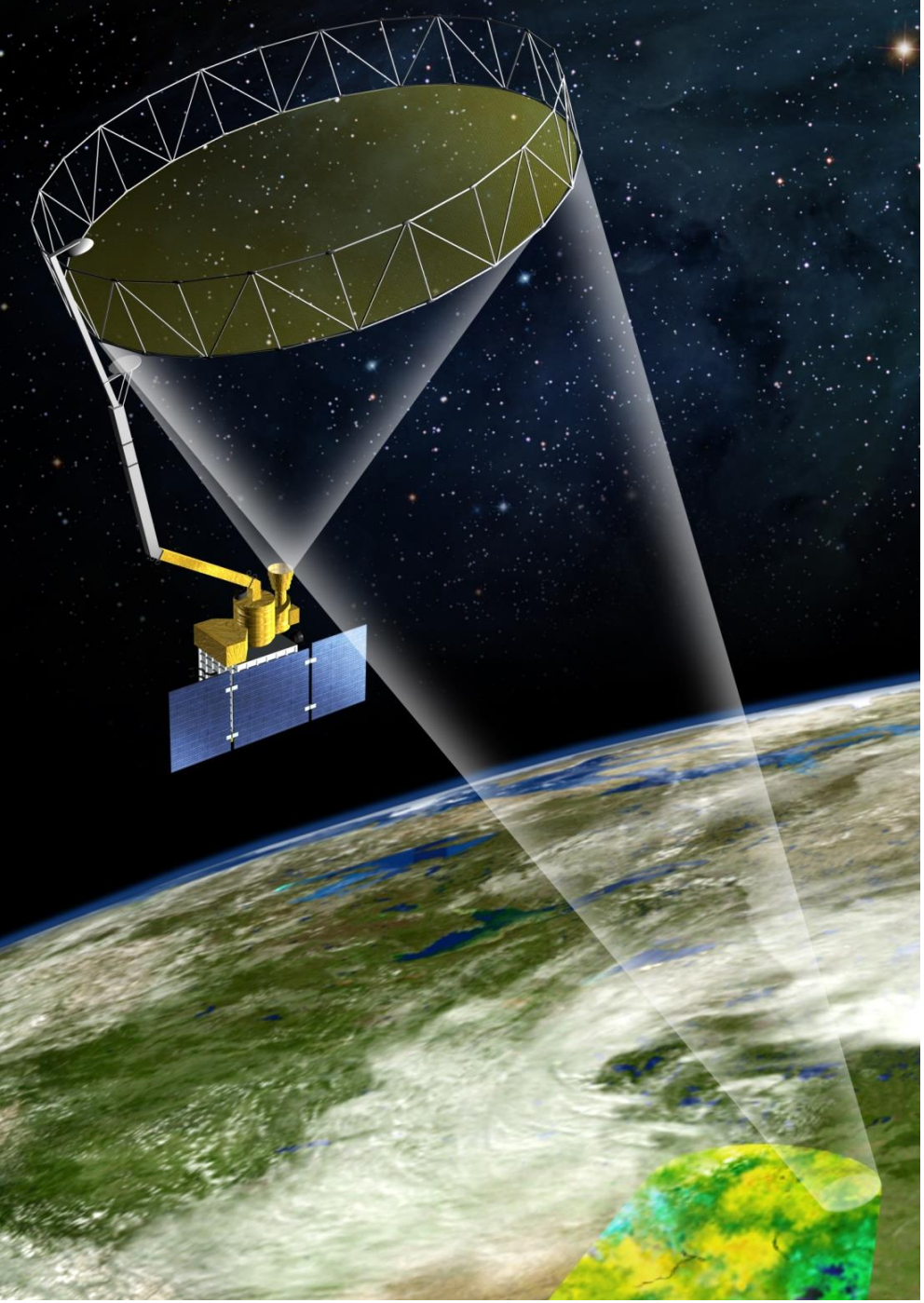

Lights Out Operations

SMAP Mission Operations and Ground Data Systems

Mission Systems and Operations Division Autonomous Operations Seminar Series
April 19, 2017

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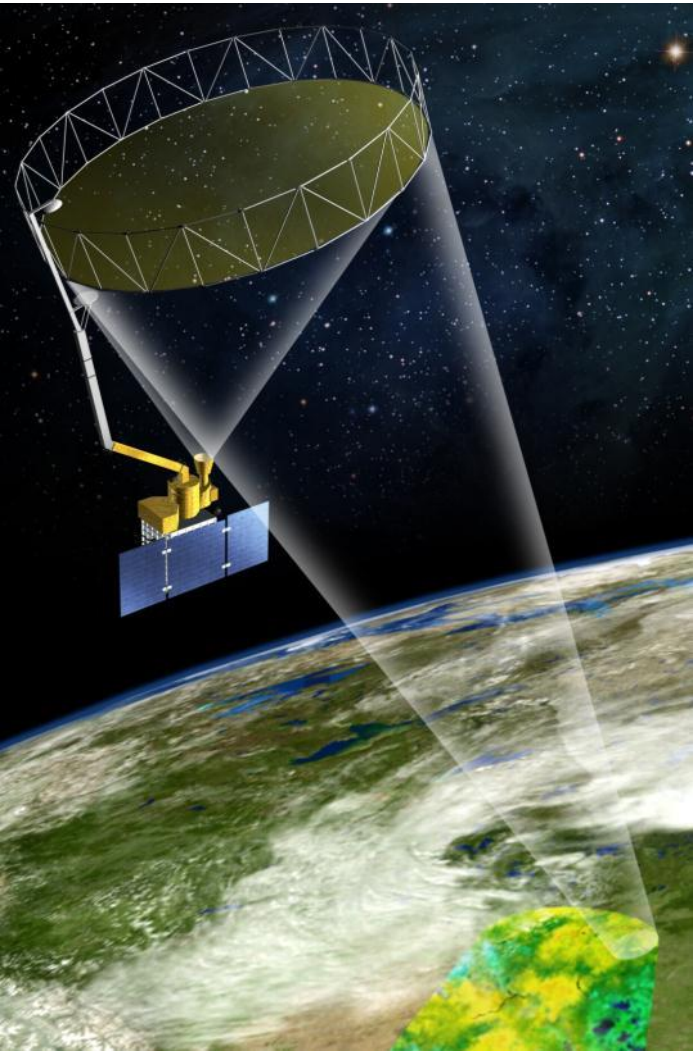
http://smap.jpl.nasa.gov

