

4STAR: Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research

Development and Results from First Test-flights



A collaboration involving:

- ▶ **PNNL:** C. Flynn, B. Schmid, C. Kluzek
- ▶ **NASA Ames:** S. Dunagan, R. Johnson, P. Russell, and J. Redemann
- ▶ **NASA GSFC:** B. Holben



4STAR: Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research

AERONET-like capability

Ground-based direct beam + sky scanning yields column-integrated properties:

- AOD
- Size distributions
- Single-scattering albedo
- Asymmetry parameter
- Sphericity
- Cloud OD

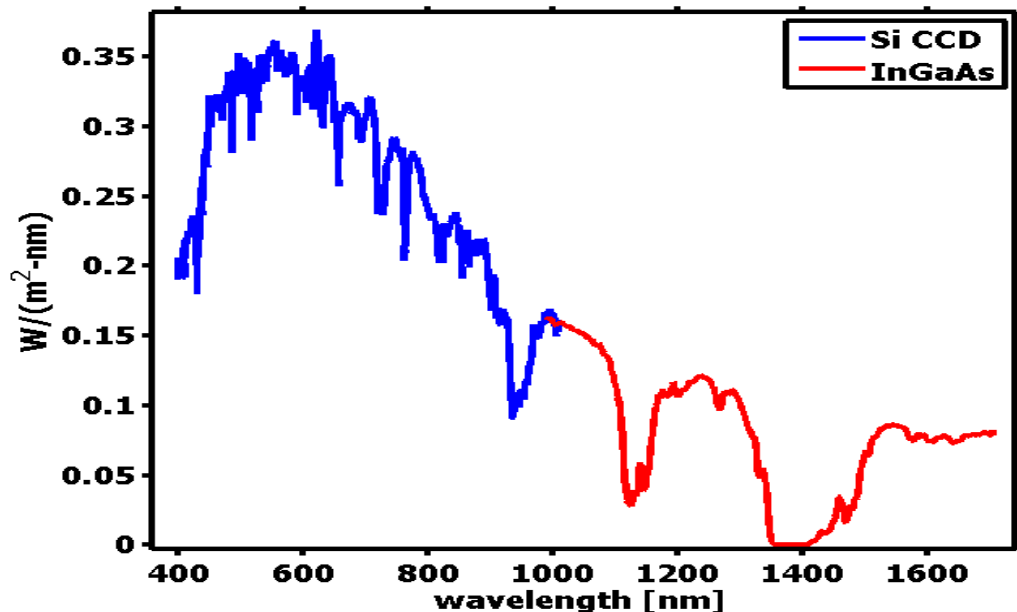


AATS-like capability:

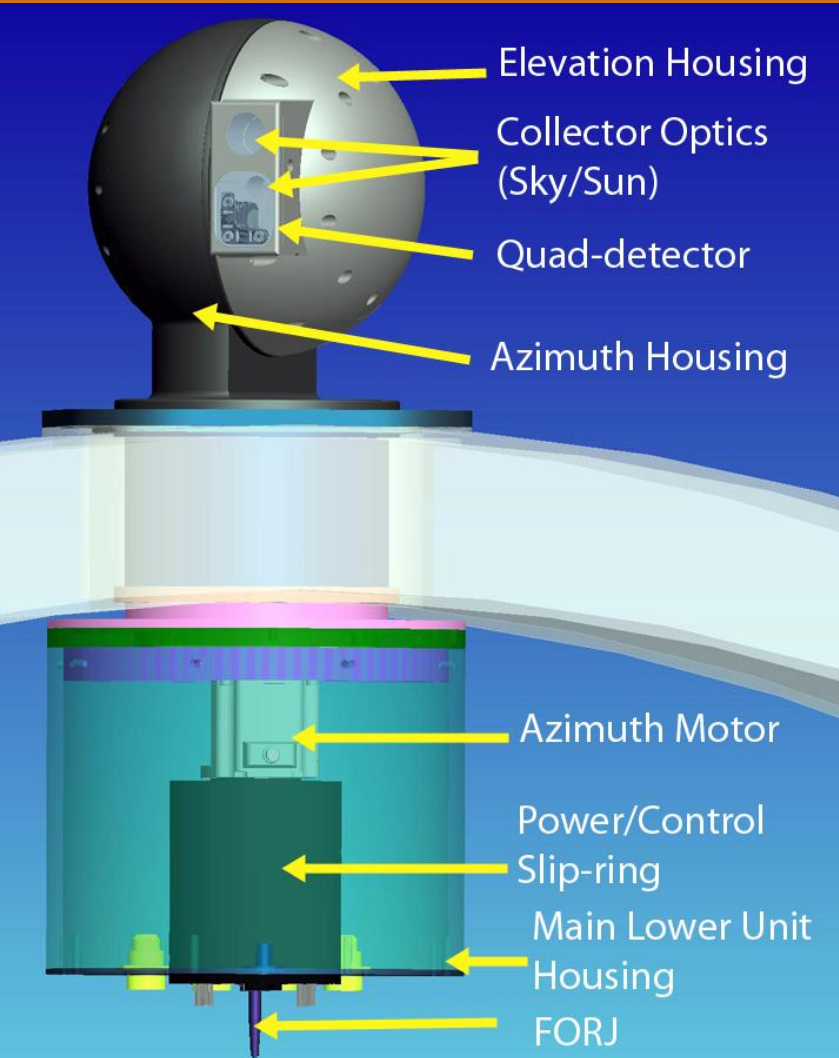
AOD at 13 wavelengths
 H_2O

horizontally and vertically resolved

Direct Solar Irradiance



4STAR Integration and test flights on PNNL/Battelle G-1, Aug-Sep 2010



Anticipated 4STAR data products:

▶ Solar Direct Beam

- Atmospheric Transmittance
- Aerosol Optical Depth and Ångstrom exponent
- Aerosol Extinction (via aircraft vertical profiling)
- Gases: H₂O, O₃, NO₂, CO₂ (column and in profile)

▶ Angularly-resolved sky radiance inversions

- Scattering phase function, asymmetry parameter
- Aerosol size distributions, fine/coarse mode fraction
- Aerosol sphericity
- Aerosol absorption

▶ Zenith radiance cloud retrievals

- Cloudy/clear transition zone (Marshak, Chiu)
- Cloud Optical Depth, Droplet effective Radius (with auxiliary measurements, Barker et al.)
- Water vapor, liquid water, ice water fractionation (Daniels et al.)

4STAR and its Use...

