2019 Astronomy Team Selection Test

Acton-Boxborough Regional High School
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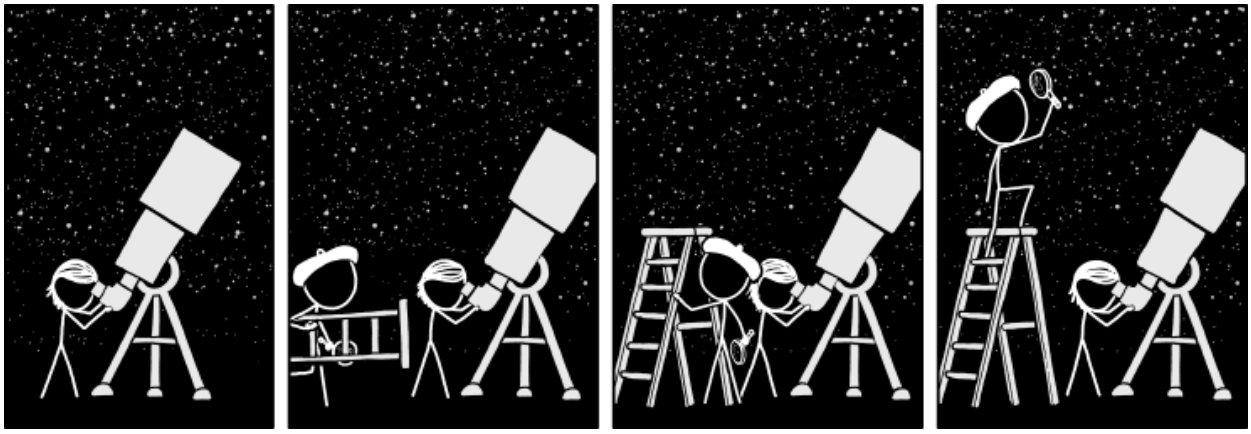

Instructions

- Do not flip over this page until instructed.
- You will have **45 minutes** to complete this exam.
- Always use 3 significant figures in calculations. Do not worry about rounding, a range of answers will be accepted.
- You are not expected to finish. This test is intentionally long and difficult.
- This exam is divided into 3 sections:
  1. Fundamentals (48 points)
  2. DSOs and related questions (119 points)
  3. Free response (80 points)
- It is **highly advised** that you look over all sections at some point during the test. There is a range of questions within each section.

Name:_____

Email:_____

Score = _____/ 247

Section 1. Fundamentals

1. Answer the following questions related to the Sun.
   (a) What is the Sun's spectral type? Your answer should be a letter followed by a number. [1]

   (a) **G2**

   (b) What is the Sun's absolute magnitude? [1]

   (b) **+4.83**

   (c) What is the Sun's apparent magnitude? [1]

   (c) **-26.74**

   (d) What is the Sun's surface temperature? [1]

   (d) **5780K**

   (e) What's the Sun's estimated lifetime on the main sequence? [2]

   (e) **10 billion years**

2. Consider the Hertzsprung-Russell diagram in Image 1.
   (a) What does the bottom axis represent? [1]

   (a) **Spectral class**

   (b) What letter(s), if any, represents the Sun's current location on the diagram? What letter(s) represents the Sun after it has become a planetary nebula? [2]

   (b) **D,Q**

   (c) What letter(s), if any, best represent where a star in an open cluster lies on the diagram? [2]

   (c) **G,T**

   (d) What letter(s), if any, best represent the stars with longest lifetimes? [2]

   (d) **E,K**

   (e) What letter(s), if any, best represent the location of a neutron star? [2]

   (e) **None**

3. Consider images 2 through 7.
   (a) Which image(s), if any, represent an irregular galaxy? [1]

   (a) **2,5**

   (b) Which image(s), if any, represent a barred spiral galaxy? [1]

   (b) **3**

   (c) In which image(s) would you find it least likely to find a Type II supernova? Why? [4]

   (c) **4,7. Little star formation.**

   (d) What is the most common type of galaxy? Why? [2]

   (d) **Dwarf. Low mass forms more easily.**

   (e) What is the nearest "large" galaxy? [1]

   (e) **Andromeda (M31)**

4. Answer the following questions regarding Cepheid variables.
   (a) What two variables are associated in Cepheids that allows them to be used for distance measurement? [1]

