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# How Fast Are You Moving When You Are Sitting Still?

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When, after a long day of running around, you finally find the time to relax in your favorite armchair, nothing seems easier than just sitting still. But have you ever considered how fast you are really moving when it seems you are not moving at all?

## Daily Motion

When we are on a smoothly riding train, we sometimes get the illusion that the train is standing still and the trees or buildings are moving backwards. In the same way, because we "ride" with the spinning Earth, it appears to us that the Sun and the stars are the ones doing the moving as day and night alternate. But actually, it is our planet that turns on its axis once a day—and all of us who live on the Earth's surface are moving with it. How fast do we turn?

To make one complete rotation in 24 hours, a point near the equator of the Earth must move at close to 1000 miles per hour (1600 km/hr). The speed gets less as you move north, but it's still a good clip throughout the United States. Because gravity holds us tight to the surface of our planet, we move with the Earth and don't notice its rotation[1] in everyday life.

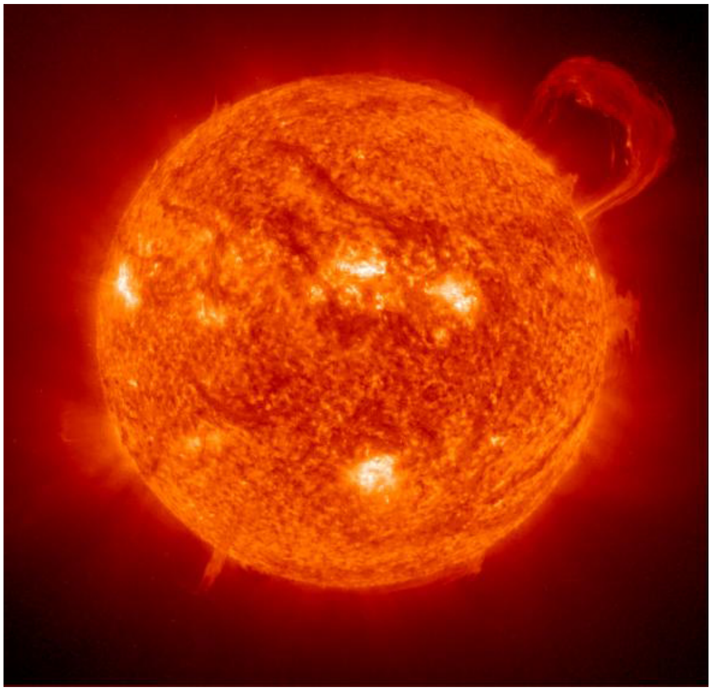
The great circular streams of water in our oceans and of air in our atmosphere give dramatic testimony to the turning of the Earth[2]. As the Earth turns, with faster motion at the equator and slower motion near the poles, great wheels of water and air circulate in the northern and southern hemisphere. For example, the Gulf Stream, which carries warm water from the Gulf of Mexico all the way to Great Britain, and makes England warmer and wetter than it otherwise would be, is part of the great wheel of water in the North Atlantic Ocean. The wheel (or gyre) that the Gulf Stream is part of contains more water than all the rivers of the world put together. It is circulated by the energy of our turning planet.

The Earth as seen by the Apollo 17 Crew on the way to the Moon.

*Image credit:* NASA

## Yearly Motion

In addition to spinning on its axis, the Earth also revolves around the Sun. We are approximately 93 million miles (150 million km) from the Sun, and at that distance, it takes us one year (365 days) to go around once. The full path of the Earth's orbit is close to 600 million miles (970 million km). To go around this immense circle in one year takes a speed of **66,000 miles per hour** (107,000 km/hr)[3]. At this speed, you could get from San Francisco to Washington DC in 3 minutes. As they say on TV, please don't try going this fast without serious adult supervision.



The Sun, seen in ultraviolet light with instruments aboard the SOHO satellite.

*Image credit:* SOHO

## The Sun's Motion

Our Sun is just one star among several hundred billion others that together make up the Milky Way Galaxy. This is our immense "island of stars" and within it, each star is itself moving. Any planet orbiting a star will share its motion through the Galaxy with it. Stars, as we shall see, can be moving in a random way, just "milling about" in their neighborhoods, and also in organized ways, moving around the center of the Galaxy.