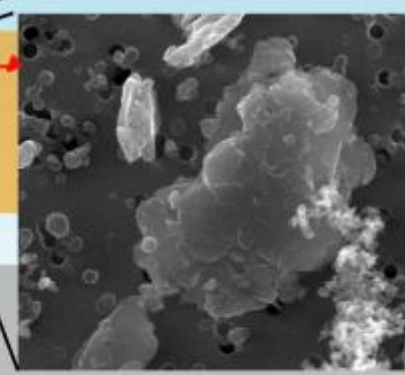
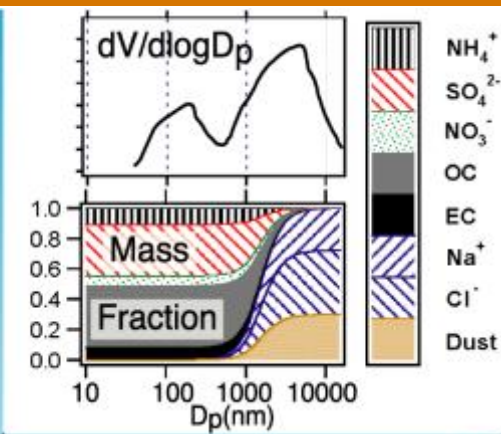
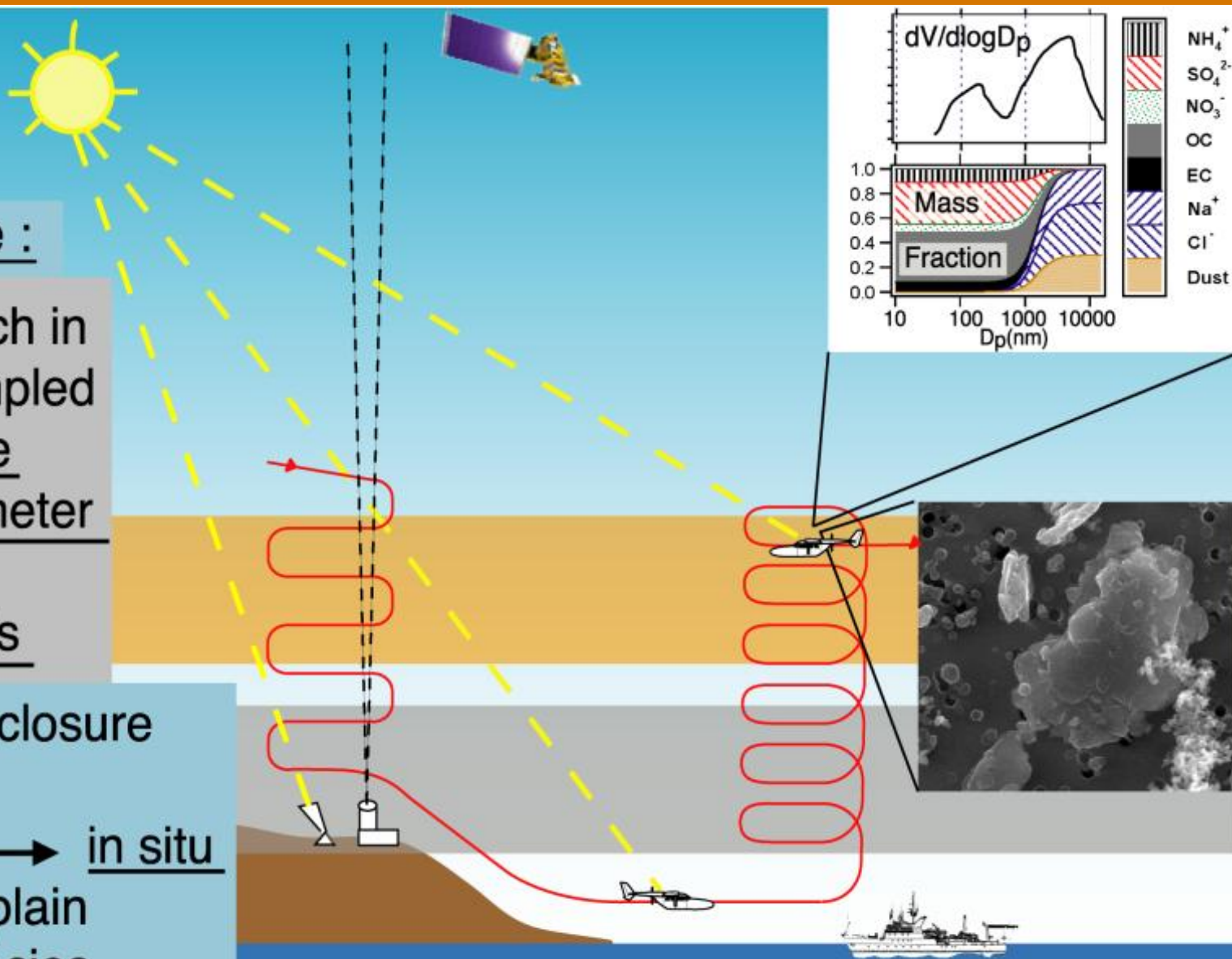
Advantage :

Exact match in layers sampled by airborne sunphotometer & in situ instruments

- Tightens closure
- Key link

Satell. ↔ in situ

- Helps explain discrepancies

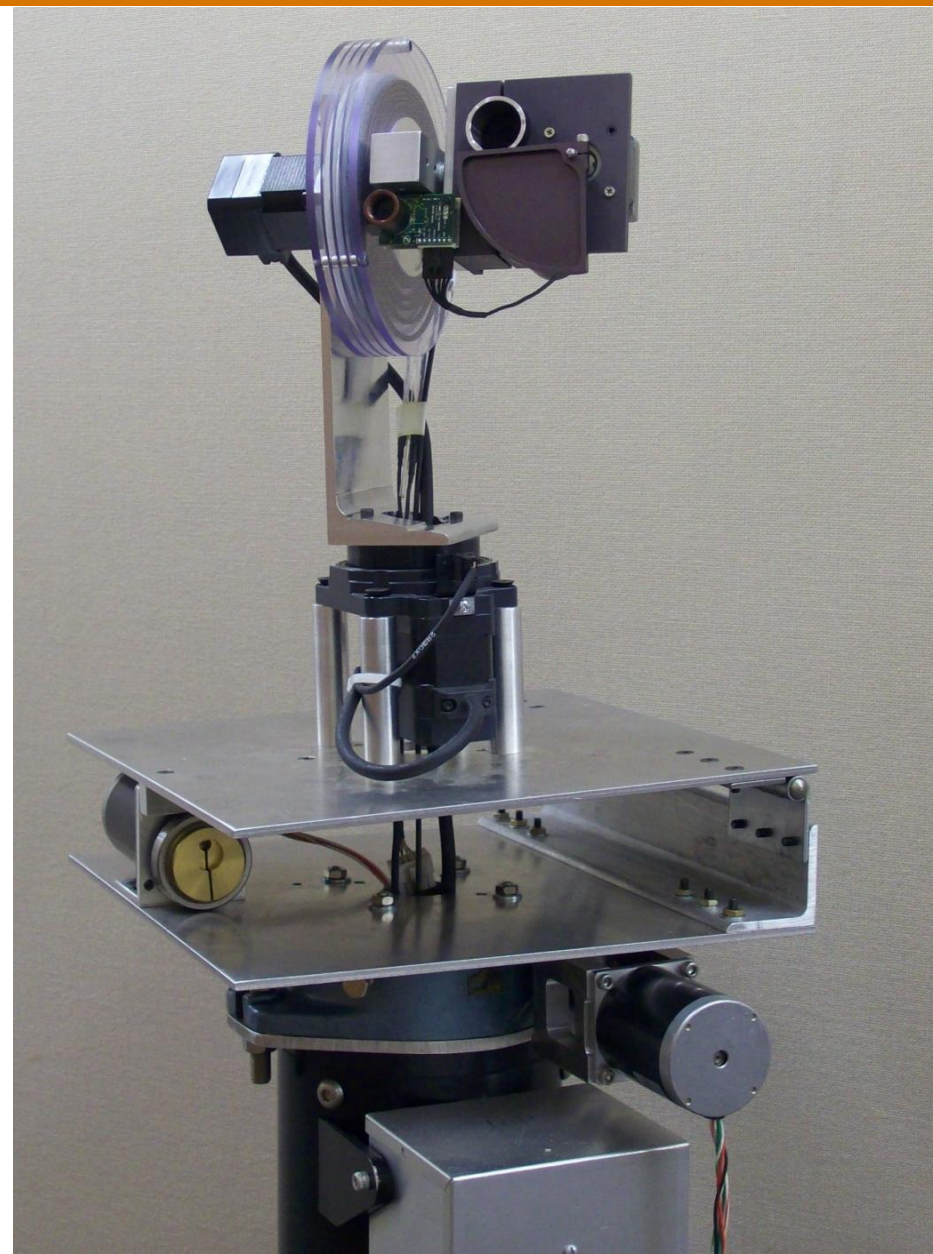
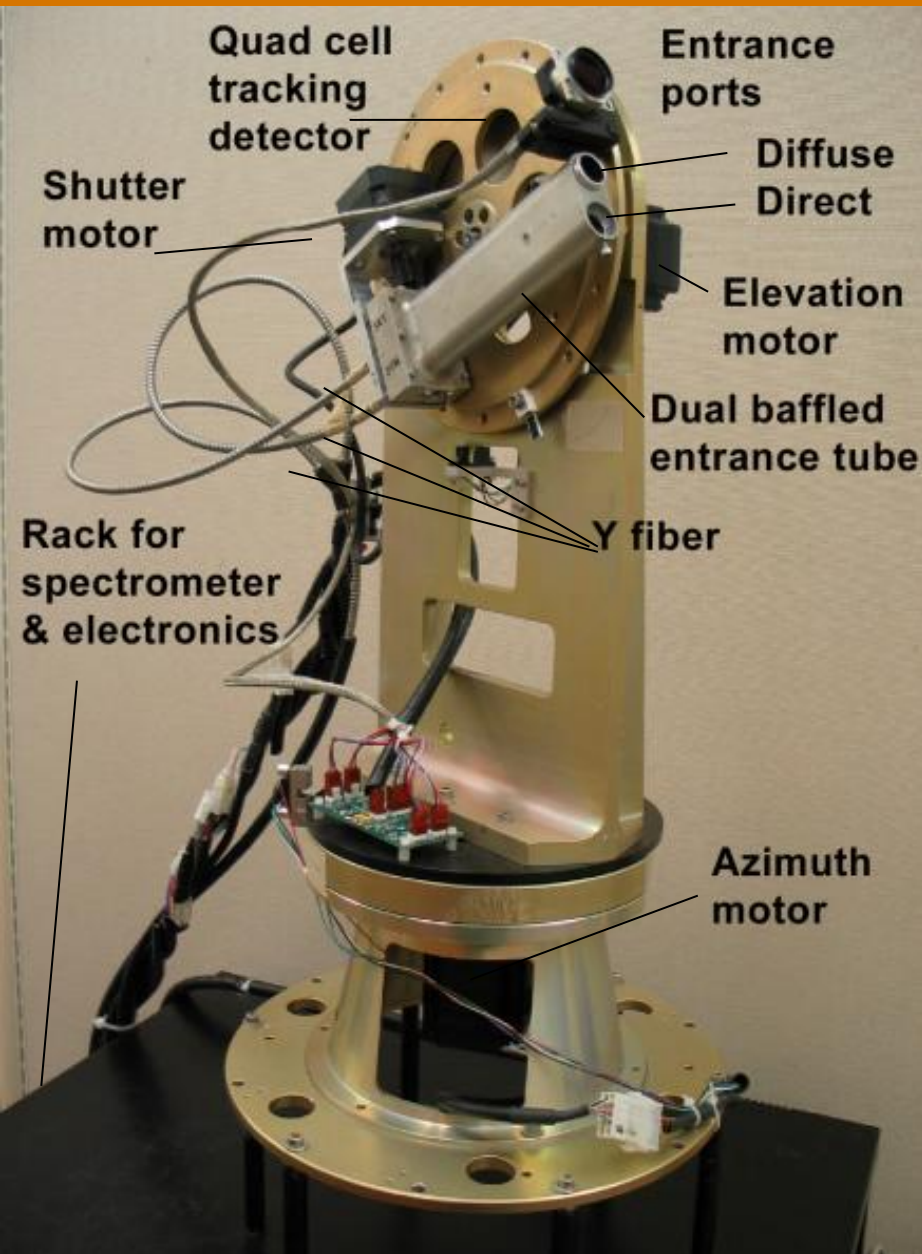


