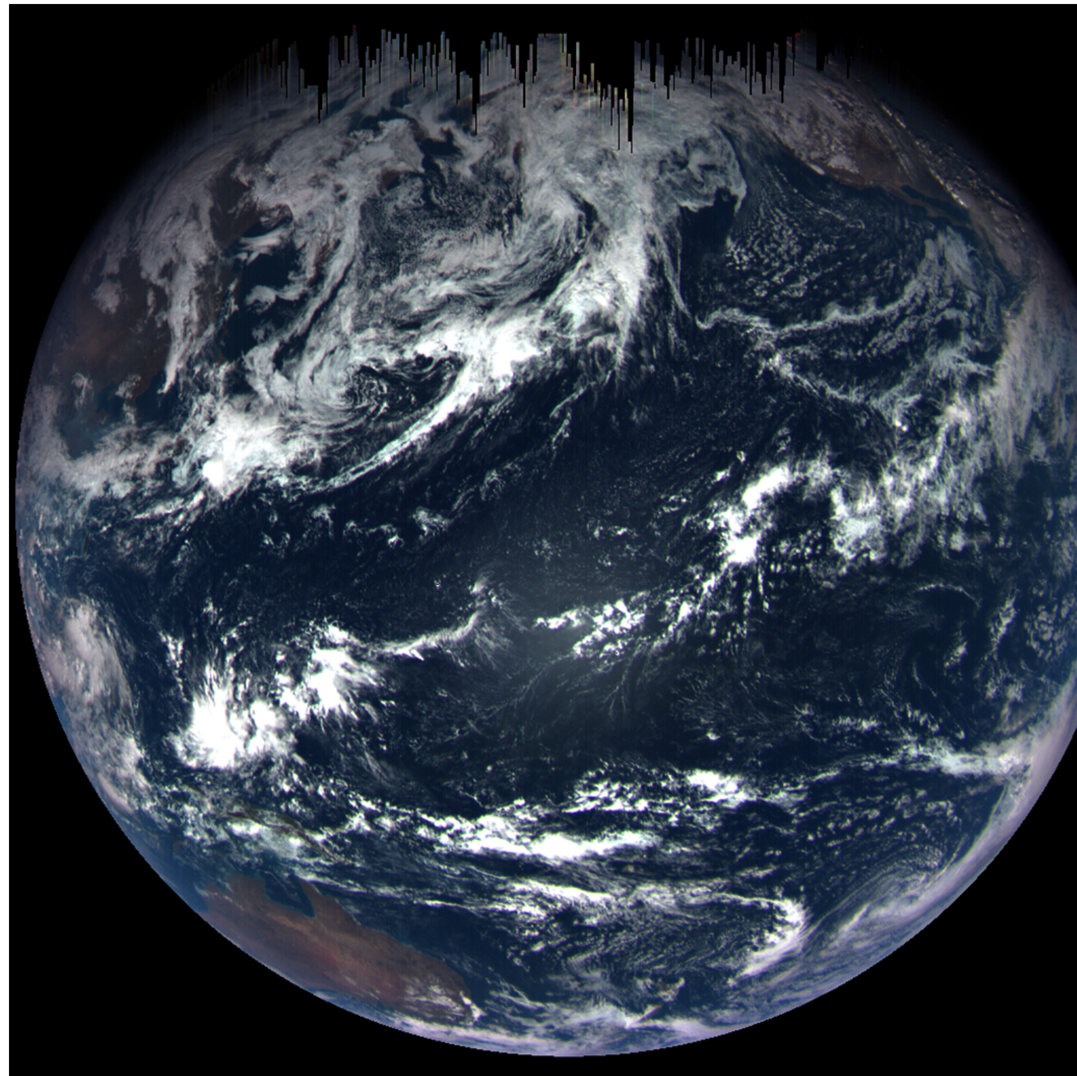
Week 11: Spacecraft flybys of Planets

Concept: Use of planetary flybys to modify spacecraft trajectories

A color composite image of Earth 9/22/17 taken by the MapCam camera on NASA's OSIRIS-REx spacecraft. This image was taken just hours after the spacecraft completed its Earth Gravity Assist at a range of approximately 106,000 miles (170,000 kilometers).

Visible in this image are the Pacific Ocean and several familiar 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.



