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BRDF Characterization of Solar Diffuser for JPSS using PASCAL

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Abstract

The Visible/Infrared Imaging Radiometer Suite (VIIRS) is a key sensor on the Suomi National Polar-orbiting Partnership (NPP) satellite launched on October 28, 2011 as well as the upcoming Joint Polar Satellite System (JPSS). VIIRS collects radiometric and imagery data of the Earth's atmosphere, oceans, and land surfaces in 22 spectral bands spanning the visible and infrared spectrum from 0.4 to 12.5 mm. Radiometric calibration of the reflective bands in the 0.4 to 2.5 mm wavelength range (M1 – M11, I1 – I3) range is performed by measuring the sunlight reflectance from Solar Diffuser assembly (diffuser is Spectralon™). The reflected sun light is directly proportional to the Bidirectional Reflectance Distribution Function (BRDF) of the Spectralon™. This paper presents the BRDF measurements of the Spectralon™ for JPSS in the 0.4 – 0.9 mm wavelength using PASCAL (Polarization And Scatter Characterization Analysis of Lambertian materials) with an uncertainty better than 1.2%. PASCAL makes absolute measurements of BRDF in an analogous fashion National Institute of Standards and Technology (NIST) Spectral Tri-function Automated Reflectance Reflectometer (STARR) facility. The entire incident light beam is collected by the detector assembly. With the sample in place, a precision circular aperture with a viewing region larger than the illuminated spot is used to collect the light. BRDF is calculated on the basis of the incident power and geometric factors eliminating the need for a standard characterized at another laboratory. Spectral definition is achieved with band pass filters. As in typical BRDF instruments, the detector rotates about the sample in the plane defined by the source beam and the azimuth rotation of the sample. Unique additional features of this instrument include the ability to vary the sample elevation and roll / clock the sample about its normal. PASCAL is set up to mount the flight Solar Diffuser assembly (Spectralon™ is 23.7 X 28.6 cm). The ability to change elevation and roll the sample about the surface normal enables measuring the BRDF in the as use configuration of VIIRS including source, Solar Diffuser, and detector geometry. A description of PASCAL, validation and the BRDF results of the Solar Diffuser will be presented.

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Outline

- Solar Diffuser BRDF measurement requirements
- PASCAL description
- Instrument Validation
- Solar Diffuser Measurements

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JPSS VIIRS Reflective Band Calibration: Solar Diffuser Assembly (SDA)

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- SDA is used with Solar Attenuation Screen (SAS) to provide the VIIRS Sensor on JPSS with a known radiance source suitable for radiometric calibration of the reflective bands (400 – 2300 nm)
- Sun shines through the SAS onto the Solar Diffuser (Spectralon®)
- Radiance from sun light reflected from SDA is given by the equation below where BRF (BRDF × π) is the SD reflectance factor

$$L_{cal} = E_{sun} \times \frac{BRF}{\pi} \cos\theta_{aoi}$$

- SD reflectance needs to be known to better than 1.2% for VIIRS sensor calibration
- Source, Solar Diffuser normal, and detector angles in laboratory need to match on orbit geometry
- Solar Diffuser is viewed by SDSM (Solar Diffuser Stability Monitor) and RTA (Rotating Telescope Assembly) so BRF characterization needs to be for both views

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Measurement Approach

- BRF (BRDF × π) measurements of the Solar Diffuser were made using PASCAL (***P***olarization ***A***nd ***S***catter ***C***haracterization and ***A***nalysis of ***L***ambertian materials)
- Measurements are relative to the source beam: reference standard not needed
  - Absolute measurement of BRF based on geometry and light intensity measurements with suitable dynamic range analogous to NIST STARR (Spectral Tri-function Automated Reflectance Reflectometer) instrument
  - Instrument validation is done by comparison of Spectralon sample measured at NIST
- Spectral definition is achieved with band pass filters in 400 – 1700 nm wavelength range
- Solar Diffuser will be characterized in ‘as used’ geometry as instrument can rotate azimuth, elevation and roll/clocking