Project Overview



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

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 management, science, spacecraft, radar, mission operations, science processing) • GSFC (science, radiometer, science processing)
Risk	• 7120.5E Category 2; 8705.4 Payload Risk Class C
Launch	• January 29, 2015 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)* *July 6, 2016 the radar experienced an unrecoverable anomaly • L-band radiometer (GSFC) • Shared 6-m rotating (13 to 14.6 rpm) antenna (JPL)

NRC Earth Science Decadal Survey (2007) recommended SMAP as a Tier 1 mission

The Challenge!

Commissioning Phase

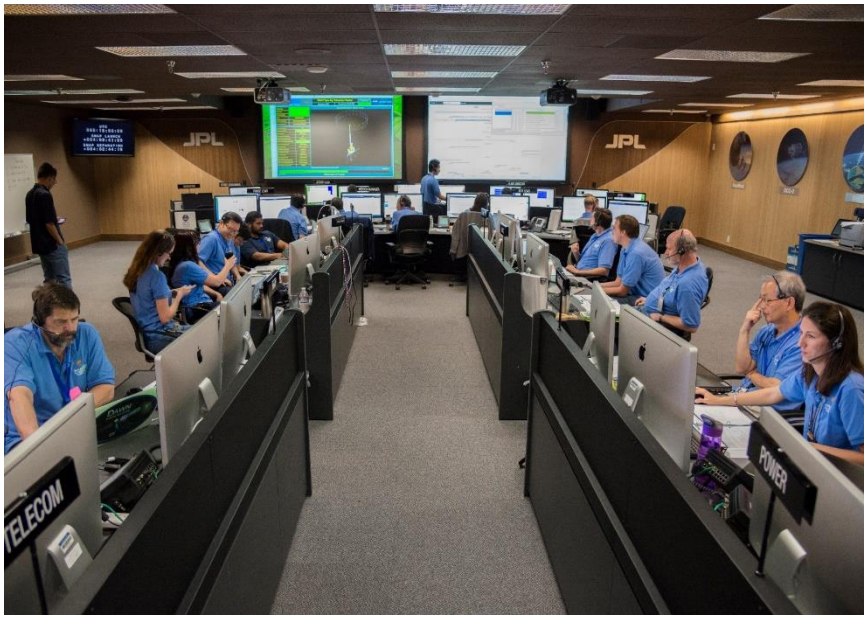
Extended Hours on Console

(Initially 24/7, then 7 day/week)

Systems/Flight/ACE/Scheduling staffing: ~10 FTE

Subsystems: ~3-4 FTE (each)

GDS: ~6 FTE



Science Phase

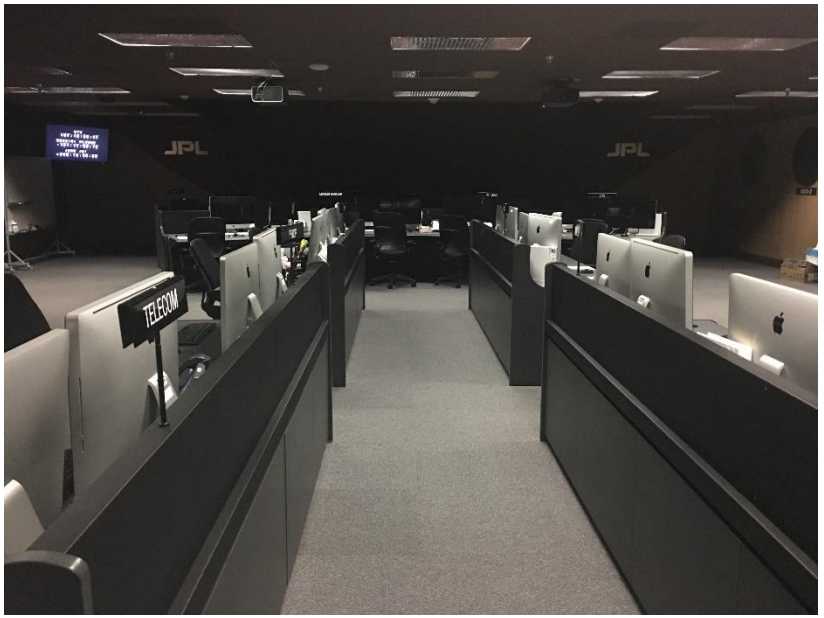
9/80 schedule

(on console ~once per month)

