USAAAO
National Astronomy Olympiad
First Round
02/10/2020-02/16/2020
Time Limit: 75 Minutes

Name: ____________________

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 02/10/2020-02/16/2020. Proctors must scan students' responses by 11:59 pm PST on 02/16/2020.

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
H_0	Hubble's constant	70 (km/s)/Mpc
k	Boltzmann's constant	1.381×10^{-23} J K^{-1}
b	Wien's constant	2.898×10^{-3} m K
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
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}
$M_\odot$	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
$I_\oplus$	Earth moment of Inertia	8.04×10^{37} kg m^2
R☾	Mean Moon radius	1.737×10^6 m
M♃	Mean Jupiter mass	1.9×10^{27} kg
R♃	Mean Jupiter radius	7.1492×10^7 m
a♃	Mean orbital radius of Jupiter	5.2 AU
a☾	Mean semimajor axis Moon orbit	3.84399×10^8 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) The spectrum of a blackbody peaks at a wavelength inversely proportional to its temperature. This is known as Wein's law and is used to estimate stellar temperatures. The sun can be approximated as a blackbody with its peak wavelength in the visible portion of the spectrum and a surface temperature of 6000K. Given this data, estimate the peak wavelength of a human being, assuming it to be a black body.

   A. 10 nm
   B. 10 μm
   C. 10 mm
   D. 10 m

Doppler Spectroscopy is a technique used to detect exoplanets. The presence of a large planet causes the star to have a finite velocity around the common center of mass which leads to periodic Doppler shifts in star's spectral lines. The next two questions will pertain to this:

2. (1 point) Calculate the speed of the sun around the center of mass due to the presence of Jupiter.

   A. 6 m/s
   B. 12 m/s
   C. 600 m/s
   D. 1200 m/s

3. (1 point) H_α is a prominent absorption line in the sun's spectrum with $\lambda = 656.281$. For an observer on α-Centauri, assuming the Jupiter-Sun orbital plane is in the line of sight, calculate the magnitude of the periodic shift in wavelength (nm) for the H_α line.

   A. 2.7×10^{-5} nm
   B. 2.7×10^{-4} nm
   C. 2.7×10^{-3} nm
   D. 2.7×10^{-2} nm

4. (1 point) Why does helium burn much faster than hydrogen in a star?

   A. The star enters a different stellar evolution phase before the helium is all used up
   B. The temperature of the star is higher during the phase of helium burning
   C. The fraction of helium is much less than the fraction of hydrogen during early evolutionary phases of a star
   D. The energy released for each helium burning reaction is much smaller than for hydrogen
   E. None of the above

5. (1 point) The Earth's rotation axis happens to be pointing almost exactly at Polaris now, but Polaris will not always be the North Star. The direction of the rotation axis precesses with a period of 26000 years. Sometime in the future, star A, which has an angular separation of $26°11'$ from Polaris, will be the North Star. How many years from now star A will be the North star?

   A. 1500 years

B. 13000 years
C. 2000 years
D. 5000 years
E. 26000 years

6. (1 point) A 13 kg telescope is mounted on a tripod such that the angle between tripod legs is $30°$. How much is the force exerted on each leg? Gravitational acceleration (g) is 9.8 m/s^2.
   A. 42.5
   B. 44.5
   C. 49
   D. 24.5
   E. 40.5

7. (1 point) Capella, the brightest star in Auriga, has celestial coordinates $05^h18^m12.78^s$, $+46°00'59.8''$. At midnight, local solar time, of the vernal equinox, which of the following is closest to the altitude of Capella above/below the horizon, as viewed from Boston? The coordinates of Boston are 42.3601° N, 71.0589° W.
   A. $-64°$
   B. $-32°$
   C. $0°$
   D. $+23°$
   E. $+67°$

8. (1 point) Kerbyn is a small rocky planet in a circular orbit around a $0.2M$ star with a semimajor axis of $0.1AU$. Kerbyn has an axial tilt of $\epsilon = 42°$ and a sidereal rotation period of $05^h59^m9.4^s$. On the vernal equinox, what is the length of the apparent solar day on Kerbyn? The apparent solar day is defined as the interval between successive crossings of the meridian by the sun.
   A. $05^h55^m39.3^s$
   B. $05^h57^m15.2^s$
   C. $06^h00^m00.0^s$
   D. $06^h01^m45.1^s$
   E. $06^h02^m39.5^s$

9. (1 point) Which of the following is responsible for the opacity of the Sun's photosphere?
   A. He^{2+}
   B. Fe-56
   C. ν
   D. H^-
   E. e^-

10. (1 point) Planet Nine is a hypothetical planet in the outer Solar System, with a semi-major axis between 400 and 800 AU. Which of the following is a possible orbital period for Planet Nine?

