Using Small Satellite Constellations for the Measurement of Aerosol and Cloud Interaction

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SmallSats:

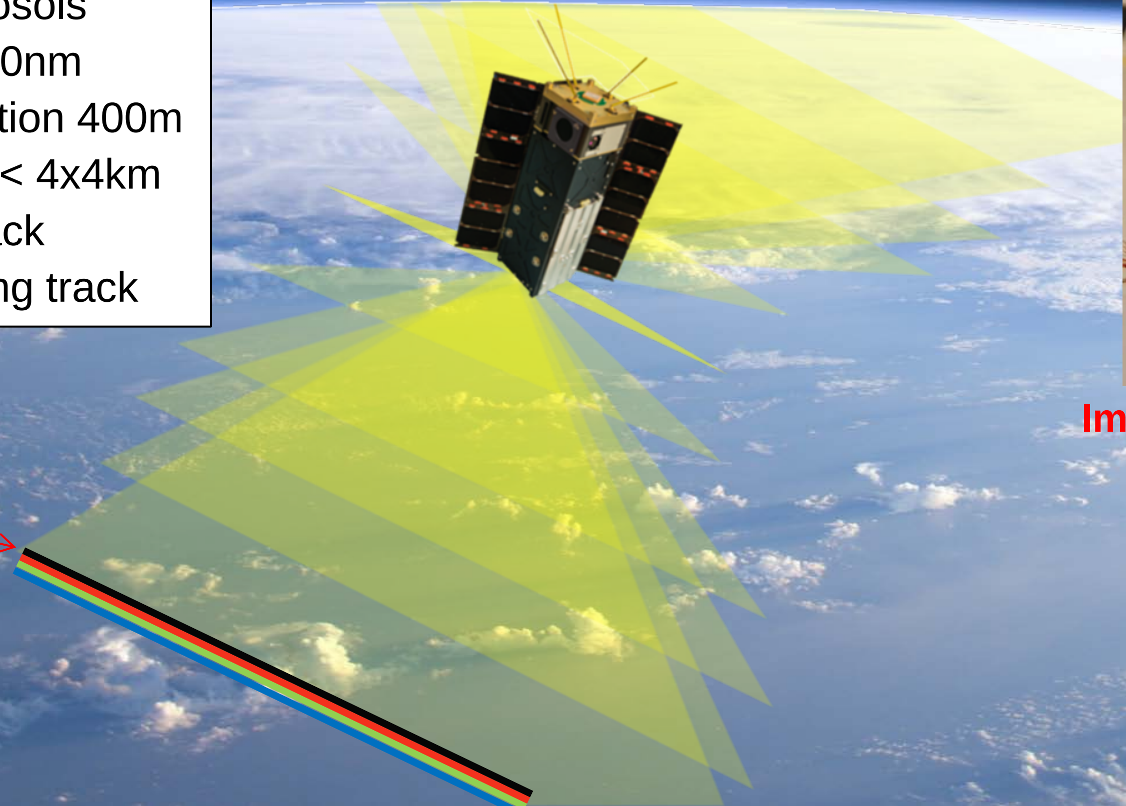
- Size of small satellites can vary from golf balls to small refrigerators
- Small satellites have evolved into real science tools for remote sensing measurements in multiple fields
- Their small cost allow for constellations that are not practical with larger platforms
- HARP as an example of science measurements from small satellite platforms
- Discuss a smallsat constellation concept for the measurement of the interaction between aerosol and clouds

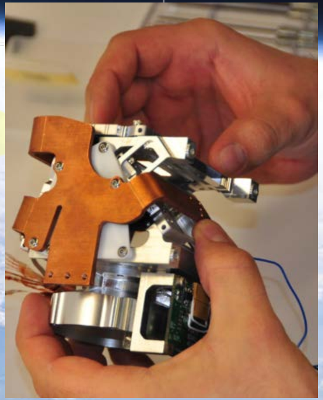
HARP CubeSat Satellite

Funding: ESTO InVEST Program
Expected launch: Spring 2019

HARP Polarimeter Specs

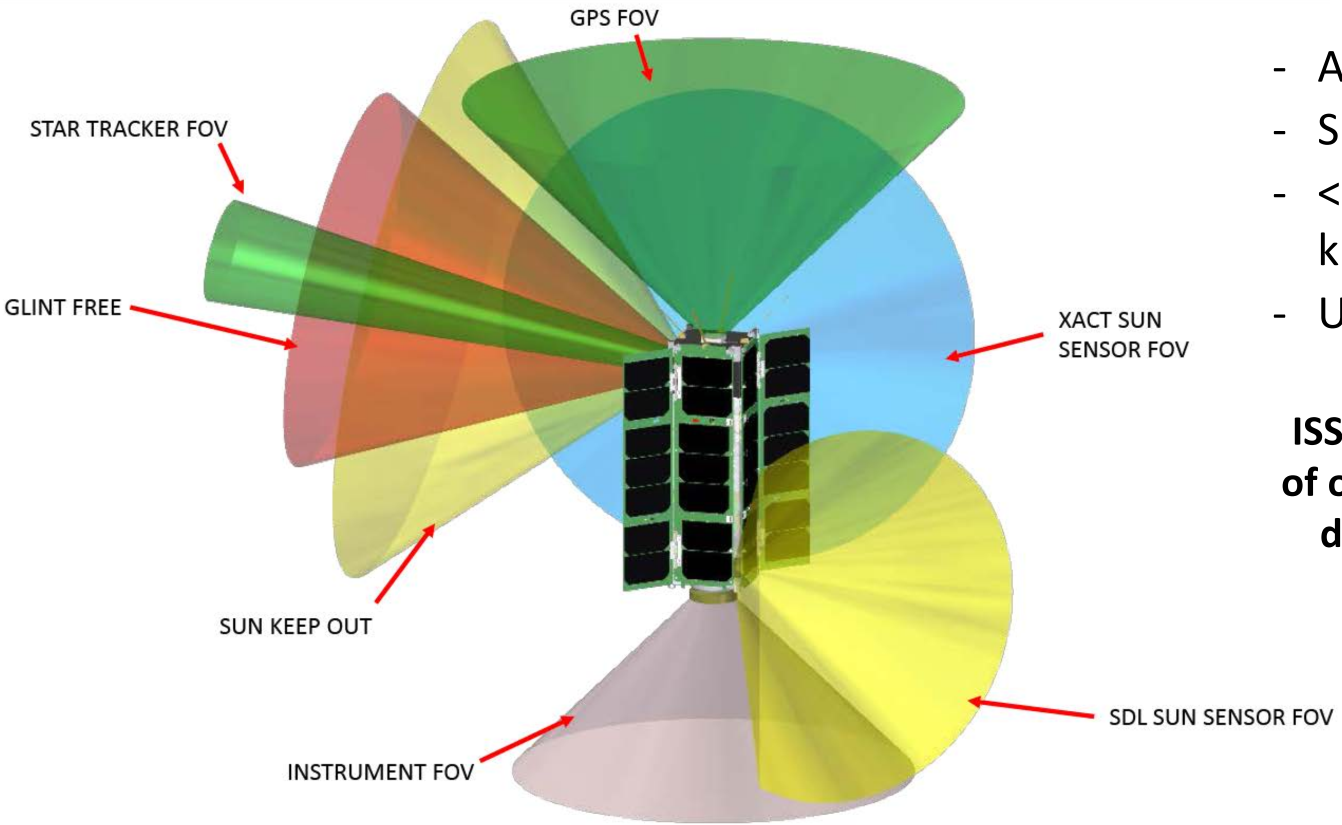
- ISS orbit
- 60 viewing angles (cloudbows)
- 20 angles for aerosols
- 440, 550, 670, 870nm
- Nadir pixel resolution 400m
- Nadir super pixel < 4x4km
- 94 deg FOV X-track
- 113 deg FOV along track





Imaging polarimeter

HARP – Full Feature Earth Sciences Satellite



- Accurate ACDS
- Sun Sensor + Star tracker
- < 0.66km pointing knowledge/geolocation
- UHF radio up to 3Mbits/s

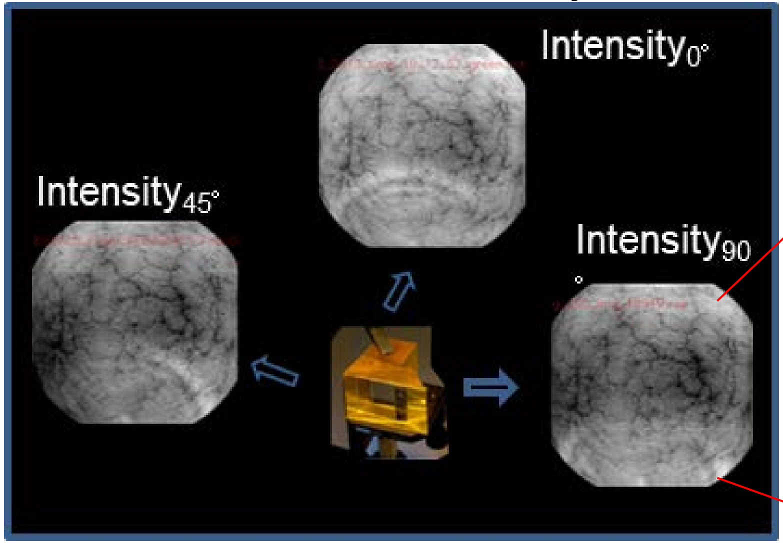
ISS orbit crosses within minutes of other satellites several times a day (example: 13 Apr 2016):

- Terra < 1 min
- NPP < 1min
- Aqua < 5 min
- Aqua < 5 min
- NPP < 5 min

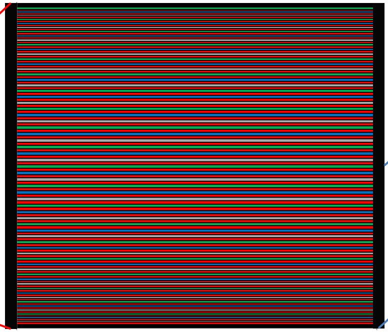
UMBC Space Dynamics LABORATORY Utah State University Research Foundation

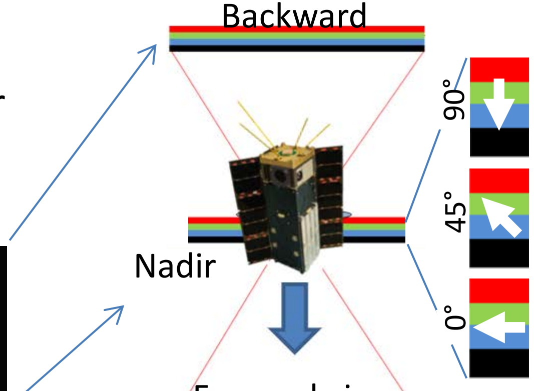
HARP Hyper-Angular Multi-Wavelength Polarization Images

HARP Prism Polarization Separation

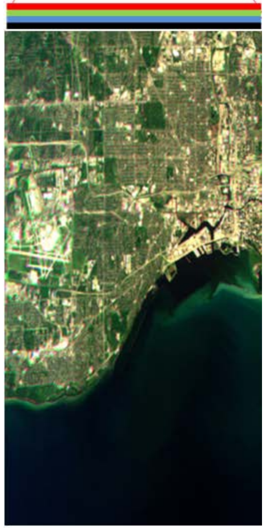


Stripe Filters: Angular and Wavelength Separation





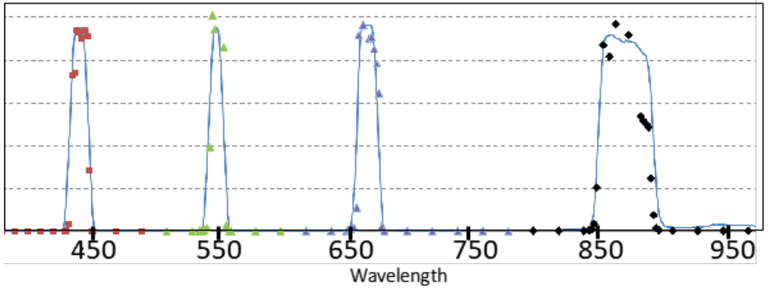
Forward view



Linearly Polarized Images at 0, 45 and 90°:

Multi/Hyper Angle with multiple pushbrooms

HARP's measured filter transmission



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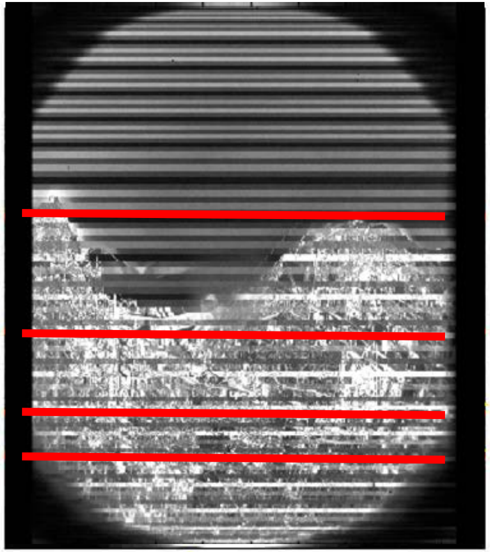
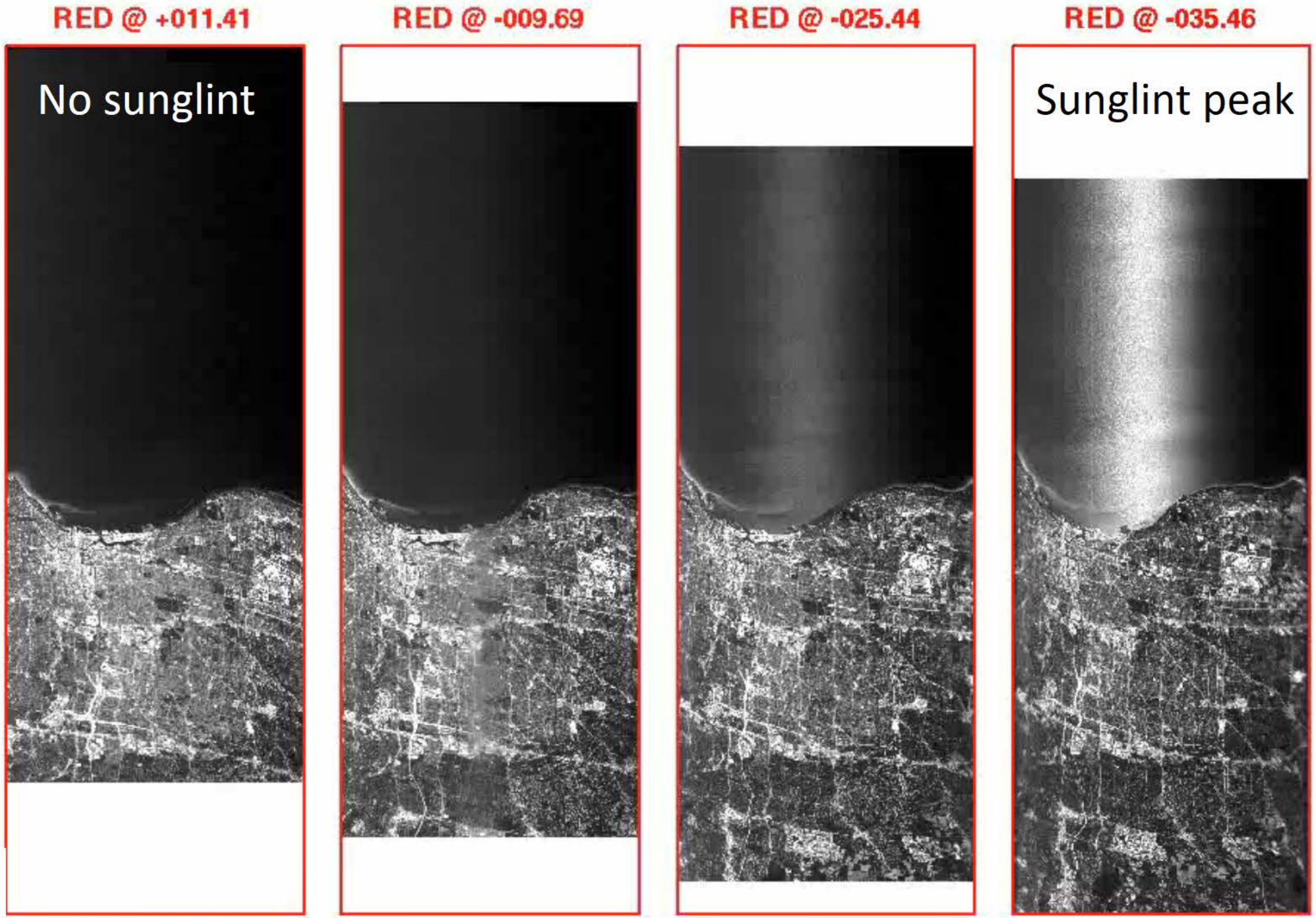
AIRHARP

Multi-Angle Observation



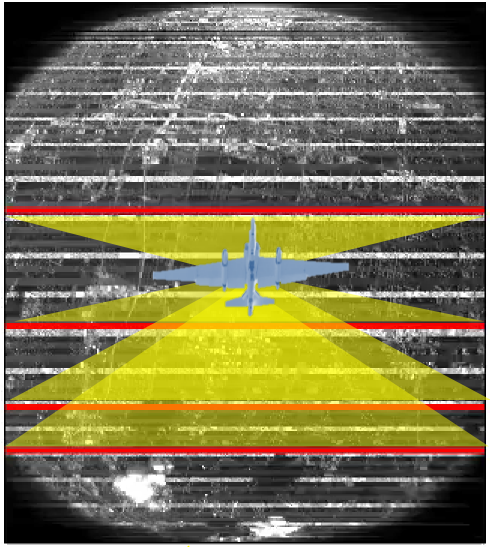
Raw Image with all angles



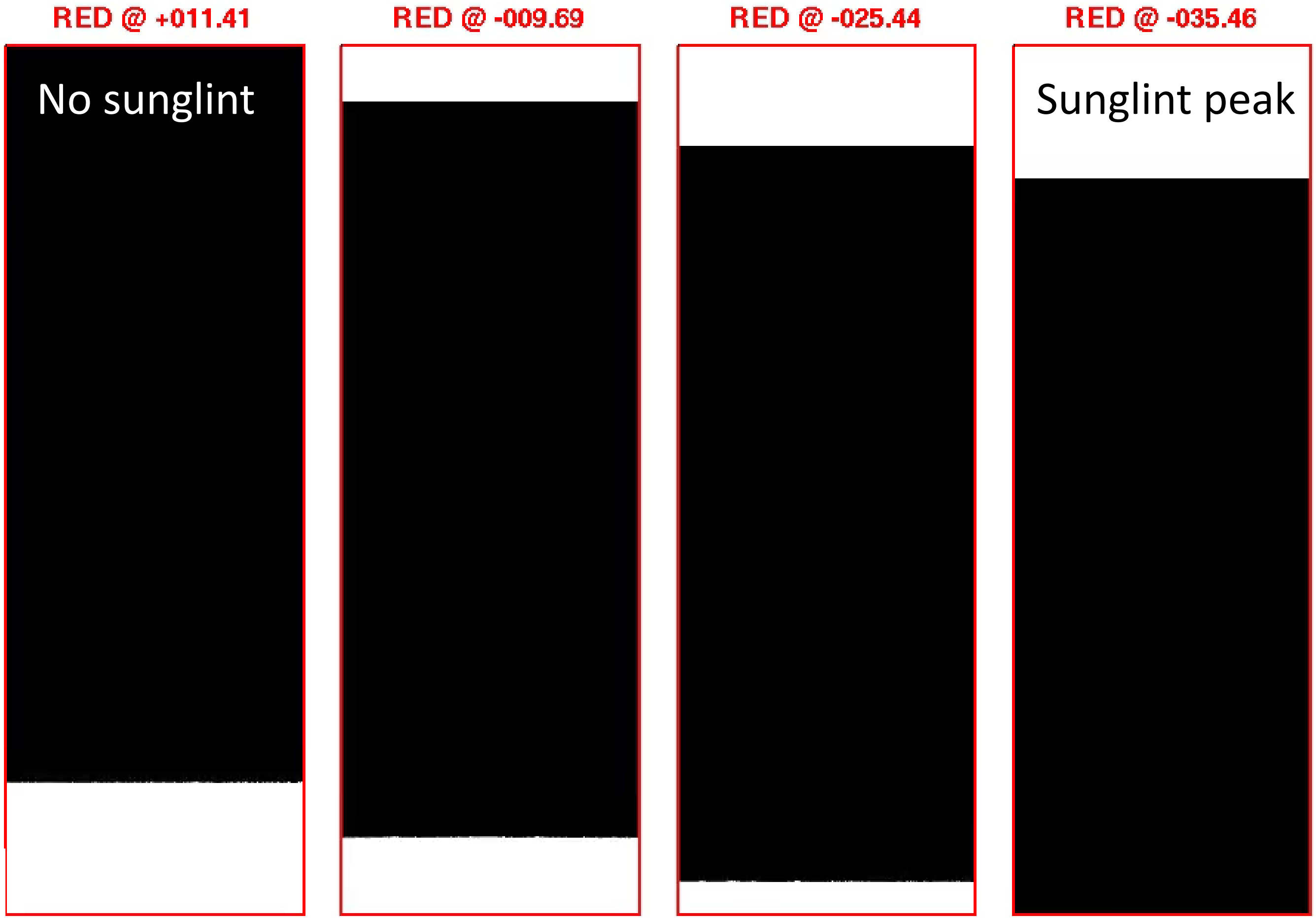
Push-broom images from individual angles

AIRHARP

Multi-Angle Observation



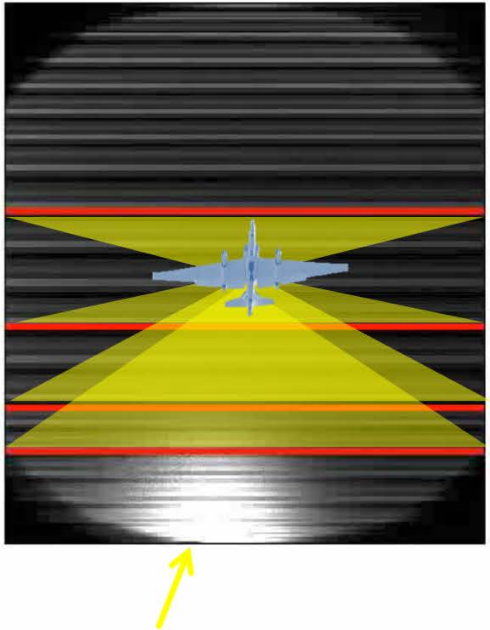
Notice that sunglint
Is not visible in all angles



Multiple Angles

AIRHARP

Multi-Angle Observation



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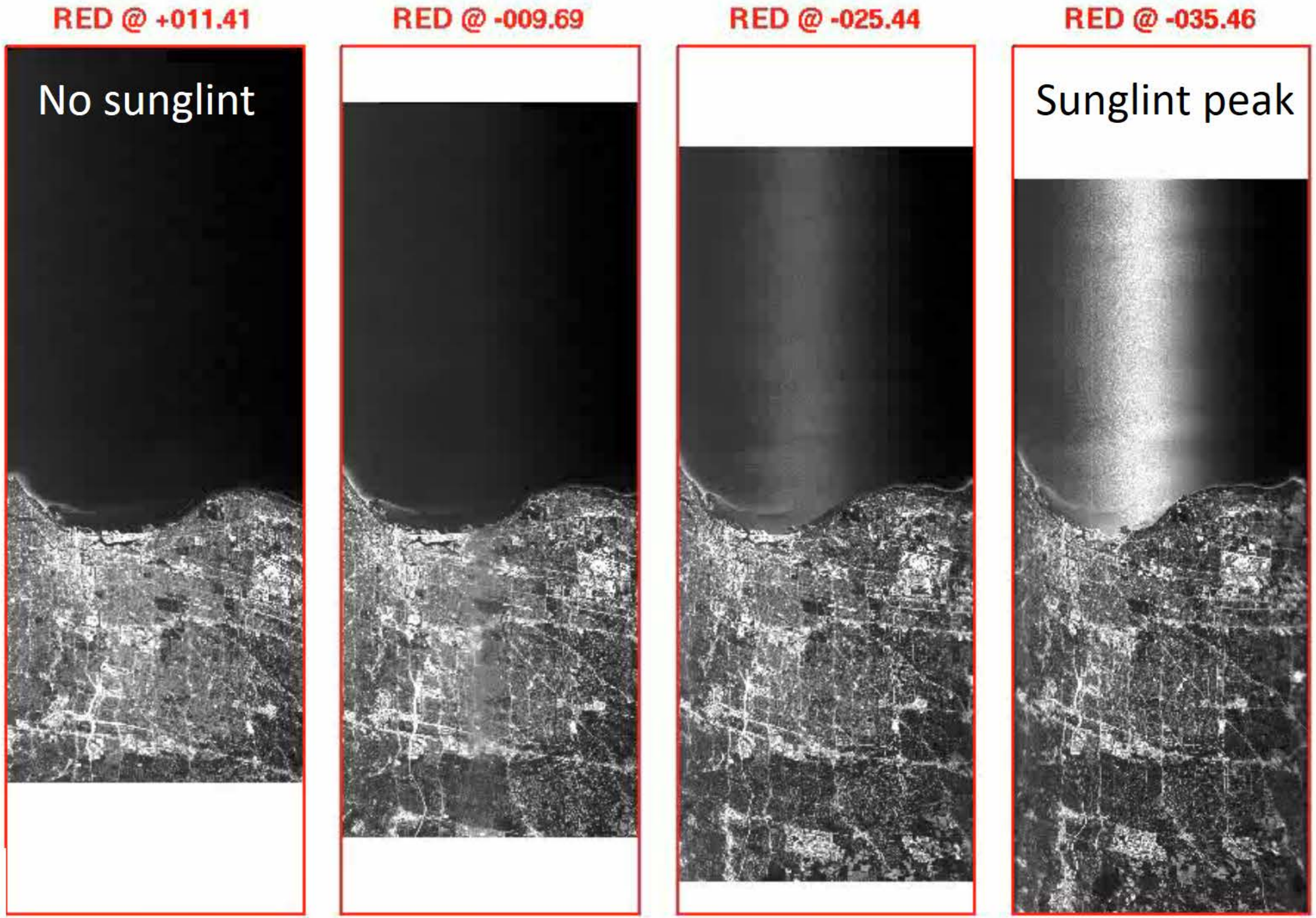
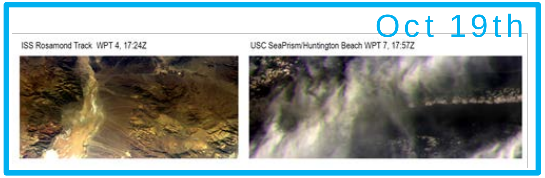
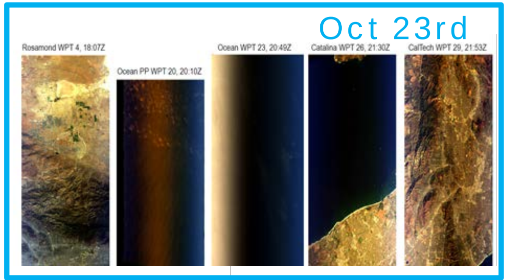


