4STAR and Improving Its Science Capabilities

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Spectrometer for **S**ky-**S**canning **S**un-**T**racking **A**tmospheric **R**esearch

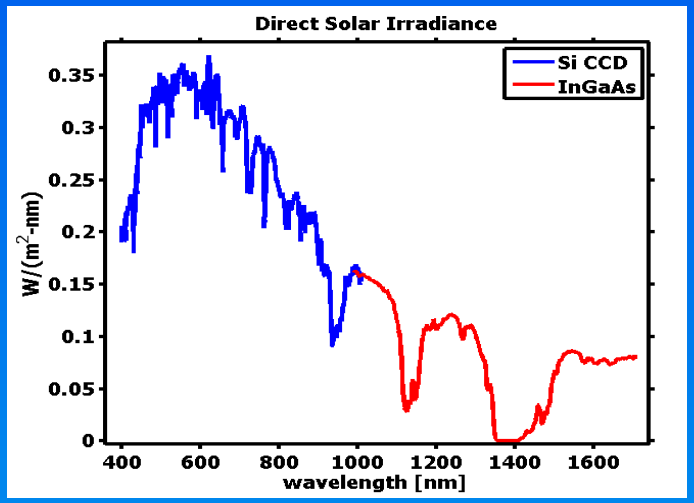
- What is the 4STAR instrument we built and what does it measure?
- What have we done with it?
- What have we found to fix in order to be capable of delivering highest quality science results.

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

Atmospheric Research

AERONET-like

- Phase function
- Size mode distributions
- $n_{re}(l)$, $n_{im}(l)$
- Single-scattering albedo
- Asymmetry parameter
- Shape
- Hence aerosol type



Improve H_2O, O_3
Add NO_2
Thus improve AOD

AATS-14-like retrievals of column amount and profiles of aerosol & H_2O.
(AATS gets O_3 when q_{sun} ~90°, AOD(600 nm)<~0.03)

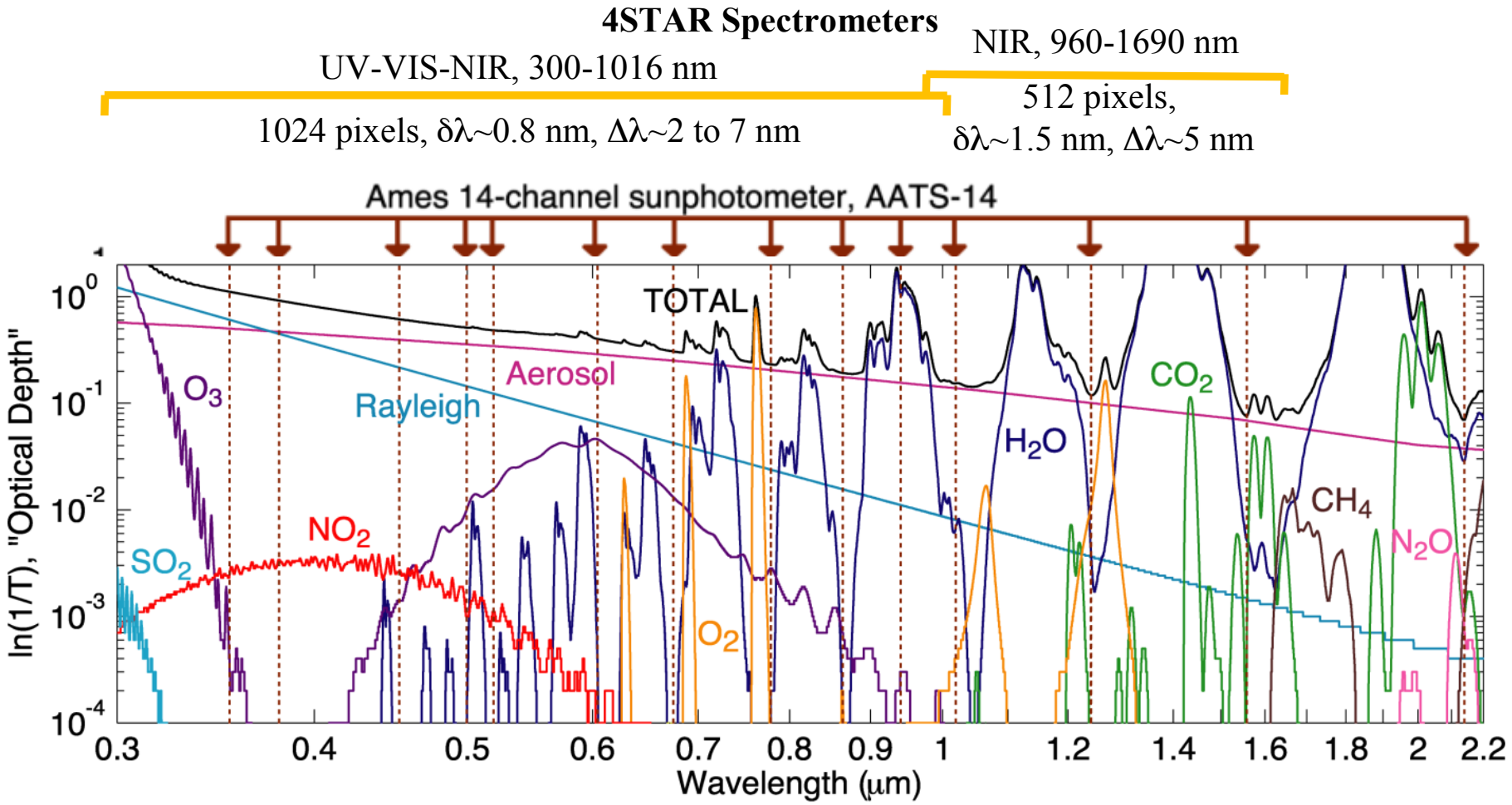
- 30-year heritage (AATS-6 &-14)
- >100 peer-reviewed pubs, diverse science +:
- Validation of ≥12 satellites/instruments (MODIS, MISR, SAGE, OMI, AIRS, TOMS, ATSR-2, GOES, …)
- Deployed on ≥10 A/C over most of the world's continents & oceans for NASA, NOAA, DOE, & Navy

4STAR Products

- Optical Depth via Transmittance (Aerosols and Trace Gases): amount of light absorbed and scattered in atmosphere
  - Calculated from dividing measured signal by TOA signal
  - TOA signal is determined by a Langley extrapolation
  - OD = -(lnT)/m
    - m=airmass, T=C/C0, $OD=S_iOD_i$, i=Ray,aer,H2O,O3, …,
      C = Channel count rate. C0 = TOA value

- Spectral Radiance: Amount of light collected in field of view
  - Directly proportional to counts measured while viewing a portion of the sky or a cloud
  - Watts/(m^2 x sr x nm)
  - Requires calibrating to a source (integrating sphere)

