Astronomy

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Disclaimer: To ensure the scientific accuracy of the test, I obtained my questions from the "Exoplanets" open course from the Australian National University. Refer to the open course for more detailed answer explanations for this test.

Names:____

Team: ____

Part I: Multiple-Choice

Directions: This section will be a mixture of conceptual questions and simple math calculations. There will be only 1 answer to each question. Write the correct answer choice on the answer key. NOTHING IN THE TEST BOOKLET WILL BE GRADED!!!

1. An exoplanet is orbiting its host star. When the planet is at its closest point to Earth, the star is...
   a. Also at its closest point
   b. At its average distance
   c. At its furthest point from Earth
   d. In Alaska

2. Imagine you observe two identical pulsars, both with oscillation periods of 30 days. The first pulsar has an observed oscillation amplitude of 3 microarcseconds, and the second has an observed oscillation amplitude of 10 microarcseconds. Assuming the two pulsars are the same distance from Earth, and assuming that both planets are much less massive than their host stars, which of the following is true?
   a. The first planet is further from its star but less massive.
   b. The first planet is closer to its host star and less massive.
   c. Both planets are about the same distance from their host stars but the first planet is less massive.
   d. Both planets are about the same distance from their host stars but the first planet is more massive.
   e. Both planets have the same mass but the first is closer in.
   f. Both planets have the same mass but the first is farther out.

3. One possible theory to explain the presence of planets around pulsars is that the planets are actually survivors, that they were orbiting the star while the star was on the main sequence, and that after the star went supernova the planets remained in orbit. What is a possible problem with this theory?
   a. The pulsar remaining after the supernova isn't massive enough to keep planets in orbit.
   b. The planets observed aren't far enough from the pulsar as theory would suggest.
   c. These host pulsars spin too slowly, suggesting that they must be isolated.
   d. The planets observed aren't massive enough to have survived the explosion

4. Another possible theory to explain the presence of planets around pulsars is that the planets formed from the "fall-back" of the stellar material expelled by the star during a supernova. Which of the following is an argument against this theory?
   a. The lack of evidence of a companion star to the pulsar in the same solar system
   b. The destruction of planets during a supernova
   c. The slow spin of the host pulsars

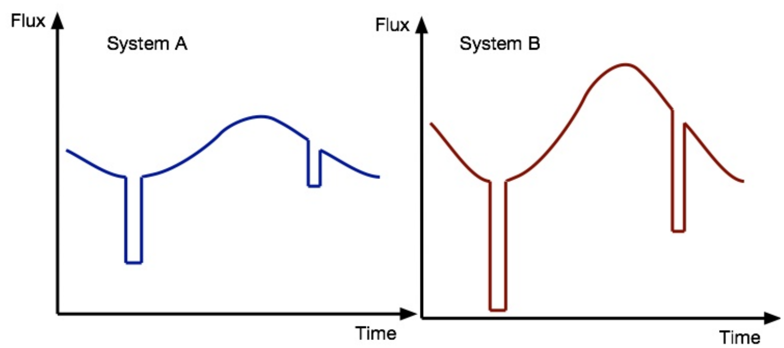
   d. The slow orbits of the planets

5. B1620 is a neutron star that resides in a globular cluster. Why is this important for explaining the presence of planets?
   a. Because close encounters between stars are common in globular clusters.
   b. Because all the stars formed in a globular cluster at the same time.
   c. Because globular clusters contain little to no dark matter.
   d. Because globular clusters have low abundances of carbon.

6. How would the apparent angular size of the reflex motion of a star vary with distance?
   a. The apparent wobble would be the same regardless of distance.
   b. The apparent wobble would be smaller at farther distances.
   c. The apparent wobble would be smaller at closer distances.
   d. Apparent wobble isn't a thing. There's only absolute wobble.

