DARK MATTER MYSTERIES

WITH

BROOKHAVEN
NATIONAL LABORATORY

WHAT IS THE UNIVERSE?

–YOU ARE HERE–

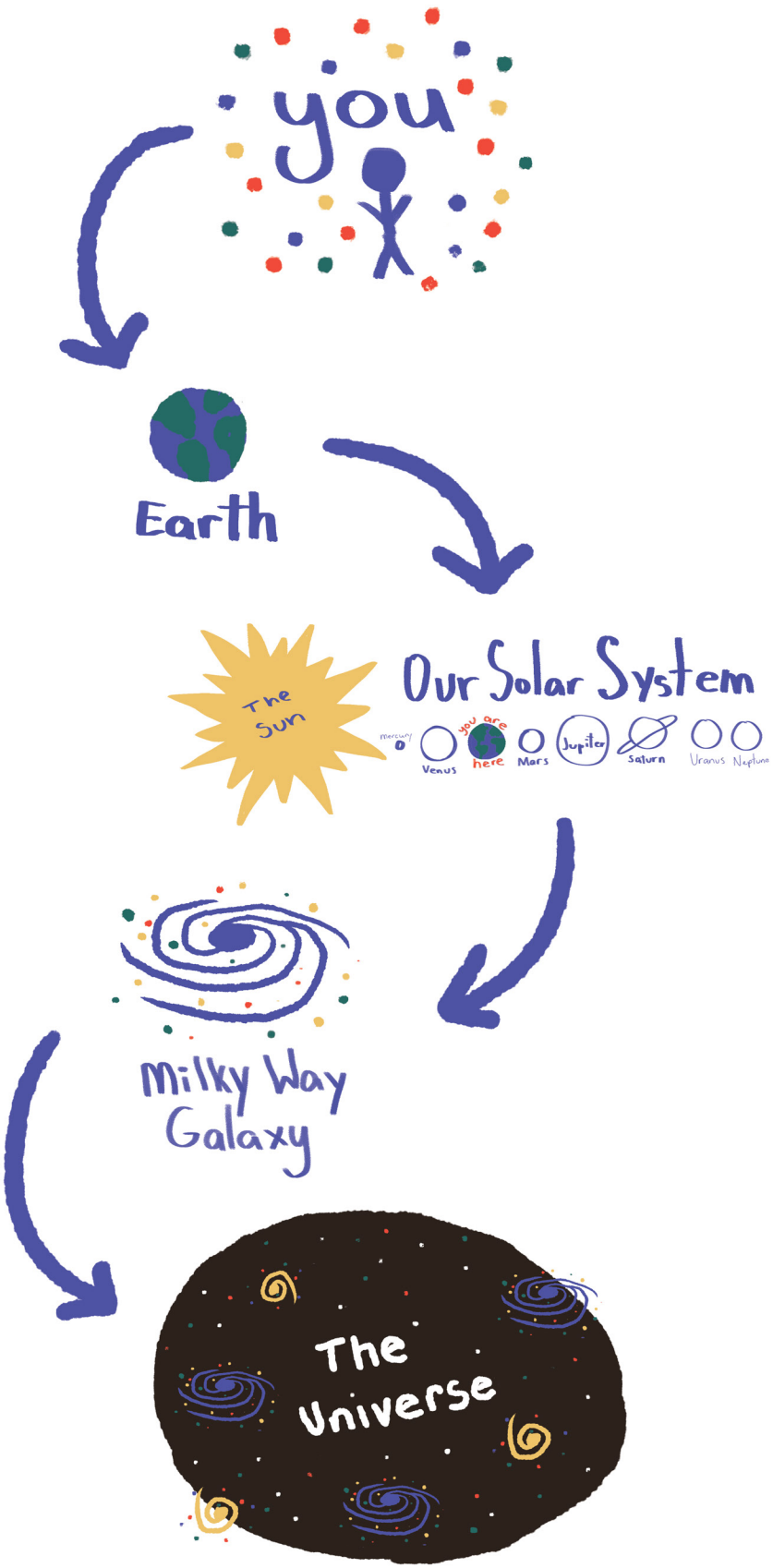
You live on a planet called Earth. Earth is a part of our solar system, which includes a star we call the sun and other planets. Our solar system is a tiny piece of the Milky Way Galaxy. Our sun is one of the hundred billions of stars in the Milky Way Galaxy, and the Milky Way Galaxy is one of a hundred billion galaxies in the universe! That's a lot of stars and galaxies.

The universe is about fourteen billion years old (you would need a huge cake to fit all those birthday candles).

But how did the universe come to be?

Watch this video to understand just how big the universe is

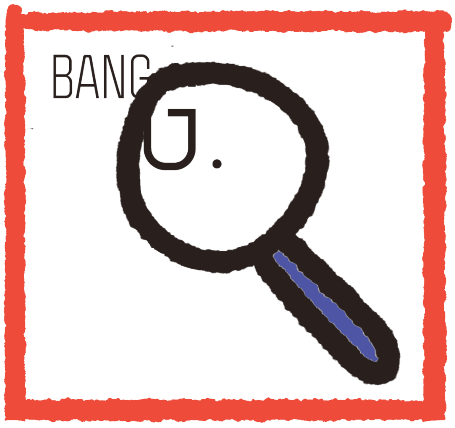
https://www.youtube.com/watch?time_continue=236&v=WYQ308U6SMV&feature=emb_logo



THE BIG BANG THEORY

Have you ever thought about how everything came to exist? Scientists believe it started with everything squished into a tiny point. To imagine how small that point is look at the sentence "it started with a bang." on the right. The period is so tiny it is almost impossible to see, to help you there is a picture of the end of the sentence under a magnifying glass. Now imagine that little period cut up a thousand times - that is about how small that point was. So much was packed into that tiny space that everything exploded out! This is how the universe born, and to this day the universe is expanding, or growing, faster and faster each second. But what exactly is everything?

