Galactic and Extragalatic Astronomy
AA 472/672
Spring Semester

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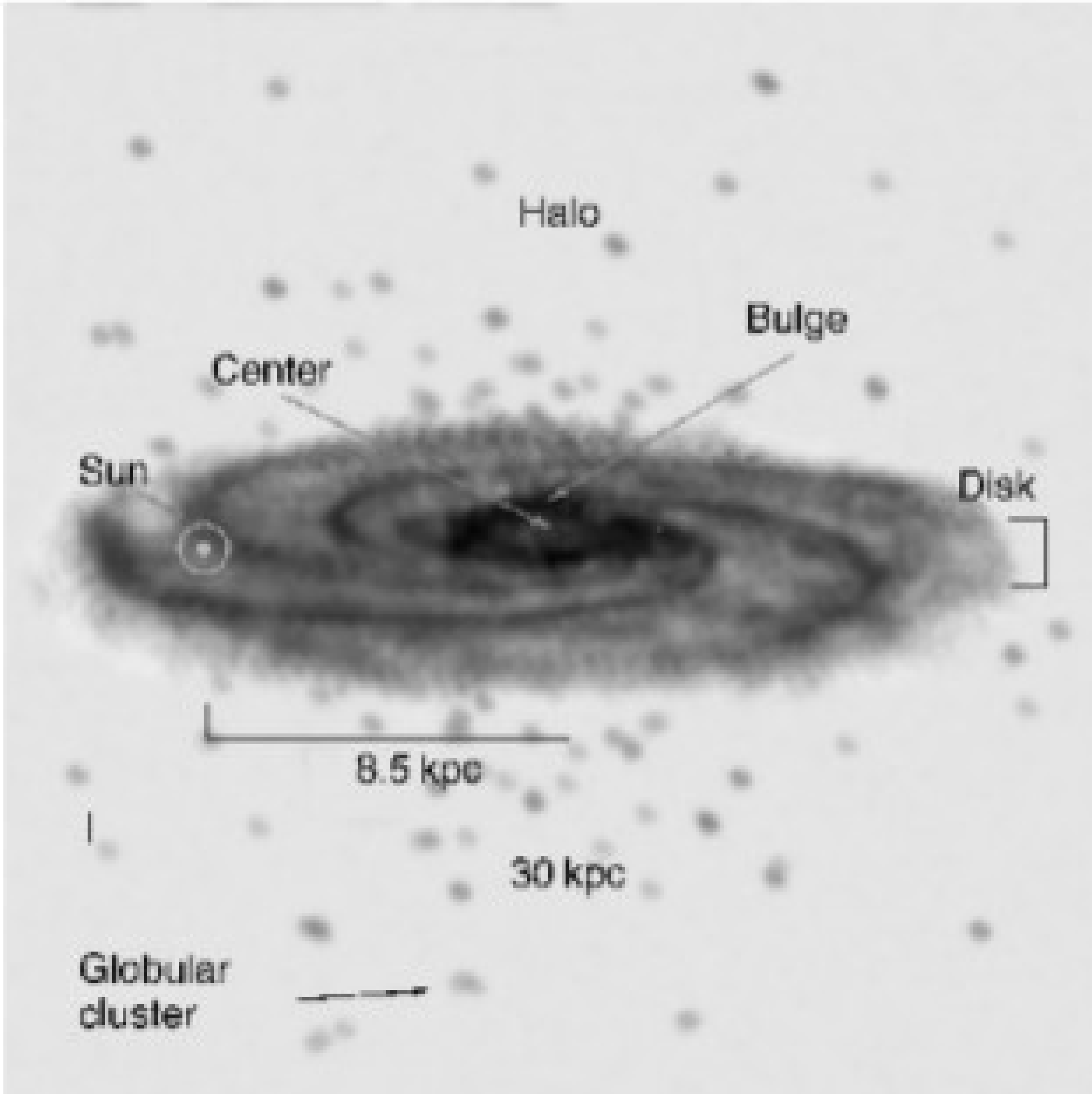
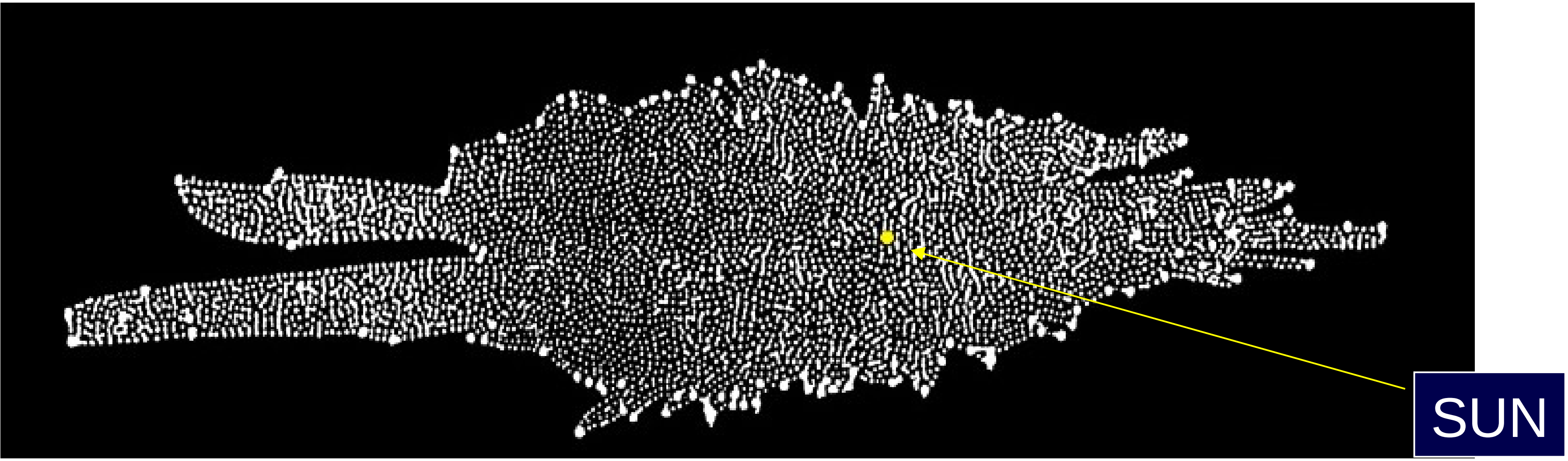

Halo
Bulge
Center
Sun
Disk
8.5 kpc
30 kpc
Globular
cluster

History of Galactic (& Extragalactic) Astronomy

- 1785 - Herschel attempted to determine the shape and size of Galaxy
  Assumptions:
  - All stars have same intrinsic brightness
  - Star are arranged uniformly throughout the MW
  - He could see to the edge of the MW



Herschel could not account well for the effects of dust.

