

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

Workshop on Polarimetric Techniques and Technology  
Lorentz Center, Leiden, Netherlands, 24-28 March 2014



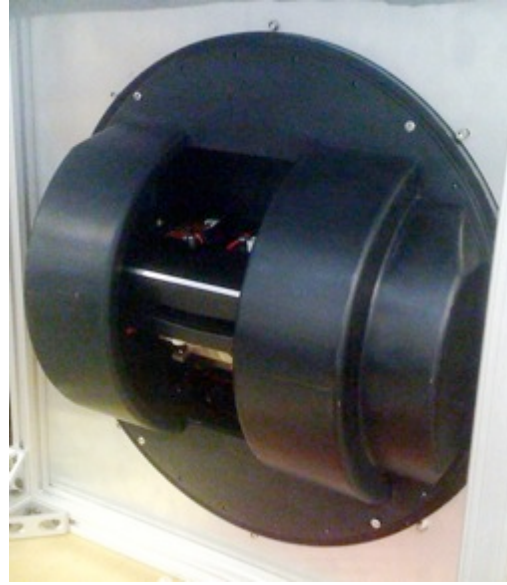
David J. Diner<sup>1</sup> and Stephen C. McClain<sup>2</sup> (presenting)

<sup>1</sup>Jet Propulsion Laboratory, Caltech

<sup>2</sup>University of Arizona

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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)

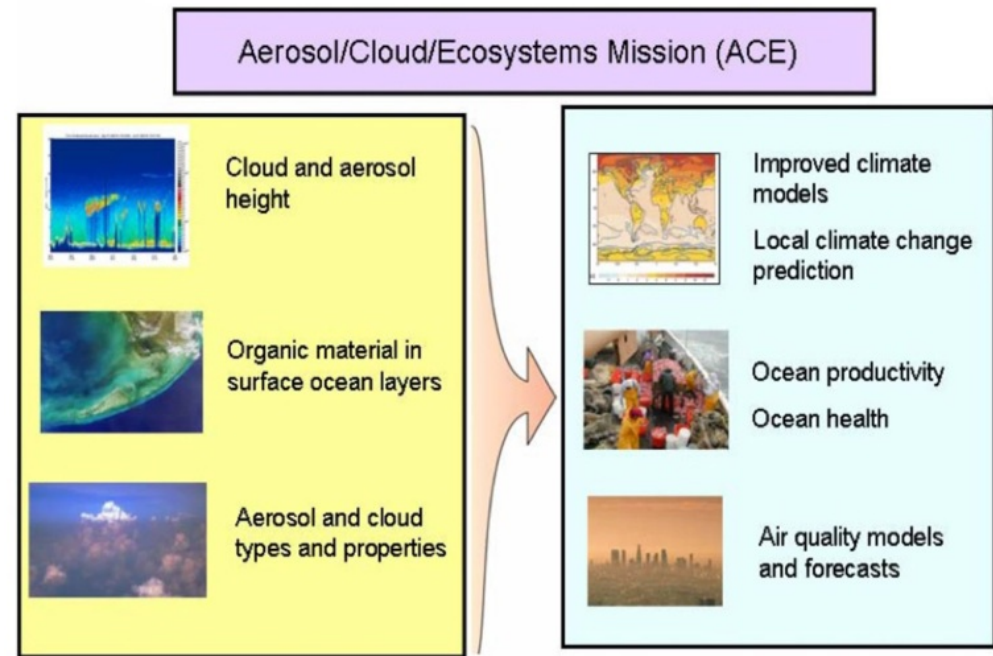
AirMSPI is mounted in a gimbal for multi-angle viewing between  $\pm 67^\circ$

# 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

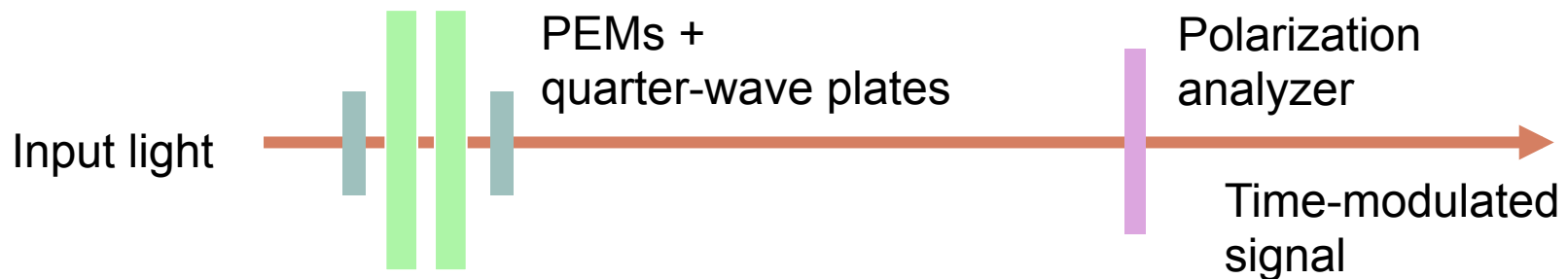
# 2013 field campaigns

- ACE Polarimeter Definition Experiment (PODEX)
  - Jan 14, 16, 18, 22, 28, 31; Feb 1, 3, 6: California
- Hyperspectral Infrared Imager (HyspIRI)
  - Apr 19; May 3, 7: California
- Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC<sup>4</sup>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



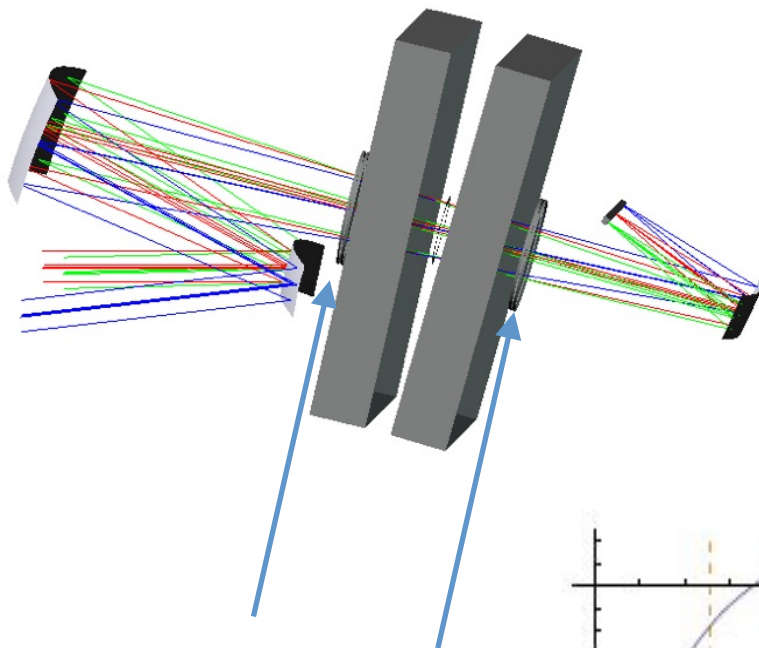
# AirMSPI dual-PEM polarimeter approach

- 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  $\sim 42$  kHz
  - Using dual PEMs with their fast axes aligned, modulation of  $Q$  and  $U$  occurs at the difference frequency (nominally  $\sim 25$  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

