Galaxy Clusters - Theory Notes

What do clusters emit X-rays at all?

To produce a X-ray of energy ϵ_x, require an e^- w/ at least that energy to be accelerated.

For a thermal gas this means particle energies

$$\frac{1}{2}mv^2 \sim KT > \epsilon_x$$

A galaxy in a cluster has a motion of $\sim 1000\,\frac{km}{s}$ which is expected from the virial theorem, so protons in these clusters have $\frac{1}{2}mv^2 \sim 6$ keV. If e^- are in equipartition then X-rays are natural.

Emission is bremsstrahlung w/ emissivity

$$\epsilon_{ff} = 6.8\times 10^{-38} Z^2 n_e n_i T^{-1/2} e^{-h\nu/KT}$$

This emissivity has to be integrated along the l.o.s. in a cluster. So, the observed surface brightness at projected radius a from the cluster center:

$$I_\nu(a) = \frac{1}{2\pi}\int_0^\infty \frac{\epsilon_{ff}(r)\,r}{(r^2-a^2)^{1/2}}\,dr \quad \text{(assuming spherical symmetry)}$$

This can be inverted:

$$\epsilon_{ff}(r) = \frac{4}{r}\frac{d}{dr}\int_r^\infty \frac{I_\nu(a)\,da}{(a^2-r^2)^{1/2}} \quad \text{[Abel integral]}$$

X-ray spectroscopy can measure the $T(r)$ & can estimate $\rho(r)$

Compare w/ hydrostatic model:

$$\frac{dP}{dr} = -\frac{GM(\leq r)\rho(r)}{r} \quad \text{where } M \text{ is the total mass}$$

Ideal gas law $P = \frac{\rho K T}{\mu m_H}$ so $\frac{dP}{dr} = \frac{\rho K T}{\mu m_H}\left(\frac{1}{\rho}\frac{d\rho}{dr} + \frac{1}{T}\frac{dT}{dr}\right) = -\frac{GM(\leq r)\rho}{r}$

$$\text{or } M(\leq r) = -\frac{KTr^2}{G\mu m_H}\left(\frac{d(\log \rho)}{dr} + \frac{d(\log T)}{dr}\right)$$

Integrate $\rho(r)$ to get the gas mass & compare to the total mass find $f_{gas} = \frac{M_{gas}}{M_{total}} \simeq 0.06$