More dust along the disk causes the distribution of stars to drop-off artificially – objects more than a few kpc from the Sun are obscured by dust.

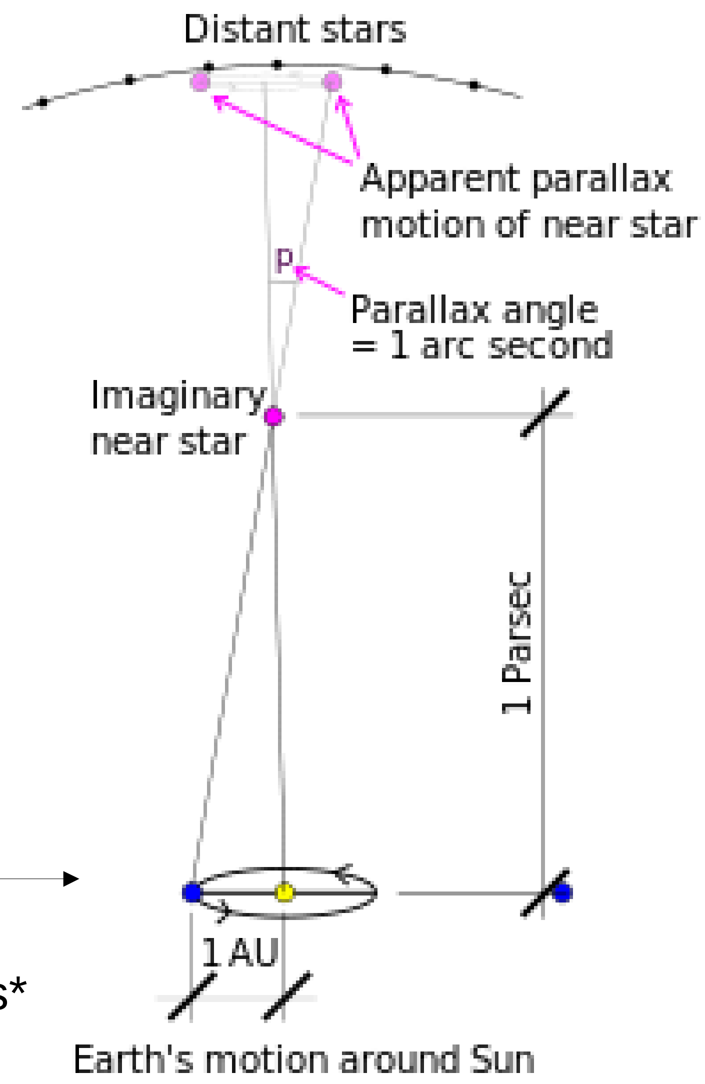
Units of Distance in Astronomy:

- Astronomical Unit (AU) = 93 million miles or 1.5×10^8 km
- Distance between Earth and Sun

- Light Year = 9.4×10^{12} km
- Distance light travels in one year

- Parsec = 3×10^{13} km
- (or 3.2 light years)

- pc (parsecs)
- kpc (kiloparsecs)