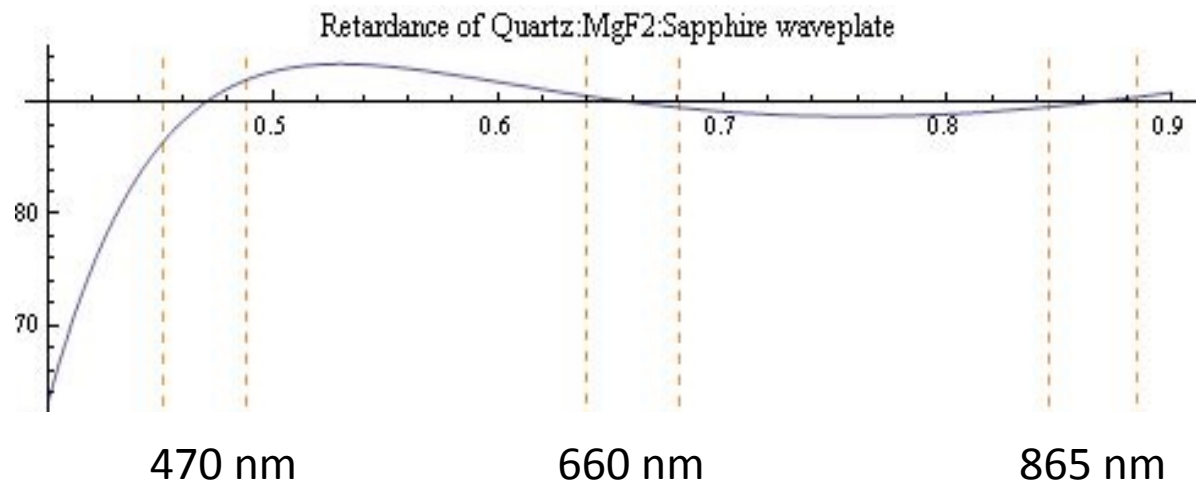
Dual PEM



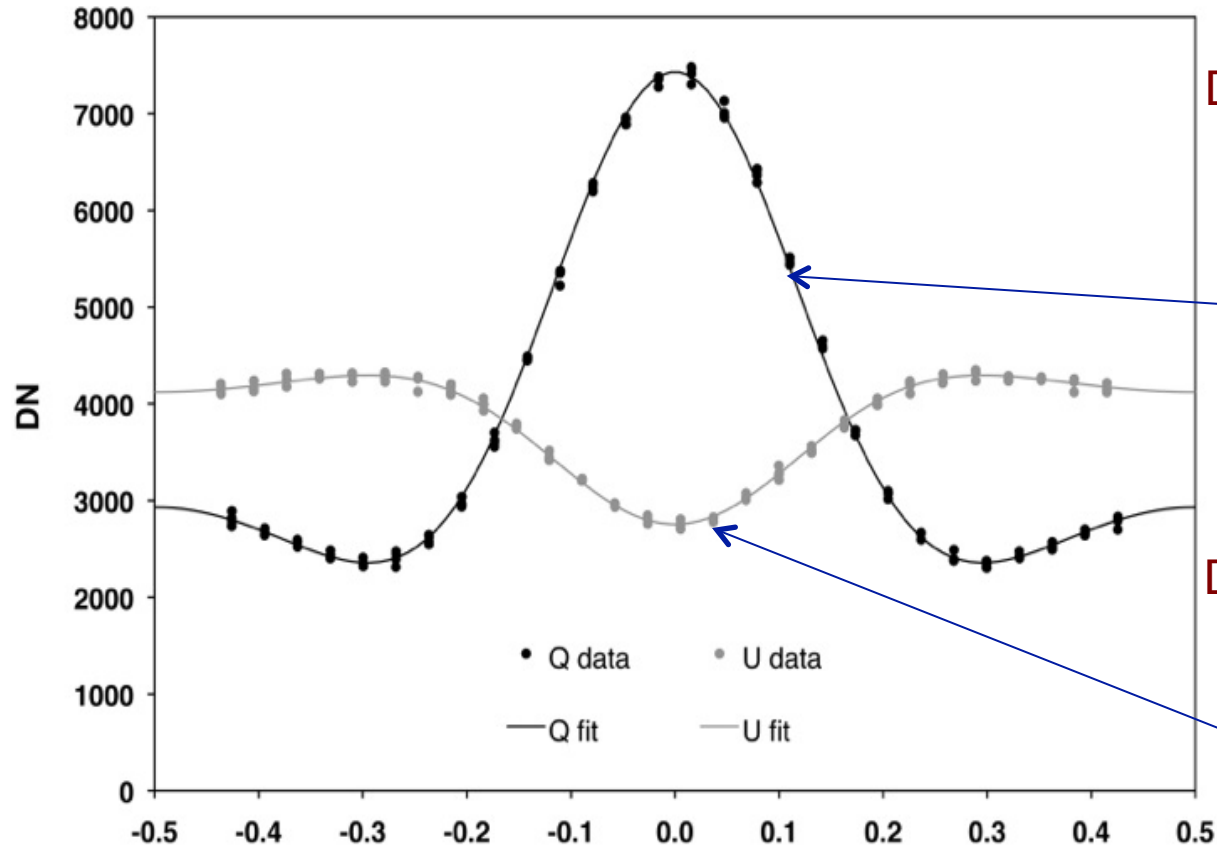
3-mirror reflective anastigmatic,  
telecentric telescope

Focal length = 29 mm

Achromatic  
quarter-wave  
plates



# Polarimetry using temporal modulation



Detector row with 0° polarizer

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

Measures  
both Q and I  
→  $q$

Detector row with 45° polarizer

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

Measures both  
U and I →  $u$

1 frame ~ 43 msec

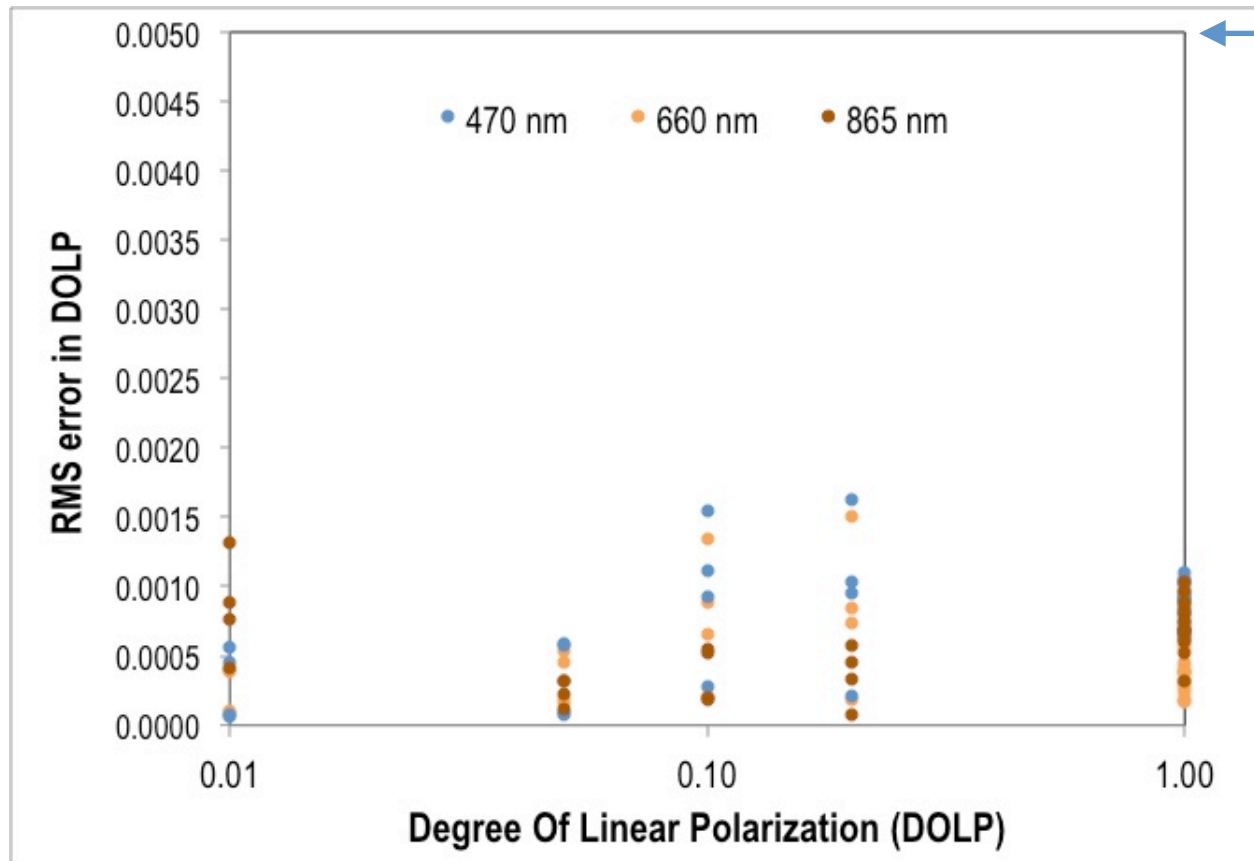
Degree of linear polarization

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

Angle of linear polarization

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

# Polarimetric uncertainty



NASA Aerosol-  
Cloud-Ecosystem  
(ACE)  
DOLP uncertainty  
requirement:  
 $\leq 0.005$

