

What Does an Asteroid Look Like?

You may have seen pictures of asteroids taken by spacecraft like you see in the figures below.



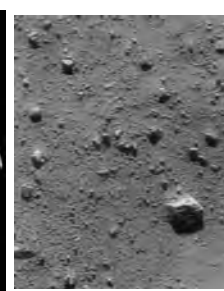
Asteroid Gaspra from Galileo (NASA)
<http://photojournal.jpl.nasa.gov/catalog/PIA00119>



Asteroid Idawithmoon Dactyl from Galileo (NASA)
<http://photojournal.jpl.nasa.gov/catalog/PIA00069>



Asteroid Eros by NEAR from 124 miles. (NASA)
<http://photojournal.jpl.nasa.gov/catalog/PIA03141>



Surface of Asteroid Eros by NEAR from 1150 meters (NASA)
<http://photojournal.jpl.nasa.gov/catalog/PIA03145>

Using spacecraft to travel close enough to asteroids to get pictures like these is very expensive. It can't be done for the hundreds of thousands of asteroids in our solar system.

Asteroids are many thousands, millions, or even billions of miles from Earth. Rather than traveling to these objects for close-up pictures, we use telescopes and cameras right here on Earth. What does an asteroid look like through telescopes on Earth? Let's get started answering that question with this simple exercise.

How does distance to an object size affect its apparent size?

- Suppose you make a drawing in a box (like one below) of something that is one meter from you. Then you make a drawing of something about 10 meters (paces) away. Label your boxes "near me" and "far away." Example shown at right: beach ball and elephant.



Near me



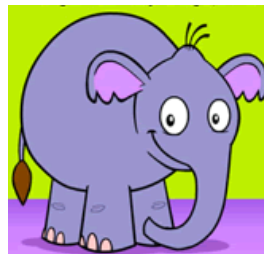
Far away

- Look at your sketches. If you were to have both objects you selected to draw sitting side by side (the same distance from your eye), which one would actually be bigger? Can you estimate about how many times bigger? [Write the following on a piece of paper and fill in the blanks appropriately.]

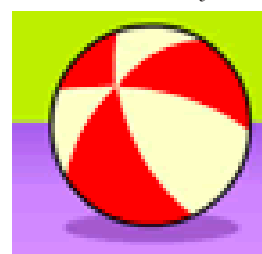
The _____ is bigger
 ... about _____ times bigger

Using an appropriate scale ruler on our drawings helps....

10 meters away

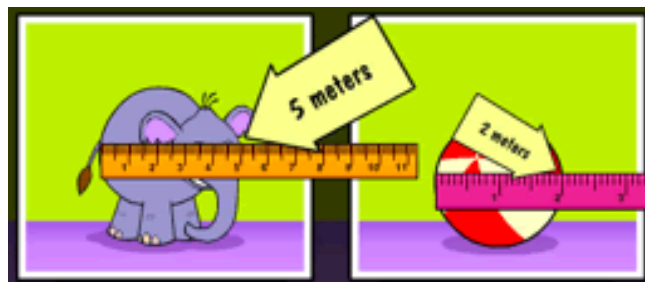


1 meter away



- Take a closer look at your drawings and use a ruler to measure the size of each object as you sketched it on your paper.

Near me: _____ Far away: _____



4. Which one, the “near me” object or the “far away” object appears to be bigger in your sketches? By how many times?

_____ times bigger

5. The key word above is “appear”. Have you ever heard the phrase, “Things aren’t always as they appear to be.” In this case please explain what caused the objects to appear to be a certain size when in reality they are different in size:

If you said “the distance you were from the object” in question 5 you’re exactly right. Now let’s apply this to asteroids. Look again at asteroid Eros in figure 3. Eros is a fairly large asteroid, and this is how big it appears to be from a distance of 124 miles, but remember we said that asteroids are thousands, millions, or even billions of miles from Earth. From these great distances, what will an asteroid look like, even if we were to magnify it 100’s of times using a telescope? The asteroid would still appear to quite tiny.

