Snooping Around: Observation Planning for the Signals of Opportunity P-band Investigation (SNOOPI)

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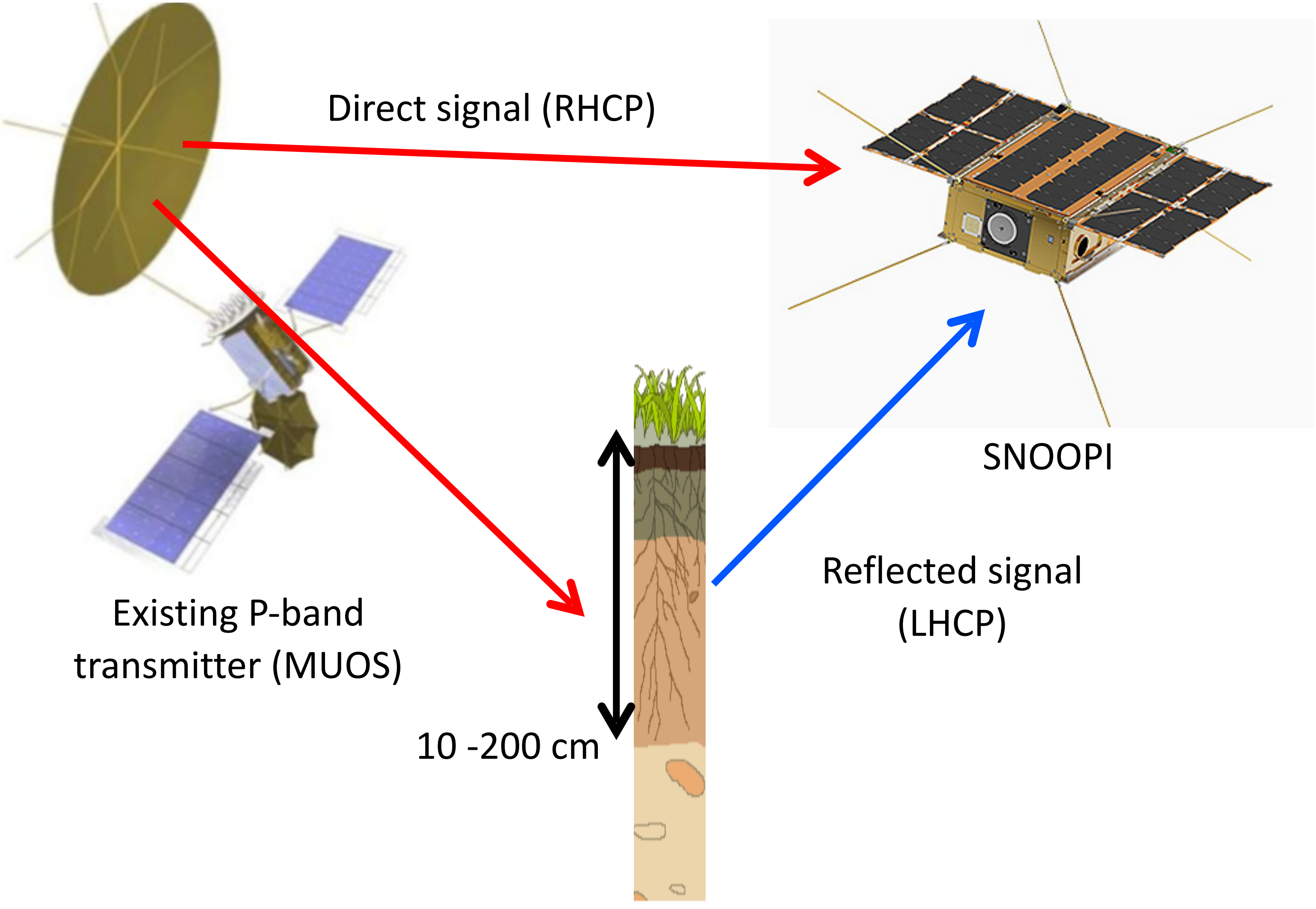
SNOOPI

