Design Overview of the Thermal Control System for the SMAP Mission

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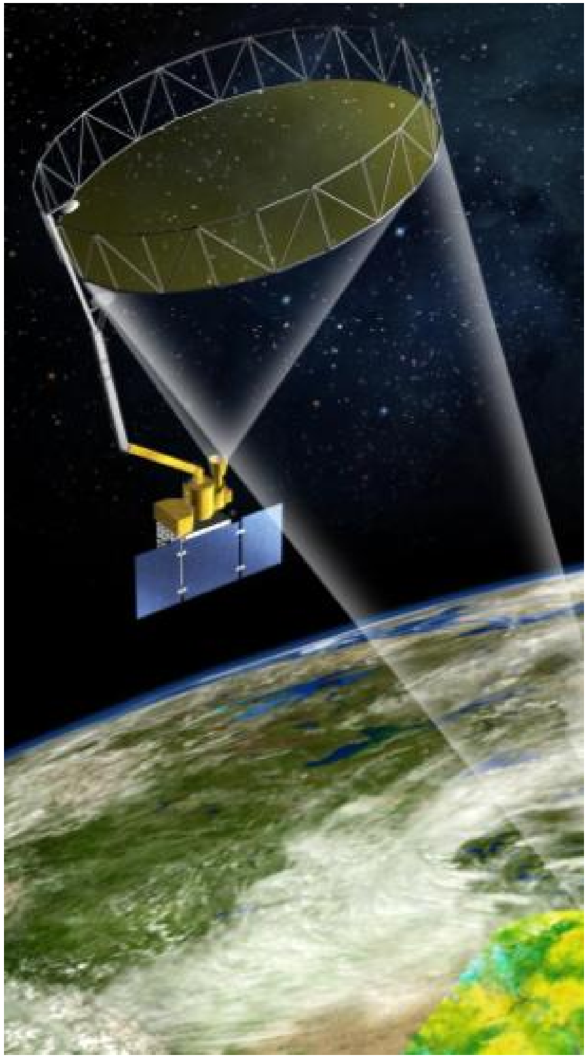
SMAP Project Overview



http://smap.jpl.nasa.gov/

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

Primary Science Objectives :

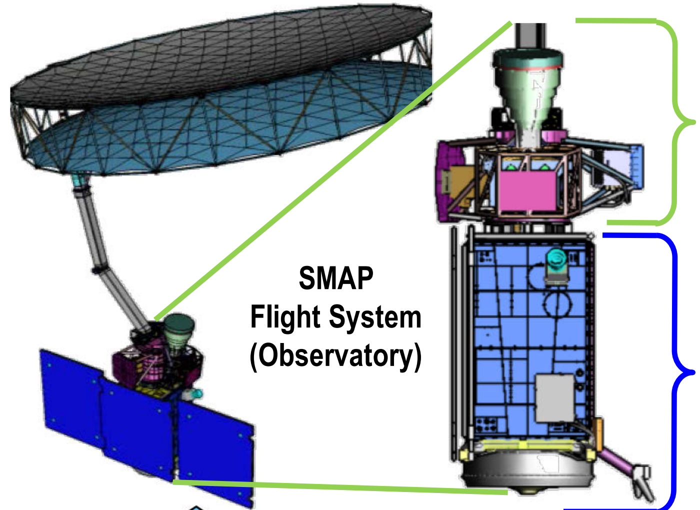
Global, high-resolution mapping of soil moisture and its freeze/thaw state to:

- 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	• 7120.5D Category 2; 8705.4 Payload Risk Class C
Launch	• Oct. 2014, Delta II LV
Orbit	• Polar sun synchronous; 685 km (equatorial) altitude, 98 minute orbit
Duration	• 3 years
Payload	• L-band (non-imaging) synthetic aperture radar (JPL) • L-band radiometer (GSFC) • Shared 6m rotating (14 rpm) antenna (JPL)

Mission Overview

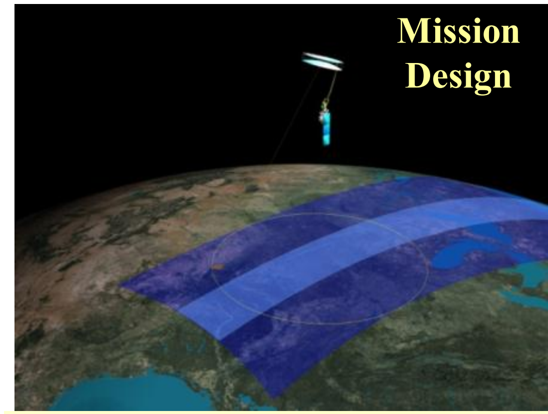


INSTRUMENT

- 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
- JPL's MSAP/MSL avionics, power assys with a small number of new mission-unique card designs
- 1160 kg wet mass (Observatory-level)
- 1100 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 mission duration

Delta II

- SMAP recently selected Delta II launch vehicle in July '12
- Planned launch date: Oct 31, 2014

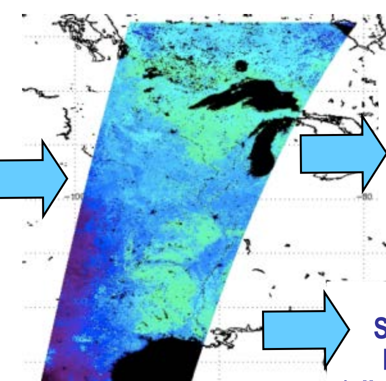
Near-Earth Network

Surface Validation

SMAP Mission Operations & Data Processing (JPL, GSFC)

