ACTIVE ACCRETION—An Active Learning Game on Solar System Origins

In *Active Accretion*, middle school students model the accretion of specks of matter in our early solar system into chondrules and asteroids—and they do it dynamically. *Active Accretion* is a great way to teach cool science concepts about our solar system's early formation and the development of asteroids and planets while burning off energy. Students will end by discussing the strengths and limits of their model.

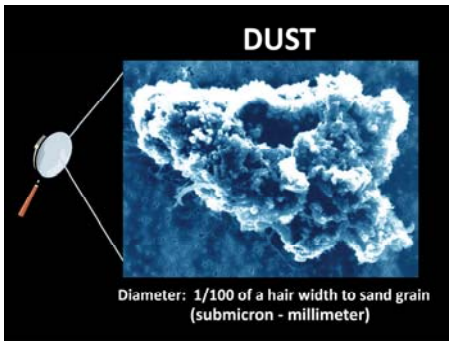
Introduction

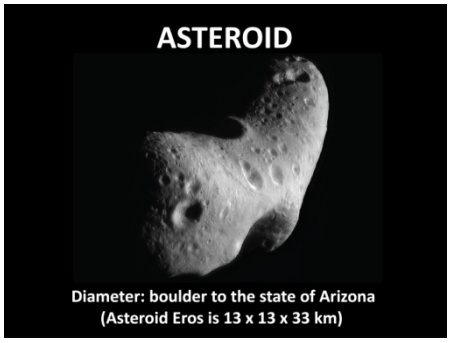
Ask students how they think bodies in the solar system formed.

Explain that they will be watching a short music video that shows the diversity of bodies that make up the solar system.

- Show the *Space School Musical* clip, "Planetary Posse." (http://discovery.nasa.gov/musical/)
- Questions to elicit student ideas:
  - How did this music video expand your thinking about the solar system?
  - What did you learn?
  - How do you think these diverse bodies—planets, asteroids—came to be?

Explain that scientists think that our solar system was a big cloud of gas and dust in the beginning of its formation. Some event made it begin to spin, and it eventually spun down into a disk of matter swirling around a massive, glowing center, our protosun (think of it as a baby Sun).





Sample Student Role Cards

TIP!
Who's seen dust in your home? Who's seen the dust clump into those dust bunnies that skitter under the bed or in the corner? Similar to what it was like in the early solar system, the dust particles "accrete" – or gather together.

As material moved around the protosun, dust grains in the disk collided with each other and started sticking together to form larger rocks. These rocks in turn collided with other rocks and either gravity held them together or they broke into smaller pieces, depending on the kind of collision and the relative gravity of the individual rocks. **Over the next few million years, these rocks combined into larger and larger bodies and eventually formed the planets and other large bodies we have today.** Evidence of these collisions is seen on the surface of the planetary bodies, including asteroids, in the form of craters left by the impacts.

In today's activity, we will actively model one theory that describes how scientists think asteroids and planets formed: **Accretion.**

The Activity

SETTING: A large open area, such as a gym or playground, where students can run.

MATERIALS:
Student Role Cards:

- *Dust* cards for each child, half that number of *Chondrules*, a quarter of that for the number of *Meteoroids,* and an eighth of that for *Asteroids*. (32, 16, 4, 2 for example)
- Video Clip "Asteroids" from *Space School Musical*
- Computer(s) with Internet for *Alien Earth* computer interactive option.

DIRECTIONS:
Similar to "tag," the goal is to tag as many students as you can as the game progresses. Learn how dust particles accrete to form chondrules, which accrete into meteoroids, which accrete to form asteroids!

When you tag a person, link arms and keep orbiting, gathering dust particles, chondrules, etc., until you are large enough to form an asteroid.

- **Distribute Dust Cards** to each student
  - All students will represent **dust** at the start of the game.
  - Have one student (or teacher/parent) be the Sun. Have that person stand in the middle of a circle of students
    - Dust particles will be orbiting the Sun!

- Students **gather** close to the center for directions.
  - The dust particles will jog (not run) in a circular path around the "Sun," which is in the center of the large open area—playground, gym, etc.
    - Counter-clockwise—as all planets and asteroids move about the Sun!
  - As they jog, students should keep their arms to their sides until they come close to another student.

- **Spread out** so that the ring is large enough for safe orbiting.
  - If one dust particle tags another, they form a pair and can now extend their arms in order to tag other dust particles.

  - Allow this to continue for several minutes and then **call time**.

- **Explain** that the students who are paired up are called **chondrules**.