IT STARTED
WITH A BANG.



MATTER

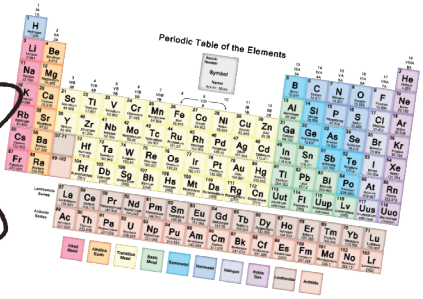
Subatomic Particles

Proton

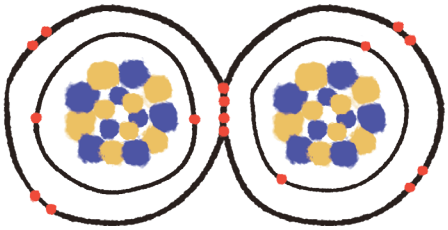
Neutron

Electron

Atoms

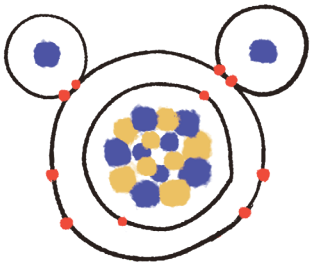


Molecules & Compounds



O_2

oxygen



H_2O

Water

Everything

WHAT IS MATTER?

Anything that takes up space is matter. That means you, pizza, videogames, air, oceans, your socks, your pets, and anything else you can think of that takes up space is matter (now if someone asks if something matters you can say technically everything that takes up space is matter).

The term "mass" tells you how much matter something is made of. For example, a basketball has more mass than a ping-pong ball.

A small chunk of matter is called an atom, which is made out of three particles, protons, neutrons, and electrons. These subatomic particles are made out of something called quarks and leptons - to learn more about those smaller particles check out the resources sections.

Atoms can be put together to make molecules and compounds. Those are big words, so let's do a mini-experiment to get on the same page.

– MINI-EXPERIMENT 1 –

The first step of our mini-experiment is to take a deep breath...aaaaand let it out.

What did you breath in?

I'll accept the answers "air" and "oxygen.' Air takes up space (that's why balloons get bigger when you blow them up), so air is made of matter. There are molecules and compounds in air, or atoms that are bonded together. To think about this imagine you are near someone you really like, so you hold hands. This is similar to what happens in a molecule or compound, but instead of holding hands, the atoms share electrons,and that keeps them together. Notice on the picture to the left, there is something called oxygen. Oxygen is a type of atom, or element, on the periodic table. One oxygen will bond with another oxygen to form an O_2 molecule, which is what we breath in! BONUS: can you count how many protons one oxygen has (hint: the protons are labeled as purple dots).

Take a look at the compound H_2O. Have you ever heard of that before? This compound is very important to your life as well. We will explore this compound on the next page.

Periodic Table of the Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.01																	2 He Helium 4.00
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.88	23 V Vanadium 50.94	24 Cr Chromium 51.99	25 Mn Manganese 54.94	26 Fe Iron 55.93	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.73	32 Ge Germanium 72.61	33 As Arsenic 74.92	34 Se Selenium 78.09	35 Br Bromine 79.90	36 Kr Krypton 84.80
37 Rb Rubidium 84.49	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium 98.91	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.90	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.85	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.20	83 Bi Bismuth 208.98	84 Po Polonium [208.98]	85 At Astatine 209.98	86 Rn Radon 222.02
87 Fr Francium 223.02	88 Ra Radium 226.03	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium 144.91	62 Sm Samarium 150.36	63 Eu Europium 151.97	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
89 Ac Actinium 227.03	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium 237.05	94 Pu Plutonium 244.06	95 Am Americium 243.06	96 Cm Curium 247.07	97 Bk Berkelium 247.07	98 Cf Californium 251.08	99 Es Einsteinium [254]	100 Fm Fermium 257.10	101 Md Mendelevium 258.10	102 No Nobelium 259.10	103 Lr Lawrencium [262]

Alkali Metal | Alkaline Earth | Transition Metal | Basic Metal | Semimetal | Nonmetal | Halogen | Noble Gas | Lanthanide | Actinide

– MINI-EXPERIMENT 2 –

To view a bigger version of this
Periodic table visit:
https://sciencenotes.org/kids-periodic-table/

Have you ever seen the diagram on the left before? This is called the periodic table of elements! Each box represents a type of atom. The atoms in the periodic table can be combined to create all matter.

Try and find oxygen on the periodic table. Do you notice there is a big "O" that stands for oxygen in the box? Did you also notice there is a small "8" in the top left of the box? This tells you how many protons oxygen has.

Which element has the least amount of protons? If you said hydrogen you'd be correct! Hydrogen only has one proton. Notice that in the box for hydrogen there is a big "H."

So here's a big question: What does H_2O actually mean? Well the "H" must stand for hydrogen (that's why there is a big "H" in hydrogen's box), the "2" must mean there's two of them, and the "O" stands for oxygen. So, H_2O is a compound that has two hydrogen atoms bonded to an oxygen atom! Take a moment to look back at the picture of the compounds, take a look at H_2O. Can you tell what is hydrogen and what is oxygen?

