
Today there are 2 Naked Eye Visible Sunspots!!
Find Leslie outside for a look. We'll spend the first 10 minutes of class outside looking at the sunspots if not cloudy.

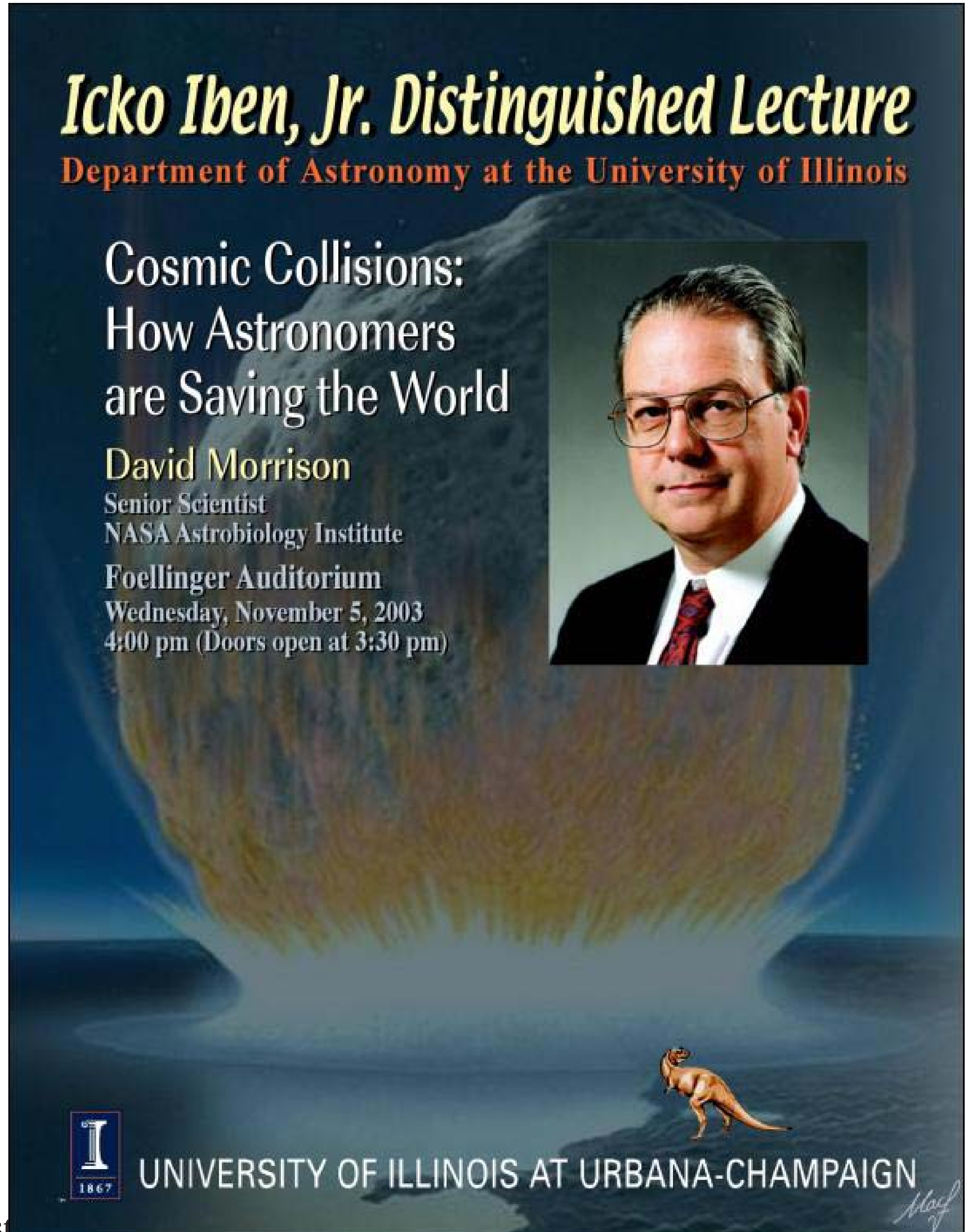
- Next homework is #7– due Friday at 11:50 am.

- Exam #2 is in two weeks!  Friday November 14th!

- Don't forget the Icko Iben Lecture next week.

# Want some extra credit?

- Download and print report form from course web site
- Attend the Iben Lecture on November 5th
- Obtain my signature *before* the lecture and answer the questions on form.  Turn in by Nov. 14th
- Worth 12 points (1/2 a homework)



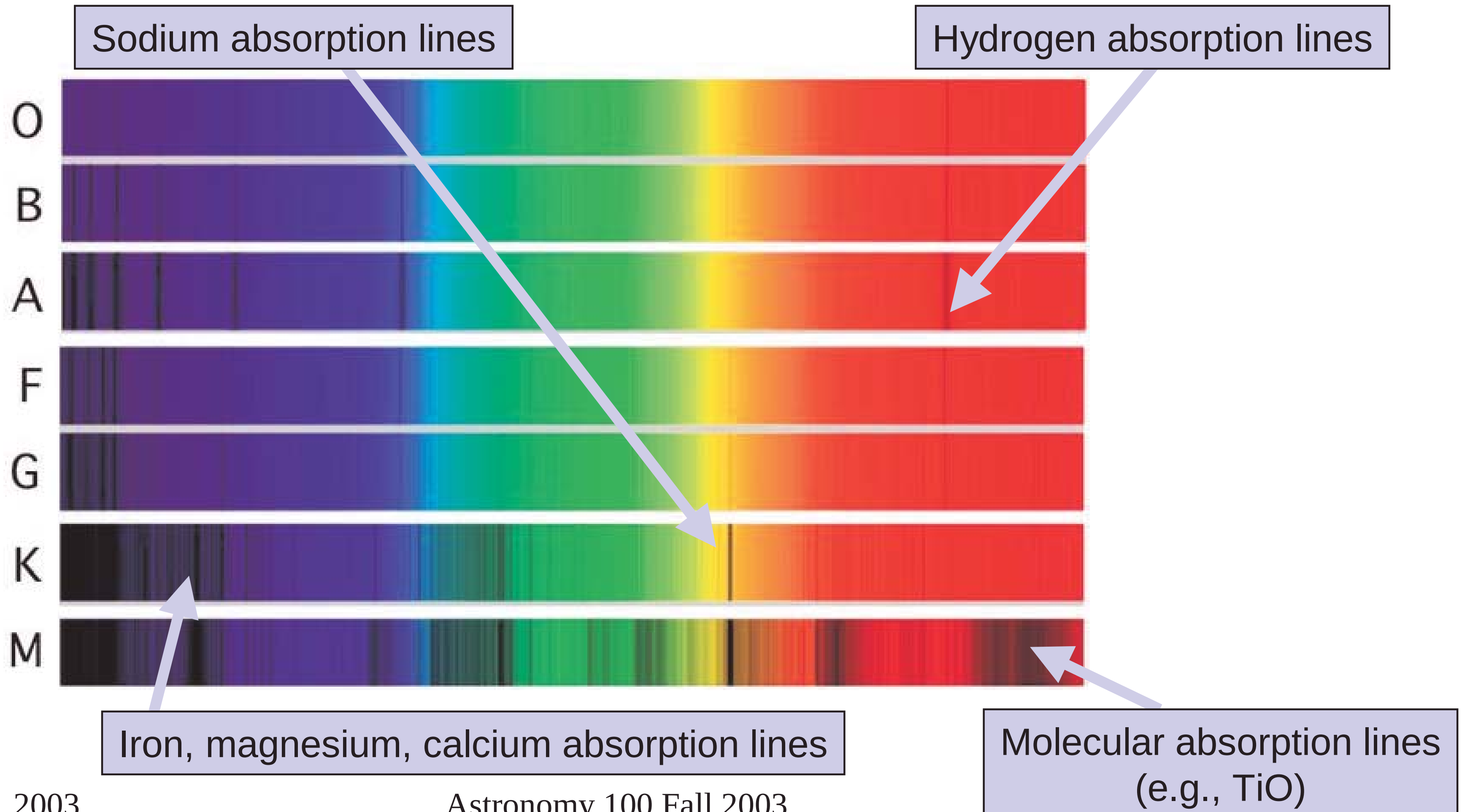
# Outline

- The HR Diagram– it's your friend.
- Main sequence stars– The Dwarves
- The Giants
- The Supergiants
- Using binary stars to probe stellar masses
- Stellar masses on the HR diagram
- The HR diagram is really telling us about the stellar lifecycle
- Stellar births

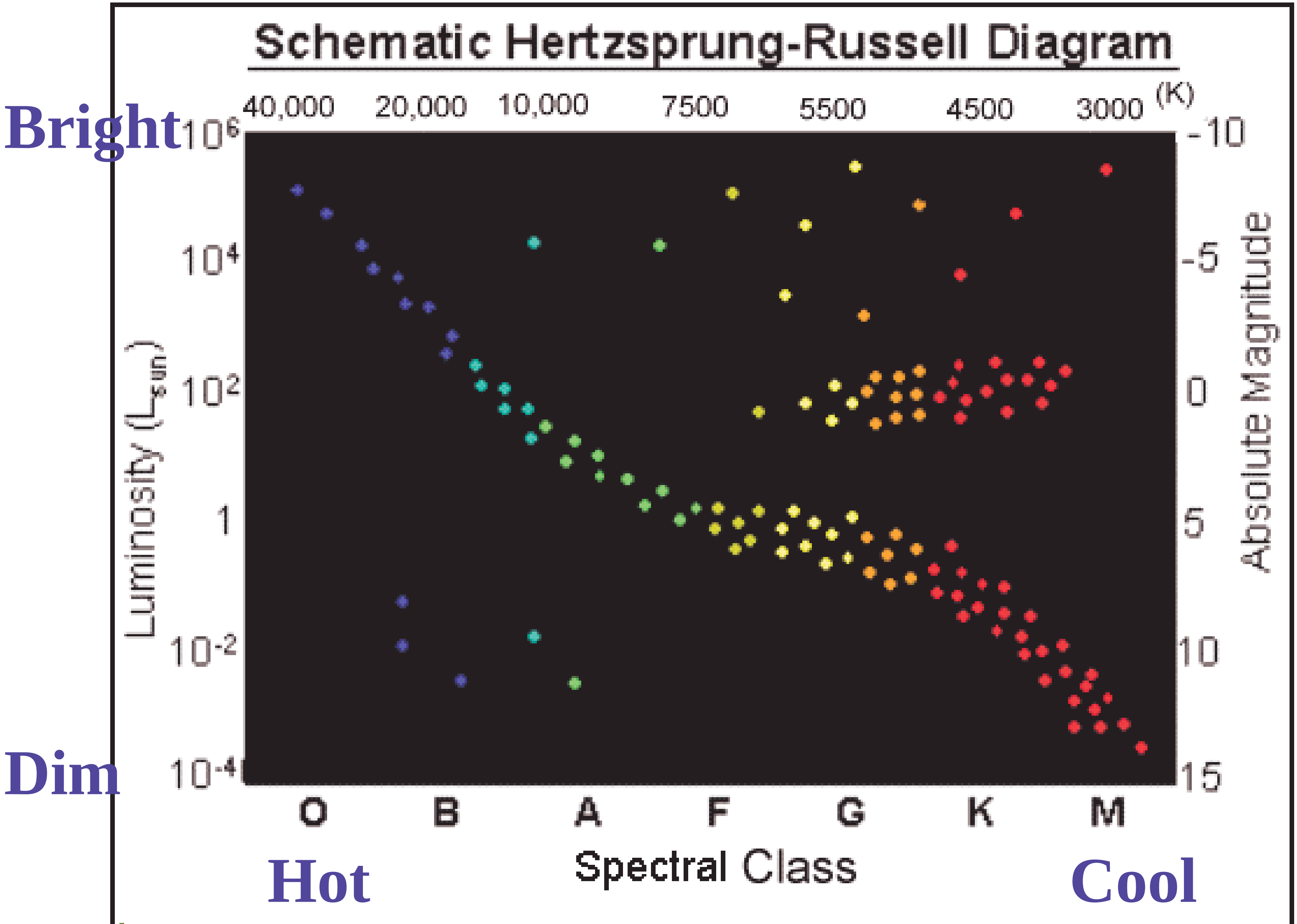
# What does our consensus tell us?

Some stars are very, very hot and the hotter they are, the brighter they are. We can look at their spectra to figure out their temperature.  These **spectral classes** are used to categorize stellar spectra.  Our Sun is a “G dwarf” star.

