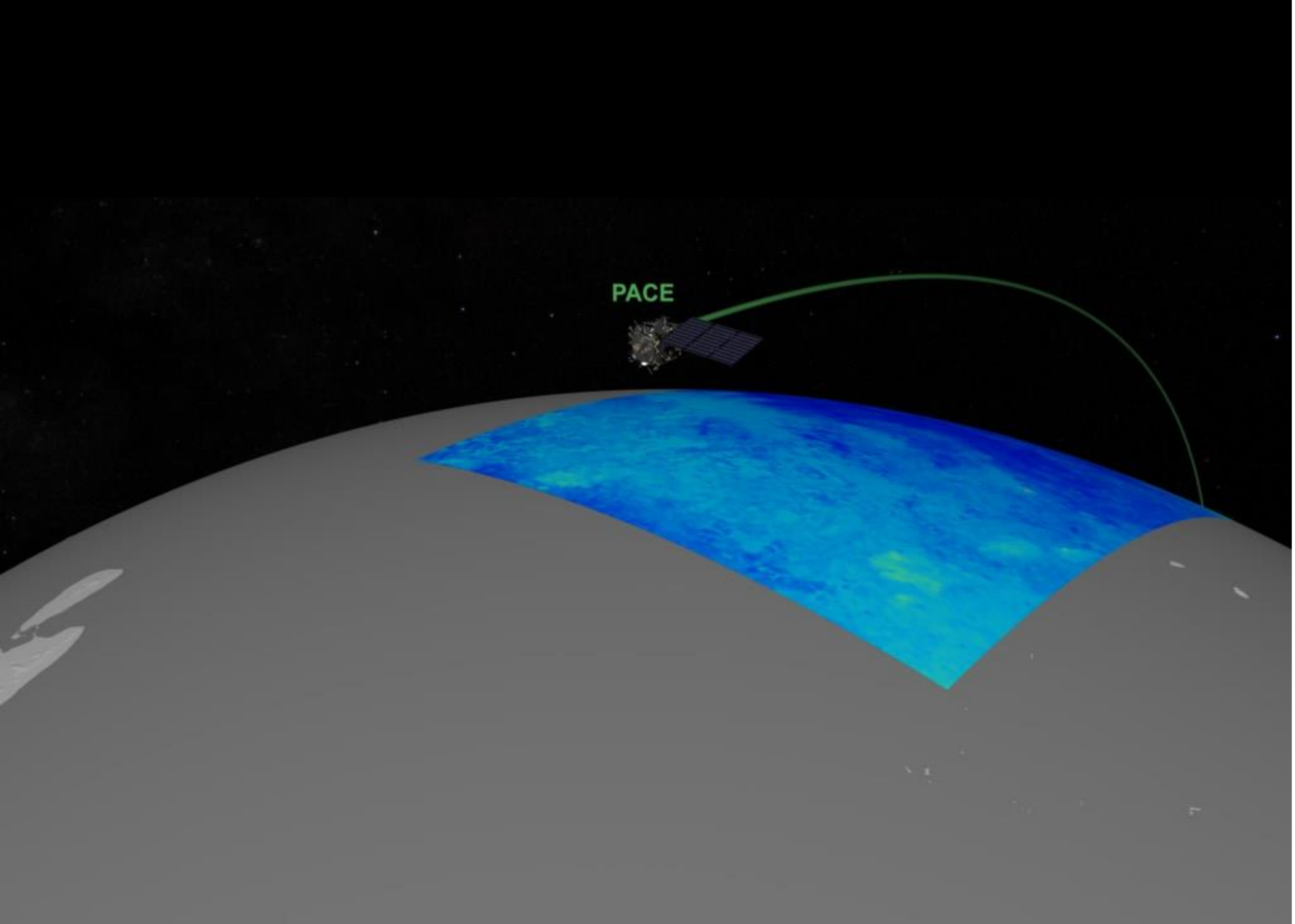
PACE update – IOCS & OCRT

8 April 2019, Busan, South Korea,

Jeremy Werdell, Paula Bontempi
NASA GSFC, NASA HQ

PACE

Plankton, Aerosol, Cloud, ocean Ecosystem



Legacies:

- CZCS
- SeaWiFS
- POLDER
- MODIS
- MISR
- MERIS
- VIIRS
- OLCI
- SGLI
- others

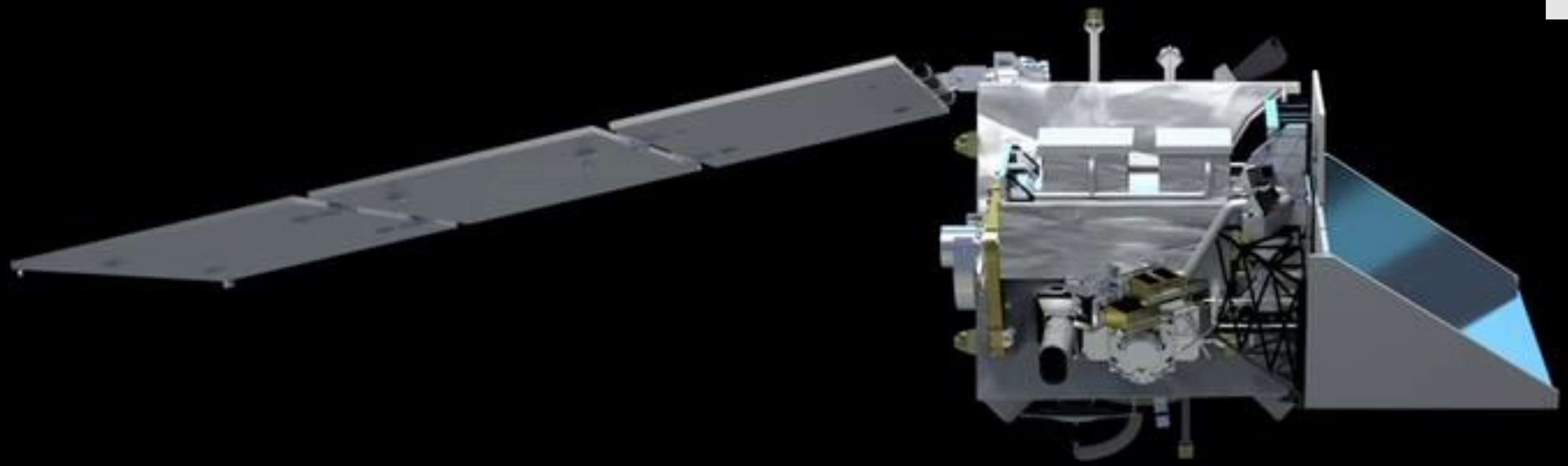
Agenda:

- mission update
- programmatic update, cal/val, & future community opportunities
- instrument updates
- Q&A

Mission update

Cost, Schedule, Lifespan

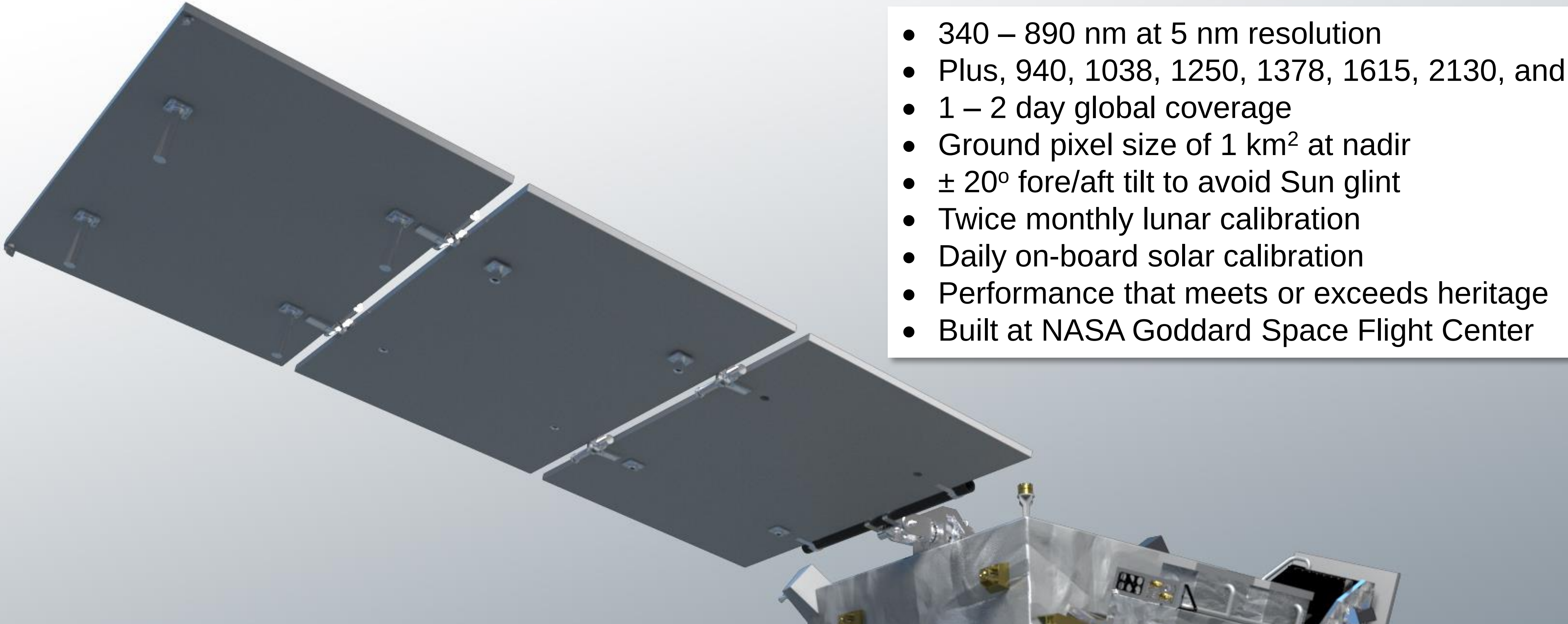
- $805M Design-to-Cost
- Category 2, Class C
- ~Dec 2022 launch
- 3-year design life
- 10-years of propellant