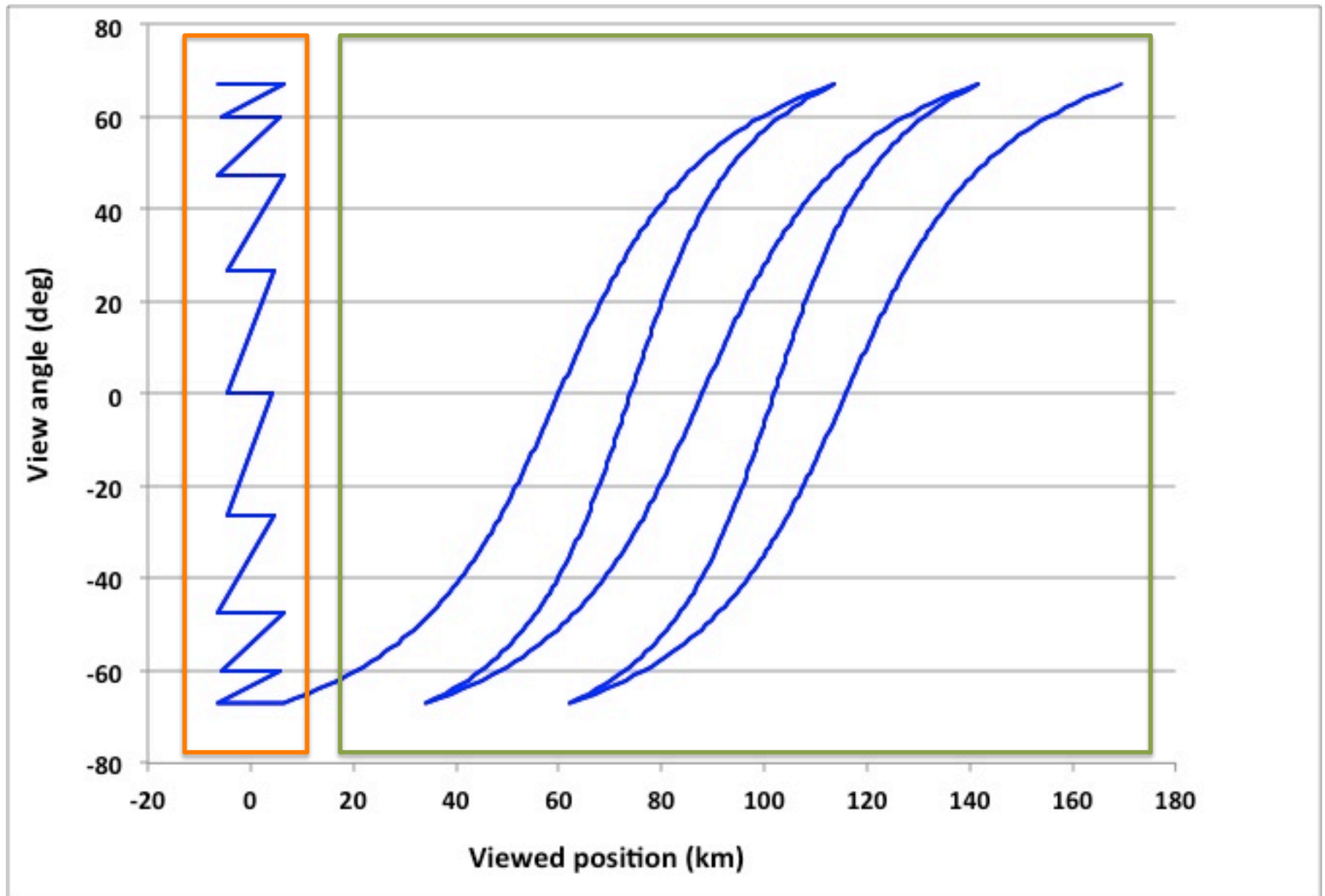
DOLP of 0.01, 0.05, 0.10, and 0.20 measured for polarizer angles 0°, 45°, 90°, 135°

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

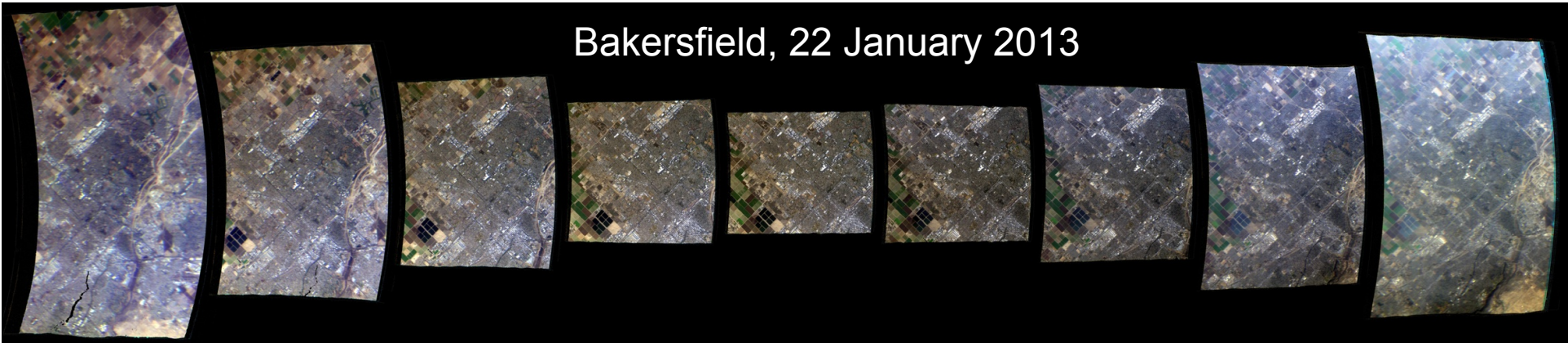
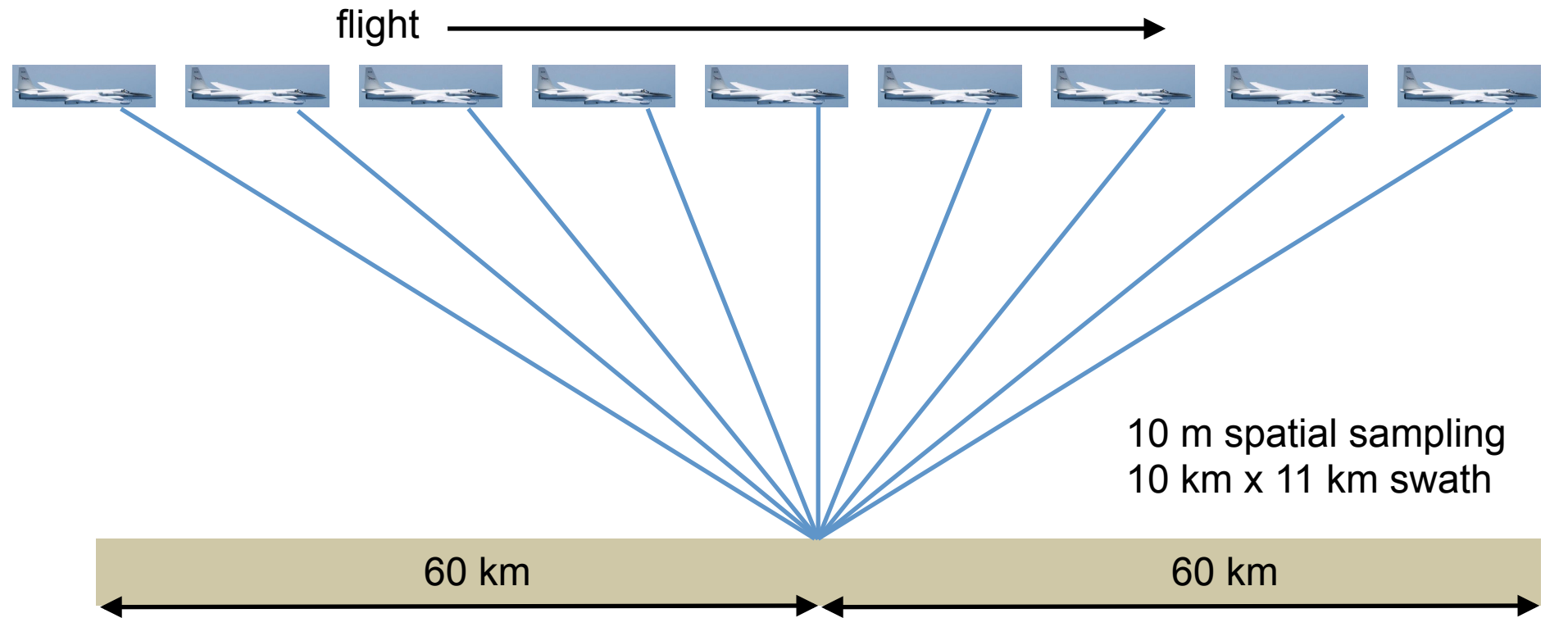


