USAAAO **Name:** _____
National Astronomy Olympiad
First Round
01/26/2019-02/01/2019
Time Limit: 75 Minutes Proctor: _____

This exam contains 8 pages and 30 questions. Each question is worth 1 point, so there are 30 points total. Students MUST take the exam between 01/26/2019-02/01/2019. Proctors must scan students' responses by 11:59 pm PST on 02/01/2019.

PHYSICAL AND ASTRONOMICAL CONSTANTS

c	Speed of light in vacuo	2.998×10^8m s^{-1}
e	Elementary charge	1.602×10^{-19} C
m_n	Neutron rest mass	1.675×10^{-27} kg
m_p	Proton rest mass	1.673×10^{-27} kg
m_e	Electron rest mass	9.110×10^{-31} kg
h	Planck's constant	6.626×10^{-34} J s
$\hbar$	Dirac's constant $(= h/2\pi)$	1.055×10^{-34} J s
k	Boltzmann's constant	1.381×10^{-23} J K^{-1}
G	Gravitational constant	6.673×10^{-11} N m^2 kg^{-2}
σ	Stefan-Boltzmann constant	5.670×10^{-8} J m^{-2} K^{-4} s^{-1}
c_1	First Radiation Constant $(= 2\pi hc^2)$	3.742×10^{-16} J m^2 s^{-1}
c_2	Second Radiation Constant $(= hc/k)$	1.439×10^{-2} m K
ε_o	Permittivity of free space	8.854×10^{-12} C^2 N^{-1} m^{-2}
μ_o	Permeability of free scpae	$4\pi \times 10^{-7}$ H m^{-1}
N_A	Avogadro constant	6.022×10^{23} mol^{-1}
R	Gas constant	8.314 J K^{-1} mol^{-1}
a_0	Bohr radius	5.292×10^{-11} m
μ_B	Bohr magneton	9.274×10^{-24} J T^{-1}
α	Fine structure constant $(= 1/137.0)$	7.297×10^{-3}
$M_\odot$	Solar mass	1.989×10^{30} kg
$R_\odot$	Solar radius	6.96×10^8 m
$L_\odot$	Solar luminosity	3.827×10^{26} J s^{-1}
$T_\odot$	Solar temperature	5770 K
$M_\oplus$	Earth mass	5.976×10^{24} kg
$R_\oplus$	Mean Earth radius	6.371×10^6 m
R	Mean Mars radius	3.390×10^6 m
1 light year		9.461×10^{15} m
1 AU	Astronomical Unit	1.496×10^{11} m
1 pc	Parsec	3.086×10^{16} m
1 year		3.156×10^7 s
1 erg		1×10^{-7} J

ENERGY CONVERSION : 1 joule (J) = 6.2415×10^{18} electronvolts (eV)

1. (1 point) Which of the following relates the intrinsic luminosity of a spiral galaxy with its asymptotic rotation velocity?
   A. The Fundamental Plane
   B. The Tully-Fisher Relation
   C. The Press-Schechter Formalism
   D. The Faber-Jackson Relation

2. (1 point) Which of the following correctly gives the location of Population I vs. Population II stars in the Milky Way?
   A. Population I - Thin Disk, Spiral Arms; Population II - Halo, Bulge
   B. Population I - Thin Disk, Bulge; Population II - Spiral Arms, Halo
   C. Population I - Halo, Bulge; Population II - Thin Disk, Spiral Arms
   D. Population I - Halo, Thin Disk; Population II - Bulge, Spiral Arms

3. (1 point) A quasar with a bolometric flux of approximately 10^{-12} erg s^{-1} cm^{-2} is observed at a redshift of 1.5, i.e. its comoving radial distance is about 4.4 Gpc. What is the bolometric luminosity of the quasar?
   A. $6.0 \cdot 10^{11}$ $L_\odot$
   B. $3.8 \cdot 10^{12}$ $L_\odot$
   C. $2.4 \cdot 10^{13}$ $L_\odot$
   D. $6.3 \cdot 10^{14}$ $L_\odot$

4. (1 point) Now, let's assume that the quasar in the previous question is observed to have a companion galaxy which is 5 arcseconds apart. What is the projected linear separation of the companion galaxy from the quasar?
   A. 107 kpc
   B. 29 kpc
   C. 74 kpc
   D. 43 kpc

5. (1 point) An observer is standing atop the Burj Khalifa, the tallest building on earth (height = 830m, latitude = 25.2N, longitude = 55.3E). Which of the following options is the closest to the shortest and longest shadow on the ground at the local noon time due to the building in a given year?
   A. 10m, 1050m
   B. 25m, 950m
   C. 35m, 850m
   D. 45m, 750m

6. (1 point) Which of the following is closest to the ratio of the farthest distance to the horizon that can be seen by an observer standing top of the Mount Everest on Earth (height = 8.8 km) and Olympus Mons on Mars (height = 25 km)?
   A. 0.1
   B. 1
   C. 5
   D. 10

7. (1 point) An observer measures the black-body spectrum for a variety of bodies as a function of temperature and wavelength in the long wavelength limit ($\frac{hc}{\lambda} \ll k_B T$) and finds that his data approximately fits the relationship $\log(I) = a + b\log(T) + c\log(\lambda)$). Here, I is the spectral intensity in terms of wavelength, T is the temperature of the body and λ is the wavelength. Which of the following are the expected values of b and c?