Bonus: Look at each of the elements in the periodic table. Do any sound familiar? Can you think of where you have seen these elements in your daily life? For example, I notice gold is on the periodic table, and I know jewelry is made out of that element!

NOW WE KNOW ABOUT MATTER BUT WHAT IS DARK MATTER?

The short answer is, no one knows! Scientists are working very hard to study dark matter to find out what it is.

But wait? How do we know dark matter exists if we don't even know what it is? It all goes back to matter.

We live on a planet called Earth, the Earth takes up A LOT of space and has A LOT of mass. Things that have a lot of matter, or a high mass, will have a gravitational pull. Gravitational pull is a big science term that means gravity!

Have you ever heard of gravity?

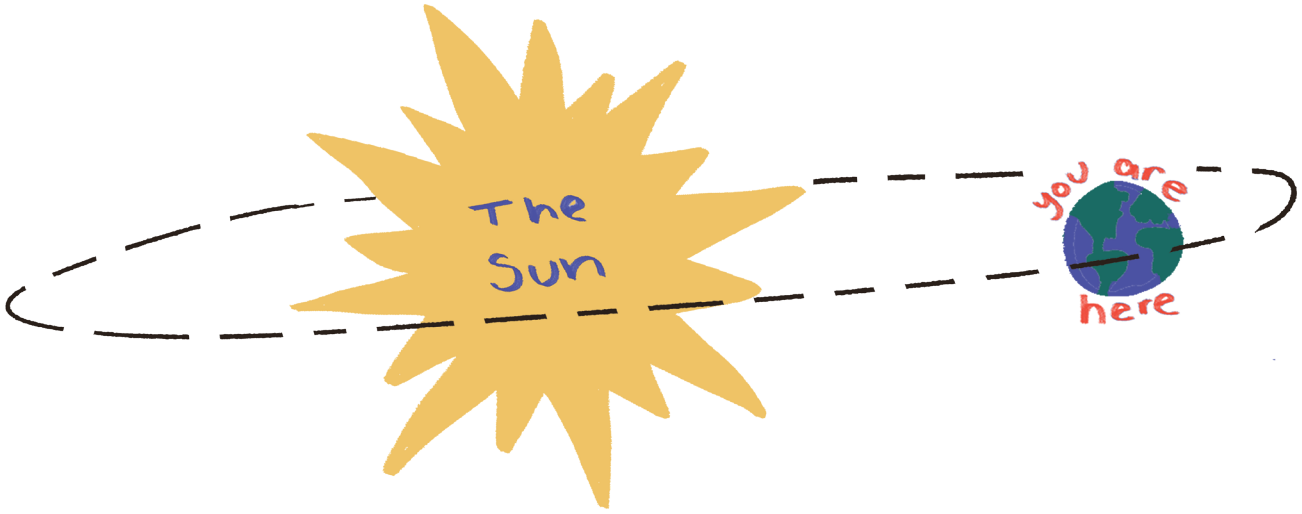
– MINI-EXPERIMENT 3 –

Take something next to you (a pencil, eraser, napkin, nothing that breaks easily), hold it over the ground, and let go.

What happened? You probably noticed the item you dropped fell to the ground!* Why did this happen? Well, Earth has so much mass, or matter, that it pulls everything toward the ground. This is why we don't float off into space. The word for this force is called gravity.

*Bonus: if you did this experiment on the moon would you get the same result? Hint: the moon has a lot less mass, or less matter, than th Earth.

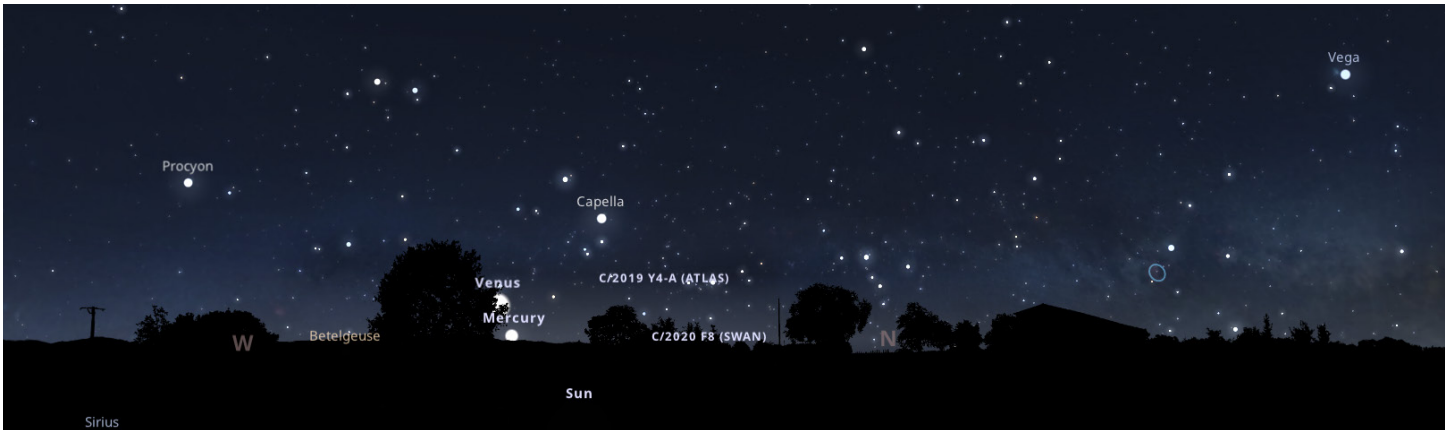
GRAVITY MAKES THE WORLD GO 'ROUND - LITERALLY



The sun also takes up a lot of space and has a high mass, which means it has a gravitational pull on the Earth. In other words the sun pull the Earth close to itself, but instead of colliding with the sun the Earth zips around the side so fast that we almost go flying into space! Lucky for us the sun's gravitational pull will pull us back. This perfect balance of speed and gravitational pull makes the Earth travel in an oval path around the sun, scientists call this an orbit.

