Designing a spacecraft to exploit Signals-of-Opportunity for Earth System Science

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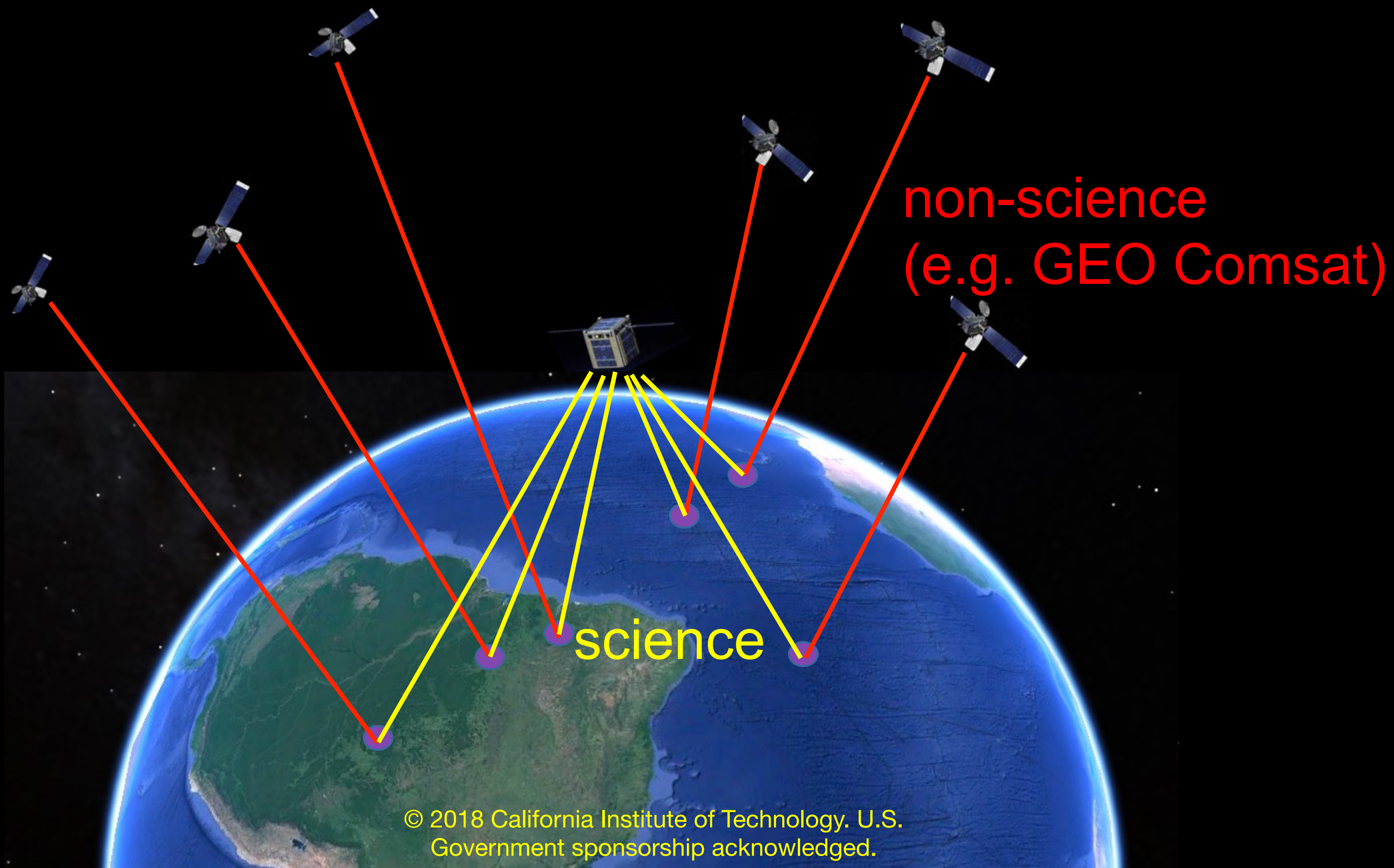
COSPAR 2018

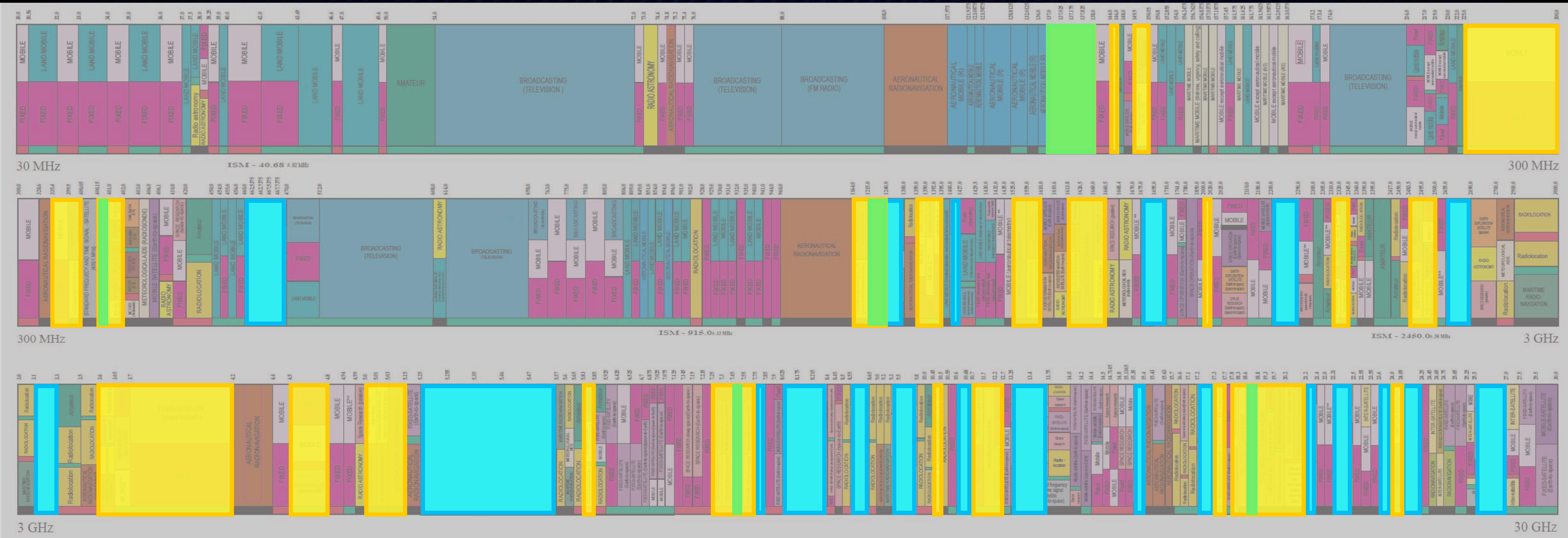
[With a lot of help from
JPL's Team-Xc]

