Dual photoelastic modulator (PEM)-based polarimetry with the Airborne Multiangle SpectroPolarimetric Imager (AirMSPI)

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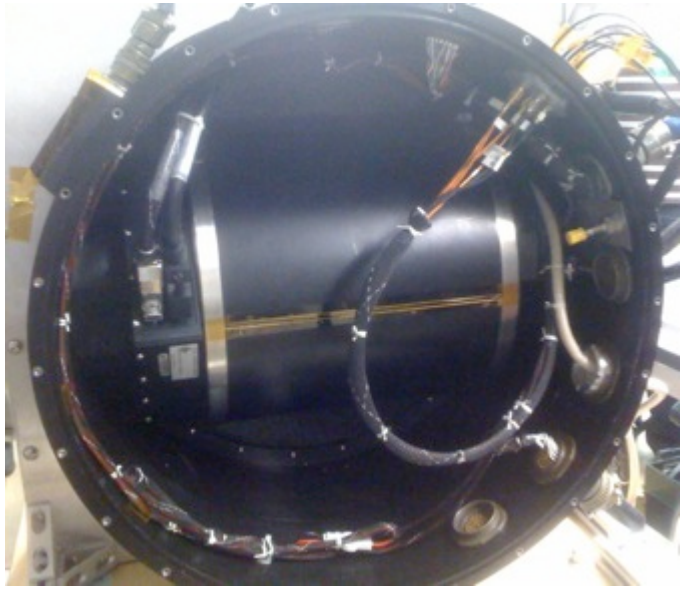
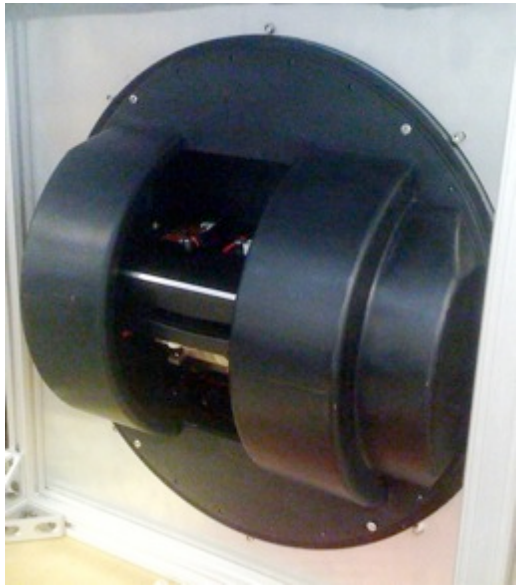
AirMSPI





Spectral bands:

355, 380, 445, 470*,555, 660*, 865*, 935 nm (*polarimetric)

The AirMSPI camera flies in the nose of NASA's ER-2 aircraft (20 km flight altitude)

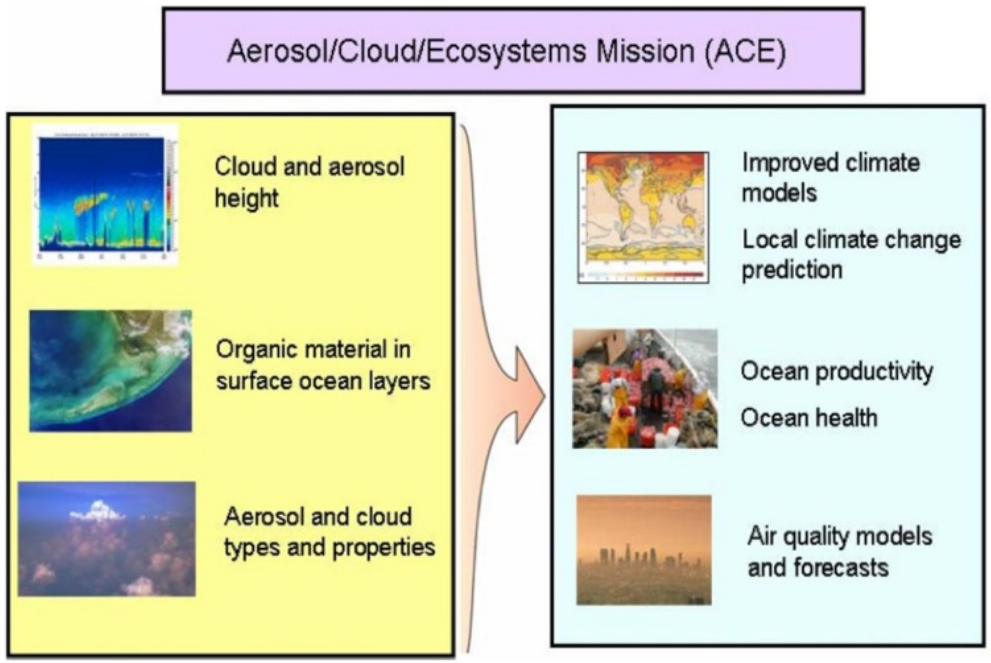
AirMSPI is mounted in a gimbal for multi-angle viewing between ±67º

Background

"The largest uncertainties in global climate change prediction involve the role of aerosols and clouds in the Earth's radiation budget"

A "highly accurate multiangle-multiwavelength polarimeter" is a key component of NASA's future Aerosol-Cloud-Ecosystem (ACE) mission

—NRC Decadal Survey (2007)



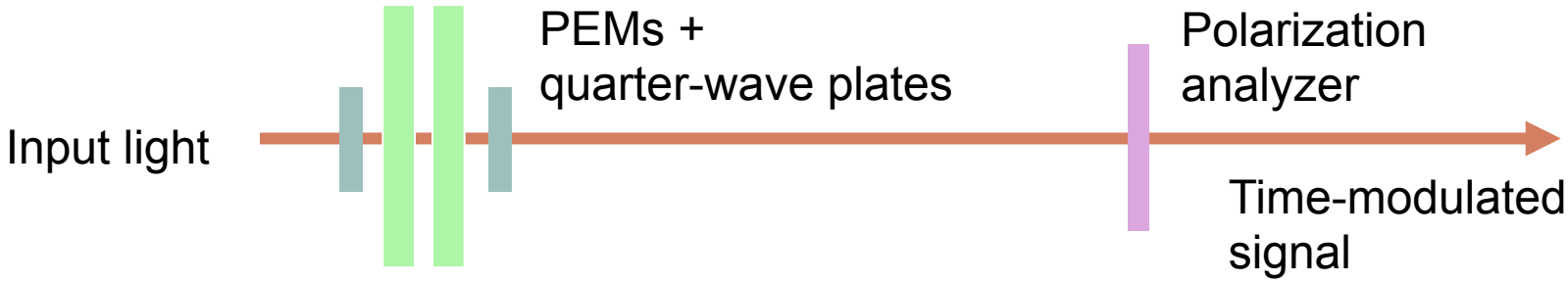
AirMSPI is a prototype for a candidate ACE polarimeter

2013 field campaigns

- ACE Polarimeter Definition Experiment (PODEX)
  - Jan 14, 16, 18, 22, 28, 31; Feb 1, 3, 6: California
- Hyperspectral Infrared Imager (HysplRI)
  - Apr 19; May 3, 7: California
- Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC^{4}RS)
  - Aug 1, 2, 6, 8, 12, 16, 19, 23, 30; Sep 2, 4, 6, 9, 11, 13, 16, 18, 22, 23:
  - Western US, Central US, Southeast US, Honduras, Canada
- Targets
  - Clear ocean with visible wave structure, sunglint patterns
  - Farmland, foothills, mountains, rivers, lakes, urban areas, snow fields, desert
  - Smoke and pollution aerosols
  - Fog, broken stratus, stratocumulus, scattered cumulus, and cirrus
  - Glories, supernumerary bows, cloudbow
  - Calibration targets: Rosamond Dry Lake, Ivanpah Playa, Railroad Valley

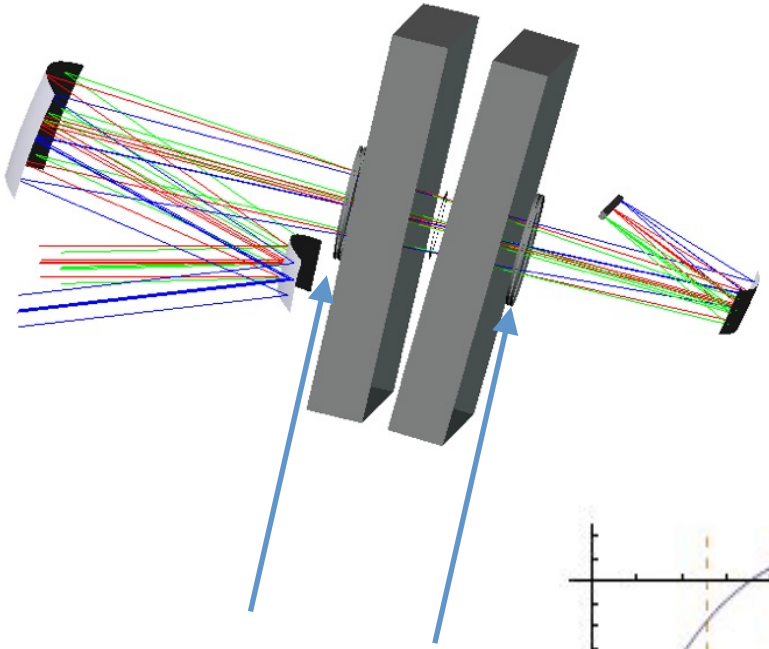
AirMSPI dual-PEM polarimeter approach

- Photoelastic modulators (PEMs) time-modulate the linear Stokes components *Q* and *U* – leaving intensity *I* unmodulated
  - PEMs are glass elements with stress-induced birefringence modulation at resonant frequencies of ~42 kHz
  - Using dual PEMs with their fast axes aligned, modulation of *Q* and *U* occurs at the difference frequency (nominally ~25 Hz)
  - The high frequency oscillation is averaged out during each sample, permitting slower demodulation
  - Enables retrieval of $q = Q/I$ and $u = U/I$ as *relative* measurements



