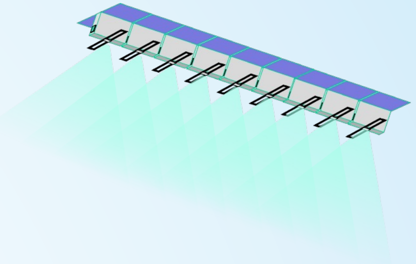

Overview of Flexible Configuration Distributed Synthetic Aperture DBF Radar (FlexDSAR)

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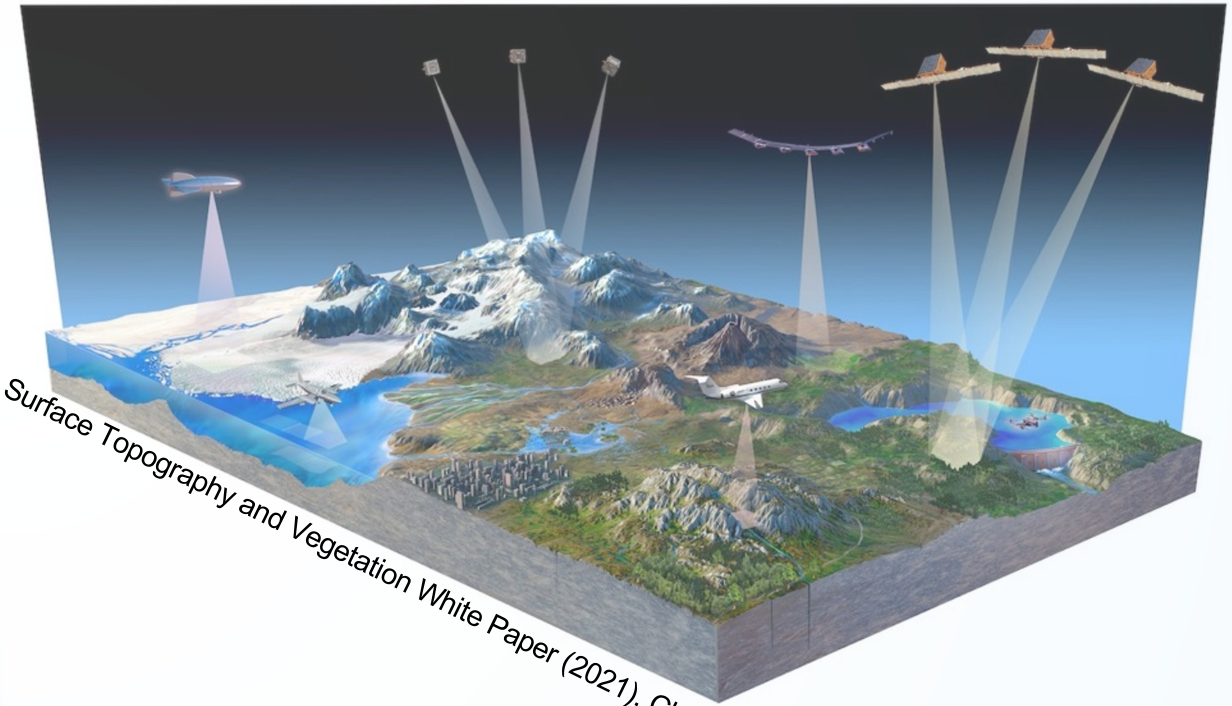
Research Rationale and Potential Applications

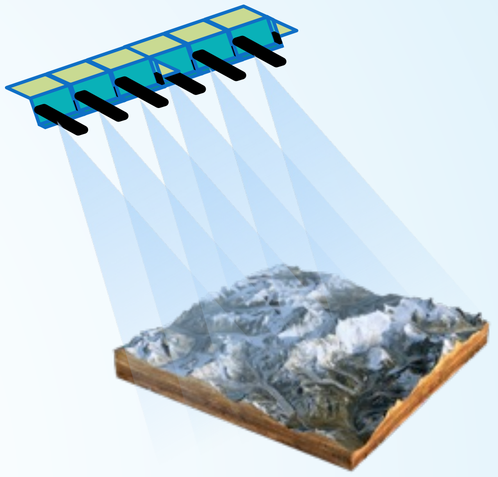
- Surface Topography Vegetation (STV) Incubation Study report recommends flexible observation strategies to address the needs of STV Targeted Observables (TOs)
  - TOs include surface topography, vegetation 3D structure and biomass change, ice surface topography, snow accumulation, permafrost dynamics, floods, etc.
  - Different radar frequency bands and imaging modes are needed to meet aspirational goals
- This project aims to address technology development that is *reconfigurable* and *frequency-agnostic*
- The proposed FlexDSAR architecture will accommodate:
  - Global, frequent, and systematic coverage
  - Rapid acquisition of high-resolution data for priority target areas



