Astronomy 150: Killer Skies
Lecture 20, March 7

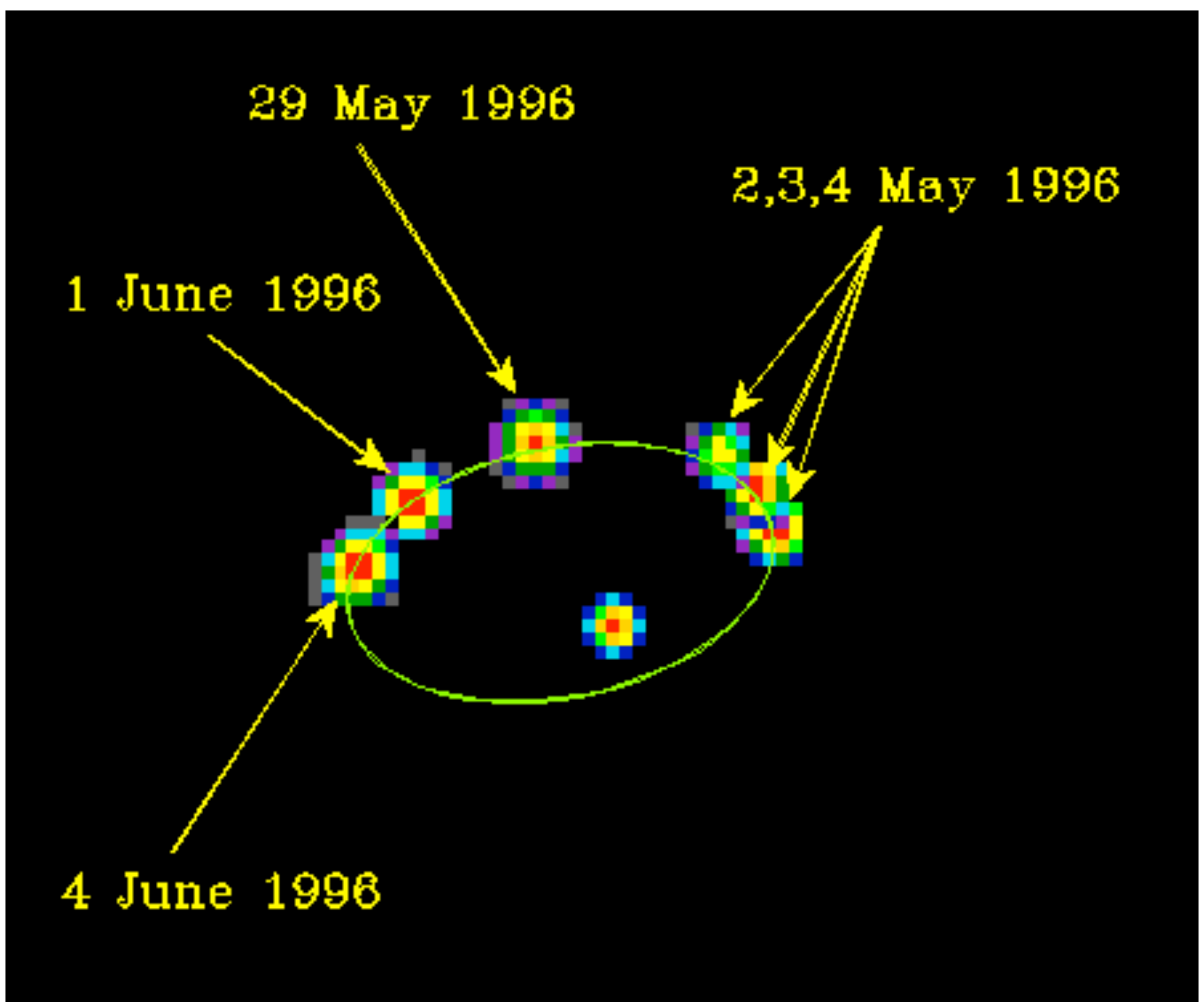
Assignments:

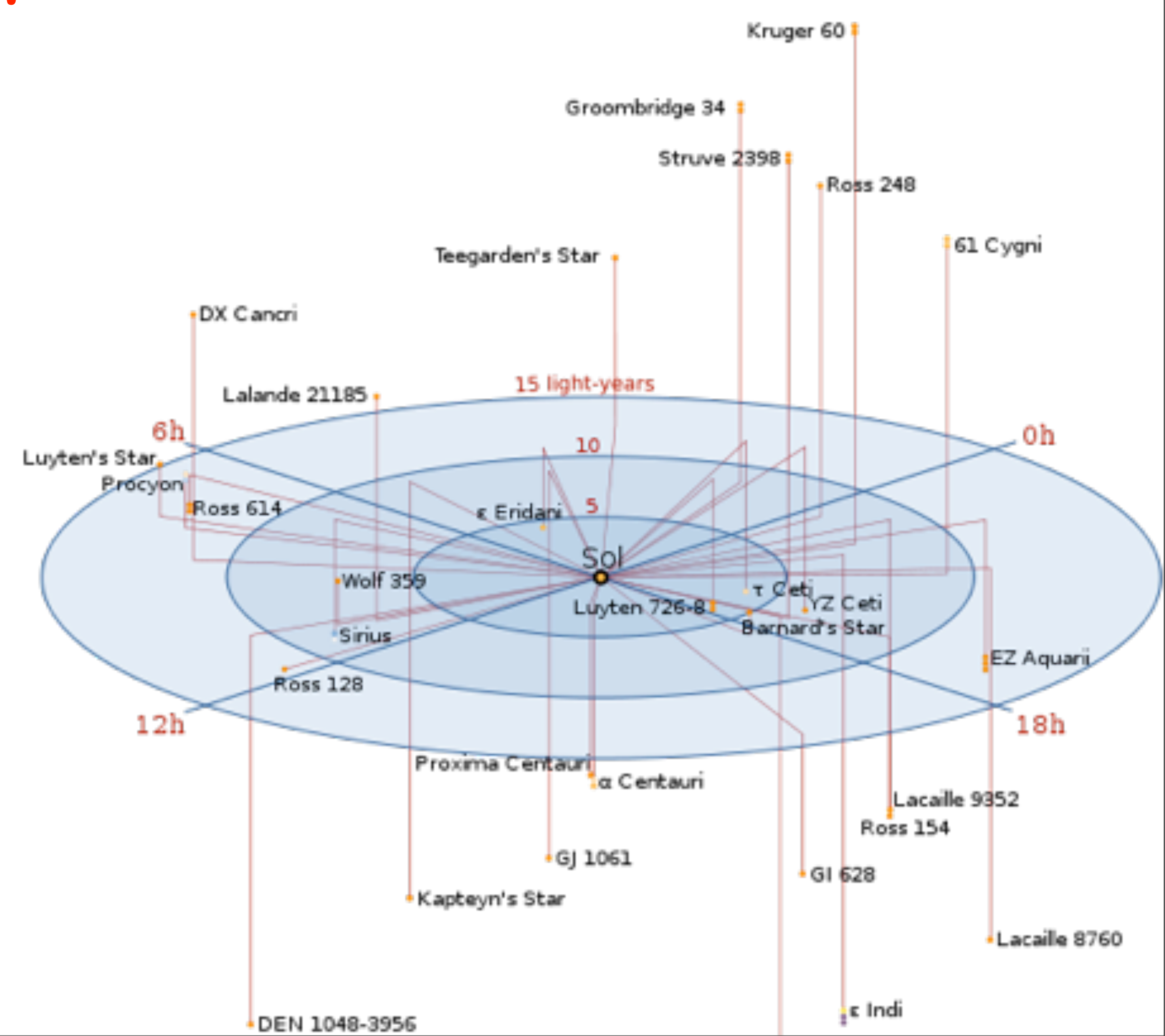
- HW6 due next time at start of class
- Office Hours begin after class or by appointment
- Night Observing continues this week, 7-9 pm

  last week! go when you get the chance!

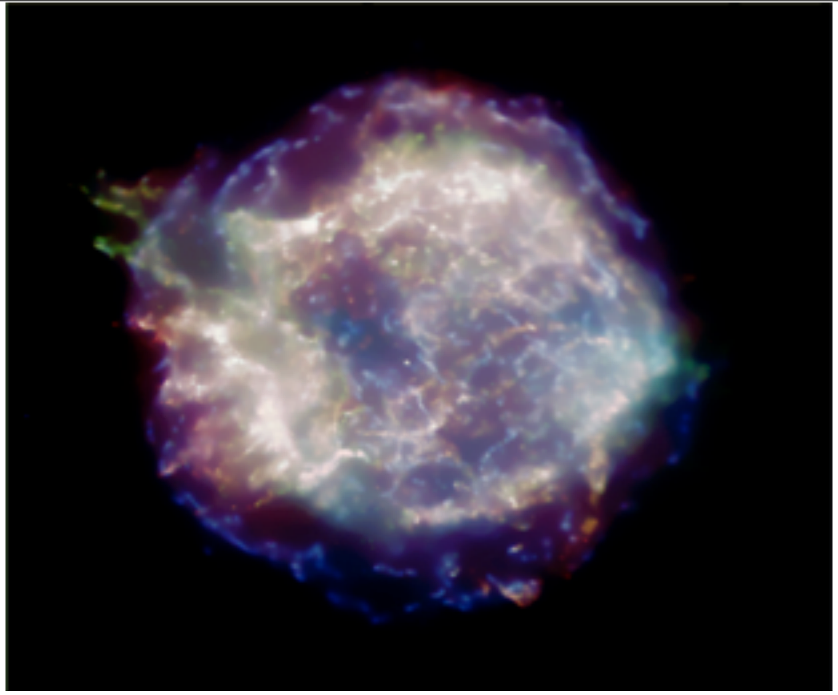
Last time: Decoding Starlight, Part I

Today: Decoding Starlight II, and Properties of Stars





Last Time



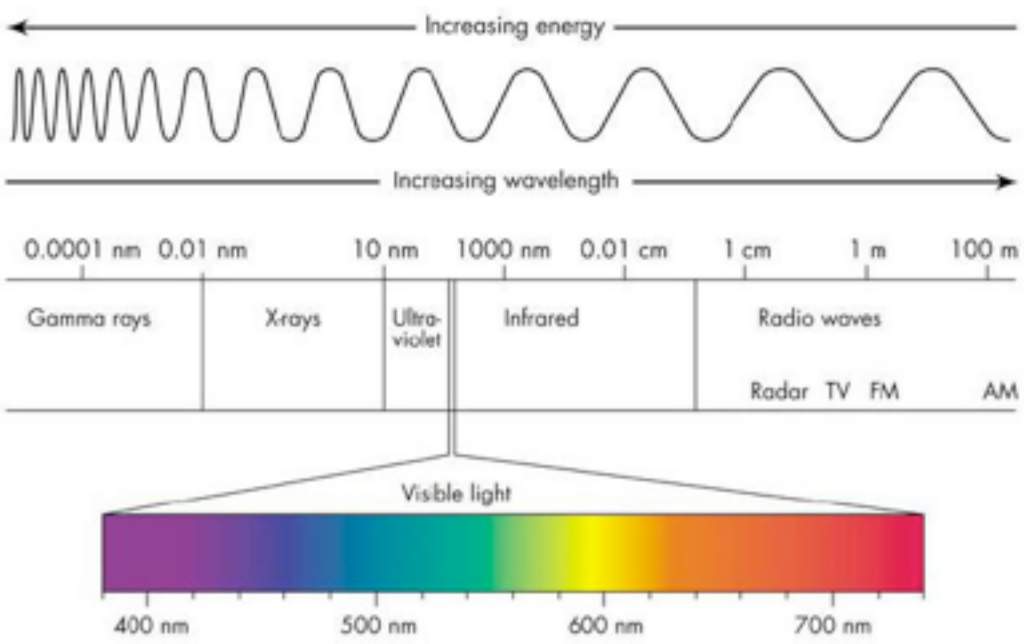
Killer stars exist!

- supernovae
- gamma-ray bursts
- black holes
- all result from deaths of stars

Risk assessment:

how often and how close are these threats?

- need to have census of stars
- need to understand life cycles



But cannot visit stars--too far away!

- Have to learn all we can by decoding starlight

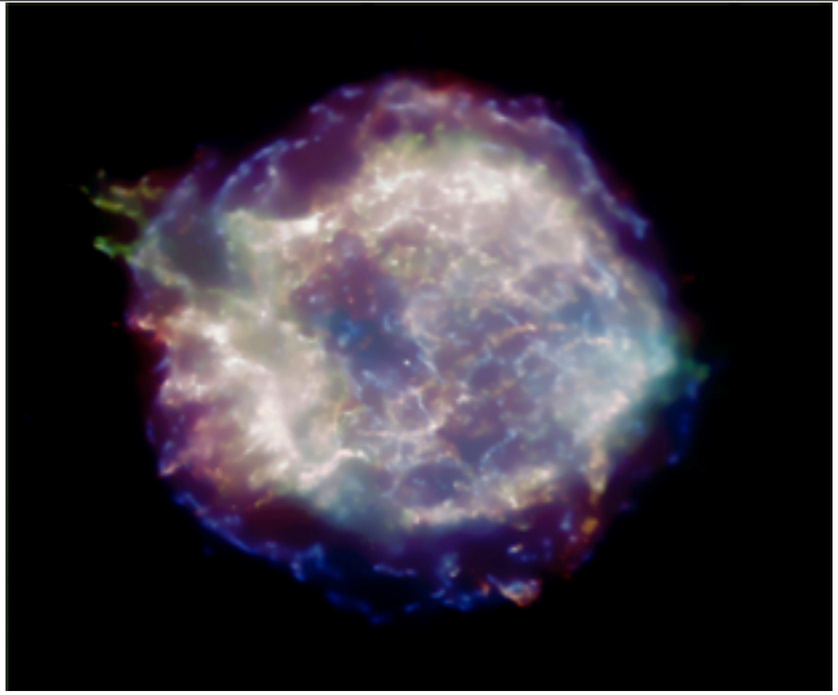
Progress so far:

- starlight is blackbody radiation
- temperature encoded in color (peak wavelength)

  cooler = longer wavelength = redder

  hotter = shorter wavelength = bluer

Last Time



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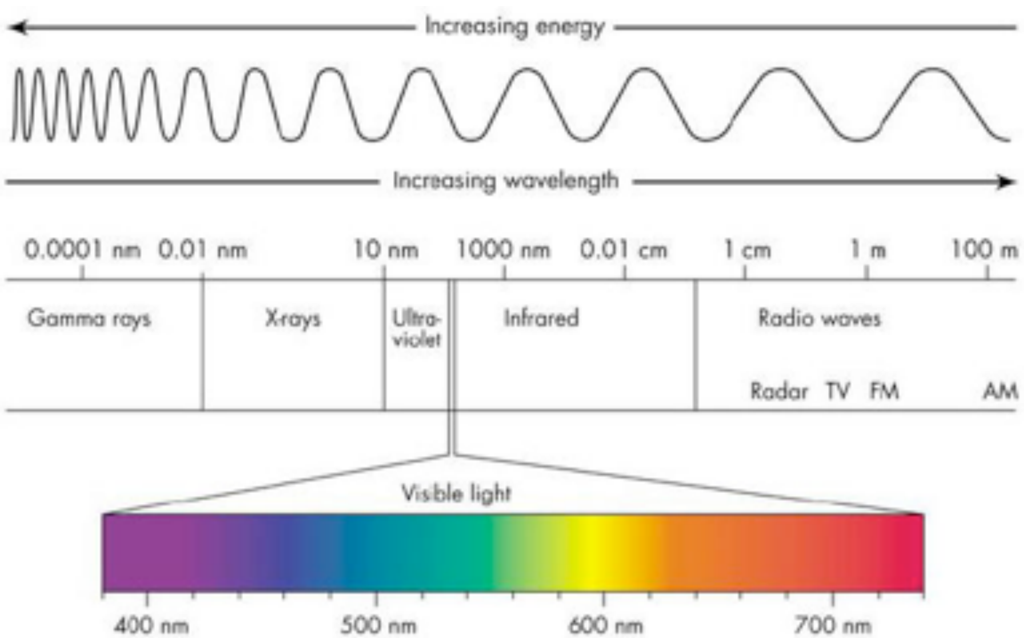

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Star's Physical

Please step on scale. Turn head. Cough.

No, really.

How to measure the properties of objects that are very, very far away?

We will have to figure out what stars are like and how they work based only only

- the light we measure
- the laws of nature

Star Power

power = rate of energy flow or consumption

= energy output/time

$$P = E/t$$

light power = total light energy outflow: luminosity

- "star wattage"
- rate of fuel consumption
- rate of energy production

iClicker Poll: Star Brightness

Vote your conscience!

Stars observable by the naked eye appear to have a wide range of brightnesses

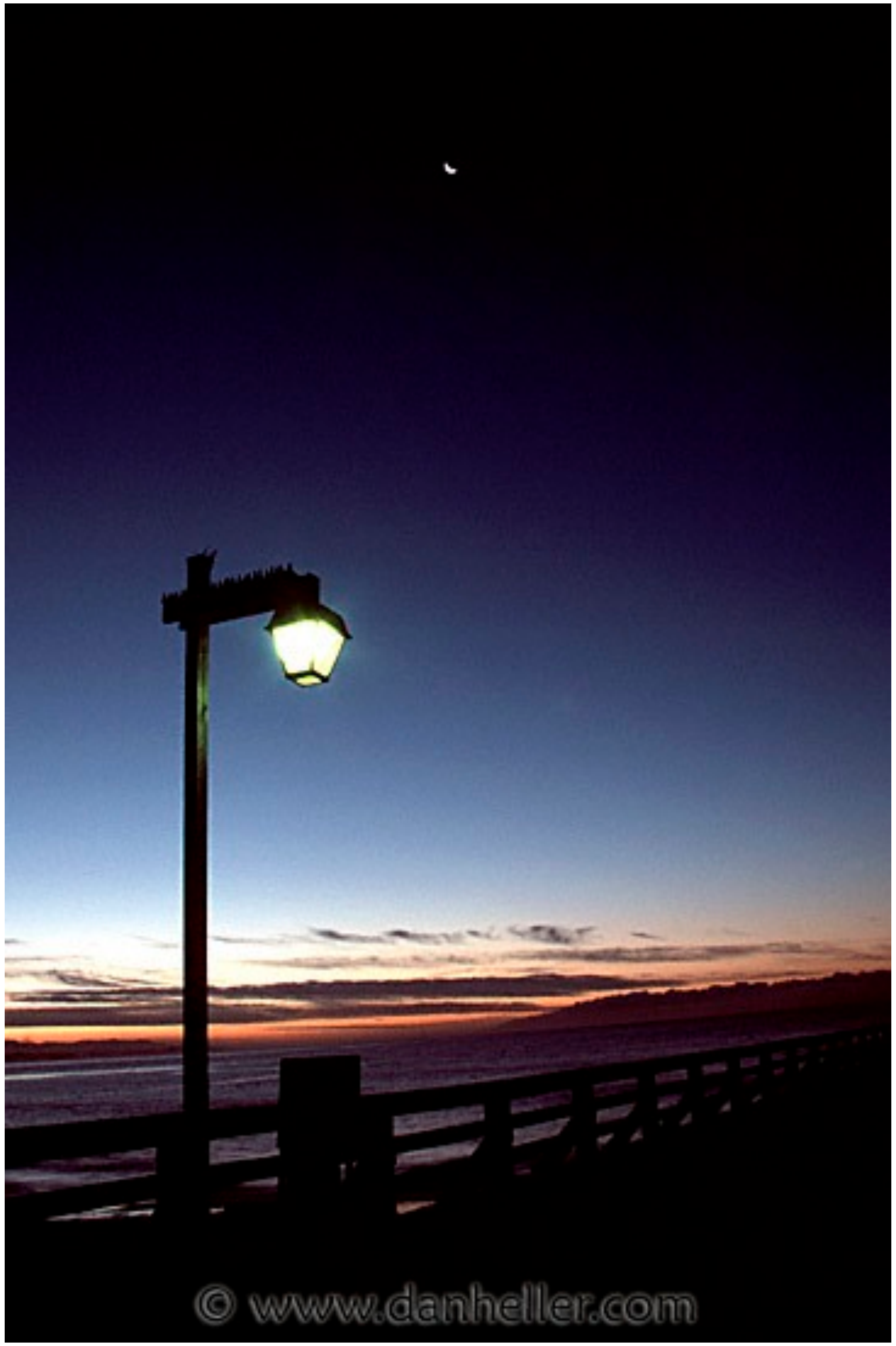
Why?

