A Year in the Life of the Cassini-Huygens Mission

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National Aeronautics and Space Administration
Jet Propulsion Laboratory
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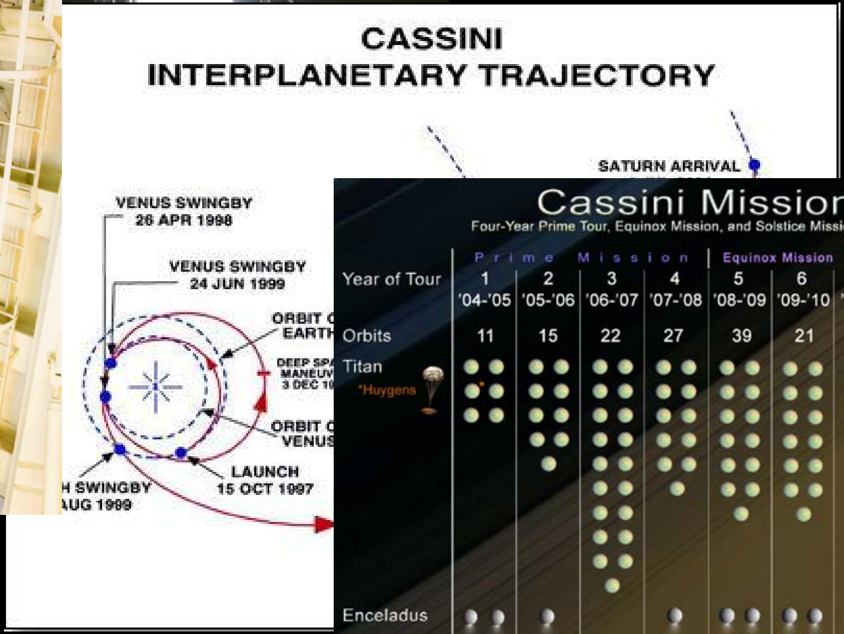
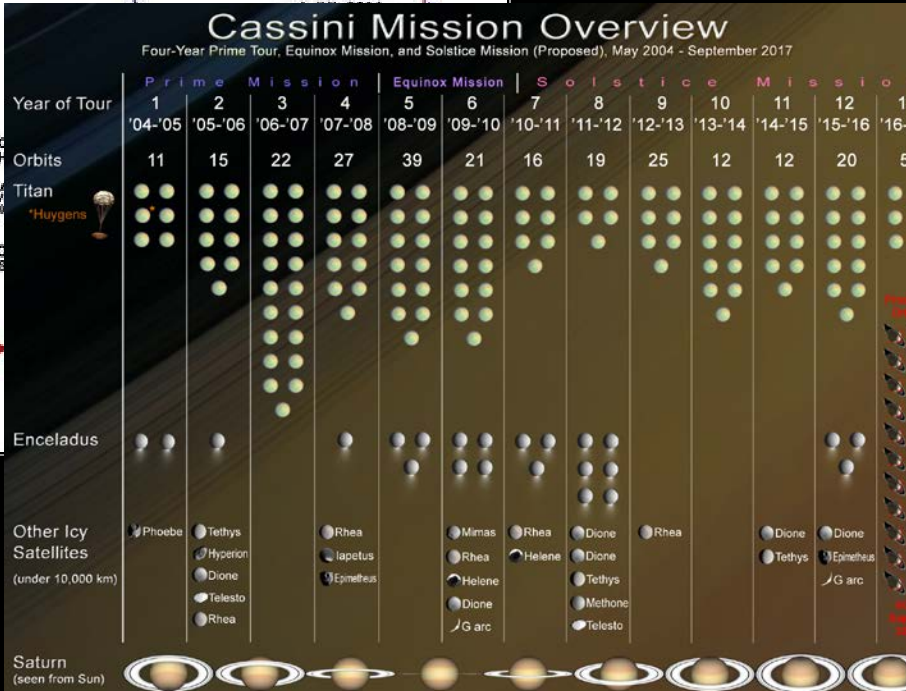
The year is 2010…

2010 in context…





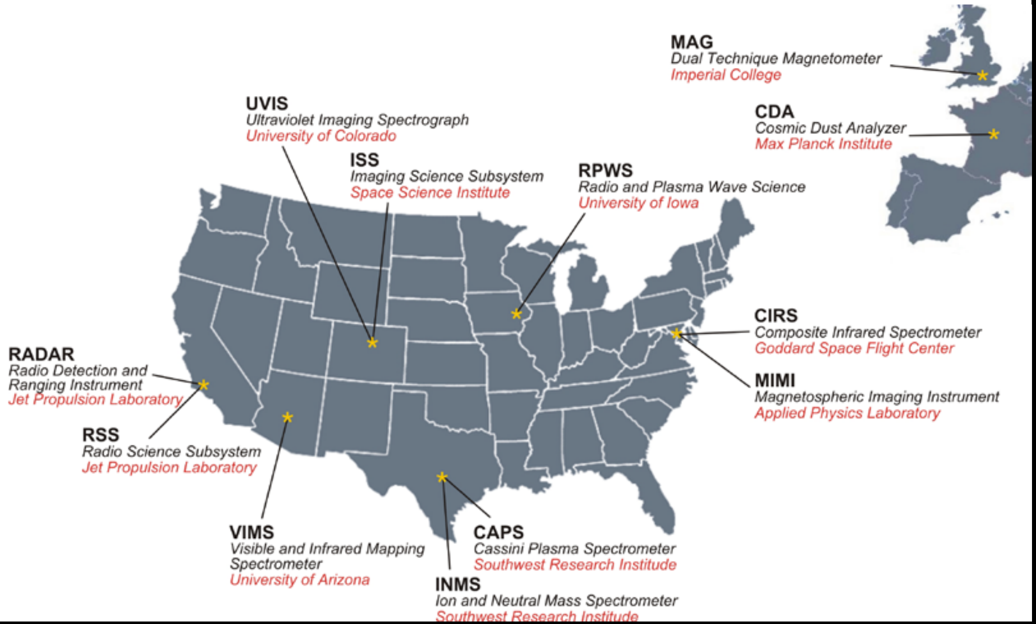
Science Planning

Three things that make Science Planning Hard…

- **Distributed operations**
  - **Additional and more complex interfaces**
  - **Extensive collection of planning rules to enforce**
  - **Substantial investment in complying with ITAR restrictions**
  - **Remoteness and time zones**
  - **Small distributed team supporting a concurrent and overlapping and iterative uplink development process**

Three things that make Science Planning Hard…

- **Distributed operations**



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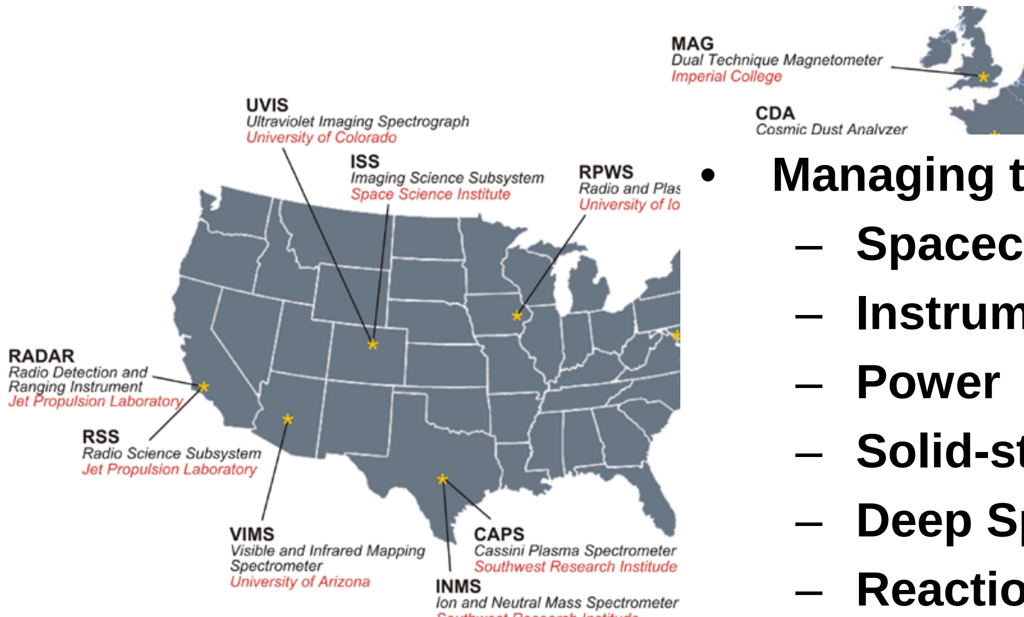
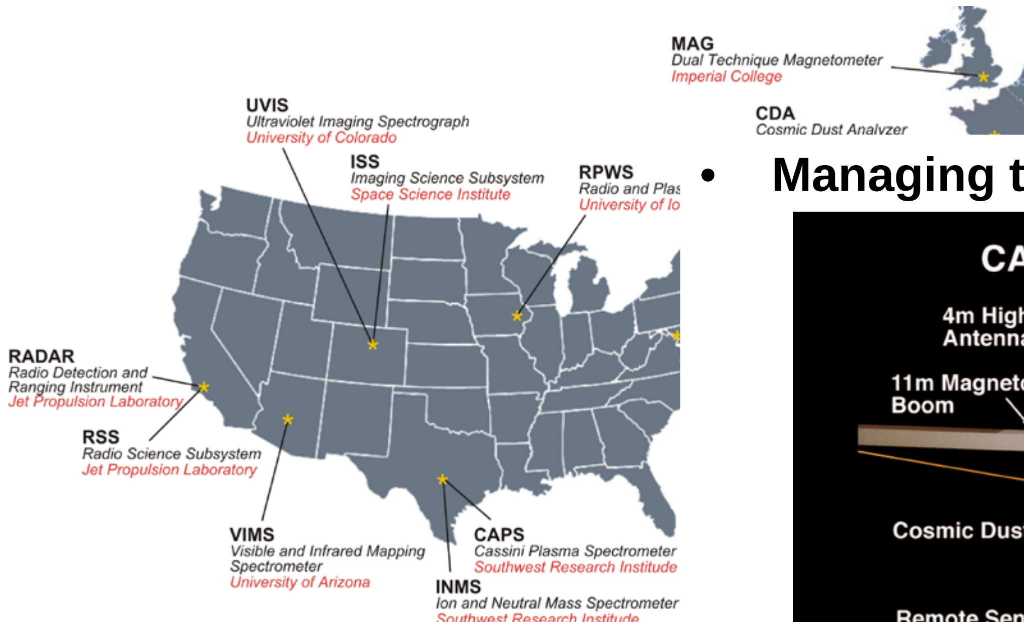


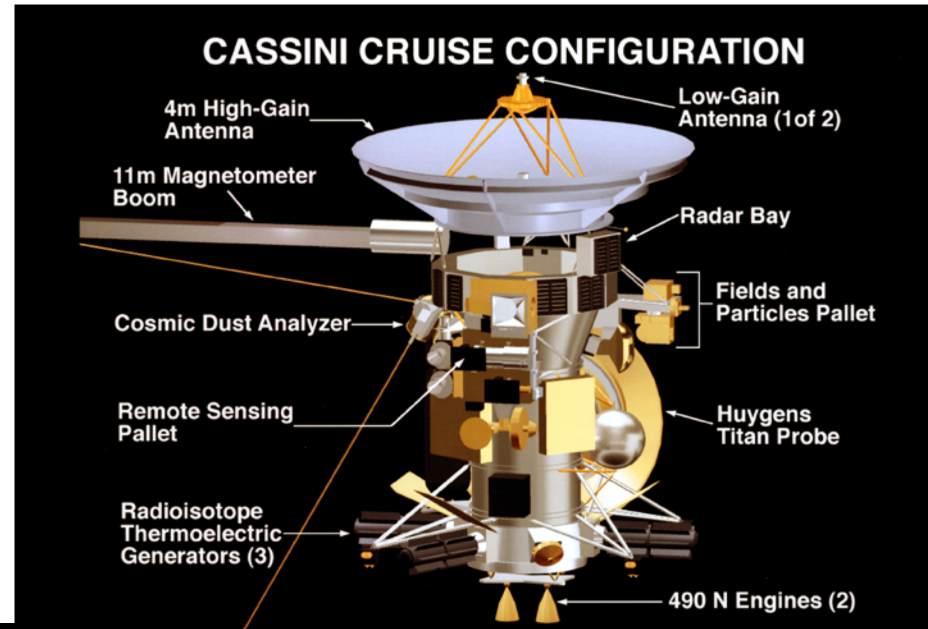
- Managing the shared spacecraft resources
  - Spacecraft pointing
  - Instrument data collection rates
  - Power
  - Solid-state recorder storage
  - Deep Space Network scheduling
  - Reaction Wheels

