MAE 4060: Introduction to Spaceflight Mechanics
Fall 2019

Introduction, Course Logistics, and an Overview of Spacecraft Systems and Space Missions

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Logistics

- For all questions, **first check the syllabus**
- Office hours will be posted on Canvas (fill out poll if you haven't already)
- First homework already posted on Canvas (due Friday).
  - Written Homework submissions must be via Canvas.
  - MATLAB submissions must be via MATLAB Grader
  - Homeworks will be **self-graded**
- Piazza page active – participation is voluntary but strongly encouraged.

Spacecraft Engineering Course Sequence

MAE 4060 – *Introduction to Spaceflight Mechanics*
Fall Semesters

Introduction to spacecraft orbit mechanics, attitude dynamics, and the design and implementation of spaceflight maneuvers for satellites, probes, and rockets. Topics in celestial mechanics include orbital elements, types & uses of orbits, coordinate systems, Kepler's equation, the restricted two-body problem, interplanetary trajectories, the rocket equation and staging, Clohessy-Wiltshire equations and relative formation flight, drag and orbital decay, and propulsive maneuvers. Topics in attitude dynamics include kinematics, Euler's equations, stability of spinning spacecraft, attitude perturbations such as gravity-gradient and magnetic torques, equations of motion of rigid spacecraft with momentum actuators and thrusters, attitude maneuvers such as nutation control and reorientation, low-speed fluid behaviors, and elementary feedback control of linearized attitude and orbit dynamics. Principles of spacecraft propulsion technology and attitude-control technology are introduced. Discussions of current problems and trends in spacecraft operation and development.

Prerequisites: MATH 2930, MATH 2940, and MAE 2030, or permission of instructor.

MAE 4160 - *Spacecraft Technology and Systems Architecture*
Spring Semesters

A survey in contemporary space technology from satellite subsystem design through launch and mission operations, focusing on the classical subsystems of robotic and human-rated spacecraft, rockets, planetary rovers, and habitats, and with an emphasis on issue of spacecraft-system architecture and design. Topics covered include subsystem technologies and the systems-engineering principles that tie them together into a spacecraft architecture. Subsystem technologies discussed include communications, thermal subsystems, structure, guidance/navigation/control, spacecraft power, space propulsion, payloads (remote sensing, in-situ sensing, human life support), entry/descent/landing, surface mobility, and flight-computer hardware and software. The final project consists of architecting a complete spacecraft system with appropriate subsystems, with designs supported by parametric analysis and simulation. Discussions of current problems and trends in spacecraft operation and development.

Co-meets with
- MAE 4161 (senior design version)
- MAE 5160 (MEng version)

MAE 6060 – *Spacecraft Attitude Dynamics*
Fall Semesters

The focus is on spacecraft attitude dynamics and its application in core space-systems areas: mission design, operations, and autonomy. Also introduces the problem of attitude estimation and treats aspects of guidance, navigation, and control unique to the context of space mission design. Readings and lectures include examples based on flight data.

MAE 6720 – *Celestial Mechanics*
Spring Semesters

Course topics include description of orbits; 2-body and 3-body problems; Hill curves, libration points; osculating orbital elements, perturbation equations; effects of various forces; applications to spacecraft orbits and the solar system.

Junior/Senior **MEng/Ph.D.**

Spacecraft Engineering Concentration Areas

Spacecraft Guidance, Navigation, and Control Options

MAE 4150 - GPS: Theory and Design
ECE 5840 - Advanced GPS Receiver Design
MAE 6969 - Seminar in GPS and GNSS
MAE 4730 - Intermediate Dynamics and Vibrations
MAE 4780 - Feedback Control Systems
MAE 6700 - Advanced Dynamics
MAE 6760 - Model-Based Estimation
MAE 6780 - Multivariable Control Theory
ECE 5210 - Theory of Linear Systems

Space Robotics Options

CS 4752 - Robotic Manipulation
MAE 4180 - Autonomous Mobile Robots
MAE 4730 - Intermediate Dynamics and Vibrations
MAE 4780 - Feedback Control Systems
MAE 6700 - Advanced Dynamics
MAE 6780 - Multivariable Control Theory
ECE 5470 - Computer Vision

Space Science Options

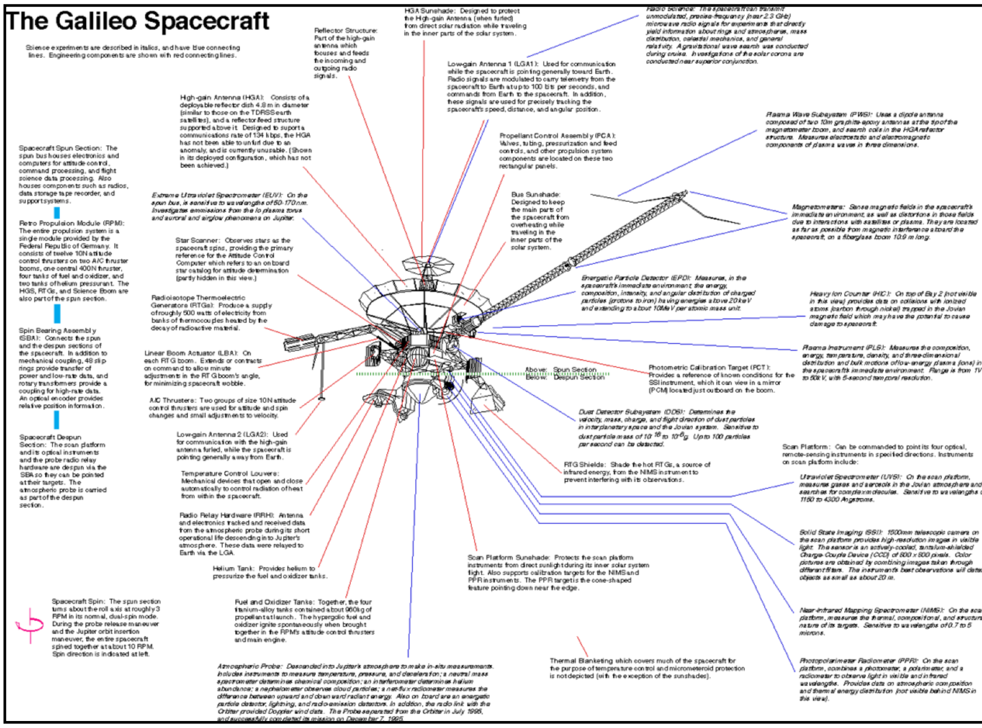
AEP 6060 - Introduction to Plasma Physics
ASTRO 4431 - Introduction to Astrophysics and Space Sciences
ASTRO 4432 - Introduction to Astrophysics and Space Sciences II
ASTRO 4410 - Experimental Astronomy
ASTRO 6523 - Signal Modeling, Statistical Inference, and Data Mining in Astronomy
ASTRO 6570 - Physics of the Planets
ASTRO 6575 - Planetary Atmospheres
ASTRO 6577 - Planetary Surface Processes
ASTRO 6578 - Planet Formation and Evolution
EAS 4260 - Structural Geology
EAS 4530 – Mineralogy
EAS 4580 – Volcanology

