Spacecraft Configurations

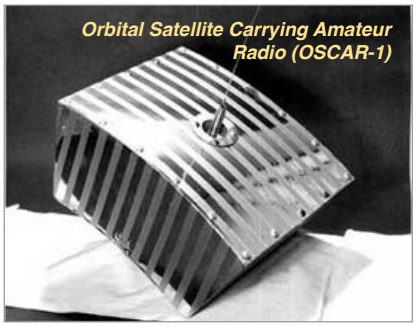
Space System Design, MAE 342, Princeton University

Robert Stengel

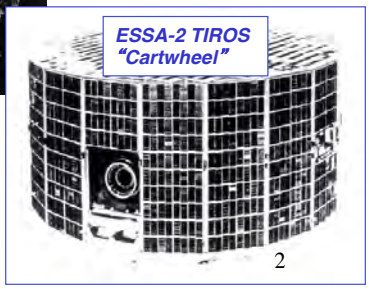
- Angular control approaches
- Low-Earth-orbit configurations
  - Satellite buses
  - Nanosats/cubesats
  - Earth resources satellites
  - Atmospheric science and meteorology satellites
  - Navigation satellites
  - Communications satellites
  - Astronomy satellites
  - Military satellites
  - Tethered satellites
- Lunar configurations
- Deep-space configurations

Angular Attitude of Satellite Configurations

- Randomly oriented satellites
  - Angular attitude is free to vary



- Spinning satellites
  - Angular attitude maintained by gyroscopic moment and magnetic coil
  - Axisymmetric distribution of mass, solar cells, and instruments



Attitude-Controlled Satellite Configurations

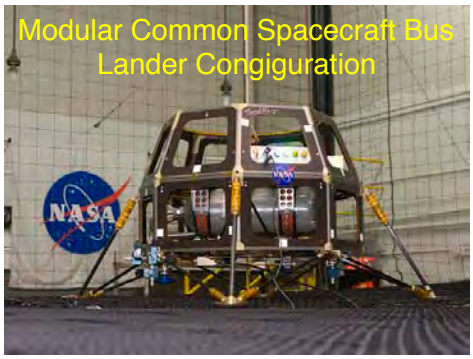
- **Dual-spin satellites**
  - Angular attitude maintained by gyroscopic moment and thrusters
  - Axisymmetric distribution of mass and solar cells
  - Instruments and antennas do not spin

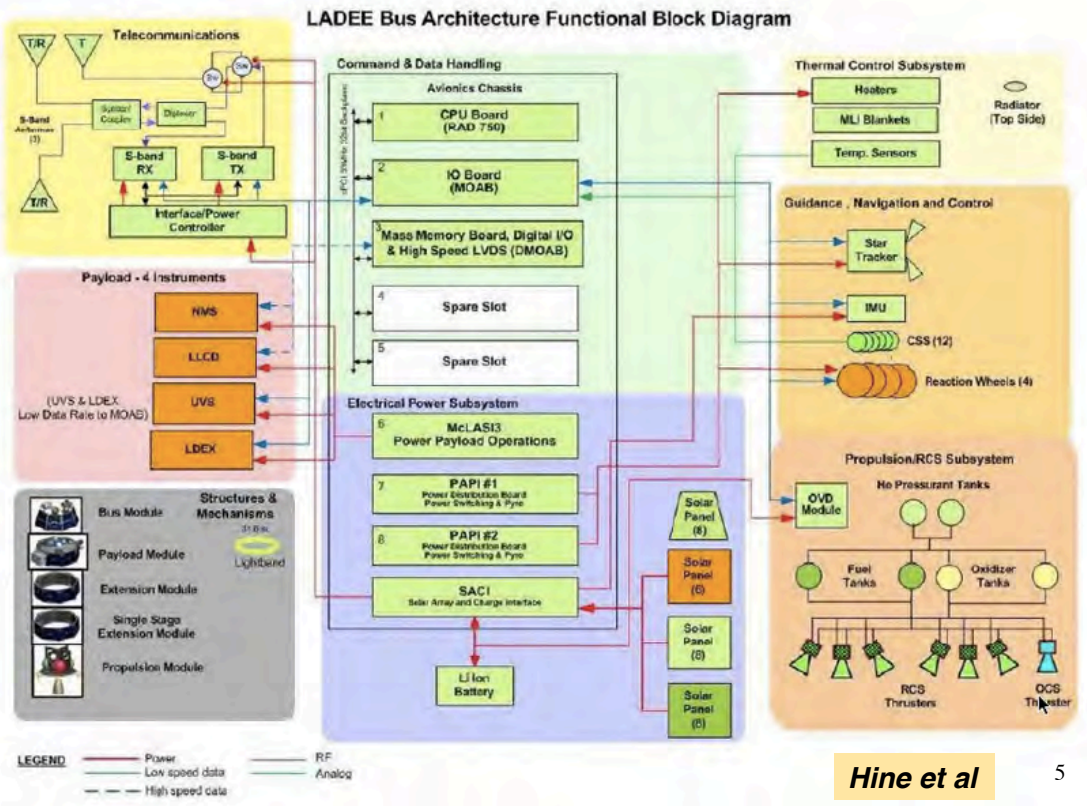
- **Attitude-controlled satellites**
  - Angular attitude maintained by 3-axis control system
  - Non-symmetric distribution of mass, solar cells and instruments

LADEE Bus Modules

Satellite Buses

Standardization of common components for a variety of missions





Hine et al

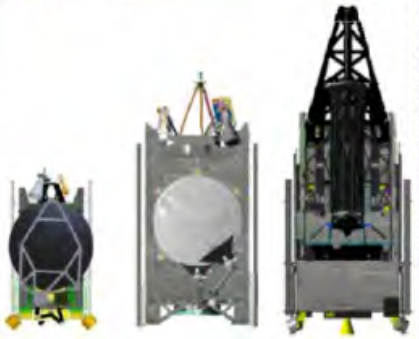
Evolution of Lockheed-Martin A2100 Bus

- 1990s to present
- Orbit maintenance with ion engines and hydrazine thrusters
- Bi-propellant liquid apogee motor

Satellite Buses

Phantom Phoenix Prototypes

702 Product Line

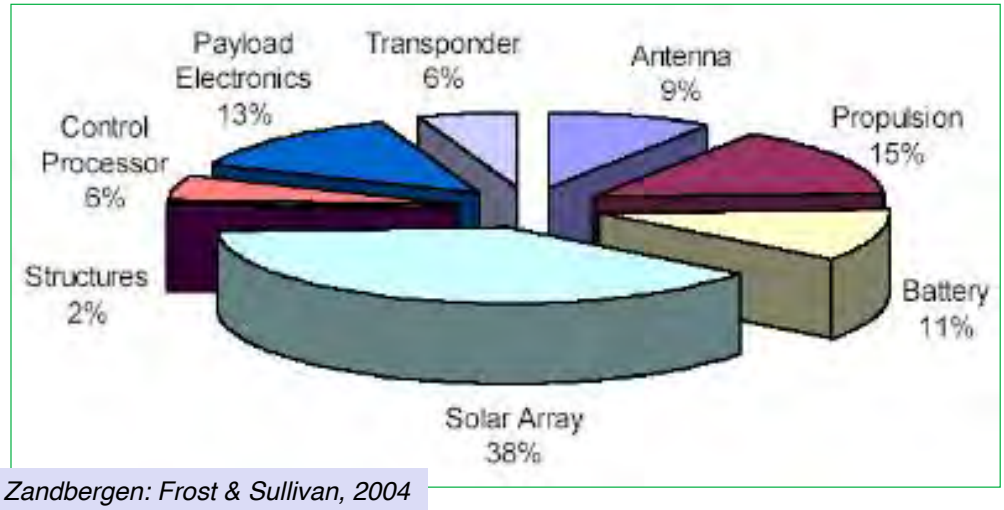


Vehicle	Phoenix Nano	Phoenix ESPA	Phoenix	702SP	702MP	702HP
Payload Power (Cont./Peak)	36W /70W	90W /135 W	280W – 700+W	3.5kW – 7.5 kW	6.0kW – 12 kW	8kw – 12+kW
Total SV Mass	4 – 10 kg	180 kg	500 – 1000 kg	1500-2000 kg	5800-6100 kg	5400-5900 kg
Design Life	1 year	1-5 years	7+ years	15+ years	15+ years	15+ years

7

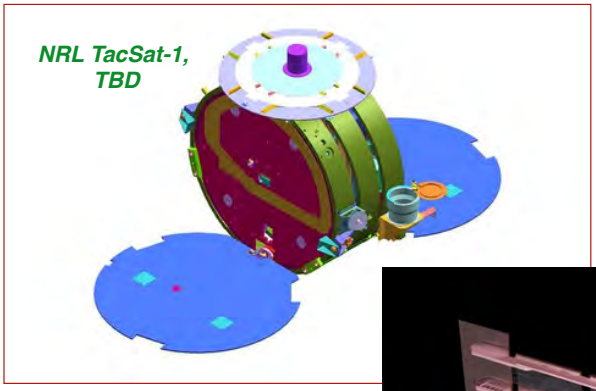
Bus Reliability Analysis

Percentage of Insurance Claims by Anomaly Type

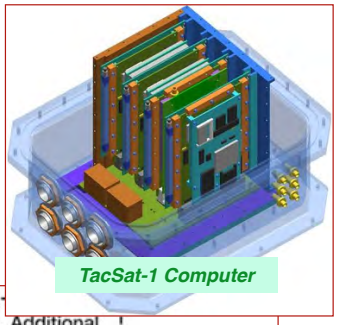


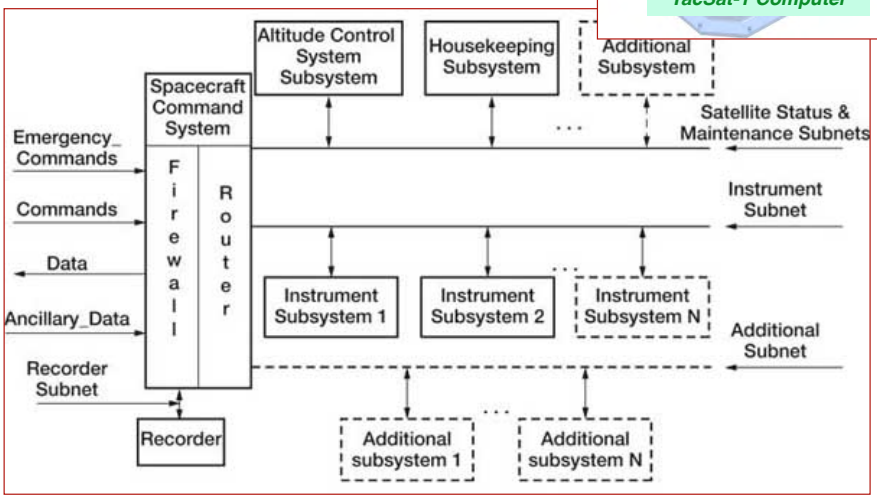
Zandbergen: Frost & Sullivan, 2004

Small Satellite Buses



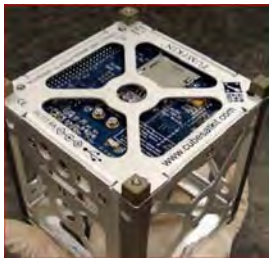
TacSat-1 Linux Instrumentation Bus

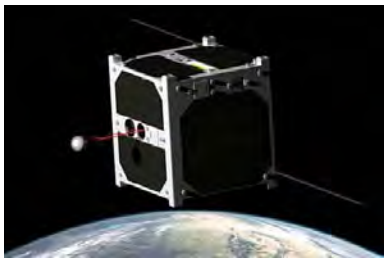




CubeSats

- **Standardized module**
  - **10-cm cube**
  - **1 liter volume**
  - **Maximum mass = 1.33 kg**
- **Multiple module designs**