Signals of Opportunity (SoOp)
Reflectometry



The Electromagnetic Spectrum: ***Valuable Real Estate***

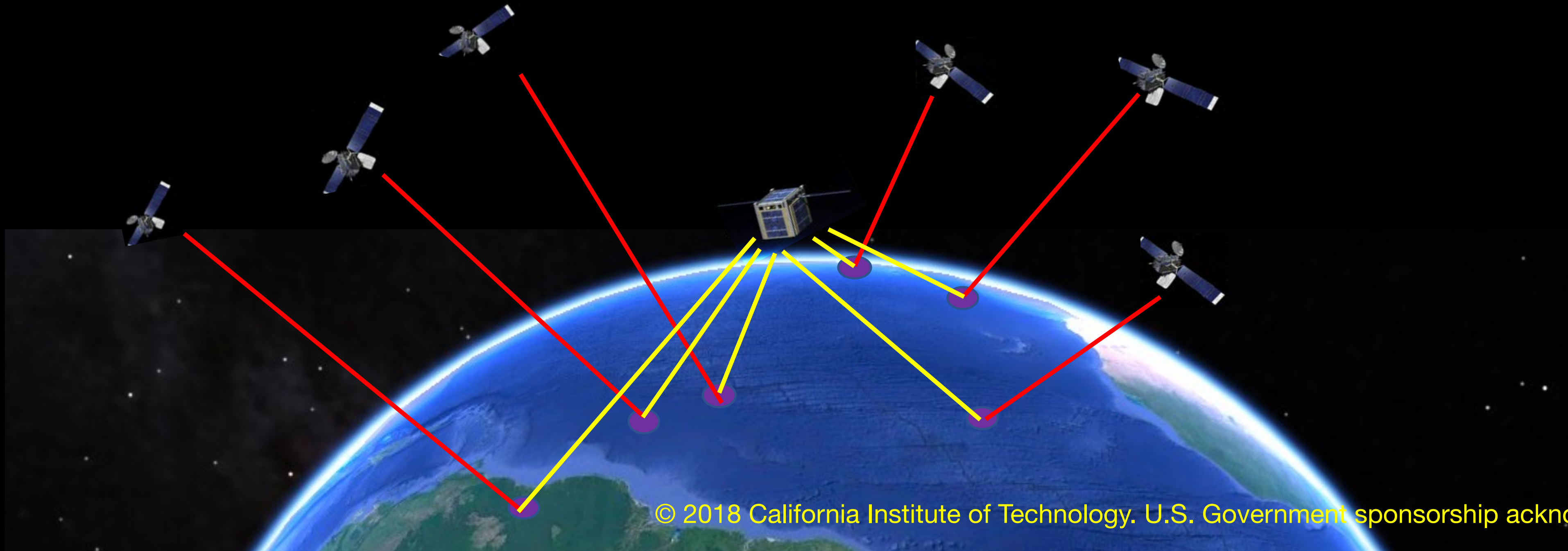
Two Windows on the Earth



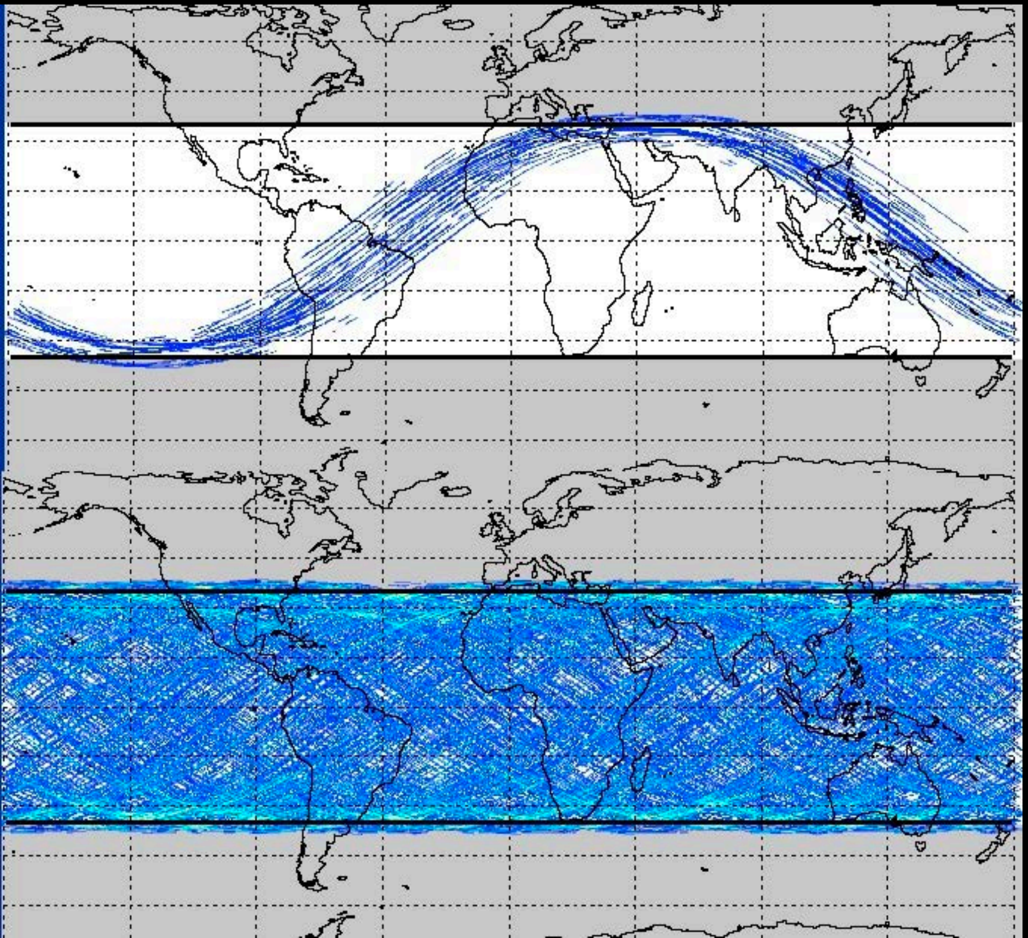
Science Optical Window Comm/Nav Microwave Window Shared

