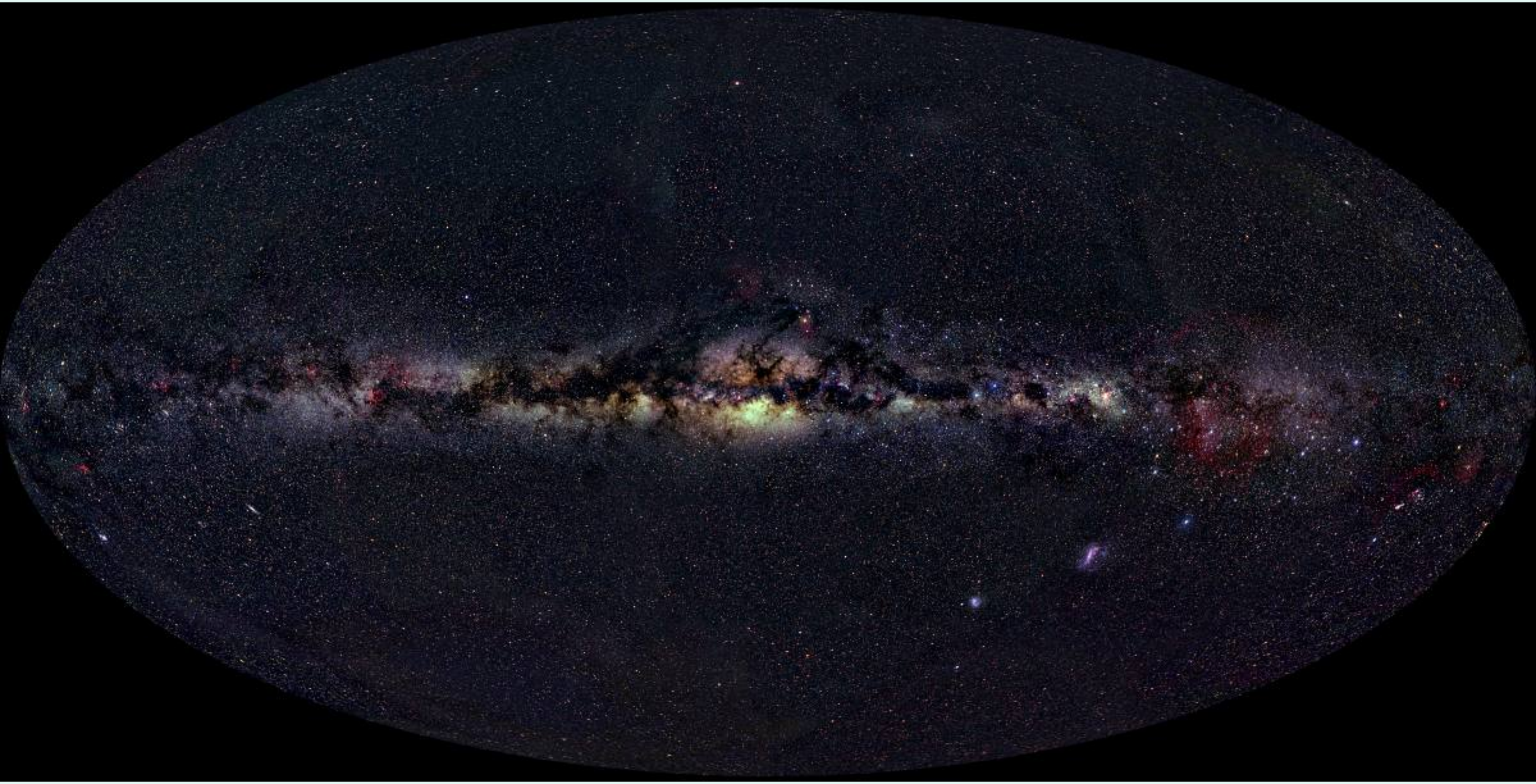
Astronomy 120



Prof. Jeff Kenney   Class 10   June 8, 2018

3 reasons it was hard to figure out that we are in a Galaxy

1. it's big -- one needs sensitive telescopes to see (individual stars) across the Galaxy

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3 reasons it was hard to figure out that we are in a Galaxy

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2. we're inside it -- hard to know relative distances; no depth perception

3. dust obscures the light from most Galaxy stars, esp. the more distant ones in the disk

If the distance to the center of the Milky Way were scaled to the size of this room, then on the same scale the solar system would be about the size of:

A. An atom
B. A water molecule
C. A molecule of DNA
D. A pin head
E. Donald Trump

The distance to the Milky Way center is 10^4 pc, and the size of the solar system is 10^{-4} pc. If the distance to the Milky Way center were scaled to the size of this room, then on the same scale the solar system would be the size of:

A. An atom (10^{-10} m)
B. A water molecule (10^{-8} m)
C. A molecule of DNA (10^{-7}m)
D. A pin head (10^{-3} m)
E. A Pinhead (1.5 meter)

key part of this problem….

you need to estimate something ….

the size of this room ~10m

this is important step in some problems:
recognizing that you need to estimate something,
then giving the estimate

- Median distance to 100 brightest stars:

  (naked eye, good night in New Haven)

- Median distance to 100 brightest stars:

  (naked eye, good night in New Haven)

  200 LY

- Median distance to 100 brightest stars:

  (naked eye, good night in New Haven)

  200 LY

- Median distance to 6000 brightest stars:

  (naked eye, good night at best sites on earth)

- Median distance to 100 brightest stars:

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  1000 LY

- Distance to Galaxy Center

- Median distance to 100 brightest stars:

  (naked eye, good night in New Haven)

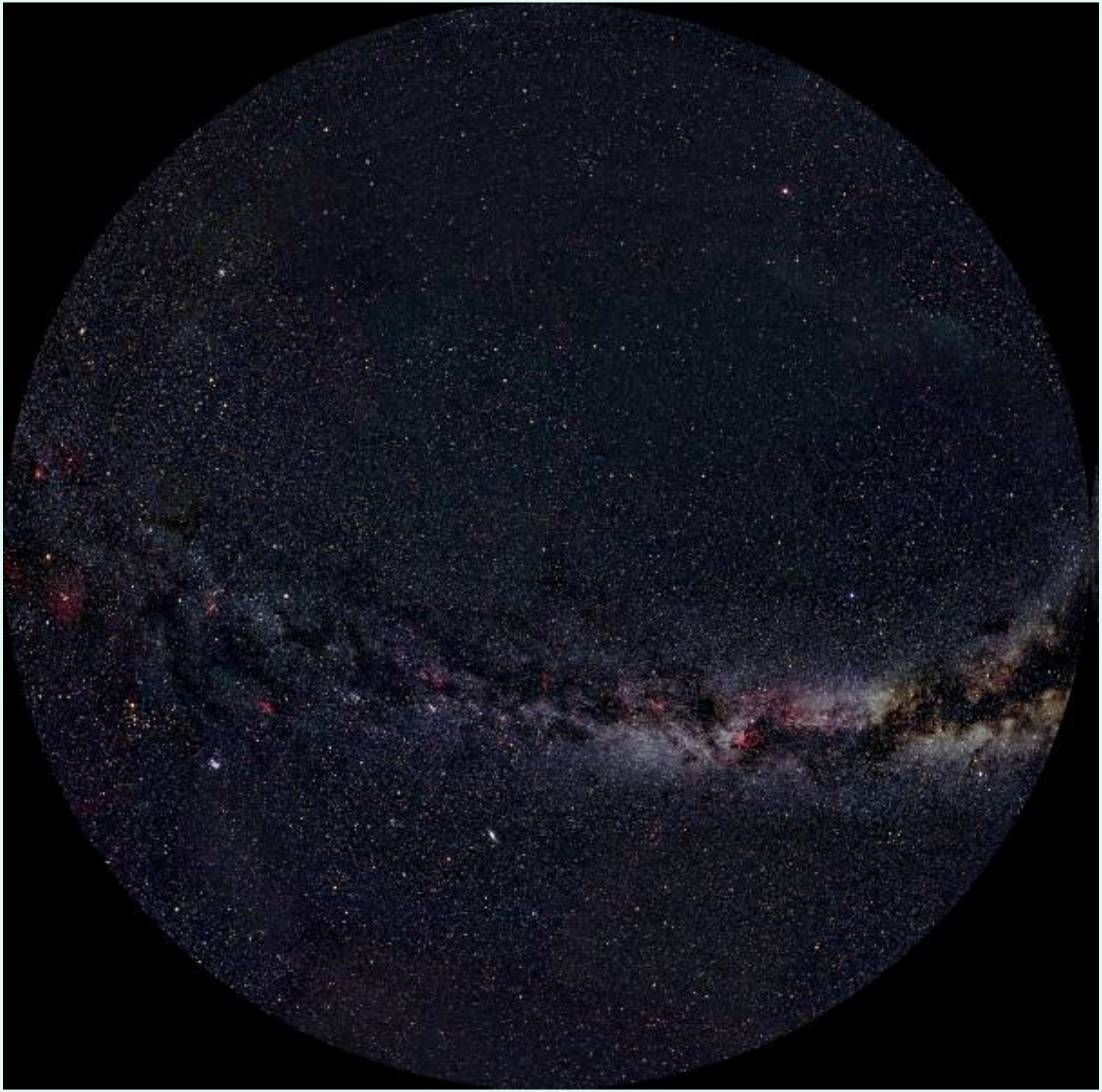
  200 LY

- Median distance to 6000 brightest stars:

  (naked eye, good night at best sites on earth)

