H–R Diagram

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Introduction

The H-R diagram is the fundamental tool astronomers use to explore the birth and death of stars. Although it began as a way to group information concerning the intrinsic characteristics of stars, it quickly became a tool to explore changes within stars as they age.

The following prior knowledge on the part of the students is assumed:

- Apparent brightness is a function of the intrinsic brightness of an object and its distance from the observer.
- Hot matter radiates and we can measure the temperature by examining the distribution of this radiation.
- Stars in the night sky appear at different apparent brightnesses and colors.

The following skills are assumed:

- Ability to plot data points on a graph and to recognize patterns. This activity will easily require two 50-minute class periods.

Materials

- Table A: apparent magnitude vs. temperature table for nearby and for brightest stars
- Table B: absolute magnitude vs. temperature table for nearby stars.
- Table C: absolute magnitude vs. temperature table for bright stars.
- Table D: evaluation stars.
- Four graph paper sheets per student, with magnitude and temperature axes marked.
- Colored pens, pencils, markers, or sharp crayons to mark points.

Standards

NSES Grades 9 – 12

Science as Inquiry

- Communicate and defend a scientific argument
- Understandings about scientific inquiry
- Earth and Space Sciences
- Origin and evolution of the universe

Engage

Sing or recite "Twinkle, Twinkle, Little Star" (see appendix 1). This may sound silly, but pay attention to the prose and think about a starry sky. Imagine that you are lying on a grassy knoll, under a pitch black sky sparkling with stars. It is absolutely dark — no artificial lighting (like street or car lights) pollutes the heavens to wash out star light.

Ask students what characteristics of stars they see in their imaginary sky. Answers may be:

- brightness variation among stars
- color
- position
- twinkling
- motion, e.g., rise and set

Ask them to imagine leaving the grassy knoll and blasting off into space.

- What happens to the appearance of stars as they travel through space?

Explore

Comparison of stars as seen in the night sky

Tell students that the magnitude indicates how faint or bright the star is – the larger the number, the fainter the star. Negative numbers are brighter than positive numbers. This seems weird to us, but the ancient Greeks who made up the system called first magnitude the brightest and sixth magnitude the faintest thing they could see.

Make a diagram

Break the class into three equal groups. Group A plots the magnitudes versus temperature for the stars in Table A. Group B plots M versus temperature for the "Nearby Stars" set in Table B. Group C M versus temperature for the "Bright Star" set in Table C. Except for the sun, refrain from labeling each point as this will most likely overcrowd the diagram. It is helpful for each group to use a different color for their plot (e.g., red, blue, or black). If your students do not need practice in plotting, try group plots. You may wish each group to make their plots on overhead transparency, or to use large graph paper hung on the board for students in the group to share.

When the plots are finished, form new groups of three. Each new group will have one A, one B, and one C plot to work with.

Tell the students to compare the plots and discuss them. They may wish to hold them up to a light and align the axes. Ask if they see any patterns. Ask them if any of them plotted the same stars? (There are a few stars common to all three groups.) The correct results are shown in Appendix 2.

Specifically, for plot A:

- Do you see any patterns in the distribution of points on Plot A? Why are the values of m and M different for the same stars? (Absolute magnitude (M) is a brightness quantity corrected for distance from the Earth. It is the apparent magnitude (m) a star would have if it were 32.6 light-years from the Earth.)

For Plot B (nearby stars):

- Do you see any patterns in the distribution of points on Plot B?
- How many stars are more luminous than the sun and how many are
- less luminous in the nearby star group?
- Is this a true statement? "As the intrinsic brightness increases, so does the temperature."

(For this plot, most of the hot stars are brighter than the majority of cool stars. But this is not yet a firm relationship. The distribution varies too much across temperature and brightness.)

For Plot C (the brightest stars):

- Do you see any patterns in the distribution of points on Plot C?

Ignoring Plot A (since there is not enough meaningful information there with which to compare stars), combine Plot B and Plot C. Combining separate overhead transparencies is useful at this point.

- What patterns and features in the whole distribution do you see?

  (The major feature is a long curve stretching from hot bright stars to cool faint stars. This is called the main sequence. Most of the stars are part of this feature. The hot stars lie at the top, bright end of the main sequence, while the cool stars are at the faint end. A few stars clump in a region indicating that they are bright yet cool.)