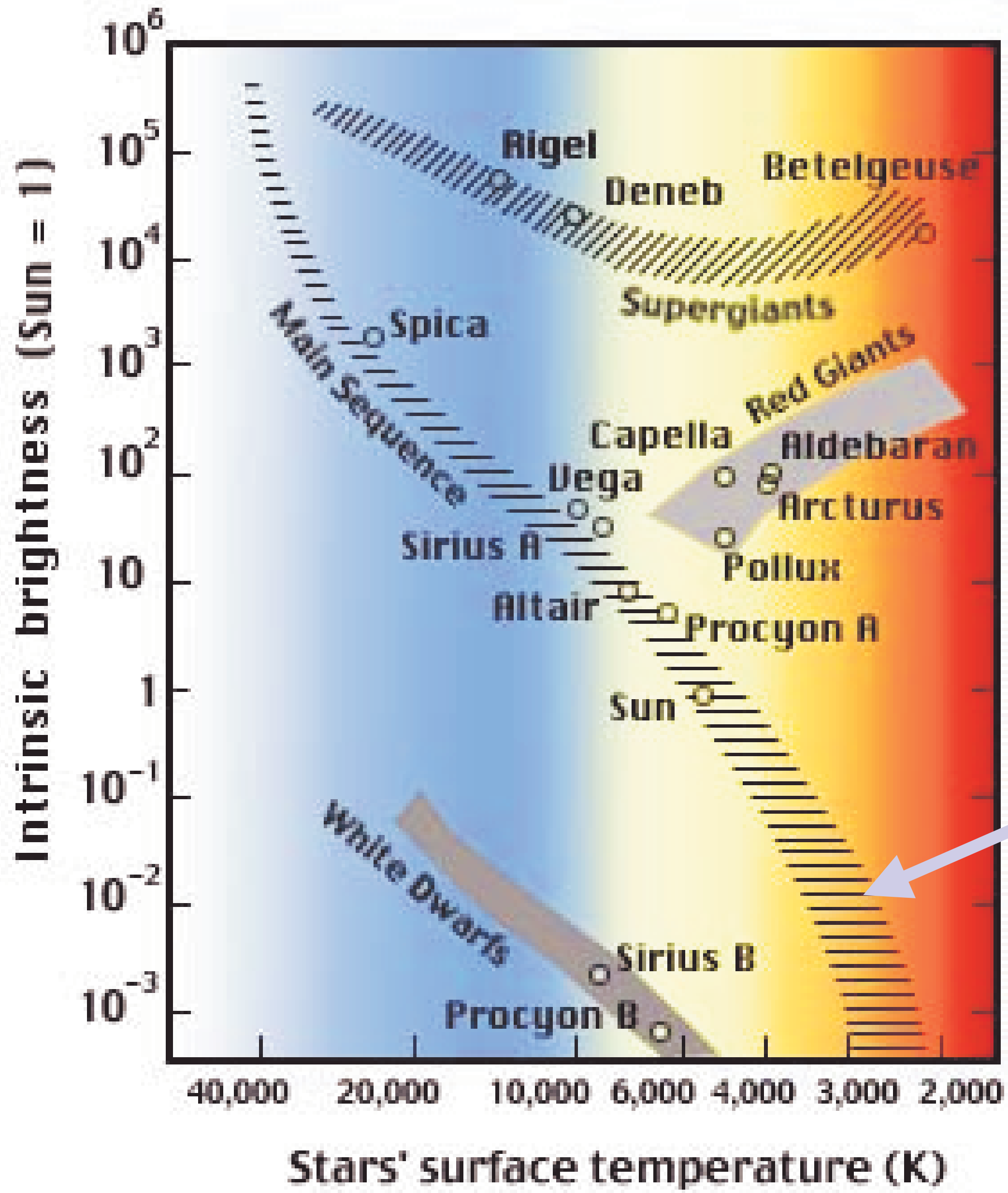
“**O**h, **B**e **A** **F**ine **G**irl (**G**uy), **K**iss **M**e”



# The Herzsprung-Russell Diagram



# The Herzsprung-Russell Diagram

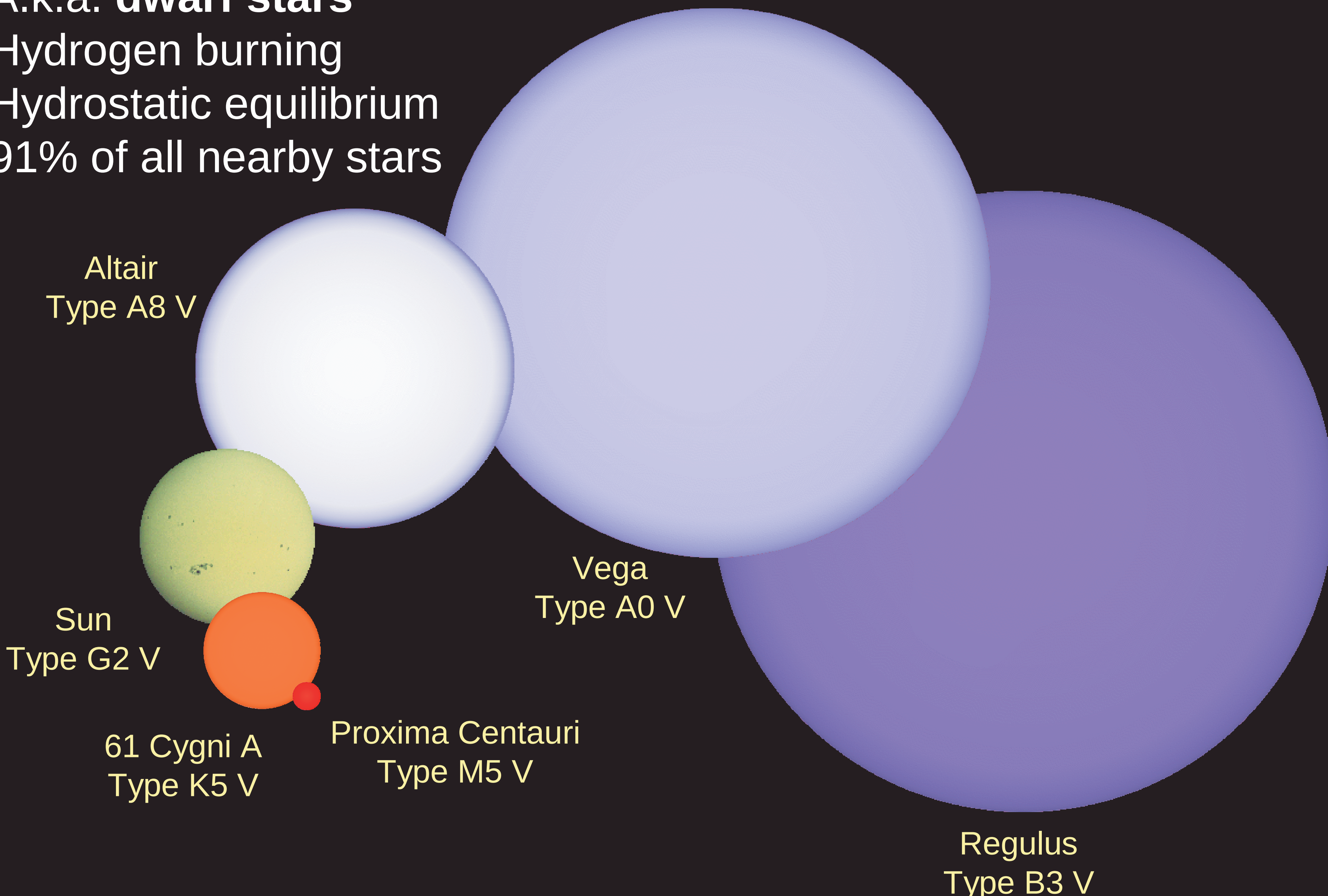


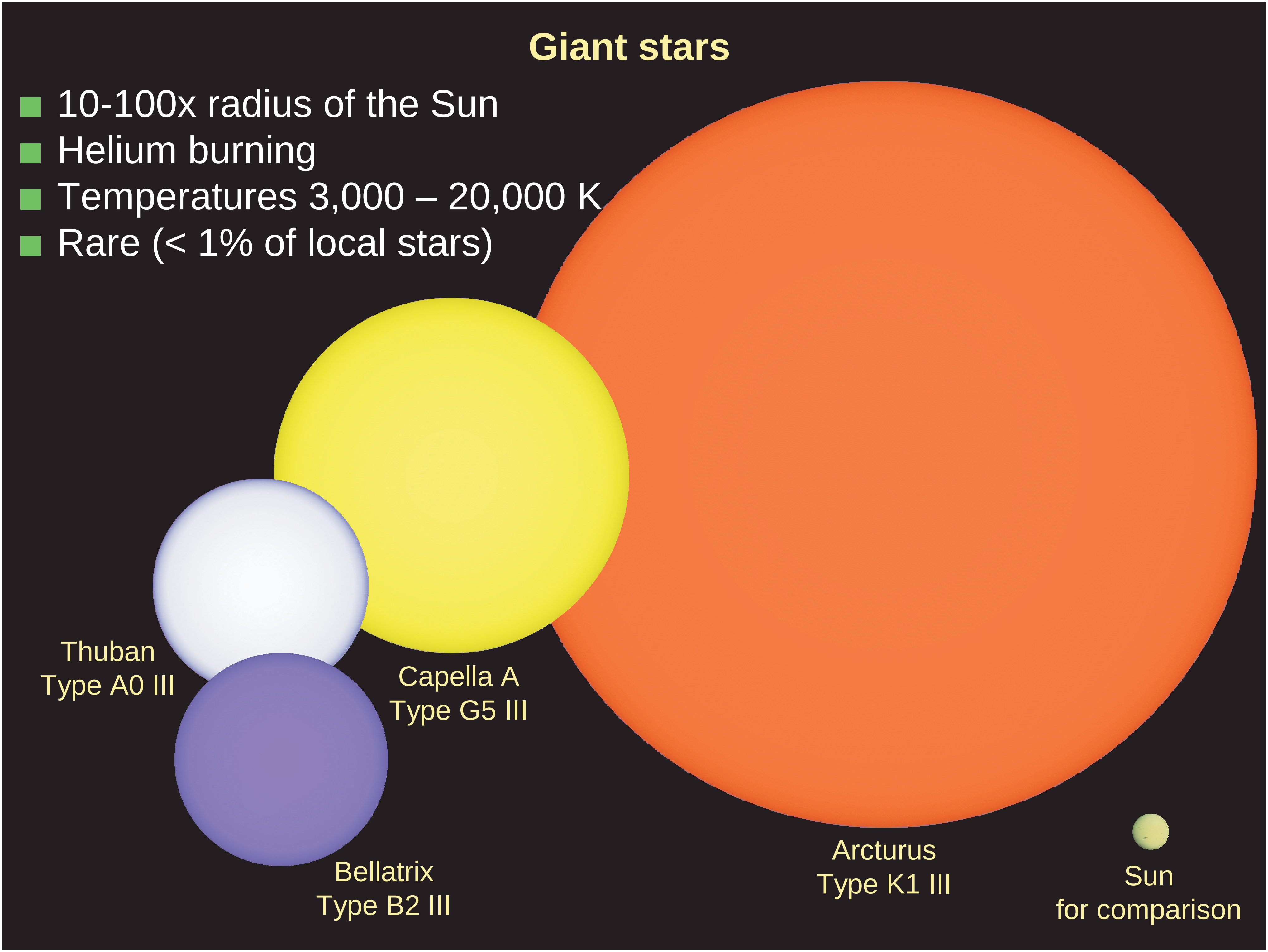

This is an important correlation, as it means that stars do not have random temperatures and brightness.