   A. 1,-4

   B. 1,4

   C. 4,1

   D. -4,1

8. (1 point) Suppose a spacecraft were orbiting in a low Earth orbit at an altitude of 400 km. The spacecraft makes a single orbital maneuver to place it into a Mars transfer orbit. Delta-v (Δv) refers to the change in velocity during an orbital maneuver. What is the Δv required for this trans-Mars injection? The semimajor axes of the orbits of Earth and Mars are 1.496×10^8 km and 2.279×10^8 km, respectively.

   A. 2.94 km/s

   B. 3.57 km/s

   C. 6.12 km/s

   D. 10.85 km/s

   E. 11.24 km/s

9. (1 point) After entering Mars orbit, the spacecraft finds that over the course of the martian year, the position of Star A varies by 613.7 milliarcseconds (mas) due to the movement of the spacecraft around the sun. Determine the distance to Star A.

   A. 1.629 pc

   B. 2.482 pc

   C. 3.259 pc

   D. 4.965 pc

   E. 6.518 pc

10. (1 point) Star A, of mass 3.5 $M_\odot$, shows radial velocity variations 24.2 m/s in amplitude and 23.22 years in period, suggesting the presence of an orbiting exoplanet. Which of the following is closest to the mass of the exoplanet in terms of Jupiter's masses (M_J)? Assume the exoplanet's orbit is circular and has inclination 90°. The mass of Jupiter is 1.898×10^{27} kg. Assume the mass of the planet is much smaller than that of Star A.

    A. 0.7 M_J

    B. 2.1 M_J

    C. 5.6 M_J

    D. 9.9 M_J

    E. 13.2 M_J

11. (1 point) Whether or not a diffraction-limited optical system is able to resolve two points as distinct can be determined by the Rayleigh criterion. β Pictoris b is one of the first exoplanets discovered using direct imaging. The star system is located 19.44 pc away, and β Pictoris b

is located 9.2 AU from the host star. When viewing in infrared ($\lambda = 1650$ nm), what is the minimum telescope diameter that is able to resolve β Pictoris and its exoplanet under the Rayleigh criterion?

A. 0.719 m

B. 0.877 m

C. 1.142 m

D. 1.438 m

E. 1.755 m

12. (1 point) The celestial coordinates of the Orion Nebula are RA $05^{\mathrm{h}}35^{\mathrm{m}}$, dec $-05°23'$. Which of the following is closest to the time (local solar time) when the Orion Nebula would cross the meridian on the night of February 1st 2019? The date of the vernal equinox of 2019 is March 20th.

A. 08:40 PM

B. 10:22 PM

C. 12:00 AM

D. 01:38 AM

E. 03:20 AM

13. (1 point) A yellow hypergiant located 1.04 kpc away has an apparent visual magnitude of 1.49 and a $B-V$ color excess of 0.29. Assuming R_V, the ratio of V-band extinction to $B-V$ color excess, is 3.1, determine the absolute visual magnitude of the star.

A. -9.5

B. -8.9

C. -8.6

D. -8.3

E. -7.7

14. (1 point) The pp chain is a primary energy generation mechanism in the Sun. Each run of the process $2H + e \rightarrow D + \nu$ releases 26.73 MeV of energy. Calculate the neutrino flux on the surface of Mars (in neutrinos per m^2), assuming that the pp chain is responsible for 100% of the Sun's energy generation. (Mars is at a distance of 1.52 AU)

A. 2.54×10^{13}

B. 3.17×10^{16}

C. 1.37×10^{14}

D. 5.94×10^{12}

E. 4.45×10^{15}

15. (1 point) A relation between which of the following pairs of properties of Cepheids variables makes Cepheids variables, specifically, useful objects for determining stellar distances?

A. Mass and Temperature

B. Period and Luminosity

C. Temperature and Period

D. Mass and Luminosity

E. Period and Radius

16. (1 point) Assuming that the Chandrasekhar Limit is 1.4 Solar masses, estimate the maximum average density (in kg/m^3) of a Chandrashekhar mass black hole.

A. 1.5×10^{22}

B. 4.7×10^{14}

C. 8.2×10^{10}

D. 9.4×10^{18}

E. 7.1×10^{26}

17. (1 point) The Sun's differential rotation can be estimated with the equation $\omega = X + Y sin^2(\phi) + Z sin^4(\phi)$, where ω is the angular velocity in degrees per day, ϕ is solar latitude, and X, Y, and Z are constants (equal to 15, -2.5, and -2 degrees per day respectively). Two sunspots are spotted along the same solar meridian, one at 0° and the other at 40°. Assuming that the sunspots do not disappear or change latitude and move with the same velocity as the surface of the sun, after how many days will the sunspots be aligned once again? Round your answer to the nearest day.

