National Aeronautics and Space Administration

Exploring the Milky Way

Exploring the Milky Way

Math textbooks routinely provide ‘real world’ examples for students using familiar examples drawn from every-day situations, but there are many other areas where proportional relationships and working with large numbers aid in understanding our physical world.

This collection of activities is intended for students looking for additional challenges in the math and physical science curriculum in grades 6 through 8, but where the topics are drawn from astronomy and space science. As a science extension, ‘Exploring the Milky Way’ introduces students to mapping the shape of the Milky Way galaxy, and how to identify the various kinds of galaxies in our universe. Students also learn about the shapes and sizes of other galaxies in our universe as they learn how to classify them.

The math problems cover basic scientific notation skills and how they apply to working with ‘astronomically large’ numbers. It also provides exercises in plotting points on a Cartesian plane to map the various features of our Milky Way.

For more weekly classroom activities about astronomy and space visit the NASA website,

http://spacemath.gsfc.nasa.gov

Add your email address to our mailing list by contacting Dr. Sten Odenwald
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Original cartoon artwork kindly provided by Nathalie Rattner (Copyright 2012).

Ms. Rattner is a highly versatile, award winning Canadian artist whose works have been sold to private collections in North America. Throughout her career, she has been inspired by her love of life, history and the diversity of the world around her. The artwork used in this book was created by her when she was in middle school !

NCTM: Principles and Standards for School Mathematics

Grade 6-8 : In grades 6–8 all students should

- Develop an understanding of large numbers and recognize and appropriately use exponential, scientific, and calculator notation;

- model and solve contextualized problems using various representations, such as graphs, tables, and equations.

- make and use coordinate systems to specify locations and to describe paths

Common Core Mathematics Standards

6.NS.6 Understand a rational number as a point on the number line. Extend number line diagrams and coordinate axes familiar from previous grades to represent points on the line and in the plane with negative number coordinates.

6.NS.6.b Understand signs of numbers in ordered pairs as indicating locations in quadrants of the coordinate plane; recognize that when two ordered pairs differ only by signs, the locations of the points are related by reflections across one or both axes.

6.NS.8 Solve real-world and mathematical problems by graphing points in all four quadrants of the coordinate plane. Include use of coordinates and absolute value to find distances between points with the same first coordinate or the same second coordinate.

7.EE.3 Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms (including scientific notation) as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies.

8.EE.3 - Use numbers expressed in the form of a single digit times an integer power of 10 to estimate very large or very small quantities, and to express how many times as much one is than the other. *For example, estimate the population of the United States as* 3×10^8 *and the population of the world as* 7×10^9*, and determine that the world population is more than 20 times larger.*

8.EE.4 - Perform operations with numbers expressed in scientific notation, including problems where both decimal and scientific notation are used. Use scientific notation and choose units of appropriate size for measurements of very large or very small quantities (e.g., use millimeters per year for seafloor spreading). Interpret scientific notation that has been generated by technology.

We all know a little bit about our nearest star – the Sun! It's a yellow-colored star, which means it is hotter than 'red hot' and sizzles with a temperature of 6,000 Celsius. It also contains a LOT of matter. In fact, there is so much matter in the sun that scientists use 'scientific notation' to write this amount numerically. Here's what it looks like in ordinary decimal form:

1,989,000,000,000,000,000,000,000,000,000,000 kg !

Review of Scientific Notation:

A decimal number is written as 1,230,000.0 or 'one million, two hundred thirty thousand'. To write it in scientific notation, ask yourself, how many times do I have to multiply 1.23 by 10 to make it into 1,230,000?

Your answer would be 6 times. So

$$10\times10\times10\times10\times10\times10 = 1{,}000{,}000 \text{ and}$$

$$1.23 \times 1{,}000{,}000 = 1{,}230{,}000.$$

We can write this using base-ten exponents so we have

$$1{,}000{,}000 = 10^{6}, \text{ and then}$$

$$1{,}230{,}000 = 1.23\times10^{6}.$$

So in scientific notation, how would you write 456.1 ?

Answer: $\mathbf{4.561\times10^{2}}$

How would you write the mass of the sun in kilograms shown in the decimal form above?

Addition and Subtraction:

OK, now that you recall the basics of re-writing numbers in scientific notation, let's review how to manipulate them using the basic operations of arithmetic:

Addition, Subtraction, Multiplication and Division.

Suppose I gave you the numbers 1.564x107 and 3.41x105 and asked you to add them together.

The easiest thing to do is to take the largest number and re-write it to the same exponent as the smaller number:
156.4×10^{5} and 3.41×10^{5}.
Now add the numbers together to get 156.4 + 3.41 = 159.81
Put the exponent term back into the number 159.81×10^{5}
Then re-write it in scientific notation as $\mathbf{1.5981\times10^{7}}$.

You can do the same steps for subtraction!

Let's try these two problems:

<u>1) Our sun has a mass of 1.989×10^{30} kg and the nearby dwarf star Proxima Centauri has a mass of 2.45×10^{29} kg. What is the difference in masses of these two stars?</u>

<u>2) The proton has a mass of $1.67262158 \times 10^{-27}$ kilograms and an electron has a mass of 9.1094×10^{-31} kilograms. What is the mass of a hydrogen atom that consists of one electron and one proton?</u>

Multiplication:

OK, now how about this. Suppose I gave you two HUGE numbers and asked you to multiply them. You have a galaxy like the Milky Way that has 250 billion stars, and each star has a mass of 2.0×10^{30} kilograms. What is the total mass of the galaxy in kilograms?

Remember that when you multiply two numbers in scientific notation, first you <u>multiply</u> the two decimal numbers (2.5 x 2.0 = 5.0, then you <u>add</u> the exponents (30+11 = 41) ...like this:

$2.5\times10^{11} \times 2.0 \times 10^{30} =$

$(2.5 \times 2.0) \times 10^{30+11} = 5.0 \times 10^{41}$ kilograms.

<u>What is the age of the universe in seconds expressed as (3.1×10^{7} seconds/year) x (1.37×10^{10} years)?</u>

Division:

Now suppose that you wanted to divide two numbers 3.2×10^{33} and 1.6×10^{-24}. First you <u>divide</u> the two decimals 3.2/1.6 to get 2.0, then you <u>subtract</u> the exponents to get 33 - (-24) = +57 and so the answer is 2.0×10^{54}.

<u>How many hydrogen atoms are there in a star expressed as (2.0×10^{33} grams) / (1.6×10^{-24} grams/atom)?</u>

More Review Problems

Convert these numbers into Scientific Notation:

1) Length of a year. 31,560,000.0 seconds =

2) Power output of sun : 382,700,000,000,000,000,000,000,000 watts =

3) Mass of an electron: 0.00000000000000000000000000000091096 kilograms =

4) Radius of hydrogen atom : 0.00000000529177 centimeters =

Write these numbers in Standard Form:

5) Stars in the Milky Way: 2.5×10^{11}

=

6) Number of stars in the universe: 9.0×10^{21}

=

7) Mass of an atom of gold in kilograms: 3.27×10^{-25}

=

Add or subtract these numbers:

8) 1.34×10^{14} stars + 1.3×10^{13} stars =

9) 7.523×10^{25} kg - 6.30×10^{23} kg + 1.34×10^{24} kg =

Perform these calculations:

10) Tons of TNT needed to make crater 100 km across:

$(4.0 \times 10^{15}$ Joules/m^3) x $(1.0 \times 10^{6}$ m^3) /$(4.2 \times 10^{9}$ Joules/ton) =

11) Number of sun-like stars within 200 light years of our solar system:

$(2.0 \times 10^{-3}$ stars per cubic light year) x 3.35×10^{7} cubic light years =

The sun is very far away too!

Astronomers have many different ways to measure its distance from Earth. From the sun to Earth it is a distance of 93 million miles. This is also the same as 150 million kilometers if you prefer metric units …which scientists do!

Once again, the distance to the sun, 150,000,000 kilometers, is more easily written in scientific notation as 1.5×10^{8} kilometers. Because there are 1000 meters in every kilometer, you can also write it in terms of meters as 1.5×10^{11} meters, or even centimeters (100 cm in 1 meter) if you want, that's 1.5×10^{13} cm !

Although it is rather easy to express distances in the solar system in terms of kilometers, when astronomers study the stars and the Milky Way galaxy, a unit like 'kilometer' is not very convenient. Instead astronomers use the **light year**. One light year (LY) is the distance light travels in one Earth year of 365.24 days. The speed of light is 300,000 kilometers/sec, so the light year is an enormous distance.

Seconds in 1 minute = 6.0×10^{1} Minutes in 1 hour = 6.0×10^{1}

Hours in 1 day = 2.4×10^{1} Days in 1 year = 3.6524×10^{2}

Speed of light = 3.0×10^{5} km/s

<u>Use scientific notation to do the math and find the number of kilometers in a light year!</u>

It is sometimes a hard thing to jump from a kilometer to a light year all in one step. Human imagination wasn't designed to keep such a large distance in clear focus. Our brains have evolved to create good mental maps of our neighborhood and the sizes of familiar things…not stars and galaxies! So we can try to sneak up on the idea of a light year by considering a shorter distance first. For example, we could use the distance from Earth to the sun as a new yardstick.

This distance is called the **Astronomical Unit** (AU) and it has a length of 149,600,000 kilometers (that's 1.496×10^{8} km), so if 1 light year is the same as 9.467×10^{12} km, then 1 light year equals 9,467,000,000,000 / 149,600,000 = 63,282 AUs.