91% of all stars are on the Main Sequence

# Main-Sequence Stars

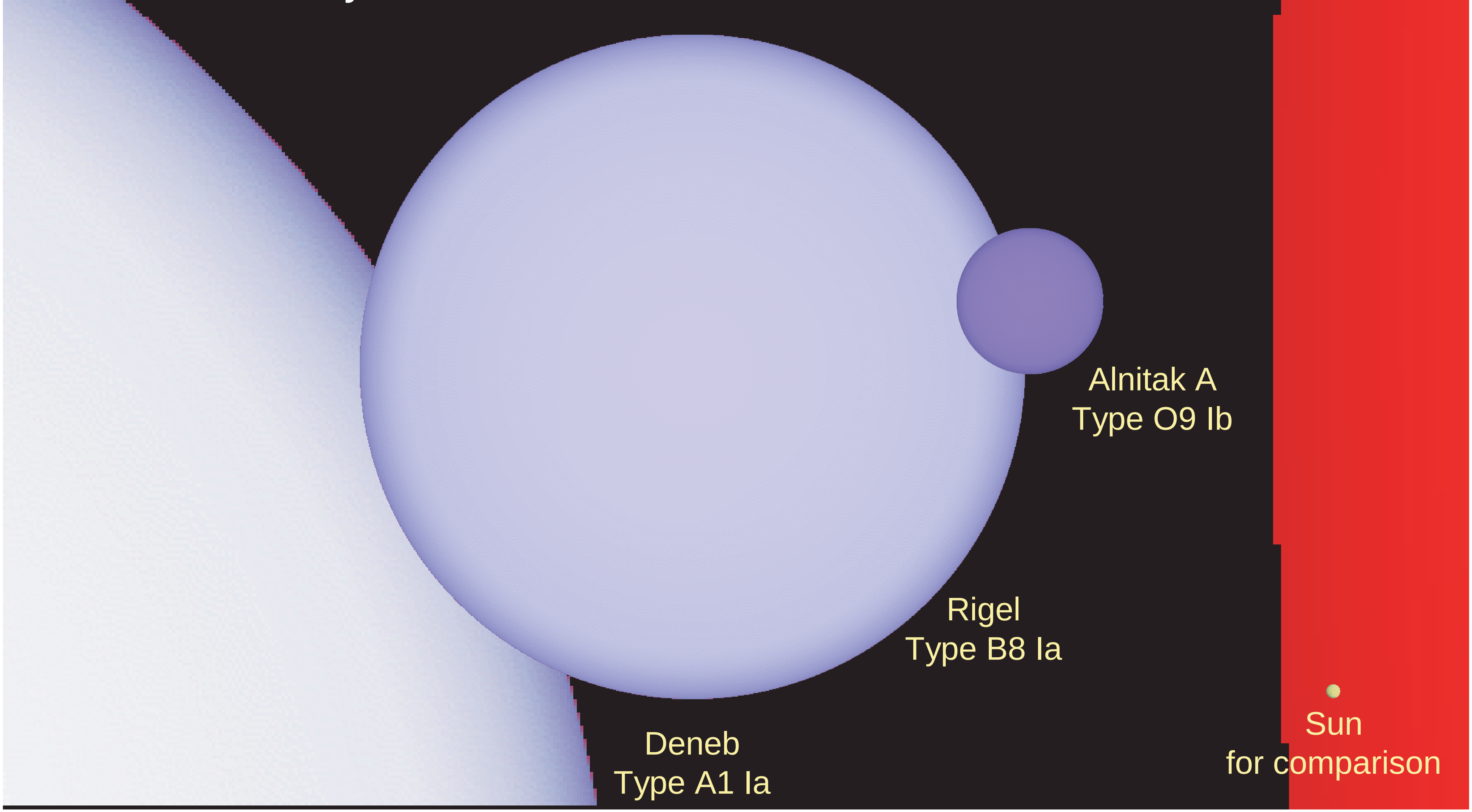
- A.k.a. **dwarf stars**
- Hydrogen burning
- Hydrostatic equilibrium
- 91% of all nearby stars




Giant stars
10-100x radius of the Sun
Helium burning
Temperatures 3,000 – 20,000 K
Rare (< 1% of local stars)
Thuban
Type A0 III
Capella A
Type G5 III
Bellatrix
Type B2 III
Arcturus
Type K1 III
Sun
for comparison

# Supergiant stars

- Up to 1000x radius of Sun
- Burning heavier elements like carbon
- Strong winds, significant mass loss
- Extremely rare:  ~ 0.1% of local stars



# White Dwarf Stars

- About the size of the Earth
- Very hot:  5,000 – 20,000 K
- No longer burning *anything*
- About 8% of local stars

Sirius B

Earth for comparison

Sunspot

Sun for comparison

# Kinds of Dwarves

## Red dwarf

*Just a very cool main-sequence star*

Gliese 229A

## White dwarf

*White-hot burned-out core of a star*

Sirius B

## Black dwarf

*A very old cooled white dwarf*

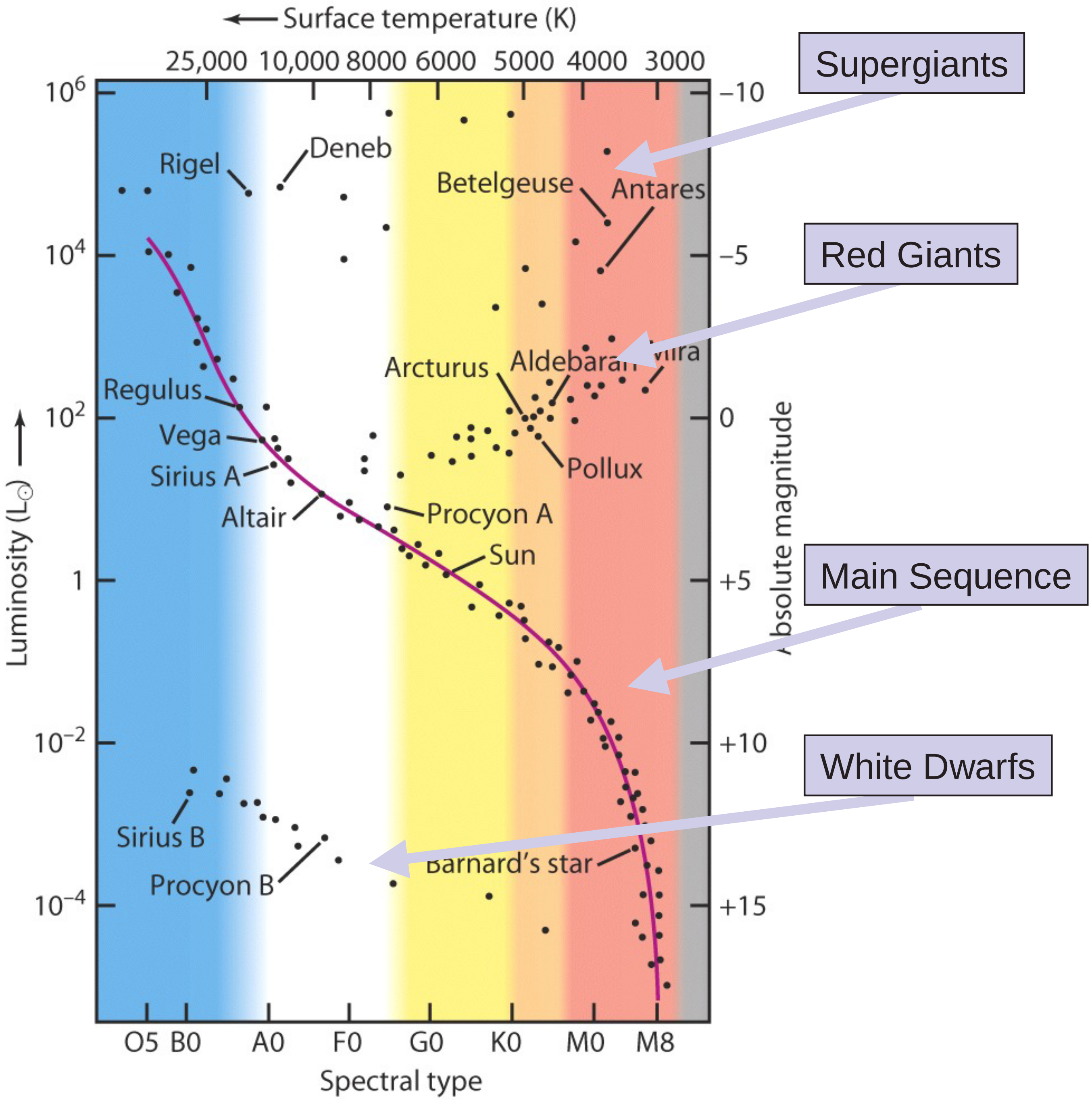
SDSS J1254-0122

UKIRT/JAC

## Brown dwarf

*Not a star at all; wasn't massive enough*

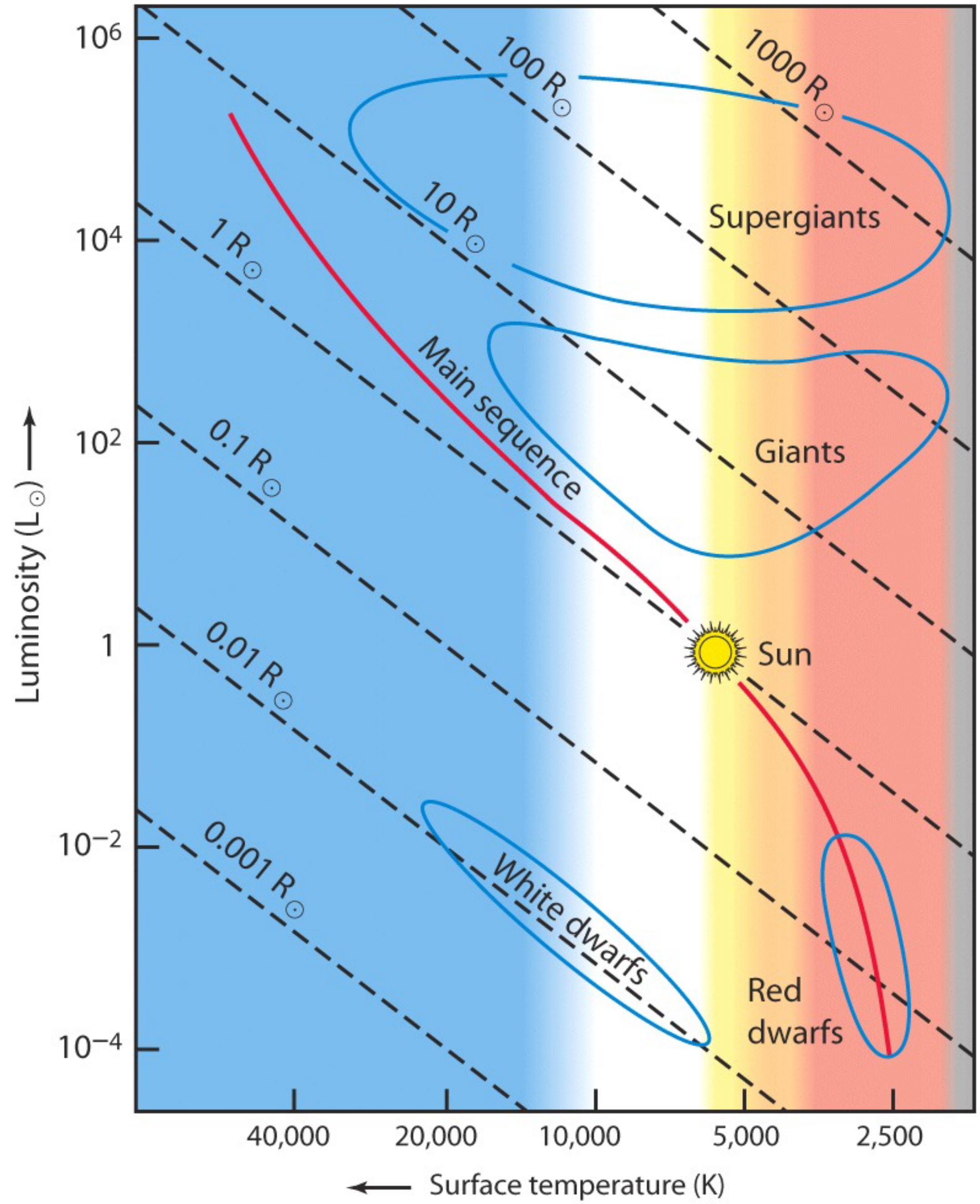
# The Herzsprung-Russell Diagram



# Radii of Stars

Stars that have higher surface temperature (with the same radius) are brighter (Stephan-Boltzmann Law), so they must move up to the left.

Stars of the same surface temperature, that are brighter, must be larger stars.



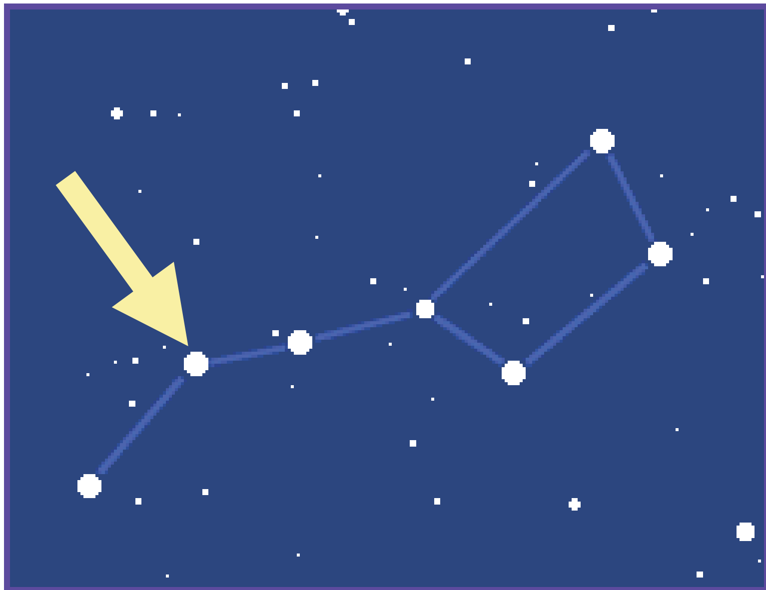
# How do we determine mass?