Remember there are hundreds of billions in the Milky Way Galaxy, and hundreds of billions of other galaxies each with billions of stars in them. That is a lot of matter out in outer-space! All this matter has gravity that pulls on other matter.

All these stars give off light, so for a long time, scientists assumed that most of the matter in the universe would glow like stars.



Notice in this picture you can actually see planets in our solar system from Earth, sometimes without a telescope, because they give off light. You can use the app Stellarium or visit https://stellarium-web.org/ to see what constellations, stars, and planets you can see where you live throughout the year.

ENTER FRITZ ZWICKY

Zwicky was a Swiss astronomer and in 1933 he studied a group of galaxies called "The Coma Cluster."

Zwicky's research question:
If the galaxies are moving really fast (faster than gravity can pull them together), then why don't the galaxies fly apart?

This was a hard question, but Zwicky was determined to figure out why the galaxies stayed together without flying apart or blobbing together. Zwicky did the math and discovered an even bigger mystery. He found that the galaxies were moving too fast (about 1000 km/s) to stay together, and yet the galaxies were clustered.

This seemed impossible! Zwicky determined there must be extra matter that we can't see that is pulling the galaxies together with gravity so they don't fly apart. Zwicky called this matter "dark matter." In fact he found that there is much more dark matter than normal matter.

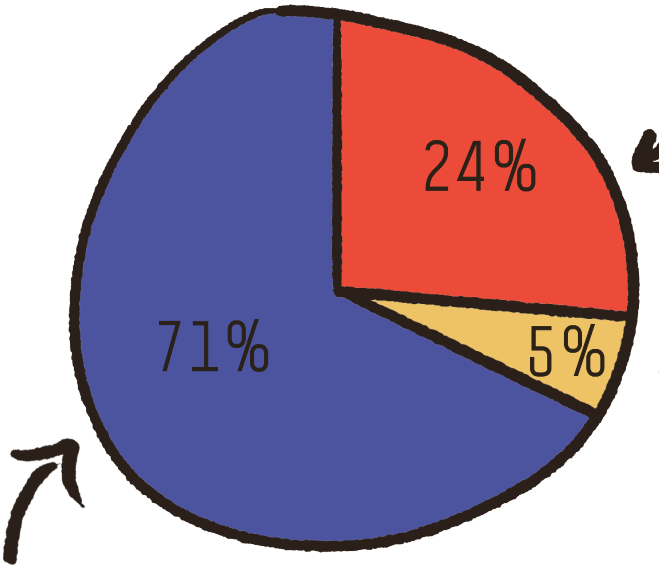
VERA RUBIN & KENT FORD

In 1970 Vera Rubin and Kent Ford worked together to find evidence of dark matter. Rubin discovered that stars on the outside of a galaxy move just as fast as the stars in the middle of a galaxy, when scientists had always thought that stars in the middle would move faster! Rubin discovered there must be dark matter pulling on the stars on the outside of the galaxy that makes them move faster.

"We have peered into a new world and have seen that it is more mysterious and more complex than we had imagined. Still more mysteries of the universe remain hidden. Their discovery awaits the adventurous scientists of the future. I like it this way."

— Dr. Vera Rubin
Astronomer

HOW MUCH DARK MATTER IS THERE?



DARK MATTER

MATTER WE KNOW ABOUT

Everything on Earth, atoms, the Sun, galaxies, etc.

DARK ENERGY

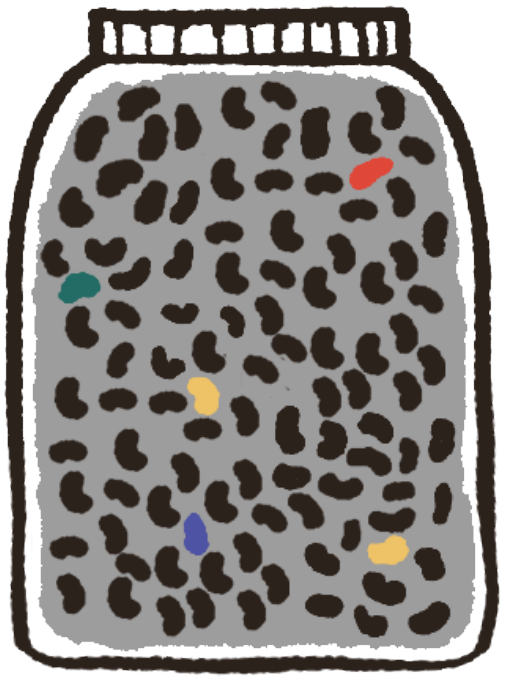
Dark energy is mysterious like dark matter. Scientists think dark energy is what makes the universe expand, or grow, faster and faster instead of slowing down.

