Tropospheric Emissions: Monitoring of Pollution

TEMPO

Straylight Correction for Mega-Pixel Imaging Spectrometer

David Flittner, *TEMPO Project Scientist*

Contributions from:

Macey Sandford, *NASA Intern*

Mijin Eo, *Ewha University*

Kelly Chance & Xiong Liu, *SAO*

Ball TEMPO Team, *Ball Aerospace Technologies Corp.*

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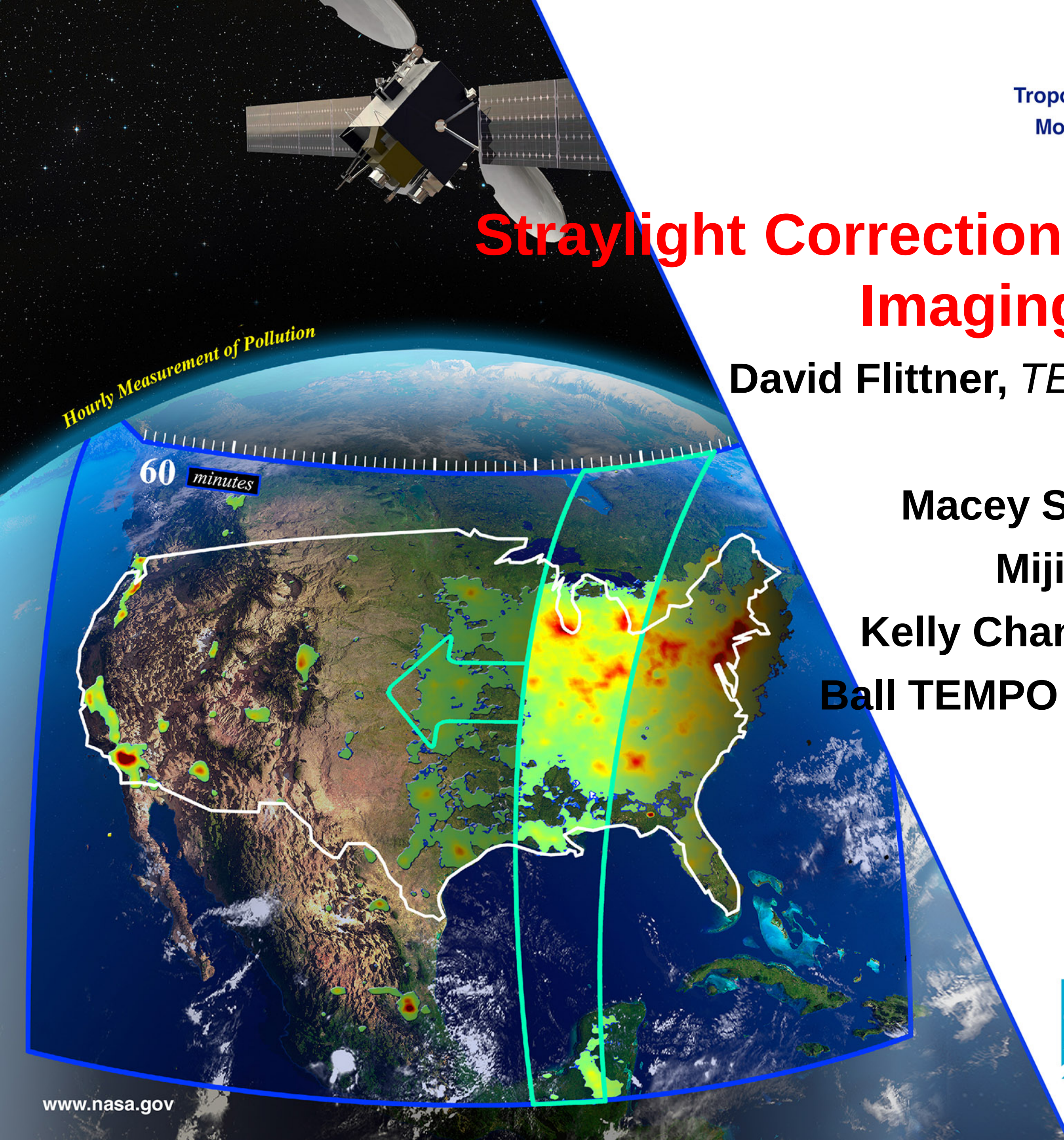
David.E.Flittner@NASA.gov



