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Star Science in the Autumn Sky

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Be honest: Do the stars all look the same to you? If you look up at the night sky, you can see anything from dozens to thousands of them, depending on where you live. To most people, the stars are just points of light, each one like the other. To astronomers, however, stars are as varied as people. There are as many different kinds of stars in our galaxy as there are people on Earth. They come in all shapes, sizes, colors, and dispositions. And stars, like people, have their life cycles. They are born, grow up, and die (don't pay taxes, though). The study of the stars and their lives, the great *People* magazine of the skies, is known as *astrophysics*.

Astrophysics sounds imposing. Say the word at a cocktail party and see how fast the conversation grinds to a halt. *Star science*, which is what astrophysics is, sounds much more friendly. The following activities will introduce you to star science as you ramble across the autumn sky. Though the stars are distant, you can come to understand their nature by making simple observations and drawing analogies to everyday things on Earth. When you can look at a star and see more than a point of light, the night sky will come alive.

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Activity 1. Finding your way with a star map

The so-called horizon map ([figure 1](#)) shows the appearance of the autumn sky in mid-evening, as seen from the latitude of the United States and southern Canada. Hold the map in front of you so that the direction that you are facing is down. If you are facing north, for instance, hold the map vertically so that the word *NORTH* is at the bottom. The sky in front of you will correspond to the bottom section of the map. The circular border of the map represents the horizon; the center of the map represents the zenith, the point directly overhead. The dots on the map represent stars; the bigger the dot, the brighter the star.

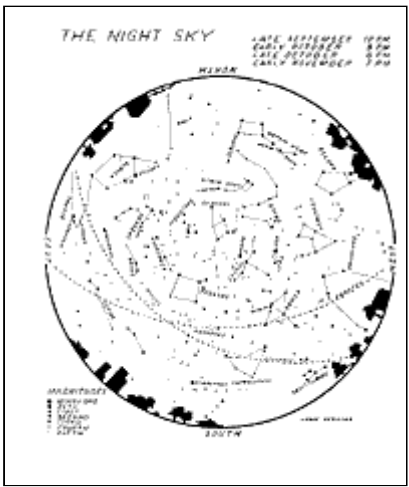


Figure 1

Road map to the autumn sky. The skies are constantly changing, but this map will guide you to the evening skies in late September to early November. It works at northern temperate latitudes. See text for instructions. Figure by John Perkins, courtesy of John Percy. Click [here](#) for a larger version.

Star maps can be confusing at first. How do you match up this dot on the paper with that point of light in the sky? As with a road map, it takes patience and practice. As with a road map, feel free to ask a knowledgeable local -- an amateur astronomer -- for directions. The best way to learn the sky is to recognize two or three key star patterns, and then use these to find other star patterns. The Big Dipper is a good place to start.

Activity 2. Exploring the Big Dipper

Face north. Hold the star map so that *NORTH* is down. You should be able to see the Big Dipper low in the sky. The Big Dipper consists of a bowl (a skewed rectangle of four stars) and a handle (a row of three stars). The Dipper is part of a larger pattern called Ursa Major, one of the 88 official constellations adopted by astronomers (see [figure 2](#)). The constellations are patterns that some people happen to see in the sky. Different cultures see different star patterns; there is nothing special about the 88 patterns we use. You can even make up your own constellations. Instead of dippers, see whether you can spot cars, TVs, or astronomy teachers.

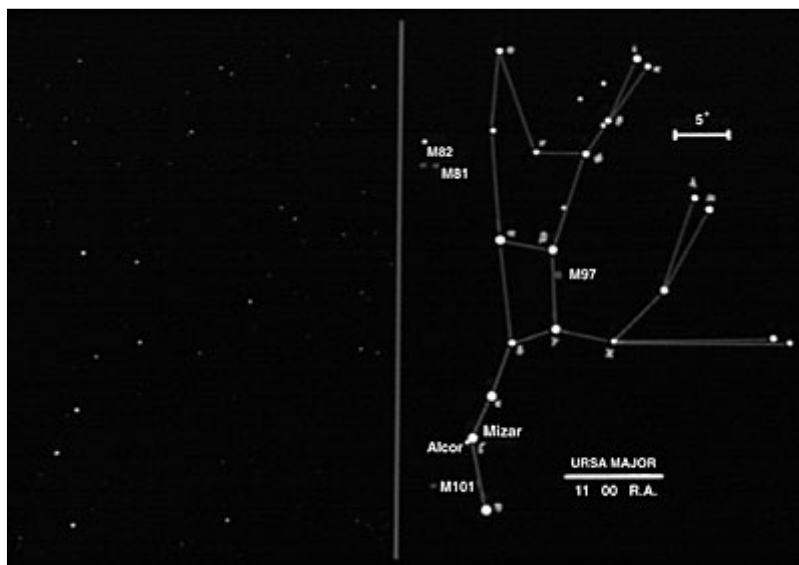


Figure 2

Ursa Major. On the left is what you actually see in the sky. On the right is a diagram of the official constellation. The Big Dipper that we know and love is the bottom left part of Ursa Major. The splotches labeled M81, M82, and M101 are galaxies; M97 is a nebula. You'd need a telescope to see these objects.

Let's take a closer look around the Big Dipper. Binoculars help, but aren't essential.

1. Follow the curve or "arc" of the handle away from the bowl. You will come to a bright star called Arcturus. A useful way to remember this is "arc to Arcturus." If you have good night vision, or binoculars, you may notice that Arcturus is slightly orange. The best time of year to look for Arcturus is late summer. On the star chart, it is located behind the church in the constellation Bootes.
2. Follow the two end stars of the bowl ("pointers" in figure 1, a and b in figure 2) out of the bowl and up the sky. After you've gone another five times the distance between these two stars, you'll come to a medium-bright star called Polaris, the North Star.
3. Look at the second star from the end of the handle of the Big Dipper. Can you see anything unusual about it?
4. Look at the seven bright stars of the Big Dipper. Is any one star noticeably brighter or fainter than the others?
5. Look at the seven bright stars of the Big Dipper. Is any one star noticeably different in color from the others?