Space-Based Earth Observation Options

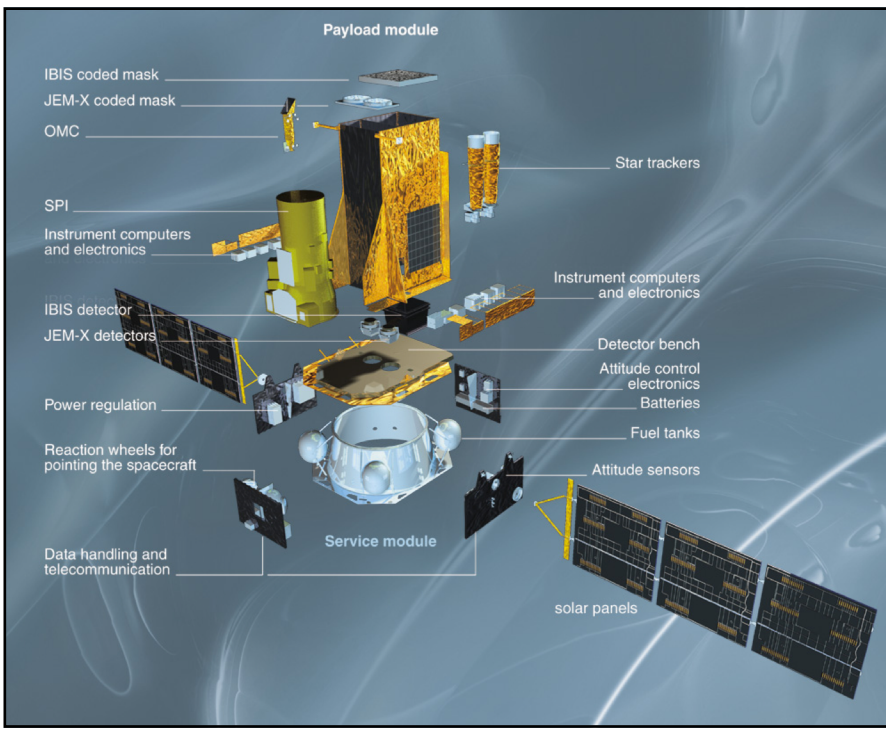
CEE 4110 - Applied Remote Sensing and GIS for Resource Inventory and Analysis
CEE 6100 - Remote Sensing Fundamentals
CEE 6150 - Digital Image Processing for Remote Sensing
EAS 4350 - Statistical Methods in Meteorology and Climatology
EAS 4400 - Seminar on Climate Change Science, Impacts, and Mitigation
EAS 4800 - Our Changing Atmosphere: Global Change and Atmospheric Chemistry
EAS 4870 - Introduction to Radar Remote Sensing
EAS 5011 - Evolution of the Earth System
EAS 5840 - Inverse Methods in the Natural Sciences
EAS 7500 - Satellite Remote Sensing Training for Biological Oceanographers
ECE 4870 - Introduction to Radar Remote Sensing

Space Travel, Exploration, Commercialization, and Settlement Options

MAE 6950 – Space Biomedical Engineering & Human Performance
MAE 5910 - Model Based Systems Engineering
MAE 5920 - Systems Architecture, Behavior, Optimization
MAE 5930 - Systems Engineering and Six Sigma for the Design and Operation of Reliable Systems
MAE 6640 - Mechanics of Bone
AEP 5520 - Physics of Life
BME 4110 - Science and Technology Approaches to Problems in Human Health
BME 4440 - Science Policy Bootcamp: Concept to Conclusion
BME 5390 - Biomedical Materials and Devices for Human Body Repair
MAE 6680 - Cancer for Engineers and Physicists
ARCH 4621 - Sustainable Architecture: The Science and Politics of Green Building
ARCH 5612 - Structural Concepts
ARCH 5613 - Structural Systems
ARCH 5611 - Environmental Systems I: Site and Sustainability
ARCH 5616 - Environmental Systems II: Building Dynamics
CEE 4510 - Microbiology for Environmental Engineering
CEE 4540 - Sustainable Municipal Drinking Water Treatment
CEE 6910 - Principles of Project Leadership
EAS 4790 – Paleobiology
ENGRG 4610 - Entrepreneurship for Engineers
ORIE 5150 - Economic Analysis of Engineering Systems



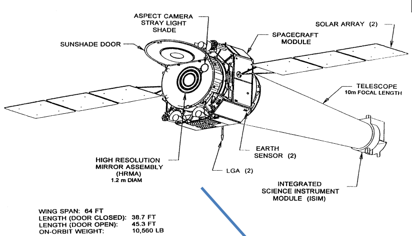
Doody & Stephan (1995)