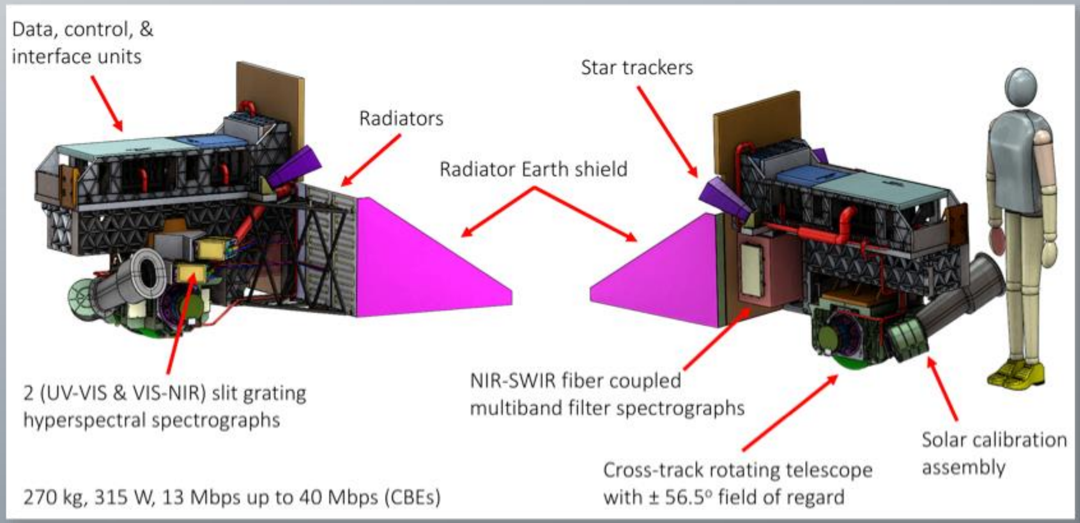


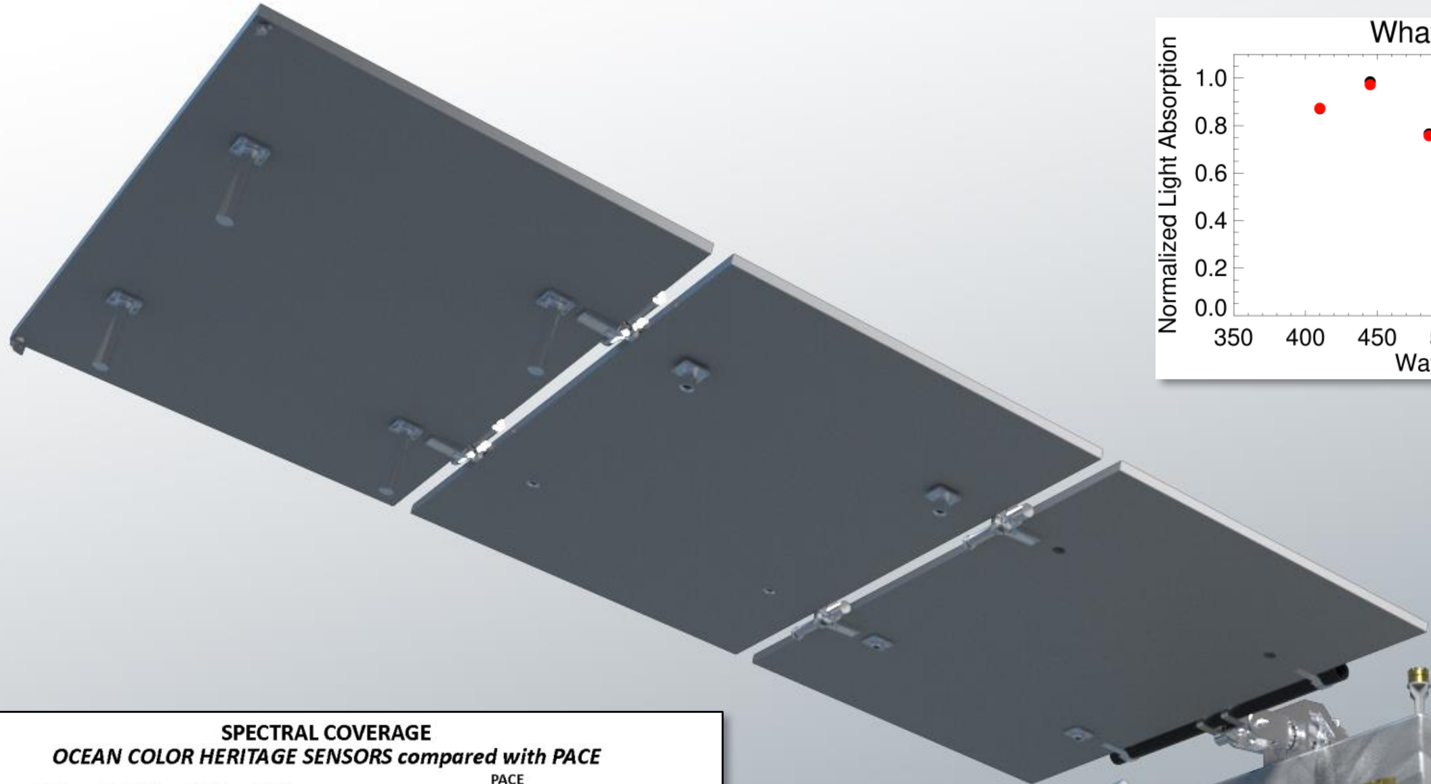
Orbit

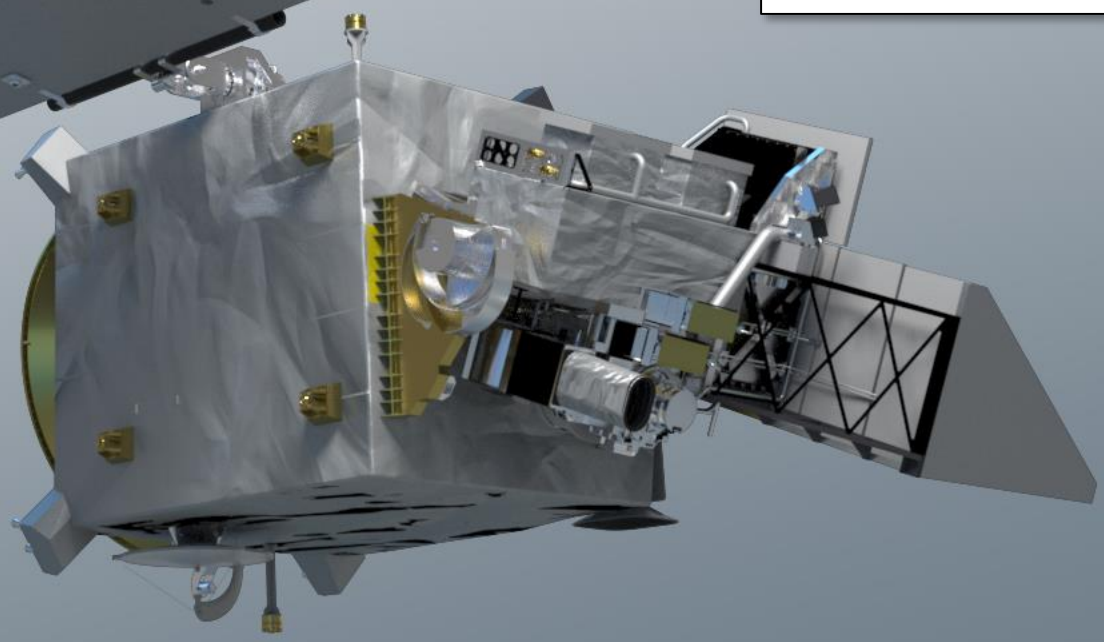
- 675.5 km altitude
- Polar, ascending orbit
- Sun synchronous
- 98º inclination
- 13:00 local Equatorial crossing

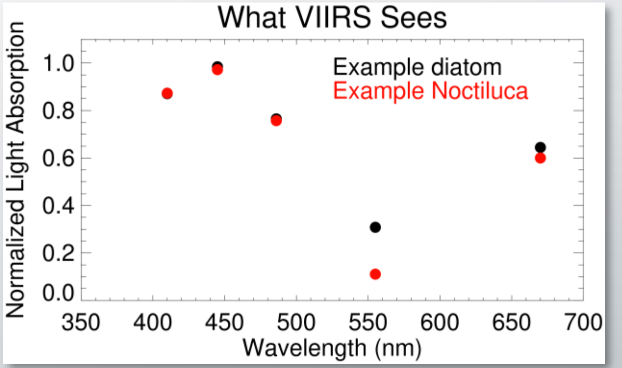
- 340 – 890 nm at 5 nm resolution
- Plus, 940, 1038, 1250, 1378, 1615, 2130, and 2250 nm
- 1 – 2 day global coverage
- Ground pixel size of 1 km^2 at nadir
- ± 20^o fore/aft tilt to avoid Sun glint
- Twice monthly lunar calibration
- Daily on-board solar calibration
- Performance that meets or exceeds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

