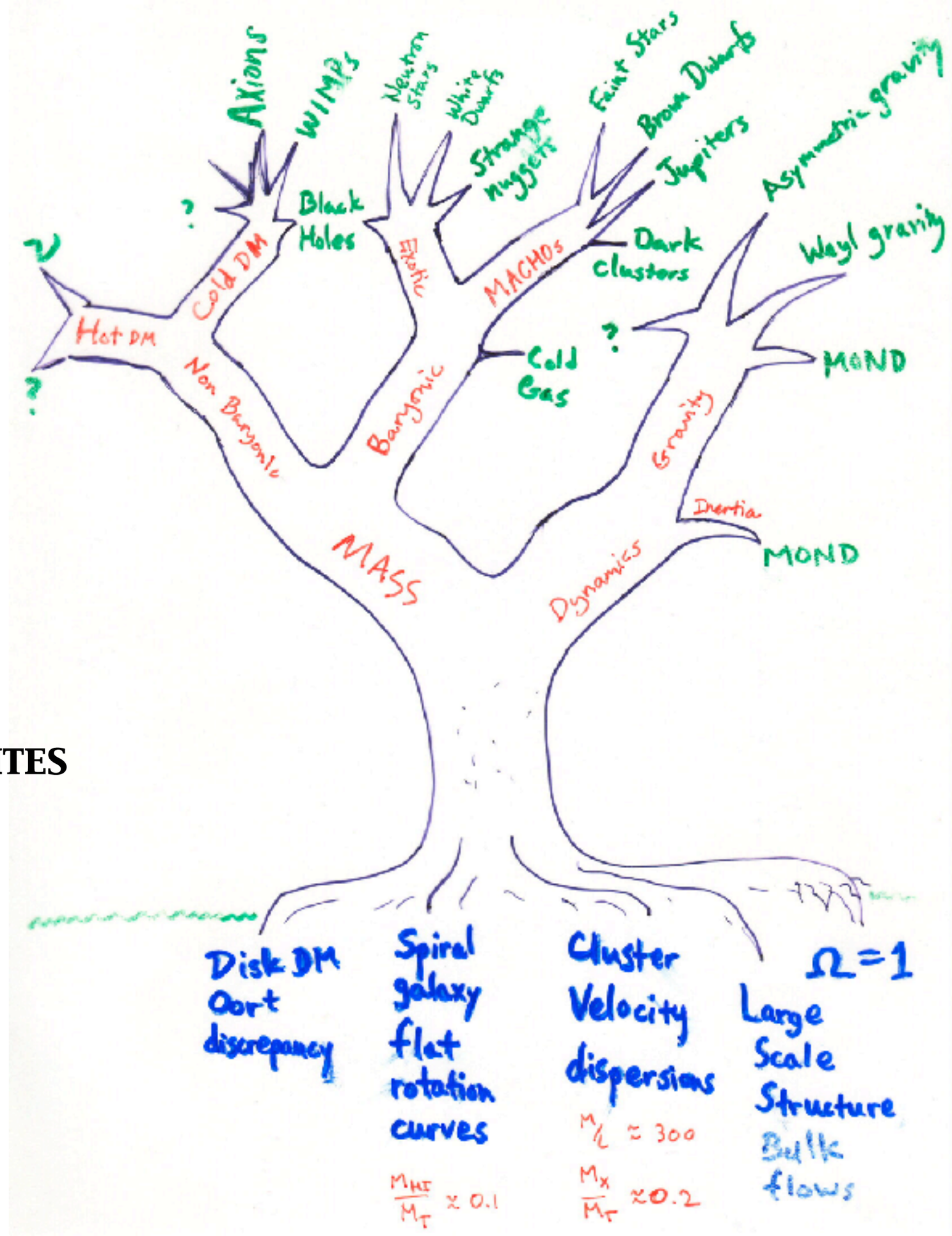
Dark Matter

ASTR 333/433
Spring 2016
T R 4:00-5:15pm
Sears 552

TODAY

- Galactic Structure
- Oort Constants
- Terminal Velocities
- MW Potential from Satellites
- Epicycle Approximation