A. they emit similar amounts of light (similar luminosities L), but are at different distances

B. they emit very different amounts of light (different L) but are at similar distances

C. they emit very different amounts of light (different L) and are also at very different distances

Which is Brighter?



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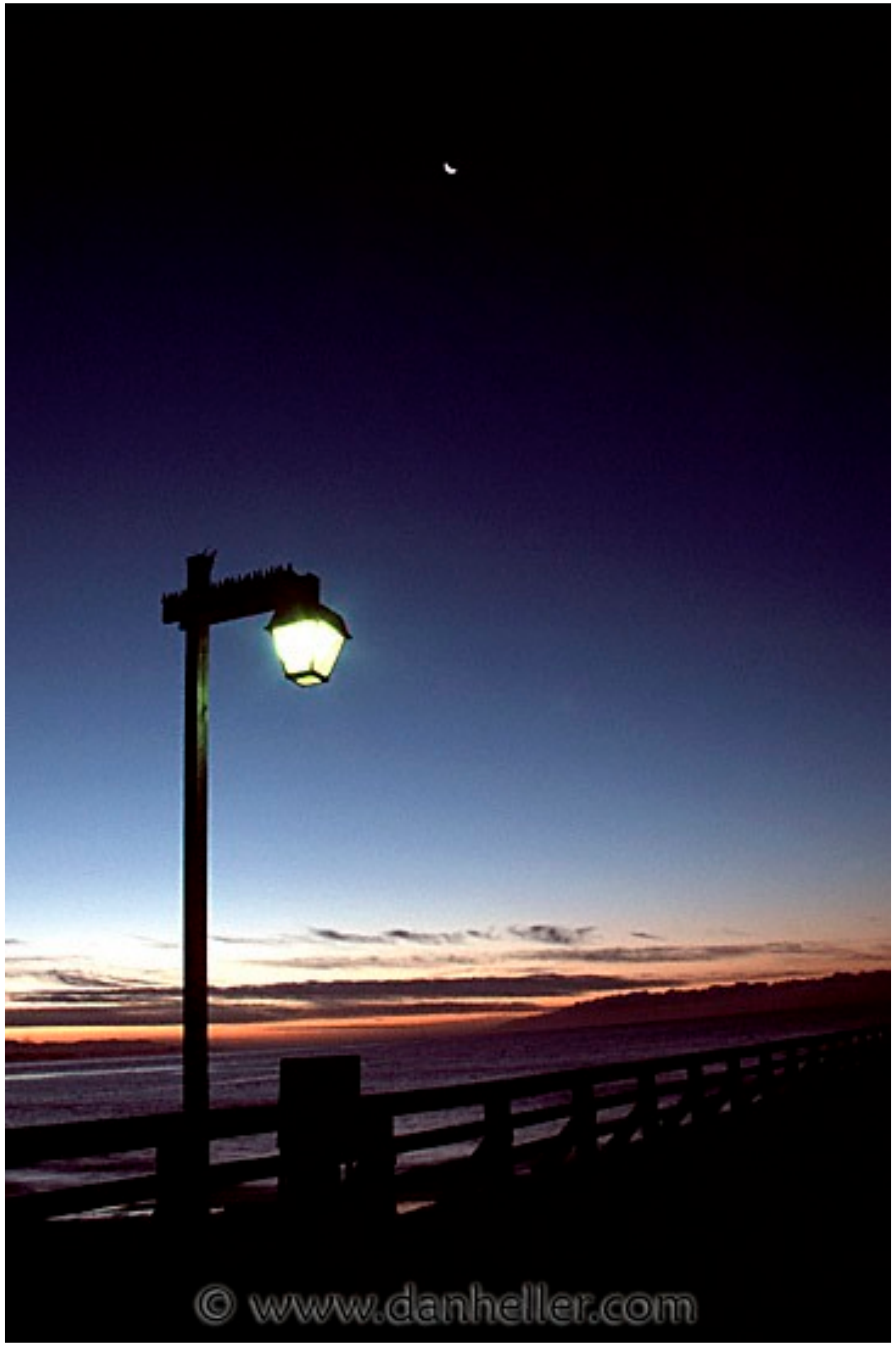
Which is Brighter?

a) Moon
b) Streetlamp



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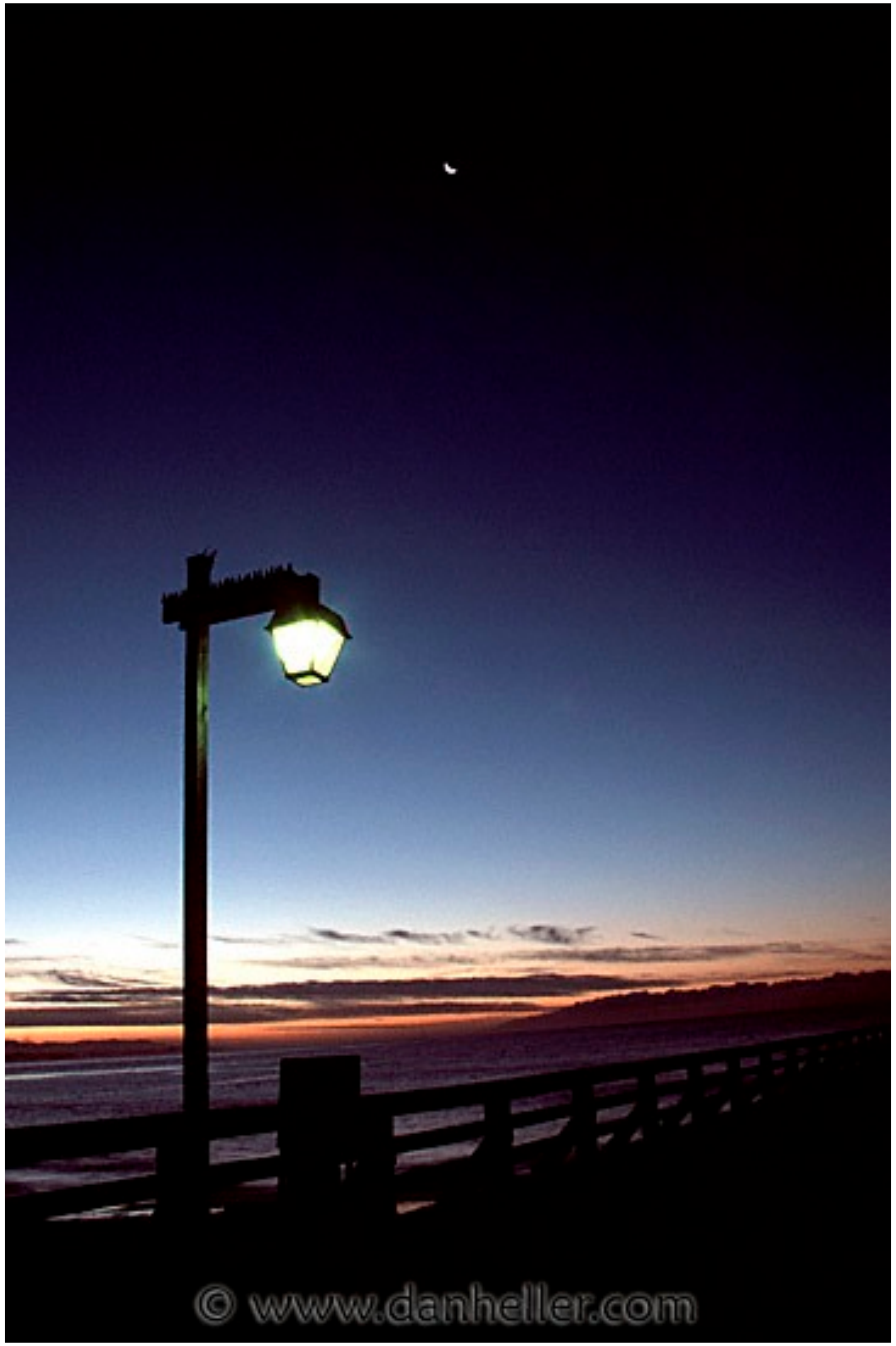

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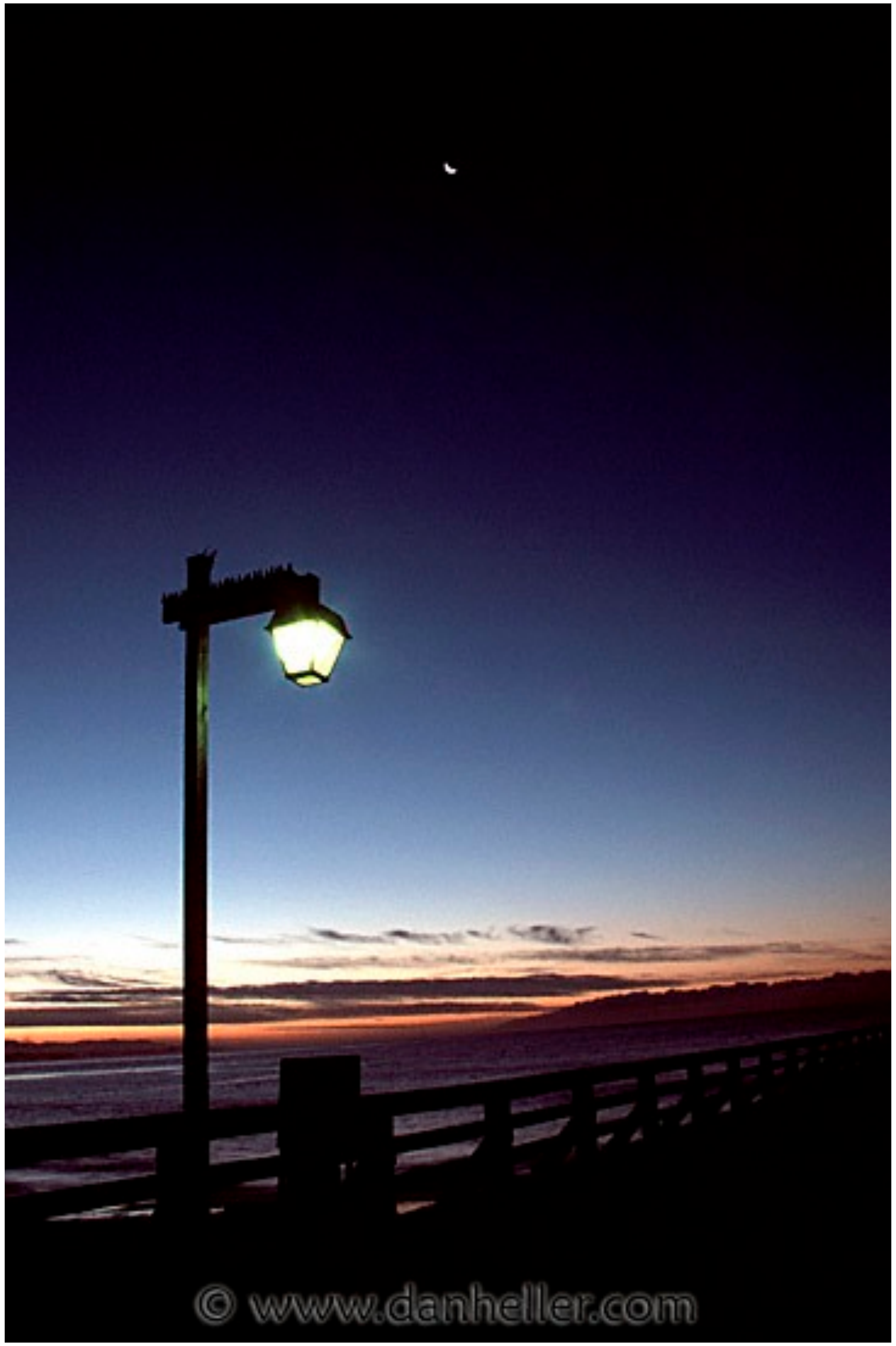
Why?

"Apparent brightness" vs "luminosity" difference.



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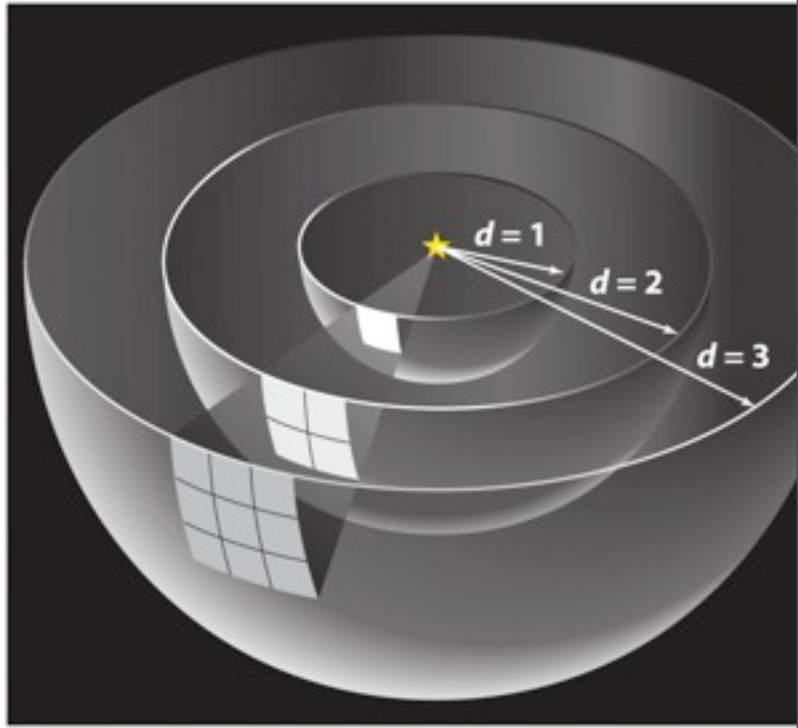
Luminosity vs Flux

Apparent brightness ≠ luminosity!

Luminosity:

- total energy output: "wattage"
- that is, total energy flow in all directions



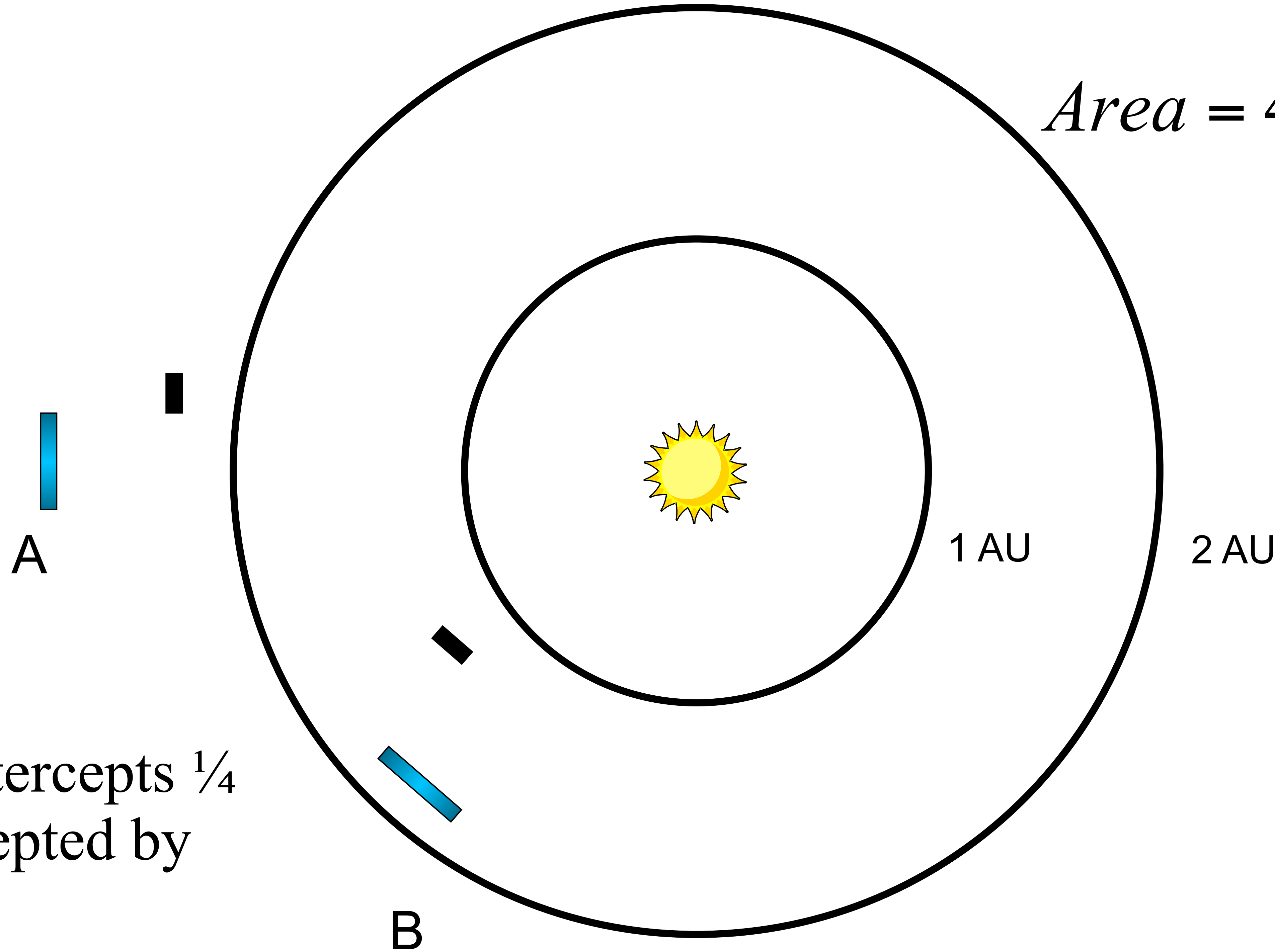
Apparent brightness

- energy flow that passes through your detector (telescope, eyeball, etc)
- depends on distance away.
- The farther, the dimmer.
- That's why it's called apparent brightness.

