The SPEXone Instrument for the NASA PACE Mission

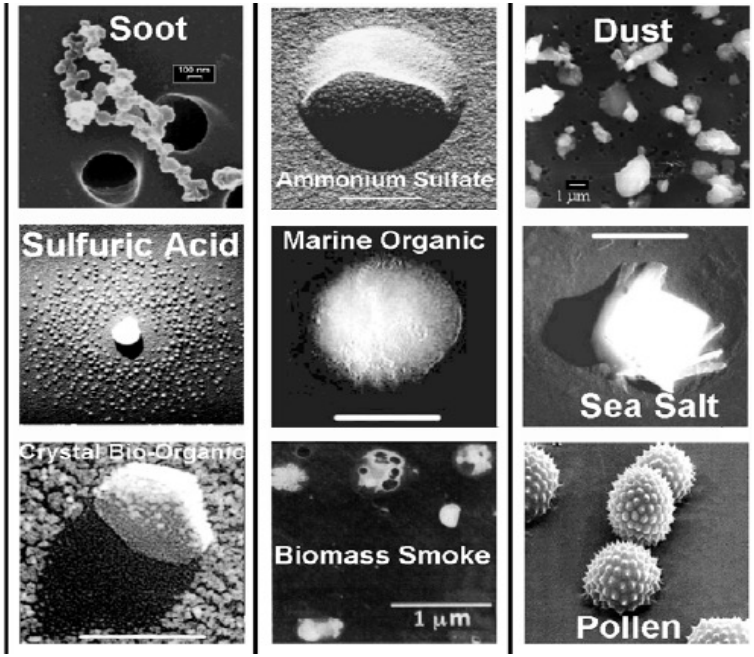
Netherlands Institute for Space Research

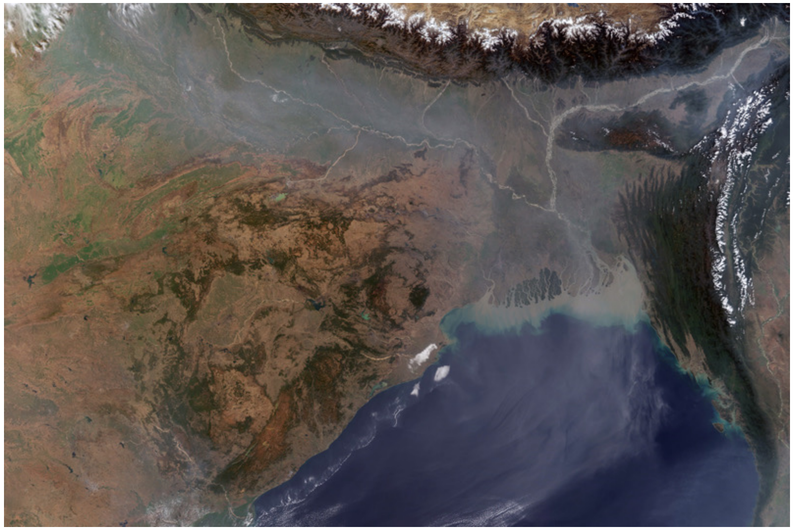
Netherlands Organisation for Scientific Research (NWO)

