Astronomy 2020 – Space Astronomy & Exploration **Fall 2020**
Homework #3 Due: Oct. 5, 2020

In questions 1-3 below, choose the best answer. Then explain your reasoning in a few complete sentences. Why is your answer correct?

1. (2 pts). What roles did the Space Shuttle play in making the International Space Station?
   a. The space shuttles were used to power and fuel the ISS.
   b. The space shuttles transported people and parts to build the ISS.
   c. The space shuttles were used to bring the ISS back to Earth for repairs.
   d. The space shuttles provided satellite guidance to the ISS.
   e. All of the above

b) is correct. The Shuttle was originally designed specifically to build the ISS – it's cargo bay is large enough to fit large components of the ISS. c) is incorrect since the ISS has never been on Earth's surface; instead, it was built piece by piece in orbit.

2. (2 pts). Which statement(s) best explain the uniqueness of the Apollo program?
   a. It is the only NASA program to have a serious mission failure.
   b. It is the largest and most expensive program in NASA history.
   c. It is the first program to send more than one American into space.
   d. It is the only program to date to send a person to another celestial body.
   e. b and d.

e) is correct because both b) and d) are true. a) is incorrect because NASA has had major failures apart from Apollo 1 and Apollo 13; for instance, there were many rocket failures during project Mercury, some of which we watched in class. c) is false since Gemini 3 launched both Gus Grissom and John Young into LEO.

3. (2 pts.) Suppose the angular separation of two stars is smaller than the angular resolution of your eyes. How will the stars appear to your eyes?
   a. You will not be able to see these two stars at all.
   b. The two stars will look like a single point of light.
   c. The two stars will appear to be touching, looking rather like a small dumbbell.
   d. You will see two distinct stars.
   e. You will see only the larger of the two stars, not the smaller one.

This is really the definition of resolution. To resolve two objects, you must be able to separate them into two separate images. But, if the resolution of your eyes or your telescope is worse than the separation between the two stars, the result will be the image of a "blob" with the brightness of the two stars combined into an unresolved image.

4. (5 pts). Let's explore some of the emerging commercial space companies that were formed over the past decade. Pick one of the following to investigate: Bigelow Aerospace, Blue Origin, Astrobotics, or Swarm Technologies. Do some research on this company on the web and answer the following questions:

For the example in the solutions, we will follow Blue Origin.

a. Define the term "business plan" and the components which comprise one. What is the company's business plan?

A business plan is a statement of the goals of a prospective business, outlining specifically how and why those goals are attainable. Blue Origin's business plan is to enable private entities to enter sub-orbital and orbital space for tourism and industrial purposes.

b. How far has the company progressed toward achieving its goals to date?

Blue Origin has been slowly moving one step at a time towards orbital flights from sub-orbital flights. They have currently conducted numerous separate sub-orbital test flights.

c. How is the company funded? Who are its investors?

Blue Origin has a few paying customers, but is currently funded through Jeff Bezos' sales of Amazon stock. They spend about $1B per year.

d. What is your assessment of this company? Will it be successful and achieve its goals?

Blue Origin is working incrementally with well-tested technology and has a reasonable, well-funded business plan. Because of this, absent some major development, it seems the company will be able to achieve its goals.

5. (3 pts). One similarity between the Space Shuttle and SpaceX's Falcon rocket is the concept of reusability.

a. Why is this important?

Rockets are incredibly expensive. Remaking an entire vehicle for each trip costs billions of dollars per launch. A reusable rocket allows for more modest costs, ideally with most costs going towards refueling as opposed to rebuilding.

b. How did the Space Shuttle apply the principle of reusability? Explain if it was successful.

The space shuttle was reusable because it was not a simple capsule, it was a lifting body like an airplane. This meant that it could land on runways just like a plane instead of dropping into the ocean. In principle, this was a good design but the retiling of the heat shield on the shuttle (and other unforeseen reusability costs) made launch costs almost as high as using a capsule.

c. What about the SpaceX Falcon is reusable? Is it successful? Why or why not?

Although the SpaceX Falcon launches a reusable capsule, its first stage is also reusable. Once it detaches from the capsule, it is landed in a controlled fashion on a barge on the ocean. Although there are some extra costs in setting up the barge and making a rocket

which can control its landing, the reusability of SpaceX's Falcon rocket and Dragon capsule are generally a success.

6. (6 pts). Let's compare the **Hubble Space Telescope** operating at ultraviolet wavelengths ($\lambda = 0.2$ microns, where 1 micron = 10^{-6} meters) with the **James Webb Space Telescope** operating at infrared wavelengths ($\lambda = 10$ microns). Use the information on each telescope provided by the assigned reading and the class notes to answer the following questions:

a. Calculate and compare the Light Collecting Area of each telescope. What do these imply about the relative sensitivity of each telescope to probe faint objects such as distant galaxies in the early Universe?

The diameter of Hubble's primary mirror is 2.4 meters, leading to a light collecting area of 4.5 m^2, using the formula $A = \pi(d/2)^2$. JWST has a primary diameter of 6.5 meters, leading to a light collecting area of 33 m^2. JWST's larger light collecting area means that it is more sensitive and so can probe fainter objects than Hubble.

b. What is the angular resolution for each telescope at its operating wavelengths given above? Given the difference in diameter of the primary mirrors of each telescope, how do you explain the difference in angular resolution for each telescope?

Using the equation θ(arcseconds) = 206,265 × (λ/D), the wavelengths provided, and the diameters from part (a), we can calculate the angular resolutions. Hubble's angular resolution is 0.02 arcseconds, whereas JWST's is 0.32 arcseconds. The wavelengths JWST is sensitive to are 50 times greater than Hubble's. Therefore JWST's primary mirror would need to have a 50 times larger diameter compared with Hubble's in order to achieve the same angular resolution.

c. Discuss the different science that will be pursued by each telescope – one operating in the ultraviolet and the other in the infrared.

(Example) The combination of JWST's larger light collecting area and its IR sensitivity means that it will be able to study the early/distant universe. Because the universe is expanding, the light coming from the distant universe is stretched to longer wavelengths. This means that whereas Hubble can observe UV light to study star formation in the local universe, JWST can use IR light to study star formation in the distant universe.

7. (4 pts.) Suppose you have a satellite TV dish that is 0.5-meter in diameter. Using the same formula for angular resolution that you used above for the telescopes above, calculate the angular resolution of your satellite dish with a wavelength of 21-centimeters. Would this be useful as an astronomical radio telescope?

Let's use the same equation as in 6(b) above for resolution:
θ) = 206,265 × (λ/D) = 206,265 x (0.21 meters/0.5 meters) = 86,631 arcseconds or 24 degrees. This is enormous on the sky! For example, the angular diameter of the Sun is 0.5 degrees. So, this dish would be useless as a radio telescope. Radio telescopes have giant dishes that are up to 100 meters in diameter.

8. (2 pts.) Suppose a wealthy donor to the University of Colorado proposed to build a major observatory with a mirror diameter of 10-meters on the campus. Would it make a good observing site? Explain why or why not.

No! The light pollution from the campus would limit the ability to see faint objects which is why you build a large telescope. It is the reason that large telescopes are placed on mountains far away from cities.

Furthermore, the heat from campus makes the air turbulent. This limits the resolution. Once again, hit mountain tops have generally more stable air and therefore permits better angular resolution imaging.