AirMSPI optical system

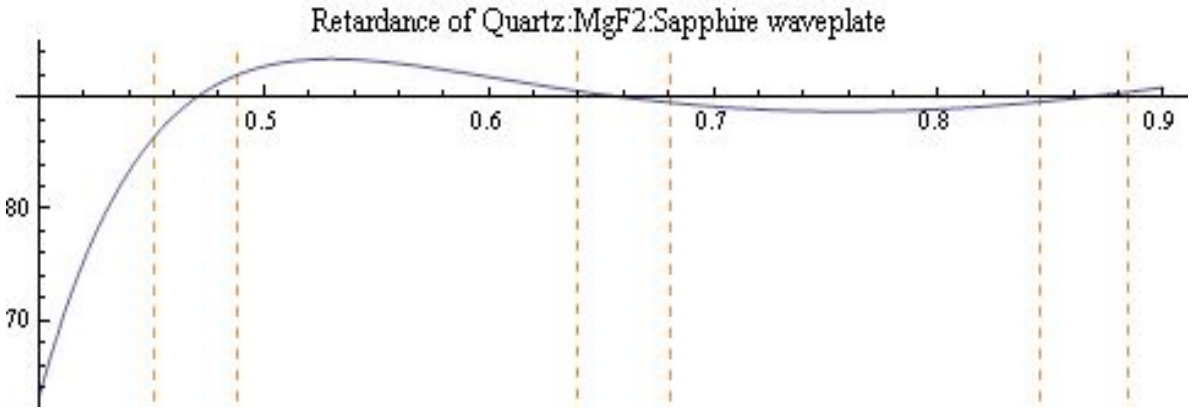
Dual PEM



3-mirror reflective anastigmatic, telecentric telescope

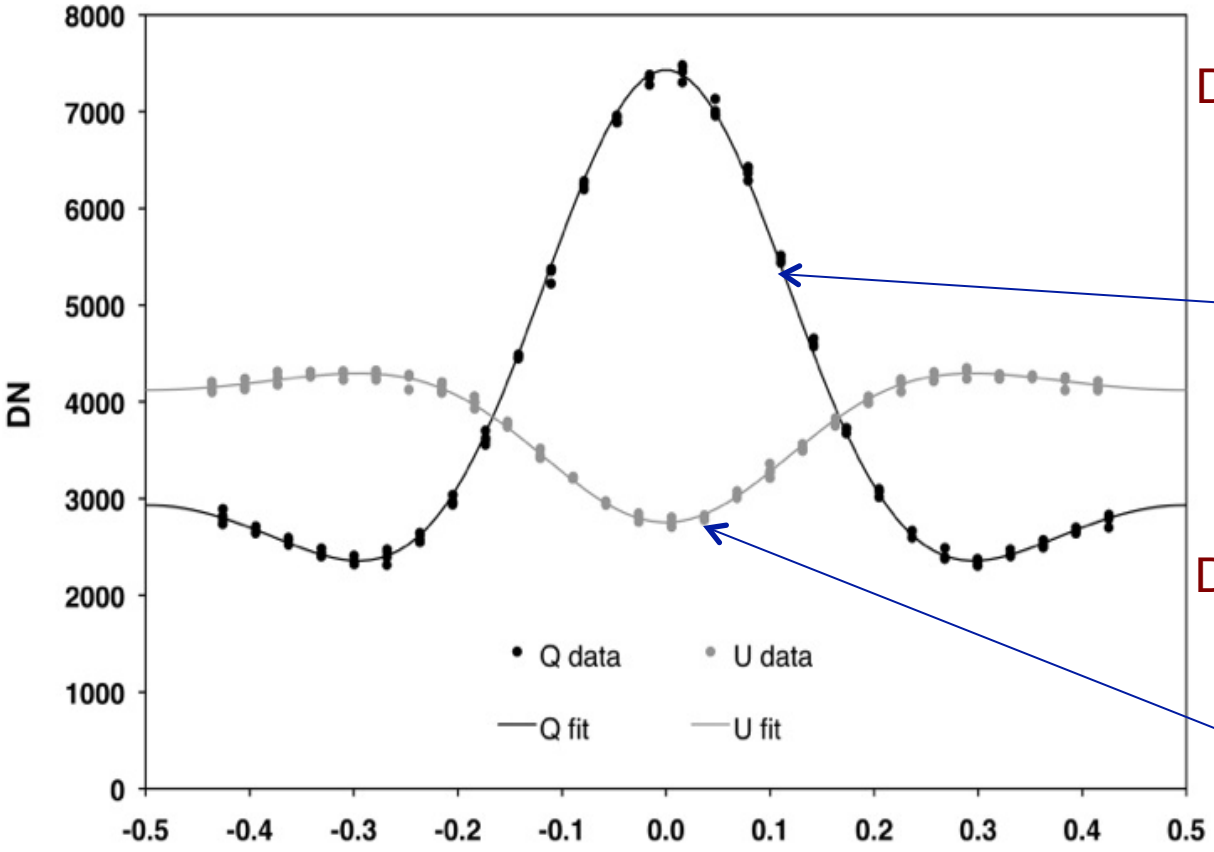
Focal length = 29 mm

Achromatic quarter-wave plates



470 nm 660 nm 865 nm

Polarimetry using temporal modulation



Detector row with 0º polarizer

$I_0 = 0.5\,[I + Q \bullet F(t)]$

Measures both Q and I → *q*

Detector row with 45º polarizer

$I_{45} = 0.5\,[I + U \bullet F(t)]$

Measures both U and I → *u*

1 frame ~ 43 msec

