1.4 Galaxy Light Distributions

List of topics

- Hubble classification scheme
  - see Binney & Merrifield text
- Galaxy surface brightness profiles (JL 2.3.1, plus additional material)
- Galaxy luminosity function (not in JL)
- The Tully Fisher relation (additional material cf JL)
- The Faber-Jackson relation (additional material cf JL)
- Metallicity and populations in typical spirals
- Metallicity and populations in typical ellipticals

See JL 2.2 for some background material only

Surface Brightness Profiles

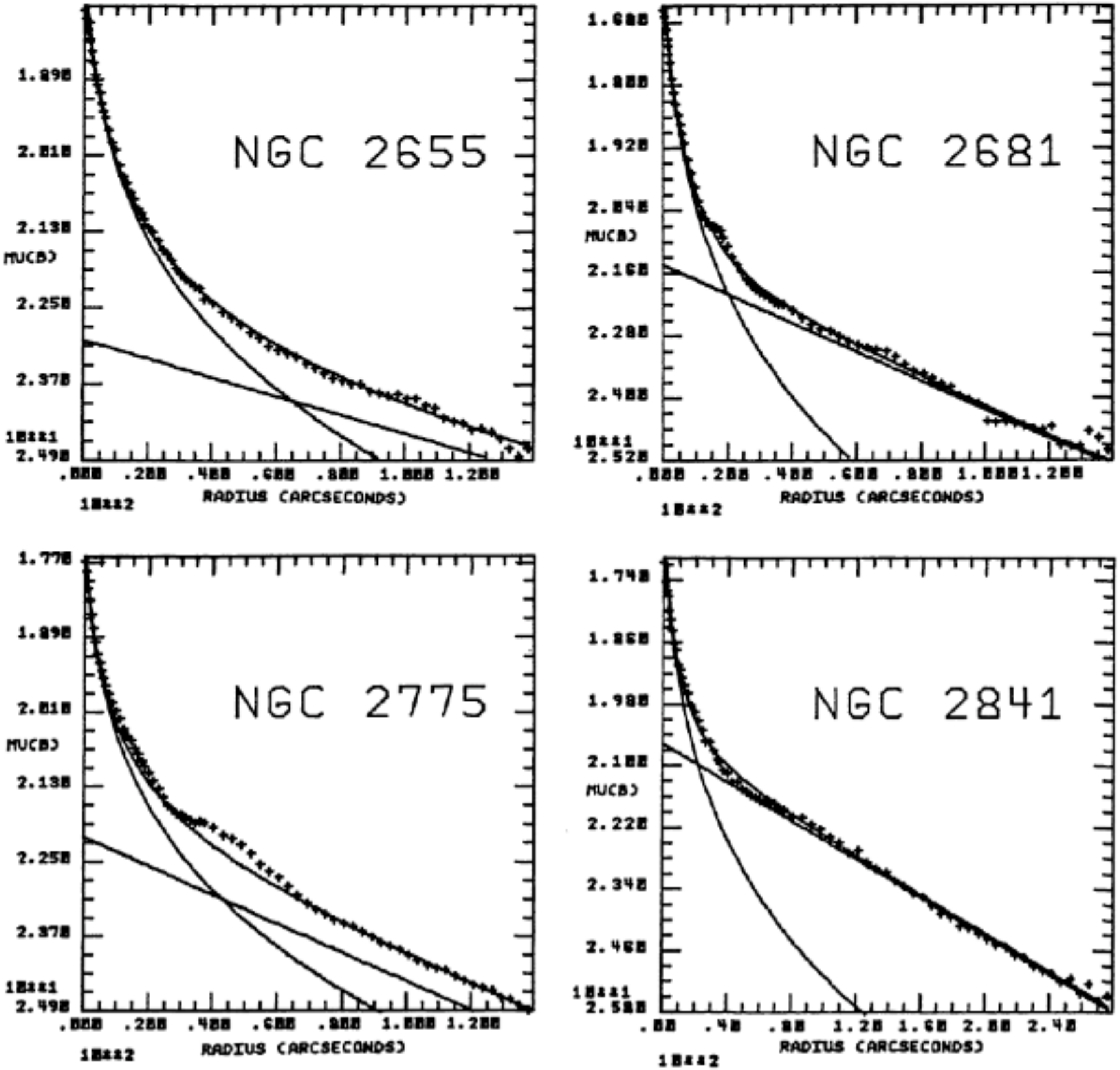
- What is the total luminosity of a galaxy?

