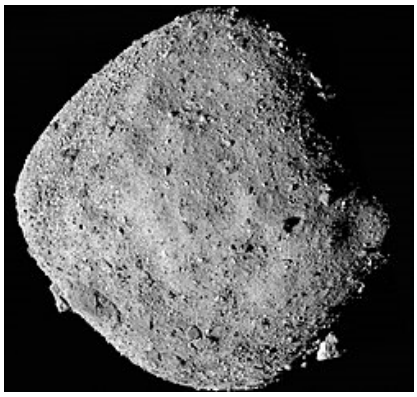
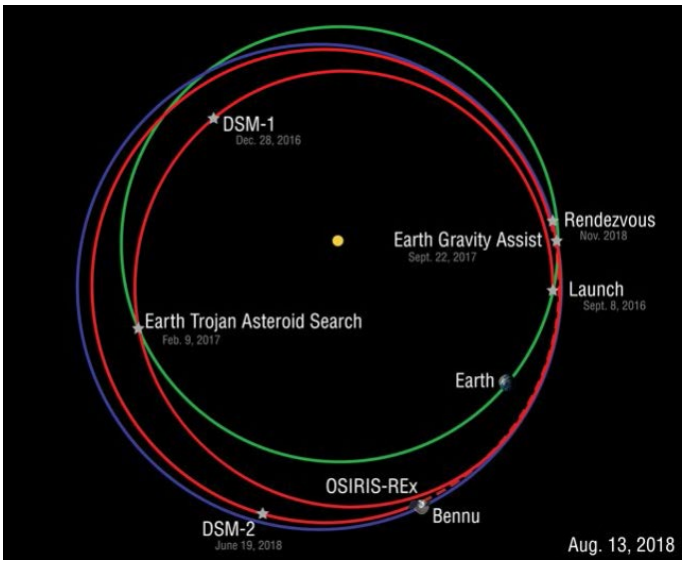
AAE 532 – Orbit Mechanics
Problem Set 1
Due: 9/4/20

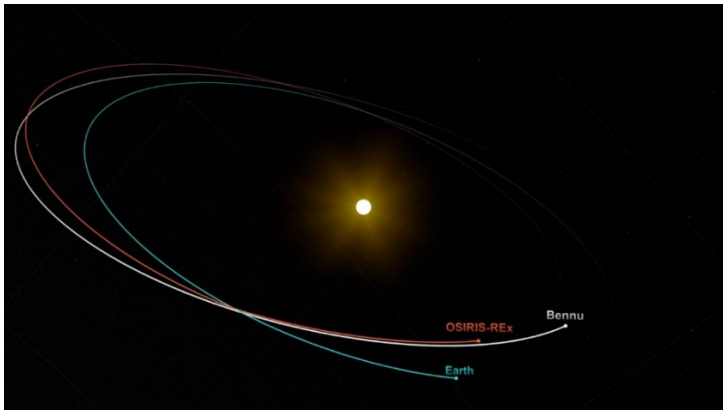
Problem 1: NASA's OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) is the first mission from the US to return an asteroid sample to Earth. The goal is a visit to an asteroid whose regolith may contain precursors to the molecules that originally seeded life. So, the spacecraft will collect a sample and then return it to Earth. The selected asteroid is 101955 Bennu. The physical and chemical properties of Bennu will also offer information concerning the natural resources of asteroids for use in future exploration missions. The spacecraft is currently orbiting asteroid Bennu and spent two years mapping the asteroid before collecting a sample and then preparing for the return to Earth.



The spacecraft was launched September 8, 2016. On December 3, 2018, maneuvers allowed the spacecraft to rendezvous with the asteroid. This step commenced the two years of mapping and now, in 2020, Osiris-Rex is ready to collect the sample. In March 2021, the appropriate phasing for a successful trajectory that returns to Earth becomes available and, after two and one half years, the spacecraft and its sample (2.1 ounces) arrives back at Earth in September 2023.



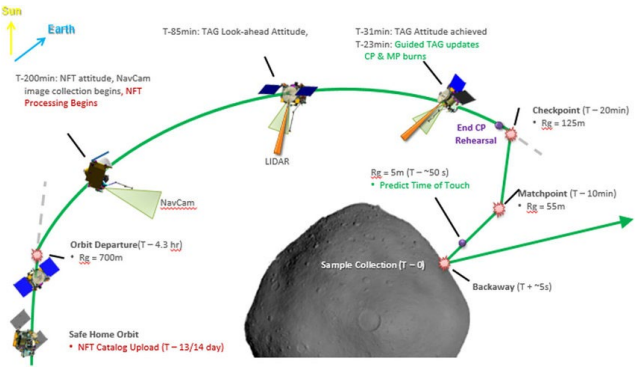
A planar projection of the trajectory path for Osiris-Rex appears on the left. On the right, the image focuses on the arrival scenario.



A video of this arrival is available at https://www.asteroidmission.org/galleries/videos/

(a) Consider the candidate asteroid 101955 Bennu. Go to a NASA website and collect information about Bennu. Information from near Earth observations suggests that Bennu has an interesting shape as shown above.
Find its size, dimensions, and density. Compare its size to a structure in your local community.
Bennu is a C-type asteroid. What does the mean?

(b) Bennu's surface is believed to be relatively rough and strewn with boulders. Can you find an image of the surface? Osiris-REx will touch down on the surface to collect a sample. Describe that plan in a short paragraph. Note the one of the concepts is reflected in this image. [For any image, please include the website and use only vetted sites. Wikipedia is not such a site.]
What date is Osiris-REx scheduled to collect the sample?