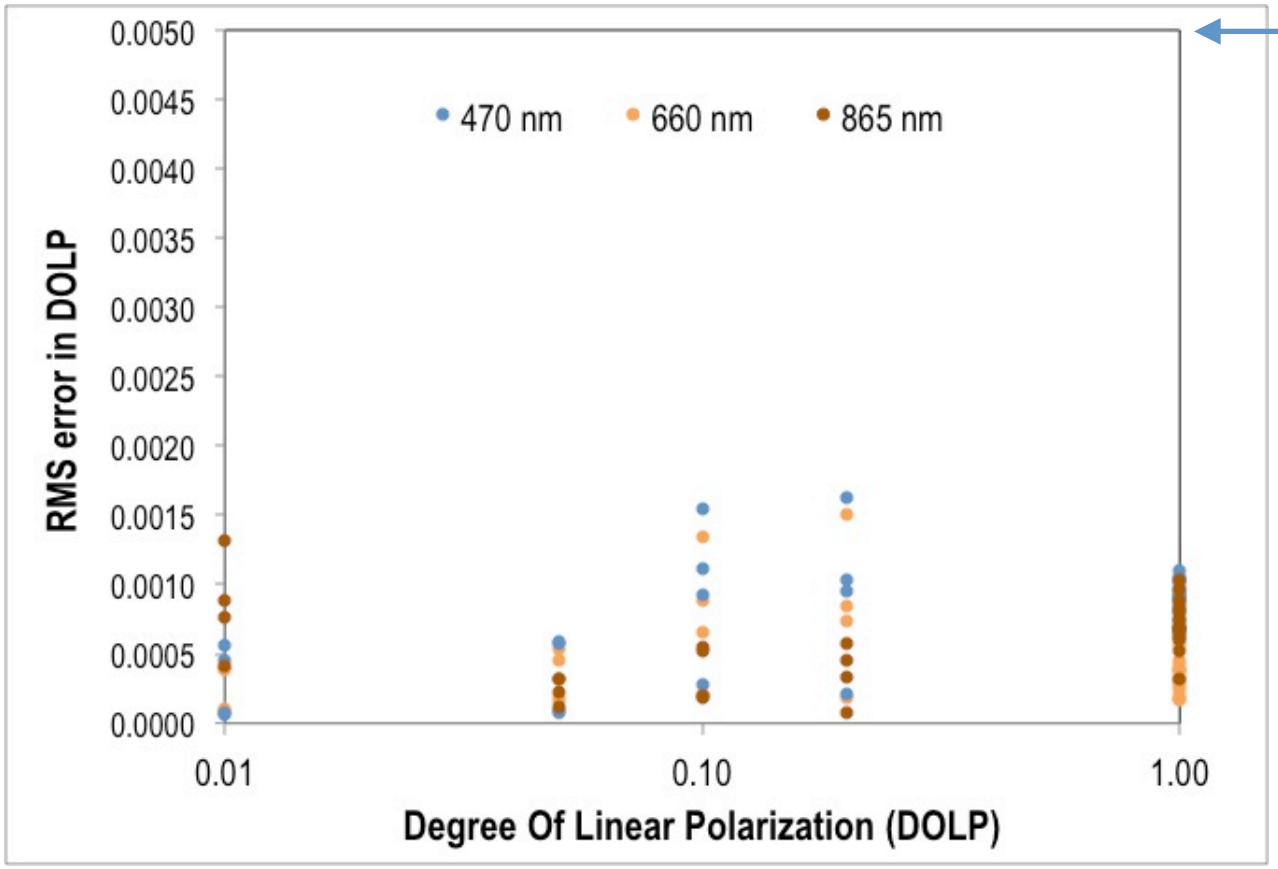
Degree of linear polarization

$$DOLP = \sqrt{q^2 + u^2}$$

Angle of linear polarization

$$AOLP = \frac{1}{2}\arctan\frac{u}{q}$$

Polarimetric uncertainty



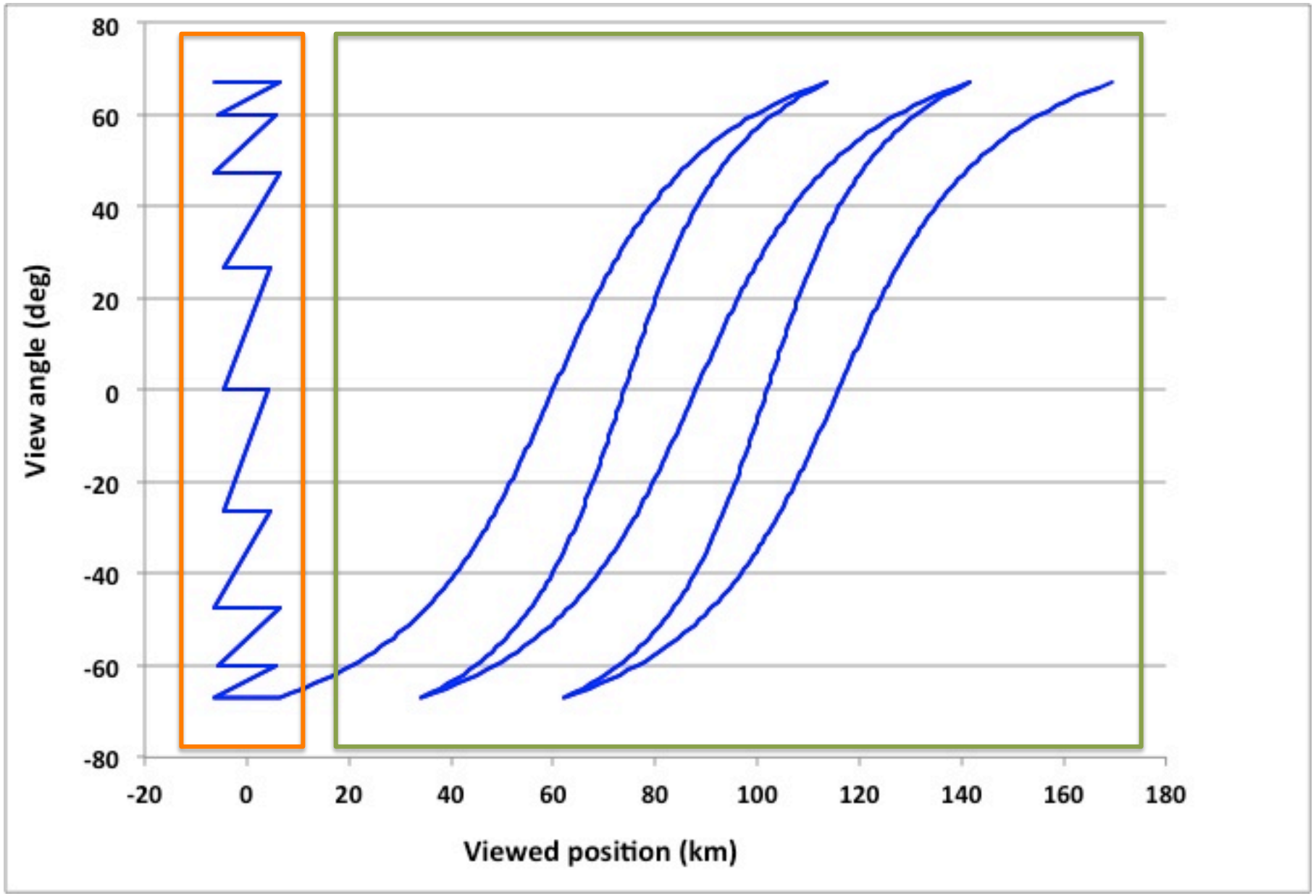
NASA Aerosol-Cloud-Ecosystem (ACE)
DOLP uncertainty requirement:
≤ 0.005

DOLP of 0.01, 0.05, 0.10, and 0.20 measured for polarizer angles 0º, 45º, 90º, 135º

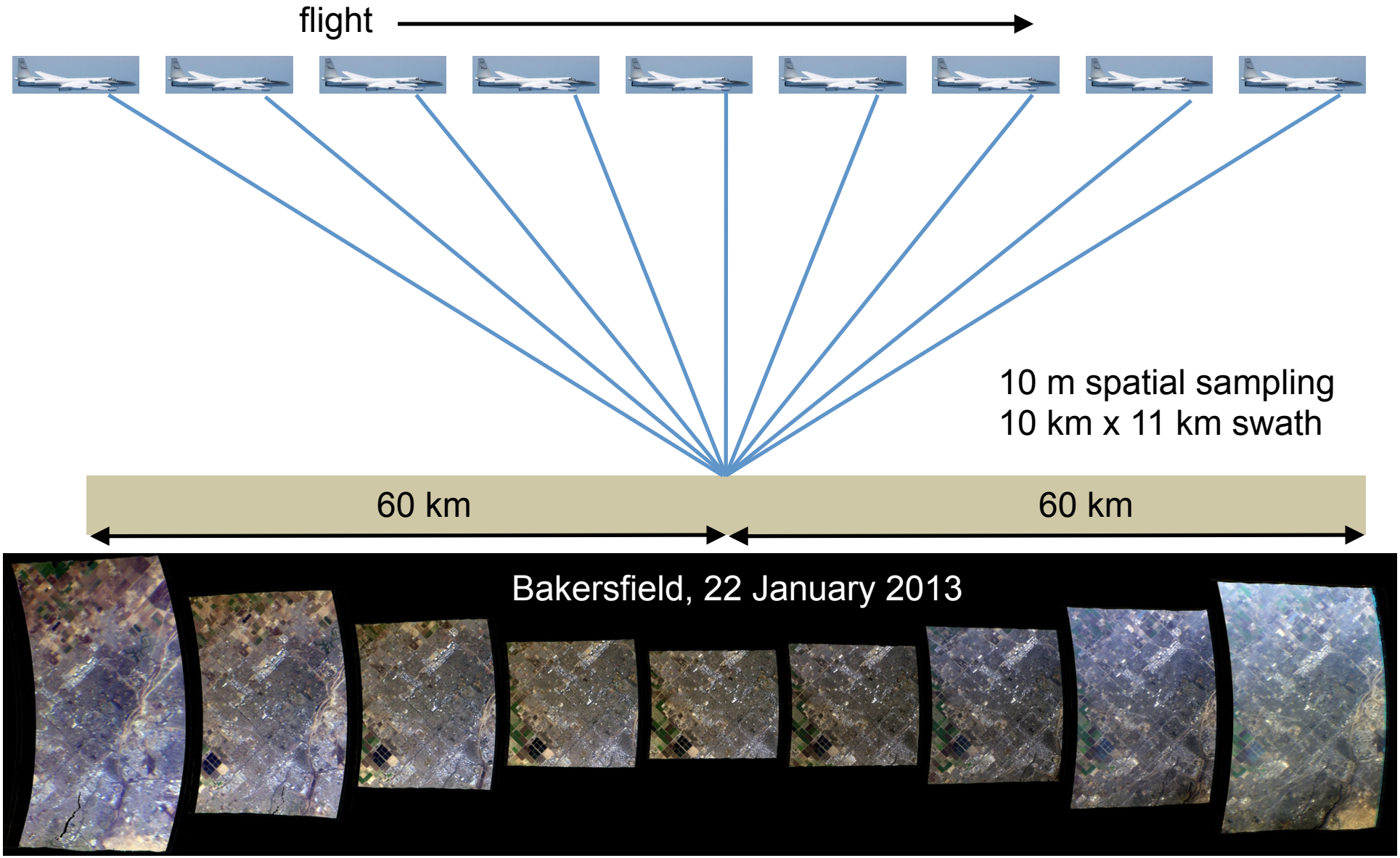
DOLP of 1.0 measured for polarizer angles from 0 – 170º in 10º steps

