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

A collaboration involving:

- **PNNL: Connor J. Flynn**, B. Schmid, E. Kassianov
- **NASA Ames:** S. Dunagan, R. Johnson, Y.Shinozuka, P. Russell, J. Redemann, J.Livingston, S. Ramachandran, J. Zavaleta
- **NASA GSFC:** AERONET Team

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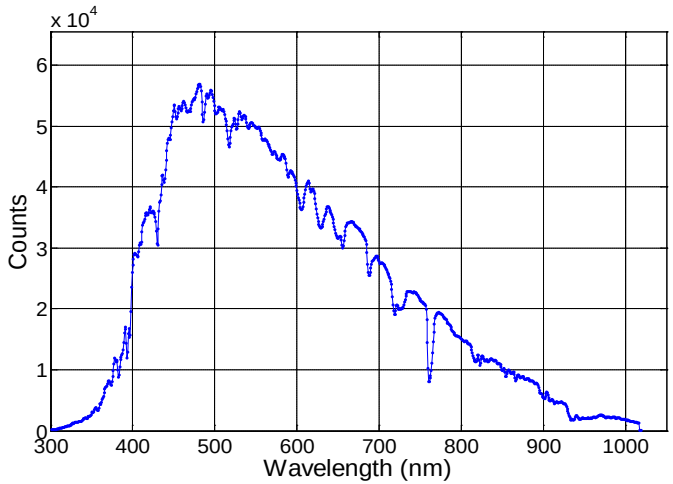
4STAR: Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research

AERONET-like capability

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

- **Size distributions**
- **Single-scattering albedo**
- **Asymmetry parameter**
- **Sphericity**



Improve gases And thus AOD

Airborne spectra yields profiles of aerosol type

AATS-like capability:

Airborne sun-tracking yields range-resolved properties from column-integrated quantities measured while profiling.

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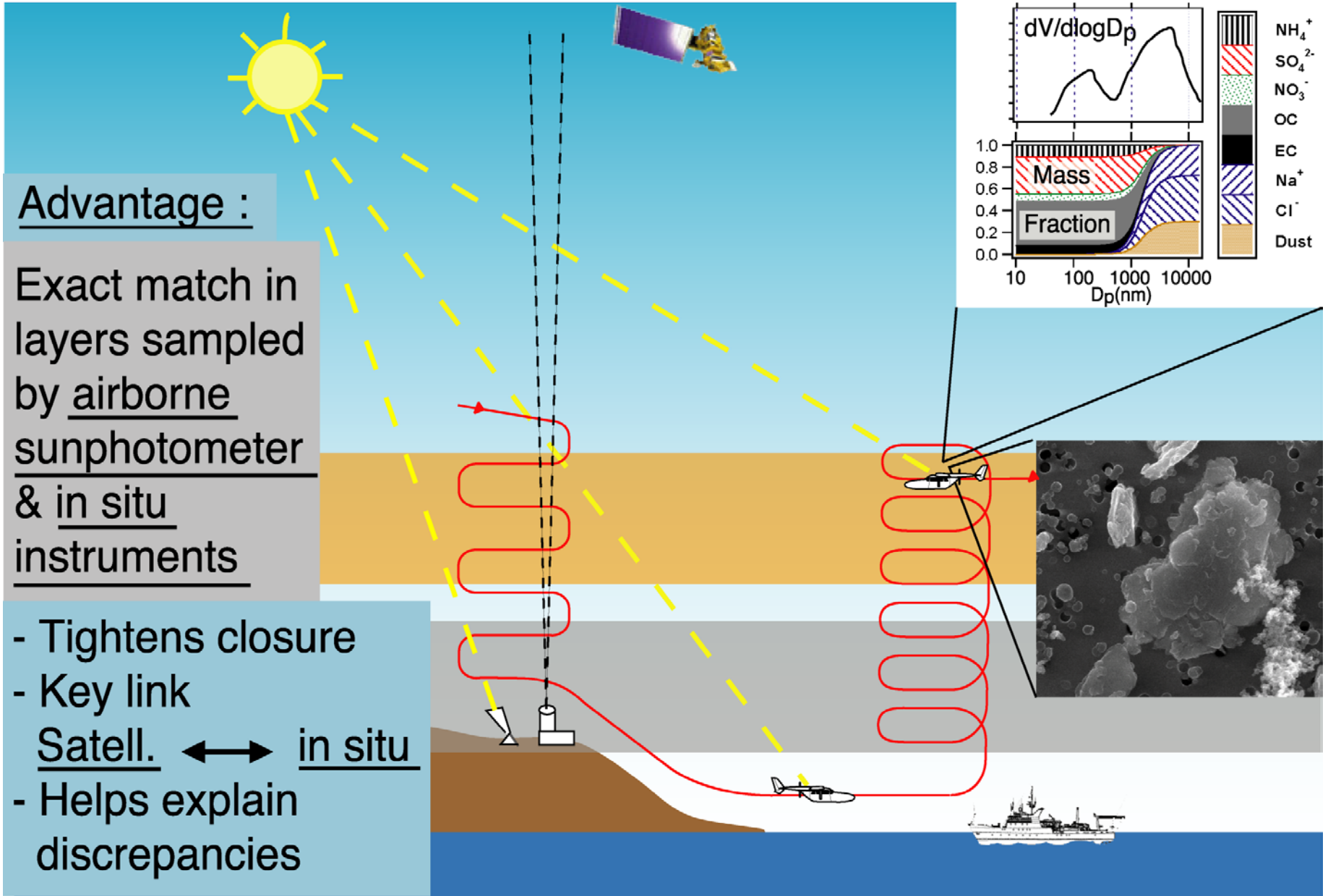
Proposed 4STAR data products:

- Direct beam [W/(m^2 nm)]
  - Aerosol Optical Depth, Extinction (via vertical profiling)
  - Gases: H_2O, O_3, NO_2, CO_2 (column and in profile)
- Angularly resolved sky radiance [W/(m^2 nm sr)]
  - Phase function
  - Asymmetry parameter
  - Aerosol Sphericity
  - Size distributions
  - Ambient aerosol absorption
  - Single-scattering albedo
- Synthesis products
  - Cloud OD, R_{eff} (Barker et al. or Min & Harrison)
- Spectral range: modular, but currently 350 nm – 1.7 μm.

4STAR and its Use…



AATS (Team) provides a bridge between orbital and various suborbital sensors

- Satellite validation (aerosol, H_2O, O_3):
  - AIRS (1), ATSR-2 (2*), AVHRR (4), GMS (1), GOES (2), GOME (1), MISR (5), MODIS (10), POAM (2), SAGE-3 (2), SeaWiFS (1), TOMS (2)
- Airborne satellite simulators (4)
- Airborne in situ aerosol (13)
- Lidars: surface (10), airborne (4)
- Radiative Forcing with Pilewskie SSFR (4)
- Atmospheric Correction (2)
- Model predictions of aerosol profiles (1)
- Surface Albedo (1)

(70+ peer-reviewed publications since 1996)

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NASA Ames Airborne Tracking Sunphotometers

13 Field Campaigns Since 1996

- TARFOX
- 2 WVIOPs
- ACE-2
- PRIDE
- SAFARI-2000
- ACE-Asia
- CLAMS
- SOLVE II
- Aerosol IOP
- EVE
- INTEX-A
- ALIVE

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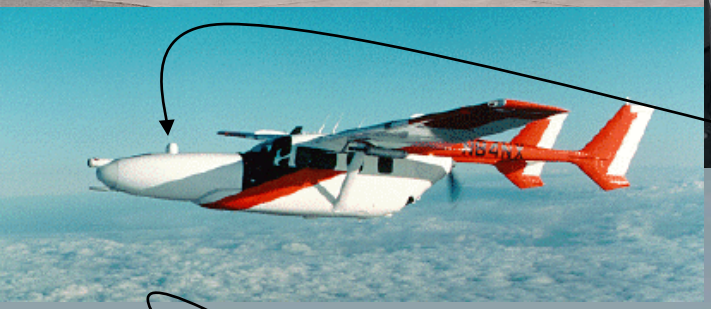
AATS-14

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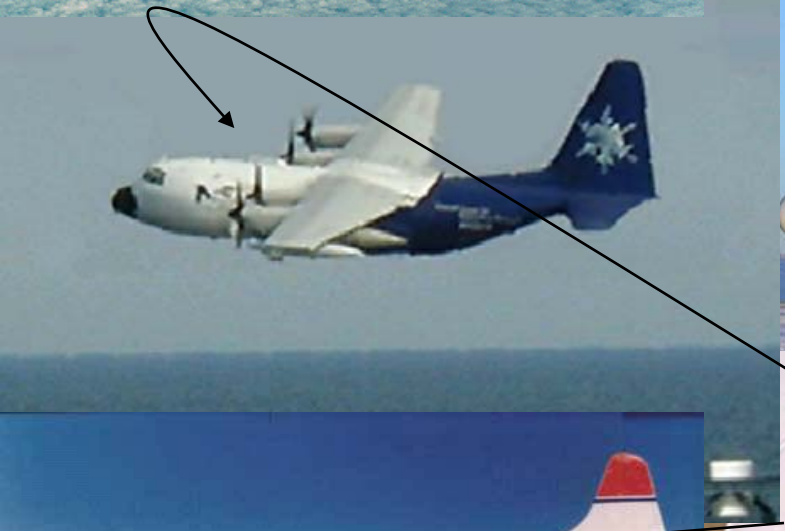