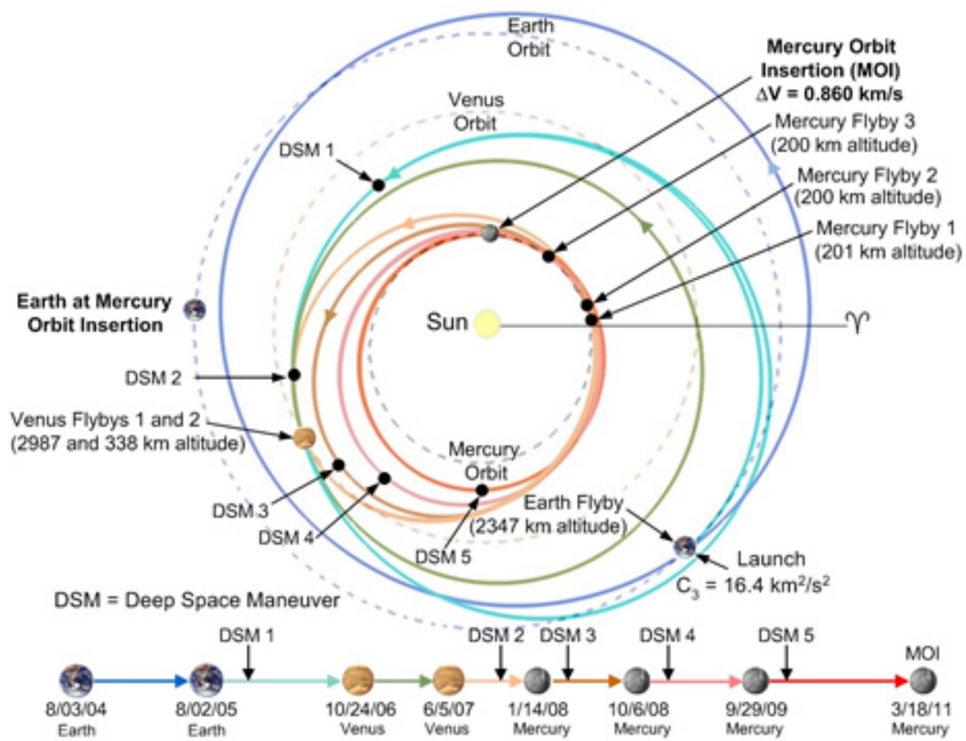
Week 11: Assignment 2 Background

Concept:

- Use of planetary flybys to modify spacecraft trajectories

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

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



Real Planetary Flybys

Animations - MESSENGER Mission Website: THIS WAS NOT WORKING FOR ME AS OF THIS WEEK…..

"Gravity Assist Simulator" (copy and paste the following link)

http://btc.montana.edu/messenger/Interactives/ANIMATIONS/grav_assist/gravity_assist.html

