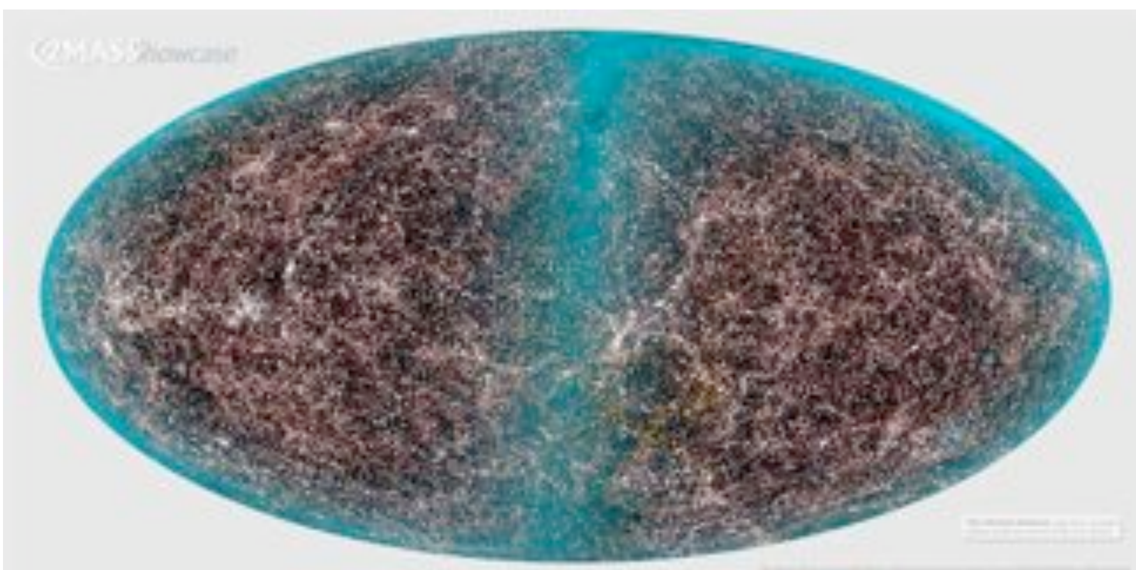
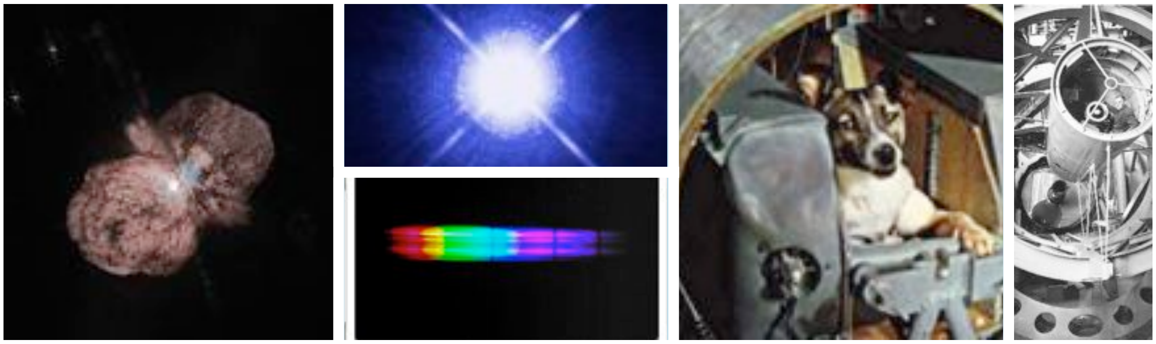
Chapter 2

The Universe in Space and Time



Introduction



Left to right: Eta Carinae, Sirius and its spectrum, Laika (the first dog in space), The Hooker Telescope on Mt. Wilson in California

The Universe is everything there is: all the stars, all the planets, all the galaxies. As far out in space as you can go, you are still in the Universe. The Universe includes all of space. The Universe includes all of time as well. As you forward in time as you can go, you are still in the Universe. The Universe includes the past as well. Everything that ever happened, that we can know about, happened in our Universe.

