GEMS L1B
: Challenge and expected performance

GEMS science team

환경부

- GEMS L0-L1B processor
- GEMS L1B Challenge
  - Spectral calibration
  - Stray light correction
  - Radiometric calibration coefficient
  - Diffuser characterization
    - Bidirectional Transmittance Distribution Function
    - Diffuser trend
- Expected performance
- Summary

I. GEMS L0-L1B Processor

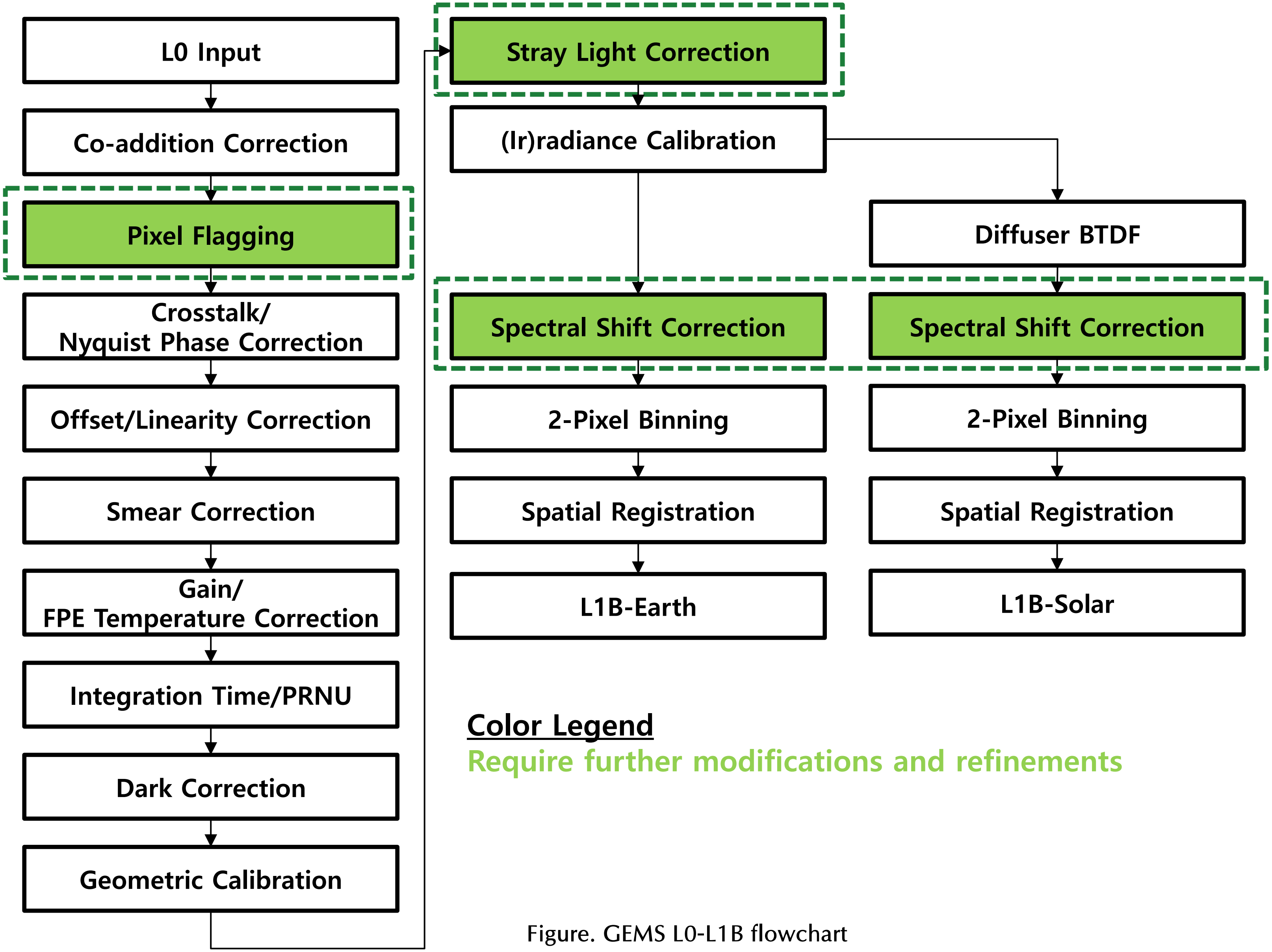


Figure. GEMS L0-L1B flowchart

I. GEMS L0-L1B Processor

Correction Algorithm	Current	Goal
Pixel flagging	Correct saturation/dead pixel	Saturation pixel Dead pixel Transient pixel (RTS) etc
Smear correction	Averaged smear value along spectral direction	Smear value weighted by the illuminated signal to avoid under/over-correction
Spectral shift correction	Based on the on-ground calibration data (0.2nm) No fitting window Aggregated along spatial direction Minimizing derivatives	Based on the reference solar data (0.01nm) Fitting windows Fitting along the every spatial direction Derivatives or integration
Stray light correction	Estimate spectral stray light using ratio with nominal scene stray light	Spectral and spatial correction based on PSF data and broadband data

I. GEMS L0-L1B Processor

◆ Spectral Calibration

	Current algorithm	shadow algorithm
Minimization	Difference btw gradient of on-ground calibration data and of measurement	Difference btw reference spectrum and measurement
Method	Simplex method	OE (Optimal Estimation) Levenberg-Marqurdt
Fitting window	Single	Single or multiple
Calibration parameter	Shift	Selectable (Shift, Squeeze Shift Polynomial Shift with mini windows)
Data to be calibrated	**Spatially averaged measurement**	Individual observation data
SRF Characterization	**Not included**	Included

I. GEMS L0-L1B Processor

◆ Stray light correction

	Current algorithm	shadow algorithm
Method	Estimate stray light using ratio with nominal scene stray light	1. Matrix multiplication based on PSF data 2. Using unilluminated pixels
Dimension	Spectral only	Spectral and spatial
Ground data for correction	Fractional stray light of GEMS nominal radiance calculated from stray light model	Point Spread Function (Braodband stray light measurement)
Limitation	Estimate stray light within 10% regardless of scene	1. Reduce the size of Stray light Distribution Function (SLDF) for matrix multiplication - 19*19 binning - Mean the PSF of different pinhole location

II. GEMS L1B challenge

- Data quality determined by three important processes
  - Spectral Calibration
    - Assignment of wavelength value to each CCD pixel
    - Prepare the spectral map & bandpass during the ground test
    - Increase the accuracy using the spectral fitting algorithm with a reference solar spectrum
    - On-orbit verification/update/monitoring of SRF accuracy after launch in highly required
  - Radiometric Calibration
    - Convert the downlinked digital count to physical parameter
    - On-orbit re-characterization of calibration data such as calibration coefficients, stray light and diffuser BTDF in highly required
    - On-orbit observation of dark current, smear, non-linearity (LED)
    - Monitoring of sensor responsivity through the solar irradiance measurement (two diffusers)
  - Geometric Calibration
    - Assignment of geo-location information to each CCD pixel
    - Ground processing assigns earth location using the landmark data within the GEMS measurement