Signals of Opportunity (SoOp)
Advantages

- Only need passive receivers
- Wide range of frequencies available
- Forward scattering geometry
- Signal can be coherent over wide bandwidth



Signals of Opportunity Examples



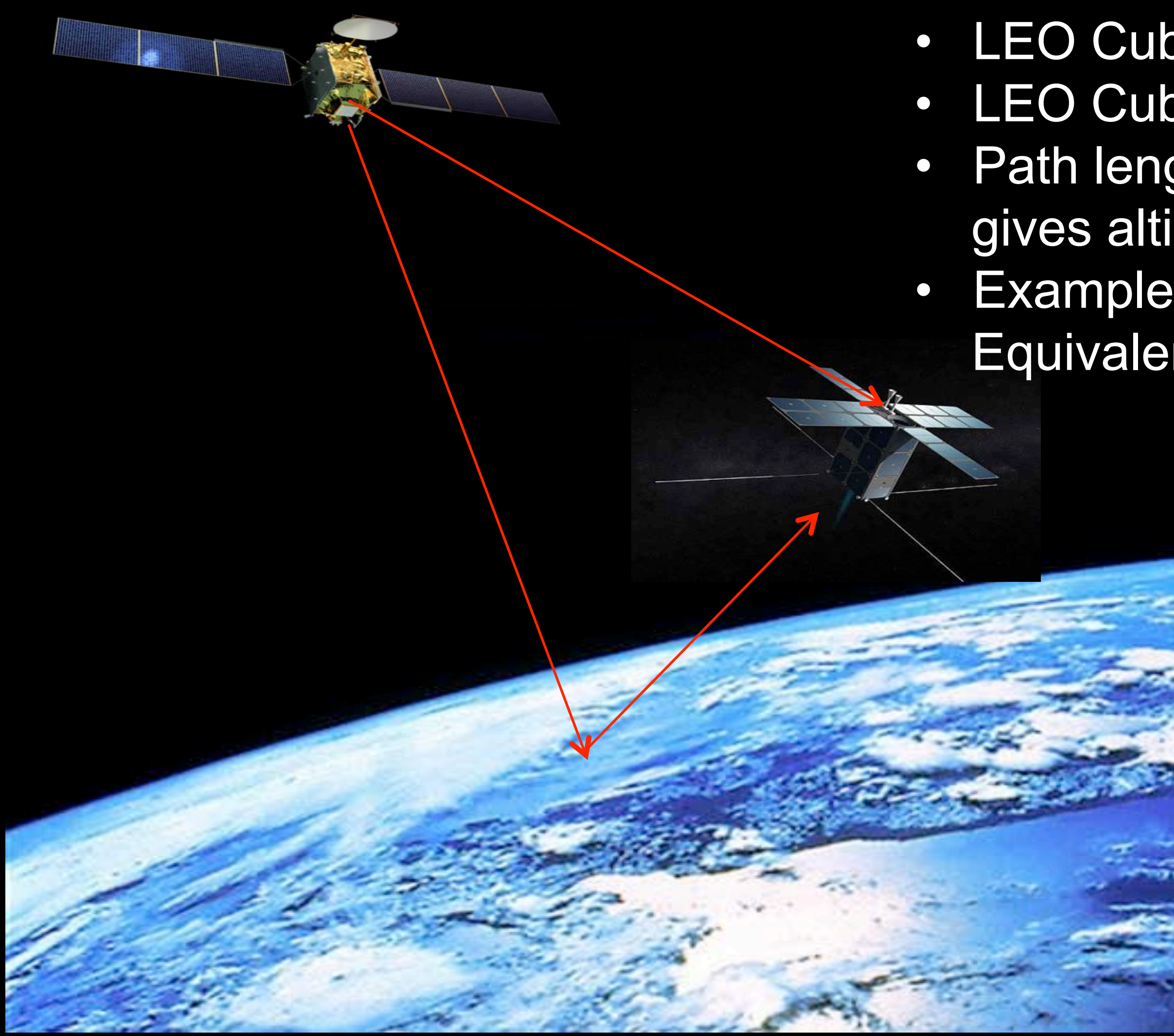
CYGNSS

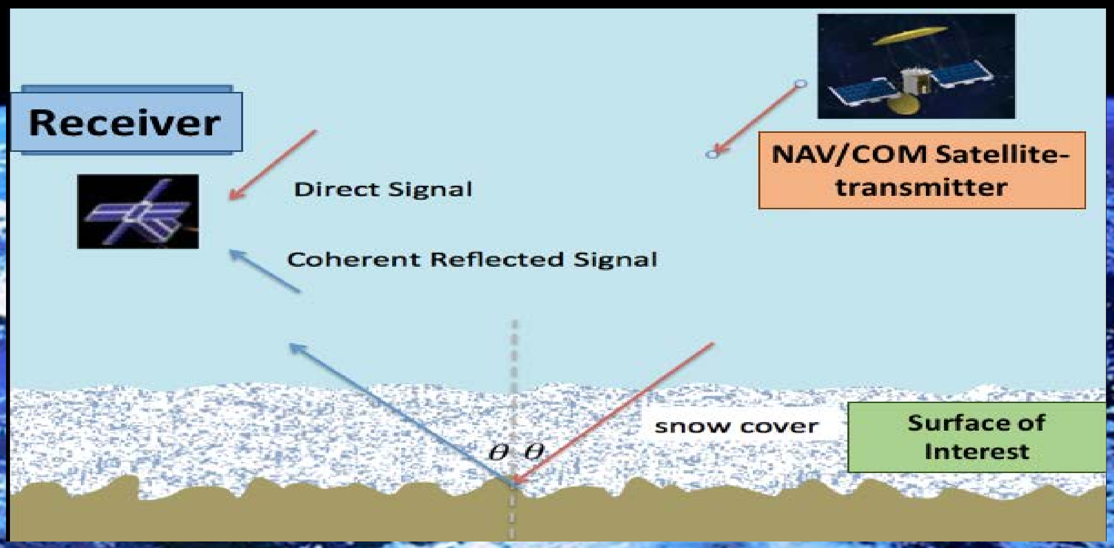
- NASA Constellation mission of 8 satellites
- Uses GPS signal as SoOp
- Objective is to measure ocean wind speed at dense spatial / rapid temporal coverage