If we want to describe the motion of a star like our Sun among all the other stars, we run up against a problem. We usually define motion by comparing the moving object to something at rest. A car moves at 60 miles per hour relative to a reference post attached to the Earth, such as the highway sign, for example. But if all the stars in the Galaxy are moving, what could be the "reference post" to which we can compare its motion?

Astronomers define a *local standard of rest* in our section of the Galaxy by the average motion of all the stars in our neighborhood[4]. (Note that in using everyday words, such as "local" and "neighborhood", we do a disservice to the mind-boggling distances involved. Even the *nearest* star is over 25 thousand billion miles (40 thousand billion km) away. It's only that the Galaxy is so immense, that compared to its total size, the stars we use to define our Sun's motion do seem to be in the "neighborhood.")

Relative to the local standard of rest, our Sun and the Earth are moving at about 43,000 miles per hour (70,000 km/hr) roughly in the direction of the bright star Vega in the constellation of Lyra. This speed is not unusual for the stars around us and is our "milling around" speed in our suburban part of the Galaxy.

The Sun travels with billions of other stars through the Milky Way Galaxy, which is thought to look much like the Andromeda Galaxy, pictured above.

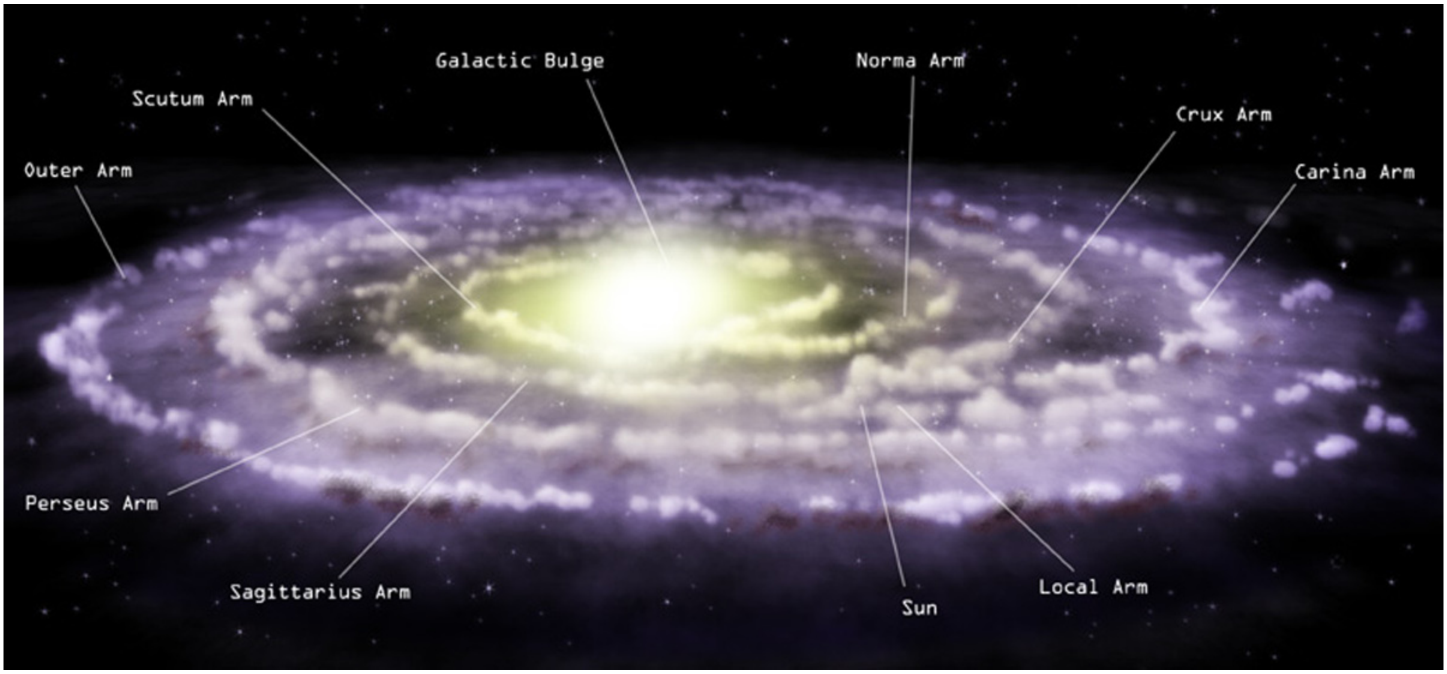
*Image credit:* NASA Marshall Space Flight Center (NASA-MSFC)