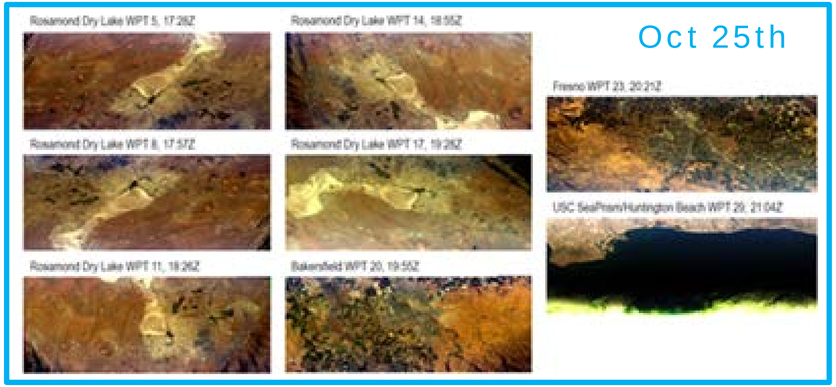
Multiple Angles

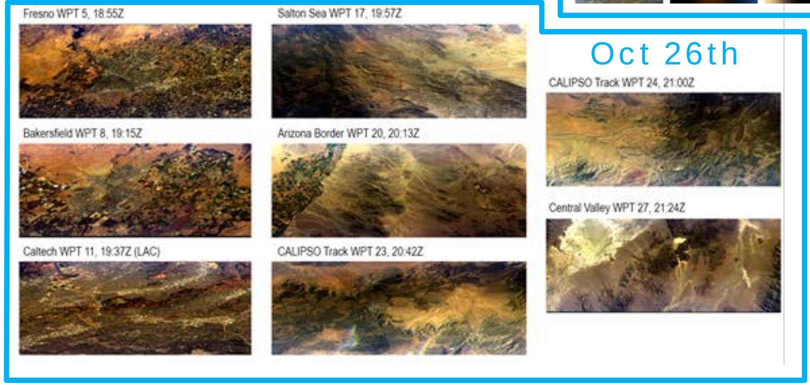
AirHARP's Image Gallery for ACEPOL

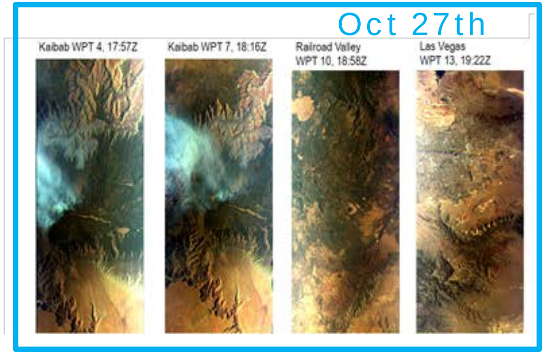
(Level 1 data under processing)

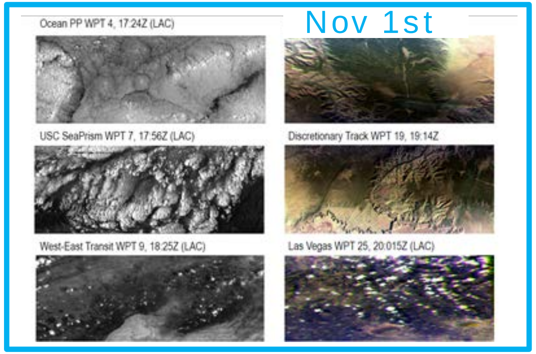


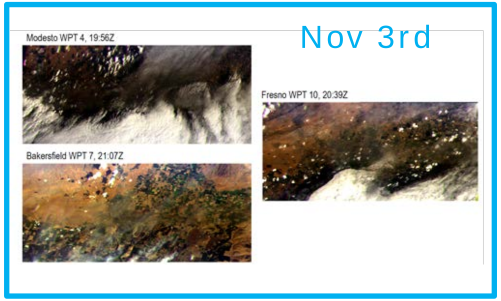


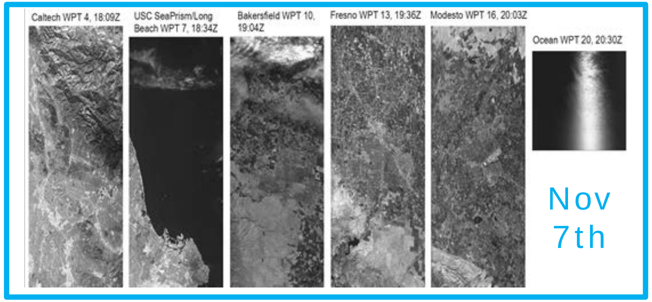


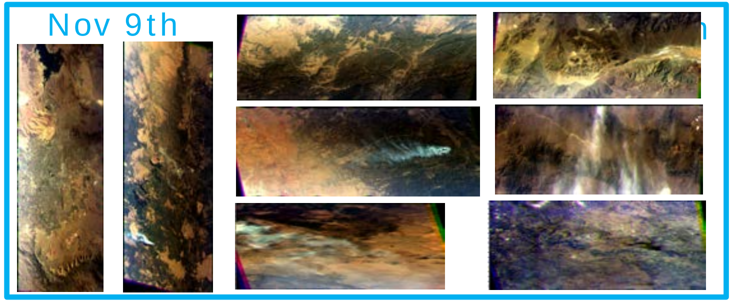




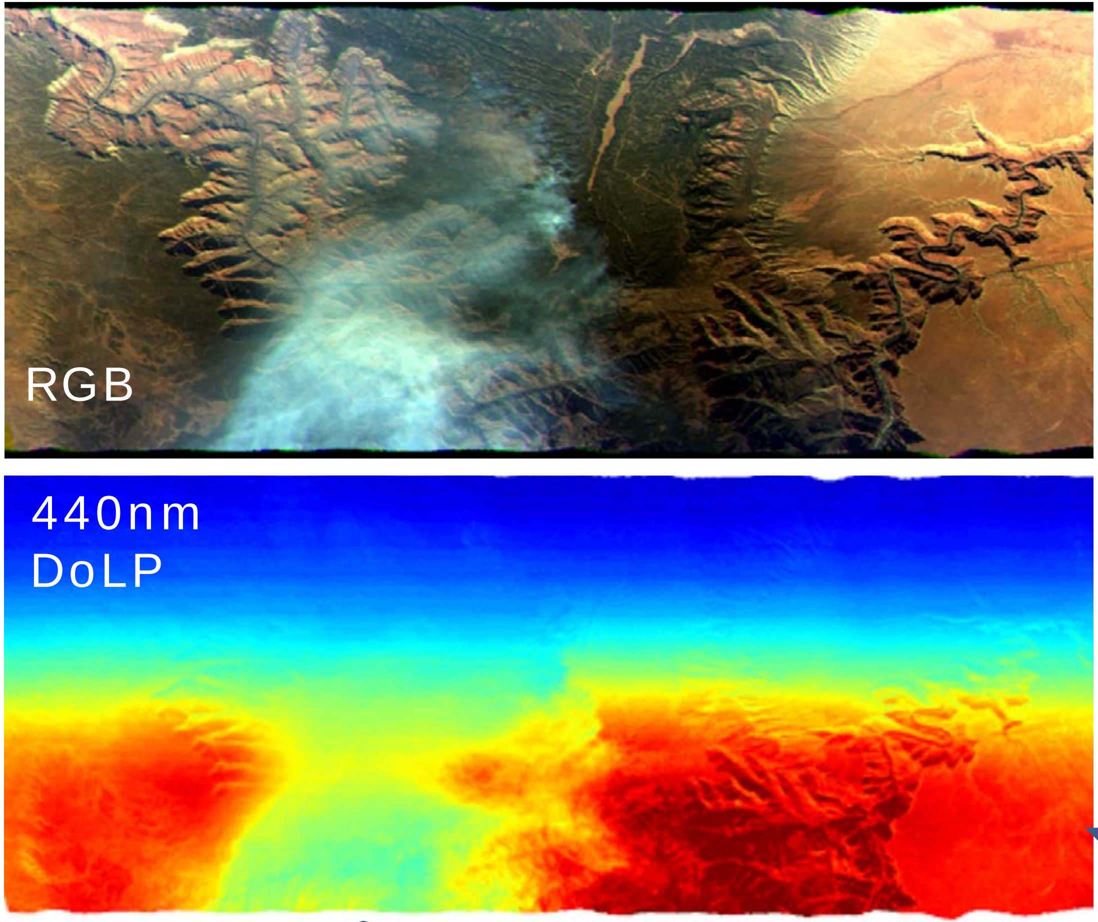








Arizona Fires During ACEPOL



Rayleigh Scattering Pattern

Low Degree of Linear Polarization from Fresh Smoke

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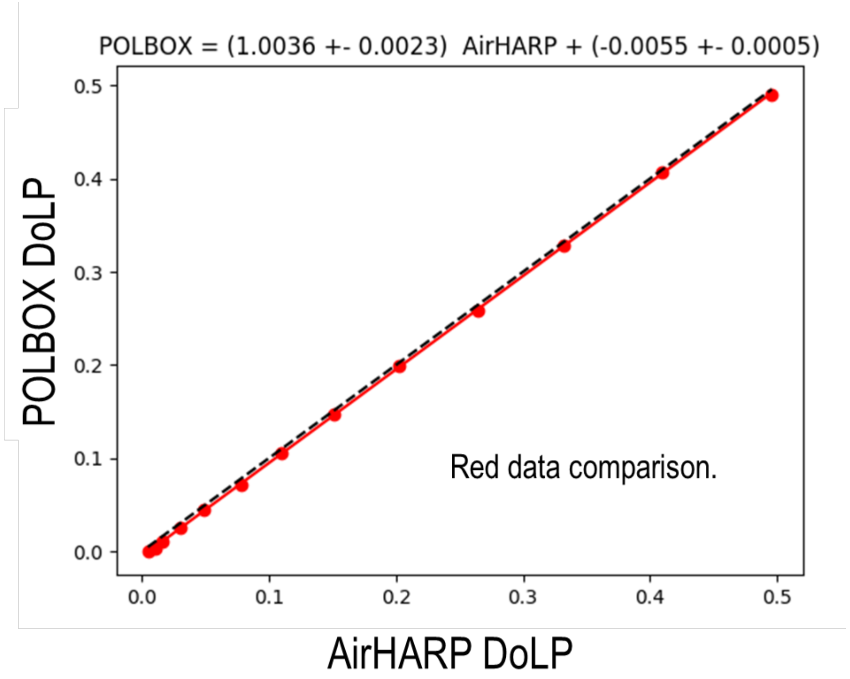
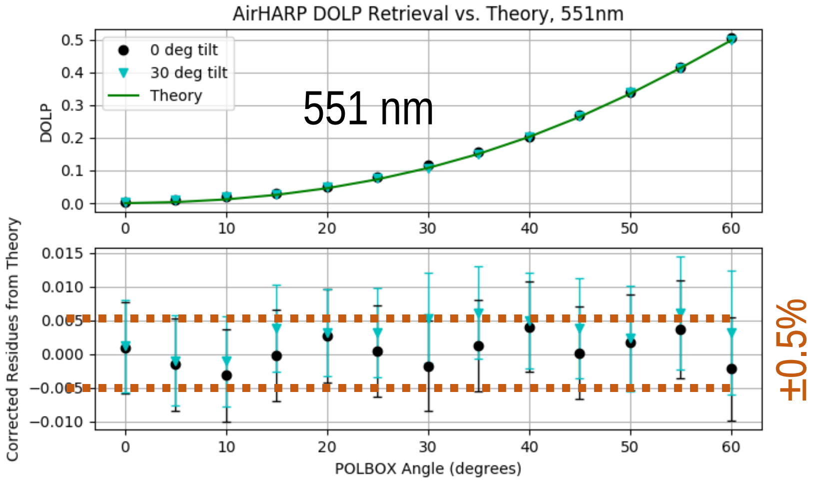
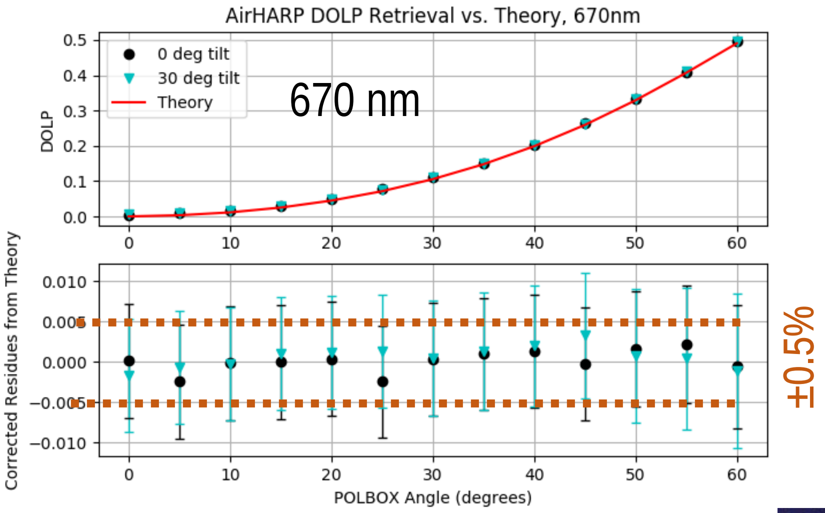
AirHARP