  1000 LY

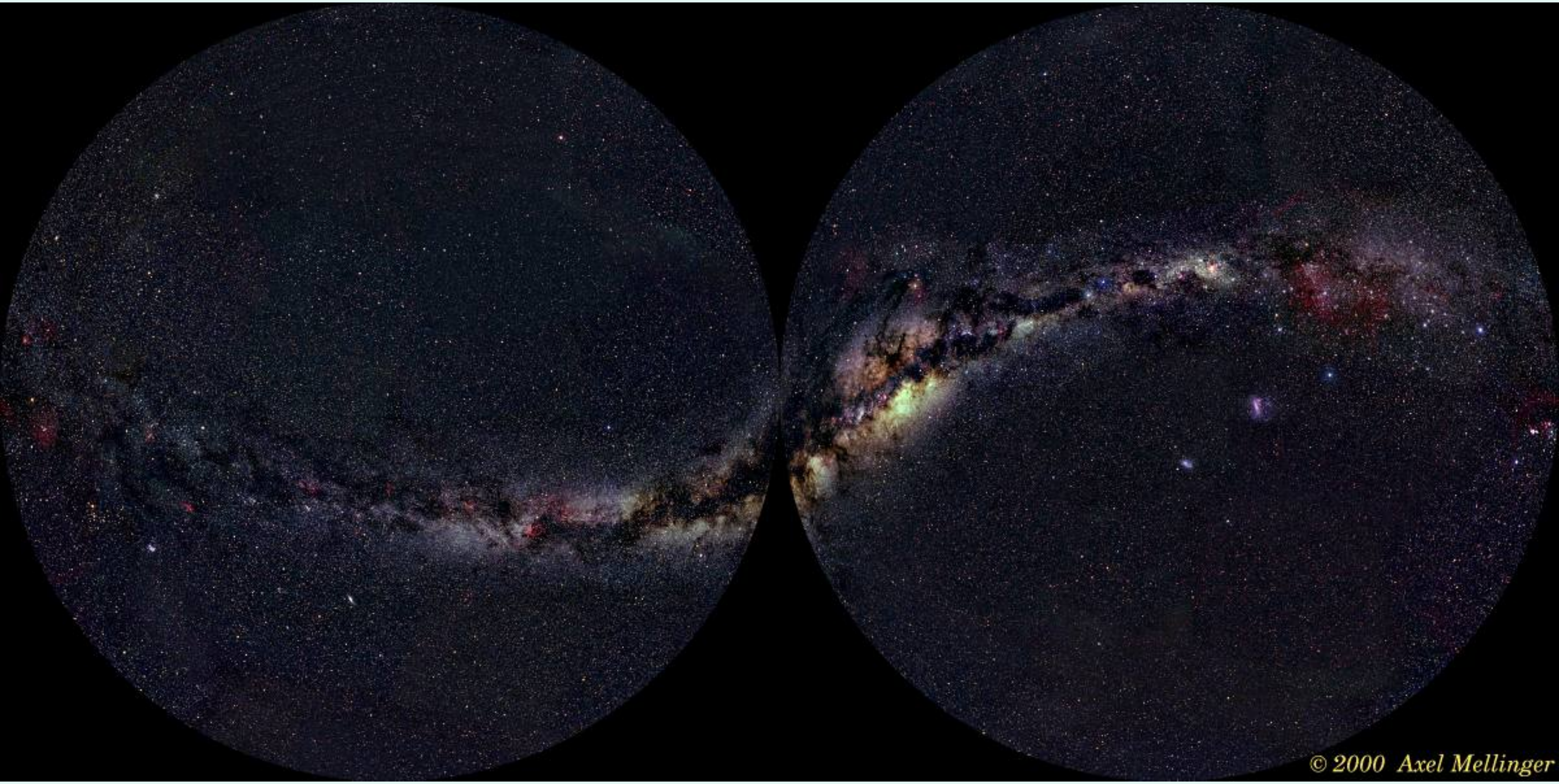
- Distance to Galaxy Center 25000 LY



The entire **Northern sky** showing the **"Milky Way"**

The entire **Southern Sky** showing the **"Milky Way"**

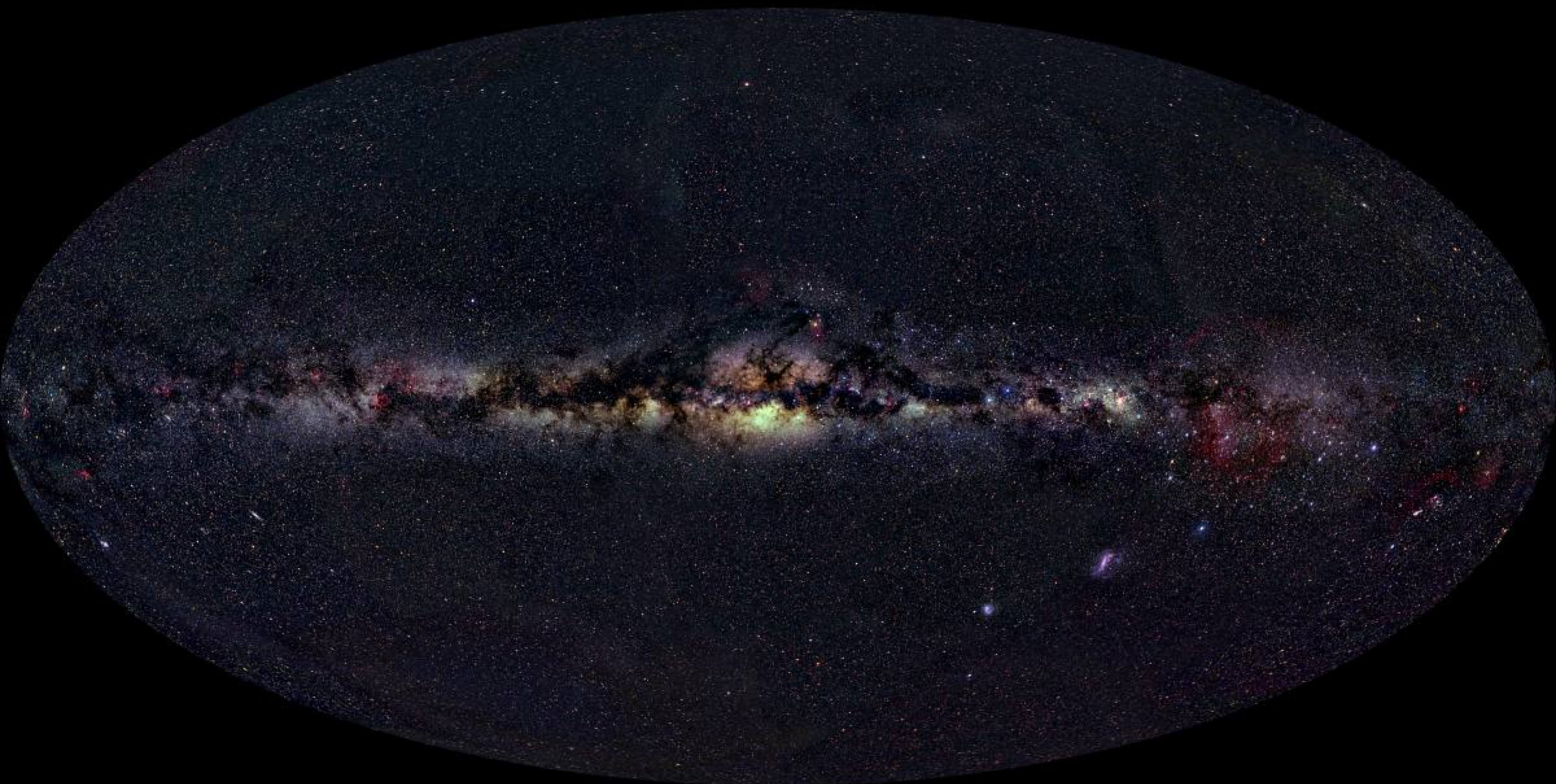
The night sky showing the Milky Way



Northern sky

Southern sky

The Deep Sky

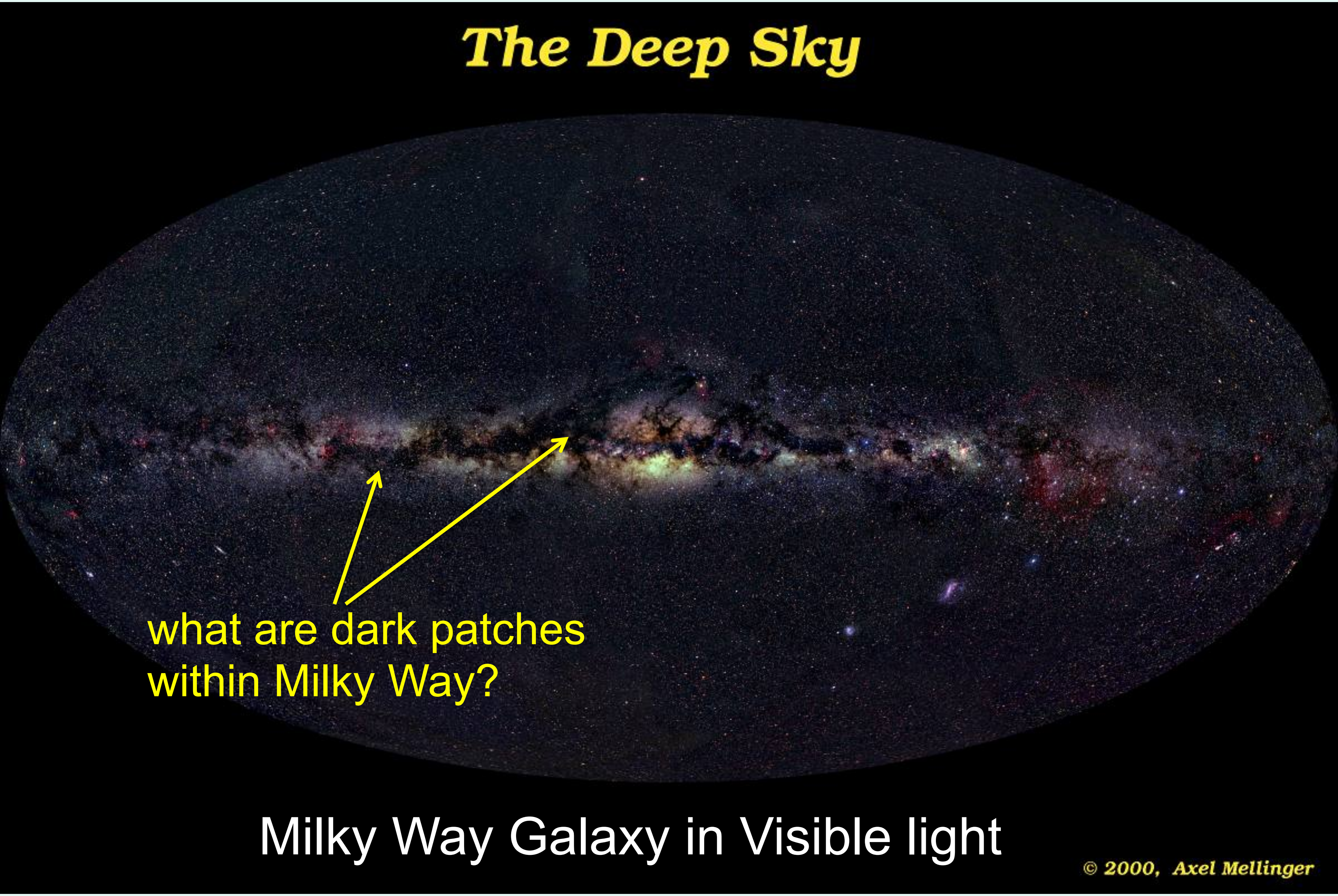


Milky Way Galaxy in Visible light

© 2000, Axel Mellinger

What is “Milky Way”

- Band of diffuse light
- Integrated light from many stars in the disk of our galaxy
- Individual stars not bright enough to be seen, but there are so many in nearly the same direction that the sum total of all the light is great enough for our eyes to see


The Deep Sky
what are dark patches
within Milky Way?
Milky Way Galaxy in Visible light
© 2000, Axel Mellinger

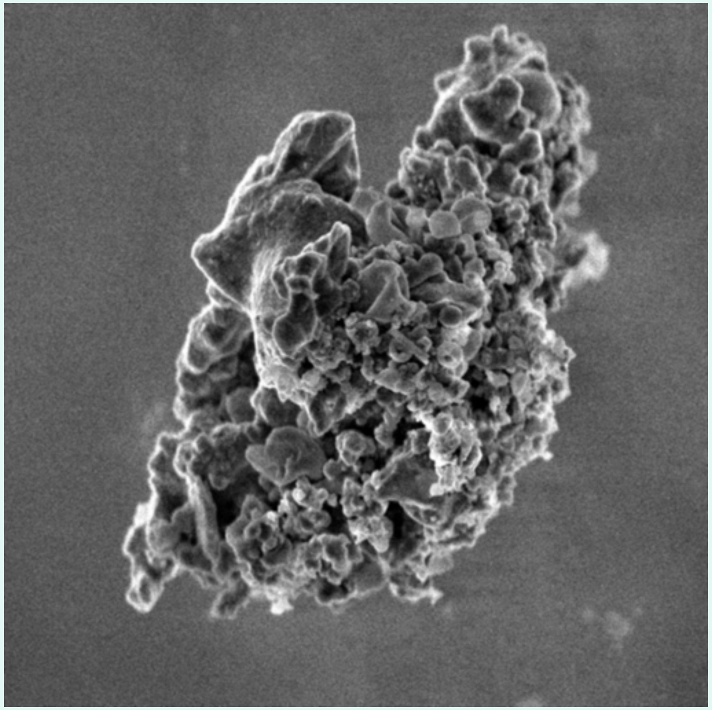
Interstellar dust cloud: Horsehead Nebula

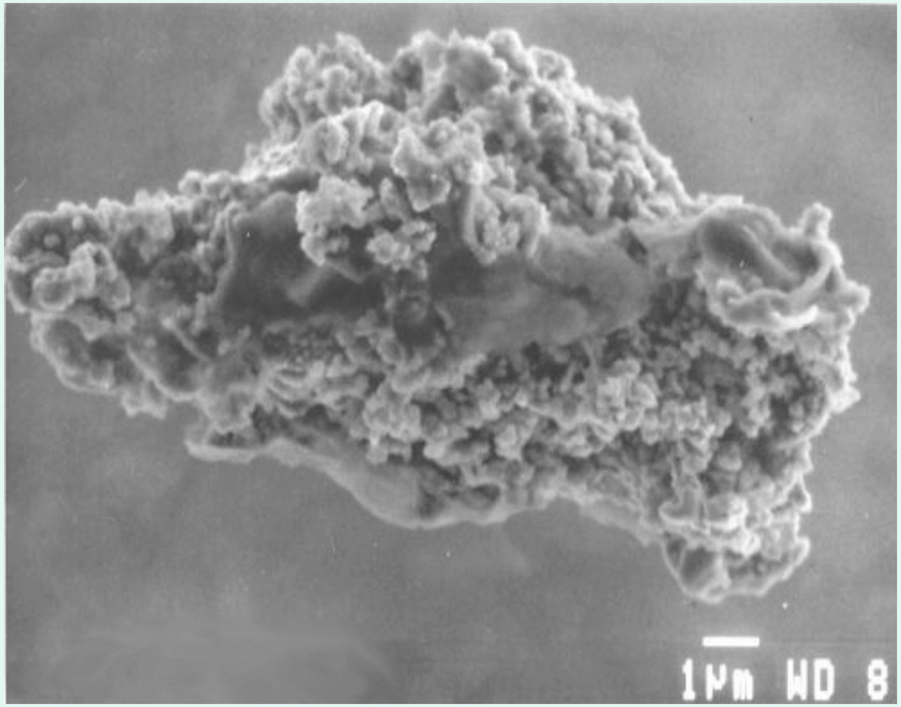
Image from ground

Image from Hubble Space Telescope

Dust obscures light from stars inside or behind dust cloud

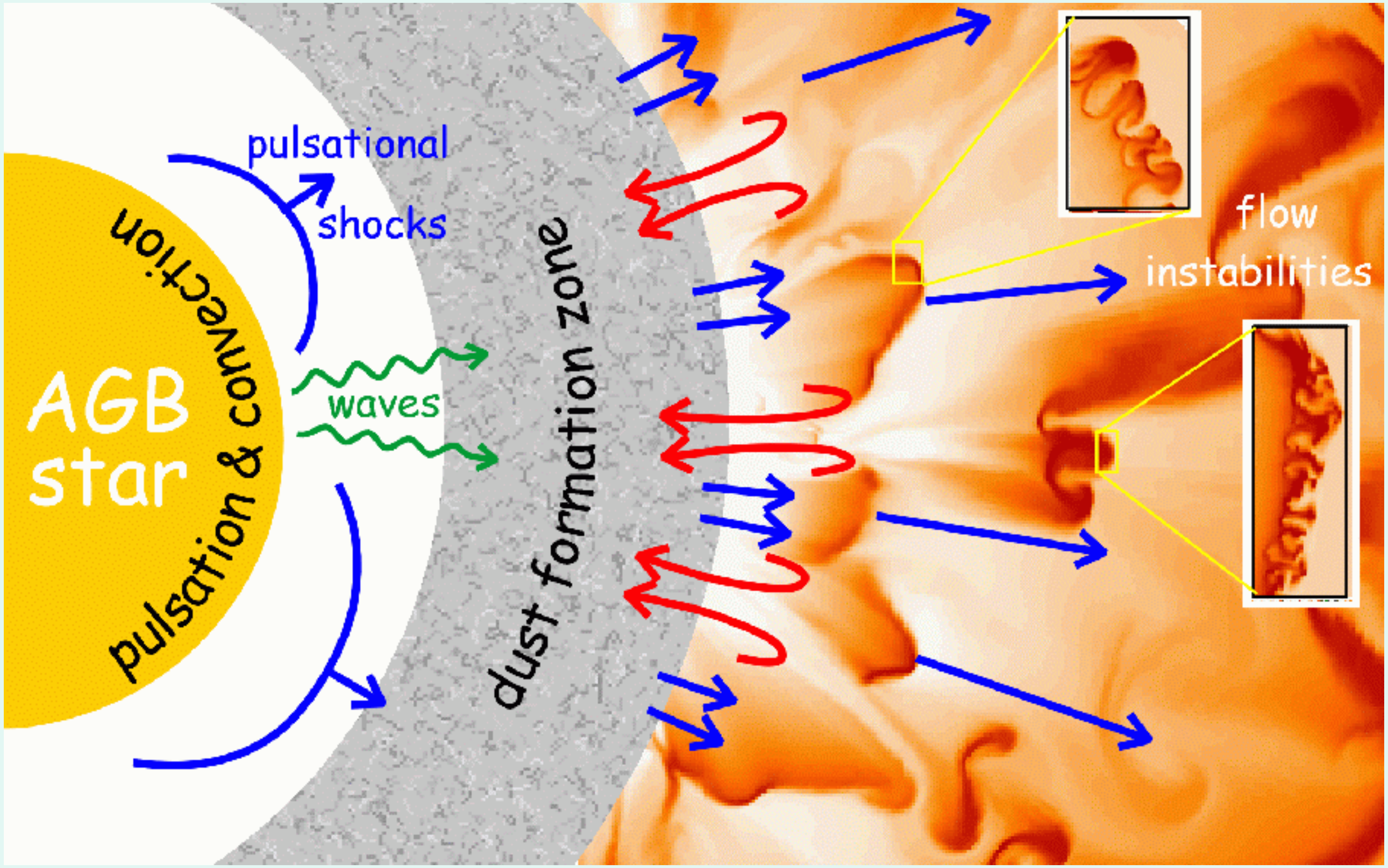
Interstellar dust grains





Small specks of solid matter, millions to billions of molecules.
Range of sizes, but typical size: $d_{dust} \sim 0.4\ \mu m$
These examples (from solar system) are much larger than typical interstellar dust grains
Chemical composition: silicates (like sand) or carbon compounds (like soot or graphite)

Formation of dust in outflowing envelope of red giant star (before planetary nebula phase)

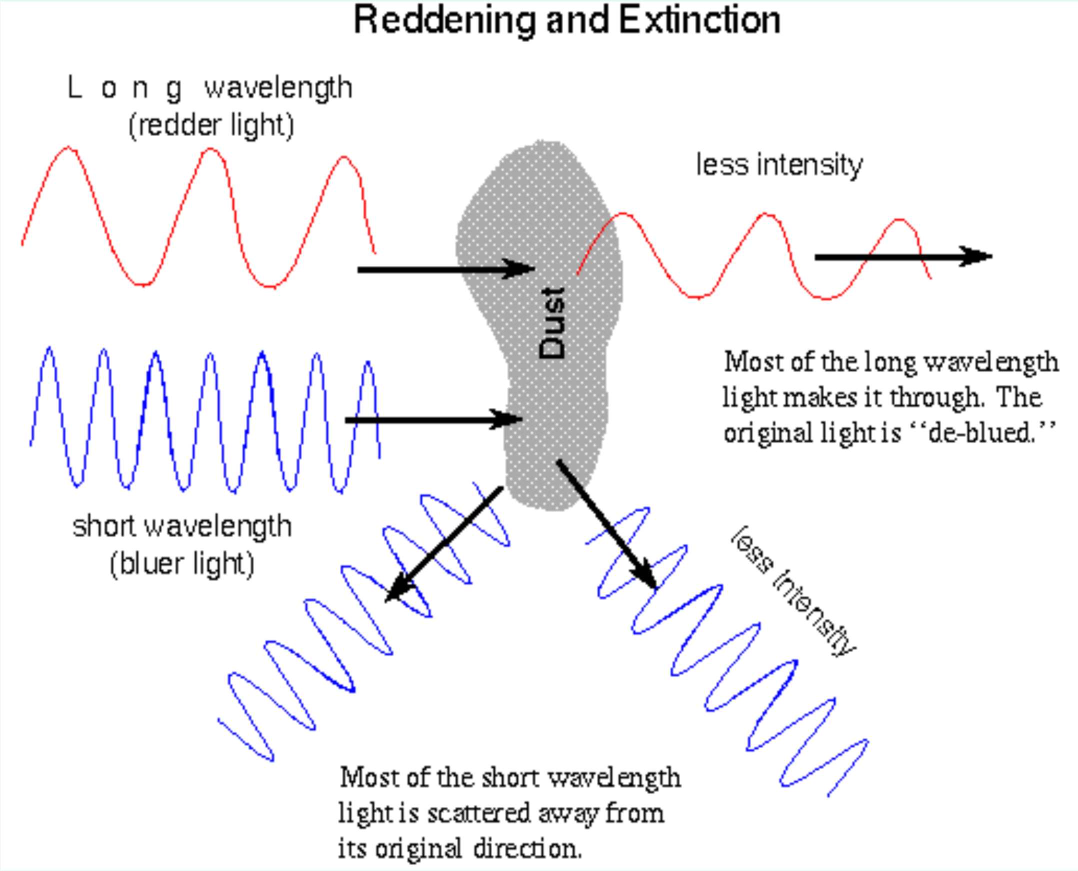


Origin of dust: *ejected outer envelopes of evolved stars*

Ejected gas cools and clumps into particles – as gas cools, it changes from ions to atoms to molecules to clumps of molecules (dust)

