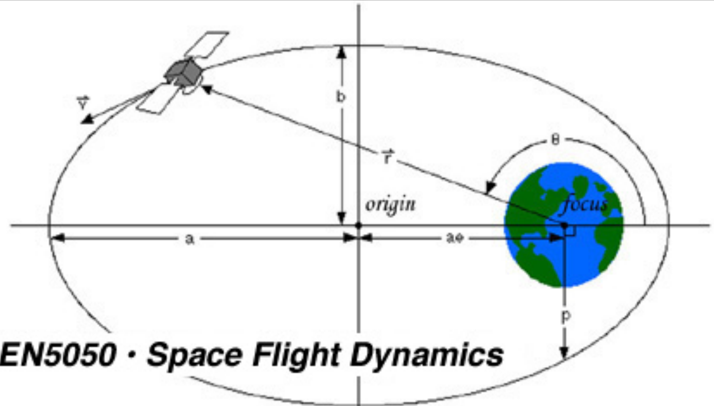


ASEN5050 · Space Flight Dynamics

Department of Aerospace Engineering Sciences

University of Colorado

Prof. R. Steven Nerem
Colorado Center for Astrodynamics Research
Dept of Aerospace Engineering Sciences
University of Colorado

Introductions

- Instructor: Prof. R. Steven Nerem
  - Email: nerem@colorado.edu
  - Office: ECNT 319
  - Office Hours: Tues/Thurs 9-10:30, or by appointment
- Class Assistant: Elena Trenholme
  - Email: Elena.Trenholme@Colorado.EDU
- Classrooms: ECCS 1B28 unless we're having an STK lab.
- Lab: Visions Lab (ECAE 1B73)

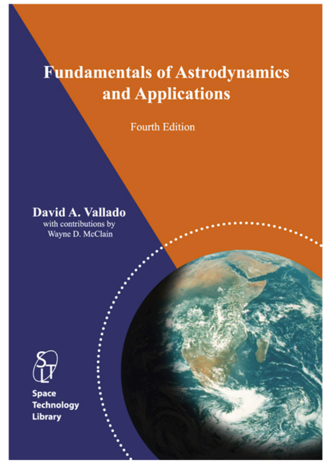
Nerem's Travels

Course Website

- Desire2Learn:
  - http://learn.colorado.edu

Course Textbook

- David A. Vallado, Fundamentals of Astrodynamics and Applications, *4th Edition*, 2013
  - Please let me know if you find any errors or anything that needs clarification!

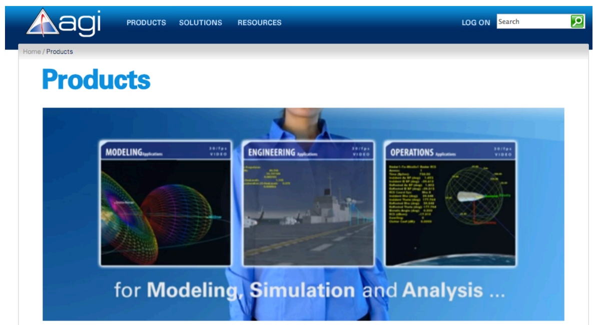


Course Material

- We'll study the forces that act upon a spacecraft
  - Gravity, atmospheric drag, solar radiation pressure, thrusters, heat, etc.
  - The same forces that act upon you! With a few exceptions.
- We'll study how to represent the spacecraft's state
  - Orbital elements, coordinate frames, time systems
- We'll study how to build orbital transfers
  - Launch to orbit, orbit transfers, plane changes, interplanetary, station keeping
- We'll study the how *and* the why to place spacecraft into particular orbits.
- You will build software tools to do much of this on your own, and you'll learn STK as an example of a commercial product that also does this.
- My challenge: to keep experienced students captured while bringing inexperienced students up to speed!

STK

- Systems Tool Kit (STK) version 10
- Built by Analytical Graphics, Inc. (AGI)
- Commercial software to model, engineer, and operate spacecraft, aircraft, ground systems, etc.



STK

- We will have four STK labs in this class.
- Labs completed in the Visions Lab (ECAE 1B73). You'll have to complete a basic form to get an account on those computers.
  - http://www.colorado.edu/aerospace/facultystaff/visions-lab-information
- Distance students must acquire STK on their own computers. I'll post instructions on D2L about how to get an Educational License (free STK for this class, expiring in December).

Grading

- Homework: 30%
- Mid-term: 25%
- Final Exam: 25%
- Research Project: 20%

- Late homework deducted 10 pts for each school day late!
  - Homework is due at the start of class.

- All due dates for distance students are one week later.

Research Project

- Extend one or more concepts introduced in this class.
- Develop your report as a *web page*
  - Take advantage of a web page's links, animations, etc. A report is far more dynamic and instructive this way than a paper report!
  - You may need to learn how to do this.
  - HTML is as simple or as complex as you want.
  - At a minimum, just save your Word document as a web page.
- See examples on this website.
  - http://ccar.colorado.edu/ASEN5050/projects/

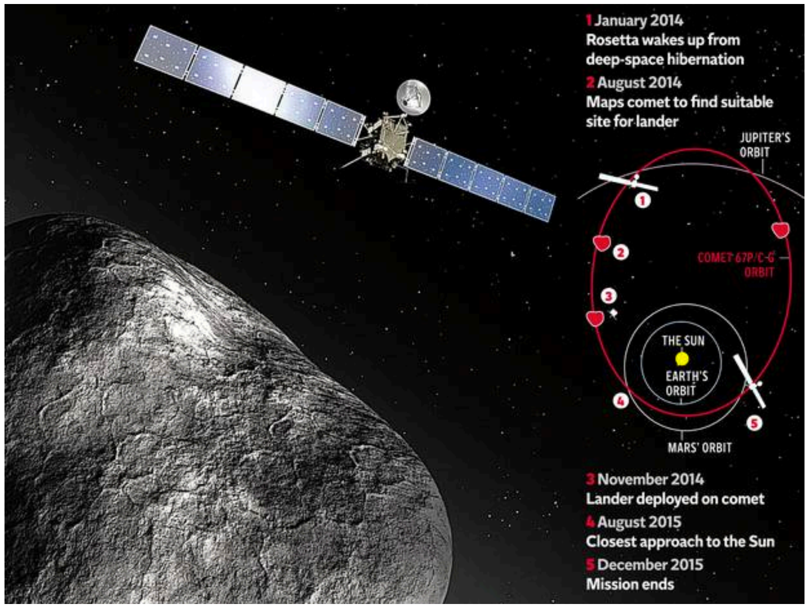
Some Policies

- Homework can be turned in at class in printed form, or turned in electronically via D2L's Dropbox.
- Many assignments require computer programming
  - Matlab recommended, but Python, IDL, or some other high-level language are acceptable.
- We do not need to see your code.
- We also, unfortunately, do not have time to debug.
- You may work together in groups or with partners, but turn in your own work!

Some Policies

- You are welcome to come and go as needed in class.
- You are welcome to be on a computer/tablet/phone/etc.
- You are *not* welcome if you disturb others or disrupt the class.
  - Turn down the brightness on your computer.
  - Silence your digital life
- Ask questions!
- Honor Code
- Please work together on homework and labs, but give each other credit if you do!