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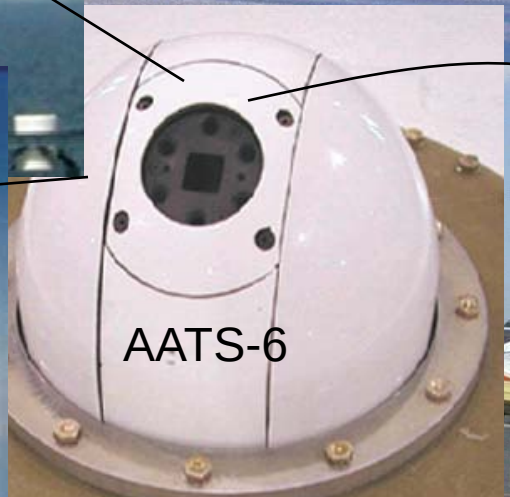
AATS-6


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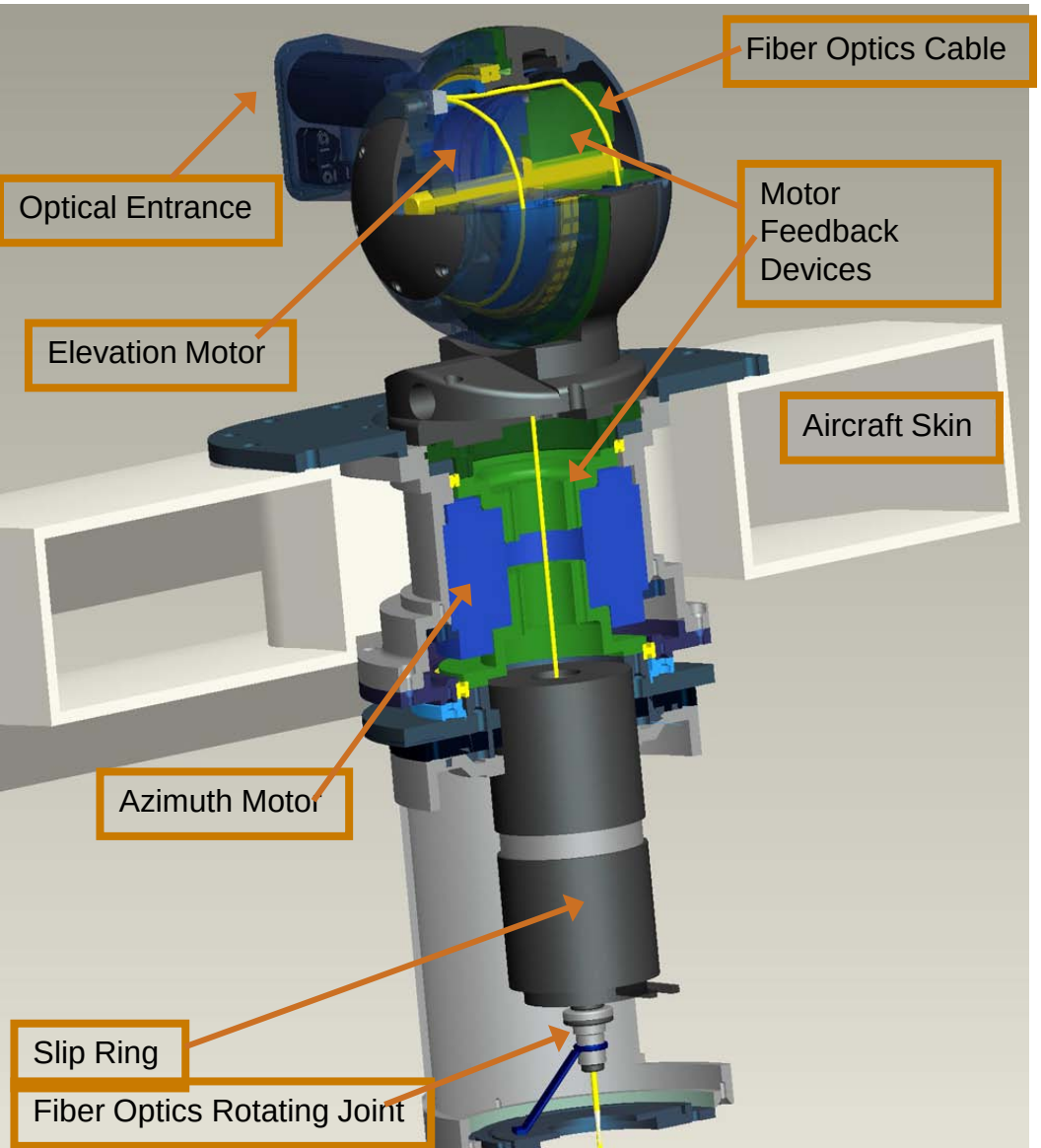
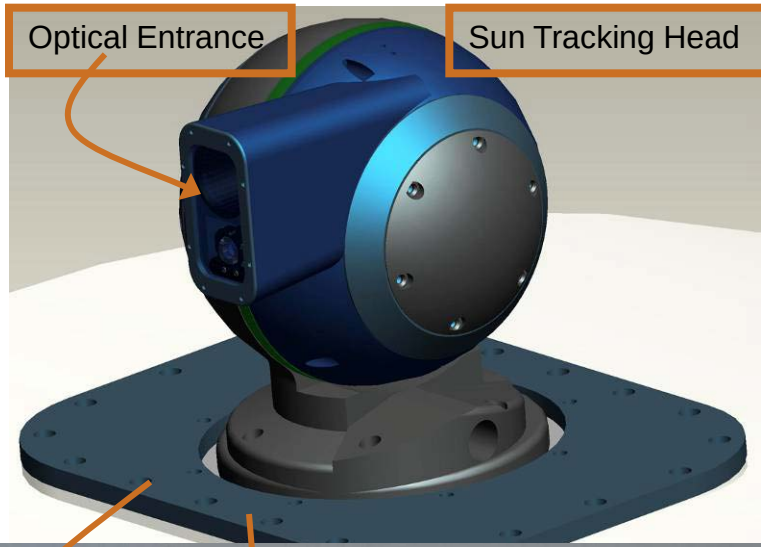
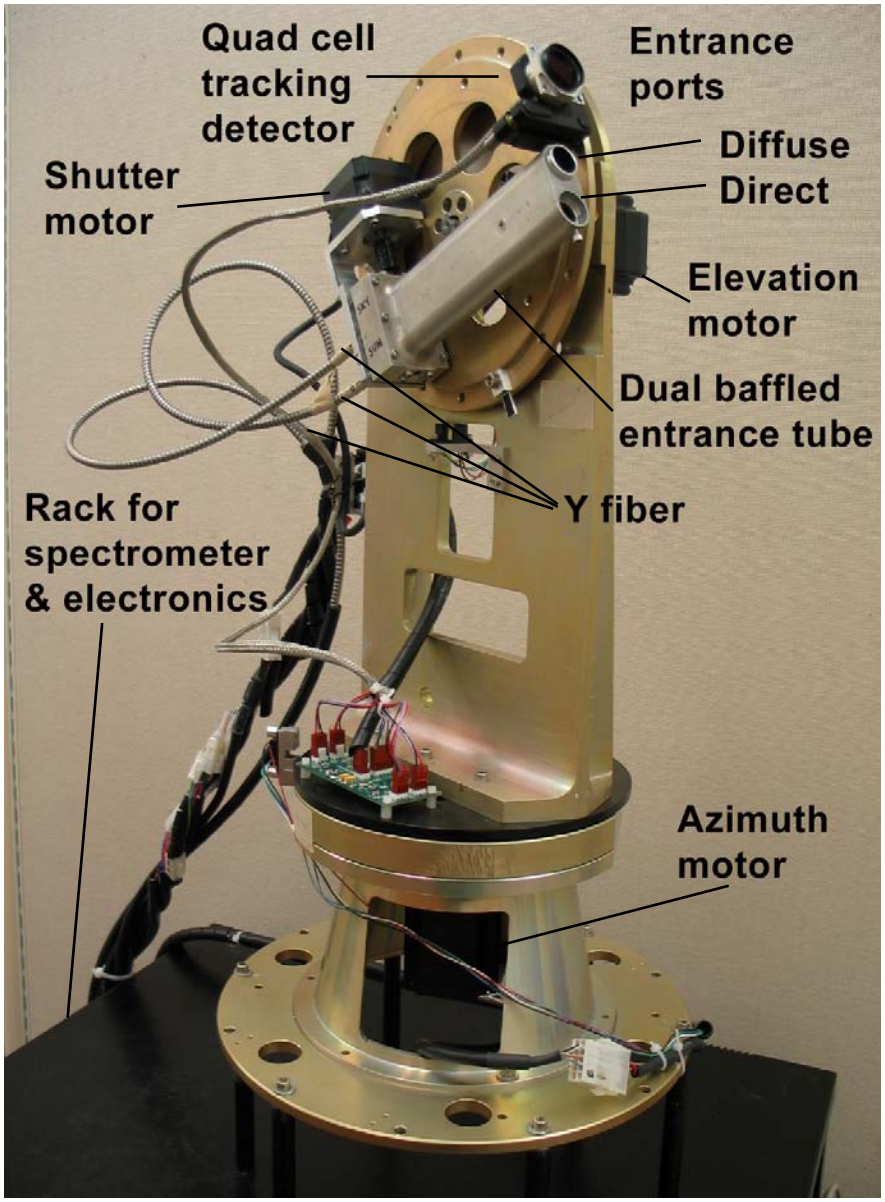
Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR)