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

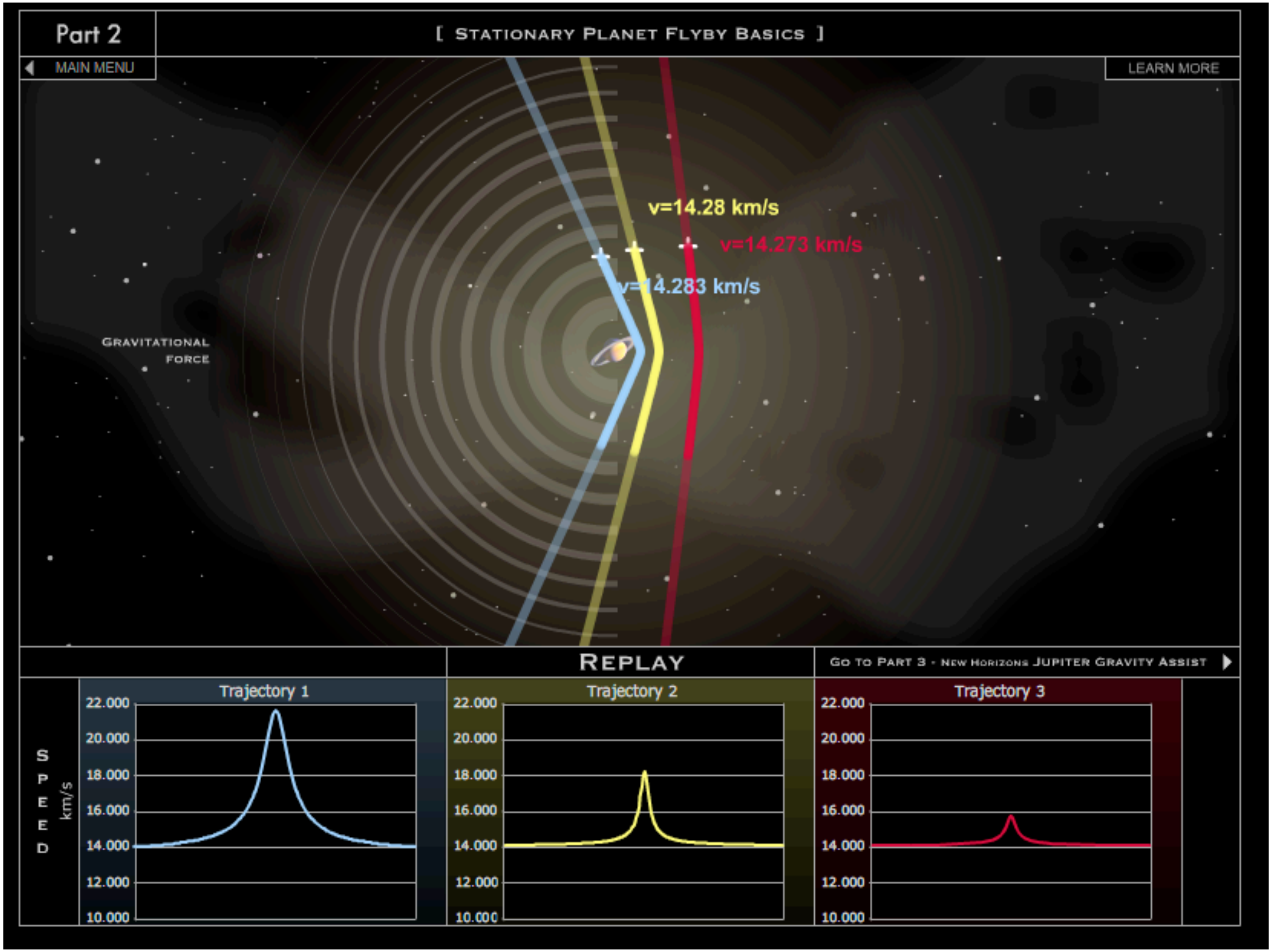
See also:

http://www.planetary.org/blogs/guest-blogs/2013/20130926-gravity-assist.html

From the planet's perspective:

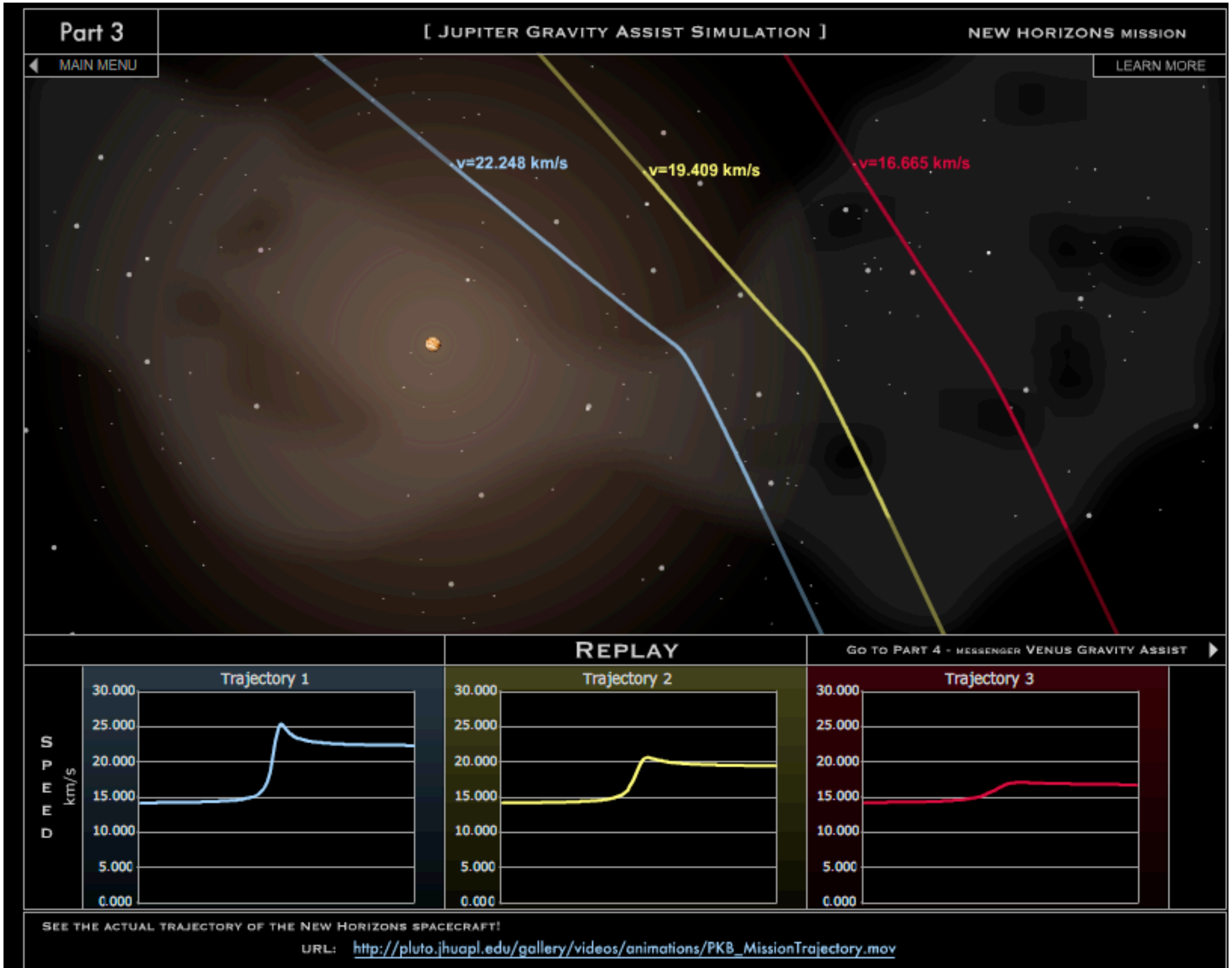
planet is stationary, spacecraft moves relative to the planet