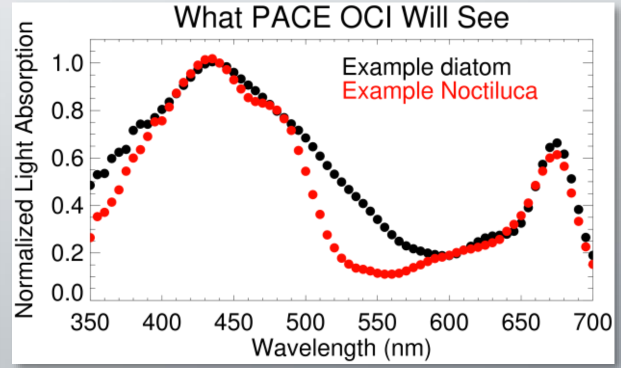




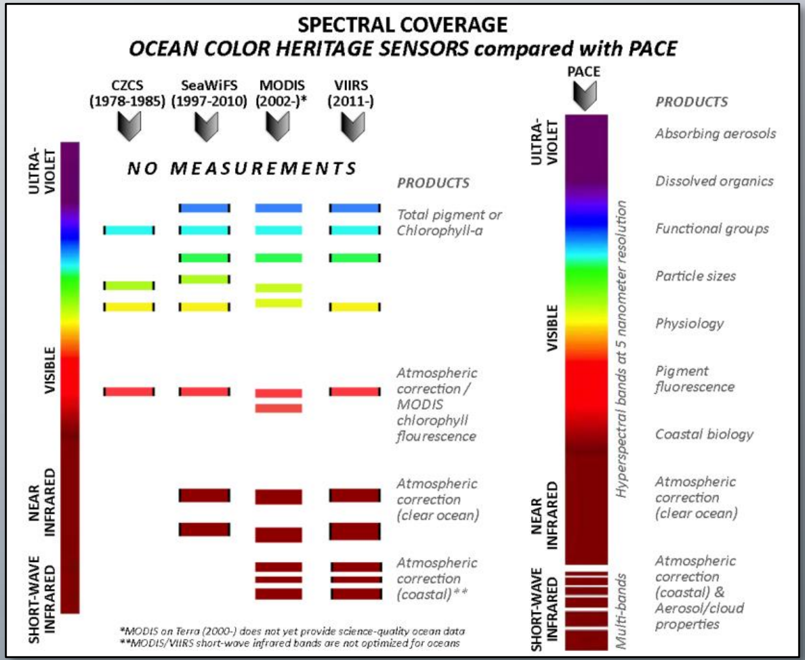




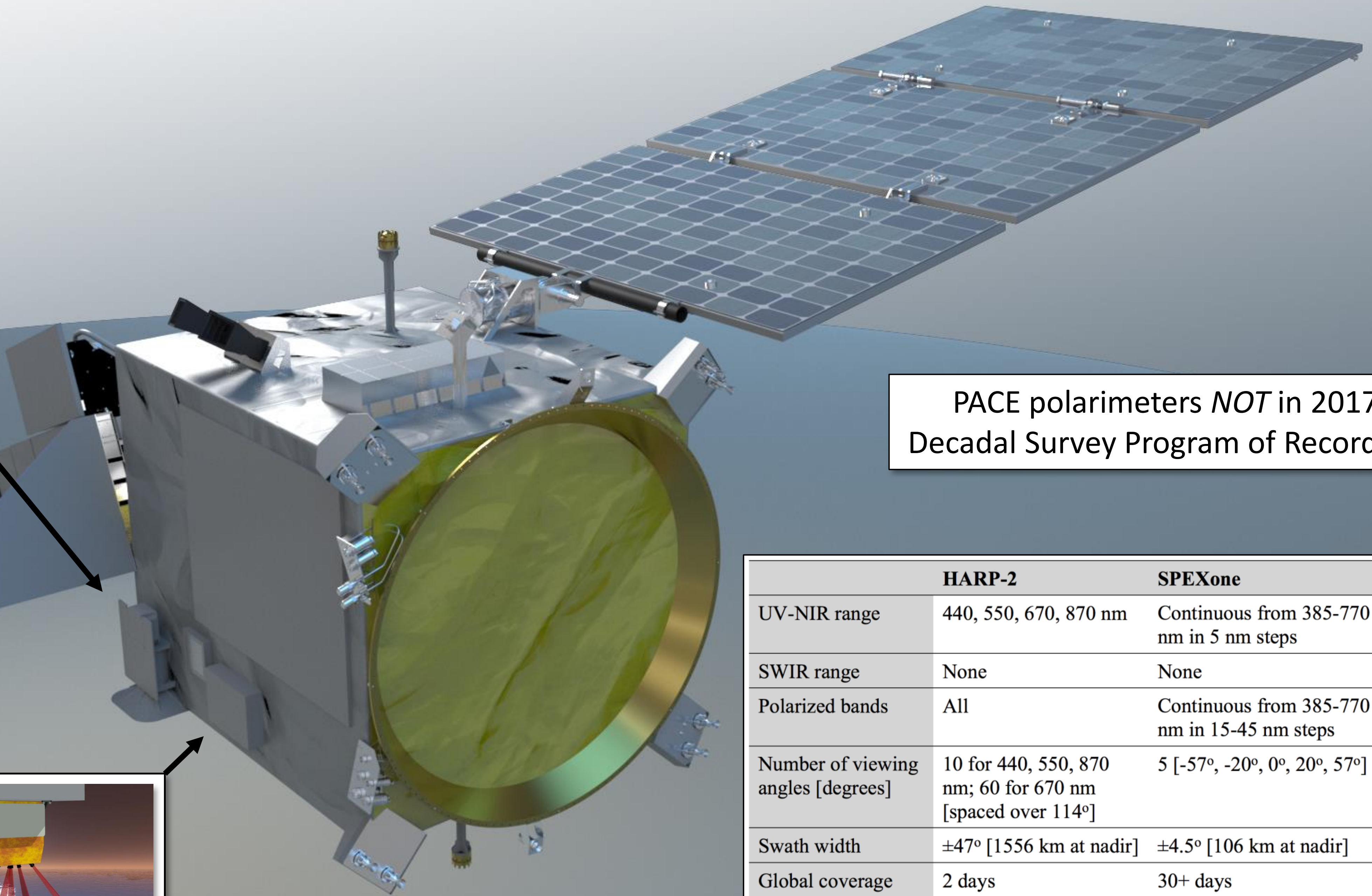




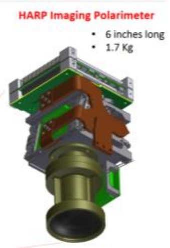
PACE OCI in 2017 Decadal Survey Program of Record



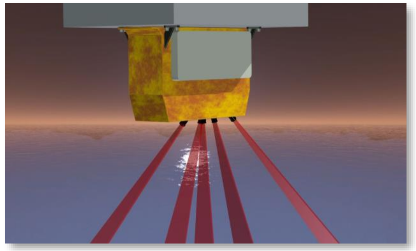
PACE polarimeters *NOT* in 2017 Decadal Survey Program of Record



UMBC Hyper Angular Rainbow Polarimeter (HARP-2)



SRON Spectro-polarimeter for Planetary Exploration (SPEXone)



	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

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

Phase B – preliminary design & technology completion (mission PDR in Jun 2019)

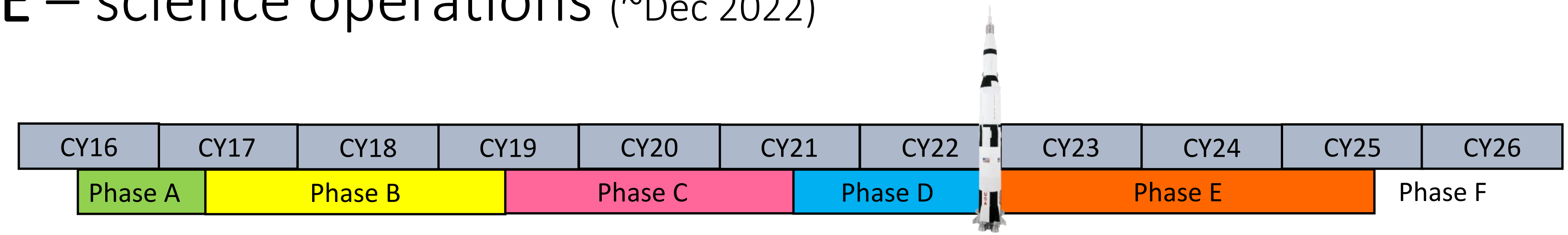
Phase C – final design & fabrication (Aug 2019)

- All mission elements must pass Critical Design Reviews (CDR) (~Dec 2019)
- 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.)
  - Interact with newly formed Science Teams

Phase D – system assembly, integration & testing, & launch (~Sep 2021)

Phase E – science operations (~Dec 2022)



Programmatic update & future science teams

Looking forward: noteworthy mentions

Budget Status: FY20 and beyond (as of early Mar 2019)

- The Budget requests a total of $21 billion for NASA, $1.7798 billion for Earth Science
- FY20 President's Budget maintains the Administration's previous termination of two Earth Science missions—PACE and CLARREO Pathfinder—lower priority science. Terminates NASA's Office of STEM Engagement.

