The Search for Dark Matter

Middle School Physical Science Unit with Earth/Space Science Connections
Science Focus: What is dark matter, what is the evidence for its existence, and how are scientists searching for it?

Lesson #	Lesson Title	Suggested Time
1	Our Modern Universe	45 minutes- part 1 45 minutes- part 2
2	Exploring the Universe through Light	45 minutes- part 1 45 minutes- part 2
3	The Role of Gravity	45 minutes
4	Exploring the Unseen	45 minutes- part 1 45 minutes- part 2 45 minutes- part 3
5	Gravity and Light: Evidence of Dark Matter	45 minutes- part 1
6***	Going Deep for Dark Matter: The LUX Detector	45 minutes- part 1 45 minutes- part 2

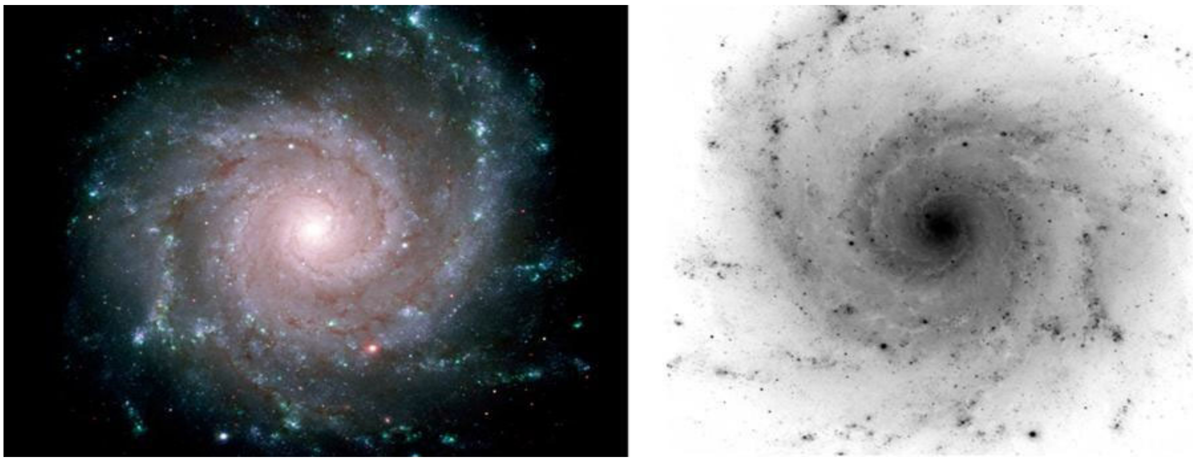
*** Additional time may be needed if a virtual tour of the Davis Campus is included

The Search for Dark Matter 6-8 (Physical Science)

Students explore dark matter, a substance that doesn't interact in the same way as everything we experience in our own world. Following the evidence for dark matter chronologically, students explore scientific concepts around the topics of matter and its interactions, as well as the scientists and technologies that make new discoveries possible. Connections to the Sanford Underground Research Facility are made through the final lesson which introduces students to the Large Underground Xenon (LUX) dark matter search.

The Search for Dark Matter

The Story:



NASA/ESA/The GMOS Commissioning Team (Gemini Observatory)

Early Greek philosophers knew a world made of four basic elements: earth, wind, fire, and water. Since that time, science understanding, with the aid of better technological advances, has shown that those four original 'elements' are made up of atoms. The atoms themselves are made up of smaller components – protons, neutrons, and electrons. Protons and neutrons are made up of quarks. The standard model of particle physics identifies two families of 'fundamental' particles, leptons (electrons and neutrons) and quarks, which are the building blocks of matter as we know it. Nuclei and atoms form from these building blocks through three interactions: strong, weak, and electromagnetic.

Since the 1970's, evidence has been mounting that the matter physicists and chemists have been studying since the time of the early Greeks is just a small percentage of all the mass in the universe. The most recent data shows that our kind of matter – atoms, molecules, rocks, water, air, stars, and all other things that interact with visible light – accounts for a mere 4.9% of the universe. A mysterious substance called dark matter accounts for 26.*%. Scientists are now calling our kind of matter 'light matter' in contrast to the much more abundant dark matter. (The remaining 68.3% is an even more mysterious, substance-less 'dark energy'). Evidence for dark matter can be found in the motion of large-scale structure in the universe – galaxies and clusters of galaxies. This evidence relies on a firm understanding of a fourth interaction, gravity. Through explorations of the very small (subatomic particles) and the very large (galaxies), along with their interactions through gravitational and electromagnetic interactions, students will gain an understanding of the scientific quest to find dark matter, which is being carried out at facilities such as the Sanford Underground Research Facility in Lead, SD. Through inquiry-based activities, they will take on the role of a scientist seeking answers to questions that can't be found in textbooks. They will practice science and engineering processes and explore crosscutting concepts such as scale, patterns, and cause and effect.

In addition, students will explore the evidence for dark matter by following a chronological roadmap. Students will learn about some of the scientists who have contributed to our understanding of the universe as well as advances in technology.

Lesson 1. Our Modern Universe

Students will be introduced to the phenomenon of dark matter through the bean jar. In the jar, the white beans represent all known matter in the universe and the dark beans represent all the 'dark matter', which is invisible to light, therefore can't be observed with normal means. This jar will sit in the front of the classroom throughout the unit and the teacher will regularly refer back to it.
The vastness of the universe, from the smallest sub-atomic particle to the largest cluster of galaxies is very difficult for us humans to understand or imagine. In this lesson, students will use a scaled model of the universe to make observations and begin formulating questions. Students will visit an interactive website that they use to explore the smallest known item to the largest known item in the universe. They will see where they, as humans, fit into the scale. They will use a graphic organizer to note just how many of the objects are too small or too far away for us to see with the naked eye.

Scientist: Early Astronomers *Technology: Eyes*

Learning Outcomes:

- Students will create and use a graphic organizer to help understand complex ideas and organize information, thereby gaining an understanding and appreciation for the size and scope of the universe from the very small to the very large.

Lesson 2. Exploring the Universe through Light

This lesson covers the basics of atomic spectroscopy as a tool astronomers use to study the universe.

Students explore the nature of light and how it – as a subset of electromagnetic radiation – can be used as a 'fingerprint' of atoms. Students will learn that when energy is added to an atom, the electrons can become 'excited' and then emit light. The energy can be added in the form of electrical or thermal. The light patterns an atom emits are a source of evidence scientists use to determine what elements are in the stars.

Day 1 - Scientist: Galileo *Technology: Telescopes*
Day 2 - Scientist: Fritz Zwicky *Technology: Telescopes*

Learning Outcomes:

- Students will realize the contribution of telescopes in pioneering the exploration of the universe.
- Students will be able to explain the electromagnetic spectrum and how scientists use spectroscopy to determine the composition of stars.

Lesson 3. The Role of Gravity

In this lesson, students learn about gravity and orbital motion.

Scientist: Vera Rubin *Technology: Telescopes/Spectroscopy*

Learning Outcomes:

- Students will be able to discuss forces in orbital motion.
- Students will apply the knowledge gained to predict what would happen if orbital balances are unbalanced.
- They will then hypothesize why stars near the edges of the galaxy that would seem to have unbalanced orbital speeds are not escaping the galaxy.

Lesson 4. Exploring the Unseen

Students are learning that scientists often have to observe and study objects that are impossible or improbable to see directly. Probes have been developed to map surfaces as small as an atom and as big as our universe. Sanford Lab began this study more than 50 years ago when the lab was Homestake Mine and scientists Ray Davis and John Bahcall built the first detector a mile underground.

In this lesson, students will use probes to explore a black box just as the Sanford Lab scientists use their tools to explore subatomic particles.

Scientist: Ray Davis *Technology: underground detector*

Learning Outcomes:

- Students will plan and carry out an investigation using indirect evidence, and use it to construct a mathematical model of an unseen landscape.
- They will relate this experience to the work scientists must do to develop theories about things too small, too far away or unable to be seen due to other reasons.

Lesson 5. Gravity and Light: Evidence of Dark Matter

In Lesson 3, students learned about the attraction of gravity on objects; in this lesson they learn about the effect of gravity on light. Bundles of light energy – photons – respond to the gravitational attraction of large masses, including dark matter. Gravitational lensing is an effect whereby light from very distant galaxies bend and distort due to dark matter between the observer (us) and the galaxy, providing one of the key pieces of evidence for dark matter.

Students will model gravitational lensing through comparisons with the refraction of light at a boundary between two mediums.

Scientist: Albert Einstein *Technology: Hubble Space Telescope*

Learning Outcome:

Students will construct arguments from evidence that there is much more matter in the universe that we cannot see than matter that we can (our bean jar model of a universe).

Lesson 6. Going Deep for Dark Matter: The LUX Experiment at Sanford Lab

In this lesson, students will make the connection to the searches for dark matter at the Sanford Underground Research Facility using the Large Underground Xenon (LUX) detector. They will explore Sanford Lab and how the detector works, and possibly take part in a videoconference or Skype connection to scientists at the Lab for a virtual tour of LUX.

Scientist: LUX Graduate Student *Technology: Cryogenic (cold) underground detector*

Learning Outcomes:

- Students will explain how the LUX detector at Sanford Lab is attempting to 'directly' detect dark matter through indirect means.
- Students will demonstrate their new understanding of the size and scope of the universe and the evidence for dark matter on the unit post-assessment.

The Search for Dark Matter

Standards Addressed in the Unit

Physical Science Standards:

MSPS1.1 Develop models to describe the atomic composition of simple molecules and extended structures.
MSPS1.4 Develop a model that predicts and describes changes in particle motion, temperature and state of a pure substance when thermal energy is added or removed.
MSPS2.2 Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.
MSPS2.4 Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.
MSPS3.4 Engage in argument from evidence to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.
MSPS4.1 Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.
MSPS4.2 Develop and use a model to describe how waves are reflected, absorbed or transmitted through various materials.

Earth/Space Science Standards:

MSESS1.3: Analyze and interpret data to determine scale properties of objects.
MSESS1.2 Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.

The Search for Dark Matter

Materials List

- **Teacher-Provided**

Lesson	Materials Needed
1	*For each student:* • Graphic Organizer – "Scale of the Universe" • Index Card *For the teacher:* • Clothesline and clothespins • Laminated timeline index cards *For each small group:* ➢ Computers w/ access to The Scale of the Universe 2 (htwins.net)
2	*For each student:* ➢ One diffraction grating ➢ Exploring Light handout *For the teacher:* • Timeline poster of Galileo and Fritz Zwicky • 3 Power Supply Stations & gas Tubes (H, He, Ne, Ar, Kr, Xe, Hg) • Gloves for handling glass tubes ➢ If classroom has fluorescent lights, have at least one incandescent light bult & lamp ➢ Matches • Safety Glasses • Copper Sulfate Crystals • 250 ml beaker • Tbsp measure • Metal loop w/ insulated handle • Candle (or Bunsen/alcohol burner) *For each small group (2):* • Set of 7 colored pencils • Spectroscope • Laminated full colors spectrum w/ wavelength measurements
3	*For each student:*

	• One "Gravity Simulator Sandbox" activity questions (pg. 2) • One "pHet Sim Gravity and Orbits" activity questions (pg. 3) *For the teacher:* • Timeline Poster of Vera Rubin • Rope w/ tennis ball attached to one end, threaded through PVC pipe *For each small group:* • Computer w/ internet access • One "Gravity Simulator Sandbox" Data Entry (pg. 1) • One "pHet Sim Gravity and Orbits" Data (pg. 1-2) • pHet Sim Gravity and Orbits Website Gravity and Orbits (colorado.edu) • Gravity Simulation Sandbox Website https://www.testtubegames.com/gravity.html
4	*For each student:* • "Quarked" Handout • "The Problem with the Missing Neutrinos" Handout *For the teacher:* • Timeline poster of Ray Davis Jr. • Particle poster (laminated) *For each group of students (3):* • Sealed Box • "Black Box" handout • 2-3 skewers marked w/ .5cm increments • 1 computer with EXCEL/Internet access OR 1 package of cm blocks/group
5	*For the teacher:* • Timeline poster of Albert Einstein *For each group of students:* • Numbered Water Goblets – stemmed • Laminated Graph Paper • Laminated galaxy map • Laminated photo of the Abell Galaxy Cluster • Plastic cup w/ penny • Graduated Cylinder

6	*For each student:* • Post assessment • Colored Pencils • One game placard on lanyard • Flashlight (if student has Xenon placard) *For the teacher:* • LUX Tag game - instructions • Setup to have zoom/digital session w/ underground scientist (optional)

Notes for Teachers

This unit has been crafted to substitute two weeks of a middle school physical science curriculum with an examination of dark matter, establishing a connection to Sanford Underground Science Facility through the Large Underground Xenon (LUX) dark matter search.

This unit has the option to set up a videoconference session for students to take a virtual tour and ask questions of scientists in the underground. Please contact the Education and Outreach Team at education@sanfordlab.org if you are interested in such an option. Availability cannot be guaranteed.

Resources:
The unit comes with a materials kit that will be shipped or delivered within South Dakota by request. Included in the kit is most of what a teacher needs to implement the unit. A notebook with the lessons and a unit flash drive are also included. The unit flash drive contains a PDF Guide file, an optional unit PowerPoint that can be used by the teacher to guide the instruction, and other media such as videos.

Science Notebooks:
Interactive science notebooks are encouraged but not required for this unit. If students already use notebooks in science class, by all means continue to use the same ones. The next page gives some guidance if the use of notebooks is new to you. Most activities come with a handout for guided learning.

Phenomenon-based Learning:
The state of South Dakota has adopted the approach towards teaching the newly adopted science standards using puzzling phenomenon, and students spend the course of the unit coming to an understanding of that phenomenon. In this unit, the puzzling phenomenon is dark matter itself. As a physical representation of the amount of dark matter in the universe, we use a jar of beans, where the black beans represent dark matter and the white beans represent normal, sometimes called 'light' matter. This jar should sit in the front of the room and be referred to as each lesson is summarized.

Timeline of Scientific Discoveries:
In this unit, we have chosen to feature a scientist in each lesson to provide historical perspective and context to each scientific discovery. We also feature the technological advances that led to each new discovery. We want to convey to students that science is not facts out of textbooks but is a series of individual stories of both success and failure that continues today and into the future.

Groupwork Norms:
The following norms are listed on the task sheet for the Black Box experiment in Lesson 4 and in the PowerPoint. If you have a different set of classroom norms for groupwork, feel free to change the slide:

Groupwork Norms

- Everyone has expertise.
- Everyone has something to learn.
- You have the right to ask for and offer help as well as a duty to assist.
- Pay attention to what others need.
- No one is done until everyone is done.