The Sombrero Galaxy — M104 HUBBLESITE.org

Surface Brightness Profiles

- What is the total luminosity of a galaxy?
  - At what radius to stop adding up?
  - Atmosphere and instrument limit radius
- Surface brightness profile = apparent surface brightness as fn of radius
  - Apparent surface brightness = energy from source, per unit area of telescope, per arcsec^2
  - Usually for a given waveband, e.g. R-band
- Usually assume
  - ellipticals: de Vaucouleurs profile: $I(R) \propto \exp(-(r/r_0)^{1/4})$
  - spirals: de Vaucouleurs bulge + exponential disk

    exponential disk: $I(R) \propto \exp(-r/r_0)$



Boroson 1981ApJS...46..177B

The Galaxy Luminosity Function

- Number of galaxies of given $\boxed{\text{L per unit V}}$
- Schechter function fits well
  - $\phi(L) = (n_* / L_*) \boxed{(L/L_*)^\alpha \exp(-L/L_*)}$
  - Where $\alpha \sim -1.1$, $L_* \sim 10^{10} L_{solar}$, $n_* \sim 0.01\ \mathrm{Mpc}^{-3}$ (depending on selection criteria of galaxies)

Sketch the Schechter function on a log-log plot

Local luminosity function

- The 2dF galaxy survey (astro-ph/0111011)

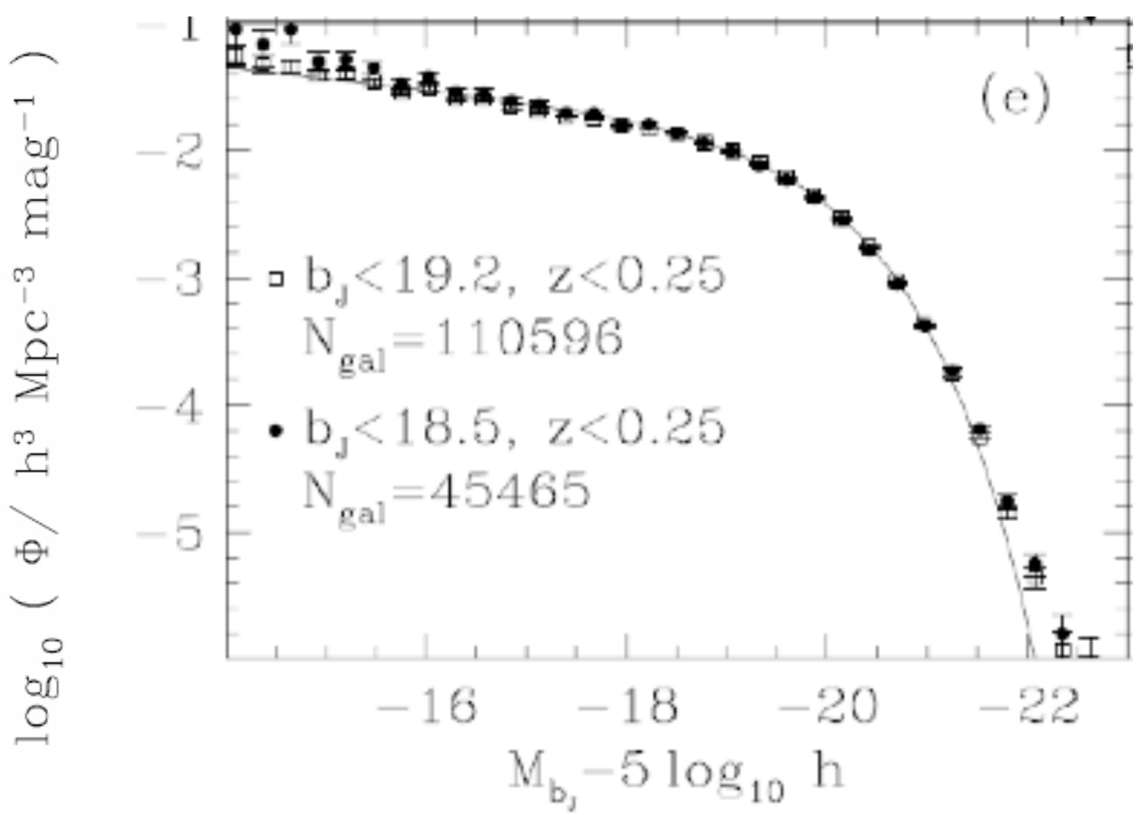


Figure 9. Luminosity functions for different subsamples of the 2dFGRS data. The smooth curve in each panel is a Schechter function with $M^{\star}_{b_J} - 5\log_{10} h = -19.67$, $\alpha = -1.21$ and $\Phi^{\star} = 1.64 \times 10^{-2} h^3 \mathrm{Mpc}^{-3}$. This is the STY estimate for the sample defined by