Ground Prototype (4STAR-Ground)



Zeiss MCS CCD spectrometer

Quasi-monolithic, no moving parts, ceramic body, Range: 250-1016 nm, Resolution ~ 2 nm

Key Technological Hurdles:

- 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 within 3° of sun
- Sky scan within 100 seconds (10 km in flight)

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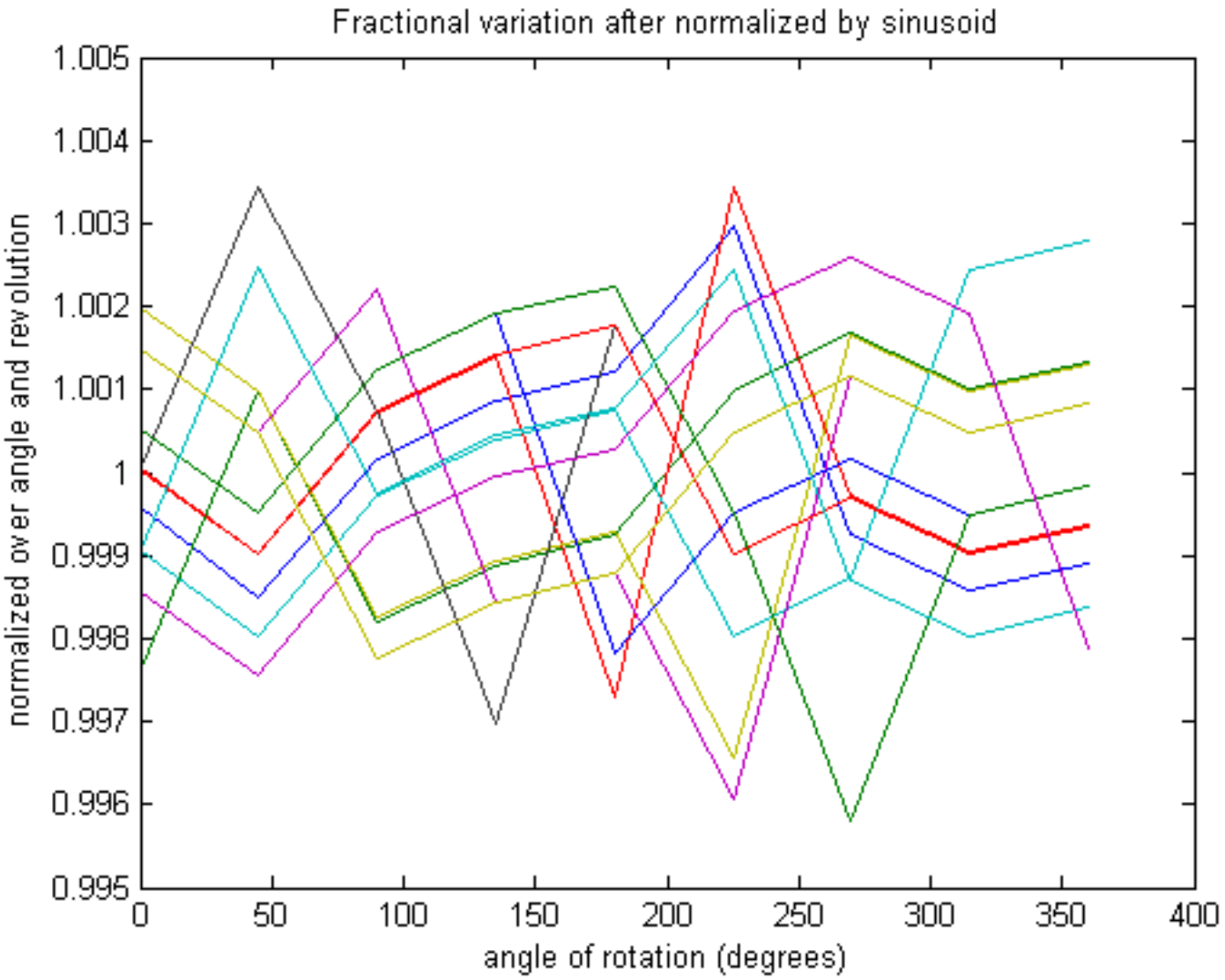
Rotating Fiber Optics Coupling Throughput Repeatability



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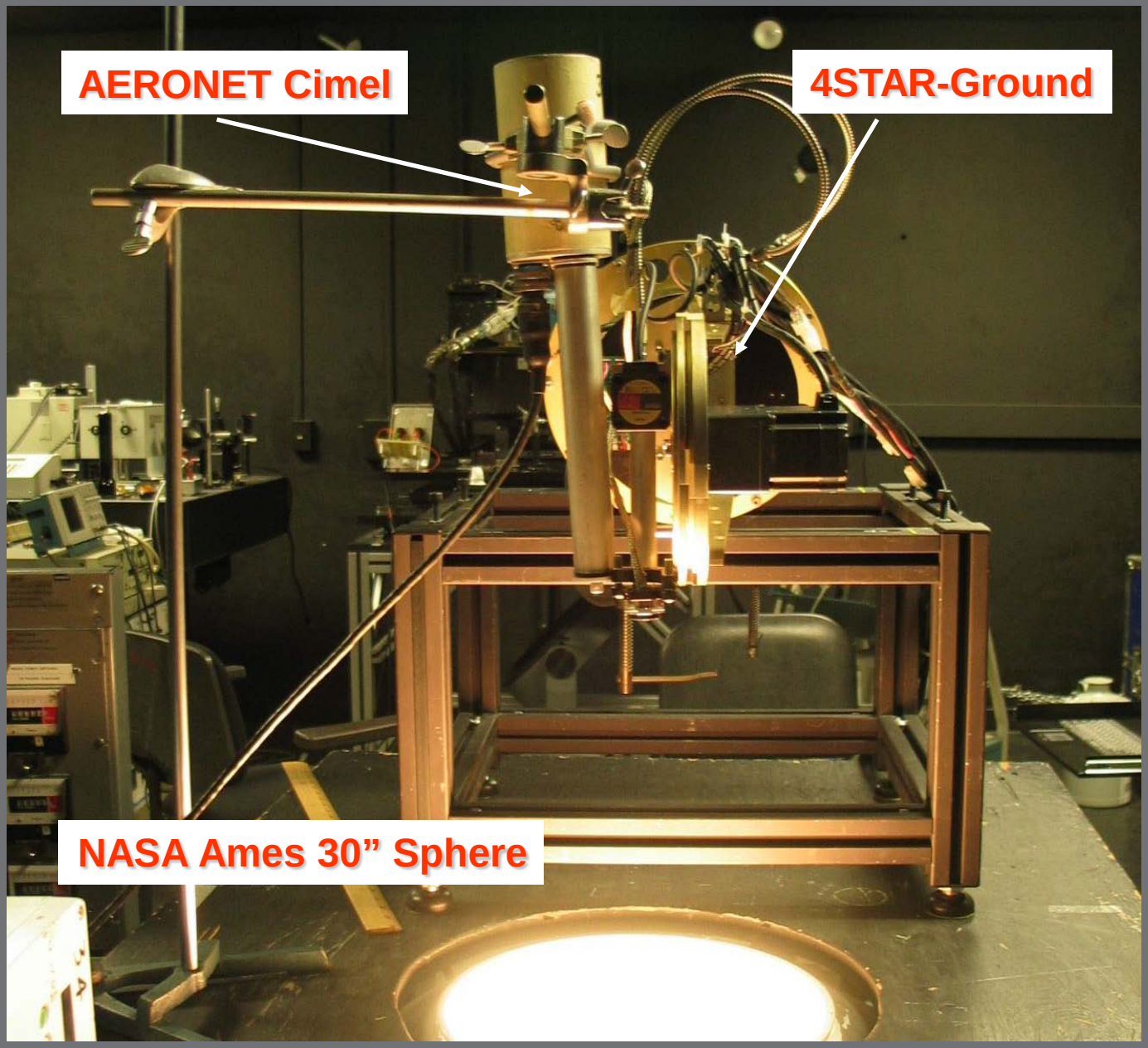
Radiance Calibration