If asteroids look like stars how are we ever to tell the difference? Hmm ... what’s different about stars and asteroids that might help us out? We know that everything in space is moving. Asteroids, comets, planets, stars, even galaxies themselves are in motion ... right? The big difference is that asteroids are a whole lot closer to Earth than stars and galaxies. Asteroids may be thousands, millions, or billions of miles away, BUT stars and galaxies are many trillions, quadrillion, or quintillion miles from Earth.

Do you remember from your sketches that objects that were farther away appeared to be smaller? Do you think the same holds true for movement? Do you think if everything is in motion, but some objects are a much closer than others, that the closer objects will appear to move a greater distance over time? Let’s -explore this concept a bit.



Here is an image from the Make An Asteroid Movie investigation. Remember which one was the asteroid?

How does distance to an object affect how fast it appears to move?

Here's the experiment set-up ...

We placed a camera on a tripod and it remained in a fixed location. We mounted two stationary light sources in the distant trees (And, unlike the trees in Lord of the Rings, these trees do not walk around.). We then mounted a fake asteroid on a small John Deer tractor/lawnmower and we took five 5-second exposures; one with the tractor parked at the beginning of the 10 meter path, and one each with the tractor moving across the 10 meter path, the 15 meter path, the 20 meter path, and the 25 meter path.

To move on with this experiment you will need to open up two jpg images; one of the test site during the day, and the second of the test site at night. You will also need a ruler to make measurements in the images.

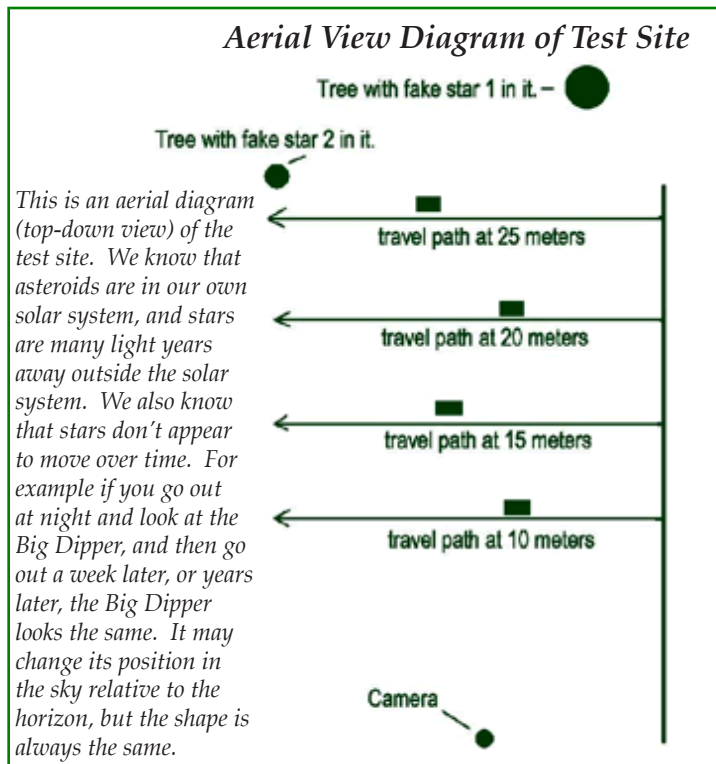
NOTE: If you're using Window's you can use Paint, or if using a Mac, Preview will work fine. If you really want to be a bit more sophisticated with your measurements, you can use something like Image J, or other software that allows you to make distance measurements on jpg images.

OPEN the following image files and make sure that you DO NOT resize either of the images. The images are the same size, and should appear to be the same size on your screen.

- Test Site Day.jpg
- Test Site Night.jpg

The images should look like the two images you see below in figures 7 and 8. REMEMBER, these images should be the same size on your computer screen.