The Galaxy Luminosity Function

- Number of galaxies of given L per unit V
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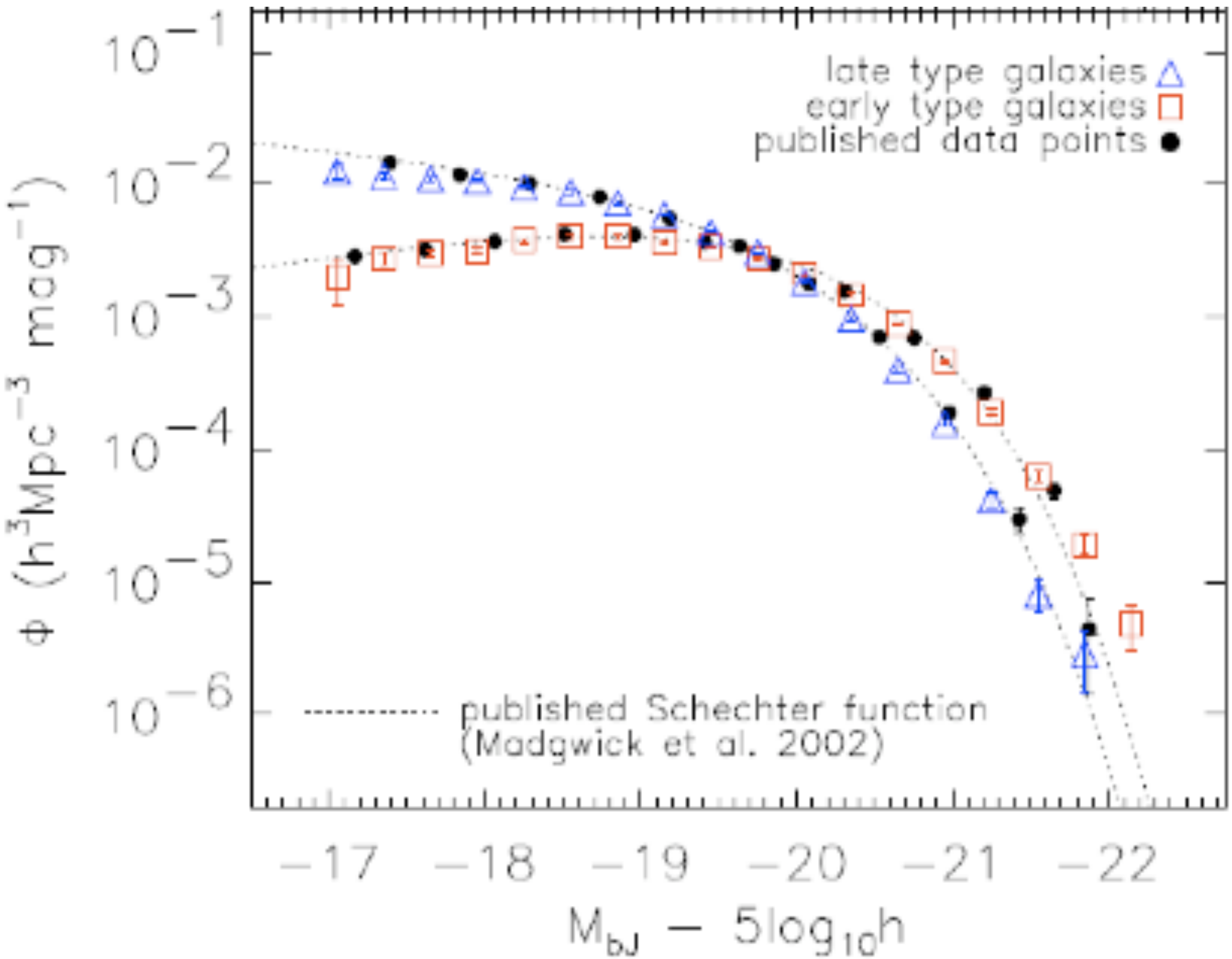
  - Where $\alpha \sim -1.1$, $L_* \sim 10^{10} L_{solar}$, $n_* \sim 0.01$ Mpc^{-3} (depending on selection criteria of galaxies)
- L_* is a typical galaxy luminosity
- n_* is a typical galaxy density
  - what is a typical intergalactic distance? $n_*^{-1/3} = 5$ Mpc
- $N = \int_{L(min)}^{\infty} \phi(L)\, dL$ diverges as L(min) -> 0
  - not physical but emphasises large number of faint galaxies

