Science Olympiad
Astronomy C Division Event
MIT Invitational

Massachusetts Institute of Technology
Cambridge, MA
January 21, 2017

Team Number: ____________

Team Name: ____________________________

Instructions:
1) Please turn in all materials at the end of the event.
2) Do not forget to put your team name and team number at the top of all answer pages.
3) Write all answers on the answer pages. Any marks elsewhere will not be scored.
4) Do not worry about significant figures. Use 3 or more in your answers, regardless of how many are in the question.
5) Please do not access the internet during the event. If you do so, your team will be disqualified.
6) This event and answer key will be available on: https://www.soinc.org/astronomy_c.
7) Good luck! And may the stars be with you!
Use the Image/Illustration Set (Pages 7-8) to answer the following questions 1-12. An H-R diagram is shown in Image 1. All sub-questions in this section are worth one point each.

1. (a) Which deep sky object is shown on the cover page?
   (b) Which two other images show this object?
   (c) Which of these two images was taken in the same wavelength as the image on the cover page?
   (d) Which image shows the light curve of this object?
   (e) At which letter (A-O) on the H-R diagram does this deep sky object lie?

2. (a) Which image shows the light curve of SS Cygni?
   (b) What class of variable star is SS Cygni?
   (c) Which object was the first of this class to be discovered?
   (d) What are the three components of this class of variable star?
   (e) Which image shows a potential schematic of this class of variable star?

3. (a) Which deep sky object is shown in image 5?
   (b) What type of object is this?
   (c) Image 16 shows a color-magnitude diagram of this object. What notable conclusion can you draw from this diagram about the ages of the stars in this object?
   (d) What is a potential explanation as to what caused the oddities in this object’s color-magnitude diagram?

4. Image 17 shows the light curve of a deep sky object. The red dots show the bolometric (total) flux, while the white dots show the visible wavelength flux alone. This object is 7.24 Mpc from Earth.
   (a) Which deep sky object is this?
   (b) What is the bolometric absolute magnitude of this object at maximum brightness?
   (c) What kind of object is this?
   (d) Based on the distance to this object, what should the recessional velocity of its host galaxy be (in km s\(^{-1}\)) if it agrees with Hubble’s law? Assume that Hubble’s constant is 65 km s\(^{-1}\) Mpc\(^{-1}\).

5. (a) Which image(s) show planetary nebulae?
   (b) Which image shows a planetary nebula with a binary white dwarf at its center?
   (c) Which image shows the youngest known planetary nebula?
   (d) Which image shows a double-shell planetary nebula?
6. RX J0806.3+1527 is the alternate identification for a deep sky object on this year’s rules.
   
   (a) Which constellation is this object in?
   (b) What are the components of this system?
   (c) Which image shows an illustration of this object?
   (d) Which image shows a light curve of this system?
   (e) According to general relativity, what type of waves should be generated by this system?

7. Image 19 shows the light curve and power spectrum for the archetype of a class of variable stars.
   
   (a) Which variable star is this?
   (b) What is the general timescale of variability of this type of variable star?
   (c) At which location (A-O) on the H-R diagram does the accretor in this system belong?
   (d) What is the orbital period of this system, in seconds?

8. Match the deep sky object below to the relevant image(s).
   
   (a) SNR 0509-67.5
   (b) Tycho’s SNR
   (c) NGC 2392
   (d) Henize 3-1357
   (e) NGC 2440
   (f) SNR G1.9+0.3
   (g) Henize 2-428

9. The following questions refer to image 1, the H-R diagram.
   
   (a) What are the units of the top x-axis?
   (b) What are the units of the right y-axis?
   (c) What is the absolute magnitude of a main-sequence A0V star?
   (d) What is the distance, in parsecs, to an A0V star if it has an apparent magnitude of 10?