SPEXONE SCIENCE CASE

Atmospheric Aerosol

Aerosols: Small Particles in the Air



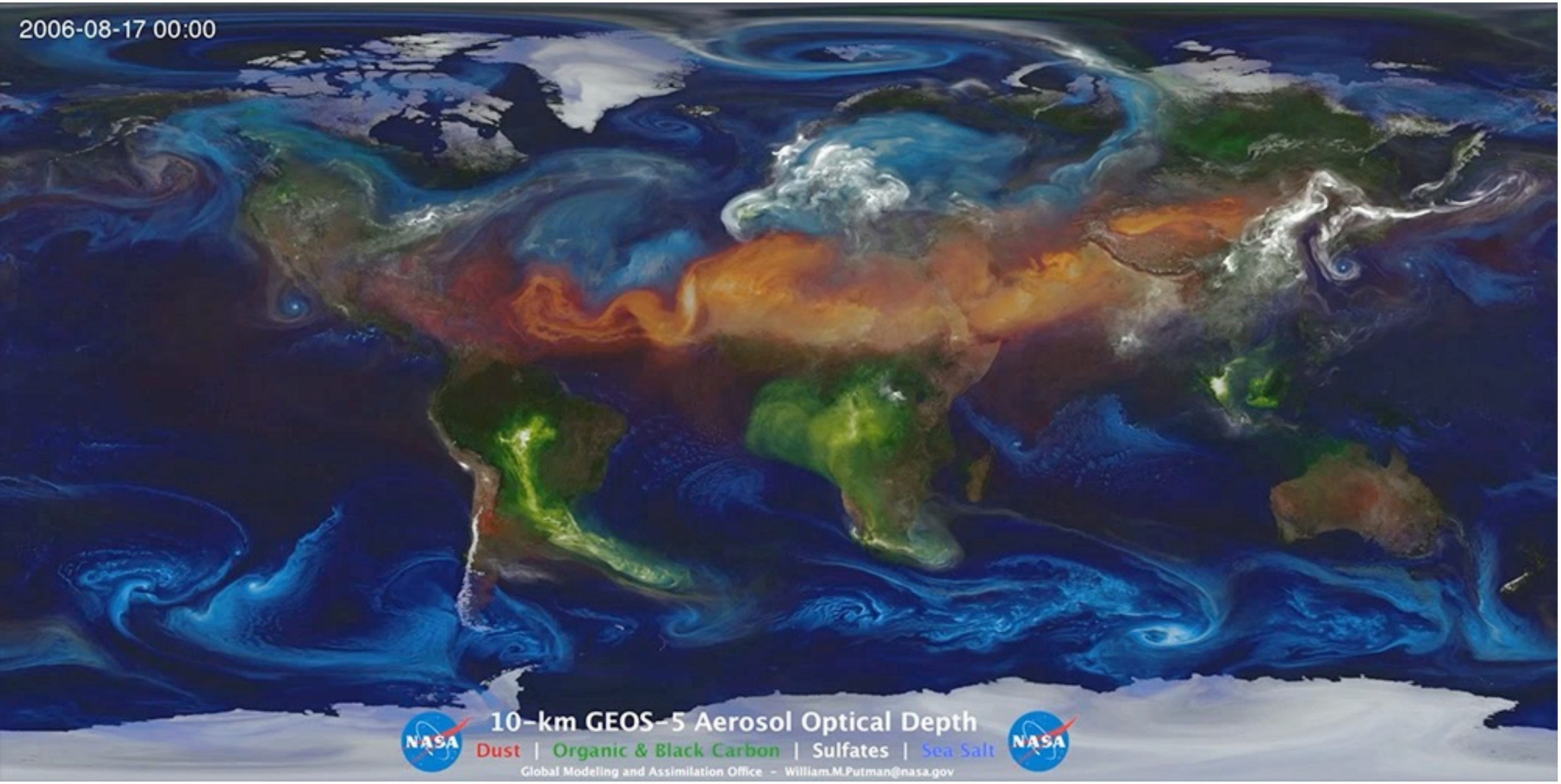


Aerosol Sources

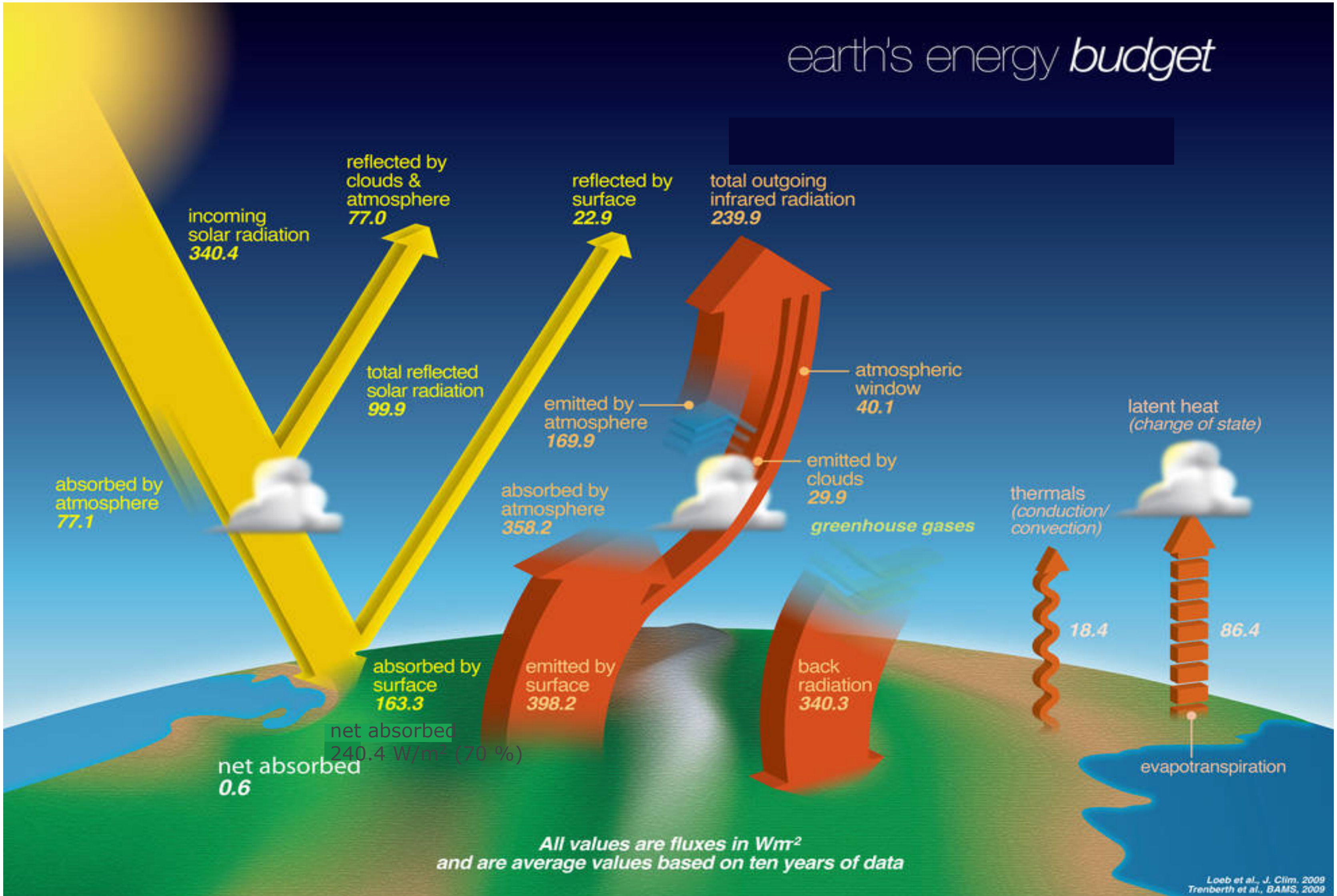




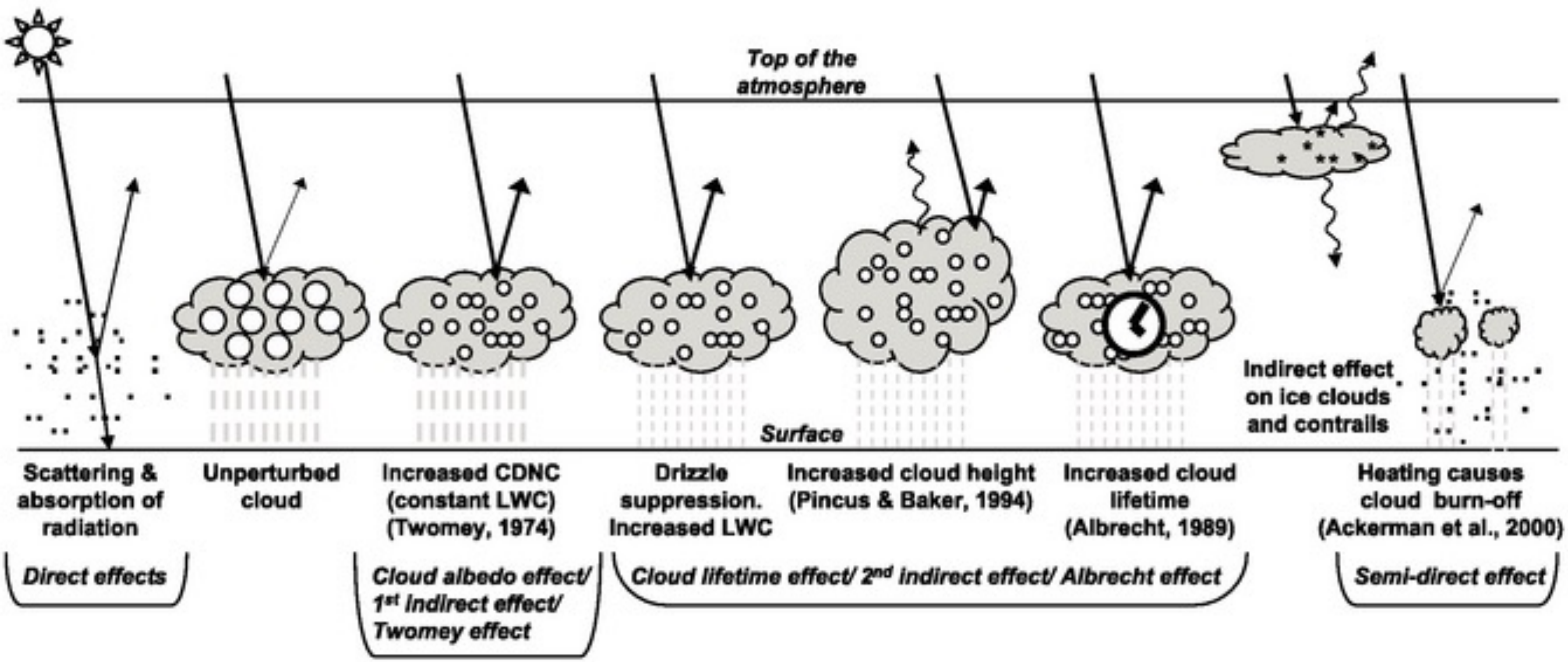

Atmospheric Transport of Aerosols



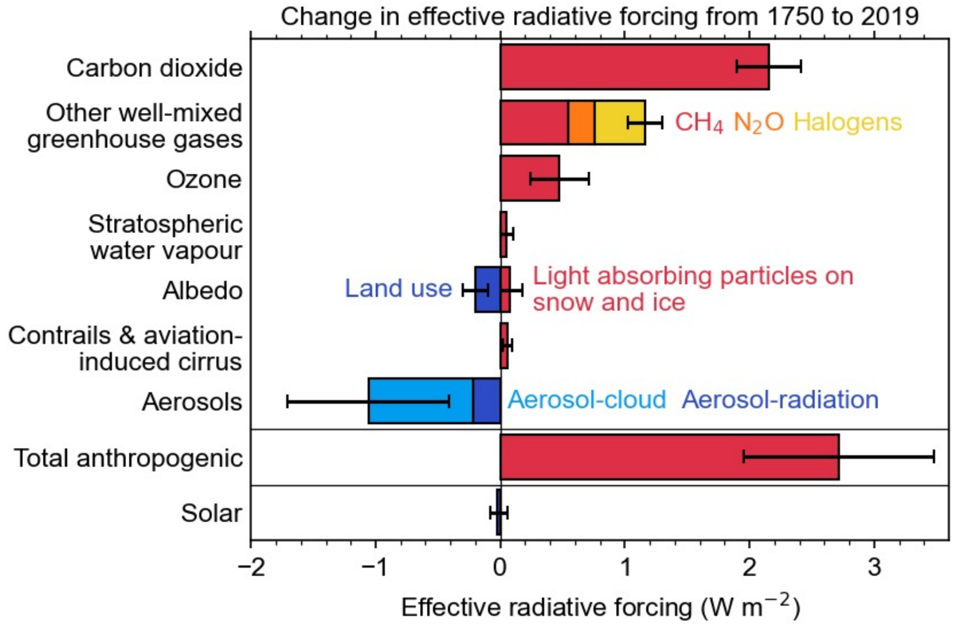
The Earth Energy Budget

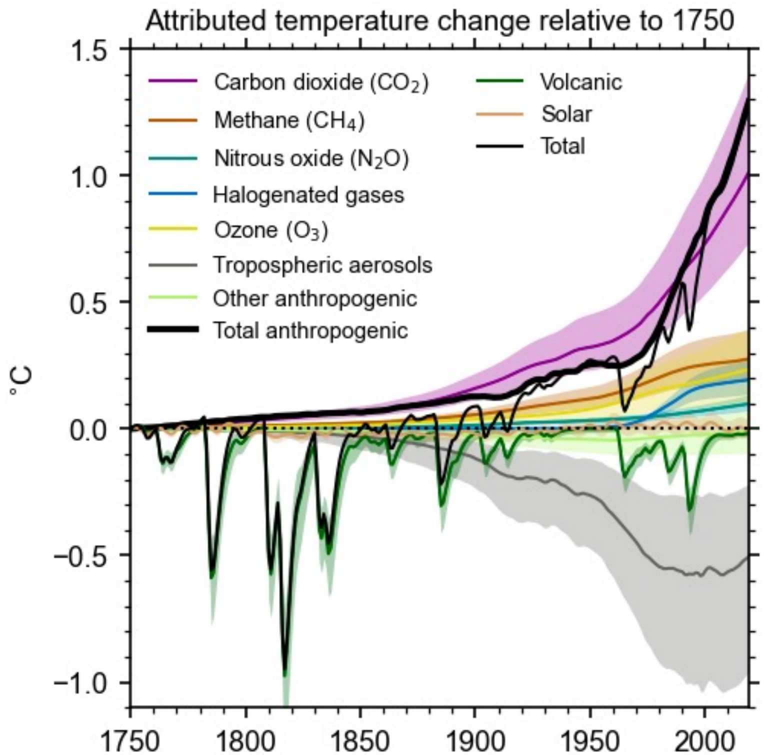


Aerosol Effects on Climate



Contributions to Climate Change





- Aerosols represent the largest uncertainty on the effective radiative Forcing.
- SPEXone is designed to provide improved aerosol observations.
- In synergy with the other instruments of PACE it is expected that the radiative forcing can be better quantified.

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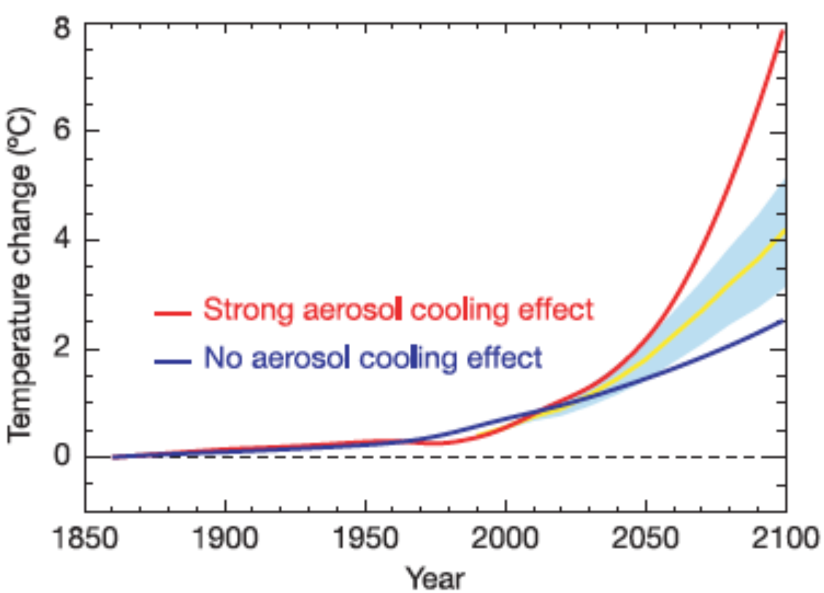
Implications aerosol radiative forcing uncertainty?

Vol 435|30 June 2005|doi:10.1038/nature03671 nature

Strong present-day aerosol cooling implies a hot future

Meinrat O. Andreae[1], Chris D. Jones[2] & Peter M. Cox[3]



Climate sensitivity

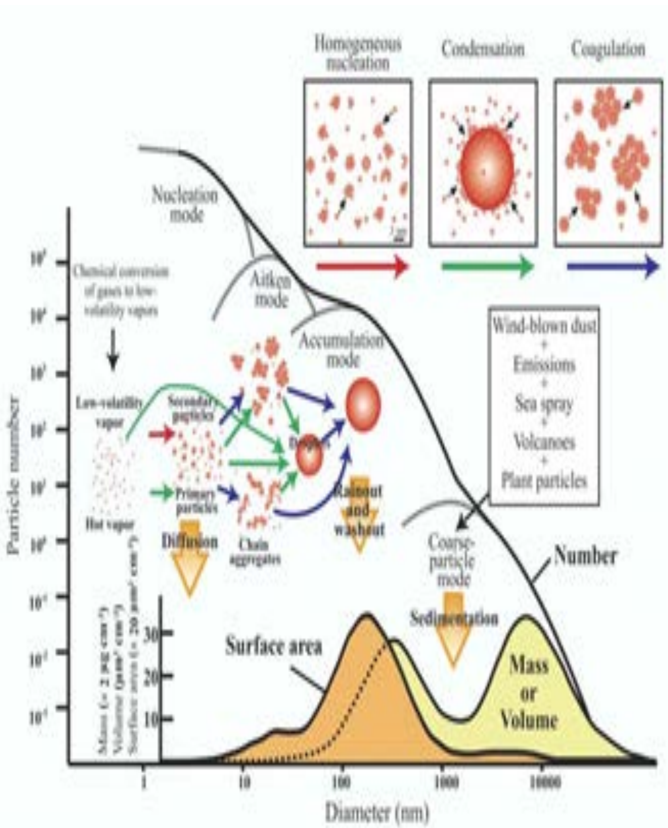
$\lambda = \Delta T / (\Delta F_{ghg} + \Delta F_{aer})$ (past ΔT)

The more negative ΔF_{aer} the larger λ.

$\Delta T = \lambda * (\Delta F_{ghg} + \Delta F_{aer})$ (future ΔT)

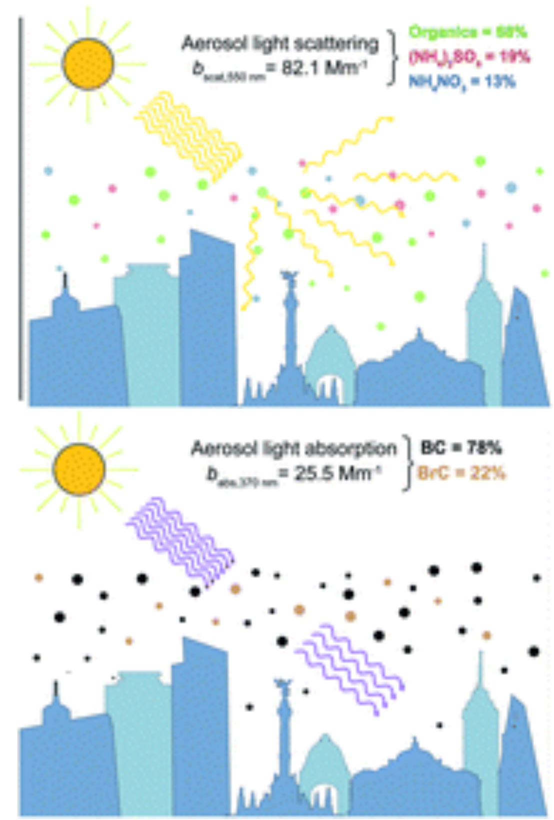
Aerosol Properties

Microphysical properties:
- ✓ Size distribution
- ✓ Shape
- ✓ Composition (refractive index)



Optical Model
(Mie / T-Matrix)

Optical properties:
- ✓ Aerosol Optical Depth (AOD) → total extinction (scattering+absorption)
- ✓ Single Scattering Albedo (SSA) → scattering / (scattering+absorption)
- ✓ Scattering Phase Matrix



Why is Aerosol Radiative Forcing so Uncertain?

We do not know how aerosols affect clouds (how much brighter, do they live longer, do they contain more or less water?) --> main uncertainty

- SPEXone will provide a better characterisation of aerosol properties that determine the suitability to act as Cloud Condensation Nuclei (CCN)
- In combination with improved cloud properties from HARP-2 and OCI this will help to better understand the effect of aerosol on clouds

We do not know what the balance is between scattering and absorption of solar radiation by aerosols.

- SPEXone will measure scattering and absorption properties of aerosol

We do not know present and pre-industrial aerosol properties and emission sources.

- SPEXone will measure properties that relate to aerosol composition (e.g. refractive index or derived quantities). This will help to quantify aerosol emission sources (in a data assimilation system) and link them to radiative forcing

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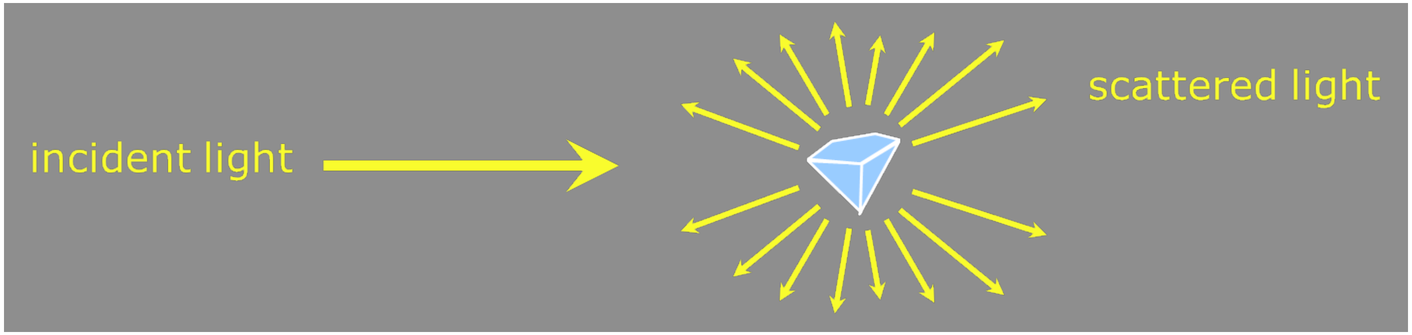
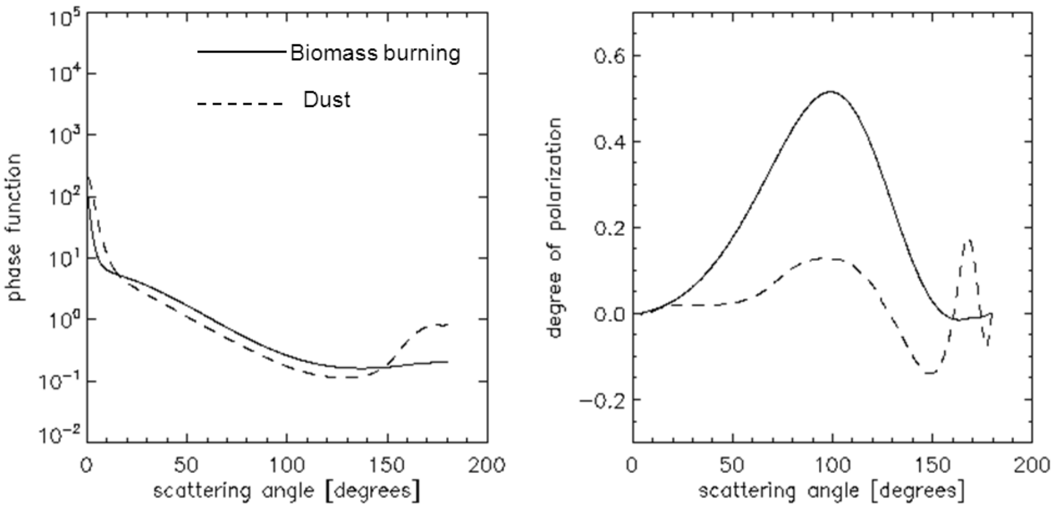
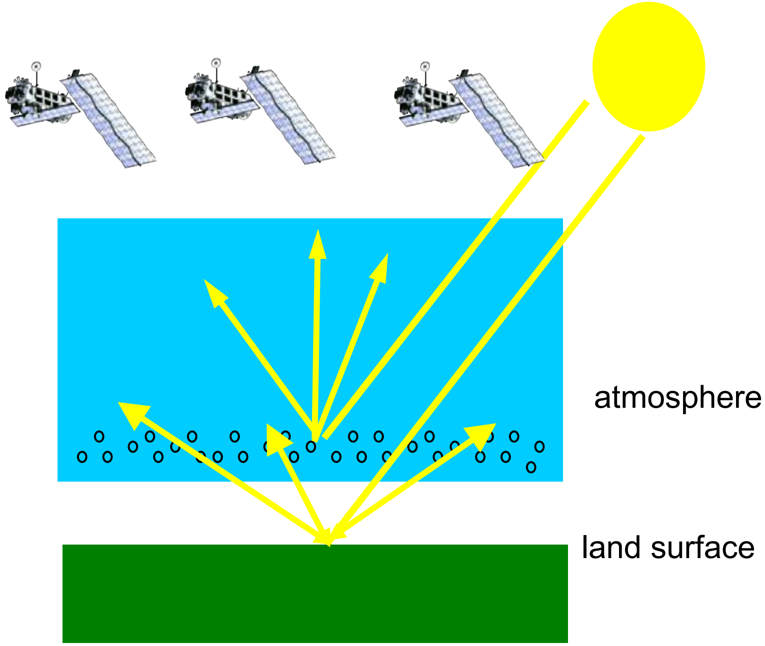
AEROSOL POLARIMETRY WITH SPEXONE

How to Best Measure Aerosol Properties with a satellite?