Calibration Validation with Partial Polarization Generator

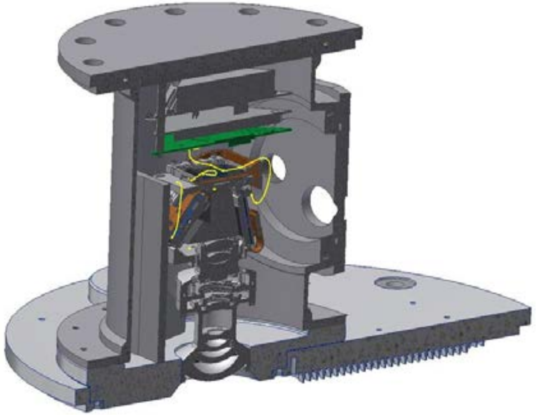




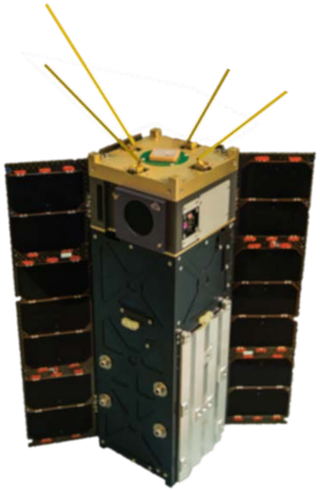


HARP Polarimeter Family:

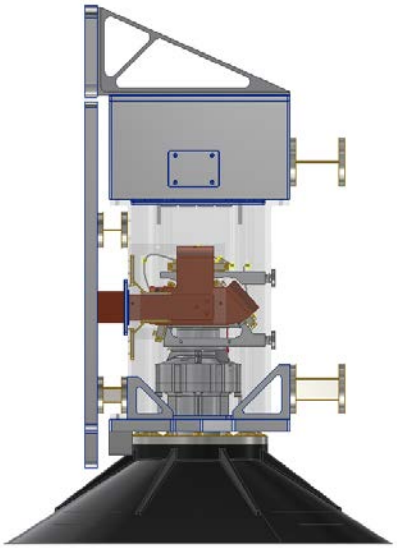
Air HARP



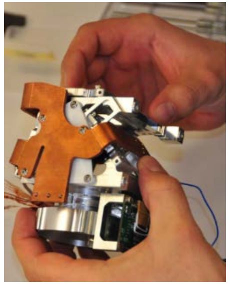
HARP CubeSat



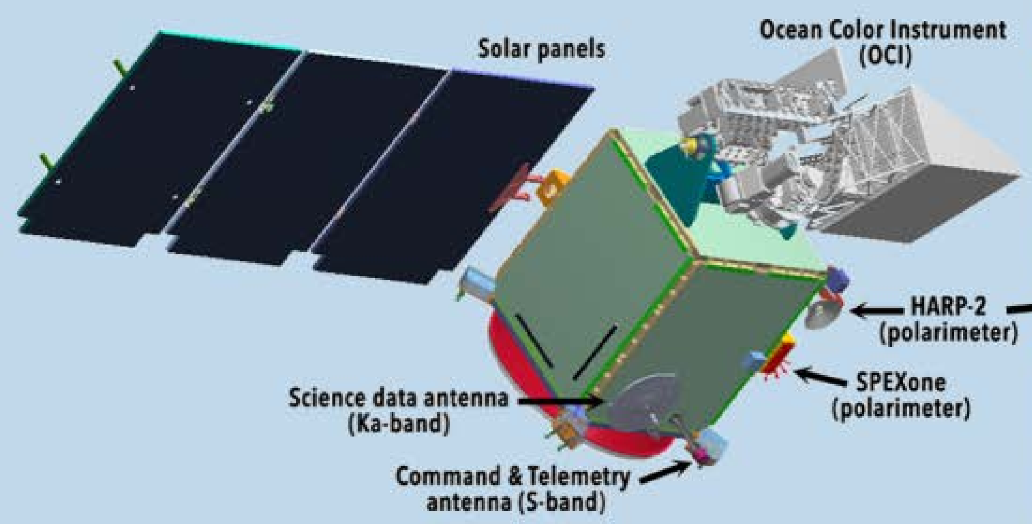
HARP2 PACE



HARP VNIR Telescope



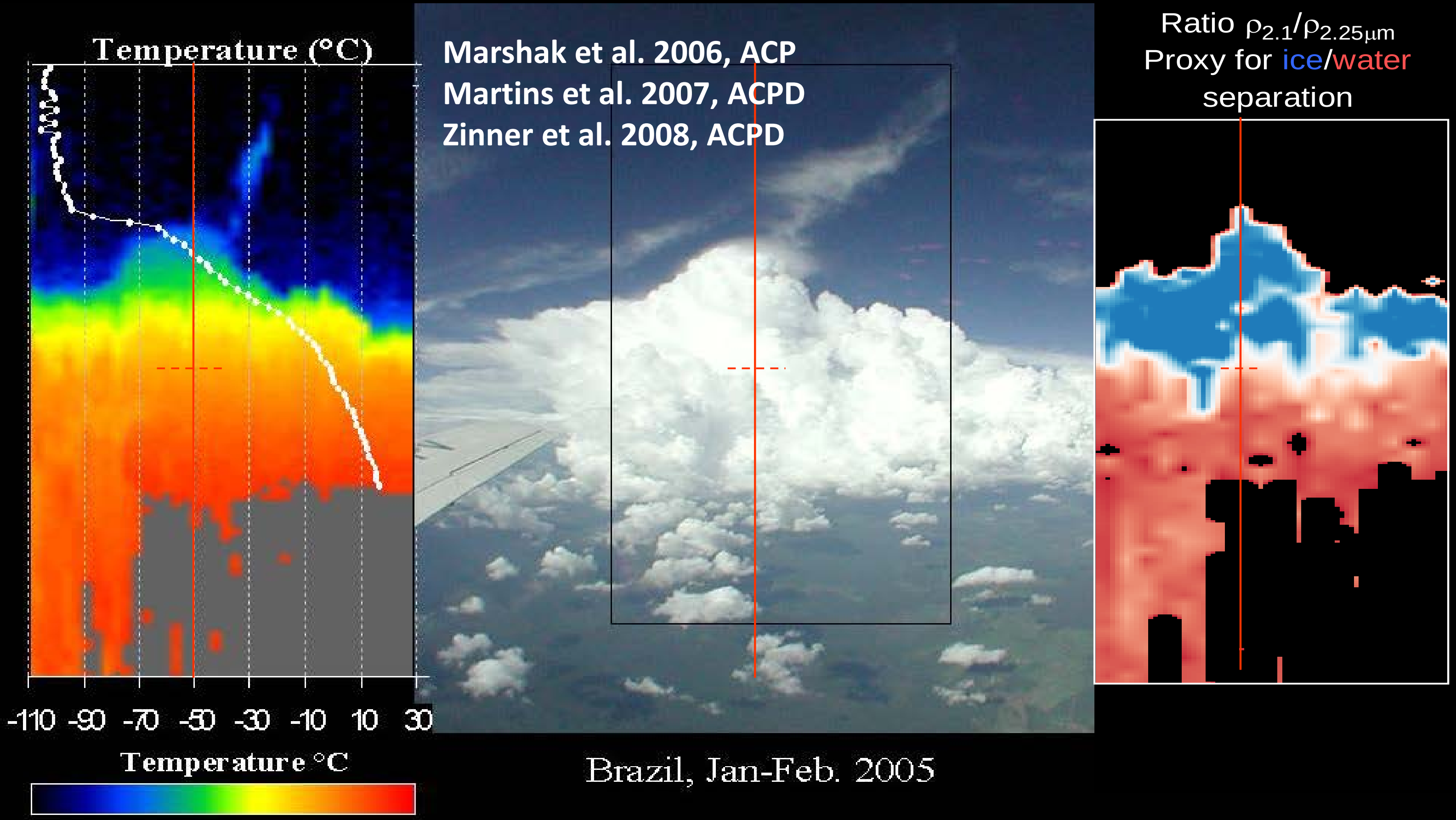
HARP2 joins the PACE Mission



PACE (Plankton, Aerosol, Cloud, Ocean Ecosystems)

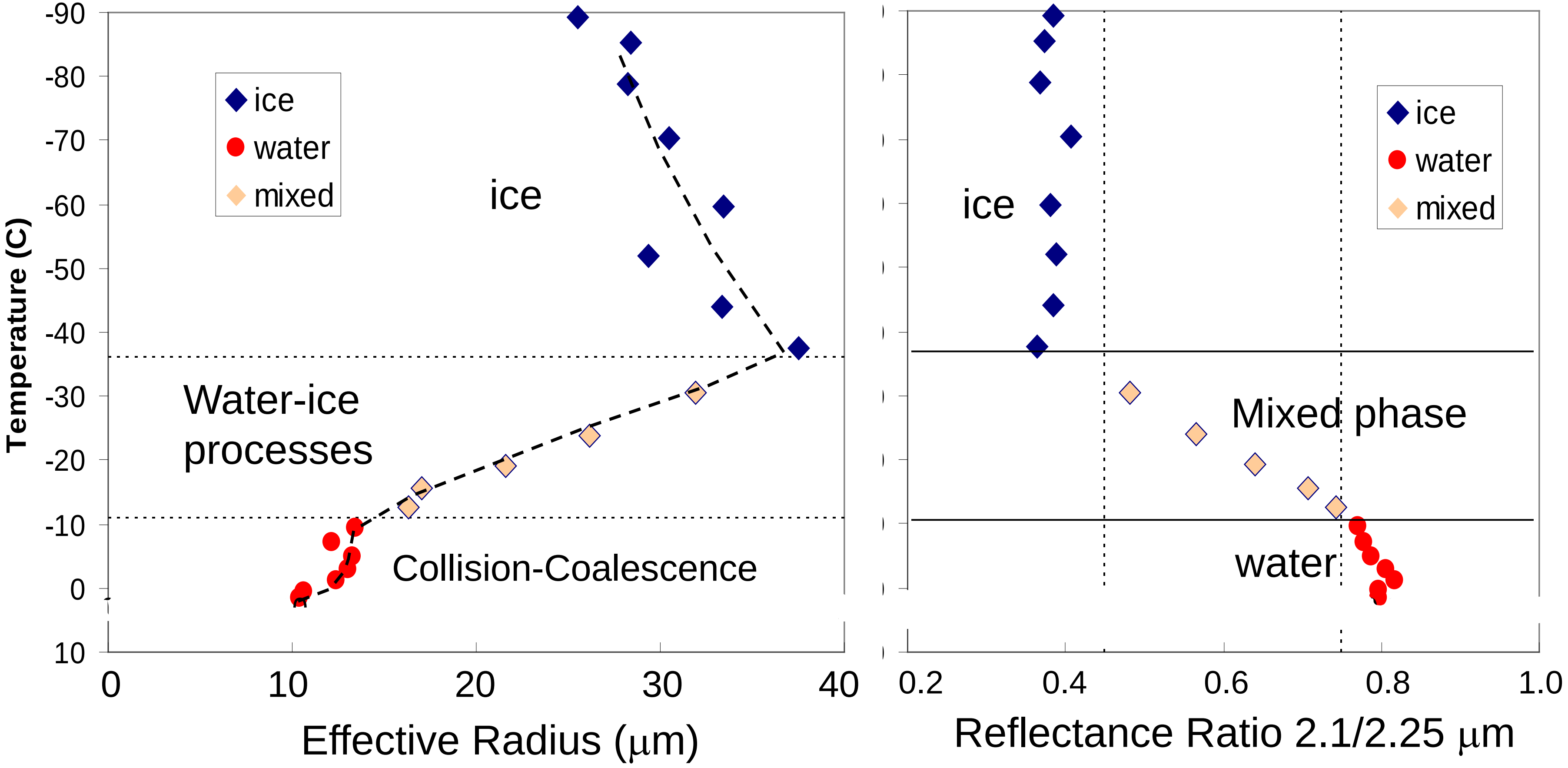
NASA GSFC mission dedicated to the measurement of Ocean Ecosystems, Aerosols and Clouds in the atmosphere