You could also get this answer with scientific notation:

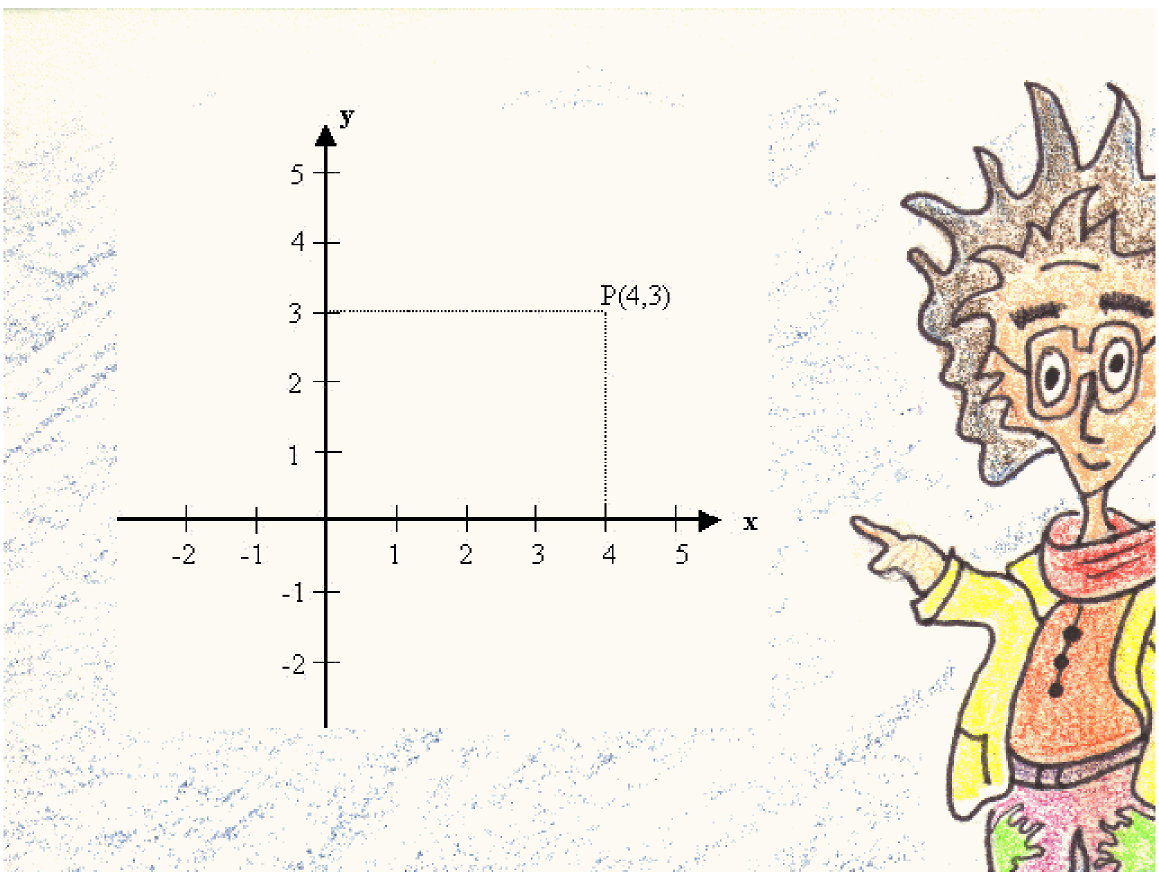
$$9.467 \times 10^{12} \text{ km} / 1.496 \times 10^{8} \text{ km} =$$
$$(9.467/1.496) \times 10^{12-8} = \quad 6.3282 \times 10^{4}$$

The distance from the Sun to Pluto is 39 AU, so in terms of the diameter of our solar system, 1 light year equals 811 times the diameter of our solar system. When describing the vast distances between the stars and the size of our Milky Way, astronomers use the light year! On this scale, the nearest star, Proxima Centauri, is located 4.2 light years from Earth.

<u>How many times the diameter of our solar system is this distance?</u>

Our sun is just one of many more stars in a vast system we call the Milky Way galaxy.

Our galaxy has billions of stars in it! It is so huge that we cannot take a picture of it, but astronomers have been able to study its shape and size by collecting thousands of clues about it. In the next few exercises, we are going to map out the major features of our Milky Way, but first we have to review how to graph points on the Cartesian plane.



Here is a point P, located at an X coordinate of +4 and a Y coordinate of +3, which forms an ordered pair (+4,+3). It is plotted on the 'XY' Cartesian plane. That's all there is to it!

Ok, now try this problem! On the grid below, plot these points and connect them with a smooth curve.

Curve A: (0,0), (-1,-2), (+2, -6), (+8,-5) (+11, +3), (+7, +11), (-4, +14) and (-14, +4)

Curve B: (0,0), (+1, +2), (-2, +6), (-8, +5) (-11,-3), (-7,-11), (+4, -14) and (+14, -4)

What is this shape called?

Where is the Origin?

When astronomers describe the Milky Way, they have a choice between placing the Sun at the Origin of the XY plane, or placing the Origin at the center of the Milky Way galaxy.

In the next exercises, we will be using data gathered by astronomers from Earth, so it makes sense that to start with, we use the Sun as the Origin of our coordinate plane. We can change this later by a simple coordinate translation to some other location as we learn more about the shape of our galaxy.

What coordinate units should we use?

The next problem is, what units should we use to mark the divisions on the plane? Kilometers? Astronomical Units? Light years?

Stars and other objects in the Milky Way are very far apart, so using kilometers is probably not a good thing to do. The Au is a big unit, but the nearest star is already over 265,000 AU from the sun, and there are stars thousands of light years away!

Instead, let's use the Light Year (LY) as our unit interval. We can adjust the tic marks on the two coordinate axis to fit the data we are plotting, the same way that we do when plotting a map of the United States on a single sheet of paper. Depending on the range of our data, we could select intervals of 10 LY per tic mark, 100 LY per tic mark, or even 1000 LY per tic mark.

When you look up at the sky you see stars!

Over the years, astronomers have figured out the distances to millions of stars, and they have also counted how many stars they find in different directions. Both of these activities give astronomers clues to what shape our Milky Way has. But you have to use the clues very carefully!

First, let's plot the ten nearest stars to our sun from this table.

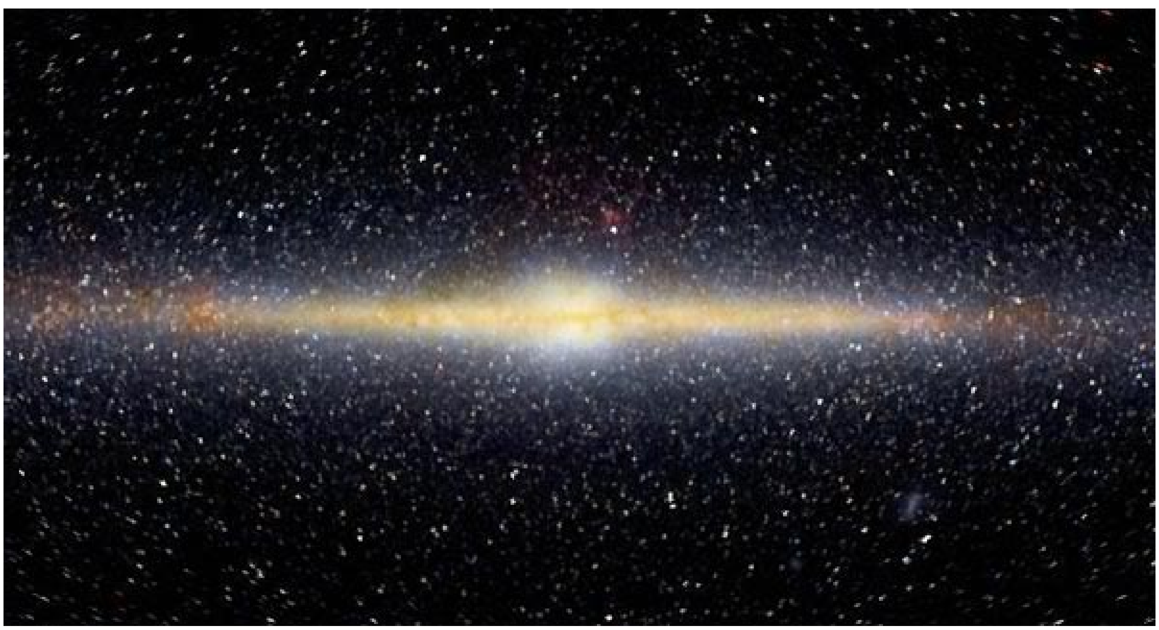
Name	X (LY)	Y (LY)
Alpha Centauri	+4	0
Sirius	+5	-5
Arcturus	+23	0
Vega	-24	+5
Castor	+10	-40
Regulus	+45	-40
Spica	+130	+100
Almach	-75	-90
Kochab	-60	-20
Gomeisa	+70	-120
Algedi	-60	+90
Eltanin	-80	+20

<u>How much farther from the sun is the red giant star Arcturus than the yellow, sun-like star Alpha Centauri?</u>

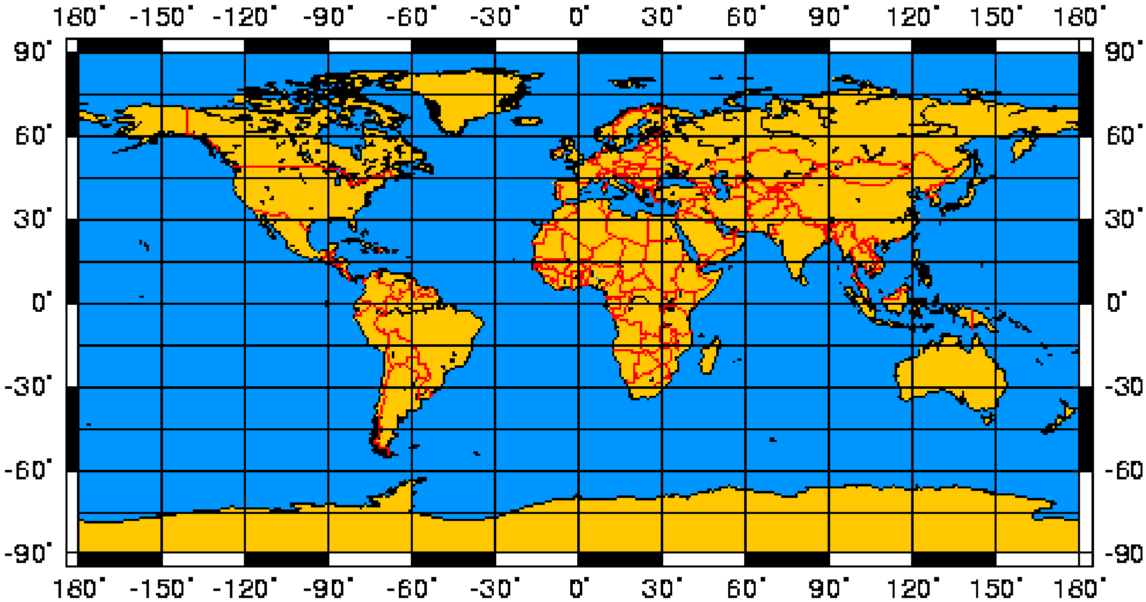
It’s hard to tell what the shape of our Milky Way might be because we have only looked at the nearest stars. The Milky Way could be a lot bigger than what only these dozen stars suggest! In fact, when you look at the sky you see thousands of stars, and millions more with a pair of binoculars or a telescope!

What happens if we plot all THOSE stars?

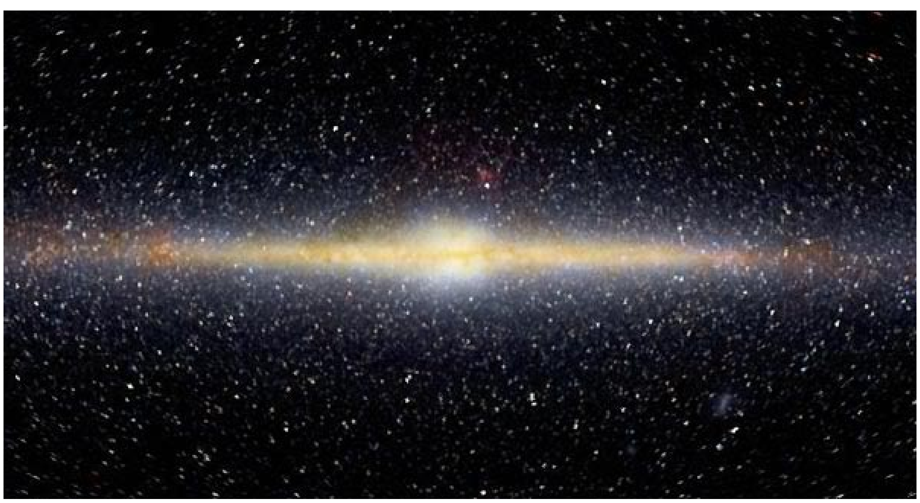
Many NASA research programs have created star catalogs containing millions of stars, and have put together all-sky panoramas that better show the shape of the Milky Way, like the one below made by the NASA Cosmic Background Explorer ‘COBE’ satellite in 1990.



