Astr 102

Lec 6: Basic Properties of Stars

- Stars are made up entirely of gas.
- Main properties: luminosity, mass, temperature, chemical composition, radius, evolutionary stage
- Main sequence

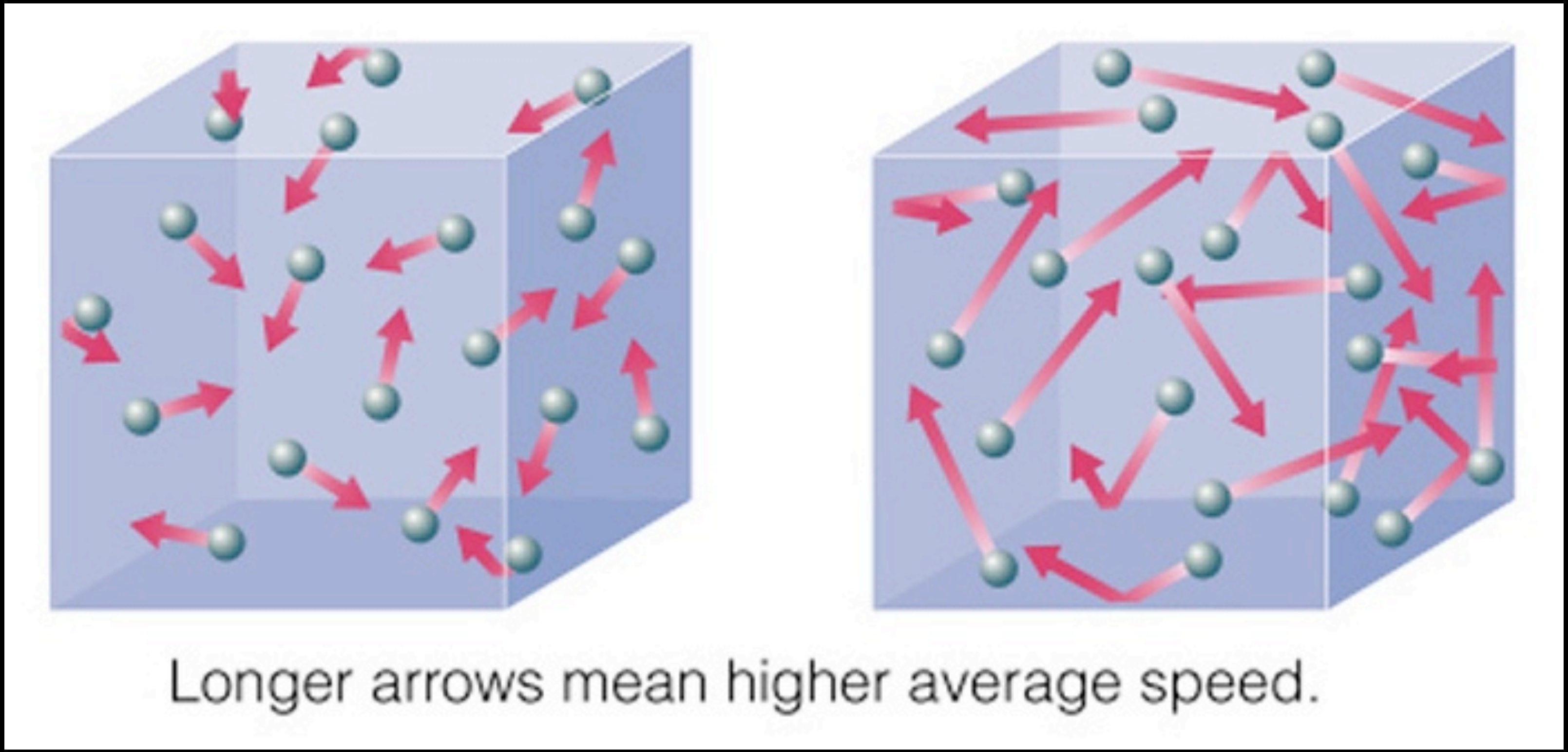
Questions of the Day

- What are density, temperature, and pressure, and how are they related?
- What is the difference between luminosity and apparent brightness?
- How does apparent brightness depend on luminosity and distance?
- What is the difference between apparent and absolute magnitude, and what do they measure?
- How do we determine chemical composition?

What are stars? Balls of gas!!

- Stars are made up entirely of gas.
- Gas has 3 main physical properties:
  - **Temperature**
  - **Density**
  - **Pressure**

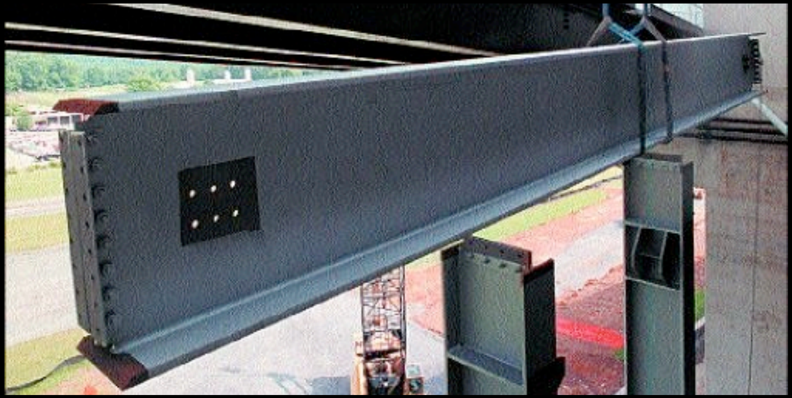
Temperature:



Higher Temp → Higher typical speeds

Density:

Mass Density: the **mass** per unit volume.



High density

Low density

ρ measured in kg/m^3

Greek letter "rho"

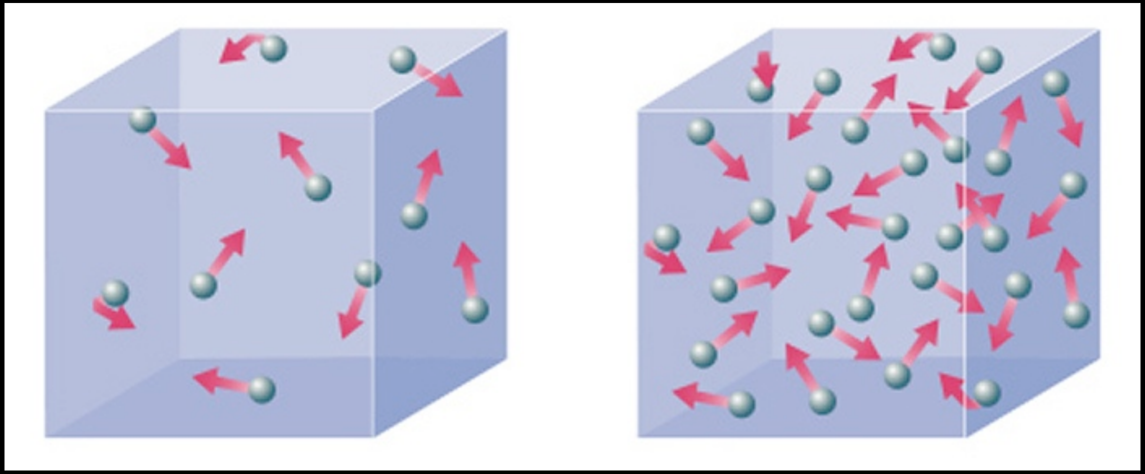
mass

Per volume

Density:

Number Density: the **number** of particles per unit volume.

Low number density



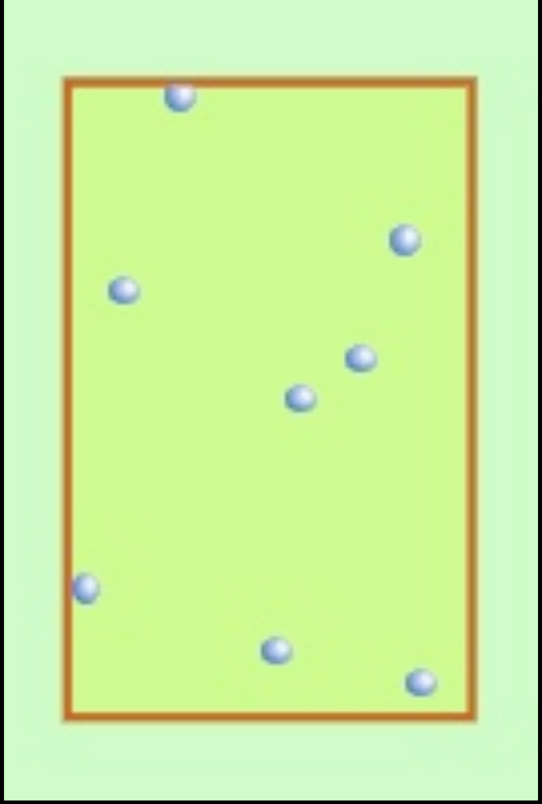
High number density

n measured in #/m^3

number

Per volume

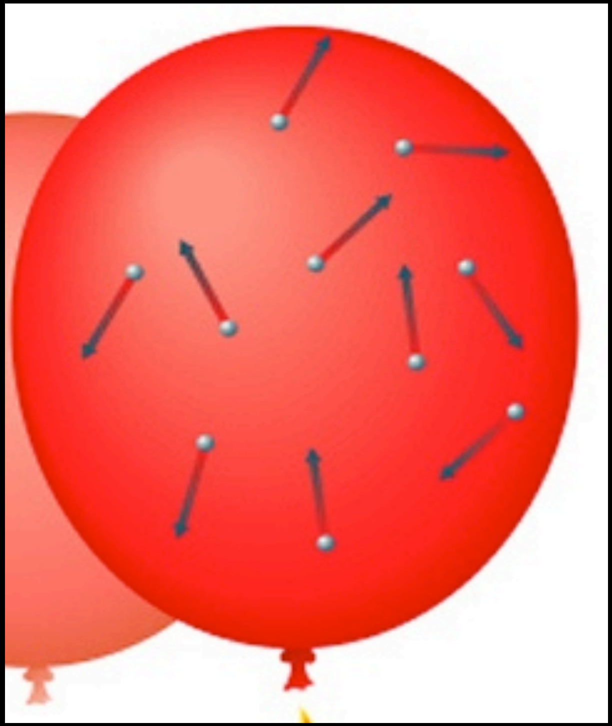
Pressure:



This force against a surface is the **PRESSURE**.