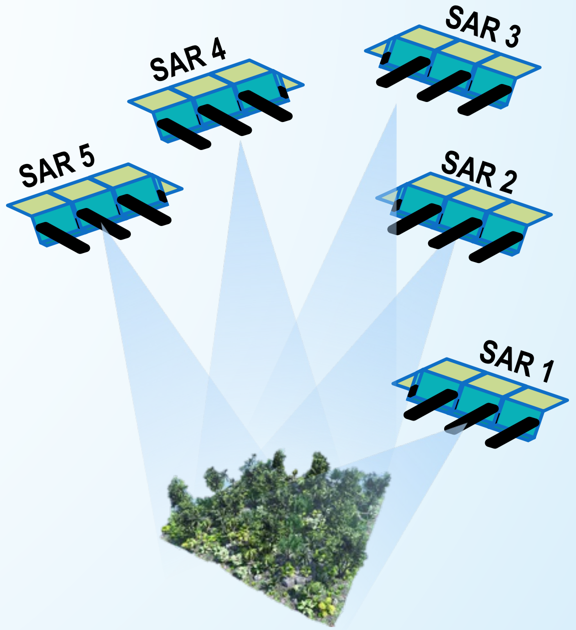
Surface Topography and Vegetation White Paper (2021), Chuck Carter

Example Science Observations

- Permafrost and snow accumulation monitoring with low frequency SAR
  - Construct a large antenna aperture with a cluster of CubeSats, each hosting an antenna element
  - The CubeSats can be docked or undocked depending on the separation of the antenna elements, which is a function of the radar wavelength



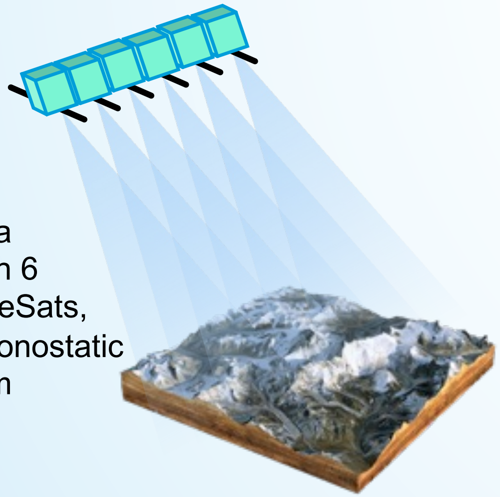
- Forest structure monitoring using TomoSAR imaging with 5 clusters of L-band CubeSats
  - Each SAR system consists of a cluster of docked CubeSats to form a large antenna array for higher transmit power
  - Vertical resolution of the 3-D vegetation map depends on the number of SAR systems and the separation between the systems



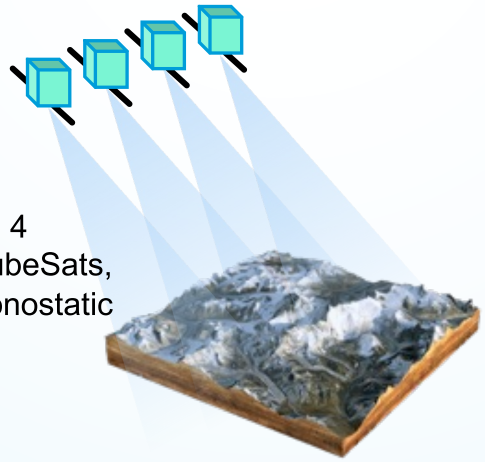
Distributed Aperture System Architecture Considerations

- ***Multi-platform clock synchronization*** for coordinated imaging -- we will leverage the technology being developed by the DARTS IIP
- To accommodate the complexity of reconfiguring the platforms for a wide variety of imaging modes, careful design of the ***radar timing hierarchy*** and ***calibration across antenna elements and platforms*** are critical to orchestrate the coordinated operation of the radar elements
- ***Experimentation and flight demonstration*** on AIRSAR-NG will ensure the proper timing in the interleaving of transmit and receive events from multiple CubeSats.