Smithsonian

Outline

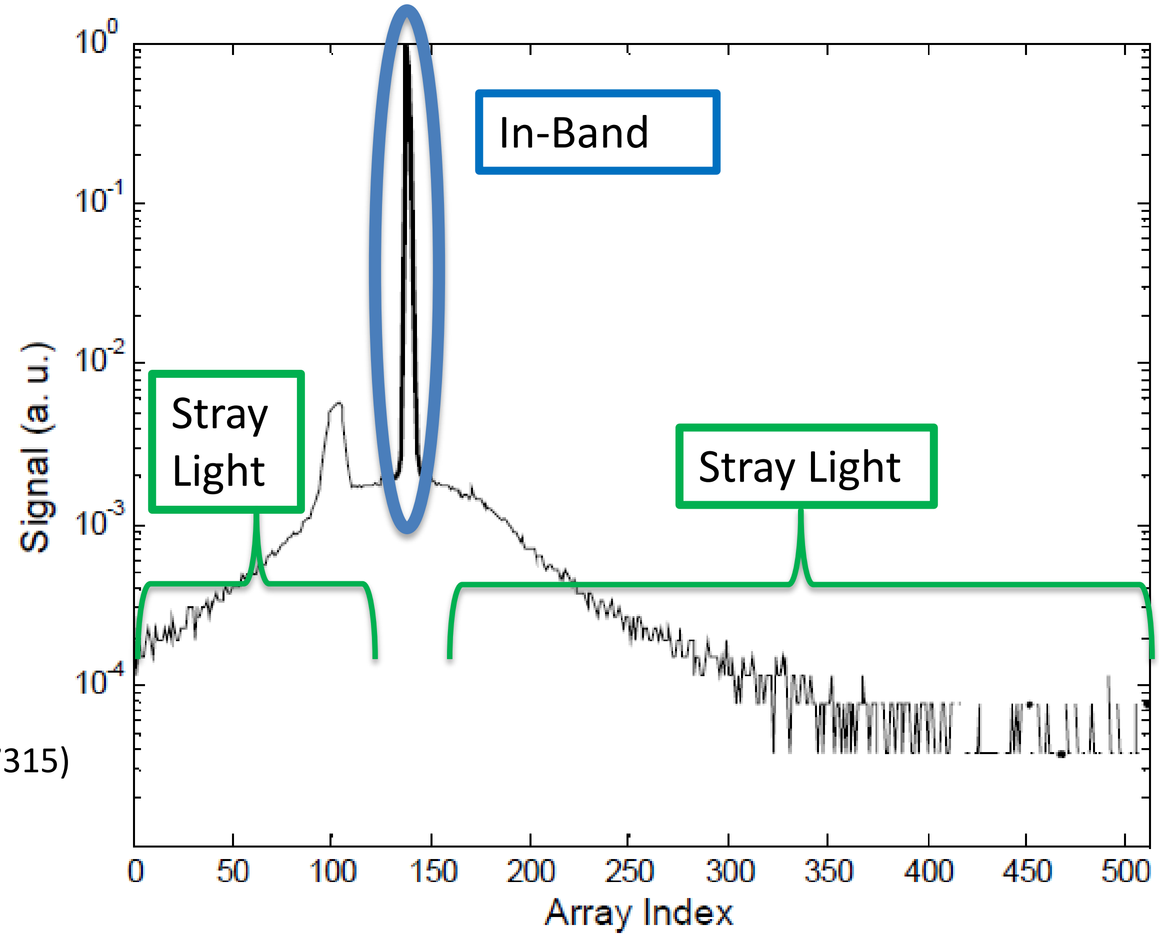
- **Stray Light Definition**
- **TEMPO – GEMS Relevant similarities & differences:**
- **Stray Light Correction:**
- **TEMPO Approach**
- **Examples**
- **Remaining work**
- **Summary**

Stray light

- **Definition: Pixel stray light is the total contributions from all sources outside the spectral and spatial region near the pixel (TEMPO: 19 x 19).**
  - Other names are Out-of-Band, Out-of-Field
- **Contributions from sources inside the near region are In-Band (IB)**

