

Week 10: Prep for Project Lab 1

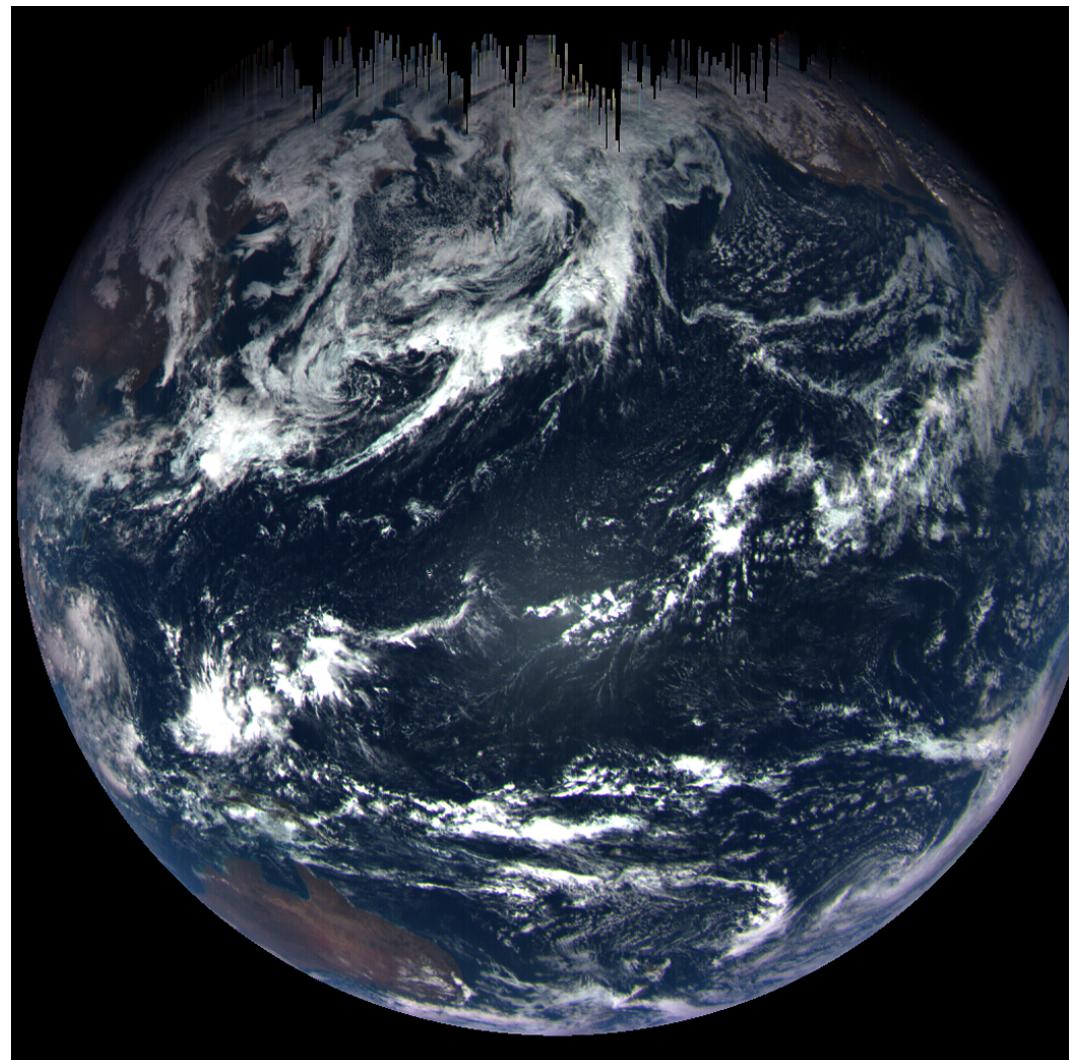
Spacecraft flybys of Planets

Concept: Use of planetary flybys to modify spacecraft trajectories

A color composite image of Earth 9/22/2017 taken by the MapCam camera on NASA's OSIRIS-REx spacecraft. Taken after the spacecraft completed its Earth Gravity Assist at a range of ~ 106,000 miles (170,000 kilometers).

