Dark matter and Dark energy (Part 1) – Discovering the main components of the Universe

What is the Universe made of?

Tran Dong Thai Han, Leiden Observatory; Massimo Viola, Leiden Observatory; Henk Hoekstra, Leiden Observatory

AGE
12+

LEVEL
Middle School, Secondary, Informal

TIME
45min

GROUP
Group

SUPERVISED
No

COST PER STUDENT
Low Cost

LOCATION
Small Indoor Setting (e.g. classroom)

CORE SKILLS
Developing and using models, Planning and carrying out investigations, Constructing explanations, Engaging in argument from evidence

TYPE(S) OF LEARNING ACTIVITY
Guided-discovery learning, Interactive Lecture, Problem-solving, Modelling, Observation based, Fun activity, Other

KEYWORDS
Dark matter, Dark energy, Invisible. Mysterious, Investigation, Galaxies, Universe, Gravity, Universe

SUMMARY

GOALS

- To understand how dark matter and dark energy were discovered.
- To understand that dark matter and dark energy, while mysterious and invisible, are the main components of our universe.
- To familiarize students with scientific thinking and working process.

LEARNING OBJECTIVES

- Students can order dark matter, dark energy and normal matter based on their proportion in the Universe, with normal matter taking the smallest portion and dark energy being the most abundant component in the Universe.
- Students will use the concepts of mass and gravity to simulate the discovery of dark matter and demonstrate dark matter properties.
- Students will visualize the effect of dark energy to oppose gravity using the analogy of a punctured balloon that can expand faster than intact balloons.
- Students will learn to think logically by conducting own investigation.
- Students can draw conclusions by combining their observations with what they already know (or what teacher already tells them).

EVALUATION

- At the end of the activity, ask students to point out which of the components of the Universe, dark matter, dark energy and normal matter, are the most and least abundant. Ask students to give few keywords about properties of dark matter and dark energy e.g. dark matter – invisible mass, creates gravity; dark energy – invisible, opposes gravity, faster Universe expansion.
- At the end of part 2 of the activity, ask students to explain their investigation, their conclusion and their reasoning. Listen to see if student reasoning combines what they just learn about gravity with what they see from measuring marble weights and comparing the dip of stretchy sheet.

MATERIALS

- A video about the known universe (in the attached material)
- A PowerPoint presentation (in the attached material)
- A computer and projector for showing the video and the presentation
- Large round washbowl (diameter minimum 30cm)
- Stretchy sheet (cut from stretchy fitted bed sheet)
- Elastic band (to fix the sheet on the wash bowl)
- Marbles (different sizes)
- Weighing scales
- Intact and punctured balloons
- Clear plastic string

BACKGROUND INFORMATION

Gravity

Gravity is a force that makes objects move, bringing things together. Everything with mass has gravity. We can feel the force of gravity as we jump up and get pulled down to the ground. Planets, stars, moons and other objects in the Universe also have gravity. That's why they orbit around each other, like for example the Earth orbits the Sun, or the Moon orbiting around the Earth, instead of flying randomly in space. That's why we see the Moon and the Sun every day. Groups of stars are held together forming galaxies and even galaxies are held together by gravity forming galaxy clusters. Thus, gravity can be seen as the universal glue.

The more mass something has, the stronger the gravity it produces. The Earth's gravity is stronger than the Moon's because it is more massive. So our bodies are pulled down on Earth more than if we were on the Moon. That's why astronauts can jump higher and more easily on the Moon than on Earth. Our bodies also exert gravitational forces on other objects, but because our mass is so low, the gravity from our bodies does not affect objects any way we can see. The strength of gravity also changes with the distance to an object. The pull between the Earth and the Moon is stronger than that between the Earth and Jupiter. This is because the Earth is closer to the Moon than to the Jupiter.

Gravity was first described by Newton as a force. Described more than 300 years ago, Newton's theory of gravity is still applied today and it was used when scientists plotted the course to land man on the moon. Although Newton's theory describes the strength of gravity fairly accurately, he didn't know what caused gravity or how it worked. These concepts were left unknown for nearly 250 years, until Albert Einstein described gravity as the curvature of space. Space has 3 dimensions: up-down, left-right and forward-backward; and it can be visualized as a fabric, like a stretchy sheet. Any object with mass deforms space, just like a marble creating a dimple on the surface of the stretchy sheet. This curvature of space causes objects to interact and move towards one another, which is seen as gravity, a natural consequence of a mass's influence on space. The more mass something has, the more the space is curved, and, therefore, the more gravity there is.

