## **VARC EST** EARTH INSTITUTE

# Current and future measurements of aerosol and cloud properties with the HARP family of Multi-Angle Imaging Polarimeters.

J. Vanderlei Martins<sup>1</sup>, Xiaoguang (Richard) Xu<sup>1</sup>, Anin Puthukkudy<sup>1</sup>, Noah Sienkiewicz<sup>1</sup>, Brent McBride<sup>1</sup>, Roberto Fernandez-Borda<sup>1</sup>, Lorraine Remer<sup>1</sup>, Oleg Dubovik<sup>2</sup>

- 1- UMBC Earth and Space Institute and JCET-UMBC/NASA GSFC
- 2- University of Lille and GRASP.

#### HARP observations

NASA



70 120 170 Scattering Angle

### The promise of multi-angle polarization

#### Observation and model



- Aerosols
  - Accurate AOD for fine and course mode
  - Aerosol microphysics: particle size and shape

- Single scattering albedo
- Real and Imaginary refractive indices
- Particle phase function
- Clouds
  - Cloud phase
  - Cloud effective radius
  - Cloud effective variance
- Surface
  - BRDF and BPDF retrievals
  - Improved atmospheric correction



#### HARP CubeSat

#### NASA-ESTO InVEST Program



#### **SDL Spacecraft**

Launched: Nov 2<sup>nd</sup>, 2019 ISS Deployment: Feb 19<sup>th</sup>, 2020 First light: April 15<sup>th</sup>, 2020 **UMBC Sensor** 



**3U size** 

**HARP** Prism



Telescope

NASA



I, Q, U

Wide FOV Optics

**HARP Stripe Filter** 

#### Camera and FPGA Electronics







- 670 nm
- 870 nm

lines in the detector (viewing angles)

## How groundbreaking can a CubeSat satellite be?

NAS

#### HARP is the only HyperAngular Imaging Polarimeter in Space!!!





#### Partial list of Current and Planned Earth Observing Polarimeters

#### Flown or Potentially flown

- HARP CubeSat UMBC/NASA US
- POSP/HJ-2: China
- SMAC/GFDM-1: China
- PCF/GF-5(02): China
- ScanPol MSIP: MAO/Ukraine

#### **Planned for Near Future**

- GAPMAP Commercial/France+US
- HARP2: UMBC/NASA US on PACE mission
- SPEXOne: SRON/Netherlands on NASA PACE mission
- 3MI: EUMETSAT/EU
- MAIA: JPL-NASA/US
- MAP CO2M: Copernicus/EU
- AOS Polarimeter NASA/US

Dubovik et al. 2020

## The HARP Polarimeter Family





#### **Airborne System**

- Frequent Ground calibration
- ~40m resolution
- Potential for HARP2 Cal/Val
- Has flown two successful flight campaigns



Launched to ISS Nov 2<sup>nd</sup>, 2019 Deployment Feb 19<sup>th</sup>, 2020 First light April 15<sup>th</sup>, 2020

- 4 km resolution
- Limited data set: 1 snapshot/day
- No calibrator onboard/only vicarious



#### Launch: 2022-23

- Improved SNR
- Better calibration features
- ~3 km resolution
- Global coverage in 2 days



#### New Concept

- Extended Wavelength range (UV to SWIR wavelengths)
- Improved SNR
- Full calibration features
- ~0.5km resolution

# ASTEC 6U e) **UV-SWIR**

#### ASTEC Polarimeter concept for SmallSat constellation

- UV-SWIR polarimeter
- Wide FOV/Global coverage

**Current Projects** 

## HARP Sensor Specs

	AirHARP	HARP CubeSat	HARP2
Spectral Coverage (nm)			
Number of Viewing Angles	20 for 440, 550, 870 and 60 for <mark>670</mark> nm		10 for 440, 550, 870 and 60 for 670 nm
Image Coverage			
Platform Height	10 - 20 km	400 km	676 km
Ground Resolution	30 m	4 km	3 km
Lifetime	2017 - Present	2020 - 2022	2024 – 2027+
Launch Platform	Aircraft	CubeSat	PACE Satellite

#### Images collected by HARP CubeSat from 2020-2022

#### HARP CubeSat Stats:

- 777 Days in orbit
- 12,432 sun sets and rises
- 62 science captures
- 111,600+ images
- 3.4+ Billion pixels







## Multi-Angle Intensity of Saharan Dust



33.82°W28.58°W23.34°W 18.1°W 12.86°W 7.62°W

#### Saharan Dust Leaving Africa and Arriving to the Americas



June 13<sup>th</sup> 2020



HARP Multi-Angle

## UMBC

### Full Algorithm Development



Dubovik et al 2011, 2014

## 13-June-2020 Saharan Dust Transport

#### 2020-06-13T09:09:47-Projected RGB





## Latitude

## 23-June-2020 Saharan Dust Transport

2020-06-23T18:42:22-Projected RGB





atıtude

## Measured dust particle properties

0.8

K AOD<sub>Coarse</sub>, 550nn



## 25-August-2020 California-Oregon Fire



## 25-August-2020 California-Oregon Fire

3

 $\mathbf{2}$ 

## Fine mode AOD





6.6 km resolution AOD retrievals

550*nm* 

5 AOD<sub>Coarse, 5</sub>

- 3

## Level-2 Cloud Microphysics Retrieval from Space



First Ever Hyper-Angular Cloudbow Retrieval from Space

#### HARP Nadir Pushbroom

## UMBC

#### **Cloud Phase Retrieval**

Polarized Radiance (670,550,440)



#### Literature Reference



Parol et al. 2004 Goloub et al., 2000

## HARP2 – being built for PACE Spacecraft





## PACE Mission Swath









# Thank you.



## Calibration/Validation with other satellites

### Anin Puthukkudy\*, Noah Sienkiewicz\*

(\*) Graduate students

## HARP Intercomparisons with other Satellites



#### 03-May-2020 HARP X Geostationary ABI



Salar De Uyuni (Bolivia) [ABI data resampled in HARP lat-lon grid]







2020-05-03T16:33:12-Projected RGB





#### 01-Jul-2020



## Comparison with VIIRS on S-NPP over the Salr De Uyuni salt flat

2020-07-01T17:03:47 #angle = 84