What conclusions can you draw from your analysis of this new combined distribution of nearest and brightest stars? For instance:

- Which stars do you think are most common in the night sky?
- Which stars do you think are most common in the solar neighborhood?
- Write a paragraph describing what you have discovered about stars.

Explain

Brightness and Magnitude

Astronomers quantify the brightness of stars using a scale of magnitudes. The brightnesses of stars span a vast range of values. Our eyes and brain cope with this range by scaling our perception of light logarithmically. Astronomers do the same with the magnitude scale. For instance, the faintest stars our eyes alone may see are apparent magnitude 6. A fairly bright star like Sirius is magnitude -1.4, while the sun is a blinding -26. For each single step up or down on the magnitude scale, the brightness changes by a factor of 2.512. And for every five steps, the brightness changes by a factor of one hundred ($2.512 \times 2.512 \times 2.512 \times 2.512 \times 2.512$). So for instance, two stars at the end of the Little Dipper's bowl (Kochab and Pherkab) differ in brightness by one magnitude. Kochab has a magnitude of 3, (third magnitude star) while Pherkab is a 2^{nd} magnitude star. If you go outside at night and look north, you will see that Kochab looks about twice as bright as Pherkab. This measure of brightness is called a star's apparent magnitude because this magnitude depends on the distance between the star and the observer. If the observer moved closer to the star, the apparent magnitude would decrease, because the star appears brighter.

A more useful measure of a star's brightness is its intrinsic magnitude. Astronomers call this absolute magnitude. It is the magnitude of the star as if observed from an arbitrary fixed distance. Astronomers have chosen 32.6 light-years for this arbitrary distance. The absolute magnitude of the star is useful because it represents one fundamental property of the star – it's total energy output or luminosity. Tell the students to label the columns on the tables A, B, and C apparent and/or absolute magnitude.

The H-R diagram

Looking up into the night sky, you see thousands of stars at varying distances from Earth. The luminosity and temperature of each star varies as well. These are the reasons behind the wide range of apparent magnitudes of stars. Imagine being able to magically pull or push each star (including the sun) to a fixed distance from Earth. Your view of the night sky would change dramatically as you would easily see a pattern. The blue stars (hottest) would appear much brighter than most of the yellow, orange, and red (progressively cooler) stars on the main sequence Although a few yellow, orange, and red stars would rival the blue stars in brightness, they do not fall on the main sequence. These bright yellow, orange or red stars are known as "giant" or "supergiant" stars. Knowing this, one can plot absolute magnitude against color (indicating temperature) and create your own version of the Hertzsprung-Russell diagram, commonly referred to as H-R diagram. The H-R diagram was named after its discoverers, Ejnar Hertzsprung and Henry Norris Russell, as described in a later section.

Each point on the H-R diagram represents the state of a star, characterized by the its temperature and luminosity. These are two of the fundamental stellar properties, with the third being the star's mass. As a result, they reveal a great deal about the star's physical state. This diagram is of such importance and utility that astronomers typically refer to stars as if they exist on the H-R diagram instead of in space. They are really referring to the star's temperature-luminosity state. Astronomers mainly refer to two types of H-R diagrams. In each type, the vertical axis marks some measure of luminosity, and the horizontal axis effective temperature (the photosphere temperature of the star). An observer's H-R diagram plots absolute magnitude verses spectral type, while a theorists may prefer luminosity verses effective temperature in degrees Kelvin.

Spectral Types and Temperature

To review from "Decoding Starlight: Temperature", recall that an astronomer may refer to a star's effective temperature in terms of the star's spectral type or in degrees Kelvin (K). The effective temperature of a star has the greatest influence over the appearance of its spectrum and the star's color. From hottest to coolest, the stellar spectral types are **O**, **B**, **A**, **F**, **G**, **K**, and **M**. Numbers 0 through 9 (hottest to coolest) divide each stellar type into finer temperature bins. For example, an **A**2 star is a little hotter than an **A**7 star. The hottest stars are type **O**. With effective temperatures exceeding 25,000 degrees K, they appear blue-white. Our sun, a yellow star, is a cooler **G**2 type star with an effective temperature of 5770 K. Red **M** type stars are the coolest at about 3000 K.

