U.S. DEPARTMENT OF ENERGY | Office of Science

Pacific Northwest NATIONAL LABORATORY

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SWS, SASZe, and SASHe Measurements

Update on SWS and SAS data quality and products

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Jim Barnard, Joe Michalsky: emiratus

Outline:

- What hardware do we have?
- What data products are produced?
- How do things look?
- Steps to take next?

ARM's shortwave grating spectrometers: SWS, SASZe, SASHe

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- SWS – ShortWave Spectrometer
  - Zenith radiance: 350-2100 nm, 1 Hz
  - UV/VIS 256-pixel Si CMOS array: 350-1000 nm
  - NIR 256-pixel InGaAs CMOS array: 970-2100 nm
  - SGP from Jan 2013 to Apr 2015
  - ENA July 2016 planned
- SASZe - Shortwave Array Spectrometer – Zenith
  - Zenith radiance 350-1700 nm, 1 Hz
  - UV/VIS 2048-pixel Si CCD array: 350-1000 nm
  - NIR 256-pixel InGaAs CMOS array: 970-1700 nm
  - SN 01: SGP, MAG 2012-2013, SGP 2014-present
  - SN 02: PGH, PVC, MAO, ASI
- SASHe – Shortwave Array Spectrometer – Hemispheric
  - Direct solar irradiance & diffuse hemispheric irradiance
  - 350-1700 nm, ~30 sec shadowband cycle
  - UV/VIS 2048-pixel Si CCD array: 350-1000 nm
  - NIR 256-pixel InGaAs CMOS array: 970-1700 nm
  - SN 01: SGP 2011 - present
  - SN 02: PGH, PVC, MAO, ASI

SWS: Characterization, calibration, and data products

- swsaux.b1
  - 1 Hz Housekeeping fields
- sws.b1
  - radiance calibration via NASA integrating sphere (annually)
  - Spectra from both spectrometers merged with weighted average spanning overlap region

SWS has recently been renovated to use new data acquisition electronics and a new optical head (equivalent to SASZe) but retains existing spectrometers and fiber optic.

Subsequent SWS datastreams will resemble SASZe in having separate spectral files for each spectrometer, etc.

SASZe data products

- saszevis.a0 and saszenir.a0
  - Housekeeping
  - Raw counts, 1 Hz, shuttered and unshuttered
- saszevis.a1 and saszenir.a1
  - Housekeeping
  - Spectral responsivity via NASA integrating sphere (annually)
  - Zenith spectral radiances
- saszefilterbands.a1
  - Housekeeping
  - Spectral responsivity via NASA integrating sphere (annually)
  - Solar spectrum at top of atmosphere, Gueymard
  - Zenith spectral radiances in 31 discrete wavelengths
  - Zenith transmittances at same 31 wavelengths
  - zenith_transmittance_calculation "= (Pi * zenith_radiance * earth_sun_distance^2) / (1000 * cos(solar_zenith) * solar_spectrum)"

So, how do things look?
SASZe: Not great, not bad, a bit uneven…

- Initial comparisons between original SWS and original SASZe not very good due to electrical problems with SWS and tracking errors with the SASZe.
- Comparisons between stationary SASZe and SSFR by Weidong Yang, Sasha Marshak, et al during MAGIC not very good in absolute but not bad in spectral shape. Evidence suggests SASZe FOV.
- Responded by retracting baffle length and developing FOV alignment kits for use at sites.
- Later spot-check comparisons with re-wired SWS and stationary SASZe better but not exhaustively examined and limited in duration.
- SASZe vs NFOV2 at MAO look good, but then NFOV2 died.

SASZe vs NFOV2 at MAO looks good

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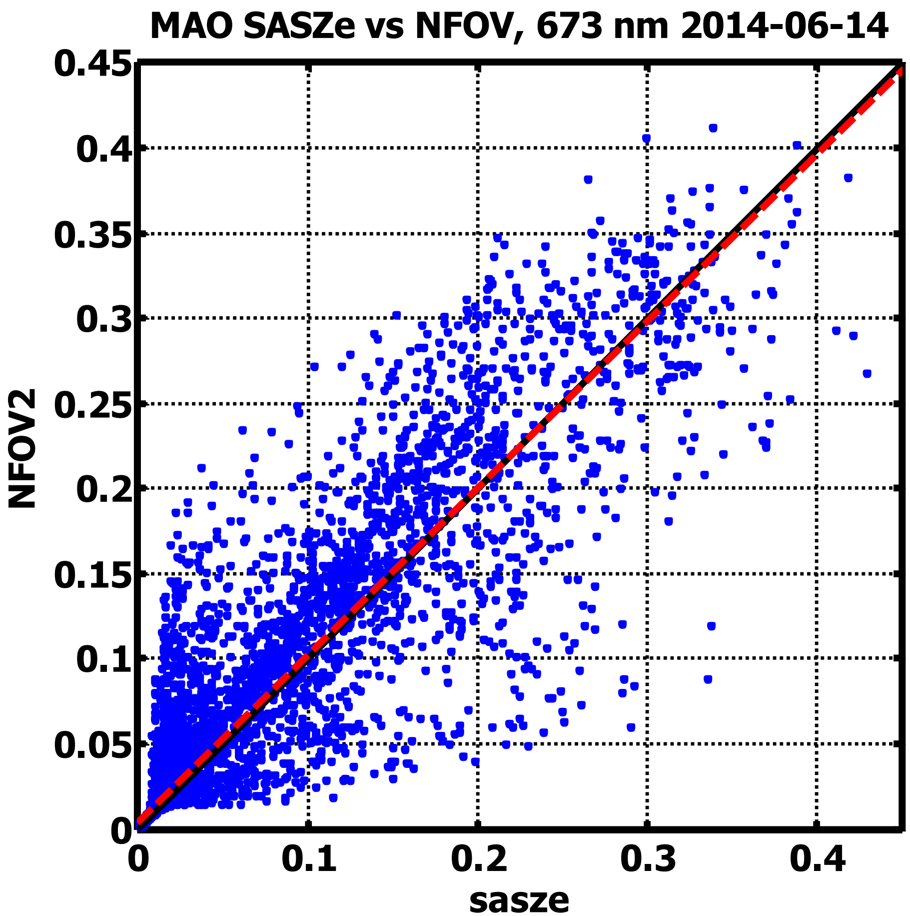

SASHe data products

- sashevishisun.a0 and sashenirhisun.a0
- sashevislowsun.a0 and sashenirlowsun.a0
  - Housekeeping
  - Raw counts, 1 Hz, shuttered and unshuttered
- sashevis.b1 and sashenir.b1
  - Housekeeping
  - Spectral responsivity (initially based on nominal lamp measurements but now based on Langley calibration and solar irradiance at top of atmosphere)
  - Direct normal, direct horiz, diffuse hemisp, and total hemisp irradiances from ~30 second shadowband sequence
- sashemfr.a1 (b1?)
  - Housekeeping
  - Spectral responsivity (initially based on nominal lamp measurements but now based on Langley calibration and solar irradiance at top of atmosphere)
  - Direct normal, direct horiz, diffuse hemisp, and total hemisp irradiances at wavelengths mapped to MFRSR nominal filter centers.

SASHe data products

- sashevislangley.c0 and sashenirlangley.c0
  - solar zenith angle, cosine solar zenith angle
  - Solar azimuth angle
  - Cosine correction
  - Airmass, airmass mask
  - Earth-sun distance
  - Solar spectrum (Gueymard)
  - Direct normal irradiance [counts]
  - Io spectra for AM and PM legs
  - Fitting statistics, std, chi-square

- The “Io” values represent extrapolation of the Langley regression to the “top of atmosphere” instrument response.

