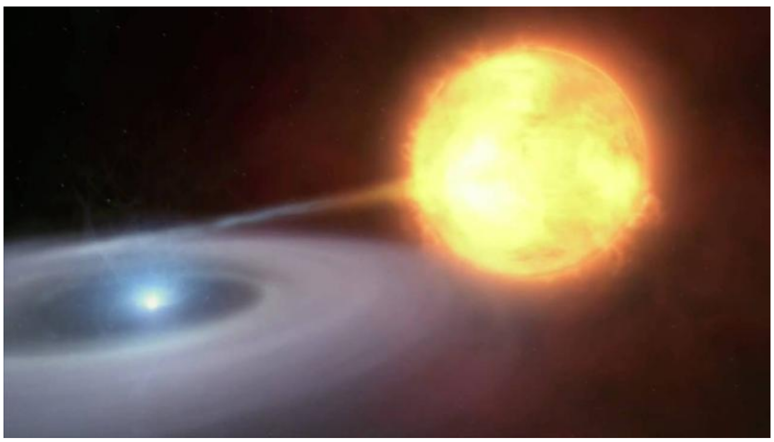
Science Olympiad

Astronomy C Division Event

Type Ia Supernovae and Stellar Evolution

SSSS 2016



Written by Aditya Shah (Adi1008)

Seven Lakes High School

School name: ____

Student name(s): ____________________ and ________________________

Team number: ______________________________

Note: At the time of writing, there were no released rules for the 2016-17 season. As a result, there aren't any specific DSO questions and the test focuses white dwarfs, Type Ia supernovae, and planetary nebulae, as I don't know what the specific topics will be.

If you have any questions/concerns, please contact me at adityashah108@gmail.com!

Good luck!

All questions are one point, unless stated otherwise! There are a total of 100 points

1)
   a) Which type of object is shown in Image 1?
   b) What letter on the HR Diagram shows the location of the star in the center of this object?
   c) Given the location the central star of this planetary nebula on the HR diagram, is its radius smaller or larger than that of the Sun?
   d) Suppose that the central star used to have a mass similar to that of the Sun. What letter on the HR Diagram shows the location of the type of pre-main sequence star that would evolve into **this sun-like star**?
   e) Which image shows a light curve for this type of pre-main sequence star?
   f) After this sun-like star leaves the main-sequence, what type of variable star will it become?
   g) Which letter(s) on the HR Diagram show the location of this type of variable star?
   h) What image shows the behavior of this type of variable star?
   i) Place the following images in order from youngest to oldest: 1, 3, 12, 13, 14, and 15 (3)
2) Image 4 shows B, V, (B - V), and (U - B) observations of SN 1986G in NGC 5128, plotted as a function of time, in Julian Date, taken from Phillips et al (1993). Image 5 shows the idealized light curve of a Type Ia supernova, plotting B magnitude vs. time, also taken from Phillips et al (1993). The parameters shown are the ones defined by Pskovskii (1977, 1984).
   a) On approximately what date, in the Gregorian calendar, was the peak luminosity of this supernova? (3)
   b) What is the peak apparent B magnitude for this supernova?
   c) What is the peak absolute B magnitude of this supernova? Hint: Type Ia supernovae don't all have the (exact) same peak absolute magnitude! (4)
   d) As established in 3(b), although all Type Ia Supernovae have similar absolute magnitudes, they are not exactly the same. What characteristic of a Type Ia supernova's light curve is directly related to its peak absolute magnitude? In your answer, include applicable terms found in Image 3: β, γ, B_{max}, B_{bend}, t_{max}, and t_{bend}. (5)
   e) Suppose that in another Type Ia supernova, SN 2016, β, the initial decline rate, is steeper (i.e. the B magnitude declines faster initially) than that of SN 1986g. Does that mean β for SN 2016 is greater than or less than β for SN 1986g? (3)
   f) How far away from Earth is this supernova, in parsecs? Use the B magnitudes and assume that interstellar extinction is negligible! (2)

Questions 3 and 4 will regard a distant planetary nebula that has just been discovered, and the astronomers are eager to determine some of its properties! The planetary nebula is in the Milky Way, but still very far from Earth.

