Science Olympiad
Crown Point Invitational
January 25, 2025

Astronomy C

Team Name and Number: _____

Participant Name(s): _____

Total Score: ____ / 68 **Rank:** ____

Directions:

- Do not begin writing or look beyond the cover sheet until the exam begins.
- Questions are valued as marked. There are 68 points total. The first 5 tie-breakers are marked in the exam. Subsequent tie-breakers are the rest of the questions in sequential order.
- Good luck! And may the stars align for you.

Useful Info:

$G = 6.673 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$	$1\,\mathrm{R_\odot} = 6.957 \times 10^{8}\,\mathrm{m}$	$1\,\mathrm{R_J} = 6.991 \times 10^{7}\,\mathrm{m}$
$c = 2.998 \times 10^{8}\,\mathrm{m\,s^{-1}}$	$1\,\mathrm{M_\odot} = 1.989 \times 10^{30}\,\mathrm{kg}$	$1\,\mathrm{M_J} = 1.519 \times 10^{27}\,\mathrm{kg}$
$M_{V,\odot} = +4.7$	$1\,\mathrm{T_\odot} = 5778\,\mathrm{K}$	$\lambda_{\mathrm{H}\alpha} = 656.28\,\mathrm{nm}$

Questions 1–16: Multiple Choice [1 pt each]

1. The Sun will likely end up as a _____.
   A. brown dwarf
   B. white dwarf
   C. neutron star
   D. black hole

2. A nebulosity created when jets from a young star collide with gas/dust along the star's rotational axis is a _____.
   A. Herbig Ae/Be star
   B. T Tauri variable
   C. Herbig-Haro object
   D. Bok globule

3. A variable pre-main-sequence star with the property $M \leqslant 2\,\mathrm{M}_\odot$ contracting along the Hayashi track is a _____.
   A. Herbig Ae/Be star
   B. T Tauri variable
   C. Herbig-Haro object
   D. Bok globule

4. A main sequence star produces energy via ___.
   A. gravitational contraction
   B. core hydrogen fusion
   C. shell hydrogen fusion
   D. core helium + shell hydrogen fusion

5. At what point will a star's deuterium most likely be used as a fusion source?
   A. During a supernova or nova event
   B. On the asymptotic giant branch
   C. On the main sequence
   D. During the protostar phase

6. A star on the horizontal giant branch produces energy via _____.
   A. gravitational contraction
   B. core hydrogen fusion
   C. shell hydrogen fusion
   D. core helium + shell hydrogen fusion

7. How does a white dwarf produce energy?
   A. Gravitational contraction
   B. Core carbon fusion
   C. Shell helium + shell hydrogen fusion
   D. White dwarfs do not produce energy

8. Horizontal branch stars have similar luminosities, but a range of temperature. What primarily determines the temperature?
   A. The initial mass of the main sequence star
   B. How much hydrogen is left surrounding the helium core
   C. How quickly the star ascended the red giant branch
   D. The amount of oxygen mixed in the helium core

9. Which spectral class has the lowest surface temperature?
    A. B
    B. A
    C. K
    D. M

10. Which spectral class has the strongest hydrogen spectral features?
    A. B
    B. A
    C. K
    D. M

11. What is the primary factor that determines the strength an exoplanet transit detection?
    A. The planet's mass
    B. The planet's distance from the star
    C. The planet's diameter
    D. The planet's composition

12. What is the primary factor that determines the strength of an exoplanet radial velocity detection?
    A. The planet's gravitational force on the star
    B. The planet's rotational speed
    C. The planet's ring system
    D. The planet's surface temperature

13. Which detection method is possible for an exoplanet system seen face-on (inclination angle of 0°)?
    A. Transit
    B. Radial velocity
    C. Direct imaging
    D. Microlensing

14. What event marks the end of a star's ascent up the red giant branch?
    A. Helium flash
    B. Nova
    C. Supernova
    D. Onset of carbon fusion

15. When does a star leave the horizontal giant branch?
    A. When shell hydrogen fusion is exhausted
    B. When core helium fusion is exhausted
    C. When the giant becomes convective
    D. When shell hydrogen fusion begins

16. What is a brown dwarf?
    A. A white dwarf that has cooled off enough that it doesn't give off much light anymore
    B. A main-sequence star with a surface temperature less than $T = 3500\,\mathrm{K}$
    C. A protostar that is cooling along the Hiyashi track
    D. A protostar that is not massive enough to begin core hydrogen fusion

Questions 17–20: Identify the detection method used for each of the following exoplanets: [1 pt each]

17. WASP-17b,
18. PSR B1257+12c,
19. Epsilon Eridani b,
20. LHS 3844b.

Questions 21–28: Match the following statements with the corresponding object in the list below. Each choice may be used once, more than once, or not at all. [1 pt each]

A. Orion Nebula	F. K2-18b
B. 30 Doradus	G. WD 1856+534
C. WASP-121b	H. Kepler-62
D. LTT 9779b	I. AU Microscopii
E. GJ 1214b	

21. This stellar remnant hosts one confirmed exoplanet, orbiting at a distance of just 0.02 au.
22. Image E is an artist's concept of this ultra-hot Jupiter which exhibits potential weather patterns on its surface.
23. A Neptune-like exoplanet discovered in 2020 by TESS.
24. This K-type main sequence star is the host of five confirmed exoplanets.
25. Gas heated to millions of degrees are highlighted in blue in the composite Image A depicting this star-forming region.
26. A planetary system with two planets in this star's habitable zone.
27. This exoplanet, thought to be a "water world" at its discovery, is located just 48 light-years from us.
28. Image D is a cropped view of this object, which exhibits a distinctive green tint produced by the forbidden transition of doubly ionized oxygen.