– IMAGINE –

To help think about how much dark matter and dark energy there is, imagine a jar full of 100 jellybeans. 95 of those jelly beans would be black, these jelly beans would represent dark matter and dark energy. Then the other 5 jellybeans would represent the matter we know about, and that you see everyday.

Take a moment to think about this. Everything you can think of: stars, Earth, your best friend, galaxies, only make of 5% of all matter out there.

Dark matter is very mysterious, but if one thing is certain, there is a lot to learn. You could even be the scientists to solve the puzzle!



Watch someone make a jellybean universe here:
https://www.youtube.com/watch?v=UDfG69K5t6k

EXPERIMENT TIME!

You've read a lot about matter and dark matter. Let's do some fun experiments to understand dark matter better.

– EXPERIMENT 1 –
UNIVERSE IN A BOTTLE

You will need:

- 2 empty water bottles
- Small household items like beads, buttons, or coins that fit into the bottles.

Step 1:

Add the beads, coins, and or buttons to each water bottle. Be sure to add the same amount to both.

Step 2:

Once you have the items in the bottles, fill one bottle full of water and put the cap on.

Full Empty

Step 3:

Hold one bottle in each hand. Swirl the beads in each bottle. What do you notice? Which bottle contains more mass (hint: the bottle with more mass will be heavier).

Full

Empty

Notice that both bottles contain beads, and both are filled with a clear matter (one is full of air, and one is full of water). Even though both are clear, and hard to see, the bottle filled with water has more mass and matter inside! This "invisible*" matter (water) has an effect on the beads because they move more slowly thorough the water than in the air.

The bottle filled with water shows what dark matter is doing in our universe! The water acts like the dark matter. In our experiment the water is hard to see because it is clear, this is like dark matter, which is completely invisible to us. However, we know that the water is in the bottle because the bottle is heavier than the bottle that contains air, and we also notice that the beads move differently in the bottle that contains water. This is also like dark matter because in space dark matter causes galaxies and stars to move in ways that wouldn't be possible without the gravity from dark matter's large mass.

* Technically water is not invisible, but for our example let's pretend that "hard to see" is close enough to invisible. In the picture to the right it is quite hard to tell which bottle is filled with water.

Photo credit: https://www.jpl.nasa.gov/edu/teach/activity/how-do-we-see-dark-matter/

– EXPERIMENT 2–
GRAVITATIONAL LENSING

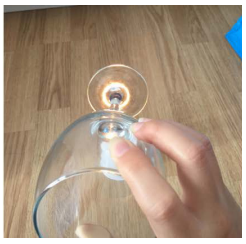
You will need:

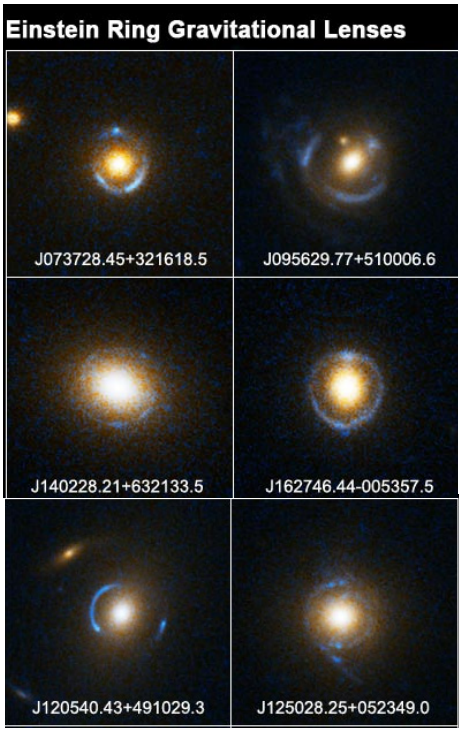
- **A drinking glass**
  A glass with a round bottom will work best, but the experiment will work either way.
- **A light source**
  Try using your TV, an LED light, or light-bulb.

!!! WARNING !!!

1. Do not use the sun or a laser pointer as your light source. Staring at these will damage your eyes.
2. You must have a grown-up help you if using a candle as your light source.

Turn on your light source, and look at it through your glass. What do you notice?





Right away you can see that the glass distorts, or changes the shape of, the light. Dark matter acts like the glass in out example. Photos from telescopes show that light coming from distant stars and galaxies are distorted, even though there shouldn't be anything in the way of the telescopes. This happens because dark matter, which is invisible to us, is in the way causing the light to bend and change shape. Scientists call these shapes "Einstein Rings."

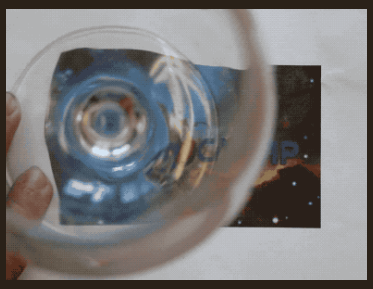
The Hubble Telescope photos on the right show pictures of large galaxies that are about 2 to 4 billion light years away. Notice the galaxy is a yellow color in the middle of the bullseye shape. The blue ring is gravitational lensing caused by dark matter distorting the light.