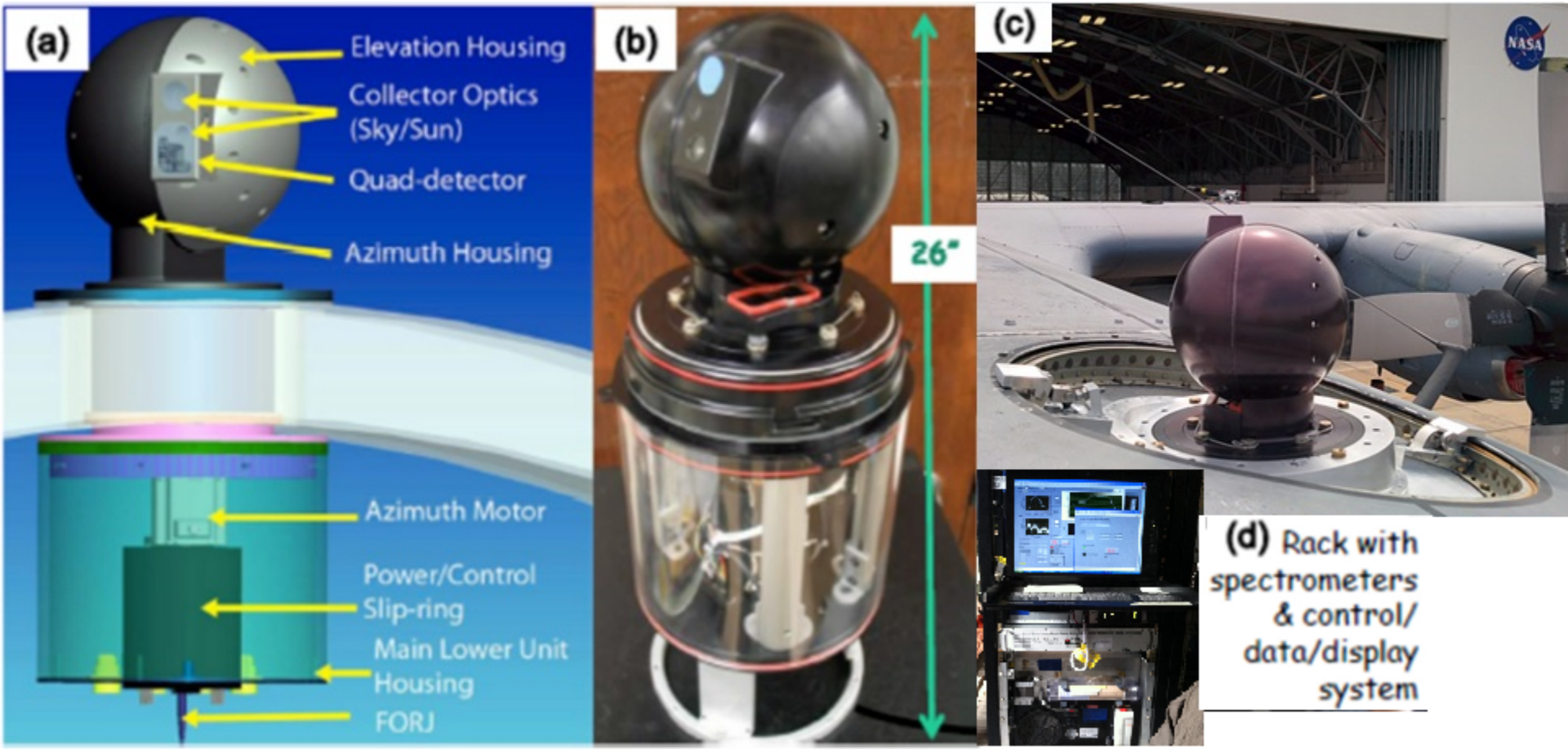
4STAR Measurement



Optical Depth spectra of direct solar beam at sea level calculated using MODTRAN-4.3 with a Midlatitude Summer atmosphere, a rural spring-summer tropospheric aerosol model (Vis = 23 km), and the sun at the zenith. Assumed O_3 = 332 DU, NO_2 = 0.22 DU.

Dunagan et al., *Remote Sens.* 2013

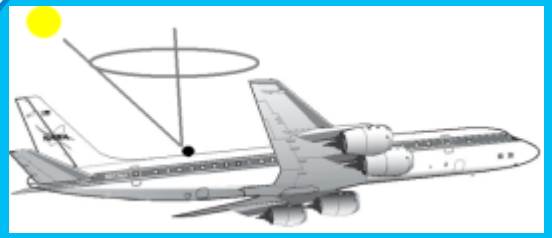
4STAR: Designed and Built



(a) Design for 4STAR tracking/scanning head and can. (b) Head and can as built. (c) 4STAR head on NASA C130 aircraft. (d) Rack and contents.

4STAR: Operating Modes

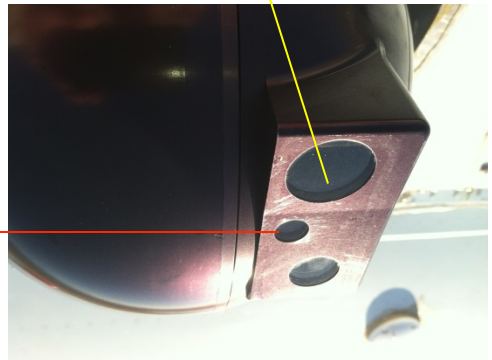
Direct sun tracking:
- **AOD** at 100s of wavelengths, **Angstrom exponent**
- aerosol extinction profiles
- **O_3**, **NO_2** and **CWV** (demonstrated); CO_2, CH_4, OH, Formaldehyde (desired)
- Thin cirrus cloud properties



Sky scanning:
Almucantar and Principal plane
- **Sky Radiances**
- AERONET-like aerosol size distribution, index of refraction, SSA, asymmetry factor, sphericity

Zenith viewing:
- Cloud property retrievals (**COD, cloud droplet effective radius**)*

* With SSFR measurements



What have we done with 4STAR?

Mechanical & electrical performance in flight campaigns

4STAR is a flight-certified instrument under revision control

TCAP, DOE G-1

- July 2012: 4STAR operated successfully on all 15 flights
- February 2013: 4STAR operated successfully on 19 science flights
- Sun Tracking, Sky Scanning and Zenith modes demonstrated.
- Science analyses in 2 journal papers: Shinozuka et al., *JGR* 2013, Segal-Rosenheimer et al., *JGR* 2014