Homework 1
DUE



Galactic mass distribution: bulge/bar, stellar disk, gas disk, dark matter

Quadrant **I**

IV

$\ell = 0°$

X

Galactic longitude

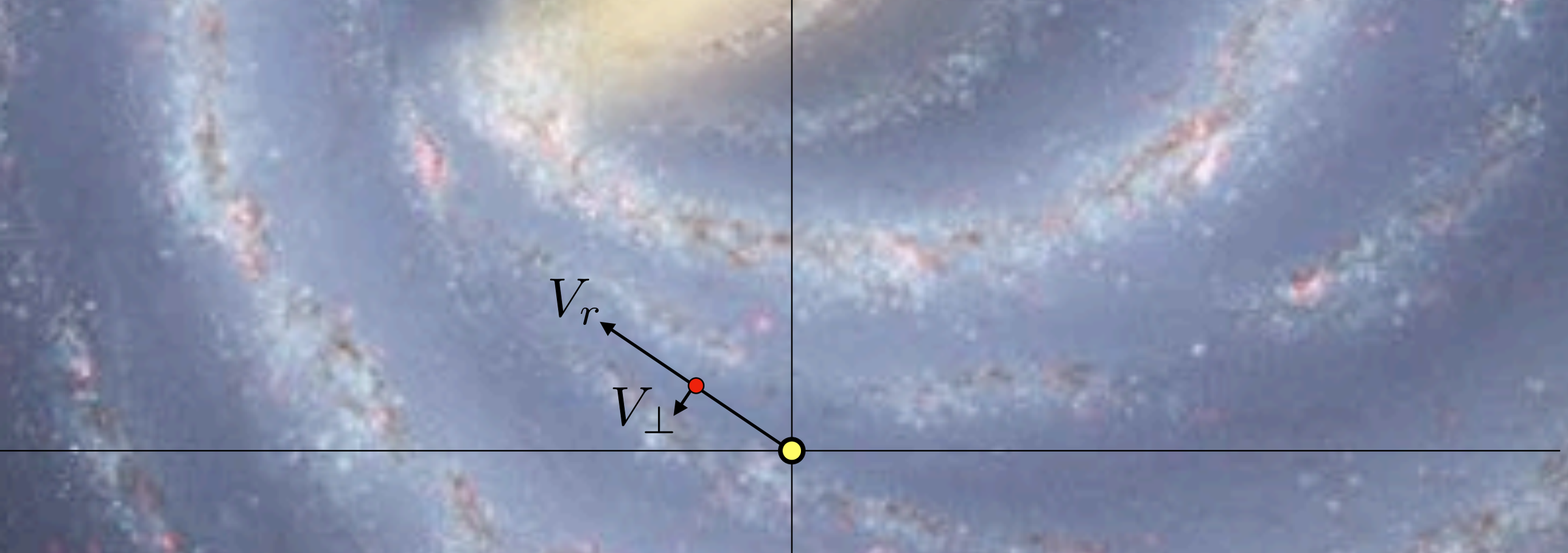
Y

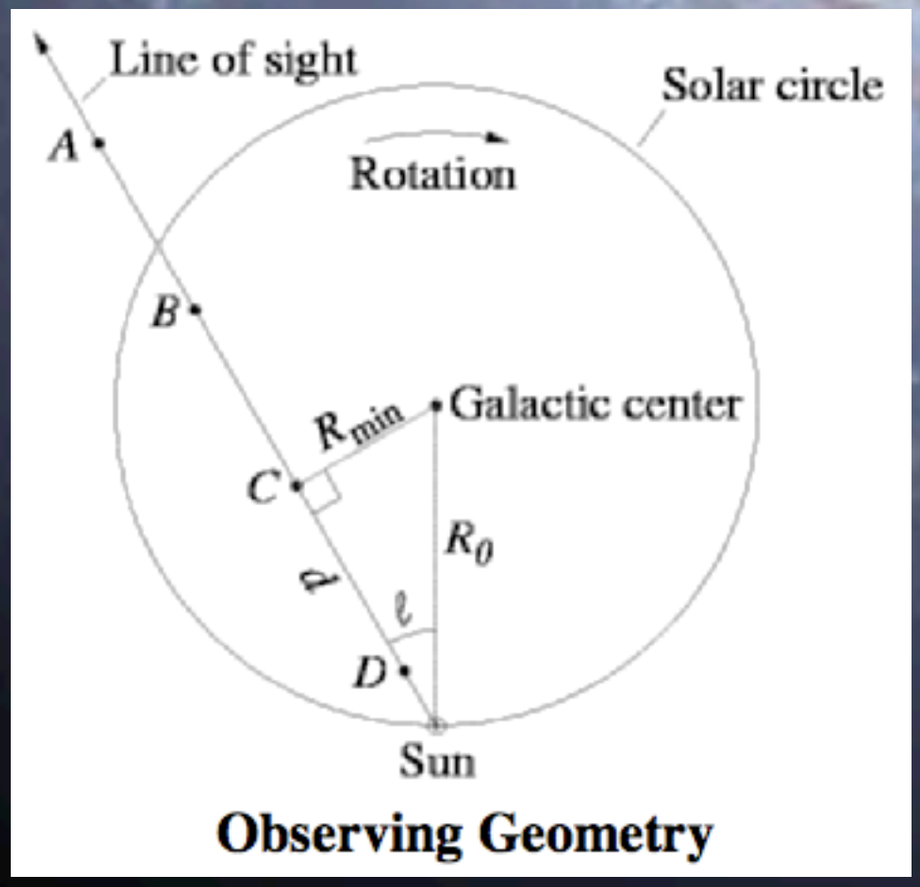
$\ell = 90°$

$\ell = 270°$

II

III

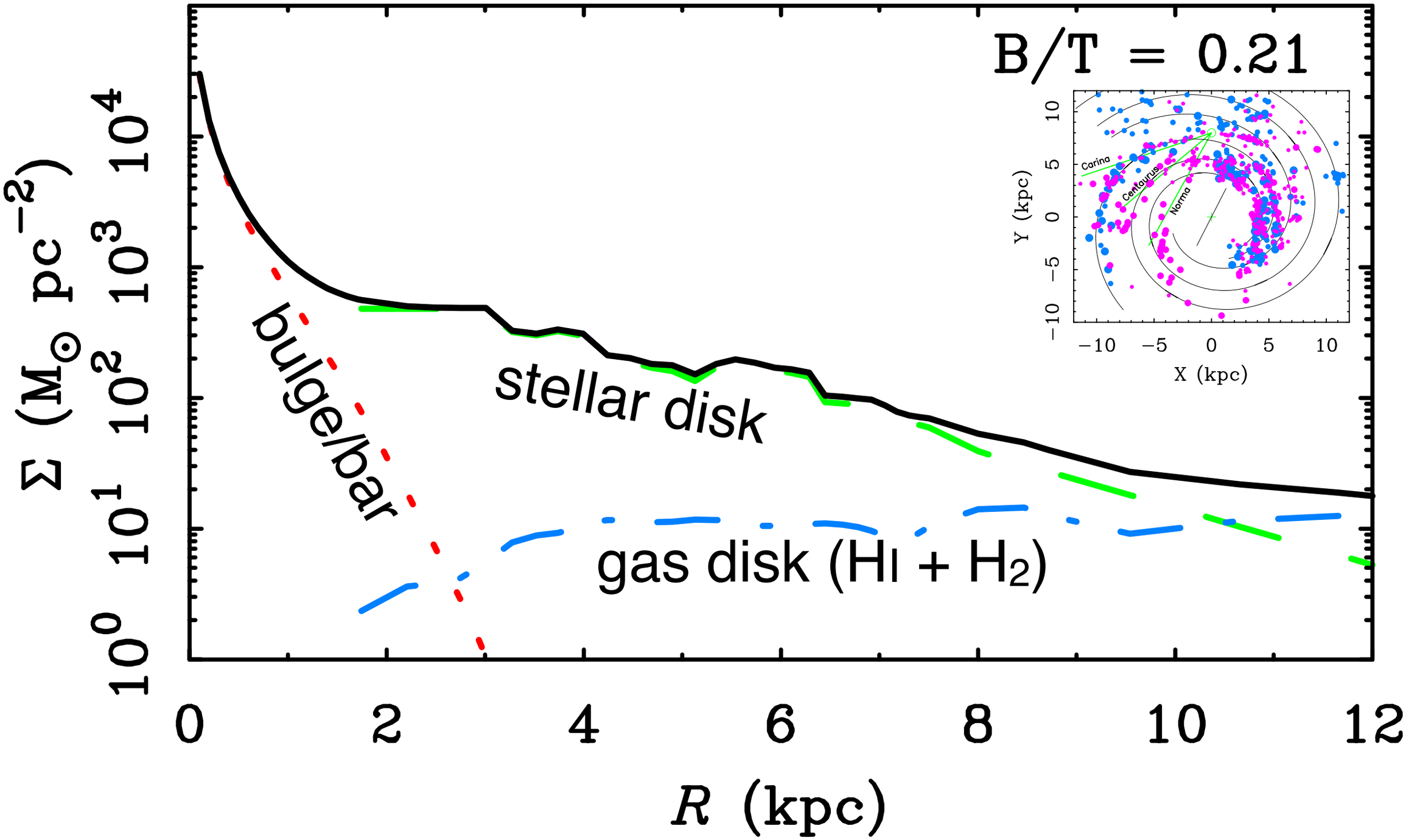




Observing Geometry

$$V_r = R_0 \sin(\ell) \left(\frac{V}{R} - \frac{\Theta_0}{R_0} \right)$$

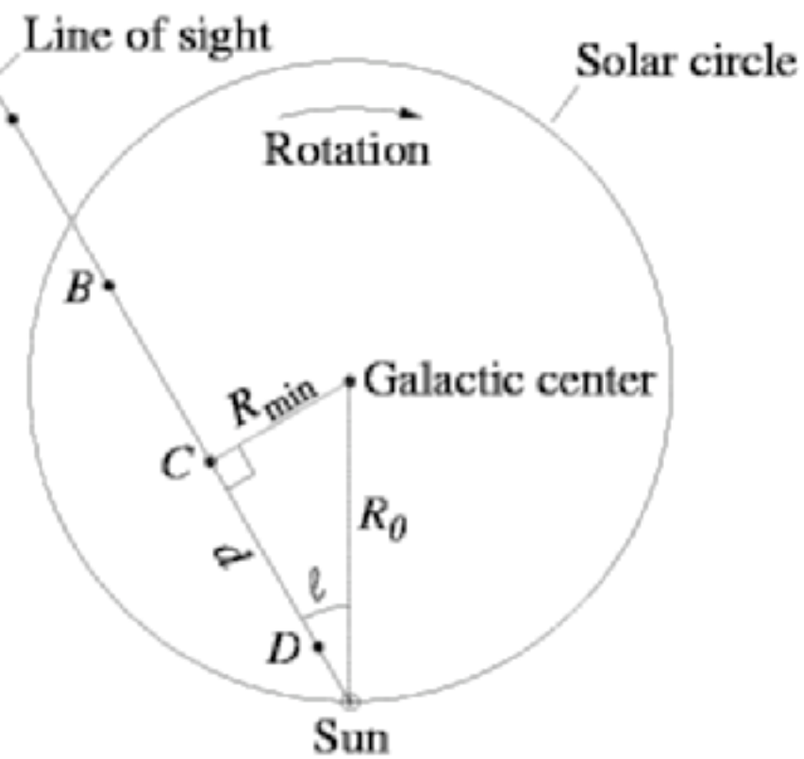