Three things that make Science Planning Hard…

- **Distributed operations**



- **Managing the shared spacecraft resources**



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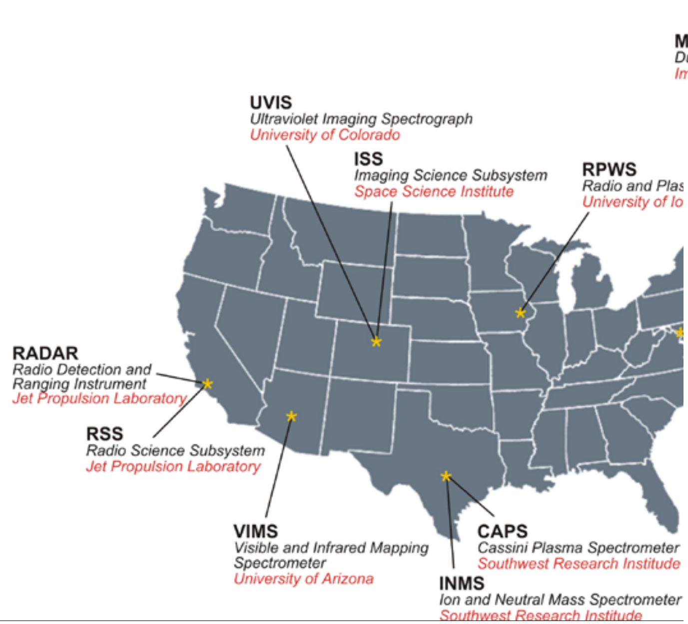
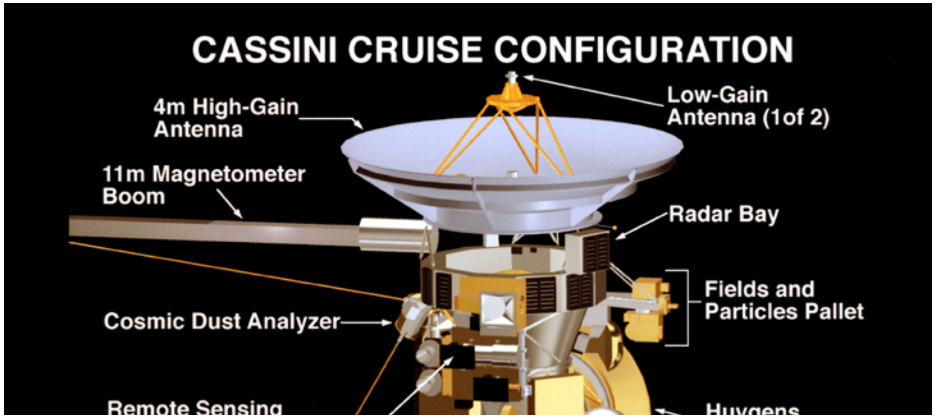


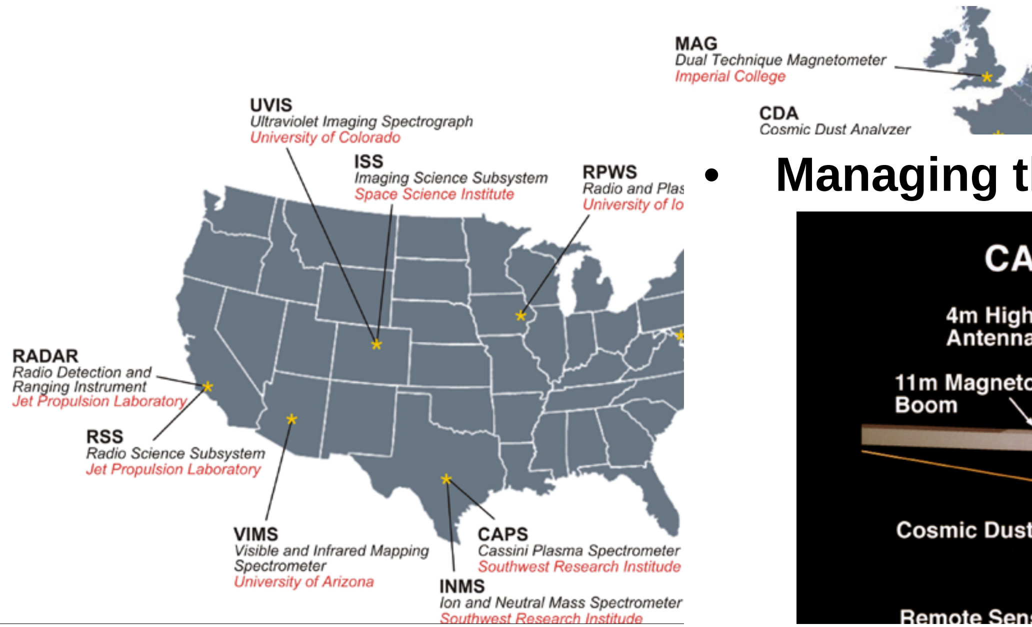
- Managing the shared spacecraft resources



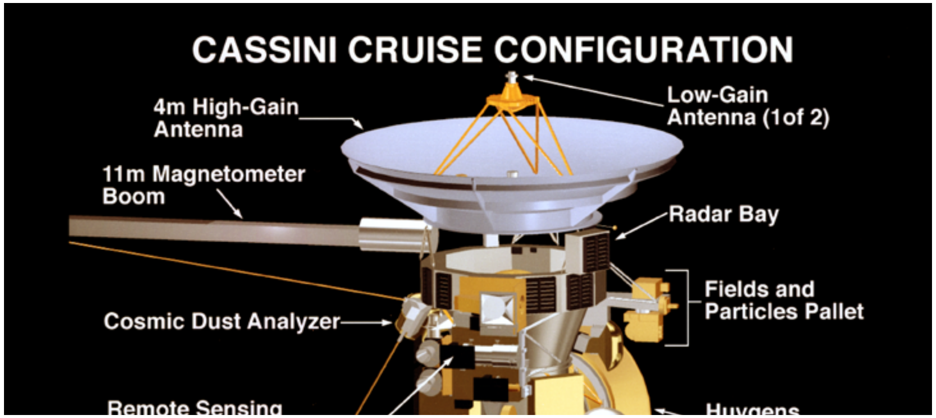
- Intense science planning
  - 12 science instrument teams
  - Competition for spacecraft resources
  - Consensus-building negotiations with science community
  - Long lead time required for planning
  - Science Teams are small teams supporting a concurrent and iterative uplink development process
  - Multi-disciplinary science objectives and opportunities

Three things that make Science Planning Hard…

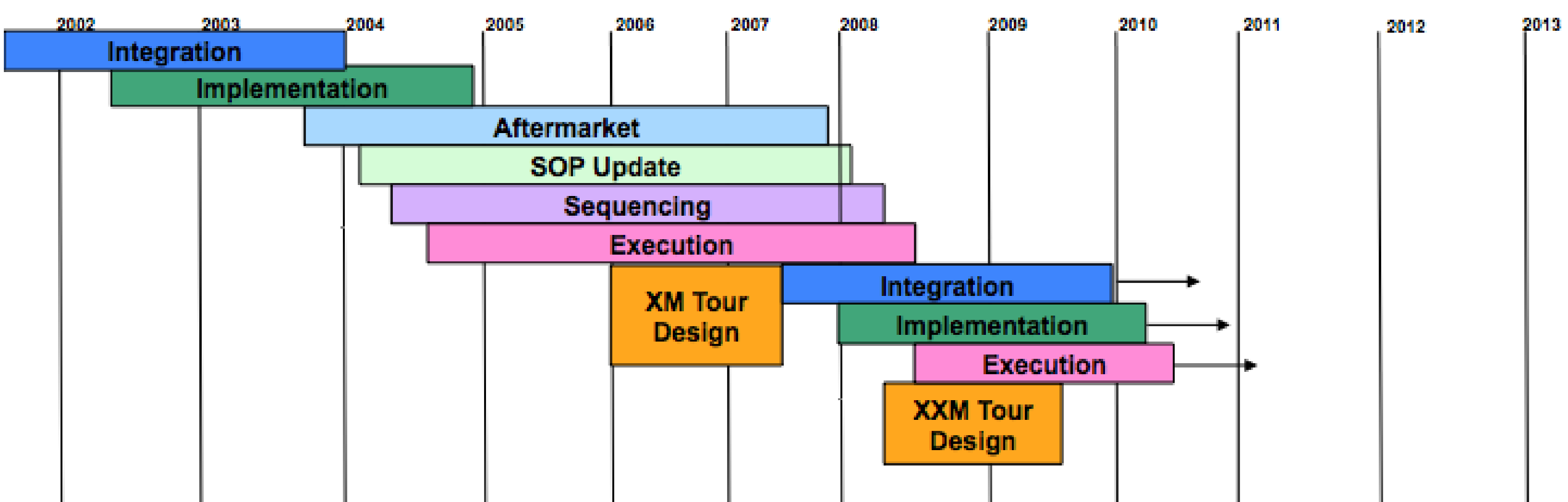
- Distributed operations



- Managing the shared spacecraft resources

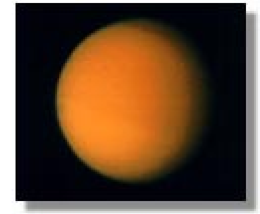


- Intense science planning



SCIENCE - Titan's Science Objectives

The Science objectives of Titan include the following:



Titan: taken by Voyager 2

1. Determine the most abundant elements, and most likely scenarios for the formation and evolution of Titan and its atmosphere.
2. Determine the relative amounts of different components of the atmosphere
3. Observe vertical and horizontal distributions of trace gases; search for complex molecules; investigate energy sources for atmospheric chemistry; determine the effects of sunlight on chemicals in the stratosphere; study formation and composition of aerosols (particles suspended in the atmosphere).
4. Measure winds and global temperatures; investigate cloud physics, general circulation and seasonal effects in Titan's atmosphere; search for lightning.
5. Determine the physical state, topography and composition of Titan's surface; characterize its internal structure.
6. Investigate Titan's upper atmosphere, its ionization and its role as a source of neutral and ionized material for the magnetosphere of Saturn.
7. Determine whether Titan's surface is liquid or solid, analyze the evidence of a bright continent as indicated in Hubble images taken in 1994.

The following table shows which instruments on the spacecraft support the corresponding science objectives above.

	CAPS	CDA	CIRS	INMS	ISS	MAG	MIMI	RADAR	RPWS	RSS	UVIS	VIMS	Huygens
1.	✔		✔	✔			✔			✔	✔	✔	✔
2.	✔		✔	✔	✔		✔			✔	✔	✔	✔
3.			✔		✔				✔	✔	✔	✔	✔
4.			✔		✔				✔	✔	✔	✔	✔
5.								✔		✔			✔
6.	✔			✔		✔	✔		✔	✔	✔		
7.								✔		✔			✔

SCIENCE - Saturn

Saturn's science objectives are as follows:

1. Determine the temperature field, cloud properties and composition of Saturn's atmosphere.
2. Measure the planet's global wind field, including its waves; make long-term observations of cloud features to see how they grow, evolve and dissipate.
3. Determine the internal structure and rotation of the deep atmosphere.
4. Study daily variations and relationship between the ionosphere and the planet's magnetic field.
5. Determine the composition, heat flux and radiation environment present during Saturn's formation and evolution.
6. Investigate sources and nature of Saturn's lightning.

Saturn

The following table shows which instruments on the spacecraft support the corresponding science objectives above.

	CAPS	CDA	CIRS	INMS	ISS	MAG	MIMI	RADAR	RPWS	RSS	UVIS	VIMS	Huygens
1.			✔		✔					✔	✔	✔	
2.			✔		✔					✔		✔	
3.			✔			✔			✔	✔		✔	
4.	✔					✔	✔		✔	✔	✔		
5.	✔		✔		✔					✔	✔	✔	
6.					✔				✔				

SCIENCE - Rings

The science objectives of Saturn's mysterious rings are as follows:

1. Study configuration of the rings and dynamic processes responsible for ring structure.
2. Map the composition and size distribution of ring material.
3. Investigate the interrelation of Saturn's rings and moons, including imbedded moons.
4. Determine the distribution of dust and meteoroid distribution in the vicinity of the rings.
5. Study the interactions between the rings and Saturn's magnetosphere, ionosphere and atmosphere.

Saturn's Rings

The following table shows which instruments on the spacecraft support the corresponding science objectives above.

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1.			✔		✔	✔				✔	✔	✔	
2.	✔	✔	✔	✔	✔					✔	✔	✔	
3.	✔	✔	✔		✔					✔	✔	✔	
4.		✔			✔				✔			✔	
5.		✔	✔		✔		✔	✔	✔		✔	✔	✔

SCIENCE - Moons

The science objectives of Saturn's moons are as follows:

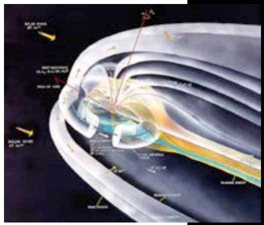
1. Determine general characteristics and geological histories of Saturn's moons.
2. Define the different physical processes that have created the surfaces, crusts or sub-surfaces of the moons.
3. Investigate compositions and distributions of surface materials, particularly dark, organic-rich materials and condensed ices with low melting points.
4. Determine the bulk compositions and internal structures of the moons.
5. Investigate interactions of the moons with Saturn's magnetosphere and ring system.

Saturn's Icy Satellites

The following table shows which instruments on the spacecraft support the corresponding science objectives above.

	CAPS	CDA	CIRS	INMS	ISS	MAG	MIMI	RADAR	RPWS	RSS	UVIS	VIMS	Huygens
1.			✔		✔						✔	✔	
2.	✔	✔			✔						✔	✔	
3.			✔		✔						✔	✔	
4.			✔		✔					✔		✔	
5.	✔	✔	✔		✔	✔	✔		✔		✔	✔	

SCIENCE - Saturn's Magnetosphere Science Objectives



The science objectives of Saturn's magnetosphere are as follows:

1. Determine the configuration of Saturn's magnetic field, which is nearly symmetrical with Saturn's rotational axis. Also study its relation to the modulation of Saturn kilometric radiation - a radio emission from Saturn that is believed to be linked to the way electrons in the solar wind interact with the magnetic field at Saturn's poles.