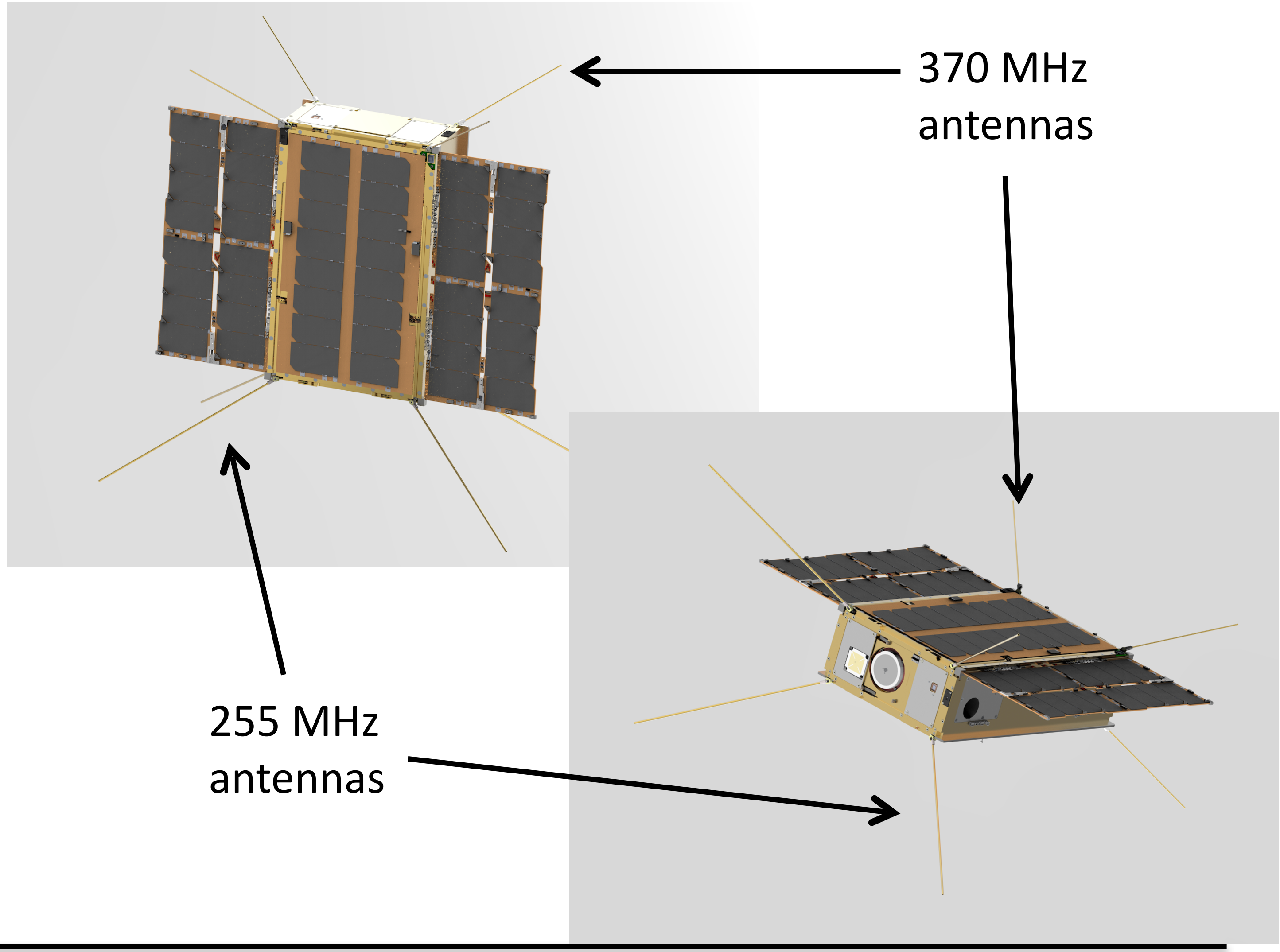
Mission Overview

- P-band frequencies (240-500 MHz) penetrate snow, vegetation, and into the root zone of soil
- Reflectivity (gain and phase) affected by soil moisture and snow water content – variables of important scientific interest
- Autocorrelation of direct and reflected signals can determine reflectivity without need to decrypt signal contents
- Key advantage: reuse of existing transmitters in heavily subscribed P-band



SNOOPI Spacecraft

- 6U (2x3) configuration
- 3-axis stabilized
  - Reaction wheels + torque rods
  - Magnetometer, sun sensors, star tracker
- Dual frequency P-band instrument payload
- Deployment from ISS via Nanoracks
- Current launch: early 2023