Stray light: continued

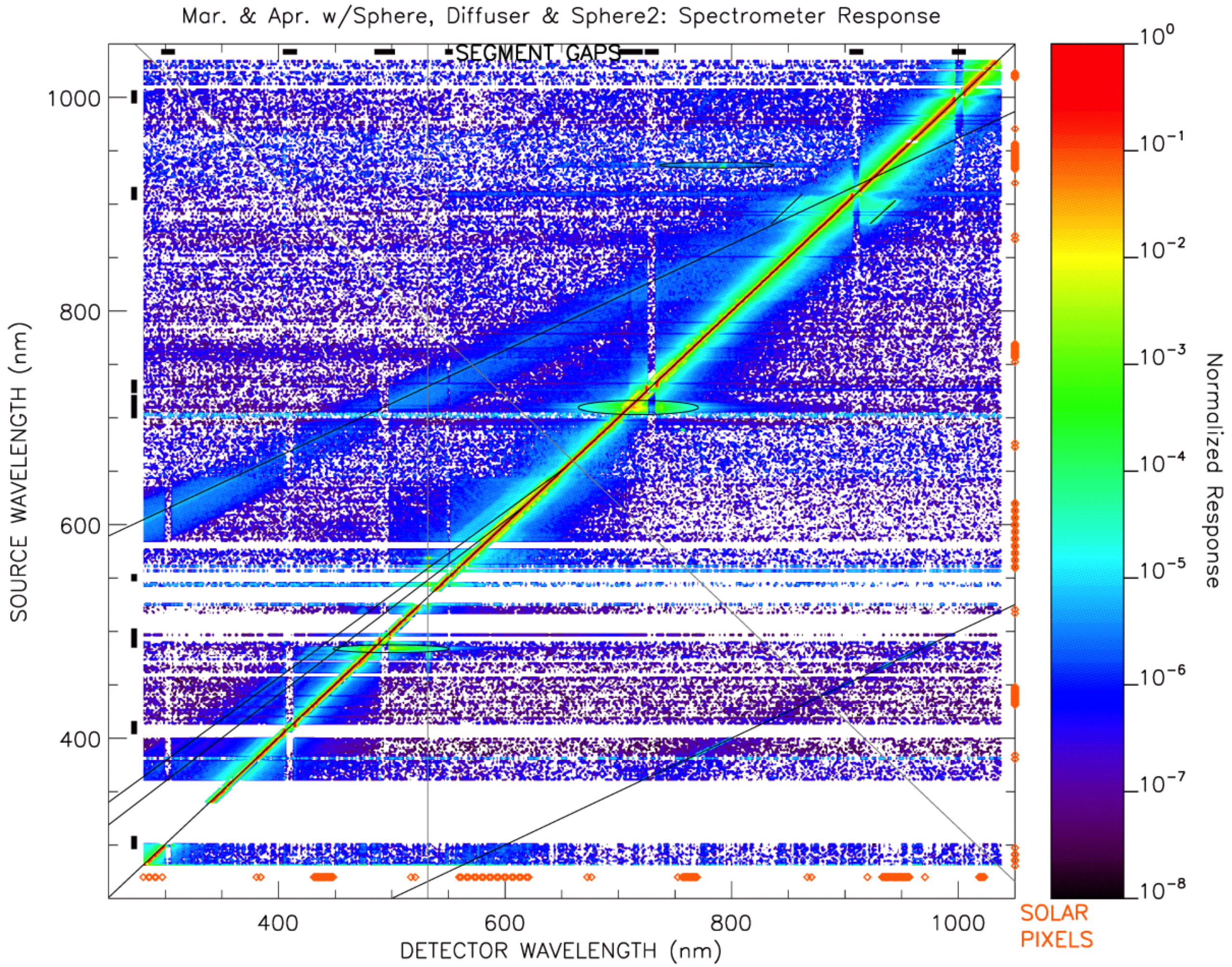
- **Point Spread Function is the instrument response to a point source.**
  - Informs IB and SL



Zong et al. 2007
(doi: 10.1117/12.737315)

Example

➢SAGE III/ISS stray light covariance map



TEMPO – GEMS salient features

- **TEMPO & GEMS are conceptually the same:**
  - Imaging spectrometer: telescope feeding entrance slit of spatially resolving spectrometer
- **Different Field of Regard, different telescope, but spatial sampling in the range of 2k pixels.**
- **Spectrometers are virtually identical, except:**
  - TEMPO spectral range is 290-490 nm and 540-740nm imaged onto 2 CCDs with a total of ~ 2k pixels.
  - GEMS spectral range is (300-500 nm) imaged onto 1 CCD with a total of ~1k pixels.
  - Same spectral resolution & sampling
- **TEMPO (4 MegaPixel) image is twice as large as GEMS (2 MegaPixel)**