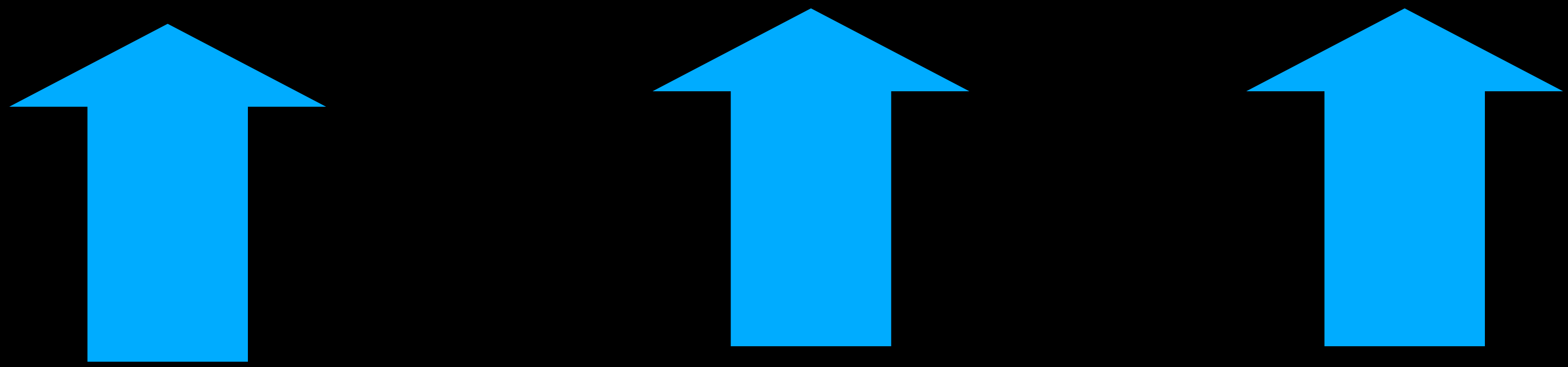
Pressure is what keeps balloons

It takes force to stretch out the rubber!



In general, for <u>normal</u> gases, if one increases, the others increase as well.

Pressure **Temperature** **Density**



What **IS** "luminosity"?

- Luminosity: <u>Energy per second</u> being emitted, total.

Low Luminosity

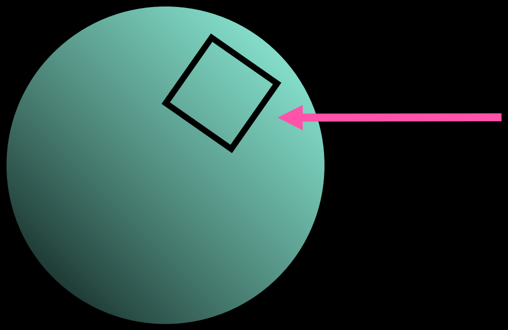
High Luminosity

more energy coming out in photons per second

Luminosity and Surface Brightness are related

- Surface Brightness is Luminosity per Area:

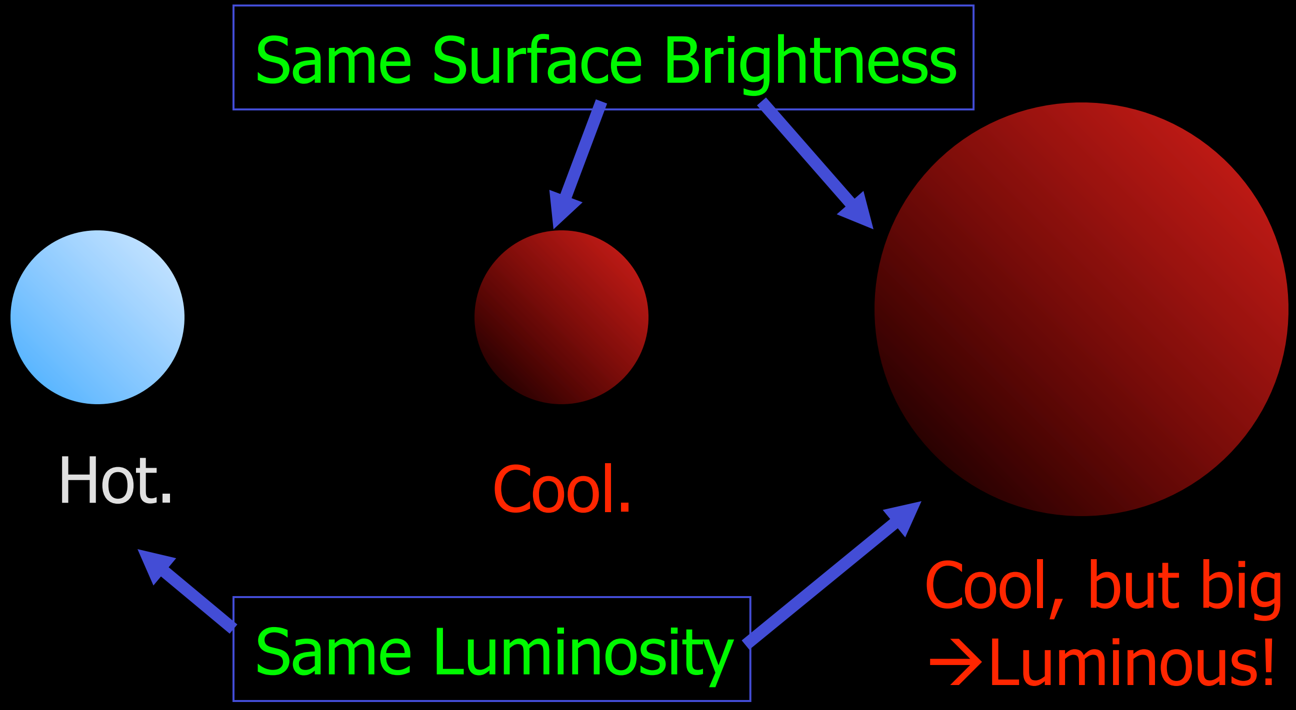
$$\text{Surface Brightness} = \left[\frac{\text{Luminosity}}{\text{Area}}\right]$$



Surface brightness is the energy per second passing through the square

But, higher surface brightness does not mean the star is brighter overall!

- Luminosity is not the same as Surface Brightness!



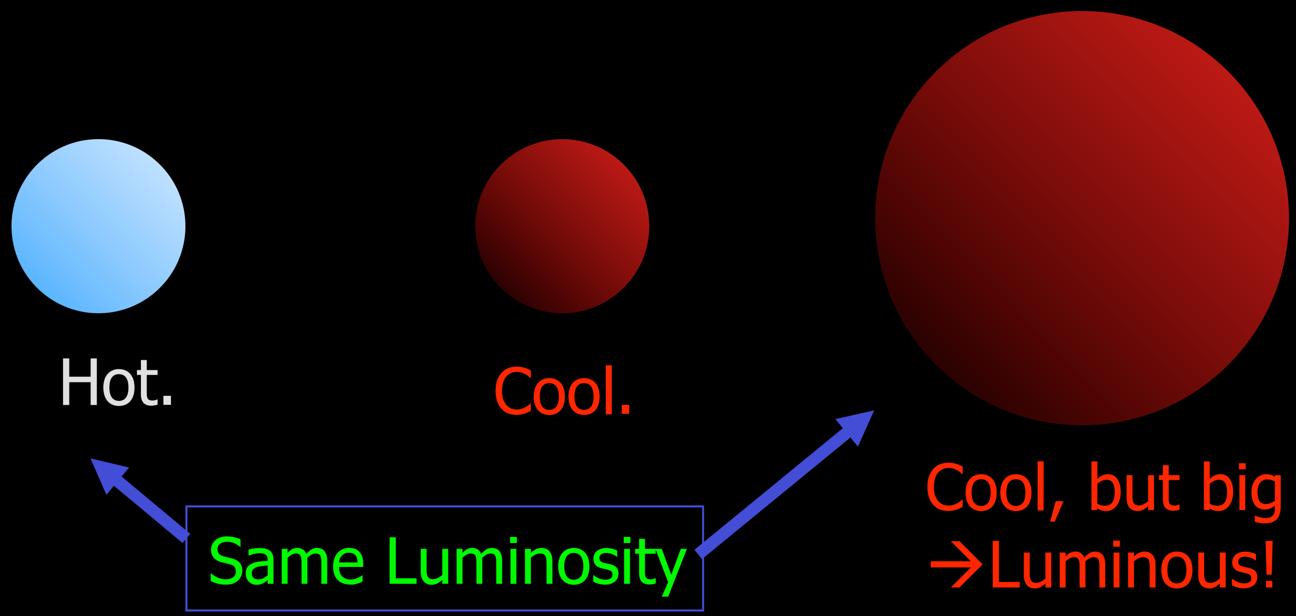
A star can be luminous if it's

$$L = \text{Surface Brightness} \times \text{Area}$$

High surface brightness (hot).

OR

Big! (large surface area).



$$L = \text{Surface Brightness} \times \text{Area}$$

$$\Sigma = \sigma T^4$$

$$\text{Area} = 4\pi R^2$$

$$L = \sigma T^4 \times 4\pi R^2$$

What are the units of Luminosity?

Remember that Luminosity is Energy Per Second.

$1 \, L_{\odot}$ = 1 Solar Luminosity

= 3.9×10^{26} Watts

= 3.9×10^{26} Joules / Second

= 3.9×10^{26} $(kg \, m^2/s^2) / s$

Walking: 10^6 Joules/hour

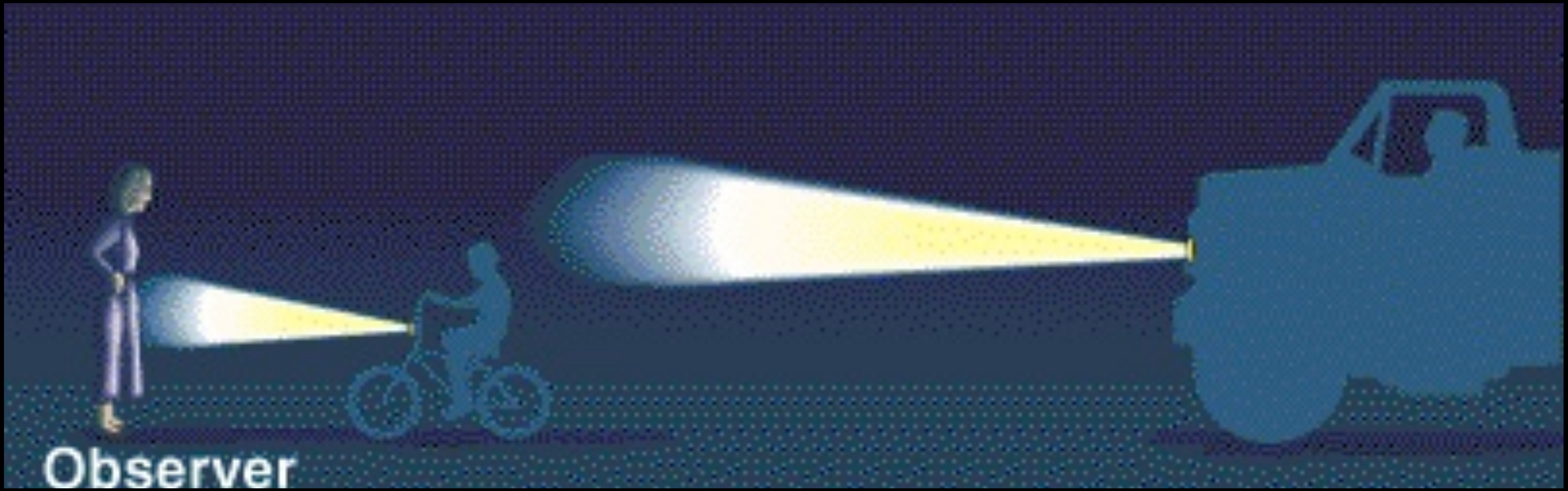
The US: 10^{20} Joules/year

It's not easy to measure luminosity!