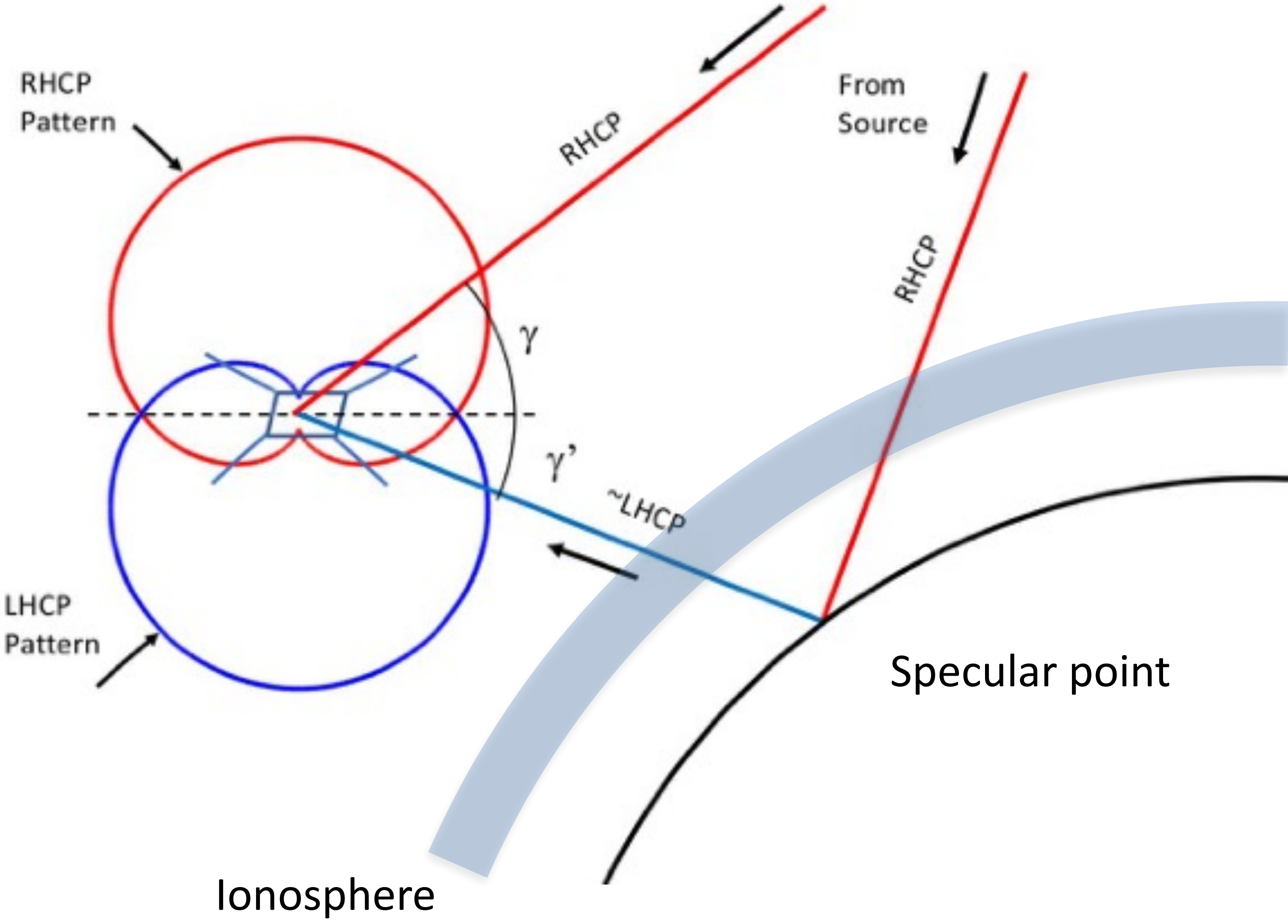
Mission Objectives

1. Validate **link budget** from orbital altitudes and speeds to quantify uncertainty in reflectivity and phase
2. Quantify **RFI effect** from space (broad field of view, global distribution of measurements)
3. Demonstrate model prediction and instrument tracking for orbital delay and Doppler with a non-cooperative transmitter

- To meet these objectives, SNOOPI will perform daily observations of RZSM/SWE over CONUS and dedicated SMAP calibration sites