Key Technological Hurdles

- ▶ Entrance window contamination
- ▶ Fiber optic couplings with $<1\%$ calibration stability (Connections/Rotation)
- ▶ Irradiance calibration to 1% over a period of months.
- ▶ Radiance calibration to a few percent.
- ▶ Stray light rejection: measure skylight down to within 3° of sun
- ▶ Sky scan within 100 seconds (10 km in flight)
- ▶ Stray light inside spectrometers



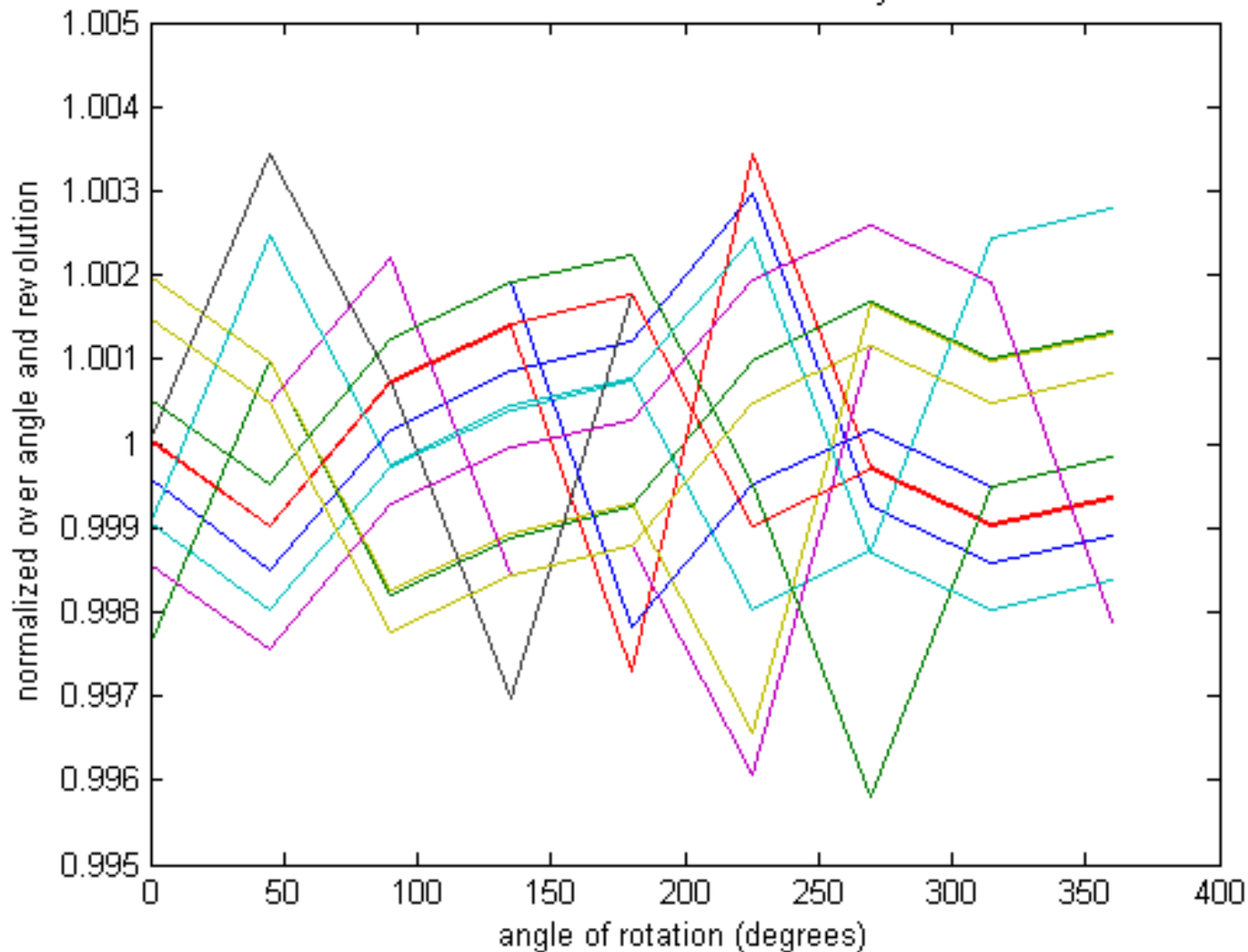
Ground Prototypes (4STAR-G)