Procedural Roles:

- The purpose of roles is to ensure a high quality discussion and a group product that are on track and on time.
- Roles relate to ***how*** the work gets done; ***intellectual roles are inappropriate***. (Intellectual roles may be: the mathematician, the reader, the scientist). If reading and math are critical to the task, then everyone in the group should be engaged in these skills and processes.
- Procedural roles must be appropriate to the task and to the number of group members.
- ***Every*** group member must have a procedural role - all the stuff in all hands.
- The procedural role is for the student to make sure that the assigned task gets done, not necessarily that the student do it alone. (e.g. the note taker makes sure everyone has notes).

Teacher Facilitation Tips for Successful Group Roles:

1. Assign roles; if you let the group choose their own roles, they will tend to give whatever they perceive as the most desirable and powerful role to the person with the highest status.
2. Make role assignments public knowledge both visually and verbally (consider procedural role name tags that refer to the student's procedural role to the group).
3. Provide a written "job description" for each role.
4. Make sure everyone knows what each role is supposed to do.
5. Provide students opportunities to learn each of the roles in low stakes environments.
6. Hold students accountable for their procedural roles.

A Teacher's Guide to the Interactive Notebook:

For this unit it is intended that students utilize an interactive notebook. If you already have a science journal, or notebook, that students maintain during the class please continue to use that format. If you do not have a journal or notebook for your classroom, use an Interactive notebook for the duration of this unit.

The interactive notebook should be kept in a spiral notebook or composition notebook.

The front side of the first piece of paper in the interactive notebook should be designated as a table of contents. The table of contents will be created as the pages of the notebook are created. Following the table of contents, all pages should be numbered, and the dates recorded.

The next front side page should be the title page. For this unit students should create a page that reads *The Search for Dark Matter*. Students are free to decorate this page any way they choose.

Beginning with the backside of the second sheet of paper the students begin to make entries into their interactive notebook. Some examples of entries could include:

* Notes taken while reading articles or textbook or watching a video (Cornell Notes is a great template to use)
* Lab results and observations
* Vocabulary terms and definitions
* Venn Diagrams
* Student sketches/modules
* Mind-maps (concept maps)
* Questions that the student is pondering about the topic

At the end of the unit students can write a summary of their understanding of the unit. If you would like to have students write a summary, have them select two items that represent their best work. Students should give the dates of their entries and then explain why they chose these two items, what they learned from these two items, and how these items reflect scientific thinking or skills. Students must use evidence to defend their choices and should not provide emotional responses such as “that is my best drawing” or “that activity was a lot of fun”. The reflection should be written on the last page of the interactive notebook for that unit.

We encourage your students to take their notebooks home to share with their parents or adults living in the home with them. The adults should look through the notebook and read the reflection with the student.

Lesson One (2 periods)	
Standard(s), Outcomes	<u>Standards:</u> **MSESS1.3** Analyze and interpret data to determine scale properties of objects. <u>Objectives:</u>

	Students will collect data of known and unknown objects and make observations about their relationship in size and where they fit, relatively, on a linear scale and an exponential scale. Students will gain understanding of measurement using exponents and their use in science exploration. Students will create and use a graphic organizer to help understand complex ideas and organize information. Learning Outcome: ● Students will gain an understanding and appreciation for the size and scope of the universe from the very small to the very large.
Background Information	The vastness of the universe, from the smallest sub-atomic particle to the largest galaxy, is very difficult for a person to understand or imagine. The range in size of the subatomic particles to the outer edge of the universe is overwhelming, and beyond anything that we could ever experience. This activity offers a perspective of this vast range and just where we fit in the universe. As an introductory lesson to this unit, the student will use "The Scale of the Universe" to make observations and begin to formulate questions. In order to compare objects, exponents will be used to label their size. A mini lesson explaining exponents will precede the activity. This background information will be presented using a PowerPoint slide and the video "Powers of Ten".
Materials	***For the classroom:*** • Bean jar model of the universe • Teacher computer with projector • Unit PowerPoint • Clothesline and clothespins • Set of teacher timeline cards to put on clothesline **For each student:** • Graphic Organizer for "Scale of the Universe" (Teacher Guide) • Index card **For each small group of students (3 optimal)** • Computers to access "The Scale of the Universe" website • "Scale of the Universe" website http://www.htwins.net/scale2/

Prior Knowledge	The interactive simulation used in this lesson scales objects of the universe using exponential values. Before beginning the activity, students need to understand exponential notations. The powers of 10 video, while dated, provides an overview of exponents and is available on the unit flash drive, or at https://www.youtube.com/watch?v=0fKBhvDjuy0 It is not necessary to go into too much detail with this, just a basic understanding of what exponents are and what is meant by power of 10. Another resource is a Khan Academy lesson online at :https://www.khanacademy.org/math/cc-fifth. The Khan Academy video tutorial is not available on the flash drive. The PowerPoint slide provided in this lesson lists the most regularly used units of measurement and their exponential values to keep the example relatable to students.
Launch	
Engagement and Communication of Student Expectations	Have video clip playing on the overhead when the students walk in. Welcome them to the unit "The Search for Dark Matter". Links are on the PowerPoint and included on the flash drive. The first link is to a YouTube video that is 3 minutes long. https://www.youtube.com/watch?v=c9X5kvVLpWQ The second link is to a YouTube video that is over 10 minutes in length. https://www.youtube.com/watch?v=onFprZBp50M Welcome the students to the unit by asking them what they are seeing when they view the videos playing as they come in (can leave playing during discussion). Ask them if there are more things in the universe that are not on the video. Tell them that throughout this unit, they will delve deeper into the universe than they have ever gone before and, in the end, understand some of the most cutting edge exploration of the universe that is taking place here in South Dakota. 1) Pre-assessment: Give students the pre-assessment handout. Remind students that this will not be graded, and they should work independently without visual or verbal conversation with other students. Ask students to make sure their names are on their papers and turn them in. These will prove to be valuable insight for the teacher about students' prior knowledge as well as entertaining hindsight for students to reflect on as the unit is complete. Teachers will use this as a pre-assessment for the unit of study using the rubric in the lesson. These scores and some sample student work will be collected and sent back with the kit for Sanford to use in their efforts

to continually improve their materials and provide input on student understanding.

2) **PRESENT THE UNIT PHENOMENON: Bean Jar Activity:** Display the jar of beans and tell students that this jar represents the universe. Ask them what they believe it is modeling? Discuss all responses. Reveal that the jar of beans represents the matter in the universe. Ask students what they believe the term "matter" means. Discuss all responses. Tell the students the white beans represent the matter that we can detect using all the technology that we have. The black beans represent matter that we theorize exists but that we cannot detect/see using current technology.

ESSENTIAL QUESTION: How do we know this matter really exists if we cannot see it? What evidence do we have that is exists?

***YOU WILL BE RETURNING TO THIS PHENOMENON THROUGHOUT THE UNIT.**

3) Begin the story of the search for dark matter by showing the PowerPoint Slide on the early astronomers.

4) Start the timeline of scientists by placing the title card at the end of a long stretch of wall or bulletin board and add the poster of the early astronomers. Each day a new scientist will be added to provide an anchor chart as you preview and review the story of the theory of Dark Matter.

Explore

Procedure

1) Show students the video on the powers of 10 to review and prepare students to understand the scope and size of the universehttps://www.youtube.com/watch?v=0fKBhvDjuy0

Teacher Tip: This could be a good stopping point for day one. Have students take home the Sanford Lab survey. If you don't stop here, you can begin the "Scale of the Universe" activity and stop in the middle, resuming on day 2. They could then take home Sanford Lab survey at the end of day 2.

2) Hand each student the graphic organizer "The Scale of Things" (Scale of the Universe Handout). This graphic organizer should be used as a guide and a "thought holder" as students visit the Scale of the Universe website.

3) Tell students they should take extra notes or write questions they may have about the simulation for the discussion to follow. Students will need internet access. The site to visit is at http://htwins.net/scale2/

4) Have the students open the website and do the row on the "human" on the site together. Allow 20-30 minutes of time for

	students to scale the universe with this website and complete the graphic organizer filling in the data for the given items and choosing other items to add. Remind students that their chosen items must follow the scale and "fit" between the given items. 5) Summarize the student's findings as a class by having them fill out an index card with one of the items they added to the graphic organizer. They are to use the card in the portrait orientation or tall and skinny. At the top, ask them to write the name of the object big and bold. Below this, they do a quick sketch of the object and under that, again largely and boldly, write its size given as an exponential number. 6) The teacher will string a clothesline across the longest side of the classroom – hopefully 10 meters long. They will put the three cards that are included in the kit (blood cell, human and sun) spread out on the line. Students will hang their card on the line as they finish making them, placing them between the other students' cards where they should fit to create a linear representation from smallest to largest object 7) Ask students if they were to create a model to scale (actual size) how many cards would fit on the line (any under 1 decameter, or $1X10^{2.}$). If time allows, you can model this. Teacher Tips: Encourage students to record the most interesting facts from the small write-up for each object, not just the first two facts.
Questions	• After visiting the observable universe, what are some of the familiar items in the universe? • After visiting the observable universe, what are some of the unfamiliar items in the universe? • Estimate the percentage of the universe you are familiar with? • Albert Einstein has said *"The more I learn, the more I realize how much I don't know."* How might that apply to this activity? Teacher Tips: With this activity, it is best to not load the students with questions before they visit the Scale of the Universe website. Be prepared for questions after they have started the activity. These are great questions to grab hold of and keep visible for students to try to find answers to as the unit progresses. Note the clever and sometimes witty narratives that pop up when you select an item. You may want to select a few of these to share with students at the onset to encourage them to explore this feature.

Summarize	
Communicate	Ask students to share some of the items added to different levels of the graphic organizer and double check scaled sizes. Ask for both familiar and unfamiliar objects.
Terminology and Concepts to Solidify	Matter - any substance that takes up space and has mass Exponent -The exponent of a number says how many times to use that number in a multiplication. It is written as a small number to the right and above the base number. (e.g., 2^3 = 2x2x2) Scale - a comparison of objects by size
Connection to Big Ideas (Phenomena)	The study of dark matter is indeed the big idea that we will be exploring throughout the unit. The fact that scientists need to find ways to study the unseen is presented so that students can themselves devise their own methods of using indirect evidence to explain phenomena. Only 4% of the universe is observable with current tools. If this interactive video shows the range of 4% that we have observed, what about the other 96%? There are things too small and too far away to be seen even with present technology. **Return to the bean jar model of the universe**. Discuss that the white beans represent light/regular matter but some of that is too far away or too small to be seen. Ask – 'What is in all the empty space between objects? Is this represented by the black beans?
Follow Up/Practice	Students will have only begun to scratch the surface of all that can be seen at this time. Provide them with the website information so that they can continue exploring at home. Students will also take home the survey to do with their parents/family and bring back when finished.
Assessment	**Day 1:** Students will take home a survey about Sanford Lab to be completed with family. **Day 2:** In their science journals or on separate piece of paper, have students reflect on their new perspective of the universe. Have students include, in the reflection, three new thoughts they will take away from the day and three questions they will hold onto for future discussions.

NAME ______________________________

The Search for Dark Matter
Pre-Assessment

#1

Use this page to draw a model of the universe with labels and explanations. Include everything you think you know about the universe. (No resources are to be used during this assessment.)

#2

"The jar of beans represents the ratio of light to dark matter in our universe."
Justify this claim using the evidence regarding dark matter.

#3

If you were a scientist trying to discover dark matter, how would you go about it?

RUBRIC FOR PRE & POST ASSESSMENT

The Search for Dark Matter

Name:________________

	3 pts.	2 pts.	1 pts.	Score	Comments
Use of terminology *Question #1	Most terms are used appropriately to show meaning	Some of the terms are used appropriately to show meaning	Few terms are used and/or are used incorrectly		
Visuals *Question #1	Drawing shows an understanding of the scope of the universe	Drawing shows components outside the solar system.	Drawing is limited to our solar system		
Atomic particles *Questions 1,2&3	Particles broken down to the sub-atomic level	Particles are at the level of individual atoms	No reference to atoms		
The Role of Gravity *Questions 2&3	Evidence of gravitational interactions are included as well as reference to orbital evidence	Evidence of gravitational interactions are included	Gravity not referenced		
Dark Matter *Questions 2&3	At least 2 examples of evidence are included, and the tools used are discussed.	At least 1 example of evidence is included, and the tools used are discussed.	Inaccurate evidence or not well explained		

What Do You Know About

THE SANFORD UNDERGROUND RESEARCH FACILITY?

PLEASE TAKE THE SURVEY AND ALSO POSE THE QUESTIONS TO TWO FAMILY MEMBERS:

QUESTION	Your answer	Family Member #1	Family Member #2
Have you heard of the Sanford Underground Science Lab at Lead, SD?			
What do you think they are studying in the lab?			
Why do they need to do this research so deep underground?			
Have you heard of particles called neutrinos?			
What do you think a neutrino is?			
What have you heard about the theory of Dark Matter?			

