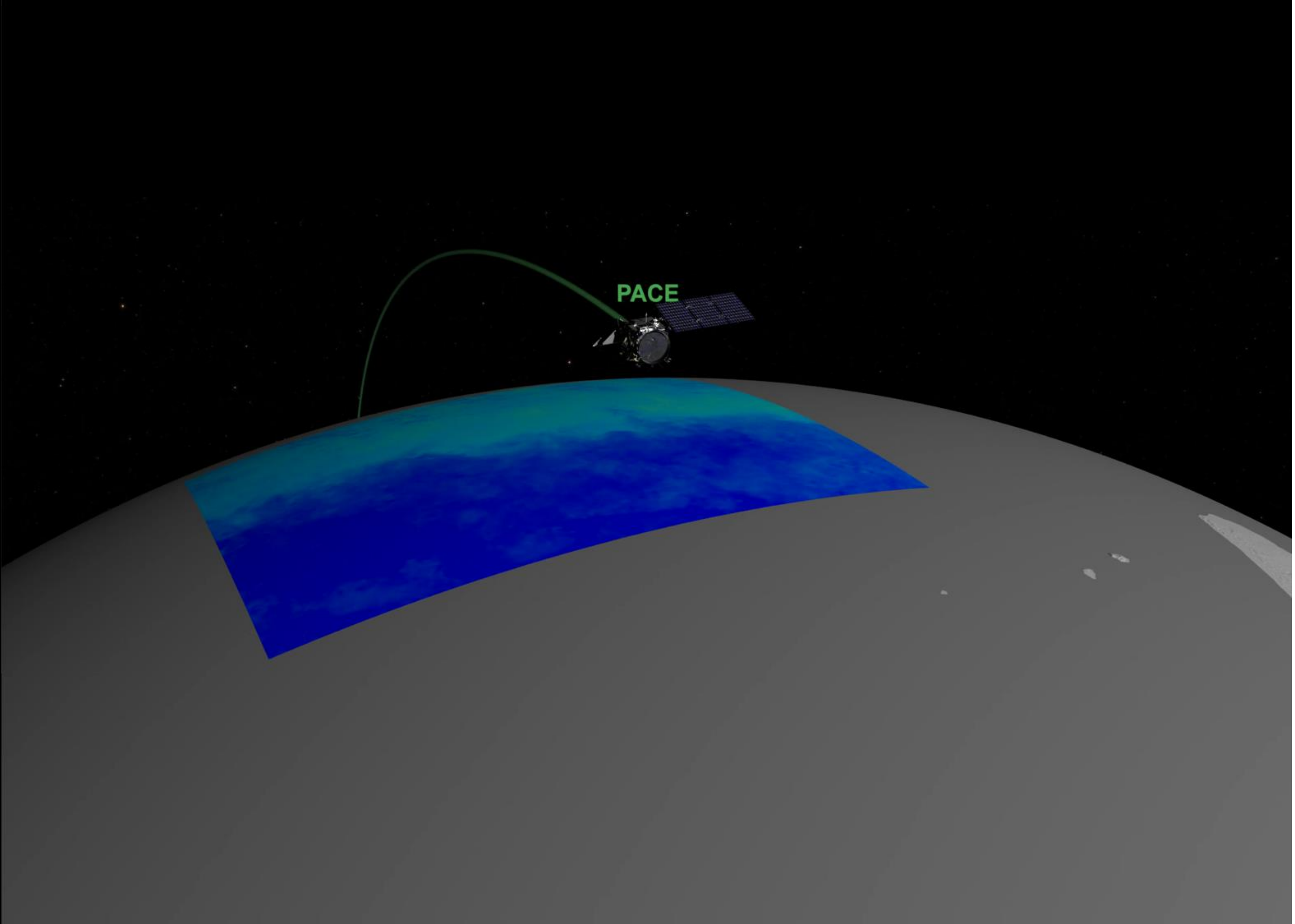
# Fall AGU Town Hall

## 10 December 2018, Washington, D.C.

Drs. Jeremy Werdell, Paula Bontempi, Brian Cairns
NASA GSFC, NASA HQ, NASA GISS

# PACE

## Plankton, Aerosol, Cloud, ocean Ecosystem

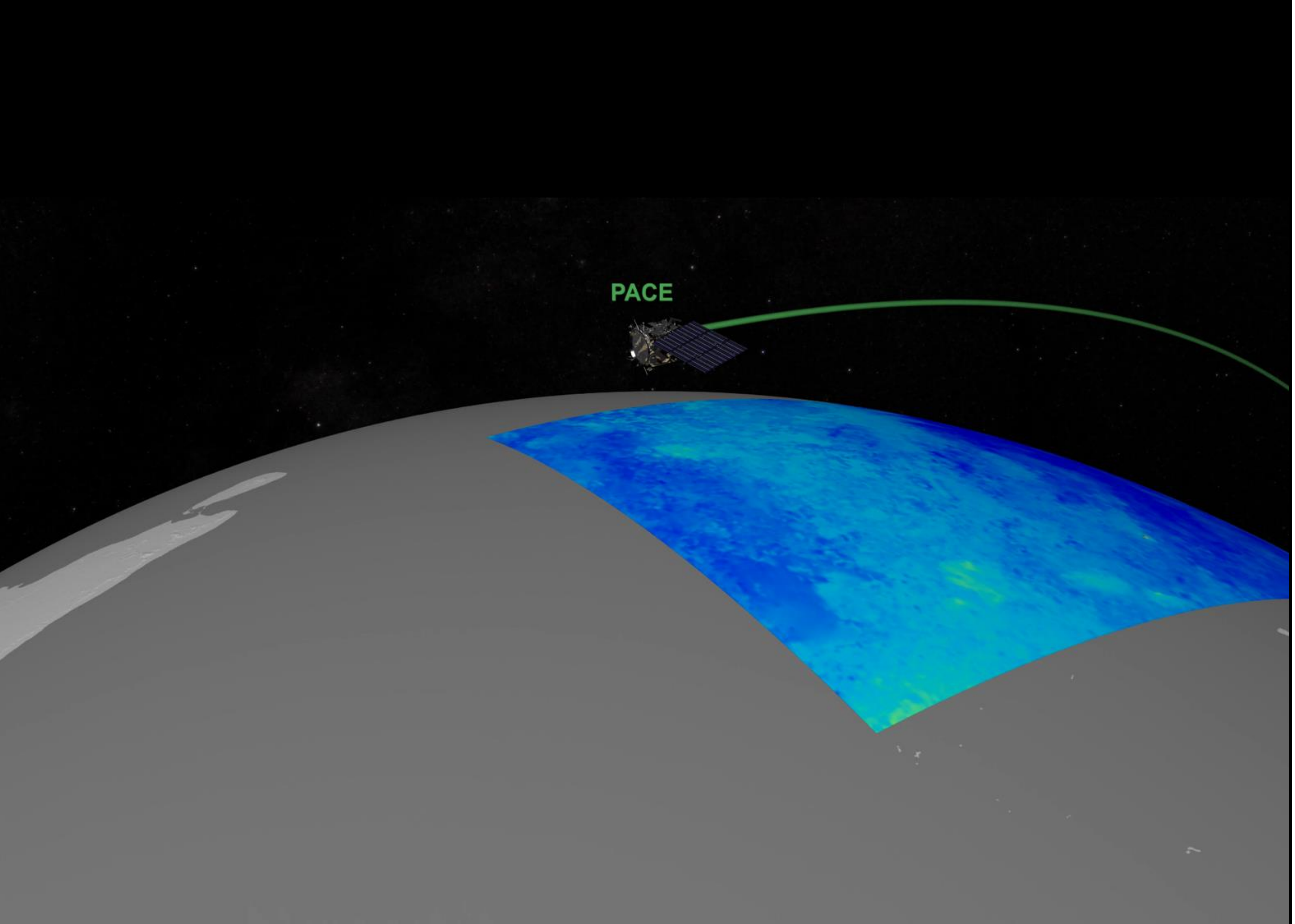



**PACE includes:**

- A UV-SWIR imaging spectrometer
- 2 multi-angle UV-NIR polarimeters

**and will produce data for studies of:**

- ocean biology, ecology, and biogeochemistry
- atmospheric aerosol particles
- clouds
- land




**Legacies:**

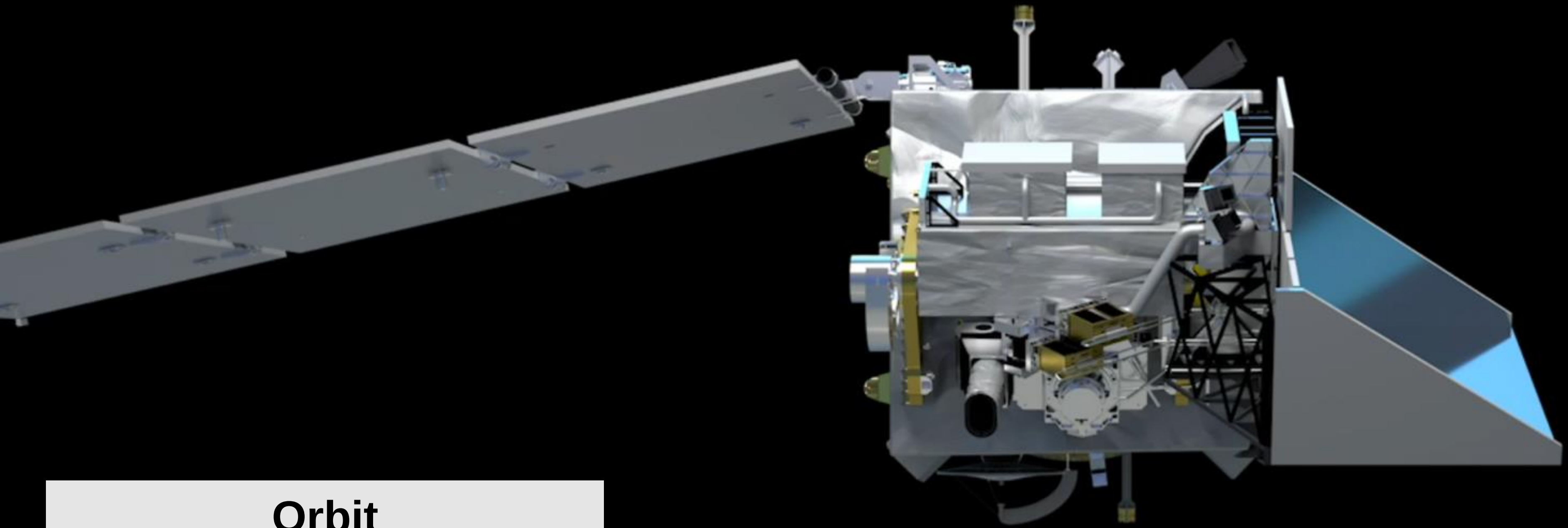
- CZCS
- SeaWiFS
- POLDER
- MODIS
- MISR
- VIIRS
- others

**Town Hall agenda:**

- mission update
- programmatic update, cal/val, & future community opportunities
- contributions to atmospheric science
- Q&A

## Cost, Schedule, Lifespan

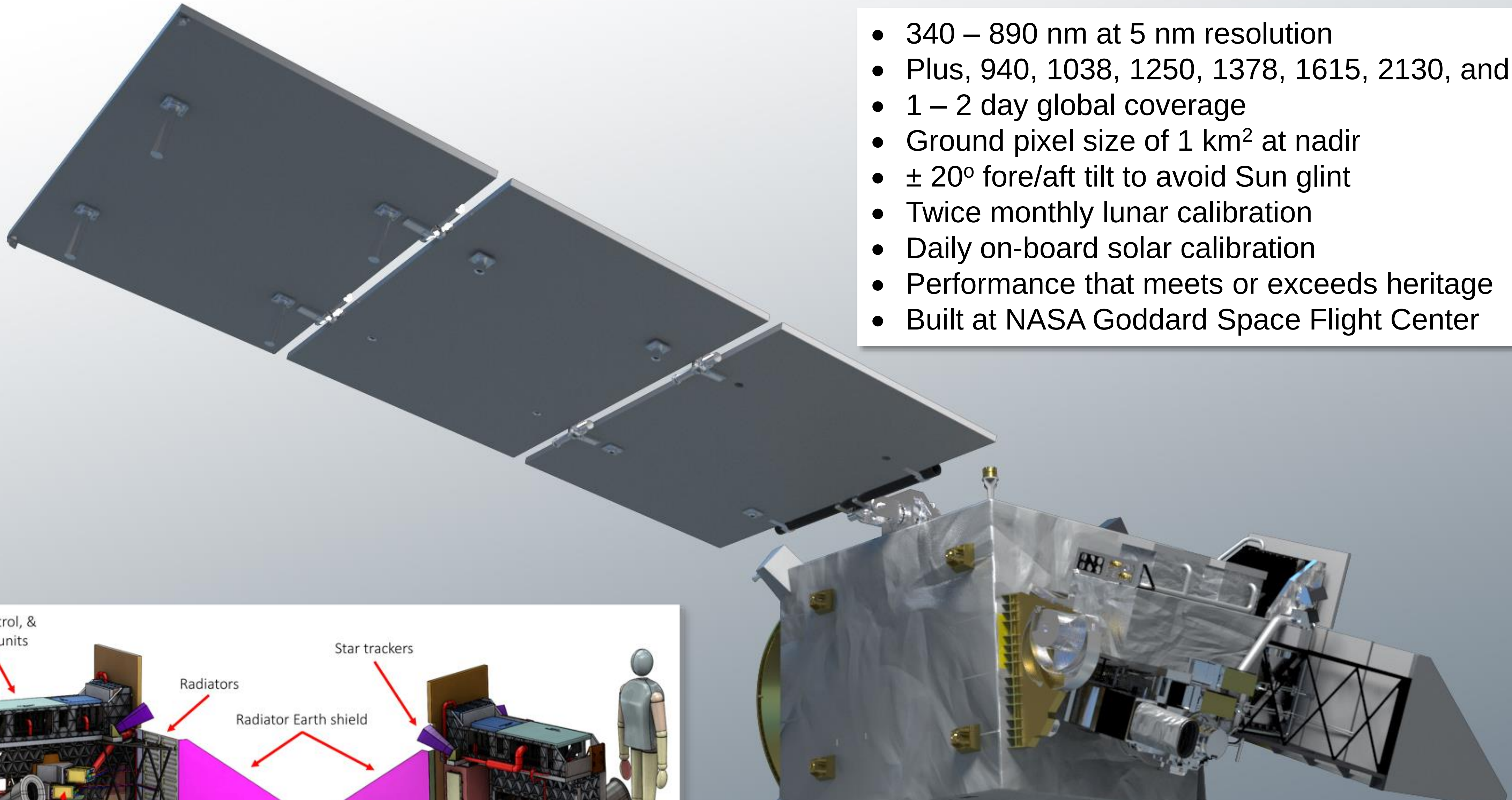
- $805M Design-to-Cost
- Category 2, Class C
- Fall 2022 launch
- 3-year design life
- 10-years of fuel

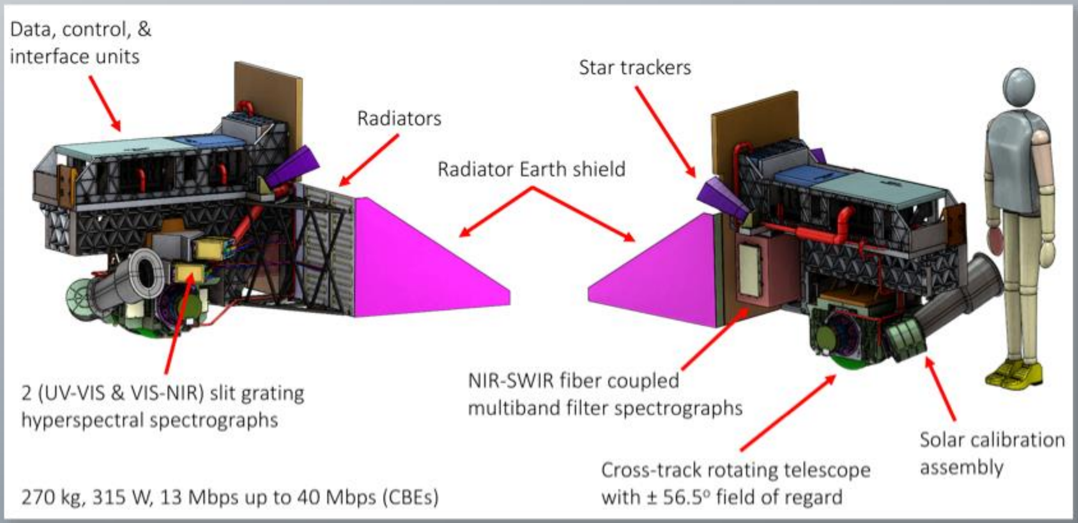


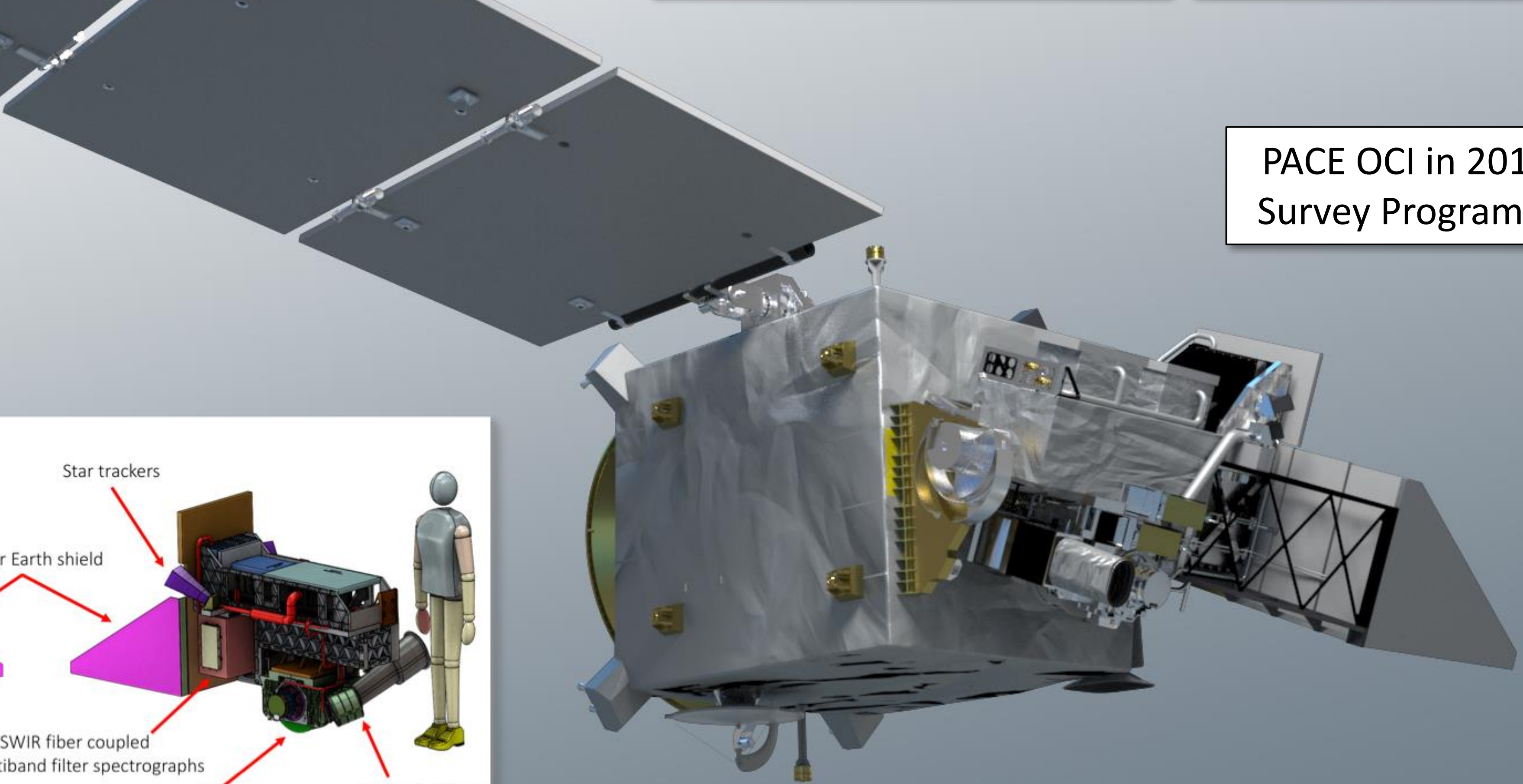
## Orbit

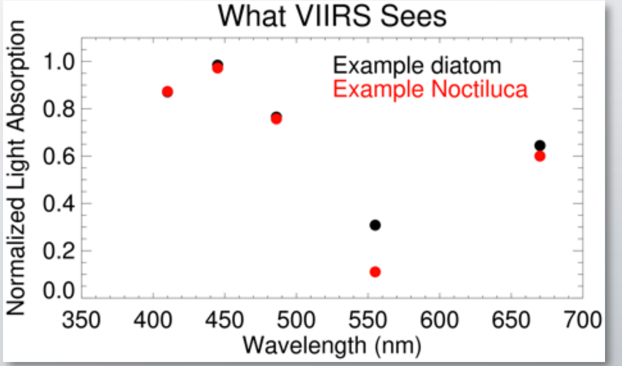
- 675.5 km altitude
- Polar, ascending orbit
- Sun synchronous
- 98º inclination
- 13:00 local Equatorial crossing