The Universe

The Earth, the planet on which we live is only a relatively small planet in the Solar system and in the vast Universe. In our Solar System, there are 8 planets, including Earth, orbiting a big star called the Sun in the center. Our Solar System also includes other smaller objects, including dwarf planets, moons orbiting planets, comets, asteroids etc. Outside the Solar System, there are similar systems, called planetary systems which also consist of planets orbiting a star. Gravity holds all these stars and planets together in something we call galaxy. We live in a galaxy called the Milky Way. It is estimated that there are about 200 billion stars in it; so it is a very big place. Outside our enormous Milky Way, there are about 100 to 200 billion more galaxies like our Milky Way. These galaxies are at enormous distances from us, in fact even with the most powerful telescope we cannot see individual stars from these distant galaxies. All the stars that we can see in our night sky with the naked eye are only within our Milky Way. All galaxies, stars, planets, from matter to energy to time itself, make up what we call the Universe. All the visible things we can observe in our Universe, we call them normal matter.

The normal matter that we know of only makes up less than 5% of the Universe. While this seems shocking, it is not that impossible. Think about what elements comprise the Earth. Everything that we encounter every day here on Earth is made of elements like nitrogen, hydrogen, oxygen, carbon and heavy elements like iron and silicon. Because we see them in such abundance, we might easily conclude that the rest of the Universe must be the same as Earth, a lot of heavy elements, a bit of hydrogen and no helium. However, these elements make up only 1% of the Sun. The Sun is composed mainly of hydrogen, some helium and not much else. Many stars, gas and other objects in space that are observable also consist of the same elements as the Sun. Just as some materials commonly found on Earth are a fraction of the Sun composition, the materials that comprise the Sun and similar space objects are not necessarily representative of all the matter in the Universe. Isn't it possible that everything on Earth and in space that we know might be as well just a tiny fraction of what really exist in the Universe? Astronomers have found evidence for the existence of other components, the main components, of the Universe; they are called dark matter and dark energy.

Dark matter

Gravity allowed scientists to discover dark matter. In 1933, a Swiss astronomer, Fritz Zwicky tried to measure the total mass of a galaxy cluster by summing the mass of each individual visible galaxy in the cluster. He found out that their total mass was not enough to create the observed gravity that holds the galaxies together to form a cluster. With just the gravity created by all of their visible matter, the galaxies would not cluster easily, if at all. Thus, Zwicky concluded that there must be something invisible, inside and around the galaxies. This matter adds the extra mass to create that gravity, strong enough to form a galaxy cluster. Zwicky called the unseen mass dark matter.

More evidence for dark matter has emerged over time. Photographs of galaxies showed that most of their light, i.e. most of their stars, were concentrated near the center. So most of the mass of a galaxy is concentrated in its center, meaning that gravity is stronger at the center of a galaxy than in the outskirt. Therefore, it is expected that the stars near the center of the galaxy would move faster than those farther away. However, the measurements indicated that the orbital speed of stars was the same everywhere, regardless of their distance from the center. The conclusion is that there must be invisible matter that spreads throughout a galaxy, such that stars far away from the center will feel the gravitational pull of not only the central material, but all the other matter between them. The extra force of gravity from dark matter can cause them to speed up roughly to the same speed of the stars near the center.

Although it's been discovered for some time, it's still unknown what dark matter really is because it is invisible and does not interact with other normal matter that we know e.g. light, magnets, electricity. Scientists have proposed various ideas about the particles that make dark matter and designed experiments to test those ideas. However, the quest to define dark matter has been a process of elimination. Experiments have only ruled out possible candidates and left a few leading hypotheses, but yet to find the exact dark matter particles. The only thing we know about dark matter is that it is what makes it possible for galaxies to exist. Dark matter makes up 25% of the entire Universe, 5 times more than the normal matter that we know.