SARP, NASA DC-8

- July 2013: 4STAR operated successfully on 4 of 5 flights

SEAC⁴RS, NASA DC-8

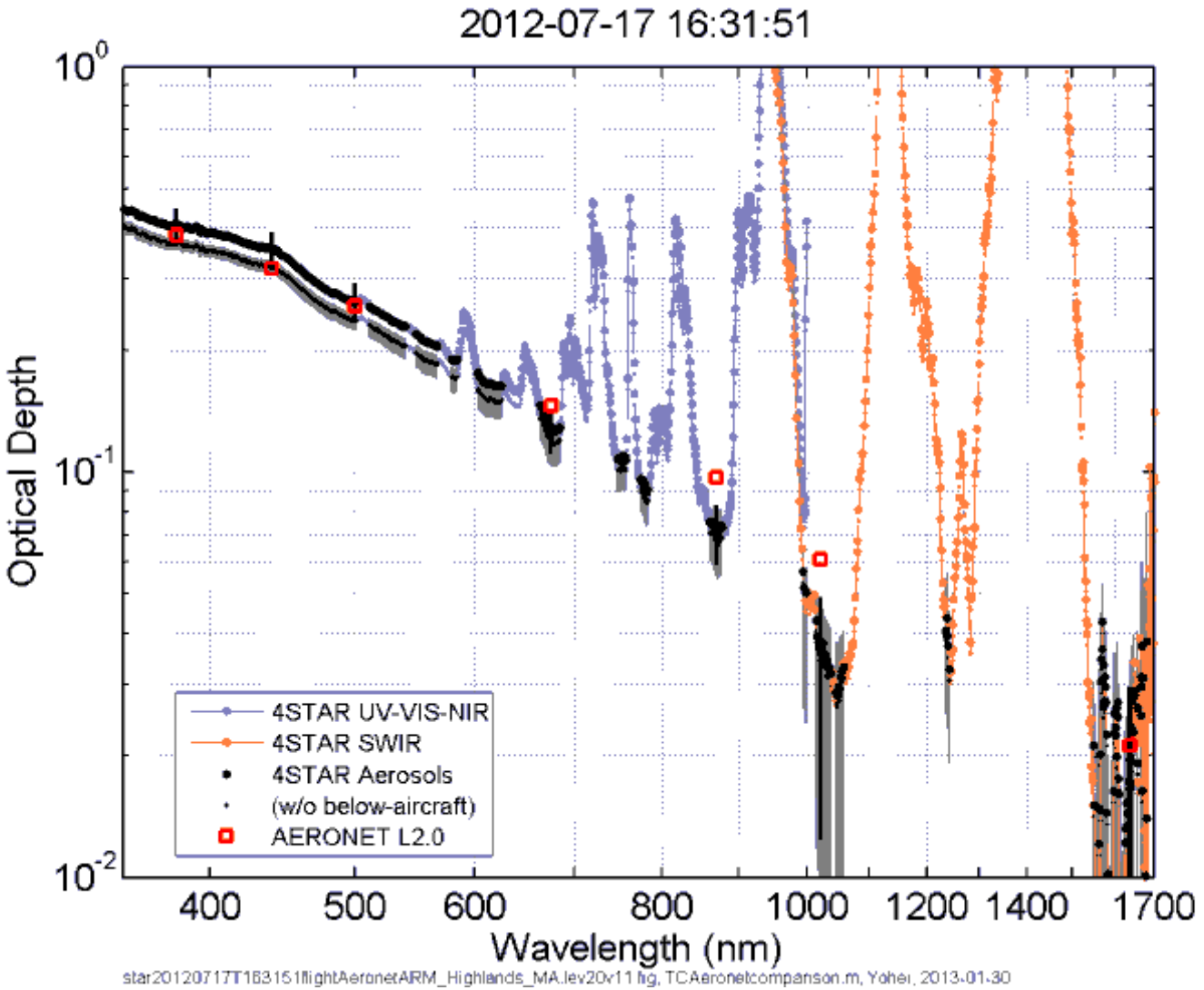
- Aug-Sep 2013: 4STAR operated successfully on all 23 flights
- Field data set archived in SEAC⁴RS archive on SEAC⁴RS schedule
- Analyses underway.

ARISE, NASA C-130

- Aug-Sep 2014: 4STAR operated successfully on all 16 data + 3 transit flights.
- New Cloud Scan Mode developed and utilized.
- Analyses underway.

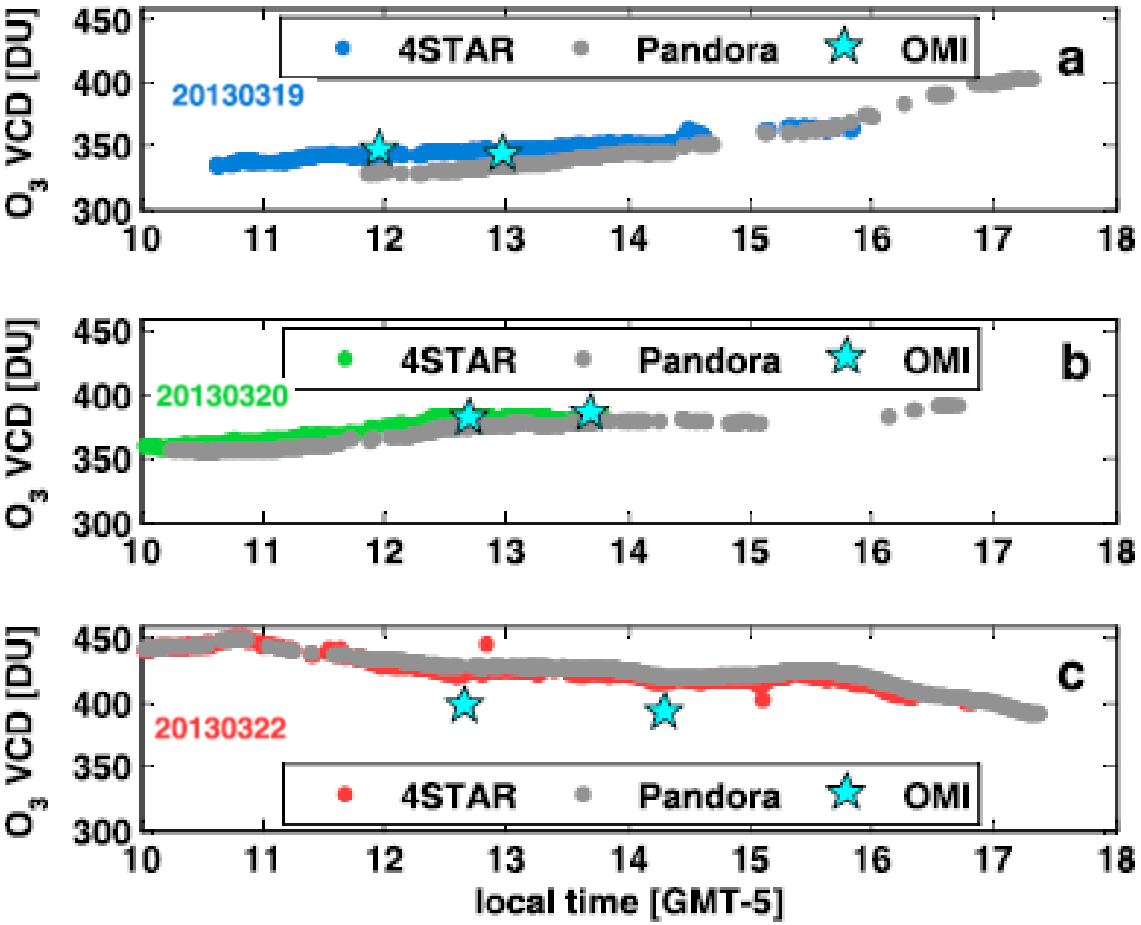
*TCAP: Two-Column Aerosol Project
*SARP: Student Airborne Research Program
*SEAC⁴RS: Studies of Emissions and Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys
*ARISE: Arctic Radiation IceBridge Sea and Ice Experiment

Optical Depth Spectrum



Shinozuka et al., *JGR*, 2013

4STAR O_3 retrieval compared to PANDORAs at GSFC



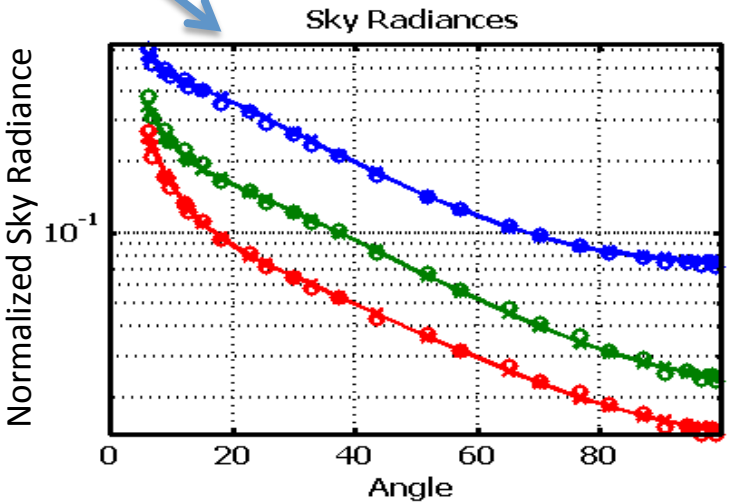
4STAR O_3 retrieved vertical column densities compared with collocated, averaged values of four Pandora instruments (#27,29,34,36) during the March 2013 Goddard ground-based inter-comparison period and with OMI overpass values (in cyan stars).