- It’s much more difficult to measure the stellar mass, but luckily in the local neighborhood, any star picked at random, will have more than a 50% chance of being a binary or multiple system.
- Remember Kepler’s 3rd law– modified by Newton?
- We can watch a binary system orbit, and derive the system mass.
- The idea is that any G-type star is the same mass, regardless if it in a binary system or not.

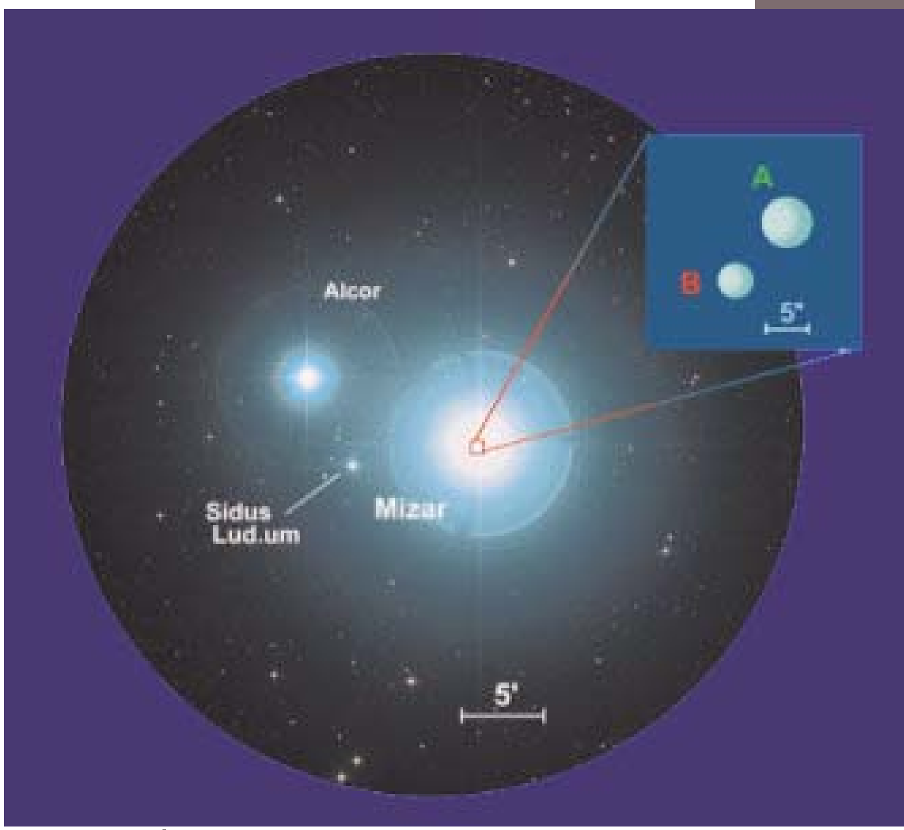
# Binary Stars

- Defined as at least two stars that orbit each other
- There are three types
  - **Visual binary** – can distinguish stars in pair
  - **Spectroscopic binary** – can only detect using Doppler shifts
  - **Eclipsing binary** – each star passes in front of the other