Now that you have an understanding of the test site, and where the fake stars, the fake asteroid, and the camera are located, it's time to make some measurements. If you're making measurements in Windows-Paint or Mac-Preview, you'll simply need a ruler. If you're using Image J, or other software, the measurement tool will be built into the software. Just keep in mind, the images should be the same size on your computer screen and make sure you



Images taken with a stationary camera. Compare these with the aerial diagram above to gain a better understanding how the test site was set up.



label the units for all measurements. It will also be helpful if you use the same units for all measurements.

6. Using a ruler and images Test Site Day.jpg and Test Site Night.jpg measure the distance between fake star 1 and fake star 2.

Write on paper: "Distance between fake star 1 and fake star 2 in TestSiteDay.jpg _____" [and fill in the blank].

and

"Distance between fake star 1 and fake star 2 in TestSiteNight.jpg _____"

NOTE: You should get the same value for the measured distance between fake star 1 and 2 in both images. You might be off a little due to human error, but since the camera lens settings were the same in both images, the field of view in both images will be the same as well. If your values were off significantly, double check to make sure you did not change image size when you opened up the images.

SPECIAL CHALLENGE #1: Can you use the small angle formula to determine the width of the white distance markers? Here's the information you will be given; a) all the distance markers (10 m, 15 m, 20 m, 25m) are the same width, and the angular distance across (the width) the Test Site Day.jpg image is 76° . HINT: How many arc seconds are in a degree?

$$D = ad/206,265$$

D = width of object

a = angular size in arcseconds

d = distance to object

206,265 = is arcseconds per radian

Take a Virtual Trip - Want to check out the actual site where the experiment took place? Use Google Earth (<http://earth.google.com/>) to visit the test site!

Here are the coordinates:
 $41^\circ 18' 33.76$ N Latitude,
 $79^\circ 28' 55.10$ W Longitude

Farmer Tim –

He's not really a farmer—he's author Tim Spuck on the tractor. He enjoys being outdoors, but not sure he could put in the long days and short nights most farmers do.

"What I really enjoy is astronomy. My father took me outside one night when I was about seven years old and showed me Venus, the Big Dipper, and Orion. From that moment on I was hooked!"

To find out more about Tim see <http://www.ocasd.org/webpages/tspuck/>.

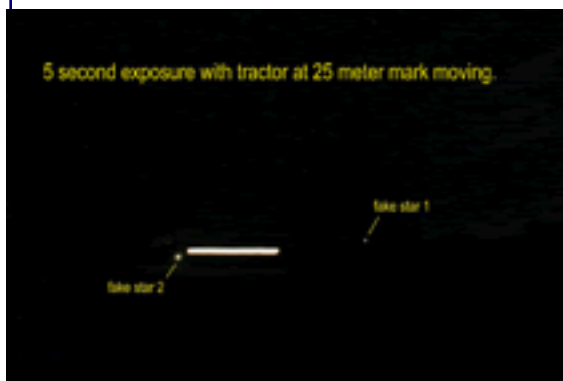
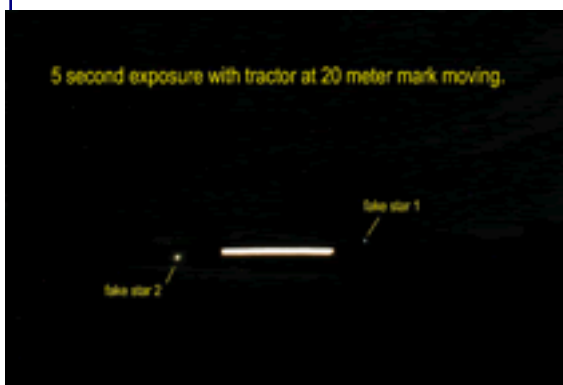
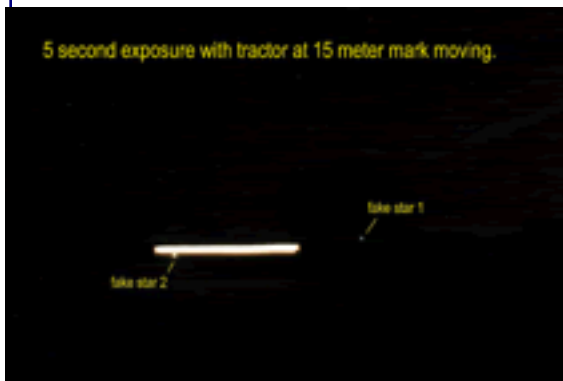
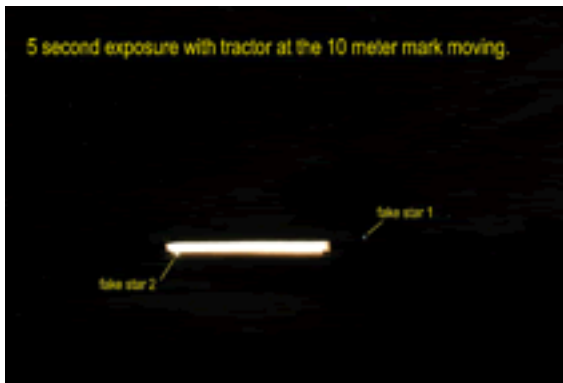