Rotating Fiber Optics Coupling Throughput Repeatability



Fractional variation after normalized by sinusoid

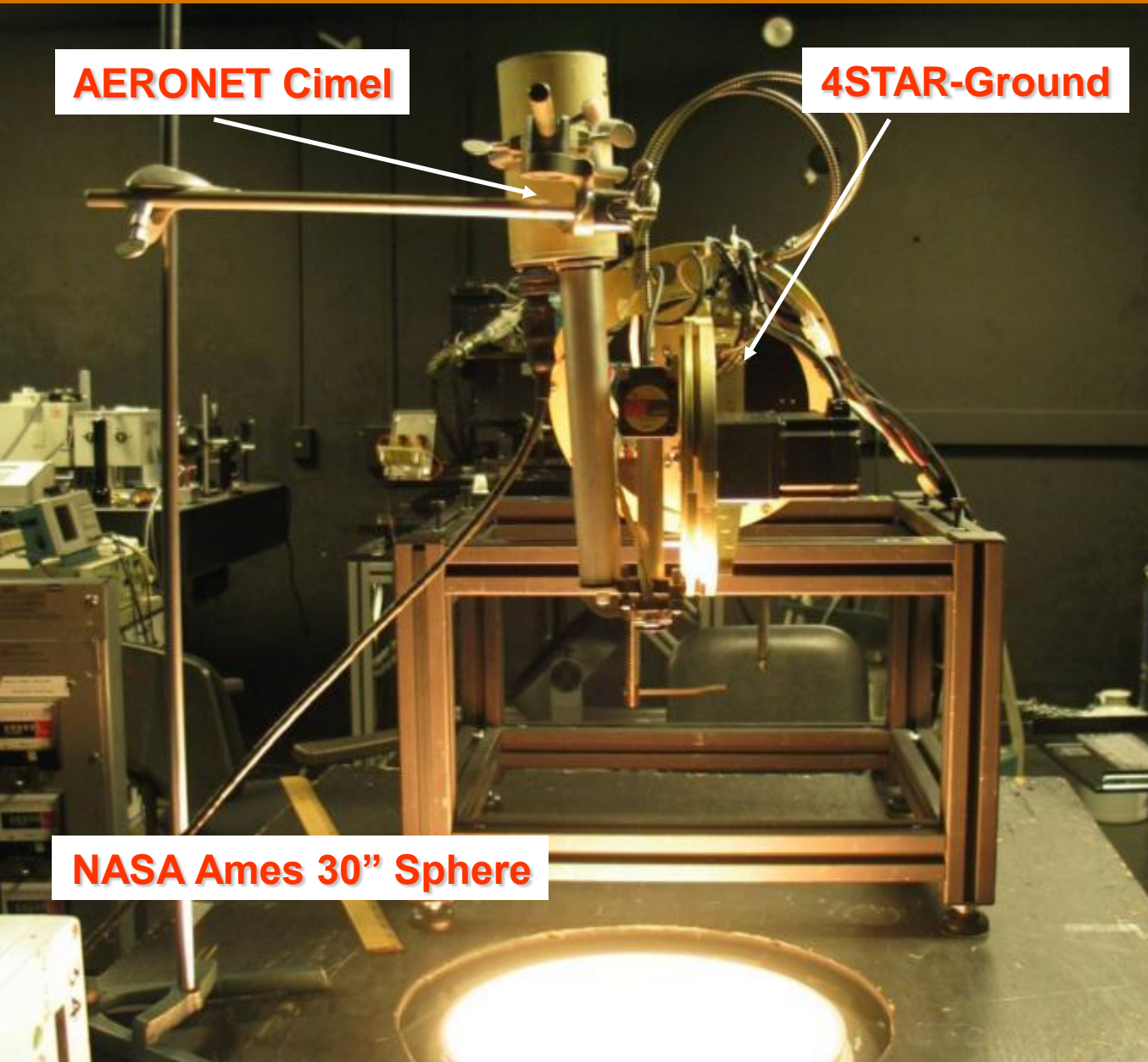


Radiance Calibration

AERONET Cimel

4STAR-Ground

NASA Ames 30" Sphere

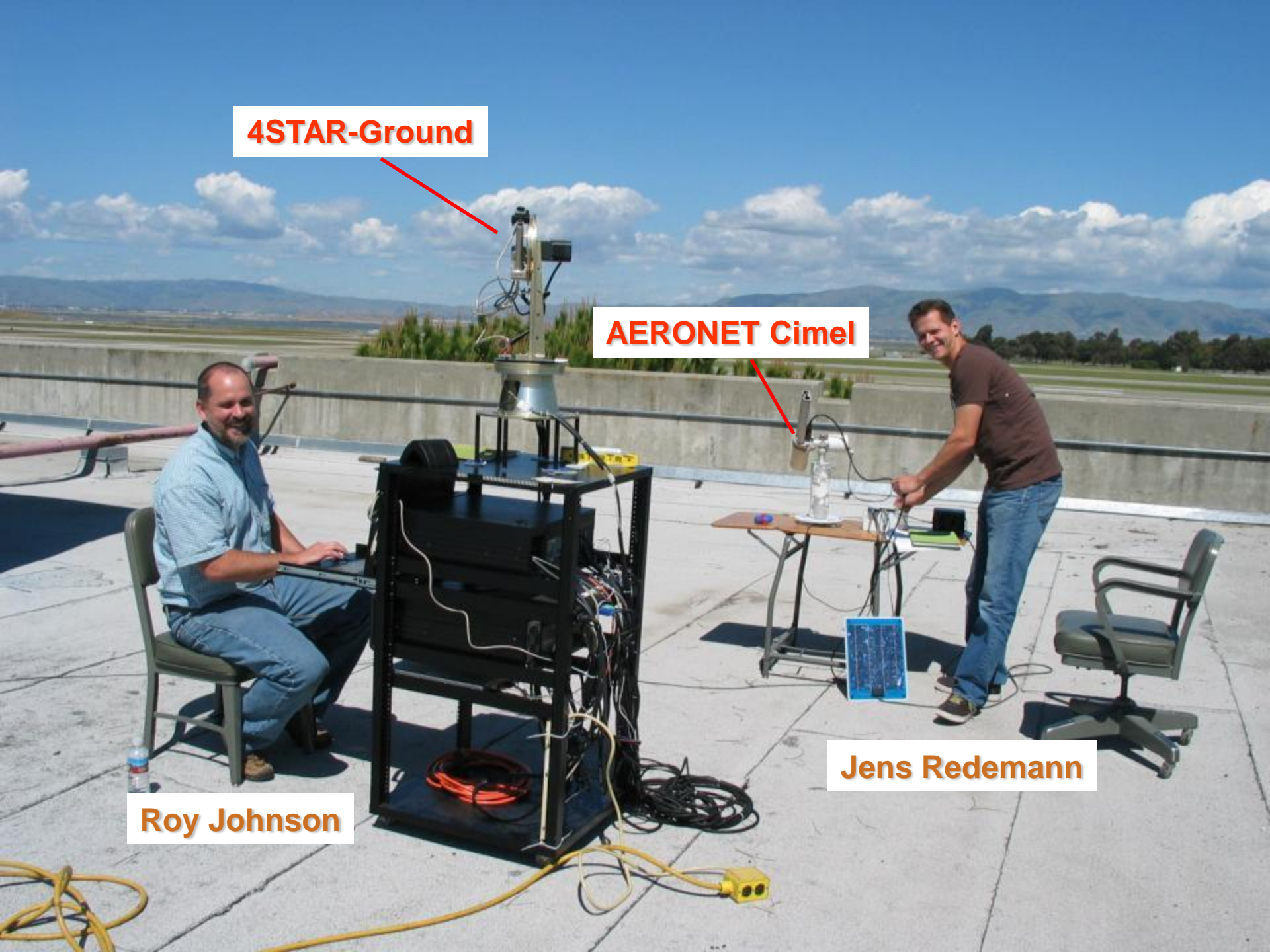


4STAR-Ground