Ruf. et al., 2012

MEASUREMENT CONCEPT FOR GEO SIGNALS

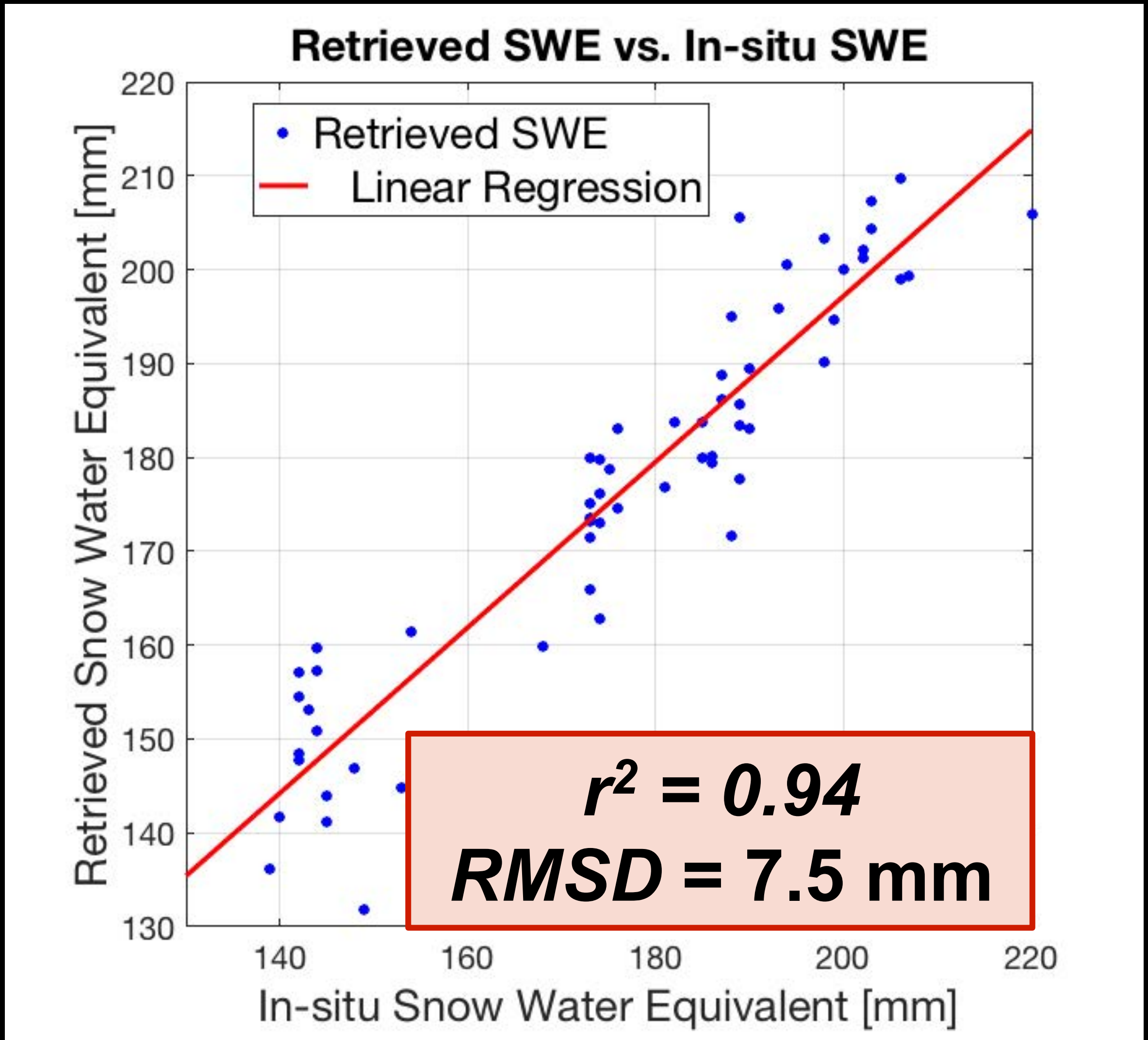
- GEO-based Comsat transmits signals
- LEO CubeSat receives both direct signal and reflected signal
- LEO CubeSat also has Precision Orbit Determination (POD)
- Path length difference between the two signals (plus POD) gives altimetry
- Example Use Cases: Sea Surface Height and Snow Water Equivalent