One thing we had to be sure of was that the speed of the fake asteroid was the same in each image. The only thing we wanted to change was the distance the fake asteroid was from the camera.

To ensure this was the case, the gearshift was always placed in 1st gear and the throttle setting was always at full (the rabbit).



Let's move on and put our fake asteroid in motion; first at a distance of 10 meters from the camera, then 15 meters, then 20 meters, and finally 25 meters from the stationary camera.



The images on this page resulted from four 5-second exposures with the tractor in motion at different distances from the camera. The streak of light that you see in the images is caused by the fake asteroid being in motion and reflecting light back toward the camera, much like an asteroid moving in orbit around the sun reflects light back toward the Earth.

Open up each of the four images...

- tractorasteroid10m.jpg
- tractorasteroid15m.jpg
- tractorasteroid20m.jpg
- tractorasteroid25m.jpg

...using Windows Paint, Mac Preview, or another preferred software. REMEMBER, do not resize the images once you open them. All four images are the same size, so they should appear to be the same size on your computer screen.

7. Use your ruler or software measurement tool (if using Image J) to measure the distance (D) between fake star 1 (f1) and fake star 2 (f2), and the length (L) of the light streak in each image. Record your results on worksheet as follows and remember to label units for all measurements.

Fake Asteroid Moving from 10 m

D f1 and f2 _____ L of streak _____

Fake Asteroid Moving from 15 m

D f1 and f2 _____ L of streak _____

Fake Asteroid Moving from 20 m

D f1 and f2 _____ L of streak _____

Fake Asteroid Moving from 25 m

D f1 and f2 _____ L of streak _____

8. Let's take a close look at your answers in question 7. Again the camera lens setting were the same in all four images, so the distance you measured between fake star 1 and fake star 2 in all four images should be the same. However, what happened to the length of the streak? If the speed of the tractor and the exposure time for each of the four images was the same, what do you believe caused the difference? [Write your answer on worksheet.]

9. Is there any correlation between distance to the fake asteroid, and how far the fake asteroid appeared to move? If so, what is the correlation?

SPECIAL CHALLENGE #2: How fast does my tractor/lawnmower travel in first gear at full throttle? The angular distance across (the width) of each of the four images (figures 10 – 13) is 76° .

$$D = ad/206,265$$

D = distance traveled a = angular distance (arcseconds)

d = distance to tractor 206,265 = arcseconds per radian

HINT: How many arcseconds are in a degree?

