## Science Olympiad
## UT Invitational
### October 25, 2025

# Astronomy C Walkthrough

In this walkthrough, we will go over some select questions from each section. References to various sources (e.g., online material, textbooks) are included to guide the reader towards resources to learn the concepts more in depth. We hope readers find it useful.

# Reference Page

Deep-Sky Objects:

- The Orion Molecular Cloud Complex,
- Sharpless 29 (NGC 6559),
- Ophion Star Family,
- HP Tau,
- Mira (Omicron Ceti),
- Helix Nebula (NGC 7293),
- Janus (ZTF J203349.8+322901.1),
- WDJ181058.67+311940.94,
- The Crab (M1),
- The Bone (G359.13),
- Cas A,
- Tycho's SNR.

Conversions and Constants:

$$1\,\mathrm{au} = 1.496 \times 10^{11}\,\mathrm{m}$$
$$1\,\mathrm{ly} = 9.461 \times 10^{15}\,\mathrm{m}$$
$$1\,\mathrm{pc} = 3.086 \times 10^{16}\,\mathrm{m}$$
$$1\,\mathrm{yr} = 365.25\,\mathrm{d}$$
$$1\,\mathrm{d} = 86\,400\,\mathrm{s}$$

$$1\,\mathrm{R}_\odot = 6.957 \times 10^{8}\,\mathrm{m}$$
$$1\,\mathrm{M}_\odot = 1.989 \times 10^{30}\,\mathrm{kg}$$
$$M_{\mathrm{bol},\odot} = +4.75\ \text{(abs. mag.)}$$
$$1\,\mathrm{R_J} = 7.149 \times 10^{7}\,\mathrm{m}$$
$$1\,\mathrm{M_J} = 1.899 \times 10^{27}\,\mathrm{kg}$$
$$1\,\mathrm{R}_\oplus = 6.378 \times 10^{6}\,\mathrm{m}$$
$$1\,\mathrm{M}_\oplus = 5.972 \times 10^{24}\,\mathrm{kg}$$

$$G = 6.674 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$$
$$b = 2.898 \times 10^{-3}\,\mathrm{m\,K}$$
$$\sigma = 5.670 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$$
$$h = 4.136 \times 10^{-15}\,\mathrm{eV\,Hz^{-1}}$$
$$H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$$

## Section A: Stars! [23 points]

1. [1 pt] The sun is classified as a G2V star under what widely-used stellar classification scheme?

   A. Harvard system
   B. Secchi classification
   C. Draper system
   **D. Morgan–Keenan system**

2. [2 pts] In this classification scheme, Roman numerals are used to denote different luminosity classes. Match each luminosity class (I, III, IV, V, VII) with its corresponding star type:

   - White dwarf — **VII**
   - Giant — **III**
   - Main sequence — **V**
   - Subgiant — **IV**
   - Supergiant — **I**

3. [1 pt] The Chandrasekhar limit is the upper bound mass to what astronomical object?

4. [1 pt] The Tolman–Oppenheimer–Volkoff limit is the upper bound mass to what astronomical objects?

> **Solution:** *(by Robert)*
>
> White dwarf and neutron star. Understanding all stages of stellar evolution is particularly important this year. Here are some resources introducing stellar remnants: basic (Archived) and intermediate.

5. [2 pts] Order these five wavelength regimes by <u>increasing frequency</u>:

   - Visible
   - Infrared
   - Gamma
   - Microwave
   - Far ultraviolet

> **Solution:** *(by Robert)*
>
> In order of increasing frequency (or decreasing wavelength): Microwave, Infrared, Visible, Far ultraviolet, and Gamma. Half credit was given if any one pair of regimes was swapped.
>
> Everything we know about the stars comes from the light we receive from them, so understanding the electromagnetic spectrum is critical, and leads us to multiwavelength astronomy!

The following five (5) questions refer to the Hertzsprung–Russell (HR) diagram in Image 1.