Systems/Flight/ACE/Scheduling staffing: ~2 FTE

Subsystems: ~0.2-0.5 FTE (each)

GDS: ~1 FTE



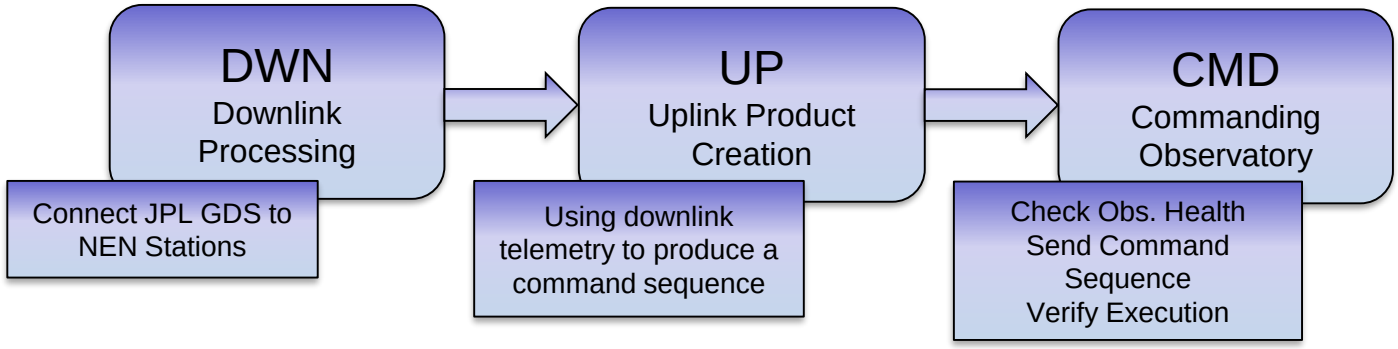
Once the deployments and initial shakedown was complete – could the observatory be operated by such a small team?

More Details

- SMAP is a JPL built spacecraft which has heritage to MSL
- SMAP uses AMPCS for the ground data system
- SMAP uses the Near Earth Network (up to 8 different antennas)
  - On average SMAP has ~20 contacts per day (~8-10 minutes)
  - S-Band downlink 512kbps, Uplink 64 kbps
- Types of routine activities:
  - Connecting to ground stations and processing downlink
  - Routing downlink data to analysis software
  - Generation of spacecraft trajectories from Doppler navigation data
  - Generation of SCLK-SCET correlation from Spacecraft time packets
  - Monitoring telemetry and alerting operations team off nominal events
  - Performing data accountability

Routine Commanding	Frequency	Notes
Command loss timer	Daily	
Data accountability (deletion/retransmit)	Every 6H	Originally planned to be weekly but missing products impact science latency.
NVM management (bad blocks)	On Demand	
Updating on board ephemeris	Daily	Originally planned to be 2/week
Scheduling maintenance activities	Weekly	
Updating instrument commanding	Daily	Originally planned to be 2/week
Bulk upload of files	On Demand	
Communications scheduling	Weekly	Manually built uplinked via automation

Where is all the Autonomy?



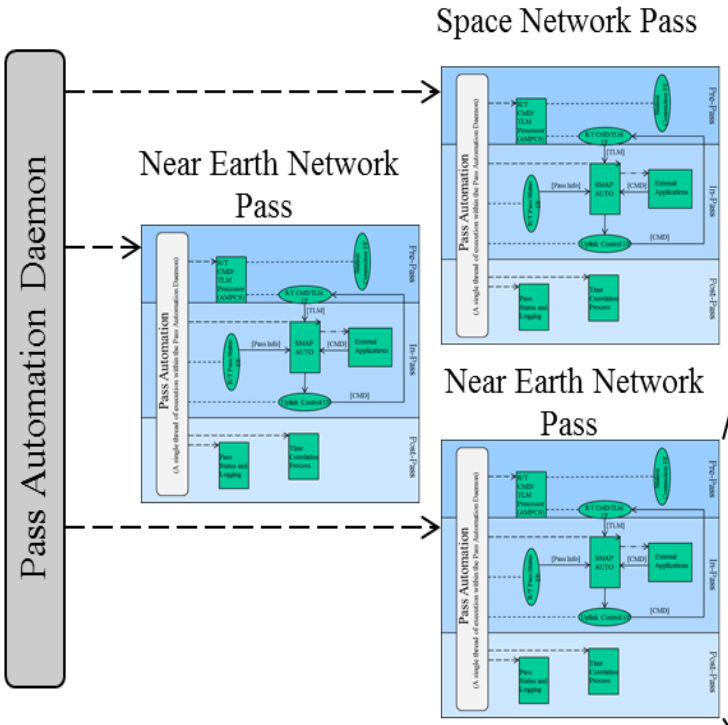
- Ground based software that automates various flight operations and ground data system tasks.
- Automation is not a monolithic system
  - Implemented by many different developers and organizations
  - Individual pieces can be phased in
  - But some automation depends on others (typically driven by level)

