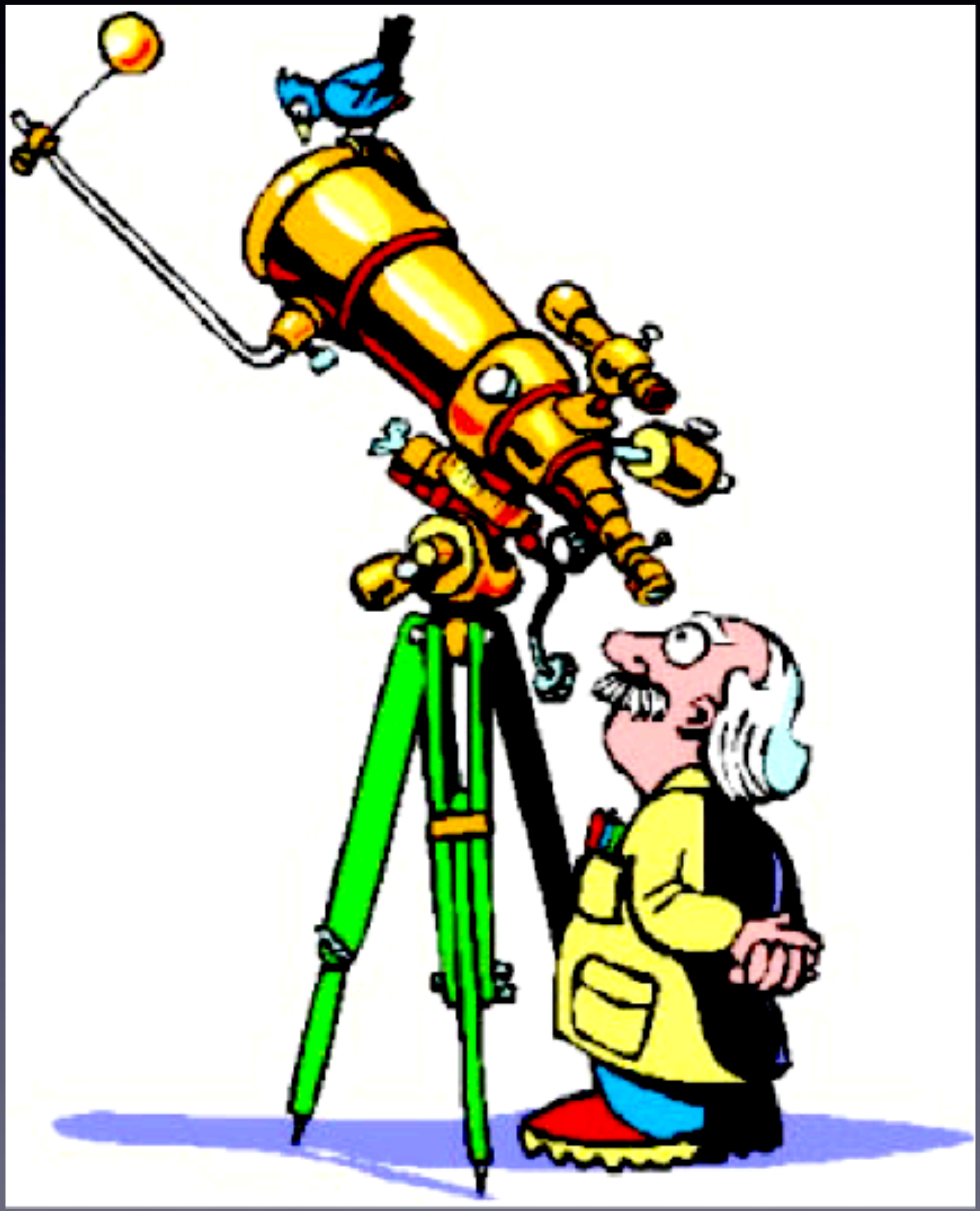
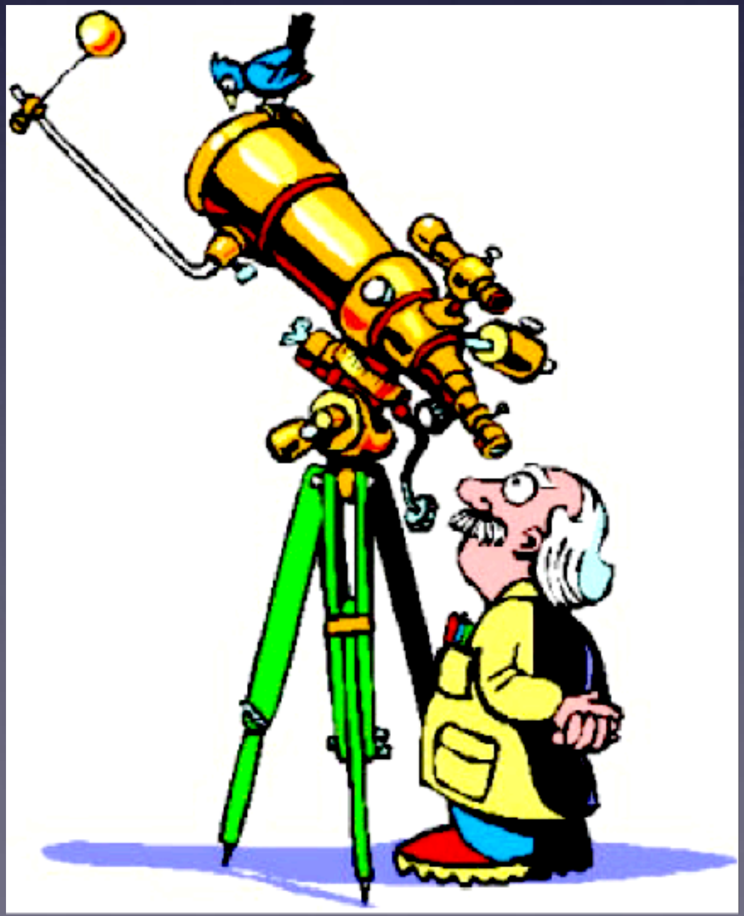
6/30/2026 ASIAA Summer Program



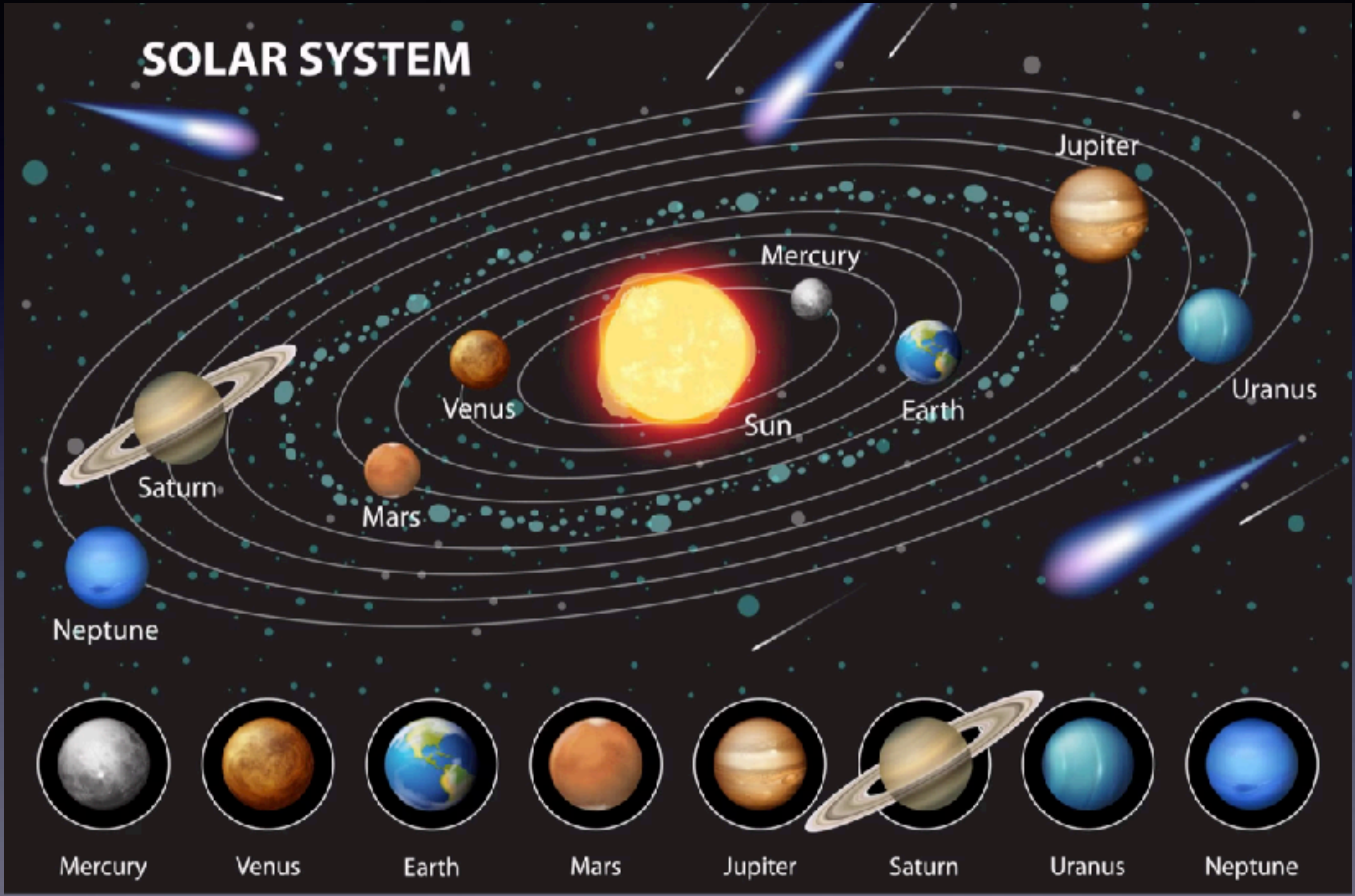
Optical & Infrared Views of the Universe

Lecturer: Hiro Takami

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

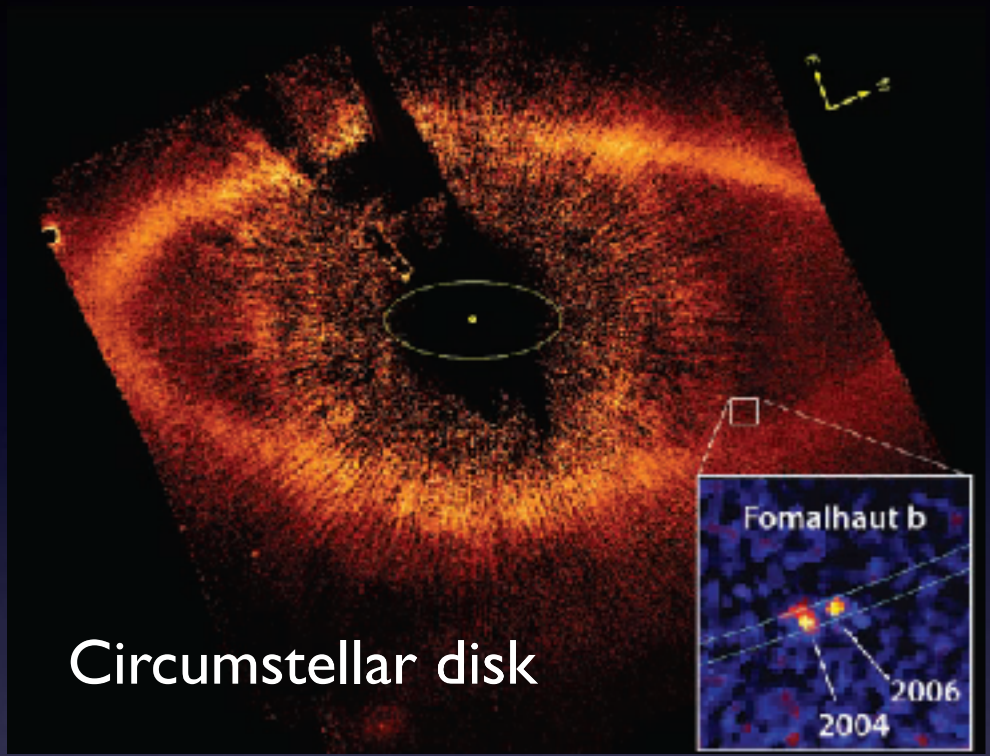


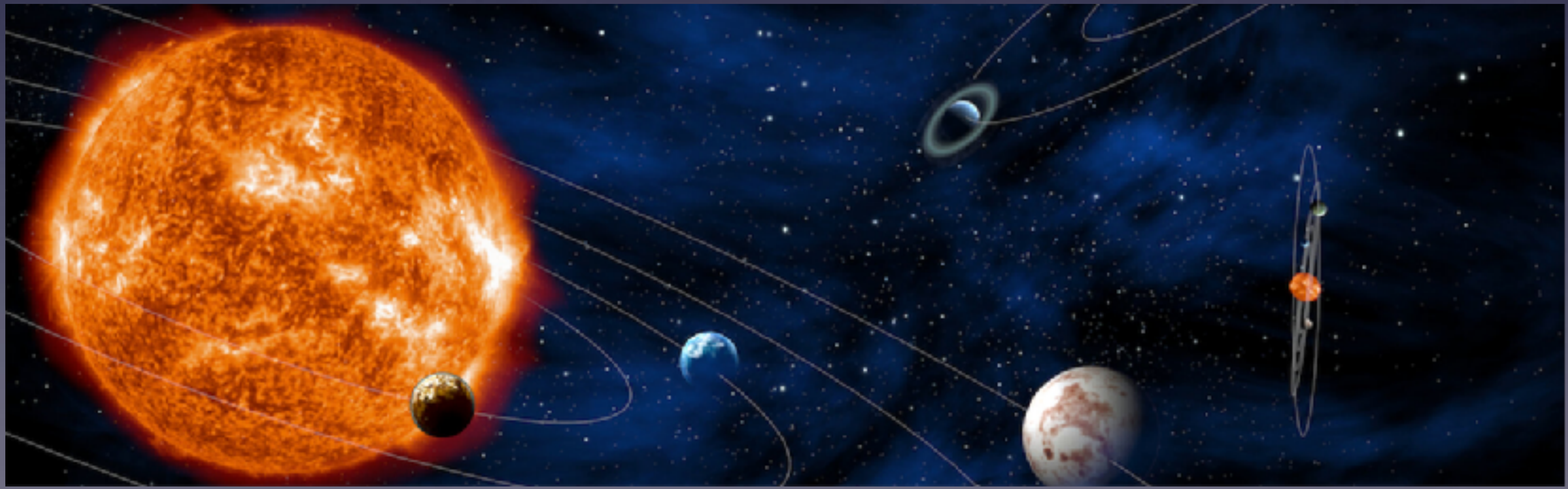
What are in the universe?



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

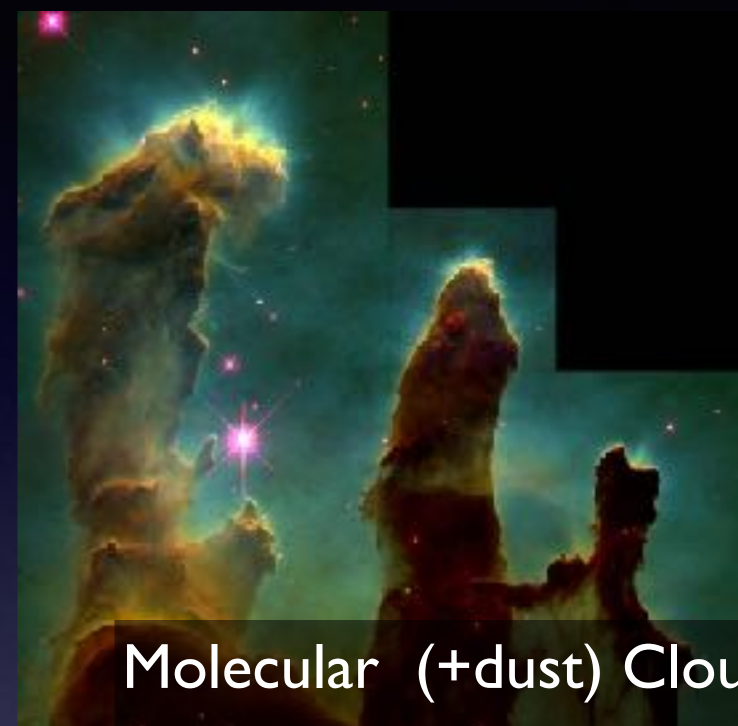
What are in the universe?

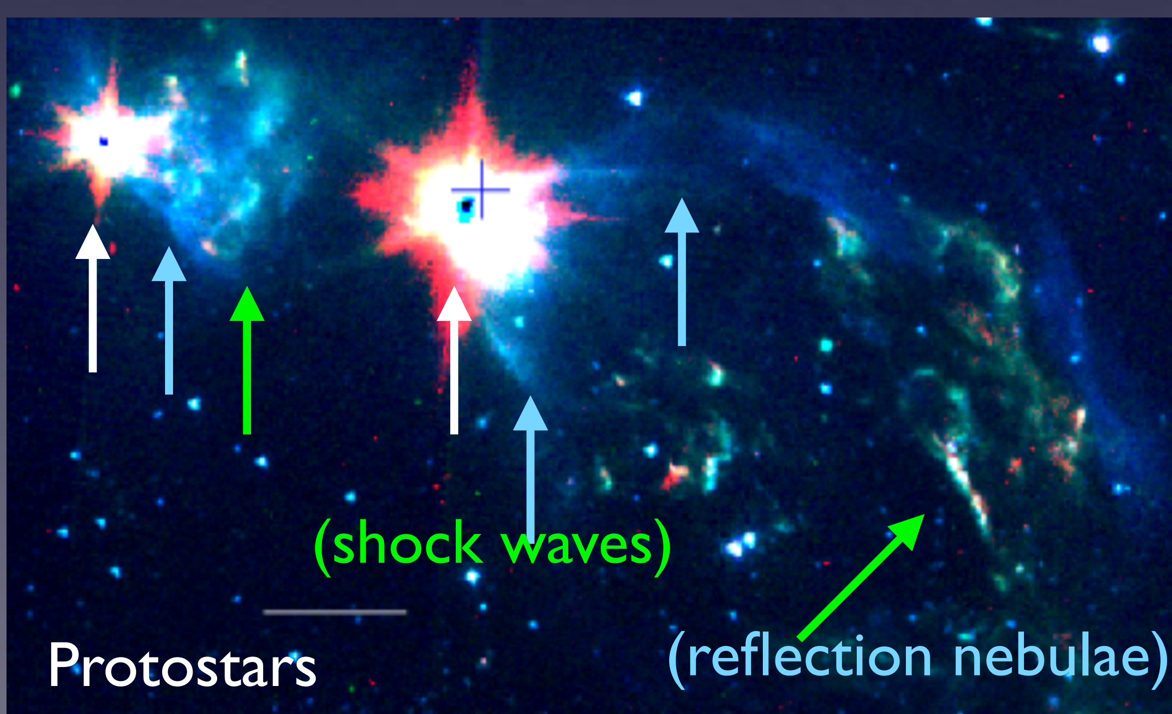


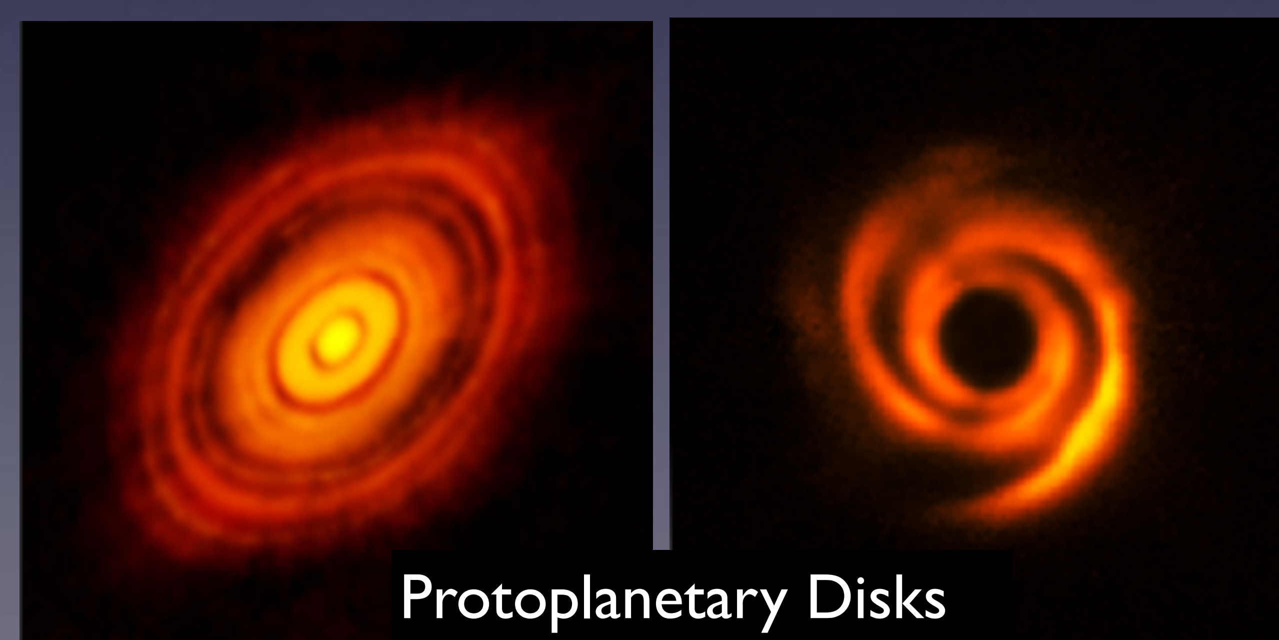


Exoplanets (ESA)

What are in the universe?

