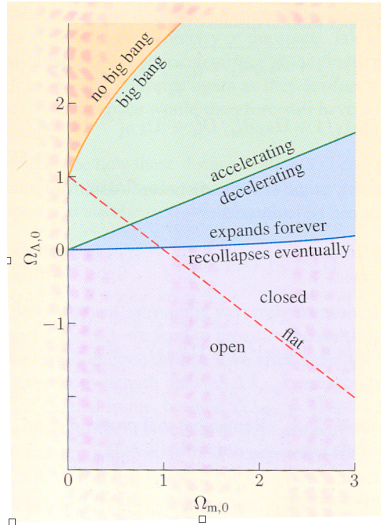


Observational Cosmology
 Problem Set 1
 Due Date: February 16, 2025
 Instructor: R. Bouwens

Here is the exercise set for lectures 1, 2, and 3 to verify your comprehension of the material. The problems will be due on Tuesday, February 16, 2025.

1. Assume $H_0 = 71$ km/s/Mpc. Assume $\Omega_r = 0$ and a flat universe. If the age of the universe is 28.0 Gyr, what is Ω_Λ ? You may need to solve the relevant equation numerically.
2. (a) Assume $\Omega_m = 0.06$, $\Omega_\Lambda = 0.94$, $\Omega_r = 0$ at $z = 0$. At which redshift, does $\Omega_m = \Omega_\Lambda$?
- (b) Assume $\Omega_r = 0.001$, $\Omega_\Lambda = 0.999$, $\Omega_m = 0$ at $z = 0$. At which redshift, does $\Omega_r = \Omega_\Lambda$?

3. Examine the following figure:



For parameters $\Omega_\Lambda > 1.0$ and $\Omega_m \sim$ small, it says “No Big Bang...” Why is this? Please explain.

4. Besides Messier 4, the other globular cluster for which we have a lower limit on the age of the universe from the white dwarf cooling sequence is

NGC6397 and 47 Tuc. What is the lower limit on the age of the universe determined from this cluster? How does its distance compare to Messier 4? Please attach a photocopy of a plot from a paper showing a color-luminosity sequence for the white dwarfs in that cluster.

5. Suppose that a universe has $\Omega_m = 2.5$, $\Omega_k = -2.0$ (so that the geometry is of a closed universe) and $\Omega_\Lambda = 0.5$. Demonstrate that such a universe will expand forever (despite the universe being closed).

6. Express $q_0 = -(R d^2 R/dt^2)/(dR/dt)^2$ (dimensionless quantity for the acceleration of the scale factor of the universe) in terms of Ω_m , Ω_r , and Ω_Λ . R is the scale factor for the universe. Give the derivation. You may start with Friedmann's equations. You should be sure that you reproduce the no acceleration line in the figure shown for problem 3 when $q_0 = 0$.

7. (a) Observations of water masers provide us with another method for establishing the distances to nearby galaxies, independent of the normal distance ladder. One of the most compelling examples of how these masers can be used to measure distances to galaxies outside our local group was made with NGC4258. Briefly explain how this method works. Why is it helpful for this method to observe water masers? Include a plot from a paper showing the line of sight velocity vs. impact parameter for this galaxy. Why was use of the VLBI essential for the distance measurement?

(b) Given that water-maser distance measurements exist for other galaxies, e.g., UGC 3789 and Mrk 1419, how easy do you expect it would be to obtain such distance measurements for a large number of galaxies? Would it be possible to put together the distance ladder based on those measurements alone?

8. Two other tools for setting up the distance ladder that will not be discussed extensively in the course are red clump stars and Mira variables.

(a) What are red clump stars and why are they useful as a distance indicator.

(b) Compare the luminosities and oscillation periods of Mira variable stars to Cepheids and RR Lyrae stars. What are the strengths and weaknesses of all three as distance indicators? How easy is it to find examples of each in distance galaxies and use as a distance indicator?