Milky Way model illustrating baryonic mass components



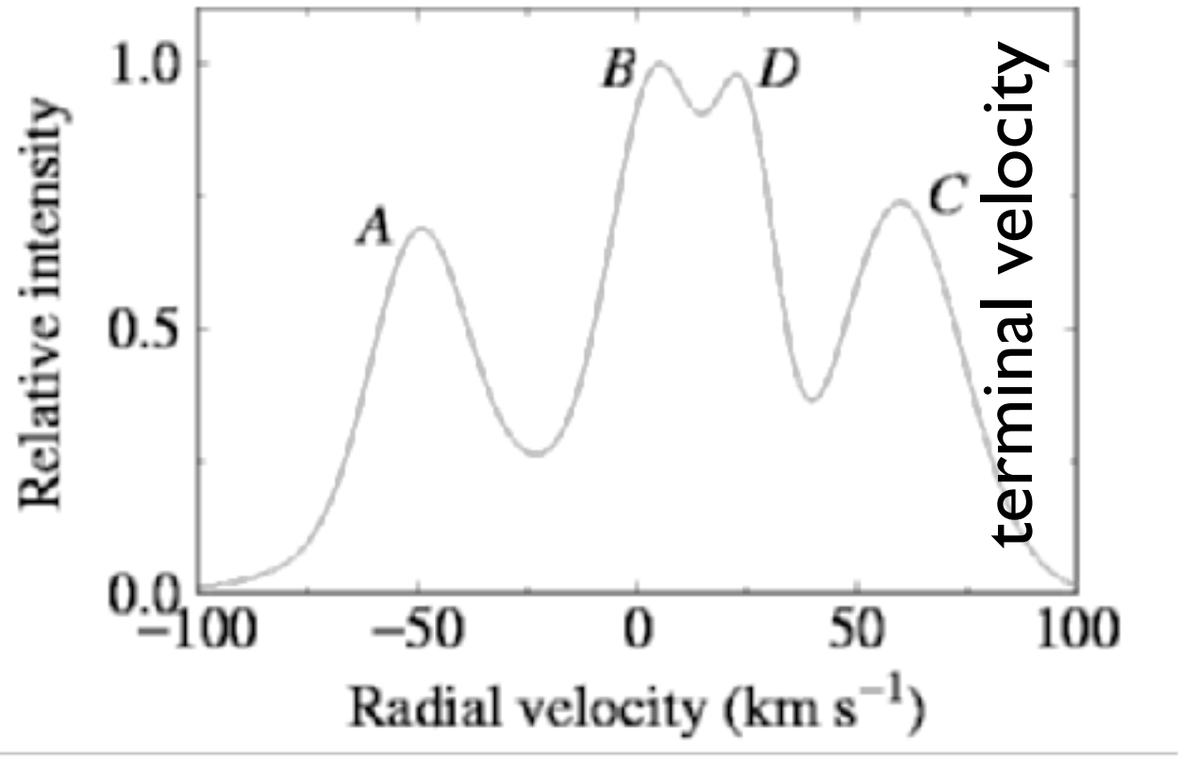
The Tangent-Point Method

Look at gas clouds in the Milky Way. Using 21-cm radio emission, we can get their radial velocity via the doppler shift.

Imagine looking at some line of sight through the galaxy and observing the gas clouds:



Observing Geometry



Observed Velocities

So $v(C) = v(R_{min}) = v(R_0 \sin(l))$.