Measure the intensity and Degree of Polarization of scattered light as a function of scattering angle and wavelength







Polarimeters in Space

2005 2013 2024 2025 2026

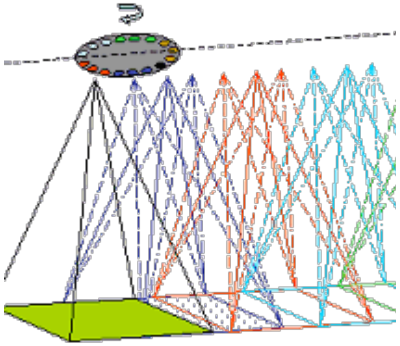
POLDER-3

PACE

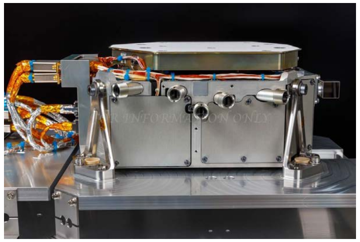
3MI

MAP/CO2M

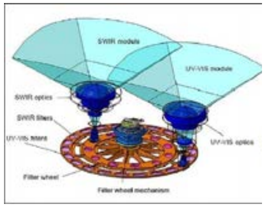
>10 year GAP!

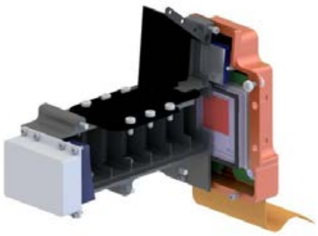


SPEXone – PACE

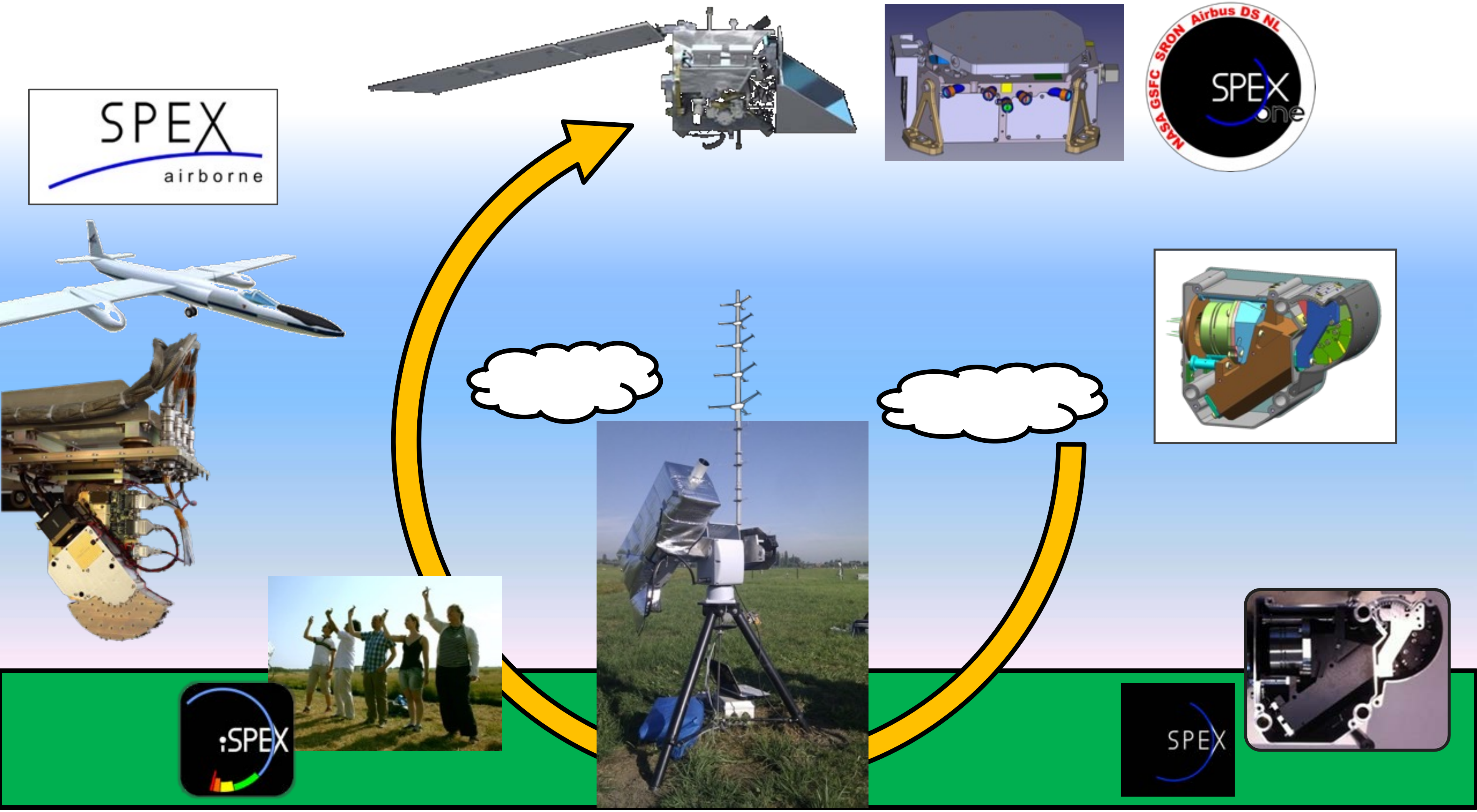


HARP2 – PACE





Breadboard - Ground-Based – Airborne - Satellite



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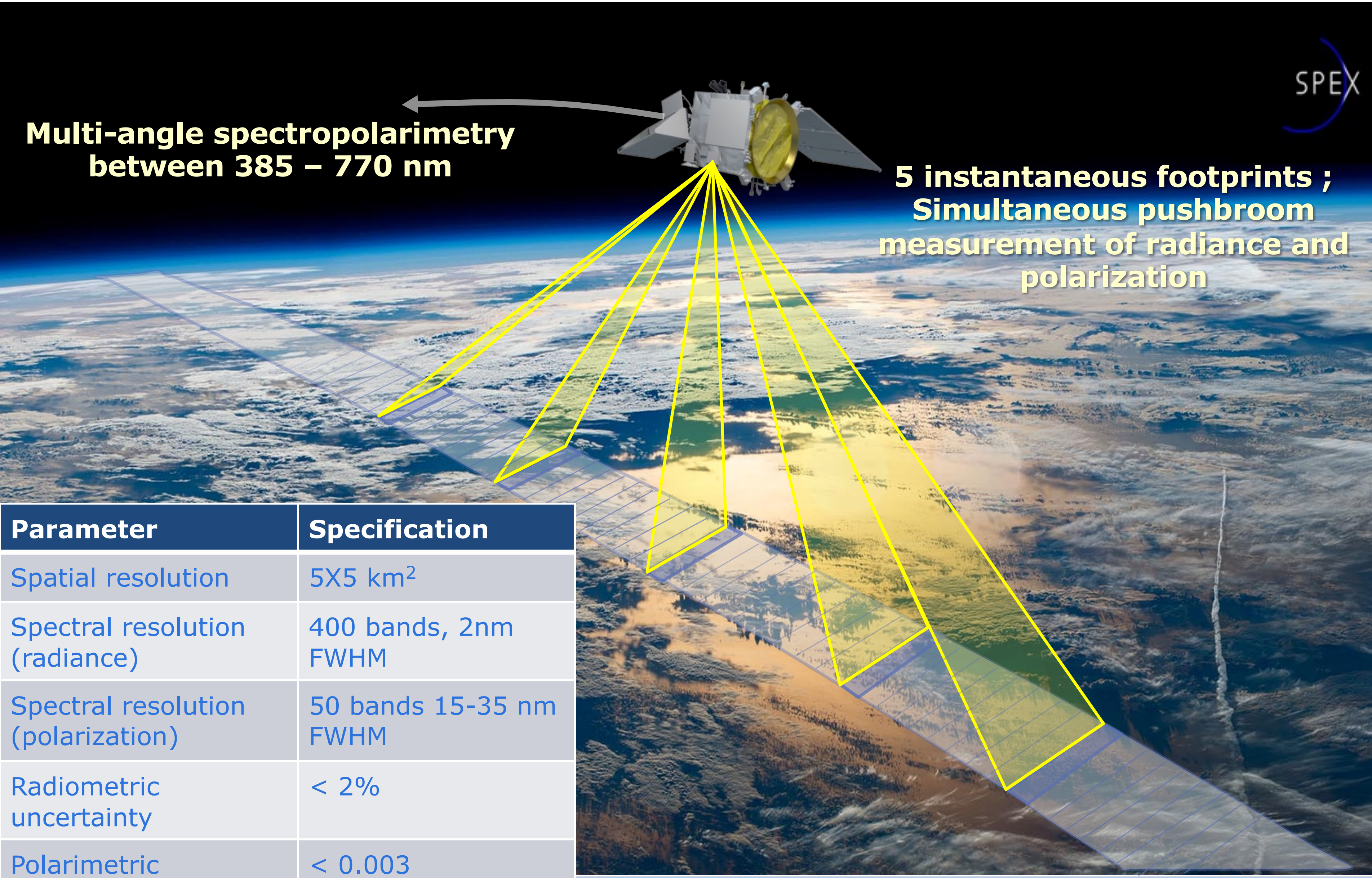
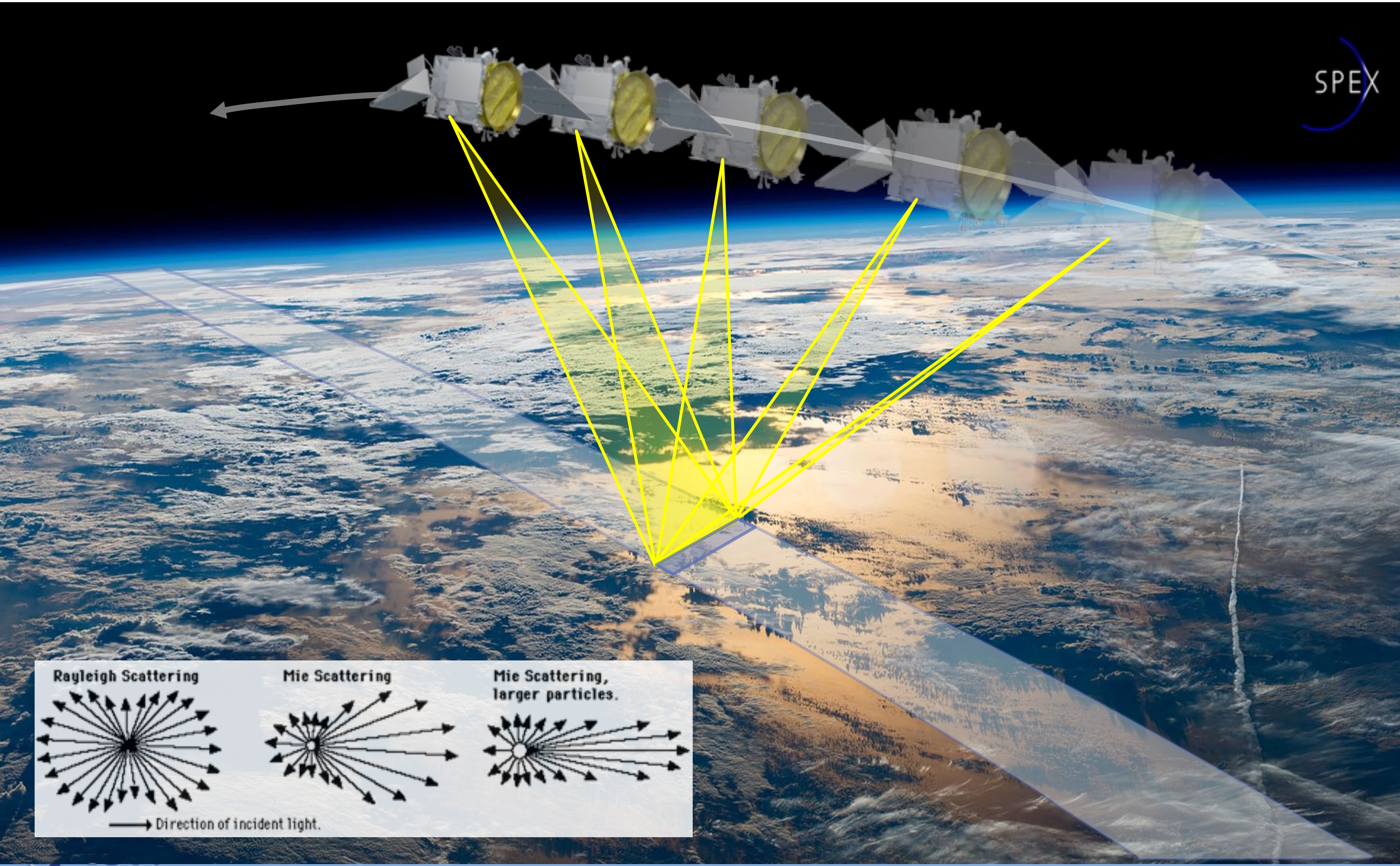
SPEXone Characteristics