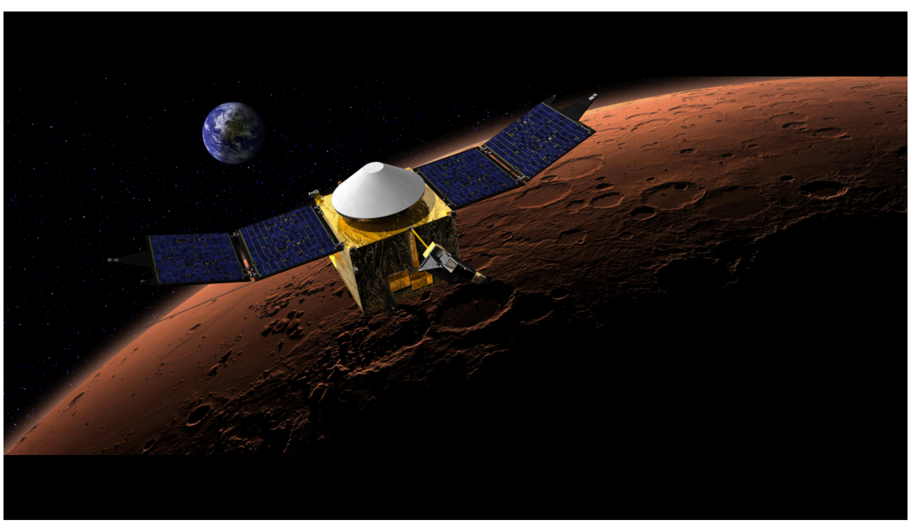
Rosetta



ASEN 5050 Lecture 1 13

MAVEN

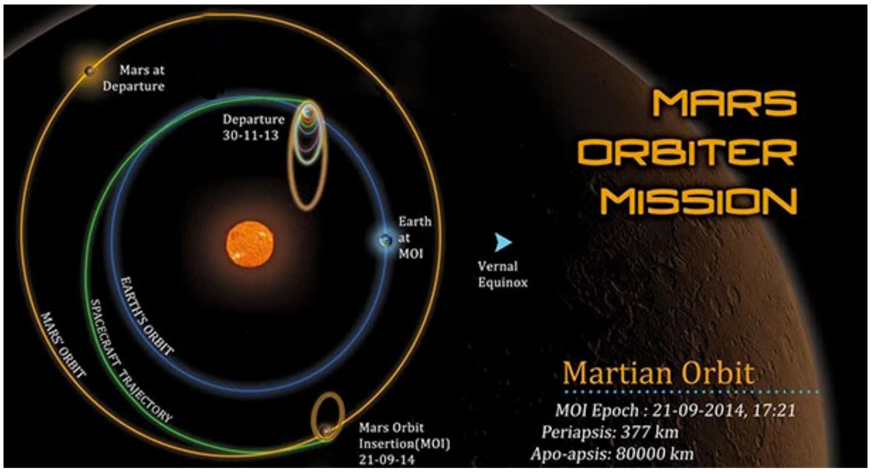
Arrives at Mars September 21! LASP is a big player in the mission!



ASEN 5050 Lecture 1 14

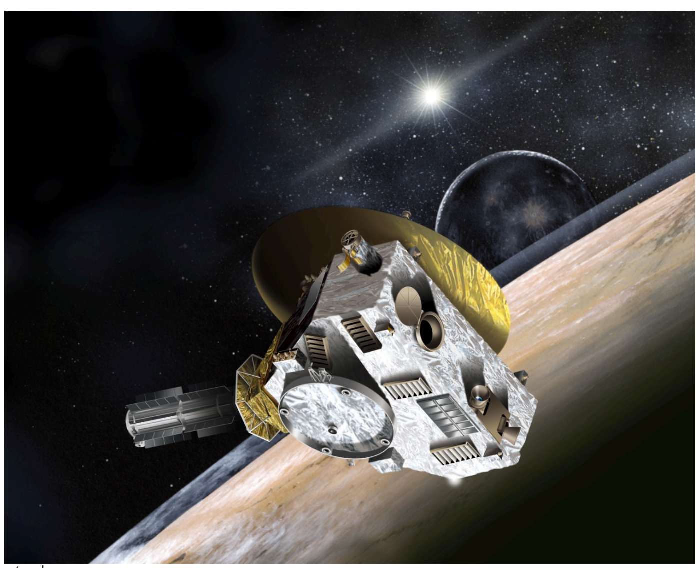
MOM

Arrives at Mars September 24!   ISRO mission, much the same as Chandrayaan-1

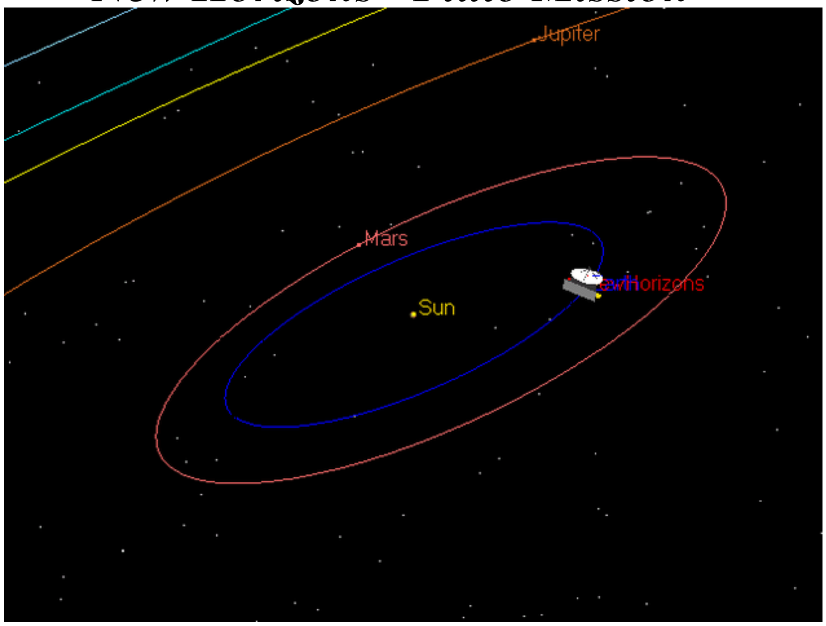


New Horizons

Arrived at Pluto July 2015!



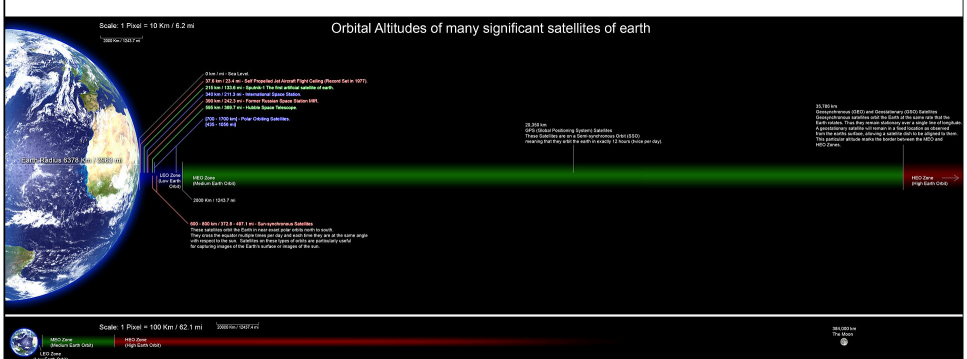
New Horizons - Pluto Mission



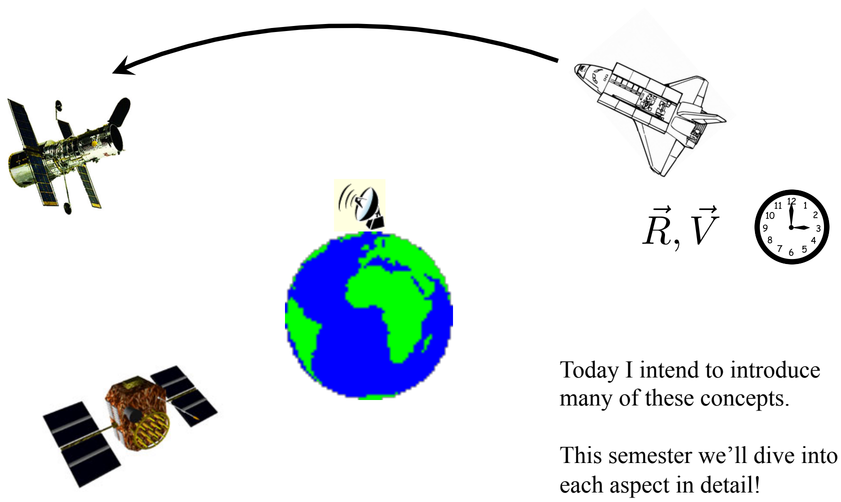
Business as Usual in Earth Orbit

- About 1100 active satellites
- About 2600 satellites that are no longer active
- These are between 2 lbs and 6 tons in mass

- In addition, there are 10s of thousands of pieces of space debris.