e.g. our assignment!!



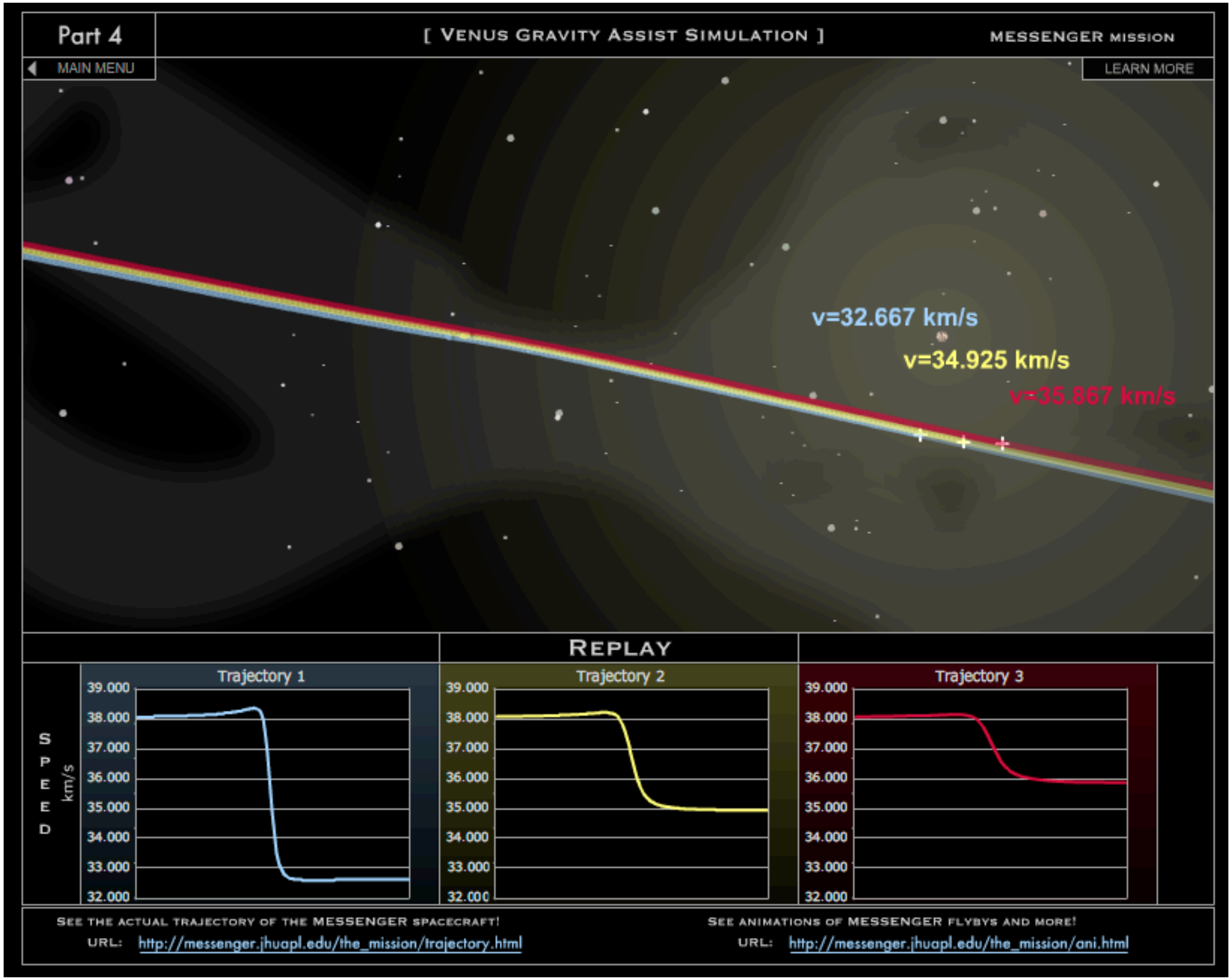
Boosting a spacecraft's speed:

e.g. getting to the outer solar system using Jupiter
e.g. New Horizons, Voyager missions,….



Slowing a spacecraft’s speed:

e.g. getting into orbit around a planet in the inner solar system
e.g. MESSENGER mission to Mercury

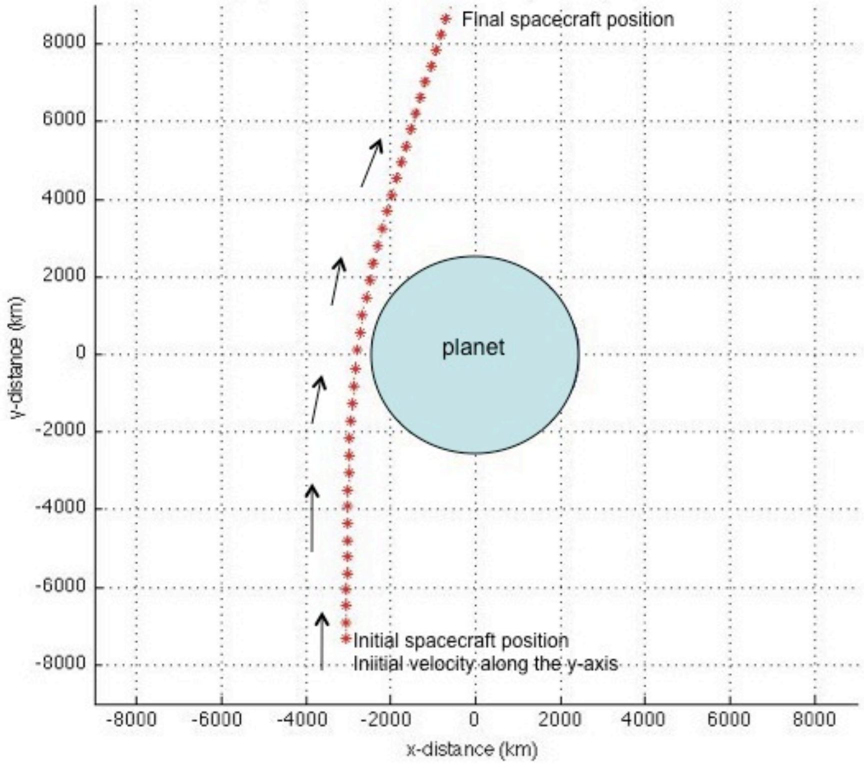


Assignment 2:

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 ~195 km of surface in our assignment (was to within 201 km of surface in actual flybys).

Aside: 7 km/s = 3600*7 km/hr, so over 25,000 km/hr!