Langley calibration for valid wavelengths

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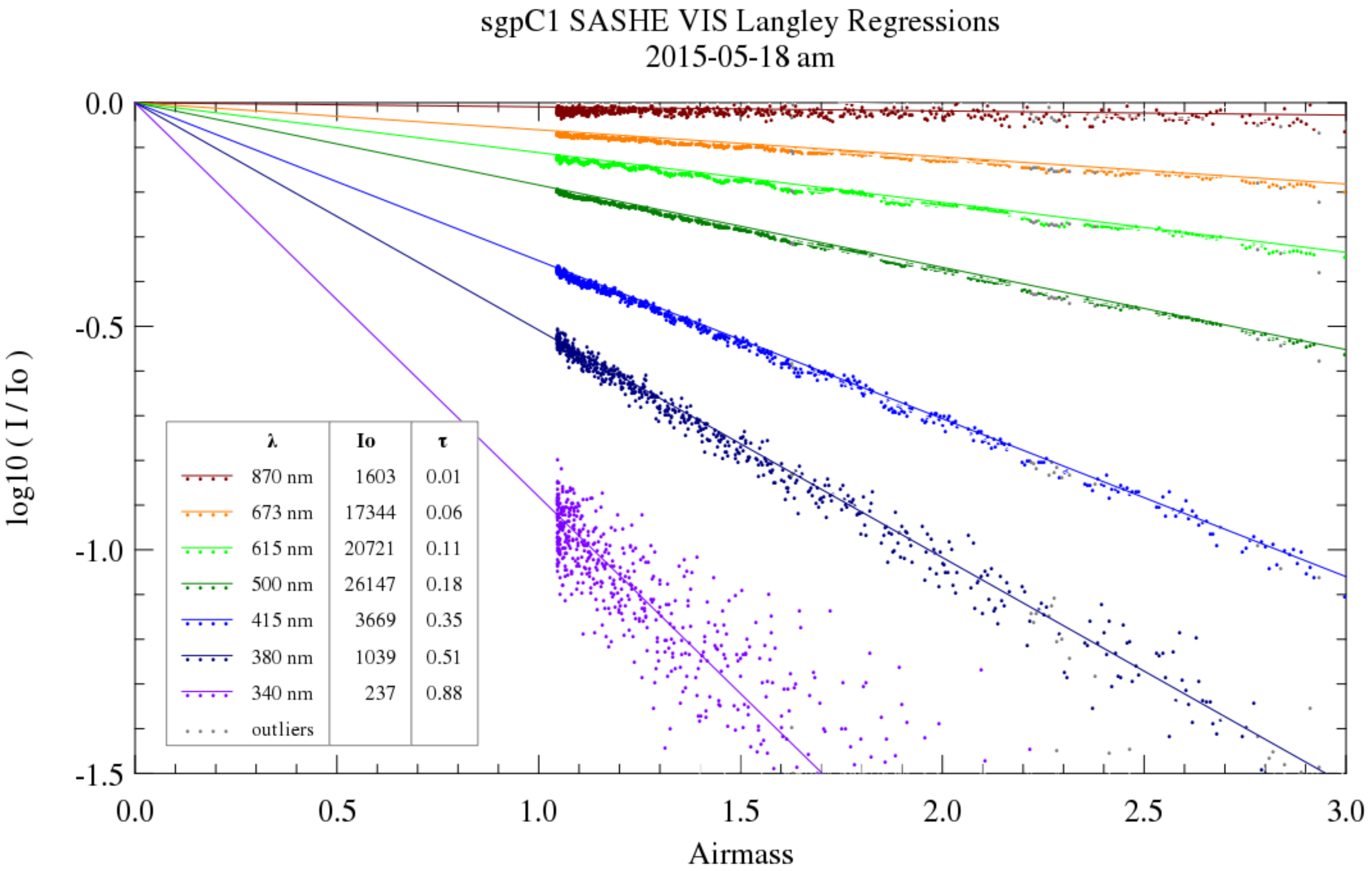
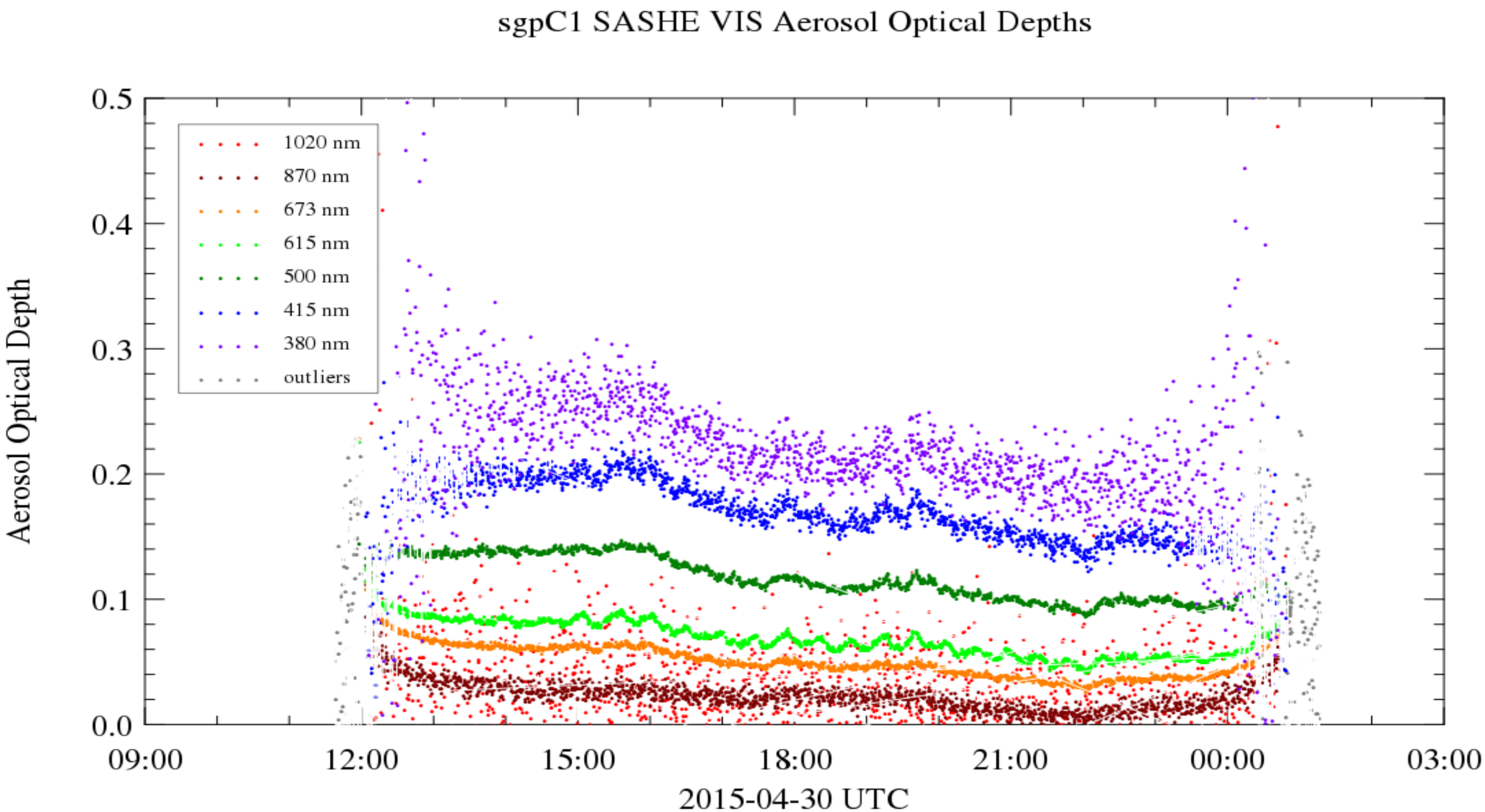
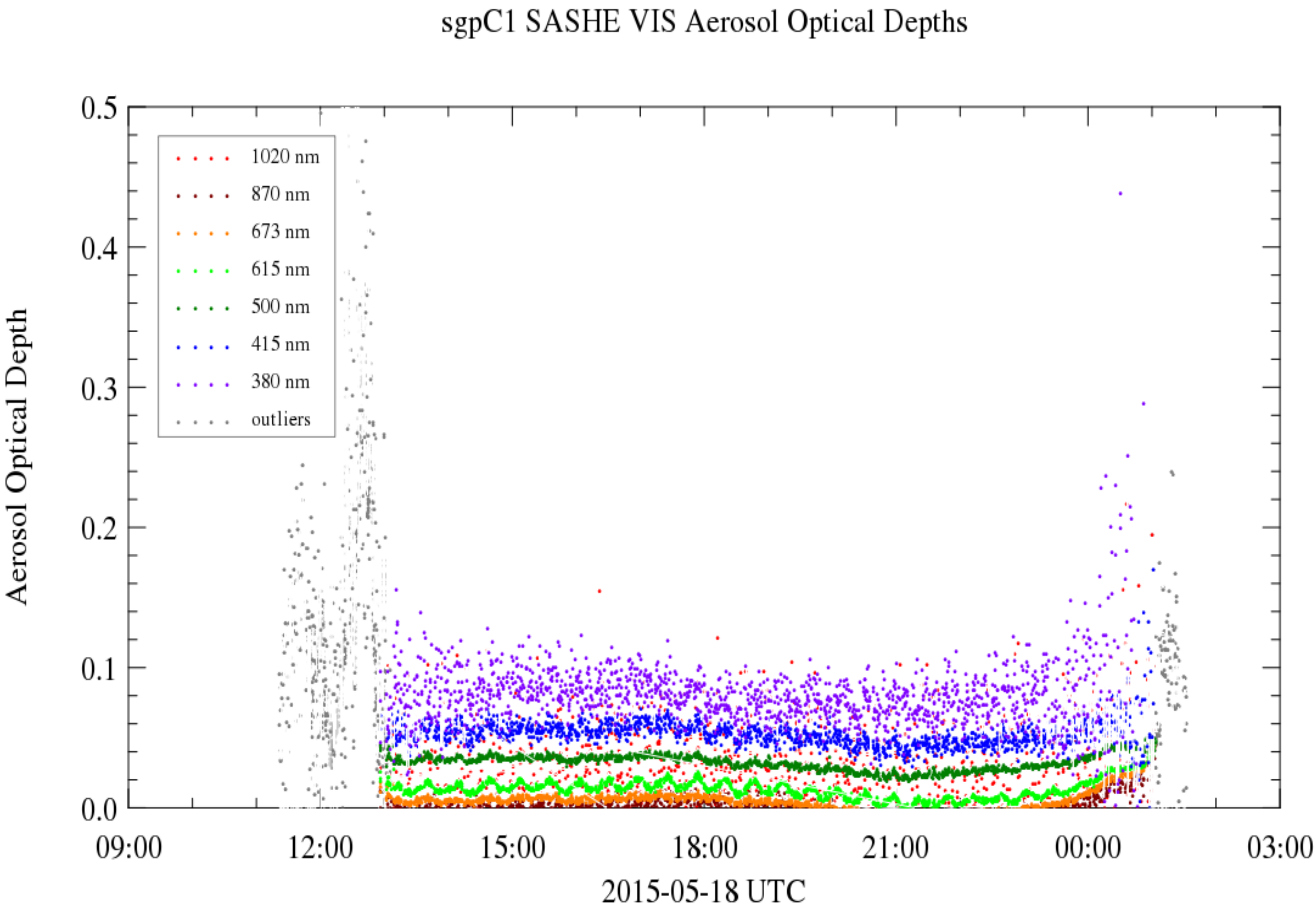