2. Determine the current systems, composition, sources and concentrations of electrons and protons in the magnetosphere.

3. Characterize the structure of the magnetosphere and its interactions with the solar wind, Saturn's moons and rings.

4. Study how Titan interacts with the solar wind and with the ionized gases within Saturn's magnetosphere.

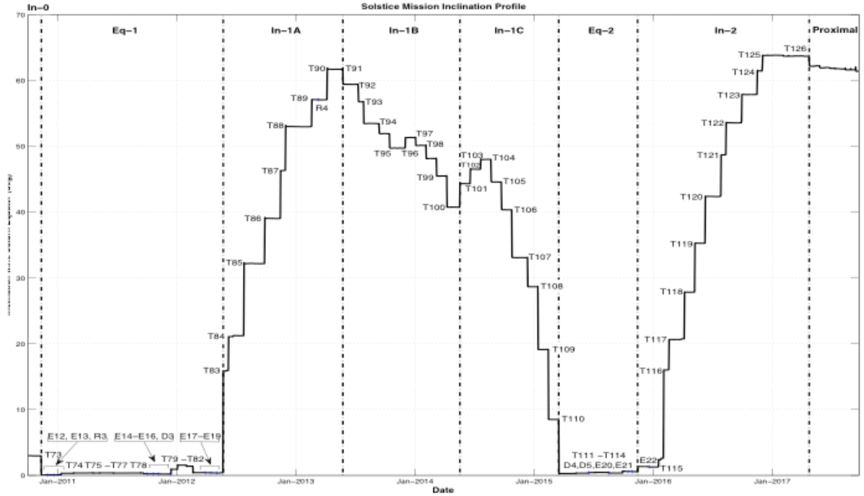
5. Investigate interactions of Titan's atmosphere and exosphere with the surrounding plasma.

The following table shows which instruments on the spacecraft support the corresponding science objectives above.

	CAPS	CDA	CIRS	INMS	ISS	MAG	MIMI	RADAR	RPWS	RSS	UVIS	VIMS	Huygens
1.						✔			✔				
2.	✔					✔	✔		✔		✔		
3.	✔					✔	✔		✔				
4.	✔			✔		✔	✔		✔	✔	✔		
5.	✔			✔		✔	✔		✔	✔	✔		

Breaking up the Solstice Mission

7 year extended mission



Tour Design (discipline)

- Maximize Science Opportunity

Integration (segment)

- Negotiate Best Science Compromise

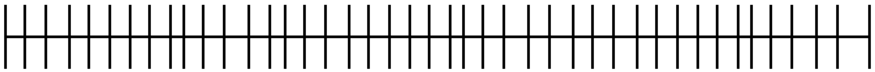
Implementation (sequence)

- Validate Basic Sequence Design

Execution

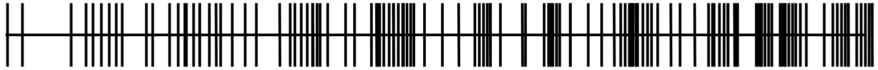
- in a good way

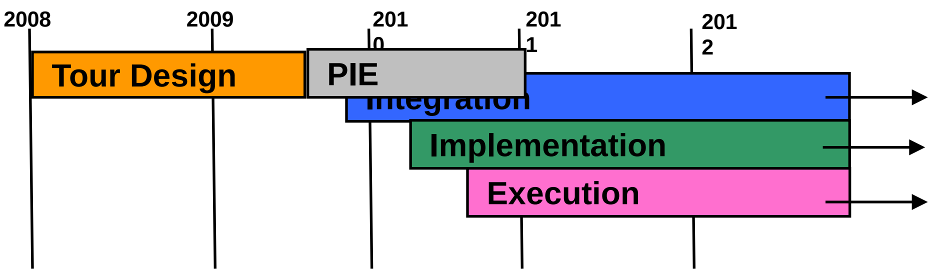
37 Sequences ~ 2 month each



Over 800 Segments by discipline

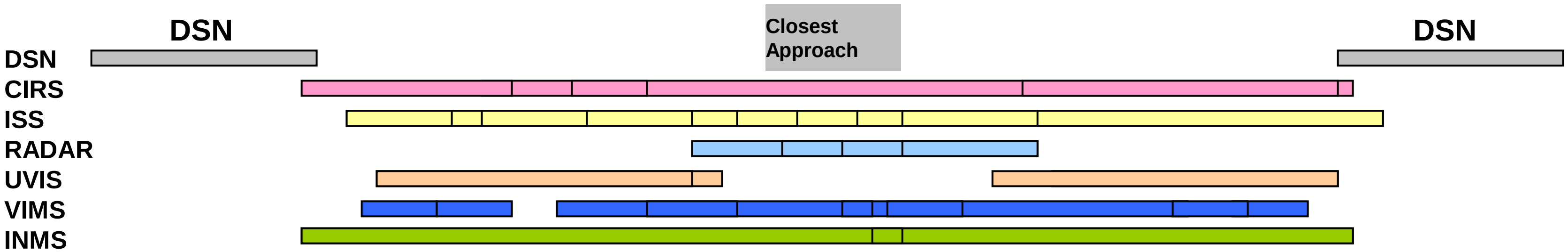
(Rings, Saturn, Icy Satellites, Titan, Magnetosphere, and XDiscipline)





Example: Integrating a Titan flyby

The integration process begins with multiple requests



Negotiation takes place with scientists and a straw-man timeline is worked out.

Integrated Timeline

DSN **CIRS** **ISS** **VIMS** **MAPS** **RADAR** **UVIS** **DSN**

Riders are added

Based on the timeline, Power and Telemetry Modes are determined

D. Equils Apr 2005 – modified by T. Ray 2011

Example: Integrating a Titan flyby

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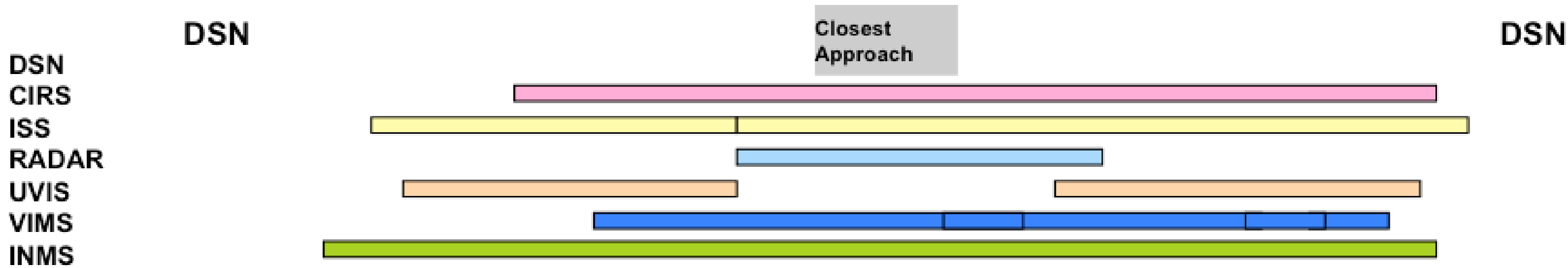

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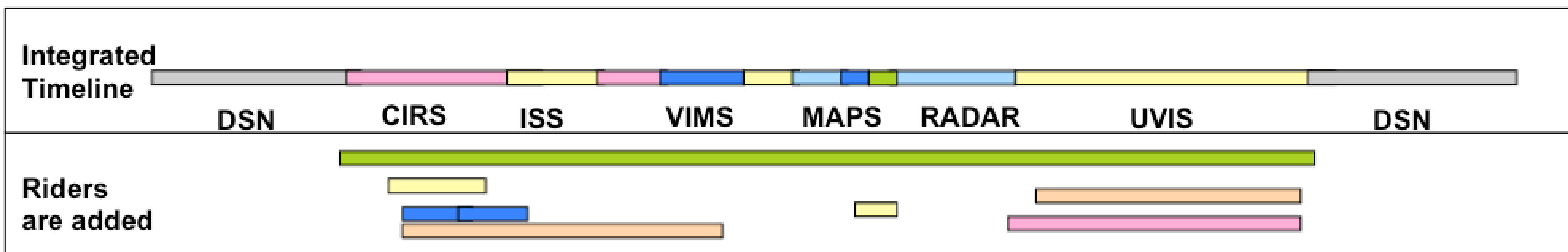

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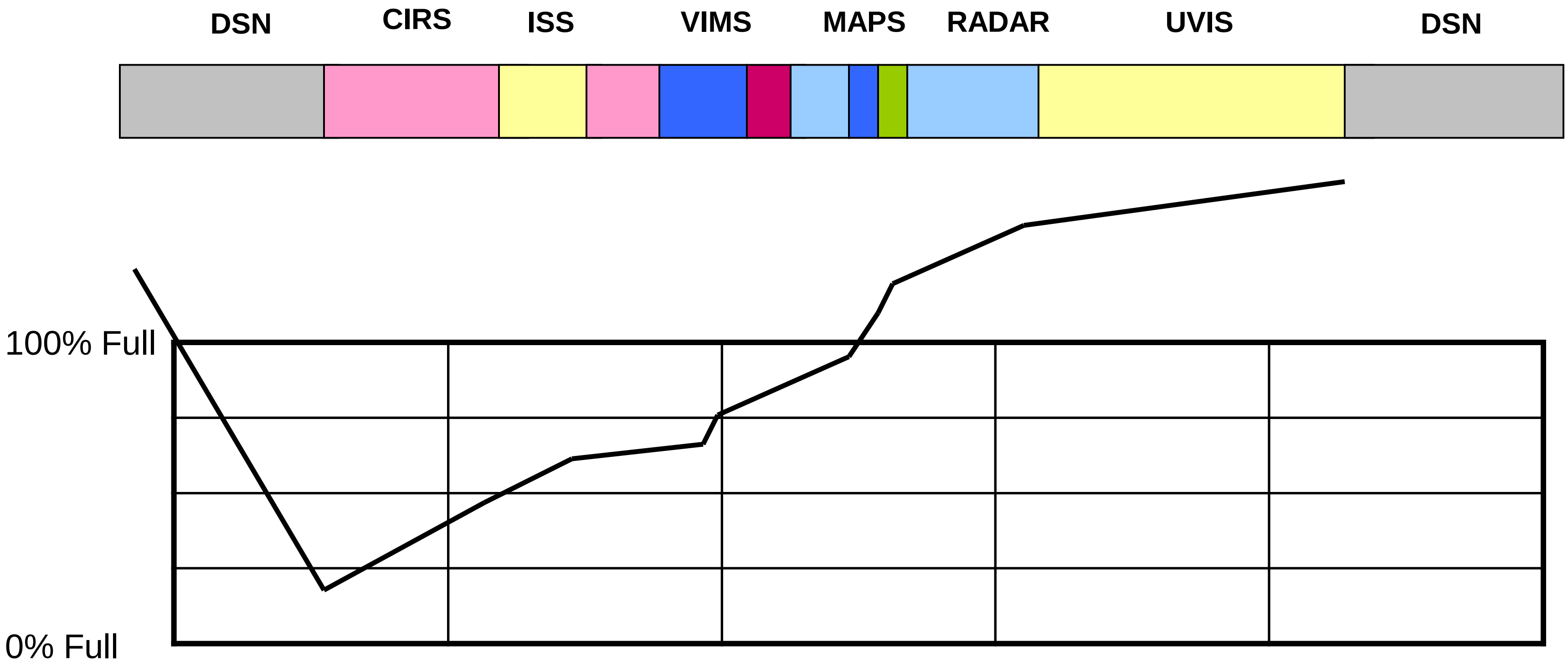
Data Volume to SSR is simulated using SMT



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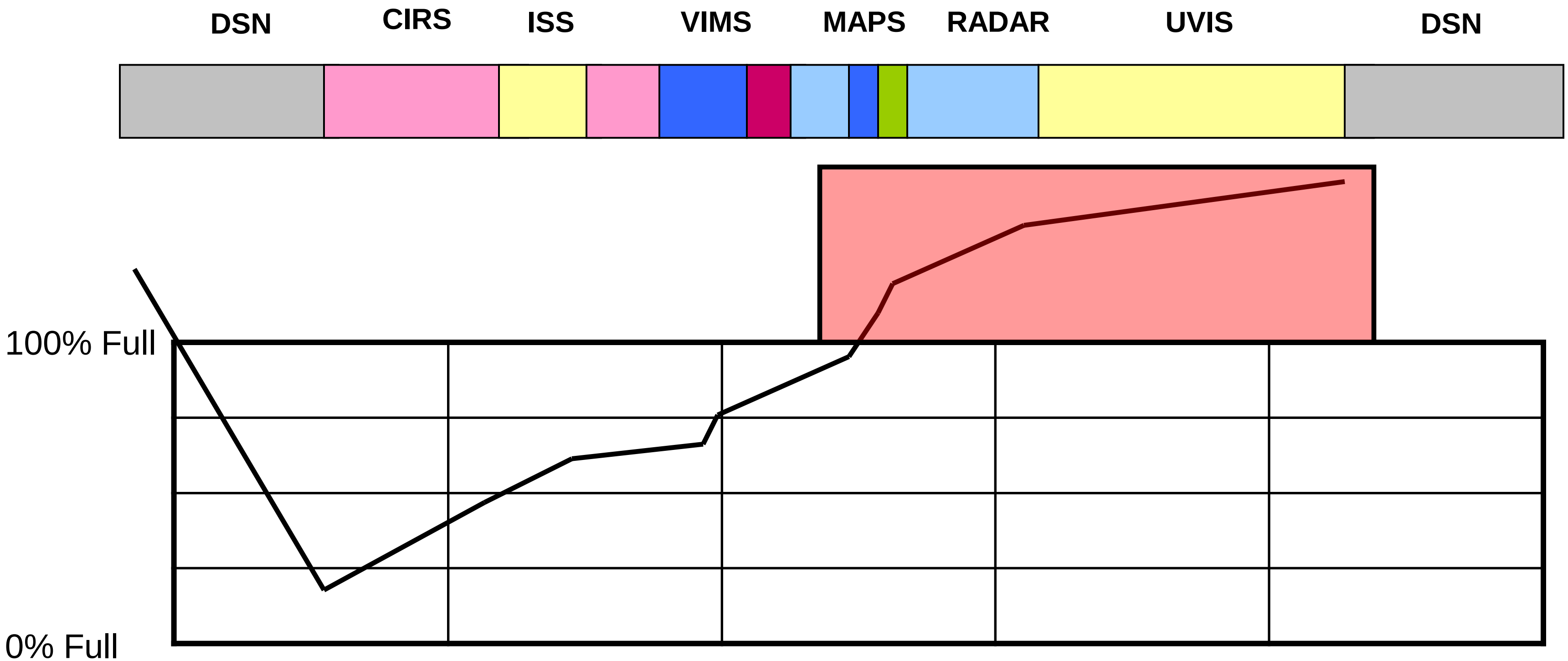


SSR overruns are identified
and data volume is cut

These steps are repeated until all issues are resolved.

