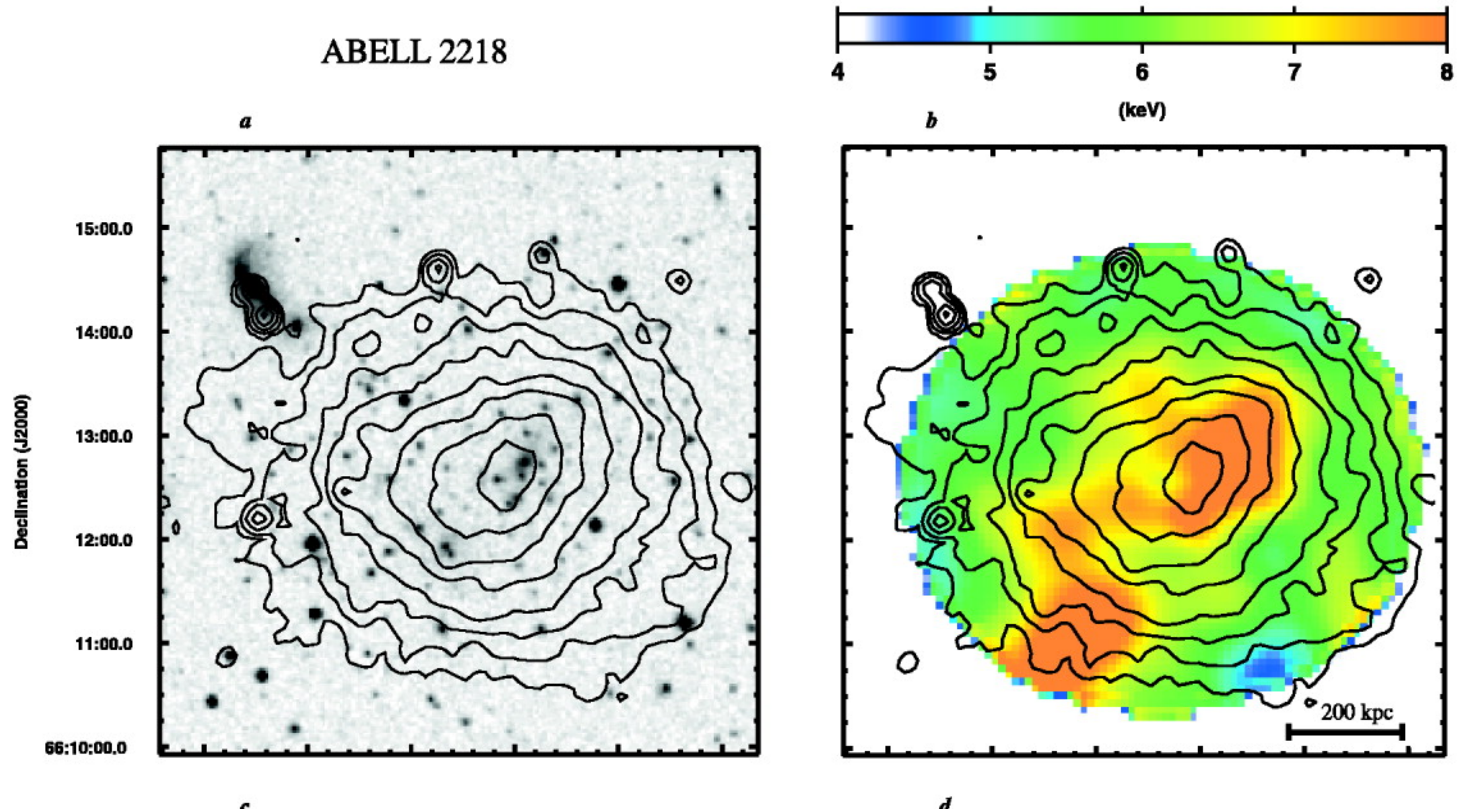
Outline

- Go over problem 7.2
- Hot gas in clusters
- Sunyaev-Zeldovich effect

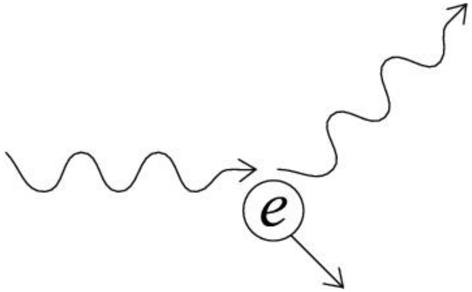
Hot Gas in Clusters



- Hot gas (kT ~ several keV) comprises most of baryonic matter in rich clusters.
- Gas is sufficiently hot that atoms are ionized – plasma of nuclei and electrons
- Typical electron energy, kT ~ several keV