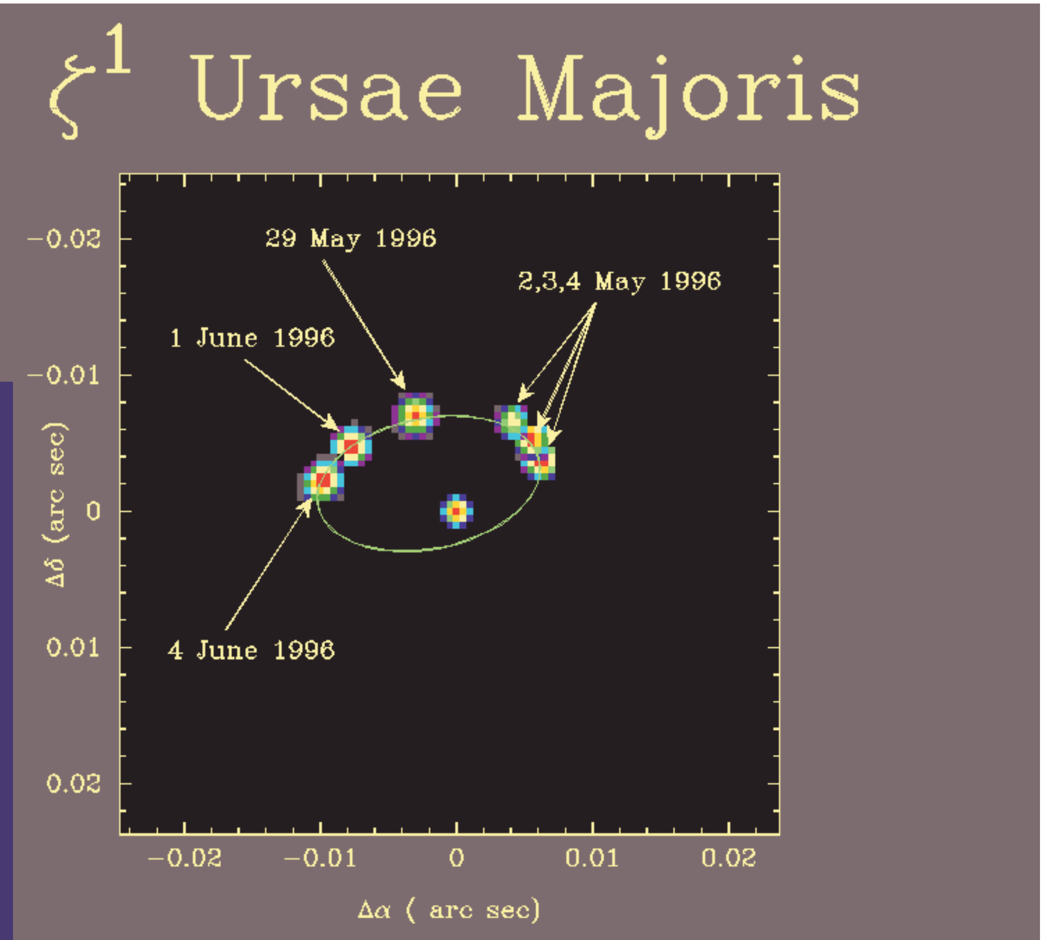
# Visual Binary



www.cosmobrain.com

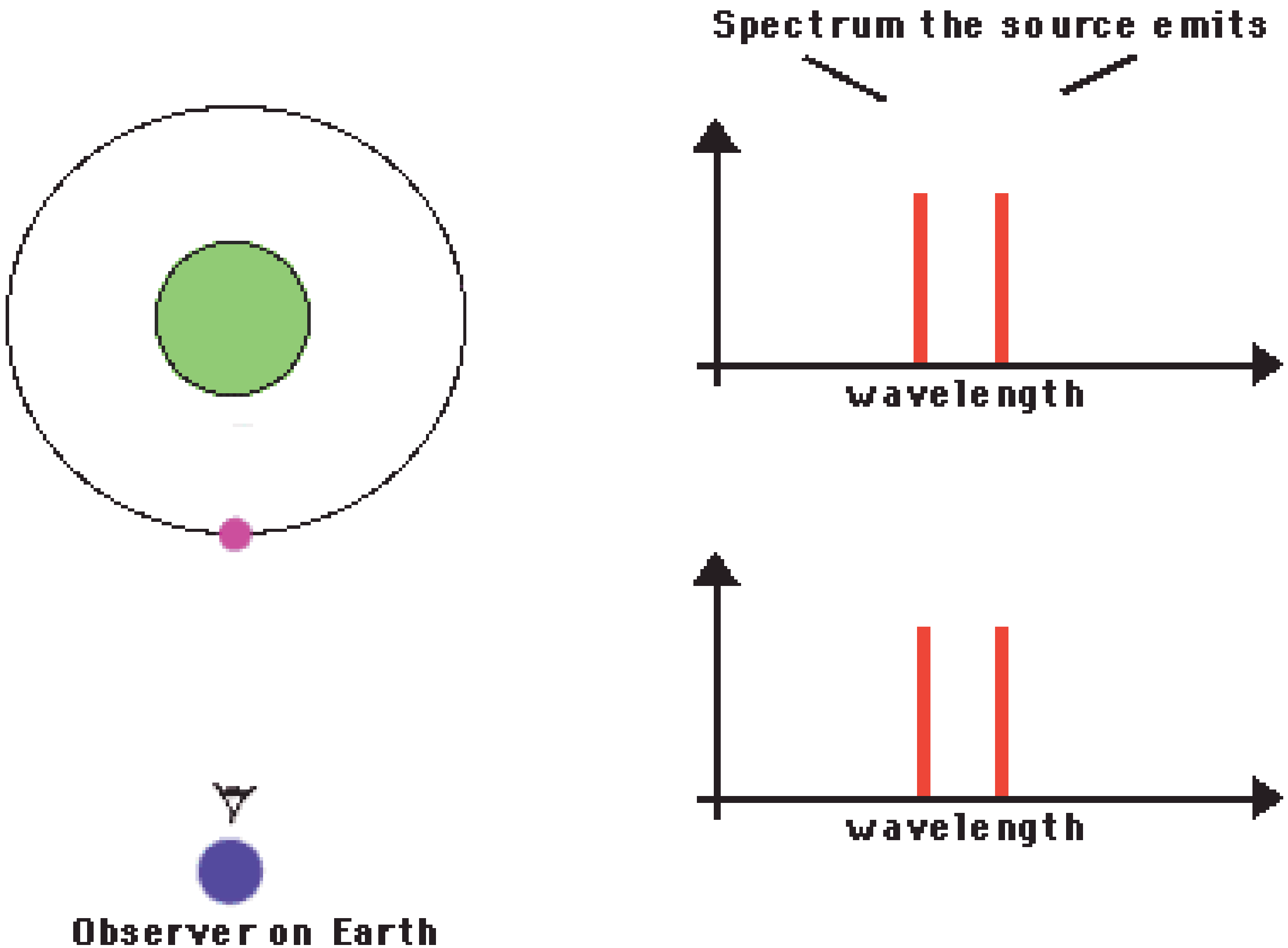



www.coelum.com




J. Benson, US Naval Observatory

# Spectroscopic Binaries

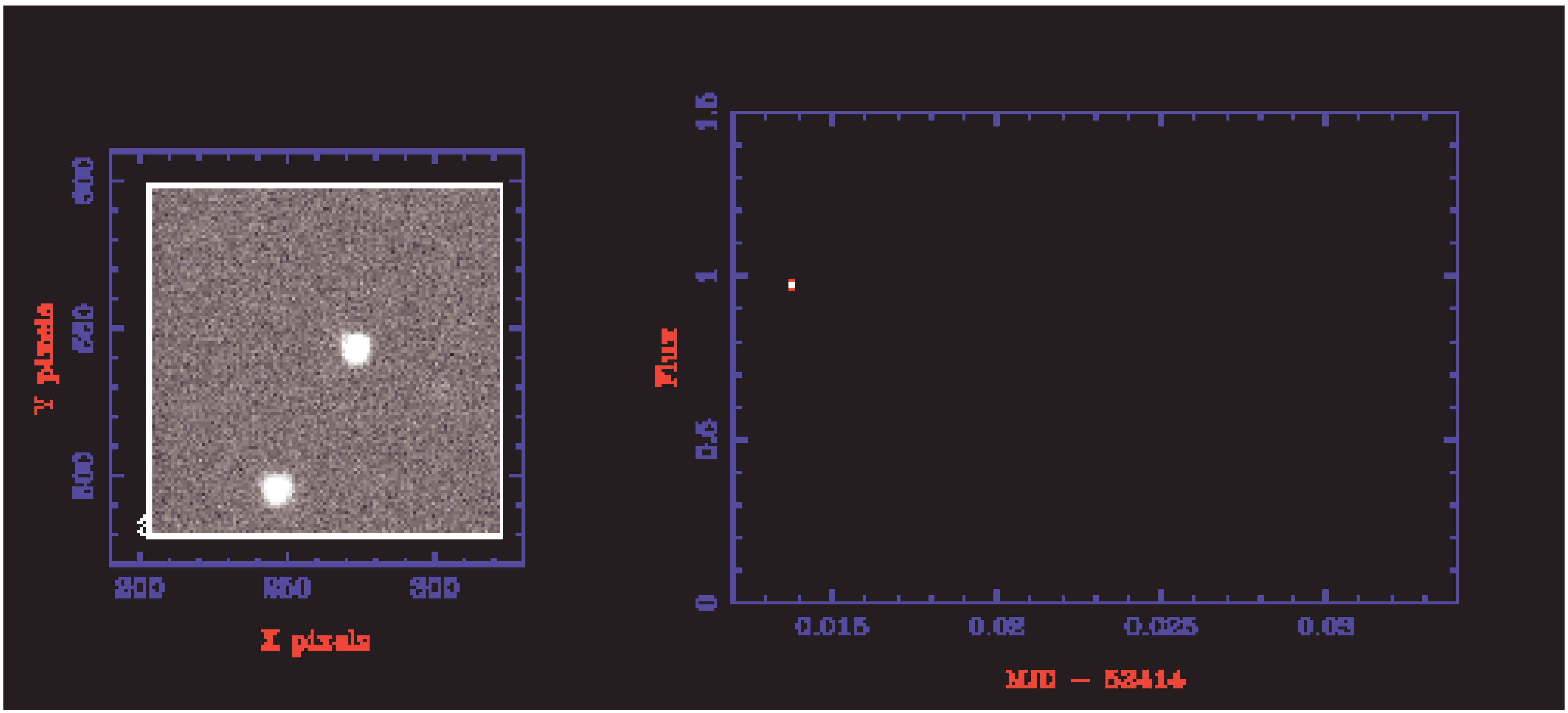



NASA

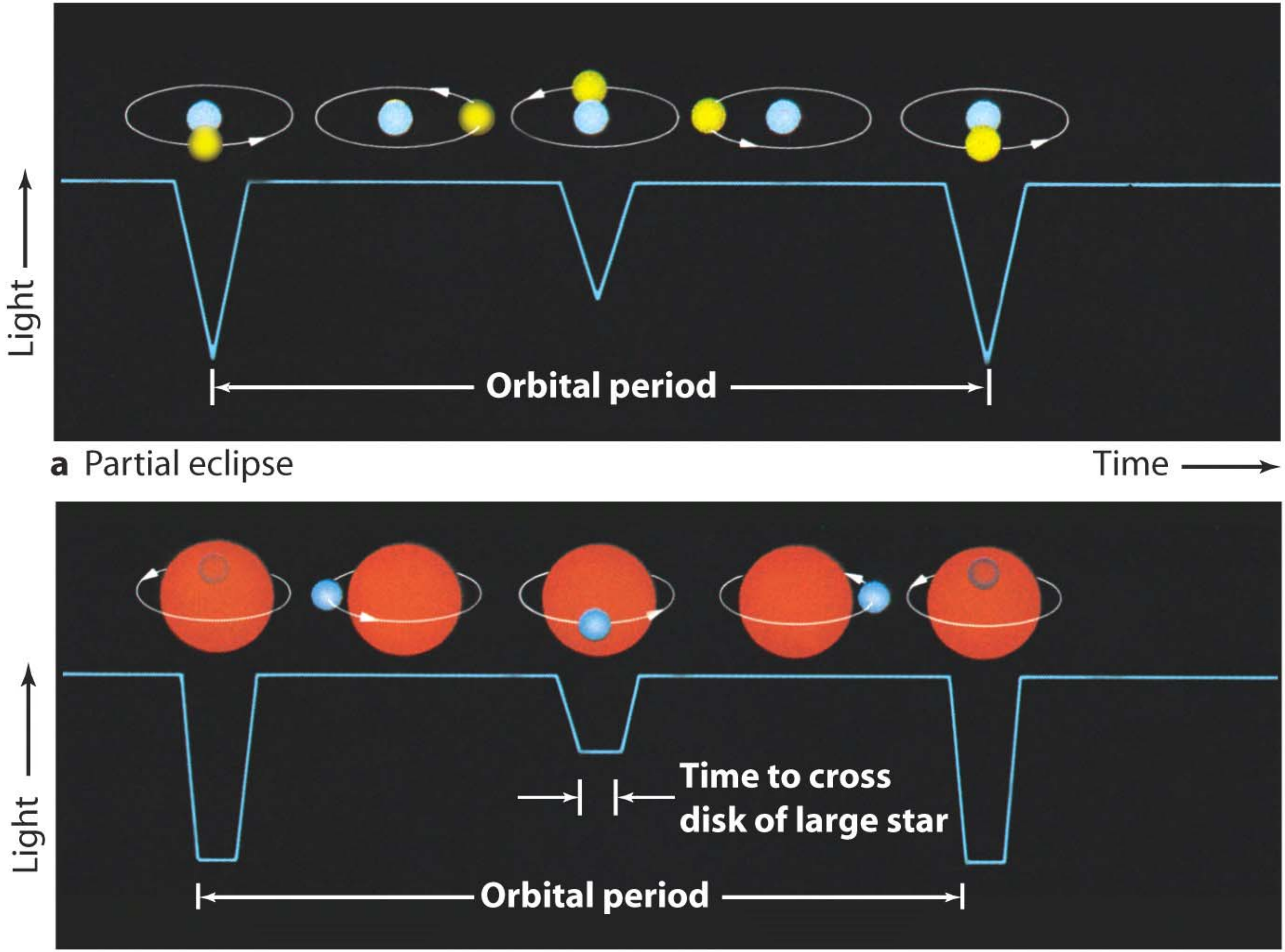
# Eclipsing Binaries

- Eclipse can happen if
  - Stars are close enough to each other
  - Orbital plane close to line of sight
- Can use to determine diameters, speed, atmospheric structure, etc.

ULTRACAM images of NN Serpentis (V. Dhillon)




http://instruct1.cit.cornell.edu/courses/astro101/java/eclipse/eclipse.htm



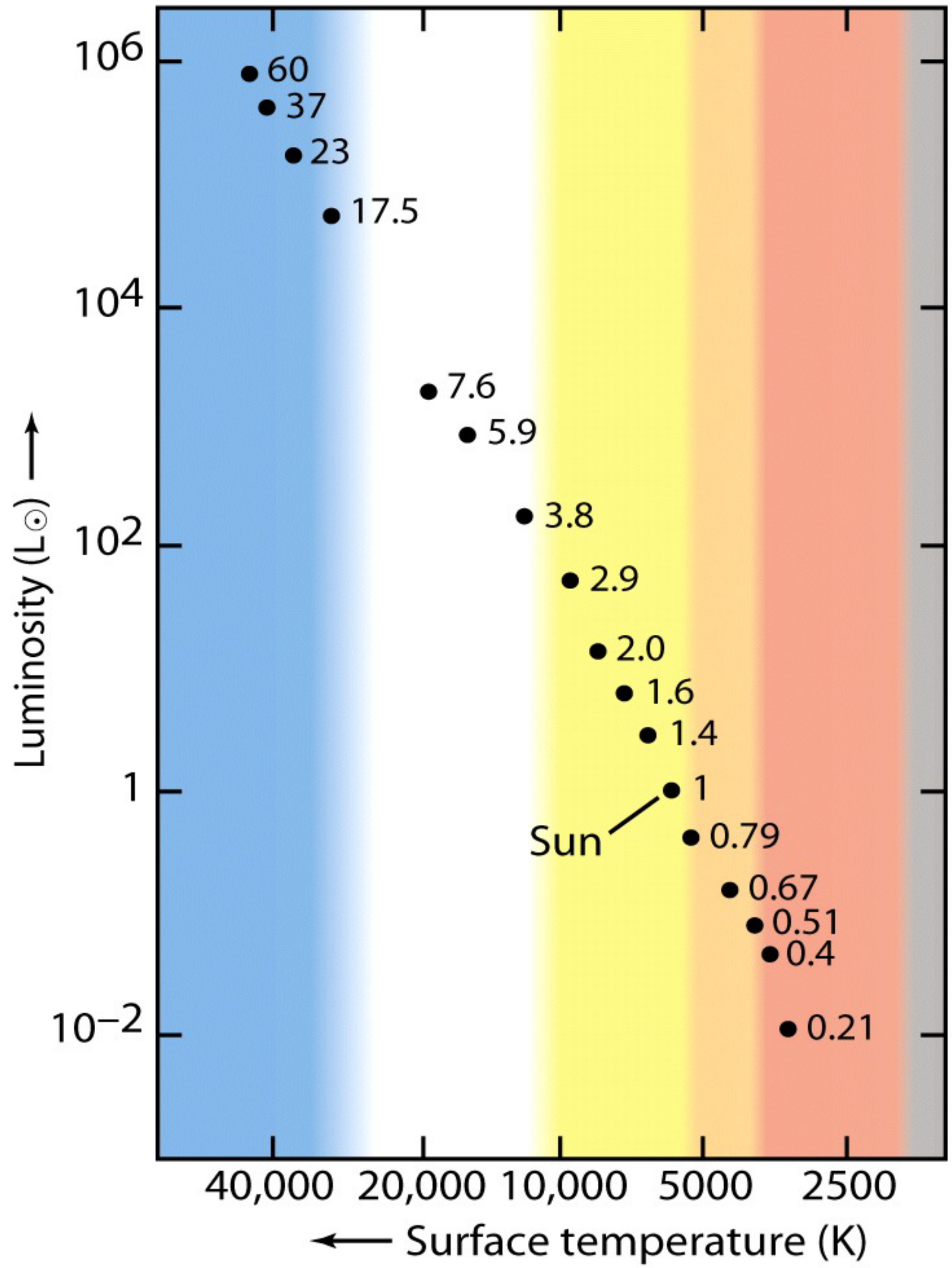

**a** Partial eclipse

Time

**b** Total eclipse

# The Mass-Luminosity Relation

- From the data of binary stars, we can find out the mass relationship of the stars on the main sequence.
- Luminosity is proportional to $M^{3.5}$
- Example:
  - •M = 3 solar masses – luminosity = 47x Sun
- → Much larger range in luminosity than in mass



# The HR Diagram shows us Stellar Lifecycles– Mosquito Style!

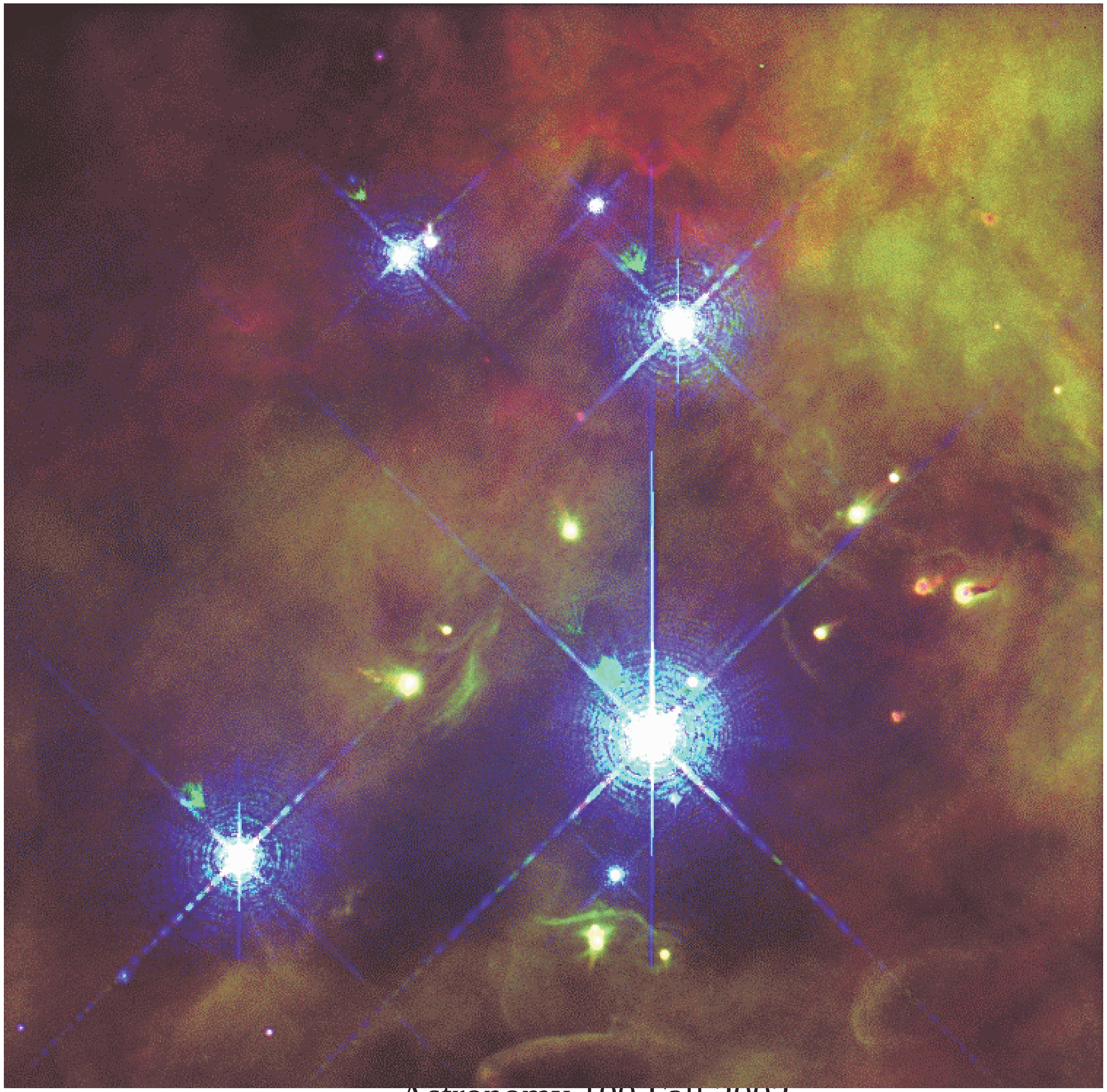
- The Main Sequence is where stars spend most of their time. Watch stars evolve– http://rainman.astro.uiuc.edu/ddr/stellar/archive/supermovie.mpg
- Example of how the Sun will evolve on the HR Diagram– http://rainman.astro.uiuc.edu/ddr/stellar/archive/suntrackson.mpg
- A high mass star lives the fast life– http://rainman.astro.uiuc.edu/ddr/stellar/archive/highmassdeath.mpg

# The Birth of Stars

- We’ve talked about how the solar system probably formed from the solar nebula about 4.6 million years ago.
- There is stuff in between the stars– dust and gas– that we call the interstellar medium.
- The interstellar medium is about 10% of our galaxies mass. Consists of 90% hydrogen, 9% helium, and 1% other.
- We can show similarities between the solar nebula of 4.6 million years ago and the interstellar medium in general, positing that star formation is ongoing right now. Sort of a new concept.