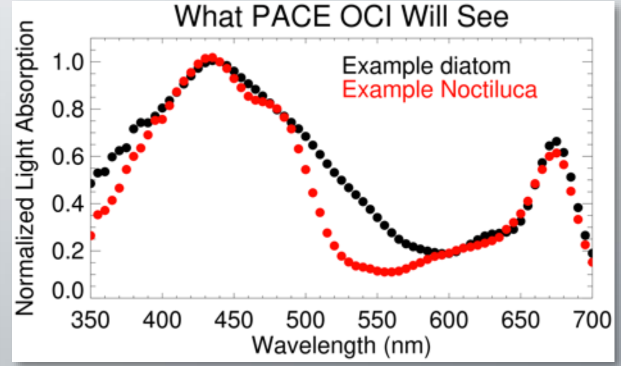
- 340 – 890 nm at 5 nm resolution
- Plus, 940, 1038, 1250, 1378, 1615, 2130, and 2250 nm
- 1 – 2 day global coverage
- Ground pixel size of 1 km$^2$ at nadir
- ± 20$^{o}$ fore/aft tilt to avoid Sun glint
- Twice monthly lunar calibration
- Daily on-board solar calibration
- Performance that meets or exceeds heritage
- Built at NASA Goddard Space Flight Center



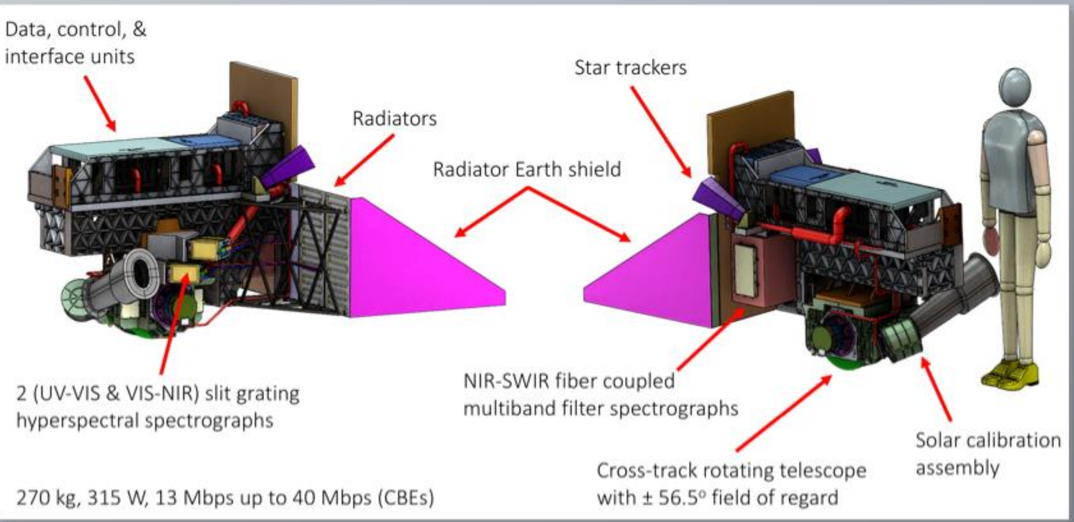


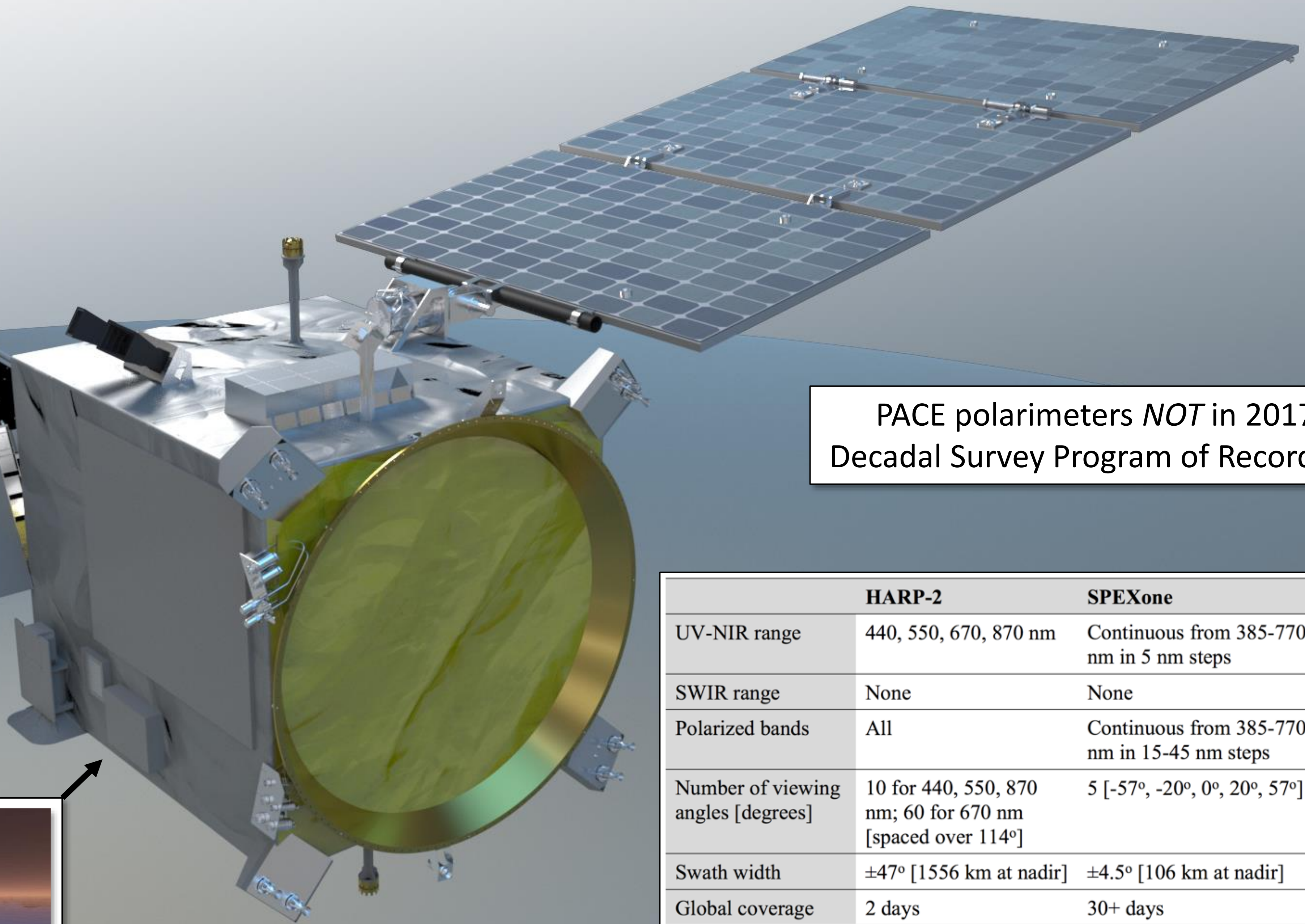




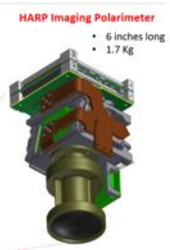




PACE OCI in 2017 Decadal Survey Program of Record





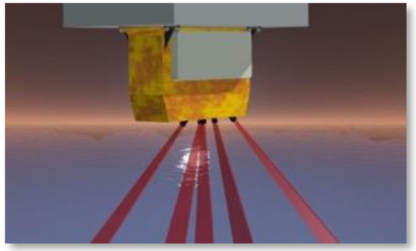
UMBC Hyper Angular Rainbow Polarimeter (HARP-2)



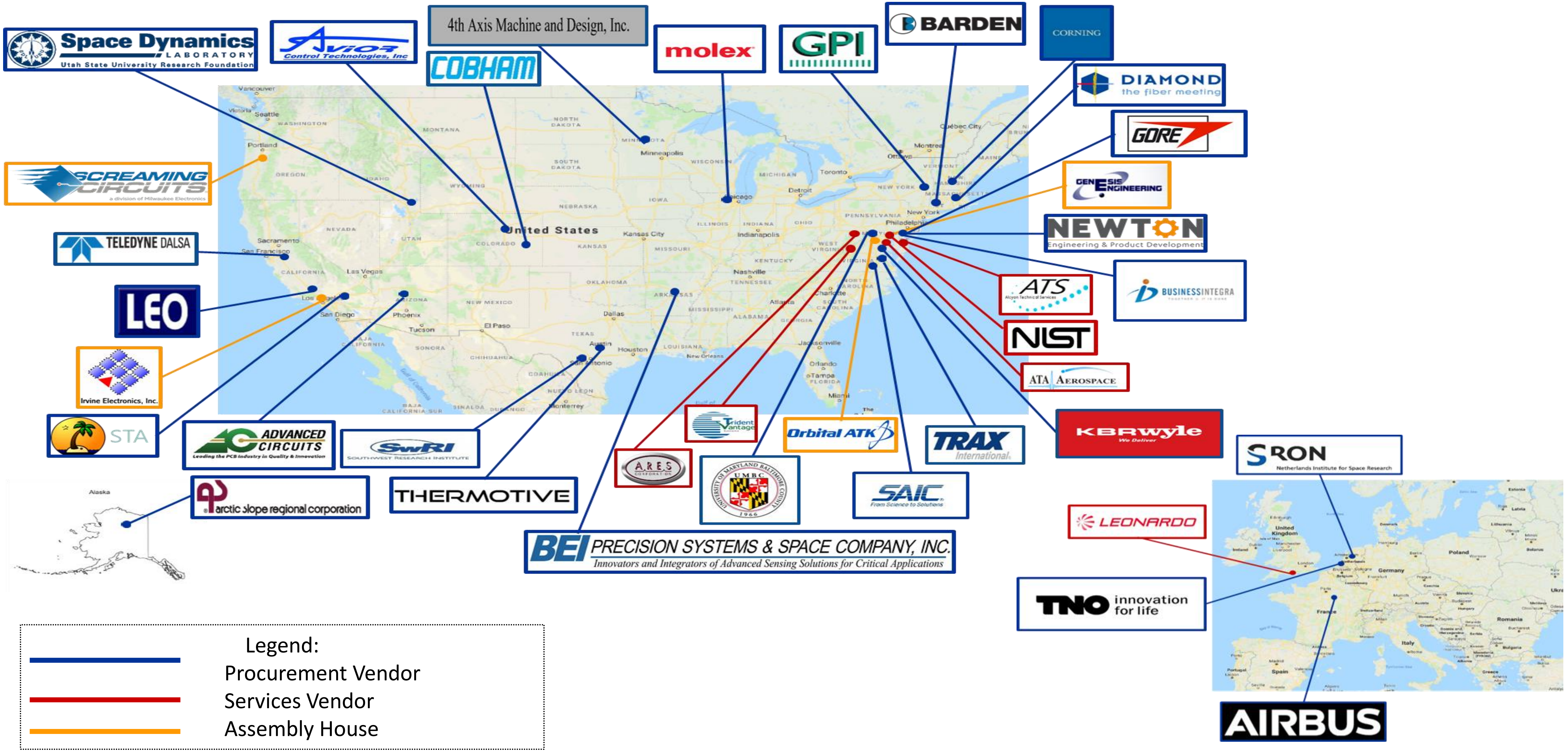

PACE polarimeters *NOT* in 2017 Decadal Survey Program of Record

| | HARP-2 | SPEXone |
|---|---|---|
| UV-NIR range | 440, 550, 670, 870 nm | Continuous from 385-770 nm in 5 nm steps |
| SWIR range | None | None |
| Polarized bands | All | Continuous from 385-770 nm in 15-45 nm steps |
| Number of viewing angles [degrees] | 10 for 440, 550, 870 nm; 60 for 670 nm [spaced over 114°] | 5 [-57°, -20°, 0°, 20°, 57°] |
| Swath width | ±47° [1556 km at nadir] | ±4.5° [106 km at nadir] |
| Global coverage | 2 days | 30+ days |
| Ground pixel | 3 km | 2.5 km |
| Heritage | AirHARP, Cubesat | AirSPEX |

SRON Spectro-polarimeter for Planetary Exploration (SPEXone)



# Who's working on PACE (as of mid Dec 2018)?



# Looking forward: the mission's coming year(s)

**Phase B** – preliminary design & technology completion

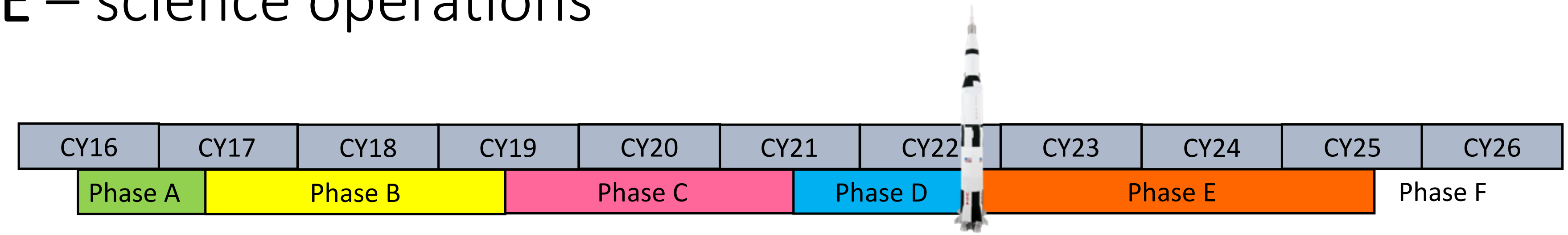
**Phase C** – final design & fabrication

- May/June 2019 – mid 2021
- All mission elements must pass Critical Design Reviews (CDR)
- Preceded by series of sub-element Engineering Peer Reviews (EPRs)

- Project & HQ Science + OBPG Science Data Processing:
  - respond to element issues (study, charge/retreat, provide therapy)
  - implement science capabilities (plans for cal, val, algs, processing, documentation, etc.)

**Phase D** – system assembly, integration & testing, & launch

**Phase E** – science operations



# Programmatic update & future science teams

# Looking forward: noteworthy mentions

## Budget Status: FY18 and beyond (as of early Feb 2018)

- “The Budget requests a total of $19.6 billion for NASA, a $500 million (2.6-percent) increase from the 2018 Budget ($61 million below NASA’s 2017 funding level)”
- FY19 President’s Budget “maintains the Administration’s previous termination of five Earth Science missions—PACE, OCO-3, RBI, DSCOVR Earth- viewing instruments, and CLARREO Pathfinder—to achieve savings.” Terminates NASA’s Office of Education and reduces ESD research

## 2017-2027 Decadal Survey for Earth Science and Applications from Space

- Free download: http://sites.nationalacademies.org/DEPS/ESAS2017/index.htm
- Program of Record – “The series of existing or previously planned observations, which should be completed as planned. Execution of the ESAS 2017 recommendation requires that the total cost to NASA of the Program of Record flight missions from FY18-FY27 be capped at $3.6B.”

