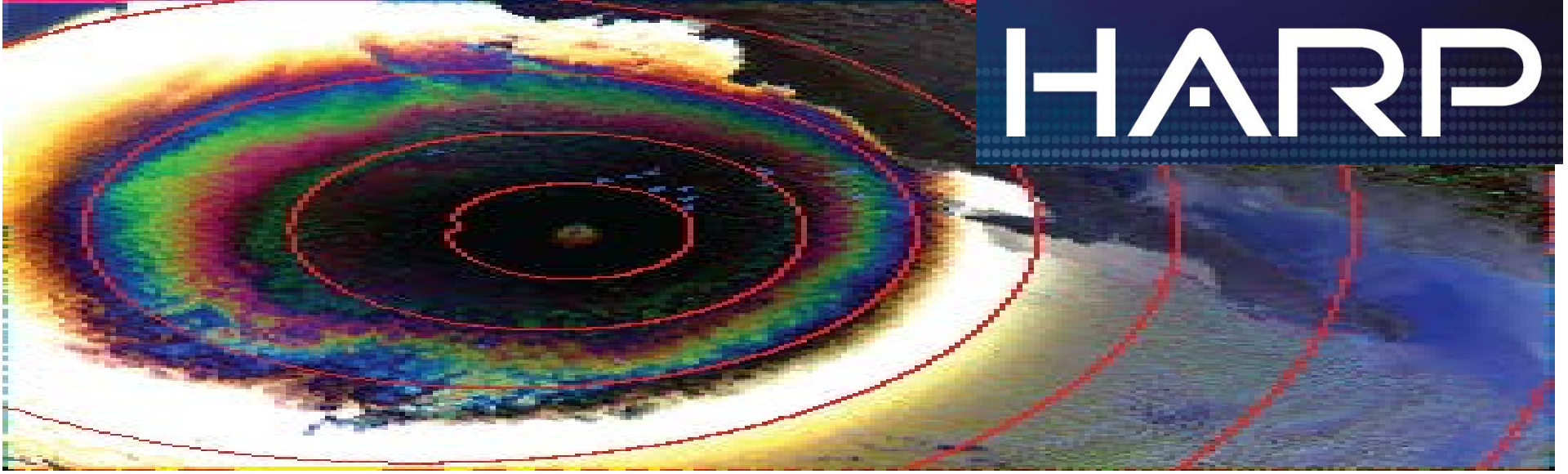


HARP CubeSat – An innovative Hyperangular Imaging Polarimeter for Earth Science Applications

J. Vanderlei Martins, Tim Nielsen, Chad Fish, Leroy Sparr, Roberto Fernandez-Borda, Mark Schoeberl, Lorraine Remer

Small Sat Pre-Conference Workshop, Logan Utah – 3 Aug 2014

NASA NOAA STC SCIENCE & TECHNOLOGY CORP. UMBC UMBC JCET NASA-GSFC Space Dynamics LABORATORY Utah State University Research Foundation

HARP Organizations

UMBC
LACO

Space Dynamics LABORATORY
Utah State University Research Foundation

JCET
The Joint Center for Earth Systems Technology

STC
SCIENCE & TECHNOLOGY CORP.

GSFC @ Greenbelt and Wallops

Funding: **ESTO InVEST**

Launch: **CSLI - ELaNa**

NOAA

HARP

HARP Objectives

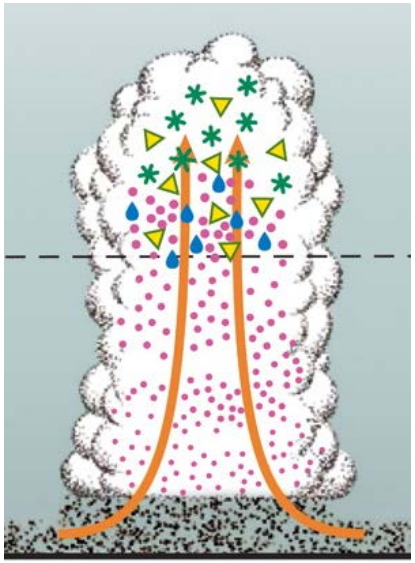
- Advance Hyperangular, Imaging Polarimetric concepts for the NASA/ACE (Aerosol, Cloud and Ecosystems) Mission
- Prove that CubeSat technology can provide science-quality multi angle imaging data paving the way for lower cost aerosol-cloud instrument developments.
- Student training.

HARP Science Goal

- Demonstrate the ability to characterize the **micro physical properties** of **aerosols and clouds** at the scale of individual moderate-sized clouds for the ultimate purpose of narrowing uncertainties in climate change.

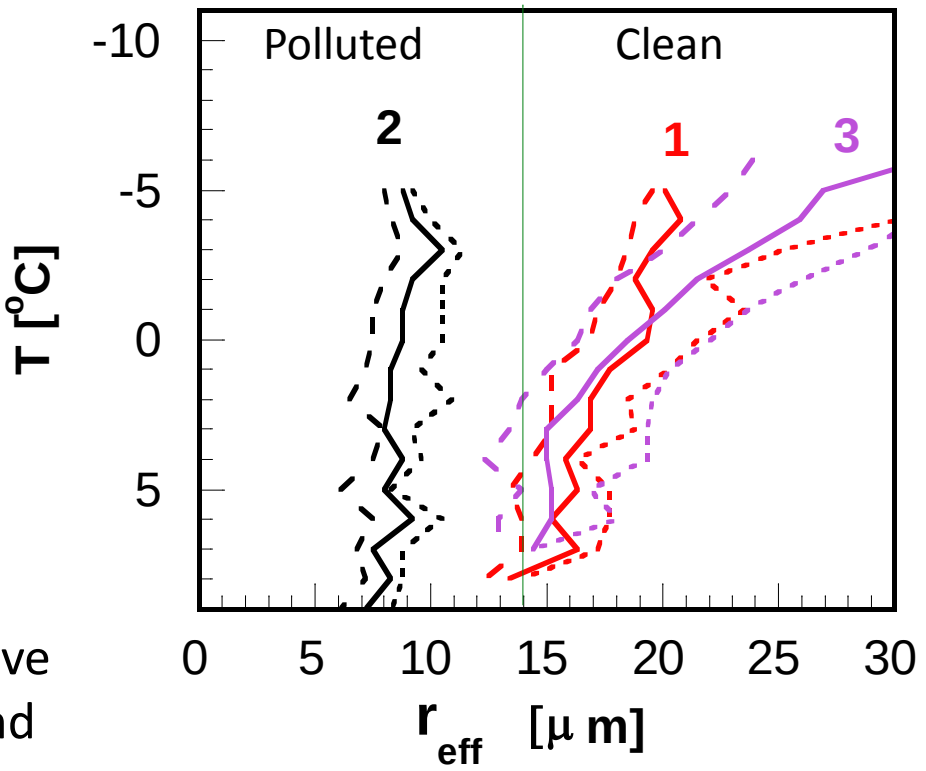
- Final Instrument: March/2015
- Full Spacecraft flight-ready: Sept/2015

HARP Science – Clouds and Aerosols

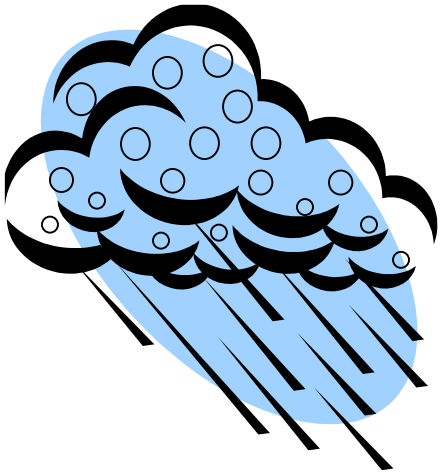


Polluted Clouds have smaller droplets and grow deeper without precipitating

Clouds

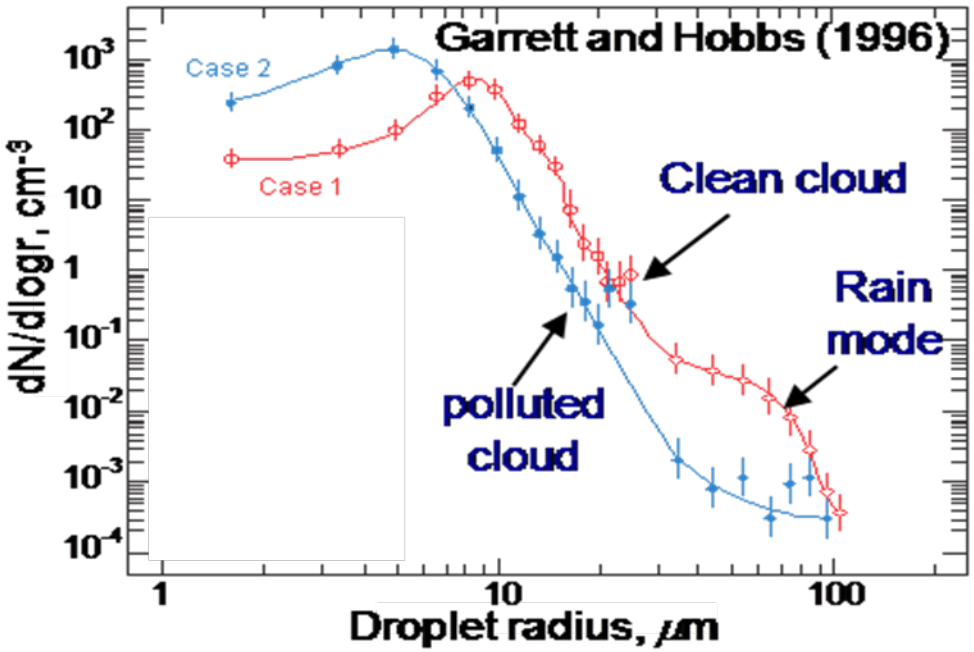


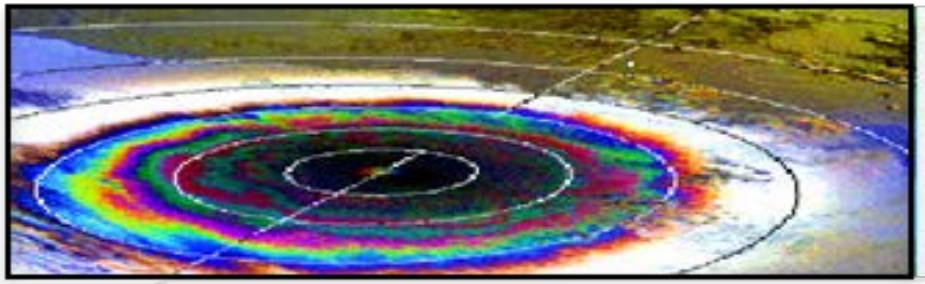
Clean Clouds have larger droplets and start earlier precipitation

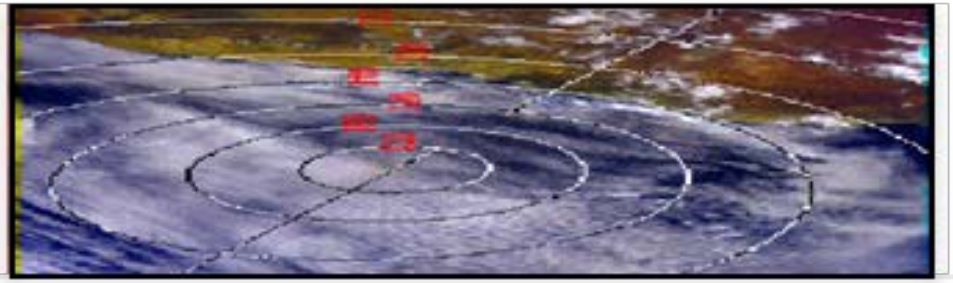


HARP Science

- *Pollution aerosols narrow cloud droplet distributions and postpones rain*
- *Smaller droplets increase cloud albedo and affect Earth's energy balance*
- *Polarized rainbow signal provides droplet effective radius and variance measurements*
- *HARP will measure pollution aerosols and cloud droplets*



