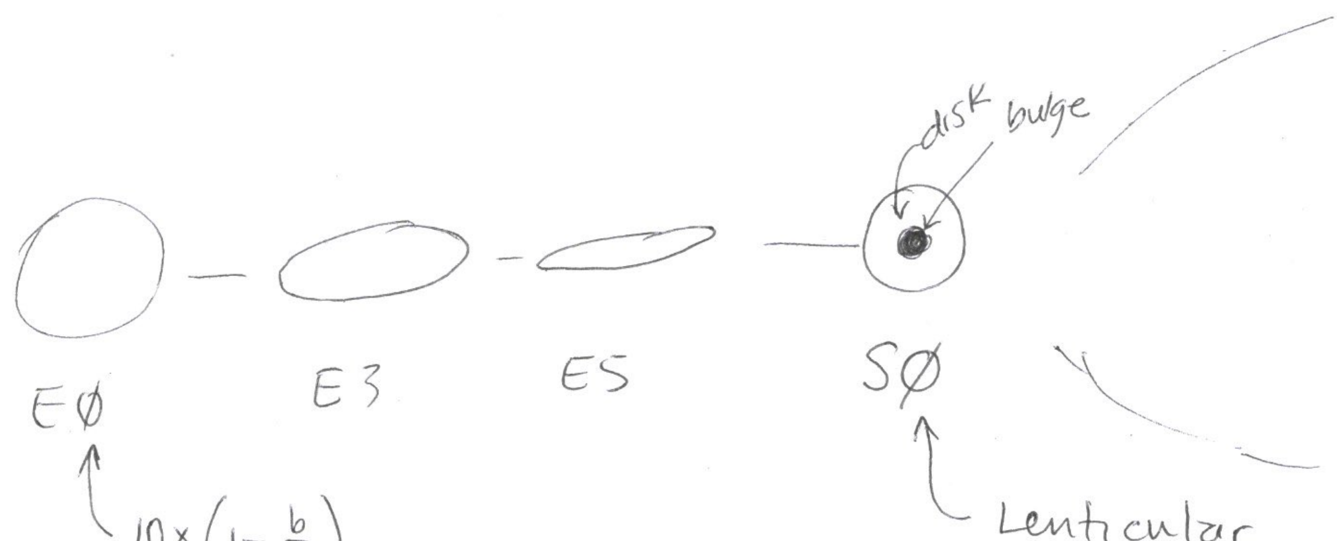
Galactic Disks

11-24-20

Hubble sequence – Morphological classification scheme invented by Edwin Hubble in 1926