How bright something **appears** to be ≠ How much **light** something emits

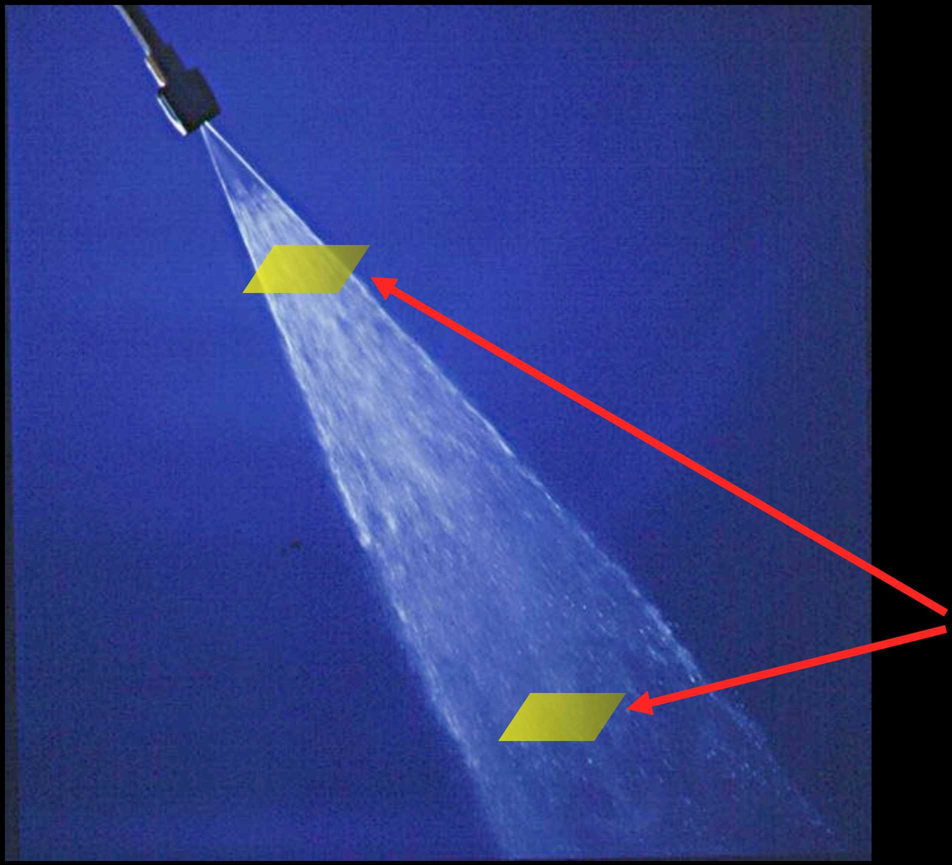
<u>Apparent</u> brightness depends on…

- Luminosity
- Distance



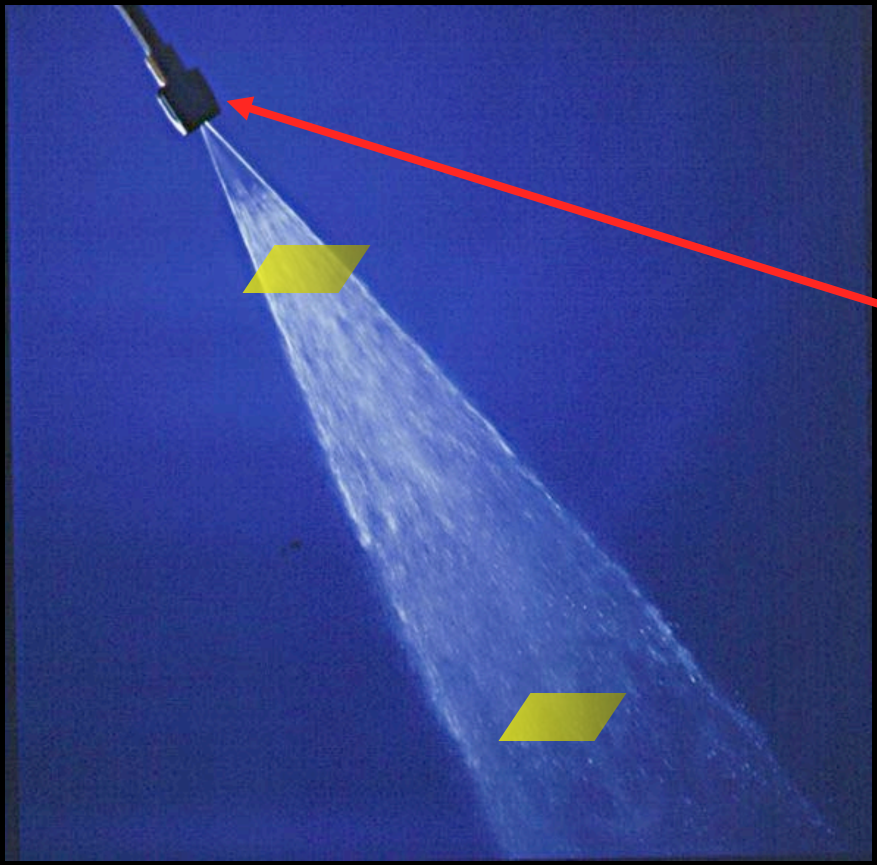
A star or galaxy will appear bright if it's **intrinsically brighter** <u>or</u> if it's **closer**.

Apparent brightness:



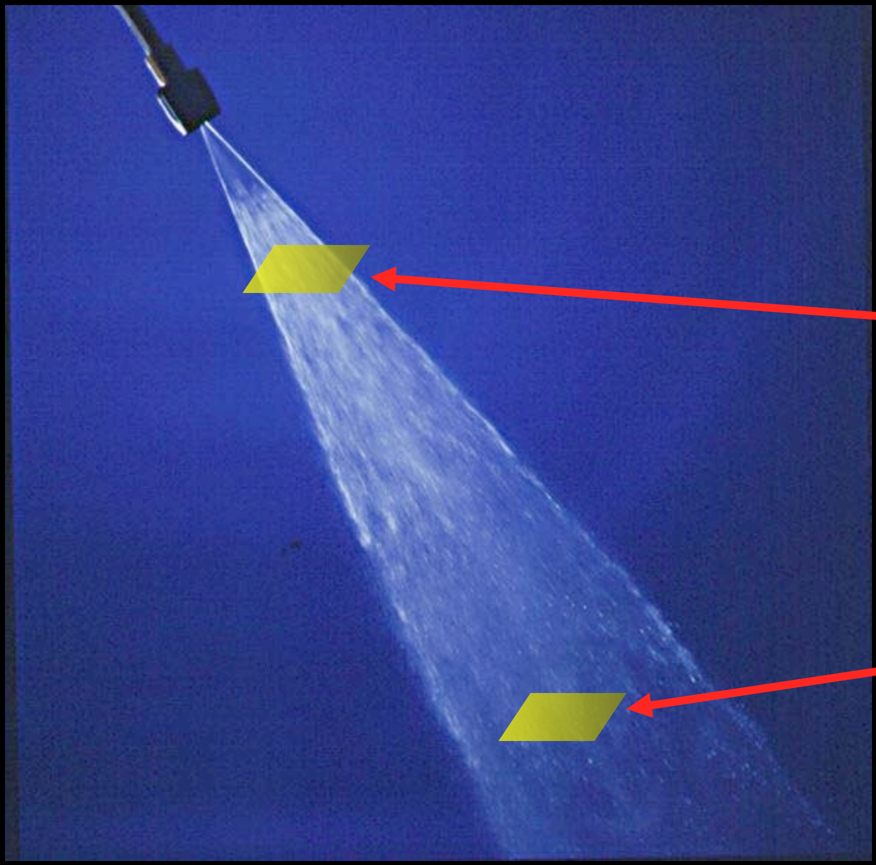
Energy in photons received per second, in the area of your detector

Apparent brightness…



…increases when more photons are emitted per second.

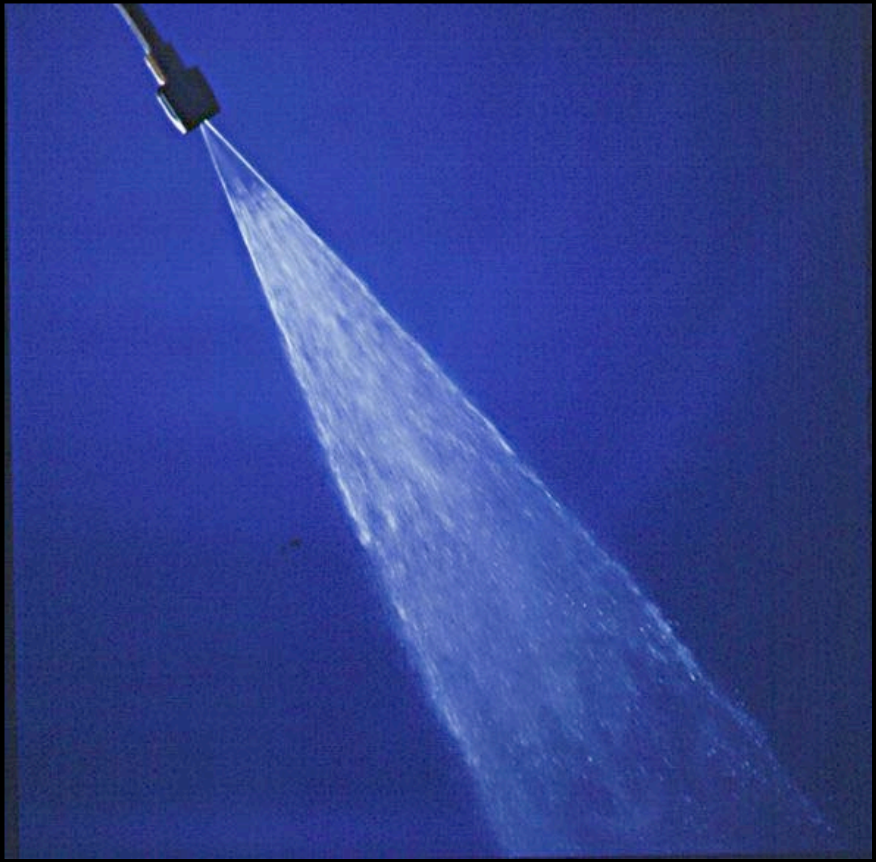
Apparent brightness:

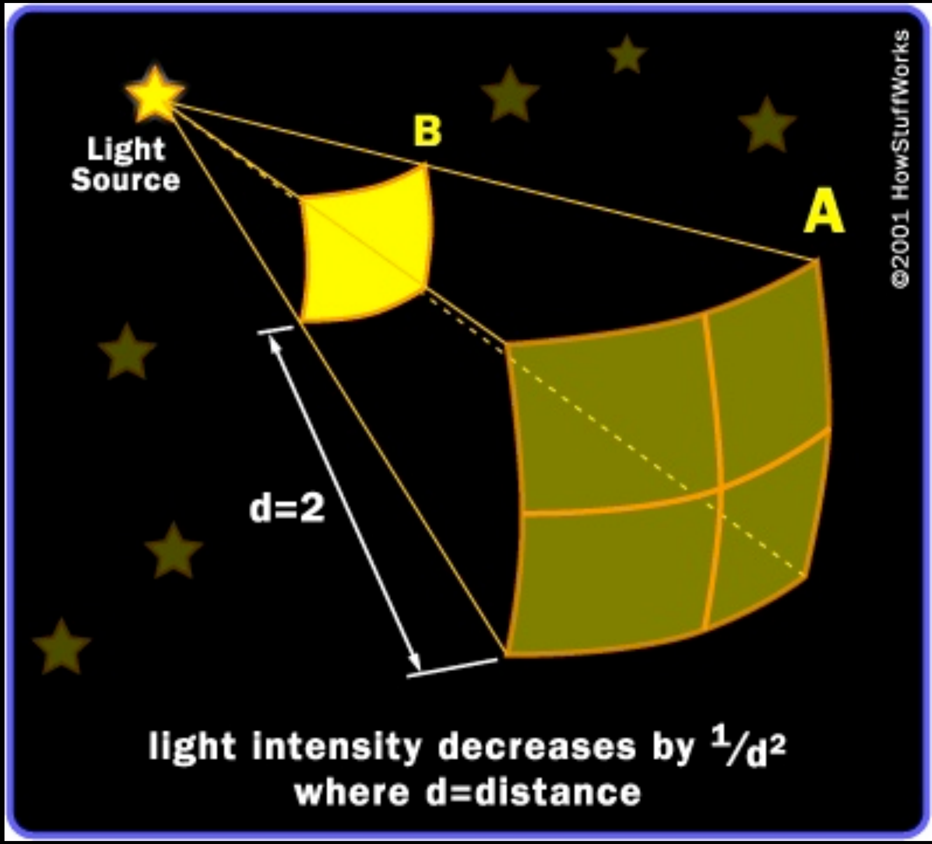


More photons intercepted here…

…than here.

$$\text{Apparent Brightness} = \frac{\text{\# of photons per second}}{\text{received per area}} = \frac{L}{4\pi d^2}$$

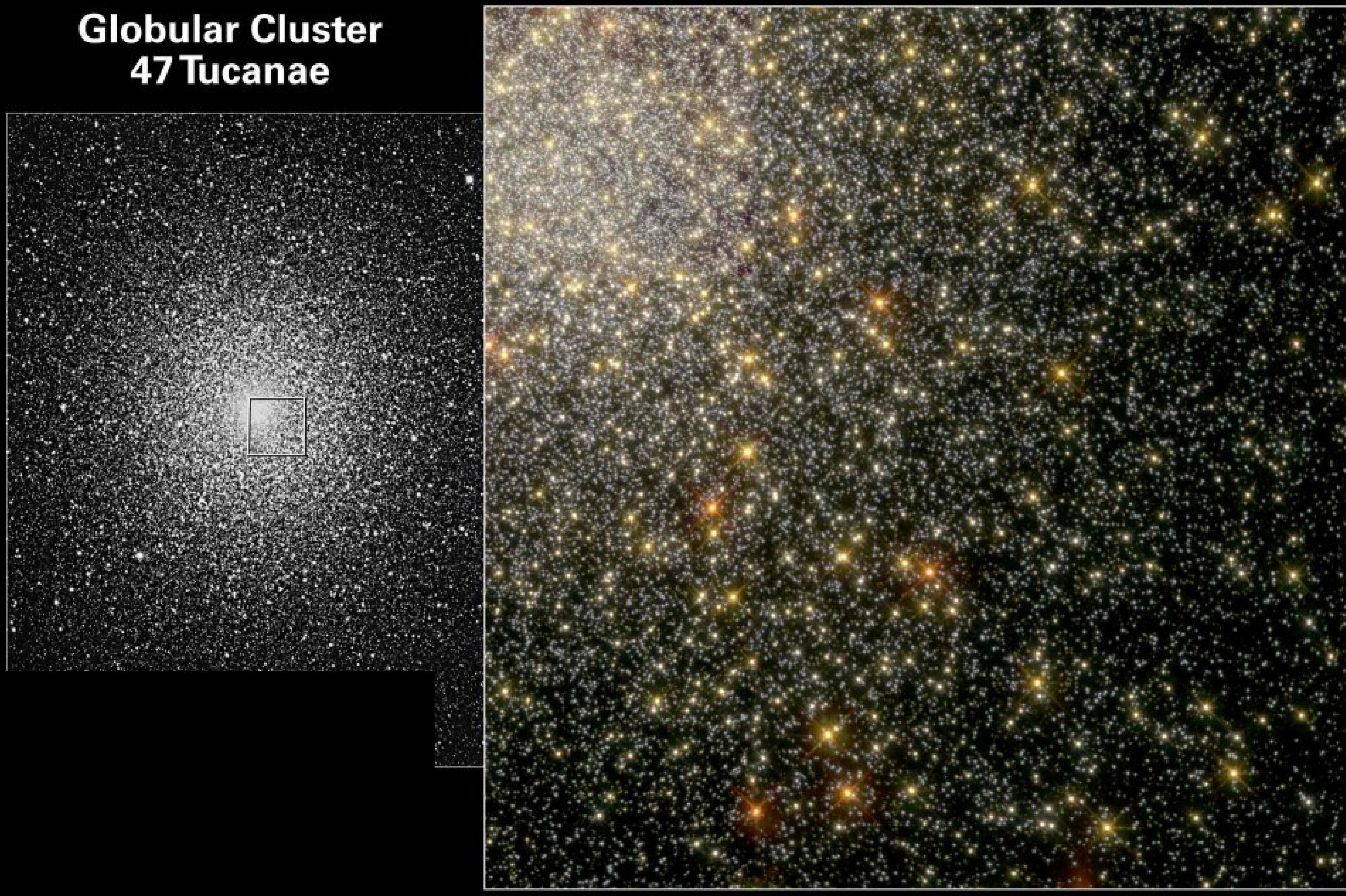




Keep in mind:

- Luminosity does not change with distance
  - Intrinsic property of a star.
- Apparent brightness does change with distance
  - Further = Fainter

- At the same distance, differences in apparent brightness reveal differences in luminosity.



Which of these stars appear bright?

Which of these stars actually is highly luminous?

One idea:

Derive from star's temperature

Measure size of the star

$$\text{Luminosity} = \text{Surface Brightness} \times \text{Area}$$

One idea:

Measure T from spectrum

THEN

Measure star's radius

$$L = \sigma T^4 \times 4\pi R^2$$

Like looking at something 0.01 cm across from a mile away!

$1\ R_{\odot} = 1.4 \times 10^6$ km

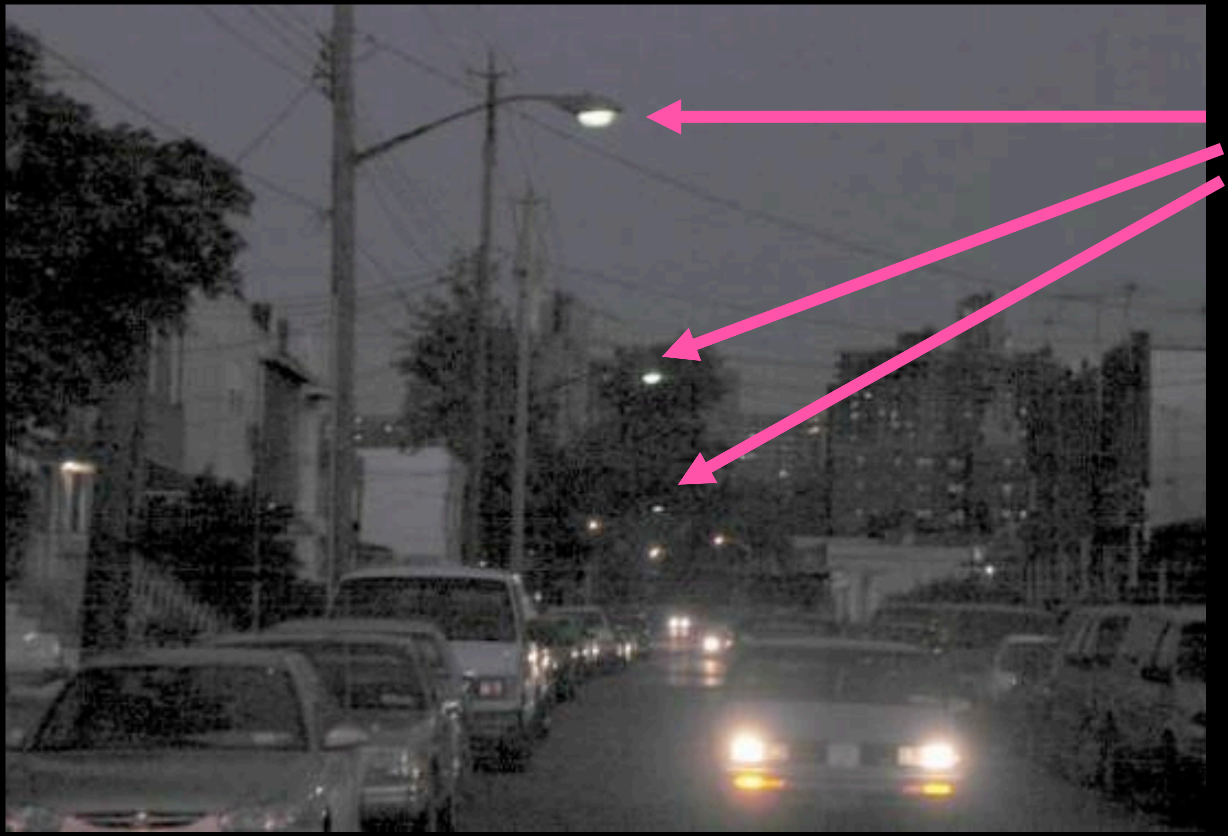
1 parsec $= 4.0 \times 10^{13}$ km

Another Idea:

These all have the <u>same</u> luminosity

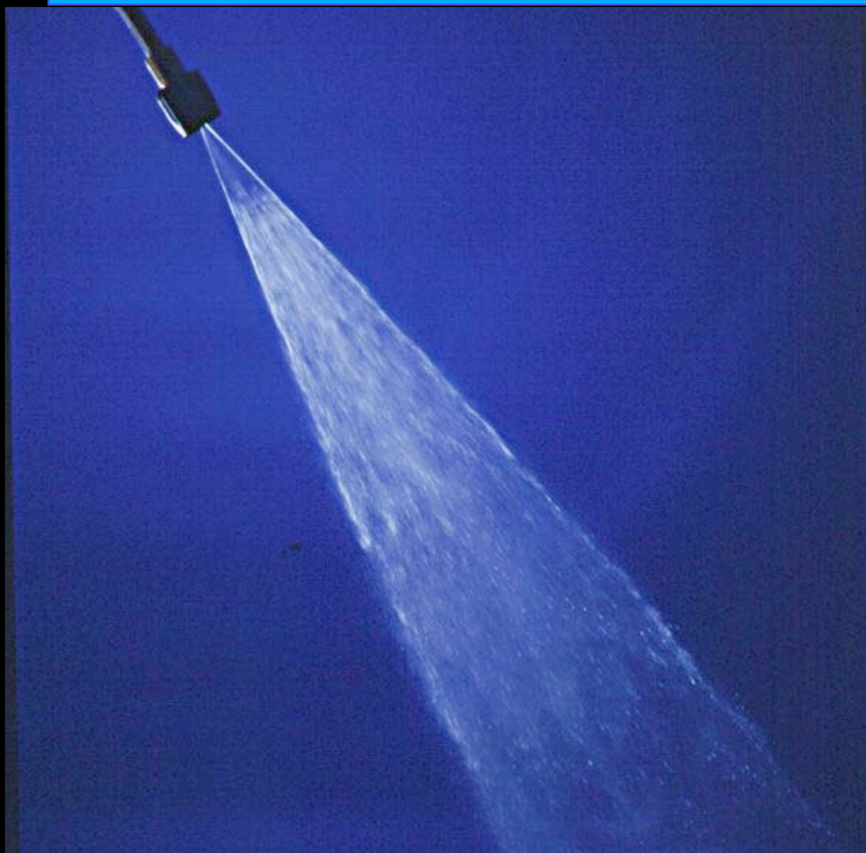
But, they have different <u>apparent</u> brightnesses

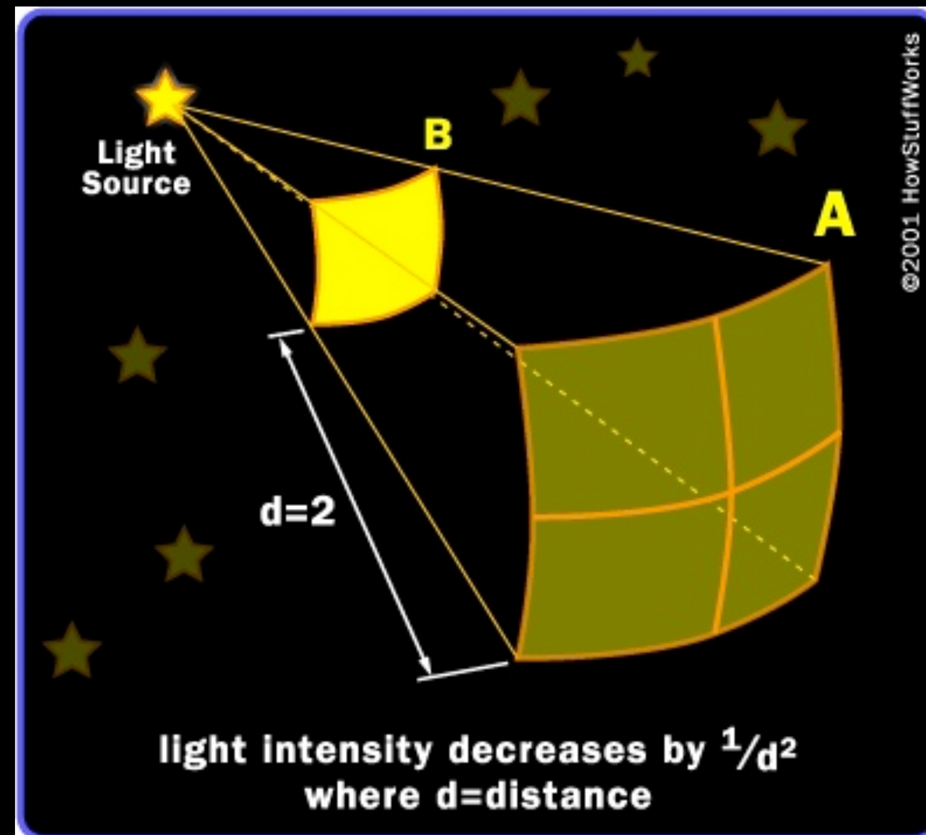
Use the apparent brightness and the distance to derive the



If you know how far these street lights are, you can figure out how luminous the light bulbs are.

$$\text{Apparent Brightness} = \frac{\text{\# of photons per second}}{\text{received per area}} = \frac{L}{4\pi d^2}$$





$$\text{Luminosity} = \text{Apparent Brightness} \times 4\pi d^2$$

So how luminous are stars?

$$L = 4\pi d^2 \times \text{brightness}$$

- Measure distance
- Measure brightness

Astronomers have some weird ways of describing luminosity and apparent brightness.

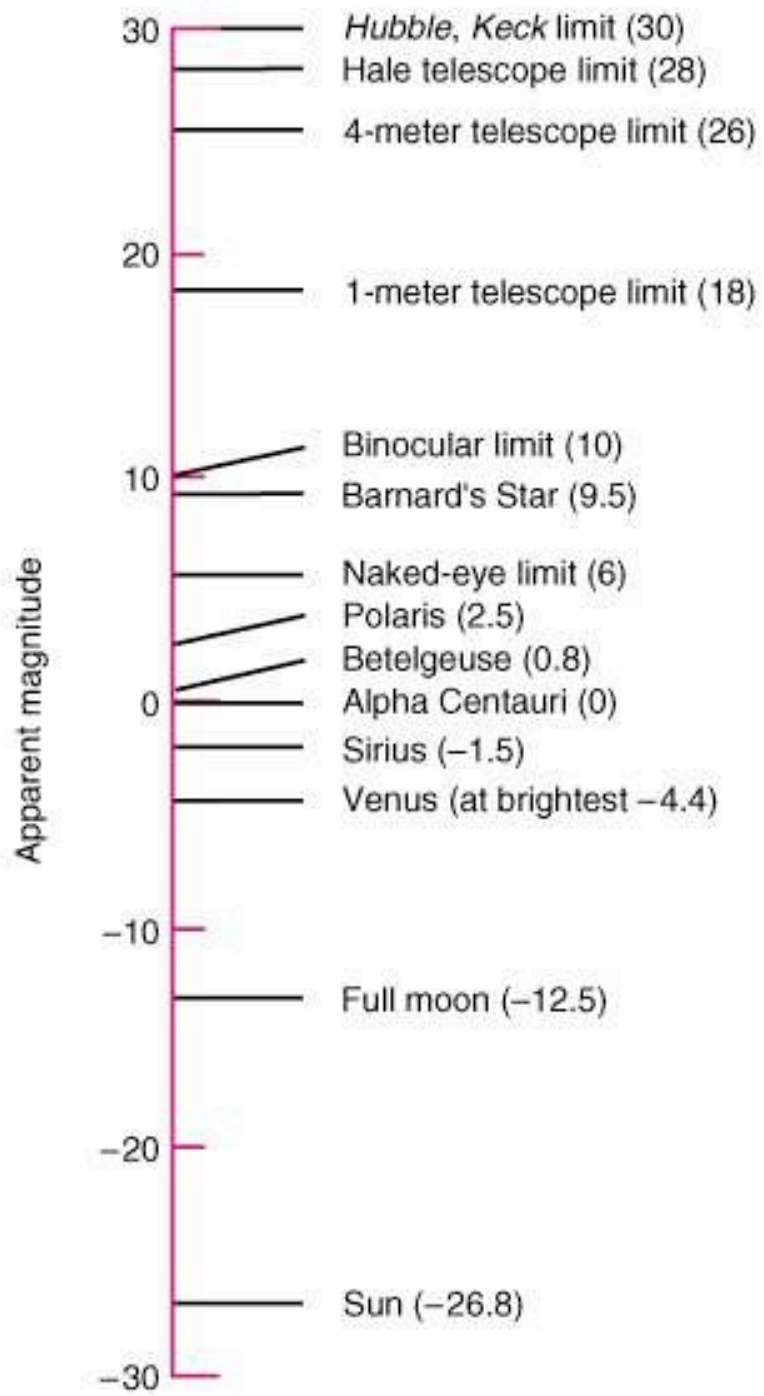
“Apparent Magnitude” → Apparent Brightness

“Absolute Magnitude” → Luminosity

Rules of thumb:

- Absolute Magnitude does not change with distance
  - Intrinsic property of a star.

- Apparent magnitude does change with distance
  - Further = Fainter = larger apparent mag.



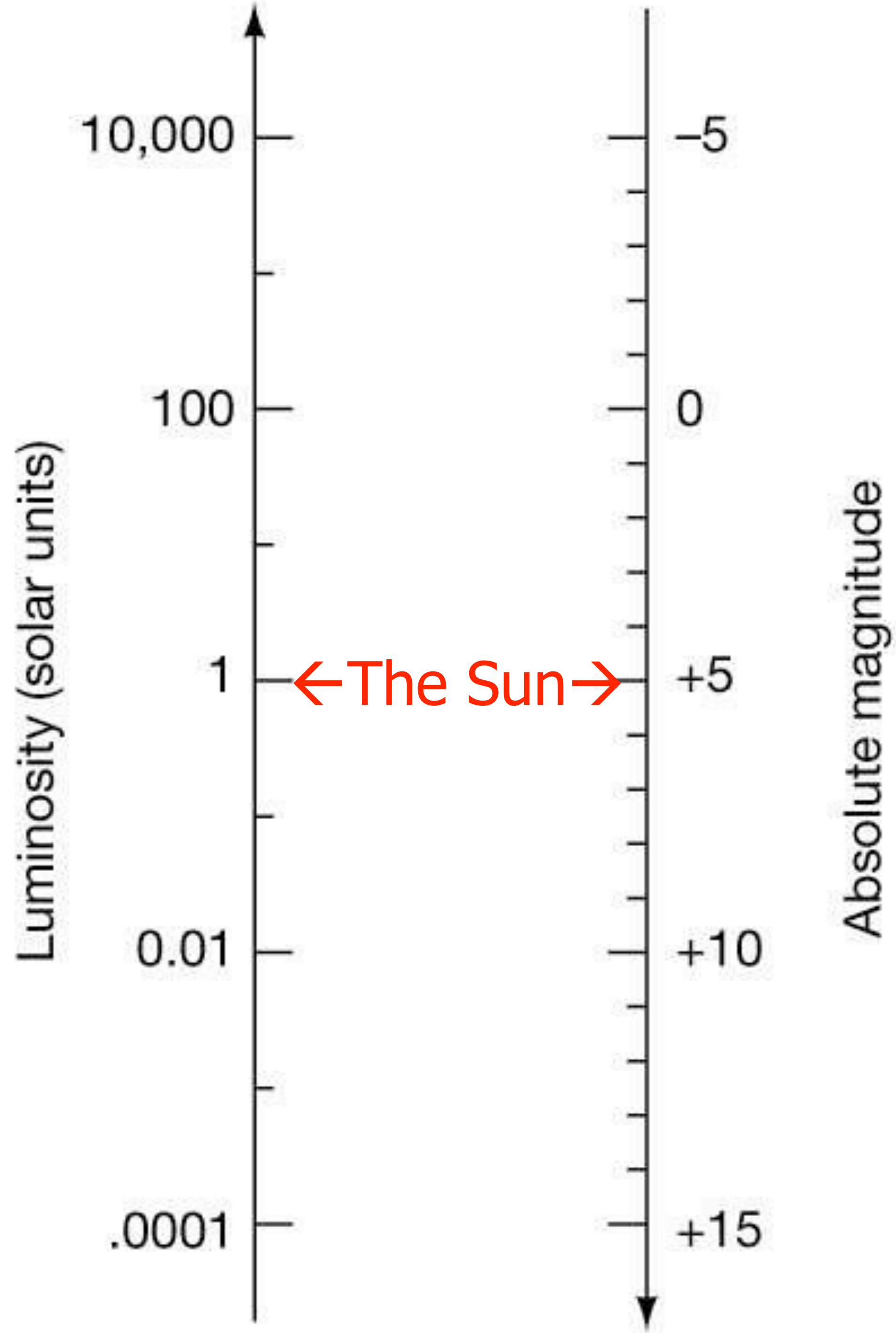
Apparent Magnitude "m"

