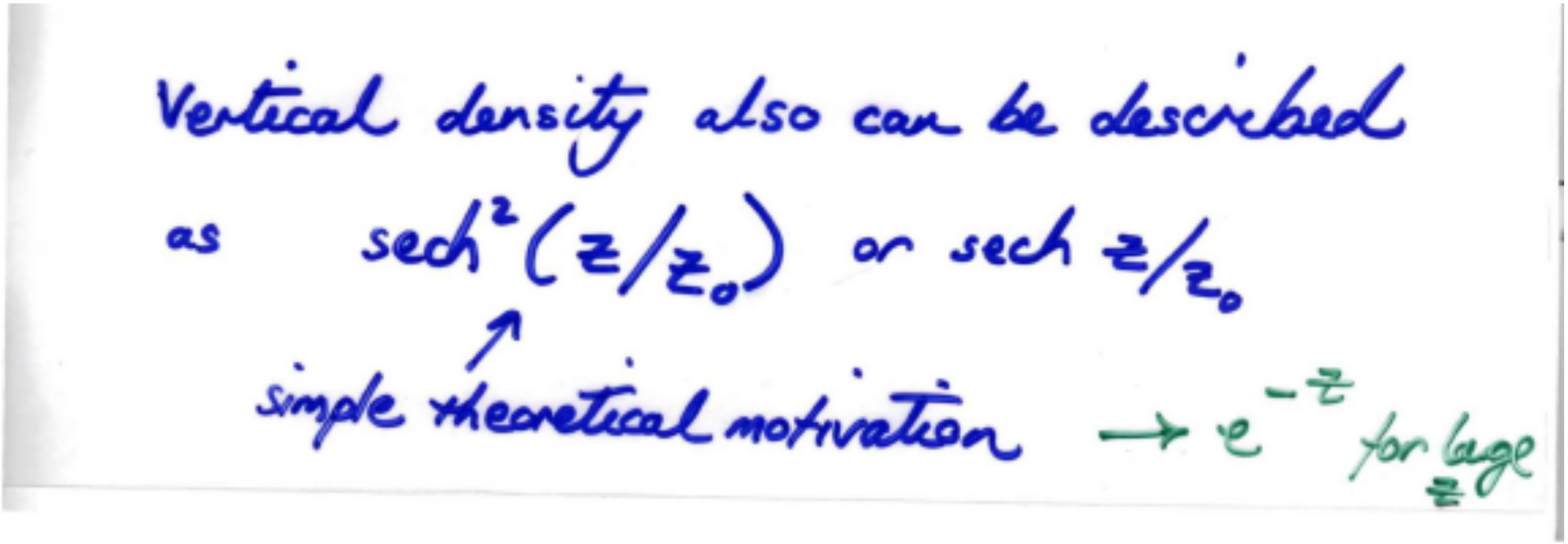
Milky Way thin disk

stellar density drops exponentially both with distance from center (cylindrical R) & height above the plane (z)

$$\rho_{\text{stars, disk}} \propto e^{-R/h_R}\, e^{-|z|/h_z}$$

h_R, h_z called scale length, height



Vertical density also can be described

as $\mathrm{sech}^2(z/z_0)$ or $\mathrm{sech}\, z/z_0$

$\uparrow$

simple theoretical motivation $\rightarrow e^{-z}$ for large z

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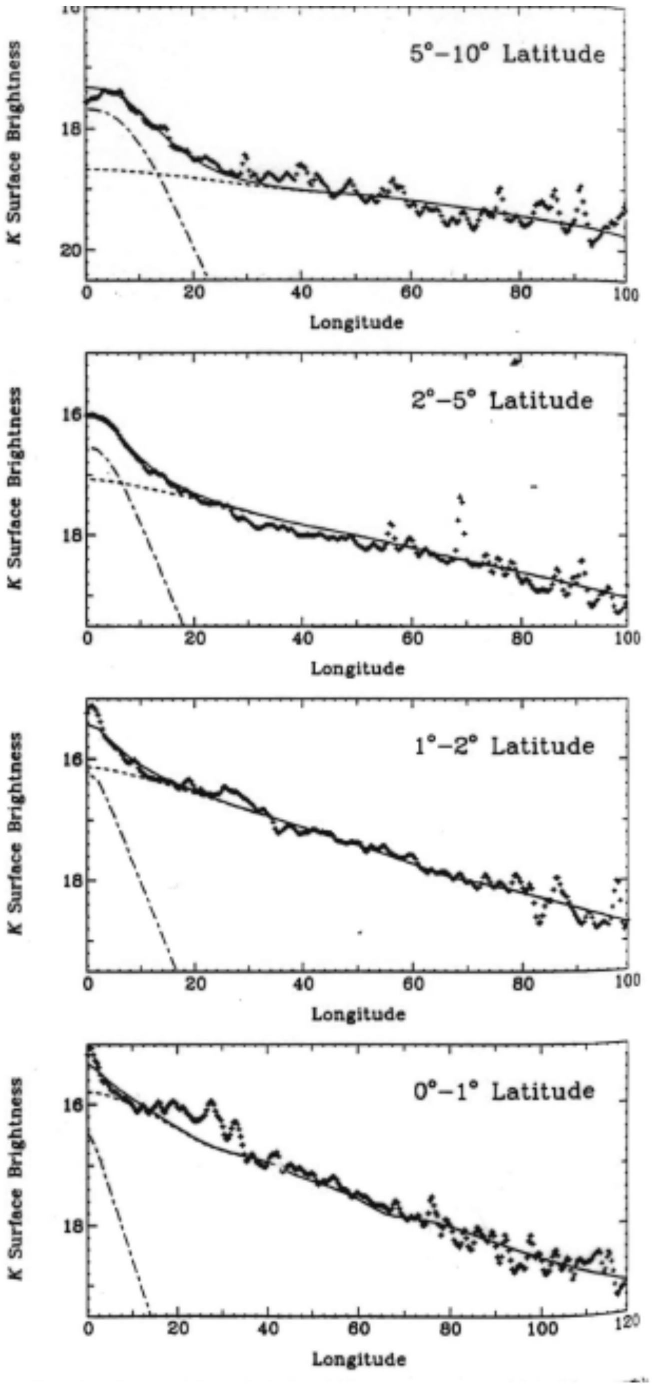
Q: in order to study the spatial distribution of the thin disk (which dominates the Milky Way luminosity) surface photometry in the K band from space has been used. What is the advantage of the K band? What sort of stars give off most of their light at 2 microns?

Q: these are Spacelab IR data, modeled with a bulge and exponential disk. What are the bumps and wiggles?



