Multi-Mission Scheduling Operations at UC Berkeley

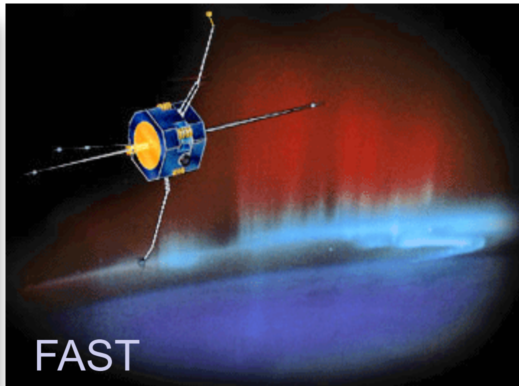
Manfred Bester, Gregory Picard, Bryce Roberts,
Mark Lewis, and Sabine Frey

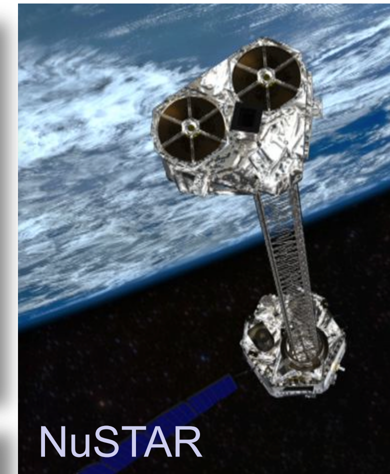
Space Sciences Laboratory
University of California, Berkeley

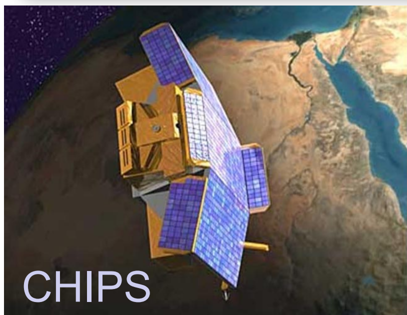
Outline

- Introduction
- Mission Planning
- Pass Scheduling
- Schedule Execution
- Lessons Learned
- Summary

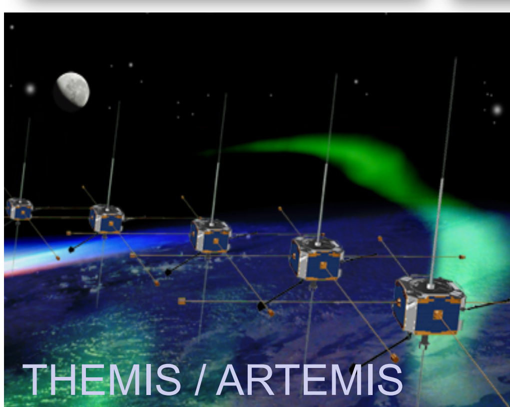
Multi-mission Operations History at SSL







UCB/SSL operated 10 NASA Explorer spacecraft over a period of more than 20 years.



Mission science topics:
FUV and hard X-ray astronomy, heliophysics, space physics

Multi-mission Challenges

Challenges with planning and scheduling

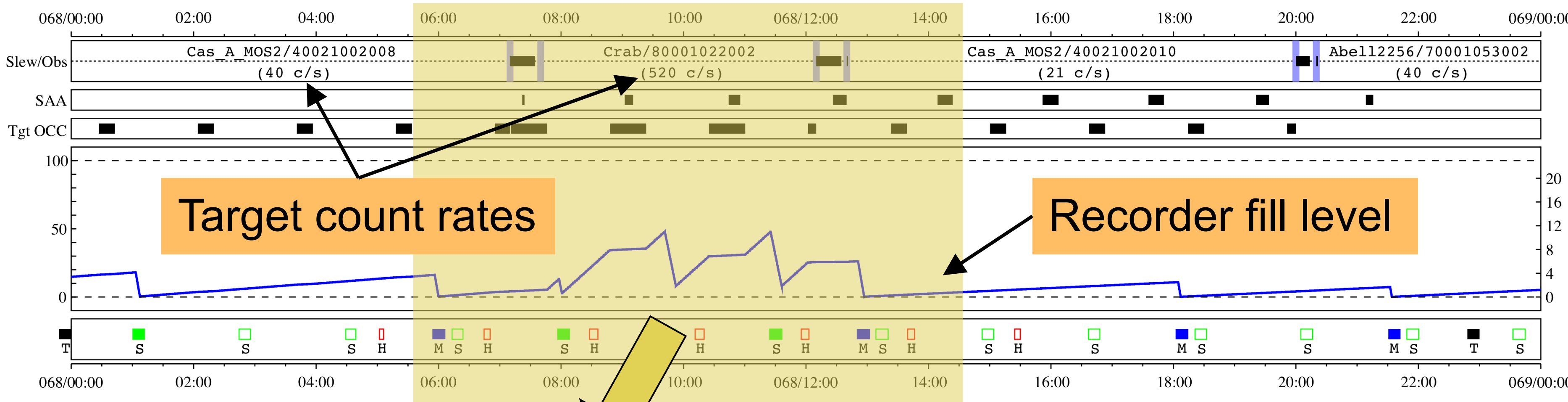
- Requirements are very different between missions
  - Mission objectives
  - Downloaded science data volumes
  - Number of passes per day or per orbit
  - Radiometric tracking for orbit determination
  - Real-time communications
- Constraints are very different between missions
  - Available ground stations
  - Available view and link access periods
  - Scheduling flexibility
  - Resource contention
  - Spacecraft constraints (power, thermal, attitude, …)
  - Staffing and work hours