Why do more distant objects look so much fainter?

- More distant stars of a given luminosity appear dimmer
- At larger distance (radius), light spread over larger area
- Apparent brightness drops as square of distance

$$Area = 4\pi r^2$$



Telescope A intercepts ¼ the light intercepted by telescope B

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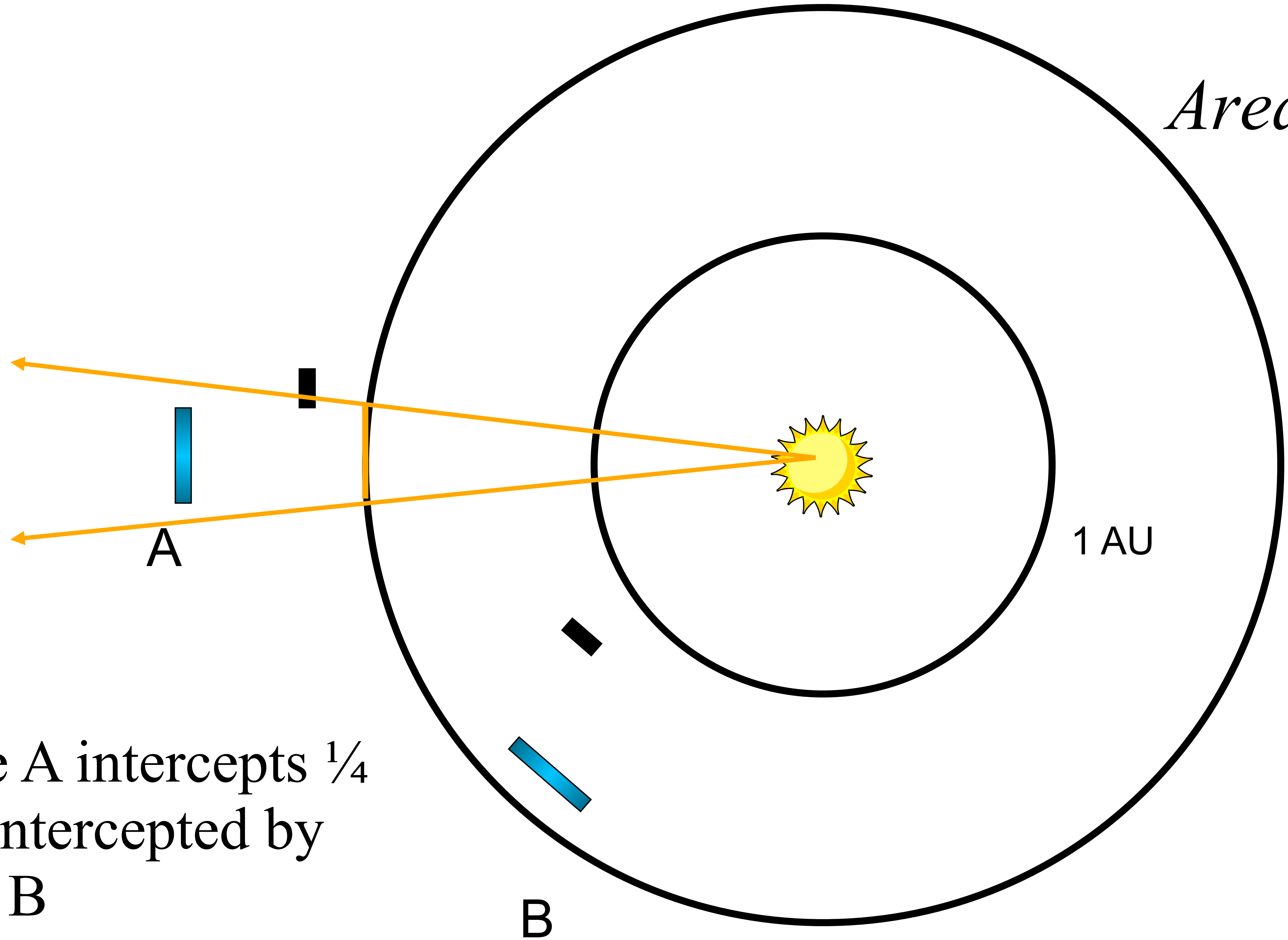

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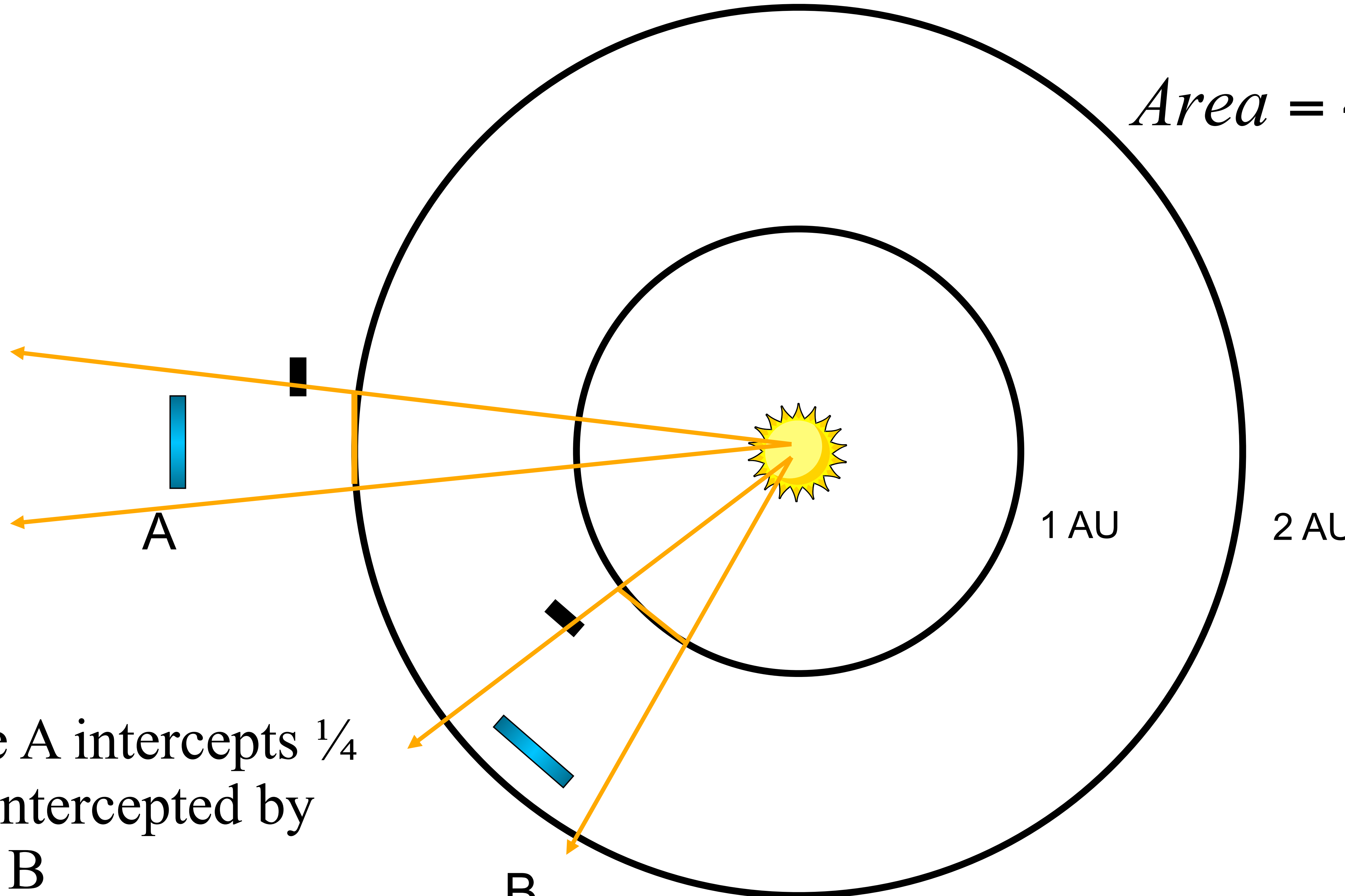


Telescope A intercepts ¼ the light intercepted by telescope B

Flux vs Luminosity

Apparent brightness: "flux":

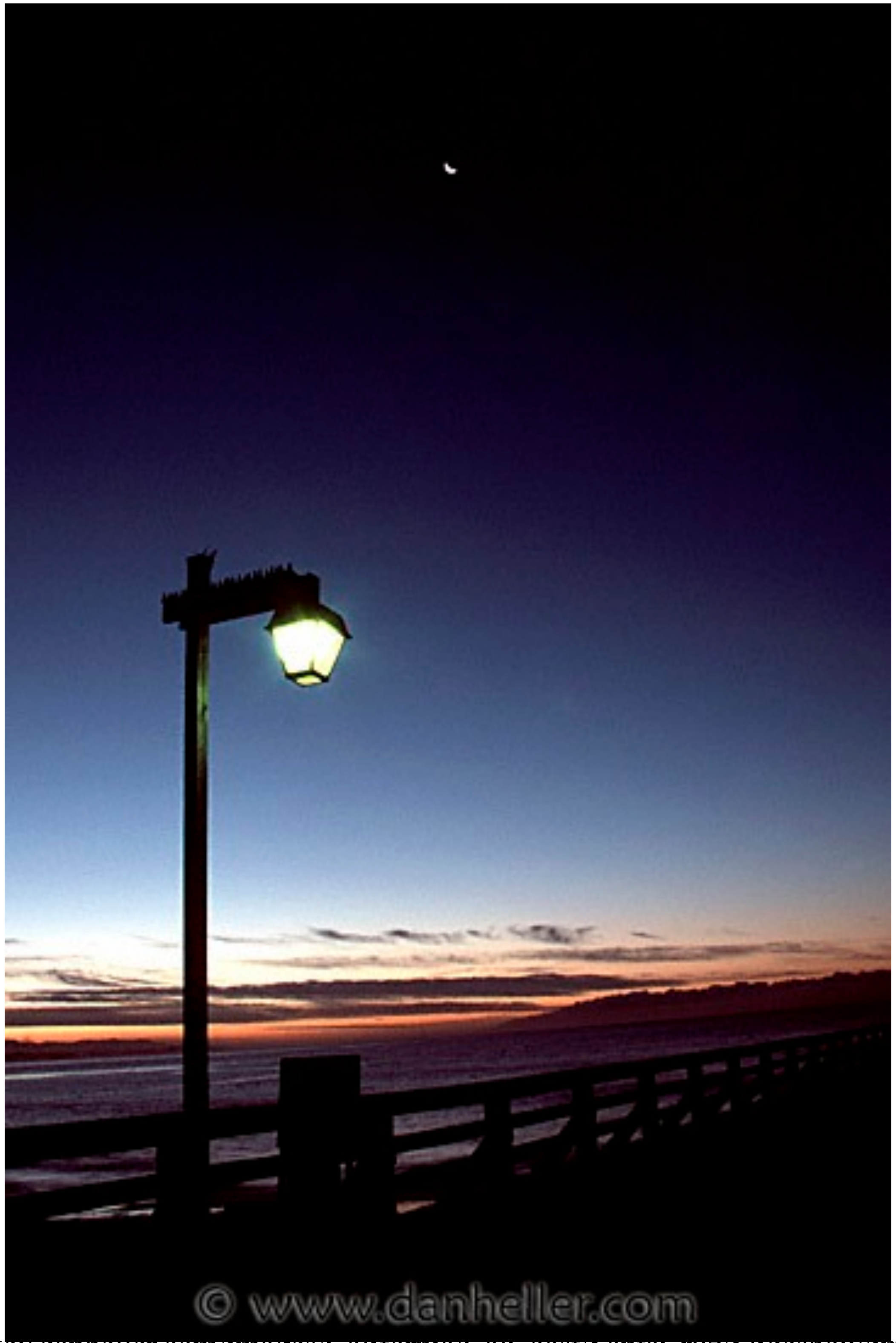
- amount of energy flow (power) through a collecting area (you eyeball, a telescope, ...)

  Flux = Power/Area

- bigger collector: more flux
- depends on observer's distance from source!
- more distant object: less energy falls detector, less flux

In picture at right:

- lamp nearby, bigger flux
- moon distant, bigger lum.



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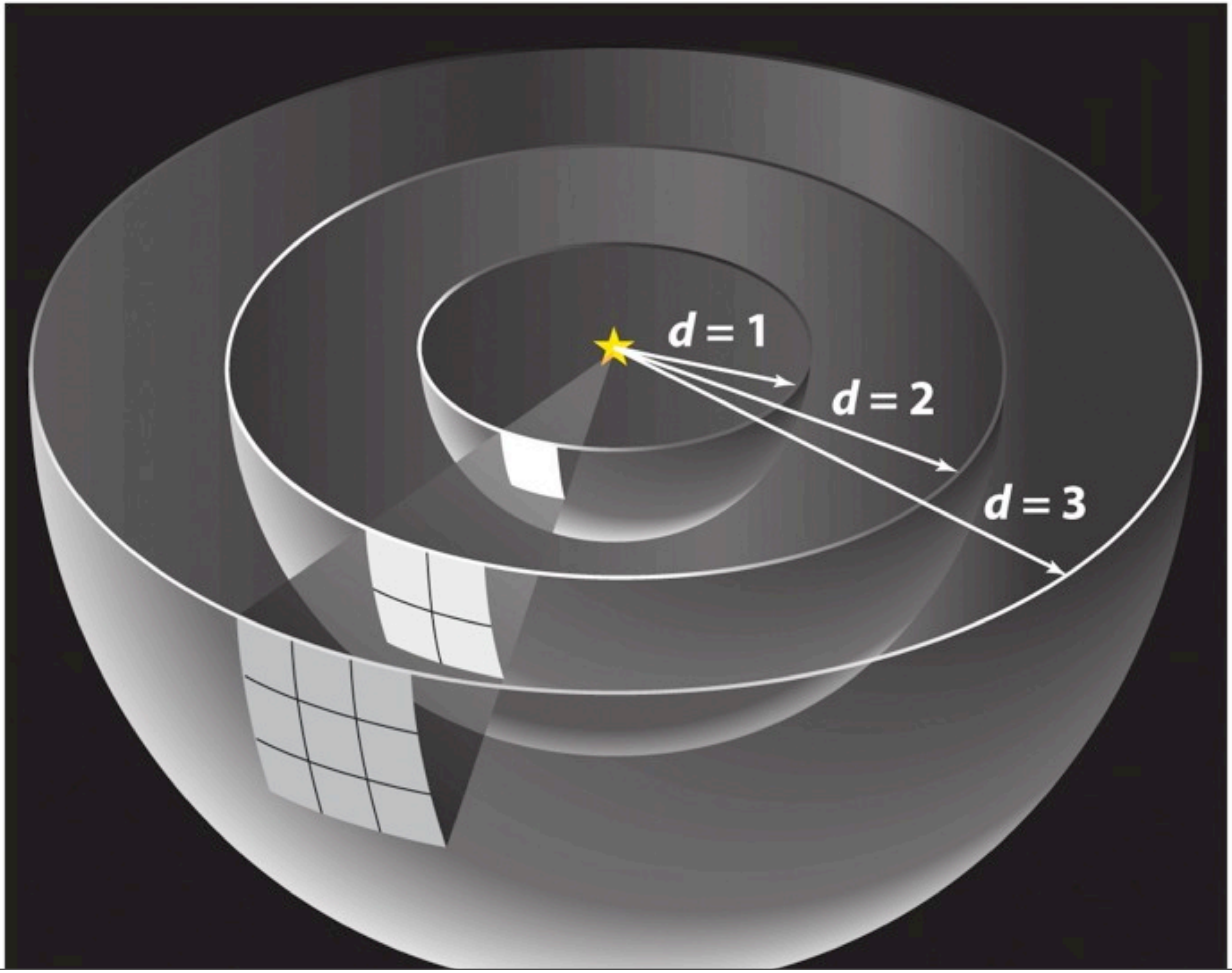
Same amount of energy coming from star, but at larger distances, spread over more area.



