There is still a lot we do not know about the universe. Understanding the existence and make-up of a mysterious substance called dark matter is one of the leading challenges scientists face today. There are many theories about what dark matter could be, but we have yet to understand its true nature. How do we even know that such a thing exists? The greatest challenge for studying dark matter is that we cannot see it. In this article, we will discuss how scientists use science and observations from telescopes to predict the existence of dark matter and why scientists think it pervades every corner of our universe.

WHAT IS DARK MATTER? IS IT EVEN REAL?

When we look up into the night sky, we notice that it is filled with thousands of stars. These bright celestial bodies include planets in our solar system, stars in our galaxy, and entire galaxies that are far, far away. These objects make up all the light-emitting matter in the
universe. With the help of different kinds of telescopes, we can observe these celestial bodies through the light they radiate. Some telescopes can detect light from millions of light years away. In fact, one super telescope you may have heard of, the Hubble telescope, can see more than 13.4 billion light years away [1]! All telescopes work by detecting light in the electro-magnetic spectrum, from visible light to X-rays, emitted by these celestial bodies. Scientists use the various wavelengths of detected light to determine key information about our universe’s celestial bodies, such as distance away, age, size, and shape. They can even use some of this information to understand the laws of the universe. Yet, there is matter in the universe that does not emit light in any part of the electro-magnetic spectrum, which means that we cannot observe it with our telescopes. This unique property makes it impossible to observe these types of matter, so scientists call it dark matter.

Some scientists, specifically astrophysicists, spend a great deal of time generating theories about what dark matter could be. Scientists know that dark matter does not emit light from any part of the electro-magnetic spectrum, but dark matter has been observed to be influenced by gravity. Astrophysicists are still unsure what dark matter is, exactly. However, they know what dark matter is not, by observing the way it behaves compared to other materials. We know that dark matter makes up ~80% of the total mass of galaxies [2]. This means that there is four times more dark matter compared to regular matter! If dark matter is so difficult to observe, why do scientists believe it actually exists? The evidence to support the existence of dark matter is extensive, and we will explore three main examples in the following sections.

DARK MATTER AFFECTS THE MOVEMENT OF STARS WITHIN GALAXIES

The first type of evidence supporting the existence of dark matter has to do with the way dark matter affects the movement of celestial bodies. In our solar system, almost all of the mass is in the sun. The innermost planets like Mercury and Venus orbit the sun the fastest. As the distance from the sun increases, the speed at which planets move decreases. This is because there is less gravitational pull from the sun on planets farther out and, to keep from spiraling into or away from the sun, they must move slower. We can apply a similar analogy to galaxies. If we assume that the bright part of a galaxy shows where most of the mass is, then most of the mass is near the center, and at the dim edge of a galaxy there should not be much mass. Therefore, objects orbiting far from the center of the galaxy should move slower than objects closer to the center, just like the planets in our solar system.

To test this hypothesis, scientists recorded the incoming light from a distant spiral galaxy (our home galaxy, the Milky Way, is also considered
The relationship between the velocity of stars and their distance from the center of the galaxy. The actual observed velocity of stars (A) that are far from the center of the galaxy is greater than what was predicted by scientists (B). This data indicates that there is a large amount of mass present in the outer part of the galaxy that we cannot see because it does not emit light, suggesting the presence of dark matter (Modified from original image by PhilHibbs and licensed under CC BY-SA 3.0).

**VELOCITY**

The distance moved between two points per unit of time. For example, a car moving 60 km/h travels 60 km from Point A to Point B in 1 h.

**DARK MATTER MESSES WITH CALCULATIONS OF GALAXY MASS**

Evidence for dark matter is not all new. Back in 1933, Fritz Zwicky, a Swiss astronomer, was one of the first to detect the presence of dark matter. Zwicky studied the light emitted by the more than 1,000 galaxies that are part of the Coma Cluster of galaxies. Zwicky determined the mass of the Coma Cluster using two methods. One method used the velocities of the galaxies, which he determined by measuring shifts in the light they emitted. The second calculation method determined mass using the total brightness of the cluster. In comparing the two resulting mass estimates, he found that the galaxy velocity measurement estimated that there is hundreds of time more mass in the Coma Cluster than the brightness estimate predicted.
An image of the Bullet Cluster produced by NASA’s Hubble Space Telescope and the Chandra X-ray Observatory. The Bullet Cluster is a combination of two galaxies that once collided. The blue areas represent the majority of the mass in the galaxies, which is made up of dark matter, and the pink areas are normal matter. We can detect the dark matter through gravitational lensing, which detects shifts in light produced by distant celestial objects [5]. The bright spots outside the colored areas are stars and galaxies that are not part of the Bullet Cluster (Credit: X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.).

