# Optimizing SmallSat Scheduling for NASA's Deep Space Network

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# Overview

- Context
  - Deep Space Network
  - SmallSats
- Scheduling Challenges
- Approaches
  - Opportunistic “Gap Fill” scheduling
  - “Block” scheduling
- Results
- Conclusions and Future Work

# Deep Space Network (DSN)

- Network of 34- and 70-meter antennas in California, Madrid, and Canberra
  - All deep space missions use DSN for communications and navigation
- DSN is currently oversubscribed
  - 35 missions / science users dependent on DSN services
  - Limited network assets
  - Multi-use equipment (antenna testing / maintenance, calibration, science users)
- Small satellites represent new customer base for network

# SmallSat Constraints

- Resource limited
- Physical operations restricted due to subsystem capabilities
- New user category for DSN process interfacing
- Upcoming CubeSat influx: Exploration Mission One (EM-1) Secondary Payload
  - Approximately 12 deep space CubeSats to be deployed

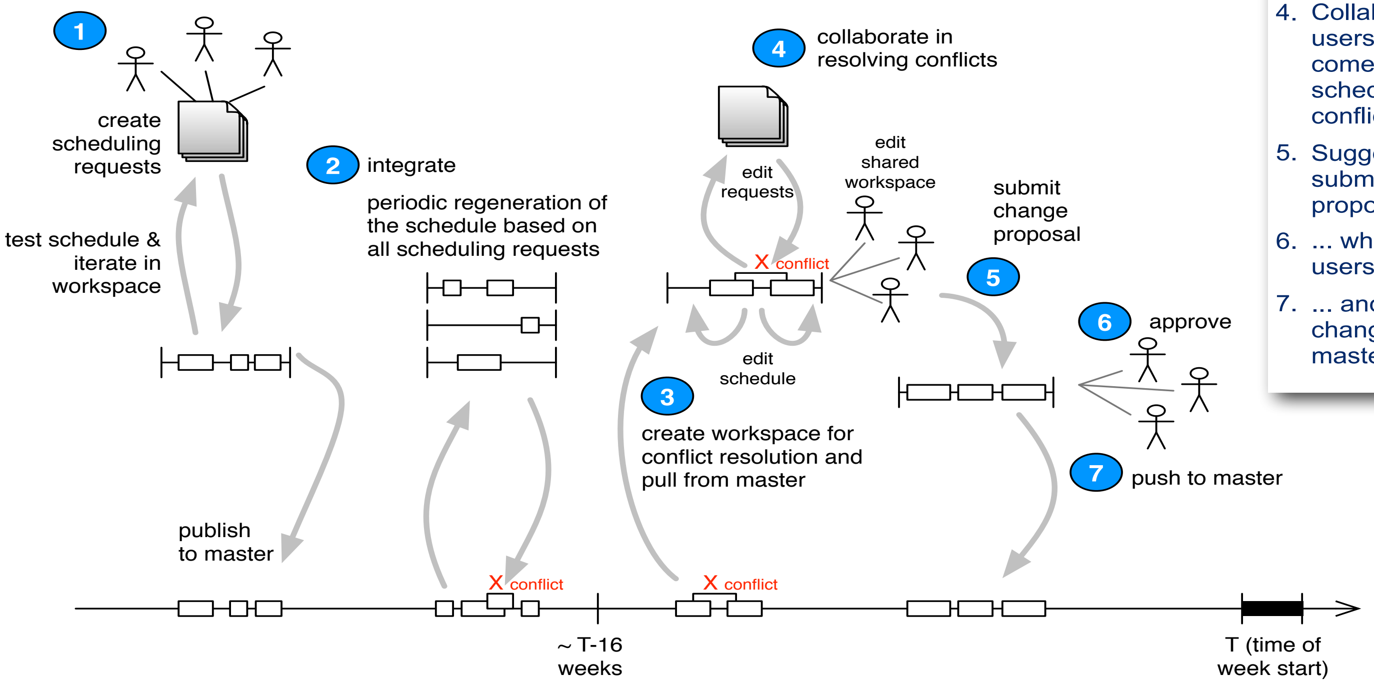
# Scheduling Process

## Collaborative Peer-to-Peer

## Highly iterative — negotiation-driven

- Main flow of events:

1. Users create & edit scheduling requests in their own workspaces to define their tracking requirements
2. Separate requests are combined into an initial integrated master schedule
3. Users work on conflict resolution in designated workspaces
4. Collaboration tools facilitate users working together to come up with acceptable schedule changes that resolve conflicts
5. Suggested changes are submitted as a change proposal...
6. ... which are approved by users ...
7. ... and then the approved changes are applied to the master schedule

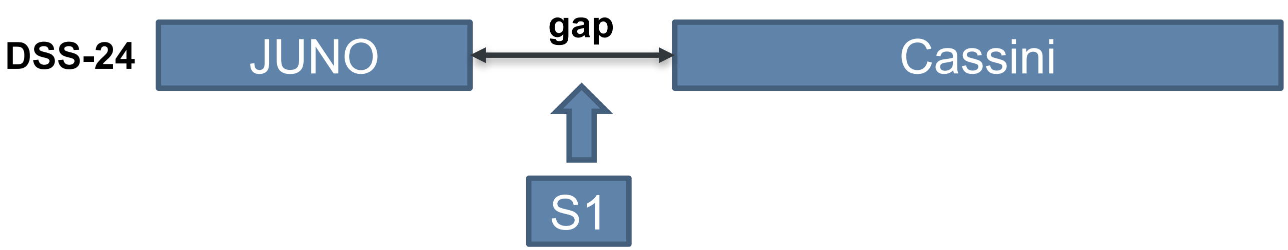


# SmallSat Scheduling in the DSN — Challenges

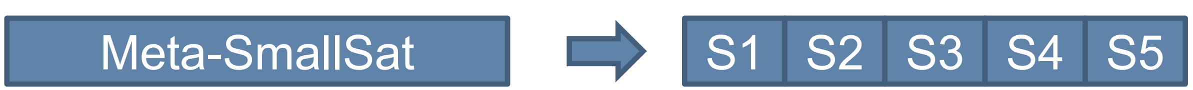
- Technically – no different than any other mission
  - DSN's requirements-driven scheduling system (Service Scheduling Software – $S^3$) can model requirements and generate corresponding activities, and provides web GUI for collaborative scheduling
- But…
  - Low-cost SmallSat missions may have limited resources to expend on negotiating with larger missions
  - Priority of SmallSats may be lower
  - Sheer number of (new) missions will complicate an already lengthy negotiation process
    - EM-1 missions increase total number of DSN users by 40%!

# Two Potential Approaches…

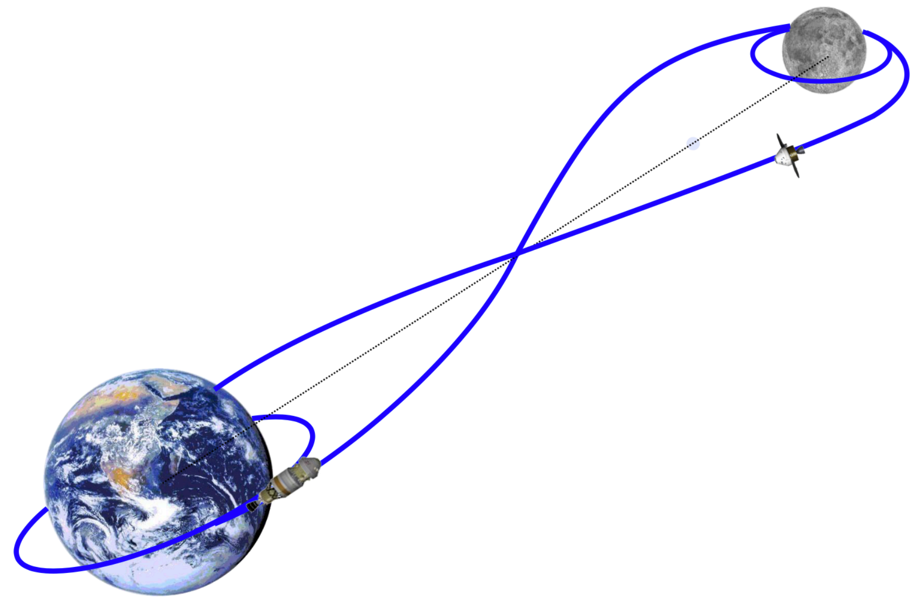
- **Opportunistic Gap Fill**
  – Identify usable gaps in the schedule and insert activities for SmallSats