Flux vs Luminosity: The Connection

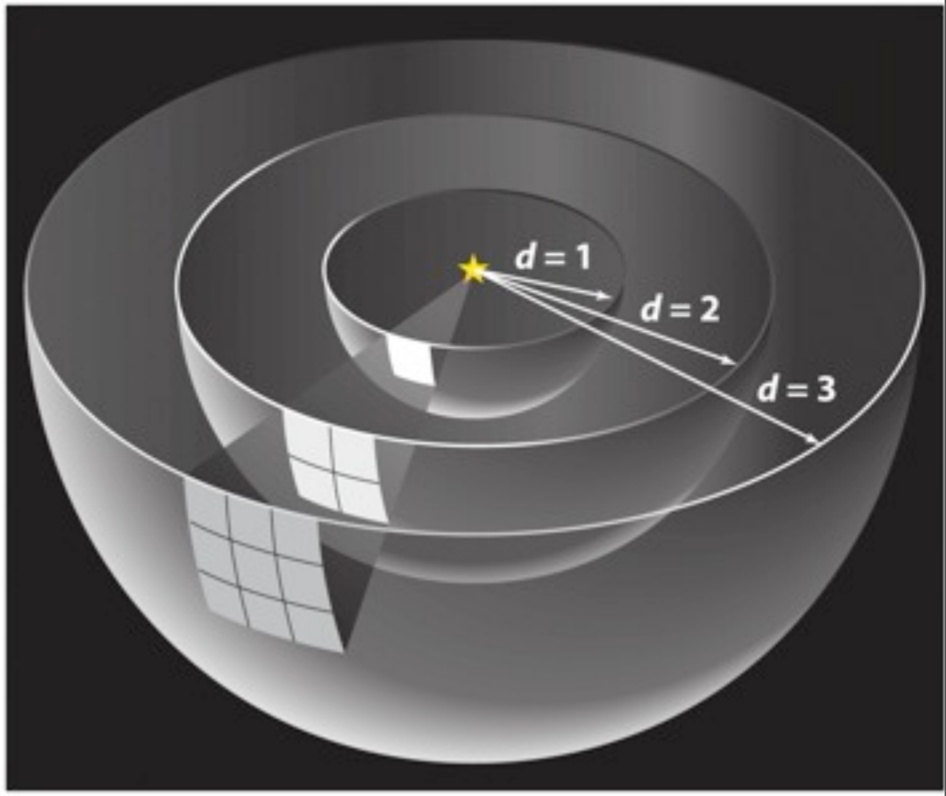
consider spherical star:

- light power output is luminosity L

when observing at distance (radius) R

- light spread over area $A = 4\pi R^2$
- so observable flux is

$$F = \frac{\text{Power}}{\text{Area}} = \frac{L}{4\pi R^2}$$



crucial facts:

- another inverse square law!
- observed F depends on L but also on R

Want to know star's L = "wattage",

- but actually measure F
- to solve $L = 4\pi R^2 F$ need distance R

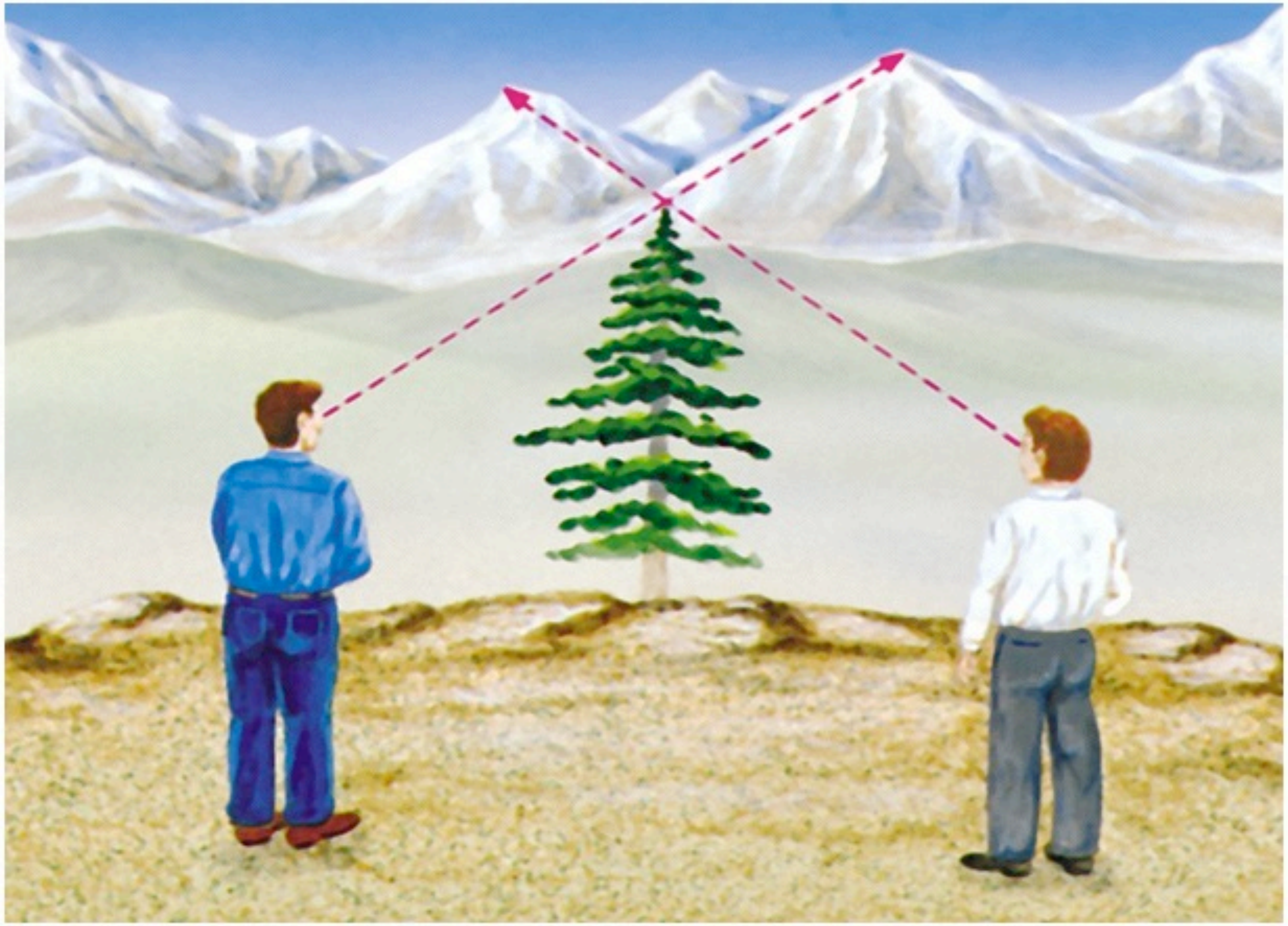
Must find a way to get distances to stars!

Distance

- We know that the stars must be very far away.
  - They don't move much as we orbit the Sun.
- But measuring the distance is a hard problem.
- We've only had the technology to do it for the last 200 yrs.

Parallax

How do astronomers measures distances to nearby stars?



How to Measure Parallax

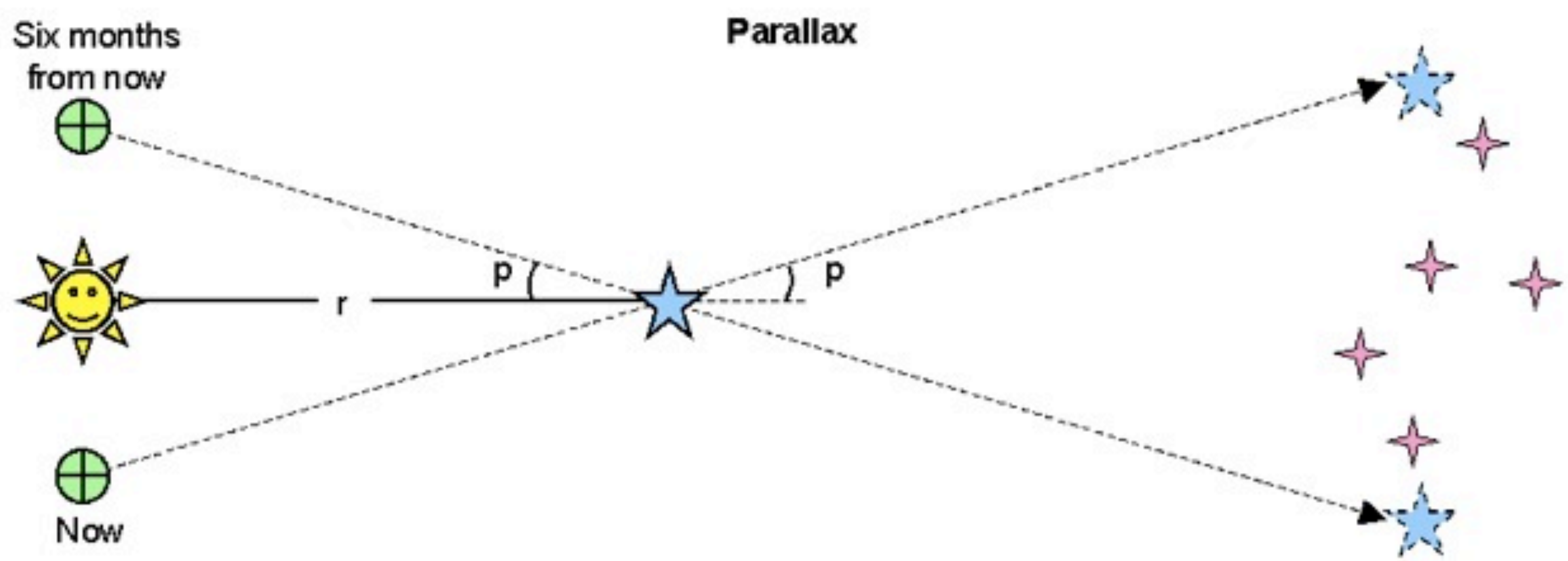
Look at a star compared to background stars.

Wait 6 months and look again.

How much, if any, has the star moved?

The amount moved is called parallax.

Experiment: thumbs-up



iClicker Poll: Parallax

Star A is closer than star B

The parallax p_B of the more distant star B will be

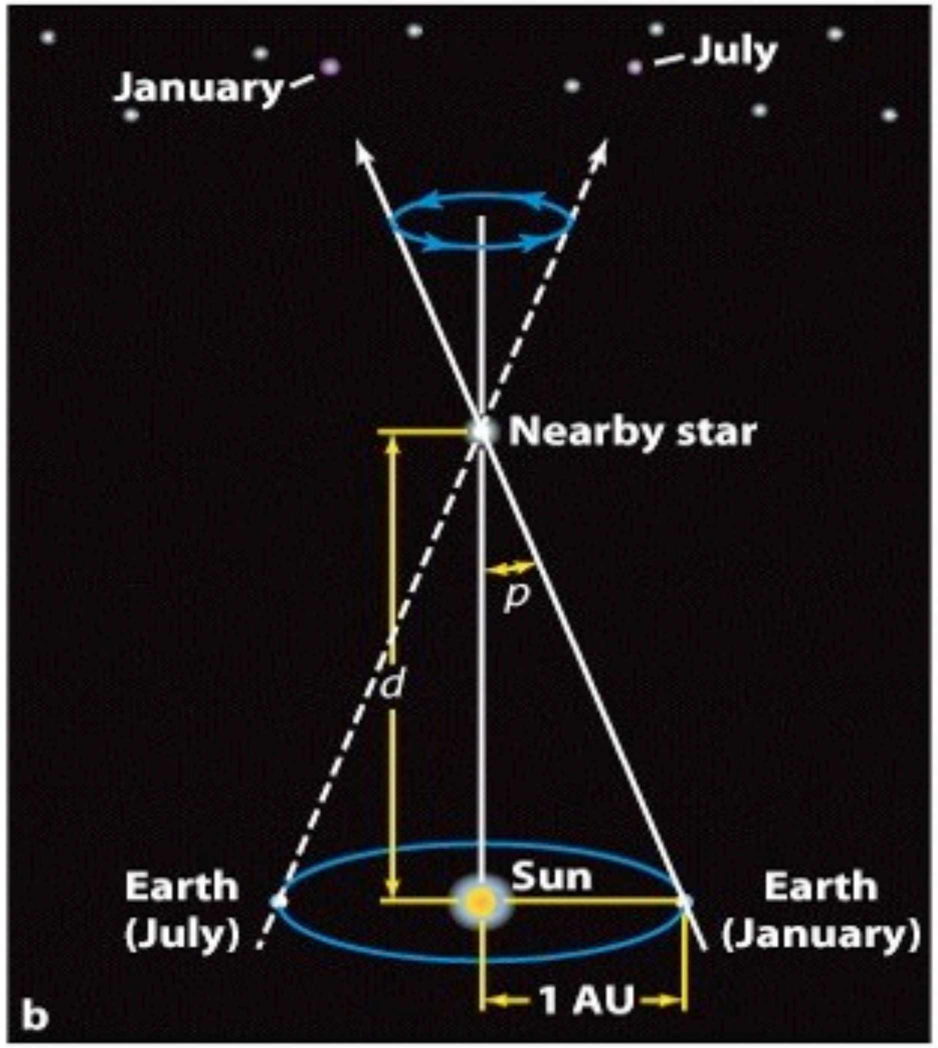
A. larger than p_A = bigger shift on sky for B

B. smaller than p_A = smaller shift on sky for B

C. the same as p_A: same Earth orbit = same shift

Hint: in thumb's up experiment, can adjust thumb distance!

Distances to Stars: Parallax



Earth orbit around Sun

- changing viewpoint on stars
- nearby stars appear to shift relative to distant stars

from parallax angle p

- can find distance! $d = 1\ \mathrm{AU}/\tan p$
- but shift very small: p is a tiny angle!
- always $p < 1$ arc sec
- where $1\ \mathrm{arcsec} = \frac{1}{60}\ \mathrm{arcmin} = \frac{1}{3600}\mathrm{degree}$

"skinny triangle" approximation $\tan p \approx p_{\mathrm{radians}}$

distance $$d = \frac{1\ \mathrm{AU}}{p_{\mathrm{radians}}} = \frac{200,000\ \mathrm{AU}}{p_{\mathrm{arcsec}}}$$

Space is Really Big!
Part II: Star Distances and Parsecs

from parallax p find distance

$$d(\text{in parsecs}) = \frac{1}{p(\text{in arcsec})}$$

new distance unit: parsec

1 parsec = 1 pc = 200, 000 AU

nearest star: alpha Centauri

d(α Cen) = 1.3 pc

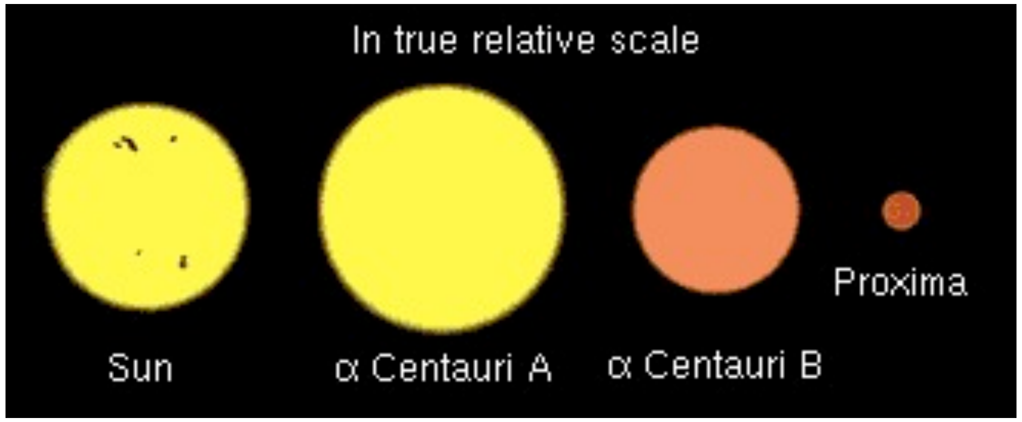
1 pc is typical distance between neighboring stars in a galaxy

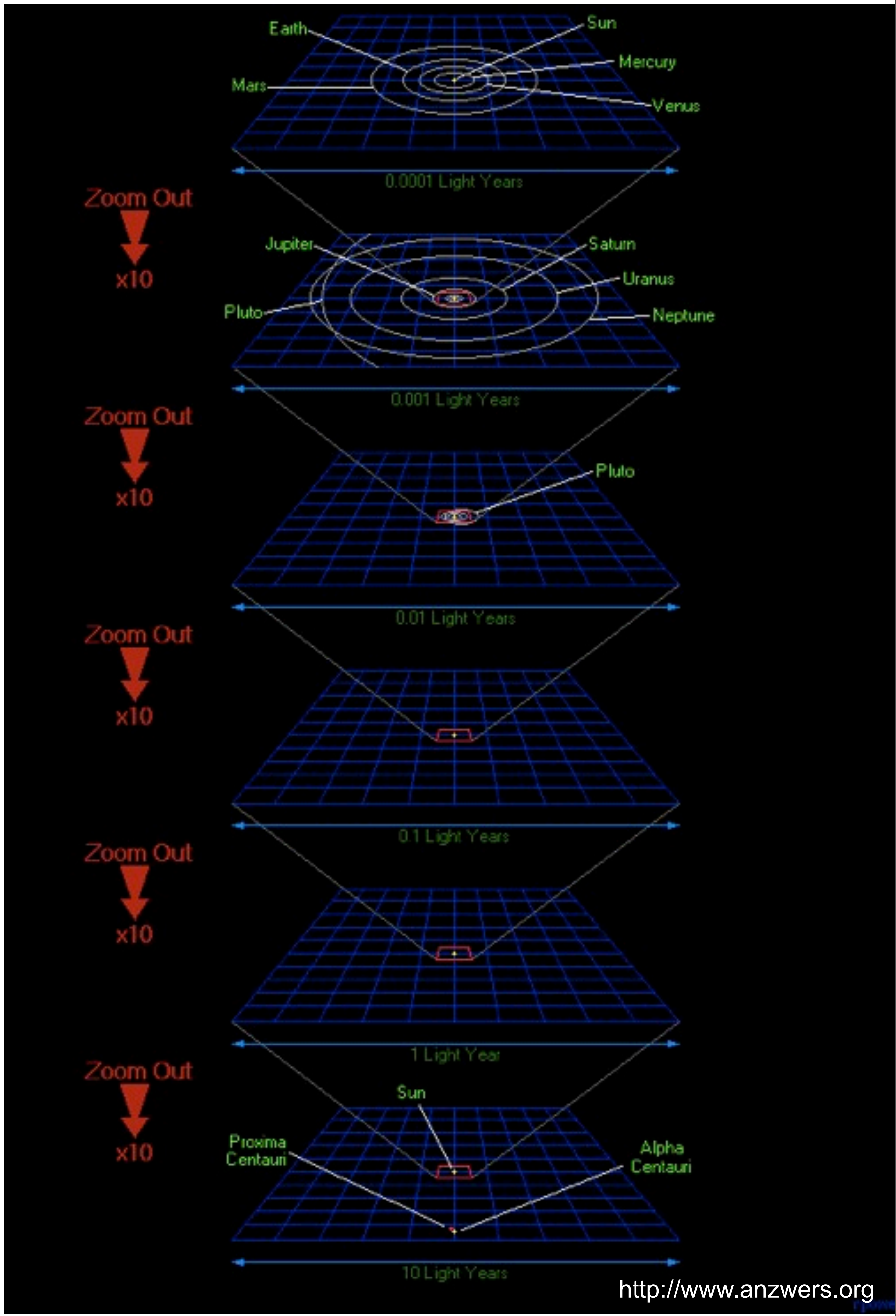
light takes 3 years to travel 1 pc!