- **Exchange** the Dust cards for a new "chondrule" card, one for each pair of students.
  - Have the kids do another round
  - When the chondrules tag the dust particles (one or more) the group will stay together and can try to tag others.

- **Play** a second round. After a few more minutes, **call time**.
  - At this point, students will notice that there are groups of various sizes…some dust, some chondrules, and some even larger!
  - Student groups of 4-10 are called **meteoroids**.

Chondrules accreting into a meteoroid

- **Exchange** as before, including changing the chondrule cards for a new "meteoroid" card.
  - Note meteoroids have a large size range!

- **Play** a third round
  - For student groups of 11 or more kids are called **asteroids**.

- ***Give*** a new "asteroid" sign to each of the student groups of 11 or more. As they tag the chondrules or dust particles, they form much larger clusters.
  - The asteroid that forms the largest cluster after the allotted time can be designated "Ceres," the largest asteroid, while the second can be designated "Vesta." These are the targets of NASA's Dawn mission.
    - Repeat the game and see if the results change.
    - Review the explanation and ask students the follow-up questions.

FOR DISCUSSION DURING ACCRETION!

What force causes these small dust particles to come together?

- Allow student responses. Many may say 'gravity.' While gravity is the force that holds the dust particles in orbit around the Sun, explain that these small dust particles do not have enough mass for the force of gravity to cause them to come together.

What other forces cause things to stick together?

- Know how socks stick to the inside of the dryer or how a balloon sometimes sticks to the wall? We call this static electricity. In the case of interstellar dust particles, we call the forces electrostatic. *Electrostatic forces are the cause of accretion until the particles are massive enough for gravity to cause attraction.*

Discussion/Explanation Following the Game

Chondrules (spherical drops of once molten or partially molten minerals)***:***

- are considered the building blocks of the planets.
- provide very good information on the earliest history of the solar system.

Meteoroids:

- are solid objects traveling around the Sun in a variety of orbits and at various velocities, ranging in size from small pebbles to large boulders.
- some cluster in streams called meteor showers that are associated with a parent comet.
- have various compositions and densities, ranging from fragile snowball-like objects to nickel-iron dense rocks.
- most burn up when they enter Earth's atmosphere.

Small Asteroids:

- are 4.5 billion years old, as old as the solar system.
- some are made up of chondrules and other material that holds them together.
- have many variations, due partly to differences in the number, size, shape, and varying mineral content of the chondrules, and where they were formed in the solar system (close to the hot Sun, far from the Sun?).

Cheerful left-over dust particle

Scientists think that asteroids formed by accretion of these dust particles in the solar nebula, the disk of gas and dust that rotated in a flattish disk shape around the early Sun. Just as in our game, dust particles accreted (came together) into larger and larger bodies: chondrules, then small rocks, and then protoplanets and planets. **Wow!**

Post-Activity Discussion Questions:

"How could dust become a rock?"
This excellent question arose during classroom trials. One way to think about this is for students to consider the tremendous amount of time involved in solar system formation. Over thousands and thousands of years, billions of dust particles eventually form into tiny grains like sand, then into little pebbles, and so forth.

1. What happened to the student dust particles at the beginning of the game?
2. How did the student chondrules interact with the student dust particles? Was the movement of the two students the same or different?
3. What happened when there were asteroids? Was the movement of the two students *after the interaction* the same or different? Was the movement of student dust particles the same as that of the student chondrules?
4. What did you notice about the dust particles at the end of the activity?

Wiped out dust particle

Wrap-up:

- How is the model different than the real thing?
  (In the activity dust (students) moved faster in an attempt to "catch" smaller objects. In reality the dust particles clump together because of electrostatic attractions and do not move faster in order to clump together. Similarly, large clumps were attracted to like and unlike dust grains in order to form planetesimals due to gravity.)
- Why are models and simulations useful?
  (While not completely accurate, physical models are useful to better understand processes that happened in the past that are not observable now.)
- What questions do you have?

ASTEROIDS! EXTENSION ACTIVITIES

1. Space School Musical, "The Asteroid Gang"

What comes to mind when you hear the term "asteroid?"

- In classroom trials, fifth grade students said, "large rocks that orbit the Sun," "meteor shower", or "comet."

How have asteroids been depicted in movies and TV?

- Students may refer to films like *Star Wars*, where asteroids are violent or hazards that spacecraft must maneuver through.
- Explain that in the asteroid belt today, these bodies are very far apart and that NASA mission spacecraft like Dawn can fly safely through the belt without worrying about maneuvering to safety, rarely coming within even hundreds of kilometers of another body of any size.