Stray light Correction

- **Two basic approaches to correction:**
  - Direct measurement via masked/shadowed pixels
    - Must be design feature of focal plane
    - Typically at edge(s) of image region
    - Assume stray light variation between measurement points
  - Processing illuminated pixels
    - Need to know point spread function
    - Deconvolution
    - Iterative, e.g. Richardson Lucy
    - Inverse (Feinholz et al. 2012)

TEMPO approach

- **Direct measure not practical:**
  - TEMPO does not have dedicated stray light pixels on the focal plane.
  - Anticipate non-trivial variation of stray light across focal plane.
    - Significant gradients on focal plane in both spectral (UV-Visible) and spatial (North-South) directions
- **Processing image can be more accurate and robust.**
  - Requires very good PSF information
  - Challenge for mega-pixel sensor is large number of detectors
  - Reduce number by reducing resolution

Method of Feinholz et al.

The total measured signal from an incident light source consists of both in-band (IB), or properly imaged, signal and SL signal: $Y_{meas} = Y_{IB} + Y_{SL}$

Each of these is a column vector consisting of n components, where n=number of pixels in detector array. We can characterize the SL in terms of the IB signal with tensor D, also known as the SL distribution matrix, whose element magnitudes are “fractional contributions from the IB signal”;

$$Y_{SL}^{i} = \sum_{j} \vec{D}^{ij} Y_{IB}^{j}$$

Thus,

$$\vec{Y}_{meas} = \vec{Y}_{IB} + \vec{Y}_{SL} = \vec{Y}_{IB} + \vec{D} \cdot \vec{Y}_{IB}$$

Feinholz et al., continued

$$\vec{Y}_{IB} = I \cdot \vec{Y}_{IB}$$

Then,

$$\vec{Y}_{meas} = [I + \vec{D}] \cdot \vec{Y}_{IB}$$

Or,

$$\vec{Y}_{IBCorr} = \frac{1}{[I + \vec{D}]} \cdot \vec{Y}_{meas}$$

Where we can write $\vec{A} = [I + \vec{D}]$ so that

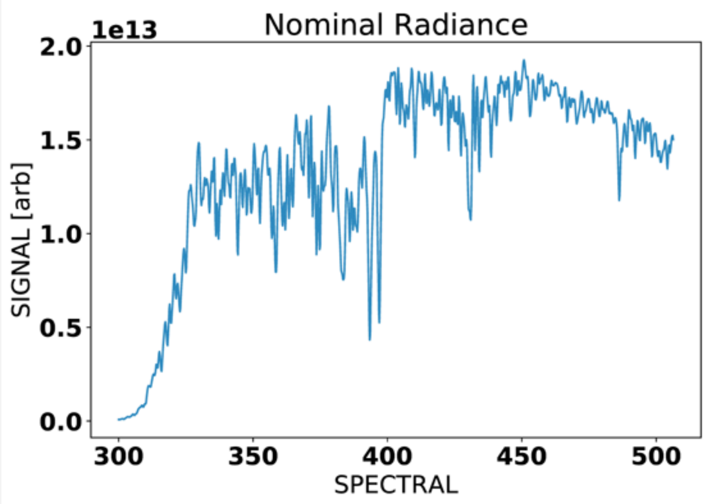
$$\vec{Y}_{IBCorr} = \vec{A}^{-1} \cdot \vec{Y}_{meas}$$