Step and stare

Sweep



# Step and stare imaging

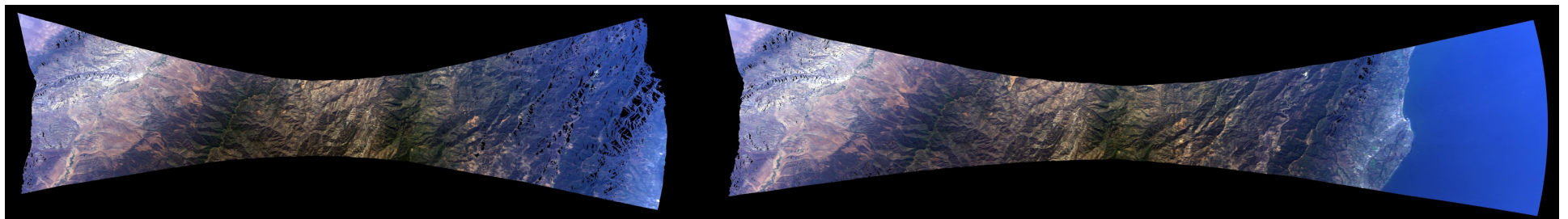
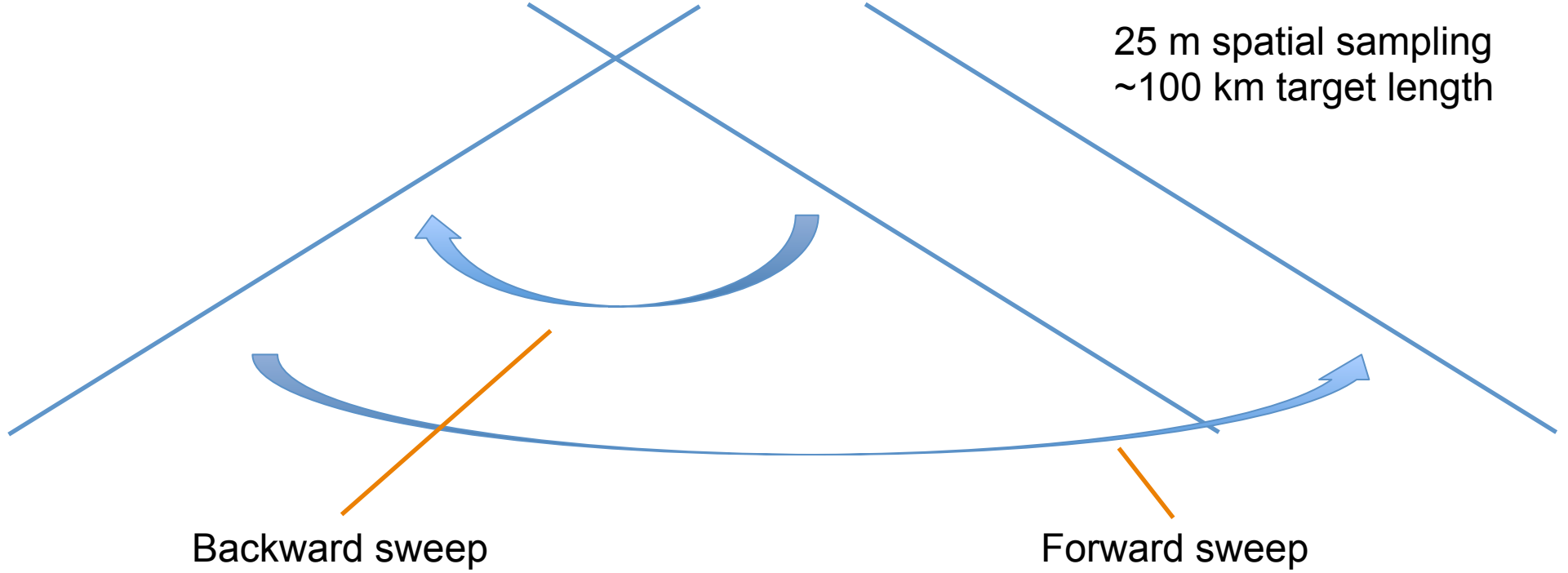