Demonstrated cloud side measurements aiming for Aerosol Cloud Interaction Studies

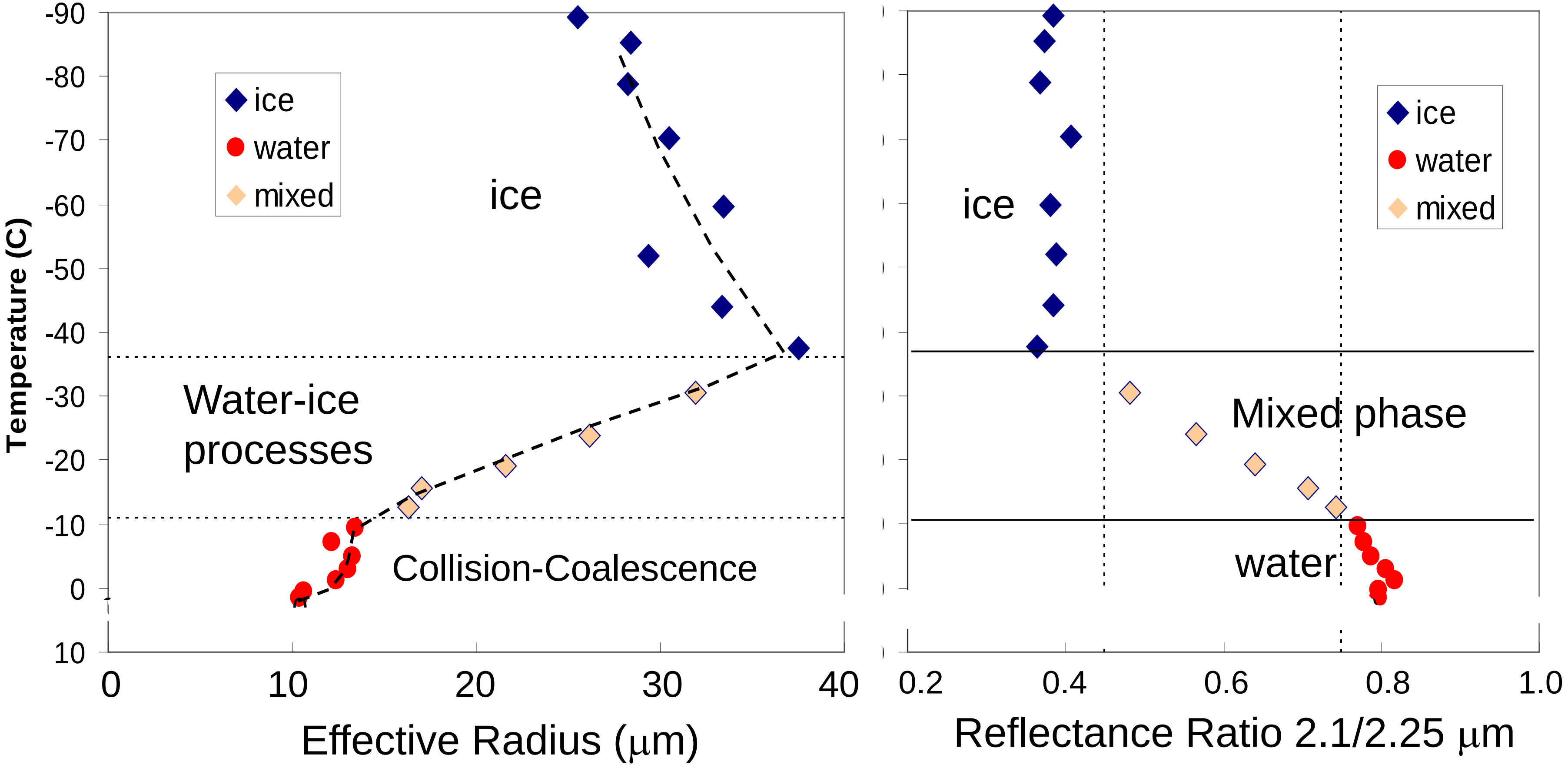


Cloud Vertical Profile from Cloud Side Observations

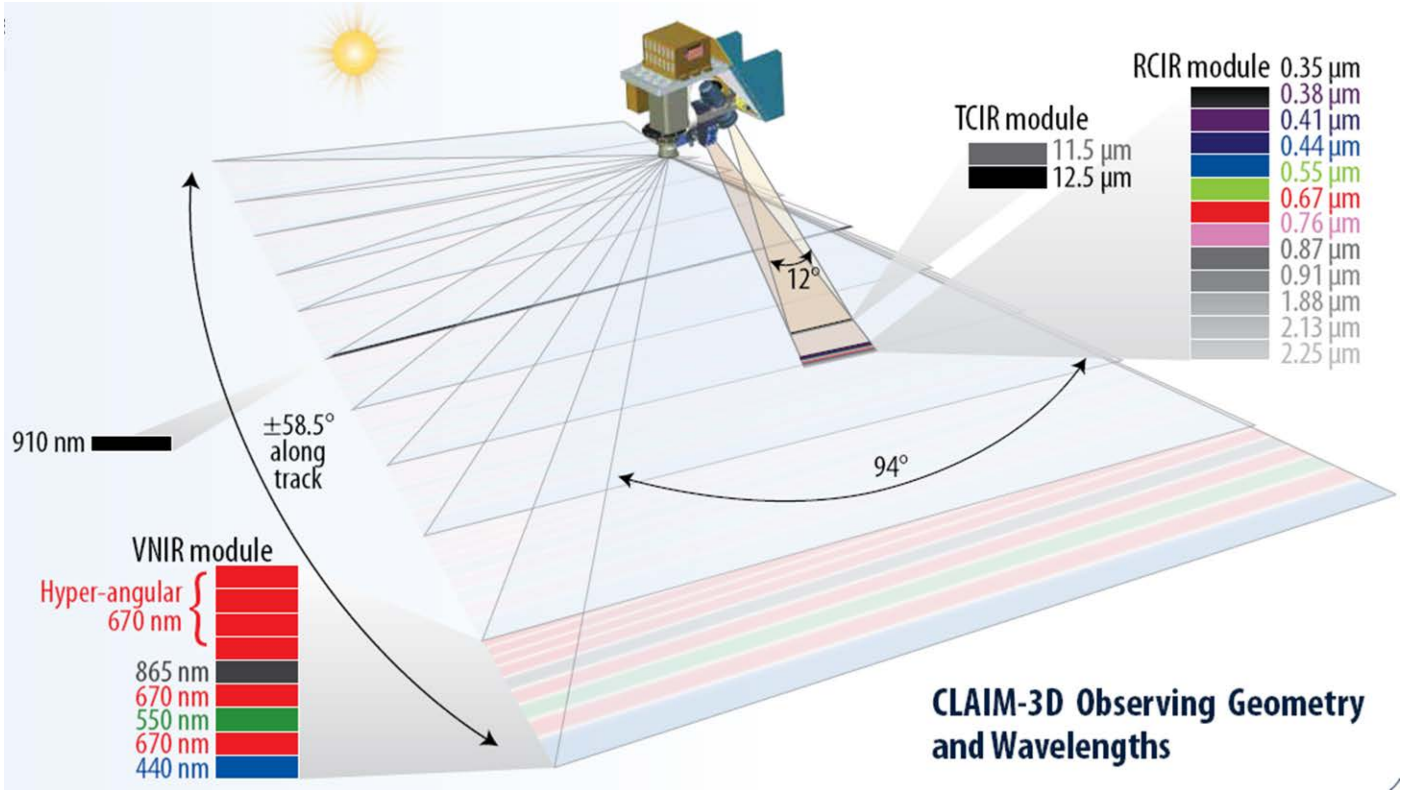
(Martins et al. 2006 – ACP)



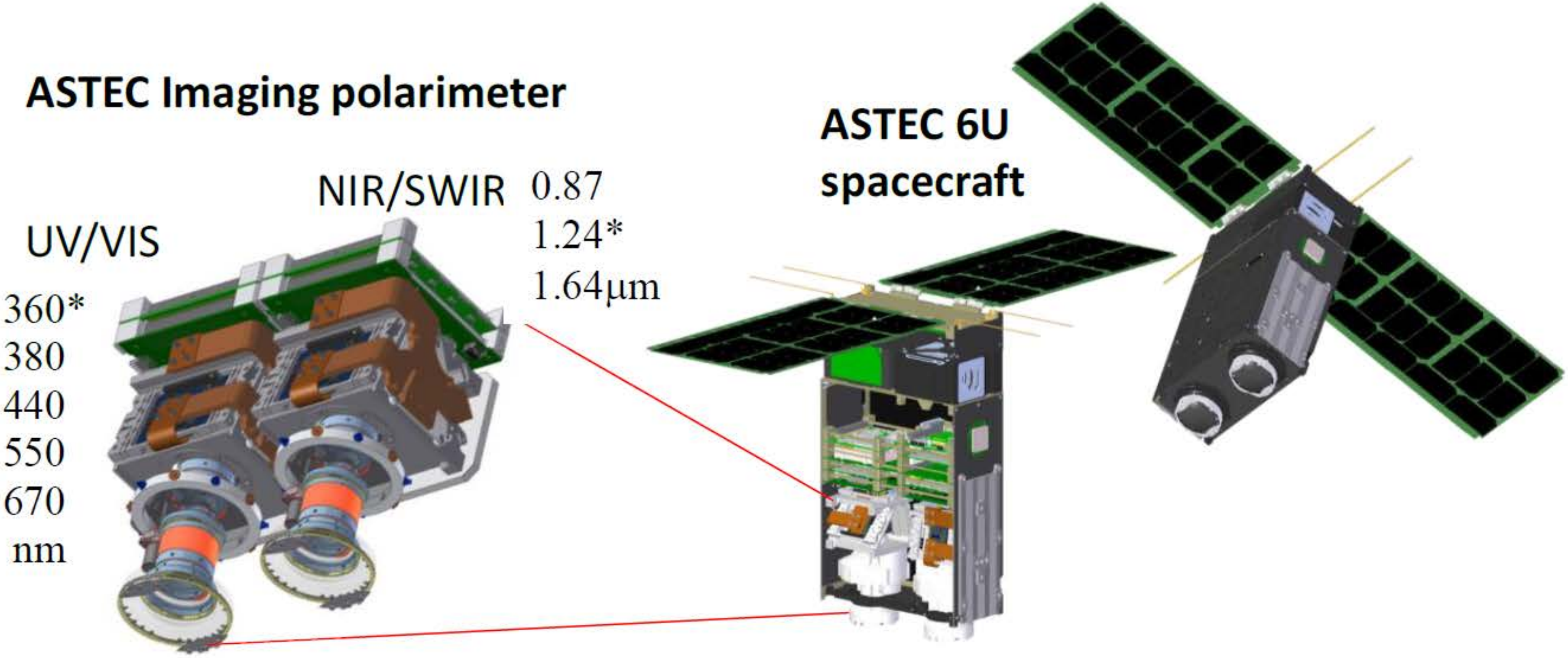
This measurements have not yet been performed from space!!!



