

You may use one sheet of notes. You may not use books or additional notes.

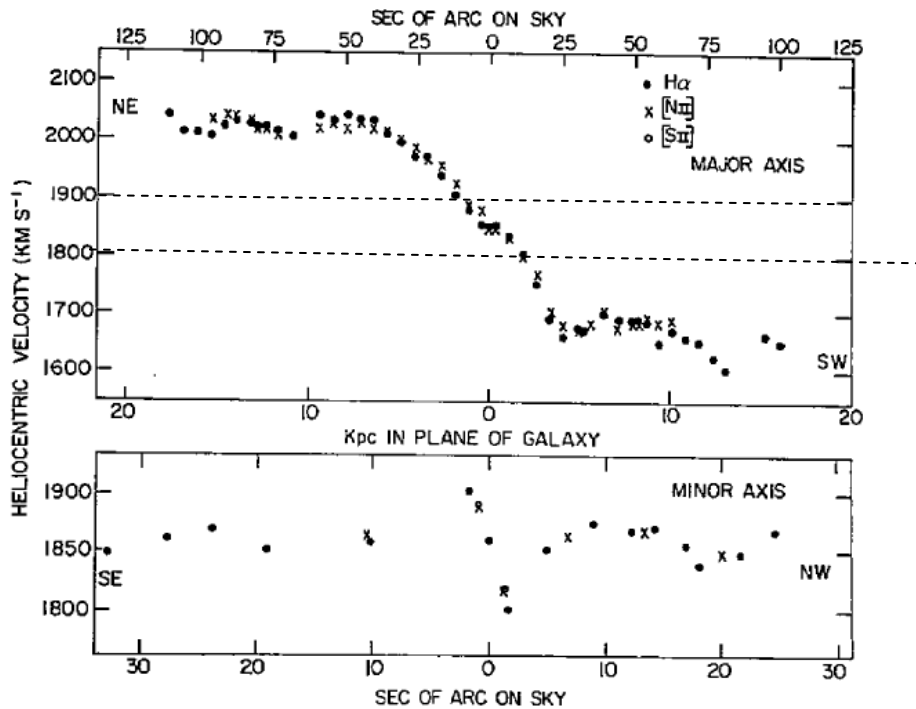
Do the easy questions first. Then go back to the harder ones.

If you need the result of a part that you cannot figure out to do the next part, use a symbol to represent the result.

Name	
PID	
1	/ 21
2	/ 9
3	/ 9
Total	/ 39

Table 1. Spectral lines of hydrogen and oxygen and their laboratory wavelengths. OII means oxygen with one electron removed, and OIII is oxygen with two electrons removed.

Line	Wavelength $\text{\AA}$	Line	Wavelength $\text{\AA}$
H $\alpha$	6562	OII	3727
H $\beta$	4861	OIII	5007
H $\gamma$	4340		
H $\delta$	4101		
H $\epsilon$	3970		



Doppler velocities of gas in NGC3762 along the major axis (top) and along the minor axis (bottom) from Rubin, Vera, Thonnard, Norbert, and Ford, W. Kent, jr., 1977, Astrophysical Journal 217, L1.

## 1. Short answers

- a. (1 pt.) At the present time, does the *value* of Hubble's constant depend on the galaxy in which the observations are made? (2 pts.) Explain your reasoning.
  - b. Simplicio erroneously believes that everything in the universe is expanding according to Hubble's Law. At an earlier time, everything did obey Hubble's Law. (1 pt.) Give an example of something that is not expanding. (2 pts.) Explain why it (or what is used to be) was able to violate Hubble's Law for the first time.
  - c. (1 pt.) How big is a white dwarf? (What is something of comparable size?) (2 pts.) Why is a white dwarf so small?
  - d. (3 pts.) The ratio of neutrons to protons falls slowly as the universe ages from 0.001s to 3min, and then it flat-lines to 1:7. Why does the ratio suddenly become constant?
  - e. "We are star dust."—*Woodstock* by Joni Mitchell. (1 pt.) Is this statement true for the hydrogen in our blood? Is this statement true for the iron in our blood? (2 pts.) Explain.
  - f. (3 pts.) There is plenty of helium in the core of the sun. Why does this helium not fuse at the present time?
  - g. (1 pt.) Where and (2 pts.) how was gold (and the other heavy elements) made?
2. Consider the measurements of the Doppler speed of the gas in the galaxy NGC 3672 (Figure on the front of this test).
- a. (3 pts.) For this part only, assume that the mass inside of the radius 4 kpc is the same as the actual galaxy and there is no matter of any kind outside of the radius 4 kpc. Find the rotational velocity at 16 kpc. You must make clear how you found the numbers that you use.
  - b. (1 pts.) In the inner part of the galaxy ( $R < 4$  kpc), how does the rotational velocity depend on  $R$ ? (2 pts.) How does the mass enclosed within  $R$  depend on  $R$ ?
  - c. (3 pts.) Imagine a galaxy X. Galaxy X has four times as much mass as NGC 3672 at every point, but Galaxy X is the same as NGC3672 in all other respects. Find the value of the Doppler speed for Galaxy X along the major axis at 15 kpc from the center.
2. The galaxy cluster 0024+1654. In the spectrum of a galaxy in the cluster, the wavelength of the  $H\beta$  line of hydrogen is  $6757\text{\AA}$ .
- a. (3 pts.) What would the wavelength of the hydrogen line  $H\alpha$  be in the spectrum of this galaxy?
  - b. (3 pts.) Compute the expansion parameter  $a$  of the universe when 0024+1654 emitted the light that we see now.
  - c. (3 pts.) What was the temperature of the radiation of the Big Bang when 0024+1654 emitted the light that we see now?