Dust: extinction & reddening

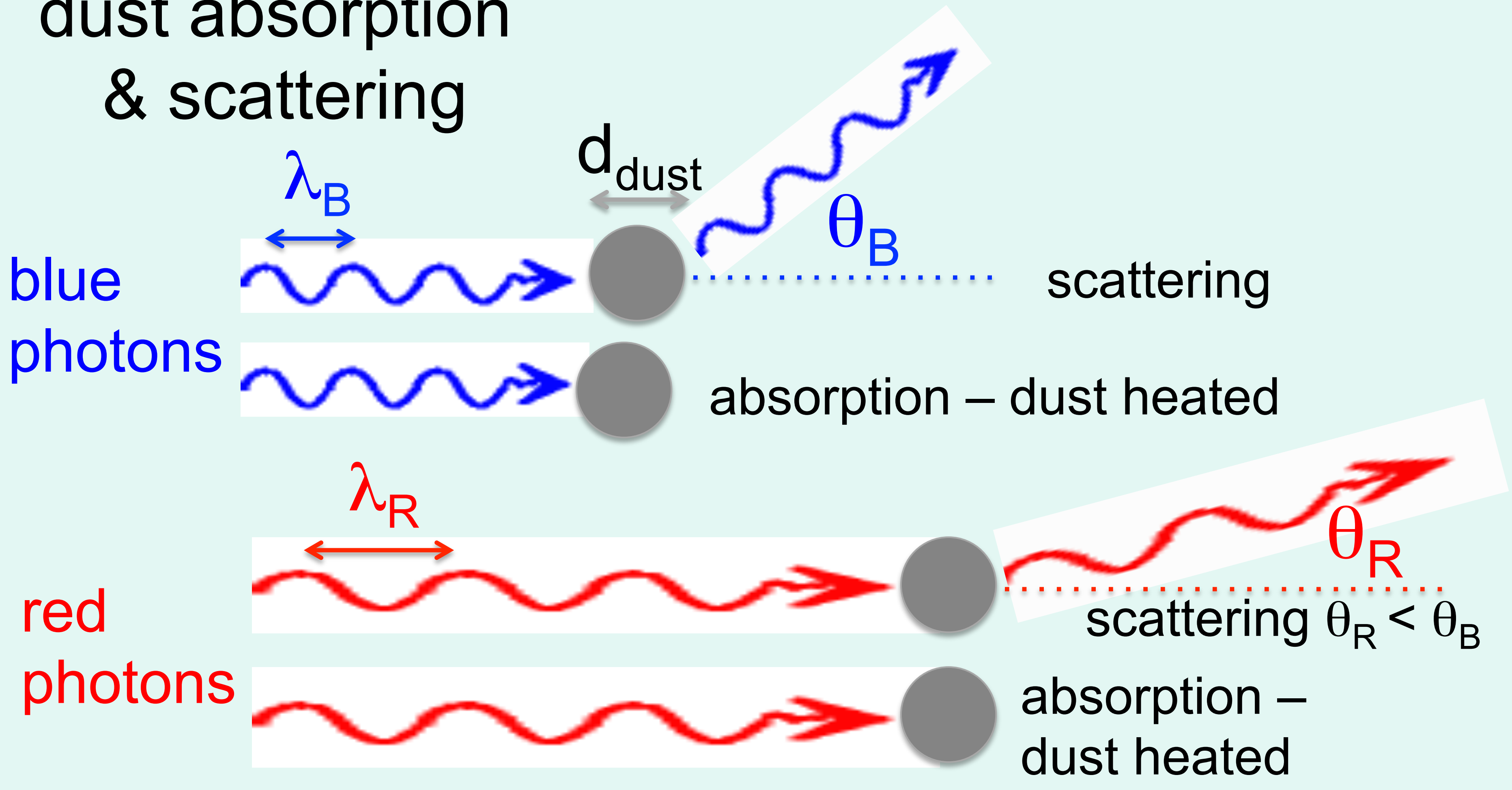
Photons are ***absorbed*** or ***scattered*** in interactions with dust grains (collectively 'extinction')



Extinction highly wavelength-dependent, most effective if $d_{dust} > \lambda$

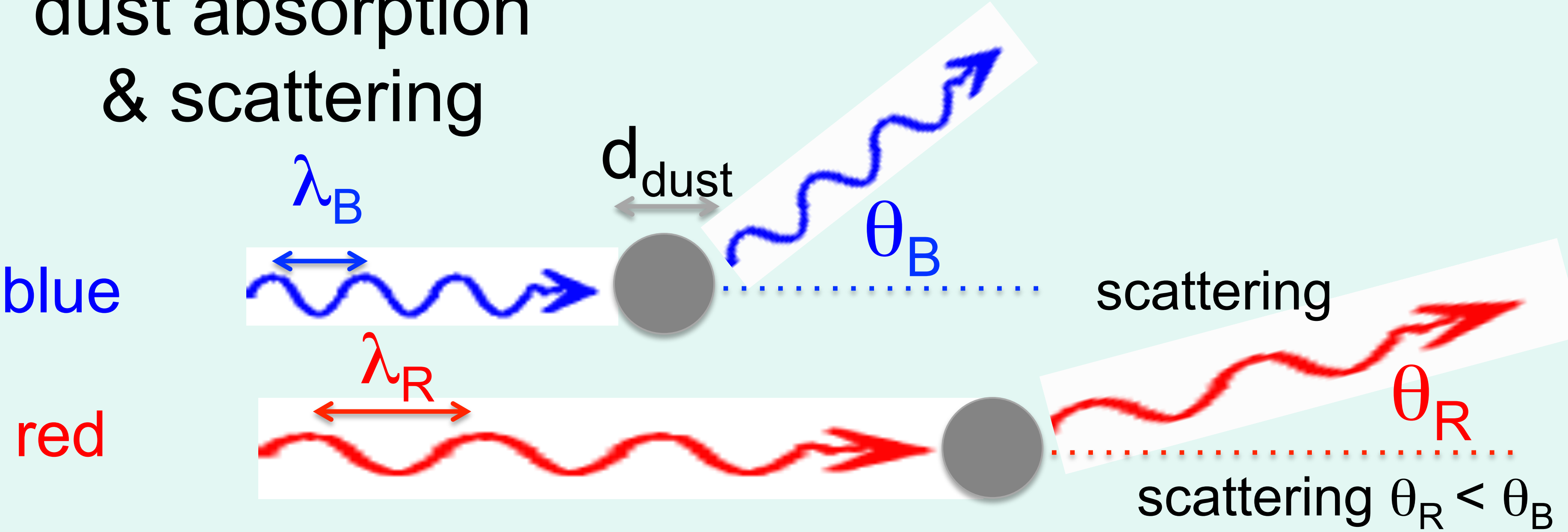
Short wavelength photons more affected than long wavelength photons – leads to 'reddening' of light

dust absorption & scattering



blue photons go shorter distance before being absorbed or scattered, and are scattered by a smaller angle

dust absorption & scattering

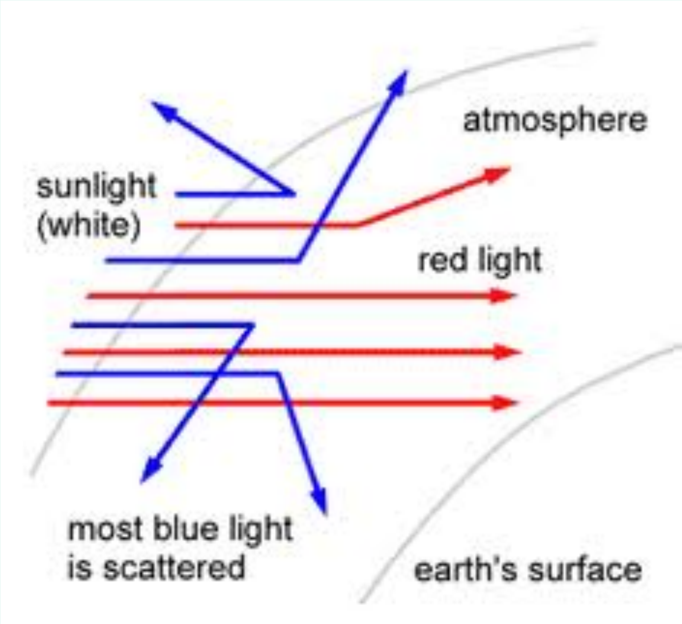


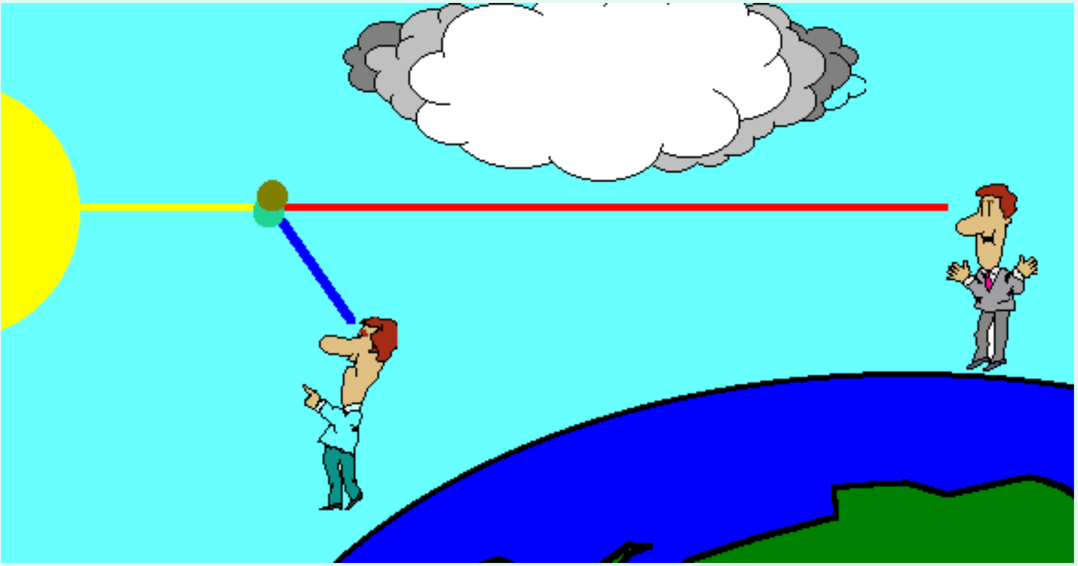
both scattering & absorption very sensitive to wavelength of photon -- **most effective if d_{dust} >= λ**

typical dust $d_{dust} \sim 0.4\ \mu m = \lambda_{Blue}$ so blue light easily scattered & absorbed

but red light with $\lambda_{Red} = 0.7\ \mu m$ has wavelength larger than typical dust particle so is less easily easily scattered & absorbed

Scattering of sunlight by molecules & dust in earth's atmosphere





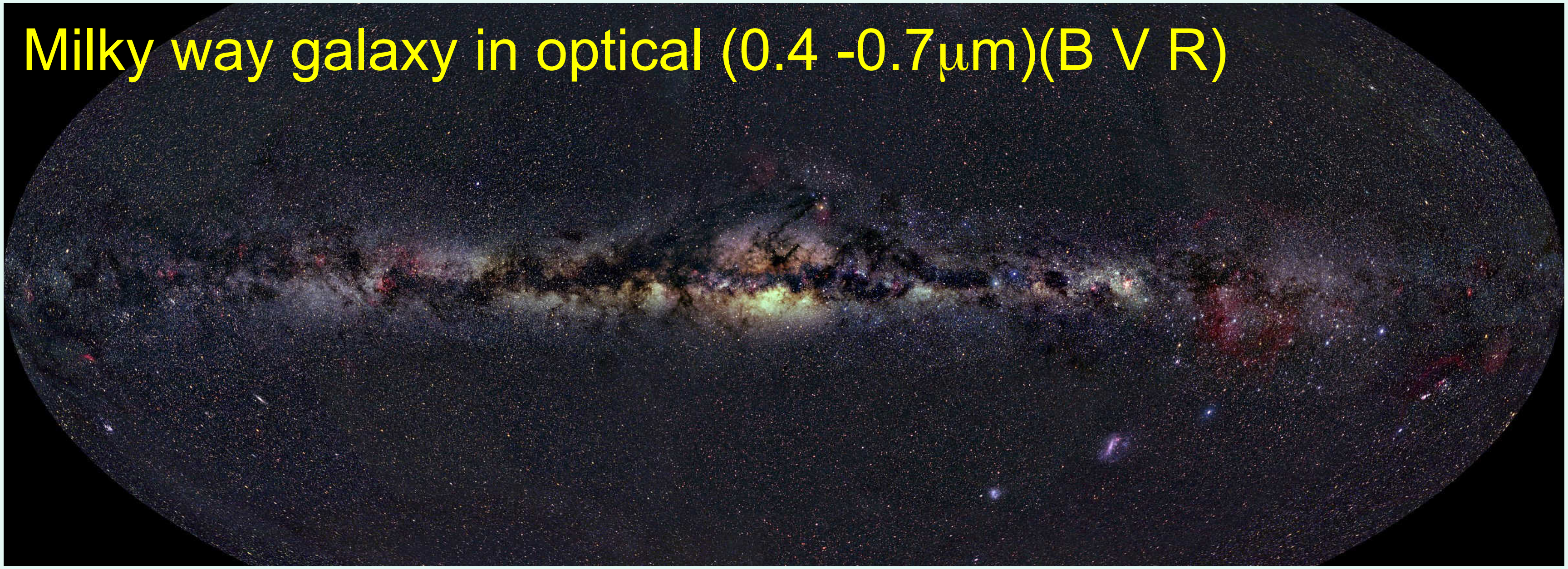
Blue light is scattered more than red light, since it has shorter wavelength

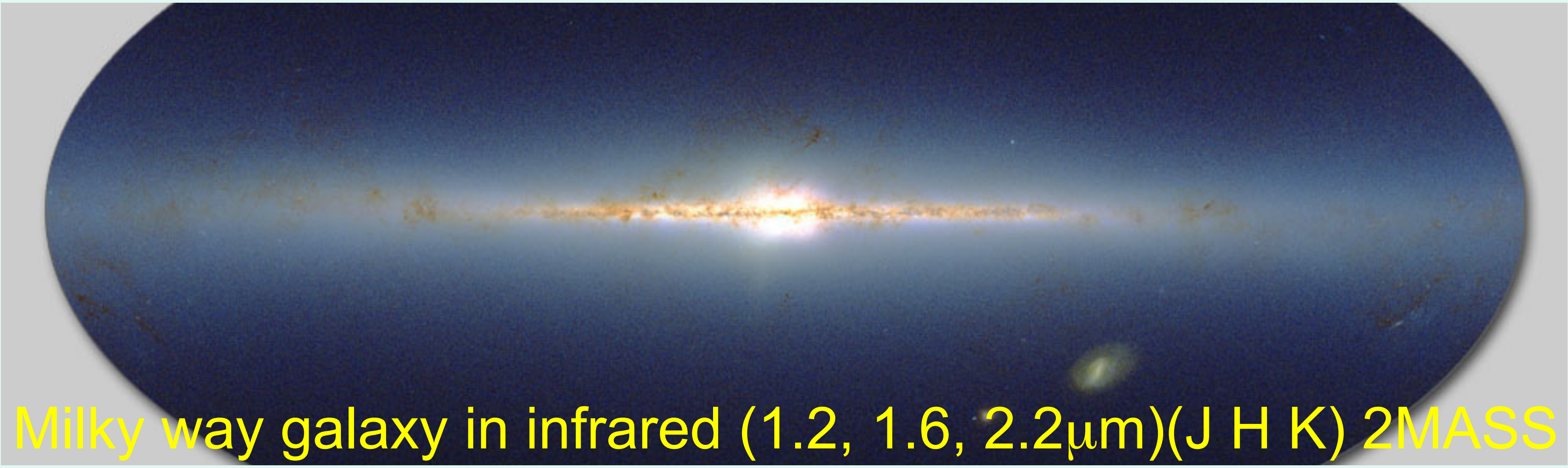
Why sky is blue.

Why sun looks red at sunset & sunrise.