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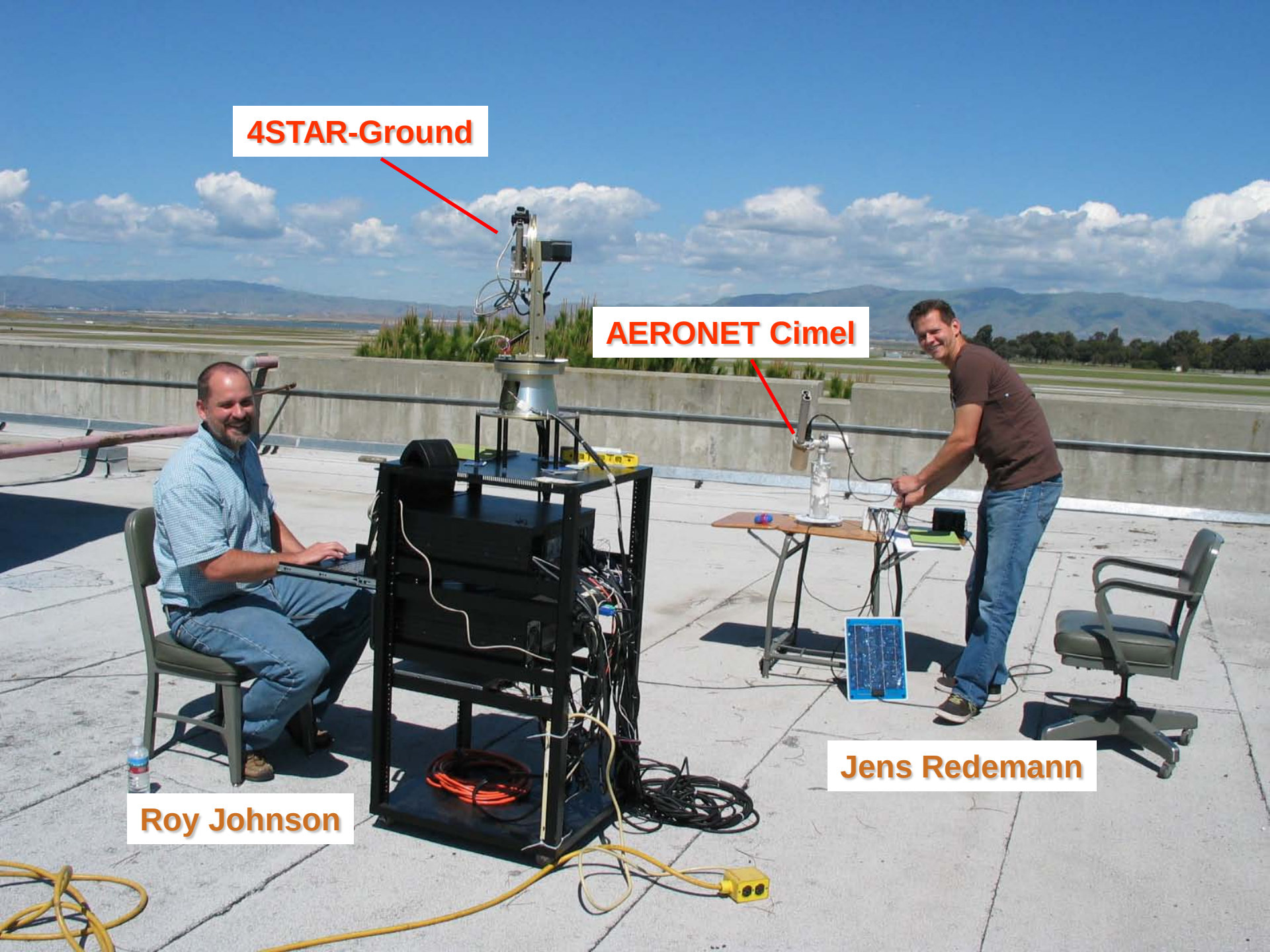
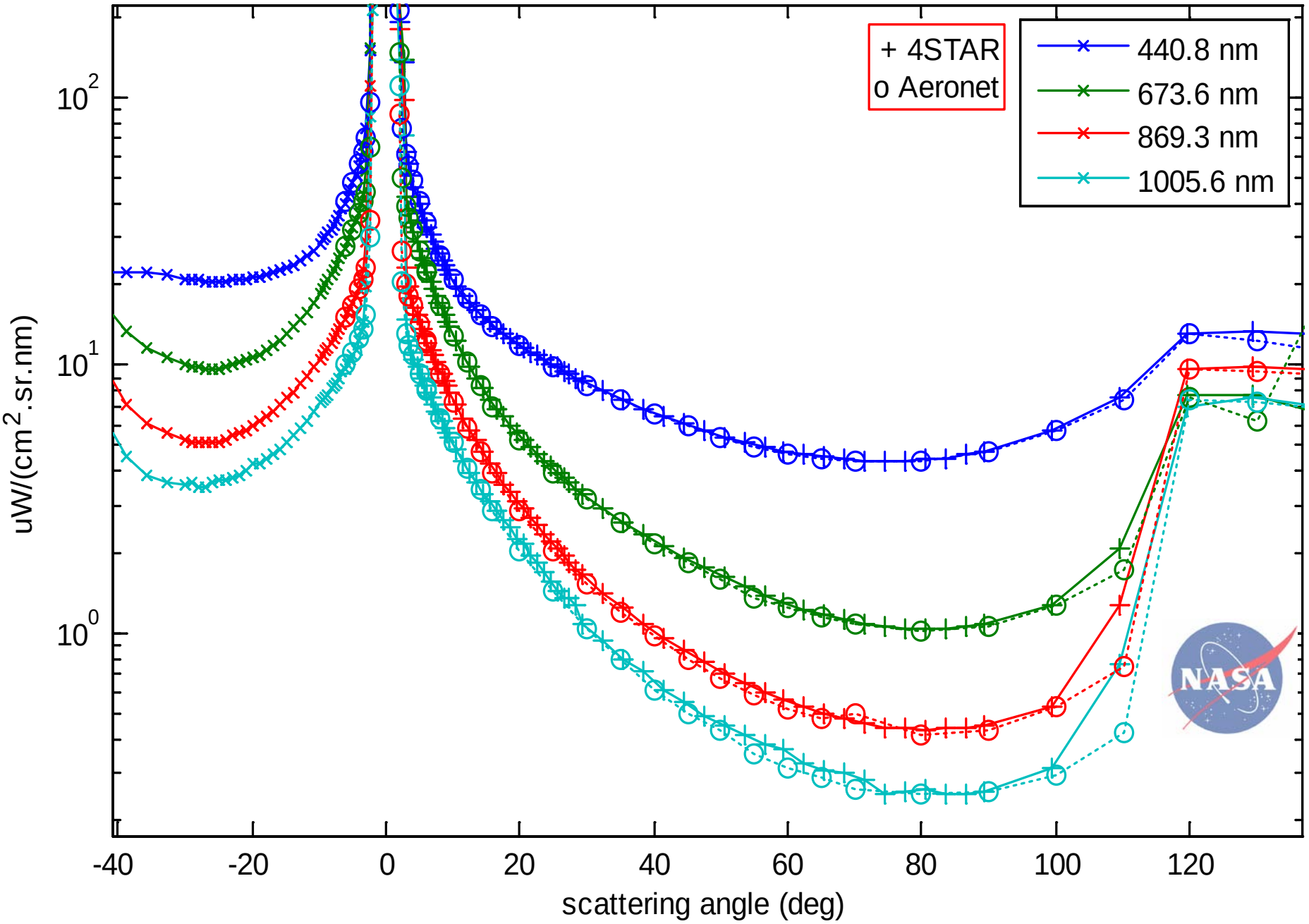
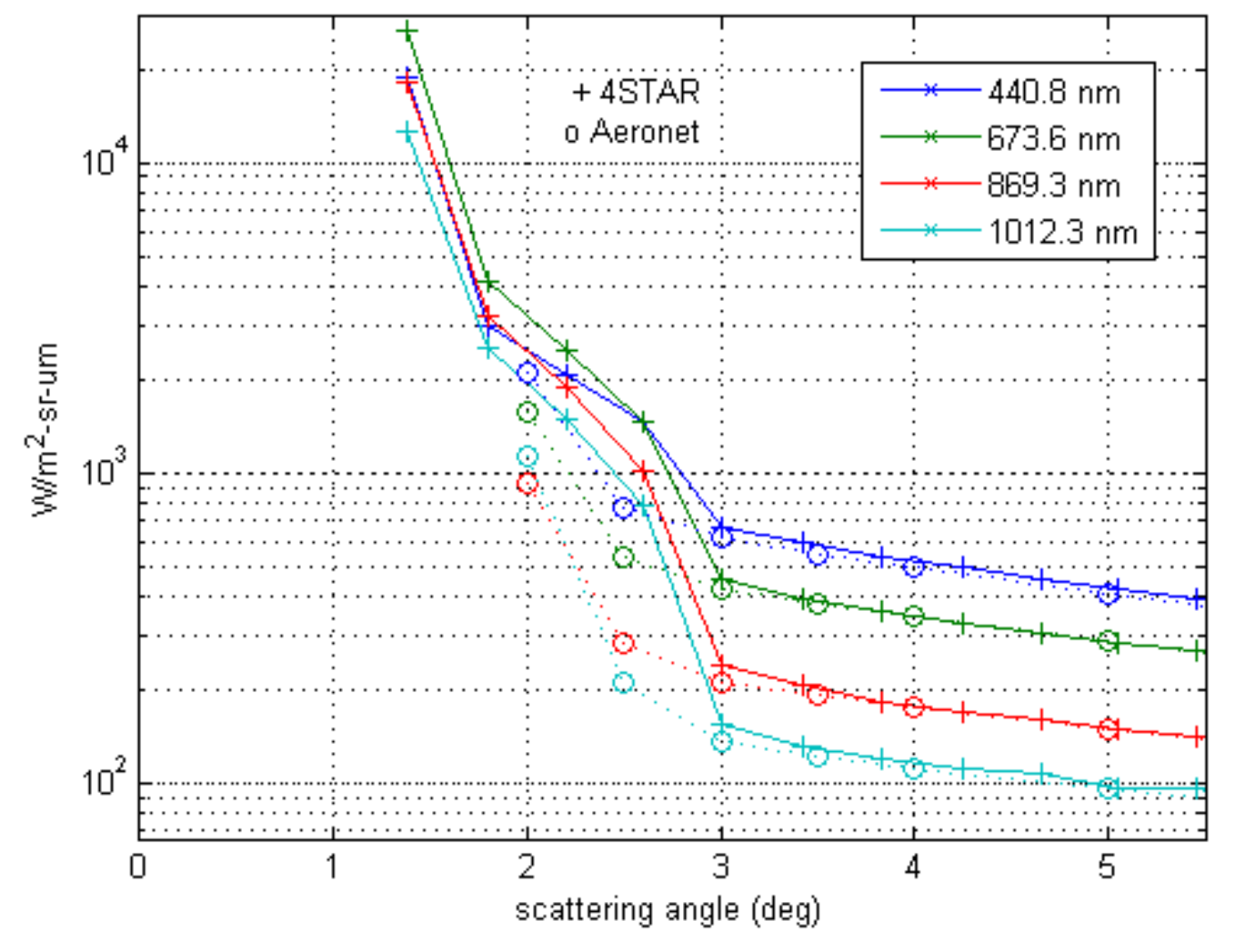

