LECTURE IV

GALACTIC EVOLUTION

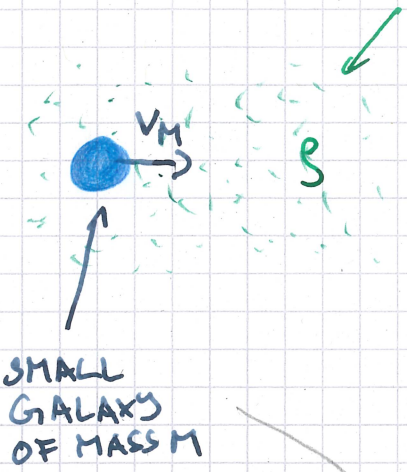
INTERACTIONS OF GALAXIES

- ALMOST ALL GALAXIES BELONG TO A CLUSTER
- LARGER FRACTION OF VOLUME THAN STARS IN STELLAR CLUSTER
- SPACING TYPICALLY 100 TIMES SIZE OF GALAXY (SEE LATER)
- DENSLY POPULATED REGIONS ⇒ MORE ELLIPTICALS SLIDE 31
- INTERACTIONS INCREASE VELOCITY DISPERSION OF STARS ⇒ DESTROY DISKS IN LATE TIME GALAXIES
- X-RAY EMITTING GAS OCCUPIES MUCH OF SPACE BETWEEN GALAXIES
- BOTTOM-UP SCENARIO:
  LARGE GALAXIES FORMED BY MERGERS OF SMALLER

DYNAMICAL FRICTION

WHAT HAPPENS WHEN GALAXIES COLLIDE?

* HARDLY DIRECT ENCOUNTERS OF STARS ⇒ GRAVITATIONALLY INTERACTING

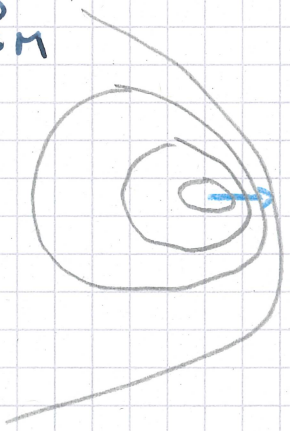


NO DIRECT ENCOUNTERS

STARS PULLED TO MASS

⇓

ENHANCED DENSITY OF STARS



⇒ FORCE FOR DYNAMICAL FRICTION

$$f_d \simeq C \frac{G^2 M^2 \rho}{v_M^2}$$ (NO DERIVATION)

↑

v_M IN COMPARISON TO σ

$v_M \sim 36$

LMC: $C = 23$

GLOB. CLUSTERS : 76

ELLIPTICALS : 160

TIME SCALES:

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

FROM: $\frac{mV^2}{r} = \frac{G M_r m}{r^2}$ (FORCES)

$$M_r = \frac{V^2 r}{G}$$

$$\frac{dM_r}{dr} = \frac{V^2}{G} \qquad \text{BUT: } M_r = \frac{4}{3}\pi r^3 \rho$$

$$\Rightarrow \frac{dM_r}{dr} = 4\pi r^2 \rho$$

$$\Rightarrow (*) \Rightarrow \frac{G M_r m}{r^2} = G \cdot \frac{4}{3}\pi r^{\cancel{3}} \rho\, m \frac{V_M^2}{\cancel{4\pi} G r^{\cancel{2}}}$$

$$\Rightarrow f_d = C \frac{G M^2}{4\pi r^2}$$

ANGULAR MOMENTUM : $L = M V_M \cdot r$

TORQUE: $\tau = r f_d$

$$\Rightarrow \frac{dL}{dt} = \tau$$

$$M V_M \cdot \frac{dr}{dt} = -r C \frac{G M^2}{4\pi r^2}$$

$$\int_{r_i}^{0} r\, dr = -\frac{CGM}{4\pi V_M} \int_0^{t_c} dt$$

$$\Rightarrow t_c = \frac{2\pi V_M r_i^2}{CGM}$$

IF t_{max} IS AGE OF GALAXY

WHAT IS MOST DISTANT ~~GC~~ ↗ CAPTURED ? CLUSTER OF STARS. (GLOBULAR CLUSTER)

$$R_{max} = \sqrt{\frac{t_{max} G M}{2\pi V_H}}$$

EXERCISE: M31

$M_{cluster} = 5 \times 10^6 M_\odot$

$V_H = 250 \frac{km}{s}$

$t_{max} = 13\ Gyr$

$\Rightarrow R_{max} = 3.7\ kpc$

RAPID ENCOUNTERS

- SO FAST THAT STARS DO NOT HAVE TIME TO RESPOND
- GRAVITATIONAL WORK OF TWO GALAXIES ENCOUNTERING INCREASES INTERNAL KINETIC ENERGY

ASSUME GALAXY INITIALLY IN VIRIAL EQUILIBRIUM

$$\Rightarrow 2K_i = -U_i = -2E_i$$

↑ TOTAL INTERNAL ENERGY

• INCREASE INTERNAL KIN. ENERGY:

$$K_i + \Delta K_{\text{ext}}$$

$$\Rightarrow \quad E_f = E_i + \Delta K$$

$\Rightarrow$ VIRIAL EQUILIBRIUM DESTABILIZED

↳ REESTABLISHMENT OF ~~THE~~ VIRIAL EQUIL.

$$\Rightarrow K_f = -E_f = -(E_i + \Delta K)$$

$$= -E_i - \Delta K = K_i - \Delta K$$

$\Rightarrow$ FOR EQUILIBRIUM: INTERNAL KINETIC ENERGY DECREASES BY $2\Delta K$!

HOW?

- EXCESS KINETIC ENERGY TURNS INTO INCREASED (LESS NEG.) GRAV. POTENTIAL
- MOST ENERGETIC COMPONENTS T CARRY KINETIC ENERGY AWAY

BOTH OCCURS

SLIDE 32

• ALSO: TIDAL STRIPPING

- STARS AND GAS ARE PULLED OUT OF ONE OR BOTH GALAXIES

⇒ POLAR RING OR GALAXIES — DUST LANE ELLIPTICALS (STRIPPED FROM OTHER GALAXIES)

- 5% OF ALL S0 HAVE POLAR RING

SLIDE

⇒ POLAR RING SENSITIVE TO OVERALL POTENTIAL

⇒ SPHERICAL DARK MATTER HALO

MERGERS OF GALAXIES

⇒ N-BODY SIMULATIONS

SLIDE ?