## Orbiting the Galaxy

In addition to the individual motions of the stars within it, the entire Galaxy is in spinning motion like an enormous pinwheel. Although the details of the Galaxy's spin are complicated (stars at different distances move at different speeds), we can focus on the speed of the Sun around the center of the Milky Way Galaxy[5].

It takes our Sun approximately 225 million years to make the trip around our Galaxy. This is sometimes called our "galactic year". Since the Sun and the Earth first formed, about 20 galactic years have passed; we have been around the Galaxy 20 times. On the other hand, in all of recorded human history, we have barely moved in our long path around the Milky Way.

How fast do we have to move to make it around the Milky Way in one galactic year? It's a huge circle, and the speed with which the Sun has to move is an astounding 483,000 miles per hour (792,000 km/hr)! The Earth, anchored to the Sun by gravity, follows along at the same fantastic speed. (By the way, as fast as this speed is, it is still a long way from the speed limit of the universe—the speed of light. Light travels at the unimaginably fast pace of 670 million miles per hour or 1.09 billion km/hr.)

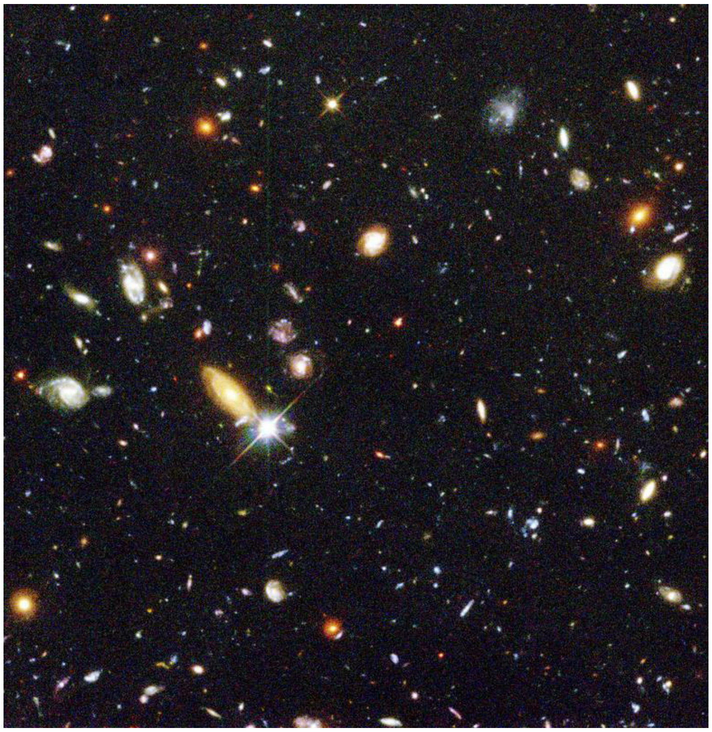


An artist's illustration of the Milky Way Galaxy

*Image credit: NASA / CXC / M. Weiss*

## Moving through the Universe

As we discussed the different speeds of our planet so far, we always needed to ask, "Compared to what are you measuring this motion?" In your armchair, your motion compared to the walls of your room is zero. Your motion compared to the Moon or the Sun, on the other hand, is quite large. When we talk about your speed going around the Galaxy, we measure it relative to the center of the Milky Way.



The Hubble Deep Field image shows some of the most distant Galaxies in the Universe.