SCIENCE DATA PRODUCTS

Soil Moisture & Freeze/Thaw State Data Products

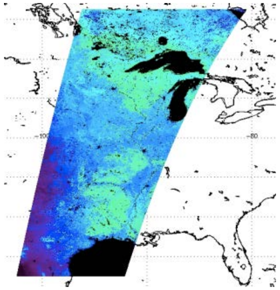


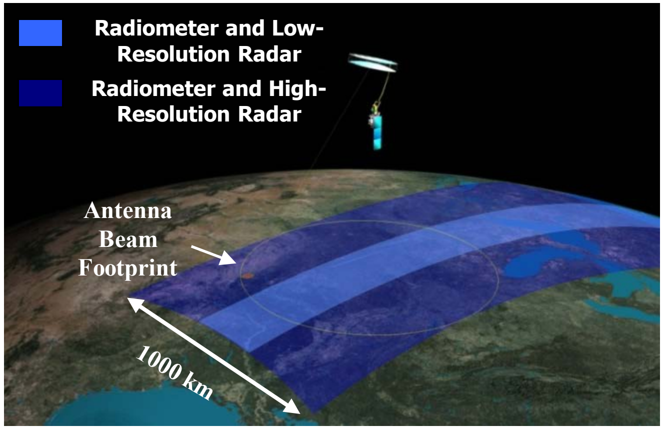
Alaska Satellite Facility Data Center (Radar L1 Products)

National Snow and Ice Data Center (all other Products)

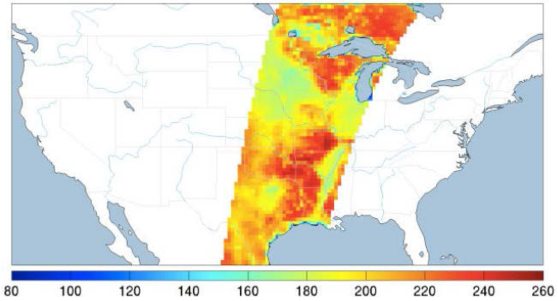
Mission/Science Driving Requirements

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



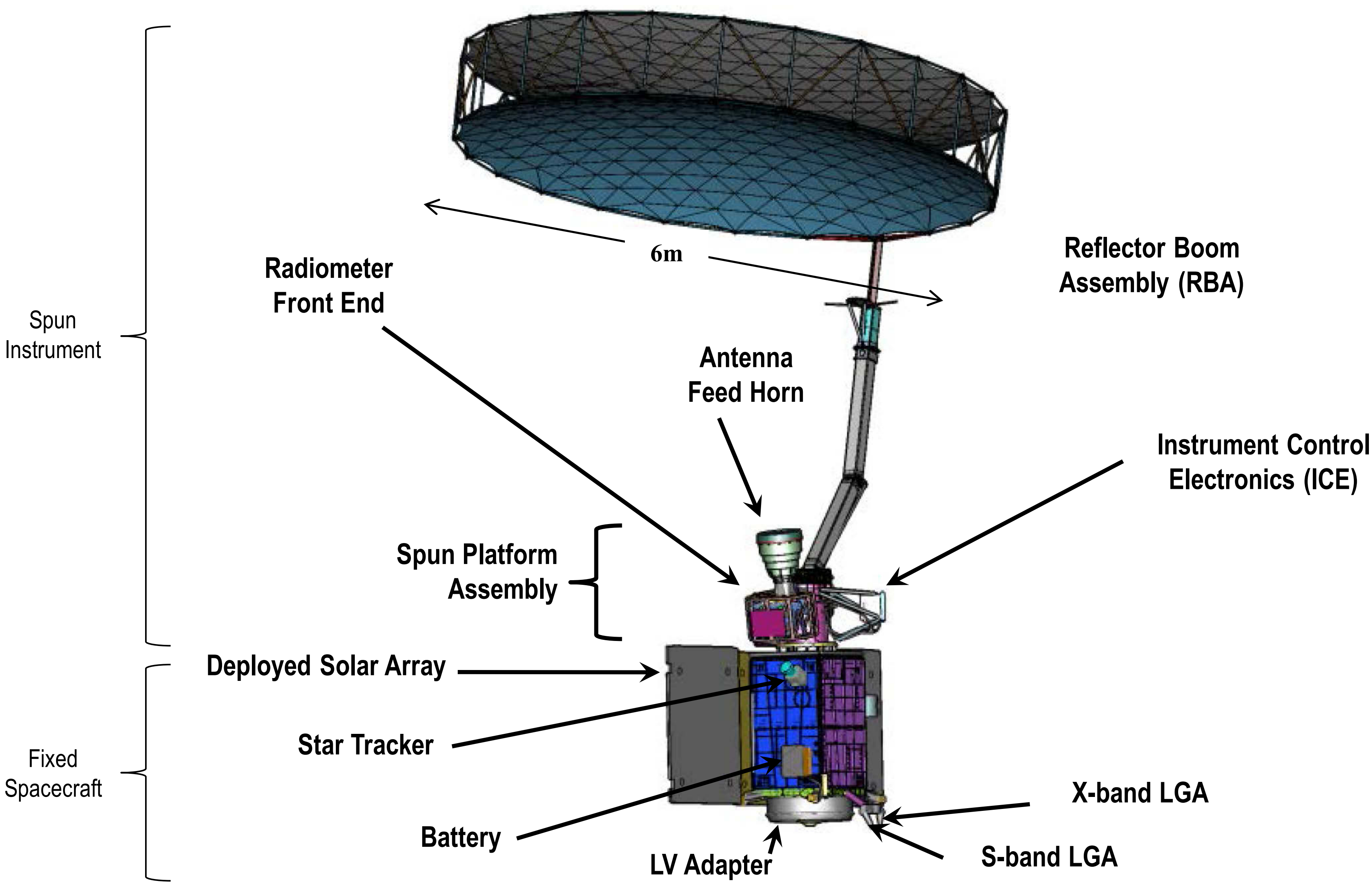


RADIOMETER BRIGHTNESS TEMPERATURE PRODUCT (40KM)