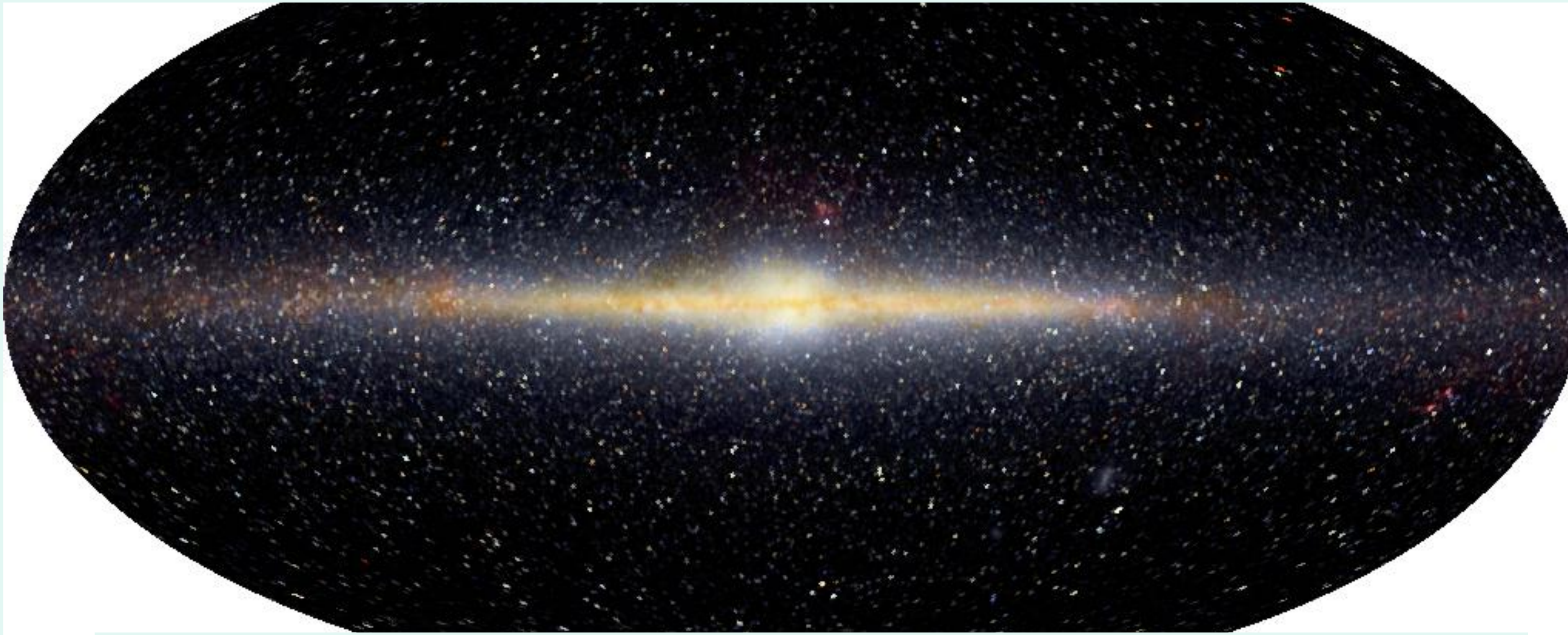
there is so much dust in the MW that even the red light from its stars is heavily obscured…. so how might we get a better view of our Galaxy?

dust extinction & reddening a bigger effect at optical than NIR wavelengths





Milky Way Galaxy in Near-Infrared light



COBE satellite 1.2, 2.2, 3.4 microns

we can see our galaxy more easily if we observe at $\lambda > \lambda_{red}$
near-infrared photons (λ = 1-5 μm) have wavelengths too big to be greatly affected by dust, which has typical size of d ~ 0.5μm

Why do the best IR images come from telescopes in space?

A. In space one is closer to the rest of the universe

B. IR photons travel faster in the near-vacuum of space

C. IR photons travel through dust unhindered

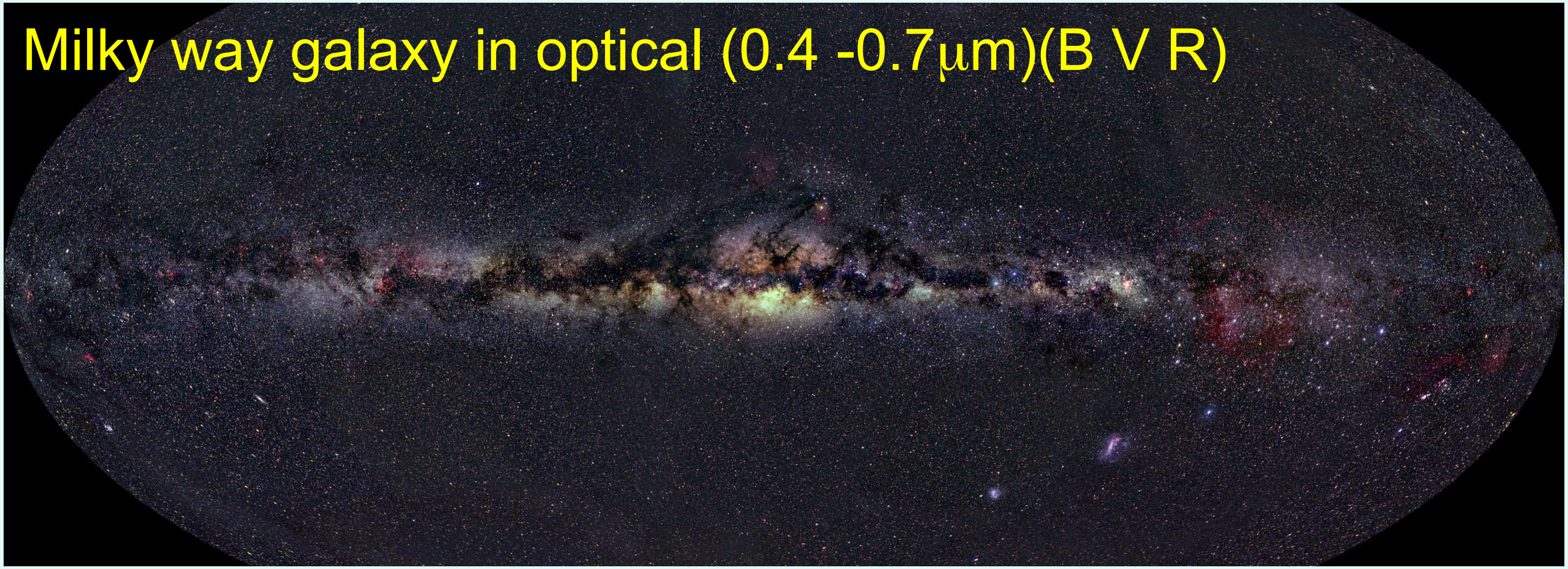
D. Earth's atmosphere is only partly transparent to IR photons (best answer)

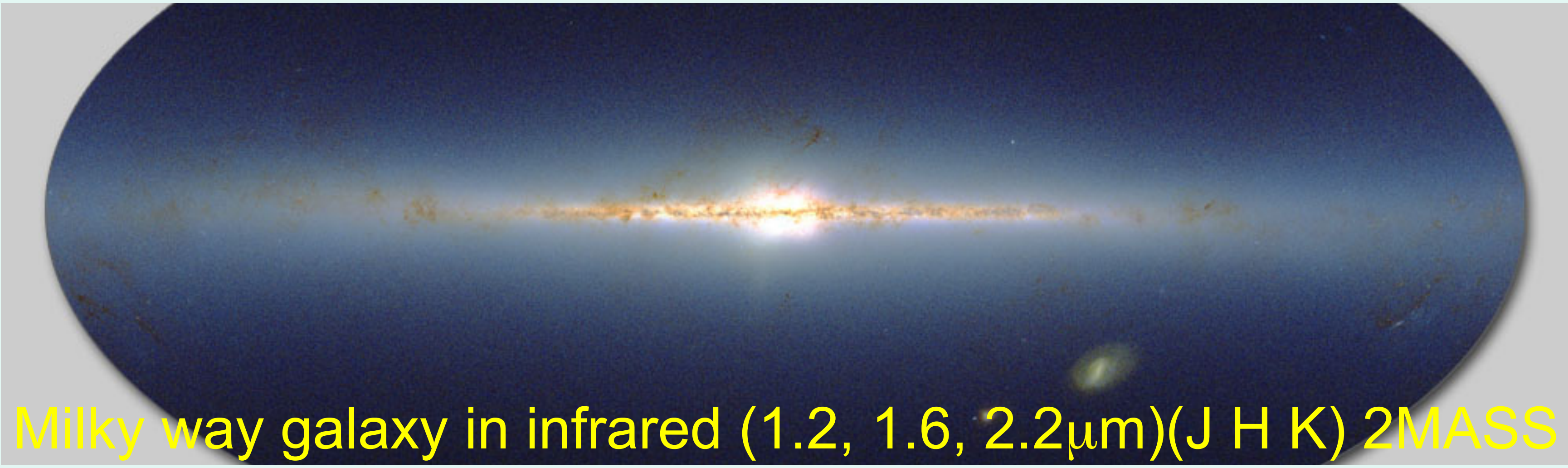
E. Earth's atmosphere causes images to be blurred (pretty good answer)

Why do the best visible light images come from telescopes in space?

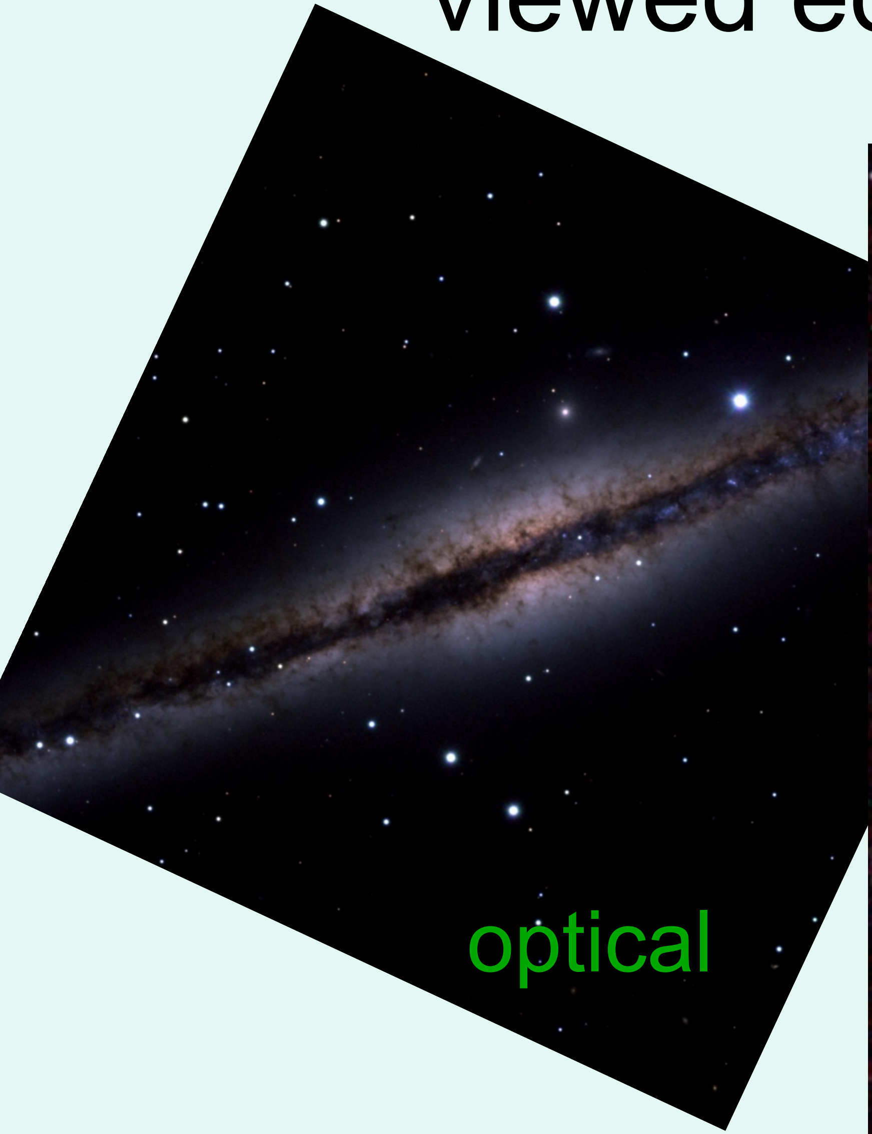
1. It's always dark in space
2. Dust in space scatters light to the telescope
3. Earth's atmosphere is only partly transparent to visible light
4. Earth's atmosphere causes images to be blurred