# Sweep mode imaging

flight

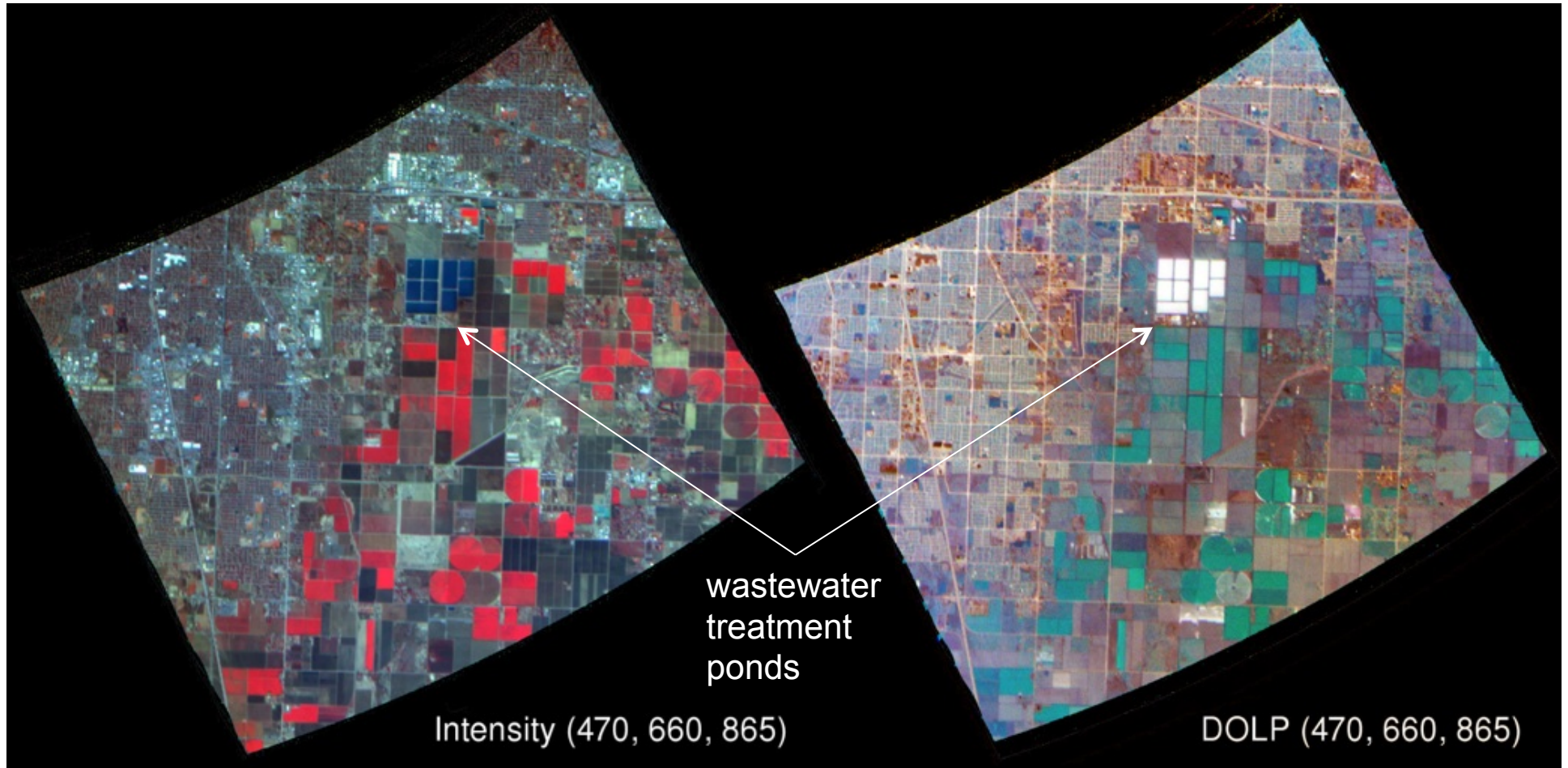


25 m spatial sampling  
~100 km target length



Santa Barbara, 1 August 2013

# Example AirMSPI imagery



Bakersfield, CA  
47.4° view angle

18 January 2013

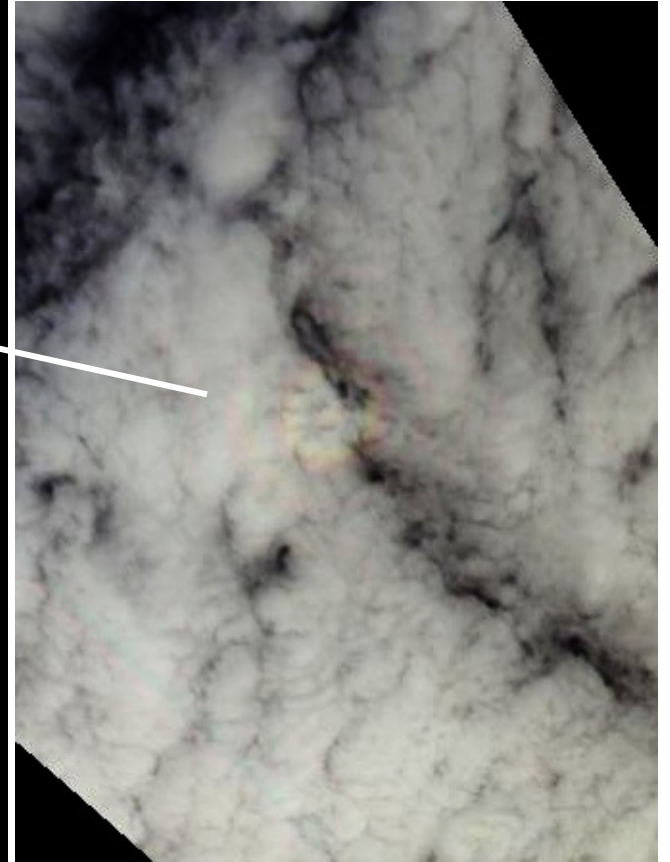
18:01 UTC

6 August 2013  
18:59 UTC  
Off the Oregon coast

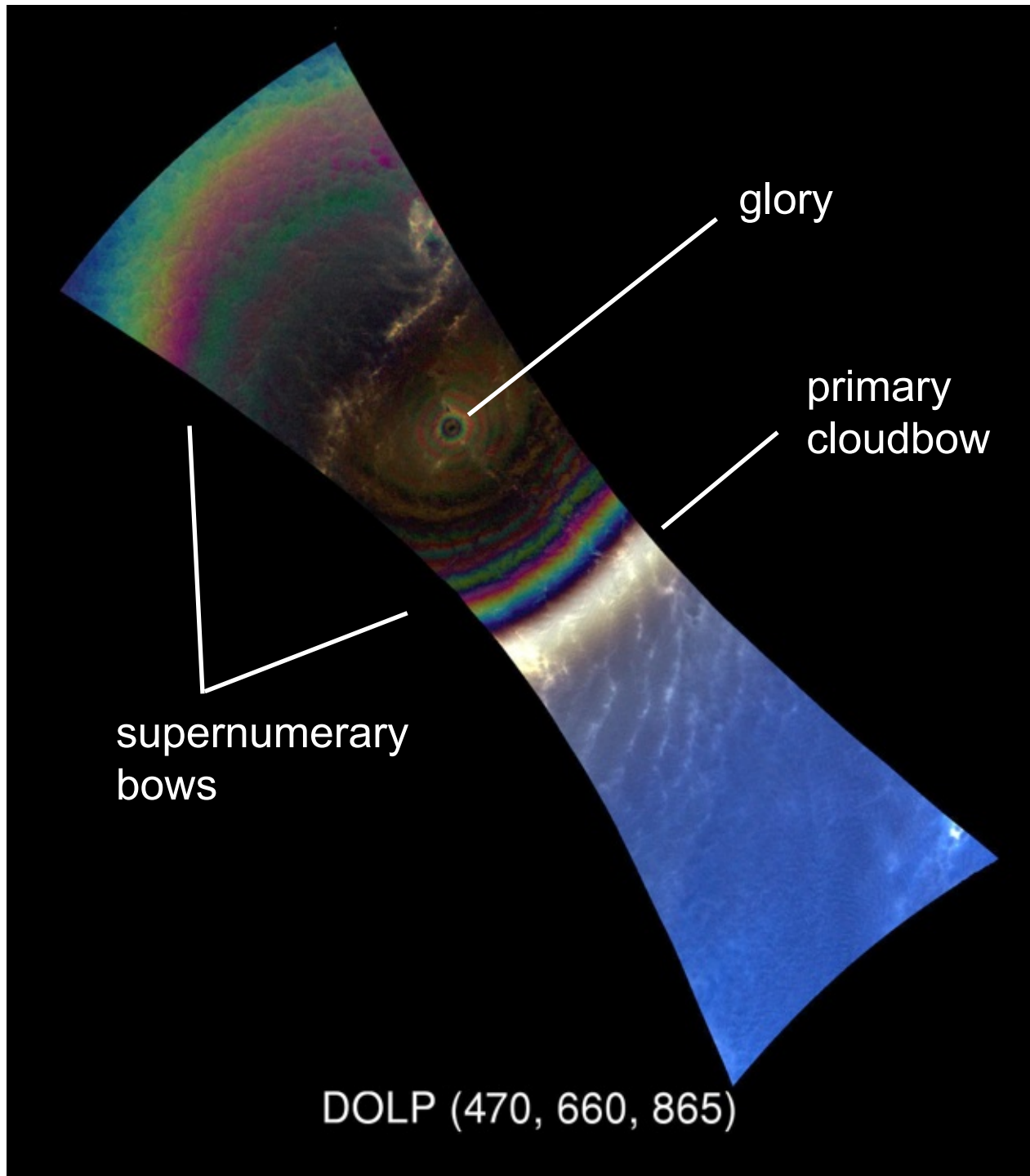
Smoke over  
cloud

brownish color  
due to smoke  
from Big Windy  
Fire

Intensity (445, 555, 660)