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
  - Pursued consensus and community-endorsed paths forward for IOPs & atmospheric correction
  - Final reports are being submitted and will be compiled into a NASA Technical Memo.
- **FY20 – 22: ROSES 2019 A.38 (3 years)**
  - Allow lead time for pre-launch scientific algorithm & applications development prior to launch
  - Initiates interface between algorithm developers and OBPG/OB.DAAC
- FY23 – 25: ROSES 2022 [TBD] (~3 years)
  - At-launch algorithms and post-launch competed science/applications for OCI's aerosol, cloud, & ocean science, plus aerosol & clouds (& oceans?) from SPEXone & HARP-2

Post-launch competed sciences teams (TBD)

- Most likely competed through ROSES 2025
- To 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 have completed analysis and tests of hardware

ROSES 2018 A.49 (amendment 22 Feb 2019)

- Select best approach and hardware for further risk reduction on instrumentation for OCI ocean color vicarious calibration
- Two selections with a down-select after 12 months
- 4 year horizon
- NOIs were due 26 March, proposal 23 May
- Completely open competition (US-based PI's); international collaborators welcome

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

2018	2019	2020	2021	2022	2023

today

one year test deployment, mistakes, etc.

one year site & system characterization

launch

Looking forward: a validation program

FY22 – FY25 (TBD): ROSES 2021 &

FY26 – FY28 (TBD): ROSES 2025

- Perform validation experiments during mission ops for all data products (aerosol, cloud, ocean color), including validation of polarimetry data products as possible
- Include airborne (as possible) and *in situ* measurements

International community (e.g., ESA, EUMETSAT, and the Copernicus Program) are investing in Fiducial Reference Measurements for Sentinel and **coordination is critical**

2018 2019 2020 2021 2022 2023

today

launch

one year of practice (VIIRS, OLCI, SGLI, etc.)

ongoing validation

Level 1 required (~threshold) products

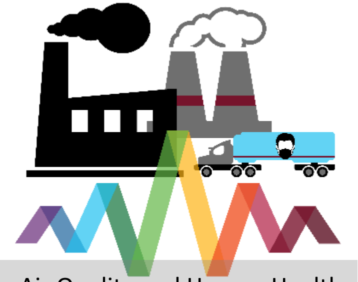
Water-leaving reflectance	Aerosol optical thickness
Chlorophyll-a	Aerosol fine mode fraction
Phytoplankton absorption	Liquid / ice cloud optical thickness
NAP+CDOM absorption	Liquid / ice cloud effective radius
Particulate backscattering	Cloud layer detection ($\tau < 0.3$)
Diffuse attenuation	Cloud 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 observation** 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

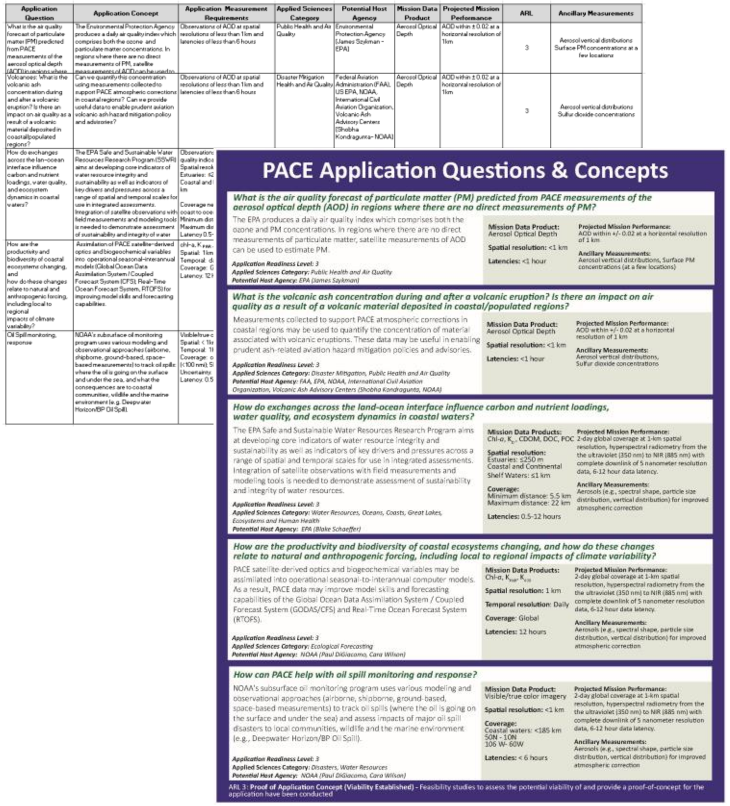
Describes the elements of the applications program for the project, its management, and deliverables from all Phases of the mission

PACE applications by development phase

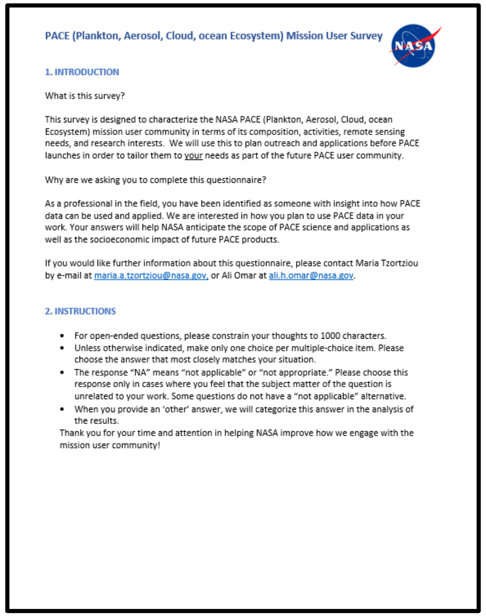
Mission Phase	Applications Activity
Pre-phase A	Assessment of the community of practice. Description of potential applications from the PACE data using the requirements established by the Science Definition Team (SDT).
Phase A	Applications website establishment. Database of user community individuals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

Applications Traceability Matrix

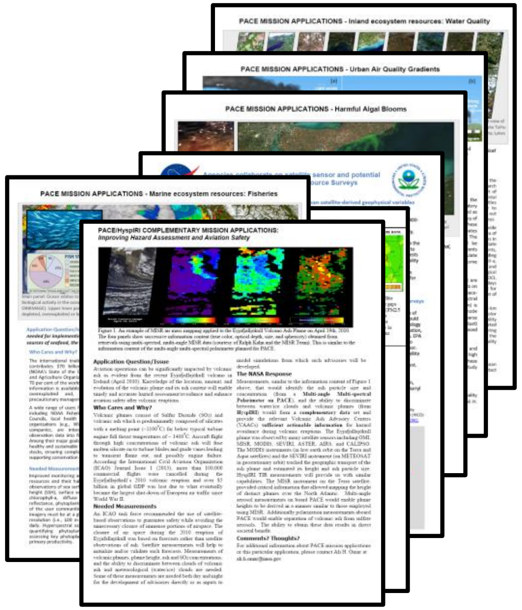
developed with input from the user community



PACE Community Survey



Applications White Papers



PACE Mission Applications - Contact Us:

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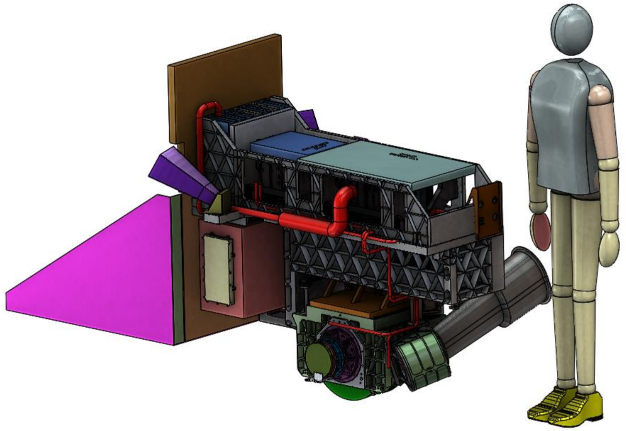
Instrument updates

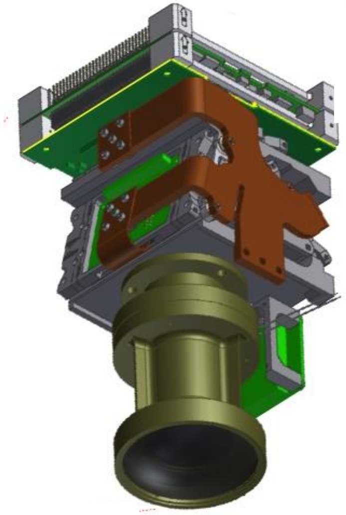
Plankton, Aerosol, Cloud and ocean Ecosystem (PACE) Instruments

(Primary) Ocean Color Instrument (OCI)

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

- Preliminary design review (PDR): Mar 2018
- Critical design review (CDR): Dec 2019





Hyper Angular Rainbow Polarimeter 2 (HARP2)

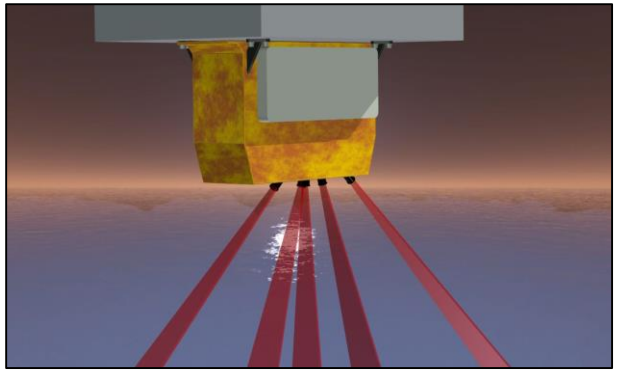
wide-swath multi-angle polarimeter, hyper-angle capability