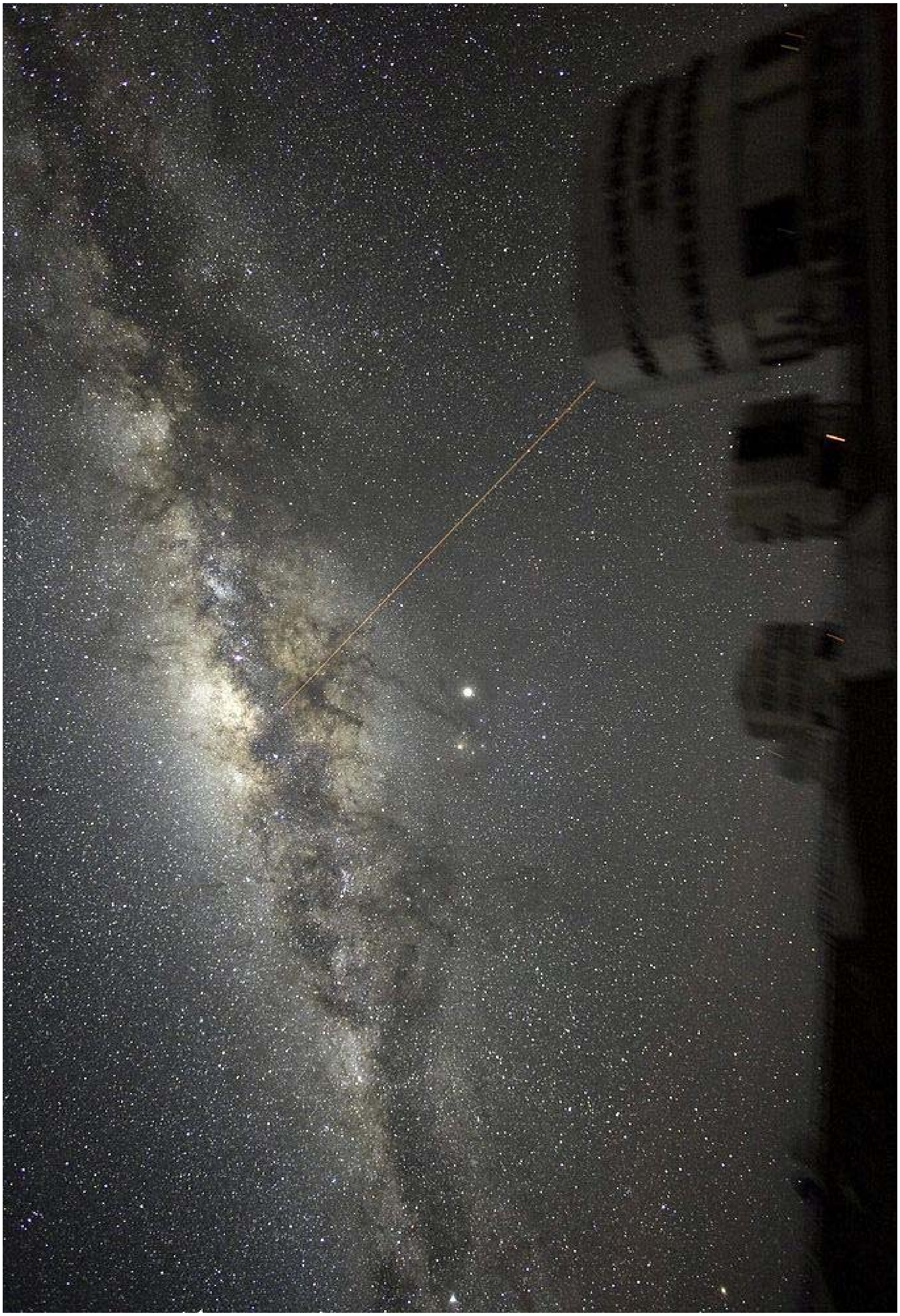
By the way, the COBE picture shows the entire sky. That means the right and left edges are actually the same edge, just unwrapped. This is called a cylindrical or Mercator map. On the next page is another Mercator projection that I bet you are familiar with!



The Equator is the horizontal line across the middle of the map. The left and right edges are actually the same place (the same longitude) on Earth's surface! This is called *geometric distortion*, but at least with this map we can start to show what the whole Earth looks like. Same thing for the COBE all-sky map seen below!



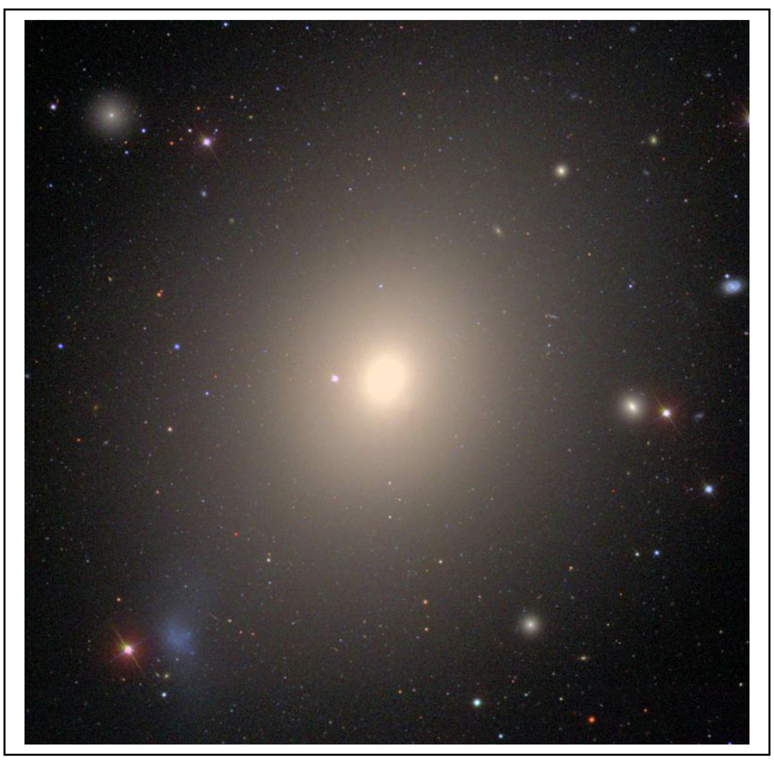
The giant 'bulge' of stars you see in the center is called the **Galactic Nucleus**. It is located towards the constellation Sagittarius.



On the facing page is a photograph of the sky towards the constellation Sagittarius taken at the Paranal Observatory by ESO astronomer Yuri Beletsky. The narrow laser beam 'line' on the facing page points to the center of the Galactic Nucleus!

Those dark blotches that you see in the picture are clouds of dust in space that hide more distant stars from us so that we can't see them. The COBE picture was made using infrared light from the stars, and this light cuts through the dust clouds in space so we can actually see clear across the Milky Way galaxy!

If you tilted the COBE picture so that you could see the full disk of stars in the Milky Way, it might look like the galaxy NGC-4472 shown below:



It looks kind of boring doesn't it?

If you only studied where the stars in the Milky Way are located, it would be like painting with only one color. Stars only give you one idea of the shape of the Milky Way and what it looks like. Your drawing would mostly show what things looked like in your neighborhood because you cannot see stars to very great distances.

If you used a simple telescope and studied the sky, you would discover that the sky contains more than just stars. Here and there, stars seem to come together into small clusters of a few dozen or even a few hundred members, crowded together in a volume of space a few light years across. These are called **star clusters**, and they represent stars that were formed together and, like planets orbiting a star, are bound together by gravity into clusters that travel through space. There are two kinds of star clusters in the Milky Way.

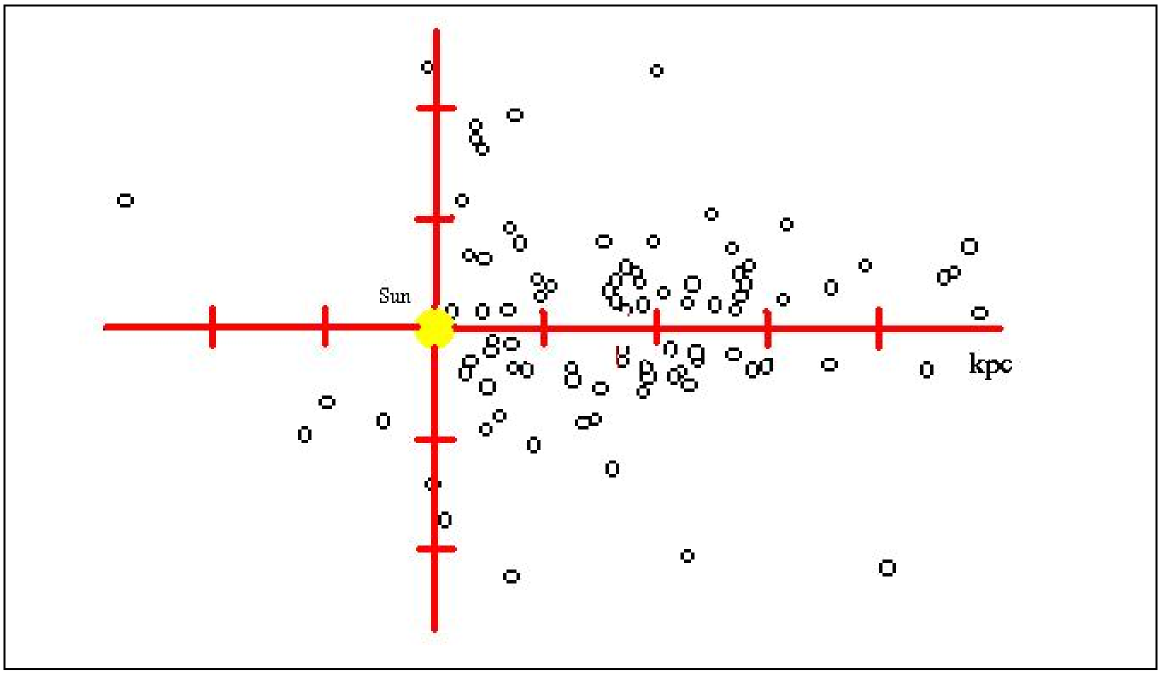
Open clusters look like small numbers of stars, such as the famous Pleiades cluster in Taurus, shown here. Sometimes they have gas clouds near them that light up like a dense fog. There are thousands of open clusters in the Milky Way!