- **Block Scheduling**
  – Define requirements and windows for scheduling multiple SmallSat missions at once in a single block, then decompose back to individual mission allocations

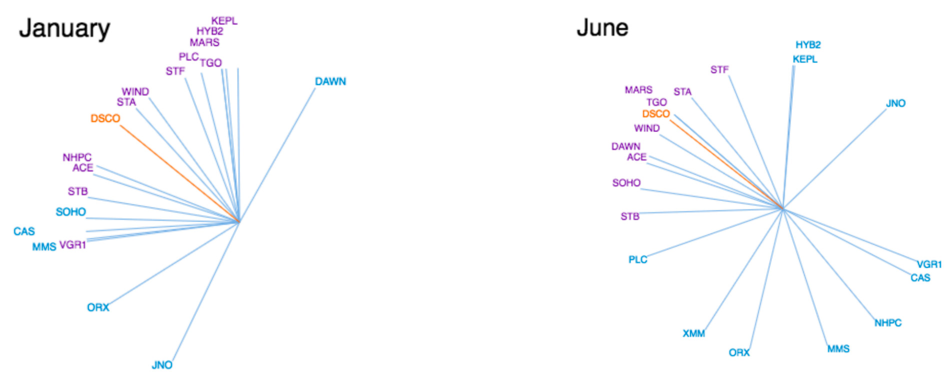


# Opportunistic Gap Fill

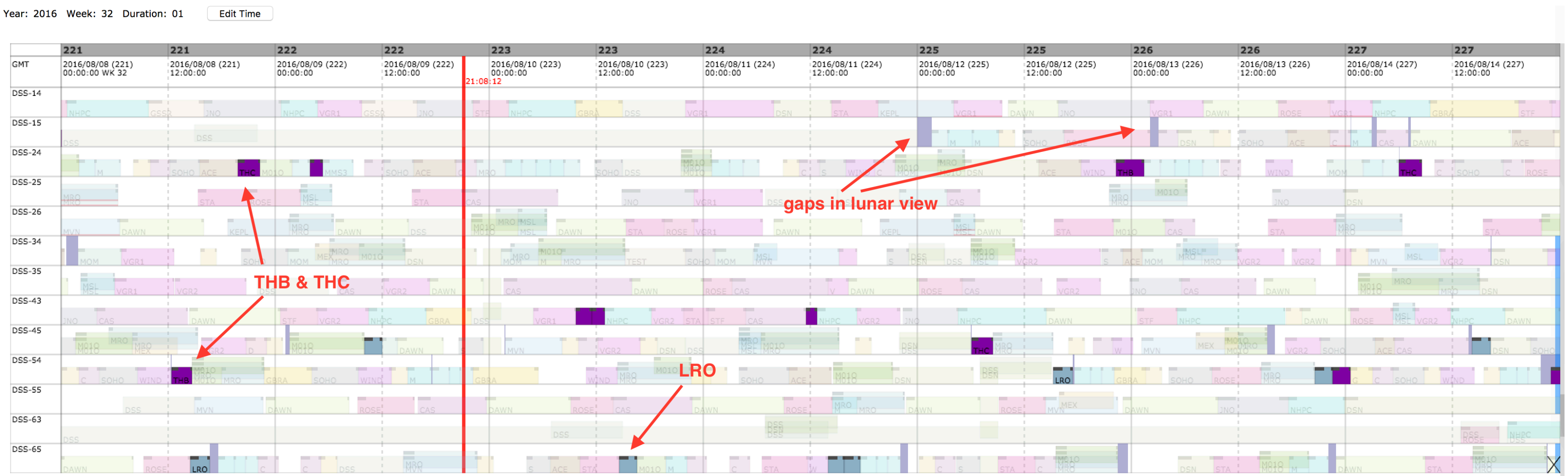


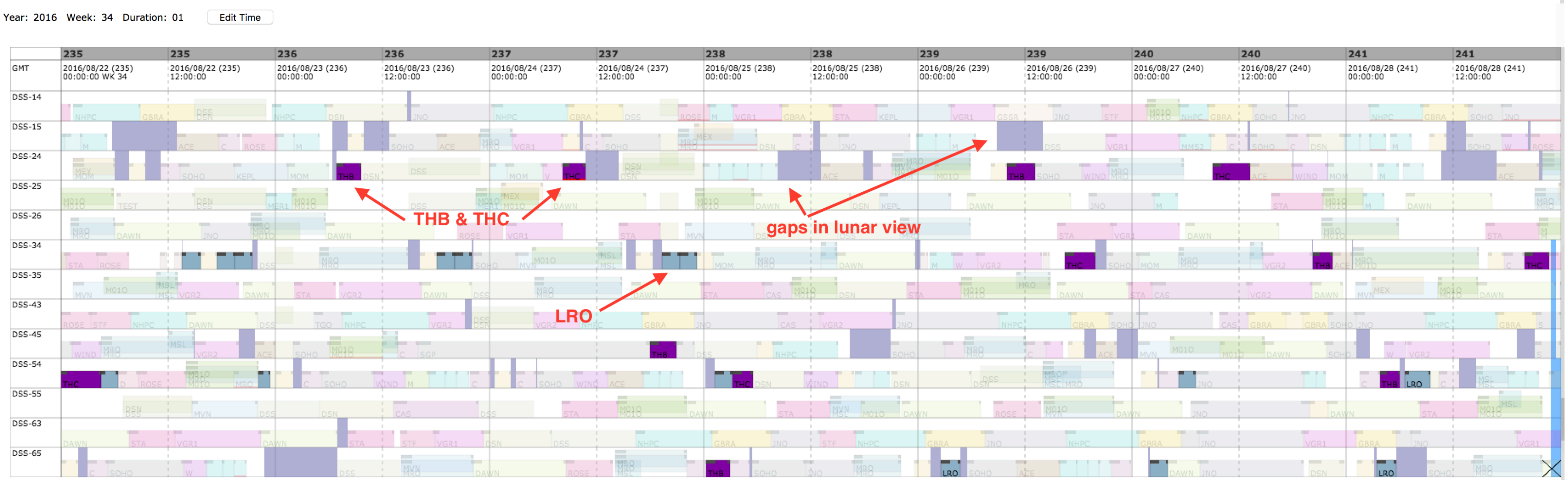
- EM-1 is a circumlunar mission, so gaps in the schedule during which the moon is in view could potentially support missions close to the moon

- How frequently do these occur in practice?
  - Caveat: there are seasonal variations in how fully the DSN schedule uses all the antenna time available: this is due to the changing alignment of the deep space missions



