Status of GEMS Calibration

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2017 GEMS Science Meeting
(2017.09.25~09.27)

Contents

- Current status of L0-L1b processor
- Spectral Calibration
  - Characterization of SRFs
  - Solar reference spectrum
- Stray light Correction
- Summary and Discussion

L0-L1b processor

Achievement (%)	0	20	40	60	80	100
Raw to L0						
Hot/Dead/RTS						
Co-adding correction						
LED/Linearity/Gain						
Offset/Smear/Dark current						
QE/PRNU/Integration time						
Stray light						
Spectral Registration						
Radiance calibration coefficient						
Band pass						
Spectral shift						
Measurement Noise						
Spatial Registration						
Goniometry						
Nominal BTDF						
Reference Diffuser Trend						
Main algorithm						

L0-L1b processor

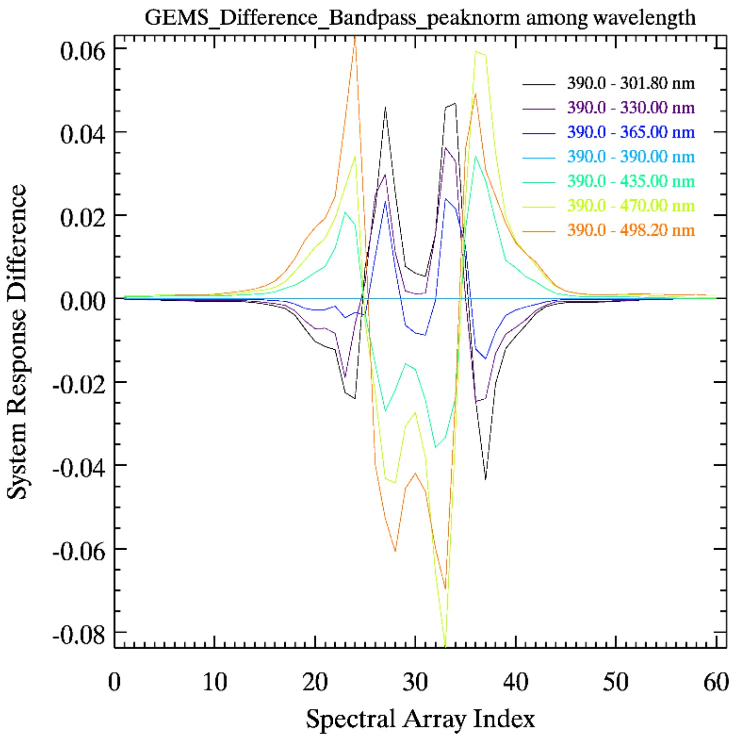
- All 16 sub algorithms has been prepared (KARI)
  - Many of algorithms are comparable with TEMPO.
  - No forward model is provided
    - End to end performance test is limited.
  - Several algorithms require improvement and optimization.
    - Update of solar reference spectrum & Accurate characterization of in-obrit SRFs for wavelength calibration
    - Stray light correction for 2D [spatial, spectral]

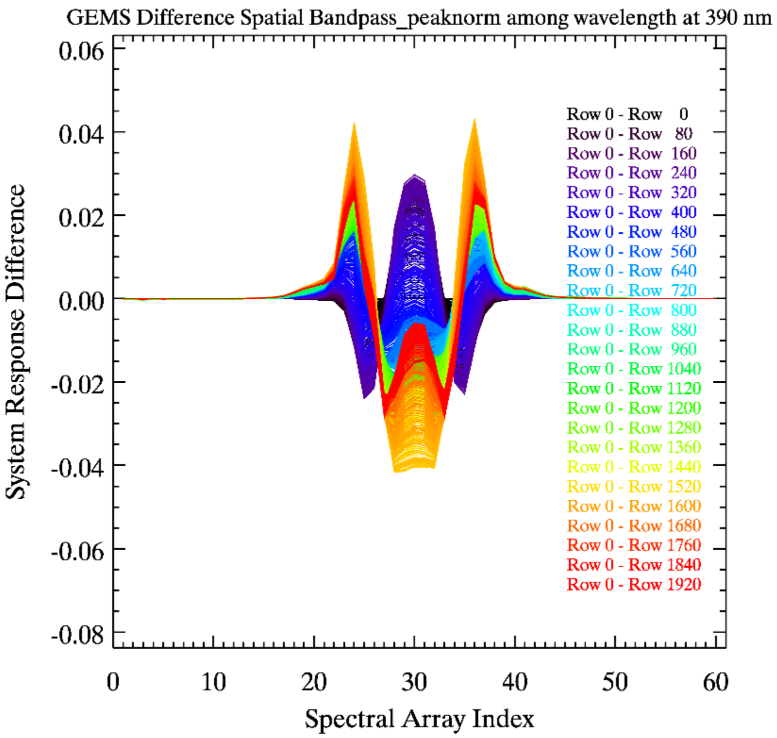
Spectral Calibration

- GEMS Ground-SRFs
  - The slit functions are provided for the 7 selected nominal wavelengths (nm)
    - [301.8, 330.0, 365.0, 390.0, 435.0, 470.0, 498.2]
  - For each nominal wavelength the slit function is given over an interval of -1.80 nm to +1.80 nm in steps of 0.06 nm, i.e. with a total of 61 data points.

Spectral Calibration

- There are slight differences in the slit function in the spectral and spatial direction, although it varies smoothly





Spectral Calibration

- Which SRF models fit better?
  - HyBrid Gaussian(HBG; Liu et al., 2015)

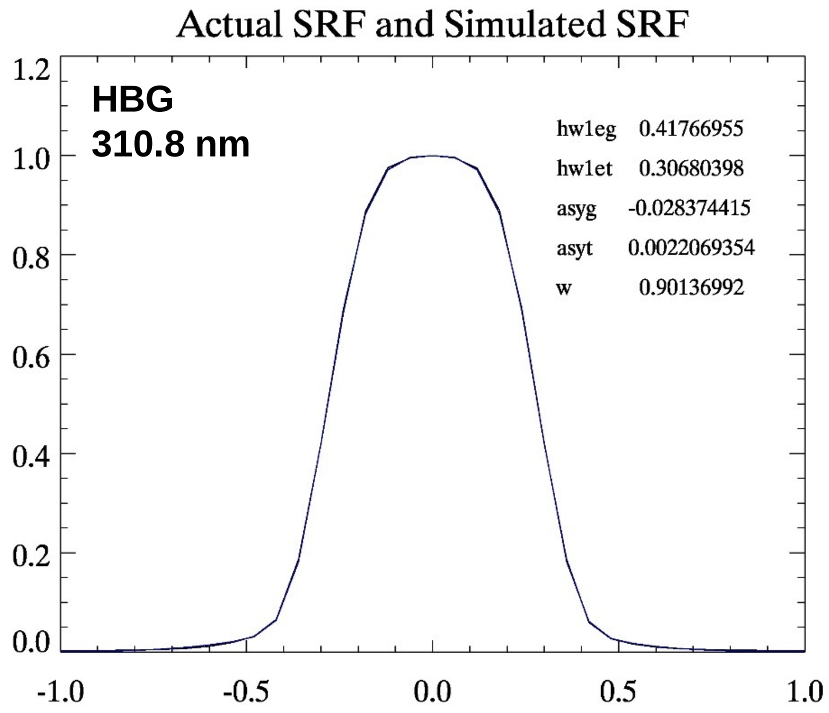
$$HBG_\lambda = \exp\left\{-\left[\frac{\Delta\lambda}{h_g(1+sgn(\Delta\lambda)a_g}\right]^2\right\}(1-f_t) + exp\left\{-\left[\frac{\Delta\lambda}{h_t(1+sgn(\Delta\lambda)a_t}\right]^4\right\}f_t$$