6. [1 pt] Which letter is closest to where our sun would be on this diagram? **B**

7. [1 pt] Which letter is closest to where our sun would be in about 5 billion years? **F**

8. [1 pt] Which letter is closest to where our sun would be in about 10 billion years? **I**

9. [1 pt] Which letter is closest to where a red dwarf would be on this diagram? **A**

10. [1 pt] What is the name of the red dashed line? **Main sequence**

**Solution:** *(by Ryan)*

Hertzsprung–Russell (HR) diagrams plot stars' luminosities against their temperatures, and the resulting plot can yield a lot of information about stars in our galaxy, including their size, how common each type is, and how they evolve.

The sun is about 5800 K and exactly 1 solar luminosity ($L_\odot$). The closest letters to that point on the diagram are B and D. Although D's temperature may be slightly closer to that of the Sun's than B's, D's luminosity is between $10^0$ and $10^1$ solar luminosities, meaning that it is a few times brighter than the Sun. Therefore, B is closest to where our sun would be on the diagram.

In 5 billion years, our sun will expand into a red giant, with a temperature of 3000 K (similar to that of red dwarfs) but a luminosity of hundreds to thousands of times that of our Sun. This would place it close to letter F on the diagram.

In 10 billion years, our sun will become a white dwarf, meaning that it will be quite hot but with a low luminosity (white dwarfs are around the size of Earth, much smaller than other stars). It would be on the bottom right of the diagram.

A red dwarf has a low temperature ($\sim$3000 K) and a low luminosity. They would be on the bottom right of the diagram, denoted by A.

Stars spend most of their lives on the main sequence, and therefore the main sequence line is the most prominent feature on an HR diagram.

11. [2 pts] Can brown dwarfs be plotted on an HR diagram? If so, what general area would they be in Image 1?

**Solution:** *(by Ryan)*

HR Diagrams plot temperature against luminosity, so anything with those two parameters, including brown dwarfs, could be plotted on an HR diagram. Brown dwarfs are even cooler and fainter than red dwarfs, so they would be further to the bottom right than the letter A. They wouldn't even fit on the provided diagram!

12. [2 pts] HR diagrams don't necessarily require temperature or luminosity themselves on the $x$- and $y$-axes—a diagram with parameters that relate to temperature and luminosity will work just as well. Name a potential set of $x$- and $y$-axis parameters that could be used.

**Solution:** *(by Ryan)*

A quick search of HR diagrams online reveals that there isn't really a standard for which parameters to use on the $x$ and $y$ axes——temperature is often replaced with spectral classification, which is itself defined by temperature. Understanding the differences between the spectral classes and their temperature ranges is important.

Another more obscure parameter is the B-V index, which is the measurement of how much light is emitted in blue wavelengths vs. visual (green) wavelengths. Hotter stars will have a lower B–V index (sometimes going into the negatives), while colder stars will have a higher B–V index. Therefore, the

B–V index could also work for the $x$-axis, although it wouldn't really be as informative as spectral class or temperature.

Luminosity on the $y$-axis is often replaced with absolute magnitude, which measures how bright the star would be at a distance of 10 parsecs. Brighter stars have a lower absolute magnitude, while dimmer stars are higher. Apparent magnitude, flux, and intensity could technically work as well, but these are all measurements of brightness that account for extrinsic properties such as the distance to a star, while an HR diagram should use a star's intrinsic properties.

Hertzsprung–Russell diagrams are a perennial topic in Astronomy and you'll find them on most tests, so it's important to have a good grasp on how they are plotted and what information they provide. Some more information about HR diagrams can be found here and here.

Spectra of two objects are depicted in Image 2. Use the spectra to answer the following three (3) questions.

13. [1 pt] What idealized object closely approximates the spectra?
14. [2 pts] Name the non-ideal features apparent in the spectra. Describe the process (at the atomic level) through which they are created.
15. [2 pts] Which object is warmer? Explain why.
16. [2 pts] Image 3 depicts the spectra of another two objects. Why can't you approximate them by the idealized object in question 13?