glory at 180°  
scattering angle



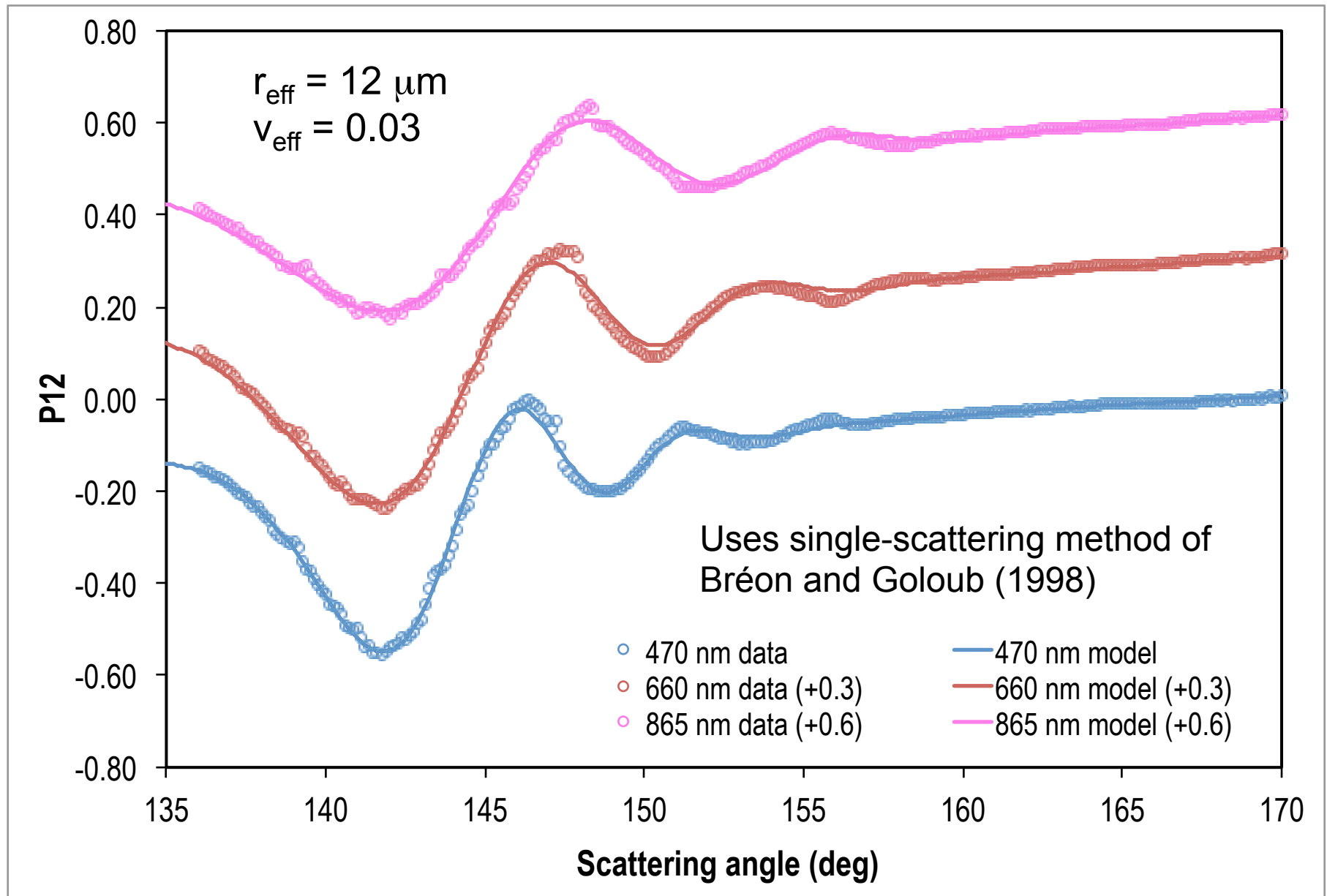
## Polarized light

The cloudbow, glory, and supernumeraries indicate spherical drops

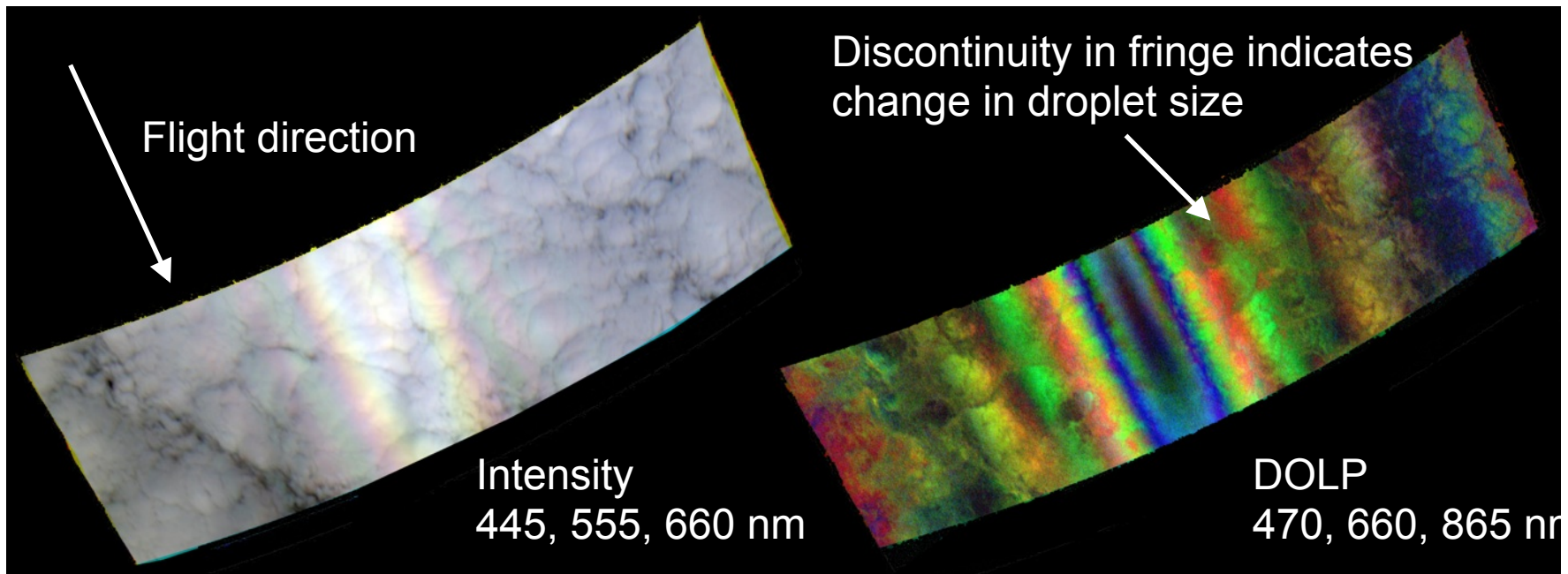
The supernumerary bows are interference fringes

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  
58.0° view angle

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

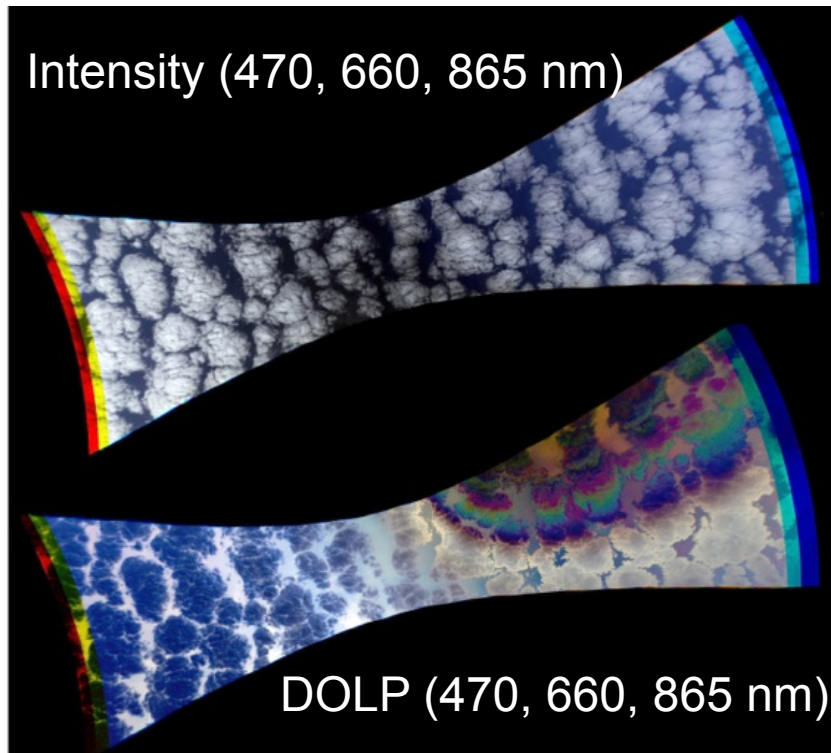
In step-and-stare, along-track angle is fixed, so fringes are stripes



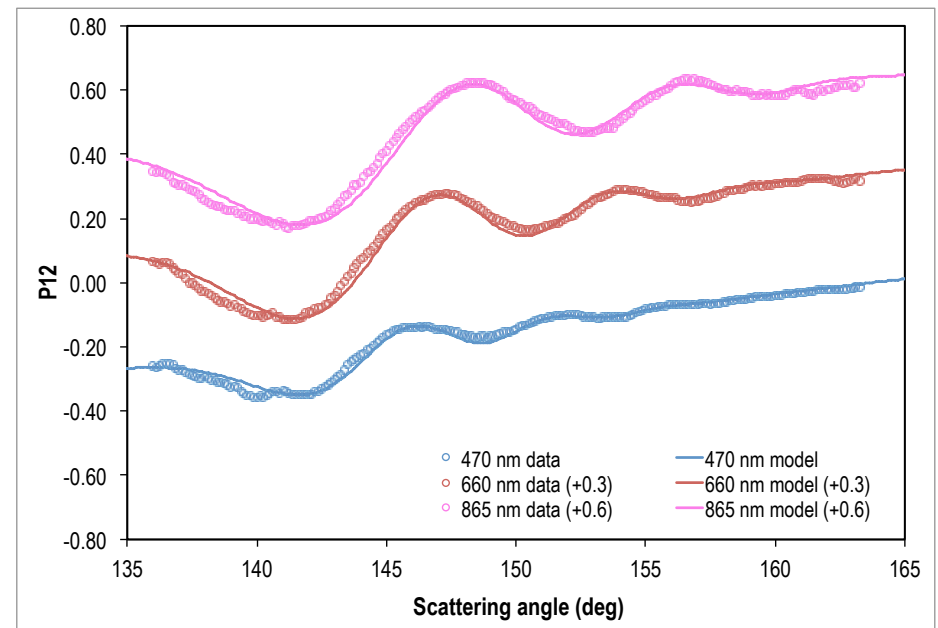
# Cloudbow analysis of broken cumulus

The droplet size retrieval also works for broken clouds

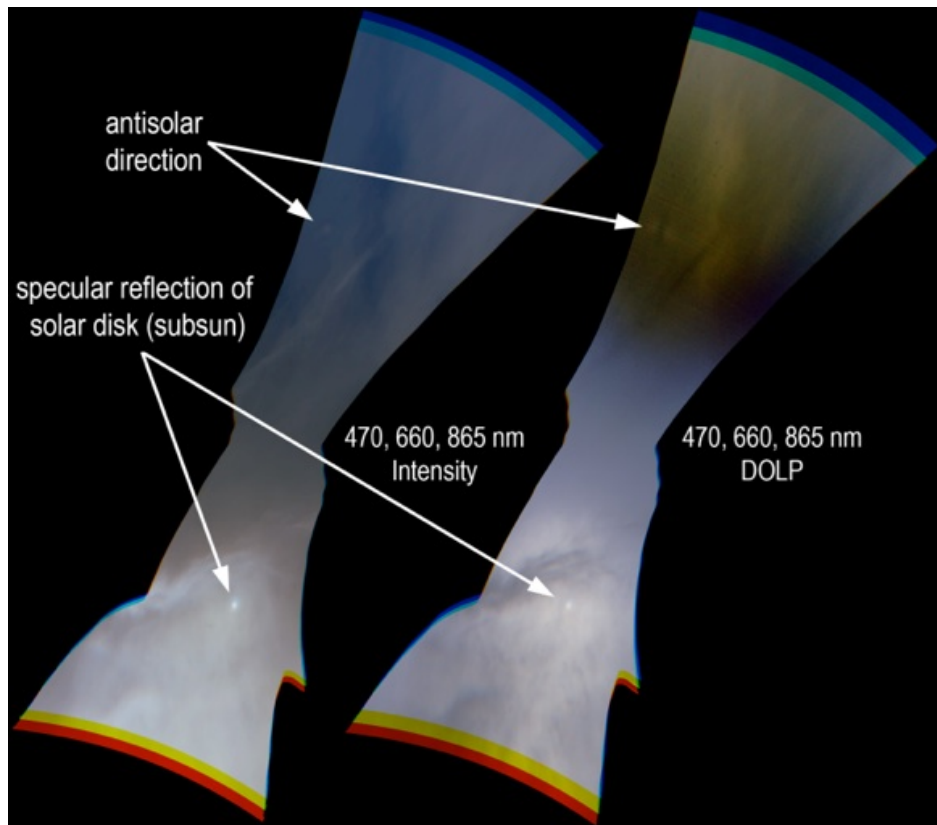
A simple intensity threshold was used to separate clouds from ocean. These data are fitted with with a distribution having an effective radius of  $12\ \mu\text{m}$  and effective variance of 0.02