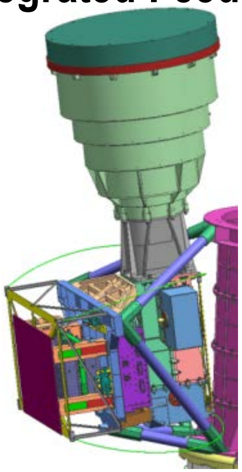
- Two to three day global coverage
  - Drives requirement for conically scanning antenna
- Spatial resolution at 10 km and 3 km for soil moisture and freeze-thaw products
  - Drives 6 meter antenna size, synthetic aperture radar design
- Soil moisture measurement accuracy, including through moderate vegetation
  - Drives requirements for combined active and passive instrument combination
  - Drives the thermal stability requirements for both radiometer and radar
  - Drives requirement for dual polarizations
- Dynamics and control of the scanning antenna to ensure pointing requirements are met while spinning at 14.6 rpm
  - Drives mass properties, antenna optics, spin rate stability/accuracy requirements of the spun instrument
- Characterizing/bounding the terrestrial RFI environment early and ensuring that mitigations are adequate to prevent unacceptable degradation to science data
  - Drives radiometer and radar electronics designs
- Compatibility with existing FAA Radars in shared L-band spectrum allocation
  - Drives radar duty cycle and peak power requirements

Observatory Configuration



Spun Instrument Configuration

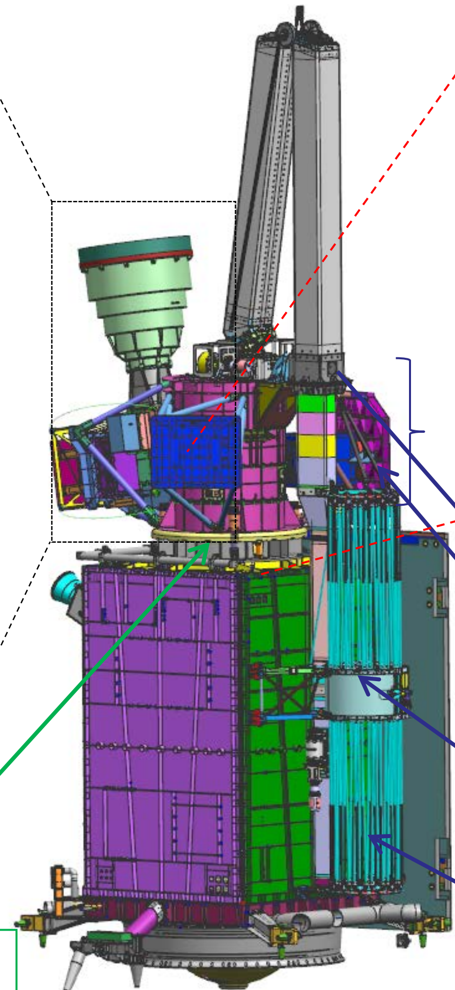
Integrated Feed Assy



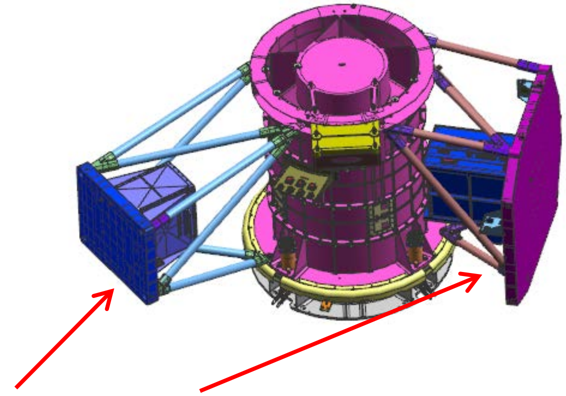
RFE & Passive RF components mounted to "stacked plate" structure

Feed Assembly mounted to RFE Plate

Assembly mounted to core structure using 3 bi-pods



ICE, RDE, RBE Support Structures



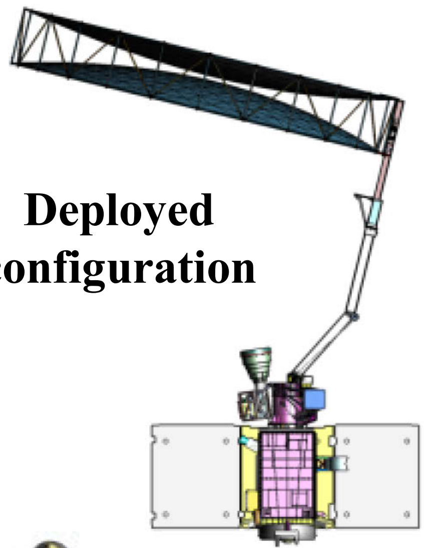
ICE and RDE/RBE mounted to separable structures with mounting surface used as radiators

RBA Launch Restraints

- -Boom Restraint
- -Upper Hoop Restraint
- -Cradle
- -Lower Hoop Restraint

Cone-Clutch Assembly

Observatory Overview



Deployed configuration

Stowed configuration

Mission Overview

- 2- to 3-day global coverage
- 685-km Sun-sync orbit, 6 p.m.