Dark energy

Something even more mysterious, called dark energy, makes up 70% of the Universe, besides normal matter and dark matter. Normal and dark matter generate gravity which holds things together. Dark energy is completely opposite to gravity; it causes things to fly apart. To understand dark energy, think about what happens when you toss a ball up into the air. It goes up and gradually slows down due to the pull of gravity. Eventually, the ball stops in mid-air and falls back to the ground. Now imagine a ball, once tossed up, keeps flying up further and further, instead of being attracted back down to the ground. This event seems impossible to happen, but this is the property of dark energy.
In the 1990s, dark energy was discovered as astronomers observed such peculiar effect in the Universe. Scientists know that Universe has continually expanded i.e. galaxies moving away from each other, since its formation, the Big Bang. They also observed that the speed of expansion has increased, which is unexpected, because like the tossed ball, the expansion should slow down as gravity pulled on all of the galaxies. Or, the Universe would stop expanding and finally collapse, if gravity won and halted the expansion. Scientists concluded that the accelerated expansion cannot be caused by dark matter and normal matter, which generate gravity for the Universe, but must be by some form of mysterious energy. As it is invisible, they called it dark energy. Remember that the Universe has always been expanding; dark energy only speeds up this expansion. By measuring how fast the Universe is expanding, which is a combined effect of dark matter pulling galaxies together and dark energy pushing them apart, astronomers can determine the proportion between dark energy and dark matter. Like dark matter, scientists have many possible explanations, but no concrete answer for the nature of dark energy. It remains one of the greatest mysteries of the Universe. If one day we understand dark energy, it will change what we already know and the way we think about the Universe.

FULL ACTIVITY DESCRIPTION

Introduction: (11 min)

1. Start with the video "The known Universe" in the accompanied slideshow.
2. Together with students, organize the structures in the Universe in a flow chart; from the Earth out to Solar system, other stars and planets outside solar system, our Milky Way galaxy, other galaxies that may form galaxy clusters. Altogether, these structures exist in a vast Universe. Use background information to aid this warm-up activity.

If not possible to use slideshow in step 1, use background information (with provided Universe image) to guide students through step 2.

3. Elicit a discussion if it is possible that these structures are only a tiny fraction of the Universe. Start by using the background information to impart the mindset that what we commonly see on Earth and know of in space might not be representative for everything.
4. Tell students that in this activity they will play the role of astronomers to find evidence for whether or not the Universe is only comprised of everything we can see, or something else exists. Previously available knowledge about the subject and observation of something unexpected usually help solving a mystery.
5. Discuss with the students that they know stars and planets are beautifully organized into galaxies. And they are held in place because of gravity.

After the introduction activity, the class can be divided in small groups to do the activity. For part 1 and 2, students can explore on their own using the activity guide sheet. Between each part, give the students a quick introduction and explanation about the activity. For part 3, it is best that the teacher instructs, explains and guides the students through the steps.

Part 1: What is gravity? (7min)

1. Use the provided background information to explain the concept of gravity as an attractive force and that this attraction can be explained as a result of space being bent.
2. Cover a a large round bowl with a stretchy sheet . Introduce the surface of the sheet as a small portion of space and point out that this is only space in 2 dimensions but in reality space is 3 dimensions.
3. Place a heavy marble on the sheet. Ask students to observe that there is a curvature in space (the sheet) due to the mass of the marble. Then roll a lighter marble on the sheet so that the light marble moves toward the heavier one and circles around it.

Figure 1: Gravity – stretchy sheet + marbles

4. Explain that an object in space has mass (like the marbles), which determines how much it weighs (heavy or light). A mass bends space just like the marble does to the stretchy sheet, causing objects to pull other objects towards each other. Point out that this effect is called gravity, which is due to the bending of space. The mass determines how much space is curved, meaning how strong its gravity is (more mass, more curve, more gravity).
5. Explain that similarly, stars and planets also bend space, creating gravity, which causes them to orbit each other and, eventually, organize into groups such as galaxies and galaxy clusters (or stars and stellar clusters). The gravity of a cluster is related to the mass of everything within the cluster, all the stars, planets, galaxies and other things. Based on this knowledge, they will solve the mystery of whether an invisible matter exists in space.