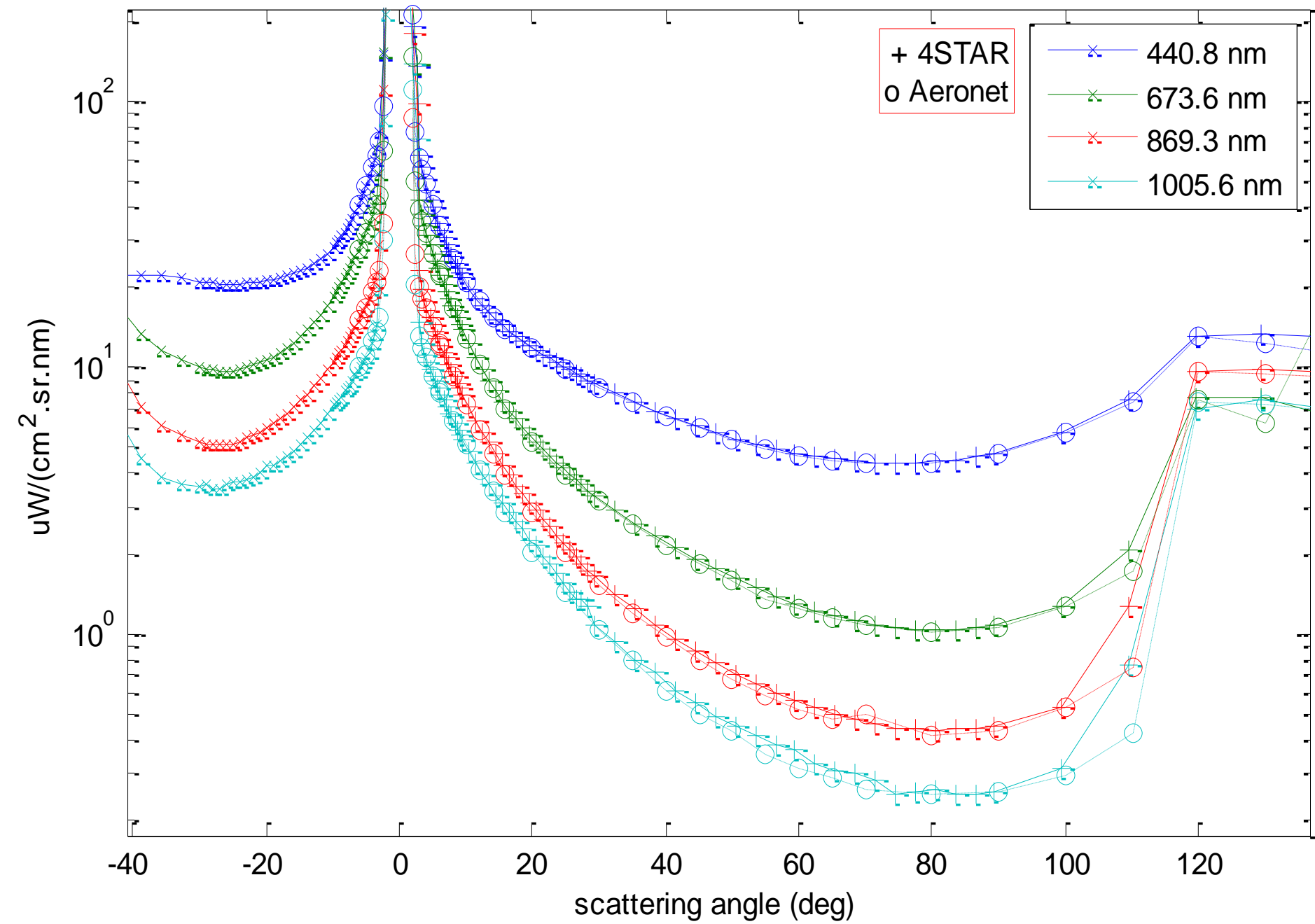
AERONET Cimel

Roy Johnson

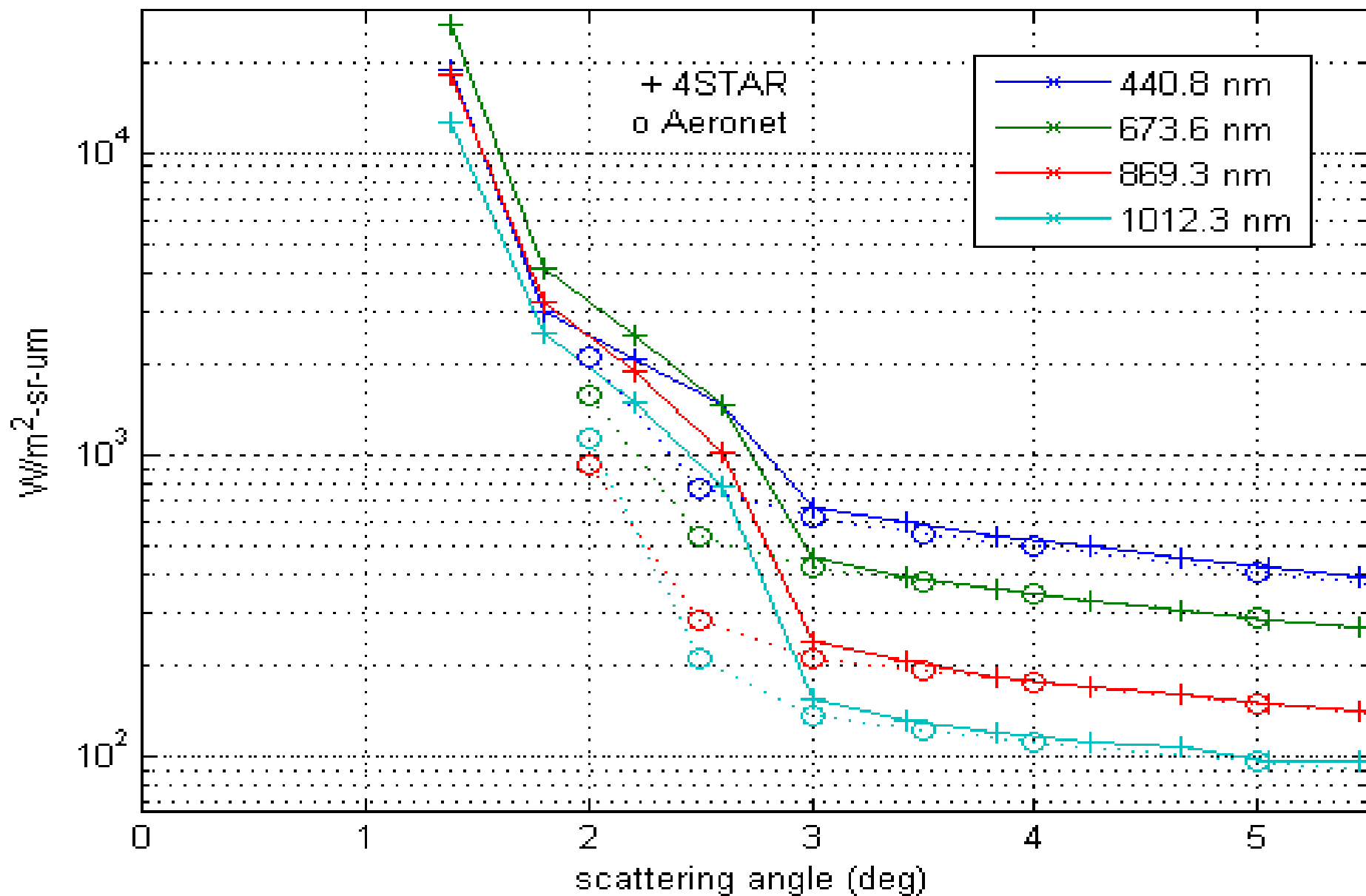
Jens Redemann



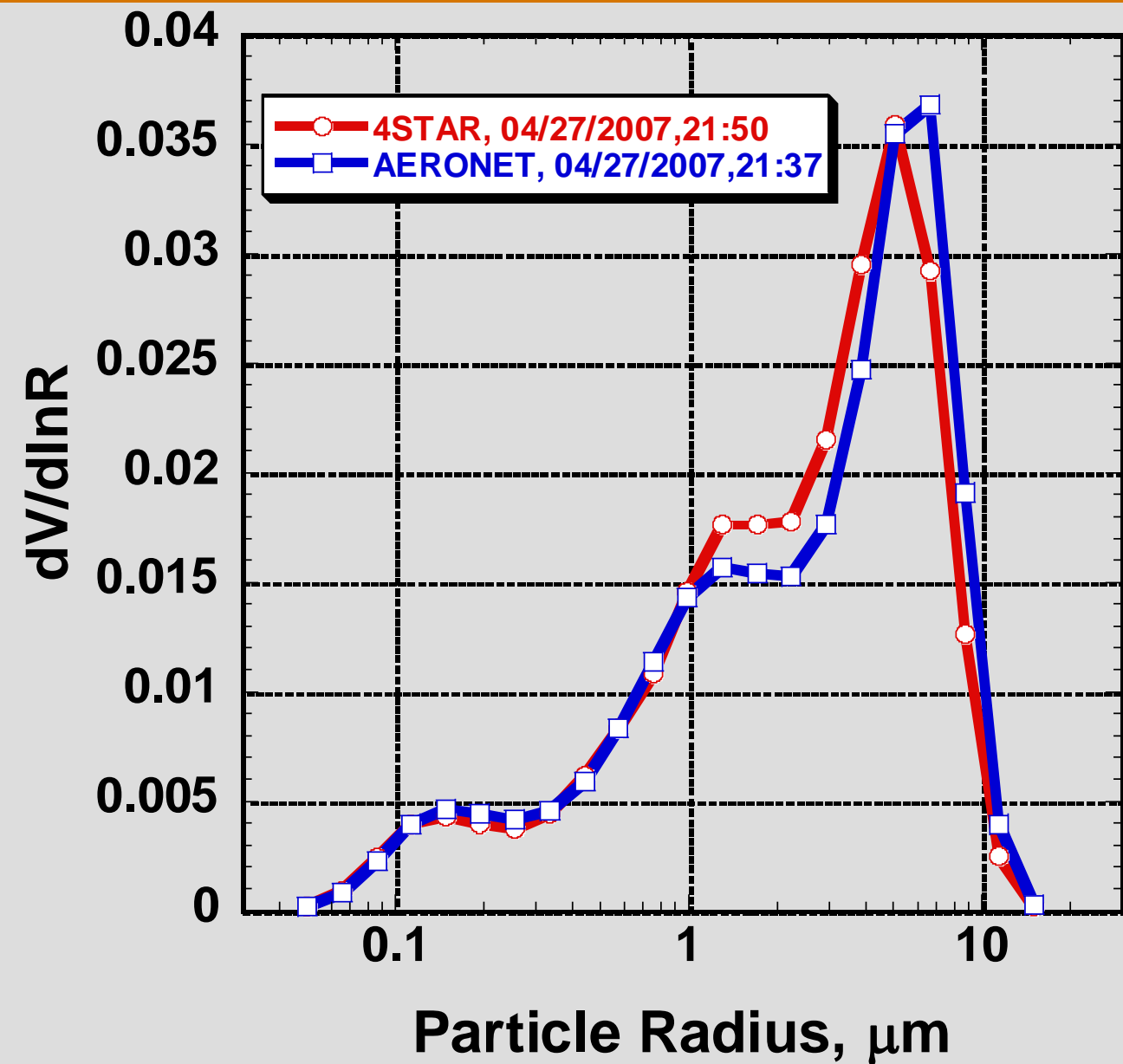
4STAR and Aeronet principal plane scans on 2007-04-30, SZA=43.8 deg
Independently calibrated at NASA Ames and NASA GSFC