You may have noticed that the second star in the Dipper handle is actually *two* stars close together. Their closeness is no accident: They are actually moving together through space, at the same distance from us. How do astronomers know this? They measured the distance to these stars using a clever technique called *parallax*.

Activity 3. Parallax

Hold your index finger upright at arm's length. Close your left eye, and look at your finger with your right eye. Notice its position with respect to the background. Now close your right eye and look at your finger with your left eye. What seems to happen to the position of your finger? Quickly alternate between looking at your finger with your right and left eyes, and you will see the effect of *parallax*: the apparent change in your finger's position. It happens because you're looking at your finger from slightly different perspectives (see [figure 3](#)). Now move your finger halfway to your nose and repeat the process. How does the parallax effect change? [It gets larger.]

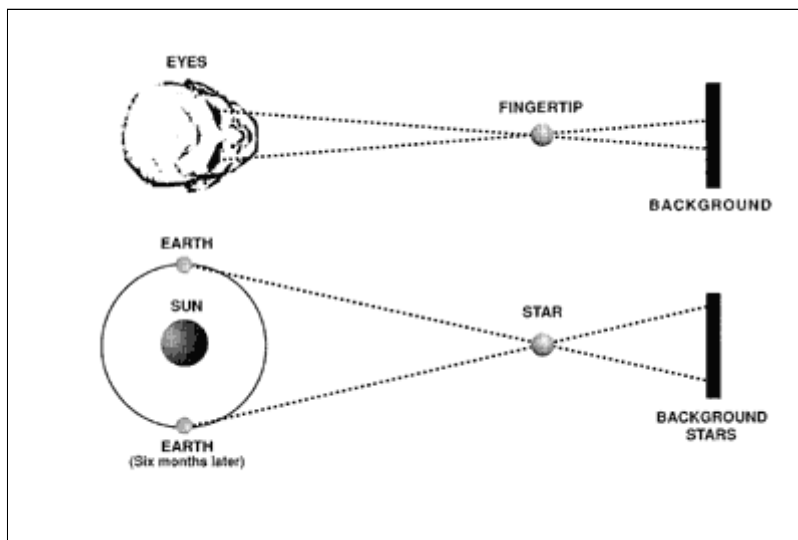


Figure 3

Parallax. This method measures distance by noticing how much an object seems to move when you look at it from different perspectives. You can use the technique to judge the distance to your finger (top) or to a star (bottom).
Figure by John Percy.

Stars, like fingers, seem to move when you look at them from different positions. In the case of stars, our vantage point changes as Earth orbits the Sun (see [figure 3](#)). When astronomers observe a star in January and again in June, they see it from opposite sides of the Sun. The star appears to change in position relative to the more distant background stars. The more distant the star, the smaller the parallax. Using simple geometry, astronomers translate parallax into distance: Distance is inversely proportional to parallax. This is how they know the stars are enormously far away.

Astronomers measure the distances of stars in *light-years*. A light-year is the distance that light travels in a year, about 10,000,000,000,000 kilometers (6,000,000,000,000 miles). The nearest star is about 4 light-years away -- or, if you like lots of zeroes, 40,000,000,000,000 kilometers (25,000,000,000,000 miles) away. At 55 miles per hour, it would take you over 10 million years to drive there, not counting stops for gas.

By using this technique of parallax, astronomers discovered that the stars -- even those in the same constellation -- are generally at vastly different distances. Two stars that look like neighbors are usually light-years apart. In some cases, though, nearby stars really are close to each other. The Big Dipper is an example. The middle five stars in the Big Dipper are at the same distance, about 65 light-years. They, along with some of the other stars in the Ursa Major region, form a *cluster* of stars moving together through space. Two other examples are the Hyades and the Pleiades.

Activity 4. Finding the Hyades and Pleiades

Face east. Hold your star map so that *EAST* is down. Notice the two tight groups of stars low in the east. If they're tough to spot, wait an hour or two until they've risen higher in the sky. The Hyades is grouped around the bright star Aldebaran, an orange star that is not part of the cluster but instead is at a different distance.

There are thousands of star clusters in our galaxy. Some are young (a few million years), others are old (a billion years or more). They are all about the same size, a few light-years in diameter. Their *apparent* size depends on their *actual* size and their distances. The same cluster, 10 times further away, will appear 10 times smaller. To measure the size, astronomers determine the angle between the direction to the bottom of the object and the direction to the top. This angle is called the *angular diameter*.



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Activity 5. Angles in the sky

What is the angle between the horizon and the zenith? [90 degrees] You can measure other angles in the sky using the following rules of thumb: At arm's length, the width of your little finger is 1 degree; the width of your three middle fingers is 5 degrees; the width of your fist is 10 degrees; the width of your outstretched thumb and little finger is 25 degrees. Using your hand as a ruler, what is the length and width of the bowl of the Big Dipper? What is the total length of the Big Dipper?

Because clusters are all about the same actual size, we can determine their distances from their apparent sizes. This gives us another handle on how distant the stars are.

Activity 6. Apparent size as a measure of distance

The Ursa Major, Hyades, and Pleiades clusters are at different distances. By measuring the angles, as in activity 5, rank these three star clusters in apparent size. How do they rank in distance? If the Big Dipper cluster is about 65 light- years away, how far away is the Hyades? [140 light-years] The Pleiades? [400 light-years] How do you know?

Stars differ not only in distance, but also in apparent brightness. In activity 2.4, you looked for the star in the Big Dipper which had a significantly different brightness from the others. It was the star that joins the handle to the bowl.

Activity 7. Ranking stars by brightness

Locate the constellation Cassiopeia. You can find it by facing north. Hold the star map so that *NORTH* is down. Find the Big Dipper and then Polaris. Cassiopeia is on the other side of Polaris from the Big Dipper. It's almost overhead in mid-evening at this time of year. It looks like either a 'W' or a giant McDonald's sign, depending on your point of view (see [figure 4](#)).