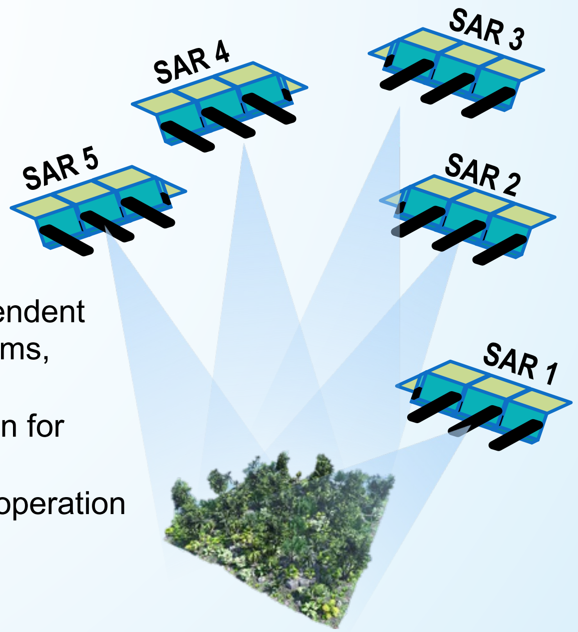
One antenna aperture with 6 docked CubeSats, forming a monostatic radar system



One antenna aperture with 4 undocked CubeSats, forming a monostatic radar system



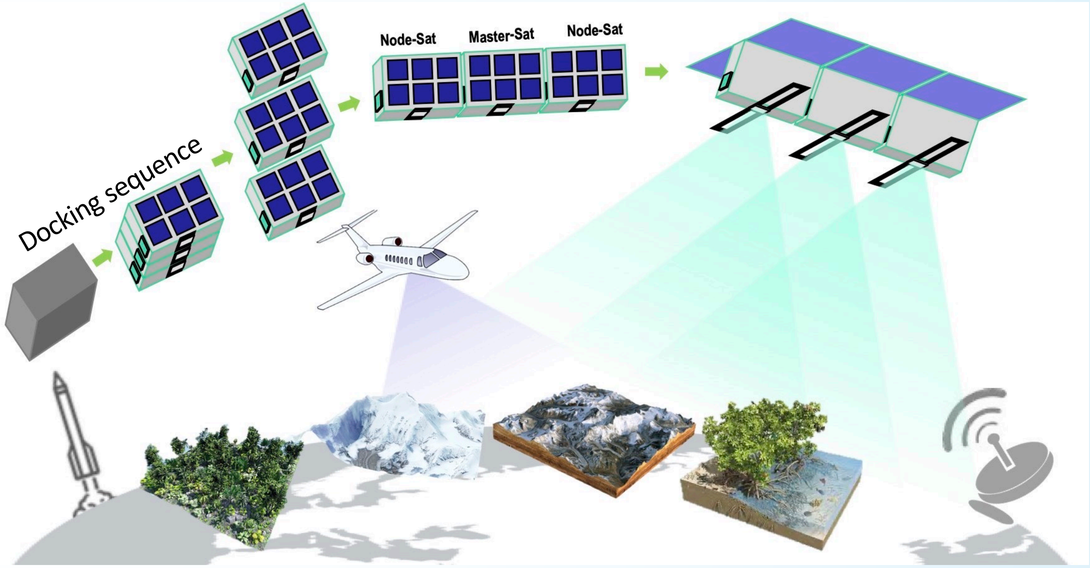
Five independent radar systems, forming a constellation for multi-static TomoSAR operation



Technology Development Objectives

- Design an architecture that is suitable for implementation on low cost distributed platforms such as CubeSats, achieving a ***large synthetic aperture via docking of multiple CubeSats***.

