Why go to space?

Why go to space?

To explore.

- Colonization, tourism, and the expansion of the limits of humanity
- Science (astrobiology, geology, physics, etc.)

For resources.

- Rare elements (gold, platinum, etc.)
- In-situ resource utilization
- Water
- Data

To look out.

- Astrophysics
- Atmospheric sounding

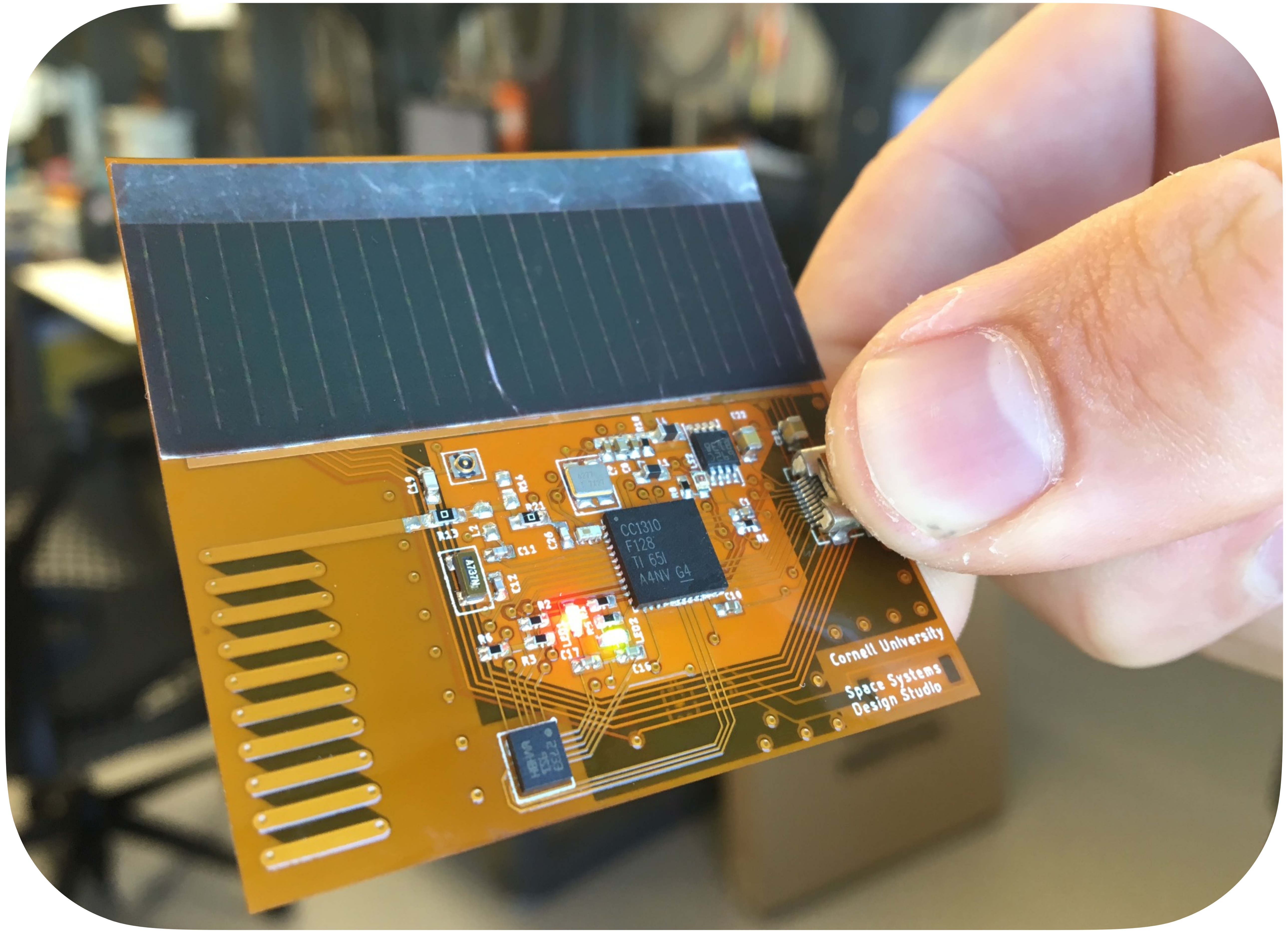
To look down.

- Surveillance (military and commercial)
- Weather forecasting/science

For microgravity.

- Science and materials processing

Monarch



I’m Hunter Adams

- Received a PhD in aerospace engineering (all space, no air).
- My research surrounds (very) small spacecraft called “chipsats.”

Going to space is hard and expensive.

- Getting permission to go to space is hard . . .
- Traveling to space is hard . . .
- Being in space is hard . . .

- Getting permission to go to space is hard . . .
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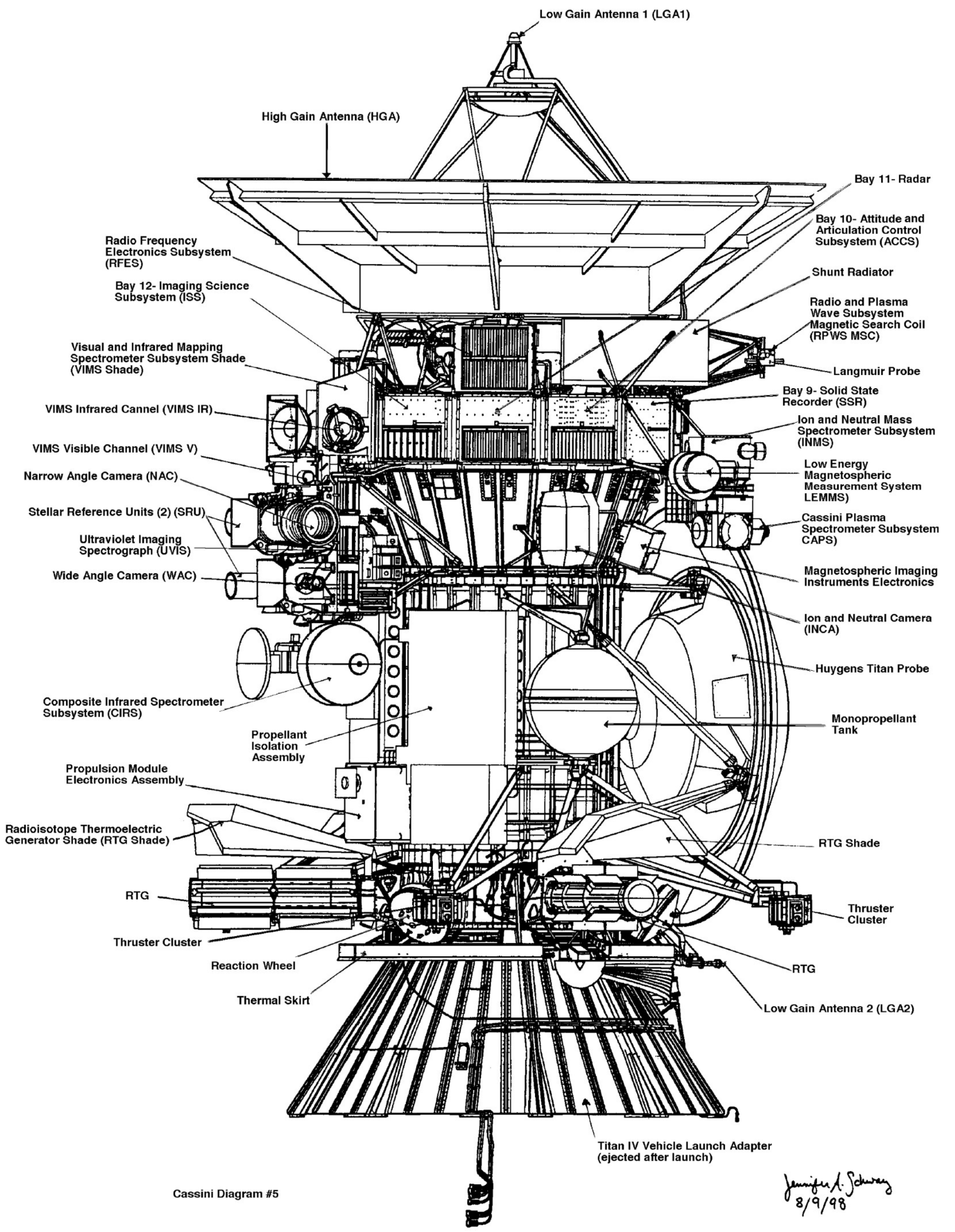
- Being in space is hard . . .

. . . in ways that are unique enough to require separate consideration.

We think about complex systems in terms of subsystems.

Spacecraft subsystems

- Attitude determination and control
- Propulsion
- Telemetry and command
- Avionics
- Flight software
- Power
- Thermal
- Structures
- Entry, descent, and landing
- Environmental control and life support systems



This course exists to understand spacecraft at a systems-level, and to understand the environment in which spacecraft exist.

Course goals

- To understand space missions and systems, and how the space environment and mission requirements drive spacecraft design.
- To understand the fundamentals of spacecraft subsystems, including propulsion, attitude determination and control, power, structures, thermal, communications, and command and data handling.
- To understand typical practices for designing space systems in a contemporary context of US commercial space and government agencies.
- To simulate a spacecraft in operation at the level of a Preliminary Design Review (PDR) using state of the art tools, and identify and characterize subsystems for a preliminary spacecraft design.

Today’s goal

To introduce the topics of this course via a case study.

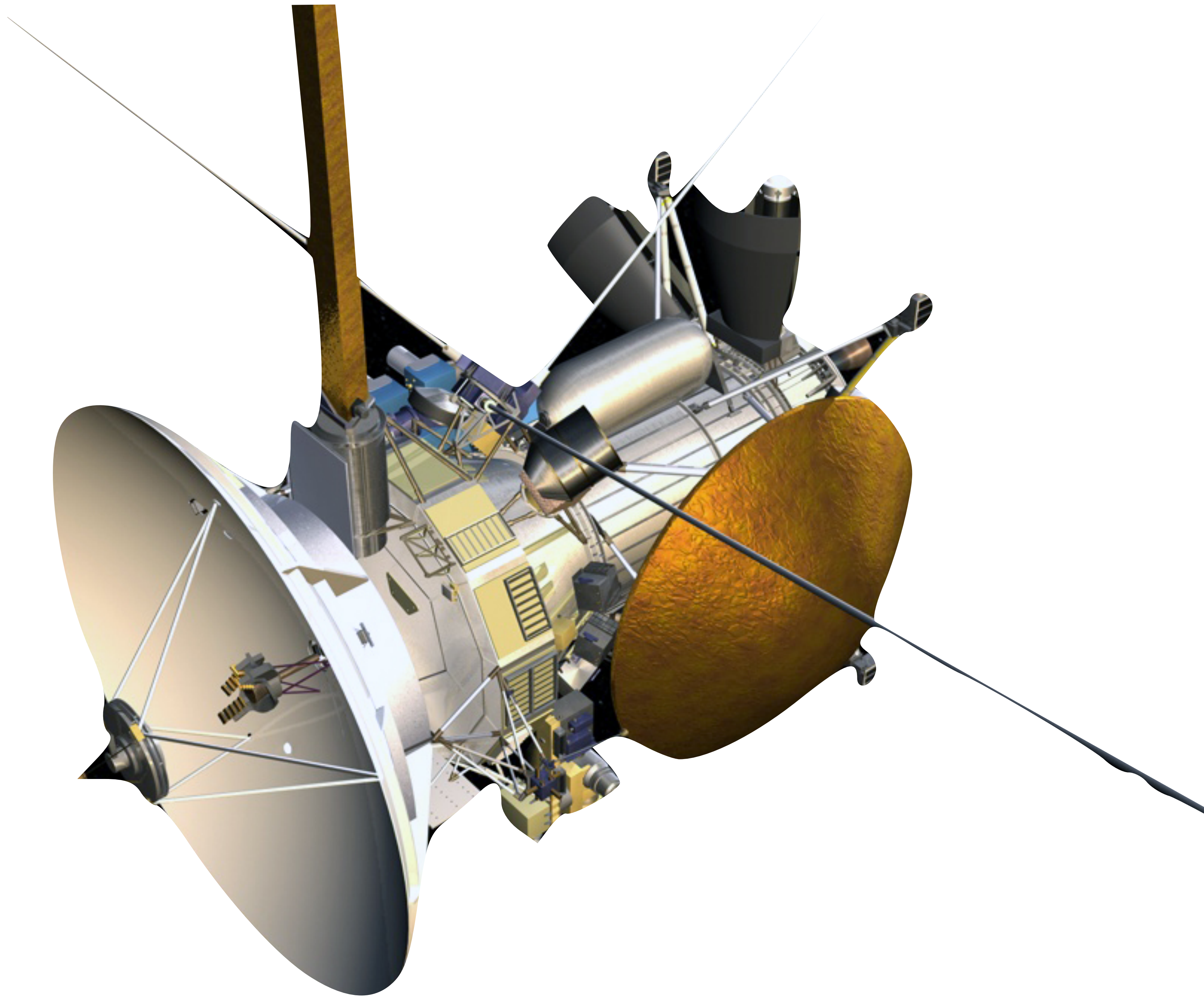
Cassini

Why start with a case study?