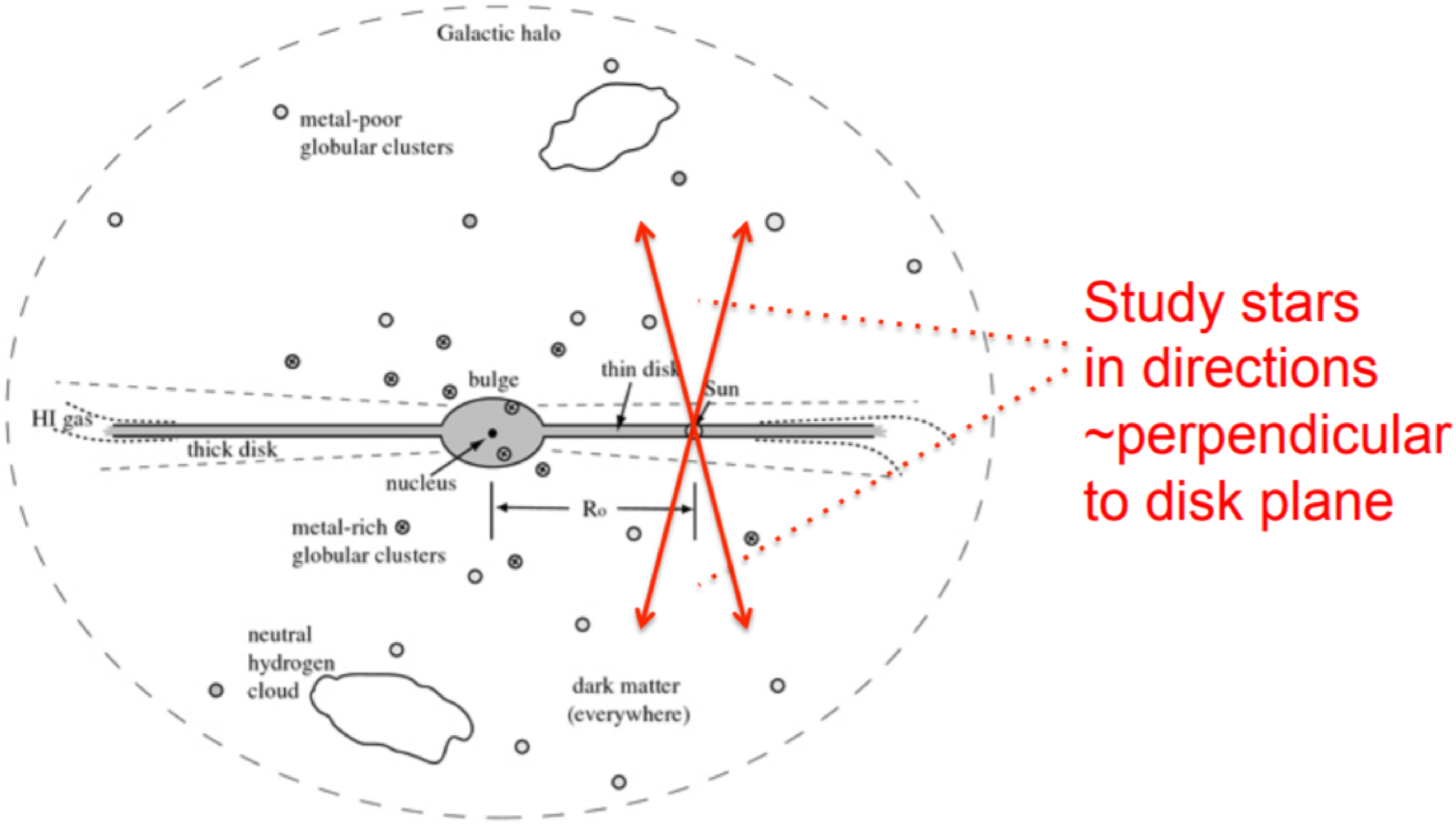


Trigonometric parallax

More on distance measurements in next classes

Fig. 1.5. The Galactic disk observed in nine different wavebands. Its appearance differs strongly in the various images; for example, the distribution of atomic hydrogen and of molecular gas is much more concentrated towards the Galactic plane than the distribution of stars observed in the near-infrared, the latter clearly showing the presence of a central bulge. The absorption by dust at optical wavelengths is also clearly visible and can be compared to that in Fig. 1.2

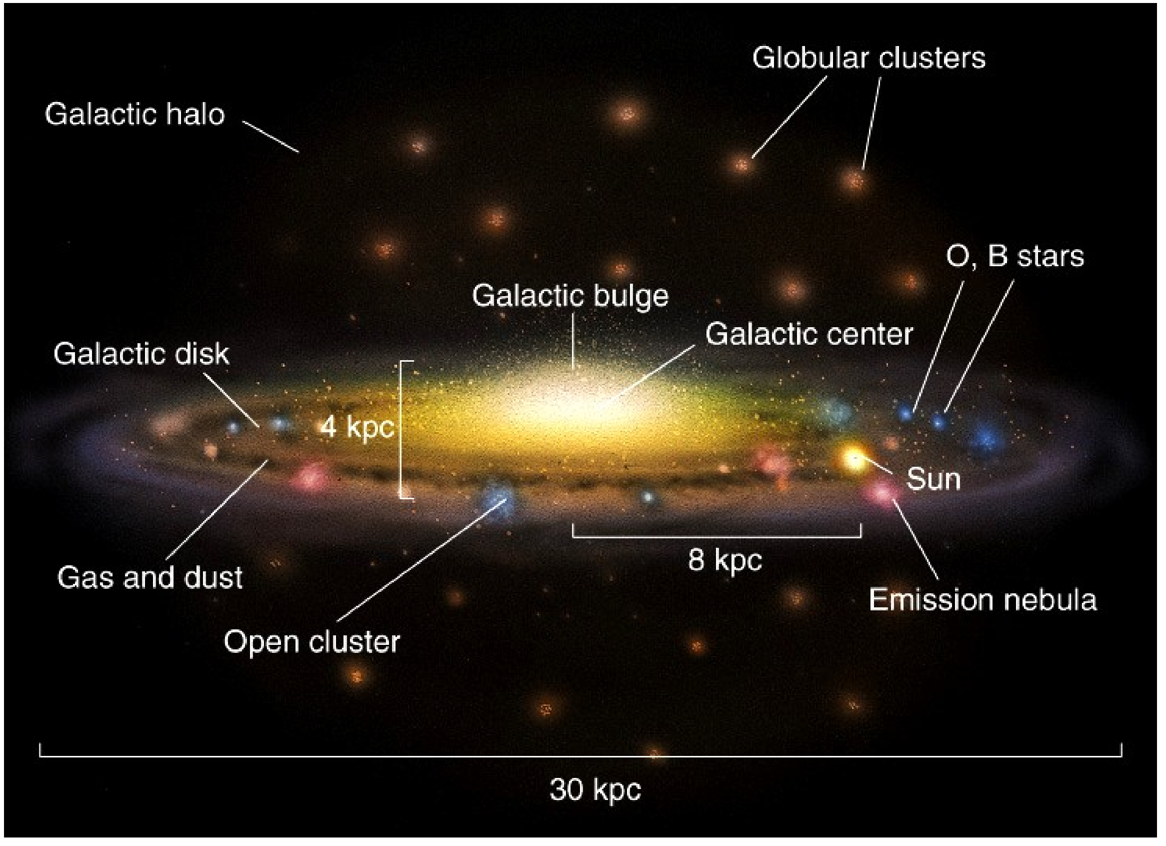
We can measure stellar distances to many kiloparsecs with spectroscopic parallax, we can examine vertical structure of Milky Way disk



The components of our galaxy (thin/thick disk, halo and bulge) also differ in the mix of the types of stars they contain

Population I: Hot, blue stars and young open clusters accompanied by gas and dust are primarily found in the disk (specifically thin disk region) of the Milky Way