The Search for Dark Matter – Lesson 1 The Scale of Things

Graphic Organizer for the website http://htwins.net/scale2/

Name: ________________

Subatomic Particles:
Size:

______________**:**
Size:

Red Blood Cells:
Size:

Human:
Size:

______________**:**
Size:

Sun:
Size:

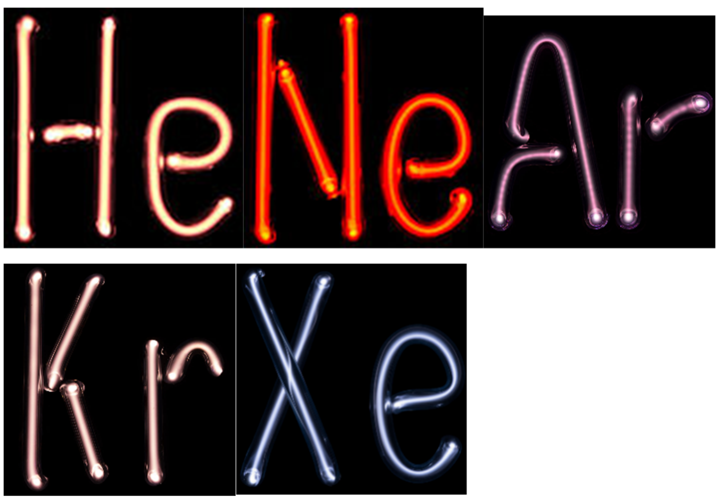
______________**:**
Size:

Local Group of Galaxies:
Size:

Lesson Two – Exploring the Universe Through Light	
Standard(s) & Outcomes	<u>Standards:</u>

	MSPS3.4 Engage in argument from evidence to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object. **MS-PS1.4** Develop a model that predicts and describes changes in particle motion, temperature and state of a pure substance when thermal energy is added or removed. Objective: Students will analyze and interpret data to determine the fingerprint of an element. Learning Outcomes: 1. Students will realize the contribution of telescopes in pioneering the exploration of the universe. 2. Students will be able to explain the electromagnetic spectrum and how scientists use spectroscopy to determine the composition of stars.
Background Information	**GALILEO**: Occupation: Scientist, mathematician, and Astronomer. He is best known for improving the telescope to be used to study the planets and stars. **TELESCOPES** In 1609, Galileo heard of an invention from Holland called the telescope that could make far away items appear much closer. He decided to build his own telescope. He made great improvements to the telescope and began to use it to view the planets. Soon Galileo's version of the telescope was used throughout Europe. Galileo made many discoveries using his telescope including the four large moons around Jupiter and the phases of the planet Venus. He also discovered sunspots and learned that the Moon was not smooth, but was covered with craters. From http://www.ducksters.com/biography/scientists/galileo_galilei.php **FRITZ ZWICKY** Fritz Zwicky was a Swiss astronomer who worked most of his life at the California Institute of Technology. He is known for his many important contributions in theoretical and observational astronomy. While studying Coma galaxy cluster in 1933, Zwicky was the first person to use the viral theorem to deduce the existence of the unseen matter. This was referred to as the 'dark matter'. After calculating gravitational mass of galaxies within the cluster, he obtained a value that was 400 times greater that than expected luminosity. He concluded that most of matter must be dark. From http://famousastronomers.org/fritz-zwicky/ **COLORED STARS**

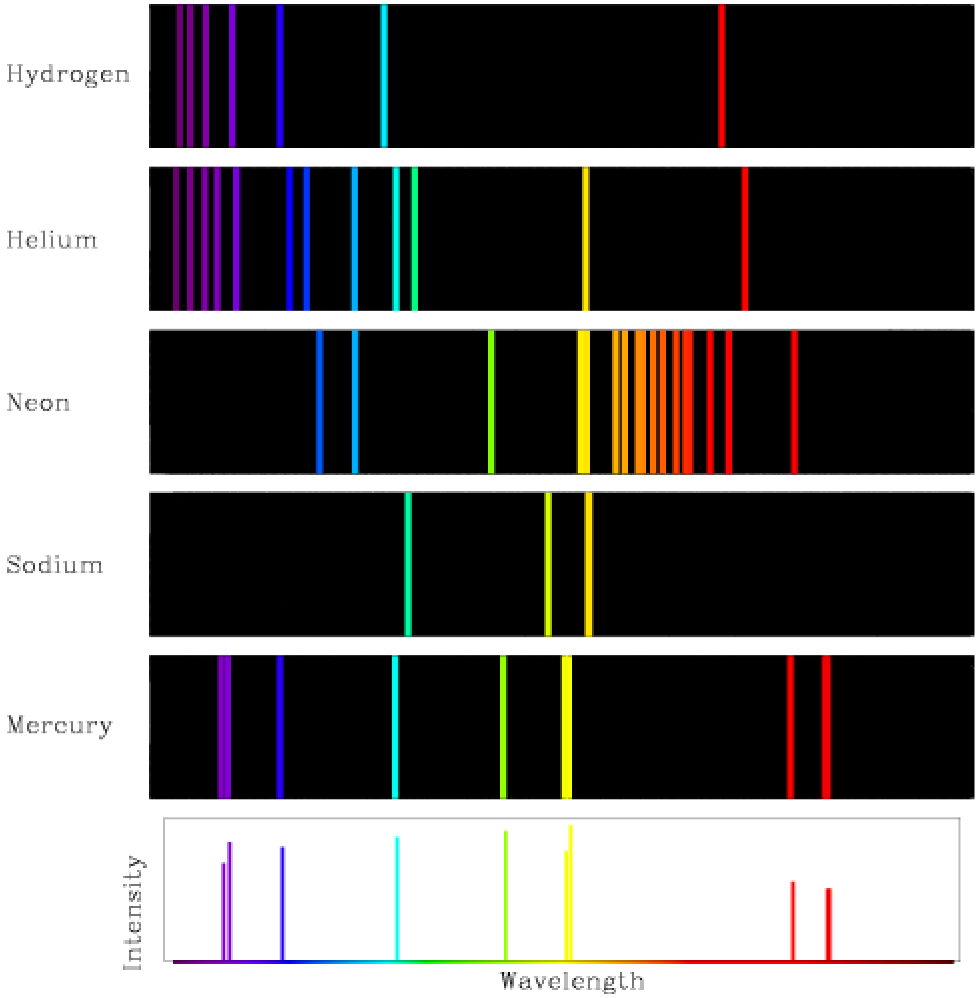
"Red, White and Blue" : A <u>cluster</u> of young stars, glowing blue, travels through the red hydrogen gas of a nebula, embedded in an enormous supercell structure. This image of the cluster, NGC 2367, was taken by the MPG/ESO 2.2-meter telescope at the European Southern Observatory's La Silla Observatory in Chile.

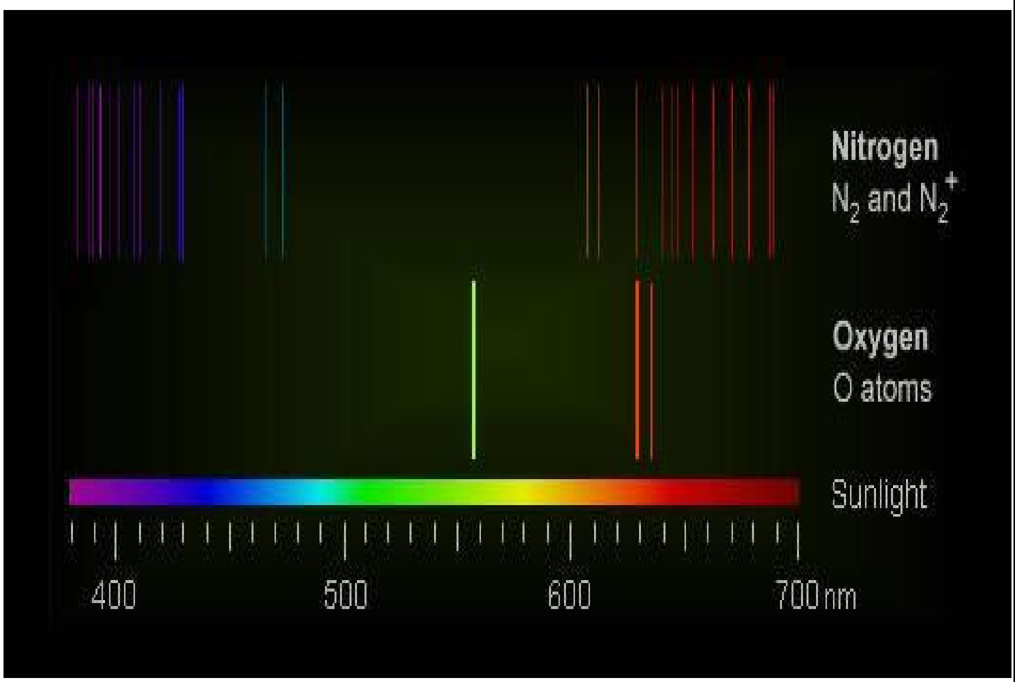


Distinct colors are emitted by the de-excitement of the electrons in a given element.

Atomic spectroscopy is the study of the electromagnetic radiation absorbed and emitted by atoms. The power supply will provide the energy needed for electrons in the atoms of the gas in the tube to give off their photons.

The diffraction grating in the glasses will separate this light into a unique spectrum for that atom. Some of the spectra for the gasses used are:


Hydrogen
Helium
Neon
Sodium
Mercury
Intensity
Wavelength


Nitrogen
N_2 and N_2^+
Oxygen
O atoms
Sunlight
400
500
600
700 nm

Materials	**For Classroom** • Timeline poster of Galileo and of Fritz Zwicky (add to timeline to start lesson) • 3 Power supply stations and gas tubes (H, He, Ne, Hg) • Teacher gloves for handling glass tubes • ^If the classroom has fluorescent lights, also have at least one incandescent light bulb and lamp or socket • Safety Glasses (for teacher) • Copper Sulfate crystals • Tablespoon measure • Small beaker of water to mix crystals into • Metal loop with insulated handle • Candle (or Bunsen or alcohol burner if available) • ^Matches ^ teacher-provided **For each student** • One diffraction grating • Exploring Light Handout (Teacher Guide) **For small groups (2 optimal)** • Set of colored pencils • Spectroscope • Laminated full color spectrum with wavelength measurements
Prior Knowledge	Students may have learned in earlier lessons that electrons are found orbits around the nucleus of an atom. The details of these orbits depend on the electromagnetic forces between the electrons and the nucleus. If they have not studied atomic structure yet, a basic review of the atom may be needed. There is a diagram in the PowerPoint to use for a review and a link to a YouTube video of a clever and brief explanation.
Launch	
Engagement and Communication of Student Expectations	1. Continue the story of the search for dark matter using the PowerPoint and the two timeline posters that go with today's lesson (Galileo and Zwicky). Discuss Galileo and telescopes and how it led to a deeper understanding of the stars. Continue with

	the slide of the electromagnetic spectrum pointing out that the early scopes only saw white light from the stars. 2. Show the slide of the new telescopes and the following slide, the “Red, White and Blue” cluster of young stars and how the technology has allowed us to see the color of the burning stars. 3. Introduce spectroscopy using the following slide showing electrons changing energy levels to release different wavelengths of light. 4. DEMONSTRATION. Mix approximately 1 Tbsp. or 5 grams of Copper Sulfate crystals into approximately 1 Cup or 150 ml of water. *Wear goggles when mixing chemicals and doing demonstration.* Dip the metal loop into the liquid to suspend a drop of liquid in the loop. Hold this loop/liquid directly above the flame of the alcohol burner or candle. Be patient, it takes time before the burning of the liquid produces a green flame due to the copper. Discuss that the electrons in the copper atoms in this case are giving off the green light as they de-energize. This is a property that helps identify copper. 5. Ask students what star color can tell us about the star. Ask students if they think that there are more than one chemical element burning in a star.
Explore	
Procedure	1. Handout the diffraction grating and instruct them to handle them by the cardboard frames to avoid getting the slide smudged with fingerprints. Now have them look at the lights around the room and outside to reveal colors making up light that are unseen with the naked eye. 2. Using the diffraction grating have students look around the room at the different light sources. Give them time to “ooh and awe” as they look at the lights. Have them describe what the light looks like without the grating, then with their grating. 3. Hand out the “Exploring Light” handout and colored pencils. Turn on an incandescent light and turn off room lights. Have students draw the spectra seen through their grating in their notebook using colored pencils in the top box of the handout. 4. Put students into pairs and give each pair a copy of the laminated full color spectrum. Have them compare this to their drawings. Discuss the wavelength measurements and refer back to the PowerPoint slide on the Electromagnetic spectrum. Ensure that they understand different amounts of energy produce different wavelengths of light.

5. Using one power source put in the hydrogen tube with the gloves on to avoid getting fingerprints on the tube and turn it on. Have students look at the glowing tube through their diffraction grating. But not draw anything yet. After one minute, turn it off. **IF THE TUBES ARE LEFT ON MORE THAN 1-2 MINUTES, THEY MAY OVERHEAT AND BREAK!** Have students trade in their diffraction gratings for a spectroscope for every two students, depending upon class size. Students need to hold the spectroscope so that the horizontal spectrum shows the red on the left and is in the area of the 700 mark on the quantitative scale. This may take a while to ensure all students are orientated properly so that what they are seeing matches the orientation of their laminated spectrum and their handout diagram boxes. It can be difficult to see the numbers on the scale and it helps to have some ambient light on in the room, such as the projector screen lit white or the lamp. When they are trying to match colors with their wavelength, they can also use the laminated full color spectrum for reference.
6. Discuss the quantitative scale and do the first spectra, for hydrogen, together as a class. You will turn the power on 1 minute, off one minute and repeat until students are done.
7. Divide the class into three groups, by combining smaller groups, that will travel to the different stations. Assign one <u>responsible</u> student in each group to turn on and off the power source box when told. Tell all other students to stay away from the box and tube.
8. Once the groups are at the three stations, announce that the power may be turned on. Allow tubes to burn for no more than 1 minute and then announce that they must be turned off. Have students discuss and compare what they saw. Repeat the on/off process. Afterward have students work together to color in the major spectral lines for their gas/station (either Helium, Neon or Mercury). Finally, repeat the on/ off process one more time so they can confirm and complete their drawings.
9. Have students rotate to the next station and repeat process in step G. Be sure only one student is near the on/off button and that other students are not too close to the tubes. There is a chance that if tubes get too hot, they can break and glass can fly. This is avoided by having the tubes on for only 1-2 minutes and off for at least one. *

*NOTE: If you are concerned about the responsibility of the students turning on and off the power, you can do all 4 tubes at the front, as a class and you can turn on and off the power. It will be more difficult for students to see from a distance, however.

	OPTIONAL: If time allows, extend the activity by observing the extra tubes/gases in the kit. There is room on the handout to draw them. Teacher Tip: Make sure students don't touch diffraction grating and use gloves that are provided for when the teacher is handling tubes. Teacher Tip: Additional tubes are included (Ar, Kr, Xe) in the kit and on the student handout if there is time. These noble gases are especially beautiful.
Questions	• Why is there just one color when you view the tubes without glasses? • Why do you think there are different colors emitted from different gases/elements? What is happening? • How can this knowledge be used?
Summarize	
Communicate	1. Collect supplies and discuss the observations the students made. 2. Show and discuss the PowerPoint slides with the actual spectra on them. 3. This pHet Simulation and activity allow students to further explore the creation and use of spectra. (15-30 minutes) **Optional Extension** https://phet.colorado.edu/en/simulations/discharge-lamps Atomic Spectra and the composition of Stars (from Teacher Guides) 4. The video link explains what causes spectra from other objects in space including the search for extraterrestrial life. (9 minutes) (**Optional Extension)** https://www.youtube.com/watch?v=crWBFuUW6kI 5. Finally, show the slide with Fritz Zwicky and discuss his observations (see background information section). Use the image of the coma cluster taken by the Chandra telescope that can detect x-rays and reveal the massive gas cloud within. (PowerPoint) 6. The teacher will then show and explain the 'red, white and blue' photo of the cosmos (slide 22) Have students write about this picture in science journal or on separate piece of paper or on the bottom of the "Exploring Light" handout. What could account

	for the colors? What do pictures like that tell us about the universe? (10 minutes)
Terminology and Concepts to Solidify	• Electromagnetic Spectrum / Visible Light/ x-rays • Wavelength - the distance from the peak of one wave to the next • Telescope technology – different types of scope are designed to probe the universe for different kinds of energy along the electromagnetic spectrum, not just visible light.
Connection to Big Ideas (Phenomena)	There are many forms of energy in the electromagnetic spectrum not visible with the human eye but with technology, we are able to “see” this energy in outer space. Dark matter, not visible to the eye, could possibly be viewed someday with newer technologies; at Sanford Lab, they are attempting to detect it through its interaction with normal matter. **Return to the bean jar model of the universe.** Discuss that although we represent dark matter with the black beans, we can see the beans and therefore it is not really “dark”. We believe that “dark matter” does NOT interact with light at all.
Follow Up/Practice	To take this study to the next level, interested students could be encouraged to try this simulation at home. Links from Summarize Section Neon lights and other discharge https://phet.colorado.edu/en/simulation/discharge-lamps
Assessment	The student reflection paragraphs on the cosmos ‘red, white, and blue cosmos’ will be collected as a formative assessment.

