Impacts & Craters
ASTR 1010

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Overview:
In this activity you will calculate crater sizes and environmental factors caused by impacts – meteoroids and comets. You will also determine if you could detect a potential impactor and how much time you would have before it hits the Earth.

Objectives:
After completing this activity, students will be able to:
• Calculate the radius of an impactor based on the crater left behind on the surface of Earth and other Solar System bodies.
• Investigate the effects of impacts at various distances from the impact site.
• Calculate the magnitude and distance of a potential impactor to determine if it can be detected from Earth before it arrives.

Definitions
Here are some terms from lecture that we will be using today in lab:

• **Meteoroid**: a small particle from a comet or asteroid orbiting the Sun.

• **Meteor**: a meteoroid that has entered and burned up in an atmosphere – aka 'Shooting Star'

• **Meteorite**: a meteoroid that has survived its trip through an atmosphere and has landed on the surface of a planet or moon.

• **Period of Heavy Bombardment**: first billion or so years after the formation of the Solar System where leftover fragments of formation impacted upon the surfaces of the major bodies in the Solar System.

• **Albedo**: a measurement of the amount of light reflected from the surface of a celestial object. Ranges from a value of 0 (no light reflected) to 1 (all light reflected).

• **Apparent Magnitude (m)**: how bright an object appears from our vantage point here on Earth. Depends on the object's luminosity AND distance from us.

• **Absolute Magnitude (M)**: how bright a star would appear from a fixed distance of 10 parsecs. Depends only on object's luminosity.

• **Astronomical Unit (AU)**: mean distance between the Sun and the Earth. 1 AU = 1.5x10 8 km

Part 1. Crater Diameter vs. Impactor Size

Several factors are involved in obtaining a reasonable estimate of impactor radius. These include the diameter of the crater (**D**), density of the impacted surface (**ρ_p**), the density of the impactor (**ρ_m**), the gravitational acceleration of the body being impacted (**g_p**), and the velocity of the impactor (**v**). Combined, you end up with an equation that looks like this:

$$R = \frac{(0.401) D^{1.28} \rho_p^{0.42} g_p^{0.28}}{\rho_m^{0.42} v^{0.56}}$$ (from de Pater and Lissaur 2001)

Fear not, let's simply things! Let's assume that sedimentary rock is being impacted by a dense rock projectile coming in at a 45-degree angle at 30 kilometers per second (Note. keep these parameters in mind, you will need them later). This will simplify our equation to:

$$R = 2.26 \times 10^{-3} \times D^{1.28} \text{ (Equation 1: for Earth)}$$
$$R = 1.49 \times 10^{-3} \times D^{1.28} \text{ (Equation 2: for the Moon)}$$
$$R = 1.73 \times 10^{-3} \times D^{1.28} \text{ (Equation 3: for Mercury)}$$

In our simplified equations, **D** (diameter of the crater) and **R** (radius of impactor) will be in units of <u>meters</u>. With our equations simplified and our reminder about <u>converting units</u>, it's time to calculate impactor sizes!

1)Barringer Crater in Arizona is a well-preserved impact from around 50,000 years ago. It has a diameter of 1200 m. Use Equation 1 to calculate the radius of the impactor in meters.

R = 2.26 × 10^-3 × (1200m)^1.28 = 19.745 m

2)Now assume a much larger impactor that leaves a diameter of 40 km! Calculate the radius of the impactor in meters using Equation 1. Next convert your answer to both km and meters.

R = 2.26 × 10^-3 × (40000m)^1.28 = 1756.89 m. 1756.89 m / 1000 = 1.75689 km

3)Going back in time 66 million years, the infamous “K-T extinction” event which killed off all the large dinosaurs, was likely caused by an impactor. Located on the Yucatán Peninsula, the Chicxulub crater has a diameter of 180,000 m. Using Equation 1, how big was the impactor in km?

R = 2.26 × 10^-3 × (180000m)^1.28 = 12,046.399 m. 12,046.399 m / 1000 = 12.046399 km.

4)One of the most prominent craters on the Moon is Copernicus. With a crater diameter of 95,000 m, how large of an impactor (in km) was required to create Copernicus?