A. 71.1 years
B. 600 years
C. 1,500 years
D. 15,000 years
E. 360,000 years

11. (1 point) The main reason why Io is volcanically active is due to:
A. Its own magnetic field
B. Tidal forces from Jupiter
C. Internal heat
D. Jupiter Torus
E. Eccentricity of its orbit

12. (1 point) Knowing that the distance between the Sun and Uranus is 2.87×10^9 km and Uranus' revolution period is 17h 14 min, determine the approximate amount of time that the Sun is above the horizon for an observer on the Uranus in the following situations:

I. At the South pole
II. At latitude 30°5'N when the declination of the Sun is 10°N

A. I = 84 years and II = 17h 14 min
B. I = 21 years and II = 12h 47 min
C. I = 42 years and II = 9h 28 min
D. I = 21 years and II = 8h 37 min
E. I = 42 years and II = 14h 53 min

13. (1 point) The angular diameter of star A with apparent bolometric magnitude of 2 is 2.5 times greater than the angular diameter of Star B with apparent bolometric magnitude of 7. What is the ratio of the temperature of star A to that of star B?
A. 2.5
B. 4
C. 2
D. 5
E. 3.5

14. (1 point) As a consequence of the virial theorem, how does the stellar temperature (T) change if we add more arbitrary energy (E) to the star?
A. Increases
B. Decreases
C. Stays the same

15. (1 point) How do we increase the reaction time for hydrogen fusion at the stellar core leaving other factors unchanged?
A. Increase the mass of the star, not by adding hydrogen atoms

B. Increase the temperature of the stellar core

C. Increase the amount of hydrogen atoms

D. None of the above

From a binary system with a neutron star (N) and a "normal" star A, two different data graphs are obtained. Graph 1 shows the time delay (τ) versus time (t) from the neutron star pulsar, and Graph 2 shows the Doppler velocity versus some time (t').

16. (1 point) Calculate the orbital velocity(v_A) of the star A with respect to its center of mass.

    A. τ_1

    B. τ_2

    C. $\frac{\tau_2 - \tau_1}{2}$

    D. $\frac{2\tau_1 - \tau_2}{3}$

    E. $\frac{2\pi\tau_1 - \tau_2}{3}$

17. (1 point) Calculate the ratio between the two masses, the mass of the neutron star to that of star A $\left(\frac{M_N}{M_A}\right)$, where the speed of the light is c and the speed of the neutron star is v_O.

    A. $\frac{2v_A t}{3\pi c(\tau_2 - \tau_1)}$

    B. $\frac{2\pi v_O t}{3ic(\tau_2 + \tau_1)}$

    C. $\frac{2\pi(v_A - v_O t)}{3ic\tau_2}$

    D. $\frac{2\pi(\tau_2 + \tau_1)t}{3icv_O}$

    E. $\frac{2\pi(\tau_2 - \tau_1)(v_A + v_O)}{3ict}$

Recently, the exoplanet Proxima Centauri b was discovered using the radial velocity method. The orbital period of Proxima Centauri b is 11.19 days, and it orbits the star Proxima Centauri, (which has a mass of 0.122 Solar masses, a radius of 0.154 Solar radii, and an effective temperature of 3042 Kelvin).

18. (1 point) Which of the following is closest to the semi-major axis of Proxima Centauri b?

    A. 0.01 AU

    B. 0.05 AU

    C. 0.1 AU

    D. 0.5 AU

    E. 1 AU

19. (1 point) Which of the following is closest to the temperature at the surface of Proxima Centauri b? Assume that the surface has an albedo of 0.3, and that the incident radiation is perfectly redistributed around the planet.