Show the *Space School Musical* clip, "The Asteroid Gang." Then ask students:

- How does this music video expand your thinking about asteroids? What did you learn?
- What do you like about the video?
- What does this asteroid gang model about asteroids that seems accurate?
- What does the asteroid gang model about asteroids that might not be accurate?

The Asteroid Gang from *Space School Musical*

2. ALIEN EARTH'S COMPUTER ACTIVITY

In *Active Accretion*, what would happen if another large group of (maybe 100) students, which might represent a large planet like Jupiter, entered the circular path where the students have been jogging?

Show this website, as a demo to start, and then allowing students to explore in pairs:
http://www.alienearths.org/online/starandplanetformation/planetfamilies.php

- The interactive is ideal if student can play the interactive in pairs after a demonstration.

- Place several small bodies onto the screen. Have students generate a list of questions they would like to ask about how these bodies move through space.
- Place Jupiter in the mix and allow students to observe what happens. What force would explain this?
- What other combinations of planets would students like to try?

Compare the virtual simulation with the physical modeling.

- How are they similar? How are they different?
- How are both of these different than the real thing?
- Why are models and simulations useful?
- What questions do students have?

3. What's the Difference Between a Meteoroid, Meteor, and Meteorite?

Have students complete a word association.

- On a piece of paper, have students write down the first thing that comes to their mind when they hear the term "meteorite."
- Don't give students much time to think about it, just have them record their first impression.
- Have students listen to the jingle for meteorite found at: http://discovery.nasa.gov/multimedia/jingles.cfml
- Ask students to revise their first impressions based on what they heard.
- Repeat this procedure for Meteor and Meteoroid.
- Ask students to use what they learned in the jingle to make a cartoon that tells a story and shows all three terms being used.

Standards Addressed

Grades 5-8

Earth in the Solar System

- The Earth is the third planet from the Sun in a system that includes the moon, the Sun, other planets and their moons, and smaller objects, such as asteroids and comets.
- Most objects in the solar system are in regular and predictable motion.
- Gravity is the force that keeps planets in orbit around the Sun and governs the rest of the motion in the solar system.

Grades 9-12

The Origin and Evolution of the Earth System

- The Sun, the Earth, and the rest of the solar system formed from the solar nebula – a vast cloud of dust and gas – 4.6 billion years ago.

Grades K-12

Evidence, Models, and Explanation

- Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power.

Active Accretion: Additional Teacher Background

Modern Solar System Origin Theory

The current *Condensation Theory of Solar System Formation** was the brain child of French philosopher Rene Descartes, who lived in the 17th century. In the 18th century, Pierre Simon de Laplace revised this theory. Both of these early astronomers based their theories on a disk-shaped solar nebula that formed when a large cloud of interstellar gas contracted and flattened under the influence of its own gravity. In the modern theory, interstellar dust is composed of microscopic grain particles that:

- are thin, flat flakes or needles about 10^{-5} m across;
- are composed of silicates, carbon, aluminum, magnesium, iron, oxygen, and ices;
- have a density of 10^{-6} interstellar dust particles/m^3.

In **Active Accretion**, these interstellar dust grains are simply referred to as 'dust.' There is some evidence that interstellar dust forms from interstellar gas. Interstellar gas, the matter ejected from the cool outer layers of old stars, is 90 percent molecular hydrogen (H_2) and 9 percent helium (He). The remaining 1 percent is a mixture of heavier elements, including carbon, oxygen, silicon, magnesium and iron. The interstellar dust from which the planets and asteroids formed was that mixture of heavier elements. The hydrogen and helium from the nebula was involved in the formation of our infant Sun and are its major components today.

According to the *Condensation Theory*, the formation of planets in our solar system involved three steps, with the differentiation between planet and asteroid formation being a part of the second step.

Step 1: Planetesimals form by ***"sticky collision" accretion***

During this phase of formation, dust grains formed ***condensation nuclei*** around which matter began to accumulate. This vital step accelerated the critical process of forming the first small clumps of matter, which then start to **collide** with each other at **low velocities.** The particles eventually stick together through **electrostatic forces**, forming larger aggregates of similar types of constituents. Over a period of a few million years, further collisions make more compact aggregates and form clumps a few hundred kilometers across. At the end of this first stage, the solar system contained millions of ***planetesimals***—objects the size of small moons, having gravitational fields just strong enough to affect their neighbors.

Step 2: Planetary embryos/cores form by ***gravitational accretion***

The loose, granular structure of planetesimals formed in Step 1 made it possible for them to continue to

- form more massive bodies through **collisional coagulation** of "nebular dustballs" and
- prevent these small objects from bouncing off by absorbing the object's energy during collision.