1 pc = 3 light years (lyr)

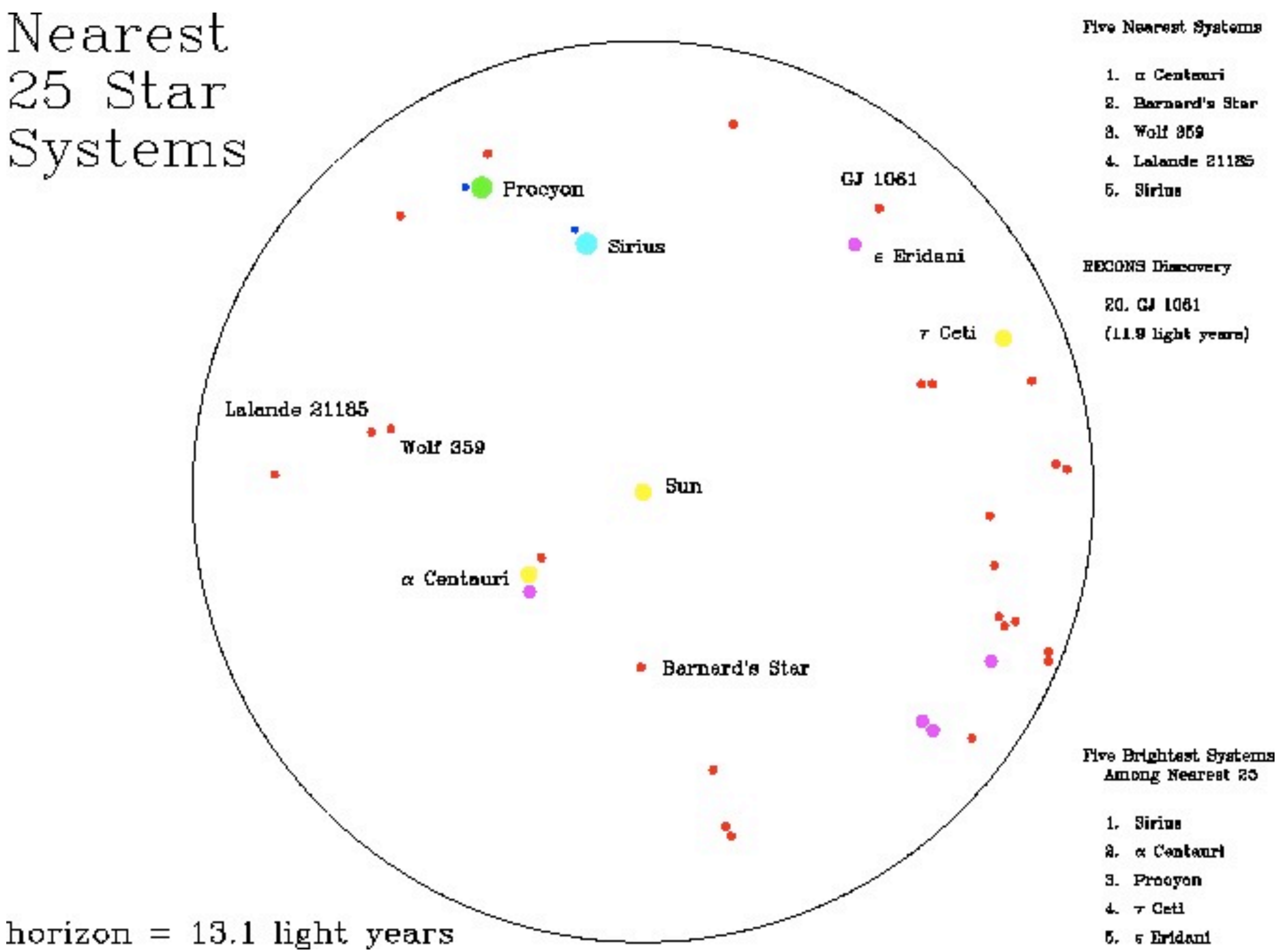
Leaving Home

- Nearest star is 4 x 10^{13} km away
  - Called Proxima Centauri
- Around 1.3 pc = 4 light years
- More than 5000 times the distance to Pluto
- Walking time: 1 billion years
- Fastest space probes: Voyagers 1 & 2, Pioneers 10 & 11) – 60,000 years at about 3.6 AU/year (38000 mi/hr)



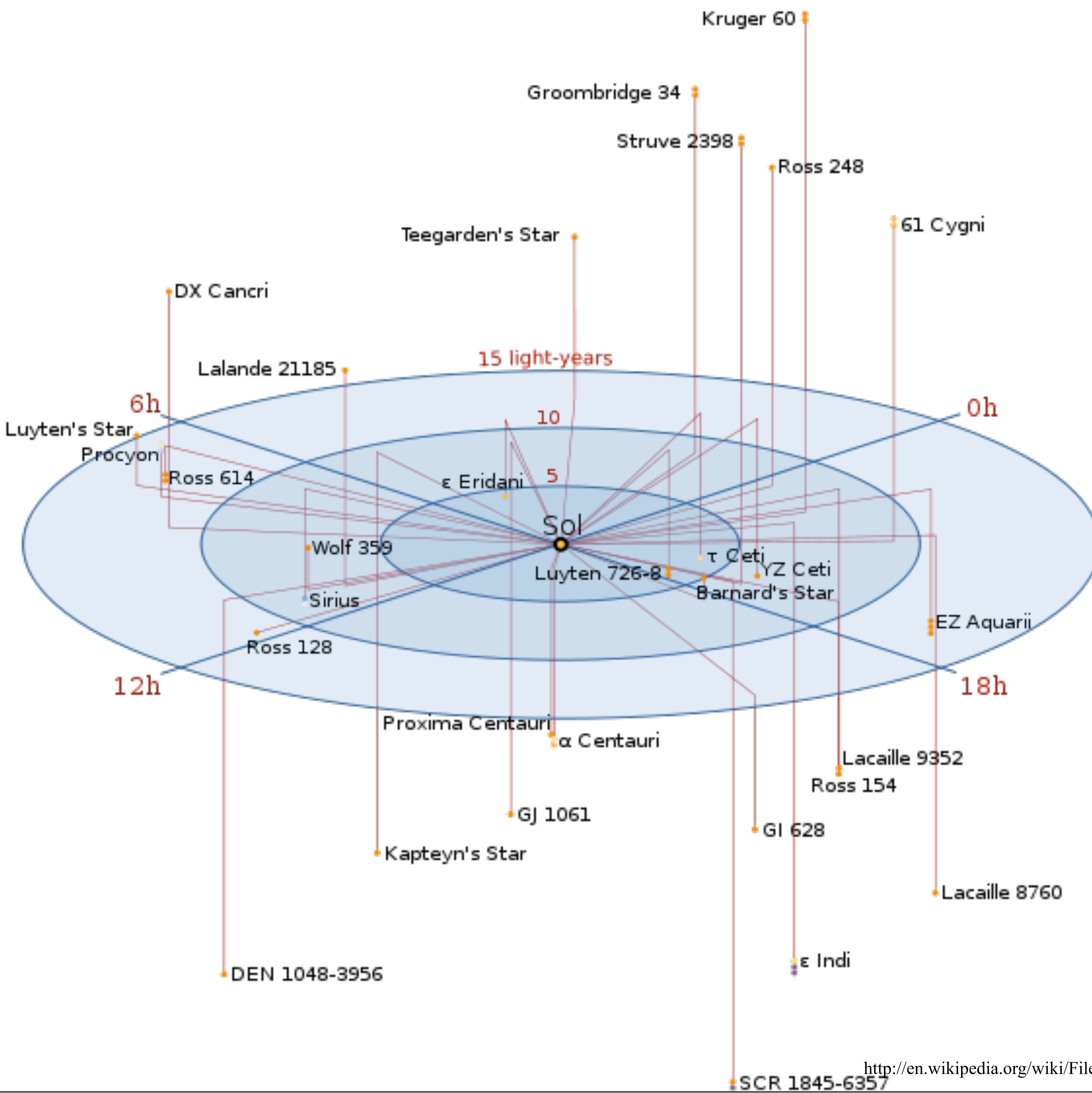


Our Nearest Neighbors



http://antwrp.gsfc.nasa.gov/apod/ap010318.html

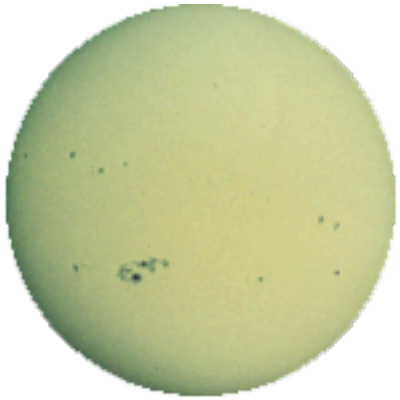
Our Nearest Neighbors: 15



http://en.wikipedia.org/wiki/File:Nearby_Stars_(14ly_Radius).svg

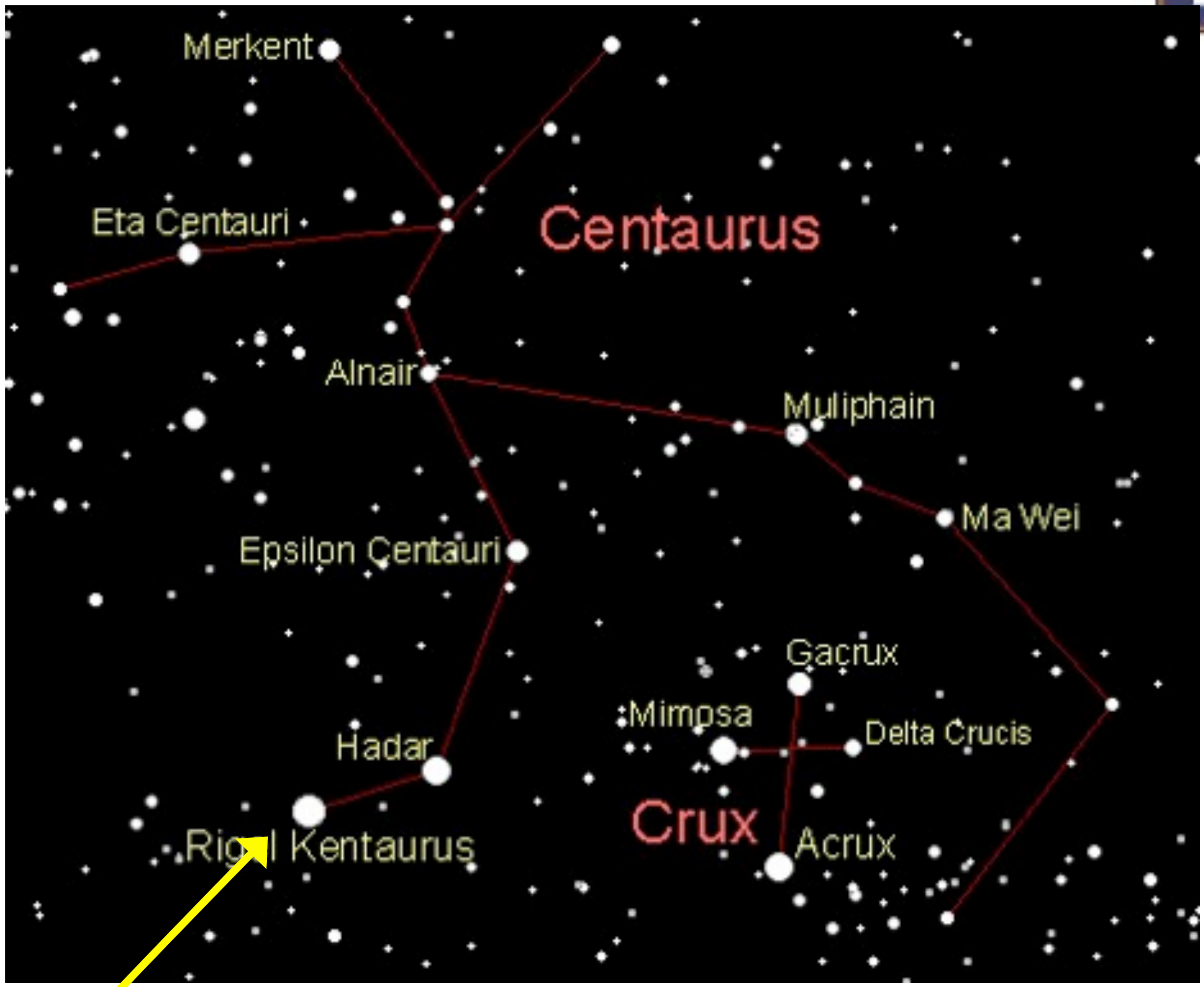
Distances to the Stars

Sun's disk seen
from Earth



1/2 degree = 1800 arcsec

Dime at arm's length



Closest star to Earth:
Proxima Centauri
(part of α Centauri system)
Parallax: 0.77 arcseconds
Distance: 1.3 pc = 4.2 ly
like a dime 2 km away

Parallax Peril

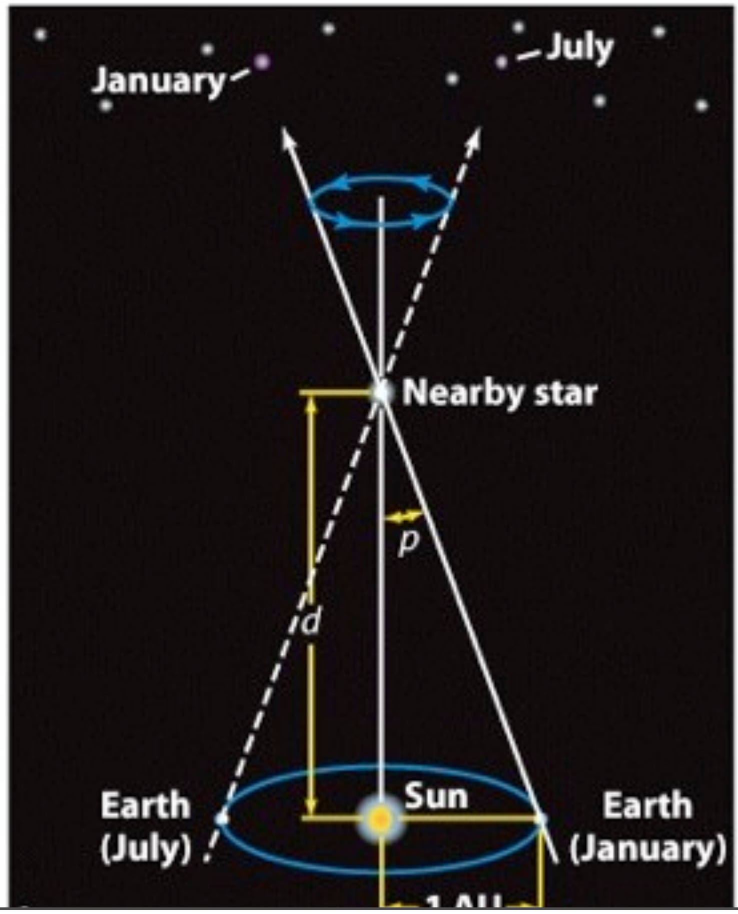
Drawback:

- parallax measurable only for nearest stars
- Angular shift becomes tiny when star very far away

Parallax immeasurable when star is beyond few 100's of lyrs

And Galaxy is 100,000 lyr across, Universe is 14 billion lyr

What to do? ... stay tuned...



A Census of Stars:
L and T

We can find the luminosity (wattage) and temperature of stars.

- luminosity: must measure both flux and distance
- temperature: must look at spectrum, find peak wavelength

Can then ask: are L and T the same for all stars?

- if so, what does this tell us?
- if not, are there patterns?

How does the Sun compare to other star?

Graph: "Hertzsprung-Russell Diagram" = HR diagram

- plot L vs T
- each star is one dot on graph

How will plot look

- if all stars have same L, same T?
- if range of T, but only one L for each T?
- if range of T, but any L possible for any T?

iClicker Poll:
A Census of Stars

Vote your conscience!

For real stars, plot L vs T (HR diagram)

What will be the pattern?

A. one single point: all stars have same L, same T as Sun!

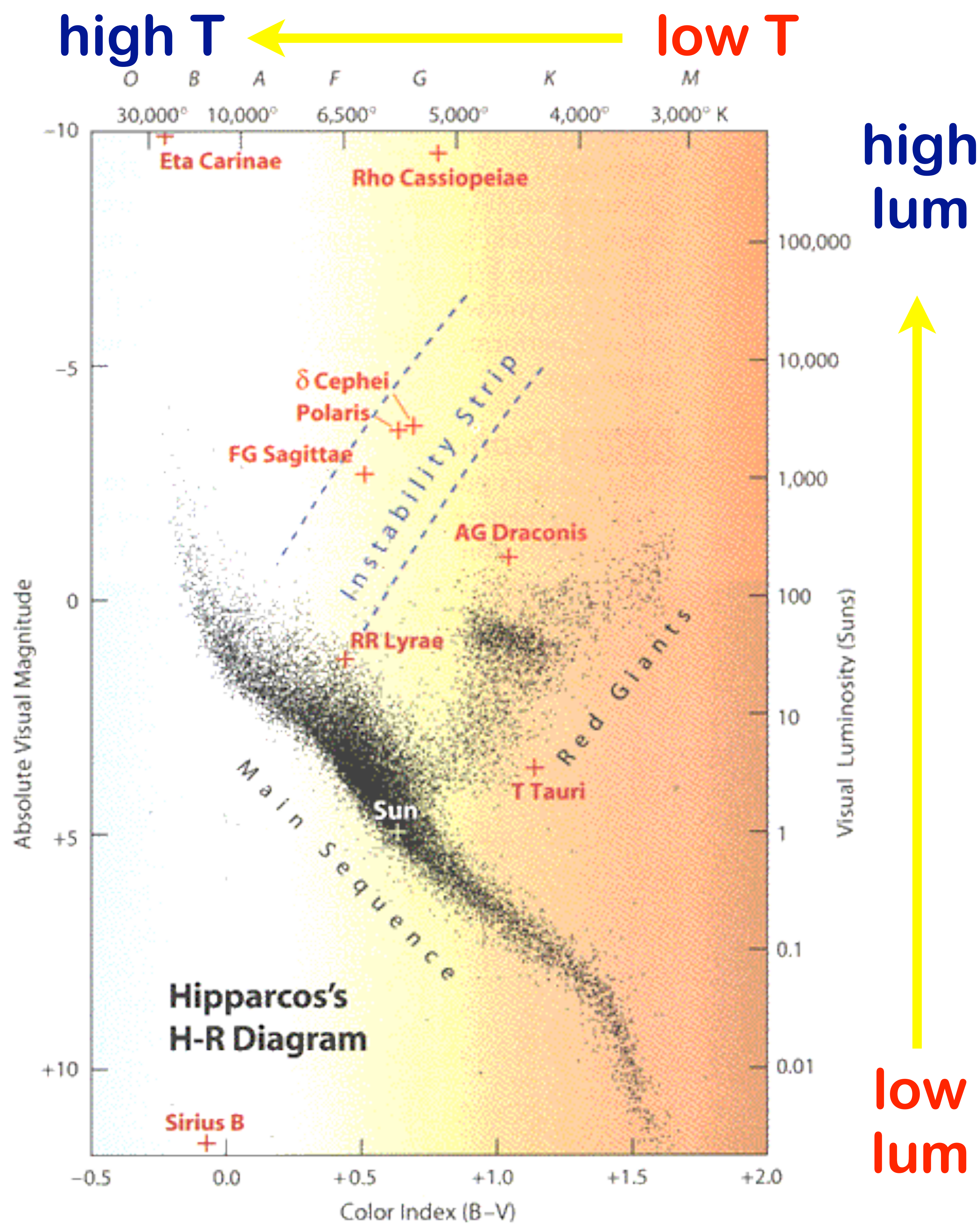
B. a line or curve: a range of T, but one single L for each T