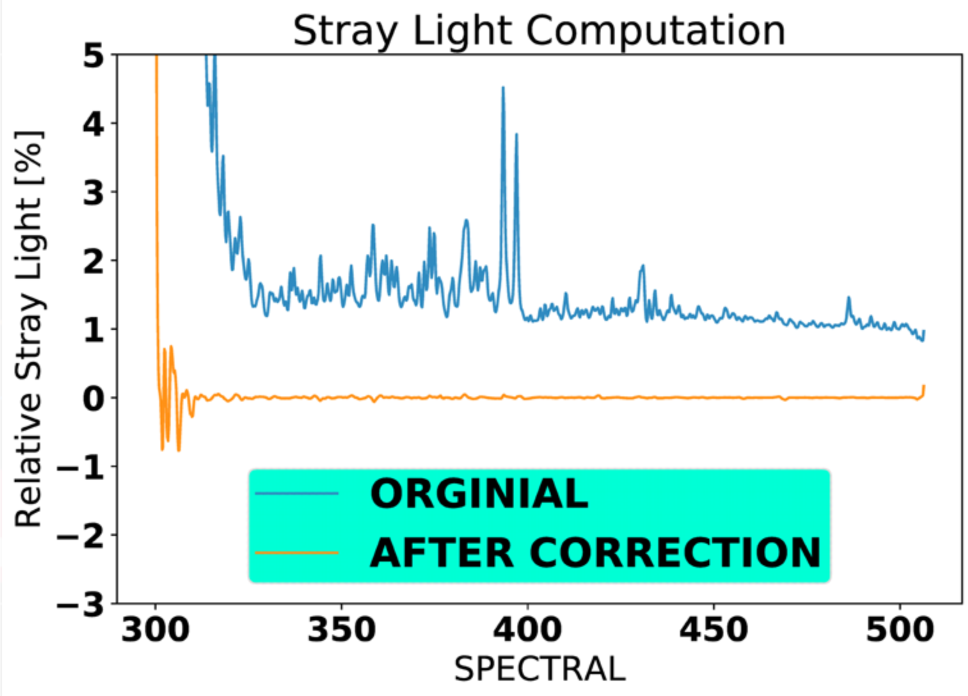
Using $C=A^{-1}$; $\boxed{\vec{Y}_{IBCorr} = \vec{C} \cdot \vec{Y}_{meas}}$

For TEMPO focal plane (2k x 2k) at full resolution C is 4M x 4M; 10^{13} elements

Example

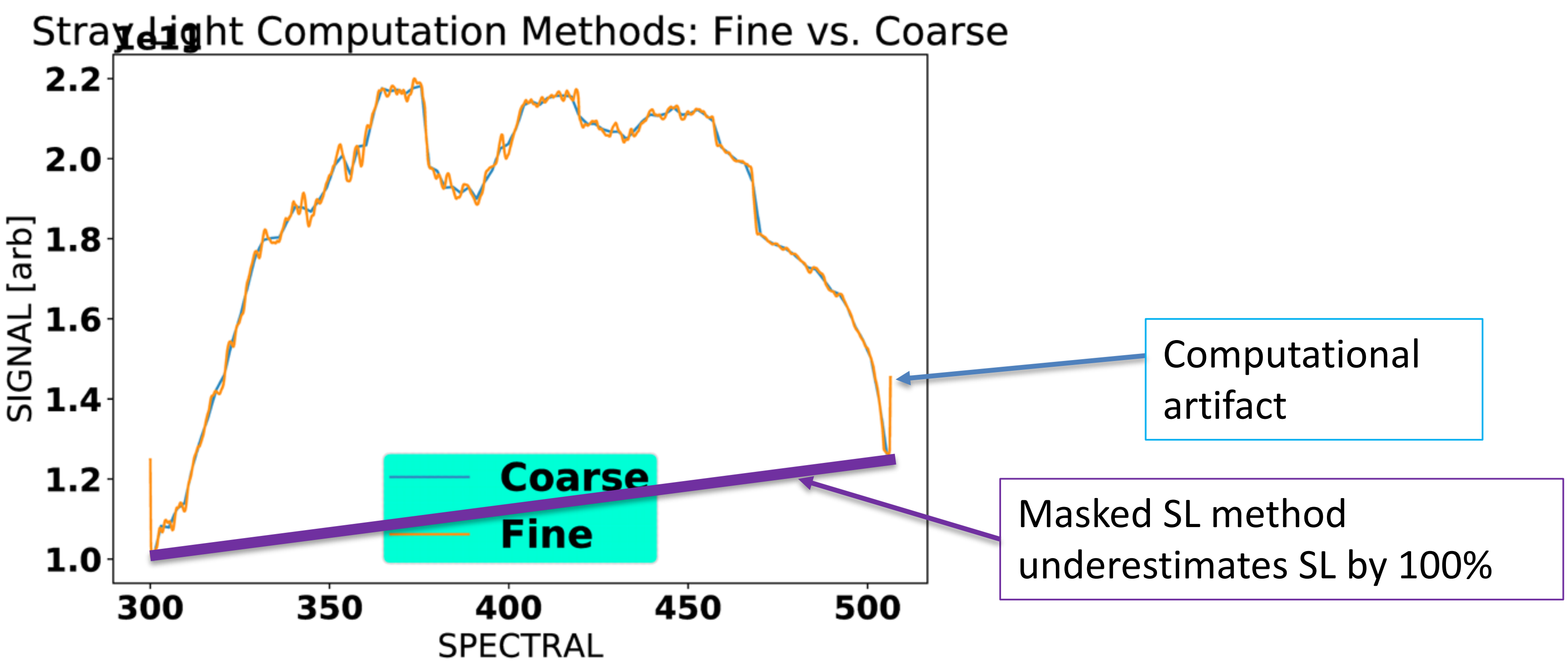
- **Illustration of stray light spectrum from hypothetical point spread function for TEMPO UV**