4STAR-Ground
AERONET Cimel
Roy Johnson
Jens Redemann

4STAR and AERONET principal plane scan



Stray light rejection close to Sun



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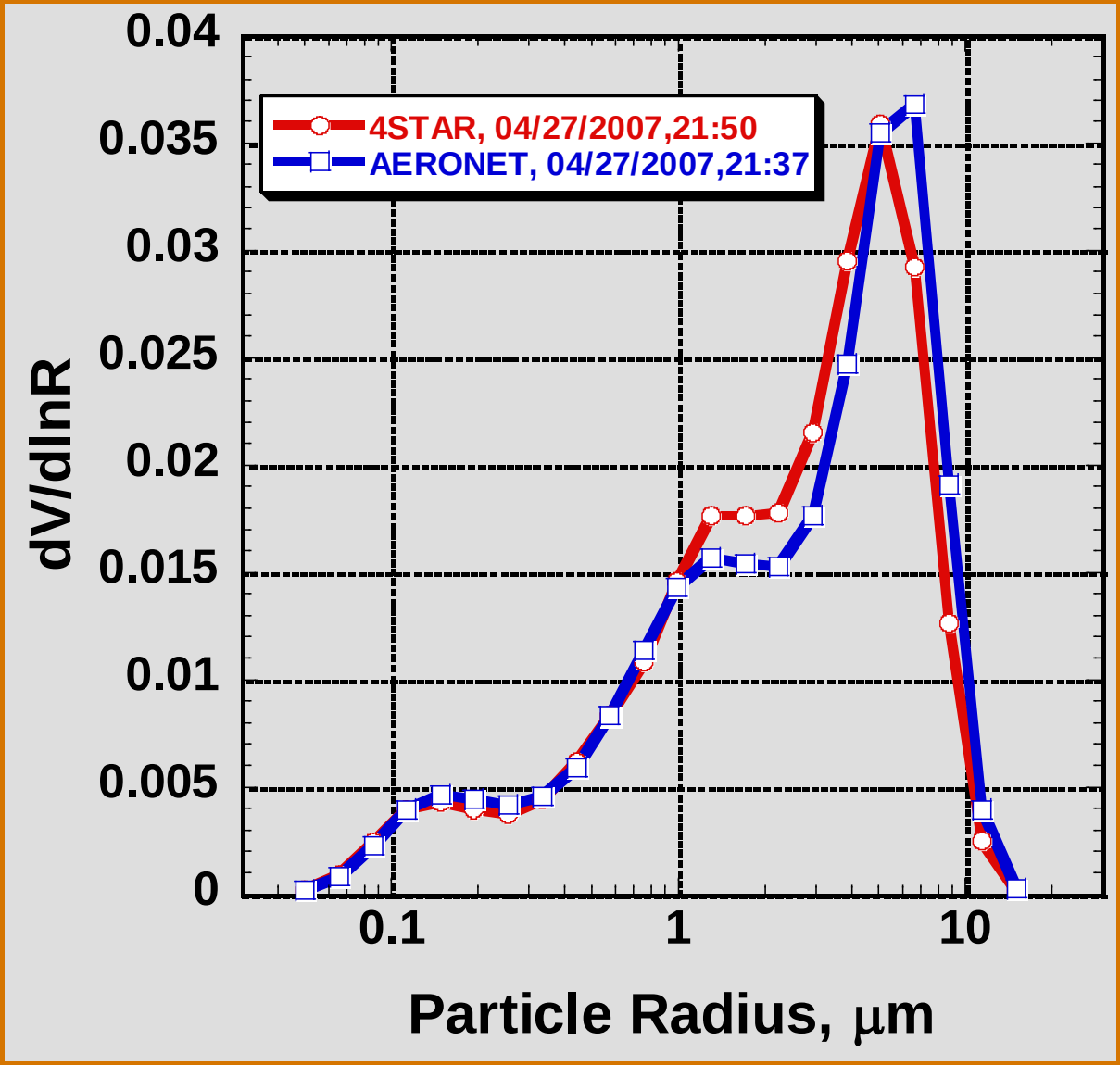
Size Distribution Retrieval using AERONET Code



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Sun Photometer Inter-Comparison Experiment (SPICE)
Mauna Loa, Aug. 24-Sept. 2 2008

4STAR

Prede

AATS-14

Cimel 037

Cimel 101

Cimel 451

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Mauna Loa Sun Photometer Inter-Comparison Experiment (SPICE)

Why Mauna Loa?

- High altitude (3.4 km), low aerosol loading (in morning)
- Intense direct beam, low sky brightness
- **➔ Good Langleys for sun channel calibration**
- Compare Langley calibrations of AATS-14, Prede, 4STAR and Cimel photometers

- Also provides a stringent test for radiance measurements with atmospheric conditions similar to flight conditions
- Confirm sufficient radiance signal levels.
- Compare sky radiances from 4STAR, Prede, and Cimels.