To avoid the "wait, what am I even doing?” moment.

Why feature Cassini?

- It is familiar.
- It was radically successful.
    - Oct. 15, 1997 - Sept. 15, 2017
    - Gathered 635 GB of data
    - Discovered 6 moons
    - Took over 450,000 photographs
    - Deployed Huygens Probe to Titan
    - Led to the publication of >4000 papers



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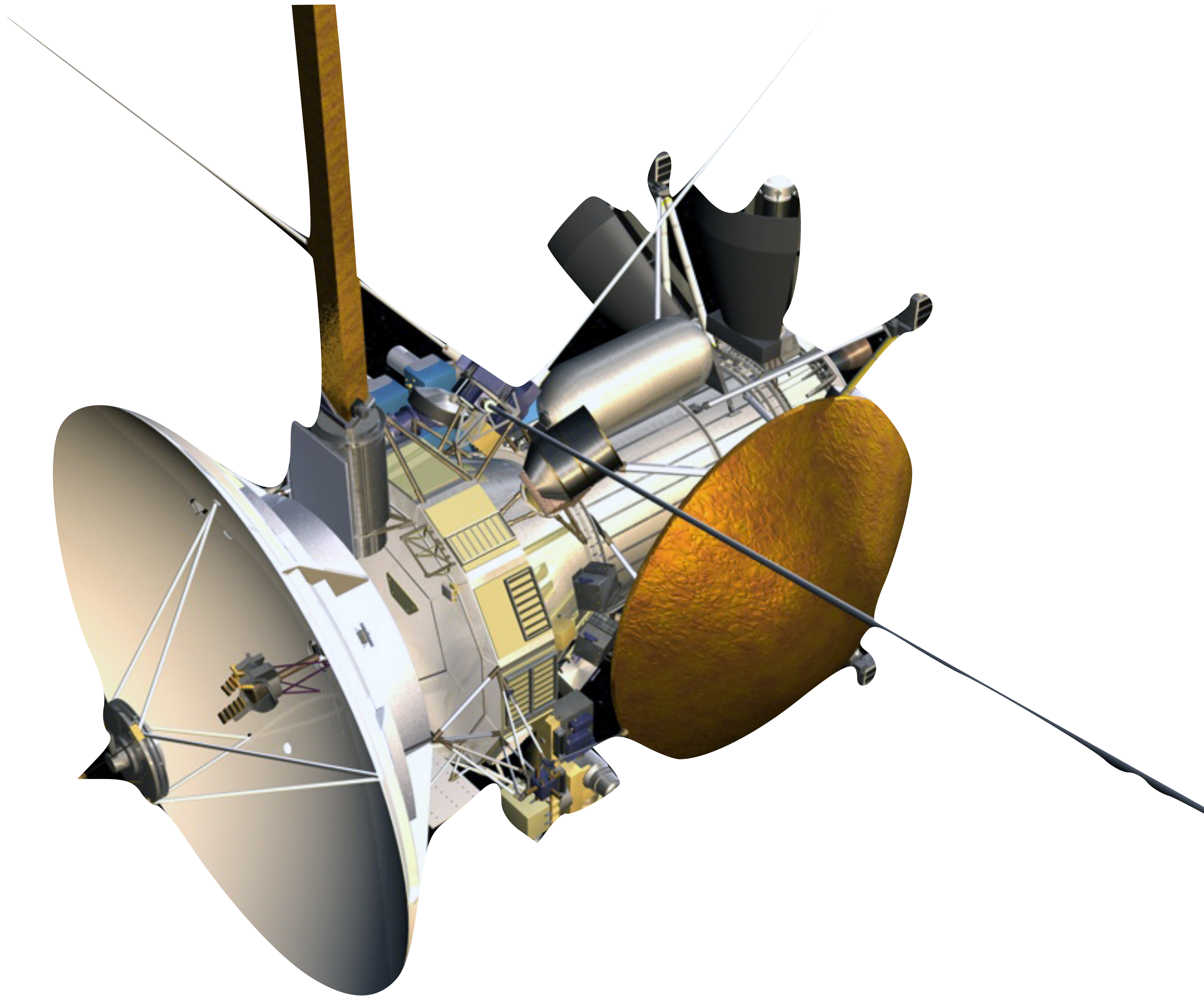


*Cassini was a success because of its **design**, and because of the **process by which it was designed.***

That process begins with *objectives*:

- Defines the *ends* to which the spacecraft is the *means.*
- May be fuzzy and imprecise.

SATURN

- Determine temperature field, cloud properties and composition of the atmosphere of Saturn.
- Measure the global wind field, including wave and Eddy components; Observe synoptic cloud features and processes.
- Infer the internal structure and rotation of the deep atmosphere.
- Study the diurnal variations and magnetic control of the ionosphere of Saturn.
- Provide observational constraints (gas composition, isotope ratios, heat flux,...) on scenarios for the formation and the evolution of Saturn.
- Investigate the sources and the morphology of Saturn lightning (Saturn Electrostatic Discharges (SED), lightning whistlers).

NASA-TM-103374, CASSINI. Report on the Phase A study: Saturn Orbiter and Titan probe. 1988.

Objectives become *requirements*:

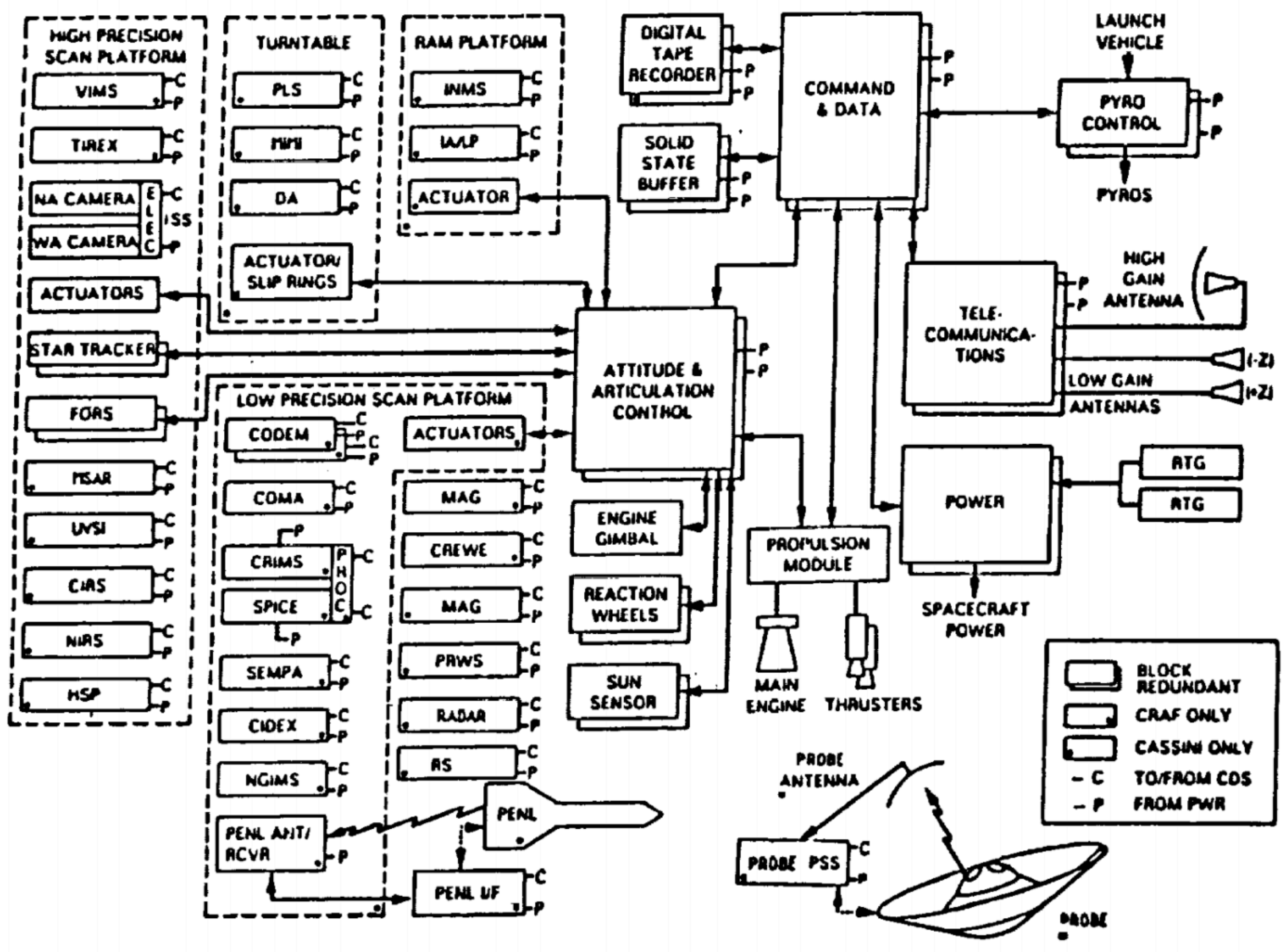
- Unambiguous, isolated, concise, measurable, unique, and consistent.
- "What must the spacecraft do?"
- Analogous to test-driven software development