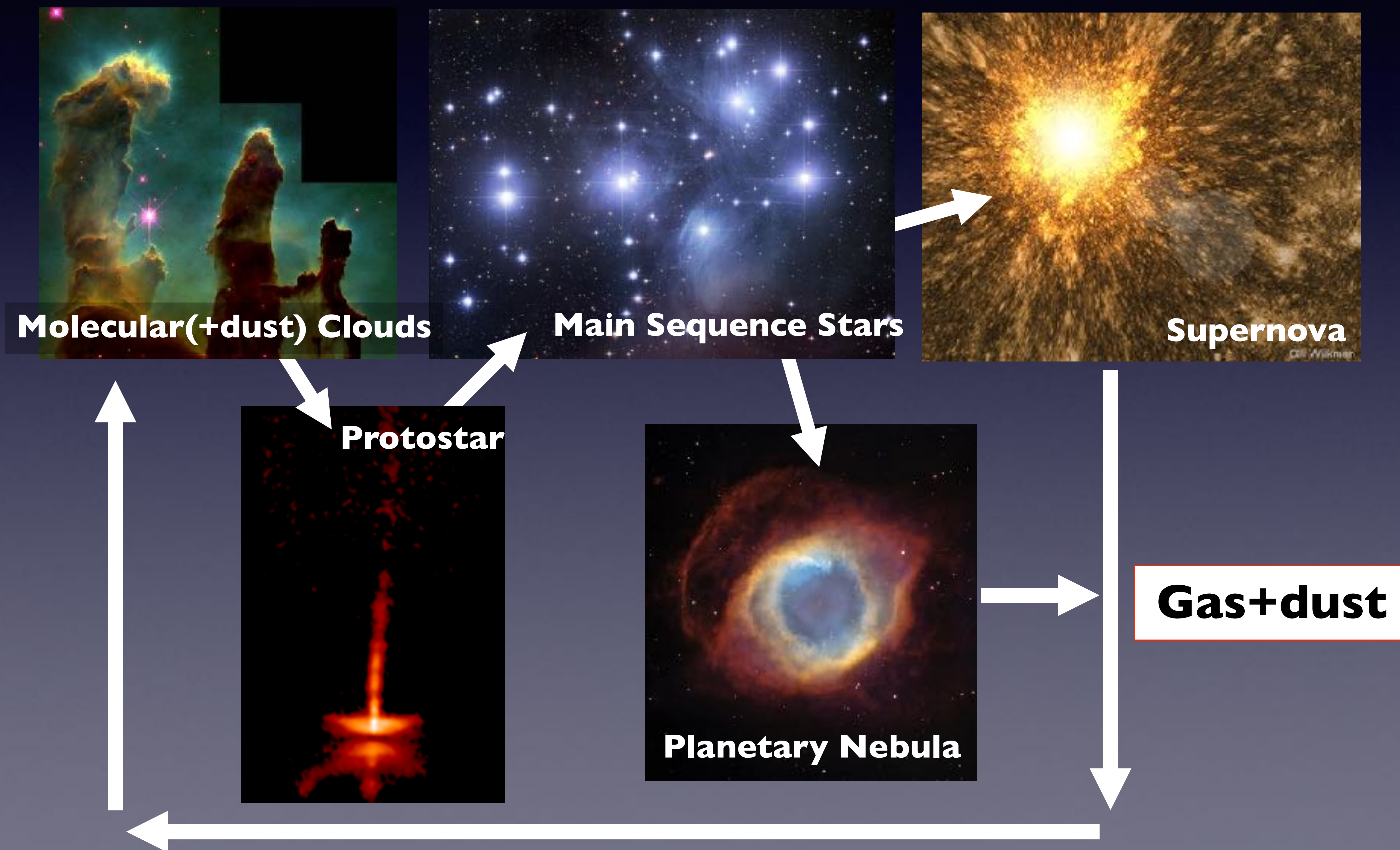




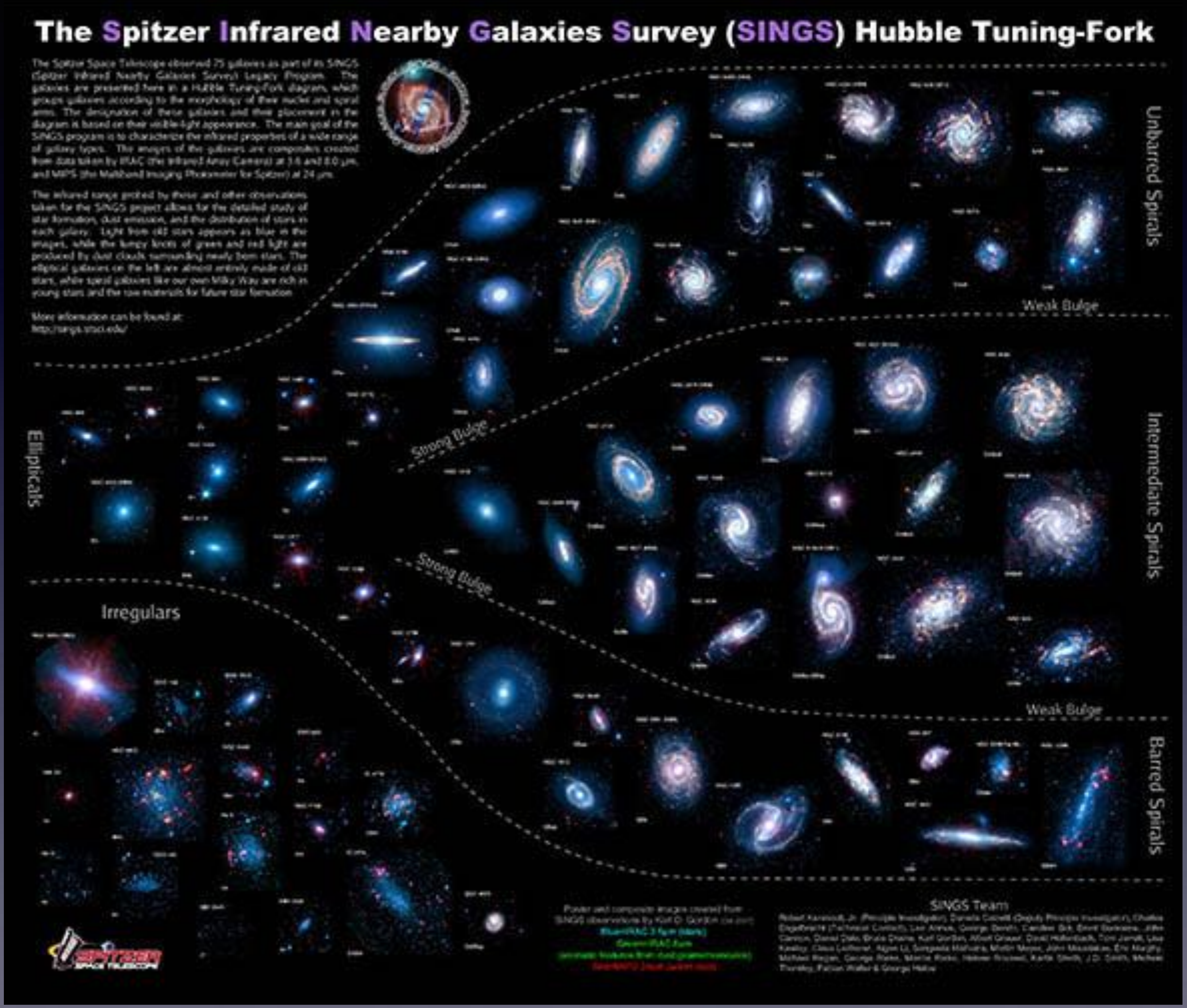


What are in the universe?

— Life cycle of stars and interstellar medium —



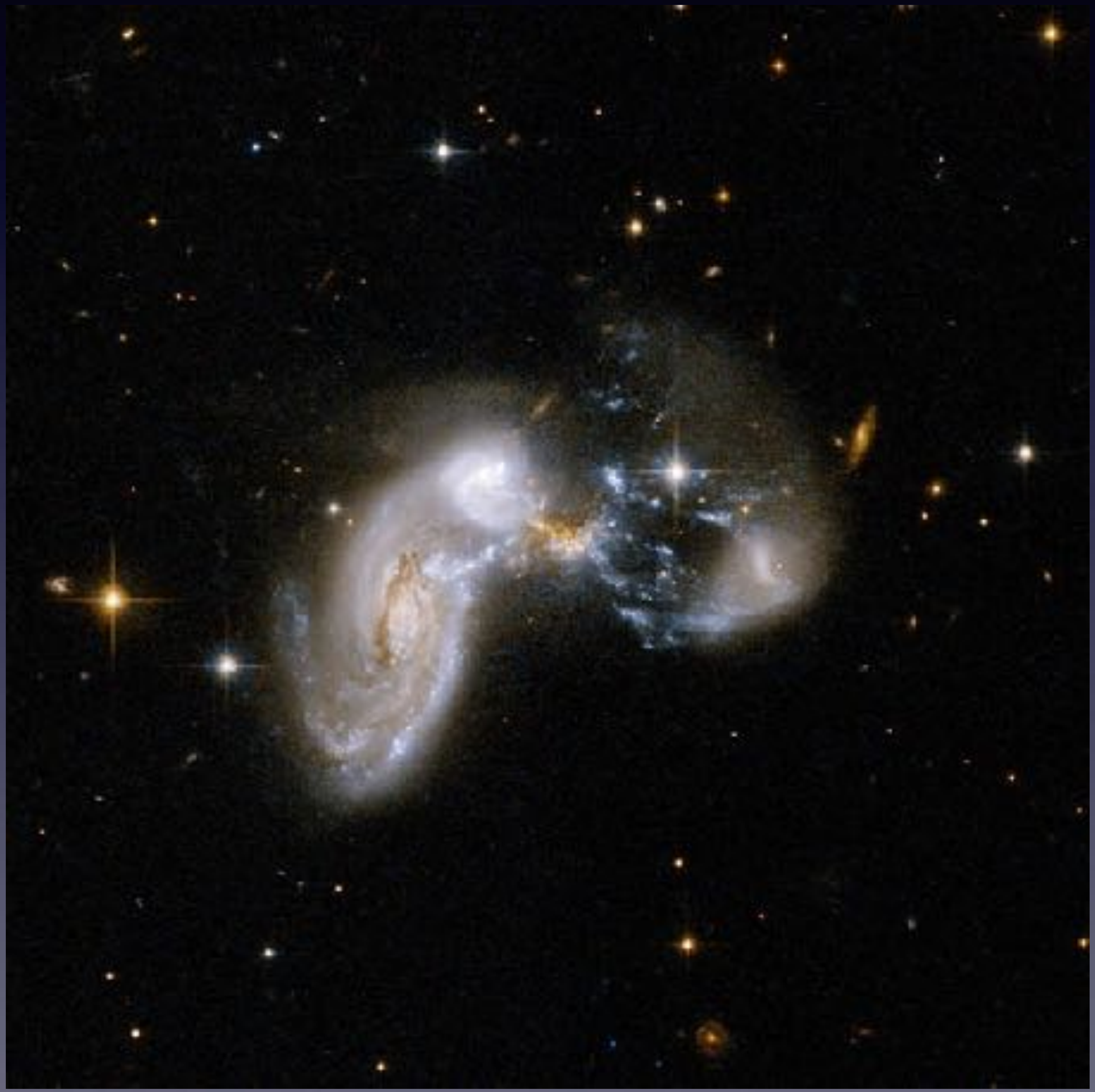
What are in the universe?



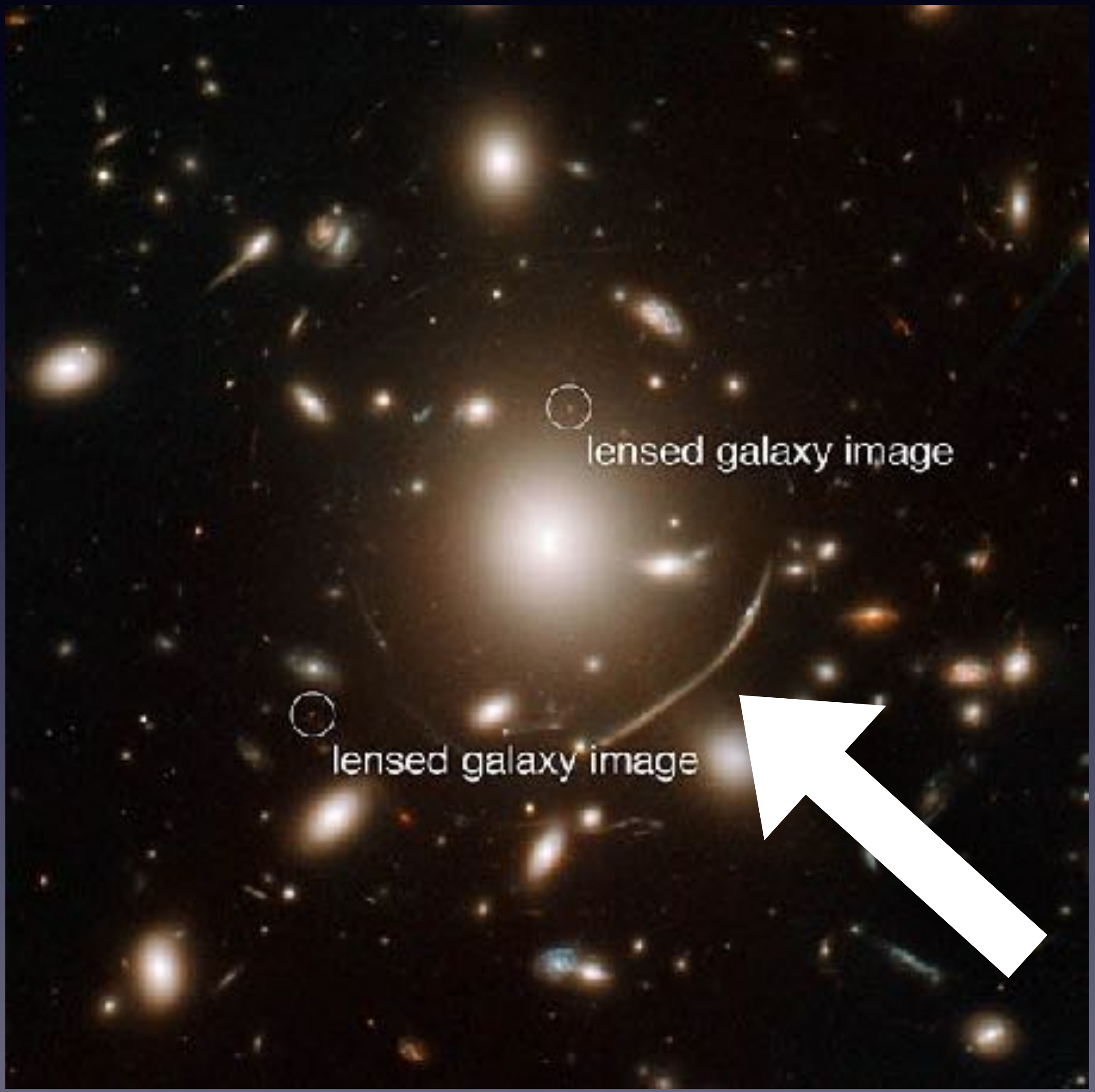
(http://www.spitzer.caltech.edu/images/)

What are in the universe?

