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20 months to launch

Soil Moisture
Active Passive
SMAP
Mission

NASA's SMAP Observatory

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Presented by Kent Kellogg, Project Manager

March 5, 2013

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Spaceborne Soil Moisture Measurements Are Challenging But Have High Returns

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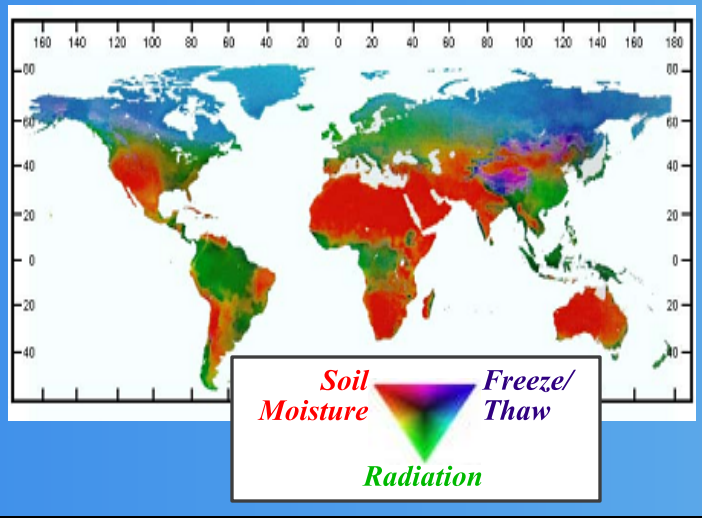
Science Returns

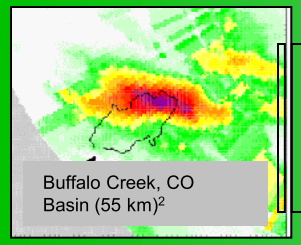
Soil Moisture *Links* the Global Land Water, Energy, and Carbon Cycles



- Estimating global surface water and energy fluxes
- Quantifying net carbon flux in boreal landscapes
- Improving climate models

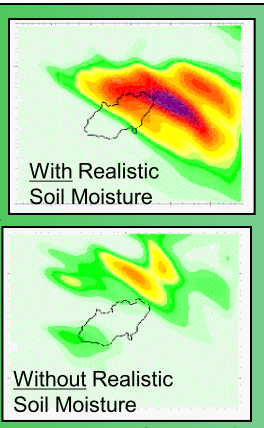
L-band radiometer and non-imaging synthetic aperture radar

Applications Returns

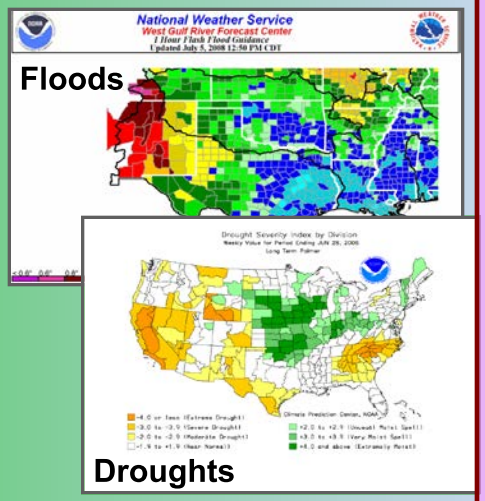


Observed Rainfall
04:00Z 13/7/96

24-Hours Ahead Atmospheric Model Forecasts



(Chen et al., *J. Atm. Sci.*, 2001)



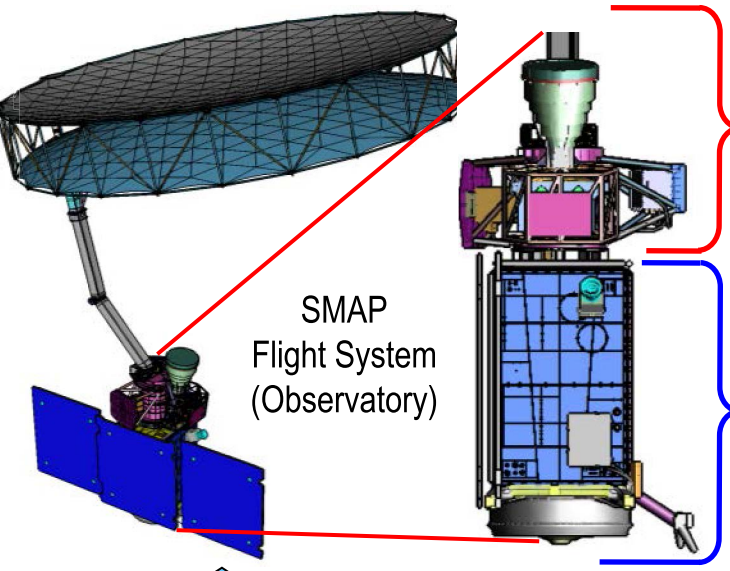
Surface soil moisture 0.04 [cm^3 cm^{-3}] accuracy

3 km freeze/thaw 80% classification accuracy

10 km spatial resolution (active-passive product)

Global coverage every 2-3 days

Mission Overview

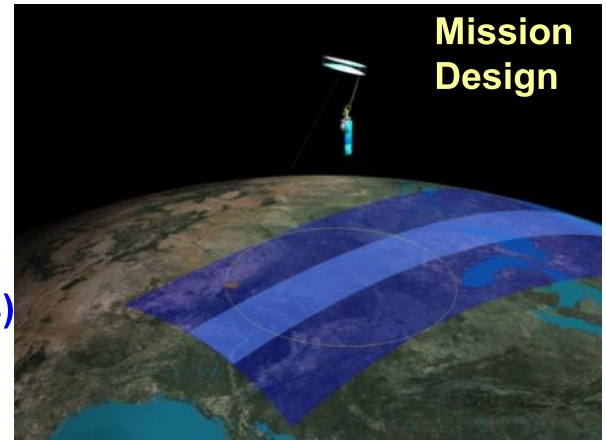


Instrument

- L-band (1.3-GHz) Radar (JPL)
- L-band (1.4-GHz) Radiometer (GSFC)
- Shared antenna (6 m diameter)
- Conical scan: 13–14.6 rpm; 40° incidence
- Contiguous 1,000-km swath width

Spacecraft (& Radar Electronics)

- JPL-Developed & Built
- 1100 kg wet mass (Observatory-level)
- 1200 W capacity (Observatory-level)
- 80 kg propellant capacity
- Commercial space electronics elsewhere

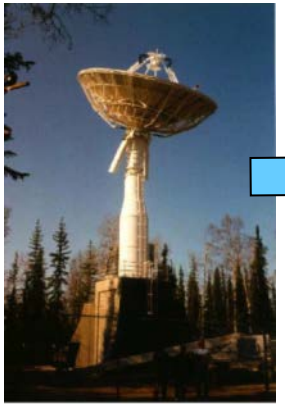


- 685-km polar orbit (Sun-sync)
- 8-day repeat ground track
- Continuous instrument operation
- 2- to 3-day global coverage
- 3-year science mission duration

Delta II 7320-10C

Target Launch:
Oct 31, 2014

Near-Earth Network

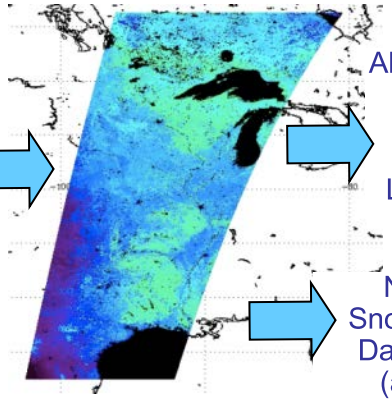


Surface Validation

SMAP Mission Operations
& Data Processing
(JPL, GSFC)

Science Data Products

Soil Moisture & Freeze/Thaw State Data Products



Alaska Satellite
Facility
Data Center
(Radar
L1 Products)

National
Snow and Ice
Data Center
(all other
Products)

Science Measurement Needs Drove Instrument and Observatory Designs

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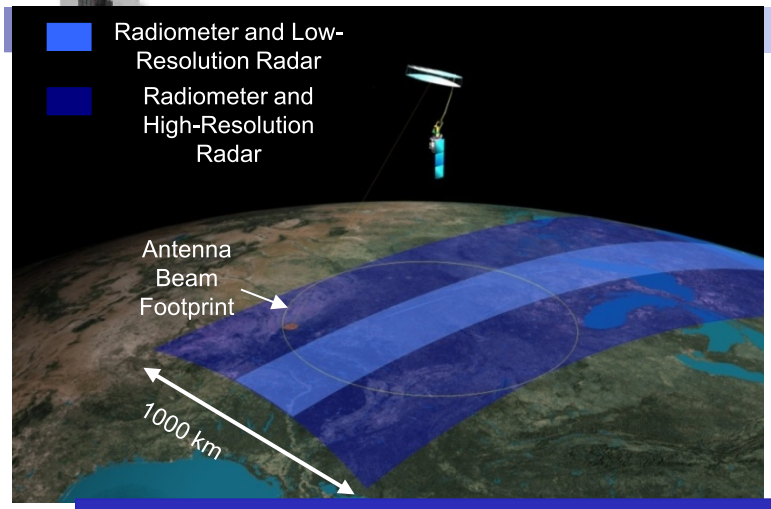
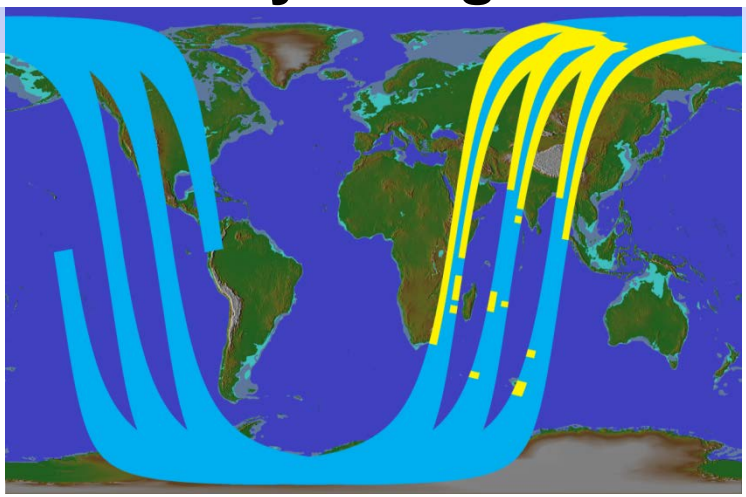