Step and stare

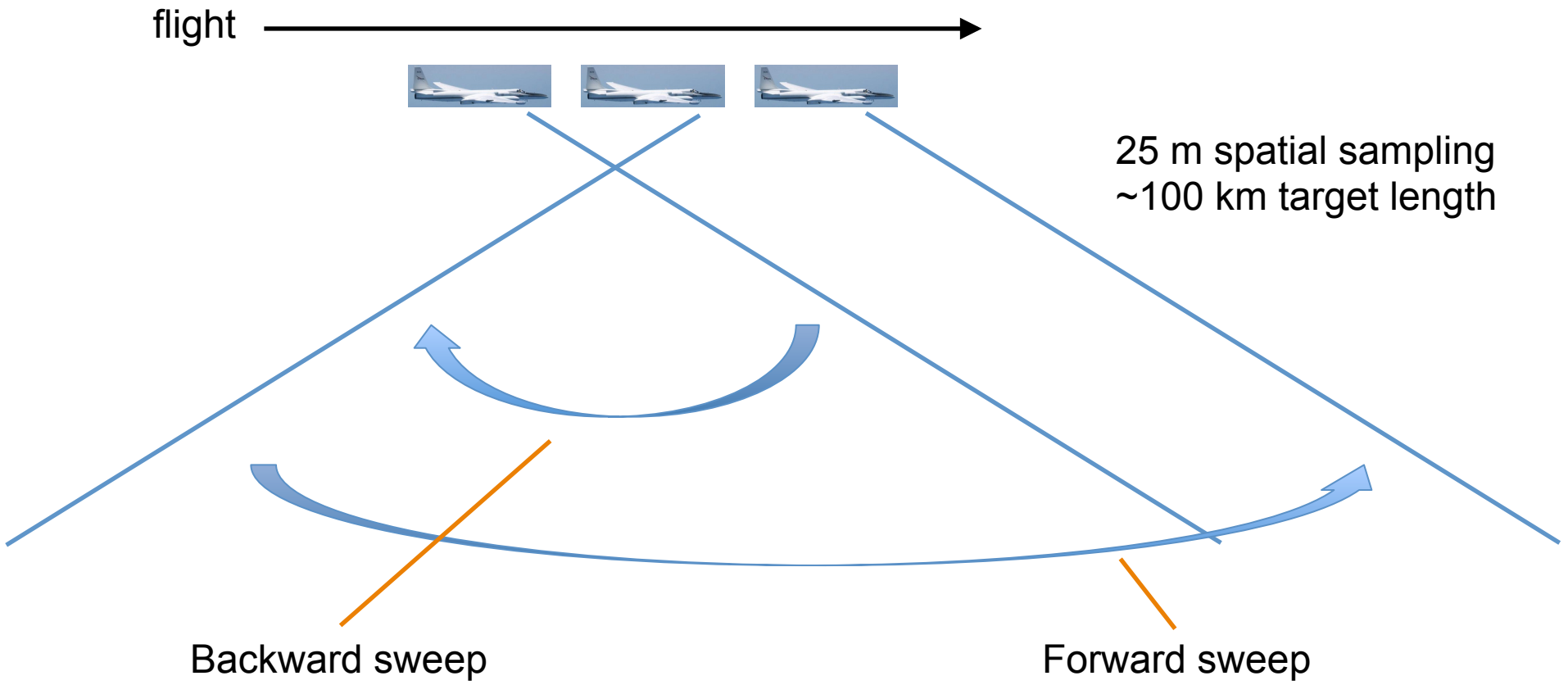
Sweep

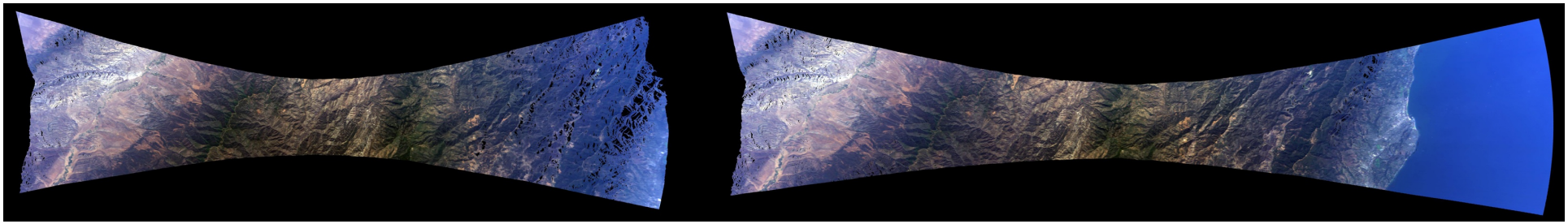


Step and stare imaging



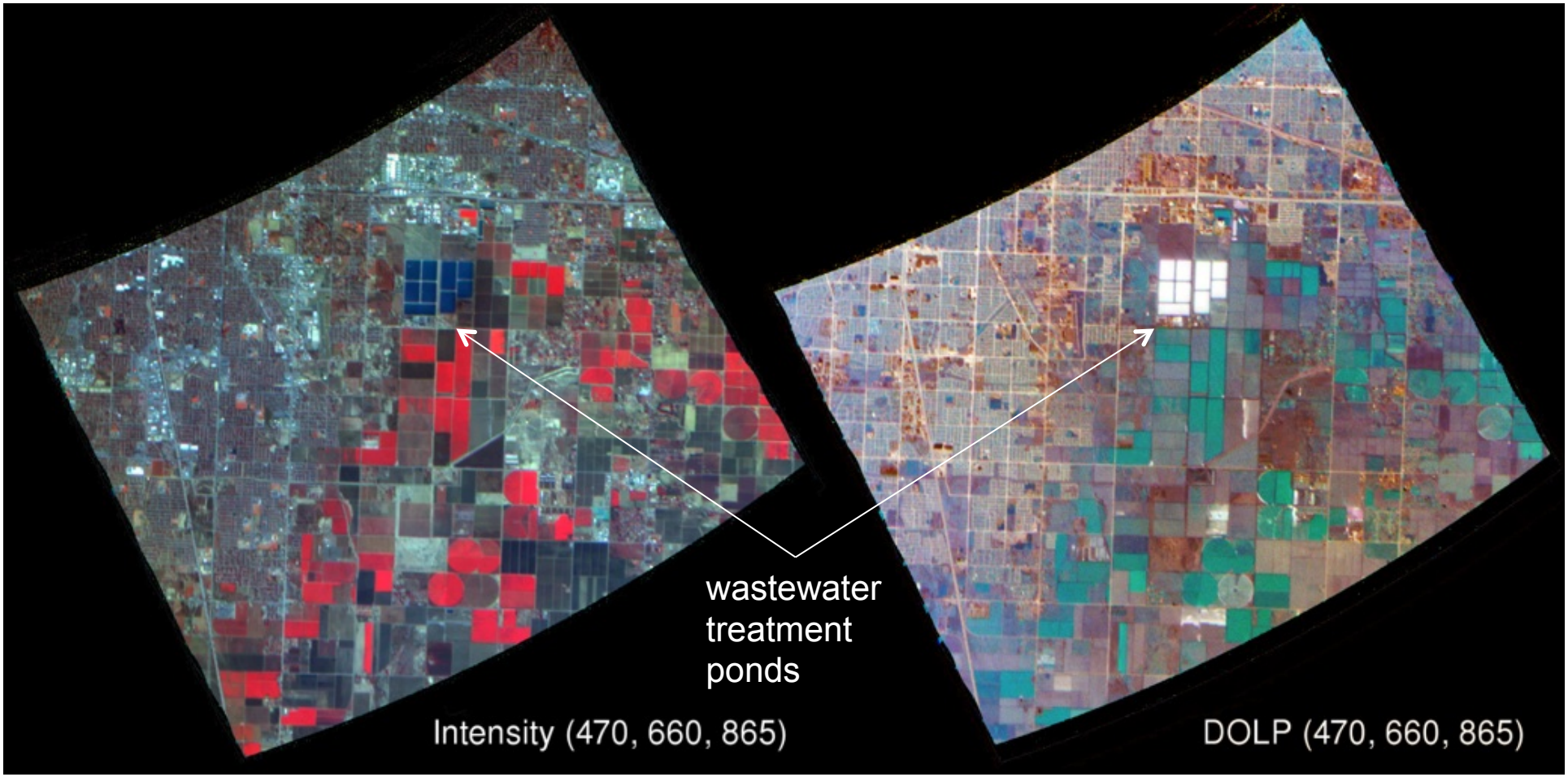
Sweep mode imaging





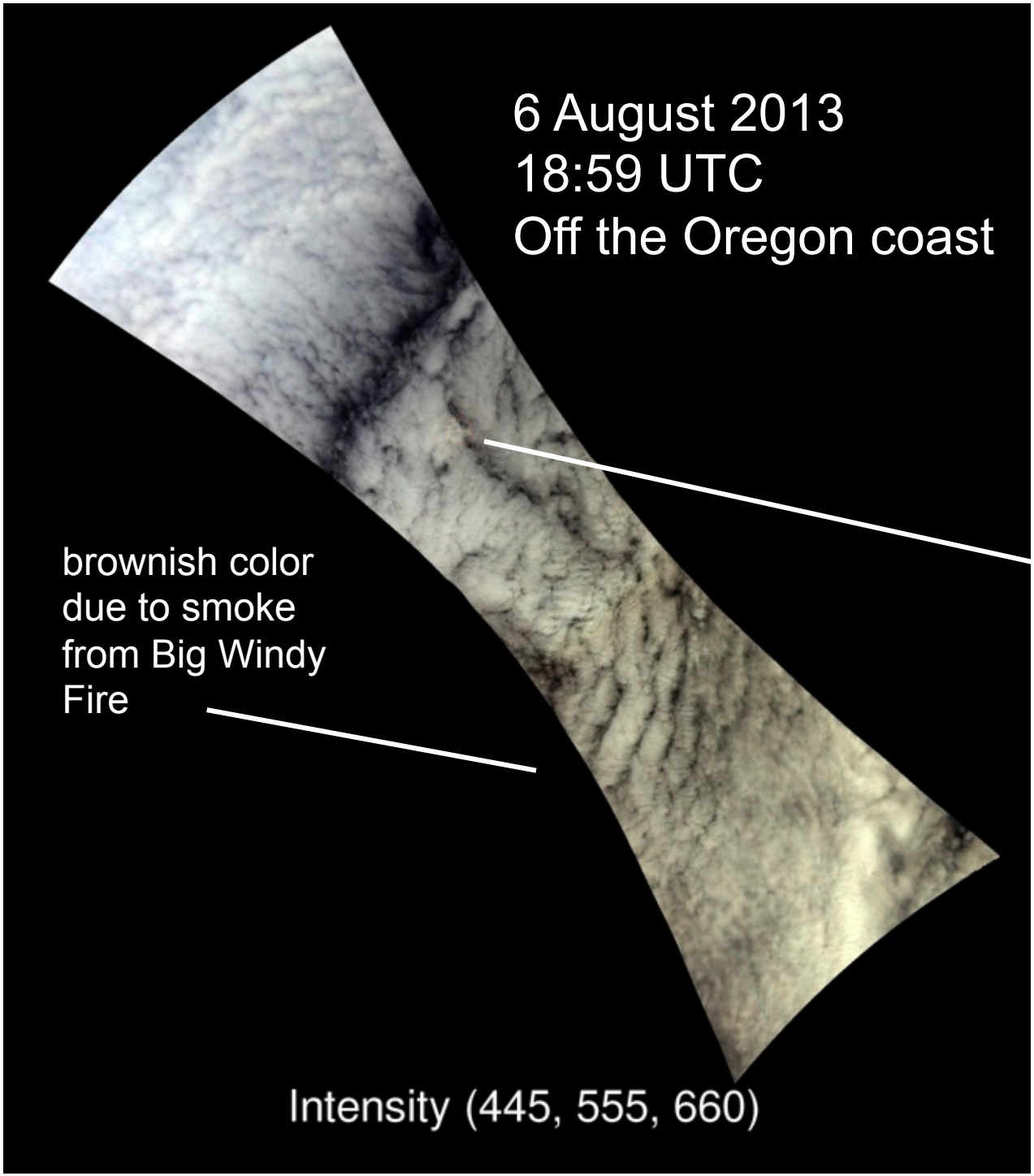
