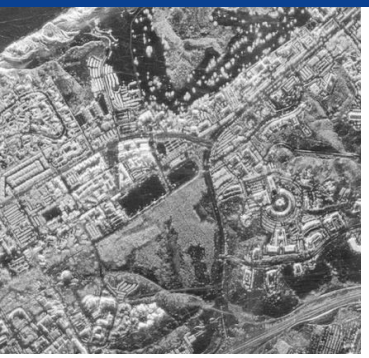
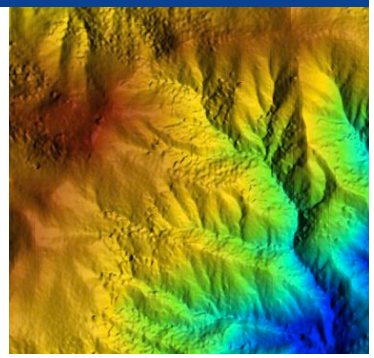
SRI International


SRI CubeSat Imaging Radar for Earth Science (SRI-CIRES): Initial Flight Demonstrations

CubeSat Developers Workshop
April 24, 2019

Presenter: Patrick Rennich (SRI)
PI: Dr. Lauren Wye (SRI)
PM: Simon Lee (SRI)

SRI Collaborators: Mark Schutzer, Leon Tao, Dave Watt, Jacob Cooper, Dean Jordan, Tyson Shimomi, Sam Phan, Mike Huff

ESTO IIP Team members

Physical Sciences Incorporated, NASA Airborne Sciences Program, Stanford University, JPL

SRI International

Earth Science Need for a Constellation of InSAR Sensors

- Time-variable geophysical processes require more frequent monitoring than a single space-borne InSAR sensor can provide
  - The revisit time of a single platform is restricted by orbital mechanics and spatial coverage requirements (e.g., every 16 days while achieving global coverage)
- Many science applications require sub-cm level deformation measurements, but each individual SAR measurement is corrupted by up to several cm of atmospheric noise.
  - Multiple acquisitions need to be averaged together to reduce atmospheric artifacts

InSAR Constellation Advances Solid-Earth Science by Understanding Geophysical Hazards

CIRES Address NASA Science Goal: Understanding Extreme Events including Earthquakes and Volcanic Eruptions

Sub-centimeter surface deformation measurements with high temporal resolution will advance our knowledge of critical Earth science questions related to natural hazards and resource mining activities.

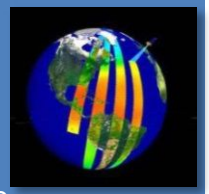
The Need for a Low-Cost Constellation of InSAR Satellites

Interferometric synthetic aperture radar (InSAR) is the only tool for measuring spatially dense deformation on a global scale.

Global spatial coverage is needed to capture the infrequent occurrence of natural and human-induced hazards.

Individual SAR satellites cannot provide the rapid revisit times required to characterize geophysical events.

On-orbit Demonstration Enables New Science Missions

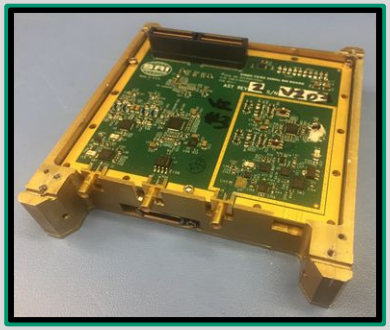


A large constellation of InSAR CubeSats with spatial-temporal flexibility is needed to properly characterize time-variable processes and improve predictive geophysical models.