Observatory Summary

- 3-axis-stabilized spacecraft, providing momentum compensation for spinning antenna
- Single-string avionics and power control/distribution electronics
- Limited redundancy in ACS sensors and actuators, and telecom radios
- S-band telecom and 130 Mbps science data return via X-band link
- Deployable, fixed solar array
- Hydrazine blowdown propulsion system
- Passive and heater-based thermal control with bus structure serving as radiators

Propellant

- 80.0 kg usable capacity
- Delta-V: 112.6 m/s (includes contingency)
- Propellant budget: 74.2 kg (includes contingency)

Combined Instruments

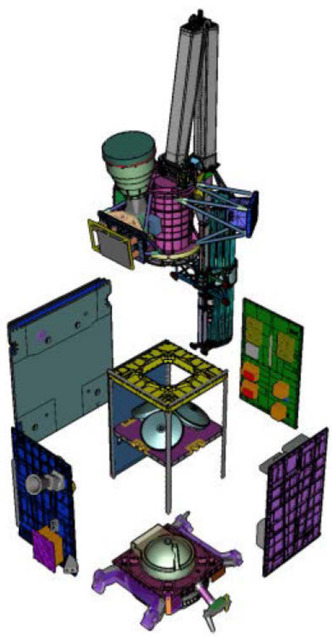
- L-band (1.26 GHz) Radar
- L-band (1.41 GHz) Radiometer
- Shared antenna (6 m diameter) rotating fixed rate 13 to 14.6 rpm

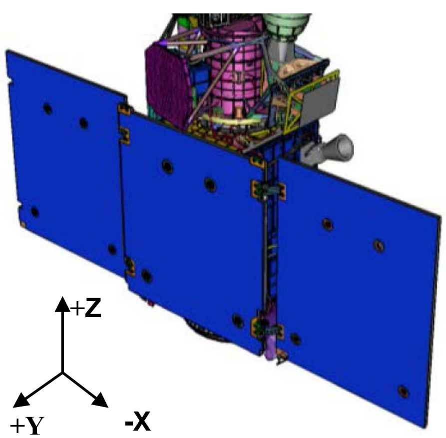
Mass

- Spacecraft: 527 kg (CBE)
- Instrument: 312 kg (CBE)
- JPL DP mass margin: 22%

Power

- 1023 W (science mode load), via 3-panel deployable solar array
- 59-Ah BOL battery for launch, eclipse, and other off-Sun modes
- JPL DP power margin: 22%
- Nominal bus voltage: 29.4 – 32.8 V
- Fault bus voltage: 24–29.4 V and 32.8–34 V





External Configuration

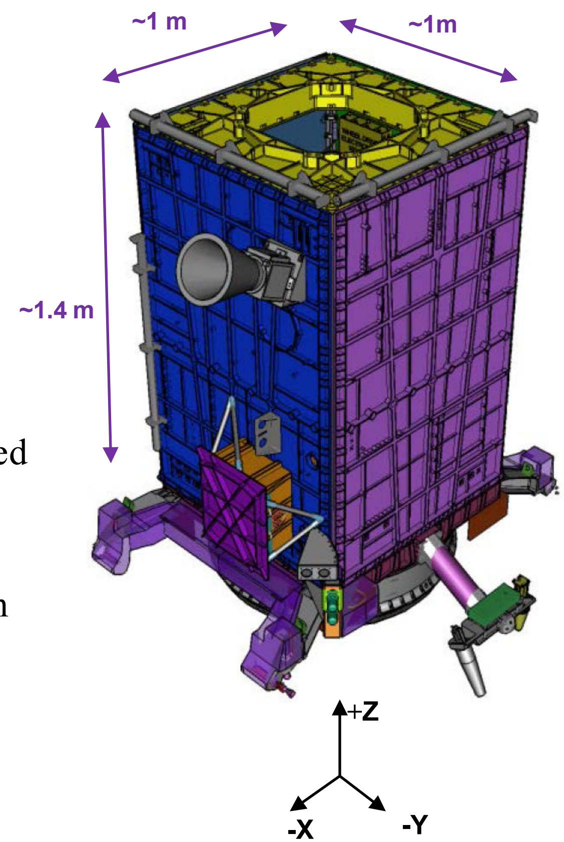
- Solar arrays are ~8.0 m^2
    - Single stage deployment
    - Cell type are triple junction, h = 28%
- 59 A-hr battery outside of –X panel
- Thruster clusters at corners of –Z deck
- Telecom antennas located on outrigger

Internal Configuration

- Highest power instrument radar H/W mounted on –Y panel (anti-sun side, thermally stable)
- Four reaction wheels on mid-deck
- Propulsion tank protrudes into LV separation plane by ~4 inches

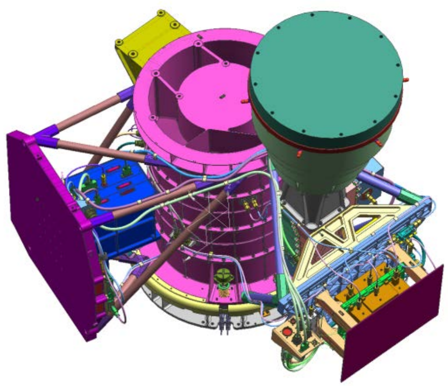
Spacecraft is 3-axis stabilized

- +X (direction SC is traveling)
- +Y (direction of sun)
- -Z (direction of earth, nadir)