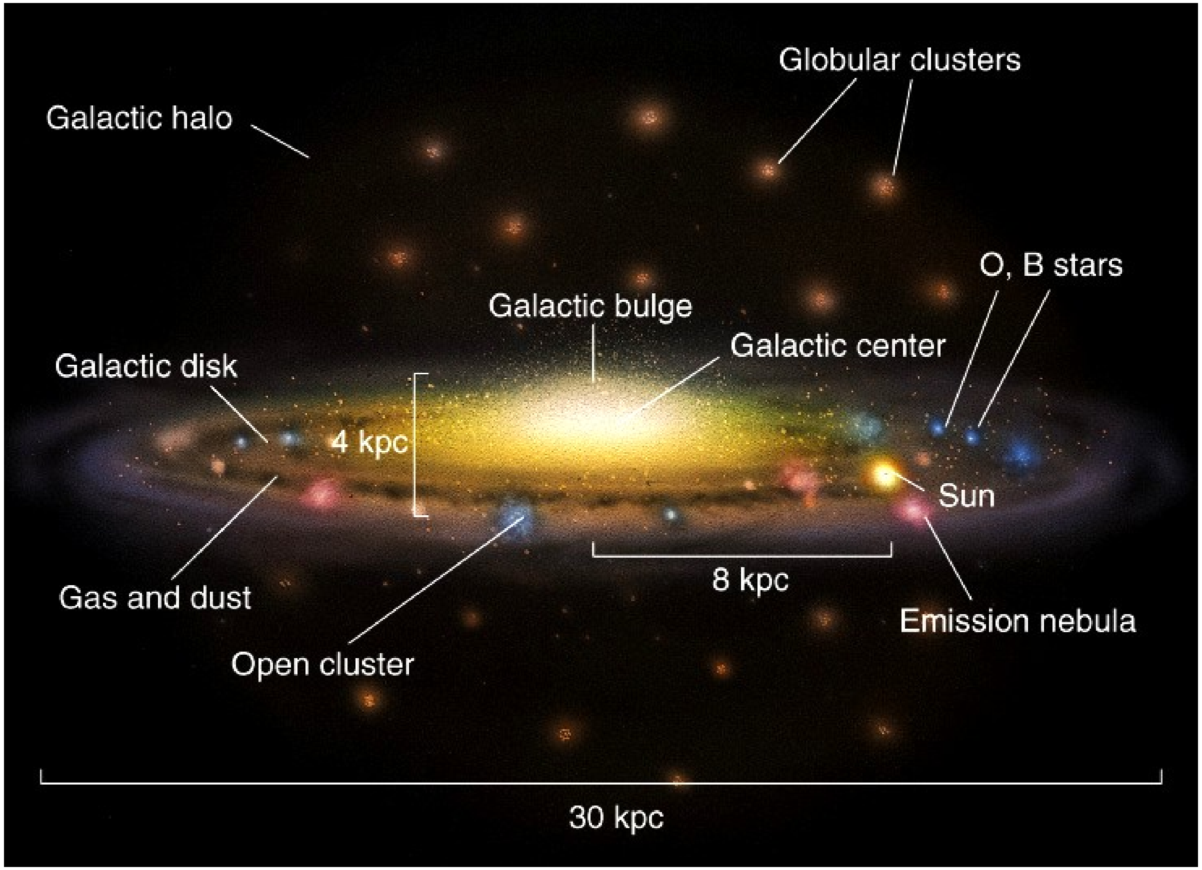
Population II: red stars and older globular clusters are found in the halo of the Milky Way or in the thick disk region



Plotting stars on HR diagrams showed that the populations differed in *age and metallicity (enrichment of elements heavier than Helium):*

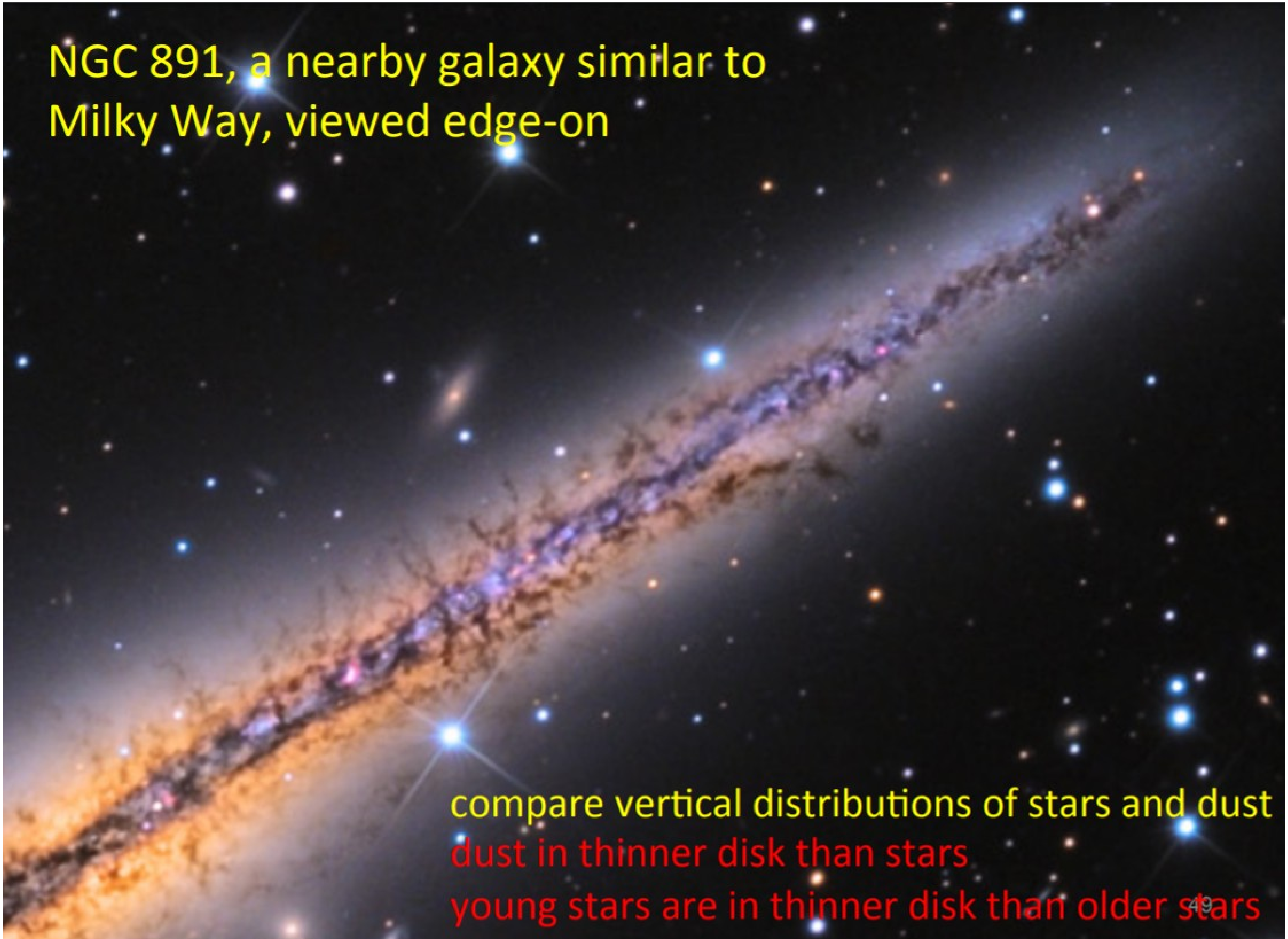
Pop I young and metal rich (Z ~ 0.02)
Pop II old and metal poor (Z ~ 0.001)