Kent et al
1991

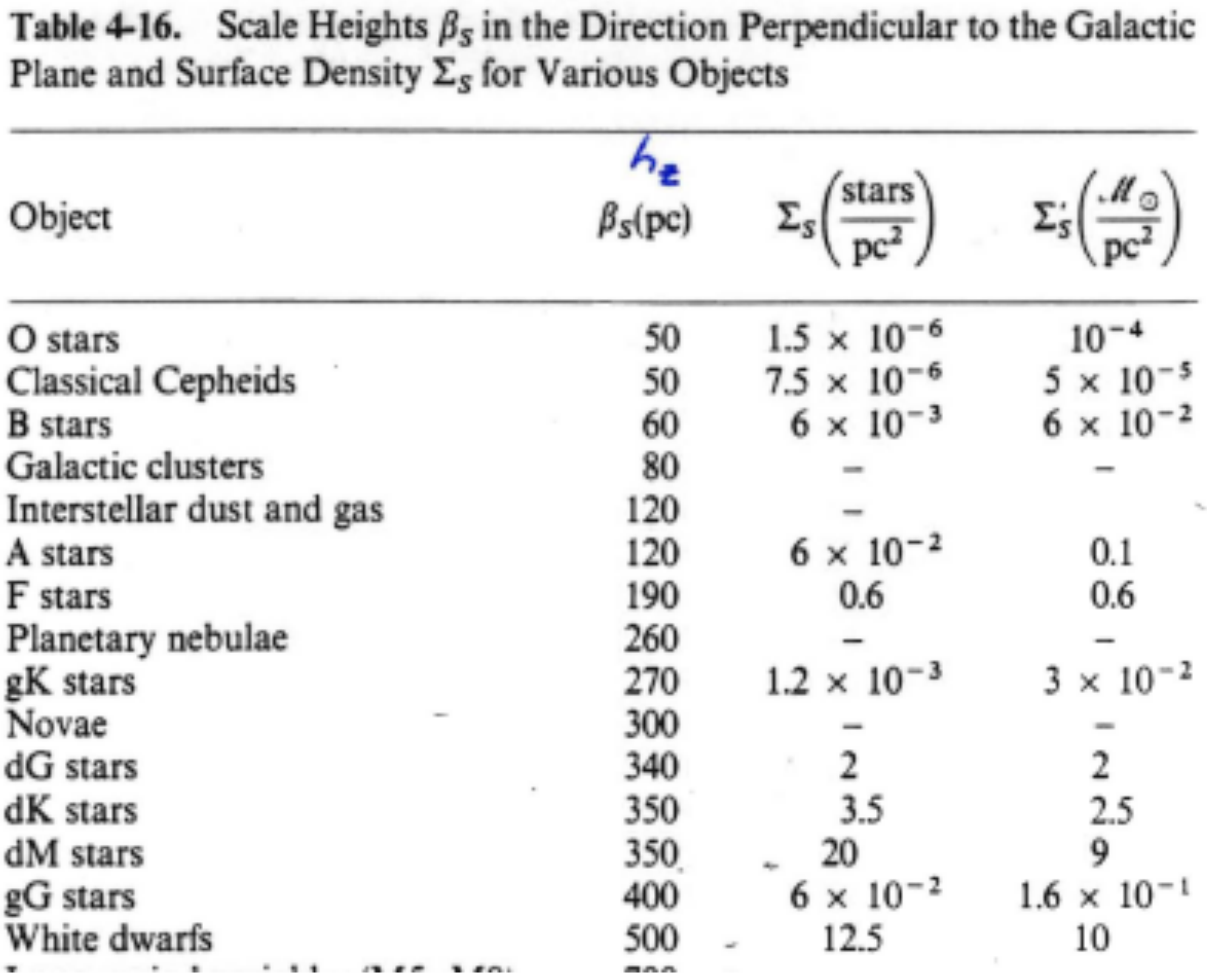


Table 4-16. Scale Heights β_S in the Direction Perpendicular to the Galactic Plane and Surface Density Σ_S for Various Objects

Object	h_z β_S(pc)	$\Sigma_S\left(\frac{\text{stars}}{\text{pc}^2}\right)$	$\Sigma_S'\left(\frac{\mathcal{M}_\odot}{\text{pc}^2}\right)$
O stars	50	1.5×10^{-6}	10^{-4}
Classical Cepheids	50	7.5×10^{-6}	5×10^{-5}
B stars	60	6×10^{-3}	6×10^{-2}
Galactic clusters	80	–	–
Interstellar dust and gas	120	–	
A stars	120	6×10^{-2}	0.1
F stars	190	0.6	0.6
Planetary nebulae	260	–	–
gK stars	270	1.2×10^{-3}	3×10^{-2}
Novae	300	–	–
dG stars	340	2	2
dK stars	350	3.5	2.5
dM stars	350	20	9
gG stars	400	6×10^{-2}	1.6×10^{-1}
White dwarfs	500	12.5	10

Mihalas and Binney Ch 4

- Scale height of stars varies with age — youngest stars (plus dust & gas) are most concentrated to galactic plane, while older stars have larger scale height. This is due to secular heating mechanisms such as giant molecular clouds. Young stars also cluster near spiral arms.
- Smooth space distribution of older stars "old disk" has scale height $h_z = 300\text{-}350\,pc$.

(from star count studies)

- Global description of disk luminosity distribution best done in near IR — space-based all-sky observations by Spacelab (85) & COBE (90's)

  ↓

  — Kent et al ApJ 378, 131 (1991) 2.4μ

$h_r = 3$ kpc

$h_z \simeq 250$ pc at Sun, varies with R

Age of thin disk

White dwarf cooling

Independent limit on age of galactic disk

Once nuclear burning stops & a star forms a white dwarf, physics of its cooling is relatively simple

disk age = 9.3 ± 2 Gyr

Galaxy formation model needed to make this into an estimate of age of Universe

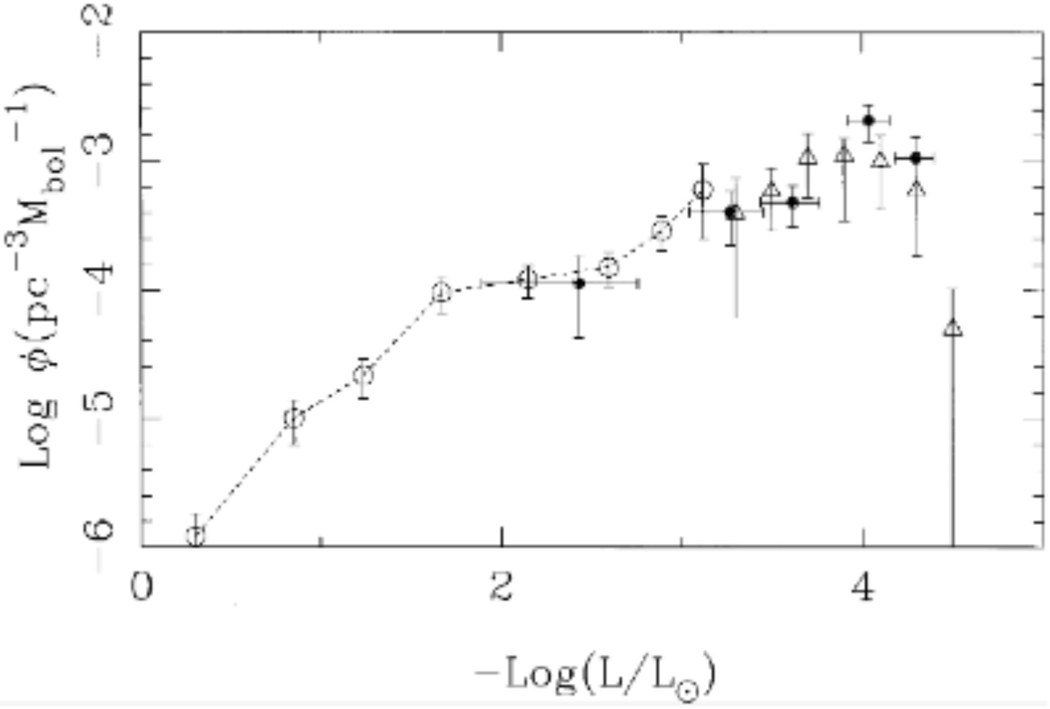


Figure 19. Observational LF with comparisons: this work (filled circles), hot WDLF based on Fleming, Liebert & Green (1986) from LDM (open circles), and the LRB redetermination of the LDM CWDLF (open triangles).