Stray light rejection close to Sun - old barrel



Size Distribution Retrieval using AERONET Code



Sun Photometer Inter-Comparison Experiment Mauna Loa, Aug. 24 - Sep. 2 2008



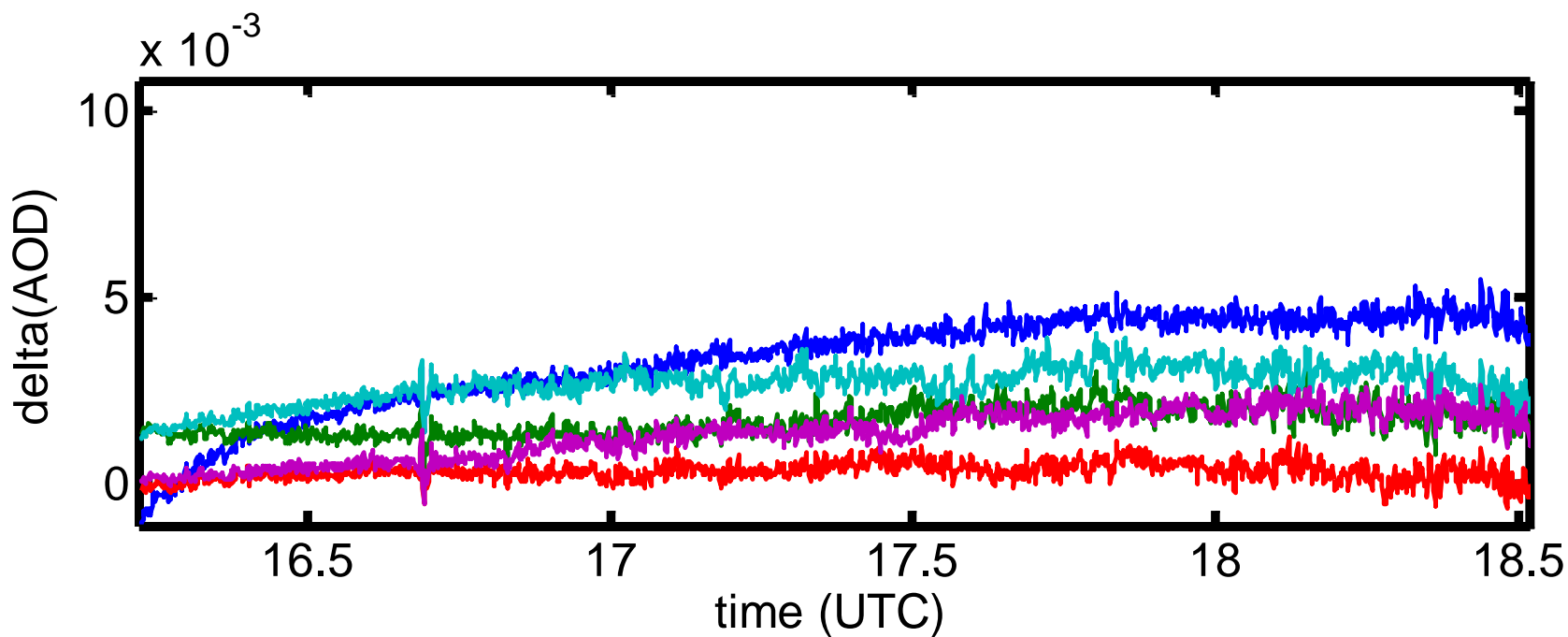
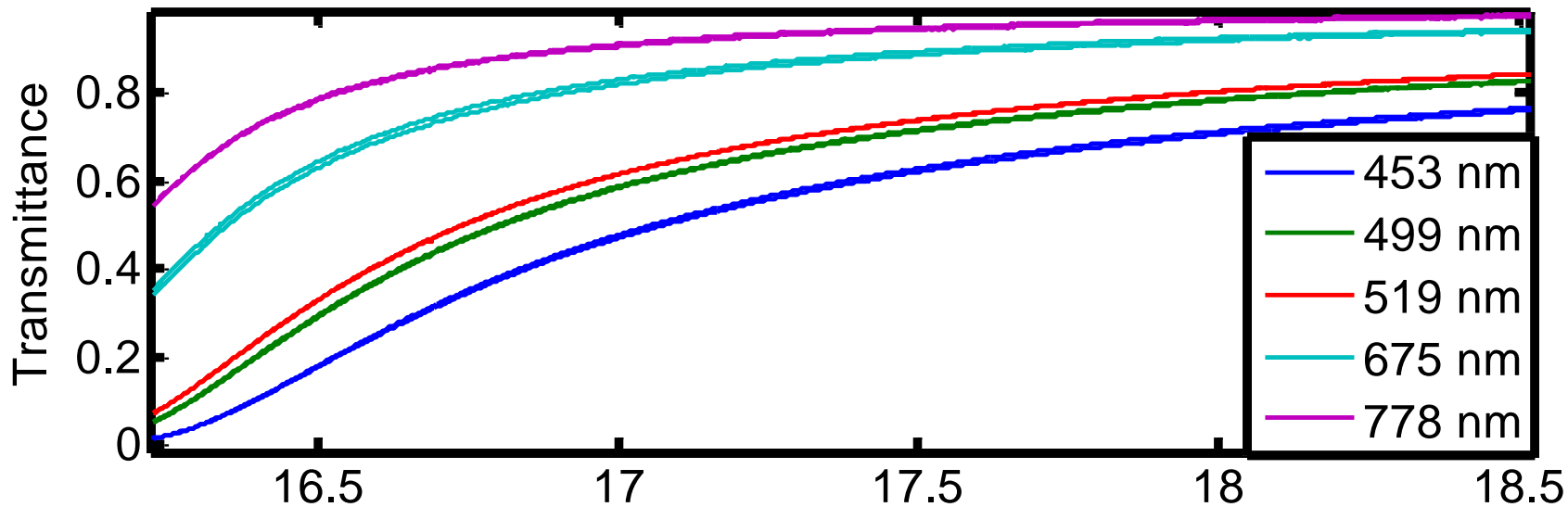
4STAR