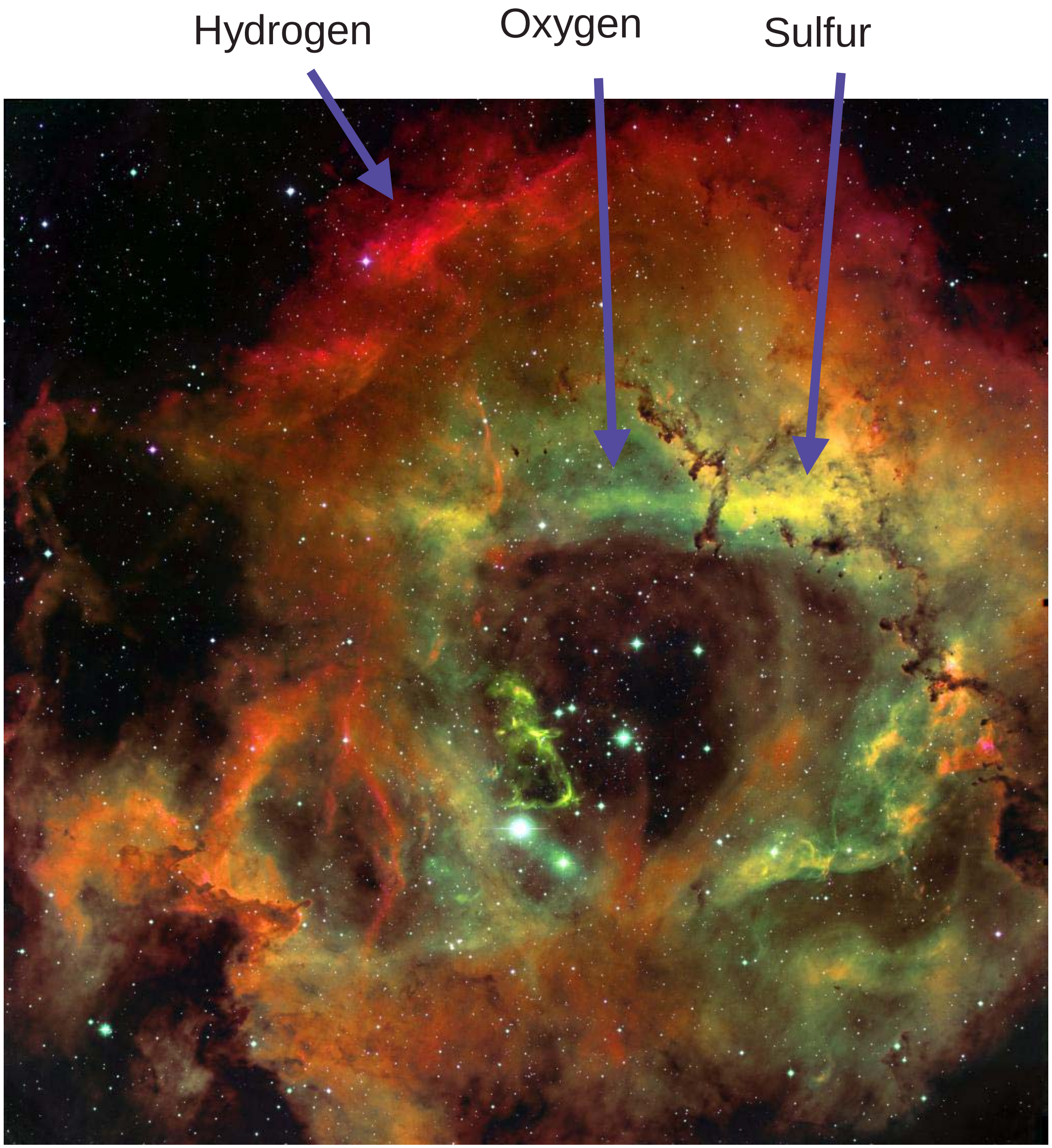
# The Birthplace of Stars

- Young stars often are seen in **clusters**
- Very young stars are also associated with clouds of gas (**nebulae**)