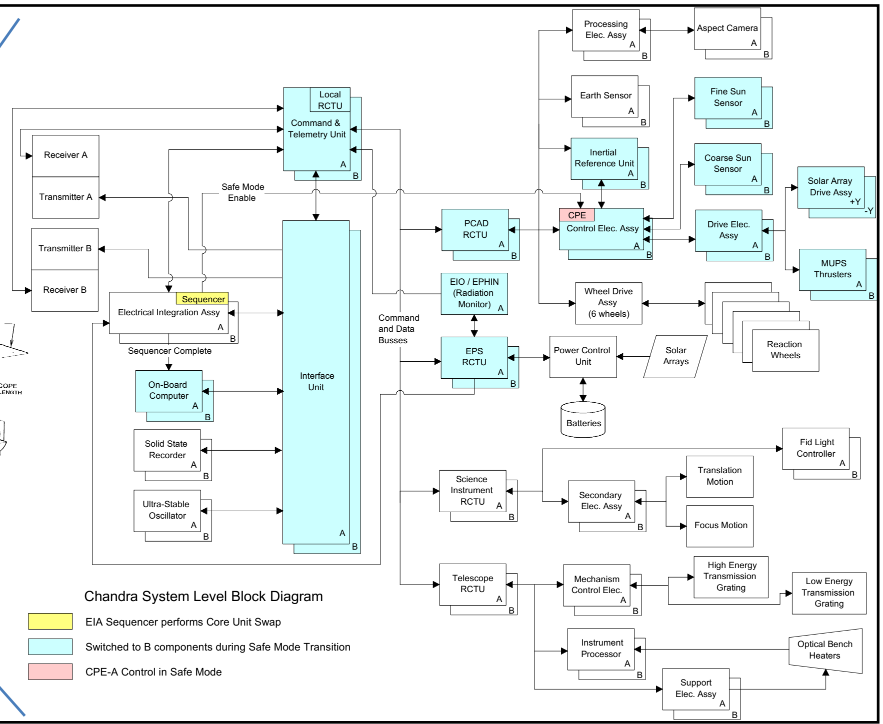


International Gamma-Ray Astrophysics Laboratory (INTEGRAL)