Globular clusters are much rarer and contain hundreds of thousands of stars, like this on called Messier-13 in the Constellation Hercules. Only 152 globular clusters have been cataloged in the Milky Way.

Globular clusters can be seen to very great distances, and their distances can be very accurately measured. This picture shows the Great Globular Cluster in the constellation Hercules. It is also called Messier-13. At a distance of 25,000 light years from our sun, it contains over 200,000 stars!

Amateur astronomers absolutely love this cluster because it is so bright you can see it with your naked eye. With a small telescope it is magnificent!

If we graphed the location of all the globular clusters in the Milky Way it would look like the graph below. The tic marks are located every 10,000 parsecs, and the circles show the locations of the globular clusters.



Harlow Shapley was the first astronomer to plot the locations of globular clusters way back in 1925. When he did this, he discovered from his plot of only 75 globular clusters, that globular clusters did not orbit in space anywhere near our sun, which in the graph is located at the Origin (0,0). Instead, they seemed to cluster around a point in the constellation Sagittarius (0,15000).

This figure uses the unit called the parsec to indicate distances. 1 parsec = 3.26 light years, and the major tic marks in the above figure are at intervals of 10 kiloparsecs or 32,600 light years. <u>How many light years are equal to a distance of 40 kiloparsecs from the sun?</u>

Combining what you know about the shape of the Milky Way from the COBE data, and from the globular cluster data, how far is our sun from the center of the Milky Way according to Harlow Shapley?

Astronomers have used many different methods since 1925 to figure out the distance to the center of the Milky Way much more accurately. The table below shows some of the methods and their results:

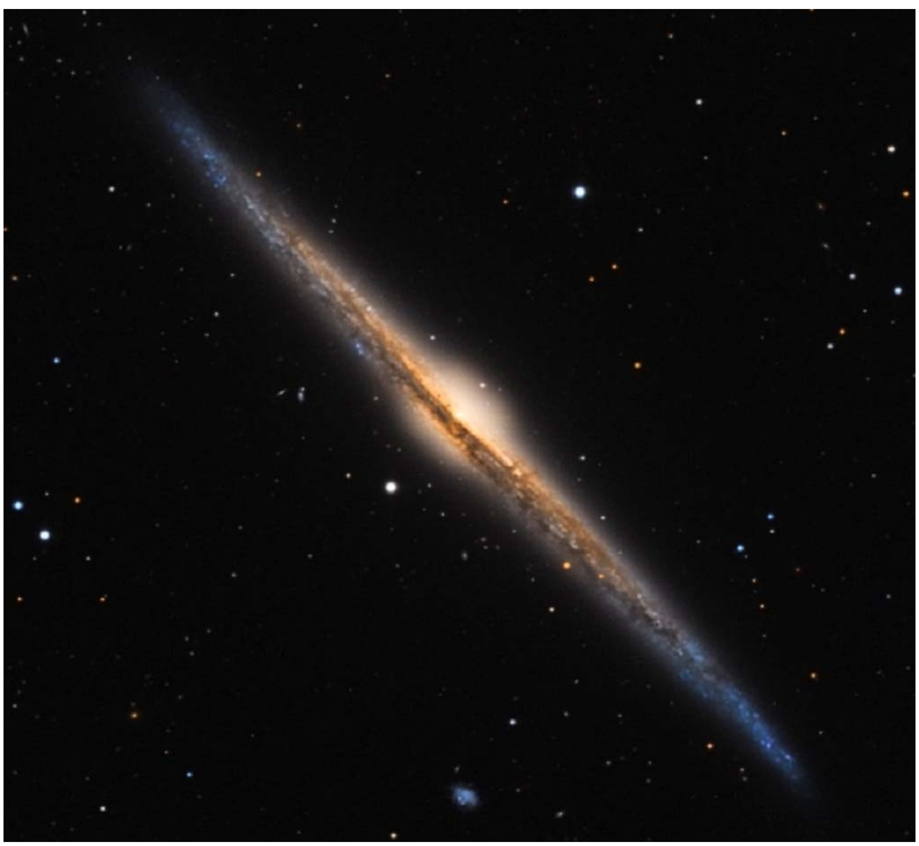
Method	Year	Estimate (light years)
Globular Clusters	1976	27,700
Sag-B2 Maser Proper Motion	1988	25,600
Globular Clusters	1989	24,400
OH and IR Stars	1993	28,700
Stellar Proper Motion	2003	25,900
Stellar Proper Motions	2004	25,800
Bulge Red Giant Stars	2006	24,500
Population II Cepheid Stars	2008	25,900
Maser Proper Motion	2009	28,000

<u>To the nearest 100 light years, what is the average distance that these methods report for the distance to the center of the Milky Way from our Sun?</u>

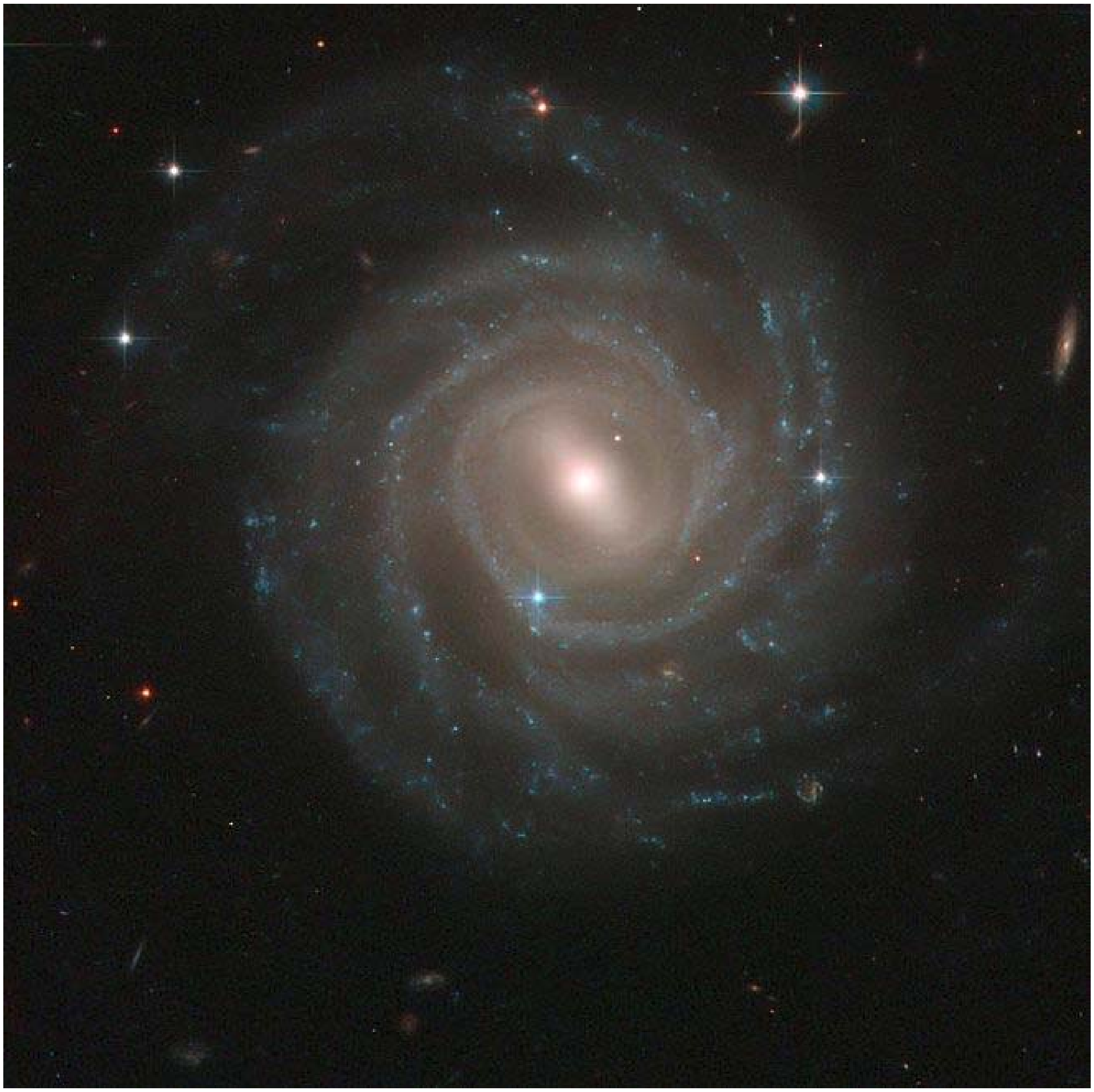
Globular clusters tell us a lot about the size of the Milky Way, but not very much about the details of its shape.

We know that it is a flat galaxy with a 'bulge' of stars in the center, called the Galactic Nucleus. We also know that globular clusters tell us we are located about 26,000 light years from the Galactic Center. But what exactly does our Milky Way look like from outside?

Here are some amazing pictures of flat galaxies like NGC-4565 shown below ! The image was obtained by Howard Trottier (SFU). Note how much it resembles the COBE image of our own Milky Way!



Messier 101 Constellation Ursa Major is located 21 million light years from the Milky Way. It has a diameter of about 170,000 light years and contains 100 billion stars. (NASA/Hubble)



The galaxy UGC 12158 is located 400 million light years from the Milky Way in the constellation Pegasus. It has a diameter of 140,000 light years and contains about 500 billion stars. (NASA/Hubble)