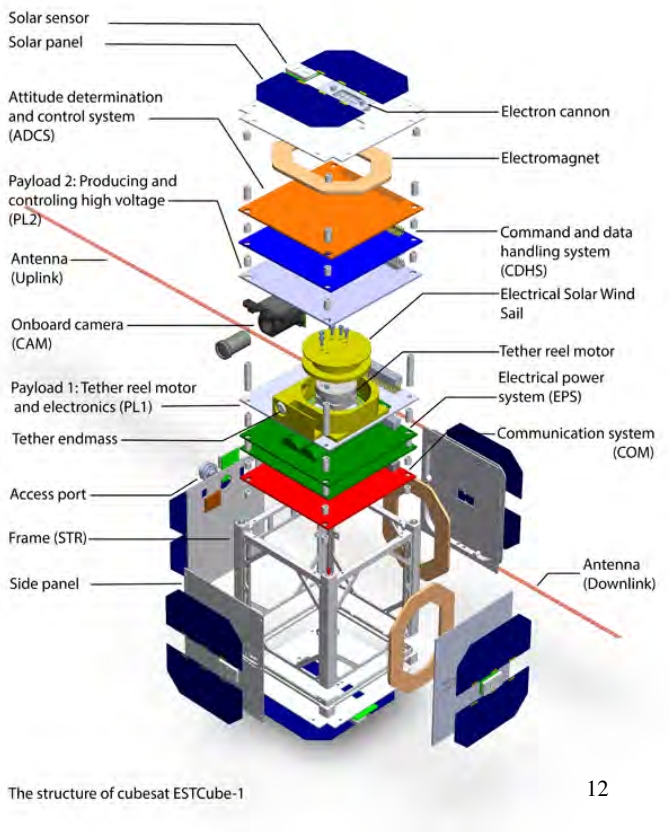




http://en.wikipedia.org/wiki/Cubesat

http://www.cubesatkit.com

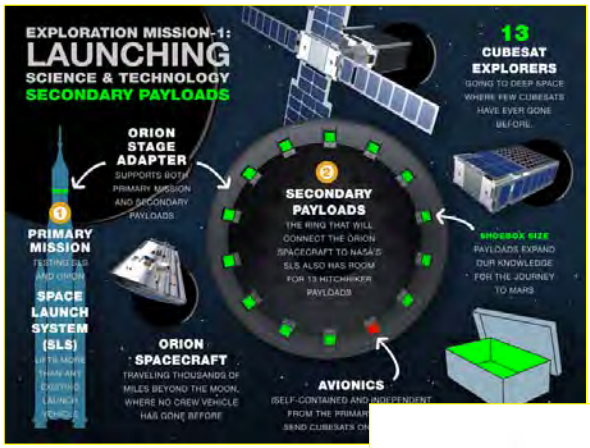
CubeSats

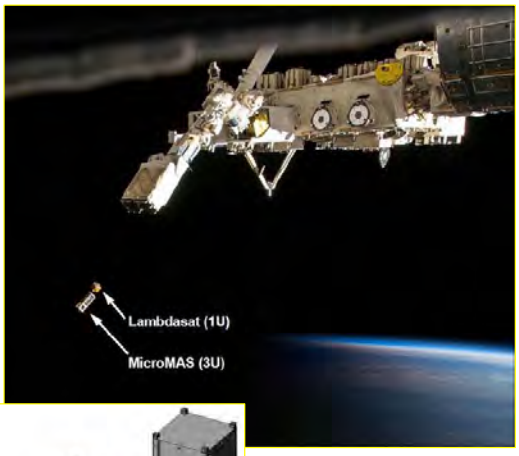


The structure of cubesat ESTCube-1

CubeSats

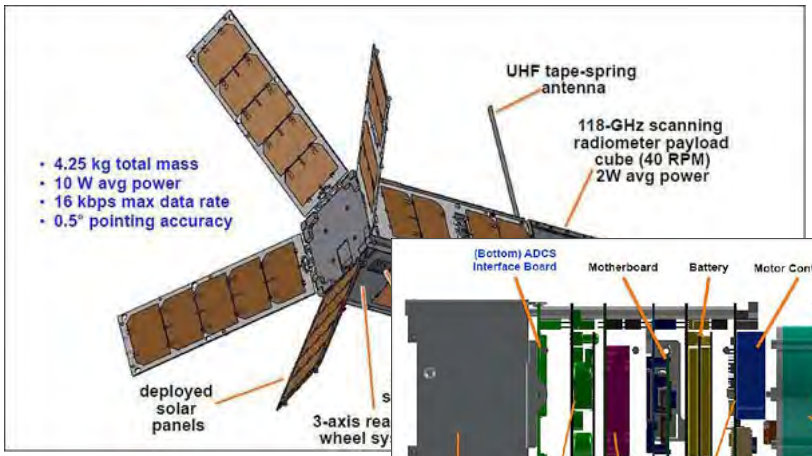
Secondary payloads or launched directly from International Space Station

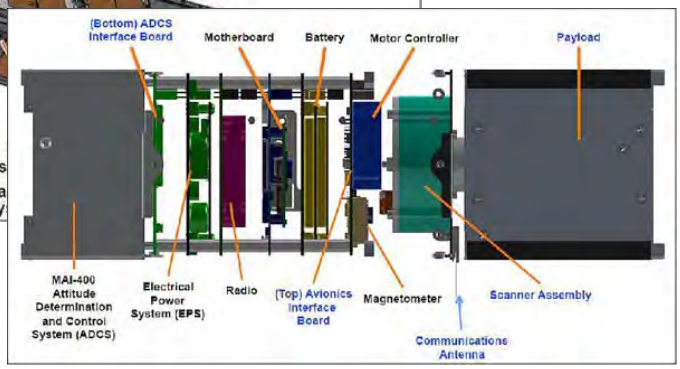




Micro-MAS 3U CubeSat

https://directory.eoportal.org/web/eoportal/satellite-missions/m/micromas-1





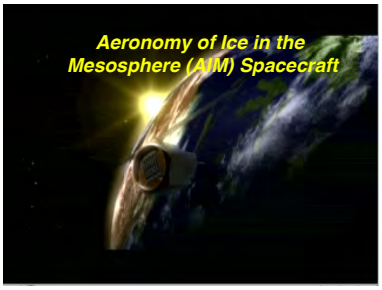
Near-Earth Spacecraft

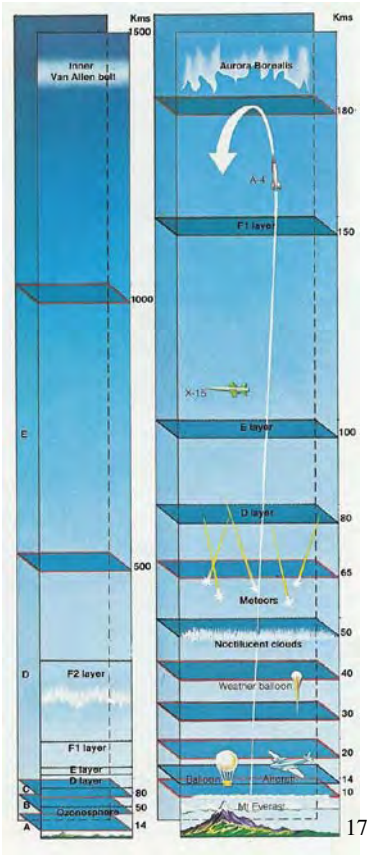
Earth Observation Satellites

- Mission
  - –Determine properties of the earth's land and water features
- Typical instrumentation
  - –Multi-spectral imaging (e.g., *Aqua*)
    - Scanning radiometer
    - Spectroradiometer
    - Microwave sounding
    - Infrared sounding
    - Humidity sounding
    - Earth's radiation budget
  - –Integration with meteorological satellites
  - –Commercial and research operators
  - –High-resolution optical imagery

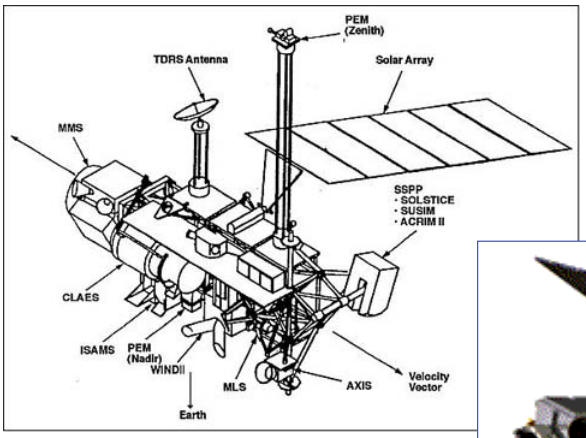
Atmospheric Science Satellites

- Mission
  - –Determine properties of the near-earth environment
- Typical instrumentation
  - –Direct measurements of the ionosphere
    - Density, temperature, ionic concentrations, cosmic radiation
  - –Magnetic and electric fields
  - –Multi-spectral transmission measurements through the lower layers
    - Radio
    - Light
  - –Spacecraft charging

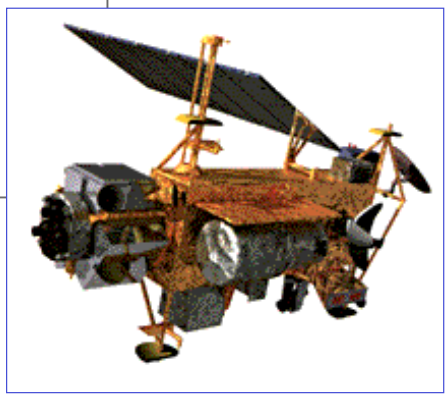




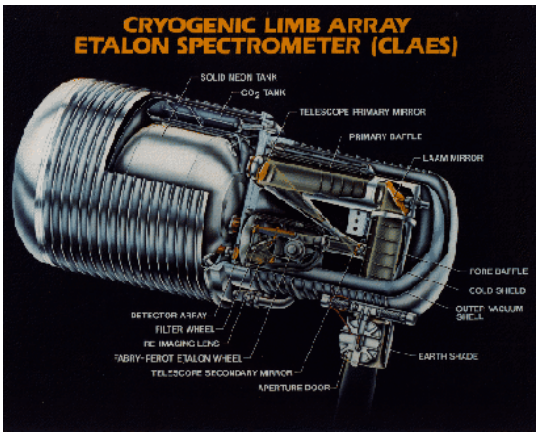
Upper Atmospheric Research Satellite (UARS)