Photo credit: https://hubblesite.org/contents/media/images/2005/32/1788-Image.html?news=true

Watch this video to learn more about gravitational lensing:
https://www.youtube.com/watch?v=4Z71RtwoOas

Bonus:
Try doing this experiment with a photograph

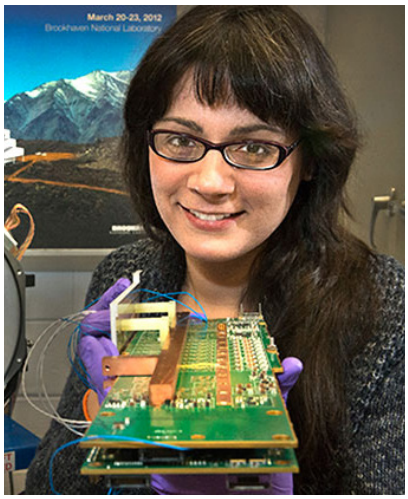
Photo credit: https://astrocampschool.org/gravity/



FUTURE DISCOVERIES!

THE LARGE SURVEY SYNOPTIC TELESCOPE (LSST)

PAUL O'CONNOR

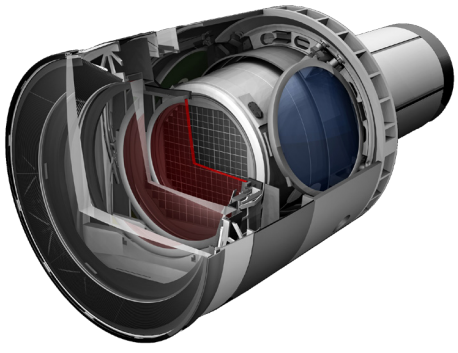


JUSTINE HAUPT

ANDREI NOMEROTSKI

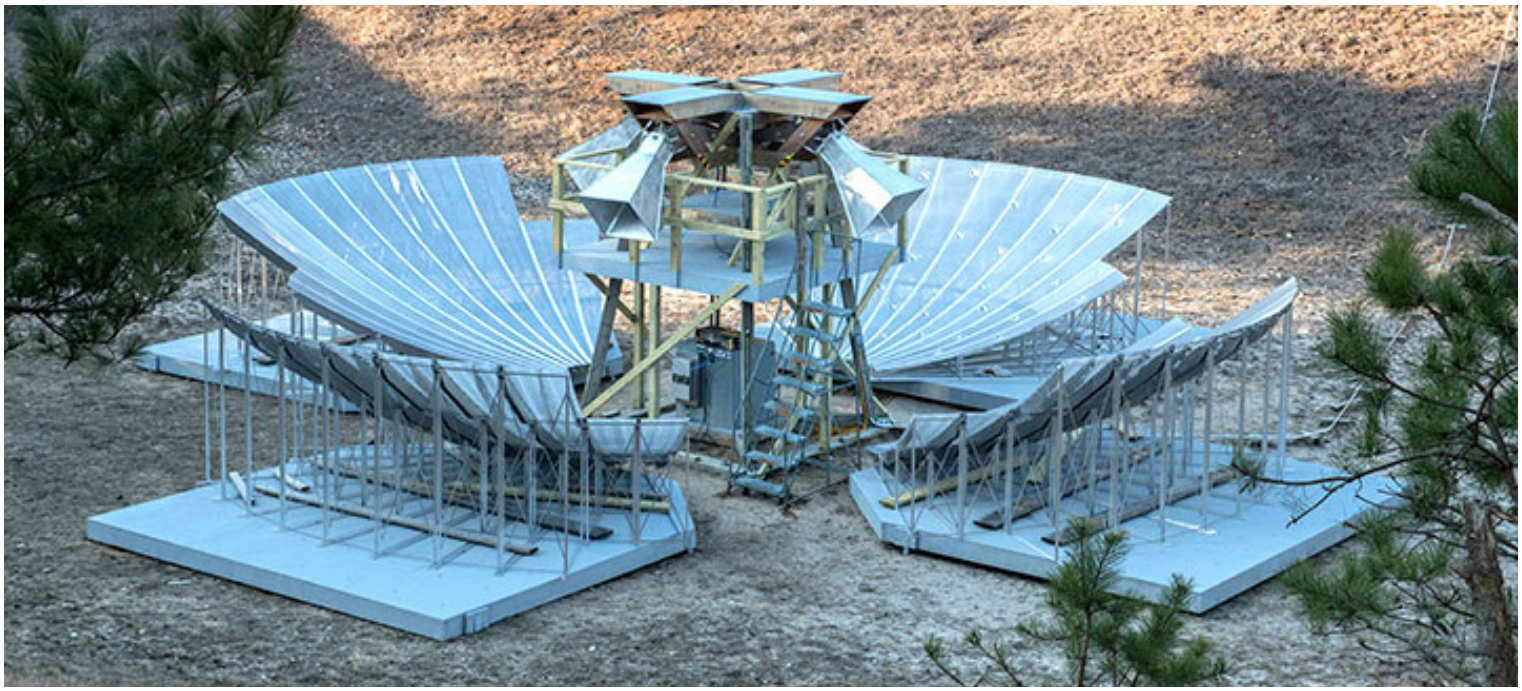
Paul, Justine, and Andrei are scientists and engineers at Brookhaven Lab. They worked together to build the camera (pictured on the right) for the world's newest research telescope, the LSST (pictured at the top of the page). One of the main goals of the LSST is to study dark matter and dark energy by mapping galaxies through time and space.

The LSST camera is very different from cameras you have seen. The LSST camera is a 3200 megapixel camera (an IPhone 11 has a 12 mega pixel camera). The camera is the size and weight of a small SUV. Each picture taken by the camera will be the size of 40 full moons, and the LSST will take pictures of 37 billion stars and galaxies.