Disk – mainly Pop I
Halo – mainly Pop II
Bulge – mix of Pop I and II



- Disk: $L_B = 19 \times 10^9 L_\odot$
- Bulge: $L_B = 2 \times 10^9 L_\odot$
- Halo: $L_B = 2 \times 10^9 L_\odot$
- Grand Total: $L_B = 23 \times 10^9 L_\odot$

- Since most stars are smaller than the sun, the Milky Way actually contains far more than 23 billion stars – more like 200 billion


NGC 891, a nearby galaxy similar to
Milky Way, viewed edge-on
compare vertical distributions of stars and dust
dust in thinner disk than stars
young stars are in thinner disk than older stars
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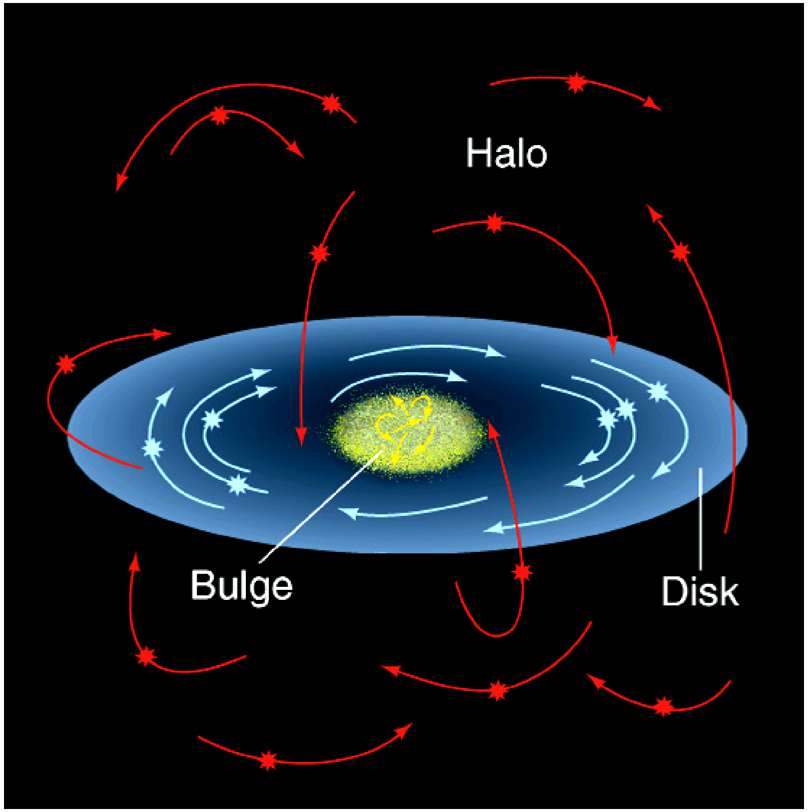
Also in the early 1900's, the first kinematic studies of the MW revealed the velocities of those globular clusters were ~250 km/s, much higher than the mass of the smaller Kapteyn galaxy model would require. So the galaxy must contain more stars (and mass) than Kapteyn originally thought in order to keep the star clusters from flying off.

- A spherical component with random motions (~250 km/s) → HALO

- A flattened component with rotational motion measured at 200 to 300 km/s near the Sun – DISK

- A third component, also spherical, exists in the center of the galaxy – BULGE
    Stars here also move on mostly random orbits