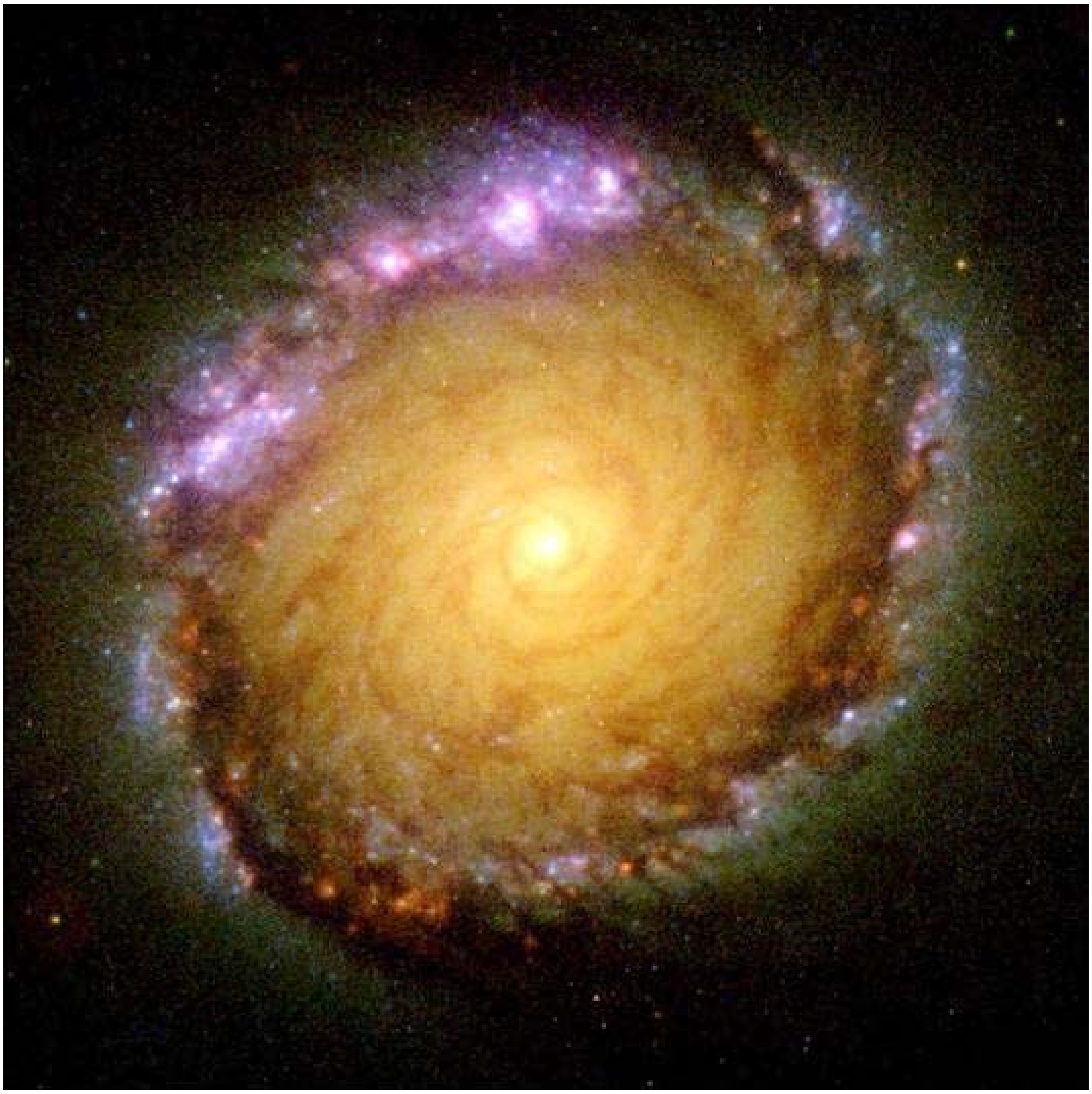
<u>What is the diameter of UGC-12158 in kilometers?</u>

NGC-1300 is 61 million light years from the Milky Way in the constellation Eridanus. It has a diameter of about 110,000 light years and contains about 200 billion stars (ESO/VLT)

What is the mass of this galaxy in kilograms if 1 solar mass = 2.0×10^{30} kilograms?

NGC-4414 is located in the constellation Coma Berenices at a distance of 60 million light years from the Milky Way. It is about 55,000 light years in diameter and contains about 100 billion stars. (NASA/Hubble)

<u>How far from our sun is this galaxy in Astronomical Units?</u>



NGC-1512 is in the constellation Horologium at a distance of 30 million light years. It is about 70,000 light years in diameter and contains about 100 billion stars. (NASA/Hubble)

Messier-109 is about 83 million light years from the Milky Way in the direction of the constellation Ursa Major. It has a diameter of about 60,000 light years and contains about 250 billion stars. (Courtesy: Dale Swanson and Adam Block /NOAO/AURA/NSF)

NGC-300 is located 5 million light years from the Milky Way in the constellation Sculptor, and has a diameter of about 45,000 light years and contains about 50 billion stars. (ESO)

<u>Which of the galaxies we have just visited is closest to the Milky Way? Farthest from the Milky Way?</u>

No two 'flat' galaxies look the same, but nearly all the ones we see look like pinwheels in space. Astronomers call them **spiral galaxies**. Now we have two questions to answer about our Milky Way:

Does the Milky Way have two arms like the barred spiral galaxy NGC-1300, or many arms like the normal spiral galaxy UGC-12158?

Does the Milky Way have a lot of space between the arms like the galaxies Messier-101 and Messier-109, or are the spiral arms all crowded together like the ones in NGC-4414 or NGC-1512?

To learn more about our own Milky Way, we are going to have to figure out how many spiral arms it has, where they are located, and where our own sun is positioned within them.

Globular clusters do not orbit within the plane of the Milky Way's flattened disk, so we are going to have to find other objects that do, and use their locations to trace out the details in the disk of the Milky Way.

Suppose we graphed the locations of some open clusters. What would that look like? Let's look at the following atlas of some spectacular and famous open star clusters and plot their coordinates on the graph paper on page 38.

Messier-29 (+4000, -900). This beautiful little cluster is in the constellation Cygnus and is only 10 million years old. It is located a bit more than 4000 light years from the sun.

Messier-45 (0,+500). This famous cluster in the constellation Taurus is also called the Pleiades. It is about 100 million years old. At a distance of 500 light years you can see gas and dust being illuminated by the stars as they pass through an interstellar cloud.

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Messier-46 (-3600, +3000) is a cluster in the constellation Pupis, and at a distance of about 5000 light years. It is about as old as the Pleiades. A beautiful ring nebula is also nearby but is not related to the cluster.

Messier-67 (-900, +2000) is an open cluster in the constellation Cancer, and is located about 2000 light years from our sun. It is estimated to be nearly 4 billion years old !

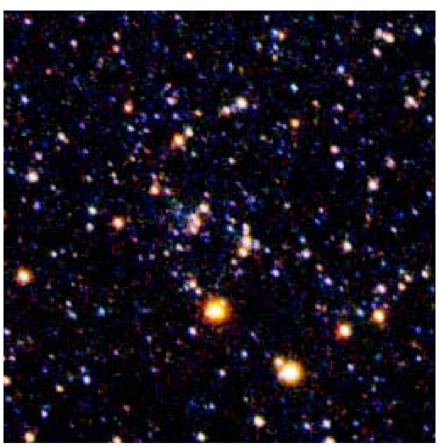
Messier-11 (+2700, -4800) in the constellation Scutum contains about 3000 stars and it is about 250 million years old. It is also called the Wild Duck Cluster !

IC-2944 (-6200, -3000) in the constellation Centaurus is located 2000 light years from Earth and is only a few million years old. Many examples of stars being formed can be found in the nebula of gas that surrounds this cluster.
(Courtesy © T. Credner & S. Kohle, AlltheSky.com)

NGC-3293 (-7800, -2300) is located in the constellation Carina and is also very young. It is about 8,000 light years from the sun and is surrounded by a complicated and colorful nebula of gas that is still forming new stars today.

Messier-103 (+6800, +5500) in the constellation Cassiopeia is about 10,000 light years from the sun and has about 170 stars that were formed within the last 25 million years.

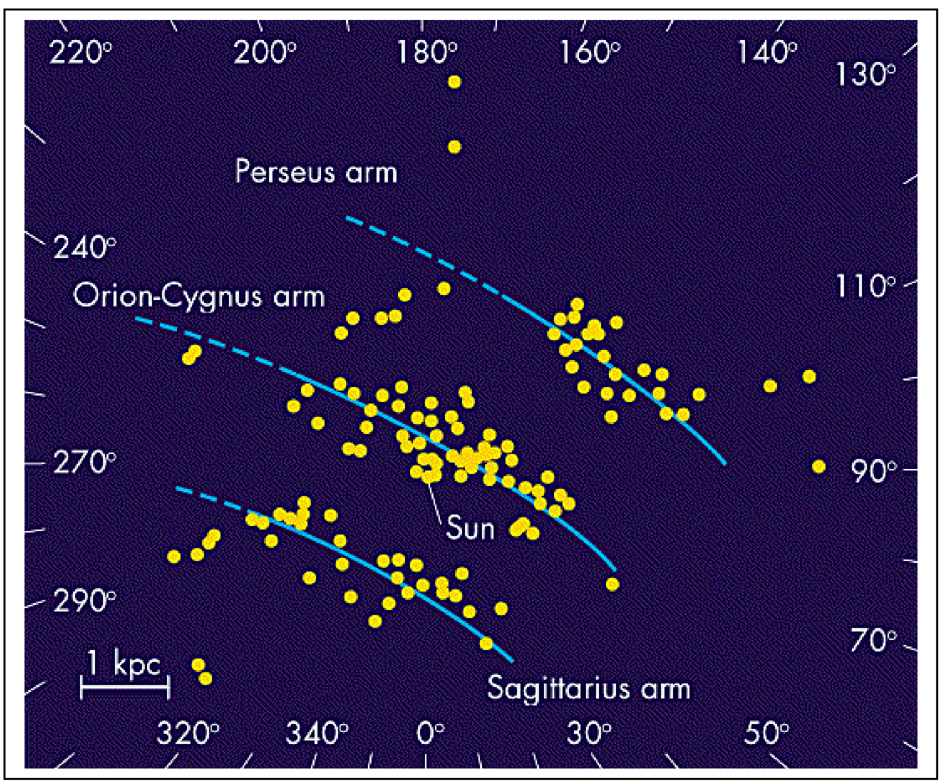
h and Chi Persei (+5000, +5000) as its name suggests, is a double star cluster in the constellation Perseus about 7,500 light years from the sun. It was formed about 3 million years ago.



NGC-1817 (-1000, +6200) in the constellation Taurus is about 2 billion years old and about 7,000 light years from the sun. (Courtesy Bernard Hubl)

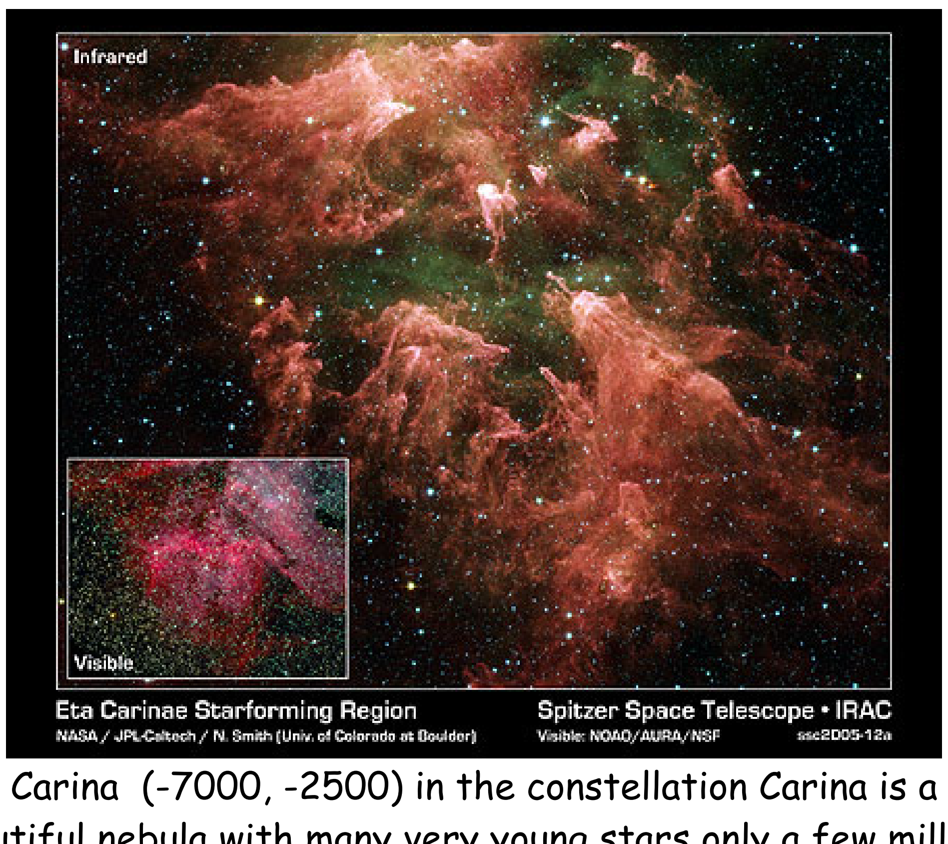
Although we have only plotted 10 of the nearly 300 star clusters astronomers have cataloged, you should notice that they are not randomly placed across the coordinate grid.