# Looking Forward: PACE Science Team pre- & post-launch schedule

## Pre-launch Science Teams

- FY15 – 17: ROSES 2013 A.25
  - Achieved consensus and develops community-endorsed paths forward for IOPs and Atmospheric Correction
  - Final reports are being submitted.
- FY20 – 22: ROSES 2019 (3 years)
  - Allow lead time for pre-launch scientific algorithm development & applications development prior to launch
  - Initiates interface between instrument developers and OBPG; OBPG/OB DAAC and algorithm developers; possible LaRC DAAC for polarimetry (not yet decided)
- FY23 – 25: ROSES 2022 (3 years)
  - At-launch algorithms and post-launch competed science/applications for ocean color instrument’s aerosol, cloud, ocean science, plus aerosol and clouds from polarimeter(s)

## Post-launch Competed Science - options

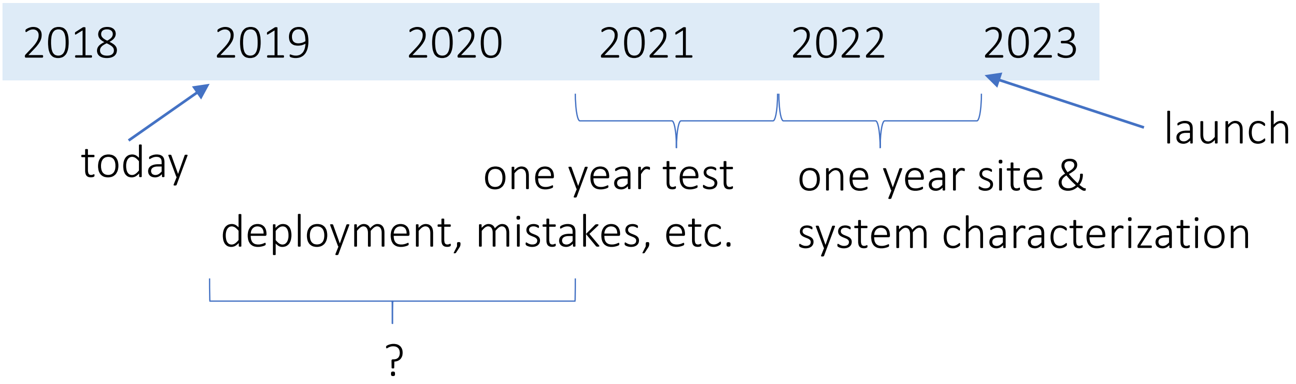
- Competed through ROSES 2025
- After launch, joint funding between EOS project, R&A, and PACE mission budget, exploring additional funding from Applied Sciences
- Mission contributions (many TBDs)
- Continue during mission extension(s)

# Looking forward: vicarious calibration

**ROSES 2014 A.3 OBB (FY15-17) - written and competed before PACE was a real mission**

- Issued under OBB, managed jointly between OBB and ESTO
- Allowed lead time for concepts to mature prior to launch + Identified technical development needs/risks for the approaches selected
- Three projects funded that are completing analysis and testing of hardware:
  - Hyperspectral radiometric device for accurate measurements of water leaving radiance from autonomous platforms for satellite vicarious calibrations - PI – Andrew Barnard, SeaBird Scientific
  - Hybrid-spectral Alternative for Remote Profiling of Optical Observations for NASA Satellites (HARPOONS) - PI – Carlos DelCastillo, NASA GSFC
  - Developing a MOBY-NET instrument, suitable for a federation network for Vicarious Calibration of Ocean Color Satellites Perform cal/val during mission operations - PI – Ken Voss, University of Miami
- **ROSES 2019 - Select best approach and hardware (pre-launch) or further risk reduction on instrumentation, if needed, for vicarious calibration of ocean color data products (OCI). Two selections with a downselect after 12-months likely.**

options: systems in development, expected external assets (BOUSSOLE, MOBY), FRM4SOC (Copernicus/EUM), other *in situ* sources, models



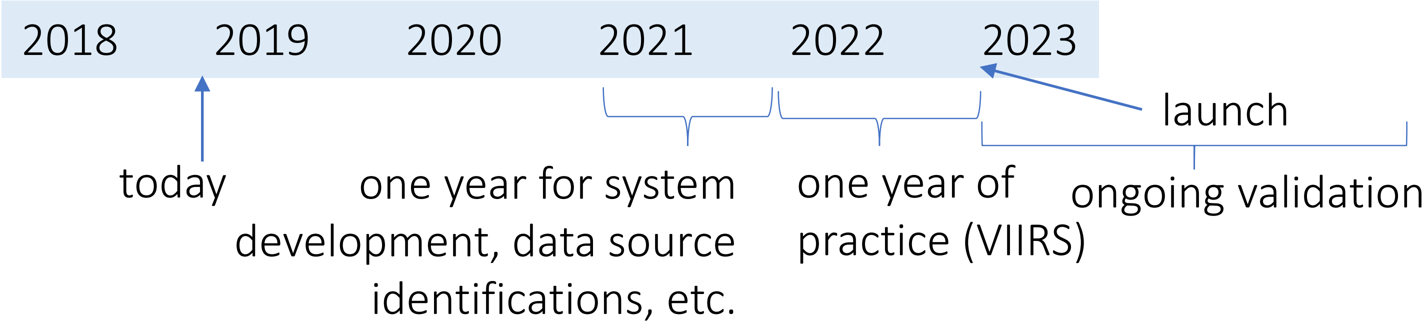
# Looking forward: a validation program

**FY22 – 25: ROSES 2021 (3 years)**

- Selects best approaches and hardware (pre-launch) or further risk reduction on instrumentation, if needed, for validation of all data products (aerosol, cloud, ocean color) – *in situ;* Calibration/validation of polarimetry data products (TBD)
- Perform cal/val during mission ops; Includes airborne and *in situ* measurements; Continue every year during mission extension(s)

**FY26 – 28: ROSES 2025 (3 years)**

- Perform cal/val during mission ops; Includes airborne and *in situ* measurements; Continue every year during mission extension(s)
- International community (EUMETSAT, ESA, and the Copernicus Program) are investing in Fiducial Reference Measurements for Sentinel and coordination is critical




## Level 1 required (~threshold) products

| | |
|---|---|
| Water-leaving reflectance | Aerosol optical thickness |
| Chlorophyll-a | Aerosol fine mode fraction |
| Phytoplankton absorption | Liquid / ice cloud optical thickness |
| NAP+CDOM absorption | Liquid / ice cloud effective radius |
| Particulate backscattering | Cloud layer detection ($\tau < 0.3$) |
| Diffuse attenuation | Cloud top pressure ($\tau > 3$) |
| Fluorescence line height | Shortwave radiation effect |

Uncertainty requirements accompany all L1 req'd data products (i.e., we need quantitative validation of all of these products)

# PACE will provide insight into systems that affect our everyday lives

With advanced global remote sensing capabilities, PACE will provide a combination of **atmosphere and ocean observations** to benefit society in the areas of water resources, disaster impacts, ecological forecasting, human health, and air quality.

Users at local, state, federal and international agencies as well as the general public will be able to apply data from PACE to make more informed and robust decisions about their activities.

Air Quality and Human Health

## Applications Community Building Activities

### Mission Applications Plan

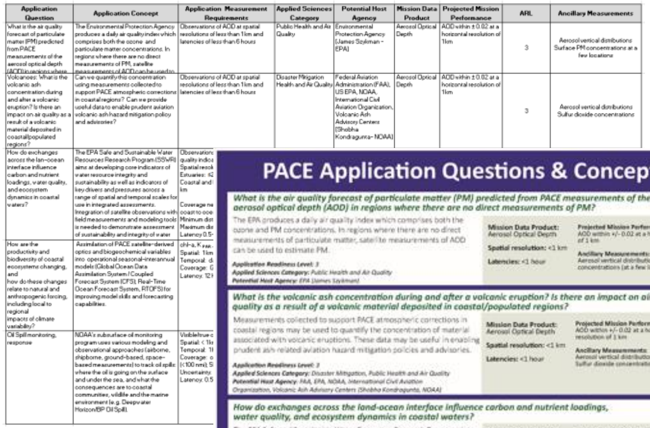

Describes the elements of the applications program for the project, its management, and deliverables from all Phases of the mission

PACE applications by development phase

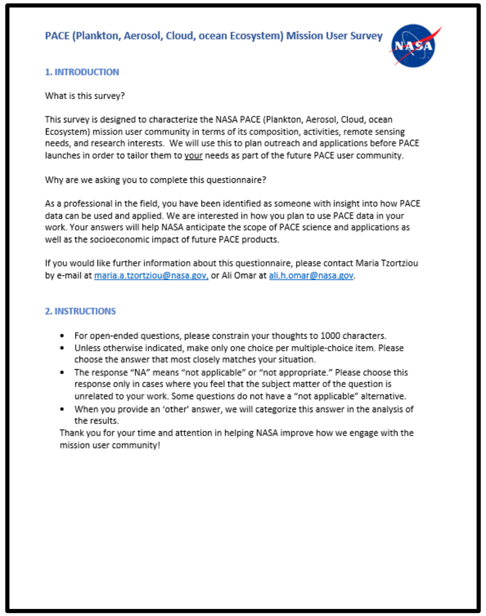
| Mission Phase | Applications Activity |
|---|---|
| Pre-phase A | Assessment of the community of practice.<br>Description of potential applications from the PACE data using the requirements established by the Science Definition Team (SDT). |
| Phase A | Applications website establishment.<br>Database of user community individuals begins.<br>Applications Plan written and posted to website.<br>Applications white papers developed and posted to the website.<br>Applications Traceability Matrices developed and posted to the website.<br>Applications Working Group established. |
| Phase B | Workshop conducted with targeted science communities to communicate key model, observation and Applied Sciences opportunities and requirements.<br>Newsletters, articles, posters, and other communications developed to expand the community of potential.<br>Early Adopters Program established. |
| Phase C/D | Annual workshop focused on results from Early Adopters.<br>Description of validation datasets to the community of practice.<br>Conference presentations and papers; newsletters and journal articles on user interaction to expand the community of potential.<br>Data workshops, short courses, focus sessions, tutorials.<br>Interaction with NASA HQ Applied Sciences to prepare funding opportunities. |
| Phase E | Documenting decision support provided by mission data.<br>Newsletter, journal articles, conference presentations of applications of data.<br>Community interaction and support of data reprocessing and improvement. Calibration/validation of data quality, format, issues.<br>Conduct Impact Workshop to assess success of Applications implementation.<br>Conduct a Quantitative PACE Data Societal Benefit Value Assessment.<br>Information for Senior Review Submissions. |

### Applications Traceability Matrix

developed with input from the user community




### PACE Community Survey



PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) Mission User Survey

1. INTRODUCTION

What is this survey?

This survey is designed to characterize the NASA PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) mission user community in terms of its composition, activities, remote sensing needs, and research interests. We will use this to plan outreach and applications before PACE launches in order to tailor them to your needs as part of the future PACE user community.

Why are we asking you to complete this questionnaire?

As a professional in the field, you have been identified as someone with insight into how PACE data can be used and applied. We are interested in how you plan to use PACE data in your work. Your answers will help NASA anticipate the scope of PACE science and applications as well as the socioeconomic impact of future PACE products.

If you would like further information about this questionnaire, please contact Maria Tzortziou by e-mail at maria.a.tzortziou@nasa.gov, or Ali Omar at ali.h.omar@nasa.gov.

2. INSTRUCTIONS

- For open-ended questions, please constrain your thoughts to 1000 characters.
- Unless otherwise indicated, make only one choice per multiple-choice item. Please choose the answer that most closely matches your situation.
- The response "NA" means "not applicable" or "not appropriate." Please choose this response only in cases where you feel that the subject matter of the question is unrelated to your work. Some questions do not have a "not applicable" alternative.
- When you provide an 'other' answer, we will categorize this answer in the analysis of the results.

Thank you for your time and attention in helping NASA improve how we engage with the mission user community!

### Applications White Papers


### PACE Mission Applications - Contact Us:

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Ali Omar
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Woody Turner
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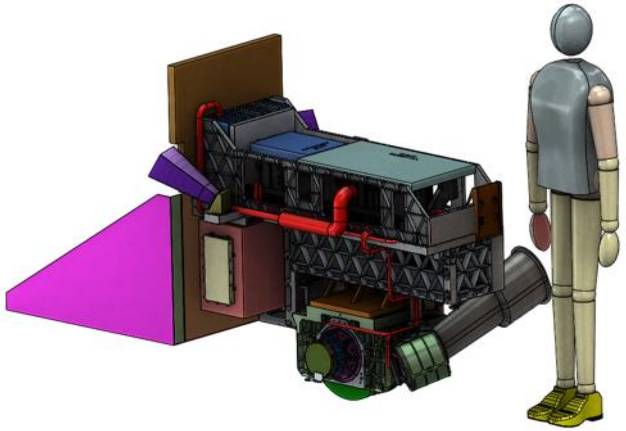
202-358-1662

@NASAOcean https://pace.gsfc.nasa.gov/ @NASAOcean

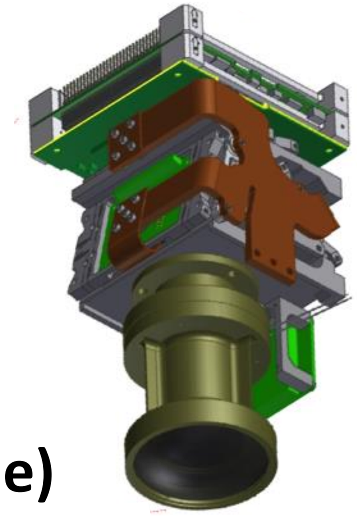
# PACE contributions to atmospheric science

# Plankton, Aerosol, Cloud and ocean Ecosystem (PACE) Instruments



**(Primary) Ocean Color Instrument (OCI)**

Wide swath, UV-VIS imaging spectrometer with SWIR channels designed for ocean color applications, useful for aerosols and clouds

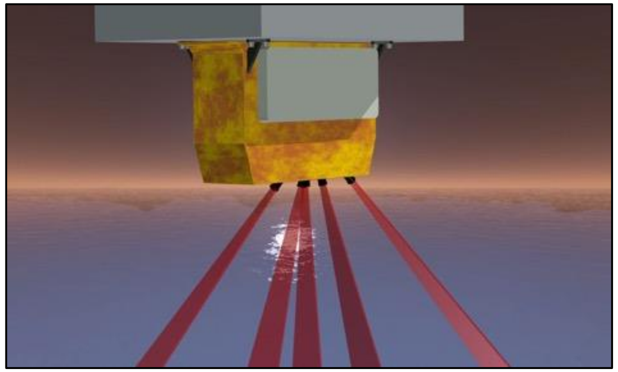


**Hyper Angular Rainbow Polarimeter 2 (HARP2)**

wide-swath multi-angle polarimeter, hyper angle capability

**Spectro-Polarimeter for Planetary Exploration (SPEXone)**

narrow-swath multi-angle polarimetric spectrometer



# PACE key mission elements

SPEXone and HARP2 are ‘**contributed**’ instruments

Requirements derive from **do no harm** philosophy alone

No requirements for successful data collection, science

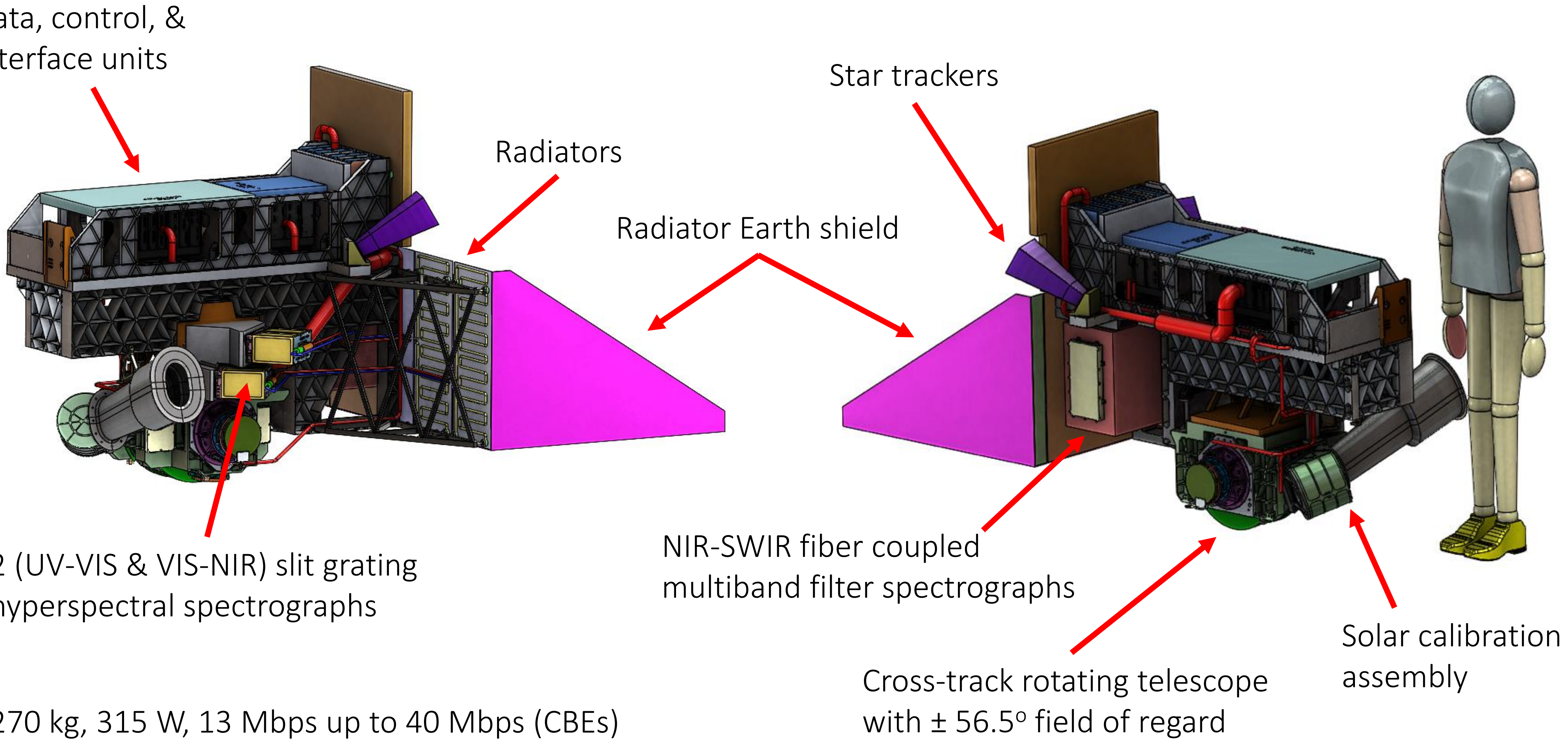
Both originally designed as cubesat scale instruments

Polarimeters will be an excellent proof of concept for atmospheric correction, aerosol and cloud retrievals