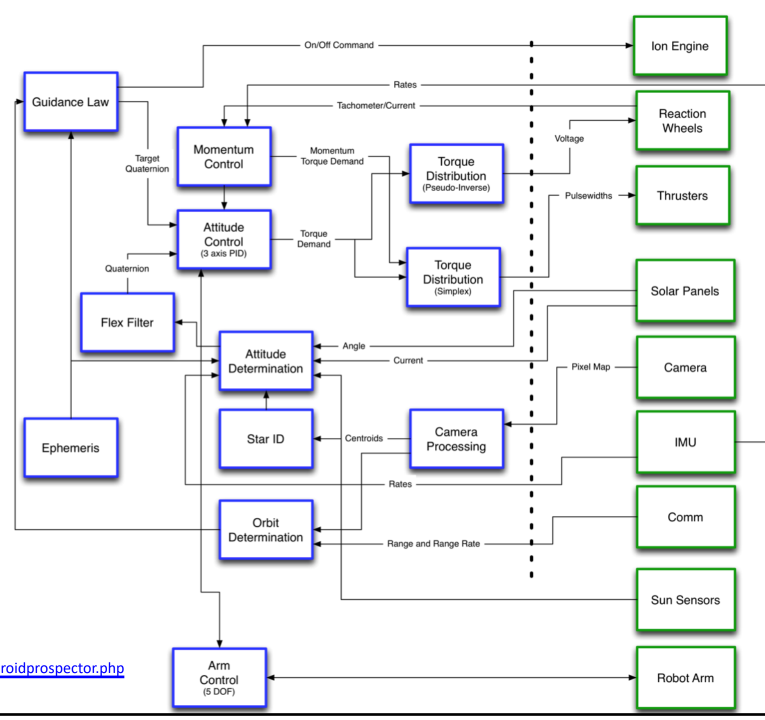
Credit: ESA

Chandra X-Ray Observatory

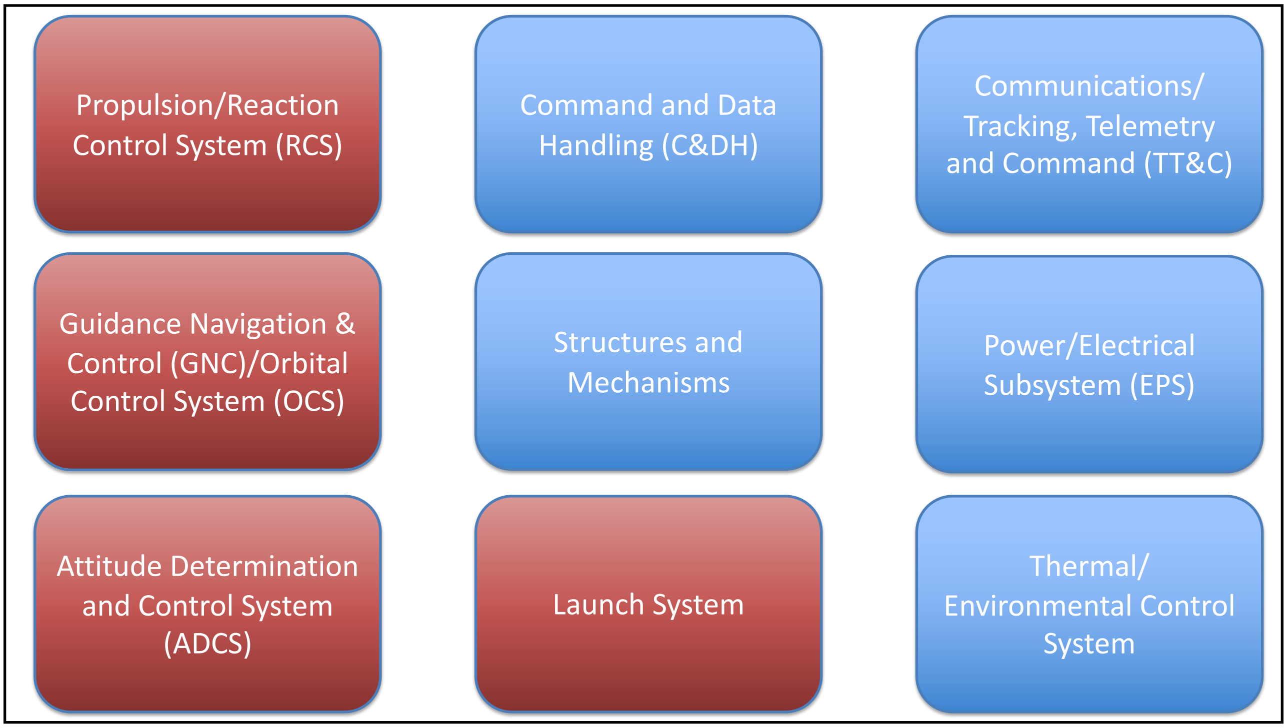


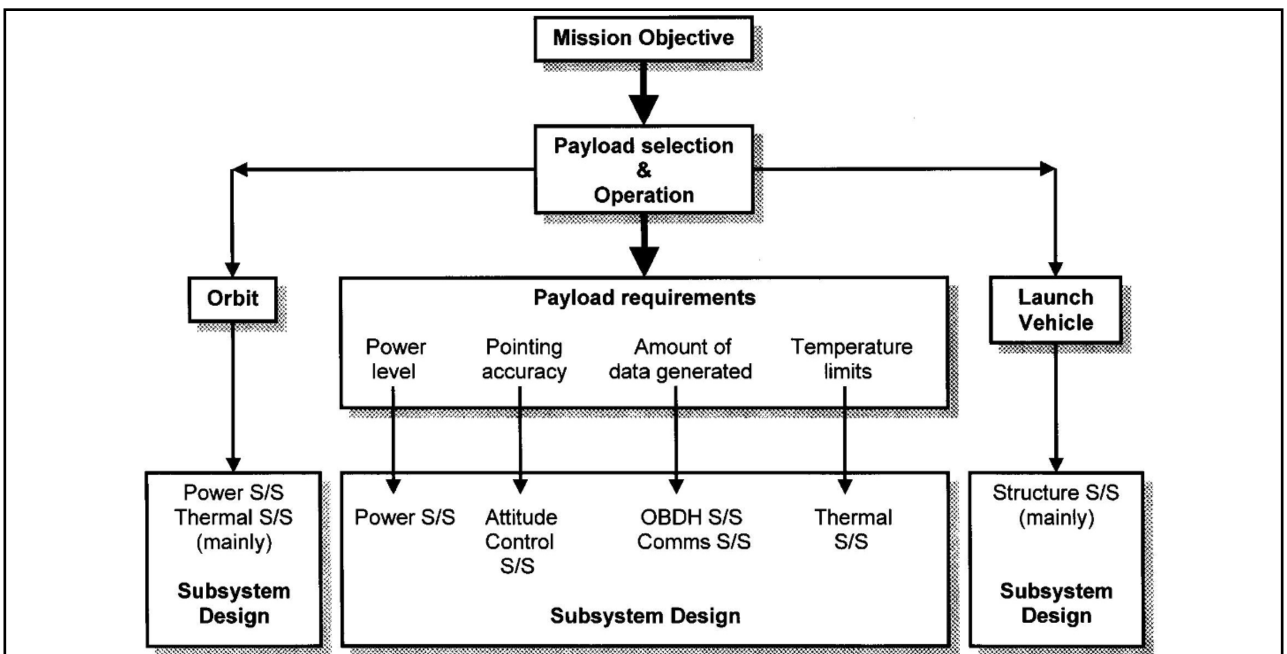


Brissenden (2001)



From:
http://support.psatellite.com/research/asteroidprospector.php





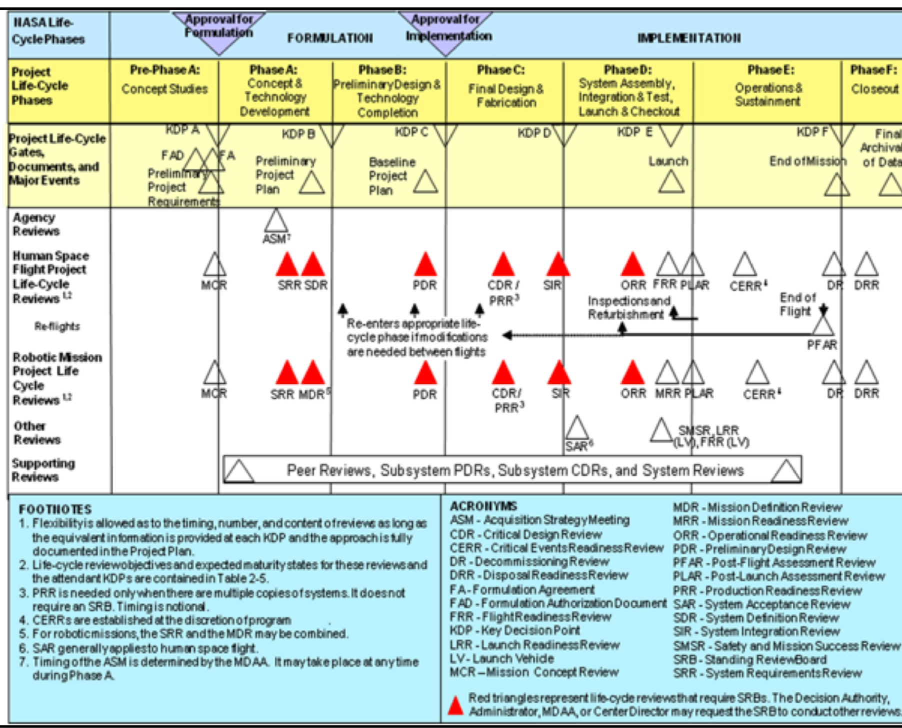
From: Swinerd (2008)

Table 3-1. The Space Mission Engineering Process. This table is relevant for a *need-based mission*, i.e., one that is intended to fulfill a specific (though possibly not well-defined) set of mission needs, and is the most common type of space mission. The alternative is a *capability-driven system*, discussed in Sec. 3.1.2.

Typical Flow	Step	Where Discussed
	Define Objectives and Constraints	
	1. Define the Broad (Qualitative) Objectives and Constraints	Sec. 3.3
	2. Define the Principal Players	Sec. 3.4
	3. Define the Program Timescale	Sec. 3.4
	4. Estimate the Quantitative Needs, Requirements, and Constraints	Sec. 3.5
	Define Alternative Mission Concepts or Designs	
	5. Define Alternative Mission Architectures	Sec. 4.2
	6. Define Alternative Mission Concepts	Sec. 4.3
	7. Define the Likely System Drivers and Key Requirements	Sec. 4.4
	Evaluate the Alternative Mission Concepts	
	8. Conduct Performance Assessments and System Trades	Sec. 5.3
	9. Evaluate Mission Utility	Sec. 5.4
	10. Define the Baseline Mission Concept and Architecture	Sec. 5.5
	11. Revise the Quantitative Requirements and Constraints	Sec. 5.5
	12. Iterate and Explore Other Alternatives	Sec. 5.5
	Define and Allocate System Requirements	
	13. Define System Requirements	Sec. 6.1
	14. Allocate the Requirements to System Elements	Sec. 6.2

SMAD Table 3-1

NASA Project Life Cycle



From:
https://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7120_005E_&page_name=Chapter2

See also: SMAD Figures 3.5 and 3.6

Table 3-3. Representative Space Mission Timeline. The names used here are generic, but fairly widely used. Each of the large space organizations have their own set of mission phases, typically defined by formal Milestone reviews that are required for "graduation" to the next phase.