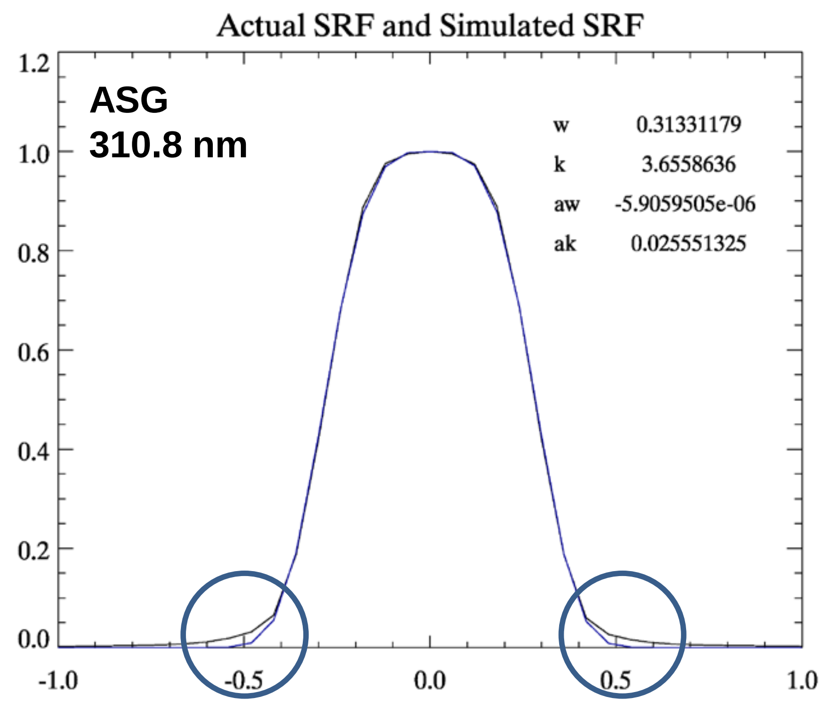
    - Five parameters to be determined
  - Asymmetric Super-Gaussian(ASG; Beirle et al. 2016)

$$ASG_\lambda(x) = \frac{k}{2\varpi\Gamma(1/k)} \times \begin{cases} e^{-\left|\frac{x}{\varpi - a_\varpi}\right|^{k-a_k}} \\ e^{-\left|\frac{x}{\varpi + a_\varpi}\right|^{k+a_k}} \end{cases}$$

Spectral Calibration

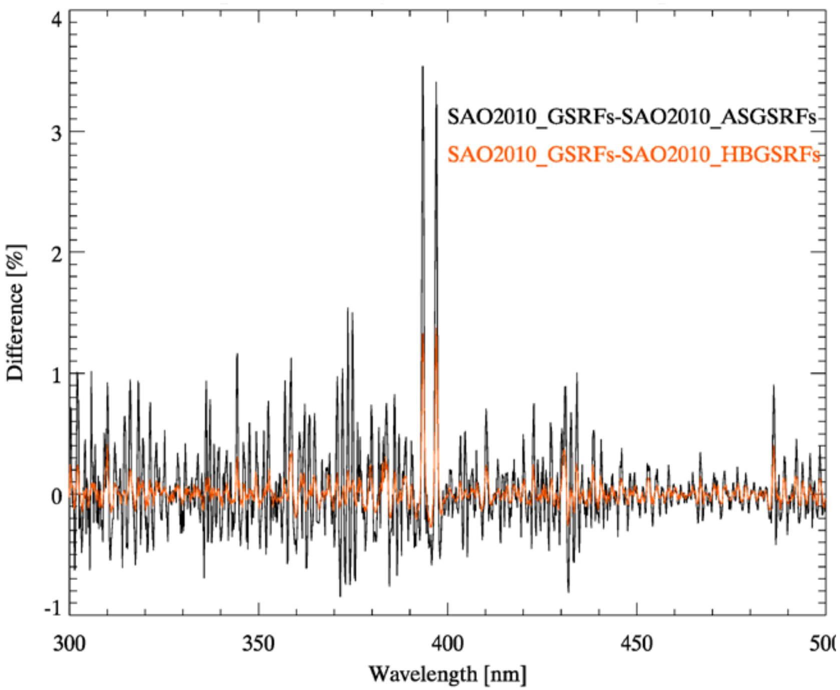
- Which SRF models fit better?
  - ❖ Asymmetric Gaussian shows a off-fitting at the wings of SRF, while the HyBrid Gaussian shows an excellent fit

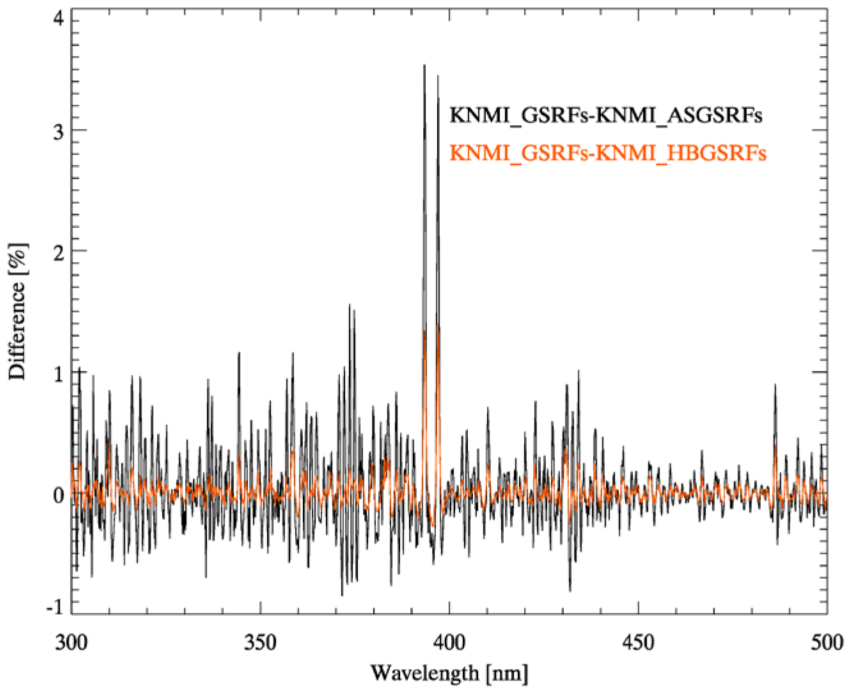




Spectral Calibration

- Which SRF models fit better?
  - The modeled SRFs produce GEMS-like irradiance within a percent of difference