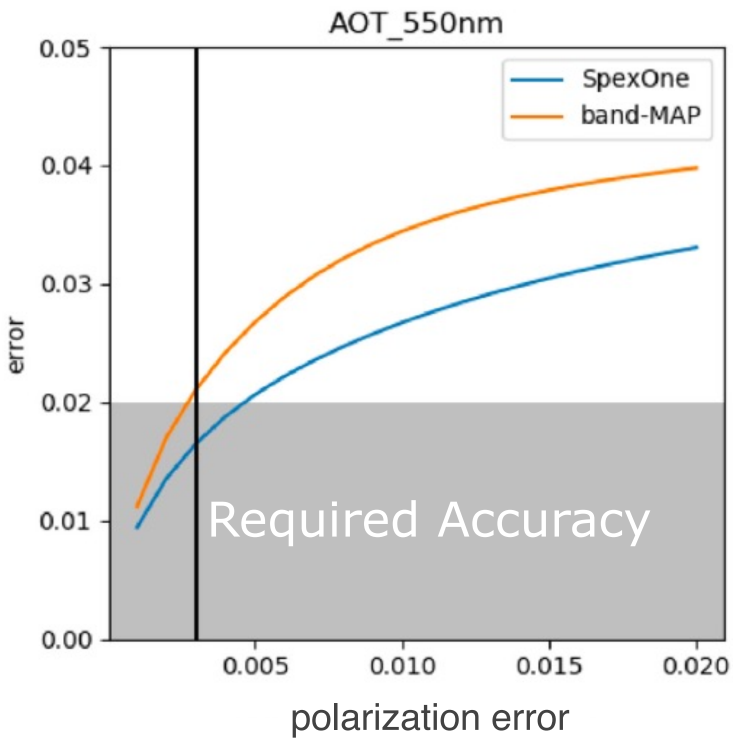


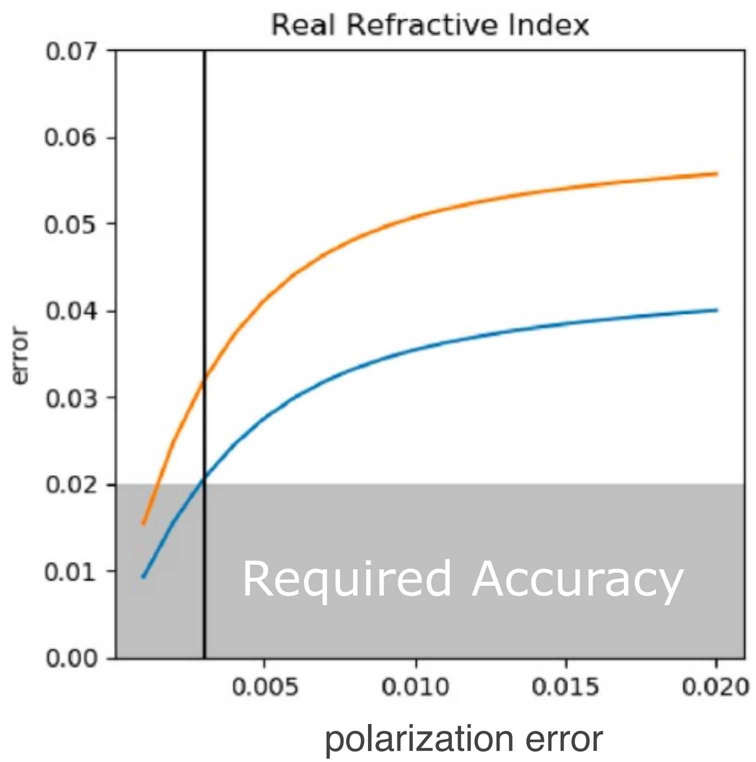
Parameter	Specification
Spatial resolution	5X5 km^2
Spectral resolution (radiance)	400 bands, 2nm FWHM
Spectral resolution (polarization)	50 bands 15-35 nm FWHM
Radiometric uncertainty	< 2%
Polarimetric uncertainty	< 0.003

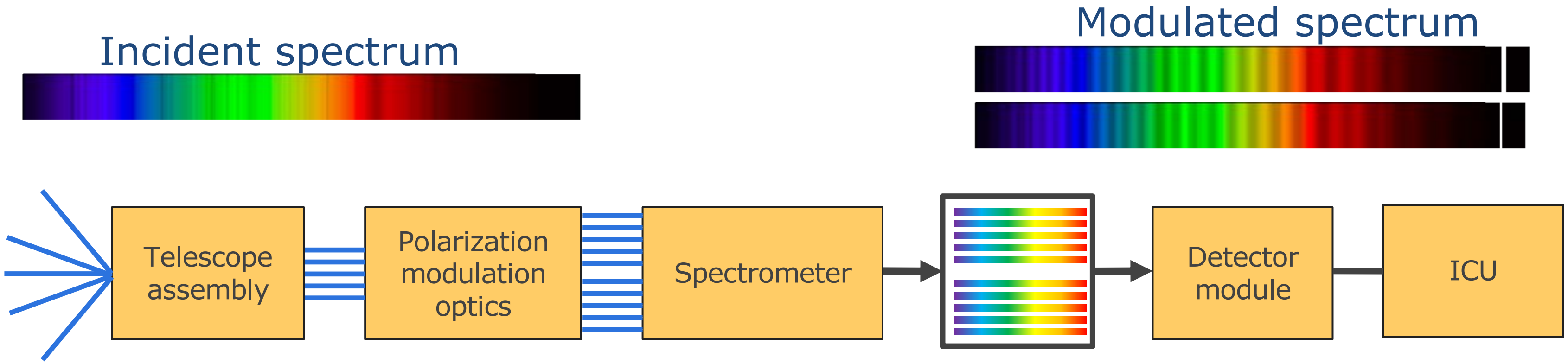
Combining Viewing Angles



Polarization Accuracy is Important





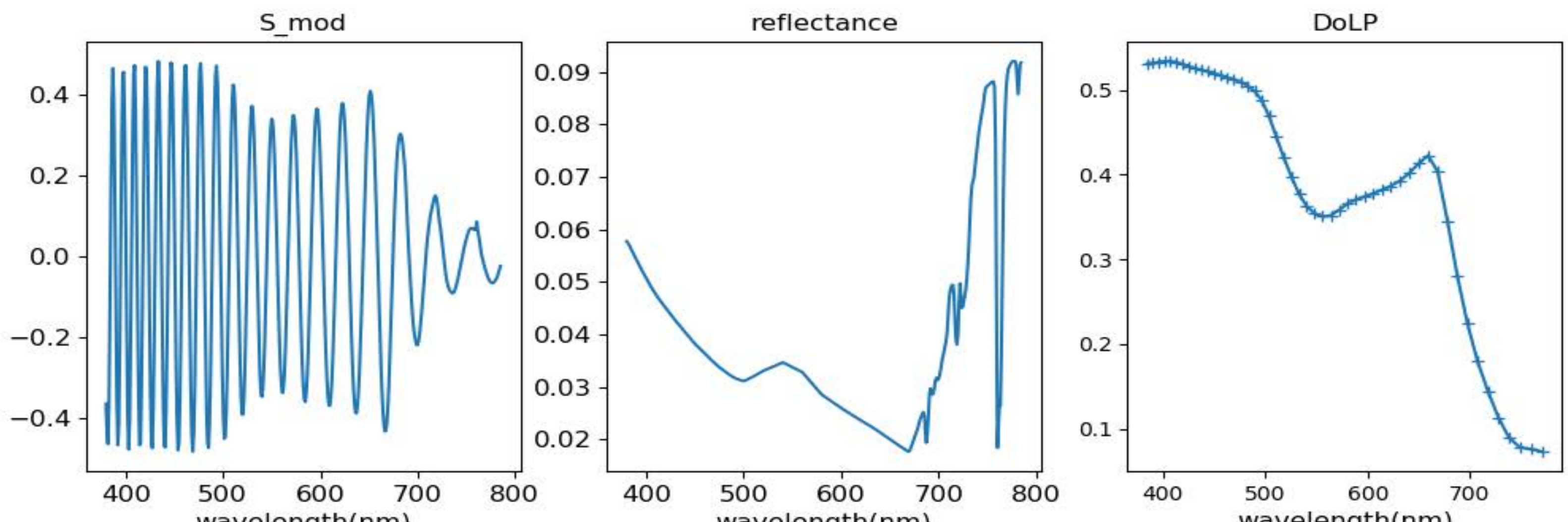


$$S_{+}(\lambda) = \frac{\mathrm{I}(\lambda)}{2}\left(1 + P(\lambda)\cos\left[\frac{2\pi\delta(\lambda)}{\lambda} + 2\varphi(\lambda)\right]\right)$$

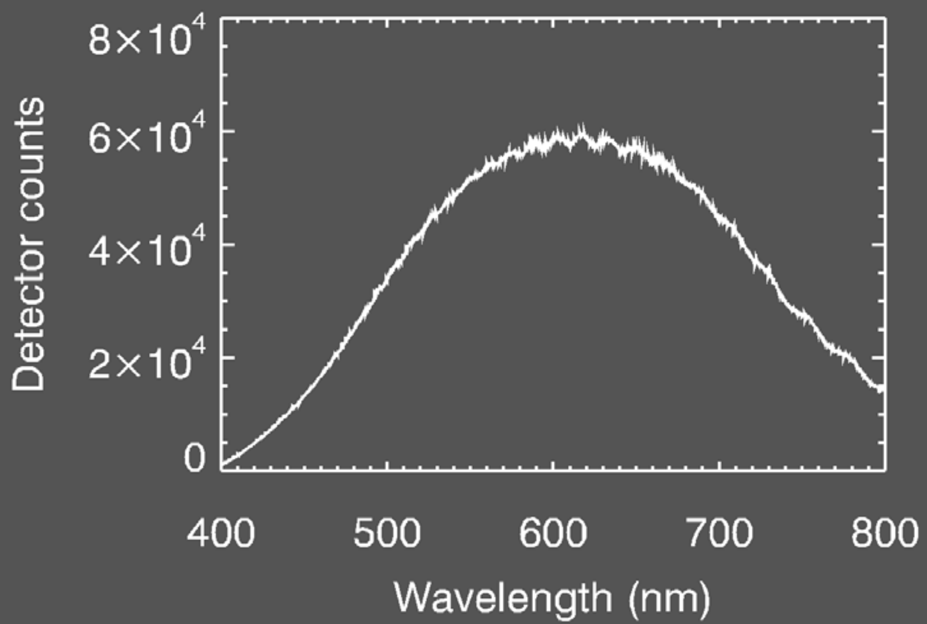
$$S_{-}(\lambda) = \frac{\mathrm{I}(\lambda)}{2}\left(1 - P(\lambda)\cos\left[\frac{2\pi\delta(\lambda)}{\lambda} + 2\varphi(\lambda)\right]\right)$$

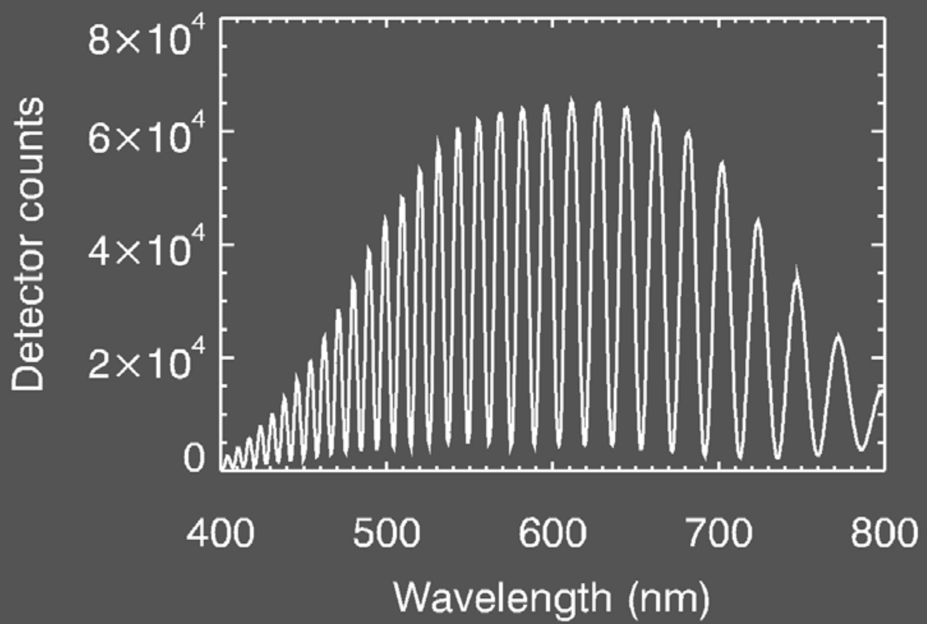
$$S_{mod} = \frac{(S_{+}(\lambda)-S_{-}(\lambda))}{(S_{+}(\lambda)+S_{-}(\lambda))} = P(\lambda)\cos\left[\frac{2\pi\delta(\lambda)}{\lambda} + 2\varphi(\lambda)\right]$$