Bos et al., "Touch And Go Cmera Syste, (TAGCAMS) for the OSIRIS-Rex Asteroid Sample Return Mission," Space Sci Rev (2018) 214:37, https://doi.org/10.1007/s11214-017-0465-2

(c) Take a look at the orbit of 101955 Bennu. Go to the website:
https://ssd.jpl.nasa.gov/sbdb.cgi?sstr=Bennu;old=0;orb=1;cov=0;log=0;cad=0#orb
This site is the JPL Small-Body Database Browser. We entered '101955 Bennu' in the Search box; it switches to the page with the 'orbit diagram' and data. There is a link on the left that says [Show Orbit Diagram] that you can click if the orbit is not already in the view. Use the 'Play' button to observe the orbit evolution. There is a menu in the upper left to adjust the view. Use 'Default' for a standard view. You can also click 'Settings' to add additional planets to the view, for example. You can use the mouse buttons to zoom in-and-out as well as rotate for a 3D view. Note that the asteroid orbit is in two different colors; where the colors change indicates the location at which the asteroid crosses the orbital plane of the Earth about the Sun, i.e., the ecliptic plane.
Locate each of the bodies in their heliocentric orbits at the dates specified below by clicking on the clock in the upper right and clicking a calendar 'Date'. The date in the bottom left of the diagram will change to reflect this selection.

(i) Save the image on the date that corresponds to YOUR birthday in 2021 in two different views: (1) one view straight down onto the ecliptic plane to assess the locations of some of the planets on the same date; (2) a view that is edge-on to the Earth's orbit to highlight the out-of-planet nature of the orbit.

(ii) On the applet, the distance of the asteroid relative to the Earth and the Sun are given in the bottom left in AU (1 AU = 1 Sun-Earth distance). On this date, how far is Bennu from the Earth? Is this distance to the Earth considered small?

(iii) Does the heliocentric orbit of Bennu cross the orbits of any of the planets? Does Bennu have a significant out-of-plane component relative to the Earth orbital plane? Where is the Sun relative to Bennu and the Earth?

(iv) Using the tables below the Java applet, find the inclination and period of Bennu. Note that the inclination is reported relative to the ecliptic plane. How do these orbital parameters compare to those of the Earth in its orbit about the Sun?

(v) Advance the date to August 1, 2023 using either the "Date" selection box or the time stepping arrows and step size options. Step through each day in the months of August and September 2023 using the time stepping arrows and determine the date on which Bennu is closest to the Earth during these two months.
What is this date? What is the smallest distance between Earth and Bennu in AU? In km?

(vi) During August/September 2023, does Bennu pass within the Moon's orbit about the Earth? (1 Earth-Moon distance ~ 384,400 km) How do you know?

(vii) On the date of Bennu's closest Earth approach, save two images using the same views as in part (i). Is Bennu significantly above, significantly below or close to the Earth's orbital plane on this date?

(viii) Imagine that you were a mission designer working on the Osiris-REx mission concept several years ago and had to select an asteroid approach date for the robotic rendezvous to eventually collect the sample. The arrival phase started in April 2018 with 'rendezvous' in December 2018. View the relative positions of Earth and Bennu over those months. Based on the knowledge you have gained during this exercise about the orbit of Bennu, why might you have selected December 2018 for the approach date? How does it compare with the arrival video in the problem introduction? Could the spacecraft have arrived in November 2018?

Problem 2: In 2006, the word 'planet' was officially given an updated scientific definition by the International Astronautical Federation; textbooks were quickly updated, and many objects were re-evaluated. Thus, the category 'dwarf planet' was also introduced. Following the new definitions, NASA relatively quickly acknowledged the first 5 dwarf planets and dwarf planet number 6 is currently on the 'watch list'. However, it is generally agreed that there may be 100 to 2000 objects that fit the definition.

(a) Go to the NASA Solar System Exploration website and obtain the definition of a dwarf planet. Identify the five that are now generally accepted as dwarf planets plus one that might be on the watch list. Include an interesting fact about each one.

(b) Using the website from Problem 1, just type the name of a dwarf planet in the 'Search' box. Then grab one image of the orbit for each of the first 5 dwarf planets. Use an image that highlights their out-of-plane motion. Find their inclinations and periods.

(c) To reduce the propulsive requirements for a spacecraft, it is most efficient in terms of propellant to approach a dwarf planet when it is close to the ecliptic plane. There are currently some early proposals for a mission to Haumea. Haumea is a triple system with two moons, Hi'iaka and Namaka, so it is intriguing. Consider an edge-on view of the orbit of Haumea. Given its period, when is the earliest month/year that a mission to Haumea can arrive at the dwarf planet as it crosses the ecliptic plane? How long do we have to wait from today? Print the image for that arrival condition.

(d) The spacecraft Dawn encountered Ceres during its recent mission. What date did Dawn arrive in the vicinity of Ceres? What date did it depart? Produce an image of the location of Ceres during Dawn's encounter. Are the encounter conditions similar to those of Osiris-REx arriving at Bennu? Differences? Similarities?

(e) Besides distance to Earth, also consider the line-of-sight (LOS) to Earth during the Bennu and Ceres arrival phases. Why might LOS be an important trajectory design condition? During the Bennu sample collection, is LOS to Earth 'clear'? What might impede LOS to Earth? When is LOS a challenge?