R = 1.49 × 10^-3 × (95000m)^1.28 = 3,504.87 m. 3,504.87 m / 1000 = 3.50487 km

5)Using the crater size of left by the Chicxulub crater (diameter = 180,000 m) and Equation 2, how large of an impactor (in km) would have to had to hit the Moon to make the same sized crater?

R = 1.49 × 10^-3 × (180000m)^1.28 = 7942.094951 m. 7942.094951 m / 1000 = 7.942094951 km

6)Comparing the impactor sizes from Questions 3 and 5, do you need a larger impactor on Earth or the Moon to make the same sized crater? *Why do you think that is?* Hint: consider that Mercury’s mass is 0.055 that of Earth (so 5.5% only). The Moon’s mass is 0.0123 that of Earth.

The larger impactor on Earth is needed to make the same sized creater than the Moon ’ s impactor because it has a larger impactor of 12.05 km, compared to Moon ’ s 7.94 km. This might be because of Earth ’ s stroger gravity compared to the Moon ’ s and the atmosphere.

7)Using Equation 3, how large of an impactor (in km) was needed to create the Caloris Basin on Mercury, which has a diameter of 1550 <u>km</u>! FYI: in comparison, the width of Georgia is 370 km.

R = 1.73 × 10^-3 × (1550000km)^1.28 = 145101.0906 m. 145101.0906 m / 1000 = 145.1010906 km.

Part 2. Effects of an Impact

Now that you have calculated impactor sizes, you are ready to investigate just how destructive such impacts can be. Depending on the size of the impactor, damage could vary between a hole in a roof to a global extinction event. For Part 2 of this activity, we will focus on the immediate environmental effects using an impact simulator you can find here:

https://impact.ese.ic.ac.uk/ImpactEarth/ImpactEffects/

This website runs a computer simulation detailing results from an impact at a particular distance away from an impact site on Earth's surface. We will use the following **parameter**:

• Distance from impact: 25 miles – this is about the distance from Atlanta to Kennesaw
• Projectile Diameter: 3514 meters
• Projectile Density: Choose "3000 kg/m^3 for dense rock" from drop down menu
• Impact Velocity: 30 km/s
• Impact Angle (in degrees): 45
• Target Type: Select 'Sedimentary Rock'

Hint: make sure to keep track of your units! Again, distance from impact is in miles, not km.

The resulting page will list the following information: Your inputs, energy, major global changes, crater dimensions (which will be different than our calculation due to the more accurate nature of the simulator), thermal radiation, seismic effects, ejecta (debris excavated during the impact is deposited on the Earth's surface), and air blast. Note: If you get an error in your output, double check the units of your input values or ask your TA for help.

8)What do you think would happen to most living organisms? How soon does this happen after impact?

Thermal radiation would living organisms within 2.09 s, causing 3rd degree burns. The shockwave on the Richter Scale with 9.2 magnitude would collapse buildings and cause landslides, hurting more living organisms. Ejecta and air blast would also have a large impact.

9)What is the Richter Scale magnitude of the earthquake from this impact? What is the worst effect listed by the Mercalli Scale Intensity? How soon does this occur after impact?

The earthquake ' s RIchter Scale magnitude from impact is 9.2. The worst effect lised by the Mercalli Scale Intensity is " Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air. " , which happens 8.05 seconds after

10) How deep is the ejecta (listed as thickness) at your location? What is your position relative to the ejecta deposit?

The ejecta is listed as 235 meters. The position relative to the ejecta deposit is beneath.

11) What is the sound intensity of the air blast and when will it arrive? List one consequence of this.

The air blasts ’ s sound intensity is 148 dB 2.03 seconds after impact. One consequence is “ Multistory steel-framed office-type buildings will suffer extreme frame distortion, incipient collapse. ”

Now, press the back button on your browser. Keeping everything as is, let us move from a distance of 250 miles, which is approximately the distance between Atlanta and Savannah.

12) Now that you are farther away, what differences do you notice? Would Savannah be much a much safer location?

Savannah is comparatively safer but still faces intense effects. Some differences between the two locations are: thermal radiation, seismic effect ’ s timing, ejecta ’ s timing, thickness, and mean fragment diameter, and air blast ’ s timing, wind velocity, and sound intensity.