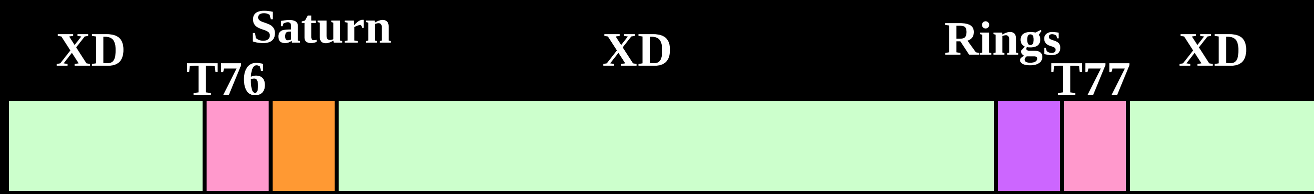
Sequence Implementation Process

Three things that make Sequencing hard…

- Some of the same things that make Science Planning hard
  - Small distributed teams at different time zones creating the commanding for 12 instruments that have to be merged
  - Complex Flight Rule checking and extensive validation and modeling of all key shared resources to make sure Science Planning got it right

- Aging spacecraft
  - RBOT
  - Decreasing Power Available (~667 W now)
  - Anomalies

- Intense Sequencing process
  - Rare and precious science opportunities lead to sequence complexity (dual playbacks, additional power modes, custom handoffs)
  - The process (even closer to execution) means that deadlines loom larger.
  - Concurrent sequence development (concurrent with planning and execution too)
  - Health and safety of the spacecraft on the line



Integration: What are we going to do.

S68 duration ~ 10 weeks

Implementation: How are we going to do it.

Execution: Time to make the science.

Sequence Implementation

Port 1	Port 2	Port 3	PSIV	FSIV

22 week process

- Port 1
  - Pointing designs finalized and checked for flight rule violations

- Port 2
  - Rider observations included. Flight rules checked, DSN negotiations begin, data volume allocations checked, RWA safety checks
- Port 3
  - Changes for RWA safety and DSN negotiations included, flight rules checked, Hydrazine use estimated. Full sequence.
- PSIV
  - Waivers approved, Flight rule checks. DSN negotiations finalized. Results in a safe flyable sequence.

- FSIV is used to correct health and safety violations.

Sequence Execution

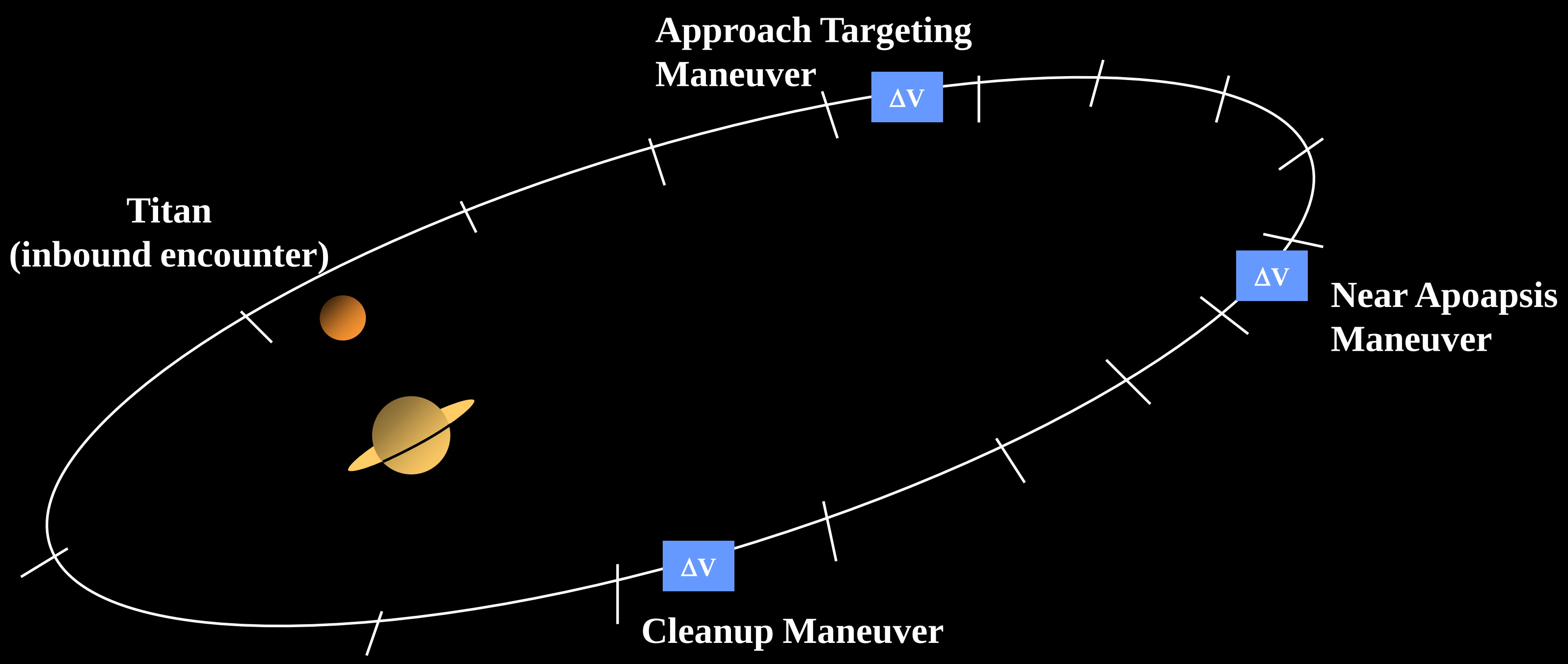
Tasks During Sequence Execution

- Sequence Lead and Engineering Team
  - Monitor Spacecraft Health
  - Live Updates
  - Real Time Commands
    - For Engineering and Science
  - Real Time DSN changes/outages
  - Orbit Trim Maneuvers
  - Anomaly Response

Cassini Orbit Trim Maneuvers

Three maneuvers per targeted encounter (206 planned for SM)

- Nine hour long primary and backup DSN passes reserved for each maneuver.
- opmode transitions for OTMs are placed in the background sequence during sequence development, all other commands have to be developed within days/hours of the maneuver.
- Maneuvers are executed during a single DSN pass.



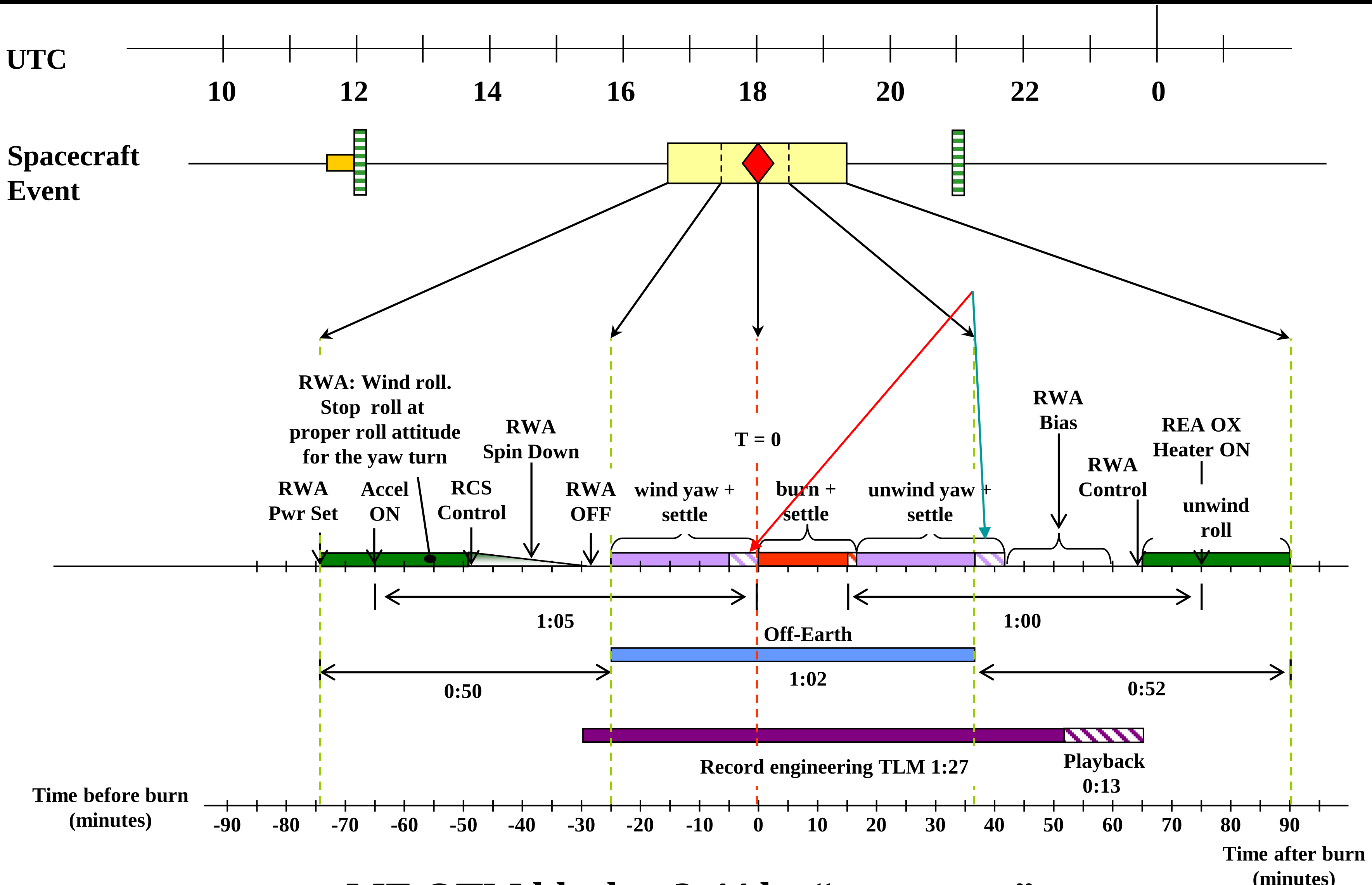
Cassini OTM Implementation and Execution

- Maneuver Design Team responsible for OTM generation.
  - Members from the Navigation team and Spacecraft Office
  - Navigation is responsible for designing the maneuver to keep the spacecraft on the planned trajectory
  - Spacecraft Office is responsible for building the block of commands that will perform the maneuver on the spacecraft, checking flight rules and managing the reaction wheel speeds.

- Maneuver Uplink Engineer
  - Verifies health and state of the spacecraft then uplinks maneuver

- Maneuver Monitoring
  - Systems engineer and subsystem leads monitor and record spacecraft telemetry during the maneuver and report a Quick Look to Project Management after maneuver
  - Science playback occurs before and after the maneuver during the DSN pass

Sample Main Engine Maneuver Block



ME OTM block = 2:44 hr “worst case”

4 Month OTM Schedule

October 2010

M	T	W	T	F	S	S
				1 274	2 275	3 276
4 277	5 278	6 279	7 280	8 281	9 282	10 283
11 284	12 285	13 286	14 287	15 288 264	16 289	17 290
18 291	19 292	20 293	21 294	22 295	23 296	24 297
25 298	26 299	27 300	28 301	29 302	30 303	31 304

November 2010

M	T	W	T	F	S	S
1 305	2 306	3 307	4 308	5 309	6 310	7 311
8 312 265	9 313	10 314	11 315 T73	12 316	13 317	14 318 266
15 319	16 320	17 321	18 322	19 323	20 324	21 325 267
22 326	23 327	24 328	25 329	26 330	27 331 268	28 332
29 333	30 334 En12					

December 2010

M	T	W	T	F	S	S
		1 335 269	2 336	3 337	4 338	5 339
6 340	7 341	8 342 270	9 343	10 344	11 345	12 346
13 347	14 348	15 349	16 350	17 351 271	18 352	19 353
20 354	21 355 En13	22 356	23 357	24 358 272	25 359	26 360
27 361	28 362	29 363	30 364	31 365		

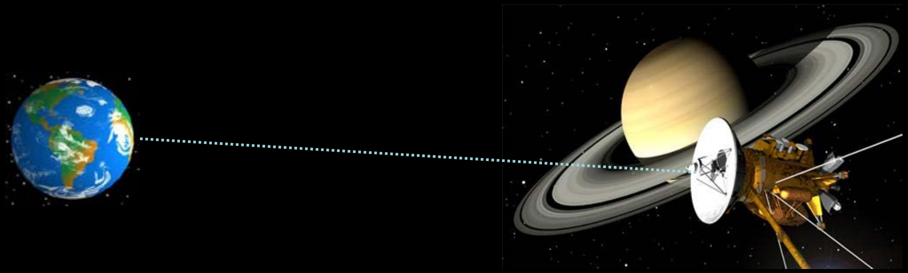
January 2011

M	T	W	T	F	S	S
					1 1 273	2 2
3 3	4 4	5 5	6 6	7 7	8 8 274	9 9
10 10	11 11 R3	12 12	13 13	14 14 275	15 15	16 16
17 17	18 18	19 19	20 20	21 21	22 22	23 23
24 24	25 25	26 26	27 27	28 28	29 29	30 30
31 31						

Purple	JPL Holiday
Light green	JPL payday
Grey	JPL Friday Off
Orange	PSG

When Things Don't Go As Planned

- Tuesday Nov 2, 2010 ~4pm
  - Engineers were loading new flight software onto the backup Attitude Control Flight Computer during a downlink pass.
  - Suddenly downlink from Cassini was lost
  - "That's not good."