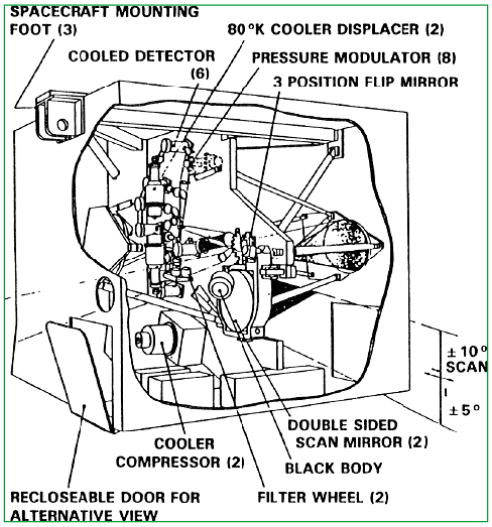
- Launched in 1991
- Deactivated in 2005
- Decayed in 2011
- Orbit altitude: 574 x 575 km
- 5,900 kg
- Power = 1.6 KW



Two UARS Instruments



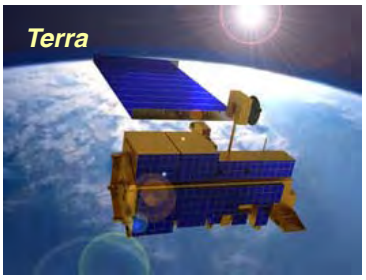
- **CLAES:** nitrogen, chlorine, ozone, water, and methane from IR signature
- **Etalon:** Fabry-Perot interferometer measures light wavelengths

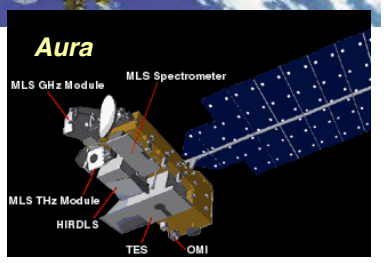


- **IR radiometer:** temperature, water vapor, nitrogen oxides, volcanic aerosols

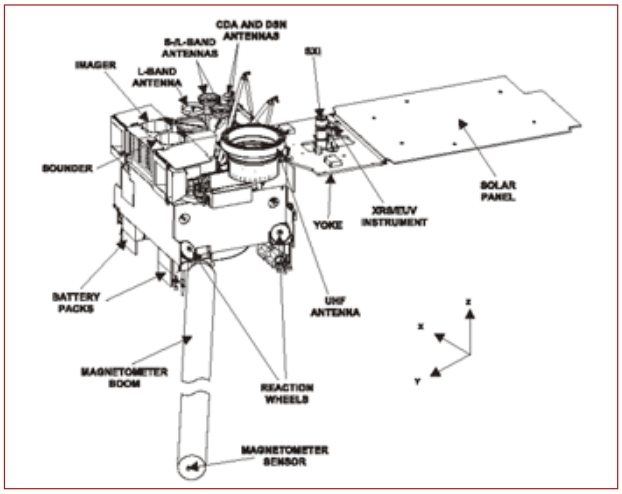
Earth/Atmosphere Observing Constellation

- Earth Observing System combines data from formation of satellites
- Successors to *UARS*
- Studying ozone, air quality, and climate
  - –High-resolution dynamics limb sounder
  - –Microwave limb sounder
  - –Ozone monitoring instrument
  - –Tropospheric emission spectrometer
- "A-Train" constellation also includes multi-national *Cloudsat*, *Calipso*, *Metop-1*, and *Parasol* satellites



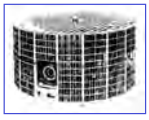


Meteorology Satellites



- Mission
  - Determine global and local weather
- Geostationary Operational Environmental Satellites (GOES), Defense Meteorological Satellite Program (DMSP) spacecraft operated by NOAA
- Typical instrumentation
  - Multi-spectral imaging of the atmosphere
  - Data relay from buoys, search & rescue beacons
  - Solar monitoring

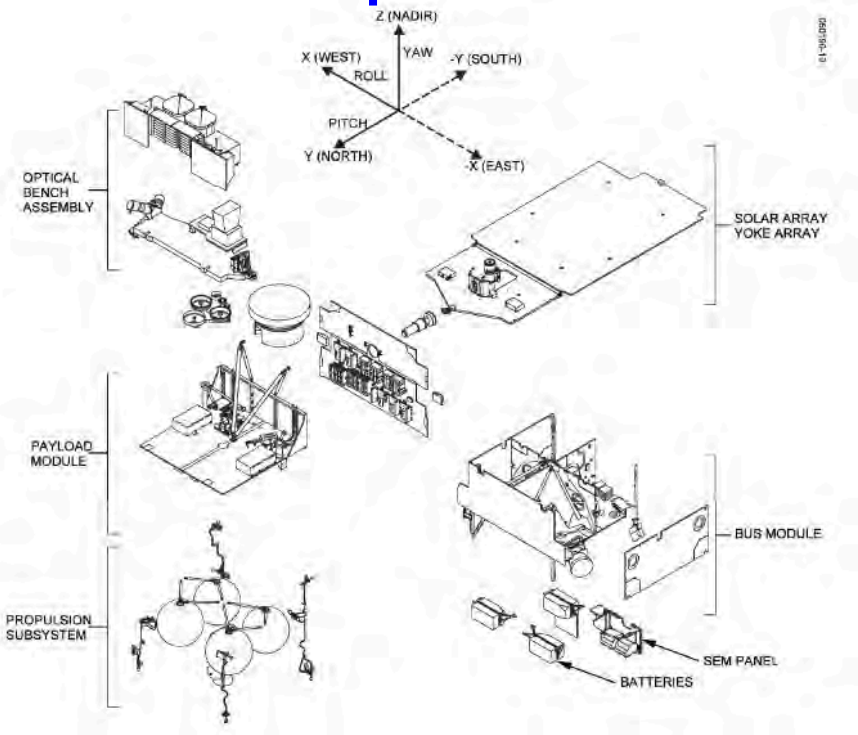
Evolution of TIROS



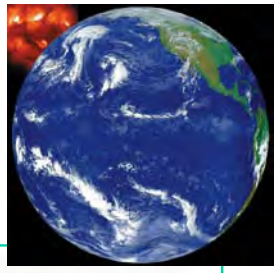
Geostationary Operational Environmental Satellite (GOES-NOP)

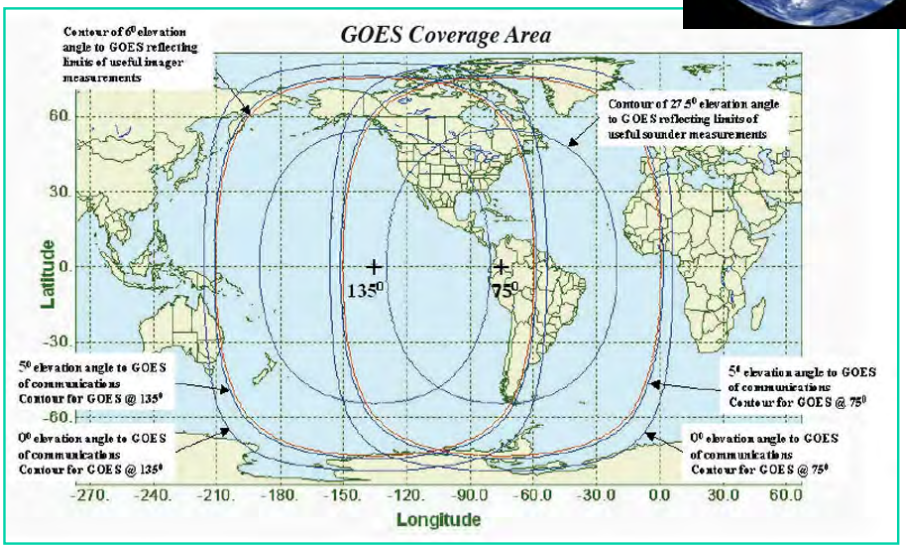
http://goes.gsfc.nasa.gov/text/GOES-N_Databook/databook.pdf