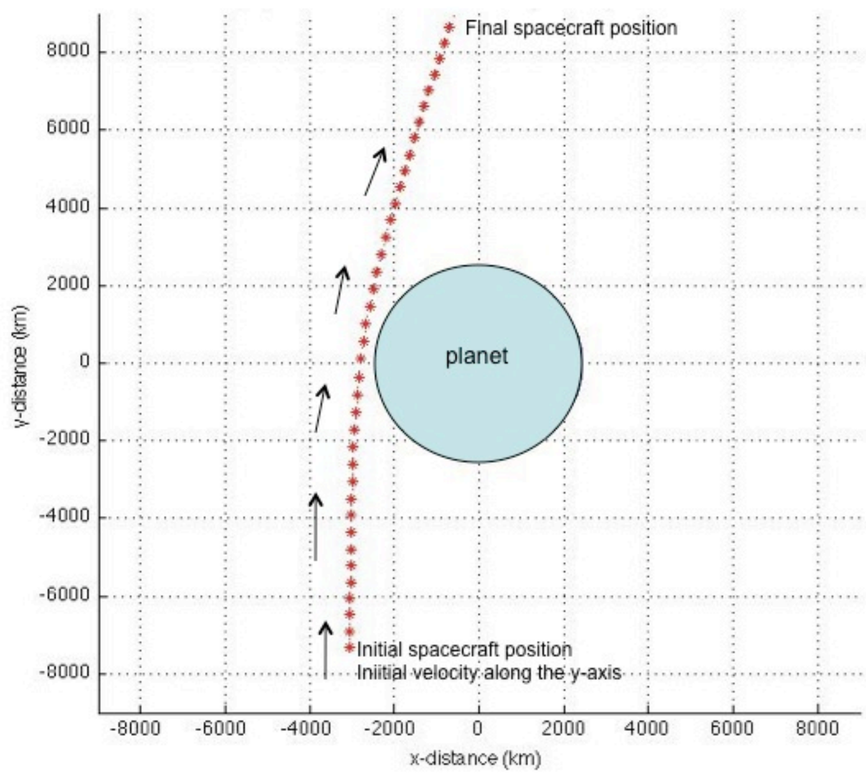


The assignment:

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

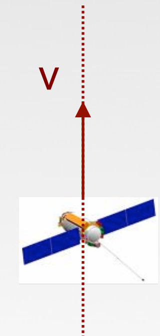
Calculate the entire spacecraft trajectory until a time $t = t_{final}$

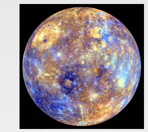


How to do this…..

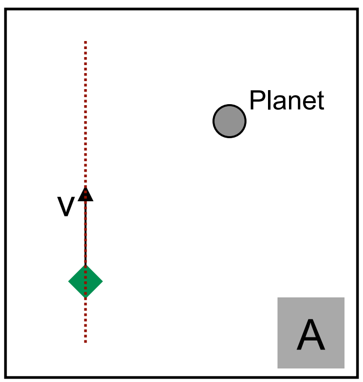
Spacecraft is moving with initial velocity, v = in the direction shown.
It is at some known position relative to the center of the planet.

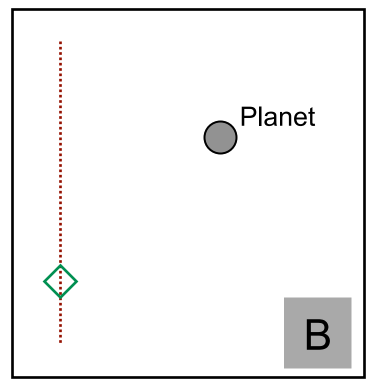
In the absence of the planet assume there are no other forces on the spacecraft (e.g., no rocket burns, no drag etc).





t=0





t=Δt

sketch the direction of the spacecraft’s acceleration

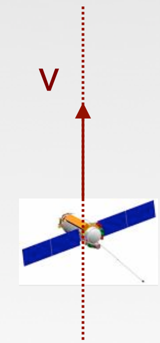
sketch the spacecraft’s

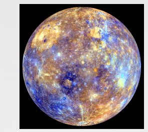
1. position
2. velocity
3. acceleration

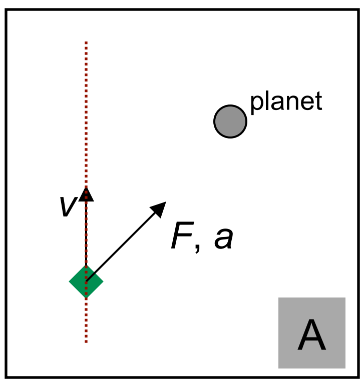
How to do this…..