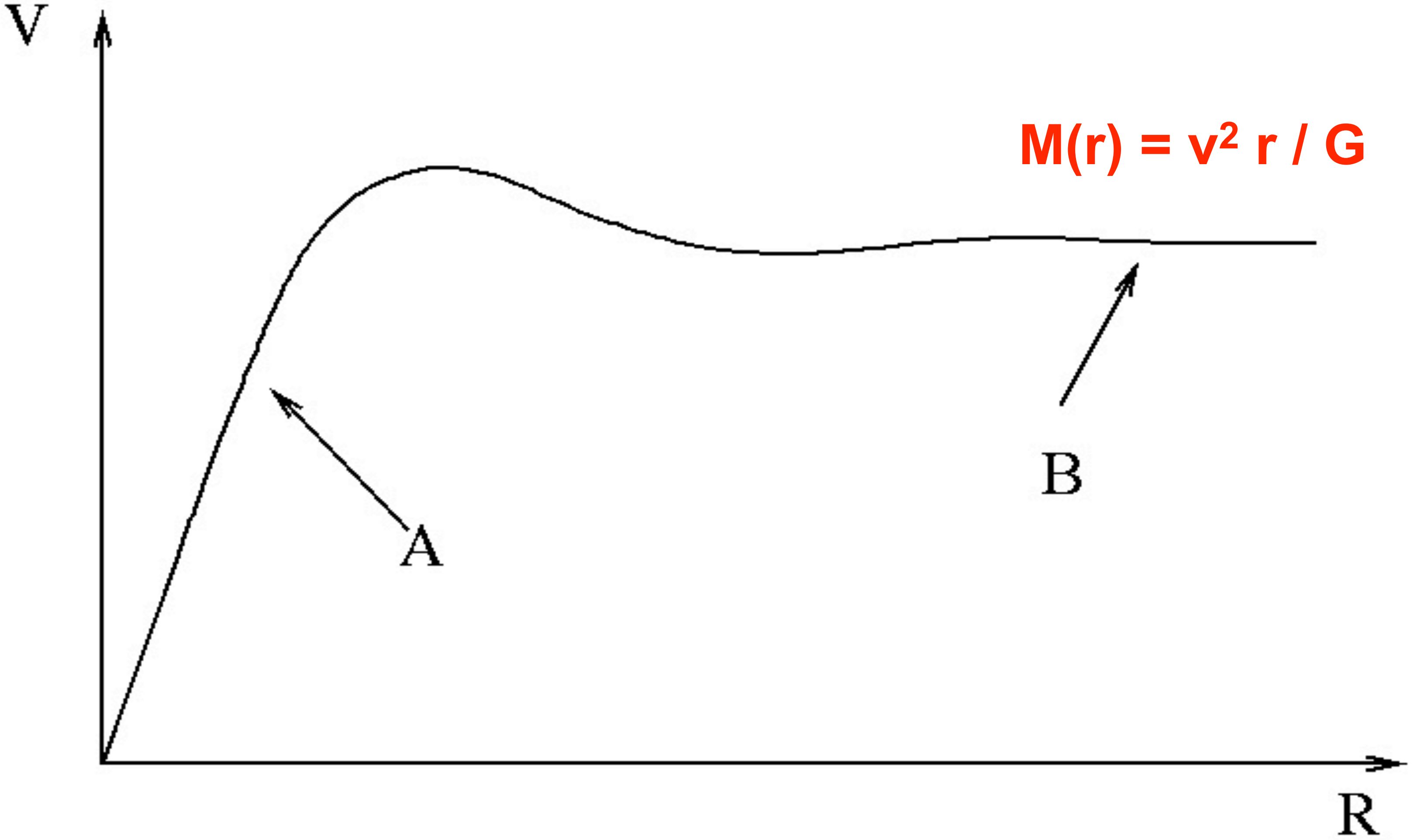
Dependence of $\phi(L)$ on galaxy type



From the 2dF survey astro-ph/0407537

The Tully-Fisher relation

- Relates luminosity to line-width for spirals
- v(r) for our galaxy is typical of spirals
  - Observe other galaxies using HI or HII

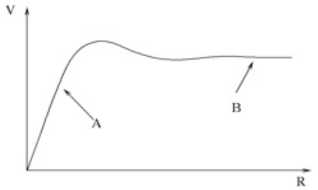


$M(r) = v^2 r / G$

http://www.astro.livjm.ac.uk/courses/exams/phys134_0699.html

The Tully-Fisher relation

- Relates luminosity to line-width for spirals
  - Tully & Fisher 1977
- v(r) shape for our galaxy is typical of spirals
  - Observe other galaxies using HI or HII
  - call v_{rot} the flattened velocity



