1. Choose the best answer and place it in Table 1 (3 points each)

(a) In science, if new observations disagree with a well established theory, then,
A. This should be accepted as part of the overall incompatibility of the universe, and both the observations and the theory should be retained.
B. The theory must be discarded immediately
C. The theory must be modified
D. The observations must be discarded

(b) An astronomical unit (AU) is:
A. the distance light travels in a year
B. the diameter of the solar system
C. the average distance between the Sun and Earth
D. the time it takes light to travel from the Sun to the Earth

(c) Suppose a star rises due east, passes directly overhead, and then sets in the west twelve hours after it rose. What is its average angular speed (in arcseconds per second)?
A. 7.5
B. 15
C. 30
D. 180

(d) The orbit period of which of the following planets is shorter than one year:
A. Uranus
B. Saturn
C. Mercury
D. Jupiter
(e) Which of the following photons has the largest energy per photon:
A. A red light photon
B. A blue light photon
C. An infrared photon
D. An X-ray photon

(f) We place a very hot solid iron bar behind a low-density cool sodium gas and make spectroscopic observations, and then replace the iron bar by a very hot solid copper bar and make spectroscopic observations again.
A. We first see sodium lines and iron lines in emission, and then see sodium lines and copper lines in emission.
B. We first see iron lines in emission and sodium lines in absorption, and then see copper lines in emission and sodium lines in absorption.
C. In both cases, we see sodium lines in absorption superimposed on a smooth continuum.
D. In both cases, we see sodium lines in emission superimposed on a smooth continuum.

(g) A refracting telescope has an objective lens of focal length 80 cm, a diameter of 10 cm, and an eyepiece of focal length 5 cm and diameter 1 cm. What is the magnifying power of this telescope?
A. 10x
B. 8x
C. 16x
D. 80x

(h) The resolution of a telescope is best for which segment of the visible spectrum?
A. red
B. yellow
C. blue
D. the resolution is the same all across the visible spectrum.

(i) Saturn’s surface temperature is lower than that of the earth, because:
A. Saturn is farther away from the sun.
B. The sun’s luminosity on Saturn is not as large as on Earth.
C. Saturn appears red and Earth appears blue.
D. Saturn is larger so radiates more than Earth.

(j) Object A has blackbody temperature of 6000K and Object B has blackbody temperature of 3000K. Then the blackbody spectrum of B peaks at the wavelength _____ times of the peak wavelength of Object A.
A. 4;
B. 2;
C. 1/4;
D. 1/2;
2. Answer the following questions: [18 points]:

(a) The apparent size of the sun is about half a degree, same as that of the moon. What do we mean by “apparent size”? Explain why the sun appears to have the same size as the moon.

(b) The sun’s diameter (in kilometers) is 400 times the moon’s diameter. It takes 500 seconds for sunlight to reach the earth. If an astronaut on the moon sends a radio pulse to the earth, how long does it take for a radio telescope on earth to receive the signal? Show your reasoning/calculation steps.

(c) Mercury’s distance to the Sun is 0.4 AU, and its diameter is 0.007 times the diameter of the Sun. During a Mercury transit when Mercury is between Sun and Earth, to an observer on Earth, how big a portion Mercury makes on the Sun, i.e., how many times larger is the Sun’s apparent size compared with Mercury?

Key:

(a) The apparent size is the angular size of an object, or the portion of the sky the object subtends with respect to an observer at a certain distance. It is inversely proportional to the distance of the observer. Since the Sun is at a much greater distance compared with the moon, so the sun appears to have the same size (angular size) as the moon.

(b) From the small angle formula, it is seen that an object’s angular size is proportional to its linear size and inversely proportional to its distance. So if the sun and the moon has the same angular size, and the sun’s diameter is 400 times the moon’s diameter, we can see that the sun’s distance is 400 times the moon’s distance. Therefore, the time it takes a photon to travel between the moon and the earth is only 1/400 the time it takes for a photon to travel between the sun and the earth. The radio signal therefore can be received on earth in 500/400 = 1.25 seconds.