GOES Expanded View

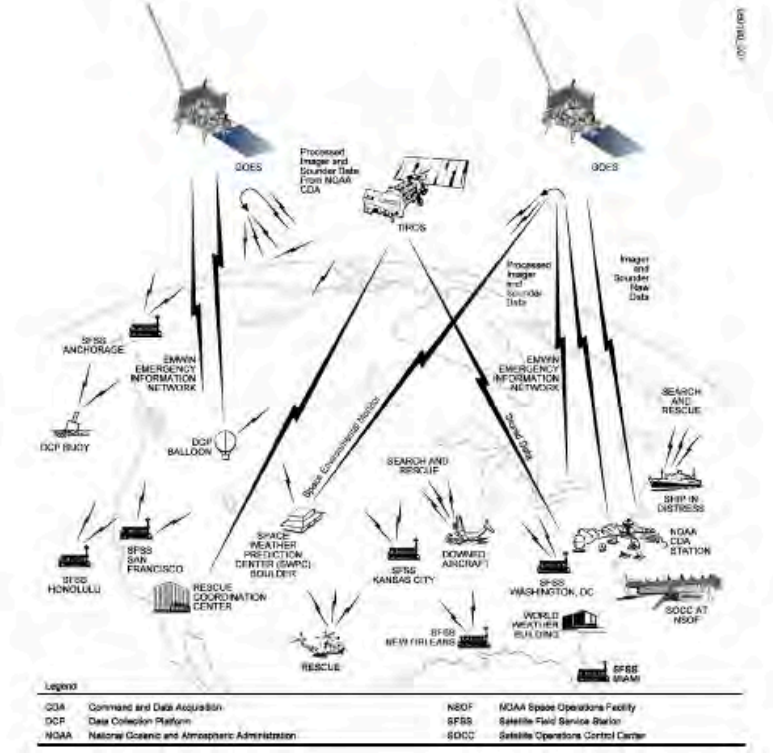


GOES Coverage Emphasizes the Western Hemisphere



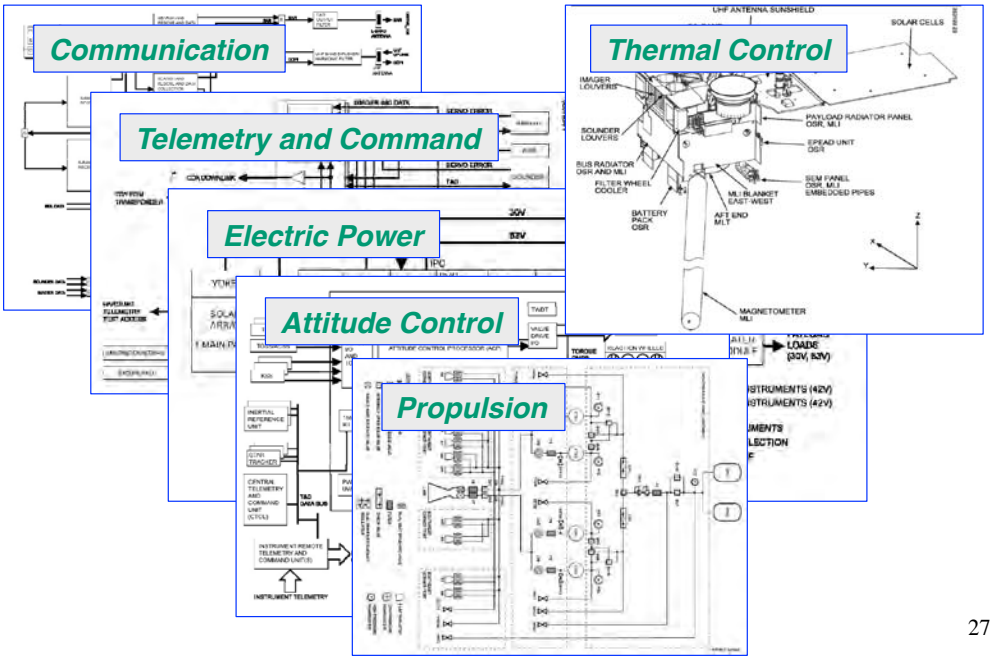


GOES Weather Watch System



GOES Sub-Systems

(details in future slide sets)



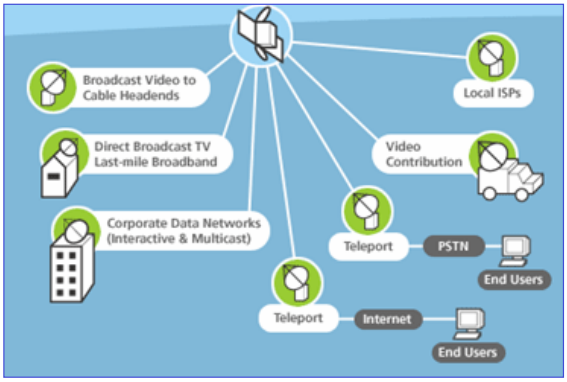
Navigation Satellites

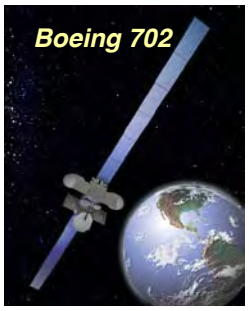
- **Mission**
  - –Aid position and velocity determination
- **Global Positioning System (GPS) Implementation**
  - –24 satellites (minimum) in circular, medium earth orbit
  - –6 orbital planes, 55° inclination
  - –Atomic clocks provide precise time reference
  - –Broadcast ephemeris (i.e., orbital elements)
  - –Pseudo-random pulse code
- **GLONASS, Galileo, Compass, DORIS, IRNSS, QZSS**

Communication Satellites

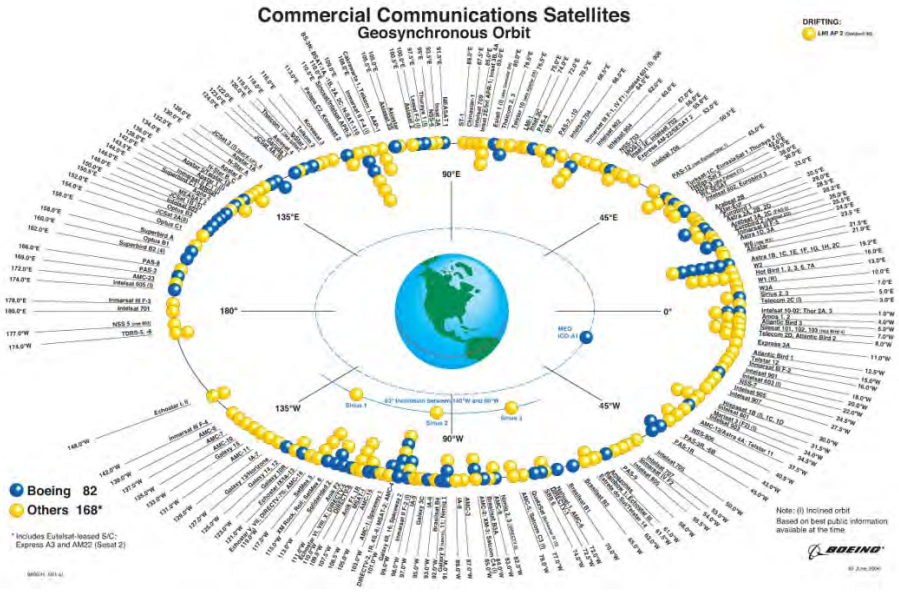
- Mission
  - –Facilitate global communications
- Implementation
  - –Transponders with dedicated coverage areas
  - –Most satellites are in geosynchronous orbit
  - –Iridium constellation of 66 satellites in low earth orbit
    - Direct connection from satellite to phone

Iridium Constellation





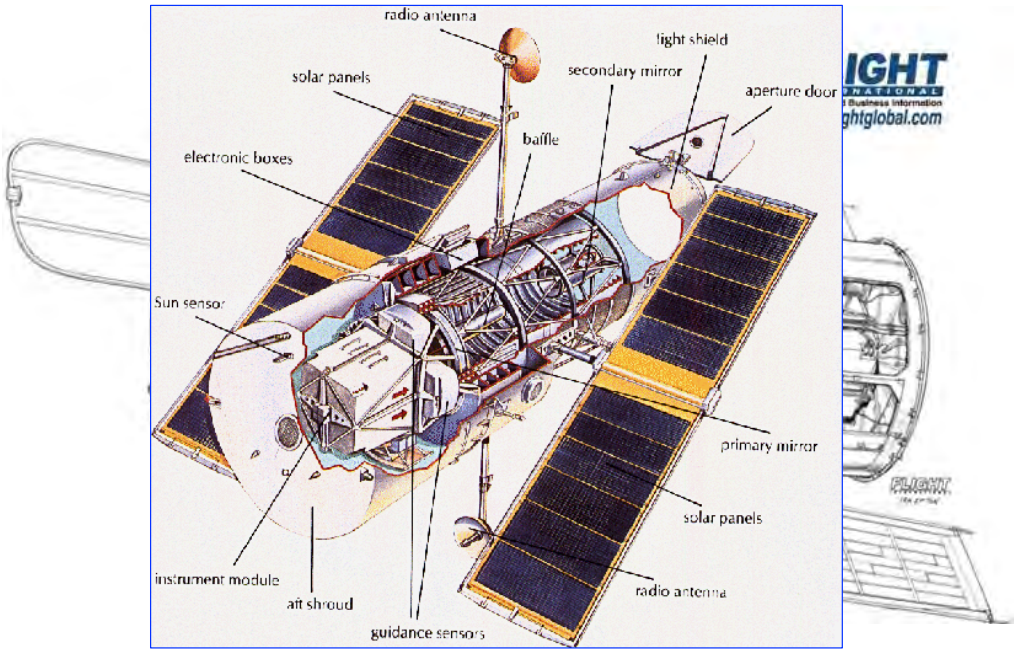
Geosynchronous Communication Satellites in Orbit, June 2006



Astronomy Satellites: Hubble

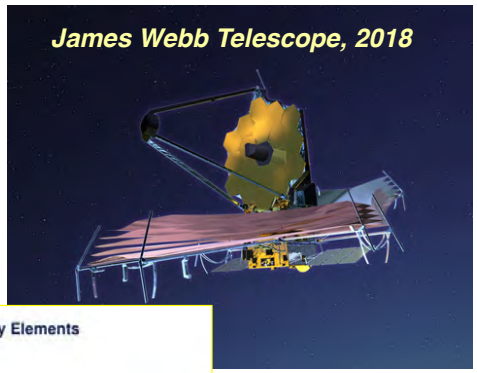
- **Mission**
  - –Conduct astronomical observations outside the earth's atmosphere
- **Typical instrumentation**
  - –Multi-spectral imaging
  - –Hubble Telescope serviced by Space Shuttle missions (590-km orbit)
  - –Telescope aberration repaired by astronauts

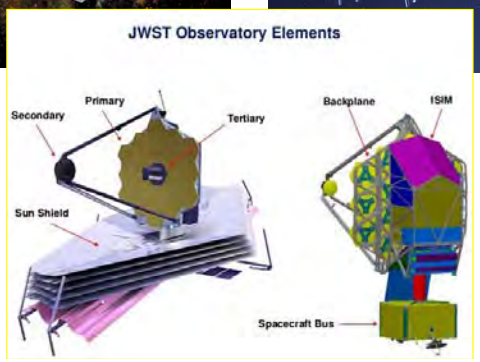
Astronomy Satellites: Hubble



Astronomy Satellites

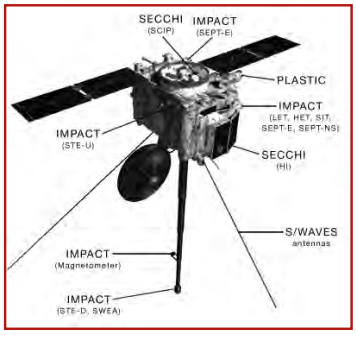
Chandra X-ray observatory (Shuttle launch, 1999)
James Webb Infrared Telescope to be located at L_2 Lagrange point





STEREO, 2006
(Solar TErrestrial RElations Observatory)