SASHe data products

- sashevisaod.c1 and sasheniraod.c1
  - Langley Io spectra (flagged for invalid Langley wavelengths)
  - Solar spectrum at top of atmosphere from Gueymard
  - Direct normal and diffuse hemispheric transmittance
  - Cloud-screened aerosol optical depth, ozone-subtracted




sgpC1 SASHE VIS Aerosol Optical Depths
Aerosol Optical Depth
0.0
0.1
0.2
0.3
0.4
0.5
1020 nm
870 nm
673 nm
615 nm
500 nm
415 nm
380 nm
outliers
09:00
12:00
15:00
18:00
21:00
00:00
03:00
2015-05-18 UTC

So, how do things look?
SASHe: Not bad but depends on location

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- SASHe #1 at SGP is starting to look uneven.
- AOD comparisons with MFRSR and AERONET were initially stronger but currently struggling.
- But issue may extend beyond direct beam and AOD. Mlawer noted too much diffuse in SASHe. Monroe identified troubling periods comparing to MFRSR.
- Have ruled out light leakage through fiber jacket and shutter issues. Seems like banding/tracking problems mainly around noon. Mechanical wear, increased slop/backlash in worm gear or belts?
- SASHe #2 at AMF (was MAO, now Ascension Island) looks fine.

Potential actions …

- SASHe
  - Combined lamp + Langley to improve calibration in regions where strong absorbers contraindicate standard Langley regression.
  - Improve QA to identify/reject banding problems from Langleys.
  - Incorporate manual or DQR screening of calibration periods
  - Assess/improve cosine correction using collocated Cimel
    - May improve both AOD and direct/diffuse and thus SSA
  - Implement O3 retrieval, other trace gases
  - Improve stray-light correction
  - Evaluate sub-cloud areal-average surface albedo
  - Deploy downlooking SASHe for surface albedo
  - SASHe CIP for SSA over wider wavelength range.
  - Replace belt and suspenders with direct drive for band and imager or linear array for banding confirmation.
  - Evaluate separate UV and UV/VIS spectrometers.
  - Evaluate InGaAs to > 1700 nm?
  - SASHe CLD OD, liquid/ice water content

Potential actions …

- SASZe, SWSZe
  - Combined Lamp + Integrating sphere calibration
    - I.S. has better SNR over wider spectral range
    - Lamp + Spectralon has better immunity to molecular absorbers
  - Implement routine QA vs AERONET zenith radiance from PPL and Cloud Mode radiance
  - Improve stray-light correction
  - Evaluate separate UV and UV/VIS spectrometers.
  - Evaluate InGaAs to > 1700 nm?
  - Evaluate use of small stable light sources to track and remove drift in radiance responsivity, $1K each, $15K for add-on to SASZe
  - Evaluate vicarious cal using spectralon and direct sun with lamp and spectral AOD to reference radiance and irradiance measurements. Reduce bias in column intensive property retrievals.

Grating Array Spectrometer Characterization

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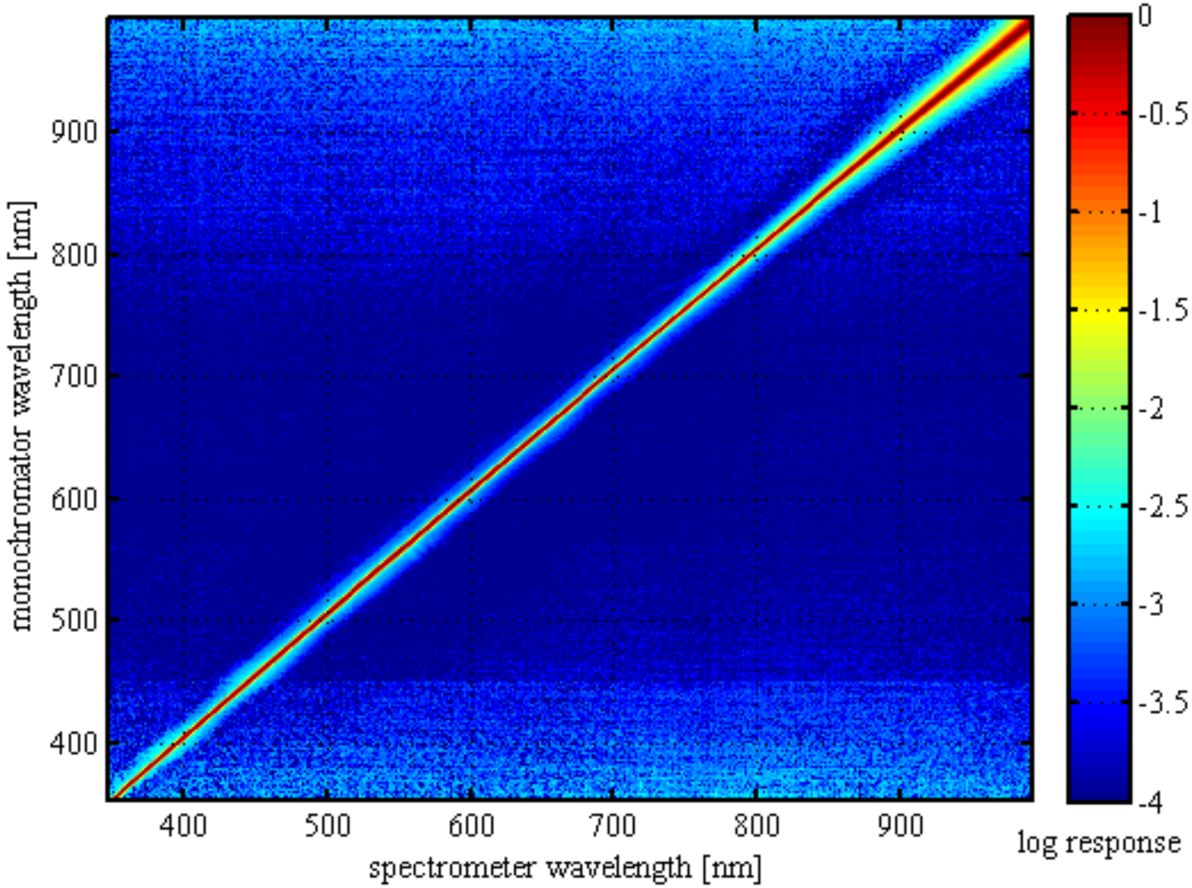
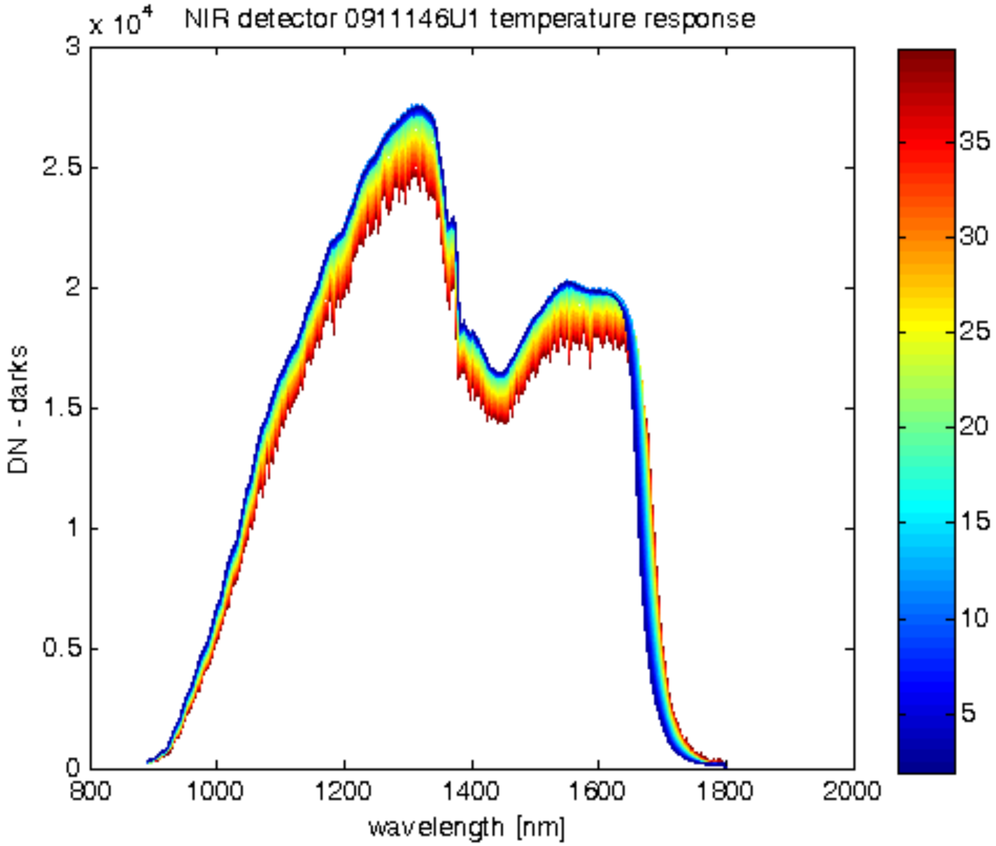
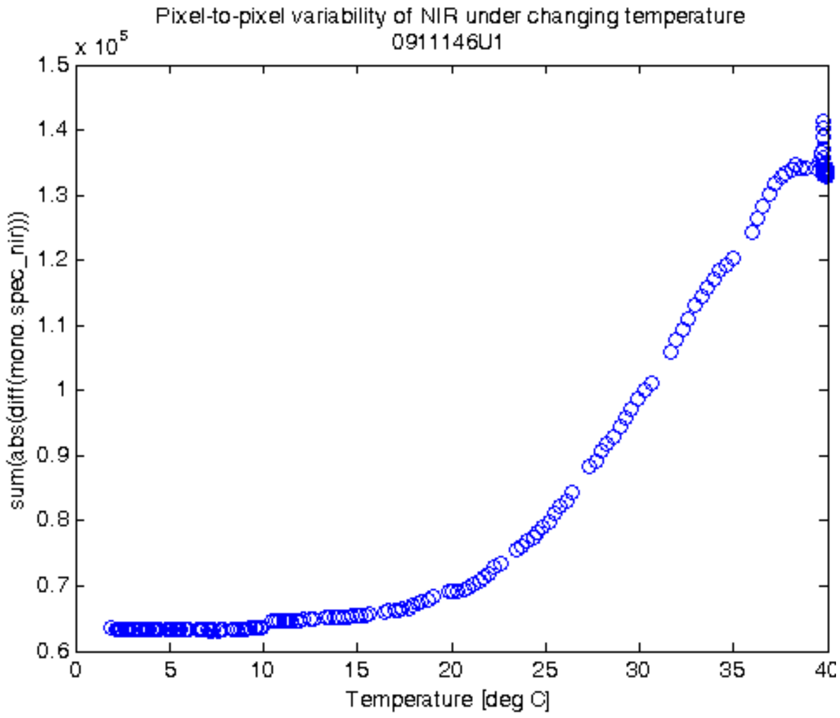
- Monochromator scans confirm negligible spectral artifacts
- Spectral resolution of both spectrometers has been mapped with a narrow scanning monochromator