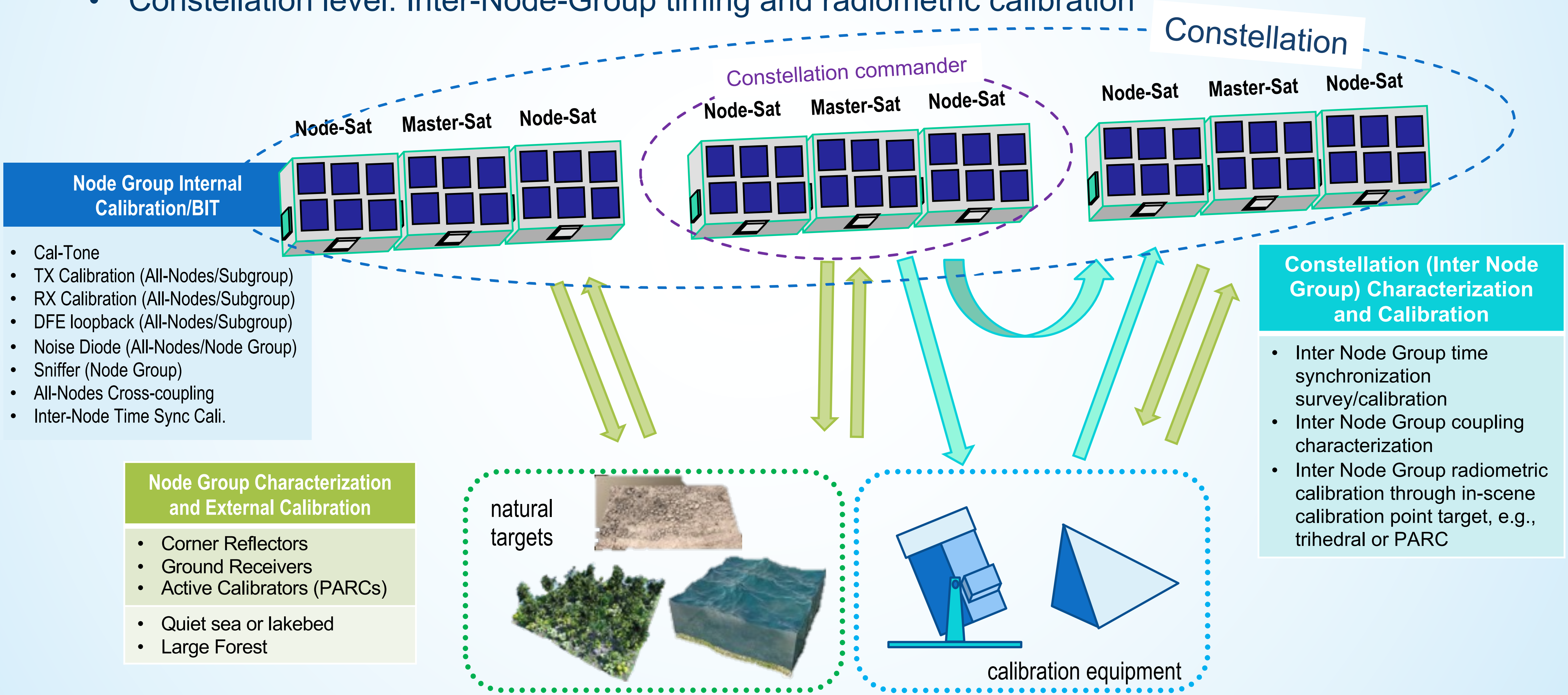
- Develop ***digital beamforming electronics*** that are flexible and scalable across a large frequency range including P & L-band, reconfigurable for different imaging modes, and reconfigurable for resolution, and spatial coverage.



- Leverage FlexDSAR technology to upgrade UAVSAR to generate science quality products to help mature technology and science algorithms in support of STV studies --> ***AIRSAR-NG***

FLEXDSAR Calibration/Built-In Test Scheme

- Calibration and BITs are defined at two levels in the FLEXDSAR architecture
  - Node Group level: internal calibration/BITs and external characterization/calibration
  - Constellation level: Inter-Node-Group timing and radiometric calibration

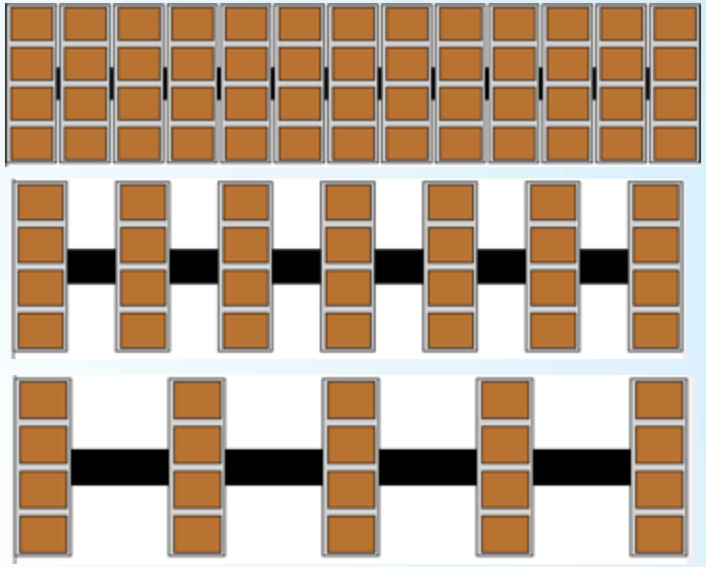


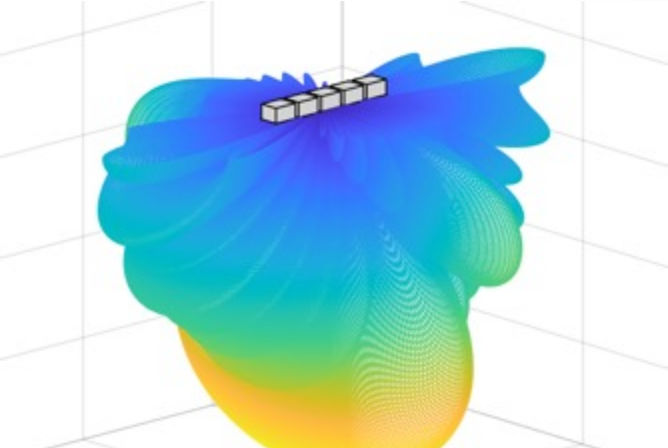
Digital Beamforming Algorithm Development

Conduct tradeoff study to determine the distributed aperture configurations that will meet the spatial coverage and radar sensitivity aspirations of STV TOs. Conduct a study of adaptive beamforming algorithms to construct an antenna array factor capable of mitigating grating lobes caused by sparse array.