Space and Time

Not only does the Universe include all of space and time, but space and time themselves are mixed together. They are mixed up in two different ways. One way, that we will explore in detail in Chapter 20, is that space and time are really aspects of a combined entity called space-time.

The other way space and time are intertwined is a consequence of the speed of light. Light travels very fast–300,000 km per second. This is about a million times faster than sound. Because light travels at a finite speed, it takes a certain amount of time for light to reach us from the stars.

For example, light takes a bit more than a second to go the 400,000 km from the Moon to the Earth. In other words, the Moon is about one **light-second** from the Earth, where a light-second is the distance light travels in a second (300,000 km).

The Sun's light travels eight minutes on its way to the Earth. We might say that the Sun is 8 **light-minutes** from the Earth. Light takes four *hours* to get to Neptune, at the edge of the Solar

System: Neptune is four **light-hours** from the Sun. Sirius is eight **light-years** from the Sun, where a light-years is the distance light travels in a year.

Quick Question. *How many kilometers are there in a light-year?*

Answer. The speed of light is 300,000 km/sec. There are about 31,000,000 seconds in a year. Therefore, light travels 300,000 x 31,000,000 km in a year. That's about 10,000,000,000,000 km–10 *trillion* kilometers.

Now, when we look at the Moon in the sky, we are seeing light that left the Moon about a second ago. Consequently, we are not seeing what the Moon looks like right *now,* we are seeing what the Moon looked like about one second ago (not a big deal, since the Moon doesn't change noticeable in a second).Likewise, when we look at the Sun, we are seeing it as it existed 8 minutes ago. When we look at Sirius, we see it as it was 8 *years* ago. This examples illustrate a fundamental fact of astronomy:

The farther out into space we look, the father back in time we see.

In other words, when we look at the night sky, we don't see what the Universe looks like right now. Rather, we see different stars and planets at different times. We see a mixture of the past and the more distant past. What we don't see is the present.

In many cases, this peculiar way we are looking into the past has no practical consequence. Sirius, for example, doesn't change noticeably in a human lifetime, so the fact that we are seeing it as it was 8 years ago is unimportant. It looks precisely the same today. We're not going to see what it looks like today for another 8 years, but when we do, we'll see that it doesn't look any different.

In other situations, however, the light-travel time is important. For example, suppose we are looking at Jupiter. Jupiter has four large moons orbiting around it. From time to time, the shadow of one of the moons falls on Jupiter. When this happens, it's interesting because you can see the shadow with even a small telescope. It takes a few minutes for the shadow to cross Jupiter's disk. But remember that you are seeing the shadow as it was in the past. You have to take that fact into account when calculating when to look for the shadow. The distance between the Earth and Jupiter varies from 32 to 48 light-minutes. Consequently, when Jupiter is at its closest, we will see the shadow about 8 minutes sooner than average, while when Jupiter is at its farthest, we will see the shadow about 8 minutes late. This phenomenon was in fact how the speed of light was discovered by Rømer in Paris in 1676.

Powers of 10

.Astronomers use powers of 10 to write very large and very small numbers. For example, a light-year is 9.6×10^{12} km. To write this number out, write down the 9.6 and add several 0's at the end. Then move the decimal point 12 places to the right.

9.600000000000^000

Astronomers deal with very small numbers as well. For example, the lifetime of a certain subatomic particle, the **muon,** is 1.06×10^{-6} s.To write this number out normally, start with the 1.06 and add many zeros to the *left.* Then move the decimal point 6 places to the left.

00^00000106

Some powers of then occur so often they become quite familiar. Here are some of the most commonly used powers of 10:

10^3	thousand	10^{-3}	thousandth
10^6	million	10^{-6}	millionth
10^9	billion	10^{-9}	billionth
10^{12}	trillion	10^{-12}	trillionth

Notice that these are steps of a *thousand:* a million is a thousand thousand; a billion is a thousand million, etc.

The Metric System

Scientists use the metric system to measure sizes, distances, and weights. Actually, they use an extension of the metric system called the **International System.** In the International System, the unit of length is the meter (m), the unit of time is the second (s), and the unit of weight or mass is the kilogram (kg).