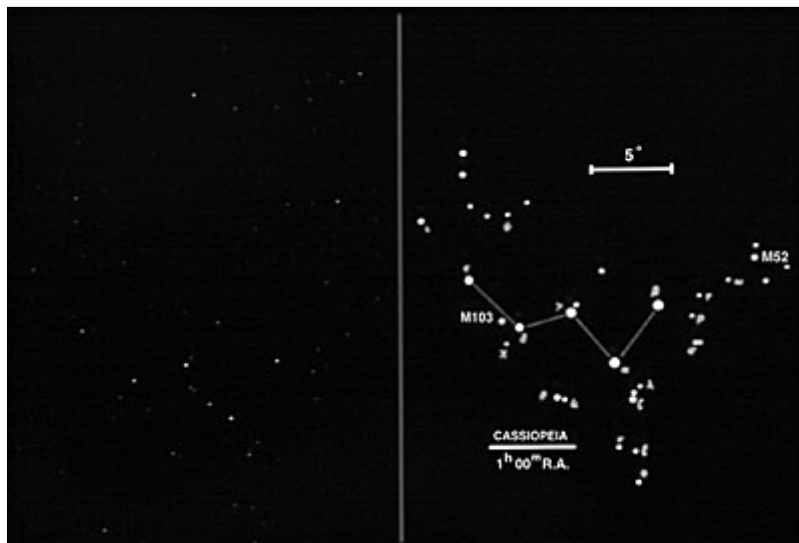


Figure 4

Cassiopeia. On the left is what you actually see in the sky. On the right is a diagram of the official constellation. The splotches labeled M52 and M103 are distant star clusters. Photo and diagram courtesy of O. Richard Norton, Science Graphics, Bend, Ore.

1. Make a sketch of Cassiopeia and rank its six brightest stars in order of brightness.
2. Look at the colors of the stars in Cassiopeia. Which star has a different color from the others?

Astronomers measure the brightness of sky objects with a system called *magnitude*. In this system, brighter objects have smaller magnitudes. The brighter stars have magnitude 0 or 1. The faintest stars visible to the unaided eye have magnitudes 5 or 6. Does part (1) suggest how this system came about?

The apparent brightness of a star depends on its distance and its *power*, the amount of energy it generates each second. The Sun's power is 400,000,000,000,000,000,000,000 watts -- a quadrillion times more energy than is produced by every electric power plant in the United States. Most of the brighter stars in the sky are much more powerful than the Sun. The brightness of the star decreases as the *square* of the distance. If the distance is twice as great, the brightness is four times less. If the distance is 10 times as great, the brightness is 100 times less. This *inverse-square law of brightness* is one of the most important tools of the astronomer (see [figure 5](#)). It provides a third means to estimate distance. If we measure the brightness, and know the power, we can determine the distance. Conversely, if we measure the brightness, and know the distance from parallax, we can determine the power.

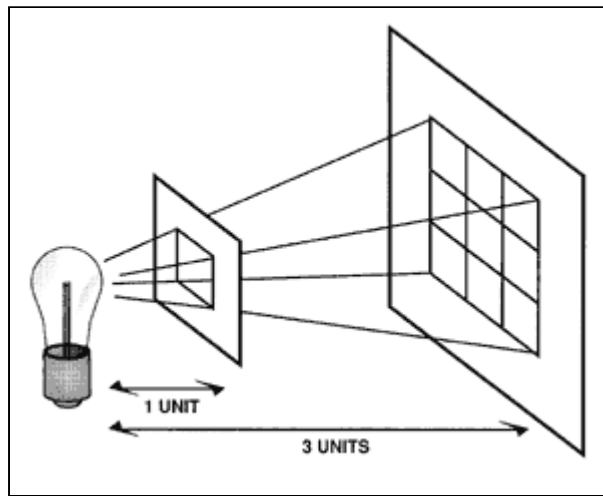


Figure 5

The inverse-square law of brightness. Because light travels in straight lines, the amount of light crossing each unit of area decreases as the square of the distance. Figure by John Percy.

Activity 8. Estimating the distance of brighter stars

At what distance would a 100-watt light bulb have the same brightness as the brighter stars? There are two ways in which you can answer this.

1. Do a real experiment. On a clear night, set up a 100-watt bulb and move away from it until you see that it has the same brightness as the brighter stars. The problem is that you may have to move several kilometers away -- you can only do this where you have lots of room: in the country, on the beach, or in any other location where you can see for miles. If you can't do that, look at the lights in a distant town or on an airplane. Streetlights and airplane beacons are usually 200-400 watts. How do their brightnesses compare to stars? Can you estimate how far away they are?
2. Do a thought experiment. You and your students have experienced the brightness of the brighter stars. You have also experienced the brightness of a 100-watt bulb. You can guess, on the basis of your experience, what the answer might be. Take a poll of your students.

The Sun is 4,000,000,000,000,000,000,000,000 times brighter than a 100-watt light bulb. According to the inverse-square law, the Sun would have to be 2,000,000,000,000 times further away than the light bulb in

order to have the same apparent brightness. So if the distance of the 100-watt light bulb was 5 kilometers, the distance of the brighter stars would be 10,000,000,000,000 kilometers, or about a light-year.

Brightness and color are the two most important identifying characteristics of a star. The color of a star depends on its temperature. The Sun is a yellowish star. Its "surface" temperature is about 5,800 kelvin (10,000 degrees Fahrenheit). The Sun and stars do not actually have surfaces; they are gases throughout. What we call the surface is the layer where the gases become so thick that we cannot see further in. Hotter stars appear blue-white; their surface temperatures may be over 20,000 kelvin (35,500 degrees Fahrenheit). Cooler stars appear reddish-white; their surface temperatures may be lower than 3,000 kelvin (4,900 degrees Fahrenheit).

Activity 9. Temperature and Color

There are plenty of everyday examples of how temperature affects the color of a hot object. Watch the element of a toaster as it heats up. It begins to glow with a deep red color, then turns orange-red as it becomes even hotter. The filaments of light bulbs are even hotter. How would you describe their color? This doesn't apply to fluorescent lights, whose light emission is due to other processes. It doesn't work with flames either, because their colors are primarily due to chemical processes.

The best example is a light with a dimmer switch. Increase the current through the bulb using the dimmer switch. Watch the color change as the temperature of the filament increases. This works best if you take off the lamp shade and use a clear bulb, rather than a frosted one.