Visible are the Pacific Ocean and several landmasses, including Australia in the lower left, and Baja California and the southwestern United States in the upper right.

The dark vertical streaks at the top of the image are caused by short exposure times (less than three milliseconds). Short exposure times are required for imaging an object as bright as Earth, but are not anticipated for an object as dark as the asteroid Bennu, which the camera was designed to image.



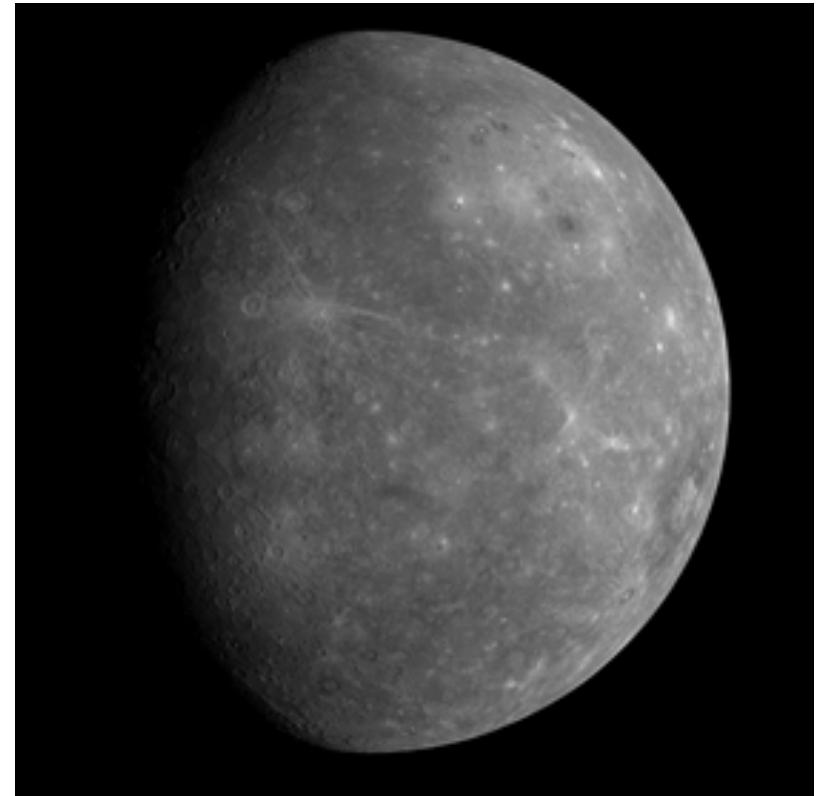
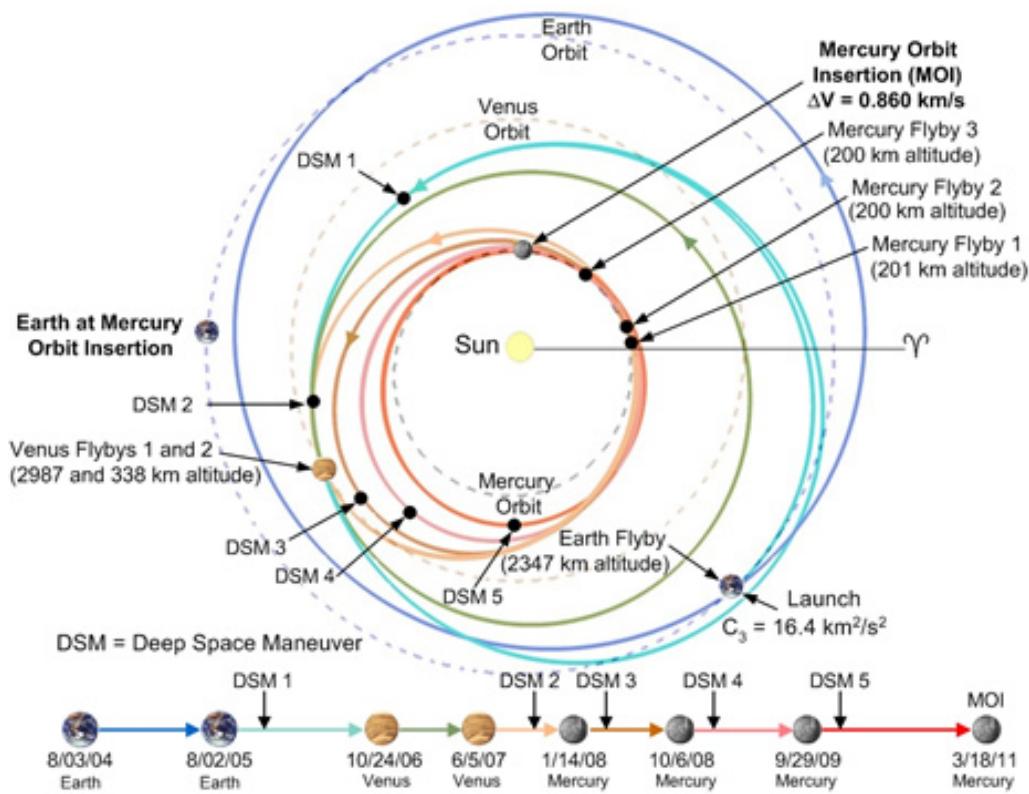
Week 10: Project Lab 1 Background