NAMES____

The Search for Dark Matter - Lesson 2: Explor Light

How do we know what elements are in other stars so that we can understand t evolution?

1. View an incandescent bulb or flashlight through your diffraction grating. In box below, use colored pencils or markers to sketch what you see. Pay special attention to the wavelength ran each of the colors you observe. Use the laminated full spectrum as a reference to the wavelength of each color

700 Red | 600 | 500 | 400 nm Violet

2. View each of the following element gas discharge tubes through your spectroscope: hydrogen, helium, neo and mercury. Record the visual color of each gas as it appears in the discharge tube then sketch the resulti pattern of each element in the appropriate box below. Don't worry about sketching every line observed - f on what you can easily observe.

   a. Hydrogen: visual color - __________

700 Red | 600 | 500 | 400 nm Violet

   b. Helium: visual color - __________

700 Red | 600 | 500 | 400 nm Violet

c. Neon: visual color - __________

700 600 500 400 nm

Red Violet

d. Mercury: visual color - __________

700 600 700 400 nm

Red Violet

The following are optional. Your teacher will tell you if you have time to complete them.

a. Argon: Visual Color: ___________________________

700 600 500 400 nm

Red Violet

b. Krypton: Visual Color: ___________________________

700 600 500 400 nm

Red Violet

c. Xenon: Visual Color: ___________________________

700 600 500 400 nm

Red Violet

Lesson Three – The Role of Gravity	
Standard(s) & Outcomes	Standards: **MSPS2.4** Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects. **MSESS1.2** Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. Objective: Students will manipulate variables and analyze date to achieve a goal/outcome in two separate simulations, "Gravity Simulator Sandbox" and "pHet Gravity and Orbits". Learning Outcomes: 1. Students will be able to discuss the factors involved in orbital motion. 2. Students will apply the knowledge gained to predict what would happen if momentum and gravity of an orbiting body where unbalanced. 3. They will then hypothesize why stars near the edges of the galaxy that would seem to have high orbital speeds are not escaping from their galaxy.
Background Information	**Summary of Gravitational Force** Gravity is a force of attraction which tries to pull two objects toward each other. Any object which has mass also has a gravitational pull. The more massive an object is, the stronger its gravitational pull is. Earth's gravity is what keeps you on the ground and what causes objects to fall to the ground. Gravity is what holds the planets in orbit around the Sun and what keeps the Moon in orbit around Earth. The closer you are to an object, the stronger its gravitational pull is. Gravity is what gives you weight. It is the force that pulls on all of the mass in your body. - from "Cool Cosmos": Cool Cosmos (caltech.edu) A **gravitational field** is the force field that exists in the space around every mass or group of masses. This field extends out in all directions. • The magnitude of the gravitational force depends upon the mass of the objects (more mass = more attraction or pull). • The magnitude of the gravitational force depends upon the distance between objects (less distance =more attraction or pull). • Weight is the measure of force of gravity acting on an object depending upon its mass. Weight therefore depends on gravity, mass does not. • The Earth and Moon exert a force, or pull, on each other even though they are not in contact. In other words, the two bodies interact with

one another's gravitational field. Another example is the interaction of the Earth and a satellite in orbit around it.

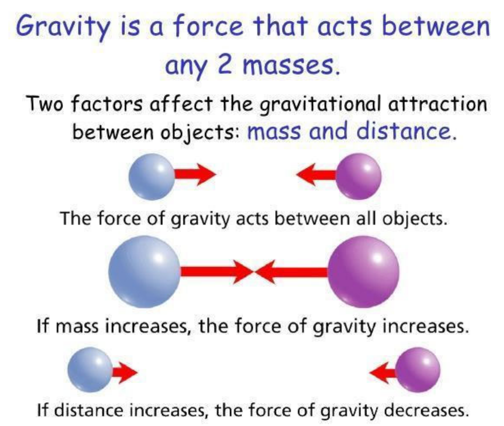
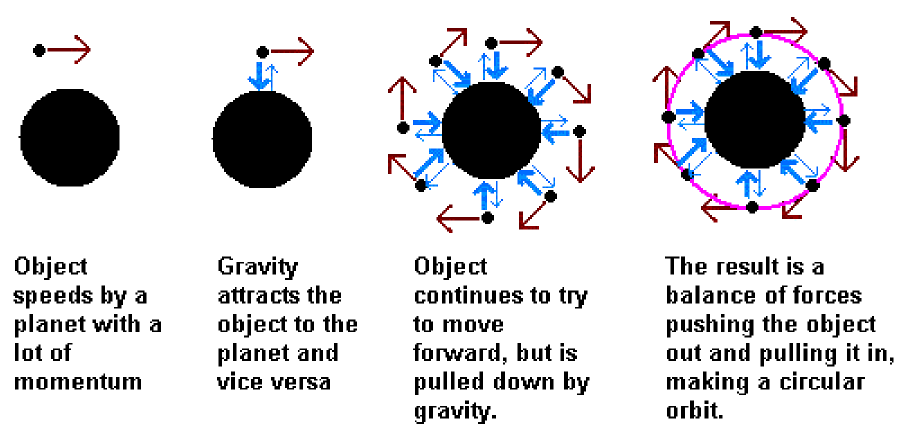


image by Grover Cleveland Middle School. [www.slideshare.net/jbishopgcms/gravity-4940766http://www.slideshare.net/jbishopgcms/gravity-4940766](http://www.slideshare.net/jbishopgcms/gravity-4940766)

What factors are involved in an orbit?

An orbit results from the balance between two things. The first is the forward motion of a body in space, such as a planet or moon. The second is the pull of gravity on it from another body in space, such as a large planet or star. There is a continuous tug-of-war between the orbiting object wanting to go forward and away and the larger body wanting to pull it in. These are referred to respectively as inertia and gravity. If the forward movement (inertia) of one object is too strong, the object will speed past and not enter orbit. If inertia or momentum is weaker than the pull of the other's gravity, it will be pulled into the other one completely and crash.



Text and image adapted from

http://www.qrg.northwestern.edu/projects/vss/docs/space-environment/1-what-causes-an-orbit.html

	Launching into Orbit The trick to achieving orbit is to find a way to launch it to a distance high enough to perform its job without overshooting and losing the capsule in outer space. It is a delicate balance of the inertia of the moving object and the Earth's gravity. Usually this first "kick" is achieved using a powerful rocket. The speed is also a key factor. The speed that is ideal for this balance on Earth is 27,000 km/hr. to 38,000 km/hr. The next challenge is to keep the satellite in its orbit. Here the balance is between two main factors: the satellite velocity and the gravitational pull between Earth and the satellite. An example of these balanced forces would be if you attach a small weight or a ball to a string and swing it around in a circle. If the string was to break, the ball would fly off in a straight line but because it is constantly pulled in—as gravity pulls a satellite—it keeps rotating. **Further Resources:** Simple activity to show effect of gravity on planetary motion http://starchild.gsfc.nasa.gov/docs/StarChild/teachers/gravity_effects.html
Materials	**For the classroom** • Timeline poster of Vera Rubin (add to timeline to start lesson) • Rope with tennis ball attached to one end, threaded thru a PVC pipe on the other end. **For each student** • One handout for “Gravity Simulator Sandbox” activity questions (page 2) • One handout for “PhET Sim Gravity and Orbits” activity questions (page 3) **For each group of students** • Computer with internet access for each student group • One handout for “Gravity Simulator Sandbox” data entry (page 1) • One handout for “PhET Sim Gravity and Orbits” data (pages 1 and 2)
Prior Knowledge	Students should have a basic understanding of gravity as it acts on Earth. They will also need to be aware of near-earth objects such as orbiting satellites and the International Space Station. Finally, they should be able to distinguish that satellites/moons orbit planets, planets orbit stars, and stars may be solo or binary and may orbit within a galaxy.
Launch	

Engagement and Communication of Student Expectations	1. Recap: The teacher will open the slide of Zwicky that ended the last lesson. Teacher will recap the story of the search for dark matter thus far. 2. Lesson set: The next slide of Vera Rubin will be shown and teacher will briefly set the stage for today's next chapter of the story. Add Vera Rubin's poster to the timeline. "The next major contribution didn't come about for over 40 years until astronomer Vera Rubin began her study of the rotation of galaxies in the 1970's. Today you will learn how stars orbit within galaxies and how Rubin observed something unusual about the speed of these stars. Her observations led to another key piece of evidence for dark matter." 3. Phenomenon: The teacher will then show the clip on the following slide of the orbiting planets. https://www.youtube.com/watch?v=f6foCDF6zI0 (on unit flash drive) *You may stop after the initial segment of the planets racing around the sun. *Optional: You may wish to continue on in the video clip where it profiles each planet and lists its orbiting speed. You could have students write these down in their notebooks to see the pattern emerge that as planets distance from the star increases, their orbital speed decreases. 4. Questions to consider: Look at the Data for AU (distance from the sun in Astronomical Units), Year length, and Orbital Speed. Why are the inner planets orbiting faster? How may mass effect the orbit? Why do the planets stay in orbit? Can we create orbiting objects (satellites)? What do we need to know to launch a satellite into orbit?
Explore	
Procedure 1	Demonstration to illustrate orbital motion: 1. Thread the empty end of the rope (no tennis ball) through the short length of PVC pipe. Hold the pipe in one hand and slide it within about a foot of the ball. Hold the bottom of the rope with the other hand. Swing the ball in a circle above your head (like a lasso). Have students note how fast the ball

is moving, then slowly let more rope pass through the pipe making the ball spin further from the pipe. Do not change the speed at which you are spinning the ball, however, the ball should slow down.

2. Discuss how this relates to the planets near the star orbit faster than those further out. Discuss the balance of orbital speed and gravitational attraction that need to exist in order for the planet to stay in an orbital path. You could let the momentum or orbital speed of the ball slow to the point that it falls into the star (you) to demonstrate an imbalance.

Gravity Simulator Sandbox:

1. Group students according to the number of available computers.
2. Give each group a handout and discuss terms they may be unfamiliar with.

Open the Gravity simulator Sandbox on the overhead using the embedded link in the PowerPoint. https://www.testtubegames.com/gravity.html

3. Show students the link for "Why do astronauts float in space?"
4. The "Find Out" link is a great place to start as it guides students while they figure out the relationship between gravity and orbits. This can also be used as a demonstration and students can discuss what they see.
5. After completing the "Find Out" activity, if used, direct students to the mission's instructions. Watch out for falling Rocks!!!
   a. Mission 1: using only the up arrow on the keyboard, can you make the astronaut "float"? Describe how you did it.
   b. Mission 2: using only the up arrow on the keyboard, can you keep the rocket and astronaut in orbit? Describe how you did it.
   c. Mission 3: using any combination of arrows to control the rocket, can you put the astronaut in sustained orbit around the earth? Describe how you did it.
   d. Mission 4: using any combination of arrows to control the rocket, can you fly your astronaut to the moon? Describe how you did it.
   e. Mission 5: If you can reach the moon, can you put your rocket in orbit around the moon? Describe how you did it. How is it different from orbit around the earth?
6. Allow 15 minutes for students to do the simulation. As groups finish, they are to pick up enough of page 2 (activity questions) for each student in the group and each complete the questions on the handout.
7. Stop the class after 15 minutes and have various groups explain the needed settings to complete a mission. They can demonstrate on

	the smartboard if time allows. They will learn that there is more than one correct way that will lead to success. 8. Depending upon time available, assign the questions individually as homework so you have time to get to the portion of this lesson on dark matter in the communicate section. 9. Collect sheets the following day as a means of formative assessment or discuss as a class. Teacher Tips: To further encourage students not to blindly try settings without discussion and thought, you may try to further limit the number of attempts per mission or make a friendly competition to see which group can use the fewest number of tries. Encourage students to ask their own questions about the simulation and test their ideas about the questions.
Questions	• In what ways do you need to utilize thrust when putting your astronaut and rocket into orbit? • How does the speed of your rocket compare to the speed of the rocks as they are all orbiting the earth? • What do you have to do to send your rocket to the moon? • To enter lunar (moon) orbit, what do you have to do to the rocket at the end of your flight to the moon? • If the rocket were to orbit Jupiter instead of the moon, what would the engineers have to consider in plotting the orbital path?
Procedure 2	PhET Sim: Gravity and orbits: https://phet.colorado.edu/sims/html/gravity-and-orbits/latest/gravity-and-orbits_en.html 1. Use student groups from Gravity Simulator Sandbox if possible 2. Give each group a handout and discuss any terms they may be unfamiliar with. 3. Guide students to the “Model” link on the site. 4. With this simulator, we want to adjust the mass of the objects in the system and observe what happens to the gravity force, the velocity, and the path.