Scheduling Across Multiple Networks

Network	Network Assets	Mission Support
NASA NEN	WLP 11M, LEOT; WHS 18M1; AGO 9M, 13M	RHESSI, THEMIS, ARTEMIS
NASA SN	WSGT, STGT, GRGT; TDRS 5, 6, 7, 9, 10	THEMIS, NuSTAR
NASA DSN	DSS-14, 15, 24, 27, 34, 43, 45, 54, 63, 65	ARTEMIS
DLR	WHM 9M, 15M1, 15M2	RHESSI
ASI	MLD 10M1, 10M2	NuSTAR
USN	USNHI 13M1, 13M2; USNAU 13M1	THEMIS, ARTEMIS, NuSTAR
KSAT	SNG 9M1	NuSTAR
UCB	BGS 11M	RHESSI, CINEMA, THEMIS, ARTEMIS

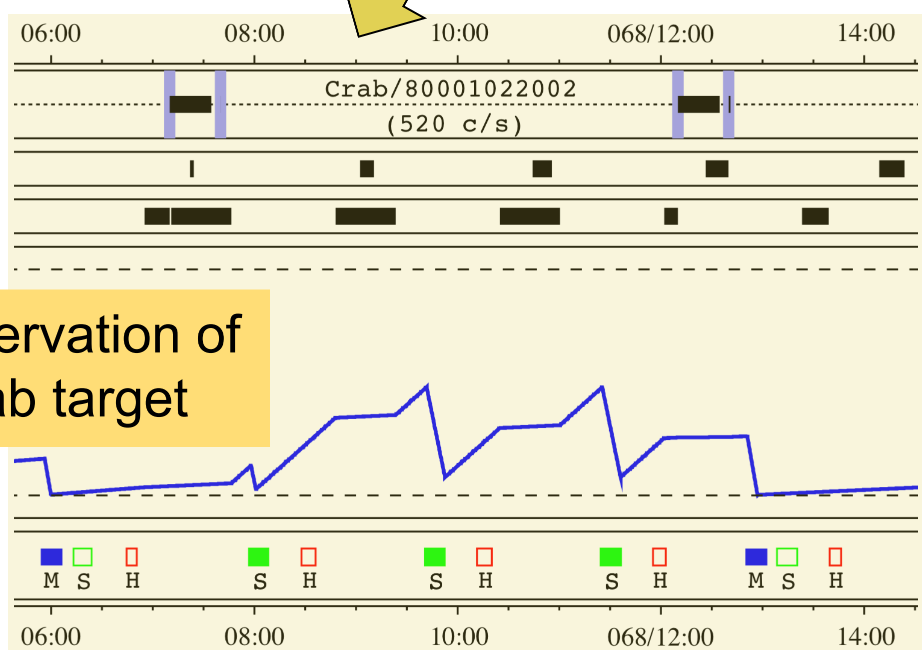
Listed ground station and space network assets are currently in operational use at UCB. Other stations such as Fairbanks, Poker Flat, and McMurdo Base were previously used for FAST support. MILA was decommissioned.

NuSTAR On-board Recorder Management

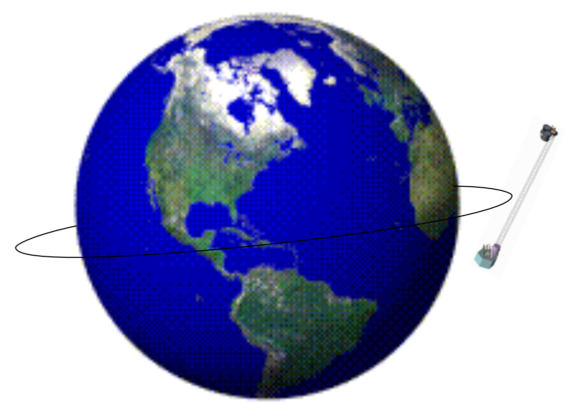


Target count rates

Recorder fill level



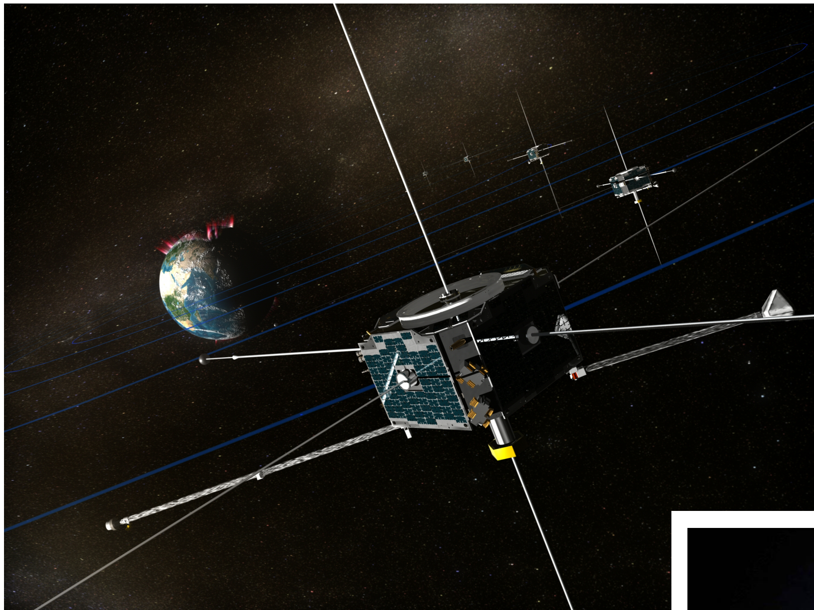
NuSTAR observation of the bright Crab target