Concept:

- Use of planetary flybys to modify spacecraft trajectories

Physics needed: Newton's laws (gravitation & motion), resolving vectors

Python: use skills from this class! Learn basics of numerical integration



Real Planetary Flybys

What happens to the spacecraft speed and direction depends on

1. How close it flies to the planet
2. The relative motion of the s/c and planet

More info:

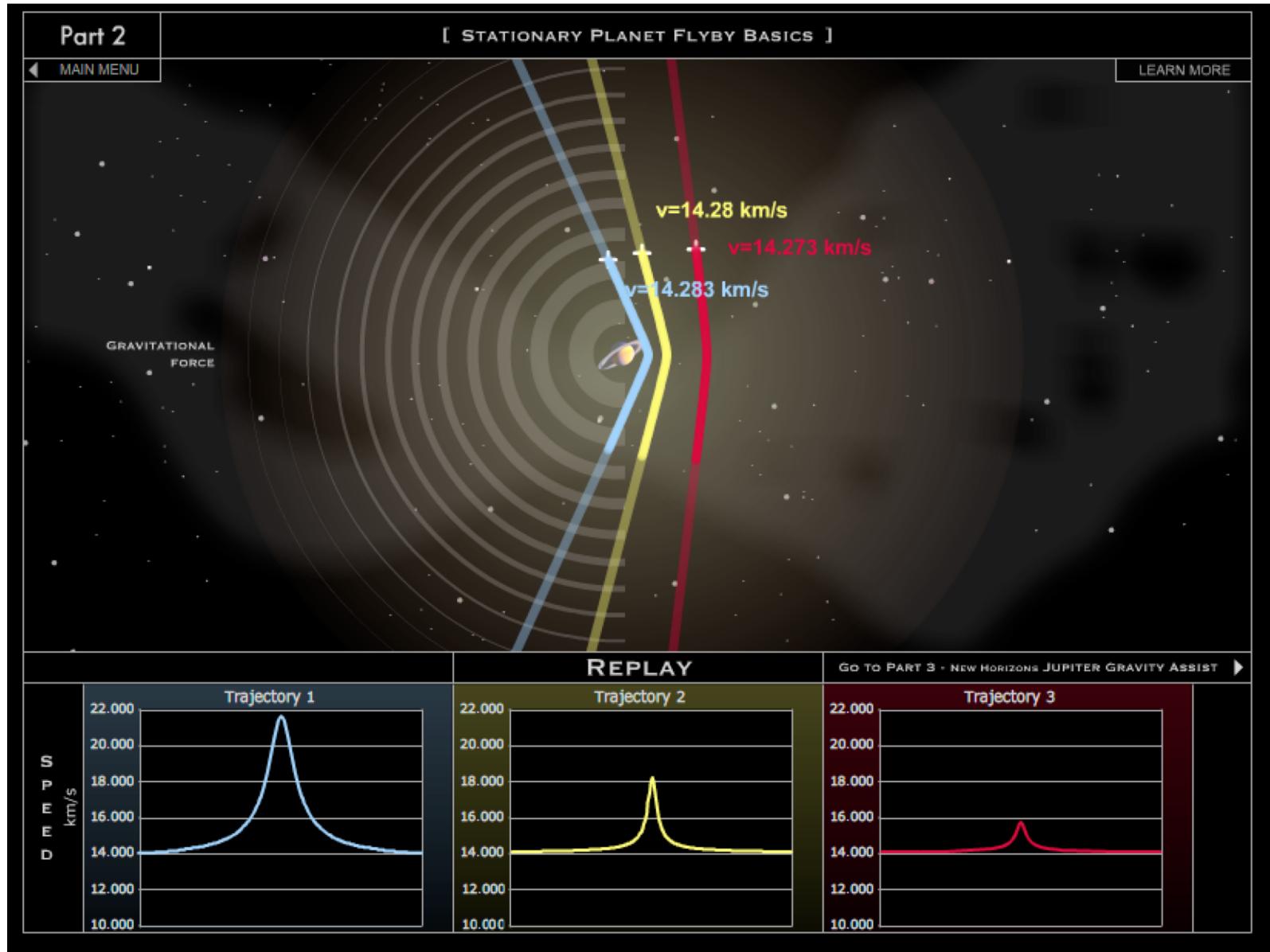
<https://www.planetary.org/articles/20130926-gravity-assist>