	5. Using the Sun/Earth system, click the boxes for gravity force, velocity, path, and grid. Press the play button and watch the system for one full orbit of the earth. Note the number of days it takes to complete an orbit. 6. Using the same system, adjust the mass of the planet to 0.5. Notice how this changes the gravity force and velocity vectors, Press the play button, and watch the system. 7. Try the 1.5 and 2.0 masses of the planet and see what results you have for each indicator. 8. Record your observations about changing planet mass before continuing. 9. Run the simulator one time to remind yourself about our initial conditions. 10. Adjust the Sun mass to .5 and run the simulation and see what happens to all the indicators in the system. You may want to zoom out. 11. Try the 1.5 and 2.0 masses for the sun, Record your observations. 12. Explore and answer your own questions, here are some examples: a. You can adjust the velocity of the planet, what changes can you make to create a sustained orbit with a Sun of different masses? b. The Sun is 333,000 times heavier than the Earth. The Earth is 81 times heavier than the Moon. Will the Earth/Moon system respond the same as the Sun/Earth system? c. What happens if you change a mass in the Sun/Earth/Moon system? d. What other questions and wonders do you have about the systems?
Questions	• How does mass change the orbit of system? • How does the difference in mass effect the system? • If you increase the mass of an object, what else must change to keep the object in orbit? • If the distance between two objects in orbit (Sun-Planet) is decreased, what has to happen to keep the objects in orbit? • What, if anything should happen to the velocity of an object in orbit if it is moved further away from the object it is orbiting?
Summarize	

Communicate	Relate concept to dark matter/galaxies: When Vera Rubin observed the rotational speed of galaxies, the speed of the stars was too fast for the amount of observed mass. The stars should have been scattered out into the universe. Demonstration continued: You can return to the rope/tennis ball apparatus to demonstrate the fact that if there were not additional mass (dark matter) holding the outer stars in the galaxy at their present velocity, they would exit the galaxy. You do this by spinning the ball overhead without the PVC pipe and let loose of the rope to allow the ball/star to fly off (choose an empty corner of the room for the ball to fly into). Wrap Up: Show the final slide of Vera Rubin and explain her contribution in studying galaxy rotation curves. Her observations lead to the idea that a huge amount of unseen mass must be holding galaxies together, possibly ten times as much dark mass as can be accounted for by the visible stars. Rubin's results have been confirmed over the subsequent decades and aided in the development of the theory of dark matter.
Terminology and Concepts to Solidify	Gravity: the attraction of an object toward any other object having mass. Orbit: the gravitationally curved path of an object about a point in space resulting in a balance of forward momentum and gravitational attraction Sustained Orbit: an orbiting object remains in orbit without any outside forces or user intervention Velocity: The motion of an object described as a combination of speed and direction Vector: Using an arrow to describe a property where the direction is towards the tip of the arrow, and the size of the arrow is related to the amount of the property Momentum: a property of a moving object determined by an objects mass and its velocity. Concepts: Gravitational attraction keeps a celestial body in orbit around another. The other factor is the forward momentum or speed of the celestial body traveling through space. When these are balanced, the body orbits the central body. If the orbiting body is further from the central body, its gravitational attraction is less, and its momentum will be less to create balance. If the

	orbiting body is closer to the central body, its gravitational attraction is more, and its momentum will be greater to balance it. If it has too much momentum, it will fly off into space. If it has too little momentum, gravity will pull the orbiting body into the central body. When studying why our sun doesn't fly off the arm of the Milky Way galaxy when it is going as fast as it is, we are looking at the possibility of dark matter accounting for the additional gravity needed.
Connection to Big Ideas (Phenomena)	In the exploration of the universe, there are stars that, based upon their speed, should be flying away from the edges of their galaxy and yet they are not. Once again, the theory of dark matter and the gravity that it would assert can help explain this observation. Galaxy rotation and the observations by Vera Rubin provide a key piece of evidence for the theory of Dark Matter. **Return to the bean jar model of the universe.** Ask students what would happen if all the beans started moving as if energized by a power source. How would the motion of one white bean be affected by the presence of the black beans around it?
Follow Up/Practice	Provide links to "Gravity Launch" and the McGraw Hill "Dark Matter Interactive" simulation for students to continue to explore at home. Students should finish questions on page 2 if they are not finished.
Assessment	The questions on the student handout (page 2) will provide the teacher with a formative assessment of their understanding.

Gravity Simulation Sandbox   Names:

Using the simulation found at the link below, complete the "Find Out" activity or follow along with your teacher. After the "Find Out" activity, complete the 5 Missions below. Be sure to describe the things you tried. When you are successful, begin the next mission. Try to complete the mission in as few tries as possibl by carefully considering how you will alter your settings after each unsuccessful attempt. Following the simulation, each of you needs to answer the questions on page 2.

https://www.testtubegames.com/gravity.html

Mission	Using only the up arrow on the keyboard, can you make the astronaut "float"?	Mission	Using any combination of arrows to control the rocket, can you fly your astronaut to the moon?
1	Success? Y/N (observations)	**4**	Success? Y/N (observations)
Mission	Using only the up arrow on the keyboard, can you keep the rocket and astronaut in orbit?	Mission	If you can reach the moon, can you put your rocket in orbit around the moon?
2	Success? Y/N (observations)	**5**	Success? Y/N (observations)

Mission	Using any combination of arrows to control the rocket, can you put the astronaut in sustained orbit around the earth?	**MISSION REPORT:**	
3	Success? Y / N (observations)	Mission 1 = _________tries	
		Mission 2 = _________tries	
		Mission 3 = _________tries	
		Mission 4 = _________tries	
		Mission 5 = _________tries	

Gravity Simulation Sandbox - page 2 Name:_______________

Questions:

1. In what ways do you need to utilize thrust when putting your astronaut and rocket into orbit?

2. How does the speed of your rocket compare to the speed of the rocks as they are all orbiting the earth?

3. What do you have to do to send your rocket to the moon?

4. To enter lunar (moon) orbit, what do you have to do to the rocket at the end of your flight to the moon?

5. If the rocket were to orbit Jupiter instead of the moon, what would the engineers have to consider in plotting the orbital path?

PhET Sim Gravity and Orbits   Names:

Using the simulation found at this link,

https://phet.colorado.edu/sims/html/gravity-and-orbits/latest/gravity-and-orbits_en.html

Go to the ***Model*** link to begin your investigation.

Using this simulator, we will adjust the mass of the objects in the system and observe what happens to the gravity force, the velocity, and the path.

Using the Sun/Earth system, click the boxes for ***gravity force, velocity, path***, and ***grid.*** Press the play button and watch the system for one full orbit of the earth. Note the number of days it takes to complete an orbit. Record your observations on the chart below.

Using the same system, adjust the mass of the planet to .5. Notice how this changes the gravity force and velocity vectors, Press the play button, and watch the system. Record your observations about how the system changes.

Try the 1.5 and 2.0 masses of the planet and see what results you have for each indicator. Record your observations in the chart below.

How does the mass of the planet effect the orbit and the system?

As the mass of the planet increases, the orbit (does this) ____

Check the box on the simulator for each property.

System Sun/Planet	Sun Mass	Planet Mass	Gravity Force (How do the vector arrows change?)	Velocity (How does the vector arrow change?)	Path (How does the orbit change?)	Grid (How big and what shape is the orbit?)
	Our Sun	Earth				
	Our Sun	.5				
	Our Sun	1.5				
	Our Sun	2.0				

Run the simulator one time to remind yourself about our initial conditions. Adjust the Sun mass to .5 and run the simulation and see what happens to all the indicators in the system. You may want to zoom out. Record your observations in the chart below. You can continue to adjust the mass of the Sun but keep the mass of the Earth constant.

How does the mass of the Sun effect the orbit and the system?

As the mass of the Sun increases, the orbit (does this) ______________________________________

System Sun/Planet	Sun Mass	Planet Mass	Gravity Force (How do the vector arrows change?)	Velocity (How does the vector arrow change?)	Path (How does the orbit change?)	Grid (How big and what shape is the orbit?)
Sun/Planet	Our Sun	Earth				
	.5	Earth				
	1.5	Earth				
	2.0	Earth				

Investigate and answer your own questions, here are some examples:

a. The Sun is 333,000 times heavier than the Earth. The Earth is 81 times heavier than the Moon. Will the Earth/Moon system respond the same as the Sun/Earth system? Try it, a data table is provided as a guide.

b. What happens if you change a mass in the Sun/Earth/Moon system? Room for your data is on the data table.

c. You can adjust the **velocity** of the planet, what changes can you make to create a sustained orbit with a Sun of different masses?

d. What other questions and wonders do you have?

System Sun/Planet	Earth Mass	Moon Mass	Gravity Force (How do the vector arrows change?)	Velocity (How does the vector arrow change?)	Path (How does the orbit change?)	Grid (How big and what shape is the orbit?)
Earth/Moon	Earth Mass	Moon mass	Gravity	Velocity	Path	Grid
	Earth	.5				
	Earth	Moon				
	Earth	1.5				
	Earth	2.0				
Earth/Moon	.5 Earth	Moon				
	1.5 Earth	Moon				

	2.0 Earth	Moon				
Sun/Earth/ Moon	Sun Mass	Earth Mass	Gravity	Velocity	Path	Grid
Sun/Earth	Sun Mass	Earth Mass	Gravity	VELOCITY	Path	Grid

PhET Sim Gravity and Orbits   Name: ________________

Questions:

1. How does mass change the orbit of system?

2. How does the difference in mass effect the system?

3. If you increase the mass of an object, what else must change to keep the object in orbit?

4. If the distance between two objects in orbit (Sun-Planet) is decreased, what must happen to keep the objects in orbit?

5. What, if anything should happen to the velocity of an object in orbit if it is moved further away from the object it is orbiting?

Lesson Four – Exploring the Unseen	
Standards, SEPs and Learning Outcomes	Standards: **MSESS1.3:** Analyze and interpret data to determine scale properties of objects. **MSPS1.1:** Develop models to describe the atomic composition of simple molecules and extended structures. Objective: Students will gather, analyze, and interpret data to construct a model of unseen objects. Learning Outcomes: 1. Students will use indirect evidence to explore things that are not able to be seen. 2. They will relate this experience to the work scientists must do to develop theories about things too small, too far away or unable to be seen due to other reasons.
Background Information	For the Black Box Activity: Scientists often have to observe and study surfaces that are impossible or impractical to see directly. Probes have been developed to map surfaces as small as the atom and as big as our universe. Sanford Lab began this study 50 years ago when the lab was the Homestake Mine and Raymond Davis and John Bahcall began probing for neutrinos. It continues today when physicists and geologists work together in their scientific studies. Middle school students will use probes to explore the black box just as the Sanford scientists use their tools to explore subatomic particles. **The Black Box Activity used in this lesson is adapted from one composed by* *Yvonne S. Kao, Anthony Cina, and J. Aura Gimm (Link is no longer active) http://www.nsta.org/publications/news/story.aspx?id=53017* For the 3D graphic representations of the box interior using EXCEL: Students can put their data into a spreadsheet and then turn it into a surface chart or a 3-D image of the inside of the box. Tutorials on how to do this can be found on the unit flash drive. The teacher can then explain how to do this with a demo or, if time allows, even show the tutorial to the students. For "Quarked" website lesson: **This lesson on fundamental particles may be too conceptual for 6th graders. You may want to try it out and select only the portions you feel your students*

	can handle. Another option is to go through the activity together on the overhead and have them fill in the handout as a class. This activity takes students past the model of the atom they may have learned that includes protons, neutrons, and electrons. It is important for students to understand that there are even smaller particles in the structure of matter. This will be necessary for them to understand how scientists are working to detect unseen particles to support the theory of dark matter. There is a document called **"Teacher Tutorial"** that reviews subatomic particles included on the unit flash drive. <u>For the Ray Davis Jr. story:</u> Following the exploration of the "Quarked" website, students will learn the story of Ray Davis Jr. and his early experiments that sought to detect one such type of tiny particle called a neutrino right here in the black hills, deep in the Homestake Goldmine in the 1960s. This story is explained well on the student handout.
Materials	**For the classroom** • Timeline poster of Ray Davis Jr. (add to timeline to start lesson) **For each student:** • "Quarked" handout (Teacher Guide) • "The Problem with the Missing Neutrinos" handout (Teacher Guide) **For each group of students:** • "black box" • "Black Box" handout (Teacher Guide) • 2-3 skewers marked with .5 cm increments • 1 computer with EXCEL and internet access OR 1 baggie of centimeter unit cubes to make a 3-D graph
Prior Knowledge	Students should have a basic understanding that all regular matter (light matter) is made of atoms. Atoms are too small to be seen. Our understanding of the atom comes about through experiments that provide indirect evidence of things unseen. Students may not be familiar with entering data into an excel program and then turning that into a 3D image. Consider showing them the tutorial (on the unit flash drive).
Launch	
Engagement and Communication of Student Expectations	1. Ask students how scientists can study dark matter, or anything that they cannot see? Tell the students they are going to see a clip from the movie "Harry Potter and the Prisoner of Azkaban". They will not

	see Harry but he is in the scene. Ask them to be able to cite three pieces of evidence that suggest Harry is in the scene but not visible to others following the clip: https://www.youtube.com/watch?v=5YP3PWYEyBU (on unit flash drive) 2. Discuss indirect evidence. For example, we can't see air so how do we know when it is there 3. Tell students that they will make a model of something that they can't see and will never actually "see". They will use indirect evidence to create this model. They will then be able to study the invisible world of subatomic particles using a fun website called "Quarked". And finally, they will learn about how scientists' study one of these tiny particles deep underground at Sanford lab in the Black Hills. It will be helpful to let students know that this is a three-period lesson. 4. Show the PowerPoint slide of Ray Davis Jr. as our scientist of the day. Add the poster of Ray Davis Jr. to the timeline. Let the students know that he did his Nobel Prize winning experiment deep in the Homestake Mine (now Sanford Underground Research Facility) here in the Black Hills in the 1960s.
Explore	
Procedure	**Black Box Activity** Encourage students to use observation skills and see what cannot be seen by collecting data and then building a model to visualize that data. It is a great introduction to their journey from small atoms and their subatomic components to the huge universe and its galaxies and the methods scientist use to detect or map what they cannot see. 1. As preparation for this activity, the teacher will assign groups (3 is optimal but 4 is okay) and hand out a task card. Give students a couple of minutes to read over the task card silently (sharing among the group). 2. Have a class discussion about the group norms listed on the task card. Why is it important for everyone to do their best to follow these norms? (If using a science notebook, hand out a copy of the norms to each student to tape or paste into their notebook.) Once all students understand the norms for working in a group, discuss the three roles listed on the task card. Does everyone understand what the responsibilities are for each role? *Data Collectors-* will use probes to test each hole in the black box top and report their readings to the data master. *Data Master -*will collect data onto a data table as the Data Collectors probe the unknown.

Model Maker -will set up and input data into the EXCEL program to create a 3D model, or alternatively, use cubes to make a 3-D map of the inside of the box.

3. Assign each student one of the roles listed on the handout.

Teacher Tip: Having the facilitator (teacher) assign roles will alleviate potential status issues that can lead to students being excluded. See the information in the front matter for the unit for more information and ideas.