II. GEMS L1B challenge

◆ Spectral calibration

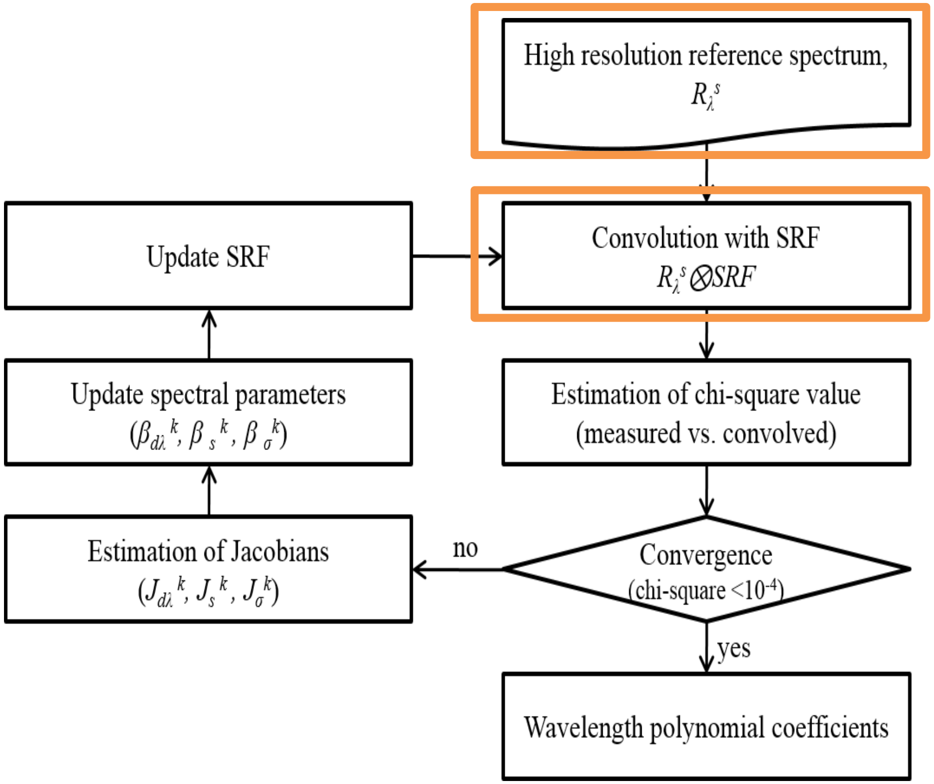


Figure . Flow chart of spectral calibration algorithm for GEMS

❖ Performance is highly sensitive to the SRF accuracy

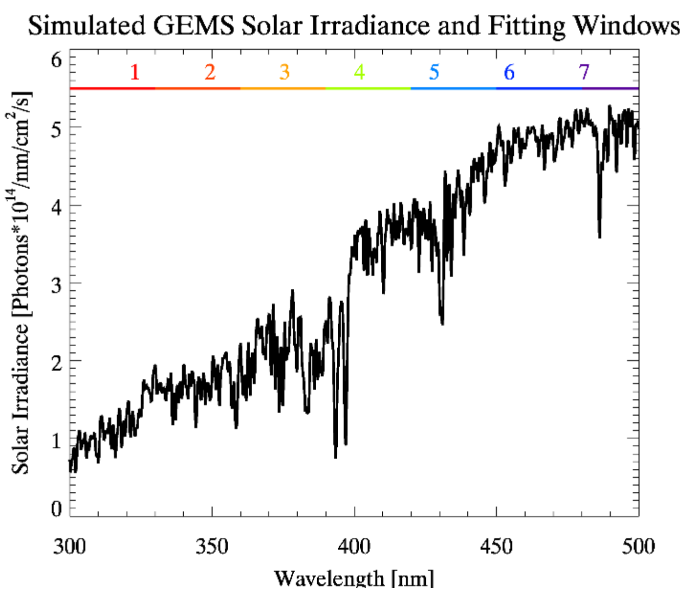
- Asymmetric Super-Gaussian function will be applied to characterize the shape and width of on-orbit SRF

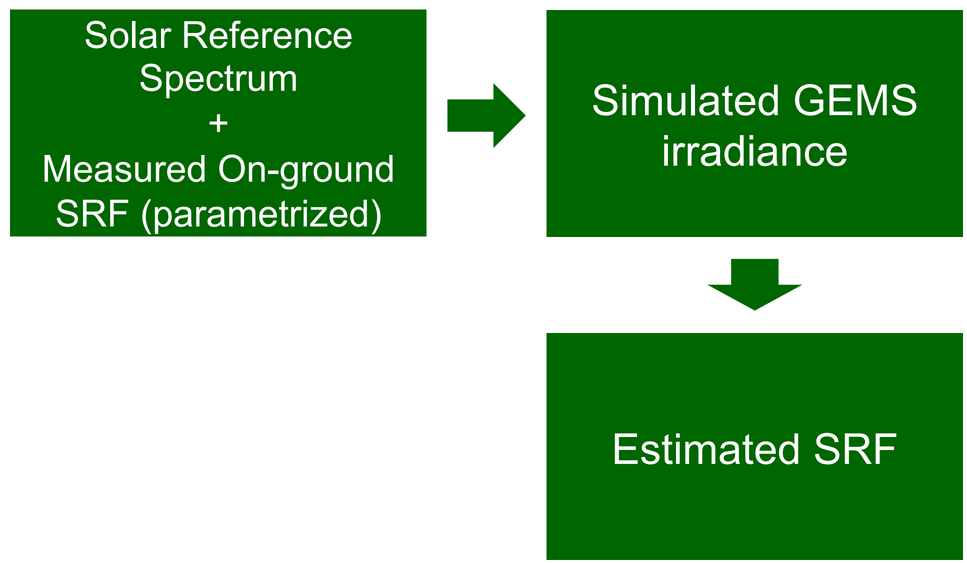
❖ Need an accurate high-resolution reference spectrum

- SAO2010 (Chance and Kurucz., 2010)
- KNMI (Dobber et al., 2006)
- QAS (Grobner et al., 2017)

II. GEMS L1B challenge

- **Possibility of deriving in-flight SRF**
  - Using the simulated GEMS irradiances (measurements; convolution of incident spectrum with the actual SRF) and analytic functions, the possibility has been tested





✓ $\boldsymbol{Simulated\ GEMS\ irradiance} = \frac{\int SAO2010_\lambda \phi_{gGEMS,\lambda} d\lambda}{\int \phi_{gGEMS,\lambda} d\lambda}$; assumed as GEMS solar measurement

✓ $\boldsymbol{Reference\ spectrum} = \frac{\int KNMI_\lambda \phi_{ASG/HBG,\lambda} d\lambda}{\int \phi_{ASG/HBG,\lambda} d\lambda}$; assumed as actual solar spectrum

