The PMOD/WRC Precision Spectroradiometer

PSR

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

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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

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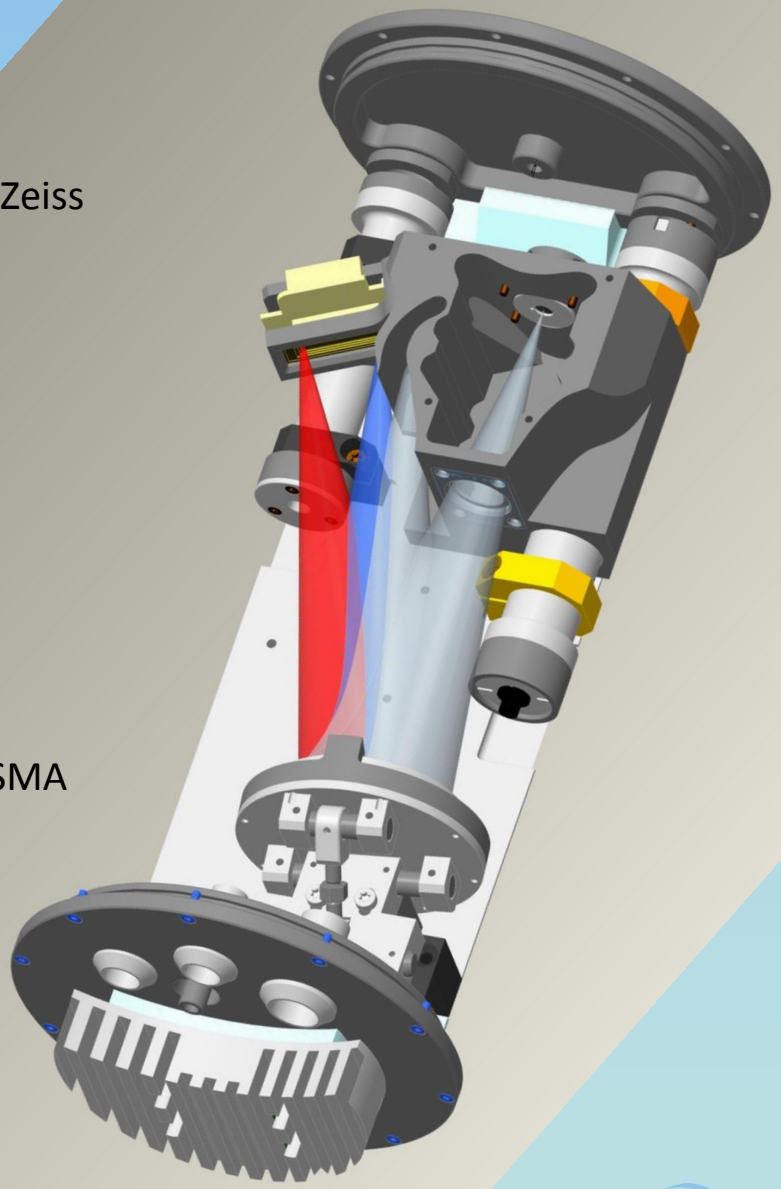
PSR Specifications

- 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



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PSR Characterisation

- Slit function and bandpass
- Linearity
- Temperature coefficients
- Stray-Light
- Telescope Flat-field
- Direct irradiance calibration

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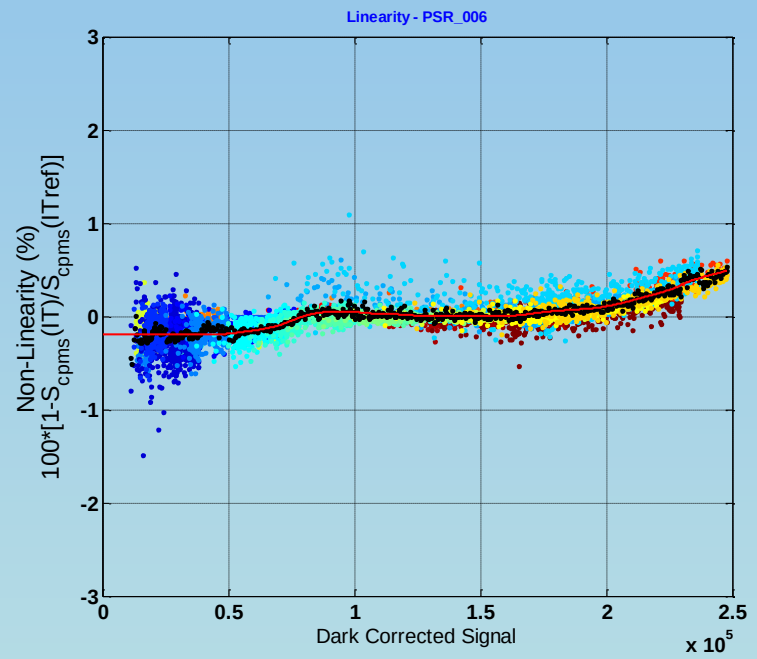
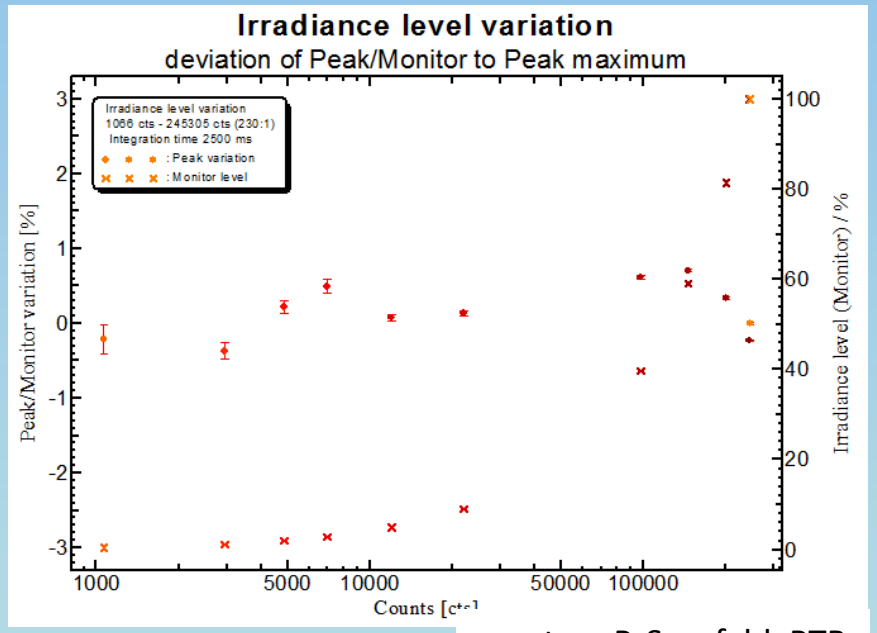
Linearity of PSR_003

Integration time variation from 10 ms to 8000ms



Irradiance flux variation



courtesy P. Sperfeld, PTB

PSR_003 is linear to better than ±1% over the full range:

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

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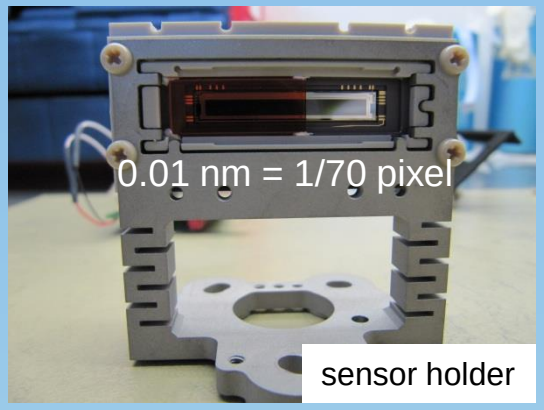
Temperature behavior of PSR



Wavelength shift versus temperature

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

1) from solar measurements and matSHIC

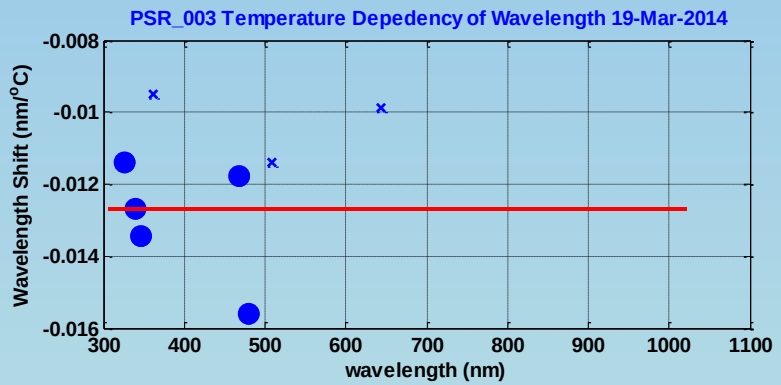
Using data from 60 days

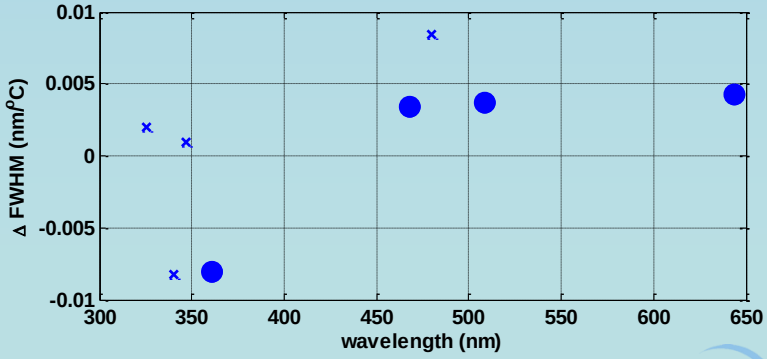
Wavelength /nm	Temp. coeff nm/K
350	**0.01 ±0.004**
500	**0.02 ±0.01**
605	**0.00 ±0.03**
795	**-0.005 ±0.02**