SWE from VHF/UHF SoOp

Fraser Experimental Forest

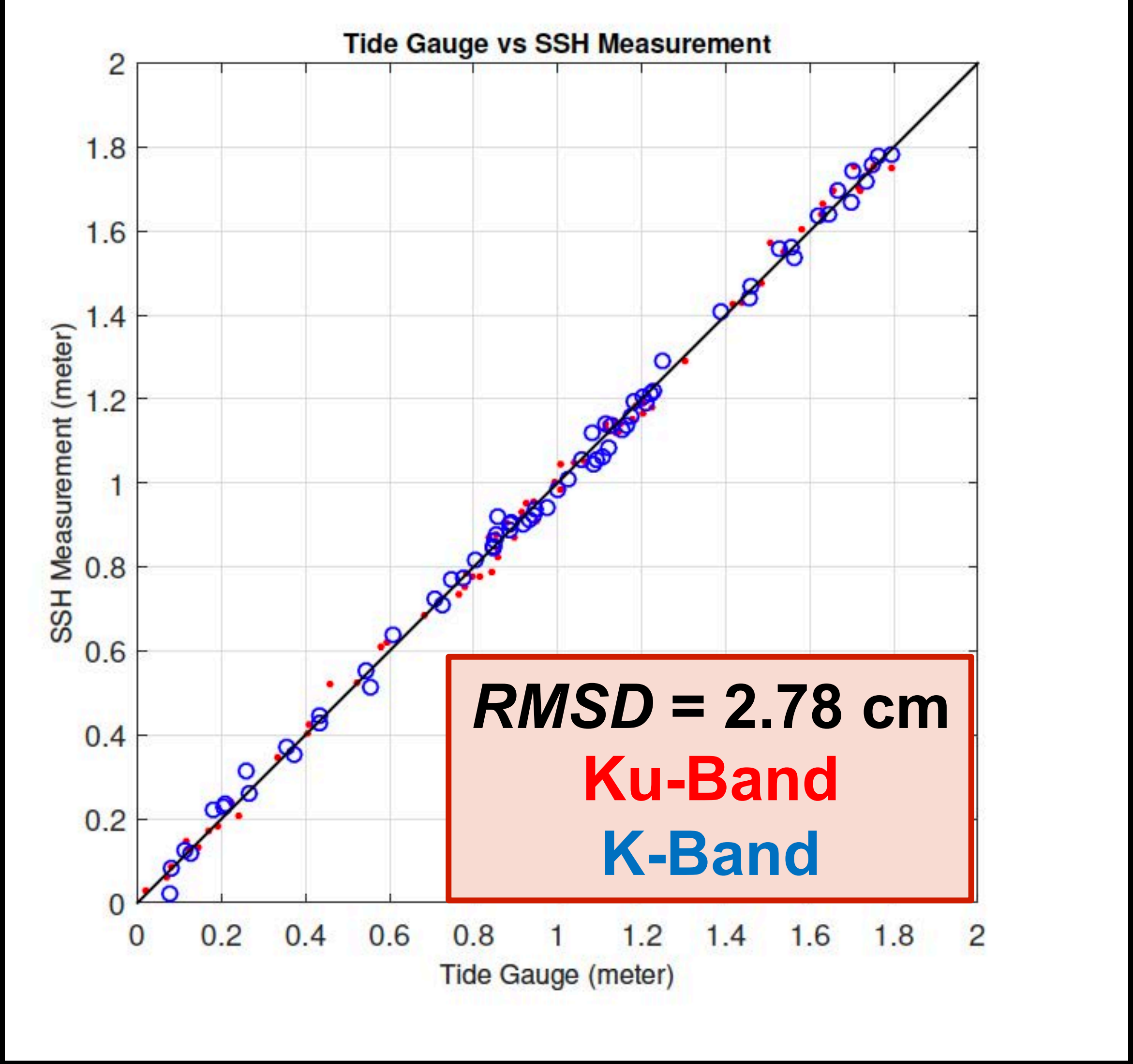


- SWE = Snow Water Equivalent
- SWE was found to be linearly related to phase change in the SoOp measurement
- At these frequencies, radar and radiometer are limited

Shah. et al., 2017

SSH FROM WIDEBAND KU/K BANDS SOOP

Platform Harvest



- SSH = Sea Surface Height
- SSH can be computed using time delay between direct and reflected signal
- Use of 400 MHz wide DirecTV spectrum ➔ SoOp is coherent over wide bandwidth