Here is a graph created by astronomers of dozens of very hot young stars in star clusters located within 5,000 light years of our sun. Notice that they mostly fall into three diagonal bands. These are the parts of the pinwheel-shaped spiral arms of our Milky Way nearest our sun, which is located at the center of the plot.



In addition to star clusters, a careful study of the sky with binoculars turns up fuzzy blotches of light called nebulae. These are clouds of gas and dust in space that emit light because certain kinds of bright stars are located inside them or nearby. Most of the time we can't even see the stars that light up these clouds, but the nebulae span dozens of light years and are usually easy to see from great distances.

Nebulae are places where stars are being born, like the nursery wards in hospitals. What pattern do we get if we plot on the same graph on page 38 a few of these nebulae?



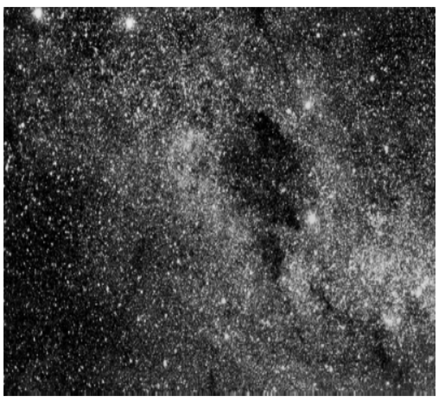
Eta Carina (-7000, -2500) in the constellation Carina is a beautiful nebula with many very young stars only a few million years old.

Lagoon Nebula (+500, -4100) in the constellation Sagittarius contains many new stars that are much more massive than our own sun.

Omega Nebula (+2000,-6000) in Sagittarius is so big that it can form almost 1000 stars. Its spectacular colors come from elements like nitrogen and oxygen. It is about 40 light years in diameter!

Pelican Nebula (+2000, 0) is a nearby nebula in the constellation Cygnus. Its gas is being quickly consumed by forming stars, and in a few million years it will be gone!

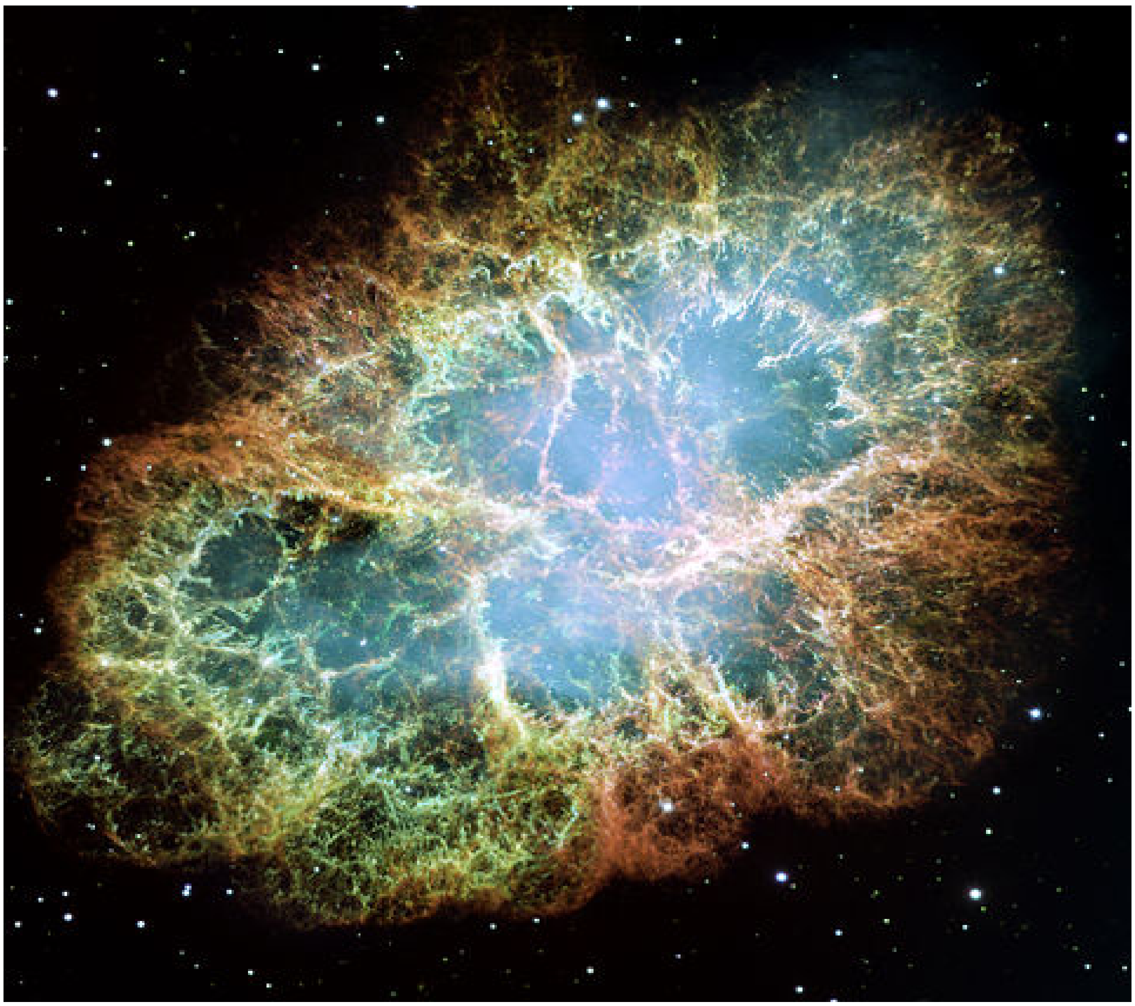
Orion Nebula (-600, +1400) in the constellation Orion is one of the closest star forming nebula to our Sun. It is rapidly forming hundreds of stars more massive than our sun, and is only about 5 million years old. The stars are furiously blasting away the gas and dust around them.



Coalsack Nebula (-300, -100) in the constellation Crux is so young that it is just a very dense cloud of dust and gas about 209 light years across. No stars have formed inside it yet to create a nebula. Light from stars behind this cloud cannot pass through the cloud so it looks like a black blob against the Milky Way.

IC-1805 (+5000, +5000) in the constellation Cassiopeia is also called the Heart Nebula. It is located about 8,000 light years away.

Rosette Nebula (-2400, +5000) in the constellation Monocerous is about 130 light years in diameter and contains enough mass to form over 10,000 stars like our sun!



Crab Nebula (-500, +6400) is all that remains of a star that exploded about 1000 years ago. In the constellation Taurus at a distance of 7,000 light years, it has a diameter of about 11 light years and is expanding at a speed of 7 million kilometers per hour.

Our first plot on page 14 showed a dozen of the nearest bright stars. About what is the largest distance between the dozen bright stars and the sun? You should get an answer of about 200 light years.

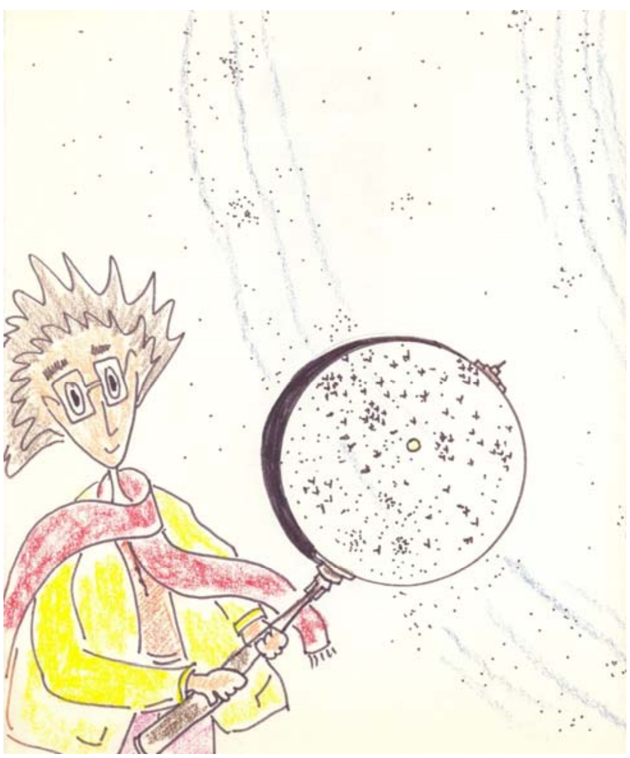
On your plot of star clusters and nebulae on page 38, draw a circle that has the same radius as the maximum star distance you estimated for page 17.

Can you now see why plotting individual stars does not give you a very good idea of just how big the Milky Way is? It does tell you something important, however.

Our 'star circle' that is 200 light years in radius actually contains about 1 million stars…not just a dozen! The vast majority of these stars have nothing to do with the star clusters and nebulae that we just plotted on page 38. In fact, they pepper the entire graph you just plotted with a nearly uniform carpet of points!

The places where you plotted the star clusters and nebulae are part of the spiral arms of our Milky Way. In fact, your plot shows that the sun is part of what astronomers call the Orion Spur. The next spiral arm outwards from the sun is called the Perseus-Cygnus Arm, and the one located just inside the Orion Spur is called the Sagittarius-Carina Arm.

In our part of the Milky Way, astronomers have figured out that the spiral arms are about 4,000 light years wide, with a gap between them of about 2000 light years. On your graph, shade-in the local spiral arms with this information. Feel free to make the arms look a bit ragged and 'cloudy looking' on their edges and lumpy, because when we look at other spiral galaxies, that's what arms look like!