dWL/T~**0.01 nm K^{-1}**

dFWHM K^{-1} **< 0.005 nm K^{-1}**

2) Laboratory measurements





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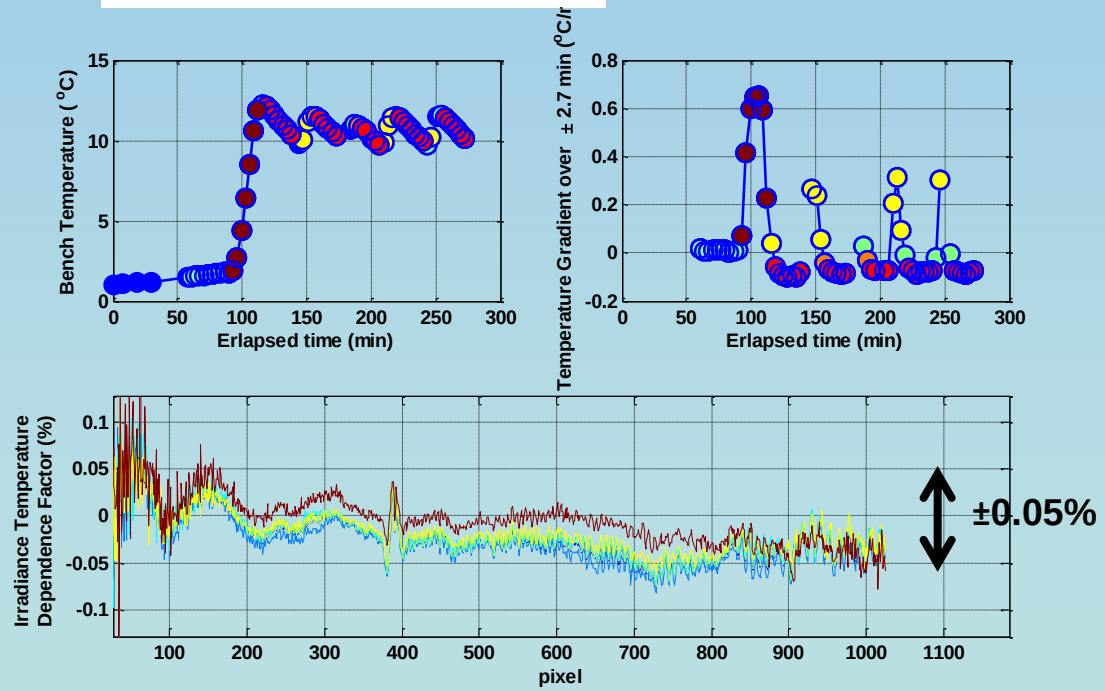
Temperature behavior of PSR

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

PSR	Temp. coeff %/K
003	**-0.08 %**
004	**< 0.04 %**
005	**-0.06 ± 0.02 %**
006	**< 0.05 %**

Example for PSR 006



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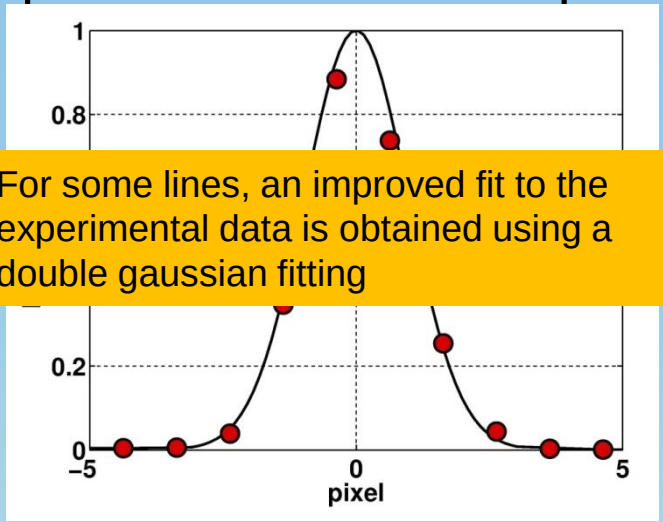
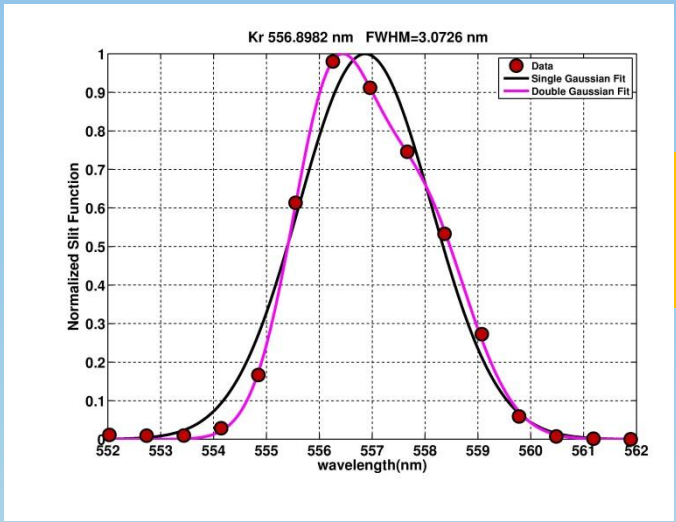
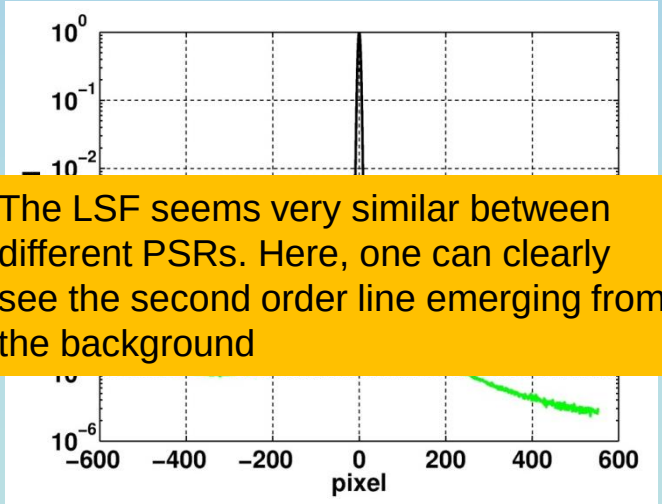
Line Spread functions of various PSRs using lasers and spectral emission lamps

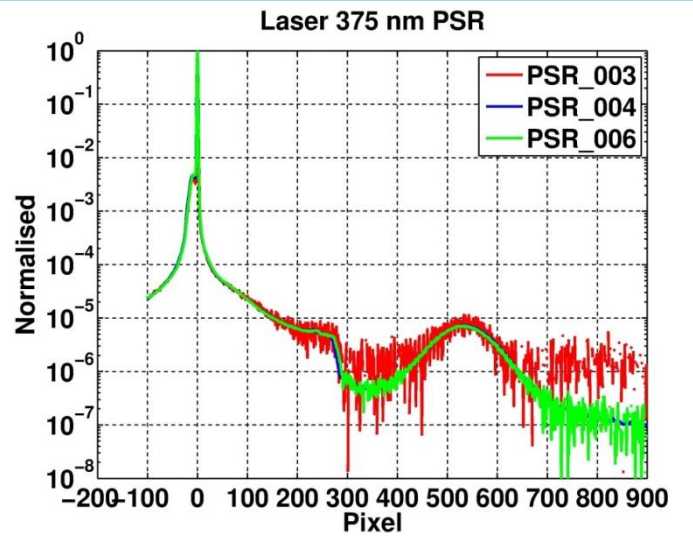


For some lines, an improved fit to the experimental data is obtained using a double gaussian fitting





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



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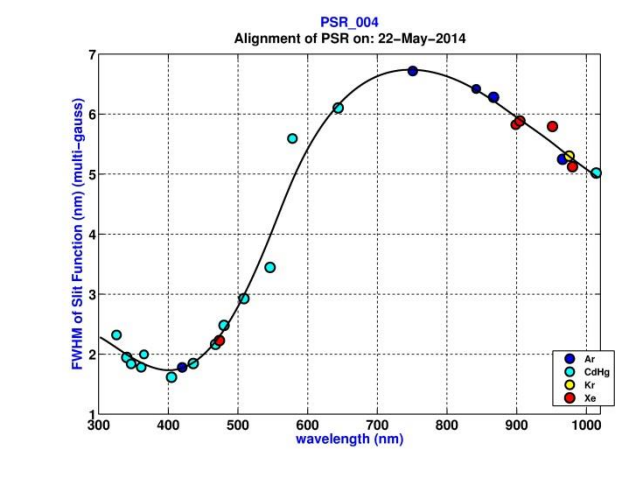
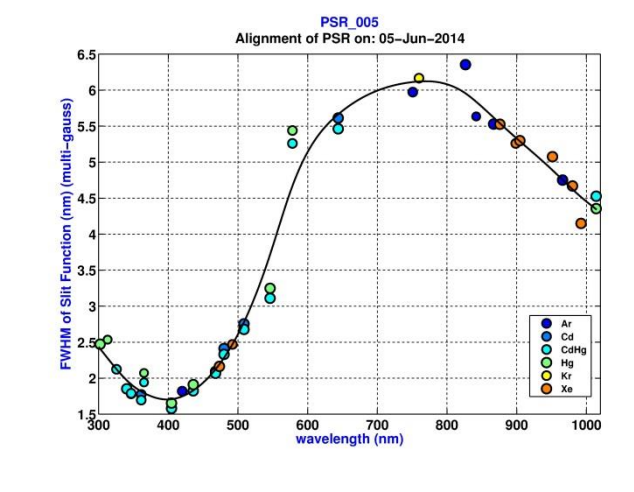
Bandpass using spectral emission lines