Simulator: Gravity assist simulator at link below.

<https://messenger.jhuapl.edu/Learn/Games-and-Interactives.html#games-and-simulations>

From the planet's perspective:

planet is stationary, spacecraft moves relative to the planet
e.g. our project lab!

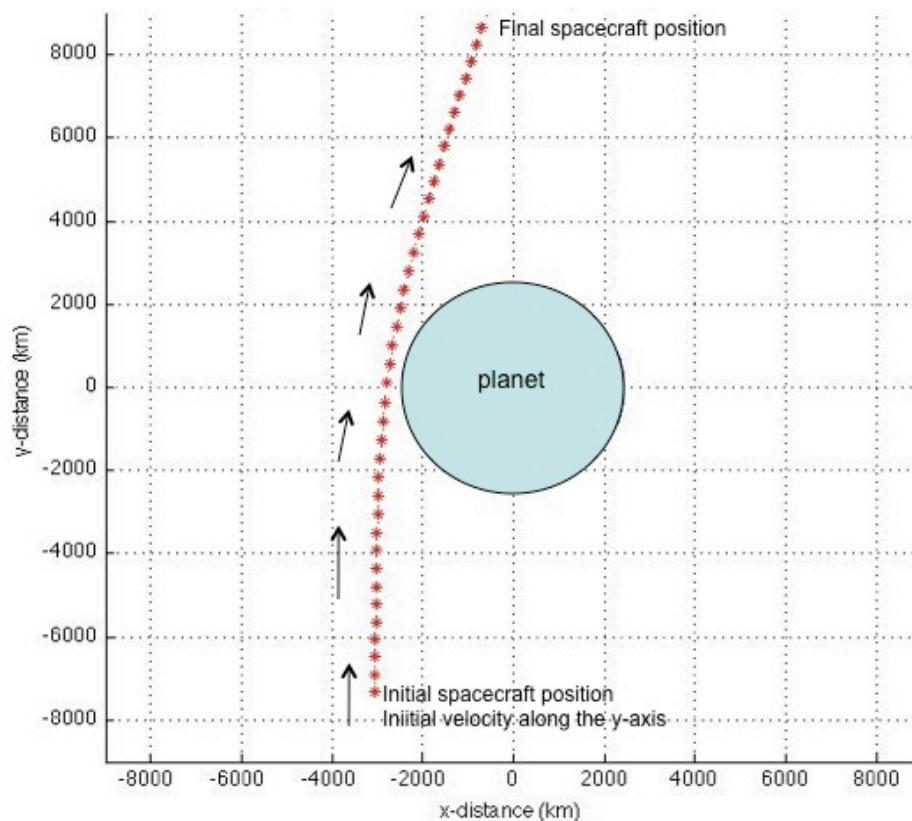


Project Lab 1:

Mimics the flybys of Mercury by the MESSENGER spacecraft

1. Spacecraft starts out distant from Mercury, with speed 7 km/s
2. Flies to within ~200 km of surface in our assignment (was to within 201 km of surface in actual flybys).