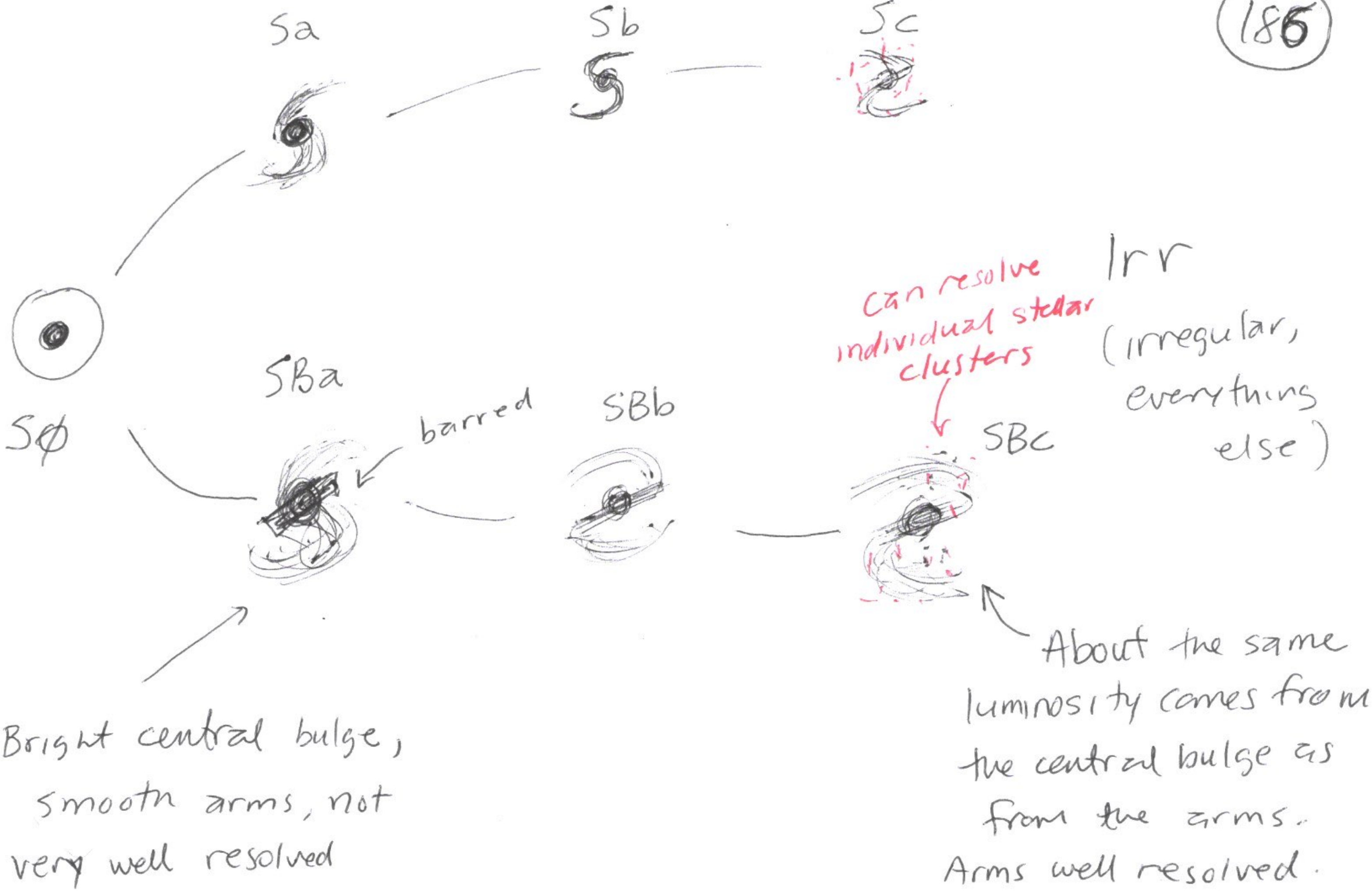
– The classification of a given galaxy is correlated with other properties, such as color, luminosity, mass, star formation rate, etc. But correlation is not causation!

– Elliptical galaxies commonly known as "early-type" and spiral galaxies commonly known as "late-type," but "The nomenclature refers to position in the sequence and temporal connotations are made at one's peril." – Hubble



$10 \times \left(1 - \frac{b}{a}\right)$

For E∅, $b = a$



☆ THE MILKY WAY IS AN SBC GALAXY.

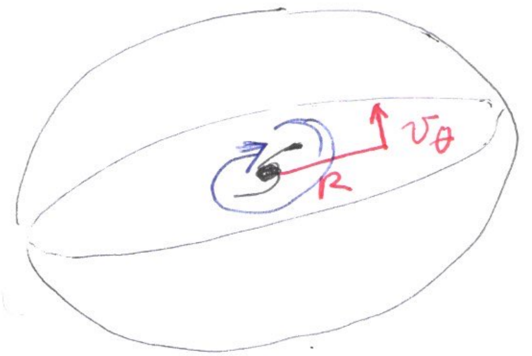
Property	Elliptical	Spiral
Shape	Sphere / ellipsoid	DISK with central bulge
Star motion	Mainly radial, with orbits around the center	rotational around the center
ISM	Very little gas or dust	Plenty of gas and dust
Star population	Mostly small and old stars Pop II	Young, massive, bright stars (Pop III) in arms, Pop II in bulge

