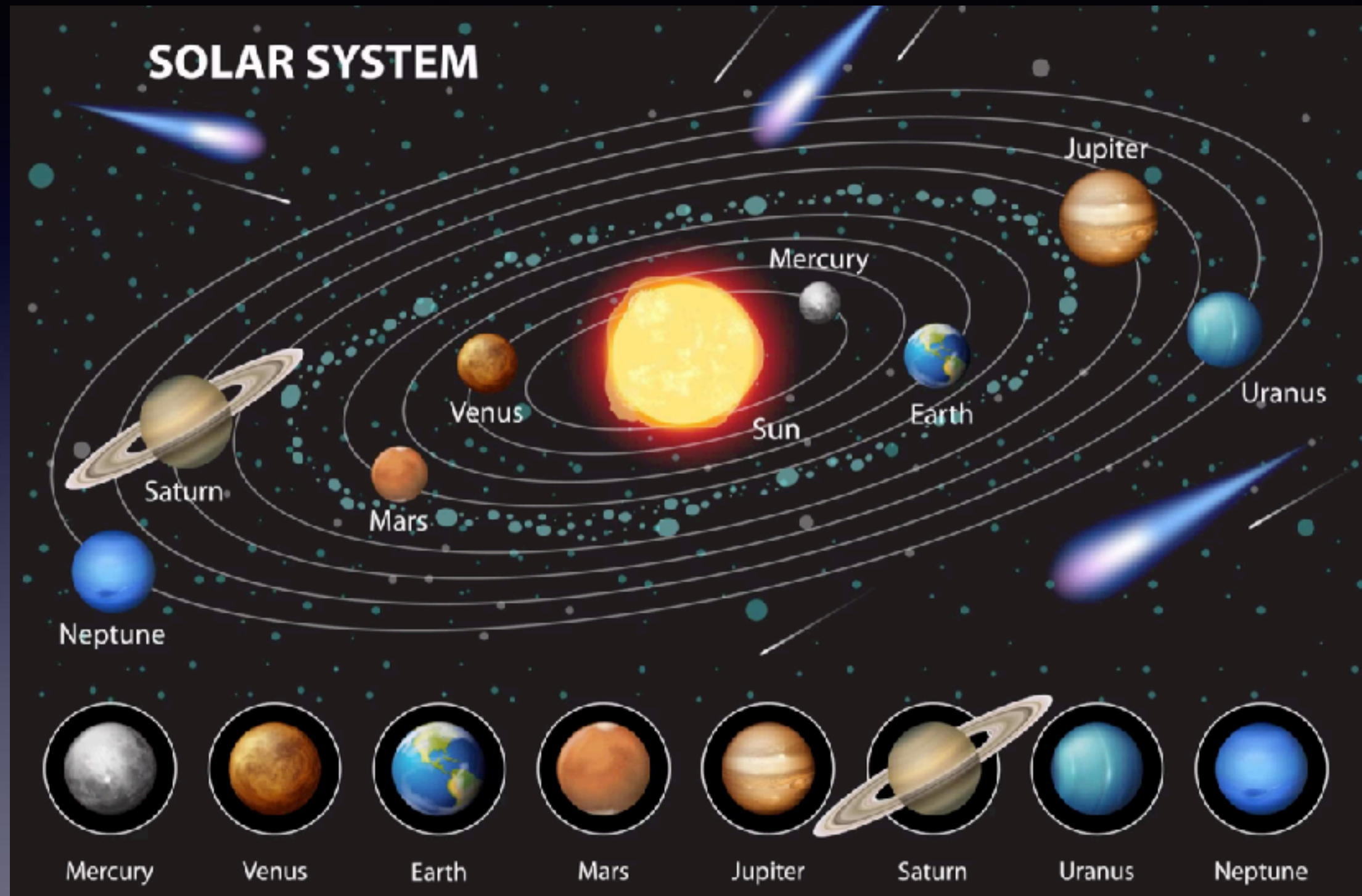
Optical & Infrared Views of the Universe

Lecturer: Hiro Takami

- What are in the universe?
- What are optical & infrared?
- What can be observed in the optical and infrared?
- How do multi-wavelength observations work?
- How does spectroscopy work?

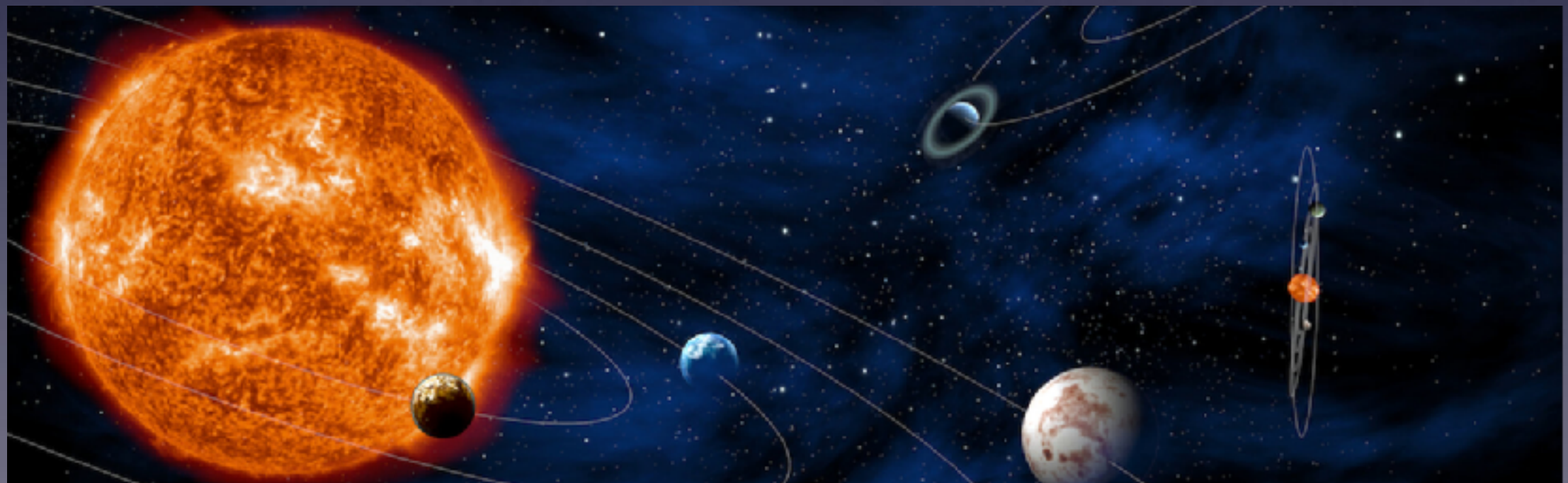
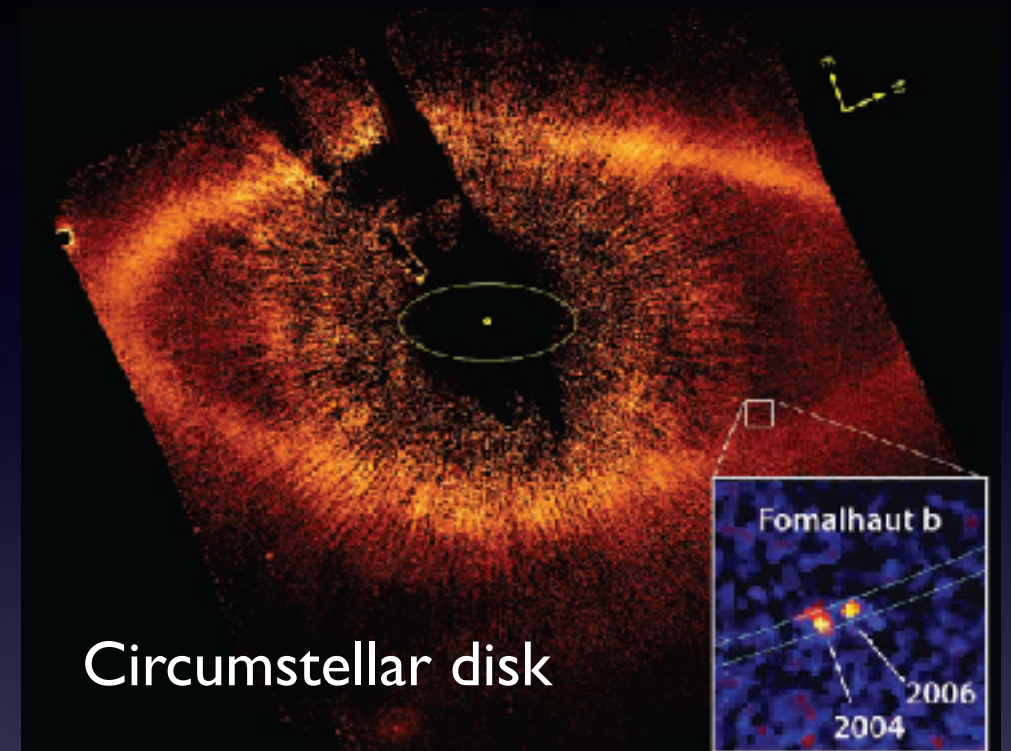


What are in the universe?



<https://www.freepik.com/free-photos-vectors/solar-system-planets>

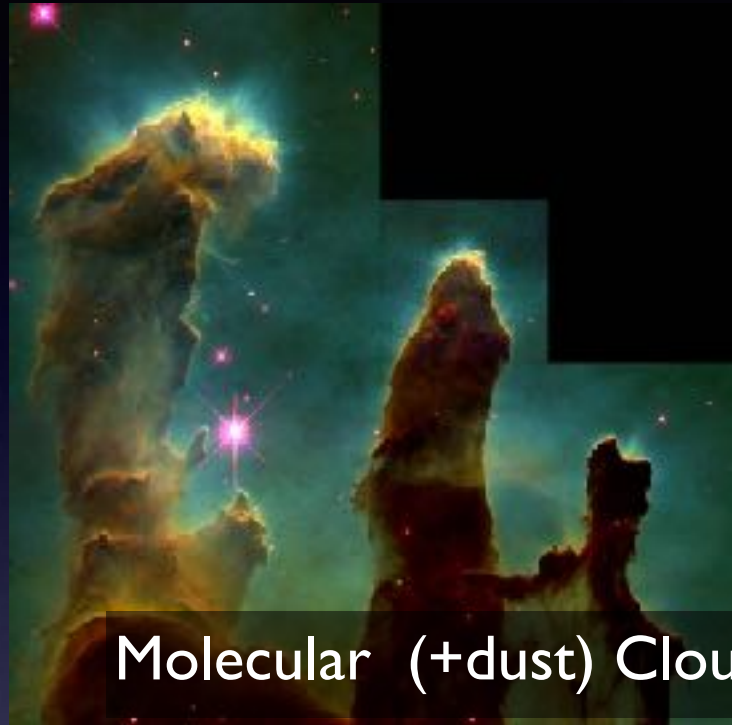
What are in the universe?



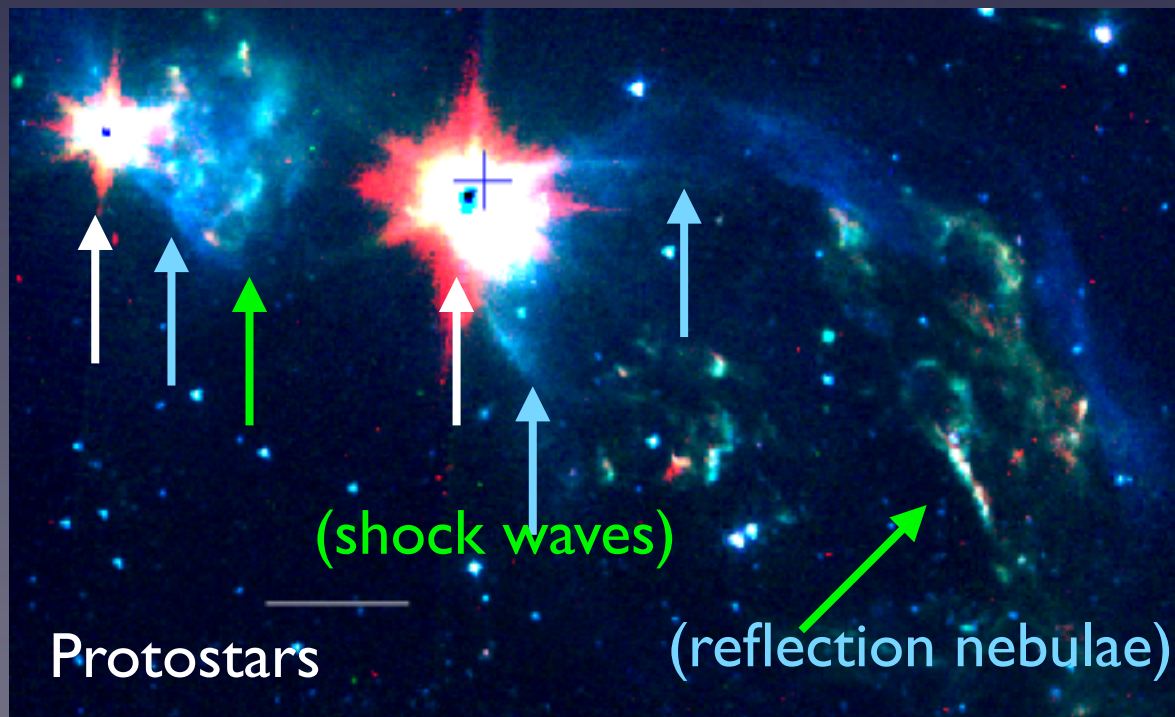
What are in the universe?



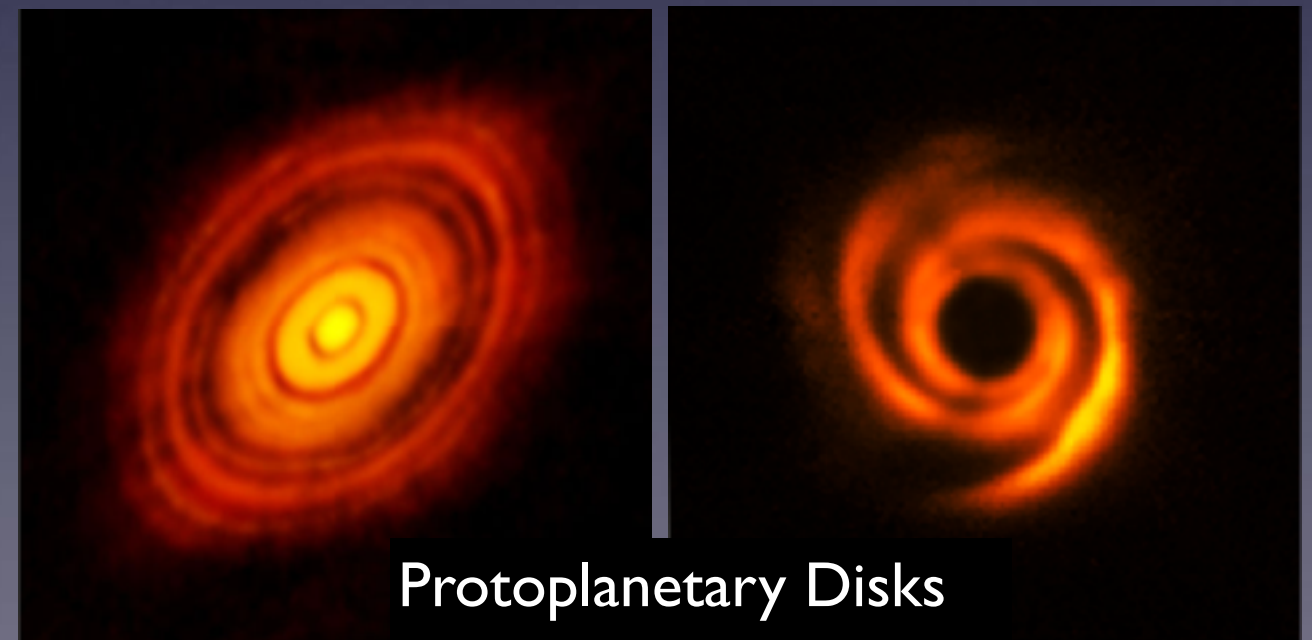
Stars



Molecular (+dust) Clouds & Star Forming Regions



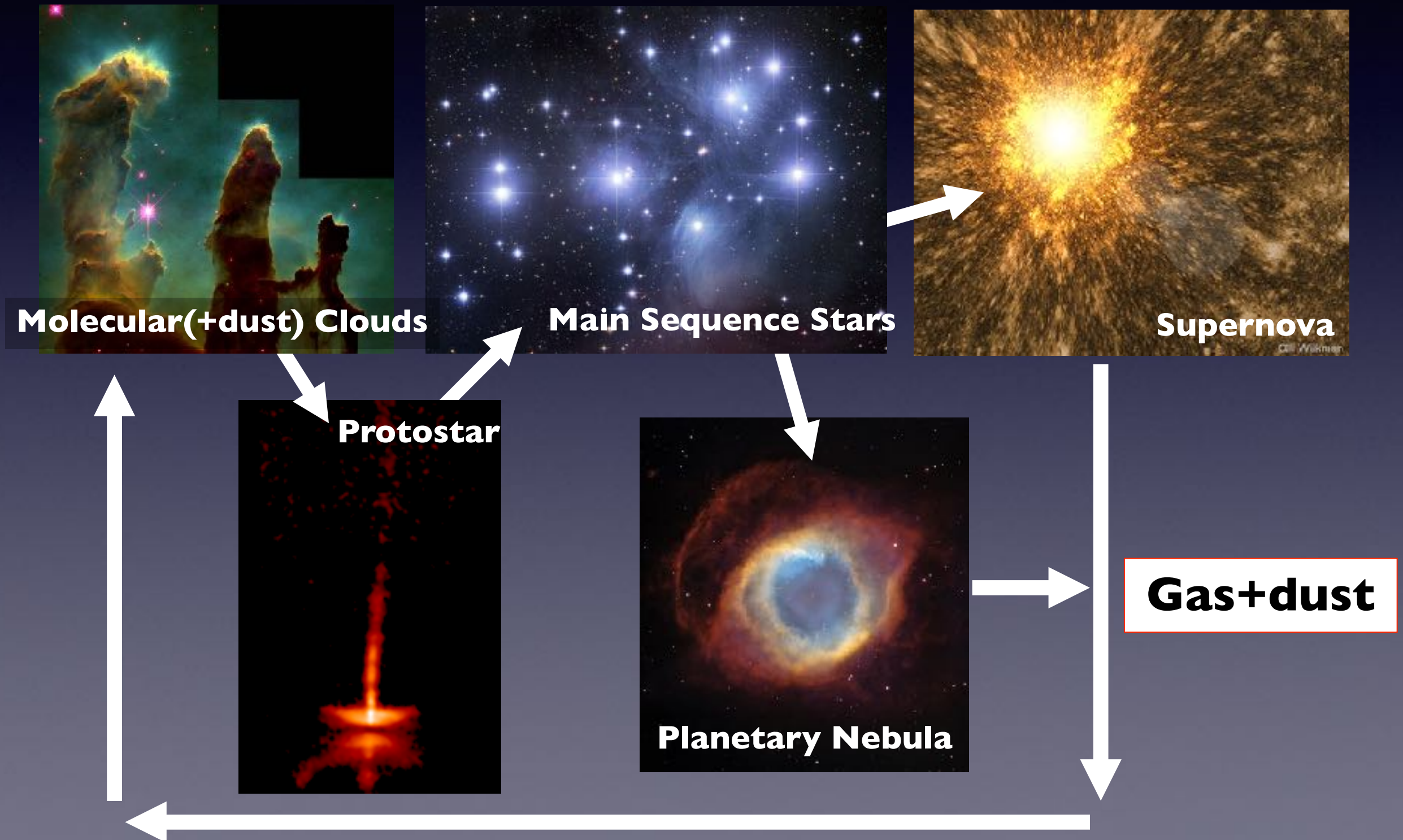
Protostars



Protoplanetary Disks

What are in the universe?