What we will learn in this class



Today I intend to introduce many of these concepts.

This semester we'll dive into each aspect in detail!

Let's give it a go

- A spacecraft's state can be represented using 6 parameters at a particular time, t:
  – 3 position: x, y, z
  – 3 velocity: vx, vy, vz

- If we take a state and propagate it forward in time, what happens?
  – x = x(t)
  – y = y(t)
  – …
  – vz = vz(t)

- How did early investigators figure out what would happen? Are we certain that we know what would happen?

Some observations

- If you hold an object at rest and then let go, what happens?
  - It starts increasing in velocity and travels toward the Earth
  - What do we mean by "at rest"?

- The object accelerates as if by an inverse square force law (this took some effort and we'll skip a few 1000 years of exploration at the moment)

$$F = ma$$

$$F = \frac{GMm}{r^2}$$

$$ma = \frac{GMm}{r^2}$$

$$a = \frac{GM}{r^2}$$

This explains the motion of a ball thrown in the air (neglecting air resistance).

It also explains the motion of a satellite.

Early observations

$$a = \frac{GM}{r^2}$$

- We didn't have this equation in its entirety, but from observations we could see that a rock that is dropped near the Earth's surface accelerated at about 9.81 m/s^2.

$$9.81 \text{ m/s}^2 = \frac{GM}{r^2}$$

- According to sources, Eratosthanes was able to estimate the radius of the Earth using geometry, based on the length of a shadow at the same time in two different locations about the Earth, in the 3rd century BC.
  - Estimates placed it at about 6400 km

$$9.81 \text{ m/s}^2 = \frac{GM}{(6400 \text{ km})^2}$$

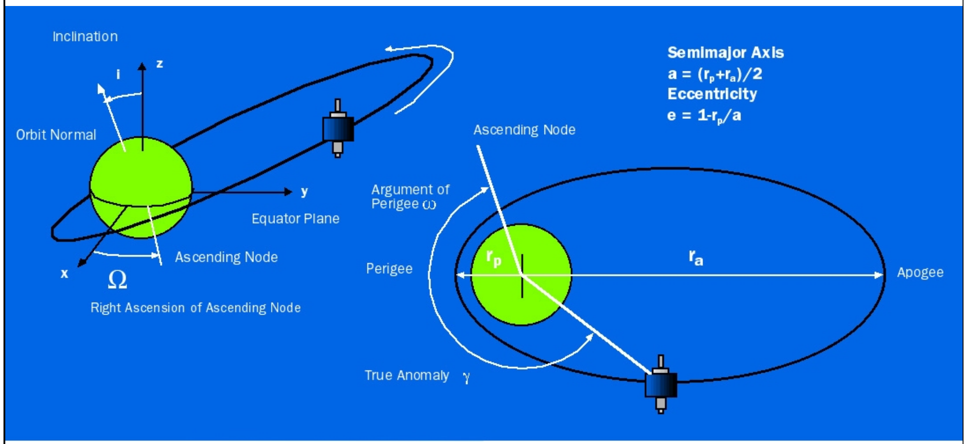
This yielded a value for *GM* of ~402,000 km^3/s^2

Modern estimates of *GM* are ~398,600.4 km^3/s^2

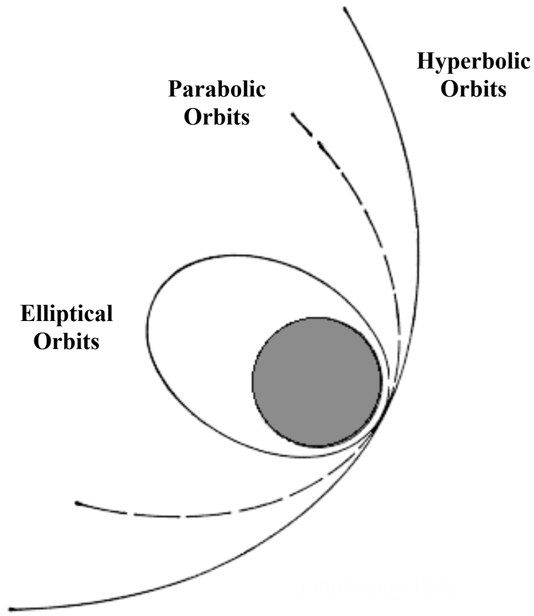
Translating that into an Analytical Model

- Turns out (and we'll go into depth here next time) that this inverse square force law describes the motion of an object on a conic section.
  - Circle, ellipse, parabola, hyperbola

Orbital Elements
Case Study: The Ellipse



Other Orbits



Orbital Elements

- The point of all of this is to illustrate that there are different ways to represent the state of a satellite
- Cartesian Coordinates
  - x, y, z, vx, vy, vz
  - All time-varying
  - Robust, but not intuitive
- Keplerian Orbital Elements
  - a, e, i, Ω, ω, ν
  - Generally constant, except for the anomaly
  - Intuitive measure for a satellite's orbit

Useful Orbits

- Which orbits are useful?
- LEO: satellites require the least amount of energy to get into LEO; they travel around the Earth in the least amount of time
- GEO: satellites orbit the Earth once per day
- Molniya: satellites orbit the Earth in 12 hours and spend most of that time either above the USA or Russia.
- Polar orbits: mapping
- Sun-synchronous: satellite orbits that are fixed to the Sun's direction
- Earth-escape: interplanetary exploration
- This course will demonstrate how to design these and other orbits!

Applications of Astrodynamics

- International Space Station
- Satellite telephones (Iridium, etc.)
- Geosynchronous communications satellites
- Remote sensing satellites (Landsat, etc.)
- Global navigation satellites (GPS, Glonass, Galileo)
- Interplanetary navigation
- Geodetic satellites (Lageos, GRACE, etc.)
- Astronomy (motions of planets, asteroids, comets)
- Orbit determination (NORAD, etc.)
- Orbit debris studies
- AMSAT
- Changes in the Earth's climate

The Motion of a Satellite

- Satellites experience perturbations in their orbits that drive them away from being in perfect conic-section orbits.

  - Gravity
  - Solar Radiation Pressure
  - Atmospheric Drag
  - General relativity
  - Others

This course will study the good and bad outcomes of these perturbations

The Motion of a Satellite

- Satellites experience perturbations in their orbits that drive them away from being in perfect conic-section orbits.

  - Gravity
  - Solar Radiation Pressure
  - Atmospheric Drag
  - General relativity
  - Others

<u>Gravitational Perturbations</u>

Plus: Science!

Minus: Undesired effects

The Motion of a Satellite

- Satellites experience perturbations in their orbits that drive them away from being in perfect conic-section orbits.
  - Gravity
  - Solar Radiation Pressure
  - Atmospheric Drag
  - General relativity
  - Others

<u>SRP Perturbations</u>

Plus: Solar sails!

