The PMOD/WRC Precision Spectroradiometer
PSR

Julian Gröbner, Natalia Kouremeti, Ricco Soder, Diego Wasser, Manfred Gyo, Fabian Dührig,
Etienne De Coulon
Physikalisches Meteorologisches Observatorium Davos, World Radiation Center, Davos
Switzerland

Thanks to Saulius Nevas and Peter Sperfeld, PTB for characterising the PSR stray light and linearity

Some of the work was performed within the EMRP project ENV03.
The European Metrology Research Programme (EMRP) is jointly funded by the EMRP participating countries within EURAMET and the European Union.
Potential Applications

• Spectral aerosol optical depth for the eventual replacement of filter sunphotometers

• Retrieval of atmospheric parameters (ozone, water vapour, aerosols)

• absolute spectral solar irradiance measurements for photovoltaic applications

• Climatological measurements of solar irradiance (direct & global)
Some history...

- **August 2008**: Project submitted to the regional Stiftung for Innovation, Entwicklung and Forschung GR
- **September 2009**: Design Study
- **October 2010**: Benchtop model
- **Jan 2011-March 2012**: Prototype Development
- **March 2012**: PSR V0 First light
- **Mar 2014**: PSR V2 First light
- **Mar-June**: PSR_003 in Izaña
- **June 2014**: First 2 PSRs delivered to customer
- **July 2014**: AOD Campaign Finokalia
PSR Specifications

- Holographic flat-field grating 200 lines/mm from Zeiss
- Hamamatsu NMOS 1024 linear image sensor
- 18 bit ADC (262 kcounts)
- 10 ms to 40 sec integration time
- Temperature stabilised sensor ±0.1K (invar)
- Temperature insensitive optical bench (carbon)
- Wavelength range 300 – 1020 nm
- Resolution 1.5 nm to 6 nm
- Wavelength step 0.7 nm
- 2 entrance optics, direct irradiance and generic SMA
- stray-light optimised optical design with zero-order light-trap
PSR Characterisation

- Slit function and bandpass
- Linearity
- Temperature coefficients
- Stray-Light
- Telescope Flat-field
- Direct irradiance calibration
PSR_003 is linear to better than ±1% over the full range:

- IT from 10ms to 8000ms
- Intensity variation between 1000 and 245000 counts

courtesy P. Sperfeld, PTB
Temperature behavior of PSR

Wavelength shift versus temperature

Optical Stability is obtained by using a carbon bench with vanishing temperature expansion coefficient.

1) from solar measurements and matSHIC

Using data from 60 days

<table>
<thead>
<tr>
<th>Wavelength /nm</th>
<th>Temp. coeff nm/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>350</td>
<td>0.01 ±0.004</td>
</tr>
<tr>
<td>500</td>
<td>0.02 ±0.01</td>
</tr>
<tr>
<td>605</td>
<td>0.00 ±0.03</td>
</tr>
<tr>
<td>795</td>
<td>-0.005 ±0.02</td>
</tr>
</tbody>
</table>

\[ \frac{dWL}{T} \sim 0.01 \text{ nm K}^{-1} \]

\[ d\text{FWHM} K^{-1} < 0.005 \text{ nm K}^{-1} \]
Temperature behavior of PSR

The temperature dependence of the sensitivity was determined for 4 PSR in the laboratory.

The change in sensitivity is less than **0.1% / K** for all PSR

<table>
<thead>
<tr>
<th>PSR</th>
<th>Temp. coeff %/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>003</td>
<td>-0.08 %</td>
</tr>
<tr>
<td>004</td>
<td>&lt; 0.04 %</td>
</tr>
<tr>
<td>005</td>
<td>-0.06 ± 0.02 %</td>
</tr>
<tr>
<td>006</td>
<td>&lt; 0.05 %</td>
</tr>
</tbody>
</table>
Line Spread functions of various PSRs using lasers and spectral emission lamps

For some lines, an improved fit to the experimental data is obtained using a double Gaussian fitting.

The LSF seems very similar between different PSRs. Here, one can clearly see the second order line emerging from the background.
Bandpass using spectral emission lines

FWHM varies between 1.5 nm and 6 nm

The location of the minimum FWHM can be selected during the alignment process

The smallest FWHM of 1.5 nm is where the image of the entrance slit is optimally focussed on the detector
Stray-light
The slit functions were determined at the tuneable laser setup PLACOS at PTB in the range 300 to 1000 nm.

The stray-light corrected signal $Y_{IB}$ can be retrieved from the measurement by applying a stray-light correction matrix $C$ to the measured signal, following the method of Zong, 2006.

$$Y_{IB} = C Y_{meas}$$
Stray-light
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The stray-light corrected signal $Y_{IB}$ can be retrieved from the measurement by applying a stray-light correction matrix $C$ to the measured signal, following the method of Zong, 2006.

Is that effort really necessary?
Why not use a single slit function to determine the stray-light matrix?
The Line-Spread functions of PSR 003 were measured at the tuneable laser facility PLACOS at PTB.

The enhanced stray-light above 700 nm is specific to PSR 003 and is not consistent with PSR 004, 005 and 006 even though the instruments were all built in house as the same batch.

For PSR 004, 005 006 we need to use a IR corrected version (gray-line in the video).
Stray-light validation

1) Tungsten-halogen lamp and Band-pass filters
2) Solar measurements and band-pass filters
3) Solar measurements at Izaña
Stray-light validation

1) Lamp & band-pass filters

Raw Spectra from a FEL Lamp Spectrum with several band-pass and cut-on filters
Stray-light validation

1) Lamp & band-pass filters

Stray-light from the LSF of the IR spectrum.
Stray-light validation

1) Lamp & band-pass filters

4 PSR, Stray-light from PSR 003 is significantly higher than from all others
Stray-light validation

1) Lamp & band-pass filters

The Stray-light correction using the appropriate SR-Matrix is effective in removing more than 95% of the SR-Signal in PSR 003
Direct optic flat field

Following WMO specifications for sunphotometers measuring direct solar irradiance:
- less than 2° field of view
- Slope angle of 1°
Direct optic flat field – spectral "waves"

Standard Diffuser, sandblasted on one side

Standard Diffuser, sandblasted on two sides, 3 times more transmission loss

±1%

±2%
Direct optic flat field – spectral "waves"

Where do these spectral waves come from? AND How to get rid of them?
Langley-Calibration campaign Izaña March-June 2014

2 May 2014

Counts

Time 2 May 2014

Direct radiance W m⁻² nm⁻¹

Wavelength /nm
Langley-Calibration campaign Izaña March-June 2014

27 May 2014

Langley Plot

Langley-Intercept and literature spectrum
Stray-light effect on solar measurements

Ratio between Langley extrapolated ET Spectrum and literature ET
Stability and comparison to literature ET

Variability ±0.8%

±5%
Spectral AOD compared to CIMEL and PFR

27 May 2014

Water vapour

CIMEL  PFR

O₂ O₂

Wavelength / nm

AOD

300 400 500 600 700 800 900 1000
Spectral AOD compared to CIMEL – 10 May 2014

PSR-CIMEL < ±0.01
Further steps...

- Investigate the strange line spread functions of PSR 003 above 750 nm, which seem to be due to enhanced light scattering (from black anodized metal?)

- Connect a telescope to the second SMA port for lunar irradiance and nighttime AOD retrieval

- Construct additional PSRs ...
The PSR Team

Etienne

Dani

Julian

Diego

Ricco

Fabian

Claudio

Silvio

Manfred

Peter

2009: 2014
>6 (wo)man-years development time