USAAAO 2022 - First Round

February 5^{th}, 2022

1. Classify the following galaxies according the Hubble galaxies classification:

Figure 1: Galaxy 1

Figure 2: Galaxy 2

Figure 3: Galaxy 3

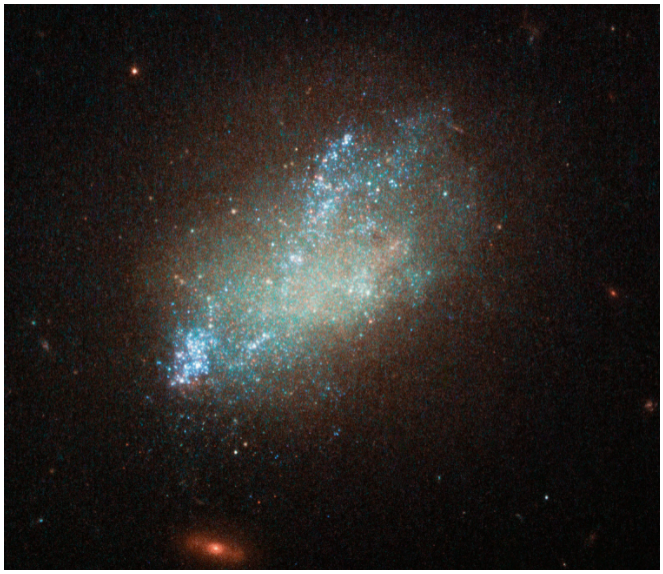


Figure 4: Galaxy 4

Figure 5: Galaxy 5

(a) Sb, Sc, Peculiar, E2, Irregular

(b) Sbc, E4, Irregular, Sb, Peculiar

(c) E3, Sbc, Sa, Peculiar, Irregular

(d) Sc,Sba, Sbc, E2, Peculiar

(e) Sa, Sbb, E3, Irregular, Peculiar

2. A comet's orbit has the following characteristics: eccentricity e = 0.995; aphelion distance $r_a = 5 \cdot 10^4 AU$. Assume we know the mass of the Sun $M_S = 1.98 \cdot 10^{30} kg$, and gravitational constant $G = 6.67 \cdot 10^{-11} Nm^2/kg^2$. Determine the velocity of the comet at its aphelion.

(a) 34.76 m/s

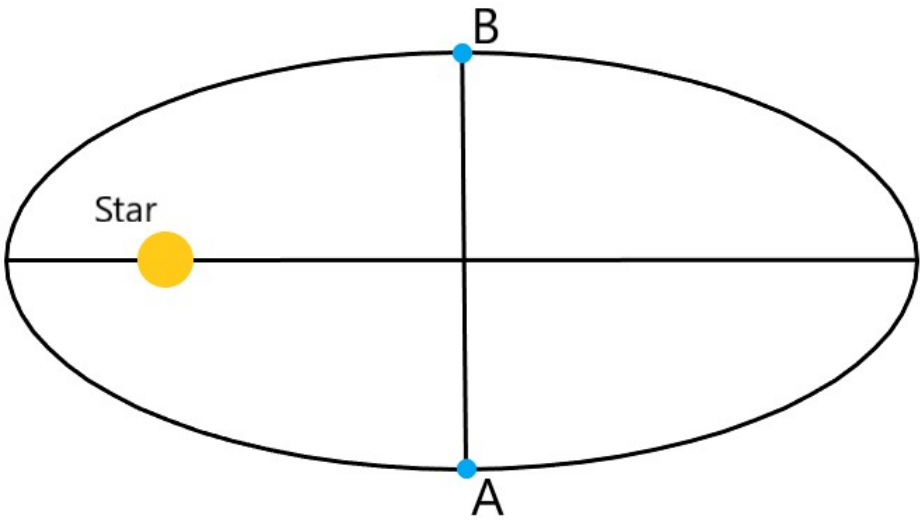
(b) 20.57 m/s

(c) 187.91 m/s

(d) 63.38 m/s

(e) 9.19 m/s

3. Consider the following elliptical orbit of a comet around a star:



Which of the following expressions corresponds to the time that the comet takes to go from point A to point B as a function of the period of the comet (T) and the eccentricity of the orbit (e)?

Assume that the direction of the orbit is **counterclockwise**.