# Ocean Color Instrument (OCI)

# Ocean Color Instrument – physical assembly

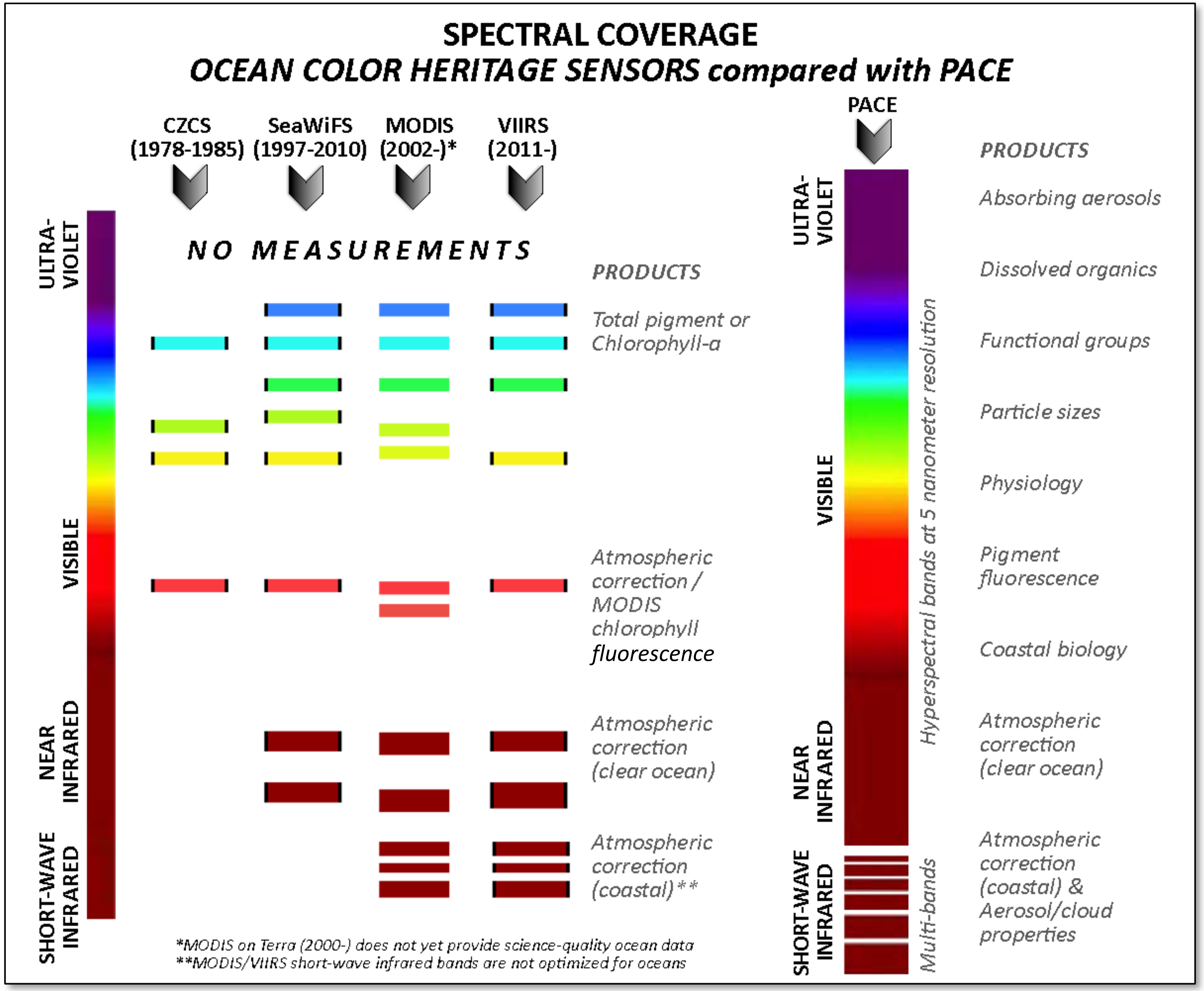
Scanning concept follows SeaWiFS and VIIRS heritage




270 kg, 315 W, 13 Mbps up to 40 Mbps (CBEs)

OCI is tilted by ±20° to avoid sun glint

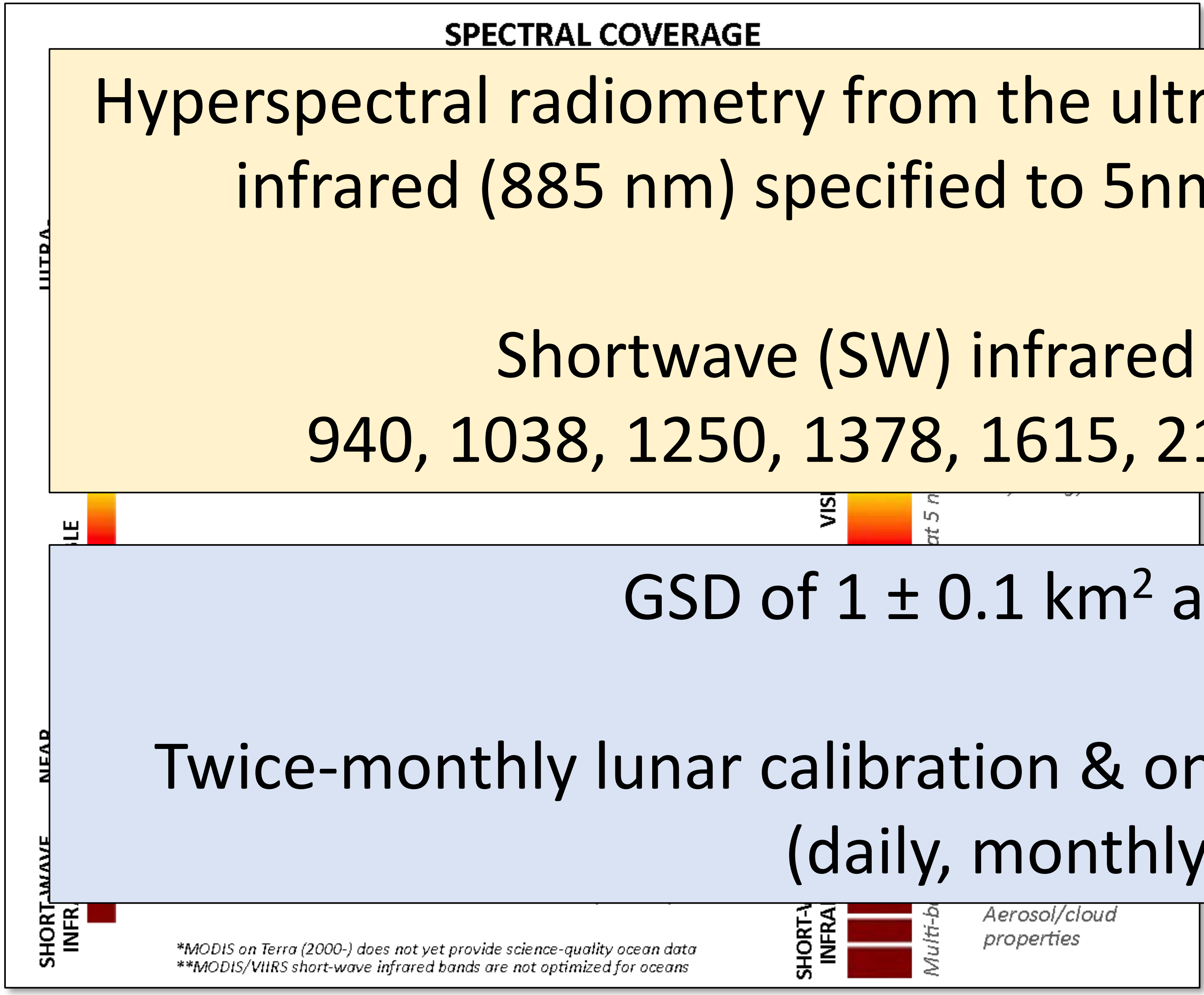
# OCI characteristics




Threshold aerosol and cloud product requirements are to be met by OCI (alone)

OCI is tilted 20° to avoid sun glint

# OCI characteristics



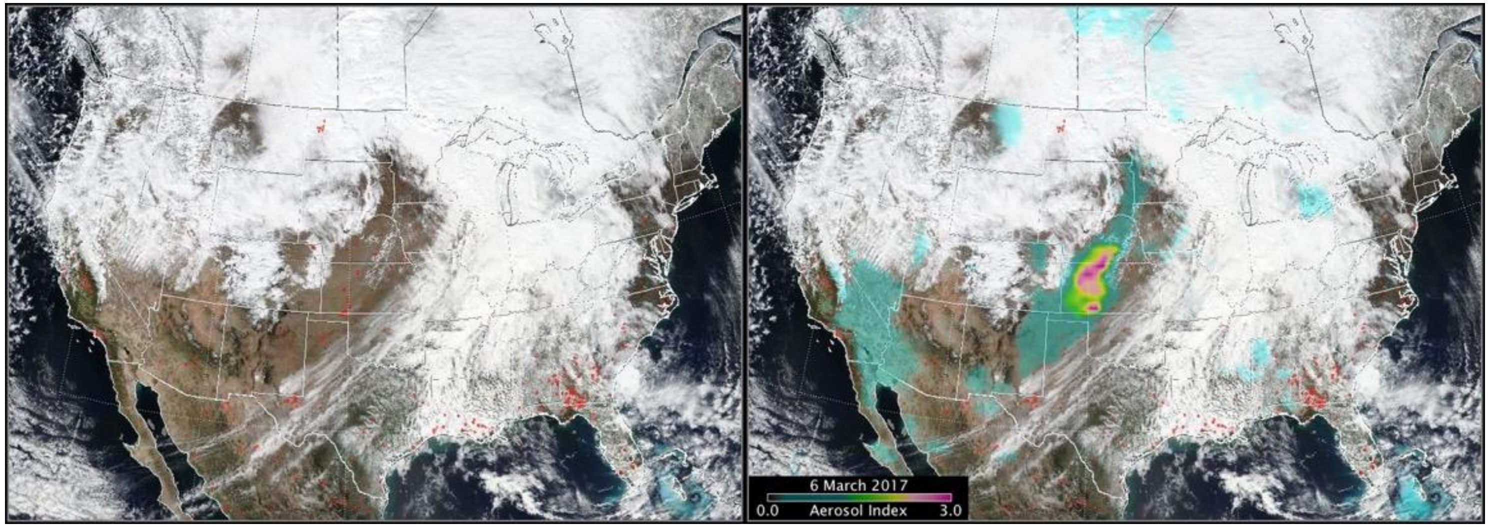

Hyperspectral radiometry from the ultraviolet (320 nm) to near-infrared (885 nm) specified to 5nm spectral resolution

Shortwave (SW) infrared (IR) bands:
940, 1038, 1250, 1378, 1615, 2130, and 2260 nm

GSD of 1 ± 0.1 km$^2$ at nadir

Twice-monthly lunar calibration & onboard solar calibration (daily, monthly)

# OCI atmospheric improvements over heritage

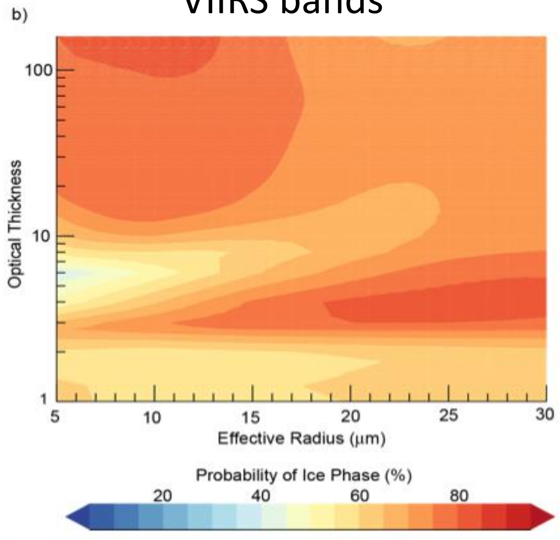



VIIRS RGB + OMPS Aerosol Index

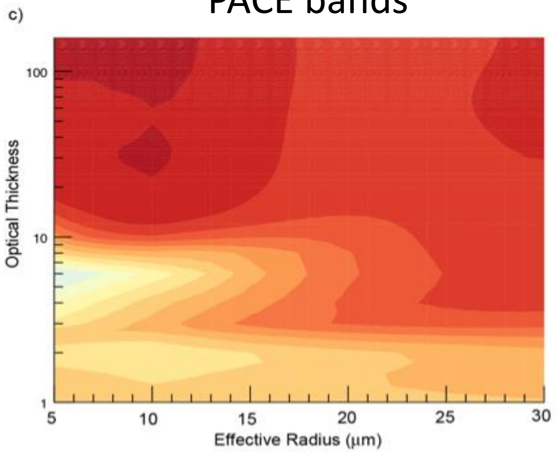
1 km resolution at nadir from UV to SWIR

UV + oxygen-A and B-bands provide opportunities for aerosol algorithms beyond heritage

VIIRS bands




PACE bands




Deeper red indicates improved probability of detection of ice phase

Two 2-μm bands (VIIRS + MODIS) improve retrievals of cloud thermodynamic phase

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2017JD026493

**Characterizing the information content of cloud thermodynamic phase retrievals from the notional PACE OCI shortwave reflectance measurements**

O. M. Coddington[1], T. Vukicevic[2], K. S. Schmidt[1,3], and S. Platnick[4]

# Multi-angle polarimeters

# Multi-angle polarimeters on PACE

For multi-angle polarimetric observations to be beneficial for aerosol and cloud characterization and atmospheric correction they need the following capabilities:

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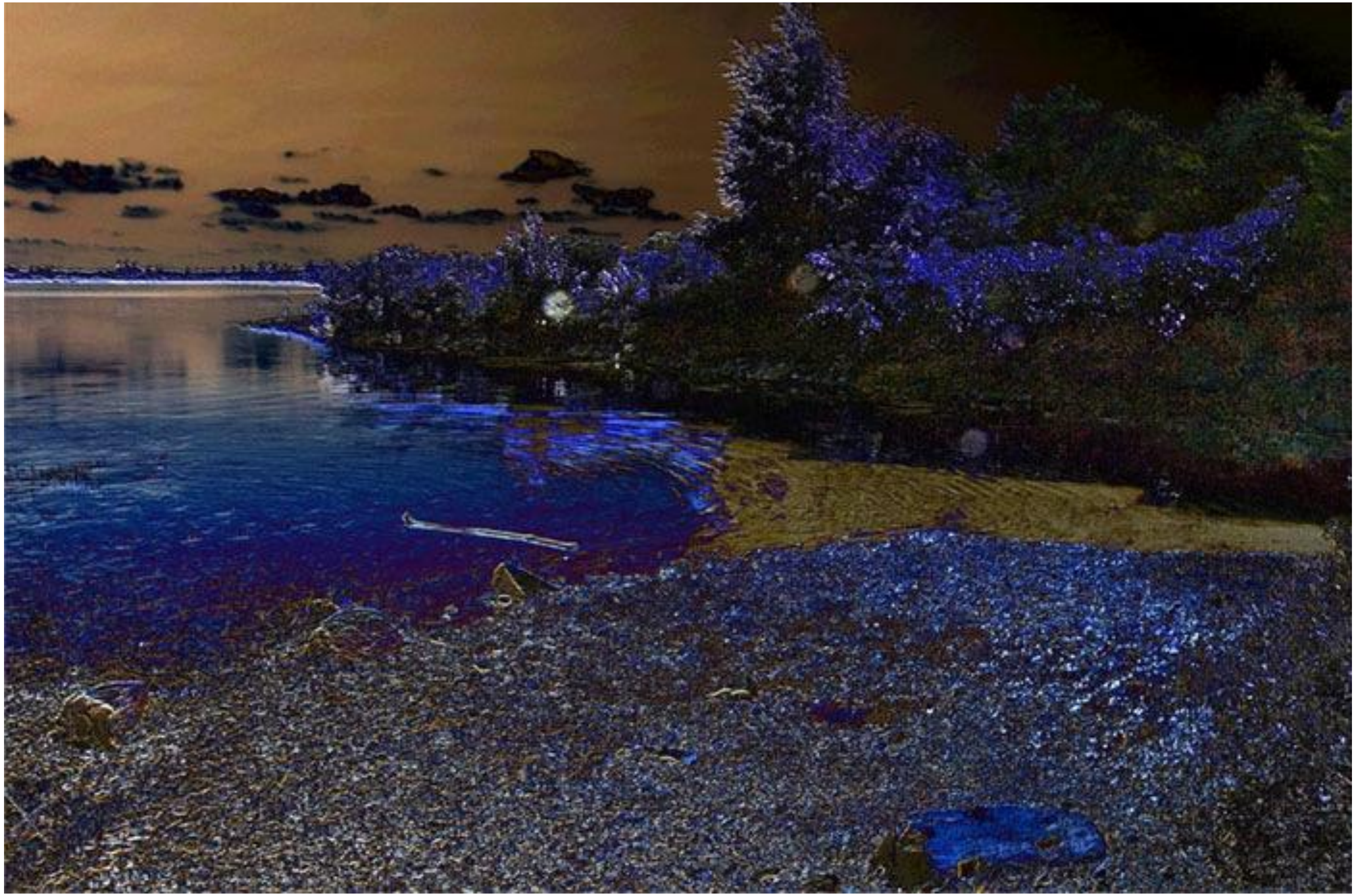
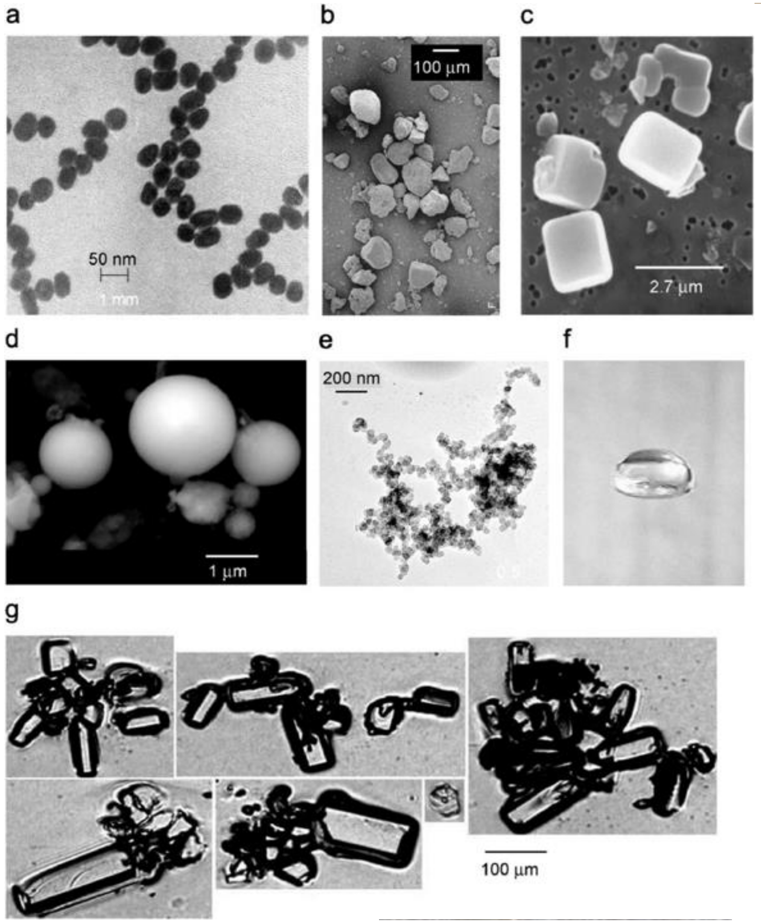


# Multi-angle polarimeters on PACE

For multi-angle polarimetric observations to be beneficial for aerosol and cloud characterization and atmospheric correction they need the following capabilities:




Example atmospheric aerosols, particles that have a wide range of sizes, shapes and chemical compositions.

## Spectral range

- Wide spectral range needed for accurate aerosol retrievals over land.