— Life cycle of stars and interstellar medium —



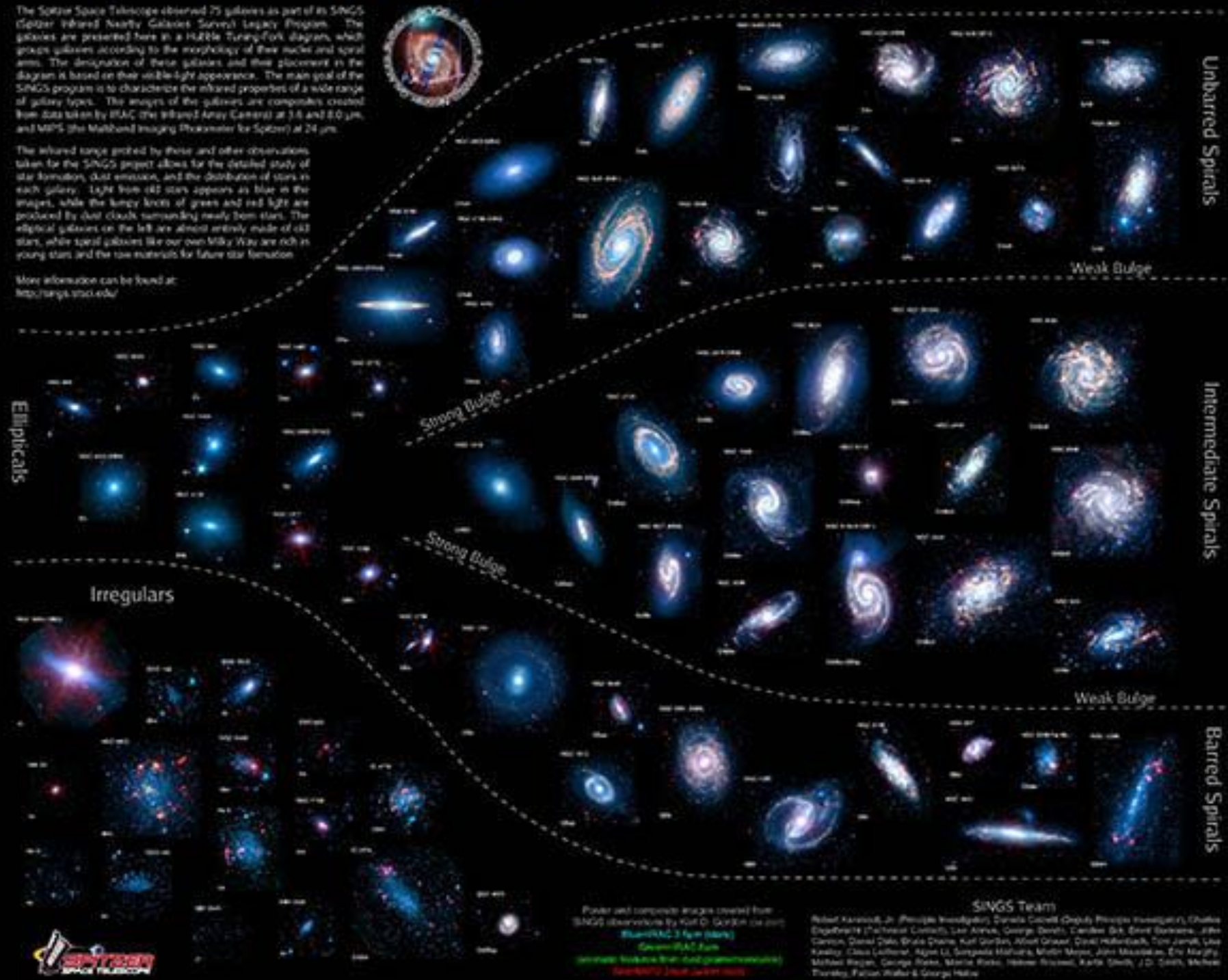
What are in the universe?

The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

The *Spitzer Space Telescope* observed 29 galaxies as part of its *SMG25* (Spitzer Selected Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the *SMG25* program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by *SMAC* (the *Spitzer* Array Camera) at 3.6 and 8.0 μm , and *MIPS* (the Multiband Imaging Photometer for *Spitzer*) at 24 μm .

The infrared image probed by these and other observations, taken by the *Spitzer* project, allows for the detailed study of the formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the hazy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at:
<http://nrga.stcr.edu/>

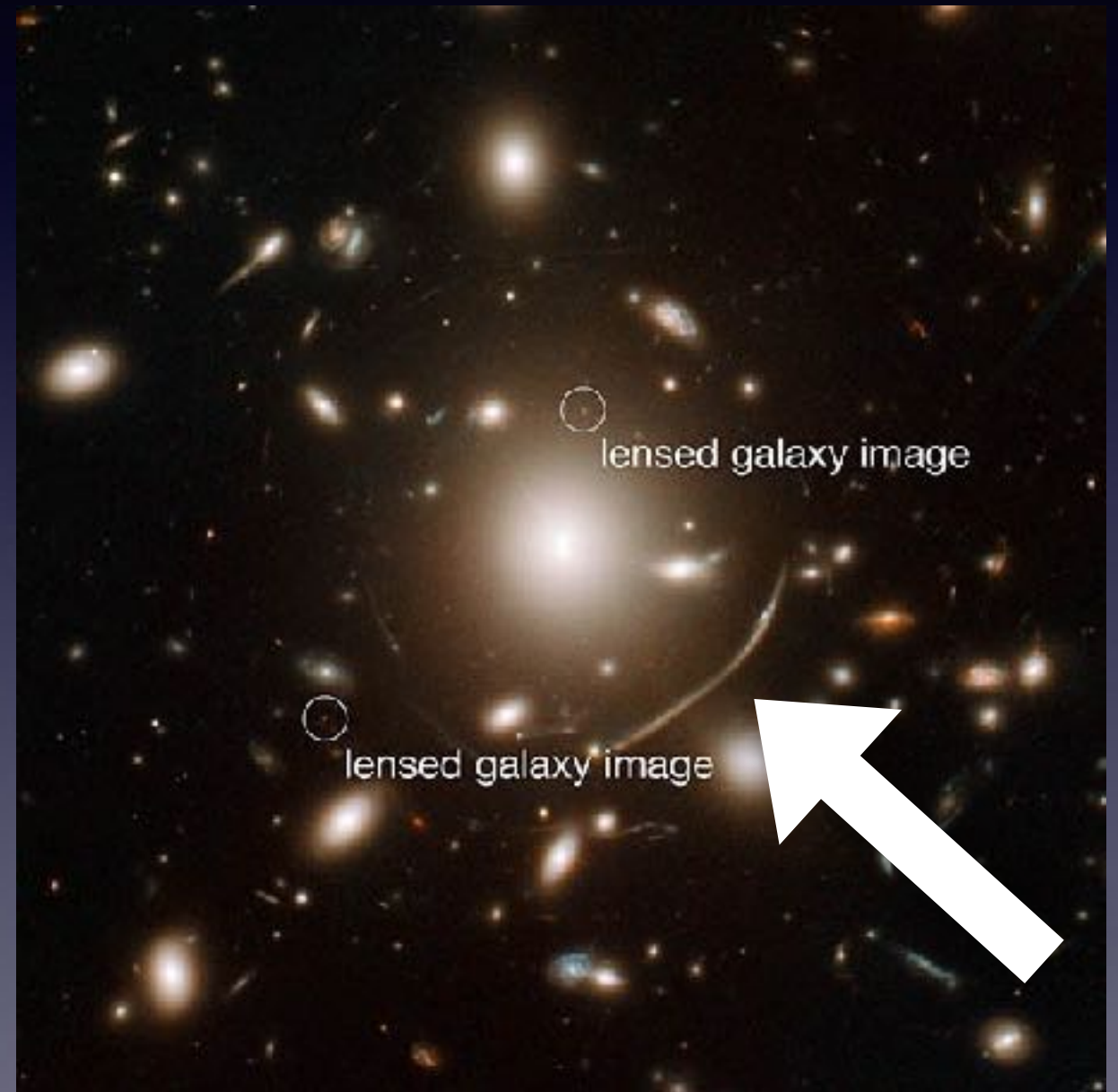


What are in the universe?

(Interacting Galaxies)



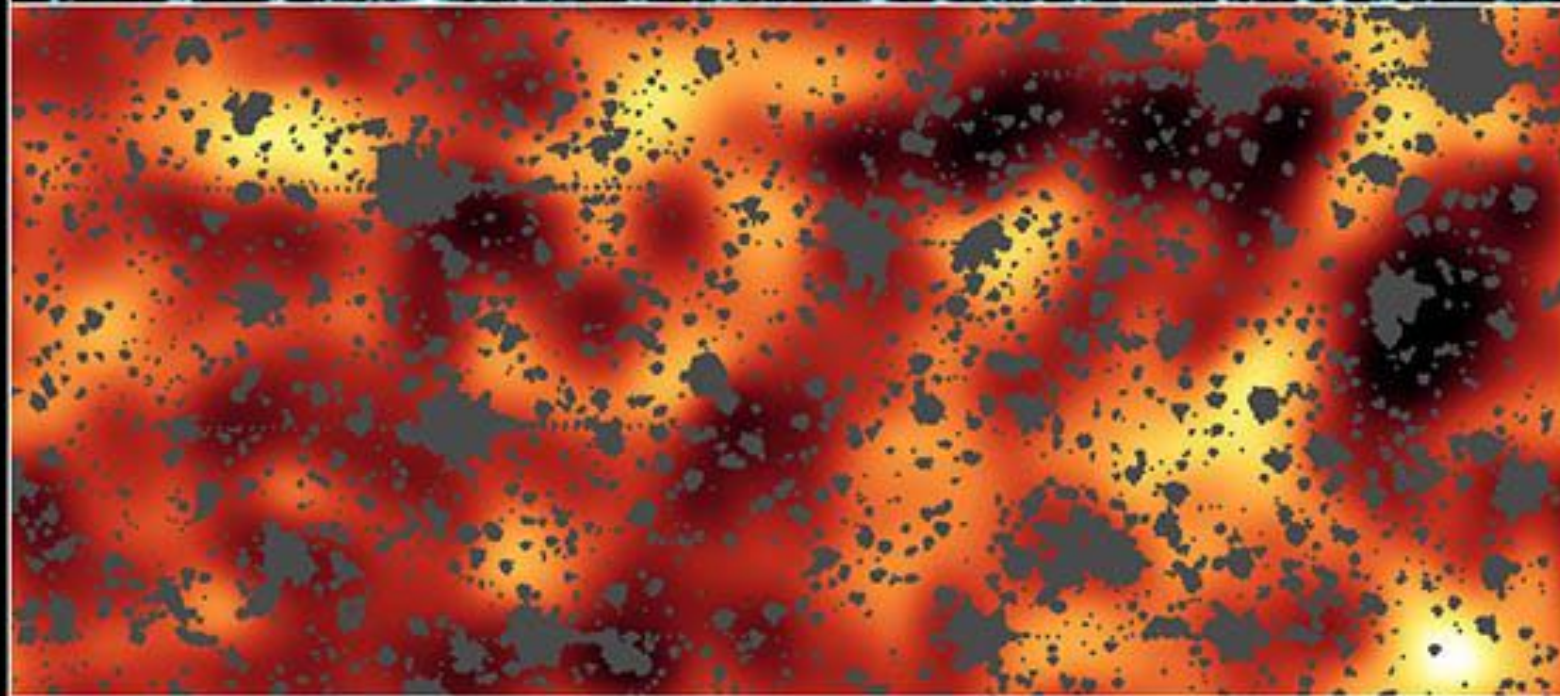
(Gravitational lensing)



What are in the universe?



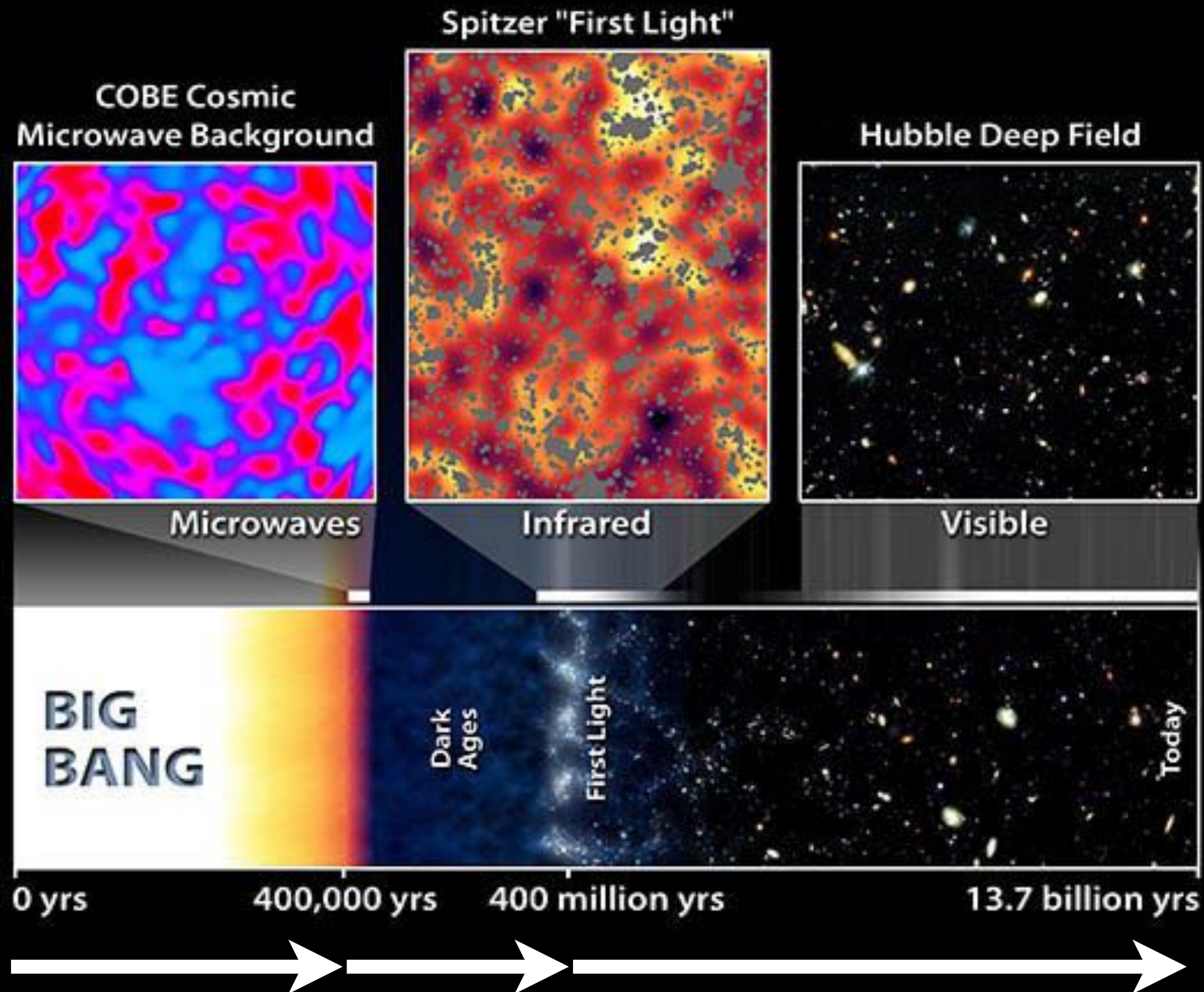
← Foreground
objects



← A number of
first stars in the
universe?

Infrared Background Light from First Stars Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / A. Kashlinsky (GSFC) ssc2005-22a

What are in the universe?