Grating Array Spectrometer Characterization

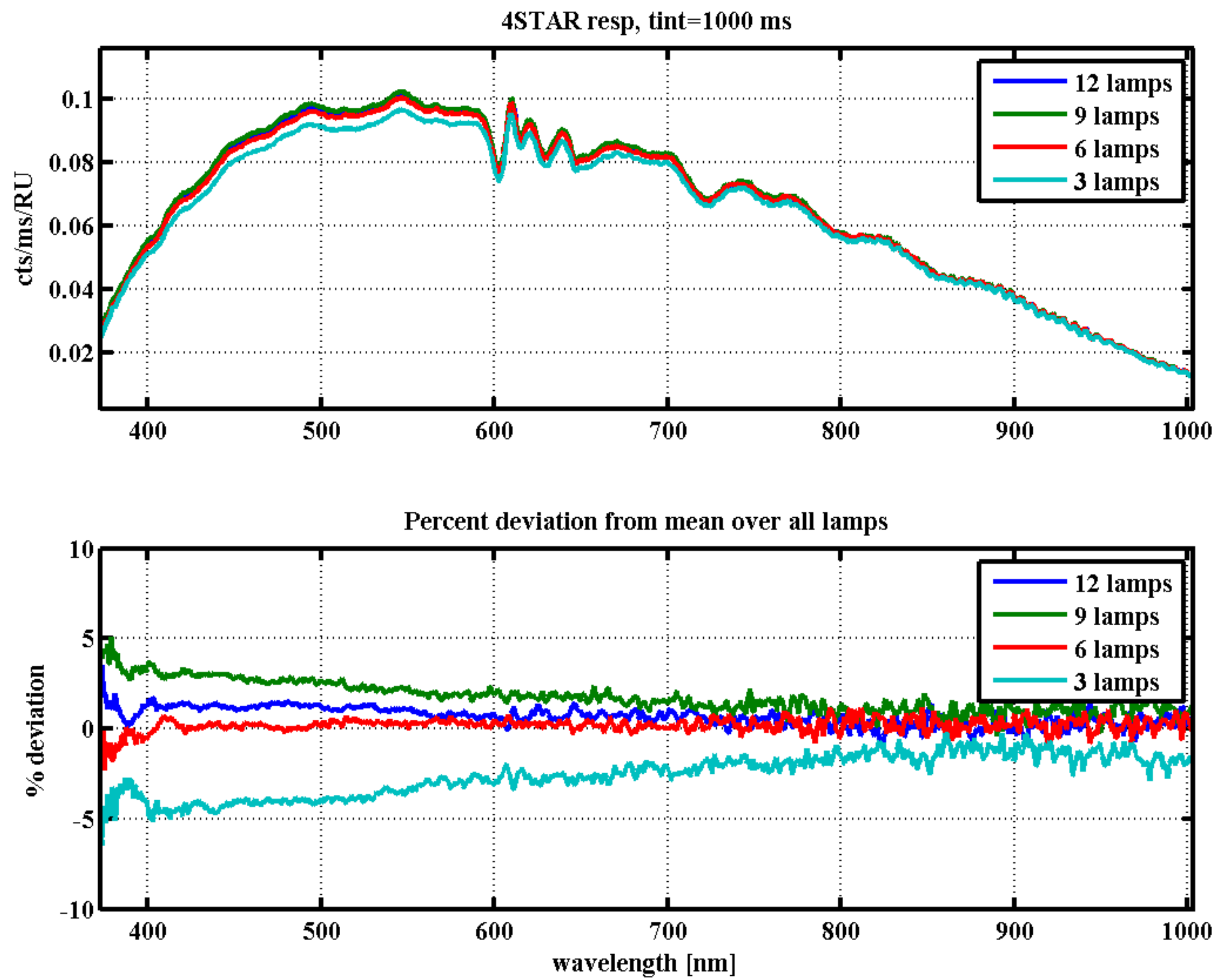
- Detector temperature sensitivity quantified. Temperature controlled.