Color	white	white-blue	blue	yellow	yellow	orange-red	red
Temperature (K) range	50,000–28,000	28,000–9,900	9,900–7,400	7,400–6,000	6,000–4,900	4,900–3,500	3,500–2,000
Spectral type	**O**	**B**	**A**	**F**	**G**	**K**	**M**

LUMINOSITY

The luminosity of a star (L) is related to the fourth power of its effective temperature (T^4) and surface area ($4\pi R^2$). It is a measure of energy radiating from the star. For instance, common household light bulbs list their luminosity at the top of the bulb in Watts (W). Typically, light bulbs radiate 60 W, while our sun radiates 3.9×10^{26} W. For easy comparison, astronomers refer to stellar luminosity in terms of our sun. Thus the relationship becomes: *

$$L_{star} / L_{sun} = R_{star}^2 / R_{sun}^2 \times T_{star}^4 / T_{sun}^4$$

* The Stefan-Boltzmann equation is $L=4\pi R^2 \sigma T^4$. The star's radius is R and $4\pi R^2$ is the surface area of the star in square meters. The star's photosphere temperature is T and σT^4 is the flow of energy in watts radiating from the star per square meter, where $\sigma = 5.67 \times 10^{-8}$ W / ($m^2 T^4$)

FEATURES OF THE H–R DIAGRAM

The most prominent feature of the H–R diagram is the long curve called the main sequence. It is densely crowed with points and stretches from the most luminous and hottest O stars down to the coolest and faintest M stars. In addition to their spectral type stars are also grouped into luminosity classes, which range from Roman numerals I to V. Stars on the main sequence are defined as luminosity class V. The sun is a main sequence star, so its spectral type and luminosity class label is G2 V. The main sequence feature suggests that stars spend the majority of their life cycle at a stable temperature and luminosity, or as an astronomer would say "on the main sequence." Another feature is the loose cluster of points representing stars with an absolute magnitude near zero, but with effective temperatures at or below 5500 K. Compared to the main sequence, this combination of relatively low temperature and high luminosity seems odd. This indicates that these stars operate quite differently than stars on the main sequence. Considering the relationship between luminosity, effective temperature and radius, these stars must be bigger than main sequence stars. Astronomers refer to these as giant stars, and classify them in luminosity class III. For example, Aldebaran A is a giant star with an absolute magnitude of -0.2 and effective temperature of 3500 K. Our sun has an absolute magnitude of 4.8 and effective temperature of 5770 K. Compared to our sun, Aldebaran's effective temperature is 3/5 that of our sun. But the difference in the sun and Aldebaran's absolute magnitude is 5, so Aldebaran is 100 times more luminous. What it lacks in temperature, Aldebaran makes up in size. Aldebaran's luminosity and temperature demand that its radius is 28 times larger than the sun, with a surface area 772 times bigger. So surface area (772) times the fourth power of the temperature $(3/5)^4$ leads to Aldebaran's luminosity of 100 times more than the sun or 100 solar luminosities.

The students created an H-R diagram by plotting nearby stars and bright stars. Ask students to examine their H-R diagrams and the star lists again and think about the following questions:

Which stars "stick out" in the distribution of nearby stars?
Compare and contrast the nearby stars and bright stars.
Which stars do you think are giant stars?
Which types of stars do you think are most common in the night sky?
Which types of stars do you think are most common in our solar neighborhood?

Most of the nearby stars are in the **K** and **M** stellar type temperature range, and are relatively low luminosity stars with respect to our sun. Four stars break this trend, or are outliers of the distribution of nearby stars: the Sun, Sirius, Procyon A, and Alpha Centauri A. Sirius and Procyon are both bright and nearby stars. Sirius is the brightest star in the sky, mainly because it lies so close to us at a mere 9 light years away. Procyon is only 11 light years away, and is a **F**5 V stellar type. It is cooler than Sirius, and thus less luminous. Alpha Centauri A and the Sun could be considered "twin" stars. They are the same stellar type (**G**2 V), which means they have about the same effective temperature, luminosity, and spectral characteristics. Alpha Centauri A is also one of the nearest stars to the Sun, at 4.4 light years.

The bright stars on the other hand are either very hot and luminous, or cool and luminous. Some are on the main sequence (hot and luminous), while others are giant stars (cool and luminous).