The more mass the planetesimals accumulated, the greater their ***gravitational attraction*** would be for surrounding objects of all sizes—from dust grains to small planetesimals—until kilometer-sized planetesimals would collide with objects made up of several planetesimals. The result would be that these large planetesimals that were loose aggregates with differing compositions. This ***gravitational accretion*** led to protoplanet formation.

As the protoplanets grew, their strong gravitational fields began to produce many ***high-speed*** collisions between planetesimals and protoplanets. These collisions led to ***fragmentation***, as small objects broke into still smaller chunks, most of which were then swept up by the protoplanets, as they grew increasingly large. A relatively small number of 10-km to 100-km fragments escaped capture to become the asteroids and/or comets.

Step 3: Planetary development

When the early asteroids were fully formed, the gas and dust continued to form planetesimals. The system of embryos in the inner solar system becomes unstable and the embryos started to collide with each other, forming the ***terrestrial planets*** over a period of 10^7 to 10^8 years. The largest accumulations of planetesimals became the planets and their principal moons.

In the third phase of planetary development, the four largest protoplanets swept up large amounts of gas from the solar nebula to form what would ultimately become the ***jovian planets*** (gas giants). The smaller, inner protoplanets never reached that point, and as a result their masses remained relatively low.

***** Often called the *modern* theory, the *Condensation Theory of Solar System Formation* built on the oldest of evolutionary models, the *Nebular Contraction Theory*.

Additional Resources

Concept adapted for NASA's Discovery Program from the Lesson 10: Building Blocks of Planets Activity C: "Crunch! Accretion of Chondrules and Asteroids" activity from *Exploring Meteorite Mysteries*
http://ares.jsc.nasa.gov/Education/Activities/ExpMetMys/ExpmetMys.htm

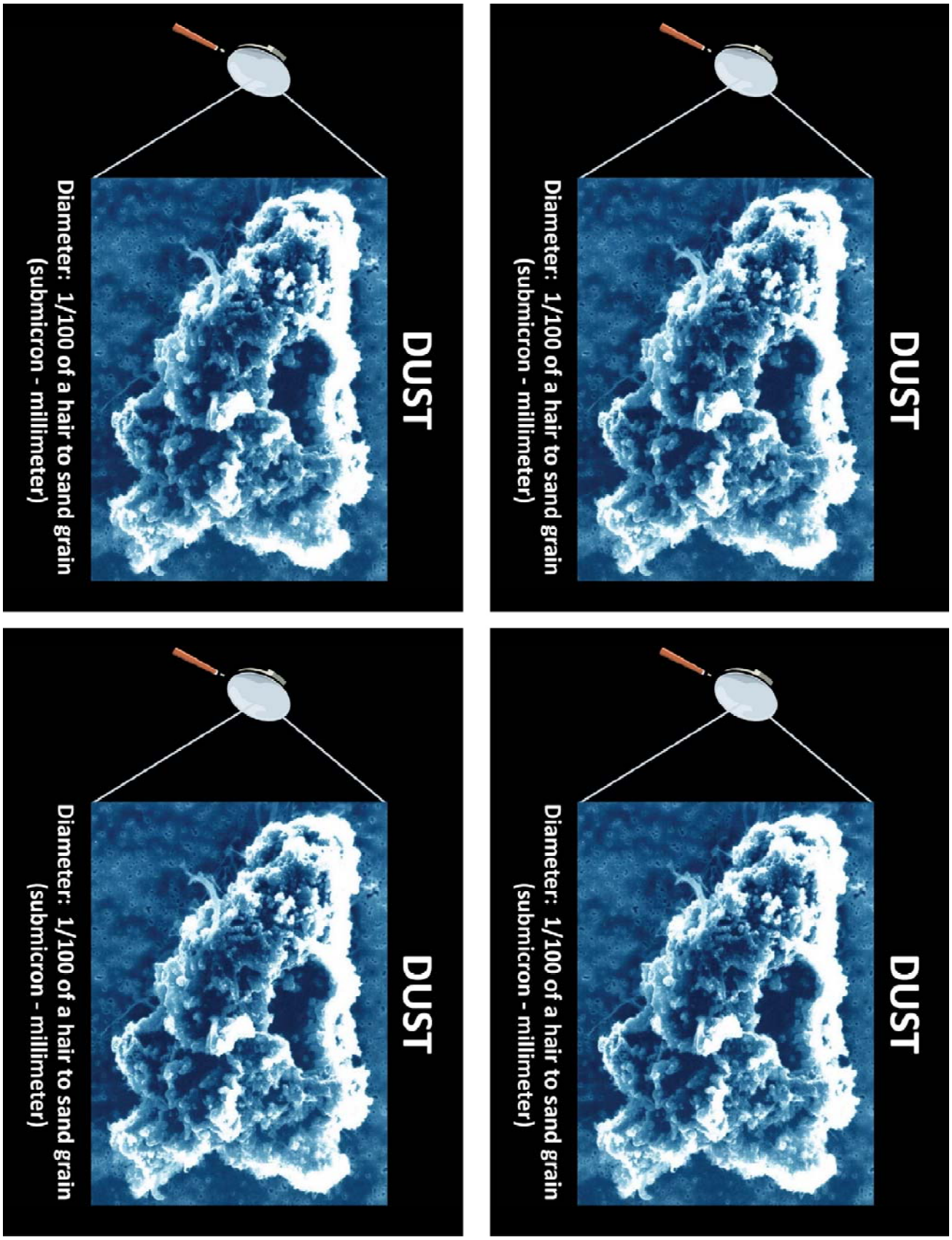
Chaisson, E., and McMillan, S. (2008). *Astronomy today*. San Francisco: Pearson Addison Wesley.