(a) $\frac{T}{2}$
(b) $\left(\frac{e}{\pi} + \frac{1}{2}\right) * T$
(c) $\left(\frac{1}{2} - \frac{e}{\pi}\right) * T$
(d) $(1 + e) * \frac{T}{2}$
(e) $\frac{T * e}{2}$

4. What is the shortest distance (along the surface of the Earth) between two points on the Equator separated by 30° of longitude? What is the shortest distance (along the surface of the Earth) between them if both the two points lie on the 60° latitude while still separated by 30° of longitude? (For simplicity, assume that the Earth is a sphere)

   (a) 3336 km, 1668 km
   (b) 3336 km, 1654 km
   (c) 6672 km, 3336 km
   (d) 3298 km, 1649 km
   (e) 3298 km, 1668 km

5. Two (spherical) asteroids, Ek and Do, are orbiting in free space around their stationary center of mass. Ek has mass $7M_{☾}$ and Do has mass $1.4M_{☾}$, where $M_{☾}$ is the mass of moon. What is the ratio of the angular momentum of the whole system to the angular momentum of Do about the center of mass of the system?

   (a) 26
   (b) 6

(c) 1.2

(d) 1.04

(e) 0.1667

6. Consider a f/9 telescope with focal length $f = 1.0$ m that operates at visible wavelength $\lambda = 5000$ Å. What is the farthest distance at which an open cluster of radius $R_C = 4.1$ pc can be resolved by this telescope?

   (a) 1.2×10^6 pc

   (b) 1.5×10^6 pc

   (c) 3.0×10^6 pc

   (d) 4.2×10^6 pc

   (e) 5.8×10^6 pc

7. Imagine the you observe transits of earth across the sun from a far away exoplanet. Assuming earth's orbit has 0 eccentricity and it transits directly across the sun's diameter (the impact parameter is 0), what is the duration of earth's transit?

   (a) 3.24 hrs

   (b) 25.93 hrs

   (c) 6.48 hrs

   (d) 1.62 hrs

   (e) 12.97 hrs

8. An exoplanet was observed during its transit across the surface of a bright star. Estimate the variation of the apparent magnitude (Δm) of the star caused by exoplanet's transit. During the transit, assume an Earth-based astronomer observes that the area covered by the exoplanet on the projected surface of the star represents $\eta = 2\%$ of the star's projected surface.

   (a) -4.247

   (b) 0.003

   (c) 0.022

   (d) 0.679

   (e) -0.003

9. Estimate the mass of a globular cluster with a radial velocity dispersion $\sigma_r = 16.2$ km/s. The cluster has an angular diameter of $\theta = 3.56'$ and is a distance $d = 9630$ pc away from us.