- PDR: Aug 2018
- CDR: Apr 2019

Spectro-Polarimeter for Planetary Exploration (SPEXone)

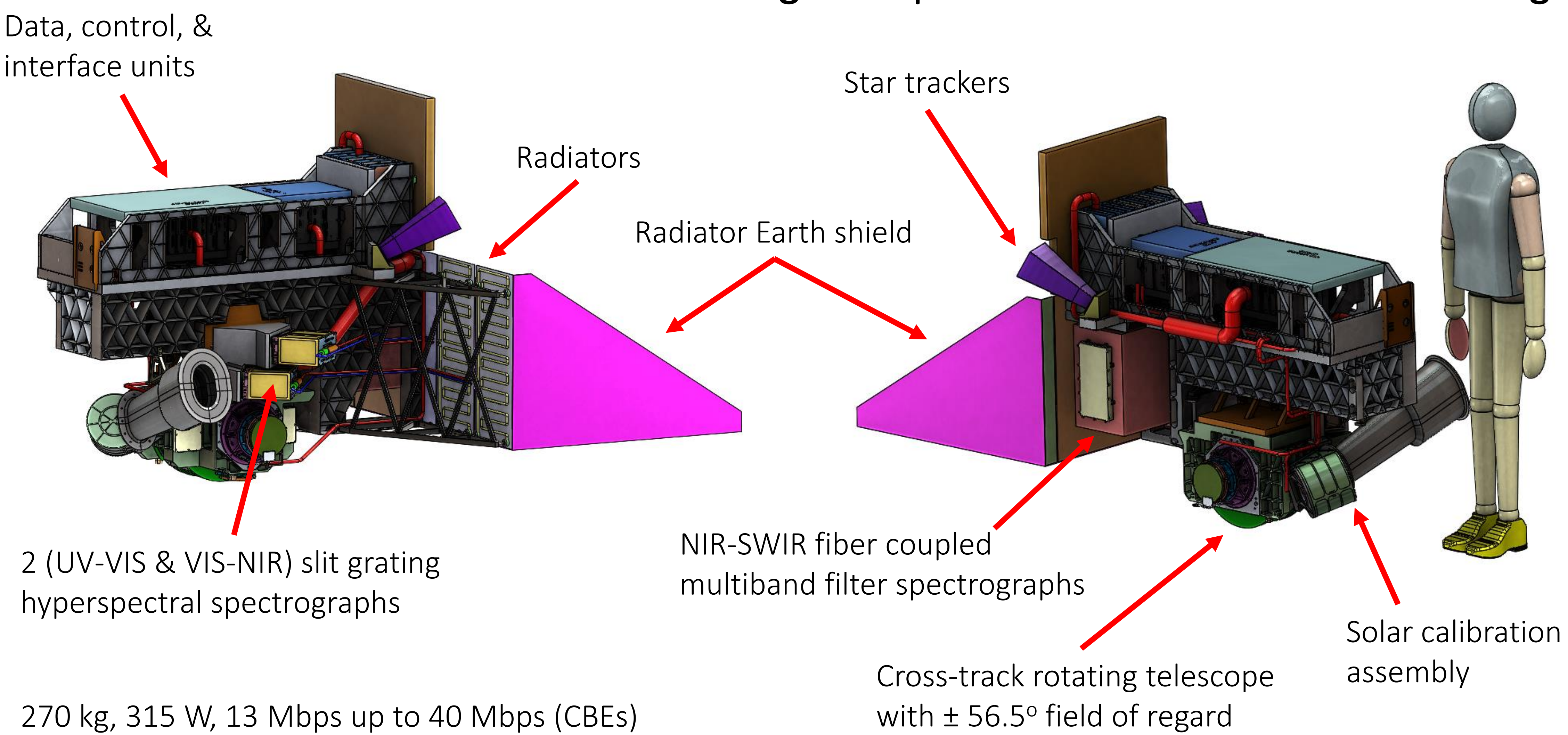
narrow-swath multi-angle polarimetric spectrometer

- PDR: Jul 2018
- CDR: Feb 2019



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

SPEXone and HARP-2 are ‘**contributed**’ instruments

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

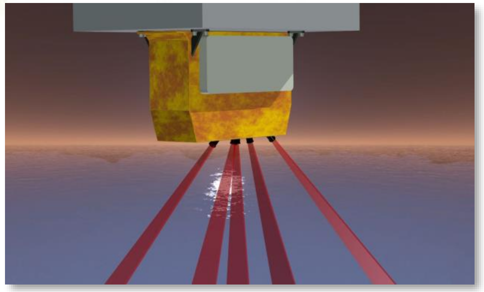
No requirements for successful data collection or science

Both originally designed as cubesat scale instruments

And, they will provide an excellent proof of concept for atmospheric correction, aerosol, & cloud retrievals

Polarimetry on PACE

Two cubesat-sized *contributed* instruments

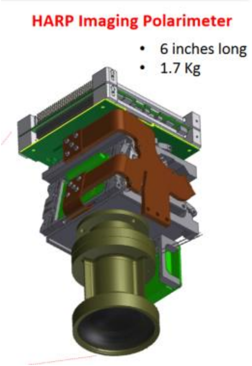


Spectro-Polarimeter for Planetary Exploration (SPEXone)

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

POC: Otto Hasekamp

Hyperspectral (UV) + narrow swath + high accuracy



Hyper Angular Rainbow Polarimeter (HARP-2)

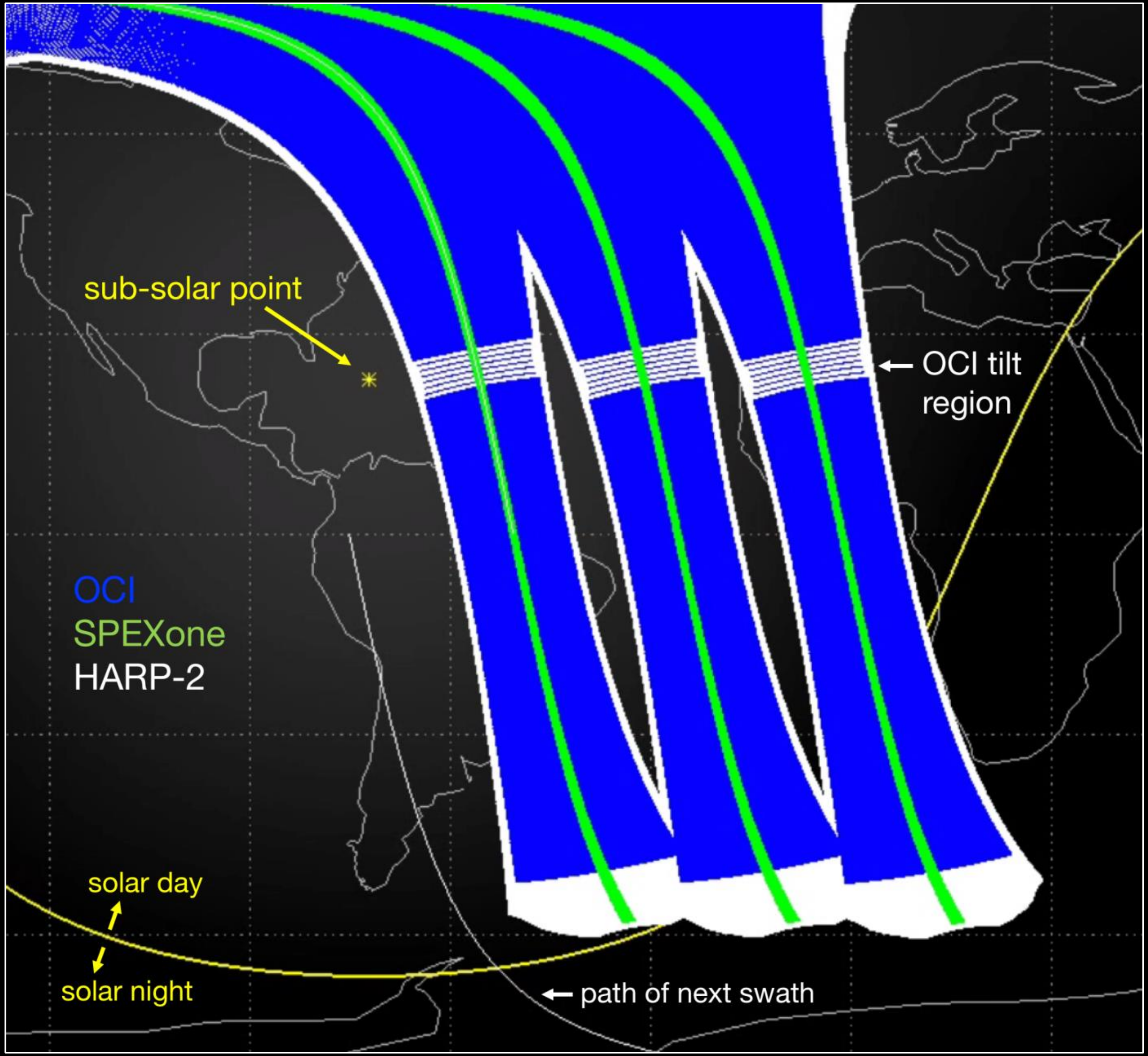
Contribution from University of Maryland Baltimore County