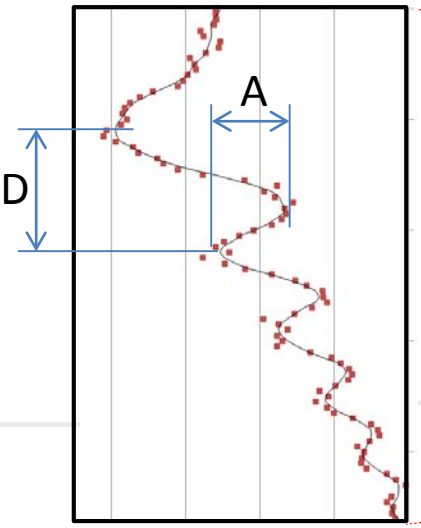


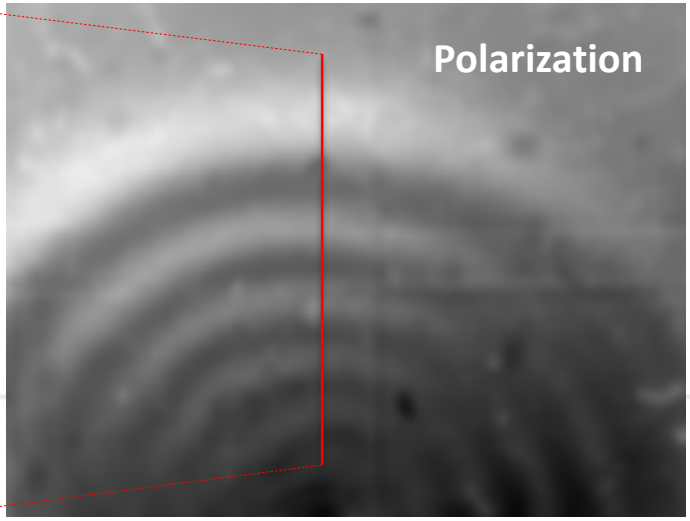


HARP CubeSat Polarimeter

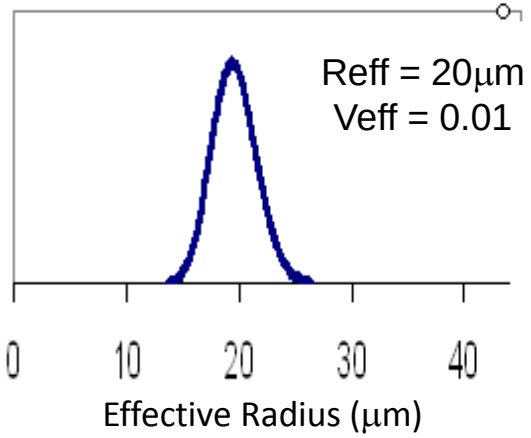
HARP Pioneering Hyper-Angular Capability will Provide Full Cloudbow Retrievals from Small Area (< 4x4km from space)

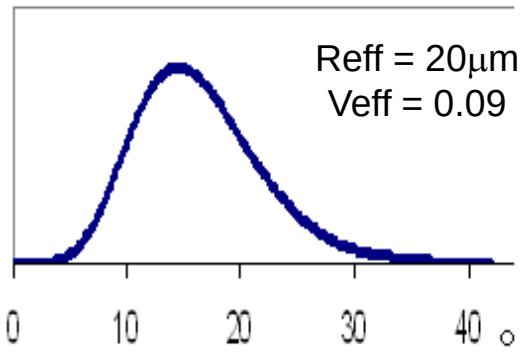
D and A produce cloud droplet effective radius and variance





Water Droplet Distribution

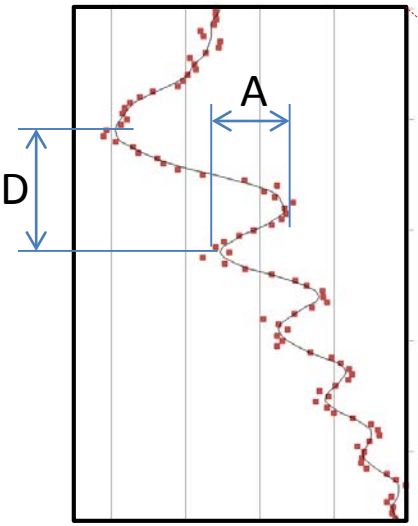


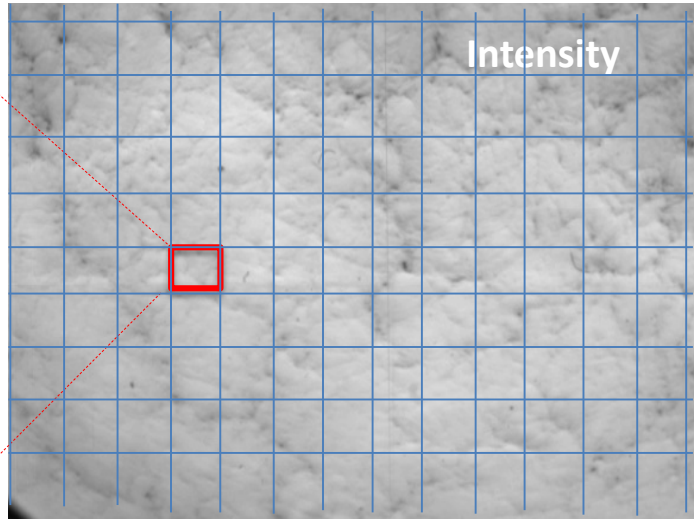


These two cases are undistinguishable from Intensity measurements only (MODIS/VIIRS)