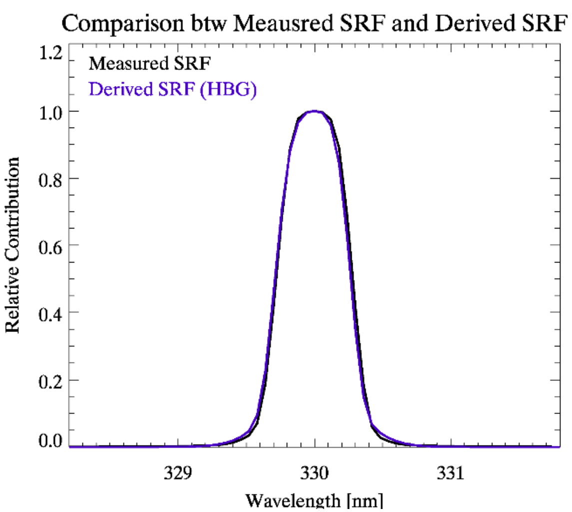
II. GEMS L1B challenge

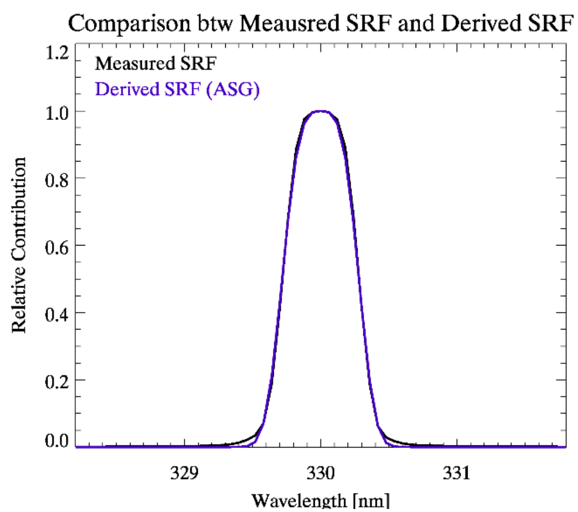
◆ Possibility of deriving in-flight SRF

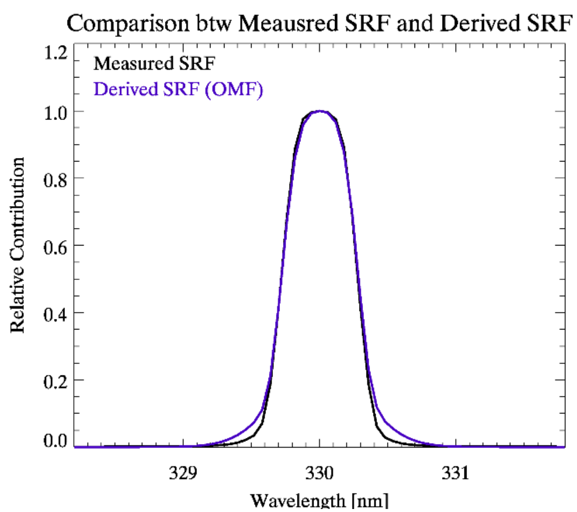
$$\chi^2 = \sum\left[\frac{\int I_{h0,\lambda}\phi_{iGEMS,\lambda}d_\lambda}{\int \phi_{iGEMS,\lambda}\, d_\lambda} - \left\{\frac{\int I_{h1,\lambda}\,\phi_{anal\ GEMS,\lambda}d\lambda}{\int \phi_{anal\ GEMS,\lambda}d\lambda}\times P_0 + P_1(\lambda-\lambda_{avg}) + P_2(\lambda-\lambda_{avg})^2 + P_3(\lambda-\lambda_{avg})^3\right\}\right]^2$$

❖ Trade-off between the number of parameters in analytic function and the stability of fitting algorithm

- The narrower the fitting window, the more SRF can be obtained







II. GEMS L1B challenge

◆ Stray light correction(PSF mean matrix multiplication)

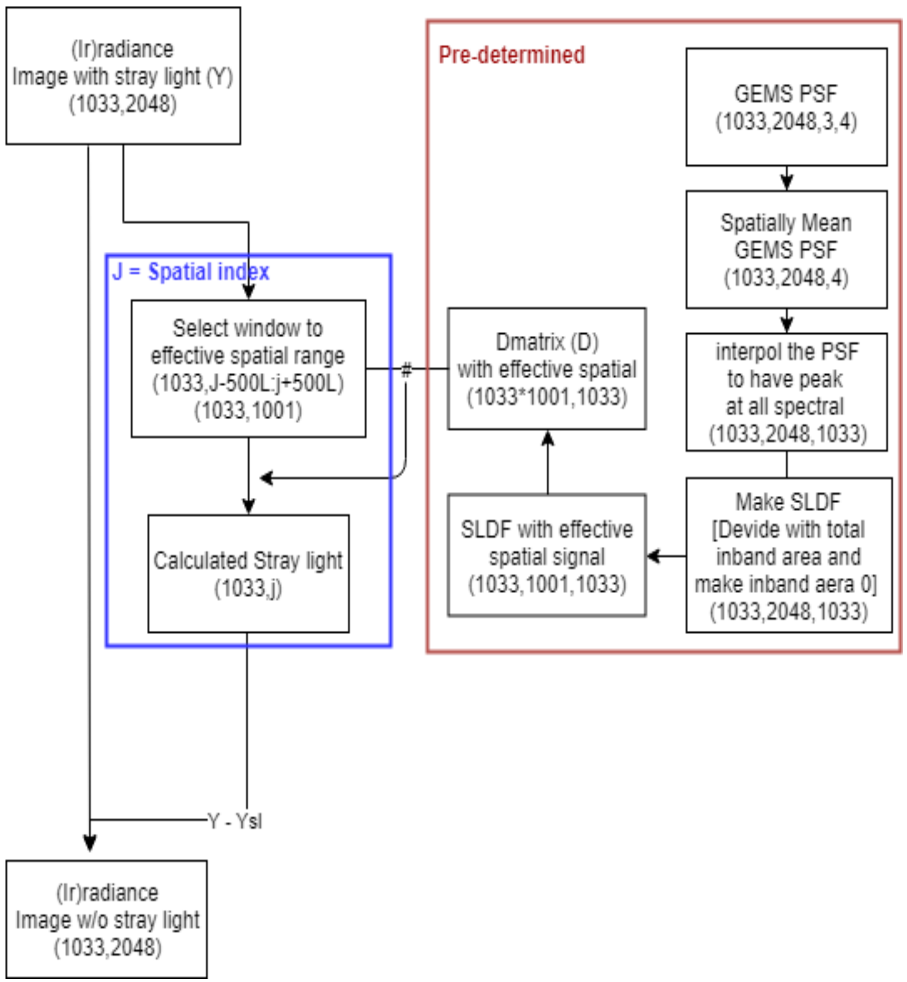


Figure. Flowchart of GEMS PSF meanstray light cirrection

❖ Assuming that there is no PSF variability in pinhole position, calculate stray light with the 1001 spatial effective pixels of spatially averaged PSF

- Based on Stray Light Distribution Function Matrix Multiplication (Zong et al., 2007), (Feinholz et al., 2012)

$$Y_{meas} = Y_{inband} + Y_{SL}$$
$$= Y_{inband} + D \cdot Y_{inband}$$
$$= [I + D] \cdot Y_{inband}$$
$$= A \cdot Y_{inband}$$

$$Y_{inband} = A^{-1} \cdot Y_{meas}$$
$$= C \cdot Y_{meas}$$

II. GEMS L1B challenge

◆ Stray light correction (Binned matrix multiplication)