POC: Vanderlei Martins

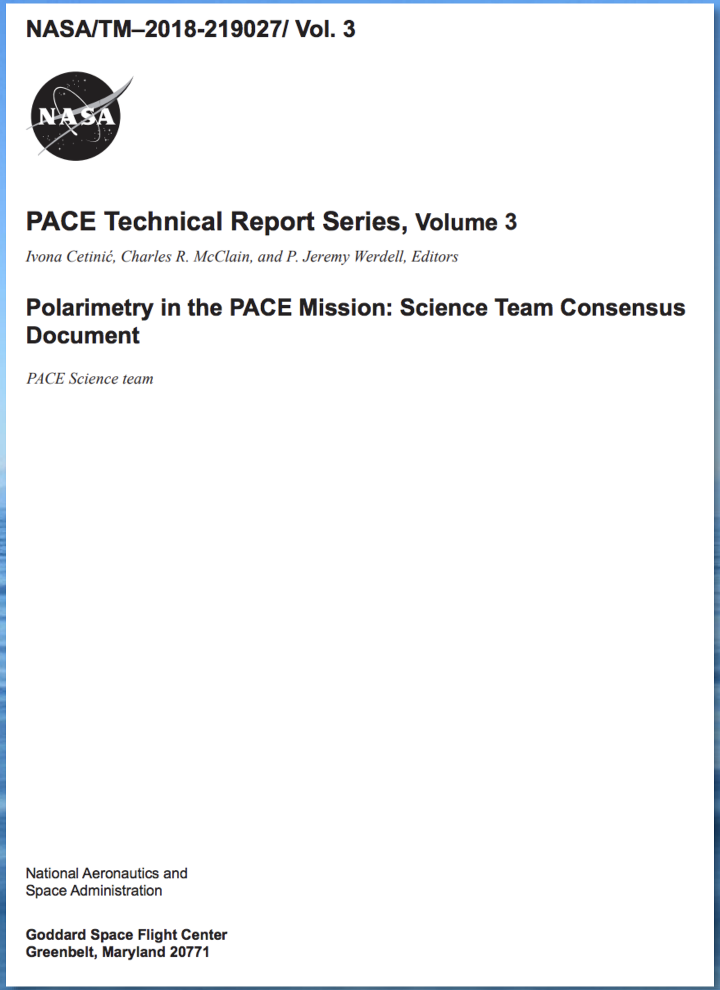
Hyperangular + wide swath

	SPEXone	HARP-2
Spectral range (resolution)	385-770 nm (continuous @ 5 nm)	440, 550, 670 nm (10) + 870 nm (40 nm)
Polarized bands	385-770 nm (continuous @ 15-45 nm)	All
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); 30+ day global cov.	94° (1556 km at nadir); 2 day global coverage
Ground sample distance	2.5 km^2	3.0 km^2
Heritage	AirSPEX, SPEX/ASPIM	AirHARP, cubesat HARP for ISS

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



Learn more about PACE



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

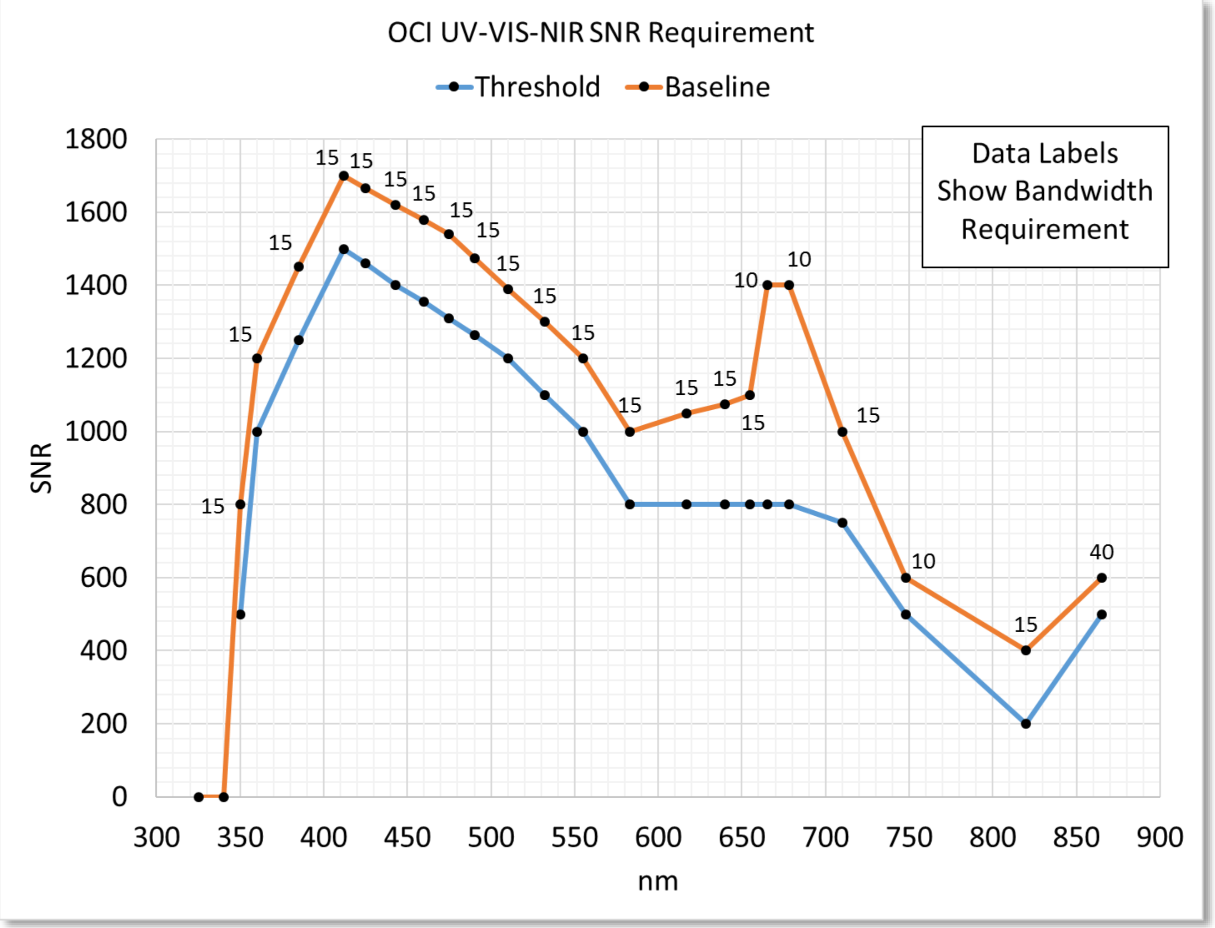
National Aeronautics and
Space Administration

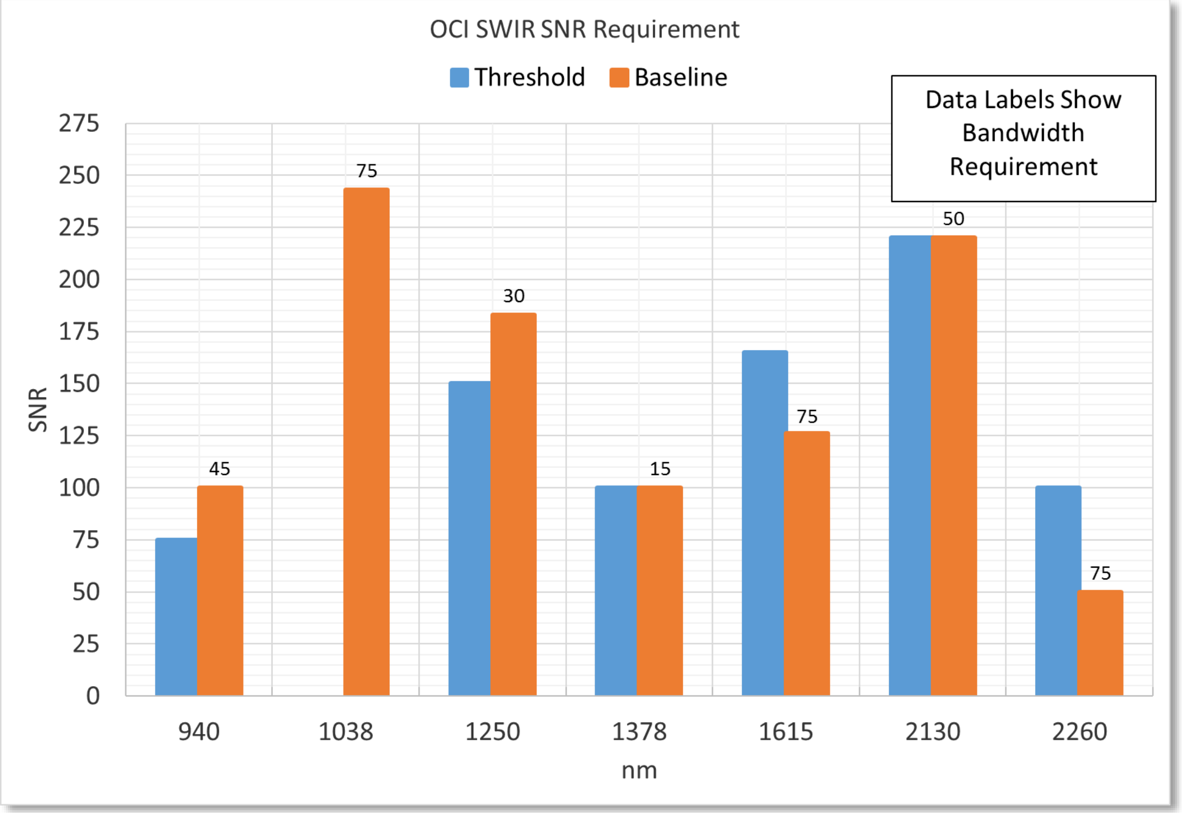
Goddard Space Flight Center
Greenbelt, Maryland 20771