Ground station views and scheduled passes:

Malindi, Singapore, Hawaii

THEMIS Mission Orbits: 2007 – 2009



Time History of Events and Macroscale Interactions during Substorms (THEMIS)

NASA Medium-class Explorer Mission Managed in PI Mode by UCB & UCLA

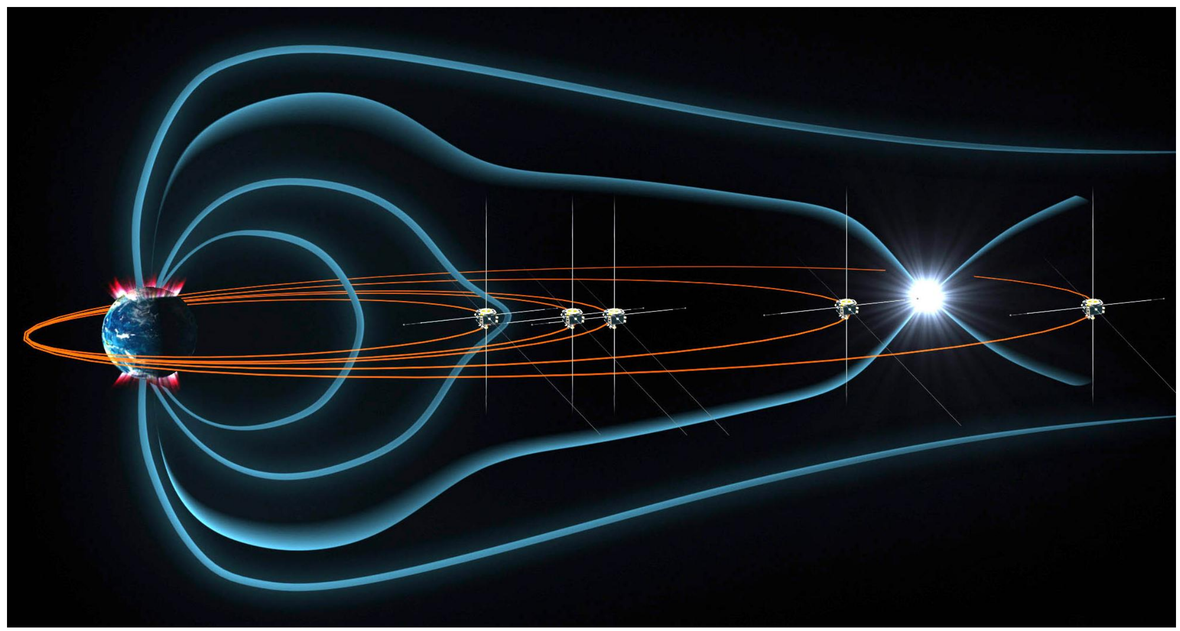
http://themis.ssl.berkeley.edu

http://www.nasa.gov/themis

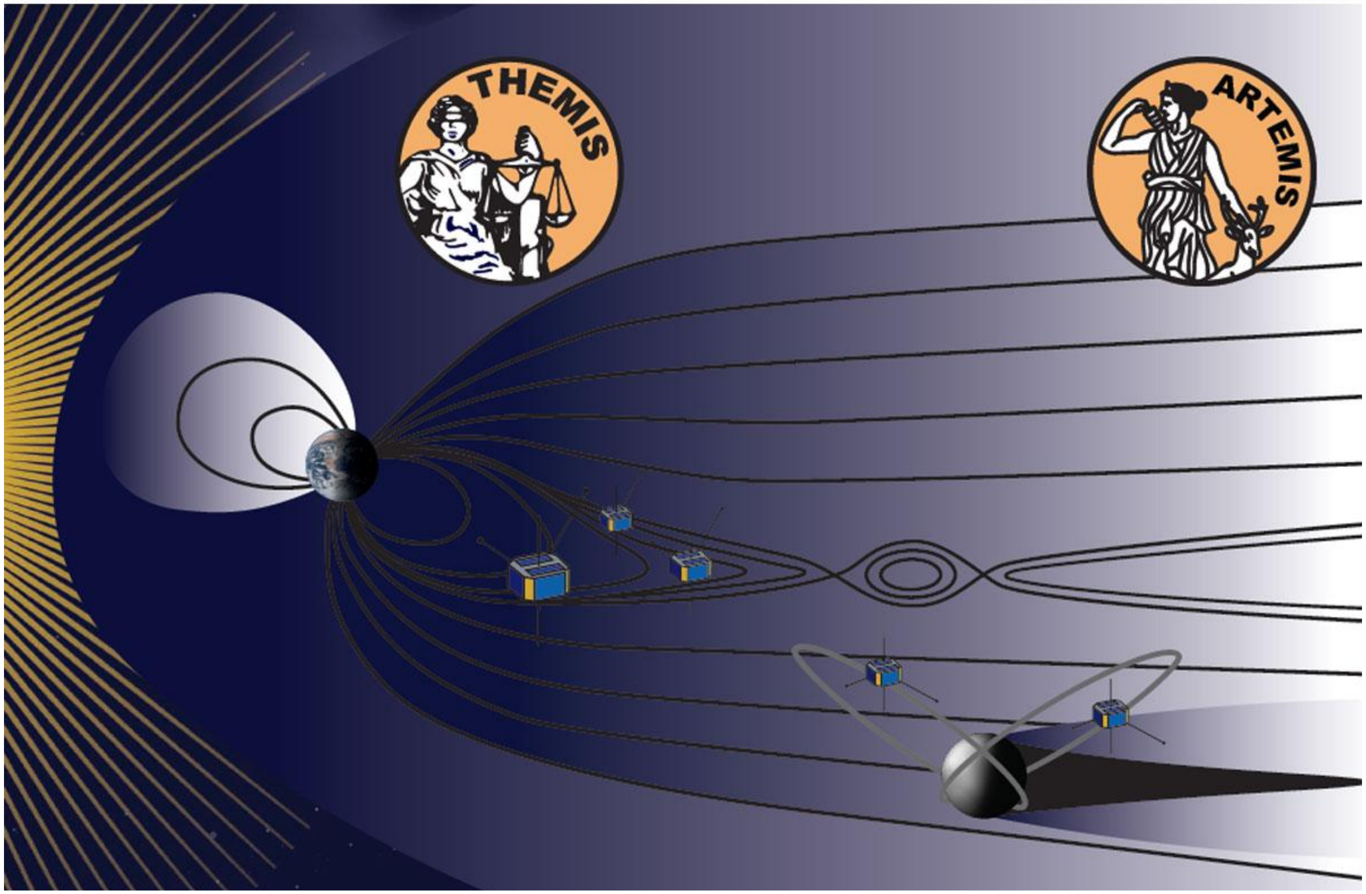
5 Probes in synchronized orbits with periods of 4, 2, 1, 1 and 4/5 days

Conjunctions formed in magnetotail every 4 days

Launched on Feb. 17, 2007



THEMIS & ARTEMIS Orbits: 2009 – 2013



Current THEMIS orbits:

P3, P4, P5: 1.16 x 11.7 R_E, 8-12 deg, 22.9 h

Current ARTEMIS orbits:

P1: 1.1 x 10.5 R_M, 163 deg, 25.1 h

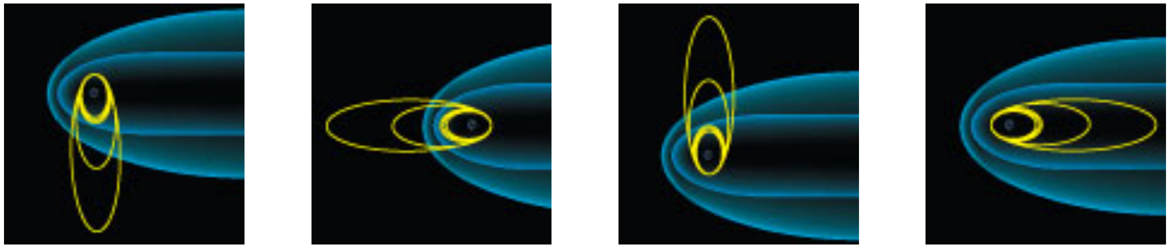
P2: 1.5 x 10.6 R_M, 37 deg, 27.1 h

Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun (ARTEMIS):

THEMIS probes P1 & P2 departed Earth in 2009; lunar libration orbit phase in 2010/2011; insertion into stable lunar orbits in 2011

Prime mission scenarios

- THEMIS science seasons



Orbit alignment with respect to the magnetosphere for different observing seasons, from left to right:
dusk (spring), dayside (summer), dawn (fall) and tail (winter)

Extended mission scenarios

- THEMIS collaborative science with Van Allen Probes
- ARTEMIS collaborative science with THEMIS, LADEE