Property	Elliptical	Spiral
Star formation rate	low to null	high, particularly in the arms
Size	10^{-1} kpc - 10^{2} kpc	10^{1} kpc
Mass	$10^{7}\ M_\odot - 10^{13}\ M_\odot$	$10^{9} - 10^{12}\ M_\odot$
Luminosity	$10^{6} - 10^{13}\ L_\odot$	$10^{8} - 10^{11}\ L_\odot$
	Much wider range for elliptical	than for spiral galaxies
Supermassive black hole	Yes	Yes
Location	Preferentially in the center of galaxy clusters	Preferentially away from galaxy clusters in low density regions
Galactic mergers	Probably have experienced a few	Probably none, or with dwarf galaxies
Frequency	About 15%	About 70%

Also, prolate rotator galaxies (cigar-shaped)

Lenticulars usually have old stars and not much gas.

As mentioned before, spiral galaxies consist of a central bulge and a thin rotating disk, and they are inside a dark matter halo that is much larger than the visible part.

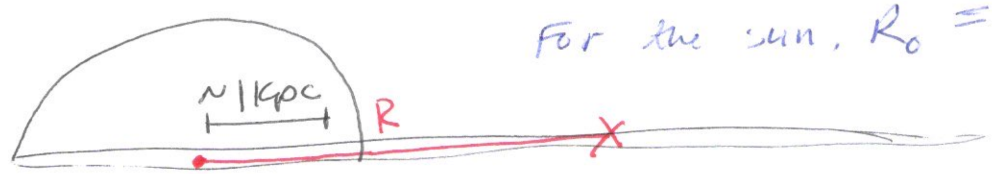


The gravitational potential can be mapped by measuring the velocities of stars, ISM, etc.

For ~~sun~~ Milky Way, rotation is clockwise

You can't see the Milky Way too far north.

For the sun, $R_0 = 8$ kpc



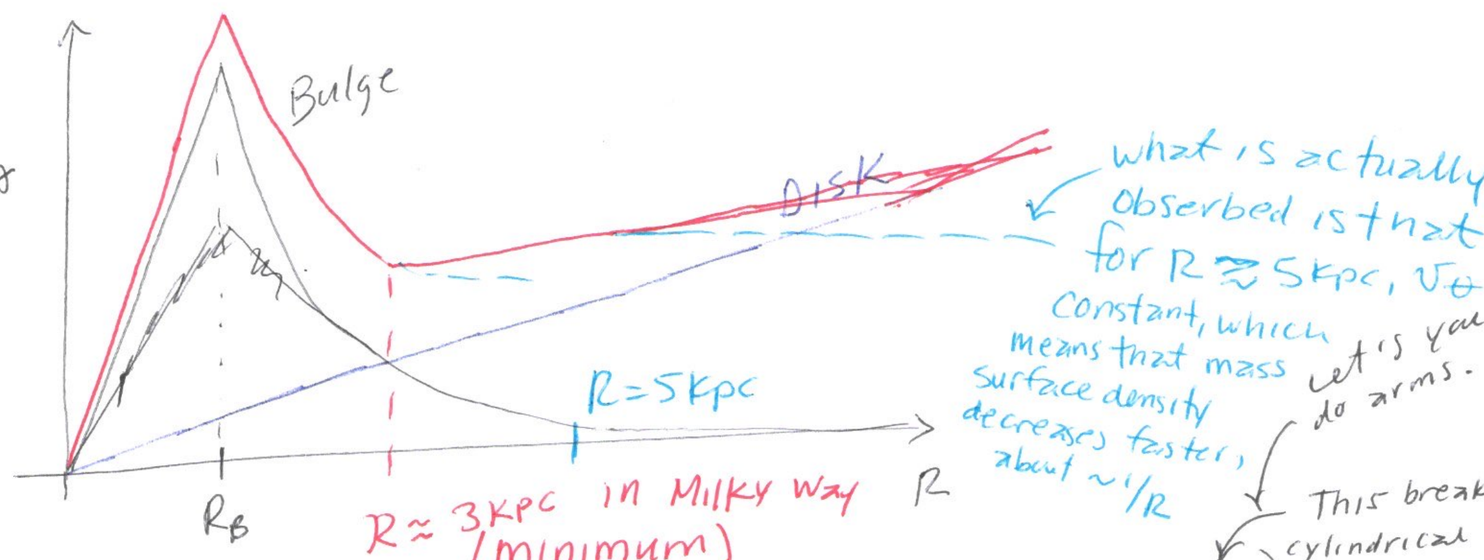
We are looking "down" from northern hemisphere