Minus: Satellite torquing

The Motion of a Satellite

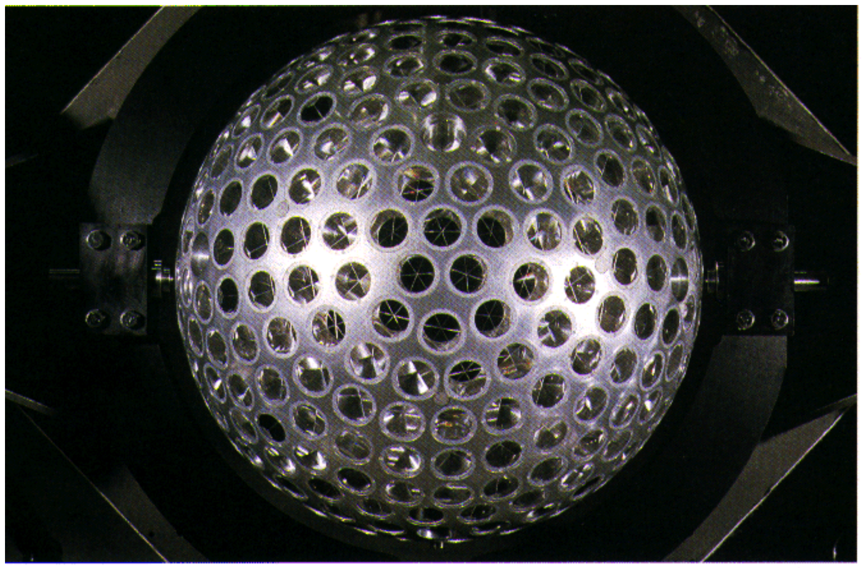
- Satellites experience perturbations in their orbits that drive them away from being in perfect conic-section orbits.
  - Gravity
  - Solar Radiation Pressure
  - Atmospheric Drag
  - General relativity
  - Others

<u>Atm Drag Perturbations</u>

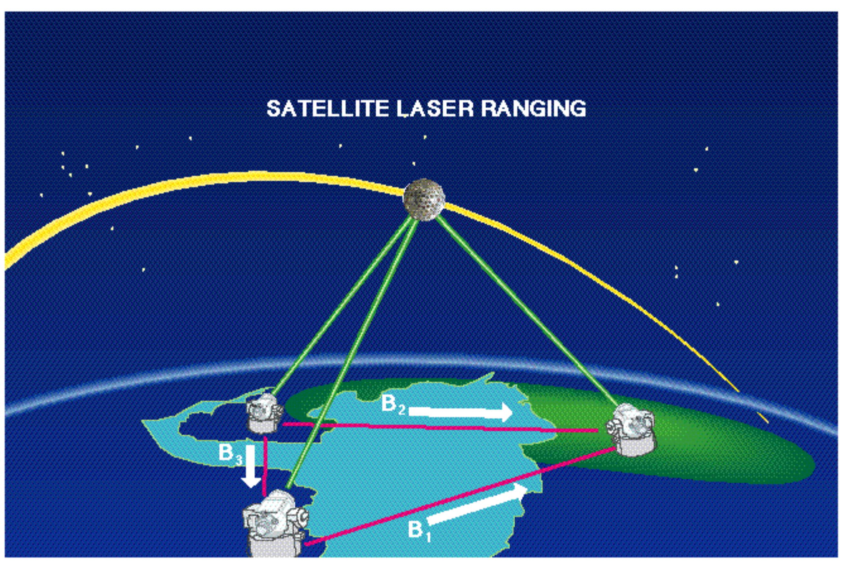
Plus: Reduces the orbital debris problem!

Minus: Operational satellites decay

LAGEOS-2 Satellite



Orbit Determination



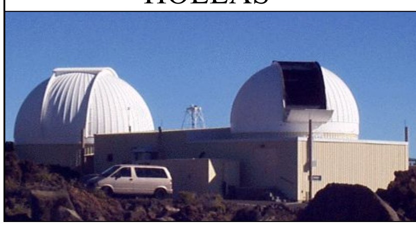
TLRS

MOBLAS

NASA Satellite Laser Ranging Network

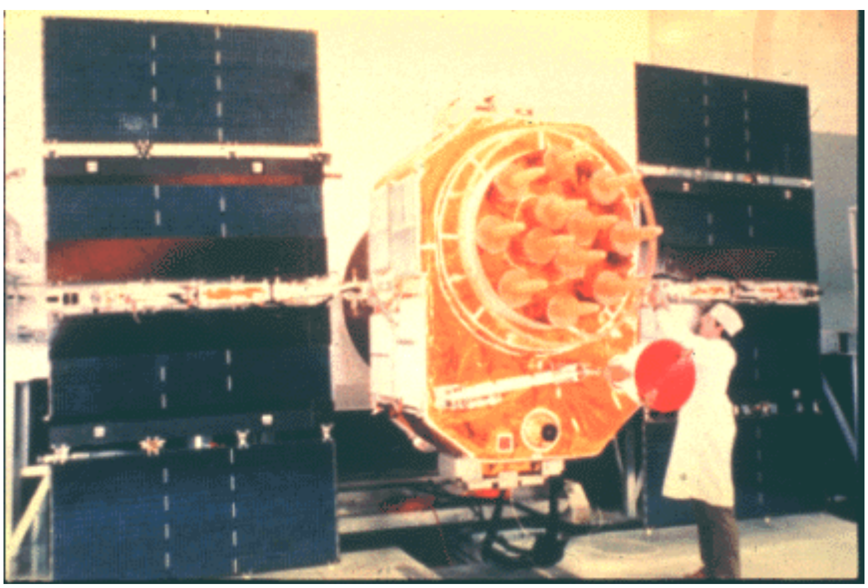
- 24 hours/day, 7 days/week operations
- Single operator
- Dominates Western & Southern Hemisphere coverage
- Most stations are transportable
- Subcentimeter ranging precision
- Hourly data processing and delivery