Milky way galaxy in optical & infrared light

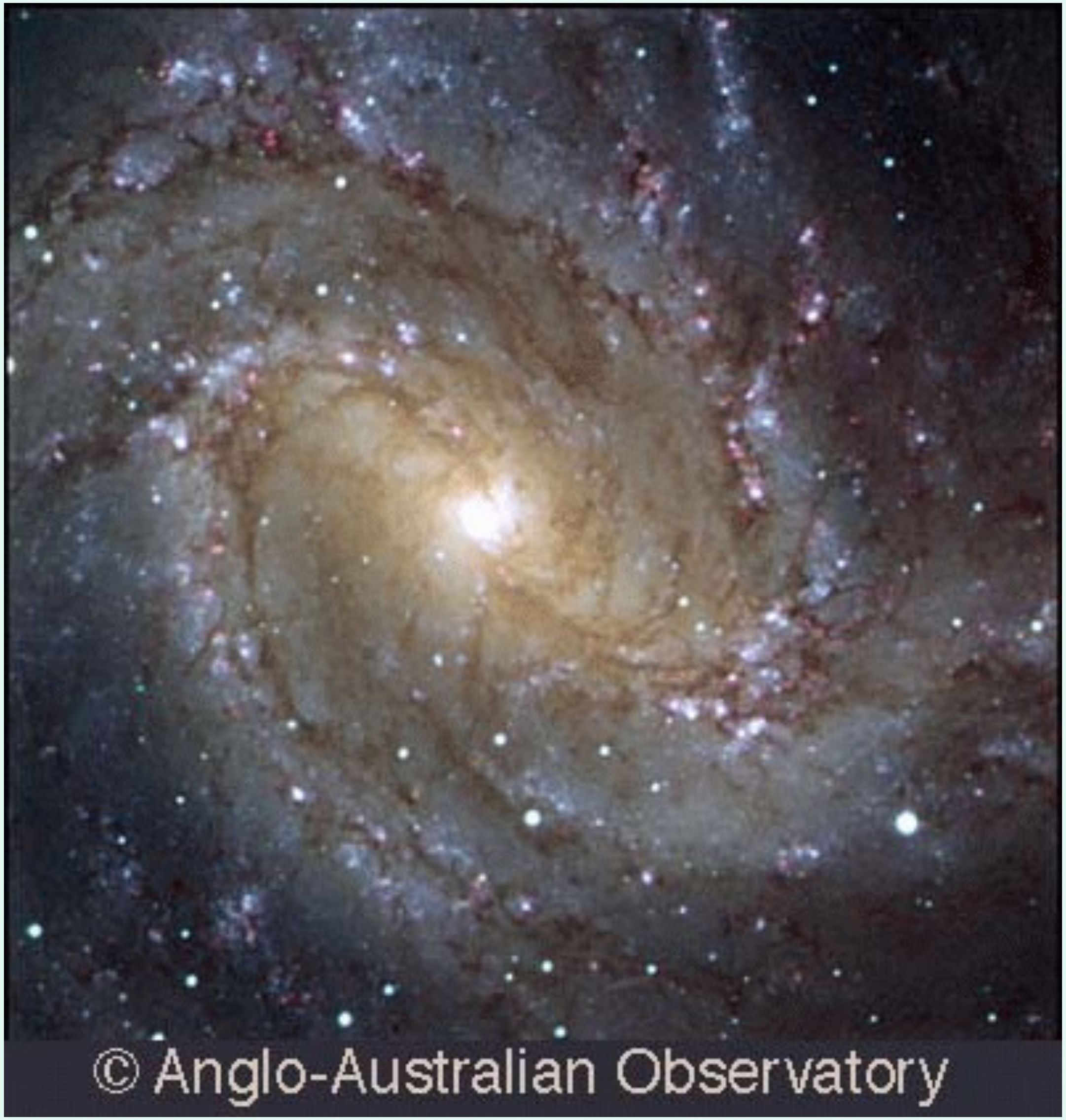




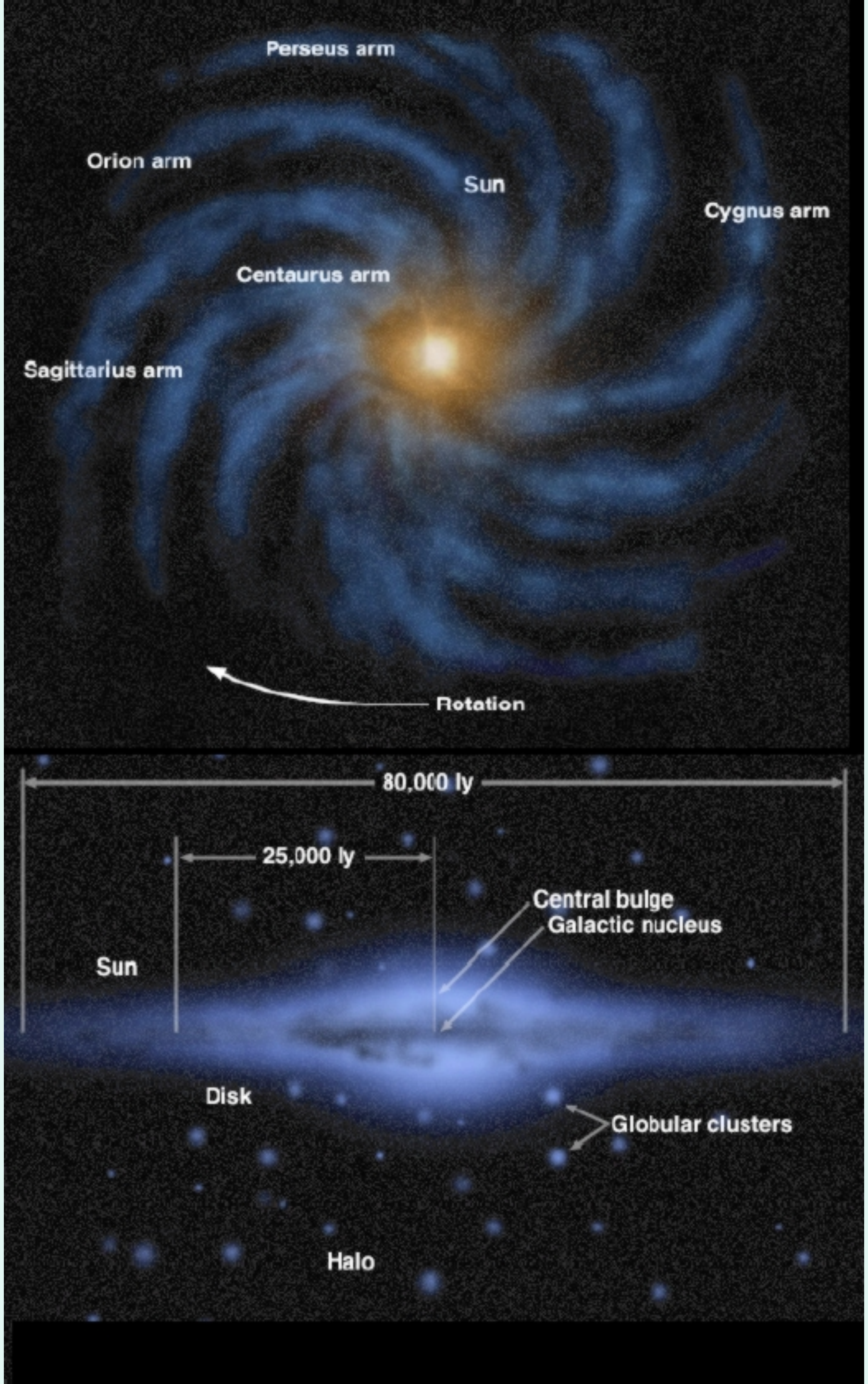
A spiral galaxy like the Milky Way viewed edge-on: NGC 891



M83: A Spiral Galaxy like the Milky Way, viewed Face-on

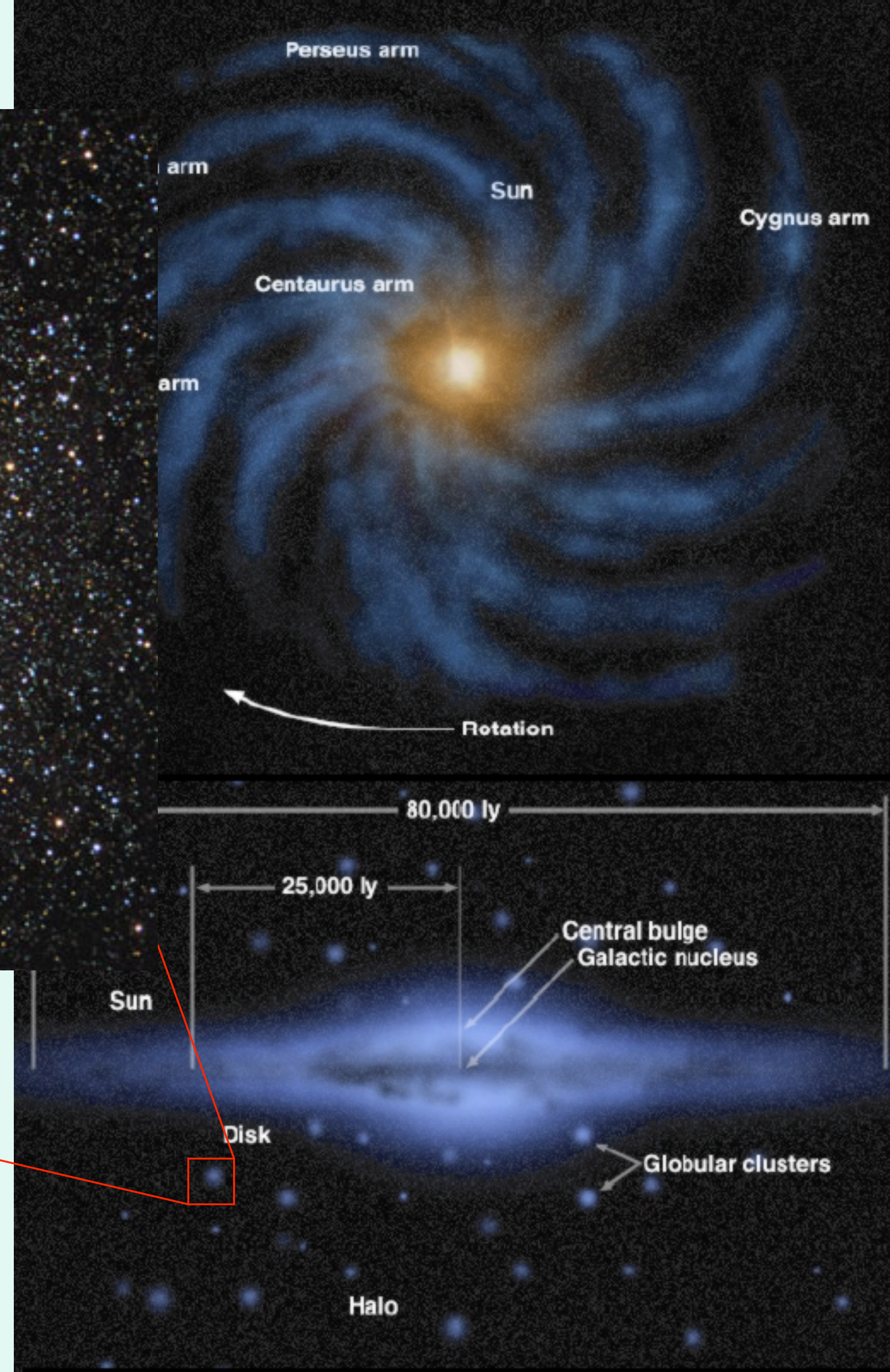


Artist's view of Milky Way Galaxy



Face-on view

Edge-on view



globular star cluster
above disk of Galaxy

Star clusters

- gravitationally-bound groups of stars
- most stars form in clusters
- clusters disperse over time
- little pieces of a galaxy that help us figure out how the galaxy formed

Globular cluster

Large: 10^5-10^6 stars

Open cluster

Small: 10^2-10^3 stars

47 Tuc globular star cluster

Age: 12 Gyr

Mass: 700,000 M_{sun}

Lum: 500,000 L_{sun}

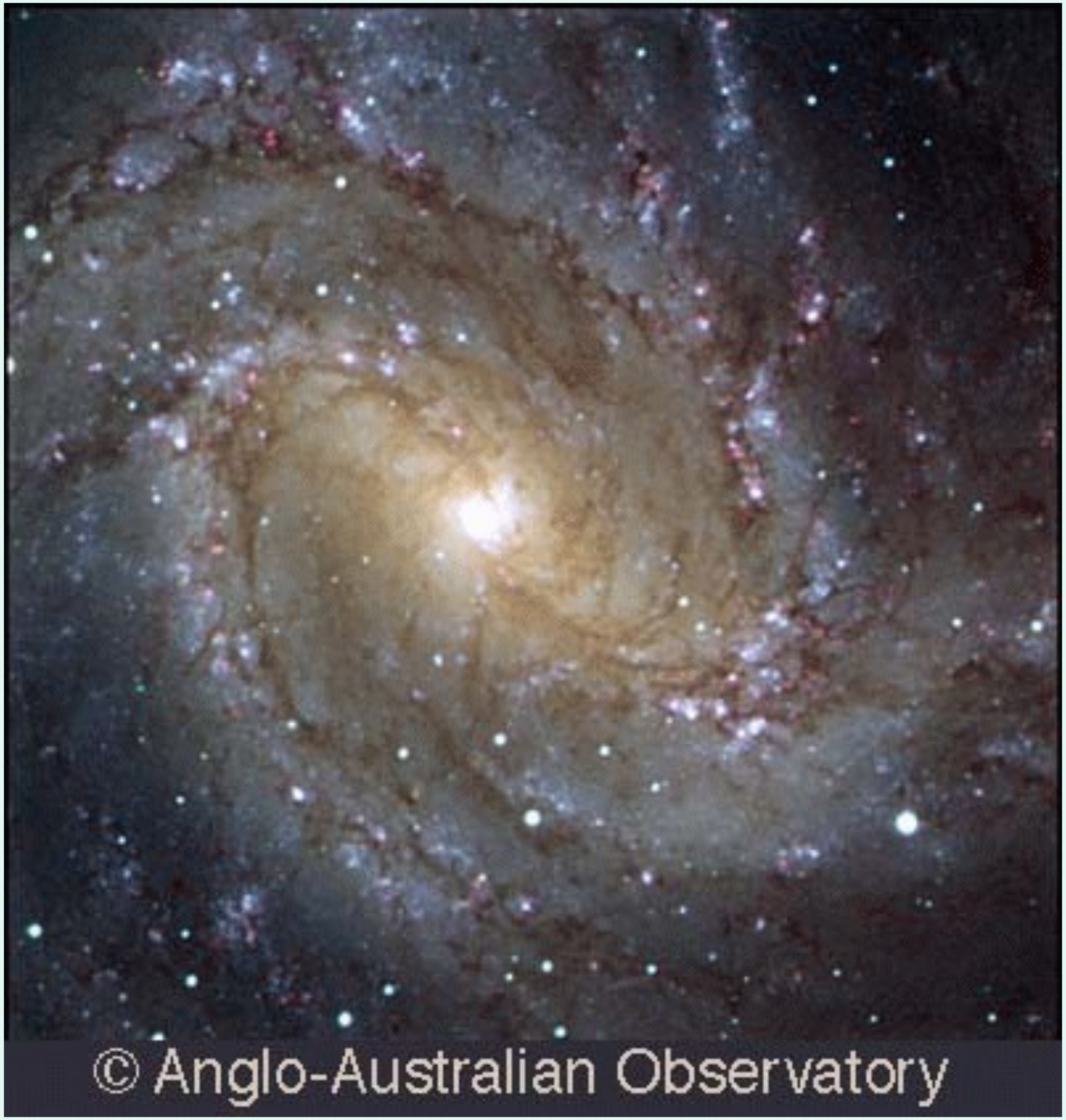
M/L = 1.4 M_{sun}/L_{sun}

Distance: 4500 pc

Rosette nebula – a star forming region which has just made a young Open star cluster

NGC 3603: a star forming region which has just made a young Globular star cluster

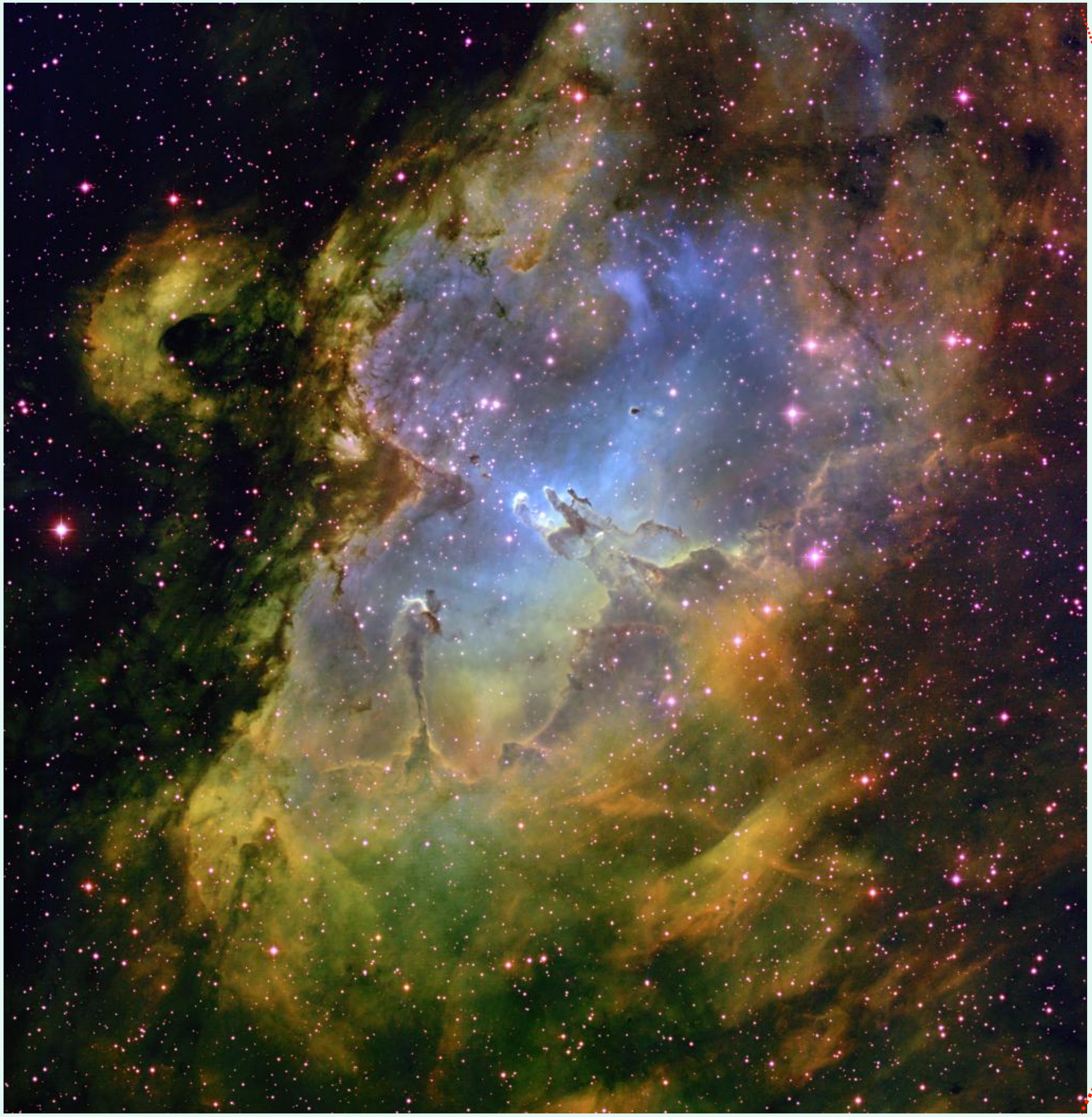
M83: A Spiral Galaxy like the Milky Way viewed Face-on



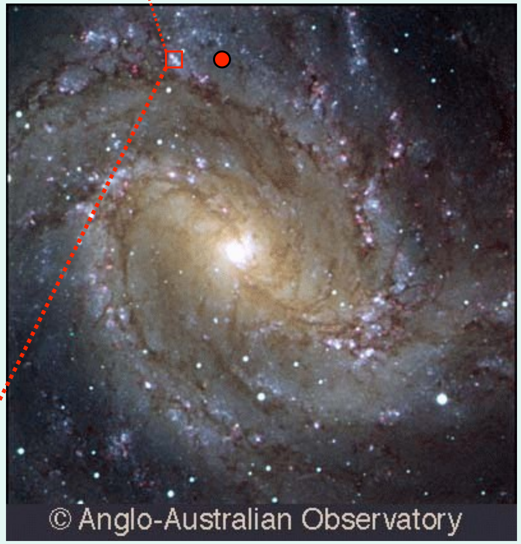
Eagle Nebula:

(in Milky Way)

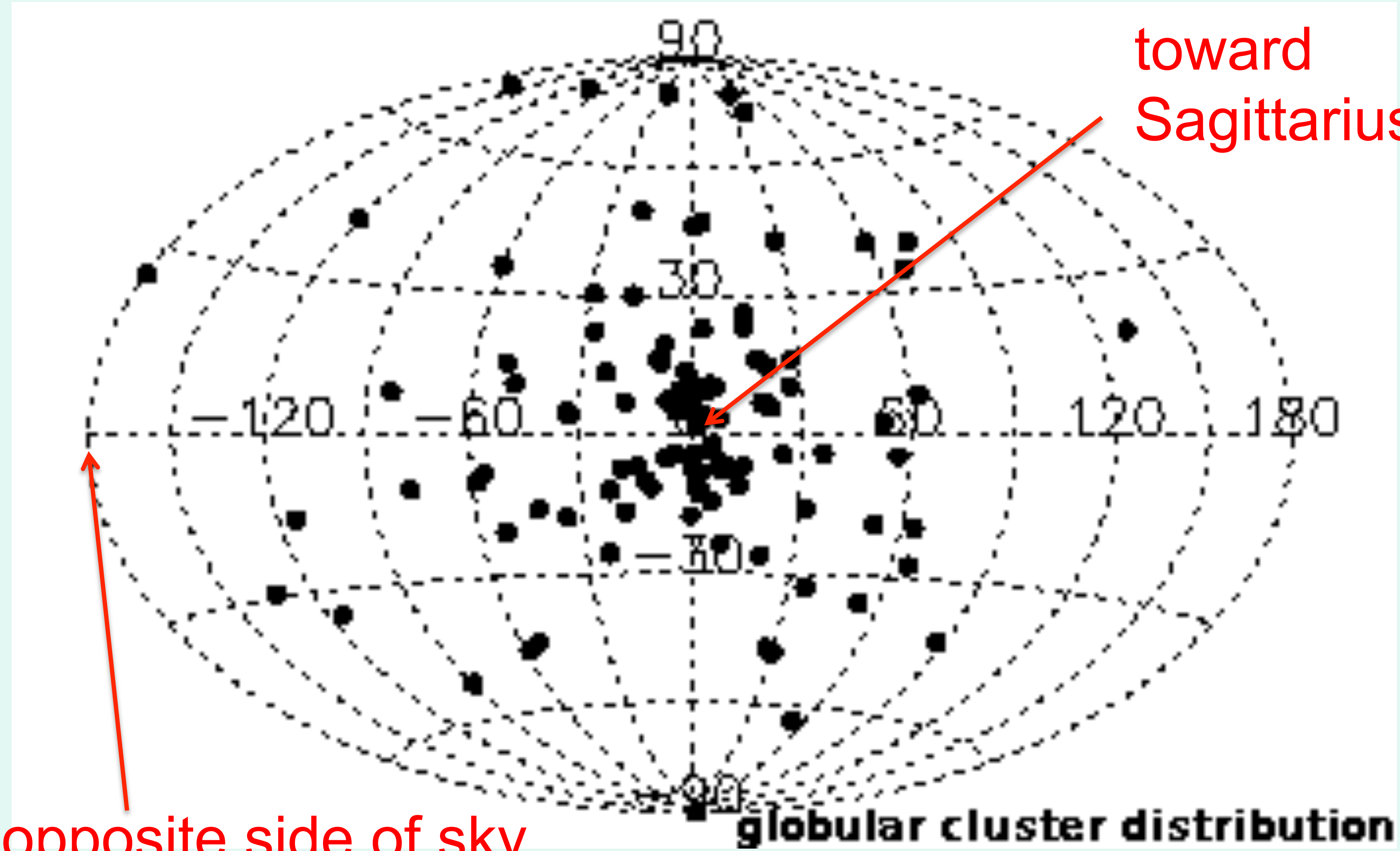
Cloud of Gas & Dust which is forming stars



M83 Spiral Galaxy

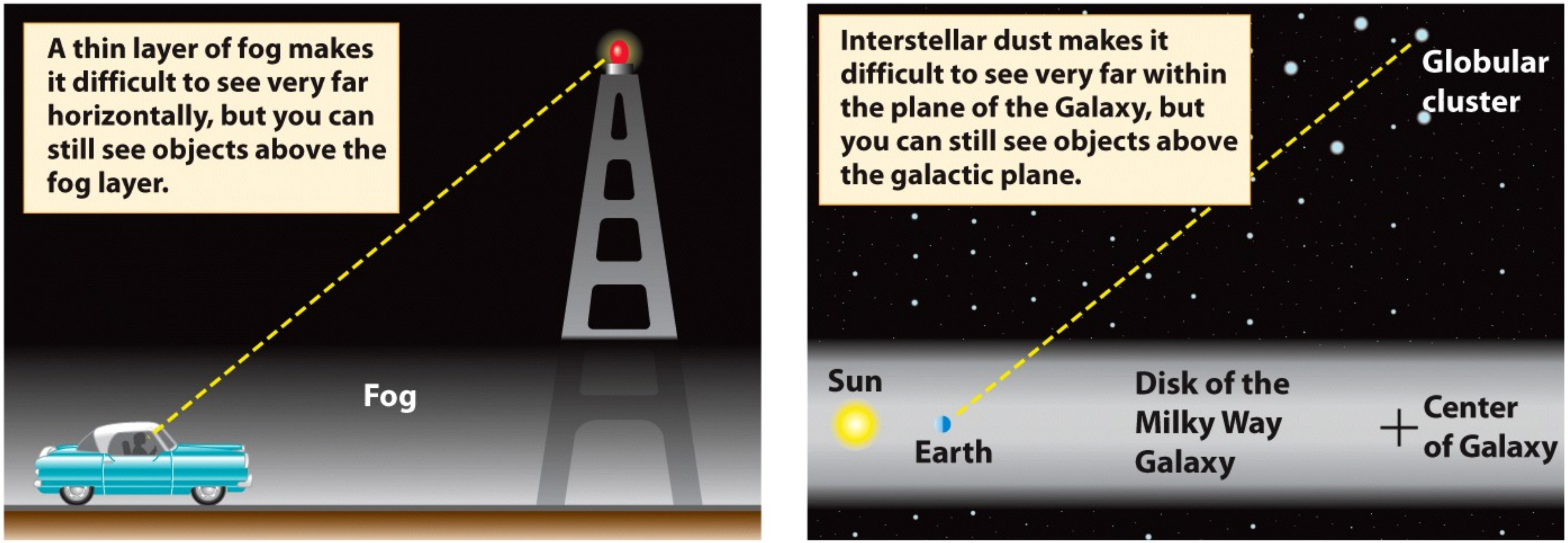


globular cluster distribution on sky



toward Sagittarius

opposite side of sky from Sagittarius



(a) Determining your position in the fog

(b) Determining your position in the Galaxy

Figure 22-3
Universe, Tenth Edition
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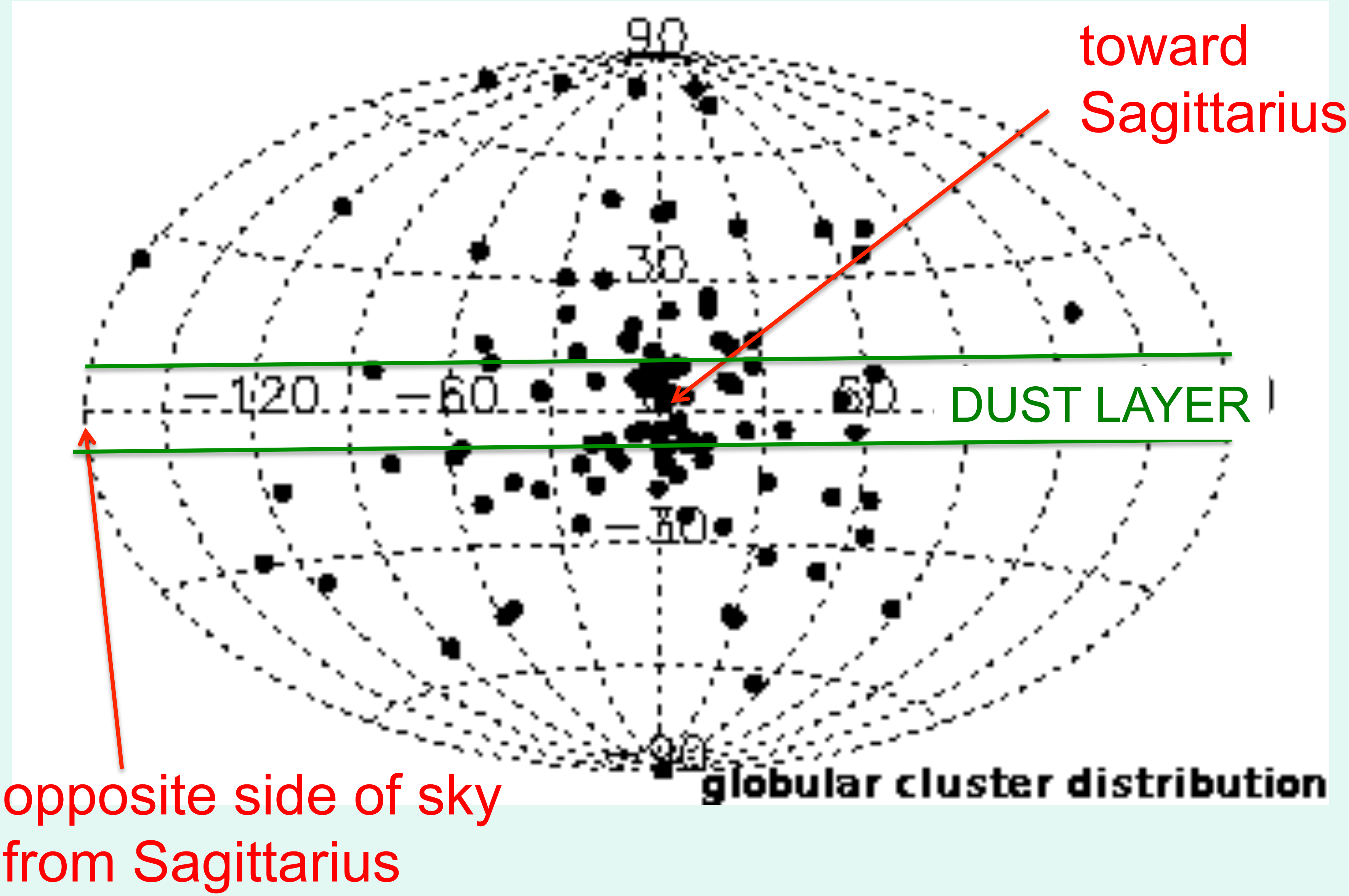
most globular clusters are above the disk plane where dust lies, so dust does not obscure the globular clusters as much as disk stars → can see globular clusters across the Galaxy

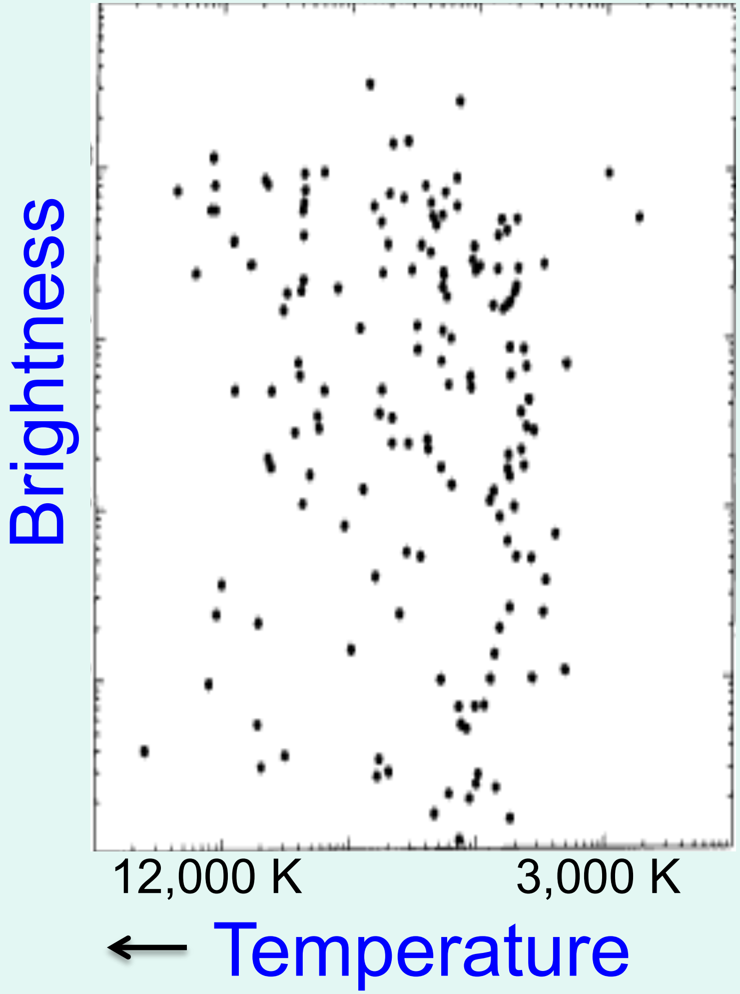
globular cluster distribution on sky



Other than surface temperature, which stellar property can you estimate simply by looking at a star on a clear night?

1. distance
2. diameter
3. density
4. mass
5. luminosity
6. brightness
7. rotation
8. velocity
9. greatness

observe brightness & temperature (color) of ***nearby stars***, put them on brightness-temperature plot…



- you get a scatter plot!
- how do you make an HR diagram ?

Q: how do you get luminosity from brightness?

A: get distance (somehow), use inverse square law: $L = 4\pi d^2 b$

Inverse square law

$$b = \frac{L}{4\pi d^2}$$

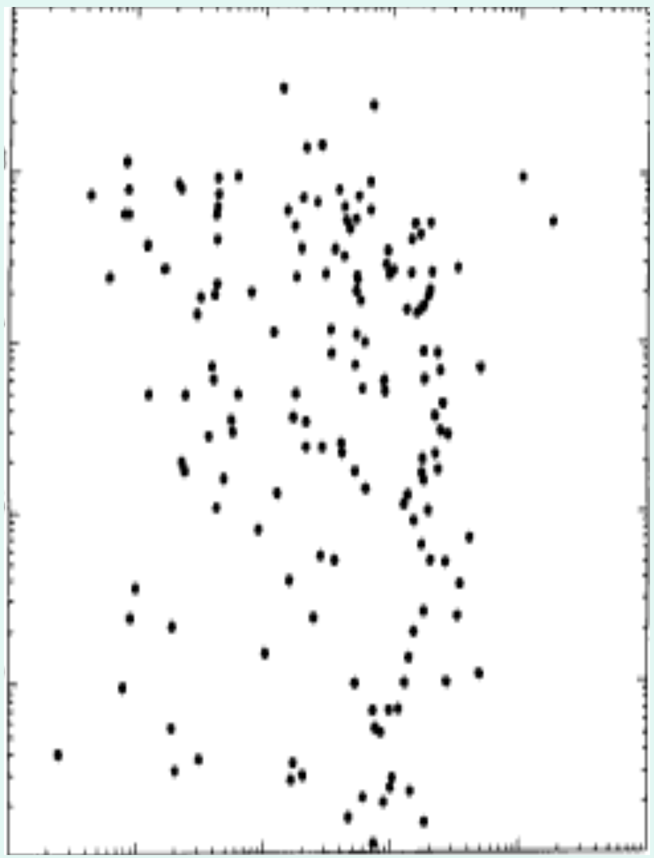
$b = apparent\ brightness\ in\ W / m^2$ = J s^{-1} m^{-2}

$L = Luminosity\ in\ W$ = Joule s^{-1}

$d = distance\ in\ meters$

if you somehow know distances to stars, can calculate luminosity from brightness & distance, and make HR (luminosity-temperature) diagram