For cylindrical symmetry, the tangential component of the velocity in the plane of the galaxy at a distance R from the center is related to the potential by Newtonian mechanics

$$\underbrace{\frac{v_\theta^2(R)}{R}}_{\text{Centripetal acceleration}} = \underbrace{\frac{d\phi(R)}{dR}}_{\text{Force per mass}}$$

For $R < 1$ kpc the potential is completely dominated by the bulge (since you would be inside), so $\frac{d\phi(R)}{dR} = \frac{GM(R)}{R^2}$

where $M(R)$ is the mass inside sphere of radius R. Since the mass increases rapidly with R, v_θ increases rapidly also. Outside of the bulge, orbits are Keplerian, so $v_\theta \propto R^{-1/2}$, so



Let's you do arms.

For a cylindrical disk, $\rho(R,\theta,z) = \delta(z)\Sigma(R,\theta)$ (This breaks cylindrical symmetry, but not problematic) where Σ is the mass per area on the disk (so the surface density). The Poisson equation is $\nabla^2 \phi = 4\pi G \rho$, in ~~spherical~~ cylindrical coordinates

$$\left[\frac{1}{R}\frac{\partial}{\partial R}\left(R\frac{\partial}{\partial R}\right) + \frac{1}{R^2}\frac{\partial^2}{\partial \theta^2} + \frac{\partial}{\partial z^2}\right]\phi(R,\theta,z)$$

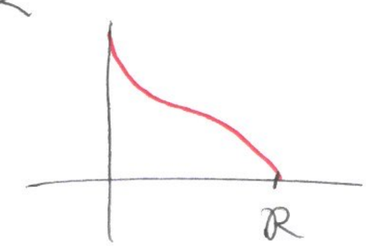
$$= 4\pi G\delta(z)\Sigma(R,\theta)$$

In general, solutions not super friendly, but e.g.

Finite Mestel Disk (FMD)

$$\Sigma_{FMD}(R) = \frac{M}{2\pi \mathcal{R} R} \arccos\left(\frac{R}{\mathcal{R}}\right) \qquad R \leq \mathcal{R}$$