3. The teams should work together to develop a procedure that ensures they are gathering accurate measurements. Rows and columns are labeled on the boxes. Some students will count the lines on the skewer that go into the box, some will count the lines remaining outside the top of the box. Later, in group discussion, you can discuss if it makes a difference in the resulting model. Caution students to make sure probes stay perpendicular to lid and do not go into hole sideways. Also, tell students to stop inserting the probe as soon as they feel resistance instead of trying to poke through the object.

4. Once all the students are finished, they can share their 3-D graphs – either EXCEL or with cubes - by doing a gallery walk. Leave the computers at the desks open to the graph and have students rotate to others stations. Then discuss what they see as similarities and differences. What caused the differences in the graphs? *Every box is different but they may see similarities in the patterns.* NOTE: If students count the lines on the skewer that disappear into the box without subtracting from the depth of the box, they will get an inverse graph (a graph of the open space instead of the bottom landscape).

Teacher Tips:

This particular activity may run into day 2 of the unit for a normal period class in order to allow enough time to work on the graphing. The logical stopping point will be at the end of data taking and before graphing, but not all groups may get that far.

Teachers should emphasize that the skewers are sharp and caution should be used only as directed so nobody gets poked.

The students will never see the inside of the box. They must stay sealed. This is science. Scientists will never be able to view dark matter and other particles directly; they must collect indirect evidence and then develop models for what dark matter is and how it behaves.

"Quarked" website activity

1. Once students have agreed there are ways to study the unseen, you will briefly review the unseen atom (proton, neutron and electron) using the PowerPoint slide. Then pose the idea that these particles are made of even smaller particles.

	2. Open the Quarked website and introduce the structure of matter using the tab marked "Subatomic Roadmap". http://www.quarked.org/ The depth to which you go will depend upon time, the level of your students and your level of comfort with the material. (We suggest skipping the Hadron part of the roadmap.) Give each student a "Quarked handout" to fill in as you discuss this top part together *Upon completing the "road map" students can work in their groups. 3. Returning to the website, point out the following areas: **"Game Zone"** including *Matter Mechanic* and *Baryon Blaster* (students will need to use instruction button and hint buttons to play the games), and **"Ask Mr. Marks".** 4. Tell students they are to work in their groups to complete the rest of the handout. They will work together but each record the answers on their own sheet. 5. Allow time for students to complete questions and then explore other games within the site as they wait for other groups to finish. 6. Collect sheets to use a formative assessment. Before leaving the website, discuss the neutrinos discussed in the final question on the handout. **Video clip: How Small is an Atom?** To connect this lesson together with lesson 1, end with this 5 min. video clip https://www.ted.com/talks/just_how_small_is_an_atom. This video will bring together the size of an atom and the nucleus of an atom and be useful in discussion of how dark matter can be detected.
Questions for student exploration	• What are some problems with the way the black box data is collected and how could you improve the data gathering method? • Would you be willing to spend your career as a scientists gathering information about something that you never will see directly? • What features of the fundamental particles make them unique? How do these properties determine how they interact to form matter? • Do you believe dark matter is made of these particles or something else entirely? Please justify your answer with evidence?
Summarize	
Communicate	**Linking subatomic particles to dark matter studies:** 1. Show the second Ray Davis Jr. PowerPoint slide and discuss how he used indirect evidence to detect neutrinos. Give each student a "Problem of the Missing Neutrinos" handout. Have them read the story silently or aloud as a class, pausing to discuss. Encourage them

	to annotate in the margins with their questions and comments. Discuss the story. 2. Read the directions for the take home assignment. If time remains, they may begin or finish these at home to be collected tomorrow.
Terminology and Concepts to Solidify	• <u>Indirect evidence:</u> The use of using observations and data to infer a hypothesis about a concept that is not viewed directly • <u>Sub-atomic particles:</u> a particle smaller than an atom • <u>Protons:</u> a stable subatomic particle occurring in all atomic nuclei, with a positive electric charge • <u>Quarks:</u> any of a number of subatomic particles carrying a fractional electric charge • <u>Neutrons:</u> a subatomic particle of about the same mass as a proton but without an electric charge • <u>Electrons:</u> a stable subatomic particle with a charge of negative electricity, found in all atoms and acting as the primary carrier of electricity in solids. • <u>Leptons:</u> is a category of fundamental particles that include neutrinos, electrons, muons. • <u>Baryons:</u> A baryon is a composite subatomic particle made up of three quarks. Protons and neutrons are baryons.
Connection to Big Ideas (Phenomena)	The study of dark matter is indeed the big idea that we will be exploring. The fact that scientists need to find ways to study the unseen is presented so the students can themselves devise their own methods of using indirect evidence to explain phenomena. **<u>Return to the bean jar model of the universe.</u>** Ask students what are some ingredients/substances in beans. (starch, sugar, even down to cell organelles) Ask students if the white beans and dark beans are made up of the <u>exact</u> same particles? What makes them different? How does this relate to matter?
Follow Up/Practice	The Quarked website link should be provided to students so they can explore it further at home. The writing assignment about the Ray Davis story will be discussed briefly tomorrow.
Assessment	The Quarked handout and the Ray Davis writing assignment will be used as either a formative assessments or as graded assignments.

THE BLACK BOX – "SEEING THE UNSEEN"

In this activity, you will work with teammates and collectively use your observation skills to see what cannot be seen. You will use probes to collect and analyze data and reach conclusions. This may sound strange, but it happens all the time in the real world. Maps are made of the ocean floor using sonic probes that send back depth information, satellites and telescopes are used in space to send back information about celestial objects.

Step 1 – Your teacher will assign you a role within your group; if there are four students in a group there will be 2 Data Collectors.

Data Collectors- will use probes to test each hole in the black box top and report their readings to the data master.

Name: ____

Name: ____

*Data Master -*will collect data onto a data table as the Data Collectors probe the unknown.

Name: ____

*Model Maker -*will set up and input data into the EXCEL program to create a 3D model OR use the cm blocks provided to make a model of the bottom of the box.

Name: ____

Step 2 -Setup

Data collectors must practice collecting measurements with the skewers and decide upon a common method of collecting and reporting measurements.

The data master will make a data table on the back of this paper that is set up like the top of the box with columns and rows so you can put the data numbers in each box as the data collectors call them out.

The model master will set up the EXCEL spreadsheet so they can easily transfer data from the table to the EXCEL program.

Step 3 – Collect, record, and analyze data.

Step 4 – Share your model with the class.

Quarked! http://www.quarked.org **Name:_____________________**

1. **Click on Subatomic Roadmap**

Atoms: Draw / label the parts of the atom.

Matter: Draw the water molecule.

Fundamental Particles: *(skip Hadron box on map)*

Quarks: *Three of them = baryon, which can be a _________ or a neutron *Name the quark types =

Leptons: *_____________, _________________ & ___________= all have a negative charge *___________= no charge / three types

2. **Click on Matter Mechanic in the Game Zone**

Name the required quarks needed to make a proton: _______, _______, _______
Name the required quarks needed to make a neutron: ________, _______, ______

3. **Click on Baryon Blaster in the Game Zone**

Record your score for building 3 protons: ____________

4. **Click on Ask Mr. Marks / All about particles/ Are there other small particles?**

What are the three types or “flavors” of neutrinos?
__________________, ____________________, ______________________
Name two ways in which neutrinos are different from protons and electrons?

Astrophysicists Raymond Davis, Jr. and John N. Bahcall stand beside their neutrino detector in the Homestake mine in the Black Hills of South Dakota in the late 1960s.

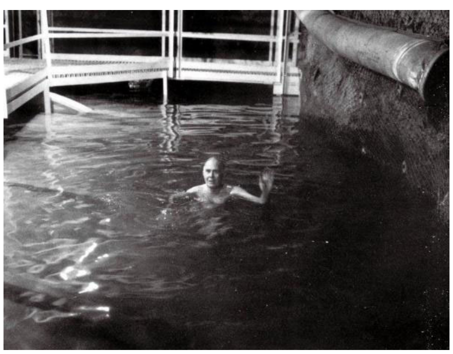
Overview

The **Homestake experiment** (sometimes referred to as the **Davis experiment**) was designed by chemist Dr. Raymond Davis, Jr. in the 1960s. At that time, scientists could measure the energy (in the form of light and heat) reaching the Earth from the Sun. But what is happening in the center of the Sun to make that energy? Scientists had a hypothesis that the high density of matter in the center of the Sun could cause atoms to fuse together into bigger atoms. But how could this be tested? We can't see into the center of the Sun.

Davis's colleague and friend, Dr. John Bahcall, made mathematical calculations of how many neutrinos should be coming from the center of the Sun when the atoms fused together. Dr. Davis figured out how to build a detector to count those 'solar neutrinos', and the Homestake Gold Mine in Lead, SD agreed to let him put his experiment a mile underground.

Once they got the experiment working, they found a problem! Their results were not what they expected. They detected far fewer neutrinos than what Dr. Bahcall had calculated with his theory. What was the explanation? Could the experiment be wrong? Could his model be wrong? This was called the solar neutrino problem. It took more than 20 years to figure out the answer. Read on to find out the solution to "the problem of the missing neutrinos"!

The Experiment



Dr. Ray Davis takes a swim in his cavern. After the tank was sealed the cavern was filled with water to further protect it from stray cosmic rays that make it through the rock.

How did they detect and count the neutrinos? The experiment took place in the Homestake Gold Mine in Lead, South Dakota. Dr. Davis placed a 100,000-gallon tank of perchloroethylene, a common dry-cleaning fluid, deep in a cavern within the mine 4,850 feet deep! It needed to be underground to prevent interference from other particles that bombard the Earth from the Sun called cosmic rays. Cosmic rays consist mostly of a sub-atomic cousin to the electron called a muon. Dr. Davis was the first to realize that if he went deep underground, the rock would act as a shield for almost all those cosmic ray muons. He chose the chemical Perchloroethylene because it is rich in chlorine. When a neutrino traveled through the tank and hit a chlorine atom, it would change it into a different atom, argon, which is a gas. The form of the argon it made is unstable, and slowly decays back to chlorine. But it takes more than 30 days for half the argon to decay away, so they could capture it and count it in that time.

So, every few weeks, Dr. Davis bubbled helium through the tank to collect the argon that had formed. Davis could count these argon atoms to determine how many neutrino collisions had occurred.

The data

Dr. Davis's count of neutrinos was only one-third of the number calculated by Dr. Bahcall. The first response from the scientific community was that one of them had made a mistake. Dr. Bahcall's calculations were checked repeatedly by many other scientists, with no errors found. Dr. Davis kept running his experiment, getting better and better data and eliminating all of the sources of error. He ran the experiment for almost 30 years, and still saw far fewer neutrinos than expected! Finally, everyone had to believe his results.

Conclusions

The solar neutrino problem remained a mystery until decades later. Finally, another theoretical astrophysicist, Dr. Pontocorvo, suggested that perhaps scientists didn't really understand neutrinos. Scientists knew that there were three kinds of neutrinos, but only electron-type neutrinos could be made in the center of the Sun. So that was the type that Dr. Davis had designed his experiment to detect. Dr. Pontocorvo calculated that in some circumstances, electron-type neutrinos could transform into one of the other two types while they traveled through space or matter. Scientists called this transformation changing 'flavor'. (Imagine your parents bought a gallon of vanilla ice cream, but by the time they got home from the store, it was 1/3 chocolate, 1/3 strawberry and only 1/3 vanilla. What if you only liked to eat vanilla ice cream?) That was what was happening for Dr. Davis.

The , Sudbury Neutrino Observatory, SNO for short, in Ontario, Canada was the first detector built to detect all three flavors of neutrinos and solve the solar neutrino problem. They showed that Dr. Bahcall's calculations were correct AND Dr. Davis's experiment was correct. And now we know that neutrinos are a very interesting, special kind of sub-atomic particle. Dr. Davis shared the 2002 Nobel Prize in Physics. He never gave up on his research and technology finally helped answer the question of the "missing neutrinos"!

Homework:

On a new sheet of paper or in your lab notebook, write a three-paragraph summary of this article that follows the following formula. Each paragraph should contain three sentences.

Paragraph 1 – Summarize the accomplishments of Ray Davis and John Bahcall.

Paragraph 2 – Discuss why the experiment was rejected until decades later. Why is this important for young scientists to read?

Paragraph 3 - What is your definition of a neutrino and why do you think are we looking for them deep underground at Sanford Lab?

The Search for Dark Matter – Lesson 4

TEACHER TUTORIAL: Indirect Evidence and Sub-atomic Particles

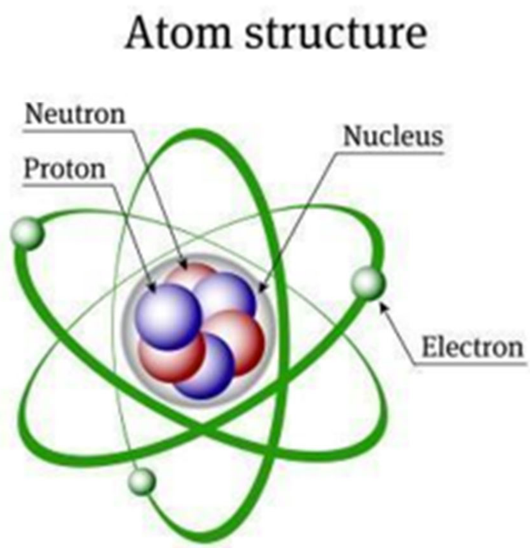
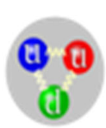


Image from http://sustainablebalance.ca/what-is-nuclear-energy/ (Link no longer active)

Sub-atomic particles:

Fundamental particles are those which cannot be broken down into anything else. They are the building blocks of matter and the things which hold matter together. Particle Physics is the study of the sub-atomic particles and their interactions.

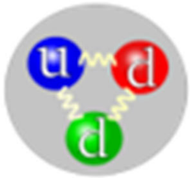
Proton. The proton is a positively charged subatomic particle with an atomic mass of about 1 amu found in the nucleus of the atom along with the neutral neutrons. The number of protons determines the chemical identity of an atom. This property is so important that it is given a special name: the atomic number. Each element in the periodic table has a unique number of protons in its nucleus and, hence, a unique atomic number.



A proton is made up of 3 quarks (2 up quarks and 1 down quark)

Neutron. A neutron has a mass of about 1 amu and no electric charge. It is found in the nuclei of atoms along with protons. The neutron is normally a stable particle in that it can remain unchanged within the nucleus for an infinite period of time. Under some circumstances, however, a neutron can undergo spontaneous decay, breaking apart into a proton and an electron.

