lecture 36

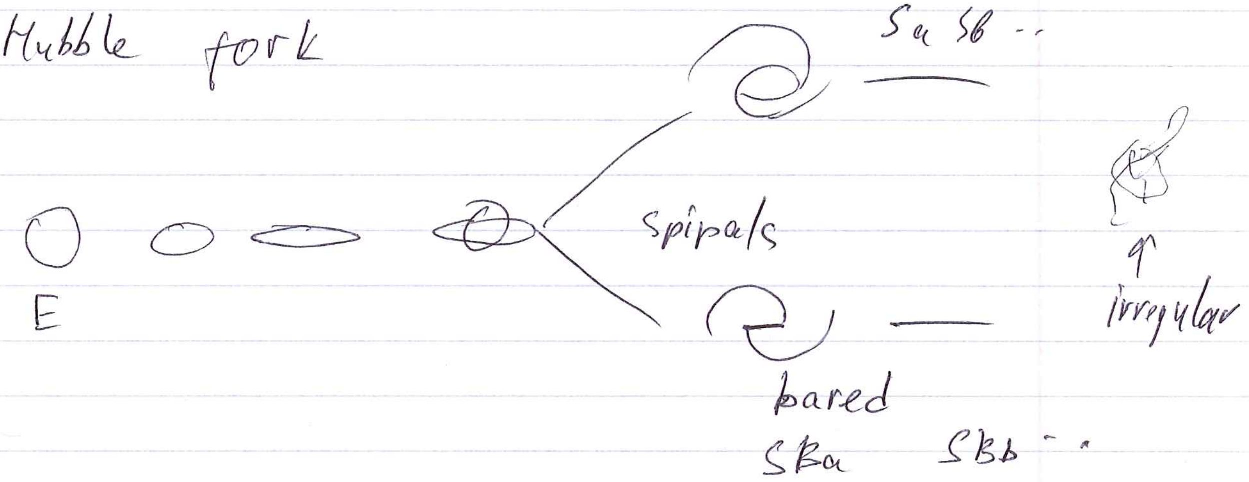
* Galaxies classification
  → Hubble fork.

* Galaxy mass estimate

* Interaction of galaxies
  * Rapid passage
  * "Friction drag" – dynamic friction

1 Galaxy ~~debate~~ are their part of Milky Way?
=> sol. Hubble measured variable stars in M31 and set distance

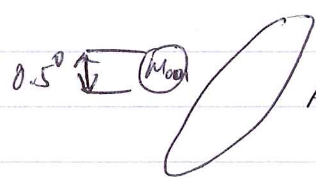
Hubble fork



Dust disk often visible

2. How big they are

M31 is ≈ 2.5Mly away
≈ 600kpc



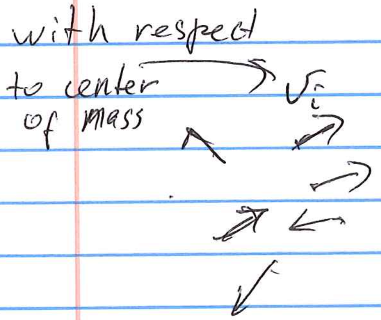
Andromeda M31

let's do crude estimate
MW $\approx_{\varnothing}$ 50kpc
let put similar Galaxy at 10 times this size

$$\theta = \frac{50}{500} = 0.1 \cdot \frac{180}{\pi} \approx 6^\circ$$ a bit too large probably

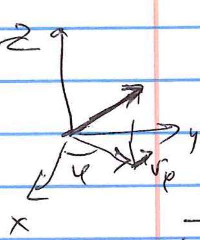
But there are neighbors
see Magellan clouds LMC and SMC

A Galaxy mass estimate



$$\boxed{\text{Virial theorem} \qquad -2\langle K\rangle = \langle U\rangle}$$

$$-2\sum_i \frac{m_i v_i^2}{2} = U$$



$$\langle v_i^2\rangle = \langle v_x^2\rangle + \langle v_y^2\rangle + \langle v_z^2\rangle =$$

$= \Big/$ cylindrical coordinates $\Big/$ $= \langle v_R^2\rangle + \langle v_\varphi^2\rangle + \langle v_z^2\rangle =$

$= 3\langle v_R^2\rangle$

all components are the same

assuming $m_1 = m_2 = \dots m_N$

assuming constant β

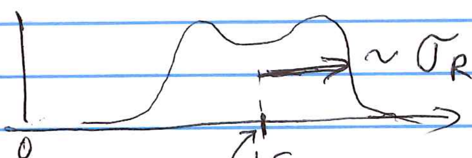
$$\Rightarrow \quad -2\langle K\rangle = -N\cdot m \cdot 3\langle v_R^2\rangle = U = -\frac{3}{5}\frac{GM^2}{R}$$

$N\cdot m \approx M$

standard variation $= \sigma_R^2$ when taken around c.M.

σ_R: standard deviation of radial speed

Rotation curve



or motion of Central of Mass

$$\sigma_R^2 = \frac{1}{5}\,G\frac{M}{R}$$

$$\boxed{M = \frac{5\cdot R}{G}\cdot \sigma_R^2}$$

Mass inside Radius R

$\sigma_R = \text{const}$ due to flat rotation curve lets assume constant mass to luminocity ratio $\frac{M}{L} = \frac{1}{C_{ML}}$

$$L = C_{ML} \cdot M = C_{ML} \cdot 5 \frac{\sigma_R^2 R}{G}$$

Big assumption

$$\frac{L}{R^2} = C_{SB} \leftarrow \text{constant surface Brightness}$$

(Recall Steffan Boltzmann
$L = \sigma \cdot A T^4$
$\Rightarrow \frac{L}{A} \sim \sigma T^4$
$A \sim R^2$ i.e. galaxy has same T)

$$L = C_{ML} \cdot \frac{5 \sigma_R^2 \sqrt{\frac{L}{C_{SB}}}}{G}$$

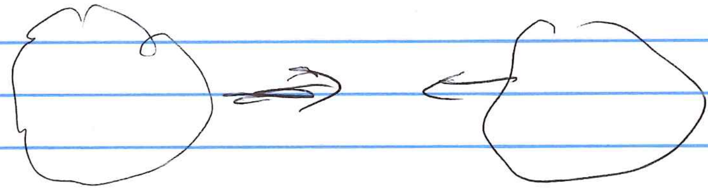
$$\boxed{L = \underbrace{\frac{C_{ML}^2 \cdot 5^2}{C_{SB} \cdot G}}_{\text{const}} \sigma_R^4}$$