10. Place the following on image 1, the H-R diagram (locations A-O, multiple locations may be required).
    
    (a) Main-sequence stars
    (b) Our Sun
    (c) Stars at the center of planetary nebulae
    (d) Flaring red dwarfs
    (e) Red giant branch stars
11. Classify the objects below into one of these variability groups: *Eclipsing, rotating, pulsating, eruptive, cataclysmic, X-ray.*

(a) SN 2011fe
(b) HM Cancri (1 point bonus for correctly stating a second variability group)
(c) Omicron Ceti (1 point bonus for correctly stating a second variability group)
(d) SS Cygni
(e) AM CVn

12. Write the word or phrase that best matches the description.

(a) Maximum mass for white dwarfs
(b) Force supporting interior of white dwarf stars against gravity
(c) Force supporting interior of neutron stars against gravity
(d) Radially pulsating variable stars with periods of 100-700 days
(e) Pulsating white dwarfs with periods of 100-1000 seconds
(f) Pulsating source of radio emissions caused by neutron star variability
(g) Classical nova that takes a few weeks to dim by two magnitudes from maximum
(h) Class of Type Ia supernovae formed by the merger of two white dwarfs
(i) Clusters of Population II stars, some of the oldest objects in the Milky Way galaxy
(j) Stage of stellar evolution between the main sequence and red giant branch
Time for some (more) physics! All relevant images for the following questions 13-21 are shown in the test itself. Sub-questions in this section are worth *two points each*.

13. A star with the same absolute magnitude of the Sun has a parallax of 0.01”. The H-α line of this star is measured to be 6565.8 Angstroms. The H-α wavelength is expected to be at 6562.8 Angstroms based on laboratory measurements.

   (a) What is the distance to this star, in parsecs?
   (b) What is the luminosity of this star, in Watts?
   (c) What is the apparent magnitude of this star?
   (d) What is the radial velocity of this star, in km s\(^{-1}\)? Is this star moving toward Earth or away from Earth?
   (e) This star has a proper motion of 50 milliarcseconds per year. What is its tangential velocity, in km s\(^{-1}\)?
   (f) What is the true space velocity of this star, in km s\(^{-1}\)?

14. A detector on Earth measures 0.25 milli-Watts of power from an X-ray binary 5 kiloparsec away. If an equally bright X-ray binary were found at 0.5 kiloparsec away from Earth, how many milli-Watts of power will the detector on Earth measure?

15. The average radial velocity of galaxies in a given cluster is 9,000 km s\(^{-1}\). What is the distance to this cluster, in megaparsecs? Assume that Hubble's constant is 65 km s\(^{-1}\) Mpc\(^{-1}\).

16. A star has a luminosity of \(10^4\) solar luminosities and a radius 370 times that of the Sun.

   (a) What type of star is this?
   (b) What is the effective temperature of this star, in Kelvin?
   (c) What is the flux emitted by this star, in Watts m\(^{-2}\)?
   (d) What is the wavelength at which the blackbody spectrum of this star peaks, in micrometers?

17. A binary system is comprised of two stars, one with the mass of the Sun and one with a mass twice that of the Sun. If the orbits of both of the stars are circular, what is the ratio of angular velocities between the primary and secondary stars?

18. What is the distance, in parsecs, to a B2III star with a bolometric apparent magnitude of 5?

19. Given a Hubble constant of 65 km s\(^{-1}\) Mpc\(^{-1}\), what is the "Hubble time," that is, the predicted age of the universe, in billions of years?
20. The image above shows the absolute bolometric light curve from a close eclipsing binary system with a period of 50 hours. For simplicity, assume that both of the stars in the system are on circular orbits, that stellar occultations completely block the disk of the eclipsed star (but not that both stars have the same radius), and that stellar luminosity scales with mass as \( L \propto M^{3.5} \).

(a) What is the separation between the two stars, in AU?
(b) How many times faster is the orbital speed of the secondary star relative to the primary?
(c) What is the radius of the primary star, in solar radii?

21. The image above shows the radial velocity curve for another eclipsing binary system. The separation between the two stars is 50 AU.

(a) What is the recessional velocity of this binary star system, in km s\(^{-1}\)?
(b) What is the mass ratio between the primary star and secondary star?
(c) What is the orbital period of the system, in years?
Figure 1. Drizzled ACS/WFC F814W image of the core of NGC 1846 (exposure 200 s). The full image has been cropped to include only WFC chip 1 and part of WFC chip 2—these cover the central cluster region. Note that the brightest stars in the cluster are saturated.