## Swath width

- A broad, OCI-matching swath is desired for atmospheric correction

## Angular range

- A wide view angle range observes scattering angles essential for aerosol size and complex refractive index retrieval.

## Polarimetric accuracy

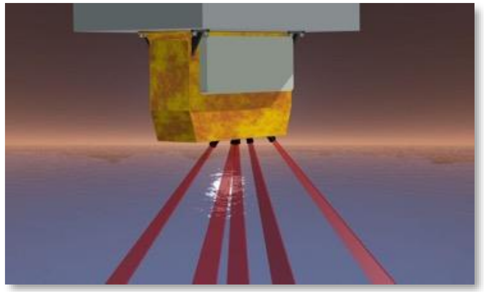
- **High accuracy needed** for best aerosol and cloud retrievals

## Number of viewing angles

- Aerosols: roughly five
- Ice clouds: roughly ten for crystal shape and roughness
- Liquid clouds: 40-60 view angles

# Polarimetry on PACE

Two cubesat-sized *contributed* instruments

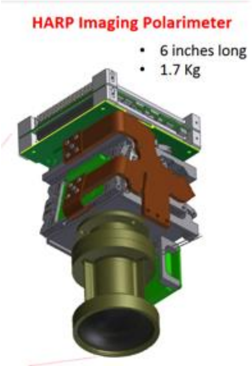


## Spectro-Polarimeter for Planetary Exploration (SPEXone)

Contribution from the Netherlands (SRON, NSO, Airbus; TNO optics)

POC: Otto Hasekamp

Hyperspectral (UV) + narrow swath + high accuracy




## Hyper Angular Rainbow Polarimeter (HARP-2)

Contribution from University of Maryland Baltimore County

POC: Vanderlei Martins

Hyperangular + wide swath

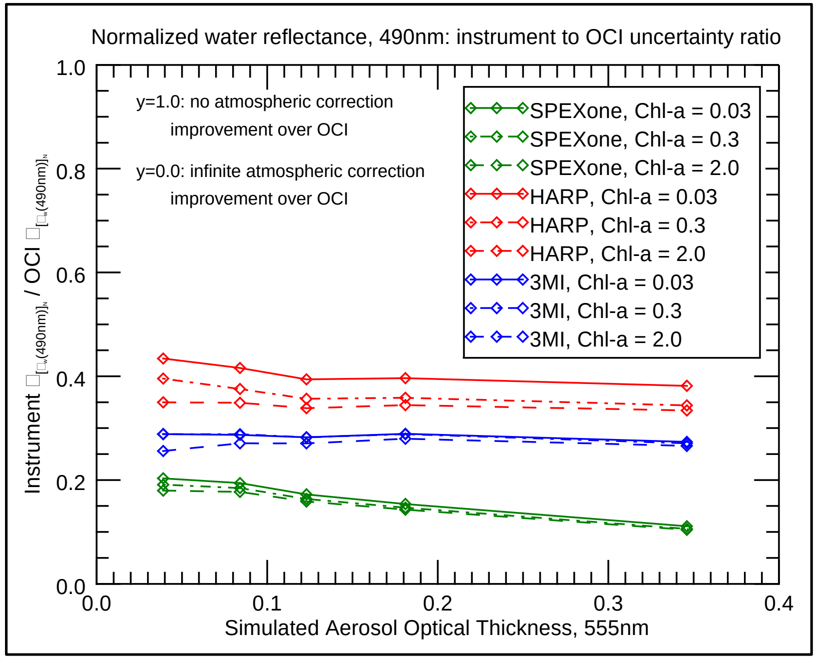
| | SPEXone | HARP-2 |
|---|---|---|
| Spectral range (resolution) | 385-770 nm (hyperspectral 2 nm) | 440, 550, 670 nm (10) + 870 nm (40 nm) |
| Polarimetric accuracy (DoLP) | 0.002 | < 0.01 |
| # viewing angles | 5 (-57°, -20°, 0°, 20°, 57°) | 10 for 440, 550, 870 nm + 60 for 670 nm (114°) |
| Swath width | 9° (106 km at nadir) | 94° (1556 km at nadir) |
| Ground sample distance | 2.5 $km^2$ | 3.0 $km^2$ |
| Heritage | AirSPEX, SPEX/ASPIM | AirHARP, cubesat HARP for ISS |

# How will PACE polarimeters perform?

Radiative transfer simulations + information content analysis (Knobelspiesse et al. 2012)

**Right – atmospheric correction improvement**: ratio of SPEXone/HARP2 water leaving reflectance uncertainty to OCI uncertainty. EUMETSAT 3MI for reference.

**Below – aerosol retrieval improvement**: degrees of freedom for signal for a simultaneous aerosol & ocean retrieval

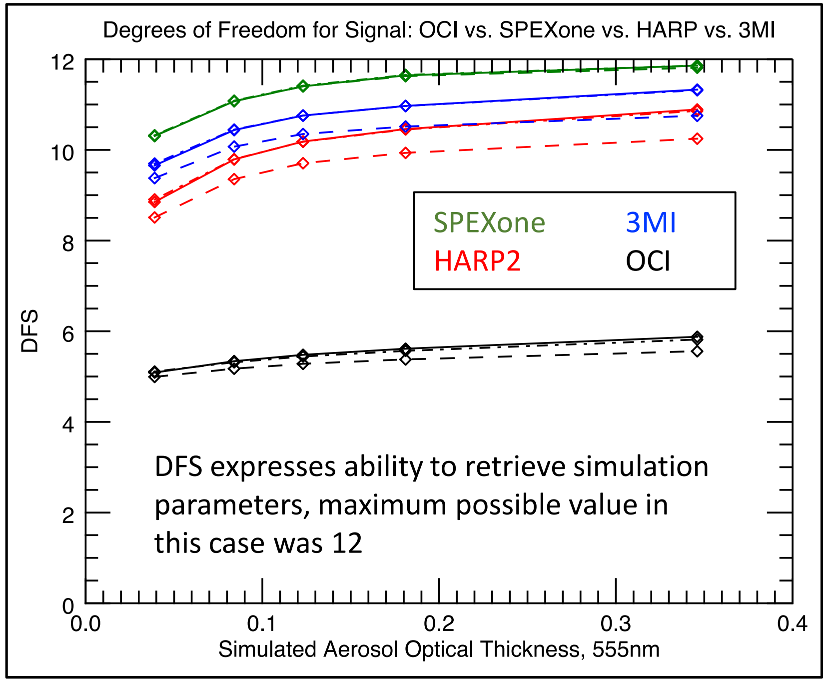



Atmospheric correction improvement

better

better

Aerosol retrieval improvement




**Both offer dramatic improvement,** comparable to 3MI

**Other characteristics must also be considered**, e.g. considerable swath width difference (SPEXone: 9˚, HARP2: 94˚).

**Cloud property retrieval**
Hyperangular capability of HARP2 can be used to retrieve droplet size distributions and to characterize ice particle roughness and aspect ratio, which reduces the uncertainty in ice particle size retrievals from OCI.

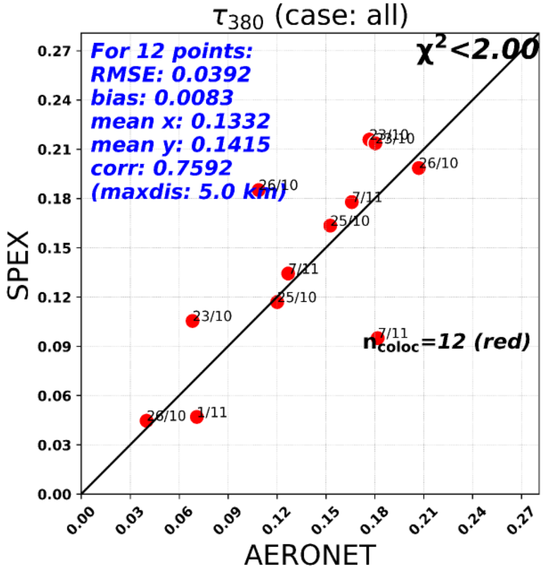
**Operational algorithms must be created to exploit this information.**

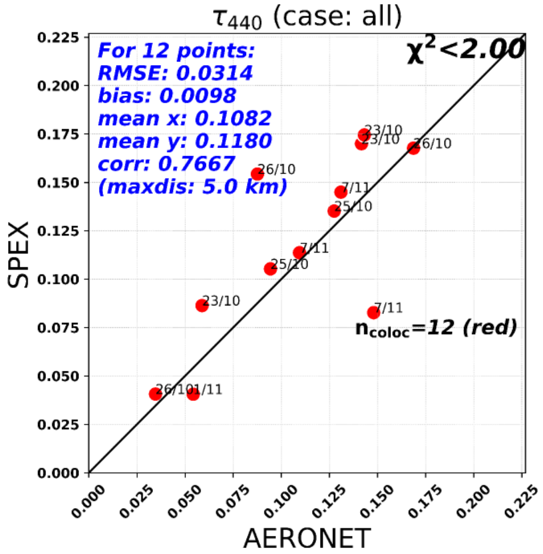
# How will PACE polarimeters perform?

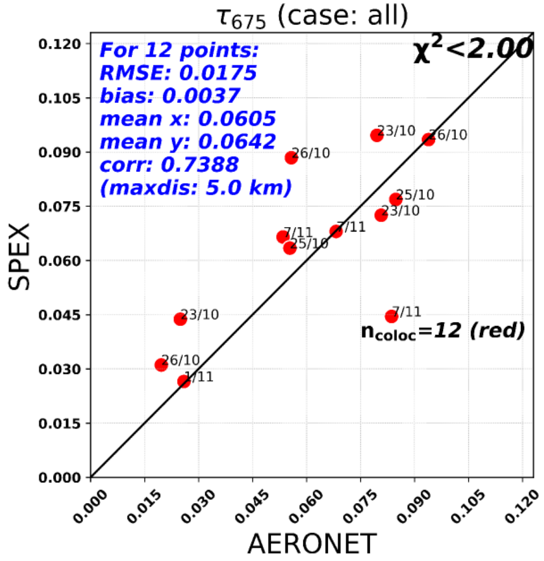
**SPEXone**:

**Example aerosol retrievals from SPEXAirborne during ACEPOL**

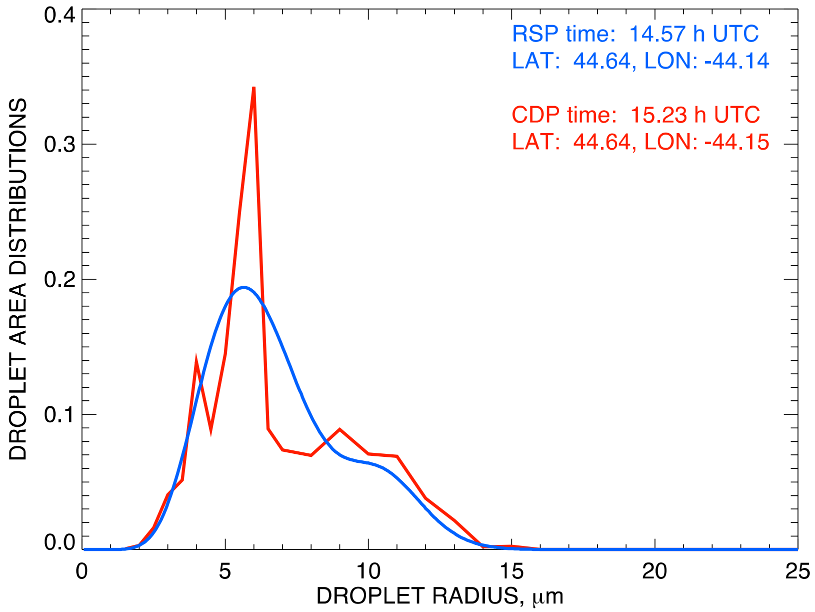
Hasekamp et al. AGU 2018




**HARP2**: **Examples of what a hyperangular capability provides**

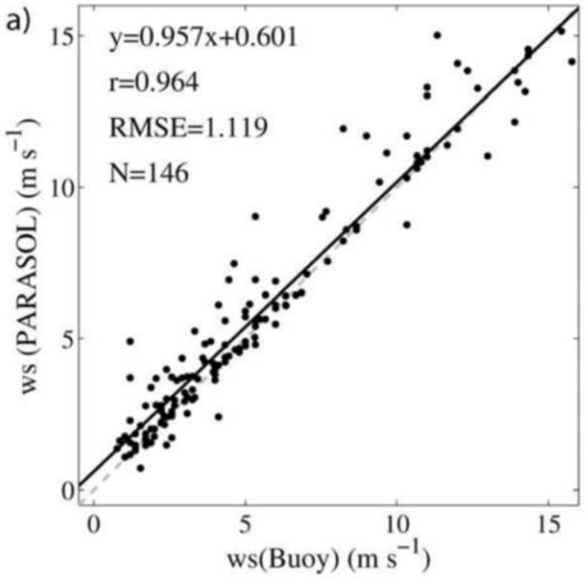


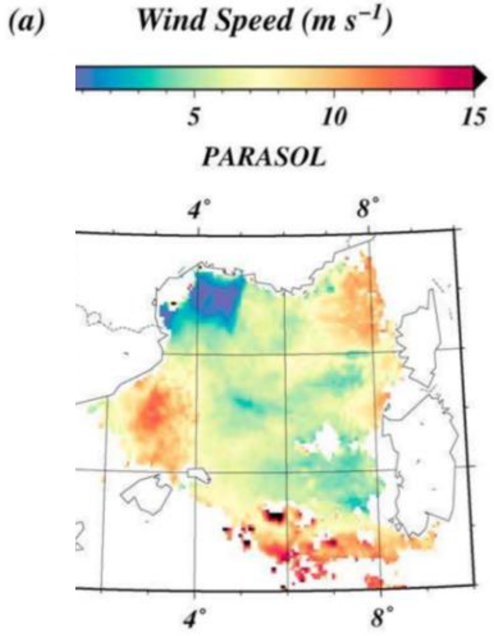

**Droplet size distributions**

Alexandrov et al. 2018

**Wind speeds**

Harmel and Chami 2012



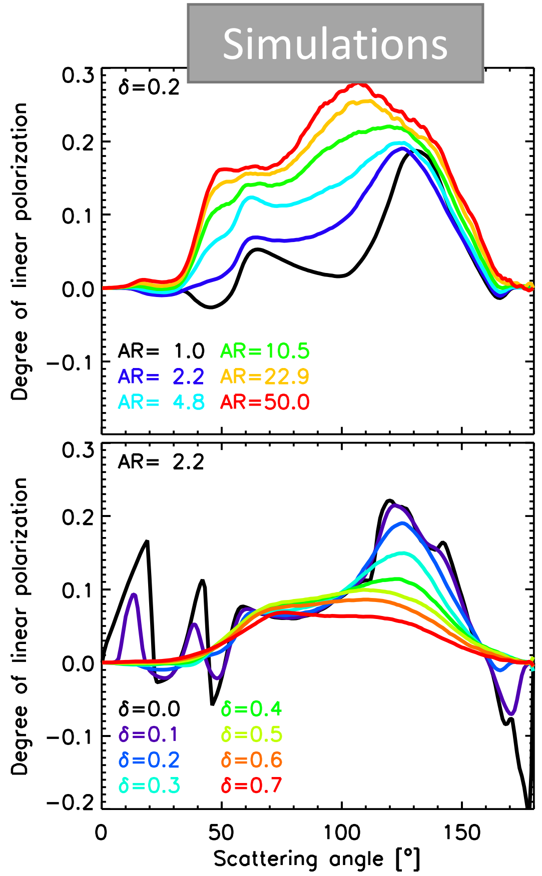



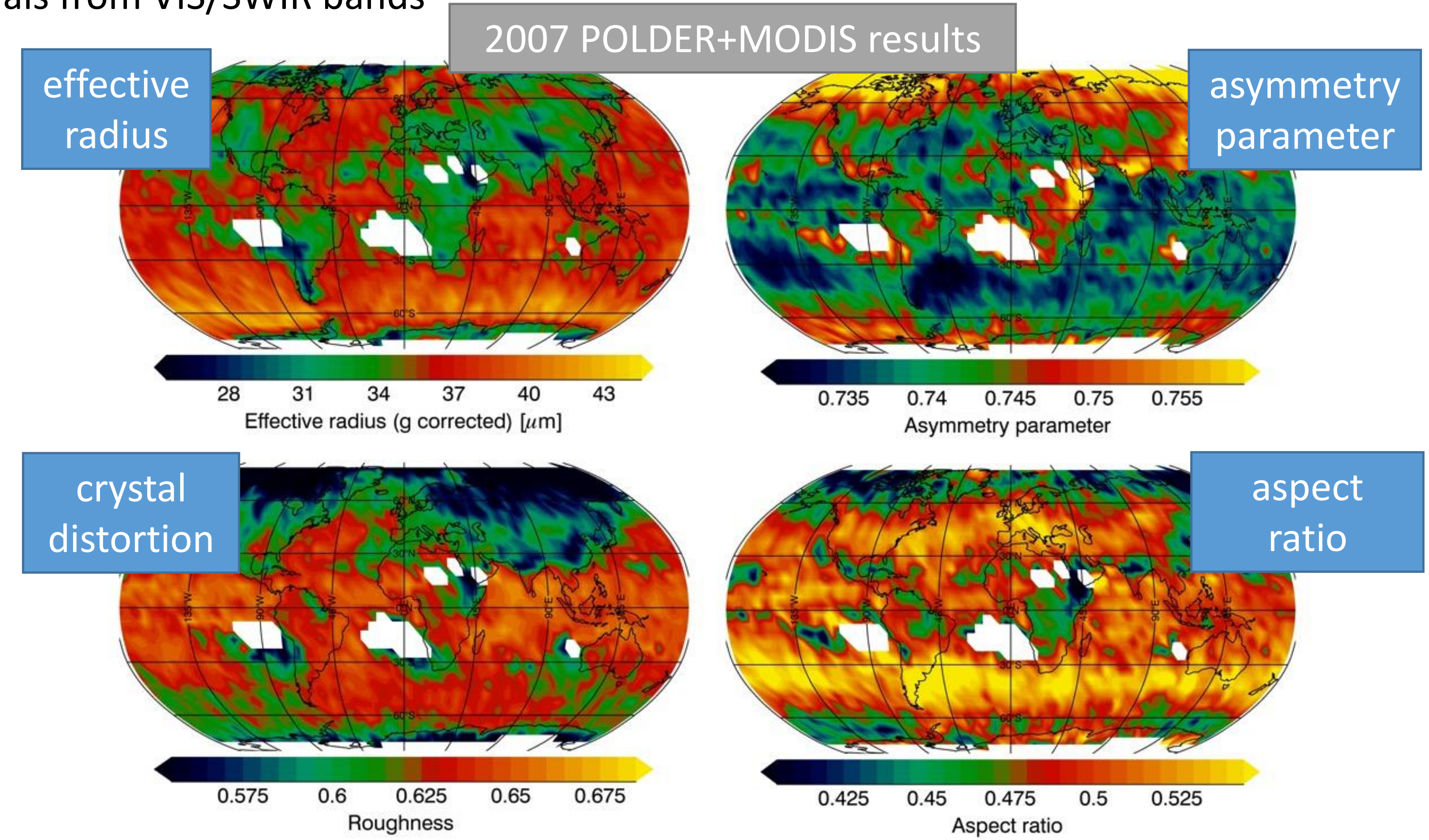
# How will PACE polarimeters perform?

