

# UV-SWIR Achromatic Quarter Wave Retarder for the Multiangle SpectroPolarimetric Imager (MSPI)

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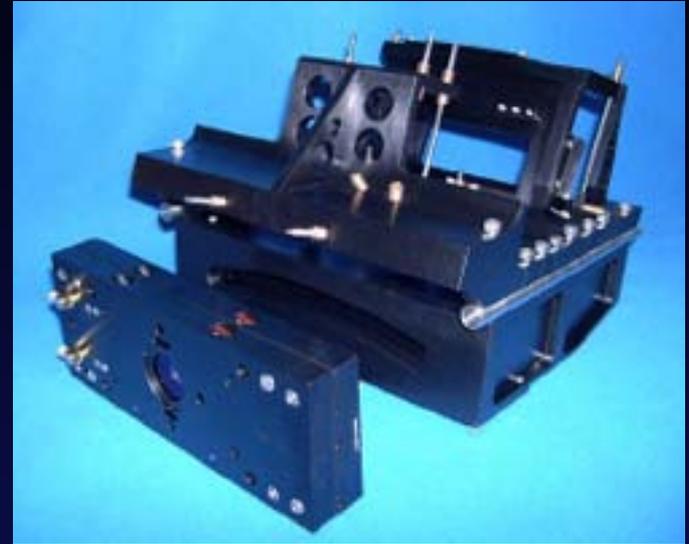
Stacey R. Sueoka, Russell Chipman, Stephen C. McClain,  
Christine Bradley  
*College of Optical Sciences, University of Arizona*

David J. Diner  
*Jet Propulsion Laboratory, California Institute of Technology*

ESTF 2011  
June 22<sup>nd</sup>, 2011

# Outline

- MSPI system overview
- Polarization architecture
- Achromatic retarder
  - Design
  - Fabrication
  - Testing and results
- Ground-based MSPI status report
- AirMSPI status report
- Conclusion/Future work



# NASA Aerosol-Cloud-Ecosystem (ACE) mission

## ■ NAS Decadal Survey, January 2007

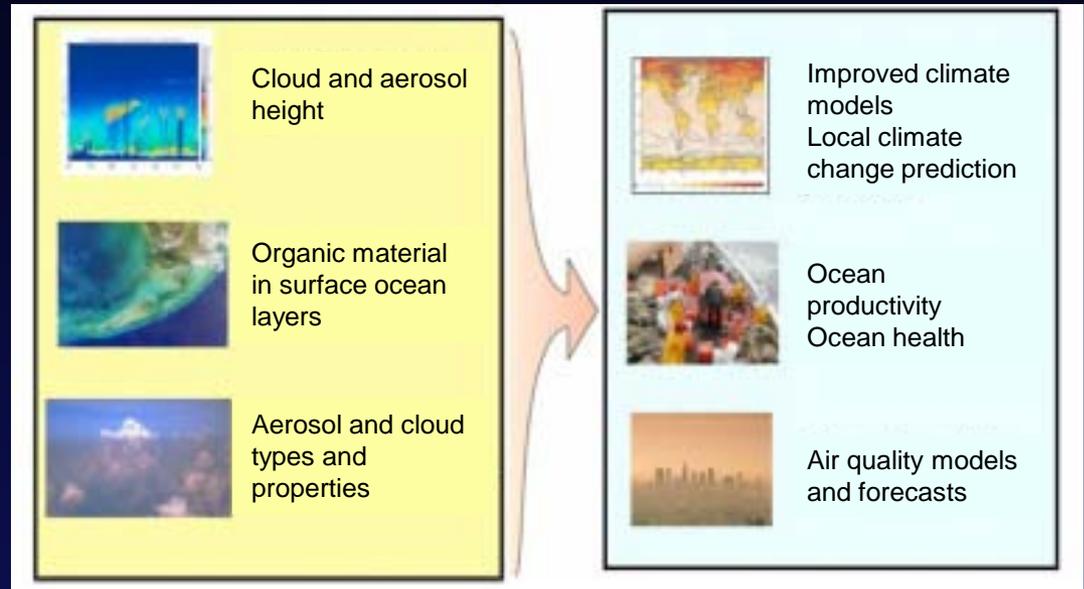
### *Sensors*

Advanced lidar

Advanced cloud radar

Ocean color spectrometer

Imaging spectropolarimeter →

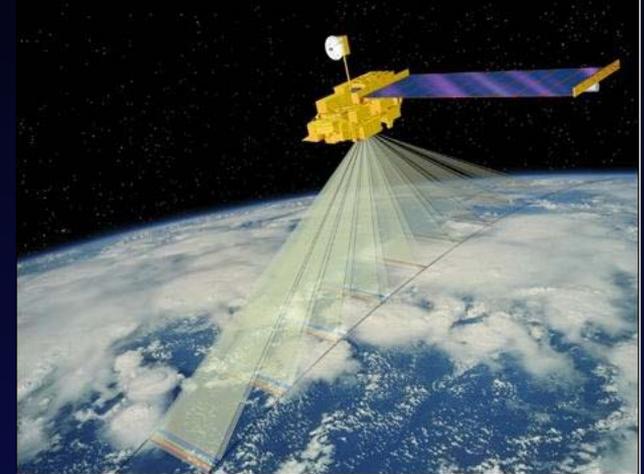


“A highly accurate multiangle multiwavelength polarimeter...with ~1 km pixel size”

MSPI is a candidate for the ACE polarimeter.

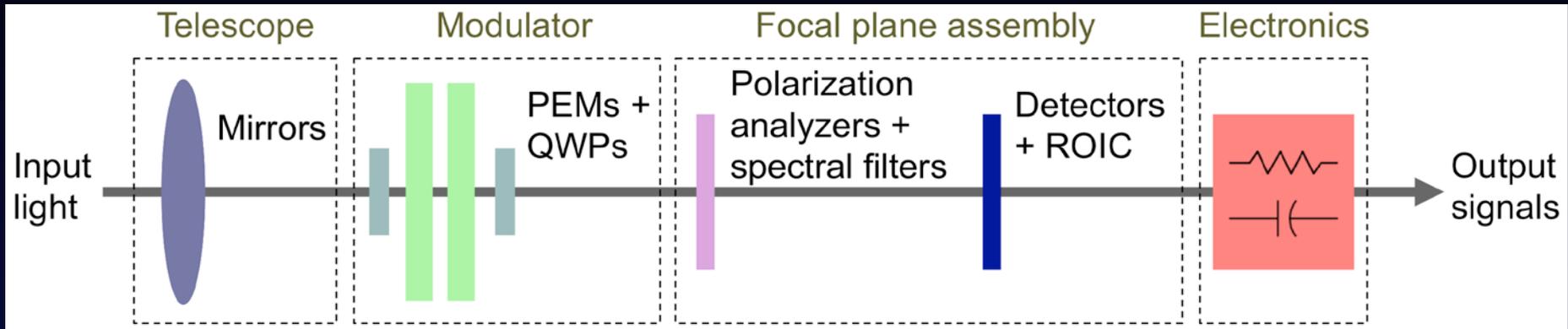
# MSPI System Overview

- Expansion of MISR capabilities
  - Broad spectral coverage (UV-SWIR)
  - Wider swath
  - High-accuracy polarimetric imaging