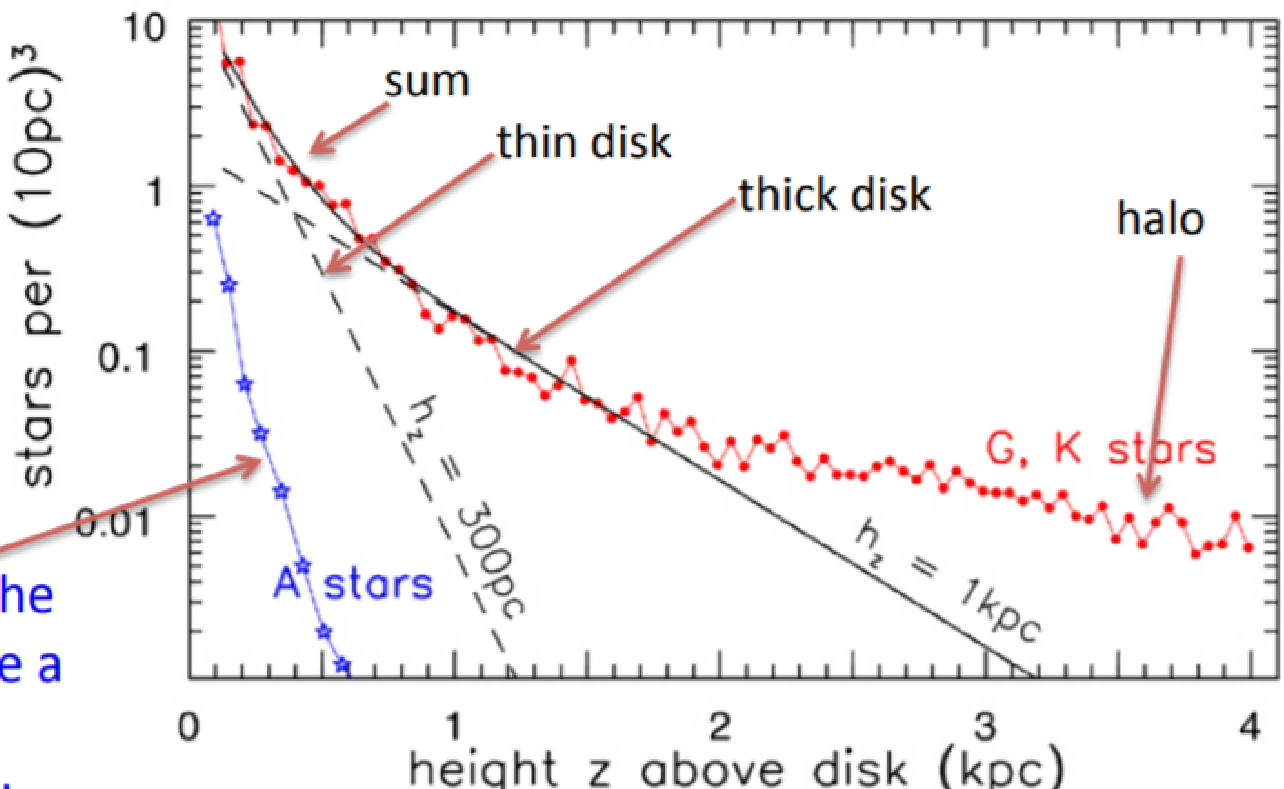


	Neutral gas	Thin disk	Thick disk	bulge	Stellar halo	Dm halo
M (10^{10}M$_\odot$)	0.5	6	0.2 to 0.4	1	0.1	55
L_B (10^{10}L$_\odot$)	–	1.8	0.02	0.3	0.1	0
M/L_B (M$_\odot$/L$_\odot$)	–	3	–	3	~ 1	–
diam. (kpc)	50	50	50	2	100	> 200
form	$e^{-h_z/z}$	$e^{-h_z/z}$	$e^{-h_z/z}$	bar?	$r^{-3.5}$	$(a^2+r^2)^{-1}$
scale-height (kpc)	0.13	0.325	1.5	0.4	3	2.8
σ_z (km s^{-1})	7	20	40	120	100	–
[Fe/H]	> 0.1	-0.5 to $+0.3$	-1.6 to -0.4	-1 to $+1$	-4.5 to -0.5	–

Points to Note

- scale height of disk stars increases with age of stars
- increase in scale height corresponds to increase in velocity dispersion and decrease in mean rotational velocity
- There are different velocity dispersions in different directions (R, φ, z)

Vertical distribution of stars near Sun in Milky Way

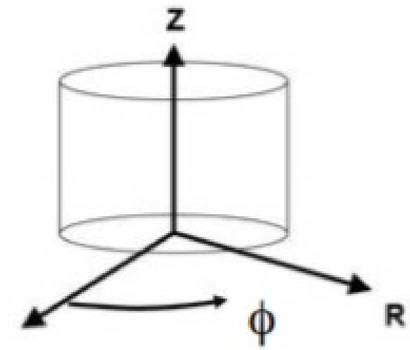


Note that the A stars have a very small scale height (main sequence A stars have age<100 Myr)

G,K stars have large age range bu many are old > 3 Gyr (these G&K stars ar mostly giant stars – can be detected at large distances)

Why do different types of stars have different vertical distributions?

assume cylindrical coordinate system (R,ϕ,z) with no azimuthal (ϕ) dependence



$n(R,z)$ number density of stars (#stars pc^{-3})

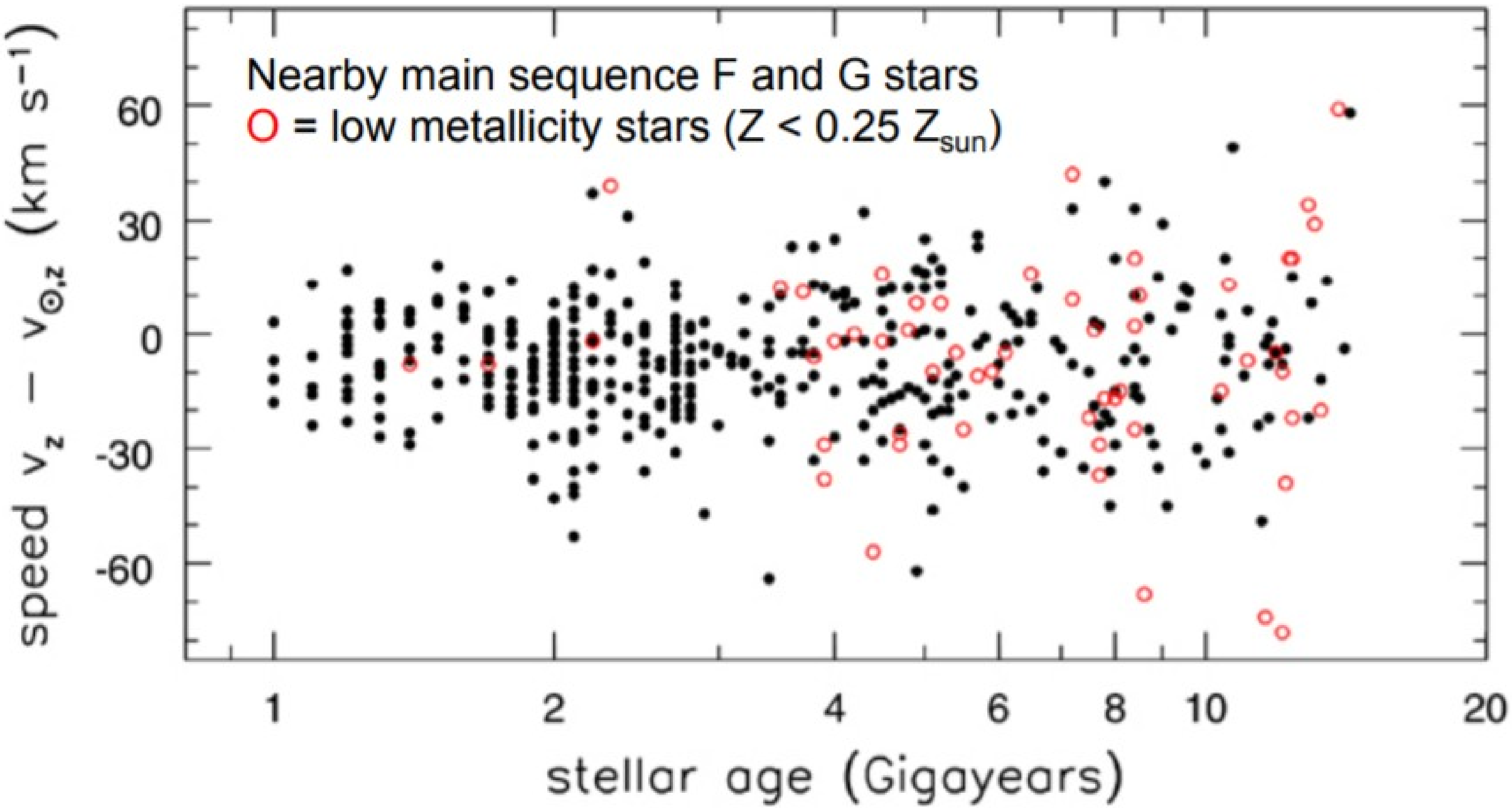
$\rho(R,z) = M_{av}\, n(R,z)$ mass density of stars ($M_{sun}\, pc^{-3}$)

