

You may use three sheets of notes. You may not use books or additional notes.

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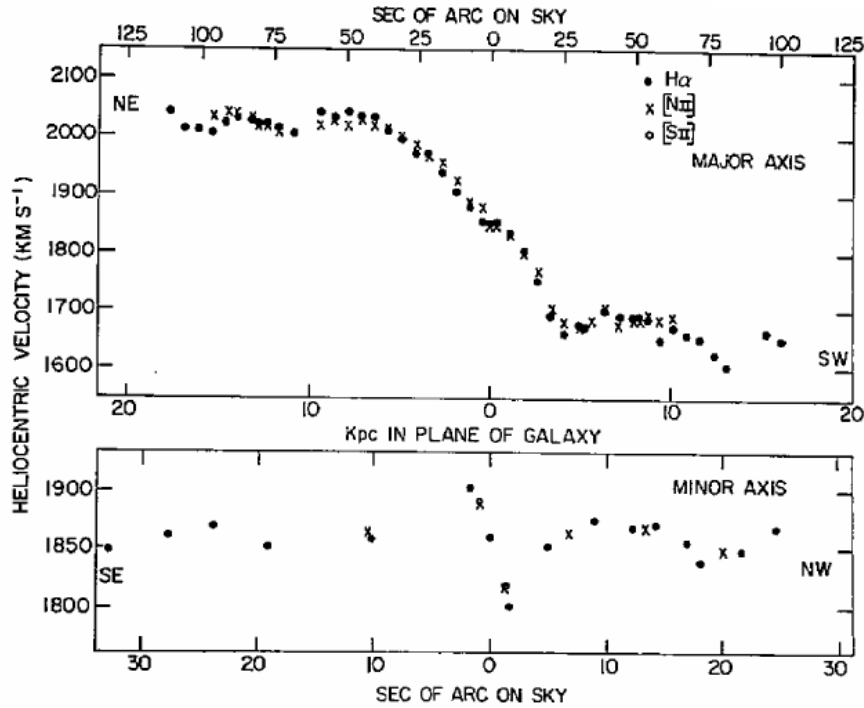


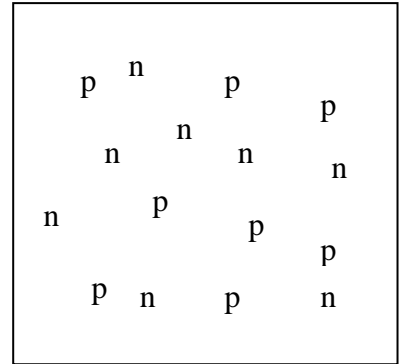
FIG. 3.—*Upper*, major axis heliocentric velocities on plane of sky, as a function of distance from the nucleus. *Lower*, minor axis velocities as a function of distance from the nucleus; note change in scale from upper plot. The steep velocity gradient in nuclear region along minor axis is prominent.

From Rubin, Vera, Thonnard, Norbert, and Ford, W. Kent, jr., 1977, *Astrophysical Journal* 217, L1.

1. Short answers

- (1 pt.) The sun will become a giant 5 billion years from now. Will Deneb, a star of spectral class A visible in the summer, be visible then? (2 pts.) Explain your reasoning.
- The sun will become a planetary nebula. (3 pts.) How has the composition of the material in the outer parts changed from when it was a protostar? (3 pts.) What prevents material in the star in the center of the planetary nebula from fusing?
- (3 pts.) Your parents experienced an exciting period in astronomy. (For this problem, assume your parents were born in 1960 and are still living.) Name three discoveries in cosmology made in their lifetime.
- (3 pts.) What is the evidence for the black hole in the center of our galaxy?

2. The picture shows a sample of the universe 0.001 s after the big bang, when the expansion parameter was 6×10^{-12} . (Recall that the expansion parameter is distance/(present distance). The box was a cube 2×10^{-11} m on a side. There are 8 neutrons, 8 protons, and lots of light in the box.



- (5 pts.) The box expands with the universe. Draw its contents just before helium formed (at 3 minutes, when the expansion parameter is 2.3×10^{-9}). The number must be precise to 10%; for example, drawing 15 protons is OK if the actual number of protons is 16. (3 pts.) What is the temperature of the radiation in the box?
 - The box expands with the universe. (3 pts.) Draw its contents at the present time. (2 pts.) How big is the box now? Assume the box is not from some special place such as in a star, or in a galaxy.
3. Consider the measurements of the speed of gas in the galaxy NGC 3672 from a paper by Rubin, Thonnard, & Ford on the front of this test.
- (3 pts.) If this galaxy were moved to twice the distance, how and by how much would the speeds in lower plot change?
 - (3 pts.) If this galaxy had twice as much mass, how and by how much would the speeds in the upper plot change?
 - (3 pts.) Explain the evidence for dark matter in this galaxy.
 - (3 pts.) Sketch the speed beyond 20 kpc (to the right) if there is no dark matter beyond 20 kpc.