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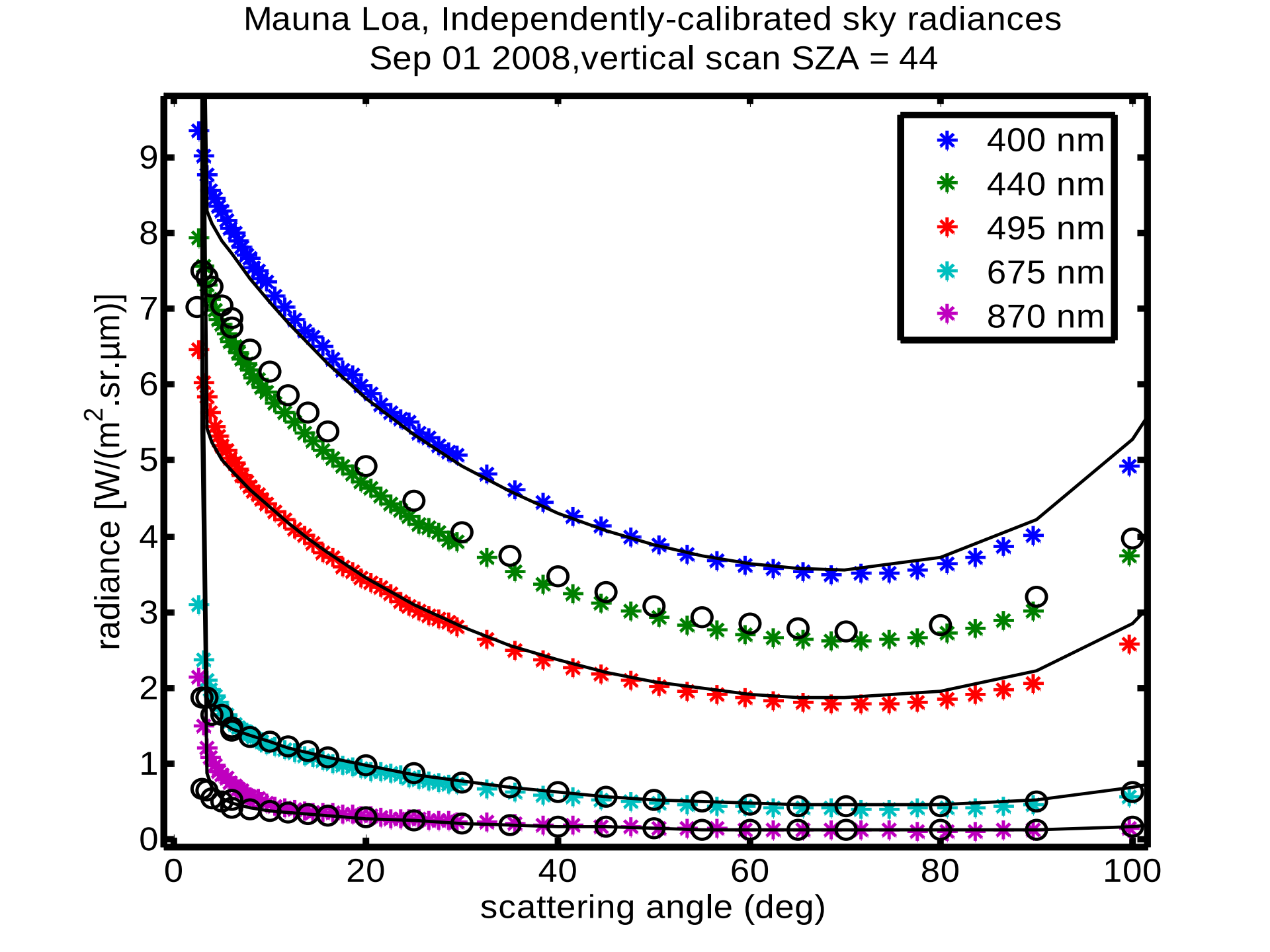
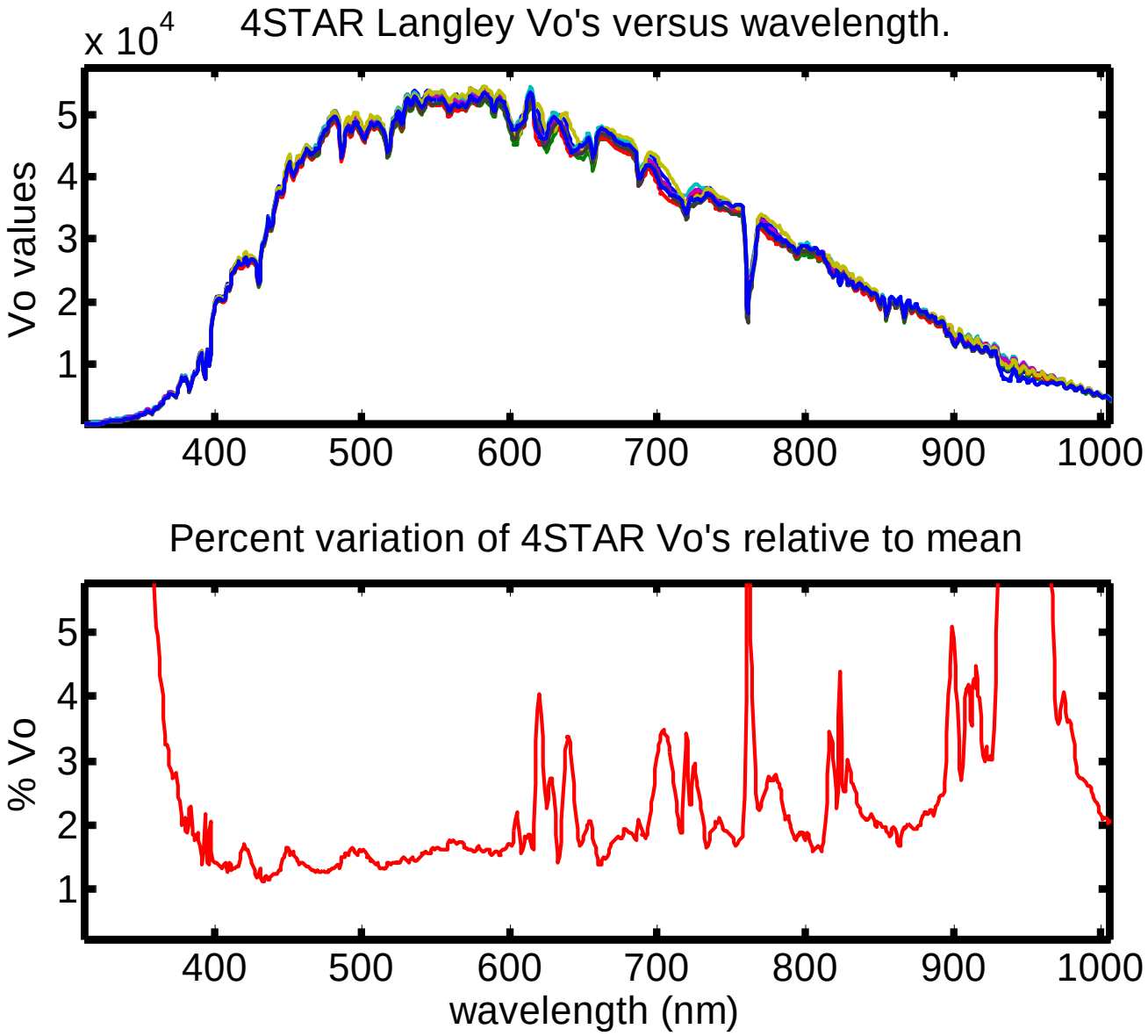

Mauna Loa, Independently-calibrated sky radiances
Sep 01 2008,vertical scan SZA = 44
400 nm
440 nm
495 nm
675 nm
870 nm
radiance [W/(m2.sr.µm)]
scattering angle (deg)
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100

Radiance comparison conclusions:

- Radiance calibration and repeatability is sufficient.
- Radiance signal levels are strong, permitting fast sky scans, ~1 sec/angle
- Stray light near sun should be further reduced.

Langley calibrations show variability



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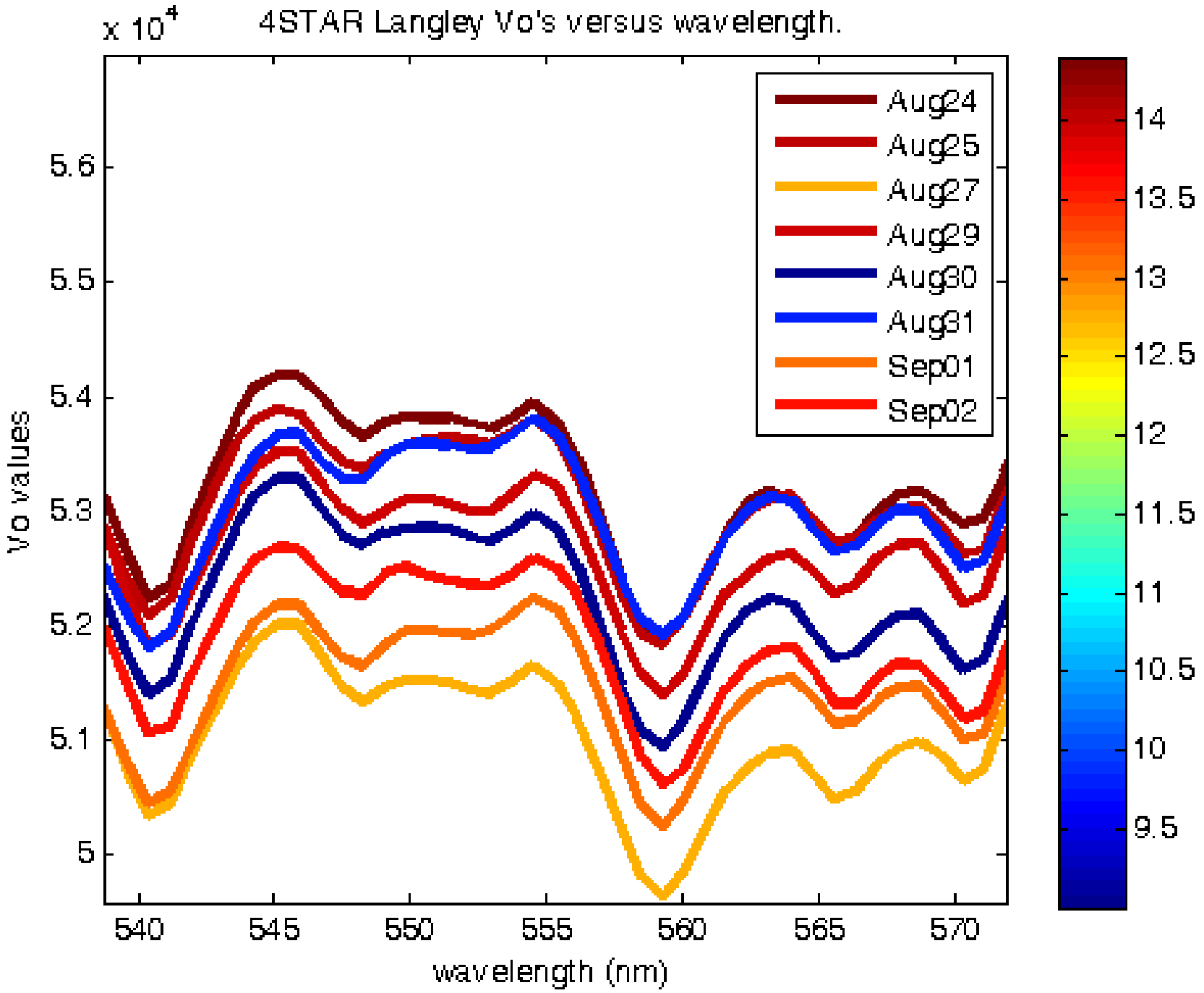
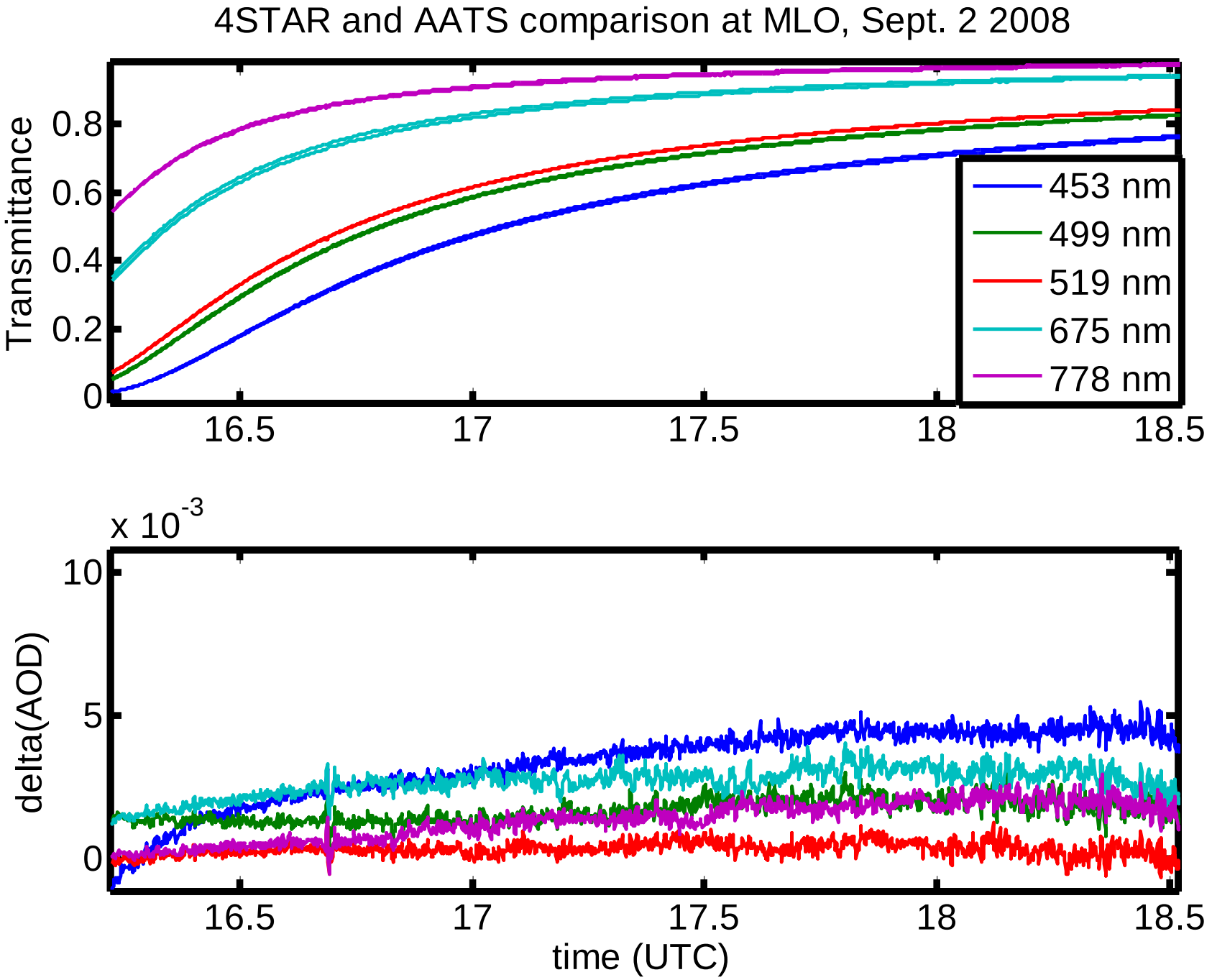