$\Sigma_{\#}(R) = \int n\, dz$ surface #density of stars (#stars pc^{-2})

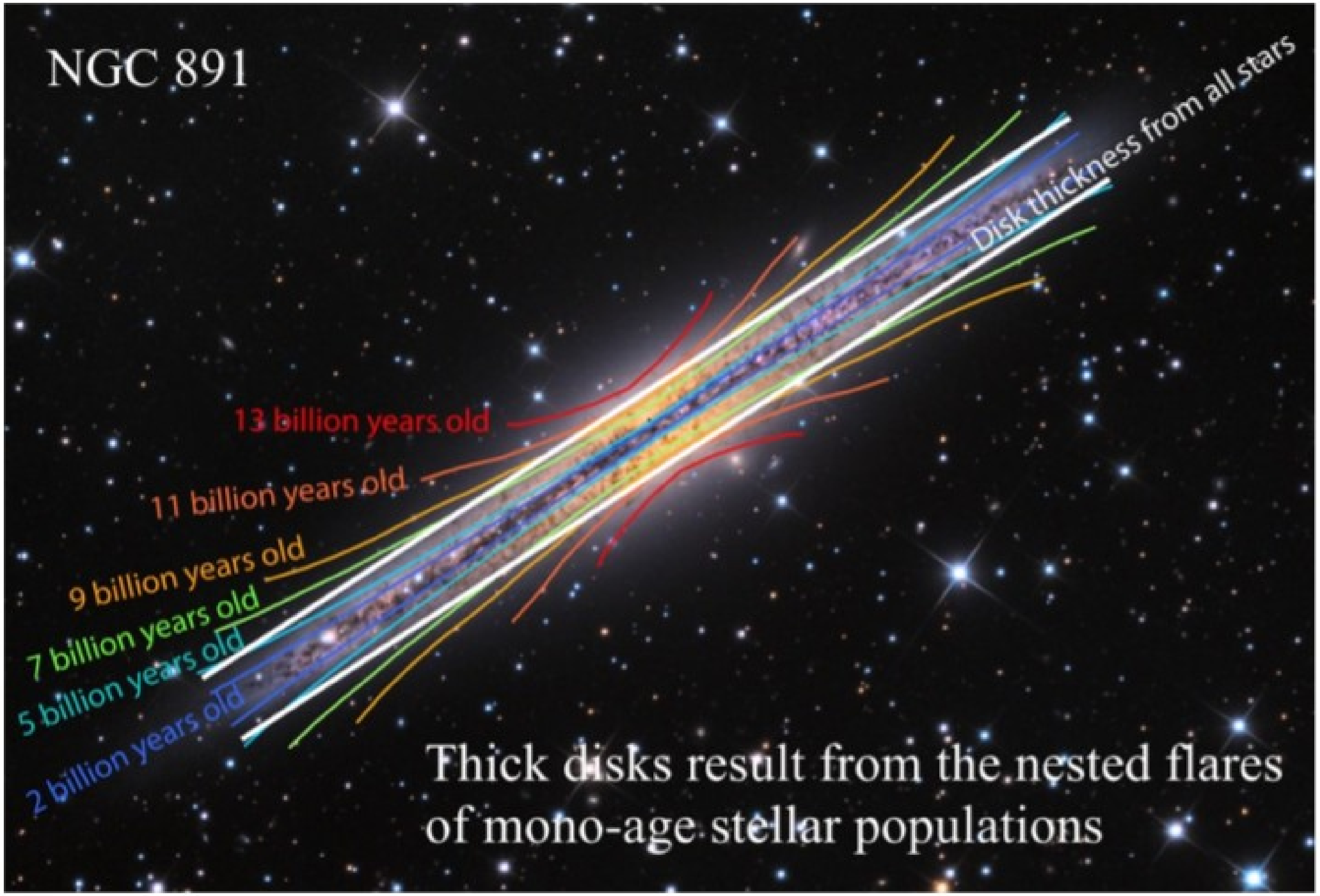
$\Sigma_{m}(R) = \int \rho\, dz$ surface mass density stars ($M_{sun}\, pc^{-2}$)

$M(<R) = \int\int \Sigma\, d\phi\, dR = \int\int\int \rho\, d\phi\, dR\, dz$ total mass within radius R of all stars

Vertical velocity vs. age



Example of a Spiral galaxy disk showing spatial extent of stars of different ages



Mass to light ratio

- Thin disk
  - The total stellar mass of the thin disk is $\sim 6 \times 10^{10}\ M_{solar}$
  - $M \sim 0.5 \times 10^{10}\ M_{solar}$ in the form of dust and gas has o be added
  - The luminosity of the stars in the thin disk is L B ≈ 1.8 × 10 10 L_{solar}
  - Combining

$$\frac{M}{L_B} \approx 3 \frac{M_\odot}{L_\odot} \qquad \text{in thin disk}$$

- Thick disk
  - $M \sim 3 \times 10^{9}\ M_{solar}$
  - $L \approx 2 \times 10^{8}\ L_{solar}$
  - M/L ~ 15 solar units

Thick disk contirbutes less significantly to the total mass and the total luminosity budget but crucial for dynamical evolution

The Galactic Disk: Dust and Gas

- Spiral arms O and B stars, HII region → blue
- Star formation takes place in arms
- Molcular gas clouds → dense and cool → collapse
- Emission in redder wavelength → old stars

- Gas → through observations of 21 cm line of HI and emissio of CO (tracer of molecular H_2)
- Milkyway optically thin to 21 cm