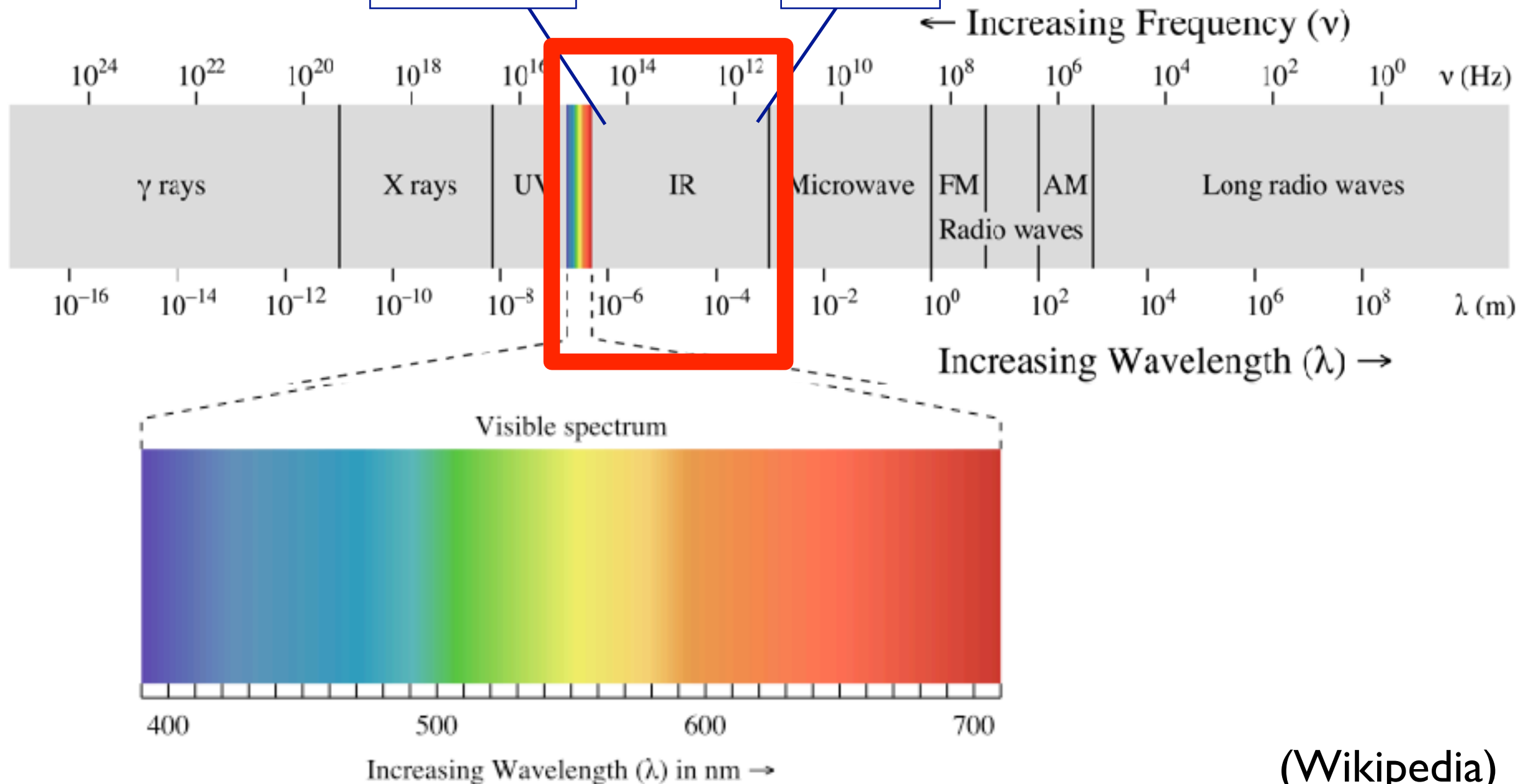


What are optical & infrared?

— Electromagnetic waves —

Near-IR

Far-IR



(Wikipedia)

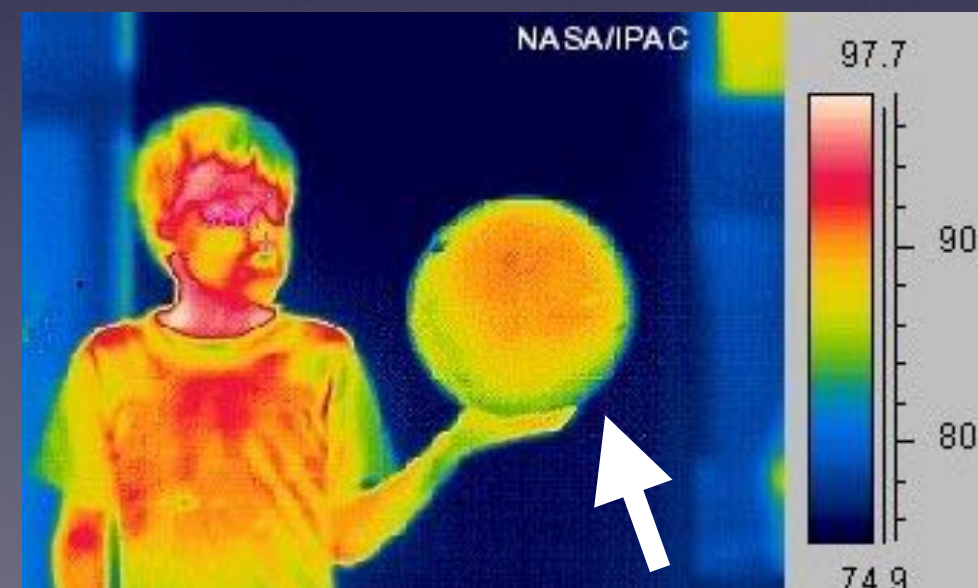
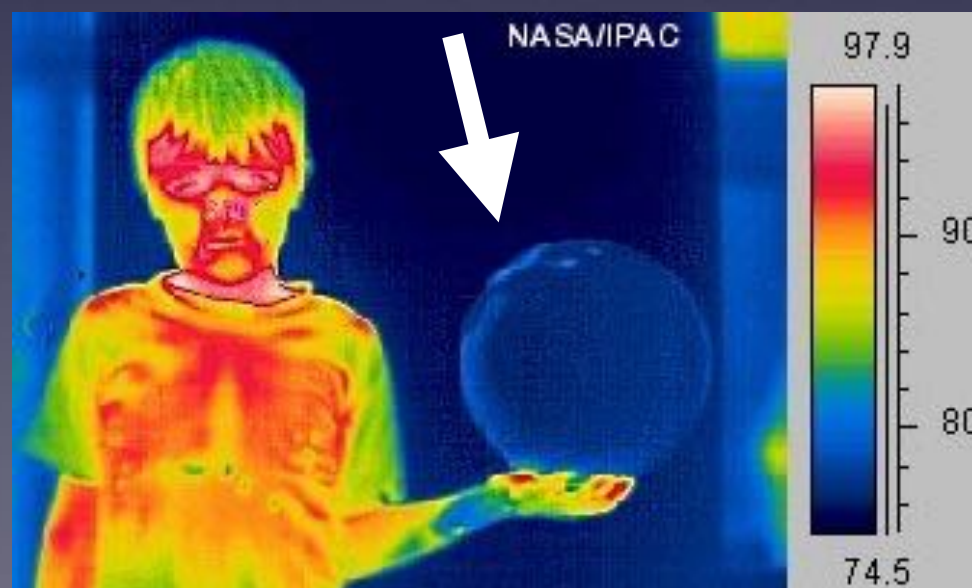
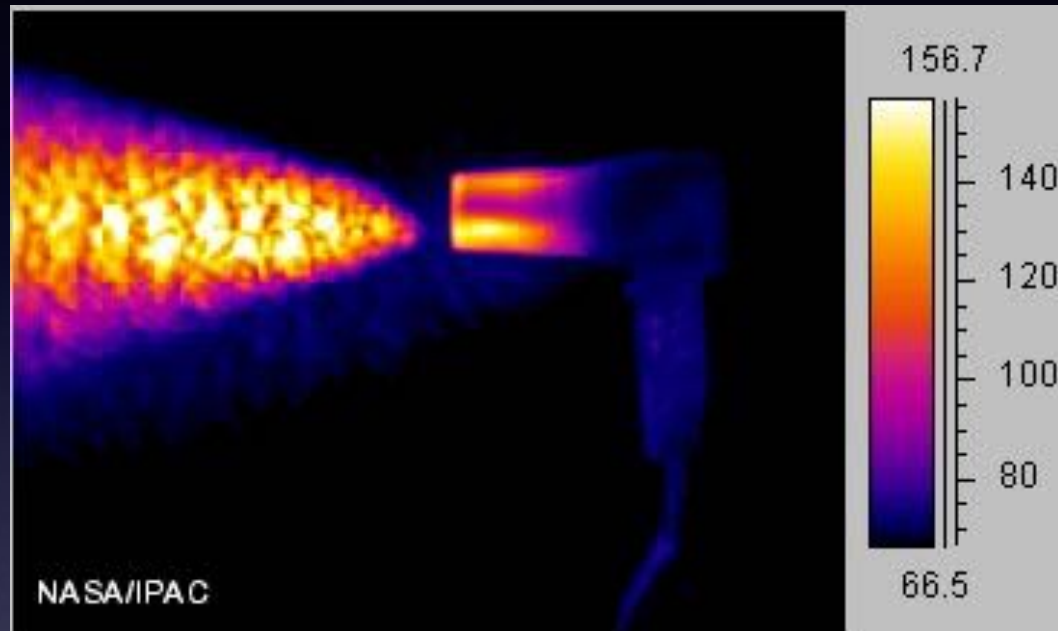
What are optical & infrared?

—Visible world on the ground —



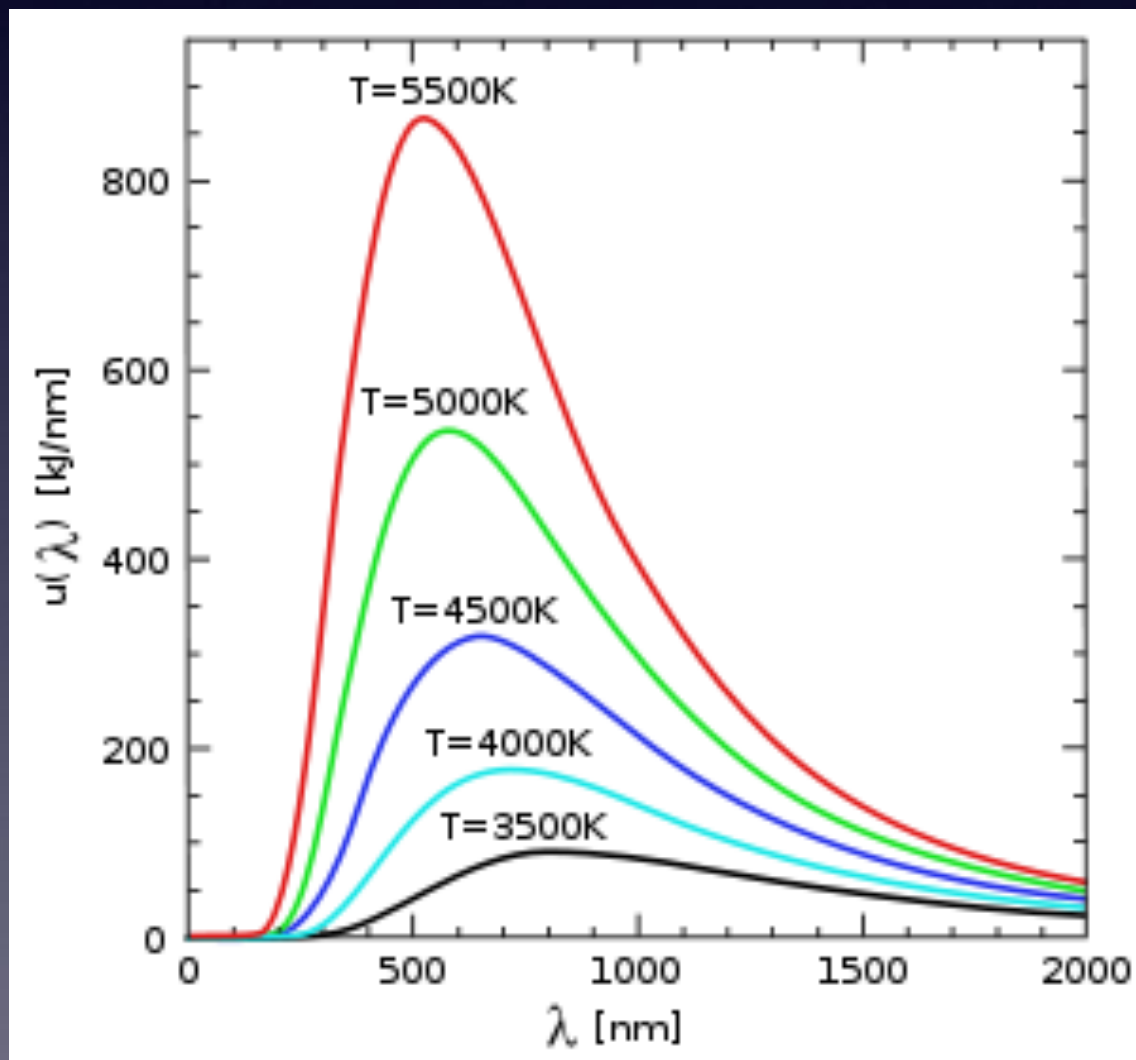
What are optical & infrared?

— Infrared world on the ground —



What are optical & infrared?

— Thermal radiation (blackbody radiation) —



(Wikipedia)

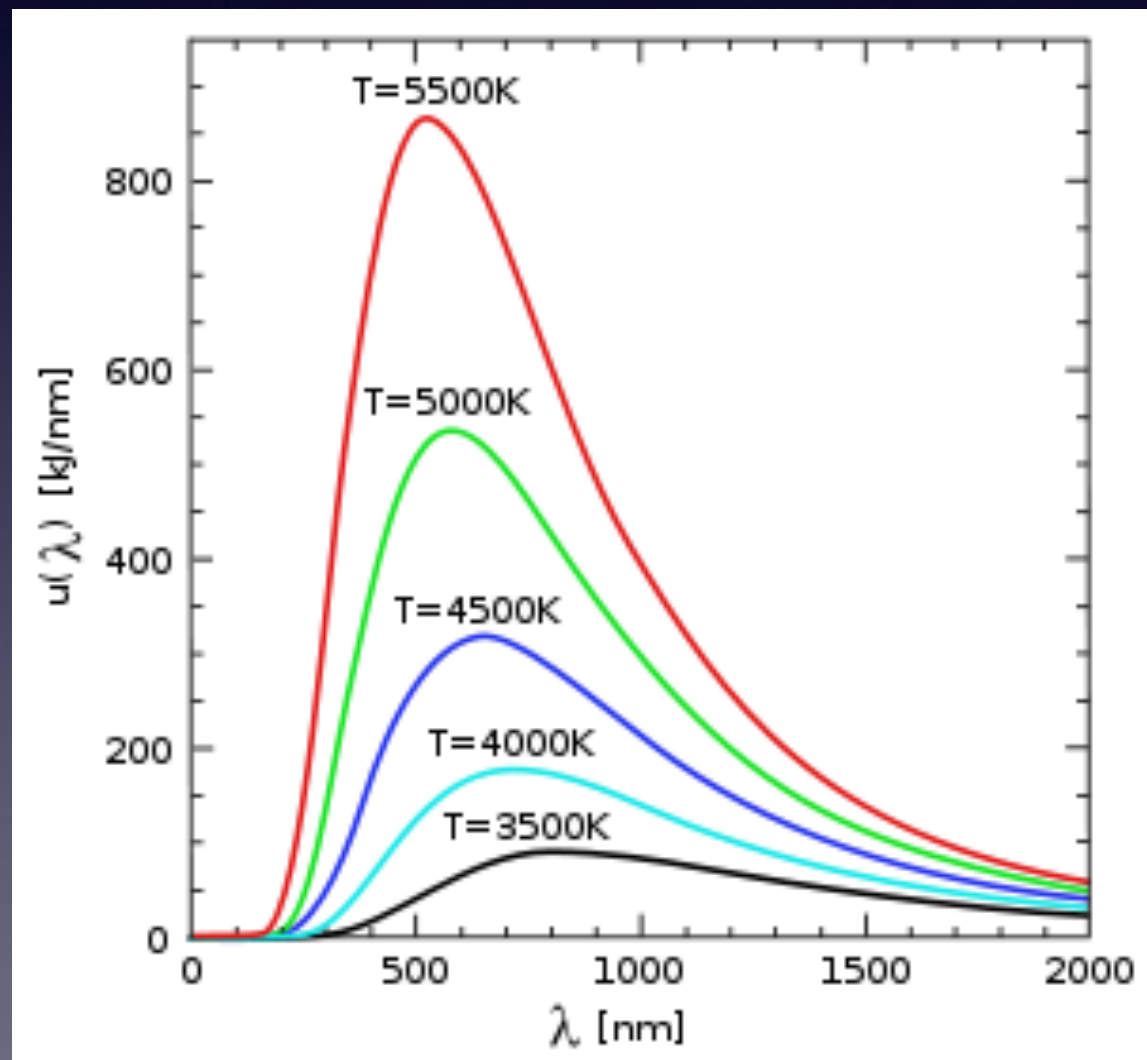
$$T(\text{K}) = T(^{\circ}\text{C}) - 273.15$$

$$B_{\nu}(T) = \frac{2h\nu^3/c^2}{\exp(h\nu/kT) - 1}$$

$$B_{\lambda}(T) = \frac{2hc^2/\lambda^5}{\exp(hc/\lambda kT) - 1}$$

What are optical & infrared?

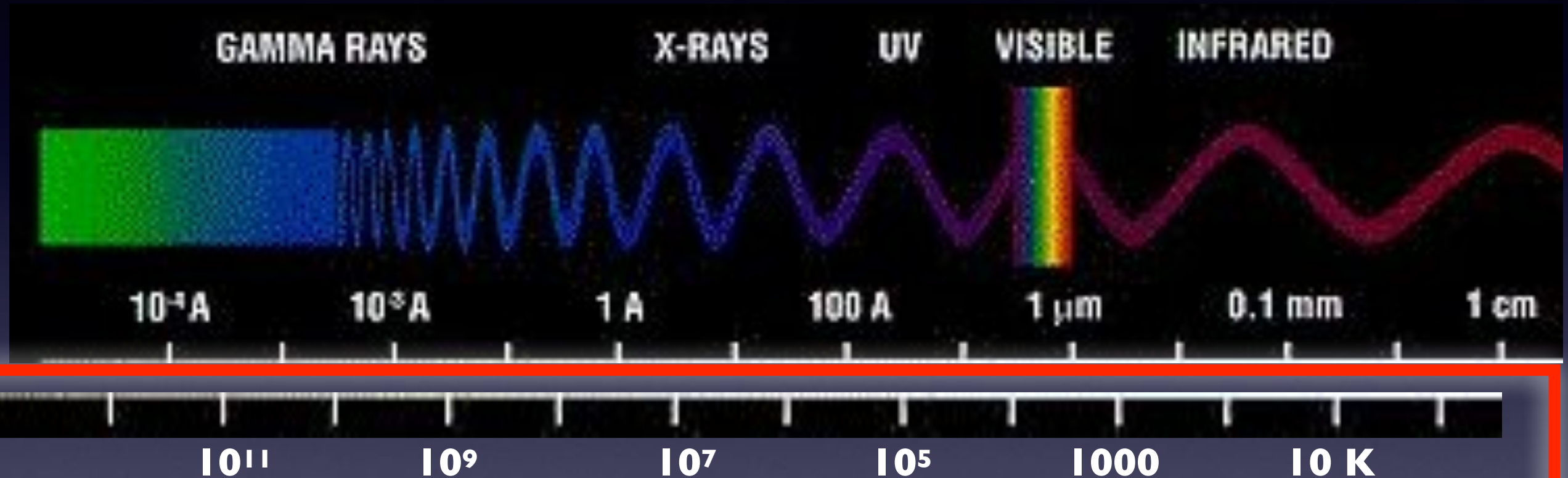
— Thermal radiation (blackbody radiation) —



(Wikipedia)

What are optical & infrared?