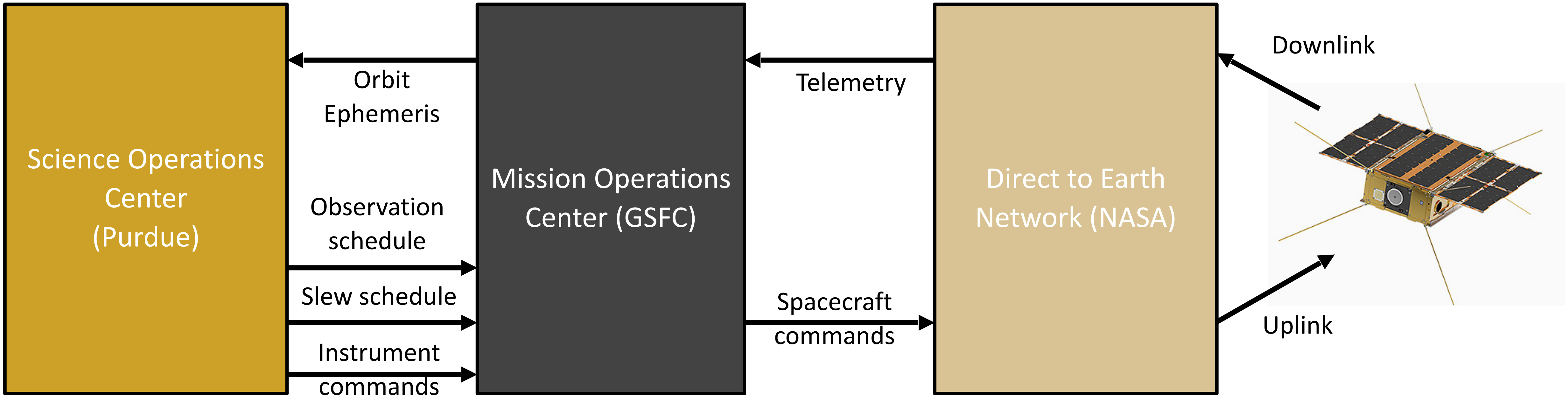
Challenges

- Mission planning must be streamlined to support measurement cadence
- Specular point where RZSM/SWE is measured depends on both receiver and transmitter positions as well as terrain
- Signal delay must be predicted and is affected by ionosphere
- Spacecraft attitude must slew to keep signal gains high