# Example gap fill – two different weeks



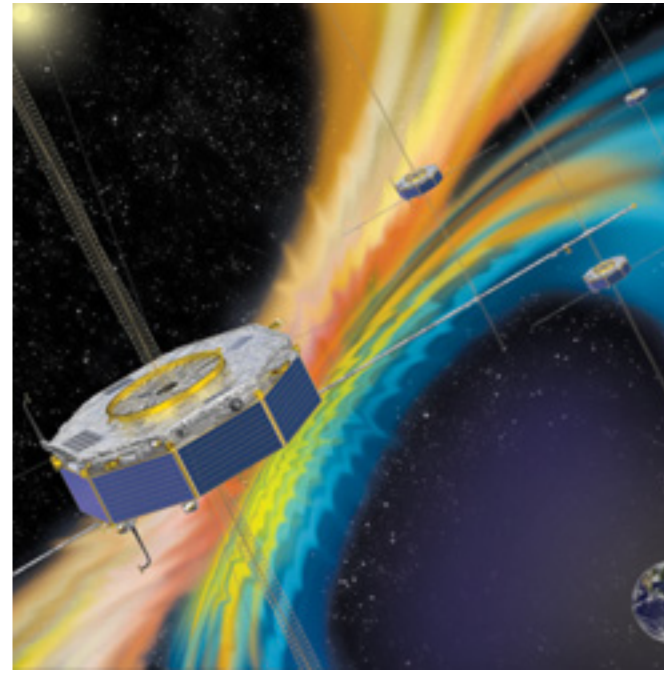
# Gap fill statistics

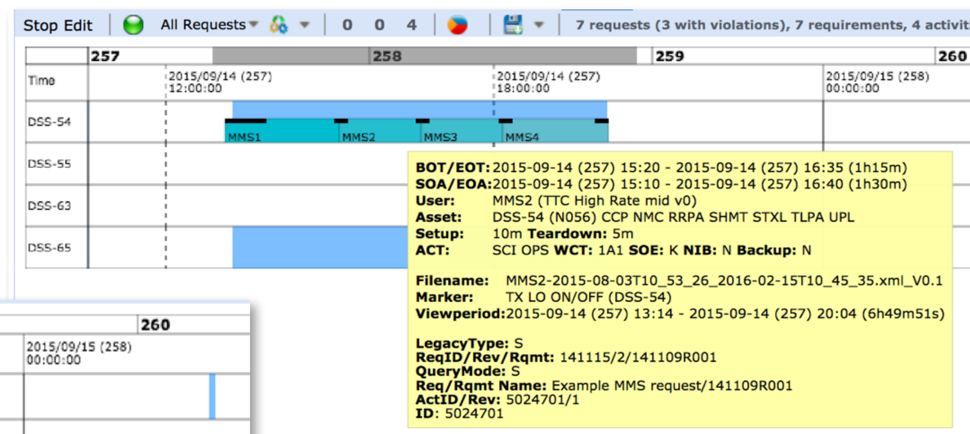
- For ≥2 hour gaps, average number of gaps/week: 4.5
- For BWG-1 antennas (that SmallSats are most likely to use),
  - average gap duration ranged from 1 to 1.8 hours
  - average # gaps/week 9.5
  - total gap time available ranged from 2.5 to 29.2 hours

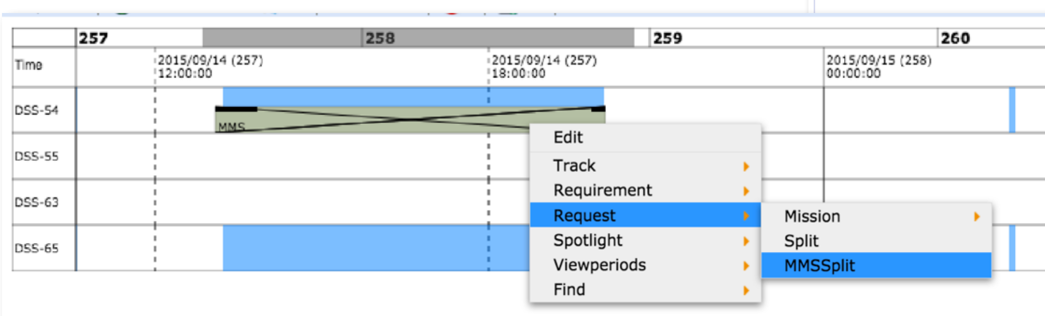
- Summary:
  - lots of variability in gap availability and duration
  - could perhaps service ~1 SmallSat but not likely to work for more than that!