The nuclei of all atoms with the exception of the hydrogen-1 isotope contain neutrons. The nuclei of atoms of any one element may contain different numbers of neutrons. For example, the element carbon is made of at least three different kinds of atoms. The nuclei of all three kinds of atoms contain six protons. But some nuclei contain six neutrons, others contain seven neutrons, and still others contain eight neutrons. These forms of an element that contain the same number of protons, but different numbers of neutrons are known as isotopes of the element.



A neutron is made up of 3 quarks (2 down quarks and 1 up quark)

Electron. Electrons are particles carrying a single unit of negative electricity with a mass of about 1/1800 amu, or 0.0055 amu. All atoms contain one or more electrons located in the space outside the atomic nucleus. Electrons are arranged in specific regions of the atom known as energy levels. They can change to a higher energy level if they absorb light or relax to a lower energy level by emitting light. Each type of atom has a unique pattern of light absorption or emission.

Electrons are leptons. Unlike protons and neutrons, they are not thought to consist of any smaller particles but are regarded themselves as elementary particles that cannot be broken down into anything simpler.

*Key Point-All electrical phenomena are caused by the existence or absence of electrons or by their movement through a material.

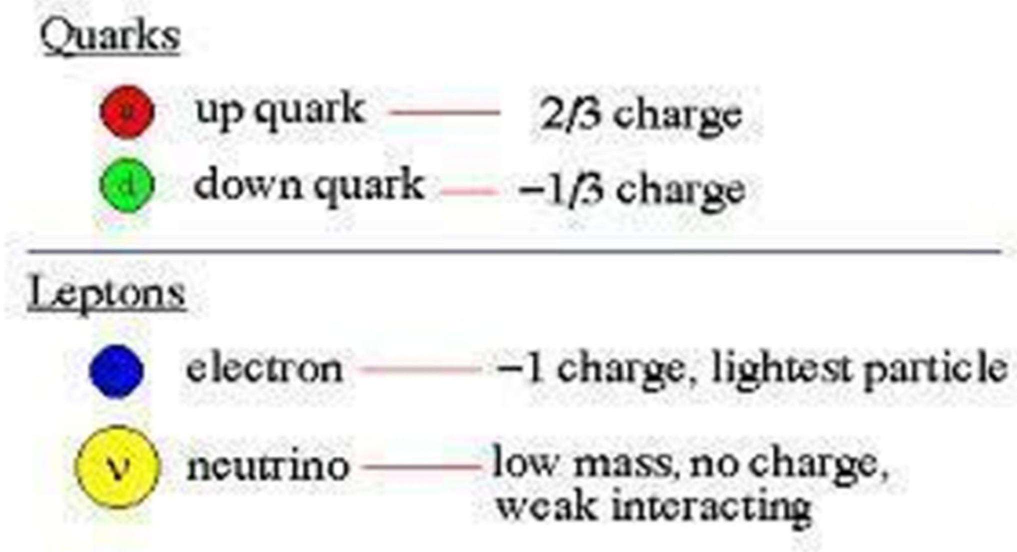
Neutrino. Neutrinos are elusive subatomic particles that are created by some of the most basic physical processes of the universe, for example, decay of radioactive elements and fusion reactions that power the Sun. They were originally hypothesized in 1930 by Swiss physicist Wolfgang Pauli (1900–1958). Pauli was trying to find a way to explain the apparent loss of energy that occurs during certain nuclear reactions.

Neutrinos ("little neutrons") proved very difficult to find in nature, however. They have no electrical charge and very little mass. They rarely interact with other matter. They can penetrate nearly any form of matter by sliding through the empty space within and between atoms. Because of these properties, neutrinos escaped detection for 25 years after Pauli's prediction.

Positron. A positron is a subatomic particle identical in every way to an electron except for its electric charge. It carries a single unit of positive electricity rather than a single unit of negative electricity.

The positron was hypothesized in the late 1900s by English physicist Paul Dirac (1902–1984) and was first observed by American physicist Carl Anderson (1905–1991) in a cosmic ray shower. The positron was the first antiparticle discovered—the first particle that has properties like protons, neutrons, and electrons, but with one property exactly the opposite of them.

Material has been found at
http://www.encyclopedia.com/topic/Subatomic_Particles.aspx



Leptons (do not feel strong force)			Quarks (feel strong force)		
electron	e^-	−1	up	u	+2/3
electron-neutrino	ν_e	0	down	d	−1/3
muon	μ^-	−1	charm	c	+2/3
muon-neutrino	ν_μ	0	strange	s	−1/3
tau	τ^-	−1	top	t	+2/3
tau-neutrino	ν_τ	0	bottom	b	−1/3

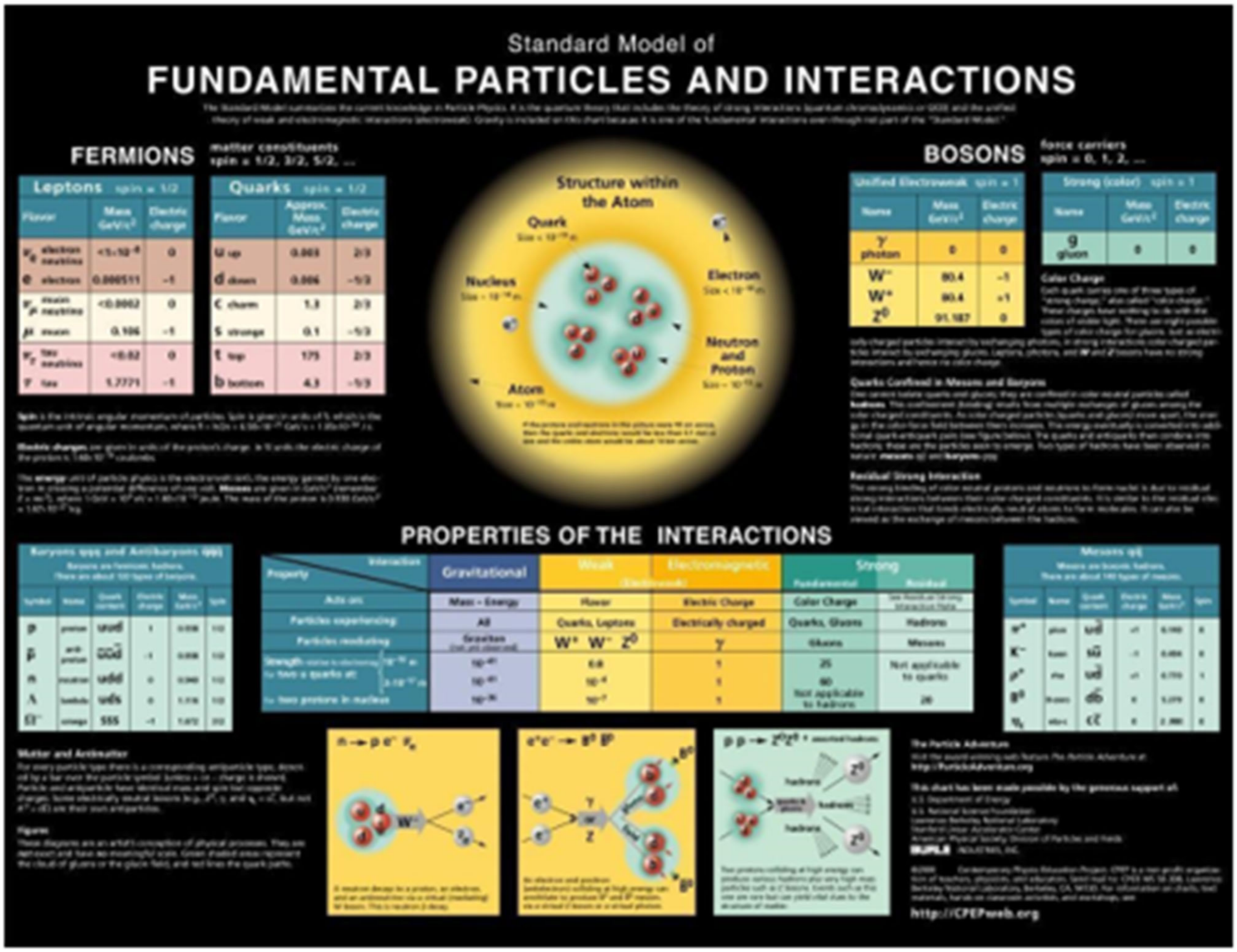
Each lepton and quark has a corresponding antiparticle

Figure 3.

Visit http://www.rothasscience.com/atomic-theory.html for more detail.

The "Quarked" website (.www.quarked.org) has many fun games in addition to those used in Lesson 4.

The Contemporary Physics Education publishes the Fundamental Particles Wallchart, which is included in poster form in the unit materials. If you want to delve deeper into these topics, visit the website that accompanies the poster: www.particleadventure.org.



<table>
<tr><th colspan="2">Lesson Five – Gravity and Light: Evidence of Dark Matter</th></tr>
<tr><td>Standard(s), SEPs and Learning Outcomes</td><td><u>Standards:</u>
MSESS1.2. Develop and use a model to describe the role of gravity in the motions within the galaxies and the solar system.
<u>Objective:</u>
Students will engage in an augment for the presence of dark matter using the evidence of gravitational lensing and observations from galactic collisions.
<u>Learning Outcomes:</u>
• Students will construct arguments from evidence that there is much more matter in the universe that we cannot see than matter that we can.</td></tr>
<tr><td>Background Information</td><td>For an introduction into the concept of dark matter and the history of its discovery see the following resources.
http://imagine.gsfc.nasa.gov/science/objects/dark_matter1.html
To summarize the reasons for the change in the images due to the stemmed glass: The bottom of the wine glass acts as a circular lens and bends the image of the paper underneath. The roundedness of the images is due to the rounded curve of the base, where the middle is thicker than the outside. Because light travels at a different speed through glass compared to air, it bends whenever it encounters glass, and thicker glass bends light for a longer period of time. Similarly, gravitational lensing acts like a circular lens bending the light of stars that are behind it. More massive objects exert a stronger force, causing a more pronounced bend in light. Astronomers search the sky to try to find locations where galaxies and stars are bent into such a curved/circular image.
<u>Dark Matter NOVA video</u> (5 minutes) for end of lesson is on unit flash drive</td></tr>
<tr><td>Materials</td><td>For the classroom
• Timeline poster of Albert Einstein (add to timeline to start lesson)
For each small group (3 optimal)
• Plastic cup with penny glued to the inside bottom
• Graduated cylinder
• Numbered Water goblets - stemmed
• Laminated Graph Paper
• Laminated galaxy map
• Laminated photo of the Abell galaxy cluster with gravitational lensing</td></tr>
</table>

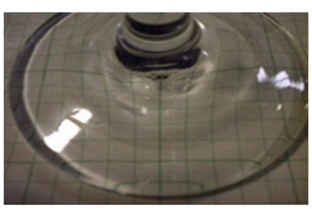
<table>
<tr><td>Prior Knowledge</td><td>Students have learned in earlier lessons that as electrons drop to an inner orbit, they give off energy as a photon of light. Remind students that this photon can act as a particle, like a tiny “package” of light.

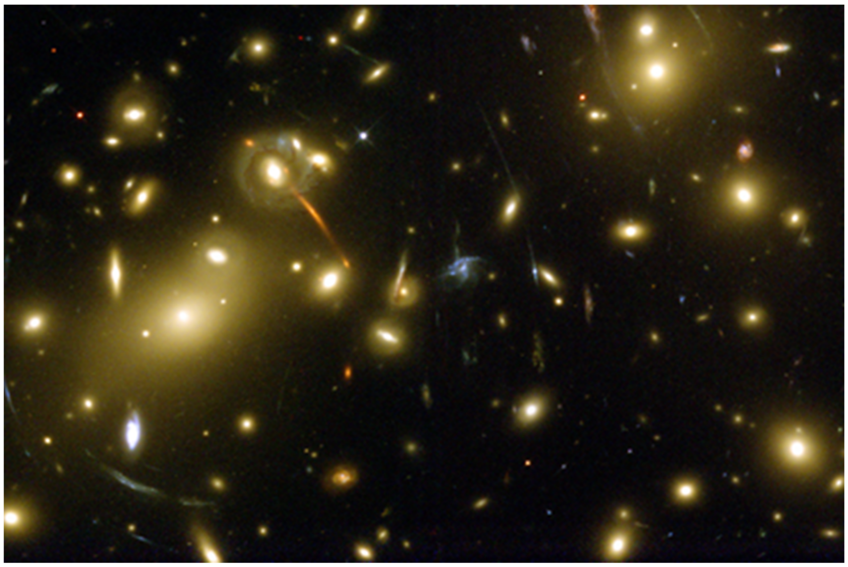
They also learned about the effect of gravitational attraction on particles, including particles (photons) of light.</td></tr>
<tr><td colspan="2">Launch</td></tr>
<tr><td>Engagement and Communication of Student Expectations</td><td>1. Introduce today’s lesson by showing the slide of Albert Einstein and adding his poster to the timeline. Tell students that “In the early 20th century, German physicist Albert Einstein (1879-1955) became one of the most famous scientists ever after proposing a new way of looking at the universe that went beyond current understanding. Einstein suggested that the laws of physics are the same throughout the universe, that the speed of light is constant in a vacuum, and that space and time are linked in an entity known as space-time, which is distorted by gravity.” (Excerpt from space.com)
2. Therefore, since today’s lesson is about light, review the idea of refraction of light by showing the students a clear plastic or glass cup of water with a pencil or straw in it. From the side it looks as if the pencil is bent as the light reflecting off the pencil has to pass through the water as well as the glass.

(Instructions for Penny Activity)
1. Place students into groups of 3.
2. Give each group a cup with a penny and a graduated cylinder. Students will need a source of water. Each group should send one student to fill the graduated cylinder to the 25 ml line with water.

Teacher Tip: If students are not familiar with how to read volume in a graduated cylinder, there is a review slide in the PowerPoint.