System	Features
LabMSPI	660 nm camera demonstrating high-accuracy dual PEM approach
GroundMSPI	UV-VNIR upgrade of LabMSPI demonstrating multispectral capability
AirMSPI	Airborne UV-VNIR version to demonstrate technology in operational environment
AirMSPI-2	Airborne version with spectral range extended into the SWIR

# Polarimeter Architecture



Two photo-elastic modulators (PEMs) time-modulate the linear Stokes components  $Q$  and  $U$ . Intensity  $I$  is unmodulated  
→  $q = Q/I$  is obtained from a single pixel (and  $u = U/I$  from another pixel) as a *relative* measurement

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

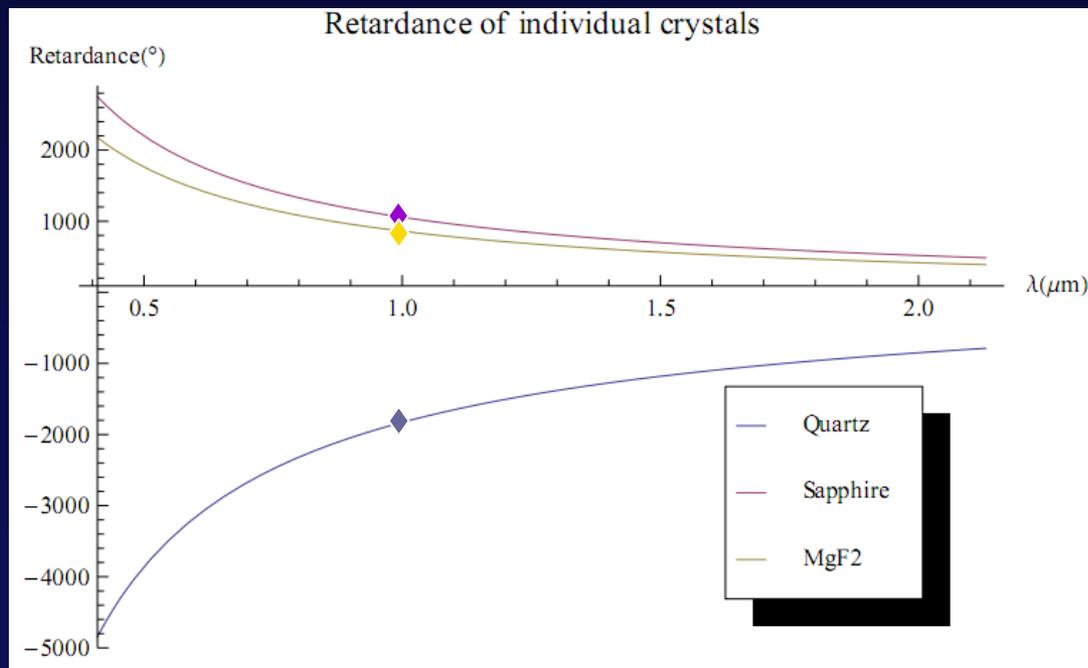
$$AOLP = \frac{1}{2} \arctan \frac{u}{q}$$

# Quarter Wave Plate Specifications for AirMSPI-2

- Wavelength range 410nm – 2130nm
- Materials must be transparent over the spectrum and space-qualifiable
- Retardance
  - $90^\circ \pm 10^\circ$  averaged over the selected filter bandpasses
  - $2^\circ$  by  $15^\circ$  field of view
- Athermalization
  - $<0.1^\circ$  change in retardance per  $1^\circ$  C temperature change

# Compound Retarder Design

- Three birefringent crystals elements selected to achieve the achromatic, athermal behavior
- Quartz, Magnesium Fluoride and Sapphire were selected from 120 other crystal combinations
- Three degrees of freedom
- Merit function is based on  $\text{Sin}[R(\lambda)]^2$  and temperature functions