- Tells how bright an object appears to be

Absolute Magnitude

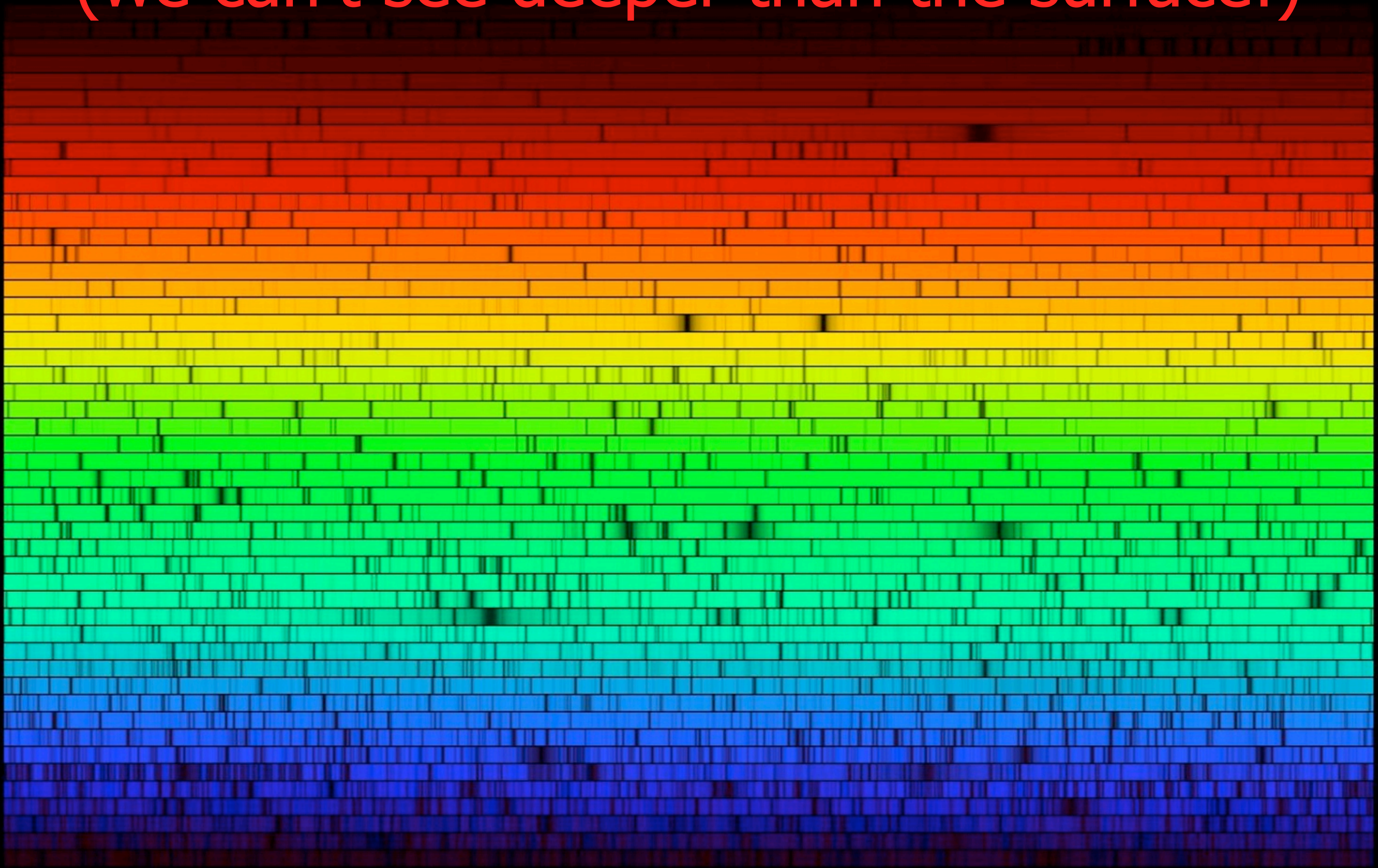
The absolute magnitude of an object is the apparent magnitude it would have at a fixed distance of 10pc.

Reflects the luminosity of the object.

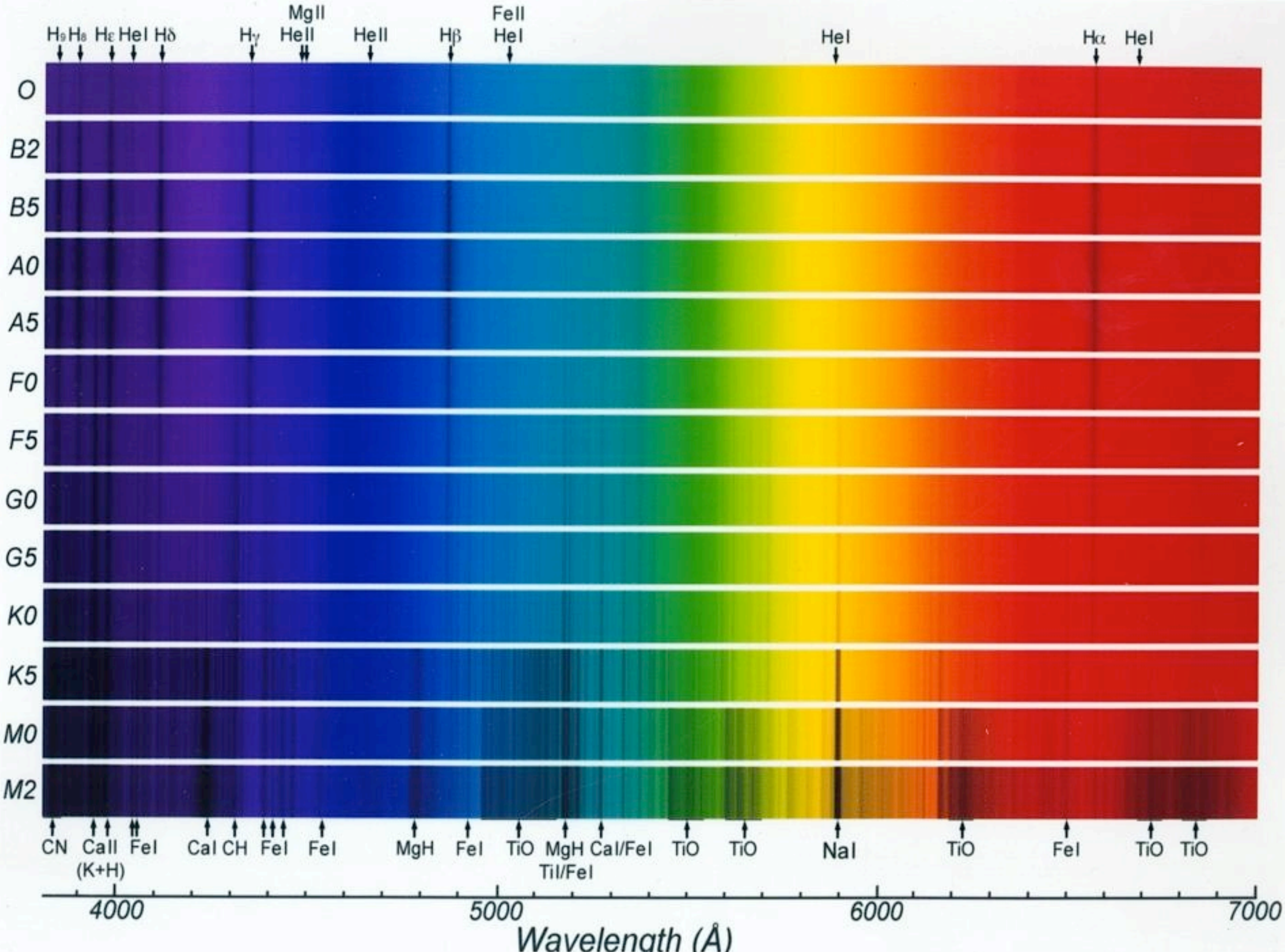


Where does a star's luminosity come from???

Hard question – stars are opaque!
(we can't see deeper than the surface!)

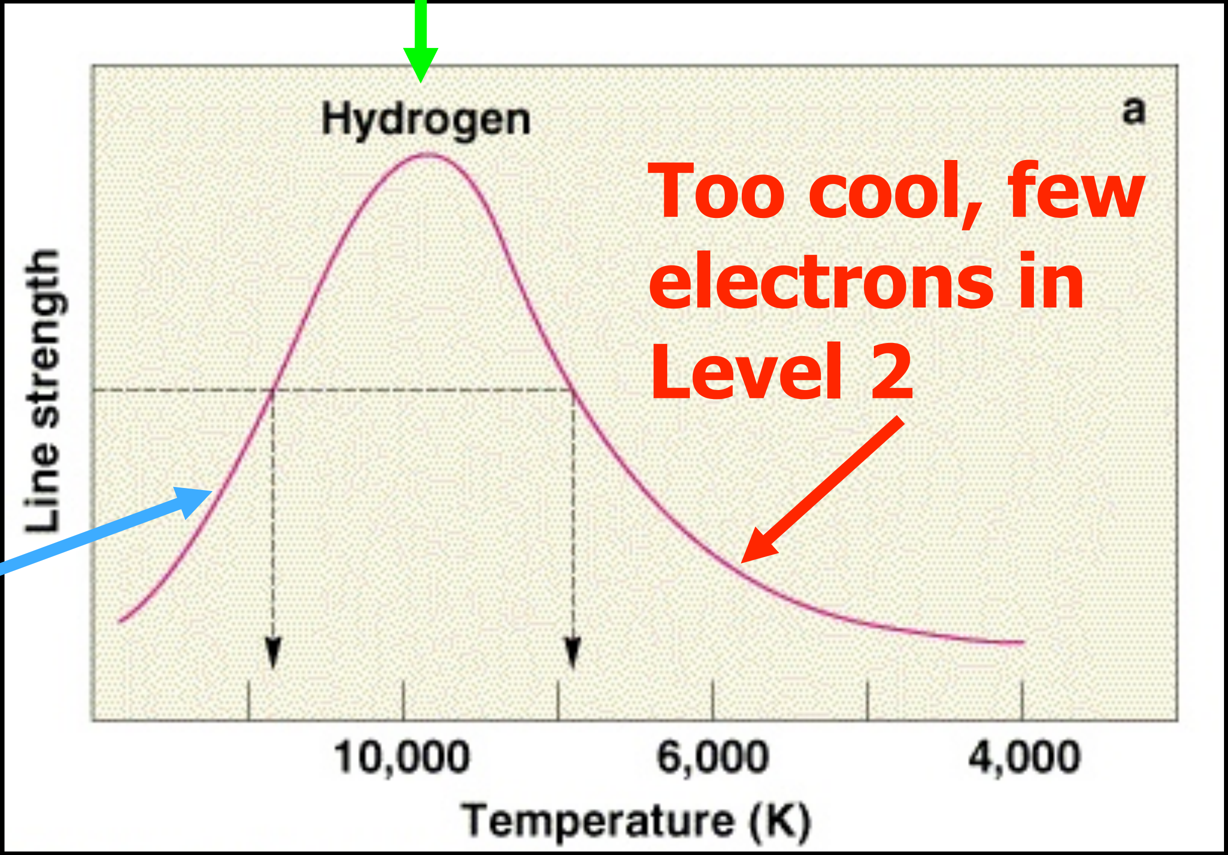


Chemical Composition: Stellar Spectra


MgII
FeII
H9 H8 Hε HeI Hδ Hγ HeII HeII Hβ HeI HeI Hα HeI
O
B2
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M2
CN CaII (K+H) FeI CaI CH FeI FeI MgH FeI TiO MgH TiI/FeI CaI/FeI TiO TiO NaI TiO FeI TiO TiO
4000
5000
6000
7000
Wavelength (Å)