Part 2: The discovery of dark matter (15 min)

1. Use the washbowl/stretchy sheet set-up from activity 1 and place a number of marbles on the sheet. Label this as set A. Prepare, in advance, another setup (labeled set B) which is a washbowl and a stretchy sheet that has an extra heavy weight tied by a string at the middle of the sheet. Fix the sheet

on the washbowl so that the extra weight is hidden and hanged underneath. Cover the dip created by the hanging extra weight by placing marbles on the sheet (total weight and number of marbles are same as set A).
Note: Prepare in advance separate marble bags for the two setups to bring into class.

Figure 2: Dark matter experiment Set A

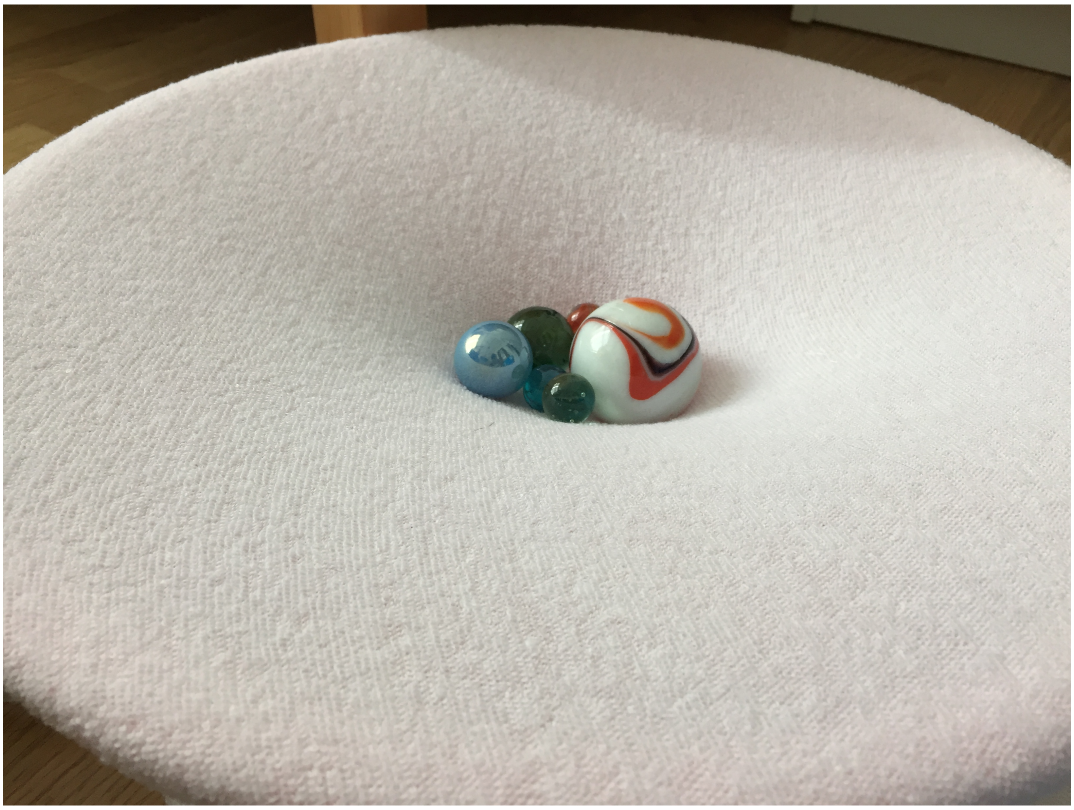

Figure 3: Dark matter experiment Set B

2. Tell students they are acting as astronomers who study the mass and gravity of a galaxy cluster. Set A represents what the galaxy cluster should look like in theory and set B is actual observation. Ask students to observe the 2 sets and point out the difference (set B curves the sheet more than set A). As astronomers, they need to find out if the two sets are just the same galaxy

cluster (consisting same galaxies) and why there is a difference.
You can have several sets A and B and some groups looking at sets A while the others look at sets B. Once they finish with a set, they can go to the other set to work.