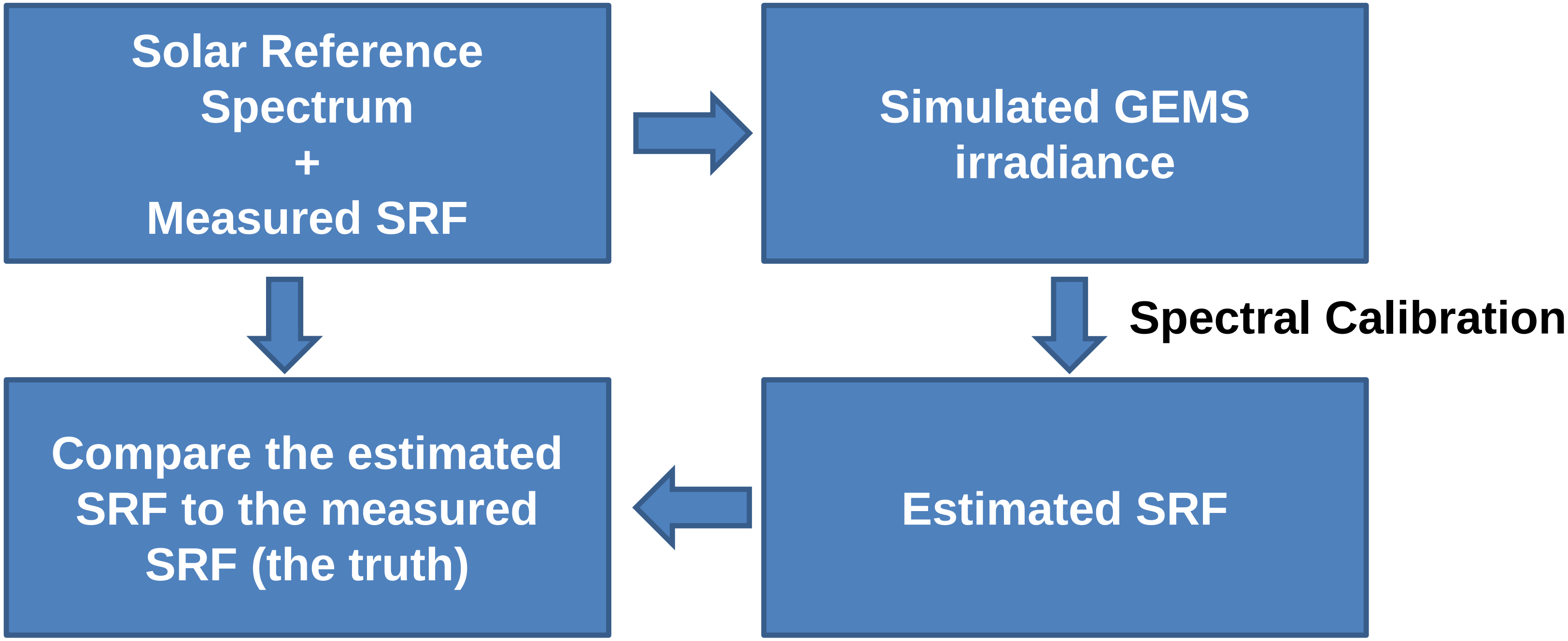




SAO2010 (Chane and Kurucz 2010), KNMI (Dobber et al 2008)

Spectral Calibration

- Can SRF be estimated in space?
  - Using the simulated GEMS irradiances, the possibility of the SRF estimation has been tested



Spectral Calibration

- Simulation exercise
  - The actual solar irradiance and GEMS measurement are similar to the reference spectra (SAO2010 and KNMI)

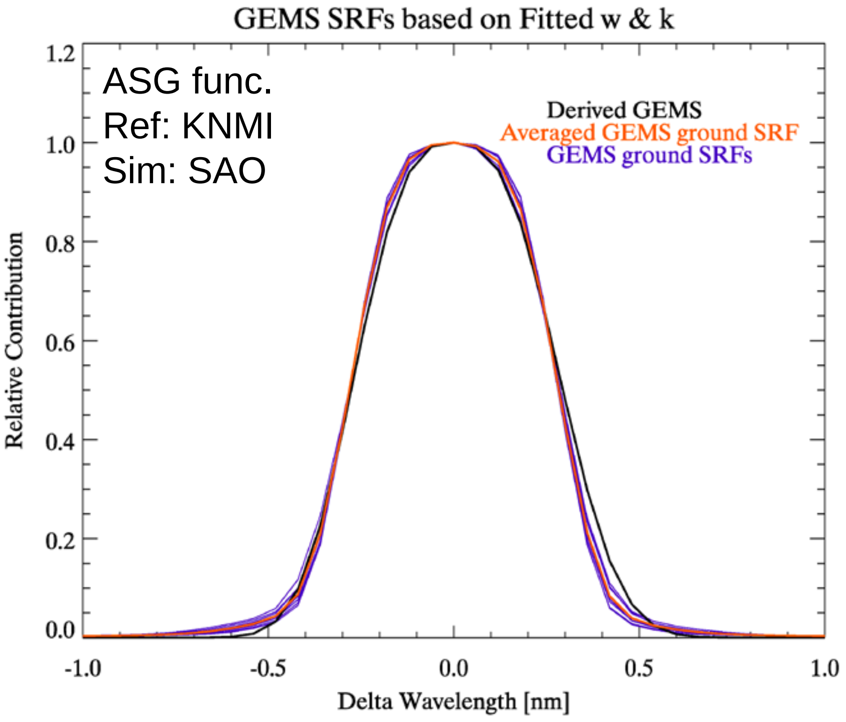
$$GEMS_{simulated} = \frac{\int SAO2010_\lambda \phi_{gGEMS,\lambda} d\lambda}{\int \phi_{gGEMS,\lambda} d\lambda}$$

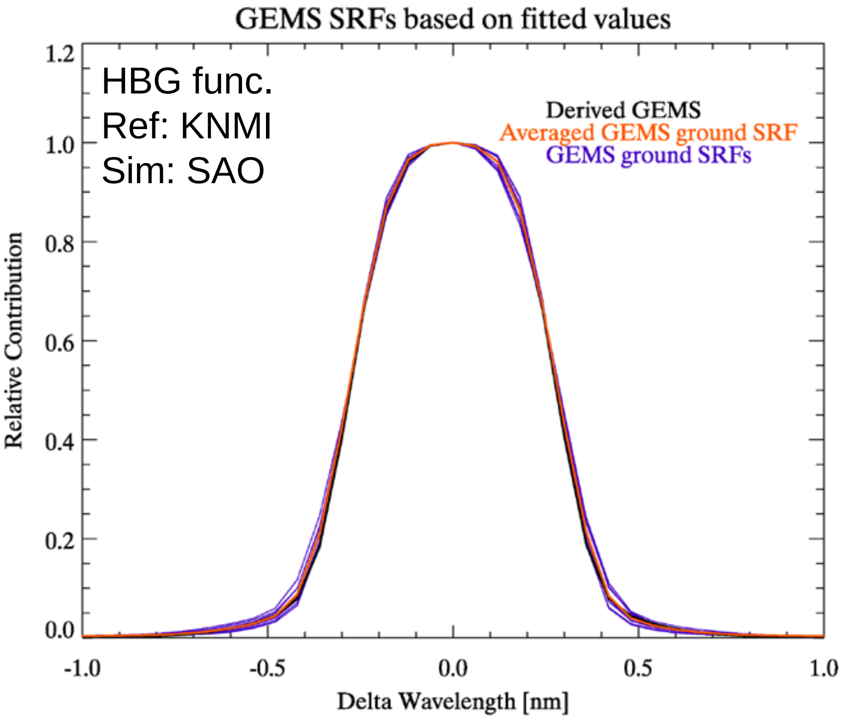
$$Reference\ spectrum = \frac{\int KNMI_\lambda \phi_{ASG/HBG,\lambda} d\lambda}{\int \phi_{ASG/HBG,\lambda} d\lambda}$$

$$\frac{\int SAO2010_\lambda \phi_{gGEMS,\lambda} d\lambda}{\int \phi_{gGEMS,\lambda} d\lambda} = \frac{\int KNMI_\lambda \phi_{ASG/HBG,\lambda} d\lambda}{\int \phi_{ASG/HBG,\lambda} d\lambda} \times A_0 + A_1(\lambda - \lambda_{avg}) + A_2(\lambda - \lambda_{avg})^2 + A_3(\lambda - \lambda_{avg})^3$$

Spectral Calibration

- The analytic function (ASG & HBG) could present the SRFs in spite of the reference solar spectrum uncertainty (HBG is more acceptable)





Spectral Calibration

- Effects on the spectral calibration
  - Highly sensitive to the choice of reference solar spectrum
    - Calibration performance could be considered as lower than actual performance
    - The derived shifts could be different from actual wavelength variability

Algorithm Input		Algorithm Output	
Reference spectrum	Assumed measurement	X^2 (e^{-6})	ΔR (%)
KNMI	KNMI	4.89	0.012
SAO2010	SAO2010	5.46	0.014
KNMI	SAO2010	275	0.077