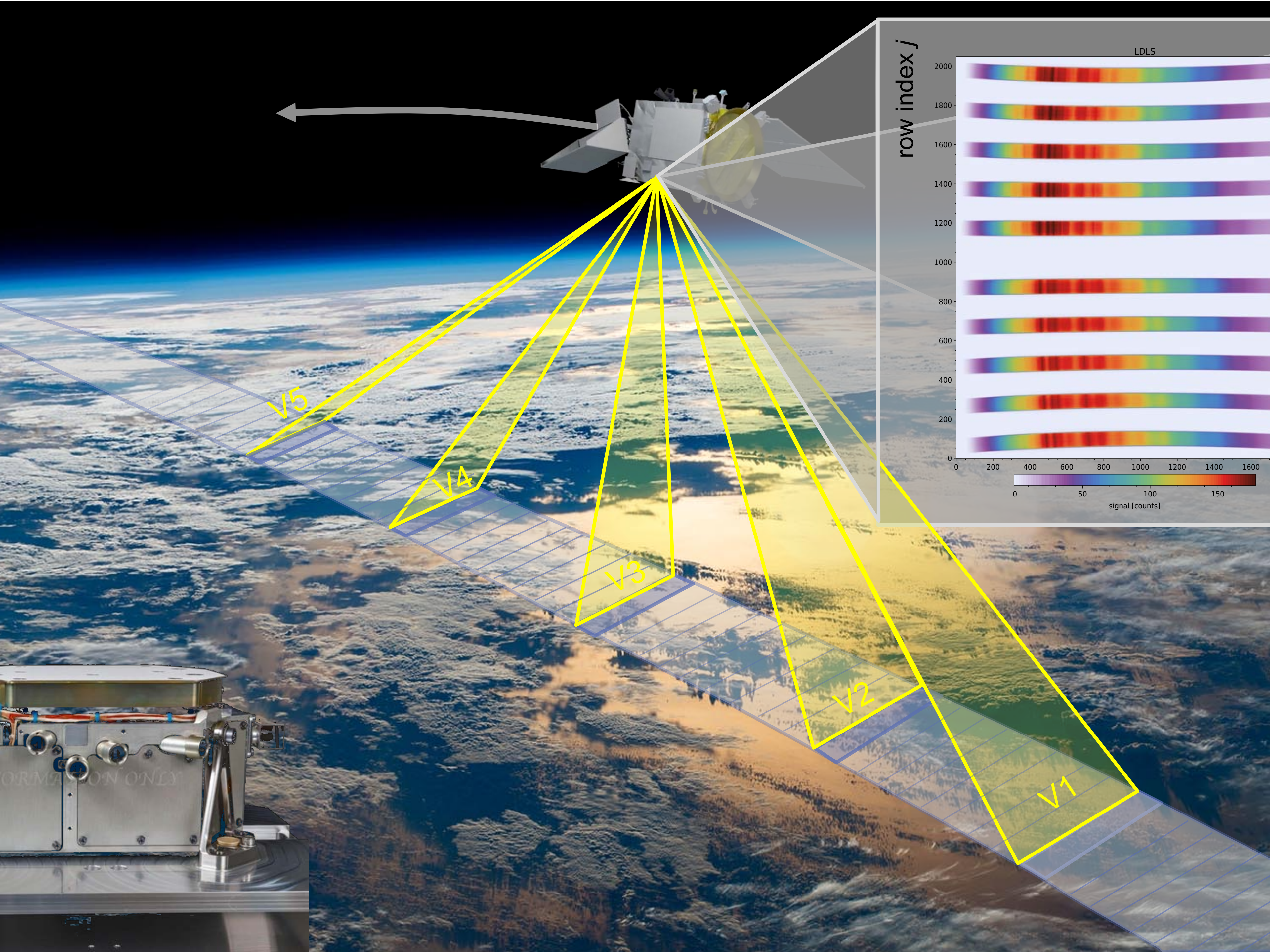
➡ amplitude proportional to P

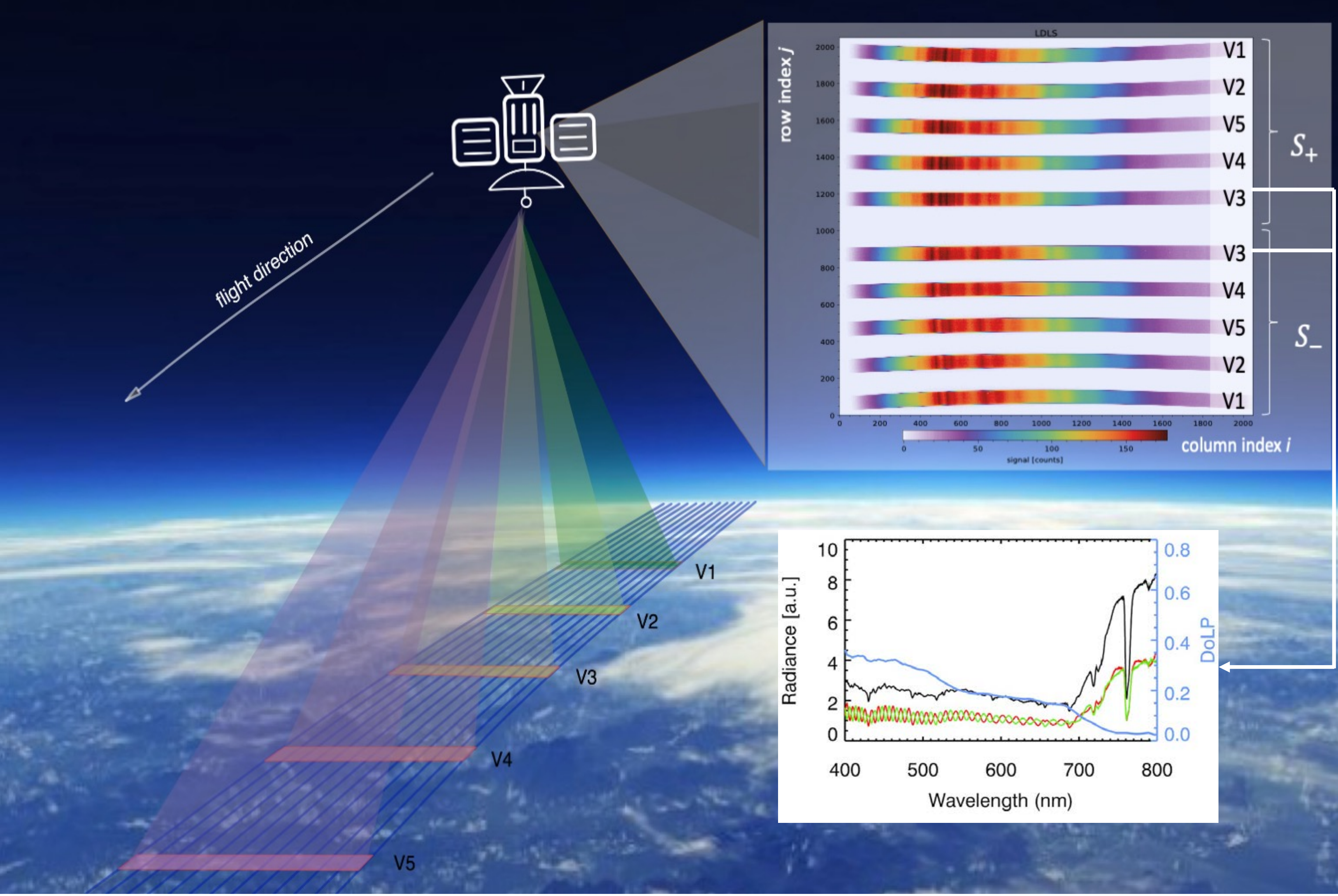


Modulated Spectra



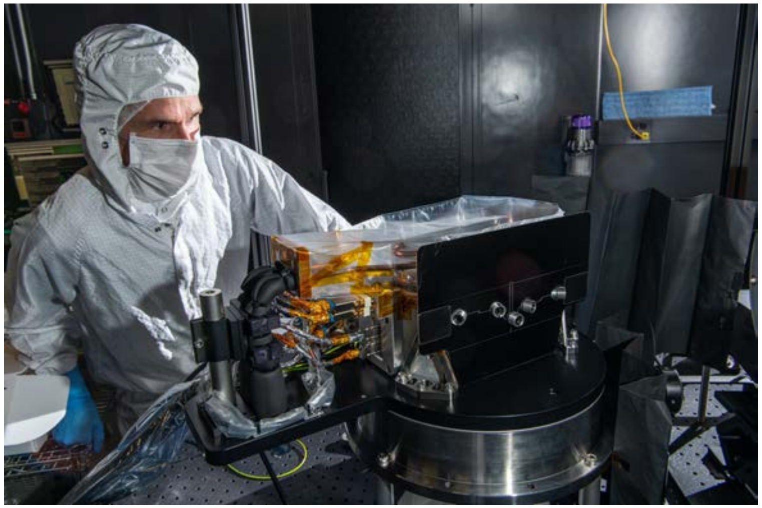


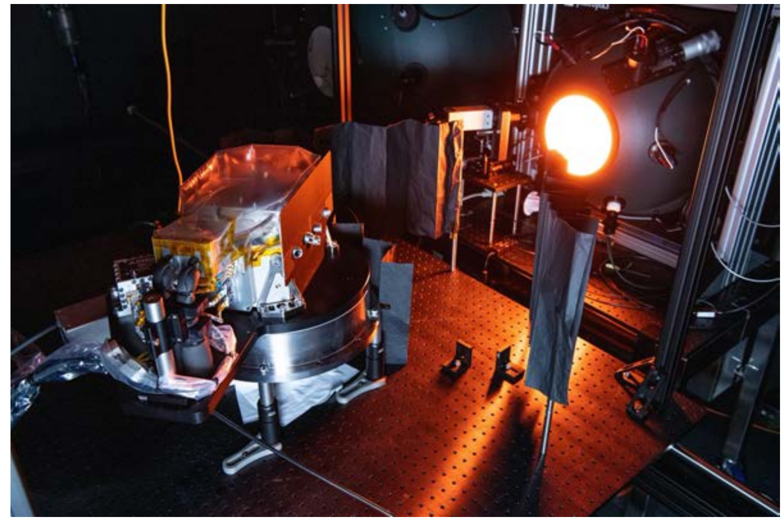

row index j
LDLS
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
1600
0
50
100
150
signal [counts]
V5
V4
V3
V2
V1

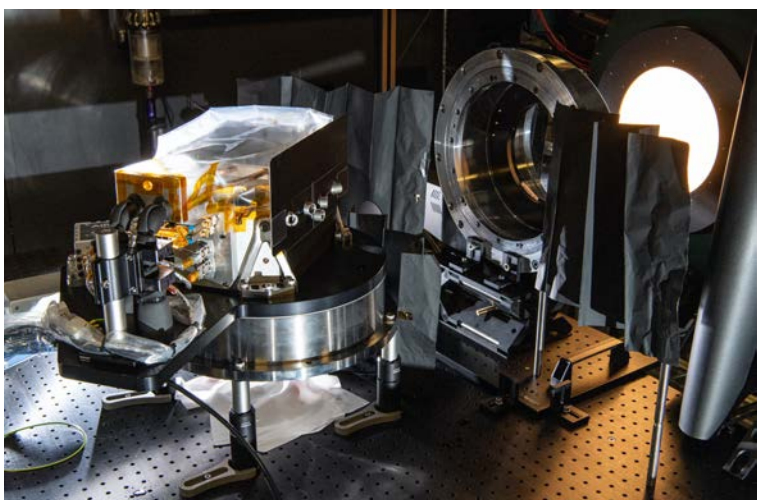


flight direction
V1
V2
V3
V4
V5
LDLS
row index j
column index i
signal [counts]
S_+
S_-
Radiance [a.u.]
DoLP
Wavelength (nm)

SPEXone Calibration Campaign







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L1A-L1B processor

gradual update of S_{ij}

I

q, u

L1B

- Data preparation
- Detector calibration
- Stray light correction
- Field of view calibration
- Spectral calibration
- Radiometric calibration
- Polarimetric calibration
- Geolocation
- Transformation to local meridian plane

Processor architecture

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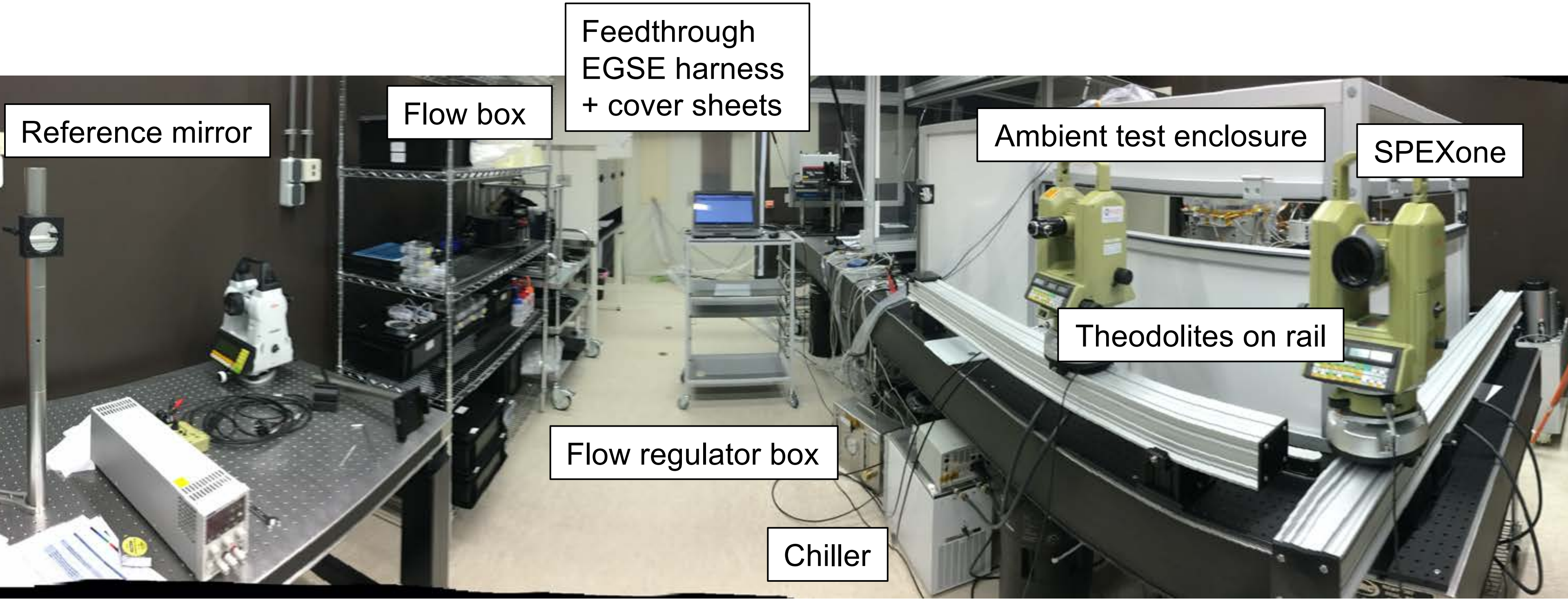
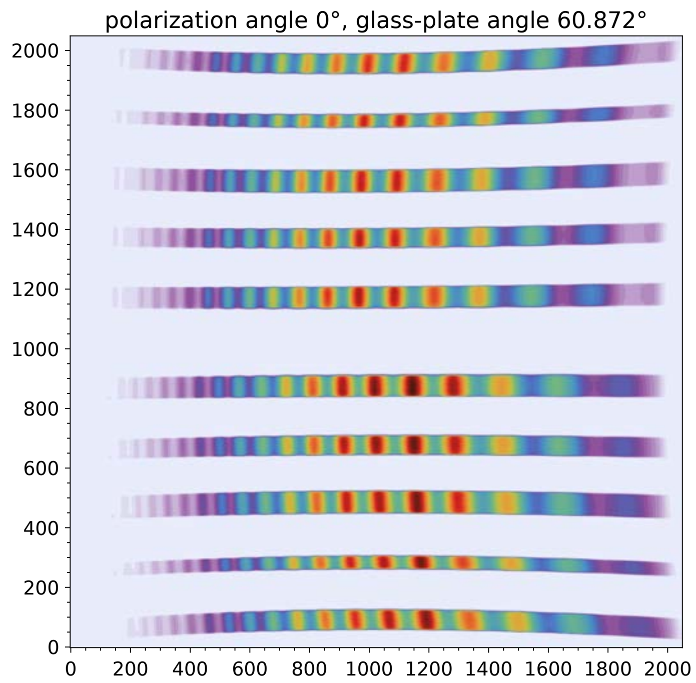
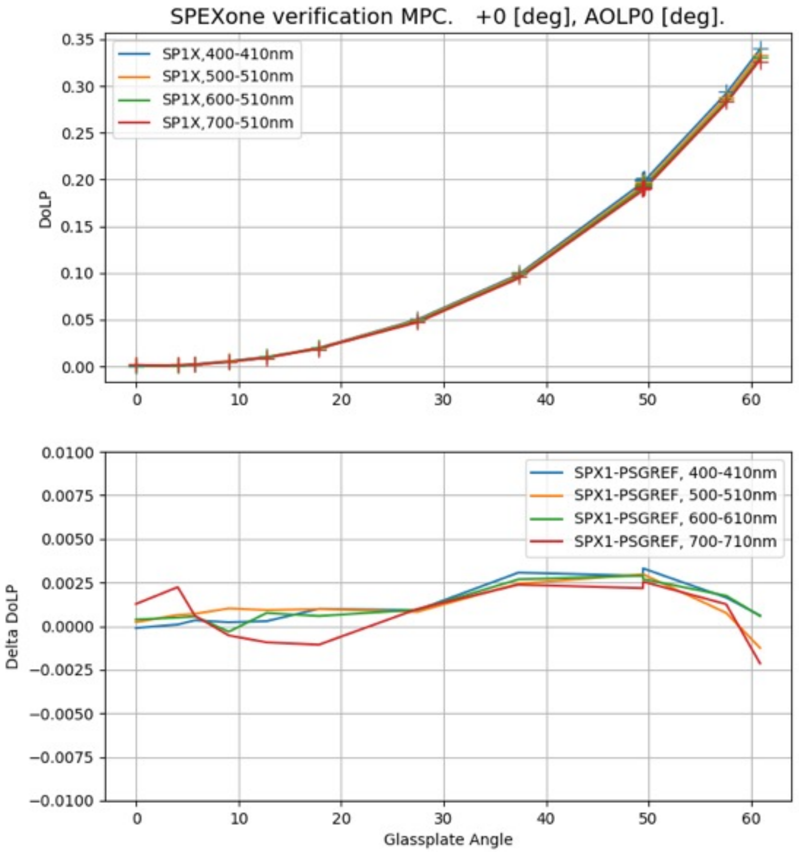
Calibration Setup @SRON