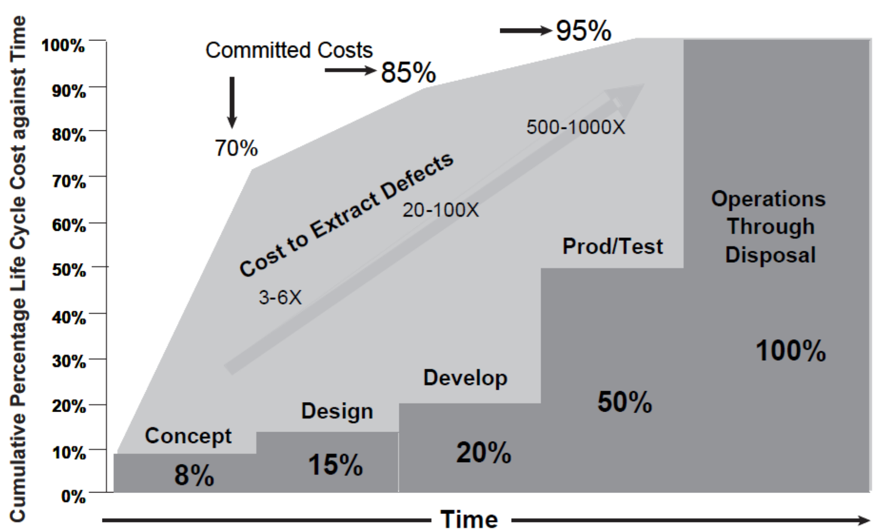
Phase	End Defined By	Typical Duration (small program)	Typical Duration (major program)
CONCEPT EXPLORATION	Start of technology funding; preliminary requirements release	1–6 months	2–10 years
	DETAILED DEVELOPMENT		
Risk Reduction/Technology Development	Start of program funding	0–12 months	1–10 years
Detailed Design and Development	Formal requirements release	2–12 months	0.5–4 years
	PRODUCTION AND DEPLOYMENT		
Production	Ship to Launch Site	6–24 months	2–5 years
Launch	Lift-Off and Arrival in Low-Earth Orbit	1 month	3 – 12 months
On-Orbit Check-Out /Transfer to Operational Orbit	Start of operations	0–10 days	1–3 months in Earth orbit***
	OPERATIONS AND SUPPORT		
Operations	Spacecraft dies or decision to be put to sleep	1 month–5 years*	5–15 years*
Disposal	Re-entry or turn-off**	0–5 years	up to 25 years

* Upper limit shown is typical design life. In practice, on-orbit spacecraft rarely wear out and can live for many years after the formal end of their design life if they have enough propellant or other consumables on board.

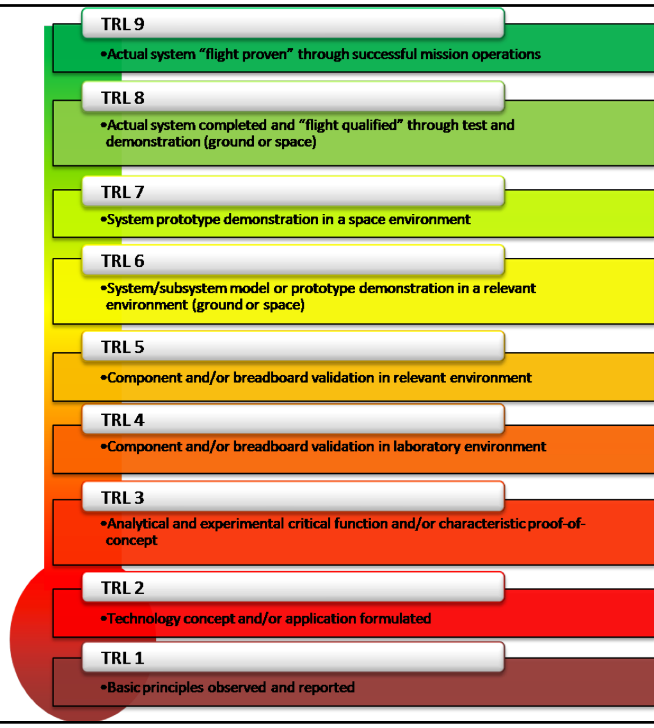
** Data analysis may continue for an extended period. *** Up to 10 years for Interplanetary

SMAD Table 3-3

Mission Architectures



Source: INCOSE systems engineering handbook

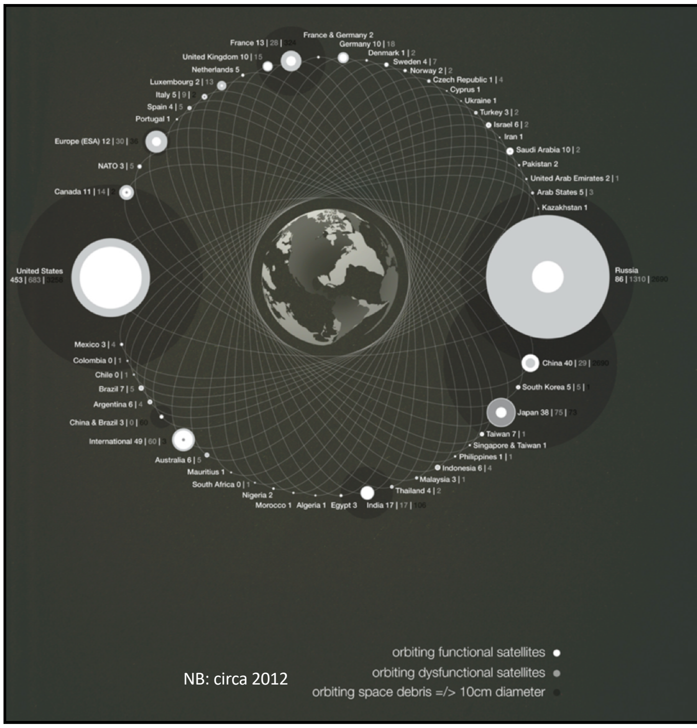


From:
https://www.nasa.gov/sites/default/files/trl.png

See also: SMAD Tables 1-1 and 1-2

Flavors of Missions/Spacecraft

- Earth Observing
- Telecommunications
- Global Navigation Satellite Systems
  - GPS, GLONASS, Galileo, BeiDou, NAVIC, etc.
- Space Weather Monitors
- Solar System Exploration (flybys/orbiters/landers/sample return)
- Astrophysical Observatories/Science Experiments
- Crewed Spaceflight