# Block Scheduling

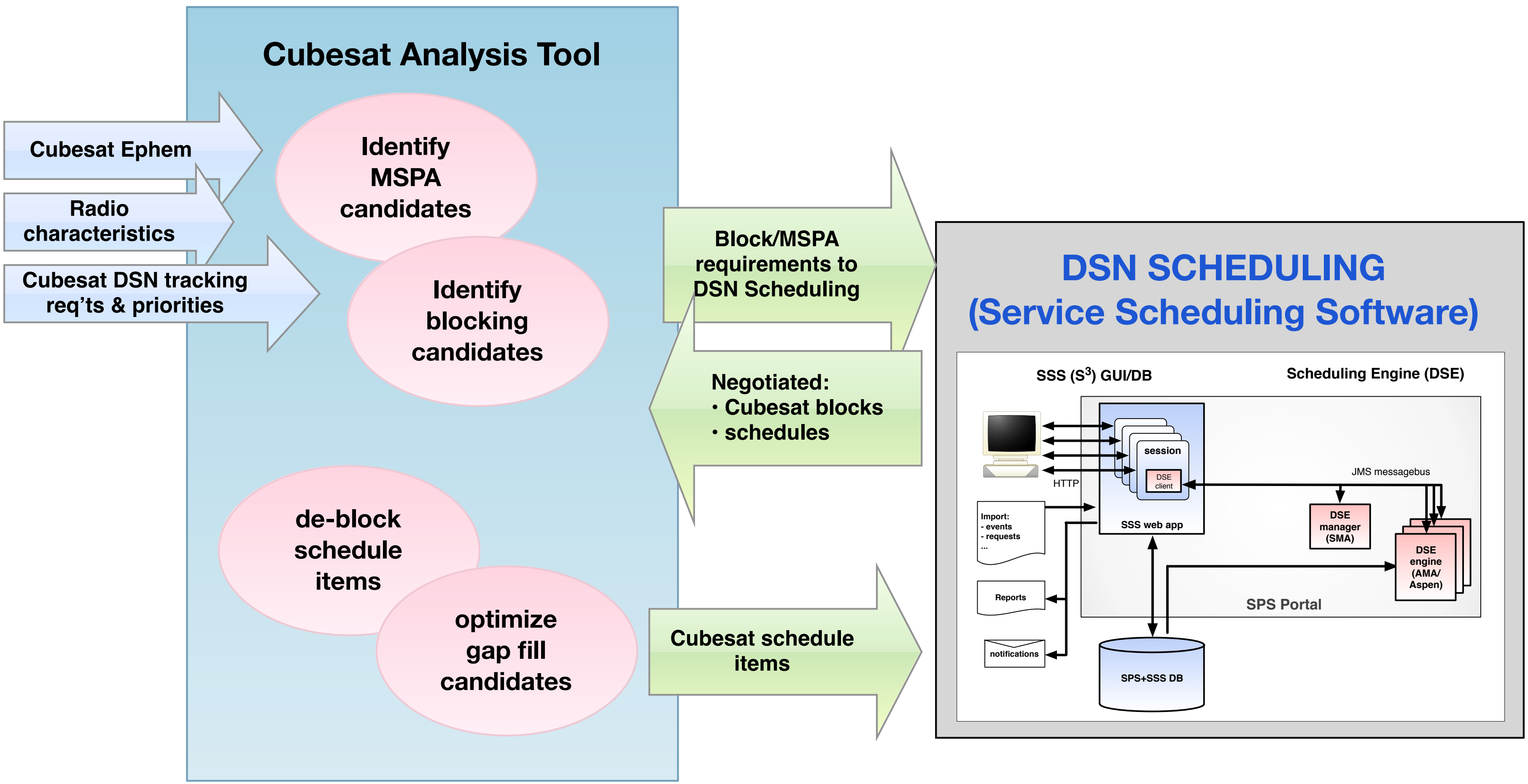
- DSN precedent: Magnetospheric Multi-Scale (MMS) – constellation of four spacecraft in near tetrahedral formation
- Scheduling supports allocation as a “block” (MMS) that can be automatically broken up into separate MMS1, MMS2 MMS3, MMS4 activities