Hahn, J. (2005). When giants roamed. *Nature,* 435, 432–433. doi:10.1038/435432a

Laboratory for Atmospheric and Space Physics. *How planets form.* Retrieved from http://lasp.colorado.edu/education/outerplanets/solsys_planets.php

Morbidelli, A., Bottke, W. F., Nesvorny, D., & Levison, H. F. (2009). Asteroids were born big. *Icarus*, 204, 558–573.

Peebles, C. (2000). *Asteroids: A history*. Washington, DC: Smithsonian Institution Press.


DUST
Diameter: 1/100 of a hair to sand grain
(submicron - millimeter)
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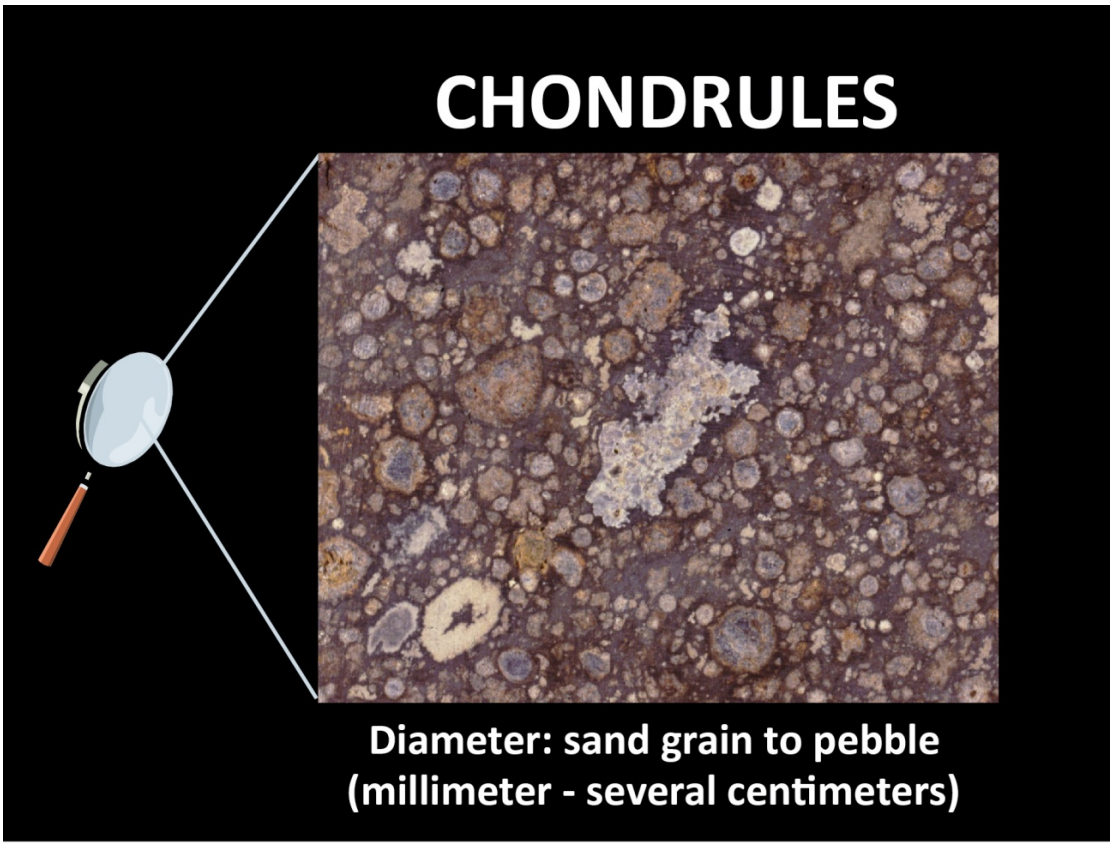