**OBSERVATIONS AND DATA REDUCTION**

Our observations were made during HST Cycle 12 on 2003 October 08 using the ACS Wide Field Channel (WFC). As a snapshot target, one frame was taken in each of two filters—F555W (dataset j8ne55z9q) and F814W (dataset j8ne55zeq). Exposure durations were 300s and 200s, respectively. The ACS WFC consists of two 2048 × 4096 pixel CCDs separated by a gap ≈ 50 pixels wide. The plate scale is 0.05 arcsec per pixel, resulting in a total areal coverage of approximately 202 × 202 arcsec. The core of NGC 1846 was positioned at the centre of chip 1 so that the inter-chip gap did not impact on the innermost region of the cluster.

In order to help with the identification and removal of hot-pixels and cosmic rays, the F814W image was offset from the F555W image by ≈ 2 pixels in both the x- and y-directions.

The data products produced by the STScI reduction pipeline, which we retrieved via the public archive, have had bias and dark-current frames subtracted and are divided by a flat-field image. In addition, known hot-pixels and other defects are masked, and the photometric keywords in the image headers are calculated. We also obtained distortion-corrected (drizzled) images from the archive, produced using the `pyraf` task `multidrizzle`. Part of the drizzled F814W image is displayed in Fig. 1.

We used the `dolphot` photometry software (Dolphin 2000), specifically the ACS module, to photometer our flatfielded F555W and F814W images. `dolphot` performs point-spread function fitting using PSFs especially tailored to the ACS camera. Before performing the photometry, we first prepared the images using the `dolphot` packages `acsmask` and `splitgroups`. Respectively, these packages apply the image defect mask and then split the multi-image STScI FITS files into a single FITS file per chip. We then used the main `dolphot` routine to simultaneously make photometric measurements on the pre-processed images, relative to the coordinate system of the drizzled F814W image. We chose to fit the sky locally around each detected source (important due to the crowded nature of the target), and keep only objects with a signal greater than 10 times the standard deviation of the background. The output photometry from `dolphot` is on the calibrated VEGAMAG scale of Sirianni et al. (2005), and corrected for charge-transfer efficiency (CTE) degradation.

To obtain a clean list of stellar detections with high-quality photometry, we applied a filter employing the sharpness and "crowding" parameters calculated by `dolphot`. The sharpness is a measure of the broadness of a detected object relative to the PSF— for a perfectly-fit star this parameter is zero, while it is negative for an object which is too sharp (perhaps a cosmic-ray) and positive for an object which is too broad (say, a background galaxy). The crowding parameter measures how much brighter a detected object would have been measured had nearby objects not been fit simultaneously. We selected only objects with −0.15 ⩽ sharpness ⩽ 0.15 in both frames, and crowding ⩽ 0.5 mag in both frames. We also only kept objects classified...
bolometric flux is plotted in Fig. 5, along with the integrated flux luminosity is presented in the last column of Table 2, and the with mean ratio and scatter of 32 UVI tometry relative to the bolometric flux, we simulated the ratio our data did not sample.

The UV flux accounts for a few percent of the evolution of the ratio of UV and NIR flux to total flux is shown in Fig. 4. The UV length range 1600–24000 Å of the UV

CHANDRA 55796 –1 5– power law was fitted to URI

The most striking and unusual feature of the CMD for the optical window. A

The colour-magnitude diagram (CMD) for NGC 1846 is presented in Fig. 2. The best non-

The derived data of explosion thus seems to be dependent on the

maximum from Sect. 2.4, we obtain

The vertical dotted lines mark the time of observations presented

the narrow (lower) RGB and the compact RC elements (see e.g., the brightest stars in Fig. 1). The accuracy of contamination has been removed leaving the cluster sequenc

The luminosity dependence is dominated by the evolution of the photosphere surface area (Riess et al. 1999; Goldhaber that the luminosity dependence is dominated by the evolution

...
1. (a) ______________________  
(b) ______________________  
(c) ______________________  
(d) ______________________  
(e) ______________________  

8. (a) ______________________  
(b) ______________________  
(c) ______________________  
(d) ______________________  
(e) ______________________  

2. (a) ______________________  
(b) ______________________  
(c) ______________________  
(d) ______________________  
(e) ______________________  

9. (a) ______________________  
(b) ______________________  
(c) ______________________  
(d) ______________________ parsecs

3. (a) ______________________  
(b) ______________________  
(c) ______________________  
(d) ______________________  