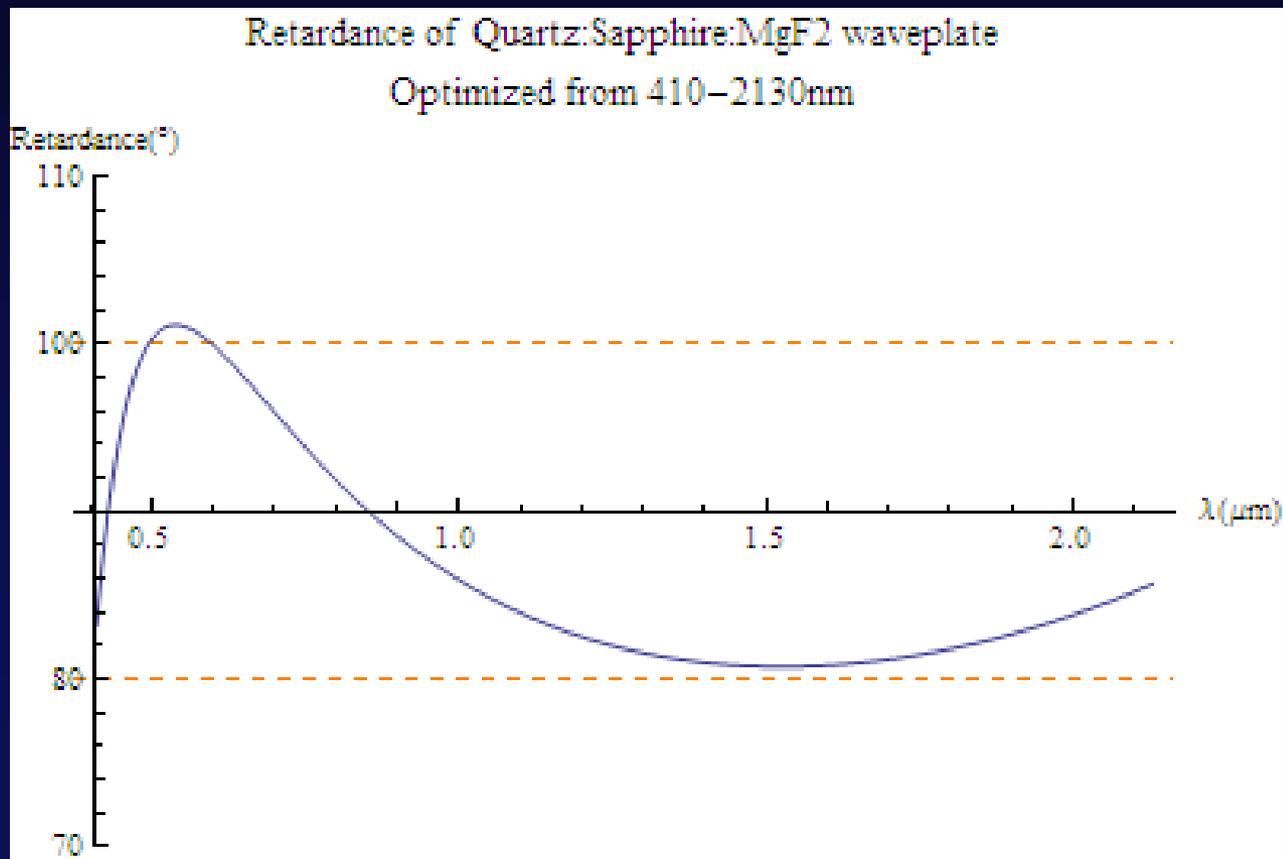


Quartz	-1829°
Sapphire	1056°
MgF2	859°

**86° at 1 micron**

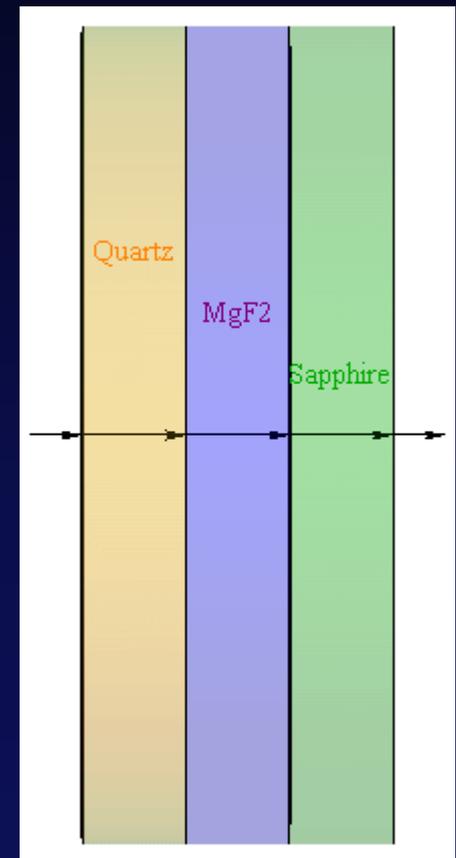
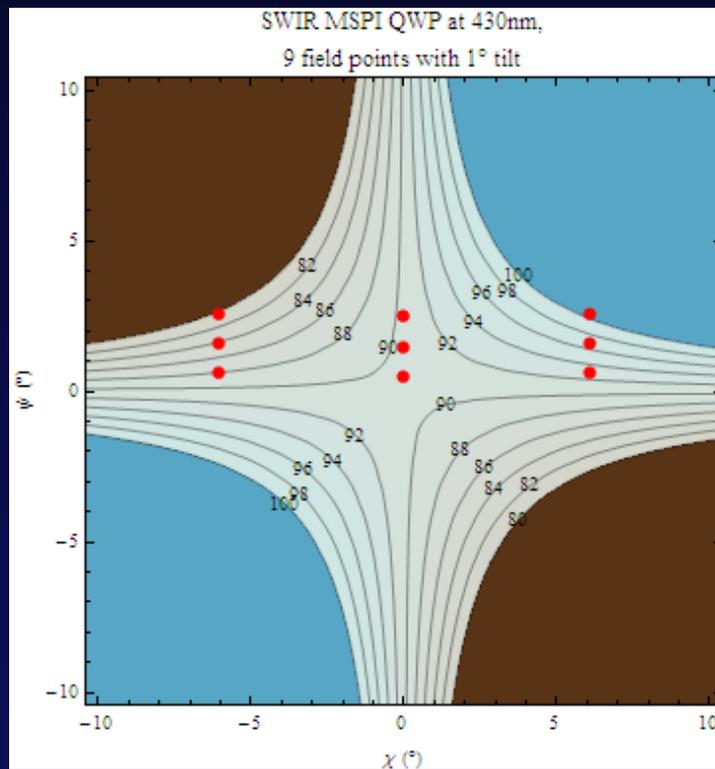
# Compound Retarder Design

- Optimized performance to meet retardance specification for nearly any band pass in the MSPI wavelength range
- Traded athermalization for retardance variation



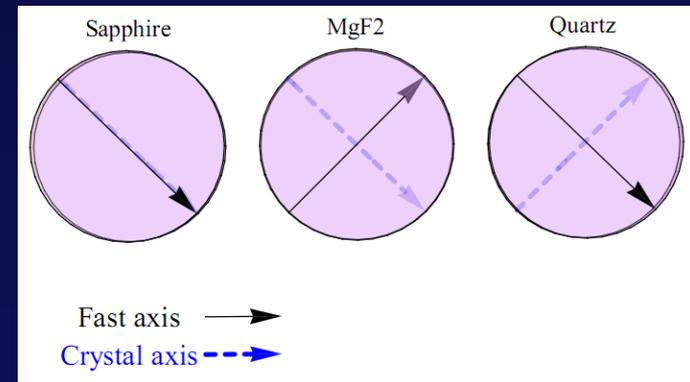
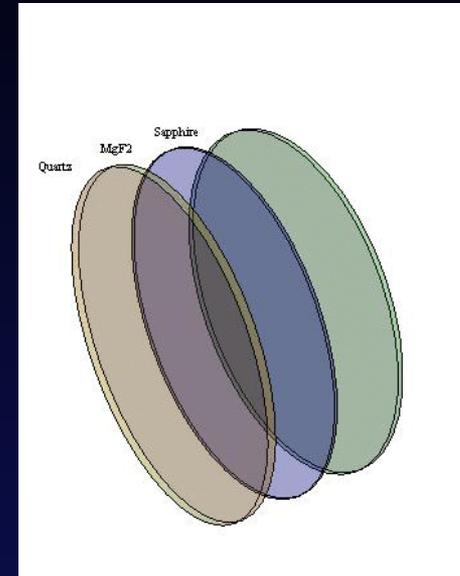
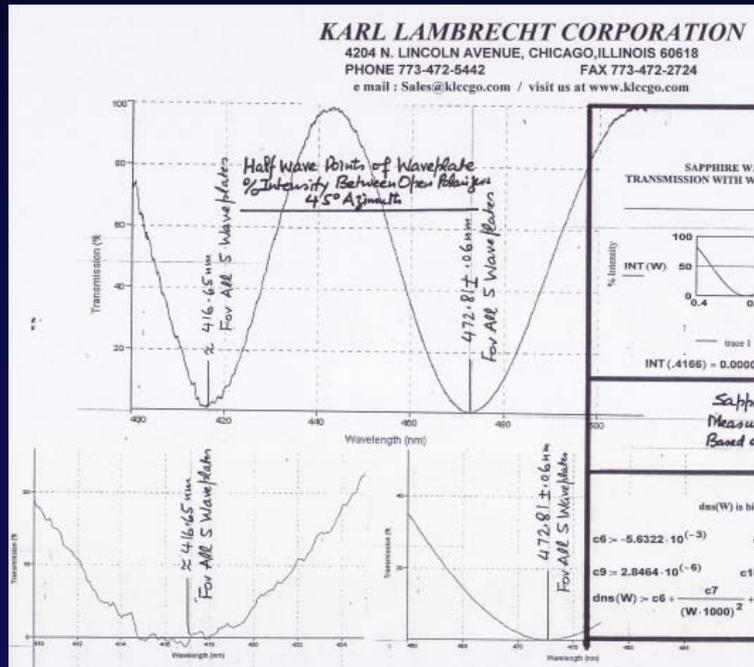
# Polaris Polarization Ray Tracing Code