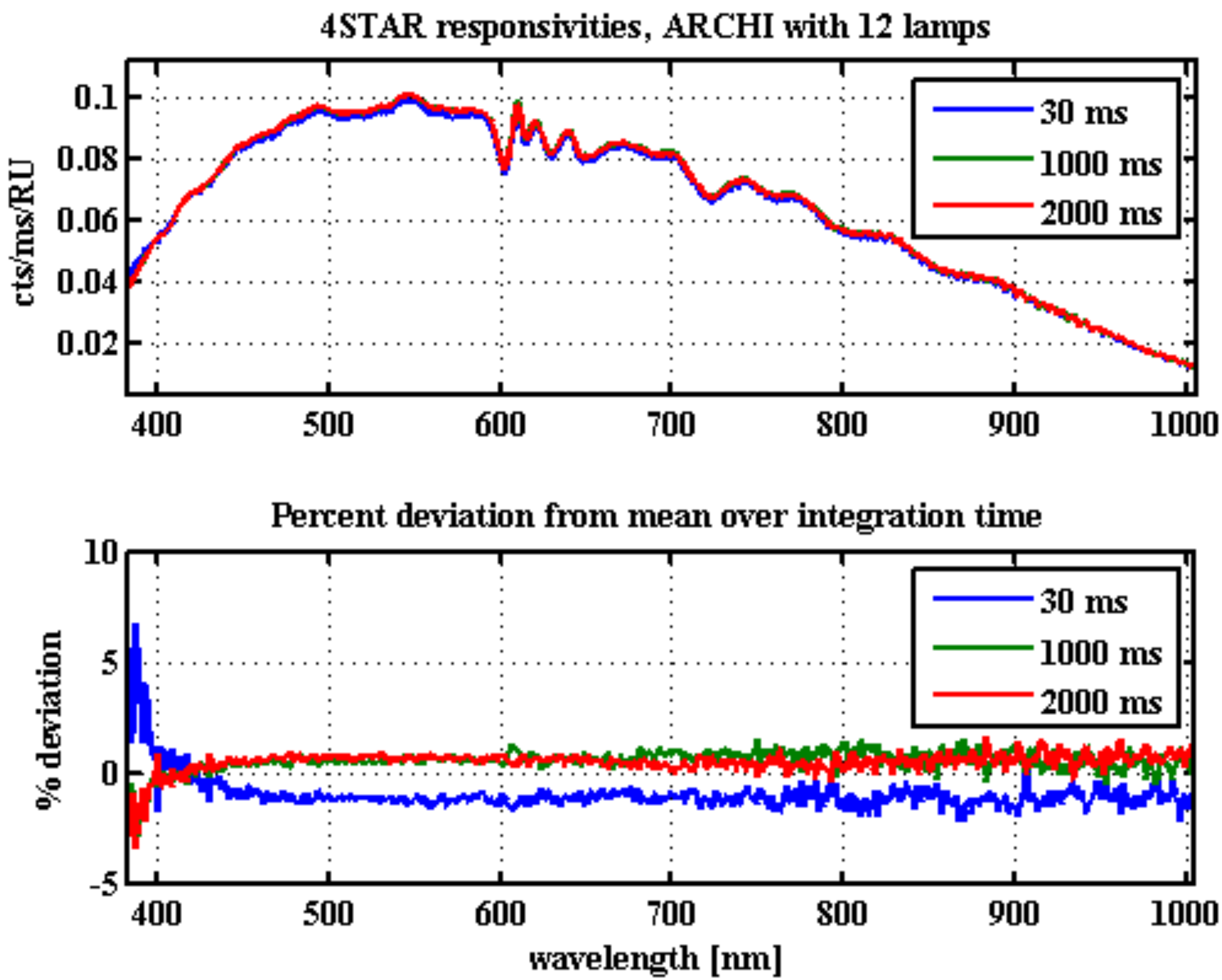


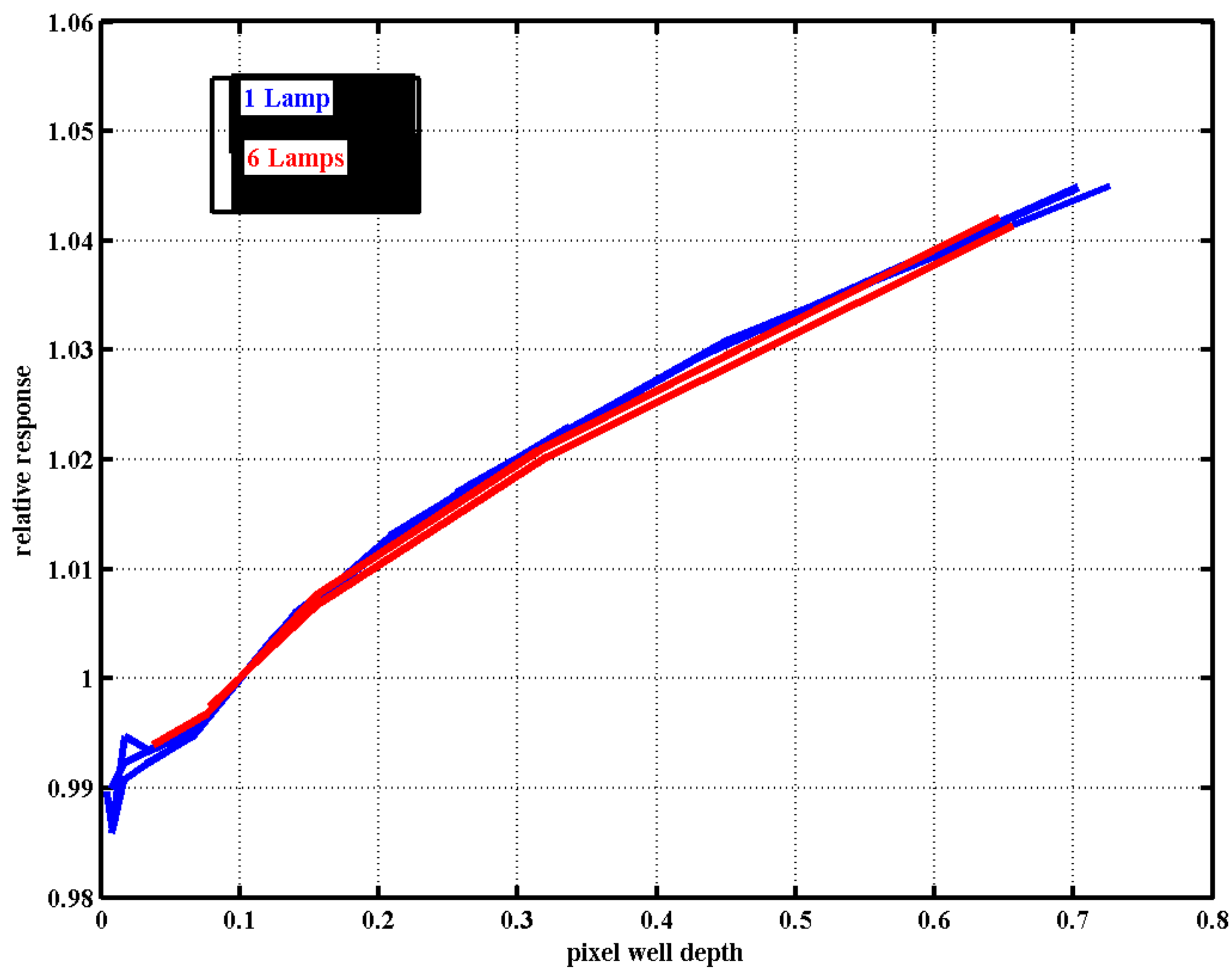


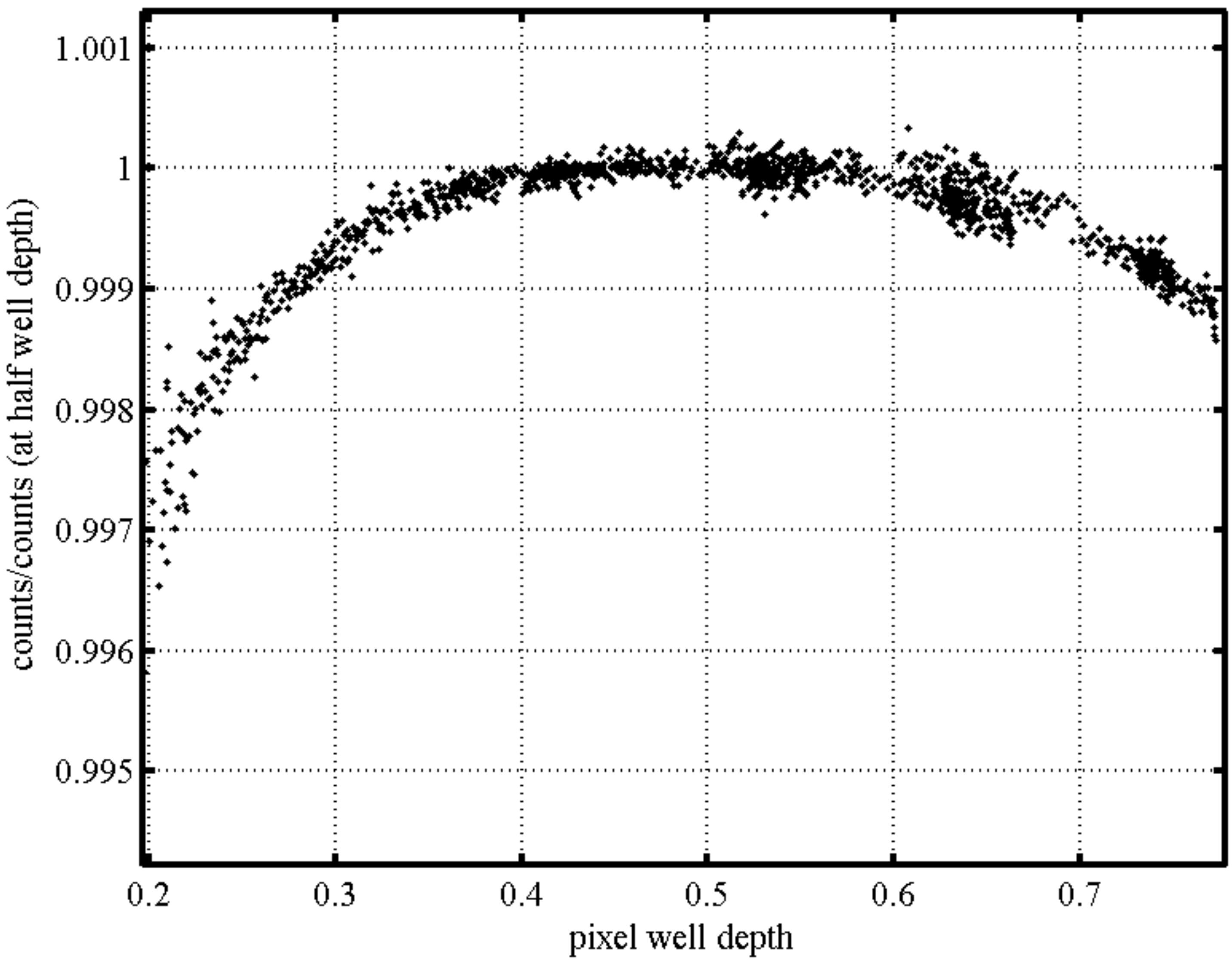
Grating Array Spectrometer Characterization

- Monochromator scans confirm negligible spectral artifacts
- Spectral resolution of both spectrometers has been mapped with a narrow scanning monochromator
- Detector temperature sensitivity quantified. Temperature controlled.
- Detector linearity has been quantified but not yet applied. A few percent over full dynamic range of detector.