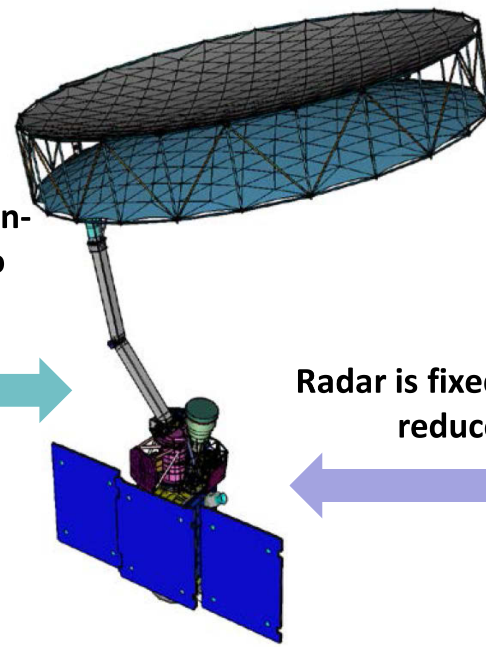


E Configuration (as of 2/19/2012)

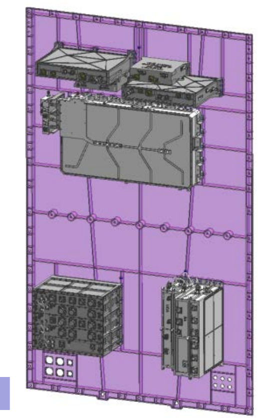
Instrument Overview



Radiometer is spun-side-mounted to reduce losses



Radar is fixed-mounted to reduce spun inertia



Radiometer

- Provided by GSFC
- Leverages off Aquarius radiometer design
- Includes RFI mitigation (spectral filtering)
- 1400–1427 MHz
- 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 and Reflector/Boom Assembly derived from heritage designs
  - RBA provided by NGAS-Astro
  - BAPTA provided by Boeing
- Spun structure & thermal from JPL
- Conically scanning at 13–14.6 rpm
- Constant incidence angle of 40-deg

Radar

- Provided by JPL
- Leverages off past JPL L-band science radar designs
- 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

Spacecraft Thermal Overview

Spacecraft Thermal Design

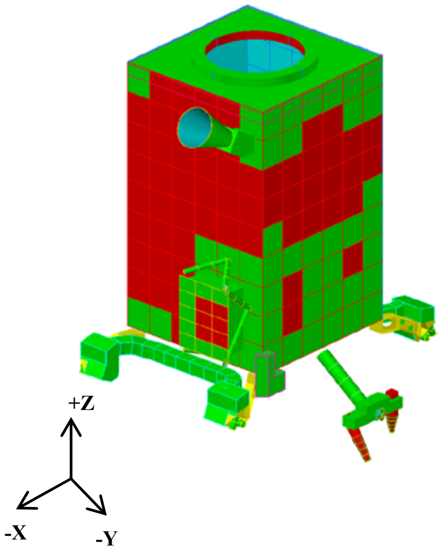
- Simple, inexpensive, low-risk thermal design
  - Mostly passive design features (MLI, radiators supply cold biasing)
  - Electronics conductively coupled to radiator panels
    - CDH / Power panel (-X) = 162 W (CBE)
    - Radar panel (-Y) = 220 W (CBE)
    - GNC / Telecom panel (+X) = 111 W (CBE)
  - MLI coverage optimized to reject electronic heat and conserve survival heater power
  - Some active design features (primary and redundant heater circuits)
    - Most Kapton film heaters controlled via mechanical thermostats
    - FSW controlled propellant line heaters
  - Battery temperature controlled via dedicated radiator/MLI/heaters
    - Externally mounted battery is thermally isolated from SC –X panel
  - Graphite heat spreaders on CDH (-X) panel under high powered H/W
    - K-Core (APG) thermal doubler from Thermacore

Observ. Design

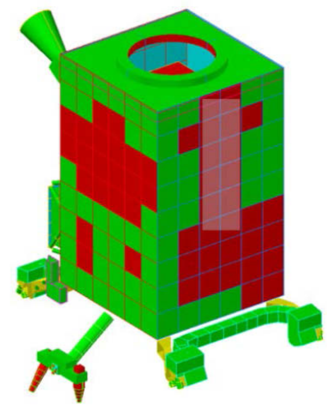
- Inst. SIA is mechanically coupled to S/C deck (by design, there is a poor thermal path from instrument to SC)
  - Integrated model assesses SC and instrument thermal performance

Mission Design

- Earth orbiter
  - 685 km altitude
  - 98° inclination (Beta angle = 58° to 89°, max eclipse = 19 min)

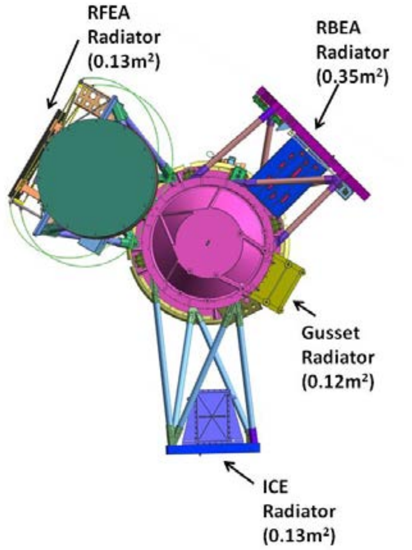


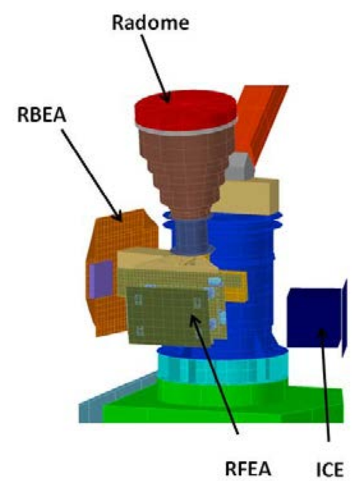
MLI/Radiator coverage
(Green = MLI)
(Red = radiator)