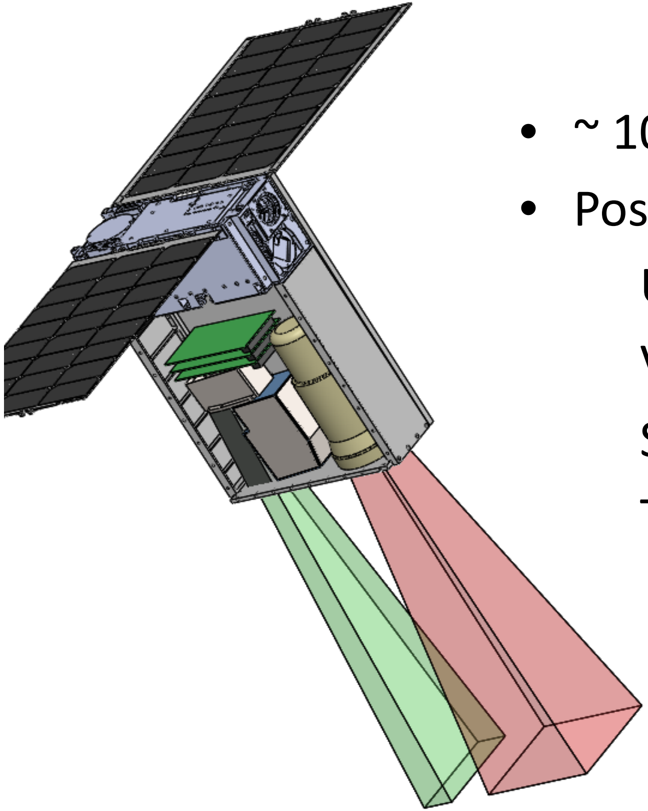
Previous CLAIM-3D Proposal: Hyperangular Polarization + High Resolution Clouds



UV to SWIR Imaging polarimeter for 6U Microsats



6U CloudScanner: Pointable Hi-Resolution Imagers from UV to TIR



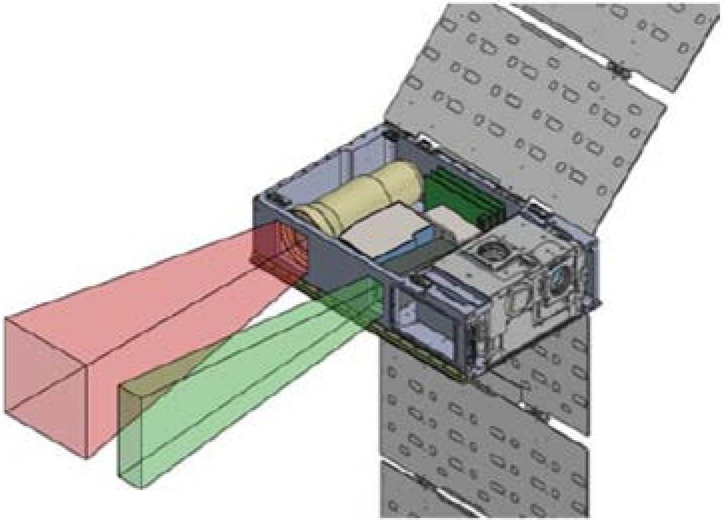
- ~ 100 m resolution
- Possible Wavelengths:

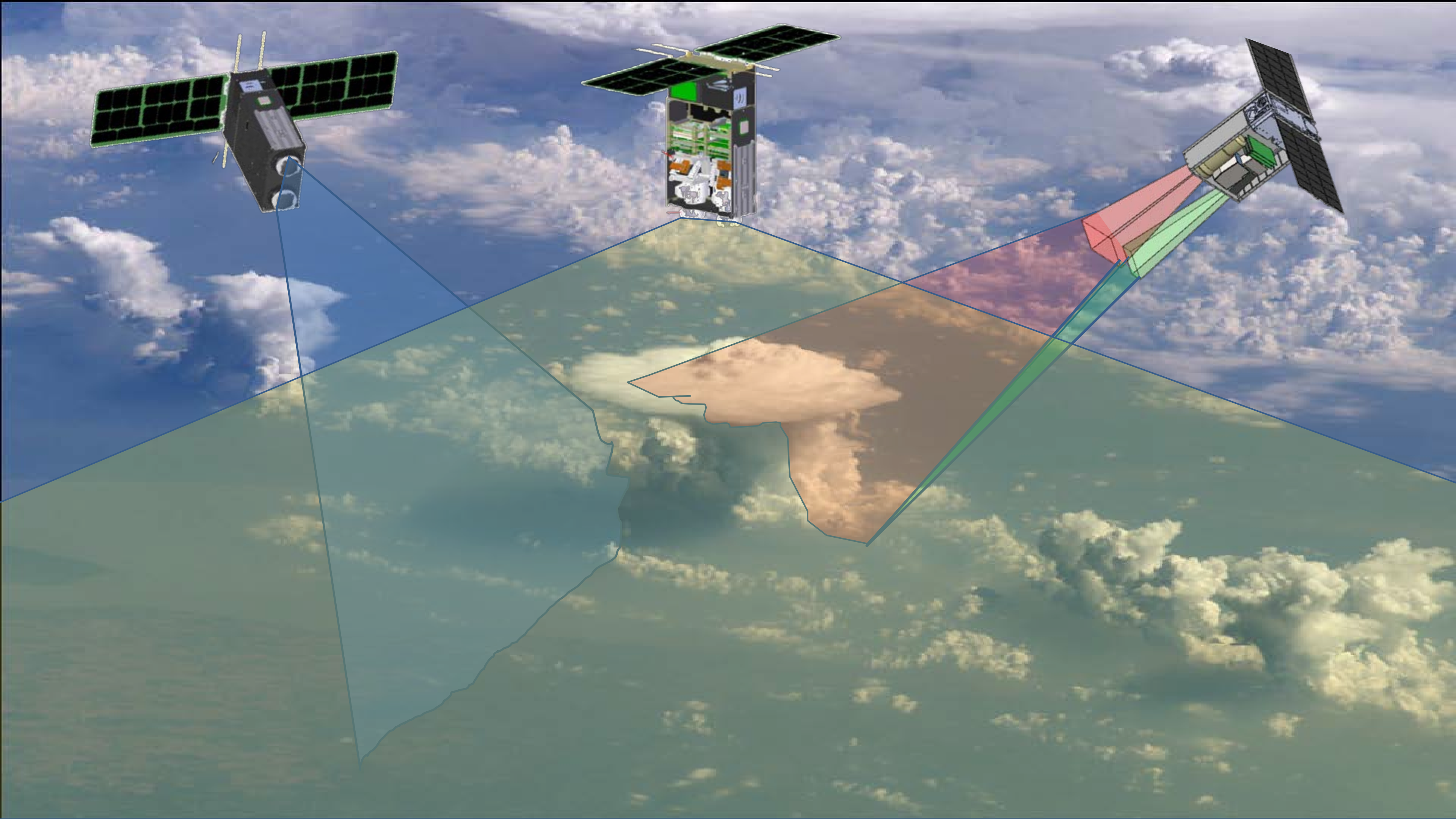
  UV: 0.34 – 0.38μm

  VNIR: 0.44 – 1μm

  SWIR: 1.2 – 2.3μm

  TIR: 8 - 12μm





Summary:

- A constellation of Small Satellites provides a real opportunity for the measurement of aerosol cloud interactions from space
- Cloud Side Measurements provide important information on the cloud vertical development, microphysics, thermodynamics and small scale cloud dynamics
- Cloud Glaciation levels are simple to measure from cloud side observations and provide important information on the interaction between Aerosols and Clouds

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Backup Slides

AirHARP – Aircraft Demonstration

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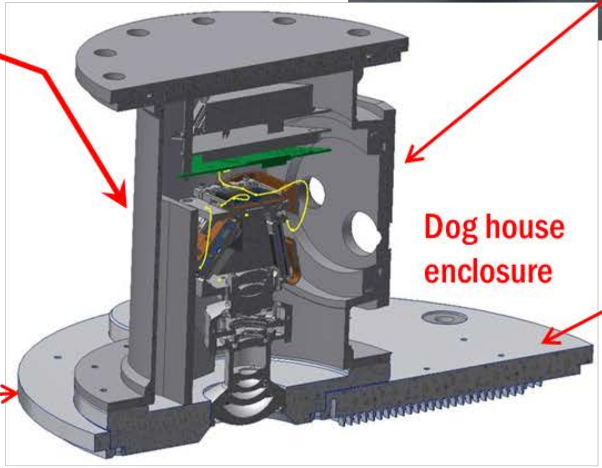
AirHARP

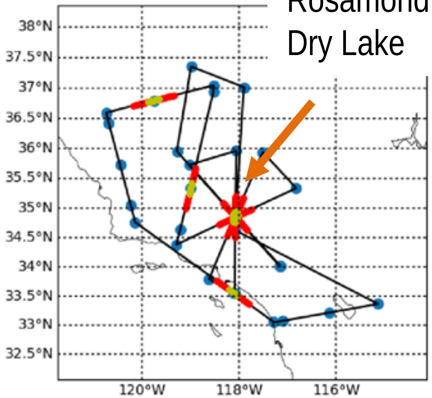
NASA ER2 - Oct 2017

NASA Langley UC12 June 2017



AirHARP front lens
underneath aircraft

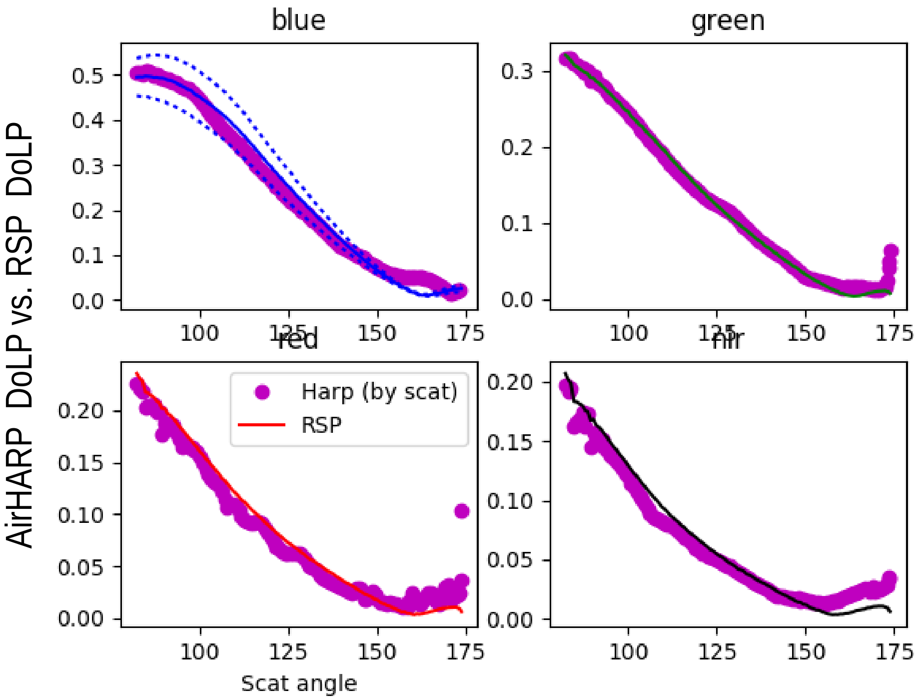
Vicarious Calibration/Intercomparison Opportunities - ACEPOL



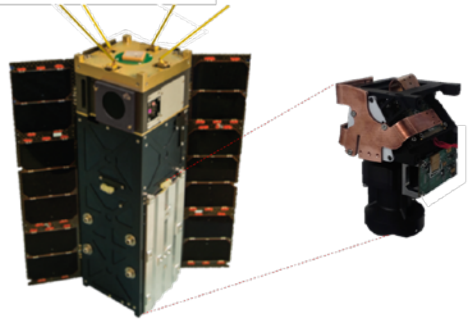
Rosamond Dry Lake

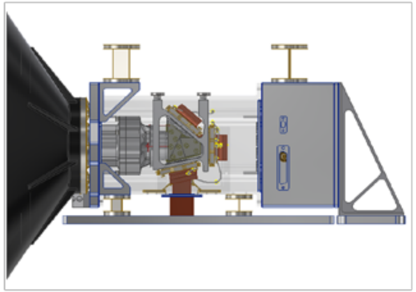
Sampling from Multiple Geometries

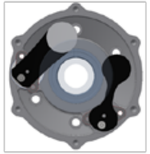
Preliminary Intercomparision with RSP (Still Needs Improvement in Pointing)



Air HARP







HARP CubeSat

- ISS orbit 400 km
- 4 km nadir resolution
- 94° cross-track, 113° along-track swath
- Up to 60 (20) view angles at 670nm (440, 550,870nm)
- Sampling: Few Thousand km per day

Onboard Calibration:

- Moon and Limb observations
- Vicarious calibrations over AERONET stations, sunglint, clouds, etc.
- Aircraft airborne polarimeters (including AirHARP) and in situ measurements