Aside: $7 \text{ km/s} = 3600 * 7 \text{ km/hr}$, so over 25,000 km/hr!

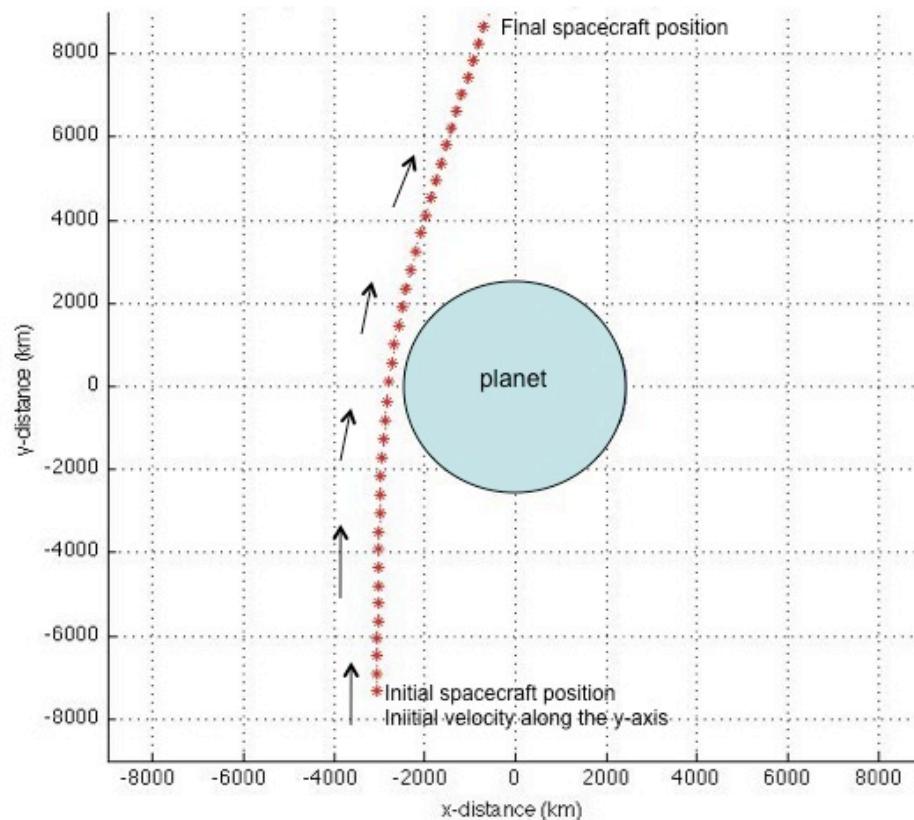


The assignment:

Given

1. the initial ($t=0$) spacecraft velocity vector
2. the initial ($t=0$) spacecraft position vector
3. a time increment at which to calculate positions

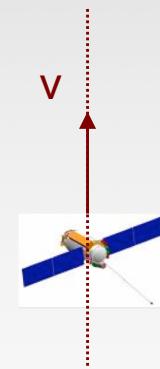
Calculate the entire spacecraft trajectory until a time $t = t_{\text{final}}$



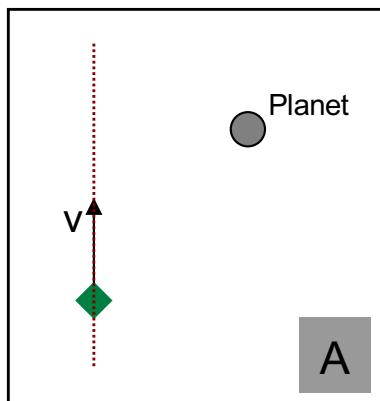
How to do this.....

Spacecraft is moving with initial velocity, v in the direction shown. It is at some known position relative to the center of the planet.

In the absence of the planet assume there are no other forces on the spacecraft (e.g., no rocket burns, no drag etc).