Scientific Regions of Interest

Approach

- Scientific regions of interest (ROIs) (26 total)
- Evaluated separately for each THEMIS and ARTEMIS probe during runs of the Mission Design Tool (MDT)
- Examples: magnetotail, magnetosheath, magnetopause, and bow shock crossings

Utilization

- Regions of interest are part of the mission ephemeris for each THEMIS and ARTEMIS probe.
- Ephemeris is in turn processed into products that are used as inputs for scheduling and sequencing.
- Sequencing uses *duration events* to dispatch activities that control on-board science data collection.

THEMIS & ARTEMIS Data Collection Modes

Instrument	Measurements
Fluxgate Magnetometer (FGM)	Ambient low-frequency magnetic fields in 3D
Search Coil Magnetometer (SCM)	Ambient high-frequency magnetic fields in 3D
Electrostatic Analyzer (ESA)	Thermal ions and electrons
Solid State Telescope (SST)	Super-thermal ions and electrons
Electric Field Instrument (EFI)	Ambient DC and AC electric fields in 3D

Collection Mode	Utilization	Data Rate
Slow Survey (SS)	Low cadency routine data capture	~0.5 kbps
Fast Survey (FS)	High cadency routine capture	~12 kbps
Particle Burst (PB)	High resolution capture of particle energy distributions and low frequency waveforms	~43 kbps
Wave Burst (WB)	High resolution capture of electric and magnetic field waveforms	~470 kbps