History of the Hertzsprung-Russell Diagram

Two astronomers independently published results of comparing a star's luminosity against its temperature. A Danish astronomer, Ejnar Hertzsprung published a table in 1905 listing 27 stars of known absolute magnitude and an early spectral scheme. The data showed the major trends - the main sequence and giants. Henry Norris Russell made a similar analysis (using the Harvard spectral classification system), and published his results as a diagram in 1913. On the vertical axis, he marked the absolute magnitude and on the horizontal axis the spectral type. His plot of about 200 stars also revealed the main sequence and giants, plus one unusual hot but faint star 40 Eridani B. This unusual star would later be known as a white dwarf. Another Danish astronomer, Bengt Strömgren suggested that this handy diagram be named after Hertzsprung and Russell. Strömgren also suggested investigating star clusters, which led to further understanding stellar evolution.

Extend

The H-R diagram helps astronomers visualize and understand how stars evolve. Throughout our galaxy are many clusters of stars, all the members born at about the same time. For any star cluster, its distance from Earth is far greater than its size. So an astronomer can regard each star in the cluster as the same distance from Earth, much like you can regard the citizens of a far away city as all living about the same distance from you. For example, the H-R diagram of a star cluster may show that the majority of stars lie on the main sequence, but others trace specific regions above and below the main sequence. Astronomers interpret this information as evidence that stars change over time, that is, as their internal energy source ages, their observable surface temperature and brightness change. Since all the cluster members are about the same age ("born" at the same time), some stars seem to evolve faster than others. Currently, astrophysicists and astronomers think that a star's life cycle ranges from a few millions years to billions of years.

Stars spend most of their lives in a steady state of fuel consumption, fusing hydrogen to make helium and release energy. The main sequence is the region of the H-R Diagram where stars exist in this steady state.

- How do you think the fuel consumption varies among stars of different types along the main sequence? For instance, which star consumes more fuel per second: an A star or a G star? Support your answer.

(The A star consumes more fuel per unit of time, since its effective temperature and luminosity are higher than the G star. The higher effective temperature (for stars on the main sequence) indicates greater energy output from the core of the star. Thus the fuel consumption rate must be higher.)

But when the steady diet of hydrogen fuel runs critically low, the star's internal structure and appearance dramatically change. During the star's struggle to survive it begins to use other elements as fuel sources, which increase the luminosity from the core. This in turn expands the photosphere of the star, puffing it up and changing the effective temperature. As a result, the star "leaves" the main sequence as it evolves. This phase of a star's life is called the "giant phase". In this phase, the core temperature and luminosity of the star has increased, but the effective temperature has decreased. The photosphere's bloated size gives it more area to radiate, so it cools down despite the increase in luminosity. The temperature of its core is actually hotter then when it was on the main sequence. Beyond this point, the star may continue its metamorphosis depending on its mass. Stars like our sun will blow off its outer layers while its core shrinks into a exotic, degenerate state of matter called a white dwarf. These are called planetary nebulae named after their appearance in a telescope. The central white dwarf stellar remnant appears surrounded by a bubble of rapidly expanding gas, once the outer layers and the photosphere of the star. The fate of more massive stars, greater than 8 solar masses, is far more explosive. Upon leaving the main sequence, massive stars expand into supergiants, which are brighter and bigger versions of giant stars. The star Betelgeuse in the constellation Orion is an example.

Betelgeuse has an absolute magnitude of -5.5 and an effective temperature of only 2,700 K. The sun's absolute magnitude and effective temperature are 4.85 and 5770 K. What is Betelgeuse's radius with respect to the sun?

Solution:

1. The difference in magnitudes is -5.5 - 4.85 = -10.35 magnitudes. Ten magnitudes is a factor of 100×100 or 10000 solar luminosities.
2. The ratio of effective temperatures is 2,700 / 5770 or 0.48
3. $L / T^4 = R^2$, 10000/0.05 = 200000
4. Betelgeuse has a radius of 447 solar radii, which is about the orbital radius of Mars.

Once the luminosity of the core can no longer resist the crushing weight of the star's surrounding layers, the star quickly collapses. The core becomes an incompressible degenerate ball of neutrons. The in-rushing stellar layers rebound off the core and explode into space as a supernova with the light of several million solar luminosities. What remains is a three solar mass core the size of a small city called a neutron star. The remainder of the star's mass expands into space to eventually form new stars, planets, and living things. Finally, super massive stars swallow themselves up into a black hole. The one factor controlling the lifetime and fate of a star is its mass.

Evaluate

Sing or recite "Deep in the Heart of Texas"

The stars at night
Are big and bright
Deep in the heart of Texas!