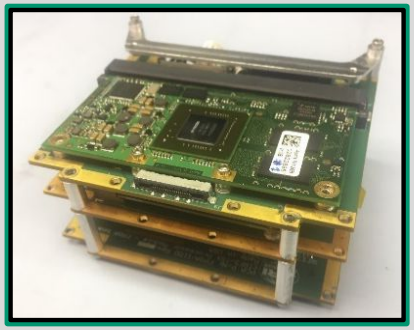
CIRES: CubeSat Imaging Radar for Earth Science

Miniaturized Synthetic Aperture Radar (SAR) payload for resource-constrained platforms
Designed to support interferometric (InSAR) operation from 500 km altitudes

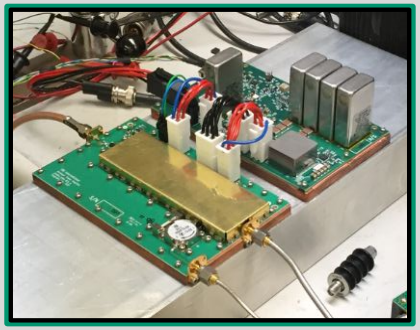
CubeSat SAR Payload advanced to 5 m resolution and extended up to 3.5 GHz



Tx/Rx Module: Transmit and Receive RF analog chains, calibration loopback circuits, integrated ADC and DAC capability.



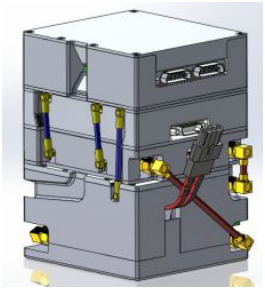
High Speed Processor Module: Power Regulation, FPGA, Data Storage, Multi-core Processor; >250 MB/s write-speed to > 1 TB non-volatile storage; >500 GFLOPs on-board processing



PA Module: 600 W peak (60 W avg), includes internal power regulation, power driver stages and RF power amplification (supports 2.9-3.1 GHz or 3-3.5 GHz)

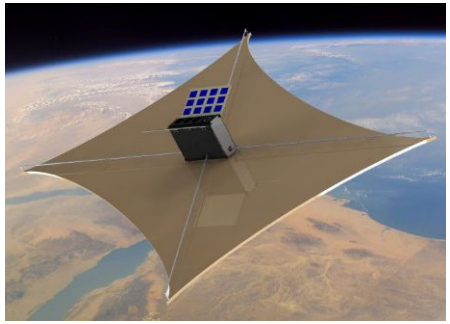
CubeSat SWaP: Radar payload electronics packaged into 1.3U CubeSat form factor

Designed to rapidly integrate with 16U bus and deployable antenna



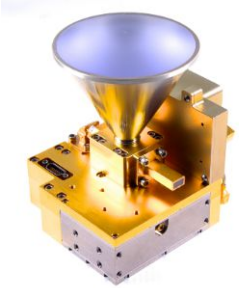
SRI SAR Electronics
(1.25U form factor)

+



~6.5 m^2 Deployable
Membrane Antenna

+



Ka-band downlink (320+ Mbps)

+

Long 16U bus

CIRES Key Technologies and Demonstrations

- Key Technologies
  - Compact S-band SAR instrument
  - On-Orbit Deployable Antenna (~6.5 m^2, Gain: >36 dB including losses)
- Instrument Demonstrations
  - CIRES SkySAR – SAR from a commercial aircraft platform**
  - CIRES UAVSAR – SAR from a group-II unmanned aerial vehicle*
  - CIRES CarSAR – SAR from a stake-bed truck*

10x30 km image, 9000 ft altitude, 20 m resolution, multiple looks, non-coherently averaged

* CarSAR test platform developed on NASA ESTO IIP funds

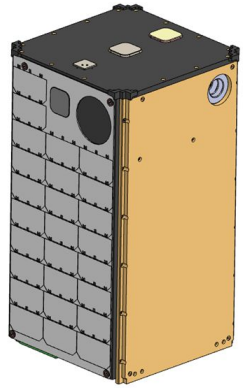
** Aircraft collections funded by SRI International