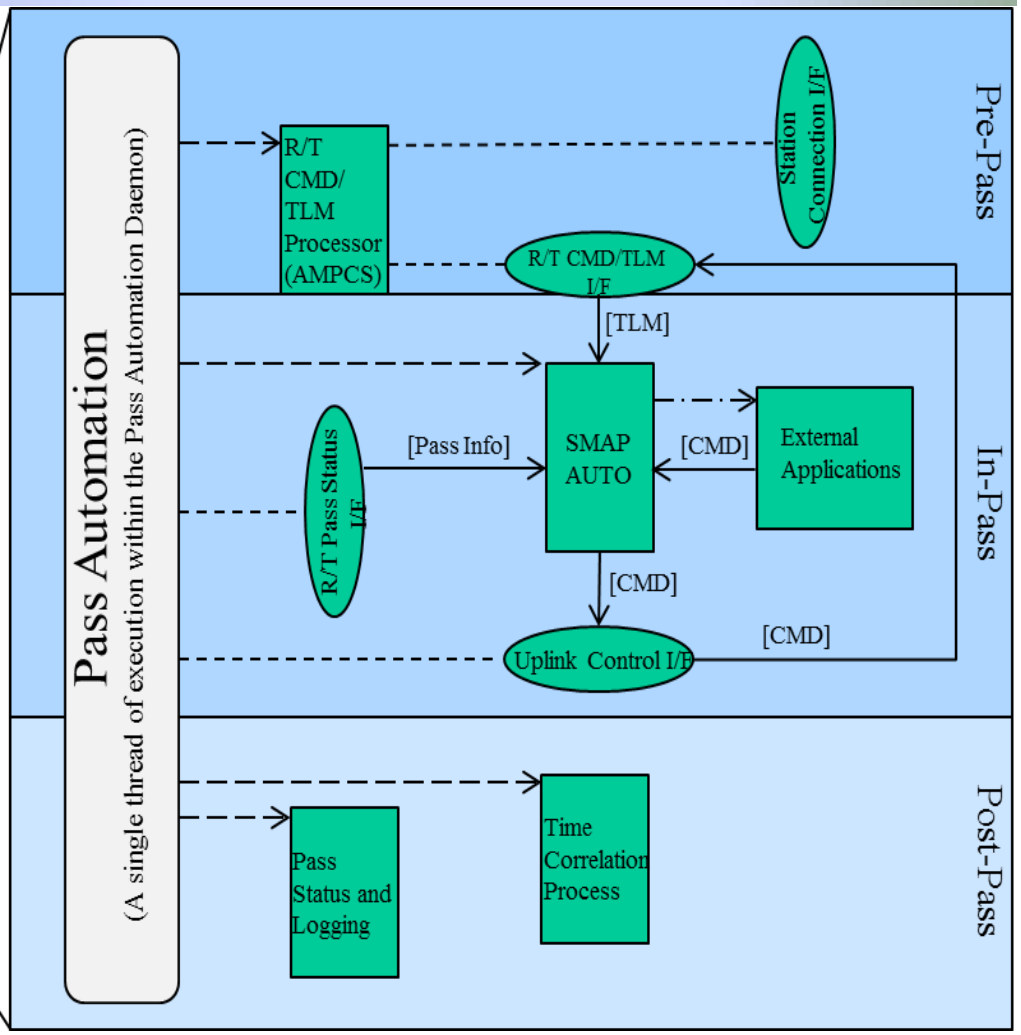
- Core Pieces of SMAP Automation
  - PAD: Pass Automation Daemon
  - FNS: File Notification Service
  - TARDIS: Traceable Automation Remote Display Interruptible Scheduler
    - Produces ephemeris from Doppler navigation data
  - ANF: Alarm Notification Filter
  - TQR: Telemetry Query and Reporting
  - ATCS: Automated Time Correlation Service
  - DMT: Data Management Tool
  - SMAP AUTO: Closed loop commanding of spacecraft

GDS Automation Design / Development Philosophy

- Inheritance
  - Leveraged GDS automation approaches from Jason-1 and WISE
- Use of Multi-mission Services
  - Leveraged existing multi-mission command and telemetry capabilities
- Proper Division of Labor
  - Between multi-mission and project developed software
  - Between GDS and Flight Operations Team
  - Layered automation approach with levels of abstraction
- Reliability
  - Component based instead of monolithic system
  - Simple standalone scripts with minimal dependencies
  - Extensive external system monitoring with auto restart capabilities
- Reusability
  - No SMAP specific code in core pass automation and workflow automation software
- Extensibility/Flexibility
  - Pass automation software is able to ingest and execute custom code during a pass
  - Pass automation supports configurable post pass activities
  - Workflow automation software supports dynamic procedure creation and modification