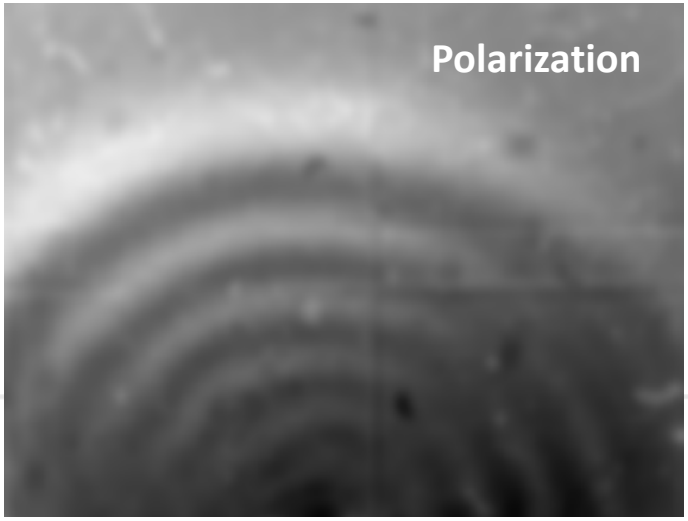
HARP CubeSat Polarimeter

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

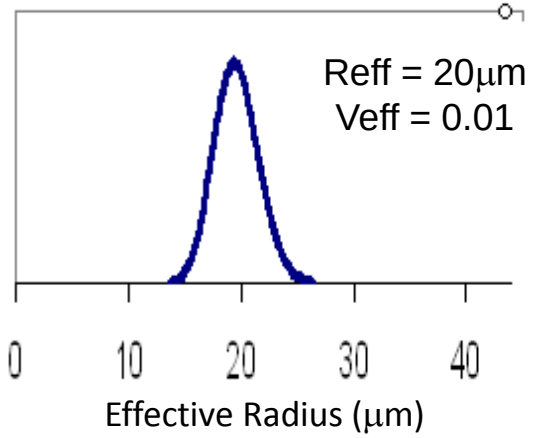


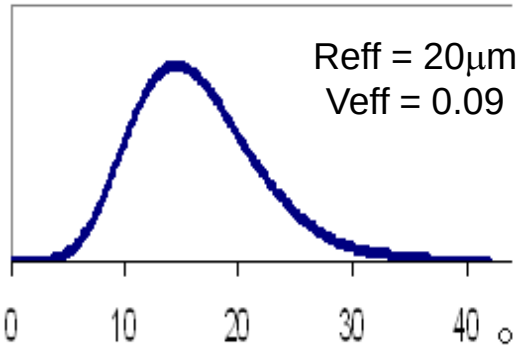


Same retrieval capability for all individual pixels with < 4x4km resolution



Water Droplet Distribution



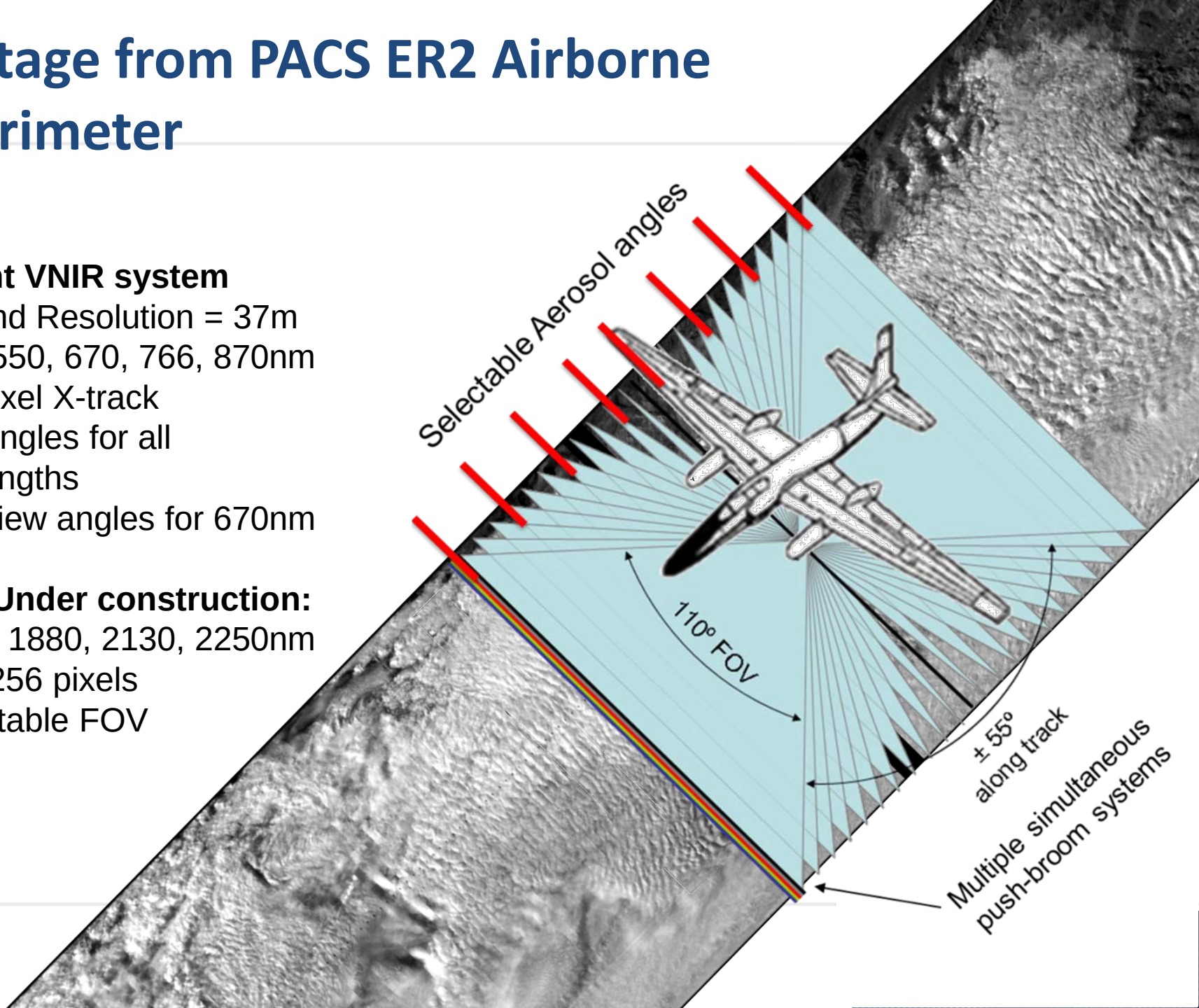


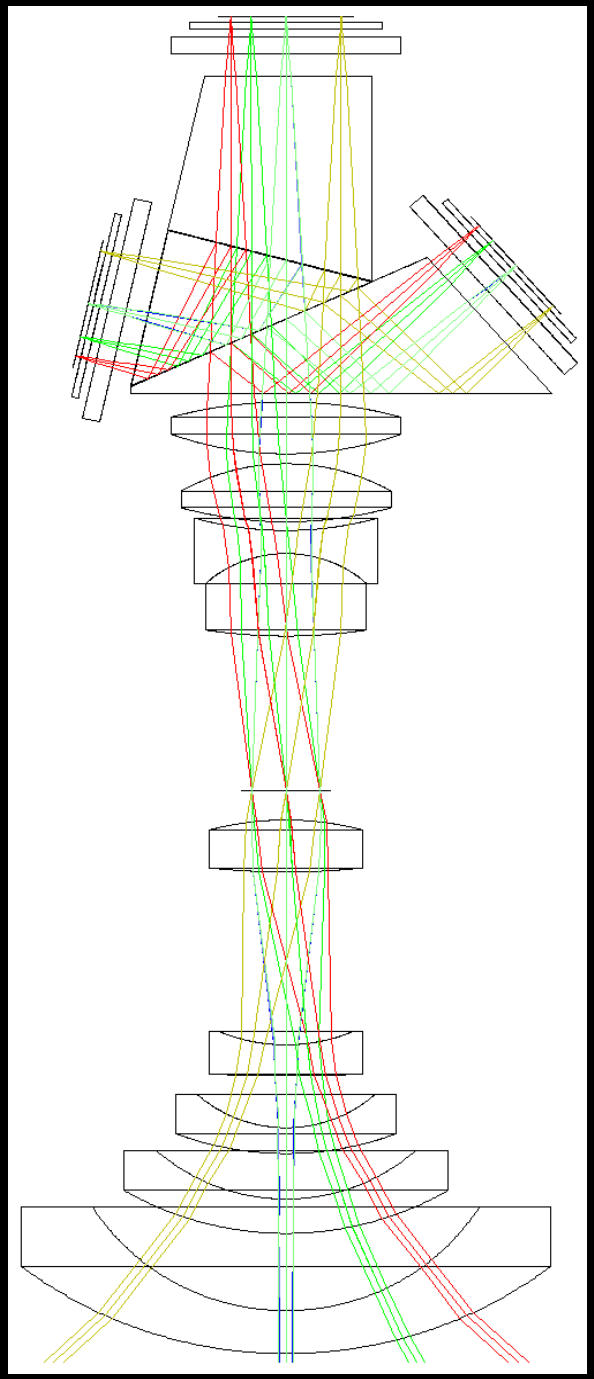
These two cases are undistinguishable from Intensity measurements only (MODIS/VIIRS)

Heritage from PACS ER2 Airborne Polarimeter

Current VNIR system
- Ground Resolution = 37m
- 470, 550, 670, 766, 870nm
- 1 K pixel X-track
- 65+ angles for all wavelengths
- 130 view angles for 670nm

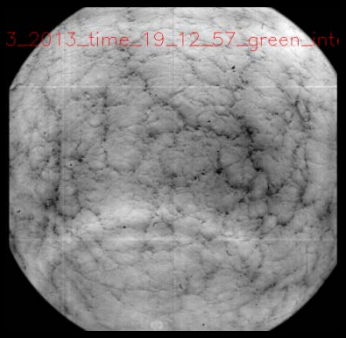
SWIR Under construction:
- 1650, 1880, 2130, 2250nm
- 320x256 pixels
- Adjustable FOV



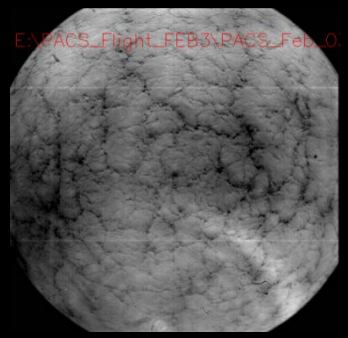


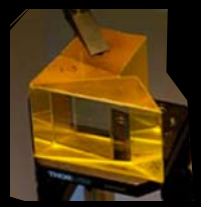
HARP Prism:

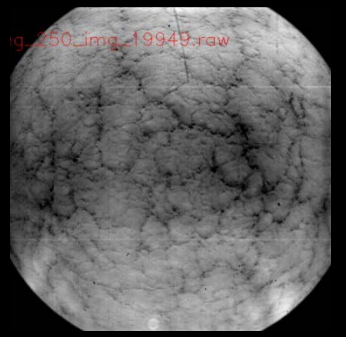
Three Polarized Images



$Intensity_{0°}$







$Intensity_{45°}$

$Intensity_{90°}$

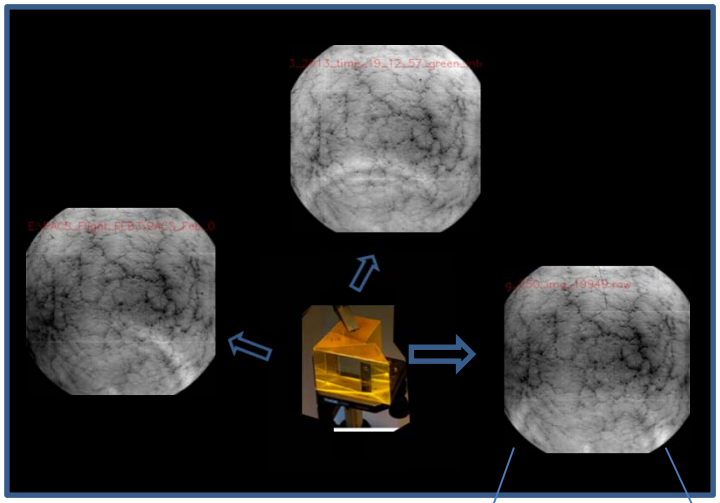
$$[I\ Q\ U]_{pixel} = [I_0\ \ I_{45}\ \ I_{90}] \cdot M$$

HARP Scheme for Hyperangular Multi-Wavelength Polarization Images

HARP

- Up to 60 viewing angles
- 440, 550, 670, 870nm
- 2.5km resolution
- 94 deg FOV X-track
- 110 deg FOV along track

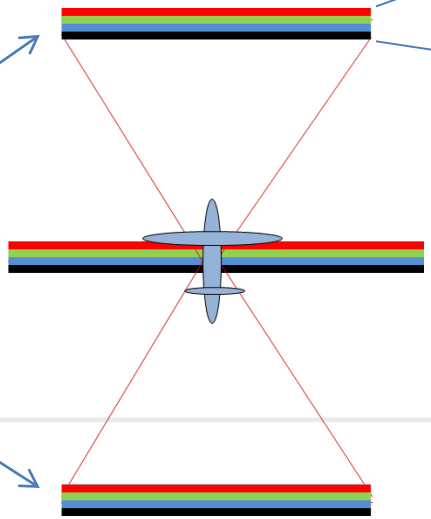
Prism/Polarization Separation



Multi/Hyper Angle with multiple pushbrooms

Multi Wavelength

Stripe Filters: Angular and Wavelength Separation

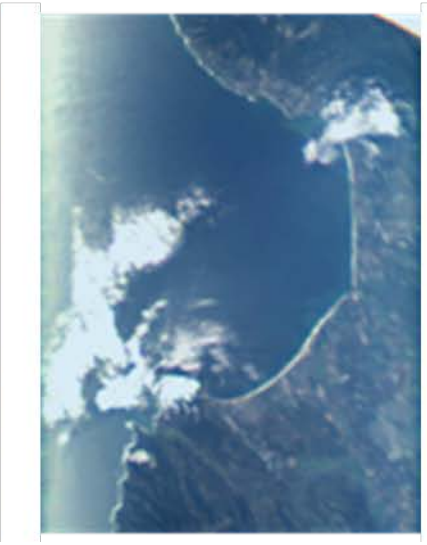


Multiple Viewing Angles (>50 angles by airborne PACS)