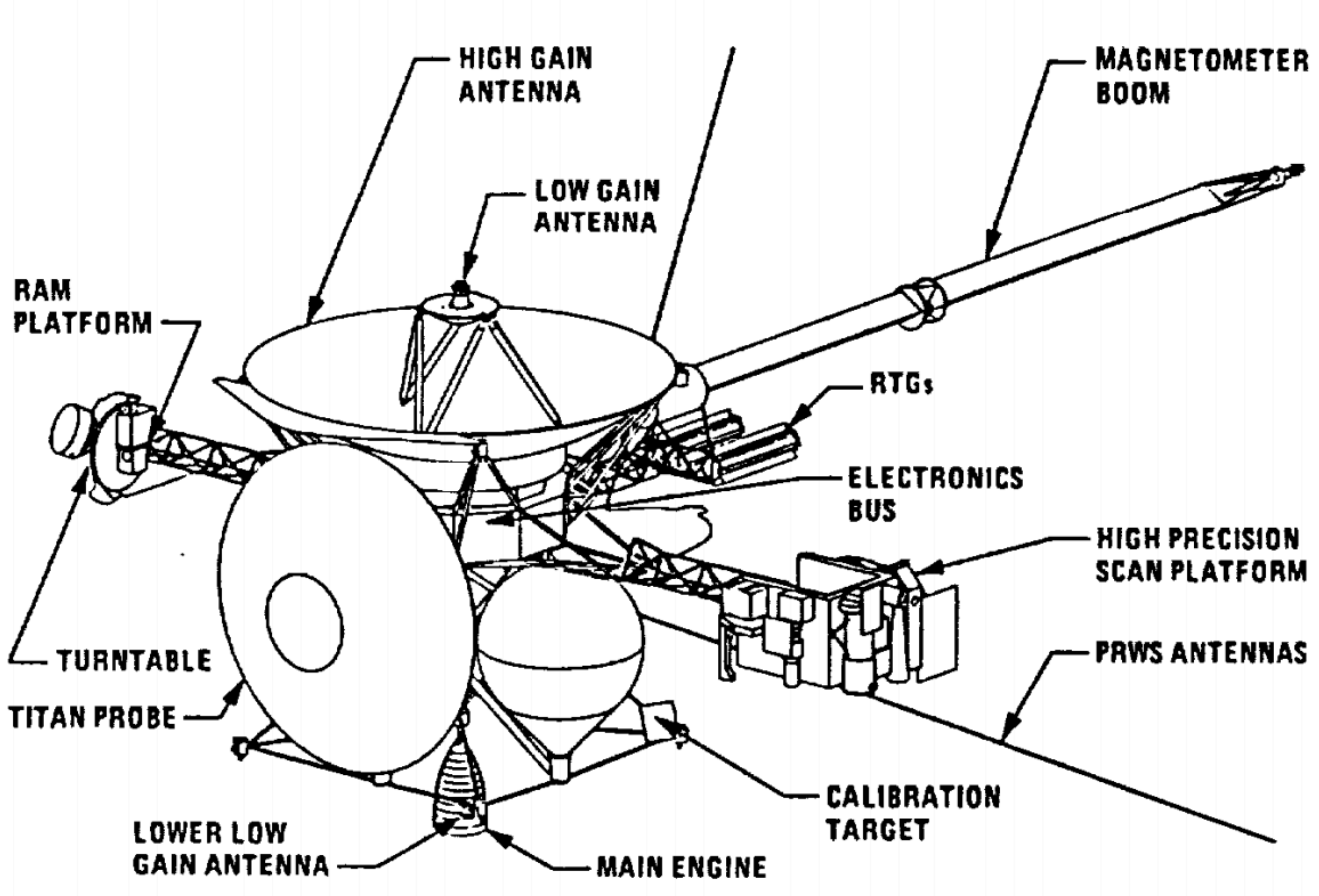
- The Orbiter shall provide telecommunications to and from 34 m and 70 m DSN stations at multiple data rates up to 115.2 kbps at the asteroid and 67.9 kbps at Saturn, and shall provide on-board storage for at least 3.6 x 10^9 bits of data for use during cruise, Probe mission and the tour.
- The Orbiter shall provide adequate pointing accuracy at Probe-Orbiter separation to establish the proper link geometry and the capability to receive Probe data for the full range of relay link geometries.
- The Orbiter shall be designed to withstand 52 R_J Jupiter flyby, Saturnian and ring plane crossing environments in the clear zones, sparsely populated regions and upper fringes of Titan's atmosphere.

NASA-TM-103374, CASSINI. Report on the Phase A study: Saturn Orbiter and Titan probe. 1988.

Requirements become *design*:

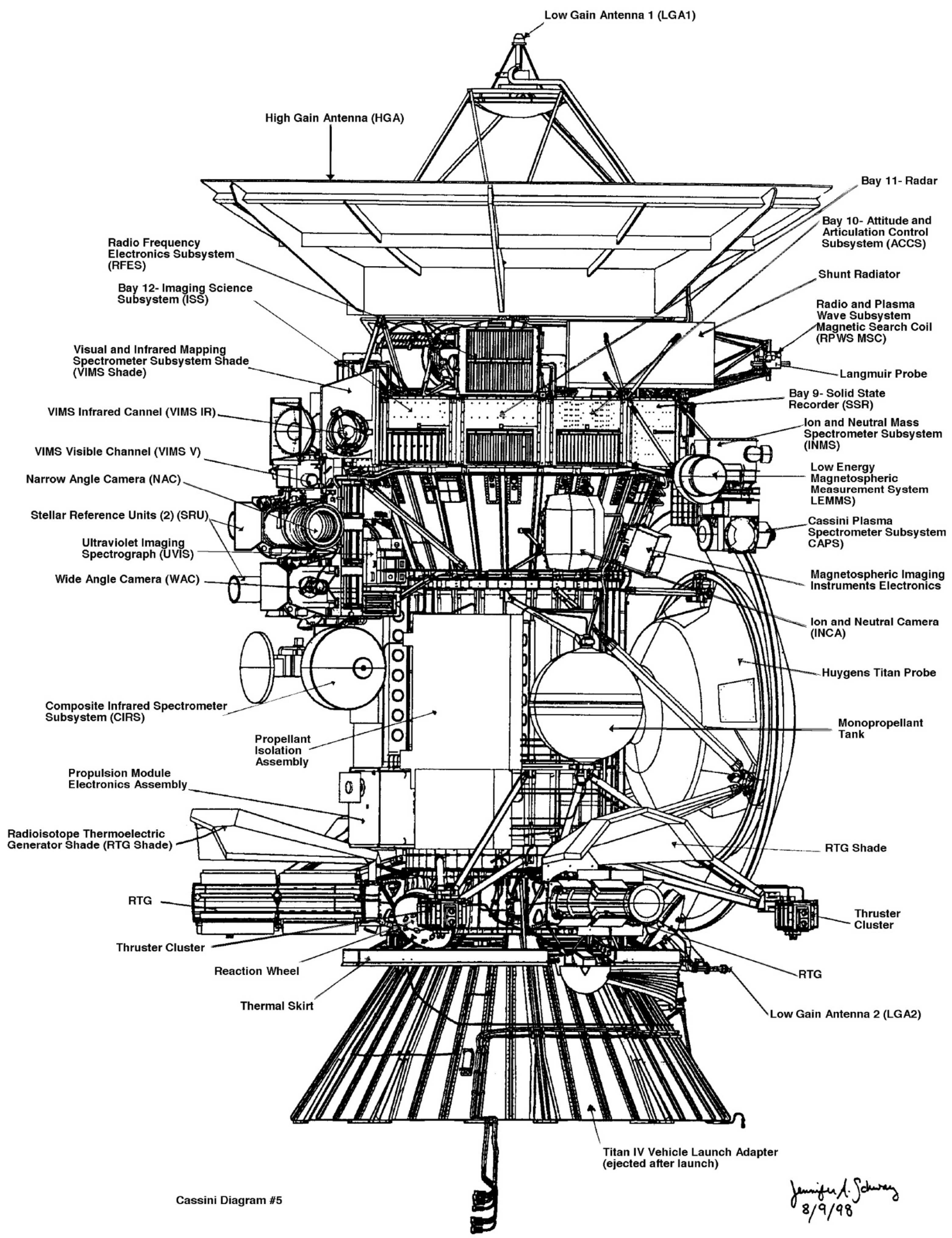
- System requirements flowdown to subsystem requirements
- Subsystems are designed to satisfy requirements.
- Design is complete when all requirements are met.





NASA-TM-103374, CASSINI. Report on the Phase A study: Saturn Orbiter and Titan probe. 1988.

Design is finalized, and the spacecraft is *fabricated*



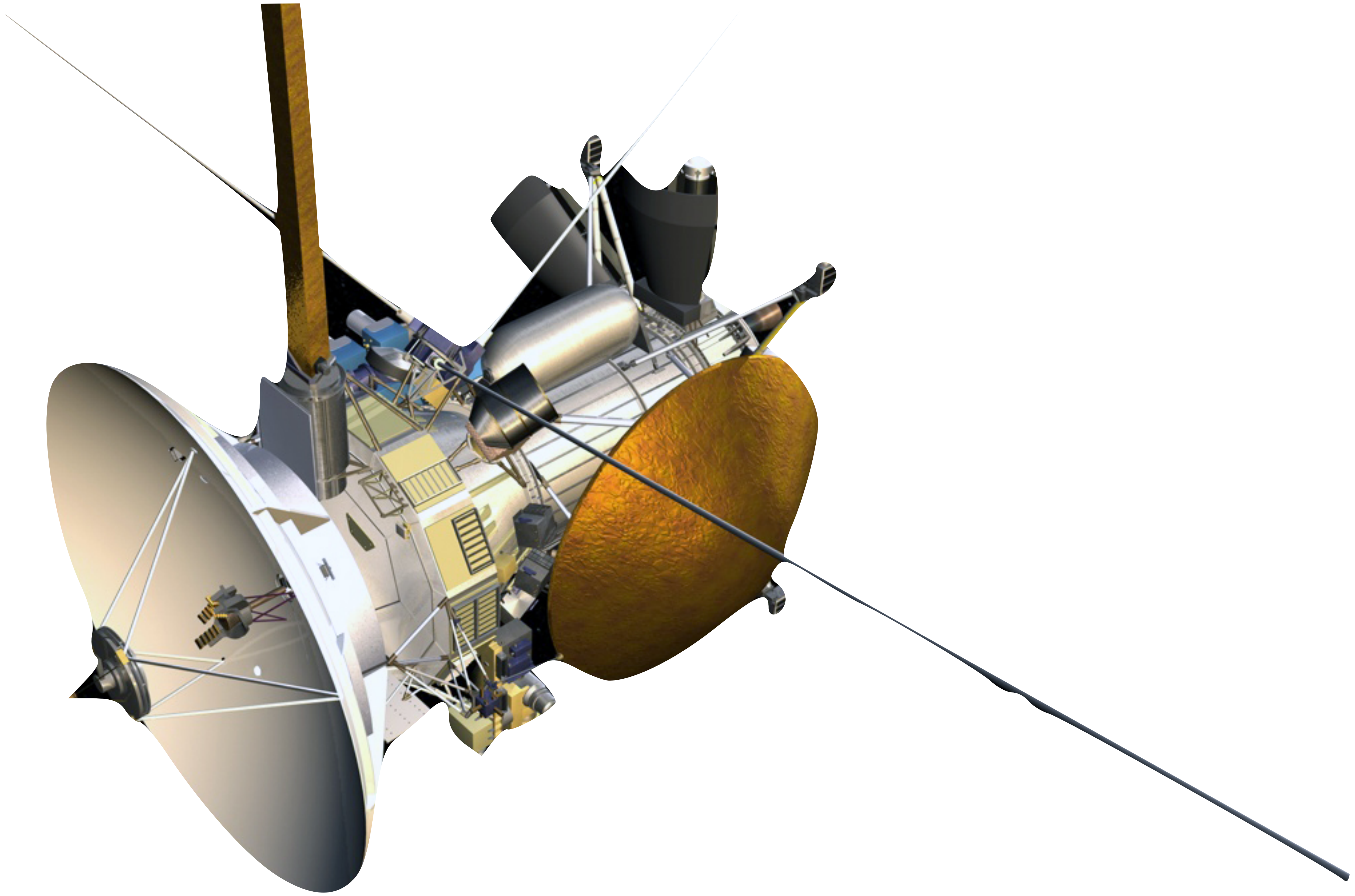
person

solarsystem.nasa.gov

What did they design?

Let’s consider Cassini one subsystem at a time.