(Interacting Galaxies)

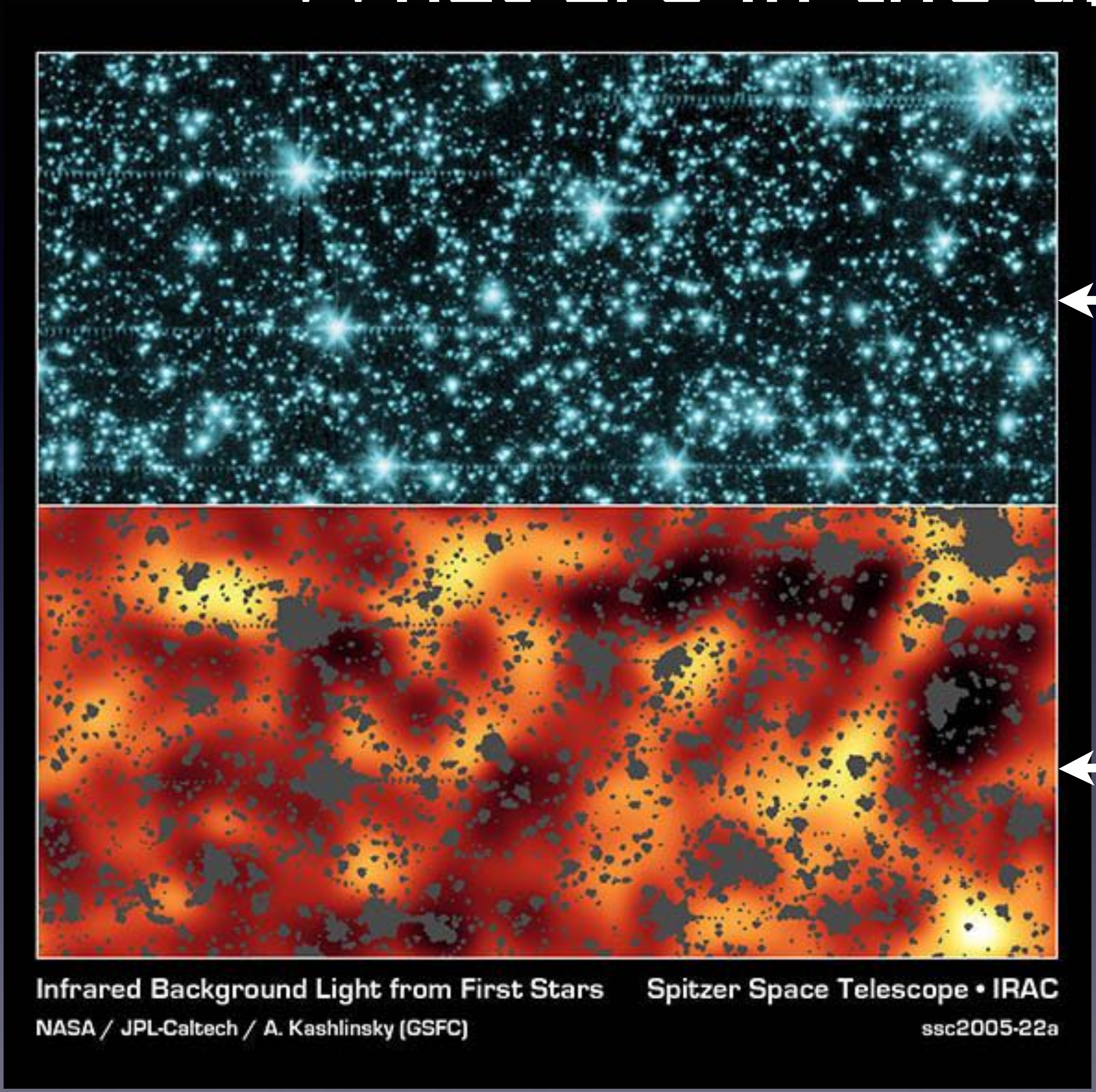


(Gravitational lensing)



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

What are in the universe?

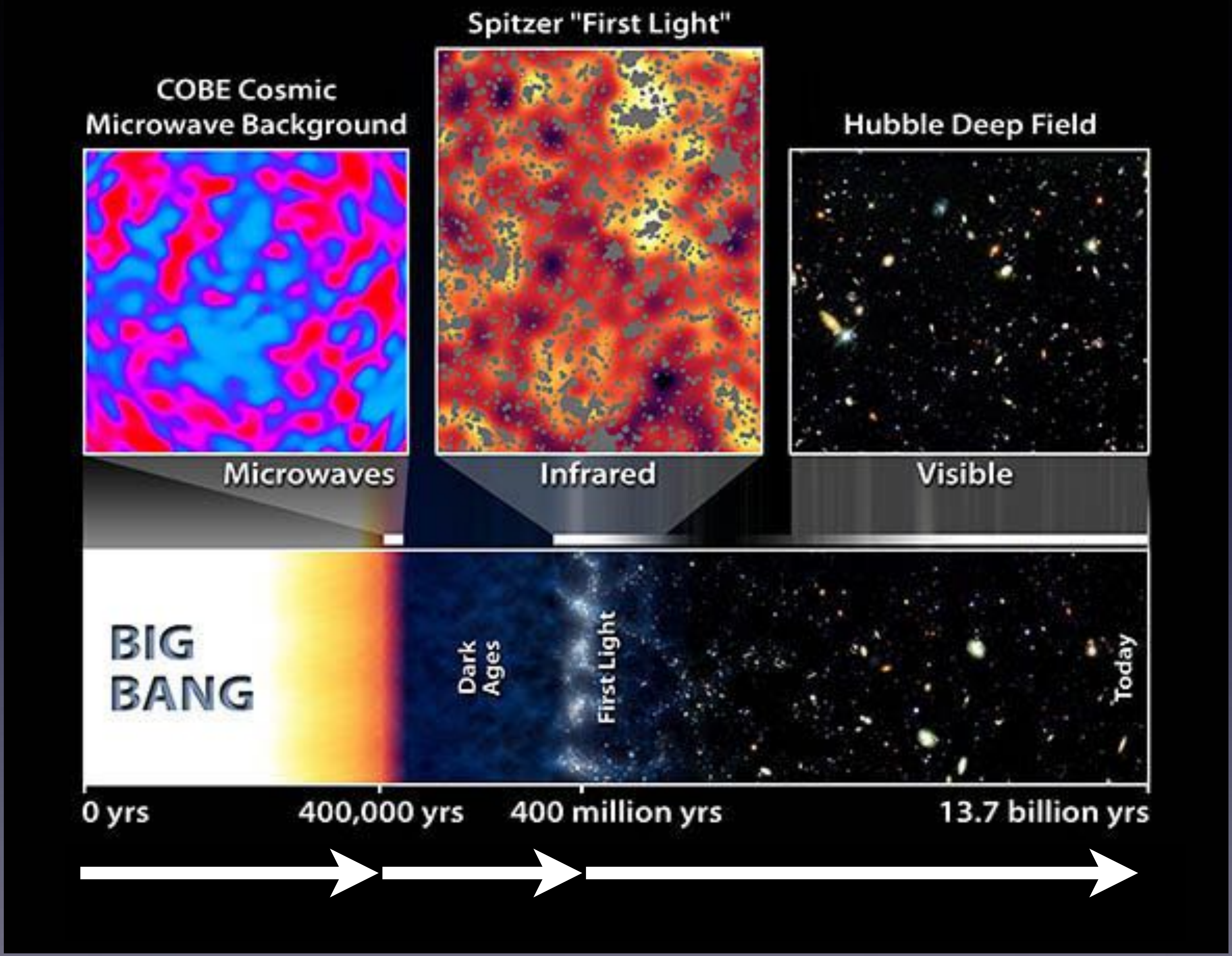


Foreground objects

A number of first stars in the universe?

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

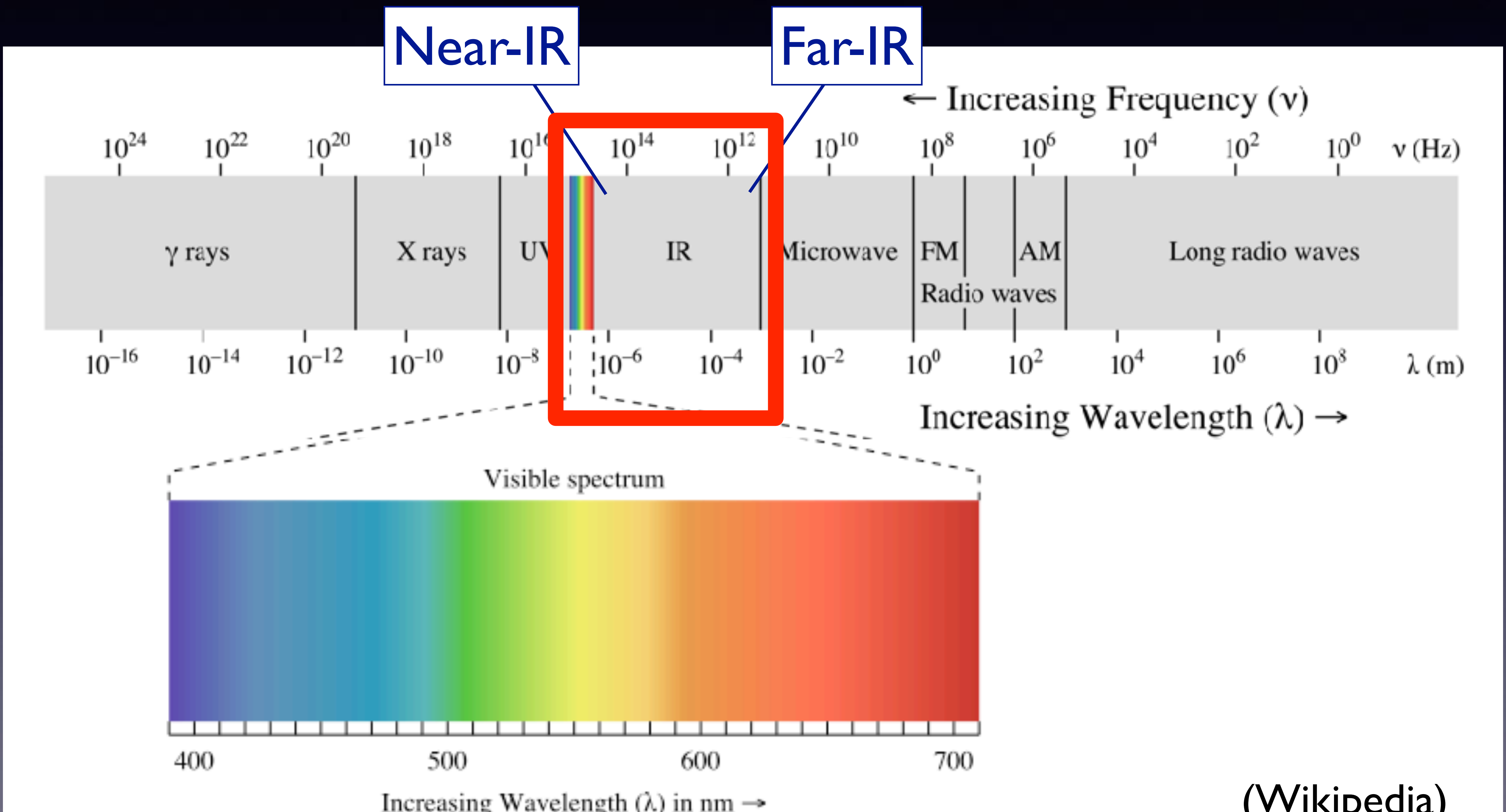
What are in the universe?



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

What are optical & infrared?

— Electromagnetic waves —



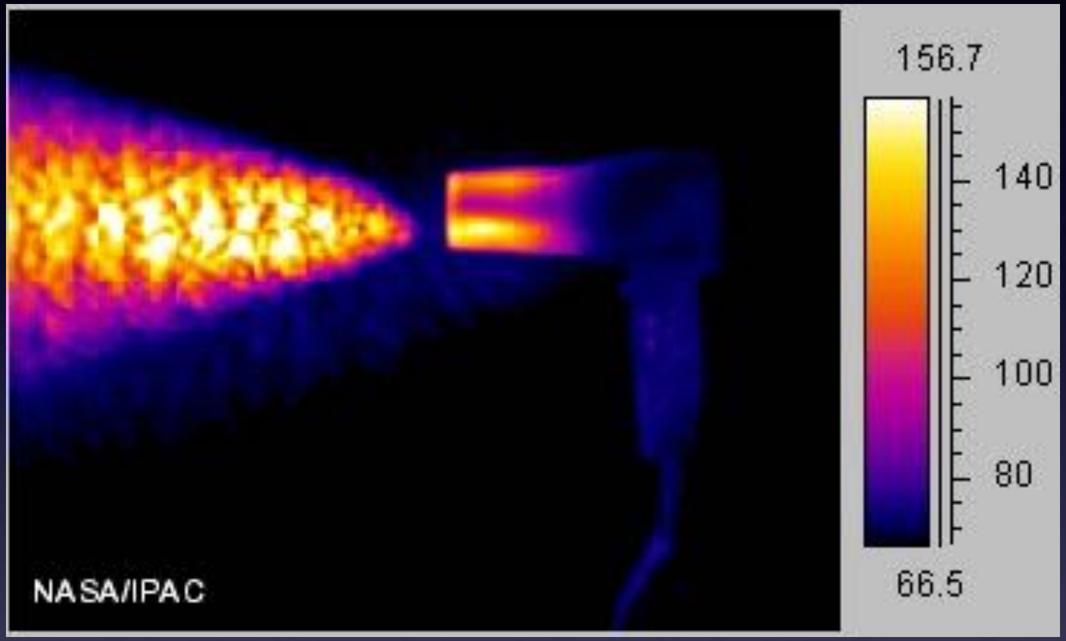
(Wikipedia)

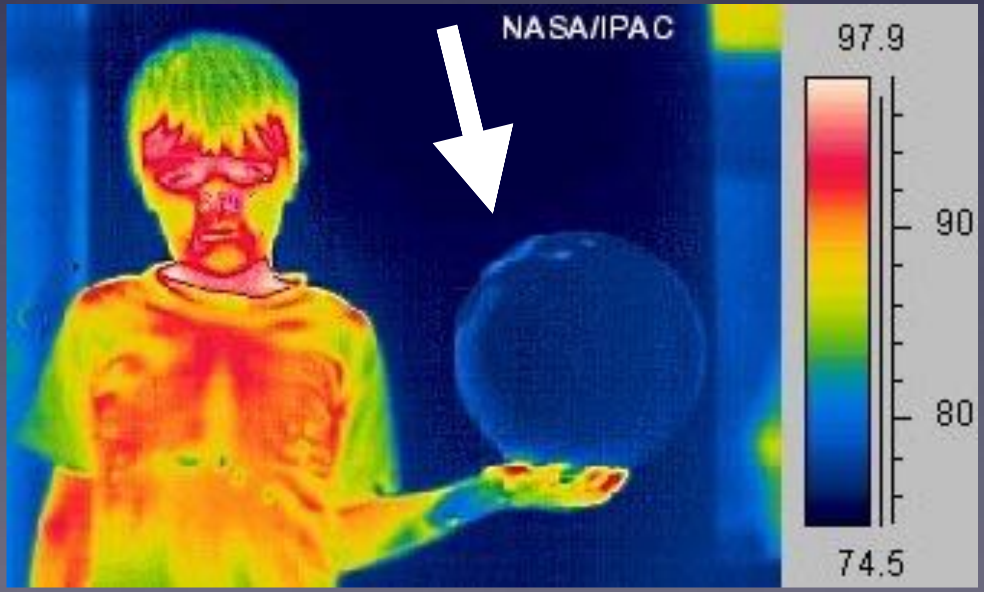
What are optical & infrared?

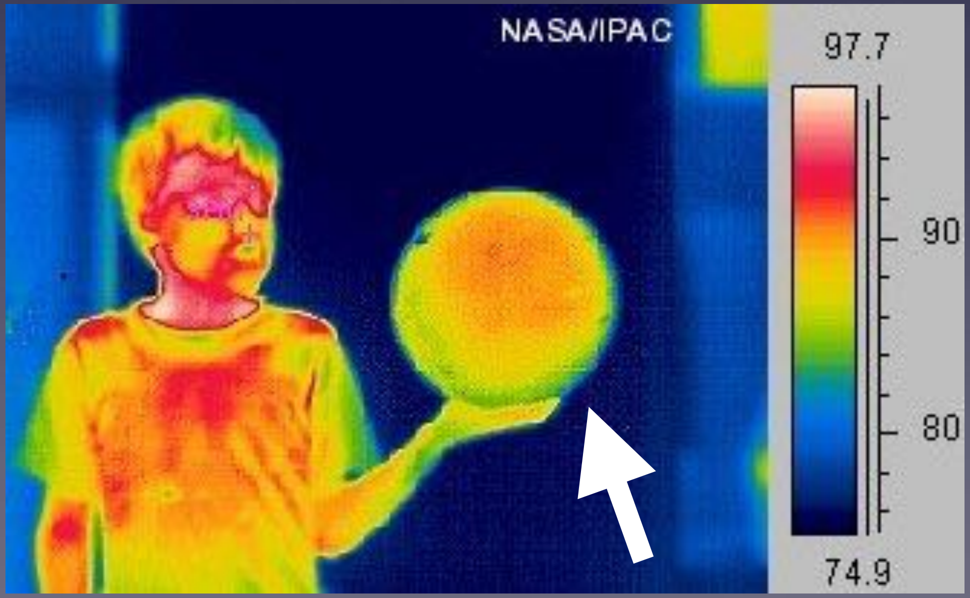
—Visible world on the ground —

What are optical & infrared?

— Infrared world on the ground —





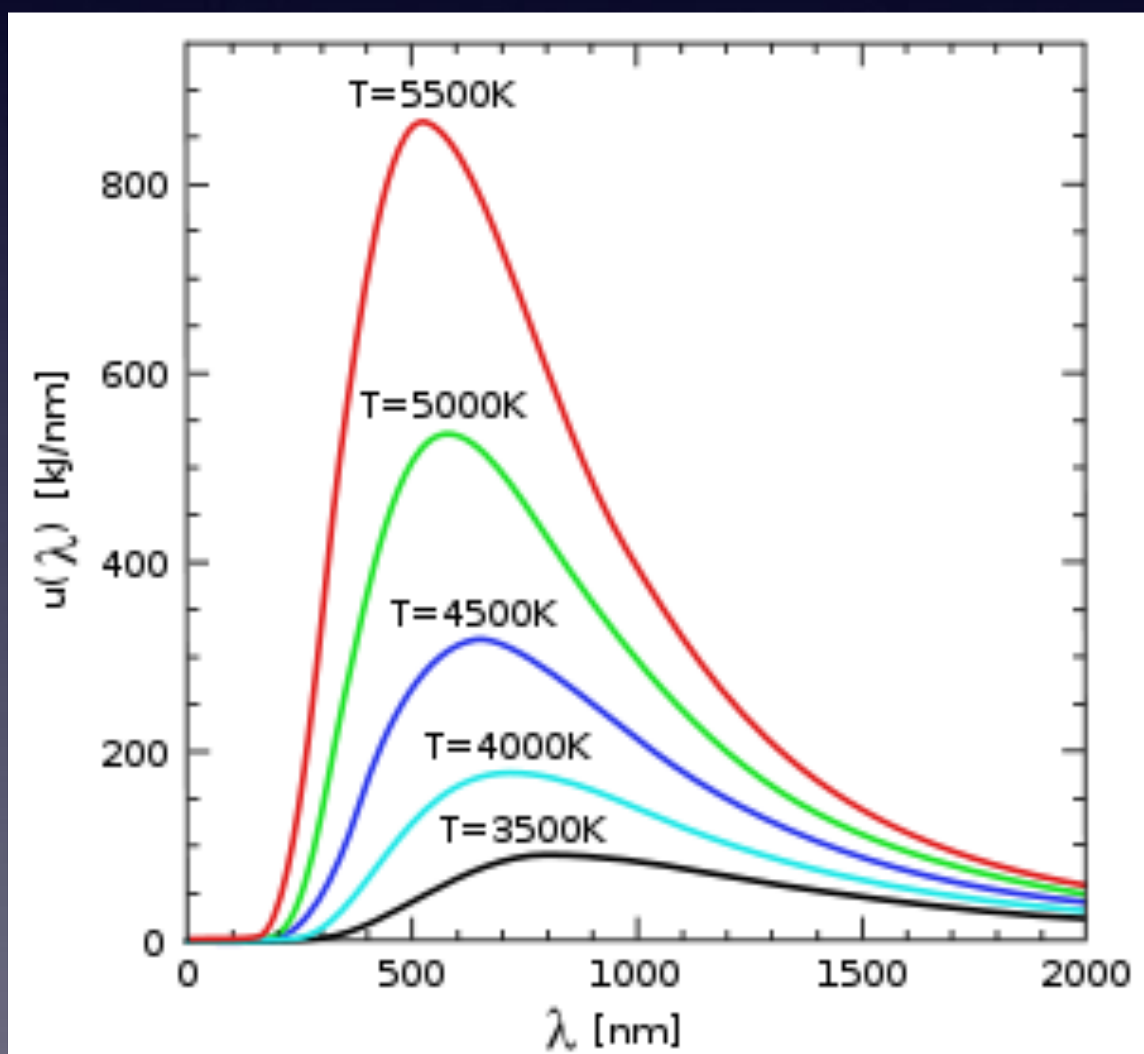


http://coolcosmos.ipac.caltech.edu/

What are optical & infrared?