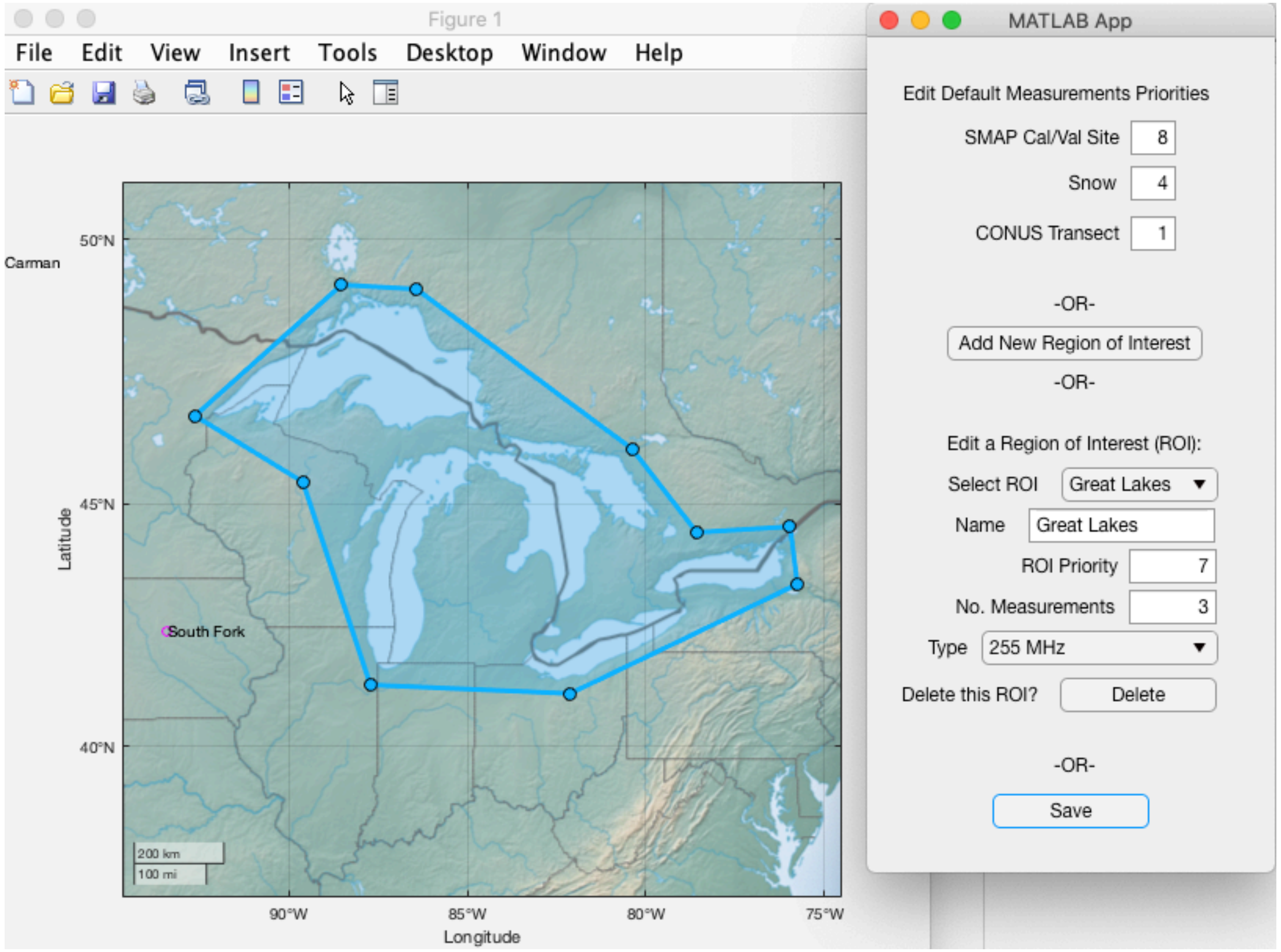
Roles

- Purdue will provide the spacecraft observation schedule along with attitude maneuvers and instrument commands



Defining Priorities

- Observation planning software begins with an app for defining regions of interest and assigning priorities from 1 to 10
- Type and number of measurements can also be defined



Scheduling

- Propagated orbits for SNOOPI and the MUOS satellites are used to solve for the specular point on a global elevation model
- Specular point ground track is searched for intersections with ROIs, CONUS, and SMAP sites
  - Each orbit is assigned a priority based on the best observation available
- Spacecraft scheduling formulated as the "Knapsack Problem":

$$maximize \ f^T x$$

Subject to: $Ax \leq b$

$$0 \leq x \leq 1$$

$$x \in \mathbb{Z}$$

Example:

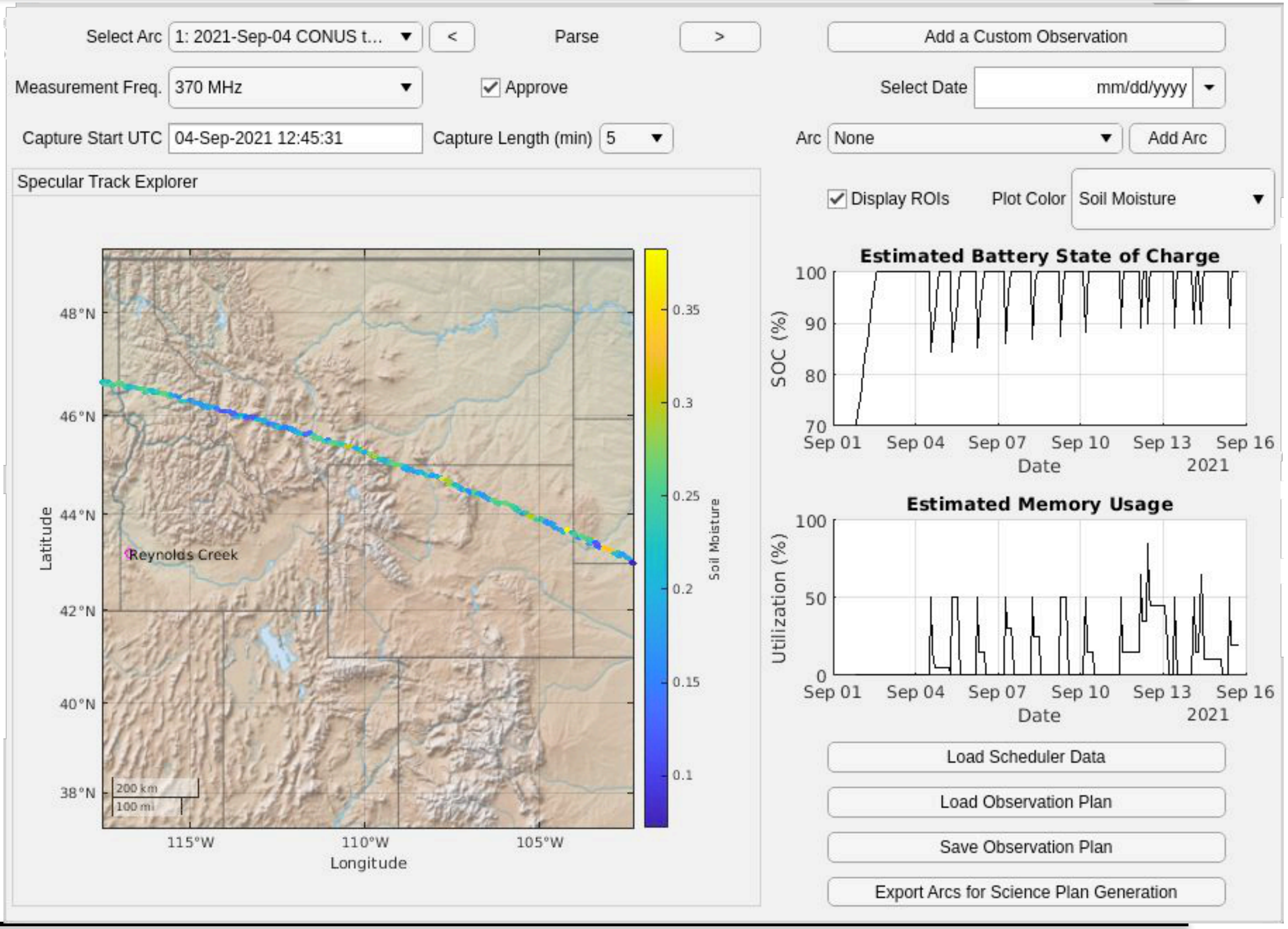
$f = [0\ 0\ 3\ 1\ 0\ 3\ 8\ 0\ 2\ 0\ 0\ 0\ 3\ 8\ 7 \ldots]$ Is the priority of each orbit