   (a) **Period and luminosity.**

   (b) What mechanism drives Cepheid variable pulsation? What element is responsible? [3]

   (b) **Kappa mechanism. Helium.**

   (c) Delta Cephei is the prototype Cepheid variable. It is also known to be a classical Cepheid. In which stellar population does Delta Cephei belong? [2]

   (c) **Population I**

   (d) Image 8 shows its light curve. Determine its absolute magnitude. [2]

   (d) **-3.1 to -3.7**

   (e) β-Cephei stars pulsate similarly to classical Cepheids, however, a different element is responsible. What element is this? [1]

   (e) **Iron**

5. Answer the following questions related to stellar spectra.
   (a) Astrophysicists define metals slightly differently than chemists. What is a metal to an astrophysicist? [2]

   (a) **Not H or He.**

   (b) Name the spectral line associated with 656.28 nm. What spectral series is it part of? [2]

   (b) **Hydrogen α. Balmer series.**

   (c) The lack of of what element in a supernova spectra indicates a Type I event? [1]

   (c) **Hydrogen**

6. The variables X, Y, and Z describe a star's chemical composition. For the Sun, $X = 0.7381$, $Y = 0.2485$, and $Z = 0.0134$.
   (a) What do X, Y, Z each represent? [3]

   (a) **Mass fraction of H,He, metals**

   (b) What stellar population does the Sun belong to according to the above values? [2]

   (b) **Population I**

7. In astrophysics, dust is extremely important. Answer the following questions related to dust.
   (a) In the interstellar medium, most hydrogen is in its ground state, namely HI. Why does this not produce emission lines? [3]

   (a) **No electrons in excited state**

   (b) However, due to the inherent randomness in an electron's location, occasionally an electron will find itself in its excited state, eventually dropping down, producing an emission line. What is the name for this line? [2]

   (b) **21cm line**

Section 2. DSOs

8. Answer the following questions related to Image 15.

   (a) Identify the object depicted in the image. [2]

   (a) **Centaurus A**

   (b) This object's morphology has been subject to considerable debate. Name two possible classifications. [2]

   (b) **Lenticular, elliptical**

   (c) Image 13 depicts a false color image of this object. What does it mean for an image to be "false color" in this context? [2]

   (c) **Image with colors assigned to different bands**

   (d) What color represents radio emissions? [1]

   (d) **Red**

   (e) Both images depict two large jets emanating from the galactic center. From what object does these jets emanate? [2]

   (e) **Supermassive black hole**

   (f) The mechanism behind the formation of relativistic jets remains uncertain, however, they can be viewed in radio using what observational technique? [2]

   (f) **Very-long-baseline interferometry**

9. Answer the following questions related to NGC 4993.

   (a) What image depicts this object? [2]

   (a) **Image 16**

   (b) NGC 4933 is significant in that it is the site of a gravitational wave event. What is the name of this event? [2]

   (b) **GW170817**

   (c) What date did this event occur? [1]

   (c) **August 17th, 2017**

   (d) Gravitational waves had been detected as early as 2016. What made this event special? [3]

   (d) **First electromagnetic counterpart of gravitational wave**

   (e) Consider two neutron stars with masses $1.52M_\odot$ and $0.89M_\odot$. Their separation is 0.05 AU. How long will it take for them to merge via gravitational wave radiation? [4]

   (e) **6.2×10^{11} years**

   (f) Name one observatory/laboratory that is responsible for the majority of gravitational wave discoveries. [2]

   (f) **LIGO**

10. Answer the following questions related to IC 10.

(a) In which constellation does IC 10 lie? [1]

(a) **Cassiopia**

(b) What is the star formation rate in IC 10, in solar masses per year? [2]

(b) **0.04-0.08 solar masses/year**

(c) According to Robataille et al., the rate of star formation in the Milky Way is between 0.7 and 1.5 solar masses per year. This is substantially greater than that of IC 10, and yet the Milky Way is not classified as a starburst galaxy. Give a plausible explanation for this discrepancy. [3]

(c) **IC 10 is substantially smaller**

(d) IC 10 is known to contain many X-ray binaries. Which image(s) depict(s) an X-ray image of such binaries in IC 10? [2]

(d) **14**

(e) Why is accretion necessary to produce X-rays in X-ray binaries? [3]

(e) **Loss of gravitational potential energy heats gas**

(f) Suppose an X-ray binary contains a black hole of mass 5 solar masses and a red giant of 2 solar masses. If the period of the system is 4 days, determine the separation in meters. [3]