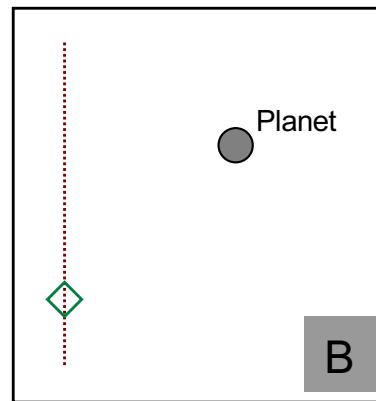


$t=0$



At $t=0$ sketch the direction of the spacecraft's acceleration

$t=\Delta t$

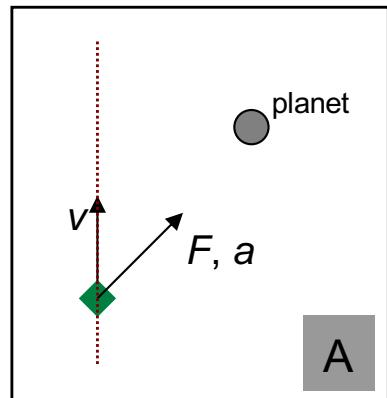
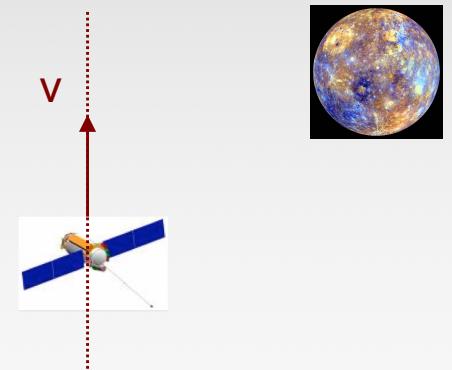


At $t = \Delta t$ sketch the spacecraft's
1. position
2. velocity
3. acceleration

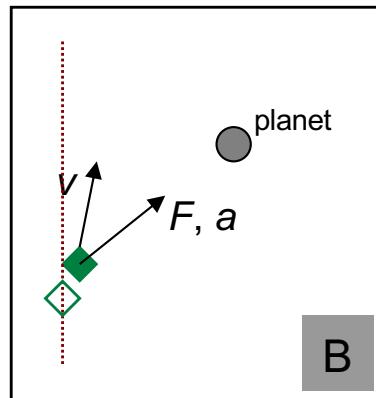
How to do this.....

Spacecraft is moving with initial velocity, v in the direction shown. It is at some known position relative to the center of the planet.

The sketches below describe the instantaneous directions of force, acceleration and velocity experienced by the spacecraft:



A) at time $t=0$



B) at time $t=\Delta t$ later

Notice that because the acceleration had components both parallel and perpendicular to the spacecraft's initial velocity both the magnitude and direction of velocity are changed

Calculating the spacecraft acceleration: the `grav_acc()` function in Part A of Project Lab 1

Direction of F, a (due to the planet) is shown in blue.