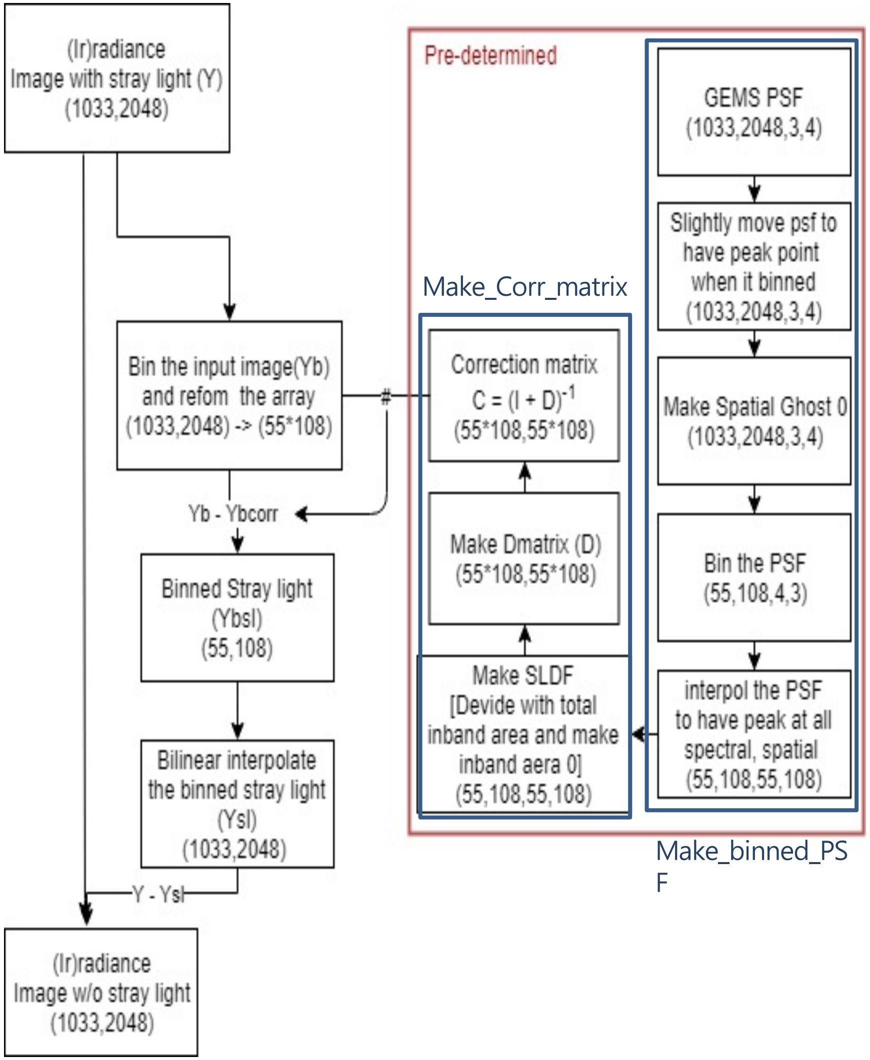
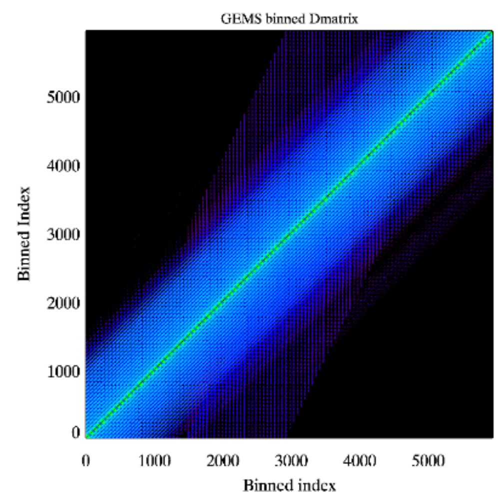


Figure. Flowchart of GEMS binned stray light cirrection

❖ Calculate stray light using 12 GEMS PSF and input scene with binning 3 FWHM * 3FWHM and restore the reduced dimensions with bilinear interpolation

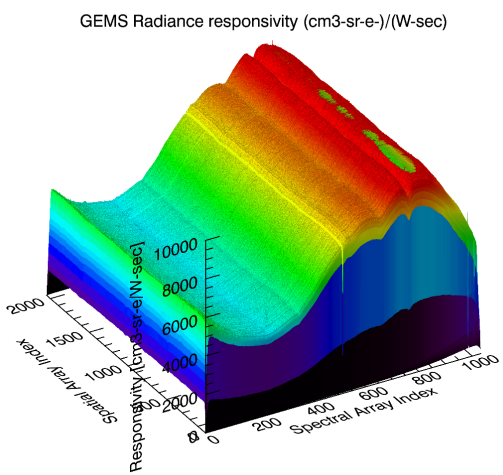
- Based on Stray Light Distribution Function Matrix Multiplication (Zong et al., 2007), (Feinholz et al., 2012)

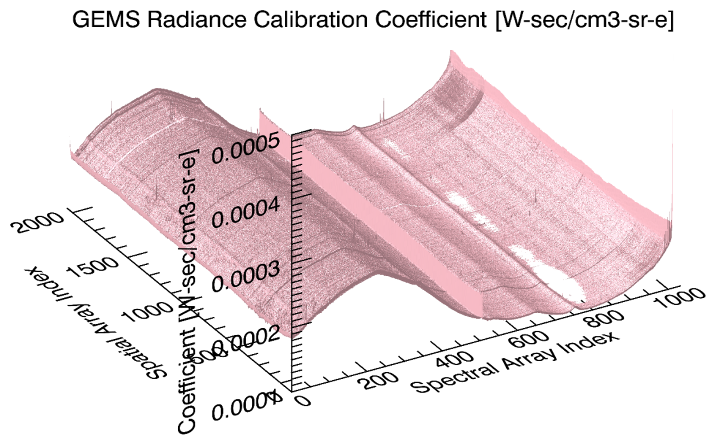


GEMS binned Stray Light Distribution Function

II. GEMS L1B challenge

- Radiometric calibration coefficient
  - Through a number of correction and calibration steps (16 for GEMS), digitized signal is transformed to give an estimate of the measured signal
  - Together with the signal, its variance is also propagated through the calibration steps and radiometric calibration coefficient could include it
  - On-orbit verification and update of radiometric calibration coefficient after launch in highly required





II. GEMS L1B challenge

◆ Diffuser BTDF

❖ 5 filed position and 8 wavelength of GEMS BTDF data are given

- GEMS filed position : [-3.87, -1.93, 0.00, 1.93, 3.87]
- GEMS BTDF wavelength = [300, 315, 325, 350, 375, 400, 425, 500]

❖ Interpolate the original BTDF map to obtain the BTDF value at GEMS spatial and spectral dimension

- Spectrally: cubic spline interpolation, Spatially: Linear interpolation
- Bilinear interpolation