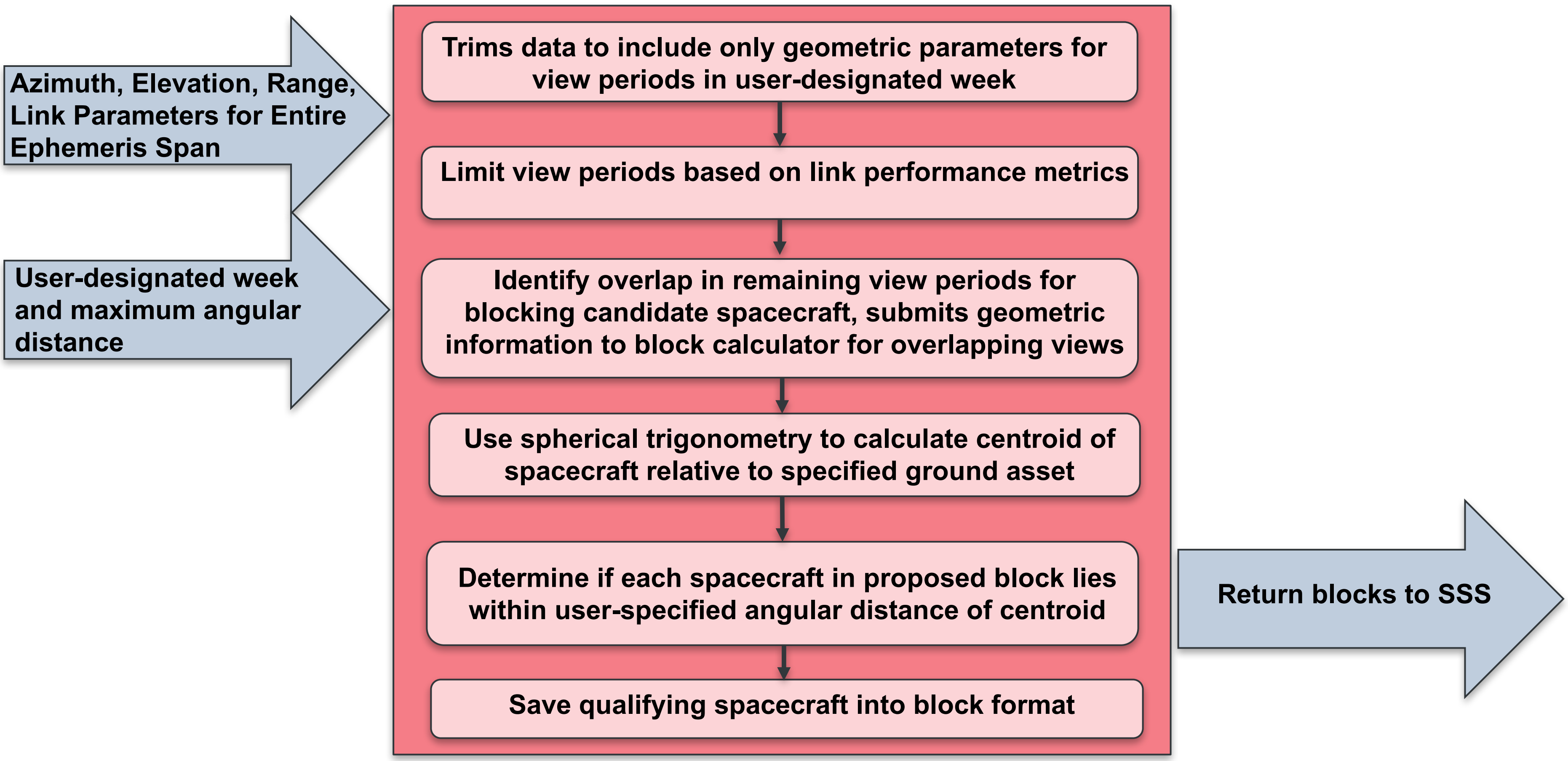
# Block Scheduling — Flow Diagram



# Experiments

- Trajectory files for EM-1 cubesats were not available
- Used flying DSN Lunar missions as proxies
  - Themis B and C (THB and THC), and Lunar Reconnaissance Orbiter (LRO)
- Network Assets
  - Used BWG-1 at each complex for test case formation
    - Based on CubeSat ULP requests and 34 m service expectation
  - Maximum slew distance of 5 degrees
    - Conservative estimate of allowable slew distance based on asset slew rates and 15 minute spacecraft transition time goal
- Spacecraft
  - Approximation of radio characteristics via IRIS specifications
  - All calculated view periods are viable for link completion
    - Tool is capable of refining block boundaries by incorporating link performance
- Time Constraints
  - Block accuracy of +/- 2.5 minutes
    - Moderate fidelity development for proof of concept