- Develop 3D antenna pattern simulation tool that allows for the concatenation of a pre-defined number of platforms
- Develop multiple approaches to understand the mitigation of grating lobes caused by thinned arrays, including beamforming techniques, but also investigating other potential options such as developing timing methods to mitigate clashing radar returns and orthogonal waveforms

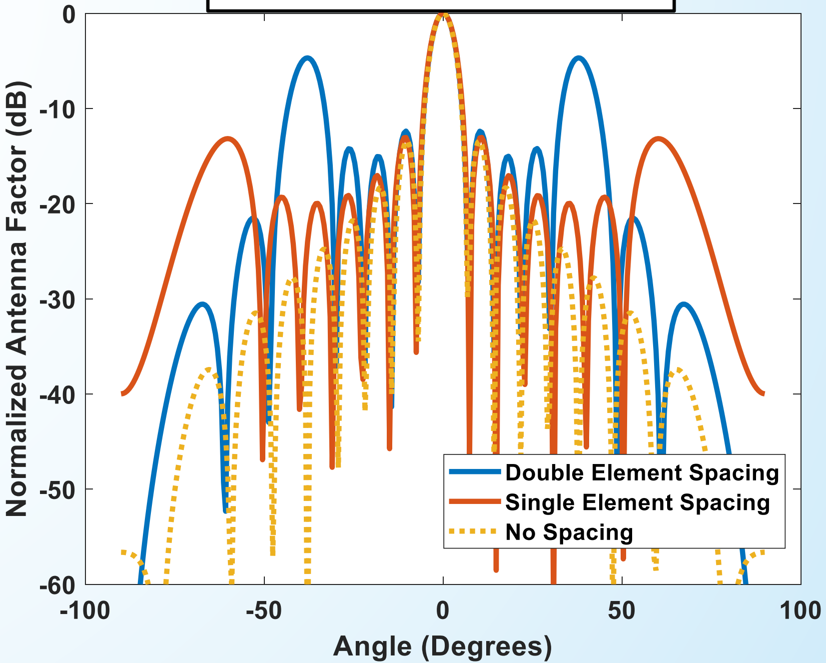
