A7000 (Apr-2021), OpenStax Ch.26: WS Solutions

Solutions

1. Describe the main distinguishing features of spiral, elliptical, and irregular galaxies.

   Spiral galaxies have a disk, spiral arms, and a central bulge. Elliptical galaxies appear as only a bulge—they do not have any disk or spiral arm structure. Irregular galaxies do not fit into either of the other categories and don’t have well-defined or clear structure.

2. Why did it take so long for the existence of other galaxies to be established?

   Astronomers had no method of determining distance to objects so far away. Geometric methods work only for the nearest stars and for a long time (until the cepheid period-luminosity relationship was discovered) there were no reliable methods for finding distances farther away. In order to find individual cepheids in other galaxies, however, we needed a larger telescope, and so distance measurement to other galaxies had to await the building of the 100-in. telescope in the 1910s. Without distances, astronomers were not sure if the fuzzy objects we now call galaxies were inside the Milky Way or not.

3. Explain what the mass-to-light ratio is and why it is smaller in spiral galaxies with regions of star formation than in elliptical galaxies.

   Mass-to-light ratio is a comparison of mass (usually in solar masses) to luminosity (usually in solar luminosities). The Sun by definition would be a 1 in mass-to-light ratio. Regions of recent star formation have many new massive stars in addition to the large number of low-mass stars that all galaxies have; thus, their mass to light ratio tends to be lower (in the range of 1–10). Elliptical galaxies tend to be devoid of gas and dust, and are not doing a lot of new star formation. Thus, many high-mass stars have consumed all of their fuel and “burnt out.” The result is that the high mass stars no longer contribute to the overall luminosity, so the mass-to-light ratio needs to increase to show this additional mass.

4. If we now realize dwarf ellipticals are the most common type of galaxy, why did they escape our notice for so long?

   They are extremely dim and small. This makes them difficult to observe and identify.

5. What are the two best ways to measure the distance to a nearby spiral galaxy, and how would it be measured?

   Method 1: Use the period-luminosity relationship for cepheid variable stars. First, look for a star that varies at a rate consistent with cepheids, then use the period to determine the luminosity of the star. Finally, compare the luminosity with the apparent brightness to determine the distance. Method 2: Type Ia supernovae can be used as a standard bulb. First, look for a supernova explosion and determine what kind of supernova it was. If it is a type Ia, it will reach the same peak luminosity as other type Ia’s. Compare that peak luminosity with the apparent supernova brightness to determine the distance.

6. What are the two best ways to measure the distance to a distant, isolated spiral galaxy, and how would it be measured?

   Method 1: Type Ia supernovae can be used as a standard bulb. First, look for a supernova explosion, and determine what kind of supernova it was. If it is a type Ia, it will reach the same peak luminosity as other type Ia’s. Compare that peak luminosity with the apparent brightness of the supernova at maximum to determine the distance. Method 2: The rotation rate of the spiral galaxy can be used to determine the distance using the Tully-Fisher relation. Take a spectrum of the galaxy. The line widths of the 21-cm line can then be used to determine the rotation rate of the galaxy.

7. Why is Hubble's law considered one of the most important discoveries in the history of astronomy?

You could answer this several ways. Hubble's law allows us to estimate the distance for galaxies that are too far away to see individual cepheids. Hubble's law describes the expansion of the universe. It validates solutions to the equations of general relativity in which the universe is in motion (rather than static, as Einstein had fudged it to be).

8. What does it mean to say that the universe is expanding? What is expanding? For example, is your astronomy classroom expanding? Is the solar system? Why or why not?

It is space (or more properly space-time) that is expanding. The matter inside the universe is not expanding—gravity holds things together at that local level. The empty space between groups and clusters of galaxy is where expansion can be seen.