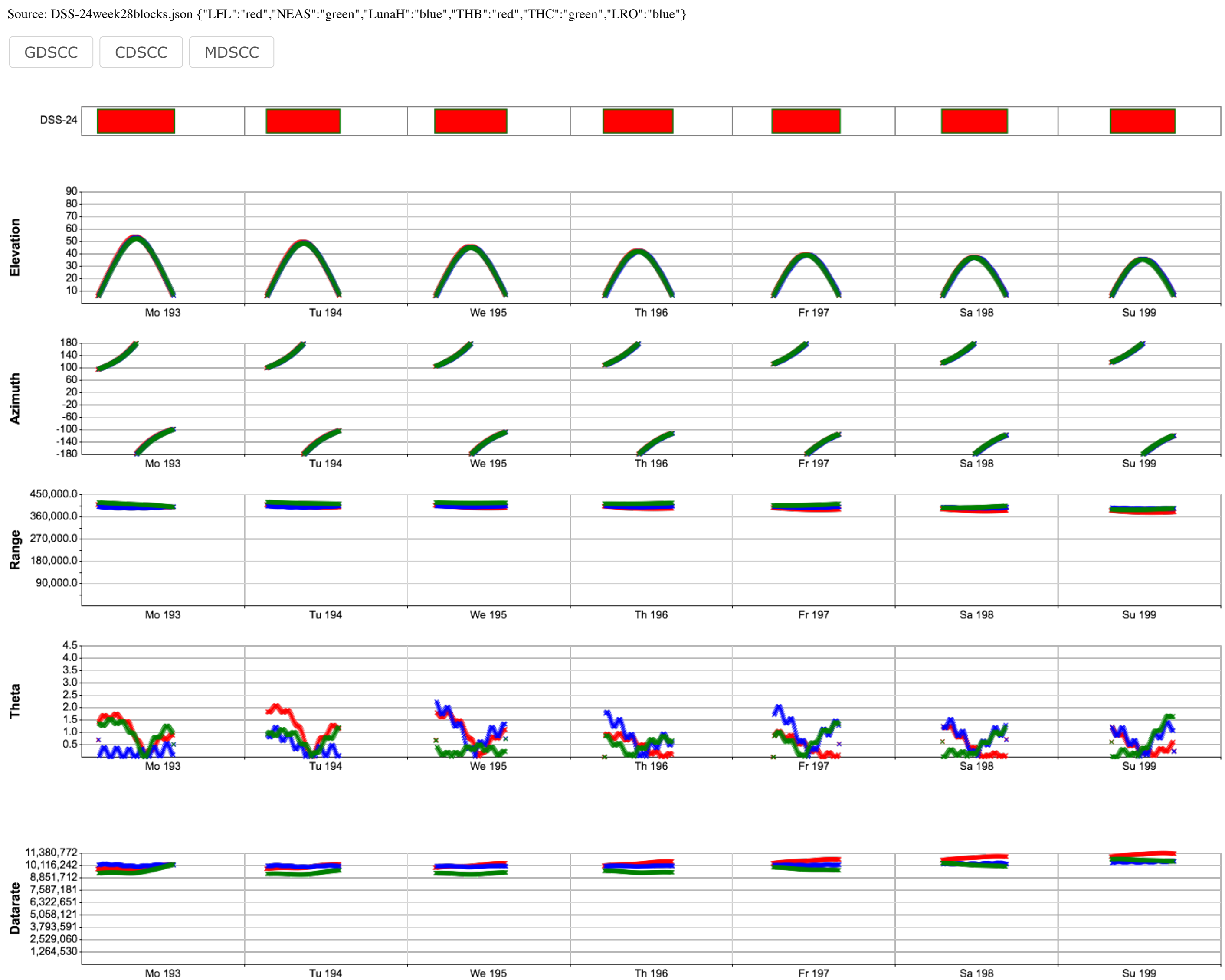
# Block Schedule Formation



# Block Opportunities — Sample results

Example:

- one week on Goldstone DSS-24 antenna
- blocking criteria:
  - < 2.5°
  - datarate
- Separate mission plots:
  - THB
  - THC
  - LRO



# Operational Recommendations

- Block scheduling paradigm for small satellite scheduling has potential:
  - Applicable for lunar orbit, and will translate naturally to constellations located at other planets
  - Potential to increase overall DSN efficiency by reducing setup/teardown overhead
    - Example Requirements: 3 tracks / week, 1 hour track duration without setup / teardown, assuming 1 hour setup, 15 minute teardown, 15 minute transition time for blocking
      - 4 spacecraft without blocking: 15 hours of setup/teardown
      - 4 spacecraft with blocking: 6 hours of setup/teardown
  - Facilitates rapid integration of multiple missions into scheduling process
  - Potential to shift some of the scheduling process workload to the SmallSat community — which will be able to most efficiently manage the tradeoffs and micro-optimization of SmallSats within allocated blocks

# Conclusions

- Gap and block scheduling have a potential role to play in reducing the impact of SmallSats in the DSN
  - block scheduling can reduce workload and antenna overhead – for missions that are close enough in the sky to group
  - gap scheduling can help find opportunities for last-minute communication and tracking
- Future work includes:
  - blocking and de-blocking strategies and tools need to be developed and deployed for routine usage
  - rules for DSN overheads need to be assessed and refined
  - user engagement and feedback from operations teams