*Image credit: Robert Williams and the Hubble Deep Field Team (STScI) and NASA*

Now we want to finish up by looking at the motion of the entire Milky Way Galaxy through space. What can we compare its motion to—what is the right *frame of reference?* For a long time, astronomers were not sure how to answer this question. We could measure the motion of the Milky Way relative to a neighbor galaxy, but this galaxy is also moving. The universe is filled with great islands of stars (just like the Milky Way) and each of them is moving in its own way. No galaxy is sitting still! But then, a surprising discovery in the 1960s showed us a new way to think of our galaxy's motion.

## The Flash of the Big Bang

To understand this new development, we have to think a little bit about the Big Bang, the enormous explosion that was the beginning of space, time, and the whole universe. Right after the Big Bang, the universe was full of energy and very, very hot. In fact, for the first few minutes, the entire universe was hotter than the center of our Sun. It was an unimaginable maelstrom of energy and subatomic particles, slowly cooling and sorting itself out into the universe we know today.

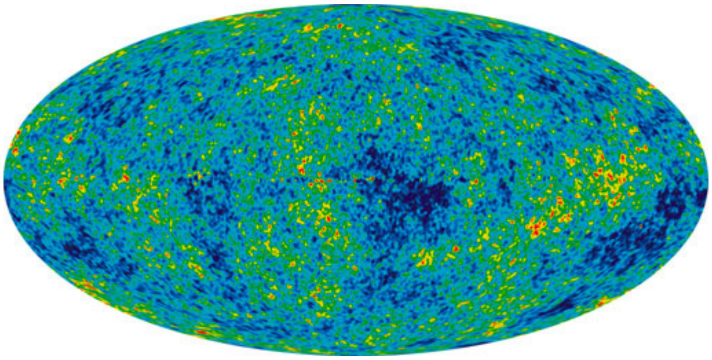
At that early time, the energy in the universe was in the form of *gamma rays*, waves of energy like the visible light we see, but composed of much shorter waves with higher energy. Today on Earth, it takes a nuclear bomb to produce significant amounts of gamma rays. But then, the whole universe was filled with them. You can think of these gamma-rays as the "flash" of the Big Bang—just like fireworks or a bomb can produce a flash of light, the Big Bang resulted in a flash of gamma rays. But these gamma rays were everywhere in the universe. They filled all of space, and as the universe grew (expanded), the gamma rays expanded with it.

When people first think about the expansion of the universe, they naturally think of other expansions they have experience with: how the American colonies eventually expanded to become the 48 states of the U.S. or how an exploding bomb might throw shrapnel in every direction. In these situations, the space into which the colonies or the shrapnel is expanding already exists. But the expansion of the universe is not like any other expansion. *When the universe expands, it is space itself that is stretching.* The galaxies in the universe are moving apart because space stretches and creates more distance between them.

What does this mind-stretching idea of stretching space mean for our gamma rays? The gamma rays are waves of energy moving through space. As space stretches, the waves that are in space must stretch too. Stretched gamma rays are called x-rays. So as the universe expanded, the waves of energy filling space stretched out to become less energetic (cooler) x-rays. As the universe continued to expand, the same waves became ultra-violet light. Later they became visible light, but there were no eyes in the hot compressed universe to see them yet. (When we take the lid of a hot pressure cooker, the steam will expand into the room and cool down. In the same way, we can think of the waves of energy in the expanding universe as cooling down—getting less energetic.)

Today, some 12 to 15 billion years after the Big Bang, there has been a lot of stretching. Space has expanded quite a bit. The flash of the Big Bang has stretched until it is now much longer, lower energy waves—microwaves and other radio waves. But the waves have stretched with the space they occupy, and so they still fill the universe, just the way they did at the time of creation.

Astronomers call the collection of all these stretched waves the *cosmic background radiation*[6] or CBR. Physicists back in the late 1940's predicted that there should be such a background, but since no one had the equipment to find it, the prediction was forgotten. Then, in the mid 1960s, two scientists working for Bell Laboratories, Arno Penzias and Robert Wilson, accidentally discovered the CBR while helping to get communications satellite technology going for the phone company. After astronomers used other telescopes and rockets in orbit to confirm that the radio waves the two scientists had discovered were really coming from all over space, Penzias and Wilson received the Nobel Prize in physics for having found the most direct evidence for the Big Bang.