From Knox et al 1999

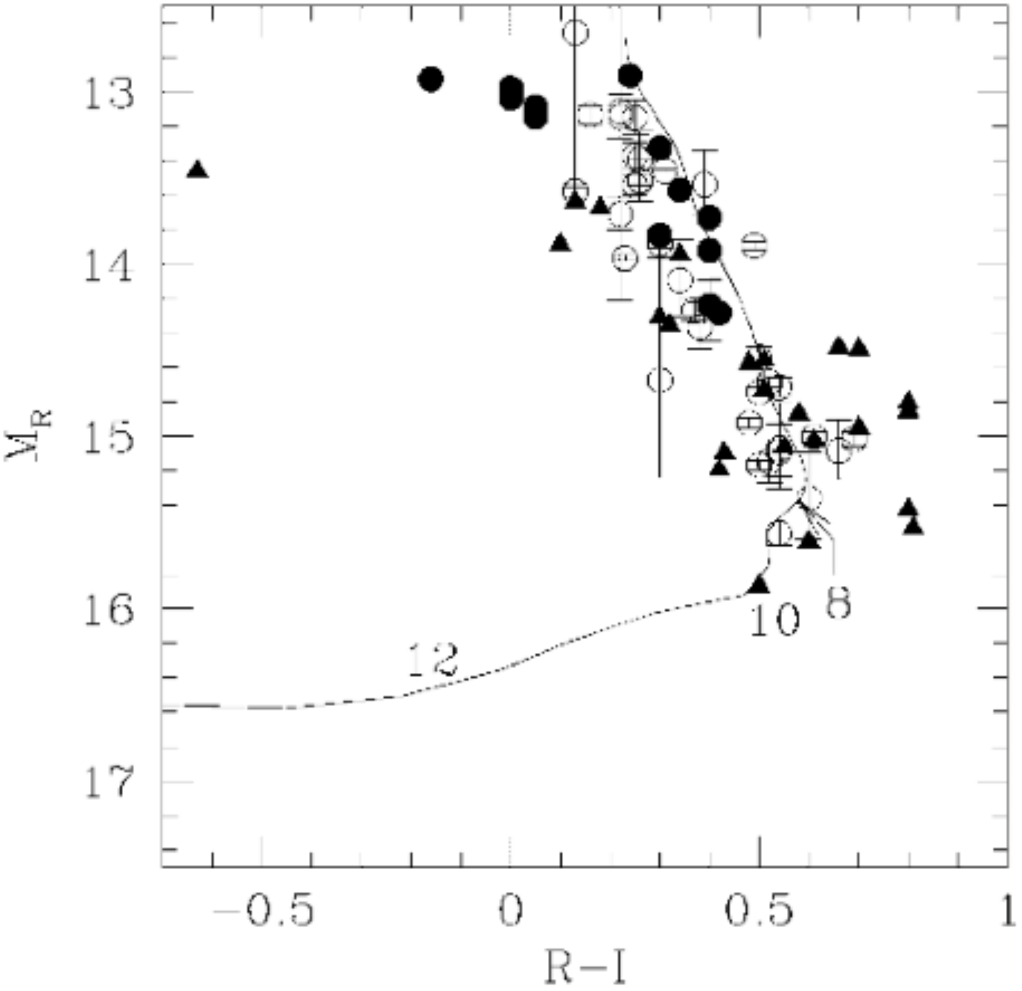


FIG. 1.—Absolute magnitudes (the 20% error bars on the photometric distances are not shown). The filled symbols are the OHDHS dwarfs (circles show $H\alpha$ and triangles do not), and the open symbols are the thin-disk dwarfs from Bergeron et al. (1997). The solid curve shows a 0.5 $M_\odot$ pure carbon core model with a hydrogen atmosphere. Note that this is not intended as a fit to the observed sample but represents the slowest cooling white dwarf plausible. The positions of white dwarfs of ages 8, 10, and 12 Gyr are shown.

Hansen 2001

Thin disk metallicity distribution

The Sun is at the metal-rich end of the thin disk metallicity distribution

Nordstrom et al 2004

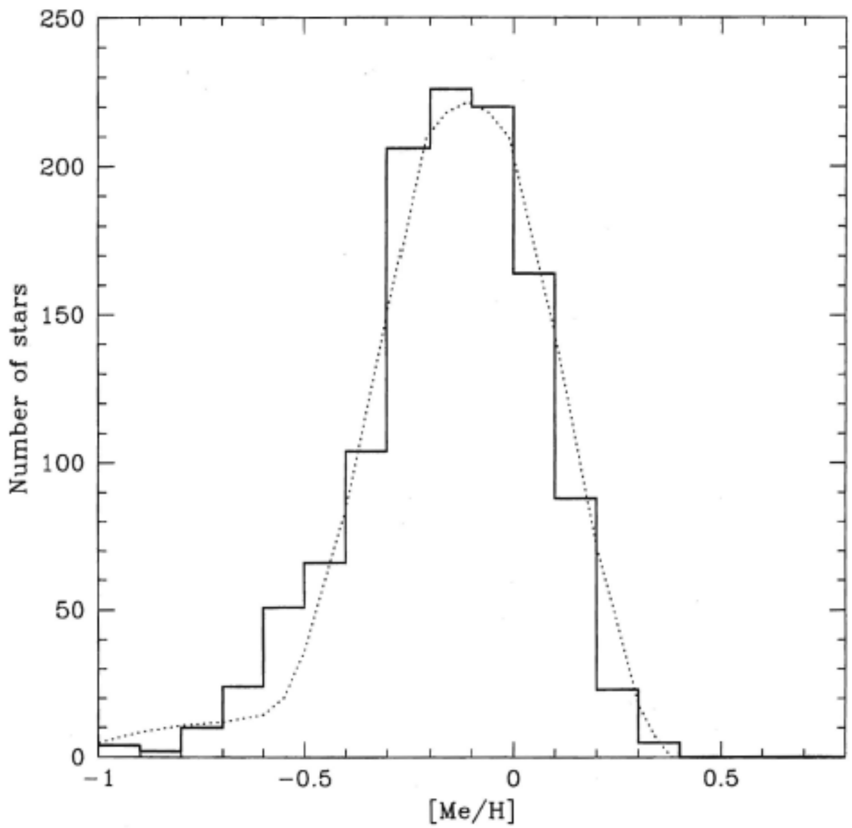
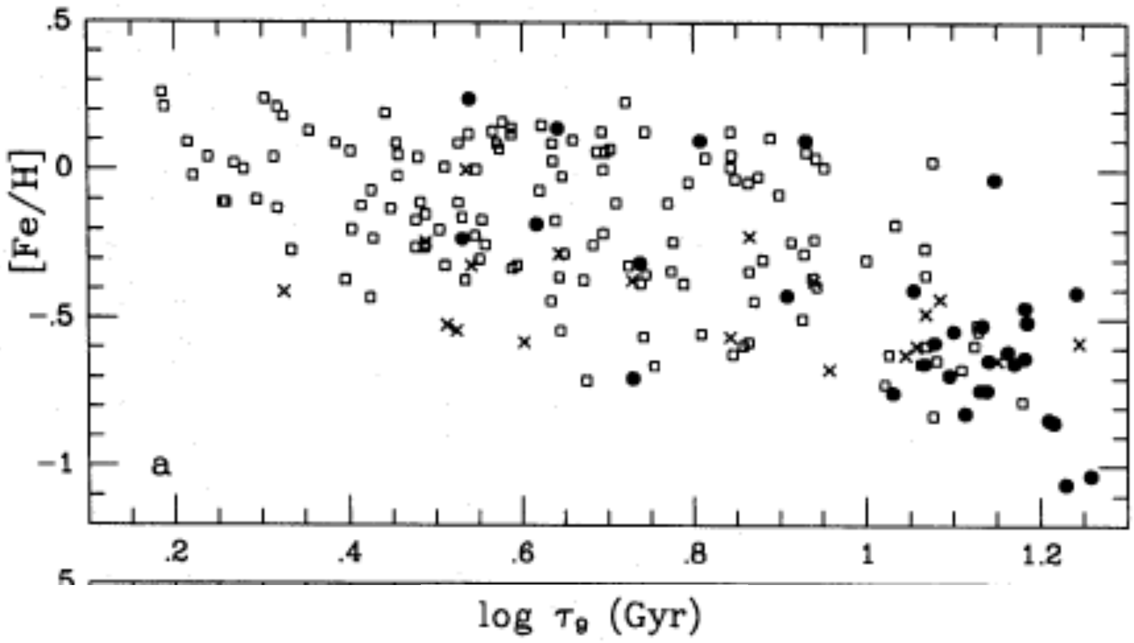


Fig. 26. Distribution of metallicities for the volume complete sampl of single stars (full histogram). For comparison the dotted curve show the reconstructed distribution for G dwarfs from Jørgensen (2000 which is corrected for scale height effects and measurement errors.