FINDING DARK MATTER

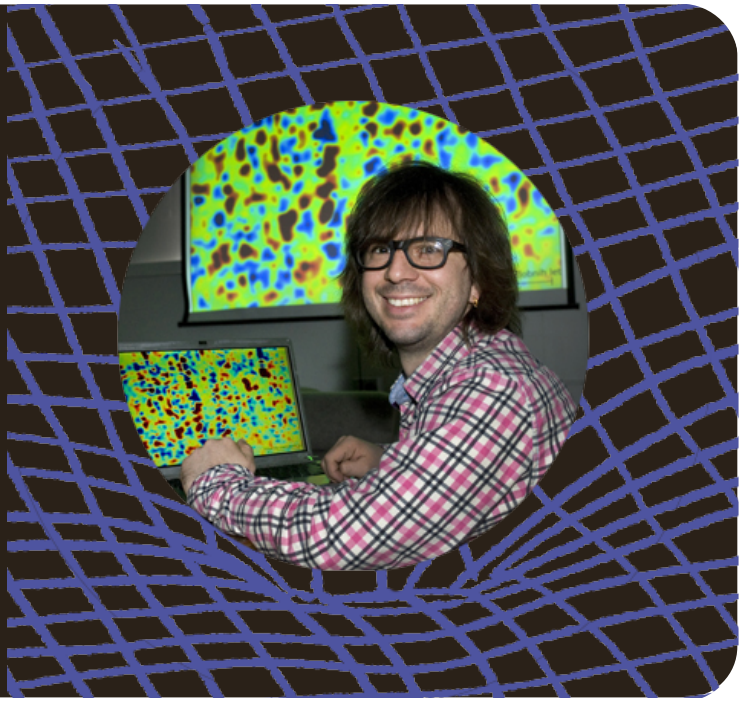
Paul, Justine, Andrei and many students also built a smaller radio telescope at Brookhaven Lab. This radio telescope is different from most because it looks at light that we can't see with our eyes called radio waves, which are given off by hydrogen atoms in distant galaxies. This telescope can get different information than the LSST to study dark energy.



BROOKHAVEN LAB'S STELLAR SCIENTISTS

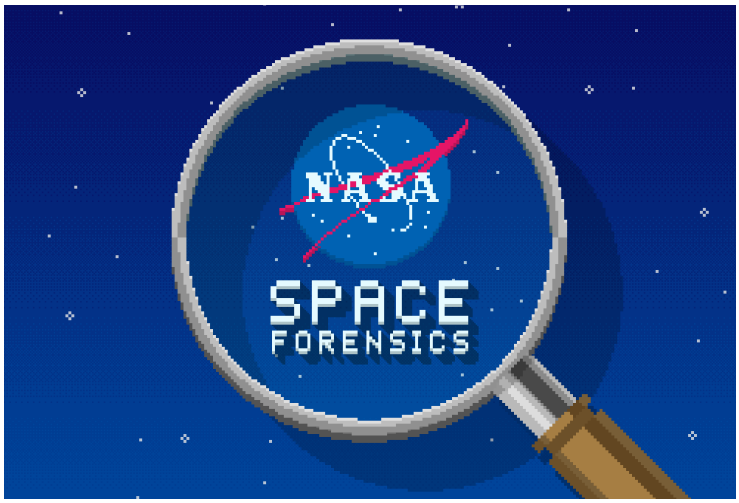
Meet Erin Sheldon! Erin studies dark matter and dark energy using gravitational lensing, which we learned about in experiment 2.

This is Anže Slosar, he also studies dark energy as well as the curvature of space.



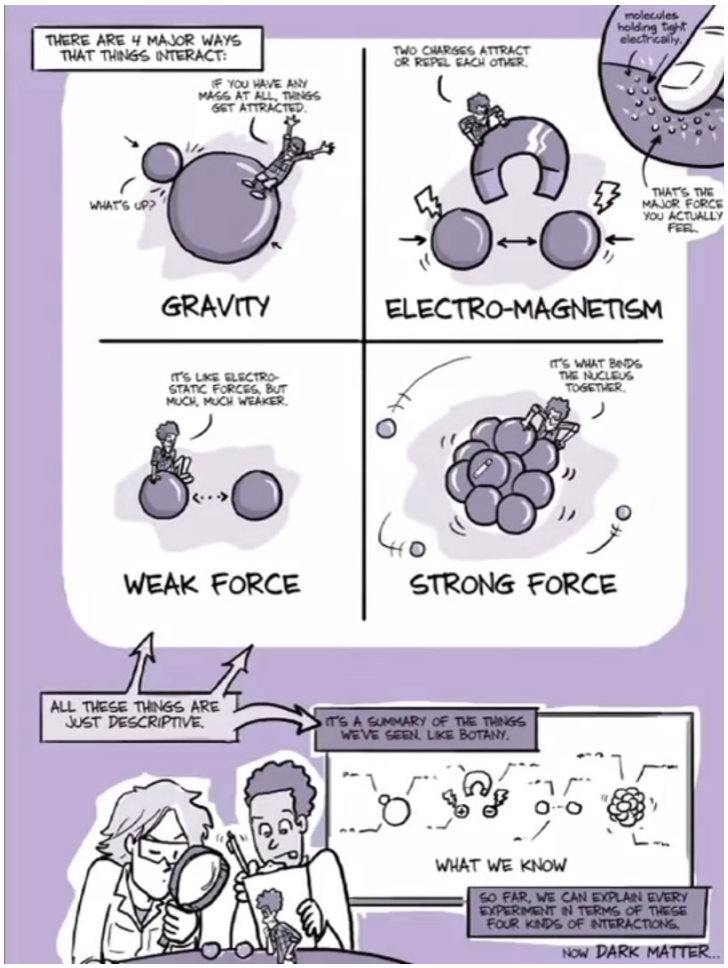
Both Anže Slosar and Erin Sheldon will study data from the LSST telescope.