Reduced resolution results

- Reduced resolution (x11 in each dimension) compares to full resolution to within 2%.
- Correction matrix is $3\text{x}10^4$ x $3\text{x}10^4$ (10^9 elements)



Work to be done

- Compilation of TEMPO point spread functions from test data
- Create correction matrix
- Identify stressing cases with realistic simulated imagery
- Examine cases with saturated pixels

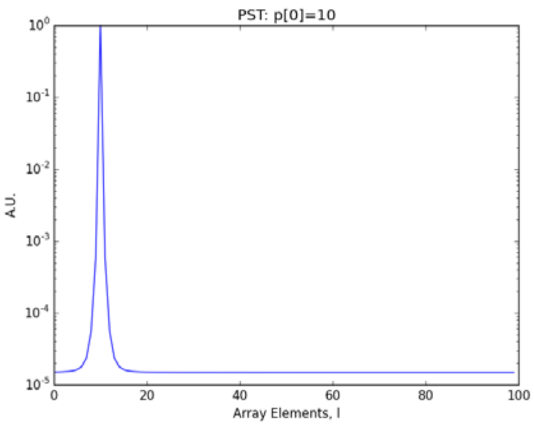
Summary

- TEMPO stray light for a pixel is defined as total contributions from all sources outside the 19 x 19 pixels spectral and spatial neighborhood of the pixel.
- Correction procedure will use processing of image with inverse method of Feinholz et al. 2012.
- Implementation will require reducing resolution in computations
- Residual stray light is expected to be ~1% or less for nominal cases
- Noise amplification is insignificant
- Need to identify stressing cases with realistic simulation imagery

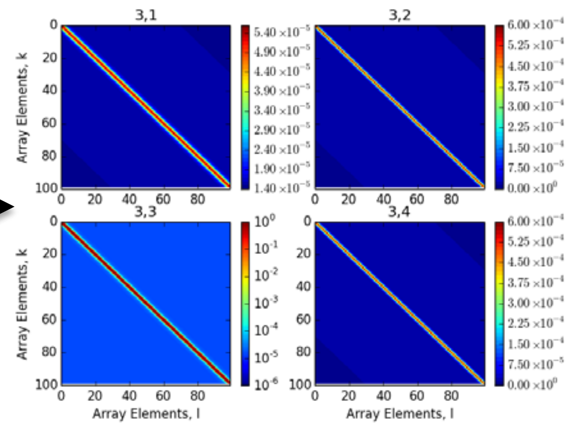
BACKUP

$$\vec{Y}_{SL} = \begin{bmatrix} \vec{Y}^1_{SL} \\ \vec{Y}^2_{SL} \\ . \\ . \\ . \\ \vec{Y}^m_{SL} \end{bmatrix} = \begin{bmatrix} \sum_j \vec{D}^{1,j}\vec{Y}^j_{IB} \\ \sum_j \vec{D}^{2,j}\vec{Y}^j_{IB} \\ . \\ . \\ . \\ \sum_j \vec{D}^{m,j}\vec{Y}^j_{IB} \end{bmatrix} = \begin{bmatrix} \vec{D}^{1,1}, \vec{D}^{1,2}, \vec{D}^{1,3} \ldots \vec{D}^{1,m} \\ \vec{D}^{2,1}, \vec{D}^{2,2}, \vec{D}^{2,3} \ldots \vec{D}^{2,m} \\ . \\ . \\ . \\ \vec{D}^{m,1}, \vec{D}^{m,2}, \vec{D}^{m,3} \ldots \vec{D}^{m,m} \end{bmatrix} \cdot \begin{bmatrix} \vec{Y}^1_{IB} \\ \vec{Y}^2_{IB} \\ . \\ . \\ . \\ \vec{Y}^m_{IB} \end{bmatrix}$$