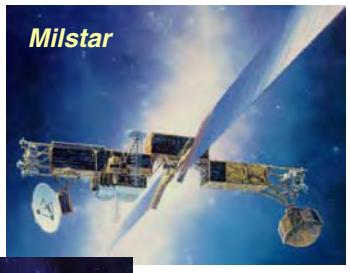
- **Dual satellites**
  - **Nearly identical space-based observatories - one ahead of other in Earth orbit**
  - **Stereoscopic measurements to study the Sun and the nature of its coronal mass ejections, or CMEs.**
- **Scientific objectives**
  - **Understand the causes and mechanisms of coronal mass ejection (CME) initiation.**
  - **Characterize the propagation of CMEs through the heliosphere.**
  - **Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium.**
  - **Improve the determination of the structure of the ambient solar wind.**



http://stereo.gsfc.nasa.gov/instruments/instruments.shtml

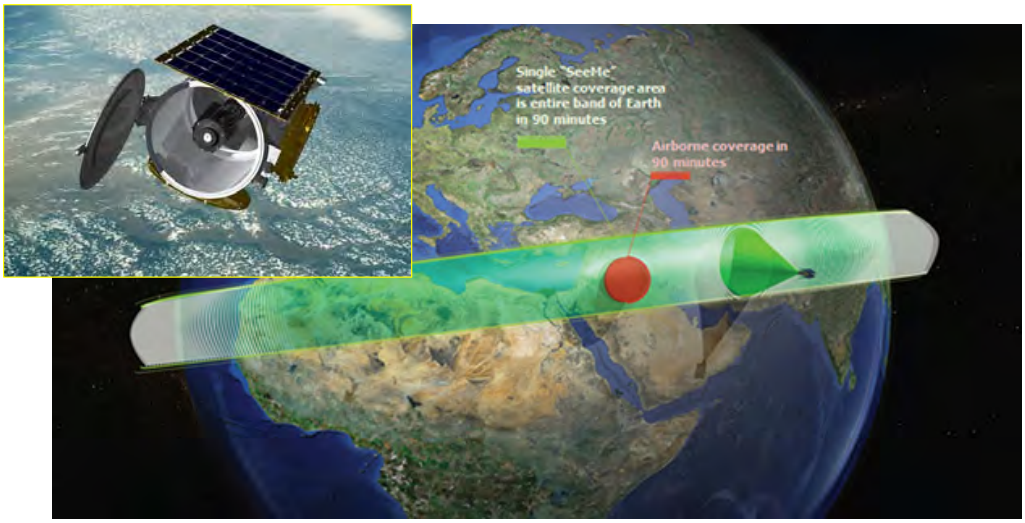
Military Satellites

- **Missions**
  - Secure observations from space
  - Early warning
  - Reconnaissance
  - Intelligence
  - Communications
  - Navigation
  - Weather
  - Weaponry



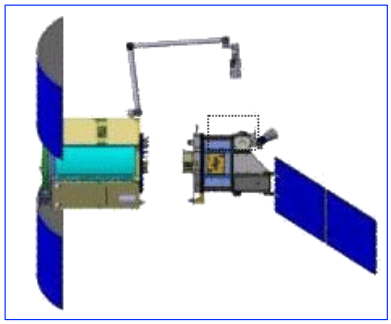
DARPA SeeMe Constellation

- Two dozen small satellites
- Low-altitude orbits, 60-90-day mission duration
- Imaging of remote locations with <90-min delay
- Downlink to handheld units



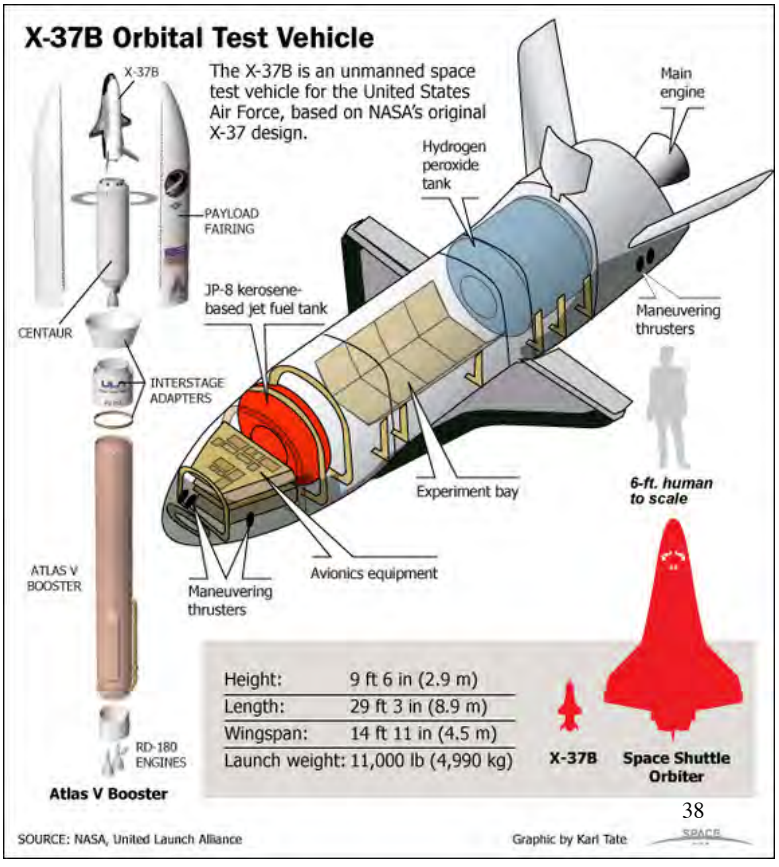
Orbital Express: ASTRO and NEXTSat

- DARPA, 2007
  - –Automatic rendezvous, docking, and undocking
  - –On-orbit transfer of replaceable units
  - –6DOF robot arm
  - –Video guidance sensor
  - –Atlas 5 launch

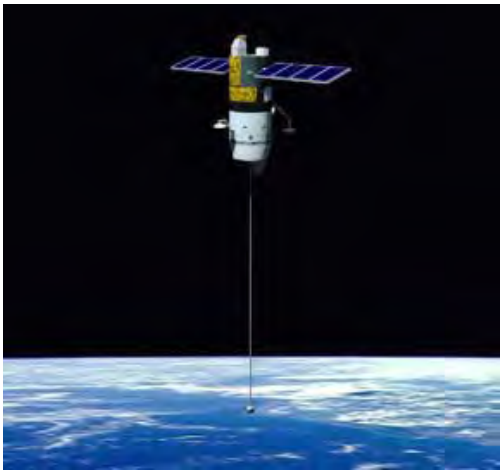


USAF X-37B

- Reusable experimental/ operational vehicle
- Unmanned "mini-Space Shuttle"
- Highly classified project
- Rocketdyne AR2-3 motor
  - H_2O_2/JP-8
  - Isp = 245 s



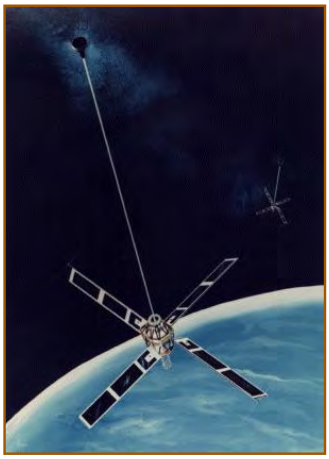
Tethered Satellites



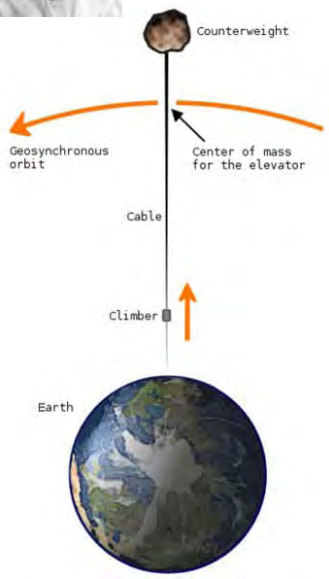
Space Shuttle STS-75 Tethered Satellite Experiment, Feb 1996
http://www.nss.org/resources/library/shuttlevideos/shuttle75.htm

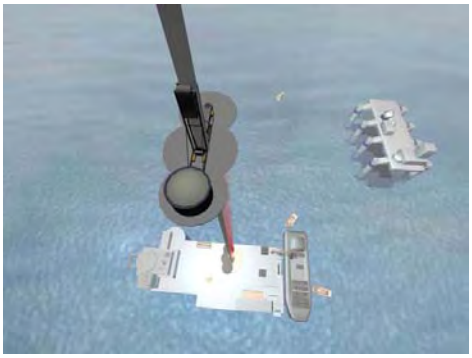
Gravity-Gradient-Stabilized Satellites

NRL TiPS ***Transit*** ***NASA TSS***



Gravity-Gradient-Stabilized Space Elevator





- Counterweight in geo-stationary orbit
- Earth station moored at the equator

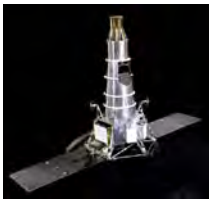
Lunar Spacecraft

Robotic Lunar Spacecraft

1959




1964

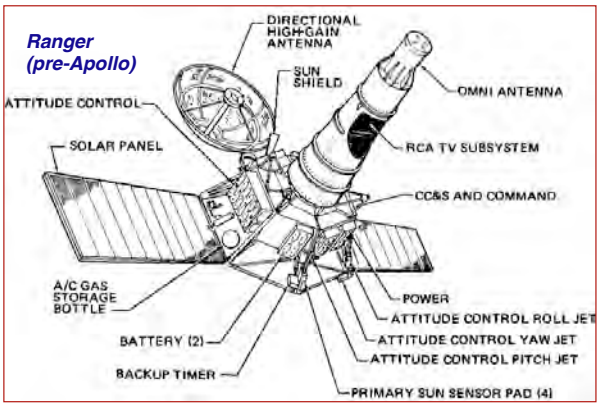


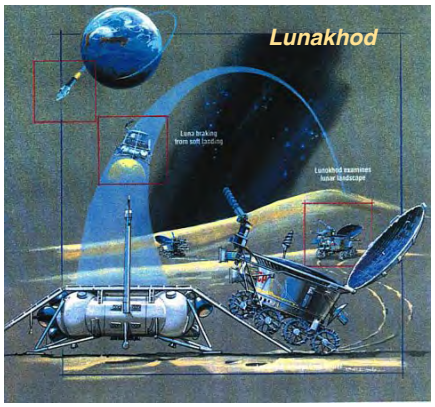
1966

1966


Early Lunar Spacecraft

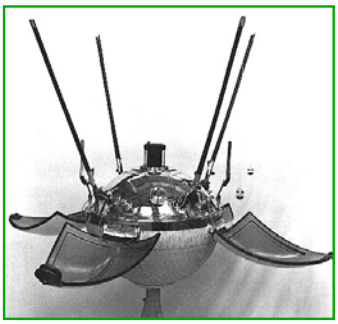
- **Mission**
  - **Scientific discovery**
  - **Preparations for human voyages to the moon**
- **Robotic exploration of the moon**
  - http://en.wikipedia.org/wiki/Robotic_exploration_of_the_Moon