HOLLAS

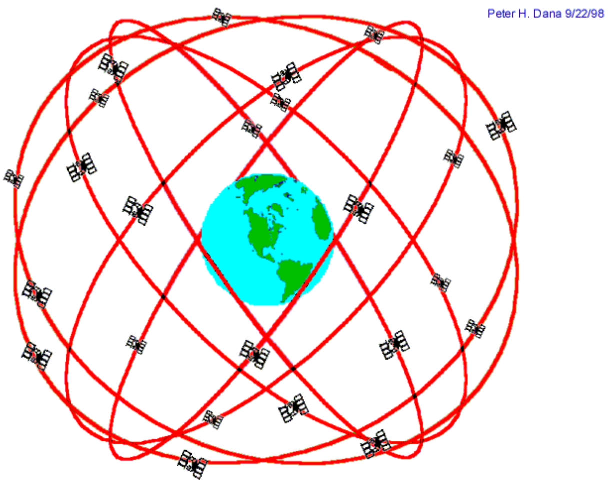


MLRS

GPS Satellite



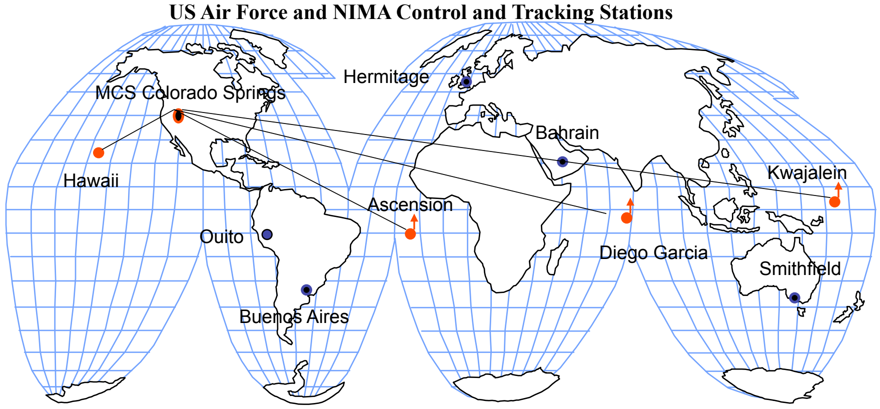
GPS Constellation



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

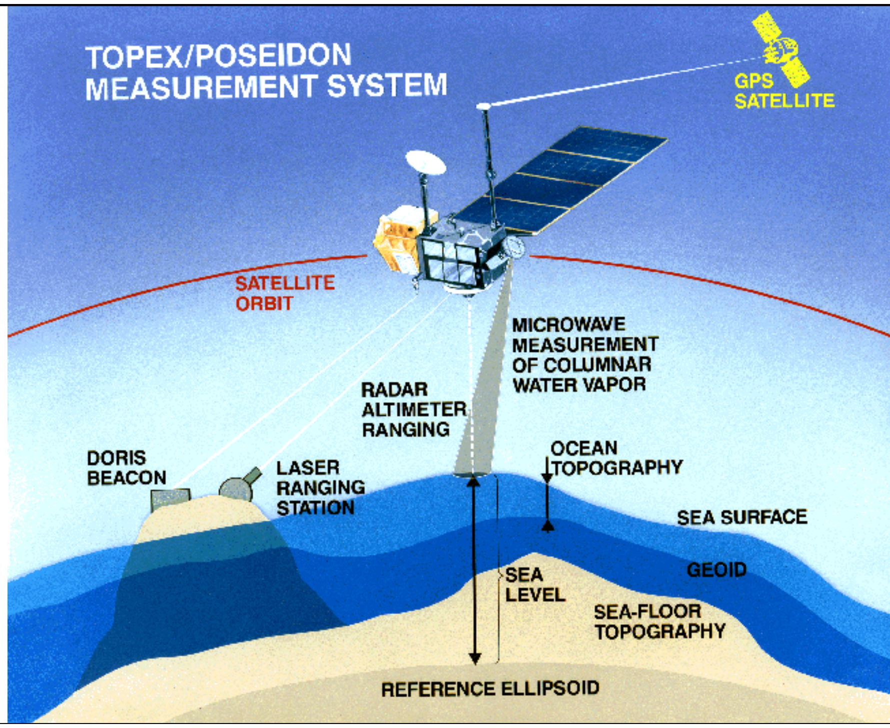
GPS Control Segment

US Air Force and NIMA Control and Tracking Stations

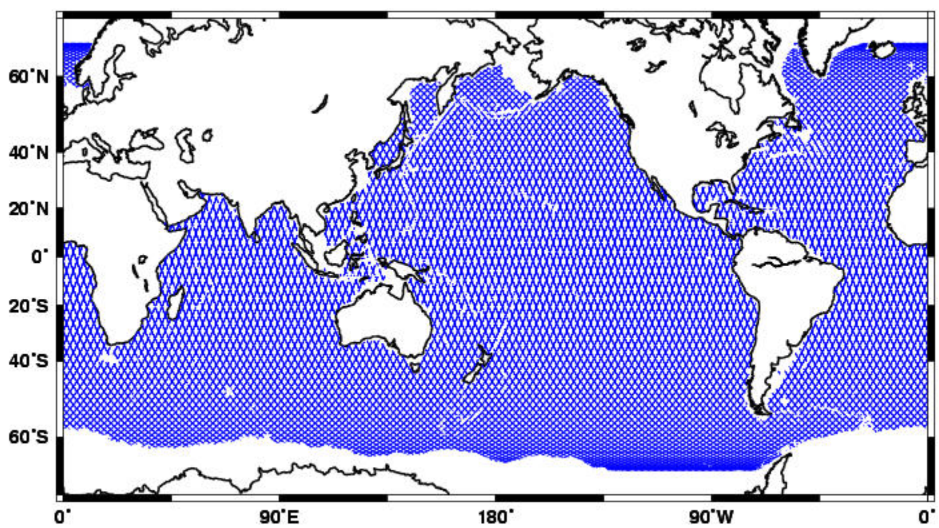


US Airforce Tracking Sites
US Airforce Upload Sites
US NIMA Tracking Sites

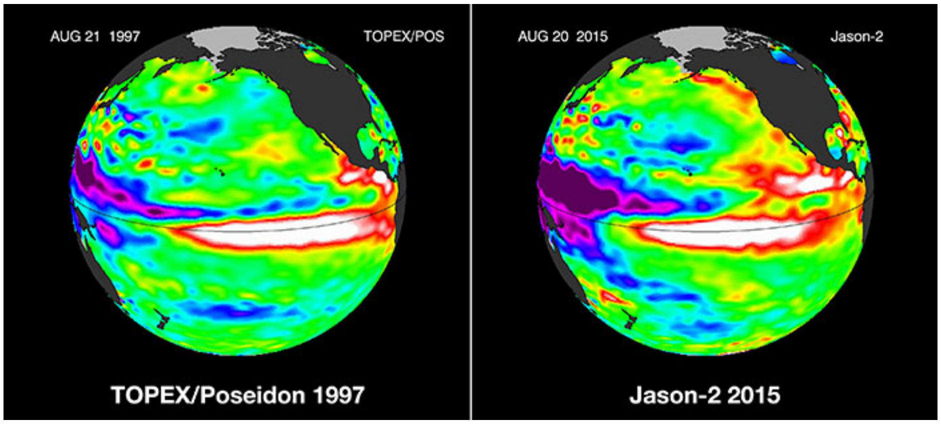
See also map at <http://164.214.2.59/GandG/sathtml>
MCS – Master Control Station