— Thermal radiation (blackbody radiation) —



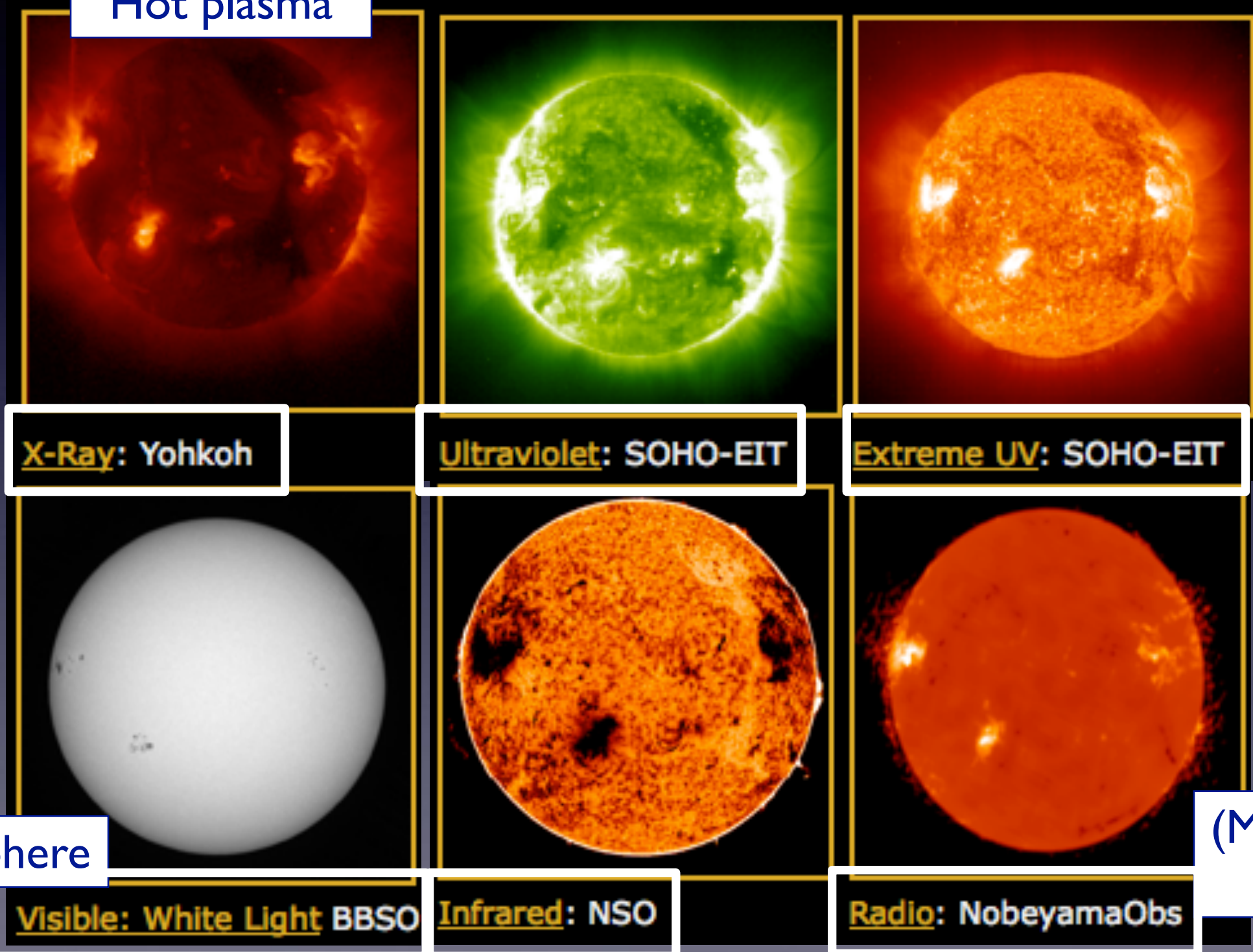
Temperature of Blackbody

(original figure from <http://coolcosmos.ipac.caltech.edu/>)

Multiwavelength observations are essential for covering targets at different temperatures

What are optical & infrared?

— Multiwavelength view of the sun —



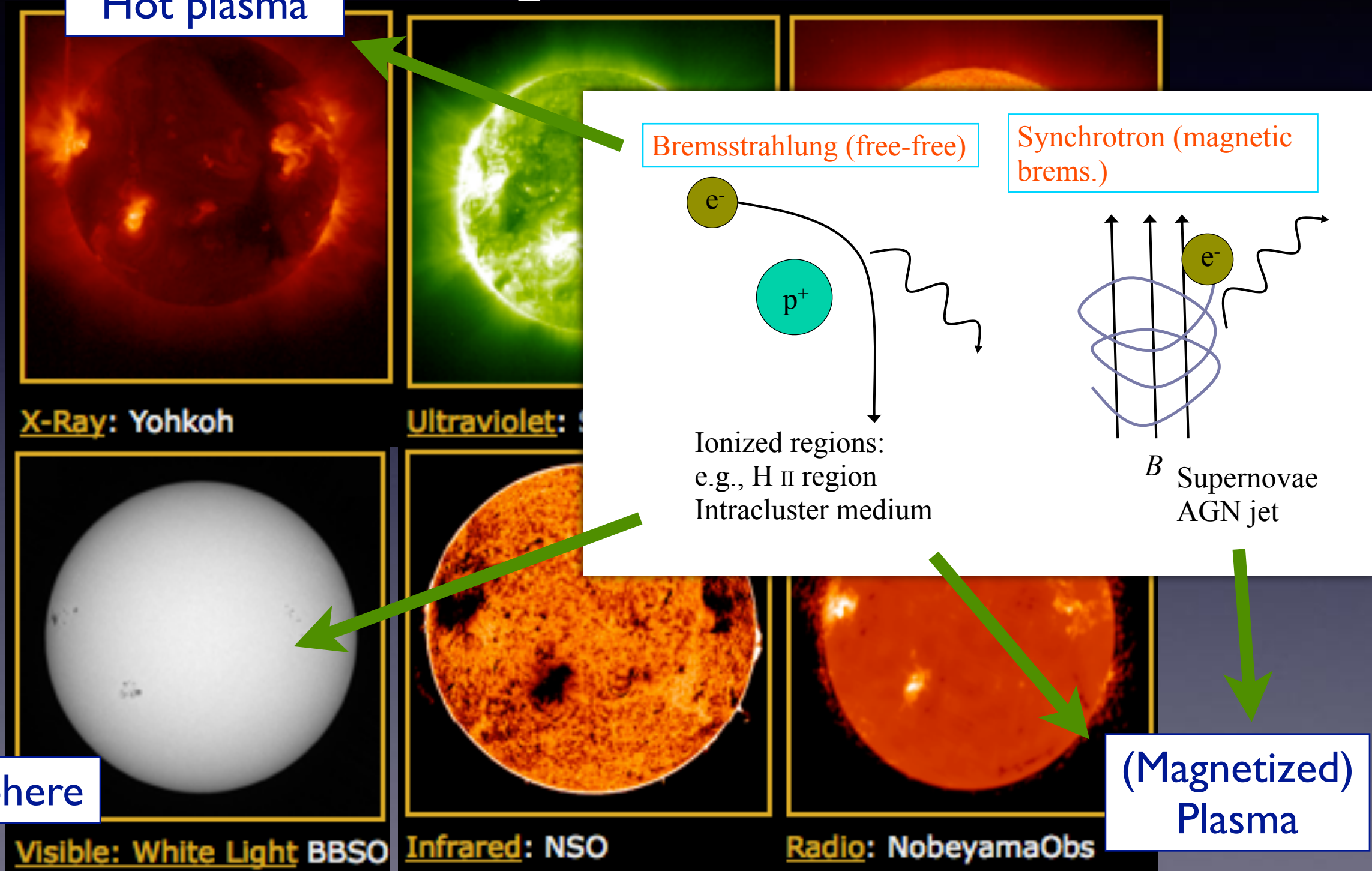
Photosphere

(Magnetized)
Plasma

(original figures from <http://coolcosmos.ipac.caltech.edu/>)

What are optical & infrared?

— Multiwavelength view of the sun —

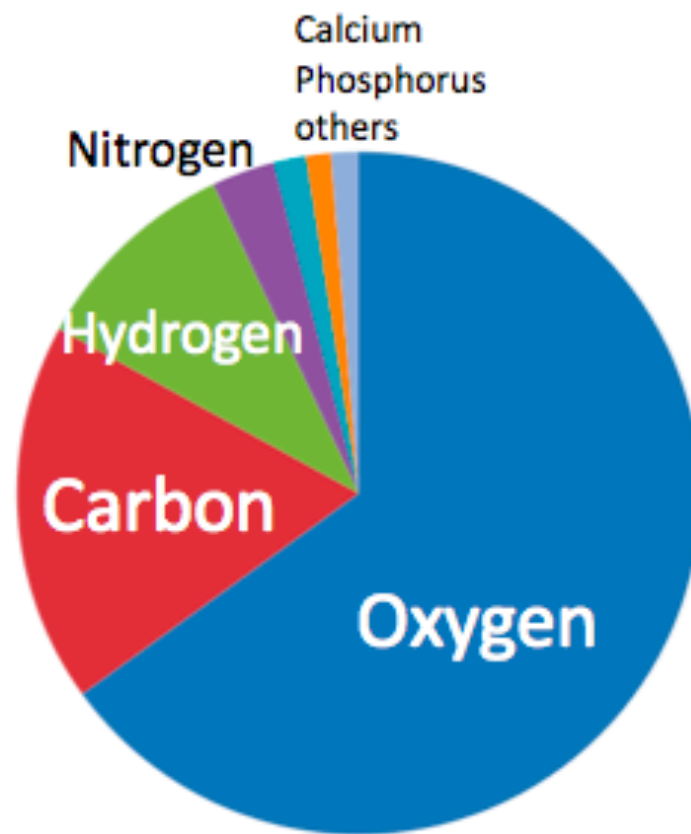


(original figures from <http://coolcosmos.ipac.caltech.edu/>)

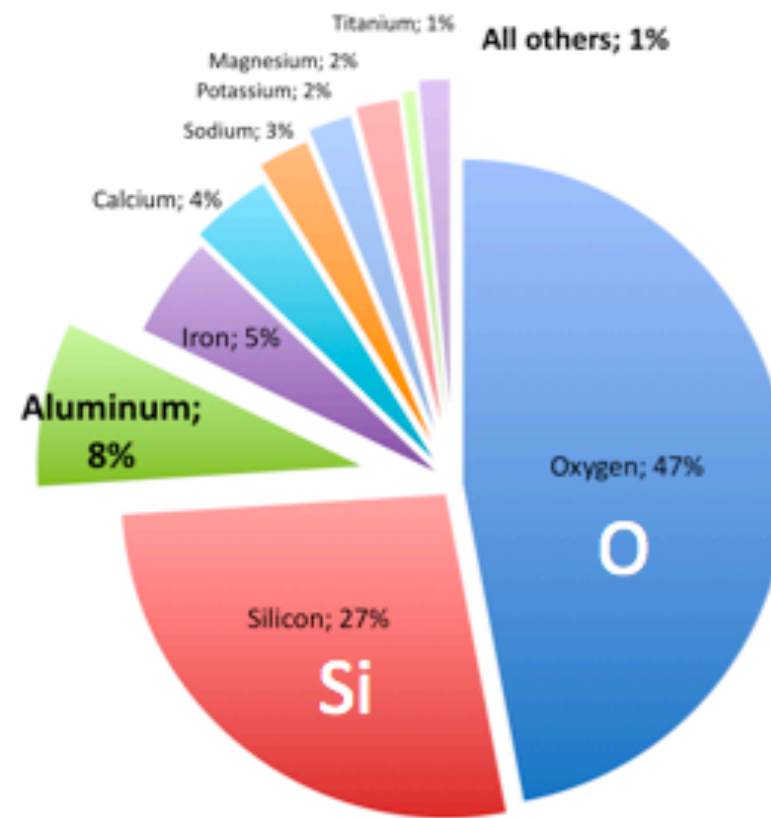
Abundance of the Elements:

“Metals” for astronomers

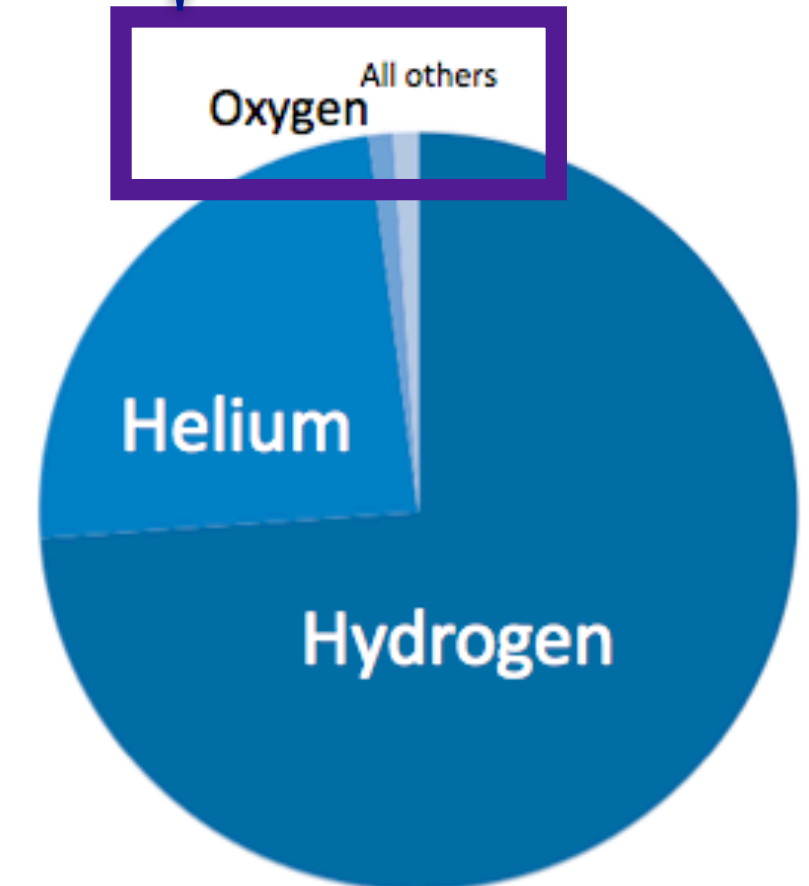
In Life



On Earth
(Earth's crust)



In the Universe



<https://clearscience.tumblr.com/post/589755566/you-are-made-of-elements-along-with-everything>

What are optical & infrared?

— Multiwavelength view of a galaxy —

Accretion disk
binary systems



X-Ray: ROSAT

Massive stars
& extinction



Ultraviolet: GALEX

More stars
& extinction



Visible: DSS



Visible: © Jason Ware

Dust heated by massive stars



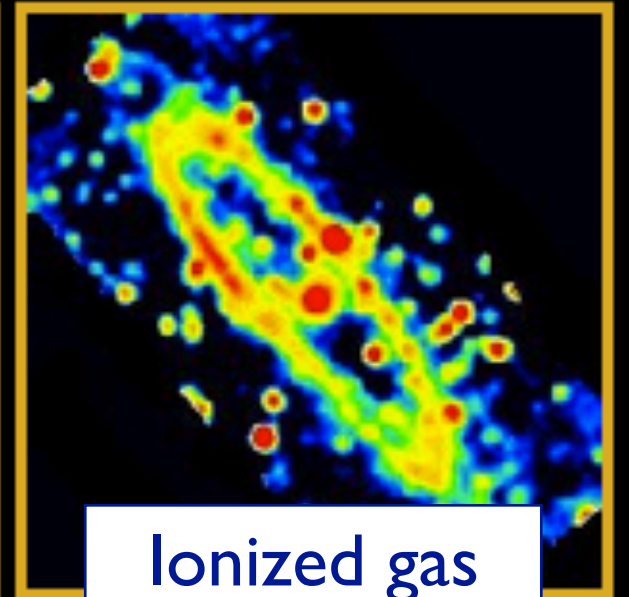
Mid-Infrared: IRAS



Mid-Infrared: Spitzer



Far-Infrared: ISO



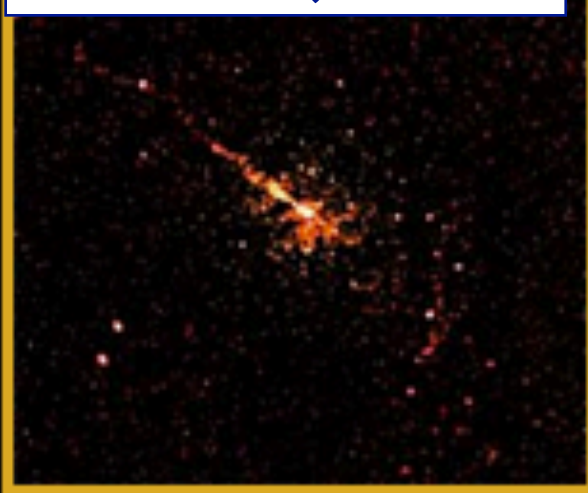
Ionized gas

Radio: Effelsberg

What are optical & infrared?