Pre-Apollo Lunar Landers

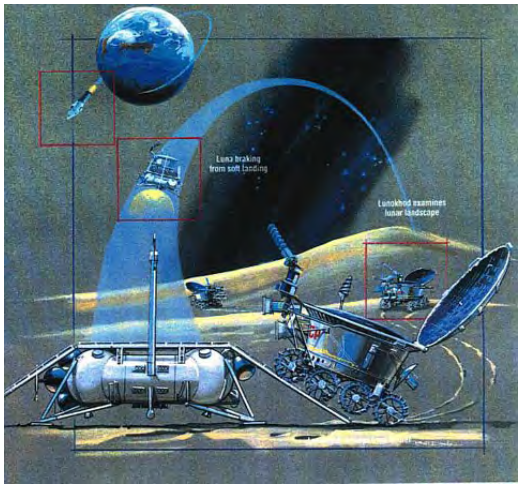
- **1966: Lunar soft landing**
  - **Luna 9**
  - **Surveyor 1**



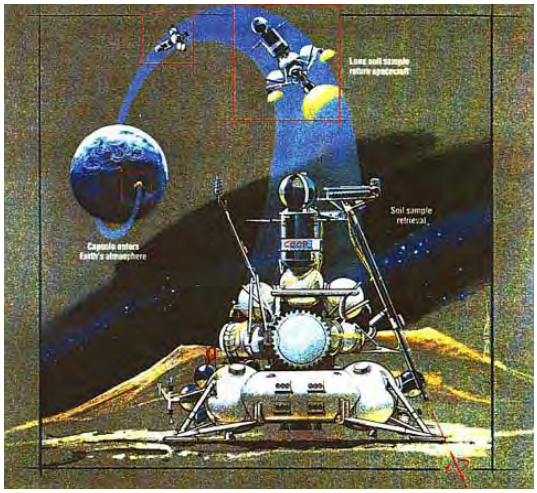
- **1967: Surveyor 3**
  - **Surface sampling tool**

Russia Perseveres with Robotic Spacecraft

Lunakhod 1, 2
(1970-73)



Luna 16, 17, 20, 24
(1970-76)



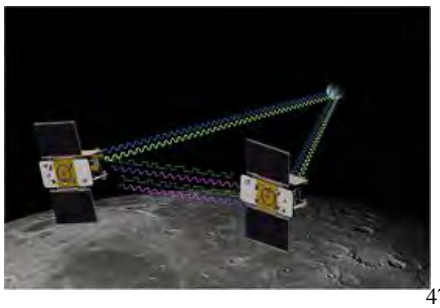
Recent US Spacecraft

LCROSS

THEMIS/ARTEMIS

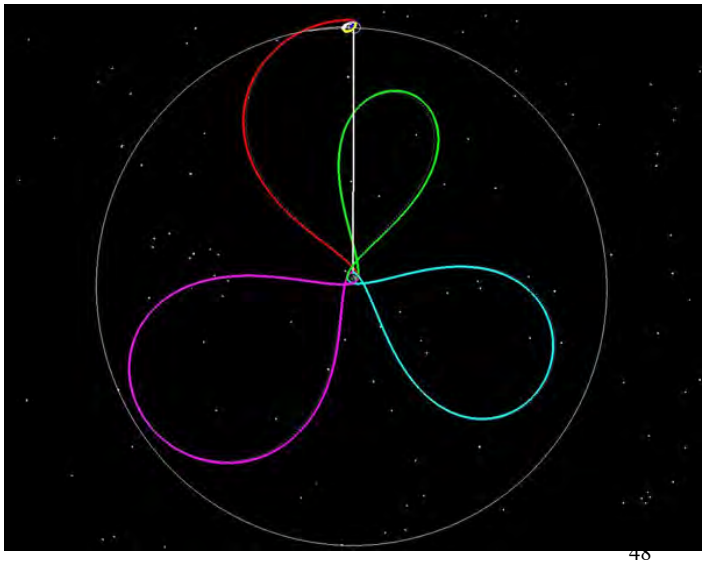
Lunar Reconnaissance Orbiter

GRAIL

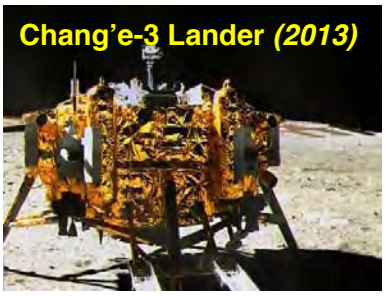


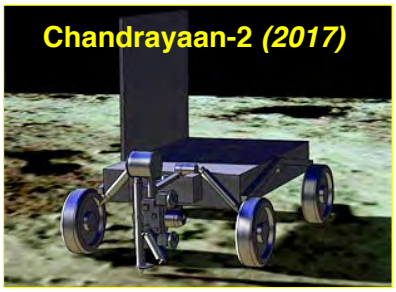
Lunar Atmosphere and Dust Environment Explorer (LADEE), *Sept 7, 2013*

- 30-day transit
- Launched from NASA Wallops Flight Facility
- Minotaur V (from Peacekeeper ICBM)

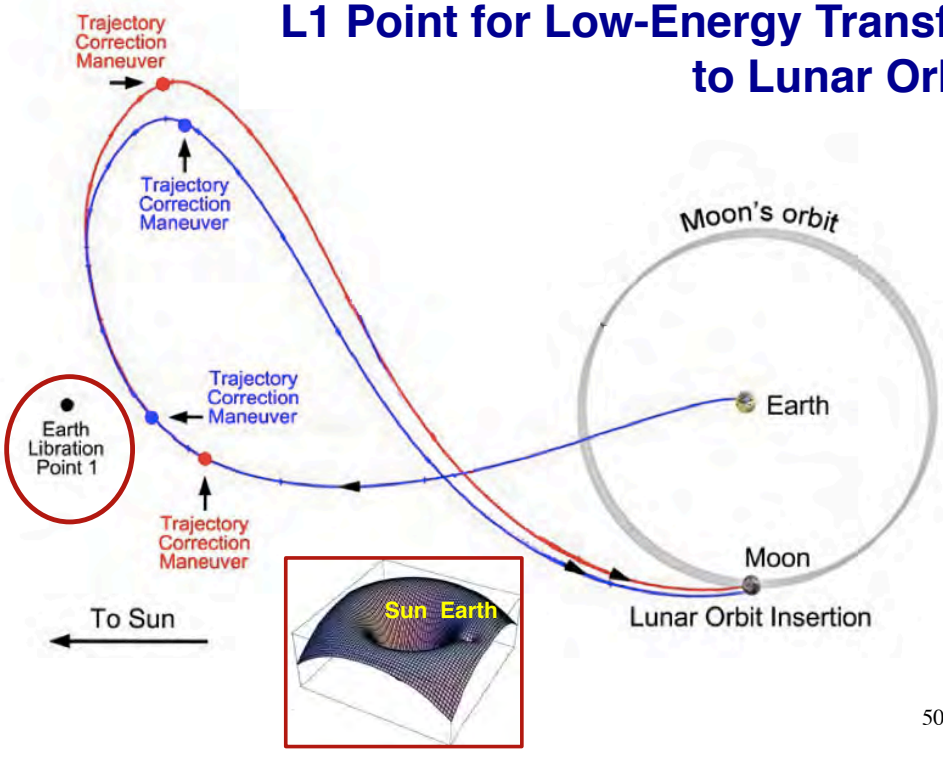


Chinese, Japanese, and Indian Lunar Exploration Programs





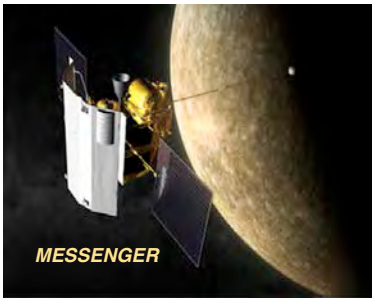
GRAIL Spacecraft Used Sun-Earth L1 Point for Low-Energy Transfer to Lunar Orbit

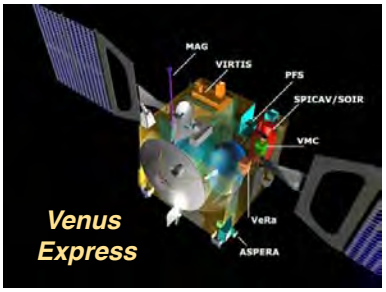


Solar System Spacecraft

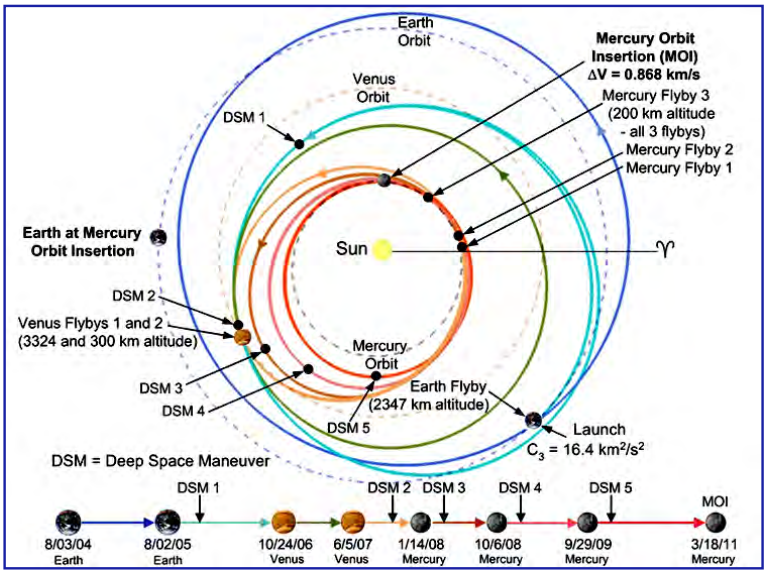
Inner-Solar-System Spacecraft

- Examples
  - –MESSENGER (2004-2011)
    - Three fly-bys of Mercury beginning in 2008
    - Orbit Mercury for 1 year, 200 x 15,193 km
    - Image entire surface of Mercury
    - Characterize surface chemistry, geology, and magnetic field
  - –Venus Express (ESA, 2006)
    - In orbit about Venus
    - Multi-spectral surface mapping
    - Measurements of interactions between solar wind and Venusian atmosphere, magnetic field, and temperature profile





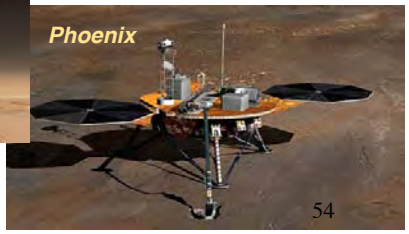
MESSENGER Fly-By Trajectories



- **MESSENGER mission**
  - *http://www.youtube.com/watch?v=y-GALKLHY-s*

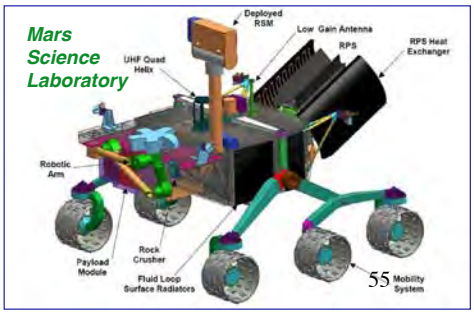
Mars Orbiters and Landers

- **Mission**
  - **Determine physical characteristics**
  - **Search for life**
  - **Prepare for human exploration**