Santa Barbara, 1 August 2013

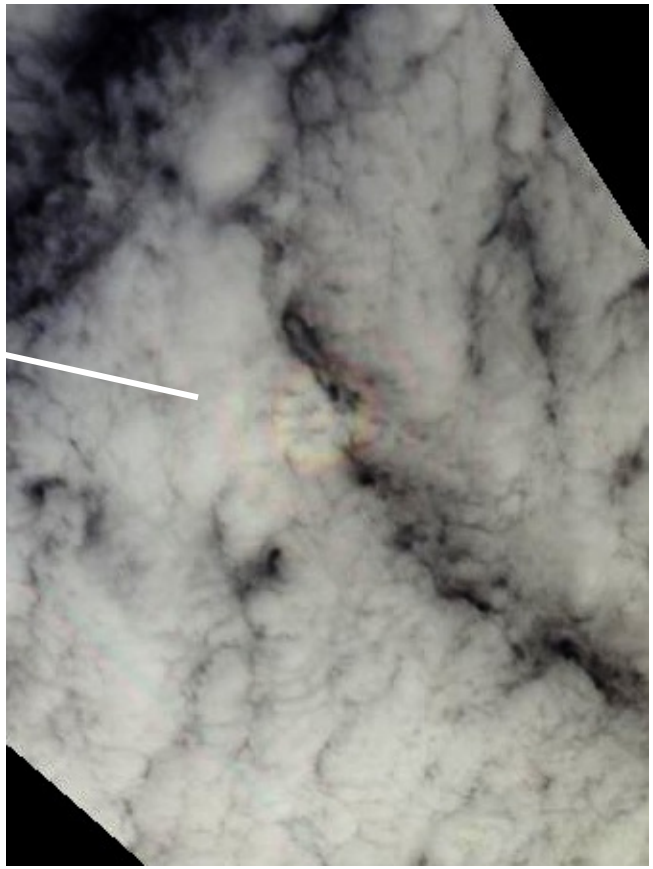
Example AirMSPI imagery



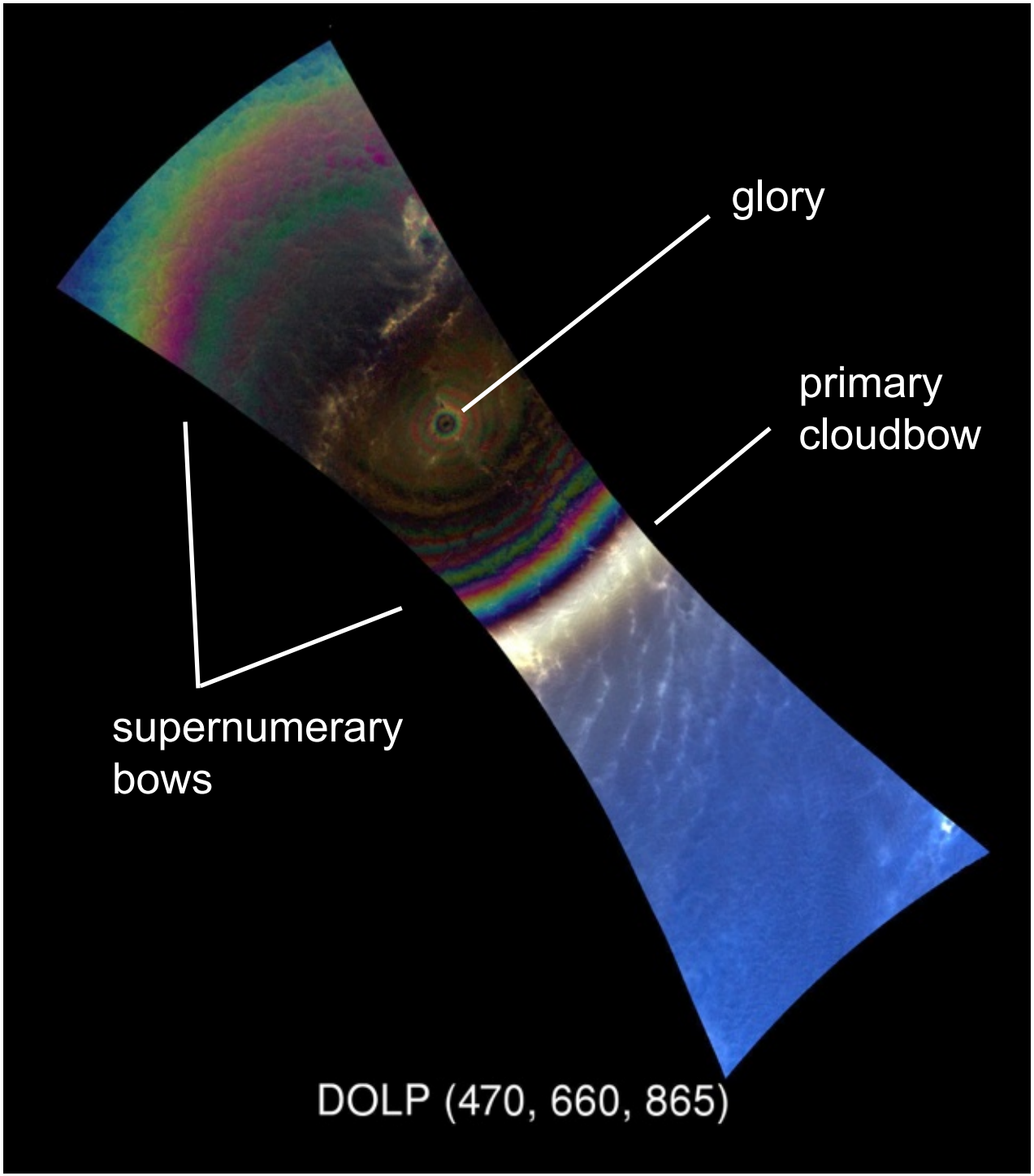
Bakersfield, CA 18 January 2013 18:01 UTC
47.4º view angle