Stars also come in different sizes. There are *giant* stars, ten or a hundred times bigger than the Sun. Arcturus and Aldebaran are examples. The *supergiant* stars are, as you might guess, even larger. One example of a supergiant is Polaris. Polaris is also a *variable star* (see below). Its brightness changes because it is expanding and contracting.

Watching a variable star gradually change brightness is an excellent observing project for high-school lab classes and junior-high science fairs (see below). Many students have even sent their observations to the American Association of Variable Star Observers, which collects and analyzes variable-star measurements from amateur astronomers all over the world. Not only can your students learn about star science, they can *do* star science.

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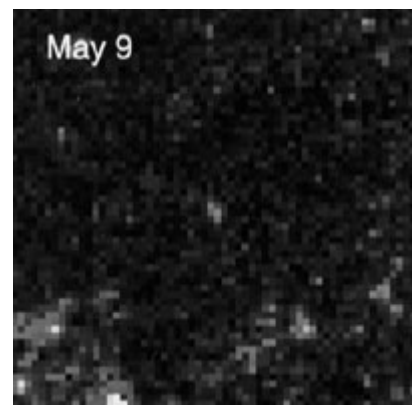
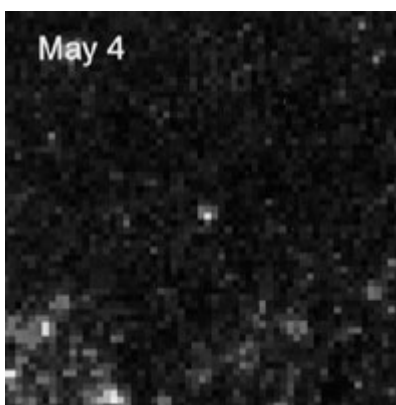
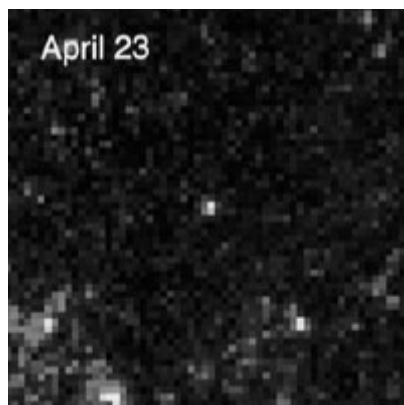
The Stars They Are A-Changin'

In autumn 1994, two groups of astronomers announced that they had discovered Cepheid variable stars in a distant cluster of galaxies. So what? Those stars have emerged as the slayers of modern cosmology, sending theorists back to the blackboards in their attempts to understand the origins and future of the universe.

Ever since Carl Wirtz and Edwin Hubble in the 1920s discovered that the universe is expanding, astronomers have used Cepheids as the yardstick of choice for measuring how far away galaxies are. Cepheids are one type of *variable star*. As the term suggests, variable stars change in brightness over time. Astronomers have cataloged over 30,000 variables. In fact most stars, including the Sun, vary if you look closely enough.

Cepheids vary in brightness because they are yellow supergiants. Such stars expand and contract because their gases become unstable as radiation passes through them. Polaris, the North Star, is a good example. Every four days it goes through a complete cycle of brightness variation. The length of the cycle, known as the *period*, depends on how powerful the star is. By measuring the period, astronomers can work backwards to deduce the power of the star. Then they compare the power to the brightness that they actually see, and calculate how far the star must be in order to appear as bright as it does.

This is how astronomers, using the *Hubble Space Telescope* and a large ground-based telescope, estimated the so-called Hubble constant that determines how big and old the universe is (see [figure 6](#)). The result splashed onto the front pages of major newspapers, namely, that the universe appears to be younger than its contents. This conundrum has yet to be resolved, but astronomers aren't too unhappy because they love a good mystery.



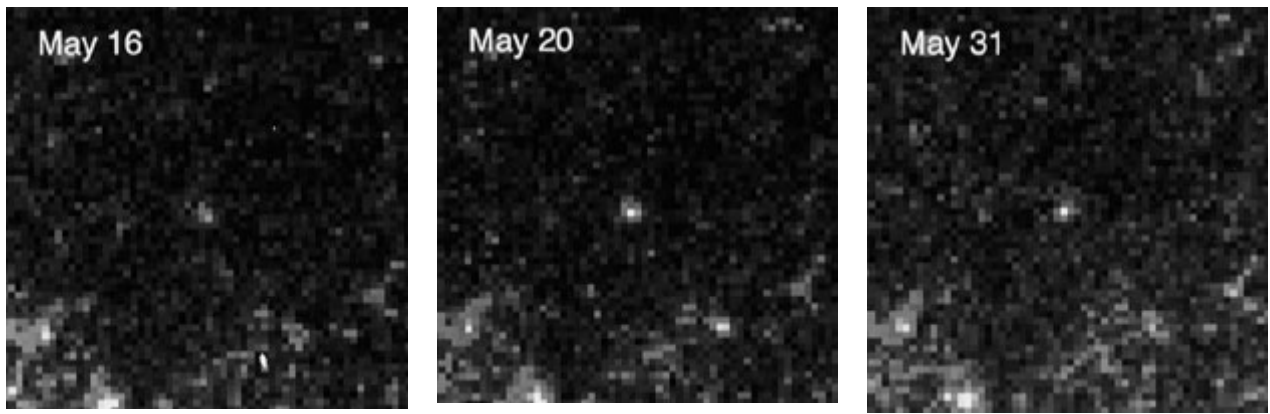


Figure 6

Cepheid variable. These are blow-ups of pictures taken by the Hubble Space Telescope last year. Notice how the star fades in and out. Astronomers were thrilled when Hubble found this star in the spiral galaxy M100, because it allowed them to calculate the distance from Earth to that galaxy. The distance turns out to be 51 million light-years. Photo courtesy of Wendy L. Freeman, Carnegie Institution of Washington, and NASA.

As it happens, variable stars are an area of astronomy where backyard observers are absolutely essential. Variables are so numerous and so unpredictable that only a network of skilled amateurs -- who don't have to worry about reserving telescope time -- can keep track of them. Variable stars are an ideal way to get high-school students doing real science, with real data, from the real sky. They make great lab exercises, science-fair projects, and science-club activities.