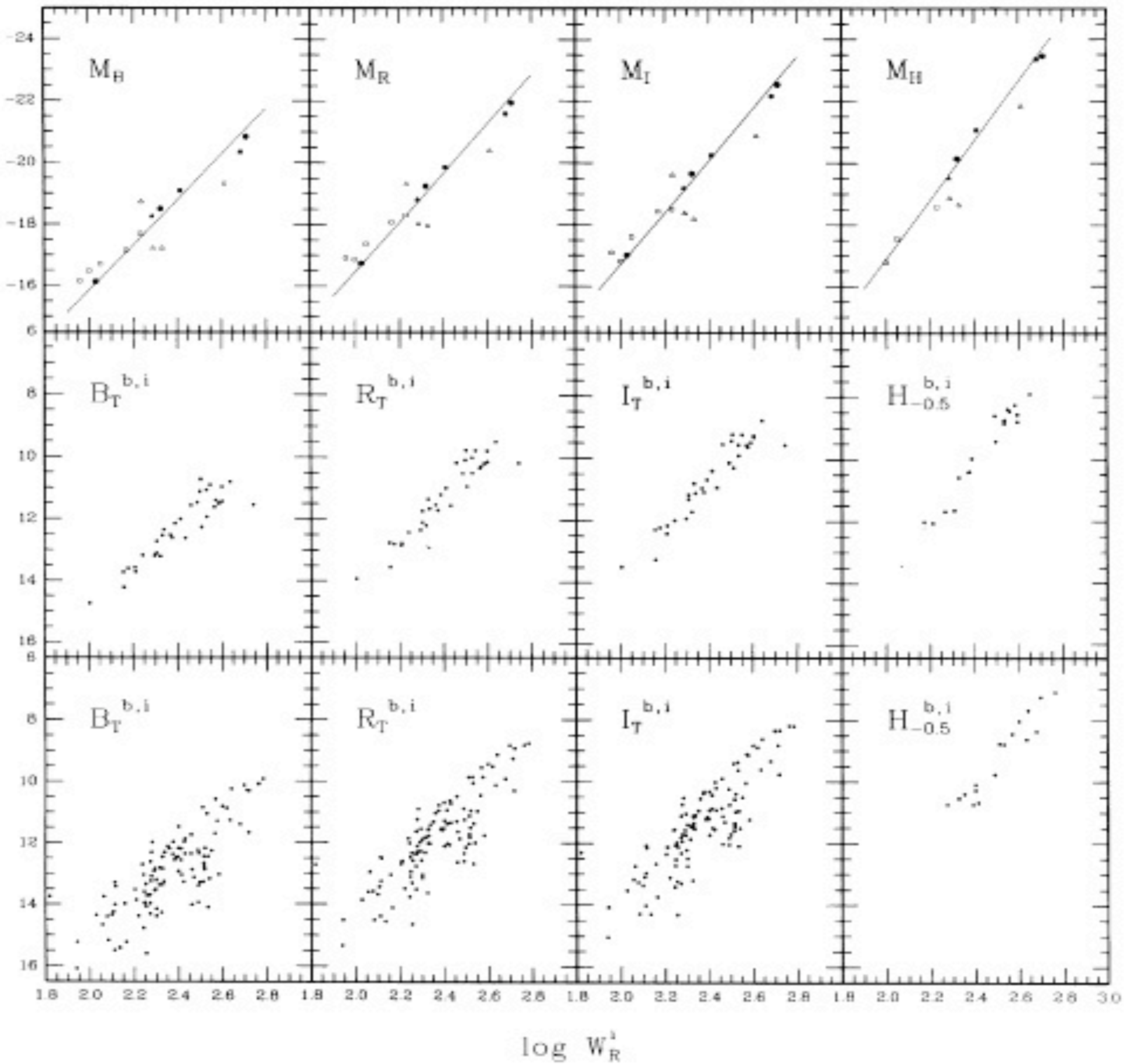
- We observe $L \propto v_{rot}^{\,\beta}$
  - $\beta \sim 2.5$ in b-band
  - $\beta \sim 4$ in the infrared
- What would you expect for β ?
  - Assume $M \propto L$ (constant mass to light ratio)
  - Assume $L = L_o \pi r^2$ (with L_o same for all gals)

What would you expect for β ?

$$L \propto v_{rot}^{\ \beta}$$

1. 1
2. 2
3. 2.5
4. 4

Assume $M \propto L$ (constant mass to light ratio)
Assume $L = L_o \pi r_0^2$ (with L_o same for all gals)



local calibrators

Ursa major

Virgo

The Faber Jackson relation

- Relates luminosity and central velocity dispersion of ellipticals
- Stars in ellipticals seem to be virialised
  - all move in random directions, velocities v
  - velocity dispersion = σ_v = $\langle v^2 \rangle^{1/2}$
  - virial theorem: 2 K.E.=-P.E. so $\sigma_v^2 \propto M/R$
- Faber-Jackson relation: $L \propto \sigma_v^4$
- The Fundamental Plane:
  - plot galaxies in 3d: L, σ_v, R
  - find $R \propto \sigma_v^{-2} L^{1.25}$

Mass-to-light in ellipticals

- Virial theorem: $M \propto \sigma_v^2 R$
- The fundamental plane: $R \propto \sigma_v^{-2} L^{1.25}$
- Suppose $(M/L) \propto L^\gamma$
  - Find γ

- The bigger the luminosity, the $\boxed{\text{bigger}}$ the mass, the more $\boxed{\text{dark}}$ matter

What type of stars do ellipticals mostly contain?