Ho. et al., 2018

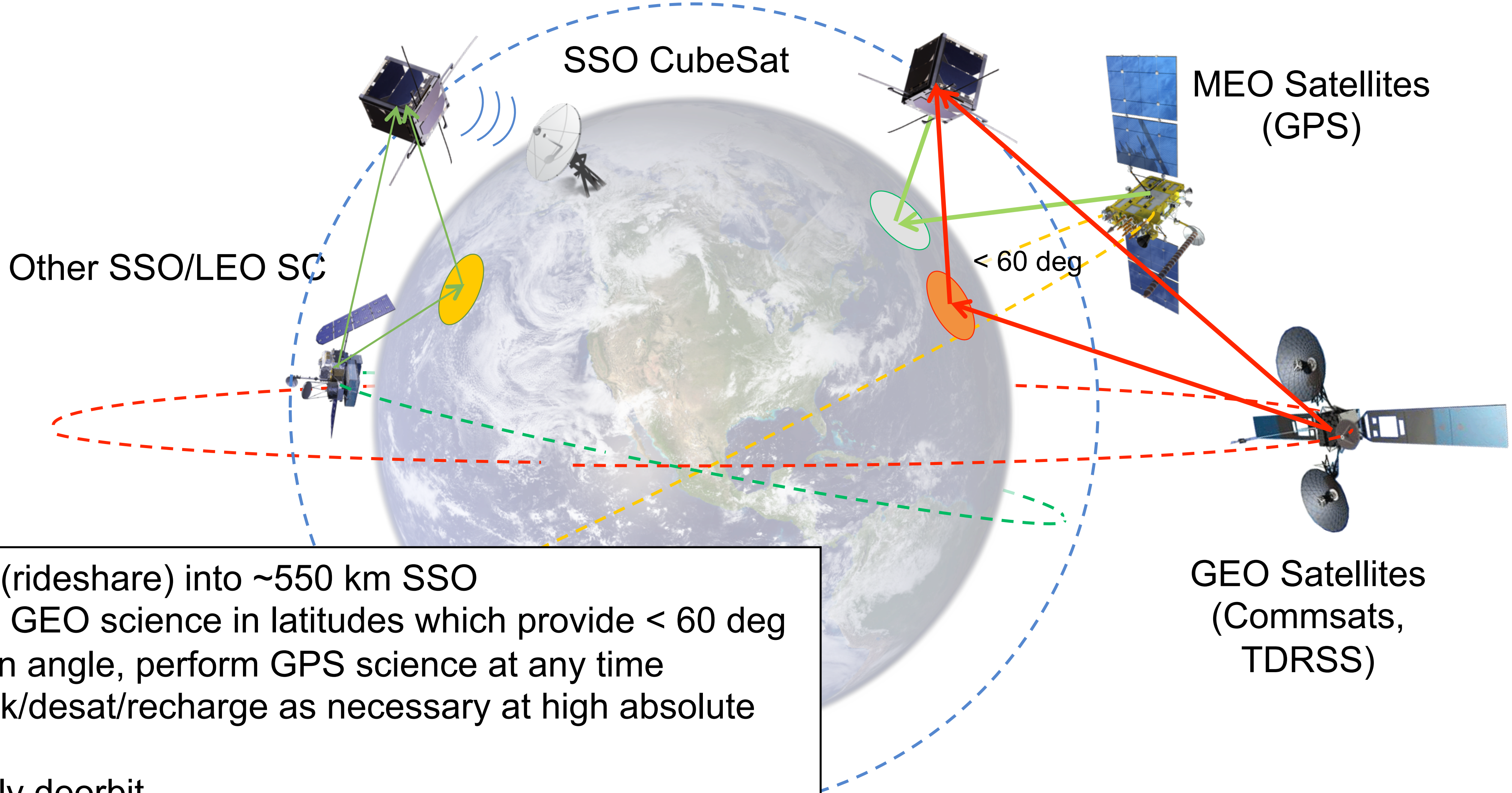
Mission Requirements

- Pathfinder for a constellation
- Launch date: Near-term (~3 yr from now)
- Mission lifetime: 10 yrs (orbit/ConOps), ~2-3 yrs (hardware)
- Orbit: Circular, 550 km sun-synchronous, dawn/dusk ideal but not strictly required
- Size: 6U-class spacecraft; Class D
- Measurements: L-band & Ka/Ku-band capability, UHF telemetry/cmd
- Data latency: Event processed/identified/downlinked in 30 min (for USA)
- Pointing requirements: 0.3 deg knowledge, <0.3 deg control, slew ~4-5 deg/min
- Position knowledge requirements: ~m on-orbit, ~cm ground post-processed
- Program requirements or concerns:
    - De-orbits: Passive de-orbit
    - Launch vehicle constraints: Rideshare to 550 km SSO using 'standard' 6U P-POD

Science Scenario/ConOps

- CubeSat in LEO, receiving reflected signals from other spacecraft
  - GEO (Comsats, TDRS) [this is the driving case]
    - Observe when signal is incident at no more than 30 deg, this is dependent on frequency, update position/downlink/charge batteries at high latitude
    - Need 2 antennas per frequency band, to measure delay between reflected and direct signals
  - MEO (GPS)
    - Can observe at any location
    - GPS signal includes timing data, differencing not required
  - LEO SC
    - Can observe when in vicinity of a LEO SC, similar angle constraints applied
- Passive listening, autonomously determining the best source for the next pass, and reconfiguring to take the proper measurement
- Listen, process data onboard and downlink products

SCIENCE SCENARIO/CONOPS



- Launch (rideshare) into ~550 km SSO
- Perform GEO science in latitudes which provide < 60 deg reflection angle, perform GPS science at any time
- Downlink/desat/recharge as necessary at high absolute latitude
- Passively deorbit

Mission Architecture

- 6U single-string CubeSat (no propulsion)
- Sun synch, 550 km orbit
- 10 year mission with changing focus:
  - Initially a science mission
  - Then a vehicle for technology demonstration
  - Third act as an educational platform
- <u>Payload:</u> 2 tunable radios with three frequency bands (L, K, Ka) each
  - Each frequency band has 2 antennas, for a total of 6 payload antennas
- Science performed over ~half an orbit.
- Data downlinked during the polar passes via a payload Ka-band radio
- UHF radio for uplinks and contingency transmits and high-latitude science

Design - Power Modes

- Low-Latitude Science Mode (~30 min)
  - ON: 2x IRIS Rx (K/Ka/L), Vulcan Rx (UHF), GPS, CDH, ADCS, EPS
  - OFF: 1x IRIS Tx (Ka), Heaters
- High-Latitude Science Mode (~15 min)
  - ON: Vulcan Rx (UHF), GPS, CDH, ADCS, EPS, Heaters
  - OFF: 2x IRIS Tx/Rx
- Downlink Mode (~8 min)
  - ON: 1x IRIS Tx/Rx (Ka), Vulcan Rx (UHF), GPS, CDH, ADCS, EPS
  - OFF: 1x IRIS Rx (K,Ka,L), Heaters
- Standby/Safe
  - ON: Vulcan Rx (UHF), CDH (low-power), ADCS, EPS, Heaters
  - OFF: 2x IRIS Tx/Rx (K,Ka,L), GPS

Design Requirements (Detailed)

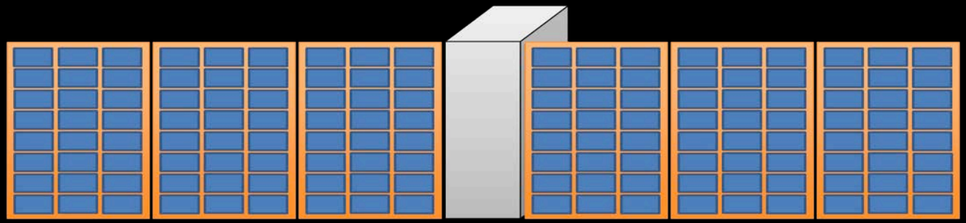
- Acquire at least 300 GB of data per receiver in a 30 minute science pass
  - Science passes require 2 receivers for 600 GB total
- Process data in near real time (to significantly reduce data volume)
  - Initially, simple tasks like feature / edge detection
  - Later adapt subsequent observations based on features detected in the data
- Adaptively reprogram data processing, e.g.:
  - Account for the observation schedule
  - Respond to features detected
  - Account for onboard resources (power, downlink, etc.)
- Accommodate significant updates to science observations, data processing, scheduling
- Maintain reliable platform
  - Handle routine satellite tasks
  - Manage science scheduling and processing