Questions 29–31: The planetary system about TOI-270 is extremely compact with TOI-270d orbiting only 0.07 au away.

29. [1 pt] What is the mass of TOI-270d in Earth masses?
30. [1 pt] (T5) Name the methodology used by Hubble and JWST to study its atmosphere.
31. [3 pts] List the three molecules whose signatures were detected by JWST.

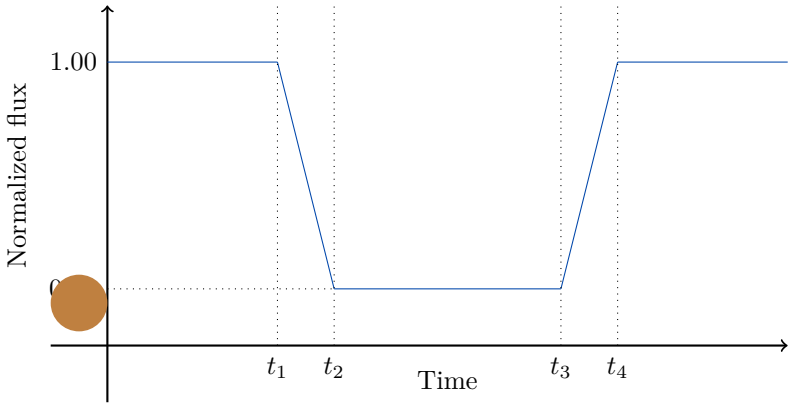
Questions 32–34: 55 Cancri A is the host star to a large planetary system only 41 ly from the Sun. 55 Cancri e is the innermost planet in this system and its atmosphere (or the potential absence of one) is of interest to scientists. Astronomers used JWST's powerful NIRCam and MIRI to capture a thermal emission spectrum of the planet's dayside, shown in Image C, using secondary eclipse spectroscopy.

32. [1 pt] How many confirmed planets are in this system?
33. [3 pts] (T2) Describe the process of secondary eclipse spectroscopy.
34. [1 pt] What atmospheric model most closely fits JWST's collected data?

Questions 35–38: HD 80606b orbits in a highly eccentric orbit ($e = 0.932$, $a = 0.460$ au, $P = 111$ d) about its host star. Image B shows where the planet is today (Jan 25, 2025).

35. [1 pt] What type of planet is HD 80606b?
36. [2 pts] (T3) Its extreme eccentricity is likely due to the gravitational influence of a second nearby star. Identify the name of this mechanism and the perturbing star.
    (Hint: The perturbing star is not HD 80606)
37. [3 pts] Today, you decide to use an ultra high precision spectrograph to collect a spectrum of HD 80606b. Based on the information in Image B, would you expect it to be redshifted or blueshifted? Explain why. Assume HD 80606 has zero radial velocity.
38. [3 pts] Today, HD 80606b is 0.815 au from its host star. How many times brighter will the host star be at periastron?

Questions 39–46: A planet is detected in circular orbit about a solar-twin (K2V) star. We observe a transit once every 32.7 d. Transits lasts about 7 hours with the precise timings given below. The star itself has an apparent visual magnitude $m = 12.2$. Assume the system is exactly edge-on (inclination angle of 90°) as viewed from Earth.



Contact	Time [hr]
t_1	0.00
t_2	1.17
t_3	5.80
t_4	6.97

39. [3 pts] How far is the planet from the star in astronomical units, au?

40. [3 pts] What is the radius of the planet in Jupiter radii, R_J?

41. [2 pts] Oh no! I spilled my coffee on the plot! What is the value of the normalized flux during transit?

42. [3 pts] (T1) If I asked you to consider that the planet itself has a blackbody temperature $T_p = 1500\,\mathrm{K}$, how much of a difference, as a percentage, would that make in your previous answer?

43. [2 pts] How far away is the star from Earth in parsecs, pc?

44. [2 pts] What is the maximum angular separation between the star and the planet as seen from Earth in arcseconds?

45. [3 pts] Careful spectroscopic measurement of the star reveals that the wavelength of the Hα line is seen to vary by as much as $10^{-4}\,\mathrm{nm}$ as the planet orbits. What is the mass of the planet in Jupiter masses, M_J?

46. [3 pts] (T4) Would you consider this to be a habitable planet? Why or why not?