What do you do when your spacecraft stops talking to you?

- Don’t panic

- Call an Anomaly Meeting
  - During the meeting, downlink was received (about an hour after it was lost)
  - Cassini was in safe mode
    - All non-essential systems are shut down and only essential functions such as thermal management, telecom and attitude control are active.

- Determine the state of the spacecraft
  - Send up commands needed immediately for subsystems and Instruments

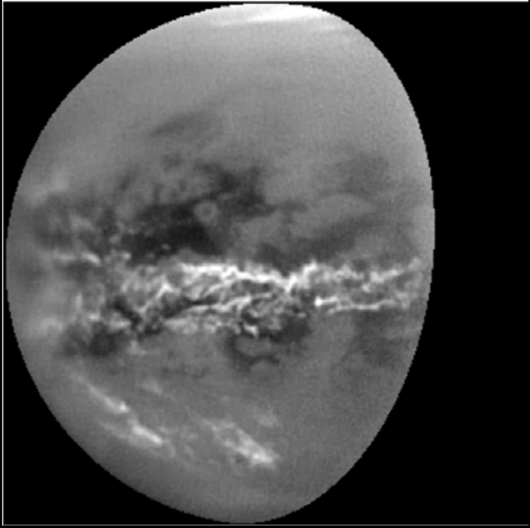
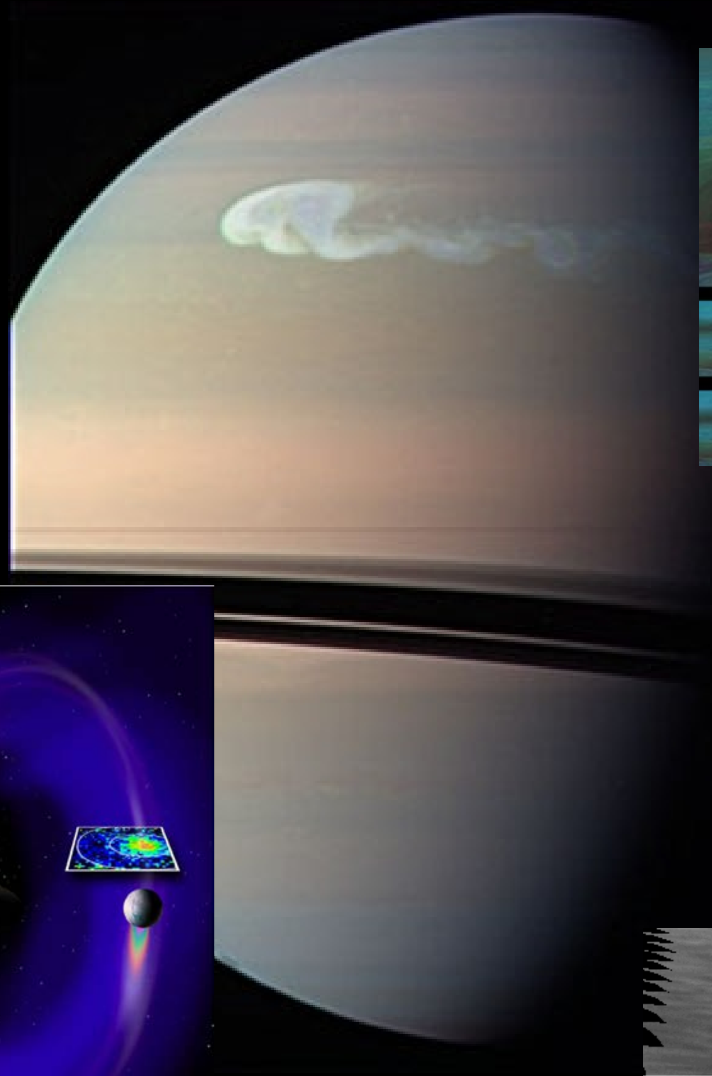
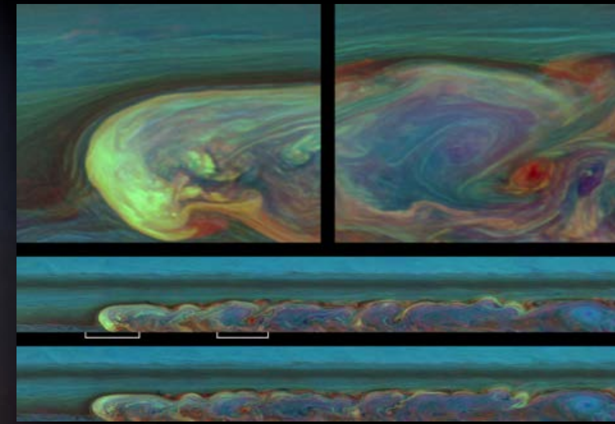
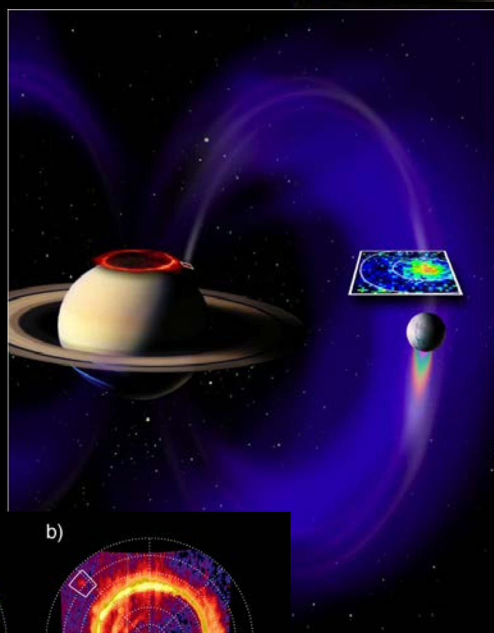
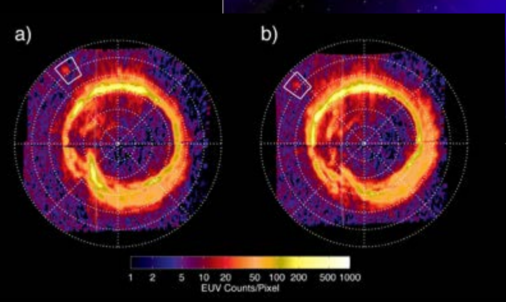
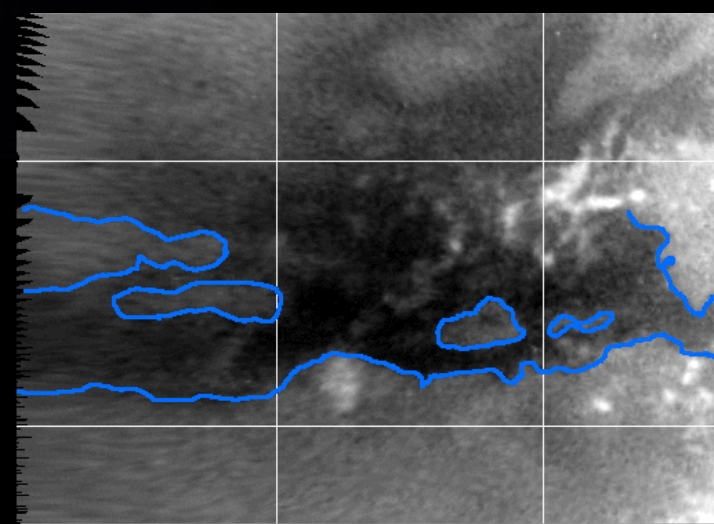
Recovery from Safe Mode

- Playback engineering data to determine what went wrong and what needs to be done to “fix” it.
- Mission Status Evaluated
  - What is necessary to stay on tour.
    - OTM256 executed on Nov 8th
  - What activities need to be accomplished prior to re-activating background sequence.
    - Load new flight software onto the backup Attitude Control Flight Computer
  - Upcoming science observations. (T73 Nov 11th, E12 Nov 30th)
- Recovery Plan created by Engineering and Science Planning
  - Decision was made to resume the background sequence at the start of the next sequence.

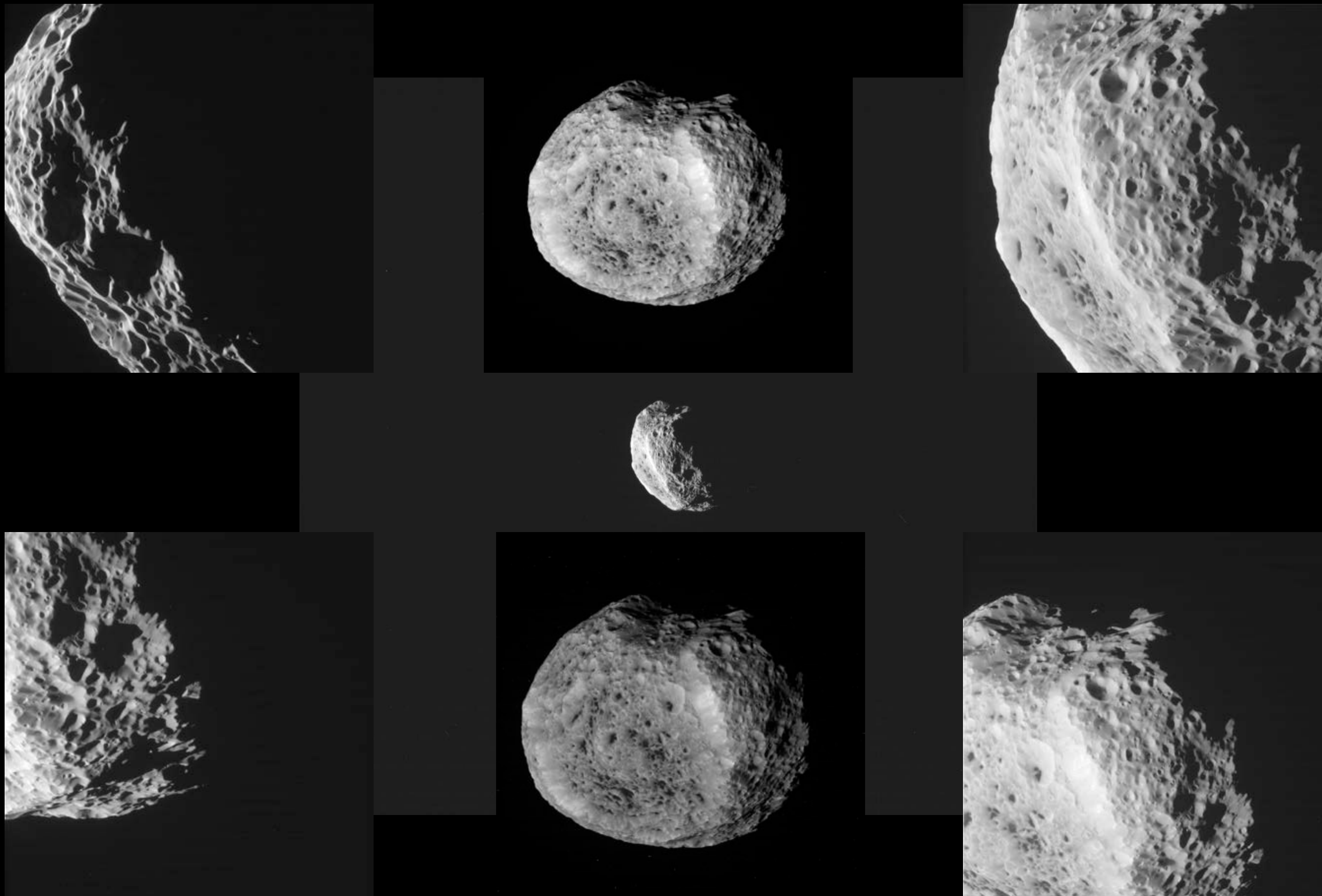
Science

(see CHARM Anniversary presentation)