BONUS ACTIVITIES!



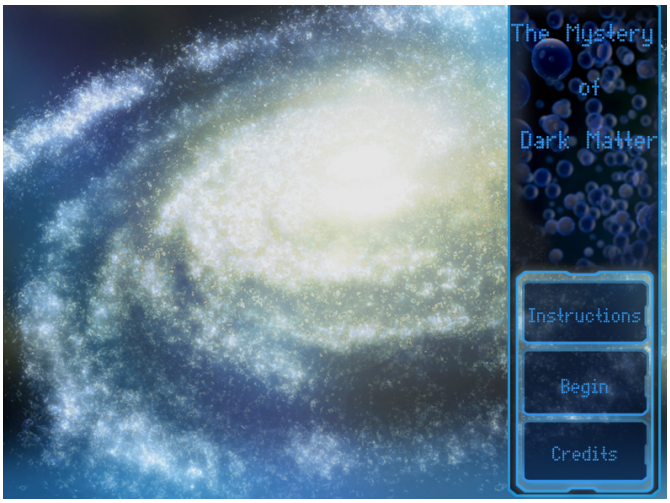
Play the "Space Forensics" video game to learn more about dark matter:

https://imagine.gsfc.nasa.gov/educators/programs/spaceforensics/



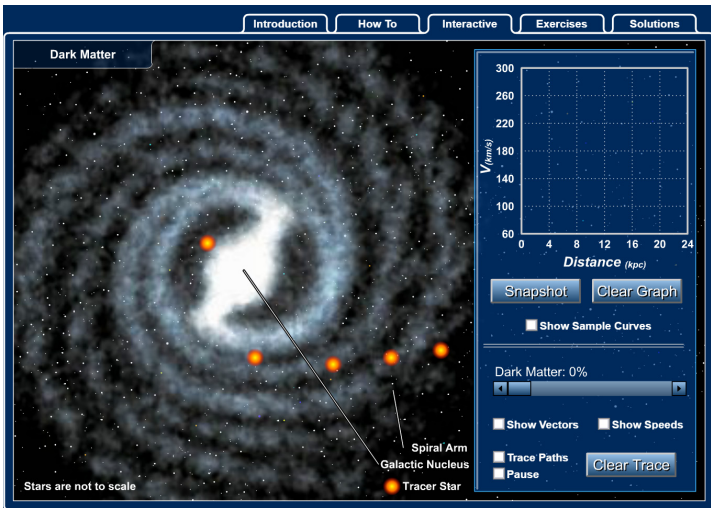
Watch this comic that interviews people studying dark matter:

https://www.youtube.com/watch?v=8kCtiOS_F_M



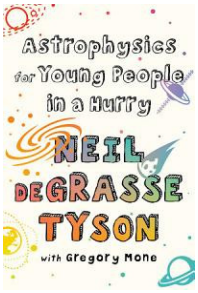
To learn more about the mass of dark matter play "The Mystery of Dark Matter" game:

https://www.perimeterinstitute.ca/dark_matter_game/index.html



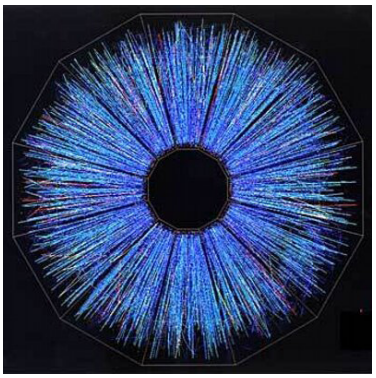
To experiment with dark matter in a virtual galaxy play this game:

http://highered.mheducation.com/olcweb/cgi/pluginpop.cgi?it=swf::100%2525::100%2525::/sites/dl/free/0072482621/78778/DarkMatter_Nav.swf::Dark%2520Matter%2520Interactive



If you love learning about the universe, read "Astrophysics for Young People in a Hurry" by Neil DeGrasse Tyson (available for free on library app Libby).

LOOK FOR US ON SOCIAL MEDIA:



@brookhavenlab

#BrookhavenSciEd

RESOURCES

- Dark Matter Day resources for parents and educators https://www.darkmatterday.com/educational-resources-dark-matter-day/
- More astrophysics activities: https://imagine.gsfc.nasa.gov/features/yba/
- Dark Matter for Kids: https://kids.frontiersin.org/article/10.3389/frym.2017.00029
- What is Dark Matter: https://spaceplace.nasa.gov/dark-matter/en/
- Dark Matter Video from Fermilab: https://www.youtube.com/watch?v=oPNrcKeqbBM
- Water Bottle Activity Resource: https://www.jpl.nasa.gov/edu/teach/activity/how-do-we-see-dark-matter/
- LSST: https://www.lsst.org/science/dark-matter
- Gravitational Lensing Activity: https://astroedu.iau.org/en/activities/1748/dark-matter-dark-energy-part-2-understanding-the-nature-of-dark-matter-and-dark-energy/
- Vera Rubin: https://www.youtube.com/watch?v=pkrljGUJOPA https://www.npr.org/sections/thetwo-way/2016/12/26/507022497/vera-rubin-who-confirmed-existence-of-dark-matter-dies-at-88