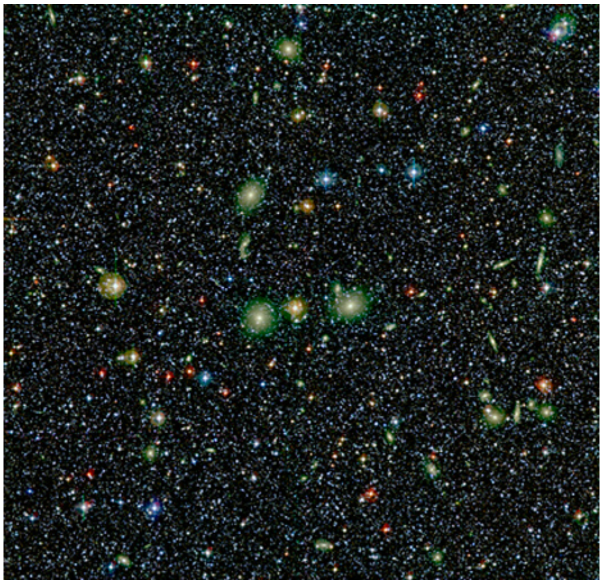
WMAP image of the Cosmic Microwave Background radiation

*Image credit: NASA/WMAP Science Team*

## Moving through the CBR

What, you might be asking yourself, does all this have to do with how fast we are moving? Well, astronomers can now measure how fast the Earth is moving compared to this radiation filling all of space. (Technically, our motion causes one kind of Doppler Shift[7] in the radiation we observe in the direction that we are moving and another in the direction opposite.)

Put another way, the CBR provides a "frame of reference" for the universe at large, relative to which we can measure our motion. From the motion we measure compared to the



There is thought to be a large concentration of mass in the  in the direction of Leo and Virgo, since the galaxies near the Milky Way seem to be streaming in that direction. A portion of this section of the sky is shown in the image above.

*Image credit: ESO*

CBR, we need to subtract out the motion of the Earth around the Sun and the Sun around the center of the Milky Way. The motion that's left must be the particular motion of our Galaxy through the universe!

And how fast is the Milky Way Galaxy moving? The speed turns out to be an astounding 1.3 million miles per hour (2.1 million km/hr)! We are moving roughly in the direction on the sky that is defined by the constellations of Leo and Virgo. Although the reasons for this motion are not fully understood, astronomers believe that there is a huge concentration of matter in this direction. Some people call it *The Great Attractor*, although we now know that the pull is probably not due to one group of galaxies but many. Still the extra gravity in this direction pulls the Milky Way (and many neighbor galaxies) in that direction.

## No Rest for the Weary

So the next time someone in your family or group of friends calls you lazy for just sitting there, you can politely remark that, although it may look as if you are just sitting, you are actually moving at great speed around the Earth, around the Sun, around the Milky Way, and through the universe. Surely, a lot of energy is required for all that motion. I'll confess this line has never gotten me out of having to do household chores for long, but perhaps you'll have better luck with it. And your students, who often have trouble sitting still, will surely appreciate learning that, cosmically speaking, they are in constant motion.

*Little Girl in Blue Armchair* by Mary Cassatt, National Gallery of Art, Collection of Mr. & Mrs. Paul Mellon

## About the Author

Andrew Fraknoi is the Chair of the Astronomy Department at Foothill College and Educational Consultant for the Astronomical Society of the Pacific. Before joining the faculty at Foothill in 1992, he served as the Society's Executive Director for 14 years and was the editor of its popular-level astronomy magazine, *Mercury*, as well as the founder of this teacher's newsletter, the Universe in the Classroom.