Metallicity vs age in the thin disk

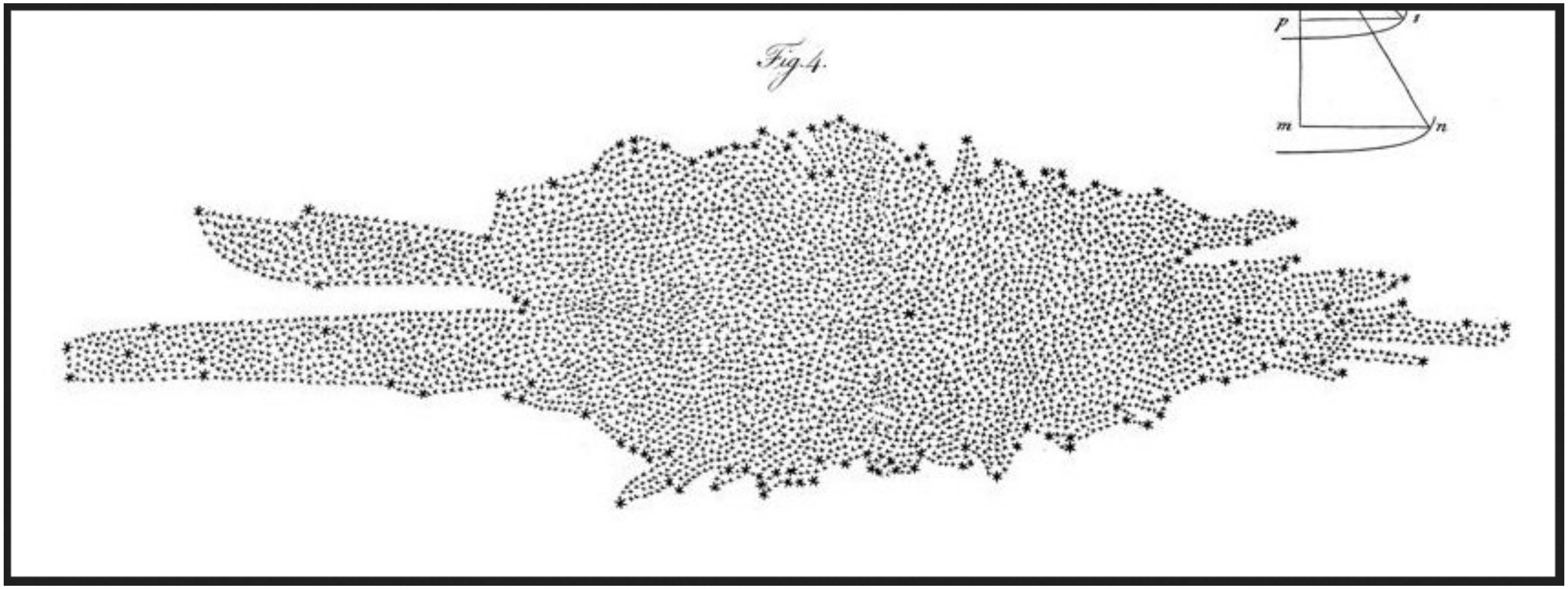


Note large spread in age for a given [Fe/H]

(ages for individual stars are difficult and controversial) from Edvardsson et al 1993

Mapping the Galaxy with star counts

The Herschels (1785) mapped the Galaxy with star counts, and got it quite wrong (why?)



Star count mapping

Q: what sort of assumptions would you need to make in order to work out the density distribution of the Galaxy using star counts?

Star count mapping

Q: what sort of assumptions would you need to make in order to work out the density distribution of the Galaxy using star counts?

→ magnitude → distance, BUT:

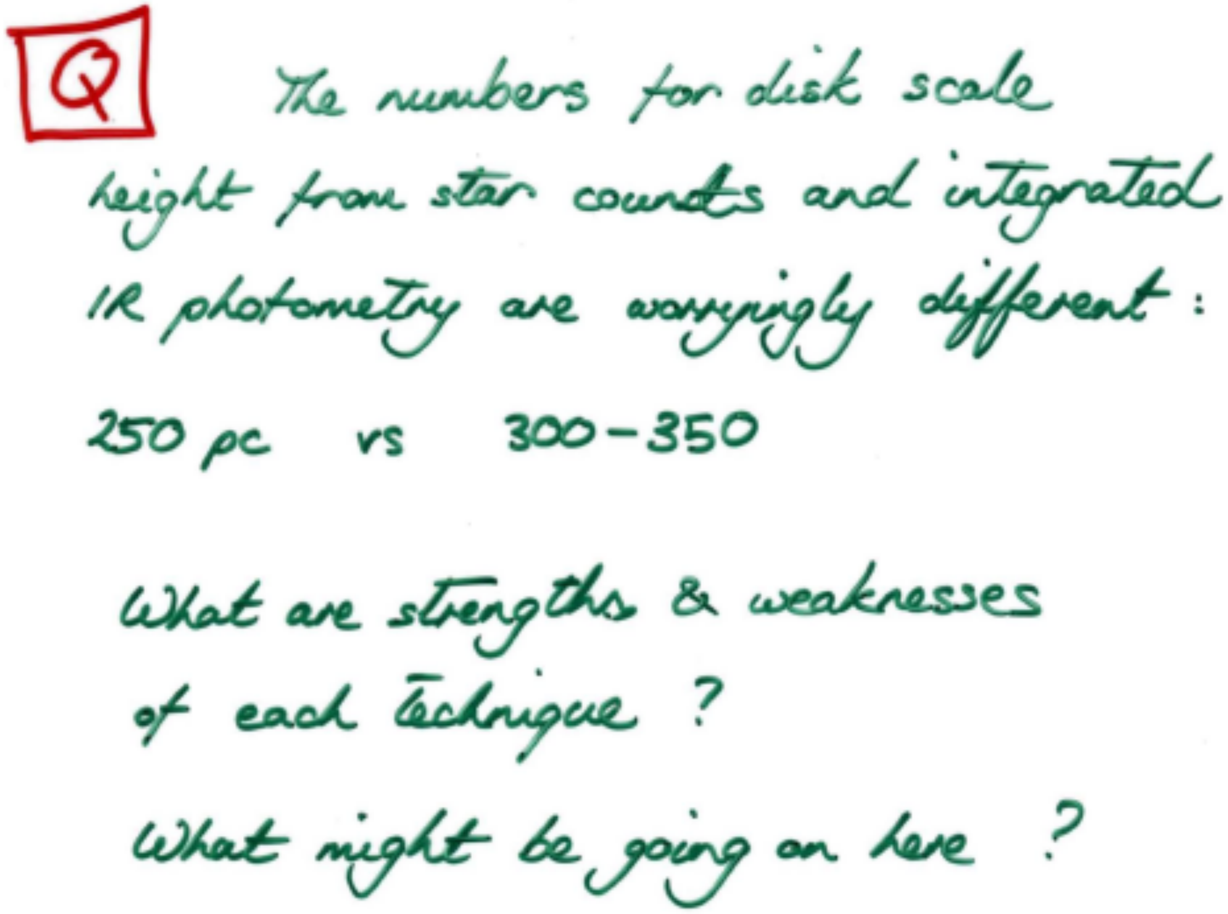
→ stars vary in luminosity → assume all on main sequence

→ there may be dust in the way (get lots of colors)

-> also metallicity affects luminosity

This works well when you can isolate a part of the HR diagram which gives a unique luminosity to a color.

Q What would work ?