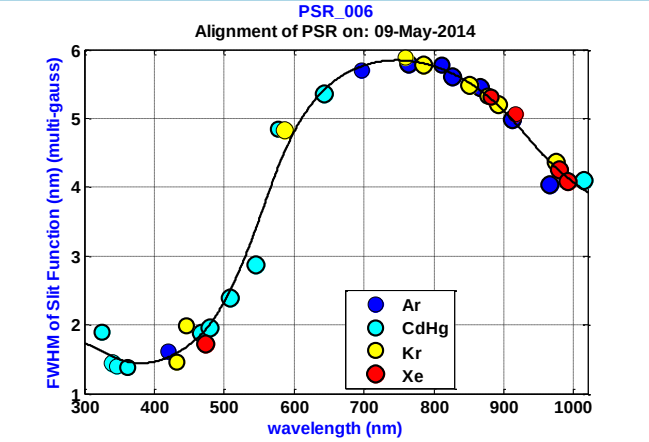




FWHM varies between 1.5 nm and 6 nm

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



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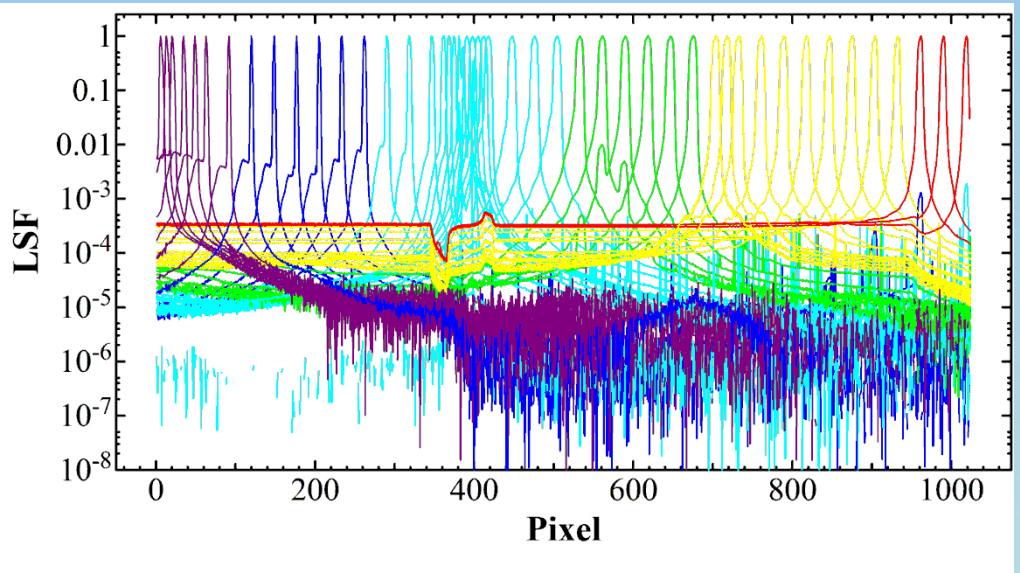
Stray-light

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

$$\mathbf{Y_{IB}=C\ Y_{meas}}$$



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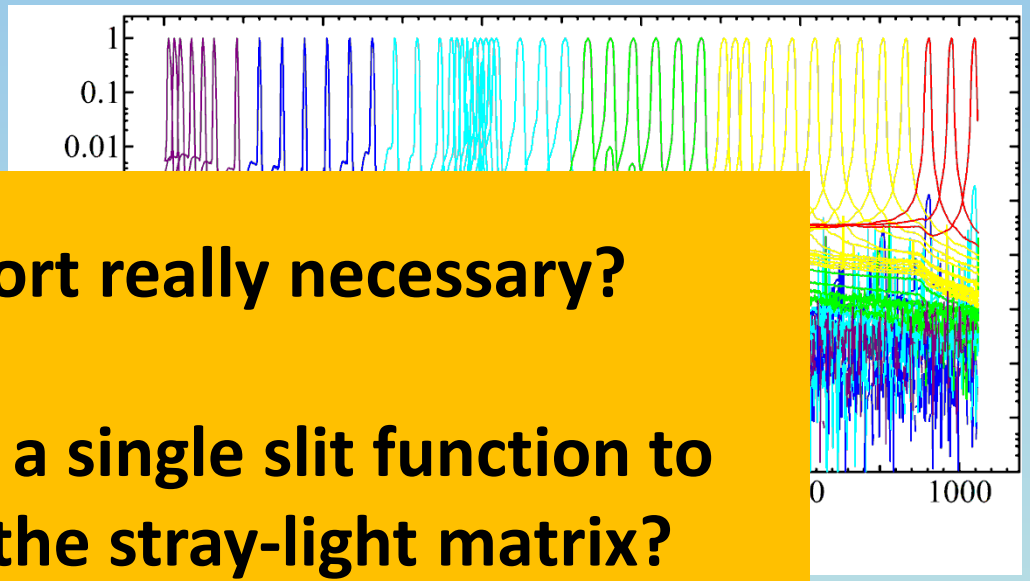
$\mathbf{Y_{IB}}$



Is that effort really necessary?

Why not use a single slit function to determine the stray-light matrix?

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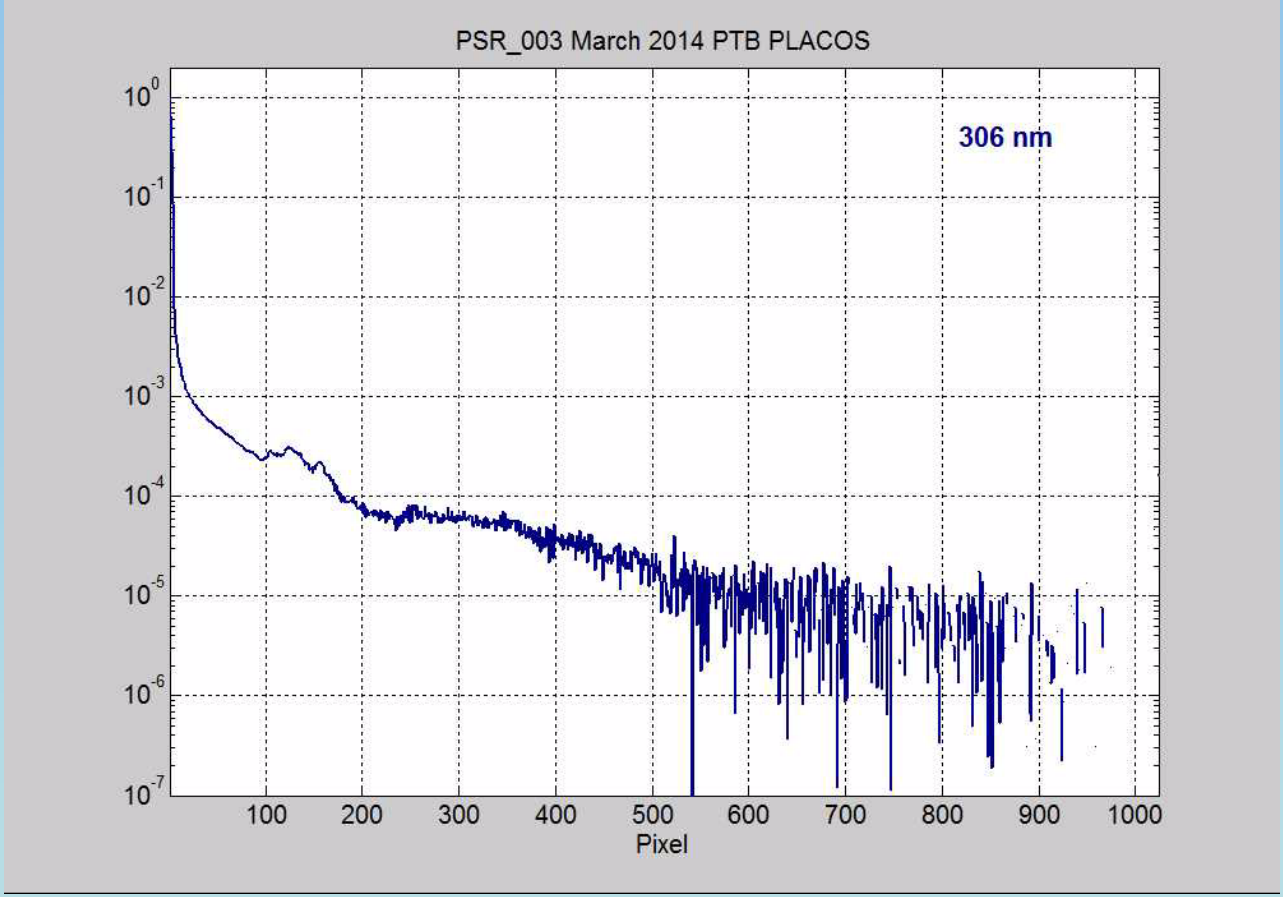
The Line-Spread functions of PSR 003 were measured at the tuneable laser facility PLACOS at PTB



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

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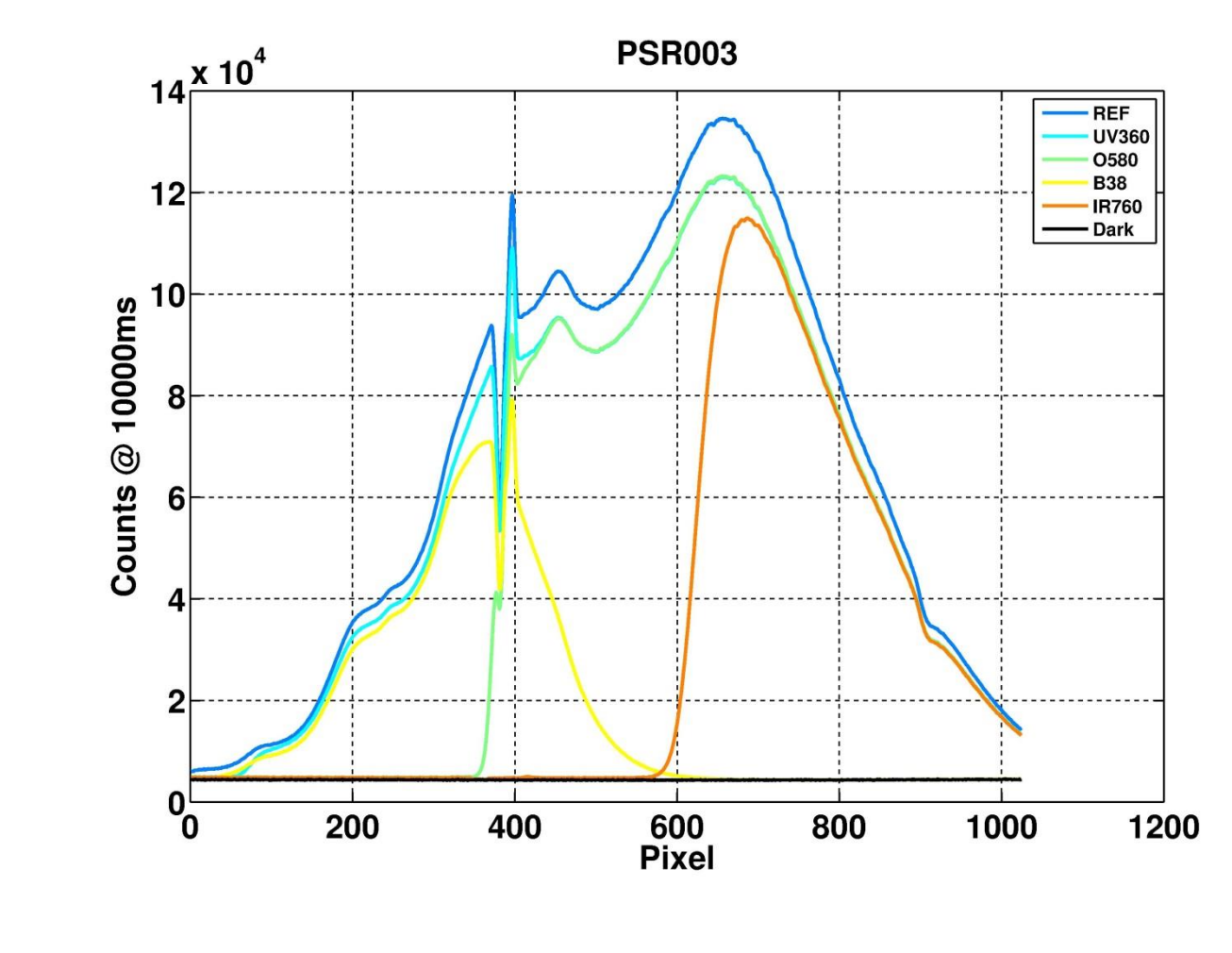
Stray-light validation