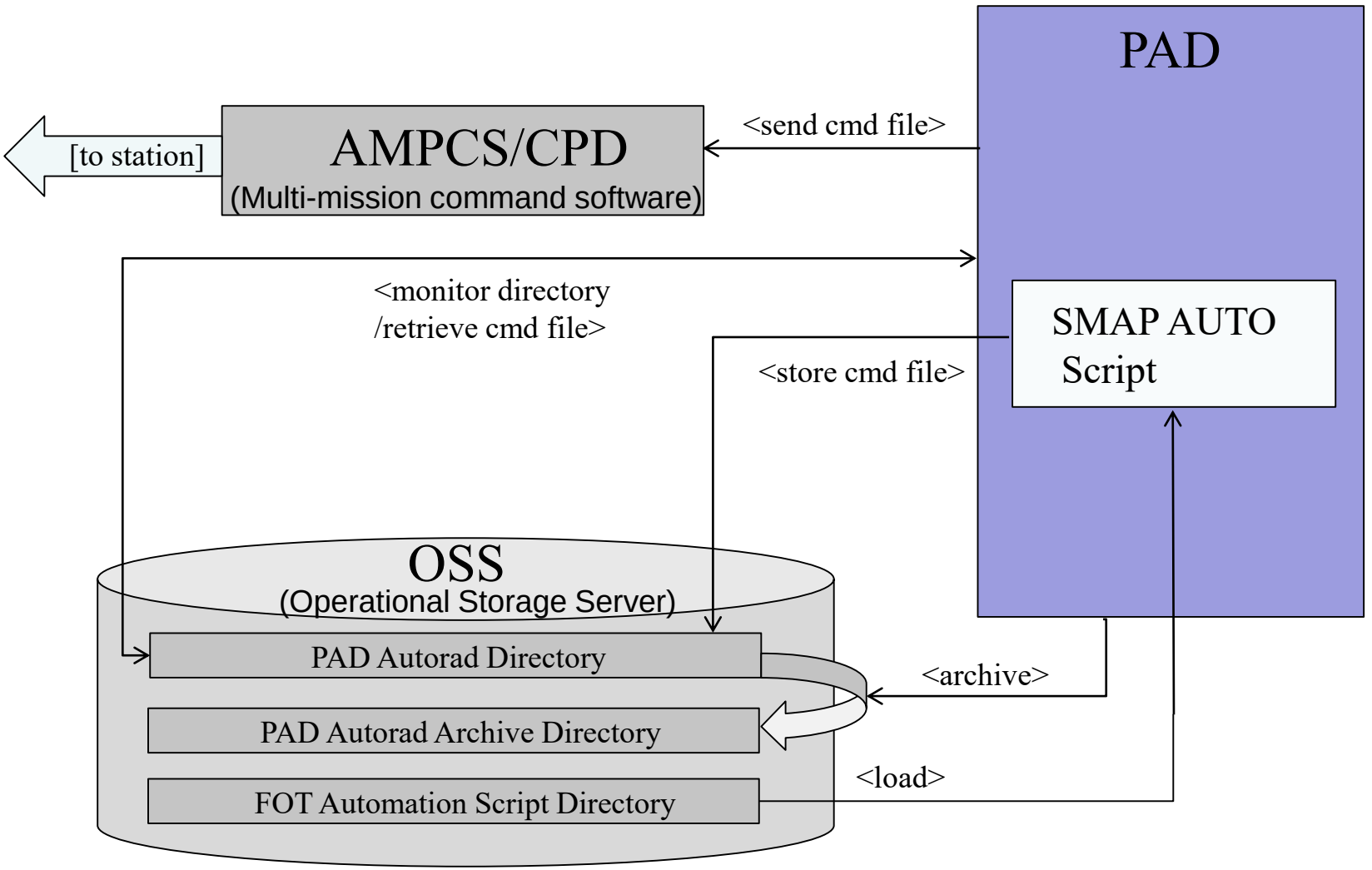
Pass Automation Daemon (PAD)