Power

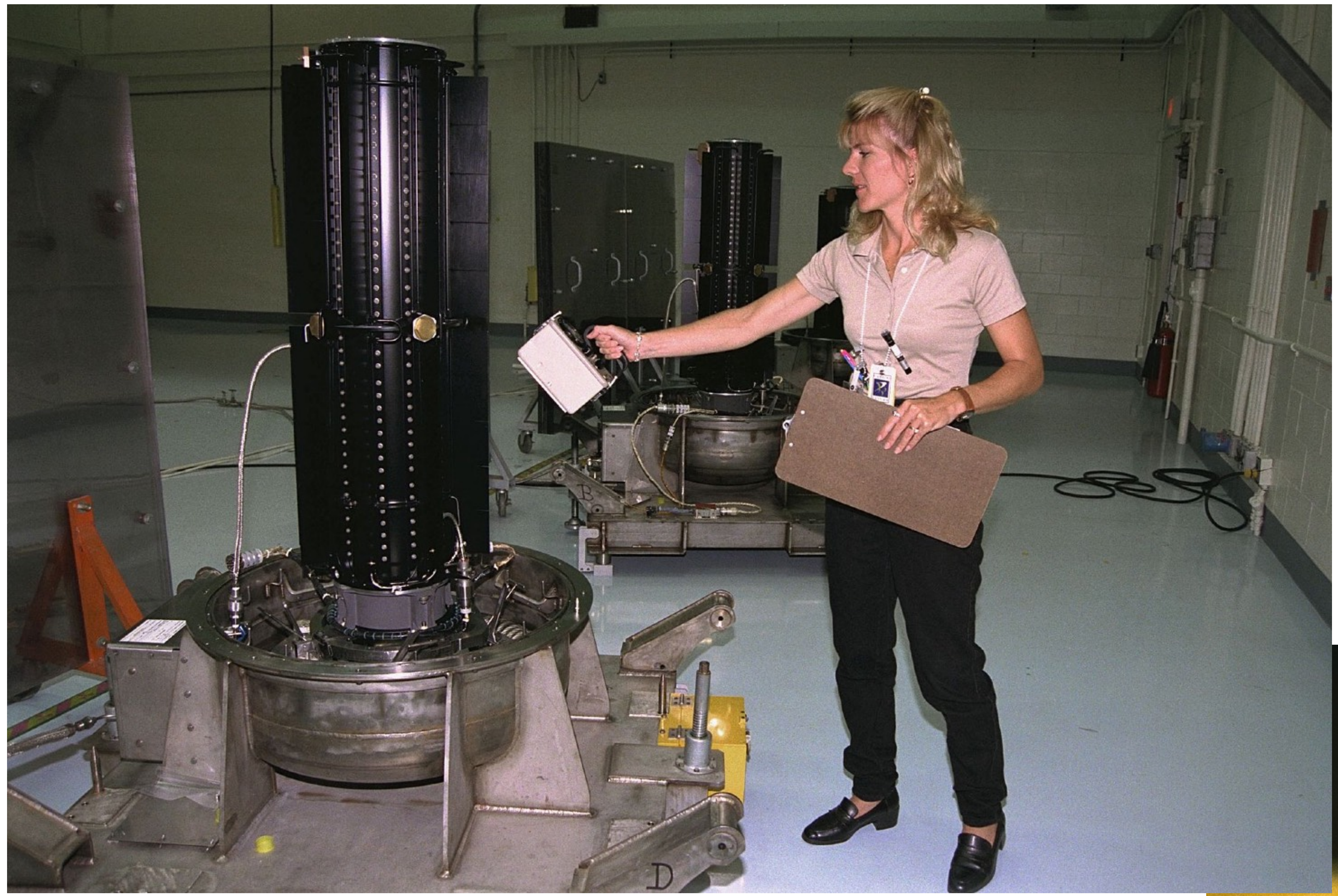


What’s missing?

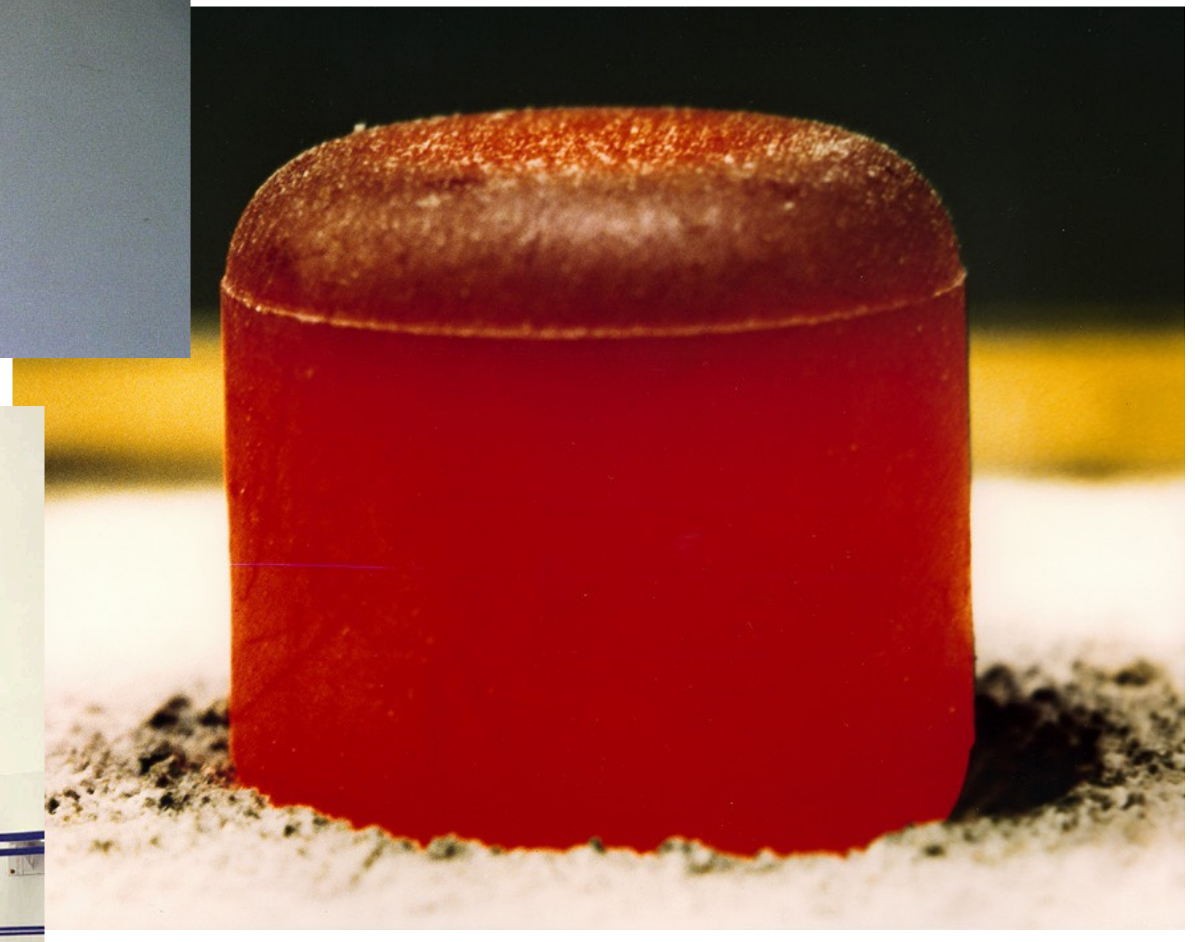
Power

Radioisotope Thermoelectric Generator (RTG)

- Cassini carried a 33 kg slug of Plutonium-238
- Converted heat generated by radioactive decay into power
- A lot of power. At the end of Cassini’s life, the RTG’s were still continuously generating 600-700W
- Also carried NiCd batteries for storage and power peaks



Cassini's RTG



Cassini's Plutonium

RTG on *New Horizons*

Wikipedia

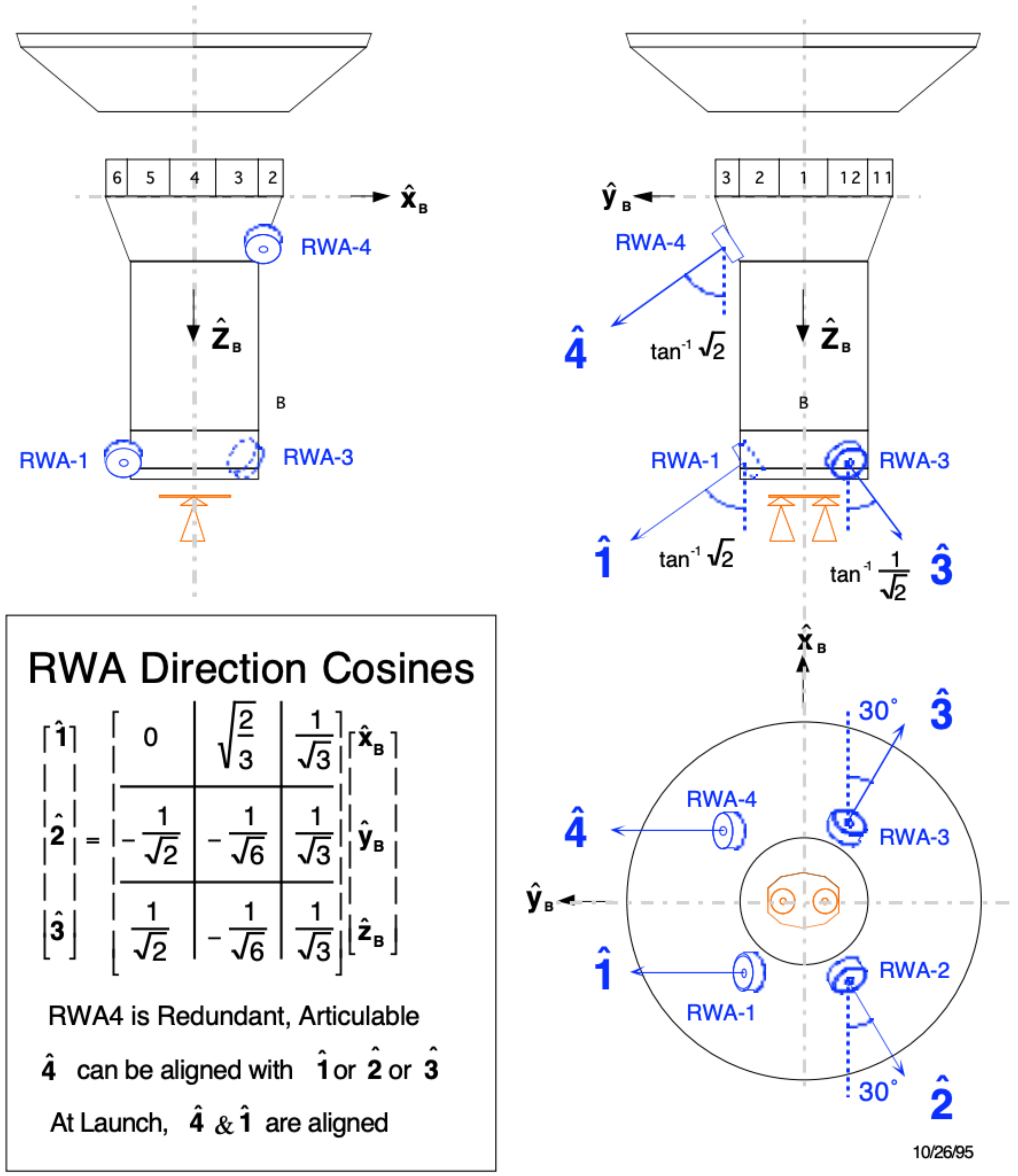
Attitude Control

Accuracy Requirements	Requirements
HGA pointing control requirement (radial 99%)	
X-band (Telecommunications)	3.2 mrad
Ka-band (Radio Science)	2.0 mrad
Ku-band (Radar Mapping of Titan)	4.6 mrad
S-band (Huygens Probe Relay)	6.0 mrad
LGA X-band pointing control requirement (radial 99%)	4.0 degrees
Science inertial pointing requirements (radial 99%)	
Control	2.0 mrad
Knowledge	1.0 mrad
Science pointing stability requirements (2σ per axis) for time windows of:[9]	
0.5 s	4 μrad
1 s	8 μrad
5 s	36 μrad
22 s	100 μrad
100 s	160 μrad
900 s	200 μrad
1200 s	220 μrad
1 hour	280 μrad
Main engine ΔV burns (1σ):	
Fixed Magnitude	10 mm/s
Fixed Pointing	17.5 mm/s
Proportional Magnitude	0.2 %
Proportional Pointing	3.5 mrad
Thruster ΔV burns (1σ):	
Fixed Magnitude	3.5 mm/s
Fixed Pointing	3.5 mm/s
Proportional Magnitude	2 %
Proportional Pointing	12 mrad

Do you think Cassini was 3-axis stabilized?

What sorts of actuators do you think Cassini used to meet these requirements?

"Cassini spacecraft attitude control system flight performance." AIAA Guidance, Navigation, and Control Conference and Exhibit. 2005.)



Attitude Control

Reaction wheels

- Cassini carried 4 reaction wheels. 3 strapped down, the fourth on a movable platform
- Reaction wheels arranged to span R3

Reaction thrusters

- 16 thrusters (8 prime, 8 redundant) for attitude control and momentum dumping.