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

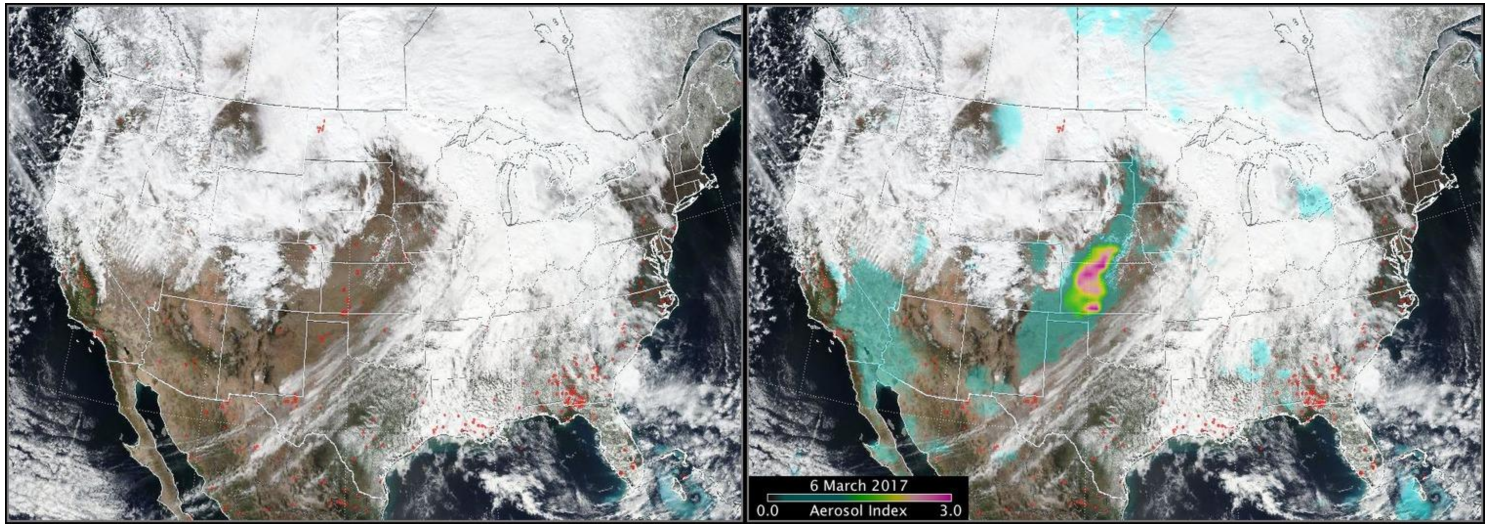
backup

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





OCI atmospheric improvements over heritage

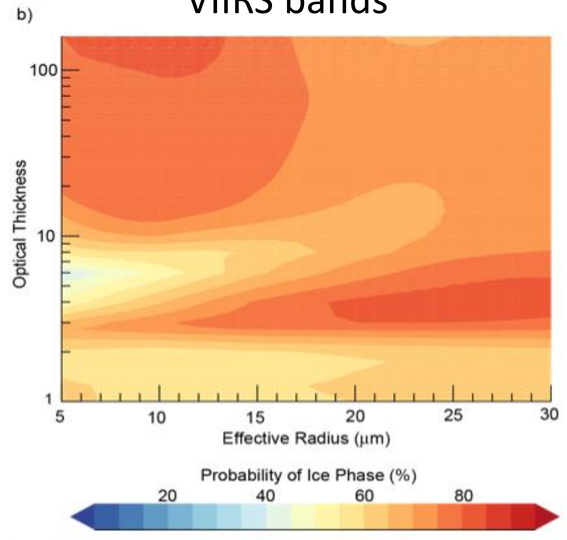


VIIRS RGB + OMPS Aerosol Index

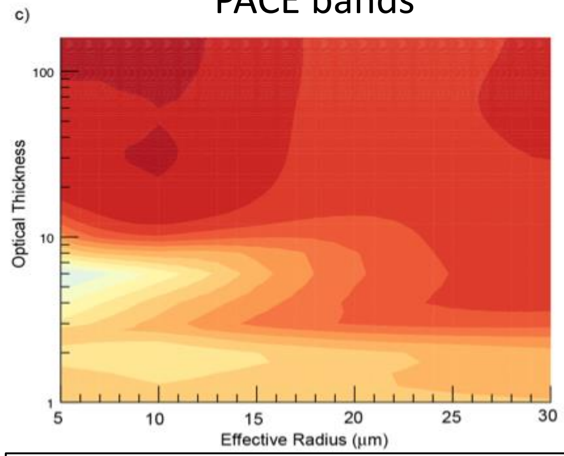
1 km resolution at nadir from UV to SWIR

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

VIIRS bands

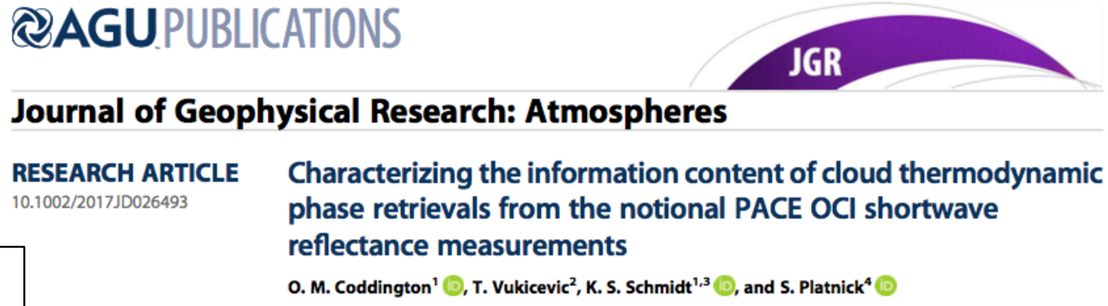


PACE bands



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

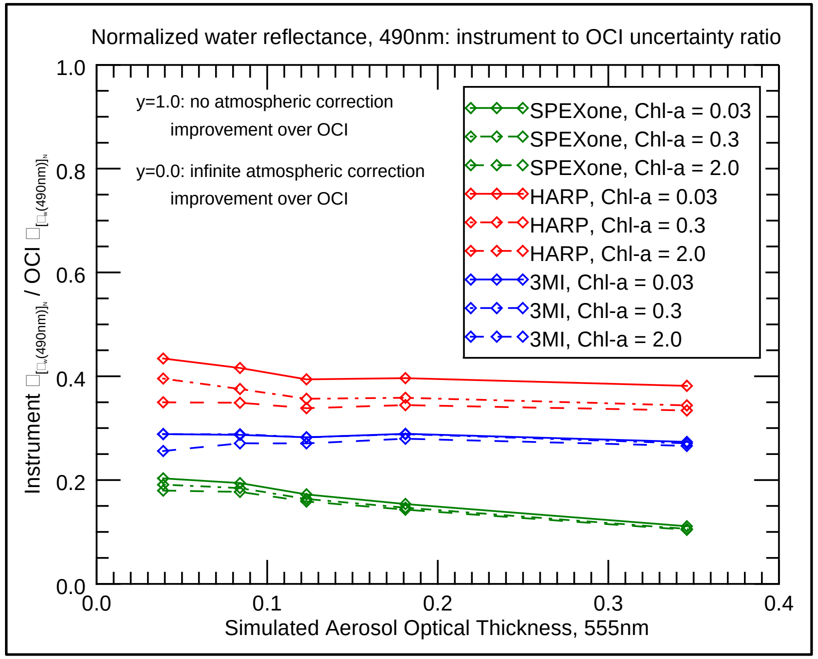
O. M. Coddington[1], T. Vukicevic[2], K. S. Schmidt[1,3], and S. Platnick[4]

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

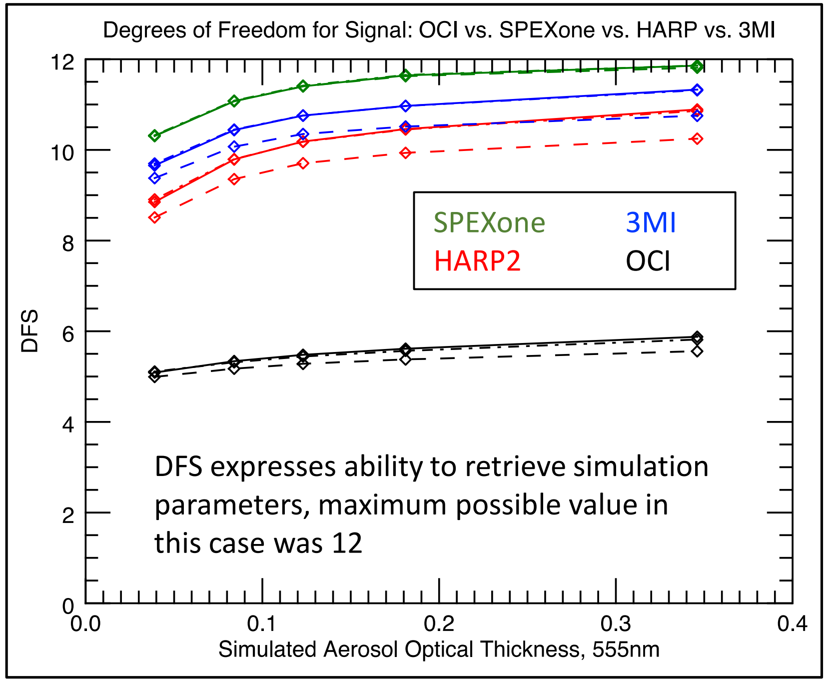


Atmospheric correction improvement

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.