Q The numbers for disk scale height from star counts and integrated IR photometry are worryingly different:

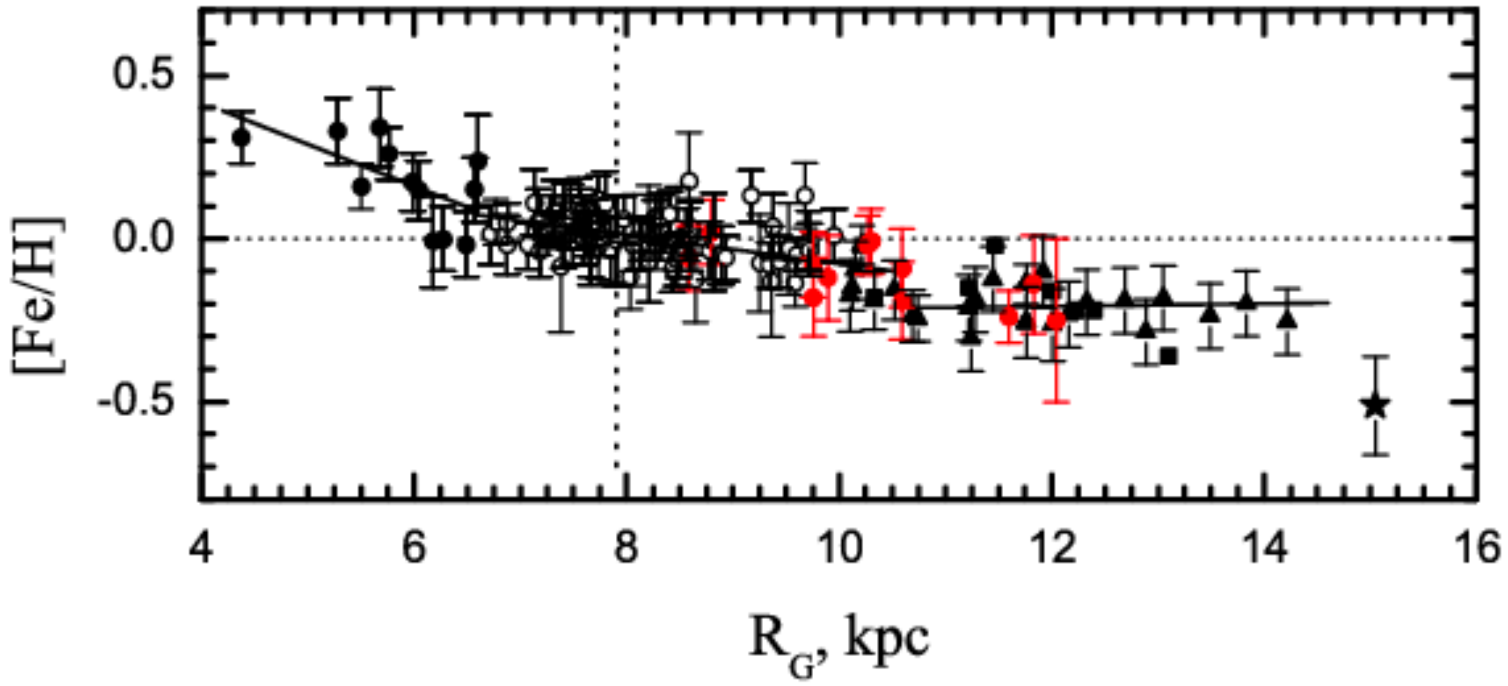
250 pc vs 300–350

What are strengths & weaknesses of each technique?

What might be going on here?

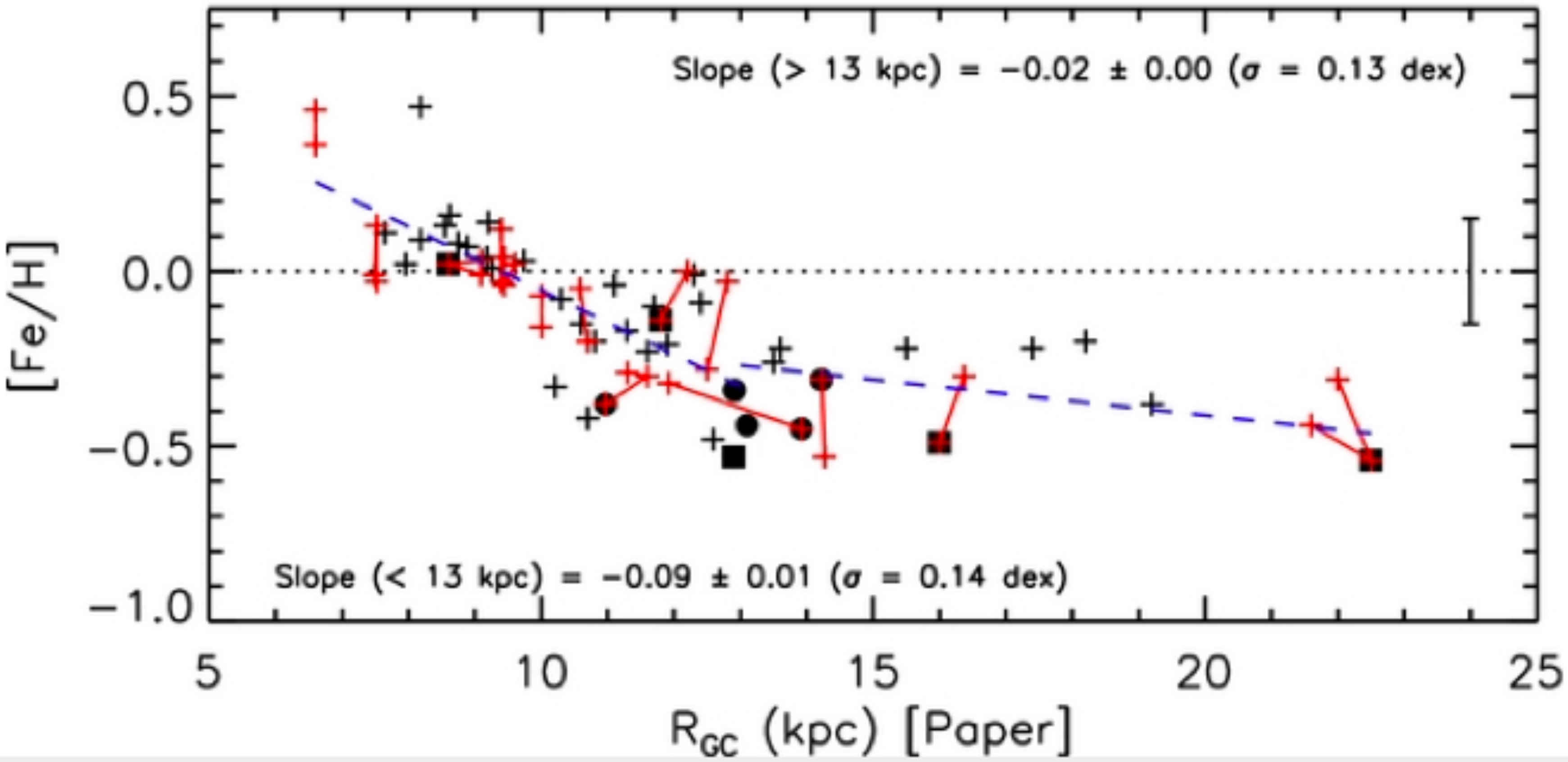
-> think of an effect that would go in the direction of making IR studies give a smaller scale height

Metallicity gradient in the disk



Andrievsky, Luck et al (2004) – gradient from Cepheids

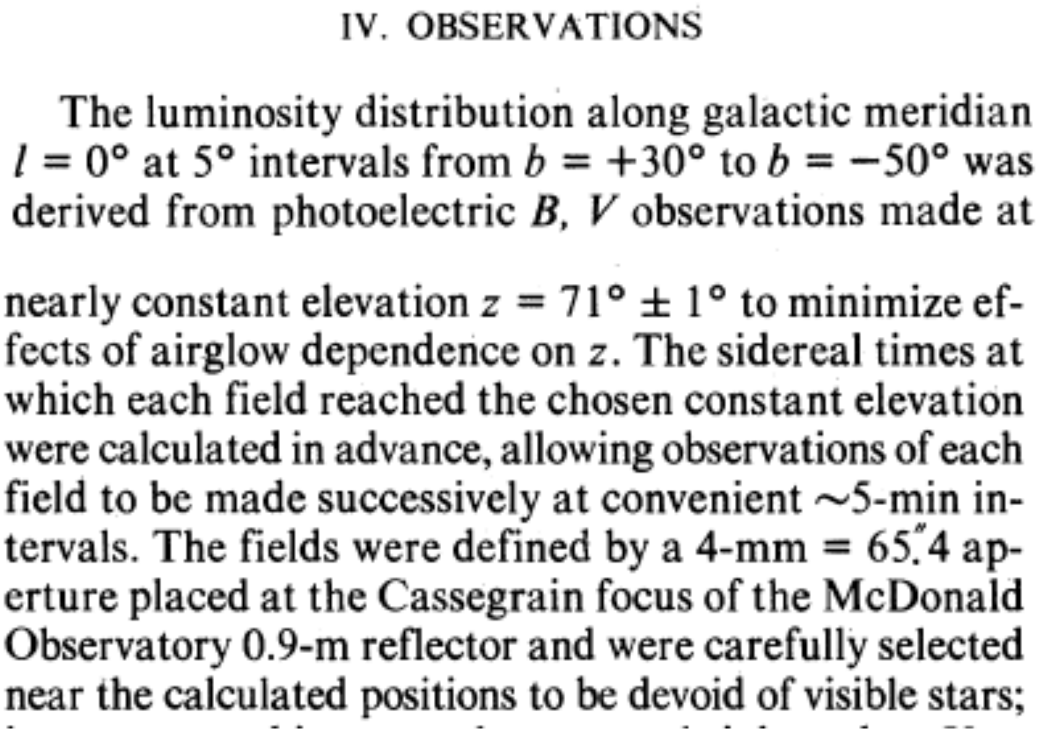
Open clusters (ages up to 10 Gyr)



