

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
Physics Department  
Earth, Atmospheric, and Planetary Sciences Department

Astronomy 8.282J-12.402J

May 5, 2006

## Problem Set 12

**Due:** Friday, May 12

Last assignment of the term to be turned in.

**Note:** The final exam will be given on Friday, May 26, from 9:00 am until noon.

A practice final exam is available in the exams section.

**Reading:** Zeilik & Gregory: finish Chapter 21; read Chapters 22 and 23; start Chapter 24.

### Problem 1

“Orbiting Galaxies”

Zeilik & Gregory, Chapter 21, Problem #1, page 431.

Refer to Figure 23–1 and Table 23–1 for relevant masses and distances. In each case, take the present separation to be equal to the semimajor axis of the orbit.

### Problem 2

“Distance Determinations”

Zeilik & Gregory, Chapter 22, Problem #2, page 445.

Refer to Table 22–1 for a helpful summary of the basic “distance indicators”

### Problem 3

“Galaxy Redshift from the Ca II K Line”

Zeilik & Gregory, Chapter 22, Problem #3, page 445.

### Problem 4

“Measuring a Quasar Redshift”

Figure 24–15 (page 478 of Z&G) shows the spectrum of 3C 273, the first quasi-stellar object (QSO) whose spectral redshift was identified (by Maarten Schmidt, 1963). If one assumes that the redshift is due to the cosmological expansion of the Universe, one can estimate the distance to the QSO by use of the empirical relationship discovered by Edwin Hubble.

a. Use the figure to determine the redshift ( $z = \Delta\lambda/\lambda_0$ ) of 3C 273. You can determine the scale of the spectrogram (in Å per mm) from the three wavelengths identified on the comparison spectrum. [The rest wavelength of the H $\beta$  line is 4861 Å.]

- b. Translate this redshift to a recessional velocity.  
 c. Use the Hubble relation (with  $H_0 = 65 \text{ km/s/Mpc}$ ) to find the distance to 3C 273.

Problem 5

“Identifying the Lines and Determining the Redshift of a Quasar”

The figure below is the visible spectrum of a distant quasar. Five prominent spectral lines can be seen in the spectrum. Also given below is a table of the laboratory wavelengths of the most observed emission lines in the spectra of quasars. Identify the lines and calculate the redshift,  $z = (\lambda - \lambda_0)/\lambda_0$ , of this quasar ( $\lambda$  is the observed wavelength and  $\lambda_0$  is the wavelength measured in the laboratory).

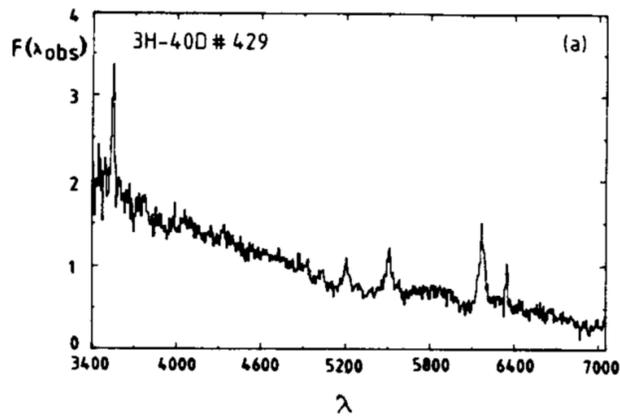


TABLE I  
 Laboratory wavelengths of the most observed  
 emission lines in the spectra of quasars

$\lambda_{\text{lab}}$	ion
6563 Å	H $\alpha$ p
5007	[O III]
4956	[O III]
4861	H $\beta$ et
4363	[O III]
4340	H $\gamma$ am
4102	H $\delta$ el
3969	H $\epsilon$ ps
	[Ne III]
3869	[Ne III]
3728	[O II]
2799	Mg II
1909	C III]
1549	C IV
1402	Si IV
	O IV]
1241	N V
1216	Ly $\alpha$ p

Hint: First measure  $\lambda$  for the five lines in the spectrum. Then look for five lines in the table such that  $\lambda/\lambda_0$  has nearly a constant value.

### Problem 6

“A Simple Determination of the Hubble Law”

Figure 22–1 in Z&G (page 435) shows five images of elliptical galaxies, all photographed with the same plate scale ( $\sim 10$  arc seconds per mm). Assume, for absolute simplicity, that all of the galaxies have the same physical size ( $\sim 40$  kpc in diameter).

- Measure the diameter of each galaxy and determine its distance in Mpc.
- Compare your answers to the values given between the two columns of figures.
- Plot the observed Doppler velocities (given in the right-hand column of spectra) vs. the distances to these galaxies as determined in part (a).
- Determine the Hubble constant,  $H_0$ , from your graph.

### Problem 7 Optional

“Free-Fall Time for a Cluster of Galaxies”

Zeilik & Gregory, Chapter 23, Problem #5, page 463.

Take the following as a model for the cluster:

Number of galaxies in cluster = 1000

Mass of each galaxy  $\sim 10^{11} M_\odot$

Radius of the cluster of galaxies  $\sim 6$  Mpc

Procedure for making a crude estimate of the free-fall timescale:

- Write the equation of motion for a galaxy near the edge of the cluster; (assume that the 1000 galaxies are distributed in space so that they effectively form a spherically symmetric mass distribution)
- Use dimensional arguments to find a characteristic time for the collapse.

### Problem 8 Optional

“Luminosity Function of Galaxies in Rich Clusters”

Zeilik & Gregory, Chapter 23, Problem #6, page 463.

Note that the units of  $\phi$  are galaxies per  $\text{Mpc}^3$ , and that  $\phi(L) = \phi^* \times (L/L^*)^{-5/4}$ .