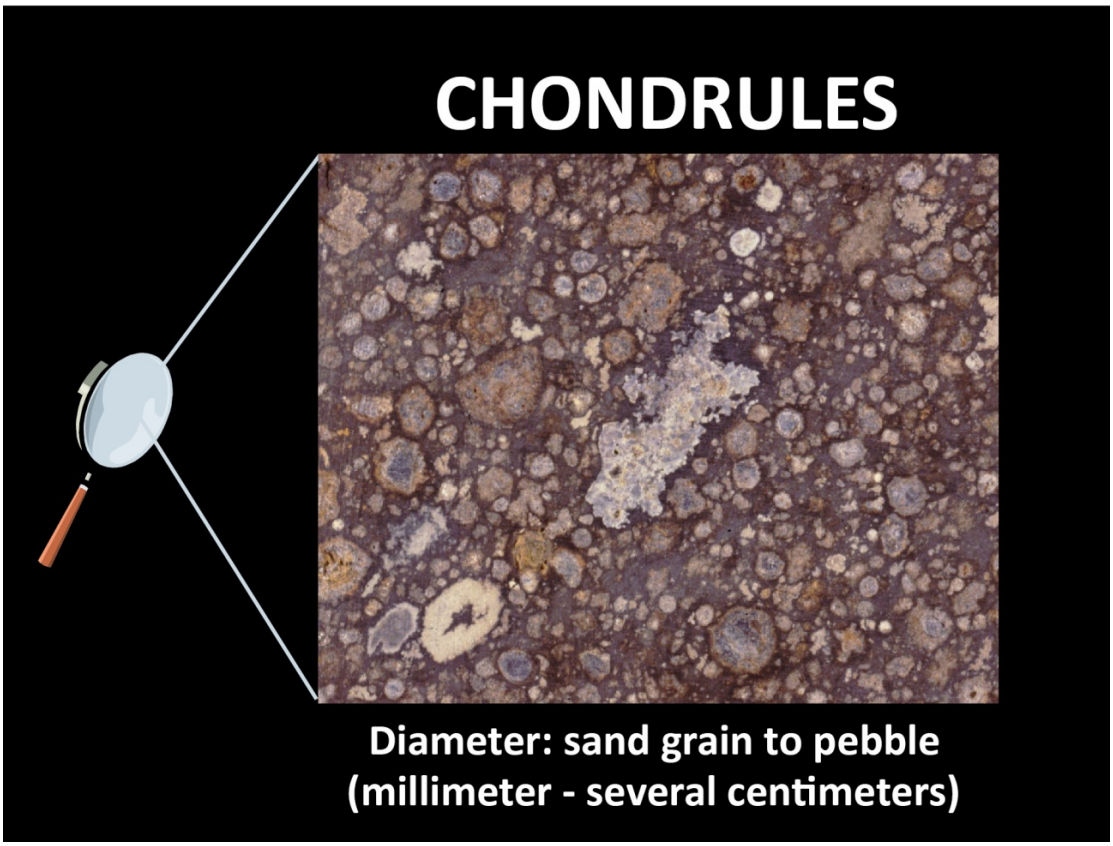
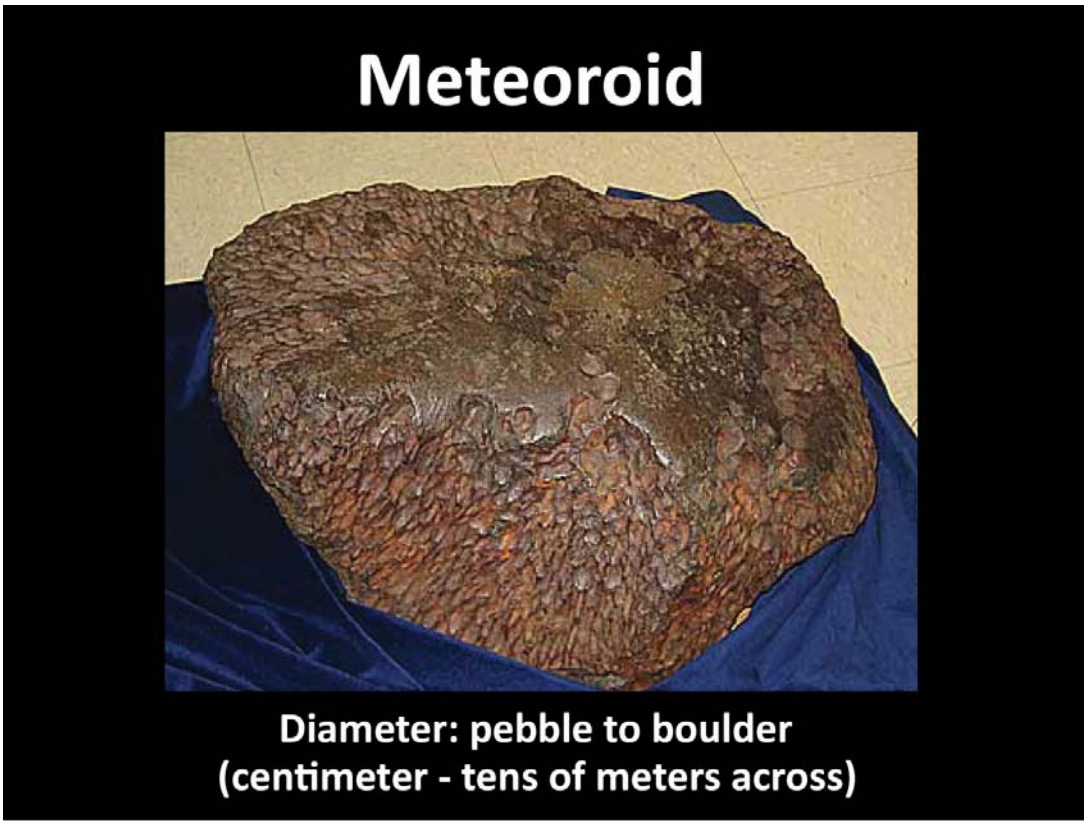
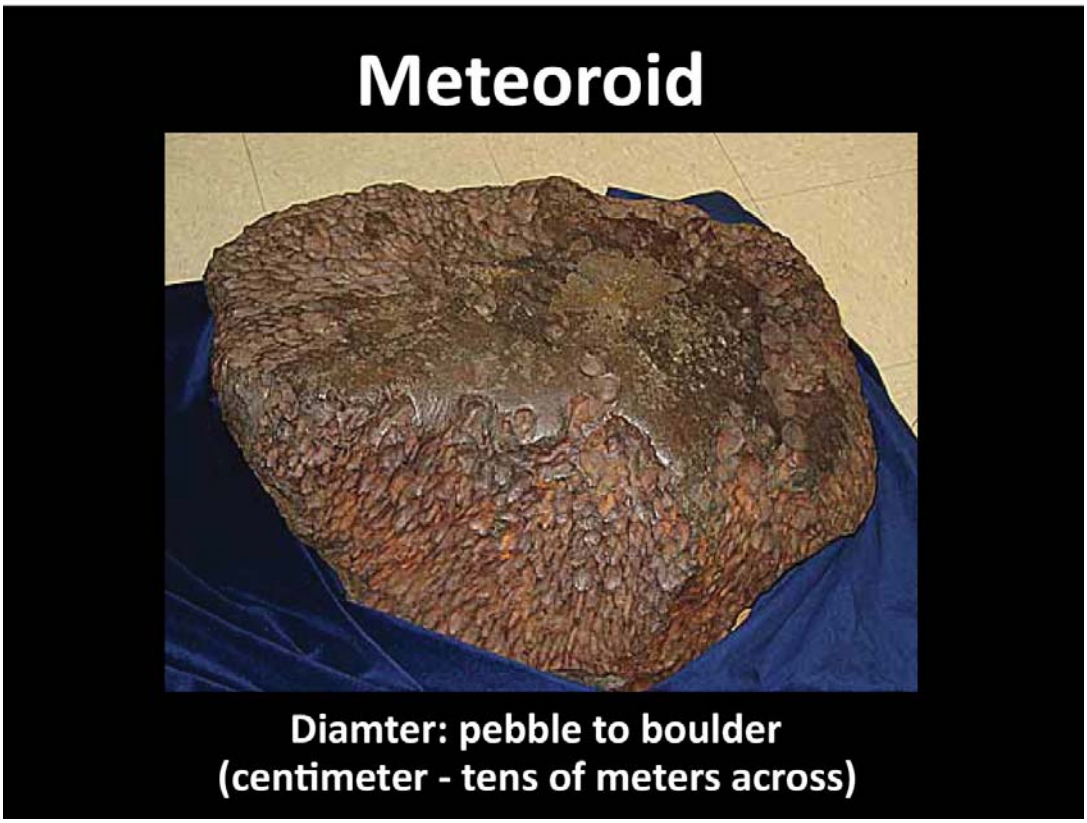
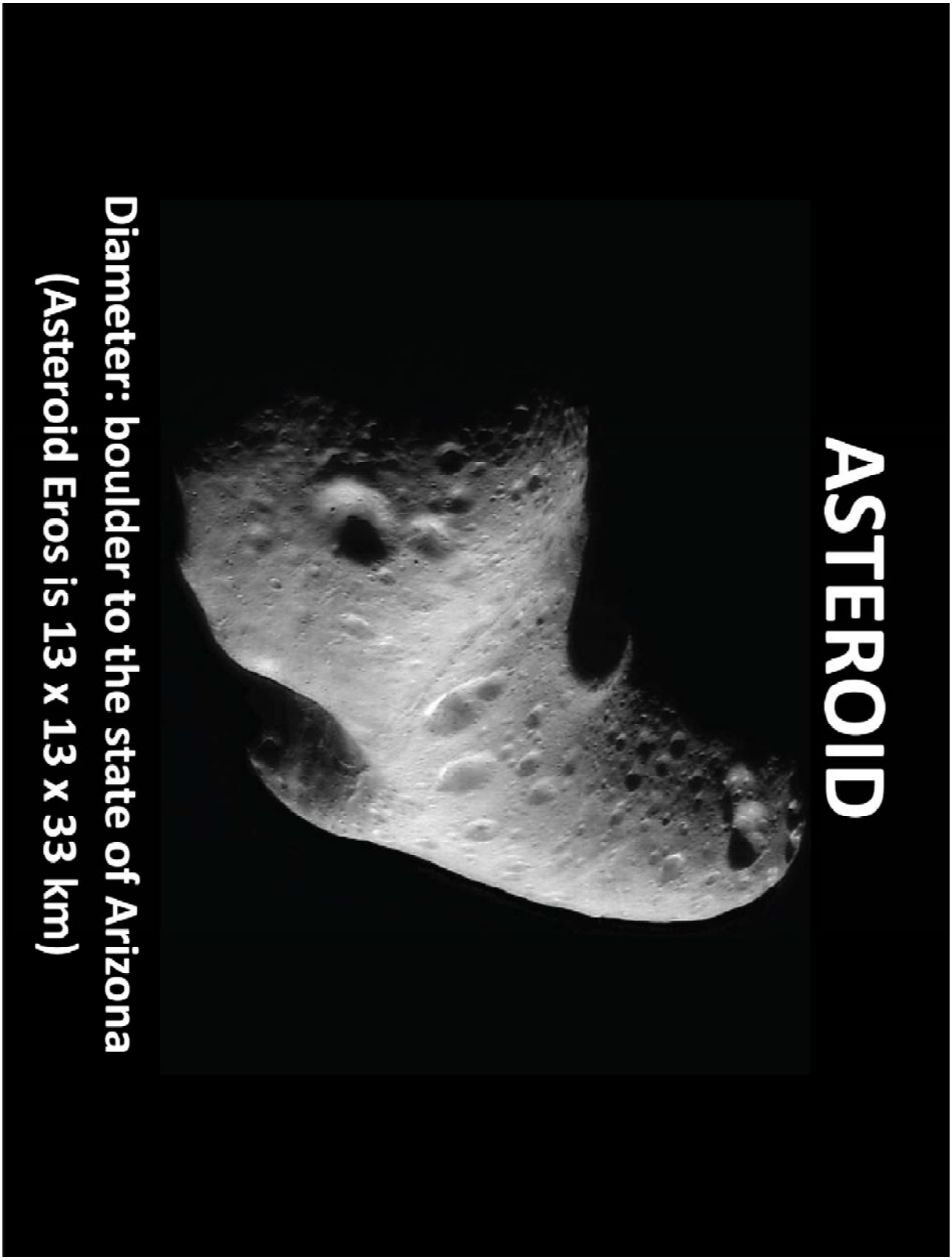

CHONDRULES
Diameter: sand grain to pebble
(millimeter - several centimeters)


CHONDRULES
Diameter: sand grain to pebble
(millimeter - several centimeters)


Meteoroid
Diameter: pebble to boulder
(centimeter - tens of meters across)


Meteoroid
Diamter: pebble to boulder
(centimeter - tens of meters across)


ASTEROID
Diameter: boulder to the state of Arizona
(Asteroid Eros is 13 x 13 x 33 km)