Smoke over cloud





glory at 180º scattering angle



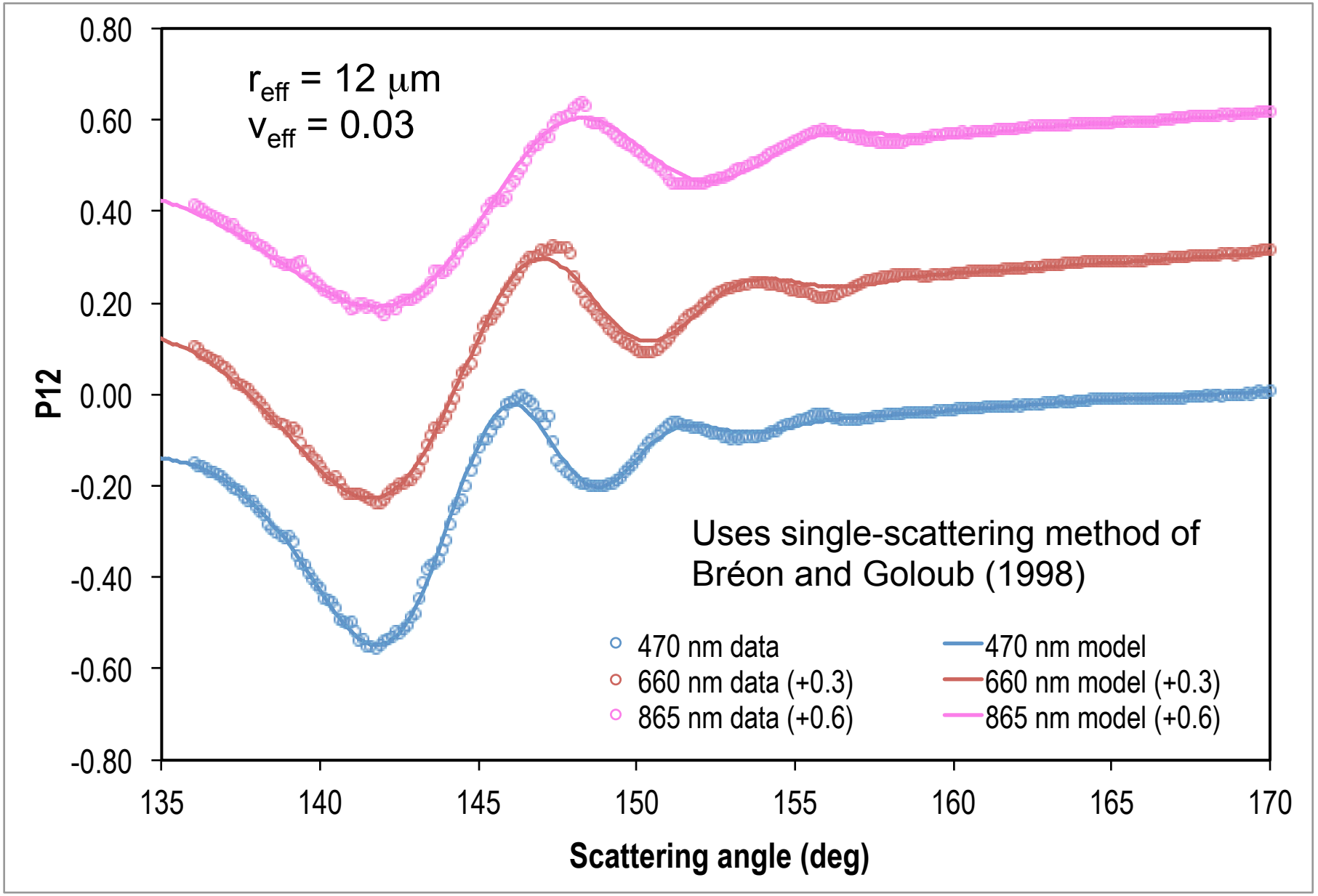
Polarized light

The cloudbow, glory, and supernumeraries indicate spherical drops

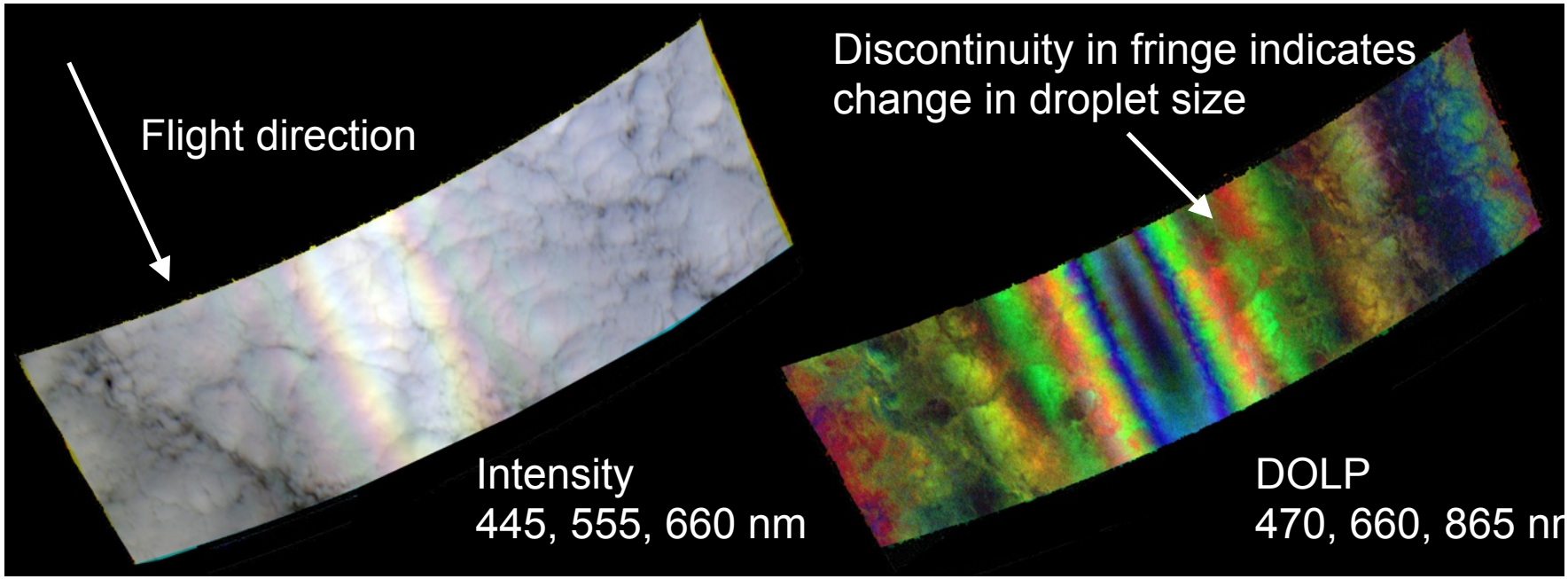
The supernumerary bows are interference fringes

Their angular positions and relative magnitudes are governed by the particle size distribution at the cloud top

Fits to supernumerary bow observations



Glory and supernumerary bows in step and stare



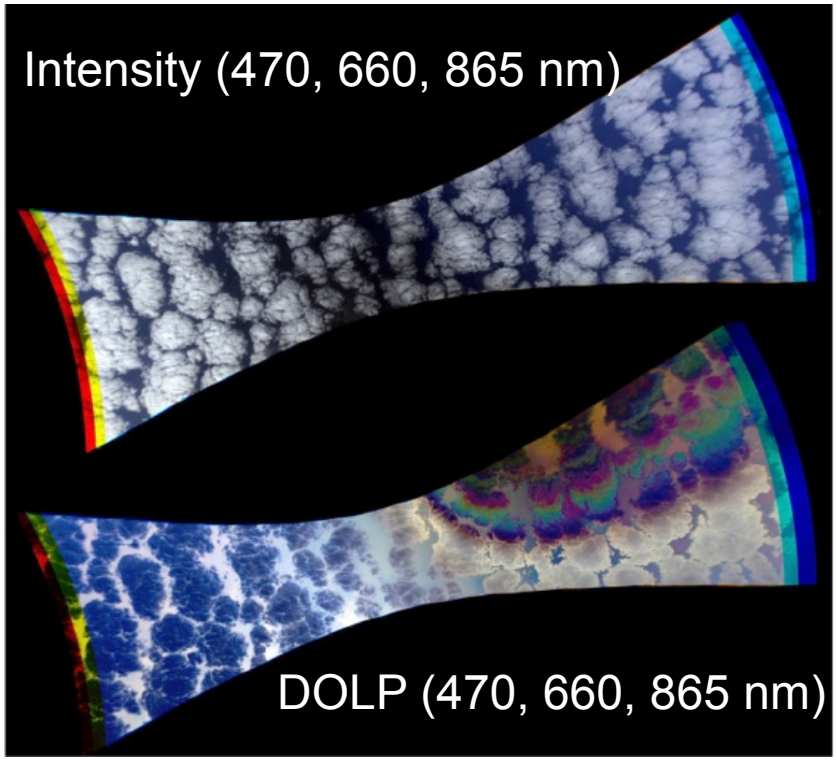
Clouds over the Pacific Ocean, 3 Feb 2013, 19:01 UTC
58.0º view angle

In sweep images, scattering angle varies both along-track and cross-track, so supernumerary fringes are circles