$$F = G M_p m / s^2$$

Newton's Law of Gravitation

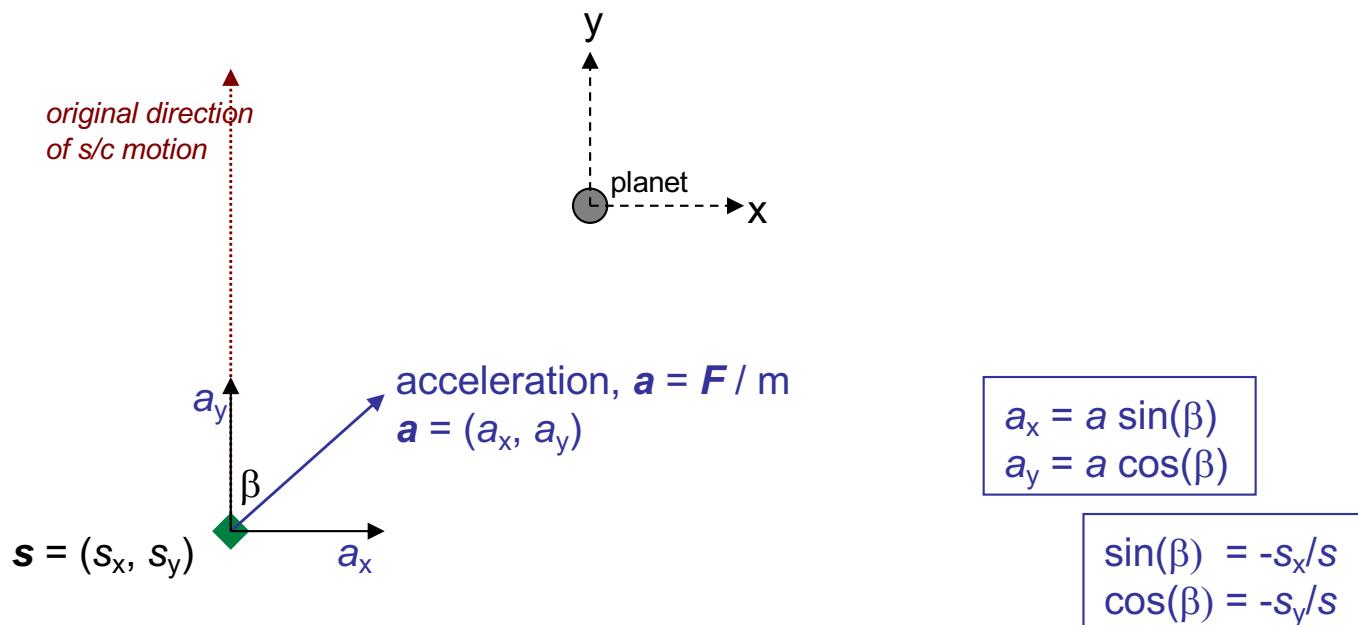
M_p =mass planet, m = mass spacecraft, s is distance between them

$$a = \text{acceleration} = F / m = G M_p / s^2$$

Newton's 2nd Law of Motion

Use a coordinate system with origin at the planet's center with x and y directions shown.

The acceleration can be resolved into two perpendicular components, a_x and a_y .



Calculating the spacecraft trajectory: Part 2 of Project Lab 1

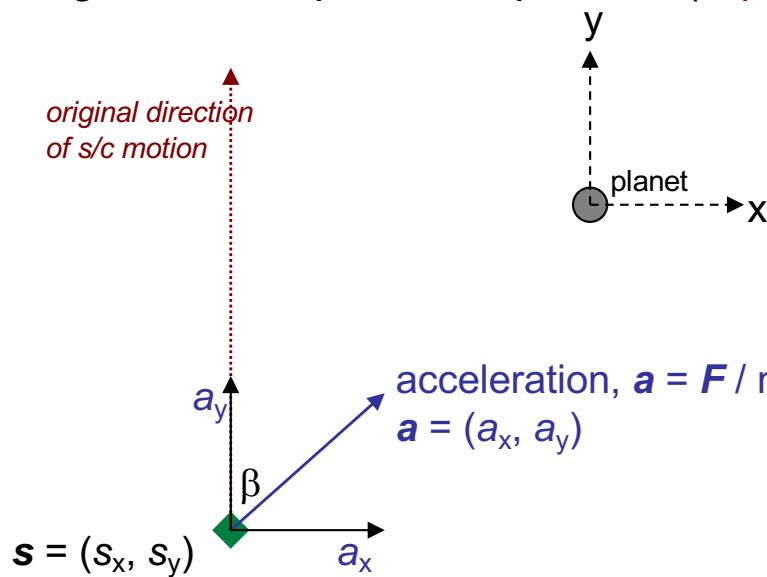
acceleration in the direction of the planet, $a = G M_p / s^2$

resolve into two perpendicular components, a_x and a_y

After a time Δt

a_x and a_y have changed the x- and y- components of the velocity (eq. 14, 15 pre-reading)
=> resulting in a new speed and new direction of motion (eq. 10, 11 pre-reading)

they also change the x- and y- components of position (eq. 16, 17 pre-reading)
=> resulting in a new spacecraft position (eq. 12, 13 pre-reading)