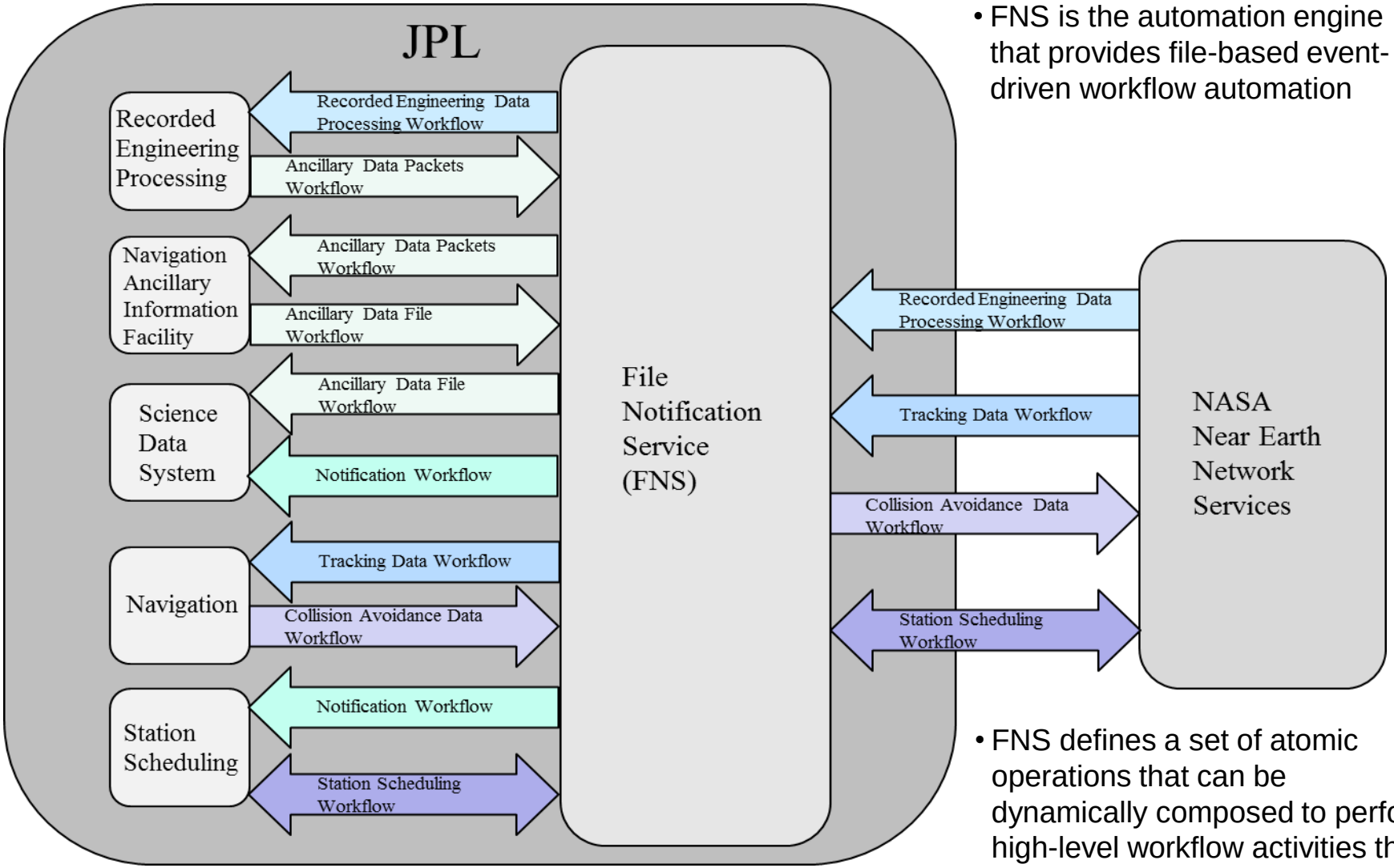


- PAD is the automation engine that drives the ground based pass automation used by SMAP
- PAD performs multiple, simultaneous, overlapping tracking passes
- PAD performs pass automation through the integration and orchestration of the capabilities of existing NASA multi-mission and project developed ground system components

Auto Commanding Via PAD – A Drop In The Bucket



File Notification Service (FNS)



- FNS is the automation engine that provides file-based event-driven workflow automation
- FNS defines a set of atomic operations that can be dynamically composed to perform high-level workflow activities that satisfy project operational tasks

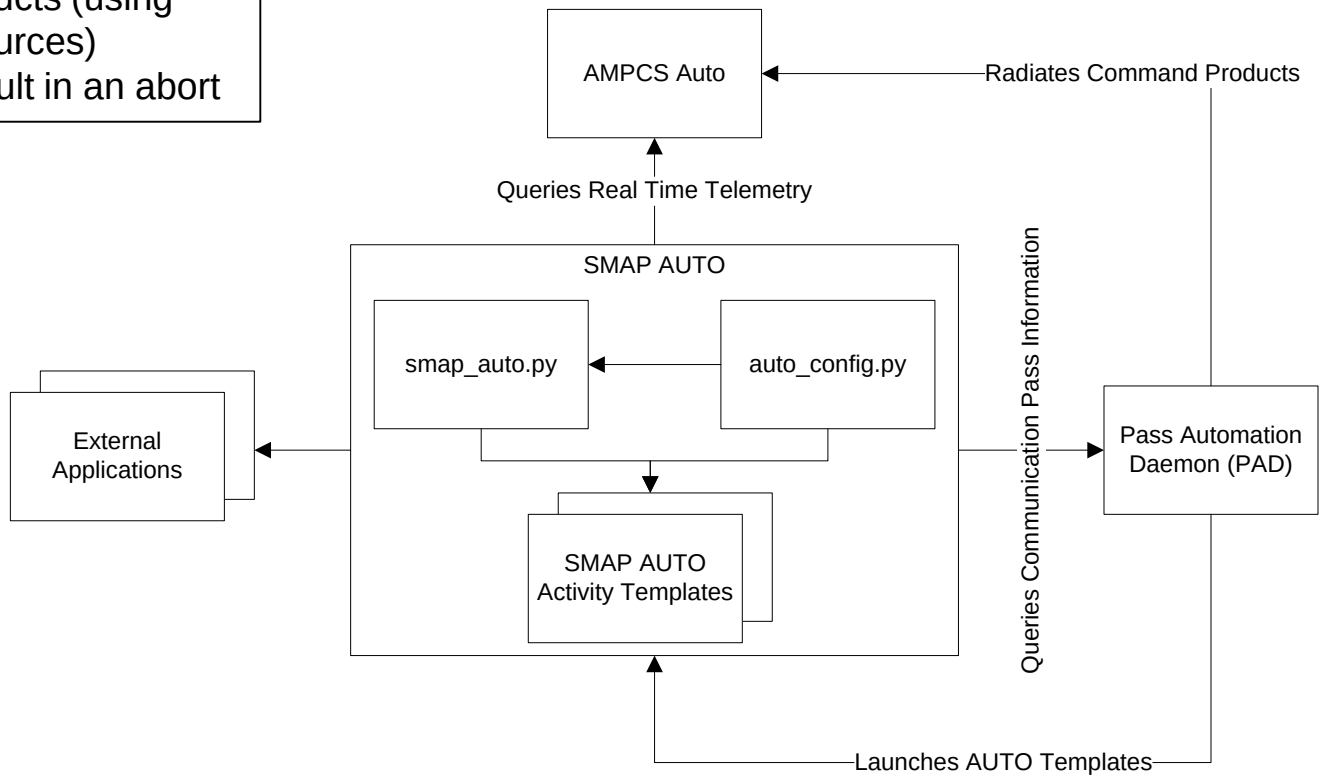
SMAP AUTO in Detail

Keep It Simple SMAP

Actions (and uplinks) performed serially
SMAP AUTO activities self contained to a single communication pass
Verifies vehicle health before any radiation
Verifies receipt of all products (using multiple telemetry sources)
All off nominal scenarios result in an abort