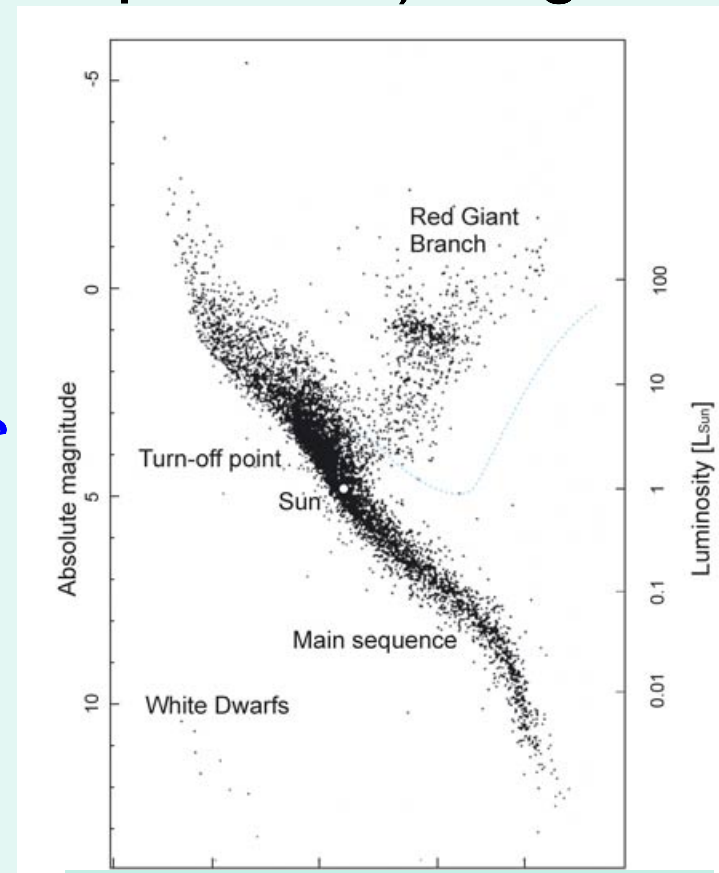
Brightness b



12,000 K 3,000 K

← Temperature

Luminosity = $4\pi d^2 b$

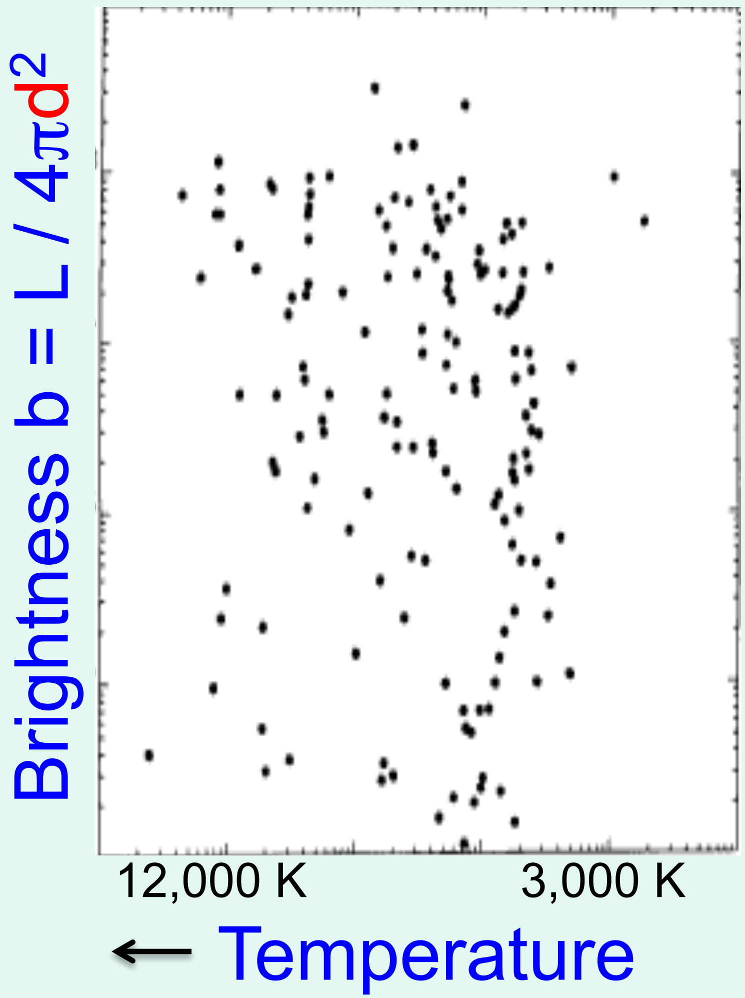


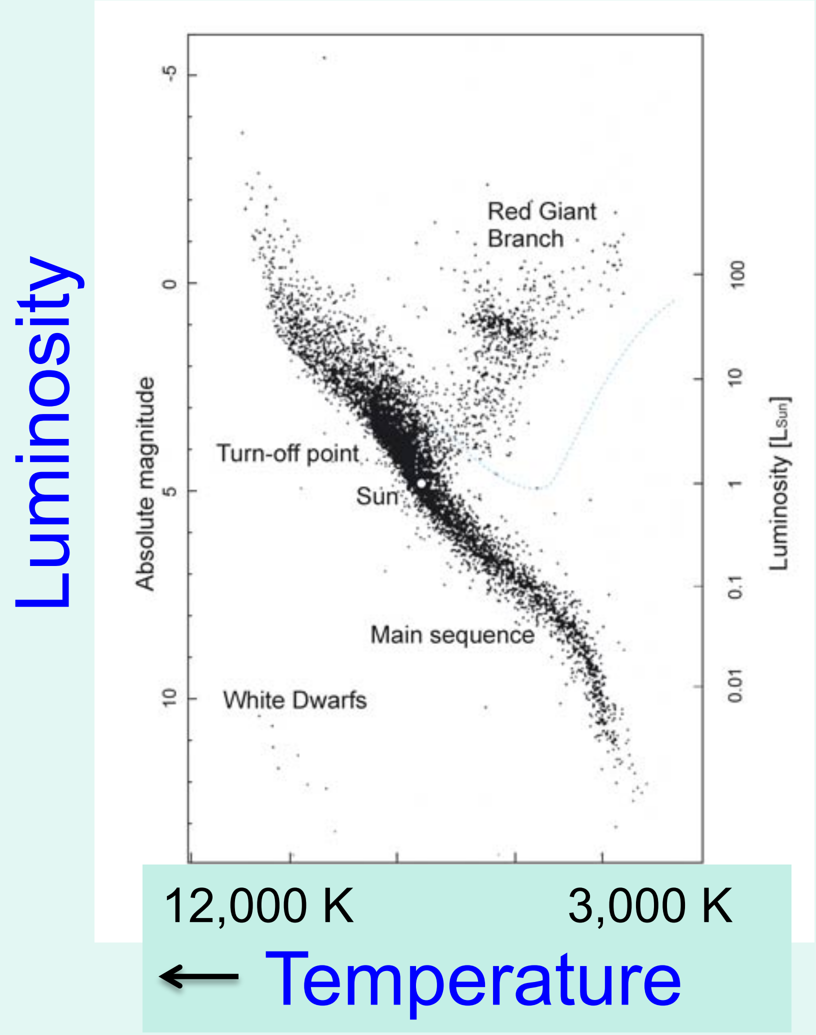
12,000 K 3,000 K

← Temperature

Q: why is the brightness-temperature plot for ***nearby stars*** a scatter plot but the luminosity-temperature plot shows a tight relation?

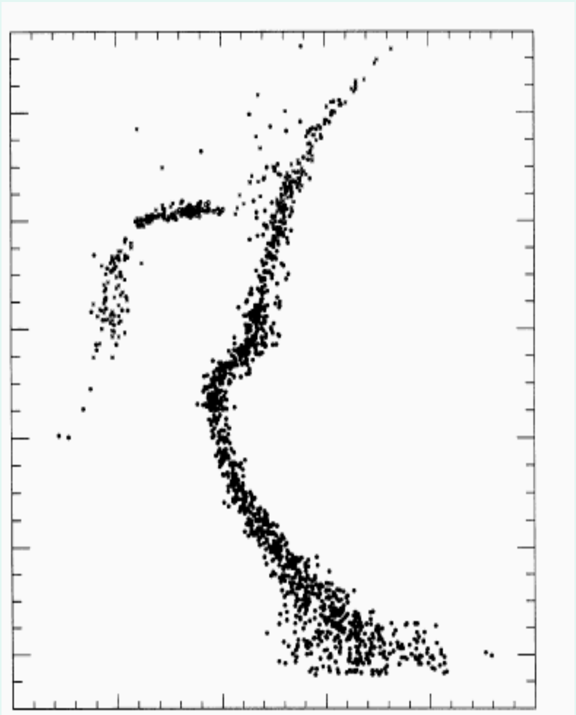
A***: nearby stars are*** at a large range of distances if you somehow know distances to stars, can calculate luminosity from brightness & distance, and make HR (luminosity-temperature) diagram





nearby stars are at a large range of distances d observe brightness & temperature (color) of **stars in *star cluster***, put them on brightness-temperature plot…

Brightness b

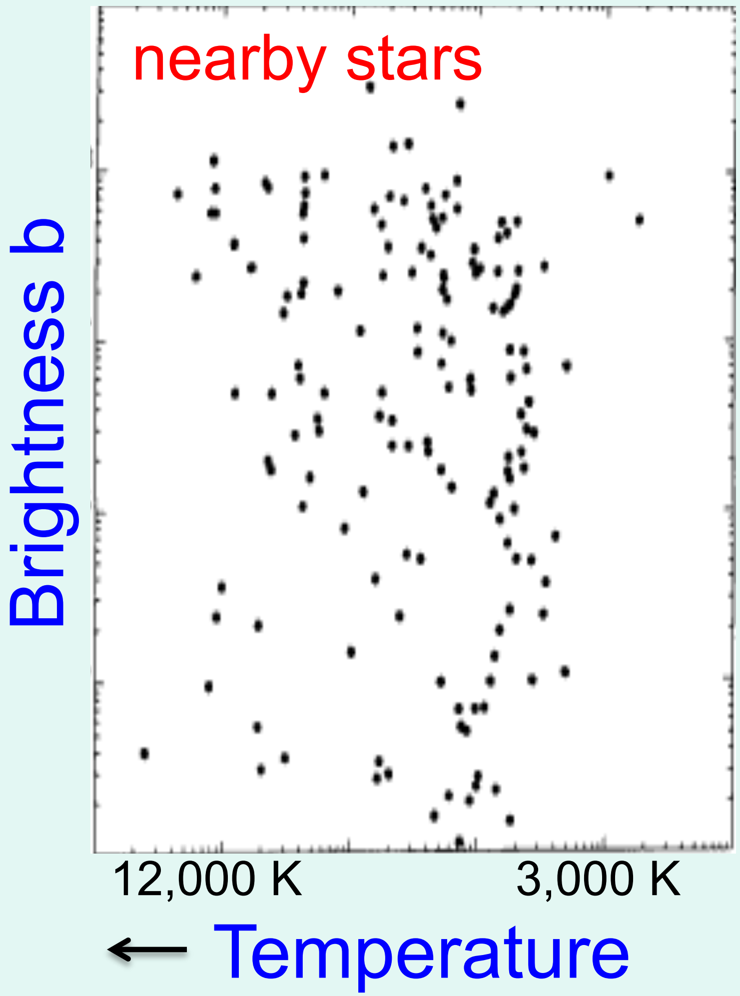


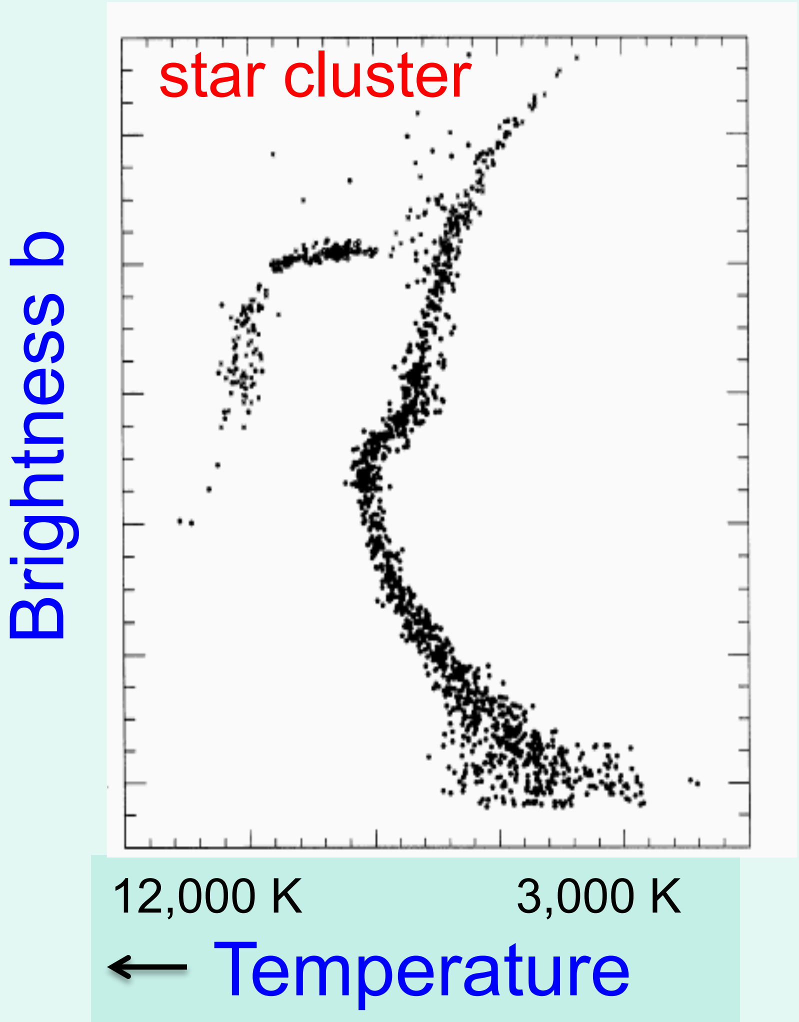
12,000 K 3,000 K

Temperature

- you get a plot that looks like HR diagram!

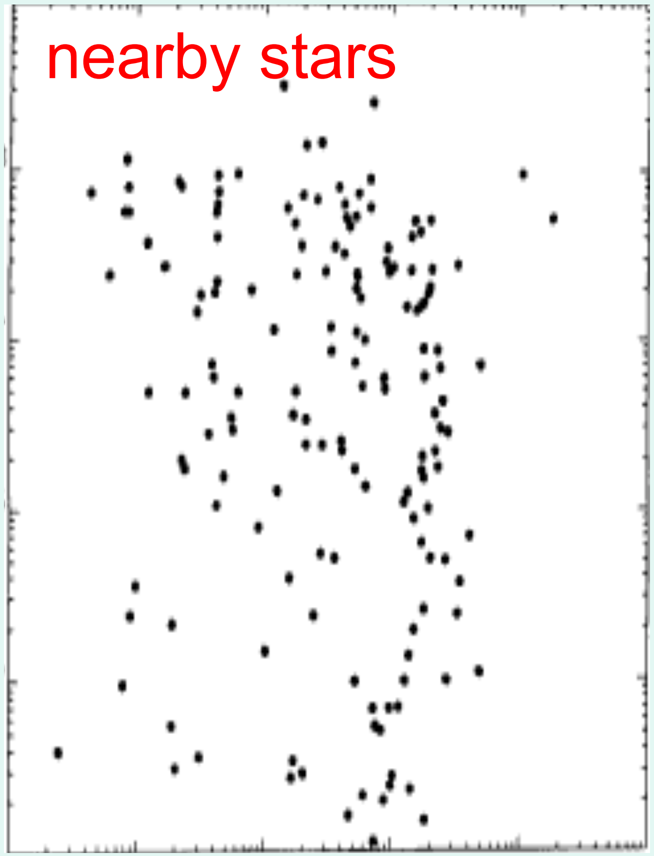
how is a ***star cluster*** different from ***nearby stars?***





