Science Olympiad
MIT Invitational
January 25, 2025

Astronomy C Answer Key

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Section A [40 points]

1. D
2. D
3. B, C, or D
4. B
5. A
6. A
7. D
8. C
9. B
10. A
11. D
12. A
13. B
14. D
15. A
16. C
17. B
18. 5
19. 8×10^4
20. D

Section B [120 points]

Subsection B-I: The Tarantula Nebula [20 points]

21. [1 pt] X-ray
22. [3 pts] Thermal X-ray emission must come from extremely high temperatures. This can be seen from Planck's law or Wien's law. From Wien's law, for example, an object which radiates predominantly in the X-ray ($\sim 1\,\text{nm}$) has a temperature of $\sim 10^9\,\text{K}$.
23. [2 pts] Shocks from stellar winds of OB type stars
24. [1 pt] Acceptable answers: NGC 2070, R136, RMC136, R136a
25. [2 pts] Supernovae [1 pt], stellar winds of OB type stars [1 pt]
26. [1 pt] O-type [0.5 pts] and Wolf-Rayet stars [0.5 pts]
27. [1 pt] Post main-sequence (any post-main sequence evolutionary stage accepted)
28. [3 pts] The red and blue dots distinguish stars which are likely past the TAMS (terminal-age main sequence) from those on the main sequence. This question was thrown out.
29. [1 pt] Zero age main sequence
30. [2 pts] Terminal age main sequence
31. [3 pts] Significantly above. From Image 1, thermal x-ray must come from hot, massive stars (e.g. O-type main sequence or Wolf-Rayet) which only exist in young, actively star-forming regions. From Image 2, we can see that the population of R136 is very young, since only the most massive stars have left the main sequence.

Subsection B-II: The Orion Nebula [22 points]

32. [2 pts] Image 6, XMM-Newton and Spitzer
33. [2 pts] 1360 ly (Accept 1350–1370)
34. [1 pt] 1330 ly (Accept 1320–1340)
35. [3 pts] $i = 22.6°$ or $i = 157.4°$ (Accept 21.6–23.6 or 156.4–158.4)
36. [3 pts] 3300 $M_\odot$ (Accept 3200–3400). Not easily because inclination is close to normal
37. [2 pts] $T = 10^7$ yr (Exact order of magnitude)
38. [3 pts] No, there is in general a significant amount of interaction with the interstellar environment as this is an active star-forming region. The approximation of simple orbital dynamics may be valid at the outer edges where interactions may be less important.
39. [3 pts] The likely explanation is that the primary dwarf (larger mass) has a strong magnetic field that prevents convection; measurement of a large rotation rate or effects of strong magnetic field on spectral lines could help confirm this.
40. [1 pt] Near-IR (Half credit for IR)
41. [1 pt] Iron clouds
42. [1 pt] Molecular hydrogen

Subsection B-III: WASP-17b [19 points]

43. [1 pt] Transit method

44. [1 pt] Retrograde

45. [2 pts] 6% (Accept 5.5–6.5 %)

46. [2 pts] Blueshifted

47. [3 pts] It is blueshifted, then redshifted. At the beginning of the transit, the part of the star that is rotating away is blocked due to WASP-17b's retrograde motion. Towards the end of the transit, WASP-17b blocks the part of the star that is rotating towards us, so that the light that reaches us is only the redshift component.

48. [1 pt] Mid-IR (Half credit for IR)

49. [3 pts] Usually (magnesium) silicates would be found in exoplanet atmospheres. Pure quartz has narrower absorption than silicates due to the more complicated molecular structure of the latter.

50. [2 pts] Molecular vibration

51. [4 pts] The lower wavelength resonance is due to CO_2 while the longer wavelength one is due to H_2O. CO_2 could have a sharper resonance for many reasons:

    (1) its nonpolar nature means it doesn't interact with other polar molecules,
    (2) it has a larger moment of inertia, so the rotational energy levels are sparser,
    (3) it is less likely to undergo collisional broadening due to weaker intermolecular forces and lower abundance,
    (4) it has weaker rotational-vibrational coupling.

Subsection B-IV: K2-18b [21 points]

52. [2 pts] Yes. Methane (CH4) and Dimethyl Sulfide (DMS)

53. [1 pt] 2016-08-26

54. [1 pt] 32.9 days (Accept 31–35)

55. [2 pts] Accept 57 500–72 900 mJy

56. [2 pts] 21.8″ (Accept 18–27)

57. [2 pts] Acceptable features: object is too far, gets subtracted out in the transit image, high relative brightness compared to star

58. [3 pts] −190.35. If the images are not perfectly aligned, a bright spot in the image would be shifted over and subtracted from a dimmer spot, leaving a large, negative value.