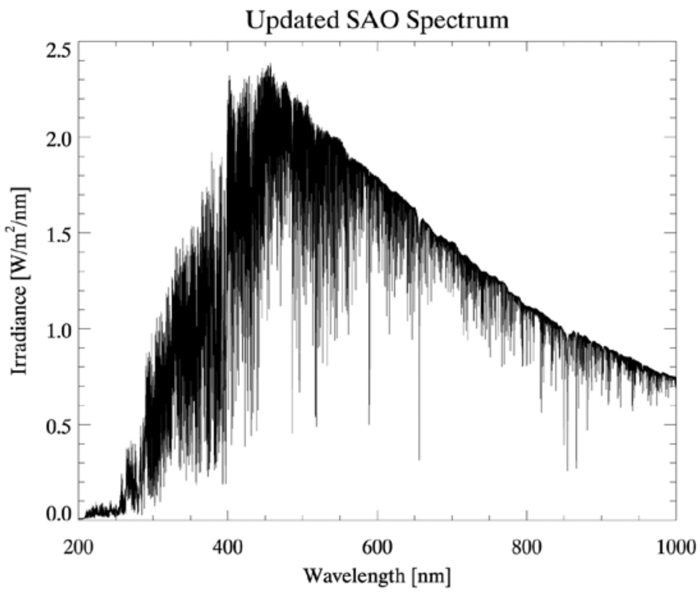
(ΔR is mean differences of radiance)

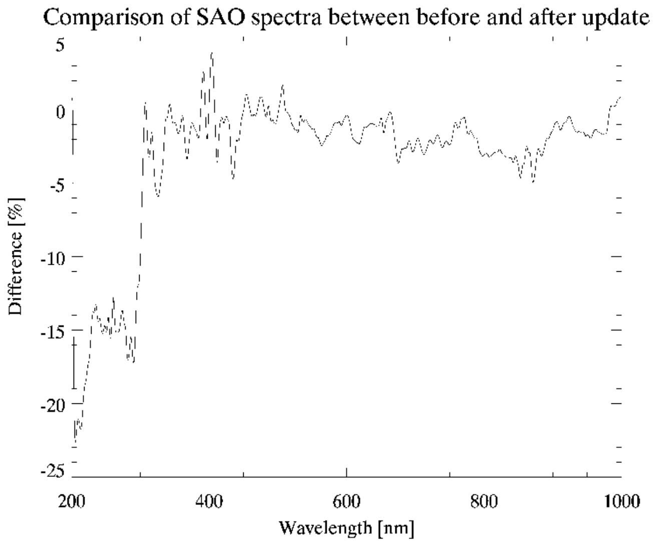
Spectral Calibration

- Preparation of high resolution solar reference spectrum for TEMPO/GEMS
  - KNMI spectrum (Dobber et al 2008) cannot cover TEMPO wavelength range.
  - SAO2010 (Chance and Kurucz 2010) spectrum requires absolutely calibrated
    - The low resolution solar reference spectra, which are radiometrically accurate are used for radiometric update of SAO2010

Spectral Calibration

◆A significant improvement in the shorter wavelength range is evident





Updated SAO spectrum

Comparison between before and after update

$$(= \frac{updated\ SAO2010 - SAO2010}{updated\ SAO2010} * 100(\%))$$

Spectral Calibration

- Comparison new SAO2010 with other reference solar spectra
  - Increased consistency among the spectra with the decreased mean radiometric differences

Reference Spectrum	Correlation Coefficient	Mean Radiometric Differences [%]
SAO2010/NRLSSI2	0.9659	1.7275
SAO2010/ATLAS3	0.9738	0.3223
SAO2010/KNMI	0.9464	1.6985
NewSAO2010/NRLSSI2	0.9754	1.4045
NewSAO2010/ATLAS3	0.9899	0.0854
New SAO2010/KNMI	0.9689	1.0593

Comparison among reference spectra for 300 -500 nm range at FWHM 1.0 nm

Stray light Correction

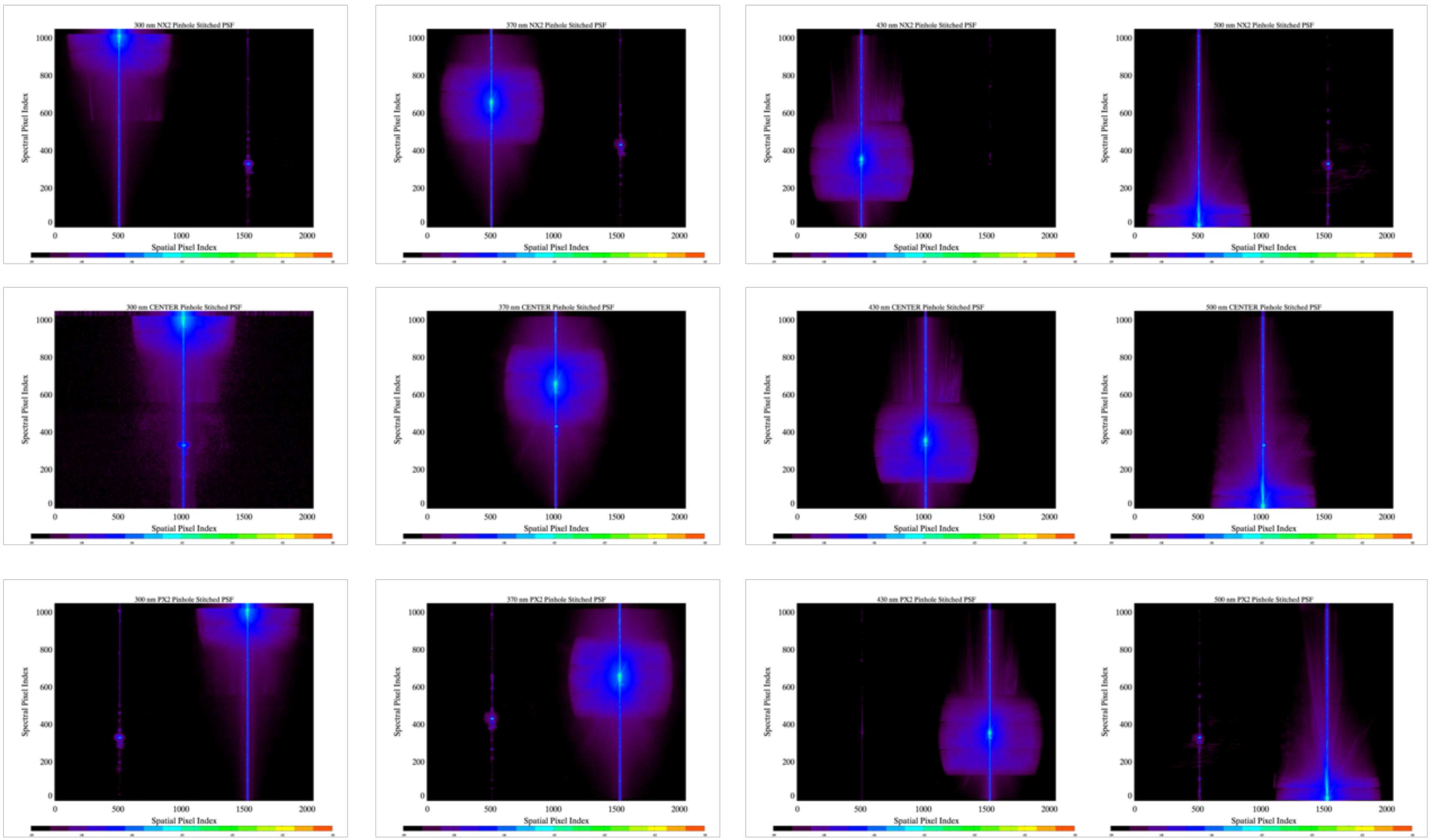
◆GEMS Point Spread Function(PSF)