7. What has been a surprising discovery from observing and finding planets through the transit method?
   a. They are incredibly close to the star
   b. They are much more common than predicted
   c. They tend to be much larger than expected
   d. They are a lot more massive than predicted

8. The brightness of two planetary systems is measured in the infrared spectrum, with the light curves shown below. Which planet has the larger day temperature to night temperature ratio?



   a. A
   b. B
   c. Both have the same ratio
   d. Not enough information to tell

9. While observing a planet transiting across a star, you notice there's an absorption spectra line that is varying in its wavelength throughout its orbit. What could cause such a variation?
   a. Strong winds in the planet's atmosphere
   b. The planet's rotation
   c. The planet's orbit around its host star

d. The star’s rotation

10. While measuring the wavelength of an emission line in the spectrum of a star, a planet transits across its disk. In the beginning of the transit, the average wavelength is larger than usual, but near the end of the transit, the average wavelength is smaller than usual. Which of the following is true?

a. The planet is orbiting in the same direction as the star is rotating
b. The planet is orbiting in the opposite direction from the star’s rotation
c. No definite conclusion can be drawn

11. Imagine you measure the spectrum of a star to deduce the properties of a planet, and you measure that it peaks at 550 nm in the optical band and at 60 microns in the infrared band. Based on this data, you deduce a planet’s distance and mass. However, more precise measurements reveal that the fraction of light coming out in the optical band is the same but that instead the star peaks at 80 microns in the infrared band instead of 60 microns. How will this new data change the determined properties of the planet?

a. The planet is closer in and larger
b. The planet is closer in and smaller
c. The planet is further out and larger
d. The planet is further out and smaller
e. The planet’s properties aren’t affected

12. The spectrum of Beta Pictoris has redshifted transient absorption lines at certain wavelengths. One of the most logical interpretations of these transient lines is the presence of comets. Why can’t they be caused by shells of gas flung out from the star’s flares?

a. Outward-flung gas wouldn’t absorb radiation
b. Flares would destroy the outward-flung gas and dust
c. Outward-flung gas would actually be blueshifted

13. Imagine two identical stars with debris disks. The first disk is made from micrometer-sized dust grains, while the second disk is made of millimeter-sized sand grains. Both disks are the same distance from the star and both have the same total mass. Which of the following is true?

a. The first star + disk system will have a 1000x greater infrared excess than the second
b. The first star + disk system will have a 31.6x greater infrared excess than the second
c. Both will have the same infrared excess
d. The second star + disk system will have a 31.6x greater infrared excess than the first
e. The second star + disk system will have a 1000x greater infrared excess than the first

14. Light from a planet can come either because it reflects starlight or because it emits its own radiation. For a hot giant planet with a temperature of about 1000K, which of these effects would generate the most light?

a. Reflected starlight only

b. Radiation emitted from the planet only
c. Reflected starlight at optical bands and the planet’s radiation in infrared wavelengths
d. Reflected starlight in infrared wavelengths and the planet’s radiation in optical bands

15. Imagine that one of your astronomy “apprentices” is calculating the temperature of a planet that forms from the collapse of a molecular cloud of gas and dust. The student makes his calculations with the assumption that the matter falls from infinity and was approximately at rest. However, you know better, and are aware that the falling matter’s angular momentum was too high for it to have fallen from rest, and that in reality it probably formed an accretion disc before the matter slowly accreted onto the planet. How does this knowledge affect the calculations of the planet’s temperature?

a. The new calculated temperature will be higher than what the “apprentice” calculated
b. The calculated temperature won’t change
c. The new calculated temperature will be lower than what the “apprentice” calculated

16. Thermal energy is directly proportional to temperature, but the rate that energy is radiated away is dictated by the Stefan-Boltzmann law. Imagine you have two planets, and one has a temperature of 1000K and the other has a temperature of 1500K. Using your knowledge of the Stefan-Boltzmann law and the relationship between thermal energy and temperature, which of the following is true about the two planets?

a. The second planet will start out hotter than the first one but will rapidly cool until its temperature is lower than that of the first one.
b. The second planet will always remain hotter than the first
c. The second planet will cool down until it has the same temperature as the first one.

Part II: Multiple-Answer Multiple Choice

Directions: The questions here will be similar to the questions in Part I, except for a slight difference - there is the possibility of one answer being correct, more than one response being correct, or none of the responses being correct. To complete this section, write the roman numerals of all the choices that you think are correct. If you think that none of the choices are correct, you MUST write “none of the choices are correct” or something to that effect so that it’s clear that you didn’t just skip or miss the question. For each extra number you write, you will lose 1 point - so negative scores are possible!!!