Maximum velocity at minimum radius along line of sight at Galactic longitude ℓ

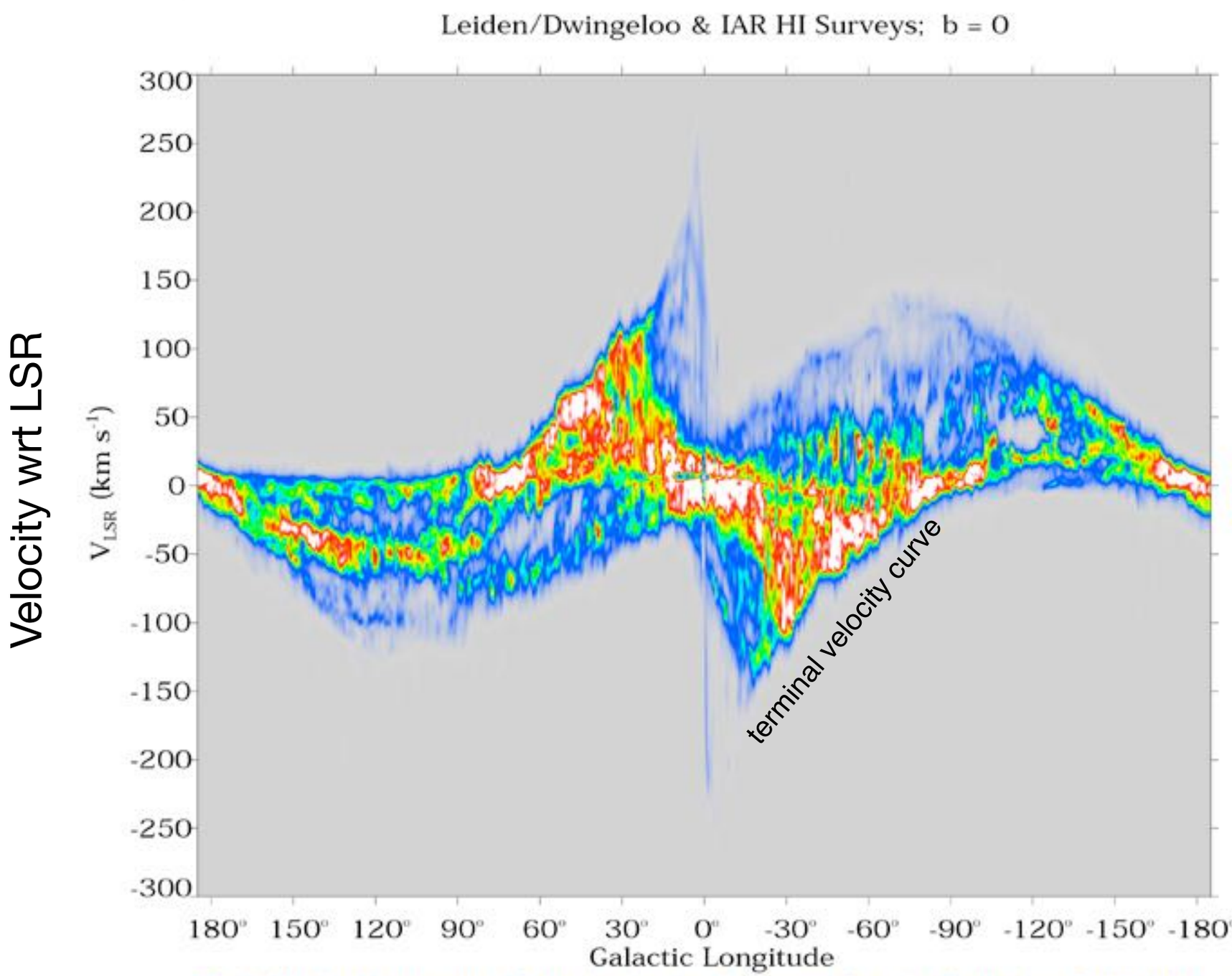
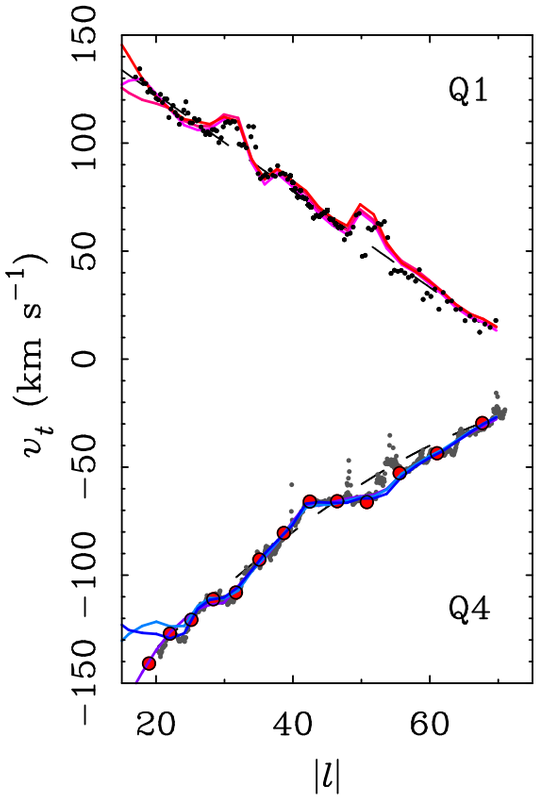