**Solution:** *(by Robert)*

This set of questions tested understanding of blackbody radiation—in particular, the different laws that govern/describe them. Blackbodies are idealized objects from physics that *absorbs all incident radiation* and, in thermal equilibrium, emits radiation according to Planck's law. Since reality is not ideal, non-ideal features are often seen when we collect the spectra of stars. Most notably, we see emission and absorption lines, and in this case, we see absorption lines which form from the absorption of photons at a particular wavelength by atoms that are energizing (lifting an electron to a higher energy level). Learn more about these lines here and here.

Some key facts about blackbody spectra:

- The spectrum is completely defined by one parameter: temperature.
- The wavelength at peak intensity decreases with increasing temperature. The exact relation is governed by *Wien's law*.
- The intensity at a fixed wavelength increases with the temperature of a blackbody. In other words, a hotter blackbody emits more intensely at *all* wavelengths than a cooler one.
- A corollary of the previous fact is that the *total* energy emitted by a blackbody increases with temperature. The exact relation is governed by the *Stefan–Boltzmann law*.

Understanding these qualitative relations for blackbody radiation will take you far! Here are some interactive simulators of blackbody spectra: PhET and UNL Astronomy. Also, you can read more about blackbodies in §3.2 of *A Student's Guide to the Mathematics of Astronomy* (2013) written by Daniel Fleisch and Julia Kregenow (hereafter referred to as GMA).

With these relations, we can conclude object A is warmer and the configuration of the two spectra in Image 3 would be impossible if they were both blackbodies. Perhaps some other physical phenomenon is at play here!

Many teams mentioned that the "shape" of the spectra in Image 3 were different. This explanation wasn't accepted because simply mentioning the shape is too vague. Also, many teams used the reasoning that there were no absorption lines. This wasn't accepted since Q14 specifies those features are *non-ideal*, so they are not a part of the idealization.

## Section B: Star Birth [25 points]

The following six (6) questions refer to the object in the cover image.

17. [1 pt] Identify the object.

18. [1 pt] What is the name of the bright red circular structure on the right side of the image?

19. [1 pt] What is the name of the red arc-like structure on the left side of the image?

20. [1 pt] What is suspected to have caused the aforementioned structures to assume their circular shape?

21. [2 pts] This object is one of the largest areas of stellar formation in our vicinity. What wavelength of light would be best suited to study this area, and why?

22. [2 pts] How old is this object? What would the stars and gas in this object look like in a few million years' time?

**Solution:** *(by Ryan)*

The famous Orion Nebula is part of a much larger Orion Molecular Cloud Complex (OMCC) which actually spans the majority of the constellation. The bright red structure on the right side is the Lambda Orionis Ring, and the red arc-like structure of the left is Barnard's Loop. These large structures were likely created by the shockwaves of past supernovae ramming into the gas from the molecular complex. These structures are still expanding, and in a few million years, they will have dissipated into the field and become too faint to detect. More information about the OMCC can be found here and here.

23. [1 pt] Name the cold, dense regions of gas and dust that lead to star formation.

24. [2 pts] As gas and dust collapses into protostars, gravitational potential energy is released. What is the energy first converted into?

25. [2 pts] This process eventually forms groups of stars like the Ophion star family. What unique property makes it different from other stellar families?

These regions are primarily (by mass) composed of $H_2$ which is difficult to detect directly due to their low temperatures.

26. [1 pt] What other abundant, simple molecule is often used as a tracer for $H_2$?

27. [1 pt] What wavelength is used to detect them?

**Solution:** *(by Robert)*

Foundations of Astronomy, 14e[1] (2019) by Michael A. Seeds and Dana E. Backman (hereafter referred to as Seeds) is a useful, all encompassing resource to get an introduction to astronomy. §11-1 gives an overview of star formation from the interstellar medium (ISM) and the sidebar on p. 211 mentions the use of CO as an $H_2$ tracer.

Some sources on the Ophion star family: ESA article (primer) and source paper (advanced).

[1] It's not impossible to find a *free* PDF of it somewhere...