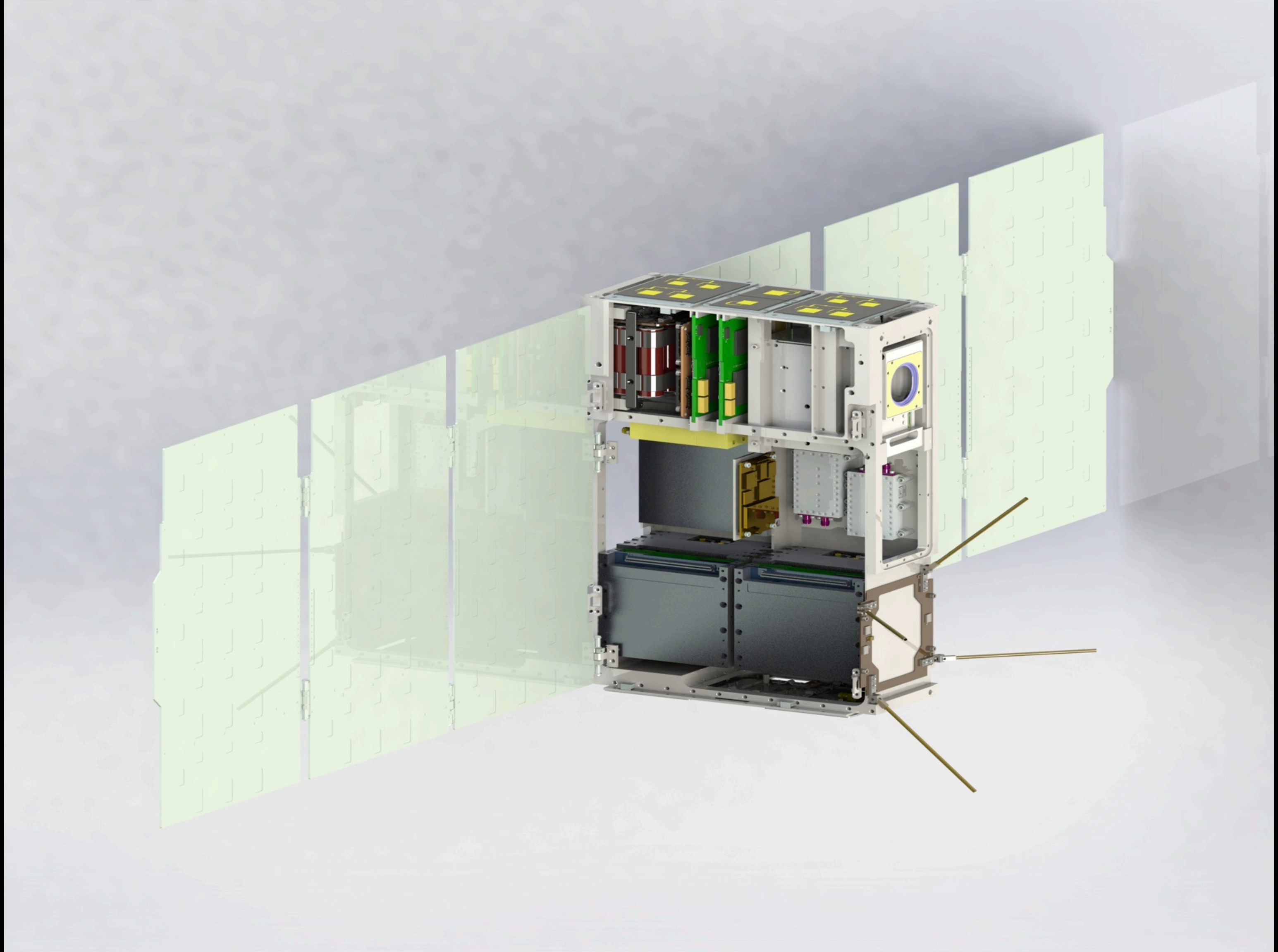
Design Assumptions

- Utilize COTS components
- Utilize Open Source software
- Reconfigure on the fly
    - Support both minor and major updates to science processing
- Handle routine satellite tasks with low power general purpose flight computer
- Real Time Operating System (RTOS) may not be necessary
    - Balance real time needs, CPU capability, and developer productivity
- Science processing with dedicated computational workhorse
    - Ingest, process, and store large quantities of data
    - Host multiple processing algorithms (not necessarily concurrently)
    - Accommodate significant upgrades to algorithms over time

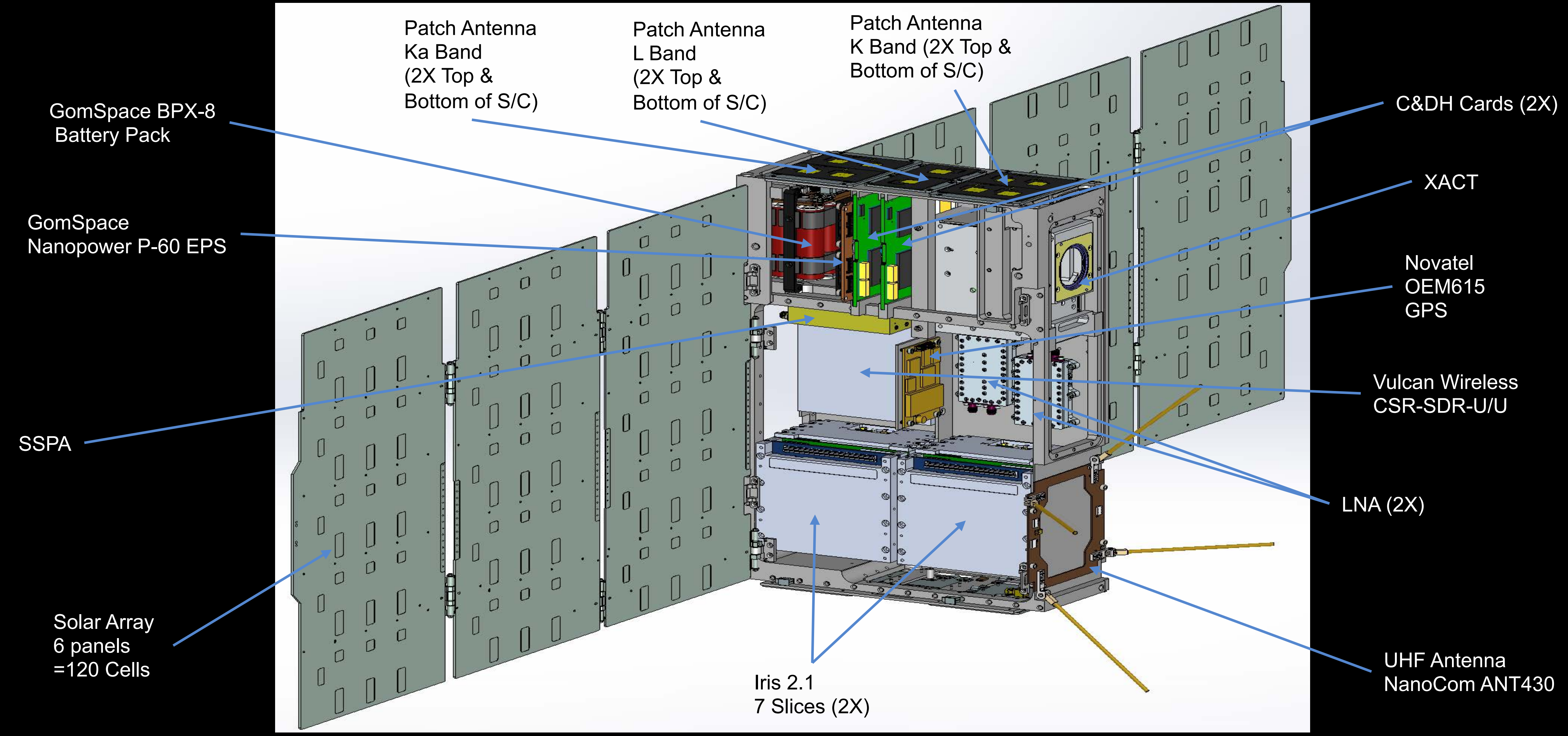
Design- Key S/C Components/ Characteristics

