

Timing argument in Local Group



M31 (vdMarel + 2012)

$$v_r = -109.3 \pm 4.4 \text{ km/s}$$

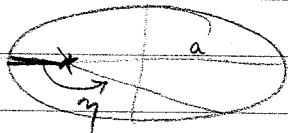
$$v_t = 17 \pm 17 \text{ km/s}$$

M31 is approaching us at $\sim 120 \text{ km/s}$ Not in Hubble expansion!
 so - what orbit is it on?

We know the universe is $\sim 13 \text{ Gyr}$ old,
 so the MW-M31 pair has had time to expand
 then turn around & start to re-collapse, but
 haven't collided yet. Kahn & Woltjer (1959)

Position on ~~tidal~~ orbit: $r = a(1 - e \cos \eta)$

$$t = \sqrt{\frac{a^3}{G(m+M)}} (\eta - e \sin \eta) \quad \text{time since pericenter}$$



e = eccentricity of orbit

a = semi-major axis

η = development parameter

$$0 \leq \eta \leq 2\pi$$

can differentiate the above expressions to obtain

$$\frac{dr}{dt} = \frac{dr/d\eta}{dt/d\eta} = \sqrt{\frac{G(m+M)}{a}} \frac{e \sin \eta}{1 - e \cos \eta} = \frac{r}{t_0} \frac{e \sin \eta (\eta - e \sin \eta)}{(1 - e \cos \eta)^2}$$

Assume $r=0$ initially at $t=0$; t_0 = age of universe.

Use measured distance (r) and velocity (dr/dt) to estimate mass
 gives $m+M$