C. a random spread of points: any L possible for any T

D. none of the above

A Census of Stars: The Real Data

HR diagram plots L vs T



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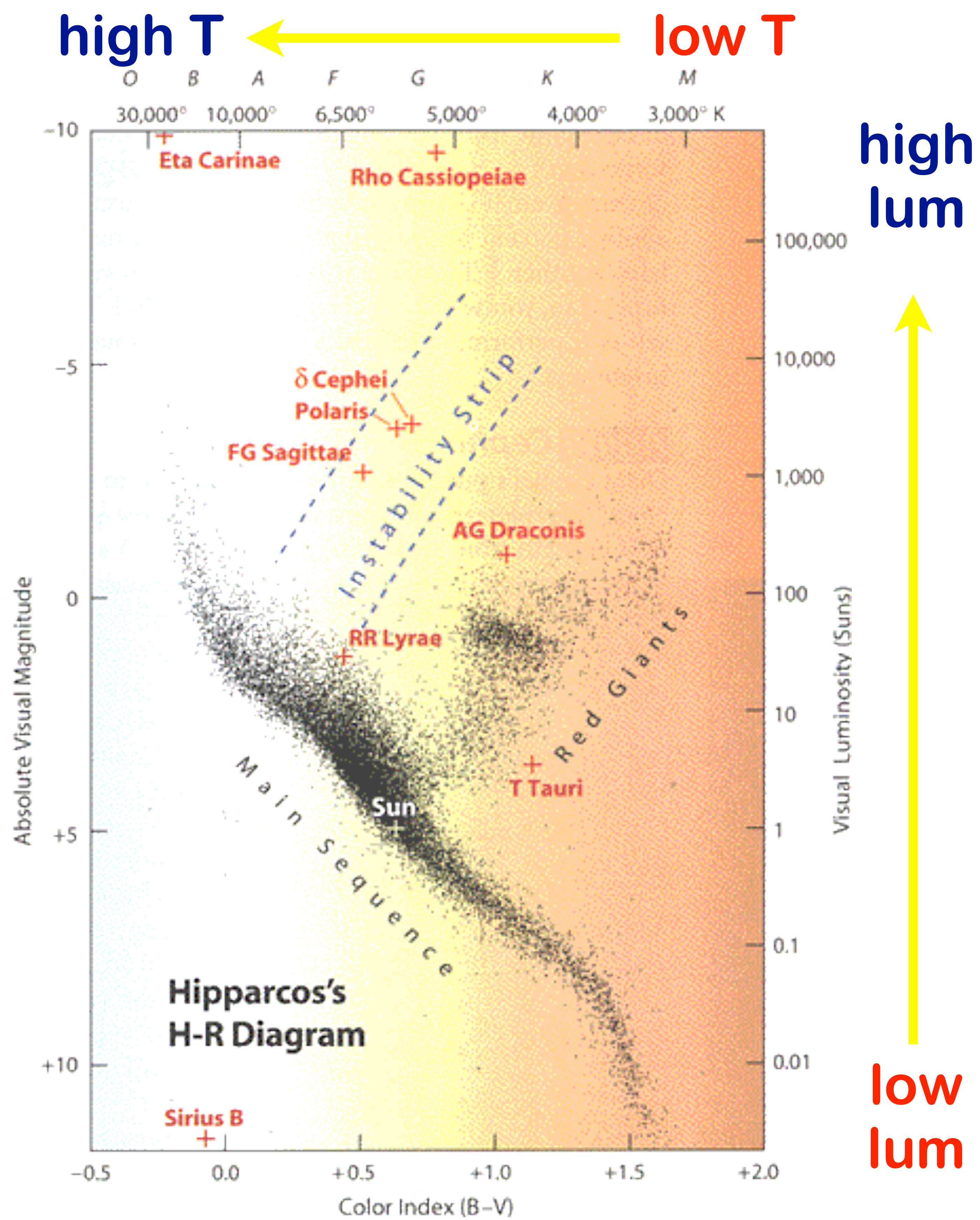
HR diagram plots L vs T

Note: T plotted backwards!
Hot at left, cool at right! Sorry!



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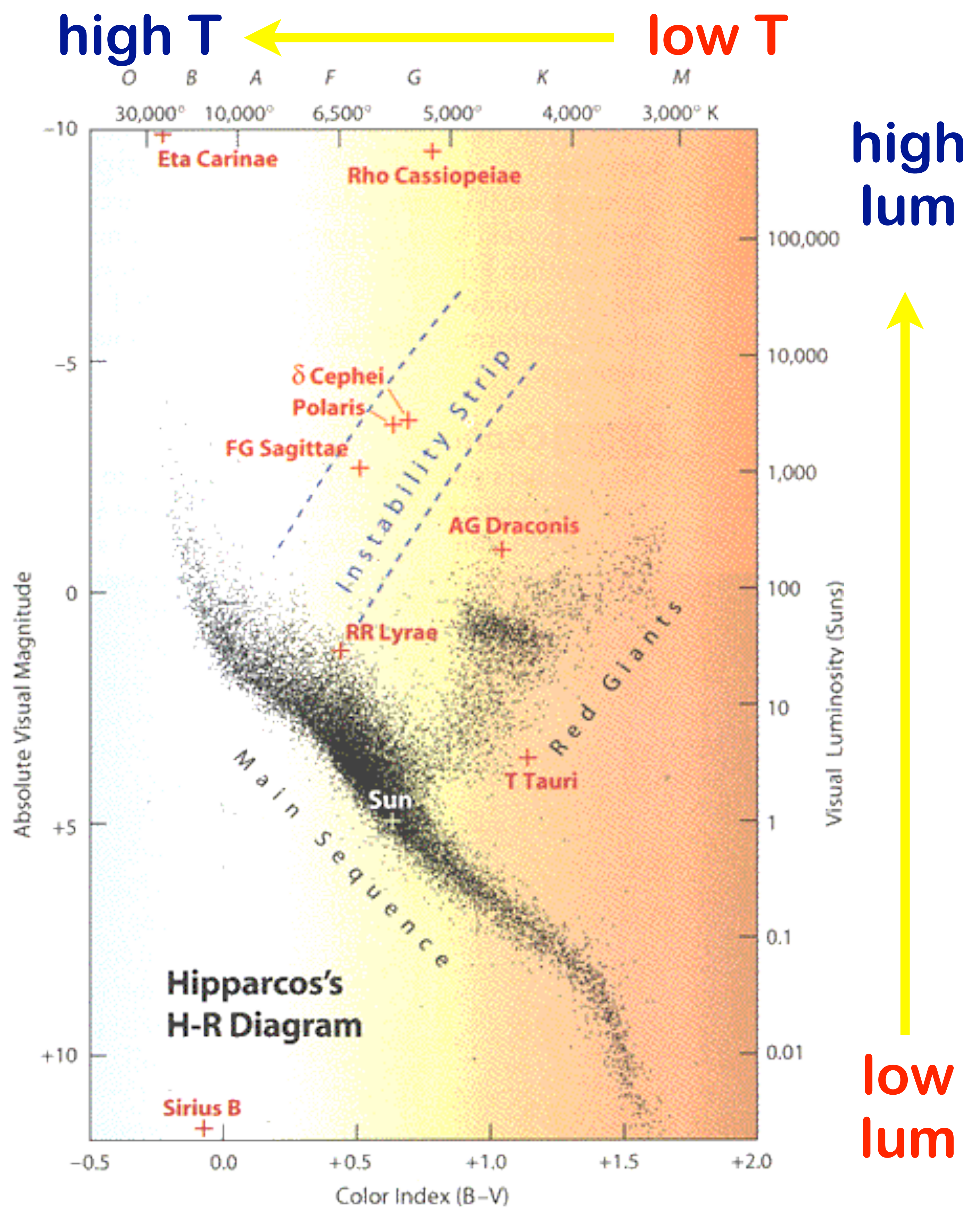
- huge range in L: from 100,000L_{sun} to 0.01 L_{sun}



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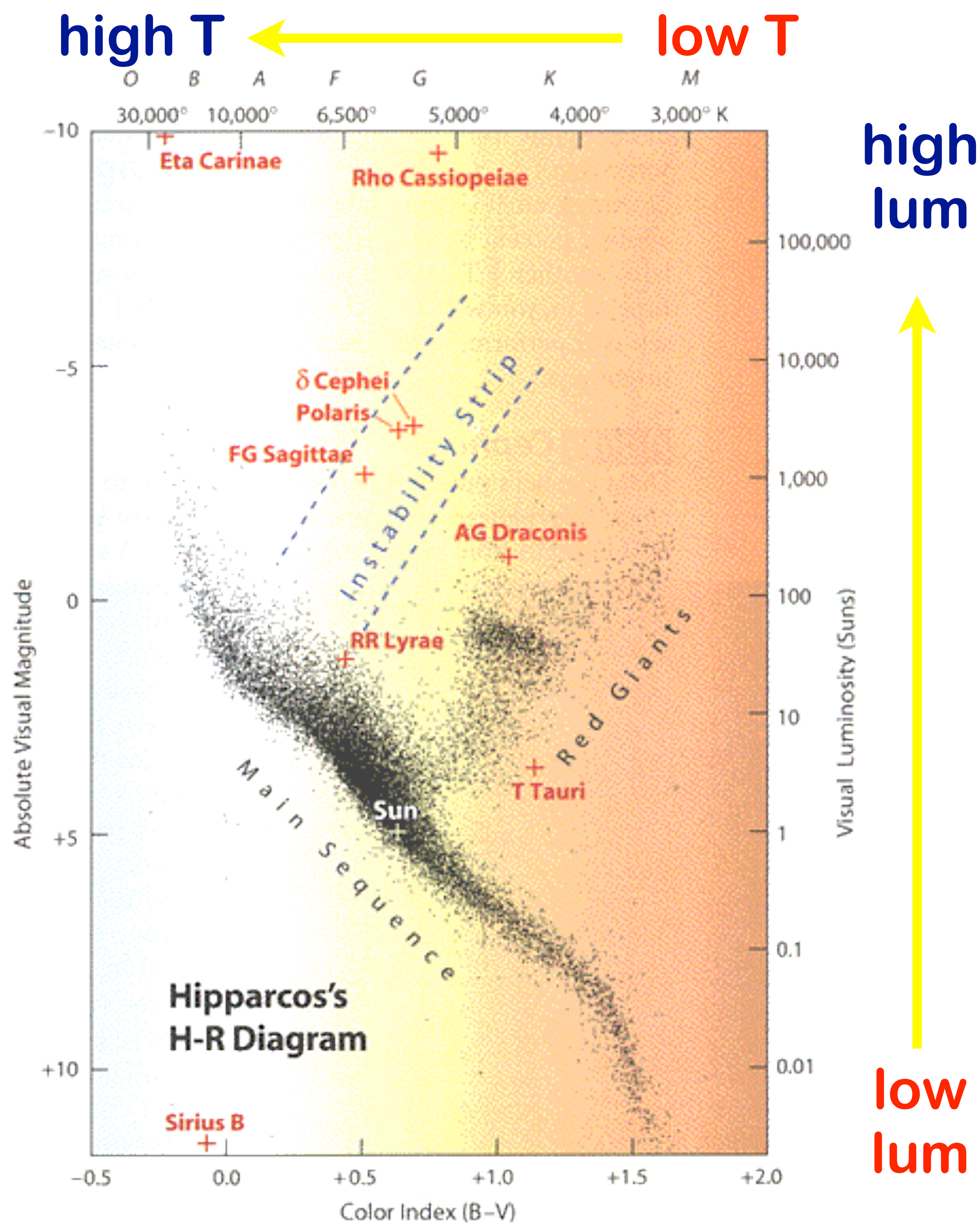
- large range in T, from 3000K to 30,000 K



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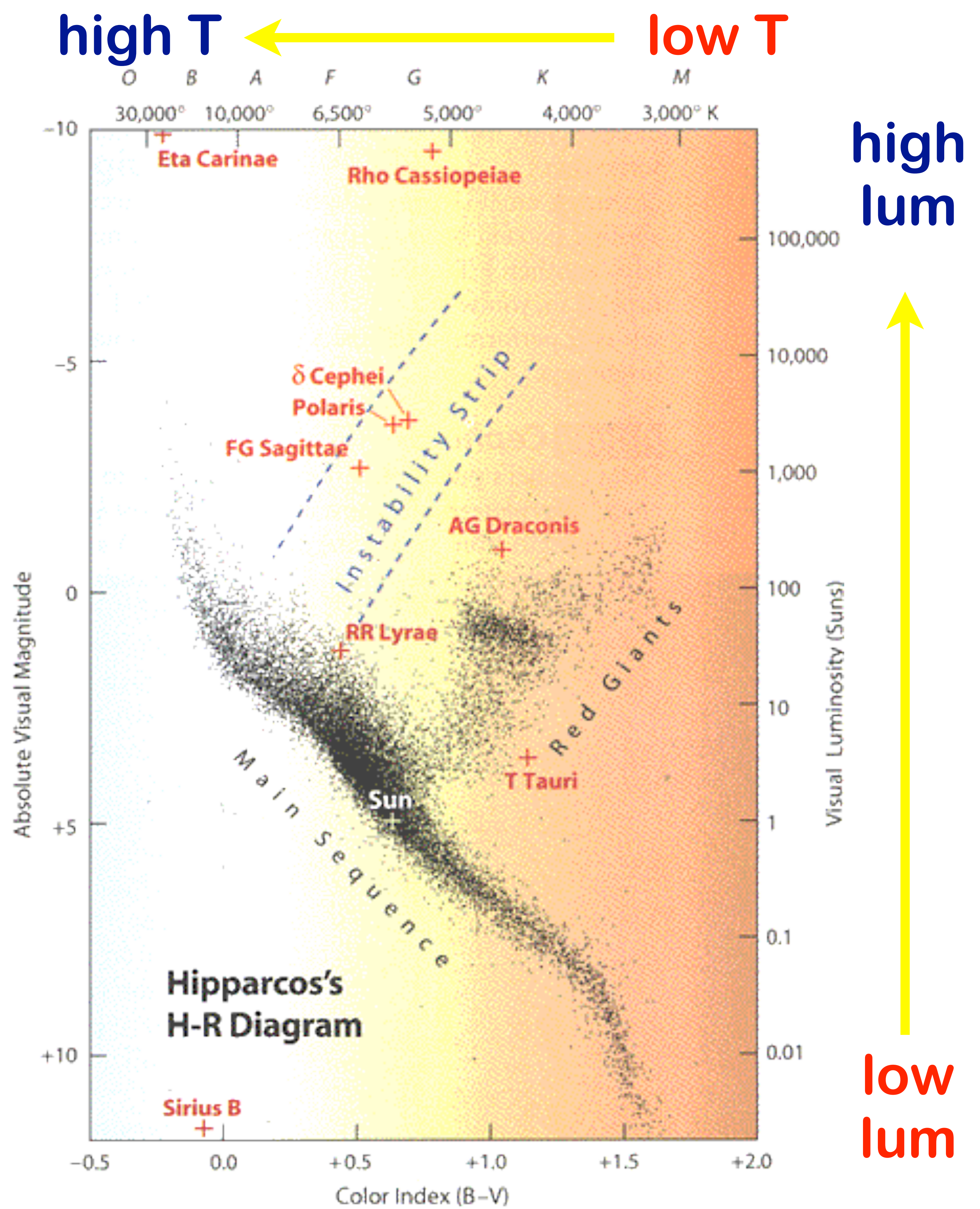
- Sun is in the middle of graph: Sun has typical L and T, not highest or lowest



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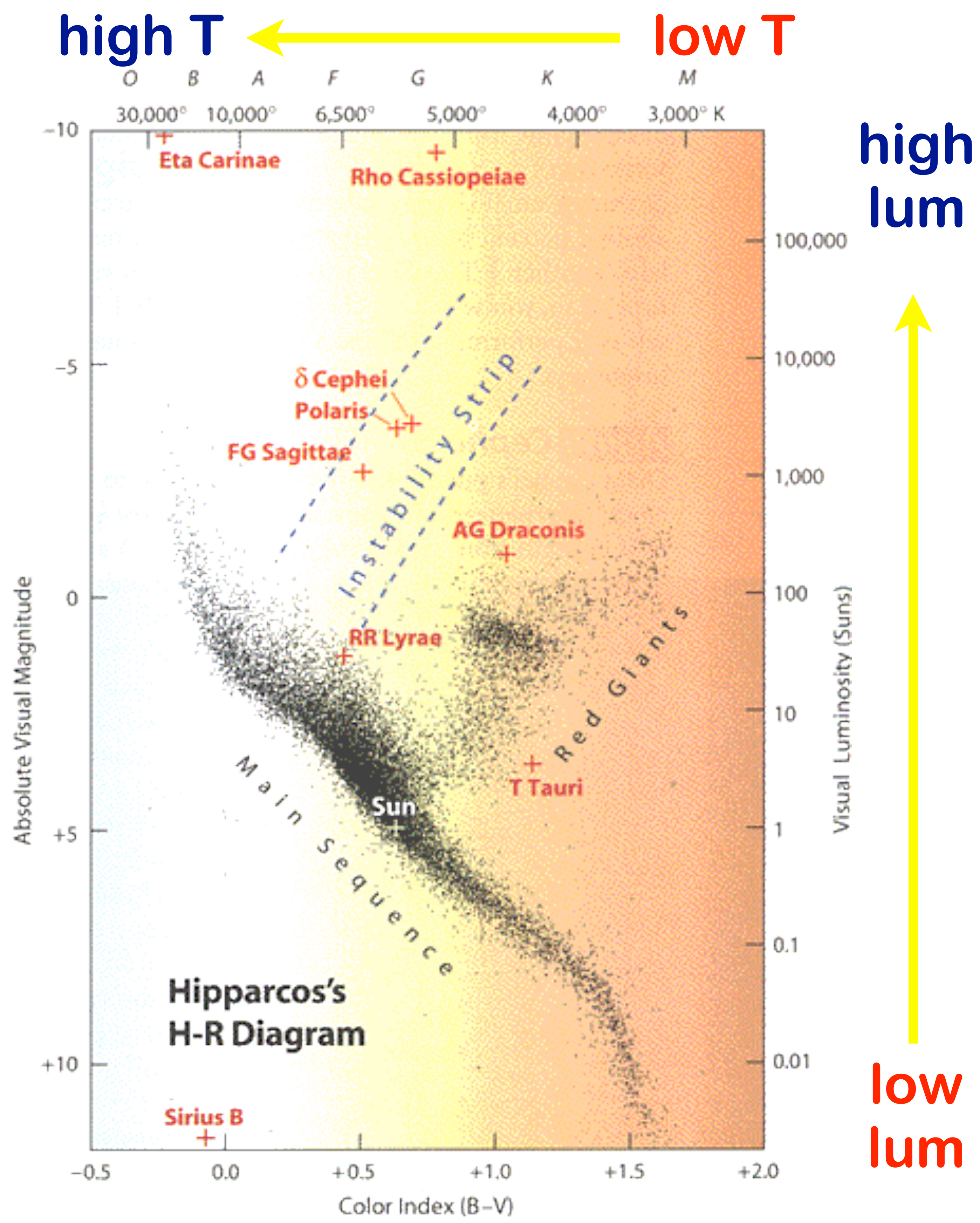
- points not randomly scattered: there are patterns