A. 200 K
B. 235 K
C. 275 K
D. 335 K
E. 600 K

20. (1 point) A star cluster with a main-sequence turn-off at around 6000 K effective temperature is about:
    A. 10 million years old
    B. 100 million years old
    C. 1 billion years old
    D. 10 billion years old
    E. 100 billion years old

21. (1 point) The 21 cm absorption line is a tracer for what kind of gas?
    A. Cold neutral atomic hydrogen
    B. Cold molecular hydrogen
    C. Warm neutral hydrogen
    D. Warm ionized hydrogen
    E. HII regions

22. (1 point) From the shortest distances to the longest, what is the correct order of distance determination techniques?
    A. Parallax, type Ia supernovae, cepheids
    B. Parallax, cepheids, type Ia supernovae
    C. Type Ia supernovae, cepheids, parallax
    D. Cepheids, parallax, type Ia supernovae
    E. Cepheids, type Ia supernovae, parallax

The information below applies to the following two questions:

In a particular compact binary system consisting of a black hole and a main sequence star, the black hole has a mass of $23.2M_{Sun}$ and the main sequence star has mass of $15.6M_{Sun}$. The two stars are separated by 1 AU.

23. (1 point) A clump of gas of mass $1M_{Sun}$ detaches from the main sequence star. When the gas is 1 km from the black hole, what is its total energy? Neglect viscous forces.
    A. $-3.06 * 10^{48}$ J
    B. $-6.12 * 10^{48}$ J
    C. $3.06 * 10^{48}$ J
    D. $6.12 * 10^{48}$ J
    E. 0 J

24. (1 point) We assume the accretion disk around the black hole is in a steady state (i.e. does not change with time) and that it has a perfectly circular cross section. We further assume that the mass transfer rate is constant. At a distance r_1 from the black hole, the temperature of the disk is T_1. What is the temperature T_2 of the disk at a distance $r_2 = 2r_1$? Hint: consider the Stefan-Boltzmann law.

    A. 2.0
    B. 1.4
    C. 0.71
    D. 0.60
    E. 0.50

25. (1 point) The $H\alpha$ line ($\lambda_0 = 656.28nm$) of a galaxy is observed to be redshifted to a value $\lambda = 814.35$. Assuming only cosmological redshift, find the approximate distance to the galaxy in Mpc.

    A. 124 Mpc
    B. 356 Mpc
    C. 524 Mpc
    D. 910 Mpc
    E. 1030 Mpc

26. (1 point) At what redshift would the (average) temperature in the universe have been hot enough to emit 1 nm photons? The current CMB temperature of the universe is 2.73 K.

    A. 10^9
    B. 10^8
    C. 10^6
    D. 10^4
    E. 10^2

27. (1 point) In April, the Event Horizon Telescope released the first image of the supermassive black hole of M87. The black hole has a diameter of approximately 270 AU and is located at a distance of 16.4 Mpc. At the observed wavelength of 1.3mm, what is the approximate minimum baseline, or effective diameter, required to image the black hole?

    A. $2 * 10^3$ km
    B. $2 * 10^4$ km
    C. $2 * 10^5$ km
    D. $2 * 10^6$ km
    E. $2 * 10^7$ km

28. (1 point) At optical wavelengths, star formation is strongly obscured by dust. Studies of protoplanetary disks therefore usually observe at infrared or sub-milimeter wavelengths. Why are these observations less strongly affected by interstellar dust?

    A. Higher angular resolution from interferometers averages out dust effects
    B. The thermal emission of interstellar dust is comparatively less at longer wavelengths

C. Dust grains scatter shorter wavelengths more efficiently than longer wavelengths

D. The optical obscuration is a result of atomic transitions not present at longer wavelengths

E. None of the above

29. (1 point) A very curious astronomer decided to cover the left half of the objective lens of a telescope with an opaque material. If he points this telescope to a region of the night sky, how will the image generated by this telescope be different from the original image generated by uncovered lenses?

A. The astronomer will only see the right half of the original image.

B. The astronomer will only see the left half of the original image.

C. The astronomer will see a blurred image.

D. The astronomer will see almost the same image, but the stars will look fainter

E. The image will be completely unchanged.

30. (1 point) An astronomer decided to use his 15x70 binoculars to observe the vehicles in a highway. If the distance between the headlights of a truck is equal to 2.10 meters, what is the minimum distance between the truck and the astronomer that would allow him to observe both headlights as a single point? Consider that visible light is centered at a wavelength of 550 nm.

Note: a 15x70 binoculars has a magnification of 15 times and an aperture of 70 mm

A. 3.4×10^3 m

B. 1.6×10^4 m

C. 4.9×10^4 m

D. 1.1×10^6 m

E. 2.2×10^6 m