$x = [0\ 0\ 1\ 0\ 0\ 0\ 1\ 0\ 1\ 0\ 0\ 0\ 0\ 1\ 0 \ldots]$ Specifies observations

$Ax \leq b$ Contains constraints for power and data (see paper)

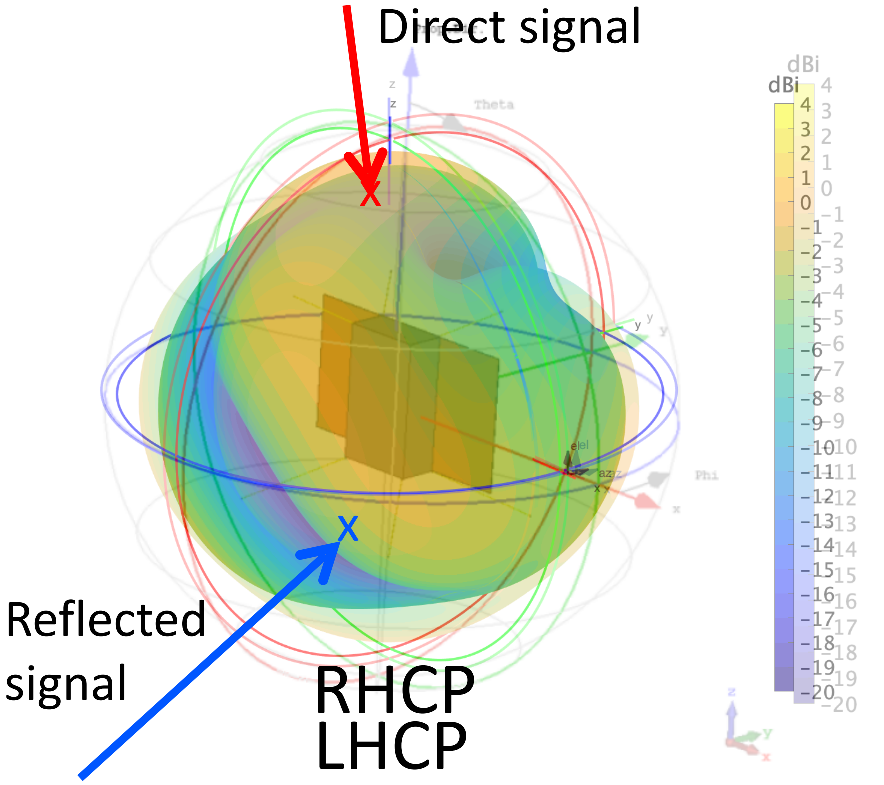
Approval App

- Linear program solver determines schedule
- A second app allows user to inspect the schedule
  - Visualize ground tracks
  - Approve or modify scheduled measurements
  - Verify constraints
  - Manually add observations to schedule