how is a ***star cluster*** different from ***nearby stars?***

Brightness b

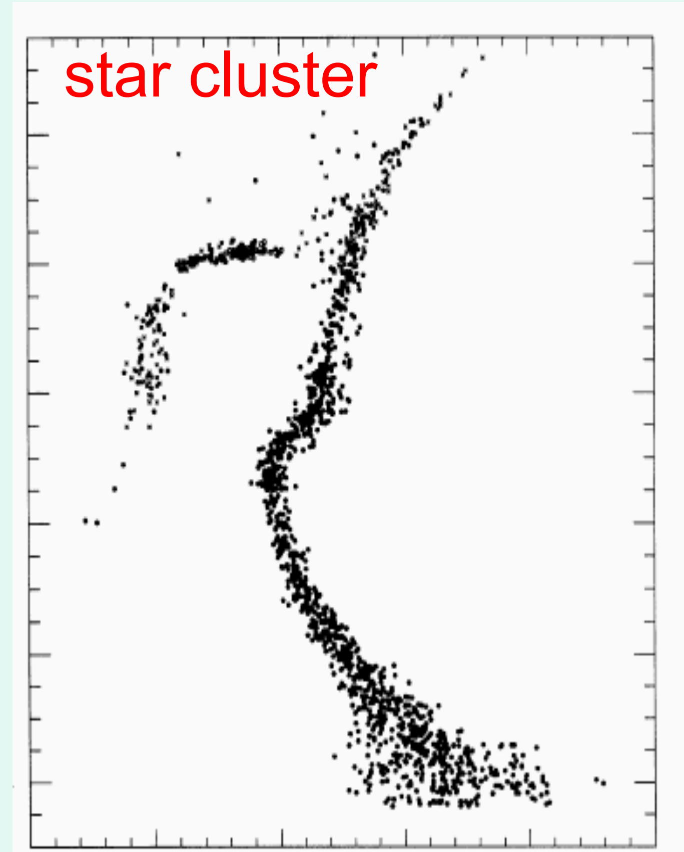


12,000 K 3,000 K

← Temperature

large range of distances

Brightness b

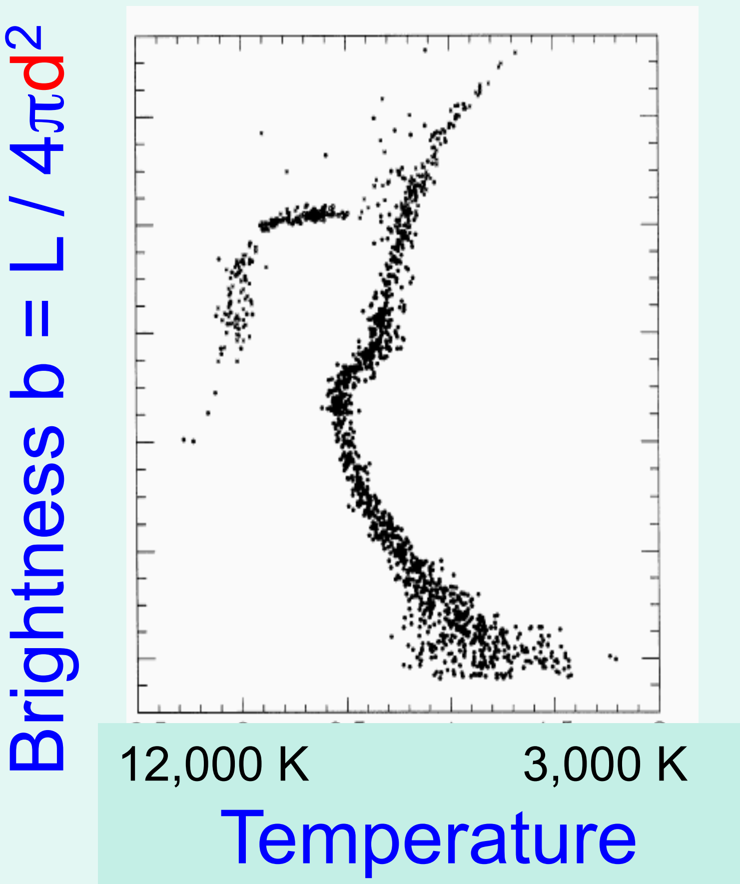


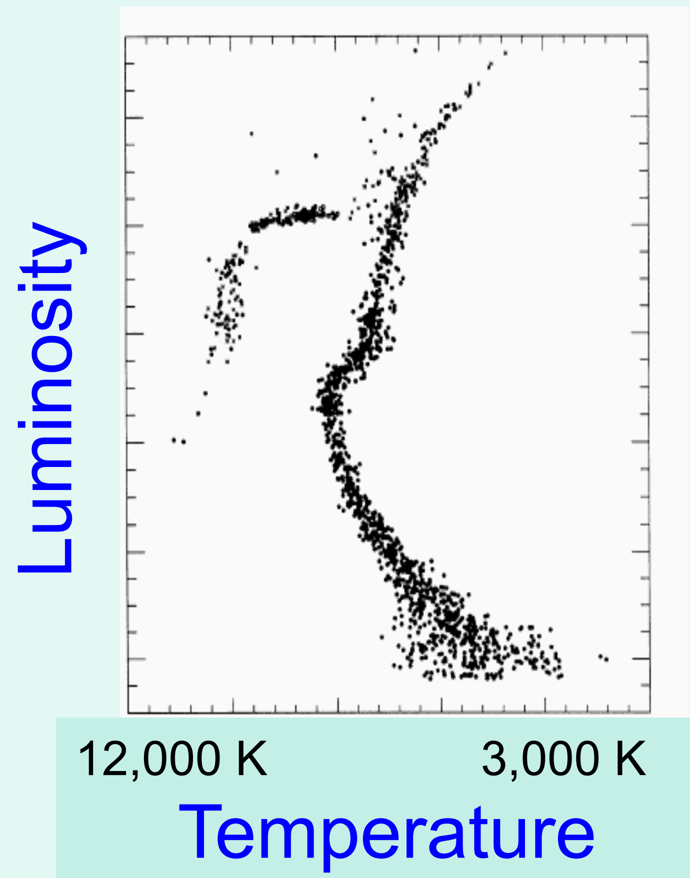
12,000 K 3,000 K

← Temperature

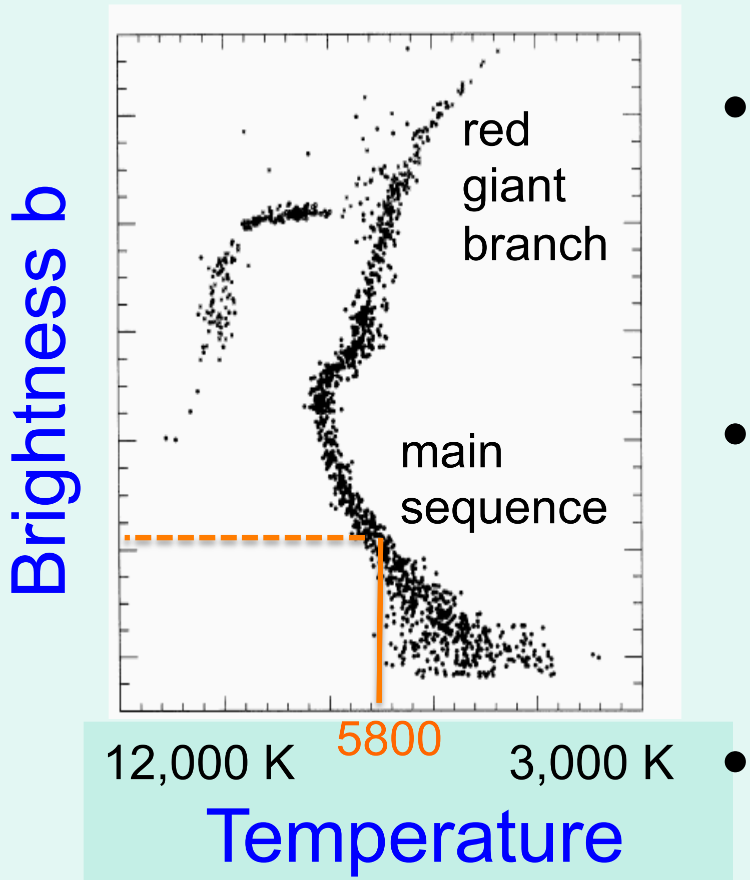
all at ~same distance

brightness vs. temperature and luminosity vs. temperature plots of **stars in *star cluster*** look the same, since all at ~same distance d

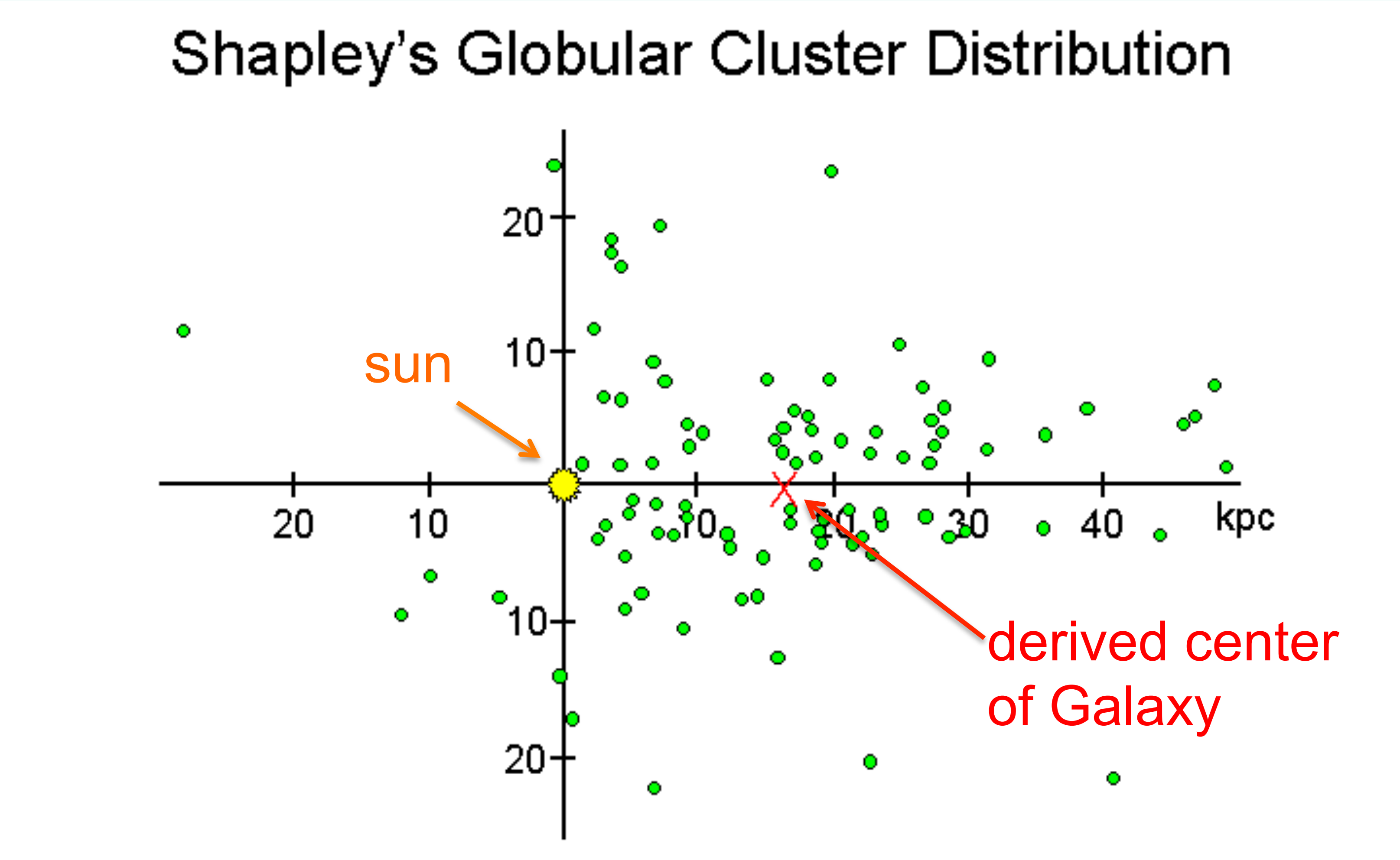




vertical axis is different, but relative distribution of stars is the same we can use brightness - temperature diagram plus knowledge of stellar temperatures and luminosities, to learn **distance** to star cluster!



- we know that main sequence stars with T=5800K have L= 1 L_{sun}
- we read the brightness of cluster MS stars with T=5800K from b-T plot
- we use d = sqrt $(L/4\pi b)$ to get distance to cluster!



Shapley (1920's) obtained rough estimate of size and shape of our Galaxy by estimating distances to globular star clusters (his distance to galactic center too high by factor or 2, but his answer pretty good for its time…)

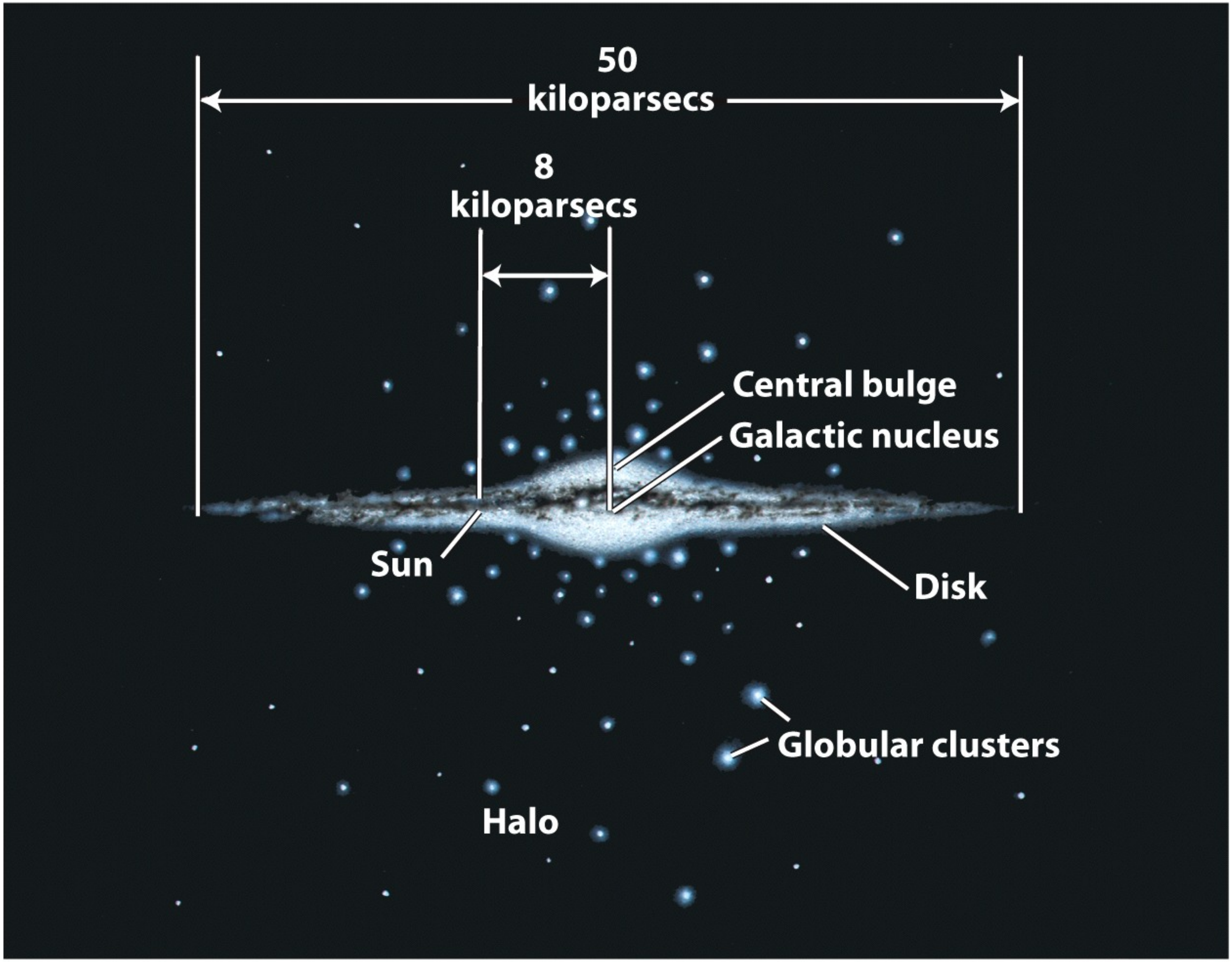


Figure 22-7
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differences in textbook editions…10th ed vs 8th & 9th ed

- all chapter assignments starting with ch 21 on are shifted by 1 in 10th edition relative to 8th, 9th editions (neutron stars had own chapter 21 in 8th & 9th, in 10th is part of ch 20 on “deaths of stars”)

- e.g. black holes ch 22—>21 (8+9th → 10th)
- e.g. our galaxy ch 23—>22 (8+9th → 10th)

- updated syllabus on class website
- different syllabi for 10th vs 8+9th editions
- “sec 0” means stuff before section 1