   (a) 6.05×10^{35} kg

   (b) 9.71×10^{35} kg

   (c) 1.01×10^{36} kg

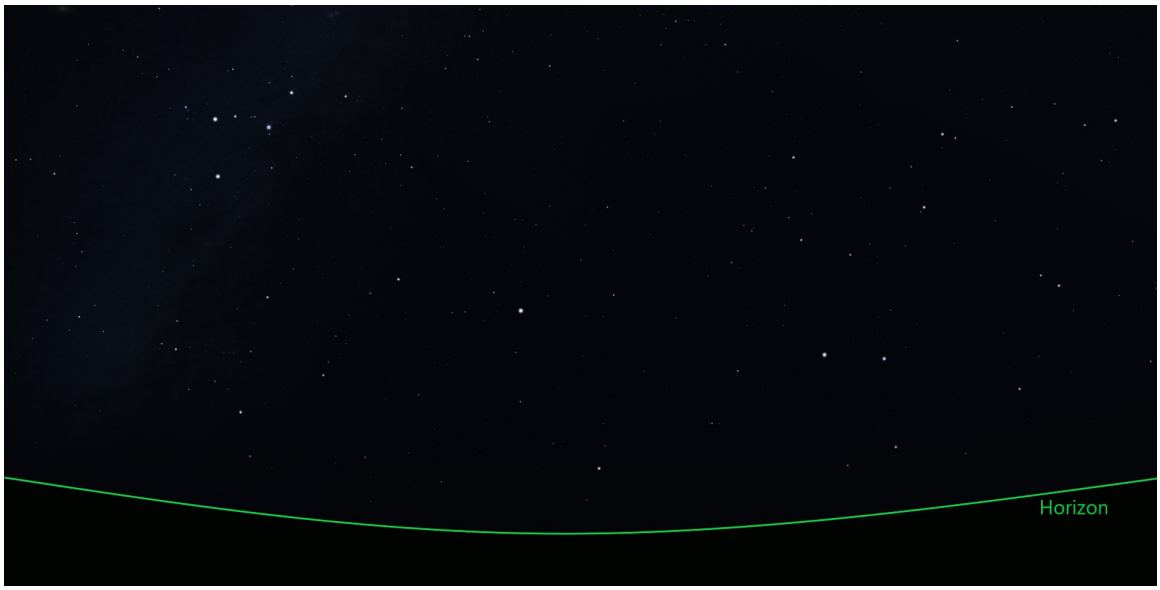
   (d) 3.03×10^{36} kg

   (e) 5.96×10^{36} kg

10. Jupiter's deep atmosphere is very warm due to convection leading to an adiabatic temperature profile that increases with increasing pressure. Assuming (for simplicity) that this outer layer of Jupiter has a temperature of 500 K, perform a back-of-the-envelope estimate of the characteristic thickness (or e-folding scale) of the envelope of Jupiter (you may find that this is independent of pressure level). You may further use that the specific gas constant in Jupiter's atmosphere is 3600 J kg^{-1} K^{-1}.

    (a) 20 km
    (b) 73 km
    (c) 568 km
    (d) 3,120 km
    (e) 10,233 km

11. An astronomer took the following picture while observing the night sky:



    What is the latitude of the place where the astronomer took the picture?

    (a) 70° S
    (b) 20° S
    (c) 2° N
    (d) 20° N
    (e) 70° N

12. Order the following phases of the Sun's evolution from first to last chronologically.

    1. Helium flash
    2. White dwarf
    3. Red giant branch
    4. Asymptotic giant branch

5. End of hydrogen fusion in the core

(a) 5, 4, 1, 3, 2
(b) 5, 3, 1, 4, 2
(c) 1, 5, 3, 4, 2
(d) 5, 2, 4, 1, 3
(e) 3, 5, 1, 4, 2

13. The orbit of some planet to its star has an eccentricity of 0.086. What is the ratio of the planet's closest distance to its star to the farthest on its orbit?

(a) 0.842
(b) 0.188
(c) 1.188
(d) 0.158
(e) None of the above

14. Figure 6 shows a 6-hr root-mean-square (rms) Combined Differential Photometric Precision (CDPP) curve for 150,000 stars observed by the *Kepler* space telescope. CDPP is a measure of the white noise contained in a light curve, so for a target with 6-hour CDPP of 100 parts per million (ppm), a 6-hour transit with depth 100 ppm would be considered a 1-σ detection.

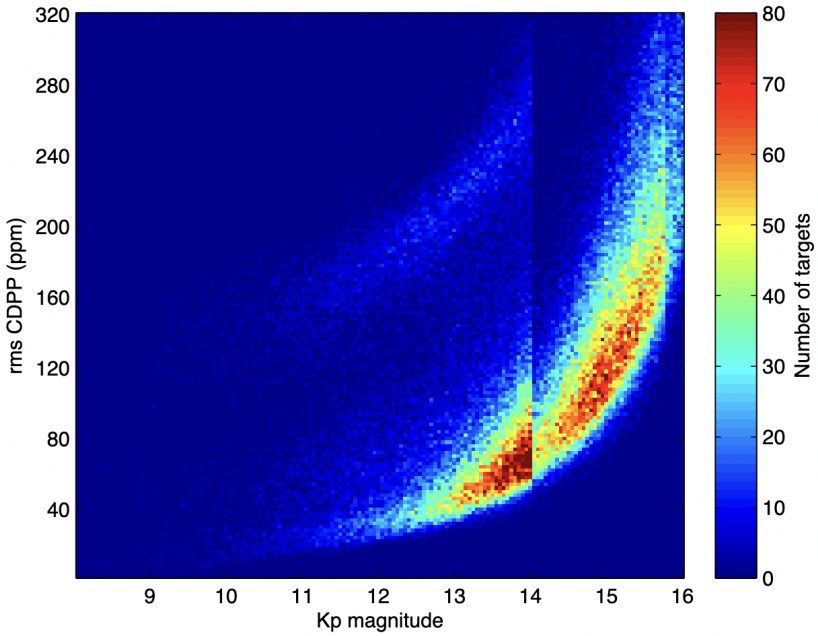


Figure 6: From Christiansen et al. (https://arxiv.org/abs/1208.0595). Original caption: The distribution of the 6-hour rms CDPP values with Kp magnitude for all Quarter 3 planetary targets.

