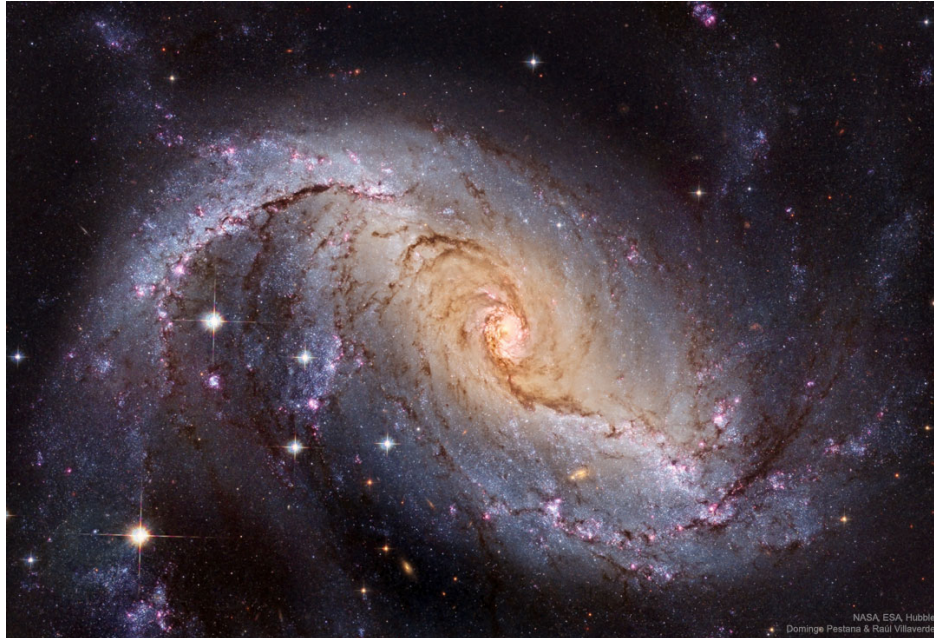


MIT Invitational, Jan 2019

# Astronomy C



Competitors: \_\_\_\_\_

School name: \_\_\_\_\_

Team number: \_\_\_\_\_

## INSTRUCTIONS

1. Please turn in **all materials** at the end of the event.
2. You may separate the pages, but do not forget to put your **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. Good luck! And may the stars be with you!

**Section A**

Each subpart is worth 1 point. Use image sheet A.

1.
  - (a) What is the name of the X-ray object in image 14?
  - (b) What image also includes the optical data for this object?
  - (c) What type of force is the material in this object being subjected to?
  - (d) What letter on the H-R diagram shows the location of the objects trailing in the wake of this object?
2.
  - (a) What type of object is plotted in image 29?
  - (b) What term is given to the stars located at position A?
  - (c) What information does the location of position A provide?
3.
  - (a) Image 26 shows the behavior of what specific type of star?
  - (b) What letter on the H-R diagram shows the general location of this type of object?
  - (c) Where is the galactic location of this type of star?
  - (d) What images contain several of these objects?
  - (e) What is the name of this object?
4.
  - (a) What is the number of another image that shows one of the galaxies located in image 17? What is the galaxy's name?
  - (b) Image 12 contains an object that resulted from a catastrophic event in this galaxy. What is the name and type of this object?
  - (c) What image shows the behavior of this object?
5.
  - (a) What type of stellar behavior is shown in image 22?
  - (b) What letter on the H-R diagram shows the location of this type of behavior?
  - (c) What 2 images show observational/data sequences for these stars?
  - (d) What is the image number and name of the galaxy from which these observations were collected?
  - (e) Which of the following categories apply to these objects: (A) Population I Classical, (B) Population II Classical, (C) Population II W Virginis, (D) Population I W Virginis
6.
  - (a) What is the name of the objects in image 1?
  - (b) What stage of stellar evolution is determined from the IR data?
  - (c) What is producing the ultra-bright sources?
7.
  - (a) What is the name of the galaxy in image 2?
  - (b) Which of the following terms apply to this galaxy: (a) radio galaxy, (b) AGN, (c) starburst d) elliptical (e) peculiar
  - (c) Is image 31 or 32 a general spectra for this type of galaxy?
  - (d) Why?
  - (e) What process produced the current status of this galaxy?
8.
  - (a) List the following methods of calculating cosmological distances from nearest to furthest using the designated letter: (A) Type Ia SNRs, (B) Period-Luminosity relationship, (C) Hubble's Law, (D) spectroscopic parallax.
9.
  - (a) What is the name and location of the radio object(s) in image 7?
  - (b) What type of object(s) is it?
  - (c) What will eventually happen to this object(s)?
  - (d) When this event happens what type of phenomena will result?
  - (e) The galaxy in image 4 contains an object that produced this same type of phenomena. What is the name of this galaxy?