9. Was Hubble's original estimate of the distance to the Andromeda galaxy correct? Explain.

No, although this was not known in the early 1920s, there are really two kinds of cepheid-like variable stars, and Hubble was using the other kind to estimate the distance to Andromeda. The distance estimate increased by more than a factor of two once it was corrected for this.

10. Does an elliptical galaxy rotate like a spiral galaxy? Explain.

No, in an elliptical, the stellar motions are randomized and do not travel systemically or in any predominant direction. We can only measure the variations of the motion of the stars within an elliptical galaxy.

11. Why does the disk of a spiral galaxy appear dark when viewed edge on?

In a spiral galaxy, dust is concentrated in the plane of the disk. When seen edge on, light from the stars must reach us by traveling through the disk, and the dust in the plane of the galaxy absorbs the starlight within the galaxy, making it appear darker.

12. What causes the largest mass-to-light ratio: gas and dust, dark matter, or stars that have burnt out?

Dark matter can create the largest mass-to-light ratios, since it dominates the mass of large galaxies and galaxy clusters without adding to the total luminosity.

13. What is the most useful standard bulb method for determining distances to galaxies?

Type Ia supernovae; cepheid variable stars are limited by distance (since individual stars are hard to make out once a galaxy gets too far away). Type Ia supernovae, on the other hand, are very luminous, and can be seen at much greater distances.

14. When comparing two isolated spiral galaxies that have the same apparent brightness, but rotate at different rates, what can you say about their relative luminosity?

Applying the Tully-Fisher method, the faster spinning galaxy should be more massive and thus more luminous.

15. If all distant galaxies are expanding away from us, does this mean we're at the center of the universe?

No, you can show that if the expansion follows a simple proportional relationship (Hubble's law), then all points in space within the expanding universe could make the same observation and claim to be the center.

16. Is the Hubble constant actually constant?

No, astronomers understand that if the universe is decelerating (because of gravity) or accelerating, then the Hubble “constant” actually changes with time. Observations suggest that Hubble’s constant has increased over time, meaning that the universe’s expansion is accelerating.

17. Why can we not determine distances to galaxies by the same method used to measure the parallaxes of stars?

Parallaxes can be measured accurately out to distances of 100 light-years or so (300 light-years from the Hipparcos data). The nearest galaxies are about 50,000–80,000 light-years from the Sun. Therefore, there is no perceptible change in the apparent position of any galaxy as we view it from opposite sides of Earth’s orbit.

18. Which is redder—a spiral galaxy or an elliptical galaxy?

Hot blue stars are more massive and go through their lives more quickly. Therefore, as time goes on, blue stars tend to die first and galaxies become redder as the blue stars die out. The less “raw material” a galaxy has available, the fewer new stars (young stars) can be seen in it. An elliptical galaxy is redder than a spiral in integrated light because an elliptical galaxy contains only old stars, while a spiral contains both old and young stars. The nuclear bulge of a spiral (that is, excluding the light from the spiral arms) is redder than its spiral arms because the central regions of spirals contain mostly old stars.

19. Suppose the stars in an elliptical galaxy all formed within a few million years shortly after the universe began. Suppose these stars have a range of masses, just as the stars in our own galaxy do. How would the color of the elliptical change over the next several billion years? How would its luminosity change? Why?

The color of the elliptical galaxy will grow redder with time as stars of progressively lower mass exhaust their hydrogen and move away from the main sequence. The magnitude of the galaxy will also fade as stars exhaust their energy supply, become black holes, neutron stars, or white dwarfs, and cease to emit the large amounts of energy that they produced when they were younger. Also, the intrinsically most luminous stars are the first to die, again causing the galaxy to grow fainter.

20. A cluster of galaxies is observed to have a recessional velocity of 60,000 km/s. Find the distance to the cluster. (Assume a Hubble constant of 22 km/s per million light-years.)

If H = 22 km/s per 10^6 light-years, then a radial velocity of 60,000 km/s corresponds to (60,000/22) = 2700×10^6 light-years = 2.7×10^9 light-years.