300 nm | 370 nm | 430 nm | 500 nm

NX2

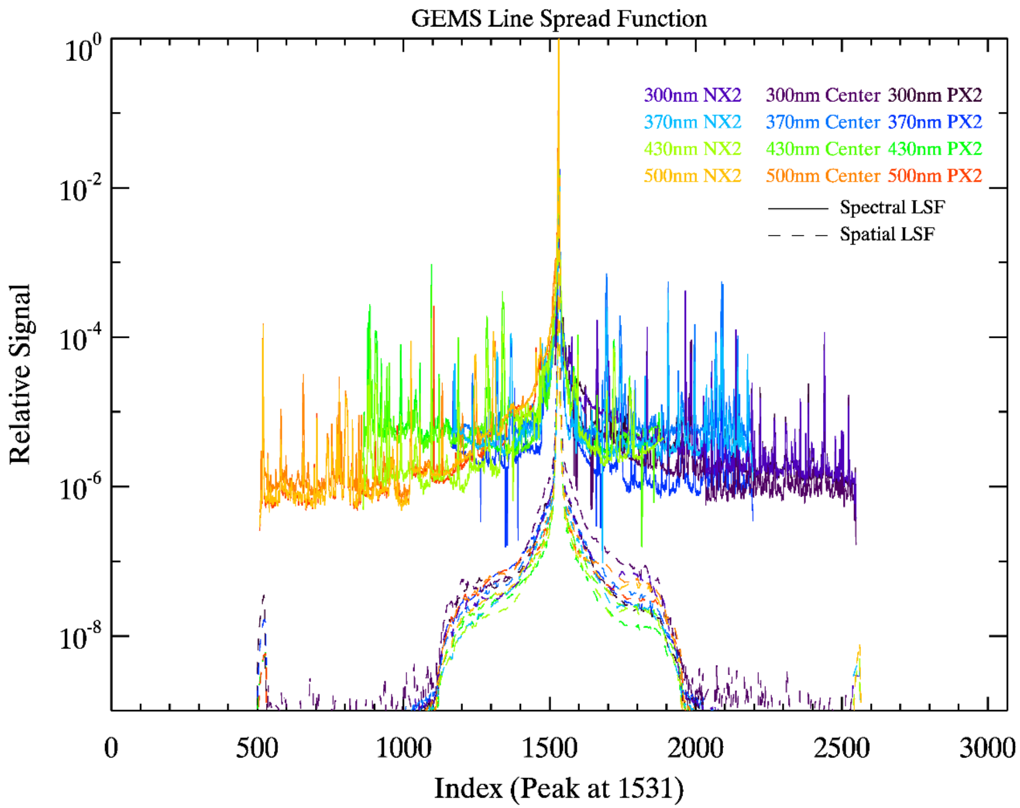
Center

PX2



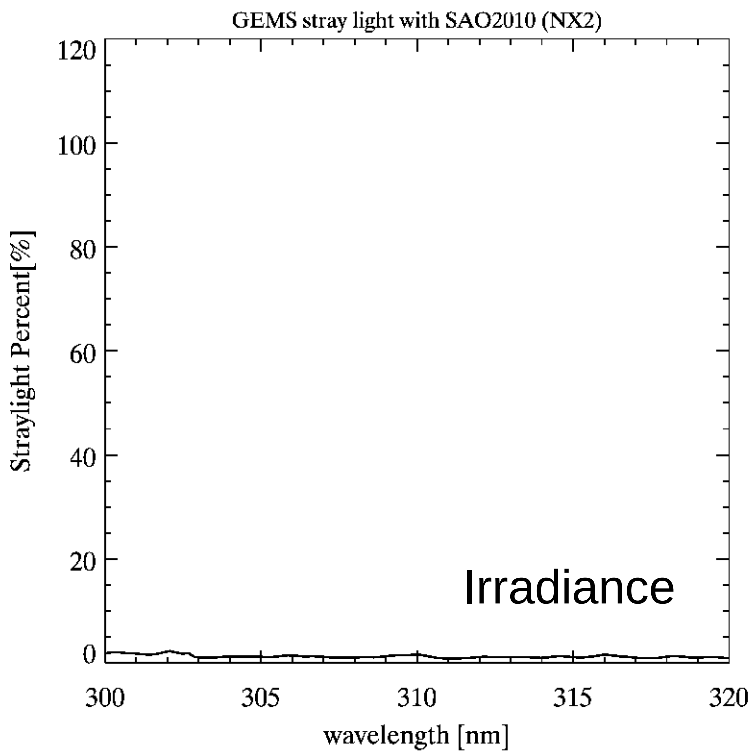
Stray light Correction

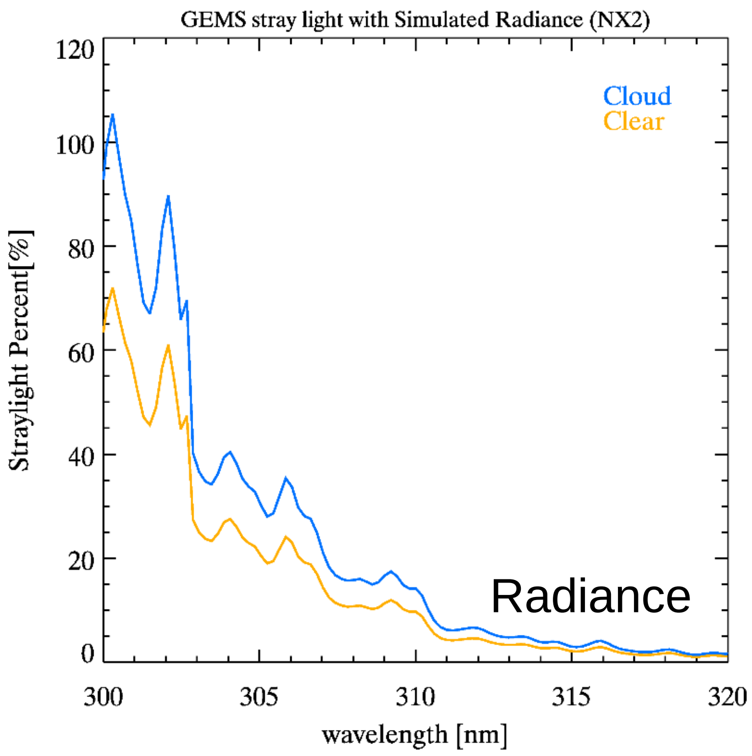
- Spatial and spectral PSF
  - Spatial Line Spread Function(LSF), Higher Spectral LSF signal and spike



Stray light Correction

- Estimated stray light
  - The largest stray light relative to the true signal occurs at 300.30 nm with105.7% (72.1%) at NX2 for cloudy(clear) sky radiance