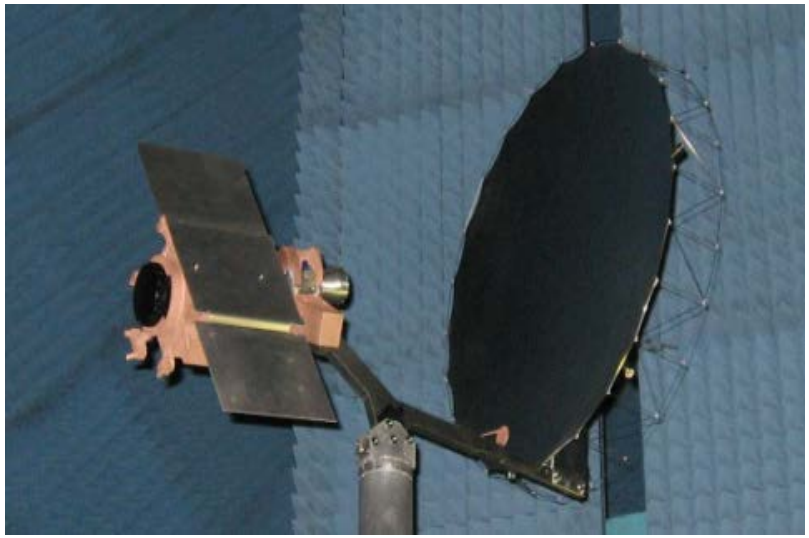
Radiometer and Low-Res Radar (40 km)

Radiometer and High-Res Radar (10 km/3km)

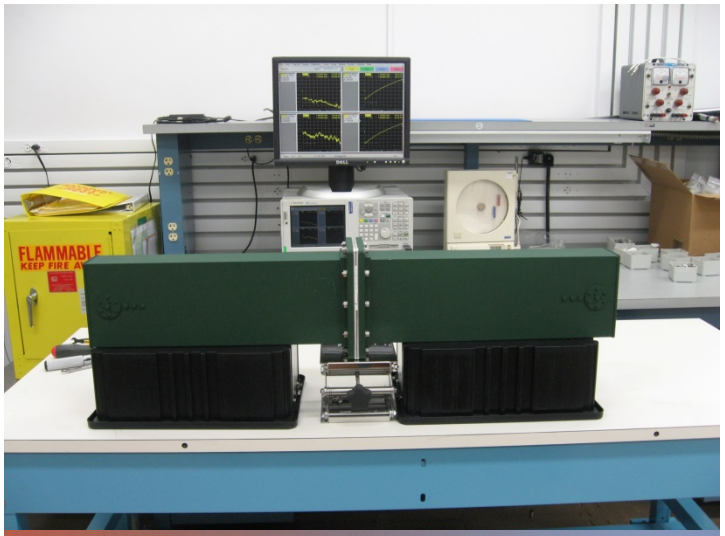
Science Requirement	Primary Instrument Design Drivers/Requirements
2-3 day global coverage	Broad measurement swath
Spatial resolution	Antenna size, synthetic aperture radar
Measurement accuracy through vegetation	Active, passive instrument combination Fixed measurement incidence angle RFI mitigation features in radar and radiometer
Instrument Requirements	**Secondary Flight System Design Drivers**
Broad Swath, Antenna size Fixed incidence angle	Rotating deployable reflector → Observatory Dynamics & Control, Mass Properties
Compatibility with L-band air traffic navigation radars	Radar duty cycle, peak power, frequency adjustability (for air traffic radar avoidance)
Synthetic aperture radar	Daily Data volume (up to 135 GB/day data return) → Ground station coverage

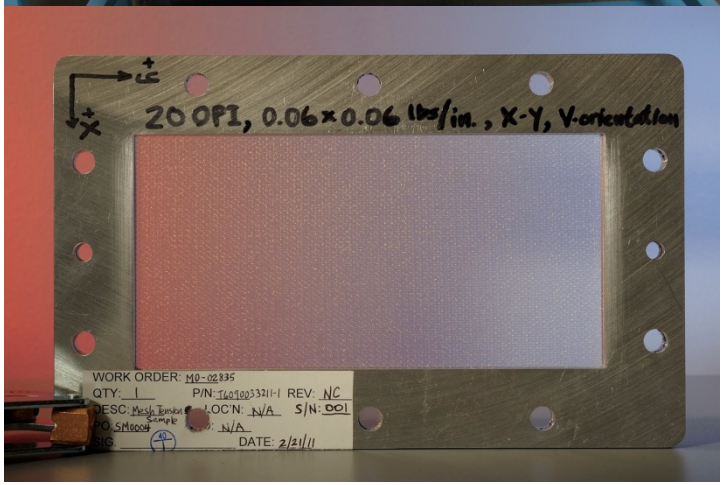
Deployable Reflector Challenges Permeate All Aspects of Observatory and Mission Design

- First L-band radiometric and radar application
  - Pre-launch RF performance characterization
- First known spinning application of this design
  - RF pointing & spin control with a small spacecraft (including verification and validation)
- Test & verification challenges because end-to-end "Test-As-You-Fly" is not practical for this system



RF pattern verification requires analytical modeling validated by scale model testing and measuring the flight feed RF performance





Characterizing mesh L-band emissivity

Reflector Packaging and Deployment Drove Observatory and Mission Designs

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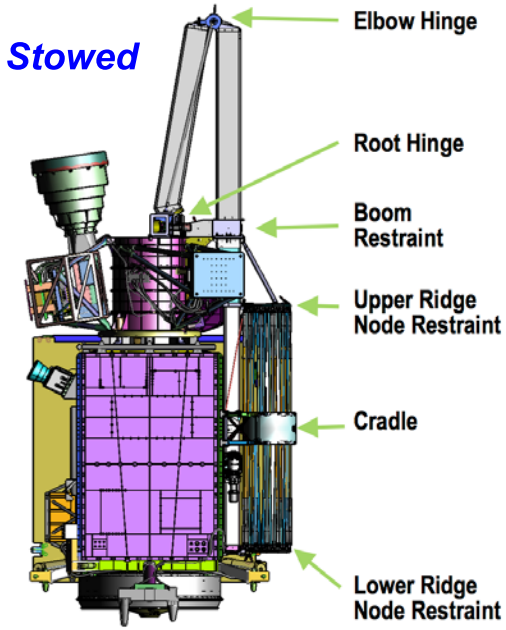
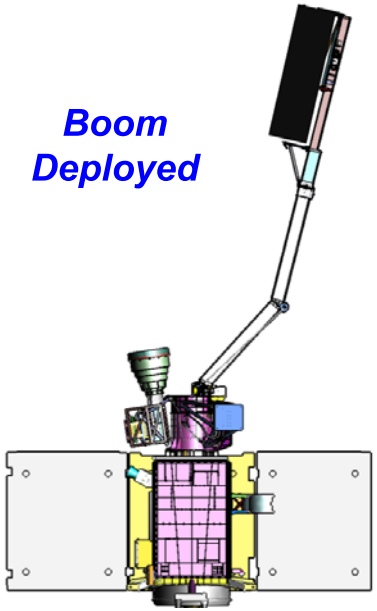
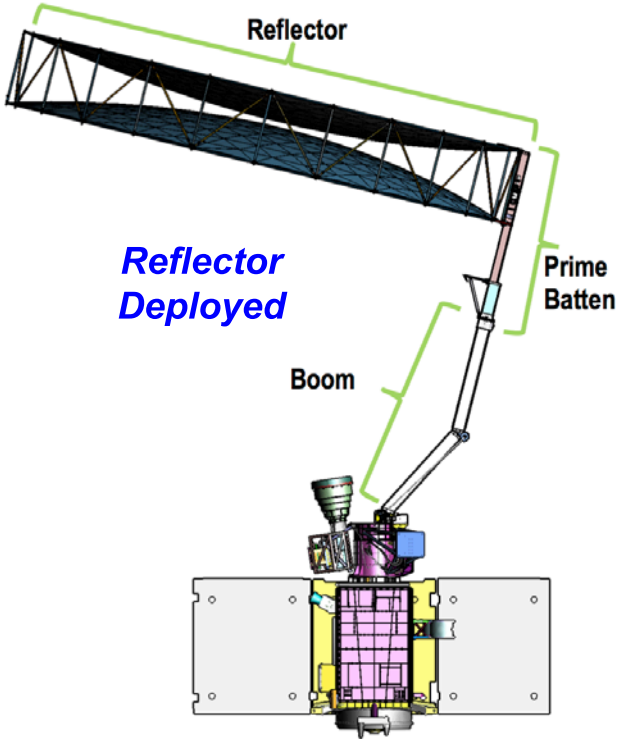
- First known use in low Earth orbit (eclipse season)
- First use of NGAS-Astro AM-Lite configuration
- Packaging and use with small fairing & spacecraft
  - Deployment constraints on observatory (ACS, power, telecom, fault protection)
  - Keeping spun momentum within fixed spacecraft reaction wheel capability







L-band Congestion Requires RFI Mitigation for Damage Protection & Science Accuracy