4STAR resp, tint=1000 ms
cts/ms/RU
0.1
0.08
0.06
0.04
0.02
12 lamps
9 lamps
6 lamps
3 lamps
400
500
600
700
800
900
1000
Percent deviation from mean over all lamps
% deviation
10
5
0
-5
-10
12 lamps
9 lamps
6 lamps
3 lamps
400
500
600
700
800
900
1000
wavelength [nm]

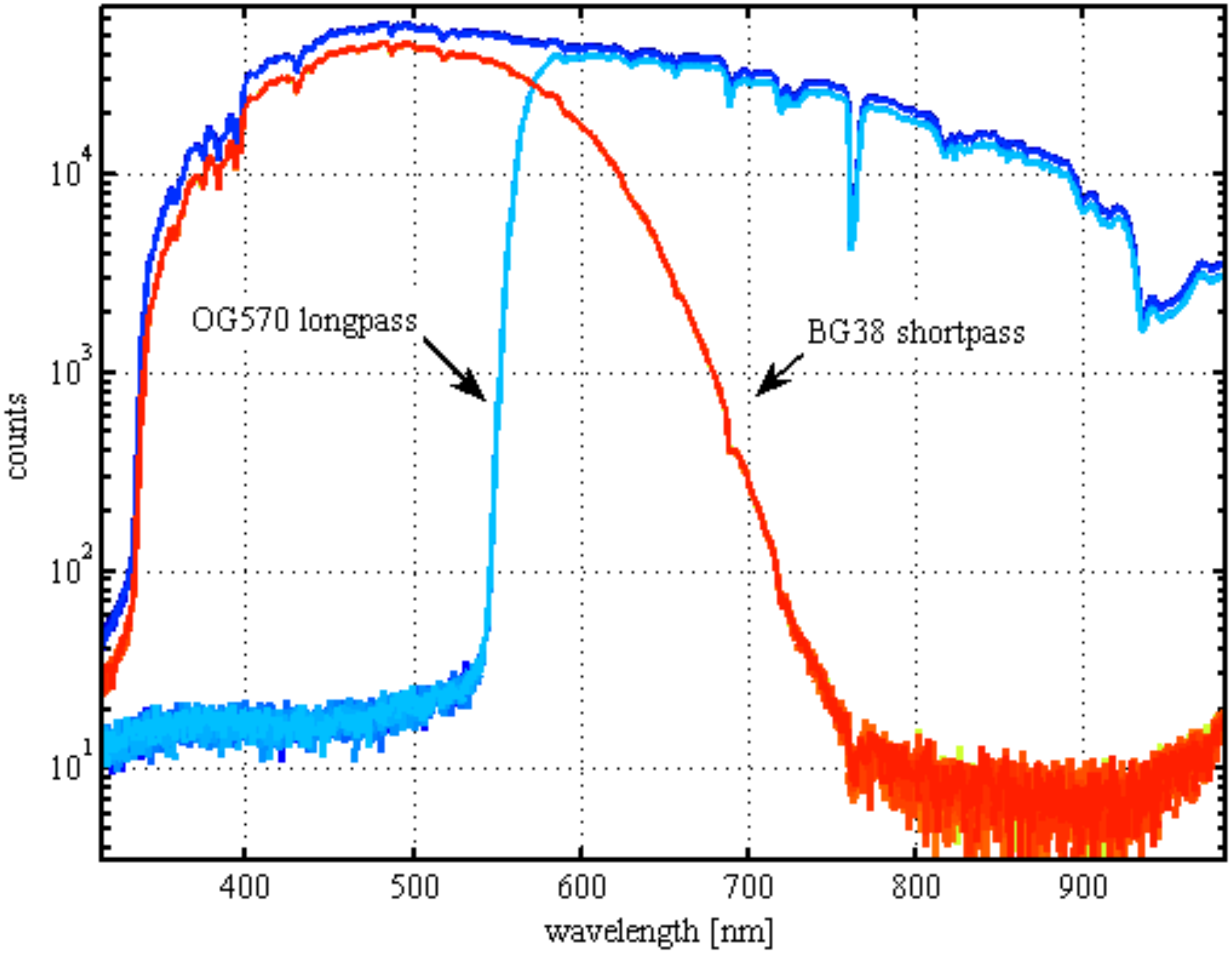

4STAR responsivities, ARCHI with 12 lamps
cts/ms/RU
0.1
0.08
0.06
0.04
0.02
400
500
600
700
800
900
1000
30 ms
1000 ms
2000 ms
Percent deviation from mean over integration time
% deviation
10
5
0
-5
400
500
600
700
800
900
1000
30 ms
1000 ms
2000 ms
wavelength [nm]


1 Lamp
6 Lamps
relative response
pixel well depth
1.06
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8


1.001
1
0.999
0.998
0.997
0.996
0.995
0.2
0.3
0.4
0.5
0.6
0.7
counts/counts (at half well depth)
pixel well depth

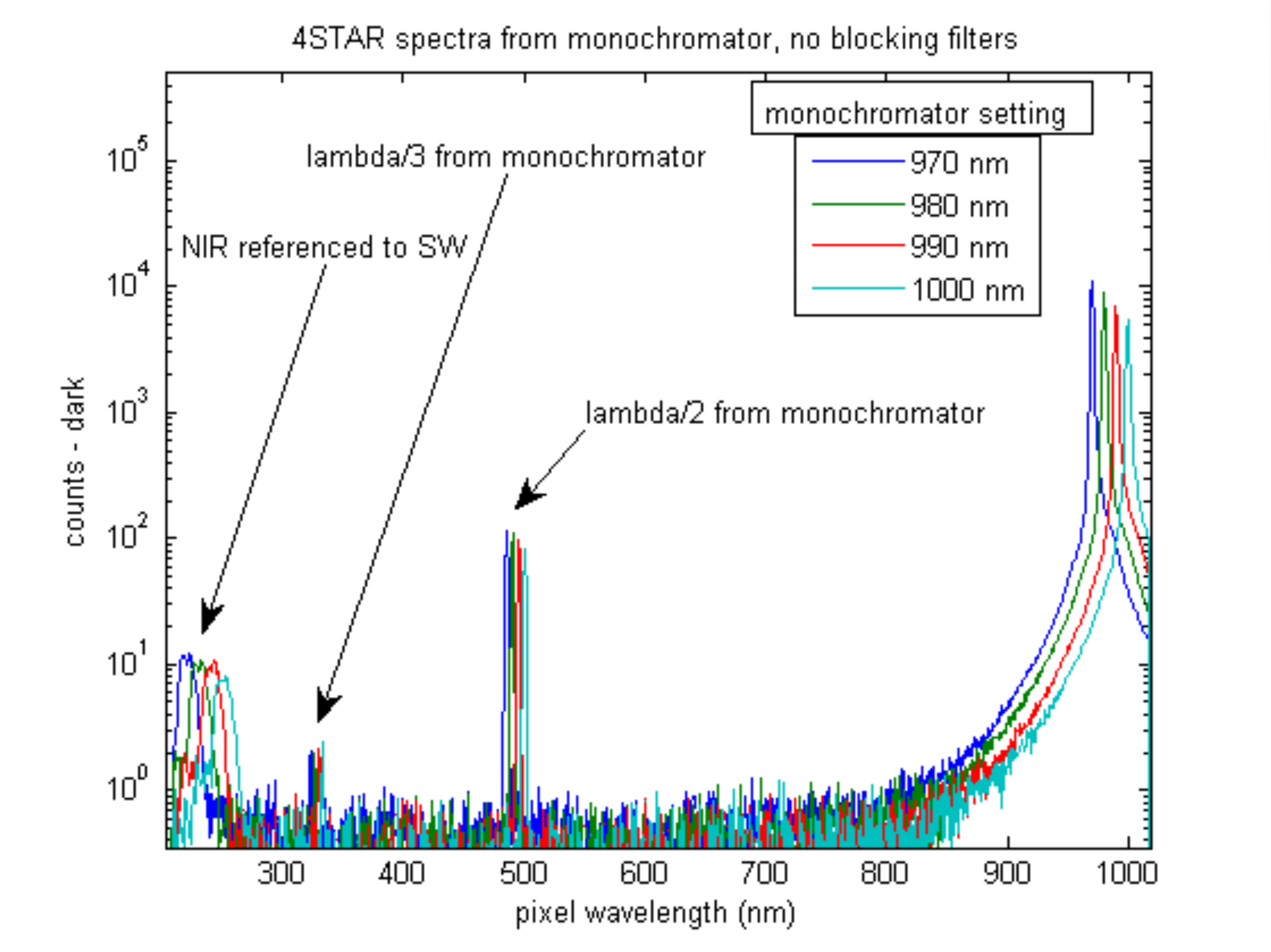
Grating Array Spectrometer Characterization