— Multiwavelength view of another galaxy —

Hot ionized gas
in a jet



X-Ray: Chandra

Massive stars
& large extinction



Ultraviolet: GALEX

More stars
& extinction

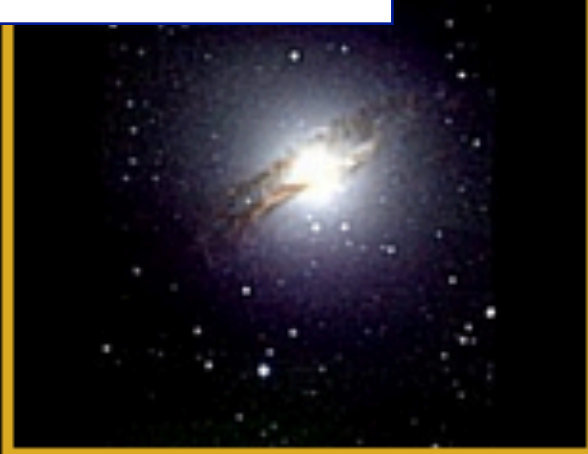


Visible: DSS



Visible: Color ©AAO

Cool stars
& less extinction

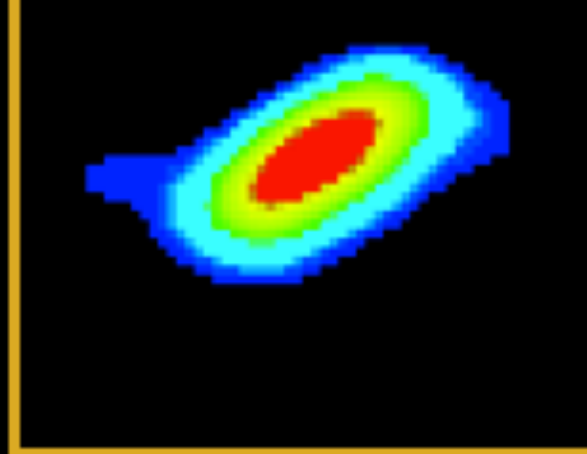


Near-Infrared: 2MASS

Dust heated by massive stars



Mid-Infrared: Spitzer



Far-Infrared: IRAS

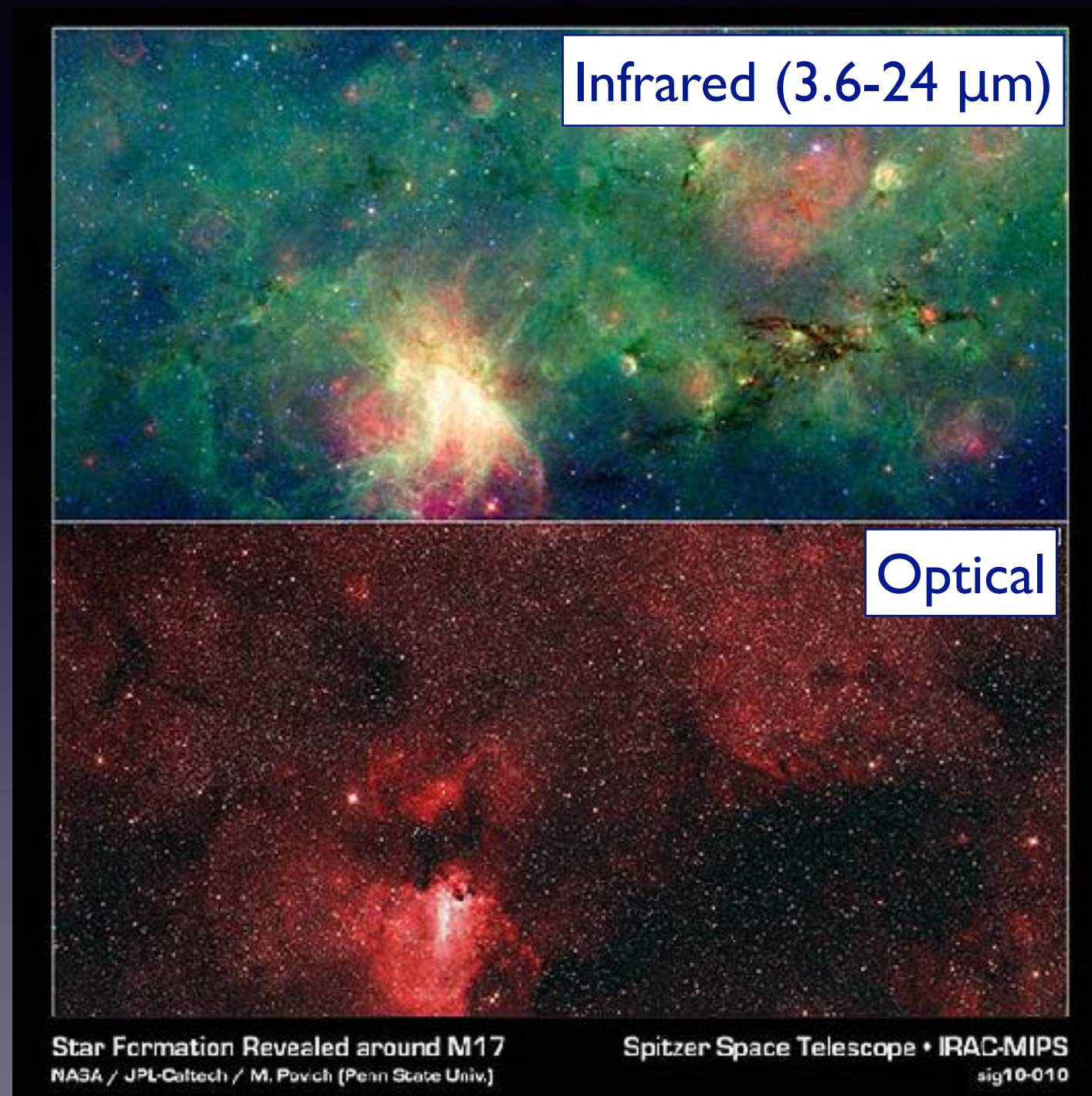


Magnetized &
ionized gas in a jet

Radio: VLA

What are optical & infrared?

— Optical and infrared views of star-forming regions —



(<http://www.spitzer.caltech.edu/images/>)

What are optical & infrared?

— Optical and infrared views of star-forming regions —

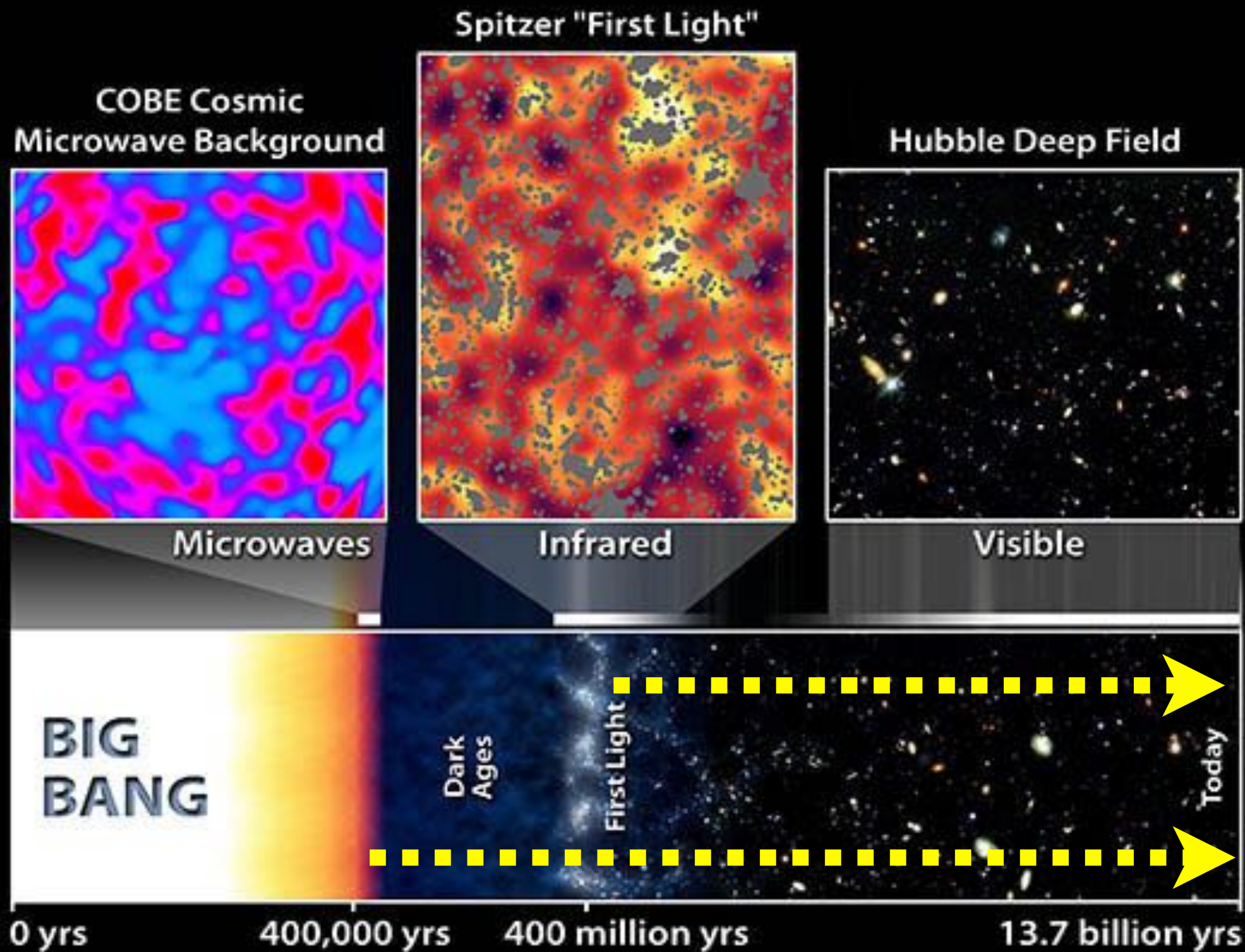


2MASS (1997), 1.3–2.2 microns



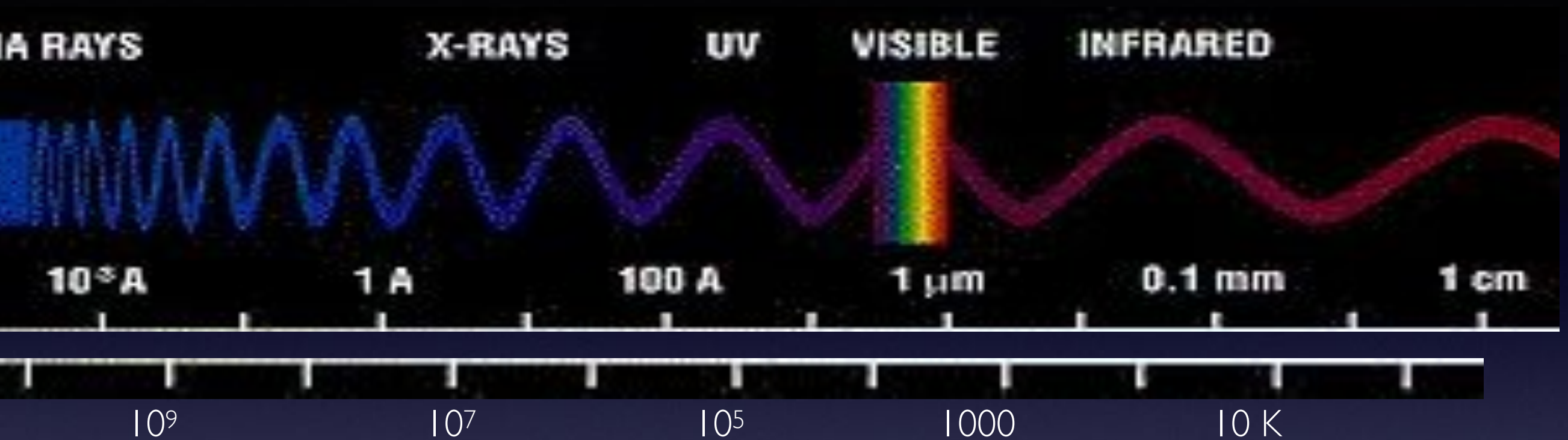
Spitzer (2003), 3.6–24 microns

What are in the universe?



$$\lambda = \lambda_0 \left(1 + \frac{v}{c}\right)$$

What are optical & infrared?



Thermal

Hot plasma

Stars

Dust (emission)

Gas ionized by UV radiation

Dust (extinction, scattering)

Synchrotron radiation

Non-thermal



What can be observed in the optical and infrared?

Astronomically:

- Stars (including protostars and evolved stars)
- Brown dwarfs, planets, asteroids
- Various kind of nebulae (gas, dust)
- Galaxies (composition of all the above)

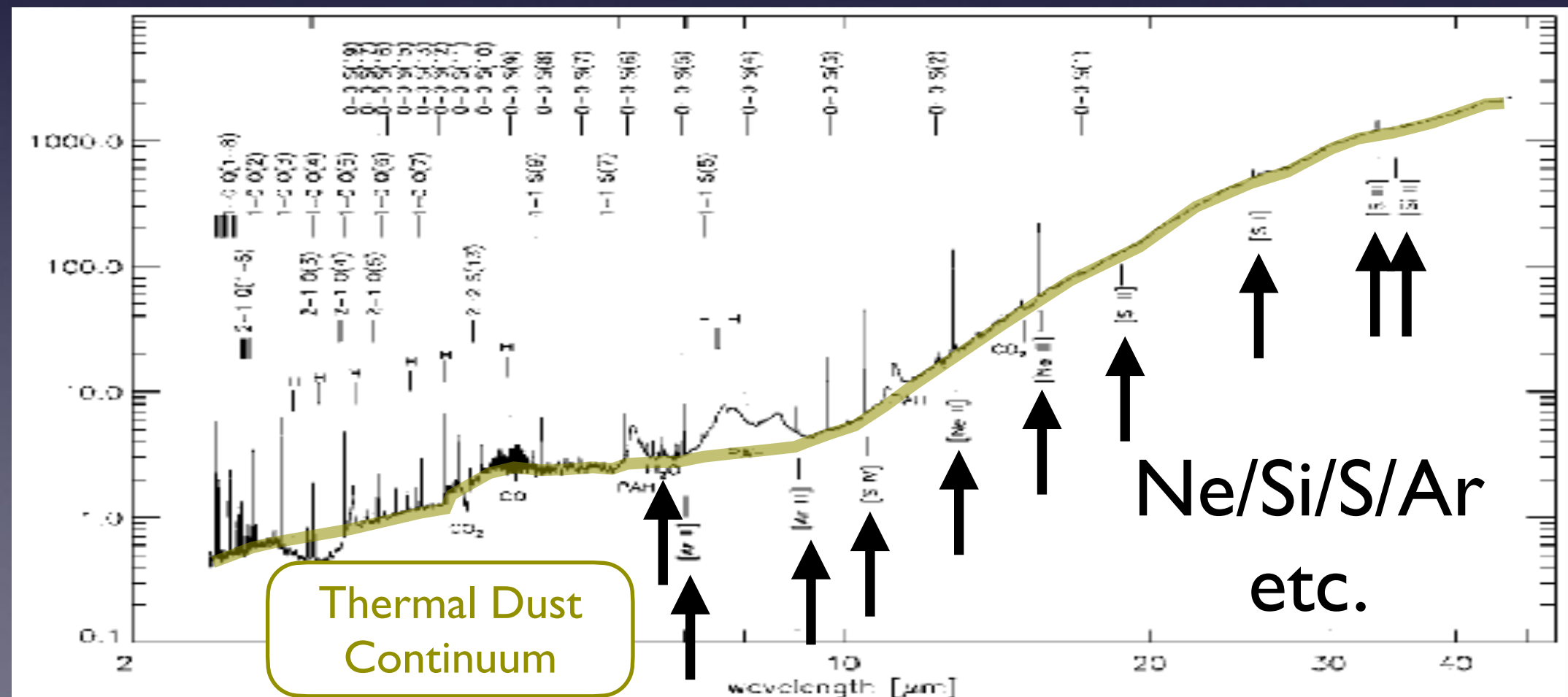
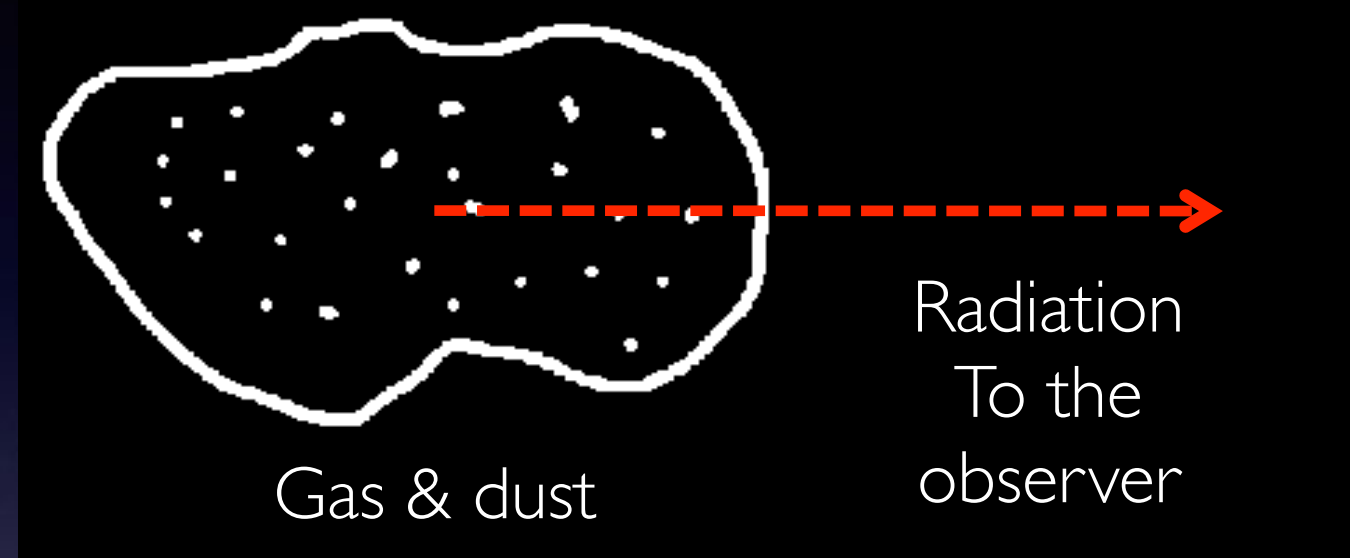
More physically:

- Continuum emission
- Emission/absorption associated with gas, dust and ice
- Scattered emission, silhouette (extinction)

How spectroscopy works

Emission spectrum of gas & dust (van Dishoeck 2004)

Emission features are seen if gas & dust are relatively transparent (*optically thin*) at some wavelengths.



