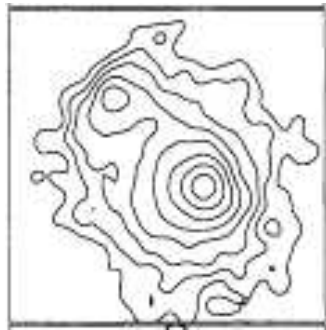


Problem 2: X-rays in Clusters [25 points]

a) Why are clusters luminous in X-rays? (a short answer is fine!)



The above picture shows the X-ray isophotes of a nearby Abell cluster.

b) Roughly how big do you think this object is (in units of length)?

c) Explain the morphology of the isophotes for this particular cluster. (short answer is fine!)

d) What type of galaxies would you expect to see centered on the peak of the X-ray distribution?

e) Suppose that for the above cluster we measure its flux in X-rays f_X and its redshift. Assuming that the measurement of the flux has a 15% fractional error and that we know the value of the Hubble constant to only 20%, what is the fractional uncertainty in the X-ray luminosity L_X which we would derive for this cluster? You may assume that the cluster is sufficiently close that distance scales linearly with redshift.

Problem 3: Cosmological Concepts [25 points]

- a) In words, what is the critical density ρ_c ?
- b) What is the density parameter Ω ?
- c) In words, why does the value of the Hubble Constant change with time?
- d) Why are universes with $\Omega > 1$ called “closed” (assuming $\Lambda = 0$)?
- e) What are the comoving coordinate ϖ and the scale factor R , and how do they relate to the physical separation r between galaxies as a function of time?

f) Briefly explain the origin of the cosmological redshift.

g) Express the redshift we would measure today for a photon which was emitted at time t , in terms of the scale factor R . Let t_0 be the current age of the universe.

h) Why does $\rho_0 = \rho(t)R(t)^3$?

Problem 4: Distance Scale Techniques [10 points]

Here is a list of techniques for measuring the distance scale. Place an “X” in the column indicating the furthest object for which each method could be used.

	Hyades Star Cluster	Magellanic Clouds	Virgo	z=1
Tully-Fisher				
RR Lyrae				
Supernovae Type Ia				
Cepheid variables (with HST)				
Cepheid variables (without HST)				
Parallax				
Brightest Cluster Galaxy				

Problem 5: Evolution of a Flat Universe [25 points]

For this question you will make use of the Friedmann equation for the evolution of the scale factor:

$$\left[\left(\frac{dR(t)/dt}{R(t)} \right)^2 - \frac{8\pi G\rho(t)}{3} \right] R^2(t) = -kc^2$$

You may assume for this problem that the universe is **flat**.

- Give a physical explanation for the two terms on the left hand side.

b) Show that the current value of the critical density is $\rho_{c,0} = \frac{3H_0^2}{8\pi G}$.

c) Show that for a flat universe, the Friedmann equation can be rewritten as:

$$\left[\left(\frac{dR(t)}{dt} \right)^2 - H_0^2 \frac{1}{R(t)} \right] = 0$$

d) Solve the differential equation from (c) to show that $R(t) = (3H_0t/2)^{2/3}$.

d) Show that for the result in Part (c), the age of the Universe is $t_0 = \frac{2}{3H_0}$.