The following activity illustrates how to study a variable star. It deals with the granddaddy of them all: Delta Cephei. Students will have to find the star Delta Cephei, watch it change brightness over the course of a month, and plot up their data. Once they get the hang of taking measurements, students need to spend just a few minutes each evening making observations. The activity is best done in groups so that students can share ideas and results with each other -- just as scientists do in practice.

Each student or team will need the following:

- a pair of eyes (binoculars are helpful but not essential)
- a sky chart to find the stars
- a log book in which to record the observations
- plenty of graph paper to plot the observations once the month is out
- a calculator to help to prepare the graph.

1. Using an sky chart, find the constellation Cepheus

That's where Delta Cephei is located. Cepheus lies in between the constellation Cassiopeia, the star Deneb in the constellation Cygnus, and the star Polaris (the North Star). When you look at Cepheus in the sky, it's about as big as your fist held at arm's length.

During this experiment, some of the stars in Cepheus -- those that don't change in brightness -- will serve as comparison stars. See [Figure 7](#) for a blow-up diagram of the constellation.



Figure 7

Cepheus. On the left is what you actually see in the sky. On the right is a diagram of the official constellation. Delta Cephei, so named because it is the fourth brightest star in Cepheus, is at the bottom left. Students can use the nearby stars to estimate the magnitude of Delta. Photo and diagram courtesy of O. Richard Norton, Science Graphics, Bend, Ore.

2. Locate the star Delta in Cepheus and estimate its brightness

Record the exact time and date in the log book. Then find Delta in the sky and compare it to its two neighboring stars, Zeta and Epsilon. From this, you can estimate the magnitude of Delta.

Magnitude is the astronomers' way of specifying brightness: the brighter the star, the smaller the magnitude. Zeta has a magnitude of 3.4 and Epsilon has a magnitude of 4.2. Delta varies from being slightly brighter than Zeta to slightly fainter than Epsilon. If Delta appears very slightly fainter than Zeta, its magnitude would be 3.7. If it were intermediate in brightness between Zeta and Epsilon, its magnitude would be 3.9. And so on.

The other stars in the constellation can also help as references. Gamma or Beta are magnitude 3.2, which makes them a tad brighter than Zeta. Pi, with a magnitude of 4.4, is a smidgen dimmer than Epsilon.

In our experience, students can estimate the brightness to within 0.2 magnitude. It helps to practice identifying and measuring Delta Cephei and the comparison stars on a 35 mm slide of the constellation. An excellent set of constellation slides is available from the ASP catalog or from Science Graphics in Bend, Ore.

If you like, you can convert the time to the standard system used by astronomers, Universal Time, also known as Greenwich Mean Time. If you are on Daylight Saving Time, subtract one hour to get Standard Time. Then convert this to Universal Time by adding 4, 5, 6, 7, or 8 hours, depending on whether you live in the Atlantic, Eastern, Central, Mountain, or Pacific time zone. If you live elsewhere in the world, consult the telephone directory or newspaper for instructions on how to convert to Universal Time. If the conversion takes you past midnight, you have to advance the date by one day. For example, Nov. 1 at 8 p.m. EST is Nov. 2 at 1 a.m. UT. Finally, for the highest accuracy, you could express the data in terms of fractional days; that is, Oct. 1 at 9 p.m. is Oct. 1.875.



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3. Measure Delta Cephei for a month

Once students get the hang of it, they can find and measure the brightness of Delta Cephei in a few minutes. They should do this as many nights as possible over the course of a month. If a student forgets to observe one night, or the sky is cloudy, that's not a problem; just try to observe as many nights as possible for a whole month. If two or more students independently measure the brightness at roughly the same time, they may decide to take the average.

4. Plot the magnitude of Delta Cephei

Such a graph is called a *light curve*. On the horizontal axis, put the day of the month. If observations spilled into the next month, pretend that the first month got longer; for instance, Oct. 10 would be Sep. 40 for purposes of plotting. On the vertical axis, put the magnitude. Flip the vertical axis upside-down so that magnitude gets smaller as you go up. That way, brightness increases as you go up. Many teachers find that this is a good time to review graphing.

5. Draw a smooth curve through the points

This is often a new experience for students, who are used to drawing a curve connecting each point. Since each magnitude measurement has an uncertainty of 0.2, it's sufficient that the curve passes within 0.2 of each point, on average.

6. Estimate the date of maximum and minimum brightness

The smooth curve should tell you the answer.

7. Estimate the period

Many variables brighten and fade regularly. The number of days it takes to go from brightest to dimmest to brightest is the *period*. Does Delta Cephei seem to behave in this way? How accurate do you think your estimate is? [The period of Delta Cephei is actually 5.366269 days, or 5 days 8 hours 47 minutes.]

8. Plot a phase diagram

If a star (or any other phenomenon) is periodic, its variation depends only on where it is within its cycle, and not on which particular cycle it's in. The location within the cycle is called the *phase*. A calculator makes it easy to calculate the phase: Simply divide the date by the period and note the decimal part. For instance, if the period is 5.4 days, the phase of the 12th day of observations is 0.22; the phase of the 40th day is 0.41.

Using a period of 5.4 days, calculate the phases of the Delta Cephei measurements. Then you can plot magnitude versus phase. You should find that the magnitudes at the same phase will be about the same -- not exactly the same, though, because of the measurement errors that inevitably creep in. The accuracy of the plots is higher when the dates are expressed in terms of fractional days.

Try recomputing phases using different periods, say, 4.0 days or whatever you want. Prepare new phase diagrams. How does they compare to the first one?

9. Compare your estimate of the date of maximum brightness with astronomers' predictions

Based on the past behavior of the Delta Cephei, the maximum brightness occurs on the following dates for the upcoming months. These dates are for the Pacific time zone; the date in other locations occasionally differs by one day.