Yong et al (2012)

The Galaxy's bulge/bar

Historically, we thought that the Milky Way had a regular $R^{1/4}$ law bulge. ie de Vaucouleurs and Pence (1978) fitted this to ground-based optical photometry:

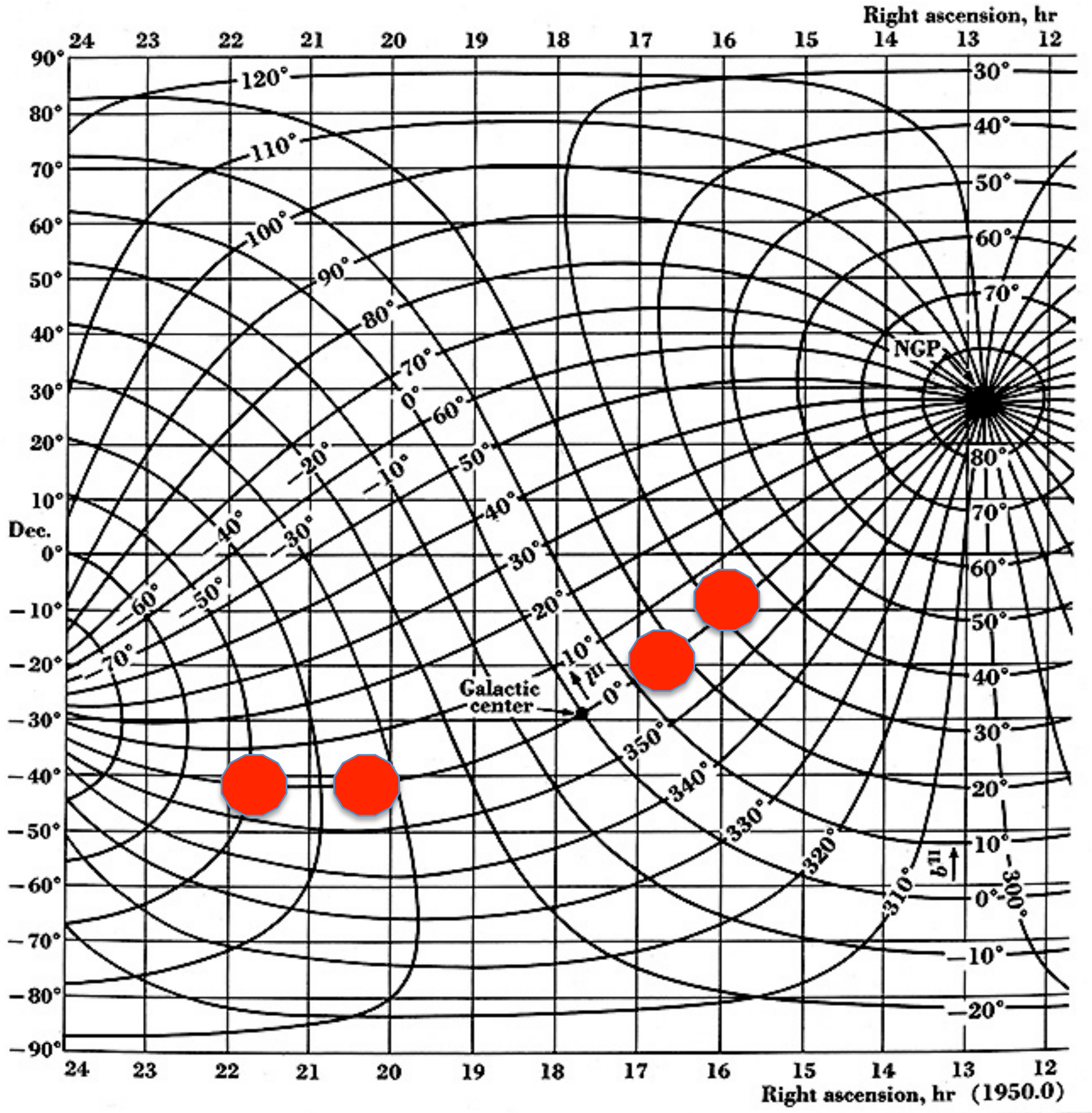


IV. OBSERVATIONS

The luminosity distribution along galactic meridian $l = 0°$ at 5° intervals from $b = +30°$ to $b = -50°$ was derived from photoelectric B, V observations made at nearly constant elevation $z = 71° \pm 1°$ to minimize effects of airglow dependence on z. The sidereal times at which each field reached the chosen constant elevation were calculated in advance, allowing observations of each field to be made successively at convenient ~5-min intervals. The fields were defined by a 4-mm = 65″.4 aperture placed at the Cassegrain focus of the McDonald Observatory 0.9-m reflector and were carefully selected near the calculated positions to be devoid of visible stars;

They derived an effective radius of 2.67 kpc.

Q: any observational issues?



http://ned.ipac.caltech.edu/level5/rip1.jpg

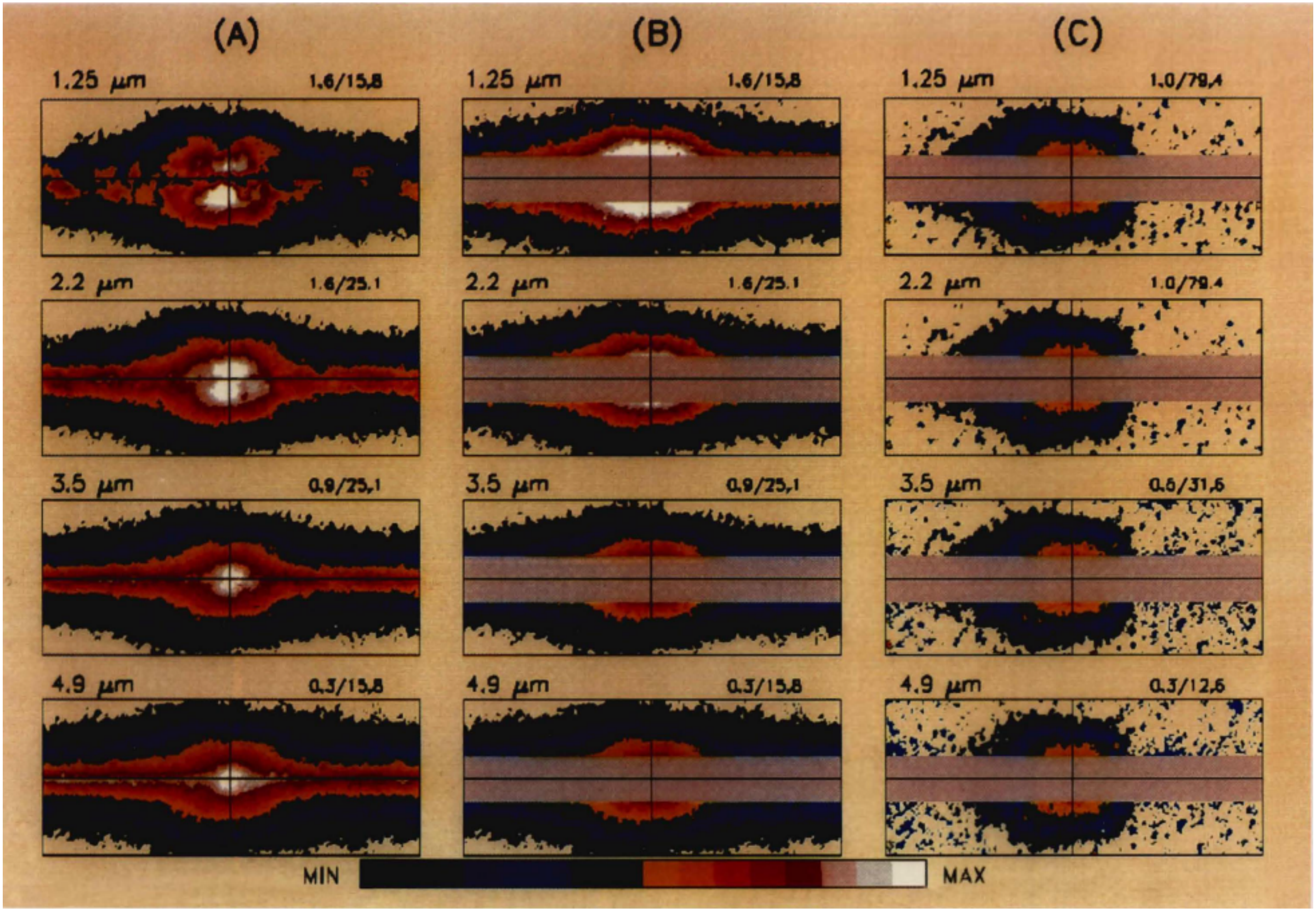
$R^{1/4}$ bulge?