1) Lamp & band-pass filters

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



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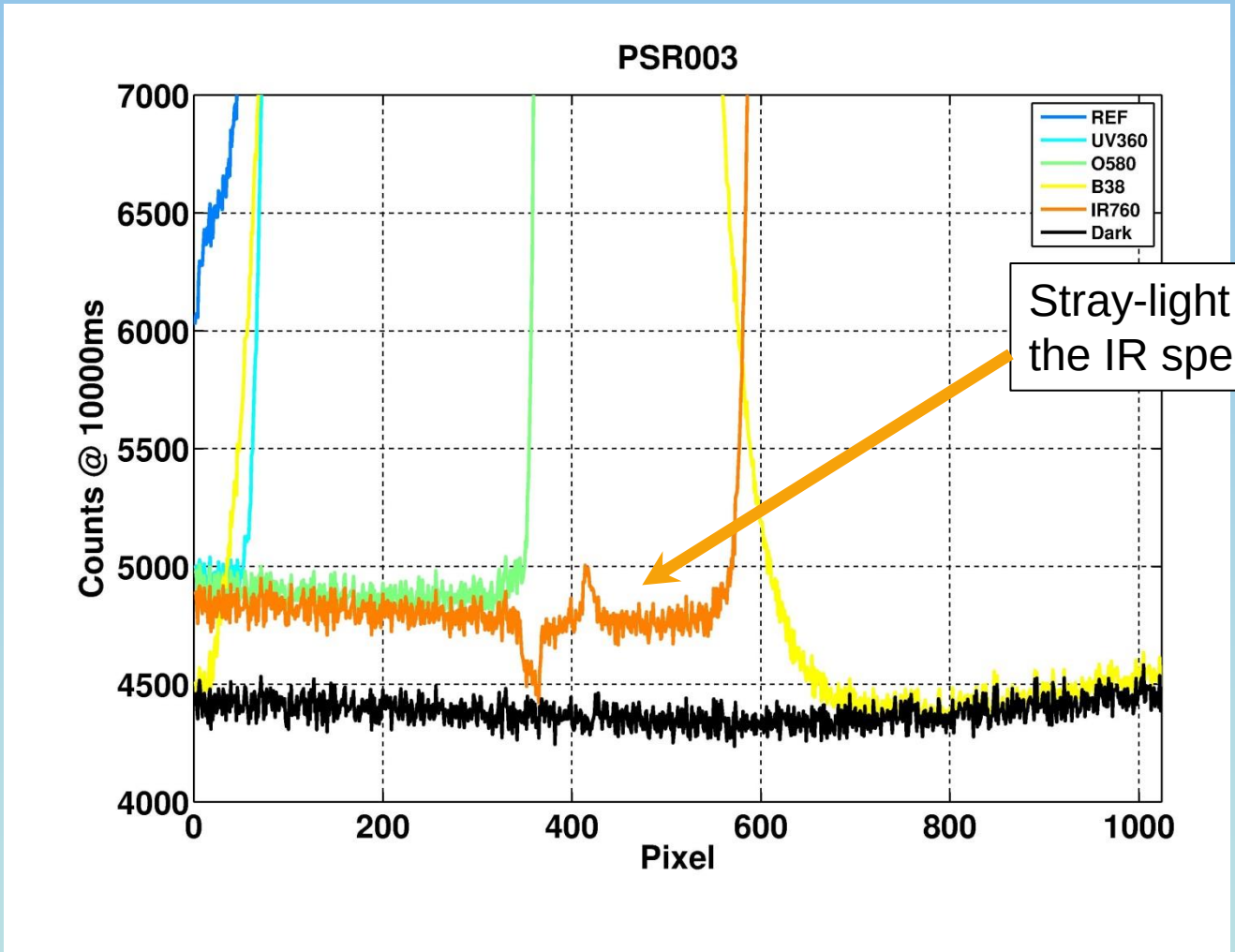
Stray-light validation

1) Lamp & band-pass filters



Stray-light from the LSF of the IR spectrum.

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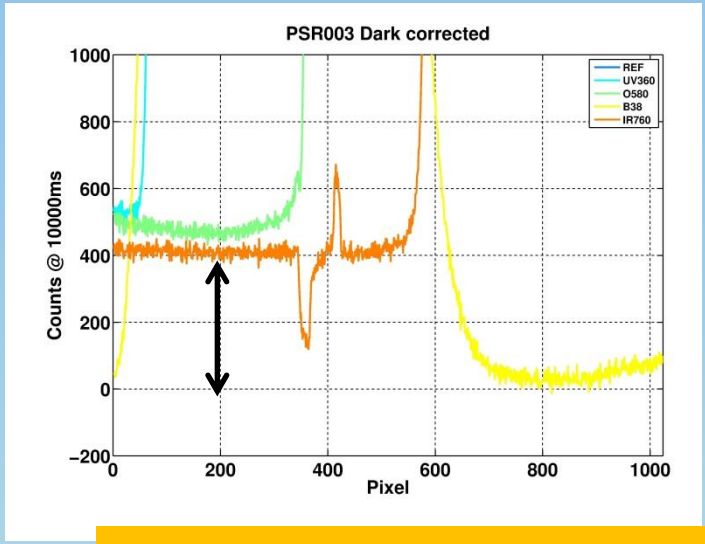
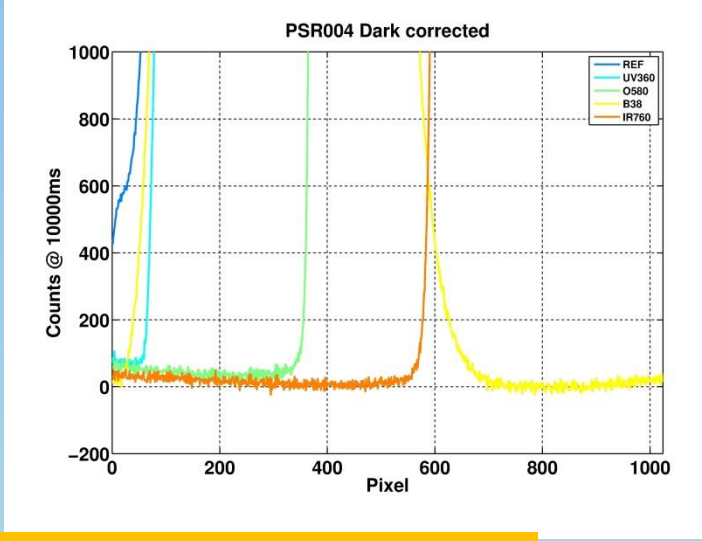
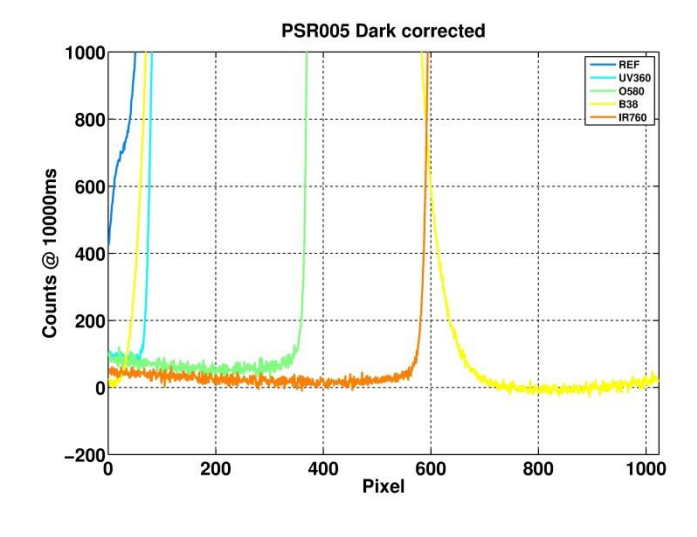
Stray-light validation