1. One of the methods of detecting exoplanets involves measuring the oscillation of these planets’ host stars over the period of its orbit around its center of mass. These oscillations are measured by telescopes. However, the oscillations that astronomers are trying to measure are quite small, and there are an ample number of sources of error. Which of the following are potential sources of error in the collected data?

    i. Imperfections in the telescopes’ lenses/mirrors and general construction distort data
    ii. The diffraction of light blurs the observed image
    iii. Earth’s atmosphere has turbulence and uneven pressures that blur images
    iv. Photons arrive randomly at the detector, creating noisy data
    v. Desirably bright targets often don’t have suitably bright reference objects

2. Along with directly observing and imaging stars, telescopes can also be hooked up to spectrographs and measure the doppler shifts of the stars to determine its orbital velocity and from there constrain the mass of the exoplanet that orbits it. However, these Doppler shifts are also quite small, just like the wobble of the stars. Which of the following make(s) it hard to properly measure very small Doppler shifts?

    i. Atmosphere turbulence makes the image wobble around
    ii. Paint on the walls of the rooms in which spectrographs reside can fluoresce
    iii. Nearby kangaroos vibrate, distorting the data
    iv. Telescopes bend as they move, which blurs the data
    v. The rotation of stars blurs spectral lines
    vi. Variations in temperature can distort the spectral data collected

3. Many of the planets discovered orbiting around stars are larger than Earth. Some of these planets are “Hot Jupiters”, which are much larger and more massive than Earth and orbit quit close to their host stars, much closer than Jupiter’s distance from the Sun. Which of the following have been proposed as possible explanations for the existence of Hot Jupiters?

    i. Planets migrate in from the snow-line until they reach the inner edge of the disk,
where

they pile up.

ii. Planets are flung from the star during stellar flares and then stabilized into circular orbits by tidal forces.

iii. Huge numbers of planets migrate in from the snow line: most fall into the star, but the planets that don't fall in by the time the protoplanetary disc clears remain in orbit where they are.

iv. Passing stars apply a torque to the star, which pulls gas out of the protoplanetary disc and forms hot Jupiters.

4. Measuring the Doppler shift of a host star is one way to help detect exoplanets. Which of the following characteristics of an exoplanet can be determined from the radial velocity method alone?

i. The mass of the exoplanet
ii. The orbital period of the exoplanet
iii. The radius of the exoplanet
iv. The temperature of the exoplanet
v. The density of the planet

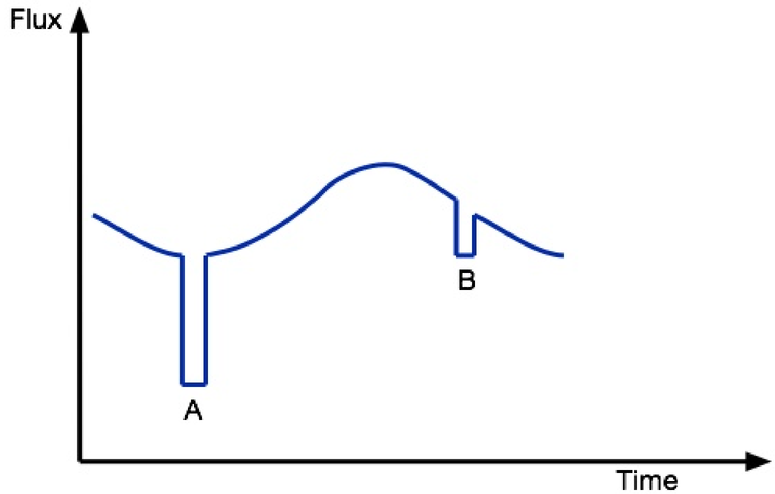
5. Which of the following techniques are used to make transit searches for exoplanets possible?

i. Wide-field telescopes to observe many stars at once
ii. Deliberately putting the telescope out of focus
iii. Comparing each star's brightness against the average brightness of other stars
iv. Transmitting the light from each star down an optical fiber
v. Placing an iodine cell in front of the detector

6. Which one or more of the following are features of the Kepler spacecraft?

i. Very wide fields of view
ii. Short observations on many fields
iii. Long observations on one field at a time
iv. Very accurate luminosity measurements
v. Very sharp images

7. Imagine that you're measuring the brightness of a star system and you get this spectrum. What can you conclude based on this light curve?



i. A is when the planet passes in front of the star
ii. The planet reflects most light in our direction when it's behind the star
iii. One side of the planet must be more reflective than the other
iv. B is where the planet passes in front of the star
v. Reflected light from the planet causes the variation in the "baseline" flux of the star