- SMAP AUTO is divided into a function library, a configuration file, and a selection of activity templates which implement a defined set of commanding.
- If SMAP AUTO encounters an off nominal scenario (at any point) it aborts and notifies the mission operations team (email/SMS).
- Each SMAP AUTO template is designed to be self contained within a typical SMAP communication pass (~8 minutes)

- AUTO is a interface provided by the JPL AMMOS Mission Data Processing and Control System (AMPCS) to query real time telemetry and radiate command products
- SMAP AUTO is a project specific library and scripts that utilize that interface to perform closed loop commanding of the SMAP spacecraft.



SMAP Automation Architecture

TARDIS generates ephemeris products from OD data

Data Driven

Comm. Driven

FNS (File Notification System)

PAD (Pass Automation Daemon)

FNS and PAD orchestrate the automation based on data flow and schedule.

TARDIS

LutSync

Activity Master Builder

Cheby Tools

DMT

AMPCS

ANF/TQR

SMAP AUTO

LutSync updates instrument commanding based on ephemeris

Cheby Tools generate on board ephemeris files from ground ephemeris

Activity Master schedules preplanned and routine activities

Alerts the Team in Off Nominal Scenarios

ANF/TQR report alarms on Real Time and Recorded Telemetry and notifies via Email/SMS

Performs routine commanding of the Vehicle

PAD Launches SMAP AUTO

DWN

UP

CMD

AMPCS processes telemetry and data products (both real time and recorded)

DMT correlates products received vs. on board and produces a command list for retransmission/deletes

SMAP AUTO confirms observatory health, builds uplink products using associated tools, sends and confirms receipt of commands.