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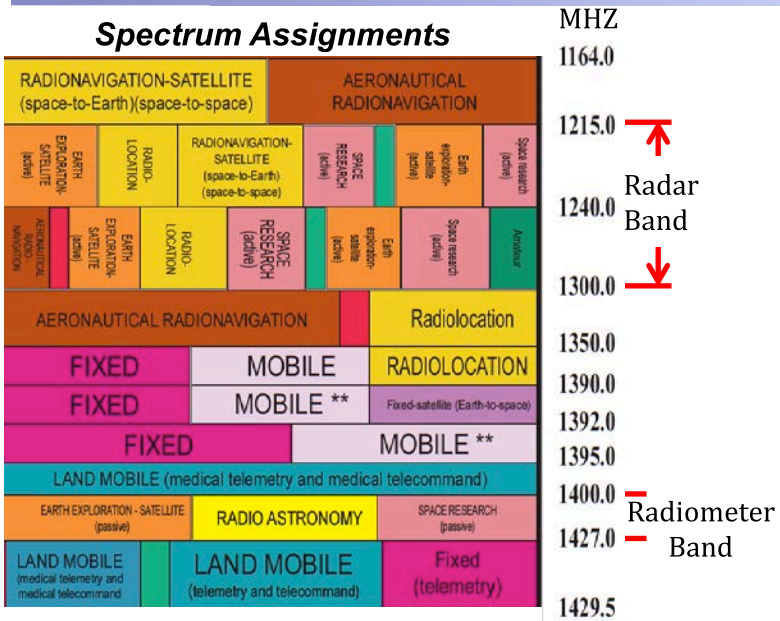
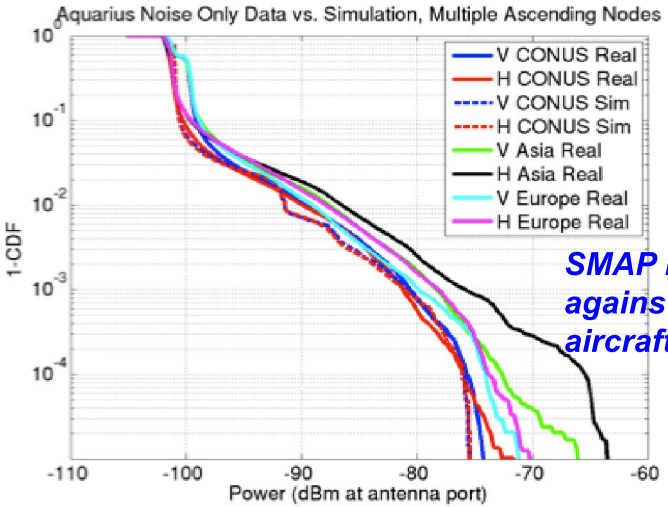
Spectrum Assignments

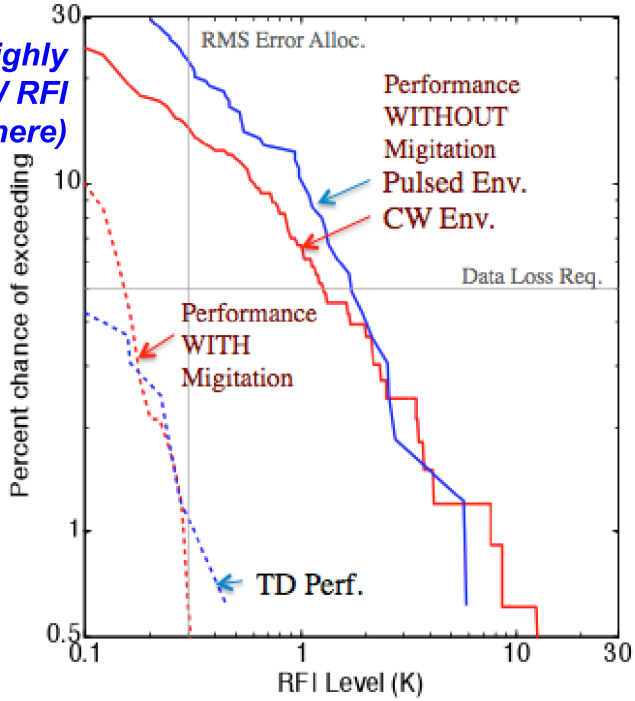


- Strategy:
  - Survive without damage
  - Detect RFI-contaminated data
  - Avoid RFI (radar only)
  - Remove RFI effects in ground processing

SMAP RFI mitigations are highly effective against pulsed & CW RFI (Radiometer results shown here)



SMAP RFI simulations are checked against operating space missions and aircraft science measurement results



SMAP Applies Extensive RFI Mitigations to Both Radiometer & Radar Measurements

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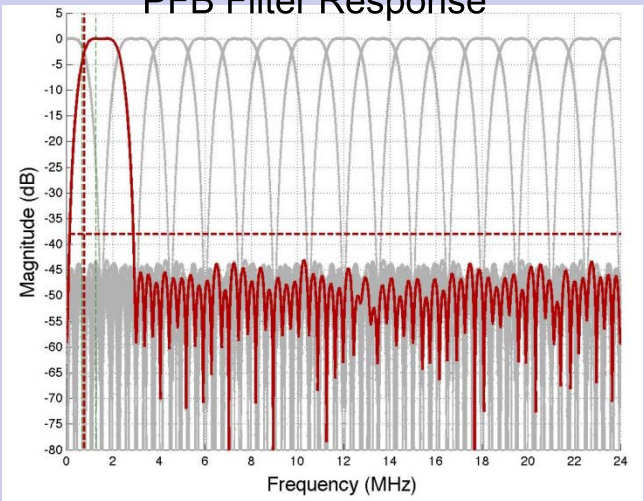
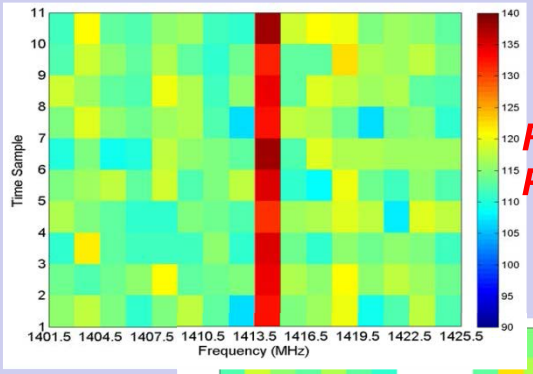
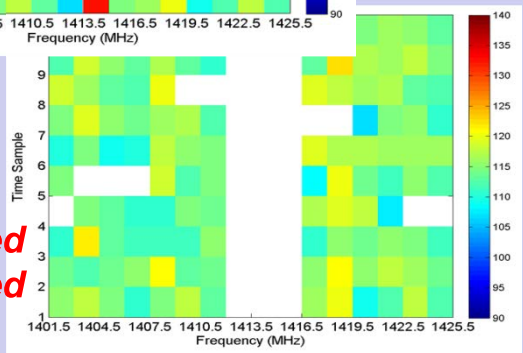
PFB Filter Response





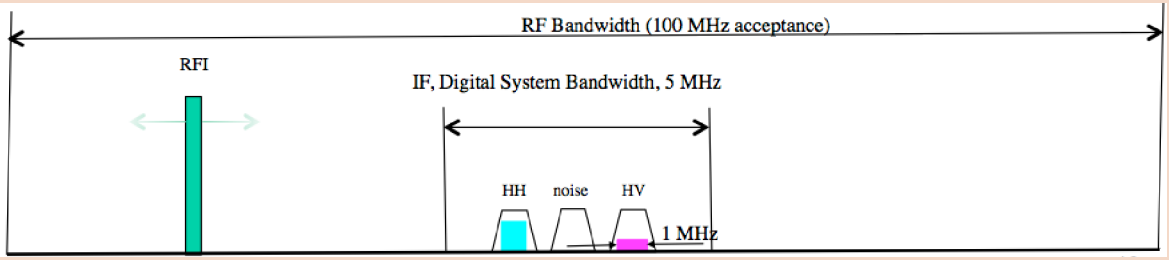
RFI Present



RFI Detected & Removed

Radar

- Ground-programmable operating frequency allows avoiding known regional RFI sources
- Filtering and dynamic range requirements assure that out-of-band RFI will avoid saturating receiver
- Residual RFI will be detected and removed during science data processing



Radiometer

- Digital spectral filtering enables RFI to be isolated within 16 radiometer subbands
- 4th Stokes is provided to further aid RFI identification
- Successfully demonstrated in Aircraft Tests
- Identification and removal is conducted in ground processing

Spacecraft and Instrument are Highly Integrated for Simplicity and Efficiency

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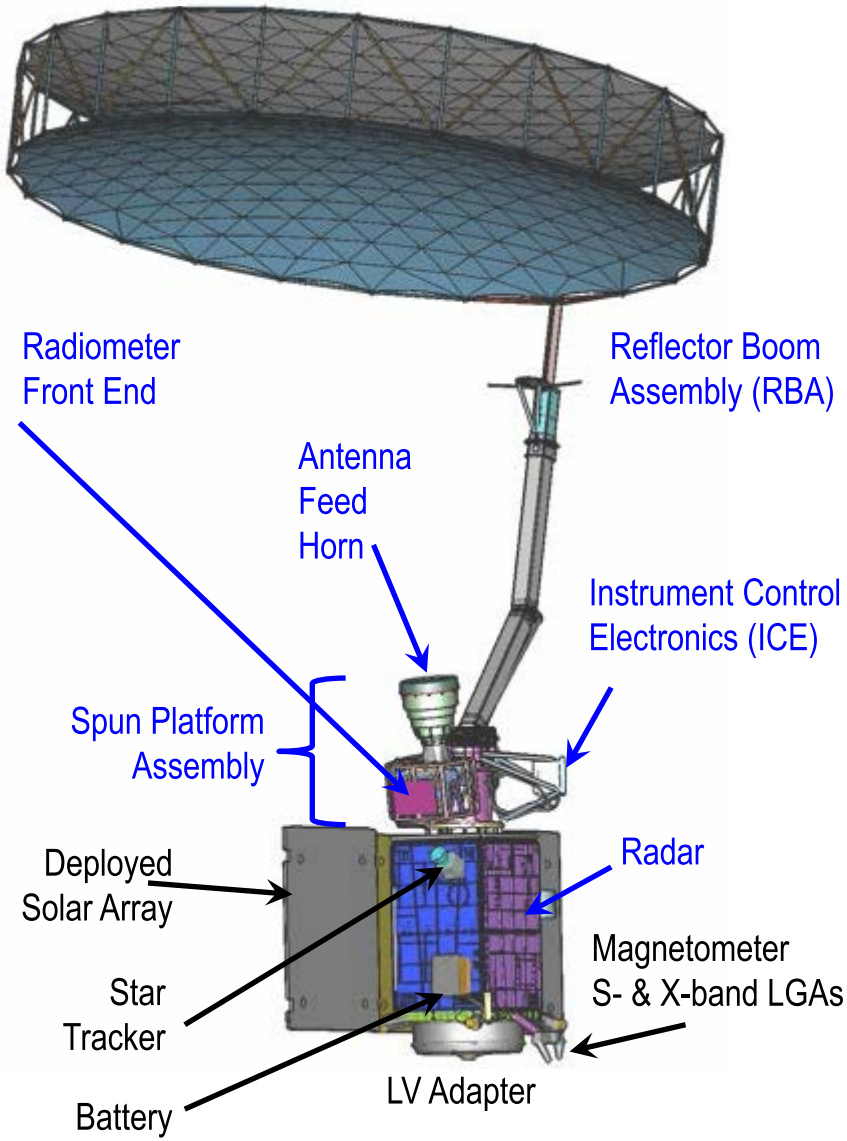
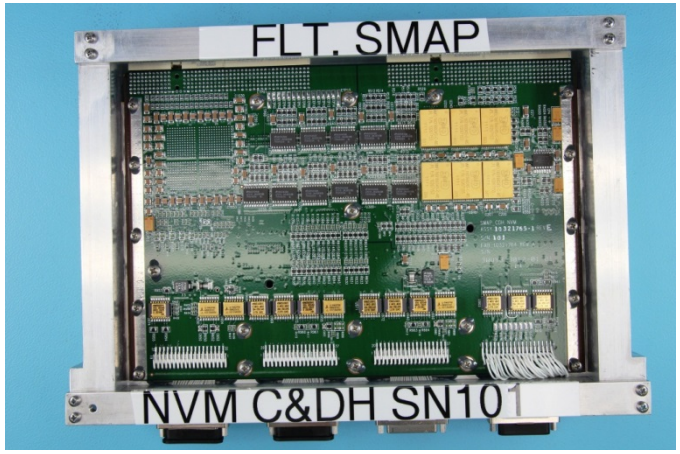