- Polaris ray splitting
- Angle of incidence dependence of retardance analyzed



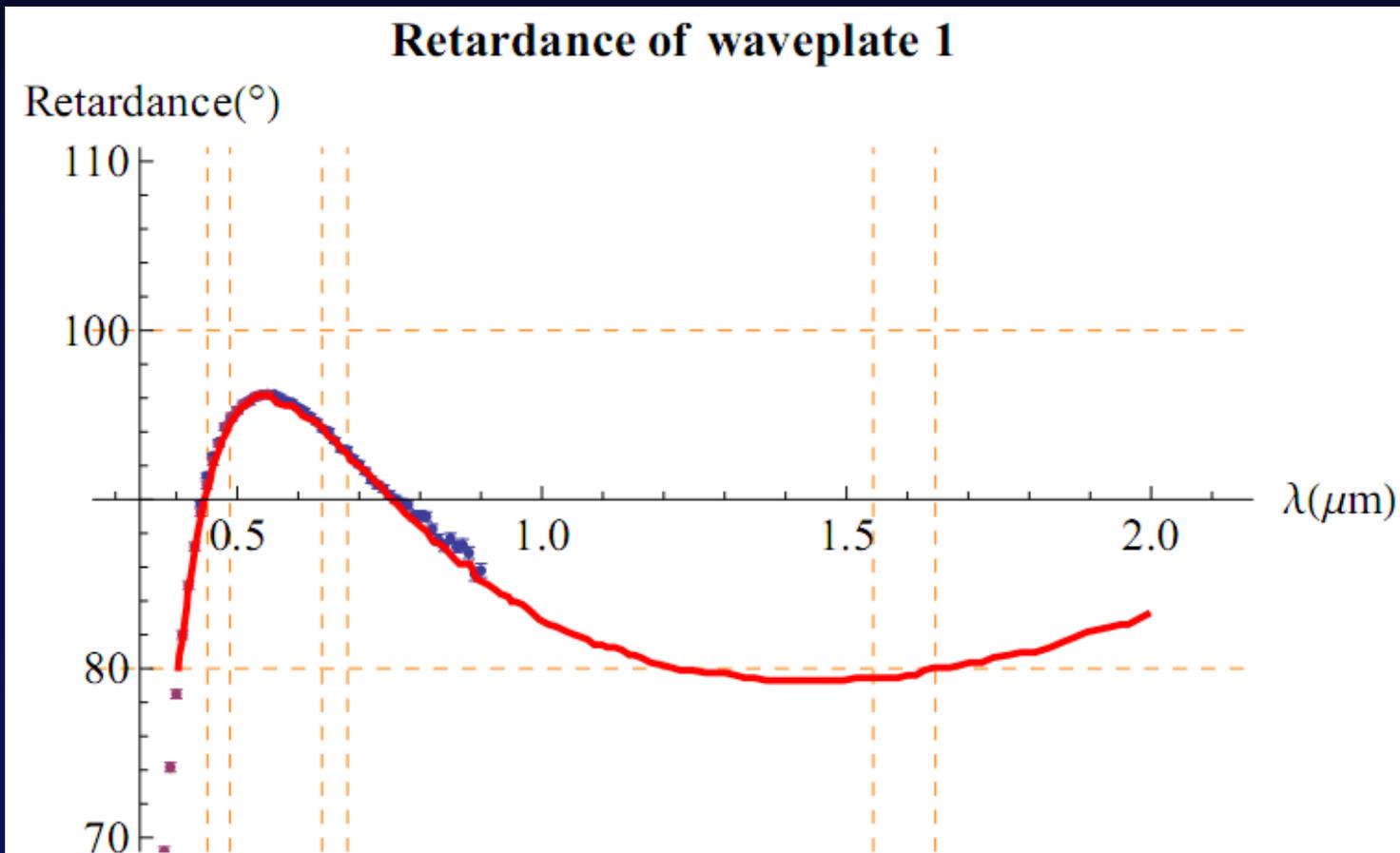
# Retarder Fabrication

- A more accurate fabrication procedure was followed by monitoring the retardance rather than measuring the plate thicknesses



# Measurements of the compound retarder

- Measured KL data: Red curve
- UV-visible polarimeter data: Dots
  - Measurements up to 0.9 microns at UA



# Ground-based MSPI

- Push-broom camera operation with a 30° FOV
- Measures linear polarization at 470, 660 and 865 nm
- Currently in operation at the University of Arizona
- Examining sky, clouds, haze and surface properties