— Thermal radiation (blackbody radiation) —

UV **Optical** **Infrared**



(Wikipedia)

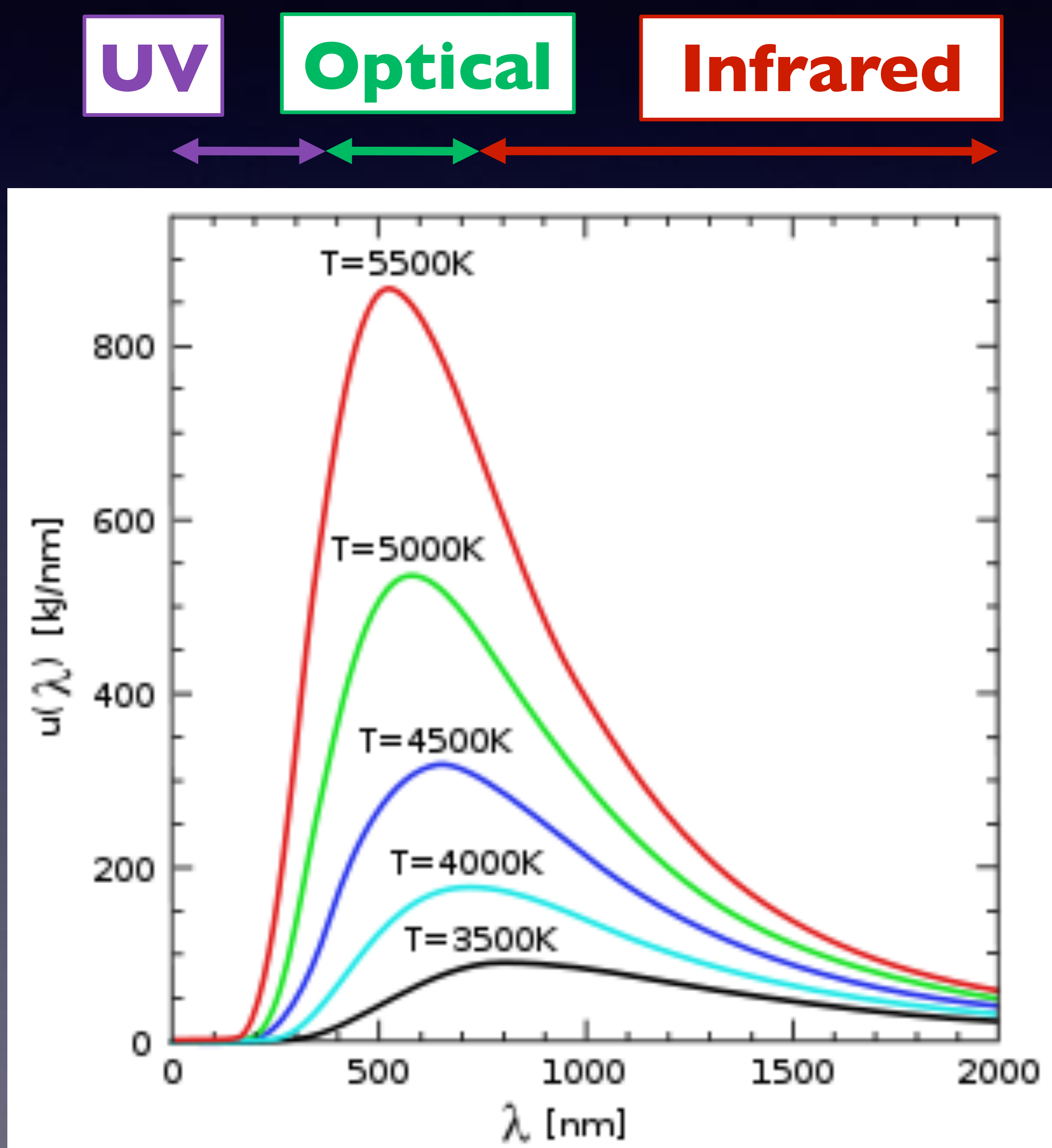
T(K)=T(°C)-273.15

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

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

What are optical & infrared?

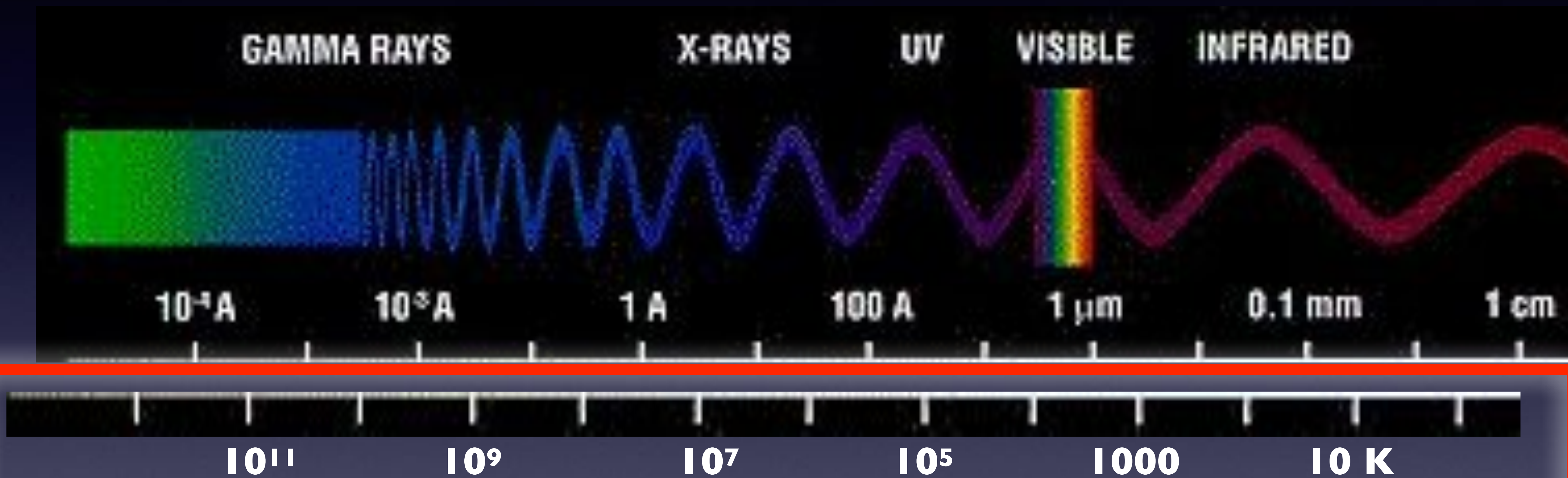
— Thermal radiation (blackbody radiation) —



(Wikipedia)

What are optical & infrared?

— Thermal radiation (blackbody radiation) —



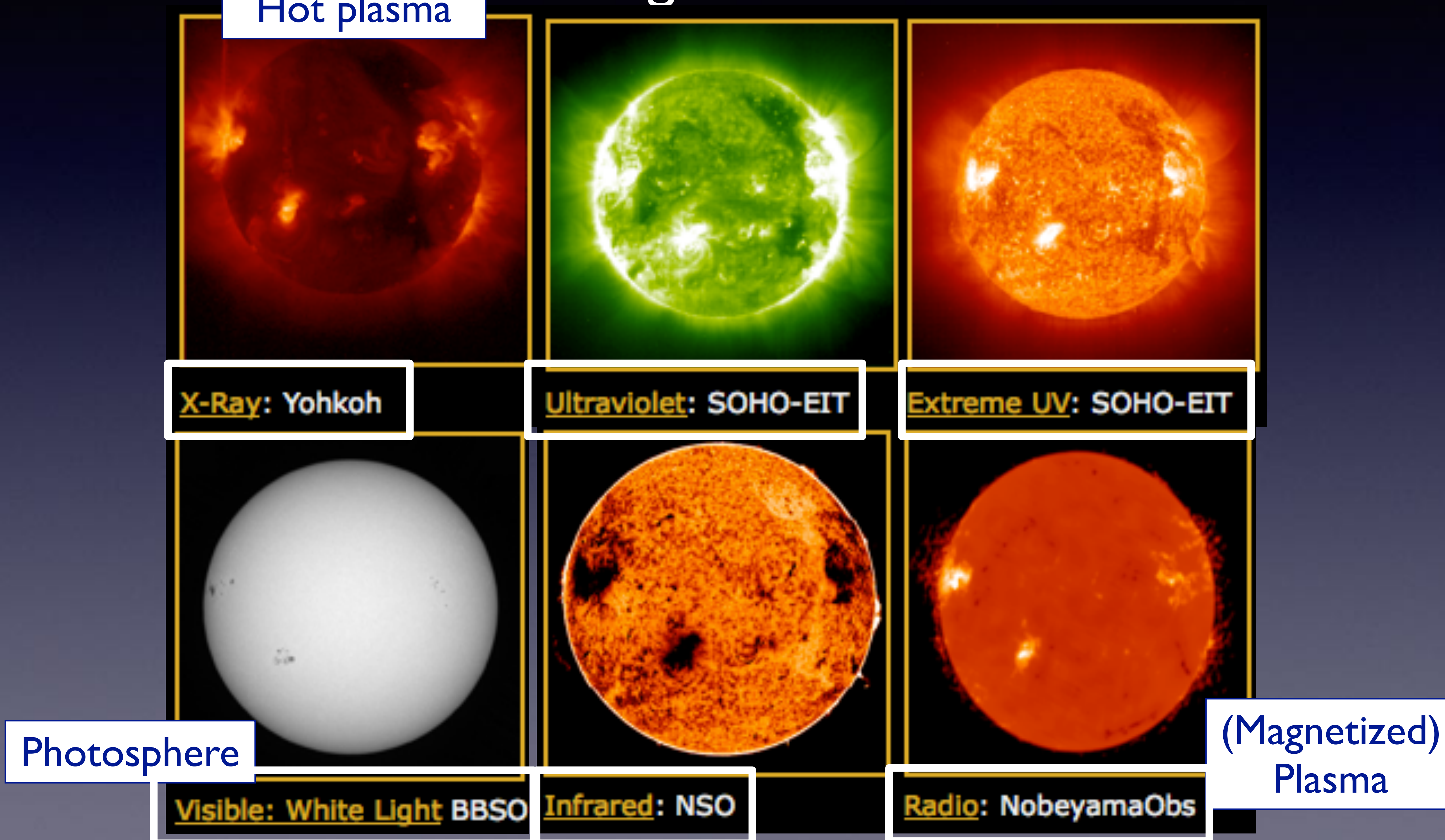
Temperature of Blackbody

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

Multiwavelength observations are essential for covering targets at different temperatures

What are optical & infrared?

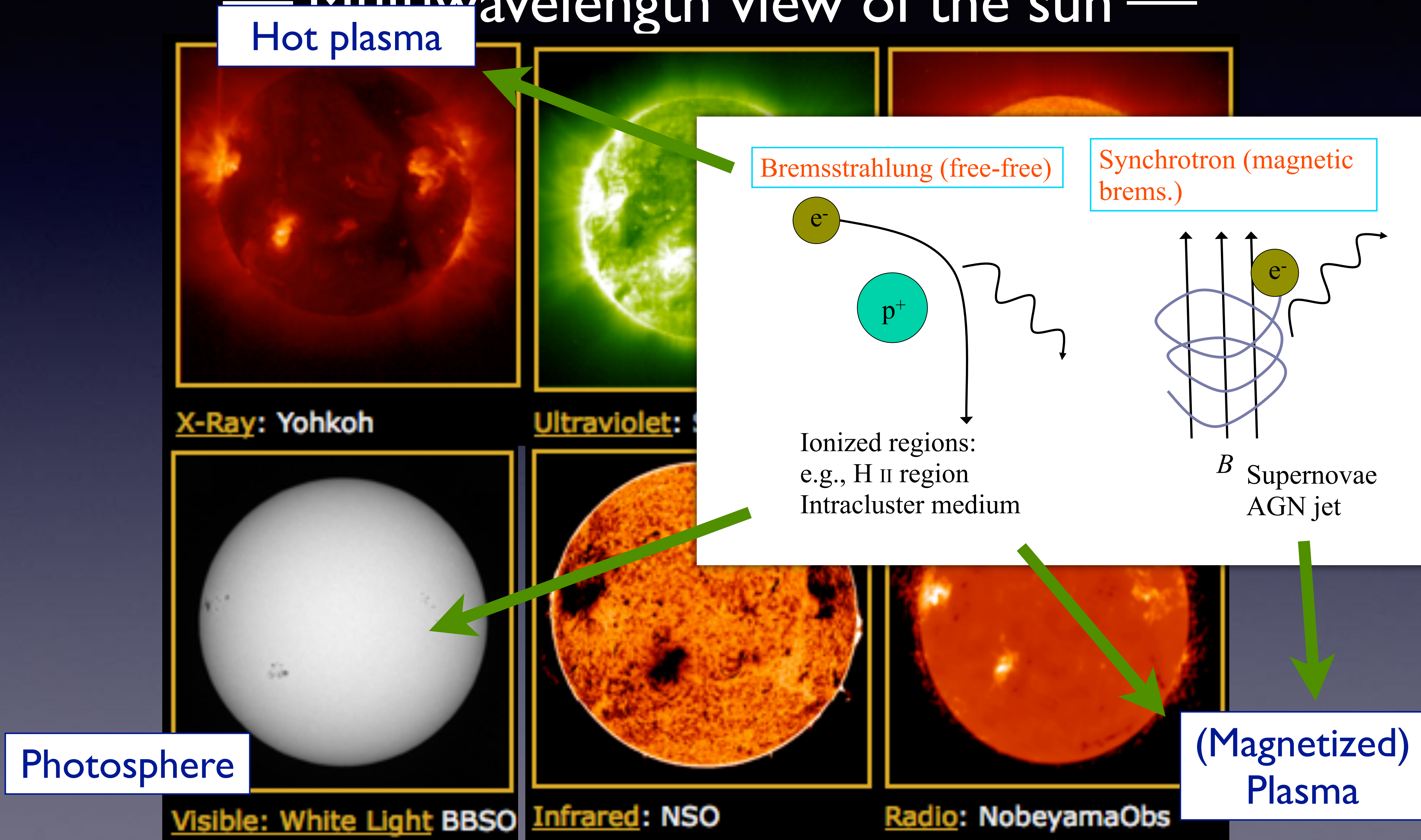
— Multiwavelength view of the sun —



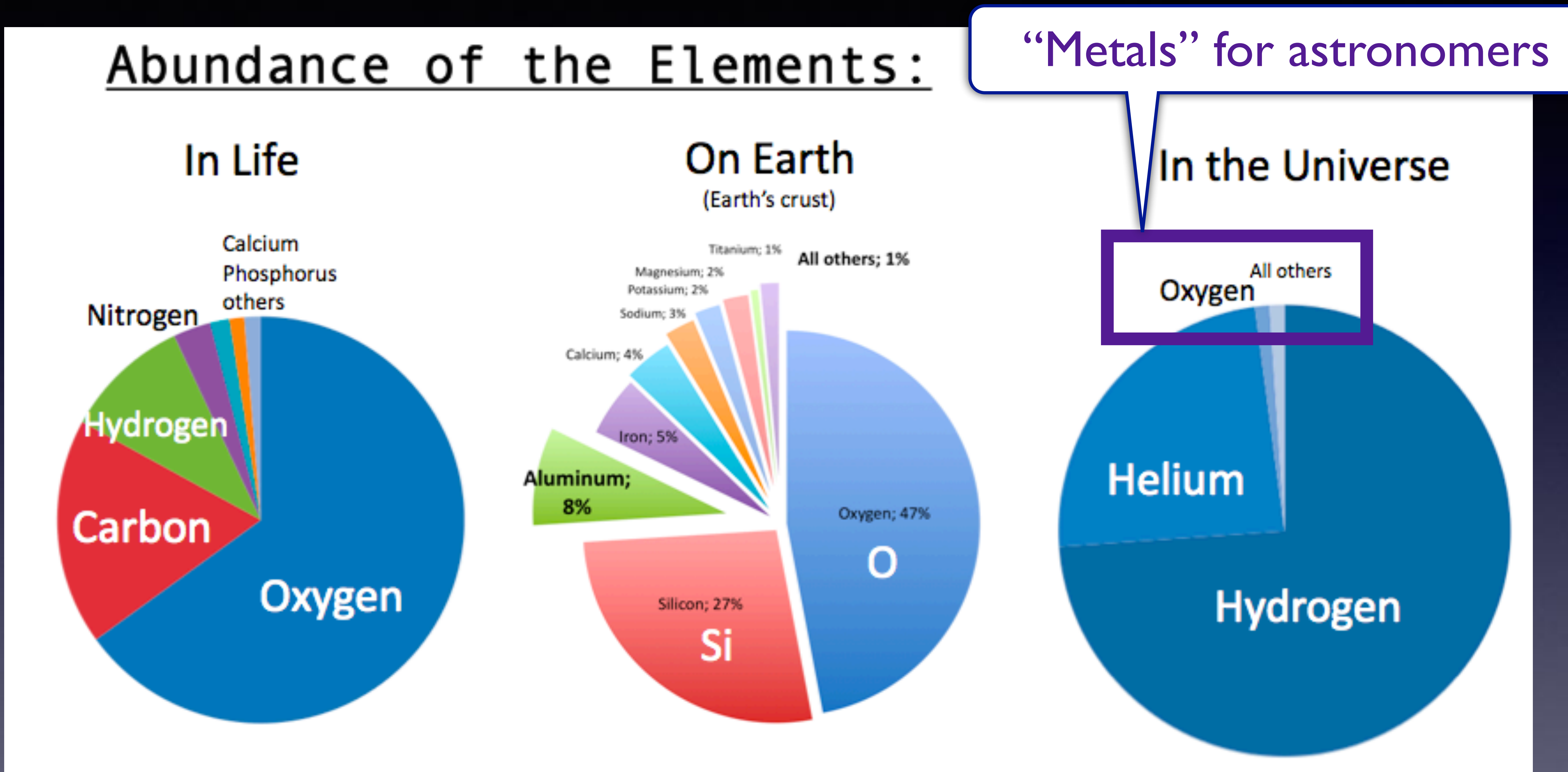
(original figures from http://coolcosmos.ipac.caltech.edu/)

What are optical & infrared?