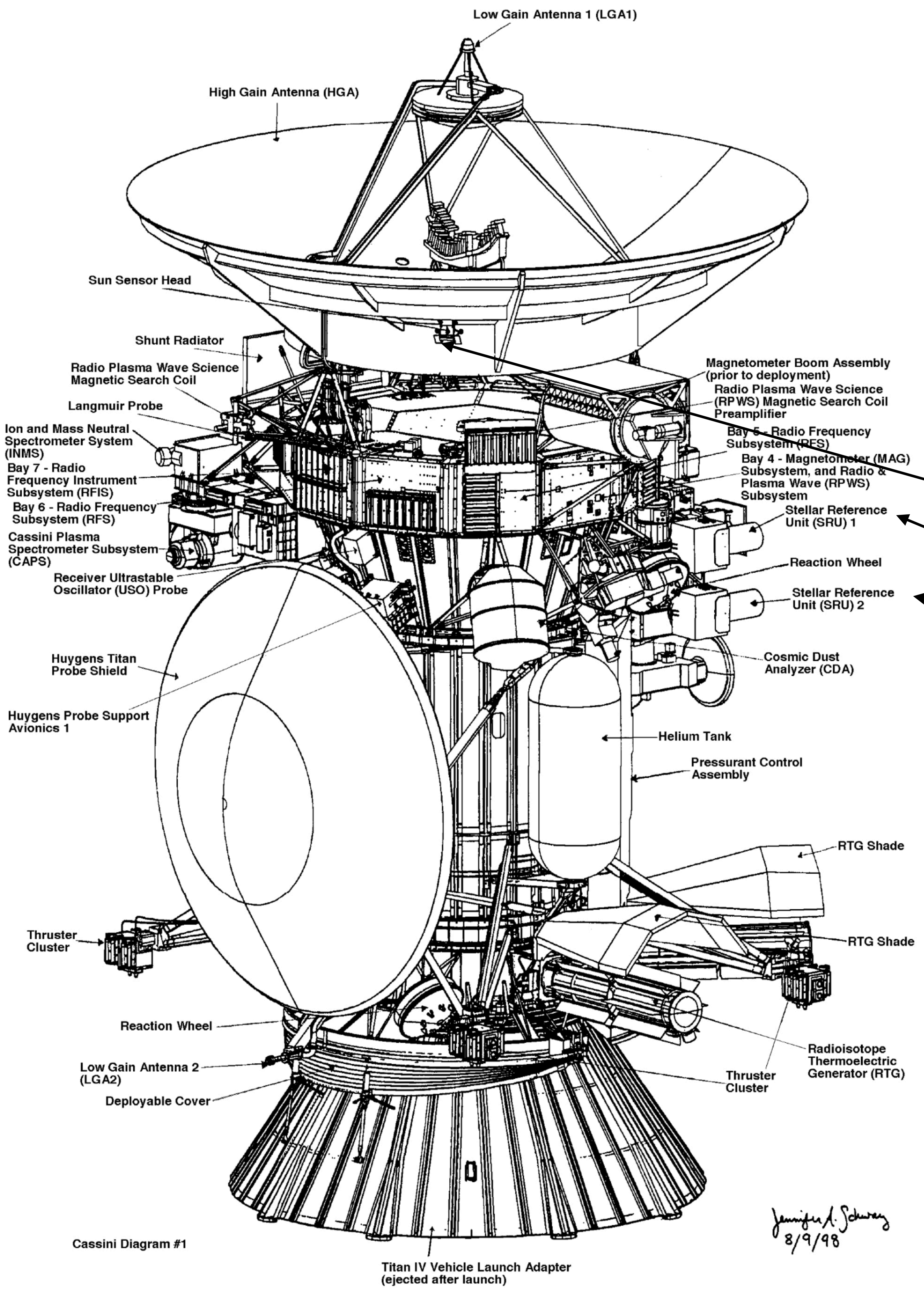
"Cassini spacecraft attitude control system flight performance." AIAA Guidance, Navigation, and Control Conference and Exhibit. 2005.)

Attitude Determination

What are the options?

What do you think Cassini used?

Attitude Determination

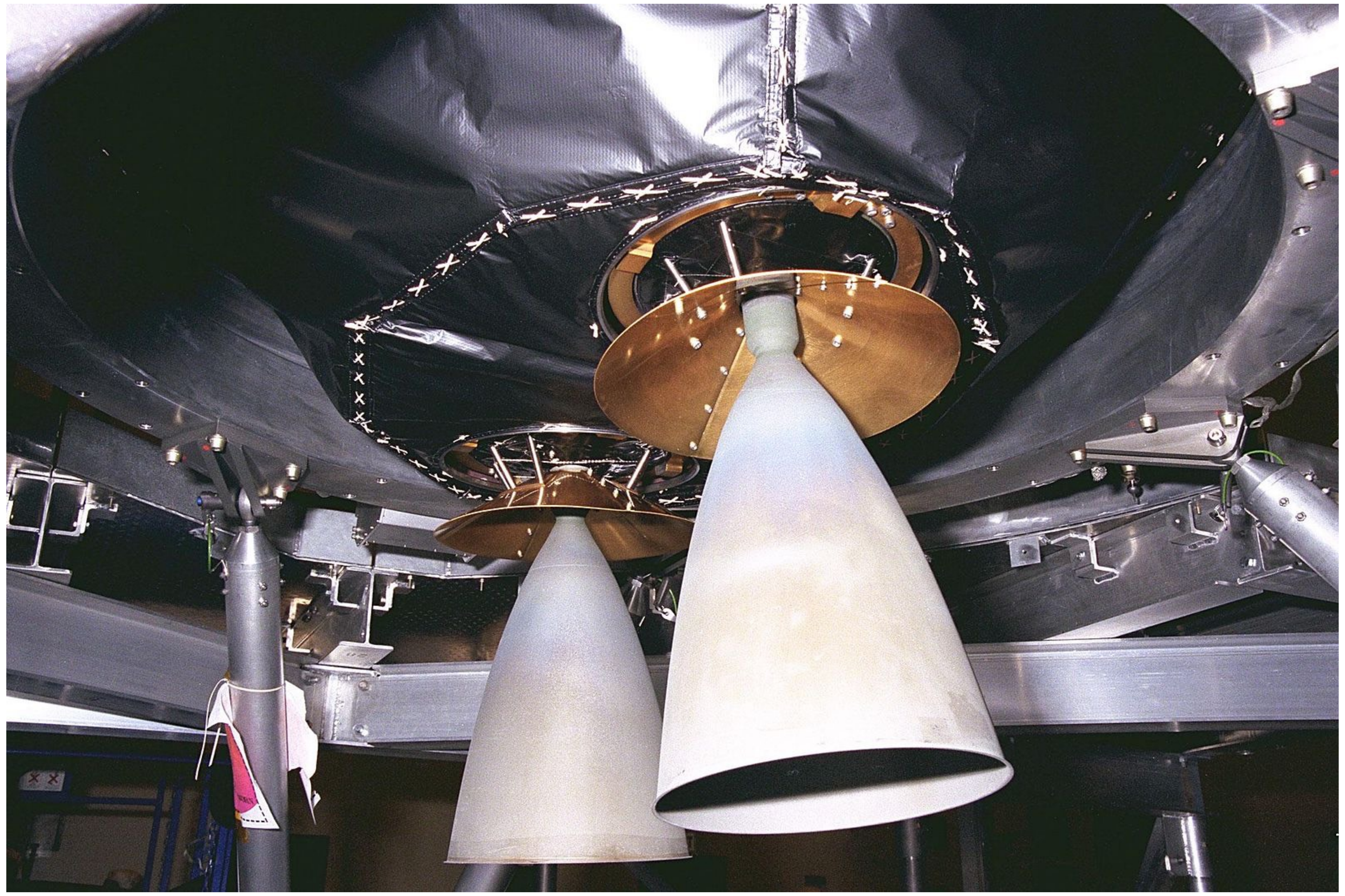


- Sun sensors (x2)
- Star trackers (x2)
- Fiber-optic gyros (x2)

solarsystem.nasa.gov

Propulsion

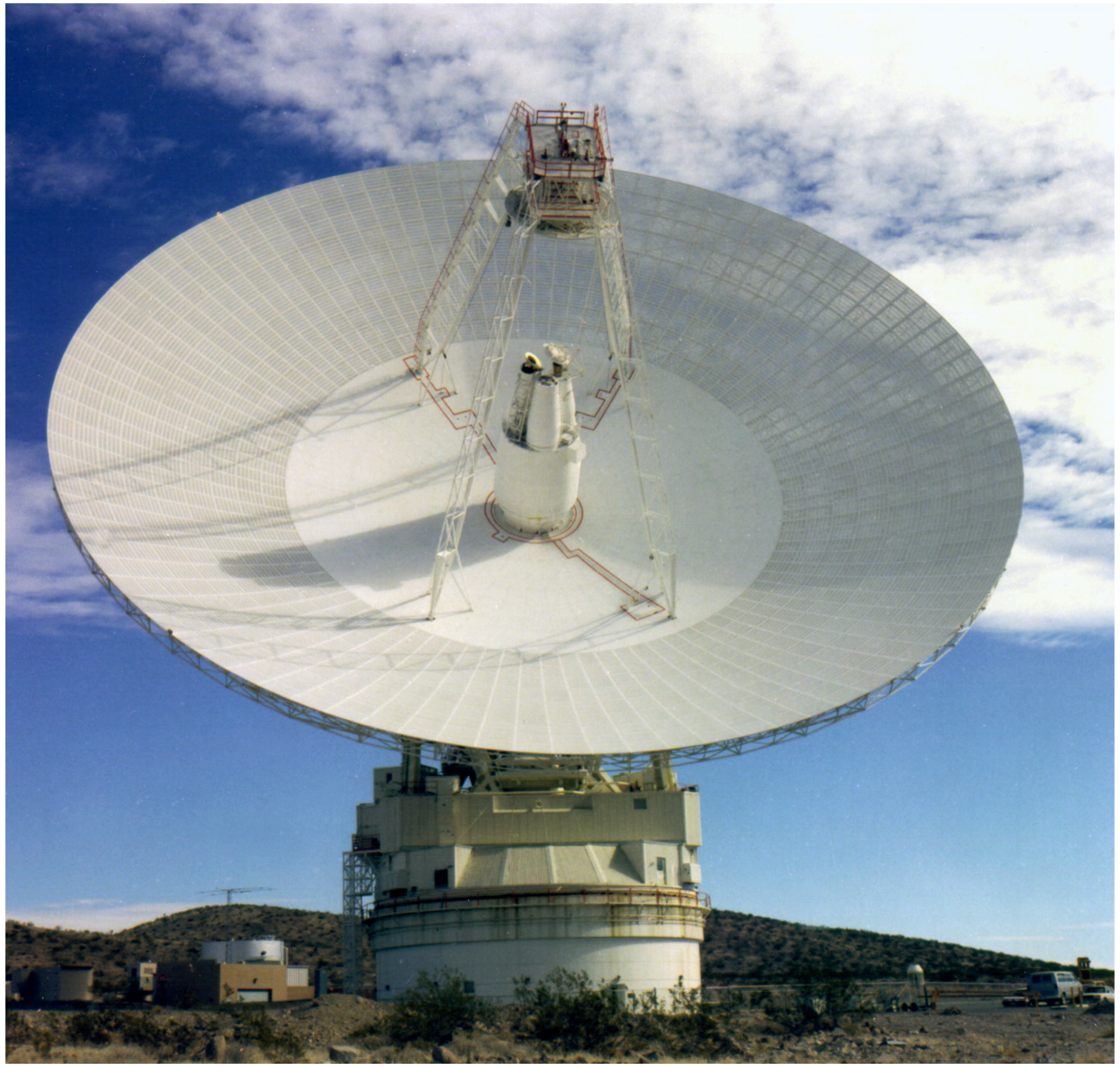
- Delta-V capability of >2040 m/s (Though Cassini's total delta-V was much greater. **How?**)
- Two redundant main engines, fueled by N2H2/N2O4 (hydrazine and nitrogen tetroxide) bipropellant stored in conispherical tanks with capacity of 3450 kg
- Delta-V measured with accelerometer