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

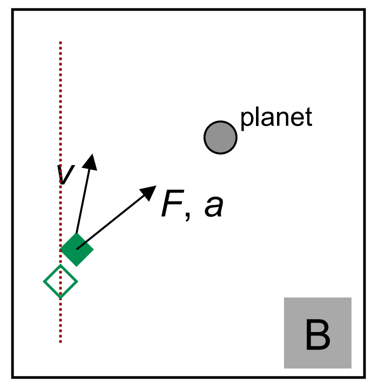
The sketches below describe the instantaneous directions of force, acceleration and velocity experienced by the spacecraft:







A) at time t= 0



B) at time t= Δt 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

How to calculate the acceleration of the spacecraft

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

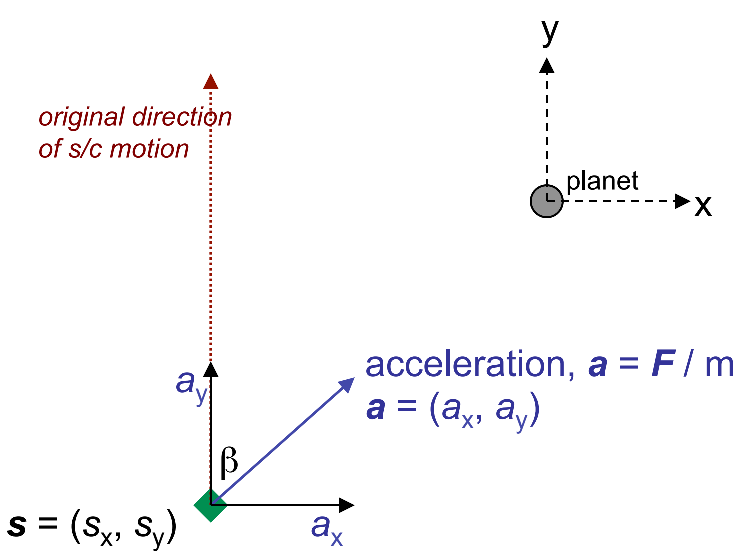
$F = G\, M_p\, m / s^2$ Newton's Law of Gravitation

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

a = acceleration = F / m = G M_p / s^2 Newton's 2^{nd} 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.



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

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

Calculating the spacecraft trajectory

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

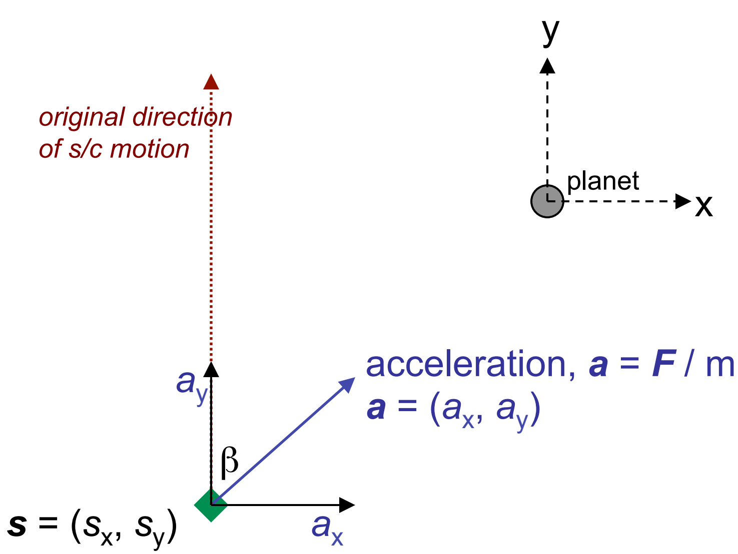
resolve into two perpendicular components, a_x and a_y

After a time Δt

a_x and a_y have changed the x- and y- components of the velocity
=> resulting in a new speed *<u>and</u>* new direction of motion

they also change the x- and y- components of position
=> resulting in a new spacecraft position