— Multiwavelength view of the sun —



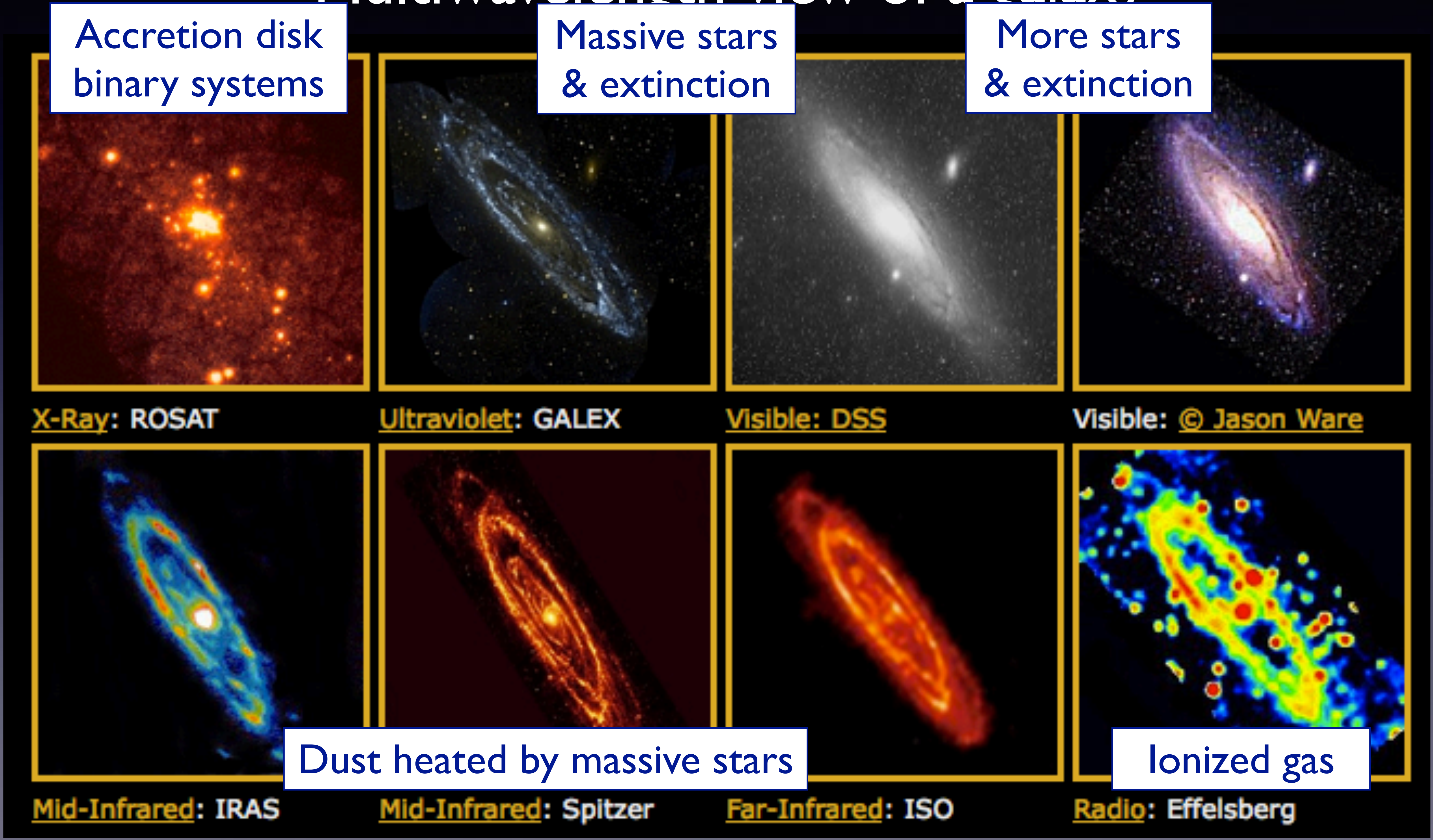
(original figures from http://coolcosmos.ipac.caltech.edu/)



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

What are optical & infrared?

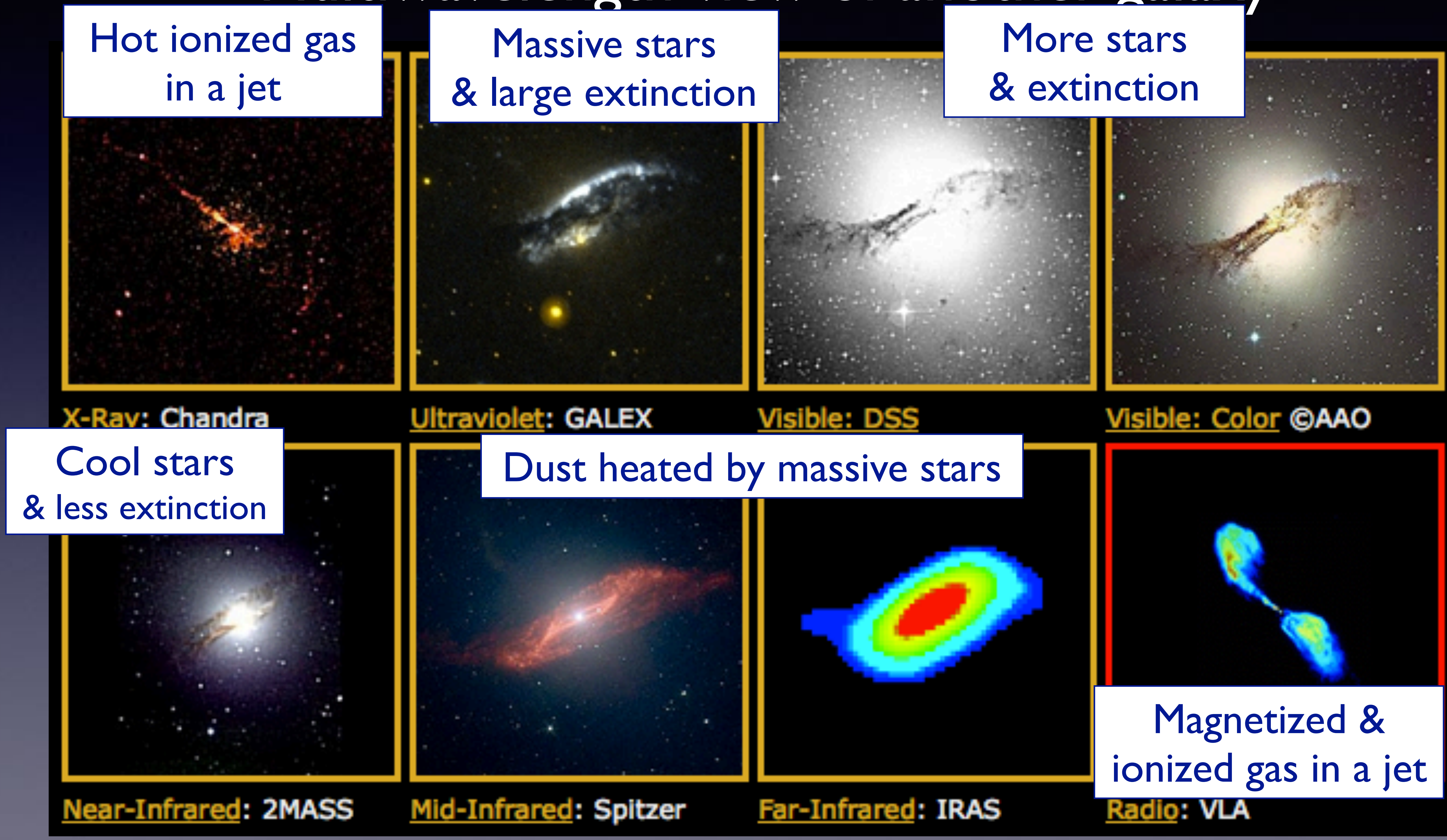
— Multiwavelength view of a galaxy —



(http://coolcosmos.ipac.caltech.edu/)

What are optical & infrared?

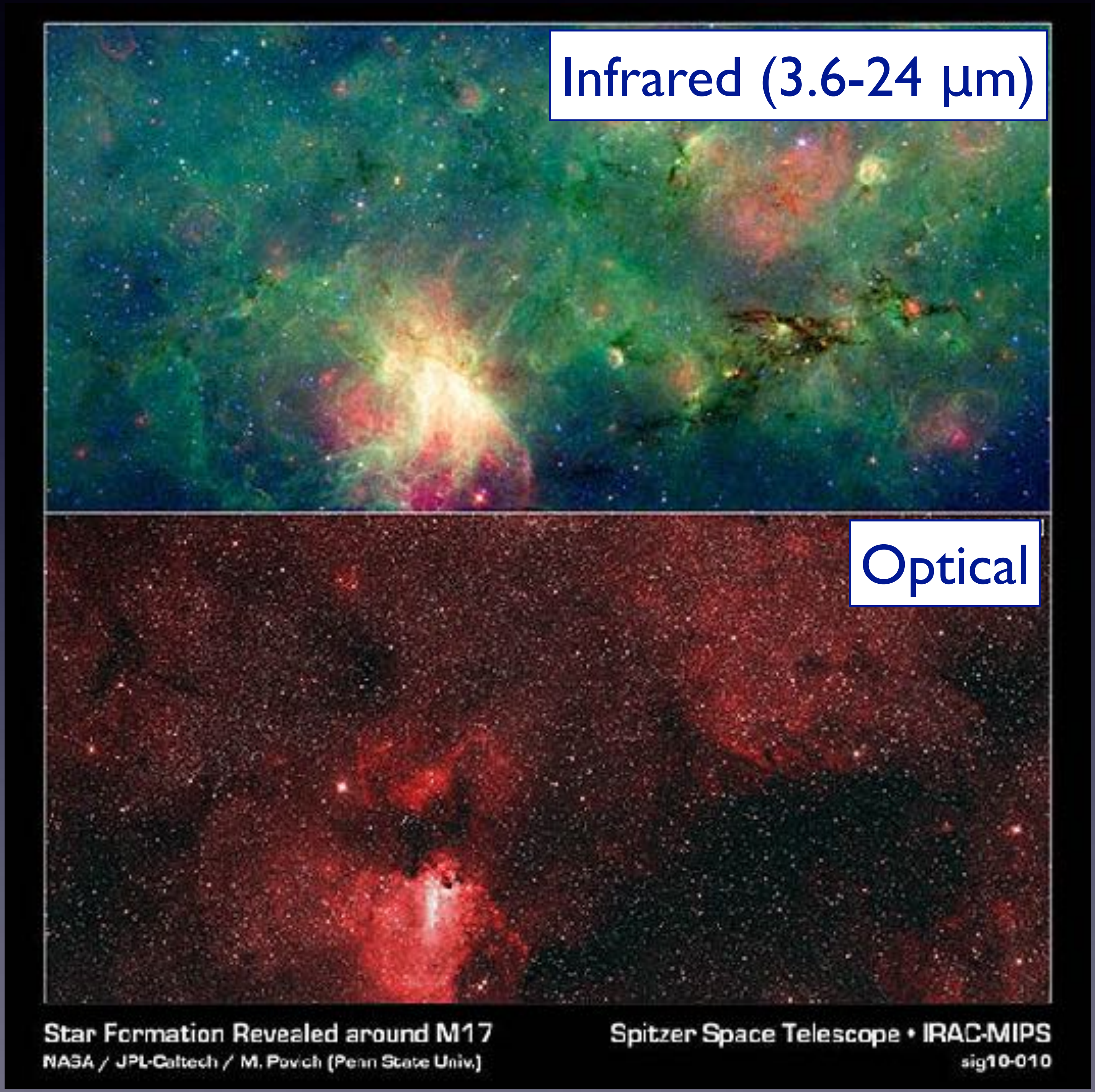
— Multiwavelength view of another galaxy —



(http://coolcosmos.ipac.caltech.edu/)

What are optical & infrared?

— Optical and infrared views of star-forming regions —



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

What are optical & infrared?

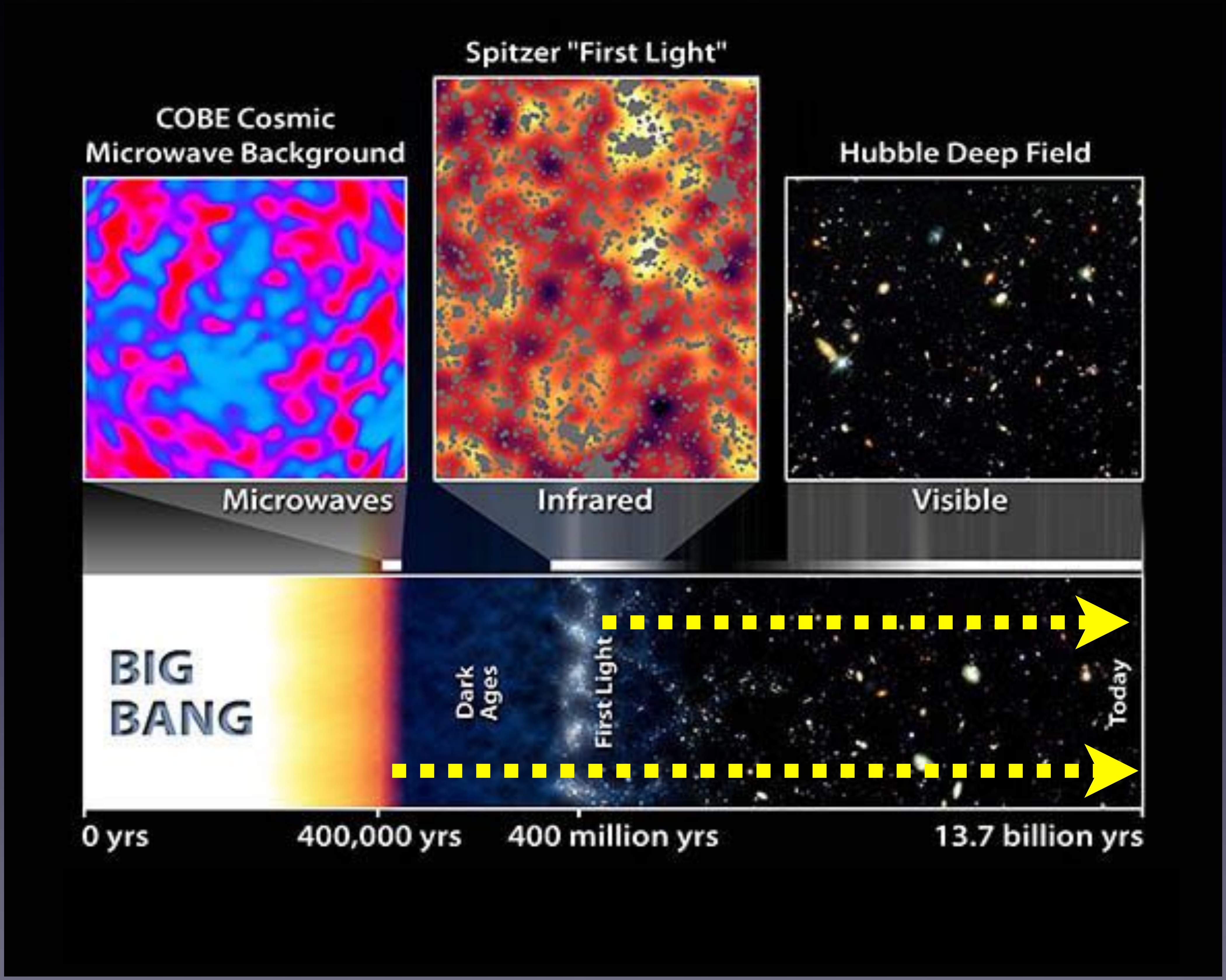
— Optical and infrared views of star-forming regions —

2MASS (1997), 1.3–2.2 microns

Spitzer (2003), 3.6–24 microns

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

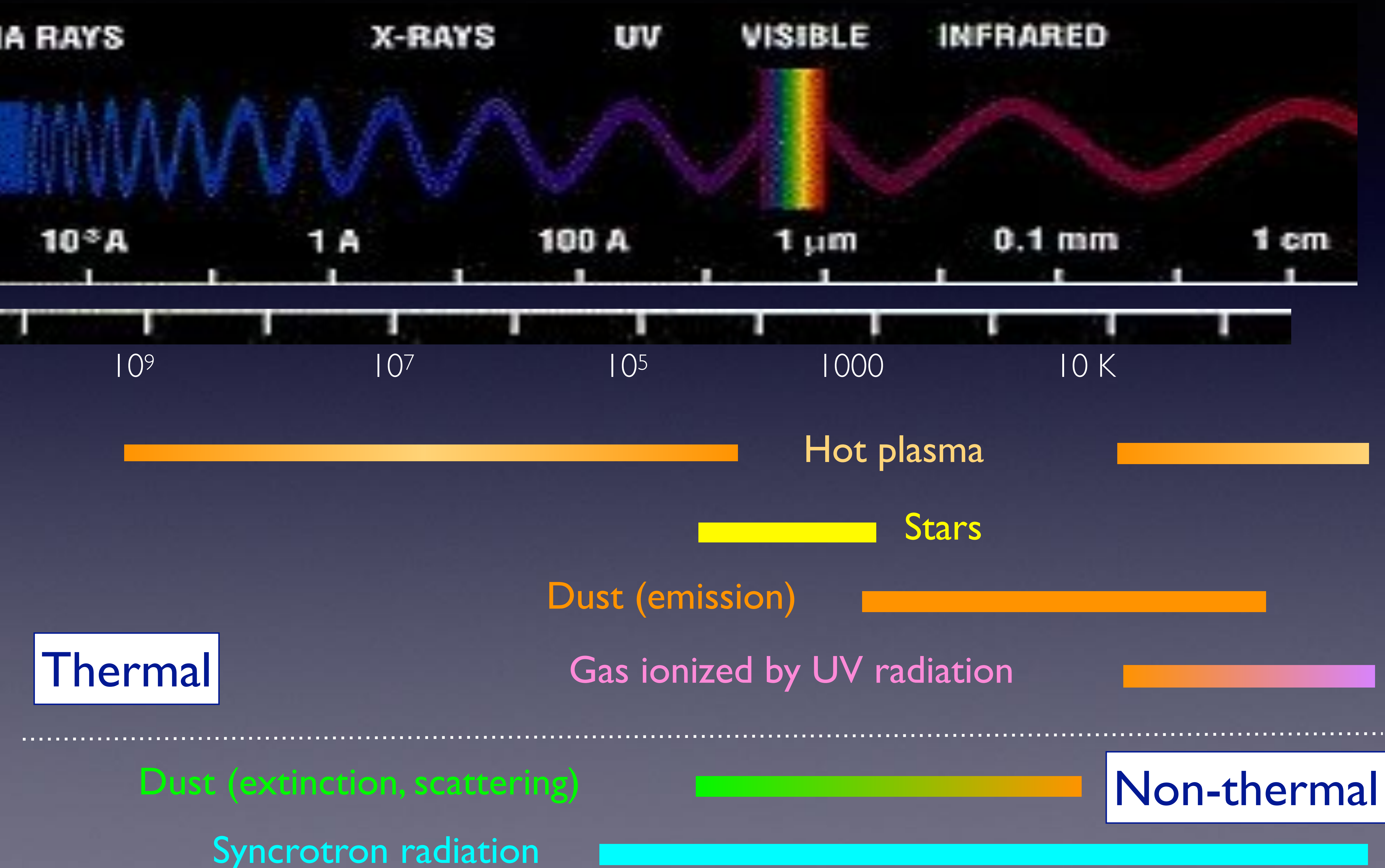
What are in the universe?