Redundant engines

Wikipedia

Guidance and Navigation



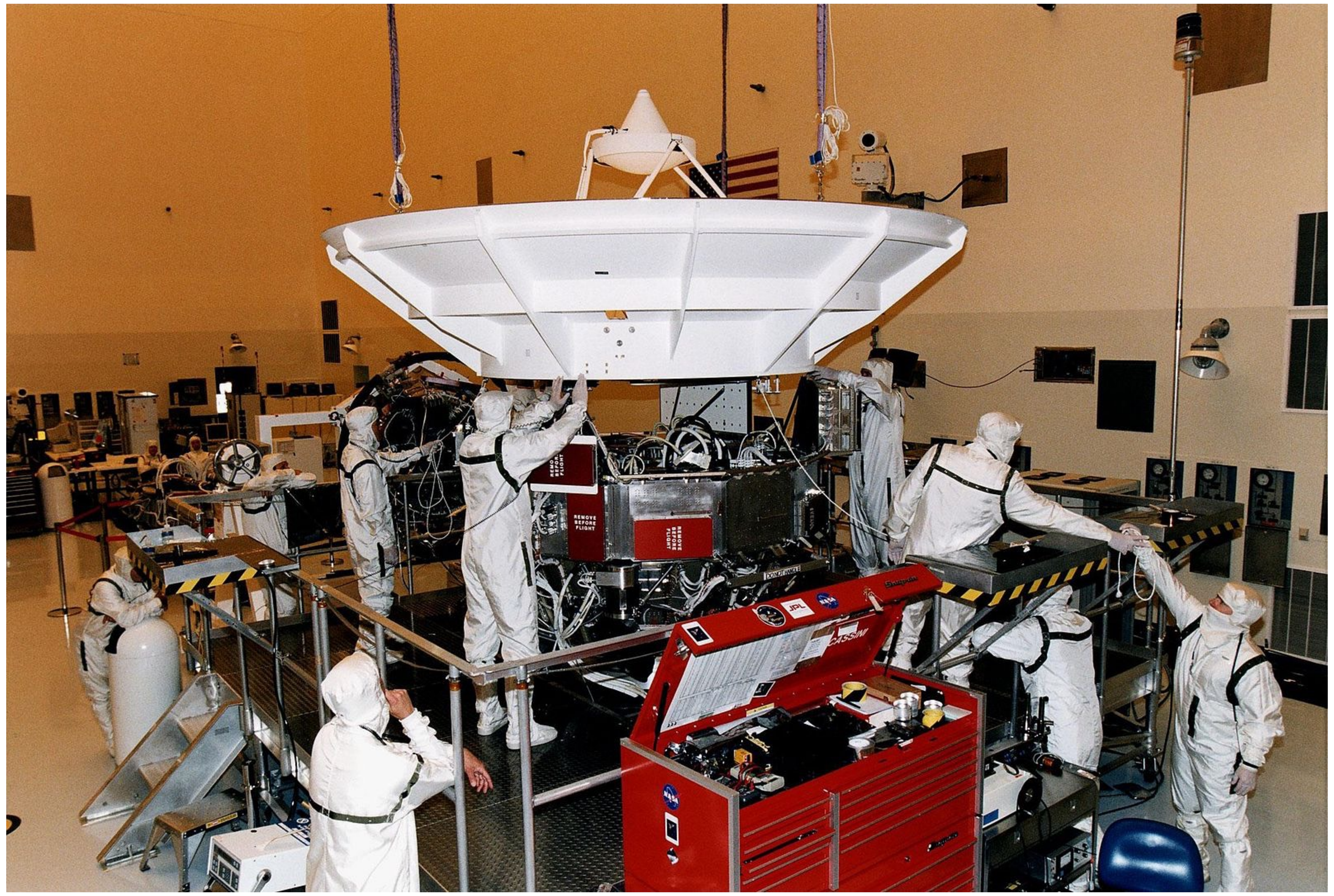
70 m DSN antenna in California

The Deep Space Network

- Network of communication facilities in California, Madrid, and Canberra. **Why these locations?**
- Used for tracking deep-space satellites' positions and velocities

nasa.gov

Telemetry and Command

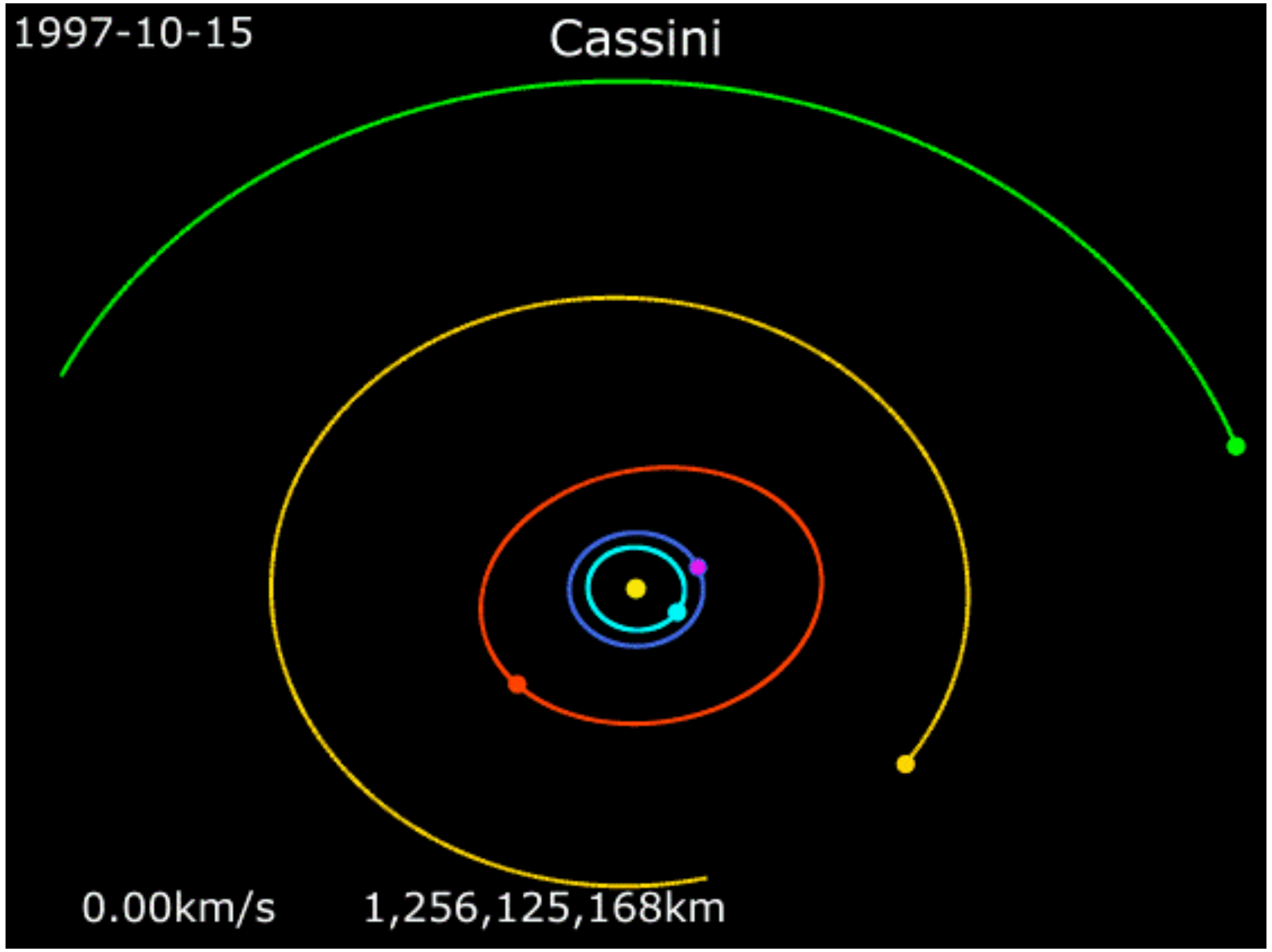


High-gain antenna

- 3.67 meter high-gain X-band antenna (rebuild of *Voyager's*)
- 26.7 kbps from Saturn, with a bit error rate of 10e-6 to 70m DSN antenna
- Reed-Solomon encoded
- Two low-gain X-band antennas for cruise phase and in the event of an emergency
- **How do we size these systems?**

Wikipedia

Interplanetary Trajectory



Trajectory:

- Venus flyby 1 - Dec. 1998
- Venus flyby 2 - June 1999
- Earth flyby - August 1999
- Asteroid 2685 Masursky - Jan. 2000
- Jupiter flyby - Dec. 2000
- Saturn arrival - Feb. 2004

~0.86 - 9.2 AU

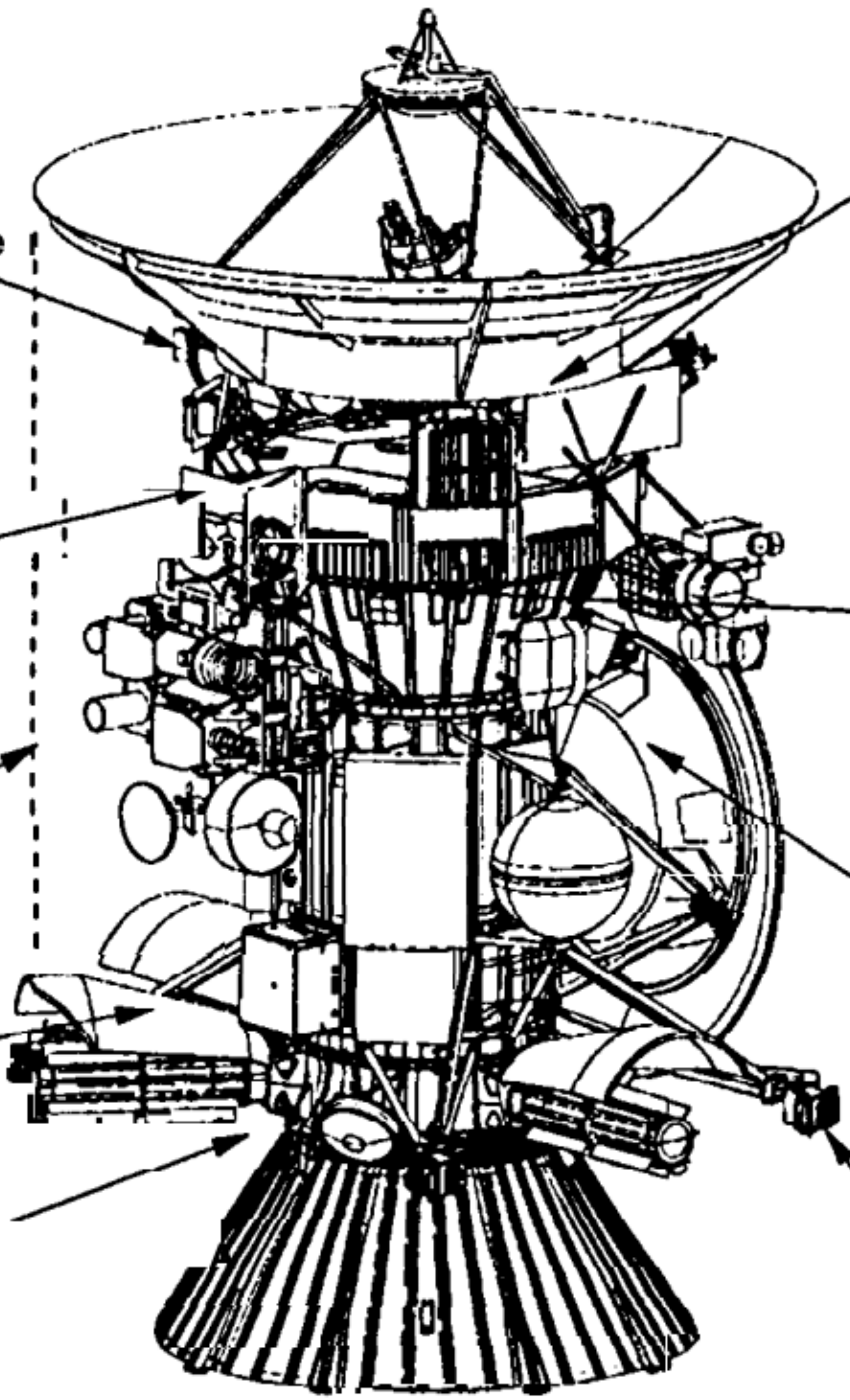
Wikipedia

Thermal

Why is this challenging, based on the trajectory that we just saw?