For the following two (2) questions, use the following information. Two mass functions are evaluated for two star clusters formed from identical regions of gas and dust, and are plotted in Image 5. A mass function represents the distribution of masses for a population of stars; in these plots, each bar represents the relative number of stars ($y$-axis) at a particular mass ($x$-axis). For example, there are 100 times more $1\,\mathrm{M}_\odot$ stars than there are $4\,\mathrm{M}_\odot$ stars in cluster B.

28. [3 pts] What is the mass ratio of cluster A captured in low-mass stars (less than 2 M)?

29. [3 pts] Which cluster is older? Justify your answer.

**Solution:** *(by Robert)*

To find the mass ratio of low-mass stars, we calculate the (relative) mass of the entire cluster and the (relative) mass of the low-mass stars. Let's suppose there is one $100\,\mathrm{M}_\odot$ star. Then there are 100 $20\,\mathrm{M}_\odot$ stars, 1000 $4\,\mathrm{M}_\odot$ stars, 10,000 $1\,\mathrm{M}_\odot$ stars, and 100,000 $0.1\,\mathrm{M}_\odot$ stars. With this, we get

$$\begin{aligned}\frac{M_\mathrm{low}}{M_\mathrm{tot}} &= \frac{10^4 \times 1\,\mathrm{M}_\odot + 10^5 \times 0.1\,\mathrm{M}_\odot}{1 \times 100\,\mathrm{M}_\odot + 10^2 \times 20\,\mathrm{M}_\odot + 10^3 \times 4\,\mathrm{M}_\odot + 10^4 \times 1\,\mathrm{M}_\odot + 10^5 \times 0.1\,\mathrm{M}_\odot} \\ &= \frac{2 \times 10^4\,\mathrm{M}_\odot}{2.61 \times 10^4\,\mathrm{M}_\odot} = \boxed{0.766 = 76.6\,\%.}\end{aligned}$$

Cluster B is older. Since the clusters are formed from *identical regions of gas and dust*, we can assume that at the initial time of formation the distribution of stellar masses were identical. Now, after some unknown amount of time, we observe cluster B having a lower ratio of high mass stars. Since high-mass stars live shorter lives than low-mass stars, the older cluster would be the one with a lower ratio of high mass stars.

Some teams used the reasoning that the *total mass* of cluster B is less than that of cluster A. This explanation is wrong since the mass function is a *proportion*, and therefore does not capture any information about the total mass of the cluster, rather it only provides information about the *relative* distribution of stellar masses.

30. [1 pt] Which image depicts HP Tau?

31. [1 pt] What type of variable star is HP Tau?

32. [2 pts] Fill in the four blanks in the provided diagram of the type of star from the previous question.

**Solution:** *(by Robert)*

Image 15 is of HP Tau, a T Tauri (variable) star, and is taken by Hubble (NASA article). Image 16 is of NGC 1818, a globular cluster, and is also taken by Hubble (APOD).

In clockwise order, starting from the bottom right blank: star/protostar, accretion/protoplanetary disk, bipolar flow/jet, sunspot. Learn more about T Tauri stars: Hyperphysics (primer), SAO Encyclopedia (primer), §11-3 of Seeds (intermediate), and §8.4 of Stellar Evolution and Nucleosynthesis (2010) by Sean G. Ryan and Andrew J. Norton (hereafter referred to as SEN) (intermediate).

## Section C: Star Death [41 points]

### Setup Instructions

- Go to nso.js9.org
- Select [The Unofficial Chandra Archive Search Page] button on the right of the screen. A pop-up should appear.
- Type "4384" in the upper left box (labeled [Chandra Obs ID]).
- Click [Search].
- Then, scroll down and drag and drop the title link into the window, as shown in Image 7.
- Select [Scale > log] so you can see the image. You can also click and drag around on the image to change the contrast/bias.

Now, select [Analysis > FITS Header(s)].

33. [1 pt] Look for the "OBJECT" field. What is the name of the object shown in this observation?

34. [1 pt] What type of object is this?

Click on the circle icon in the top bar to create a circular region. Don't change the size of this region. Place this region around the central object, shown in Image 8.

35. [2 pts] What are the coordinates of this central object?