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

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

What are optical & infrared?



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)

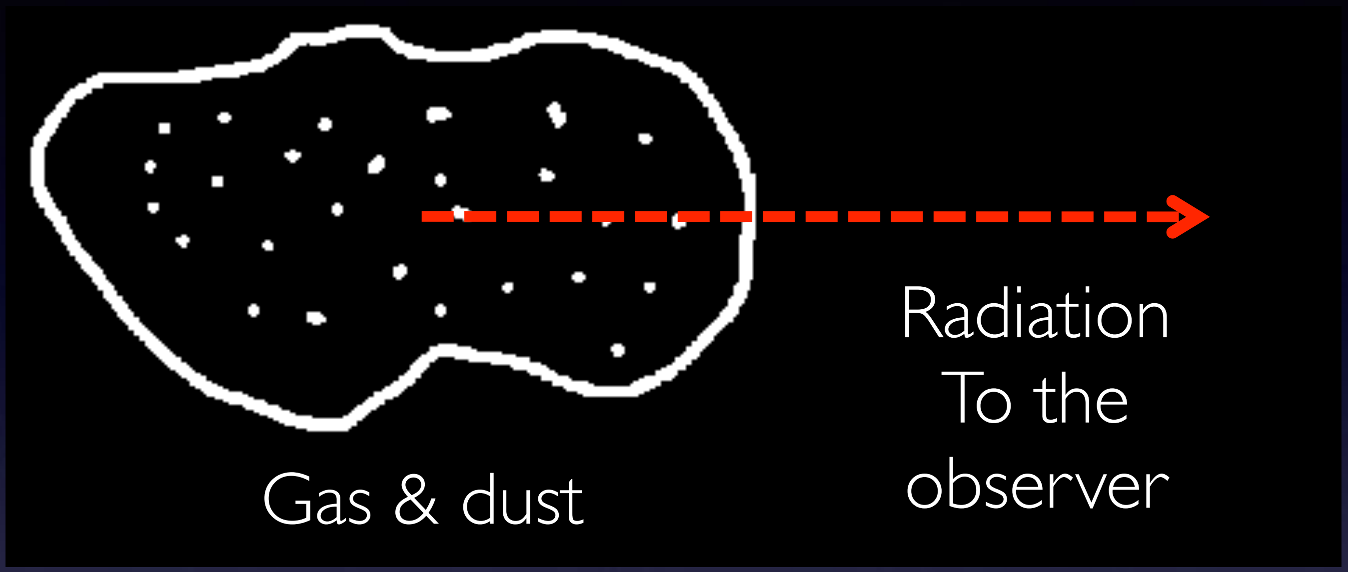
More physically:

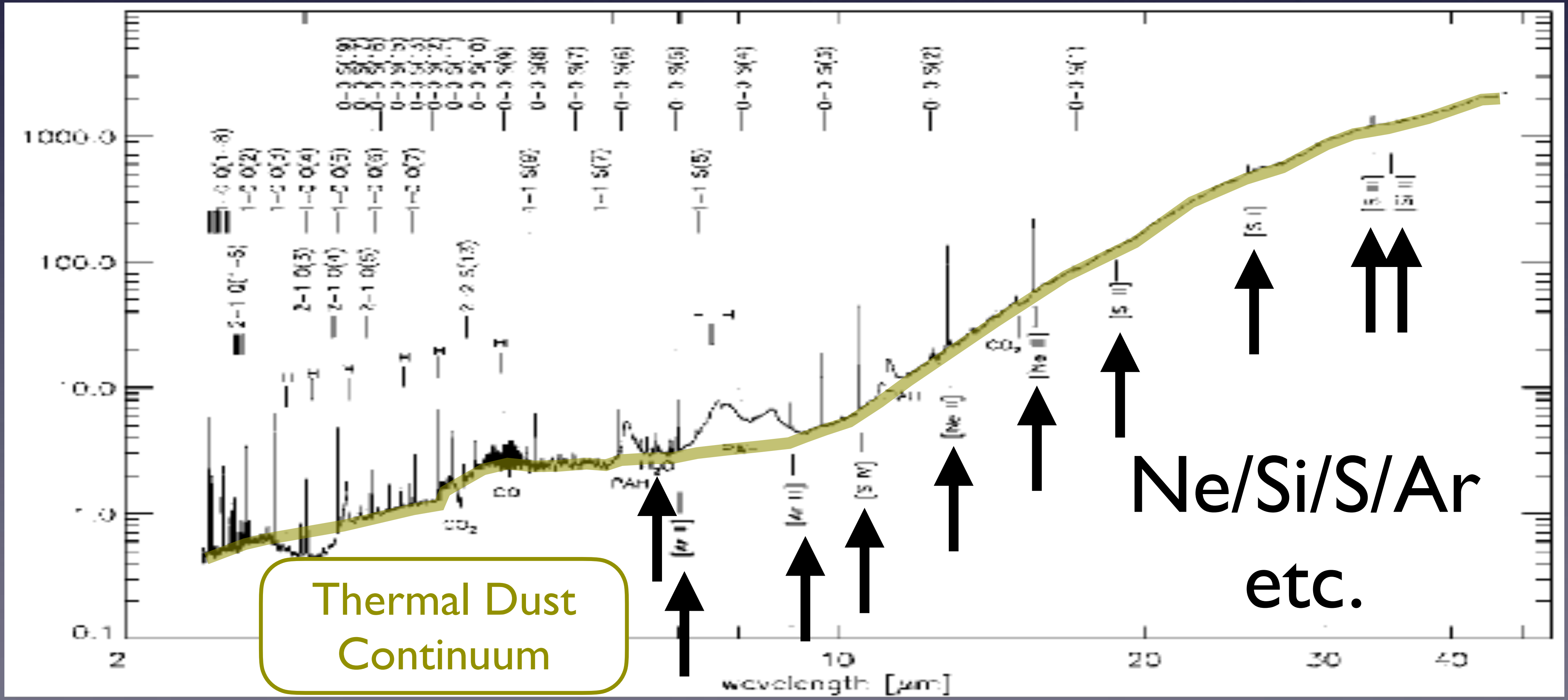
- Continuum emission
- Emission/absorption associated with gas, dust and ice
- Scattered emission, silhouette (extinction)

How spectroscopy works

Emission spectrum of gas & dust (van Dishoeck 2004)

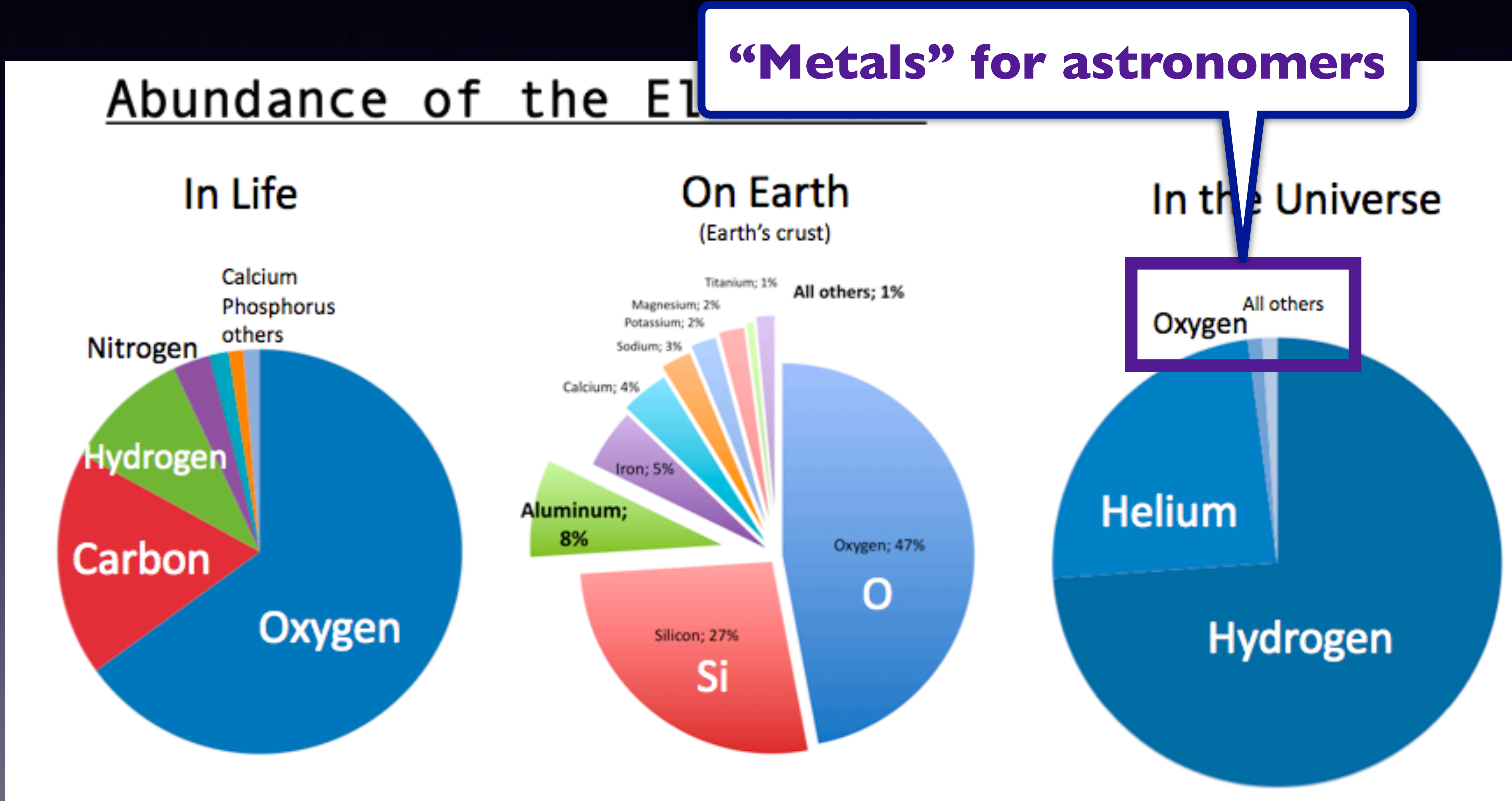
Emission features are seen if
gas & dust are relatively transparent
(*optically thin*)
at some wavelengths.





How spectroscopy works

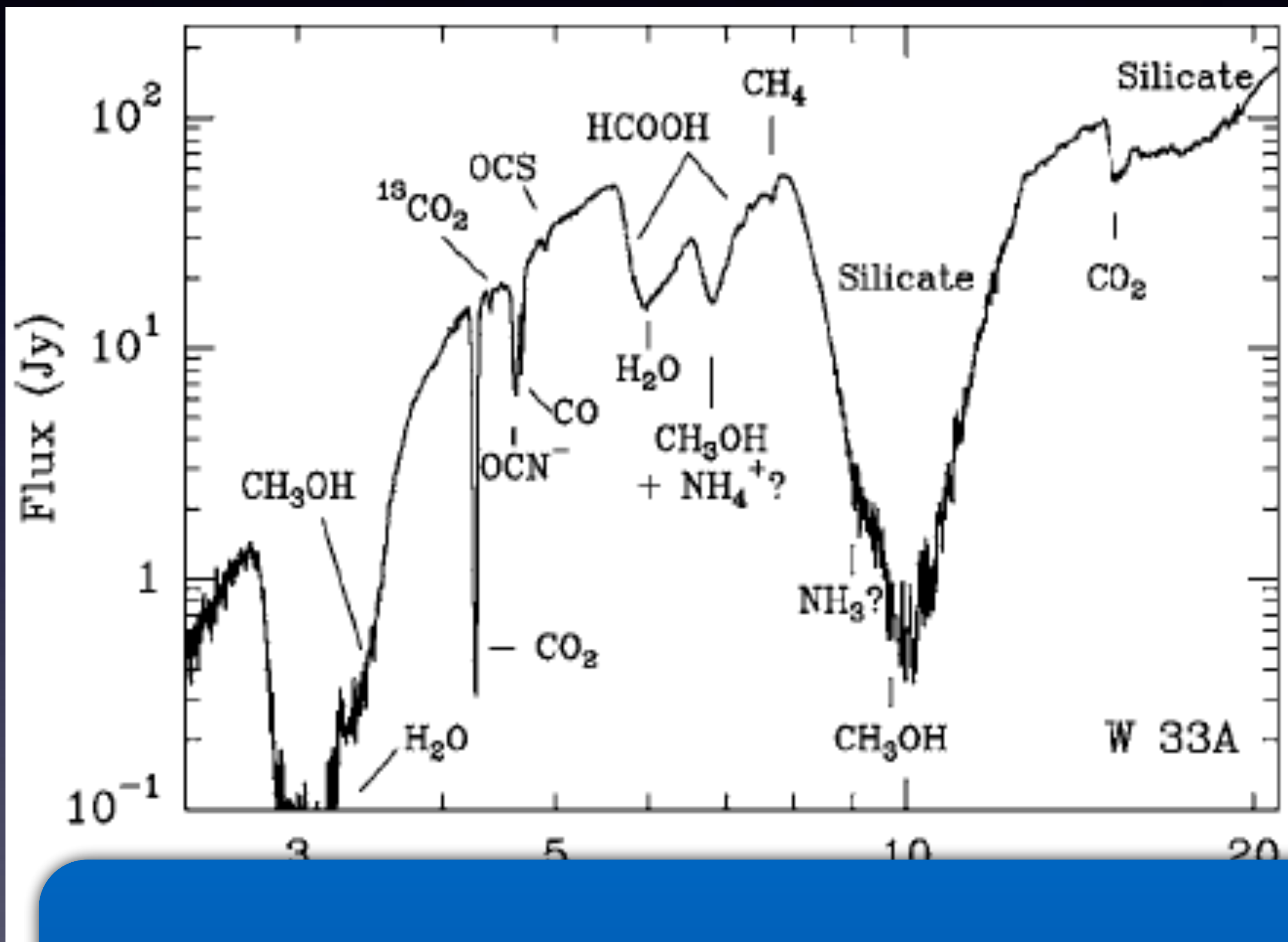
Elemental Abundance in the Universe

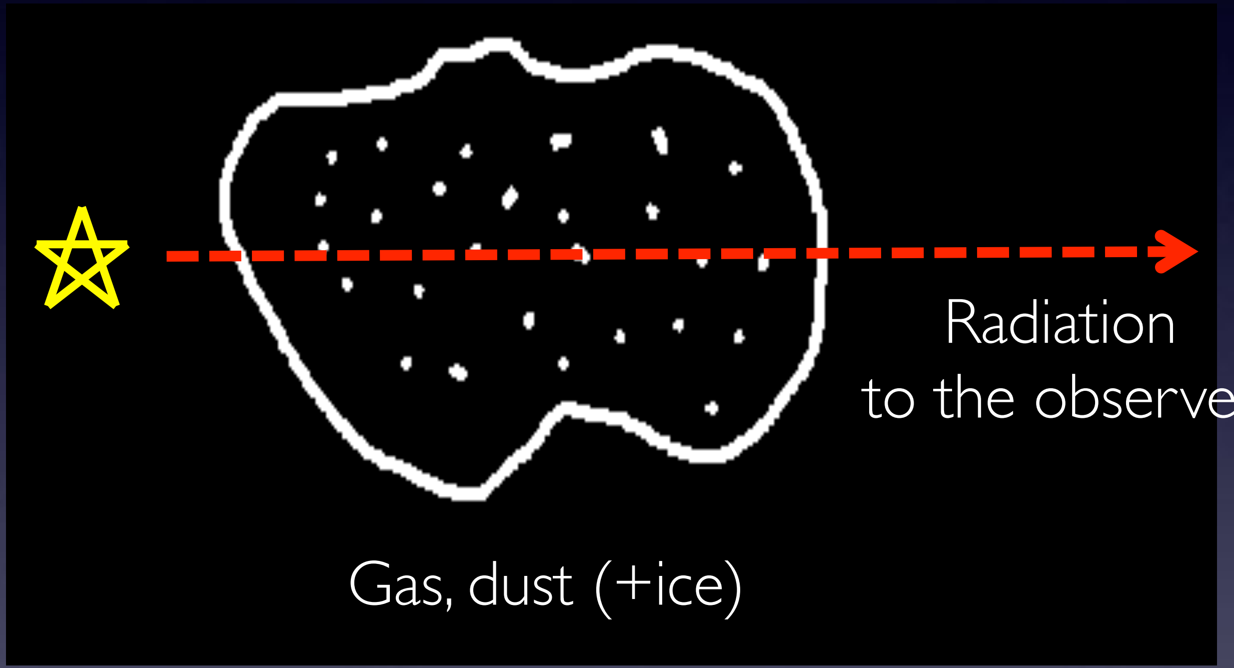


https://clearscience.tumblr.com/post/589755566/you-are-made-of-elements-along-with-everything

How spectroscopy works

Absorption spectrum of dust & ice (van Dishoeck 2004)





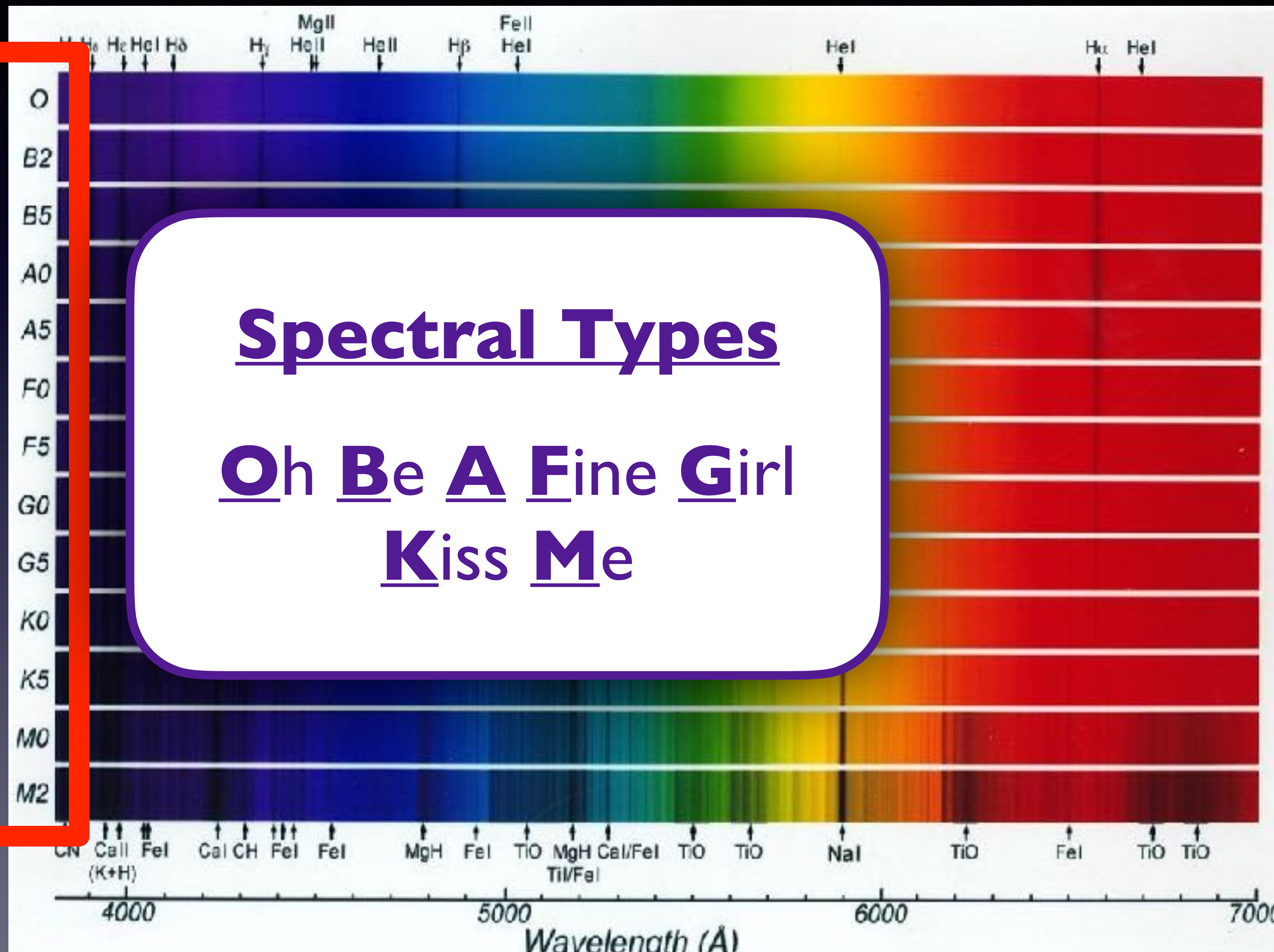
Absorption features are seen if ice/gas/dust:-