10. (a) ______________________  
(b) ______________________  
(c) ______________________  
(d) ______________________  
(e) ______________________  

4. (a) ______________________  
(b) ______________________  
(c) ______________________  
(d) ______________________ km/s

11. (a) ______________________  
(b) ______________________  
(c) ______________________  
(d) ______________________  
(e) ______________________  

5. (a) ______________________  
(b) ______________________  
(c) ______________________  
(d) ______________________  

12. (a) ______________________  
(b) ______________________  
(c) ______________________  
(d) ______________________  
(e) ______________________  
(f) ______________________  
(g) ______________________  
(h) ______________________  
(i) ______________________  
(j) ______________________
Astronomy C: Answer Page continued

13. (a) _______________________________ parsecs
    (b) _______________________________ Watts
    (c) _______________________________
    (d) _______________ km s$^{-1}$, _______________________________
    (e) _______________________________ km s$^{-1}$
    (f) _______________________________ km s$^{-1}$

14. _______________________________ milli-Watts

15. _______________________________ Mpc

16. (a) _______________________________
    (b) _______________________________ Kelvin
    (c) _______________________________ Watts m$^{-2}$
    (d) _______________________________ µm

17. _______________________________

18. _______________________________ parsecs

19. _______________________________ Gyr

20. (a) _______________________________ AU
    (b) _______________________________
    (c) _______________________________ Solar radii

21. (a) _______________________________ km s$^{-1}$
    (b) _______________________________
    (c) _______________________________ years
Astronomy C: Answer Page

1. (a) Mira/Omicron Ceti
   (b) 2.3
   (c) 3
   (d) 15
   (e) G/D

2. (a) 14
   (b) Dwarf novae
   (c) U Gem
   (d) white dwarf, main sequence star, accretion disk
   (e) 13

3. (a) NGC 1846
   (b) Globular cluster
   (c) Double main-sequence turnoff
   (d) Capture of two star clusters

4. (a) SN 2011fe
   (b) $-18.9 \pm 1$
   (c) Type Ia supernova
   (d) 470.6 km/s

5. (a) 6, 7, 8
   (b) 7
   (c) 6
   (d) 8

6. (a) Cancer
   (b) two white dwarfs
   (c) 12
   (d) 18
   (e) Gravitational waves

7. (a) AM CVn
   (b) 1-60 minutes
   (c) C/F

8. (a) $10$
   (b) 4
   (c) 8
   (d) 6
   (e) 11
   (f) 9
   (g) 7

9. (a) Kelvin
   (b) Solar luminosities
   (c) $0 \pm 1$
   (d) 1000 $\pm$ 200 parsecs

10. (a) K,E,L,A
   (b) E
   (c) C,F
   (d) A
   (e) M/N (one or both okay)

11. (a) Cataclysmic
   (b) X-ray and Cataclysmic
   (c) Pulsating and Eruptive
   (d) Cataclysmic
   (e) Cataclysmic

12. (a) Chandrasekhar mass
   (b) Electron degeneracy pressure
   (c) Neutron degeneracy pressure
   (d) Long-period variables
   (e) ZZ Ceti stars
   (f) Pulsar
   (g) Fast nova
   (h) Double-degenerate
   (i) Globular clusters
   (j) Sub-giant branch
Astronomy C: Answer Page continued

13. (a) 100 parsecs
    (b) $3.8 \times 10^{26}$ Watts
    (c) 9.83 ± 1
    (d) $137 \pm 15$ km s$^{-1}$, away from Earth
    (e) $23.7 \pm 3$ km s$^{-1}$
    (f) $139.2 \pm 15$ km s$^{-1}$

14. 25 milli-Watts

15. 138 Mpc

16. (a) red (super)giant/asymptotic giant branch/Mira variable
    (b) 3000 ± 300 Kelvin
    (c) $(4.59 \pm 1) \times 10^6$ Watts m$^{-2}$
    (d) 0.967 ± 0.1 µm

17. 1

18. 903 ± 250 parsecs

19. 15 ± 0.5 Gyr

20. (a) 0.037 ± 0.005 AU
    (b) 1.37 ± 0.1
    (c) 2.89 ± 0.3 Solar radii

21. (a) 25 km s$^{-1}$
    (b) 3
    (c) 5.33 ± 0.5 years