PASCAL makes ‘absolute’ BRF measurements analogous to STARR

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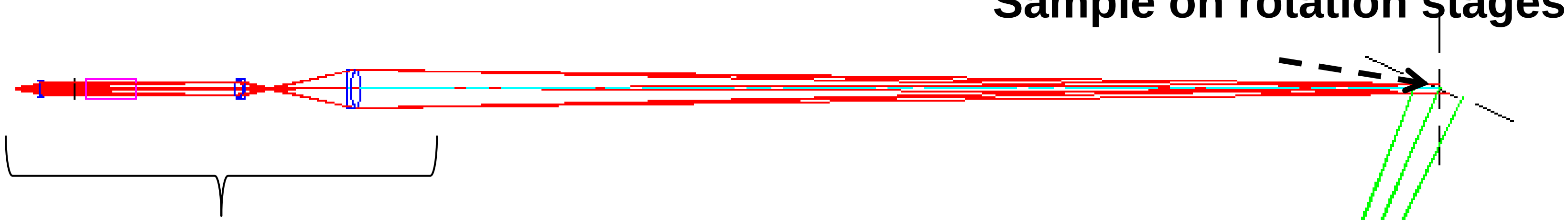
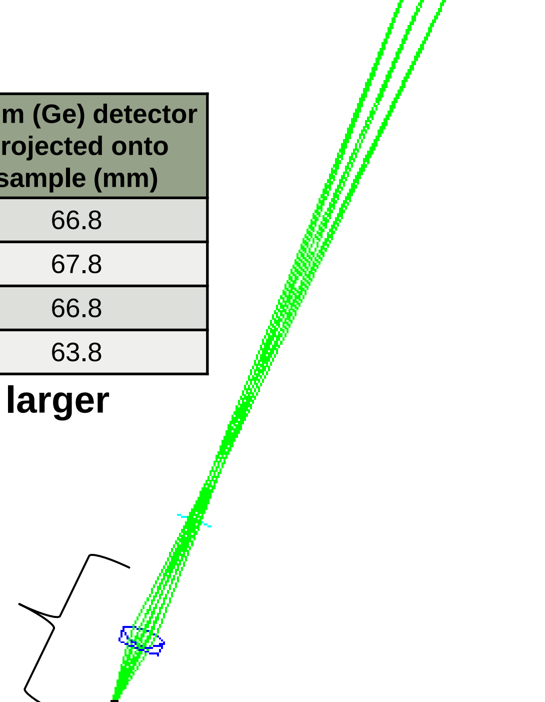
PASCAL Layout



Wavelength	Illuminated spot size 1460 mm from last lens Full diam (mm)	White light meas (mm)	7.98 mm (Si) detector projected onto sample (mm)	5 mm (Ge) detector projected onto sample (mm)
400 nm	20	13 - 16	106	66.8
632.8 nm	17	13 - 16	110	67.8
900 nm	16.4	13 - 16	109	66.8
1700 nm	25	13 - 16	105	63.8

- **Angle of incidence elongation at 60° AOI results in 2X larger spot: still significantly less than either Silicon or Germanium viewing area**



Detector viewing area is larger than illuminated spot

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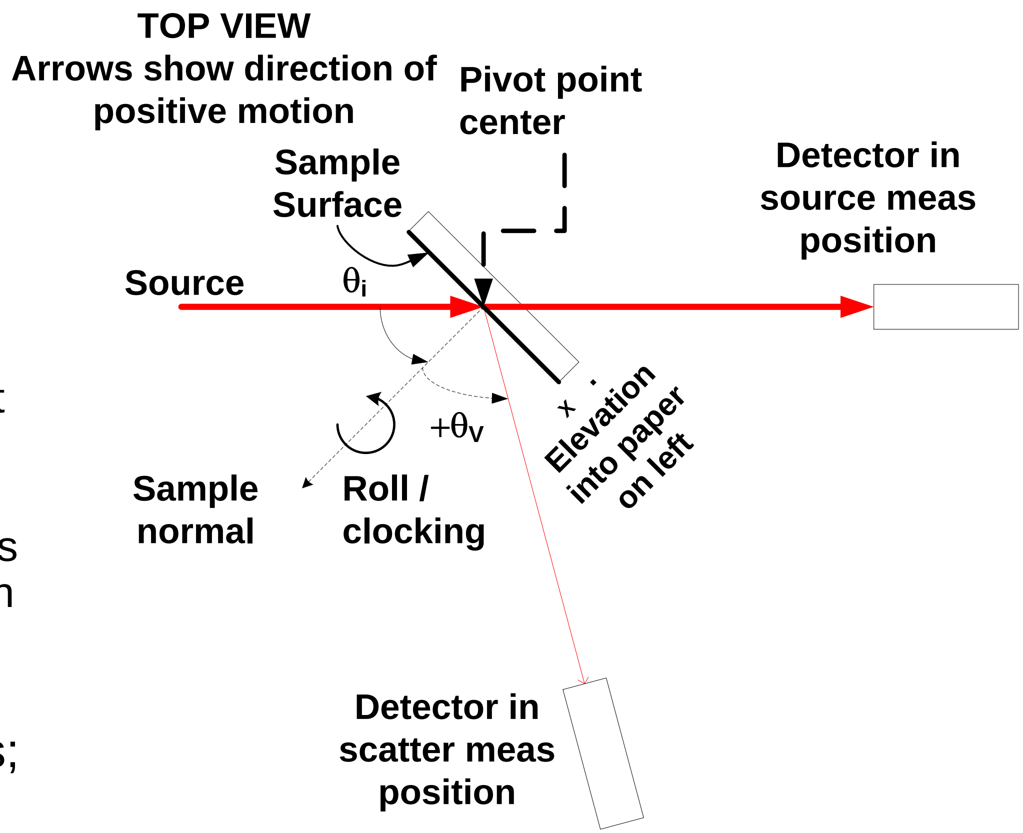
Measurement Method

- Calibration to incident beam done by capturing entire incident beam by positioning detector in path of source beam (linearly polarized)
  - Optical modeling shows entire source beam captured by detector assembly
  - Verified by showing that some changes in aperture do not affect signal level
  - Preamplifier and lock-in amplifier gain characterized over ~5 orders of magnitude by stepping through decreasing signal levels
- Sample face at intersection azimuth, elevation & clocking axes; signal measured at desired angle of incidence and viewing angle