- 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



Spectral Types

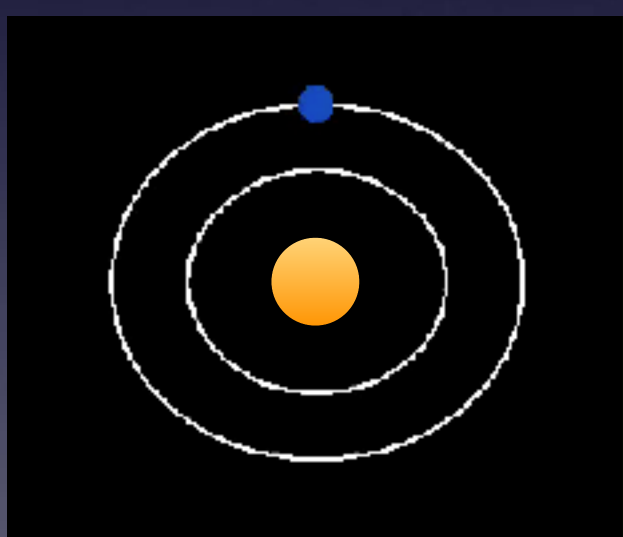
Oh **B**e **A** **F**ine **G**irl **K**iss **M**e

Stellar Spectra (http://www.astro.uu.se/~be/spectra.html)

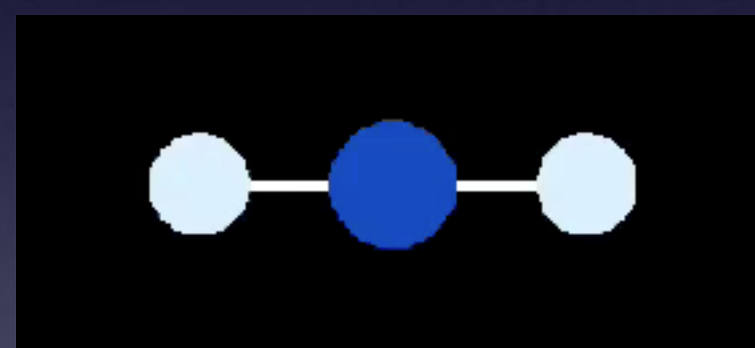
How spectroscopy works

— Transitions which make emission/absorption lines —

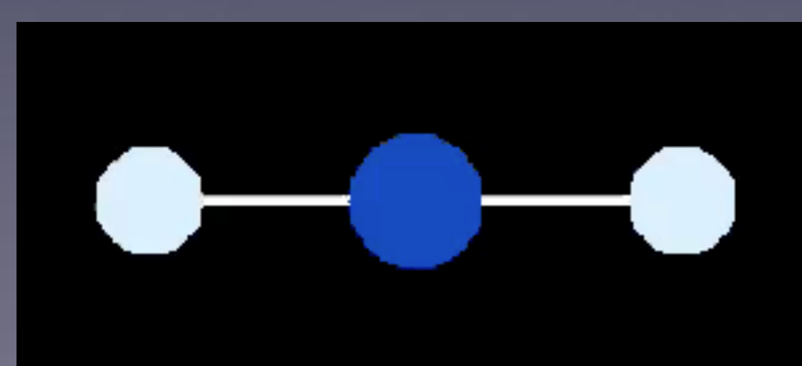
When an atom or molecule changes a quantum state, it can emit or absorb a photon.



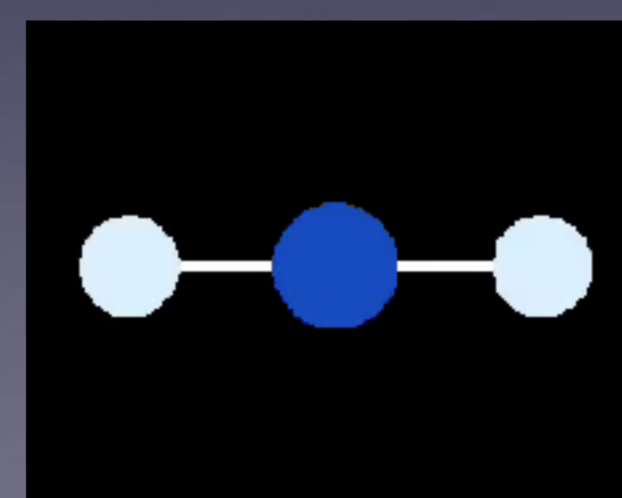
electronic
(UV to Far-IR)



vibrational
(near- to mid-IR)



rotational
(mid-IR to radio)



How spectroscopy works

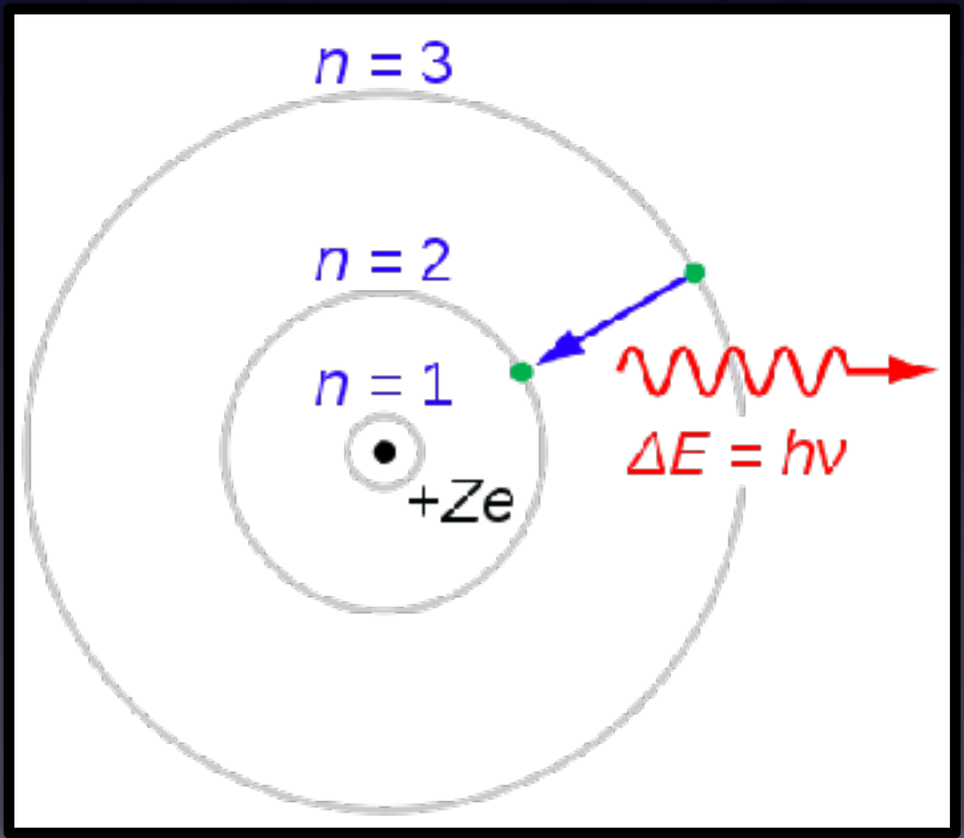
—What can we measure using OIR spectroscopy? —

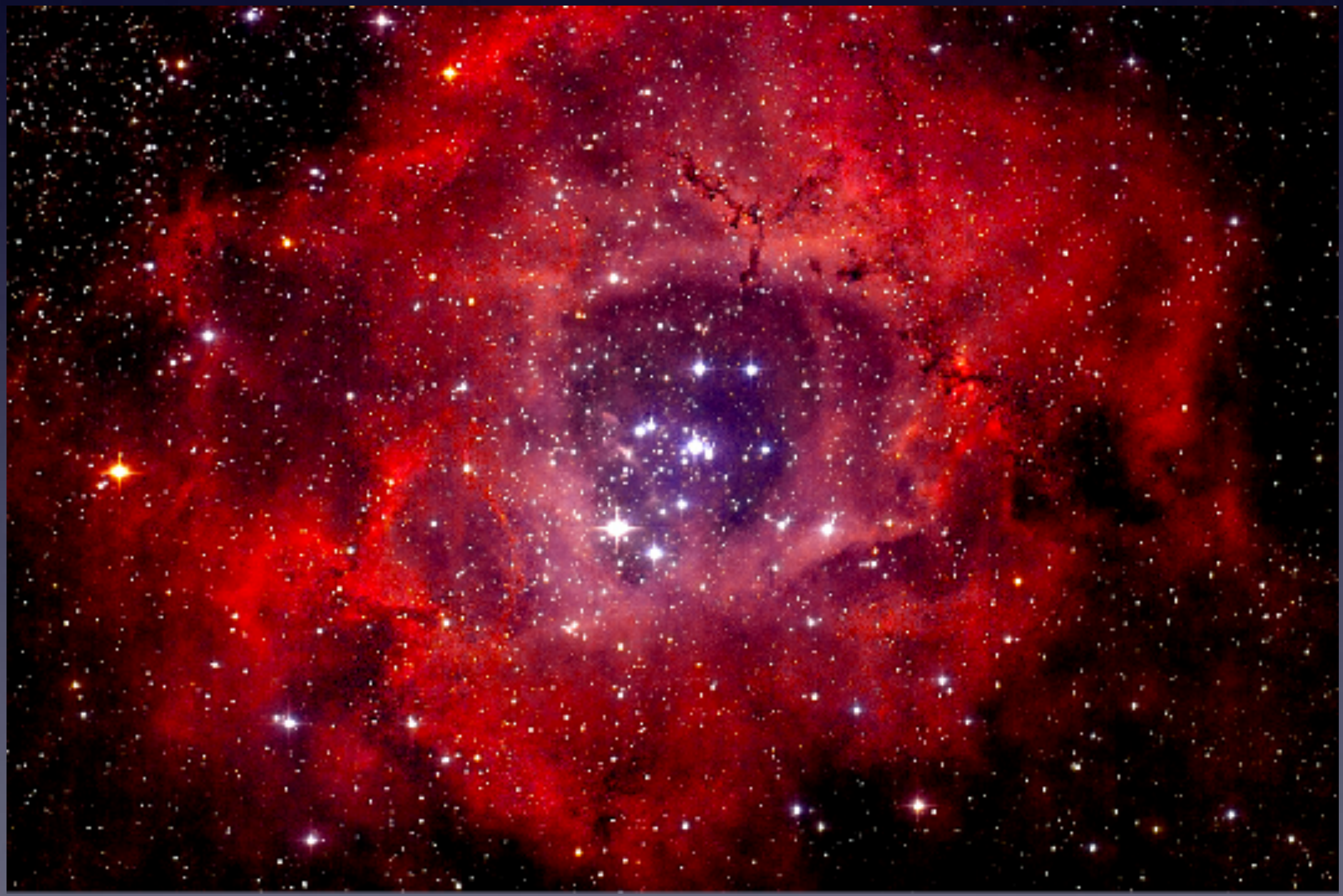
- Temperature of stellar atmosphere
  - stellar mass & evolutionary stage
- Temperature & density of interstellar & circumstellar medium
- Amount and composition of metals, molecules & ices
  (cf. metal = everything but H & He)
- Velocity
  - Masses of stars, extrasolar planets etc.
  - Distance to very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

How spectroscopy works

Rest wavelength (6562.8 Å)

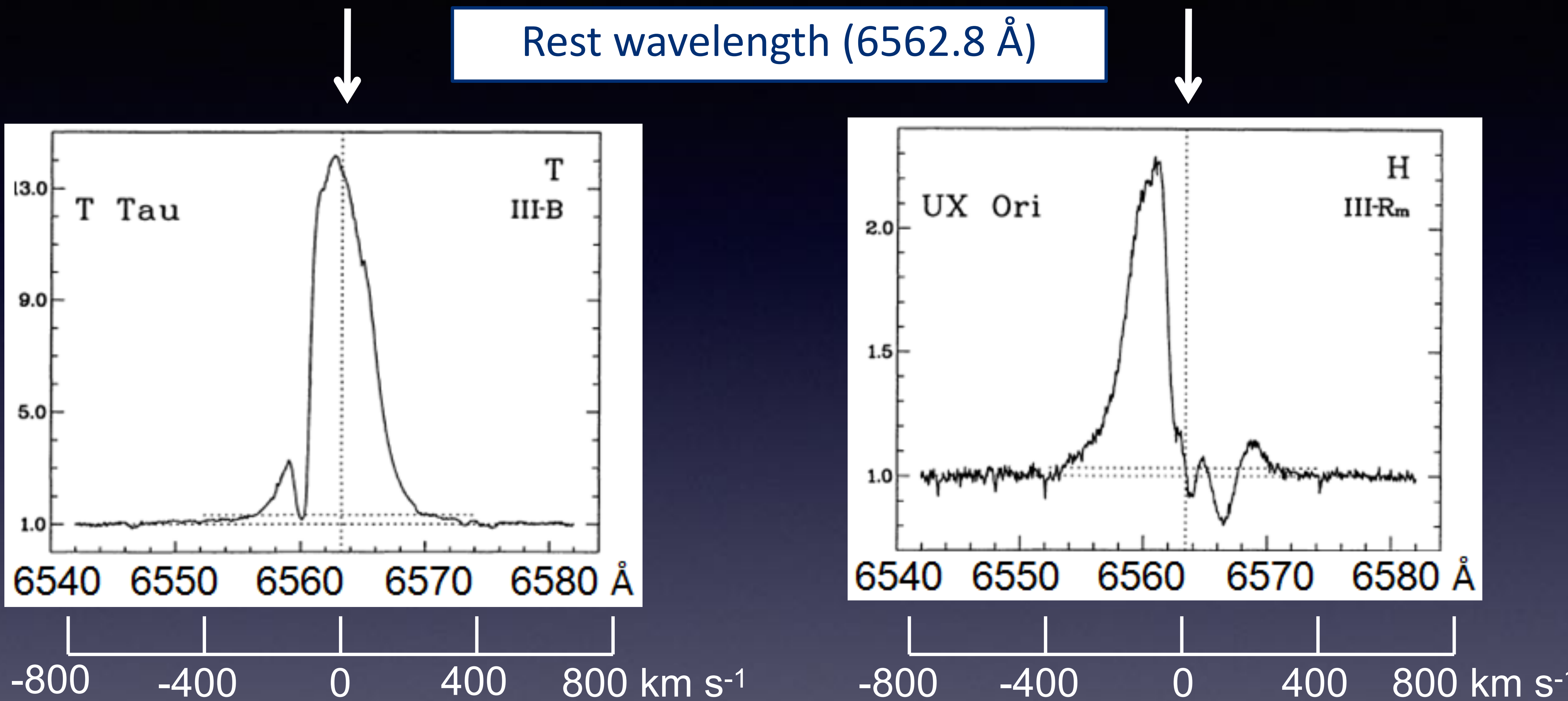
Hα





(Wikipedia)