13) Finally, let us consider Miami, FL which is about 660 miles away. What are the major differences between being in Miami during the impact event and basically anywhere in GA?

Some of the major differnces between Miami and GA are: thermal radiation, seismic effect ’ s timing, ejecta ’ s timing, thickness, and fragment diameter, and air blast ’ s timing, peak overpressure, wind velocity, and sound intensity.

Part 3. Impact Prevention

For the final part of this activity we will do some simple calculations to determine if we could see an object impactor. The absolute brightness of an impactor (asteroid or comet) is determined by its diameter and its albedo (how well it reflects light). The darkest asteroids have an albedo of 0.05 and the absolute magnitude (M) can be estimated by the following equation:

$$M = -5 \ x \ log(2R) + 34 \quad \text{(Equation 4)}$$

Where **R** is the <u>radius</u> of the impactor in meters.

14) What is the absolute magnitude of the impactor we used in the simulator?

Using the first simulation ’ s radius of 11.25 miles: M = -5 x log(2(11.25 miles)) + 34 = 27.24 miles.

NASA has a Center for Near Earth Object Studies that is constantly monitoring and determining the likelihood of any potential impacts. A typical telescope that monitors such “hazards” has an aperture size of about 1 meter. These telescopes can detect objects down to an apparent magnitude (**m**) of about 20. The following equation allows you to calculate the distance to the object given **m** and **M**:

$$d = 10^{(m-M)/10} \text{ (Equation 5)}$$

15) Calculate the distance in astronomical units (AU) at which the asteroid can be detected by a 1-meter telescope. Let **m** = 20 and use the **M** value calculated in the previous question.

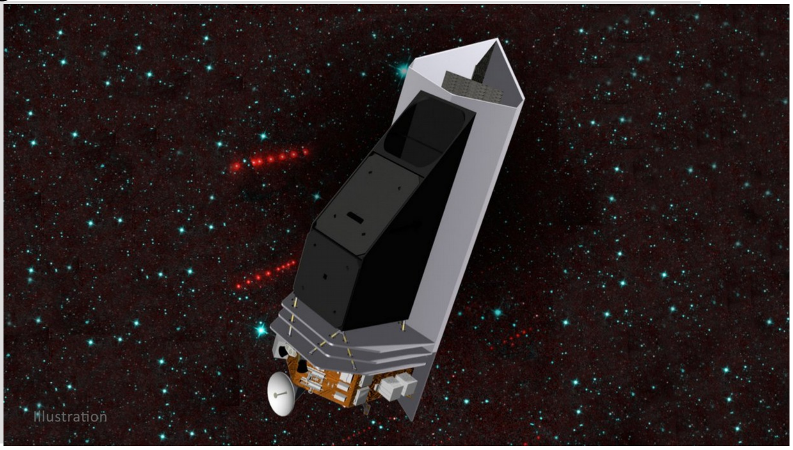
d = 10^((20 - 27.24)/10) = 0.1889 miles.

16) How long would it take for this object to hit Earth if it were on a crash course from the distance you just calculated? Assume that the impactor is traveling 30 km/s, and remember that 1 AU = 150,000,000 km. Give your answer in years. Hint: recall that time = distance / velocity. Show your work.

Converting the above answer to km gives: 0.1889 x 150000000 = 28325821.77 km. Then, time = 28325821.77 km / 30 km/s = 944194.06 s. Time = 944194.06 s / 31536000 s = 0.02994 years.

17) Thought Question: NASA is currently working on and planning to launch the Near-Earth Object Surveyor in 2027. The Surveyor is designed to discover about 90% of asteroids that are 140 meters in diameter or larger. Imagine an asteroid such as the one we analyzed in this lab was discovered, and it was slowly heading towards our planet. What would you suggest we do? Can you think of a possible way to try and minimize damage, or avoid it altogether? Feel free to discuss!

Being a huge sci-fi movie fan, I would first say we look for ways to break the asteroid apart and calculate the debris ’ damage to Earth. Another possibility is to evacuate citizens but that ’ s easier said than done—depending on how long there is left before the asteroid ’ s impact.



NEO Surveyor – Credit: NASA/JPL-Caltech