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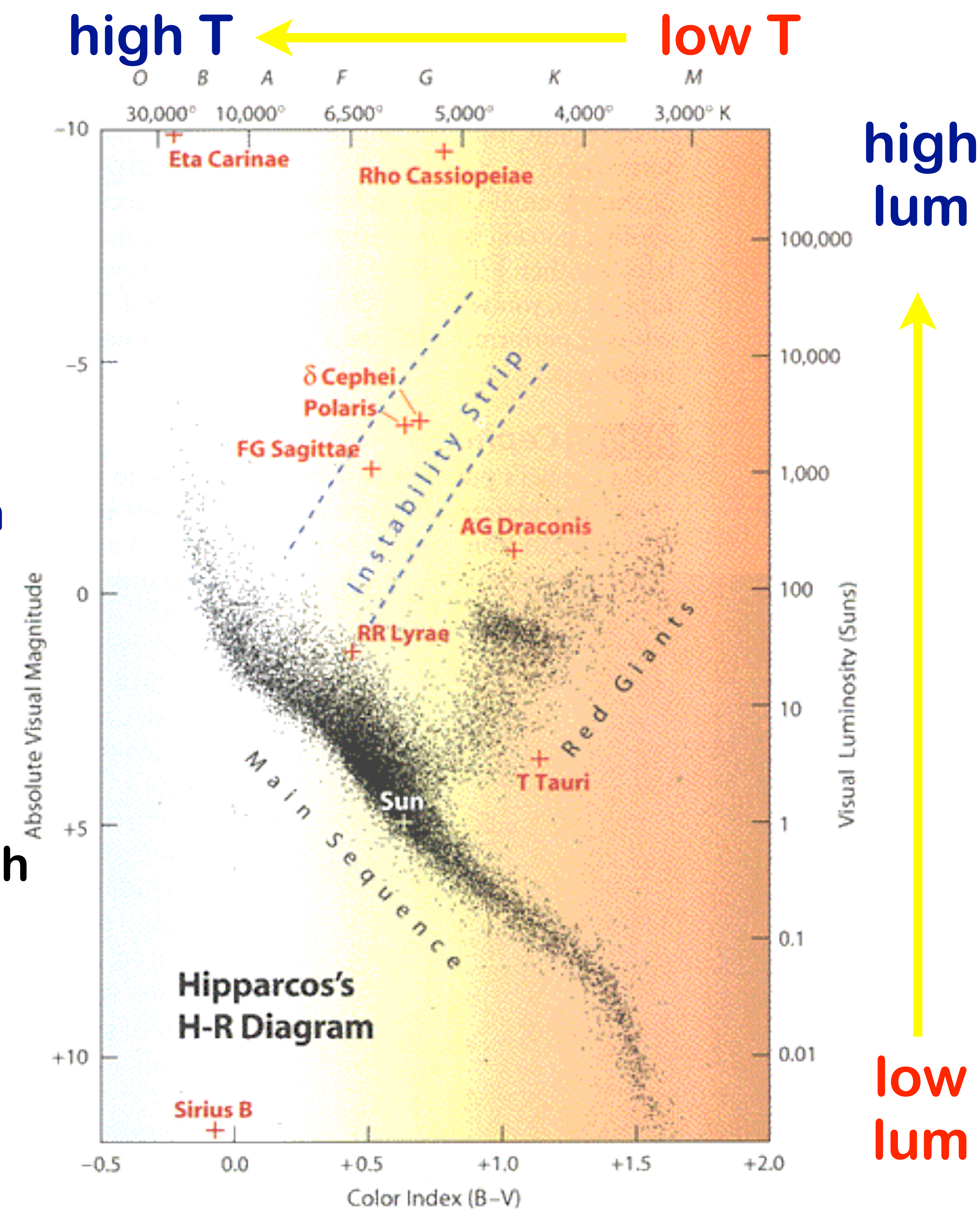
- **large range in T**, from 3000K to 30,000 K
- Sun is in the middle of graph: **Sun has typical L and T**, not highest or lowest
- points not randomly scattered: there are **patterns**
- **most (90%) of stars fall on one curve: "main sequence"** -- for each T, one L



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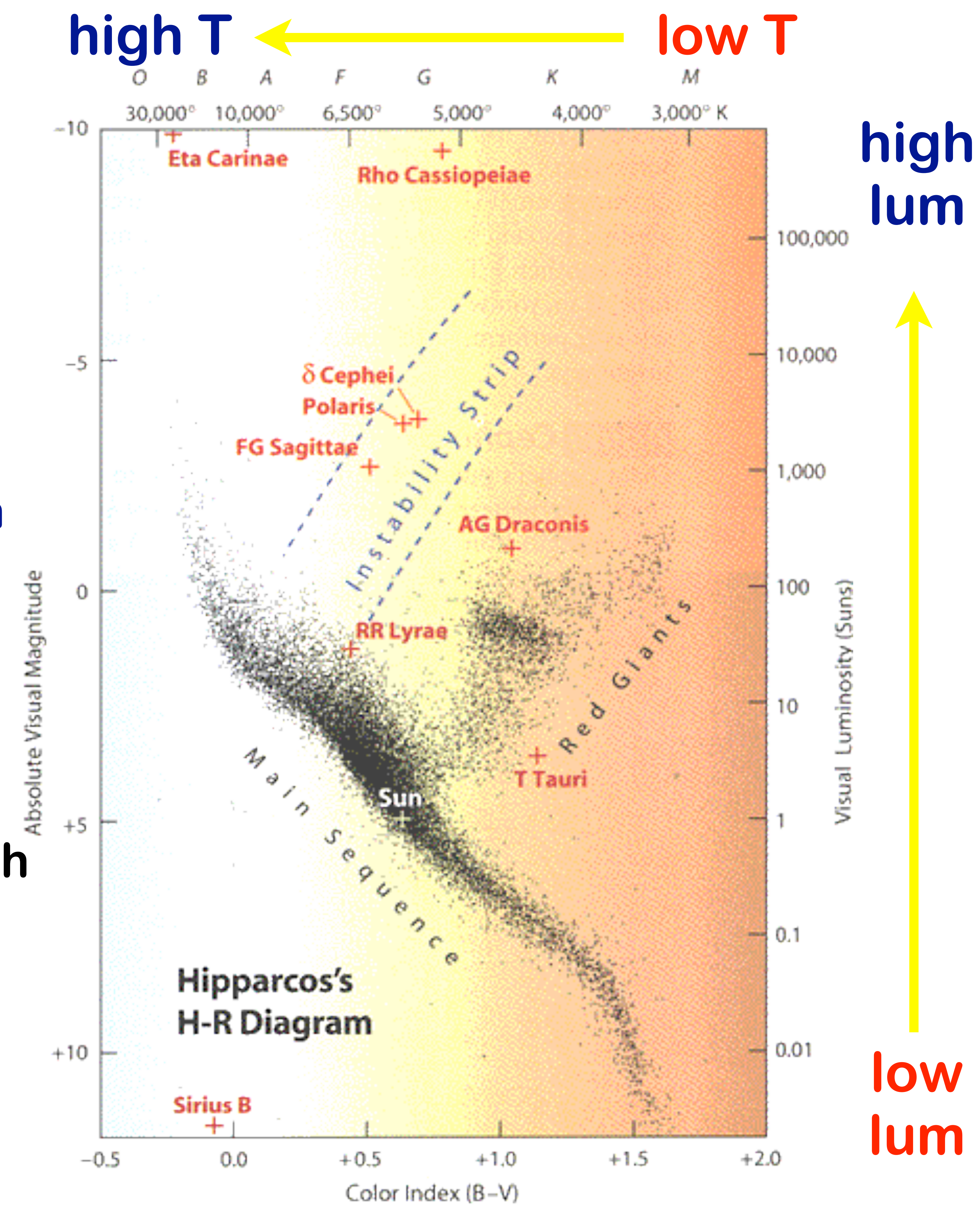

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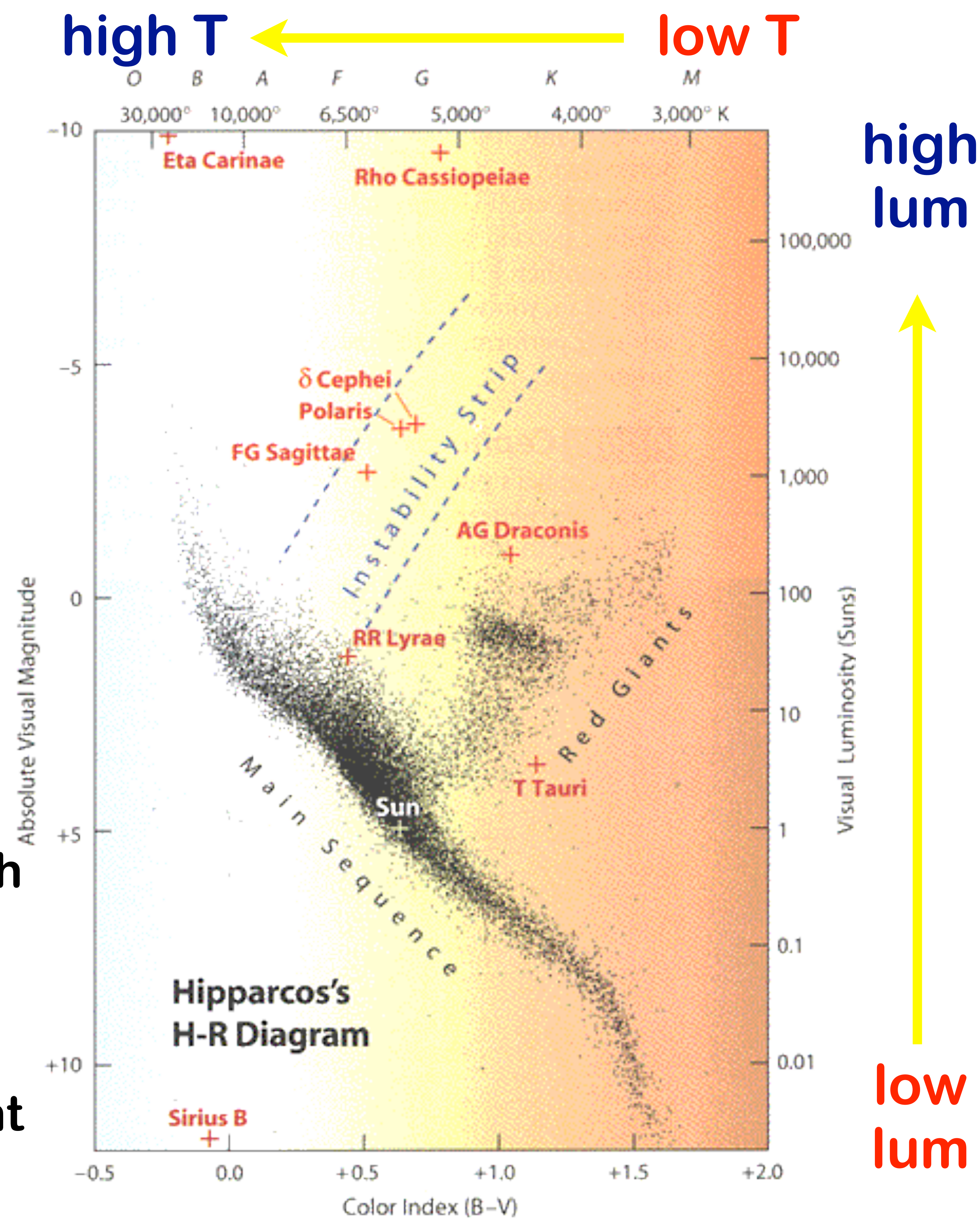
- most (90%) of stars fall on one curve: “main sequence” -- for each T, one L
- the Sun is a main sequence star -- we are in the 90%!
- Q: what makes stars have different L and T on main sequence?



Star Masses

Mass is difficult to measure for single, isolated stars

But: most stars are not single!

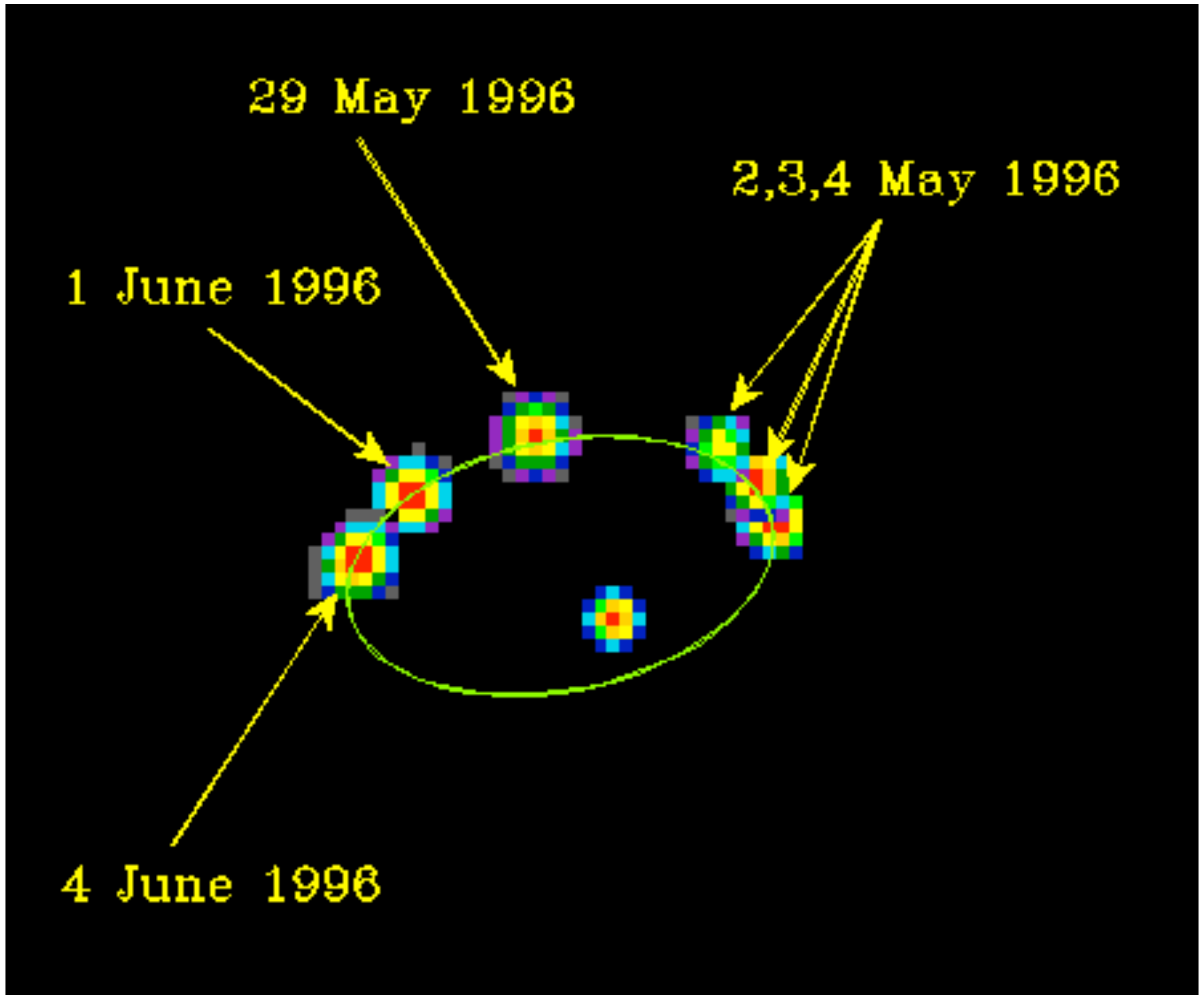
- most stars bound together by gravity into groups of multiple stars
- most common: binary = 2 stars in bound orbits
- systems exist with 3 or more stars!

In binary: can watch the orbits!