Spectral bands

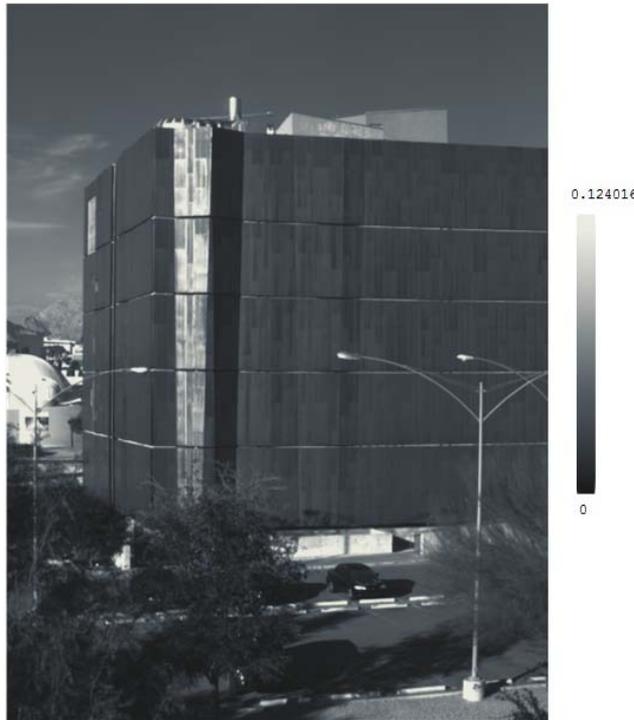
355, 380, 445, 470\*, 555, 660\*, 865\*, 935 nm (\*polarimetric)

# Ground MSPI Imagery

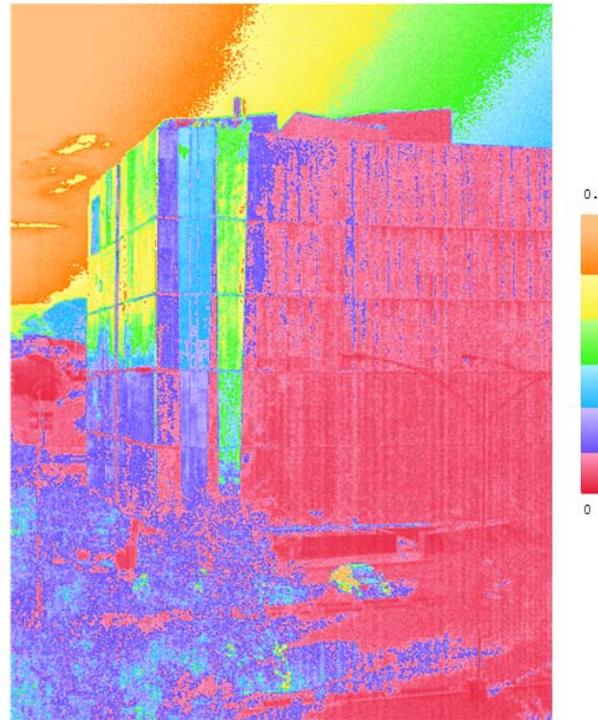
## ■ Meinel building at the University of Arizona

MSPI camera Cherry Garage roof  
(4pm Dec 28, 2010)