Since the extra matter was not emitting light he said, “If this would be confirmed, we would get the surprising result that dark matter is present in much greater amount than luminous matter” [3]. Very soon after, a similar result was obtained from the Virgo cluster of galaxies. However, measuring techniques at the time were not as precise as modern methods and the controversial nature of the result—that the universe is dominated by some kind of unknown dark matter—caused scientists to reject this hypothesis until almost 50 years later.

**DARK MATTER BENDS LIGHT**

The third area of evidence supporting the existence of dark matter comes from a study of the Bullet Cluster, which is the name given to two galaxies that recently collided. Astronomers have found a way to discover the mass of a celestial object, like a galaxy, using a technique known as gravitational lensing [4]. Gravitational lensing is based on the fact that the mass of an object influences the density of space around it. When light travels through this dense space, it bends. To make this clear, let us imagine a flat stretched sheet. The sheet represents space when no masses are near it. Now, imagine placing a bowling ball on the sheet. We know that the sheet will get pulled down by the bowling ball. The ball would curve the sheet in a similar manner to how masses curve spacetime. When light passes near an object in space, it travels on the curved surface, which bends the light waves. The larger the mass of the object, the more the light bends. With the help of this theory, we can determine the mass of a celestial object by watching how much the light from a star right behind it bends.
Figure 3
The entire circle represents all the matter that was present 380,000 years after the birth of the universe. You can see that the amount of dark matter is much greater than all other kinds of matter. The amount of dark matter remains similar today [2], and the mass of the universe has not changed much since the era shown in the figure. Chart created by NASA/WMAP Science Team is Public Domain.

Using gravitational lensing, scientists determined the total mass of the Bullet Cluster, including the dark matter [5]. Figure 2 shows that most of the mass of the Bullet cluster is not located where the source of the X-ray emissions are originating—meaning it is not from the matter we can see. Hence, these galaxies are composed of much more dark matter than regular matter.

WHAT COULD DARK MATTER BE?

Scientists have proposed many different theories to attempt to solve the dark matter puzzle. Some scientists believe that dark matter is just regular matter that is concentrated in difficult-to-detect objects, such as large planets or black holes. However, scientific observations make this theory unlikely.

So, what is dark matter made of, then? Scientists have already discovered one type of particle that makes up dark matter, called neutrinos. Neutrinos are particles that do not emit light, just like dark matter. However, neutrinos can make up only a fraction of the total amount of dark matter, because they are too light and, when they were created in the early universe, they were moving too fast. So, other yet-to-be-discovered particles must be involved. Two of the most promising candidates are proposed particles called WIMPS and axions. Neither type has been observed yet, and many experiments around the world are currently searching for them.

NEUTRINOS
Tiny particles, smaller than atoms, that do not have an electrical charge. Neutrinos are one of the components of dark matter.
CONCLUSION

Dark matter makes up about 63% of all matter in the universe (Figure 3). Indeed, our ability to understand dark matter will help us learn more about the universe, including details of the universe’s origin and formation. Many experiments are being carried out around the world, including experiments at the Large Hadron Collider in Switzerland,¹ to determine the nature of the tiny particles that can tell us about the conditions in which dark matter is formed. Far more work needs to be done, but one thing is for certain—there is a lot to look forward to in the fields of astrophysics and particle physics!

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**YOUNG REVIEWERS**

**NOAH, AGE: 10**
Hi! My name is Noah. I am 10 years old, and I just started 5th grade. Ever since I was 3 years old, I have wanted to become an astronaut. I know a lot about space, aviation, science, and history. I love to read and learn new things. I also like playing with my cousins and friends and participating in a local EAA youth chapter.

**OSCAR, AGE: 12**
Hello! My name is Oscar, I live in France, close to Paris. My favorite hobby is playing video games with my friends. I also like hikings and sports, and I like Science a lot. I also like mathematics and physics.

**SANAH, AGE: 14**
Hi! My name is Sanah. I live in France, close to Paris. I am very curious about the world, I love Science and especially astronomy, neurosciences, and psychology. When I grow up I want to become a researcher, and help to cure diseases. I also love contemporary dance and music.

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Vishnu Bhathe recently graduated from Carleton University in Ottawa, Ontario, Canada with a Bachelor of Science degree. Ever since he was a child, he has been curious about science and how people use the lessons from science to better the world. He is also interested in entrepreneurship and aims to use scientific research to fuel innovation. In his free time, he likes to ride bikes, paint, read books, and exploring new things.

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