By Michael Paukner

See also: http://stuffin.space/

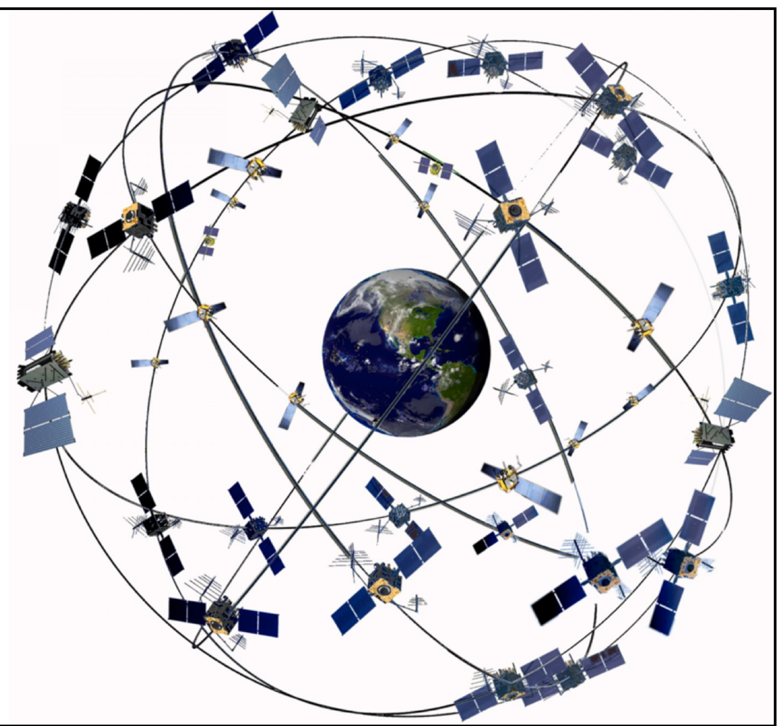
~8,000 man-made objects launched into space since 1957
See: https://nssdc.gsfc.nasa.gov/nmc/spacecraftSearch.do

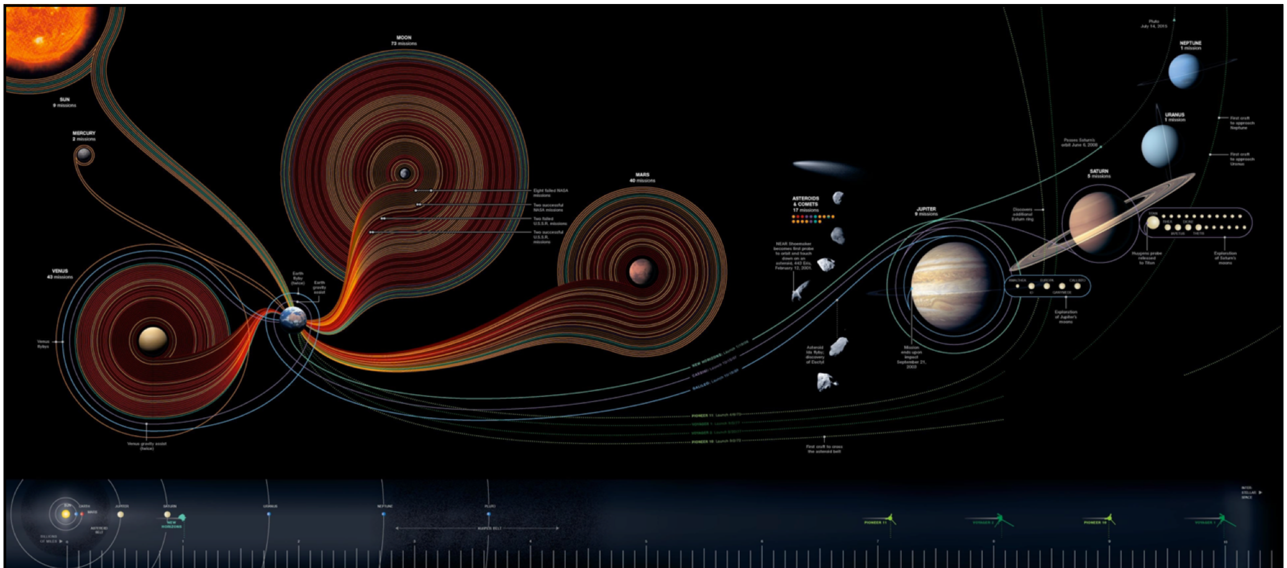
~1,750 active satellites currently in orbit