Polarimetric Calibration and Verification





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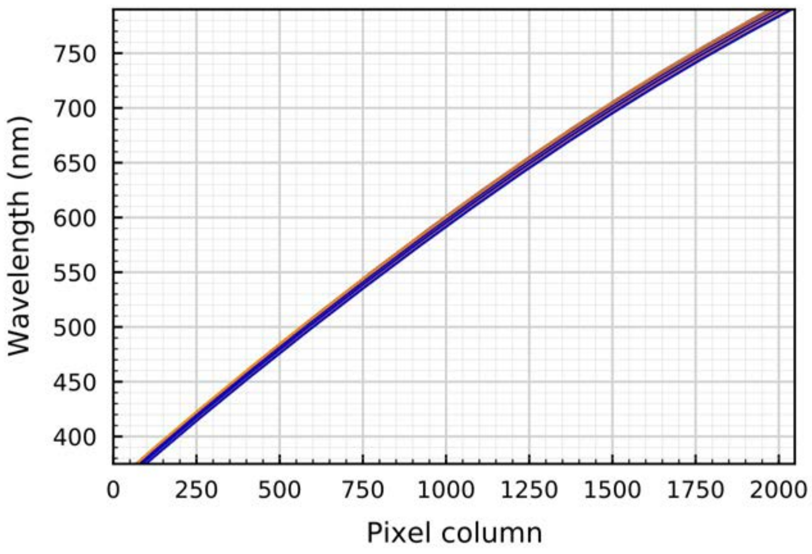
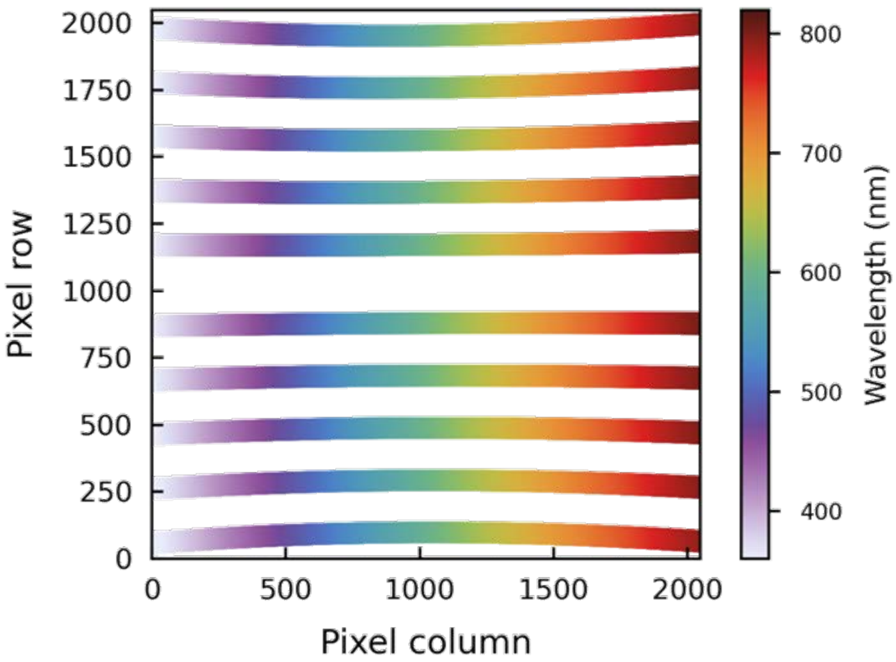
Spectral Calibration

- Full spectral range is covered
- 375 – 785 nm can be downlinked in-flight
- Uniform behavior over viewing angles and swath

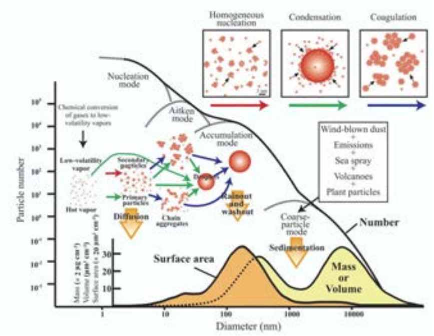




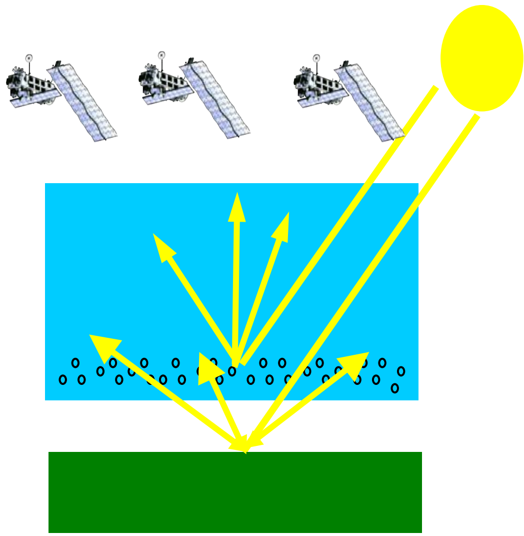
Retrieving Aerosol Properties from SPEXone Measurements

compare

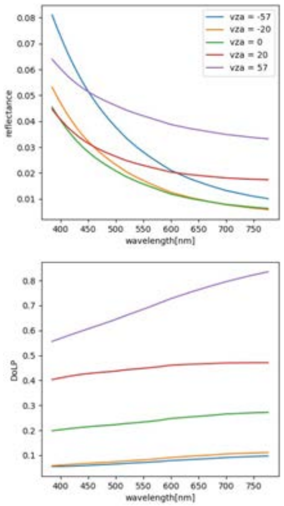
state vector:
aerosol and surface properties



Forward Model:
Simulate the measurement



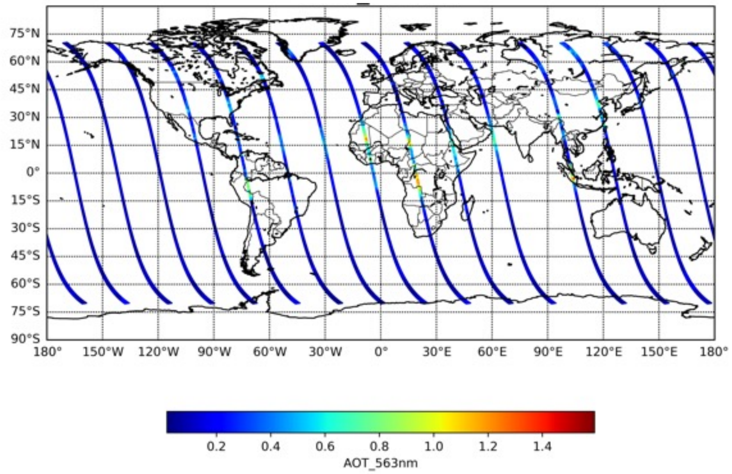
measurement:
radiance and DoLP



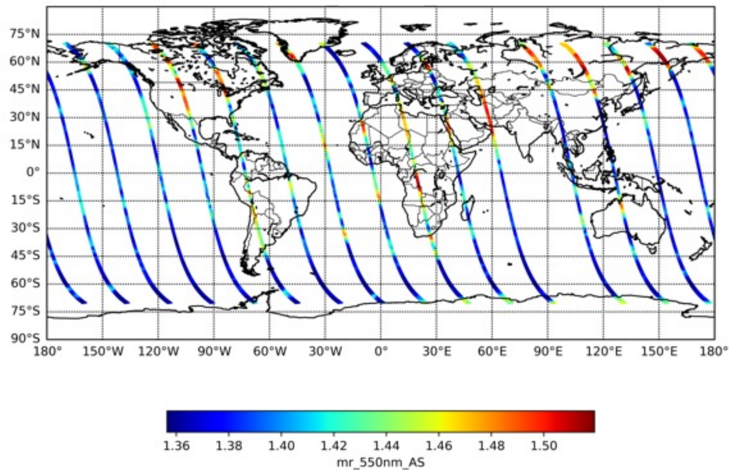
update till optimal agreement

Testing the Retrieval Algorithm with Simulated Measurements (1)

AOD



Real Refractive Index



- Using aerosol properties from an aerosol-climate model → more complex aerosol description than used in retrieval.
- Land and ocean properties from satellite climatology.
- Coverage, solar-, and viewing geometry from PACE orbit simulator.
- Simulate SPEXone measurements: radiance and DoLP as function of wavelength for 5 viewing angles. Include noise on measurements
- Apply retrieval algorithm to synthetic measurements and compare retrieved values to the truth.

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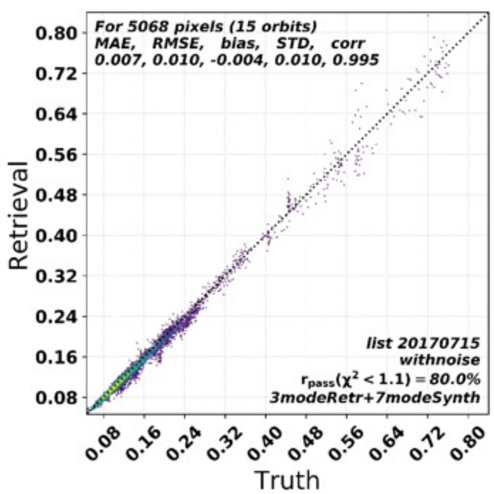
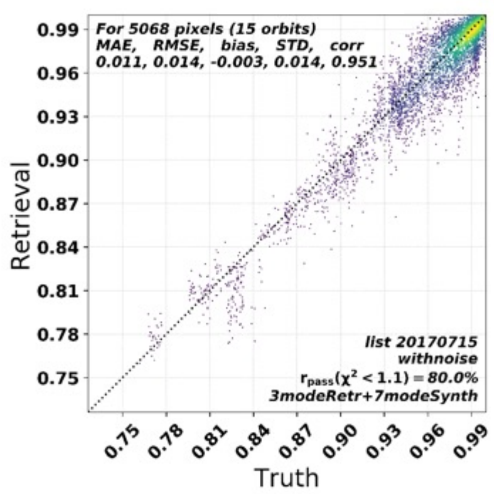
Testing the Retrieval Algorithm with Simulated Measurements (2)

Retrieved vs true values for Aerosol Optical Depth (AOD) and Single Scattering Albedo (SSA)

AOD



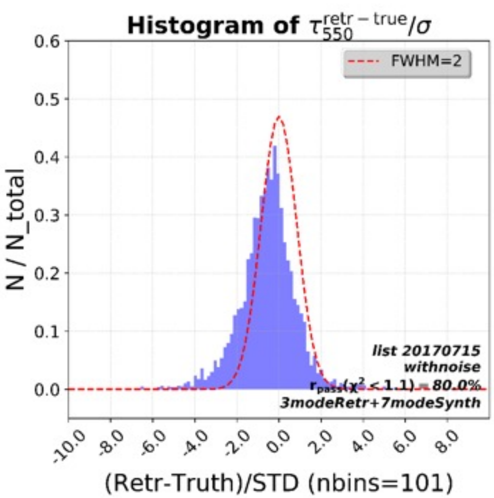
SSA

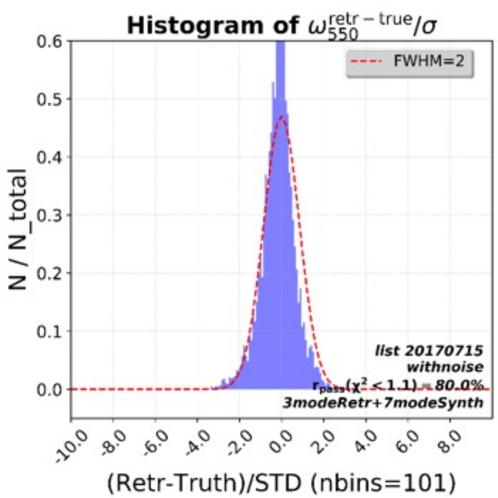


Validate uncertainty estimate:

Distribution of
(retrieved – truth) / uncertainty

should be a normal distribution.





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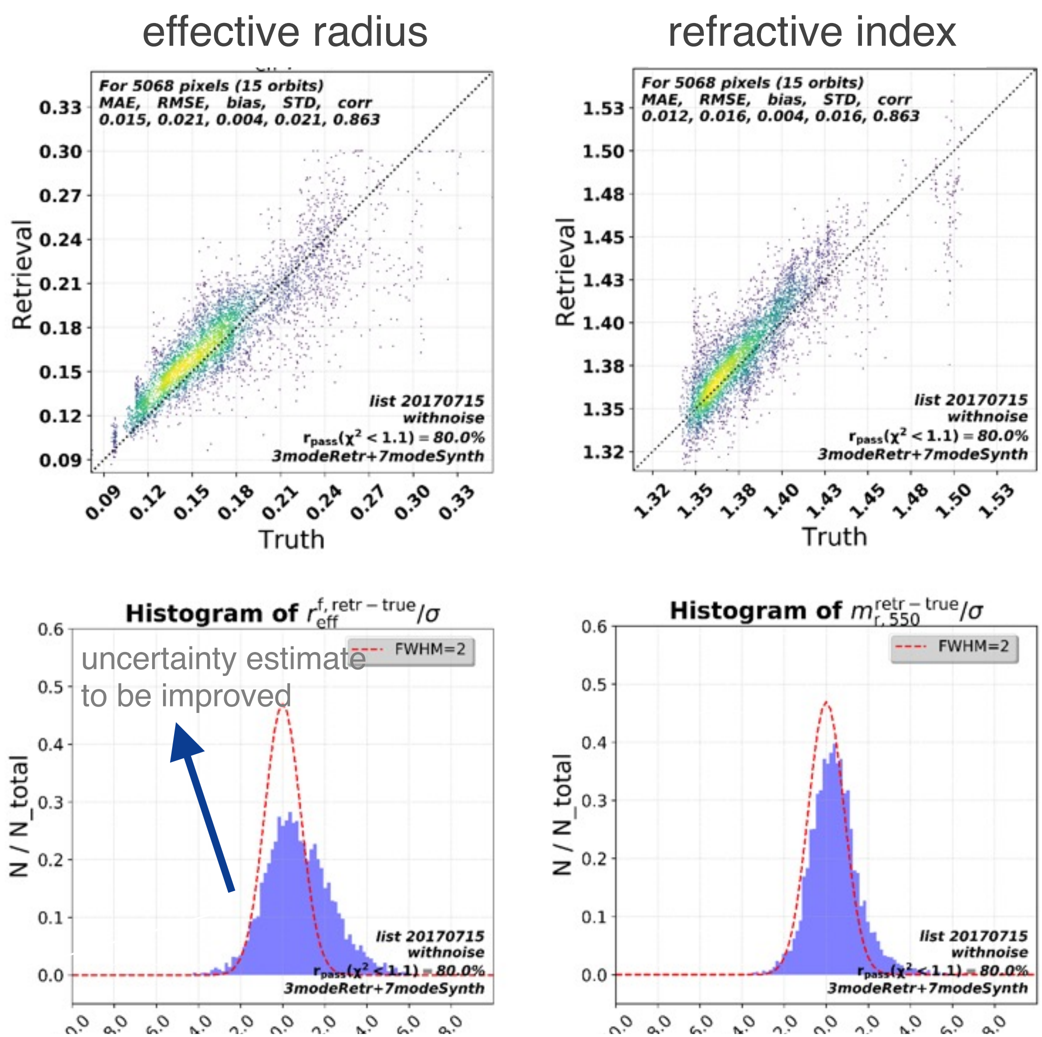
Testing the Retrieval Algorithm with Simulated Measurements (3)