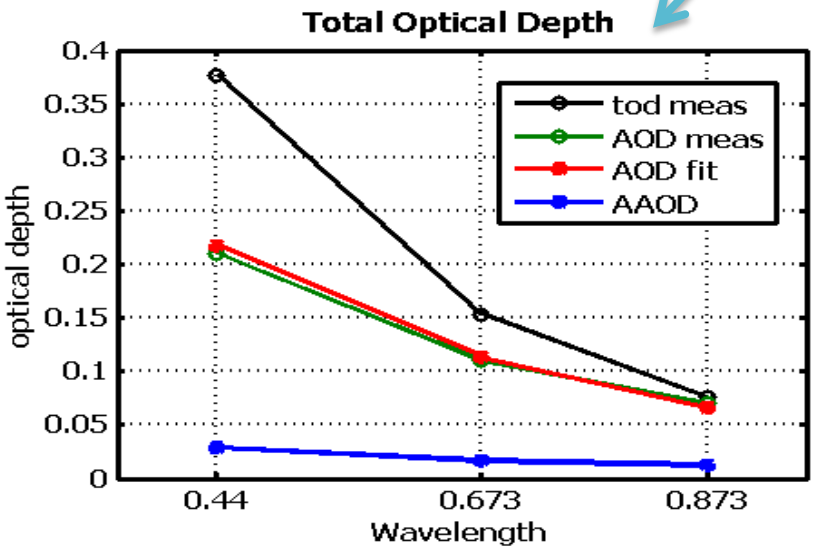
4STAR-PANDORA difference O_3: 1% RMSD, 0.1% bias.

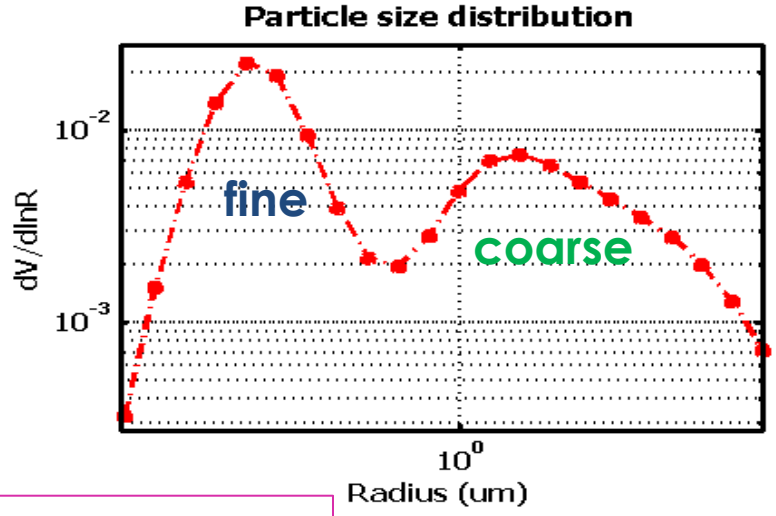
Segal-Rosenheimer et al., *JGR* 2014:

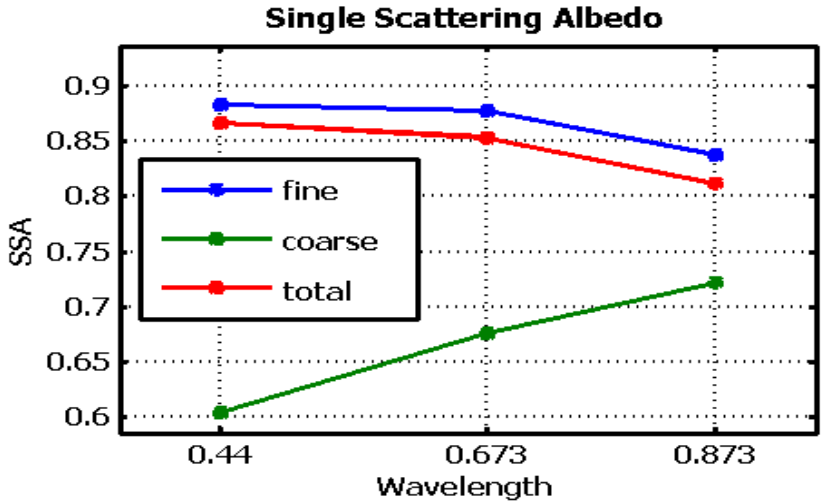
Sky/Sun Retrieval

4STAR sky scan: 20130827_079_SKYA



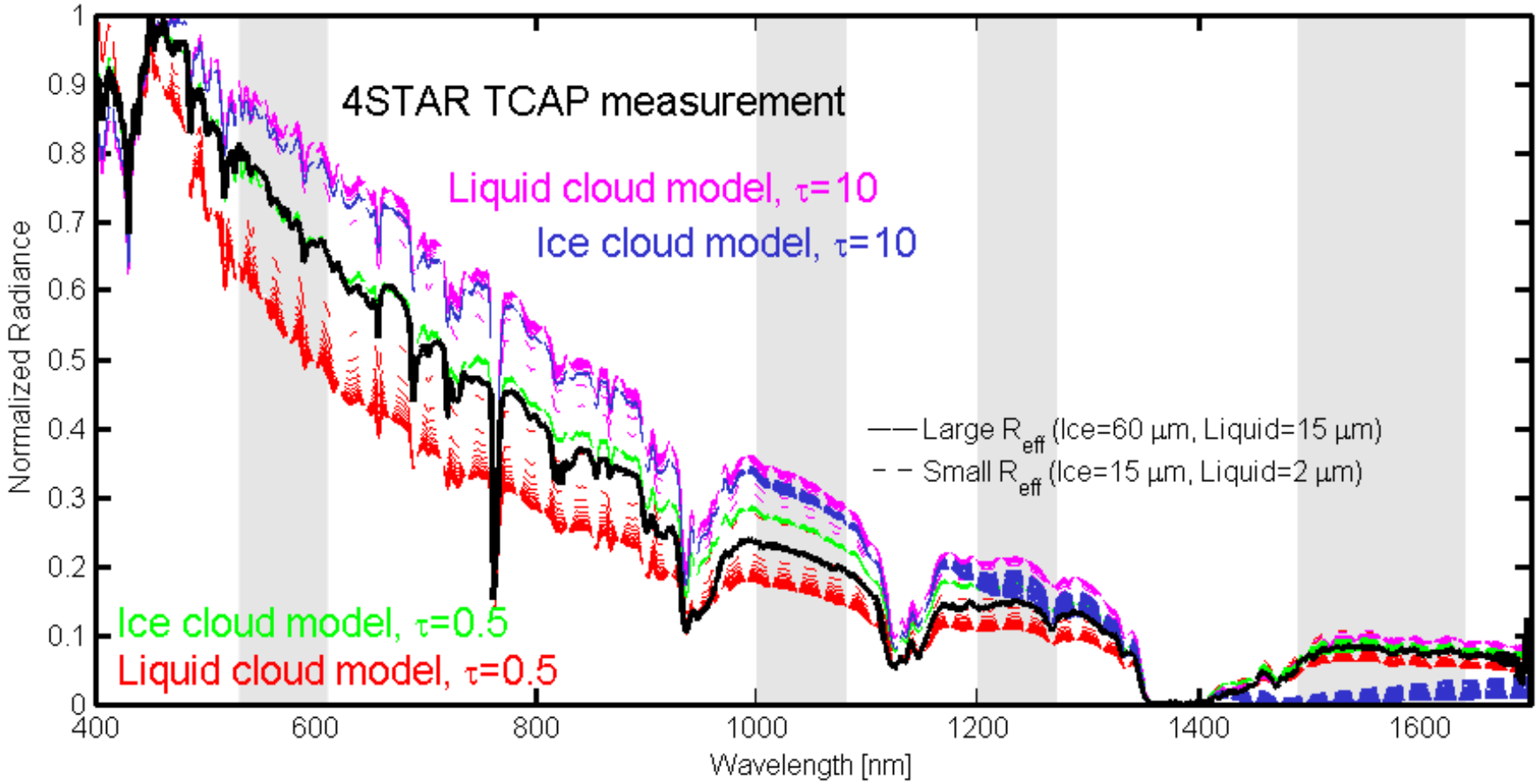






Flynn, *unpublished*

Zenith Radiance Cloud Retrieval

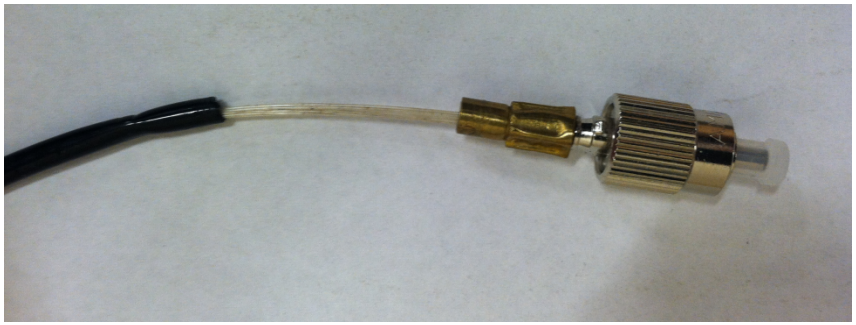


LeBlanc, *unpublished*

How Are We Improving 4STAR to Deliver the Highest Quality Science?

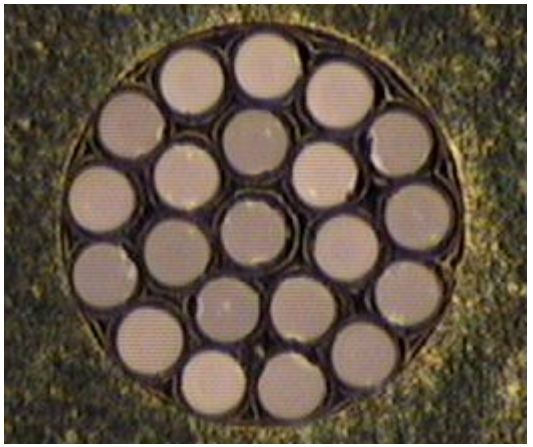
With help from the Earth Science Technology Office and Airborne Instrument Technology Transition (ESTO – AITT)

Fiber Optic Cable Issues

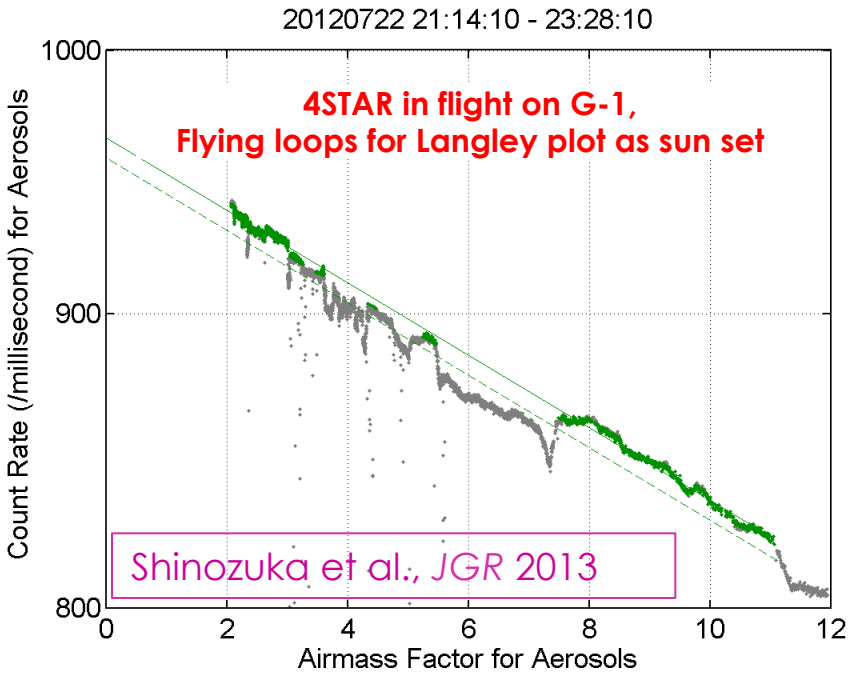


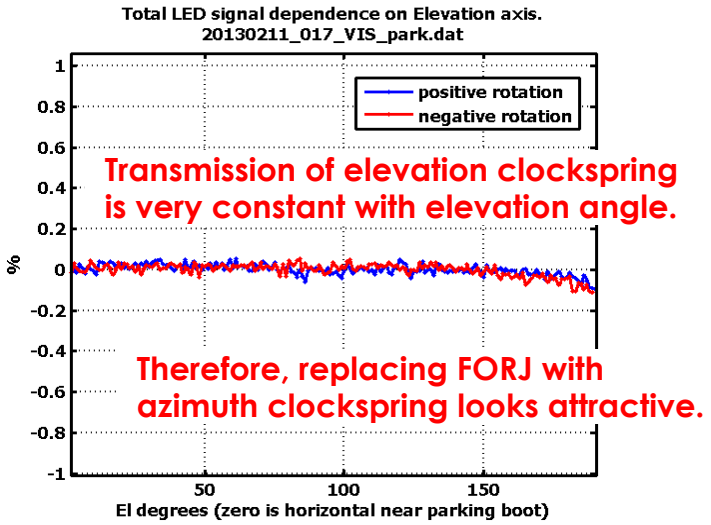
- Prototype fiber optic cabling began failing after TCAP campaign.
- Newly designed steel-jacketed cables flown in ARISE proved to be very durable.

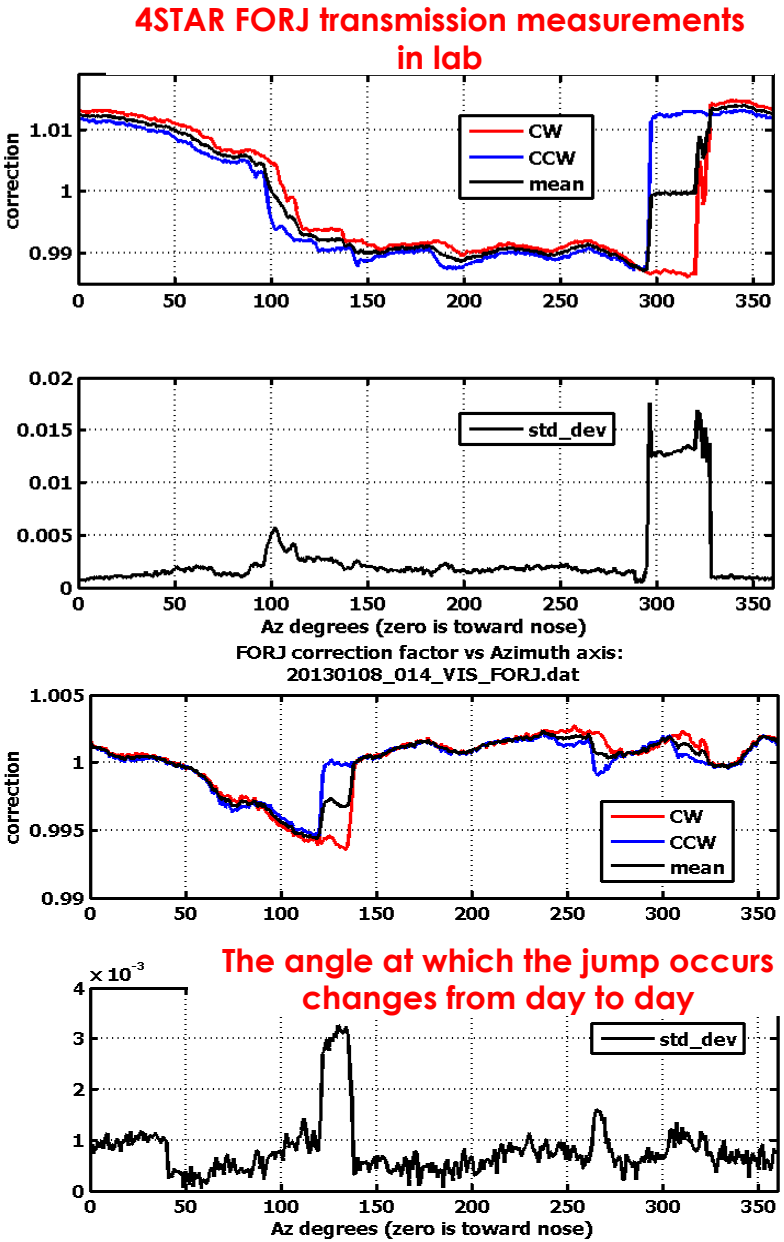
- Two barrels and two spectrometers means using multi-fiber cables for splitting signal.
- We're investigating physical optic wave guide effects launching into the fiber cladding.