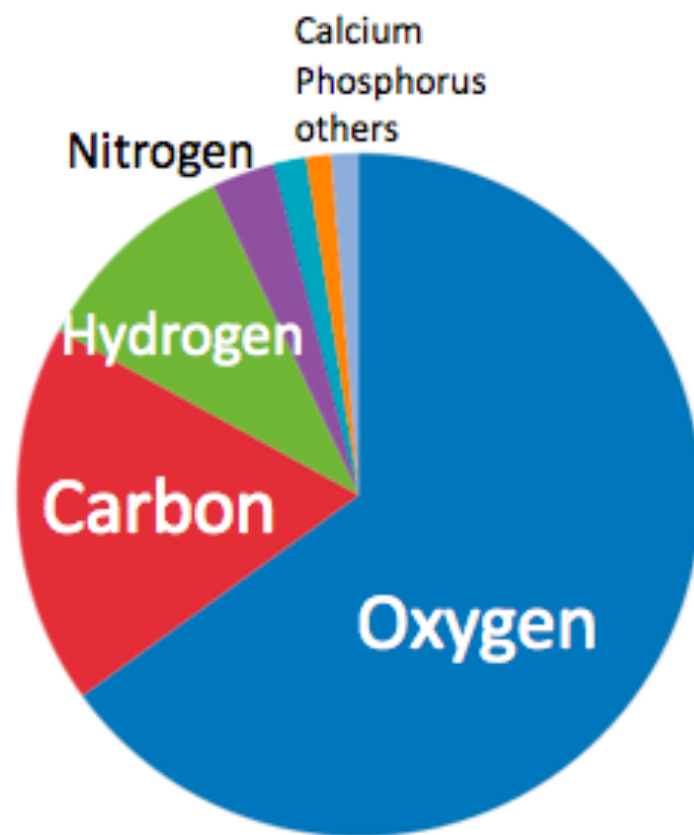
How spectroscopy works

Elemental Abundance in the Universe

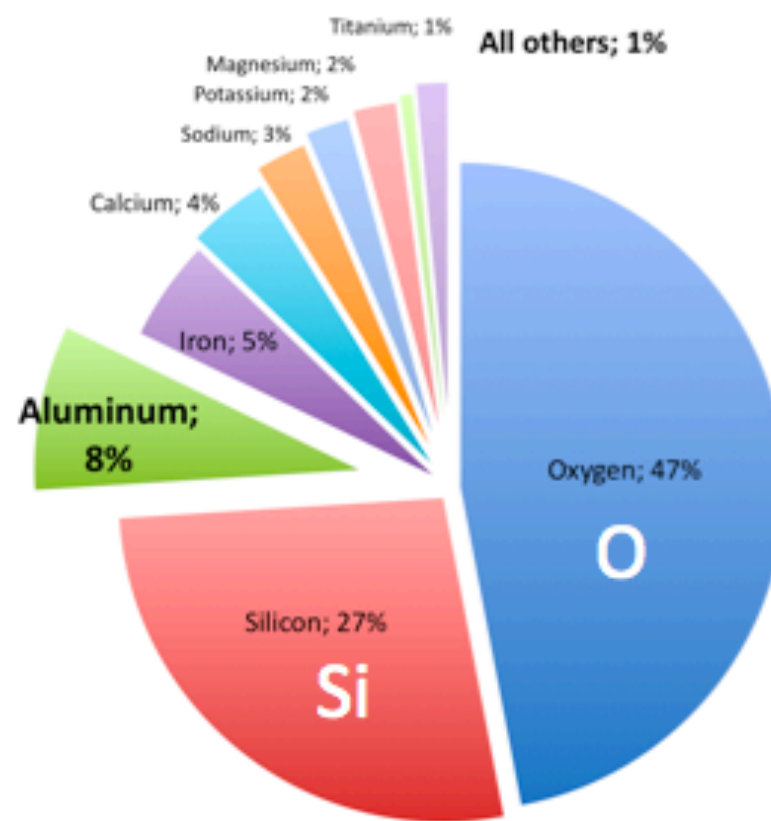
“Metals” for astronomers

Abundance of the Elements

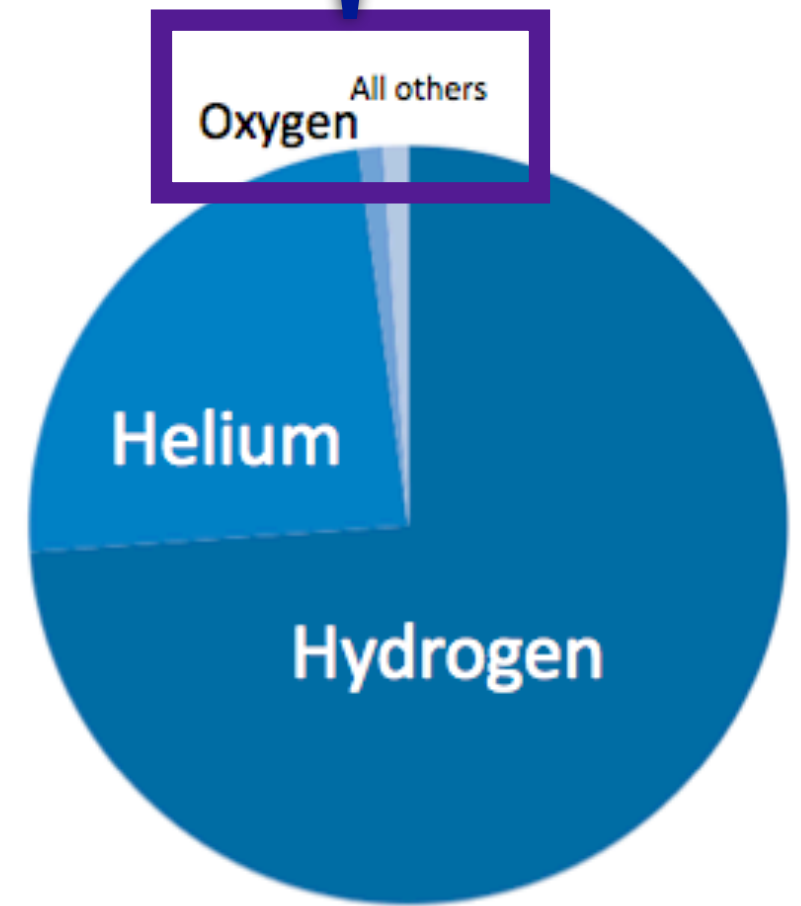
In Life



On Earth
(Earth's crust)

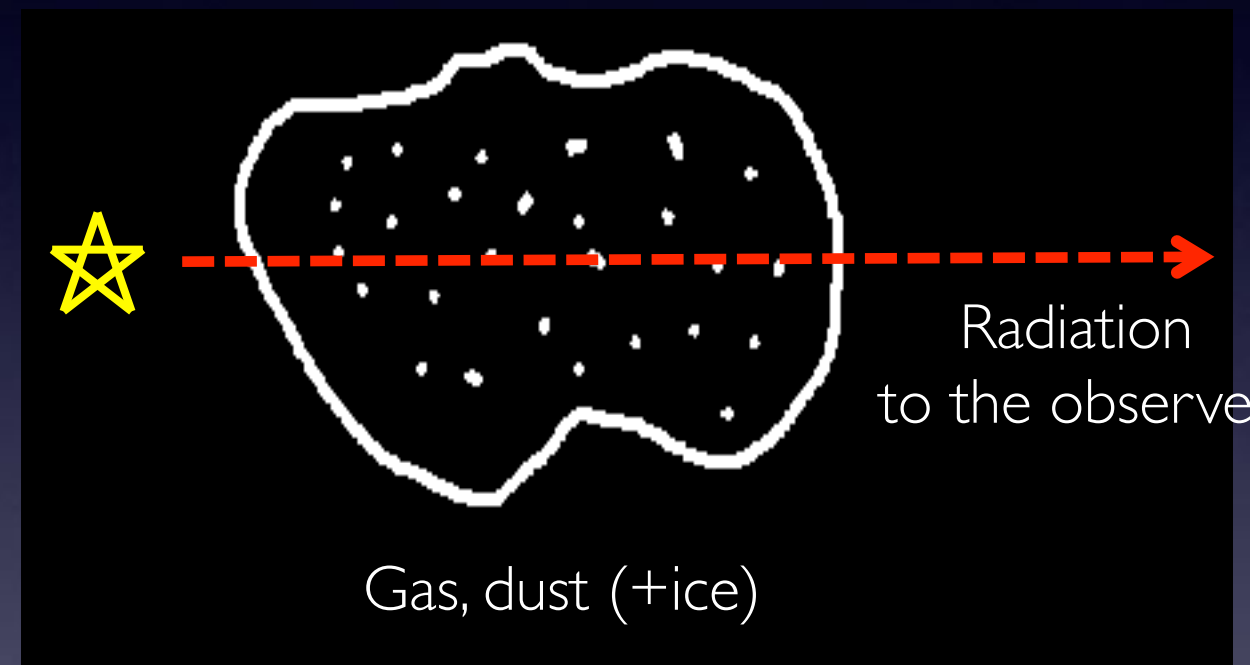
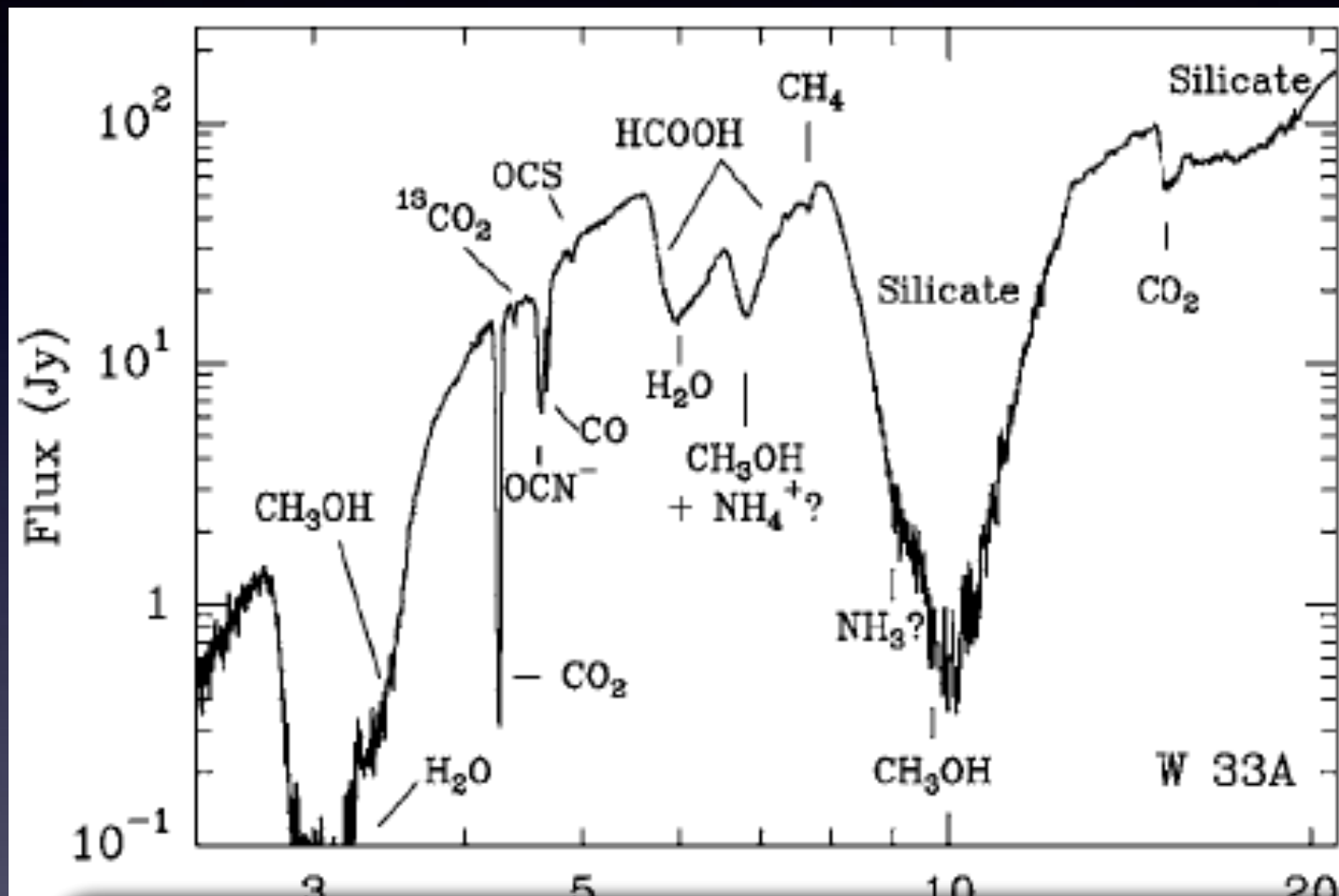


In the Universe



How spectroscopy works

Absorption spectrum of dust & ice (van Dishoeck 2004)



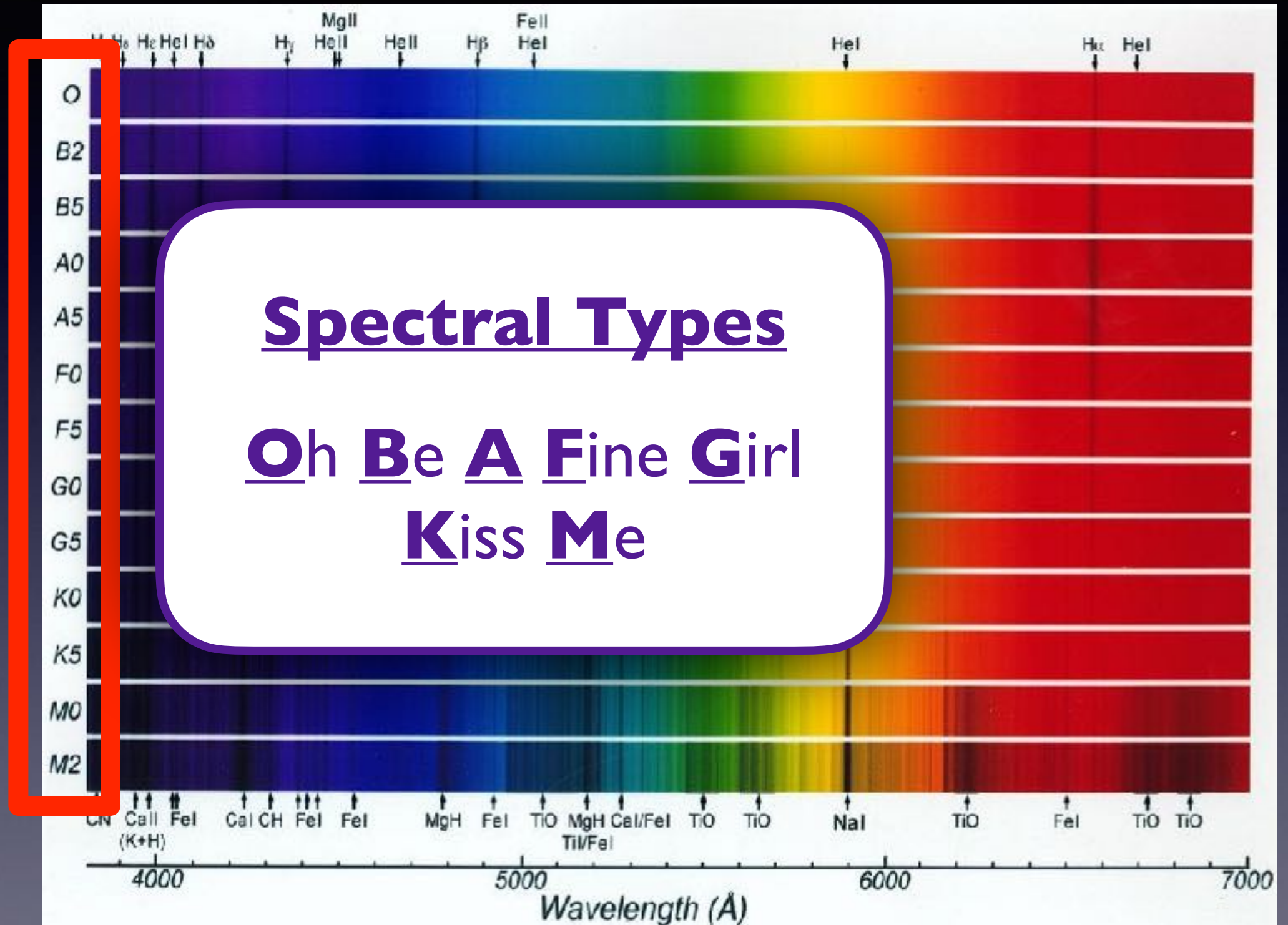
Absorption features are seen if ice/gas/dust:-

- lie between the observer & background source
- are *not* opaque (*optically thick*) at all wavelengths
- are colder than the background source

How spectroscopy works

Blue, hot, massive stars

Red, cool, low-mass stars



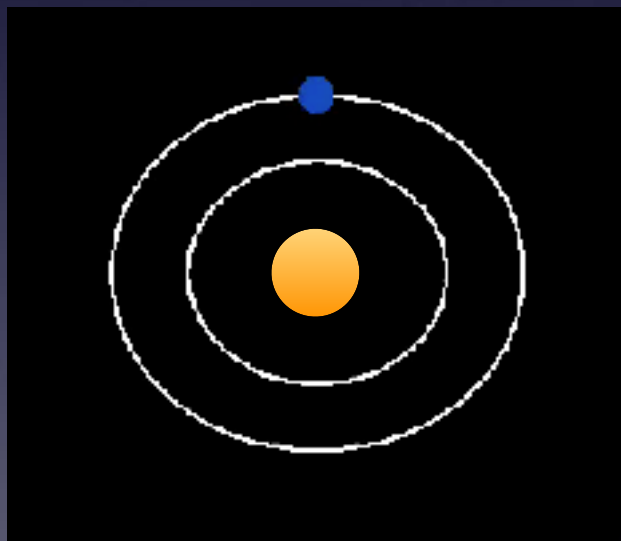
Stellar Spectra

(<http://www.astro.uu.se/~be/spectra.html>)

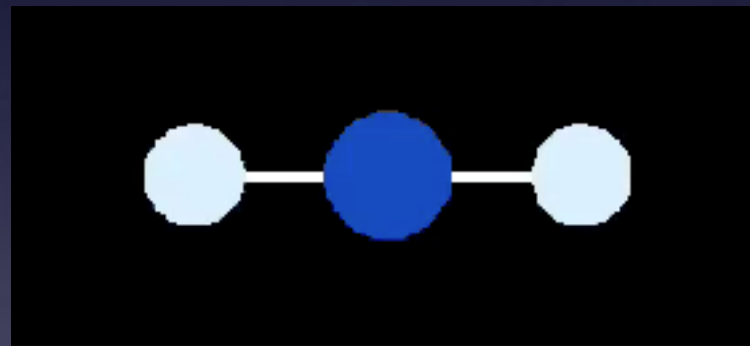
How spectroscopy works

—Transitions which make emission/absorption lines—

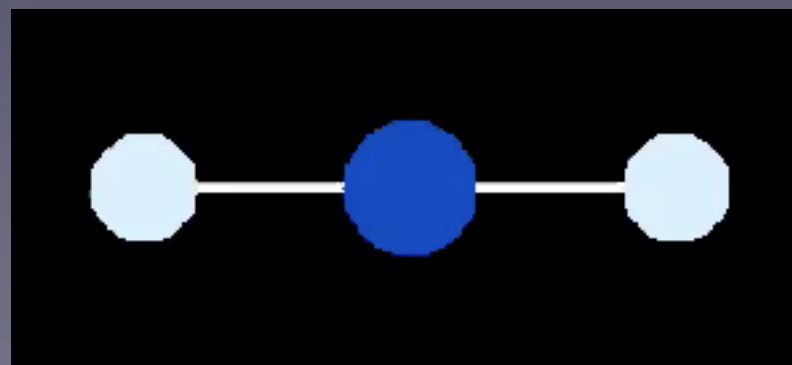
When an atom or molecule changes a quantum state, it can emit or absorb a photon.