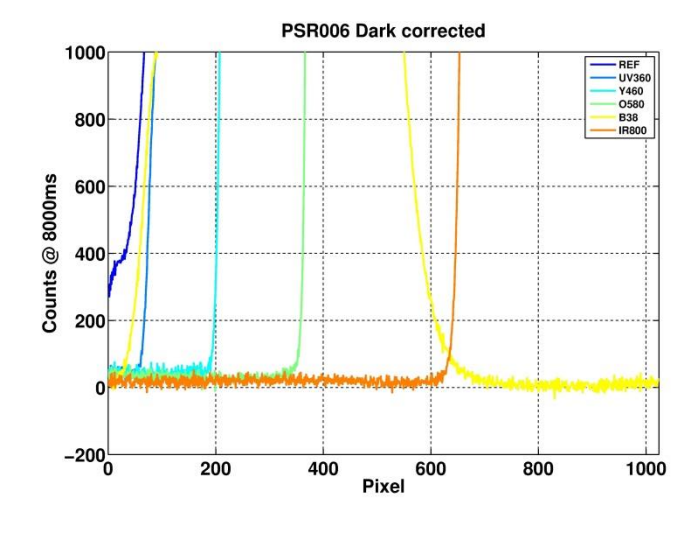
1) Lamp & band-pass filters





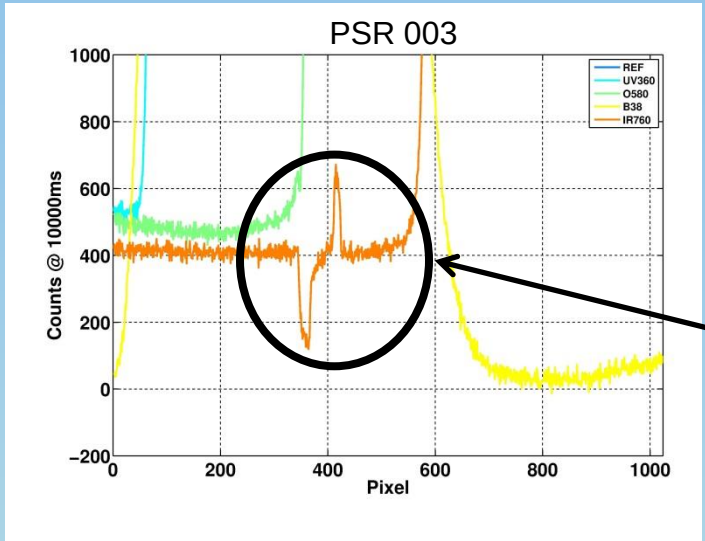
4 PSR, Stray-light from PSR 003 is significantly higher than from all others

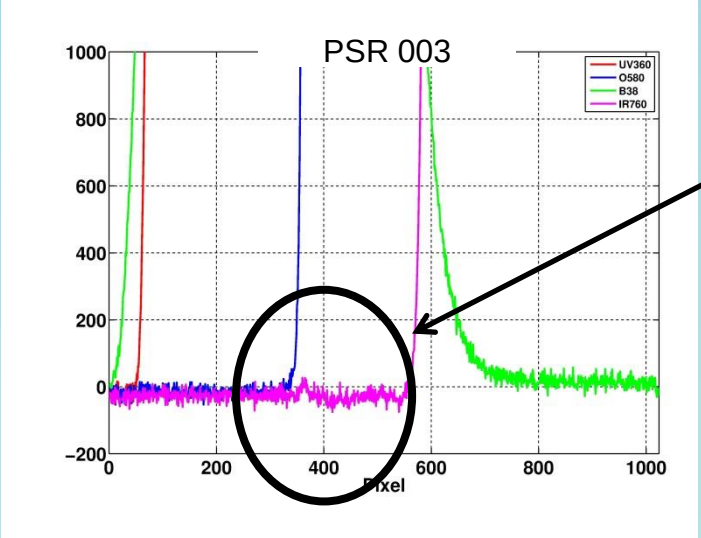


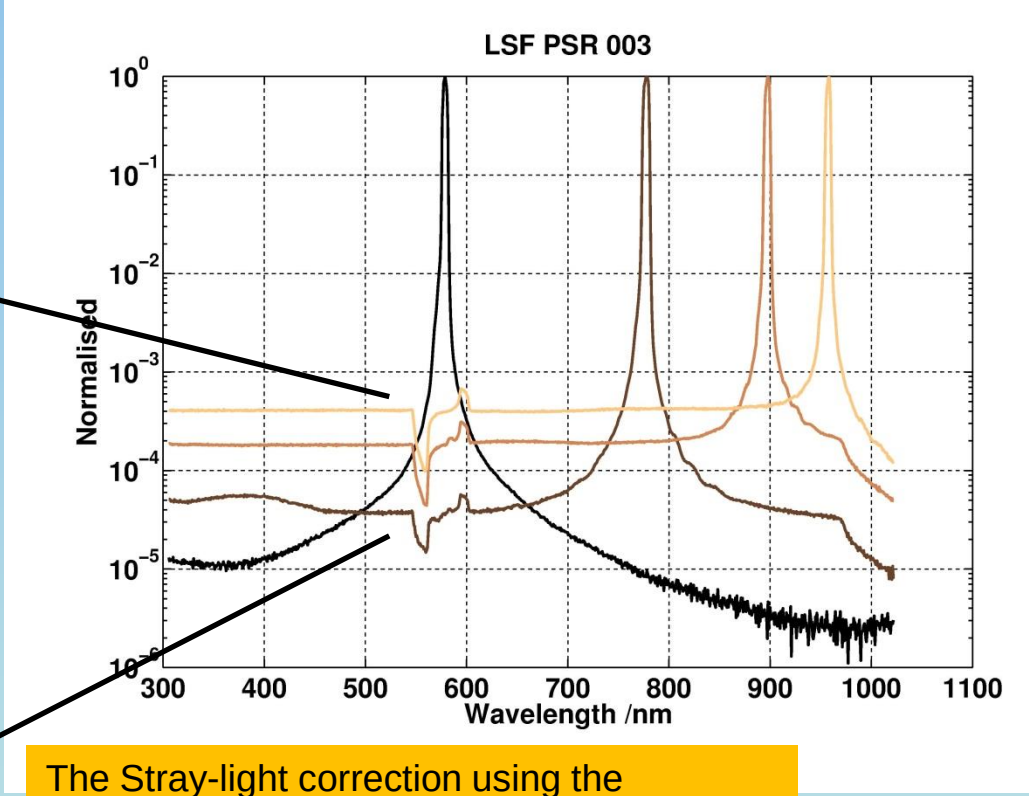


Stray-light validation

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

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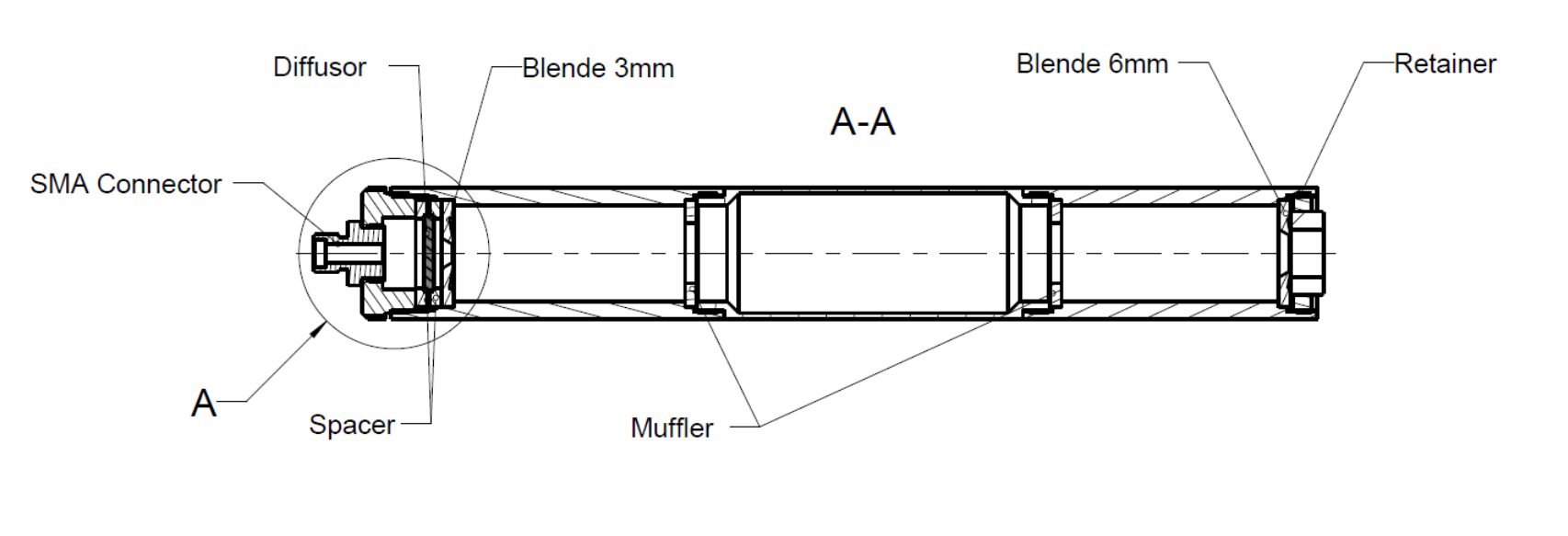
Direct optic flat field

Following WMO specifications for sunphotometers measuring direct solar irradiance:

- less than 2° field of view
- Slope angle of 1 °



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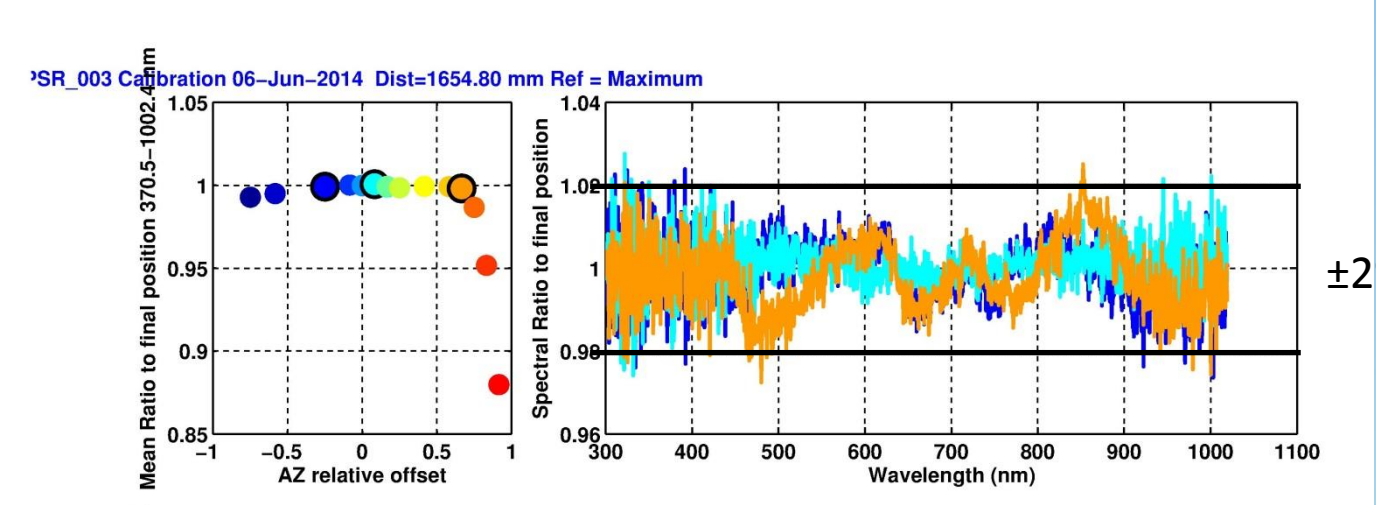
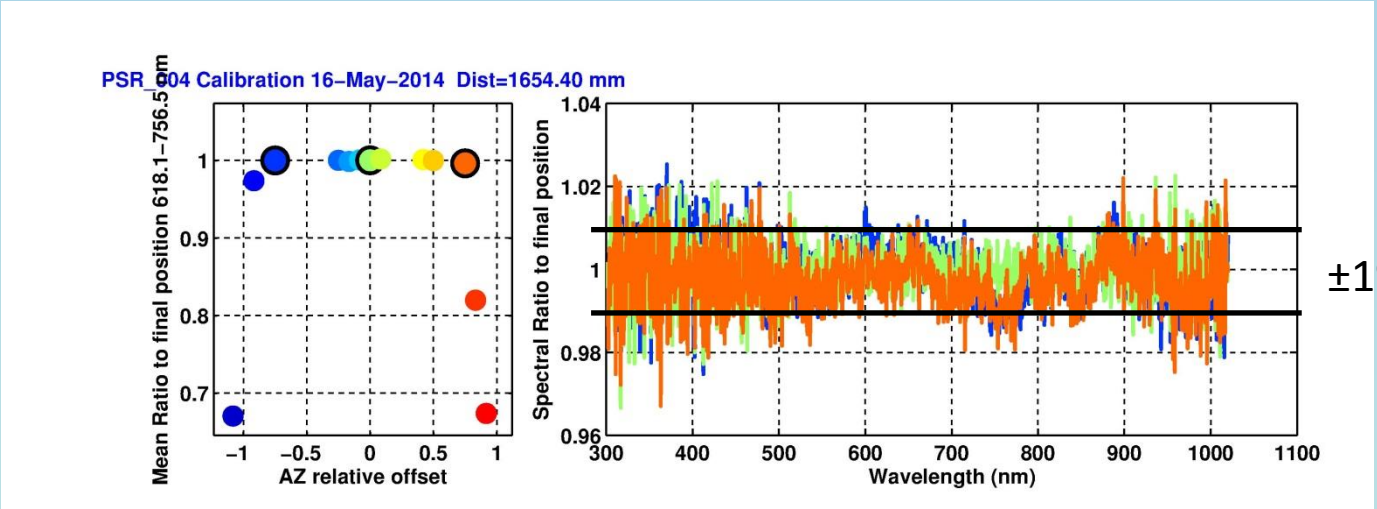
Direct optic flat field – spectral "waves"

Standard Diffuser, sandblasted on one side



±2%

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

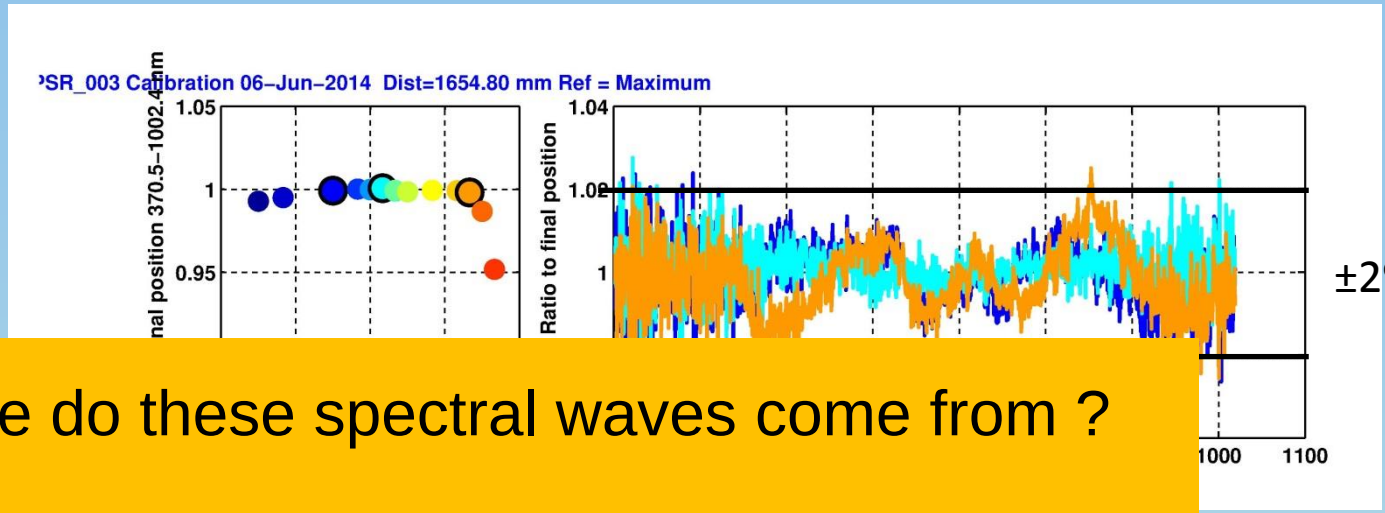


±1%

pmod wrc

Direct optic flat field – spectral "waves"

Standard Diffuser, sandblasted on one side



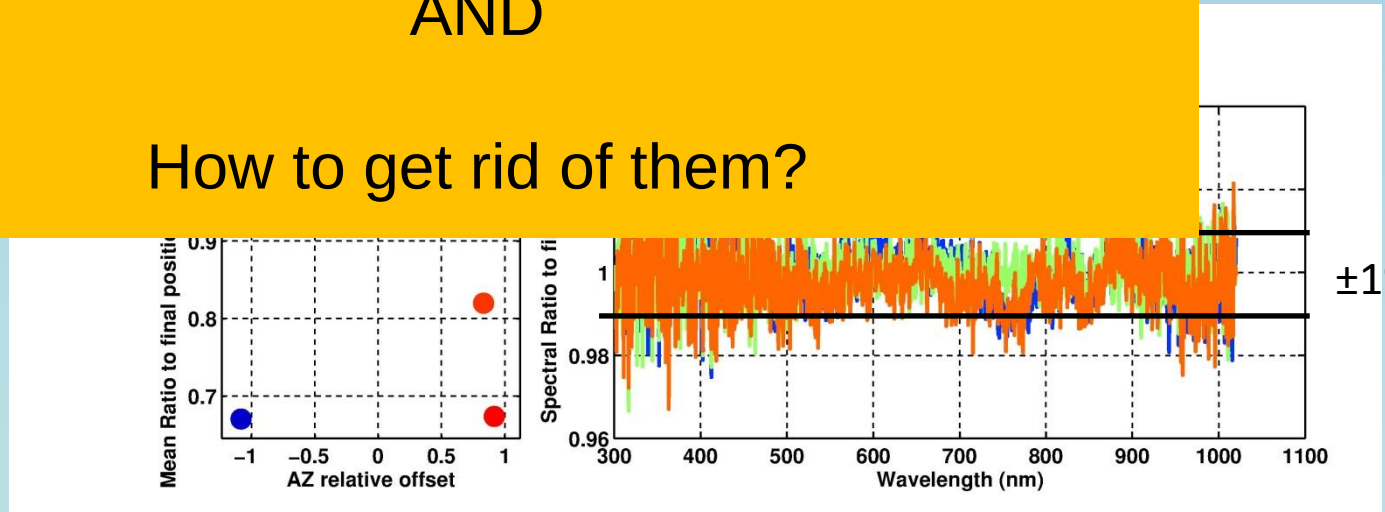
±2%

Where do these spectral waves come from ?

AND

How to get rid of them?

Standard
sandblasted on two sides,
3 times more transmission loss



±1%

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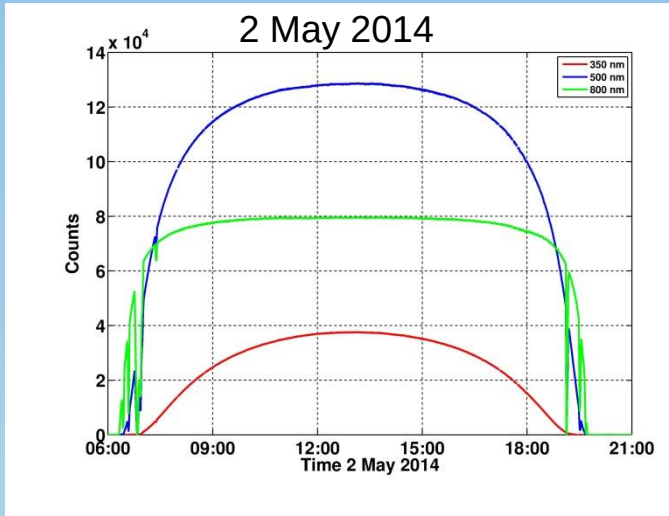
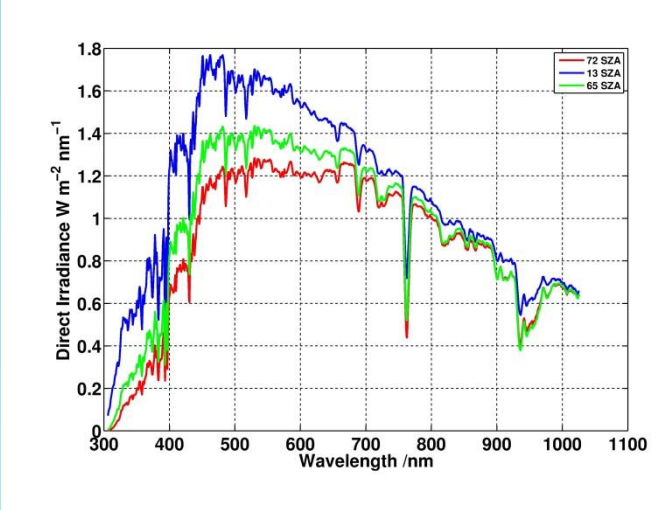
Langley-Calibration campaign Izaña March-June 2014