Dates of Maximum Brightness of Delta Cephei			
Sep. 29	Oct. 31	Dec. 2	Jan. 4, 1996
Oct. 4	Nov. 6	Dec. 8	Jan. 9
Oct. 10	Nov. 11	Dec. 13	Jan. 14
Oct. 15	Nov. 16	Dec. 19	Jan. 20
Oct. 21	Nov. 22	Dec. 24	Jan. 25
Oct. 26	Nov. 27	Dec. 29	Jan. 30

Extra credit

If you're looking for a way to challenge advanced students, have them express their data in terms of "Julian date," an astronomical calendar system described in almanacs (such as *The World Almanac*) and books for advanced amateurs (such as *The Observer's Handbook*). The integer part of a Julian date represents the number of days elapsed since noon on Jan. 1, 4713 B.C. The fractional part represents the Universal Time. One quirk of the system is that a Julian day begins at noon, rather than midnight. The Julian date for midnight Jan. 1, 1995 is 244 9718.5; for midnight Jan. 1, 1996 the Julian date is 244 0083.5.

If students express their data in terms of Julian date, they can send them to the American Association of Variable Star Observers in Cambridge, Mass. (email: aavso@aavso.org). The maximum brightness of Delta Cephei occurs at the Julian dates $2449722.05 + 5.366269 N$, where N is an integer.

The following table lists the measurements of Delta Cephei made by one amateur astronomer in autumn 1990. Your students can use these data for practice.

Measurements of Delta Cephei, Autumn 1990		
Calendar Date (Pacific time zone)	Julian Date	Magnitude
Oct. 5	2448170.63	4.0
Oct. 8	2448173.55	4.4
Oct. 10	2448175.58	4.0
Oct. 11	2448176.58	3.5
Oct. 12	2448177.55	3.8
Oct. 13	2448178.57	4.0
Oct. 15	2448179.59	4.4
Oct. 16	2448181.54	3.7

Oct. 17	2448182.55	3.8
Oct. 19	2448184.49	4.0
Oct. 20	2448185.51	4.2
Oct. 21	2448186.55	4.0
Oct. 23	2448188.55	4.0
Oct. 27	2448192.59	3.8
Oct. 28	2448193.50	4.0
Oct. 29	2448194.49	4.1
Oct. 30	2448195.57	4.3
Nov. 1 (Oct. 32)	2448197.51	4.0
Nov. 5 (Oct. 36)	2448201.50	4.5
Nov. 6 (Oct. 37)	2448202.51	4.1

Source: American Association of Variable Star Observers

This activity is a simplified version of one that appeared in *Hands-On Astrophysics*, a series of activities prepared by the American Association of Variable Star Observers with support from the National Science Foundation.



Star Science in the Autumn Sky

Here Is My Journey's End: Galileo Finally Arrives at Jupiter

by James J. Secosky, Bloomfield Central School

In summer 1994, the biggest news in astronomy was the collision of comet Shoemaker-Levy 9 with Jupiter. During this school year, Jupiter will charge back into the limelight with the arrival of the *Galileo* spacecraft (see [figure 8](#)). On Dec. 7, following a tortuous six-year ramble through the solar system, *Galileo* will begin its two-year mission studying Jupiter and its gaggle of moons.



Figure 8
Galileo. Photo courtesy of NASA Jet Propulsion Laboratory.

If you thought the *Voyager* pictures of Jupiter were beautiful, wait till you see *Galileo's*, which will be taken with a sharper camera and from a closer vantage point. Besides the camera, *Galileo* will carry instruments capable of identifying minerals on Jupiter's moons. And its atmospheric probe, launched from the main spacecraft in July, will give us our first look inside a gas giant.

Named after the Roman king of the gods, the planet Jupiter is quite a king. It is the largest planet in our solar system, 11 times the diameter and 318 times the mass of our Earth. A view through a backyard telescope readily reveals its four main moons, cloud bands, and Giant Red Spot, thought to be a long-lived hurricane bigger than three Earths (see [figure 9](#)).

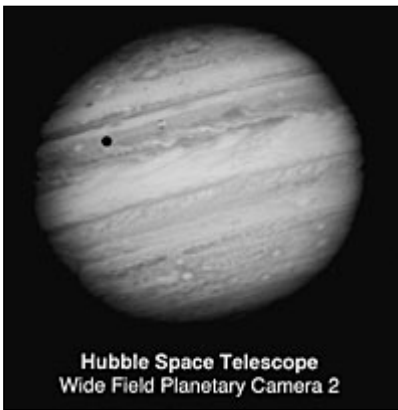


Figure 9

Jupiter. The black spot is the shadow of Io. Photo courtesy of H.A. Weaver, T.E. Smith, J.T. Trauger, R.W. Evans, and NASA.

Jupiter, along with Saturn, Uranus, and Neptune, is classified as a gas giant because its chief ingredient is hydrogen. Yet most of the planet is actually liquid. The planet's imposing mass creates a crushing gravity so strong that the hydrogen is squeezed into liquid metal. This metallic form of hydrogen is unknown anywhere else in our solar system except Saturn. It lurks 20,000 kilometers (12,000 miles) below the upper cloud decks, far deeper than *Galileo's* atmospheric probe will penetrate.

The liquid hydrogen, combined with Jupiter's rapid 10-hour rotation, generates a magnetic field 25 times stronger than Earth's. The magnetic field, in turn, traps ions in a huge volume called the *magnetosphere*. Jupiter's magnetosphere is the largest structure in our solar system, bigger even than the Sun. Its tail extends past the orbit of Saturn. If we could see the magnetosphere, it would appear as large as the Moon in our sky. The ions and electrons within the magnetosphere are a form of radiation 10,000 times more intense than Earth's deadly Van Allen belts. *Pioneer 10*, the first spacecraft to go through the belts, received a dose of radiation 500 times that needed to kill a person.

The 16 known moons that orbit Jupiter constitute a planetary system in their own right. The four largest are called the Galilean satellites, since it was once believed that Galileo Galilei discovered them; actually the German scientist Simon Marius discovered them at the same time. Larger than some planets, the Galilean satellites undergo not only the usual geologic processes, but also the effects of Jupiter's gravity and magnetosphere. They fall into two groups: Io and Europa are about the size of the Moon and consist largely of rock; Ganymede and Callisto are larger, the size of Mercury, and consist largely of ice -- as indicated by their densities of less than 2 grams per cubic centimeter.