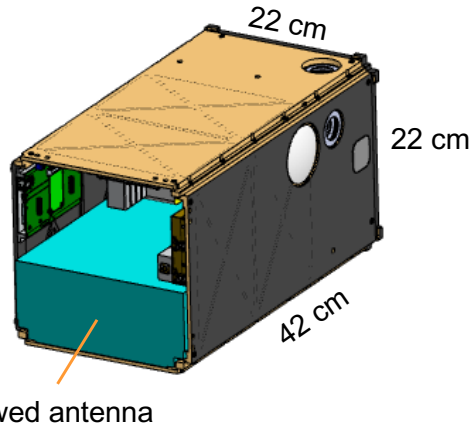
CIRES Space Concept

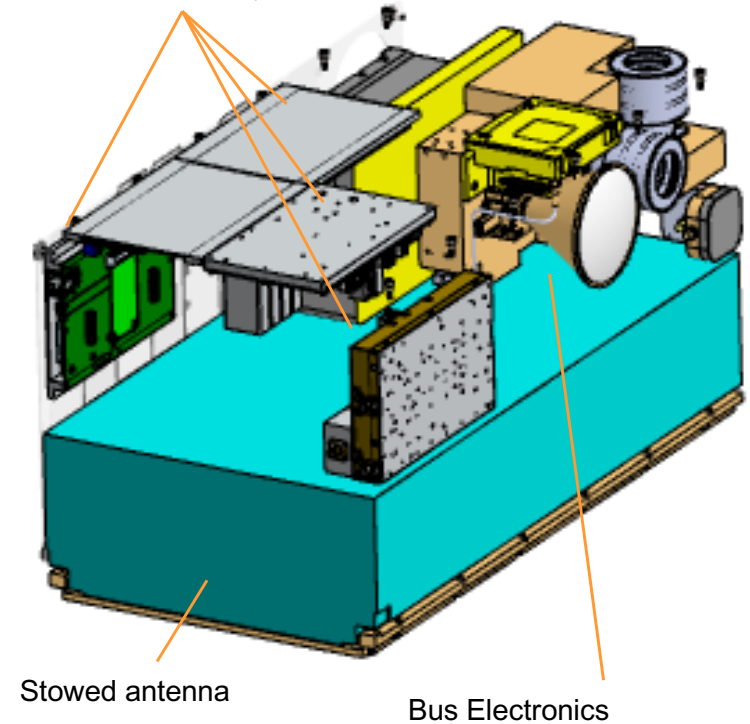
Designed to support interferometric (InSAR) operation from 500 km altitudes

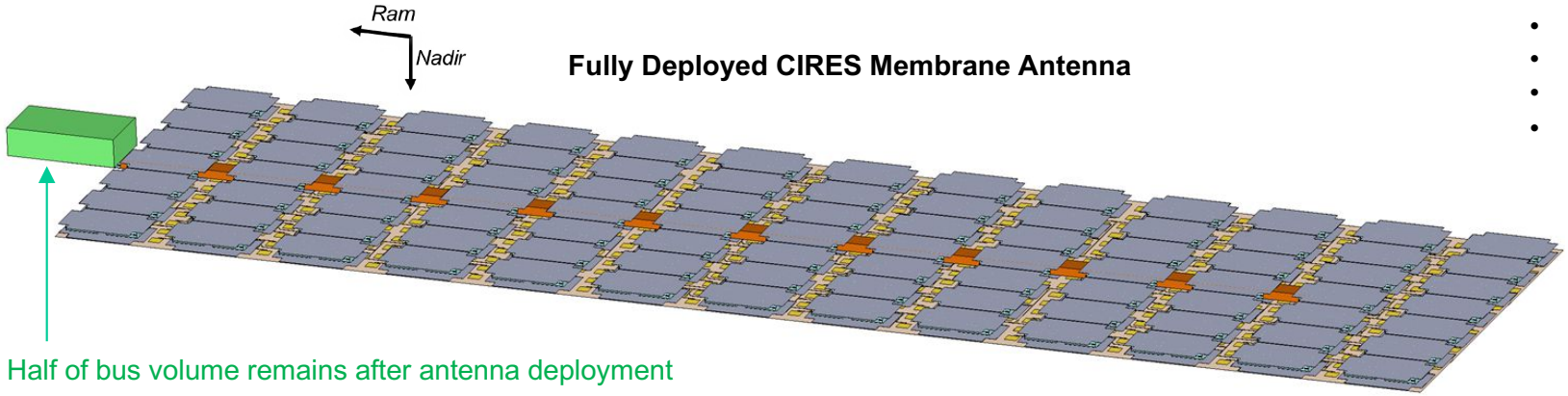
- Instrument designed for 16U CubeSat to facilitate high-gain deployable antenna (>38 dB)
  - Commercial CubeSat buses in 12U-16U form factors have been space-qualified.
- S-band (2.9-3.5 GHz hardware support; fits NTIA 3.1-3.3 GHz Active Earth Exploration band)