3. Students should record the total weight of all the 'galaxies' (marbles on the sheet) and compare the gravity (sheet curvature) of the 2 sets. As they compare the curves, they confirm that set B has more gravity than set A. And as they realize that both sets have same total mass of marbles, they should indicate that this much mass should create space curvature as seen in set A, and not set B.

Figure 4: Dark matter set A

Figure 4: Dark matter set B

Figure 4: Dark matter experiment Set A (left) vs Set B (right)

4. Students should record the strange observation that a curve exists even after all the marbles have been removed in set B. Students should come to the conclusion that there must be “invisible” extra mass that creates the extra gravity. Show students the extra weight hanging underneath.
5. Tell students that sometimes what we observe, or the outcome of an experiment, doesn’t match our prediction. Use the background information to relate this activity to how scientists discovered dark matter. They measured the total mass of galaxies in a galaxy cluster and this was not enough to create the gravity that holds the cluster. There must be extra invisible mass that creates extra gravity. They called it dark matter.
6. Clarify that dark matter is invisible, it cannot be seen like the extra weight. Scientists are still unsure what dark matter really is and there are still many ongoing research about this topic.

Part 3: Dark energy (15min)

1. Use the accompanying materials (slideshow or chart) to point out scientists calculated that all the visible matter (seen in the warm-up video) contributes only 5% of the Universe. Dark matter is only 25% of the Universe. The remaining 70% is something else completely different from normal matter and dark matter. It’s called dark energy and, like dark matter, also invisible.

2. Tell students that dark energy was discovered from an unexpected observation, different from the facts that we already knew and what we expected. Present students
Fact 1: The Universe has continually expanded since its formation. It’s like an expanding balloon.

3. Slightly inflate a balloon with some dots drawn on it. Tell students that this is our Universe at birth, everything is compact (the dots are close together). Continue to blow the balloon and the dots on the balloon move far away from each other. This is like our Universe, it has been expanding and the dots are like the galaxies moving apart in our expanding Universe.