10.
  - (a) What is the name of the X-ray object in image 19?
  - (b) What are the brightest sources called?
  - (c) What have these sources been determined to be?
  - (d) How many of these objects have been found in the Milky Way Galaxy?
11.
  - (a) What image is an optical image of the X-ray object in Question 10 above?
  - (b) What type of activity is taking place in the red/pink areas?
  - (c) Which of the two spectra shown in image 23 (A or B) shows the rate of star formation in this type of galaxy and why?
12.
  - (a) What image shows Sag A\*?
  - (b) This image is a composite from what two wavelengths?
  - (c) These observations give the best evidence yet for the presence of what suspected feature?
  - (d) What more prominent feature may indicate a secondary outflow of materials surrounding the feature named in part (C) above?
13.
  - (a) What is the name of the object(s) illustrated in image 20?
  - (b) What is carving out the cavities in the plasma surrounding the central galaxy?
  - (c) What is happening to the material around the cavities?
  - (d) How is this activity affecting the rate of star formation?
14.
  - (a) What is the name of the object that resulted from a merger of two neutron stars within the object in image 4?
  - (b) What type of phenomena is it?
  - (c) The observations provided the first evidence that this type of event produced what type of radiation?
  - (d) The emission of this type of radiation provides the missing link between this type of phenomena and what type of radiation?
15.
  - (a) The Tully-Fisher relationship correlates what two characteristics?
  - (b) What is the number of the image that shows a plot of this relationship?
  - (c) What does the separation on this image show?
  - (d) What objects were used to calibrate this relationship?
16.
  - (a) What is the name of the object in image 9?
  - (b) What types of systems are located in this object?
  - (c) What type of phenomena will these systems eventually provide?
17.
  - (a) What is the name of the galaxy in image 11?
  - (b) What type of evidence showed that the energy produced by this galaxy is from an explosion of star formation instead of a supermassive black hole?
18.
  - (a) What is the name of the observation shown in Image 8?
  - (b) What evidence originally calculated from this observation proved to be flawed and therefore unproven?

## Section B

Each subpart is worth 2 points. Be sure to use image sheet B. For calculations, just write the final answer (be sure to answer in the units requested).

19. Image 1 shows a JS9 visualization of data collected by the Hubble Space Telescope.
- (a) What is pictured?
  - (b) Image 2 shows the  $x$ -projection (taken via arithmetic mean) of the data in the green box. The  $x$ -axis of the graph represents the pixel number, starting from the left edge of the box. What does the  $y$ -axis measure?
  - (c) Observe the color scale at the bottom of image 1. What kind of scaling function is being used (i.e. linear, quadratic, cubic, logarithmic, sinh, or something else)? Why might this kind of scale make sense for astronomical data?
  - (d) What band of light was most likely captured in this image? Hint: consider the telescope.
  - (e) After messing with the color scale some more, you end up with image 3. Your friend notices the dark region encircled in image 3 and says, "If you had taken this image in infrared, that would be one of the brightest parts in the image!" Is she right? Why or why not?
20. Consider a binary system involving an evolved star and a black hole. The average separation between the two is determined to be 3 AU, and the orbital period is 0.8 years.
- (a) What is the total mass of the system, in solar masses?
  - (b) How hot (in Kelvin) does the accretion disk have to be if the thermal radiation peaks in the X-ray band? (A range of answers will be accepted.)
  - (c) The temperature of the disk depends on distance from the black hole:  $T \propto r^{-1/2}$ . Your friend predicts that the majority of the disk luminosity will come from the outer regions of the disk, since there's more gas to emit radiation. Is she right? Explain why or why not.
21. Determining the distances to galaxies is important in astronomy, and there are a lot of different techniques to do it.
- (a) Consider a Type I Cepheid with a period of 25 days, and an average apparent magnitude of 19.1. Using image 4, estimate its distance, in parsecs.
  - (b) Suppose the measurement of the peak apparent brightness of a type Ia supernova had an uncertainty of  $\pm 0.5$  magnitudes. What is the corresponding uncertainty in distance? Express your answer as a ratio between the upper and lower error bounds.
  - (c) Imagine that you tracked a type Ia supernova and determined its distance. But then, your friend (who works at a gravitational wave lab) says that he measured a gravitational wave "chirp" originating from the supernova. (Let's say that this is in the future, where gravitational wave detectors are much more sensitive than they are today.) Is this information relevant (i.e. should you modify your distance calculation)? Why or why not?
  - (d) The 21-cm line of a distant spiral galaxy is shown in image 5. (Warning: read the  $x$ -axis carefully.) Estimate the distance to the galaxy, in megaparsecs. Hints: The 21-cm line has a wavelength  $\lambda = 21.106$  cm. Use  $H_0 = 72 \text{ km s}^{-1} \text{ Mpc}^{-1}$ . Be sure not to round too soon!
  - (e) Using both image 5 and the Tully-Fisher relation shown in image 6, estimate the mass of the galaxy, in solar masses.

## Section C

Each subpart is worth 3 points, unless otherwise specified. Be sure to use image sheet C.