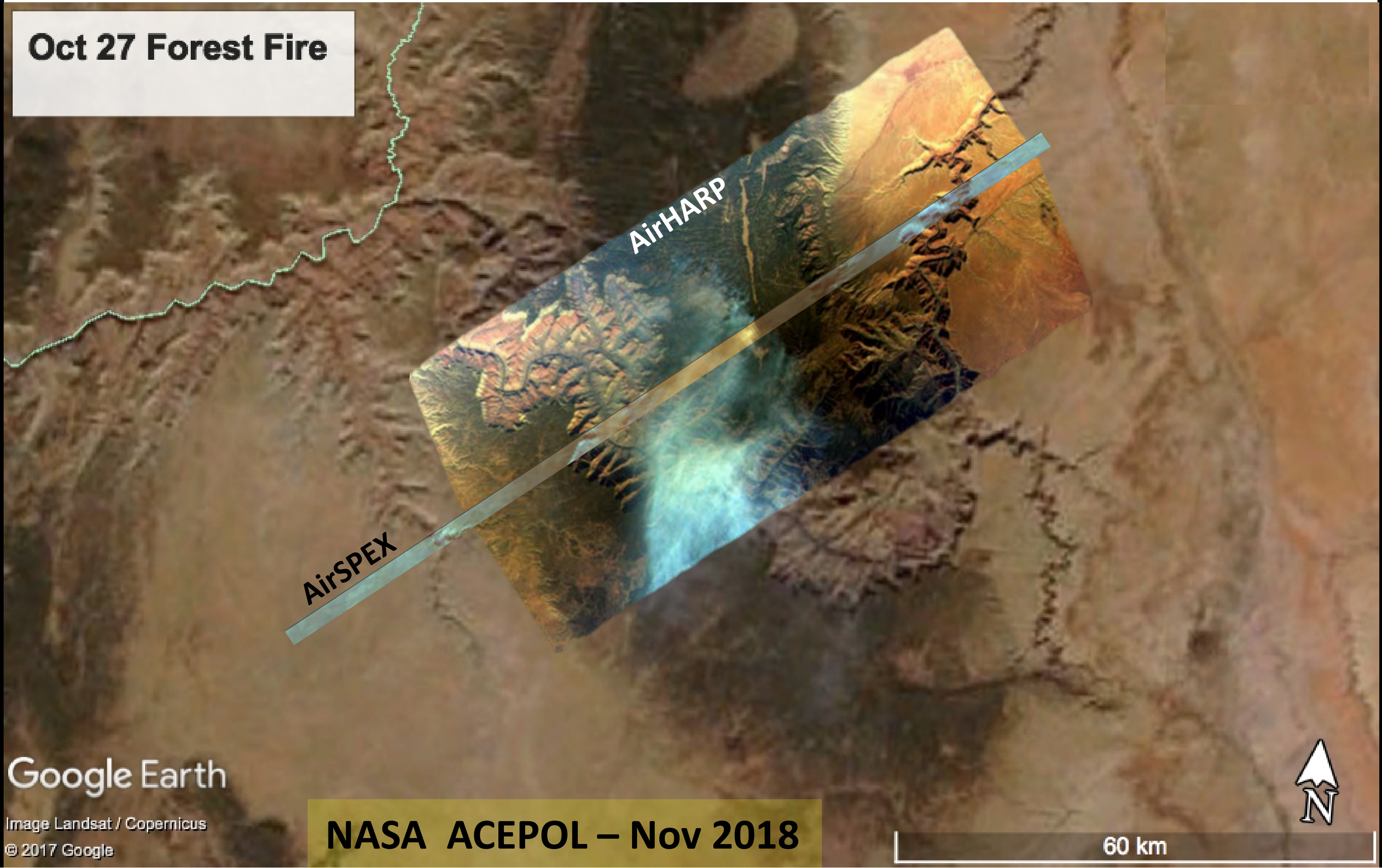
HARP2 PACE

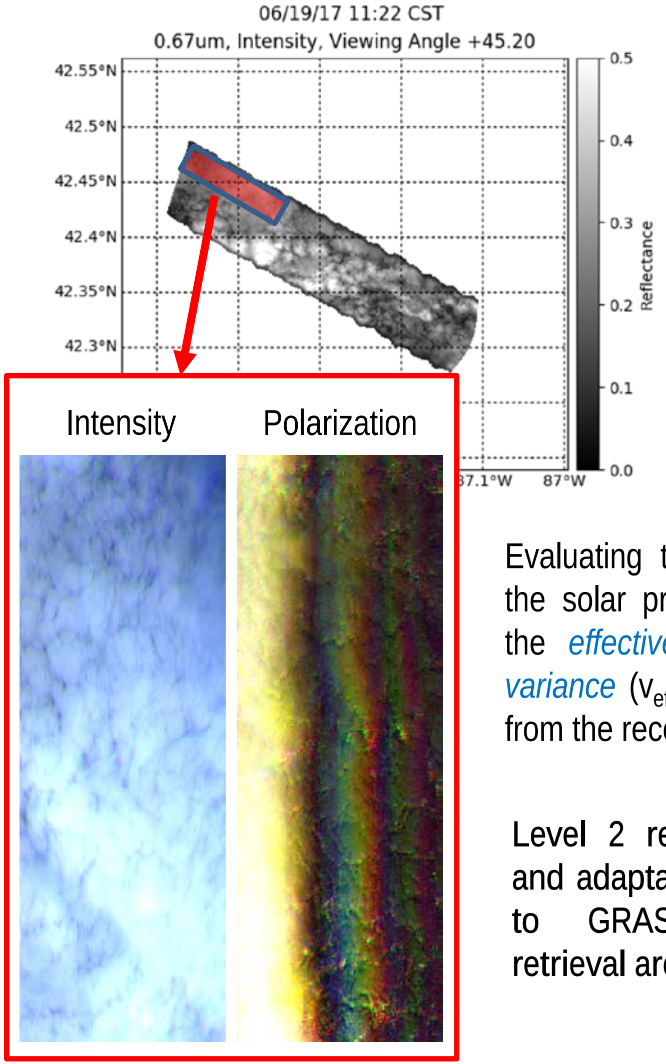
- Sun-synchronous 676km – 1PM
- 3 km nadir resolution
- 94° cross-track, 113° along-track swath
- Up to 60 (20) view angles at 670nm (440, 550,870nm)
- Global Coverage in 2 days
- Improved SNR – DoLP accuracy goal < 1%
- Improved Polarization at 870nm

Onboard Calibration:

- Radiometric cross calibration with OCI
- Polarimetric/Radiometric cross calibration with SPEXOne
- Moon and Limb observations (OCI cal)
- Vicarious calibrations over AERONET stations, sunglint, clouds, etc.
- Aircraft airborne polarimeters/in situ
- Goal: *Onboard flat field reference for extending calibration to all FOVs (in discussion for solar cal)*

UMBC AirHARP and AirSPEX from ER2





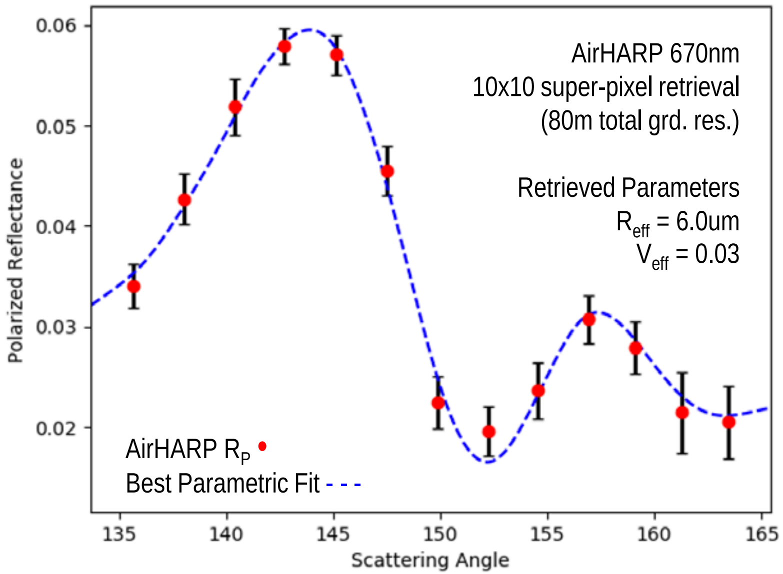
HARP cloud retrievals can be done for any pixel in the FOV, even for **heterogeneous clouds**, like this case (left) from LMOS on June 19, 2017.

Polarized radiance is converted to reflectance (*Rp*) and parametrically matched to Mie phase functions:

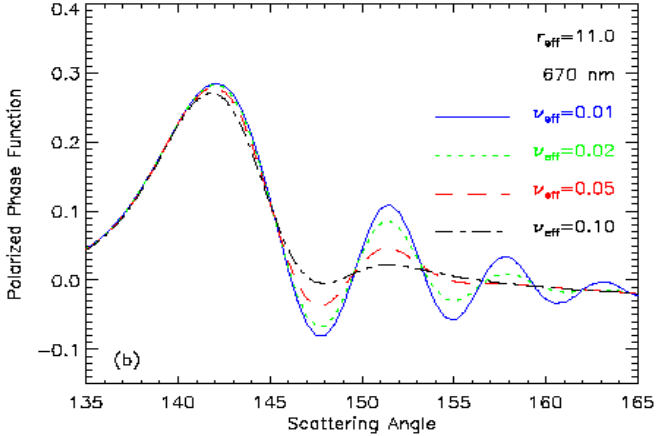
$$R_P = \frac{\pi\sqrt{Q^2 + U^2}}{F_0 \cos\vartheta_z} = \alpha\, P_{12}(\vartheta) + \beta \cos^2\theta + \gamma$$

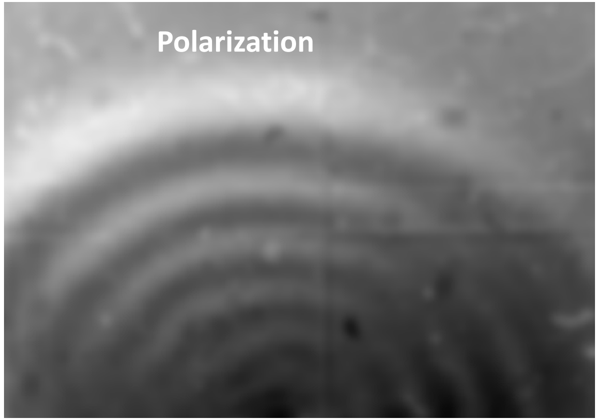
Evaluating this relationship on the solar principal plane gives the *effective radius* (r_{eff}) and *variance* (v_{eff}) of a cloud scene from the recovered Mie P_{12}.

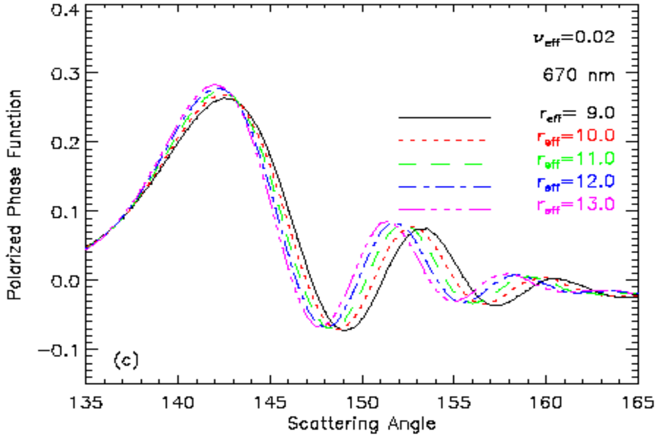
Level 2 retrieval algorithms and adaptation of HARP data to GRASP for aerosol retrieval are underway.