x 10^4
4STAR Langley Vo's versus wavelength.
Aug24
Aug25
Aug27
Aug29
Aug30
Aug31
Sep01
Sep02
5.6
5.5
5.4
5.3
5.2
5.1
5
Vo values
540
545
550
555
560
565
570
wavelength (nm)
14
13.5
13
12.5
12
11.5
11
10.5
10
9.5


4STAR and AATS comparison at MLO, Sept. 2 2008
Transmittance
0
0.2
0.4
0.6
0.8
16.5
17
17.5
18
18.5
453 nm
499 nm
519 nm
675 nm
778 nm
x 10-3
delta(AOD)
10
5
0
16.5
17
17.5
18
18.5
time (UTC)

Langley comparison conclusions…

- 4STAR Langley calibrations show acceptable relative stability (with respect to wavelength) but insufficient day-to-day stability.

- Temperature sensitivity as possible source
  - Dark counts exhibit temperature variability
  - Possibly a temperature-dependent gain.
  - Enclosing spectrometers in temperature controlled box.

- Small light leak might contribute to instability as well.

Next steps…

- Add SWIR 900 nm -1700 nm spectrometer for more size and absorption information
- Reduce stray light in skylight measurements
- Provide temperature stability
- Eliminate light leak
- Continue spectral inversion development
- Harden design for airborne deployment

Funding outlook

- NASA and Battelle/PNNL internal bridge funding
- NASA ROSES proposal is pending
  - If successful, this will carry us to a configuration for unpressurized airborne operation.

Requesting support for final hardening sufficient for pressurized airborne operation, test flights, and for participation in Western Atlantic Tropospheric Aerosol Campaign (WATAC) 2011 or similar.

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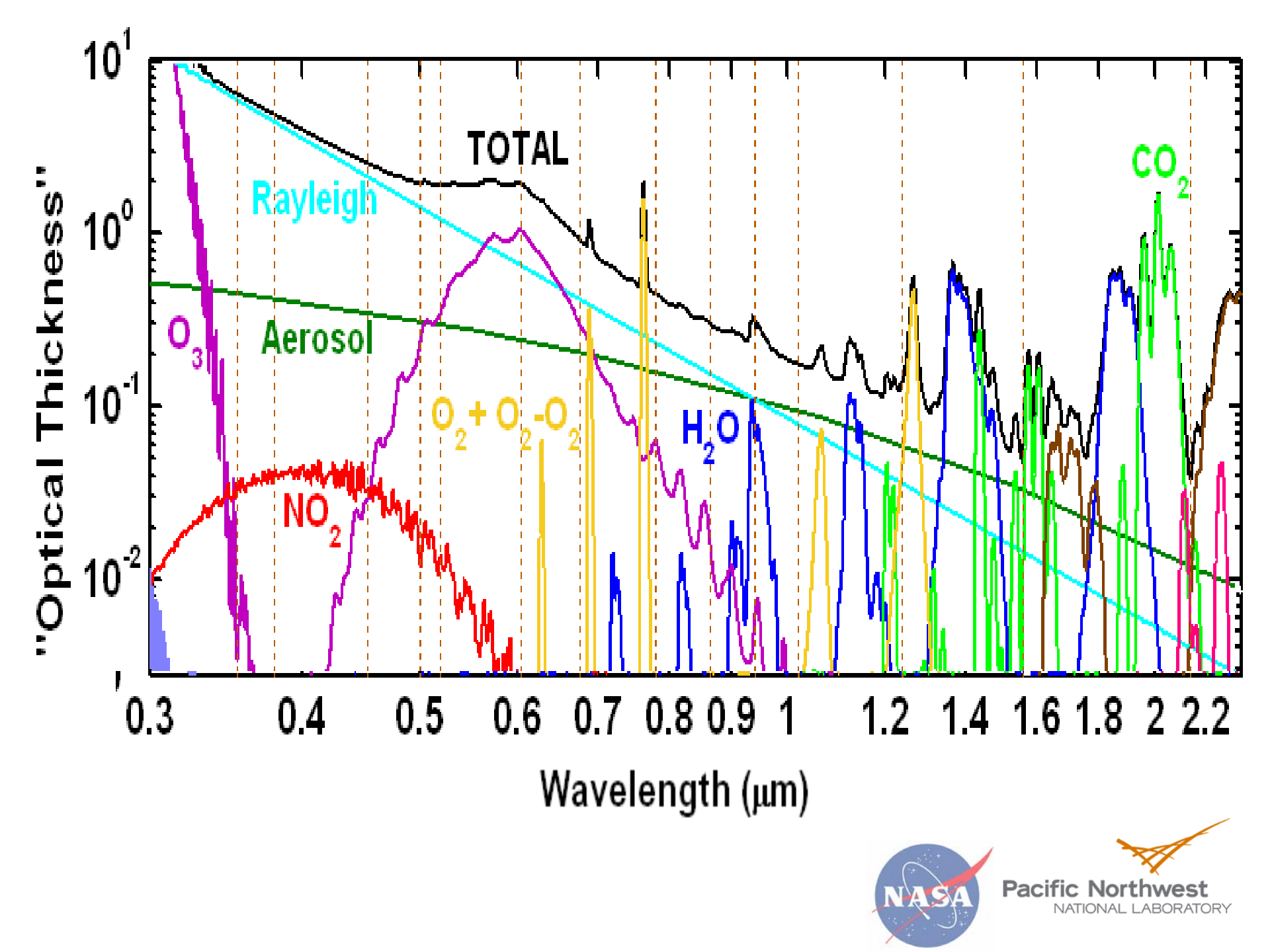