3. Instruct one member of the group to place the cup with the penny on the edge of the table and stand beside it, looking into the cup at the penny.
4. That student is to then back up slowly, keeping their eye on the penny until they can no longer see the penny over the edge of the cup.
5. Their partner will slowly pour the water into the penny cup until the water bends the light enough so that the student can again see the penny.
6. Record how much water is remaining in the graduated cylinder and subtract to get the amount poured into the cup.
7. Students will switch roles and repeat with the other students in the group.
8. The group will compare the volume of water required for each student and discuss why more water is needed to bend the light for some students than others.</td></tr>
</table>

	Questions/Discussion for Penny Activity • Did you and your partners have the same data? If so, why? If not, why not? • What made it possible for the penny to come into view again? • What observations about the penny did you make as the water was added? 3. Next begin a discussion about how gravity can also bend light in the way the water did. This will be a foreign concept for students. Explain to them that they can think about light as a packet of energy called a photon traveling in a wave. If light is traveling through space, it will go in a straight line unless it encounters an object. But what do students think happens when it runs into objects in space? Will it go through, go around, or get stopped? 4. Fabric of Time and Space video: This video gives students a good idea of how the fabric of time and space could work to explain gravity in a new way; on flash drive or at https://www.youtube.com/watch?v=MTY1Kje0yLg
Explore	
Procedure	**Instructions for Observing Gravitational Lensing in a Water Goblet** Students can stay working in their groups of three. Give each group a water goblet, or two depending upon your number of groups, a sheet of laminated graph paper and a laminated photo of the picture of the star/galaxy map. 1. First, have students place a water goblet on top of the graph paper. 2. Ask students to look through the base of the goblet and slowly slide the glass across the paper. Discuss what the students are seeing. (The graph lines that are closer to the center of the base will bend more than the lines that are near the edge of the base. 3. Now that they know what to look for, have them replace the graph paper with a printout of a star/galaxy map. Move the glass around and watch the stars/galaxies bend and curve. Have them swap glasses with other groups and try it again.  4. Ask students to write the numbers of the goblets in their notebooks and to describe the features of the goblet and how the distortion compares to the other goblets. They also will draw the shapes that the goblets create as it passes over the galaxy to show its distortion.

	5. Continue passing the goblets until students have recorded data and drawings for 3-4 goblets. The teacher will pass out a Hubble Deep Space Image of clusters of galaxies that show lensing effects. Students will pick out lensing effects and compare them to their drawings in their notebook. Are there different effects they couldn't make with their goblets? **Model of gravitational lensing using glass -  -Image from Hubble Telescope
Questions for student exploration	• Into how many different shapes can you make the galaxies on your chart distort? • Does it matter how thick the glass is? • What features of the glass cause the most distortion? Why?
Summarize	
Communicate	1. After discussing the questions above, the teacher will discuss what possible explanations there can be for the distortion of light coming from distant galaxies. 2.The teacher will then shift to the Nova "Science Now" video clip that talks about the bullet cluster, yet another piece of evidence for dark matter. Dark Matter NOVA video for end of lesson:(5 minutes) on flash drive. 3. To wrap up the lesson, finish the PowerPoint slides for lesson 5 that summarize all the evidence for dark matter, ending with the Bullet Cluster.
Terminology and Concepts to Solidify	Refraction: the bending of a wave when it enters a medium where its speed is different. Since light is a wave, light refracts when crossing a boundary such as between water and air.

	Gravitational Lensing: Massive objects can cause a warp in the "fabric" of space, bending light and distorting the images we see with telescopes.
Connection to Big Ideas (Phenomena)	Dark matter could explain the mass that causes the warping responsible for gravitational lensing images. **Return to the bean jar model of the universe.** Ask the students if there is anything about the bean jar model that correlates to today's lesson. The answer is no because, although the beans do have a gravitational pull on one another, they are too small to have enough gravity to bend light. Models are limited.
Follow Up/Practice	Have students weigh in on their current opinion about whether Dark Matter exists. Have them write a paragraph discussing their reasons for supporting the existence of Dark Matter or their reasons for believing it doesn't exist. Encourage them to list specific evidence to support their thinking.
Assessment	The opinion paragraphs will give the teacher a formative assessment to see if students are understanding the Dark Matter studies thus far. The class could set up in teams and debate the question if time allows.

Lesson Six – Going Deep for Dark Matter: The LUX Detector at SURF	
Standard(s), SEPs and Learning Outcomes	Standards: **MSESS1.2** Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system. **MSPS1.4** Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. **MSPS3.4** Engage in argument from evidence to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object. Objective:

	Throughout the unit, students have been obtaining evidence for dark matter. In this lesson they will be evaluating and communicating how their ideas of the universe has changed since the pre-assessment. <u>Learning Outcomes:</u> 1. Students will explain how the LUX detector at Sanford lab is gathering evidence for the theory of dark matter. 2. Students will demonstrate their new understanding of the universe on the post-assessment.
Background Information	The LUX detector in Sanford Underground Research Facility collected data over a period of approximately 300 days. The data is currently being analyzed to see if there were any collisions of WIMPs, the theoretical particles of dark matter with the Xenon in the detector. WIMP stands for weakly interacting massive particles. Efforts are underway to build a new detector that is 5 times larger called the LZ detector (LUX/Zepplin).
Materials	**For the classroom** • LUX Tag game teacher instructions • Videoconference setup to have a session with the underground scientists (optional) **For each student** • Post Assessment (Teacher Guide) • Colored pencils • One game placard on lanyard • Flashlight (if student has a Xenon placard)
Prior Knowledge	The terms and concepts learned throughout the unit will be recalled and communicated by the students.
Launch	
Engagement and Communication of Student Expectations	1. Using the timeline of scientists, review the story of the evolution of the theory of Dark Matter. Add the slide of the Sanford scientists and explain that today, we will see how all this indirect evidence is being used to detect Dark Matter particles deep underground at Sanford. Today's lesson will explain how they are going about this detection. 2. Discuss what we know about dark matter using PowerPoint slides.
Explore	

Procedure	1. Watch this Science Friday episode about the LUX detector, on the unit flash drive or at: https://www.youtube.com/watch?v=YxMGWQMoR10 Teacher Tip: If you set up a videoconference session with the underground you will shorten the video and possibly skip the LUX Detector TAG game. A good stopping point on the video at 11:21 minutes. Otherwise, you can watch it in its entirety (17.19 minutes) Teacher Tip: If you watch the whole video clip, point out that since this was made the LUX data has been gathered and is currently being analyzed. A larger version of the LUX called the LUX-Zeppelin is being constructed. 2. Show the PowerPoint slide that has an animation of the LUX detector simulation and go through it several times, explaining each step. Point out the Xe atoms, the Wimps, the photomultiplier tubes (at the top and bottom) that catch the light signals given off by the collision. Explain that WIMPS aren't the only particles to pass through the detector. Radioactive decay of the parts making up the detector itself give off particles that set off collision signals as do particles called Muons (recall from lesson 4). The scientist needs to analyze the light signals to see what collisions created them to rule out these stray particles. This process is ongoing at Sanford Underground Research Facility. 3. LUX Detector TAG game. (read teacher direction document) - Give each of your students a placard card to hang around their neck. Explain that they are particles within the LUX detector. Show the slide that explains what the particles are and how they interact. Go to an open area and have the Xenon particles spread out at least an arm's length apart and close their eyes. They hold the flashlight and when they touch a particle, they flash the light to indicate a collision. The D (ground and detector radiation particles) and M (cosmic ray muons) can be touched by the Xenon arms but the WIMP can only count as a collision if it bumps into the body of a Xenon as it doesn't react electrically with the arms(electrons). NOTE – Particles passing through walk quickly and in a straight line. 4. Bring students back and collect supplies. Discuss the interactions and possibly tally the total collisions. Tell the Xe students that there were times the WIMP didn't even enter the detector (see teacher instruction document). Teacher Tips: The Xenon cannot move their feet, only wave their arms. The other particle must pass through the detector in a straight line, no dodging. Once they are through the detector, they can go through the opposite direction. No running, just slow or fast walks.
Questions for student exploration	• Xenon is a gas at room temperature. Why do scientists cool down the xenon to very low temperatures for this experiment?

	• If these massive, neutral particles are traveling through everything then why are they not detected in some way?
Summarize	
Communicate	Take a mental trip through the last couple of weeks and highlight what was learned in each lesson – briefly. Ask questions of students as you go along: • What indirect evidence is there to give us clues about dark matter? • What was your biggest surprise as we have studied dark matter these last few weeks? • What do you believe is the most important work being done at Sanford Lab? • What are some possibilities that could result if dark matter were to be discovered there?
Terminology and Concepts to Solidify	A **Weakly Interacting Massive Particle (WIMP)** is a theoretical particle with no electric charge and approximately as much mass as 100 protons. Many scientists believe that it is the most likely candidate for the dark matter in the universe.
Connection to Big Ideas (Phenomena)	The search for dark matter has been an idea in the making for decades. Now, as evidence becomes clearer, a detector located at the Sanford Underground Research Facility - as well as other detectors around the world - stands on the brink of detecting WIMPs, dark matter particles.
Follow Up/Practice	Students will review their notes and worksheets from the unit in order prepare for tomorrow's post assessment. Show the PowerPoint slide with the Rubric that will be used on the post assessment, so student know the expectations of them.
Assessment	The post assessment will be given tomorrow.

NAME ________________________________

The Search for Dark Matter
Post-Assessment

#1

Use this page to draw a model of the universe with labels and explanations. Include everything you think you know about the universe. (No resources are to be used during this assessment.)

#2

“The jar of beans represents the ratio of light to dark matter in our universe.”

Justify this claim using the evidence regarding dark matter.

#3

If you were a scientist trying to discover dark matter, how would you go about it?

RUBRIC FOR PRE & POST ASSESSMENT
The Search for Dark Matter

Name:_________________

	3 pts.	2 pts.	1 pts.	Score	Comments
Use of terminology *Question #1	Most terms are used appropriately to show meaning	Some of the terms are used appropriately to show meaning	Few terms are used and/or are used incorrectly		
Visuals *Question #1	Drawing shows an understanding of the scope of the universe	Drawing shows components outside the solar system.	Drawing is limited to our solar system		
Atomic particles *Questions 1,2&3	Particles broken down to the sub-atomic level	Particles are at the level of individual atoms	No reference to atoms		
The Role of Gravity *Questions 2&3	Evidence of gravitational interactions are included as well	Evidence of gravitational interactions are included	Gravity not referenced		

	as reference to orbital evidence				
Dark Matter *Questions 2&3	At least 2 examples of evidence are included, and the tools used are discussed.	At least 1 example of evidence is included, and the tools used are discussed.	Inaccurate evidence or not well explained		

The Search for Dark Matter A Refurbishment Inventory

Lesson	*Quantity*	*Item*
All	1	Facilitator Binder w/ USB
	3	Shipping Tote
	1	Jar of Beans
	1	Timeline Posters
Lesson 1	1	Clothesline
	30	Clothespins
	200	Index Cards
	Set of 3	Laminated Timeline Cards
Lesson 2	3	Power supply for gas tubes
	7	Gas Tubes
	15	Spectrum Cards
	1	Pair of Gloves
	1	Small Tote Box for Tubes
	30	Diffraction Grating
	1	Candle
	1	CuSo4 (CopperII Sulfate)
	1	Wire Loop
	1	Safety Glasses
	1	Tbsp Measure
	1	Beaker
	15	Colored Pencils
	15	Spectroscopes
Lesson 3	1	Tennis Ball/PVC/Rope
Lesson 4	10	Black Boxes
	20	Bamboo Skewers
	10	cm Blocks (packs of 150)
	1	Particle Poster (Laminated)

Lesson 5	2	Tote Box for Goblets
	10	Small Stemmed Water Goblets
	10	Graph Paper (Laminated)
	10	Map of Galaxies (Laminated)
	10	Abell Galaxy Cluster (Laminated)
	10	Plastic Cup w/ Penny
	10	Graduated Cylinder
Lesson 6	1	LUX Tag Game – Instructions
	30	LUX Game Placards
	11	Flashlights
	1	WIMP Shirt

The Search for Dark Matter B Refurbishment Inventory

Lesson	*Quantity*	*Item*
All	1	Facilitator Binder w/ USB
	3	Shipping Tote
Lesson 1	1	Jar of Beans
	1	Timeline Posters (set of 9)
	1	Clothesline
	24	Clothespins
	200	Index Cards
	1	Timeline Cards (Laminated, set of 3)
Lesson 2	3	Power Supply for gas tubes
	7	Gas Tubes
	1	Gloves
	1	Small Tote for Tubes
	24	Diffraction Grating
	1	Candle
	1	CuSo4 (CopperII Sulfate)
	1	Wire Loop
	1	Safety Glasses
	1	Tbsp Measure
	1	Beaker
	12	Colored Pencils
	12	Spectroscope
	12	Spectrum Cards
Lesson 3	1	Tennis Ball/PVC/Rope
Lesson 4	8	cm Cubes (set of 150)
	8	Black Boxes
	16	Bamboo Skewers

	1	Particle Poster (Laminated)
Lesson 5	8	Small Stemmed Water Goblets
	8	Grids (Laminated)
	8	Map of Galaxies (Laminated)
	8	Abell Galaxy Cluster (Laminated)
	8	Plastic Cup w/ Penny
	8	Graduated Cylinder
Lesson 6	1	LUX Tag Game – Instructions
	23	LUX Game Placards
	10	Flashlights
	1	WIMP Shirt

The Search for Dark Matter C Refurbishment Inventory

Lesson	*Quantity*	*Item*
All	1	Facilitator Binder w/ USB
	2	Shipping Tote
	1	Jar of Beans
	1	Timeline Posters
Lesson 1	1	Clothesline
	18	Clothespins
	200	Index Cards
	1	Timeline Cards (Laminated)
Lesson 2	3	Power Supply for Gas Tubes
	7	Gas Tubes
	1	Gloves
	1	Small Tote for Tubes
	18	Diffraction Grating
	1	Candle
	1	CuSo4 (CopperII Sulfate)
	1	Wire Loop
	1	Safety Glasses
	1	Tbsp Measure
	1	Beaker
	9	Colored Pencils
	9	Spectroscopes
Lesson 3	1	Tennis Ball/PVC/Rope
Lesson 4	6	Unit Cubes (Bag of 150)
	6	Black Boxes
	12	Bamboo Skewers

	1	Particle Poster (Laminated)
Lesson 5	1	Tote Box for Goblets
	6	Small Stemmed Water Goblets
	6	Map of Galaxies (Laminated)
	6	Abell Galaxy Cluster (Laminated)
	6	Plastic Cup w/ Penny
	6	Graduated Cylinder
Lesson 6	1	LUX Tag Game- Instructions
	18	LUX Game Placards
	8	Flashlights
	1	WIMP Shirt

NOTICE: THE HEADER/FOOTER AND REVISION HISTORY OF THIS ATTACHMENT IS NOT INCLUDED IN THE PRINTED DELIVERABLE.ANY BLANK PAGES ARE LEFT SO INTENTIONALLY.

Revision History

Rev	Date	Section	Paragraph	Summary of Change	Authorized by
01	2/27/2024	NA	NA	Initial Release	CCR 911