

OpenStax Astronomy, Ch.21: WS Solutions (Apr-2021)

Solutions

1. Why is star formation more likely to occur in cold molecular clouds than in regions where the temperature of the interstellar medium is several hundred thousand degrees?

Stars can form when gravity (which pulls things together) exceeds the local pressure (which tends to push atoms apart.) Pressure is higher in hot material and lower in cold material, so colder clouds put up less resistance to gravity and can collapse more readily. Also, at lower temperatures, molecules form. Because molecules are heavier than individual atoms, they move around more slowly and can congregate in a small volume of space, increasing the local matter density and thereby the local gravity.

2. Why have we learned a lot about star formation since the invention of detectors sensitive to infrared radiation?

As stars form (during the proto-star stage) they are collapsing and heating up. For much of the formation process they give off a considerable part of their emission in the infra-red. Star formation happens best in great (molecular) clouds of gas and dust, which have a lot of dust particles. Infrared radiation can penetrate the dust but visible light cannot. Thus, the ability to use infrared detectors lets us see through the dust deep into the clouds where the star formation is happening.

3. Describe what happens when a star forms. Begin with a dense core of material in a molecular cloud and trace the evolution up to the time the newly formed star reaches the main sequence.

Generally, collapse leads to central heating, which eventually leads to hydrogen ignition temperatures. Specifically, when gravity exceeds pressure in the molecular cloud, material from the outer reaches of the cloud transfers gravitational potential energy into kinetic energy as it falls in towards the center of the cloud. When it reaches the center of the cloud, the kinetic energy is converted to thermal energy as the material is either added to the central Protostar or spun out into the protoplanetary disk. The protostar increases in temperature and luminosity as more material is added. Its central pressure and temperature also increase until temperatures of 10–15 million K are achieved and nuclear fusion begins. In the meantime, other processes related to conservation of angular momentum shape the material surrounding the collapsing core and limit the amount of material involved in the collapse.

4. Describe how the T Tauri star stage in the life of a low-mass star can lead to the formation of a Herbig-Haro (H-H) object?

Tauri stars show a stellar wind, a flow of atomic particles away from the star. While the star is still surrounded by an accretion disk around its equator, the wind is stopped in that direction, and it emerges far more effectively in two cones or jets, perpendicular to the accretion disk. As these jets plow into the surrounding material, they can occasionally collide with a somewhat-denser lump of gas nearby, transferring energy and exciting its atoms, causing them to emit light. These glowing regions are called Herbig-Haro (HH) objects, after the two astronomers who discovered them. There are often two such objects, one on each side of the star where the jets emerge.

5. Two protostars, one 10 times the mass of the Sun and one half the mass of the Sun are born at the same time in a molecular cloud. Which one will reach the main sequence stage, where it is stable and getting energy from fusion, first?

As you can see in Figure 21.12 Evolutionary Tracks for Contracting Protostars, the more massive a star is, the more quickly it goes through each stage of being a protostar. Thus, the 10 solar mass star will become a real star (one that supplies its energy through fusion) first.

6. Compare the scale (size) of a typical dusty disk around a forming star with the scale of our solar system.

The dusty disks range in size from 10 to 1000 AU. Jupiter's orbit is about 10 AU wide. The orbit of Pluto has a diameter of 80 AU. The outer diameter of the Kuiper belt of smaller icy bodies is about 100 AU. Eris' orbit has an average diameter of about 136 AU.

7. Why is it so hard to see planets around other stars and so easy to see them around our own?

Planets only reflect light and so are much fainter than their host stars when viewed at large distances. Therefore, glare from the host stars often completely washes out the planetary light.

8. Why did it take astronomers until 1995 to discover the first exoplanet orbiting another star like the Sun?

The first discovery of an exoplanet took place by finding the changing Doppler shift in the spectrum of the star as the planet moved in orbit around it. To measure the really small variations in the spectra of stars in a stable way over long periods of time, astronomers had to build very precise spectrometers.

9. Which types of planets are most easily detected by Doppler measurements? By transits?

The Doppler technique measures the motion of the star caused by the pull of one or more planets around it. The gravitational force is proportional to the mass of the planet and inversely proportional to the square of the separation. So the easiest planets to detect with this method are massive and close to the star. That's why the hot Jupiters were found first. The transit probability (the chance that the orbit will bring the planet in front of the star for a transit) is greatest for close-in planets. The size of the planet must be big enough to give a measureable decrease in the brightness of the star. Since astronomers need to wait for three transits before they feel comfortable confirming their observation, that means that the longer the planet takes to orbit its star, the longer it will take to confirm the existence of a transiting planet. So this method works best for planets of larger size, orbiting close to their stars.