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PASCAL Incident & Reflected Beam Polarization

- As the source is fixed in laboratory coordinates, changing azimuth and declination of the source relative to the solar diffuser requires rotating the solar diffuser in both azimuth and elevation in laboratory coordinates with elevation angle changing for each azimuth and declination pair
- As average polarization BRDF is needed, the incident polarization is set to two orthogonal polarizations (0° and 90°) so that an effective random polarization source is obtained by combining the two cases
- For both 0° and 90° incident polarization the detector wire grid polarizer are set at 0° and then 90° for incident as well as reflected light
- The response of the detector wire grid polarizer at 0° and 90° is added for each incident polarization and the results are averaged to calculate BRDF
  - A wire grid polarizer is used in the detector assembly as the detector assembly is known to have a polarization dependence (see Reference cited) and use of the polarizer enables correct addition of two orthogonal exiting polarizations
  - Reference: V. Murgai, J. M. Nixt, E. M. Moskun, C. M. Jones, C. E. Payton, and J. D. CdeBaca, “PASCAL: Instrument for accurate precise characterization of Lambertian materials” Proc. of SPIE Vol. 7792 (2010)

Two orthogonal polarizations used to obtain net random polarization

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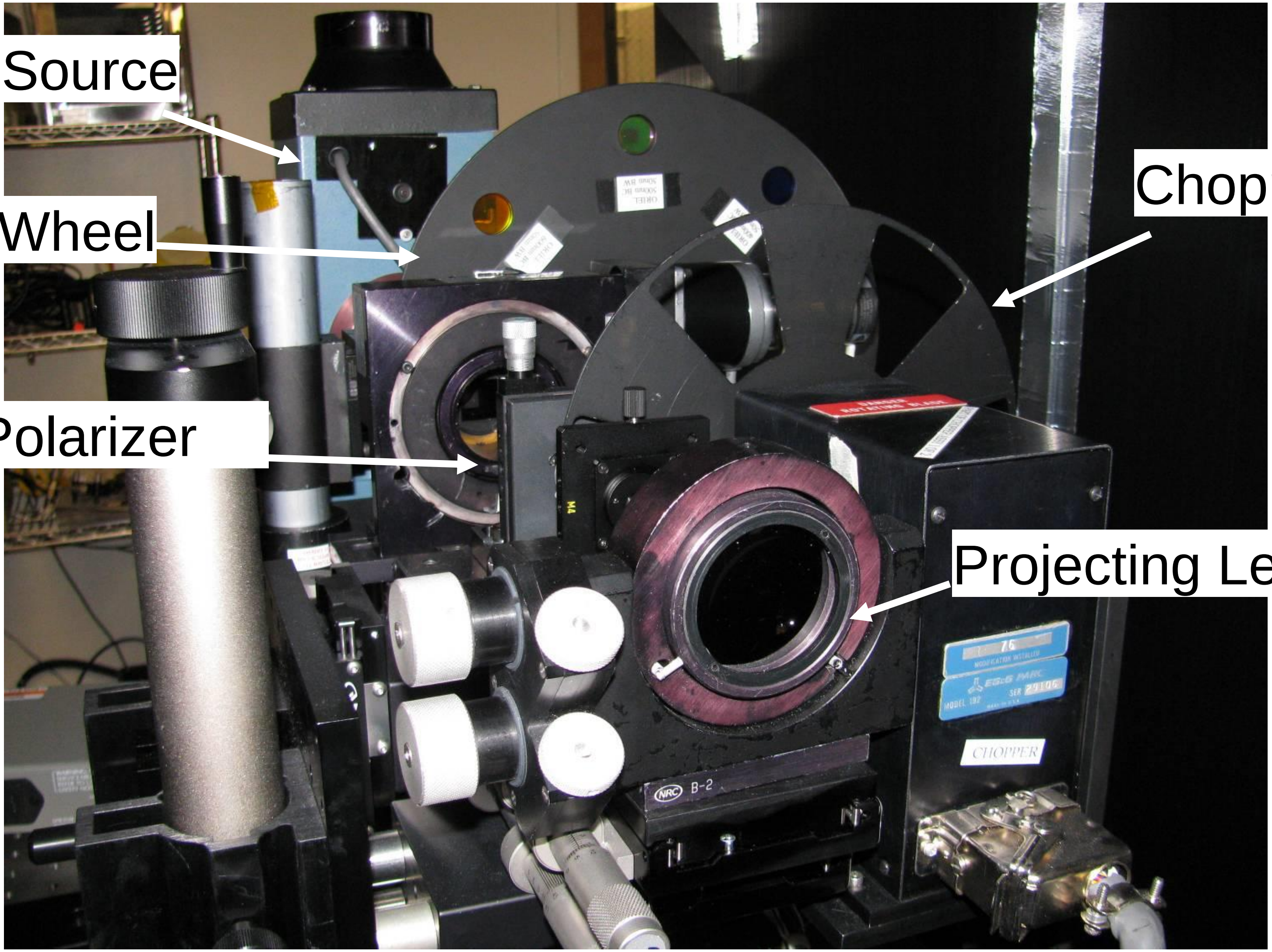
PASCAL Light Source Assembly