Spun Instrument Thermal Overview

- SMAP instrument thermal design is challenging and requires frequent interaction with the mechanical team to implement
  - Highly variable thermal environment results from fast spinning platform
  - Tight thermal stability is critical to success of radiometer
  - BAPTA bearing gradient is coupled to the SC top deck temperature
- 4 thermal enclosures are part of the spun platform; each has a dedicated radiator for proper thermal management
  - RFEA (Radiometer Front End Assembly) = 11.0 W (CBE+unc)
  - RBEA (Radiometer Back End Assembly) = 62.9 W (CBE+unc)
  - ICE = 35.7 W (CBE+unc)
  - BAPTA/RJA = 8.24W (CBE+unc)
- Silvered teflon used for radiators to meet temporal stabilities
- RFEA and OMT enclosed within an MLI cocoon for better short term stabilities
- Active control for RFEA to address gain glitches (control authority range of 15^{o}C)
- Feedhorn closed by EPS radome to eliminate sun illumination
- Single string survival heater architecture to minimize slip ring usage





* RFEA cocoon and RBEA MLI tent removed

Thermal Design Philosophy

- **Maintain a simple, reliable, inexpensive thermal design**
  - Primarily passive design (use radiator/MLI as thermal control surfaces)
  - Most active heaters use mechanical thermostat control for replacement heat
  - Flight software controls external propellant line heaters and RFE heaters
- **Each electronics box conductively coupled to structural panel (doubles as a radiator)**
  - Contact conductances results in 2-5°C gradients between elec boxes and panels
  - Instrument subassemblies each have their own dedicated radiators and replacement heaters
- Must maintain components within Allowable Flight Temperatures (AFTs) per ERD
  - Initial goal was to size radiators to give ~5°C hot-case margin to AFT
  - Thermostat-controlled heaters sized to keep 2°C (redundant heaters) to 5°C (primary heater) margin against cold Op/Non-op AFTs during cold/safe cases
- **MLI blanketing (15 layer) used to block off panel area** on outside of –X, +X, and -Y panels to provide required radiator area
  - MLI blanket properties: $\varepsilon^*_{hot} = 0.02$ and $\varepsilon^*_{cold} = 0.05$
- Optical properties
  - **End-of-life (EOL) for hot cases, Beginning-of-life (BOL) for cold cases**

Power/Mass Inputs to Thermal Model

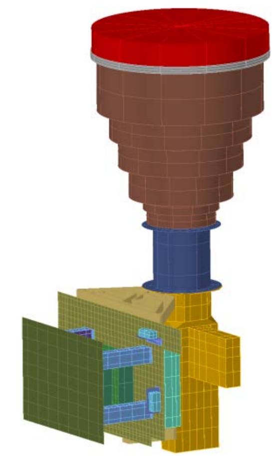
- Component power dissipations
  - Hot Science: "Science and Telecom" CBE + Contingency from PEL (10-30% contingency for most components)
  - Cold/Safe Mode: 90% of "Science" or "Safe" CBE
    - For Safe Mode - spacecraft is nadir pointed, similar to science orbit
      - Fixed attitude is conservative compared with safe mode rotisserie roll
- Component Mass
  - Use CBE from MEL (less mass is conservative for any stability calculations)

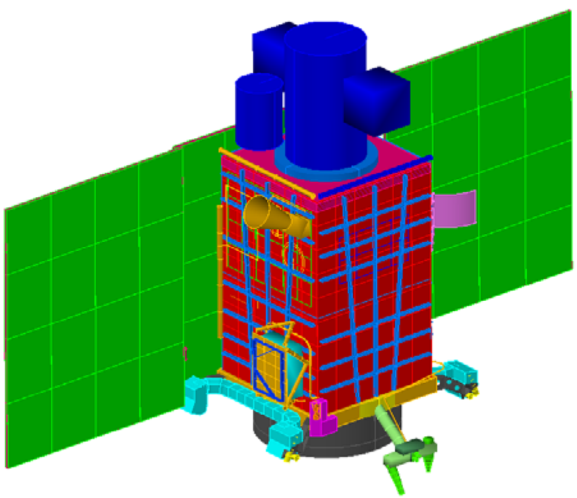
Summary of Thermal Control Hardware

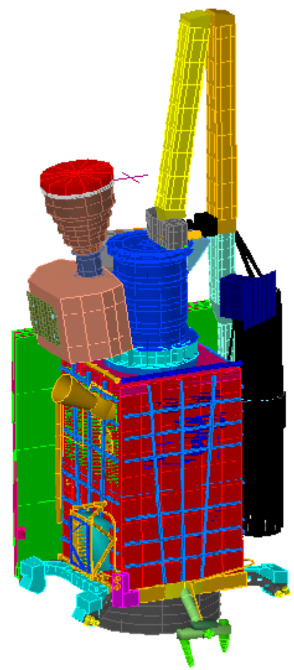
- Kapton film heaters (Tayco)
  - SC uses primary and back-up circuits, with 2 thermostats per heater
    - Flight software controlled heaters on the external propellant line
  - Instrument uses single string survival heaters, with 4 thermostats per heater except RBA heaters
    - SIA operational heaters are powered by ICE
- Thermostats (Honeywell)
  - Thermostats primary turn-on temperature is 3-5C above AFT (with 7C dead-band)
- Thermal sensors (Honeywell/Goodrich PRT or Boeing Thermistor)
  - Use 500, 1000, or 2000 ohm PRT or Boeing thermistor for health & status and active heater control
- APG Doubler/Bracket (K-Core)
  - High conductivity APG used to transfer heat along SC panel
  - Instrument is using it as a highly conductive structural member to support RFEA radiator
- Passive thermal control elements
  - Thermal paints, coating, and isolators use typical JPL parts/processes
  - MLI provides passive isolation from external environment. Typical JPL blankets will be used throughout SMAP