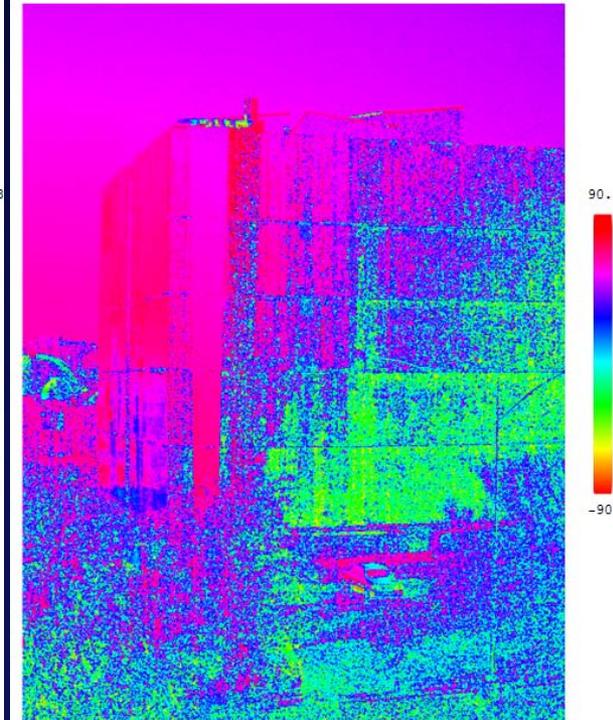
Intensity 660



DOLP 660



AOLP 660



# Ground MSPI Imagery

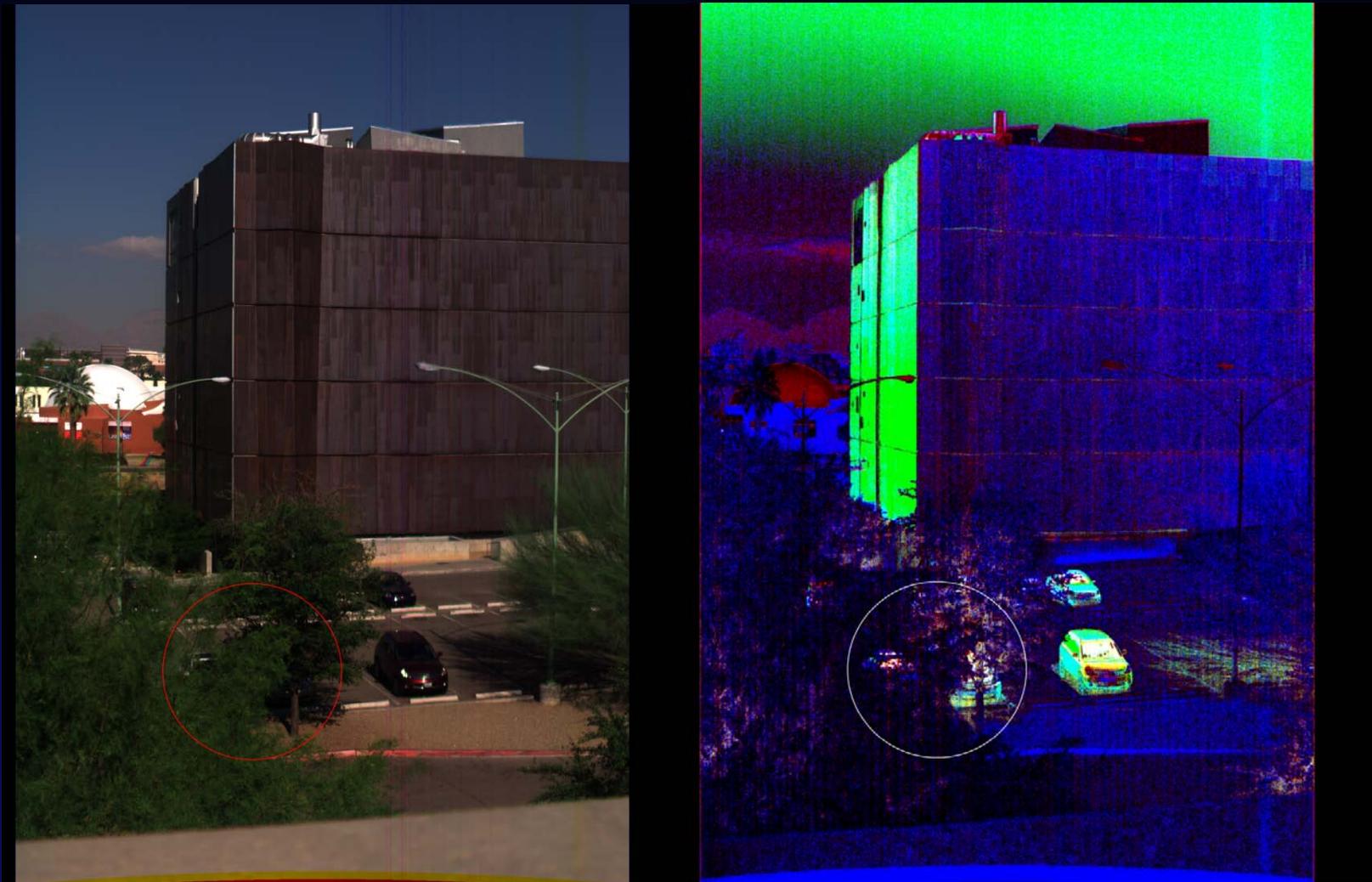


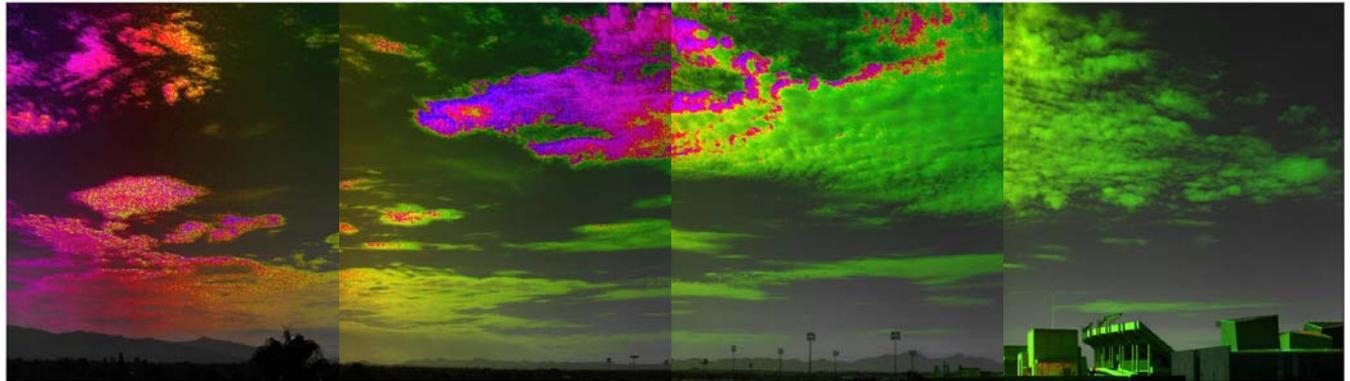
Image of cars shows up far more clearly in a Principal Component Analysis polarimetric image (right) than a conventional intensity image (left).

# Panoramic Scene



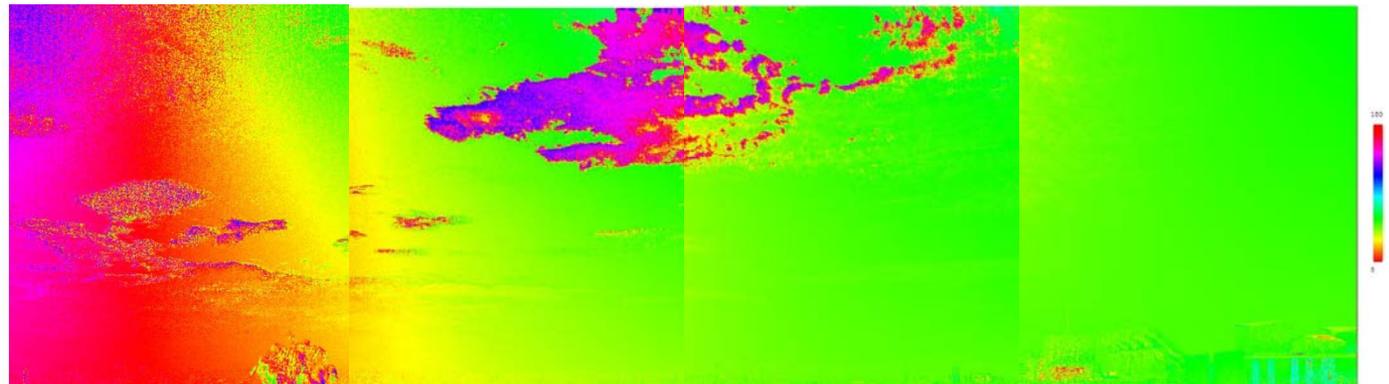
Combination  
Image

Brightness – Intensity  
Saturation – DoLP  
Hue - AoLP



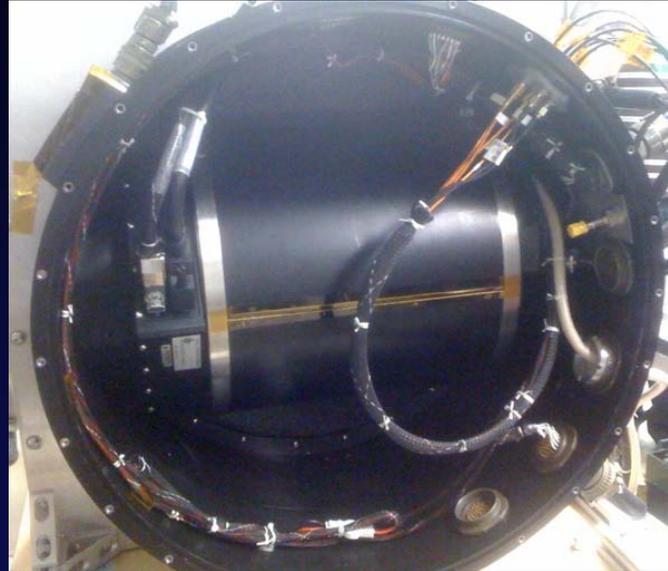
SW ← → SE

Angle of Linear  
Polarization



# Airborne MSPI

- Two successful check out flights aboard the ER-2.
  - October 7<sup>th</sup> and 26<sup>th</sup>, 2010