## SPEXone + HARP2 + OCI: Polarimetric observations compliment OCI ice cloud retrievals

- Polarimetry allows retrieval of ice crystal aspect ratio and crystal distortion, which are fundamental properties determining the scattering asymmetry parameter
- Retrieving asymmetry parameter avoids the need to assume an ice optical model for optical thickness and effective radius retrievals from VIS/SWIR bands

van Diedenhoven et al. (AMT 2012, JGR 2014)



# How will PACE polarimeters perform?

**SPEXone: highest accuracy, (hyper) spectral range includes UV, but has narrow swath.**
Excellent for aerosol characterization and atmospheric correction, but utility of latter for OCI is limited by swath.

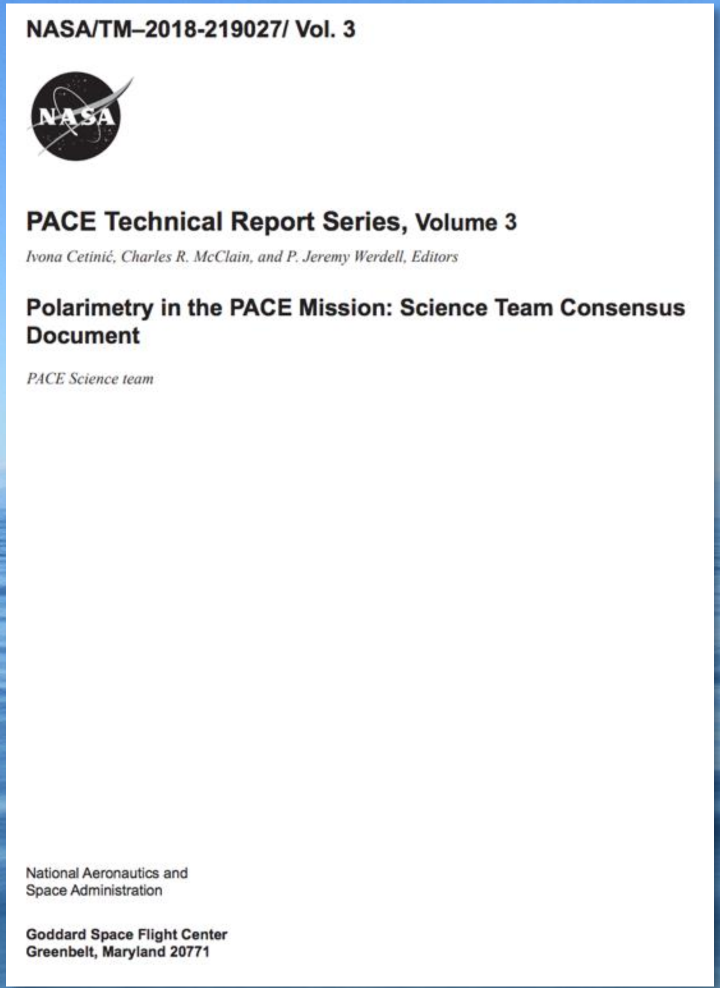
**HARP2: broad swath, hyperangular, more limited spectra (no UV)**
Good for aerosol charcterization and atmospheric correction, can do latter for most of OCI swath. Excellent for cloud droplet size and ice particle shape/roughness retrieval, does so in entirely different manner than heritage dual-band OCI algorithms.

**SPEXone + HARP2 + OCI**: Hyperspectral + Hyperangle + highly accurate radiometric and polarimetric observations means PACE would have far greater information content than any current instrument for ocean color, aerosol and cloud observations.

SPEXone and HARP2 both make all polarization measurements simultaneously which guarantees their level of accuracy no matter what scene is being observed.  This is not the case for rotating filter band instruments (POLDER, 3MI) which use sequential observations that can be affected by ”false polarization”.

# Learn more about PACE

https://pace.gsfc.nasa.gov
@NASAOcean (Twitter)
@NASAOcean (Facebook)
Technical Memo. series

NASA/TM–2018-219027/ Vol. 3

**PACE Technical Report Series, Volume 3**

*Ivona Cetinić, Charles R. McClain, and P. Jeremy Werdell, Editors*

**Polarimetry in the PACE Mission: Science Team Consensus Document**

*PACE Science team*

National Aeronautics and
Space Administration

**Goddard Space Flight Center
Greenbelt, Maryland 20771**

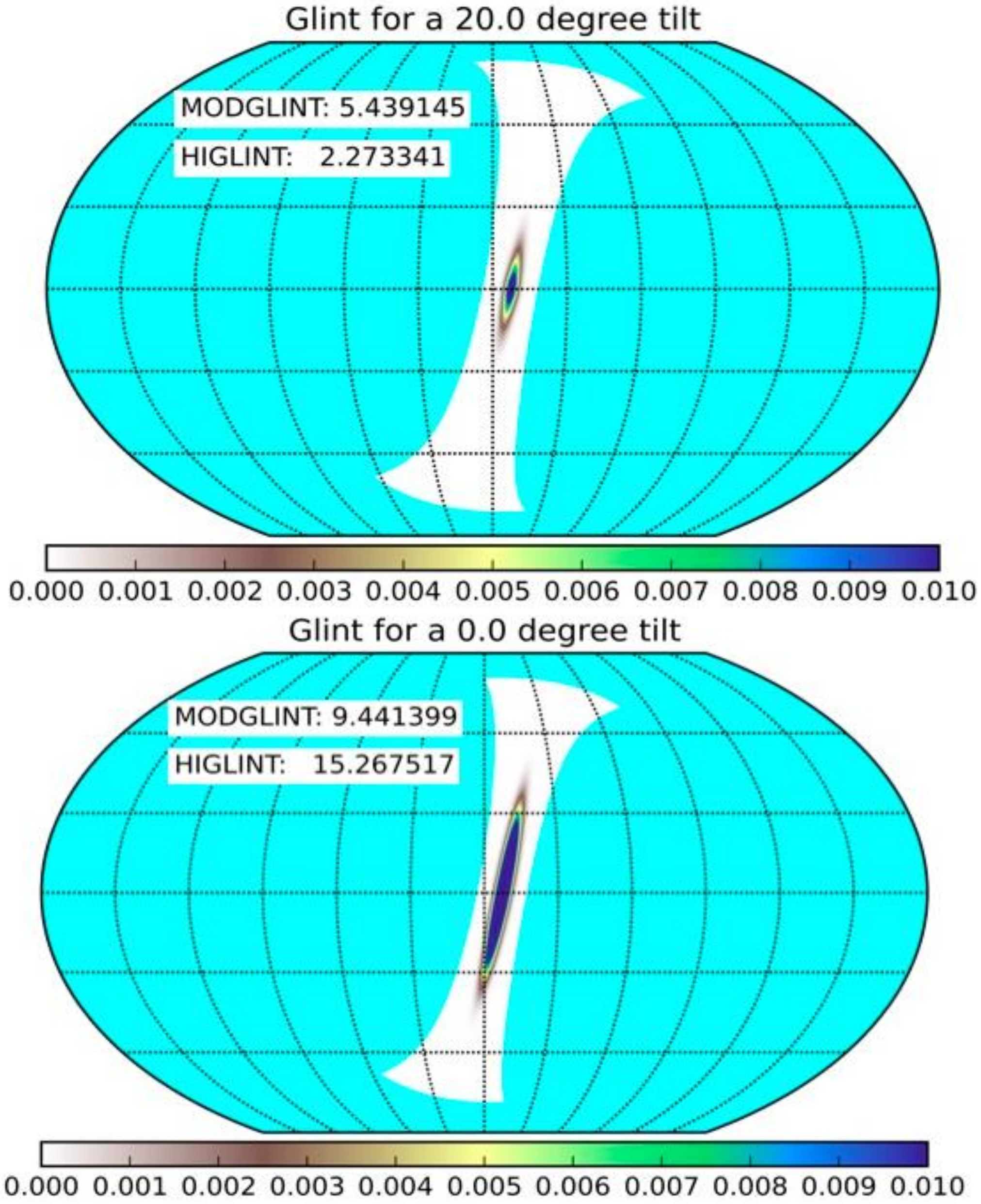
backup

# PACE Threshold aerosol and cloud product requirements

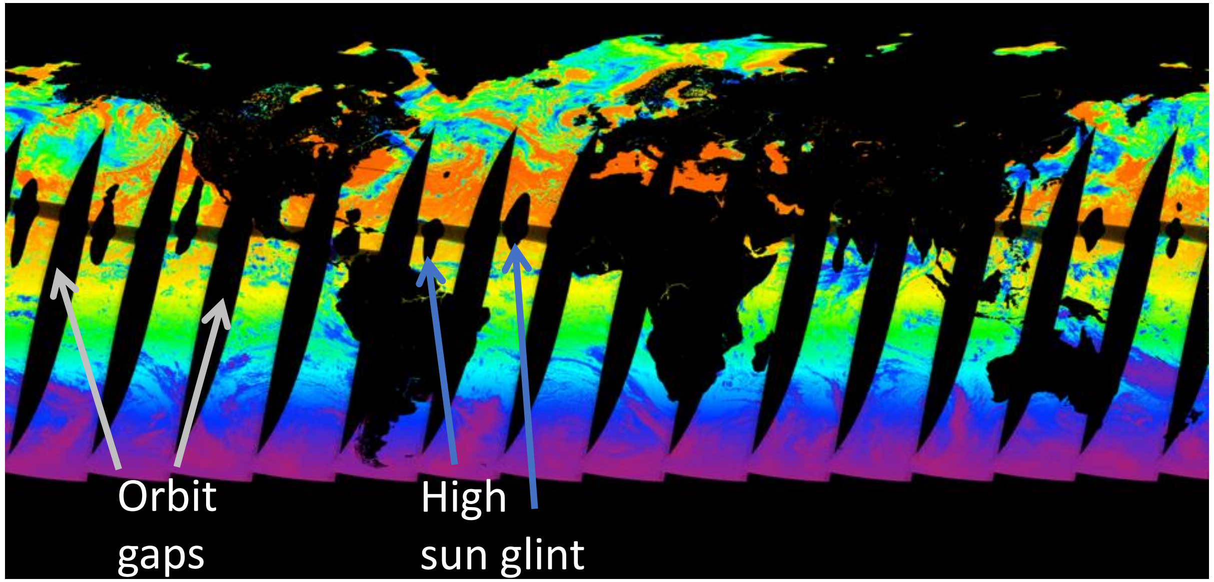
| Data Product | Range | Uncertainty |
|---|---|---|
| Total aerosol optical depth at 380 nm | 0.05 to 5 | 0.06 or 40% |
| Total aerosol optical depth at 440, 500, 550 and 675 nm over land | 0.05 to 5 | 0.06 or 20% |
| Total aerosol optical depth at 440, 500, 550 and 675 nm over oceans | 0.05 to 5 | 0.04 or 15% |
| Fraction of visible aerosol optical depth from fine mode aerosols over oceans at 550 nm | 0.05 to 1 | ±25% |
| Cloud layer detection for optical depth < 0.3 | NA | 40% |
| Cloud top pressure of opaque (optical depth > 3) clouds | 100 to 1000 hPa | 60 hPa |
| Optical thickness of liquid clouds | 5 to 100 | 25% |
| Optical thickness of ice clouds | 5 to 100 | 35% |
| Effective radius of liquid clouds | 5 to 50 μm | 25% |
| Effective radius of ice clouds | 5 to 50 μm | 35% |
| **Atmospheric data products to be derived from the above** | | |
| Water path of liquid clouds | | |
| Water path of ice clouds | | |
| Shortwave radiation effect | | |

These "heritage" requirements are to be met by OCI (alone)

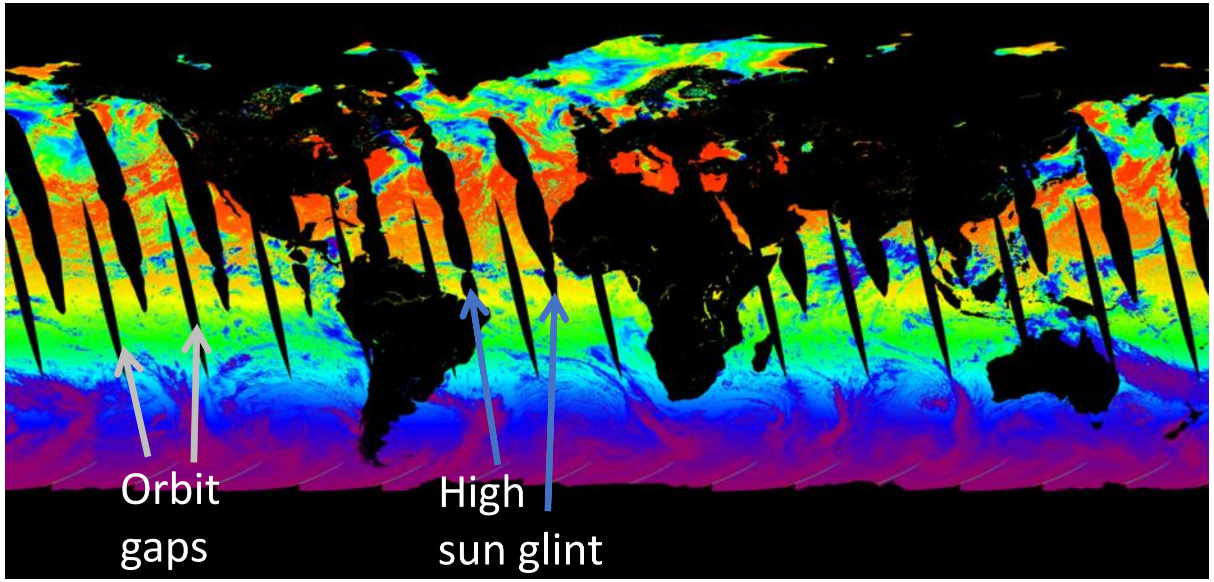
# OCI is tilted 20˚ to avoid glint




SeaWiFS PAR - June 21, 2007 (with tilt)

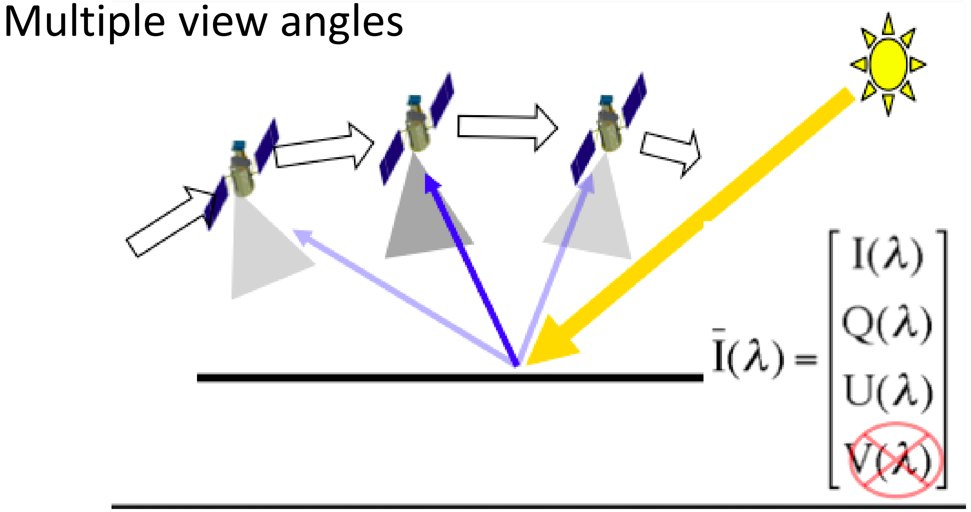



MODIS-Aqua PAR - June 21, 2007 (without tilt)