36. [2 pts] Click [Analysis > Energy spectrum]. Estimate the energy corresponding to the peak of the continuous emission, in eV.

37. [2 pts] Select [Analysis > Counts in Regions]. Record the number from the "net_counts" column.

Now, move the region to the bright knot region around the top, shown in Image 9. Again, don't change the size of the region.

38. [2 pts] Select [Analysis > Energy spectrum]. What additional feature(s) do you observe in this spectrum from the central object spectrum?

39. [1 pt] Select [Analysis > Counts in regions]. Is this knot brighter or dimmer than the central object in x-rays?

40. [2 pts] Given the type of object this is, what is likely happening in this region that results in these x-ray bright knots?

**Solution:** *(by Rio)*

TBR.

41. [1 pt] What object is shown in Image 10?

42. [1 pt] How far is this object, in parsecs?

43. [2 pts] This object is a planetary nebula, but this name is a misnomer as its extended envelope is not related to planets. How does this extended envelope form and why does it glow?

44. [2 pts] Identify the type of object at the center of Image 10 and list the two elements it is primarily composed of.

**Solution:** *(by Robert)*

The Helix Nebula is shown in UV (Chandra article) and is located around 200 parsecs away from Earth (or 650 light-years). Read more about the Helix nebula: NASA article (primer) and Chandra article (intermediate).

Planetary nebulas form in the final stages of low to intermediate mass stars as they balloon up to giant stars. As the star expands, its gravitational pull on its outermost layers weakens and they begin to shed as radiation pressure overcomes the weakened gravity. This stellar wind (physical material lost by the star) glows because it is eventually ionized by the exposed core of the star. This exposed core is what is at the center of the Helix nebula: a white dwarf, which are typically composed of a carbon-oxygen or oxygen-neon mix. §6.1 and §6.2 of SEN give an overview of planetary nebulae and white dwarfs.

45. [1 pt] Which of the following best explains why not all neutron stars are pulsars?

    A. Only neutron stars whose progenitors had a high angular momentum became pulsars.

    **B. Many neutron stars used to pulsate, but have since lost rotational energy and no longer do.**

    C. Pulsars require a lot of energy transfer from supernovae, and only the most massive progenitor stars end up as pulsars.

    D. Pulsars require mass transfer from a secondary object to generate rotational energy, and many neutron stars are not accompanied by another star.

46. [1 pt] What object is portrayed in Image 11?

47. [2 pts] This image is a composite image of infrared, visible, and x-ray light. Which three telescopes helped to create this image?

48. [1 pt] This object is an extremely young stellar remnant! What year did it form, and how old is it right now, in years?

49. [2 pts] How many revolutions per second does this object complete?

50. [3 pts] Despite being very young and energetic, many other pulsars spin even faster than this object. What are these pulsars called, and why do they spin faster despite being much older?

**Solution:** *(by Ryan)*

This image of the Crab Pulsar (Chandra article) is a composite of images taken by Chandra, Hubble, and Spitzer. It is a remnant of the supernova observed by multiple civilizations around the world in

1054 CE, and has a rotational period of 33.4 milliseconds, meaning that it completes 29.94 revolutions per second.

Even though the Crab Pulsar is one of the youngest known pulsars, there are other (often very old) pulsars that spin even faster than the Crab Pulsar—these pulsars are called millisecond pulsars (or recycled pulsars), and they spin much faster because they are accreting material from a companion star in a close binary system. This process is called Roche lobe overflow.

On Question 45, many teams chose A as the answer—while this is true, this only accounts for a small portion of the neutron stars that don't pulsate. Pulsars lose angular momentum over time and eventually stop pulsating after around 10 million years (see here), and most neutron stars in our galaxy are actually former pulsars which have now crossed the pulsar death line.

The next four (4) questions focus on Cas A.

51. [1 pt] Identify the image of it.

52. [1 pt] What type of supernova is it? Be specific.

53. [1 pt] Although this supernova formed over three centuries ago, its spectrum was recently reconstructed to confirm its classification. How was this done?