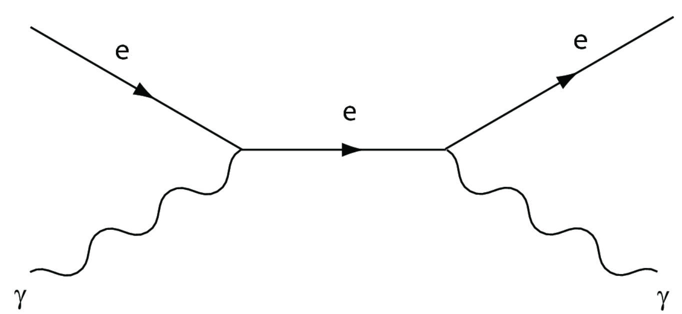
Electron-photon scattering

- Thomson scattering cross section is valid for a low energy photon scattering on a low energy free electron, $E << m_e c^2$, usually taken to be initially at rest.



$$\sigma_T = \frac{8\pi}{3}\left(\frac{e^2}{m_e c^2}\right)^2 = 6.7\times10^{-25}\,\mathrm{cm}^2$$

- Compton scattering describes same process, but with no restriction on energy (initial or final or photon or electron).
- Energy can transfer either way.

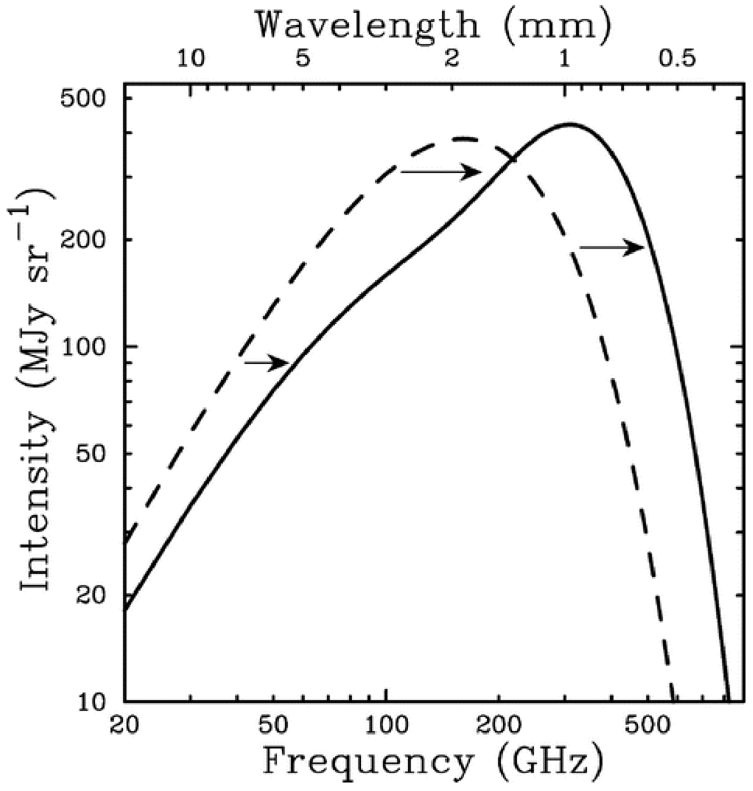


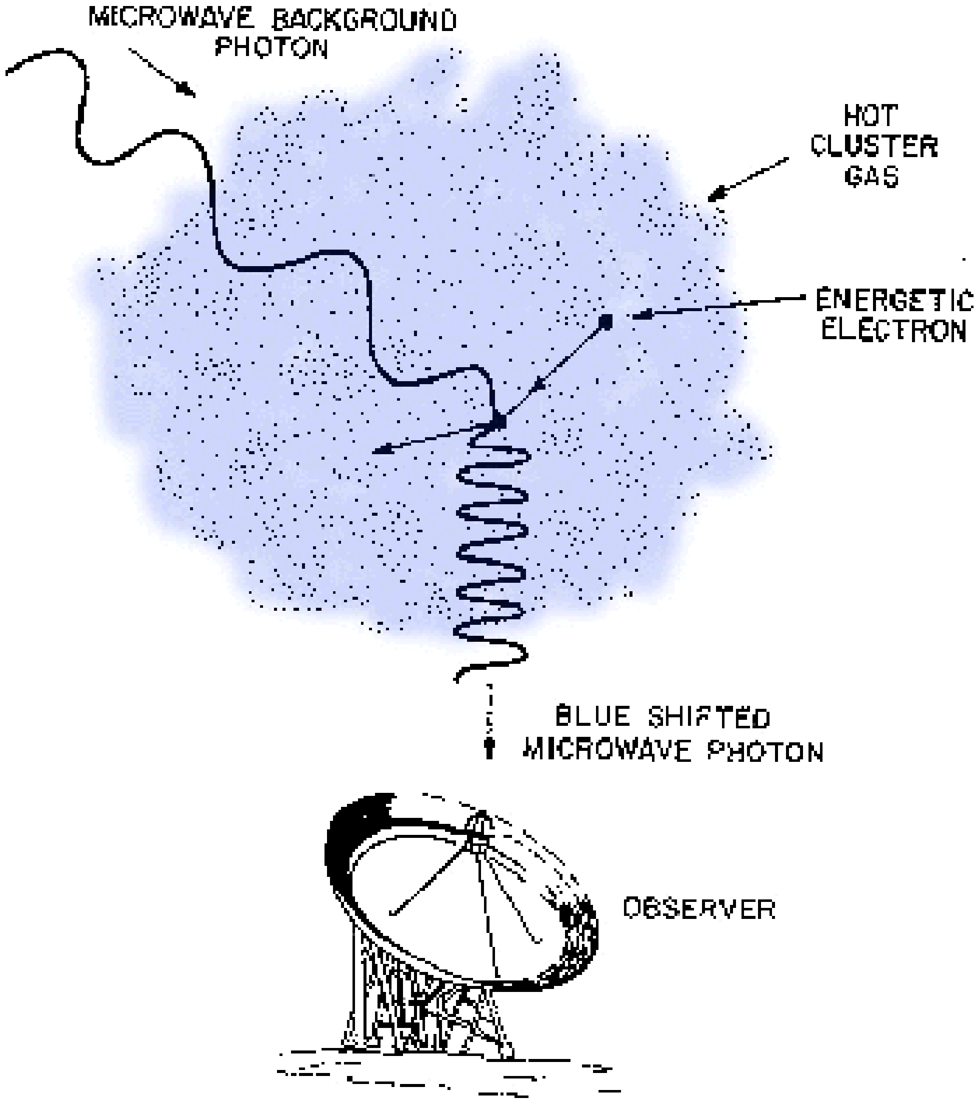
Inverse-Compton Scattering

- Inverse-Compton scattering is when a low energy photon scatters off a higher energy electron.
- If we think about cosmic microwave background photons (T ~ 3K) scattering off of cluster gas electrons (T ~ 10^7 K), then energy will transfer from the electrons to the photons, "boosting" them to higher energies.
- This is still in the non-relativistic regime, $E << m_e c^2$, so we could call this inverse-Thomson scattering, but no one does.

Sunyaev Zel'dovichEffect

- Cosmic microwave photons scatter on electrons in hot cluster gas.
- This changes the CMB spectrum we see from near the cluster.





Sunyaev Zel'dovichEffect

- The change in the CMB spectrum is proportional to the integral of nkT along the line of sight $M = \int nkT\, dl$, where n is the electron density in the cluster and T is the electron temperature. If we approximate nkT as uniform, then $M \sim nL$.
- X-ray emission from the gas occurs when two charged particles interact leading to either scattering or recombination. Thus, the X-ray luminosity is proportional to n^2. If we consider the luminosity along a line of sight through the cluster then X $\sim \int n^2\, dl \sim n^2 L$.
- This enables us to estimate the cluster size $L \sim M^2/X$. Do on board.
- Comparing with the cluster angular size, gives the distance. Note that one assumes the cluster gas is spherically symmetric.
- SZ effect provides cluster distances independent of the distance ladder.

Homework

For next class: problem 7.3