Retrieved vs true values for effective radius and refractive index

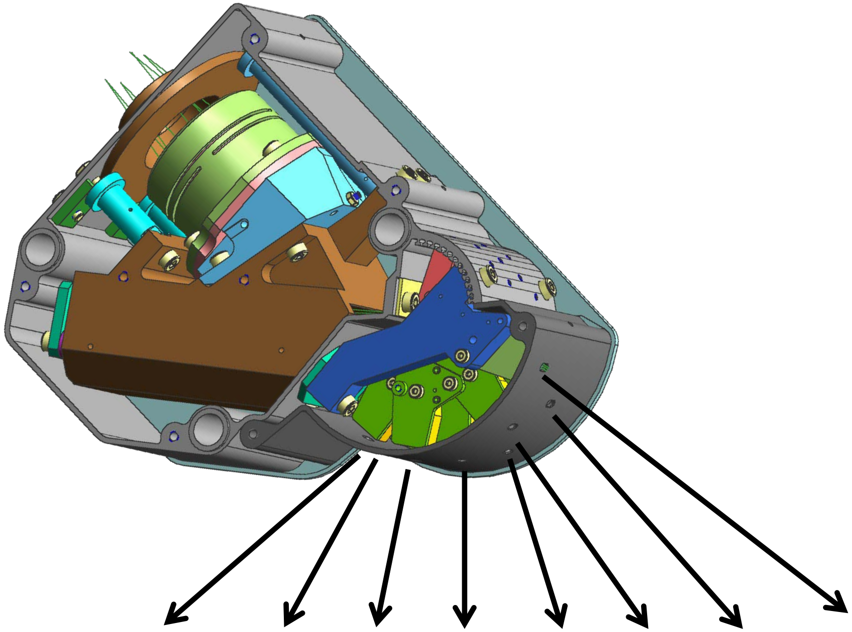
SPEXone is expected to provide aerosol microphysical and optical aerosol properties with unprecedented accuracy



SPEX AIRBORNE

SPEX airborne

- Airborne Precursor for SPEXone
- Using the same spectral modulation method.
- 9 viewing angles (instead of 5 for SPEXone)
- Spectral range 400-800nm (385-770nm for SPEXone)
- Several improvements in SPEXone (optical, spatial sampling)



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ACEPOL Oct-Nov 2017

Aerosol Characterization from Polarimeters and Lidars

ER-2 instruments

- SPEX airborne
- RSP
- HSRL-2
- AirMSPI
- CPL
- AirHARP

Ground-based instruments

- AERONET
- MPLNET

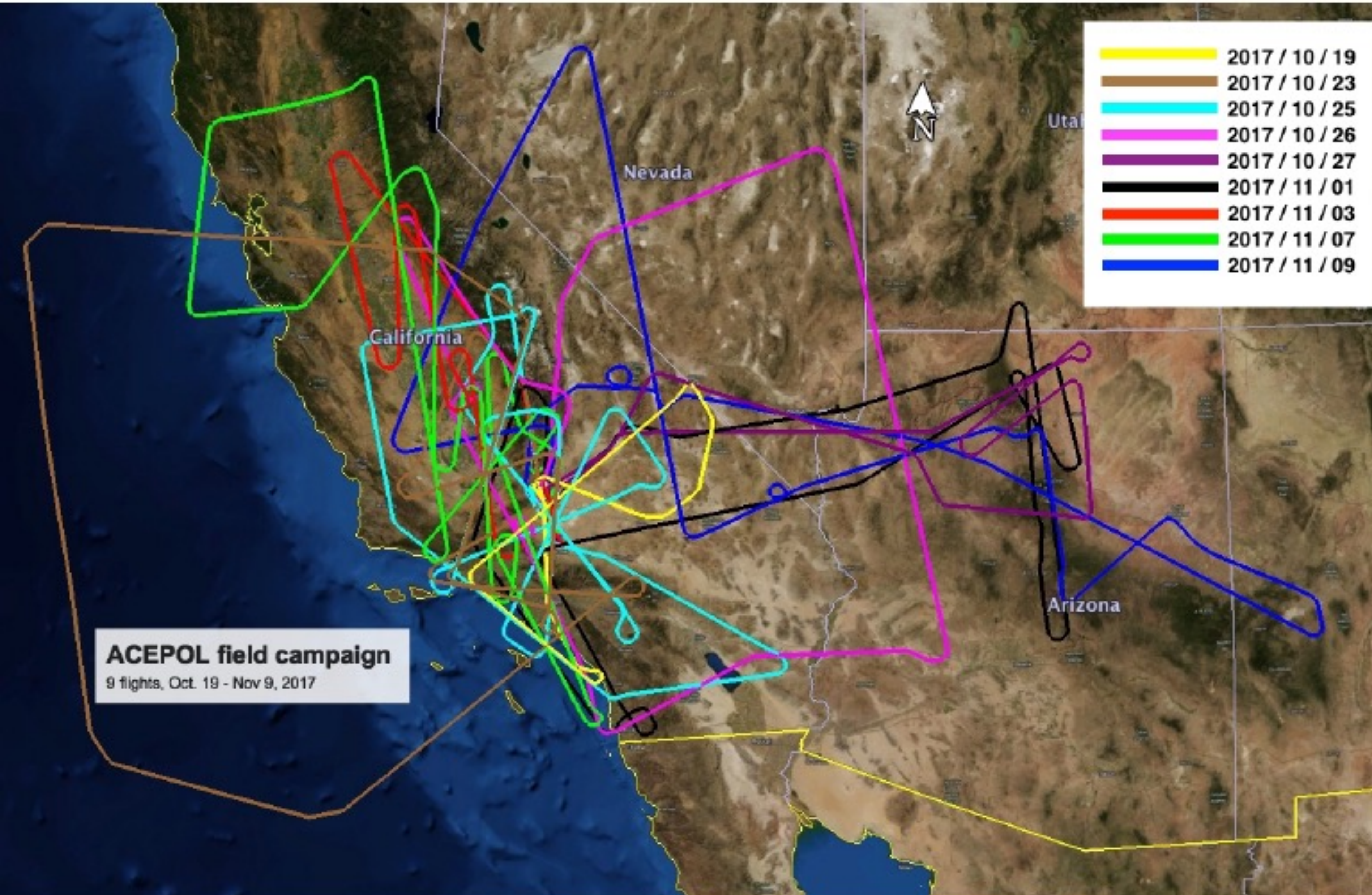
Satellite overpasses

- CALIPSO, CATS
- MSIR, MODIS, VIIRS

NASA and SRON collaborated in the ACEPOL field campaign to acquire data with advanced active and passive remote sensors. These data will be used to develop and assess algorithms for retrieving profiles of aerosol optical and microphysical properties for various atmospheric applications. The measurements and algorithms are applicable to future satellite missions such as ACE, PACE, METOP-SG, and EarthCare.

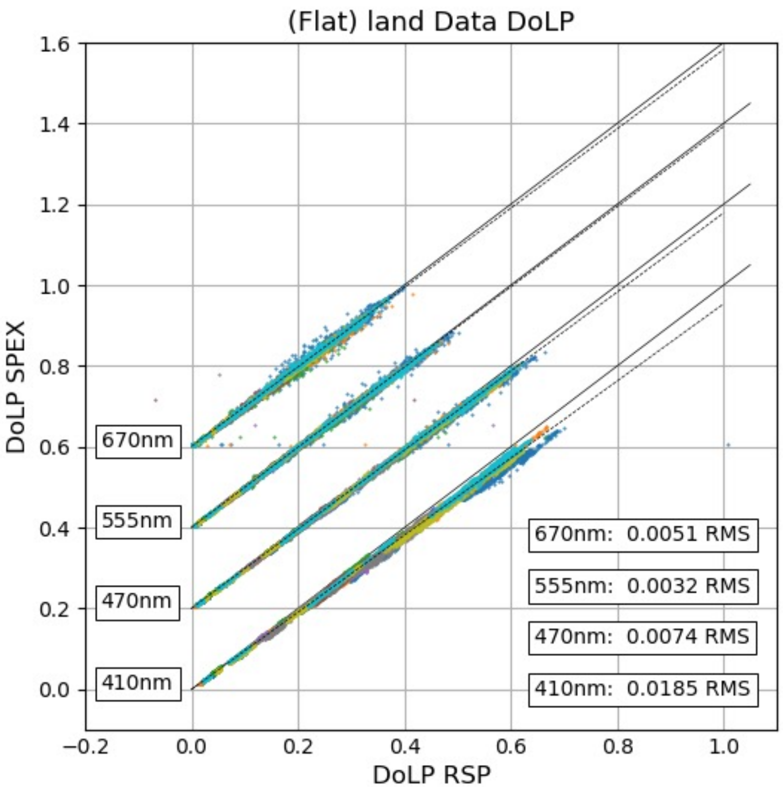
Mission Scientists: Richard A. Ferrare (LaRC); Kirk Knobelspiesse (GSFC), Otto Hasekamp (SRON); Felix Seidel (HQ)
NASA support: Hal Maring, Felix Seidel (HQ); Arlindo da Silva (GSFC)

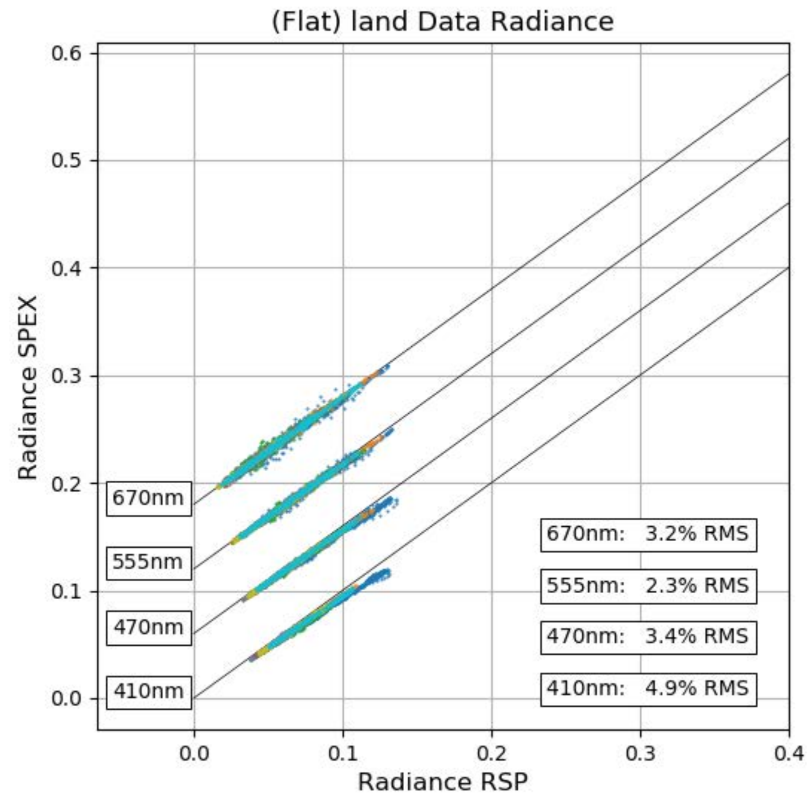
ACEPOL: 9 flights, 41.3 hours



Validation of DoLP and Radiance measurements with RSP

RSP is considered a reference polarimeter (> 20 years proven performance)





- Very good agreement in DoLP (RMSE = 0.003) at mid-visible wavelengths
- Larger differences towards shorter wavelengths. Reduced sensitivity, has been improved for SPEXone.
- At 410 nm the spectral response of RSP is different than for SPEX → no accurate comparison