Fig 2.20 (D. Hartmann) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

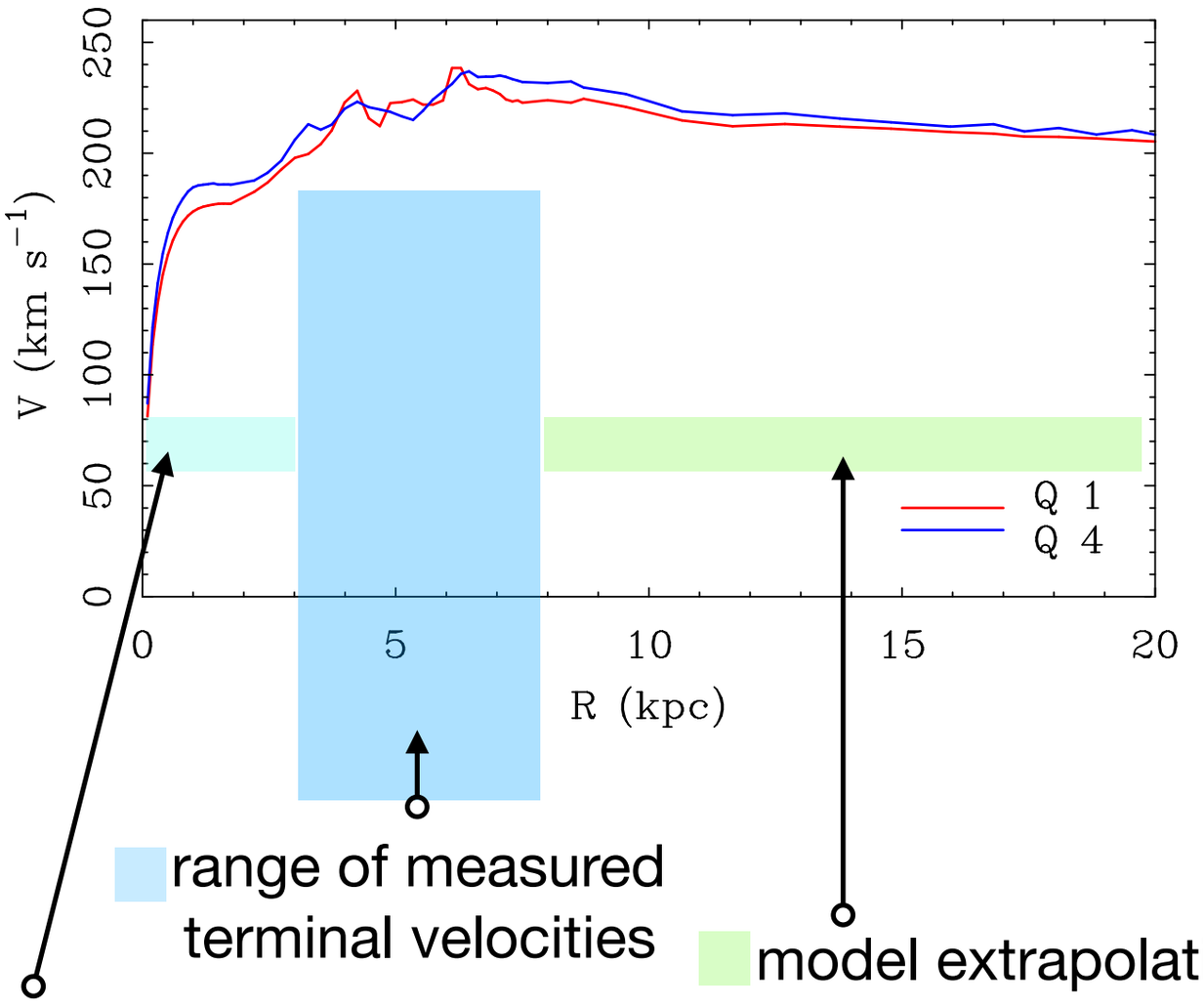
terminal velocities

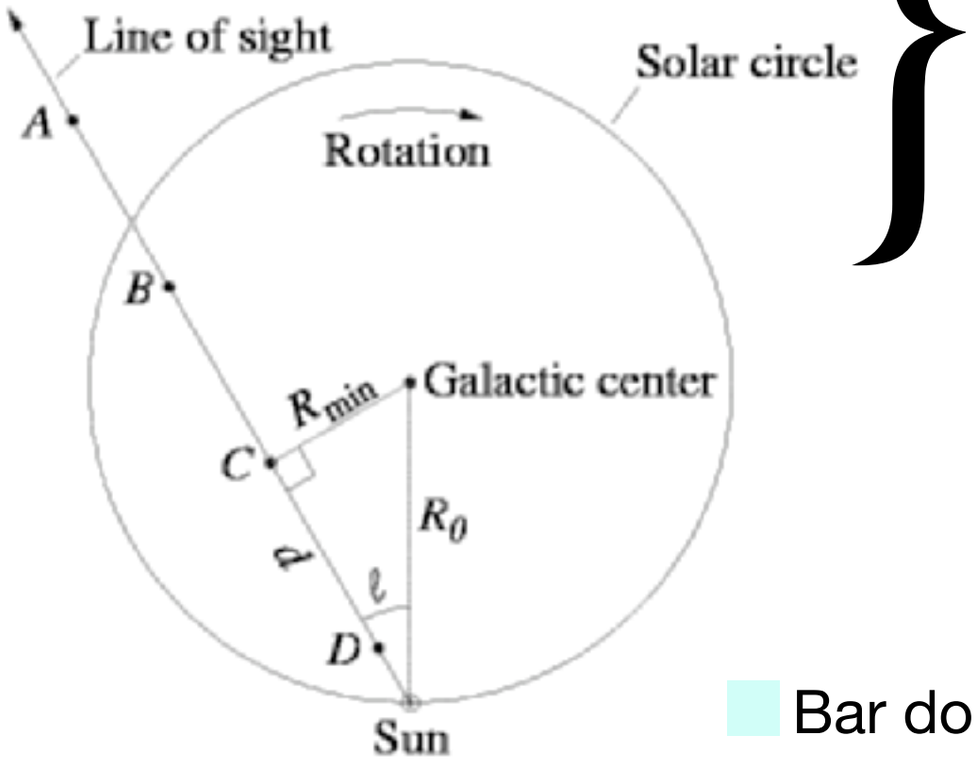


$$R = R_0 \sin \ell$$

$$V = v_t + \Theta_0 \sin \ell$$

Milky Way rotation curve



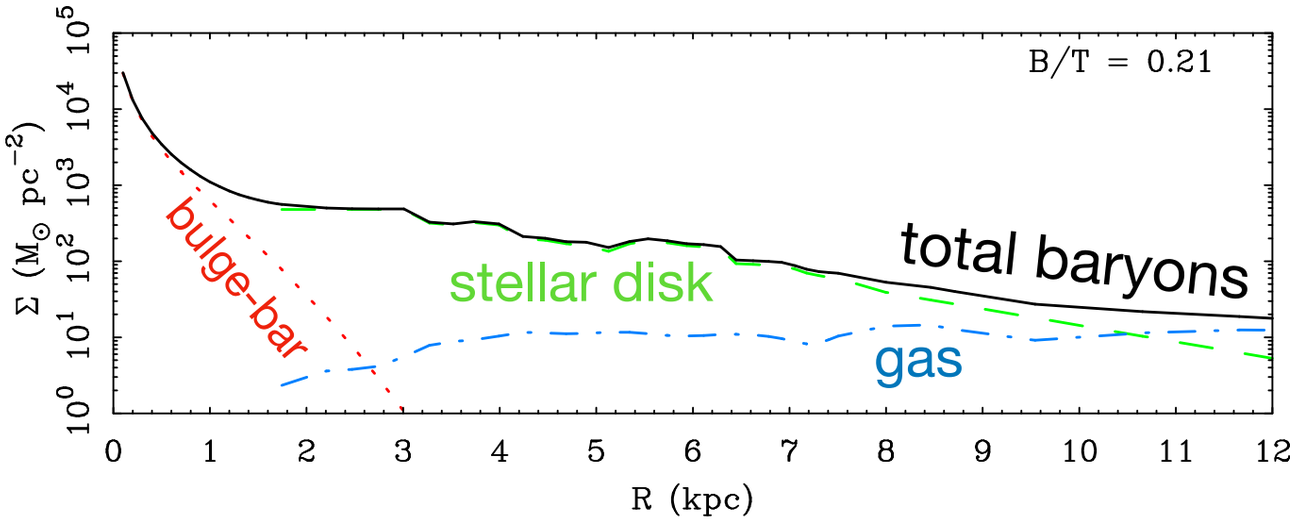


Observing Geometry

