Signals of Opportunity P-band Investigation (SNOOPI): A Technology Validation Mission

James L. Garrison¹, Rajat Bindlish², Jeffrey R. Piepmeier², Rashmi Shah³, Manuel Vega², David A. Spencer¹, Roger Banting², Cynthia M. Firman², Benjamin Nold¹, and Kameron Larsen³

¹Purdue University, West Lafayette, IN, USA
²NASA Goddard Space Flight Center, Greenbelt, MD, USA
³Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA
Outline

• SNOOPI Mission Description
• Motivation: P-band Signals of Opportunity (SoOp)
• Instrument Heritage
• Mission Design
SNOOPI Mission Description
Snow Water Equivalent

- SWE retrieval from SoOp phase
  \[ \phi_s \approx a \cdot f \cdot SWE \]

- Long (~1m) P-band wavelength – increase phase wrapping interval
Root-zone Soil Moisture

- Root-zone soil moisture provides the critical link between surface hydrology and deeper processes (hydrologic linkage to the GRACE mission)
- Provides the root uptake for plant growth
- Accurate soil moisture data in the root zone are critical to agriculture (especially food production) and are of global importance.
- Account for rainfall estimate uncertainty in models
- Soil moisture profile information will allow accurate estimates of soil hydraulic properties
Difficulty of Sensing < 500 MHz

- Large antenna size to meet resolution requirements
- Few protected bands
- High RFI from terrestrial sources

MOSS: 435 & 137 MHz

ESA-BIOMASS
435 MHz (limited Ops.)

[DOI:10.1109/TGRS.2007.898236]

[ESA SP-132, 2010]
Signals of Opportunity
SNOOPI Instrument Heritage

- Low Noise Front End (LNFE): NASA GSFC
  - CubeSat form factor (90 x 96 mm) derived from IIP13 experience
  - 4 channels, 80 dB available gain, internal calibration paths
**SNOOPI Instrument Heritage**

- Digital Back End (DBE): NASA JPL
  - Based on Cion GNSS receiver for Tyvak / CICERO (TRL-8)
  - Changes:
    - Off-the-Shelf Rad-tolerant high-rel CSP computer (TRL 8)
    - P-band capability
P-Band Signals of Opportunity Airborne Demonstrator (SoOp-AD)

SLAP

2x2 element S-band array

P-band elements

To GEO Sat.
P-band SoOp Demonstrations

- Snow observations

[Shah, et al., 10.1109/LGRS.2016.2636664]
SNOOPI Mission Description

• Objective – In Space Validation of the SoOp **technique** in P-band
• Necessity of Space validation:
  1. Demonstrate sufficient **signal coherence** at orbital altitudes and speeds to make phase measurement
  2. Quantify **RFI from space** (broad field of view, global distribution of measurements)
  3. Model prediction and instrument tracking validated for orbital delay and Doppler.
Spacecraft Overview
SNOOPI Mission Design

- Link Budget Assumptions:
  - 10 ms integration, 1 sec incoherent avg.
  - Receiver in 410 km orbit.
  - Receiver noise based on SoOp-AD

<table>
<thead>
<tr>
<th>Center Freq.</th>
<th>240-270 MHz</th>
<th>360-380 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel BW</td>
<td>25 kHz</td>
<td>5 MHz</td>
</tr>
<tr>
<td>EIRP</td>
<td>27 dBW</td>
<td>37 dBW</td>
</tr>
<tr>
<td>Orbit</td>
<td>GEO</td>
<td>GEO</td>
</tr>
<tr>
<td># Channels Available</td>
<td>~10</td>
<td>4</td>
</tr>
</tbody>
</table>
SNOOPI Milestones

- Project Initiation: 01/19
- System Requirement Review: 06/19
- Critical Design Review: 03/20
- System Integration Review: 11/20
- Flight Readiness Review: 03/21
- Deliver to Launch site: 06/21
- Launch: 09/21
- 1 year mission operation: 09/22
Summary

• P-Band SoOp Technique will be validated in this mission.
  • Coherence time
  • Quantify RFI measurements
  • Robustness to DDM uncertainty

• All hardware is high-TRL components
  • Digital Back End (DBE) – Cion heritage
  • Low Noise Front End (LNFE) – Miniaturized SoOp-AD. (IIP-13) instrument
  • Antennas – COTS

• SNOOPI data will be publically available

• SNOOPI mission is excited to partner with others on validation of SWE estimates from SoOp observations
Acknowledgement

This work was supported by NASA InVEST program Grant 80NSSC18K1524, “Signals of Opportunity P-band Investigation (SNOOPI)”
BACKUP
Signals of Opportunity Airborne Demonstrator (SoOp-AD)
NASA IIP-13 Selection

Reflectivity vs. Volumetric Moisture
(S = 40%, C = 20%)

Reflectivity, \( \Gamma \)

Volumetric Moisture, \( m_v \) (%)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SoOp Airborne</th>
<th>SoOp Spaceborne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution*</td>
<td>100m</td>
<td>870m</td>
</tr>
<tr>
<td>Antenna Size</td>
<td>75 x 75 cm</td>
<td>75 x 75 cm</td>
</tr>
<tr>
<td>Sensing Depth</td>
<td>0-30cm</td>
<td>0-30cm</td>
</tr>
<tr>
<td>Sensing Precision**</td>
<td>0.04 m^3/m^3</td>
<td>0.04 m^3/m^3</td>
</tr>
</tbody>
</table>

*Specular Reflection Assumed
**SMAP Requirement
P-band SoOp Demonstrations

- Signals of Opportunity Airborne Demonstrator (IIP-13)

Strong Response over water

Resolution approximately First Fresnel zone

Possible RFI?
Motivation: Snow Water Equivalent

• SWE estimates from multi-frequency microwave

• Model spreads of -50% to 250%, - common in mid-latitude regions

Mudryk et al., 2015
SNOOPI Mission Design

SMAP Cal-Val Sites

Cumulative Observations

Days
SNOOPI Mission Design

• SMC Error in Single Observation

0 deg
50 deg
70 deg.

[4 soil types from Peplinski, 1995 model]
SNOOPI Mission Design

• SMC Error: 1 sec avg. over SNOOPI Channels

[4 soil types from Peplinski, 1995 model]