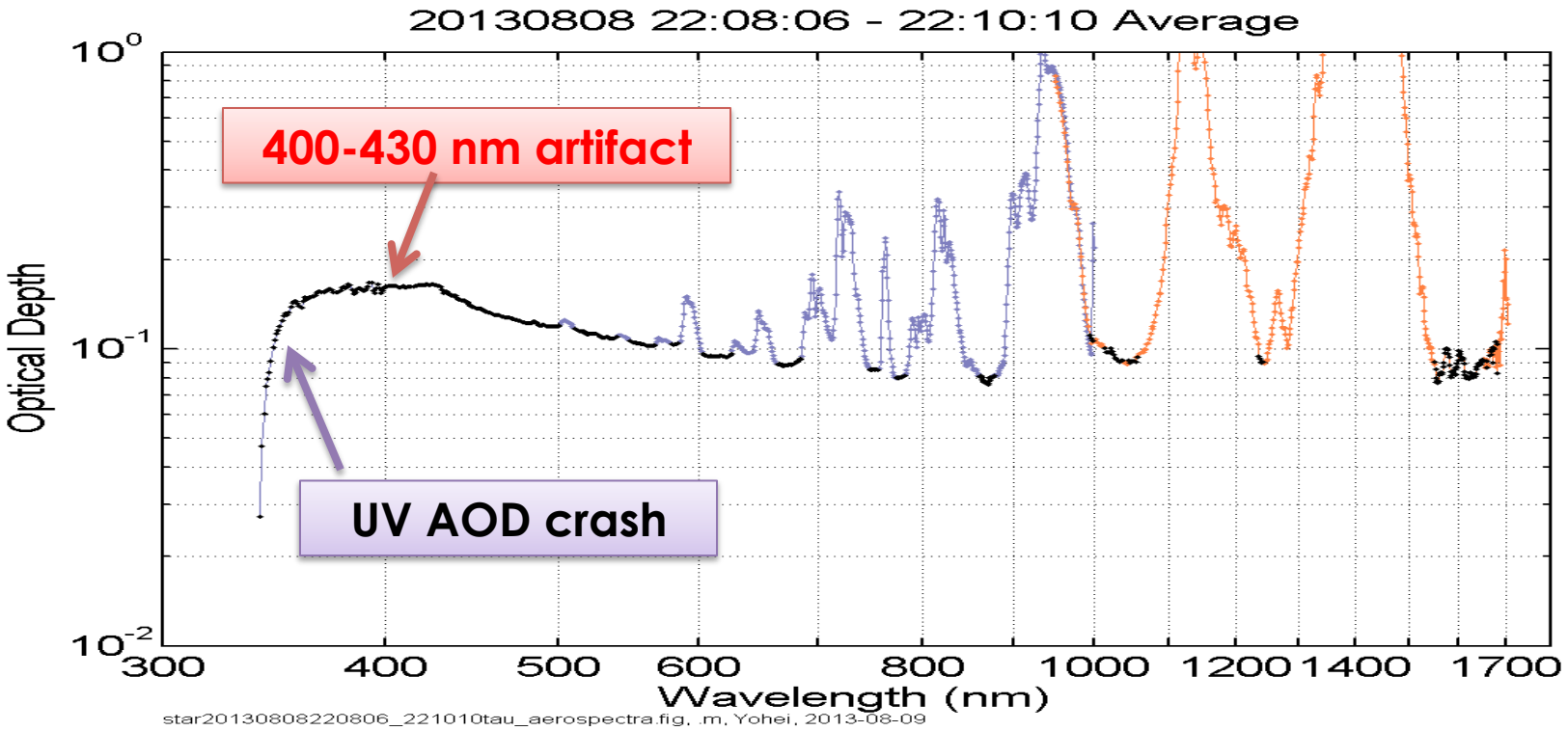
Fiber Optic Rotating Joint (FORJ) Issues







Spectrometer Issues

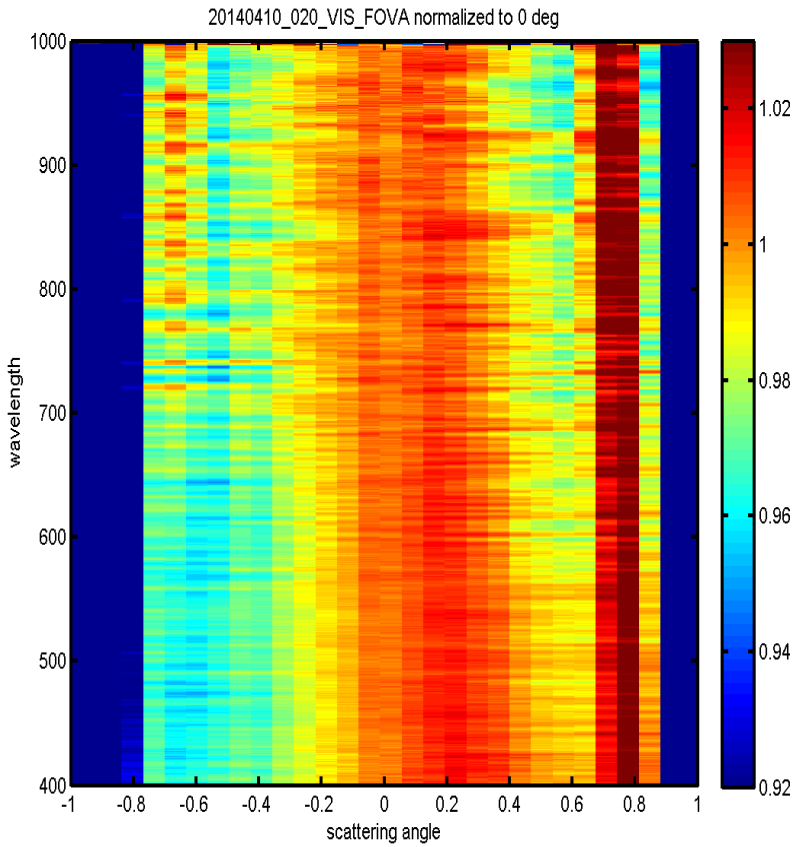


-Analysis: Long wavelength light is bouncing into the short wave in the spectrometer making too much light in the UV
-Solution: Work to characterize the effect in order to compensate
-Solution: New spectrometers procured.