Multi-mission Pass Scheduling Challenges

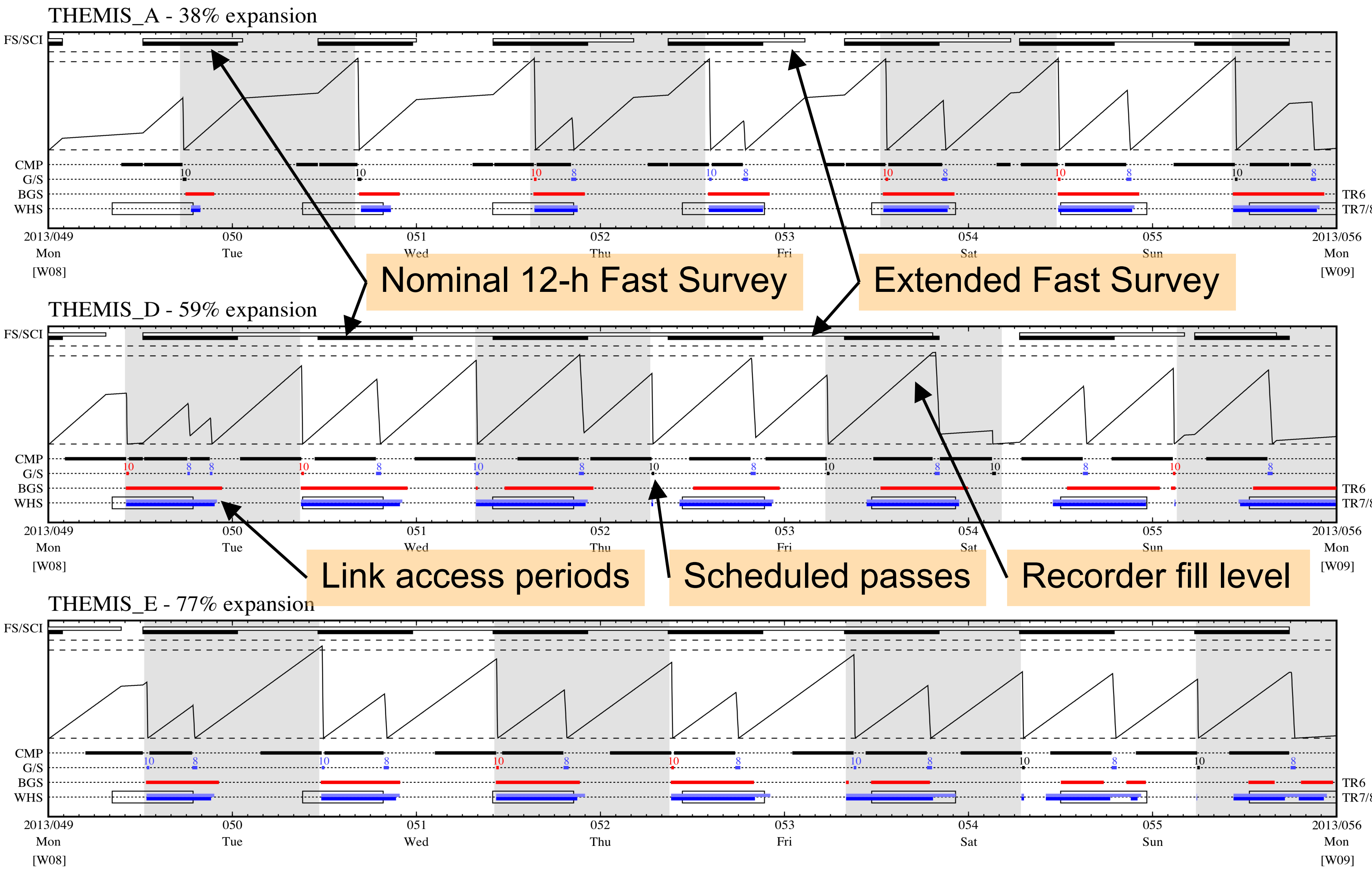
THEMIS challenges

- Collaborative science with Van Allen Probes calls for quasi-continuous collection of *Fast Survey* data
- Higher on-board recorder fill levels require data recovery from apogee at reduced data rates
- Deviation from sidereal orbits shifts view periods