16U Bus









CIRES Science Relevancy Demonstration

July 2018: SRI IR&D-funded collection campaign to obtain scientific-relevant data for IIP processing validation

CIRES Kilauea Collection

Date: 3-5 July 2018, **Location**: Island of Hawai'i, Kilauea Volcano,
Frequency: S-band, **Bandwidth**: 12.5 MHz

- Dates: 30 June - 5 July 2018
- Location: Kilauea summit and rift zone
- Science utility:

  InSAR measurements of active summit deformation can inform subsidence and conduit collapse, processes that drive hazardous explosive eruptions and thus have a direct impact on the surrounding community.

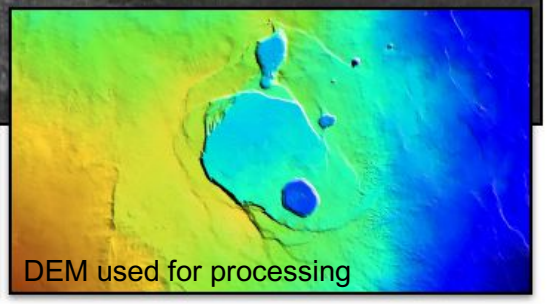
Accomplishments

- Collaborative mission planning:
  - Worked closely with USGS volcano hazard scientists to arrange and execute collections of scientific interest
- Collection campaign experience:
  - Initial integration of CIRES 12.5 MHz radar onto a Cessna 206 in approximately 6 hours
  - Final integration in approximately 1 hour
  - De-integration in 15 minutes
  - Five flights for test and mission collections
  - 15 collection passes on Kilauea summit
  - 1 collection at rift zone
- Instrument and processing validation
  - Backprojection imagery processed
  - Initial interferogram formed