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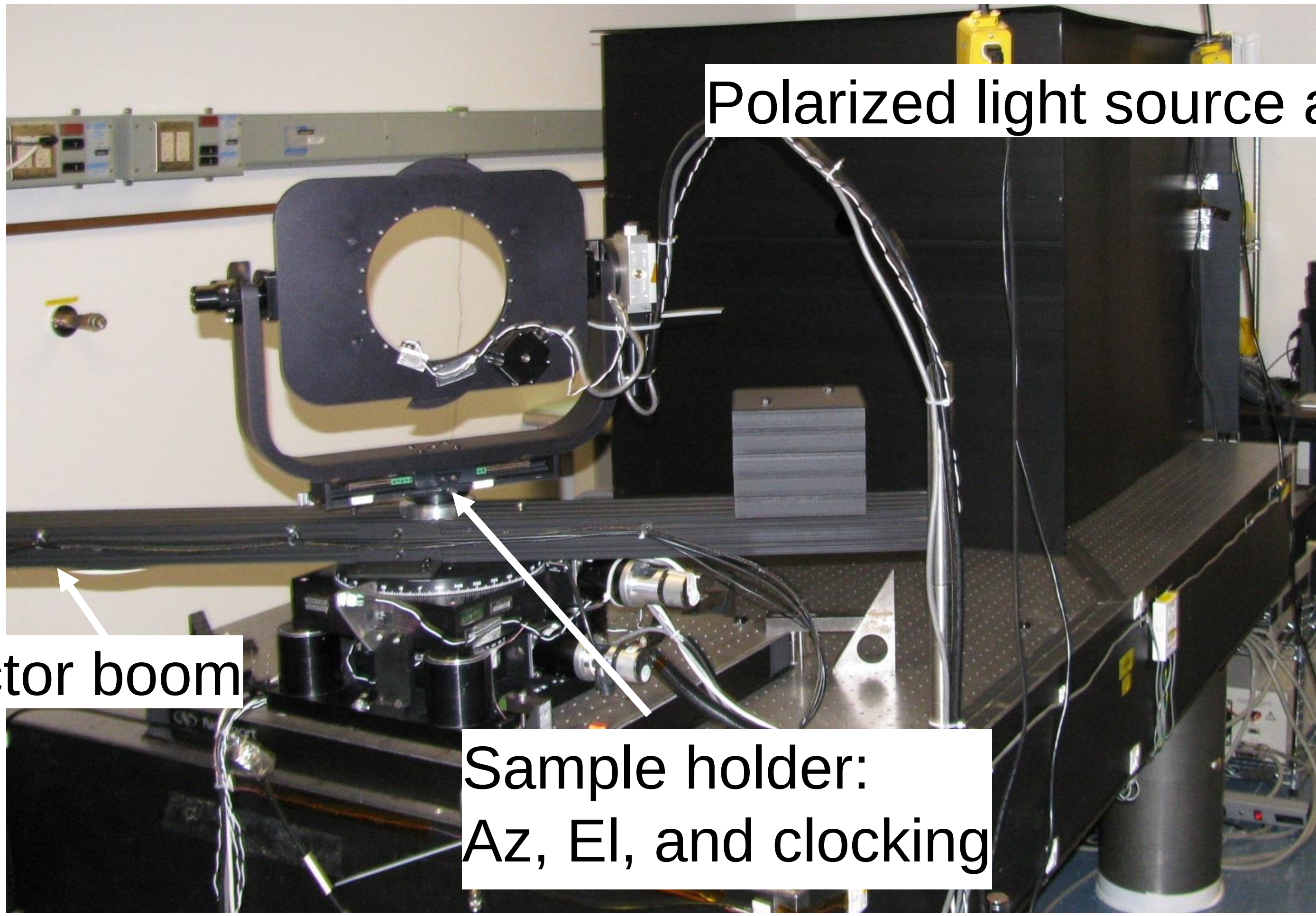
PASCAL



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Instrument Validation

- PASCAL is an absolute instrument: error tree based on physical parameters measured with calibrated / characterized devices
- Validation is done by measuring a NIST traceable sample
- Comparison of NIST traceable sample and PASCAL are made at 400, 500, 600, 700, and 900 nm with a Silicon detector at 45/0 and at 700 nm for 60 AOI from -30 to +60 viewing angles and at 900 nm at 45/0 with a Germanium detector
- Comparison of ‘absolute’ measurements of a sample by different instruments is done by calculating
  - Normalized error, E_n, of PASCAL referenced to STARR of NIST is defined as below (at k=2)
  - If E_n <1, the error of PASCAL-measured BRDF from NIST-measured BRDF is within the combined measurement uncertainty.

$$E_n = \frac{\left| BRF_{NIST} - BRF_{PASCAL} \right|}{\sqrt{U_{NIST}^2 + U_{PASCAL}^2}}$$