- Dust from measuring extinction (IR bands, IRAS, COBE)
- one needs to combine maps at different frequencies in order to determine column densities and temperatures
- Molecular hydrogen (H 2) and dust are generally found at 3 kpc ≤ R ≤ 8 kpc, within |z| ≤ 90 pc of both sides of the Galactic plane
- Atomic hydrogen (H I) is observed out to much larger distances from the Galactic center (R ≤ 25 kpc), and scale heights of 160 pc

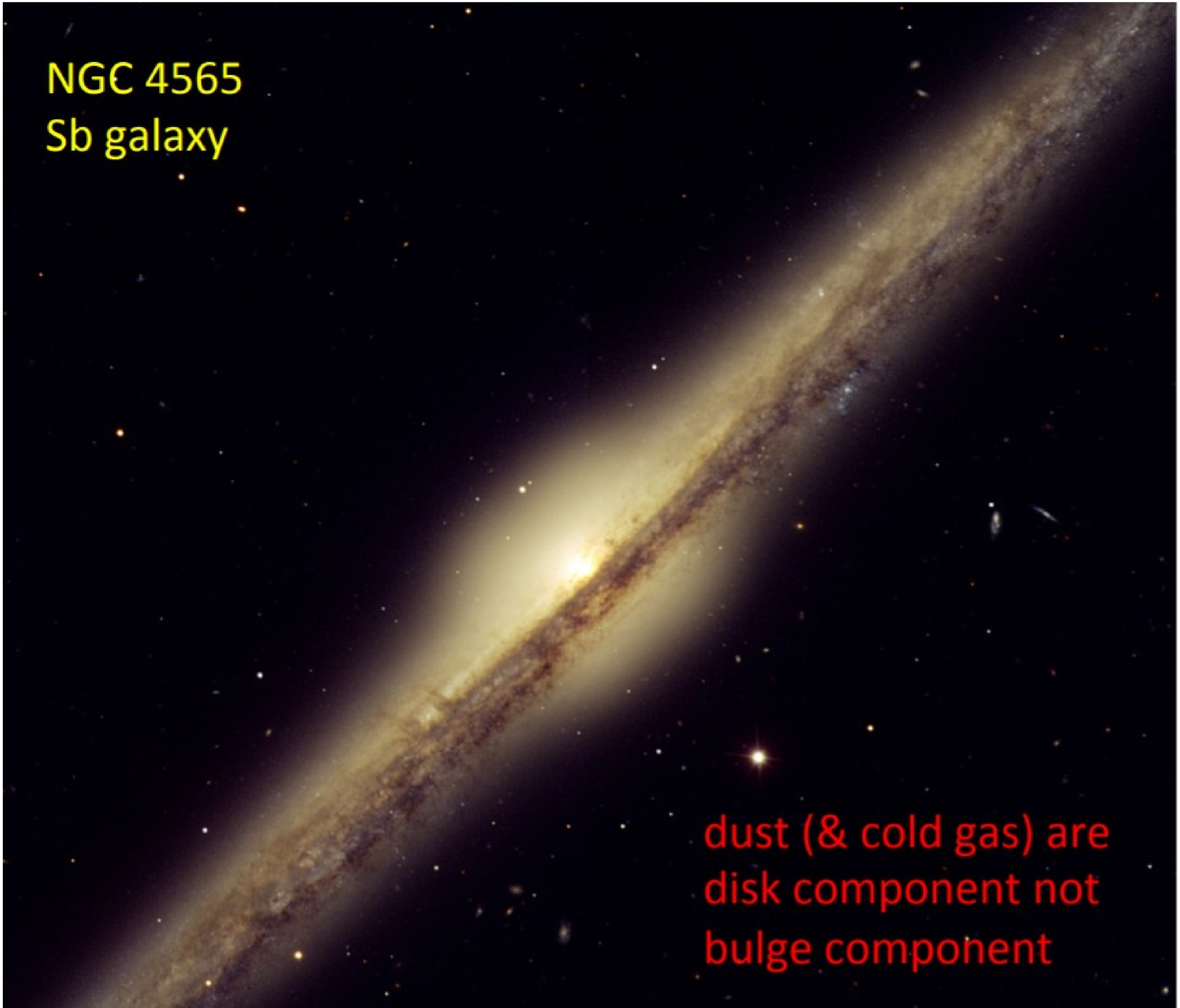
Magnetic Field

- Polarization of stellar light
- The Zeeman effect : 21 cm line
- Synchrotron radiation
- Faraday rotation $\Delta\theta = RM\ \lambda^2$

Magnetic field of Milkyway disk ~ 4 X 10^{-6} G

High energy Radiation (Gamma-ray) from Milkyway

- Cosmic rays
  - Charged very high-energy particles
  - Steep spectrum (going significantly upto 10^{18} eV)
  - Possible acceleration in Supernova and supernova remnants
  - 10^{15} -10^{18} eV Galactic origin; higher → extragalactic (AGNs?)
  - Even higher energy → disintegrates
- Turbulent ISM
- Magnetic field effects
- Stellar emission
- Pair production (annihilation radiation)


NGC 4565
Sb galaxy
dust (& cold gas) are
disk component not
bulge component

Galactic bulge

- Older Stars
- Very metal poor stars also present
- High metallicity
- Molecular gas

De Vaucouleurs Profile

$$\log\left(\frac{I(R)}{I_e}\right) = -3.3307\left[\left(\frac{R}{R_e}\right)^{1/4} - 1\right]$$

$$\int_0^{R_e} \mathrm{d}R\, R\, I(R) = \frac{1}{2}\int_0^{\infty} \mathrm{d}R\, R\, I(R)\,.$$

$$I(R) = I_e \exp\left(-7.669\left[(R/R_e)^{1/4} - 1\right]\right)$$

De Vaucouleurs Alternative form

$$L = \int_0^{\infty} \mathrm{d}R\, 2\pi R\, I(R) = 7.215\pi I_e\, R_e^2$$

$$\frac{M}{L} \approx 3\frac{M_\odot}{L_\odot} \quad \text{in the bulge}$$

$M \sim 10^{10}\ M_{solar}$

$L \sim 10^{9}\ L_{solar}$

Suppose we have a good spectrum of a star. From the spectrum, plus its flux and temperature, plus some basic knowledge about stars, how can we determine the star’s distance?