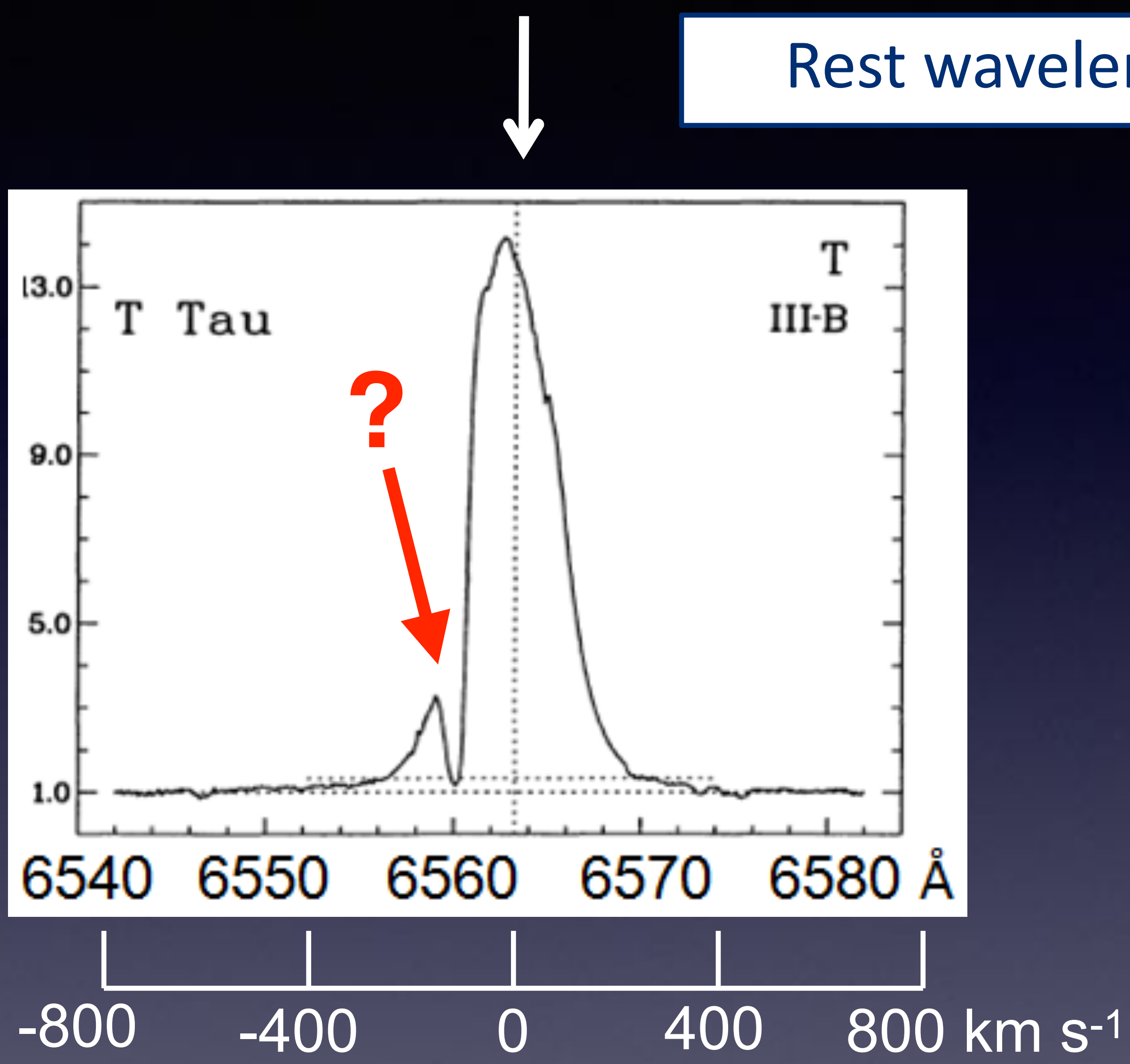
How spectroscopy works

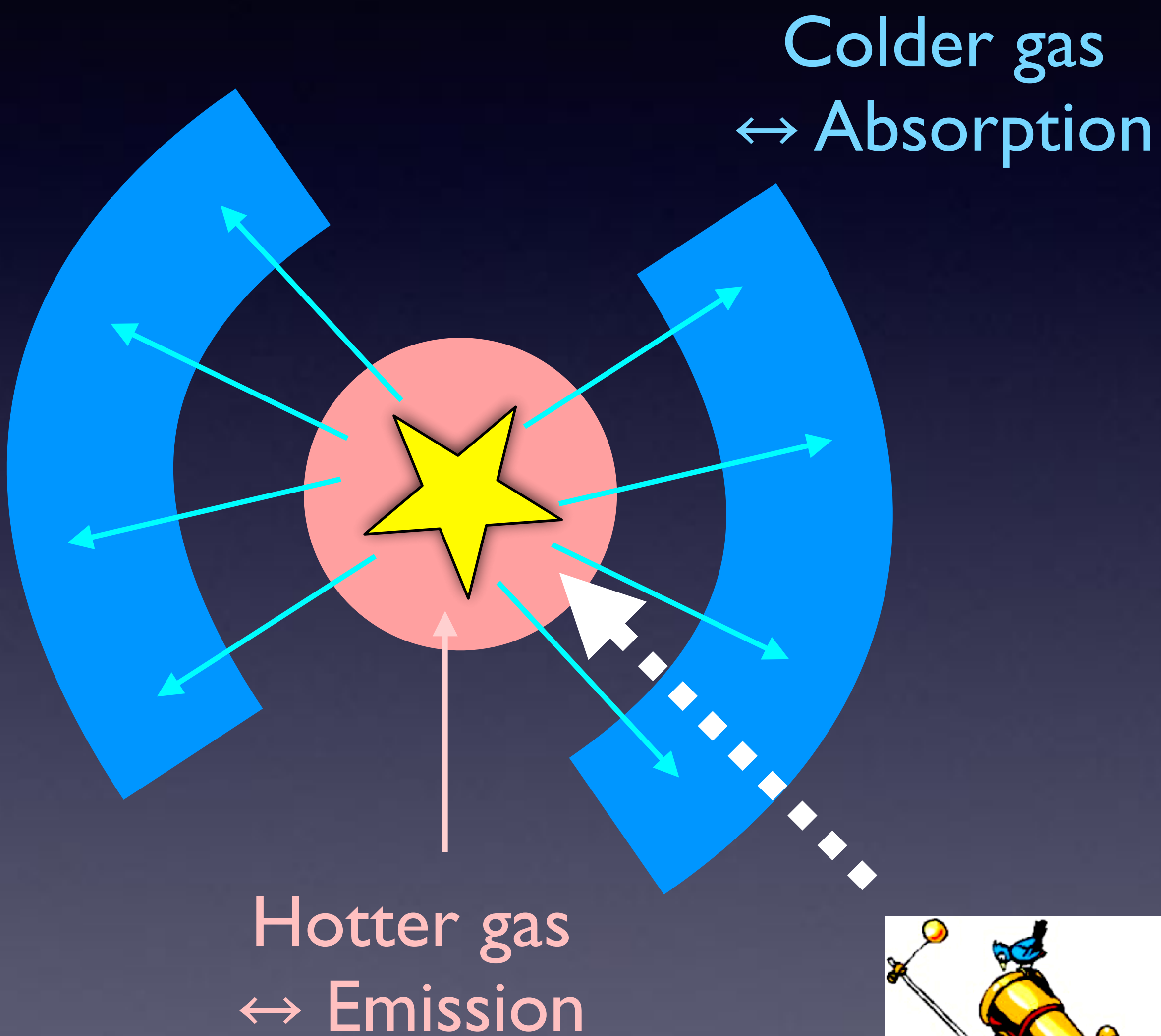


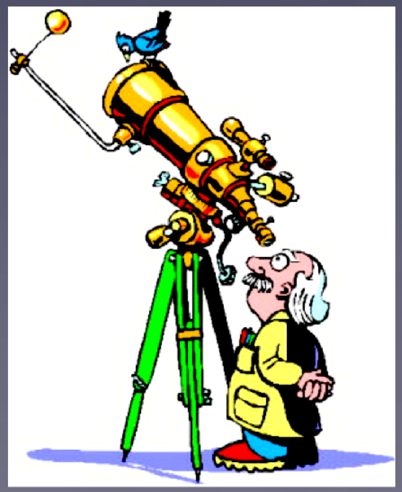
<u>Example of measuring velocities</u>

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

How spectroscopy works

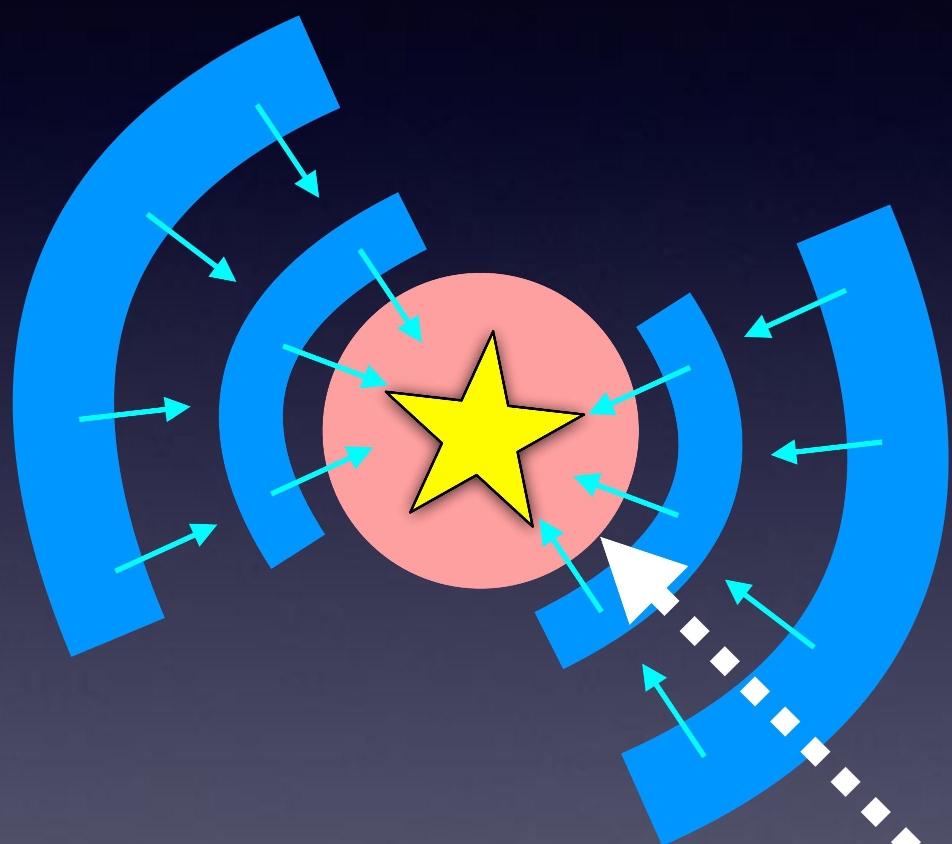


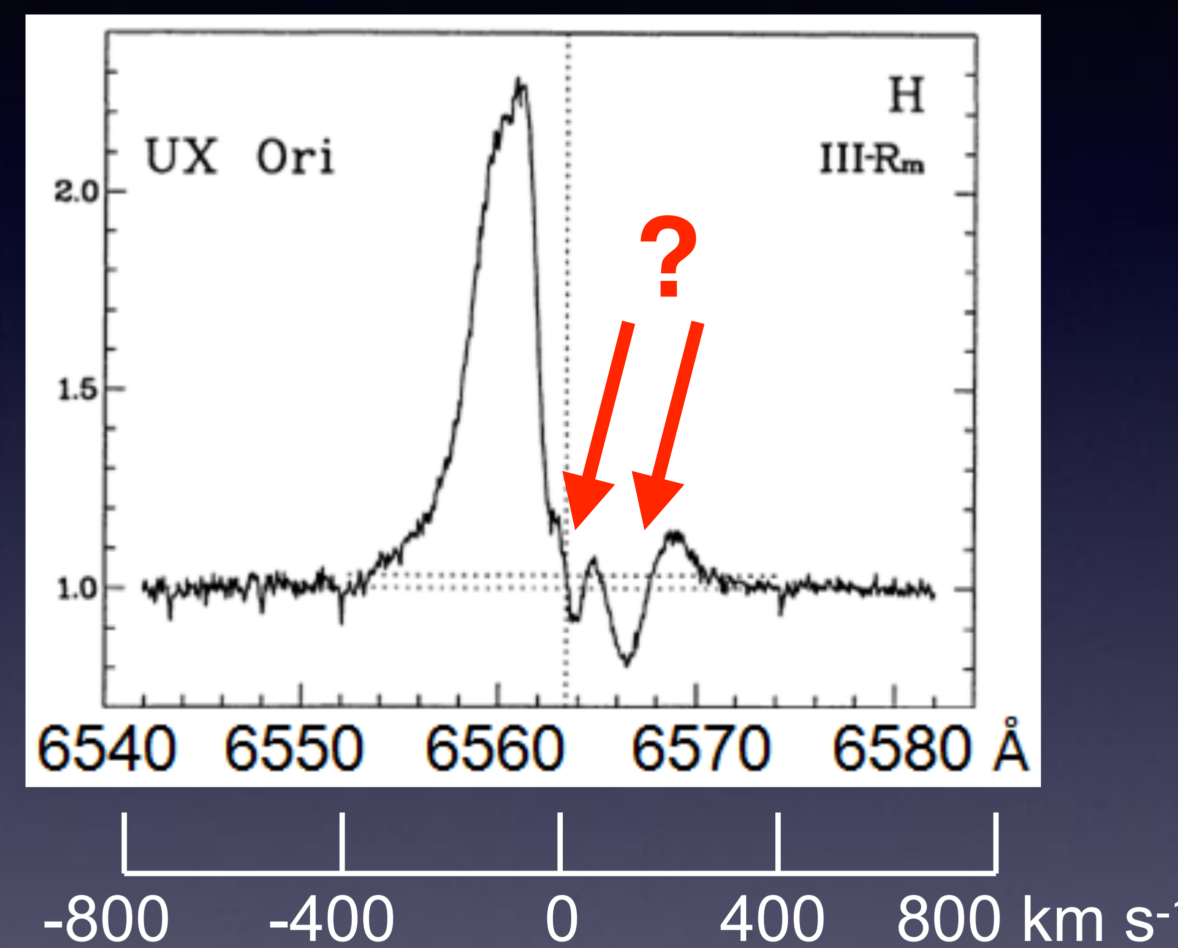




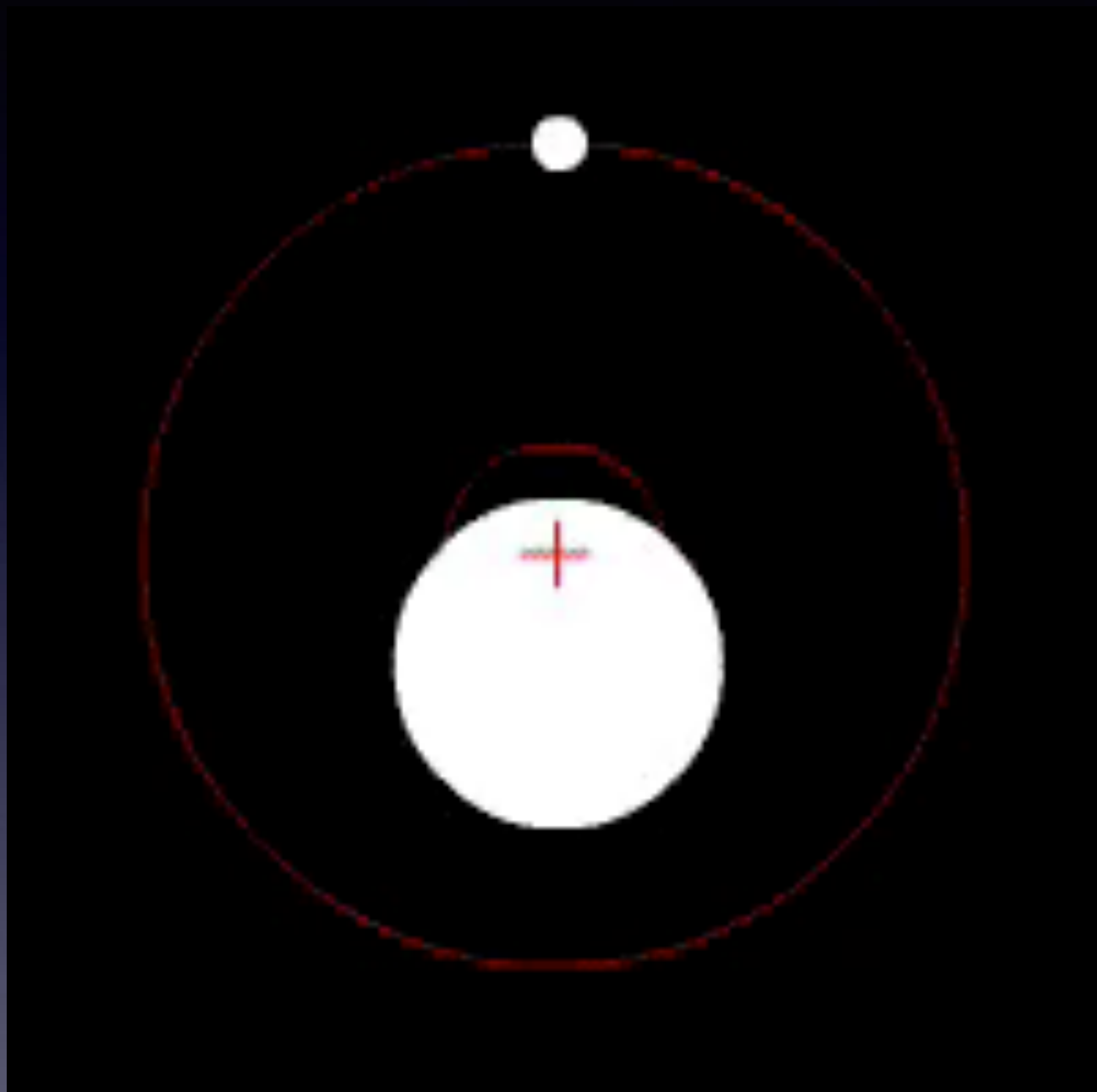
How spectroscopy works

Rest wavelength (6562.8 Å)





How spectroscopy works



(Wikipedia)

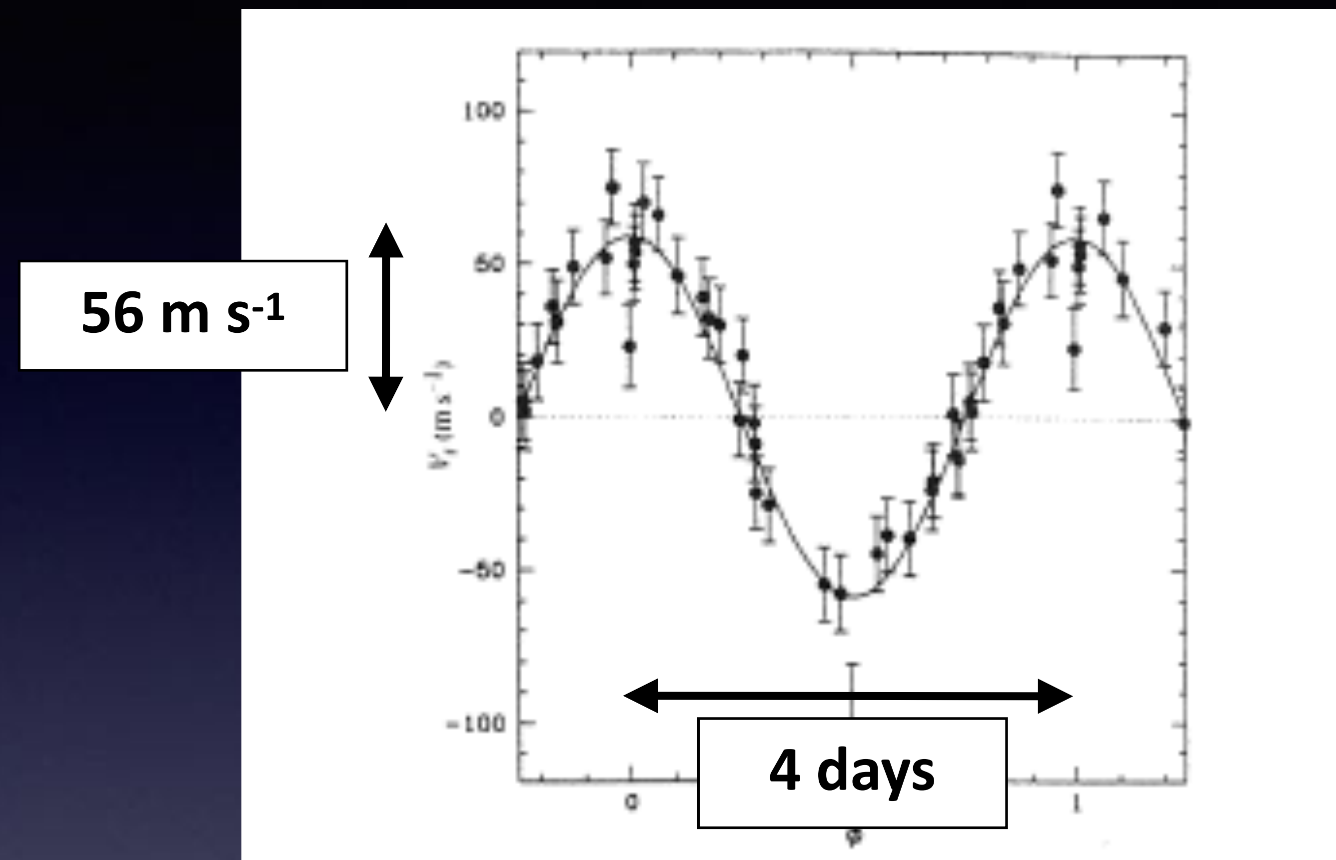


FIG. 4 Orbital motion of 51 Peg corrected from the long-term variation of the γ-velocity. The solid line represents the orbital motion computed from the parameters of Table 1.

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

<u>Accurate measurements of the velocity of the stars allow us to search for extrasolar planets</u>