L-band Airborne Antenna





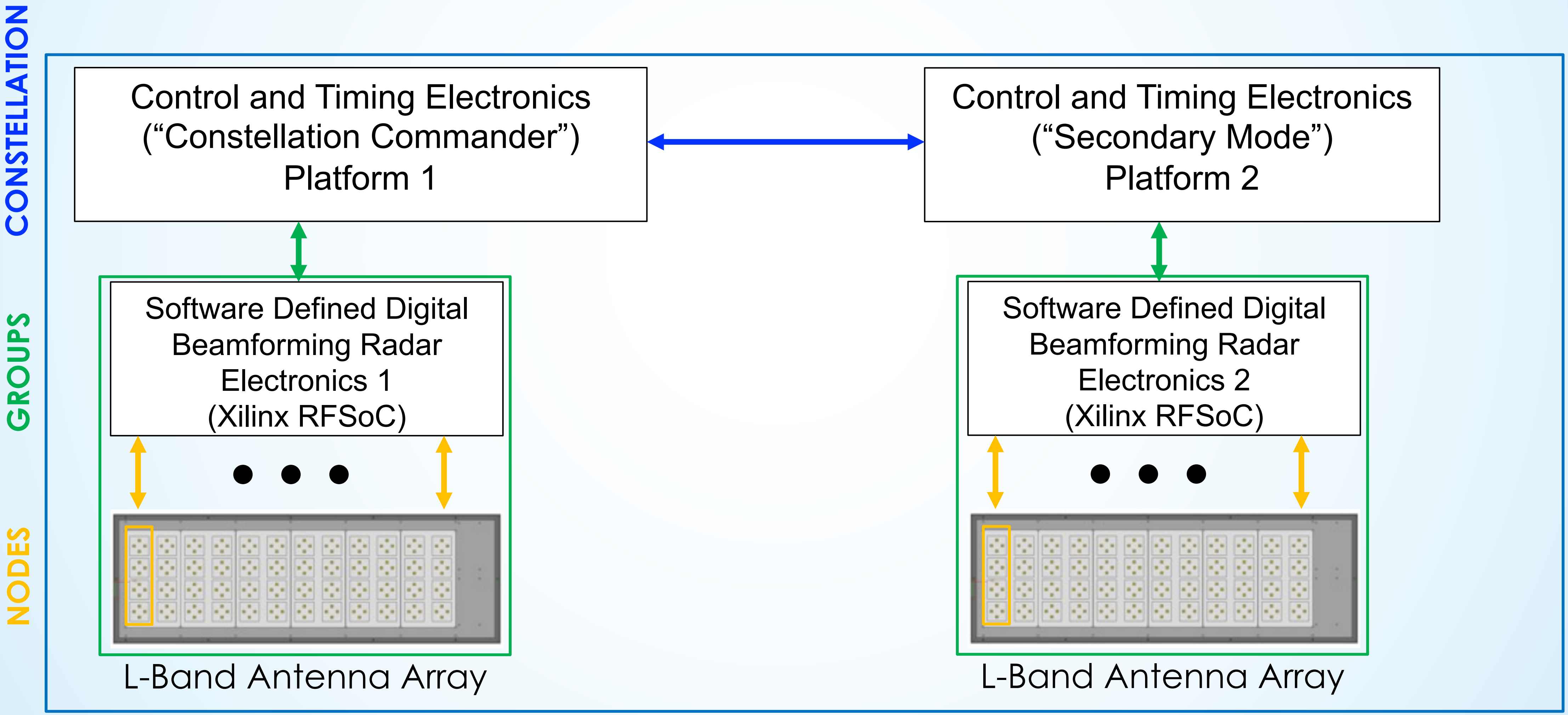
Radiation Pattern – 3D

Array Factors



Multi-Static Imaging Demo Configuration

- A multi-static radar will require exchange of commands, timing, position, and attitude information between the control and timing electronics in each platform.



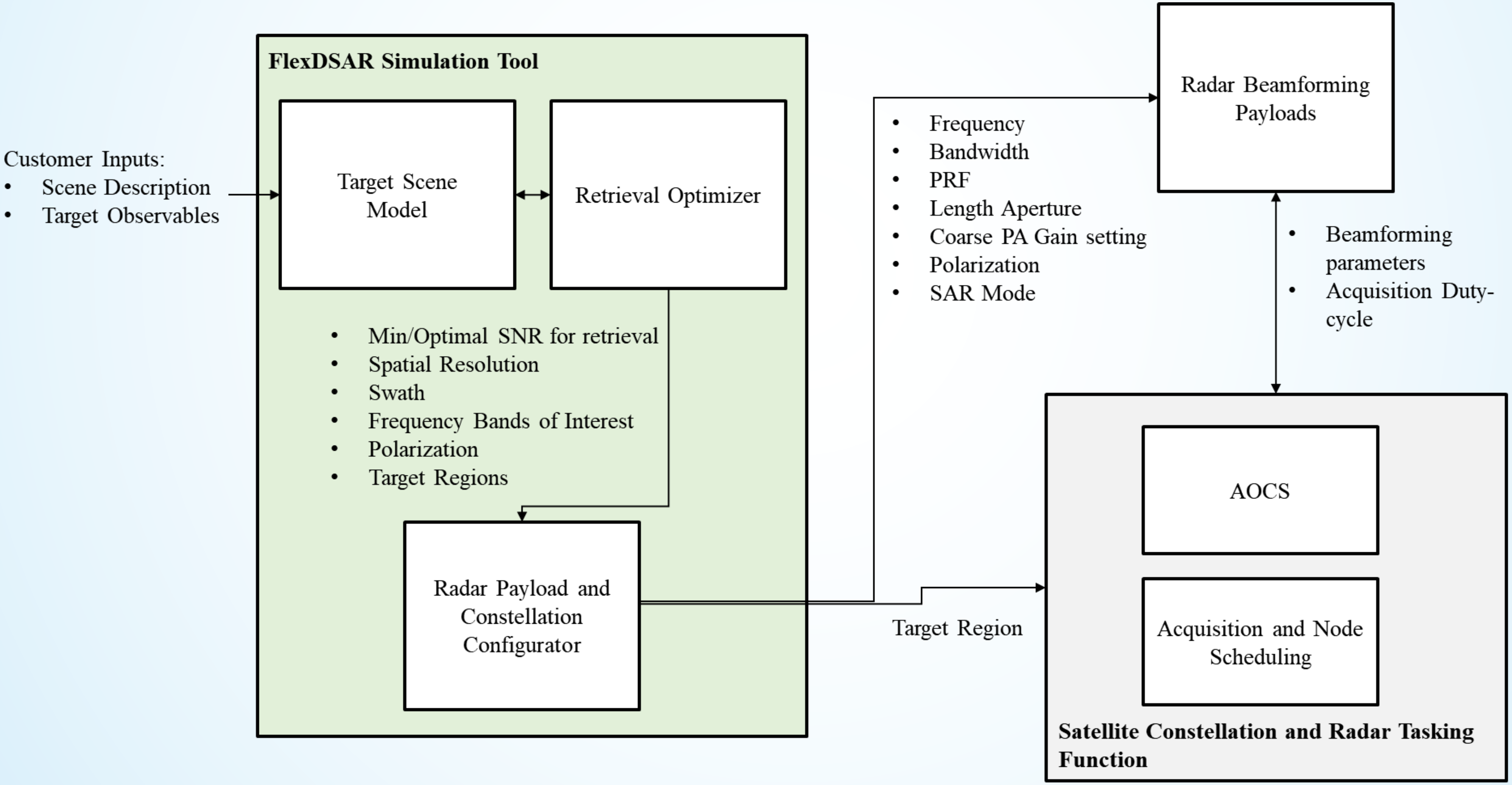
Software Defined Radar Electronics Development