(f) **$1.0 - 1.8 \times 10^{11}$ meters**

11. Answer the following questions relating to Image 9.

(a) What object does this image depict? [2]

(a) **Phoenix Cluster**

(b) What's notable about star formation in the central galaxy? [2]

(b) **Undergoing massive starburst**

(c) At the central galaxy's center, there exists a supermassive black hole with estimated mass of 20 billion $M_\odot$. Calculate the Schwarzchild radius in Gkm. [4]

(c) **50.0 - 70.0 Gkm**

(d) At what rate is the central black hole growing, in solar masses per year? [2]

(d) **60 solar masses per year**

(e) This object was discovered using a technique involving measuring the distortion of the cosmic microwave background through inverse Compton scattering with high energy electrons. What is this effect called? [2]

(e) **Sunyaev–Zel'dovich effect**

12. Answer the following questions relating to M81/M82.

(a) i. Which image depicts this DSO? Does it depict M81 or M82? [2]

i. **10, M82**

ii. What telescope took this image? In what wavelength? [2]

ii. **Hubble, visible**

iii. The image from part i. is not an accurate representation of the true colors as viewed by a human. In particular, one color represents the distribution of hydrogen. What color is it? [1]

iii. **Red**

(b) i. M82's redshift has been measured to be +203 km/s. Does this mean it's moving towards or away from the Earth? [1]

i. **Away from.**

ii. Use the above information to calculate the distance to M82 in Mpc. Assume $H_0 = 70$ (km/s)/Mpc. [3]

ii. **2.8-3.0 Mpc**

iii. Your answer above should differ from the commonly used distance, namely $3.5 - 4.0$ Mpc. Give a plausible explanation for this. In particular, why might redshift not be the best way to determine distance? [3]

iii. **M82 part of cluster which could affect its motion**

(c) i. M82 is known to be a starburst galaxy. What does this signify? [3]

i. **High rate of star formation**

ii. Would you expect there to be a greater number of starburst galaxies 10 billion years ago? Why or why not? [3]

ii. **Yes. Galaxies closer then, more means interactions**

iii. A starburst galaxy has strong broad emission features of the 468.6 nm HeII line. What type of starburst galaxy might this be? [3]

iii. **Wolf-Rayet galaxy**

(d) M82 is also host to an important supernova, SN 2014J. Answer the following questions related to it.

i. What type of supernova is SN 2014J? [2]

i. **Type Ia**

ii. What element would you not expect to find in the spectrum of SN 2014J? [2]

ii. **Hydrogen**

iii. This supernova low emissions in X-rays. What does this suggest about the environment of the progenitor? [3]

iii. **Little matter around it**

iv. Assuming the absolute magnitude of this supernova type as -19.5, and an apparent magnitude of $+10.5$, calculate the distance in Mpc. [3]

iv. **10.0 Mpc**

v. The value you calculated should be greater than the commonly accepted value of 3.5 Mpc. Give a plausible explanation for this. [2]

v. **Extinction, not using Phillips relation, etc.**

13. (a) Answer the following questions relating to 47 Tucanae.

i. What image depicts this object? [2]

i. **Image 18**

ii. What type of cluster is 47 Tuc? [3]

ii. **Globular Cluster**

iii. What stellar population would we expect the stars within the 47 Tuc to be? [2]

iii. **Population II**

iv. Image 17 shows a plot of 47 Tucanae, with $B - V$ on the x-axis and V on the y-axis. What type of plot is this? [2]

iv. **Color-color diagram**

v. Consider the boxed region on the plot. Name the stars within this region. [3]

v. **Blue stragglers**

(b) Answer the following questions related to X9.

i. What image depicts X9? [2]

i. **Image 11**

ii. What makes this object special? [3]

ii. **Closest known orbit between a star and black hole**

iii. What is the orbital period of this system? [2]

iii. **25 minutes**

iv. Large quantities of oxygen were detected in the system. What does suggest about the components of the binary system? [2]

iv. **One is likely a white dwarf**

(c) In 2000, Gilliland et al. conducted a survey to detect planets within 47 Tuc.

i. What telescope was used in the survey? [2]

i. **Hubble Space Telescope**

ii. What type of planets did the survey specifically search for? [3]

ii. **Hot Jupiters**

iii. What exoplanet detection method did they employ? [2]

iii. **Transits**

iv. What conclusion did Gilliland et al. reach regarding planets within globular clusters? [3]

iv. **Planets are rare in globular clusters**

v. However, this conclusion has been contested recently, most notably with Masuda et al. in July 2017. They used more thorough more recent *Kepler* data to redefine the expected number of identifiable planets within 47 Tuc. How might this change the result? [4]

v. **Null result is not statistically significant**

Section 3. Free Response

Partial credit will be awarded for calculation questions within this section if work is shown.