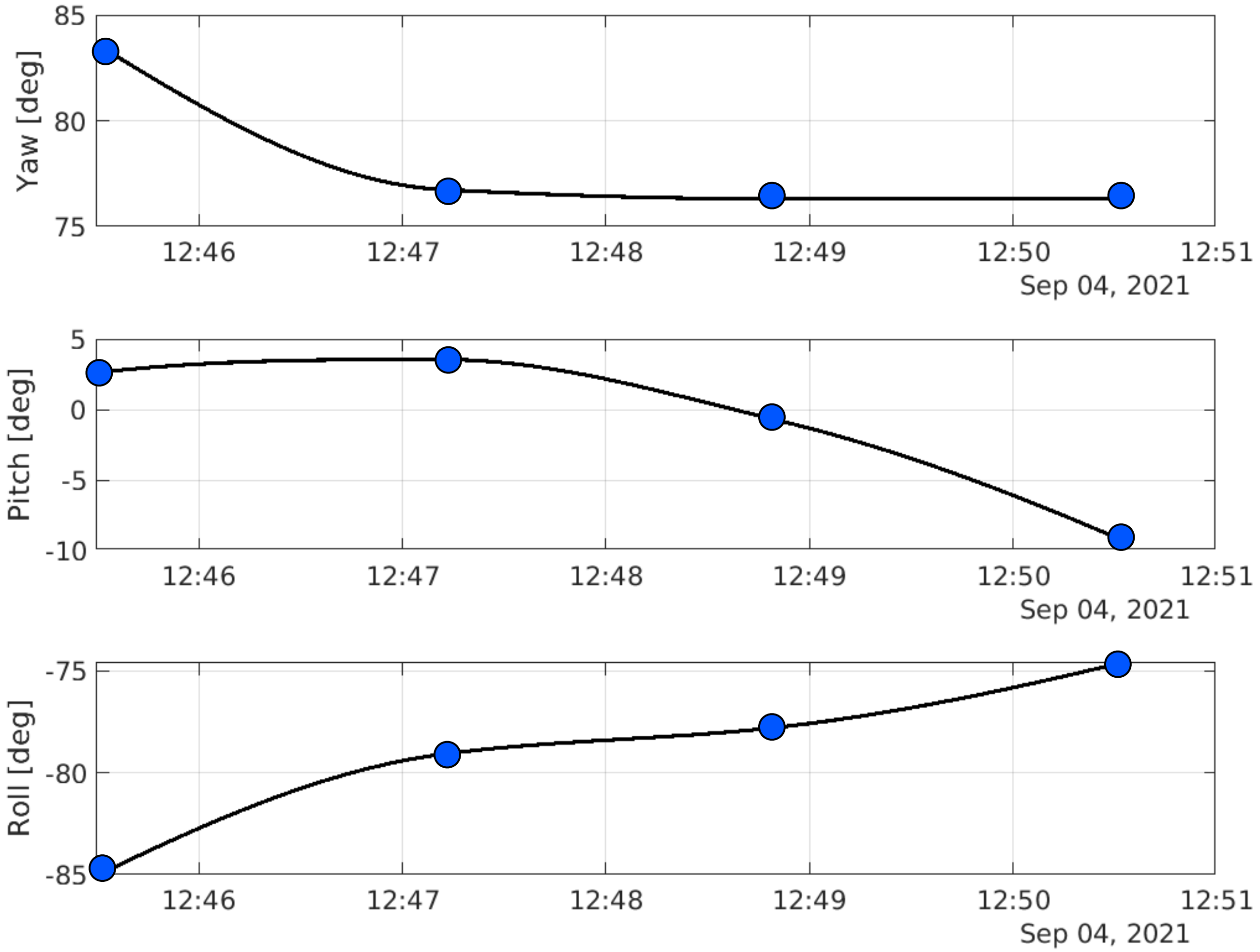
Slew Maneuver Design

- As direct and reflect signals change, attitude must be slewed to maintain adequate gain on fixed antenna patterns