54. [1 pt] What is the main distinction between type I and II supernovae?

**Solution:** *(by Robert)*

Image 14 shows Cas A in optical, taken by Hubble (from Chandra). Image 12 is of Tycho's SNR in X-ray (from Chandra) and Image 13 is of N49 in optical, also by Hubble (from Chandra).

Cas A is a type IIb supernova which was confirmed through the observation of a scattered light echo by Spitzer (primer). Astronomers were able to reconstruct its spectrum with this data and determine information about its progenitor: Science paper and arXiv copy (advanced).

The primary distinction between type I and II supernovae is the presence (or absence) of hydrogen absorption lines. Some resources on supernovae classification: astrobites article (primer), SAO Encyclopedia, §7.1.4 of SEN (intermediate), and §13-4 of Seeds (intermediate).

55. [5 pts] Your friend Maddy has come up with a few models for the orbital motion of a double white dwarf binary system. Image 6 depicts three possible configurations of the system, with a white dwarf in blue and one in red. For each one, tell her if it is valid or not. If it is, estimate the ratio of the masses to the nearest integer (i.e., $M_{\text{blue}} : M_{\text{red}}$), and if it is not, explain to her why.

56. [1 pt] What law can be used to determine the total mass of the system?

57. [1 pt] Which object in this year's list is a double white dwarf binary?

58. [1 pt] That binary system is predicted to merge in 23 million years. What is the source/cause of the orbital decay of the system?

**Solution:** *(by Robert)*

The key fact for answering Q55 is using Kepler's 1st law: planets orbit in ellipses with the star at the focus. This result can be extended to general binary system, with each object orbiting in an ellipse with the center of mass at a focus.

Knowing this, we can conclude configuration A is invalid, since the center of mass is located at the *center* of both orbits, not at one of the foci. On the other hand, configuration B is valid and since they are in similarly sized orbits, we can conclude the ratio of their masses is 1:1. Finally, configuration C is invalid due to the stars being in an "impossible" configuration—notably with the center of mass in the wrong location. If the red star was rotated counterclockwise $\sim 45^\circ$, then this configuration could be feasible; but, as it stands, the diagram has them *out of phase*.

The total mass of a binary system relates to the period and semi-major axis through *Kepler's 3rd law*. You can read more about Kepler's laws in §2.3 of *A Student's Guide to the Mathematics of Astronomy* (2013) written by Daniel Fleisch and Julia Kregenow (hereafter referred to as GMA).

From the object list this year, WDJ181058.67+311940.94 is the only double white dwarf binary. The orbit of these two are decaying as they lose angular momentum through *gravitational wave radiation*. Read more about the binary: Smithsonian article (primer) and Nature paper (advanced).

## Section D: Star Math [16 points]

**A Twinkling Star.** Katrina runs an observatory and wants to determine some properties of a star.

59. [2 pts] Using the spectrum in Image 4, help her find the effective surface temperature of the star, in kelvin.

60. [3 pts] With her expertise, she determines the star has an absolute, bolometric magnitude of +4.75. She asks you to calculate the radius of the star, in km.

**Solution:** *(by Robert)*

Using Wien's law, we get:

$$T_{\text{eff}} = \frac{b}{\lambda_{\text{peak}}} = \frac{2.898 \times 10^6\,\text{nm K}}{500\,\text{nm}} = \boxed{5800\,\text{K.}}$$

See §3.2 of GMA. The spectrum in Image 4 (Source) is of our own sun!

The luminosity–magnitude relation is

$$M - M_\odot = -2.5\log_{10}\left[\frac{L}{\text{L}_\odot}\right],$$

where $\text{L}_\odot$ represents 1 solar luminosity and $M_\odot$ is the absolute magnitude of the Sun. (§5.3 of GMA describes the magnitude system in more detail.) Plugging in and solving, using the fact that $M_{\text{bol},\odot} = +4.75$, we find $L = 1\,\text{L}_\odot$. With this information, we can now use the Stefan–Boltzmann law to find the radius of the star (also §3.2 of GMA):

$$\frac{L}{\text{L}_\odot} = \left(\frac{R}{\text{R}_\odot}\right)^2\left(\frac{T}{\text{T}_\odot}\right)^4 \quad\Longrightarrow\quad R = 1\,\text{R}_\odot = \boxed{6.957\times10^5\,\text{km.}}$$

**Climbing the Ladder.** The cosmic distance ladder is an important arsenal of methods for measuring distances that covers the many magnitudes found in astronomy. In this problem, we'll climb up the most important rungs.