Consider a $1R_\odot$ target with Kepler magnitude $K_p = 13.5$ that's among the best targets for its magnitude with respect to noise in Figure 6. Also consider three independent exoplanet scenarios for exoplanets with radii:

- I. 0.5 $R_\oplus$
- II. 1 $R_\oplus$
- III. 10 $R_\oplus$

Using a $1-\sigma$ detection threshold (and assuming 6-hour transit durations), which planet(s) transits would we likely **fail** to observe due to noise?

(a) I

(b) III

(c) I and II

(d) II and III

(e) I, II, and III

15. A star with mass M goes through an energy generating nuclear reaction $4\ {}^1H \rightarrow\ {}^4He + Energy$. Here, the burning efficiency of the p-p(proton-proton) chain is 0.007, meaning that each mass m yields $0.007mc^2$ of energy. Assuming that the has a total available hydrogen mass for nuclear reaction amounts to half of its original mass, and the luminosity(L) stays constant throughout the burning phase, get an expression of the hydrogen burning lifetime of the star.

(a) $1.625 \times 10^{18} s(\frac{M}{M_\odot})^{-2}$

(b) $3.15 \times 10^{14} s(\frac{M}{M_\odot})^{-2}$

(c) $1.625 \times 10^{18} s(\frac{M}{M_\odot})^{2}$

(d) $3.15 \times 10^{14} s(\frac{M}{M_\odot})^{2}$

(e) None of the above

16. In 2025, the Parker Solar Probe will pass just 6.9×10^6 km from the Sun, becoming the closest man-made object to the Sun in history. It will make five orbits, passing close to the Sun once every 89 days, before the planned end of the mission in 2026. How fast will the Parker Solar Probe be traveling at its closest approach to the Sun?

(a) 38 km/s

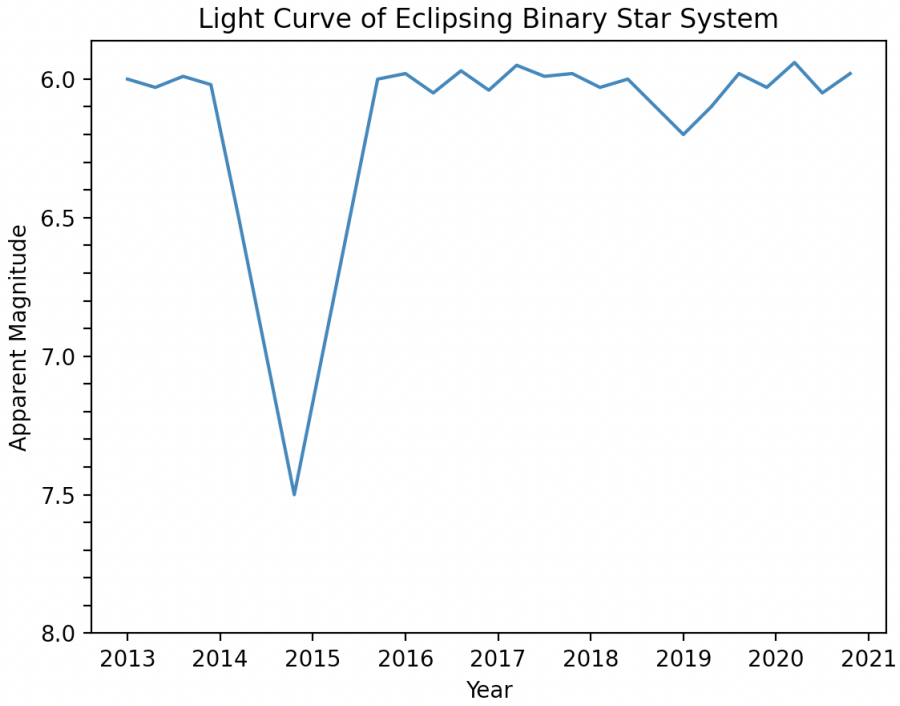
(b) 48 km/s

(c) 139 km/s

(d) 190 km/s

(e) 196 km/s

17. An astronomer observes an eclipsing binary star system from Earth, and he plots the following light curve.



Suppose that both stars have circular orbits and the distance between the stars is 14.8 AU. What is the total mass of the binary star system in terms of solar masses?