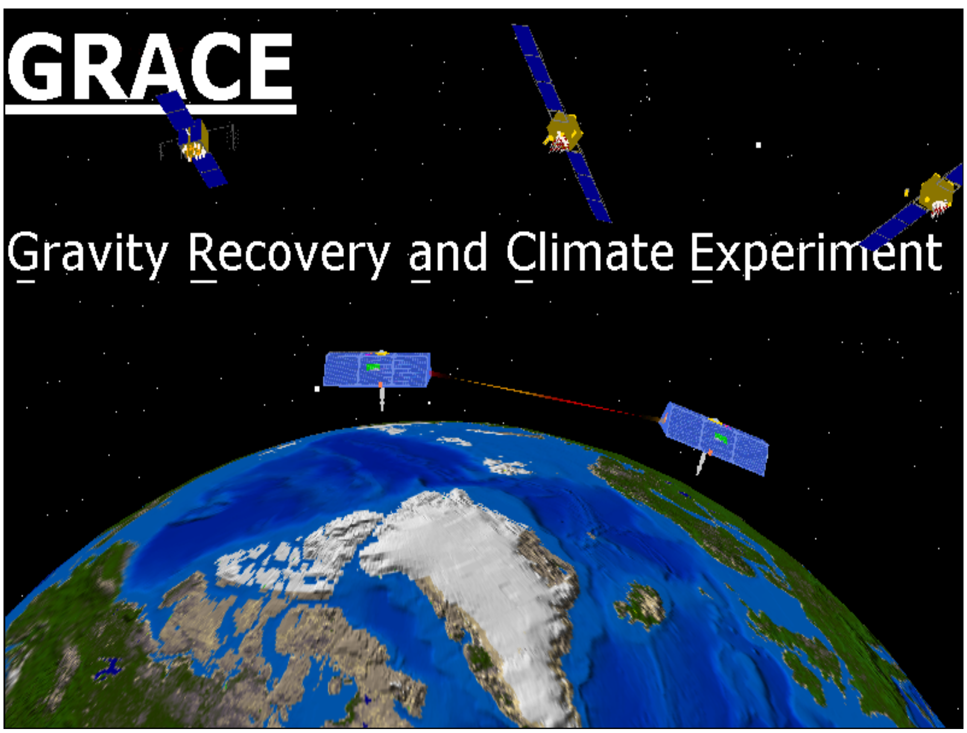


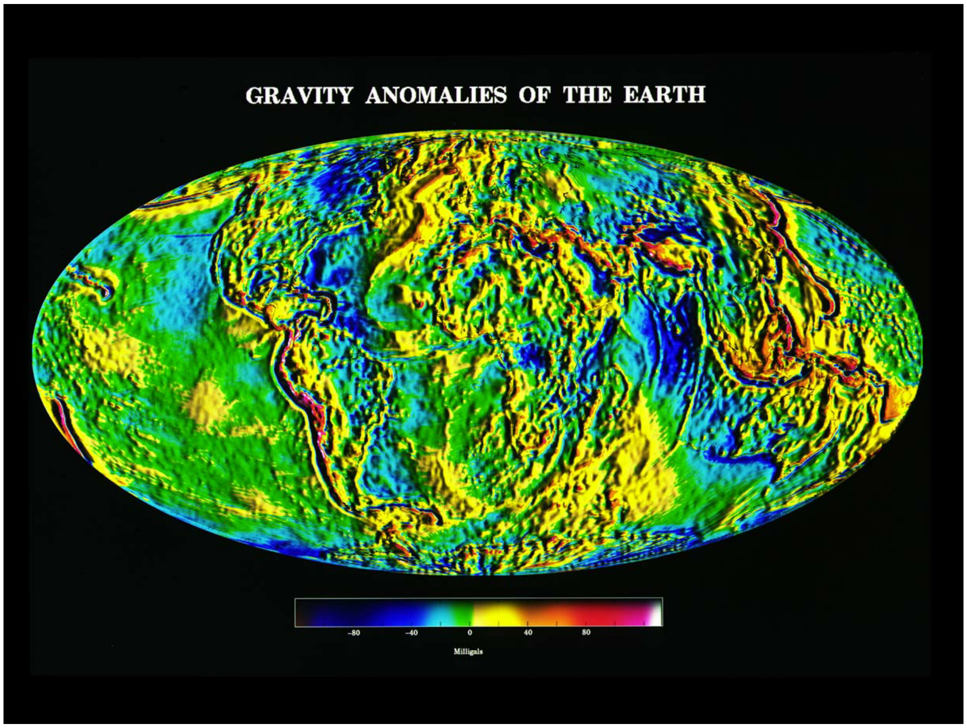
TOPEX/POSEIDON Groundtrack

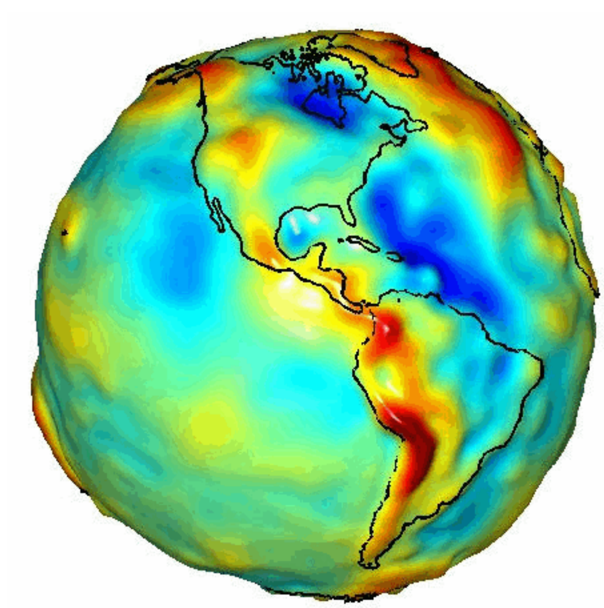


El Nino is Coming!