range of measured terminal velocities

model extrapolation

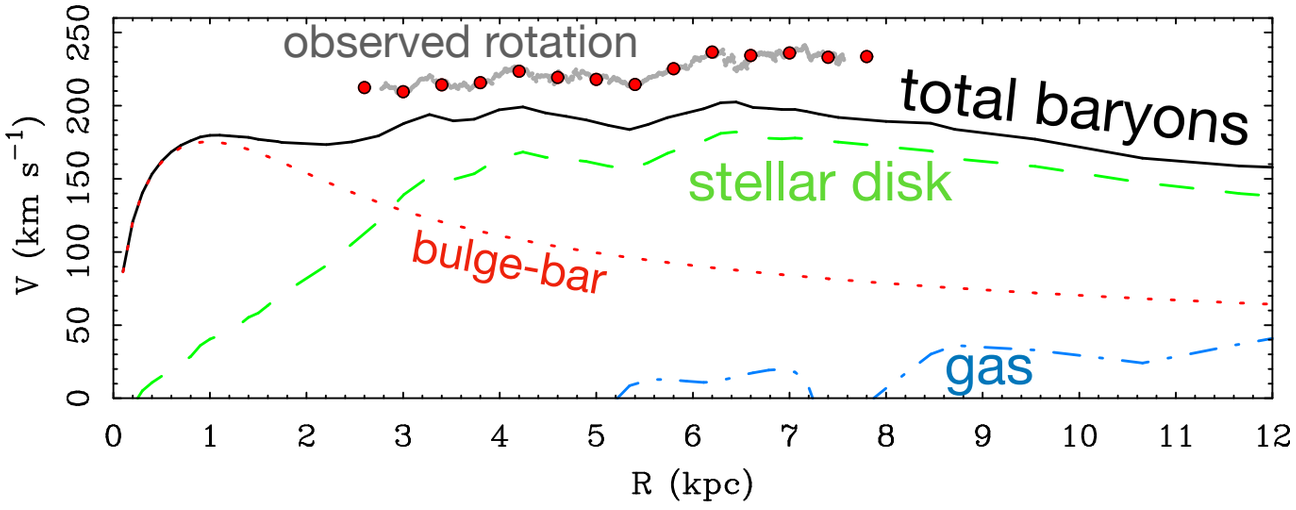
Bar dominates inner radii - assumption of circular motion not valid



Surface density profile

$\Sigma(R)$ *from observed surface brightness profile*

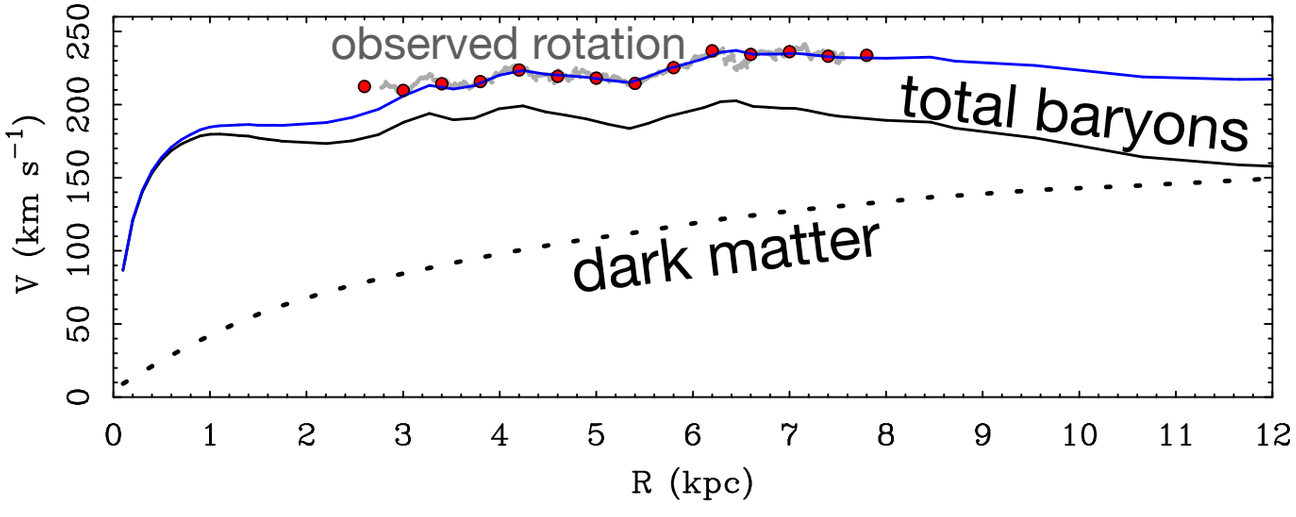
The main uncertainty is the mass-to-light ratio of the stars.