“Line Strength” depends upon

Line is Strongest at this Temperature



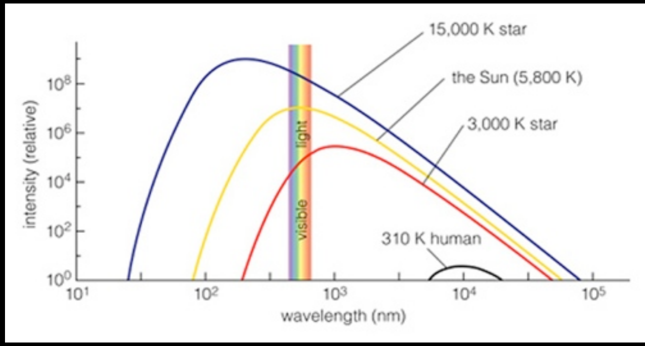
Too cool, few electrons in Level 2

Too hot, few bound electrons

When the temperature of a star varies:

SPECTRAL CLASS	APPROX TEMP (K)	HYDROGEN BALMER LINES	OTHER SPECTRAL FEATURES	NAKED-EYE EXAMPLE
O	40,000	Weak	Ionized helium	Meissa (O8)
B	20,000	Medium	Neutral helium	Achernar (B3)
A	10,000	Strong	Ionized calc weak	Sirius (A1)
F	7,500	Medium	Ionized calc weak	Canopus (F0)
G	5,500	Weak	Ionized calc med	Sun (G2)
K	4,500	Very weak	Ionized calc strong	Arcturus (K2)
M	3,000	Very weak	TiO strong	Betelgeuse (M2)

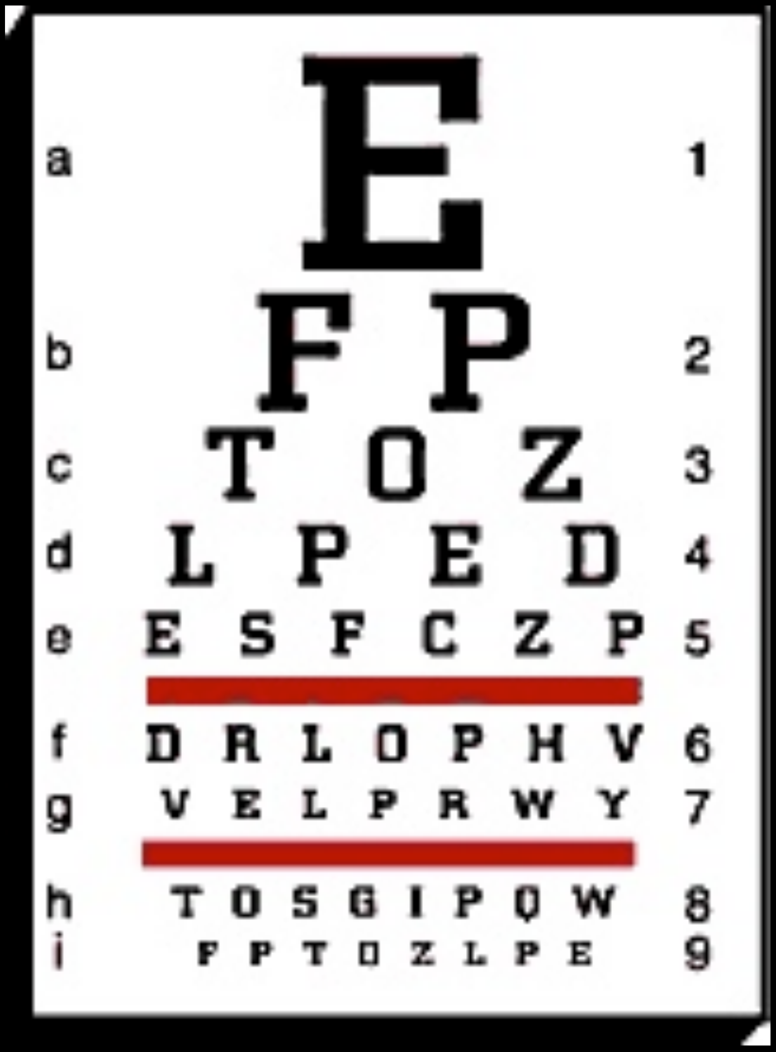
- "Spectral Type" (OBAFGKM) varies
- Color varies
- Surface brightness varies



$$\Sigma \propto T^4$$

Harder to see detail in distant objects.

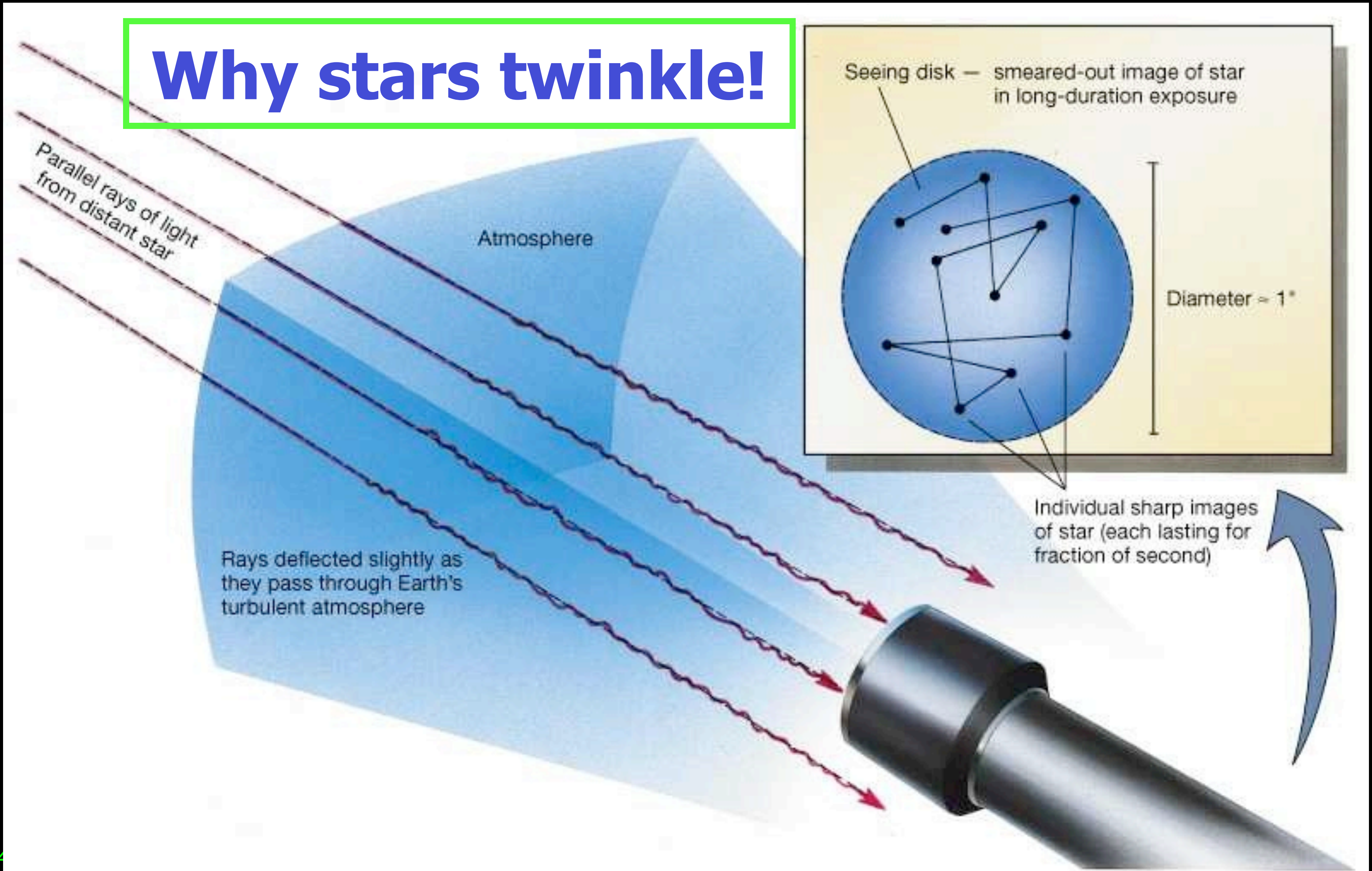
Resolution



a E 1
b F P 2
c T O Z 3
d L P E D 4
e E S F C Z P 5
f D R L O P H V 6
g V E L P R W Y 7
h T O S G I P Q W 8
i F P T O Z L P E 9