7 km

Optical image from test plane

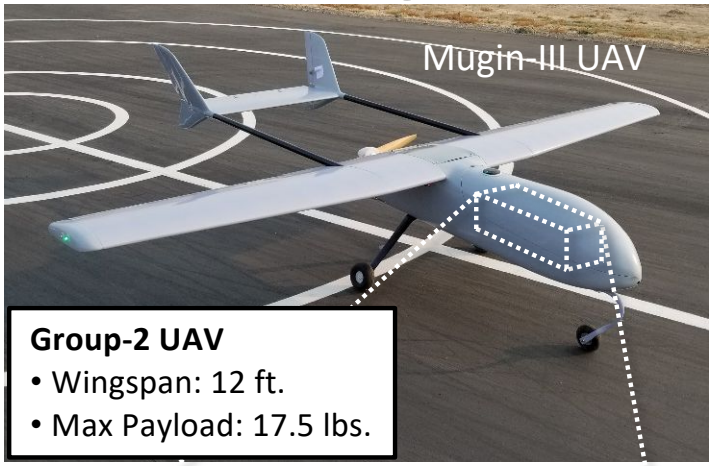

Cessna 206 platform


DEM used for processing

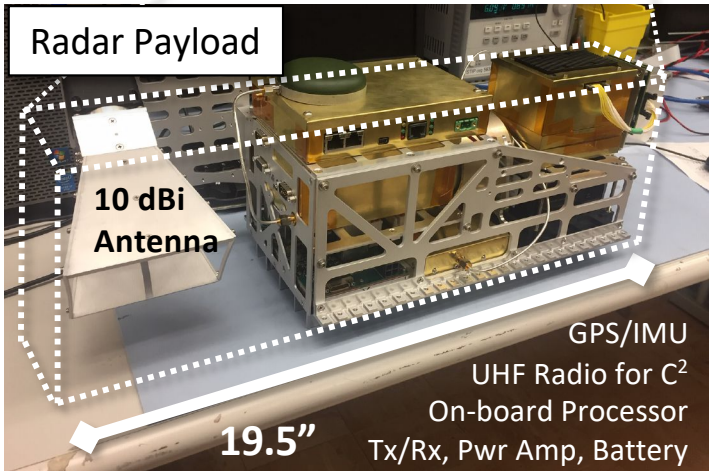
CIRES UAVSAR Demonstration

SRI IR&D to add second receive channel for GMTI

- **COTS Mugin III UAV**
  - **Built/tested by SRI**
- **Upgrade Path**
  - **200/500 MHz,**
  - **2nd Rx Channel**



Group-2 UAV
- Wingspan: 12 ft.
- Max Payload: 17.5 lbs.

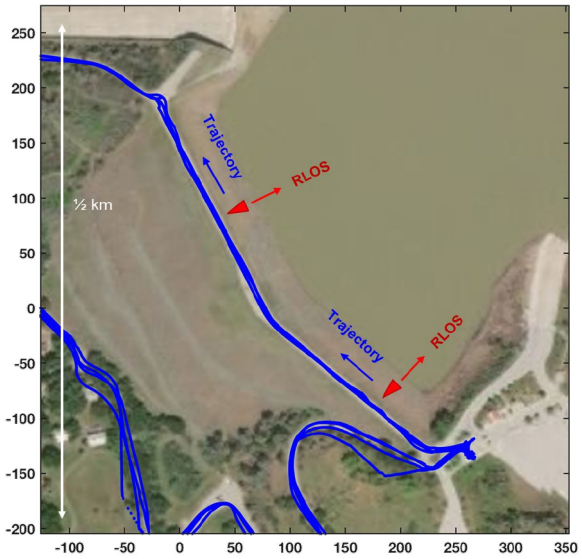


Frequency	S-band
Bandwidth	40 MHz (upgrade: 200 MHz)
Resolution	6×6 m (upgrade: 1×1 m)
Weight	16 lbs (includes 3 lbs. battery)
Power	60 W (ave) 600 W (peak)
Endurance	1.5 hrs (depends on battery)

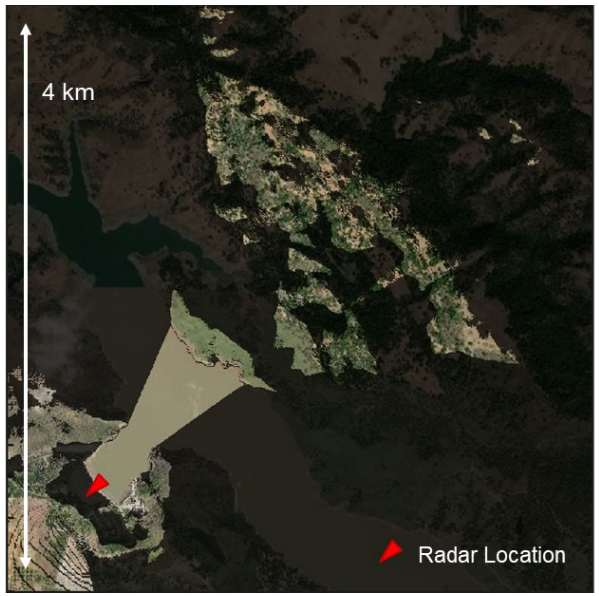
CIRES InSAR Capabilities evaluated from CarSAR