but…






a)
b)
1 2 5 10 20 50 100 200 500 1000
EUV Counts/Pixel


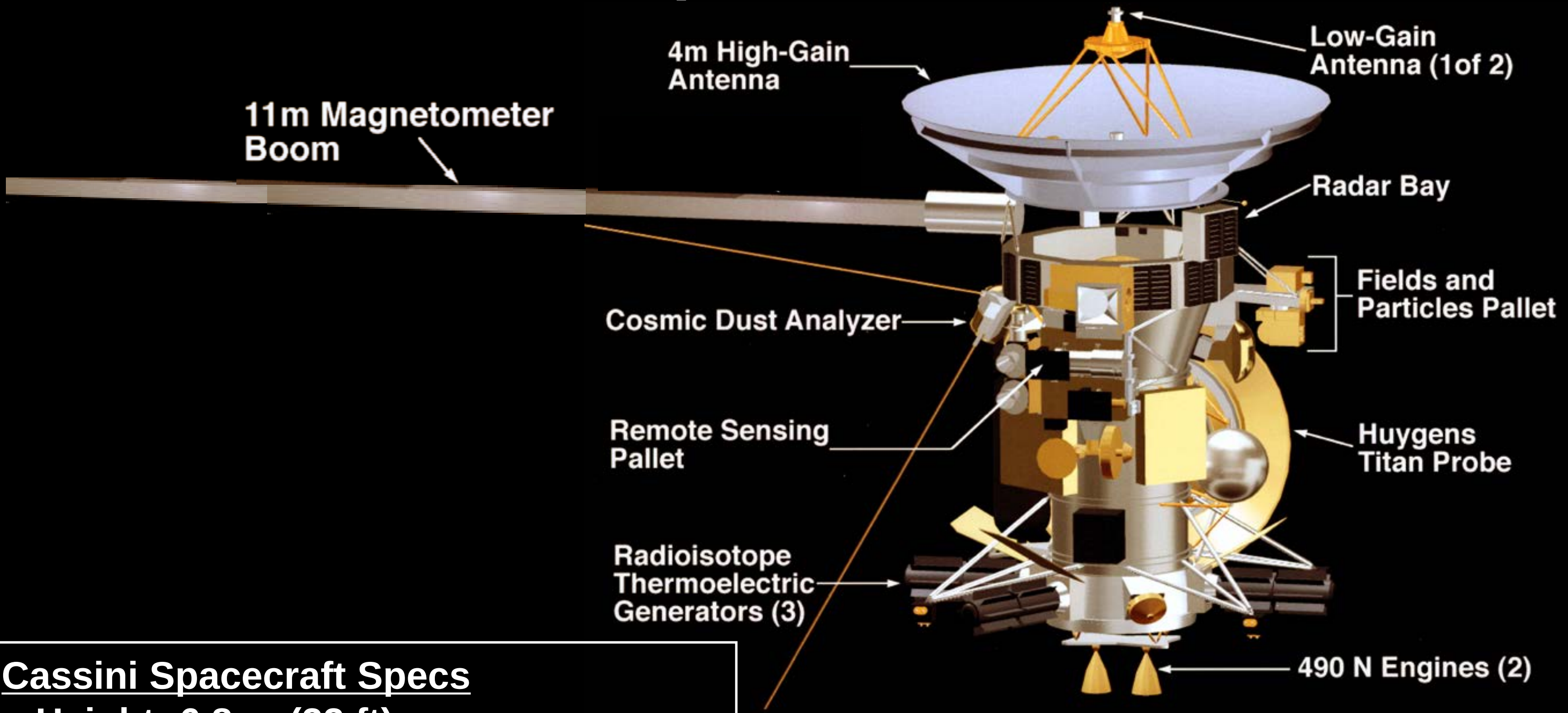
Hot Off The Press! Hyperion!



Come join us! http://saturn.jpl.nasa.gov

Backup Slides

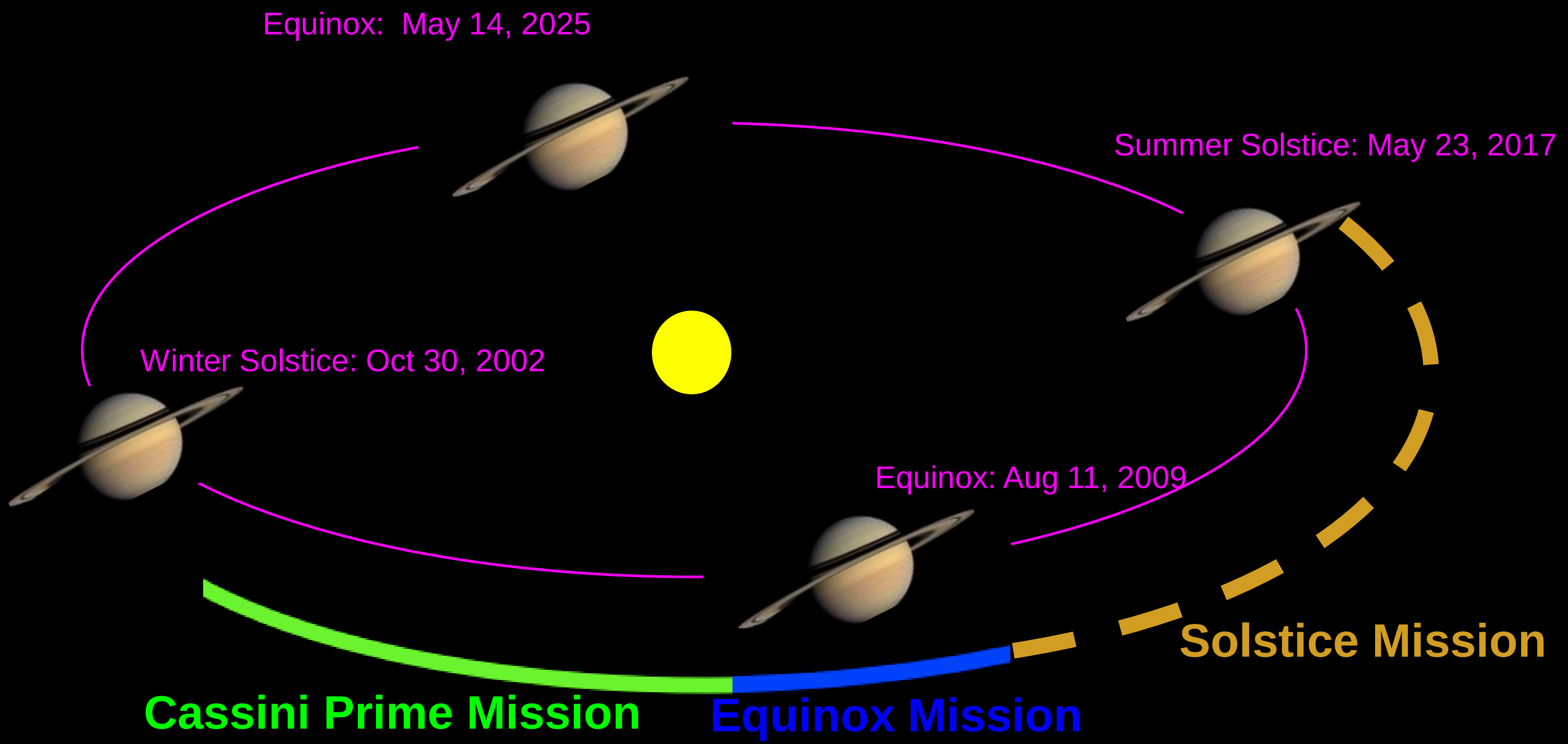
Cassini Spacecraft



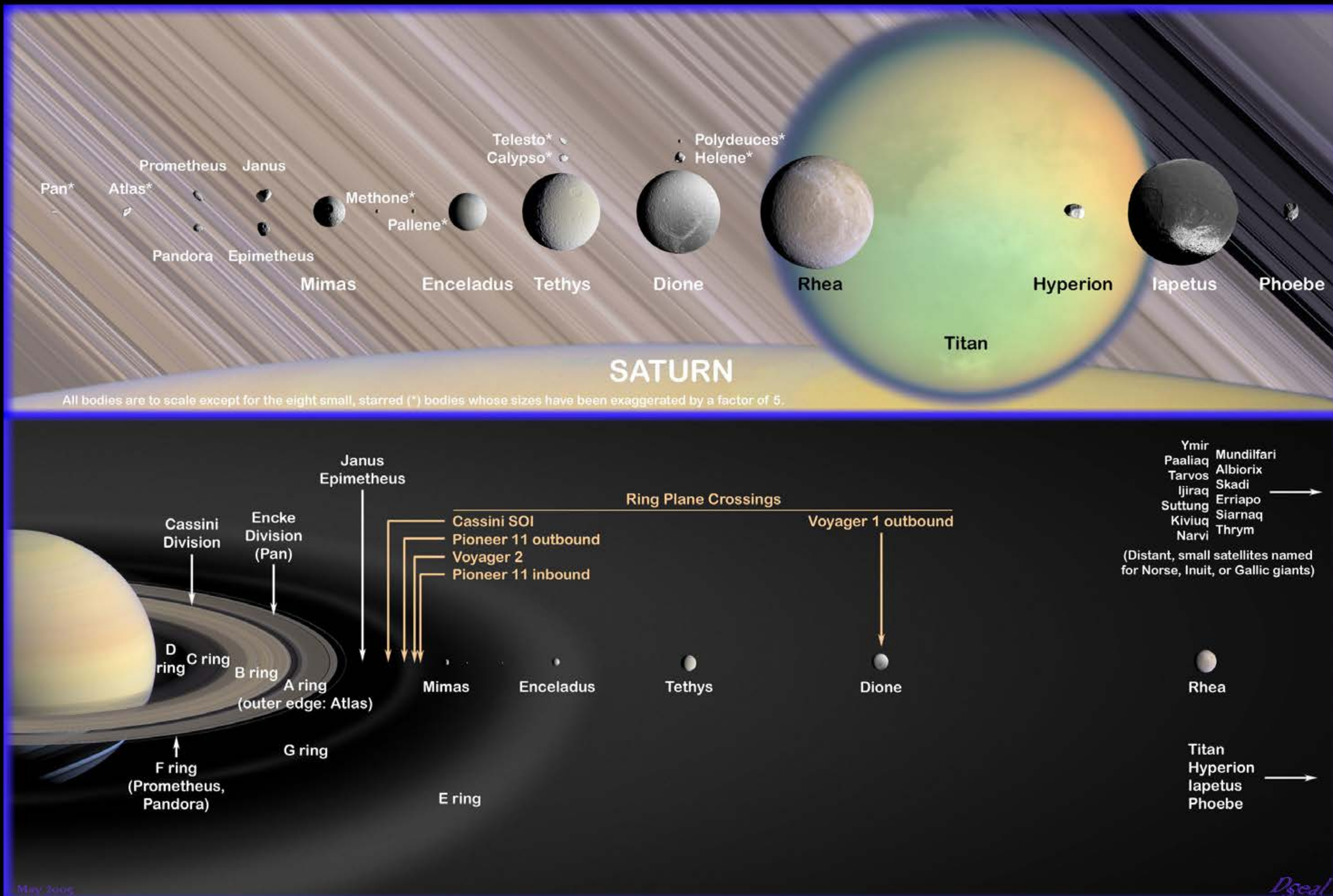
Cassini Spacecraft Specs

- **Height: 6.8 m (22 ft)**
- **Diameter: 4 m (13 ft)**
- **Mass: 2125 kg (2.8 tons)**
  (fueled+probe): 5574 kg (6 tons)
- **Power: 875 Watts at Launch**
  670 Watts currently
- **.5 GB recorder**
- **Huygens Probe:**
  320 kg (~700 lbs)

Saturn Year


Equinox: May 14, 2025
Summer Solstice: May 23, 2017
Winter Solstice: Oct 30, 2002
Equinox: Aug 11, 2009
Solstice Mission
Cassini Prime Mission
Equinox Mission

THE SATURNIAN SYSTEM

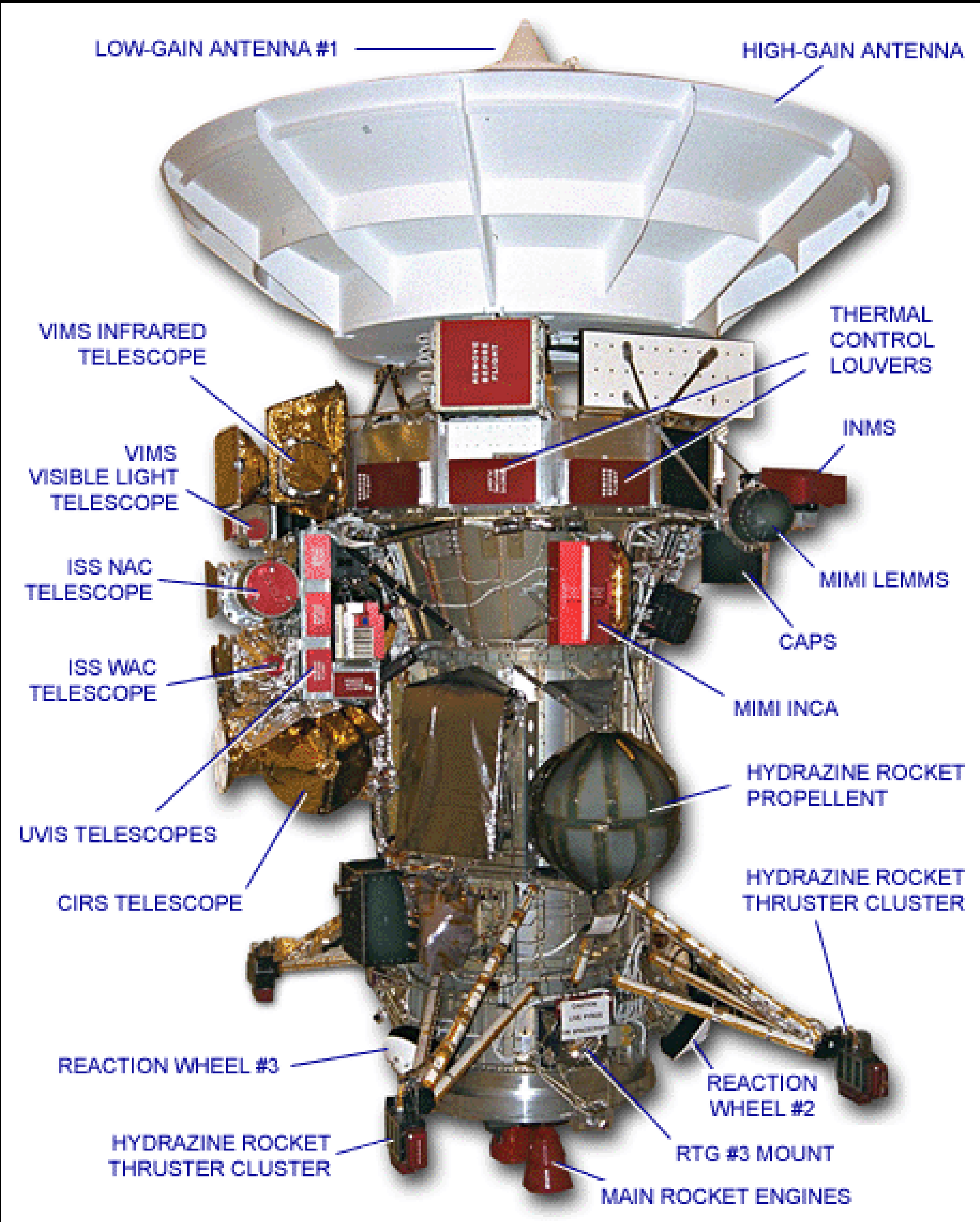


Cassini Orbiter & Huygens Probe

Cassini Spacecraft Specs

- Height: 6.8 m (22 ft)
- Diameter: 4 m (13 ft)
- Mass: 2125 kg (2.8 tons)
  (fueled+probe): 5574 kg (6 tons)
- Power: 875 Watts at Launch
  670 Watts currently
- .5 GB recorder
- Huygens Probe:
  320 kg (~700 lbs)