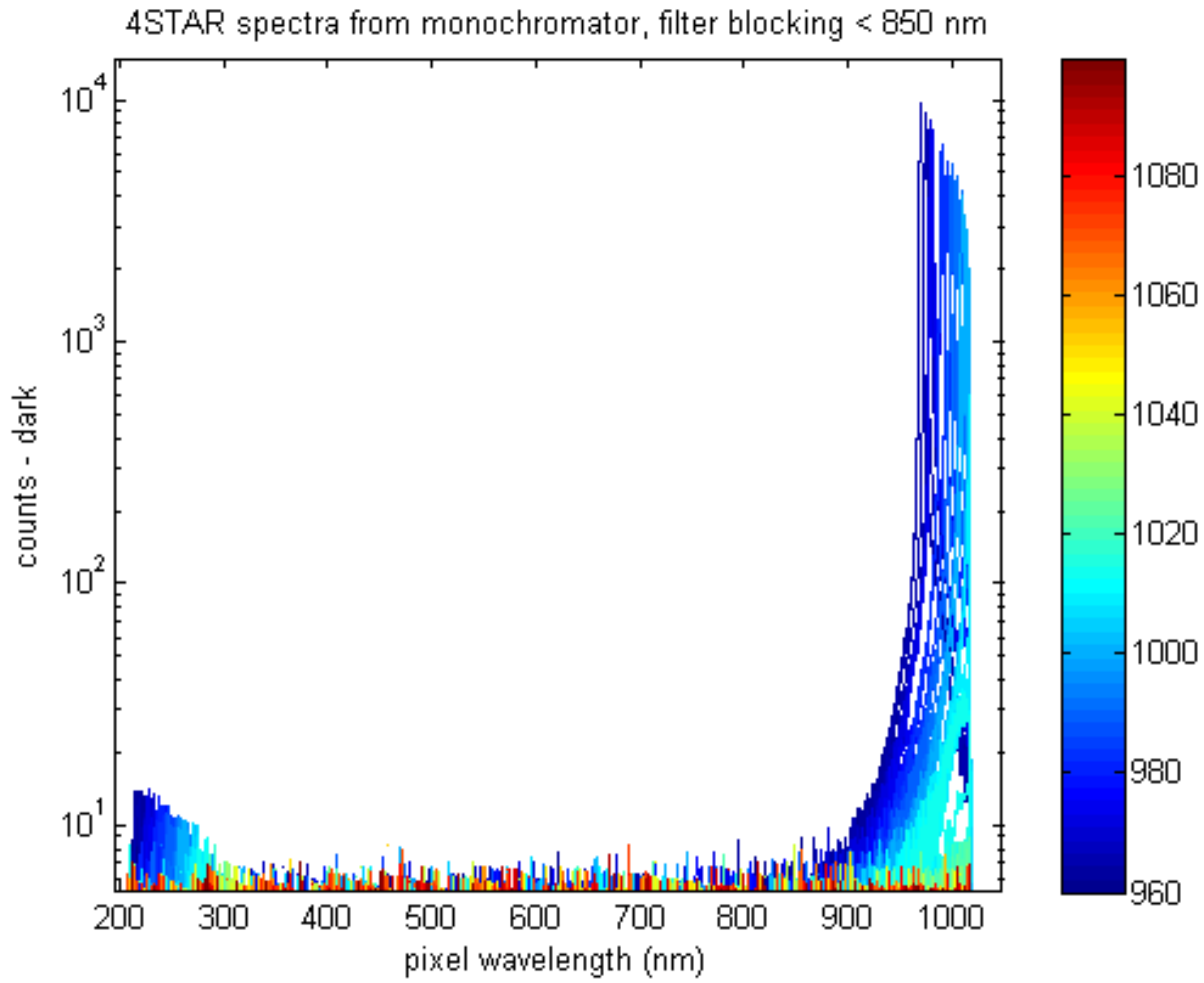
- Internal stray light has been observed < 0.1%. Non-negligible at edges of spectrometer response or near deep absorption features. Not yet corrected.

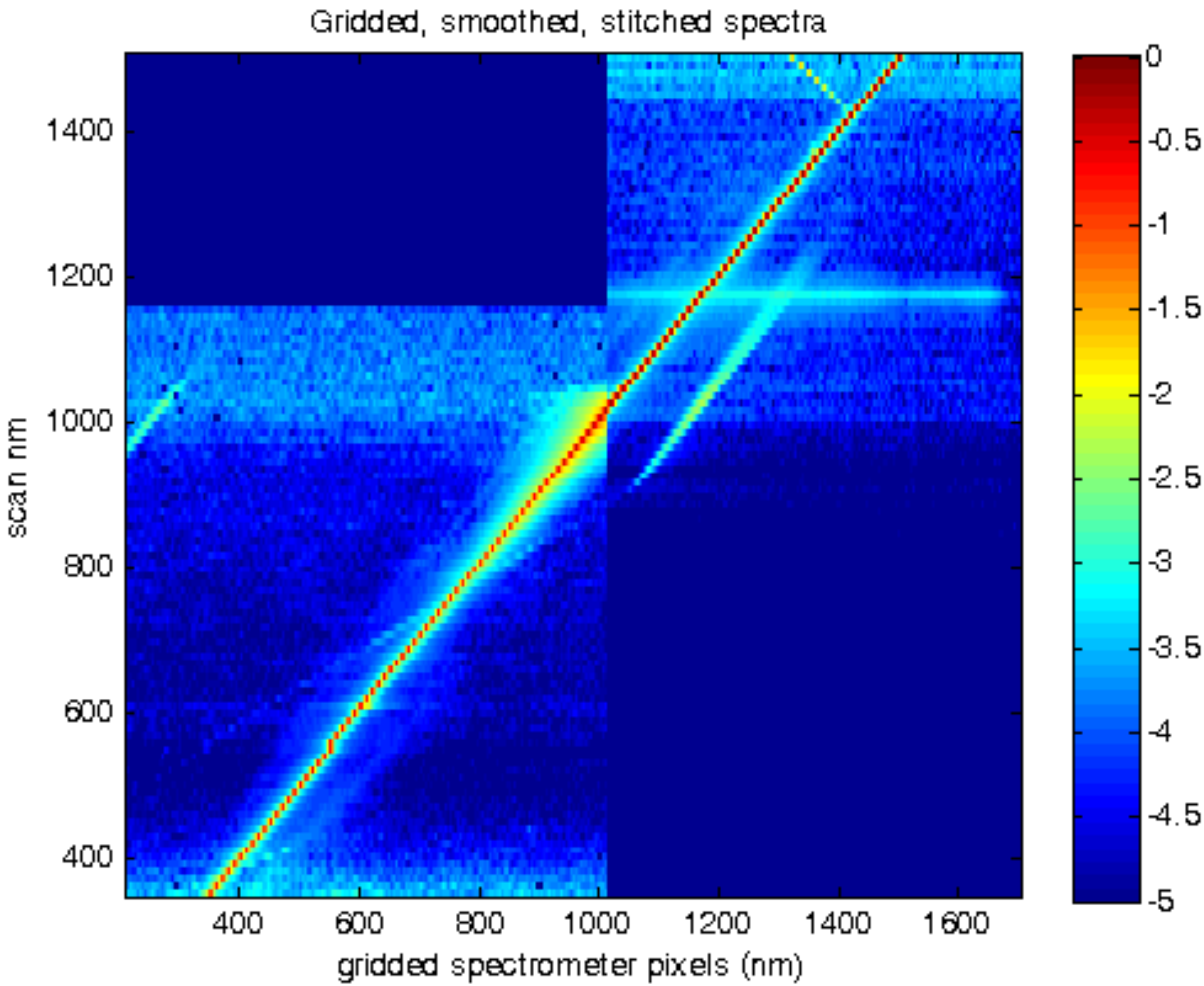


Grating Array Spectrometer Characterization

- Wavelength registration confirmed using Hg-Ar discharge lamp to be within 1 pixel of vendor calibration.
- Active wavelength correction using Fraunhofer lines and sharp absorption lines possible, not yet implemented.
- Relative spectral responsivity for irradiance using lamp or for radiance using integrating sphere or lamp with spectralon diffuser