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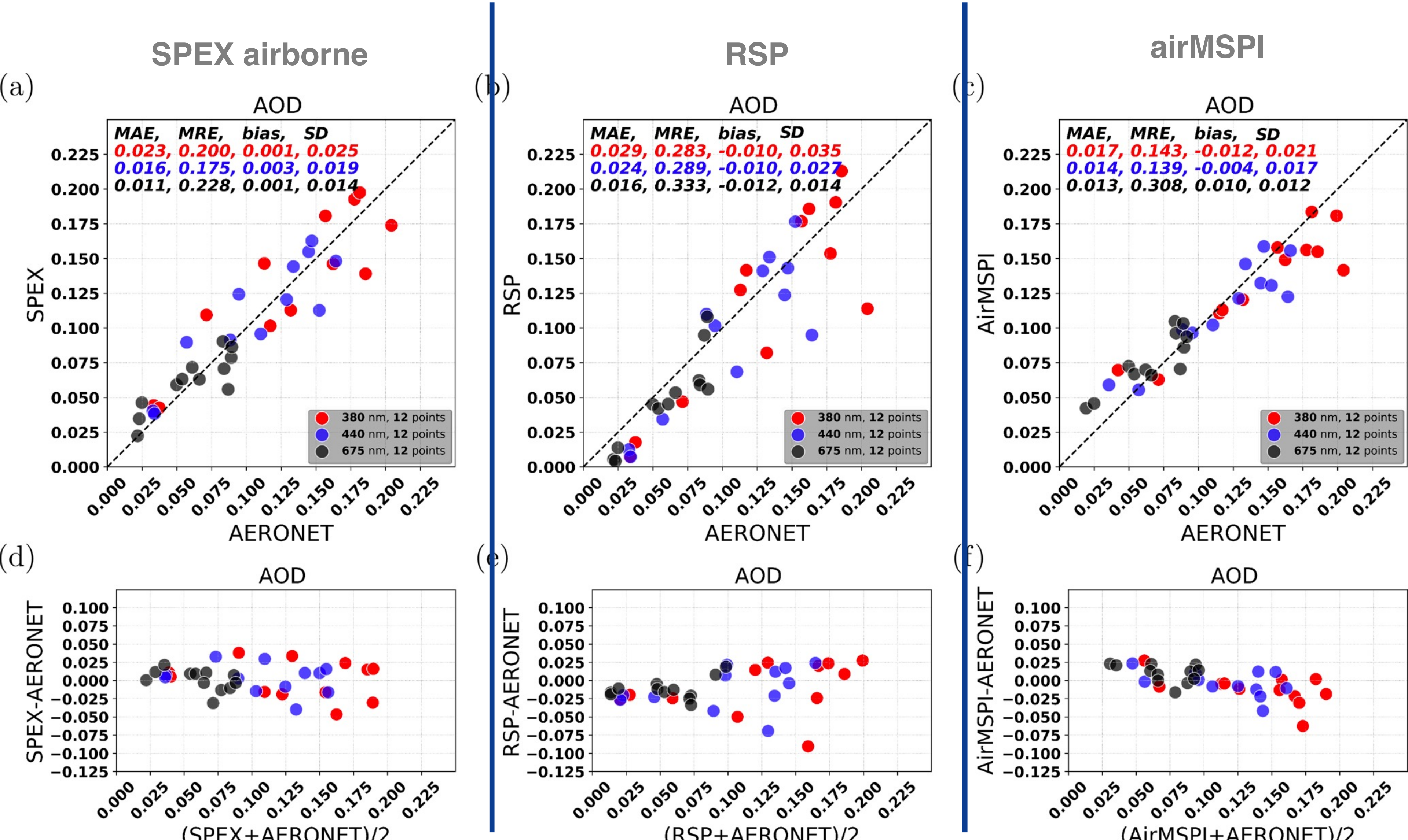
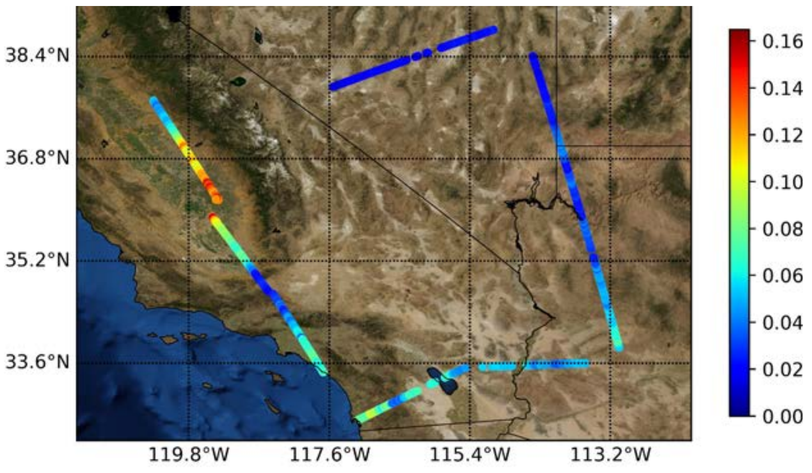
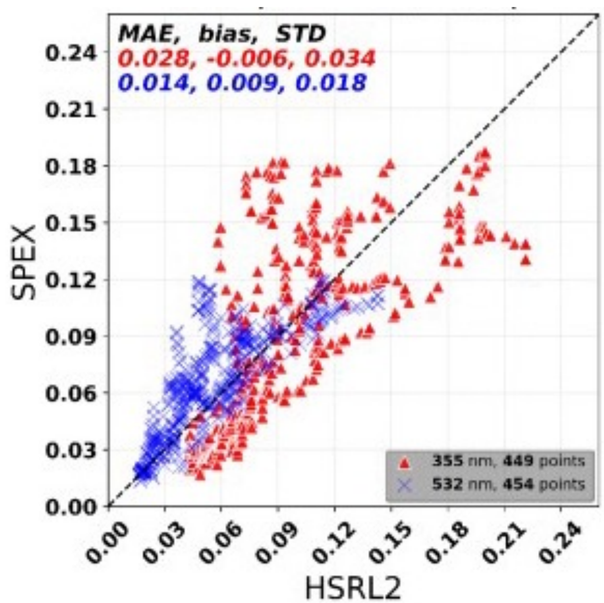
Validation against AERONET for SPEX, RSP, airMSPI

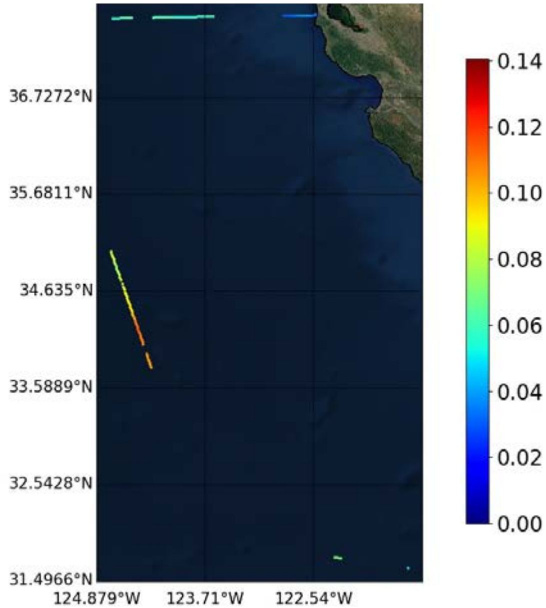


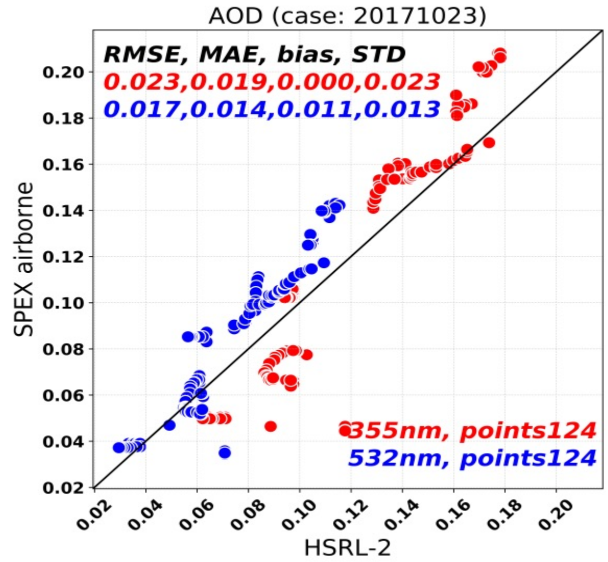
SPEX airborne aerosol retrievals: Comparison to HSRL2





Fu et al., 2020, AMT



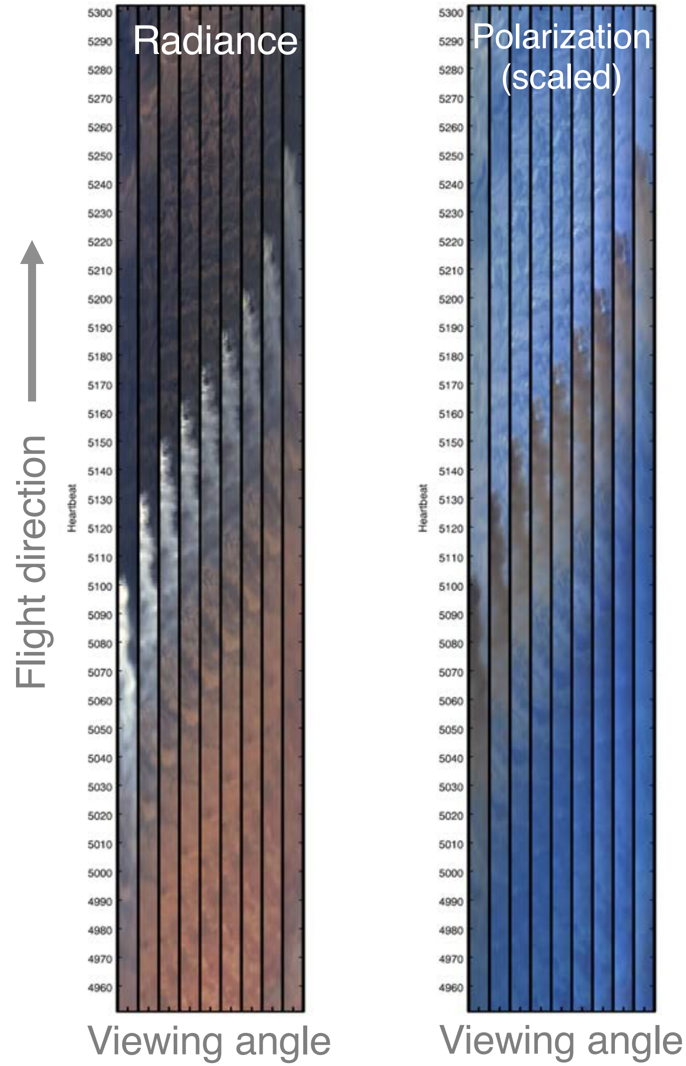


Fan et al., 2019, Remote Sensing,

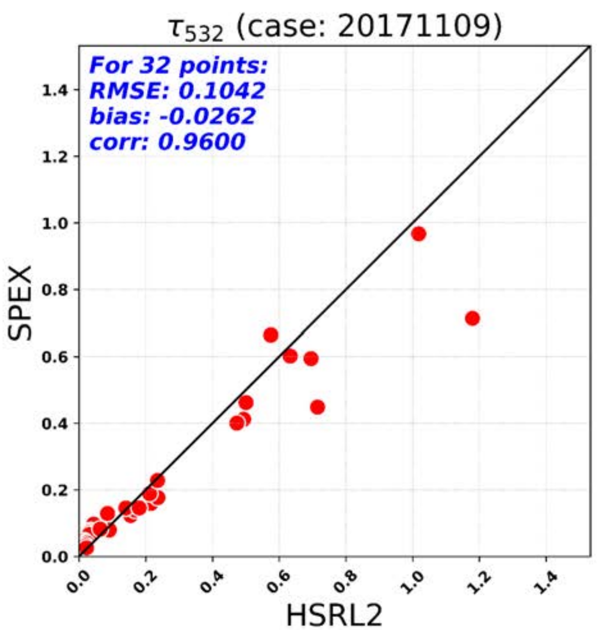
Forest fires in Arizona (1)

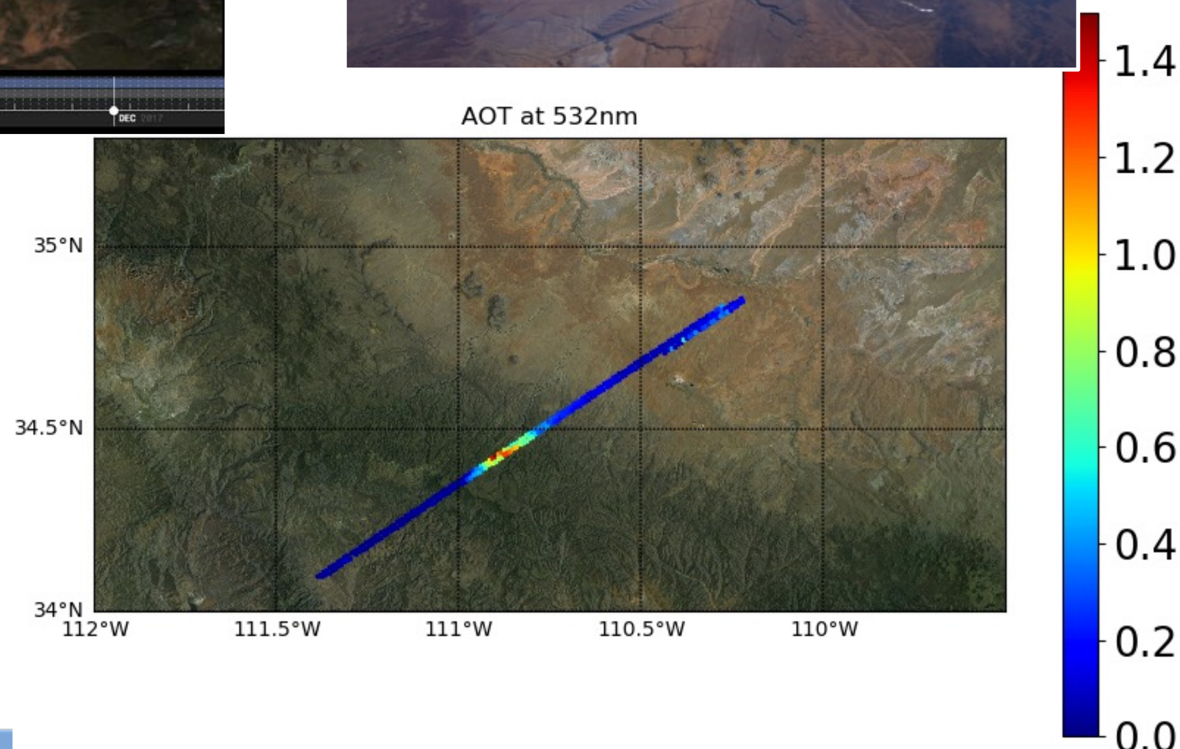
As seen from the ER-2 cockpit

As seen by SPEX airborne



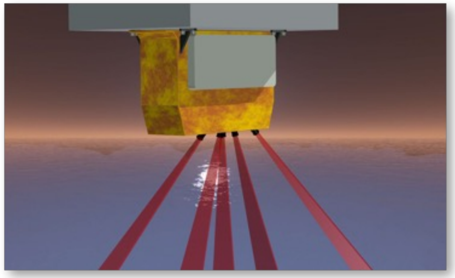
Forest Fires in Arizona (2)



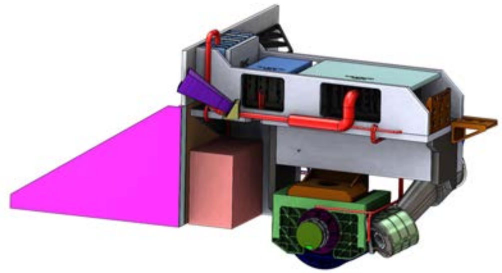


Synergy SPEXone with OCI and HARP-2

SPEXone

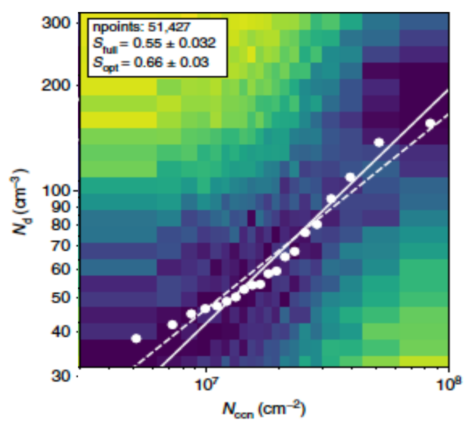


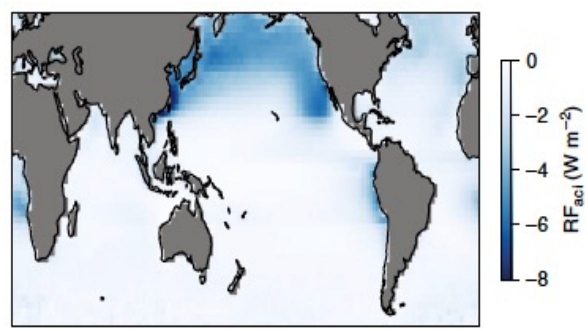
OCI



- Hyperspectral, multi (5)-angle, radiance and polarization measurements for 385-770 nm
- Hyper-angular radiance and polarization measurements at 4 spectral bands (440-870 nm)
- Hyperspectral single viewing angle measurements 340-890 nm + 6 SWIR bands

Study relation ships between aerosols and clouds





Hasekamp et al., NatComm., 2019