(a) $2.3M_\odot$
(b) $5.7M_\odot$
(c) $6.8M_\odot$
(d) $23M_\odot$
(e) $46M_\odot$

18. Assume that the smaller star in the above binary star system is brighter than the larger star. What is the ratio of the radius of the smaller star to the radius of the larger star?

(a) 0.21
(b) 0.76
(c) 0.82
(d) 0.95
(e) 0.98

19. The resolution of a space telescope is theoretically limited by diffraction from its primary mirror. In this problem, we will compare the diffraction limit of the Hubble Space Telescope (HST) (primary mirror diameter $d = 2.4\,\text{m}$) and the James Webb Space Telescope (JWST) ($d = 6.5\,\text{m}$). The operating wavelengths for the two telescopes are 500 nm and 10 µm respectively. Calculate the ratio of the diffraction limited angular resolution $\frac{\theta(\text{HST})}{\theta(\text{JWST})}$. Which telescope can resolve smaller angular features if limited only by diffraction?

(a) 0.014, JWST
(b) 0.14, HST
(c) 1.4, JWST
(d) 14, HST
(e) 140, JWST

20. The eccentricity of Pluto's orbit is 0.25. Estimate the maximum change in magnitude of Pluto as seen from Earth in one orbit of Pluto. You may assume that the semi-major axis of Pluto's orbit is much greater than 1 A.U.

(a) 0.2
(b) 1.2
(c) 2.2
(d) 3.2
(e) 4.2

21. A satellite is in a circular, equatorial orbit, and can fire its engines to accelerate in any of the following directions:

1. In the direction of motion
2. Against the direction of motion
3. Towards Earth, perpendicular to direction of motion (against radial vector)
4. Away from Earth, perpendicular to direction of motion (along radial vector)
5. Towards the North Celestial Pole (perpendicular to both direction of motion and radial vector)

Consider a small change of velocity in each of these directions. For how many of these maneuvers will the perigee of the orbit decrease?

(a) 1
(b) 2
(c) 3
(d) 4
(e) 5

22. For the five maneuvers described above, rank the resulting apogees from lowest to highest. Assume the change in velocity is small relative to orbital velocity, but not negligible.

(a) $2 < 3 = 4 = 5 < 1$
(b) $2 = 3 < 5 < 4 = 1$
(c) $2 < 3 = 4 < 5 < 1$
(d) $2 < 5 < 3 = 4 < 1$
(e) $2 < 3 < 5 < 4 < 1$

23. An exoplanet discovered by the radial velocity method is found to have an orbital period of 2.45 days around a Sun-like star. Assuming the planet has zero albedo (i.e., absorbs all incoming starlight) and perfectly transports heat across its surface, estimate the temperature at the photosphere of the planet.

(a) 395 K

(b) 954 K

(c) 1231 K

(d) 1476 K

(e) 2071 K

24. Deneb is a very important star in the Northern hemisphere as it is one of the three stars in the Summer Triangle. Deneb (α Cyg) is also the brightest star in the Cygnus constellation. Knowing the following information calculate the distance between Deneb and Albireo (β Cyg).

	Deneb	Albireo
Parallax (π)	2.29 mas	7.51 mas
Declination (δ)	45 ° 17'	27 ° 57'
Right ascension (α)	20h 41min	19h 31min

(a) 569 pc

(b) 102 pc

(c) 432 pc

(d) 317 pc

(e) 459 pc

25. Suppose you are in Houston ($29°46'N\ 95°23'W$) on the fall equinox and you just observed Deneb culminating (upper culmination). Knowing the data in the table of exercise 24, what is the hour angle of the Sun?