In step-and-stare, along-track angle is fixed, so fringes are stripes

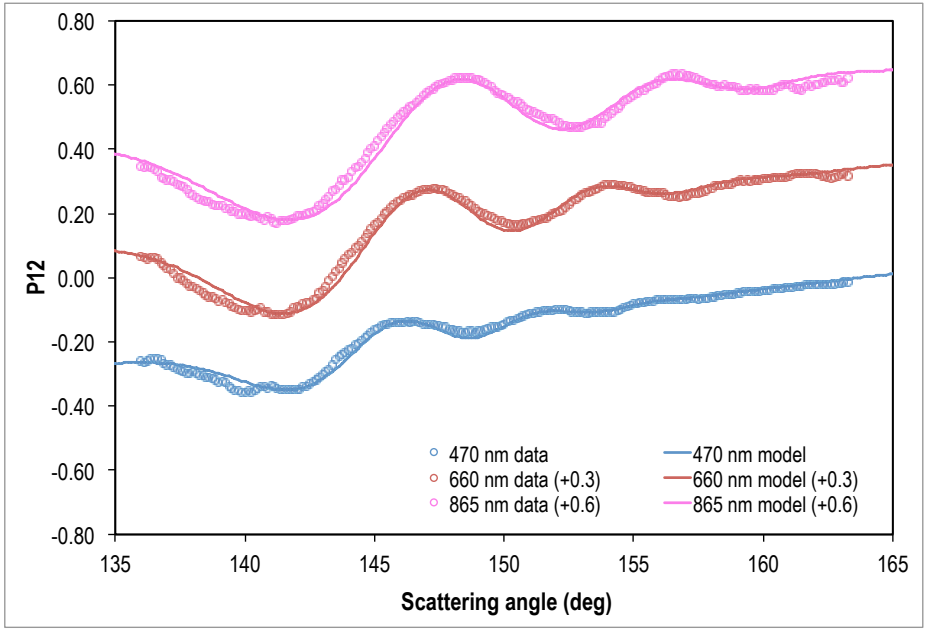
Cloudbow analysis of broken cumulus

The droplet size retrieval also works for broken clouds

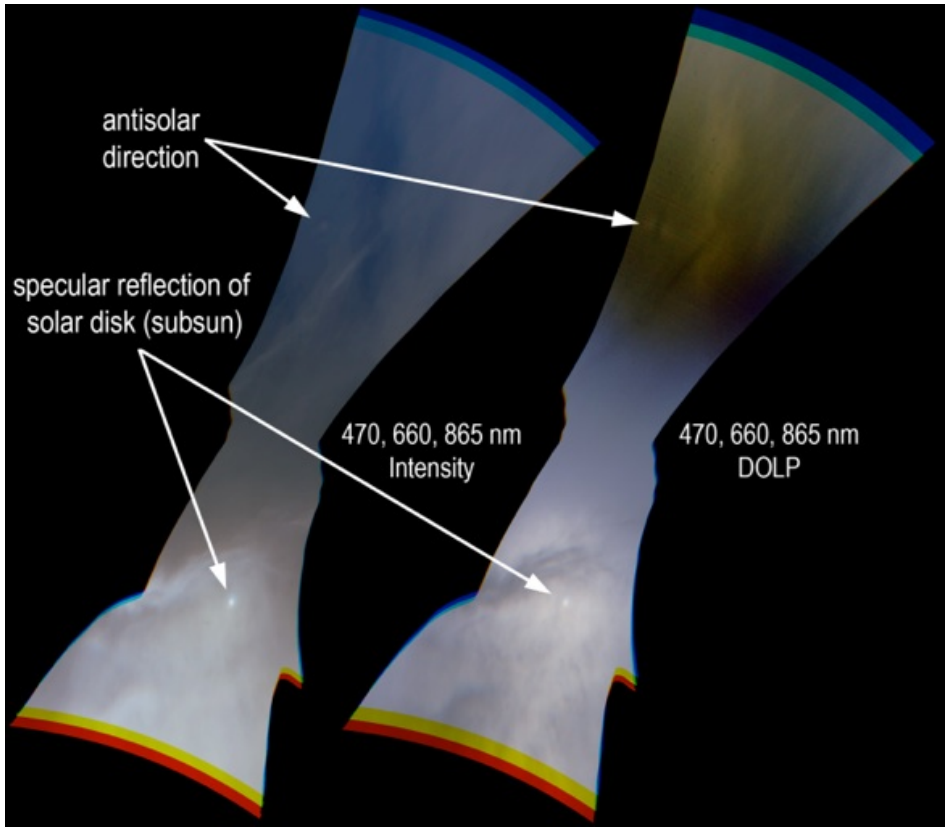


6 February 2013, 22:26 UTC
- Pacific sweep image

A simple intensity threshold was used to separate clouds from ocean. These data are fitted with with a distribution having an effective radius of 12 μm and effective variance of 0.02



Identification of cirrus from atmospheric optics

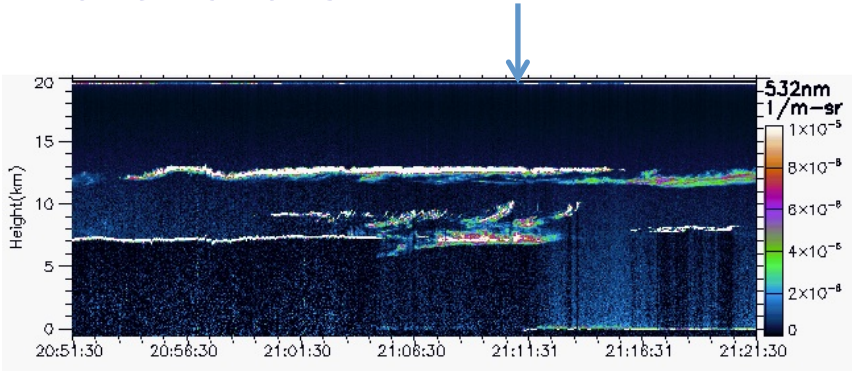


Clouds over ocean – 1 February 2013, 21:11 UTC

The subsun is the reflection of the solar disk from horizontally-oriented ice crystal plates.

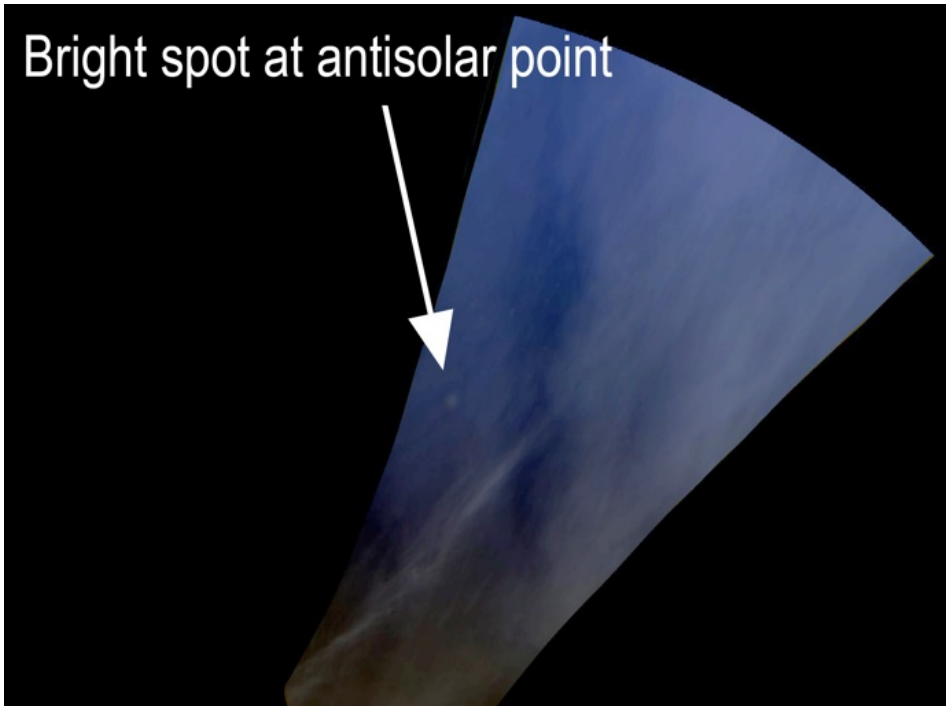
The DOLP of the subsun is 0.65, less than for pure specular reflection, possibly due to:

- light from a lower cloud deck
- plates with non-horizontal orientations



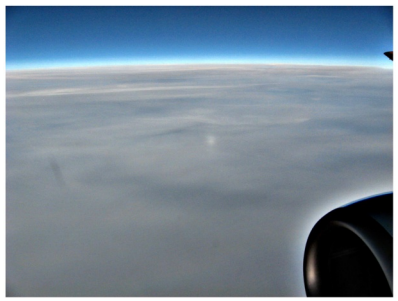
Cloud Physics Lidar (CPL) data show cirrus above lower cloud

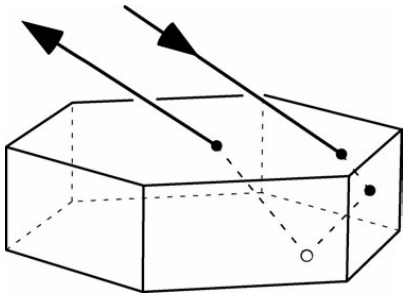
Feature at antisolar point



Clouds over ocean
1 February 2013, 21:11 UTC

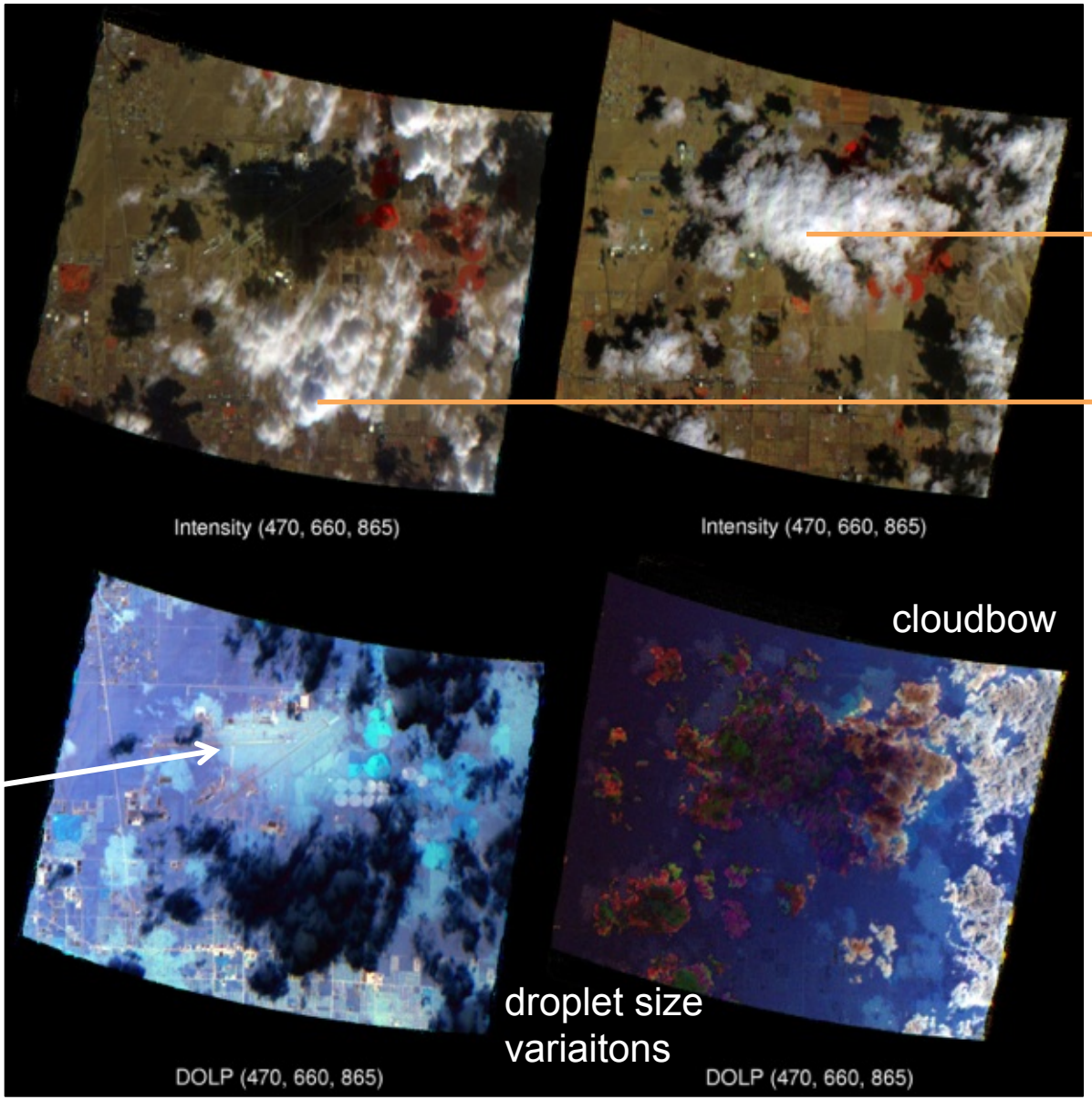
- Possible causes:
  - Glory from quasi-spherical ice particles (Sassen et al., 1998)
  - Anthelion from horizontal hexagonal columns (Lynch and Schwartz, 1979)
  - “Antisolar halospot”: superimposed subparhelic circles from hexagonal plates (Können et al., 2008)