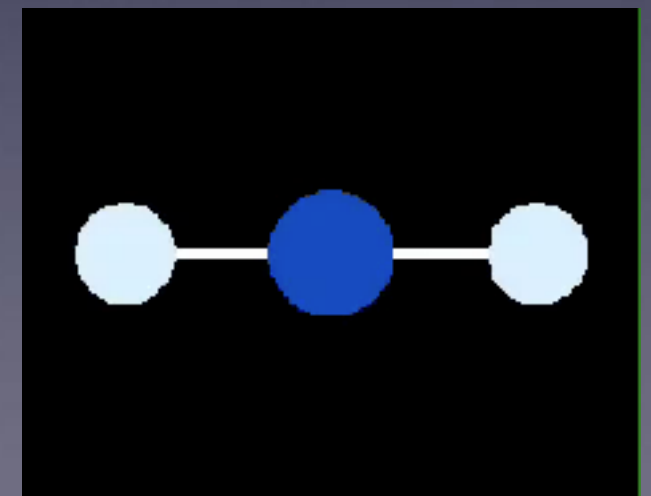
electronic
(UV to Far-IR)



vibrational
(near- to mid-IR)



rotational
(mid-IR to radio)



How spectroscopy works

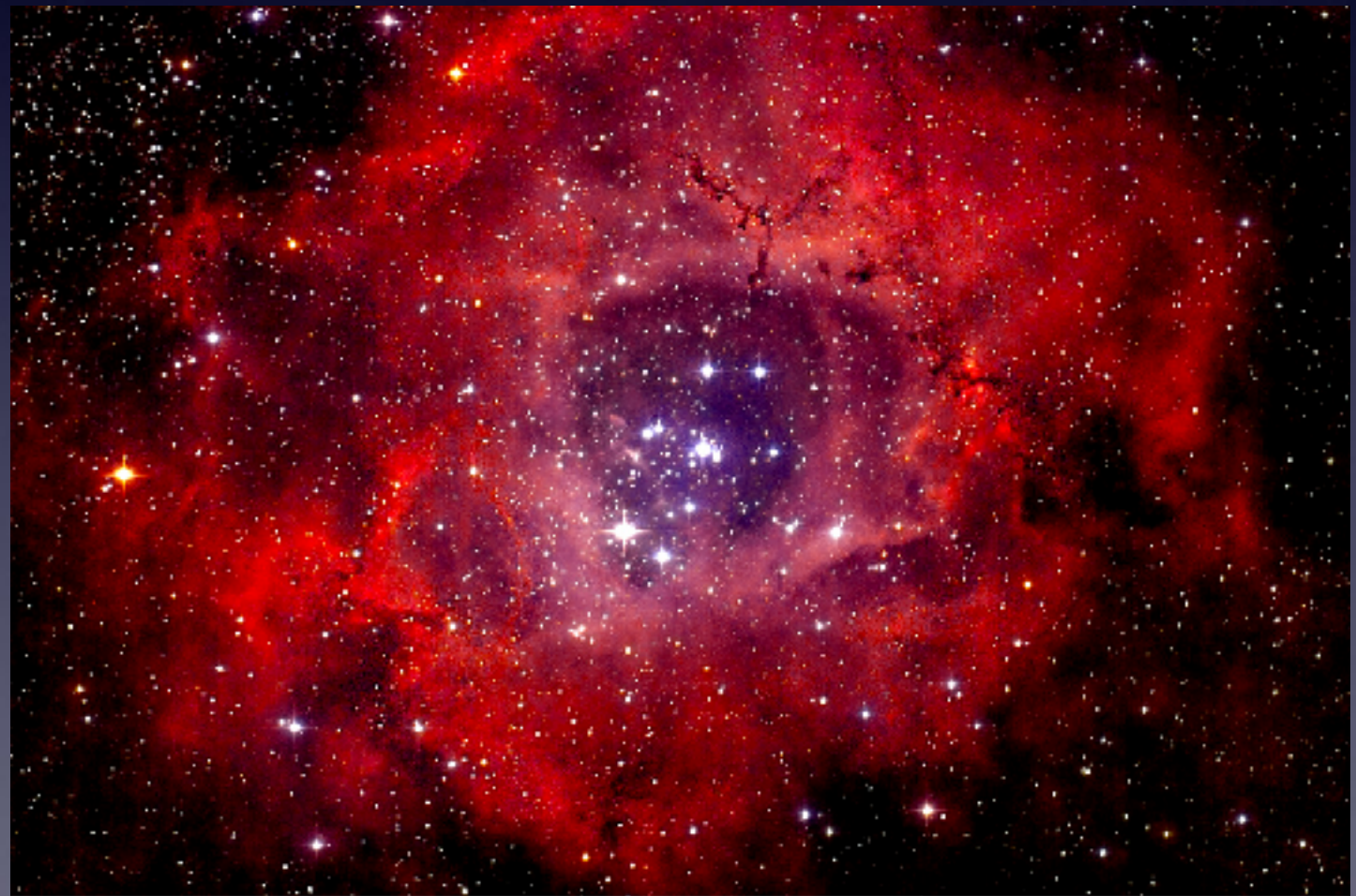
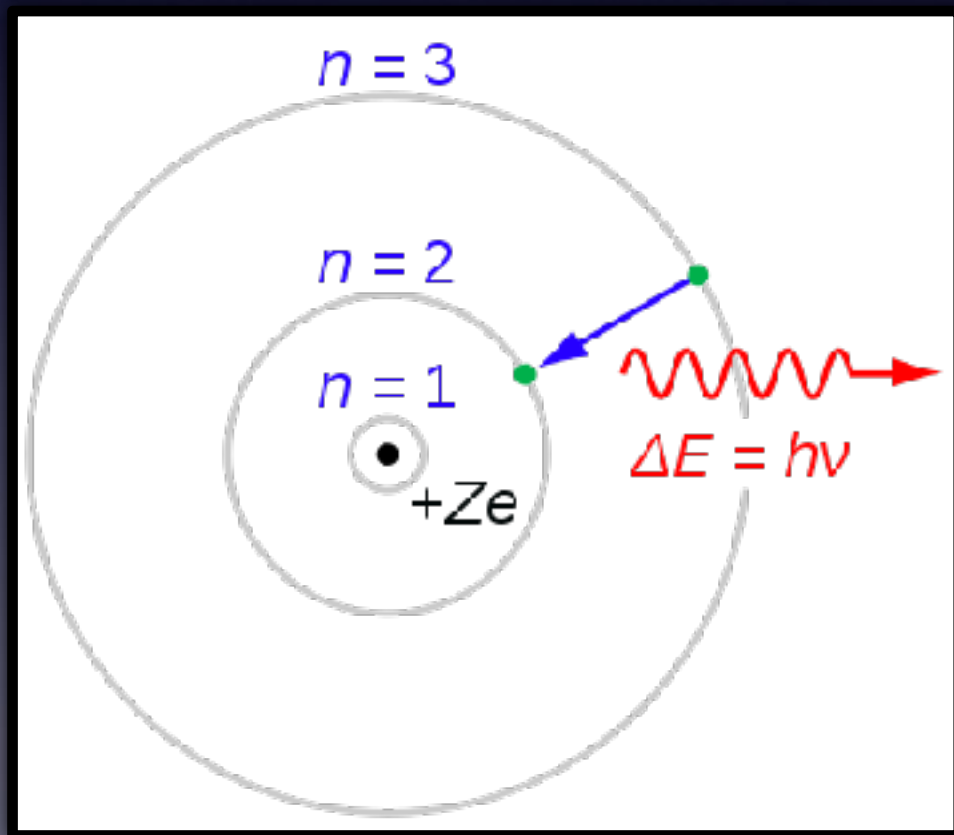
—What can we measure using OIR spectroscopy? —

- Temperature of stellar atmosphere
 - stellar mass & evolutionary stage
- Temperature & density of interstellar & circumstellar medium
- Amount and composition of metals, molecules & ices
(*cf. metal = everything but H & He*)
- Velocity
 - Masses of stars, extrasolar planets etc.
 - Distance to very far galaxies

How spectroscopy works

Rest wavelength (6562.8 Å)

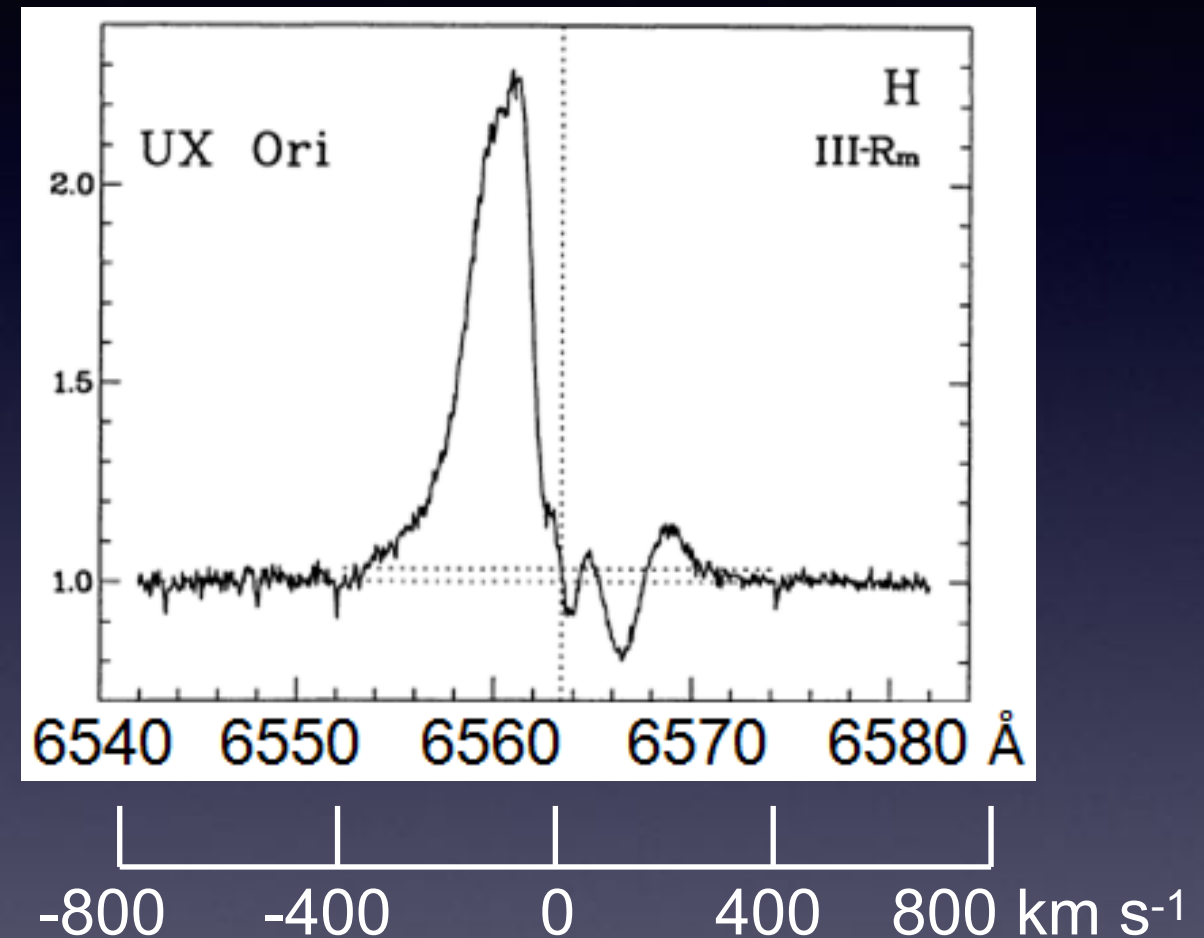
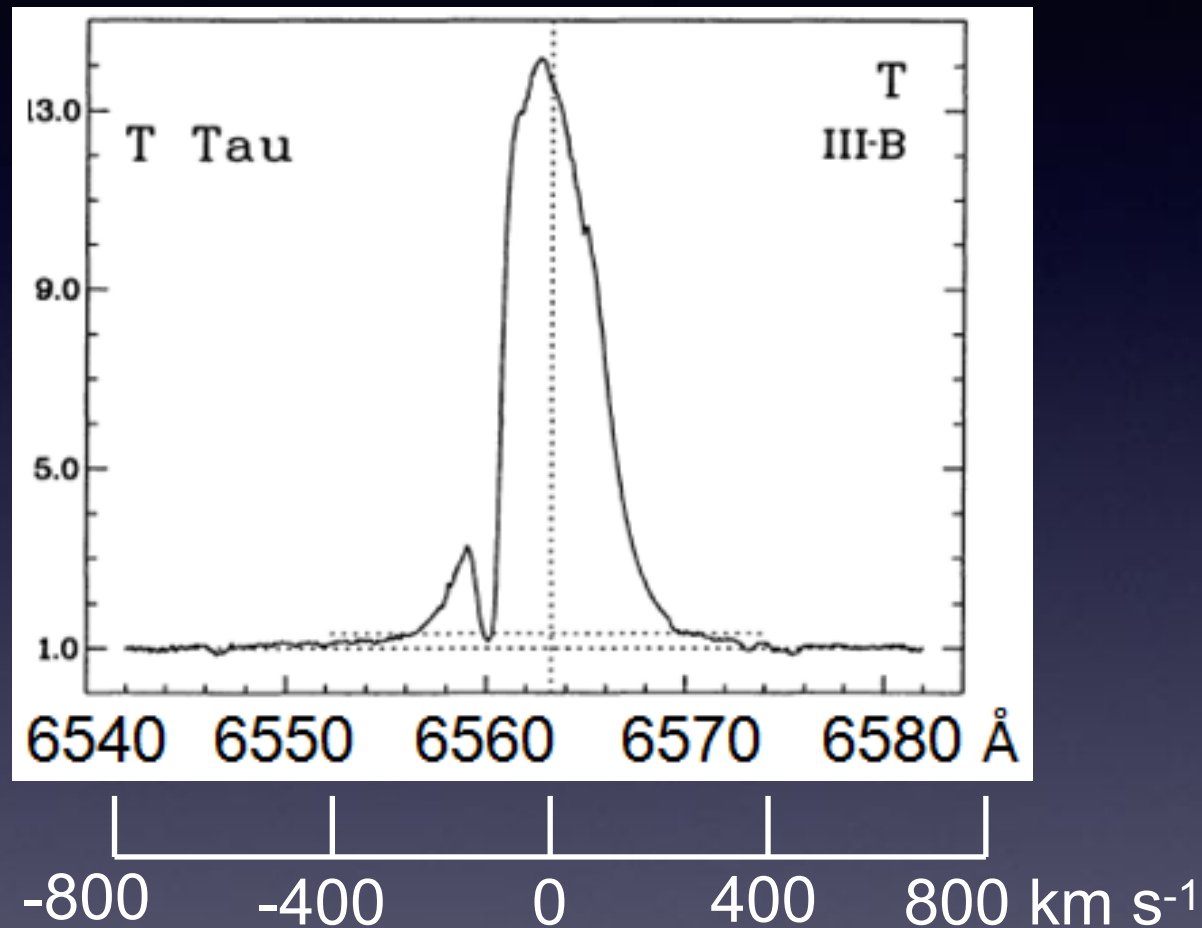
H α



(Wikipedia)

How spectroscopy works

Rest wavelength (6562.8 Å)