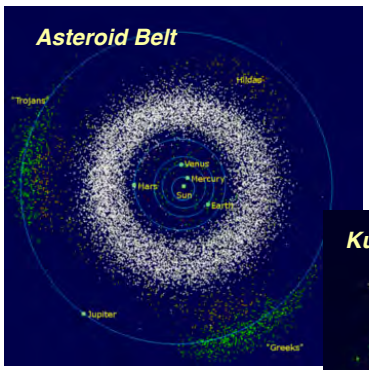


Mars Rovers

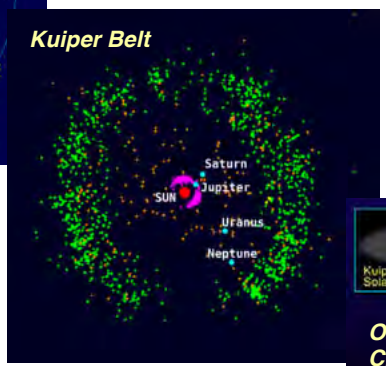
- Mission
  - Scientific discovery
  - Search for life
  - Prepare for human exploration
- Sojourner
- Mars Exploration Rovers
  - http://www.youtube.com/watch?v=O74DVxfrWkg
- Mars Science Laboratory
  - http://www.youtube.com/watch?v=noy8o0lN1fE



The Outer-Solar System and Beyond

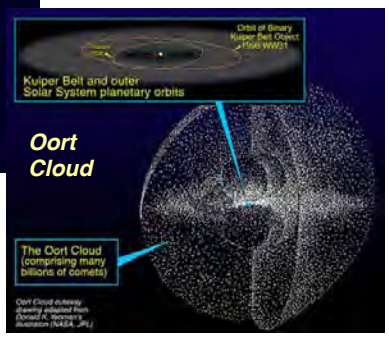


- Rock and metals
- Between Mars and Jupiter

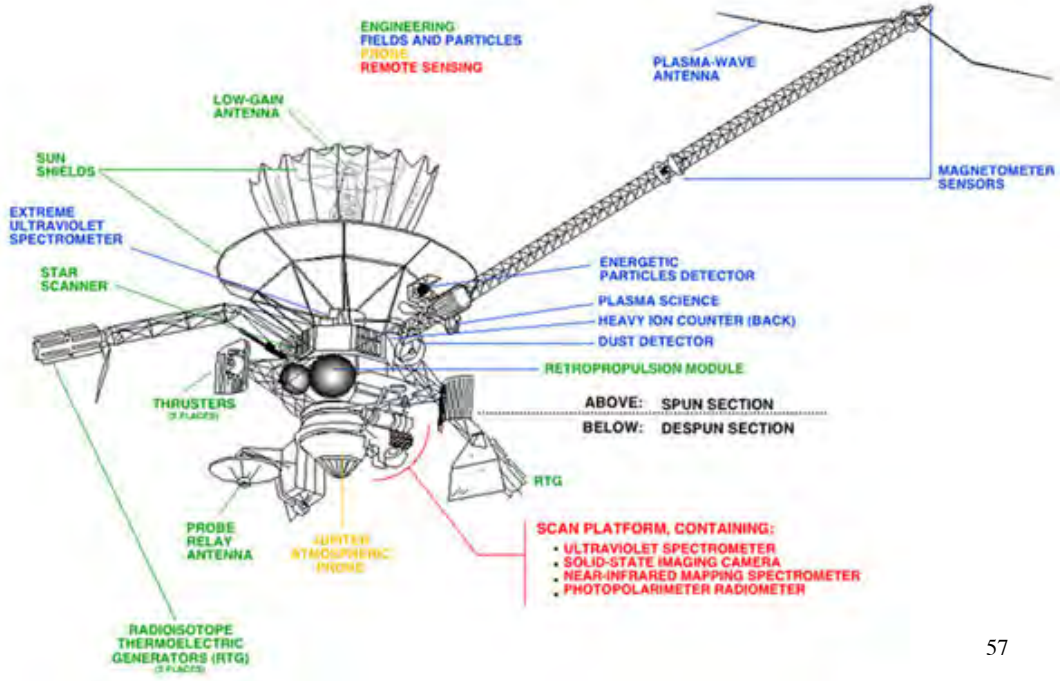


- Water, ammonia, and methane
- Beyond Neptune

- Postulated home of comets
- > 50,000 AU

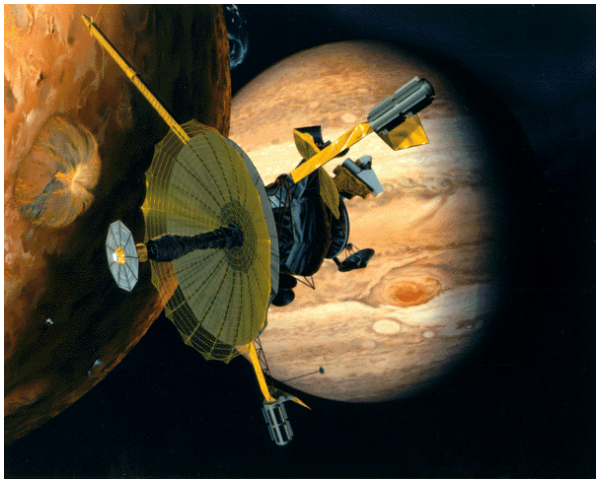


Outer-Solar-System Spacecraft: Galileo



Outer-Solar-System Spacecraft: Galileo

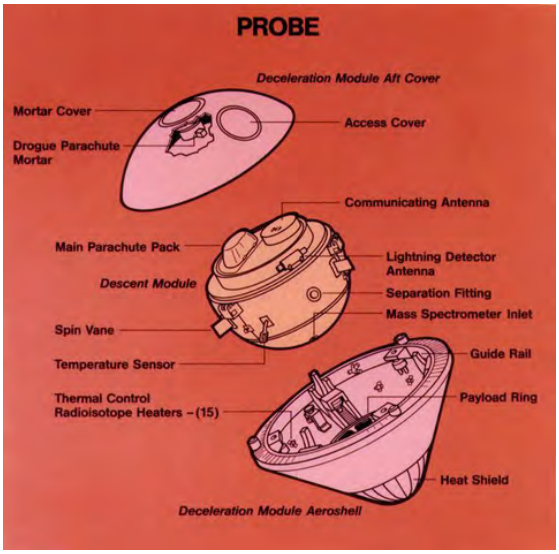
- Mission
  - Explore Jupiter and its moons
  - Probe Jupiter's atmosphere
  - Launch: October 1989 (Space Shuttle, boosted by Boeing Inertial Upper Stage)
  - Two Earth fly-bys, one Venus fly-by
  - Jupiter arrival: December 1995
  - http://en.wikipedia.org/wiki/Galileo_spacecraft

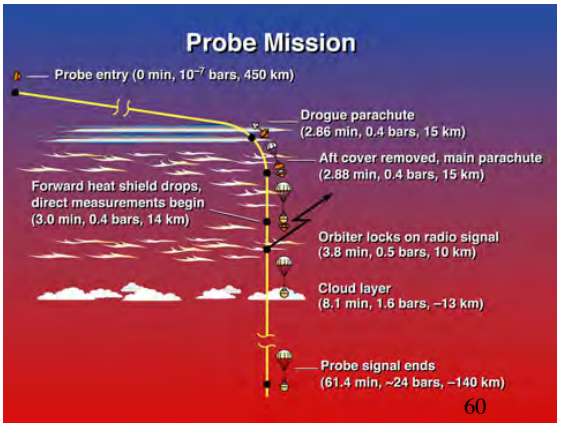


- Mission terminated by 50-km/s descent into Jupiter's atmosphere: September 2003
- First asteroid fly-by (951 Gaspra)
- Discovered first moon of an asteroid, Ida's Dactyl
- Mass = 2,380 kg

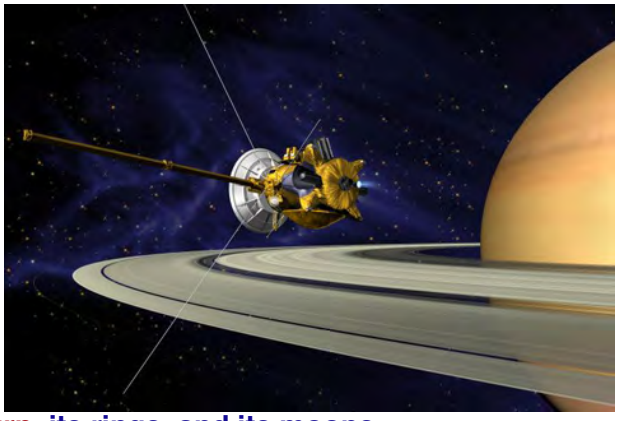
Galileo's Asteroid Images

Galileo's Probe



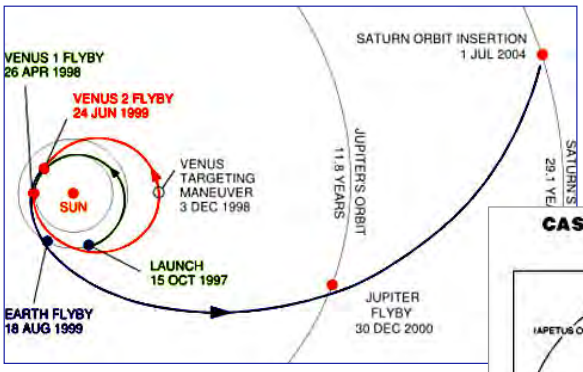


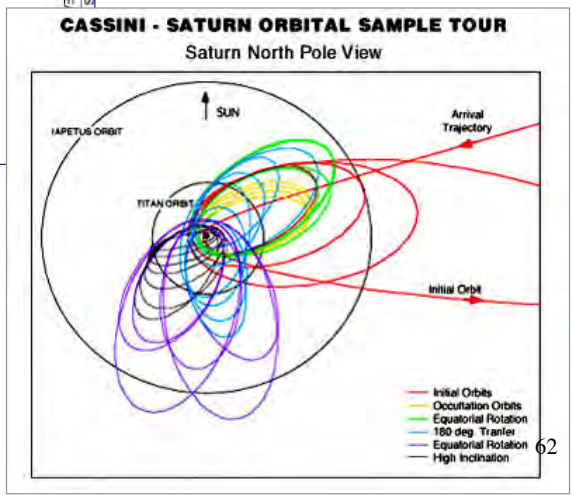
Outer-Solar-System Spacecraft: Cassini



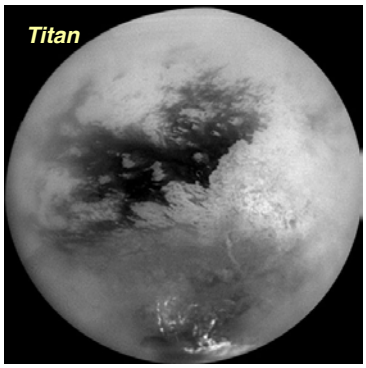
- Mission
  - –Explore Saturn, its rings, and its moons
  - –Launch: October 1997 (Titan 4B/Centaur)
  - –Two Earth fly-bys, one Venus fly-by
  - –Saturn arrival: July 2004
  - –Huygens Probe entered atmosphere of Saturn's moon Titan in January 2005
  - –$3.26B mission
  - –http://en.wikipedia.org/wiki/Cassini_spacecraft