The Trapezium

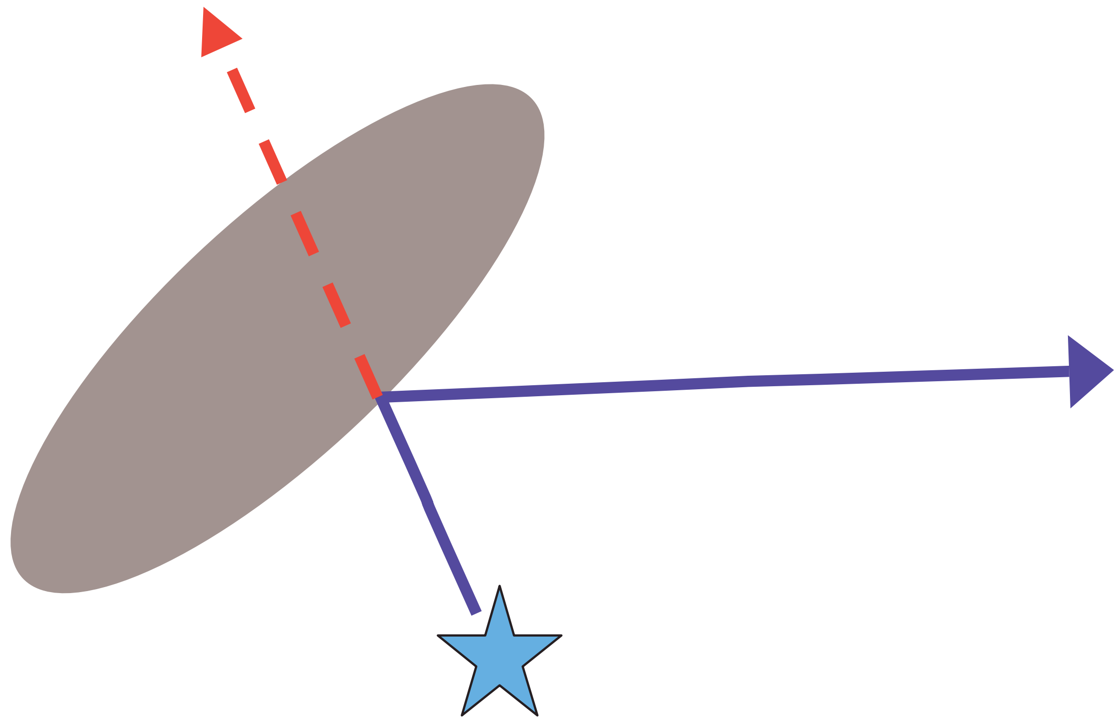
# Emission (Fluorescent) Nebulae



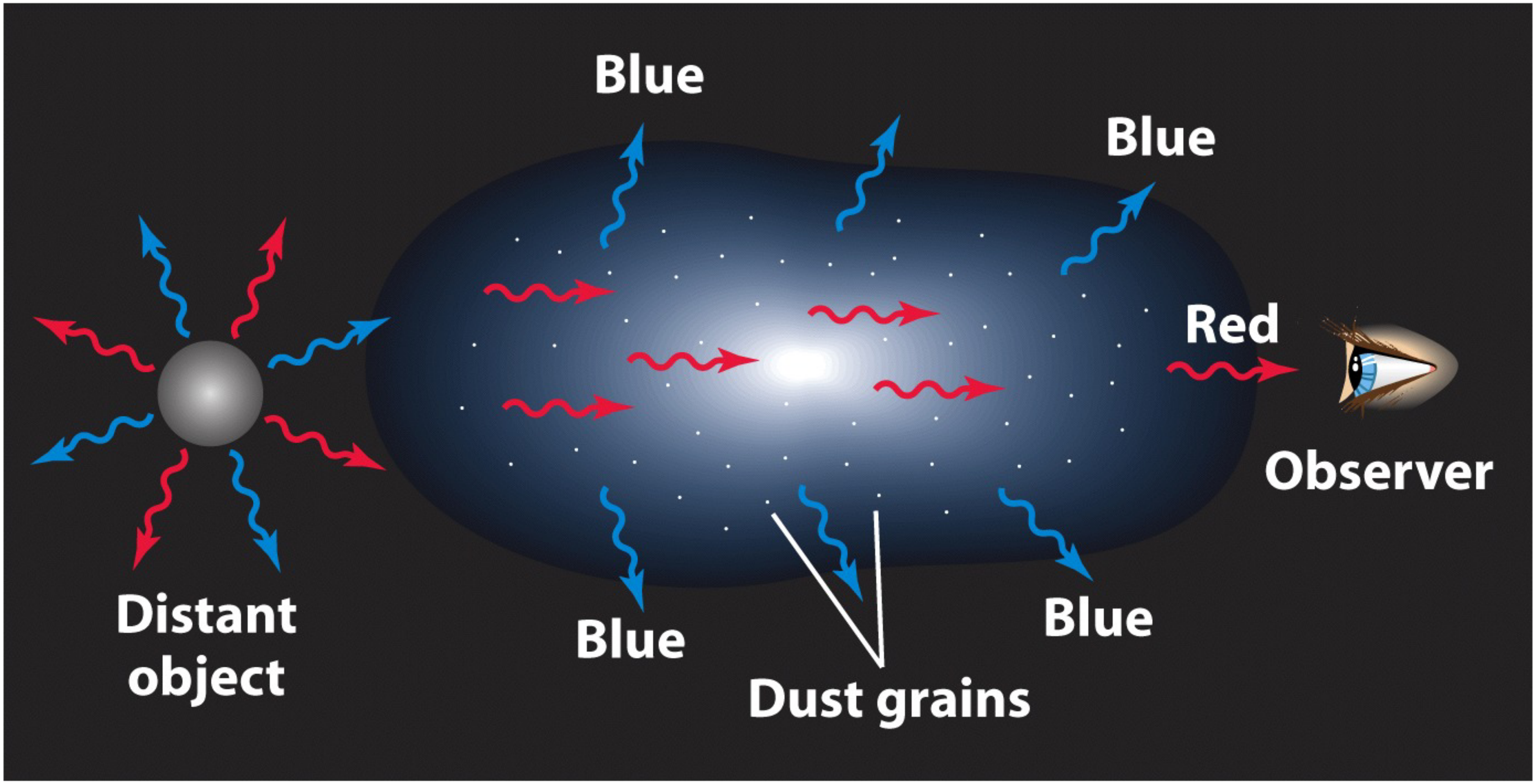

Rosette Nebula

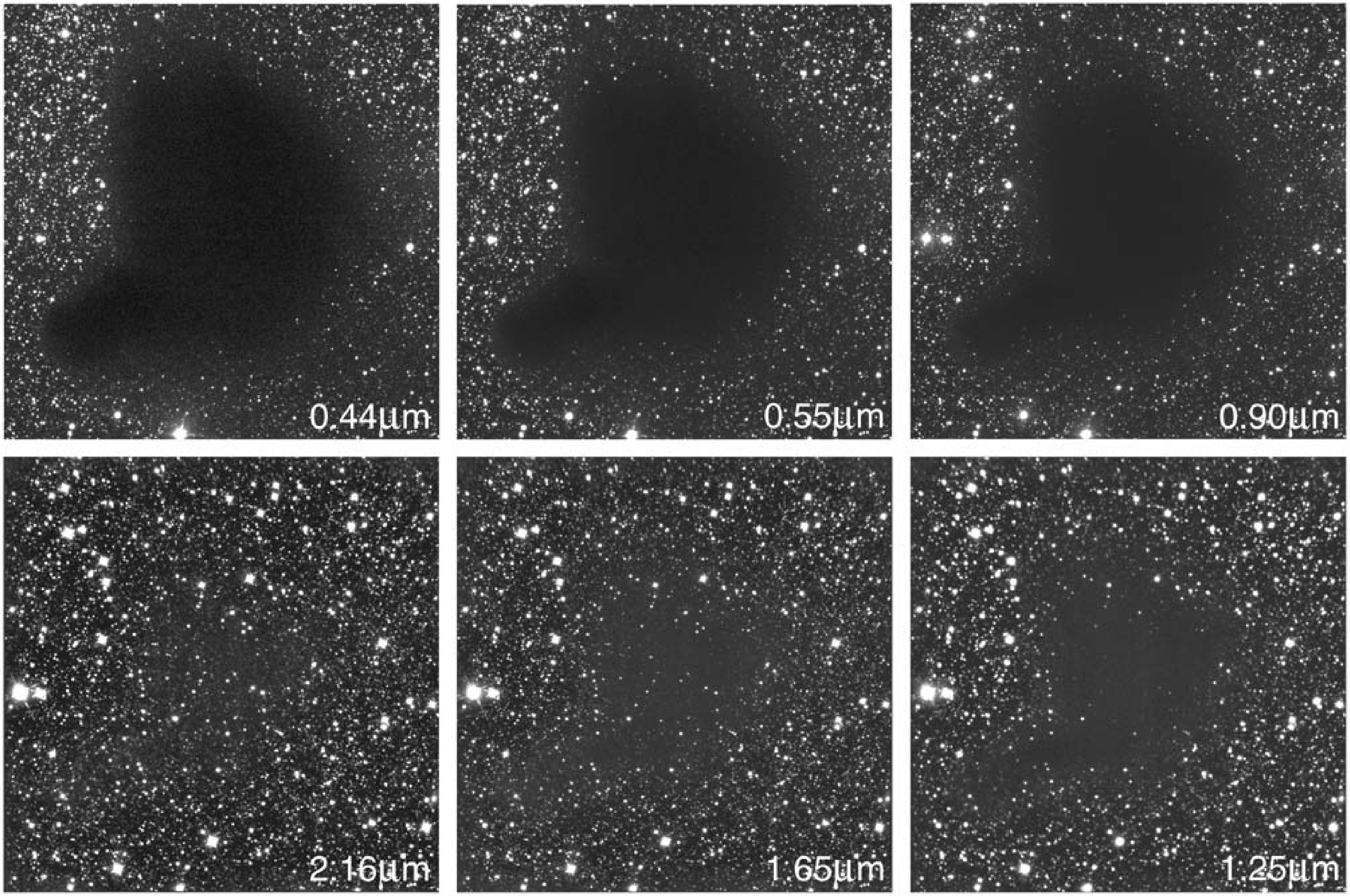
# Reflection Nebulae


NGC 1435



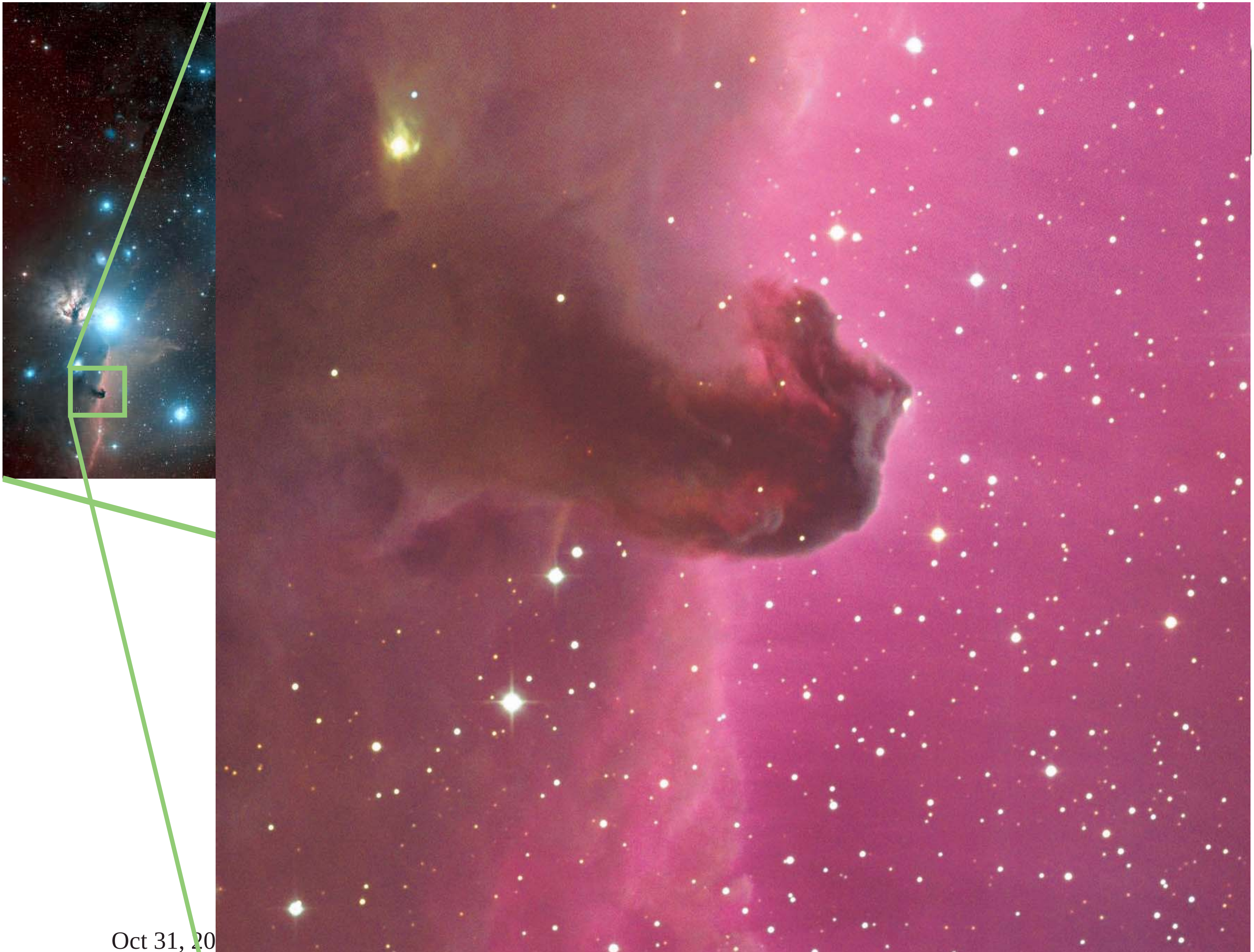
# “Dark” Nebulae

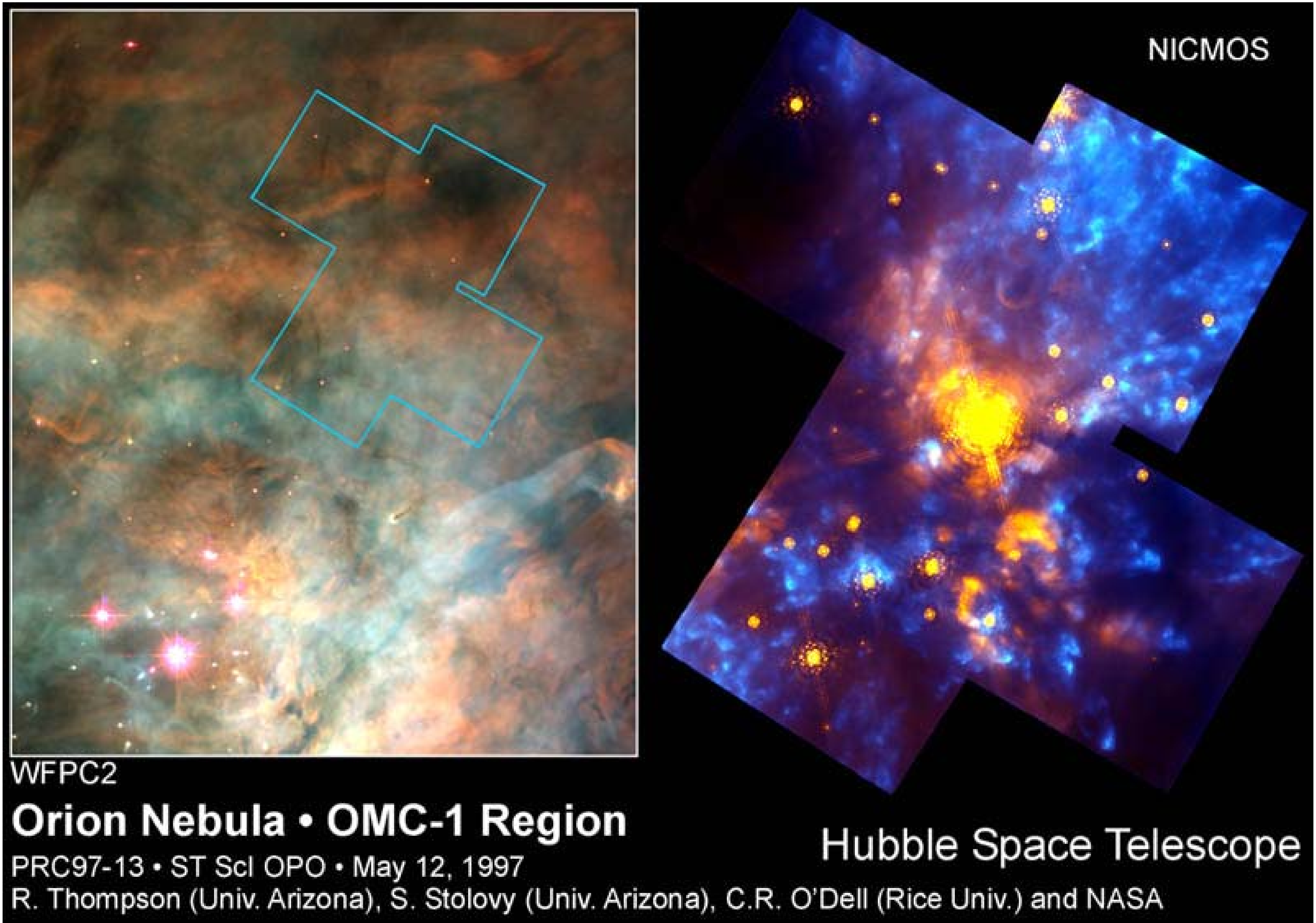





The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

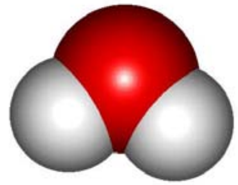
ESO PR Photo 29b/99 ( 2 July 1999 )

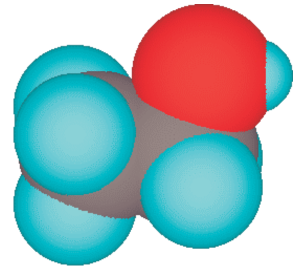


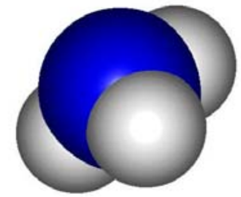

NICMOS
WFPC2
Orion Nebula • OMC-1 Region
Hubble Space Telescope
PRC97-13 • ST ScI OPO • May 12, 1997
R. Thompson (Univ. Arizona), S. Stolovy (Univ. Arizona), C.R. O'Dell (Rice Univ.) and NASA

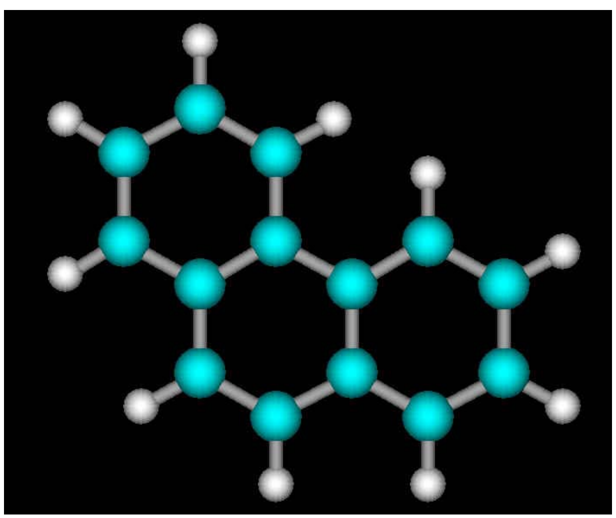
# Other Things Besides Hydrogen in Molecular Clouds

- Molecules (e.g.)
  - Carbon monoxide ($CO$)
  - Water ($H_2O$)
  - Ammonia ($NH_3$)
  - Formaldehyde ($H_2CO$)
  - Ethyl alcohol ($CH_3CH_2OH$)
  - Glycine ($NH_2CH_2COOH$)
  - Acetic Acid ($CH_3COOH$)
  - Urea [$(NH_2)_2CO$]
- Dust particles
  - Silicates, sometimes ice-coated
  - Soot molecules