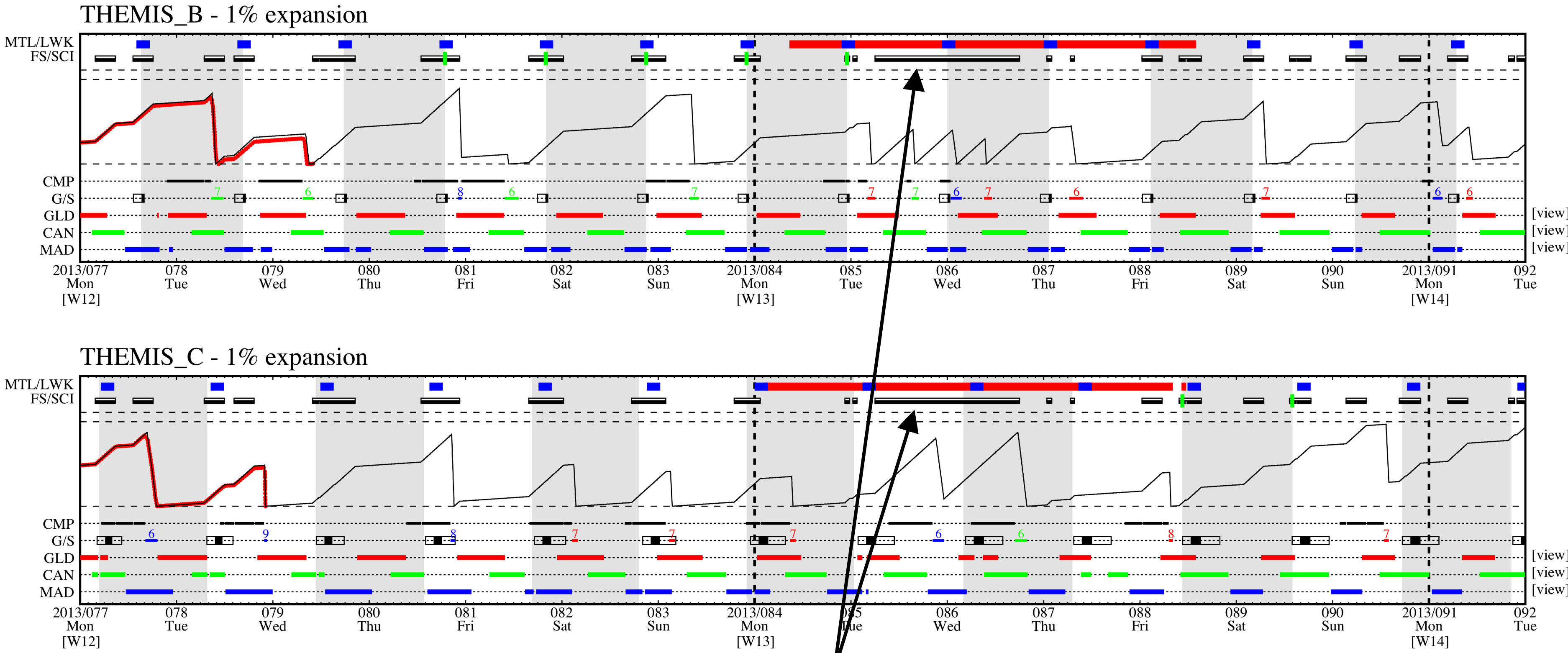
ARTEMIS challenges

- Support requirements of one 3.5-h pass per day at a 34-m station cannot be met due to resource contention
- Pre-pass set-up times reduced to resolve conflicts, but radiometric tracking services sacrificed
- DSN offered 70-m stations as alternative, resulting in higher telemetry data rates, but uplink not available

THEMIS On-board Recorder Management



ARTEMIS On-board Recorder Management



Additional Fast Survey data collection is scheduled when the Moon carries the two probes through the distant magnetospheric tail.

DSN passes are augmented with additional tracking passes at White Sands, USN Australia and Hawaii, and Berkeley to obtain two-way Doppler tracking data for orbit determination.