The 12 Orbiter Instruments



Cassini Instruments:

Optical Remote Sensing (ORS)

CIRS: Composite Infrared Spectrometer
ISS: Imaging Science Subsystem
UVIS: Ultraviolet Imaging Spectrograph
VIMS: Visual and Infrared mapping Spectrometer

Microwave Remote Sensing

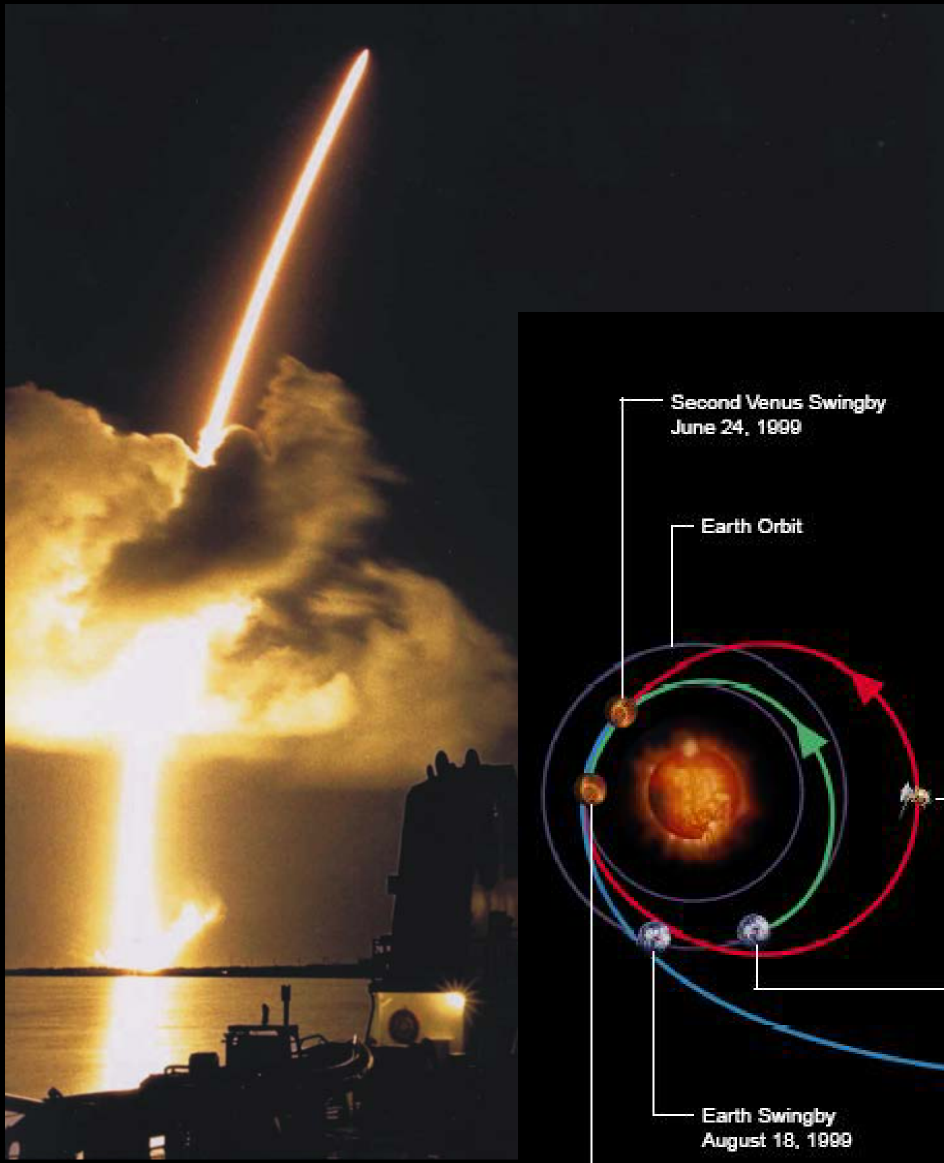
RADAR: Cassini Radar
RSS: Radio Science Subsystem

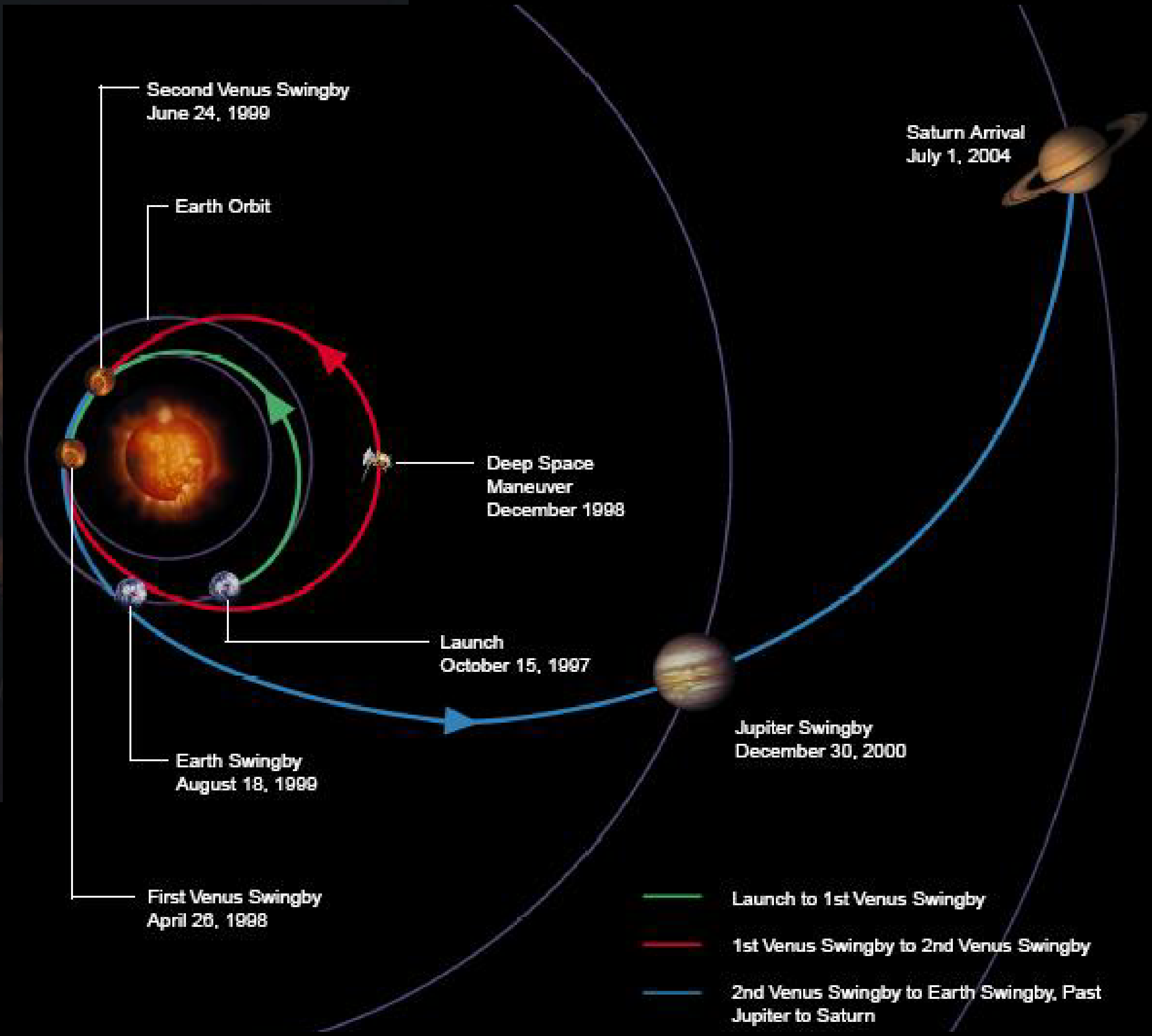
Magnetospheric and Plasma Science (MAPS)

CAPS: Cassini Plasma Spectrometer
CDA: Cosmic Dust Analyzer
INMS: Ion and Neutral Mass Spectrometer
MAG: Magnetometer
MIMI: Magnetospheric Imaging Instrument
RPWS: Radio and Plasma Wave Science

Launched on October 15, 1997 from KSC

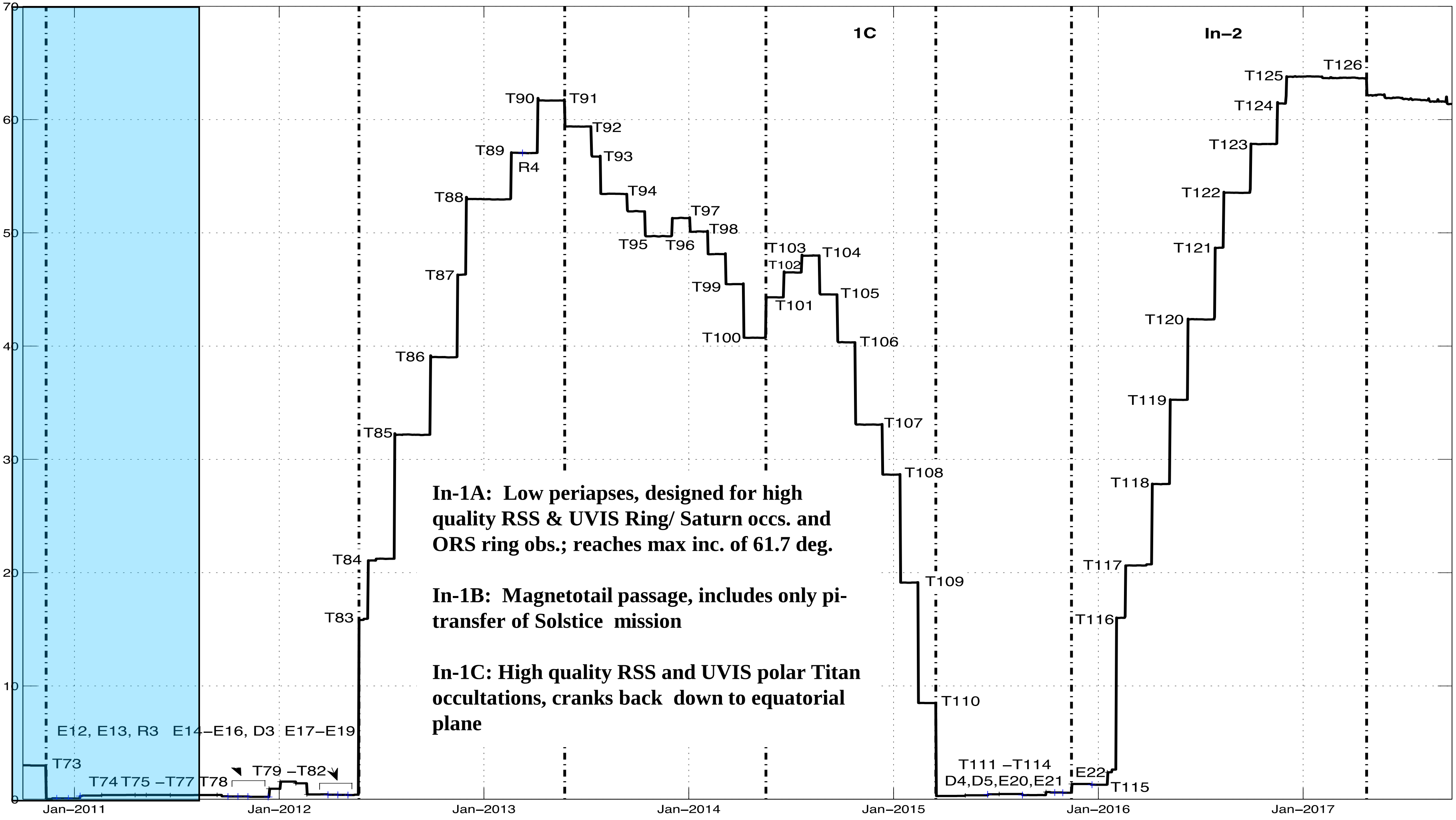
7 year cruise on VVEJGA trajectory





Solstice Mission Inclination Picture

The last year



SCIENCE - Titan's Science Objectives

The Science objectives of Titan include the

1. Determine the mc scenarios for the atmo
2. Deter the a
3. Obse gase: sourc of su aeros
4. Meas circu
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The followi correspond

	CAPS
1.	✔
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6.	✔
7.	