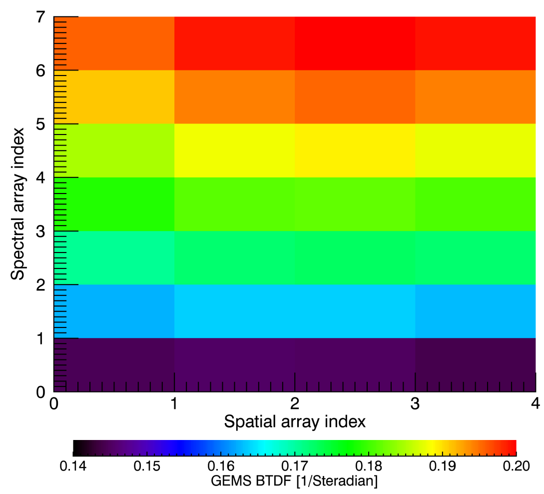
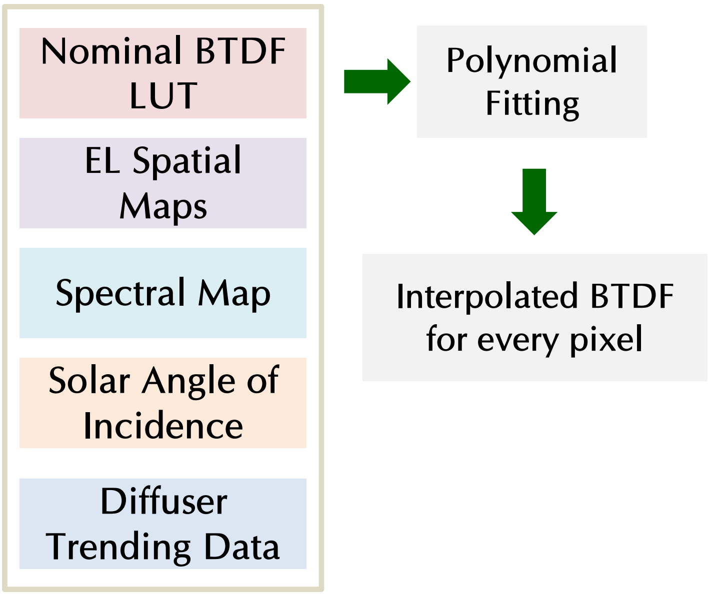


Figure . GEMS Original BTDF map



Credit: KARI

II. GEMS L1B challenge

◆ Diffuser BTDF

❖ Interpolated BTDF value for every pixel differ up to 2.8% depending on the method of interpolation

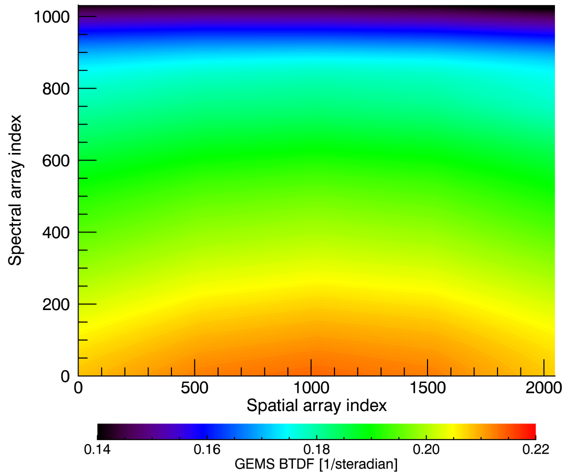


Figure. Interpolated GEMS BTDF map [Cubic spline, Linear]

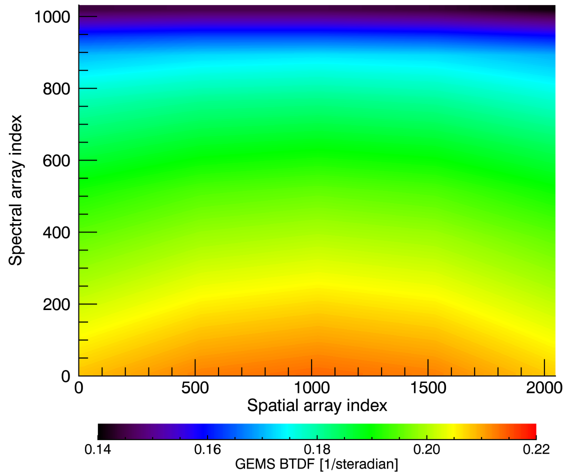


Figure. Interpolated GEMS BTDF map [Bilinear]

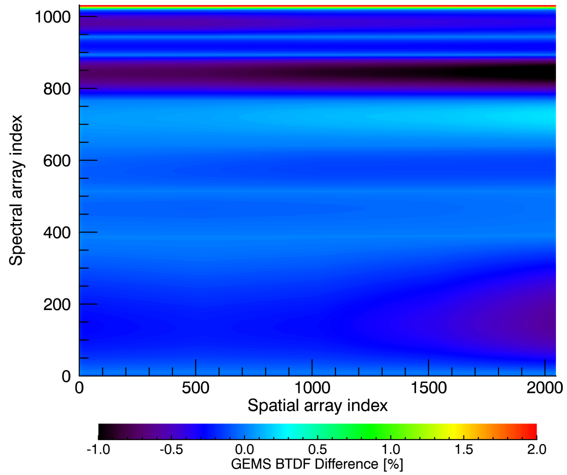


Figure. BTDF difference dependiong on interpol method

❖ Characterization of diffuser BTDF through the solar irradiance measurement would be required to verify and check the prelaunch characterization and on-orbit performance

II. GEMS L1B challenge

◆ Diffuser trend

- ❖ GEMS has two diffusers (working and reference)
- ❖ Working diffuser will be performed daily and reference diffuser will be performed at least once every 6 months to monitor for changes in the spectral transmission of the working solar calibration diffuser
  - Any changes that are detected will be applied in the form of a scale factor to the day-one irradiance calibration coefficients.

- ❖ The diffuser degradation rate is a function of the solar measurement rate
  - A quantity is the working (W) to reference (R) signal ratio

$$r = \frac{W}{R}$$

$W=f(t_W)$, $R=f(t_R)$

$t_R/t_W = dt_R/dt_W = n_R/n_W$

III. Expected performance

◆ GEMS HW requirement

System Attributes	Requirements
Spectral range	300 nm to 500 nm
Spectral resolution	< 0.6 nm
Spectral sampling	< 0.2 nm
Data quantization	> 12 bits
MTF (instrument level)	> 0.3 in N/S direction @ Nyquist frequency > 0.3 in E/W direction @ Nyquist frequency
Radiometric calibration accuracy	< 4%
Spectral calibration accuracy	< 0.02 nm
Spectral calibration stability	< 0.02 nm (within 8 imaging)
Polarization factor	<2% No inflection point within 20nm for all the wavelength range
Spectral Feature	< 0.05% (within 3 nm)
Stray Light	< 2%

IV. Summary

- GEMS L0-L1B algorithms have been prepared for the GEMS data quality but some algorithms require improvement and optimization for better data accuracy

- On-orbit verification/update/monitoring of calibration data such as SRF, calibration coefficient, stray light and characterization of diffuser after launch in highly required

- Need closer cooperation
  - Image quality is the most important for the better utilization of GEMS data
  - It is determined by at least three important calibration activities, Geometric, Spectral, and Radiometric.
  - All of these calibration require a closer collaboration of all stakeholder including user, sensor/spacecraft engineer, ground processing and scientific algorithm developer