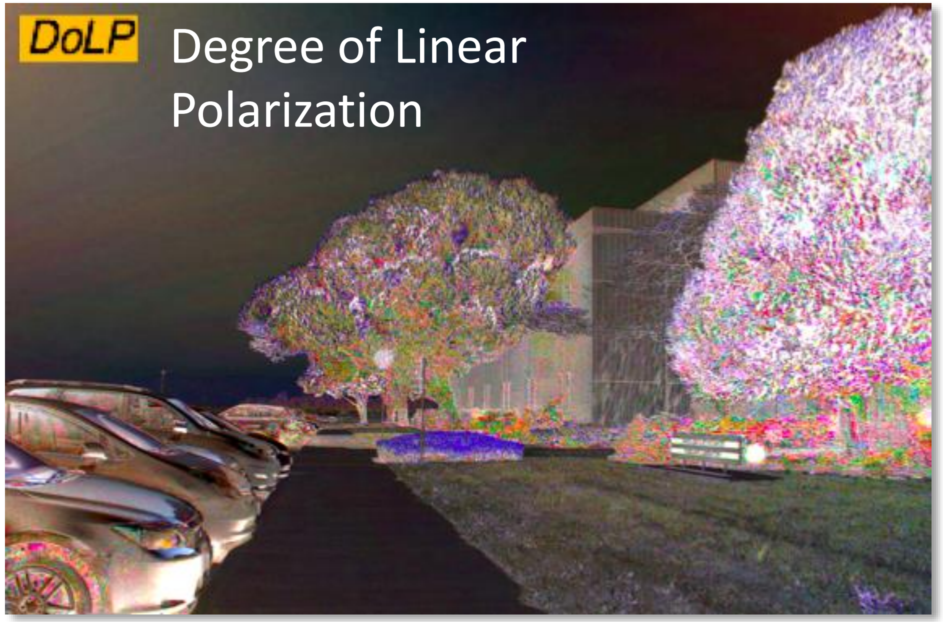


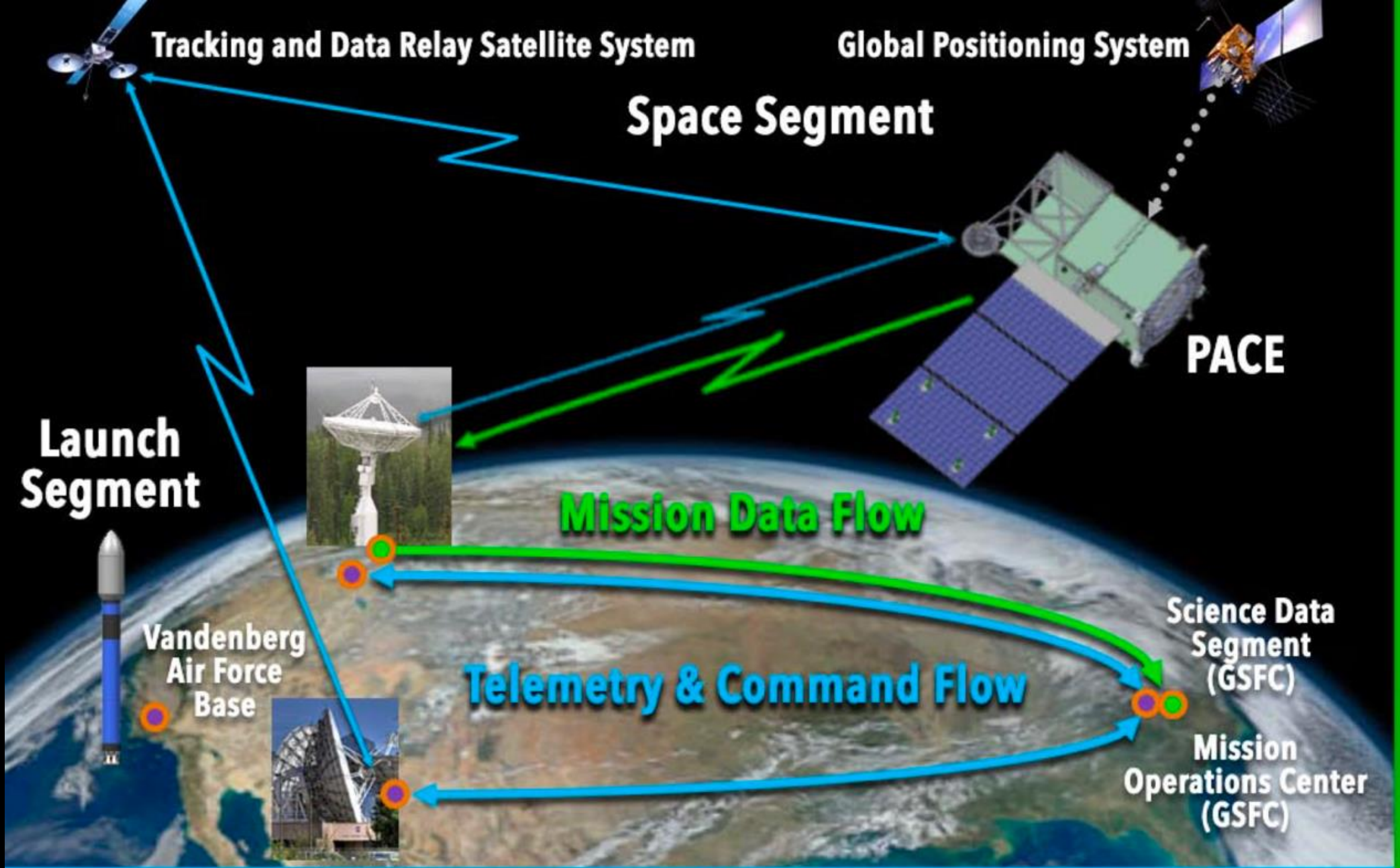

PAR = Photosynthetically Available Radiation

# Multi-angle polarimetry adds dimensions of information








## Mission Characteristics

*Orbit*

- 675.5 km altitude
- Polar, ascending orbit
- Sun synchronous
- 98º inclination
- 13:00 local Equatorial crossing

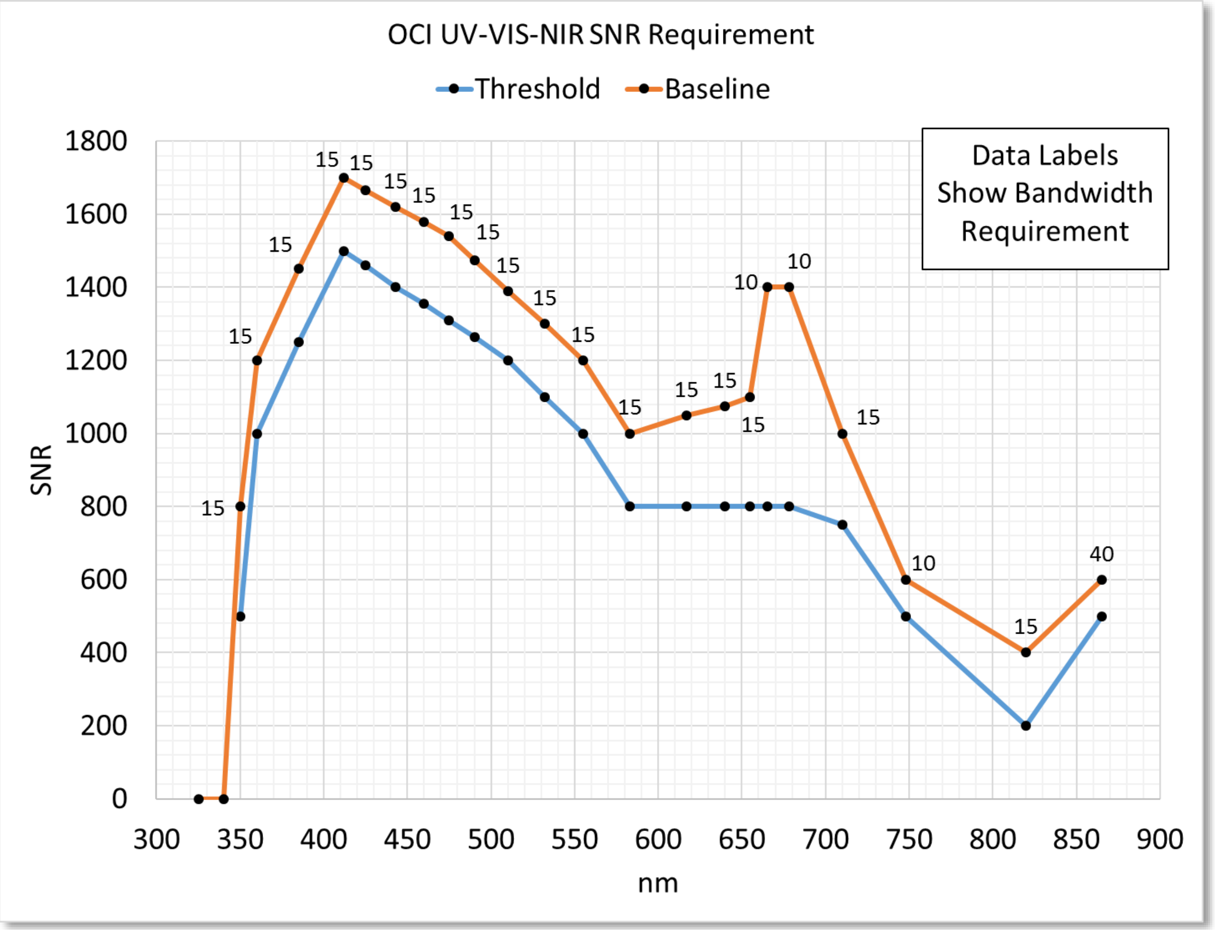
*Communications*

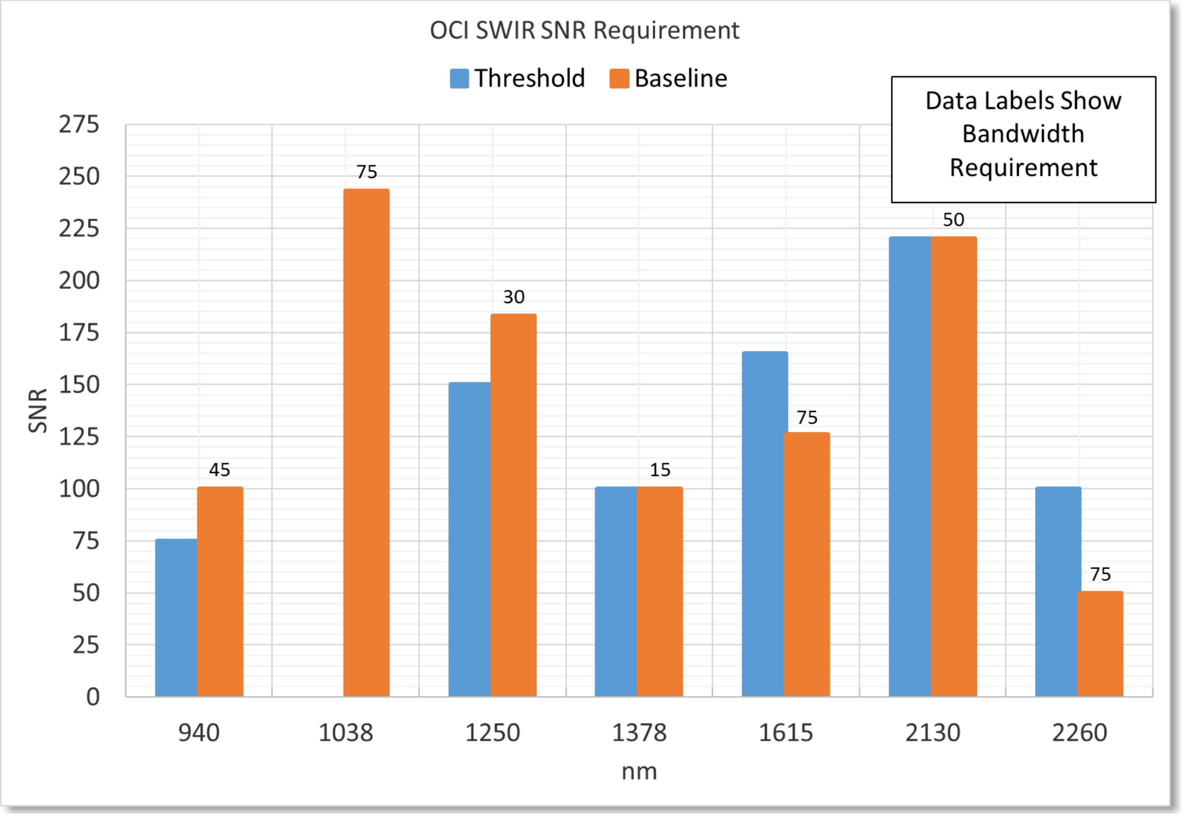
- Ka direct to ground
- 600 Mbps data transfer

*Cost, Schedule, Lifespan*

- $805M Design-to-Cost
- Category 2, Class C
- Fall 2022 launch
- 3-year design life
- 10-years of fuel

# Ocean Color Instrument (OCI) – signal-to-noise (SNR)



# Required science data products (OCI)

Required data products & additional expected data products:

## Level 1 required (~threshold) products

| | |
|---|---|
| Water-leaving reflectance | Aerosol optical thickness |
| Chlorophyll-a | Aerosol fine mode fraction |
| Phytoplankton absorption | Liquid / ice cloud optical thickness |
| NAP+CDOM absorption | Liquid / ice cloud effective radius |
| Particulate backscattering | Cloud layer detection ($\tau < 0.3$) |
| Diffuse attenuation | Cloud top pressure ($\tau > 3$) |
| Fluorescence line height | Shortwave radiation effect |

Building capabilities to produce this full suite of OCI products from proxy data using preliminary/heritage algorithms by the end of 2018

# Advanced & evaluation science data products

Required data products & additional expected data products:

### Incomplete list of advanced (~baseline) products

| | |
|---|---|
| Carbon stocks & fluxes | Liquid / ice cloud water path |
| Phytoplankton pigments | Polarimeter-specific products |
| Phytoplankton physiology | Applied sciences-specific products |
| Community structure (PFTs) | Land data products (TBD) |
| Productivity | Your very favorite data product that |
| PAR, light attenuation, water quality | I forgot to list (*so plz don't ask*) |

**General expectations for future PACE science teams**:

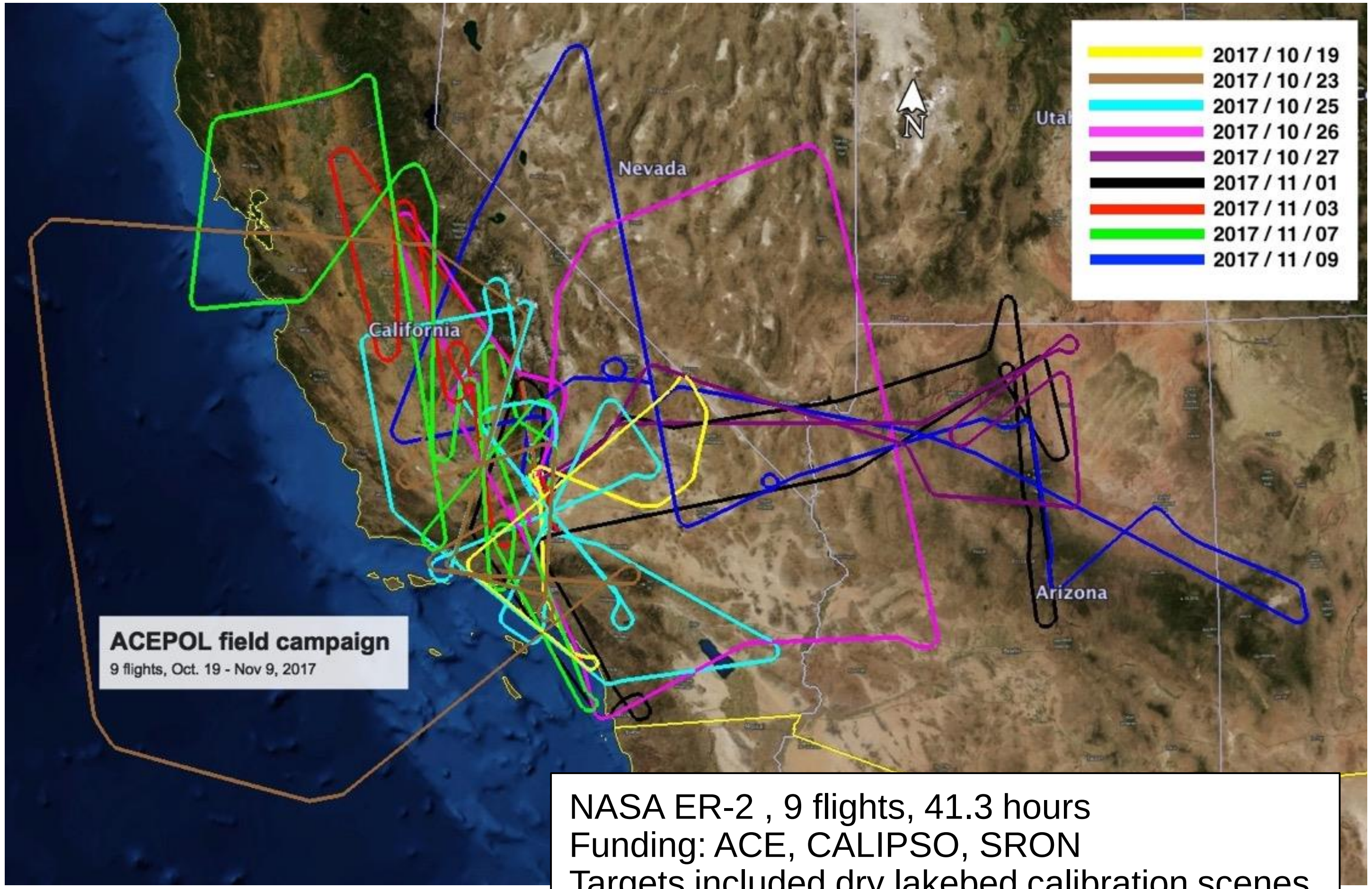
- *Novel* methods for required products (exploit spectral capabilities)
- Methods for advanced products + scientific applications

# ACEPOL: airborne polarimeter prototypes flew together

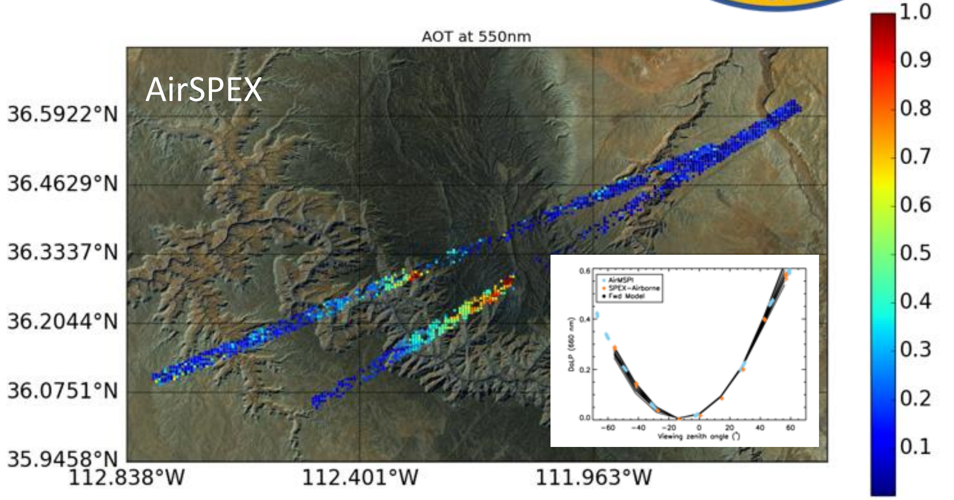
Airborne versions both flew as part of the Aerosol Characterization from Polarimeter and Lidar (ACEPOL) field campaign, Oct-Nov 2017 (alongside other polarimeters and lidars).