Mass model

$$\frac{V^2}{R} = -\frac{\partial \Phi}{\partial R} = 2\pi G \Sigma(R)$$

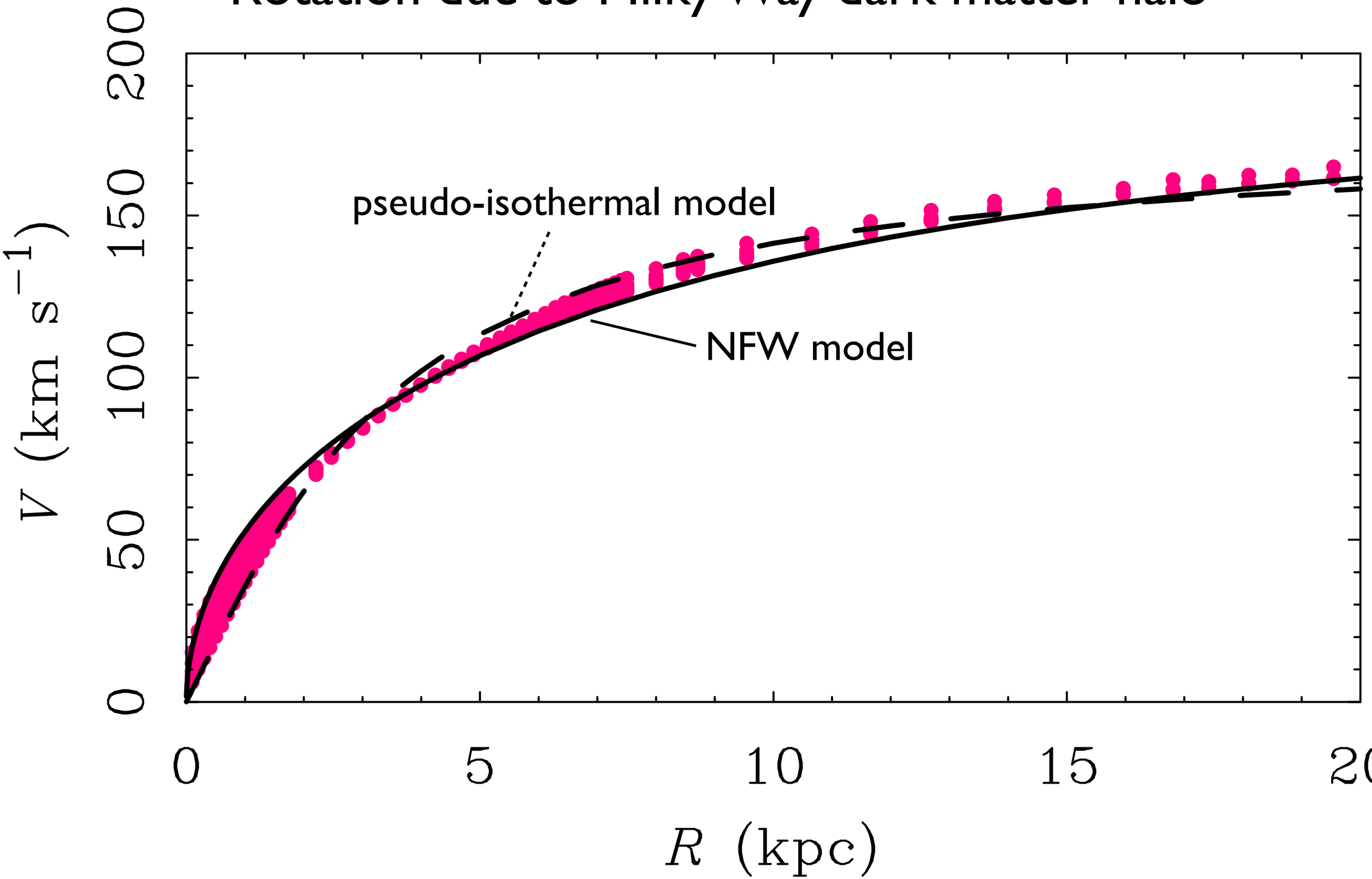
$$V_{DM}^2 = V_{obs}^2 - V_{bar}^2$$



Mass model with DM halo

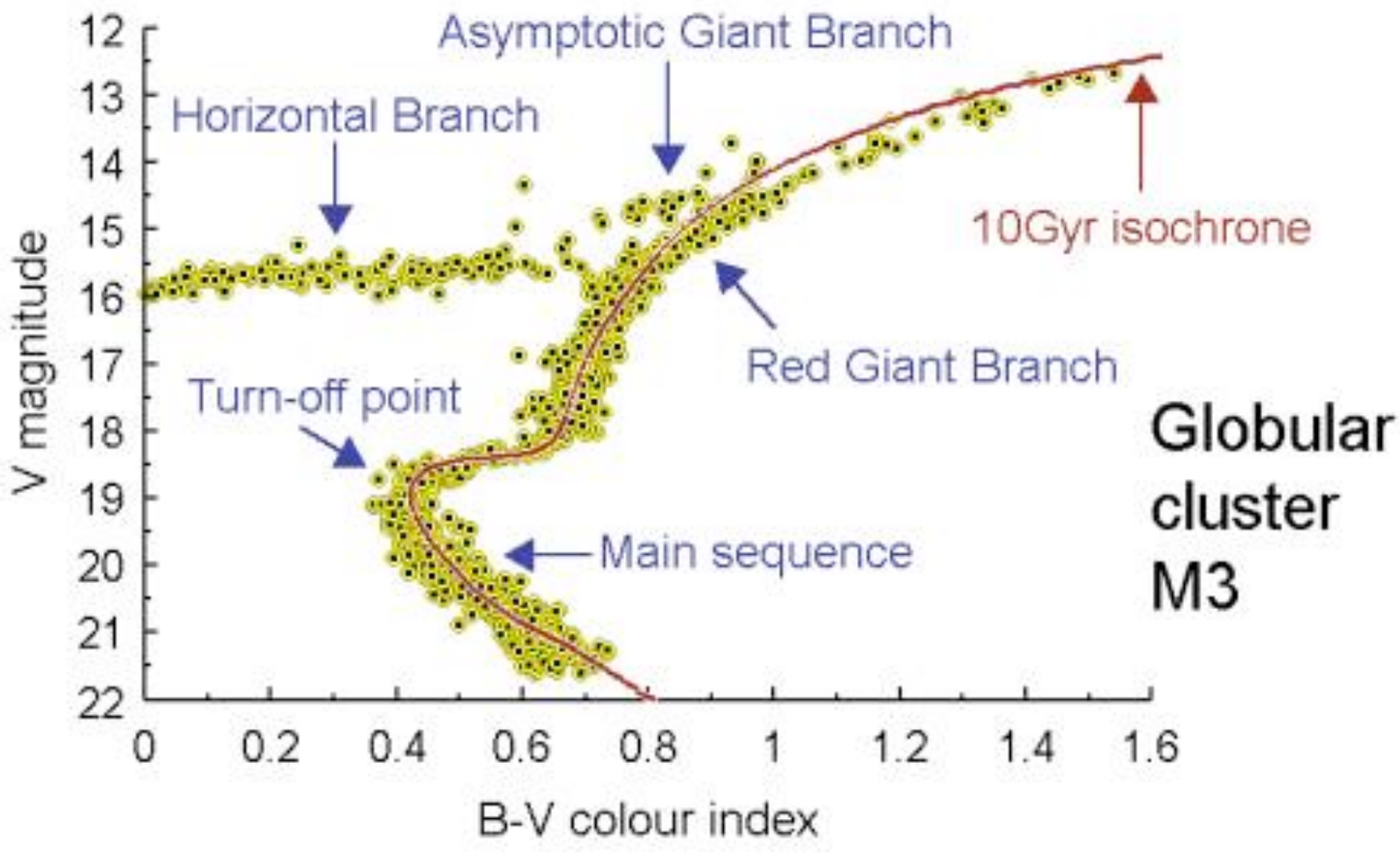
Total rotation decomposed into baryonic and dark components