1. Pop I
2. Pop II
3. Pop III

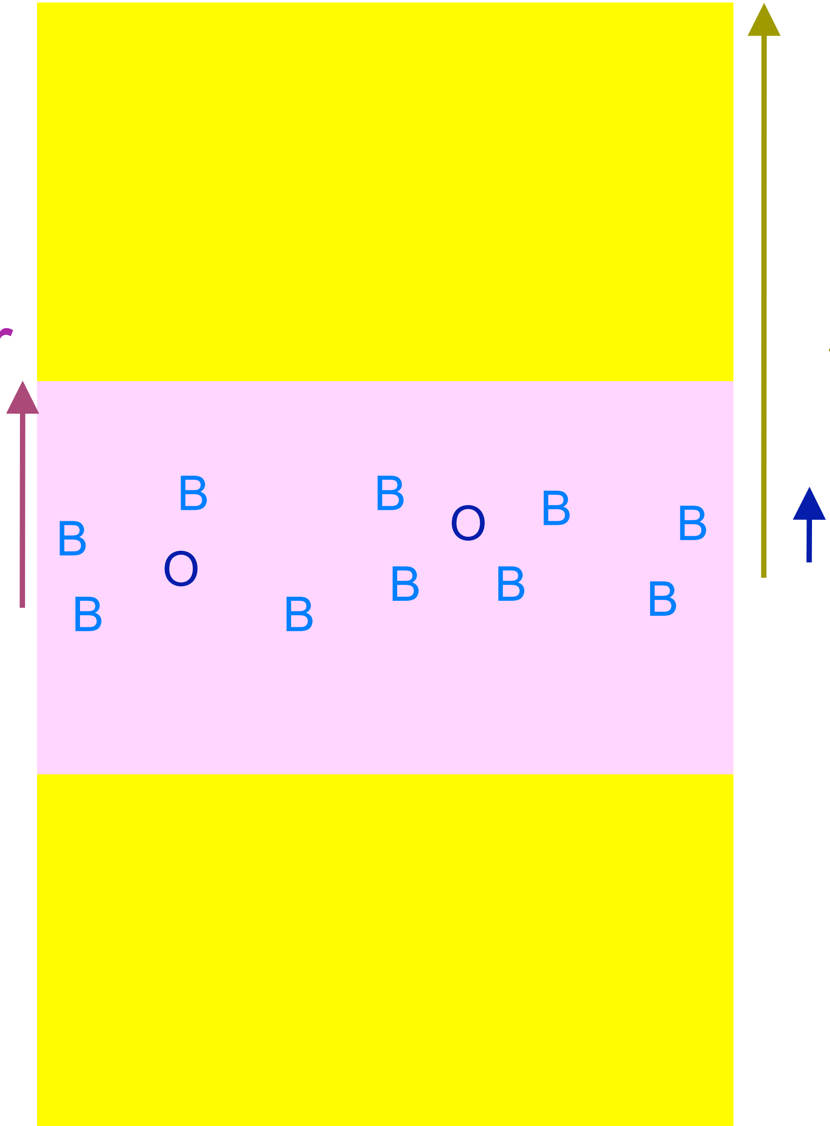
Spiral galaxies

- See notes on our galaxy
- Blue spiral arms, young, high Z
- Older disk population, medium Z
- Old low mass Pop II stars in bulge and spheroid
- Decrease in Z with increasing r
  - e.g. bulge metallicity is higher than solar

Elliptical galaxies

- Little sign of gas or recent star formation
- Stellar populations are old and red (Pop II)
  - (B-V ~ 1)
  - most light from red giants
- Small E/S0 gals have low metal content
  - Large E/S0 galaxies are relatively metal rich

The thin disk



Interstellar
gas, dust
h ~ 120pc

Main sequence stars
G, K, M
h ~ 350 pc
$\Sigma \sim 13\ M_o\ pc^{-2}$

Young stars
B, O
h ~ 50 pc
$\Sigma \sim 10^{-3}\ M_o\ pc^{-2}$

Why???

Why does the gas have a larger scale height than the O and B

1. The gas has diffused since the O and B stars formed
2. Formation of O and B stars depends linearly on the gas density
3. ✓ Formation of O and B stars depends non-linearly on the gas density

Read JL last paragraph on p 36

Why do the G, K, and M stars have a larger scale height than the gas?

1. Formation of G, K and M stars depends non-linearly on the gas density
2. ✓ The G, K and M stars have drifted away from the disk since forming
3. The gas has condensed towards the central plane since the stars formed

Read JL first paragraph on p 36

Are spiral arm stars

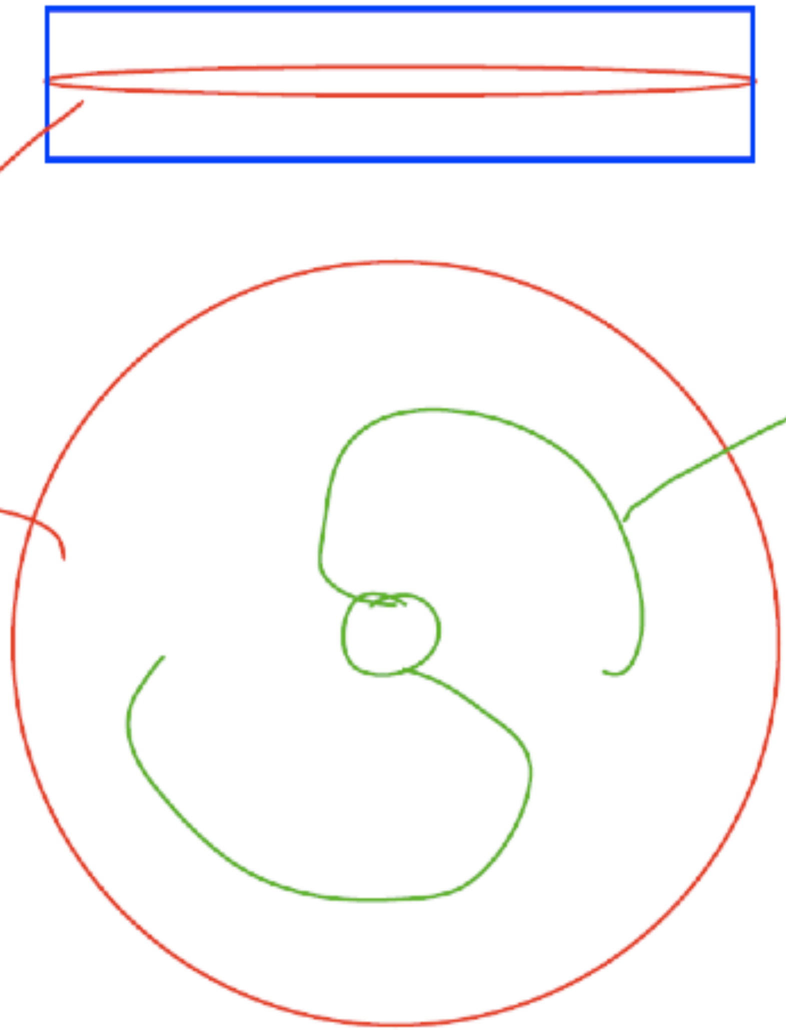
1. Very young (<0.1 Gyr)
2. Young (0.1 – 1 Gyr)
3. Intermediate age (1 – 10 Gyr)
4. Old (10 – 14 Gyr)