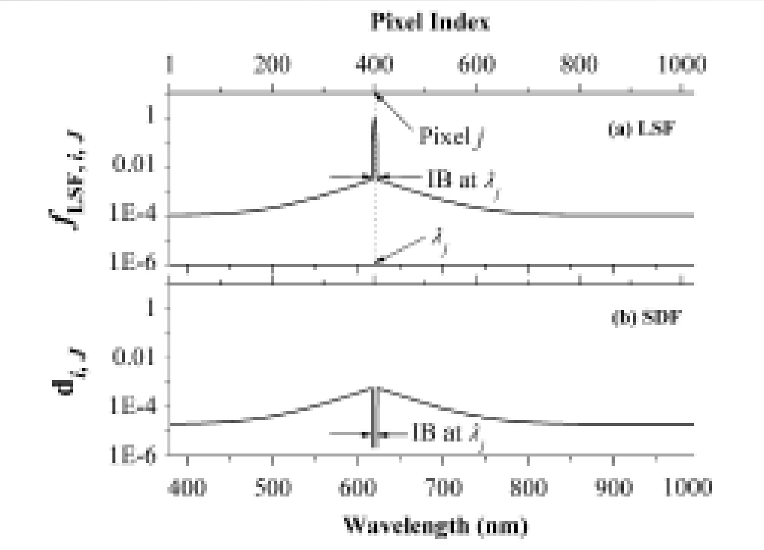

4STAR spectra from monochromator, no blocking filters
monochromator setting
970 nm
980 nm
990 nm
1000 nm
lambda/3 from monochromator
NIR referenced to SW
lambda/2 from monochromator
counts - dark
pixel wavelength (nm)
300
400
500
600
700
800
900
1000

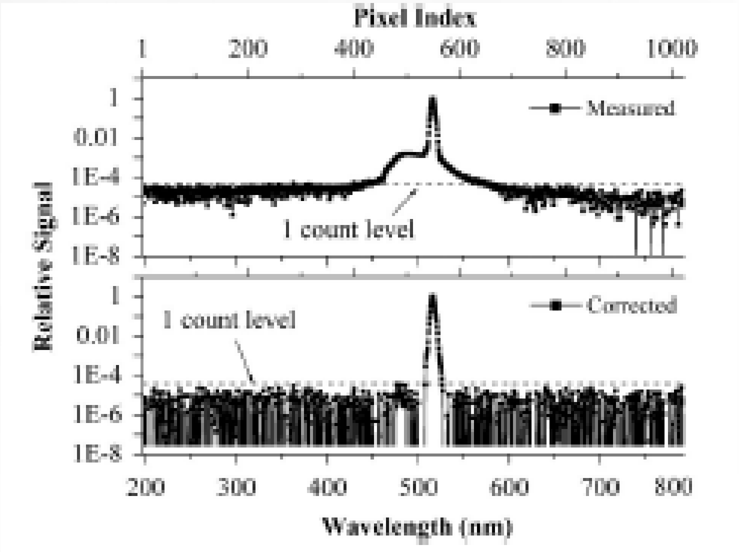

4STAR spectra from monochromator, filter blocking < 850 nm
counts - dark
10^4
10^3
10^2
10^1
200 300 400 500 600 700 800 900 1000
pixel wavelength (nm)
1080
1060
1040
1020
1000
980
960

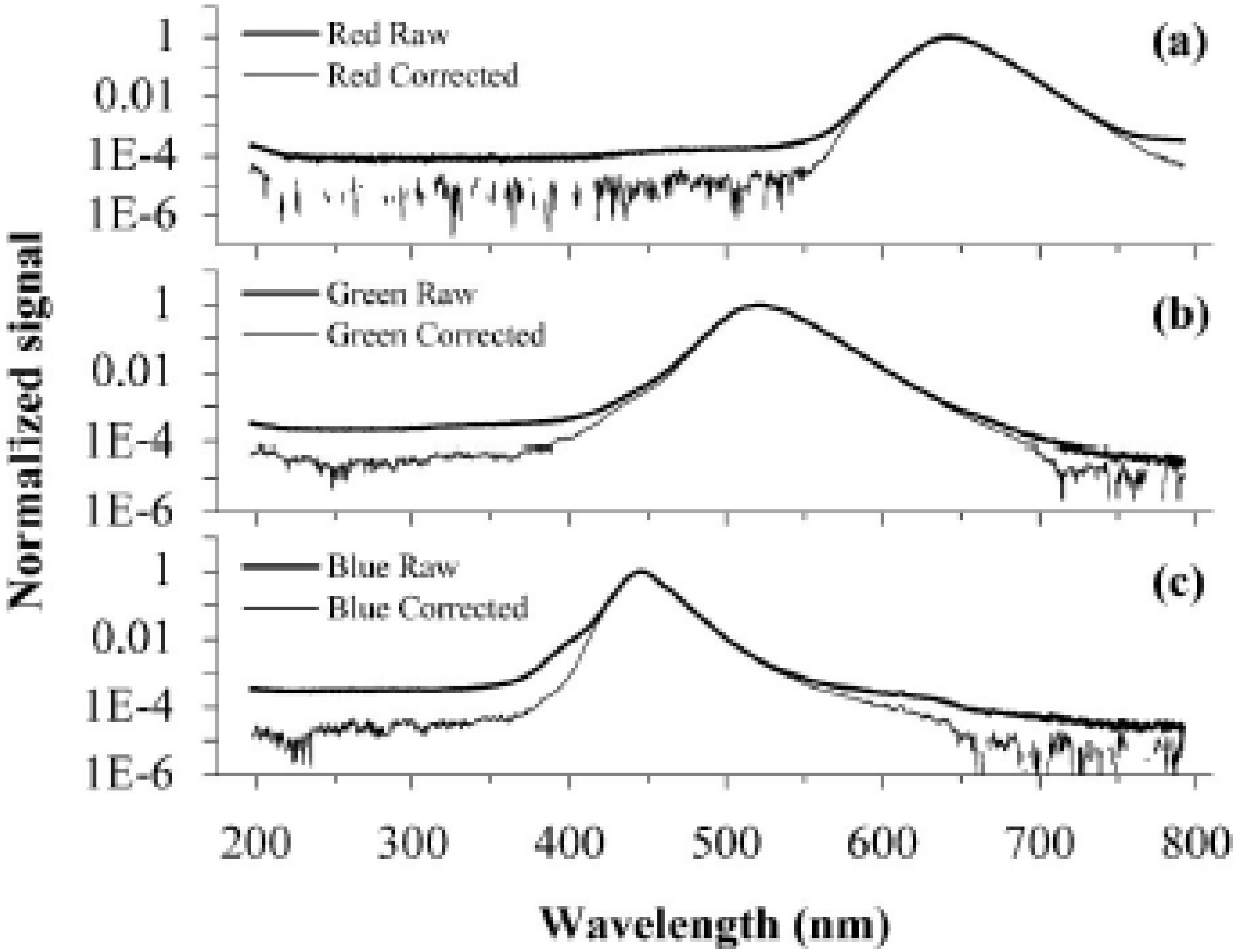

Gridded, smoothed, stitched spectra
scan nm
1400
1200
1000
800
600
400
400
600
800
1000
1200
1400
1600
gridded spectrometer pixels (nm)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5

Simple spectral stray light correction method for array spectroradiometers

Yuqin Zong, Steven W. Brown, B. Carol Johnson, Keith R. Lykke, and Yoshi Ohno






Red Raw
Red Corrected
(a)
Green Raw
Green Corrected
(b)
Blue Raw
Blue Corrected
(c)
1
0.01
1E-4
1E-6
Normalized signal
200
300
400
500
600
700
800
Wavelength (nm)

Aerosol Intensive Properties

- Need precise and accurate AOD and accurately specified lower bound radiative contribution (surface albedo or “flight level” albedo)
- MFRSR or SASHe needs accurate cosine correction to obtain accurate diffuse / direct ratio. Improve cosine correction through comparison with sun tracking measurements.
- AERONET and 4STAR need accurate sky radiance, preferably tied to irradiance. Uncertainties inherent in lamp calibrations limits retrieval applicability to high aerosol loading. Should explore options to tie sky radiance to irradiance calibration, which is itself either self-referential or tied to a common extraterrestrial solar irradiance.

Radiance registered against Irradiance

Call the raw signal from the sky barrel "D". Then we want to determine the direct irradiance Do at the top of the atmosphere which would produce the measured intensity "D_panel" at the surface.

Do = D_panel * (2pi / ref) * 1/(exp(-tau*airmass));

ref is the reflectance of the Spectralon panel at the observation incident angle

tau is the total optical depth (molecular + aerosol).

The factor of 2*pi accounts for the hemispheric reflectance from the spectralon panel.

Repeated throughout the day, and also day after day, this quantity "Do" should be stable - and the degree to which it is stable will tell us whether this approach can improve on the existing integrating sphere calibrations.

Ultimately, one would divide sky barrel measurements by Do to yield diffuse transmittance in units of inverse steradian. This is what the AERONET intensive property retrieval needs as input. For applications needing actual radiance, we merely multiply the diffuse transmittance by an extraterrestrial solar irradiance value of choice to get radiance in units of W/m^2/sr.

Preliminary results using a Spectralon panel at MLO showed Do variability < 1% of over several days.