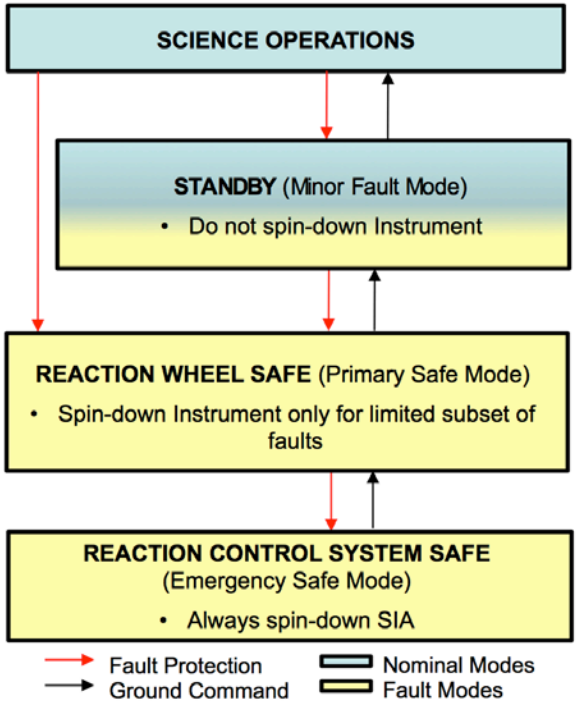
- 3-axis-stabilized spacecraft, large internal reaction wheels provides momentum compensation for spinning reflector
  - Attitude control and instrument spin subsystem designs and V&V are highly integrated
- Hydrazine blowdown propulsion system provides orbit adjust & emergency control if needed
  - Delta-V: 112.6 m/s (includes contingency)
- Radar boxes are mounted internally within spacecraft bus on anti-sun panel
- Single-string avionics and power control/distribution electronics
  - Provides storage, formatting for instrument data
- Redundant S-band transponders (commands & telemetry) & X-band transmitters (science data)
- 3 panel deployable, fixed solar array
  - Avoids interference with telecom, instrument antenna fields of view
- Passive and heater-based thermal control with bus structure panels serving as radiators

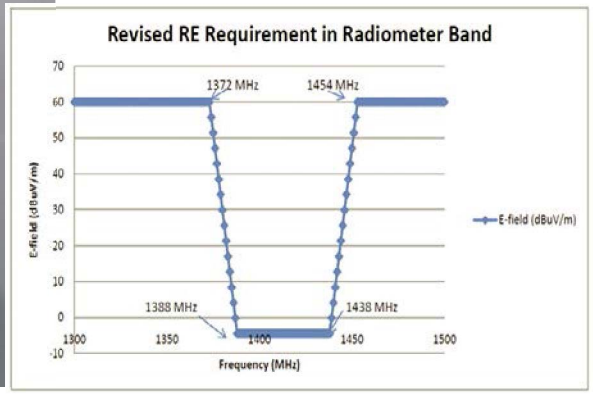
Observatory Design Accommodates a Number of Drivers and Constraints



JPL planetary heritage avionics have been adapted to high data volume required by radar

Fault Protection is unique to large spinning reflector; minimizes science down time





Design provisions are included to reduce EMI to science measurements (especially the radiometer)

Instrument RF Pointing Control & Knowledge is Aided by Design Frequency Separation

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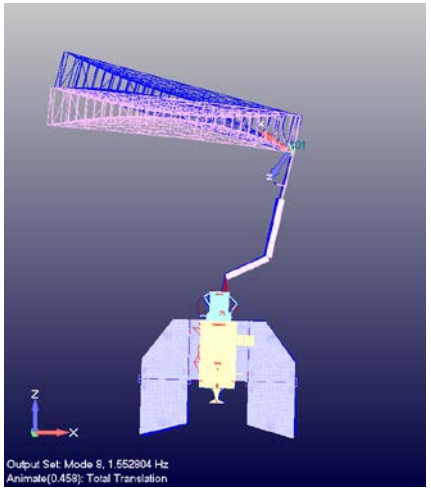
- Fundamental elements of D&C:
  - Flexible Body Effects
  - Momentum Compensation
  - Rotational Dynamics (largest challenge)
  - Attitude Stabilization
- Frequency separation is the key to meet stability and performance requirements

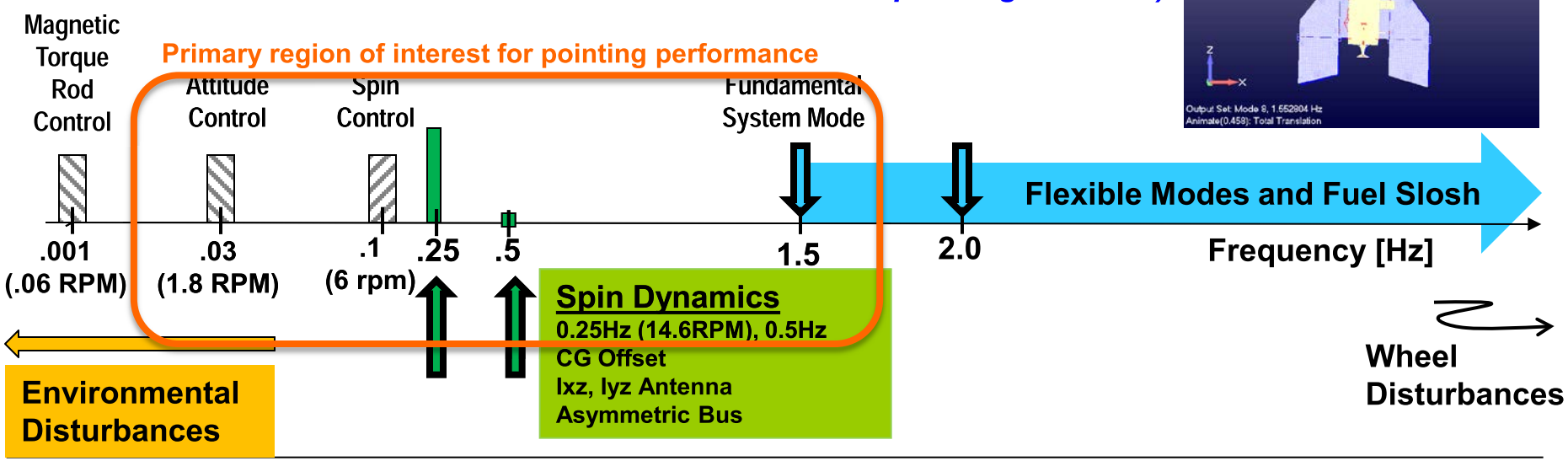
- Detailed multi-body/flexible body models provide good representation of dynamics below 10 Hz
- Models confirm system is well-behaved and meets pointing needs of mission

Mode 1: 1.55 Hz

"Nodding", rotation about y-axis

RBA FEM includes realistic mesh modes (important to model RF pointing behavior)





Pointing Approach Allows a Large Spinning Mass to be Controlled by a Small Spacecraft

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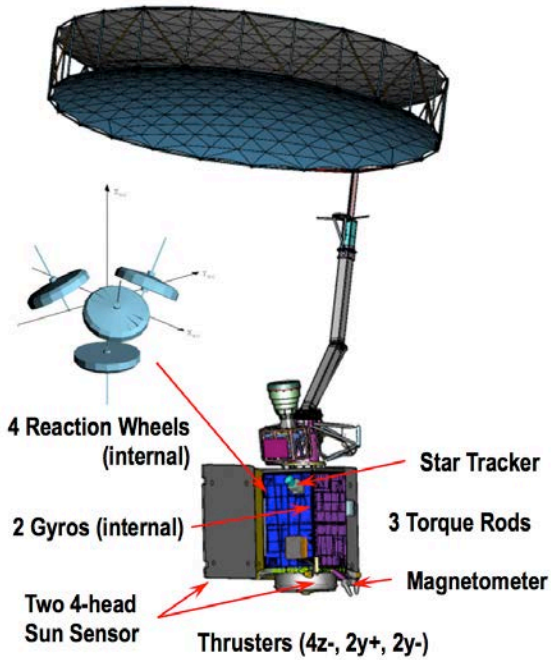