Timing and Command Architecture

- Implementation builds on the DARTS SD (Software Defined) Radar
- Separate “constellation” functions from “node” and “node group” functions
  - Enable multiple radars to be synchronized and operated simultaneously
- Constellation responsibilities
  - Exercise **overall control** of data takes
  - Command the node groups via Ethernet
  - Provide **master timing** reference signals
- Node group responsibilities
  - Implement any operations with **strict timing requirements**
  - Control the transmit, receive, calibration and sync operations, including changes to radar parameters during a data take
  - **Time tag** received data
  - Calculate and implement TX/RX **beamforming** coefficients

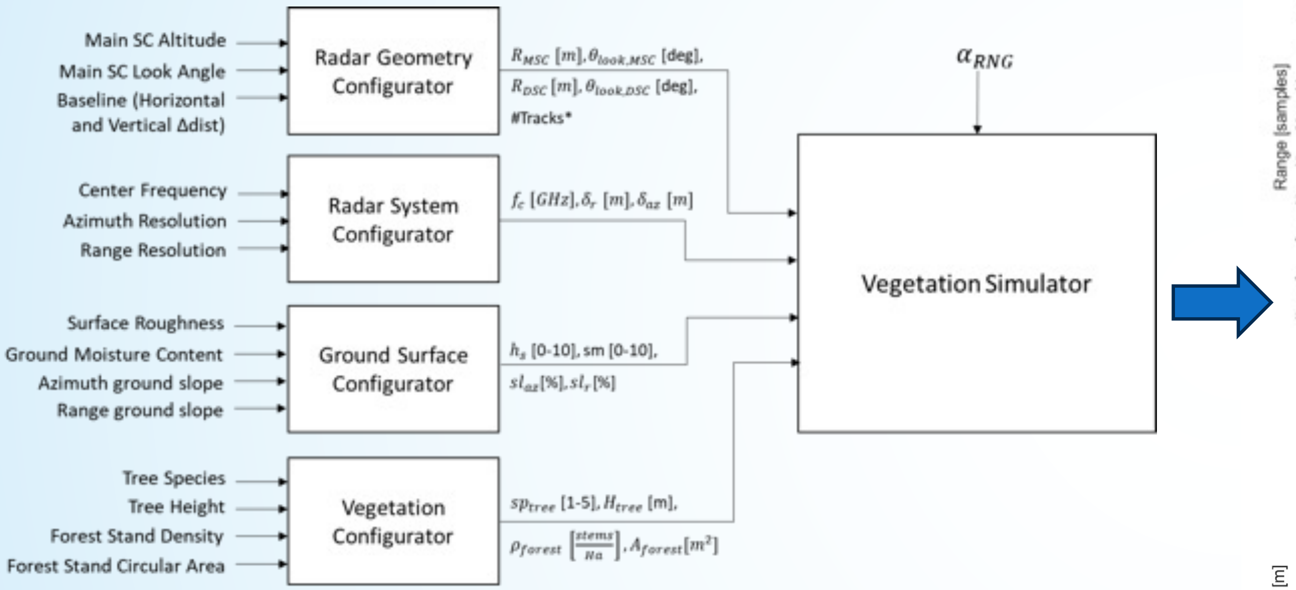
Multi-frequency & Imaging Trade Study

Build a unified simulation environment based on existing electromagnetic or signal models for select STV/SDC observables. This tool will be used to conduct sensitivity analyses and trade-space studies to arrive at optimal observation scenarios for the ensemble of these observables.