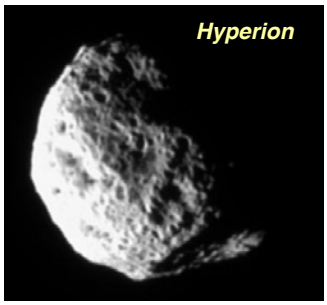
Outer-Solar-System Spacecraft: Cassini

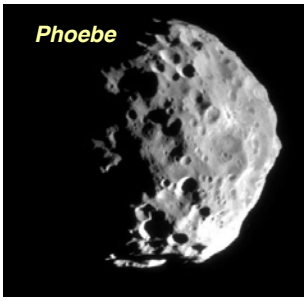




Cassini's Huygens Probe and Moon Images





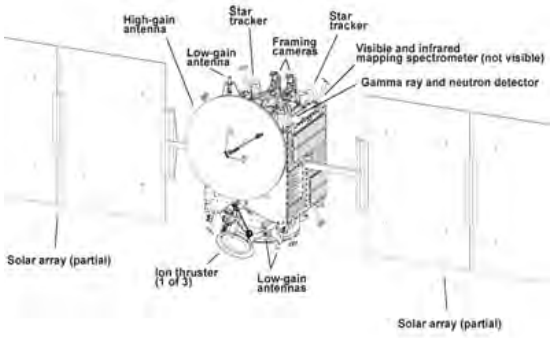


Outer-Solar-System Spacecraft: New Horizons

- Mission duration: 2006-2015+
- Destination: Pluto and its moons
- Radioisotope thermal power generator
- Spin-stabilized in cruise, 3-axis control (hydrazine RCS) for science
- May also fly by Kuiper Belt objects, Trojan asteroids at Neptune's L_5 point
- Fastest spacecraft to date (V_{earth} = 16.21 km/s, Atlas 5)
- 546,700-kg initial mass
- Payload = 478 kg
- Jupiter fly-by adds 4 km/s to speed
- http://en.wikipedia.org/wiki/New_Horizons

Outer-Solar-System Spacecraft: Dawn

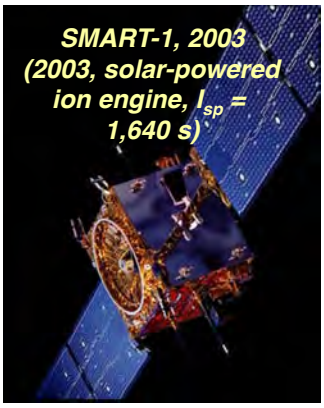
- Mission duration: 2007-2015
- Orbited both Vesta and Ceres ("proto-planets"), transit asteroid belt
- Ion thrusters provide ΔV of 13 km/s
- Mass = 1,285 kg
- *http://en.wikipedia.org/wiki/Dawn_Spacecraft*

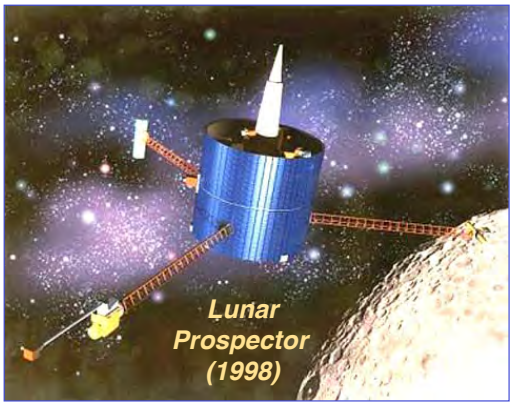


Next Time: Spacecraft Dynamics

Supplemental Material

Lunar Spacecraft





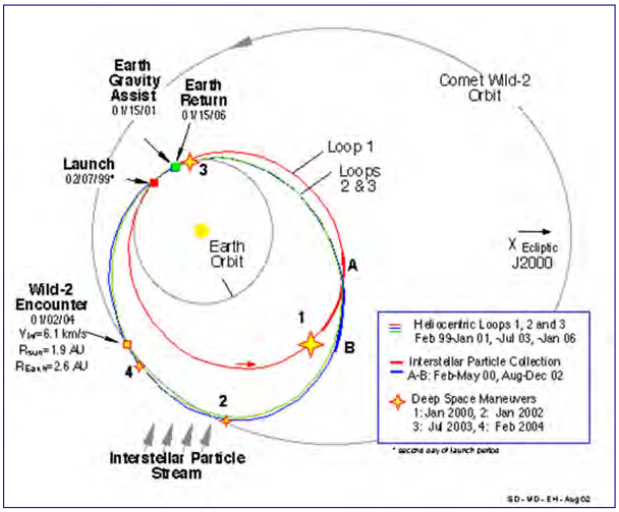
http://en.wikipedia.org/wiki/List_of_future_lunar_missions

Genesis Spacecraft

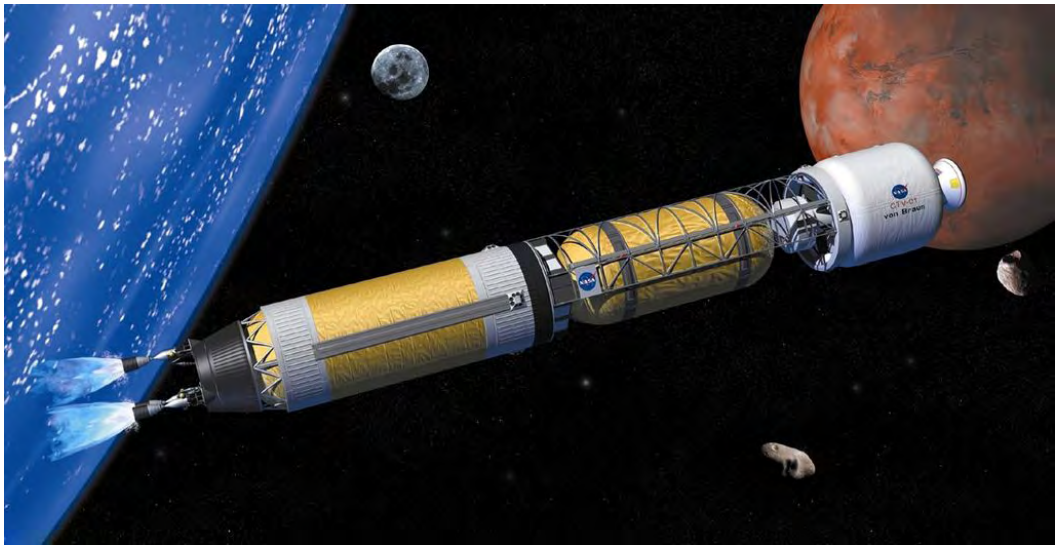
- **Genesis Solar Wind Sample Return**
  - **Launch: August 2001**
  - **Return: September 2004 (parachute did not open)**
  - **http://en.wikipedia.org/wiki/Genesis_spacecraft**

Stardust Spacecraft

- **Stardust Wild 2 Comet Tail Sample Return**
  - **Launch: February 1999**
  - **Return: January 2006**



Nuclear-Powered Spacecraft



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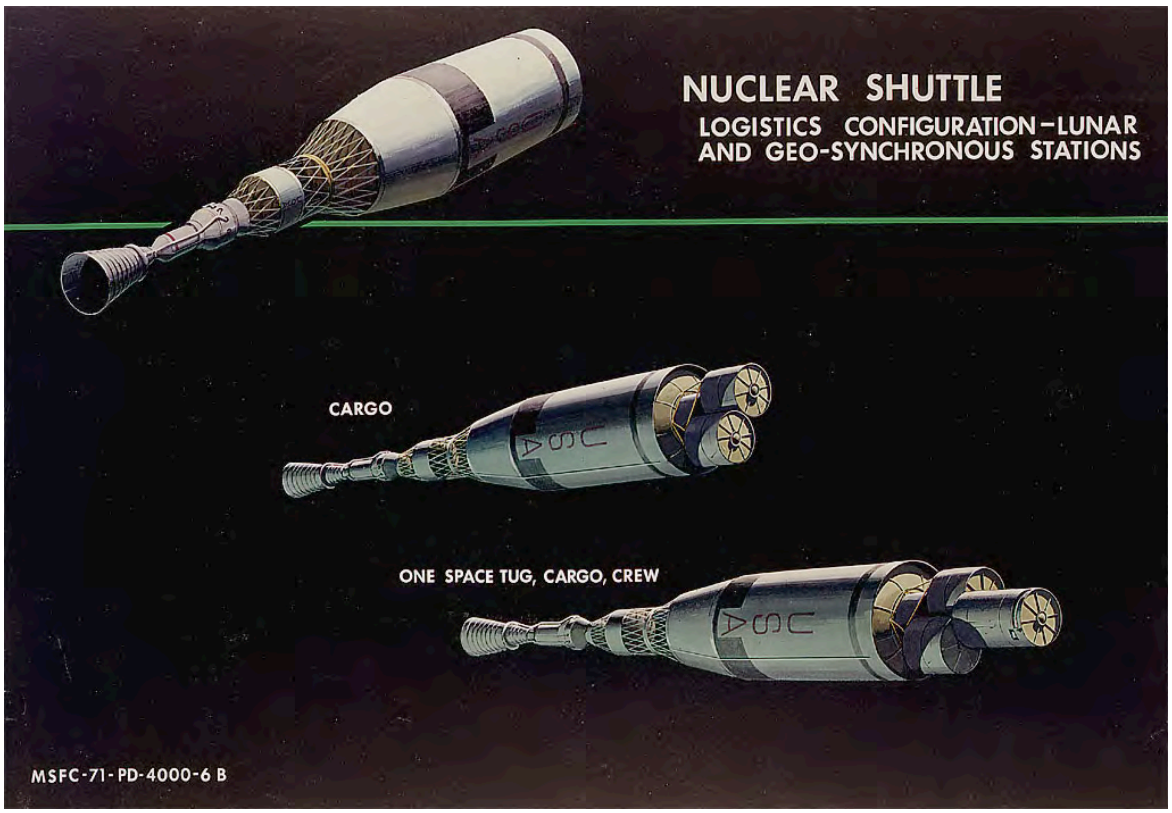

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