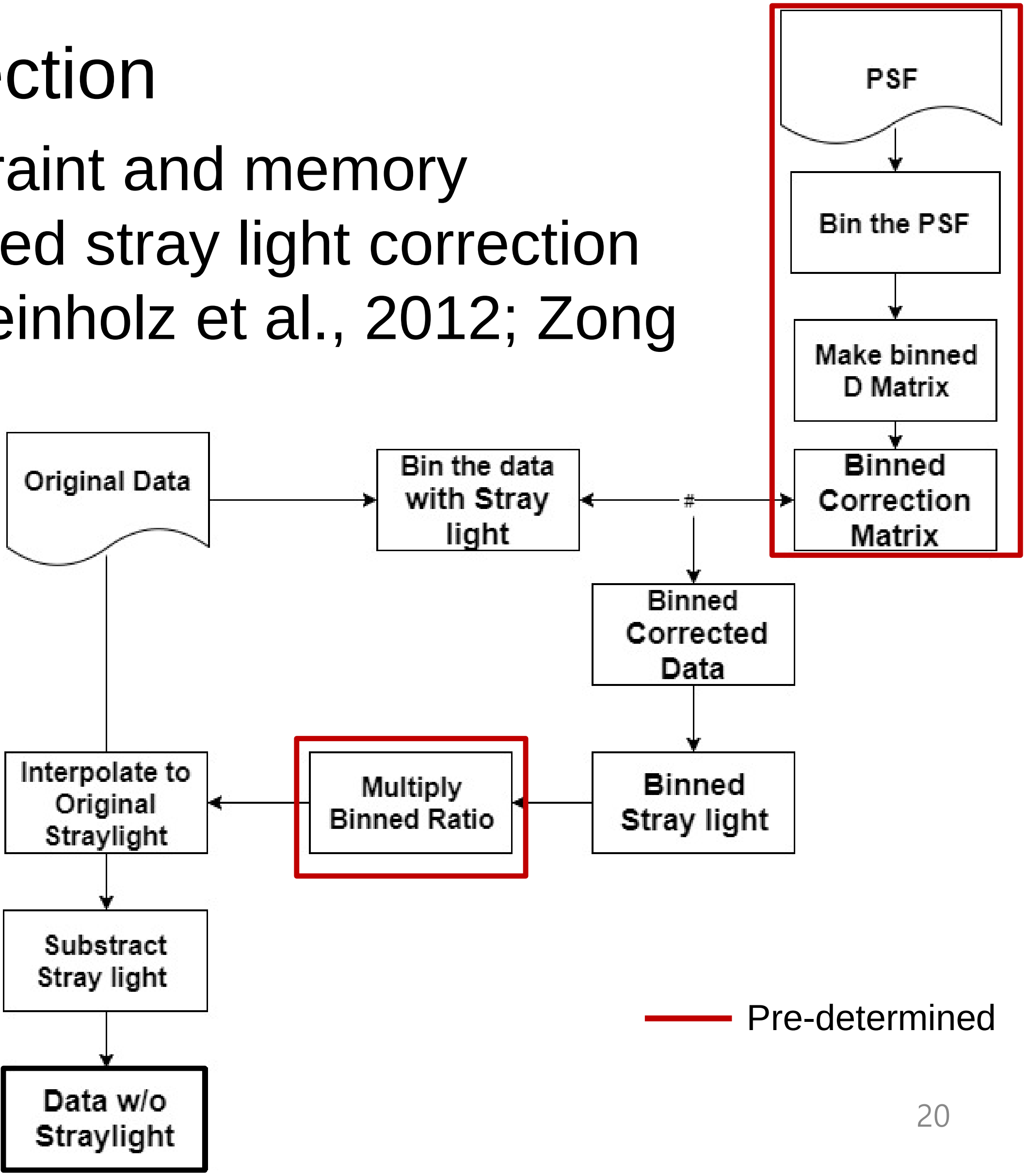




Stray light Correction

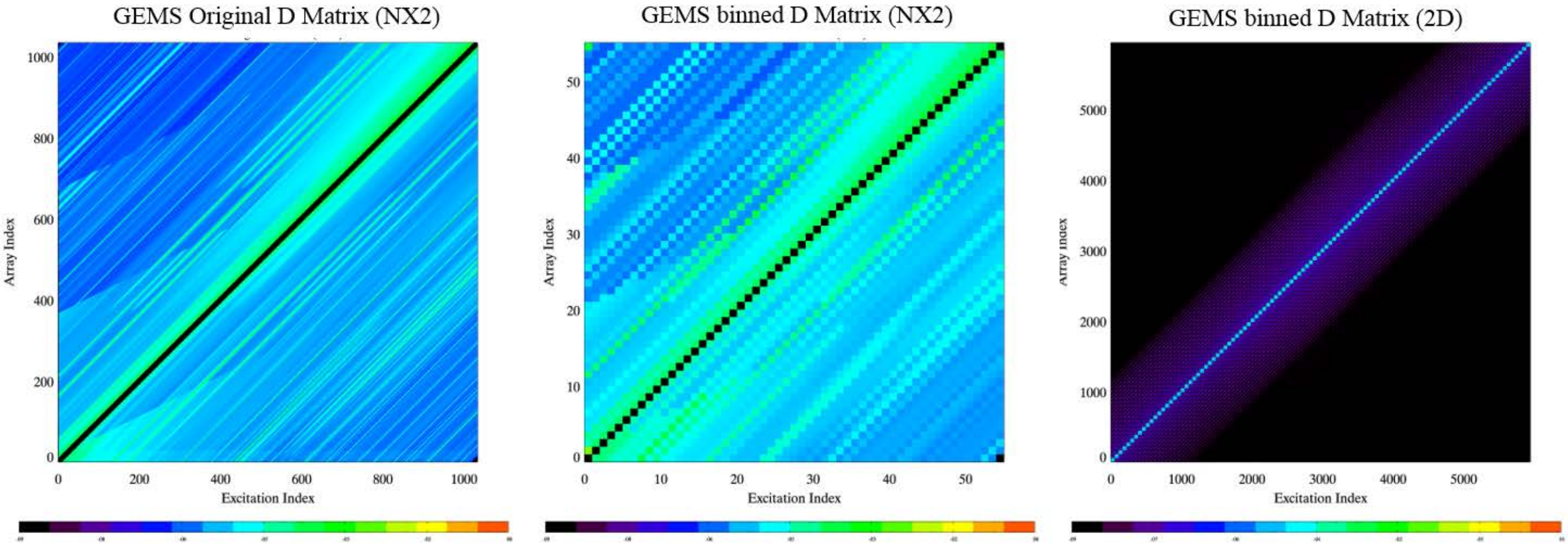
- 2D Stray light correction
  - To meet time constraint and memory requirement, a binned stray light correction has been tested (Feinholz et al., 2012; Zong et al., 2007)

$$Y_{meas} = Y_{ib} + Y_{sl}$$
$$Y_{meas} = Y_{ib} + D \cdot Y_{ib}$$
$$Y_{meas} = [D + I] \cdot Y_{ib}$$
$$Y_{ib} = [D + I]^{-1} \cdot Y_{meas}$$



Stray light Correction

- Binned matrix
  - Reduce the stray light matrix size 10^{12} to 10^7
  - Choose center pixel within every 19 pixels to bin [1033,2048] -> [55,108]
  - PSF for every pixel on focal plane interpolated from provided 12 GEMS PSF results



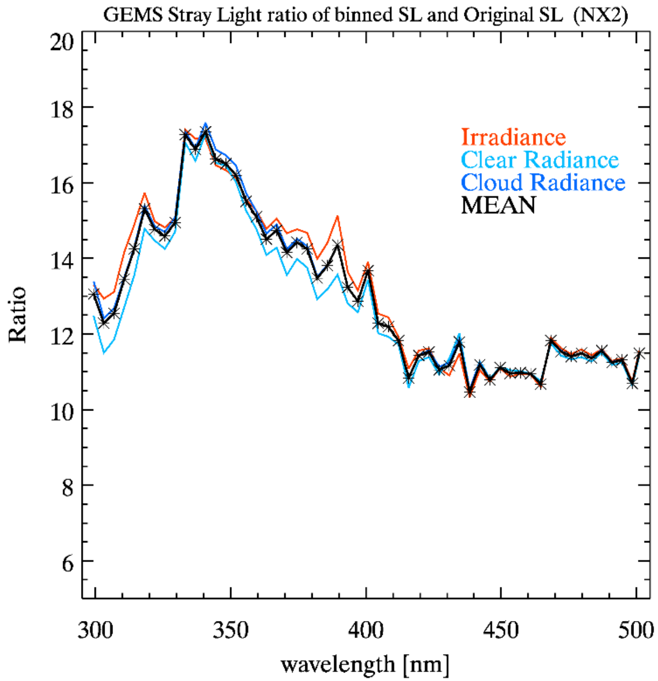
Stray light Correction

- Binned matrix
  - Prepare the ratio between original and binned stray light (reflects the reduced trace of D matrix with binning)

$$
\vec{Y}_{\mathrm{SL}} = \begin{bmatrix} \vec{Y}^{1}_{\mathrm{SL}} \\ \vec{Y}^{2}_{\mathrm{SL}} \\ \vdots \\ \vec{Y}^{m}_{\mathrm{SL}} \end{bmatrix} = \begin{bmatrix} \sum_j \overleftrightarrow{D}^{1,j} \vec{Y}^{j}_{\mathrm{IB}} \\ \sum_j \overleftrightarrow{D}^{2,j} \vec{Y}^{j}_{\mathrm{IB}} \\ \vdots \\ \sum_j \overleftrightarrow{D}^{m,j} \vec{Y}^{j}_{\mathrm{IB}} \end{bmatrix}
$$