See
Worksheet

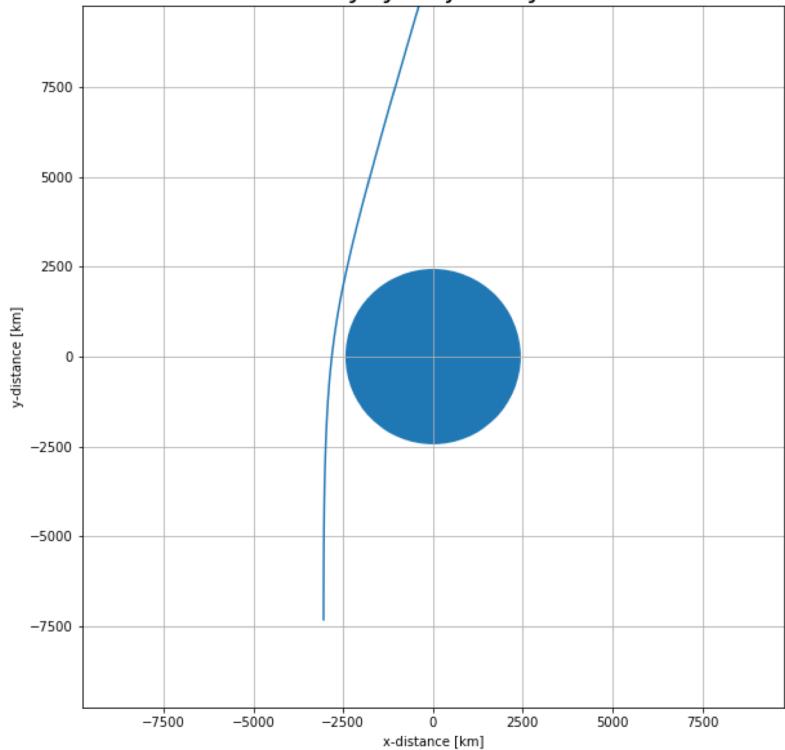
$$a_x = a \sin(\beta)$$
$$a_y = a \cos(\beta)$$

$$\sin(\beta) = -s_x/s$$
$$\cos(\beta) = -s_y/s$$

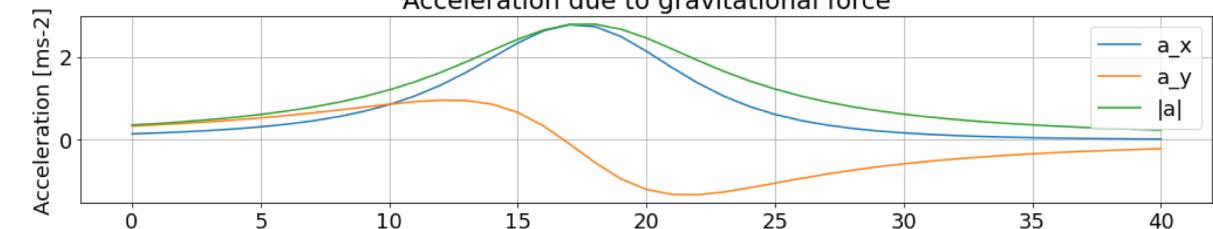
Project Lab 1:

Part 2 – Build A Complete Trajectory

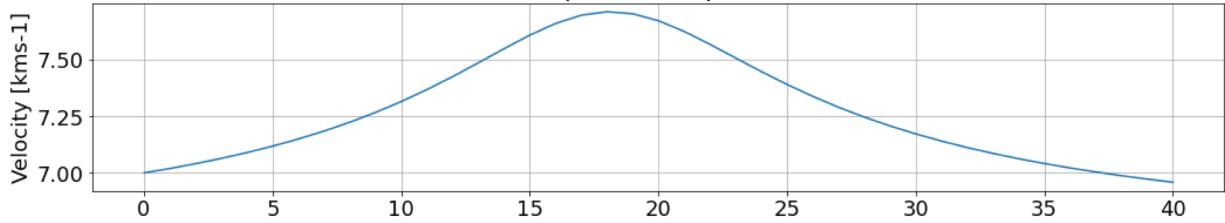
Flyby trajectory



Acceleration due to gravitational force



Spacecraft speed



Spacecraft altitude