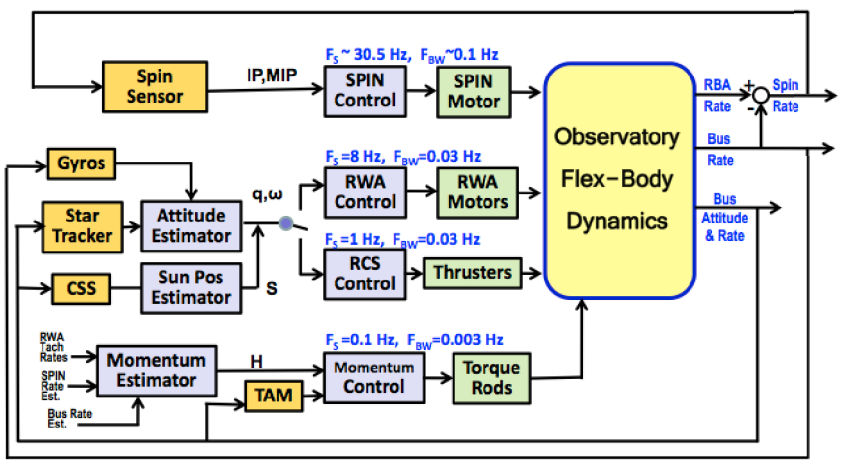

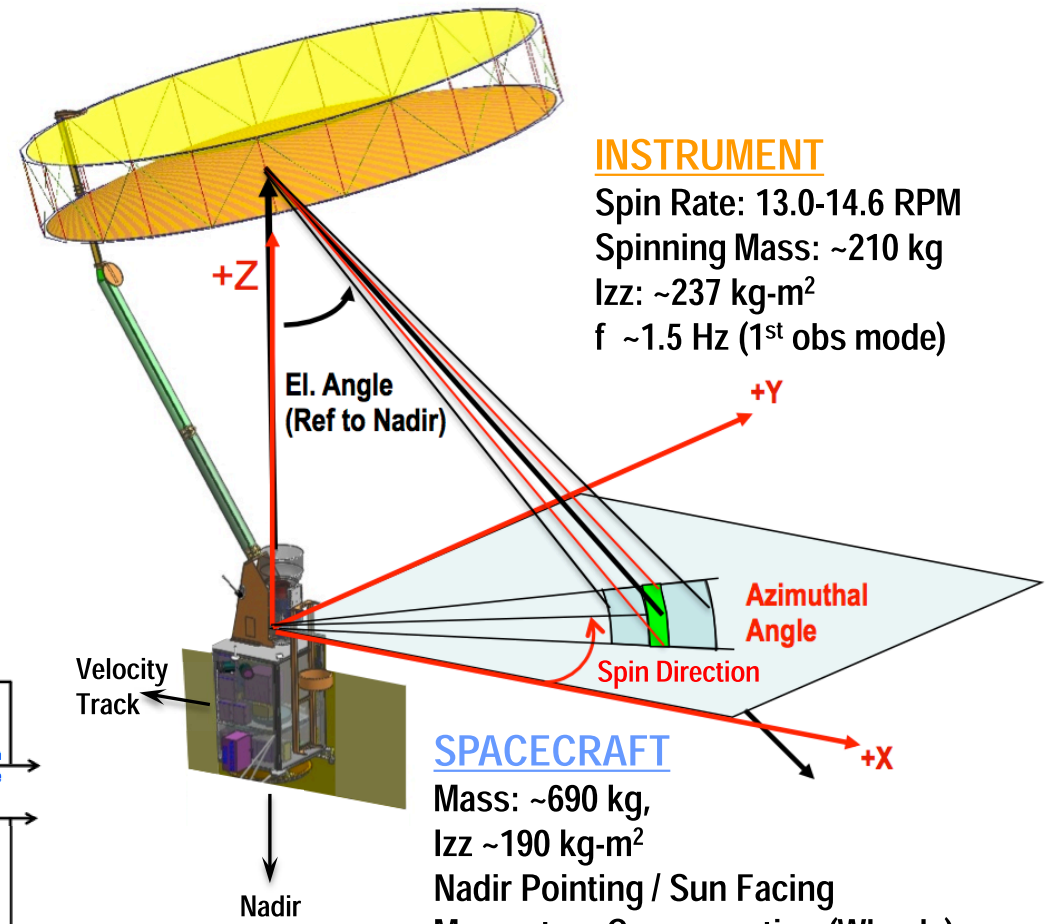

INSTRUMENT

Spin Rate: 13.0-14.6 RPM
Spinning Mass: ~210 kg
Izz: ~237 kg-m^2
f ~1.5 Hz (1st obs mode)

SPACECRAFT

Mass: ~690 kg,
Izz ~190 kg-m^2
Nadir Pointing / Sun Facing
Momentum Compensation (Wheels)
3-Axis Stabilization (Wheels)

Accommodated Late Launcher Selection with Conservative Environments & Flexible Adapter

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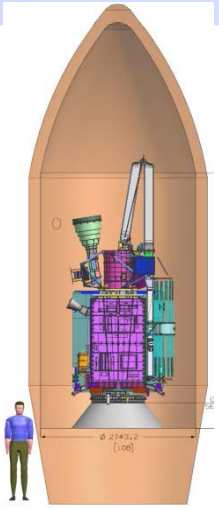
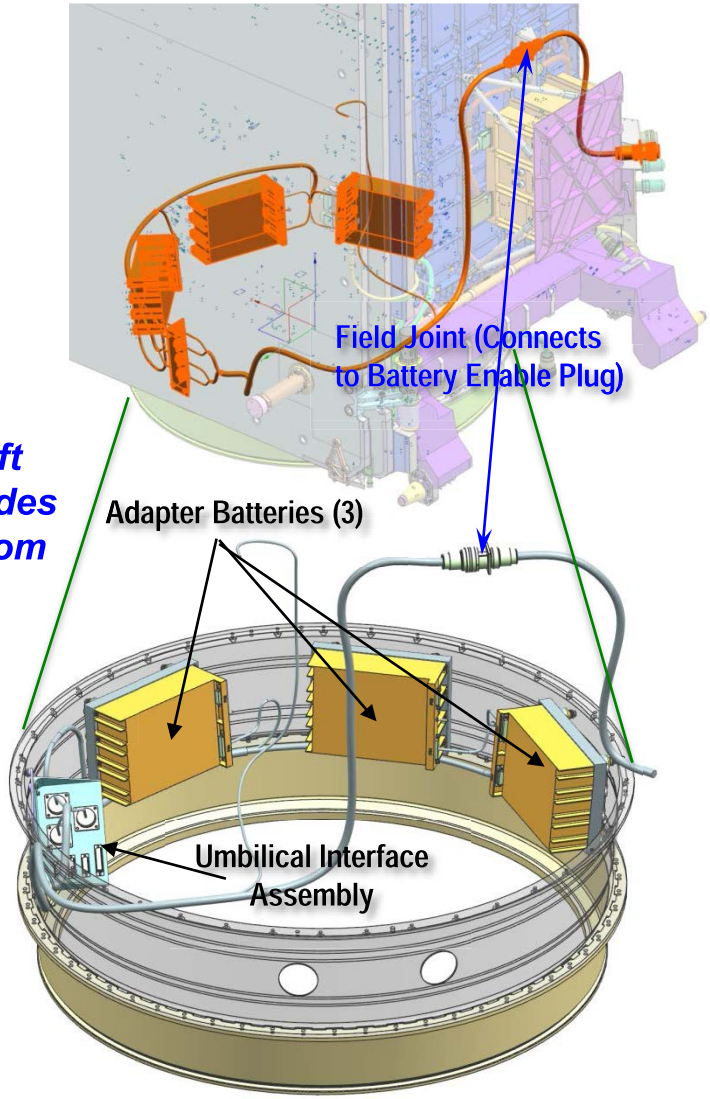
Observatory design held compatibility with a number of potential launchers throughout its design phase

Minotaur IV 92" fairing was primary driver



Delta II 10 ft fairing provides plenty of room



- SMAP design accommodated a number of potential vehicles throughout its development
  - Minotaur IV was driving in most cases
- Delta II was selected at Project CDR (July '12)
- SMAP's strategy isolated vehicle uncertainty using a flexible launch vehicle adapter design
- Applied bounding environments, mission designs accommodations to remainder of observatory

A Few Excluded Charts

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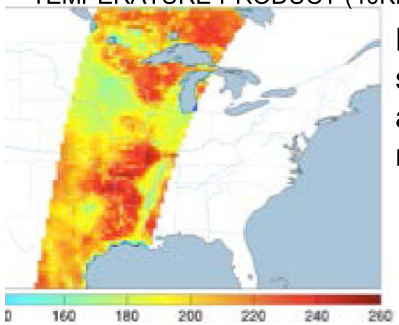
Instrument Overview

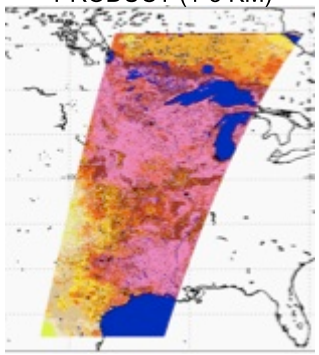
RADIOMETER BRIGHTNESS TEMPERATURE PRODUCT (40KM)

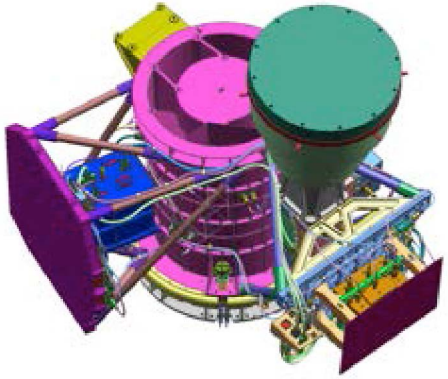


Radiometer for high soil moisture accuracy at moderate spatial resolution

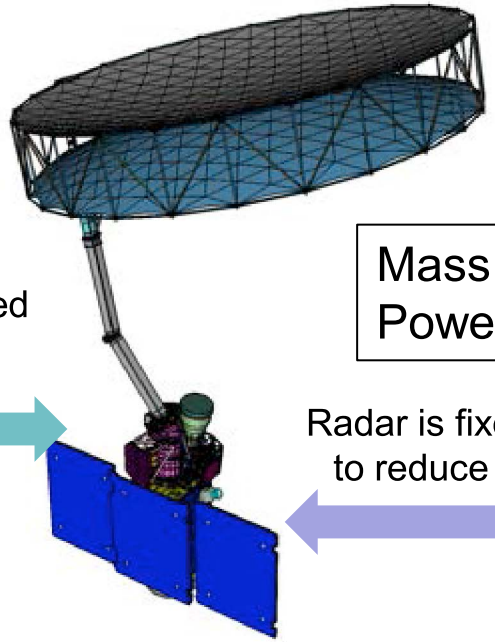
Radar: Unfocused SAR for high spatial resolution & freeze/thaw detection