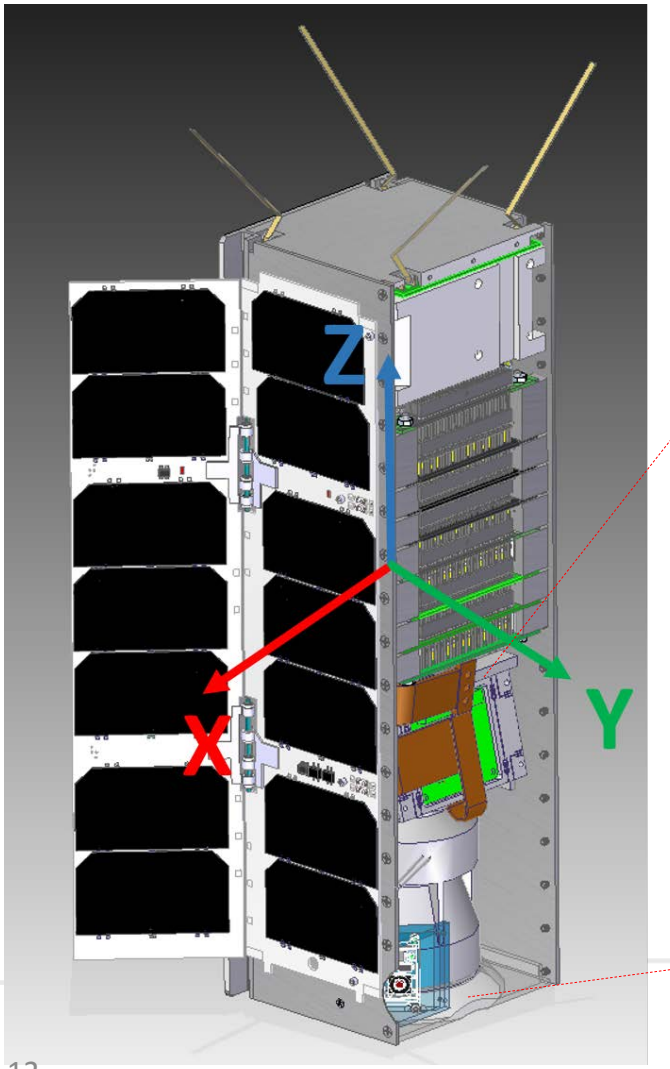


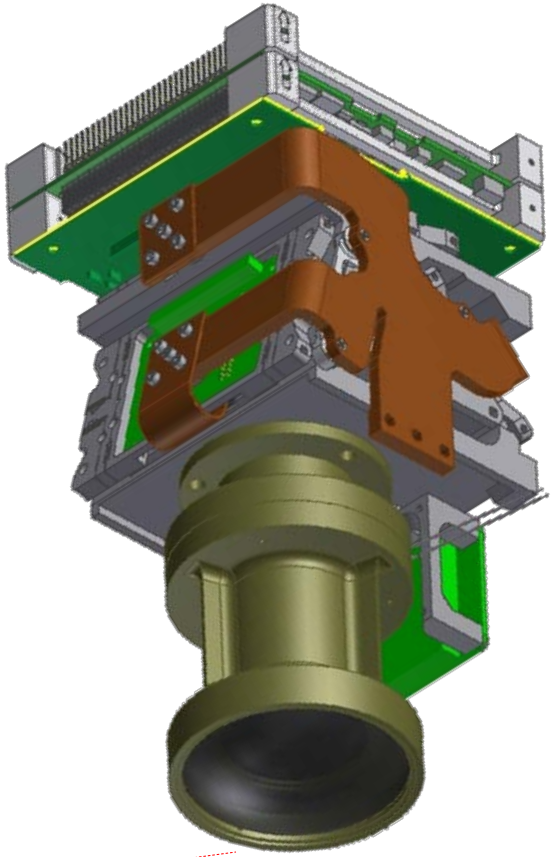
HARP

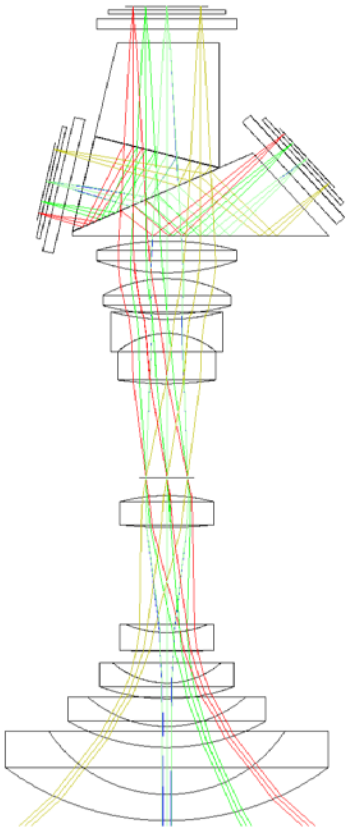
HARP Instrument & Spacecraft

SDL Spacecraft

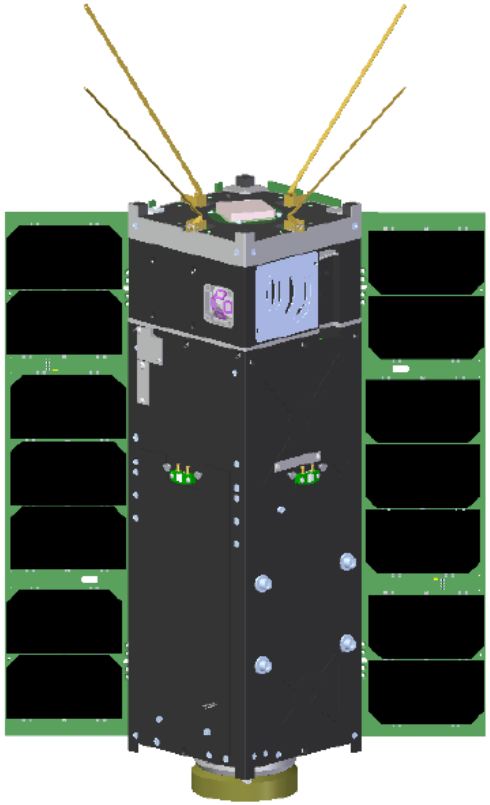


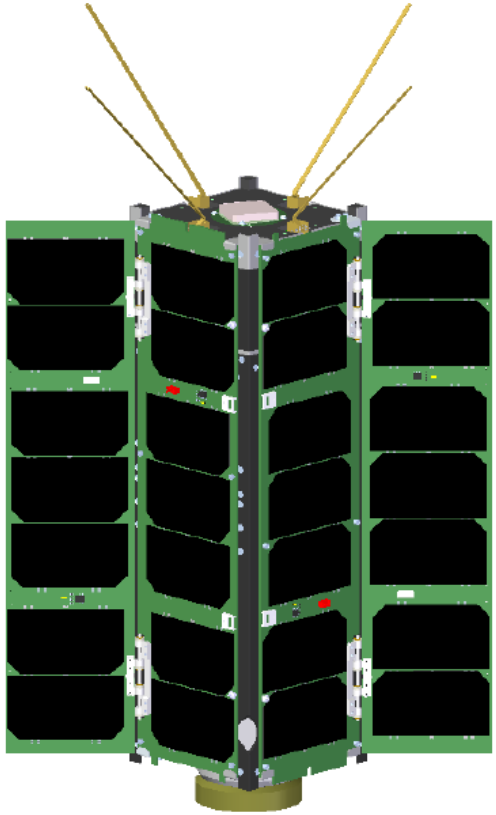
UMBC Imaging Polarimeter

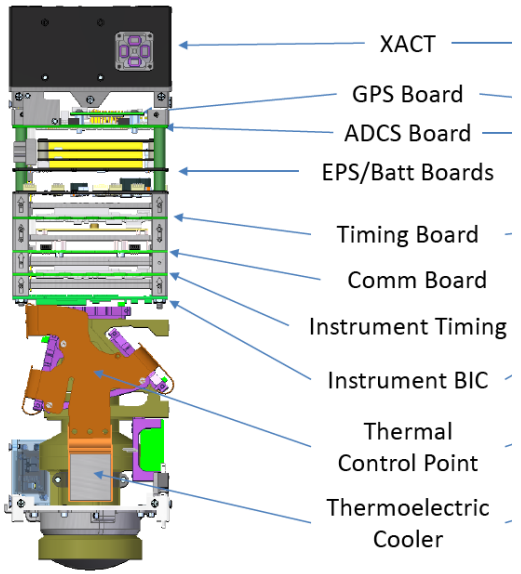




Spacecraft Views







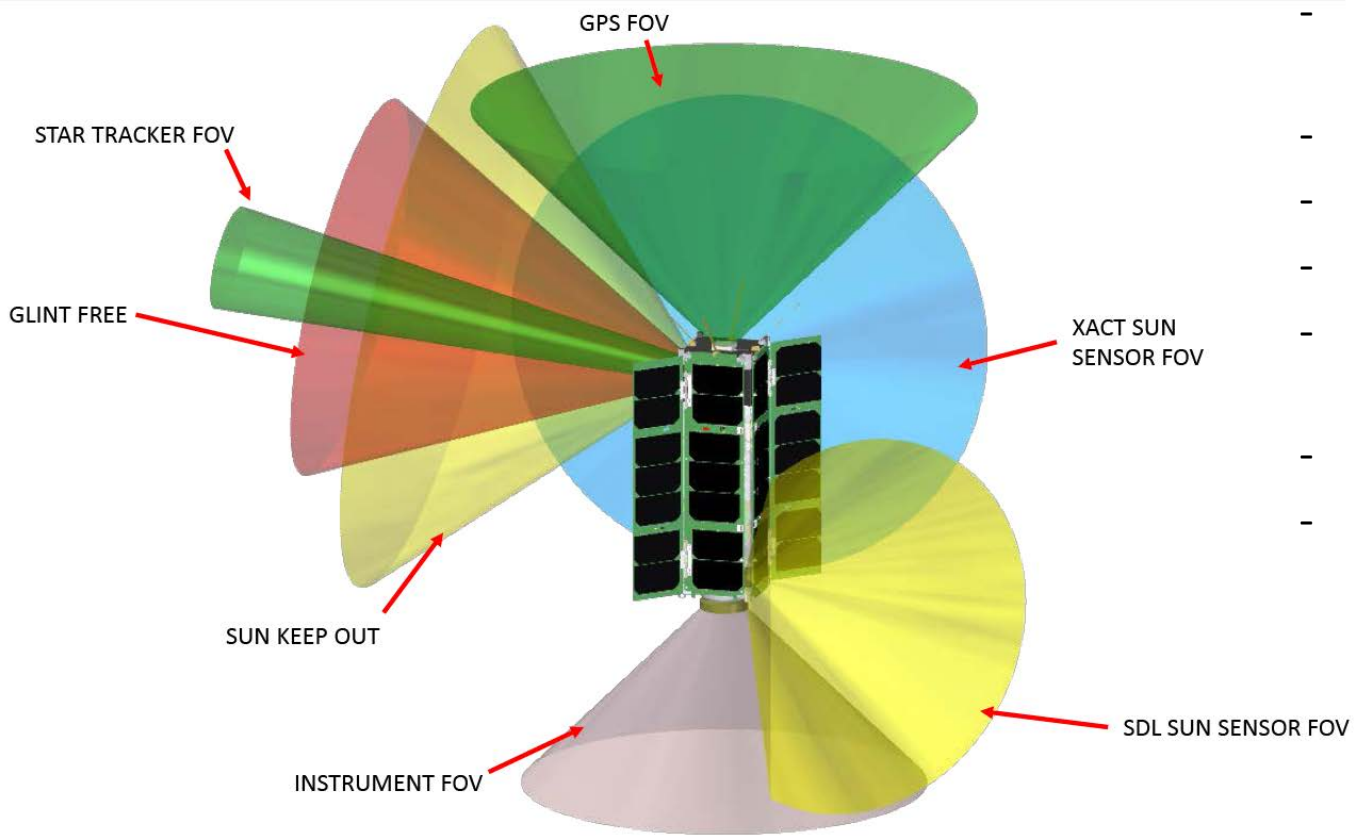
Back view

- Thermal Radiators
- Star Camera aperture
- Sun Sensor
- GPS Patch Antenna

Front view

- Deployed Solar Arrays and Antenna
- ADCS Sensors
- Instrument aperture at the bottom

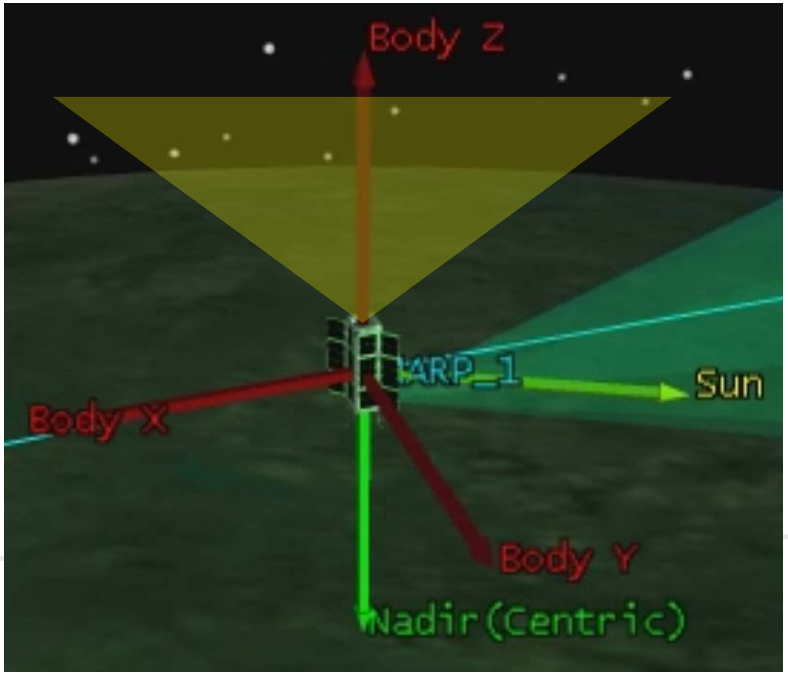
HARP – Full Feature Earth Sciences Satellite



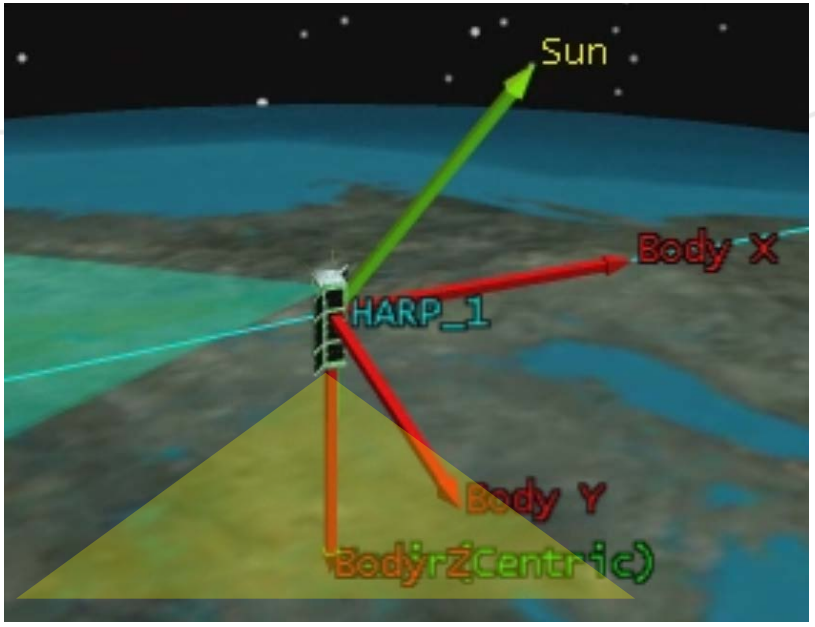
- XACT Blue Canyon ACDS
- Sun Sensor + Star tracker
- Wide FOV hyperangular, polarized imaging payload
- 4 wavelengths
- L3 UHF radio
- Telemetry: 1.43 Gbits/day
- Data Acquisition: up to 8.6Gbits/day
- 2.5km spatial resolution
- 0.66km pointing knowledge/geolocation