WORKSHEET



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

$\sin(\beta) = -s_x/s$
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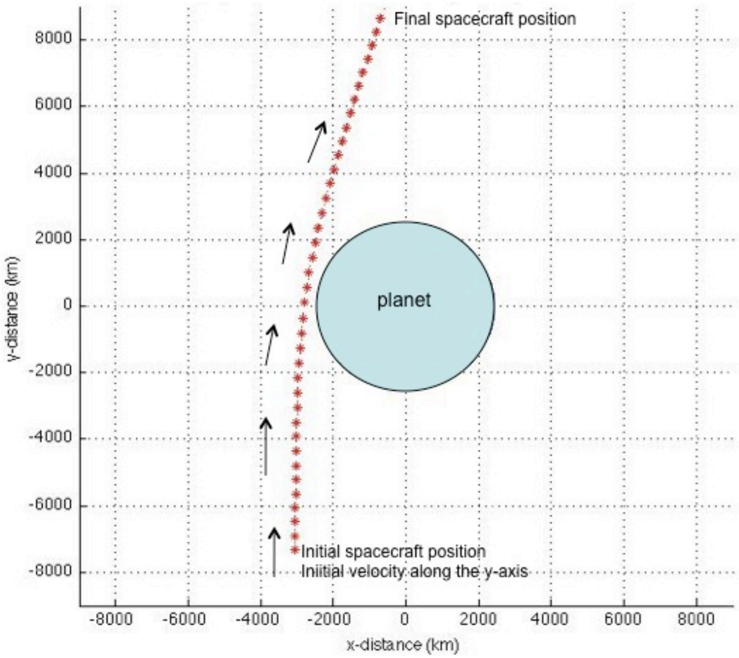
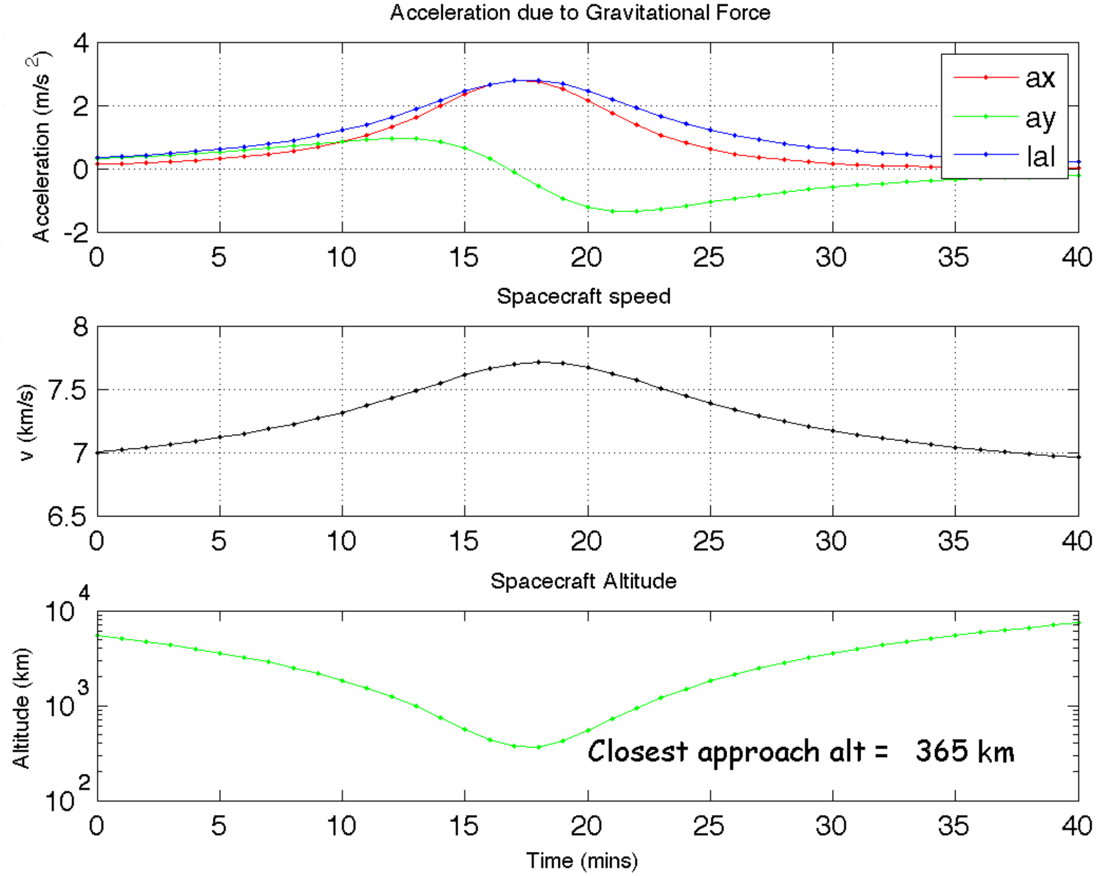
Part 5 Results





And … unrelated to flybys but also planetary…

InSight Landing – Nov 26, 2018 = MONDAY Week 13, Noon PST.

https://mars.nasa.gov/insight/timeline/landing/watch-online/

Stop by to ‘watch’ in the Pacific Museum of Earth, EOS Main Lobby
11:00 am – 1:00 pm, 11/26/2018