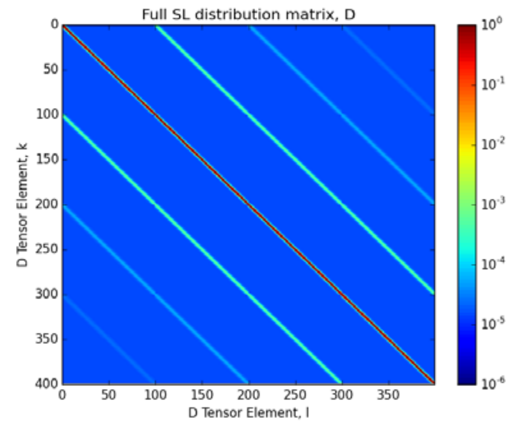
Example



Calculated PSF (point spread function) based on an actual instrument; Values greater than 1% (10^{-2}) of the peak value are considered IB



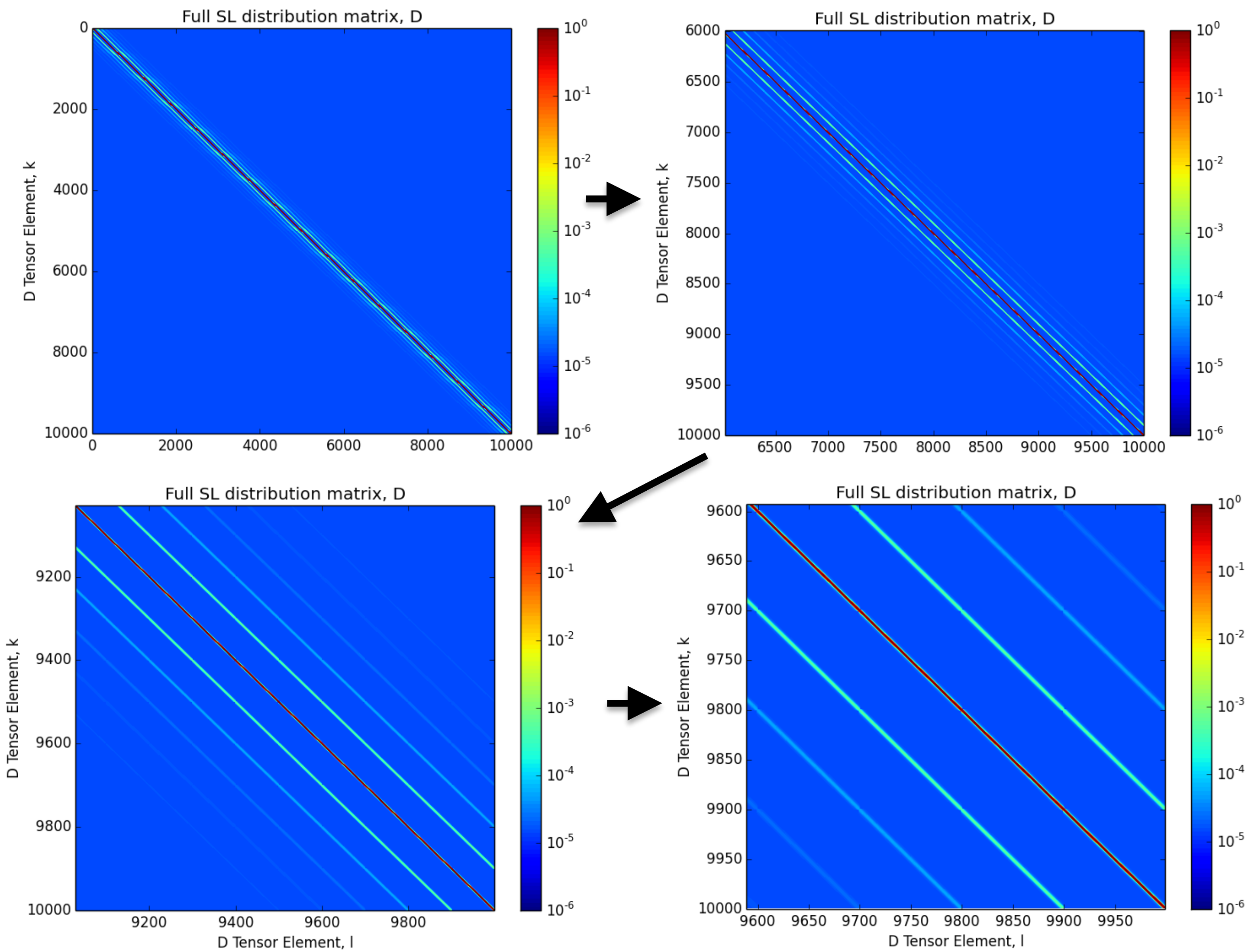
Four contour plots of D submatrices ($D^{i,j}$) displaying scattering from channels 1,2,3,4 into channel 3; i.e. $D^{3,1}, D^{3,2}, D^{3,3}, D^{3,4}$.