SCIENCE

Saturn's sc

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5.	✔
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SCIENCE - I

The science

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2. Map th
3. Investi includi
4. Determ in the
5. Study ionospl

The following correspondin

	CAPS	CD
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3.	✔	✔
4.		✔
5.		✔

SCIENCE

The scienc

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3. Inve: surfa rich melt
4. Dete struc
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The followi correspond

	CAPS
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3.	
4.	
5.	✔

SCIENCE - Saturn's Magnetosphere Science Objectives

The science objectives of Saturn's magnetosphere are as follow

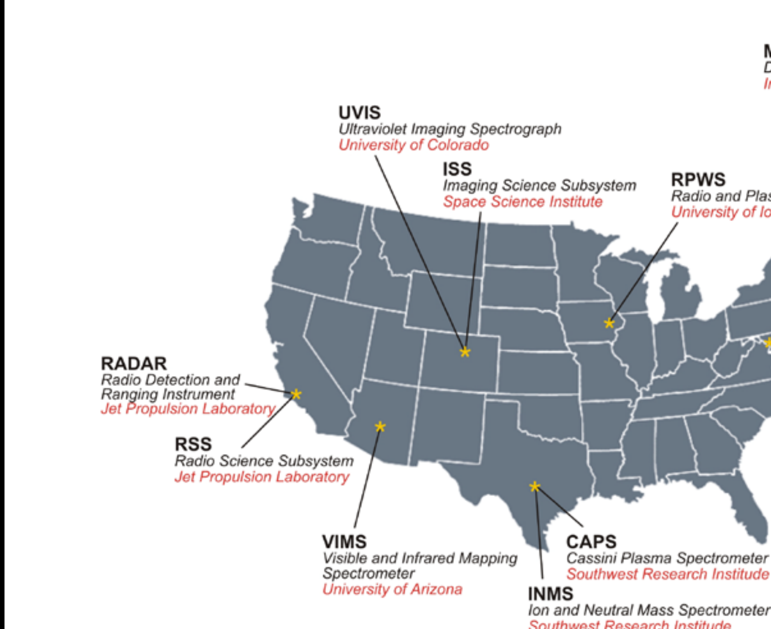
1. Determine the configuration of Saturn's magnetic field, w symmetrical with Saturn's rotational axis. Also study its modulation of Saturn kilometric radiation - a radio emiss believed to be linked to the way electrons in the solar wi magnetic field at Saturn's poles.
2. Determine the current systems, composition, sources an electrons and protons in the magnetosphere.
3. Characterize the structure of the magnetosphere and its solar wind, Saturn's moons and rings.
4. Study how Titan interacts with the solar wind and with th Saturn's magnetosphere.
5. Investigate interactions of Titan's atmosphere and exosp surrounding plasma.

The following table shows which instruments on the spacecraft corresponding science objectives above.

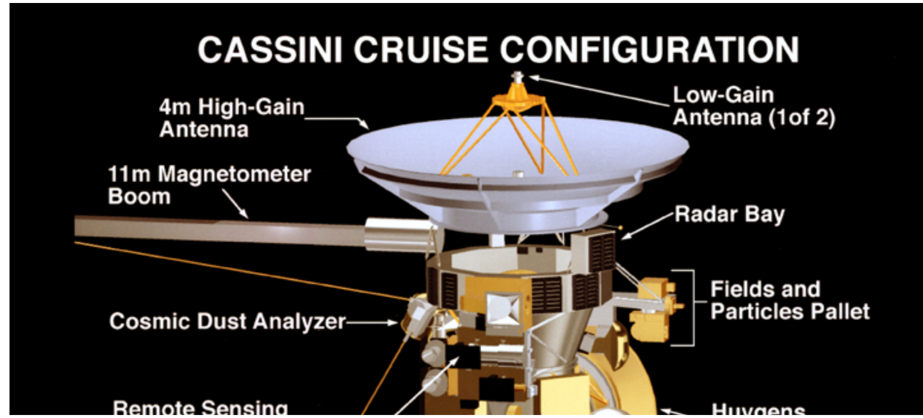
	CAPS	CDA	CIRS	INMS	ISS	MAG	MIMI	RADAR	RPWS	RS
1.						✔			✔	
2.	✔					✔	✔		✔	
3.	✔					✔	✔		✔	
4.	✔			✔		✔	✔		✔	✔
5.	✔			✔		✔	✔		✔	✔

Three things that make Science Planning Hard…

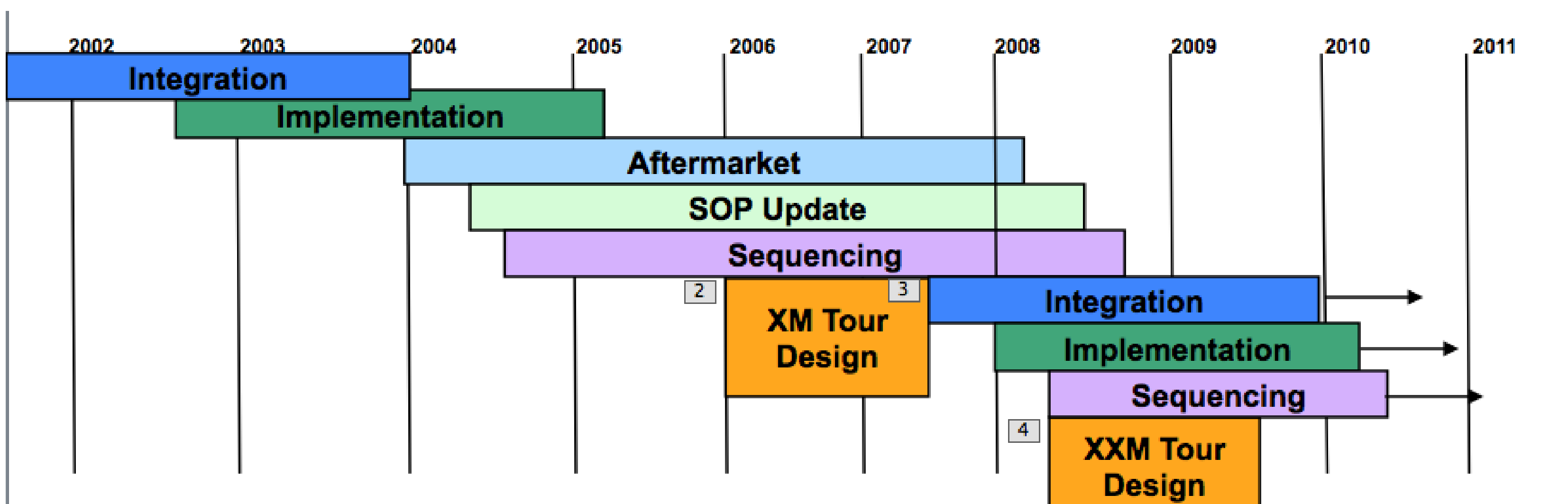
- **Distributed operations**



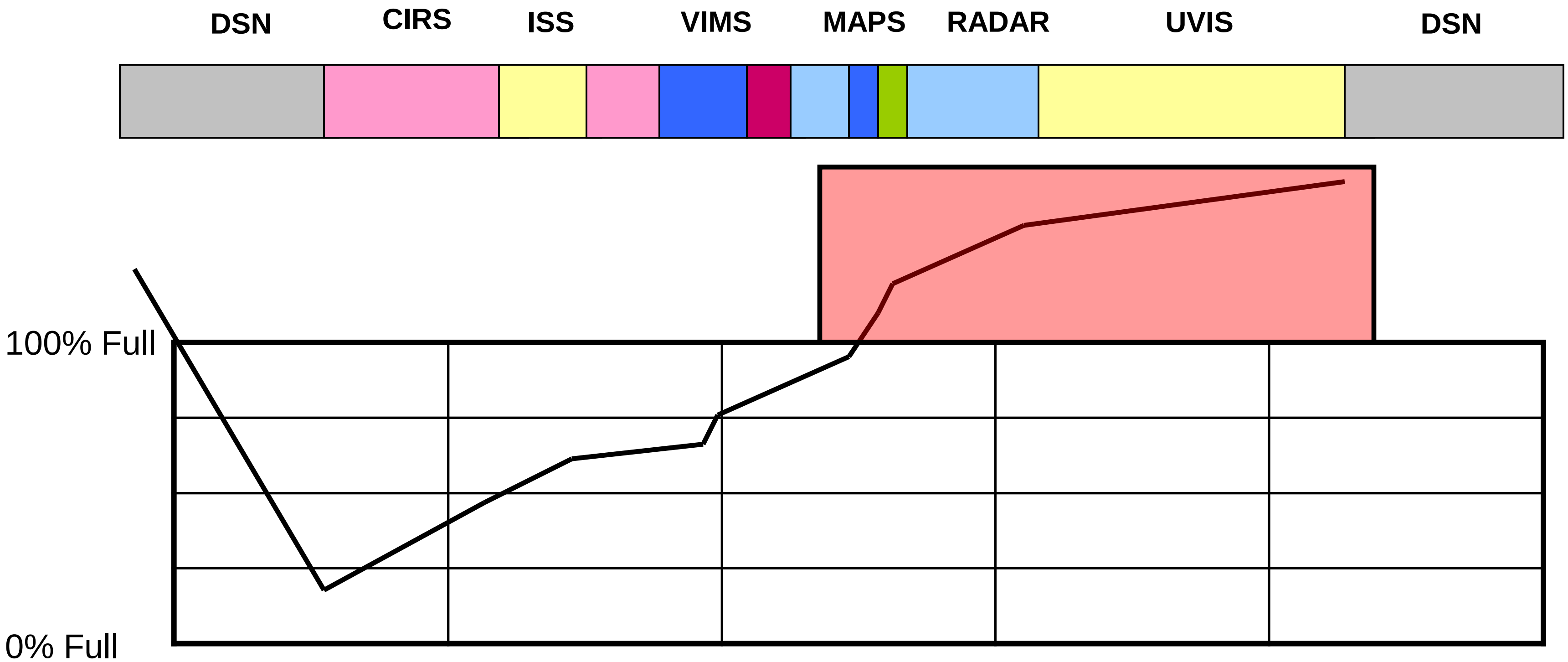
- **Managing the shared spacecraft resources**



- **Intense science planning**

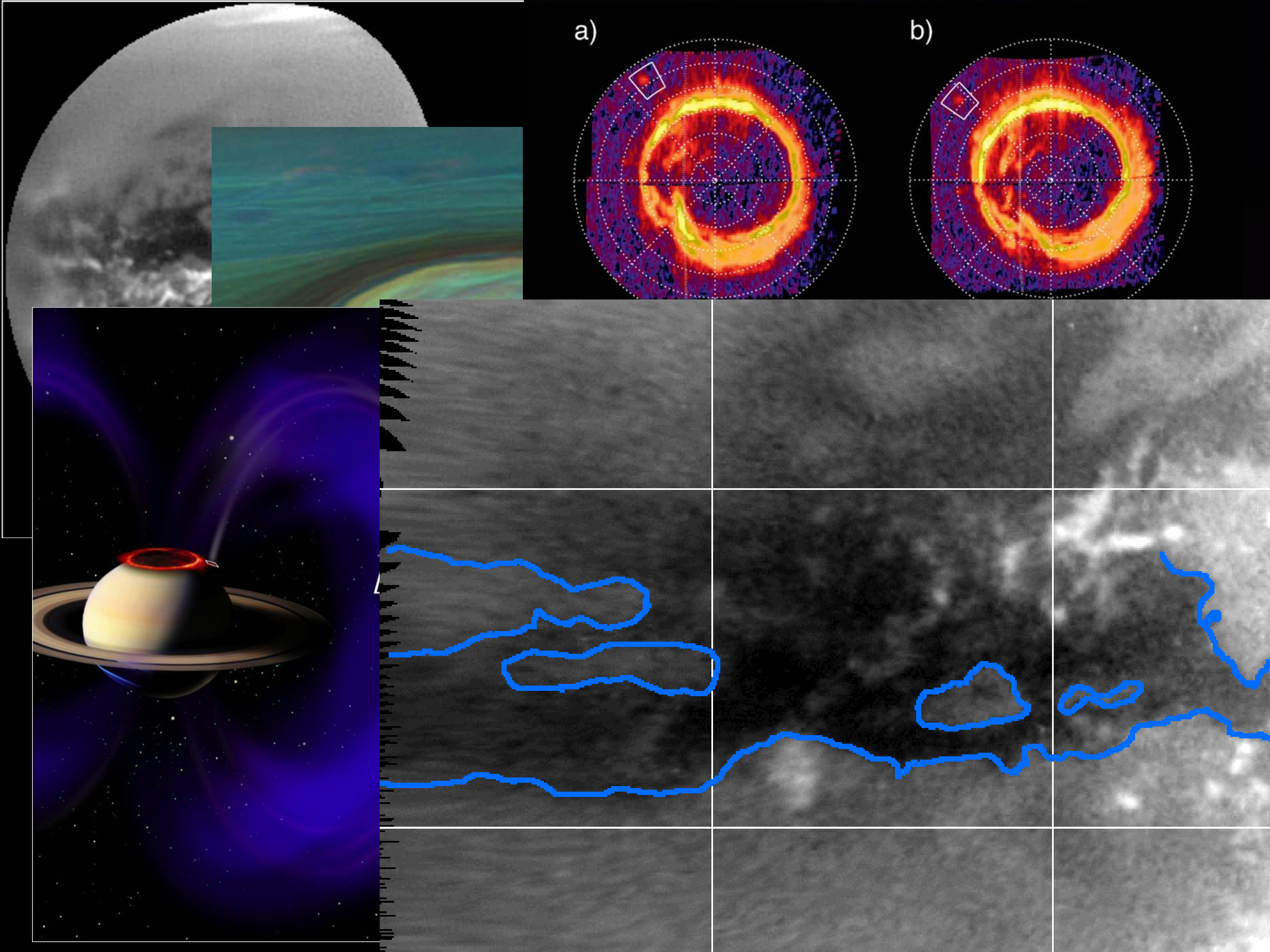


Data Volume to SSR is simulated using SMT



SSR overruns are identified and data volume is cut

These steps are repeated until all issues are resolved.


a)
b)