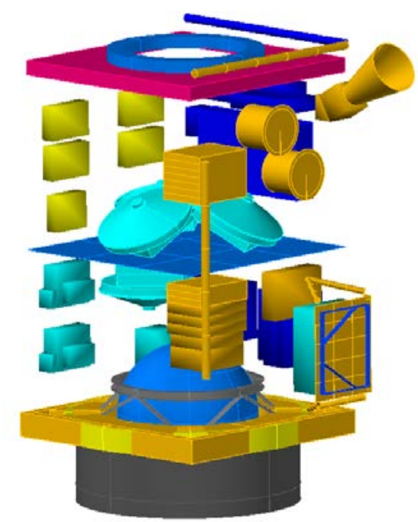
Thermal Desktop Model Description

- AutoCad Mechanical 2012 – Create geometry
- Thermal Desktop 5.4 – Calculate radiation exchange factors, describe orbits and calculate heat rates
  - Absorbed flux vs time arrays used for transients (orbital average for any steady state runs)
- Sinda Fluint 5.4 – Calculate temperatures/heat flows



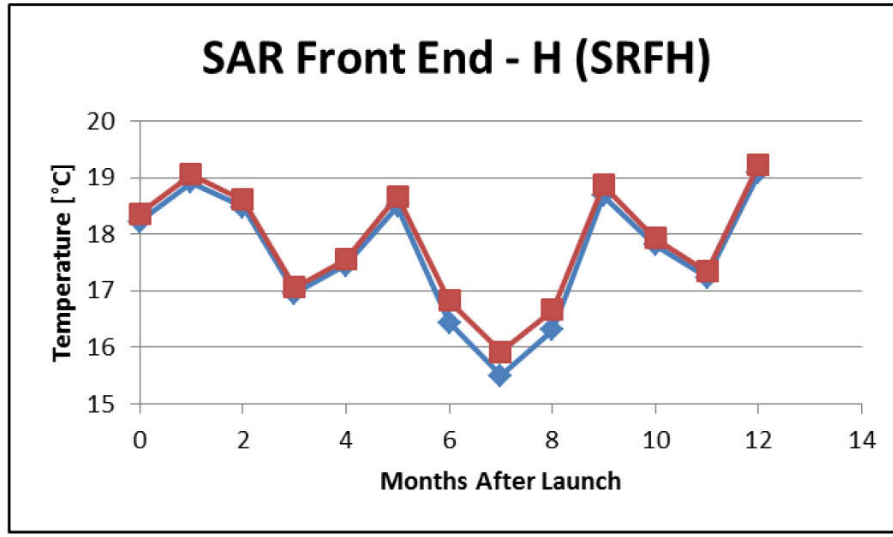


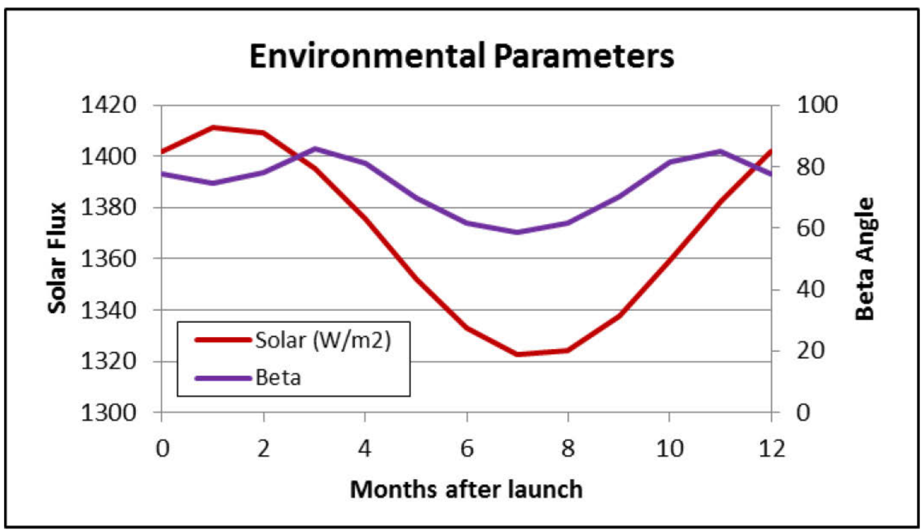


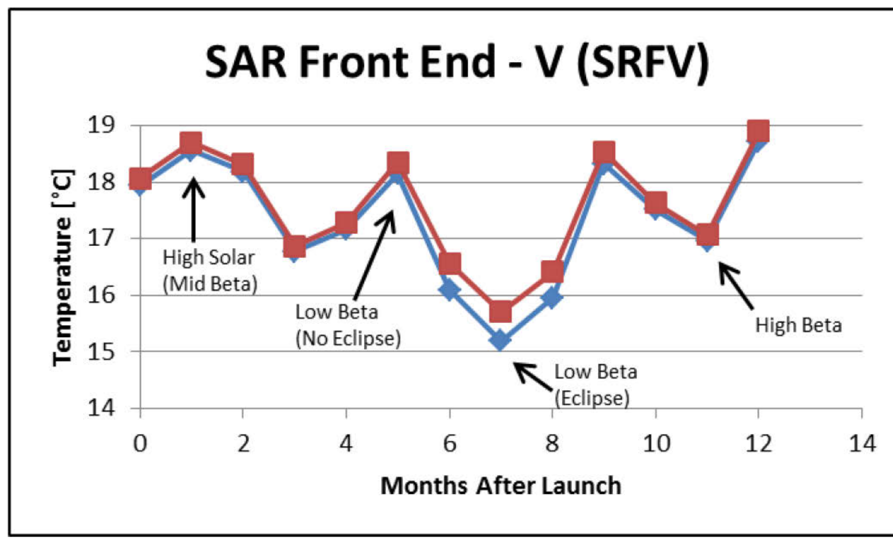


Radar Seasonal Temperature Variations

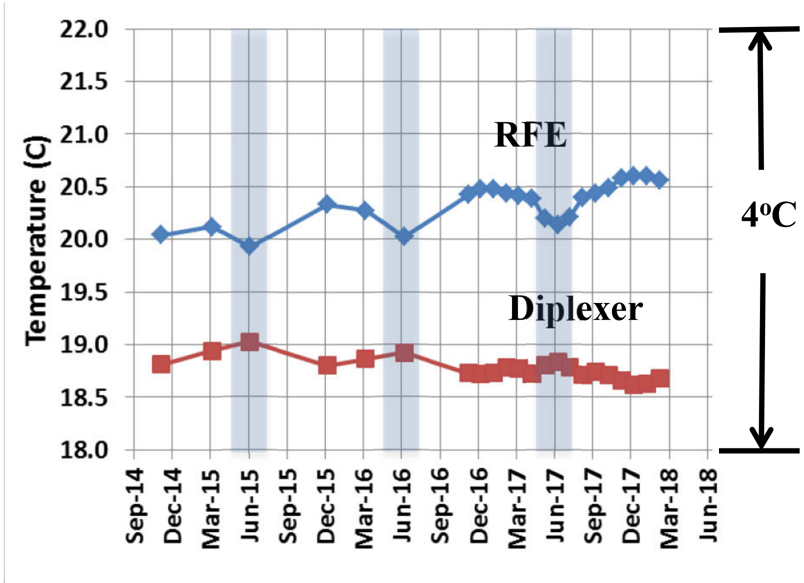
- Temperature trends follow the expected environmental loads (solar / beta inputs and optical property degradation)
- Low beta/long eclipse period results in largest orbital variation
  - Radar panel is most thermally stable (constantly viewing cold space)
- Yearly variations are small compared to 10°C requirement