(a) 8h41min

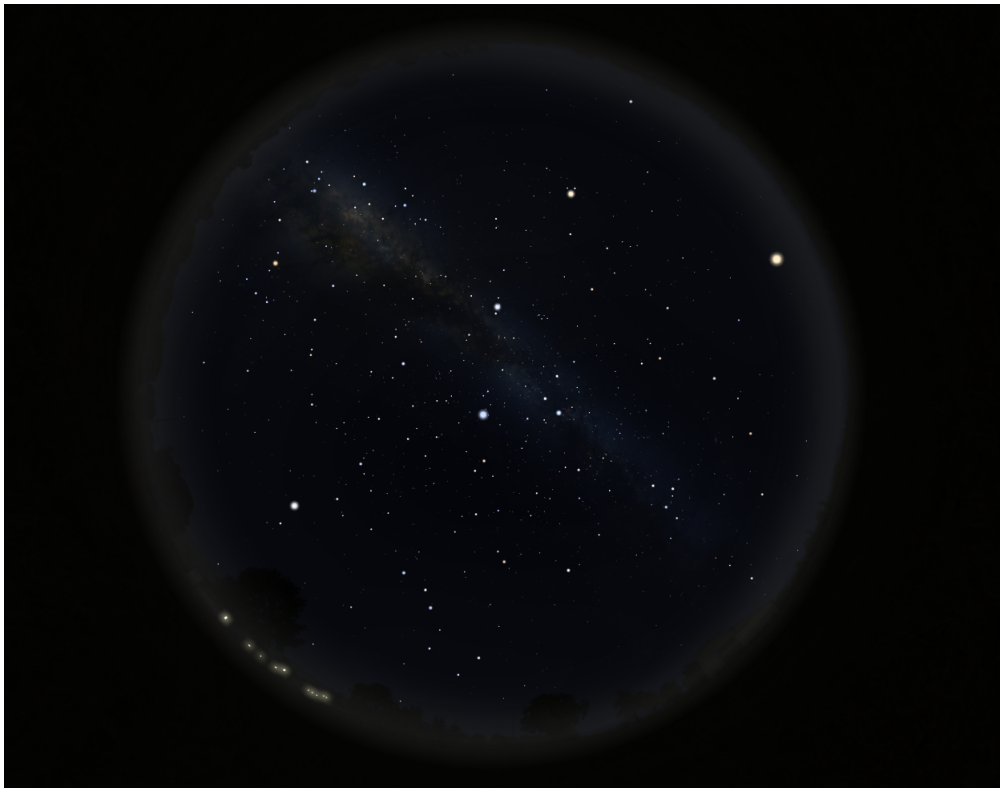
(b) 20h41min

(c) 12h00min

(d) 14h19min

(e) 18h22min

26. Knowing that the following image was taken at at 11:59pm, determine the name of which constellation was the sun passing in front of in that same day.



(a) Scorpius
(b) Virgo
(c) Big Dipper
(d) Cancer
(e) Taurus

27. An astronomer observes a galaxy in very foggy weather. So far, she has an image of signal-to-noise ratio of approximately 1, imaging for about 5 seconds. if she wants to reach a signal-to-noise ratio of 10. How long, in total, must she observe the galaxy for?

(a) 15 seconds
(b) 20 seconds
(c) 25 seconds
(d) 50 seconds
(e) 500 seconds

28. Dubhe (declination $\delta = 61.75^\circ$) is a star in the constellation of Ursa Major. Is it circumpolar from the city of San Francisco (latitude $\lambda = 37.7^\circ$ N)? How about from the city of Miami (latitude $\lambda = 25.8^\circ$ N)?

(a) Yes, Yes

(b) Yes, No

(c) No, Yes

(d) No, No

(e) Need more information

29. An astronomer takes a spectrum of a galaxy and observes that the hydrogen-alpha emission line is at a wavelength of 721.9 nanometers. In a laboratory on Earth, this same emission line is observed at a wavelength of 656.3 nanometers. Approximately what is the (proper) distance to this galaxy?

    (a) 66 Mpc

    (b) 430 Mpc

    (c) 480 Mpc

    (d) 3900 Mpc

    (e) 4700 Mpc

30. What is the time difference between the longest day of the year and the shortest day of the year in San Francisco (37.7° N, 122.4° W)?

    Neglect atmospheric refraction.

    (a) 2h30min

    (b) 3h32min

    (c) 4h08min

    (d) 5h12min

    (e) 6h25min