Speed = distance/time

WARNING: Don't Get the Wrong Idea

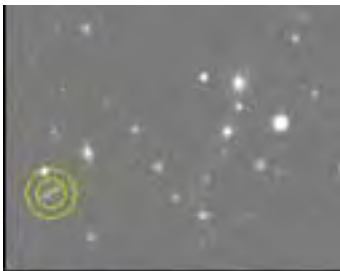
In the example above, it was the fake asteroid on the tractor that was in motion relative to the “stationary” camera on the ground that caused the streak in the photographs. In space, the Earth is spinning on its axis once every 24 hours, the Earth is orbiting around the Sun at a speed of 100,000 km/hour (about 67,000 miles per hour), and the asteroid is orbiting the Sun. All these objects are in motion relative to each other.

In real life, when we see an asteroid moving against the background stars, as you will see in the next activity, the vast majority of the apparent motion, or asteroid streak, is caused by the Earth's motion around the Sun. So, if we were to have sufficient space and resources, it would have been more accurate to put the camera and asteroid in motion around a central point, and place the asteroid MUCH further away, and the stars many times that. However, for our purposes the activity demonstrates sufficiently well what happens when objects are in motion relative to each other.

The Real Thing

You've discovered that more distant objects moving at relatively the same speed as a closer object can show less motion. As a result, asteroids that are much closer to Earth than stars and galaxies will appear to move, while stars and galaxies appear to remain stationary.

You may be asking yourself, “What does that look like?” It looks a lot like our fake asteroid in the images you just observed.



Date: 03/23/98
UT: 07:07:40.4



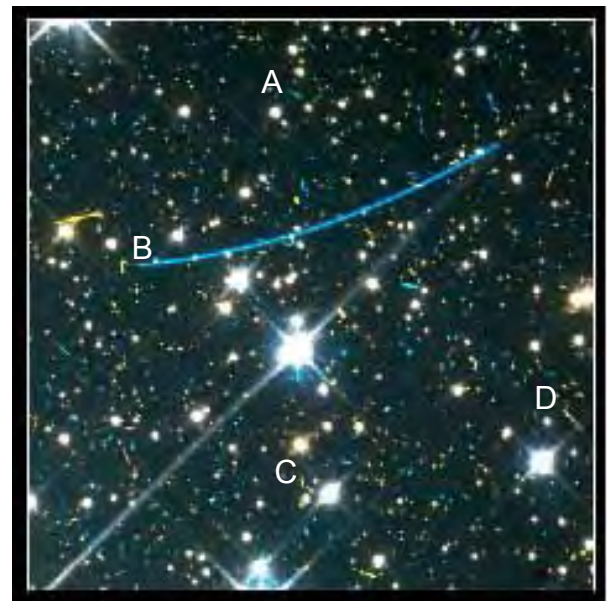
Date: 03/23/98
UT: 08:36:57.3



Date: 03/23/98
UT: 09:25:10.2

The images above of an asteroid captured using the Cerro Tololo Inter-American Observatory (CTIO) Blanco 4 Meter telescope. Each exposure was 10 minutes in length, and figure 15 was taken about 1.5 hours after figure 14, and figure 16 was taken about an hour after figure 15. Notice how the asteroid appears to move while the distant stars and galaxies stay in the same place. In reality, everything in the images is in motion, but the asteroid is much closer so it appears to move while other objects appear to remain stationary.

Take a minute and go back and look at the asteroid image in the “Make An Asteroid Movie” investigation. You'll notice there is no “asteroid streak” like you see in the images above, but there really is an asteroid there. The primary difference is that with the images in the above images, the telescope camera shutter was open for ten minutes, while the image exposure in the Movie investigation was only two minutes in length making the asteroid streak much shorter and therefore less noticeable.



FINAL TEST – This is an image taken by the Hubble Space telescope (NASA). Virtually all the streaks you see in the image are asteroids. Order asteroids A, B, C, D in order from closest to farthest away..