Are spiral arm stars mostly

1. Low metallicity ($Z<0.002$)
2. Lower than solar metallicity ($Z < 0.02$)
3. Higher than solar metallicity ($Z > 0.02$)

Stellar populations in the disk

Intermediate pop
thick disk stars
~ 10 Gyr
$Z \sim 0.002 - 0.1$



Pop I
thin-disk stars
1–10 Gyr
$Z \sim 0.005 - 0.04$

Pop I spiral arm
stars

$\lesssim 0.1$ Gyr

$\gtrsim Z_0$

Read JL p28,29

Why are spiral arm stars high metallicity?

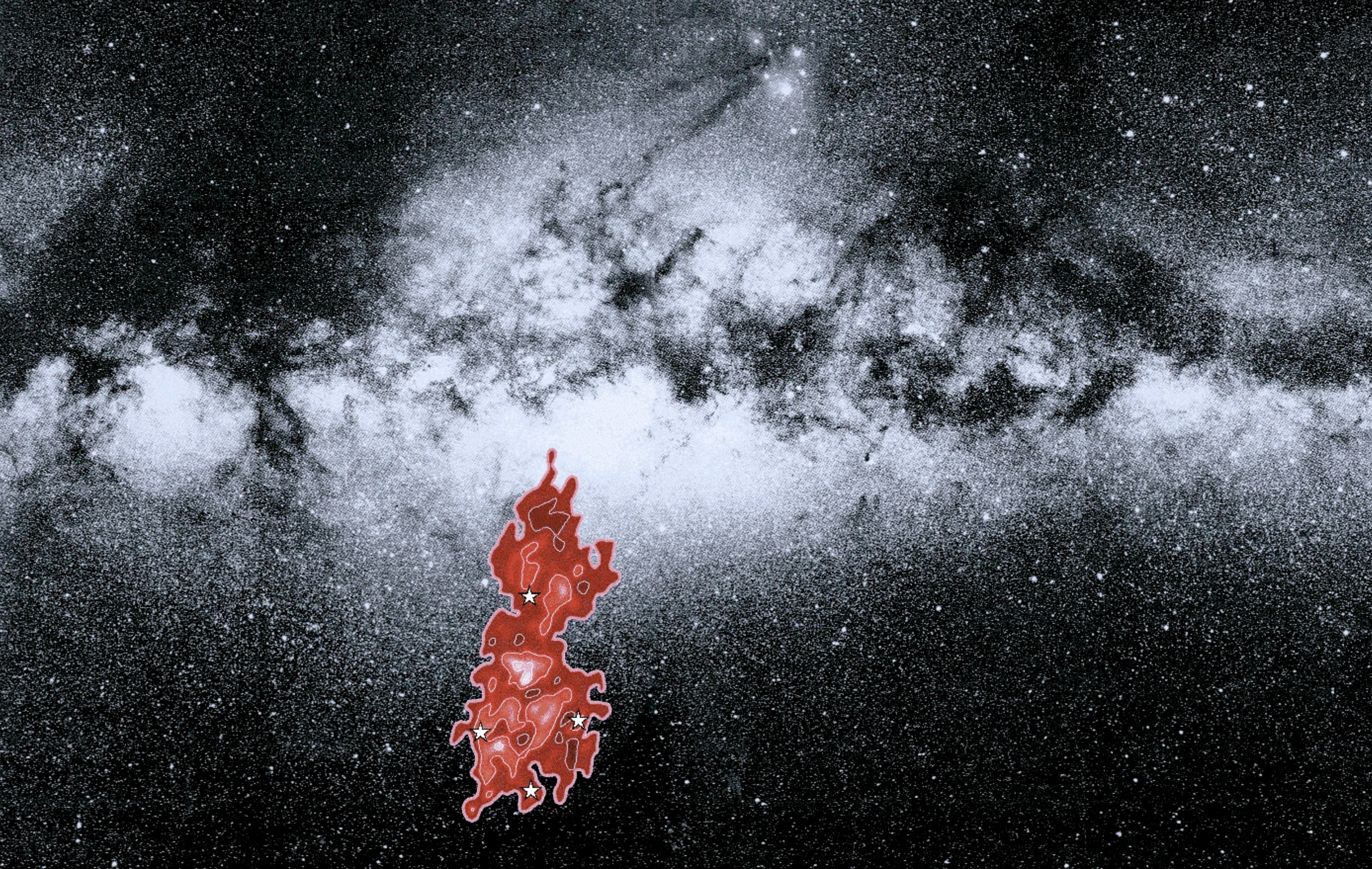
1. They are old and so have produced a lot of metals
2. They are high mass and so have produced a lot of metals
3. Gas they formed from was metal rich

See JL p 19 (Q 1.4, 1.5)

Why is the gas the spiral arm stars formed from more metal rich than that which formed the other disk stars?