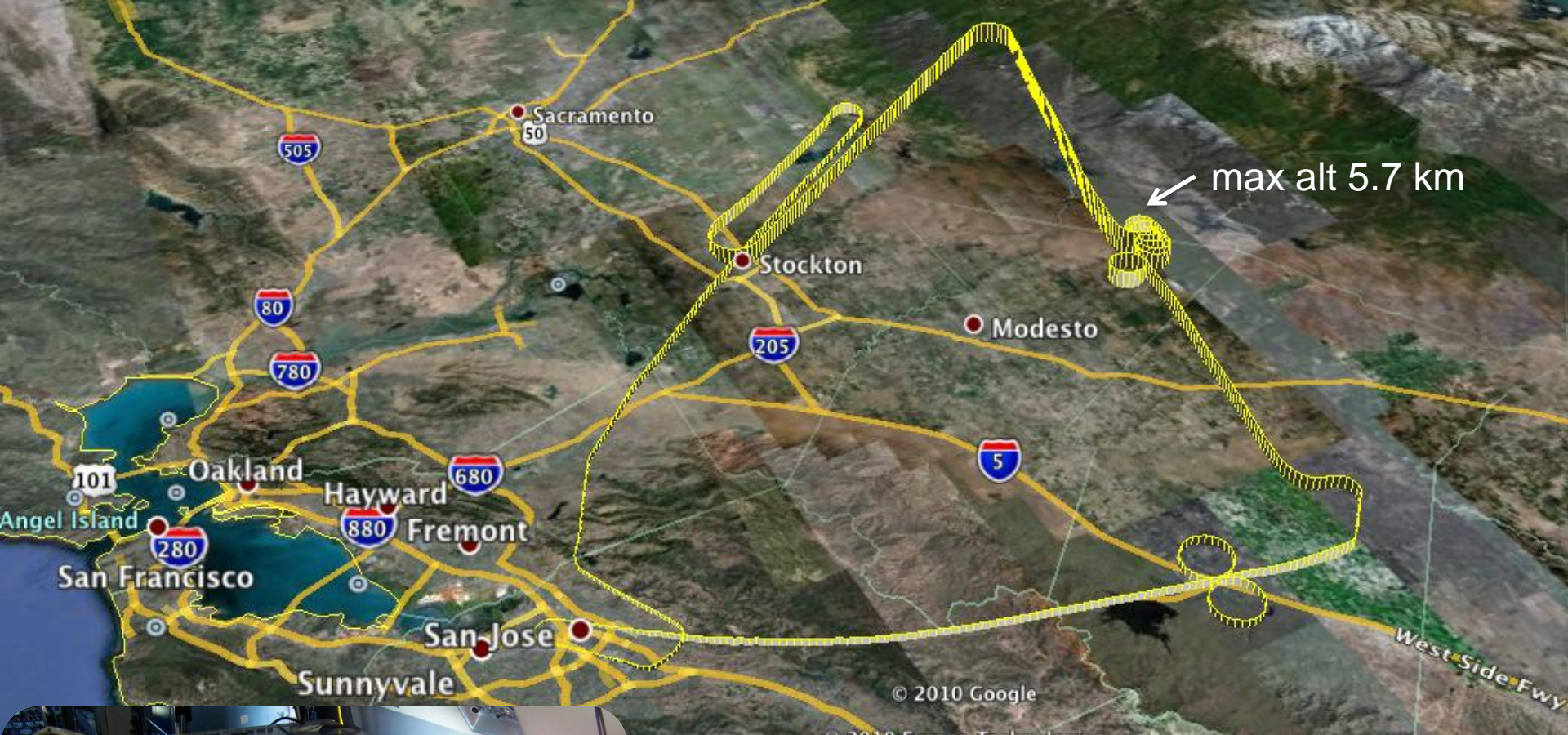
3 Cimels

Prede

AATS-14

4STAR and AATS comparison at MLO, Sept. 2 2008





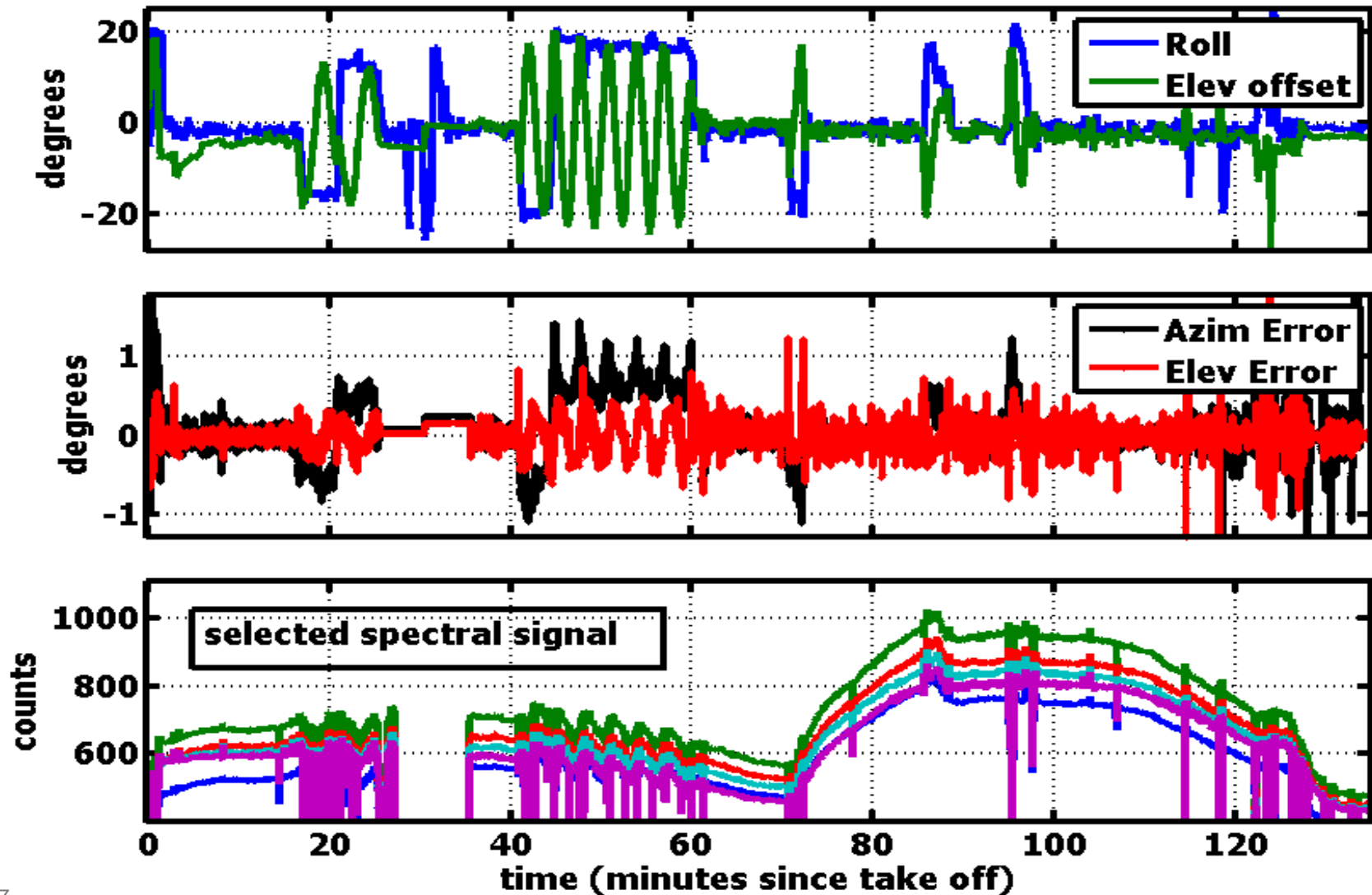
3 flights in Sep 2010:

- 1. Pilots only: Airworthiness certification**
- 2. Science ops: Pasco, WA to San Jose, CA**
- 3. Science ops: San Jose local**

**Flights met all goals (sun tracking only).
Large data set to guide improvements &
test/demo flights in 2011.**

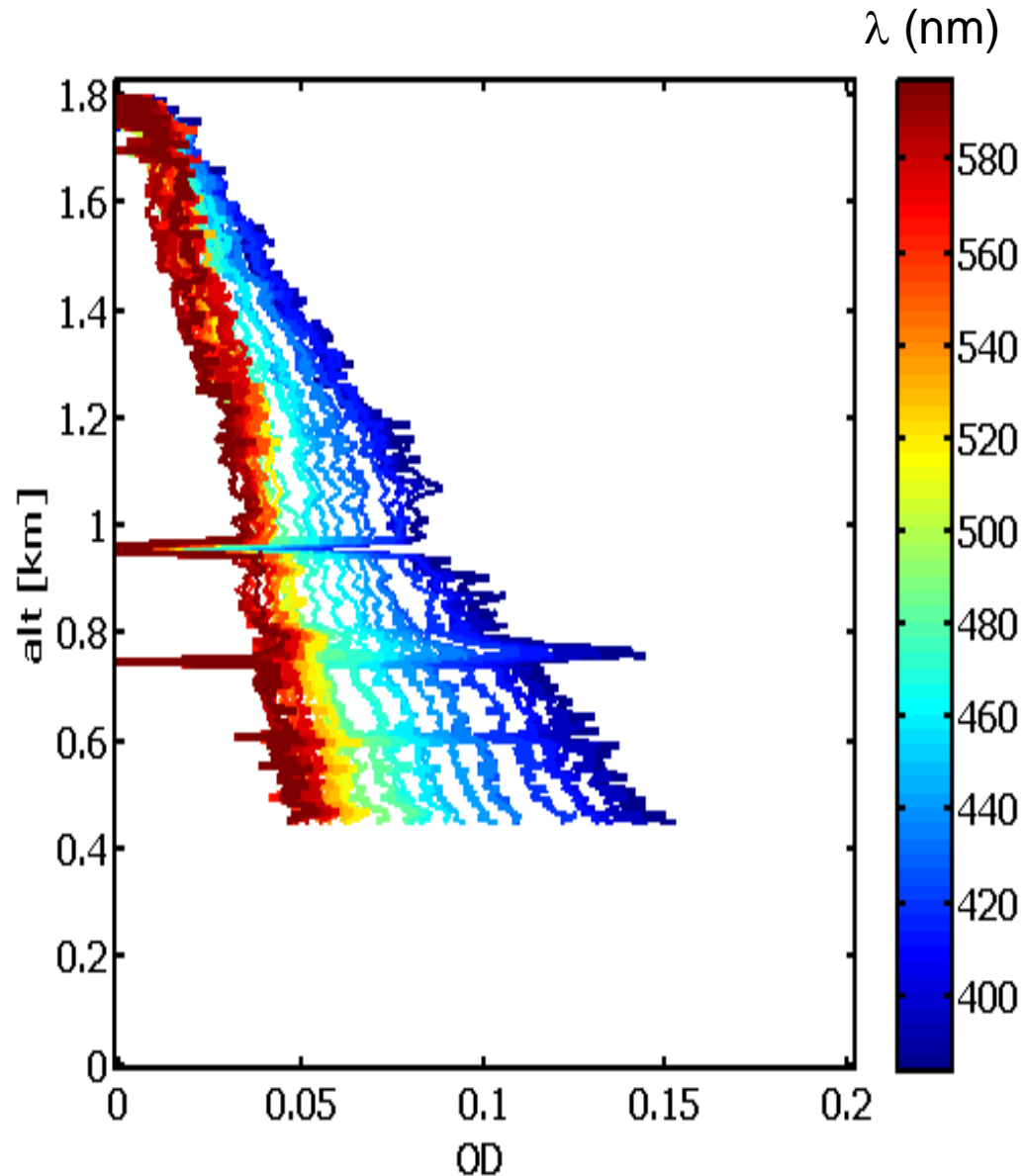
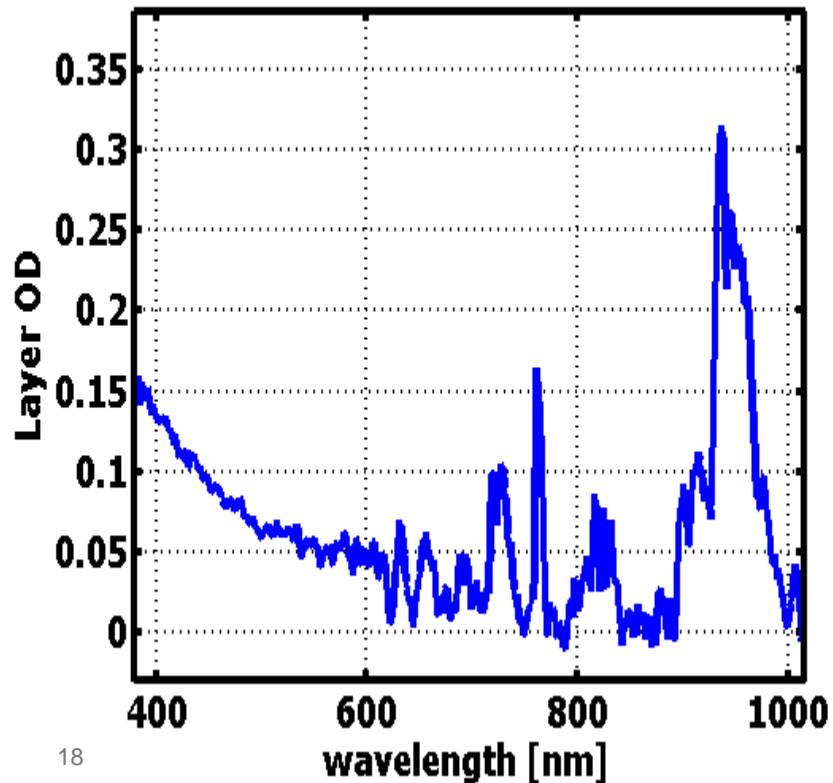
Sun Tracking Performance

9/28/2010; SJC t/o ~10 am



Vertical profile of optical depth (normalized to top of layer)

9/28/2010
SJC ~10 am



Next steps...

- ▶ In FY11: bring 4STAR to full science capability
 - Install/characterize skylight optics
 - Improve FOV uniformity of sun optics
 - Make tracking immune to glint
 - Adding temperature-stabilized enclosure for spectrometers and electronics
 - Apply correction of stray light inside spectrometer
 - Full characterization in test-flight series on G-1 in April, Jul, Sep
 - Next flight April 11 focusing on sky scan and cloud-mode
 - Mauna Loa Calibration
- ▶ In FY12
 - Hardening and retrieval algorithms
 - 4STAR/AATS-14 intercomparison flight on NASA P-3
 - DOE/ARM Mission on G-1, Cape Cod, Summer and Winter 2012