PASCAL validation done by error calculation and comparison with sample measured at NIST

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Comparison with NIST: BRF wavelength variation

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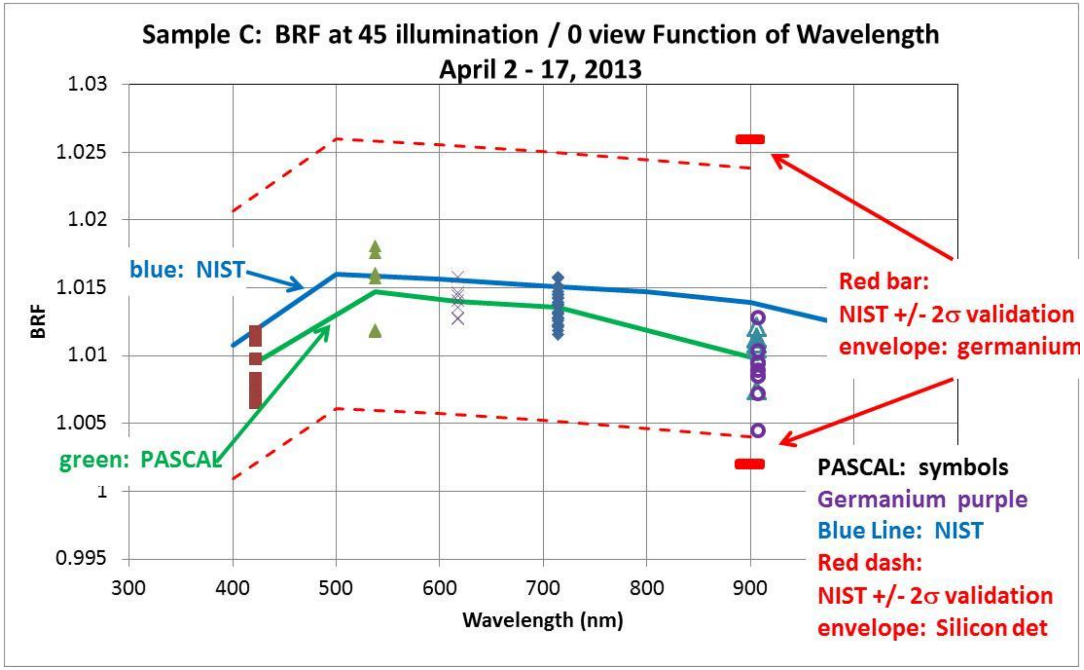
- Sample C measured by NIST in 2012
- Comparison function of wavelength at 45° angle of incidence 0° angle of view (45/0)
- BRF values are shown along with expanded uncertainty 2 sigma validation envelope
- Average of PASCAL measurements within E_n =1 for combined uncertainty
- At 900 nm PASCAL Germanium and Silicon detector average values agree within 0.18%!! PASCAL works for both detectors!!

PASCAL measurements are within NIST validation envelope for 45/0 for 900 nm for Germanium detector

Silicon & Germanium at 900 nm agree within 0.18%!!!



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Comparison with NIST: BRF angular dependence Silicon detector

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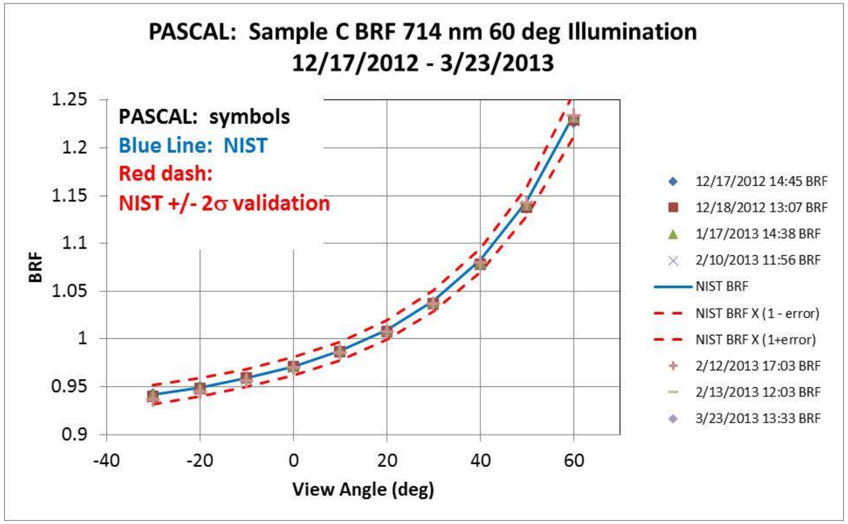
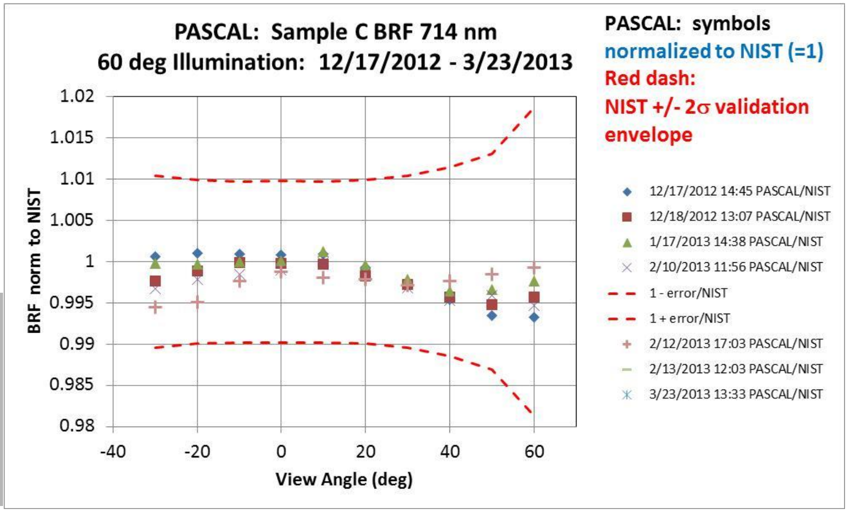
- Sample C measured by NIST in 2012
- Comparison as a function of view angle at 714 nm (PASCAL) and 60° angle of incidence measurements from 12/17/2012 – 3/23/2013
- BRF shown: symbols are PASCAL, blue line NIST and dashed red line NIST +/- 2σ validation error
- Plot shows ~30% variation in BRF with viewing angle
- Bottom figure shows same data normalized to NIST along with validation envelope
- PASCAL measurements within E_n = 1 validation envelope