- Camera slews to multiple view angles



# ER-2 rollout from the hanger



# Ports of Los Angeles and Long Beach

26° backward  
view at 865 nm



I

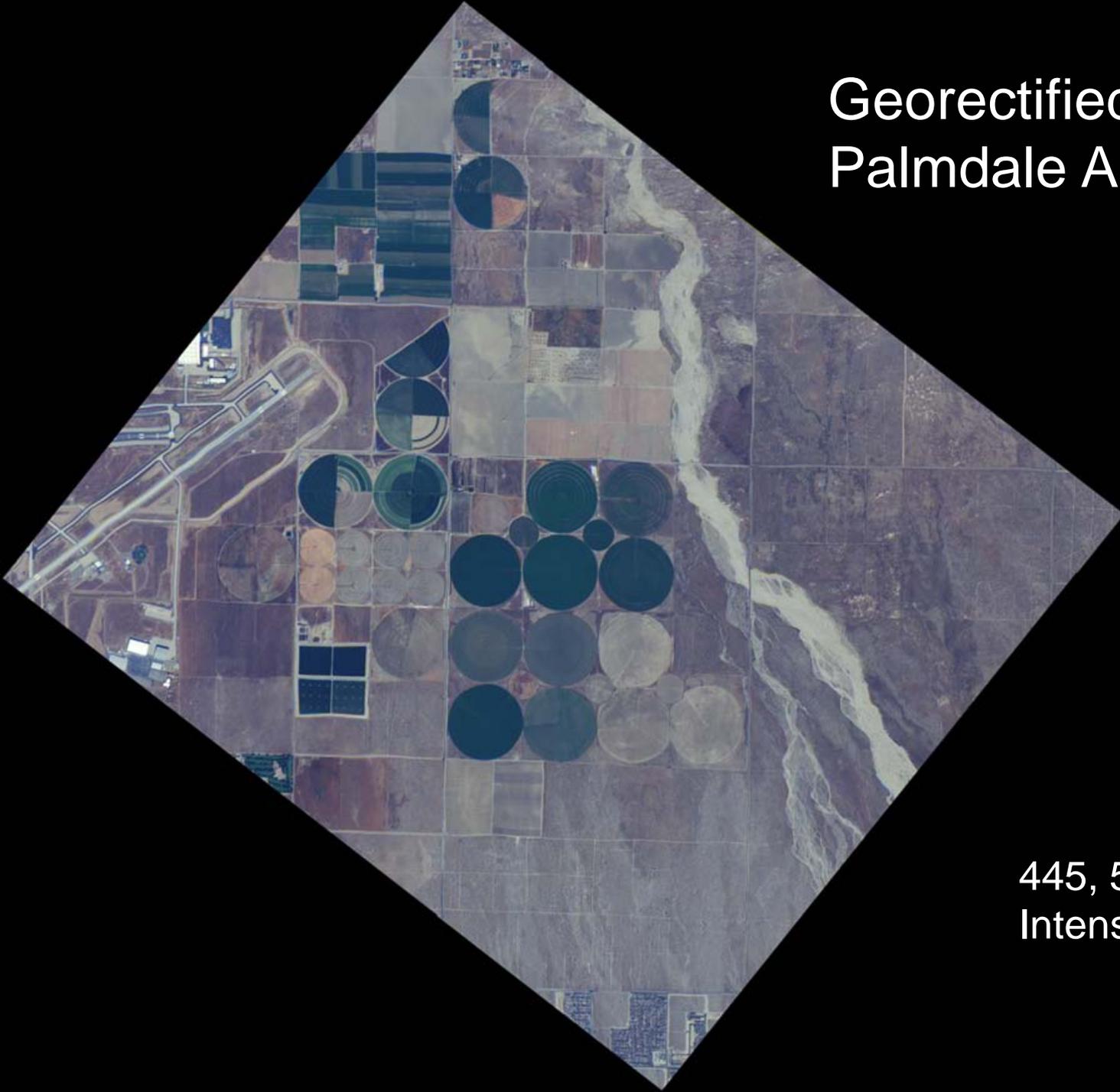


Q



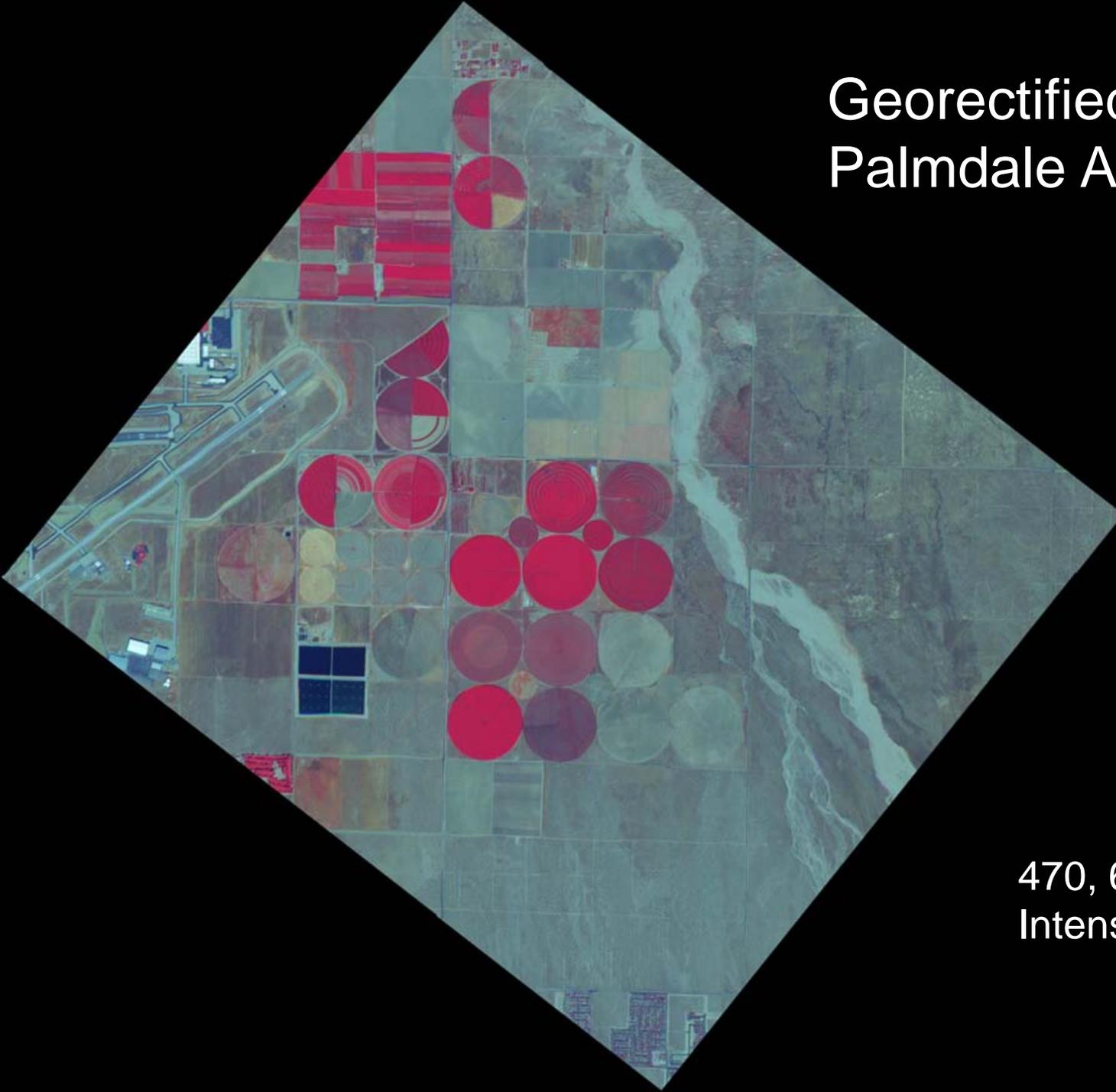
U

# Georectified image of Palmdale Airport



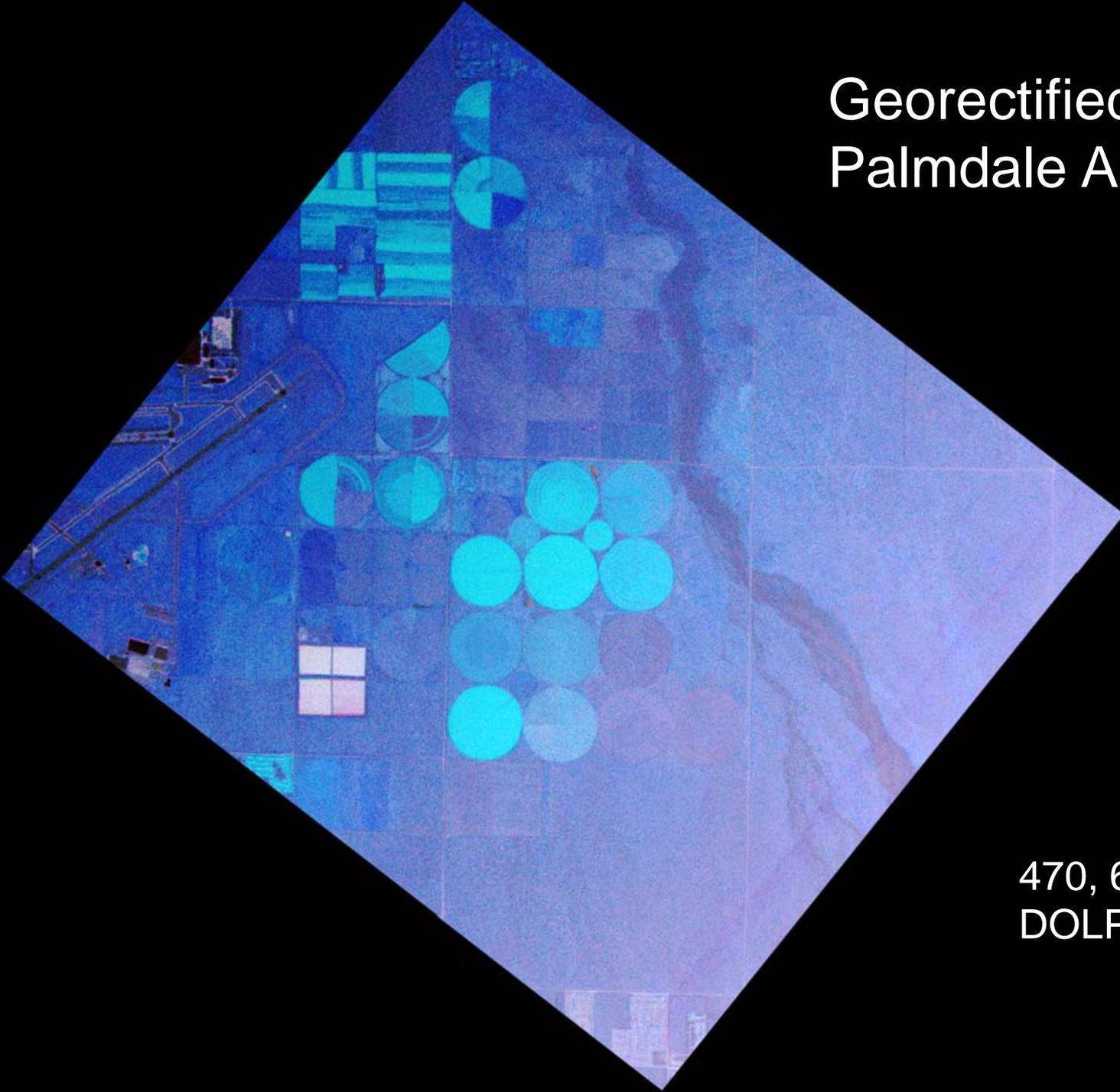
445, 555, 660 nm  
Intensity

# Georectified image of Palmdale Airport



470, 660, 865 nm  
Intensity

# Georectified image of Palmdale Airport



470, 660, 865 nm  
DOLP

# Conclusion/Future work

- Quarter Wave Retarder
  - Designed and fabricated retarders that successfully perform from UV-SWIR
  - Incorporate retarders into AirMSPI-2 camera
- Future work:
  - Alignment of AirMSPI-2 optical components under IIP-07
  - Development of UV-VIS-SWIR focal plane under IIP-10
- Further exploratory Ground-based MSPI measurements performed at University of Arizona
- Scheduled AirMSPI flights from Palmdale, CA: July 12-14, 2011

# Acknowledgments

## ■ Quarter Wave Retarder

- Nasrat Raouf (JPL)
- Russell Chipman, Steve McClain, Brittany Foster (University of Arizona)
- Anna-Britt Mahler (Aerospace Corp.)
- Vinod Vats (Karl Lambrecht Corp.)

## ■ MSPI Collaboration Team

- David Diner, Sven Geier, Ab Davis, Gary Gutt, Bruce Hancock, Chris Wrigley, Amy Wu, Tom Cunningham, Dave Rider, Brian Rheingans, Michael Bull, Veljko Jovanovic, Jose Rodriguez, Steve Macenka (JPL)
- Brian Daughtery, Greg Smith, Karlton Crabtree, Christine Bradley (University of Arizona)

## ■ NASA/ESTO's Instrument Incubator Program (IIP)

## ■ NASA/ESTO's Advanced Information Systems Technology (AIST)

## ■ NASA's Airborne Instrument Technology Transition (AITT)