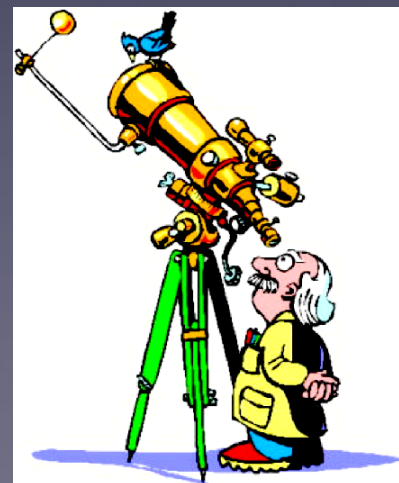
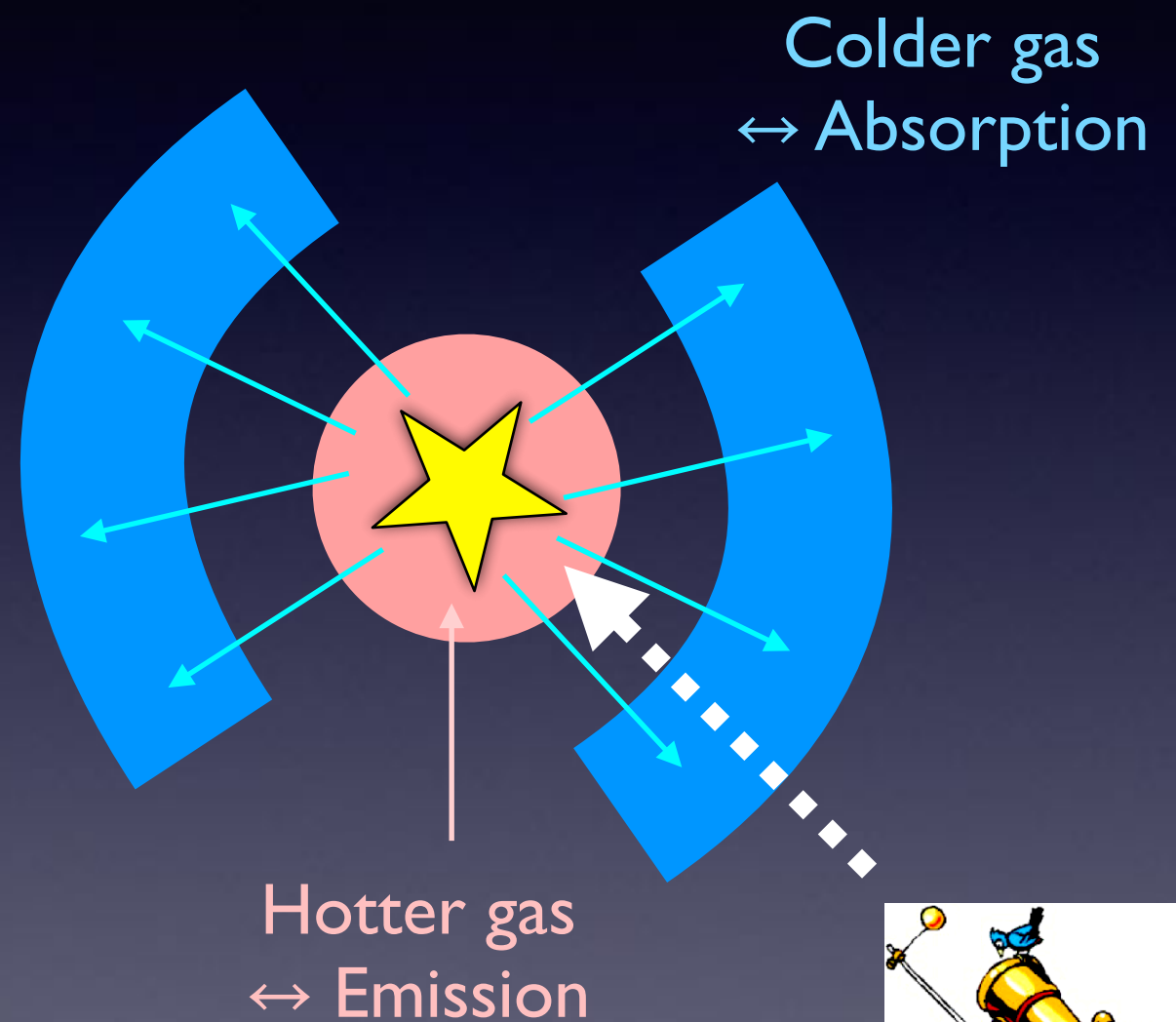
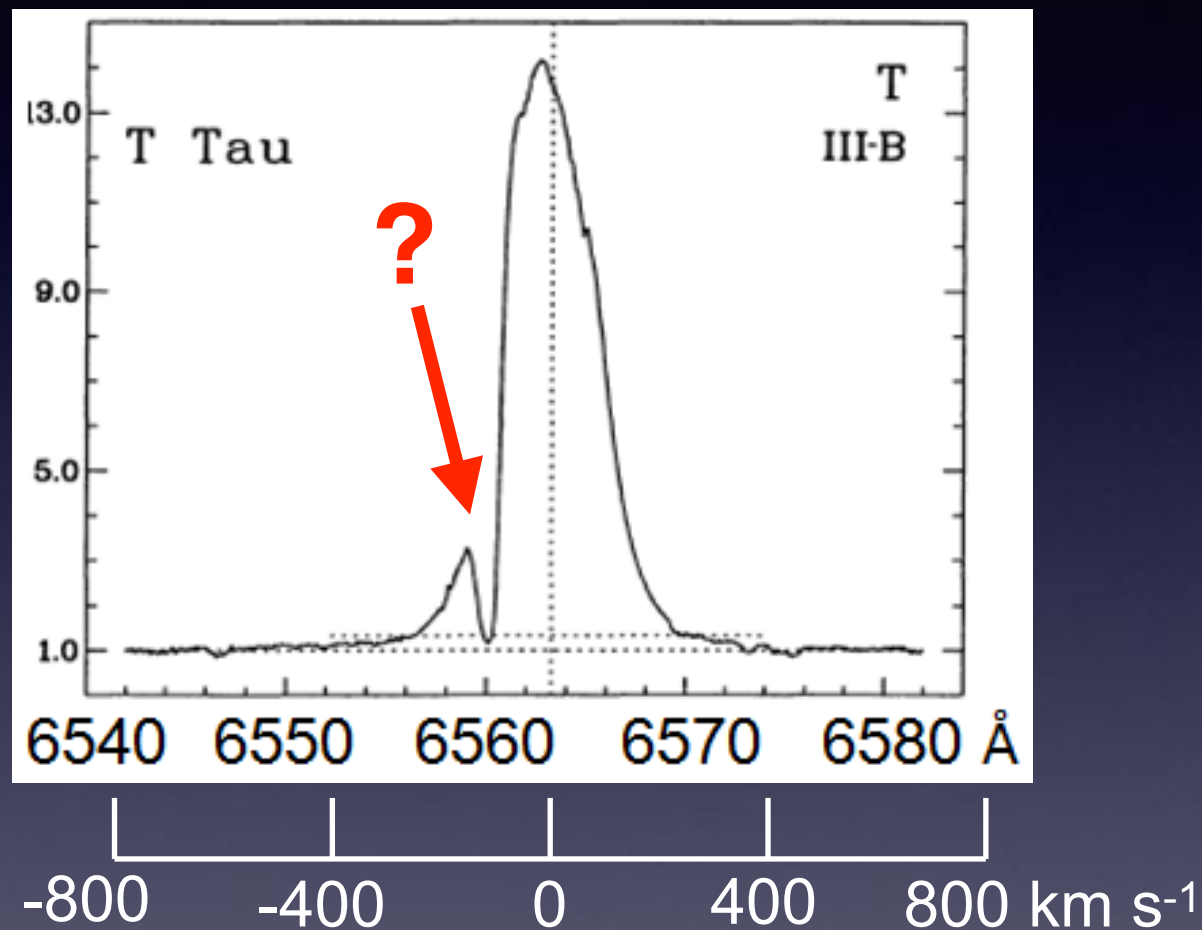


Example of measuring velocities

The above line profiles show gas at a variety of velocities due to the “Doppler shift”

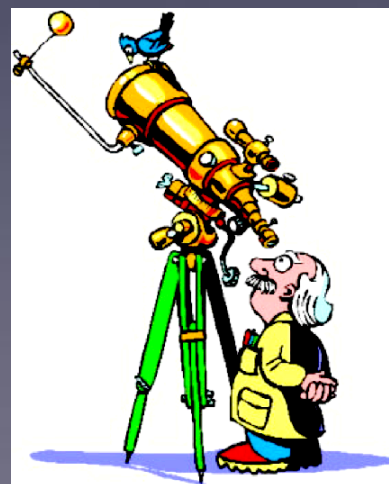
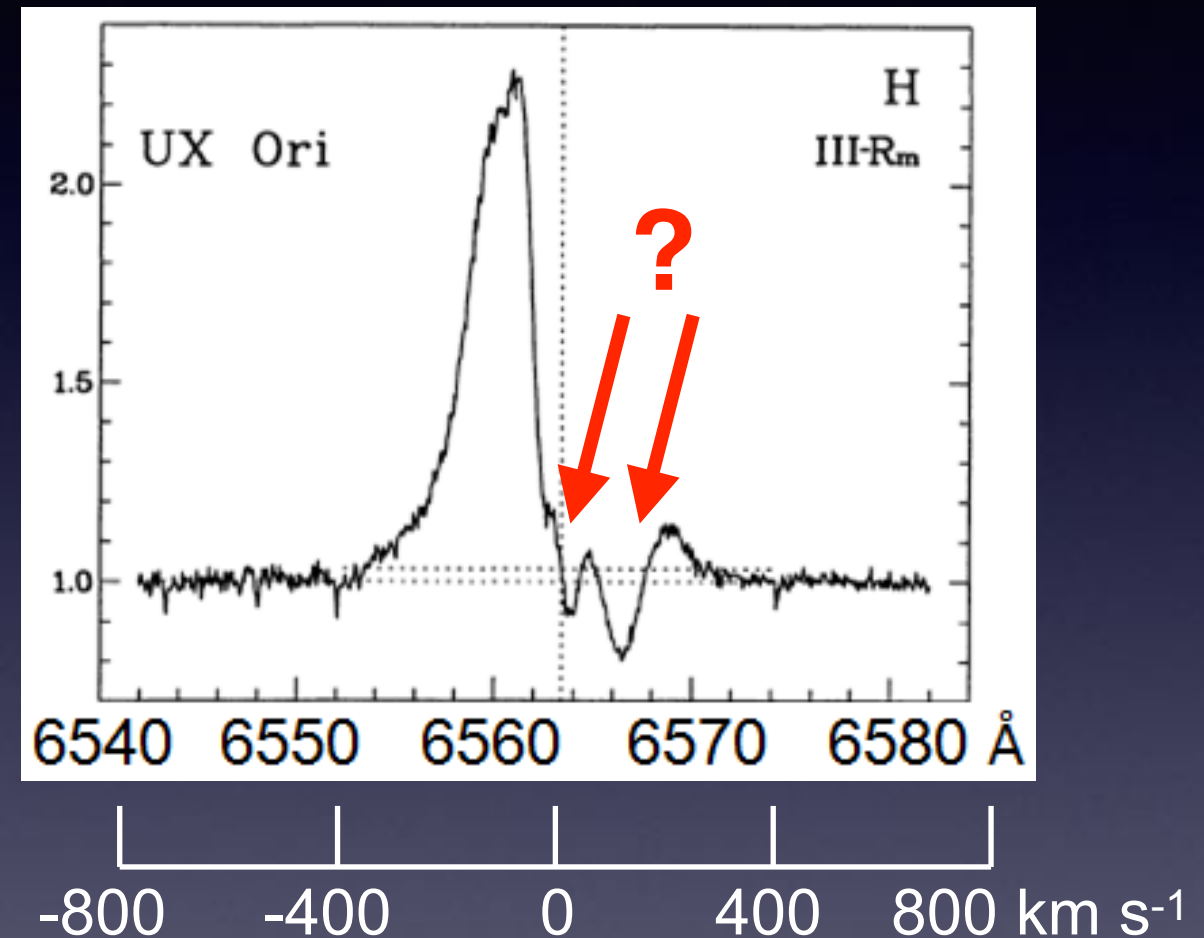
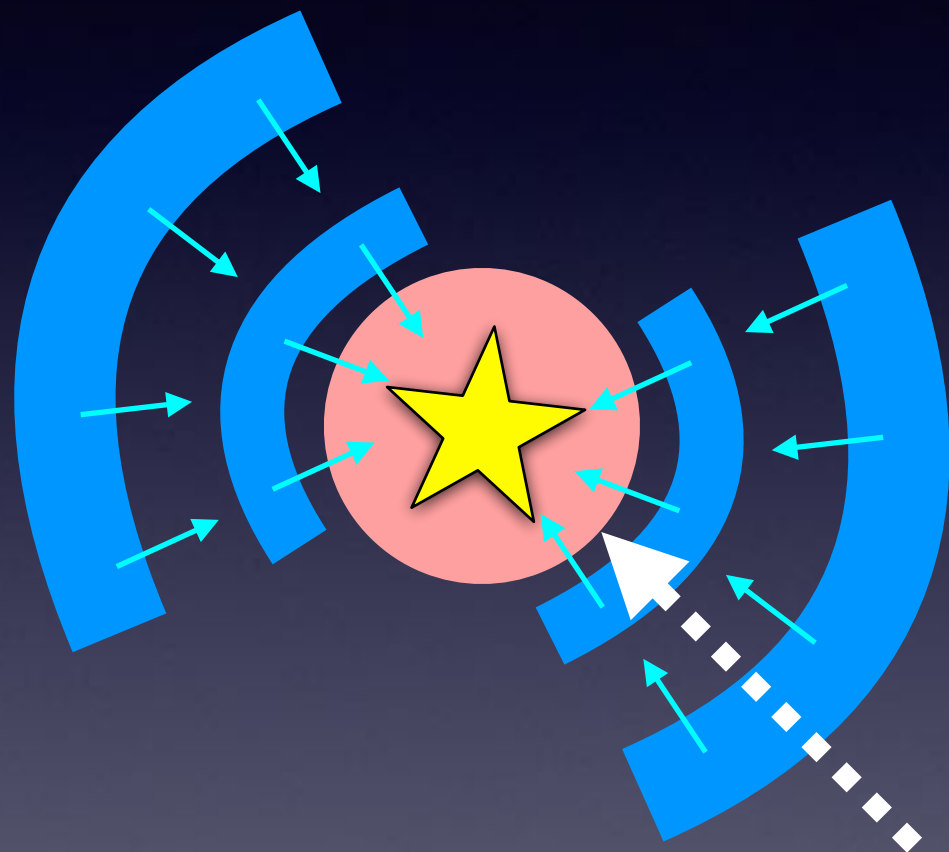
How spectroscopy works

Rest wavelength (6562.8 Å)

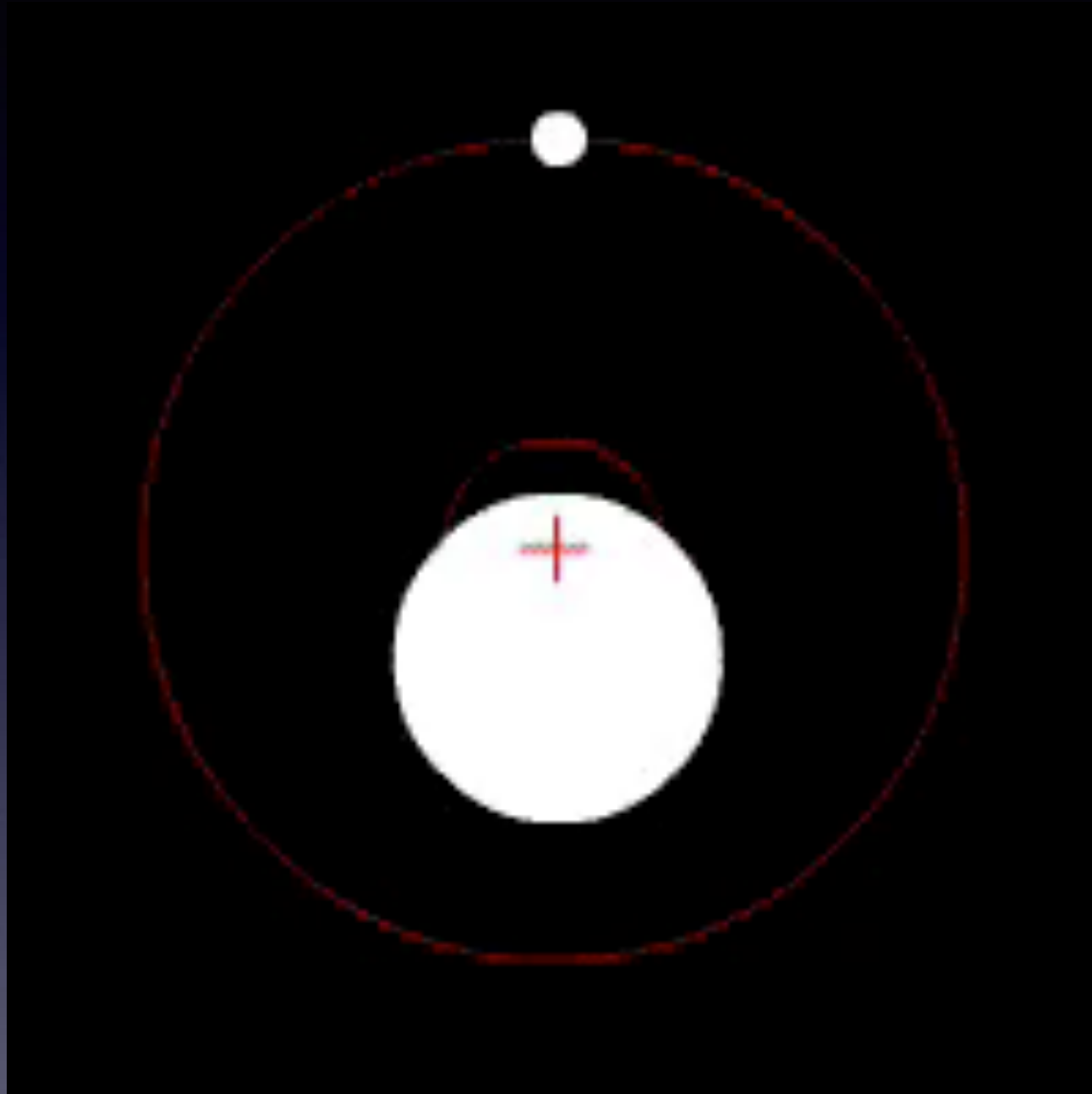


How spectroscopy works

Rest wavelength (6562.8 Å)



How spectroscopy works



(Wikipedia)

56 m s⁻¹

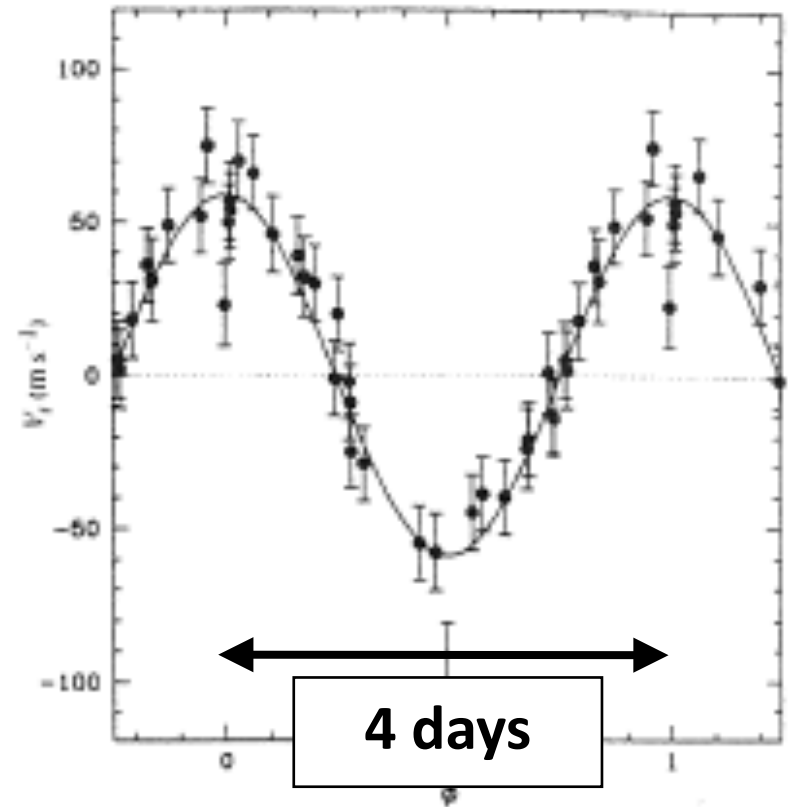


FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the γ -velocity. The solid line represents the orbital motion computed from the parameters of Table 1.

First extrasolar planets discovered
toward a sun-like star
(Mayor & Queloz 1995)

Accurate measurements of the velocity
of the stars allow us to search for extrasolar planets