22. A luminosity function is a “distribution” representing how many objects exist at a certain luminosity, with the amount on the y-axis and the luminosity on the  $x$ -axis. Image 1 shows a simulation of luminosity functions of white dwarfs for a galaxy at different ages between 8 Gyr and 16 Gyr, each depicted as a different curve. Notice how the curves show practically no dependence on age towards the beginning but diverge considerably at lower luminosities.
- (a) As white dwarfs age, what happens to their temperature and luminosity?
  - (b) Which curve (A or B) represents the galaxy when it is younger?
  - (c) Curve A has a distinct lack of extremely dim white dwarfs, while the Curve B has significantly more. From a stellar evolution perspective, briefly explain why.
  - (d) In the interval  $0 > \log(L/L_{\odot}) > -4$ , the luminosity function appears to be strictly increasing. Why is this so?
23. The Schmidt law is an empirical relation between gas surface density and star formation rate (SFR) in galaxies, first examined in 1959 by Maarten Schmidt. In his paper, he suggested that gas density and SFR are related as such:

$$\Sigma_{SFR} \propto (\Sigma_{gas})^n$$

Data from 15 galaxies (some normal spirals and some starbursts) have been given in image 2.

- (a) Based on the data, would you expect  $n$  to be greater than 1 or less than 1?
  - (b) Give a brief qualitative explanation for the physical basis of Schmidt law. Based on this, would you expect starburst galaxies to have higher or lower gas surface densities than their normal spiral counterparts?
  - (c) The SFR for the starburst galaxies in this sample were derived from measurements of their FIR luminosities (LFIR). Explain why astronomers can use FIR luminosities to derive SFRs for starburst galaxies with reasonable accuracy, but not with normal spiral galaxies.
  - (d) (6 points) Image 3 shows a comparison of FIR and Br $\gamma$ -derived SFRs for starburst galaxies. The solid line shows the correlation expected if the two sets of SFRs were equivalent. An astronomer looks at this plot and notices that the FIR-derived SFRs appear to be higher than their Br $\gamma$ -derived counterparts.
    - i. What is a physical limitation of Br $\gamma$  which could account for the discrepancies between FIR-derived SFRs and Br $\gamma$  SFRs?
    - ii. What is an observational limitation which could account for the discrepancies between FIR-derived SFRs and Br $\gamma$  SFRs?
24. One way of helping answer the age-old question of “where did we come from?” is to observe the progenitors of our own galaxy, the Milky Way. In order to look far back in time, we have to look for galaxies far away, which can get difficult. One creative way of finding these distant galaxies is by looking for objects that seem to “drop out” when we image them in different filters (wavelengths). Image 4 shows the spectra of two distant galaxies, labelled A and B.
- (a) Both galaxies are receding at very high velocities due to the expansion of the universe, which causes their spectra to get redshifted. If their radial velocities relative to us were zero, at what wavelength would we notice the “break” in the spectra? What causes this “break” in the spectra?
  - (b) Based on image 4, what are the redshifts of each galaxy? Which one is further away?
  - (c) An astronomy student attempts to use this method to investigate nearby galaxies with a ground-based telescope. They search for a “break” in the spectrum, like the one shown in image 4, but are unable to find any useful information. Why is this so?
  - (d) Let’s put it all together. Suppose you examine a patch of the sky and collect the pictures shown in image 5, each taken through different photometric filters, denoted by the letters U, B, V, and I. Estimate the upper and lower bounds for the distance to this galaxy (shown by the yellow arrow), in megaparsecs.

**Answer Sheet**

- |        |         |
|--------|---------|
| 1. (a) | (e)     |
| (b)    | 10. (a) |
| (c)    | (b)     |
| (d)    | (c)     |
| 2. (a) | (d)     |
| (b)    | 11. (a) |
| (c)    | (b)     |
| 3. (a) | (c)     |
| (b)    | 12. (a) |
| (c)    | (b)     |
| (d)    | (c)     |
| (e)    | (d)     |
| 4. (a) | 13. (a) |
| (b)    | (b)     |
| (c)    | (c)     |
| 5. (a) | (d)     |
| (b)    | 14. (a) |
| (c)    | (b)     |
| (d)    | (c)     |
| (e)    | (d)     |
| 6. (a) | 15. (a) |
| (b)    | (b)     |
| (c)    | (c)     |
| 7. (a) | (d)     |
| (b)    | 16. (a) |
| (c)    | (b)     |
| (d)    | (c)     |
| (e)    | 17. (a) |
| 8. (a) | (b)     |
| 9. (a) | 18. (a) |
| (b)    | (b)     |
| (c)    |         |
| (d)    |         |

19. (a)

(b)

(c)

(d)

(e)

20. (a)

(b)

(c)

21. (a)

(b)

(c)

(d)

(e)

22. (a)

(b)

(c)

(d)

23. (a)

(b)

(c)

(d) i.

ii.

24. (a)

(b)

(c)

(d)