Thank you

I. GEMS L0-L1B Processor

Algorithm	Description	Used in
Hot/Dead/RTS	Generating hot/dead/RTS pixel to avoid those pixels	E, S, D, L
Co-adding correction	Division by number of co-added images	E, S, D, L
LED/Linearity/Gain	Correction of the deviation from the linearity, electronic gain	E, S
Offset/Smear/Dark current	Subtraction of unwanted signal from pixel values	E, S, D, L
QE/PRNU/Integration time	Correction of QE, PRNU, and integration time	E, S, D, L
Stray light correction	Subtraction of out-of-band and out-of-filed stray light	E, S
Spectral Registration	Assigning each pixels with its center wavelengths	E,S
Radiance calibration	Converts earth-view images from counts to spectral images	E, S
Band pass function	Calculation of bandpass functions for each pixels	E, S
Spectral shift correction	Wavelength correction using solar/earth image data	E, S
Measurement Noise	Summarize total measurement noise value for each pixels	E, S
Spatial Registration	Assigning each pixels with elevation and azimuthal angles	E, S
Goniometry	Diffuser image correction for observation angles	S
Nominal BTDF	Creates pre-launch databased of working/ref diffuser BTDF	S
Reference Diffuser Trend	Trends on-orbit diffuser degradation and corrects calibration	S
Main algorithm	Integrate all the algorithms described above	E, S, D, L

Credit: KARI

I. GEMS L0-L1B Processor

◆ Pixel flagging

Quality Flag Name	Discription
Missing pixel flag	Pixel doesn't have information at L0 data
Dead pixel flag	High or low sensitivity pixel at input signal
Bad pixel flag	Pixel responsivity is very hot or cold to all input signal
Saturation flag	Saturated pixel which digital count exceed the maximum ADC bit or incident photon over pixel well capacity
Pixel adjacent to saturated pixel flag	Saturation possibility pixel due to adjacent saturated pixel
Negative dark current flag	Negative Pixel signal at dark current
RTS (random telegraph signal) flag	Damaged detector grid pixel due to radiation particle of space
Transient pixel flag	Transient pixel due to additional particle at detector

I. GEMS L0-L1B Processor

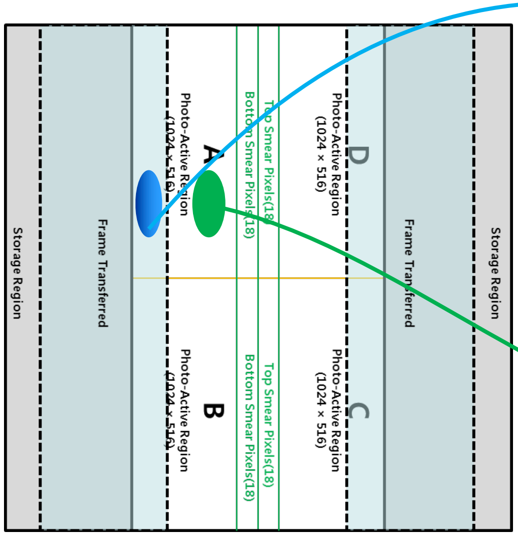
◆ Smear correction

❖ Added contribution of the signal due to continued exposure during frame transfer from active CCD region to storage region

- Smear signal; ~25 % at 290 nm, ~12 % for 300 nm. (from TEMPO analysis)

❖ Smear correction for GEMS

- Scene-based method



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

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

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

$$\vdots$$

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

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

Credit: KARI

II. GEMS L1B challenge

◆ Spectral calibration

Consists of two steps of the spectral registration and spectral shift correction

❖ Spectral registration

- The 1st order wavelength assignment considered optical bench temperature gradient

❖ Spectral shift correction

- For a better accuracy, minimization of spectral fitting could be used with the Fraunhofer lines
- Levenberg-Marquardt method which use the error covariance and Jacobian of each parameters for non-linear least square fitting is used.

$$\chi^2 = \sum_i [R_i - (\alpha_0 + \alpha_1 i + \alpha_2 i^2) \times f(solref, \sigma^*, \lambda_0 + d\lambda^* + is^* \Delta\lambda_0) - \beta^*]^2$$

i^*: pixel number, σ^*: FWHM, $d\lambda^*$: Shift, s^*: Squeeze, β: dark current

II. GEMS L1B challenge

- A new high resolution reference solar spectrum for GEMS
  - There are non-negligible differences between SAO2010 (Chance and Kurucz 2010) and KNMI (Dobber et al 2008) at GEMS resolution/range
  - Minimum chi-square value of algorithm increases more than an order
  - Absolutely calibrated reference solar spectrum has been derived

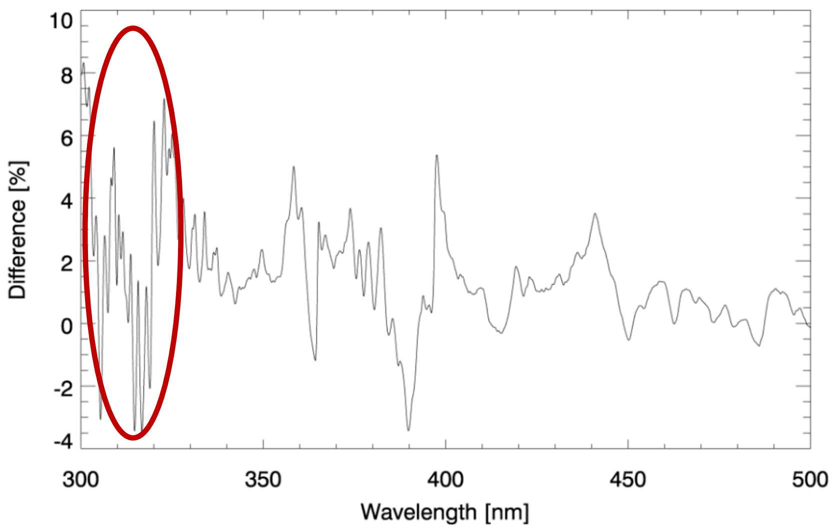


Fig. Comparison between irradiance spectra
SAO spectrum (Chance and Kurucz, 2010), OMI spectrum (Dobber *et al.*,2008)

Algorithm Input		**Algorithm Output**
Reference spectrum	Assumed measurement	X^2 (e^{-6})
KNMI	KNMI	4.89
SAO2010	SAO2010	5.46
KNMI	SAO2010	275

II. GEMS L1B challenge

◆ Spectral calibration for L1b Earth Radiance

$$I(\lambda) = \left[(AI_o(\lambda + \Delta\lambda) + \sum_i a_{1,j} X_{1,j}(\lambda)) \times exp\left(-\sum_i n_i \sigma_i(\lambda)\right) + \sum_i a_{2,i} X_{2,i}(\lambda) \right] P_s{}^m(\lambda) + P_b{}^m(\lambda)$$

Additional fit of spectral feature

by the trace gas absorption, Mie/Rayleigh scattering and the Ring effect

Need to consider time requirement

Will be compared/determined between two approaches

- Spectral assignment (parameterization)
  - Doppler effect
  - OPB temperature variation
  - Scene inhomogeneity
- Spectral fitting (Linearization)
  - Apply Taylor expansion instead of OE (optimal estimation) method

II. GEMS L1B challenge

◆ Current Stray light correction

- ❖ Stray light is calculated by multiplying the ratio of nominal radiance and observed data to pre-calculated stray light of nominal radiance

$$Q_{sl}(i,j) = \frac{\dfrac{Q_{Nominal\ local}}{global}(i,j)}{\dfrac{Q_{input\ local}}{global}(i,j)} * SL_{nominal}(i,j) * Q'_{input}(i,j)$$