unpublished

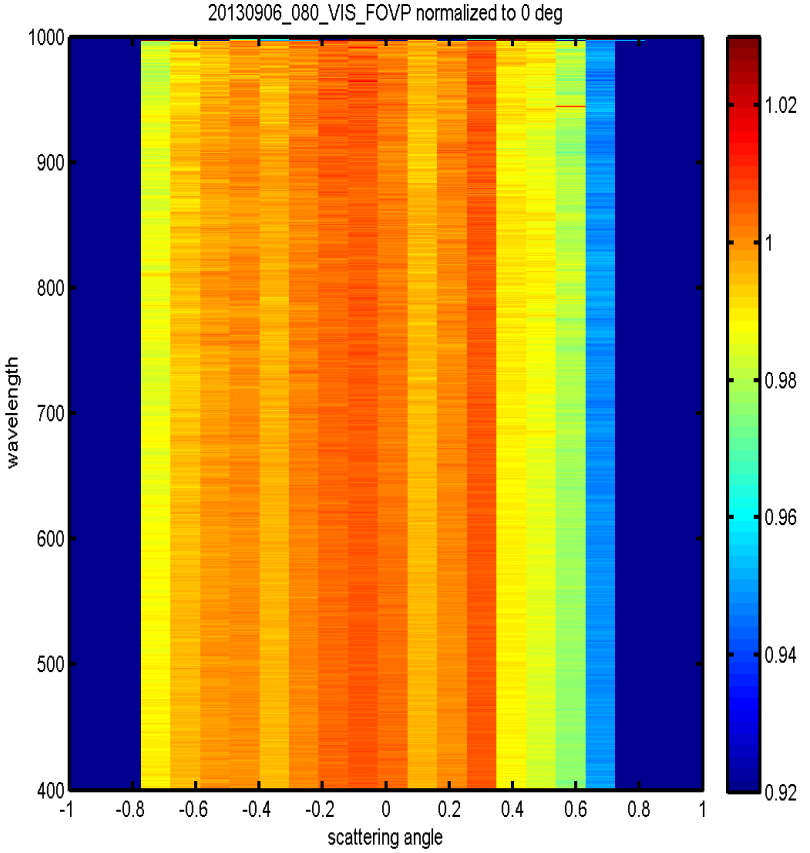
Diffuser Issues Part 1

No Spectralon Diffuser



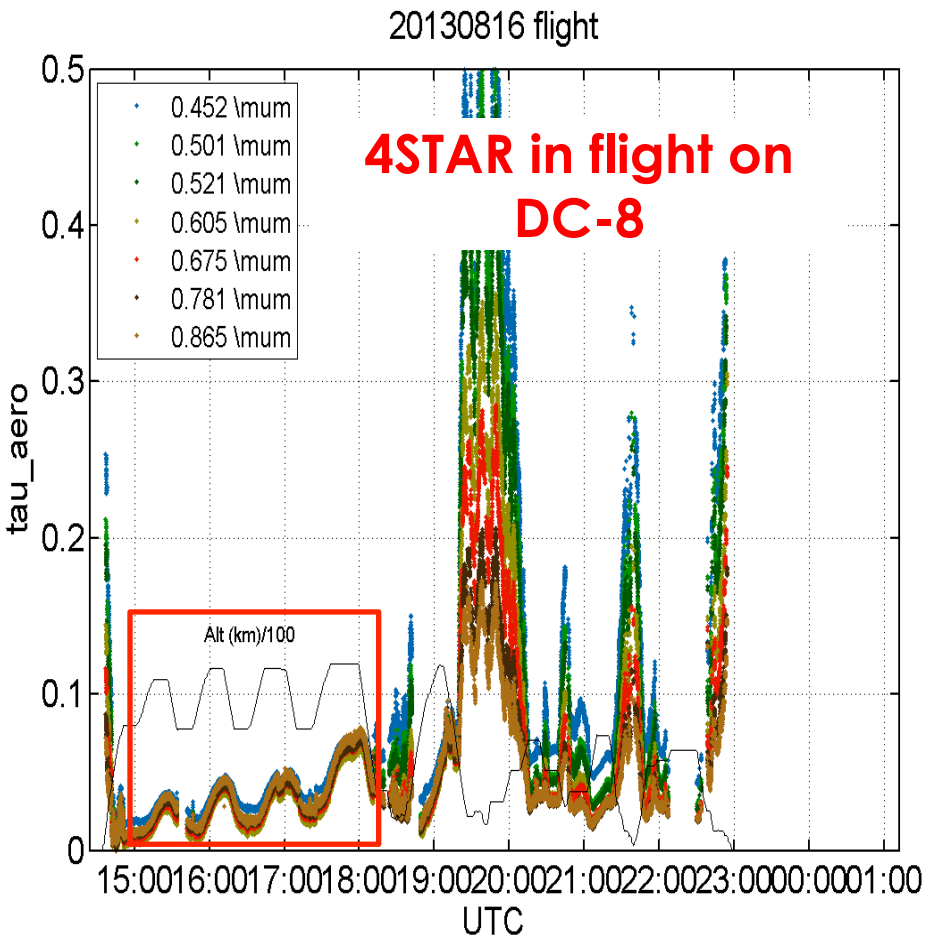
FOV of direct sun barrel has both spectral and signal level variation that creates errors when tracking the sun.

With Spectralon diffuser



Implementing a Spectralon diffuser does a nice job of correcting both the spectral and signal variablility….. **BUT**

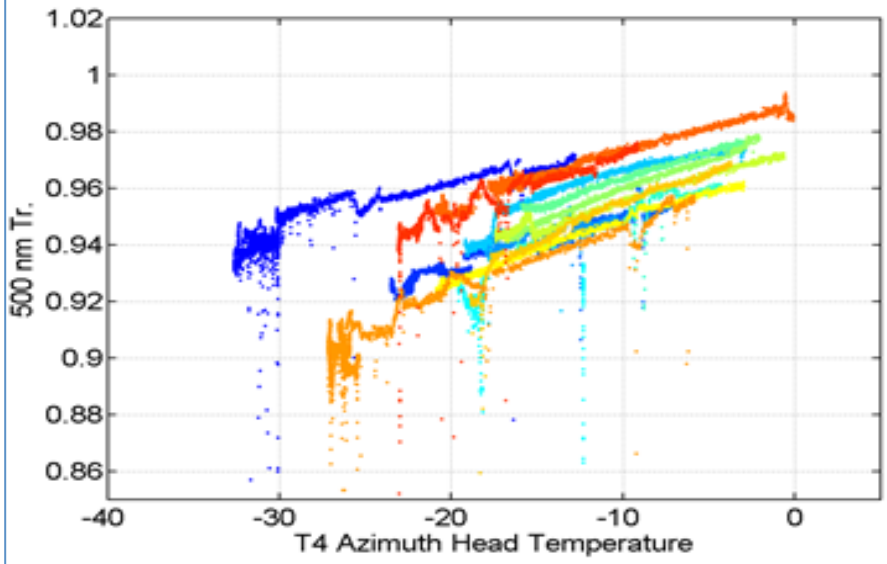
Diffuser Issues Part 2



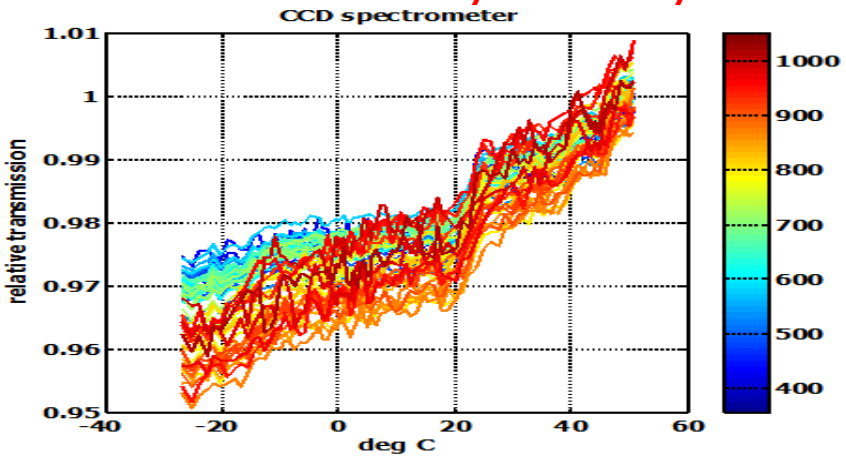
4STAR-derived AOD increases with increasing altitude. We expect it to do the opposite.