Callisto

With a surface covered with craters upon craters, Callisto is possibly the oldest landscape in the solar system. The more craters a surface has, the older it is -- just as the older a shooting target is, the more bullet holes it contains. One crater, Valhalla, seems to be surrounded by frozen shock waves that extend 2,000 kilometers from its center, giving it a bull's-eye appearance (see [figure 10](#)). All the craters on Callisto are flattened because the surface, largely composed of ice, tends to settle and flow. Not a single volcano or fault line appears on the surface of Callisto.

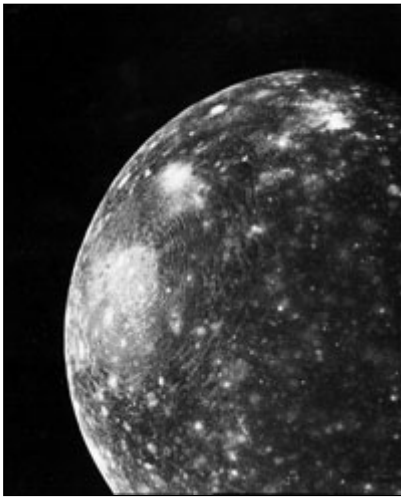


Figure 10

Callisto as seen by *Voyager 1*. The bull's-eye on the left is the crater Valhalla. When the meteoroid that formed Valhalla struck the surface, it set off ripples in the ice. These ripples froze into place, forming the bull's-eye rings. The bright circular spot at the center of the bull's-eye is about 600 kilometers (380 miles) across. Image courtesy of NASA Jet Propulsion Laboratory.



Star Science in the Autumn Sky

Ganymede

Ganymede is the largest moon in our solar system, larger even than the planets Pluto and Mercury. Some scientists used to think that Saturn's moon Titan was bigger, but later measurements showed that some of Titan's apparent diameter is actually a very thick atmosphere. Ganymede is the only place, besides Earth, with lateral faults similar to California's infamous San Andreas fault. Ganymede's surface consists of two main types of terrain: old, dark polygonal units, and young, bright valleys and ridges (see [figure 11](#)). White marks on Ganymede are young craters. These bright white marks may be the natural consequence of a high-speed impact onto an icy surface. In a similar way, hitting a large block of ice with a hammer makes white marks.

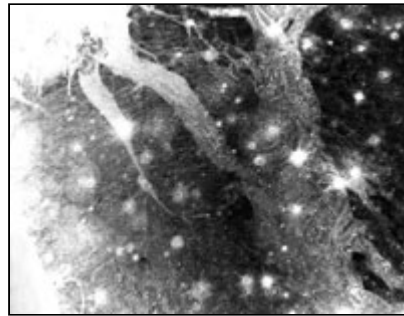


Figure 11

Ganymede as seen by *Voyager 2*. This satellite's claim to fame, besides the fact it's the largest moon in the solar system, is its strike-slip faults. One appears in the lower left corner of this picture. These faults look a lot like the San Andreas fault in California, raising hopes that studying Ganymede will help geologists to understand terrestrial earthquakes. The dark region on the right is ancient terrain. The grooved, light-colored regions are younger. Image courtesy of NASA Headquarters.

Io

Io looks like a giant pizza. One of the prettiest -- and strangest -- bodies in the solar system, Io is sure to be on magazine covers when the pictures arrive from *Galileo*. The moon is famed for its giant volcanic eruptions, discovered by NASA engineer Linda Morabito (see [figure 12](#)). Although it is only about the same size as our moon, Io is the most active volcanic body in the solar system, even more than Earth. There has been so much geologic activity that the entire planet may have passed through volcanoes at one time or other.



Figure 12

Io as seen by Voyager 1. On the limb of the planet you can see a volcanic explosion. The explosion threw solid material to an altitude of 160 kilometers (100 miles) at a speed of 2,000 kilometers per hour (1,200 miles per hour). Unfortunately this black-and-white image doesn't show Io's yummy pizza color. The reddish and orangish colors of the moon are probably due to sulfur compounds. Image courtesy of NASA Jet Propulsion Laboratory.

Some of the volcanic fountains, or plumes, cover an area larger than Texas. They are active for different periods of time. In the four months between the *Voyager 1* and *Voyager 2* flybys in 1979, one volcano stopped erupting, while two started up and subsequently stopped. Scientists can't wait to see which volcanoes are active during the two-year *Galileo* mission. Volcanism might have changed the appearance of the surface since the *Voyagers*, although the *Hubble Space Telescope* has not detected major changes.

Io is so active because it is caught in a tug of war between Jupiter's and Europa's gravity. The tug of war locks helpless Io into an elliptical orbit, so that its distance to Jupiter -- hence the effect of Jupiter's gravity -- keeps changing. The constantly changing gravity stretches, squeezes, and kneads Io. A similar thing happens when you bend a wire coat hanger back and forth: It gets hot.

The vibrant reds, yellows, and blacks on Io's surface are probably sulfur compounds. Some researchers predict that the entire visible surface is sulfur; others feel that silicate lava flows must be present. *Galileo's* instruments will be able to tell the difference.

Europa

Europa has the flattest surface of any body in our solar system. It has no mountains and hardly any craters. The whole moon could be encased in a layer of ice, and under the ice may be a global ocean of water. Europa is crisscrossed with lines called *linea* and *flexus*, thought to be cracks in the ice (see [figure 13](#)). Some scientists speculate that the cracks could contain primitive life forms, such as blue-green algae. In Earth's Antarctic, algae thrive beneath tens of meters of ice.

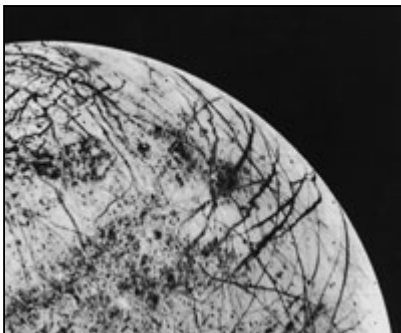


Figure 13

Europa as seen by Voyager 2. Cracks crisscross this mottled moon. They

may be breaks in a thin ice crust that covers water or softer ice. Because Voyager couldn't spot any large impact craters, scientists have concluded that the moon's surface is young. Image courtesy of NASA Jet Propulsion Laboratory.