~2,900 dead satellites still in orbit

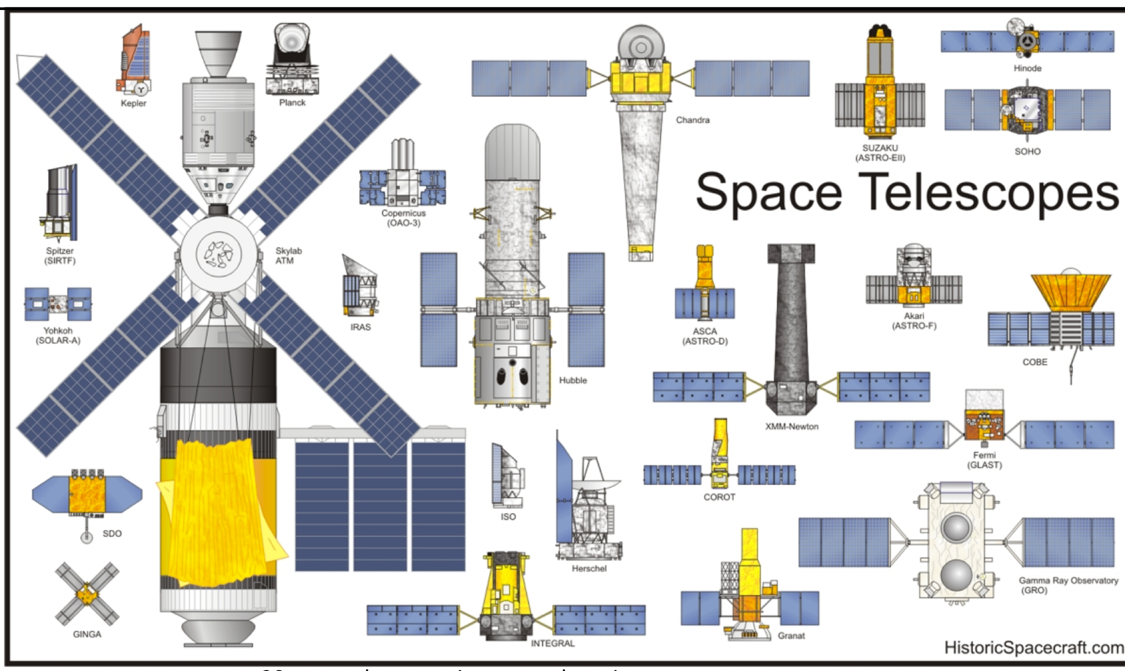
Source: Lockheed Martin

32 Satellites (31 active)

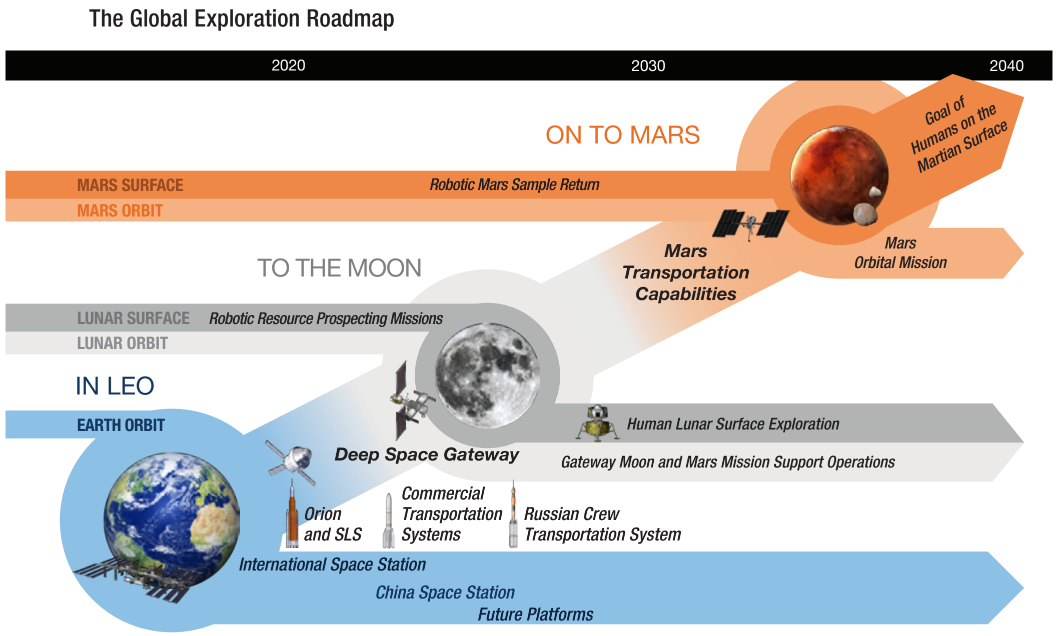




See: http://www.5wgraphics.com/img/gallery/5w-sample-001-space-travel.jpg
>200 interplanetary missions flown



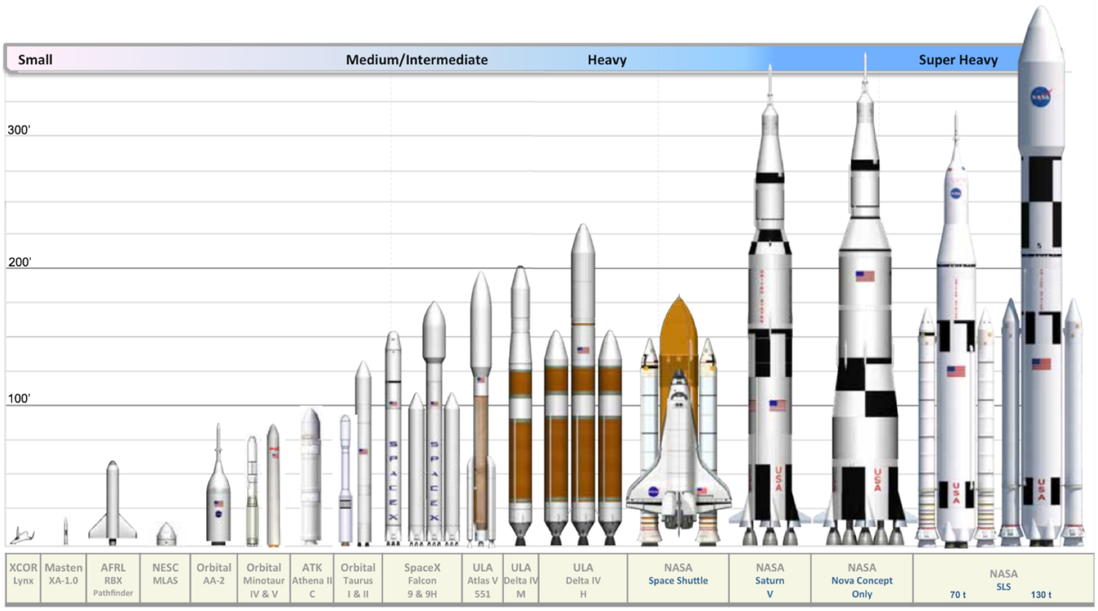
30 space observatories currently active
Coming soon: Euclid (2020), IXPE (2021), JWST (2021)



See: https://www.nasa.gov/sites/default/files/atoms/files/ger_2018_small_mobile.pdf

You only get to bring what you can lift

Active launch vehicles (more or less)
Credit: Embry-Riddle Aeronautical University



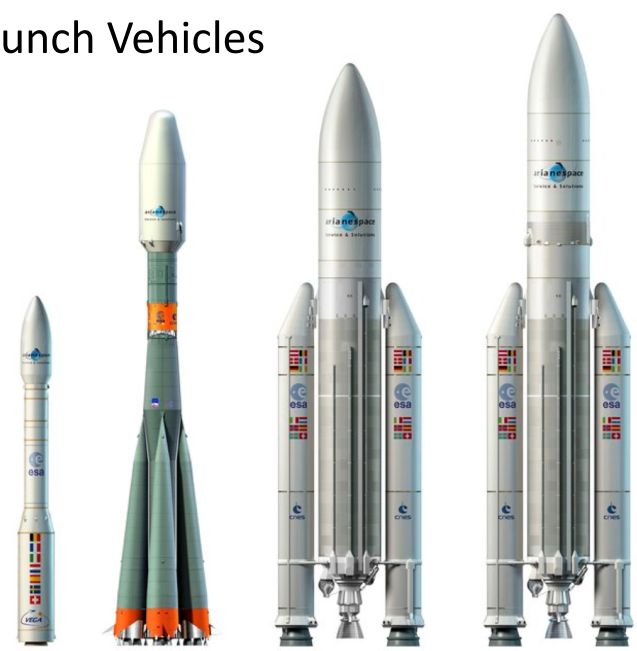
Sample of Proposed and Fielded U.S. Systems