Shinozuka and Flynn: unpublished

Signal change with Temperature



Lab measurements of a spectralon diffuser transmission at PNNL by Connor Flynn

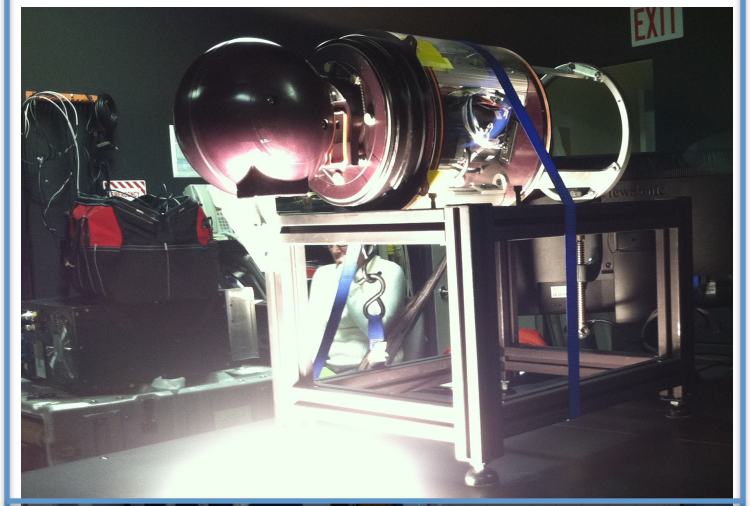


Instrument Calibration and Measurement Stability

To increase confidence in measurements and science products we will track calibration variability by:

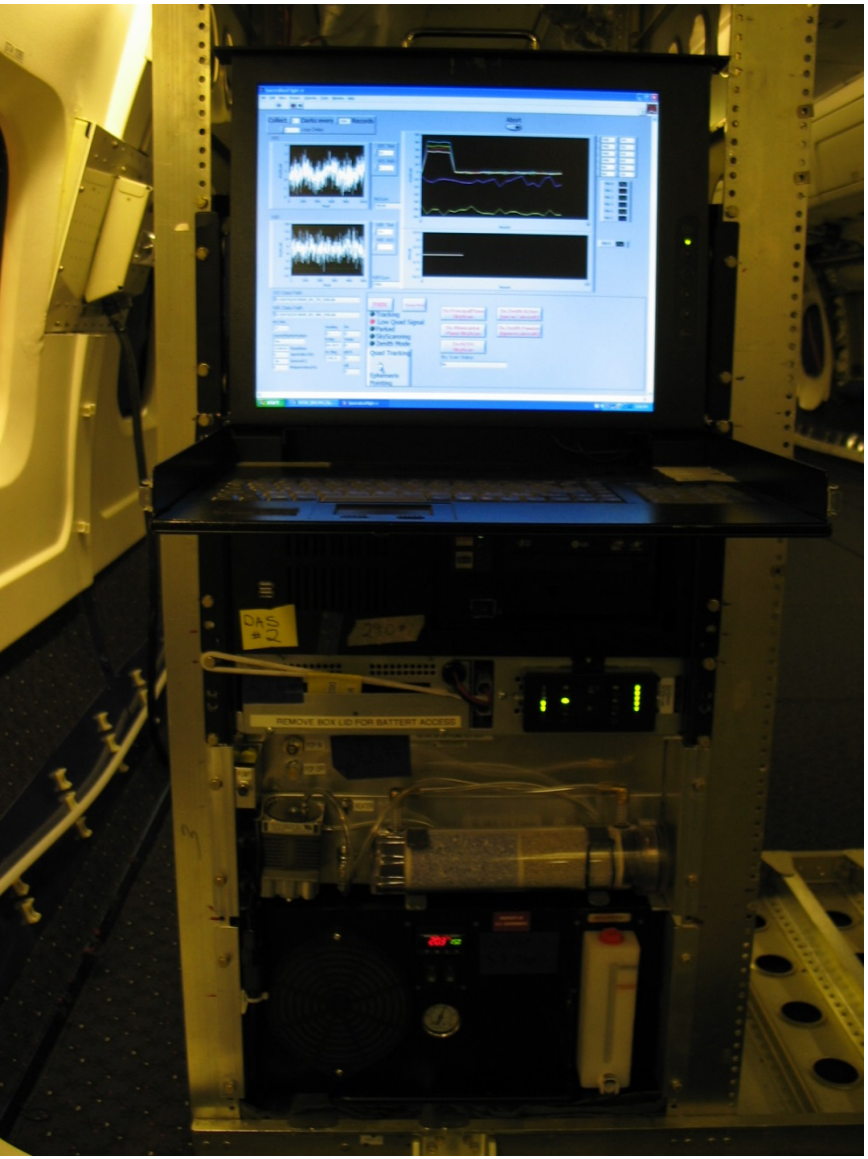
- Building a small field-deployable sun tracker with a stable and linear PDA spectrometer
- Building a field calibration light source

Lab-radiance calibration.



4STAR + AATS-14 calibration using Langley Extrapolation.

Other Issues



- Software Improvements
  - Usability for easier airborne operation
  - Sky Scan flexibility and "intelligence"
- Electronics
  - Upgrade off-the-shelf hardware with more rugged and compact equipment suitable to aircraft environment
  - Upgrade motion control to a more direct control
- Tracking
  - Experiment with Velocity control to replace discrete motion of current proportion control

Thank You

- We welcome advice or can share our experience with:
  - High accuracy fiber optic transmission
  - Spectrometers
  - Optics
  - Motion Control
  - Airborne instrumentation
- Roy Johnson: Roy.r.johnson@nasa.gov

- http://geo.arc.nasa.gov/sgg/AATS-website/index.html

Journal publications re 4STAR

Kassianov, E., C. Flynn, J. Redemann, B. Schmid, P. Russell, and A. Sinyuk: Initial Assessment of the **4STAR-based Aerosol Retrieval: Sensitivity Study**, *Atmosphere* **2012**, *3*, 495-521; doi:10.3390/atmos3040495 (Special issue: Advances in Studies of Atmospheric Aerosol and Clouds Using Remote Sensing Techniques).

Dunagan S., R. Johnson, J. Zavaleta, P. Russell, B. Schmid, C. Flynn, J. Redemann, Y. Shinozuka, J. Livingston, M. Segal-Rosenheimer, 4STAR Spectrometer for Sky-Scanning Sun-Tracking Atmospheric Research: **Instrument Technology**, *Remote Sens.* **2013**, *5*, 3872-3895; doi:10.3390/rs5083872

Shinozuka, Y., Johnson, R., Flynn, C., Russell, P., Schmid, B, Redemann, J., Dunagan, S., Kluzek, C., Hubbe, J., Segal-Rosenheimer, M., Livingston, J., Eck, Chand, Berg, Rogers, Ferrare, Hostetler, **Hyperspectral aerosol optical depths** from TCAP flights, *J. Geophys. Res.*, 2013.

Segal-Rosenheimer, M, et al., **Tracking Elevated Pollution Layers** with a Newly Developed Hyperspectral Sun/Sky Spectrometer (4STAR): Results from TCAP 2012-and 2013 campaigns, *J. Geophys. Res.*, 2014.