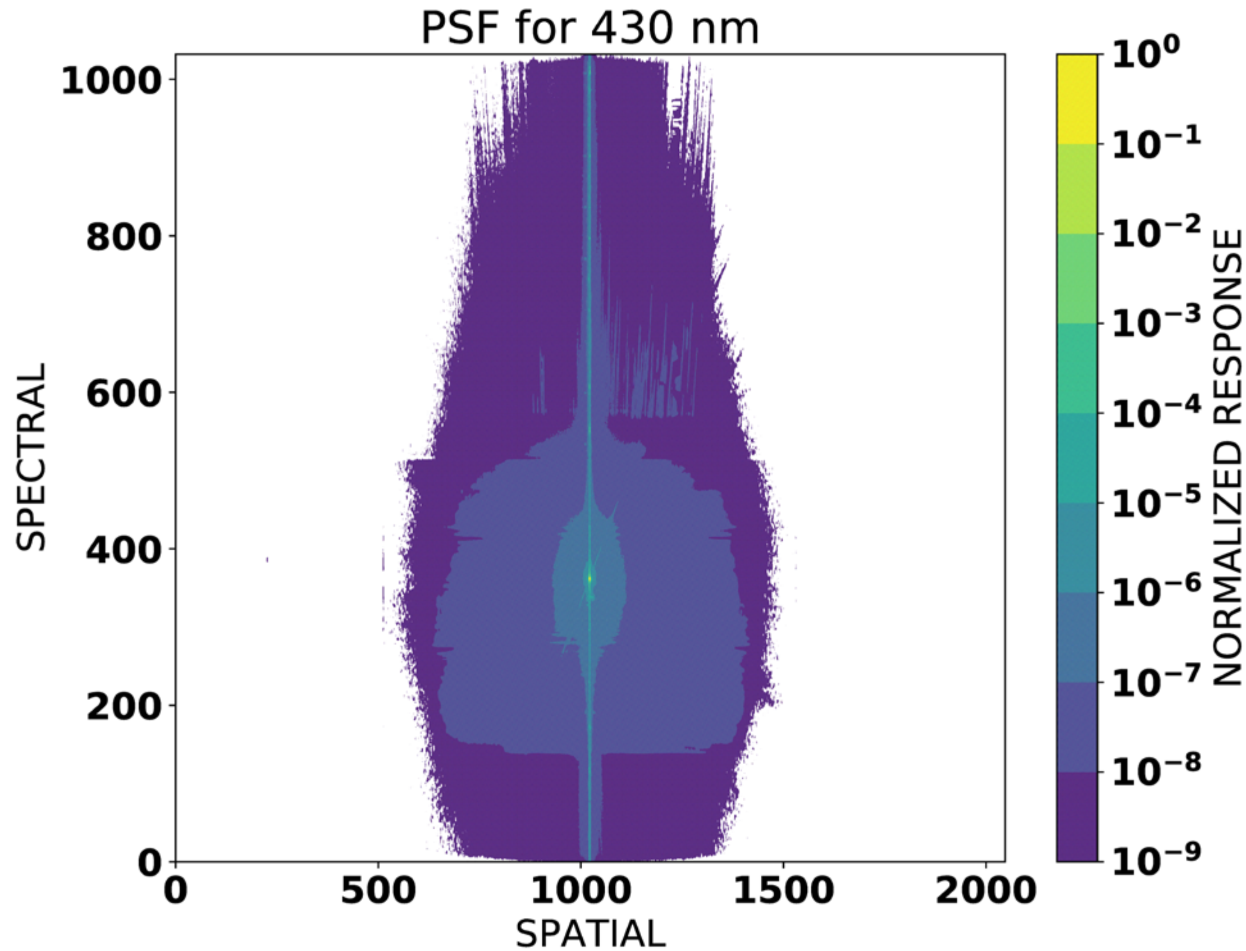
D tensor for 100x100 elements, 4 channels; 400x400 resulting elements

Example, continued

D Tensor for 100x100 element arrays with 100 channels: 10^4x10^4



TEMPO-like PSF



Courtesy BATC

TEMPO