PASCAL measurements are within NIST validation envelope for -30° to 60° viewing angles for 60° AOI

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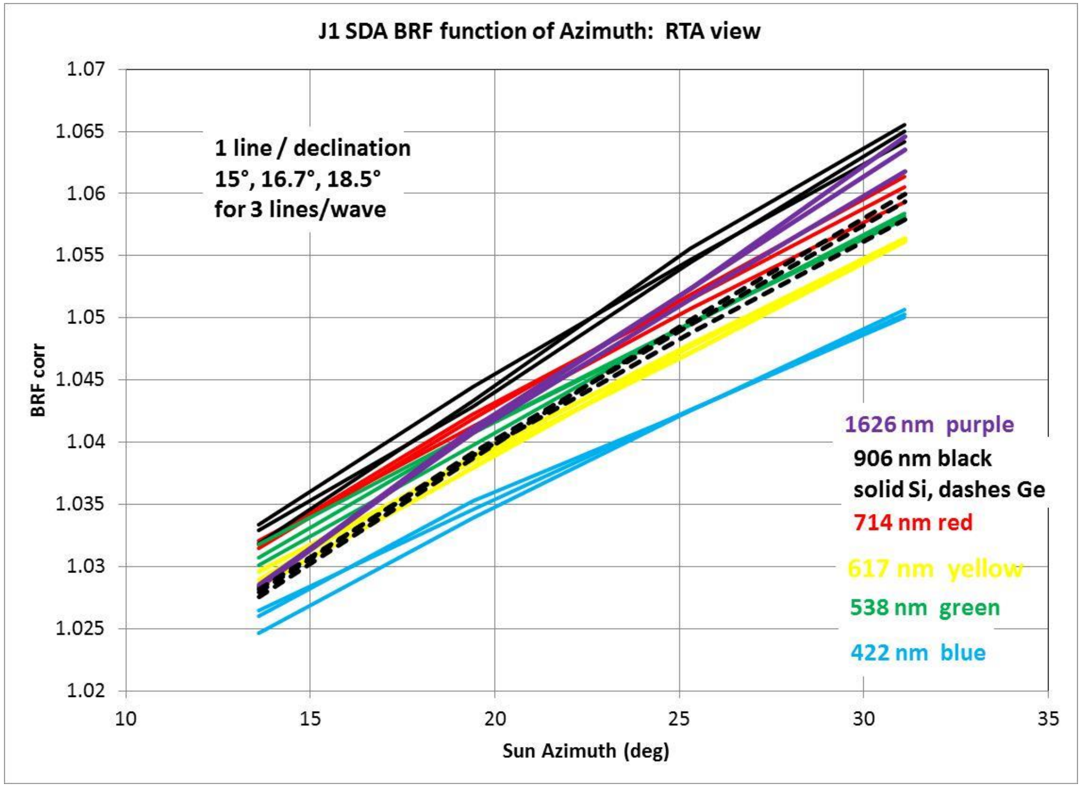
J1 SDA BRF RTA view function of Sun Azimuth

- Figure shows J1 SDA BRF for RTA view at several wavelengths as a function of Sun Azimuth for each of three declinations: 15°, 16.7°, and 18.5°
- BRF varies primarily with azimuth with minor changes with declination: for fixed azimuth BRF variation (range) is from 0.0001 to 0.003 BRF corresponding to <0.015% (0.03 / (2 x BRF)) error by ignoring declination



- Can use line fits for each declination to interpolate to desired angle
  - Declination variation for intermediate angles is then done by linear interpolation between values calculated for the three known declination values

RTA view BRF a function of sun azimuth only within measurement uncertainty

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J1 SDA BRF SDSM view function of Sun Azimuth