HARP Pointing Modes

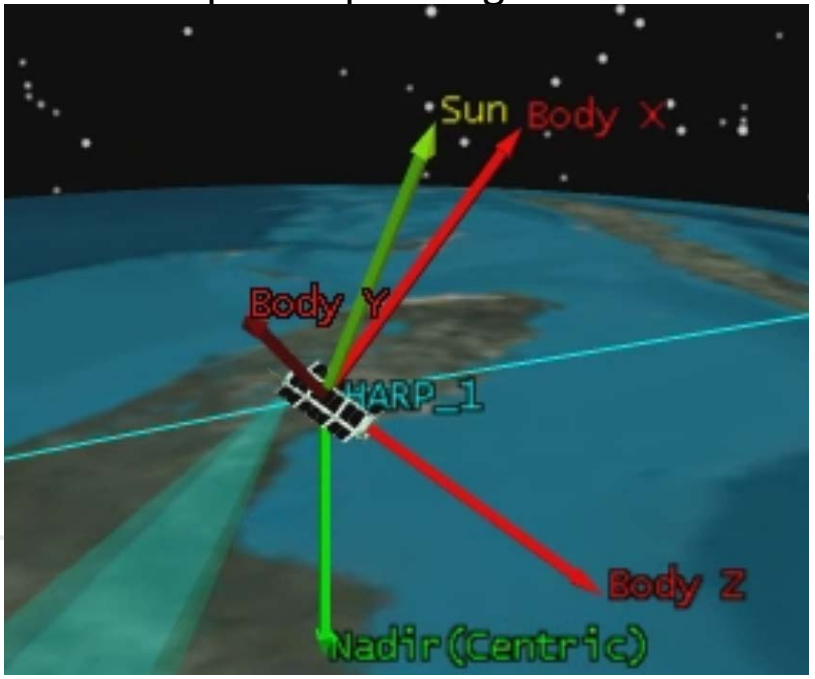
- Deep Space - Dark Reference
- Moon calibration
- Horizon calibration

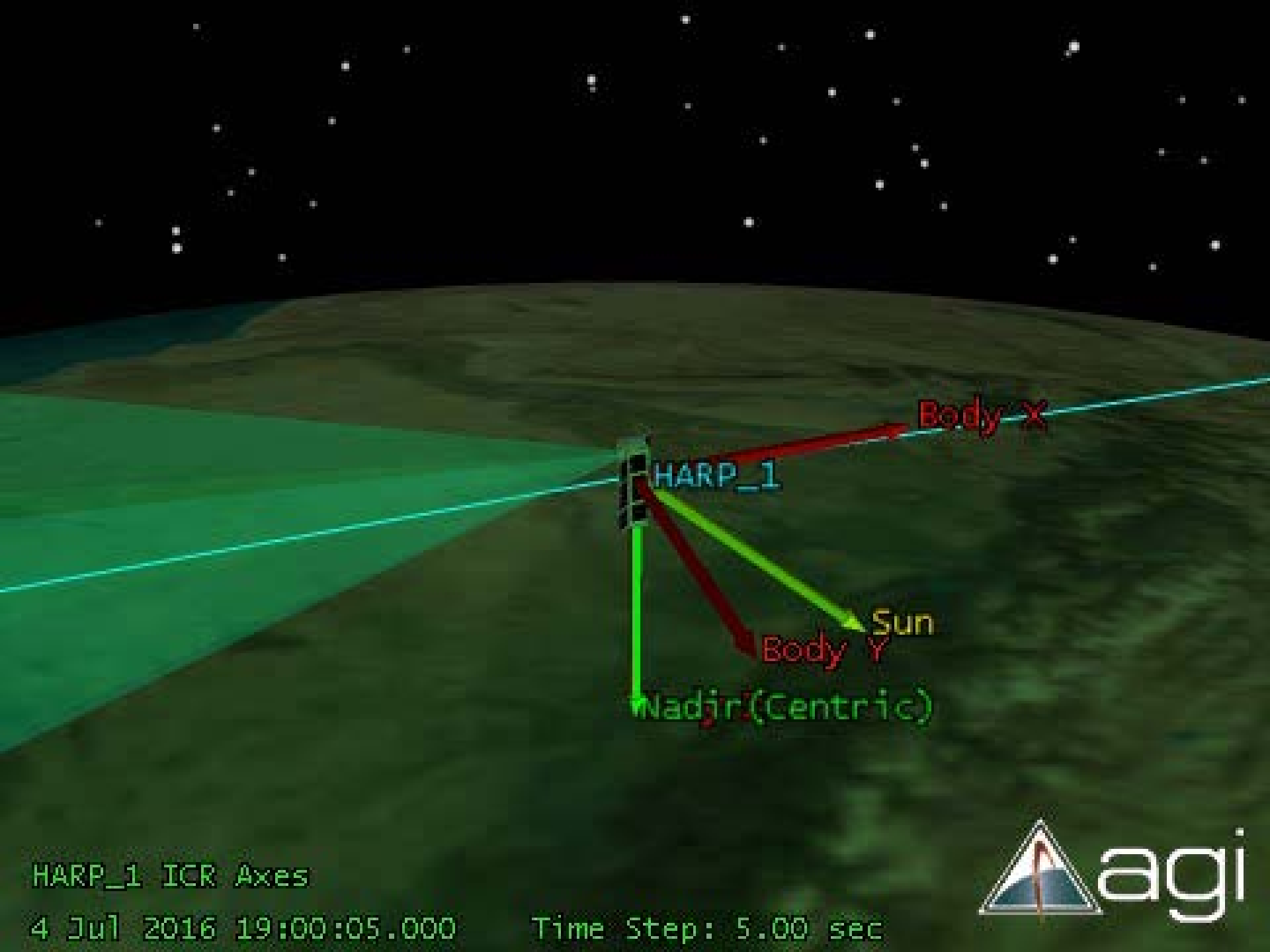


Nadir Data Collection

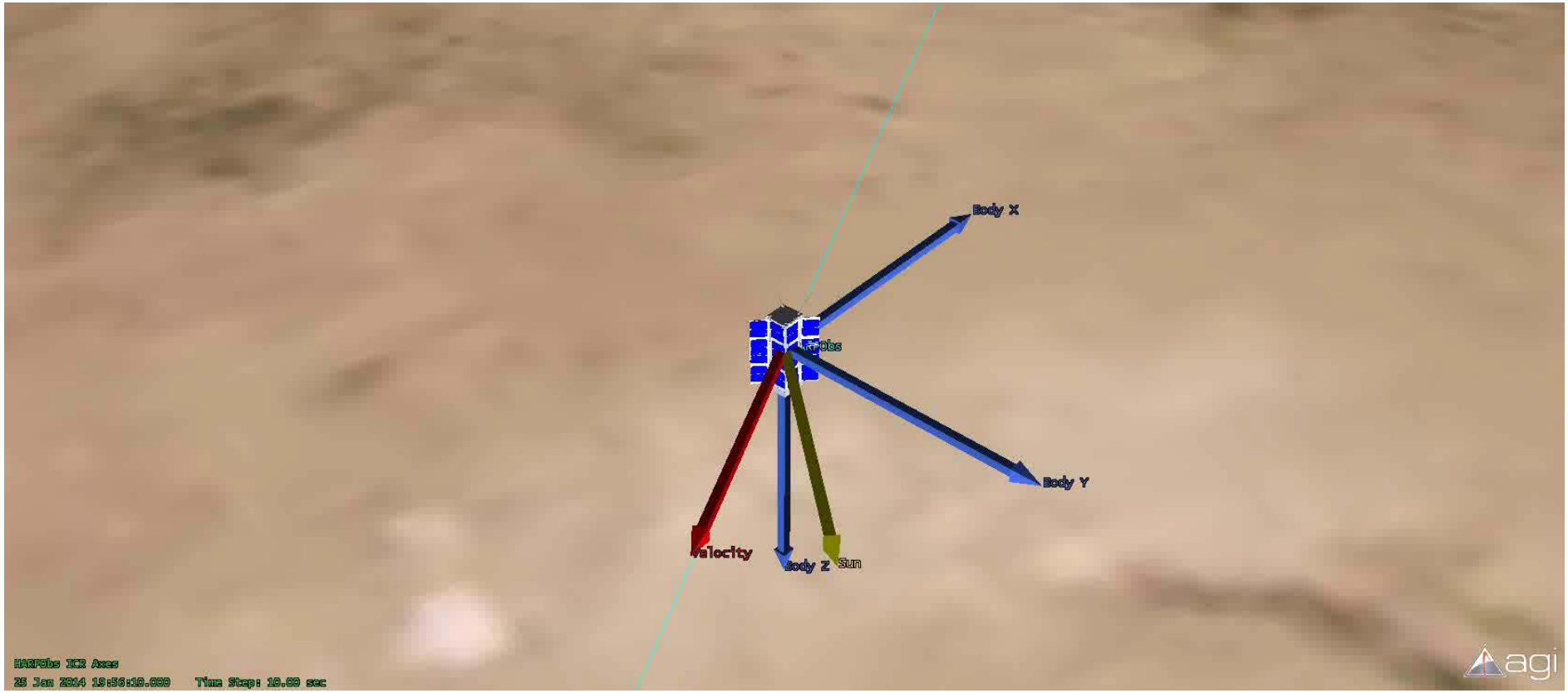


Solar panels pointing at the Sun

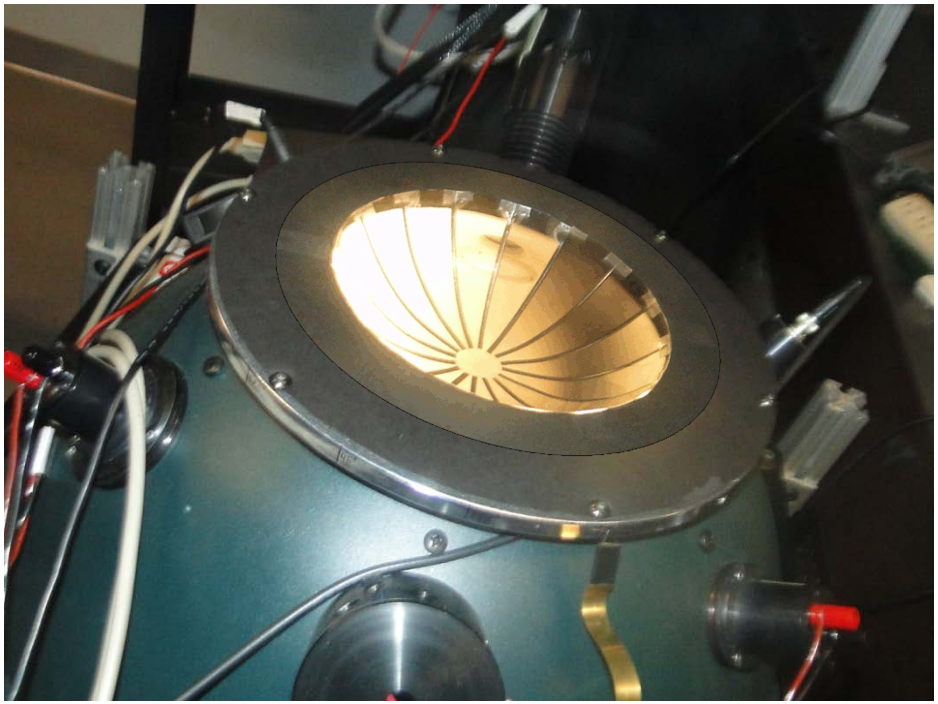



Body X
HARP_1
Sun
Body Y
Nadir(Centric)
HARP_1 ICR Axes
4 Jul 2016 19:00:05.000
Time Step: 5.00 sec
agi

Power Acquisition Scenario



UMBC Calibration/Testing Facilities



Polarization Calibrator

Thermo-Vac testing

- ESD benches
- Thermo-Vac testing
- Machine shop
- Clean room; etc.

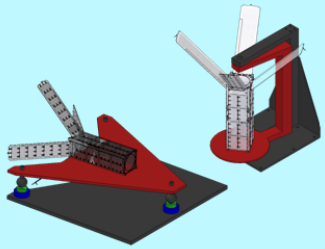
SDL Facilities

- Certified facilities (ESD, etc.)
- Thermo-Vac, shake tables
- Machine shop
- Clean rooms , etc.