HARP Pioneering Hyper-Angular Capability from Space will Provide Full Cloudbow Retrievals from Small Area (~4x4km)



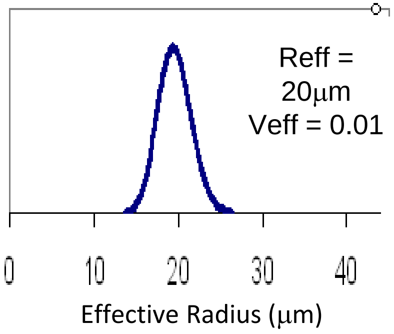




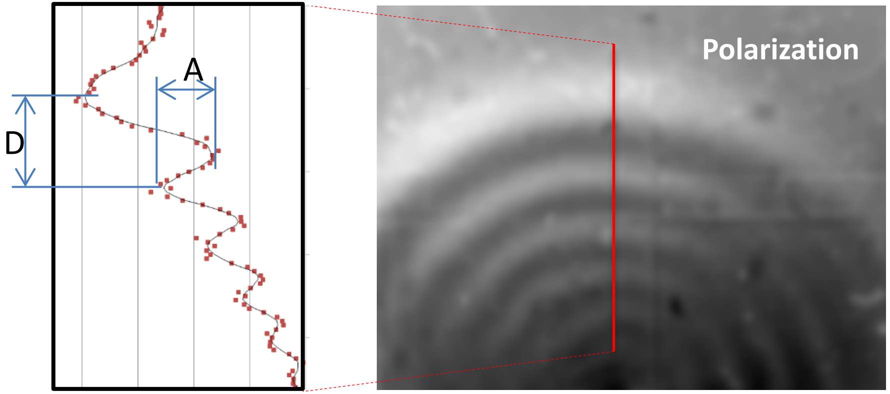
HARP CubeSat Polarimeter

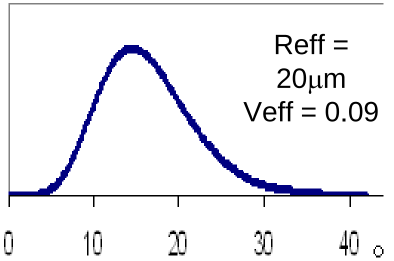
HARP Pioneering Hyper-Angular Capability will Provide Full
Cloudbow Retrievals from Small Area (< 4x4km from space)

Water Droplet



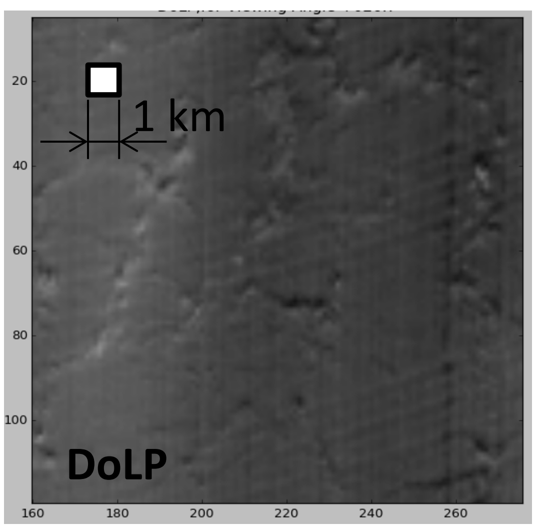
D and A produce cloud droplet effective radius and variance

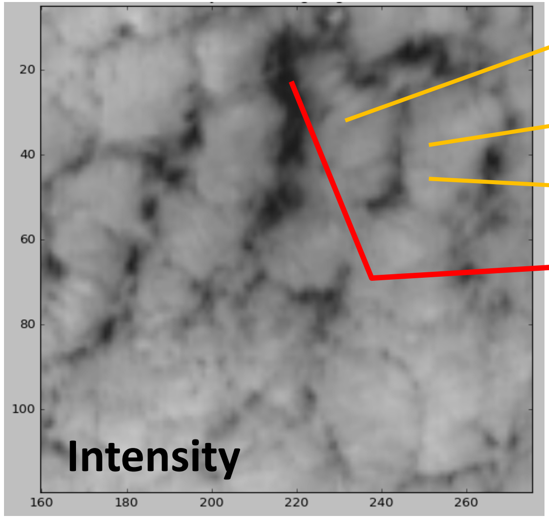


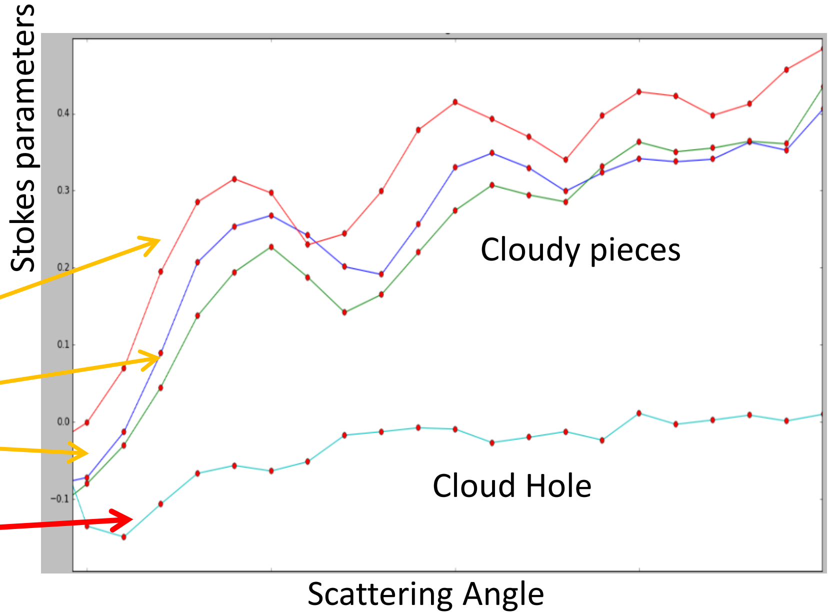


These two cases are undistinguishable from Intensity measurements only (MODIS/VIIRS)

HyperAngular High Resolution Cloudbow

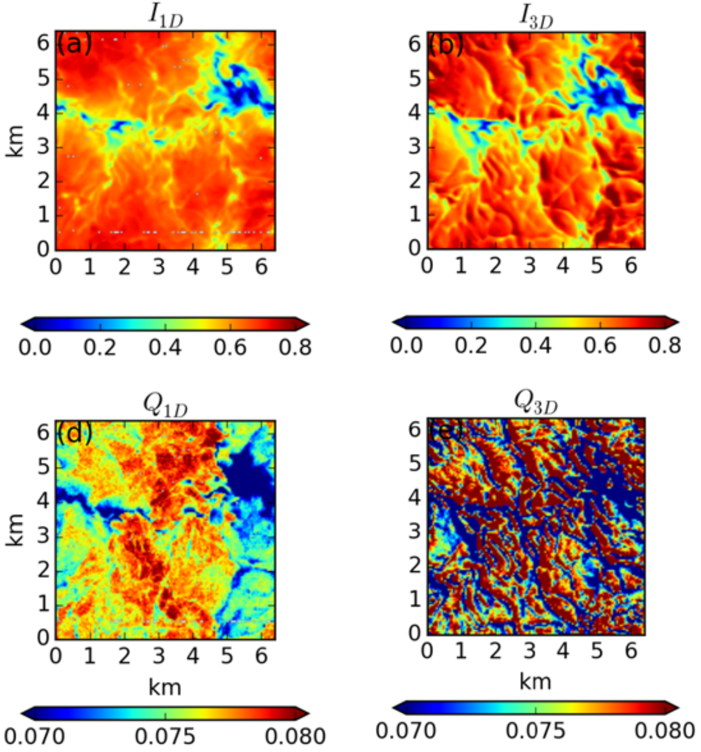




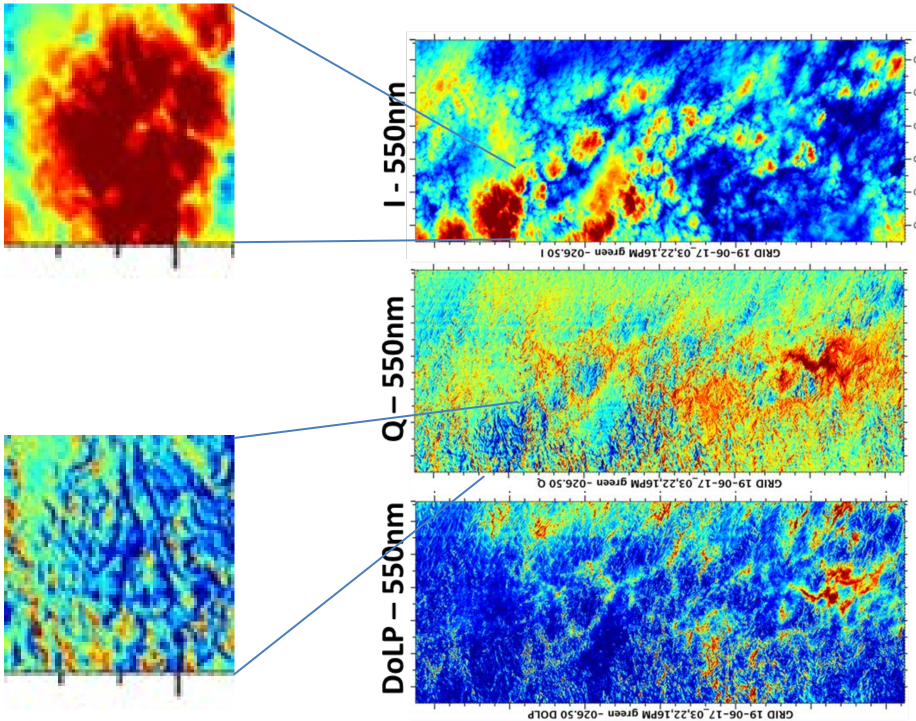


Evaluation of Cloud 3D Properties

LES and 3D RT simulations by
Chamara Rajapakshe and Zhibo Zhang

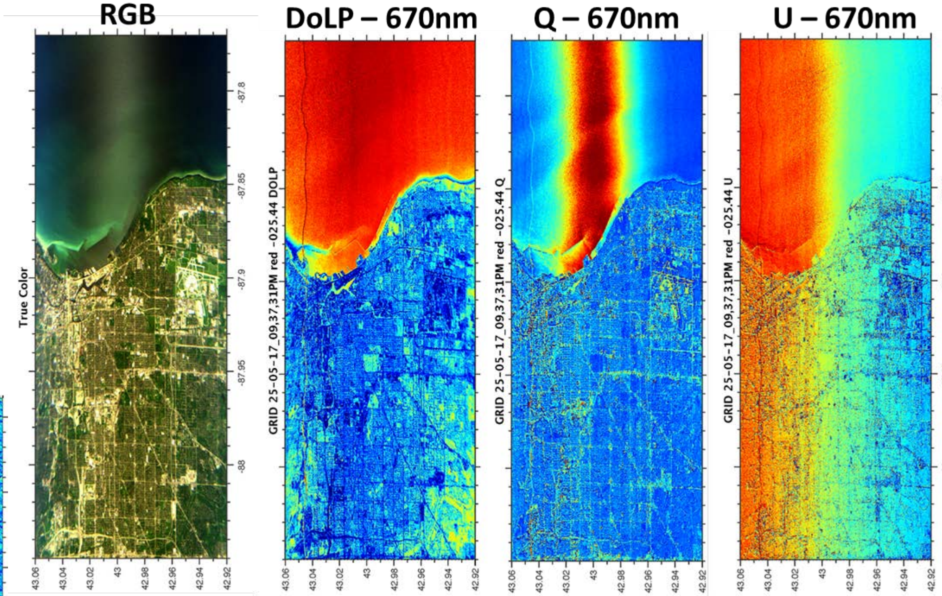


AirHARP Data Set by Vanderlei Martins,
Brent McBride and H. Barbosa

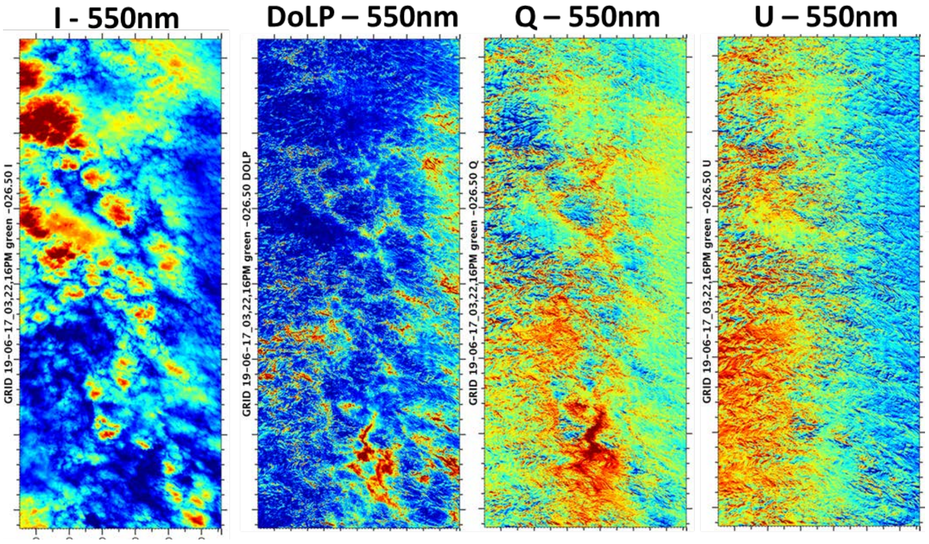


Preliminary AirHARP Data
LMOS Campaign June 2017

Water and Land



Low Clouds



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Latest News

August 29, 2018
HARP CubeSat successfully completed open air communication testing at NASA Wallops Flight Facility, in preparation for final environmental test and launch integration.

August 27, 2018
HARP CubeSat performed final radiometric, polarimetric, and alignment calibration at NASA GSFC.

August 20, 2018
ESI welcomes Dr. Xiaoguang (Richard) Xu as a new member to support algorithm development and data analysis for the HARP and HARP-2 projects.

August 8, 2018
The ESI support of the HARP-2 project led to a successful Preliminary Design Review at GSFC.

July 14, 2018
The first Level 1B AirHARP datasets from the NASA LMOS and ACEPOL campaigns are live on the Langley DAAC archive.

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