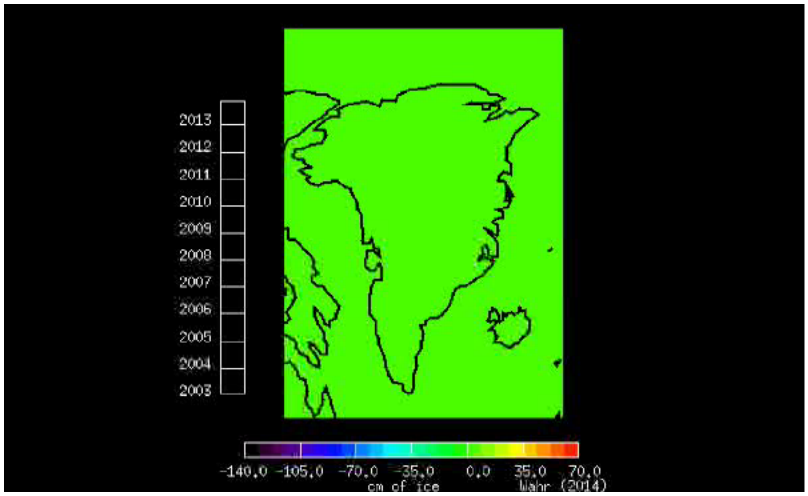




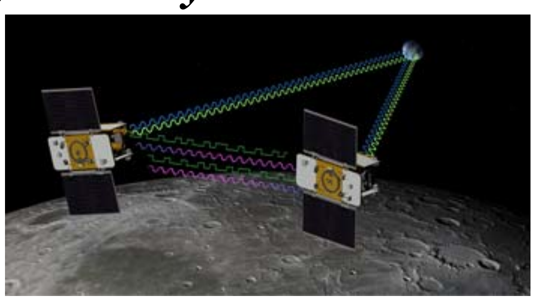

GRAVITY ANOMALIES OF THE EARTH
-80
-40
0
40
80
Milligals

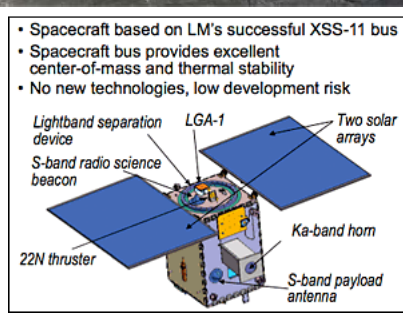


Greenland Mass Changes from GRACE

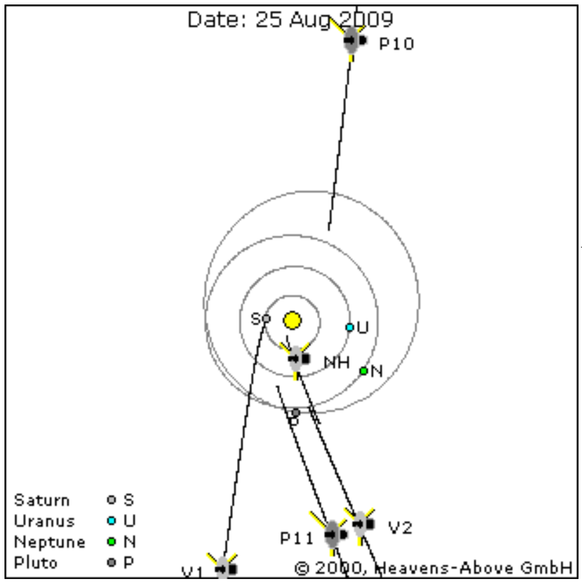


GRAIL
Gravity Recovery and Interior Laboratory





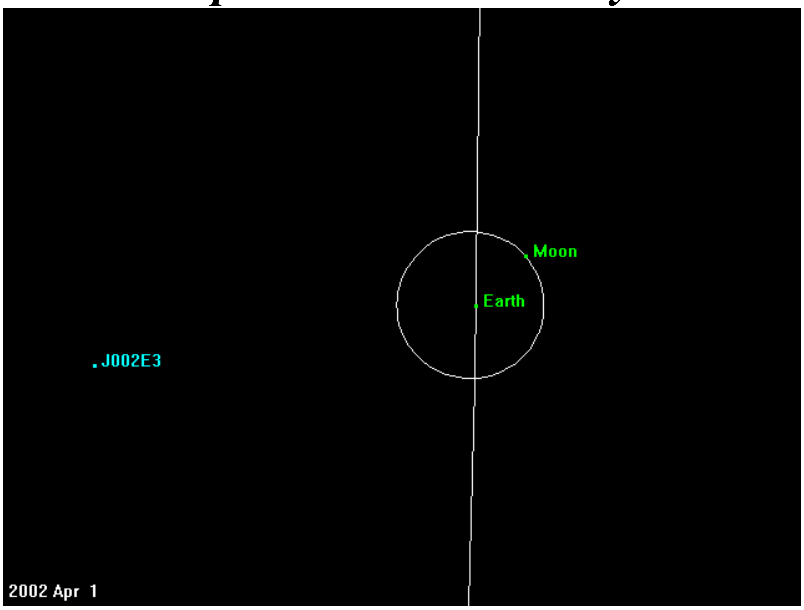
Escaping the Solar System

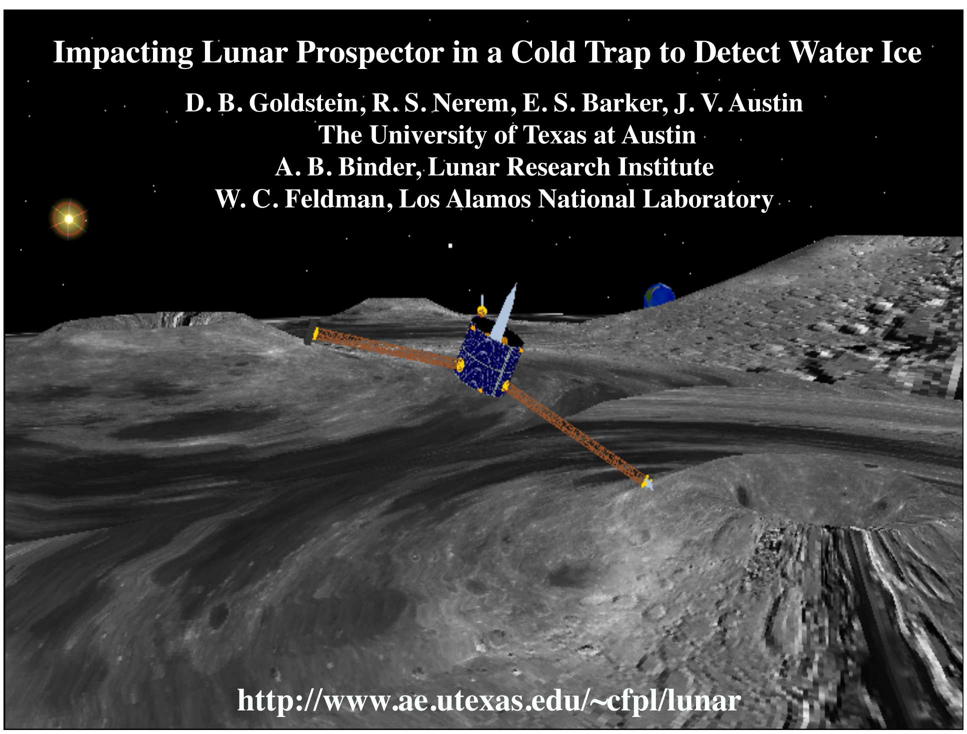


$$V_{escape} = \sqrt{\frac{2\mu}{r}}$$

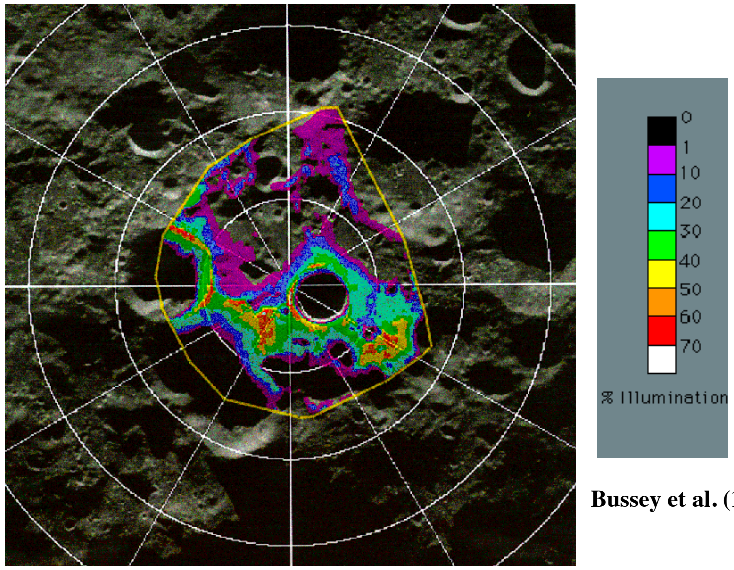
Mysterious Objects?

Apollo 14 Rocket Body



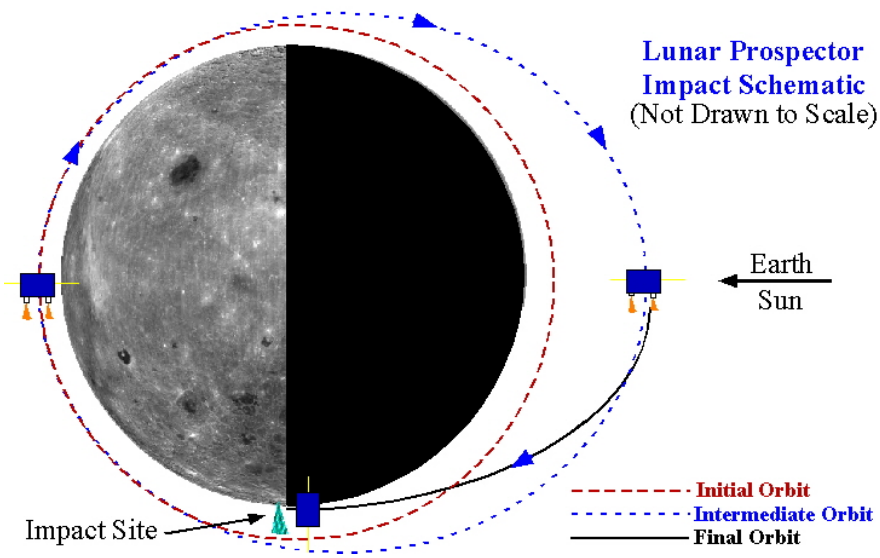


Illumination at the Lunar South Pole

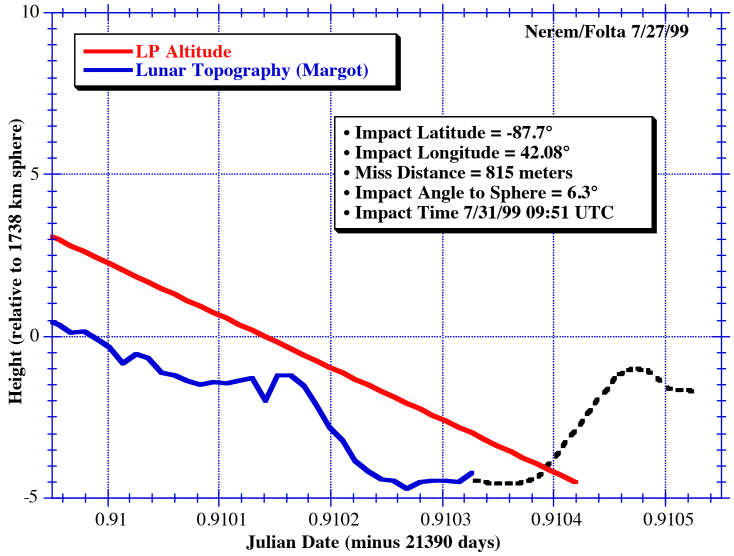


Bussey et al. (1999)