Rotation due to Milky Way dark matter halo

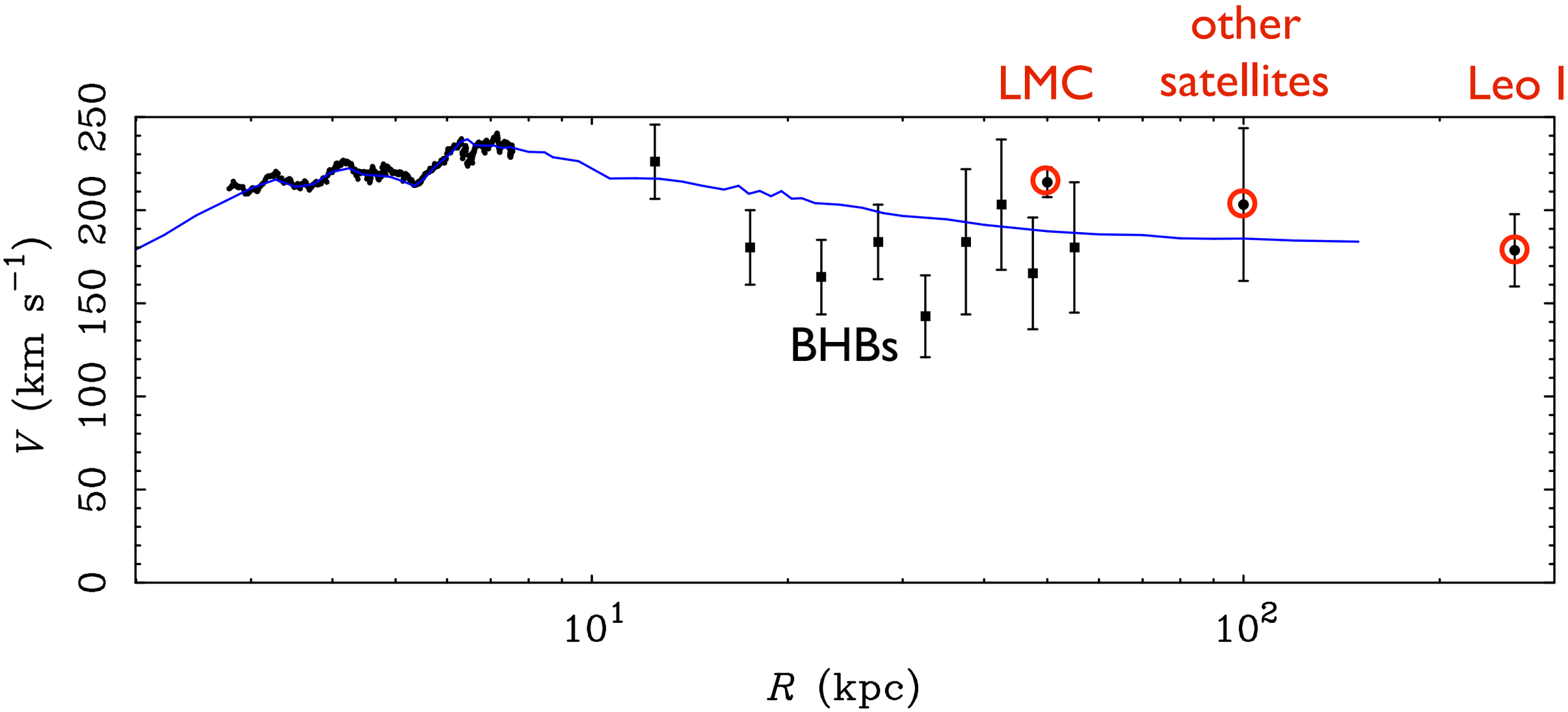


The tangent point method only works inside the solar circle.
Need to measure distances as well as velocities for $R > R_0$.

One approach is to use Blue Horizontal Branch stars in the Galactic halo



BHB stars provide population of approximate standard candles so distance can be estimated as well as velocity

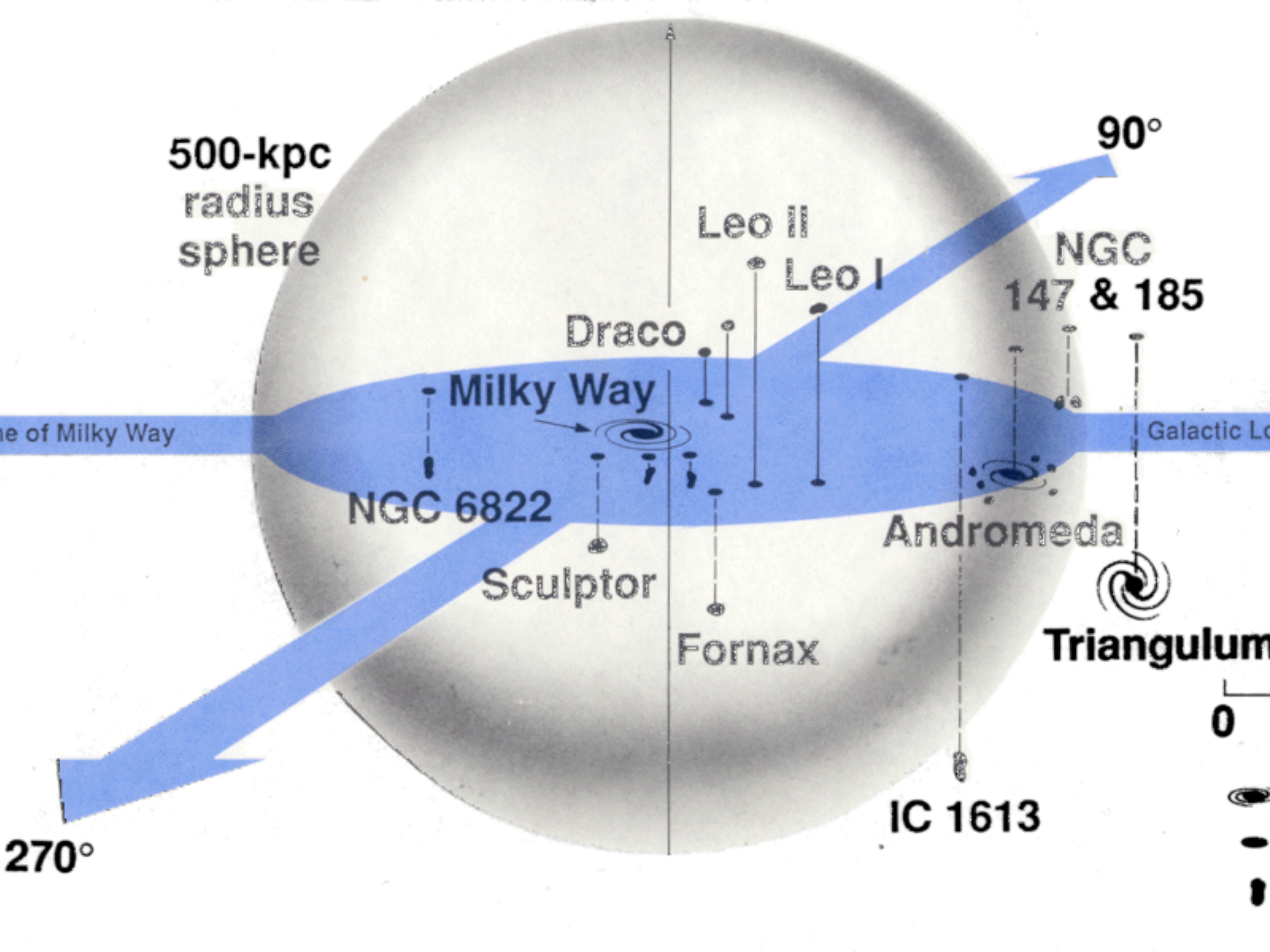


LMC $M_{MW}(< 50 \text{ kpc}) = 5.5 \times 10^{11} \text{ M}_\odot$

other $M_{MW}(< 100 \text{ kpc}) = 1.8 \times 10^{12} \text{ M}_\odot$

Leo I $M_{MW}(< 263 \text{ kpc}) = 2.5 \times 10^{12} \text{ M}_\odot$

The LMC may be a non-negligible perturbation to the outer halo, which may not remain spherical.


500-kpc
radius
sphere
90°
Leo II
Leo I
NGC
147 & 185
Draco
Milky Way
ne of Milky Way
Galactic Lo
NGC 6822
Andromeda
Sculptor
Fornax
Triangulum
0
IC 1613
270°

sparsely sampled mass estimator

$$M = \frac{C}{G}\langle V_{los}^2 R\rangle \approx \frac{C}{G}\frac{1}{N}\sum_{i=1}^{N} V_{los,i}^2 R_i$$

$$C \approx \frac{32}{\pi}$$

give or take a factor of 2
depending on the orbital isotropy
and the shape of the potential

Orbits of individual stars: the epicycle approximation