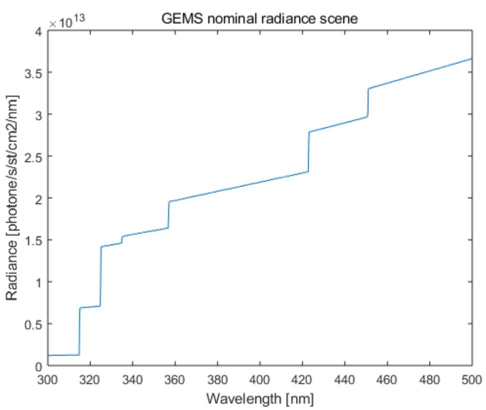


Figure . GEMS nominal radiance

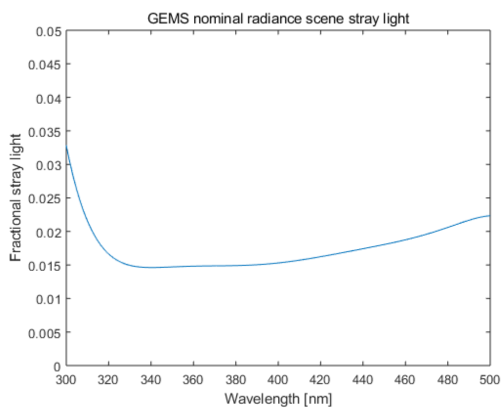


Figure . Pre-calculated stray light of GEMS nominal radiance

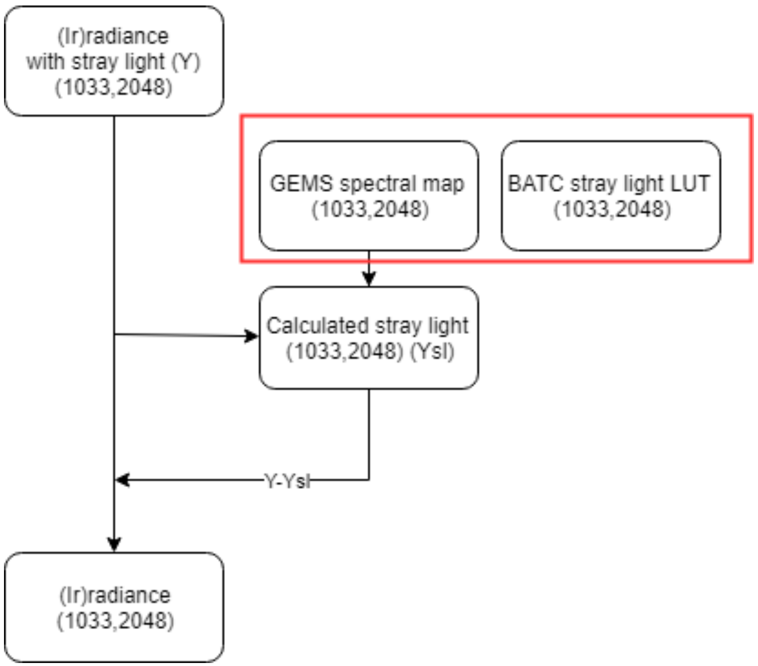
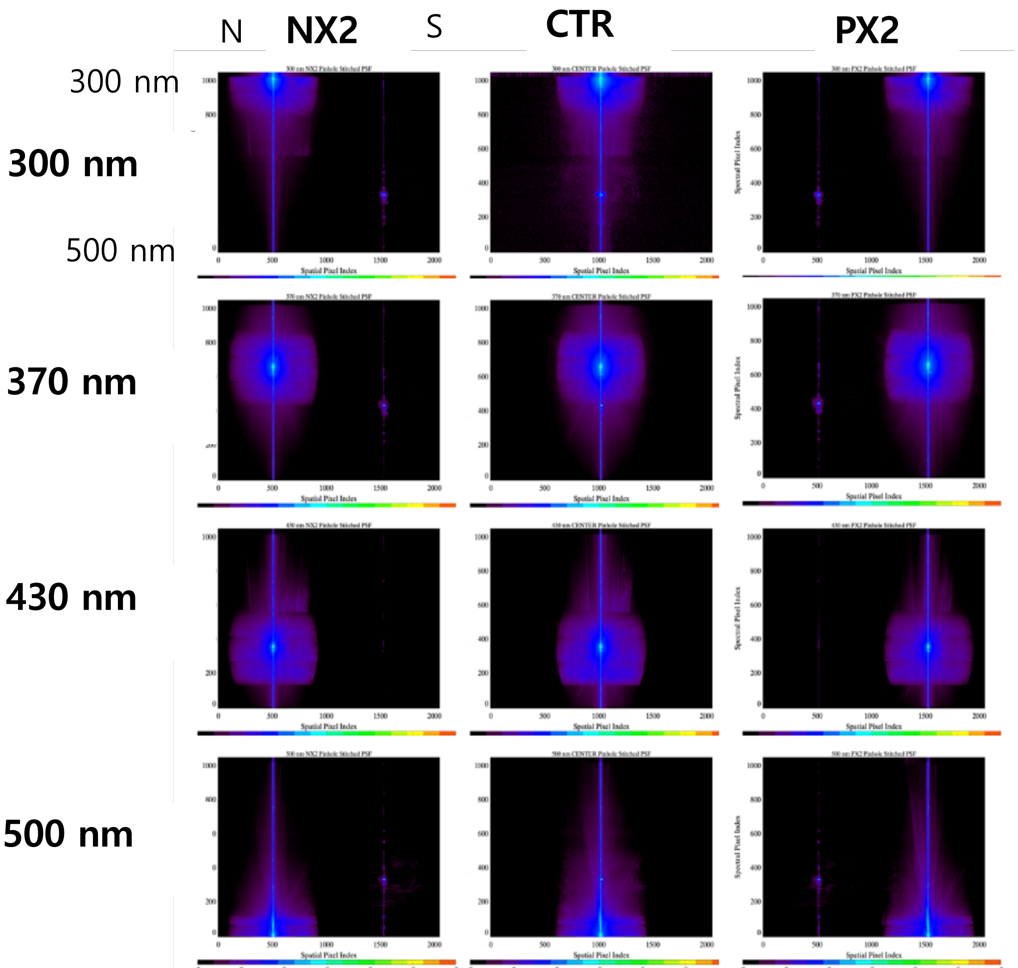


Figure . Flowchart of current GEMS stray light correction

II. GEMS L1B challenge

◆ GEMS Point Spread Function (PSF)