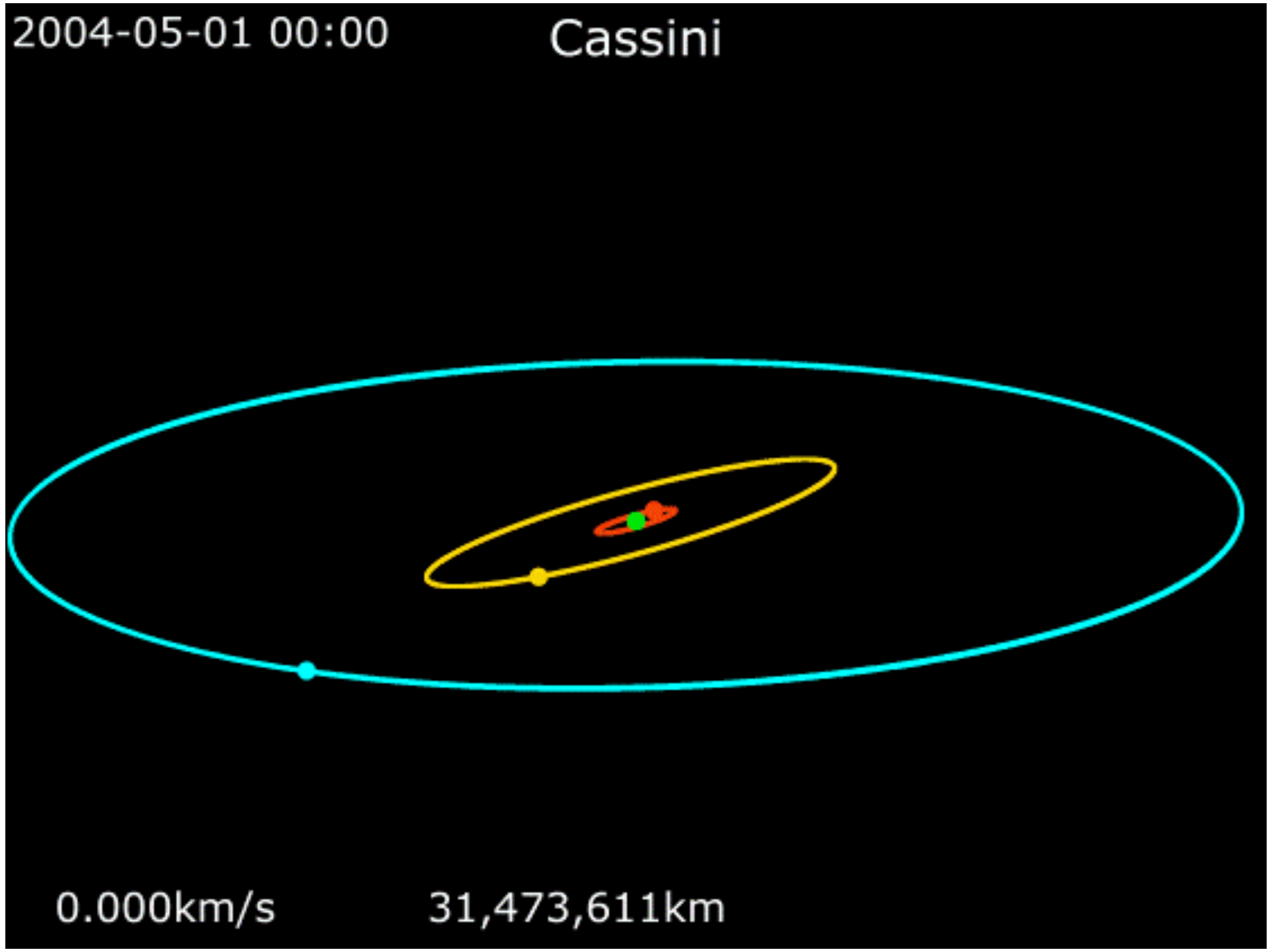
What other subsystem can we utilize for thermal management?

Thermal



Mireles, Virgil, and Glenn T. Tsuyuki.
"A summary of the Cassini system-level thermal balance test: Engineering subsystems." SAE transactions (1997): 940-953.