- measure period P
- and semi-major axis a

then use gravity laws:

- get masses for each star!



http://apod.nasa.gov/apod/ap970219.html

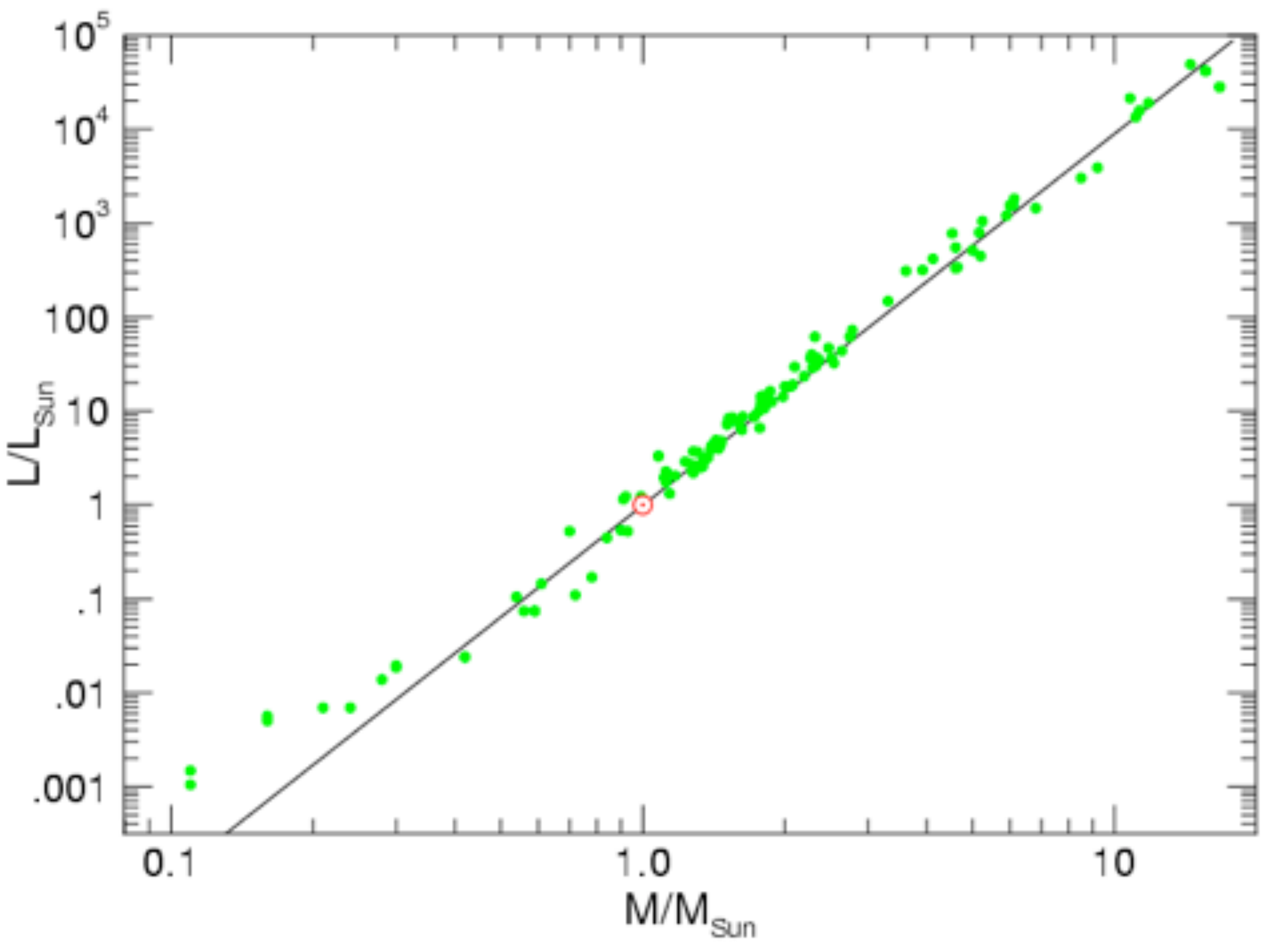
Mass-Luminosity Relationship for Main Sequence Stars

For main sequence stars:

- More massive stars are much more luminous
- Luminosity ~ $Mass^{3.5}$

This rule applies ONLY to main sequence stars

Non-main sequence stars do not follow this relationship

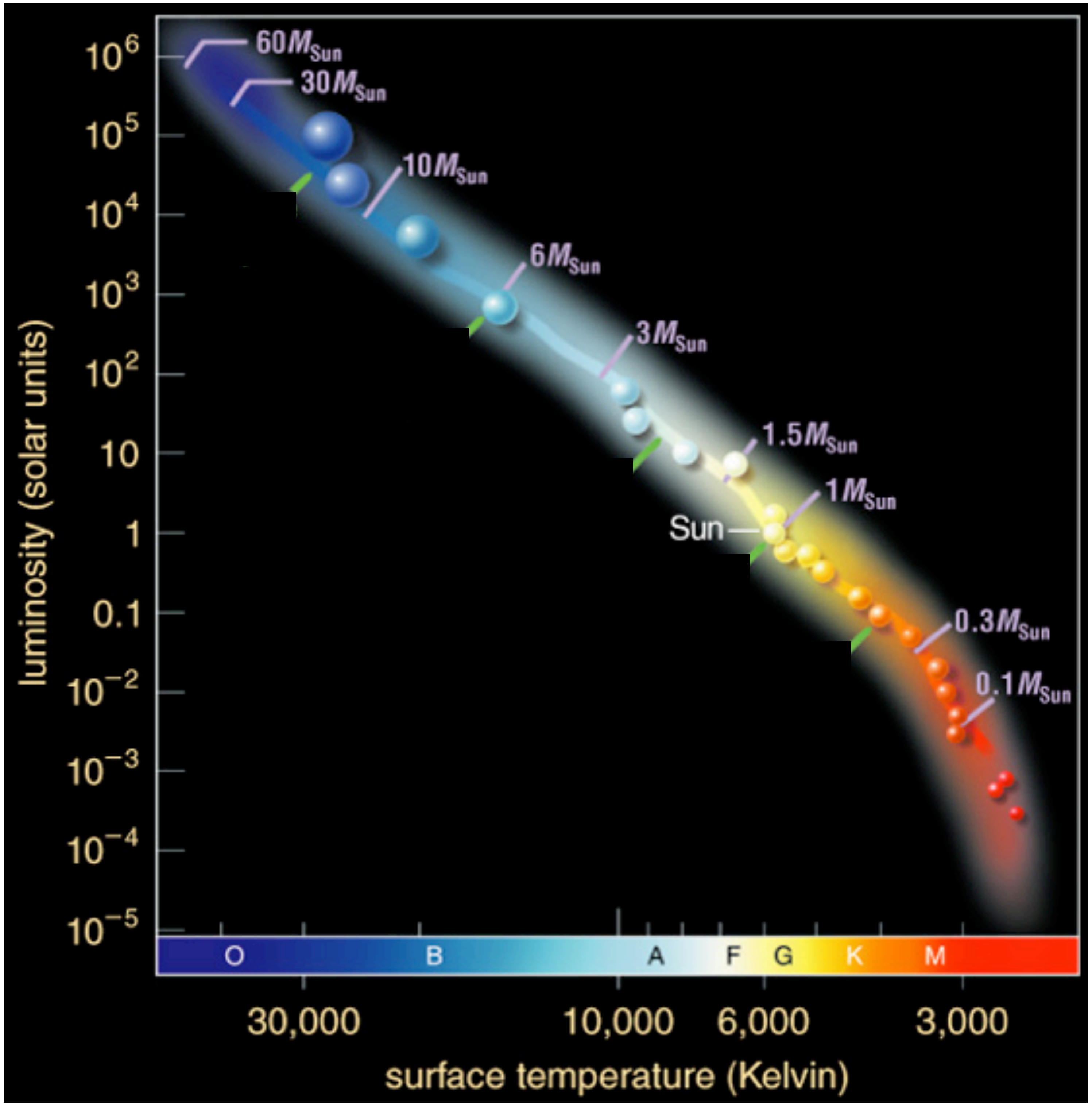


A star's mass is its most important property!

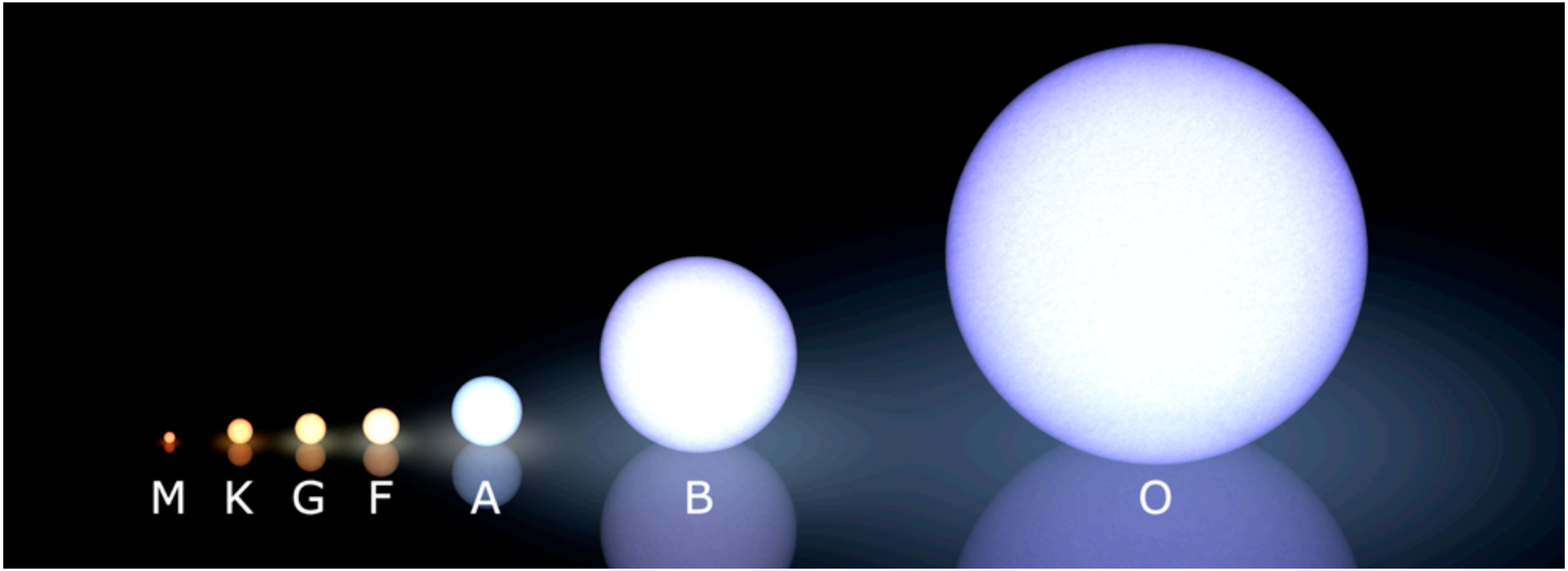
The main sequence is a sequence of different star masses!

More massive stars are hotter, brighter, and bluer

Less massive stars are cooler, dimmer, and redder



Sizes of Main Sequence Stars



This illustration shows the relative sizes and colors of main sequence stars, from smallest (Class M) to largest (Class O)

the Sun: class G

Lifespan

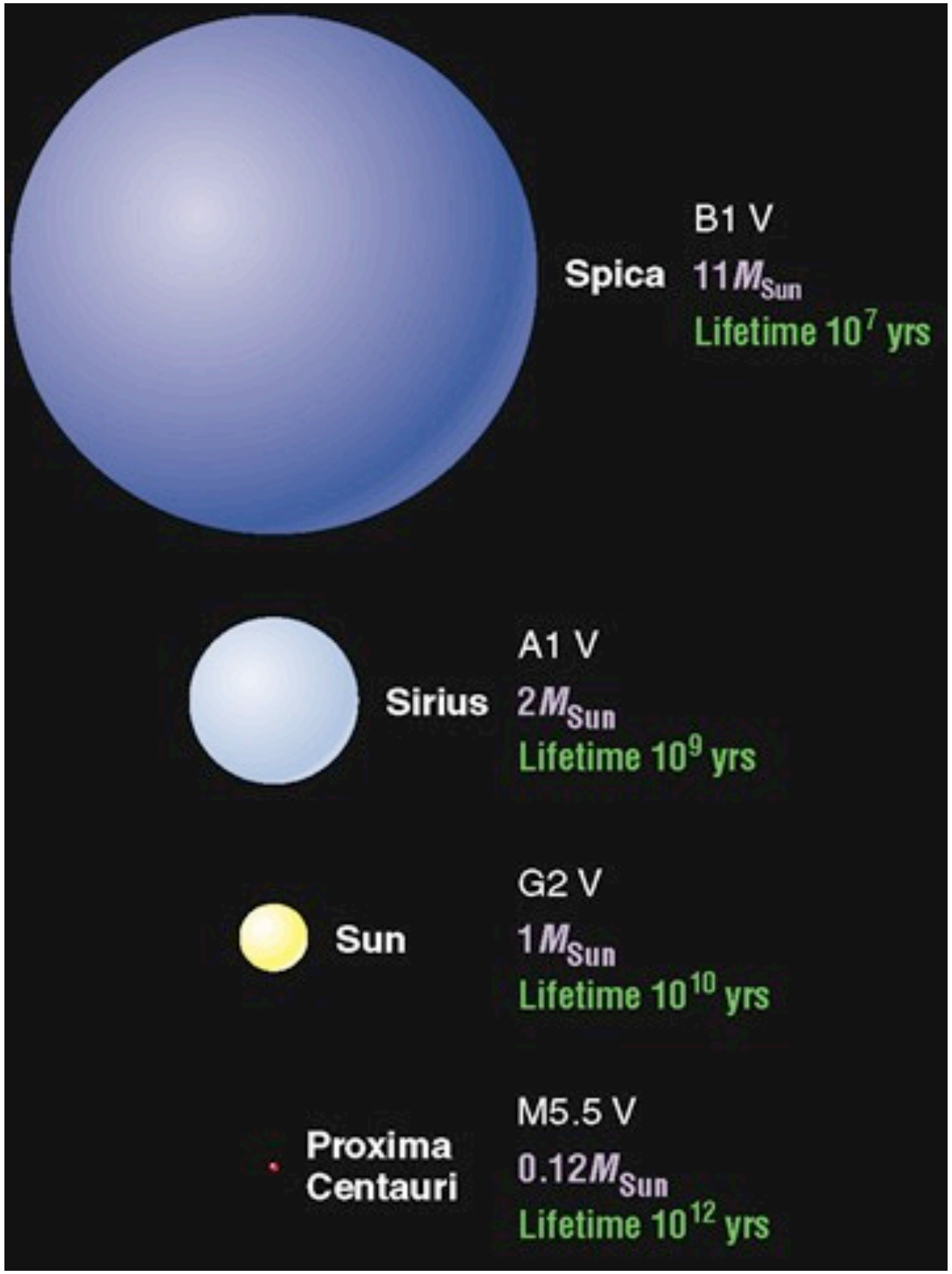
High mass star

- More hydrogen fuel
- But, much greater luminosity = "burn rate"
- Luminosity ~ Mass$^{3.5}$

High mass stars "burn" fuel much faster than low mass stars

Leads to short lives for high mass stars!

- 20 Msun: few million year lifespan
- 1 Msun: 10 billion year lifespan
- 0.1 Msun >100 billion year lifespan = longer than age of Universe



High mass stars = Hummers
Low mass stars = Priuses

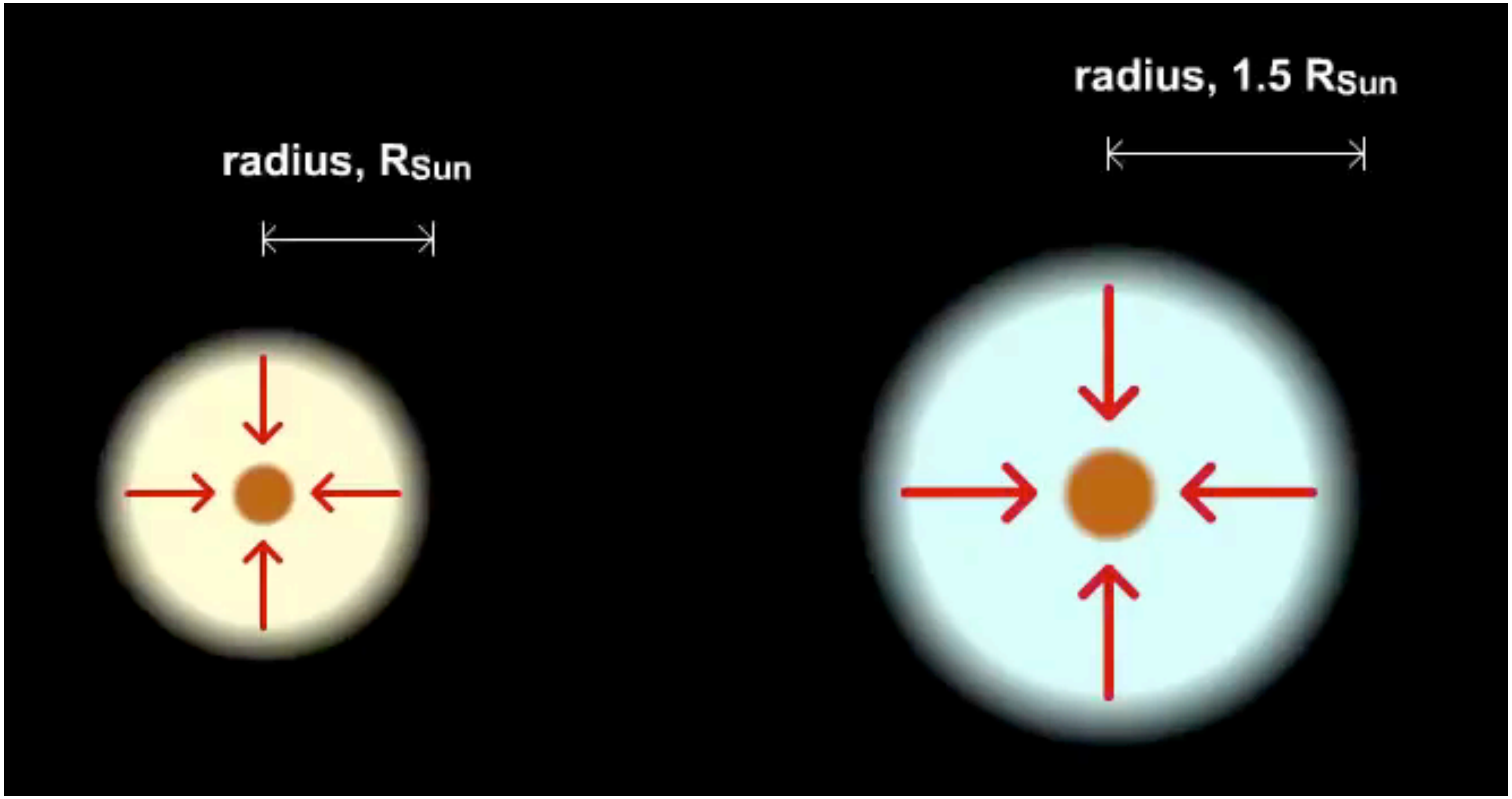
High-mass stars:
"gas guzzlers"

- High luminosity, large, blue
- Live short lives, millions of years

Low-mass stars:
"fuel efficient"

- Low luminosity, small, red
- Long-lived, hundreds of billions of years

What causes high-mass stars to live short lives?



Low Mass Star:
Lower Pressure
Lower Temperature
Slower Fusion
Lower Luminosity

High Mass Star:
Higher Pressure
Higher Temperature
Rapid Fusion
Higher Luminosity

Main Sequence: Properties Summarized

Main sequence is a sequence in star mass

high T:

- high luminosity
- high mass
- large size
- short lifespan

low T:

- low luminosity
- low mass
- small size
- long lifespan