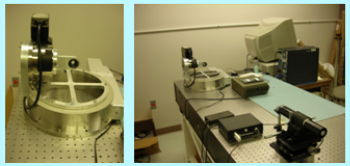
NOVA LAB

NanoSat testing

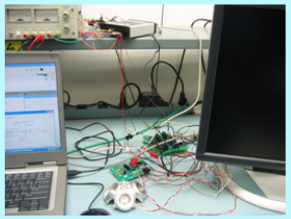
Mass Properties
- Center of mass
- Moments of inertia



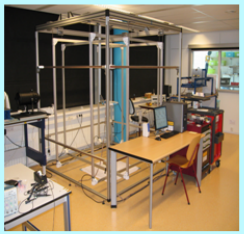
Sun Sensors
- Calibrate and test sun sensor



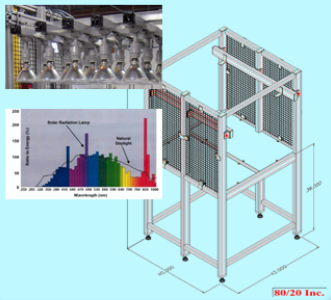
Reaction Wheels
- Test, characterize, and calibrate



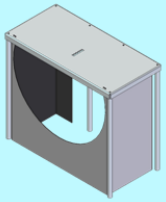
Torque Coils
- Test and characterize



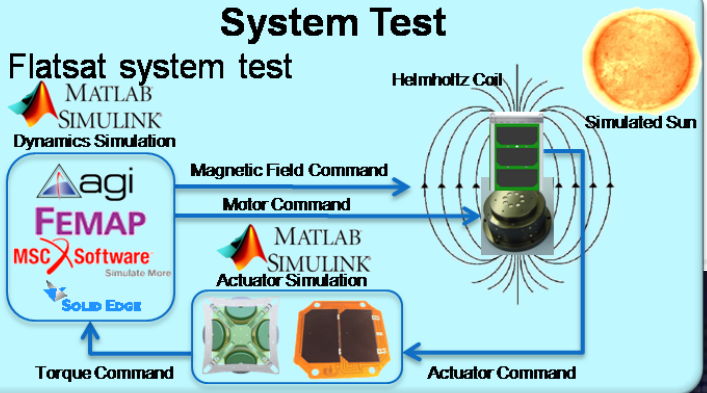
Solar Arrays
- AM0 illumination



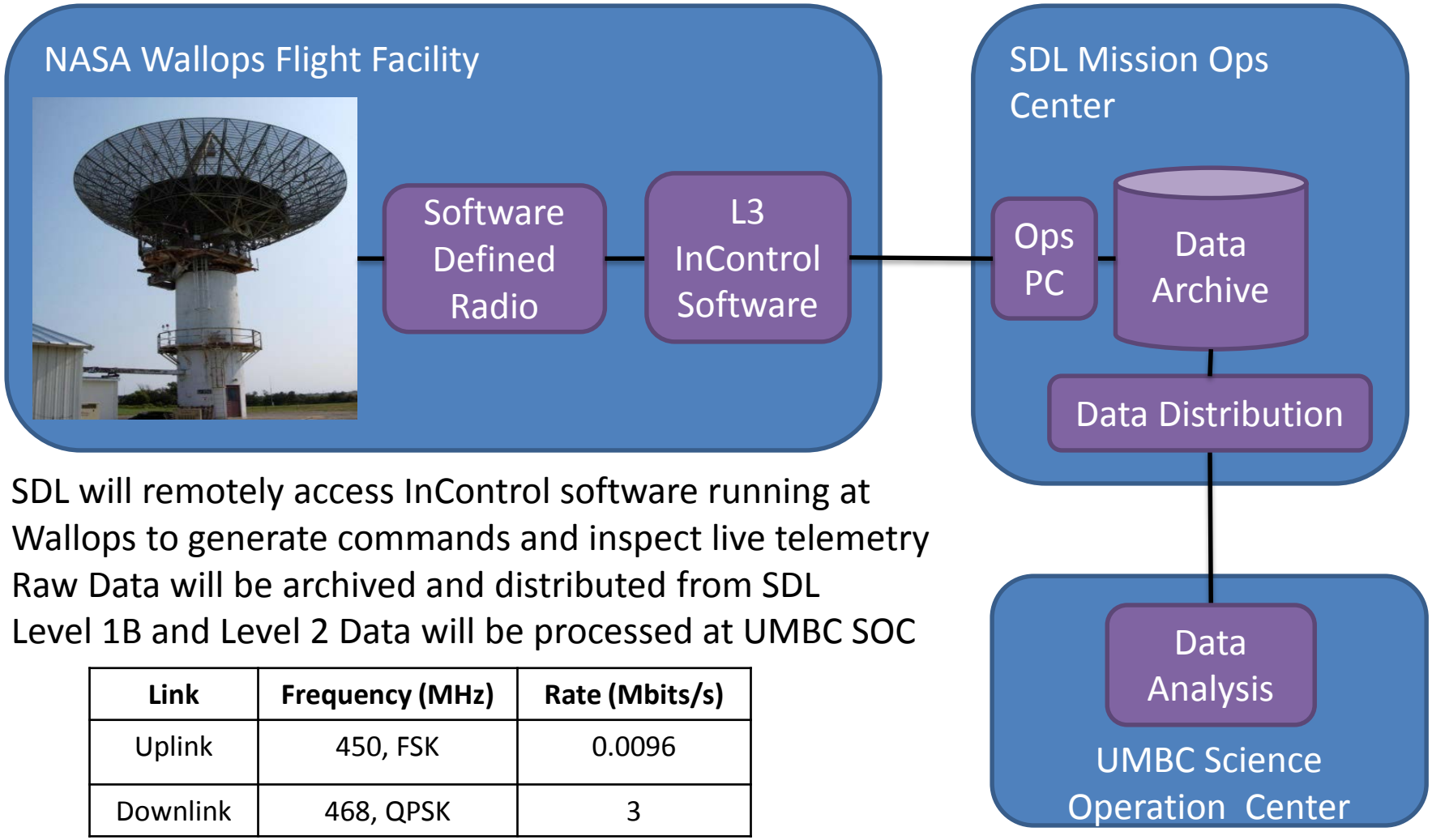
Horizon Sensors
- Earth/space simulator
- Sensor mount rotates



System Test
- Flatsat system test

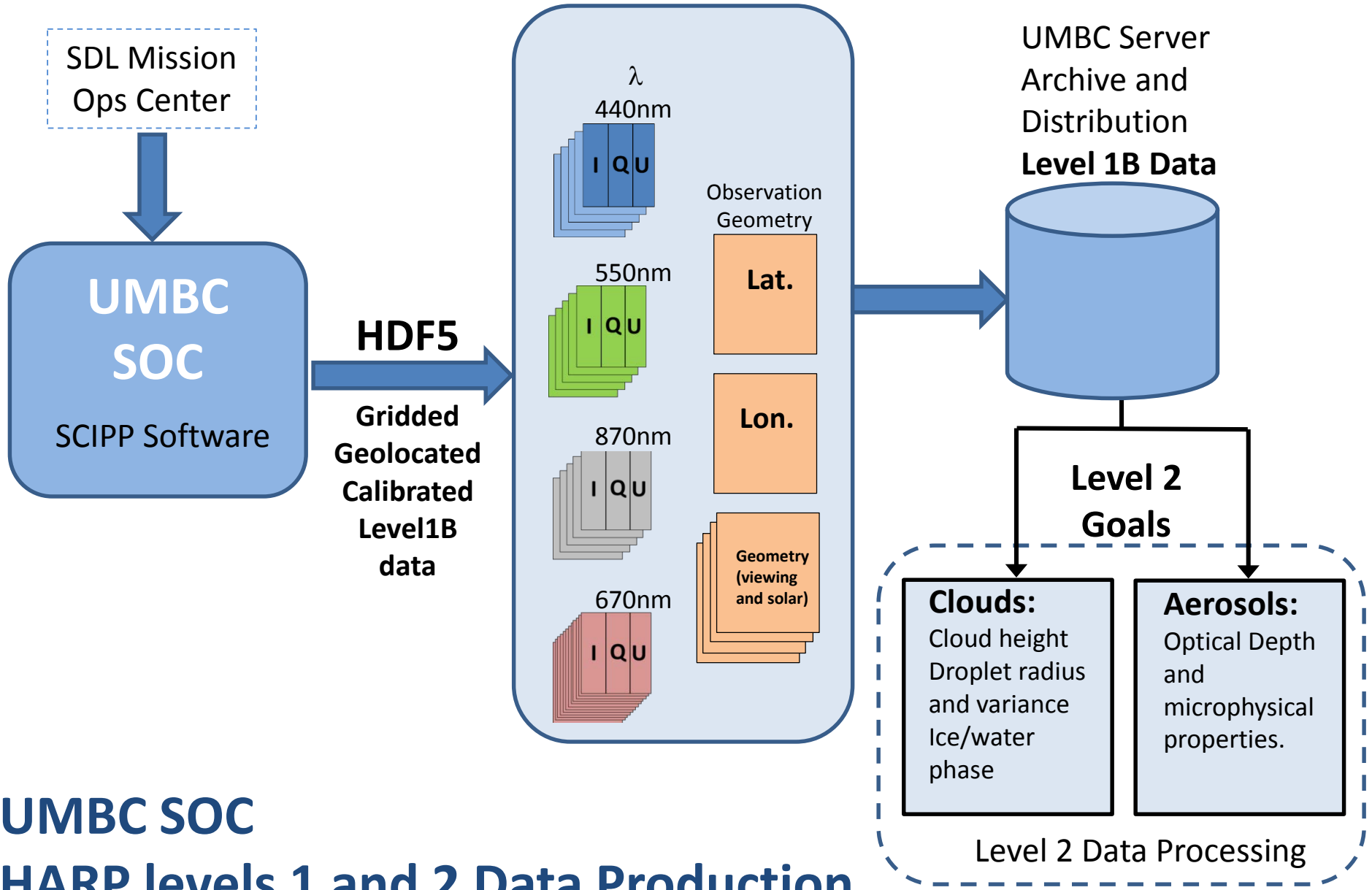


Ground Station Architecture



- SDL will remotely access InControl software running at Wallops to generate commands and inspect live telemetry
- Raw Data will be archived and distributed from SDL
- Level 1B and Level 2 Data will be processed at UMBC SOC

Link	Frequency (MHz)	Rate (Mbits/s)
Uplink	450, FSK	0.0096
Downlink	468, QPSK	3



UMBC SOC
HARP levels 1 and 2 Data Production

HARP

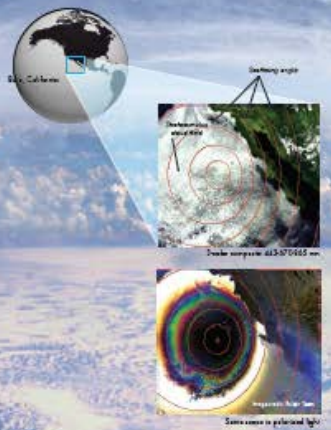
Hyper-Angular Rainbow Polarimeter

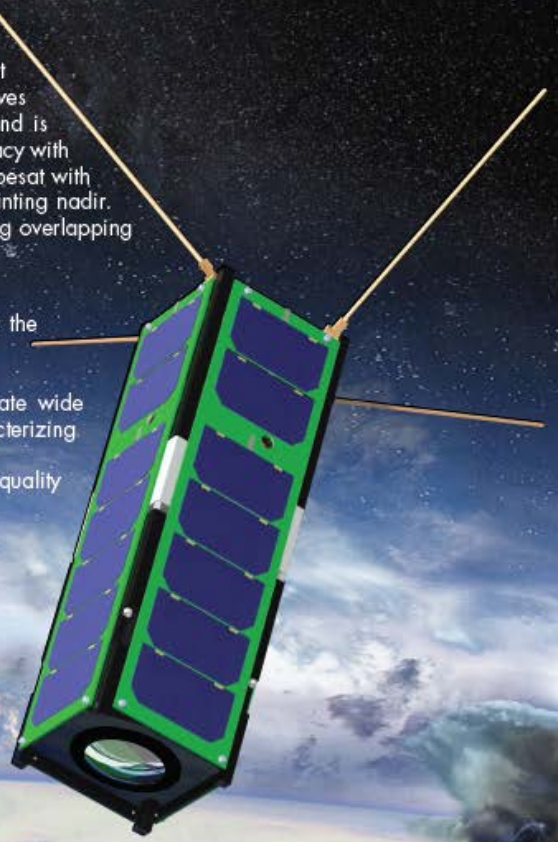
In-Space Validation of Earth Science Technologies (InVEST)

The HARP payload is a wide FOV imager that splits three spatially identical images into three independent polarizers and detector arrays. This technique achieves simultaneous imagery of three polarization states and is the key innovation to achieve high polarimetric accuracy with no moving parts. The spacecraft consists of a 3U Cubesat with 3-axis stabilization designed to keep the imager pointing nadir. The hyper-angular capability is achieved by acquiring overlapping images at very fast speeds.