A. Which types of stars are big and bright, and why?
B. How would you expect them to appear in the night sky?

Stars appear big and bright in the sky because lots of their light gets to our eyes. They can be nearby or far away. Of the 25 nearby stars listed, only Sirius and Procyon A are more luminous (have smaller absolute magnitude) than the sun. So these two stars should be "big and bright" in our sky. Sirius is the brightest star in the night-time sky. Procyon A is only one magnitude dimmer. Consider the other stars on the nearby star list. Most of their absolute magnitudes (M) are higher than the sun, so they are less luminous. Any star with an apparent magnitude (m) greater than six (assuming a crystal clear and dark sky) will be invisible to the human eye without optical aide. With that in mind, most of the stars on the nearby list are not "big and bright", but rather "small and dim". Their apparent magnitudes are also high, so most are invisible in the sky.

However, on the bright star list, nearly every star is intrinsically brighter than the sun. But most of these stars are far away, much further than the stars on the nearby star list. Nonetheless, their apparent brightness is still well below 6, most hovering around zero. These are the "big and bright" stars. Were they also nearby (like Sirius on the nearby list) their apparent magnitudes would rival Venus (-4 in the evening or morning sky). Just look at their absolute magnitudes – that's the apparent magnitude the star would have were it only 32.6 light years away. At a mere 32.6 light years distance, the star would appear on the nearby star list.

2. Ask students to classify the stars as main sequence, giant, super giant, or white dwarf. Plotting the star on the H–R diagram will help classify the star.

Note: Alioth, Merak, and Dubhe are stars in the Big Dipper asterism, part of the constellation Ursa Major. Polaris is the north star.

3. Compare the differences in m and M for each star.

A. Which stars are far away?

If (m - M) is greater than zero, the star is far away. These stars are farther than 32.6 light years. HD 224014 is a faint looking star in the constellation Cassiopeia. But it is also a supergiant with tremendous luminosity, so it

Star	m	M	T	H-R diagram group
Pollux	1.2	1.1	4,758	Giant
Alioth	1.8	-0.2	9,520	Main Sequence
Merak	2.3	0.4	9,520	Main Sequence
Dubhe	1.8	-1.3	4,750	Giant
Polaris	2.0	-4.1	6,400	Supergiant
HD 224014	4.5	-9.5	5,200	Supergiant
ZZ Ceti	14.1	12.3	10,300	White Dwarf

can be seen from a great distance. This is the most distant star in the list, with (m - M) = 15.05.

B. Which are nearby?

If (m - M) is less than zero, the star is a nearby star. In this case, the star is less than 32.6 light years from our solar system. This distance may seem far, but compared to the size of our galaxy (100,000 light years in diameter) these stars are in our relative "back yard".

B. What is the distance for a star if m = M ?

If m = M, then the star must be 32.6 light-years away.

4. Where on the H-R diagram are the stars with the largest diameters? The smallest?

Luminosity is proportional to the star's radius squared times its temperature to the fourth power ($L \sim R^2T^4$). Consider what temperature and luminosity values would increase and maximize radius. Solving $L \sim R^2T^4$ for radius shows that:

$$\frac{L}{T^4} \text{ is proportional to } R^2$$

Since the temperature is in the denominator and raised to the fourth power, a star with low temperature may be enormous (large radius), depending on its luminosity. If the luminosity increases while the temperature decreases, the radius increases. Therefore, the largest stars on the H-R diagram are low temperature, high luminosity stars, toward the upper right corner of the diagram. Supergiant stars like Betelgeuse and Antares are good examples. They are cool stars that are also extremely luminous. They are so bloated, that our solar system up to Jupiter could fit inside these stars. At the lower left corner of the H-R diagram are the smallest stars. Stars like Sirius B and Procyon B are just the opposite of the supergiants. They are extremely hot, dense, and dim. These are white dwarf stars that are about the size of the earth, and about as massive as the sun.

The Star or
Twinkle, Twinkle, Little Star
by Jane Taylor, 1806

Twinkle, twinkle, little star,
How I wonder what you are.
Up above the world so high,
Like a diamond in the sky.
~
When the blazing sun is gone,
When he nothing shines upon,
Then you show your little light,
Twinkle, twinkle, all the night.
~
Then the trav'ller in the dark,
Thanks you for your tiny spark,
He could not see which way to go,
If you did not twinkle so.
~
In the dark blue sky you keep,
And often thro' my curtains peep,
For you never shut your eye,
Till the sun is in the sky.
~
'Tis your bright and tiny spark,
Lights the trav'ller in the dark:
Tho' I know not what you are,
Twinkle, twinkle, little star.