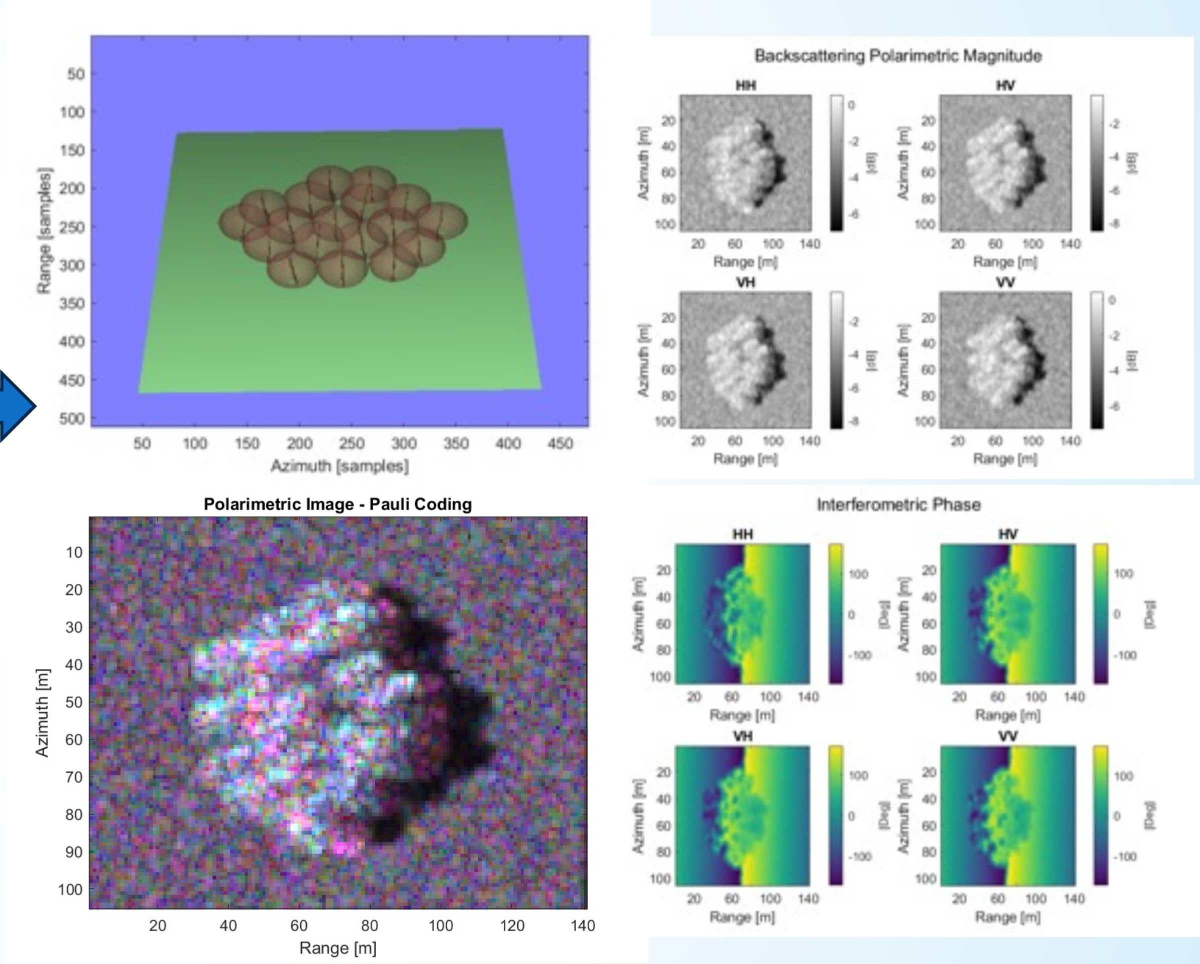


Multi-frequency & Imaging Trade Study (cont.)

Scenario and Inputs to the Simulator



Example simulated SAR images



Frequency of 1.3 GHz (L-band) used as input and look angle of 45 degrees.

Technology maturation paths for FlexDSAR and DARTS

FlexDSAR

Multi-freq. & imaging trade study → Technology for CubeSat-based Flexible configuration distributed synthetic aperture DBF radar → Demonstration on AIRSAR-NG & Proof-of-concept science products

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Suborbital radar capability for multi-sensor fusion campaigns and algorithm development

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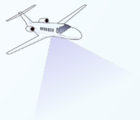
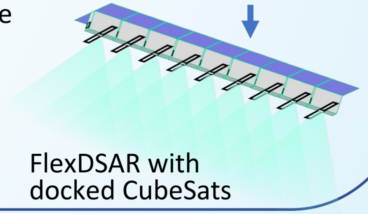
Technology infusion path for CubeSat-based FlexDSAR and cost study



FlexDSAR airborne testbed



FlexDSAR with docked CubeSats

DARTS

Multi-platform clock synchronization for coordinated imaging

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End-to-end TomoSAR & PolInSAR performance modeling & evaluation

↓

3D formation optimization study

STV: 3D observations from lidar, radar, and photogrammetry