OBJECTIVES:

- Space validation of new technology required by the NASA Decadal Survey Aerosol-Cloud-Ecosystem (ACE) mission
- Prove the on-flight capabilities of a highly accurate wide FOV hyper-angle imaging polarimeter for characterizing aerosol and cloud properties
- Prove that cubesat technology can provide science-quality Earth Sciences data

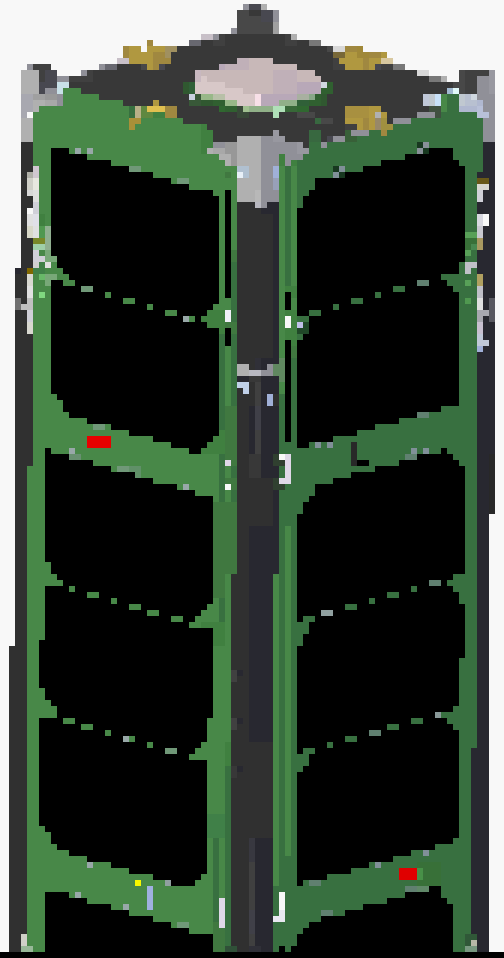




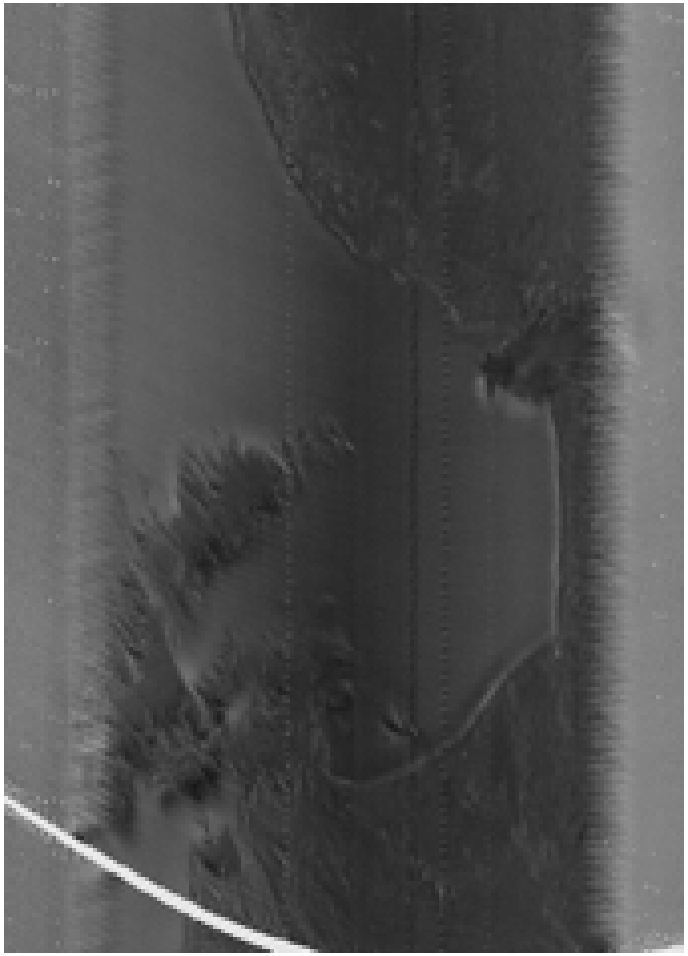
Thank you!!!

UMBC NASA STC JCET NOAA Space Dynamics Laboratory

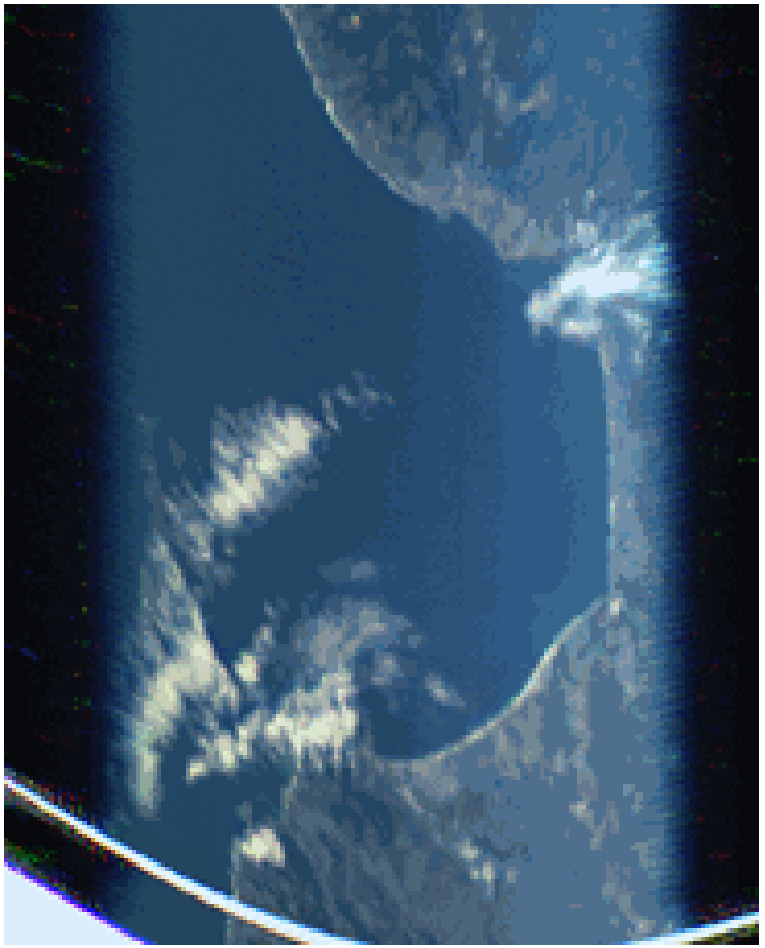
Backup Slides:



Example of hyperangular observations of sunglint from PACS-Aircraft

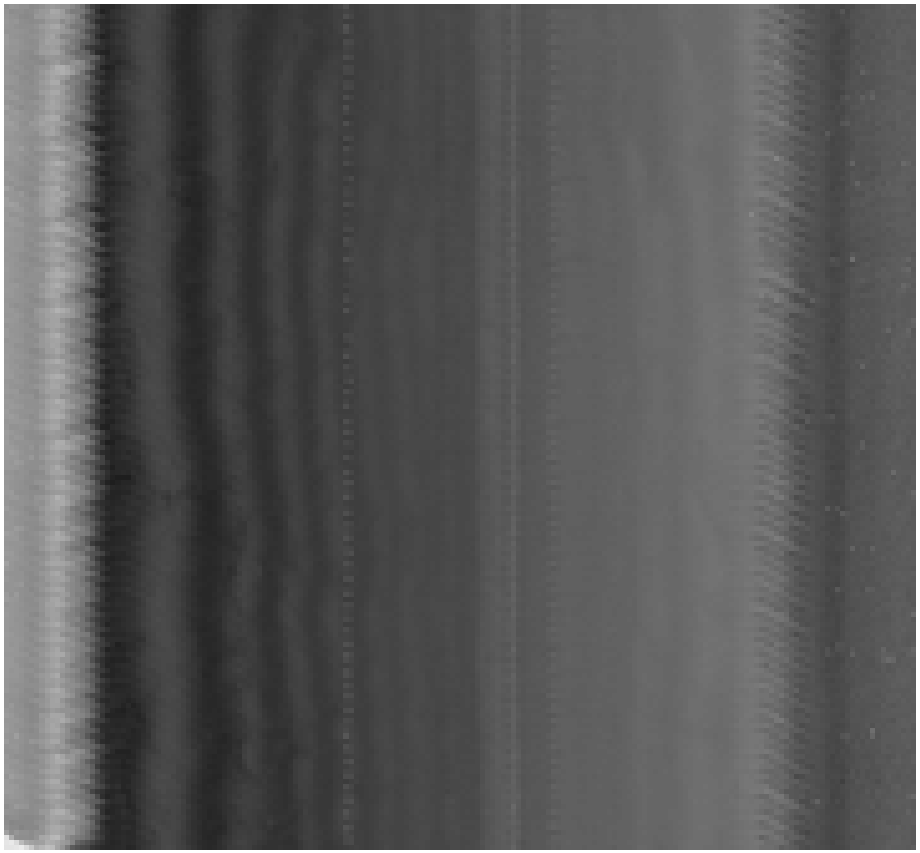


DoLP - Red

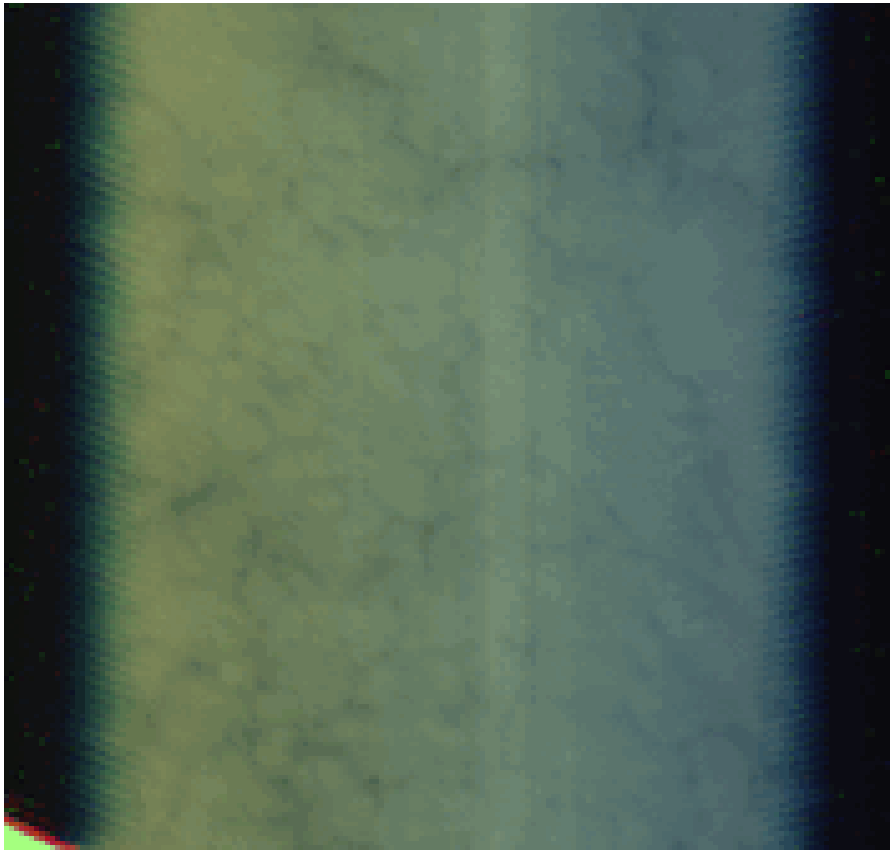


Intensity RGB

Hyperangular Movie of Cloubow from PACS-Aircraft

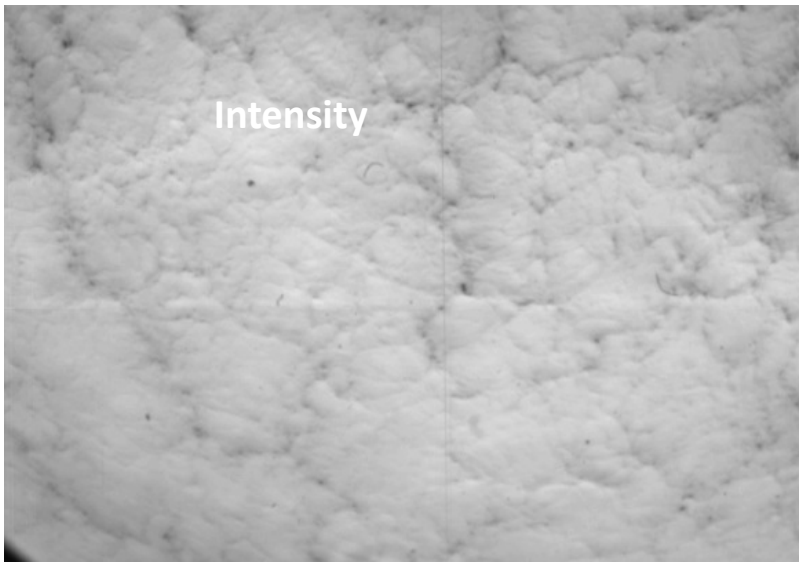


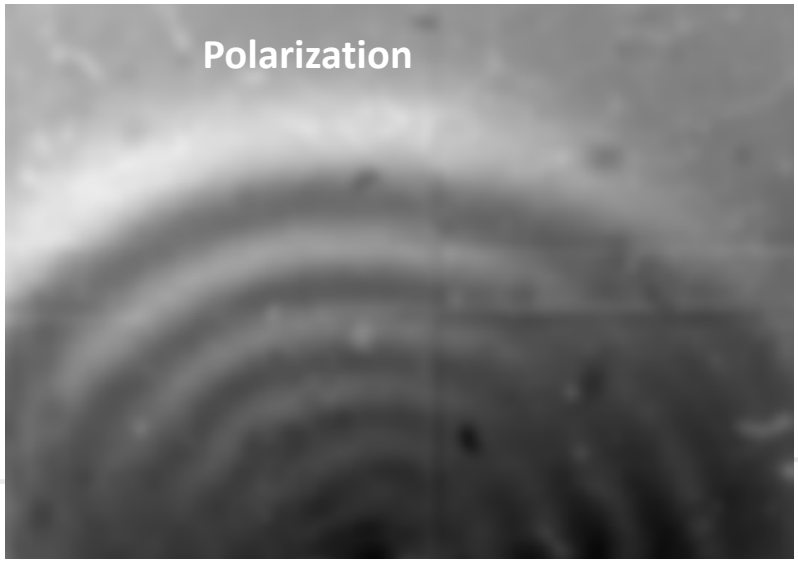
DoLP - Green

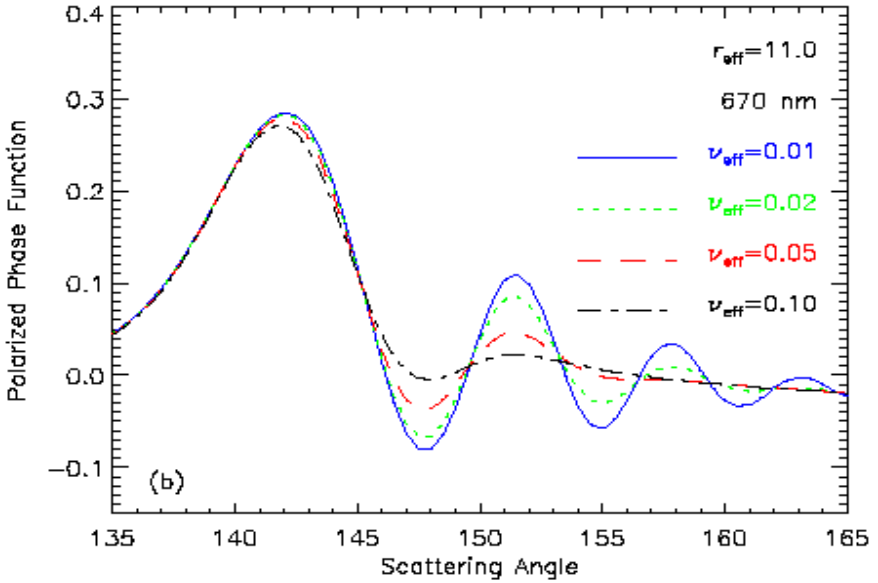


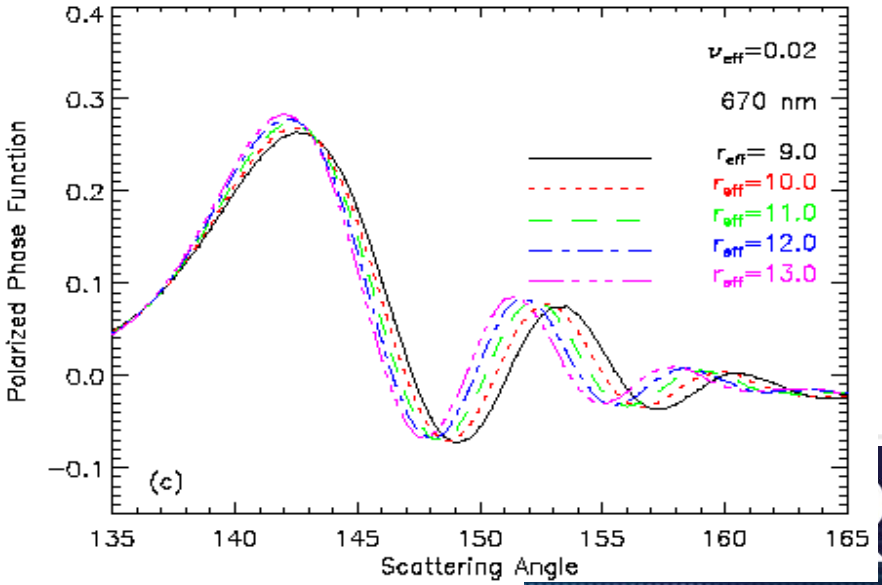
Intensity RGB

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

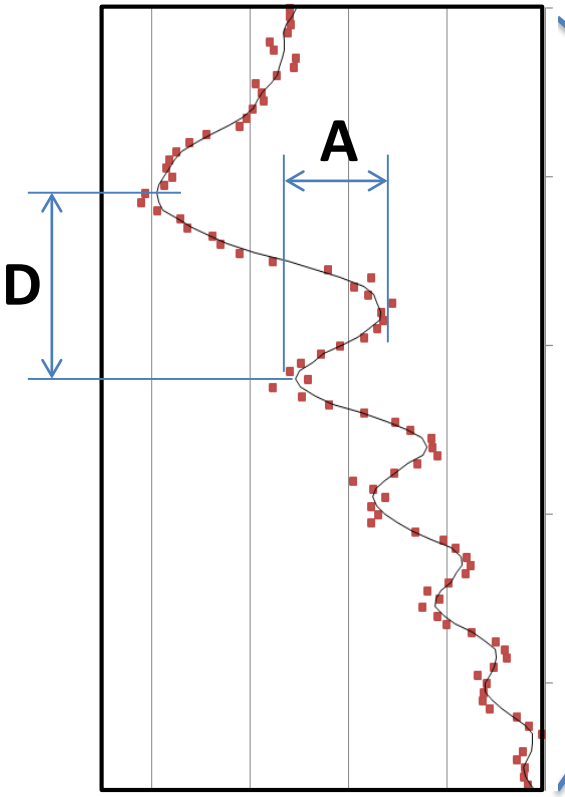




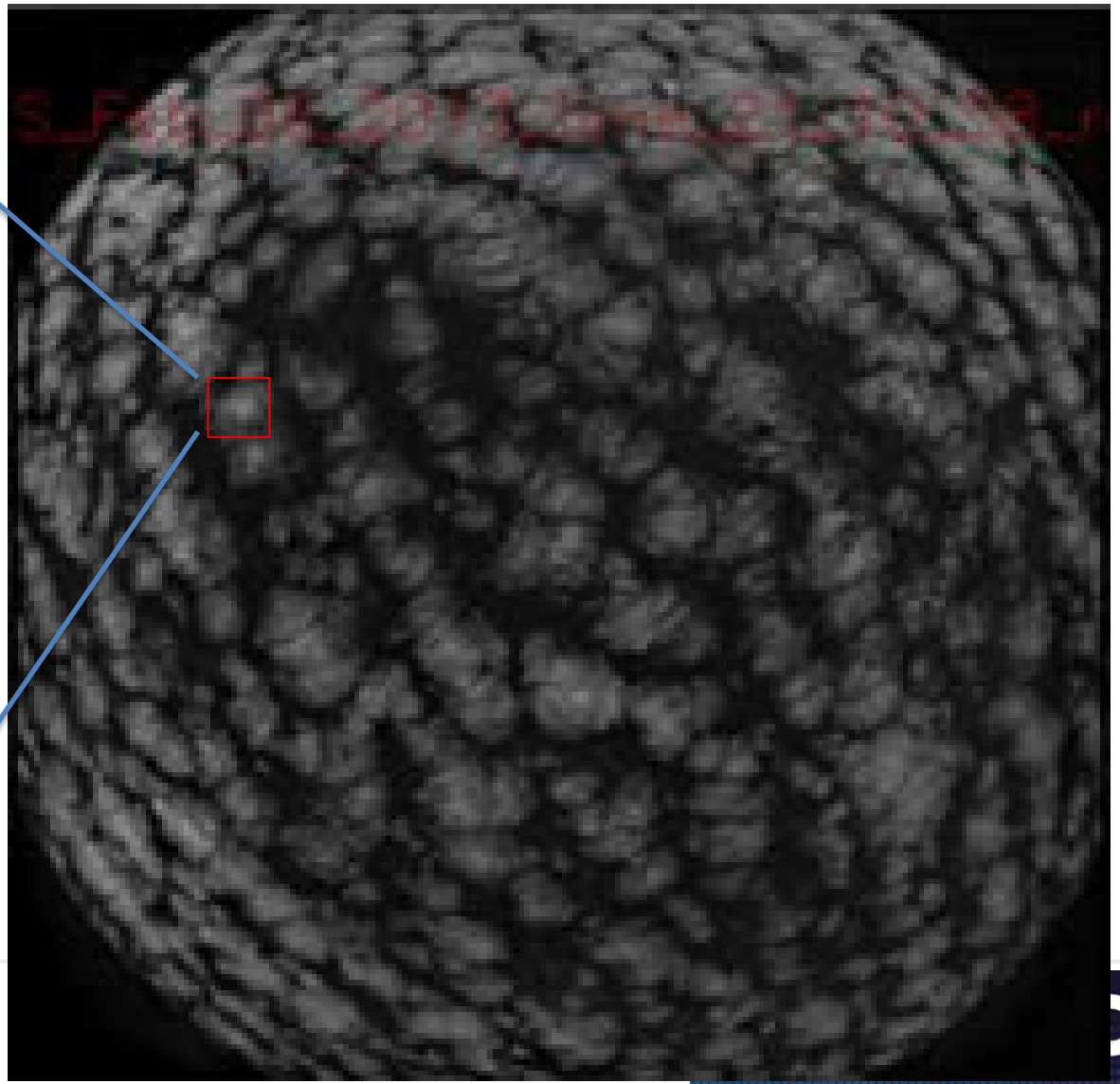




Cloudbow Measurements Possible for highly variable Scenes



D and A parameters allow for measurements of cloud droplet effective radius and variance



Major Program Milestones

Program Milestone	Target Date	Status
Requirements Review	10/2013	Completed
Instrument Single Design Review	2/10/2014	Completed
Preliminary Design Review	2/11/2014	Completed
Mission Critical Design Review Instrument Delta SDR	07/3/2014	Completed
Delivery Functional Instrument Unit #1	1/2015	On schedule
Hot Swap with Flight Unit #2 (Allows for extra calibration on flight unit)	3/2015	On schedule
Observatory Integration	2/2015	On schedule
Launch Readiness	9/2015	On schedule
Observatory Operations	TBD	
Science Observations	TBD	