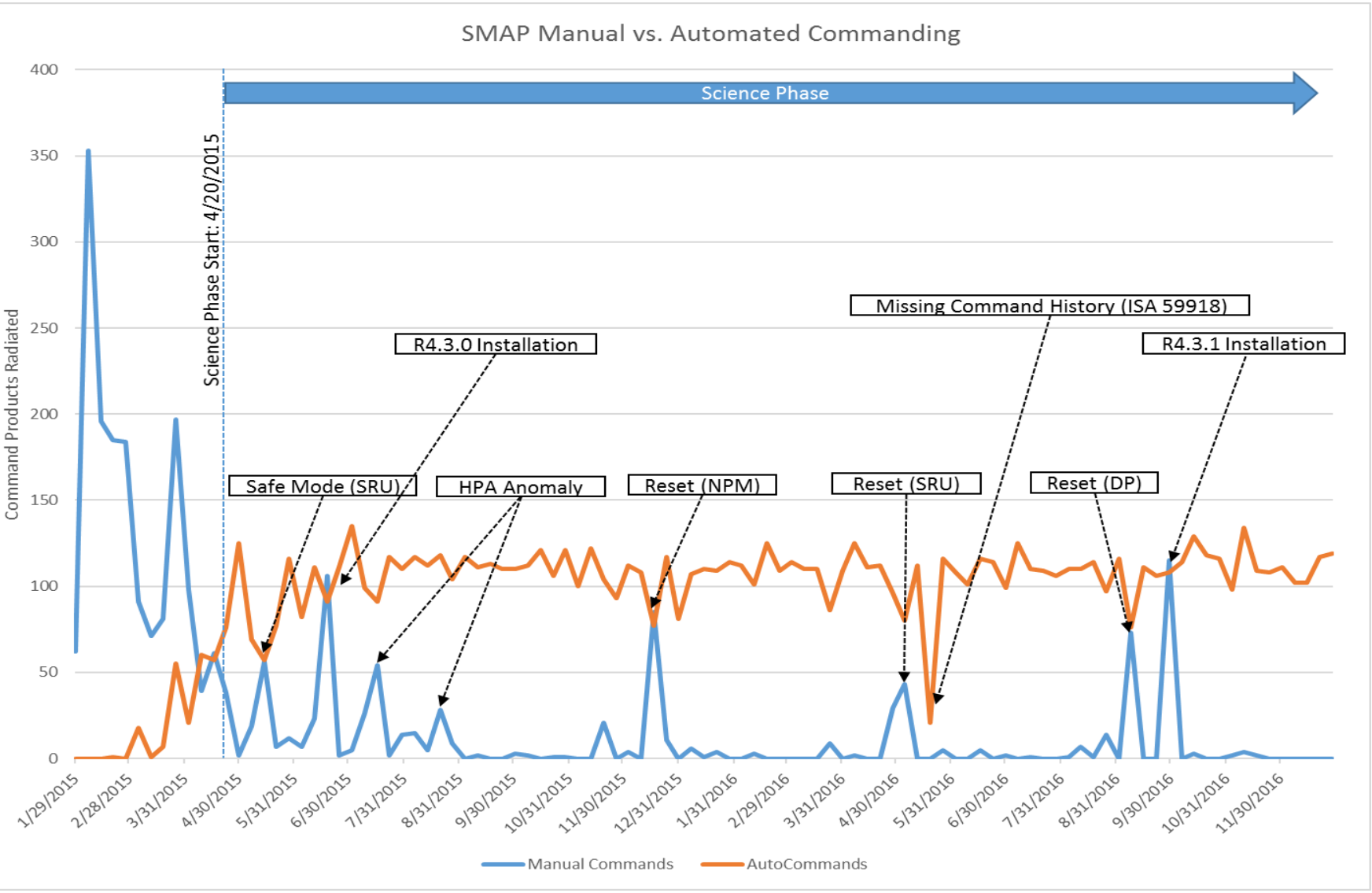
The Road to Flight

- PAD/FNS and SMAP AUTO followed a similar path to flight.
- Both started, at some level, as heritage from other projects.
  - PAD/FNS came from Jason-1/WISE automation work
  - SMAP AUTO came from experience with MTAK in the MSL/SMAP testbeds
- Both were architected with testing in mind.
- Both were tested on the highest fidelity testbed available
  - PAD/FNS – SMAP Operations Testbed
  - SMAP AUTO – SMAP Integrated Test Lab (ITL)
- Both were introduced with a gradual level of oversight in flight
  - PAD/FNS were live at launch but had close monitoring during commissioning
  - SMAP AUTO was introduced during the commission phase.
    - Initially SMAP AUTO executed, built uplink products, and human operators reviewed and uplinked them.
    - Once confidence was established that it was working as intended the automation was allowed to run closed loop.

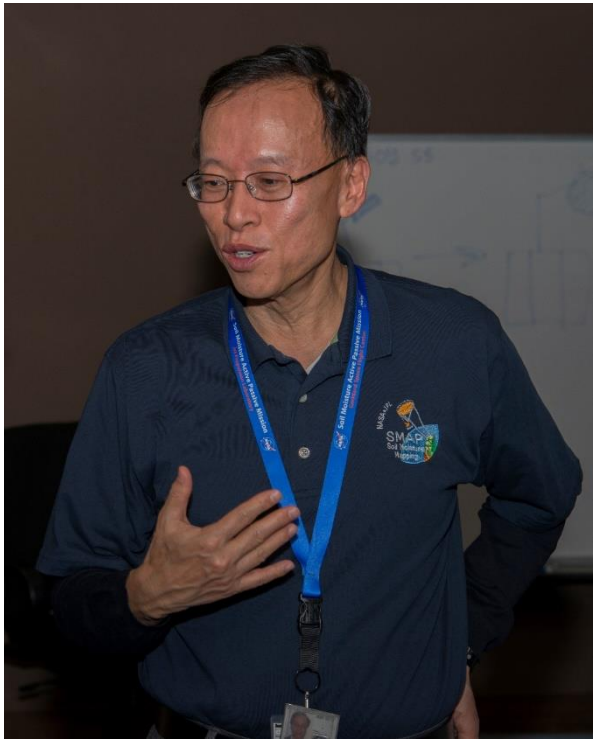
By The Numbers

- PAD
  - Successful Automated Passes (1/31/2015 – 4/16/2017): 13,236
  - Missed/Failed Tracking Passes: 90
    - Includes ground station outages, does not include SMAP AUTO anomalies
  - Success Percentage: 99.3% (PAD tracking pass orchestration: ~99.8%)
  - Provides an estimated workforce savings of 3-4 FTE
- FNS
  - Successfully Performed Workflow Activities (1/31/2015 – 4/16/2017): 536,790+
  - Failed Workflow Activities: 482
  - Success Percentage: 99.9%
  - Provides an estimated workforce savings of 3-6 FTE
- SMAP AUTO
  - Between Transition to Science Phase (4/20/2015) to now (1/3/2017)
    - 10347 Command products were produced and sent to the spacecraft
    - 892 Manual (8.6%) , 9455 Automated (91.4%)
  - Decreases data latency, improves on-orbit pointing accuracy
  - Robust to off-nominal scenarios
    - Encountered multiple in-flight anomalies, aborted, notified mission operations team.
  - Provides an estimated workforce savings of 8-10 FTE

SMAP AUTO Performance



Lessons Learned / Challenges



A big part of the success of the automation was management (Ben Jai / Brian Hammer) believing it could be done and then empowering the people to go do it.

- Interface with the NEN/SN was a challenge
  - Differences in protocols and configurations stations and services.
- Once something is automated it can scale
- When negotiating interfaces with other, larger systems ask for the basics and build on that.
  - Larger systems are less agile
- Profiling and monitoring a distributed system is something that can be tricky and could have been done better.
  - SMAP did well on system level monitoring (after some tuning) but could have done better on application and performance monitoring.
- If possible, utilize developers with operational and test experience.
- Gradual “phase in” of automation was both necessary and valuable.
- Adding automation access to existing multi-mission software
  - E.g. not feasible to enable automated access to all AMPCS features.

This Sounds Awesome – Where do I sign up?

- The first step is to start trusting your tools… and testing them accordingly
- PAD/FNS are both Multi-mission
- AUTO is a Multi-Mission capability of AMPCS
  - Sends SCMFs, Query Real Time EH&A and EVRs
- SMAP AUTO is project specific
  - Essentially the SMAP AUTO functionality mimics the actions of the operations team and the flight controller. While other operators perform similar types of commanding, the specifics vary and could impact the implementation of AUTO significantly.
  - For example:
    - SMAP always uplinks products and verifies receipt serially because of short passes, negligible light time, and high telemetry rates.
    - A mission (Mars) with more significant light time but longer pass durations could uplink all files and then verify their receipt after they are all on board.