Why doesn't Europa freeze solid? Like Io, it is heated by tides produced from the interaction of Jupiter's gravity with the other Galilean moons. The tidal forces are 10 percent as powerful as those that affect Io.

Recently the *Hubble Space Telescope* discovered that Europa has a thin oxygen atmosphere. On Earth oxygen is a product of life, but on Europa it has a more prosaic origin: Impacts by dust and charged particles knock water molecules off the icy surface, whereupon a series of chemical reactions produce hydrogen and oxygen.

As *Galileo* goes through its motions, The Planetary Society will be working with the Jet Propulsion Laboratory to provide updates. This will be done on the World Wide Web and through a toll-free telephone number. More information on this special service can be obtained by calling The Planetary Society at 818-793-5100 or visiting their [website](#).

Activity: The Size of Jupiter's Moons

Jupiter's moons fascinate planetary scientists partly because they are large, about the same size as some planets. This activity compares the sizes of the moons and some planets. With a drawing compass and the following table, draw circles to show the size of some planets and moons. With forethought, you should be able to get all of them on a single sheet of paper. Your students may enjoy drawing sample geologic features, such as volcanoes or cracks, on the Galilean satellites.

	Radius (km)	Scaled radius (cm)
Earth	6,375	6.4
Mars	3,400	3.4
Mercury	2,400	2.4
Ganymede	2,638	2.6
Callisto	2,410	2.4
Moon	1,738	1.7
Io	1,816	1.8
Europa	1,563	1.6
Pluto	1,150	1.2

JAMES J. SECOSKY is a science teacher at Bloomfield Central School in Bloomfield, N.Y. He has worked with professional astronomers on *Hubble Space Telescope* projects, and has an upcoming article in *The Universe in the Classroom* on space travel.



Star Science in the Autumn Sky

THE NIGHT SKY

LATE SEPTEMBER 10 P.M.
 EARLY OCTOBER 9 P.M.
 LATE OCTOBER 8 P.M.
 EARLY NOVEMBER 7 P.M.

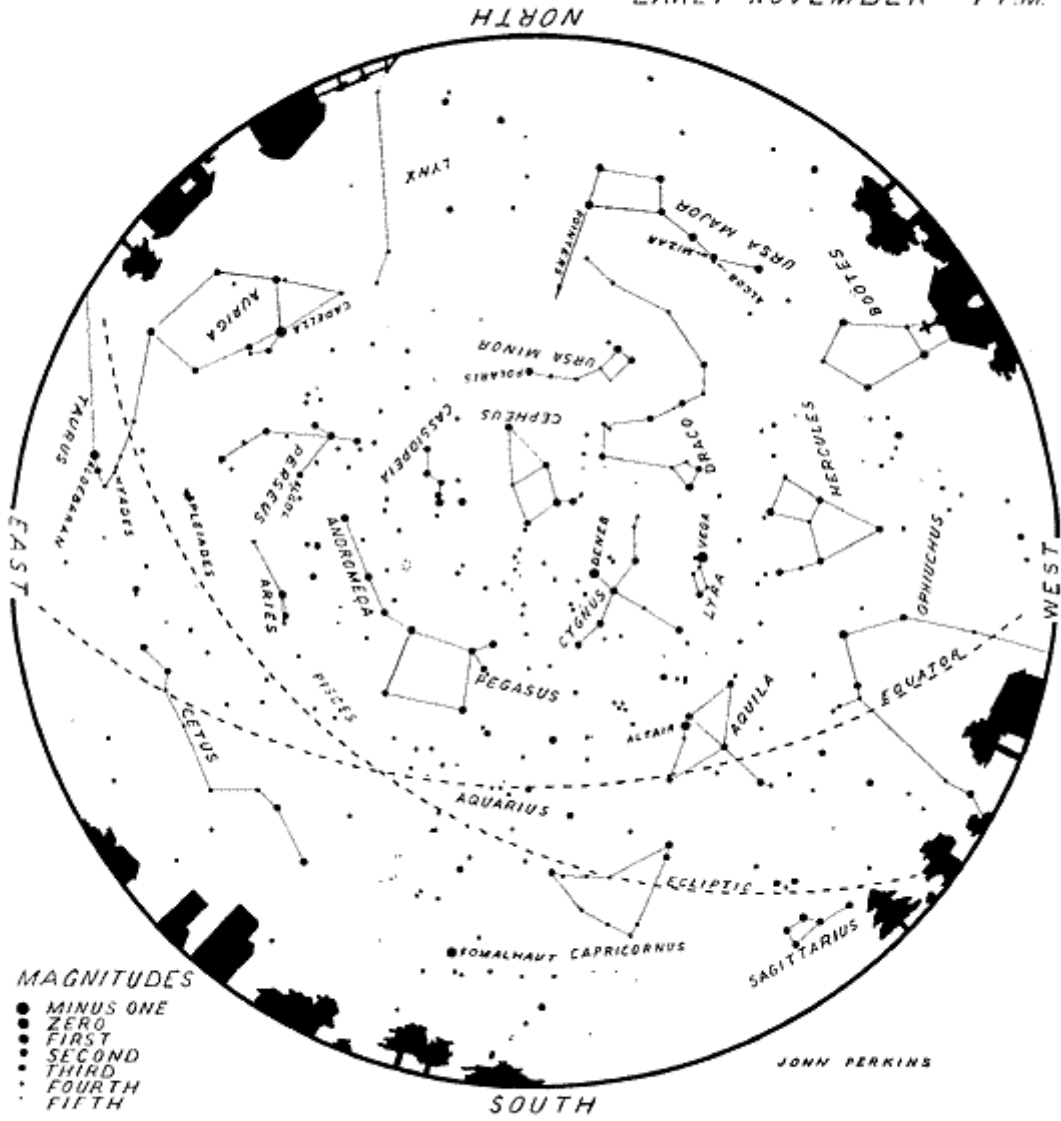


Figure 1

Road map to the autumn sky. The skies are constantly changing, but this map will guide you to the evening skies in late September to early November. It works at northern temperate latitudes. See text for instructions. Figure by John Perkins, courtesy of John Percy.