Ann Taylor
1782-1866
Hymns for Infant Minds, Original Poems,
Rhymes for the Nursery.
Denio & Phelps' 1st ed. Greenfield, Mass 1817.

H-R Diagram Table A

Stars	m	T Effective temperature in degrees Kelvin
Sun	-26.8	5,770
α Centarui A	0.0	5,800
α Centarui B	1.4	4,000
Barnard's Star	9.5	2,600
Wolf 359	13.5	2,400
BD +36°2147	7.5	2,700
Sirius A	-1.4	9,500
Sirius B	8.4	28,000
Luyten 726-8 A	12.6	2,500
Luyten 726-8 B	13.0	2,400
Ross 154	10.4	2,650
Procyon A	0.4	6,500
Betelgeuse	0.5	2,700
Canopus	-0.6	6,400
Arcturus	-0.1	3,900
Vega	0.0	9,700
Capella A	0.1	5,000
Capella B	0.1	3,200
Rigel A	0.2	11,000
ε Indi	4.7	4,000
Altair	0.8	7,700
Aldebaran	0.9	3,500
Spica	1.0	19,500
Pollux	1.2	4,100
Achernar	0.5	13,500

H-R Diagram Table B: Nearby Stars

Nearby Stars Less than 12 light-years away	m	M	T Effective temperature in degrees Kelvin
Sun	-26.8	4.8	5,770
α Centarui C	11.0	15.8	2,600
α Centarui A	0.0	4.4	5,800
α Centarui B	1.4	5.8	4,000
Barnard's Star	9.5	13.2	2,600
Wolf 359	13.5	16.8	2,400
BD +36°2147	7.5	10.5	2,700
Luyten 726-8 A	12.6	15.4	2,500
Luyten 726-8 B	13.0	15.8	2,400
Sirius A	-1.4	1.4	9,500
Sirius B	8.4	8.4	28,000
Ross 154	10.4	13.3	2,650
Ross 248	12.3	14.7	2,500
epsilon Eridani	3.7	6.1	4,500
Ross 128	11.1	13.5	2,600
61 Cygnus A	5.2	7.5	4,000
ε Indi	4.7	7.0	4,000
BD +43°44 A	8.1	10.3	2,950
BD +43°44 B	11.1	13.2	2,700
Luyten 789-6A	12.3	14.9	2,500
Luyten 789-6B	12.3	15.9	2,200
Procyon A	0.4	2.7	6,500
Procyon B	10.7	13.0	7,000
BD +59°1915A	8.9	11.1	2,650
BD +59°1915B	9.7	11.9	2,600

H-R Diagram Table C: Bright Stars

Bright Stars	m	M	T Effective temperature in degrees Kelvin
Sun	-26.8	4.8	5,770
Sirius A	-1.4	1.4	9,500
Canopus	-0.6	-3.1	6,400
α Centauri A	-0.3	4.4	5,800
α Centauri B	-0.3	5.8	4,000
Arcturus	-0.1	-0.3	3,900
Vega	0.0	0.5	9,700
Capella A	0.1	-0.7	5,000
Capella B	0.1	9.5	3,200
Rigel A	0.2	-6.8	11,000
Procyon	0.4	2.7	6,500
Betelgeuse	0.5	-5.5	2,700
Achernar	0.5	-1.0	13,500
β Centauri	0.6	-4.1	20,000
Altair	0.8	2.2	7,700
α Crusis A	0.9	-4.0	19,500
α Crusis B	0.9	-3.5	16,500
Aldebaran	0.9	-0.2	3,500
Spica	1.0	-3.6	19,500
Antares	1.0	-4.5	2,700
Pollux	1.2	0.8	4,100
Fomalhaut	1.2	1.6	8,720
Deneb	1.3	-7.5	9,080
β Crusis	1.3	-4.0	29,000
Regulus	1.4	-0.6	13,000

H-R Diagram Table D

Star	m	M	T Effective temperature in degrees Kelvin	Star Type Main sequence, Giant, Supergiant, or White Dwarf
Pollux	1.2	1.1	4,758	
Alioth	1.8	-0.2	9,520	
Merak	2.3	0.4	9,520	
Dubhe	1.8	-1.3	4,750	
Polaris	2.0	-4.1	6,400	
HD 224014	4.5	-9.5	5,200	
ZZ Ceti	14.1	12.3	10,300	