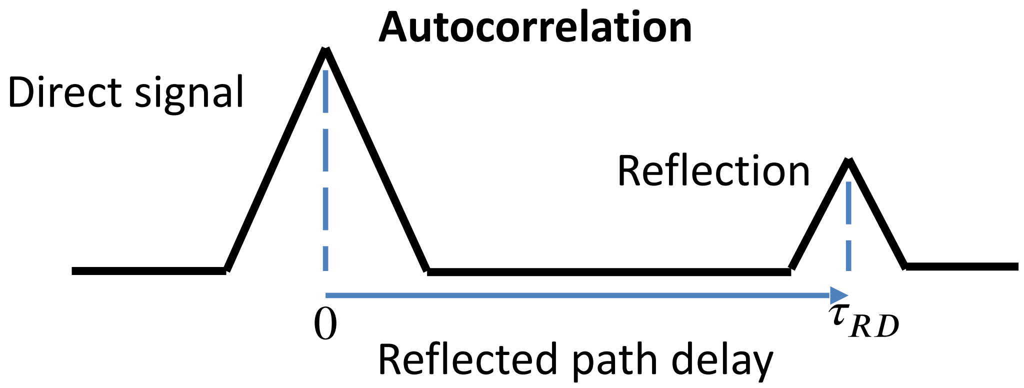
Slew Maneuver Design

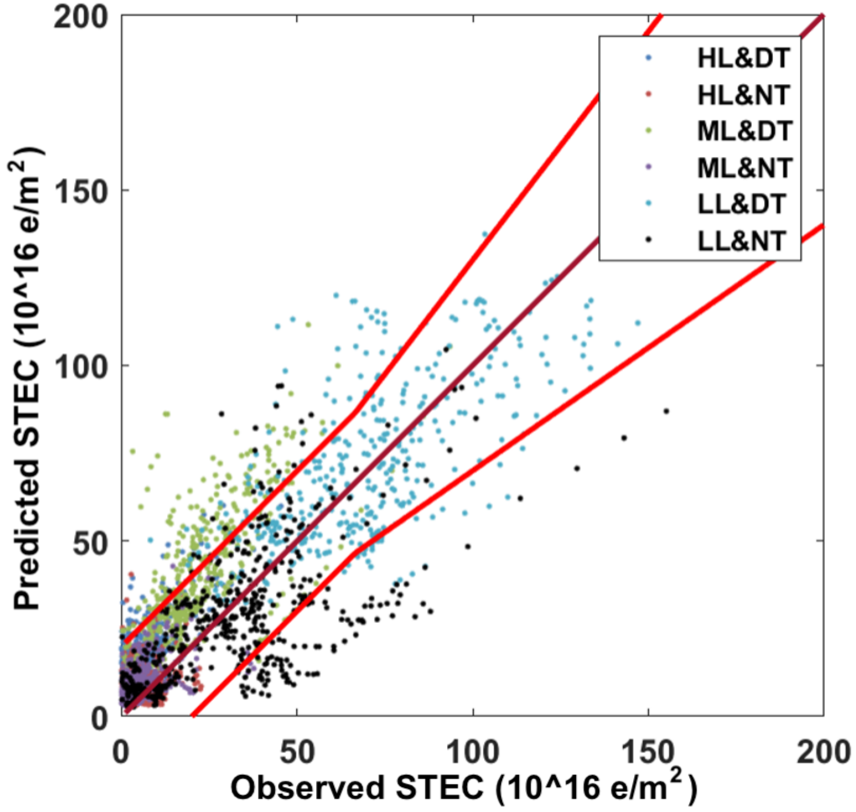
- Slew design formulated as optimization
- Maximize the time integral of the direct gain subject to:
  - Refl. gain within 3 dB of direct gain
  - Star tracker pointing constraints
  - Max slew rate constraint
  - GPS antenna visibility
- Design vector: Euler angles of 4 attitude “nodes” defining the slew
  - Intermediate attitudes determined using cubic interpolation
- Optimization solved using generalized pattern search



Ionospheric Correction

- Relative delay needed by instrument to perform autocorrelation
- NeQuick-2 model used to predict STEC and correct delay





- F10.7 cm solar flux forecast used to predict 3D ionosphere electron density
- Model evaluated by comparison to TEC observations by GPS tracking stations

Status and Mission Outlook

- SNOOPI ground software at Purdue University is ready to:
  - Predict specular point ground tracks
  - Optimize the spacecraft observation schedule
  - Design attitude slews for observations
  - Produce signal delay tables that correct for ionospheric delay
- SNOOPI is currently undergoing final testing at GSFC in preparation for November delivery and launch in early 2023

Acknowledgement

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SNOOPI Team Photo

Image Credit

- Joseph Kan, Mobile User Objective System, Selected Acquisition Report, 16-F-402, December 2015, https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Selected_Acquisition_Reports/FY_2015_SARS/16-F-0402_DOC_72_MUOS_DEC_2015_SAR.pdf