Mass-to-Light Ratio of Groups

Milky Way

$M(\text{dark}) = 5.4 \times 10^{11}\, M_\odot \qquad (R < 50 \text{ kpc})$

$M(\text{stars + gas}) = 8.1 \times 10^{10}\, M_\odot$

$L_B = 2.3 \times 10^{10}\, L_\odot$

$$\frac{M}{L_B} = \frac{6.2 \times 10^{11}}{2.3 \times 10^{10}} = \boxed{27 \, \frac{M_\odot}{L_{B,\odot}}}$$

Local Group ($\simeq$ 50 galaxies)

Milky Way ($L_B = 2.3 \times 10^{10}$), LMC $\longleftarrow$ $v_r = -119 \frac{\text{km}}{\text{s}}$ M31 ($L_B \approx 4 \times 10^{10}$), M33

$\longleftarrow$ $r = 780$ kpc $\longrightarrow$

$$M \simeq \frac{v_r^2\, r}{G} = 5.1 \times 10^{42} \text{ kg} = 2.6 \times 10^{12}\, M_\odot$$

A more exact estimate gives $M \gtrsim 4 \times 10^{12}\, M_\odot$

$L_B \simeq 6.6 \times 10^{10}\, L_\odot$ of the whole group

$$\frac{M}{L_B} \simeq \frac{4 \times 10^{12}}{6.6 \times 10^{10}} = \boxed{60 \, \frac{M_\odot}{L_{B,\odot}}}$$

Coma Cluster (several thousand galaxy members)

$z = 0.0232$

$cz = 6960 \text{ km s}^{-1}$

$d = \frac{cz}{H_0} = \frac{6960}{71} = 100 \text{ Mpc}$

$R_{1/2} = 1.5 \text{ Mpc}$ — considering galaxies as point masses

$\sigma_r = 880 \text{ km s}^{-1}$

$$M \approx \frac{7.5\,\sigma_r^2 R_{1/2}}{G} = 4 \times 10^{45} \text{ kg} = \boxed{2 \times 10^{15} M_\odot}$$

$M(\text{gas}) \simeq 2 \times 10^{14} M_\odot$ at $T \simeq 10^8 \text{ K}$

$M(\text{stars}) \simeq 2.5 \times 10^{13} M_\odot$

$L_B = 8 \times 10^{12} L_\odot$

$$\frac{M}{L_B} = \frac{2 \times 10^{15}}{8 \times 10^{12}} = \boxed{250 \frac{M_\odot}{L_{B,\odot}}}$$

Does the virial theorem apply? Only if the galaxies have had time to cross the diameter of the cluster. The crossing time is

$$t_{cr} = \frac{2R_{1/2}}{\sigma_r} = 1 \times 10^{17} \text{ s} = 3 \times 10^9 \text{ yr}$$

$$t_{cr} < \frac{1}{H_0} \approx 13.7 \times 10^9 \text{ yr}$$

Thermal Plasma (Collisional emission)

Suppose the gas has the same σ_r as galaxies

$$\frac{3}{2} kT = \frac{1}{2} m_H \langle v^2 \rangle = \frac{3}{2} m_H \sigma_r^2$$

$$T = \frac{m_H \sigma_r^2}{k} = 9.4 \times 10^7 \text{ K}$$

$$kT = 1.3 \times 10^{-15} \text{ J} = 8100 \text{ eV} \quad \text{(X-ray)}$$

(Note: $1 \text{ eV} = 1.602 \times 10^{-19}$ J)

L_X (Observed X-ray luminosity) $= 8 \times 10^{37}$ W

(Inferred from) ← $n_H \approx 300 \text{ m}^{-3} = 0.0003 \text{ cm}^{-3}$

↳ Cooling Function

$$\frac{\Lambda(T)}{n_e n_H} = 2.5 \times 10^{-36} \text{ W m}^3 \quad \text{for } T = 10^8 \text{ K}$$

$$L_X = 2.5 \times 10^{-36} \, n_H^2 \left(\frac{4\pi}{3} R_{1/2}^3 \right)$$

($\frac{4\pi}{3} R_{1/2}^3 = 4.1 \times 10^{68} \text{ m}^3$)

$$n_H = \sqrt{\frac{8 \times 10^{37}}{2.5 \times 10^{-36} \times 4.1 \times 10^{68}}} = 300 \text{ m}^{-3}$$

$$M(\text{gas}) = 2 \times n_H m_H \frac{4\pi}{3} R_{1/2}^3 = 4 \times 10^{44} \text{ kg}$$

$$= 2 \times 10^{14} M_\odot$$

↑ correct for 1/2 mass radius