61. [2 pts] Tycho owns an observatory and discovers a bright star in the night sky. Over the course of a year, he observes an annual parallax of 200 milliarcseconds. How far away is this star, in parsecs?

Unfortunately, direct measurements—even from space—are currently limited to the order of kiloparsecs. Fortunately, Tycho discovers some variable stars in a globular cluster at a distance of 10 kpc. He notices these stars are not Cepheid nor RR Lyrae stars, so he observes them in detail and lists the apparent magnitude ($m$) and period ($P$) of four such stars in the table below.

| Star | $m$ | $P$ [days] |
|---|---|---|
| Jeff | 10.9 | 5 |
| Britta | 12.1 | 20 |
| Abed | 12.9 | 55 |
| Troy | 13.8 | 190 |

62. [3 pts] For each of the four stars, find their absolute magnitude and the base 10 logarithm of their period.

63. [2 pts] Plot these two parameters in the given space, with the base 10 logarithm of their period ($\log_{10} P$) on the $x$-axis and the absolute magnitude ($M$) on the $y$-axis. Make sure to include axes labels and appropriate tick marks.

64. [3 pts] Draw a line of best fit to the data computed above and determine a period-luminosity relationship for this class of variable stars (i.e., find the slope $\alpha$ and $y$-intercept $\beta$ for the line $M = \alpha \log_{10} P + \beta$).

65. [1 pt] Variable stars are often used as standard candles. What type of supernova is also used as one?

**Solution:** *(by Robert)*

This question tests your understanding of parallax (and §4.1 of GMA). With the parallax, we can find:

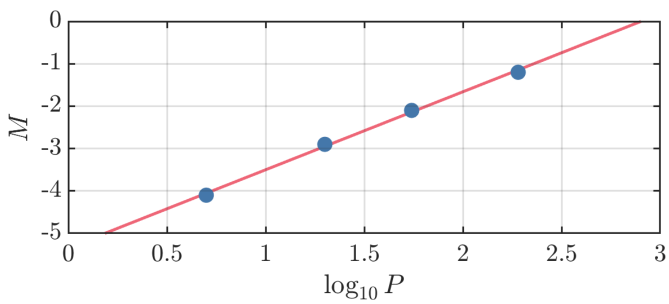
$$d = \frac{1}{p} = \frac{1}{0.2''} = \boxed{5\,\text{pc}}$$

where $d$ is the distance and $p$ is the parallax angle. Many teams forgot to do the conversion from milliarcseconds to arcseconds, so their answers were off by a factor of $10^3$.

The absolute magnitude of a star is the apparent magnitude of the star if it was at a distance of 10 pc. Since the stars are located at a distance of 10 kpc, they are $10^3$ times further away, and thereby are $10^6$ times dimmer. This corresponds to three hundredfold decreases in brightness, so a distance modulus (i.e., change in magnitude) of 15 ($M = m - 15$). The base 10 logarithm of their period is evaluated directly with a calculator. We get the filled in table below.

| Star | $M$ | $\log_{10} P$ |
|---|---|---|
| Jeff | $-4.1$ | 0.699 |
| Britta | $-2.9$ | 1.30 |
| Abed | $-2.1$ | 1.74 |
| Troy | $-1.2$ | 2.28 |

Plotting these points and fitting them linearly, we get the following figure and the parameters $\boxed{\alpha = 1.84}$ and $\boxed{\beta = -5.34.}$




Type Ia supernovae are used as standard candles due to their high luminosity and predictability. Learn more: RIT lecture notes (intermediate) and review paper (advanced).