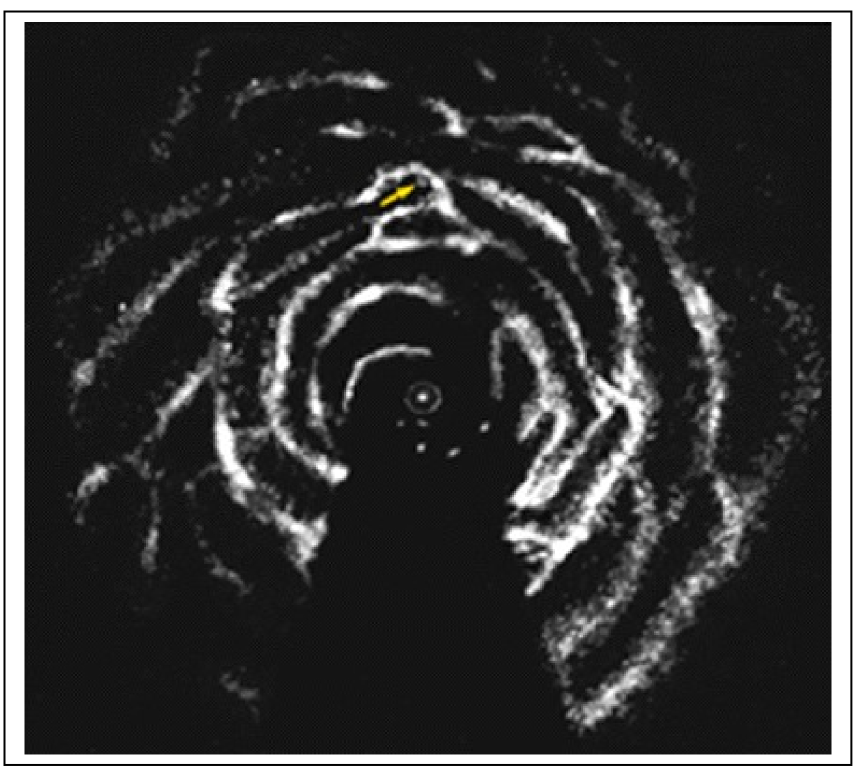
Even after we have plotted star clusters and nebulae that we can easily see from Earth, the Milky Way is so big we still can't see the whole thing. From the globular cluster data, we figured out that the sun is located 26,000 light years from the center of our galaxy. Astronomers can plot even more distant objects in our Milky Way!

When very massive stars form, they produce so much ultraviolet light that this light can easily strip the electrons from hydrogen atoms as far away as 10 light years from the star…or more. These collections of ionized gas are called HII regions (pronounced 'H two') by astronomers.

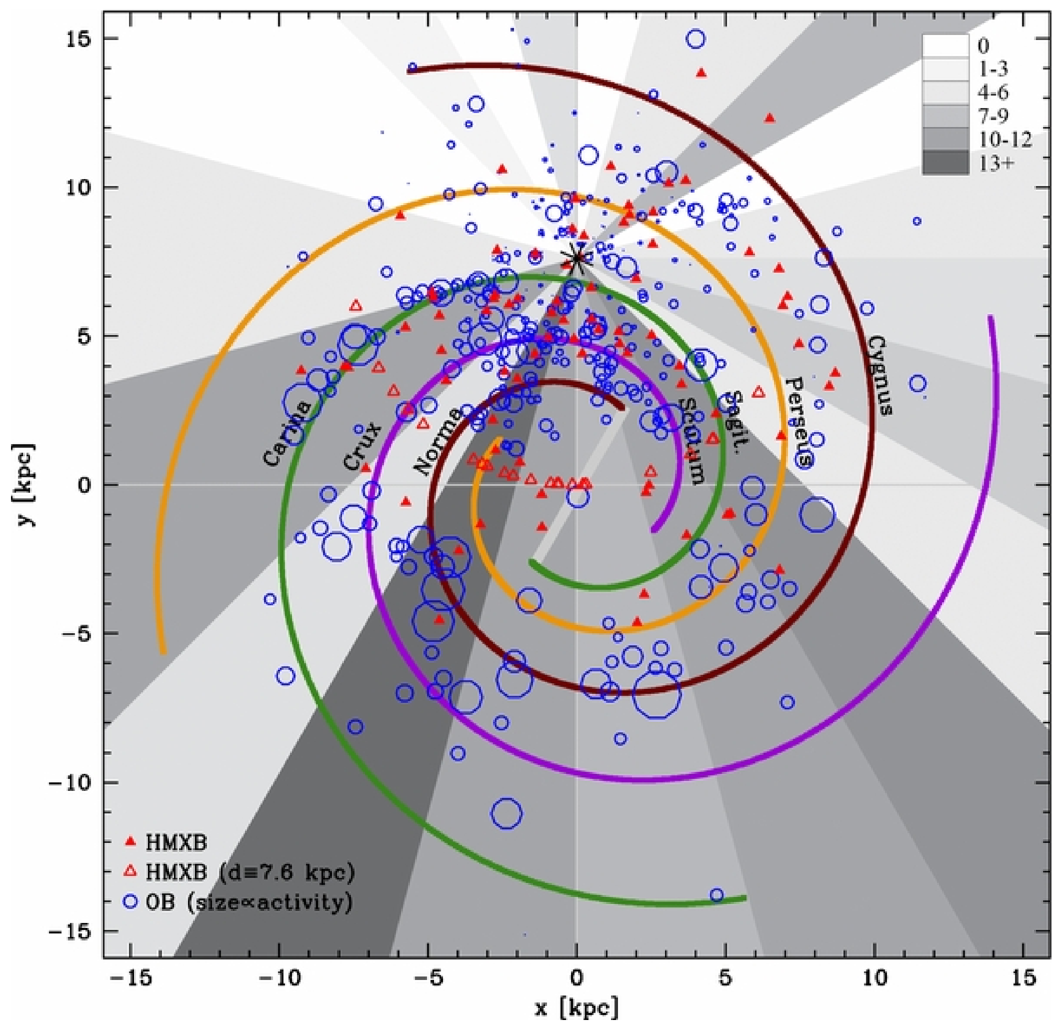
The neat thing about HII regions is that, although you may not see the light from the nebulae they produce, that are very strong sources of radio signals in space. By using radio telescopes, astronomers can detect them across then entire span of the Milky Way galaxy even though they can't see the nebula at all! This picture shows the Parkes radio telescope in Australia. It can see an object like the Orion Nebula to a distance of over 50,000 light years from the sun!

By carefully determining the location and distances to HII regions, astronomers have been able to identify the locations of four major spiral arms, and map them from the galactic center, and out beyond the orbit of the sun.

Astronomers have also used radio telescopes to map out the locations of the hydrogen gas clouds that exist between the stars. First they map out where the hydrogen clouds are across our entire sky, then they use the speeds of these clouds to estimate their distances from Earth. When they put this information together into a map of the Milky Way they get a picture that looks like the one below. The arrow points to the location of our sun, and the center of the figure is the center of the Milky Way. Note how the spiral arms show up very nicely when you use hydrogen gas in these arms to trace them out! You can also see that the Milky Way isn't a perfect pinwheel at all. There are many cross-links between the arms called 'spurs'. Our own sun seems to be in one of these spurs, which astronomers call the Orion Spur. It is connected to the Perseus Spiral Arm, which is the next one out from the sun's location.



When you put all of this information together, you get a map like the one below looking down from a position just above the Galactic North Pole. It was created in 2012 by astronomer A. Bodaghee and his colleagues at the University of California, Berkeley and shows many different kinds of objects plotted. The blue circles are clusters of hot, young stars. The triangles are binary stars that emit x-rays. The sun is located at (0, +8) where all the colored triangles come together.



This is the galaxy Messier-51 photographed by the Hubble Space Telescope. We have flipped the original picture left – to right so that it looks more like the sketch of the Milky Way on the previous page. On the next page is an enlargement of part of this spiral galaxy. Can you see the following objects?

1) <u>Spiral arms</u> where young stars and star clouds are found?
2) Star clusters where swarms of stars exist in space?
3) <u>Nebulae</u> where stars are forming?
4) <u>Dark clouds</u> soon to become nebulae?
5) The <u>Galactic Center</u>?

Now let's test just how good you are at classifying galaxies by looking at their shapes! Take a look at the next two pages and classify the galaxies as to whether they are spiral, barred-spiral, elliptical, lenticular or irregular galaxies! Here is some information about these types.

Spiral – Bright, round nucleus with two or more narrow or 'fluffy' looking pinwheel arms connected to the nucleus and spiraling out to great distances.

Barred-spiral - Instead of a round nucleus, it is a bright bar of stars, with one or more spiral arms attached to each end of the bar.

Elliptical - Round or elliptical shape with no spiral arms and only a cloud of starlight. Sometimes a disk of dark dust can be seen in silhouette.

Irregular - Lots of individual, very bright stars and gas clouds but no round or spiral shape .There can sometimes be nebulae mixed in with the faint stars.

Lenticular - Looks like a flat, spiral galaxy, but with no arms. Just a bright disk of starlight. Often described as spindle-shaped or lens-shaped.

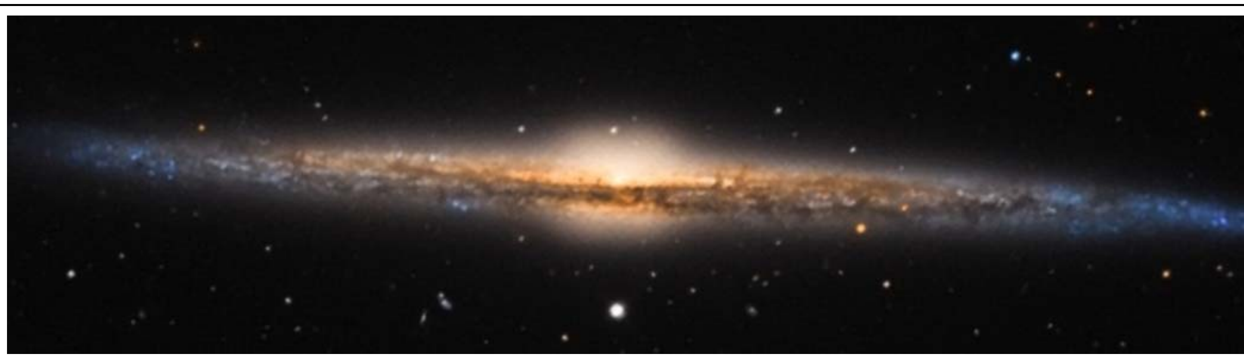
<u>From these definitions, can you classify the galaxies?</u>