So we connected luminocity of a galaxy to its rotation speed

Fast passage of the objects
trough each other

~~mean velocity~~ $\cancel{>}$ ~~than change in speeds for the interraction time~~

~~Obj~~ ~~Stars did not~~ shift from their initial position around an object C.M.
but velocity did change.



So energy exchange is kinetic energy change

After interraction objects separates so we can treat them as stand alone.

let's say we gain some energy ΔE
and wait long time to reach equilibrium

$$K_i + \Delta K + U_i + \Delta U = E_i + \Delta E$$

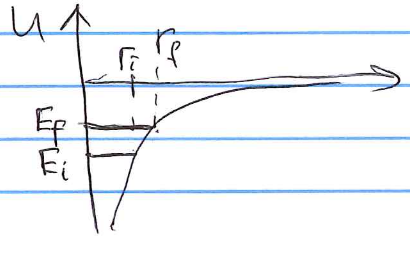
Virial theorem $-2K = U \Rightarrow -2\Delta K = +\Delta U$

$$\Delta K + \Delta U = \Delta E$$
$$\Delta K - 2\Delta K = \Delta E$$

$$K_f - K_i = \boxed{\Delta K = -\Delta E}$$

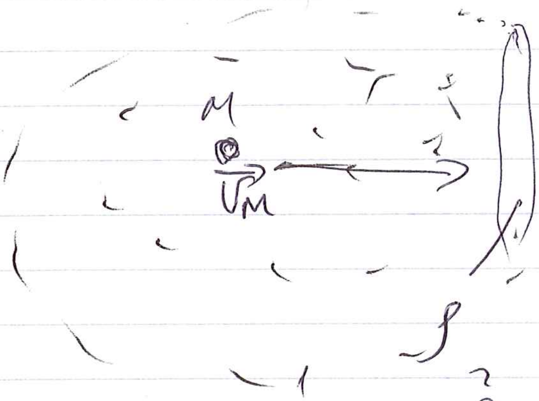
i.e. after equilibrium reached the kinetic energy decreases

So to drop kinetic energy you need to decrease potential. $\boxed{\Delta U = 2\Delta E}$



1) expand $r_f > r_i \Rightarrow$ rings
2) through away parts $\Rightarrow$ tails

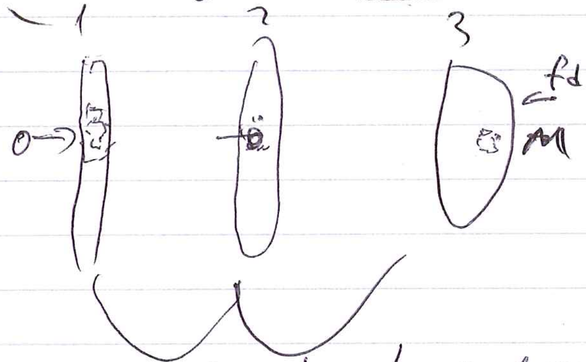
Dynamic friction



force

$$f_d = C\,\frac{G^2 M^2 \rho}{v_M^2}$$

Pulls in masses but they lag behind



density clamp formation due to G pull ⇒ fd

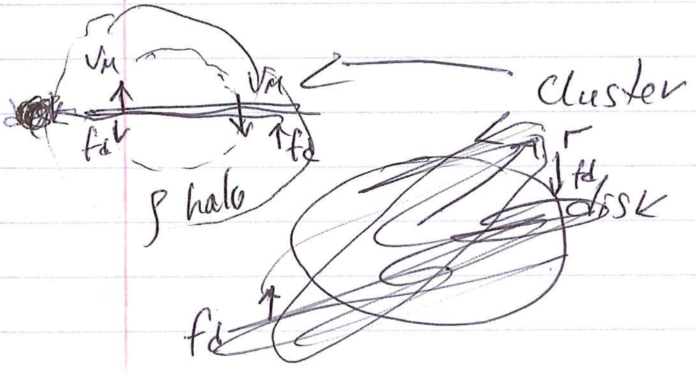
Dark Matter density

$$\rho(r) = \frac{v_M^2}{4\pi G r^2}$$

rotation speed

$\approx v_M$

$$f_d = C\,\frac{G^2 M^2 \rho}{v_M^2} = C G^2 \frac{M^2}{v_M^2}\,\frac{v_M^2}{4\pi G r^2} = C G \frac{M^2}{4\pi r^2}$$



Cluster motion

torque

$$\frac{dL}{dt} = \frac{d\,M v_M r}{dt} = -f_d \cdot r$$

ang moment

$$M v_M \frac{dr}{dt} = -GC \frac{M^2}{4\pi r}$$

$$\int_{r_i}^{0} r\,dr = \int_{0}^{t_c} \frac{GCM}{4\pi v_M}\,dt$$

$$r_{max} = \sqrt{\frac{t_{max}\, C G M}{2\pi v_M}}$$

capture radius

galaxy age