March 4, 2019: InSAR Verification at Anderson Reservoir, CA

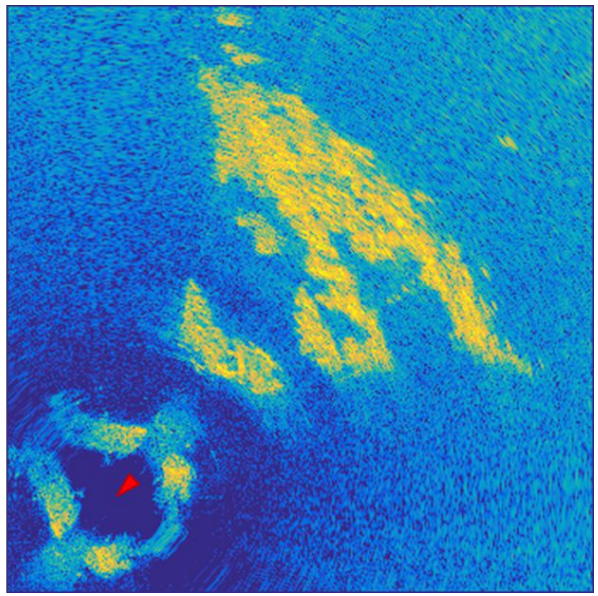
- CarSAR testing enables early diagnosis of interferometric instrument calibration and operation
- Anderson dam provides straight and level trajectory for CarSAR
- Natural terrain on far side of reservoir provides good test scene for InSAR



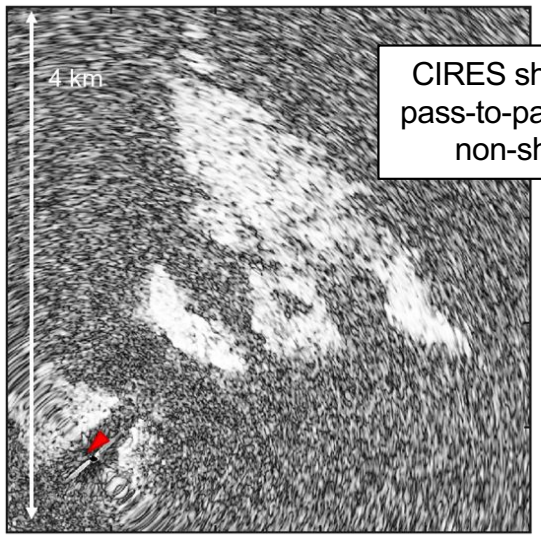
Test Site (with shadowing)



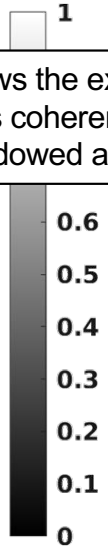
Radar Imagery



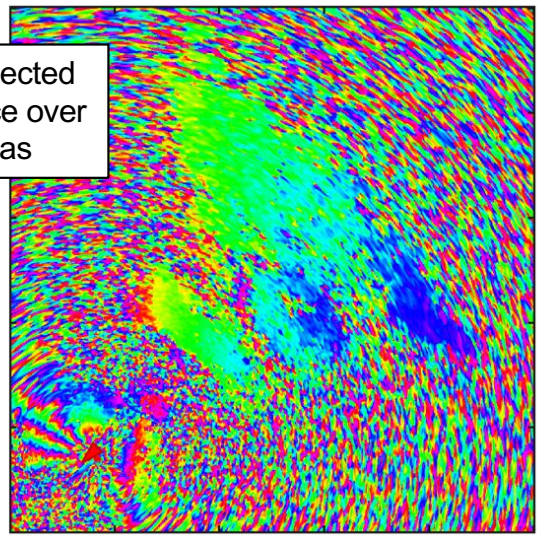
Coherence Magnitude

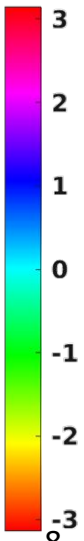


CIRES shows the expected pass-to-pass coherence over non-shadowed areas



Coherence Phase





Summary

- SRI-CIRES designed and developed for limited-resource environments (e.g., CubeSats, UAVs)
- CIRES instrument tested and verified on moving ground vehicle and airborne platforms demonstrating InSAR coherence
- CIRES instrument to be integrated with SIERRA-B UAV mid-2019
- UAV-based science relevancy demonstrations to be conducted in 2019 on NASA ESTO IIP funds
- CIRES on-orbit antenna in development

QUESTIONS?