However, even de Vaucouleurs classified the Milky Way (in the same paper) as a barred spiral: SAB(rs)bc

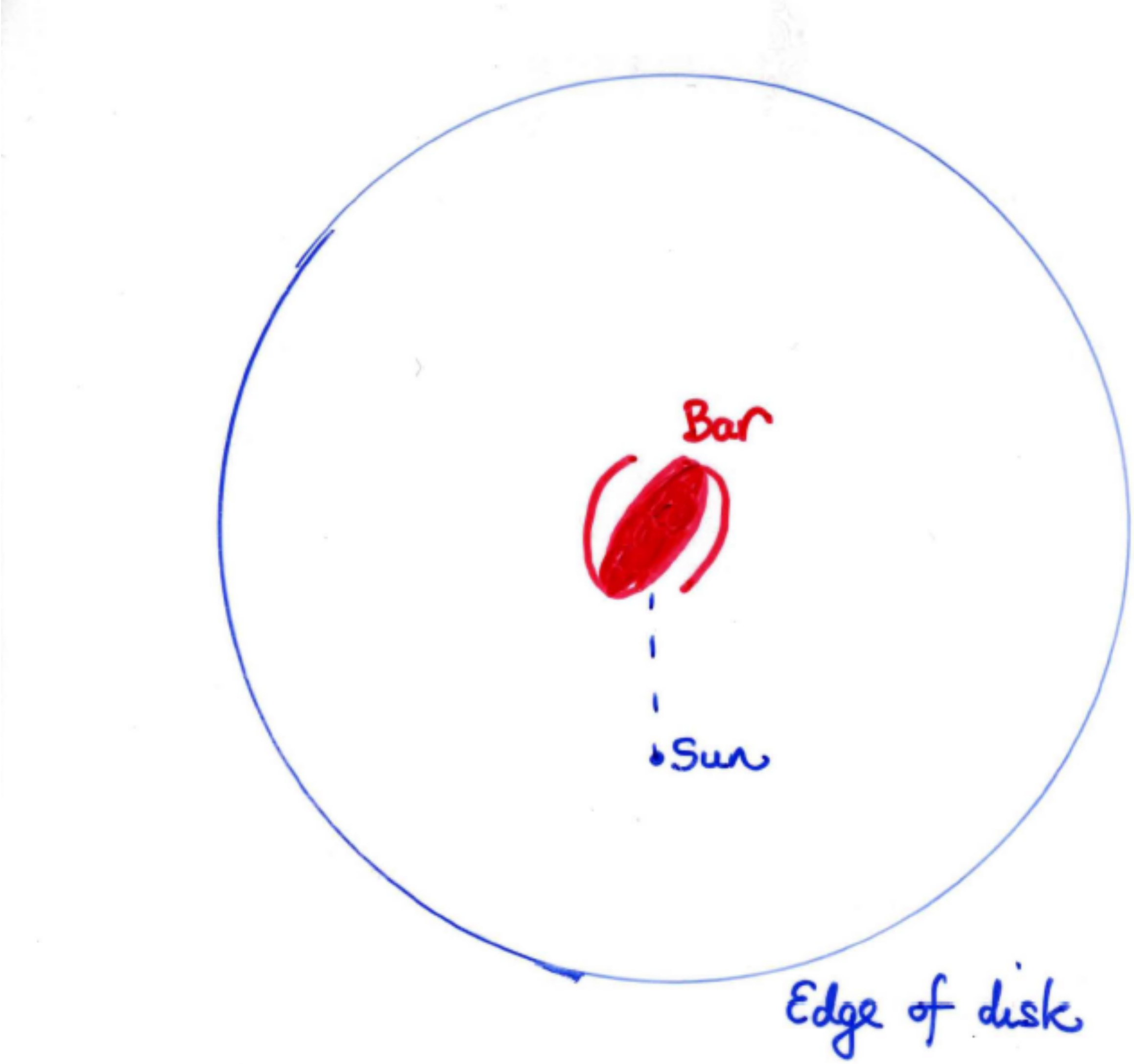
- Kent et al (op cit) noted that an exponential law fitted the Spacelab data better than an $R^{1/4}$ law; scale ht $h_z = 378$ pc.

A bar!

- Suggestions from gas kinematics (Binney et al 1991) and photometry (Blitz and Spergel 1991) were confirmed by the COBE satellite data (Dwek et al 1995): we live in a barred galaxy.


(A)
(B)
(C)
1.25 μm
1.6/15.8
1.25 μm
1.6/15.8
1.25 μm
1.0/79.4
2.2 μm
1.6/25.1
2.2 μm
1.6/25.1
2.2 μm
1.0/79.4
3.5 μm
0.9/25.1
3.5 μm
0.9/25.1
3.5 μm
0.6/31.6
4.9 μm
0.3/15.8
4.9 μm
0.3/15.8
4.9 μm
0.3/12.6
MIN
MAX