National Aeronautics and Space Administration

8065_MAF Industry Day.11

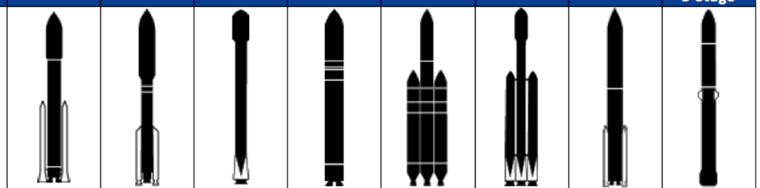
ESA Launch Vehicles

Source: ESA



Vega Soyuz Ariane 5 GS Ariane 5 ECA

Deep Space Travel (US Market)

	NASA	Commercial Currently in Service				Commercial Currently in Development		
	SLS Block 2	Atlas V	Falcon 9	Antares 230	Delta IV Heavy	Falcon Heavy	Vulcan ACES	New Glenn 3-Stage
								
Scheduled completion date	No earlier than 2028	Currently in service	Currently in service	Currently in service	Currently in service	2017	2023	Not reported
Cargo payload fairing size (meters)	10	5	5.4	3.9	5.2	5.2	5	
Upmass to low Earth orbit (metric tons)	130	7.4–17.9	11.2–15	4.4	25.5	–	–	
Upmass to cislunar orbit (metric tons)	52	2.1–6.3	1.9–3.5	1.5[a]	10.5	6.1–12.9	14	
Upmass to Mars (metric tons)	41	1.4–4.8	Not applicable	1[a]	8.1	3.9–9.3	10.5	

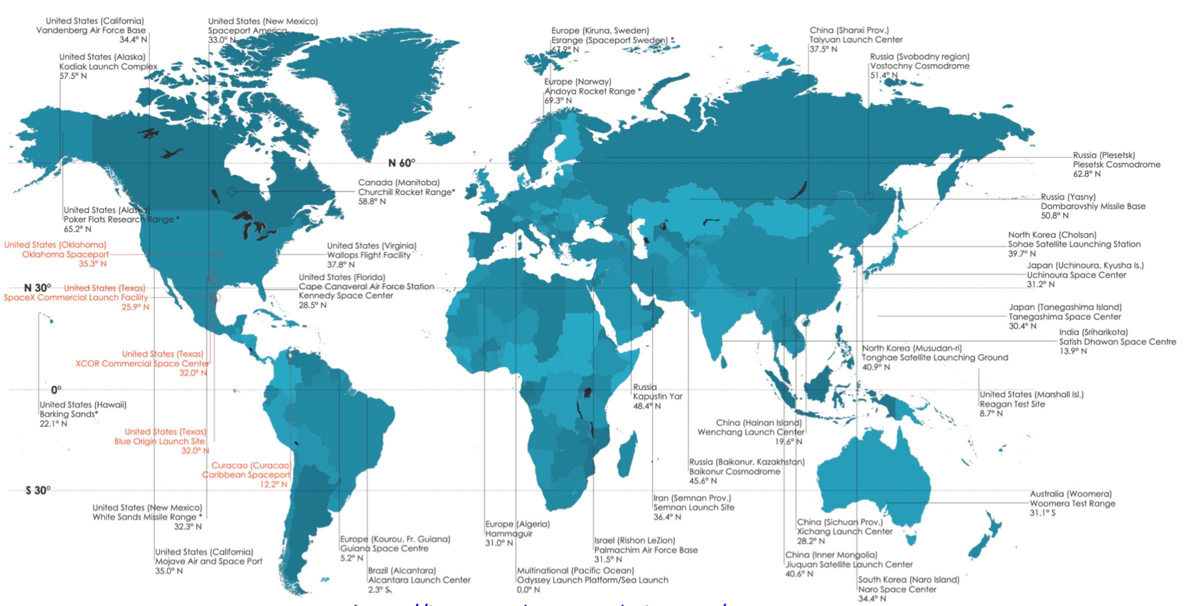
Source: NASA and NASA Launch Services Program information.

Note: Upmass figures include calculations and assumptions from NASA's Launch Services Program.

[a] Denotes upmass value for Antares 232 variation.

OPERATIONAL SPACEPORTS / SPACE LAUNCH FACILITIES & SPACEPORTS IN DEVELOPMENT

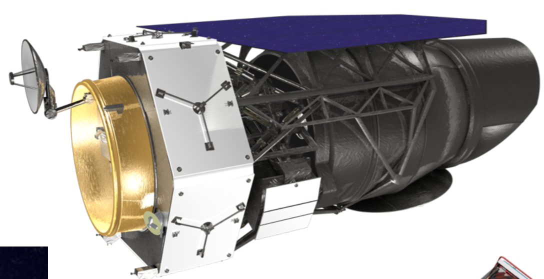
Sovereignty / (Location)
Site Name
Latitude



https://integratedspaceanalytics.com/spaceports

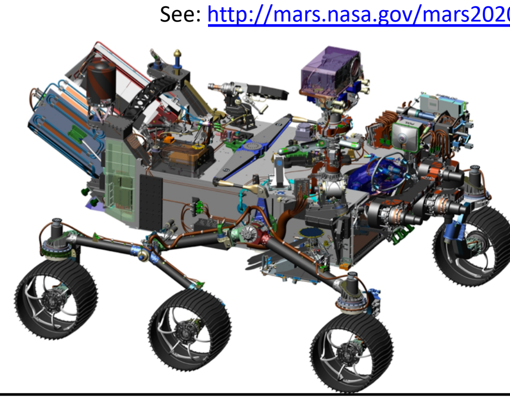
See: http://www.nasa.gov/offices/oct/home/roadmaps/index.html

What's Next?



See: http://wfirst.gsfc.nasa.gov/

See: http://mars.nasa.gov/mars2020/



See: https://jwst.nasa.gov/