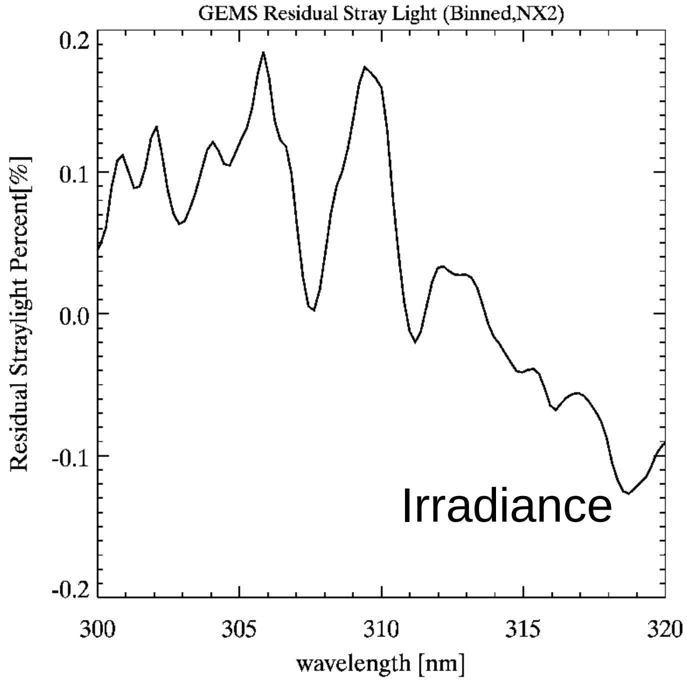
$$
= \begin{bmatrix} \overleftrightarrow{D}^{1,1} & \overleftrightarrow{D}^{1,2} & \overleftrightarrow{D}^{1,3} & \ldots \overleftrightarrow{D}^{1,m} \\ \overleftrightarrow{D}^{2,1} & \overleftrightarrow{D}^{2,2} & \overleftrightarrow{D}^{2,3} & \ldots \overleftrightarrow{D}^{2,m} \\ \vdots & & & \\ \overleftrightarrow{D}^{m,1} & \overleftrightarrow{D}^{m,2} & \overleftrightarrow{D}^{m,3} & \ldots \overleftrightarrow{D}^{m,m} \end{bmatrix} \cdot \begin{bmatrix} \vec{Y}^{1}_{\mathrm{IB}} \\ \vec{Y}^{2}_{\mathrm{IB}} \\ \vdots \\ \vec{Y}^{m}_{\mathrm{IB}} \end{bmatrix}.
$$

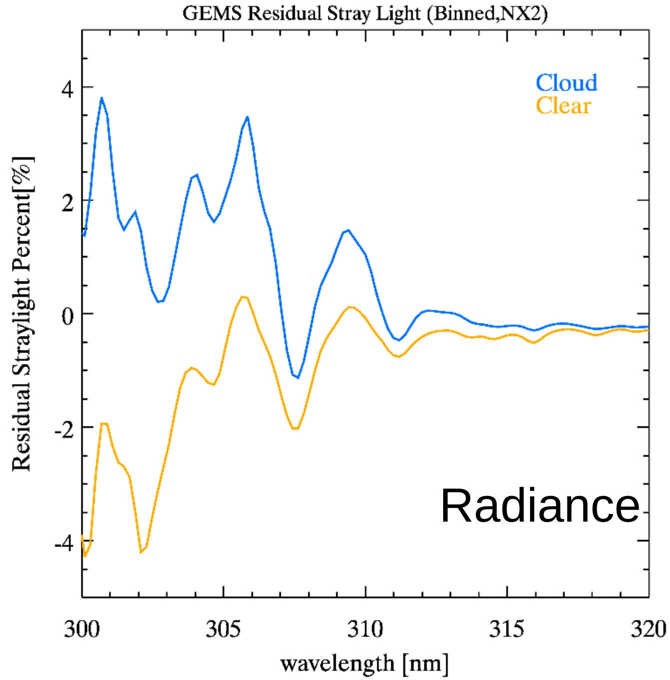
(Feinholz et al., 2012)



Stray light Correction

- Algorithm performance
  - Residual stray light after binning stray light correction is within 0.2 % in irradiance and 4 % in radiance for wavelengths > 300 nm





Summary and Discussion

- Most of important issues for the GEMS data quality are identified and reflected into the GEMS L0-1b processor
- Spectral calibration
  - The differences among ground-SRFs indicate that spectral variations are larger than spatial one.
  - The functions such as ASG and HBG accurately characterize the simulated in orbit SRFs
  - The solar reference spectrum has been updated
- Stray light correction
  - Prototype 2-D stray light correction based on the binned matrix approach has been tested to show a good candidate for a feasible solution

Thank you for you attention

Current status

- Key issues for three important calibrations
  - Radiometric Calibration; Albedo Calibration
    - Requirements for the albedo estimation are not specifically provided
  - Spectral Calibration; Reference Solar Spectrum, SRF
    - In-orbit verification/update/monitoring of SRFs is highly required.
    - Absolutely calibrated high resolution solar reference spectrum is required to prepared.
  - Geometric Calibration; Limited number of landmark
    - Require more uniformly distributed good landmarks and better ranging information
    - Limited portion of spectral data will be used for Landmark extraction, which may introduce spectral mis-alignment
    - Correction based Rayleigh component in Earth radiance

Solar Reference Spectrum

- Updating SAO2010/JPL
  1. **Fitting the SAO2010/JPL** with reference (WHI/ATLAS) to obtain SRF of reference & scaling factors; **same spectral feature**
  2. Convolution of the SAO2010/JPL spectrum with the derived function ;**same spectral resolution**
  3. Calculating the ratio between convolved spectrum with reference (R)
  4. Obtaining the new convolved SAO2010/JPL applied ratio (R') to SAO2010/JPL;