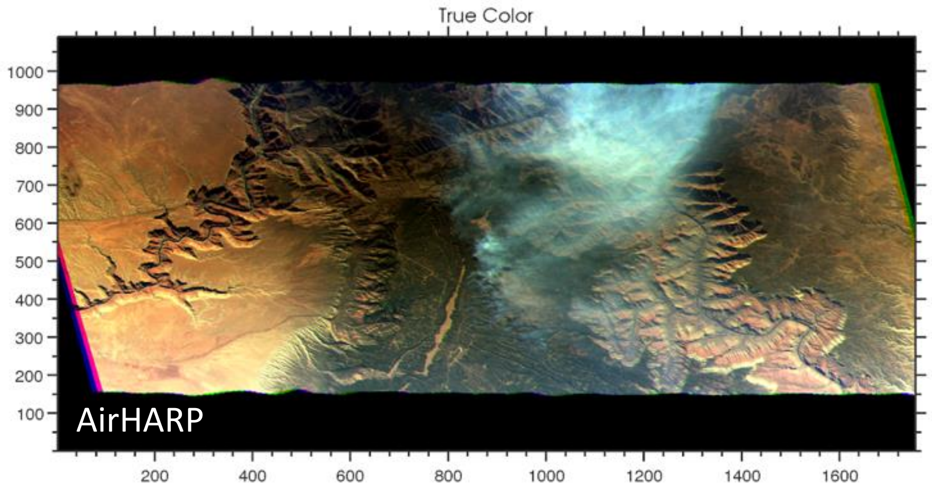
Polarimeters: AirMSPI, AirHARP, RSP, AirSPEX

Lidars: CPL, HSRL-2




NASA ER-2 , 9 flights, 41.3 hours
Funding: ACE, CALIPSO, SRON
Targets included dry lakebed calibration scenes, clouds, smoke aerosols, cloudless oceans



**Extend** key systematic **ocean** biological, ecological, & biogeochemical climate data records and **cloud** & **aerosol climate data records**

Make **new global measurements of ocean color** that are essential for understanding the global carbon cycle & ocean ecosystem responses to a changing climate

Collect **global observations of aerosol & cloud properties**, focusing on reducing the largest uncertainties in climate & radiative forcing models of the Earth system

**Challenge addressed**: signals from the ocean are small & differentiating between constituents requires additional information relative to what we have today

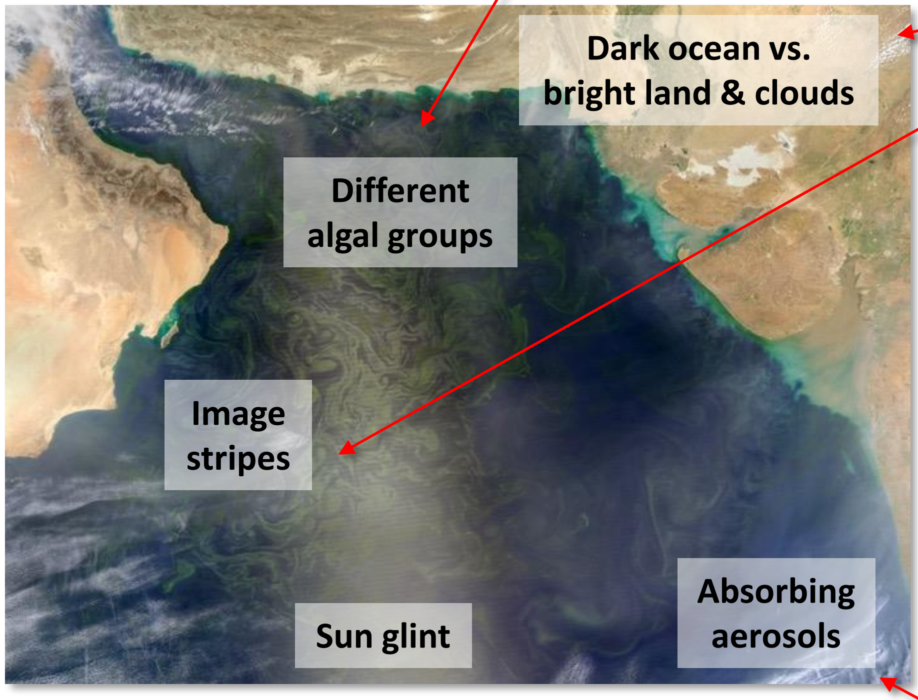
*GSD of 1 ± 0.1 km² at nadir*

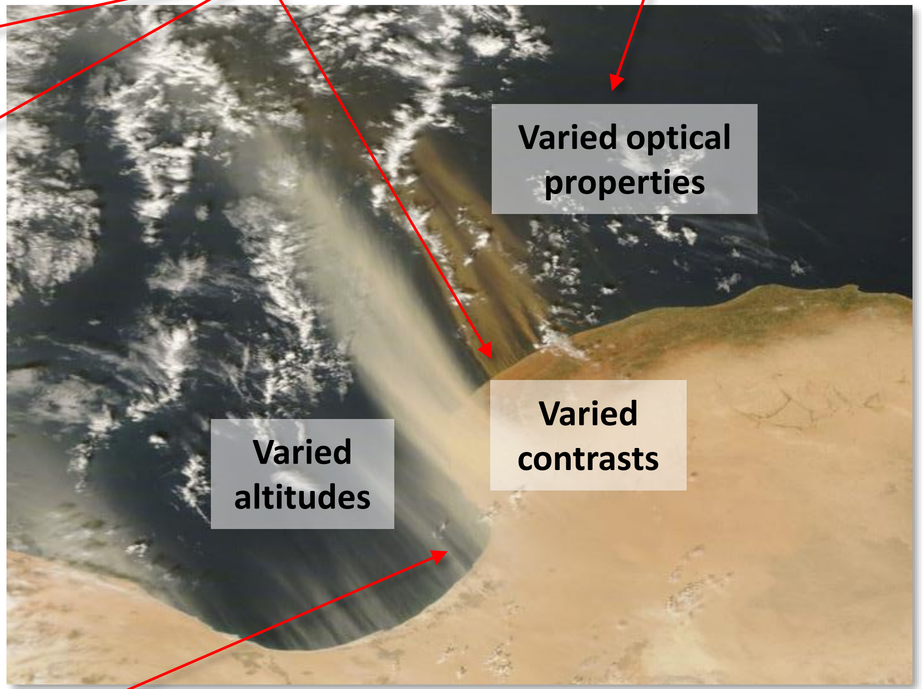
*Twice-monthly lunar calibration & onboard solar calibration (daily, monthly, dim)*

*Spectral range from 350-865 @ 5 nm*

*940, 1038, 1250, 1378, 1615, 2130, 2260 nm*

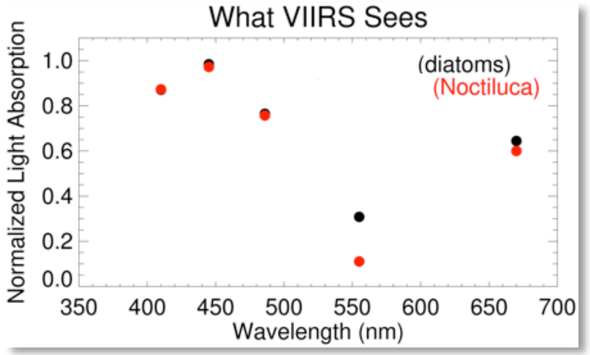
*Instrument performance requirements*

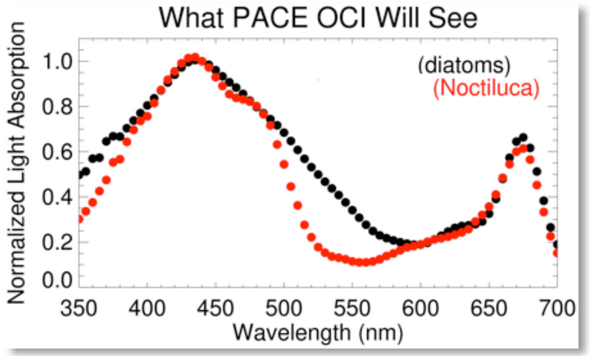



*Tilt ± 20°*

*Spectral range goal of 320-865 @ 5 nm*




Improve our understanding of how **aerosols influence ocean ecosystems & biogeochemical cycles** and how **ocean biological & photochemical processes affect the atmosphere**

**Extend** key systematic **ocean** biological, ecological, & biogeochemical climate data records and **cloud** & **aerosol climate data records**

Make **new global measurements of ocean color** that are essential for understanding the global carbon cycle & ocean ecosystem responses to a changing climate

Collect **global observations of aerosol & cloud properties**, focusing on reducing the largest uncertainties in climate & radiative forcing models of the Earth system

Challenge addressed: aerosol, cloud, climate interactions are complicated and difficult to observe

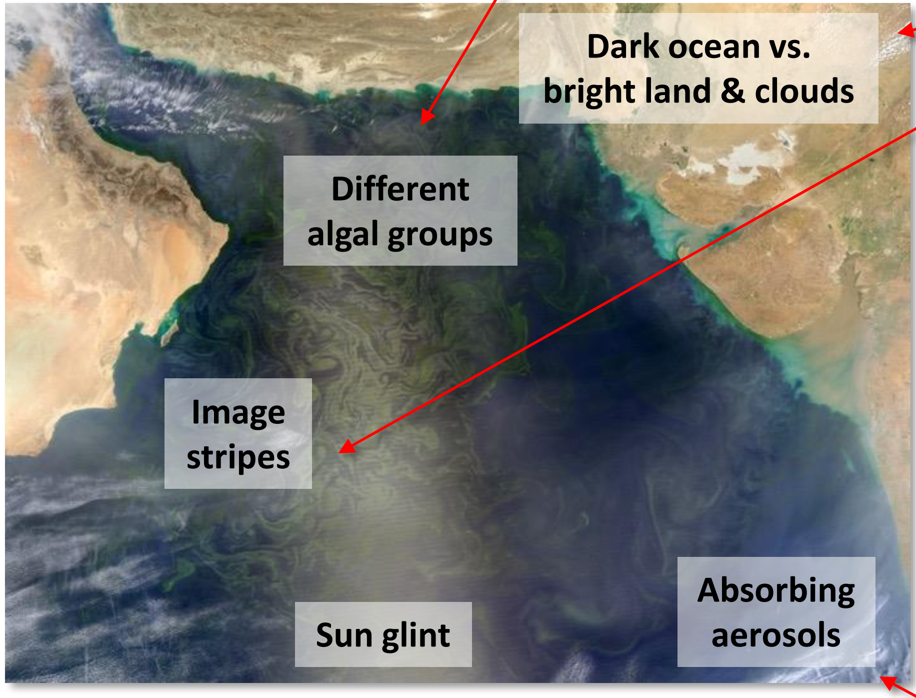
*GSD of 1 ± 0.1 km$^2$ at nadir*

*Twice-monthly lunar calibration & onboard solar calibration (daily, monthly, dim)*

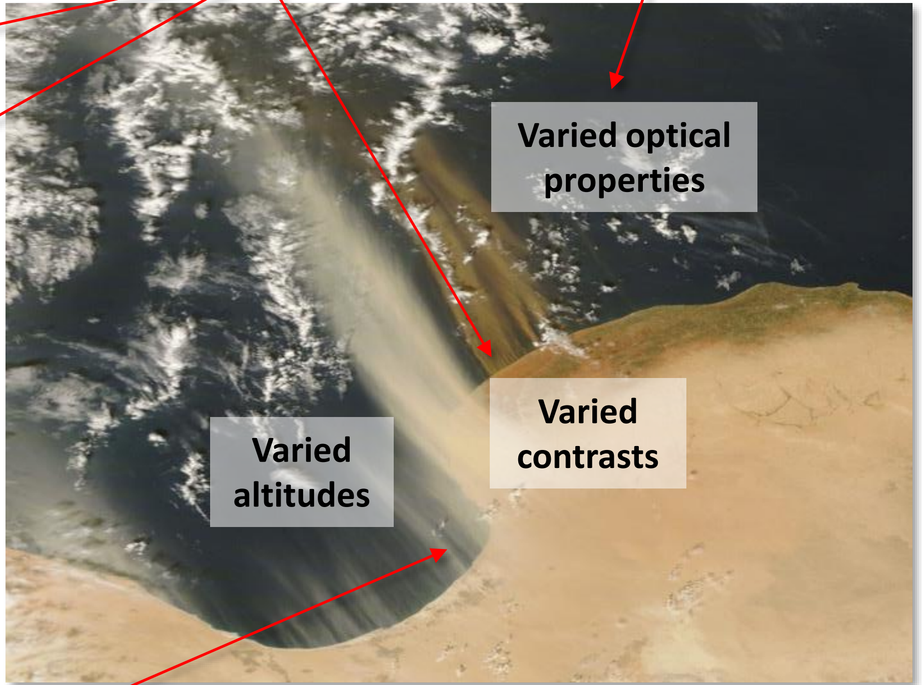
*Spectral range from 350-865 @ 5 nm*

*940, 1038, 1250, 1378, 1615, 2130, 2260 nm*

*Instrument performance requirements*




*Tilt ± 20$^o$*

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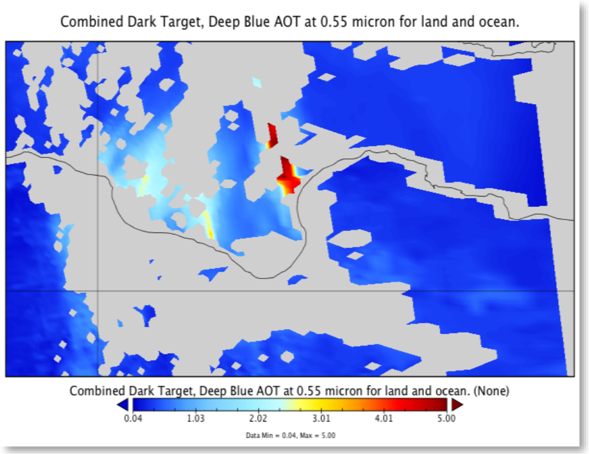



PACE will have:

- an OCI with UV bands to 350 nm (320 nm goal) & two 2 μm bands
- multi-angle polarimetry
- (no thermal bands)

Improve our understanding of how **aerosols influence ocean ecosystems & biogeochemical cycles** and how **ocean biological & photochemical processes affect the atmosphere**

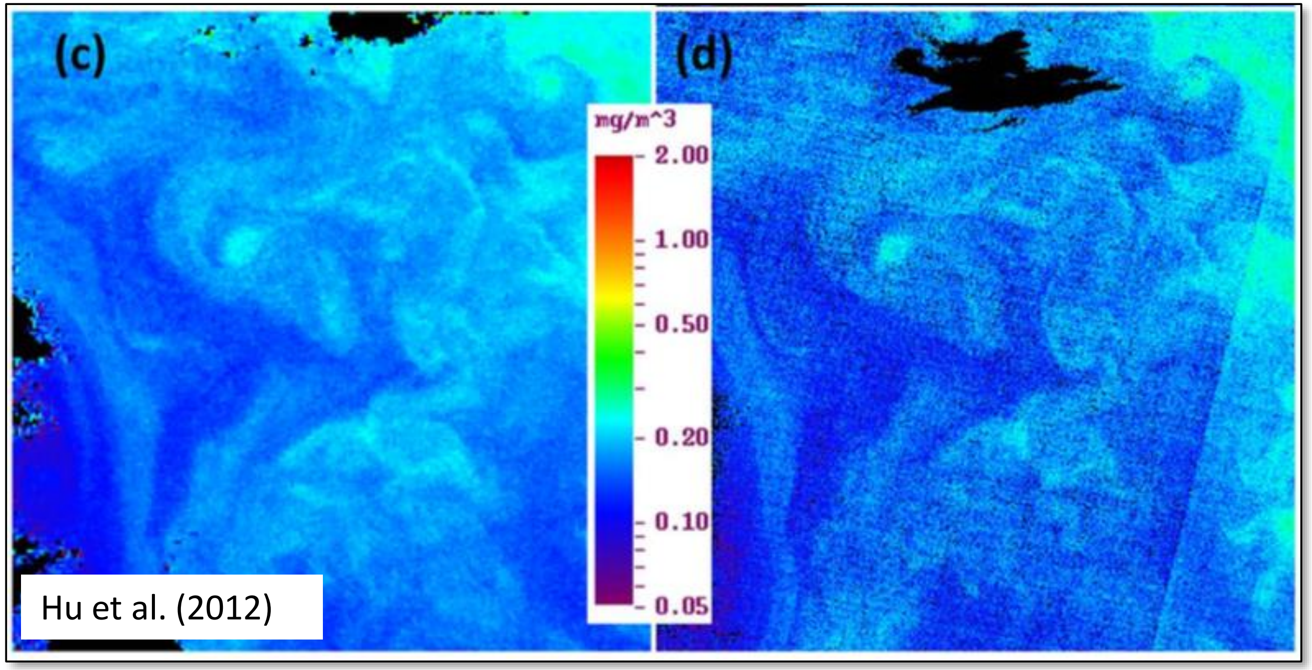
## PACE Polarimeters characteristics

| | Thresholds | SPEXone (SRON, Airbus) | HARP2 (UMBC) |
|---|---|---|---|
| **Polarimetric analysis method** | no req't. | Spectral Modulation<br>Full Linear (Stokes I, Q and U) | Amplitude Split with Philips Prisms<br>0°, 45°, 90° |
| **DoLP accuracy** | < 0.01 in aerosol,cloud, atmos. correction | **0.002 (goal)** | < 0.01<br>* likely < 0.005 but it will depend on vicarious calibration efforts |
| **Radiance accuracy** | 5% aerosols, clouds, atmos. correction | 2% | est. 3% from ground cal |
| **Spectral Range** | four in 400-1600 nm, 2200 nm desired | **385-770 nm, spectrometer** | 440, 550, 670, 870 nm |
| **Spectral Resolution** | no threshold req't. | **2 nm** | 10nm / 40 nm for 870 |
| **# Viewing angles** | 4 aerosols<br>5-6 cloud<br>4 atmos. correction | 5<br>(-52°, -20°, 0°, 20°, 52°) | **20 for 440, 550, 870 nm;<br>60 for 670 nm<br>* limited by data rate** |
| **Along track viewing angle range** | ±50° view angle range from nadir | 103.2° | 114° |
| **Swath** | ±15° aerosol, cloud<br>±25° atmos. correction | ~9°(100km) | **94° (1550 km)<br>*(compare to 113° for OCI)*** |
| **GSD** | 5km$^2$ aerosol, cloud, atmos. correction | 2.5 km$^2$ | 2.5km$^2$<br>* this is an estimate as the GSD can vary with binning approach |
| **Prior History** | n/a | 1) AirSPEX | 1) cubesat HARP for ISS<br>2) AirHARP |

# Image artifacts & instrument design

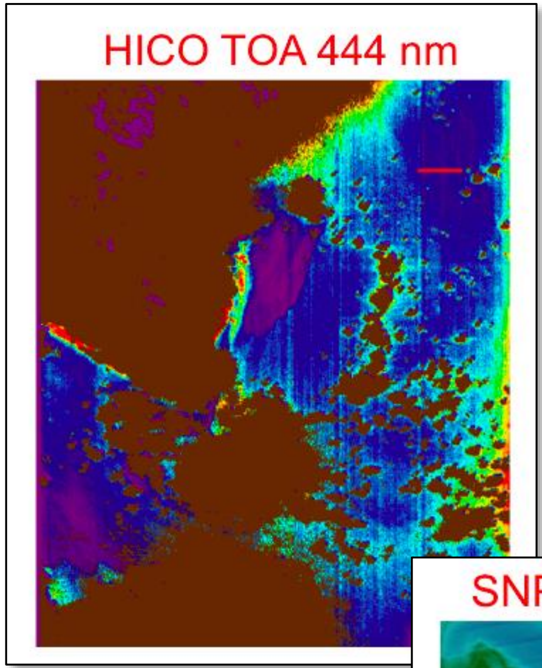
SeaWIFS (rotating telescope)
1 science detector

MERIS (pushbroom)
multiple science detectors




often larger science pixels
(1 km)

often smaller science pixels
(30-300 m)




All multiple detector instruments show stripes in ocean color imagery (more detectors to calibrate)