

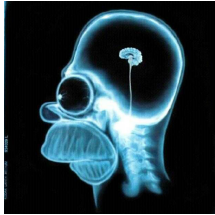
General Astronomy II, Spring 2019

PROBLEM SET 3



Deadline: 11PM THURSDAY, MAY 9, 2019

Submission: iLMS PLATFORM



Early one morning, you bumped into Homer Simpson in a coffee shop. Homer had his own ideas of how and why everything is in the universe and insisted that his ideas were right. But you know that a lot of his thoughts may not be correct, not any better than what shows in an X-ray image of his brain.

After hearing what Homer had to say, you decided to convince him with what you have learned in the class. You must let Homer know which part of his arguments went wrong.

1. **Hubble Law and Redshifts (30%).** Edwin Hubble found all nearby galaxies are receding from us with their velocity linearly proportional to distance. Later, astronomers apply the Hubble law to distant galaxies at high redshift, where the redshift is defined as

$$z \equiv \frac{\Delta\lambda}{\lambda} = \frac{\lambda_{\text{obs}} - \lambda_{\text{emit}}}{\lambda_{\text{emit}}}, \quad (1)$$

where λ_{obs} is the observed wavelength, λ_{emit} is the emitted wavelength, and z is the redshift.

Homer: I know Hubble law, which gives an increasing velocity of recession with distance for galaxies (Fig. 1). The receding velocity, v_r , is determined by the Doppler effect, that is,

$$\frac{v_r}{c} \simeq \frac{\Delta\lambda}{\lambda} = \frac{\lambda_{\text{obs}} - \lambda_{\text{emit}}}{\lambda_{\text{emit}}}. \quad (2)$$

I heard in the news that the highest redshift objects have $z > 10$, so these galaxies are moving away from us at a speed faster than $10c$ according to the Doppler effect.

- (a) (10%) Do you agree with Homer's idea about applying the Doppler effect to high redshift galaxies? If not, tell him what is the expected outcome of his idea?
- (b) (20%) Can you tell him why those galaxies show redshift larger than one, even up to 10?

2. **Cosmic Microwave Background (CMB) (30%).** In 1965, Arno Penzias and Robert Wilson made the first detection of the CMB with a horn antenna.

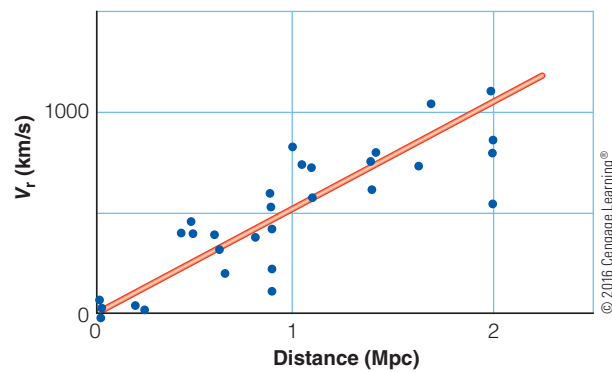


Figure 1: A reproduction of Edwin Hubble's first diagram of apparent velocities of recession and (recalibrated) distances of galaxies.

Homer: I have heard about the Big Bang. The Universe started like an extremely hot fireball, the so-called big bang, and now it has cooled down to 2.725 K over 13.8 billion years. This big bang theory is verified by the CMB. This is just like an oven in any kitchen. The oven cools down a couple of hours after I roast my Thanksgiving turkey.

- (a) (10%) Do you agree with Homer's idea about the CMB like residual warmth in an oven? If not, tell him what is the expected outcome of his idea?
- (b) (20%) Can you tell Homer how the CMB appears to be at a temperature of 2.725 K?