Orientation of bar wrt Sun



Perspective causes angular scale height to be larger on nearside

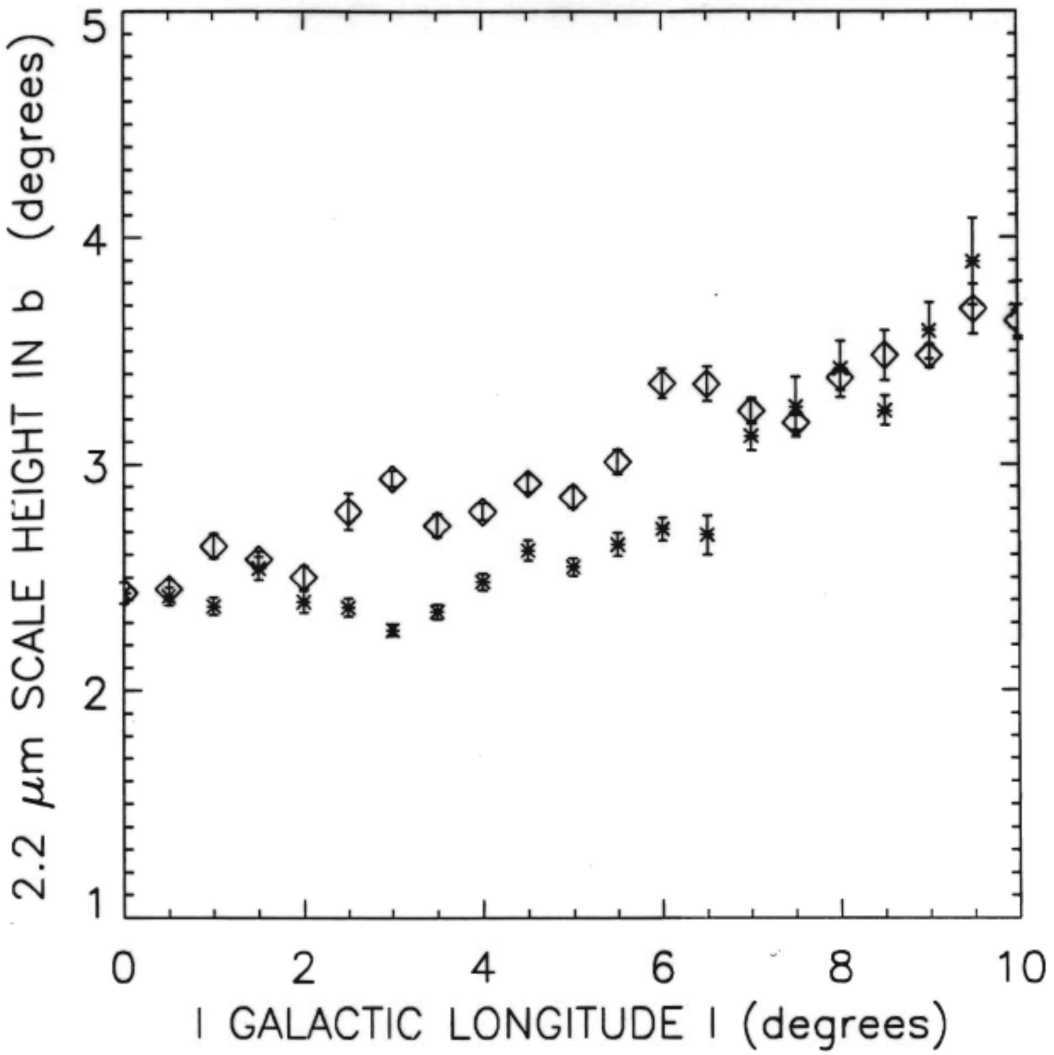
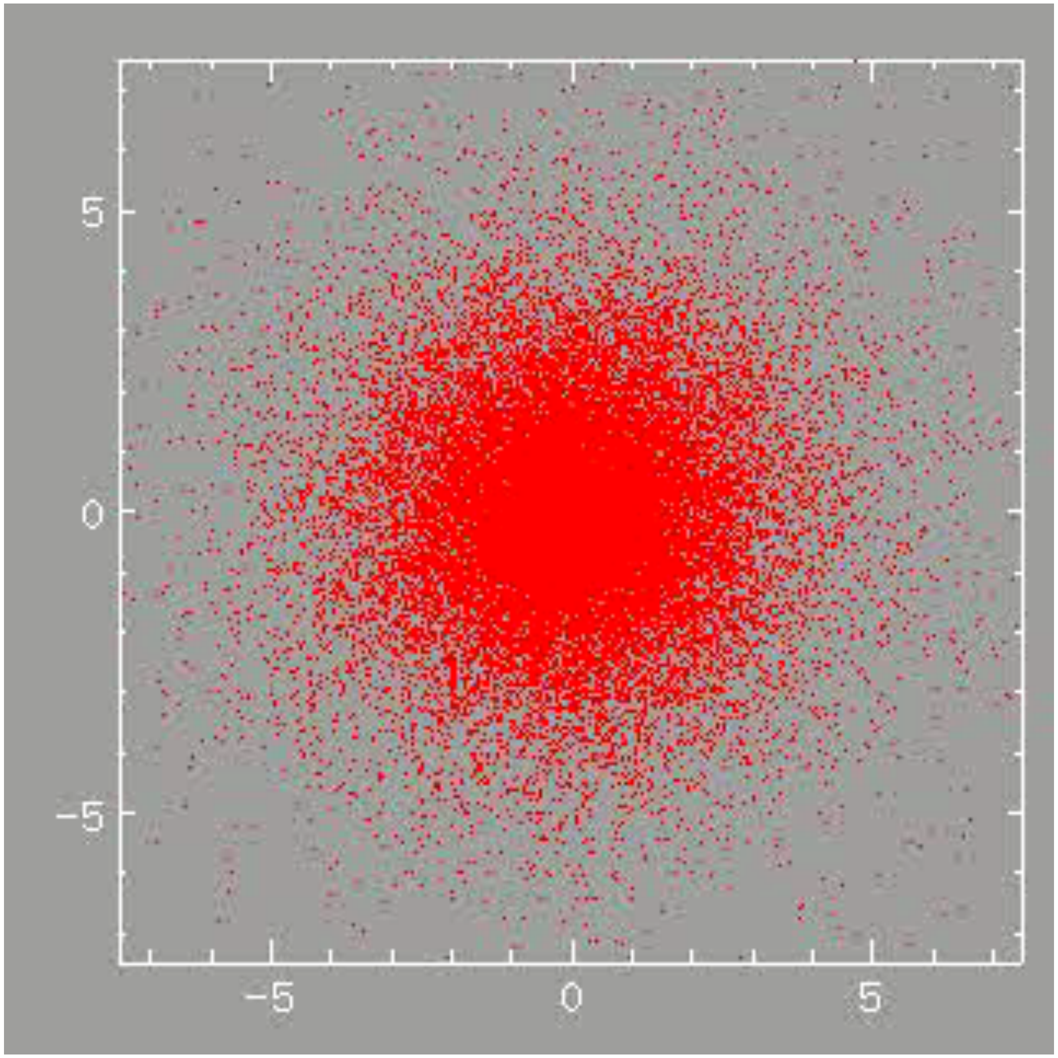


FIG. 2.—2.2 μm angular scale heights at fixed longitude. Scale heights for $l < 0°$ are represented by asterisks, whereas diamonds are for scale heights at positive Galactic longitudes. The error bars represent 1 σ errors on the computed scale height.

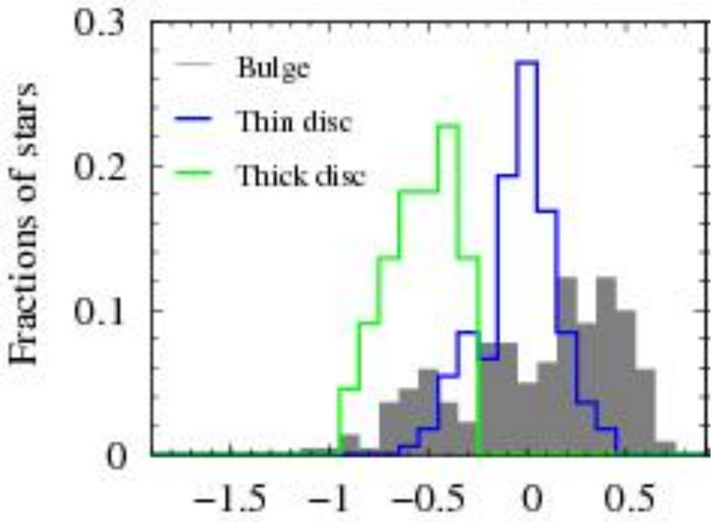
It’s hard to STOP disks forming bars



Movie from Prof Mihos

Age and metallicity

- Bulge/bar stars are old: of order 10 Gyr
- They are also metal-rich; more so than the disk near the Sun
- However, so are inner disk stars



Hill et al 2011; note that thin and thick disk stars are from solar neighborhood

Summary

Originally it was thought that our Galaxy had an $R^{1/4}$ bulge

We now know that it’s possible to model all the luminosity of the central regions by a bar

Since bars are dynamical states of a disk, we do not need a separate stellar population for the bulge; the bar is part of the inner disk

Many galactic astronomers still say ‘bulge’ which is confusing ☹