Fraknoi is author or coauthor of 14 books on astronomy and astronomy education, editor of the Universe at Your Fingertips, a frequent guest on national radio programs, a member of the Board of Trustees at the SETI Institute, and a Fellow of the Committee for the Scientific Investigation of Claims of the Paranormal (CSICOP). Together with Sidney Wolff, he also edits Astronomy Education Review, an on-line journal for astronomy educators.

## Classroom Activity #1: Your Galactic Address

In this activity, students explore the different realms of the cosmos and our place in the larger universe by addressing a letter to a friend in a distant galaxy. Rather than just including house number, street, city, state and country, they also include their place in the solar system and the galaxy.

The entire write-up for this activity is available here[8]. This activity is printed here with permission from Planetarium Activities for Student Success (PASS; http://lhs.berkeley.edu/pass), produced by the Lawrence Hall of Science, University of California, Berkeley. Copyright 1993 by the Regents of the University of California. A number of astronomy activities are available for free download on the PASS website.

## Classroom Activity #2: Cosmic Calendar

Cosmology—the study of our universe, how it began, and how it has evolved—can seem incomprehensible to students because of the vast eons of time between today and the beginning of the universe. This activity will provide a "bridge" across time that will make the numbers more meaningful.

In "Cosmic Calendar" [9], students scale the evolution of the universe to a one year calendar, with the Big Bang occuring on the first moment of January 1st. Students estimate where on this one year time line significant events (like the formation of the solar system, the appearance of dinosaurs and the emergence of humanity) should be placed. More advanced students can research the dates of significant events and calculate when in the model timeline these events occurred.

This activity appears in the Universe at Your Fingertips and was written by Therese Puyau Blanchard and the staff of Project ASTRO. Copyright © 1995, Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112.

## Resources

1. Ask An Astronomer: Are we able to feel the Earth spin?
http://curious.astro.cornell.edu/question.php?number=665

2. Coriolis Effect: how the spinning of the Earth affects the tides and winds
http://books.nap.edu/html/oneuniverse/motion_32-33.html

3. Ask An Astronomer: At what speed does the Earth move around the Sun?
http://curious.astro.cornell.edu/question.php?number=356

4. The Solar Neighborhood
http://www.americanscientist.org/template/AssetDetail/assetid/21173/page/2

5. The Milky Way Galaxy
http://www.windows.ucar.edu/tour/link=/the_universe/Milkyway.html&edu=mid

6. Cosmic Microwave Background
http://map.gsfc.nasa.gov/m_uni/uni_101bbtest3.html

7. Redshift and the Expanding Universe
http://www.exploratorium.edu/origins/hubble/tools/doppler.html

8. Classroom Activity: Your Galactic Address from PASS at the Lawrence Hall of Science
http://lhs.berkeley.edu/pass/passv09/PASSv09-GalacticAddress.pdf

9. Classroom Activity: Cosmic Calendar
http://www.astrosociety.org/education/astro/act2/cosmic.html

## Additional Resources

**Ask An Astronomer**
On this page, a Cornell astronomer answers the following question: Considering the motion of the Earth, the solar system, and the galaxy, how fast am I moving while lying in bed asleep?
http://curious.astro.cornell.edu/question.php?number=507

**"Where Are We Going? Notes on the Absolute Motion of the Solar System Through Space."**
by Timothy Ferris, Sky & Telescope, May, 1987 (available in most large libraries)

**The NASA Universe Forum**
From the Harvard Smithsonian Center for Astrophysics, this is a national center for teaching and learning about the Universe.
http://cfa-www.harvard.edu/seuforum/index.htm

**One Universe: At Home in the Cosmos**
This book details the origins and fate of the Unverse, with chapters on motion and energy. Written at a good popular level by well-know astronomers and science educators Neil De Grasse Tyson, Charles Lui, and Rober Irion, the entire text is available for free online.
http://books.nap.edu/html/oneuniverse/index.html

**An Ancient Universe: How Astronomers Know the Vast Scale of Cosmic Time**
This special edition of The Universe in the Classroom gives some of the background on how scientists have been able to measure cosmic ages as well as some references to classroom activities and resources for further exploration of some the astronomical discussed.
http://www.astrosociety.org/education/publications/tnl/56/index.html