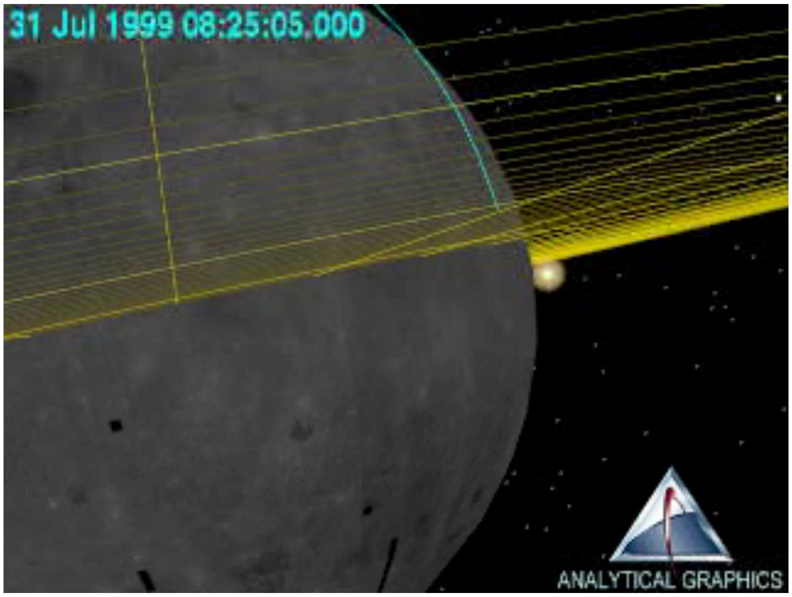
LP Impact Maneuver Design



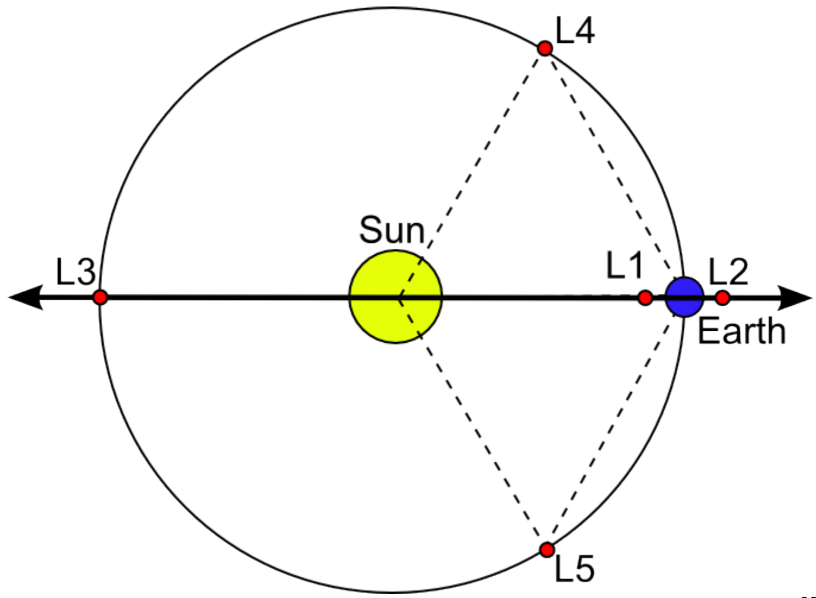
Lunar Prospector Impact Profile



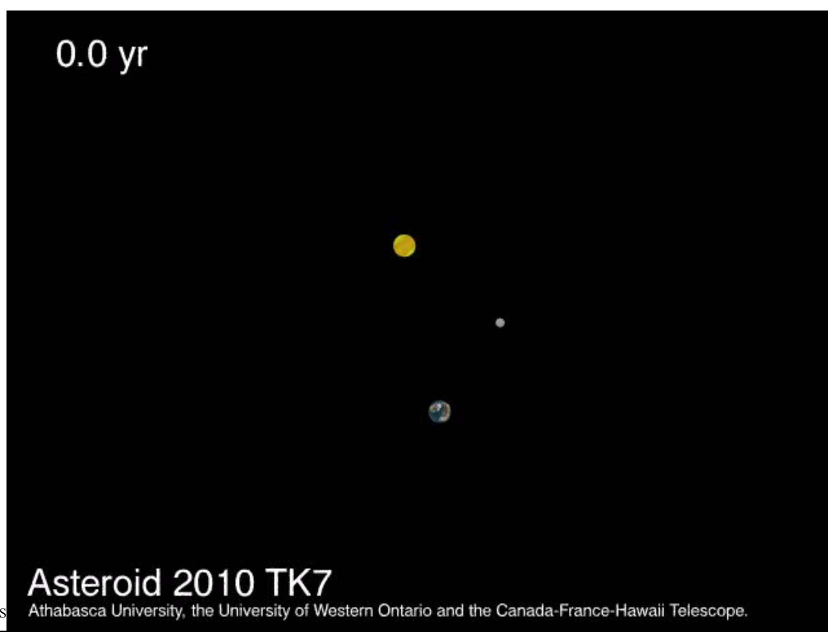
Lunar Prospector STK Simulation



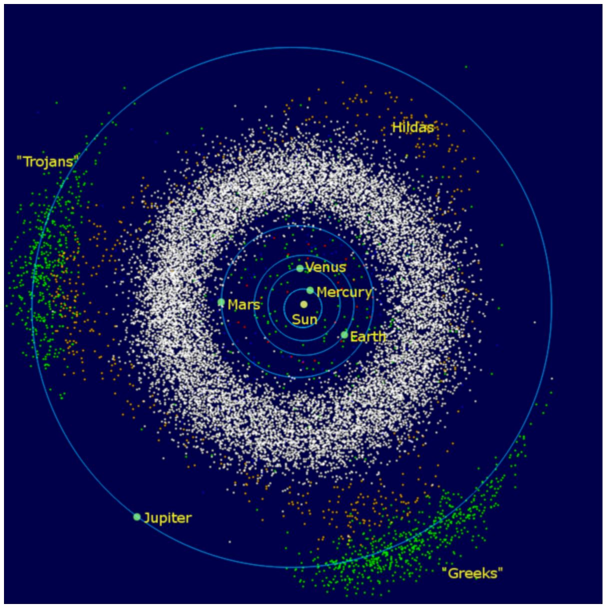
Earth-Sun Lagrange Points



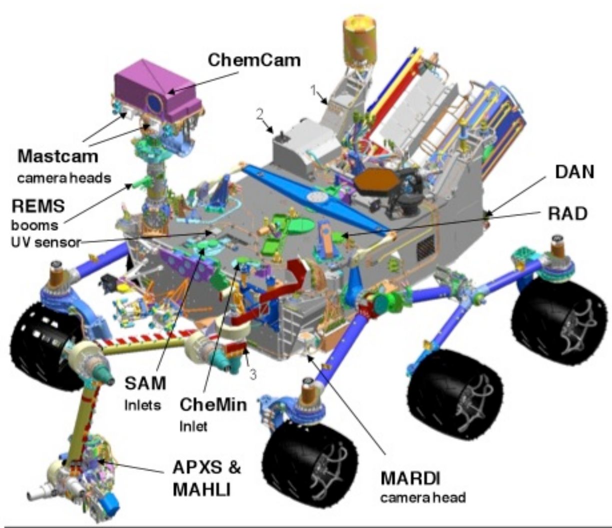
Trojan at Earth-Sun L4



Jupiter-Sun Trojans



Mars Curiosity Rover



Goals

- I'll be using as many real-world examples from spaceflight experience as I can.
- A similar class really changed the direction of my career – I hope I can do the same for you!
- Human spaceflight as well as robotic spaceflight, natural satellites as well as artificial satellites.

Final Statements

- This should be an exciting semester, and there's more to talk about than there will ever be time to talk about it!
- Homework 1 has already been assigned
  - Due in one week!
  - Explore the website "Heaven's Above"
- Distance students: request STK from me. In-class students: let me know if you need STK at home (academic version that expires after this semester)