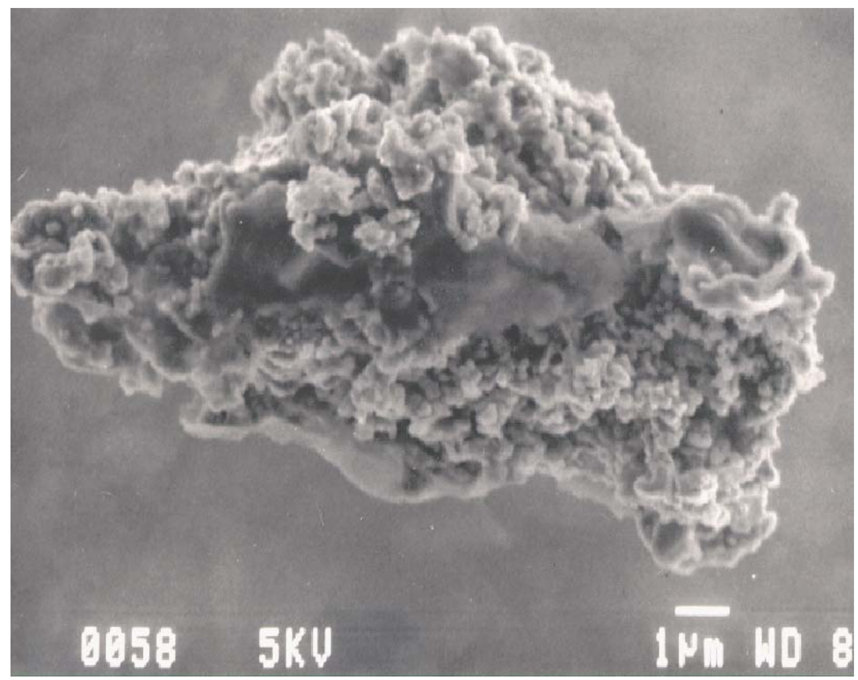








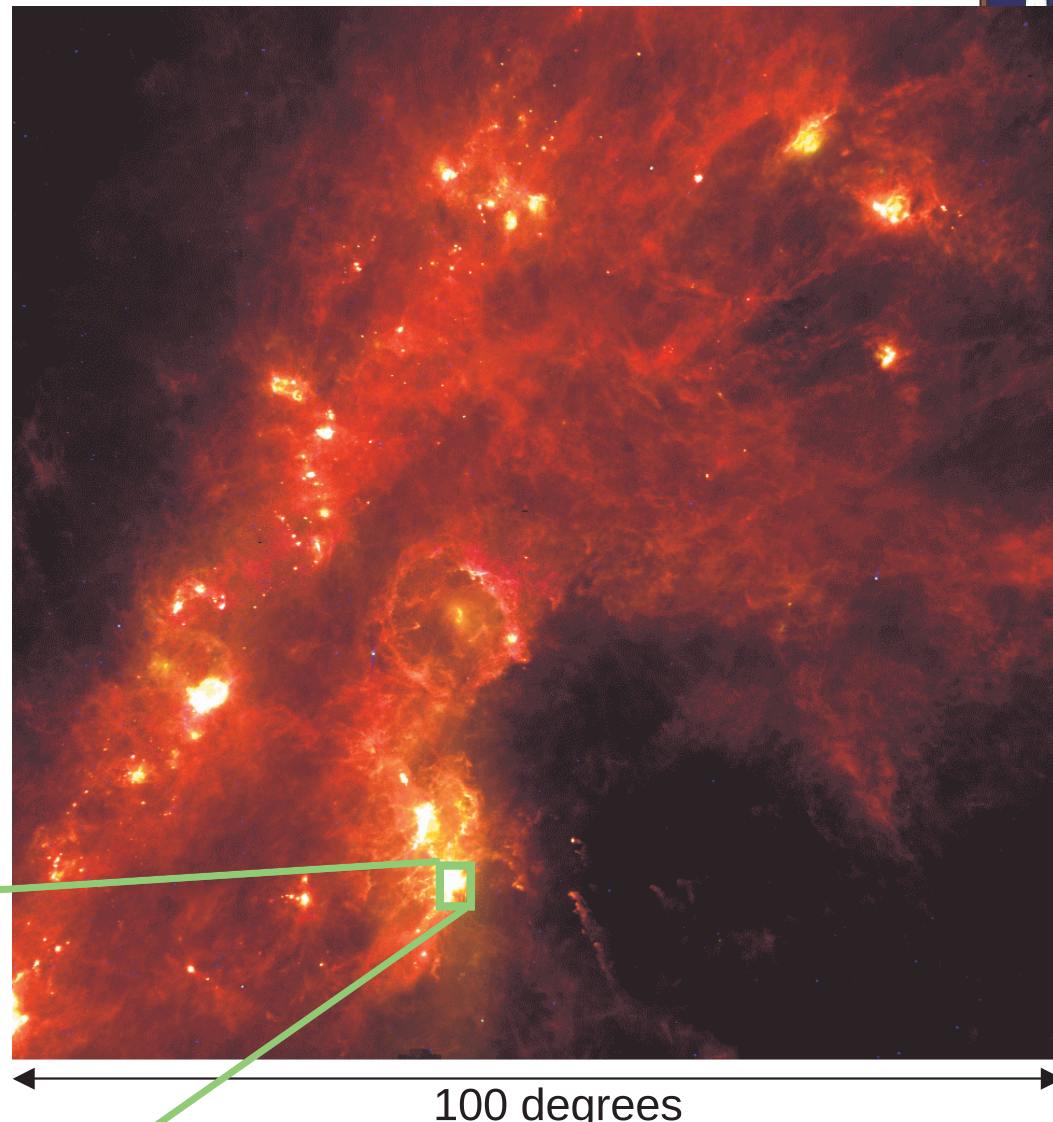
Polycyclic aromatic hydrocarbons (PAH)




Dust particle (interplanetary)

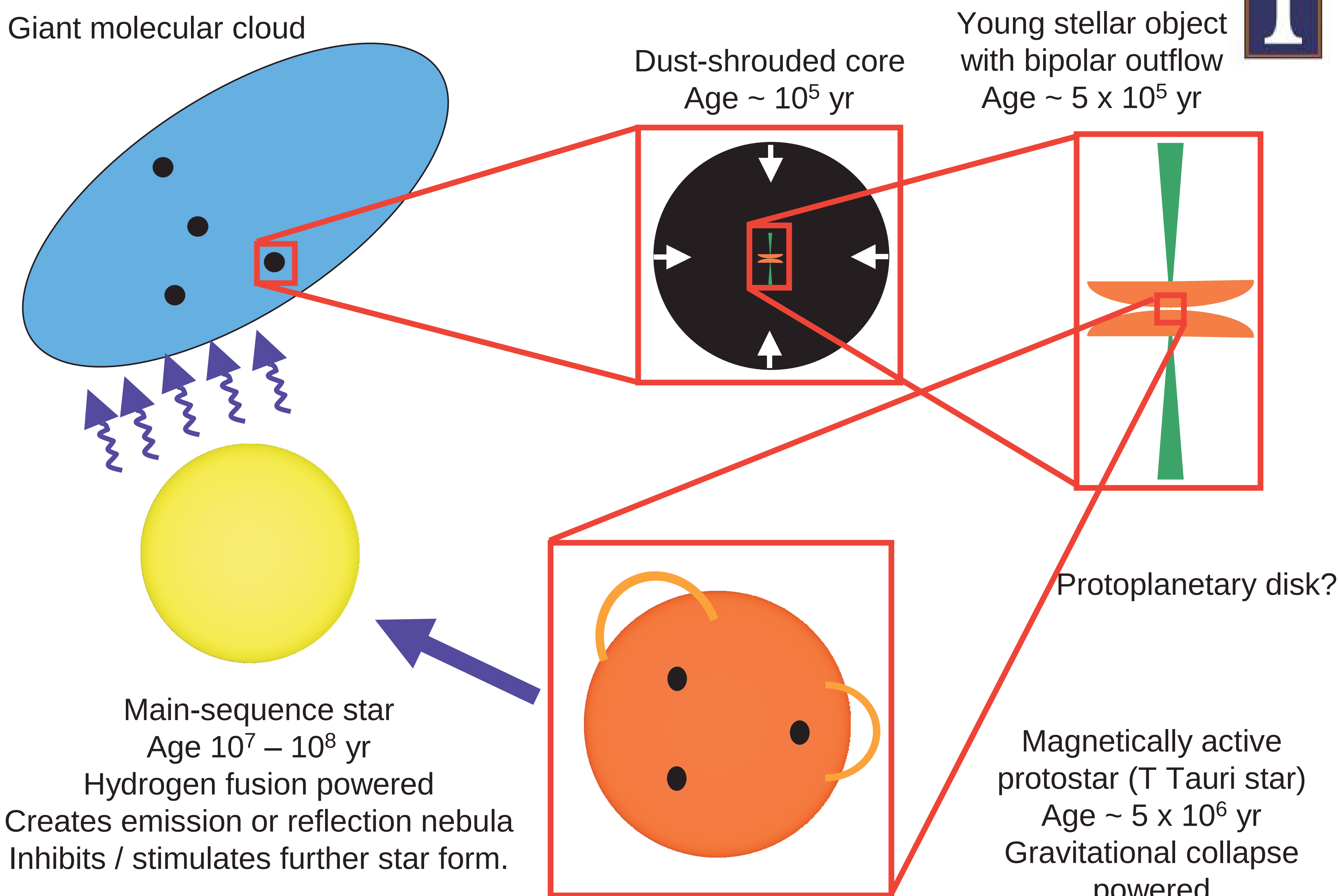
# Giant Molecular Clouds

- Cool: < 100 K
- Dense: $10^2 - 10^5$ $H_2$ molecules/cm$^3$
- Huge: 10 – 100 pc across, $10^5 - 10^6$ solar masses
- CO molecular emission & dust emission trace structure



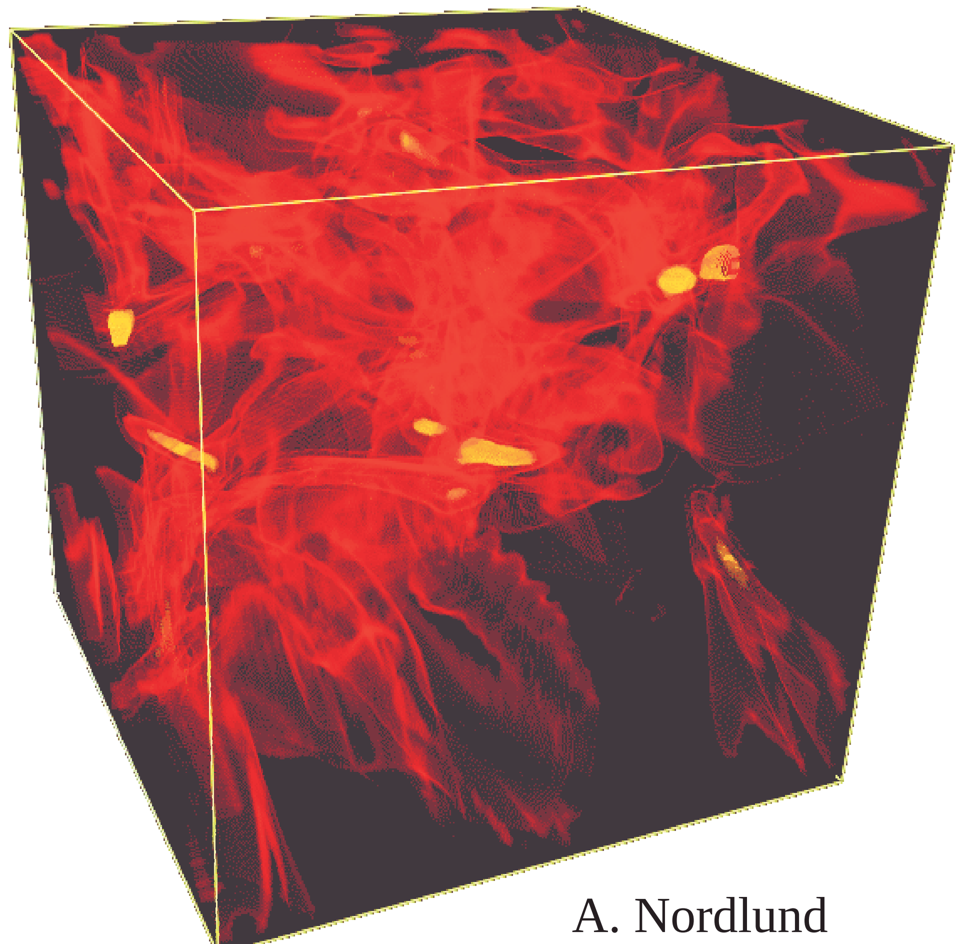

Infrared image from *IRAS*

# Star Formation - Summary



# Some outstanding Star Formation Issues

- Why do the cores collapse, but not the entire molecular cloud?
- What sets the sizes of cores, and hence masses of stars?
- What determines how stars cluster, group together, or form multiple systems?



A. Nordlund