(c) In this problem we can scale the small angle formula to find the proportionality. Mercury is only 0.007 of Sun’s size, so its angular size would be 0.007 of Sun’s angular size if Mercury is at the distance of the Sun. But Mercury is closer to Earth with its distance 0.6AU, so its angular size should be greater by a factor of 1/0.6 = 1.7, or its angular size is 0.007x1.7 = 0.012 of Sun’s angular size. Or the Sun is about 80 (= 1/0.012) times larger than Mercury when observed on Earth.
3. A star has a surface temperature of 14,500 K. Answer the following questions [26 points]:
   (a) Explain how astronomers determine the surface temperature of this star from spectral observations.
   (b) What is its wavelength of maximum emission in nanometers? What color is this star viewed by human eyes?
   (c) If both the star’s surface temperature and distance to Earth were increased by a factor of two, would the star’s radiation flux received on Earth become larger or smaller? By what factor?
   (d) For this star, suppose we observed a strong absorption H-alpha line (656.28 nm at rest) shifted to 656.35 nm. Explain what this observation tells us. And, is the source of the H-alpha line coming toward us or moving away from us? At what speed?

Key:

(a) astronomers observe the continuum spectrum of the star, which gives the intensity of electromagnetic radiation as a function of wavelength. From the continuum, the wavelength of peak intensity can be determined, which is then used to compute the temperature of the surface of the star, such as by using Wien’s law. (In reality, more sophisticated spectral fitting or color index methods are used to determine the temperature.)

(b) Using Wien’s law, 
\[
\lambda_{\text{max}} = \frac{0.0029 \text{ K m}}{T} = \frac{0.0029 \text{ K m}}{14500 \text{ K}} = 2 \times 10^{-7} \text{ m} = 200 \text{ nm}
\]
so the peak emission occurs at 200 nm in the ultraviolet range, and the star would look blue.

(c) Stefan-Boltzmann law gives the radiation flux of a star at its surface, which is proportional to \( T^4 \). The radiation flux received at a certain distance \( d \) from the star is inversely proportional to \( d^2 \). Therefore, if \( T \) is increased by a factor of two, the star’s radiation flux at the surface would increase to \( 2^4 = 16 \). If the distance is also increased by a factor of two, the flux received at the distance decreases by a factor of \( (1/2^2) = 1/4 \). The combined effect is that the observed radiation flux would increase by \( (16 \times 1/4) = 4 \) times.

(d) The absorption H-alpha line is formed in a gas cooler than the star, for example in the star’s atmosphere or interstellar clouds with hydrogen atoms. The line is shifted toward longer wavelength, or red-shifted, so the stellar atmosphere or cloud is moving away from us. The speed of the motion can be determined by
\[
\nu = c \left( \frac{\lambda - \lambda_0}{\lambda_0} \right) = 3 \times 10^8 \text{ m/s} \times \frac{656.35 \text{ nm} - 656.28 \text{ nm}}{656.28 \text{ nm}} = 3 \times 10^4 \text{ m/s} = 30 \text{ km/s}
\]
4. Answer the following questions [26 points]:
   (a) List 3 reasons for the necessity to build big and long telescopes.
   (b) List 2 advantages of space telescopes over ground-based telescopes.
   (c) Two laser headlights separated by 2 meters are placed on a vehicle on the moon. The Earth-moon distance is 400,000 km. The headlights emit at the wavelength of 500 nm. Using the Keck telescope of 10 m diameter, can an observer on Earth distinguish these two laser lights?

Key:

(a) Telescopes with larger diameters will have greater light gathering power, which is proportional to the area of the lens or mirrors. Telescopes with large diameters will also have better diffraction limited angular resolution, which is inversely proportional to the diameter. So larger telescopes would allow us to better observe faint objects and see smaller details. Long telescopes will magnify the images since the magnification is proportional to the focal length of the primary mirror.

(b) Telescopes in space are not affected by the turbulence in Earth’s atmosphere, thus can achieve observations with the diffraction limited angular resolution. Space telescopes can also observe in infrared, ultraviolet, and X-ray wavelengths. Radiations at these wavelengths do not penetrate Earth’s atmosphere to be observed by ground-based telescopes.

(c) Viewed from Earth, the angular distance between the two headlights is derived using small angle formula:

\[ \alpha = 206265 \frac{D}{d} = 206265 \times \frac{2 \text{ m}}{3.8 \times 10^8 \text{ m}} = 0.001 \text{ arcsec} \]

For a telescope to distinguish the two headlights, the angular resolution of the telescope must be smaller than the angular distance between the two headlights, or \( \theta = 2.5 \times 10^5 \frac{\lambda}{D} \leq \alpha \), where \( D \) here is the diameter of the telescope.

\[ D \geq 2.5 \times 10^5 \frac{\lambda}{\alpha} = 2.5 \times 10^5 \times \frac{500 \text{ nm}}{0.001} = 2.5 \times 10^5 \times 5 \times 10^{-7} \text{ m} = 125 \text{ m} \]. Therefore, the Keck 10-m telescope cannot resolve this angular distance.