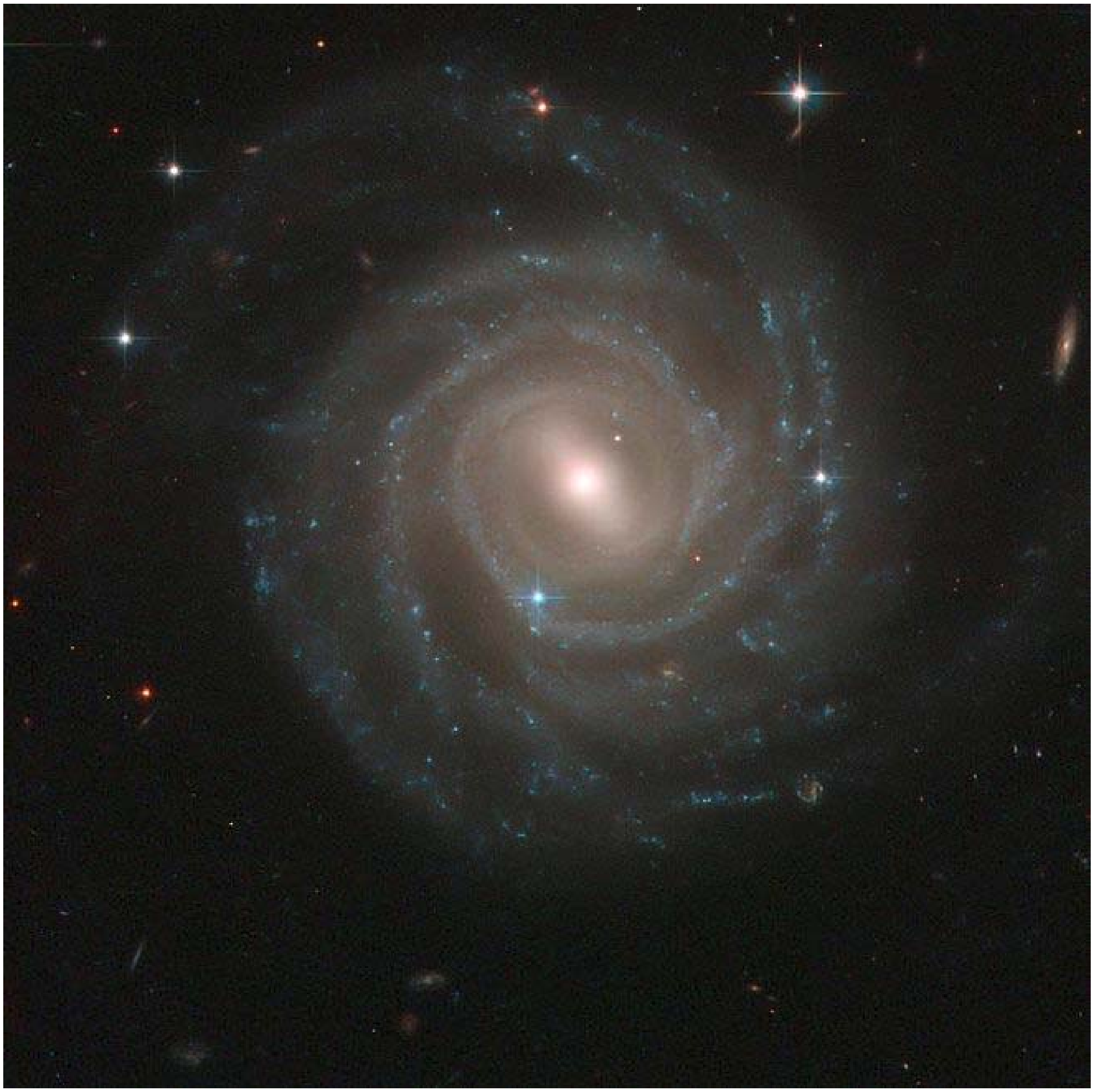


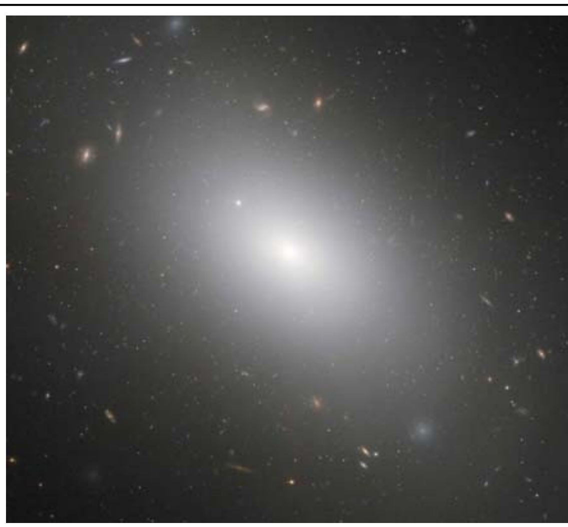










What we have learned!

Problem 1 - How big is a light year in kilometers?

Problem 2 - What is the distance to the Galactic Center from our sun in light years?

Problem 3 – From your map of the Milky Way's spiral arms, what kind of spiral galaxy is it? Barred? Normal? or Lenticular?

Problem 4 - From the data on the spiral galaxies in this book, about how many stars do you think our Milky Way has if it is an average spiral galaxy?

Problem 5 - Between which two spiral arms is our sun and solar system located?

Problem 6 - From the list of nearby stars in this book, what star is closest to our sun? What star is farthest from our sun?

Problem 7 - About what is the diameter of our Milky Way in light years?

Answers

Page 5 - 1.989×10^{30} kilograms.

Page 6 – 1) 19.89 - 2.45 = 17.44 so the difference is 1.744×10^{30} kg; 2) 16726.2158+9.1094 = 16735.3252 so the sum is $1.67353252 \times 10^{-27}$ kg.

Page 7 - (3.1×10^{7} seconds/year) x (1.37×10^{10} years) = 4.247×10^{17} seconds.
(2.0×10^{33} grams) / (1.6×10^{-24} grams/atom) = 1.25×10^{57} atoms.

Page 8 – 1) 3.156×10^{7} sec 2) 3.827×10^{26} watts 3) 9.1096×10^{-31} kg 4) 5.29177×10^{-9} cm 5) 250,000,000,000 stars 6) 9,000,000,000,000,000,000 stars 7) 0.00000000000000000000000327 kg 8) 1.47×10^{14} stars 9) 7.72×10^{25} kg 10) 9.52×10^{11} tons 11) 6.7×10^{4} stars.

Page 10 - 1 LY = 6.0×10^{1} seconds/minute x 6.0×10^{1} minutes/hour x 2.4×10^{1} hours/day x 3.62524×10^{2} days/year x 3.0×10^{5} km/s. So 1 LY = 9.467×10^{12} km.

Page 11 - That is the same as 4.2 x 811 = 3,406 times the diameter of our solar system.

Page 14 – A double spiral. Note that both of the coordinates for Spiral B have the opposite sign of Spiral A.

Page 16 – Only the change in the y-coordinate matters: (23 – 4) = 19 light years.

Page 24 – 40 kiloparsecs is 40,000 parsecs. Since 1 parsec = 3.26 light years, we have 40,000 x 3.26 = 130,400 LY.

Page 25 - Average the 9 values to get 26,278 light years, which rounds to 26,300 light years.

Page 28 - 140,000 light years x 9.467×10^{12} km/ly = 1.33×10^{18} km.

Page 29 - 200 billion stars x 2.0×10^{30} kg/sun = 4.0×10^{41} kg.

Page 30 - 60 million light years x 63,282 AU/ly = 3.8×10^{12} AU.

Page 33 – Closest is NGC-300 at 5 million ly; farthest is UGC-12158 at 400 million LY.

Page 52 -Top row L to R: Lenticular, barred-spiral, elliptical; Middle row, L to R: spiral; barred-spiral, spiral; Bottom row ,L to R: Barred-spiral, irregular, irregular. Bottom: spiral edge-on.

Page 53 - Top: Barred-spiral; Lower row Left: elliptical; Right: irregular.

Page 54 - What we have learned!
Problem 1: 9.5 trillion kilometers;
Problem 2: 26,300 light years; - See Page 25.
Problem 3: Barred Spiral.
Problem 4: Look at the star data for Messier-101, UGC-12158; NGC-1300, NGC-4414, NGC-1512, Messier-109 and NGC-300 and average them together to get (100+ 500+ 200+ 100+ 100+ 250+ 50)/7 = 185 billion stars.
Problem 5: The Perseus and Carina Arms.
Problem 6: Closest=Alpha Centauri; Farthest=Spica.
Problem 7: Students can estimate twice 26,000 light years = 52,000 light years, or from their graph including the Perseus Arm, about 2 x (20,000 + 26,000) = 92,000 light years.

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Front and back cover credits:

Front) Milky Way artistic view by Nick Risinger (2009: Wikipedia.com)
Back) NGC 6744 Courtesy ESO, 2.2-meter LaSillia Observatory, Chile

Inside Illustrations:

Pg 20 - Parnal Observatory, ESO Yuri Beletsky (http://www.eso.org/public/images/eso0733a/)
Pg 21 – NGC-4472 – Courtesy McDonald Observatory
Pg 22, 23 – Pleiades: NASA/Hubble Space Telescope; M-13: 2MASS Sky Survey
Pg 26 - NGC-4565: Howard Trottier SFU (http://www.sfu.ca/~trottier/index.html) trottier@sfu.ca
Pg 27 – Messier 101 - NASA/Hubble Messiar 101; Pg 28 – UGC-12158 NASA/Hubble
Pg 29 – NGC-1300 ESO/Very Large Telescope;
Pg 30, 31 – NGC-4414 – NASA/Hubble; NGC-1512 – NASA/Hubble
Pg 32 – Messier 109 – Dale Swanson / Adam Block / NOAO / AURA (http://www.noao.edu/outreach/aop/observers/m109.html)
Pg 33 – NGC 300 Wide-Field Imager (WFI) MPG/ESO 2.2-m telescope. La Silla Observatory. ESO (http://www.eso.org/public/images/eso0221a/)
Pg 35: M-29: 2MASSS/CalTech Pleiades; NASA/Hubble, M-46 2MASS Survey/CalTech/ M-67; 2MASS/CalTech
Pg 36 – M-11 2MASS/CalTech/IPAC ; IC2944 Till Credner and Sven Kohle (http://www.allthesky.com/constellations/chamaeleon/dsos.html) ; NGC-3293 MCG Australian Observatory (http://tas.astroshots.net/Pingley%20Site/NGC3293.html)
Pg 37: M-103 2MASS Sky Survey/Caltech/IPAC ; h Chi Persei Courtesy Andrew Cooper @ Wikipedia: acooper@pobox.com ; NGC-1817 Bernard Hubl (b.hubl@astrophoton.com)
Pg 39; Unknown.
Pg 40 – Eta Carina; NASA/Spitzer Space Telescope
Pg 41, 42, 43 – Lagoon Nebula; Omega Nebula; Pelican Nebula; Orion Nebula; Coalsack Nebula; IC-1805; Rosette Nebula; Crab Nebula (NASA/Hubble Space Telescope)
Pg 46 – Parkes Radio Telescope, David Darling (http://www.daviddarling.info/encyclopedia/P/ParkesRT.html)
Pg 47 – HI map of Milky Way Courtesy G. Westerhout et al (1958)
Pg 48 – The Astrophysical Journal 744 (2012) 108
Pg 49, 50 – Messier 51 –NASA/ Hubble Space Telescope
Pg 52: ESO-243-49: NASA, ESA, and S. Farrell (Sydney Institute for Astronomy, University of Sydney)
Messier 109: Dale Swanson / Adam Block / NOAO / AURA
(http://www.noao.edu/outreach/aop/observers/m109.html)
NGC-1316, 1232 and 1365 ESO
NGC-634: NASA/Hubble
NGC-1097: European Southern Observatory (NACO/VLT)
IC-10: The Survey Team of the Lowell Observatory
NGC-1427A: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)
NGC-4565: Howard Trotter (SFU)
Pg 53: UGC-12158: ESA/Hubble & NASA; NGC-1132: NASA/Hubble Space Telescope; NGC-4449: NASA/Hubble Space Telescope.

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