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



# Identification of cirrus from atmospheric optics

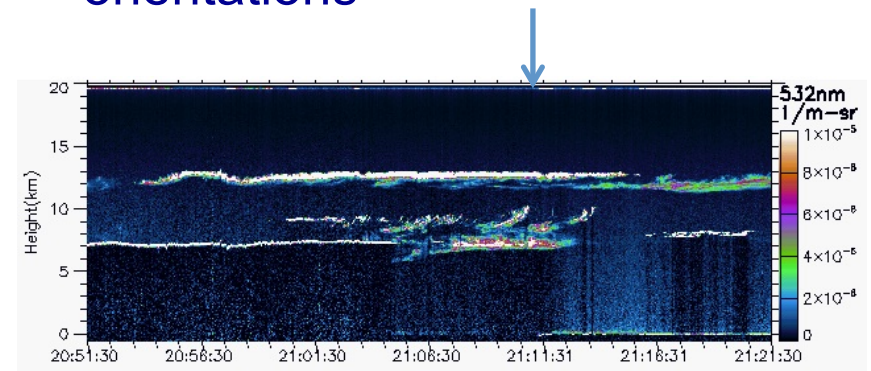


Clouds over ocean – 1 February 2013, 21:11 UTC

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

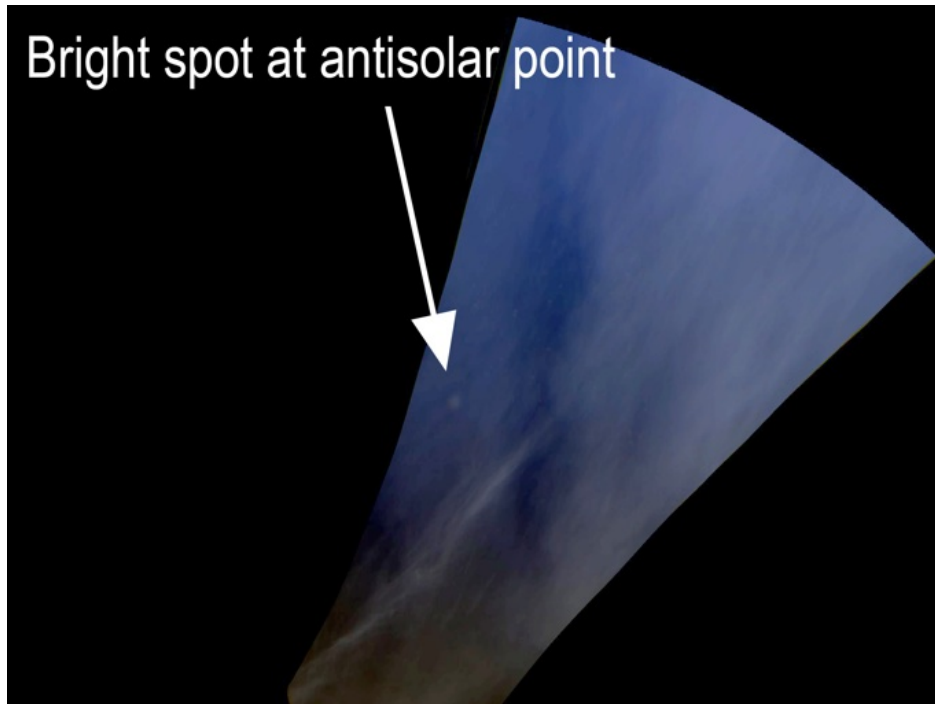
The DOLP of the subsun is 0.65, less than for pure specular reflection, possibly due to:

- 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

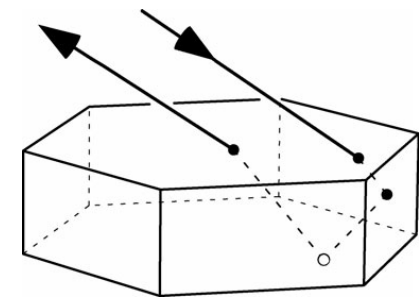


Clouds over ocean  
1 February 2013, 21:11 UTC

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

## ■ 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)



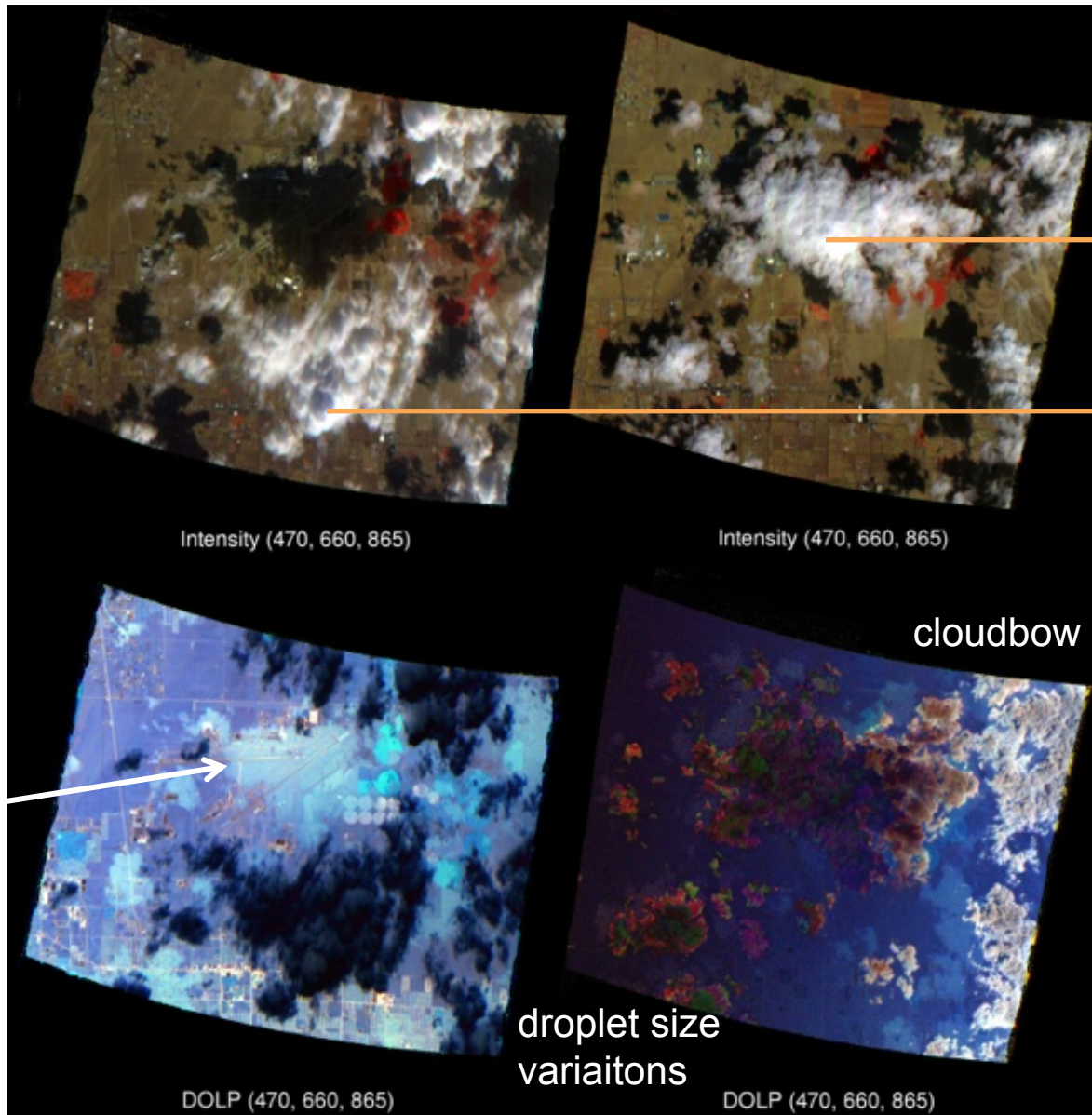
# Other features of interest

47° forward view

47° backward view

Palmdale, CA  
28 January 2013  
19:14 UTC

flight  
direction



stereo parallax

seeing into  
shadows



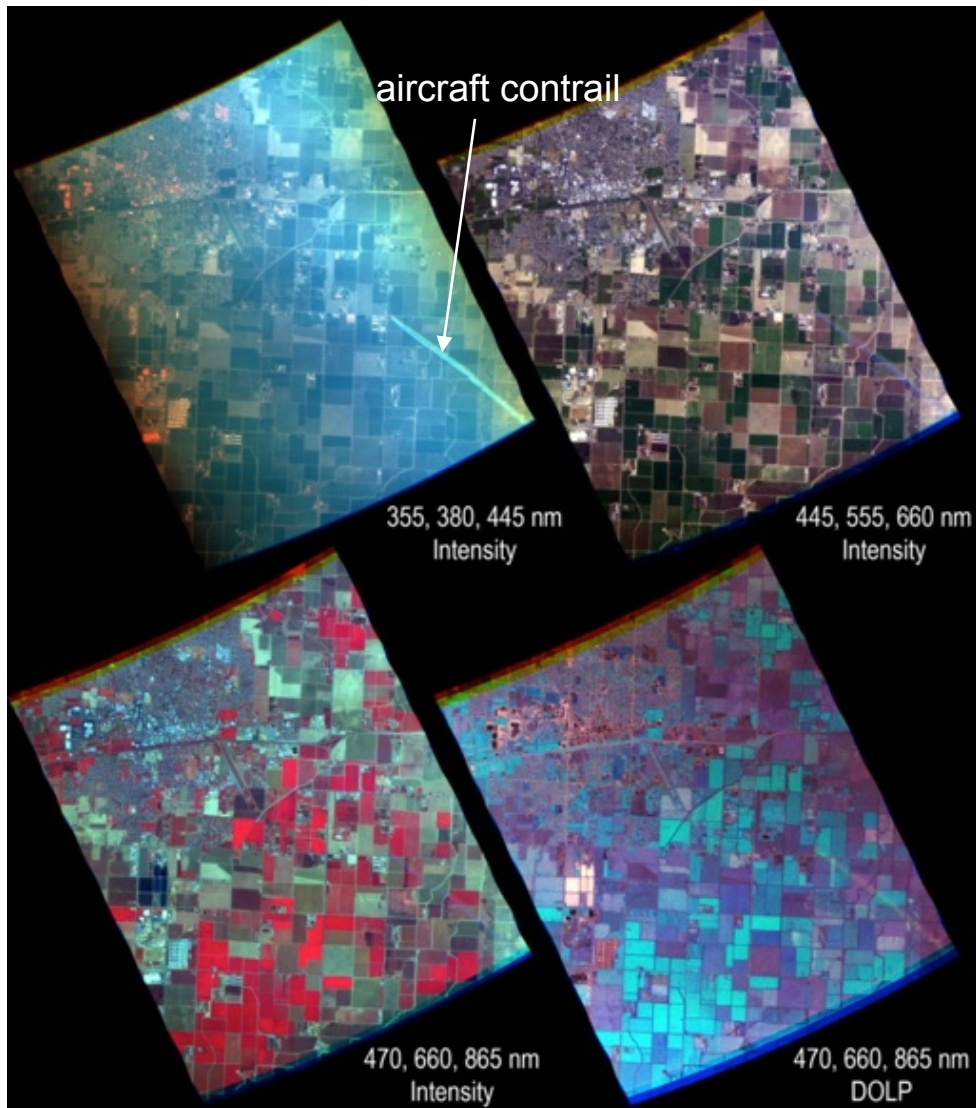
droplet size  
variations

cloudbow

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

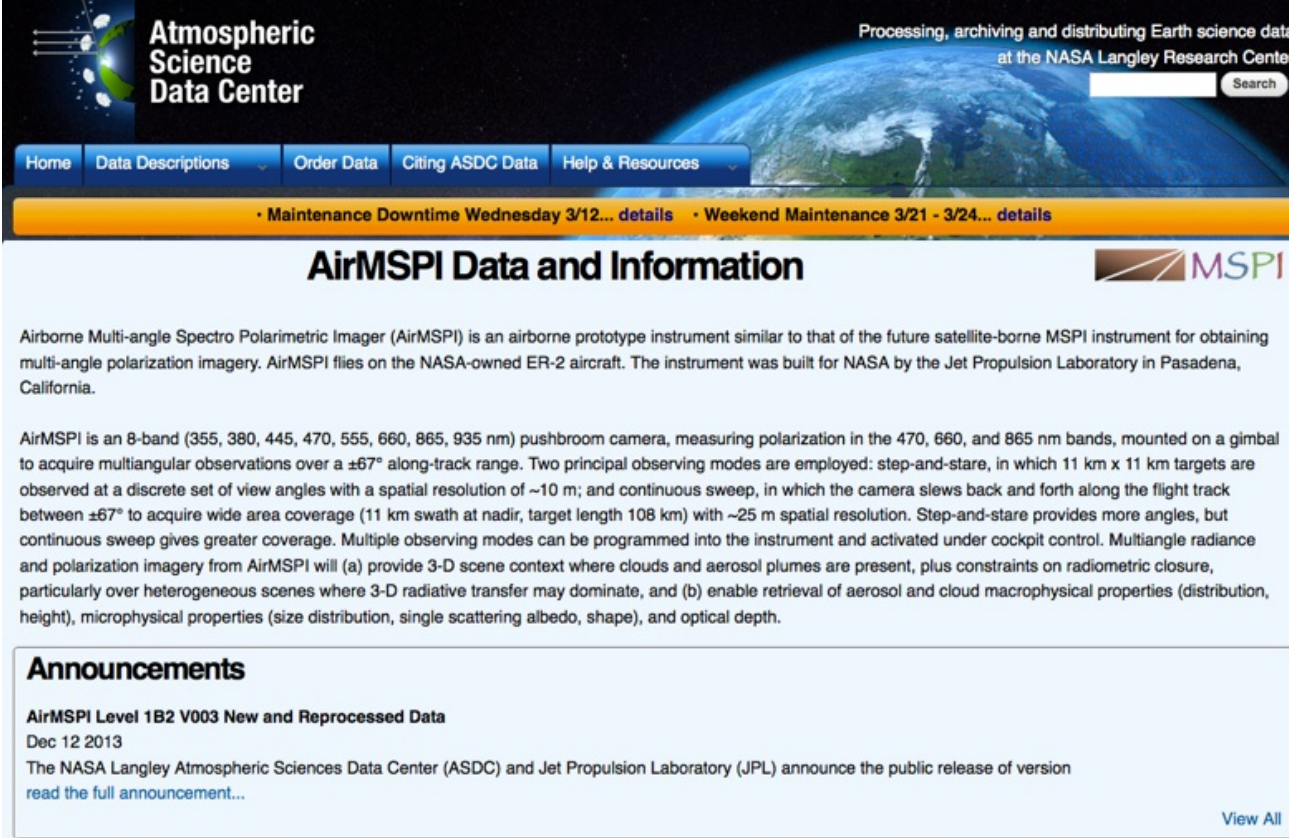
An aerosol retrieval algorithm  
using a Markov Chain vector  
radiative transfer code and  
optimized inversion is currently  
being tested

# 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](https://eosweb.larc.nasa.gov/project/airmspi/airmspi_table)



The screenshot shows the NASA Langley Atmospheric Science Data Center website. The header includes the logo and text: "Atmospheric Science Data Center" and "Processing, archiving and distributing Earth science data at the NASA Langley Research Center". A search bar is visible. The navigation menu includes "Home", "Data Descriptions", "Order Data", "Citing ASDC Data", and "Help & Resources". A yellow banner below the menu contains maintenance notices: "Maintenance Downtime Wednesday 3/12... details" and "Weekend Maintenance 3/21 - 3/24... details". The main heading is "AirMSPI Data and Information" with an "MSPI" logo. The text describes the AirMSPI instrument and its capabilities. An "Announcements" section is highlighted, featuring a notice about "AirMSPI Level 1B2 V003 New and Reprocessed Data" dated Dec 12 2013, with a link to "read the full announcement...". A "View All" link is located at the bottom right of the announcements box.

**Atmospheric Science Data Center**  
Processing, archiving and distributing Earth science data at the NASA Langley Research Center

Home Data Descriptions Order Data Citing ASDC Data Help & Resources

Maintenance Downtime Wednesday 3/12... details Weekend Maintenance 3/21 - 3/24... details

## AirMSPI Data and Information

**AirMSPI**

Airborne Multi-angle Spectro Polarimetric Imager (AirMSPI) is an airborne prototype instrument similar to that of the future satellite-borne MSPI instrument for obtaining multi-angle polarization imagery. AirMSPI flies on the NASA-owned ER-2 aircraft. The instrument was built for NASA by the Jet Propulsion Laboratory in Pasadena, California.

AirMSPI is an 8-band (355, 380, 445, 470, 555, 660, 865, 935 nm) pushbroom camera, measuring polarization in the 470, 660, and 865 nm bands, mounted on a gimbal to acquire multiangular observations over a  $\pm 67^\circ$  along-track range. Two principal observing modes are employed: step-and-stare, in which 11 km x 11 km targets are observed at a discrete set of view angles with a spatial resolution of  $\sim 10$  m; and continuous sweep, in which the camera slews back and forth along the flight track between  $\pm 67^\circ$  to acquire wide area coverage (11 km swath at nadir, target length 108 km) with  $\sim 25$  m spatial resolution. Step-and-stare provides more angles, but continuous sweep gives greater coverage. Multiple observing modes can be programmed into the instrument and activated under cockpit control. Multiangle radiance and polarization imagery from AirMSPI will (a) provide 3-D scene context where clouds and aerosol plumes are present, plus constraints on radiometric closure, particularly over heterogeneous scenes where 3-D radiative transfer may dominate, and (b) enable retrieval of aerosol and cloud macrophysical properties (distribution, height), microphysical properties (size distribution, single scattering albedo, shape), and optical depth.

### Announcements

**AirMSPI Level 1B2 V003 New and Reprocessed Data**  
Dec 12 2013  
The NASA Langley Atmospheric Sciences Data Center (ASDC) and Jet Propulsion Laboratory (JPL) announce the public release of version  
[read the full announcement...](#)

[View All](#)

# Acknowledgments

## *AirMSPI engineering and operations*

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## *AirMSPI calibration*

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