The nice thing about the International System is that it comes with a built-in set of prefixes based on powers of 10. This makes it easy to write down both big and small numbers. The most commonly used prefixes are

10^{3}	kilo- (k)	10^{-3}	milli- (m)
10^{6}	mega- (M)	10^{-6}	micro- (μ)
10^{9}	giga- (G)	10^{-9}	nano- (n)
10^{12}	tera- (T)	10^{-12}	pico- (p)

Notice that the "small" prefixes on the right are written in lower case letters, while the "big" prefixes on the left are written in upper case letters, with the exception of k (kilo-). Using the prefixes, we can write, for example, 1,200,000 m = 1.2 Mm and 0.0025 seconds= 2.5 ms.

Check Question.

Write out the following numbers:

1 light-second = 300 Mm = 300,000,000 m

1 light-minute = 18 Gm = ______________ m

1 light-hour = 1.08 Tm = ______________ m

1 light-day =25.92 Tm = ______________ m

1 light-year = 9.47 Pm = _______________ m

In the last example, 1 Pm = 1 **petameter** = 10^{15} m.

The Astronomical Number Word

The critical number word in astronomy is *billion.*

When we are talking about space, the most distant galaxies we can see are billions of light-years away. When we are talking about time, we are seeing those galaxies as they existed billions of years ago. The Universe itself is billions of years old. That's easy to say, but it's not so easy to prove. Indeed, it's taken two thousand years of studying the skies to learn that the Universe began a few billions of years ago. This book tells the story of how we figured that out.

How much is a billion? After all, a billion and a million sound pretty similar, don't they? To the mind, the difference between them is just one letter. But in realty there is an enormous difference: a billion is a *thousand* million.

An example may make the difference clearer. How long would it take you to count to a million? If you counted one number a second, and counted continuously without stopping to eat or sleep, you would reach a million in about 12 days. If you wanted to count to a *billion,* it would take you 12,000 days—about 32 years. That's a long time to go without sleep!

It's important to understand that in astronomy a million years is a *short* amount of time. The Universe is thousands of millions of years old–it doesn't change much in one or two milion years. But a *billion* years—now we're talking serious time!

Check question.

How long would it take you to count to a trillion?

SPACE

Space is made of superclusters, which are made of galaxy clusters, which are made of galaxies, which are made of solar systems.

Solar Systems

A solar system contains one or more stars, some planets, and lots of small stuff. The solar system we live in is simply called *the* Solar System. Our Solar System has just one star, the Sun (so far as we know). It also has several planets (although the precise number is subject to some dispute).

Stars are hot balls of gas. Because they are hot, they shine—they give off light.

Planets are cold spheres. They may be made of gas or they may be solid, like the Earth. Because they are cold, they do *not* give off light. They can be seen only because they reflect the light of their star.

Stars are, in general, bigger than planets. However, they are not always bigger: the biggest planets and the smallest stars are about the same size.

The fundamental difference between stars and planets in one of **mass**. "Mass" is the word we use in science for weight. Stars are more massive—heavier— than planets. For example, the smallest stars, **red dwarf** stars, are about the size of the planet Jupiter but are 100 times more massive.

Solar systems are a few light-hours across.

Star Clusters

A group of stars is called a **star cluster.** The stars of a cluster were born together out of a cloud of gas called a **nebula.** All the stars in the cluster are about the same age. Neighboring stars inside a cluster are about a light-year apart.

There are two kinds of star clusters. **Open clusters** are small clusters containing a few dozen to a few hundred stars. **Globular clusters** are much larger and may contain more than a million stars. Open clusters don't last forever. After a few hundred millions years, the stars in the cluster wander away and the cluster disperses. Our Sun was born in an open cluster 4.5 billion years ago. The stars in its cluster disperse long, long ago. Globular clusters, on the other hand, live practically forever.

Open Clusters are maybe 10 light-years across. A globular cluster is about 100 light-years across.