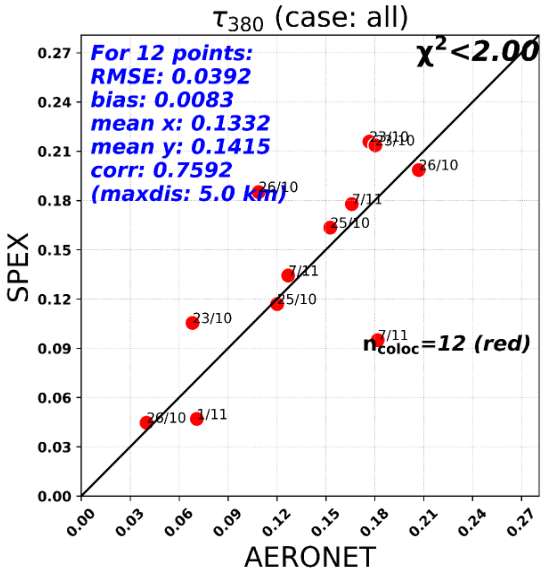
Operational algorithms must be created to exploit this information.

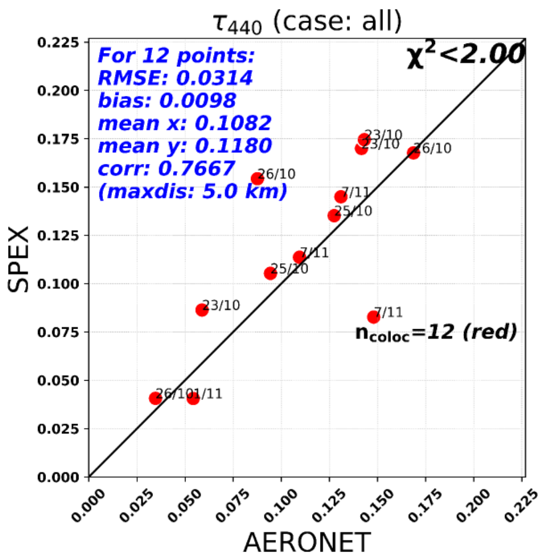
How will PACE polarimeters perform?

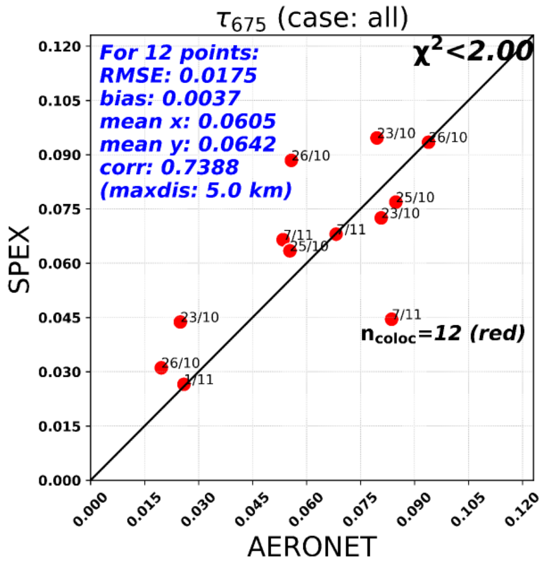
SPEXone:

Example aerosol retrievals from SPEXAirborne during ACEPOL

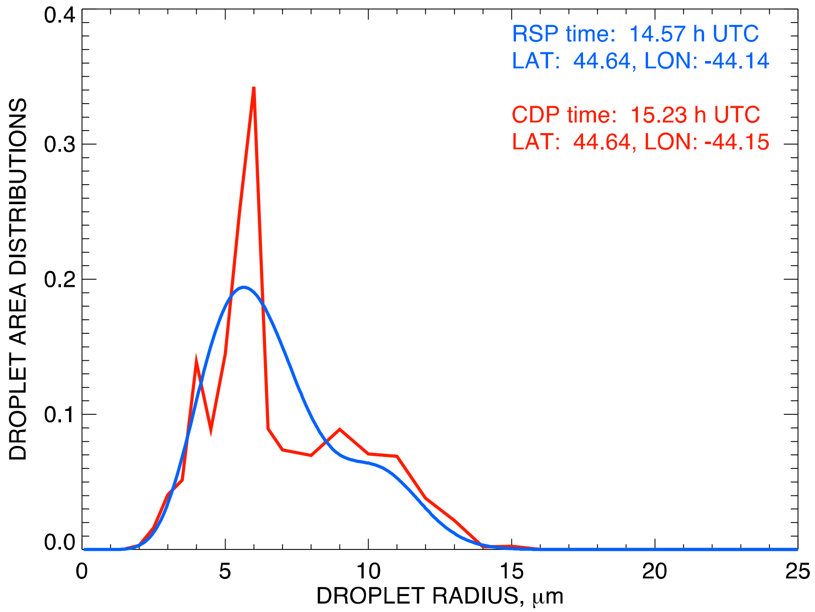
Hasekamp et al. AGU 2018







HARP2: Examples of what a hyperangular capability provides

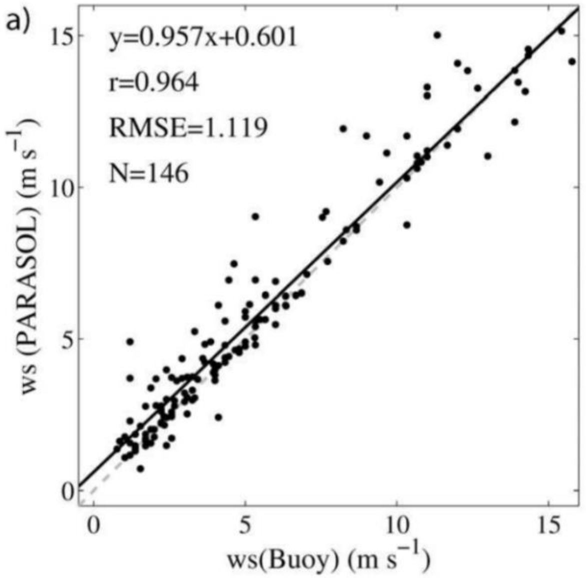


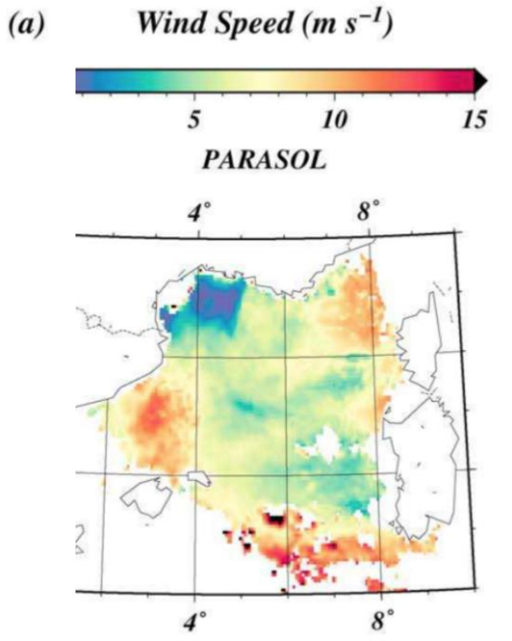
Droplet size distributions

Alexandrov et al. 2018

Wind speeds

Harmel and Chami 2012





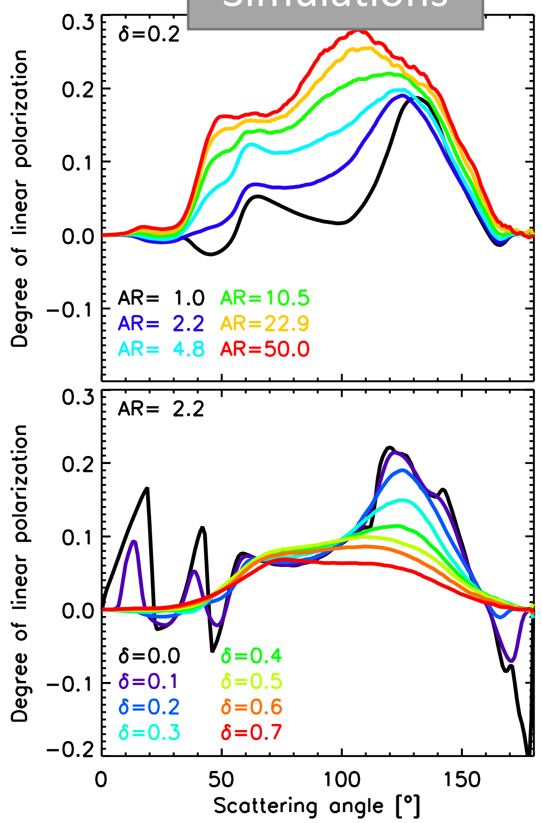
How will PACE polarimeters perform?

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)

Simulations



2007 POLDER+MODIS results