total radius of disk



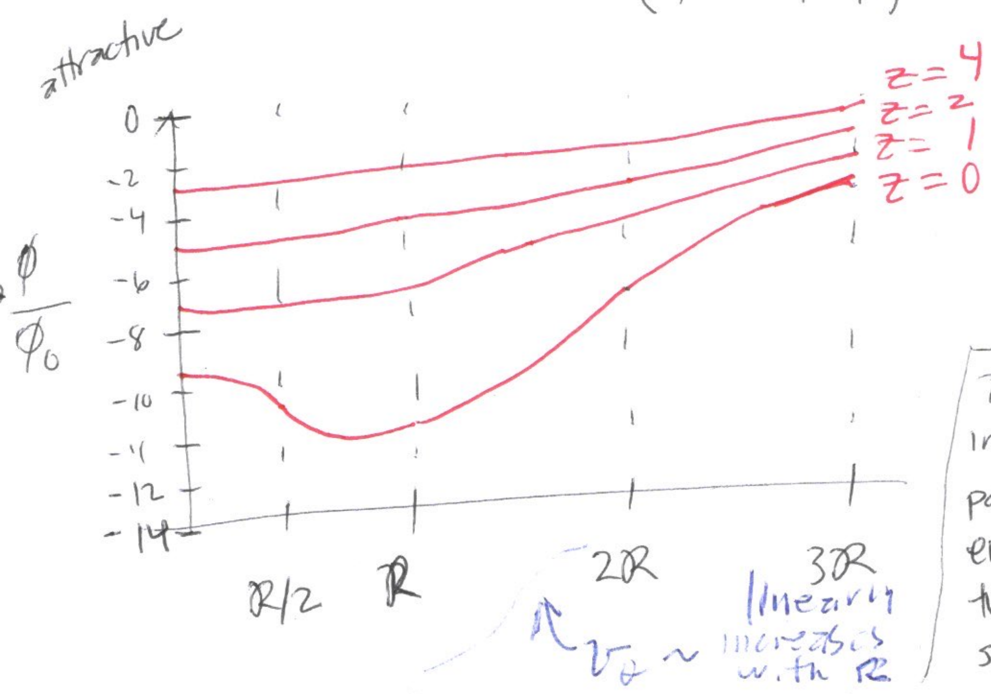
Maclaurin Disk

$$\Sigma_M(R) = \frac{3M}{2\pi \mathcal{R}^2} \sqrt{1-(R/\mathcal{R})^2}$$

Kuzmin potential

$$\phi_K(R,z) = -GM(R)\left[R^2 + (|z| + z_0)^2\right]^{-1/2}$$

$$\phi_K(R,z)\Big|_{z_0=0} = -\frac{GM(R)}{(R^2+|z|)^{1/2}}$$

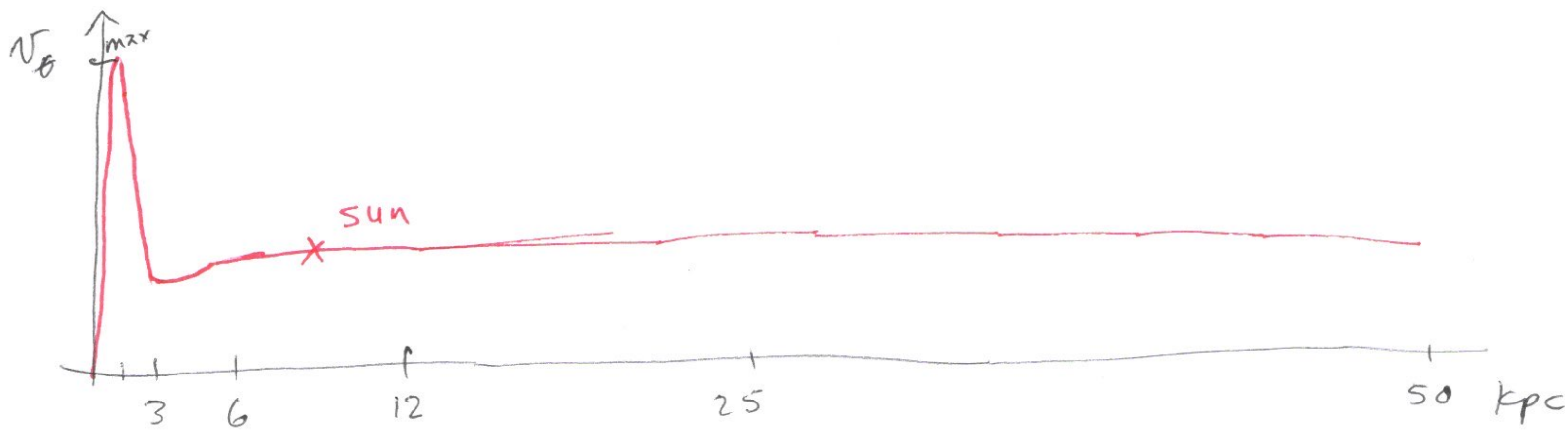


Kuzmin potential with uniform surface density

Take home message: even though in spherical symmetry the potential depends only on the mass enclosed and not on its distribution this is not true for cylindrical symmetry

At distances $R \gtrsim 20$ kpc for Milky Way, which ~~190~~ 191

has a visible disk radius of about 50 kpc, v_θ is about constant



It is assumed that this is due to Dark Matter with mass distribution (spherical, or close to) $M(R) \sim R$