Multi-mission Ground Systems Design

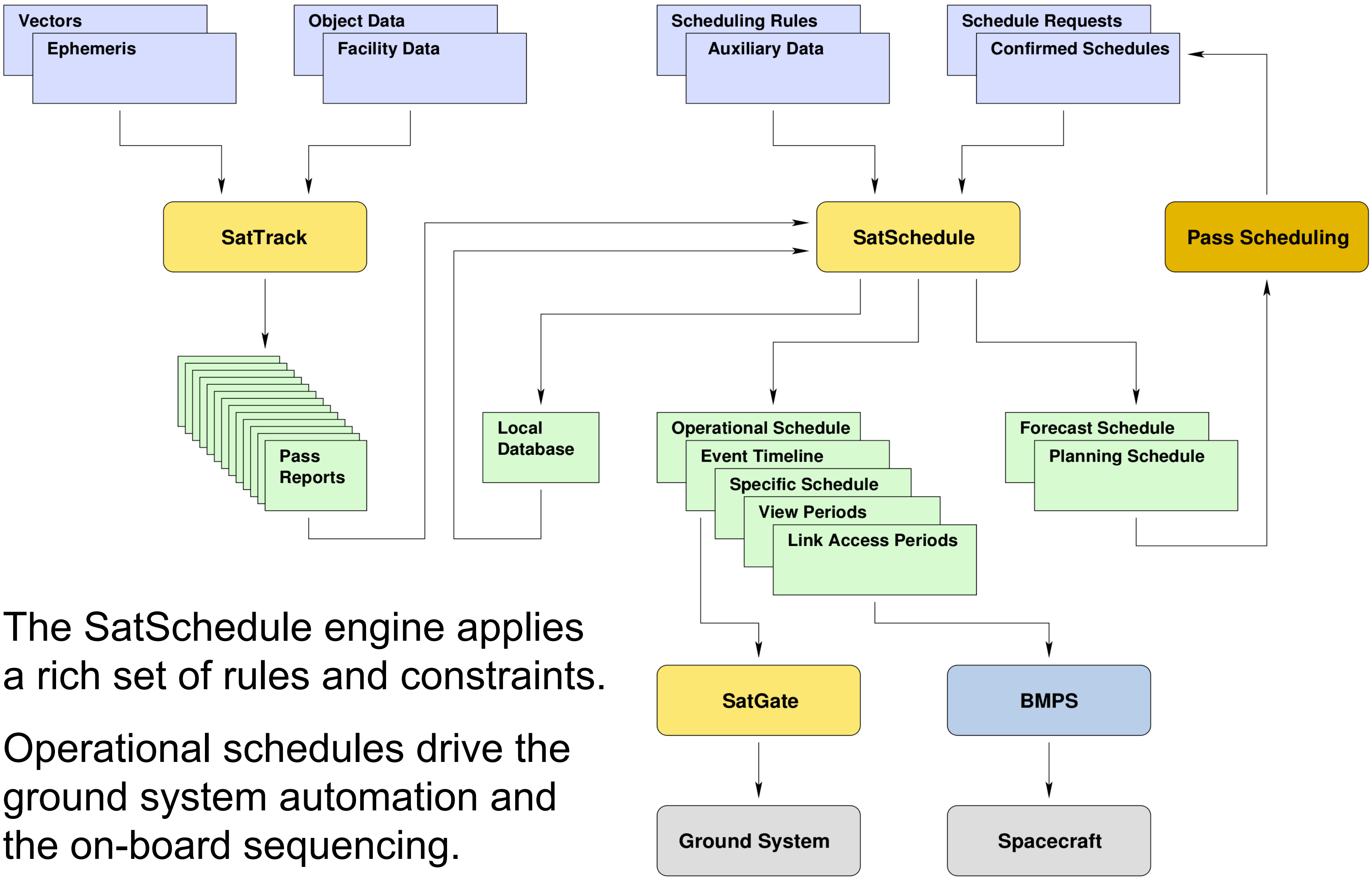
Architecture

- Hybrid structure is mainly a service-oriented architecture with some aspects of message-oriented middleware
- Standardized interfaces for electronic schedule exchange and real-time socket connections with multiple communications networks
- Reliable process automation for full lights-out operations

Components

- Various GOTS, COTS and in-house developed tools
- ITOS spacecraft command and control system
- Blended and integrated into a highly automated system