HI-RES RADAR BACKSCATTER PRODUCT (1-3 KM)



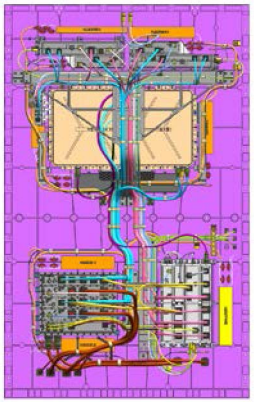


Radiometer is spun-side-mounted to reduce losses



Mass: 356 kg
Power: 448W

Radar is fixed-mounted to reduce spun inertia



Radiometer

- Polarizations: V, H, 3rd & 4th stokes
- 1.3-K accuracy
- 40-km resolution
- 4.3-Mbps data rate

Common 6-m Spinning Reflector

- Spin Assembly (Boeing) and Reflector/Boom Assembly (NGAS-Astro) derived from heritage designs
- Conically scanning at 13–14.6 rpm
- Constant incidence angle of 40-deg

Radar

- 1-MHz chirps tunable over 1217–1298 MHz
- Polarizations: VV, HH, HV
- 500-W SSPA (9% duty cycle)
- 3-km spatial resolution
- 35-Mbps data rate

Observatory Design has Accommodated a number of Constraints

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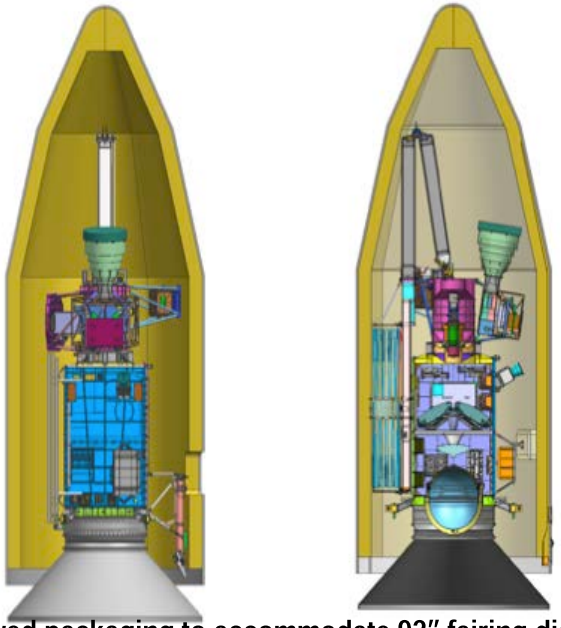
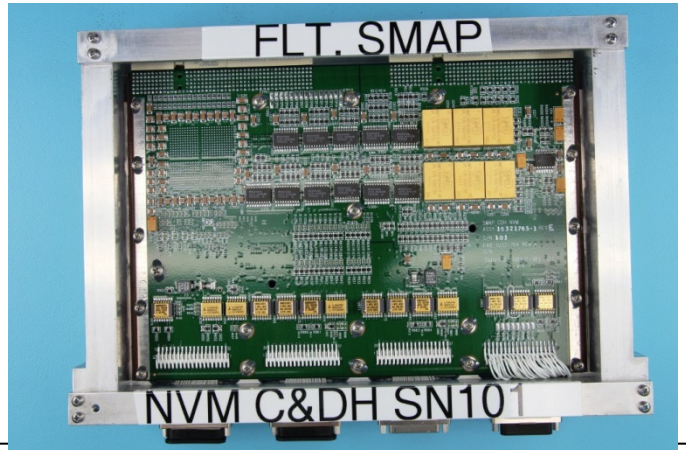
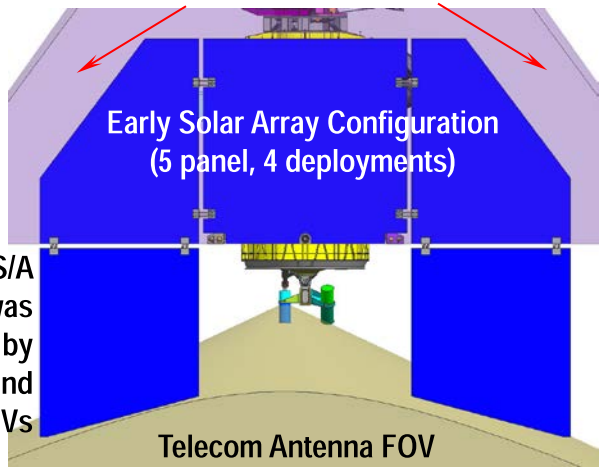
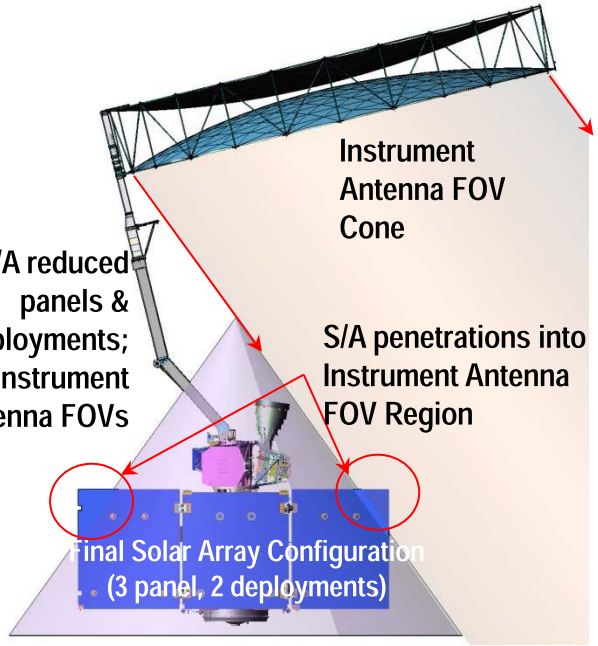


Stowed packaging to accommodate 92" fairing diameter (Minotaur IV launch option) was a major driver



Adapting planetary heritage avionics to high data volume requirements of an Earth science mission (using a SAR...)



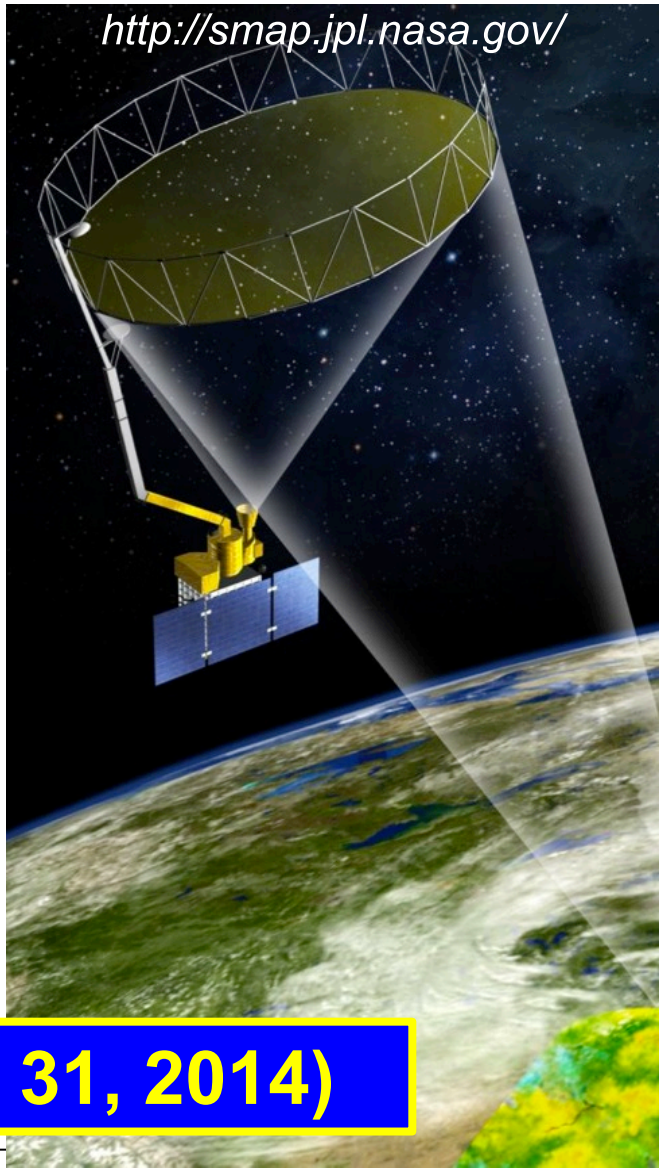


SMAP Lessons Learned

- Coordinate science radar frequencies and scenarios early with regulatory functions
  - Primary spectrum users are increasingly wary about potential secondary user interference
- Select the launch vehicle early – particularly for new observatory designs where design iterations can be driven by constraints, conservative bounding environments
- Integrated observatory design—spacecraft and instrument—can leverage spacecraft capabilities to greatly simplify instrument design and operation.
- Avoiding unnecessary complexity creep is a challenge in Formulation as new design insights incrementally unfold and thereby often reveal new issues to be resolved within the design.
  - Occasional team ‘resets’ were imposed to reassess local requirements and design complexity – these resulted in significant simplification and reduced development risk.
- Realistically identify development challenges early and apply resources to mature these design areas, and qualify critical essential electronics parts and subassemblies to reduce downstream risk.