Saturn Trajectory

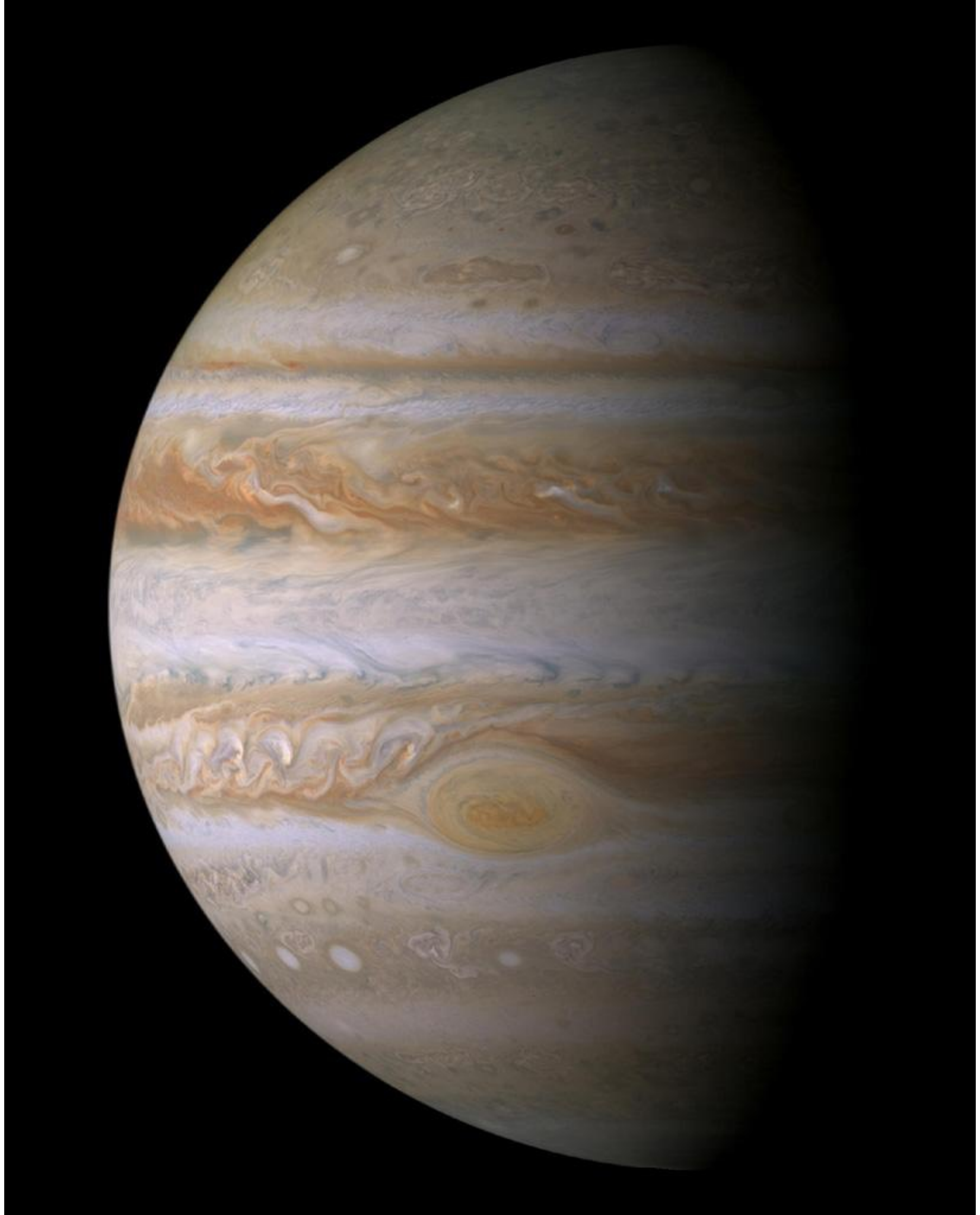


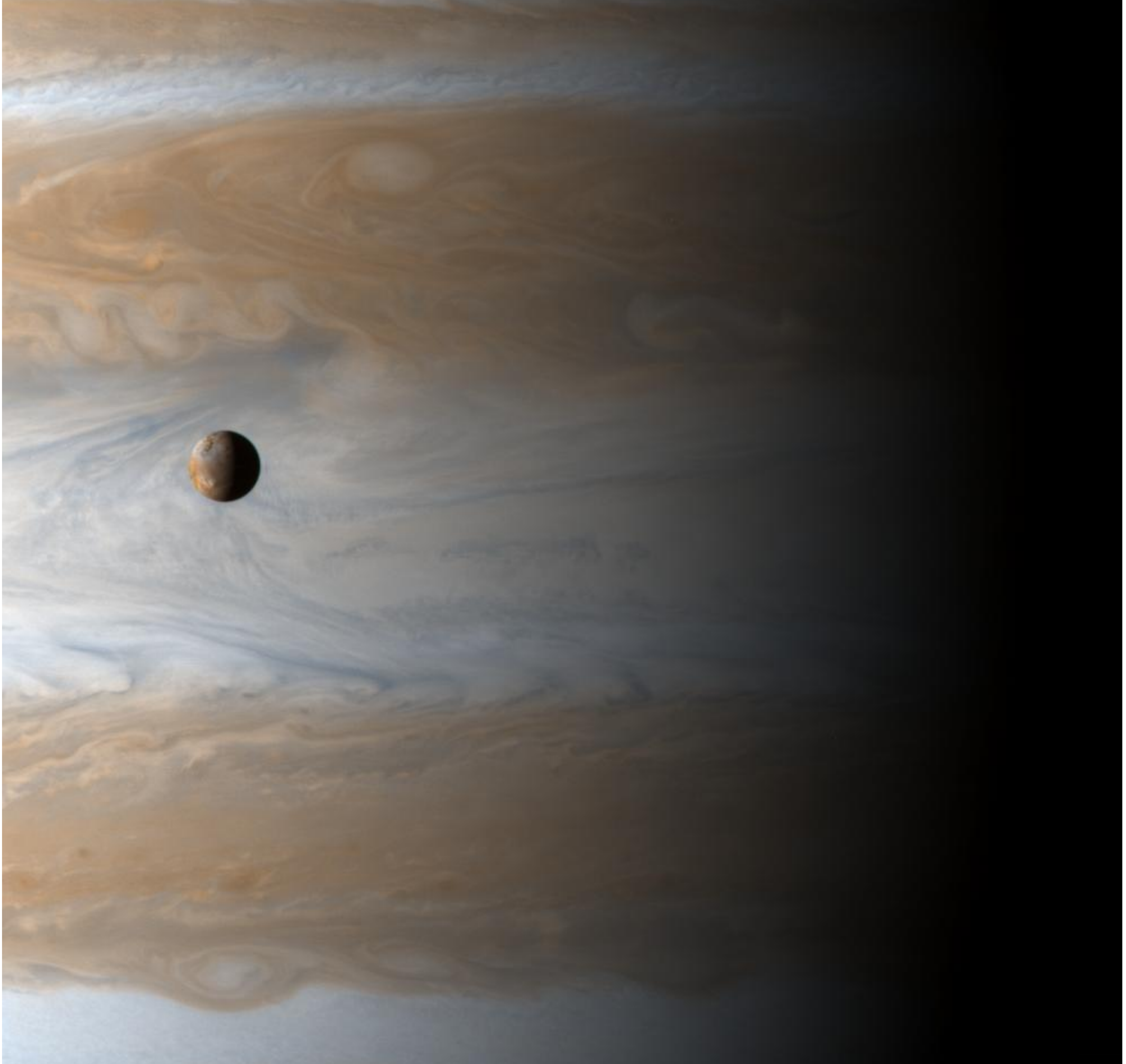
13 years at Saturn

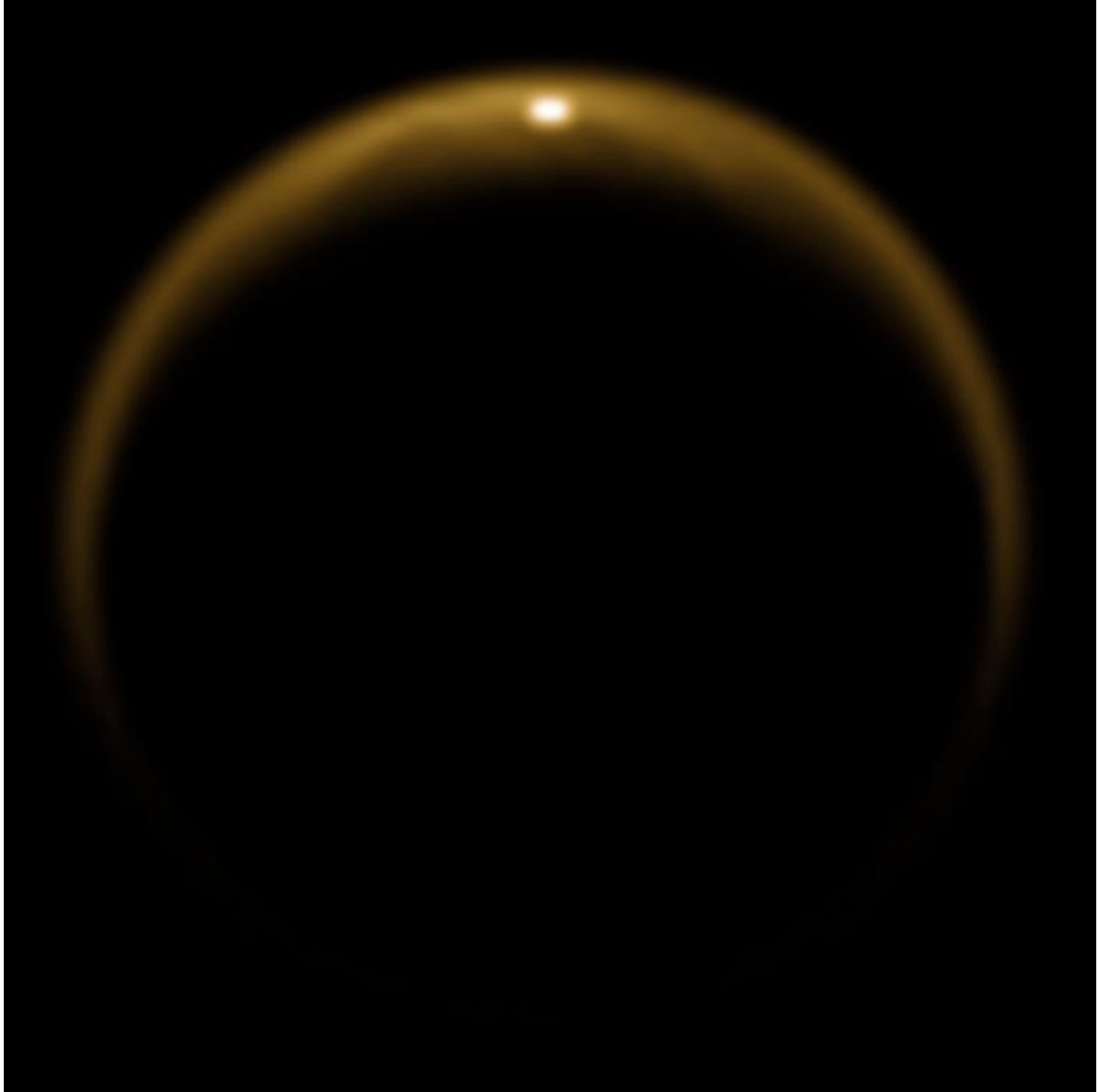
- Discovered lakes on Titan
- Observed a hurricane on Saturn
- Discovered 6 new moons
- Determined length of day on Saturn
- Imaged plumes of Enceladus
- …

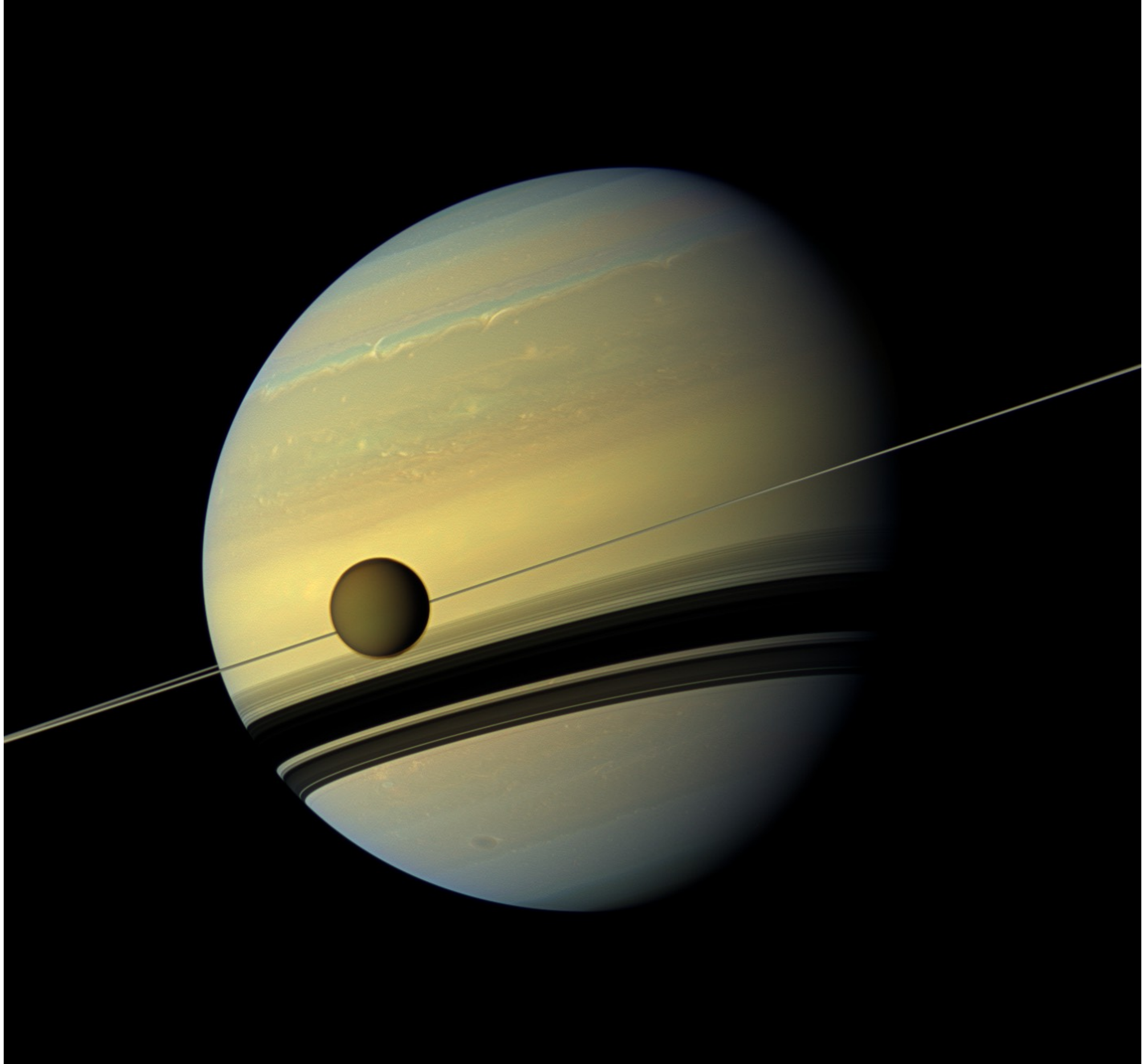
Wikipedia

What did we get in return for this effort?



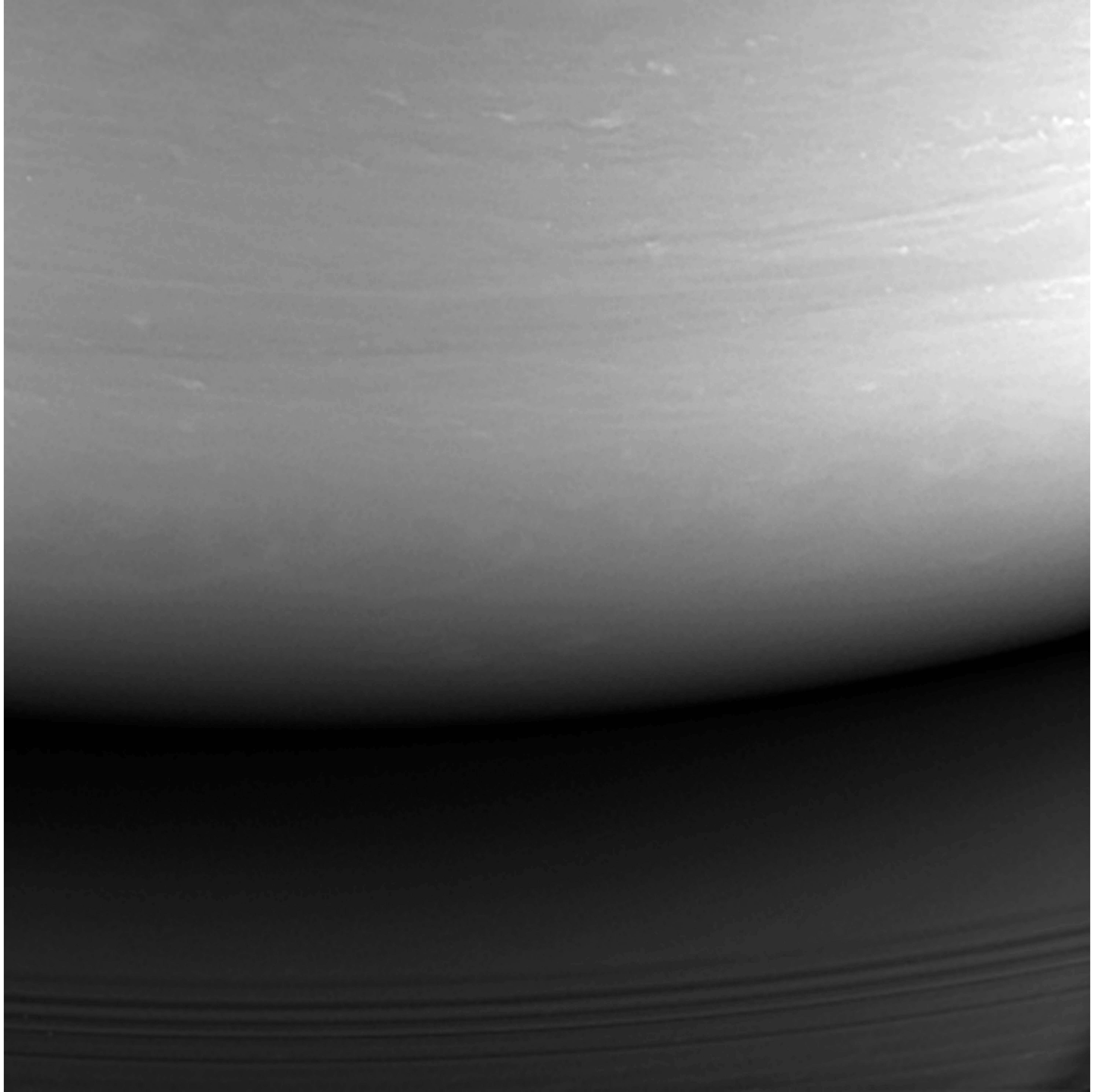






Mars
Venus
Pallene's ring
Mimas
Janus
Janus' ring
Prometheus
Spokes
Pandora
Enceladus
Epimetheus
Clumps
Earth-Moon
Tethys

Why did we stop?



These are *places.* You can get there from here.

Before next time:

- Read the syllabus, come with questions
- Read lecture supplements 1 & 2