14. Answer the following calculation questions.

(a) A star has parallax of 0.01 arcseconds. What's its distance in parsecs? [2]

100 pc

(b) Canopus is the second brightest star in the sky, and has an apparent visual magnitude of -0.74. If Canopus also has an absolute magnitude of -5.71, determine the distance to Canopus in parsecs. [2]

98.6 pc

(c) In a binary system, the apparent magnitude of the primary star is 1.0 and that of the secondary star is 2.0 Find the maximum combined magnitude of this system. [4]

Use Flux equation. +0.64

(d) A K-type star on the Main Sequence has a luminosity of $0.40L_{\odot}$. This star is observed to have a flux of $6.23 \times 10^{-14} W/m^2$. What is the distance (in parsecs) to this star? [3]

450 pc

(e) Use the Tully-Fisher relation to calculate the absolute magnitude of an Sb galaxy with maximal rotation velocity 200 km/s. [6]

-20.7

15. Answer the following questions related to spiral galaxy rotation.

(a) Suppose that a spiral galaxy's arms originally formed as a single line. Assuming differential rotation, what will happen to the arms? [3]

After a few rotations, the arms will become too tightly wound to be observed.

(b) Lin and Shu proposed that spiral arms arise from quasistatic density waves. Explain how this produces spiral arms. [5]

Spiral arms are areas of greater density, which stars move through with the rotation of the galaxy.

(c) How does this theory explain the number of young stars within spiral arms? [6]

Higher density means that gas and dust is compressed, so young stars form more easily due to greater likelihood of exceeding the Jeans mass.

16. A supernova is observed in a distant galaxy.

(a) Astronomers measure the Si II line in the remnant shell (they don't observe strong hydrogen lines), finding it to be redshifted to 6551.34 Å. The rest wavelength is known to be 6347.103 Å. How fast is the shell expanding in km/s? [3]

9650 km/s

(b) What type of supernova is this? Why? [3]

Type Ia. Presence of Si II and no H]

(c) What is the diameter of the remnant 100 days after the explosion in meters. What assumption is being made? [5]

Assuming constant rate of expansion. 1.66×10^{14} meters

(d) The angular diameter of the remnant is 0.972 milliarcseconds. Determine the distance to the remnant in Mpc. [5]

1.14 Mpc

(e) The supernova was observed to have apparent magnitude +7.78. Determine its absolute magnitude. [4]

-17.5

(f) Is the above brighter or dimmer than expected? Give two plausible explanations. [6]

Interstellar extinction, super-Chandrasekhar limit supernova

17. Answer the following questions related to supernovae and stellar remnants.

(a) What is the maximum mass of a white dwarf? Of a neutron star? [2]

Chandrasekhar limit, Tolman-Oppenheimer Volkoff limit

(b) Give a plausible explanation of how a white dwarf may *exceed* its 'maximal' masses. (This has been observed in SN2003fg) [4]

A white dwarf with high rotation can reduce the pressure on the core, allowing for more mass to be added above the Chandrasekhar limit.

(c) Would a Type II supernova be more likely to produce a white dwarf or a neutron star? Why? [3]

Neutron star. White dwarfs are produced from lower mass stars expelling their outer layers.

(d) Explain the role of photodisintegration in Type II supernovae events. [5]

Photons now possess enough energy to destroy heavy nuclei, reducing the pressure, and triggering collapse.

(e) Some supernovae events produce black holes. What three variables can completely describe a black hole? What theorem states this result? [3]

Mass, angular momentum, electric charge. No Hair theorem.

(f) One of the most important predictions regarding black holes is the emission of Hawking radiation. Explain how Hawking radiation arises, and its implications for a black hole's fate. [6]

Quantum vacuum fluctuations produce particle-antiparticle pair near the event horizon. One falls into the black hole, and the other escapes. The escaped one cases the black hole to lose mass. This means that black hole lifetimes are finite.