Conclusion

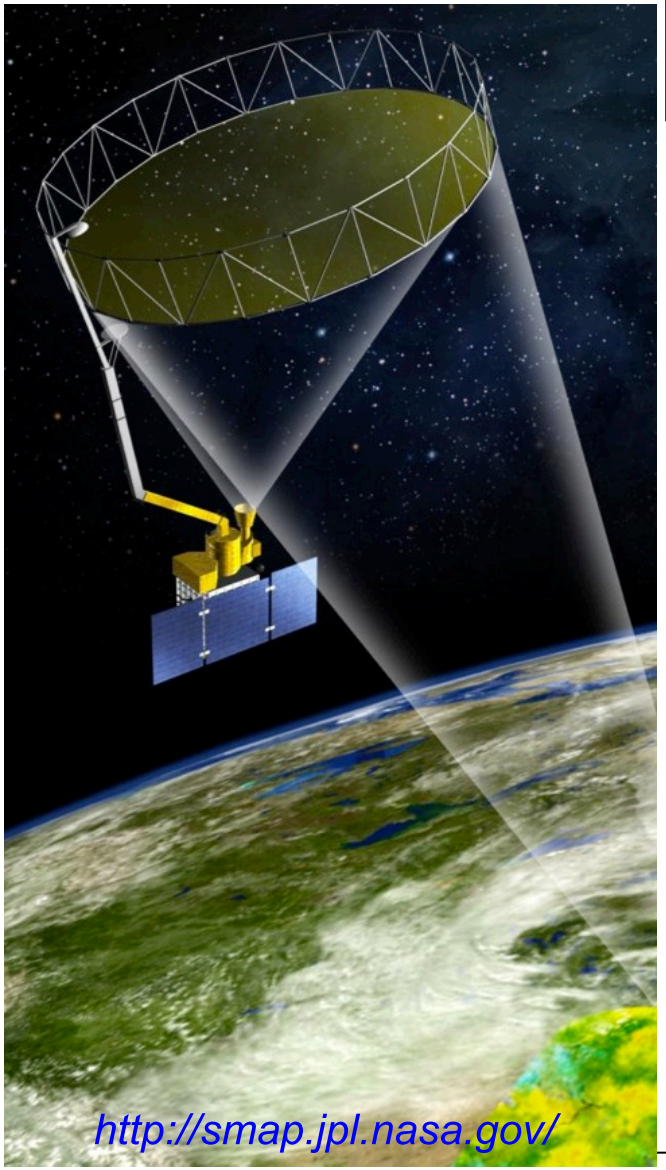
- SMAP observatory has addressed many unique challenges
- Global coverage every 2-3 days
- High accuracy, high resolution measurements
- Minimizing science data loss
- Mesh deployable reflector use for science application
- Mechanical packaging; late launch vehicle selection
- Fault protection
- Adapting planetary heritage avionics
- EMC design
- Dynamics and control



20 months to launch (Oct 31, 2014)

Some Other Charts that were initially in the mix

Project Overview



SMAP is a first-tier mission recommended by 2007 NRC Earth Science Decadal Survey

Primary Science Objectives

- Global, high-resolution mapping of soil moisture and its freeze/thaw state to:
  - Link terrestrial water, energy and carbon cycle processes
  - Estimate global water and energy fluxes at the land surface
  - Quantify net carbon flux in boreal landscapes
  - Extend weather and climate forecast skill
  - Develop improved flood and drought prediction capability

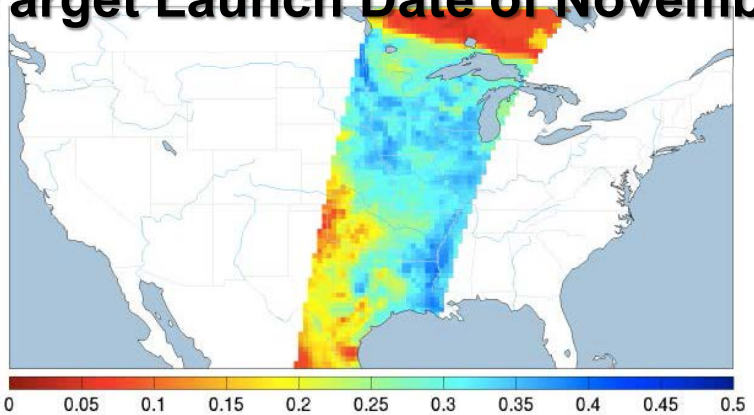
Mission Implementation:

Partners	• JPL (project & payload mgmt., science, spacecraft, radar, mission operations, science processing) • GSFC (science, radiometer, science processing)
Risk	• 7120.5 Category 2; 8705.4 Payload Risk Class C
Launch	• Oct. 31, 2014 on Delta 7320-10C Launch System
Orbit	• Polar sun synchronous; 685 km altitude
Duration	• 3 years
Payload	• L-band (non-imaging) synthetic aperture radar (JPL) • L-band radiometer (GSFC) • Shared 6m rotating (14 rpm) antenna (JPL)

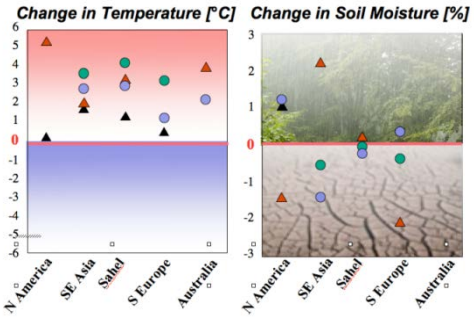
Jet Propulsion Laboratory
California Institute of Technology

Project Overview

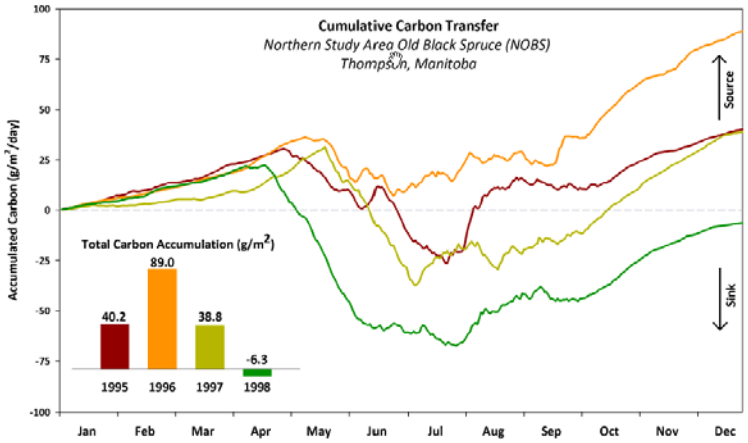
SMAP Completed Initial Mission Formulation; NASA Established a Target Launch Date of November 2014

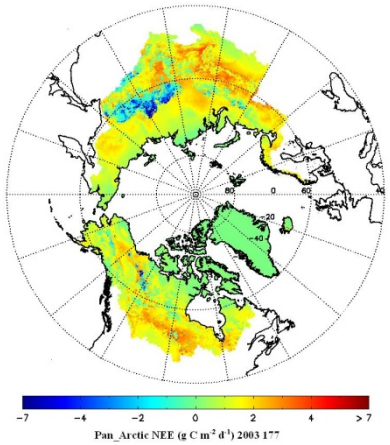


% vol. soil moisture



Improved climate models





Carbon Storage Estimate

SMAP will use a rotating 6-m deployable mesh antenna shared by an L-band radar & radiometer to map soil moisture at 10 km resolution and its freeze/thaw state at 3 km resolution globally every 2-3 days

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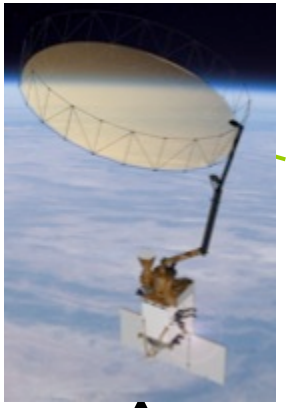
Mission Systems Overview



Telemetry Visibility for Critical Events

TDRSS

S Band
X Band

Near Earth Network

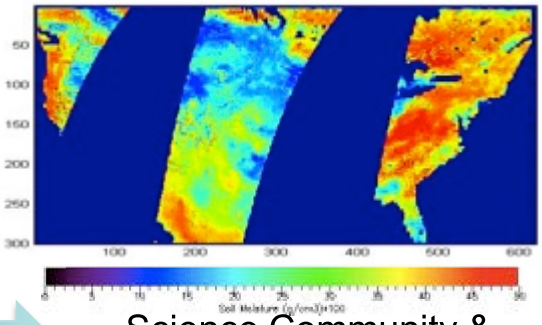
GSFC Comm Cloud & EDOS

JPL SMAP MOS Facility

JPL SMAP SDS Facility (L1-L3 products)

GSFC GMAO (L4 products)

Data Centers: ASF (Radar L1) NSIDC (Other)



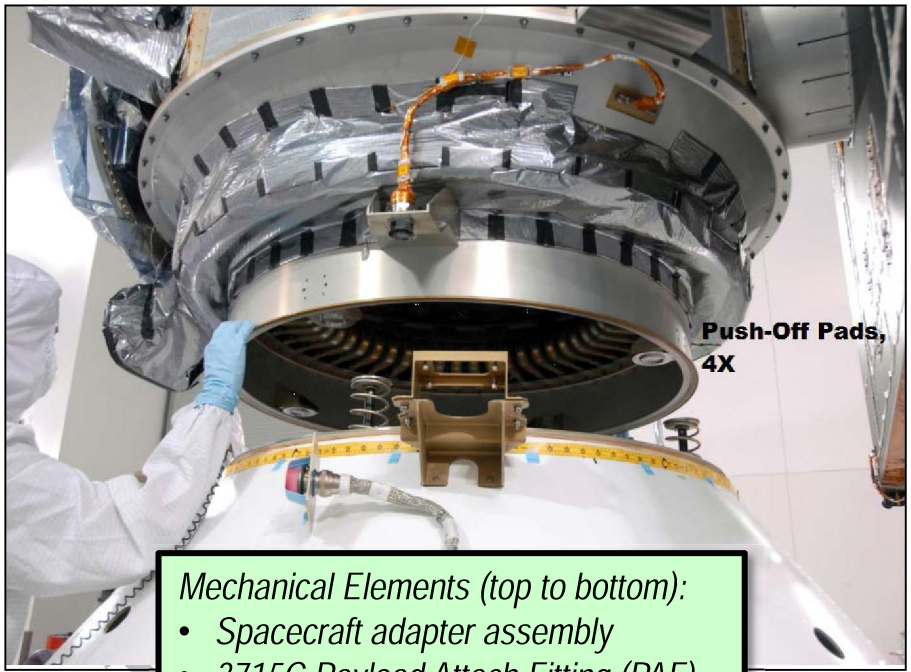
Science Community & Applications Users

- SMAP would use JPL's Earth Science Multi-Mission Facility
- NEN used for routine science data and T&C