3) An analysis of its [O III] forbidden line (assume λ = 500.7000000 nanometers) shows it to be redshifted to λ = 500.7006676 nanometers.
   a) How fast is the planetary nebula moving away from the observer on Earth, in meters per second?
   b) One astronomer suggests using trigonometric parallax to determine the distance. Why would this approach not work? (3)
   c) Another astronomer looks at the recession velocity and proposes using Hubble's Law to determine the distance to this planetary nebula by simply dividing the recession speed by the Hubble constant. Why would this approach not work? (4)
   d) The [O III] line has a special significance in determining the distance to a planetary nebula. What famous method uses this forbidden line?
   e) Image 6 shows a graph of this relation. Is this relation linear, quadratic, or exponential?
   f) Would the method found in 4(d) be suitable for determining the distance to this PNe? Why or why not? (3)

4) After deliberating on many different ways to determine the distance to this PNe, the team comes across the Hα S-r relation, which appears like it may work. Images 7 and 8, both from Frew (2015), show graphs involving this relation, with radius of the PNe plotted on the x-axis and energy flux plotted on the y-axis. Image 8, specifically distinguishes between galactic and extragalactic PNe.
   a) According to either image, are bigger PNe brighter or fainter in the Hα band? (3)
   b) What do the colored shapes in the top right corner of Image 7 represent? (2)
   c) Is the y-axis dependent on distance? (4)
   d) Why is using the Hα emission line in advantageous? Give two reasons. (1 point for each reason)
   e) According to Image 8, does this method seem suitable for determining the distance to this PNe? (2)
   f) Briefly explain the steps the team of astronomers would take to determine the distance to this object using the Hα S-r relation, even if this method is not suitable for this specific PNe (5)
   g) For this PNe, log S(Hα) ≈ -0.375 and angular diameter $\theta = 1.8336$ arcseconds. How far away is this PNe, in light years? (3)
   h) What does the size of this PNe imply about the age relative to the other PNe plotted in Images 7 and 8? I.e., is this PNe older or younger than the majority of PNe plotted in Images 7 and 8?
   i) Suppose that additional observations indicate that this PNe expands at a rate of 23 km/s. Assuming that this expansion rate is constant and that the planetary nebula is circular, how old is this PNe, in years? (3)
   j) 100,000 years later, an alien civilization decides to observe this same patch of sky using these astronomers' star chart. To their surprise, they don't see this PNe! In fact, after analyzing countless record, they realize that astronomers have never observed a planetary nebula older than about 50,000 years old. Why is this so? (2)

5) A Type Ia Supernovae is observed. It's determined that the absolute magnitude of this supernova is -19.3, and when observed from Earth, the apparent magnitude is 8.
   a) At first, the team of discoverers thinks that interstellar extinction is negligible. Using this assumption, how far away is this supernova, in kiloparsecs?
   b) After further observation, the team learns that a planetary nebula 0.5 kiloparsec thick is in the line of sight, accounting for extinction at a rate of 1.5 magnitudes per kiloparsec. How far is the supernova in reality? (3)
   c) Based on these distances, is this supernova in the Milky Way?

Questions 6 and 7 deal with a binary star system of two stars, X and Y, where one is a white dwarf! Records from an ancient alien civilization show that Star X is more massive than Star Y, but that's all it tells us.

6) Image 11 shows the apparent motion of the two members, X and Y
   a) Which line (A, B, or C) shows the path of Star X?
   b) What does the dashed line in the center represent?
   c) About how many revolutions are shown in this figure? (3)
   d) What is the length of a period for this system? (2)
   e) During the years right before and after 1940, was Star X at periastron or apastron? (2)
   f) During the years right before and after 1940, was Star Y at periastron or apastron? (2)
   g) During which years (give a range) was Star Y traveling with its lowest orbital velocity? (2)
   h) Suppose that for Star X, the sum of the distances at apastron and periastron is twice that of the difference between apastron and periastron. What is the eccentricity of its orbit? (2)
7) Suppose that now after a series of observations astronomers have deduced some properties of this pair of stars. The parallax angle of this system is 0.0555…". The mean separation of these two stars appears to be 1.11".
   a) How far away is this system, in parsecs?
   b) What is the semimajor axis of this binary star system, in AU? (2)
   c) What is the sum of the masses of these two stars, in solar masses? Use the period you calculated from 6(d). (2)

d) Analysis of the radial velocities, of these two stars found from looking at how redshifted their spectra were, shows that $v_x/v_y = 0.2800$. Assume (incorrectly) that both stars have a constant speed throughout their orbit, i.e., the orbit is circular. What are the masses of Star X and Star Y? (2)
e) Which star is the white dwarf? (2)
f) Which letter on the HR Diagram shows the location of Star X?
g) Will this star eventually evolve into the type of star at A?