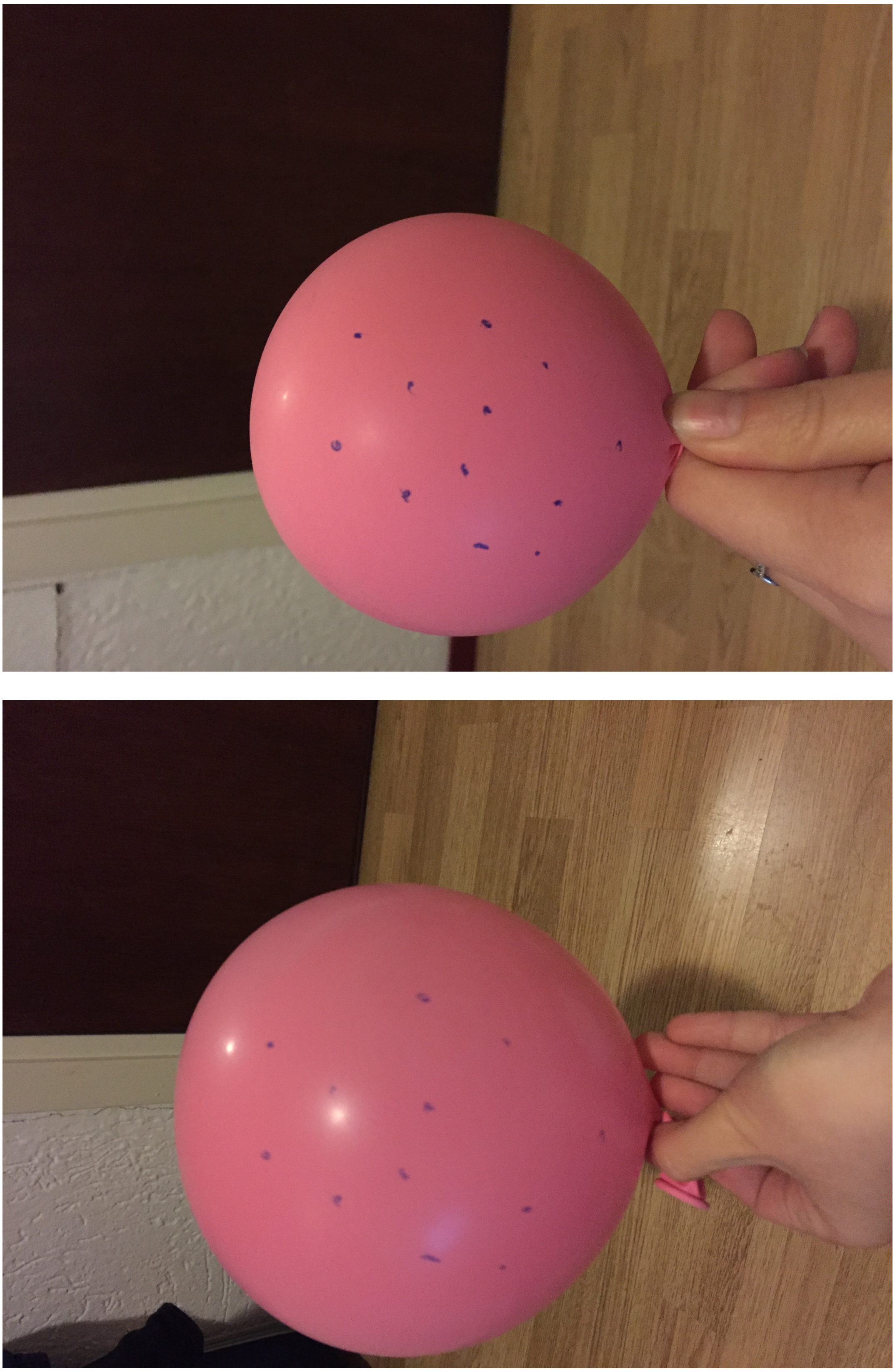

Figure 5: Dark energy experiment balloons

4. Tell students Fact 2: Gravity of dark matter and normal matter holds everything in Universe together. Despite this effect of gravity, Universe has been expanding and galaxies fly away from each other. Tell students that in fact Universe expansion has become faster. Help students to make an analogy to this Universe acceleration with the balloon model. Students

should relate the Universe expansion to an imaginary punctured balloon that does not collapse but can expand even faster.

5. As scientists observed faster Universe expansion, this must be the effect of something else that exists in more quantity and opposes the gravity caused by the normal matter and dark matter. They called it dark energy. (Ensure that students are not confused that dark matter and dark energy are related by emphasizing their completely opposite effects).

Part 6: Wrap up (3 min)

1. Conclude that the normal matter we know is only a tiny fraction; the main components of our Universe are invisible. However, it's still not known what dark matter and dark energy really are. Scientists are still working and debating on different theories they have.
2. Go through the entire activity with the students to point out how they have worked like a scientist. Working in the field of science means there will always be unexpected results, which must be carefully recorded as they may signal for something new to be discovered. To solve the mysteries, it requires observation, deduction, make hypothesis based on observation and available knowledge, and finding proof to support one's idea.
3. Point out the fluid nature of science as our view and understanding continuously evolve with changes or updates in current knowledge, made by observations, measurements and theories.

CURRICULUM

ADDITIONAL INFORMATION

The use of stretchy sheet and marbles for demonstration of gravity is inspired by previous Astroedu activity 'Model of a black hole' (http://astroedu.iau.org/en/activities/1304/model-of-a-black-hole/).
For more activities about finding proofs for dark matter and to understand how much scientists currently know about what make dark matter and dark energy, continue with the second session using the Activity Part 2 - Understanding the nature of dark matter and dark energy.

CONCLUSION

In this activity, students play role of scientists to explore the possible existence of other components of the Universe besides the normal matter. As they understand how dark matter and dark energy are discovered, they also realize that science understanding can change over time as new discoveries are made, adding to or modifying our prior knowledge. They also realize that what they can see is not everything in the Universe, there are still a lot of mysteries. This activity helps students develop scientific thinking and method of scientific investigation.

ATTACHMENTS

- Images for printing
- The known Universe movie
- Presentation
- Worksheet

ALL ATTACHMENTS

All attachments

CITATION

Han Tran; Massimo Viola; Henk Hoekstra , 2018, *Dark matter and Dark energy (Part 1) – Discovering the main components of the Universe* , astroEDU,

ACKNOWLEDGEMENT

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