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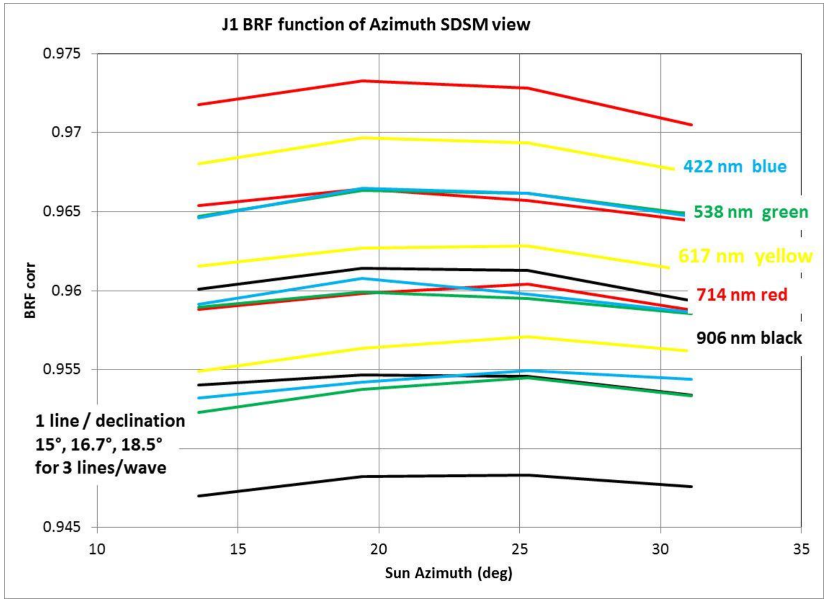

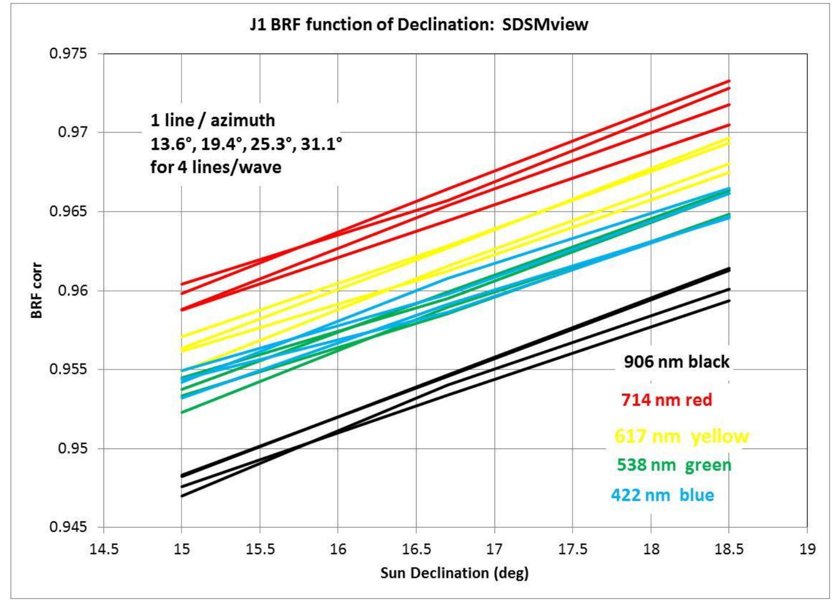

- Figure on left shows J1 SDA BRF for SDSM view at several wavelengths as a function of Sun Azimuth for each of three declinations: 15°, 16.7°, and 18.5°
  - There is a weak dependence on sun azimuth but significant variation with declination
- Figure on right shows the same data as a function of sun declination for each of 4 azimuth values: 13.6°, 19.4°, 25.3° and 31.1° showing an approximately linear response with declination
  - BRF variation with azimuth for fixed declination is 0.008 to 0.014 corresponding to range /(2*BRF) of about 0.7% so that need to fit a response surface to BRF to interpolate

BRF varies approximately linearly with declination with some variation (up to ± 0.7% with azimuth for fixed declination)

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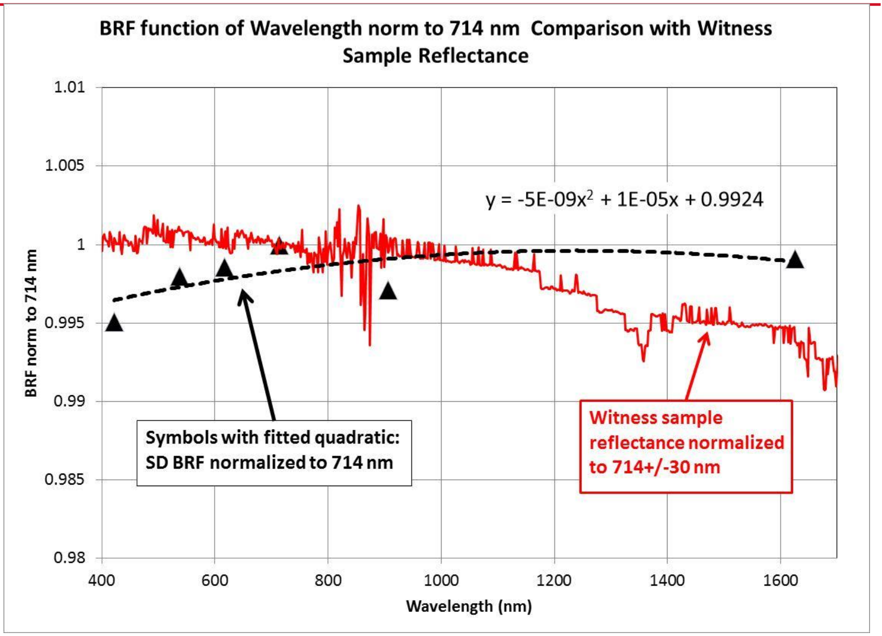
J1 SDA BRF Spectral Dependence