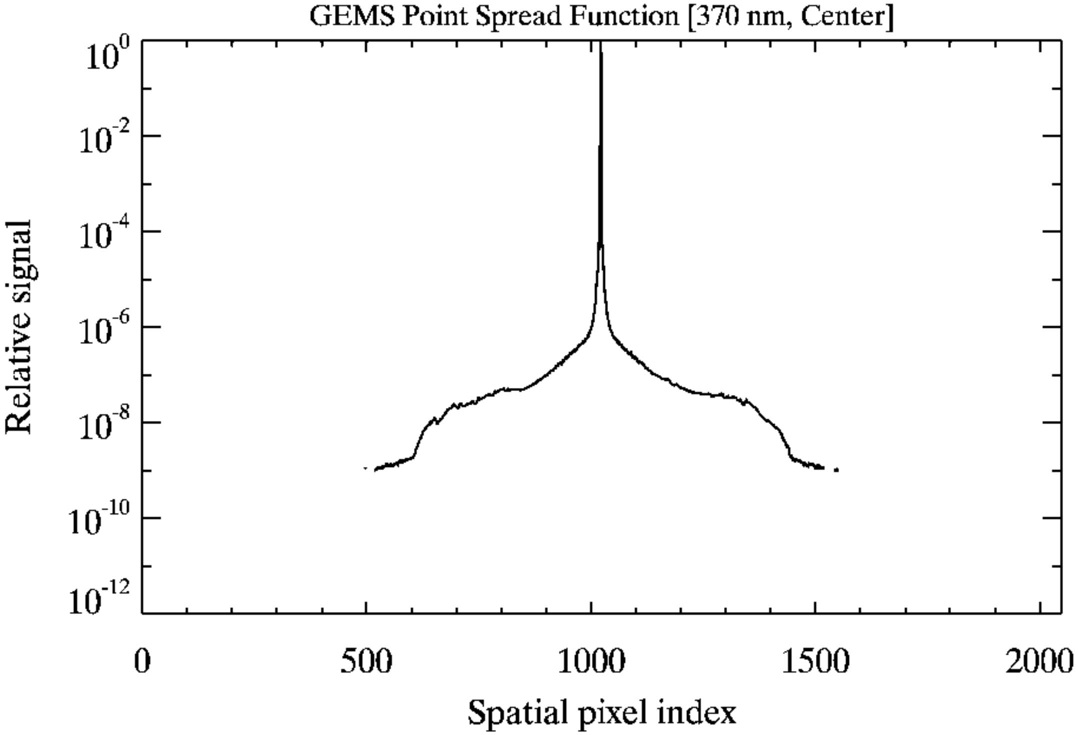


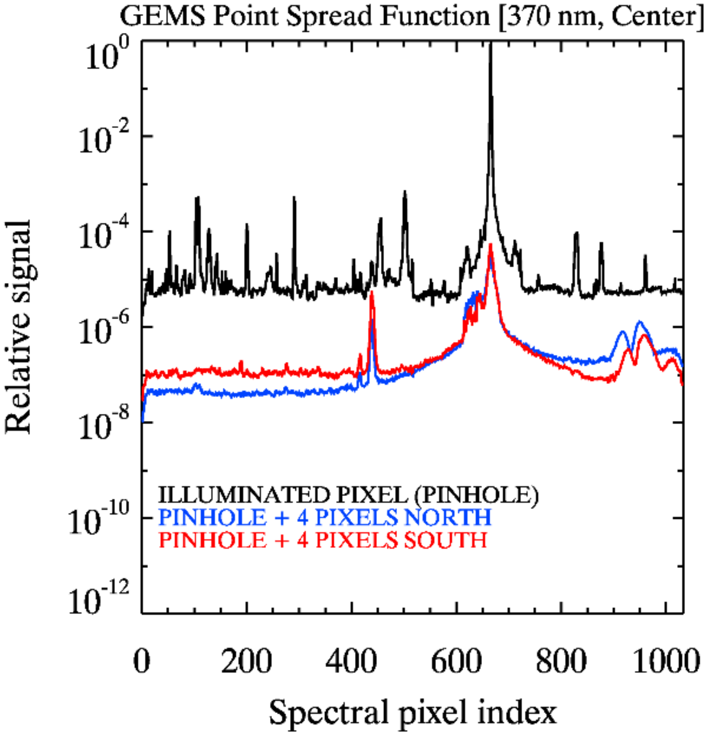
- ❖ GEMS PSF at four discrete wavelengths and at three discrete location within the GEMS FOV(Field of view)
  - Pinhole : NX2, Center, PX2
  - Wavelength (nm) : 300, 370, 430, 500
- ❖ GEMS detector size
  - [1033(Spectral),2048(Spatial)]
- ❖ Spectral and Spatial Ghost at specific location
- ❖ Defines the 19(3 FWHM) * 19 pixel box centered on the PSF peak as inband area

II. GEMS L1B challenge

◆ GEMS Point Spread Function (PSF)

- ❖ Signal of Spectral Line Spread Function(LSF) is stronger than Signal of Spatial LSF





II. GEMS L1B challenge

◆ GEMS Point Spread Function (PSF)

❖ Spectral Spike

- Similar spike at same wavelength but different pinhole location
- The distance between peak value and spectral spike did not show constant pattern

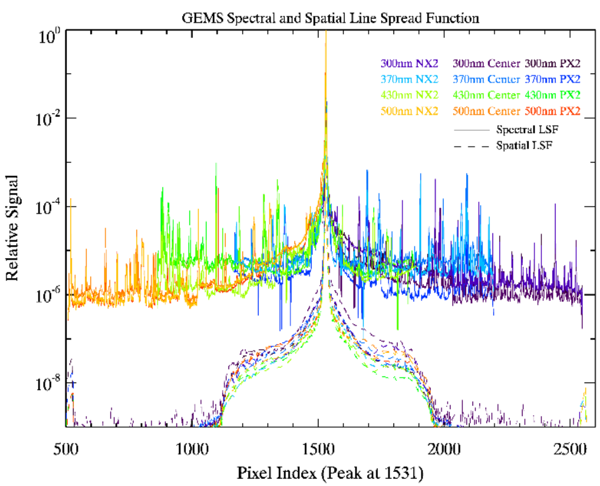


Figure. GEMS Spectral and spatial Line Spread Function by corresponding each peak

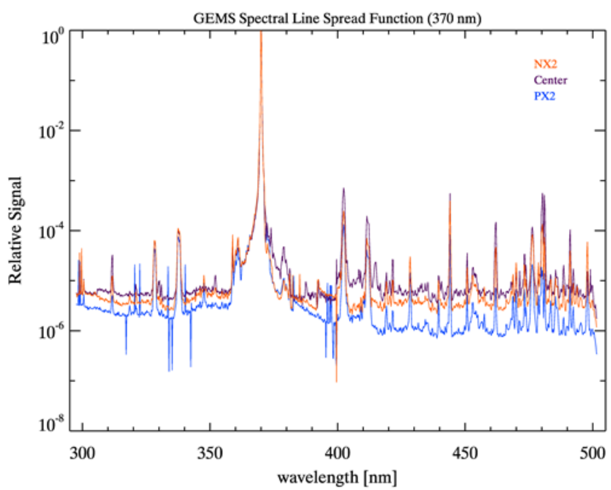


Figure. GEMS Spectral Line Spread Function which peak wavelength is 370 nm

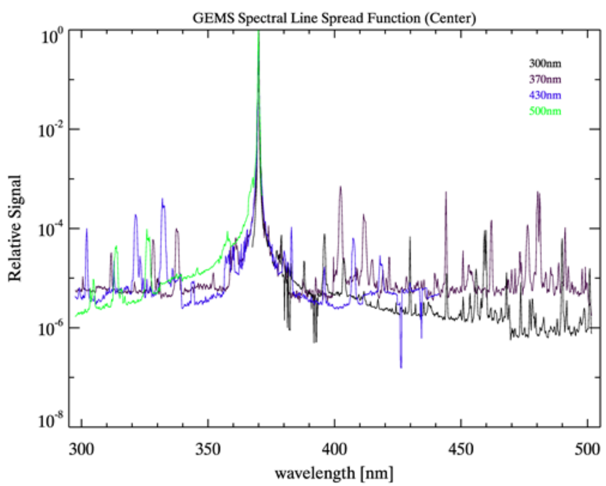


Figure. GEMS Spectral Line Spread Function at center pinhole location