- Orbital variations are small (1°C) compared to 4°C requirement

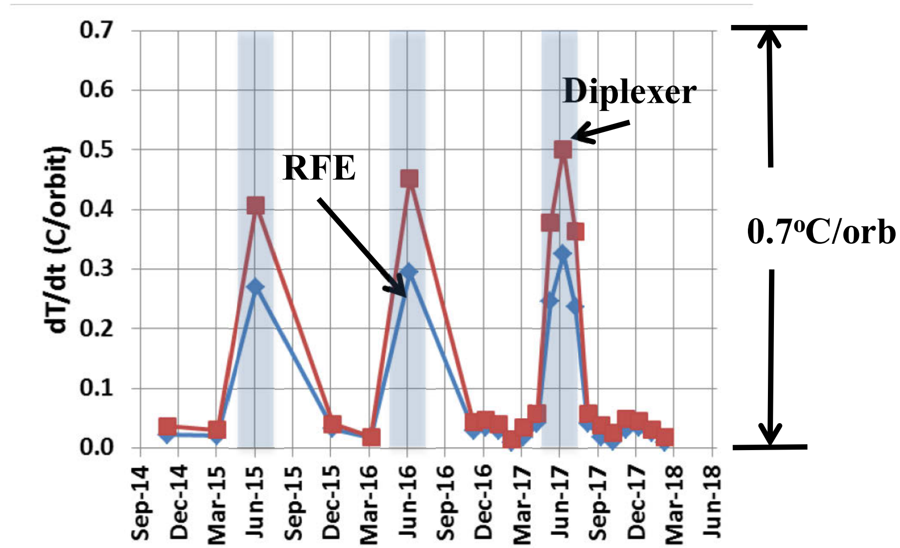


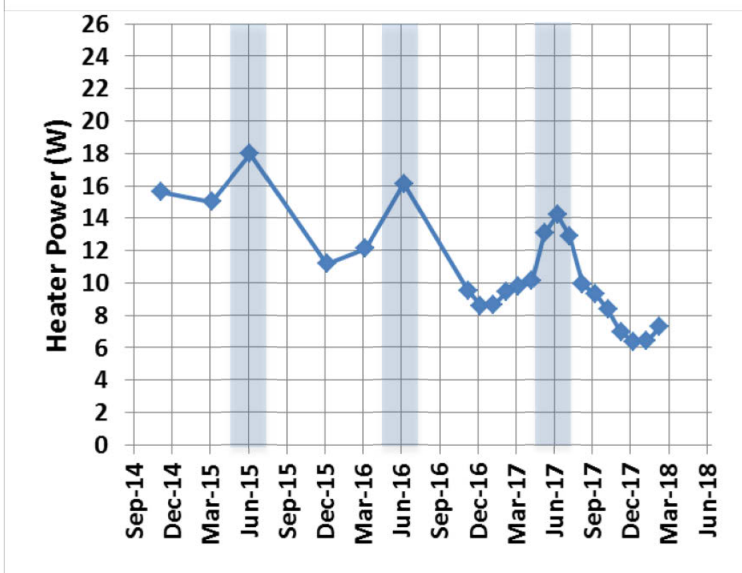




Radiometer 3 Year Mission Life







- Modified P control is good enough to meet all stability requirements
  - The design meets stability requirements with passive thermal design
  - ATC used solely to correct for gain glitch temperature set point (has been seen on previous radiometers)

Conclusions

- Primarily passive thermal control (MLI/thermal control surfaces) provide simple/robust solution
  - Some active components (FSW and mechanical thermostatically controlled heaters) used for survival and operational heaters
- Current work demonstrates that the current thermal design is acceptable and will meet all thermal requirements
- Thermal stability requirements for radar and radiometer are met