8. Debris disks give birth to planets in solar systems. Therefore, the dynamics of debris disks is very important. Which of the characteristics is needed to maintain a debris disk (in other words, to keep planets from forming to avoid clearing out the debris disk)?
i. Most of the mass in big clumps (> 100 km)
ii. Gas to keep the orbits circular
iii. A planet to keep the rocks stirred up
iv. Most of the matter in small grains

9. HR 8799 is one of our DSOs (as I'm sure you're aware), and its planets were among the first to be confirmed via direct imaging. Direct imaging is difficult, as telescopes have significant aberrations which hinder its ability to find and identify planets. Which of these techniques was used to overcome these telescope aberrations to find its planets?
i. The telescope was rotated to separate out the aberration from the planets.
ii. The planets were observed at multiple wavelengths to distinguish between aberrations
and planets.
iii. A two-deformable mirror adaptive optics system cancelled out aberrations and atmospheric effects.

10. Going back to question #10, why couldn't the spectrum of Beta Pictoris observed be due to transiting planets?
i. Planet transits would occur at regular intervals

ii. Planet transits wouldn't cause redshifted absorption.
iii. Planetary transits would cause absorption at all wavelengths.

11. Fomalhaut is one of everyone's beloved DSOs, and was discovered by the Hubble Space Telescope. However, space telescopes like the Hubble Space Telescope aren't supposed to be able to see planets because the diffraction in these telescopes is too large. Which feature(s) of this planet system allow(s) Hubble to observe it?
i. The difference in brightness between the planet and Fomalhaut is less than anticipated
ii. The planet reflects more starlight than expected
iii. The planet is further out than anything in our Solar System.

Part III: Mathematical Calculations

Directions: This will be an extended response math section. You must write all your calculations on the answer sheet to get credit. SHOW ALL YOUR WORK! An answer without relevant supporting work will not get credit!!

1. Imagine that you have been measuring the radial velocity of a star of mass 2×10^{30}kg. The star shows a sinusoidal oscillation in its radial velocity of amplitude 17.1 m/s and period 91.0 days. You interpret this oscillation as evidence for a planet orbiting the star in a circular orbit.

a. What is the radius of the planet orbit (in m)? You may assume that $G=6.67\times10^{-11}m^3 kg^{-1}s^{-2}$.
b. What is the minimum mass of the planet?

2. You are observing a star which has a normal measured flux of 24.0 photons per second. The brightness of the star shows regular dips - transits caused by a planet in an edge-on circular orbit. During each dip, the brightness of the star decreases by 0.072 photons per second. Transits repeat every 5.2 days. **Assume the planet has an albedo of 1**.

a. If the star has a radius of 4.1×10^8m, a mass of 1.6×10^{30}kg and a luminosity of 1.3×10^{26}W, what is the radius of the planet (in metres)?
b. How far (in metres) is the planet from the centre of the star?
c. How hot (in Kelvin) is the planet surface, if it is in equilibrium with the radiation from its star?

3. You observe a star with an infra-red excess. The excess infra-red emission peaks at a wavelength of 30.7μm. What is the temperature of the material producing this excess emission (in K)?

4. If a star of luminosity 4.0×10^{26}W has a debris disk of temperature 71.0 K, how far out from the star must this disk be? You may assume that the Stefan-Boltzmann constant is $\sigma=5.67\times10^{-8}$W m^{-2} K^{-4}. What is the distance between the centre of the star and the disk (in metres).

5. Imagine that a star is surrounded by a debris disk that lies a distance D from it. The disk contains n spherical grains, each of radius r. Derive an equation for the fraction f of the light from the star intercepted by the dust grains.

6. Imagine you have imaged an exoplanet which is in orbit around a star 9.27 parsecs from the Earth. The planet appears to be 3.12 arcseconds from the star. If the apparent separation is the true orbital radius, how far (in metres) is the planet from the star?

7. While observing a star 2.2 parsecs from the Earth, you notice a speck of light next to it. The flux you measure from this speck is 1.32×10^{-14}W m^{-2}. If you assume that this dot is actually a planet in orbit around this star, what is the luminosity (in W) of this planet?

8. A planet of temperature 1630 K and luminosity 3.3×10^{22}W lies 32.9 astronomical units from a star. The star is 33.7 parsecs from the Earth. If the planet is emitting as a black body, what is its radius? ($\sigma=5.67\times10^{-8}$W m^{-2}K^{-4}).