Figures from Können et al. (2008), Appl. Opt., vol. 47

Other features of interest



Palmdale, CA
28 January 2013
19:14 UTC

flight direction

stereo parallax

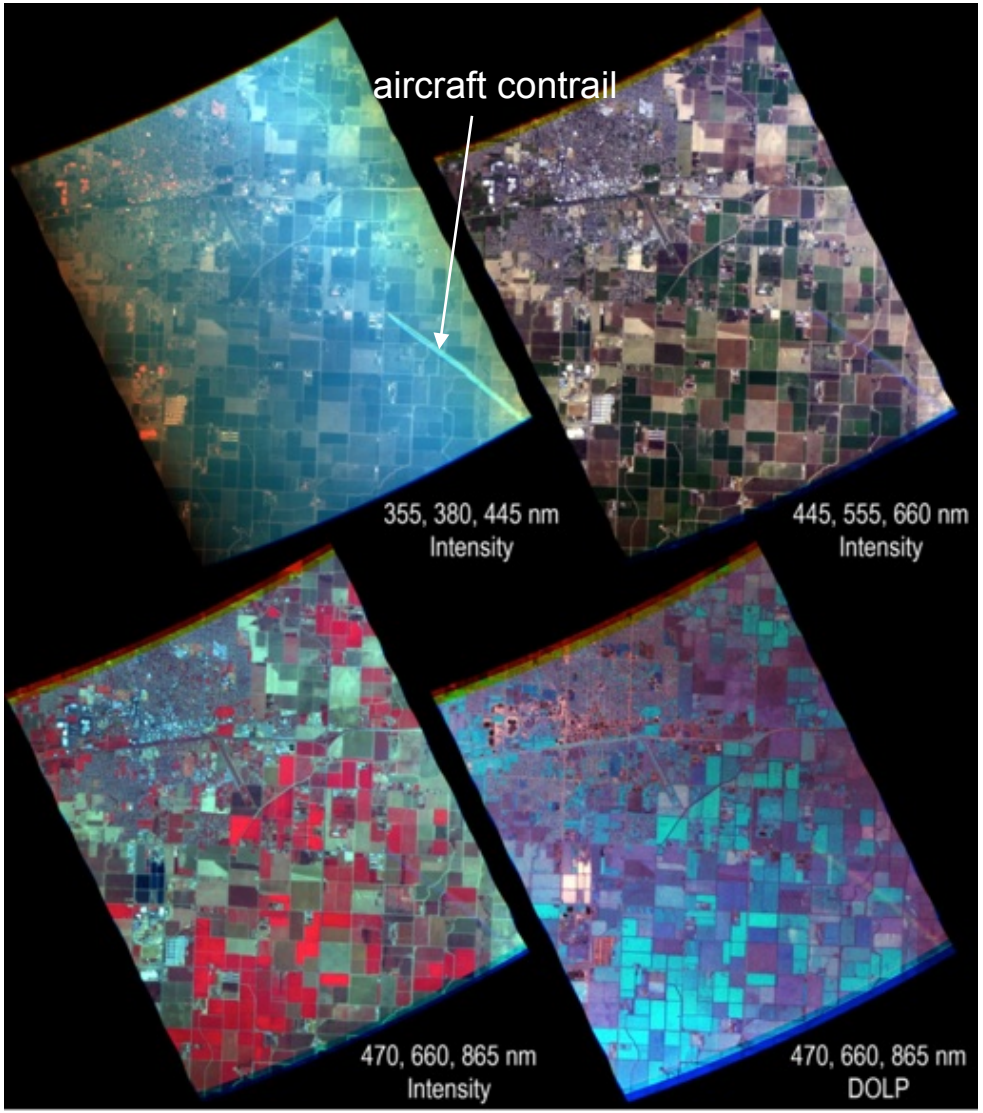
cloudbow

seeing into shadows

droplet size variaitons

line of constant scattering angle

AirMSPI data facilitate aerosol retrieval algorithm development



Hanford, CA
22 January 2013, 19:59 UTC

Enhanced scattering in the UV and blue

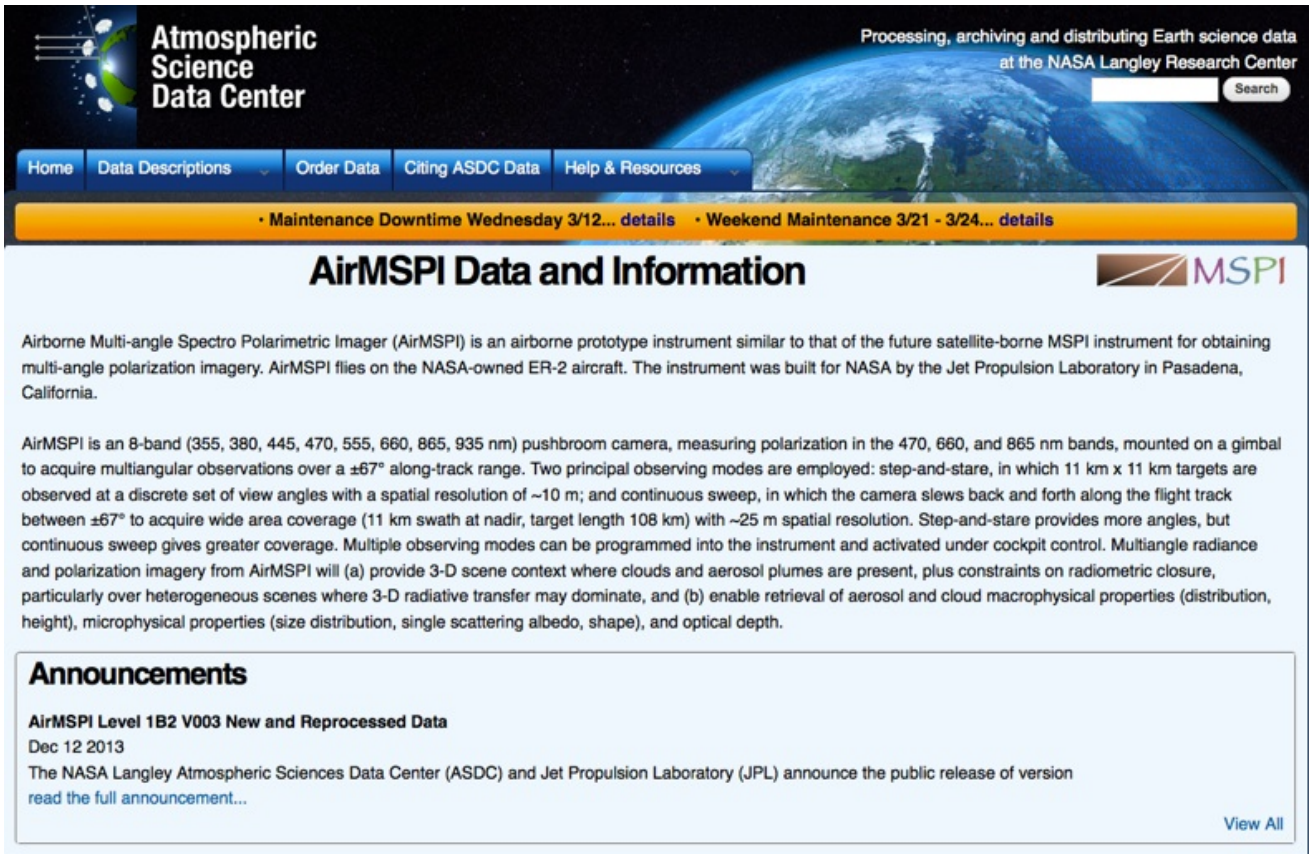
An aerosol retrieval algorithm using a Markov Chain vector radiative transfer code and optimized inversion is currently being tested

Public release of AirMSPI data

AirMSPI data are made publicly available in HDF5 format at the NASA Langley Atmospheric Science Data Center (ASDC)

Documentation available online

https://eosweb.larc.nasa.gov/project/airmspi/airmspi_table



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