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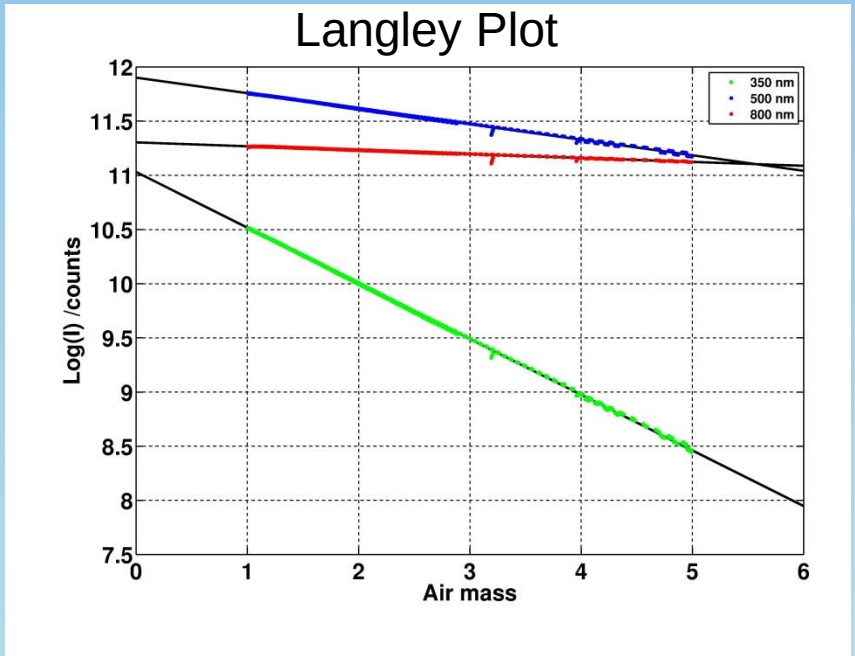
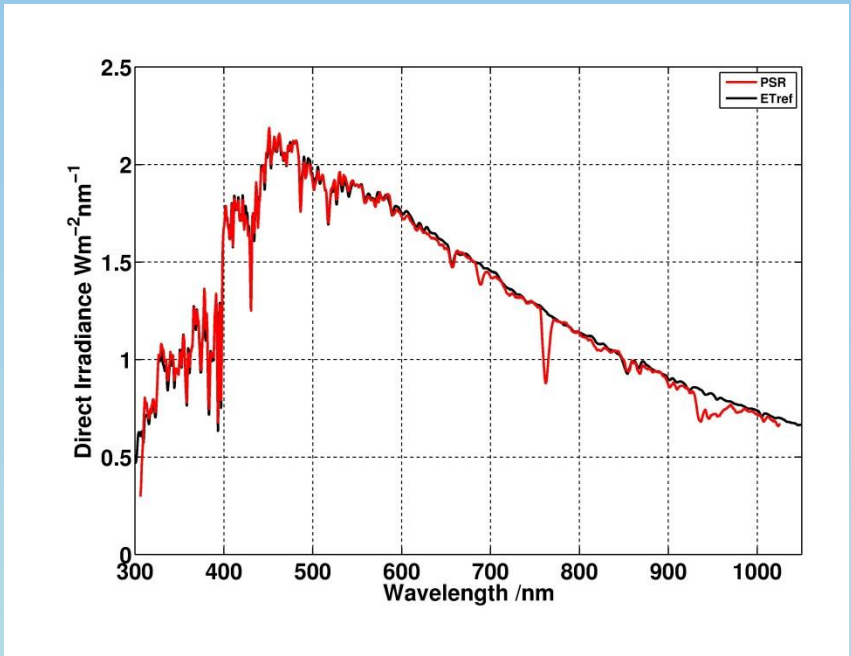
Langley-Calibration campaign Izaña March-June 2014

27 May 2014





Langley-Intercept and literature spectrum

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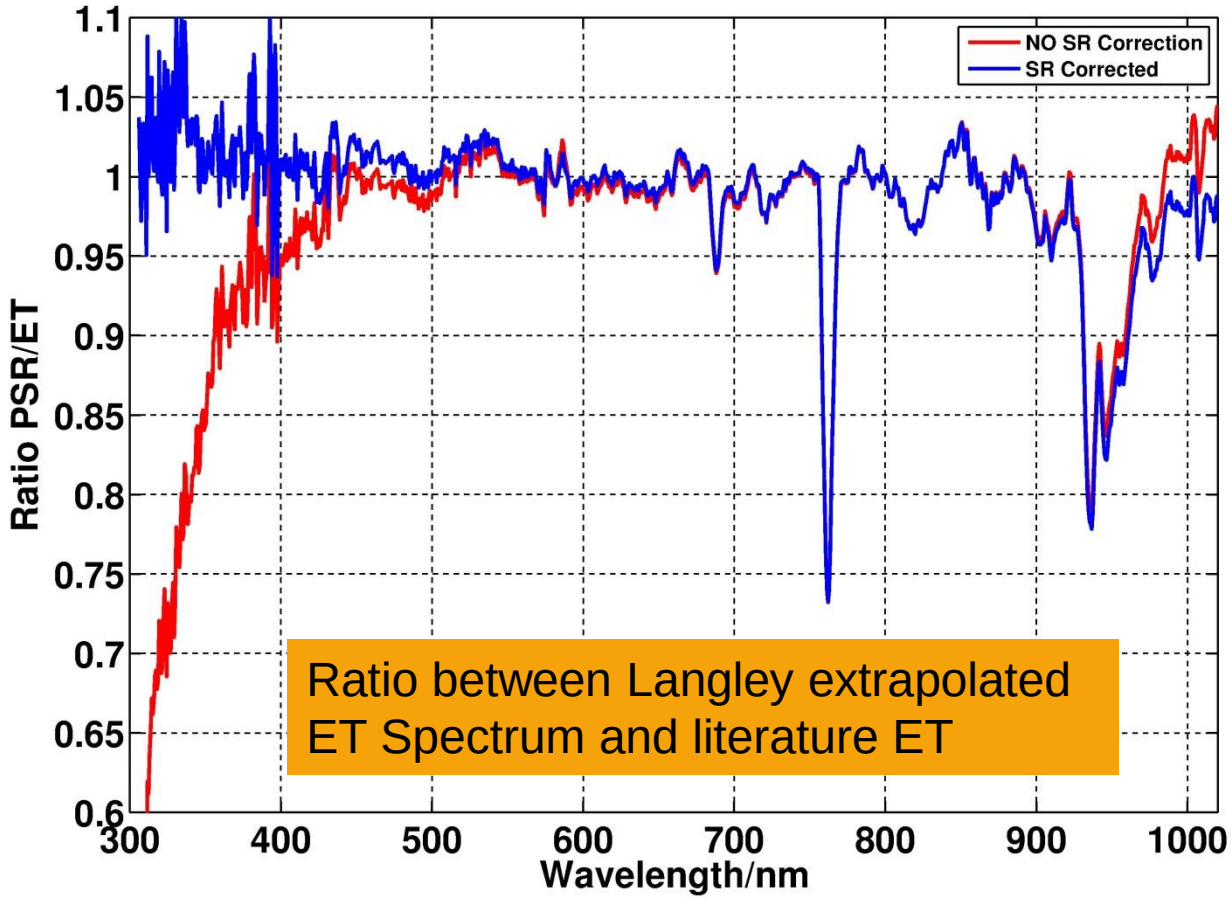
Stray-light effect on solar measurements



Ratio between Langley extrapolated ET Spectrum and literature ET

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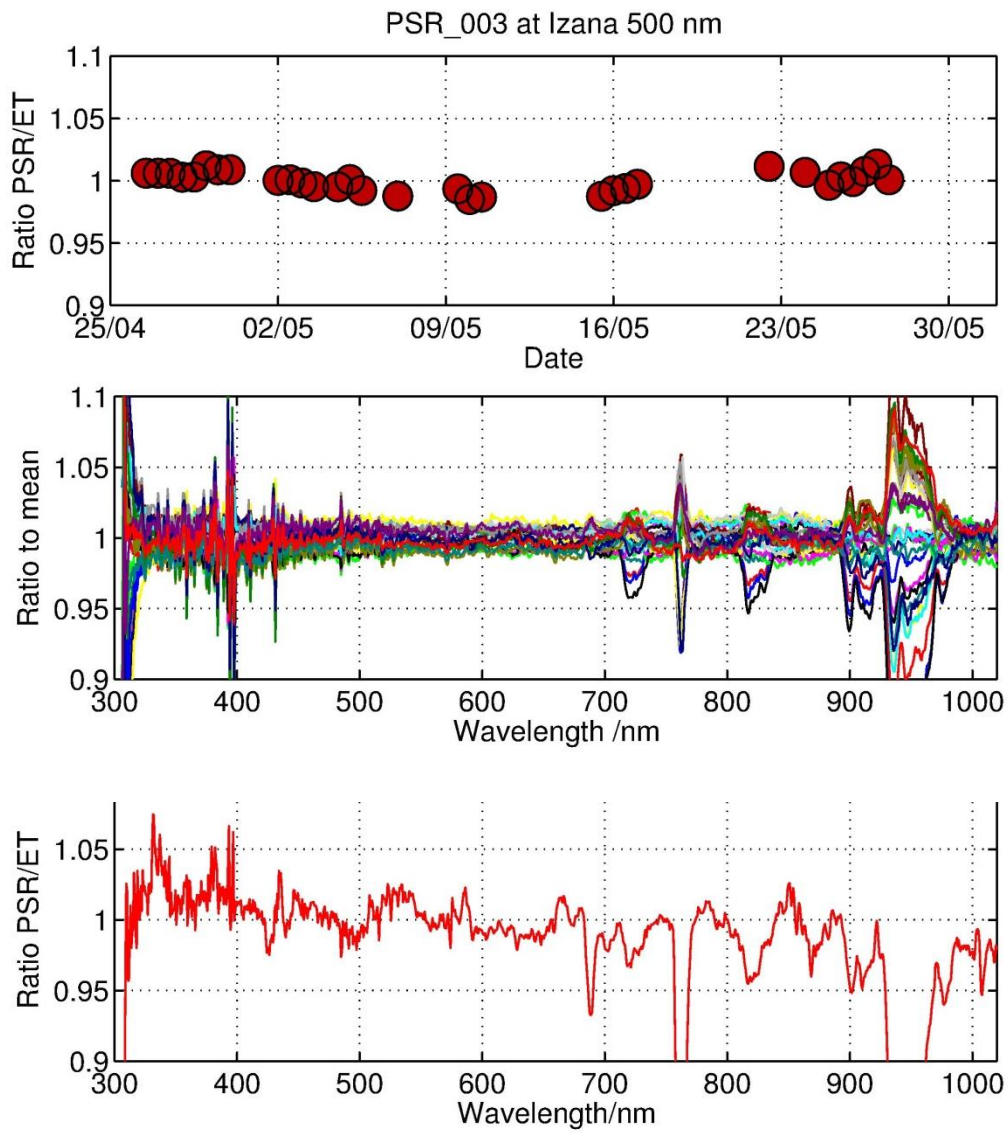
Stability and comparison to literature ET