Johannes Kepler's Laws of Planetary Motion

The problems and messiness associated with epicycles would not be overcome until Johannes Kepler (1571–1630 A.D.) came to the rescue. Kepler worked with renowned Danish astronomer, Tycho Brahe in Prague. Kepler was assigned the task by Tycho Brahe to analyze the observations that Tycho had made of Mars. Of all the planets, the predicted position of Mars had the largest errors and therefore posed the greatest problem. Tycho's data were the best available before the invention of the telescope and the accuracy was good enough for Kepler to show that Mars' orbit would precisely fit an ellipse. Kepler inherited Tycho's post as Imperial Mathematician when Tycho died in 1601. In 1605 he announced his first law of planetary motion.



<http://kepler.nasa.gov/johannes/>

Kepler's First Law:

1. Planets move in ellipses with the Sun at one focus.

For a circle the motion is uniform as shown above, but in order for an object along an elliptical orbit to sweep out the area at a uniform rate, the object moves quickly when the radius vector is short and the object moves slowly when the radius vector is long.

Circular and Elliptical Orbits Having the Same Period and Focus

Kepler's 2nd Law: The planet's radius line sweeps equal areas in equal times.

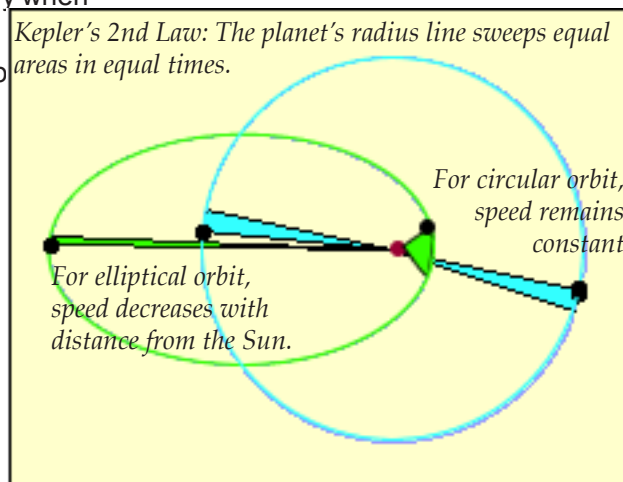


Illustration of Kepler's Second Law of planetary motion. Here we see two orbits with the same focus point ("center") semi-major axis ("diameter"), and orbital period: one a circle with an eccentricity of 0.0; the other an ellipse with an eccentricity of 0.8. Eccentricity is a measure of how "skinny" an ellipse is, with a circle having an eccentricity of "0" being the "fattest" kind of ellipse, and the very "skinniest" of ellipses having eccentricities approaching "1." An animated version of this diagram is on this web page <http://kepler.nasa.gov/johannes/>

In work starting in 1602, Kepler calculated the p

of the Earth in its orbit and after several years discovered that an imaginary line connecting the Sun and Earth sweeps out greater areas when the Earth is closer to the Sun, indicating Earth is moving faster in its orbit when it is closer to the Sun. Kepler stated his finding more precisely in his second law.

Kepler's Second Law:

2. The planet's radius line describes [sweeps] equal areas in equal times.

Kepler published his first two laws in 1609 in his book *Astronomia Nova*.

It wasn't until May 15, 1618 that he arrived at his third law.

Kepler's Third Law:

3. The squares of the periodic times are to each other as the cubes of the mean distances.

This law he published in 1619 in his *Harmonices Mundi*. It can be stated mathematically as follows for any two planets labelled "1" and "2":

$$\frac{T_1^2}{T_2^2} = \frac{R_1^3}{R_2^3} \quad \text{where } \begin{array}{l} T_1 = \text{period of planet 1} \\ T_2 = \text{period of planet 2} \\ R_1 = \text{orbit radius of planet 1} \\ R_2 = \text{orbit radius of planet 2} \end{array}$$

Sample problems: Assuming Earth's period is 1 year and its orbit radius is about 150,000,000 km, using Kepler's 3rd law,

- what is Mars' orbit radius if it takes 687 days to orbit the Sun and
- how long is Jupiter's year if its distance from the Sun is about 780,000,000 km?