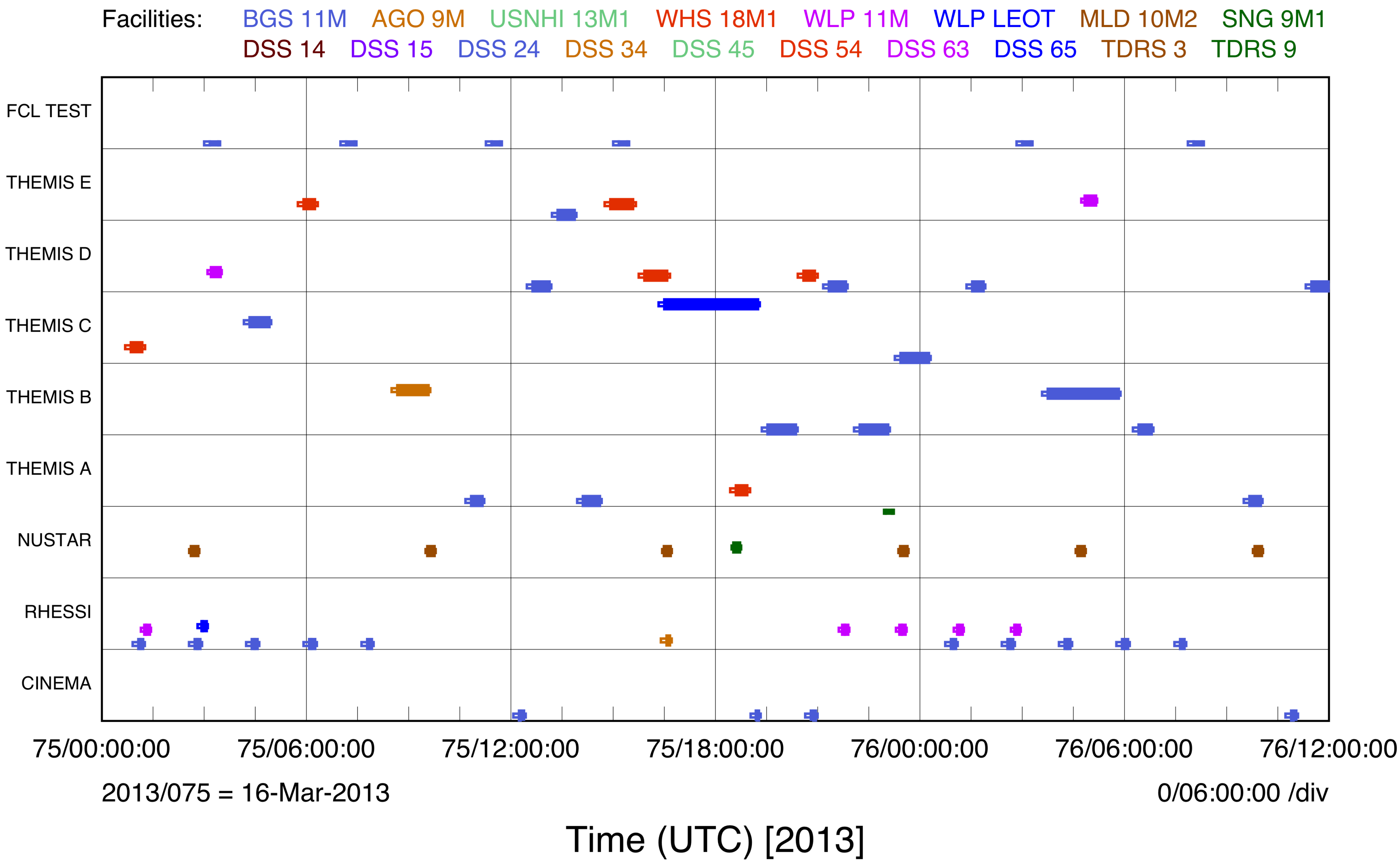
Scheduling Flow



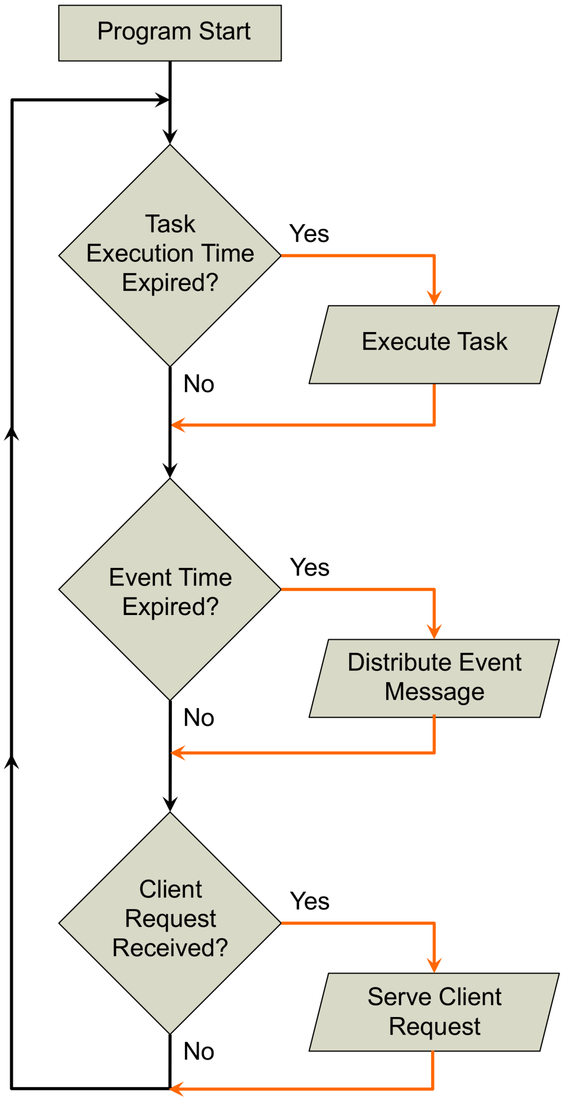
The SatSchedule engine applies a rich set of rules and constraints.

Operational schedules drive the ground system automation and the on-board sequencing.

Deconflicted Operational Schedule



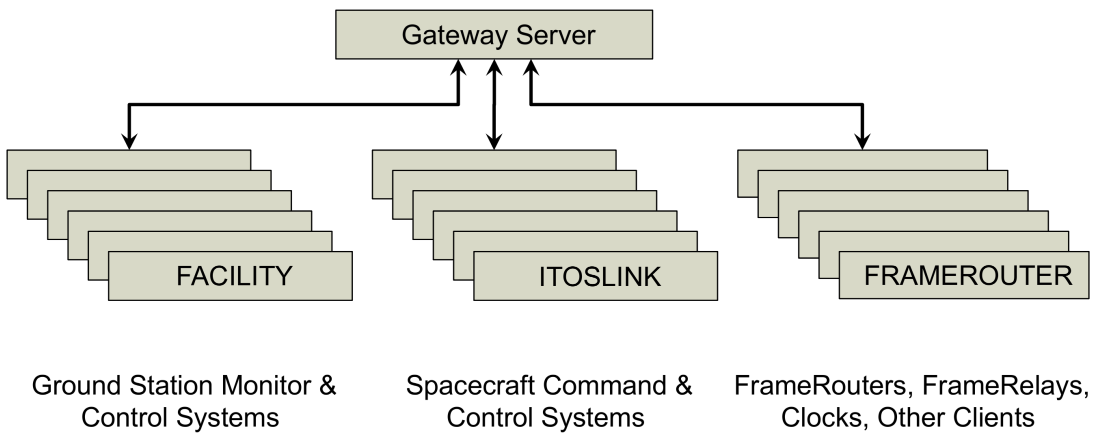
Event Driven Control Center Automation



A central Gateway Server runs in a continuous loop to perform 3 primary functions:

1) Execute tasks
2) Distribute event messages
3) Serve client requests

Clients connect to the server via TCP/IP sockets to exchange text based messages



Experiences & Lessons Learned

Mission design

- Concept of using regions of interest to plan science data collection has worked well.

Scheduling environment

- Working with multiple networks and scheduling offices requires excellent communications skills, and an understanding of their capabilities and constraints.
- Making concessions and understanding requirements of other missions is essential to achieve success.
- Looking for new ways to utilize network assets provides options to implement new mission requirements and to work around resource contention.

Summary

- THEMIS & ARTEMIS mission designs and mission planning are fairly complex.
- Different ways were implemented to push the link performance with network communications.
- Implemented software tools and scheduling procedures work very well, but can be improved.
- Multi-mission operations can be handled by a relatively small team.
- A high degree of ground systems automation is used to successfully reduce workloads in the team.