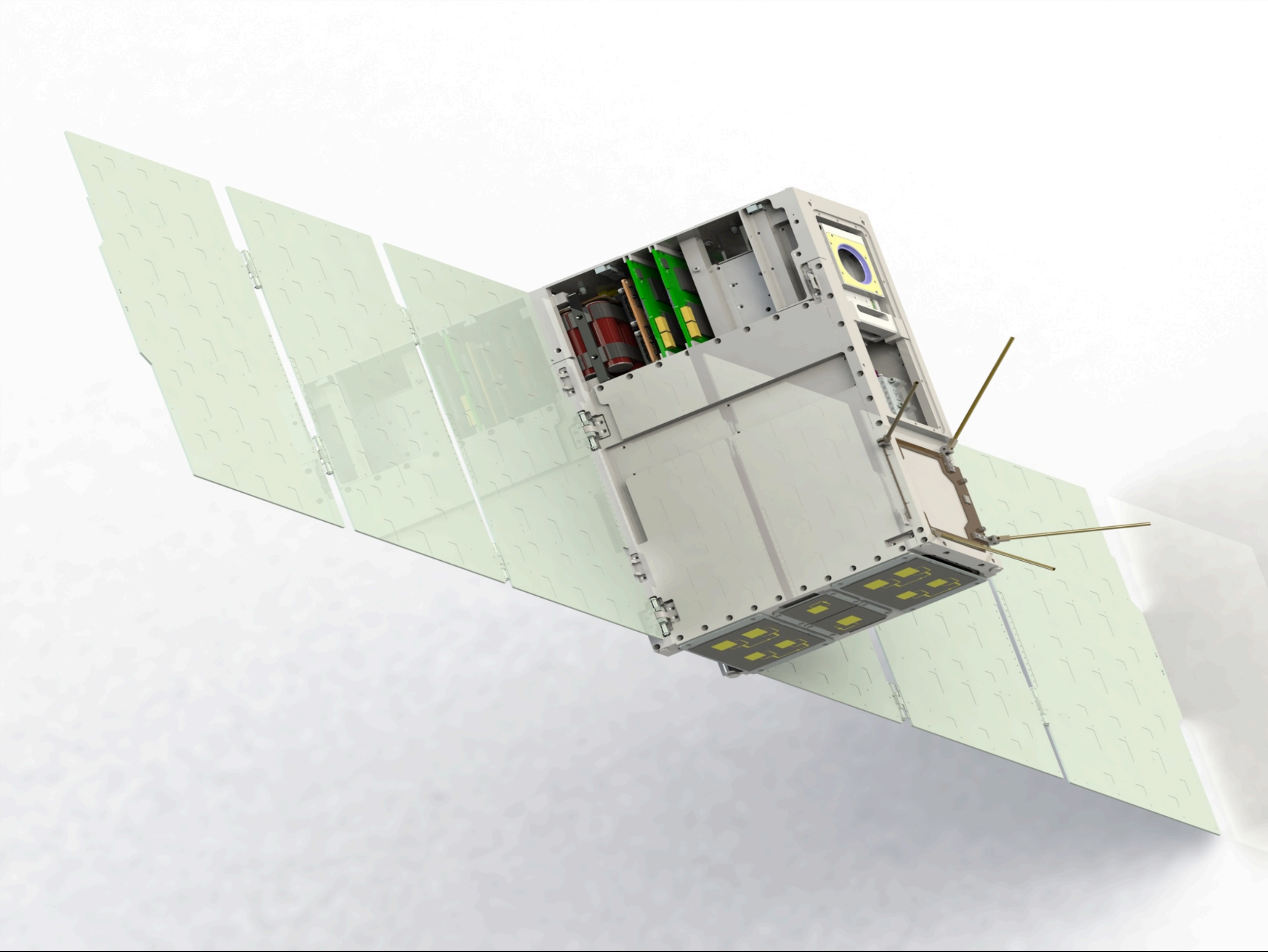
- Payload: 2x Iris CubeSat Radios
  - Rx: K, Ka, L
  - Tx: Ka
- Telecom: Vulcan Radio
  - Tx/Rx: UHF
- Power:
  - BCT Solar Arrays (2x wings of 3x panels of 2U x 3U)
    - 146 W BOL, 114 W EOL
  - Energy Storage: 65 Whr BOL, 52 Whr EOL
- Thermal: Active heating, passive cooling (-20-55^{o} C)
- ADCS: BCT XACT
- C&DH:
  - Control OBC and workhorse ARM/GPU
  - 2 TB SSD





DESIGN: CONFIGURATION





Summary

- Presented a pathfinder SoOp mission concept
- Follow-on work:
    1. Add more frequency bands
    2. Add more science applications
    3. Flight Demonstration
    4. Repeat Steps 1-3
    5. Build and fly constellation