59. [2 pts] Accept 188–260 mJy

60. [2 pts] Accept 2.5×10^{-3} to 4.5×10^{-3}

61. (a) [1.5 pts] Radius estimate: Accept 16 000–22 000 km
    (b) [1.5 pts] Actual Radius: Accept 15 115–16 646 km
    (c) [1 pt] Percent error: Expect values ~20 %. Could range from 0 % to 46 %

Subsection B-V: LTT 9779b [9 points]

62. [1 pt] Cloud formation/condensation or ice formation/freezing. Do not accept evaporation.

63. [2 pts] $T = b/\lambda$. $T =$ 2500 K (Accept 2400–2600)

64. [2 pts] No, the temperature is well above 100 °C (and 0 °C).

65. [2 pts] High metallicity leads to condensation of silicate and titanium clouds. Half credit for mentioning thick clouds.

66. [2 pts] Possible theories: high albedo and prevalence heavy metals lead to less atmospheric escape, X-ray faint host star, late inward migration followed by Roche-lobe overflow

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Subsection B-VI: PSR B1257+12 [8 points]

67. [2 pts] $c = \lambda f$. $\lambda =$ 0.697 m (Exact)

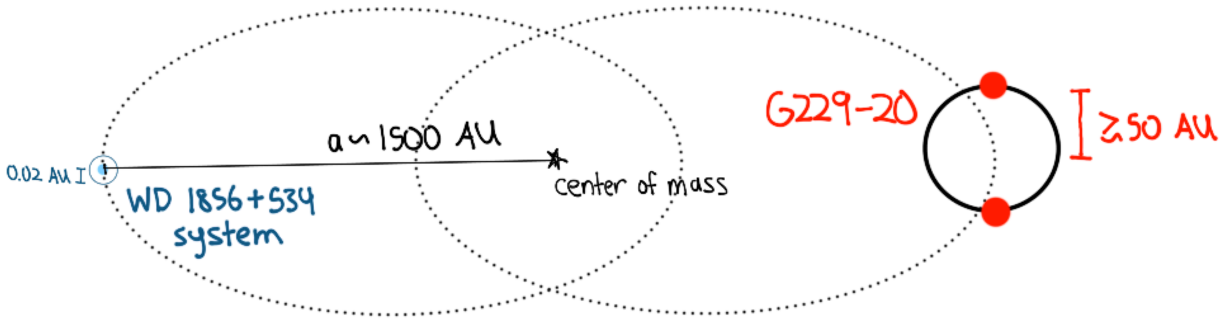
68. [2 pts] Constant time between pulses. Accept any answer mentioning a constant rate/frequency.

69. [2 pts] The planets are much lower mass than the pulsar, so it is reasonable to assume they do not have a significant influence each other's orbits.

70. [2 pts] A 3:2 mean motion resonance perturbs the orbits of planets B (c) and C (d).

Subsection B-VII: WD 1856+534 [21 points]

71. [2 pts] [0.5 pts for each: two ellipses, center of mass, G229-20 system, WD1856+534 system.] Distance labels not necessary.



72. [1 pt] White dwarf [0.5 pts], hydrogen lines present [0.5 pts]

73. [2 pts] It is difficult to measure the mass of the planet directly from the **radial velocity method** [1 pt], as we cannot observe the shifting of the spectral lines [1 pt].

74. [2 pts] $30\,\mu\text{Jy} / (2^2) = 7.5\,\mu\text{Jy}$. (Half credit given for showing the correct reading of $30\,\mu\text{Jy}$.)

75. [3 pts] The optical and infrared transit depths are the same, which means there is no detectable infrared emission from the transiting object. This is because black body radiation demands that a cool object such as a planet or brown dwarf emits more in the infrared than visible. Using the model, one can then set a bound on the mass of the object and show that it is a planet ($<13\,M_J$ for deuterium burning).

76. [2 pts] Common envelope evolution occurs when the **envelope of the primary extends past its Roche lobe, causing mass transfer and runaway shrinking of the orbit** until the secondary (planet) is engulfed inside the star. The orbit is then tightened further via drag forces inside the star.

77. [2 pts] Examples of accepted answers: AM CVns, X-ray binaries, binary black hole mergers/compact binary coalescences. (Many types of interacting compact systems are thought to involve common envelope evolution.)

78. [2 pts] The orbital/gravitational potential energy of the secondary

79. [3 pts] Orbital energy is proportional to the mass, and WD 1856+534b's relatively wider orbit means it did not lose as much orbital energy to eject the envelope and stop common envelope evolution.

80. [2 pts] The Lidov-Kozai mechanism occurs when a binary orbit is perturbed by a third object (here, the red dwarf binary G229-20) on an outer orbit.