10. List three ways in which the exoplanets we have detected have been found to be different from planets in our solar system.

In other planetary systems, gas giant planets can reside close to the star (hot Jupiters) or in highly elliptical orbits around the star. Super-Earths and mini-Neptunes have been found around other stars, but we don't have any in our solar system. In other solar systems, small rocky planets are commonly found inside of Mercury's orbit. Some exoplanets have been discovered to orbit binary stars.

11. List any similarities between discovered exoplanets and planets in our solar system.

Over 500 planetary systems are similar to our solar system in having more than one planet orbiting the same star; we find a range of planetary masses among the planets in the same system. Kepler is sensitive to co-planar planetary systems, so many systems that have been discovered appear to be co-planar like our solar system.

12. What revisions to the theory of planet formation have astronomers had to make as a result of the discovery of exoplanets?



We now understand that planets can migrate in the protoplanetary disk through gravitational friction or drag. For example, Jupiters can migrate inward and be quite close to their stars (hot Jupiters). We now understand that planet formation is more chaotic and less orderly than we imagined. Instead of all the planets orbiting in one plane and in the same direction, we now see some planets orbiting at right angles to the plane of the other planets or even moving backward. We also learned that it is possible to have stable planets orbiting a system of two stars.



13. Why are young Jupiters easier to see with direct imaging than old Jupiters?

Young Jupiters have more internal heat from the process of accretion and formation. This energy is radiated as infrared, and so young Jupiters will be brighter infrared sources. Since the planet cools with time, younger Jupiters are more luminous and easier to see with direct imaging techniques.

14. Suppose you wanted to observe a planet around another star with direct imaging. Would you try to observe in visible light or in the infrared? Why? Would the planet be easier to see if it were at 1 AU or 5 AU from its star?

The planet will be easier to see if it is farther away from its parent star; closer planets would be even more likely to be lost in the glare of the parent star. The ratio of the brightness of the planet to the brightness of the star is very small at all wavelengths, but will be larger in the infrared than in visible light so observations should be made in the infrared.

15. Why were giant planets close to their stars the first ones to be discovered? Why has the same technique not been used yet to discover giant planets at the distance of Saturn?

A complete orbit is required in order to model or detect the presence of a planet with the radial velocity technique. From Kepler's laws, we know that the closest planets have short periods. In the case of the close-in giant planets (so-called "hot Jupiters"), these orbits can be as short as a few days. It does not take long to observe over all phases of these short orbits. However, Saturn has a 30-year orbit. Thus, we would have to observe Saturn for at least 30 years in order to detect that planet. A further complication is that when the planet is far away, the gravitational tug on the star is weaker and harder to detect. Saturn only induces a velocity in the sun of 2.7 m/s. Doppler surveys with sufficient precision to measure this signal only began around 2003. It is also worth noting here that even though small planets may be close to their parent stars and have short periods, their small masses make it much more difficult to observe either gravitational tugs or transits; thus, it is much easier to detect massive planets in short-period orbits around their host stars than it is to detect any low-mass planets or to detect high-mass planets at great distance from the star.

16. An exoplanetary system has two known planets. Planet X orbits in 290 days and Planet Y orbits in 145 days. Which planet is closest to its host star? If the star has the same mass as the Sun, what is the semi-major axis of the orbits for Planets X and Y?

Planet Y is in the shorter period orbit and therefore resides closest to the star. For Planet X, the period is 0.79 years, so (using Kepler's laws) the semi-major axis is $p^2 = a^3$. So $p = 290 \text{ d} \times (1 \text{ y}/365.25 \text{ d}) = 0.79 \text{ y}$, $p^2 = (0.79 \text{ y})^2 = 0.624 \text{ y}^2$, $1 \text{ y}^2 = 1 \text{ AU}^3$, $0.624 \text{ AU}^3 = a^3$, $a = 0.85 \text{ AU}$. ; for Planet Y, the period is 0.40 years so the semi-major axis is $p^2 = a^3$. So $p = 145 \text{ d} \times (1 \text{ y}/365.25 \text{ d}) = 0.40 \text{ y}$, $p^2 = (0.40 \text{ y})^2 = 0.16 \text{ y}^2$, $1 \text{ y}^2 = 1 \text{ AU}^3$, $0.16 \text{ AU}^3 = a^3$, $a = 0.54 \text{ AU}$.