Variability ±0.8%

±5%

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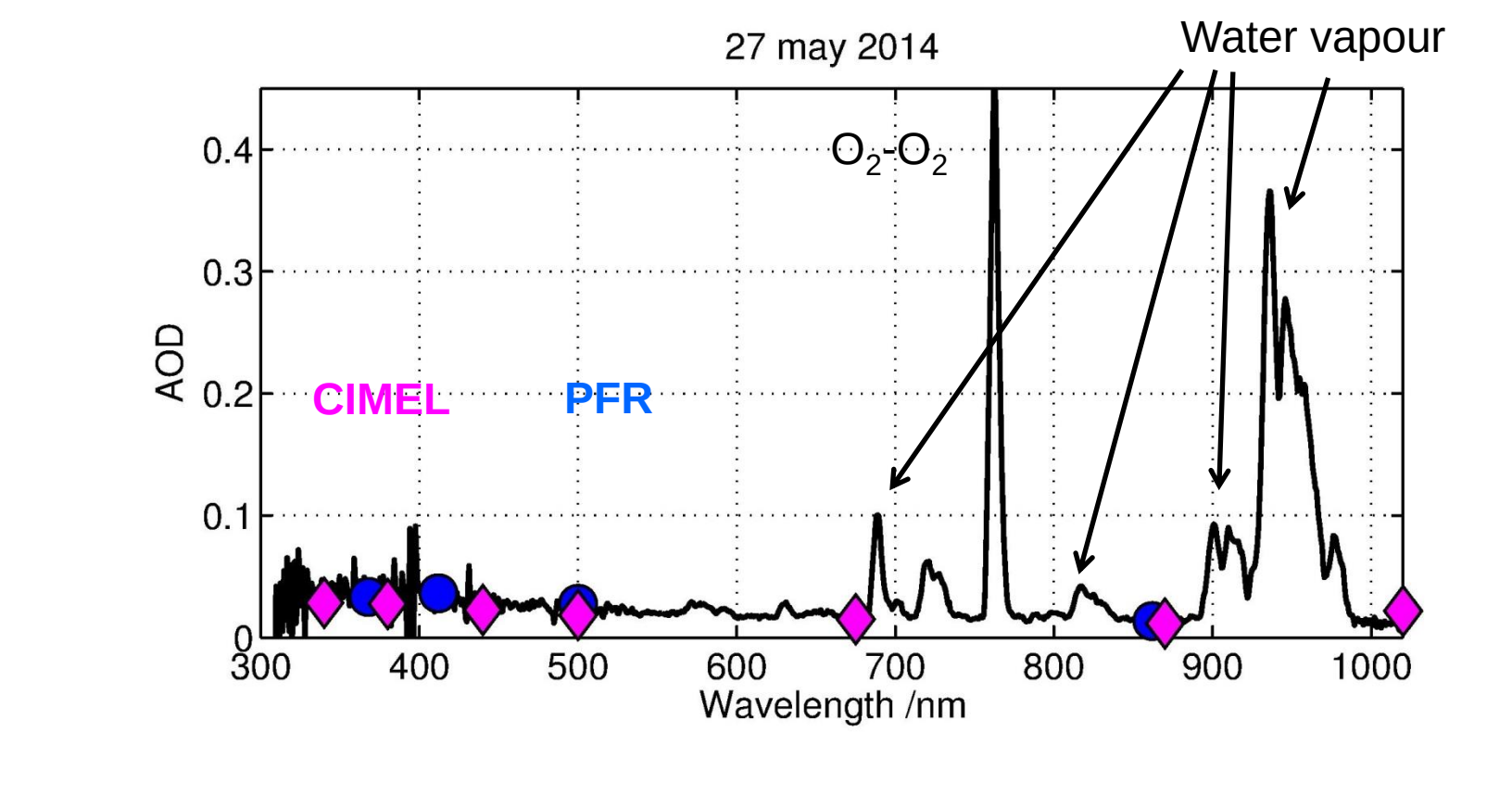
Spectral AOD compared to CIMEL and PFR



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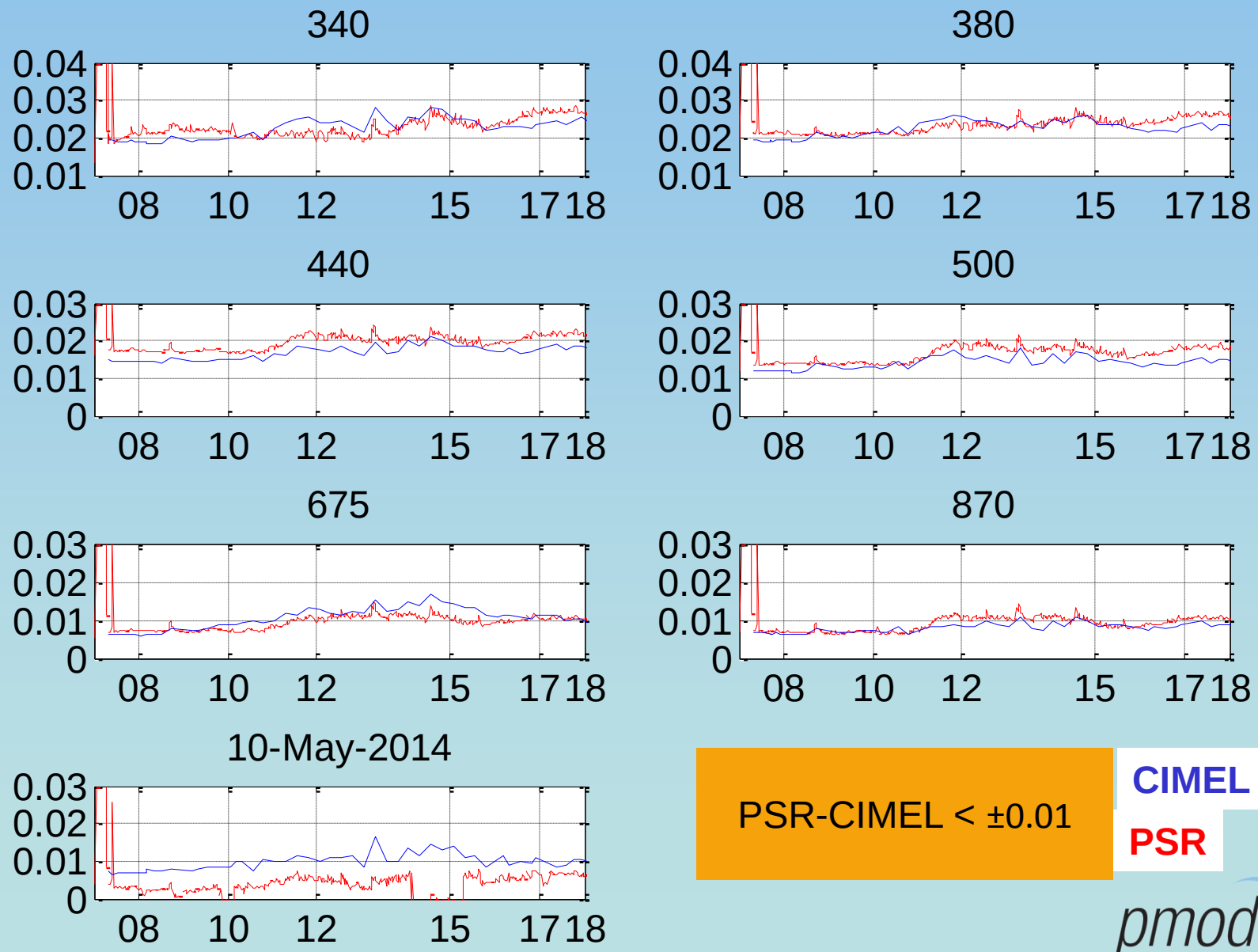
Spectral AOD compared to CIMEL – 10 May 2014



PSR-CIMEL < ±0.01

CIMEL

PSR

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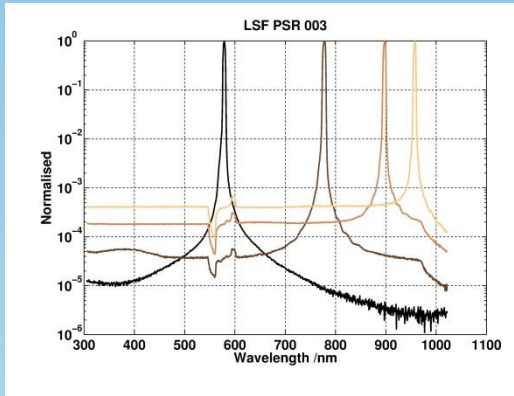
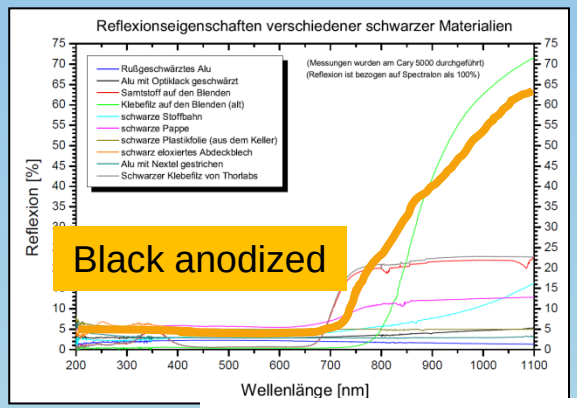
Further steps...

- 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?)





Courtesy Andreas Höpe, PTB

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

- Construct additional PSRs ...

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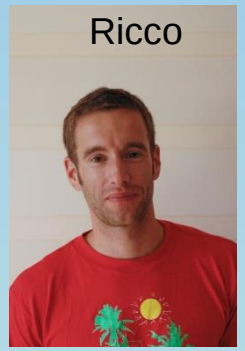
The PSR Team

Etienne



2009: 2014

>6 (wo)man-years development time

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