1. The spiral arms are higher metalicity than the rest of the disk
2. Metals accumulate over time and the other disk stars were formed long ago

The Sagittarius dwarf galaxy
Stuff is still falling into our Galaxy



http://www.sdss.jhu.edu/~wyse/

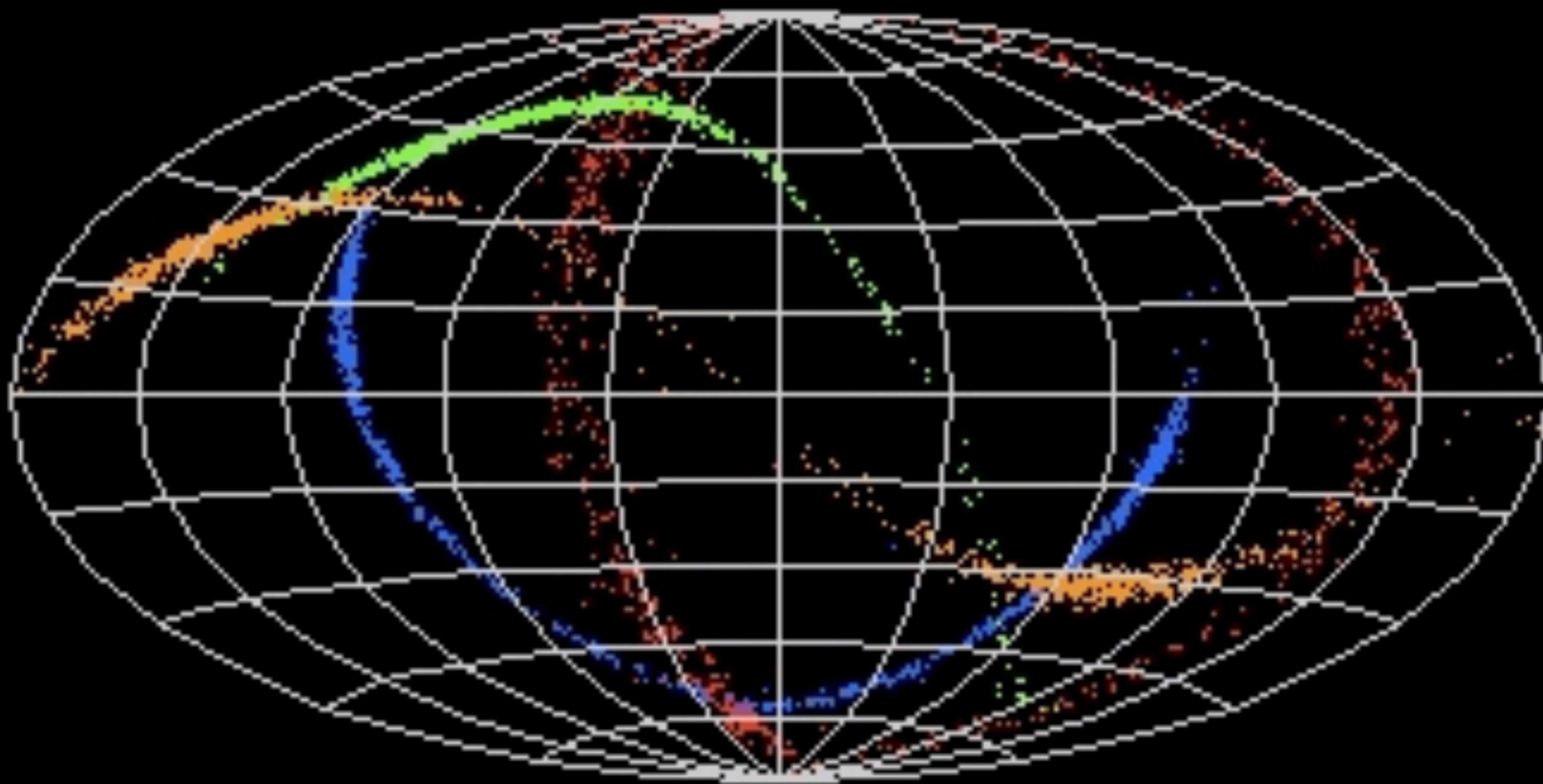
Galactic Archaeology

- Observe positions and velocities of all stars in our galaxy
- Compare with simulations to constrain models

http://astronomy.swin.edu.au/rave/RAVEfig3.jpg

Surface brightness prediction

http://www.physics.uci.edu/~bullock/StellarHalo/halo.html



http://www.astro.wesleyan.edu/~kvj/halo.html

Galactic Archaeology

- Observe positions and velocities of all stars in our galaxy
- Compare with simulations to constrain models
- Future experiments:
  - RAVE: just started, Australia
  - GAIA: satellite
  - WFMOS: proposed, UCL is involved