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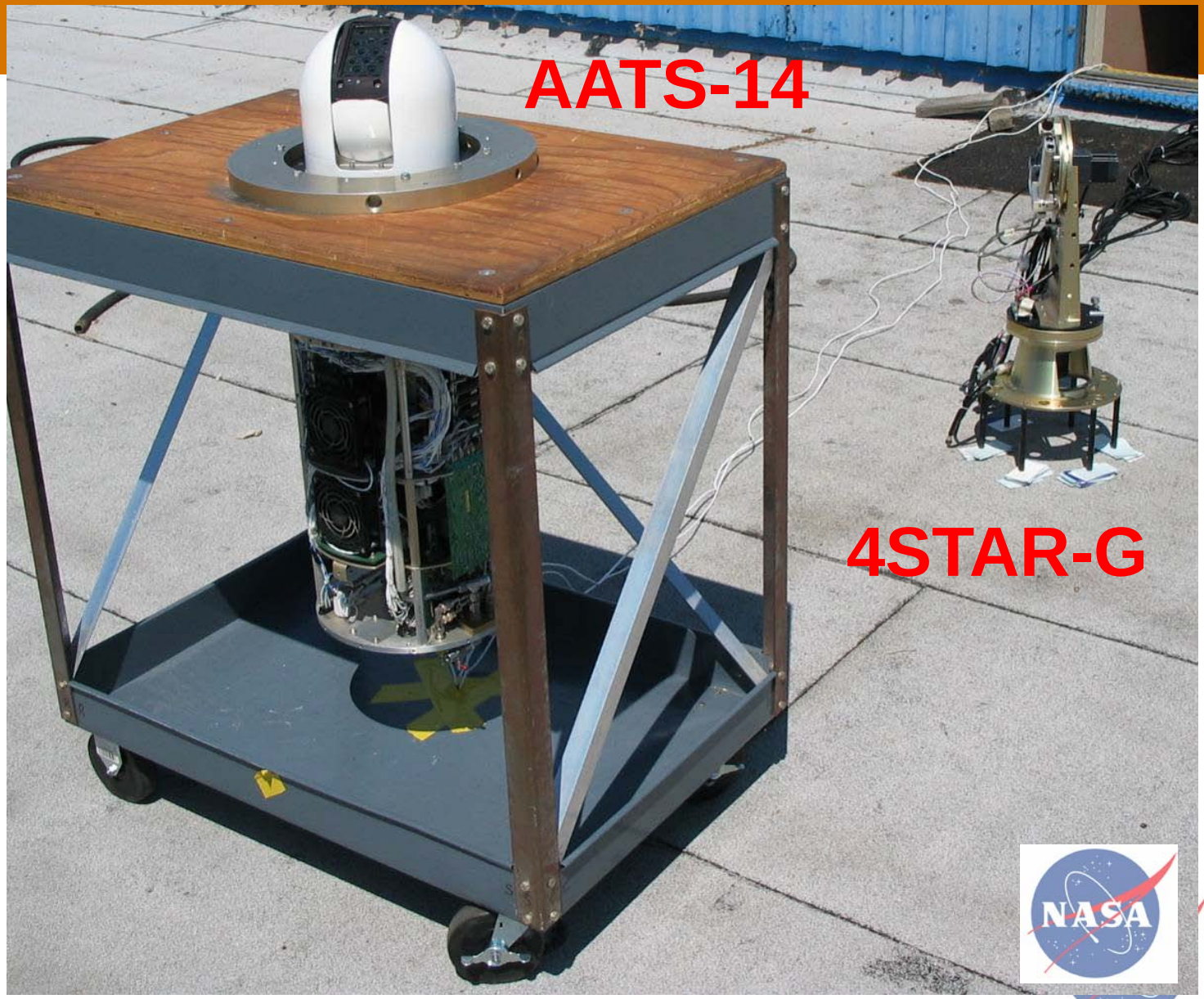
Direct Beam Comparison



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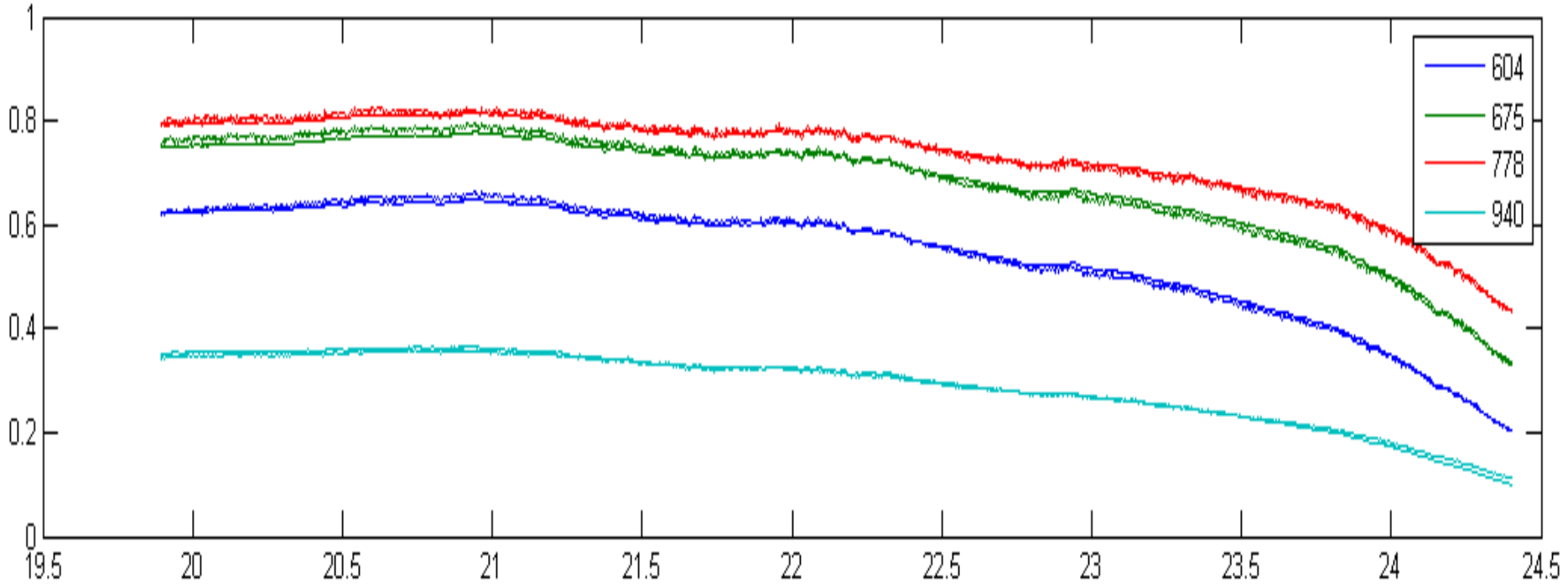
Direct Beam Comparison AATS-14 & 4STAR-Ground



- Tracking stable enough
- Short term calibration is okay.

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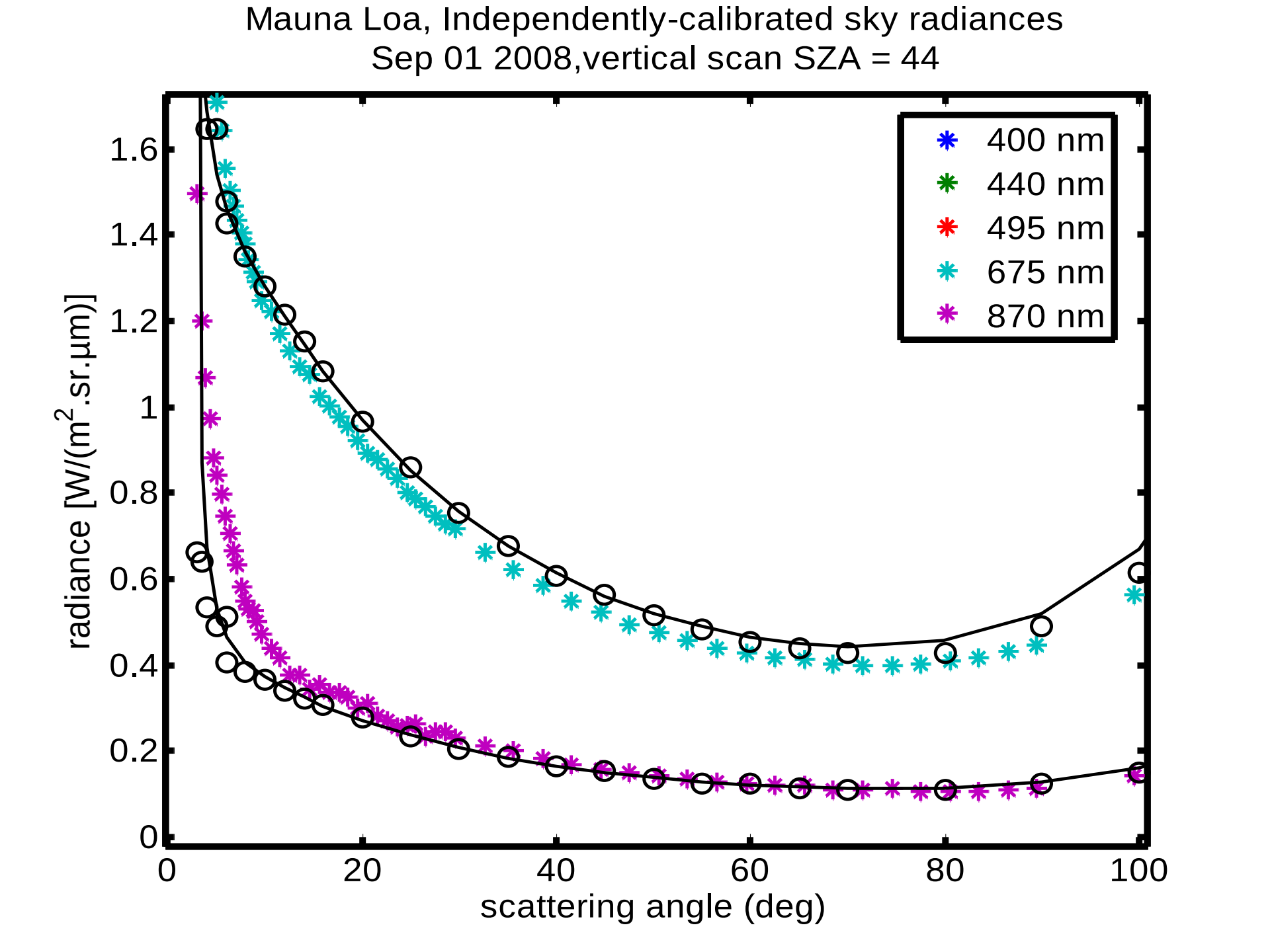
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