Galaxies

A **galaxy** is a system of billions of stars.Like stars clusters, galaxies are groups of stars. For one thing, they are much bigger. They look different, too. There are two common kinds of galaxies. **Elliptical galaxies** are more or less round and lack spiral arms. **Spiral galaxies** are flat—flat as a pancake—and generally have spiral arms. Galaxies that don't look like either elliptical or spiral galaxies are called **irregular galaxies.**

Our galaxy is called the **Milky Way Galaxy.** It is a spiral galaxy, and our Solar System is located in one of the spiral arms, the **Orion arm.** Because we live in a flat galaxy, when we look it our Galaxy at night, it looks like a band of light that forms a circle that goes all the way around the sky. That circle of light is the Milky Way, after which the whole Galaxy is named.

Galaxy clusters

Like stars, galaxies form groups called clusters. The difference is that most stars *don't* belong to a cluster, but most *galaxies* do. Galaxy clusters come in all sizes. Small galaxy clusters may contain only a few galaxies. The largest galaxy clusters contain thousands of galaxies, each containing billions of stars.

The Milky Way Galaxy belongs to a small galaxy cluster called the Local Group. It's not a very imaginative name, but it's accurate! Besides our Galaxy, the Local Group contains two other spiral galaxies, the **Great Andromeda Galaxy** and the **Triangulum Galaxy,** plus about 30 small elliptical and irregular galaxies.

The typical distance between neighboring galaxies in a galaxy cluster is a million light-years. The distance between neighboring clusters is about 10 million light-years.

Superclusters

Galaxy clusters themselves form clusters of clusters! It was only natural to call a cluster of galaxy clusters a **supercluster.** A supercluster may be 100 million light-years across.

Our Local Group is located in the fringes of a supercluster called the **Virgo Supercluster.** The center of the Virgo Supercluster is a rich galaxy cluster called the **Virgo Cluster,** located about 50 million light-years away.

You might wonder, is there such a thing as a cluster of superclusters? Well, not exactly. What happens on the largest scales is that the superclusters link together to form long strings of galaxies or walls that surround vast empty regions called **voids.** The voids themselves are hundreds of millions of light-years across. The voids fill most of space.

So you see, galaxies are mostly space, as the stars are light-years apart. The space between galaxies is mostly devoid of stars. But the voids are *really* almost completely empty. The structure of the Universe has been likened to a bubble bath. The bubbles are the voids and the galaxies are found only on the film of the bubbles.

TIME

The story of the Universe is a familiar one.

1) The Universe had a begining.

2)The Universe changes as it gets older.

3) The Universe will have and end one day.

The Big Bang

The Universe began with a Big Bang 14 billion years ago.

The Big Bang is when matter, space, and time all came into existence. So far as we know, there was nothing before the Big Bang—no matter, no space, no time. Then again, maybe there was. We simply don't know.

We have known for fifty years that the Big Bang happened a few billion years ago, only we didn't know if it was five billion or 20 billion. Only in this century have we pinned it down to 14 billion years ago. It will take this whole course to explain how we know. For now, it's enough to remark that we live at a special time in the history of mankind—the first decade in which we can say with confidence that the Universe began with a Big Bang 14 billion years ago.

The Expanding Universe

Since the Big Bang, space has been expanding. The way we know that is that we observe that the galaxy clusters are moving away from each other. It's not that the galaxies are spreading out into empty space—it's the space itself that is expanding, making the empty spaces between the galaxy clusters bigger.

The galaxies inside each galaxy cluster, however, aren't getting farther apart. They're held together by gravity. In the same way, the stars inside each galaxy are held together by gravity.

The Aging Universe

As the Universe grows older, it changes. In the Big Bang, only two elements were created: hydrogen and helium. These elements are both gasses. Stars are made of these two elements. Stars produce energy by turning hydrogen into helium and other elements like oxygen, carbon, and iron. When stars die, these heavier elements are ejected out into space, where they become incorporated in the next generation of stars.

Planets like the Earth are made of heavy elements like oxygen, carbon, and iron. Many generations of stars had to be born and then die before there were enough heavy elements to make planets like the Earth.

The Solar System, including the Sun and the Earth, was formed 4.5 billion years ago. The Universe itself was already 9 billion years old. That is to say, the Universe is three times older than the Solar System.

Stars are born, stars die, and from the debris of the dying stars, new stars and planets are formed. This is the great cycle of star birth and star death.