- Relative spectral dependence of the BRF was calculated by
  - Calculating average of all 5 measurements at 714 nm (including spatial variation sets) at each angle pair setting for each of two views (24 average values calculated)
  - Normalizing the BRF at 422, 538, 617, and 906, 908 (Ge), 1626 (Ge) nm to the average at 714 nm for at the corresponding angle pair and view
    - All 906 and 908 nm data sets were averaged together
    - All 1626 nm data including spatial variation was averaged



- Taking an average of the 12 angle pairs X 2 views for a total of 24 for an effective spectral dependence
- Black symbols show average response normalized to 714 nm as a function of wavelength
  - Range of variation with wavelength is <0.5%
- Red curve is reflectance of Spectralon witness sample normalized to 714 nm
  - Reflectance measurements are relative to a standard measured at Labsphere relative to a standard traceable to NIST with uncertainty ~0.5% per Labsphere and estimated to be 2.0% per Raytheon Primary Standards Lab

SDA BRF shows small spectral dependence from 400 – 1630 nm

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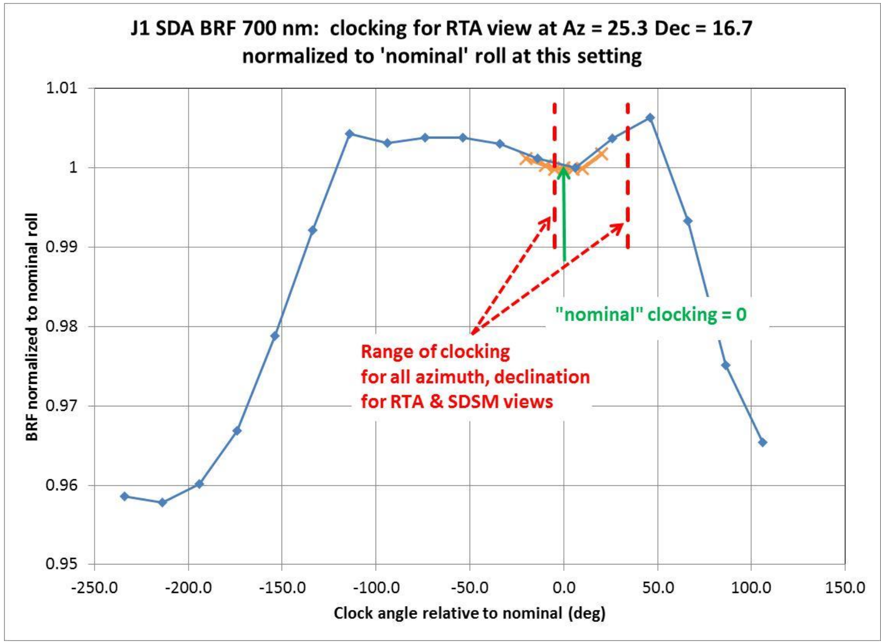
SD Clocking Error Variation

- Figure on right shows BRF normalized to nominal roll angle in RTA view at sun illumination Azimuth = 25.3 and declination 16.7 with two sets of roll tests
  - Nominal and ±5°, ±10°, and ±20° for local variation
  - 20° steps for entire Solar Diffuser roll performance
- Roll variation for all azimuth and declination for two views is 229.1° to 267.5° for a range of 33.6° (limits are red dashed lines in figure)



- For 340° roll, variation in BRF is 4.8% for J1 SDA
- Variation due to clocking is part and orientation specific so only need to use region near clocking for analysis
- For Solar Diffuser roll range of interest, maximum normalized rate of change of BRF with roll angle is 0.000648 which for a 0.21° error corresponds to 0.000136

Spectralon BRF variation with clocking is part dependent: 4.8% for SDA

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Summary

- PASCAL is an absolute instrument for measuring BRF (BRDF x π) with a measurement uncertainty better than 0.65%
  - Measures parts in as use configuration including elevation and clocking of part
  - PASCAL measurement errors are based on geometry errors, detector uniformity, gain ratios etc
- Measurement of VIIRS J1 Solar Diffuser was performed with an overall error better than 0.8%
- Clocking of J1 Spectralon Solar Diffuser shows significant variation of 4.8% in BRF with clocking angle
- Essential to measure BRF at correct clocking in addition to azimuth and elevation angles of incidence as clocking response is part dependent

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