A. 142

B. 202

C. 262

D. 312

E. 372

18. (1 point) An observer generates a light curve of a binary system, and notices two different minima that repeat periodically (in an alternating fashion). The time between when the light curve reaches the first minima and the second minima is 285.7 days. In solar masses, estimate the total mass of the binary system if the two stellar bodies are separated by a mean distance of 4.1 AU.

A. 0.0002

B. 0.0008

C. 28

D. 56

E. 112

19. (1 point) Eltanin, the brightest star in Draco, has the approximate coordinates RA: 17h 56m, Dec: +51.5°. Given that at the observer's location, the latitude is +50° and the local sidereal time is 14:00, how far above the horizon will Eltanin appear? Round your answer to the nearest degree.

A. 26

B. 54

C. 59

D. 89

E. The star is below the horizon

20. (1 point) Stellar bodies located in the top left of a Hertzsprung-Russell diagram necessarily have which properties?

A. Low absolute magnitude, Low effective temperature

B. Low absolute magnitude, High effective temperature

C. High absolute magnitude, High effective temperature

D. High absolute magnitude, Low effective temperature

E. Intermediate absolute magnitude, Intermediate effective temperature

21. (1 point) Which of the following correctly orders the following distance indicators from the smallest to largest scale?

A. Stellar parallax, spectroscopic parallax, RR Lyrae variables, Hubble constant

B. Spectroscopic parallax, stellar parallax, RR Lyrae variables, Hubble constant

C. Stellar parallax, RR Lyrae variables, spectroscopic parallax, Hubble constant

D. Stellar parallax, spectroscopic parallax, Hubble constant, RR Lyrae variables

E. Spectroscopic parallax, stellar parallax, Hubble constant, RR Lyrae variables

22. (1 point) As seen from Mars, what phase will Earth appear to be in when Mars is at quadrature from Earth?

A. New

B. Crescent

C. Quarter

D. Gibbous

E. Full

23. (1 point) Which of the following stars is almost always never visible to observers in the Northern hemisphere?

A. Alpha Aurigae

B. Gamma Cygni

C. Alpha Lyrae

D. Sigma Octantis

E. Beta Orionis

24. (1 point) Two amateur astronomers A and B living in Ecuador are standing on the Equator at the Galapagos Islands (height 0 m, longitude 91° W) and Volcan Cayambe (height 5790 m, longitude 78° W) respectively. What are the differences (in degrees) of the altitudes from the horizon and zenith distances of the Sun measured by these two astronomers on March 20, 2019 when it is local noon for observer B? Neglect refraction and give your answer to the nearest degree.

A. Difference in altitudes: 15, Difference in zenith distances: 13.

B. Difference in altitudes: 13, Difference in zenith distances: 13.

C. Difference in altitudes: 13, Difference in zenith distances: 15.

D. Difference in altitudes: 11, Difference in zenith distances: 13.

25. (1 point) The spectra of two stars A and B peak at wavelengths 500 nm and 250 nm respectively. What is the ratio of their luminosities if they form black holes with Schwarzschild radii in the ratio 8:1? Assume that their densities were uniform and identical before they collapsed to form a black holes and that they did not lose any mass while forming the black holes.

A. 2:1

B. 4:1

C. 1:4

D. 1:2

26. (1 point) Two stationary observers at a distance 100 AU from the sun observe transits of Mercury across the diameter of the Sun's disk when Mercury is at perihelion and aphelion respectively. Which of the following is closest to the ratio of the aphelion transit time to the perihelion transit time? You are given that the semi-major axis and eccentricity of Mercury's orbit are 0.387 AU and 0.21 respectively.

A. 1:1

B. 2:1

C. 4:1

D. 8:1

27. (1 point) Find the total sum of the binary system of the star Capella, if semi-major axis between them is 0.85 AU, and period of 0.285 years.

A. 5.5 solar masses

B. 6.5 solar masses

C. 7.6 solar masses

D. 8.5 solar masses

E. 9.5 solar masses

28. (1 point) The New Horizons spacecraft completed a flyby of 2014 MU69 on New Year's day of this year. 2014 MU69 is a Kuiper Belt Object with a semi-major axis of 44.58 AU. Estimate the maximum temperature at the surface of 2014 MU69, in Kelvin, assuming the object has zero albedo.

A. 41.7 Kelvin

B. 58.9 Kelvin

C. 83.3 Kelvin

D. 117.9 Kelvin

29. (1 point) HD 209458b is an extrasolar gas giant planet with a radius of 1.38 Jupiter radii and a mass of 0.69 Jupiter masses (1 Jupiter radius = $6.99 \cdot 10^7$ m, 1 Jupiter mass = $1.90 \cdot 10^{27}$ kg). Which of the following is closest to the pressure at the very center of HD 209458b, in bars?

A. 10^9 bars

B. 10^6 bars

C. 10^5 bars

D. 10^3 bars

30. (1 point) Imagine that our Sun was suddenly replaced by an M-dwarf with a mass half that of the Sun. If our Earth kept the same semi-major axis during this change, what would Earth's new orbital period be around the M-dwarf?

A. 0.707 years

B. 1 year

C. 1.414 years

D. 2 years