Increasing resolution means

Turbulence in the atmosphere



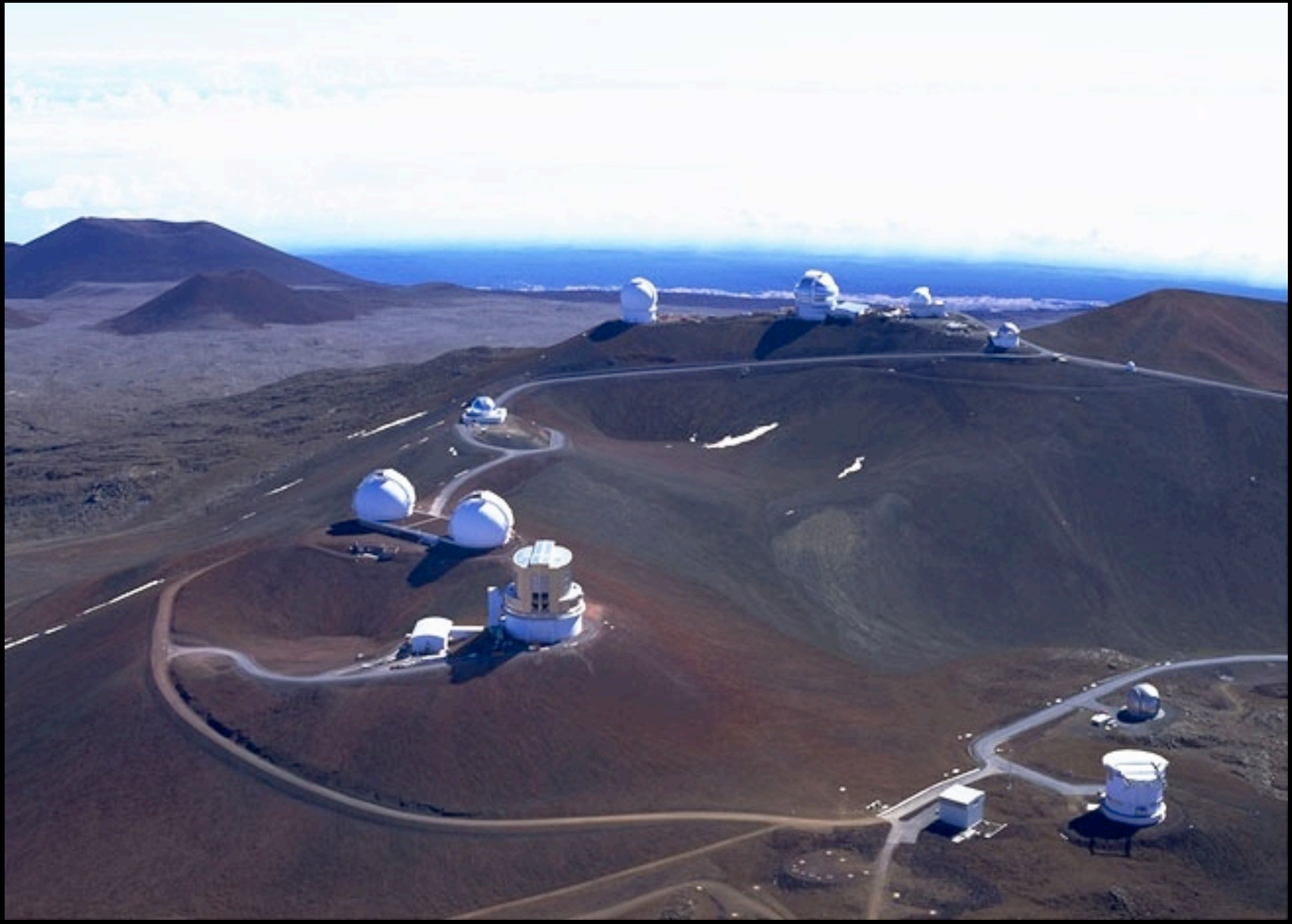
The Hubble Space Telescope is above the Earth’s atmosphere.

Image from the Ground

Image from space!

Go to telescopes, take images of

Scientific telescopes are usually on remote mountaintops near deserts.



Sunny, Tropical Hawai'i!

Why Mountaintops?

- Above more of the atmosphere → better resolution
- Dry (usually) → better weather
- **DARK** → easier to see faint things

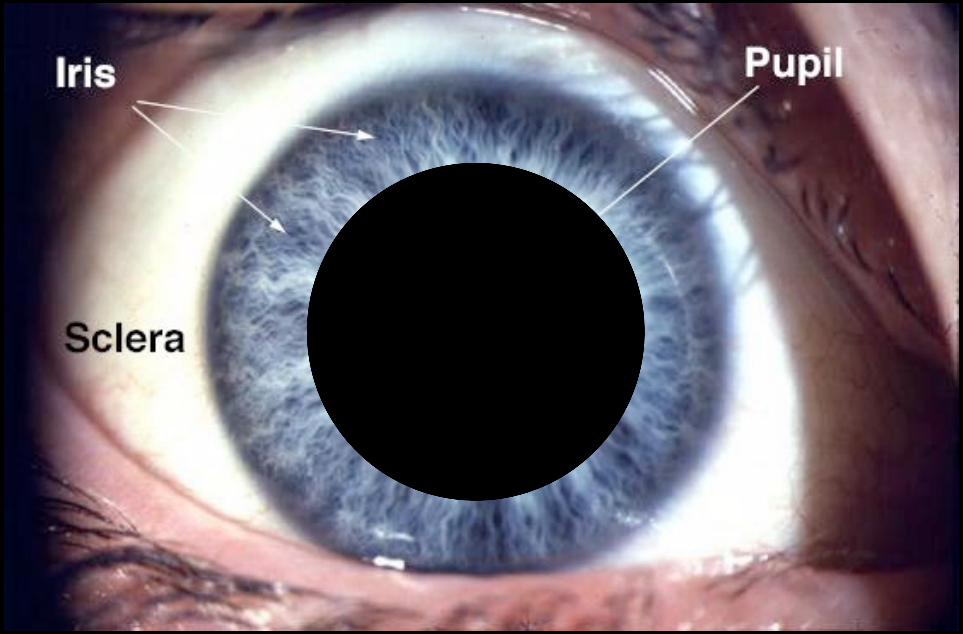
The city of Hilo

(a long exposure, so you can see the effect of the earth turning)

3 hour exposure near Cloudcroft, NM
(note the different colors of the stars!)

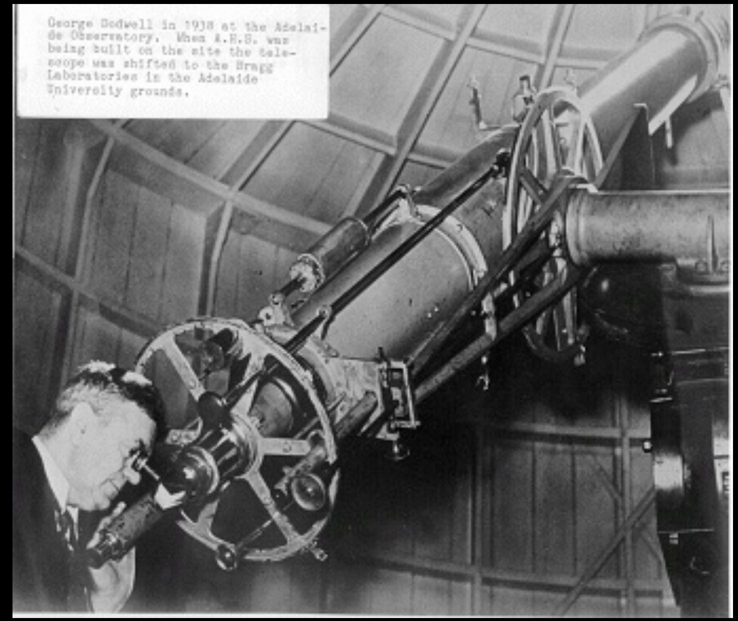
Why telescopes? Bigger "eye"

When it's dark, your pupil dilates (i.e. opens wider) to let in more light.



Telescopes take this to an extreme!

The old way:

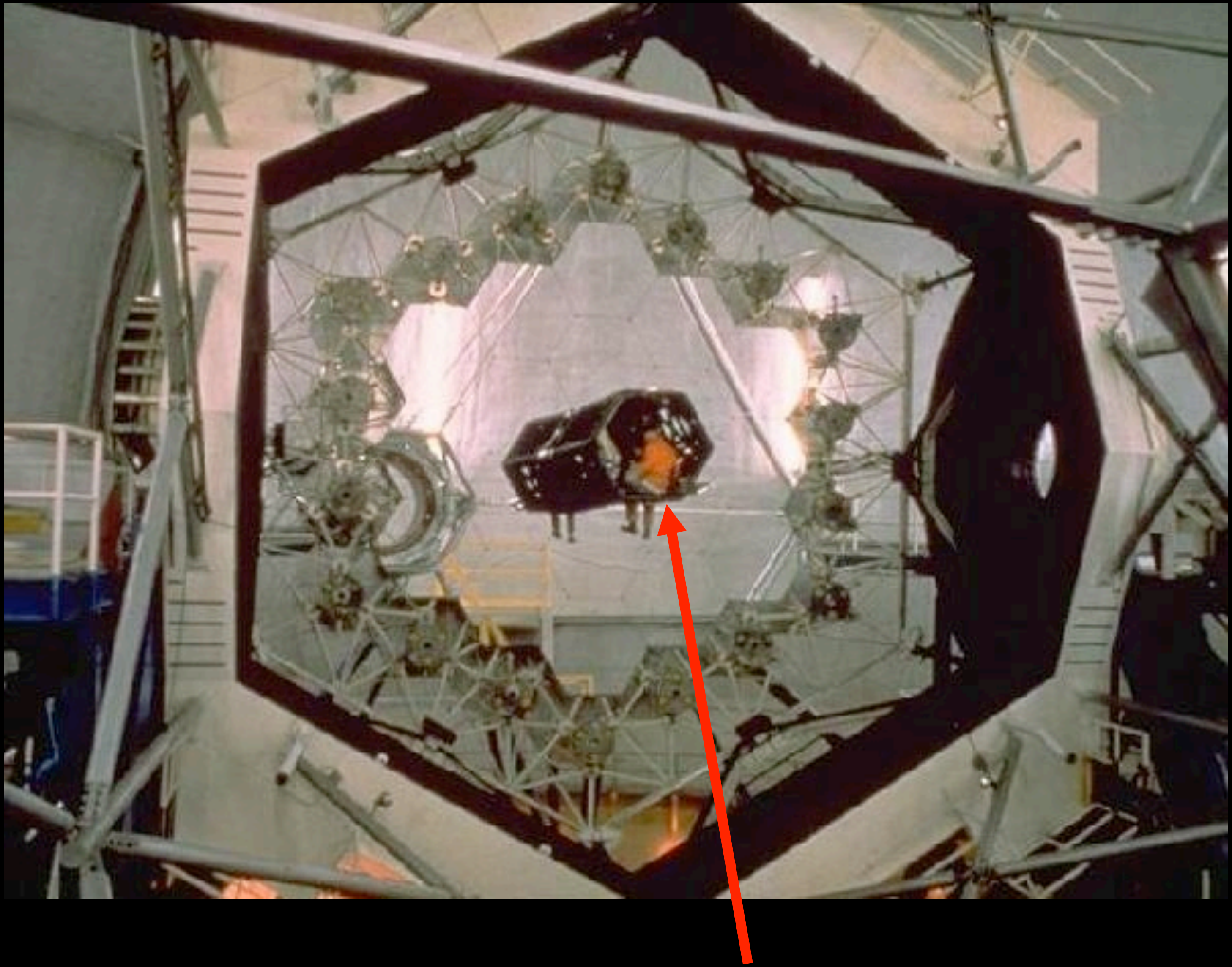


The new way:

Two of the biggest eyes…

The twin Keck telescopes in Hawai'i

One of the biggest eyes...



This is the mirror of one of the Keck telescopes.

It has a 10m diameter!

Keck’s giant mirror is made of 36 hexagonal segments. “Acctuators” push continuously on the back to keep the mirrors aligned