     new convolved SAO2010/JPL

     = convolved SAO2010/JPL * R

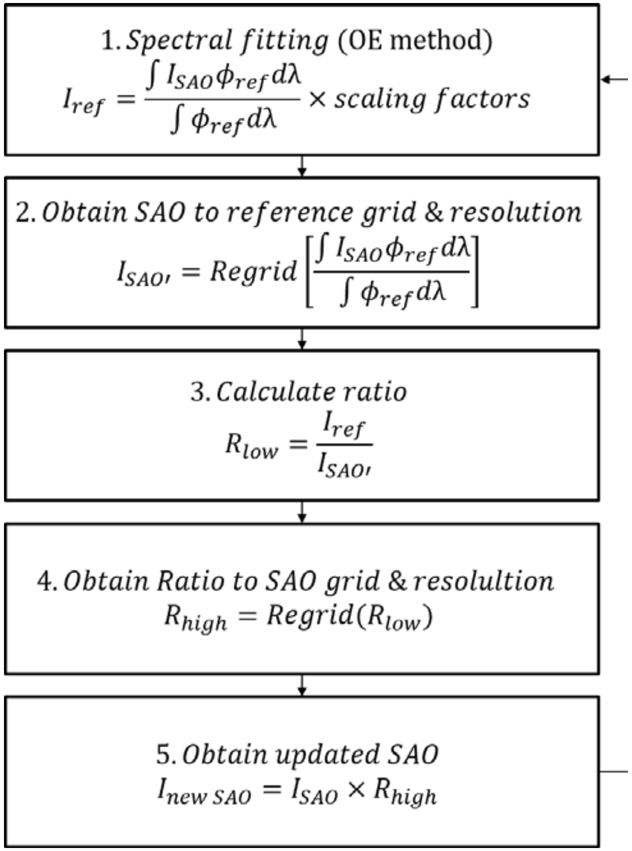
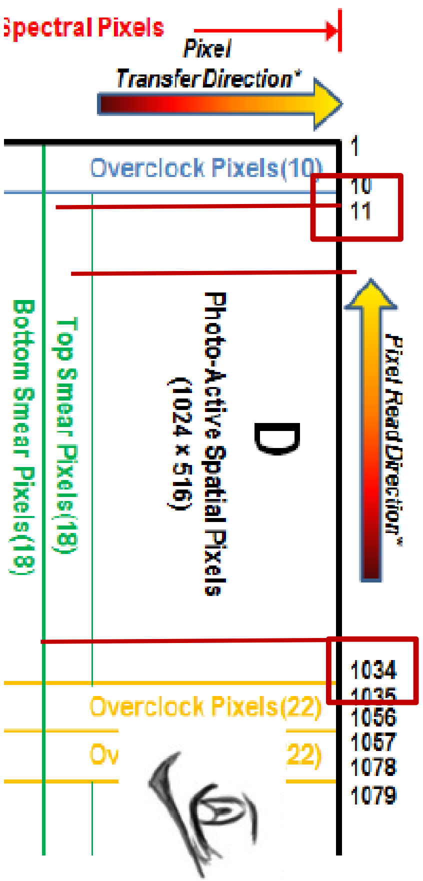
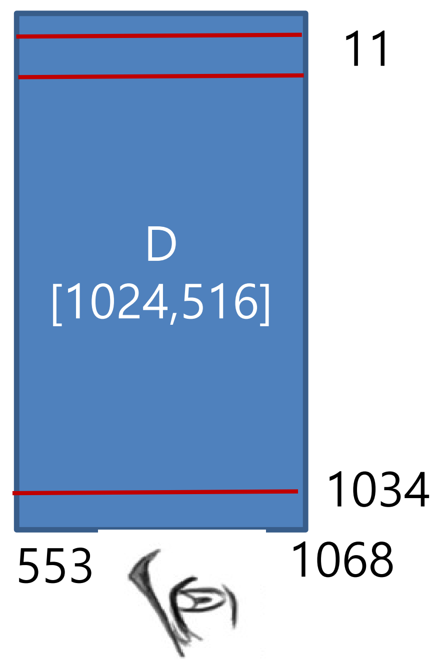
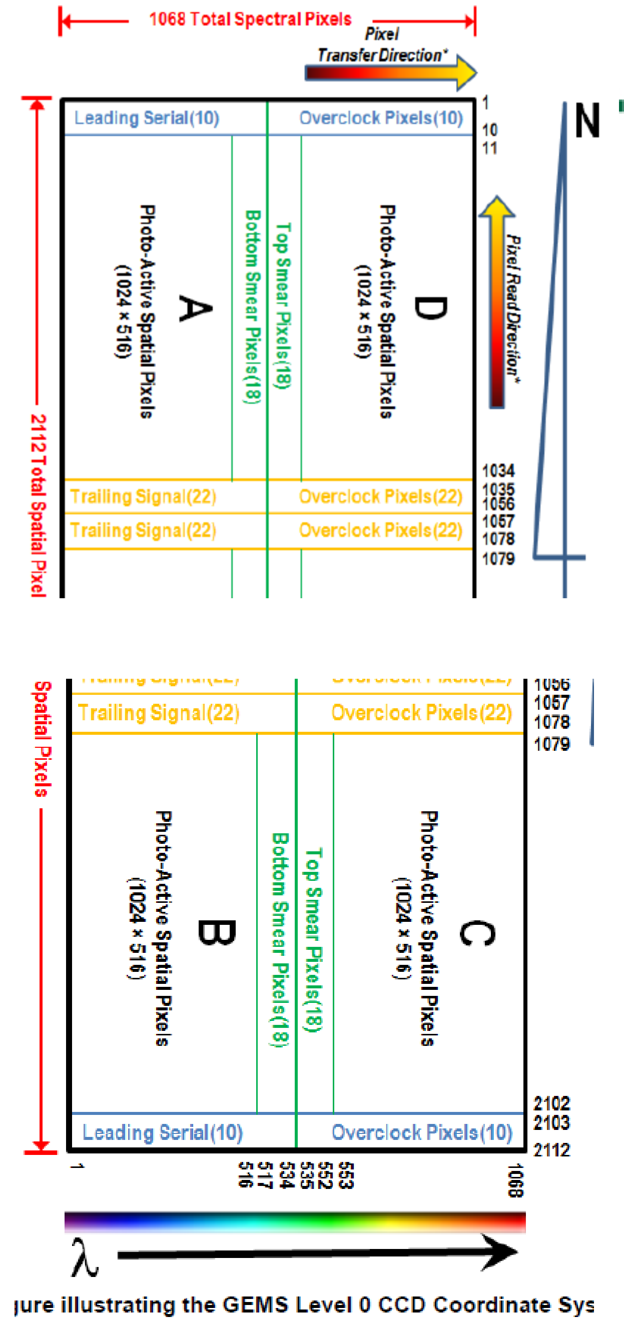


Figure. Process for updating SAO2010





Row (가로줄)1024개
Column (세로줄) 516개



Smear Correction

◆Scene-Based Smear Correction

- ❖GEMS corrects the smear in consideration of the ratio between integration and frame time
  - ➢Current frame smear & previous frame smear can reflect the variation of signal rate

Storage region

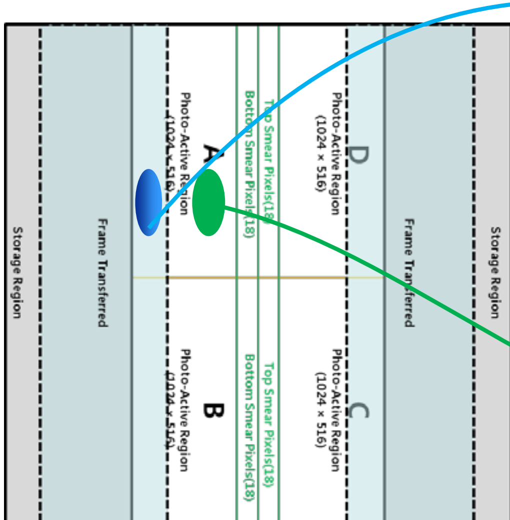


Photo-active region

$$DN'^{k}_{1} = DN^{k}_{1}$$

$$DN'^{k}_{2} = DN^{k}_{2} + \frac{T_{ft}}{T_{int}} \cdot \frac{1}{516} \cdot DN'^{k}_{1} + \frac{T_{ft}}{T_{int}} \cdot \frac{1}{516} \cdot DN'^{k-1}_{2}$$

$$DN'^{k}_{3} = DN^{k}_{3} + \frac{T_{ft}}{T_{int}} \cdot \frac{1}{516} \cdot (DN'^{k}_{2} + DN'^{k}_{1}) + \frac{T_{ft}}{T_{int}} \cdot \frac{2}{516} \cdot DN'^{k-1}_{3}$$

$$\vdots$$

$$\vdots$$

$$DN'^{k}_{516} = DN^{k}_{516} + \underbrace{\frac{T_{ft}}{T_{int}} \cdot \frac{1}{516} \cdot (DN'^{k}_{515} + DN'^{k}_{514} \cdots DN'^{k}_{2} + DN'^{k}_{1})}_{\text{Current Frame Smear}} + \underbrace{\frac{T_{ft}}{T_{int}} \cdot \frac{515}{516} \cdot DN'^{k-1}_{516}}_{\text{Previous Frame Smear}}$$

$$DN_{sm} = \frac{T_{ft}}{T_{int}} \cdot \frac{1}{516} \cdot (D'^{k}_{516} + D'^{k}_{515} \cdots D'^{k}_{2} + D'^{k}_{1})$$

Courtesy of Dai ho Ko