  NEN upgrades to support DS missions are being put in place for SMAP (will be completed within next year)
- TDRSS used for critical events telemetry visibility and commanding if necessary
- EDOS provides L0 processing & routing
- JPL performs L1-3 processing
- GSFC/GMAO performs L4 processing
- Data Centers: NSIDC and ASF

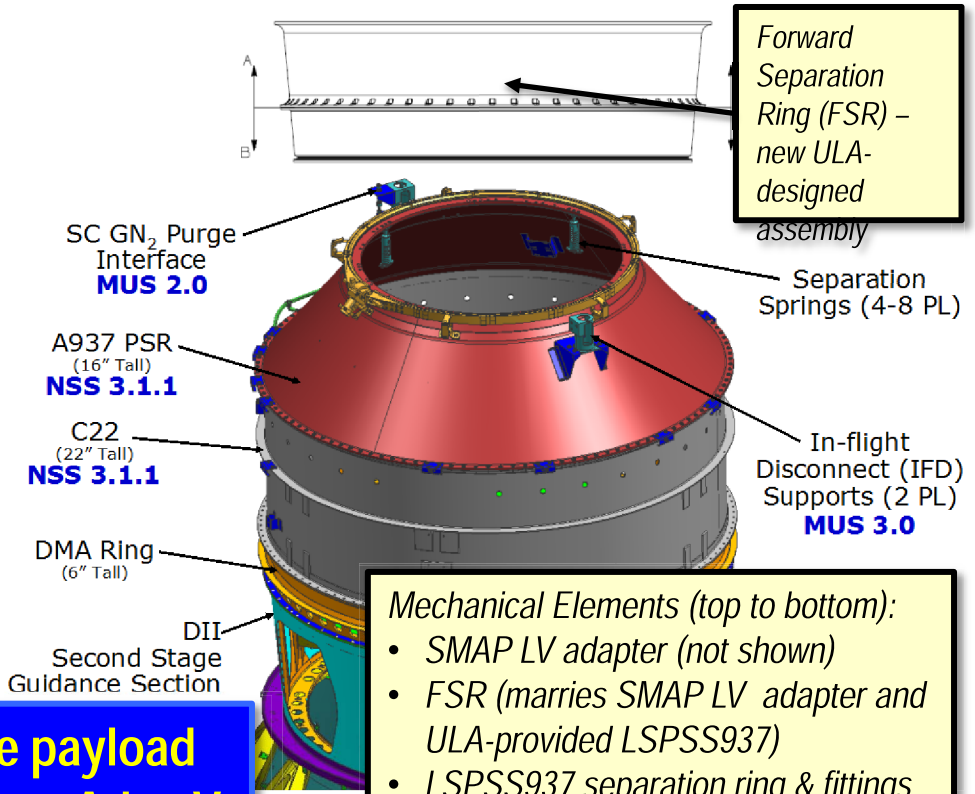
Delta II for SMAP Uses Alternative Interface Elements to Replace Those No Longer Available

Legacy Delta II Config. (WISE Mission, 2009)



Mechanical Elements (top to bottom):
- *Spacecraft adapter assembly*
- *3715C Payload Attach Fitting (PAF)*
- *Integrated 3715C separation fittings*

Delta II Configuration Concept for SMAP

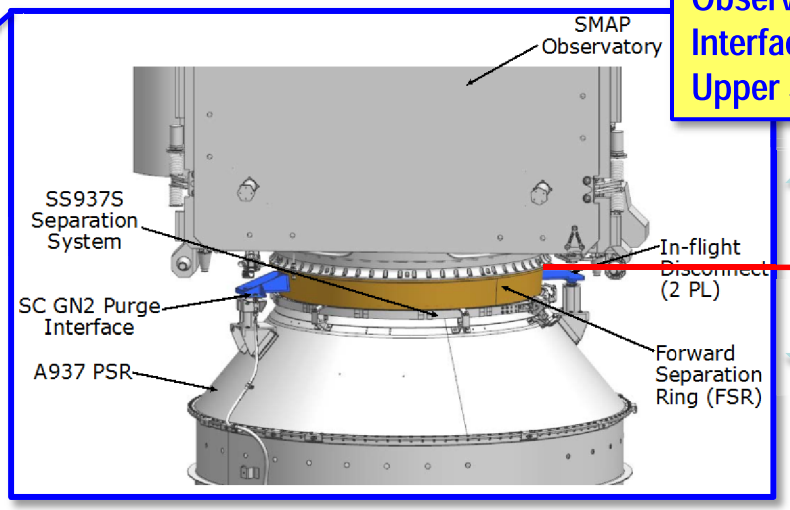


Mechanical Elements (top to bottom):
- *SMAP LV adapter (not shown)*
- *FSR (marries SMAP LV adapter and ULA-provided LSPSS937)*
- *LSPSS937 separation ring & fittings*
- *A937 Payload Separation Ring (PSR)*
- *Atlas C22 skirt*

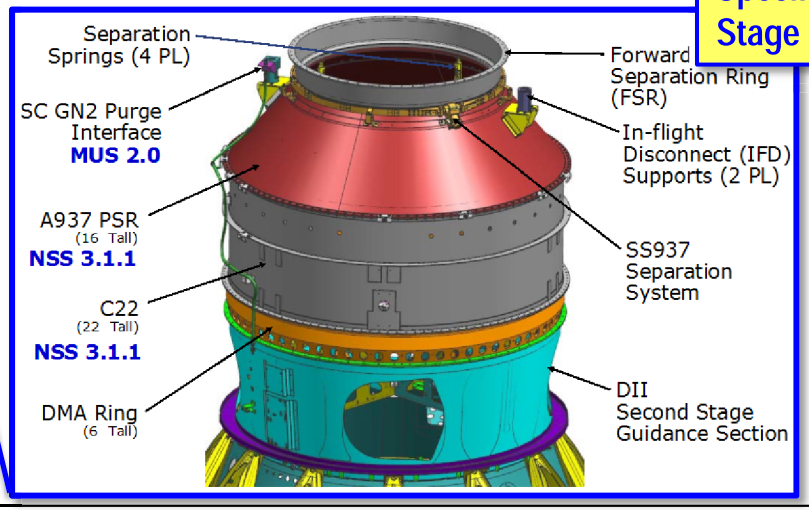
New mechanical elements for SMAP include payload attach fitting, separation system adapted from Atlas V and custom forward separation ring

Delta II Launch Vehicle Integration Activities are Progressing on Schedule

Observatory Interfaces to Upper Stage



Delta II Mission-Specific Upper Stage Hardware

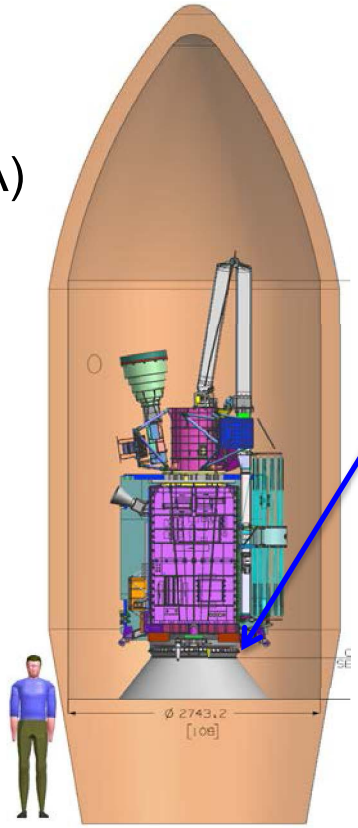


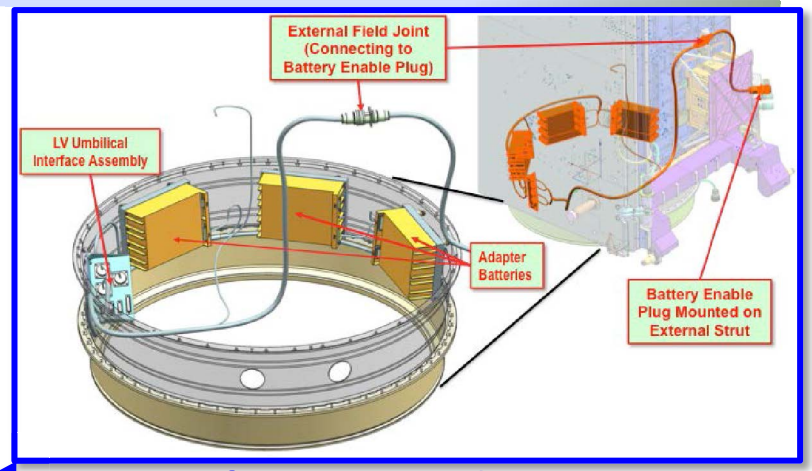
Delta II 7320-10C for SMAP:

- 3 strap-on solid rocket motors
- **Two stage configuration**
- Uses payload adapter from Atlas V
- **10 ft. diameter composite fairing**

Observatory-Side of Delta 2 Interface has Matured According to KDP-C Plan

- Mission design updated for Delta 2; will inject nearly directly into science orbit
- Launch vehicle adapter (LVA) design has matured
  - Substantially isolated observatory design from persistent launch vehicle uncertainty
  - LVA PDR completed in November
  - LVA CDR completed
- Launch Complex Equipment (LCE) has been built and delivered to testbeds





SMAP Launch Vehicle Adapter

LCE controls umbilical interface to Observatory