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# 2. MDIS Calibration

**Brett Denevi**
*Johns Hopkins University Applied Physics Lab*
*MDIS Deputy Instrument Scientist*

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# Calibration Agenda

- Radiometric Calibration
  - Particular emphasis on responsivity variation with time (contamination event)
- Scattered Light
- Photometric Normalization

# MDIS Radiometric Calibration

- Five main components of calibration
- Radiance = Linearity(Raw DN - Dark - Smear)/(Flat * Exposure time * Responsivity)
  - Nonlinearity is small, correction works well
  - Dark model performing well (errors < 5 DN)
  - Frame transfer smear – small update to correction
  - Flatfields updated from ground calibration for two filters
  - Responsivity: temperature dependent, time dependent

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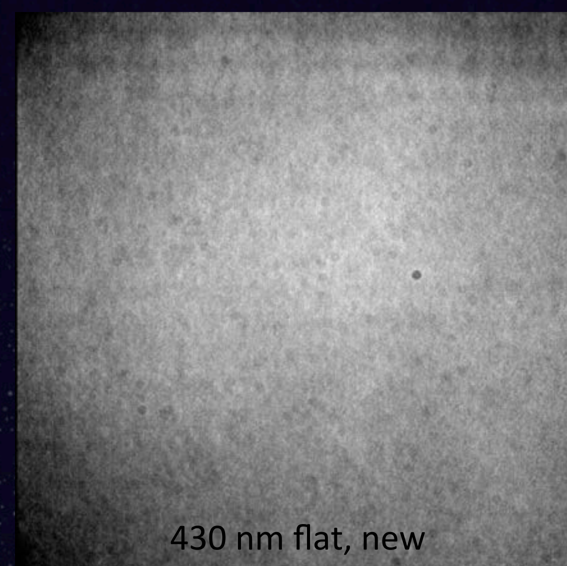
# Flatfields

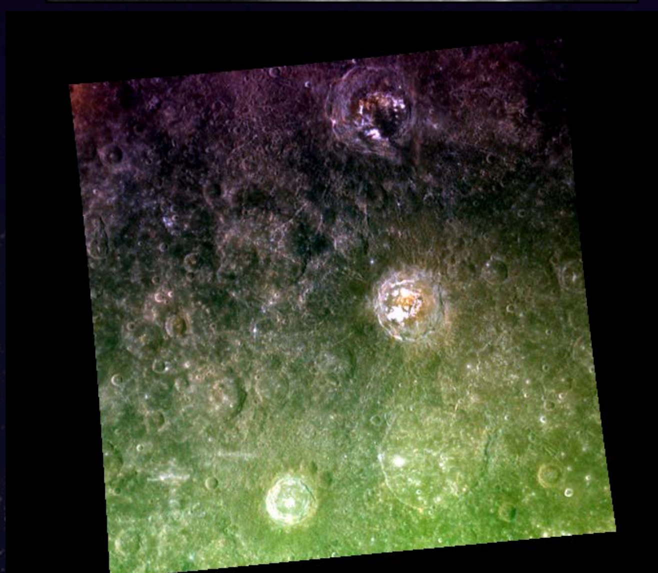
- Pre-flight flats were saturated for top portion of 430 and 480 nm bands
- Created new flats using all orbital images with entire scene on the planet, incidence < 80°
- Overall change is small
- Current flatfields appear to be performing well

430 nm flat, old



430 nm flat, new

# Frame transfer smear



RGB: 1000, 750, 430 nm
RGB: 22, 6, 51 ms exposures

- 3.84 ms to transfer frame from active portion of the CCD to memory, lines transferred one at a time from top to bottom 3.7 µs at a time
- For short exposure times, smear can be >50% of signal at bottom of image
- Small errors (up to 5%) in previous frame transfer times being used, offset of 16 lines not accounted for
- Update working well

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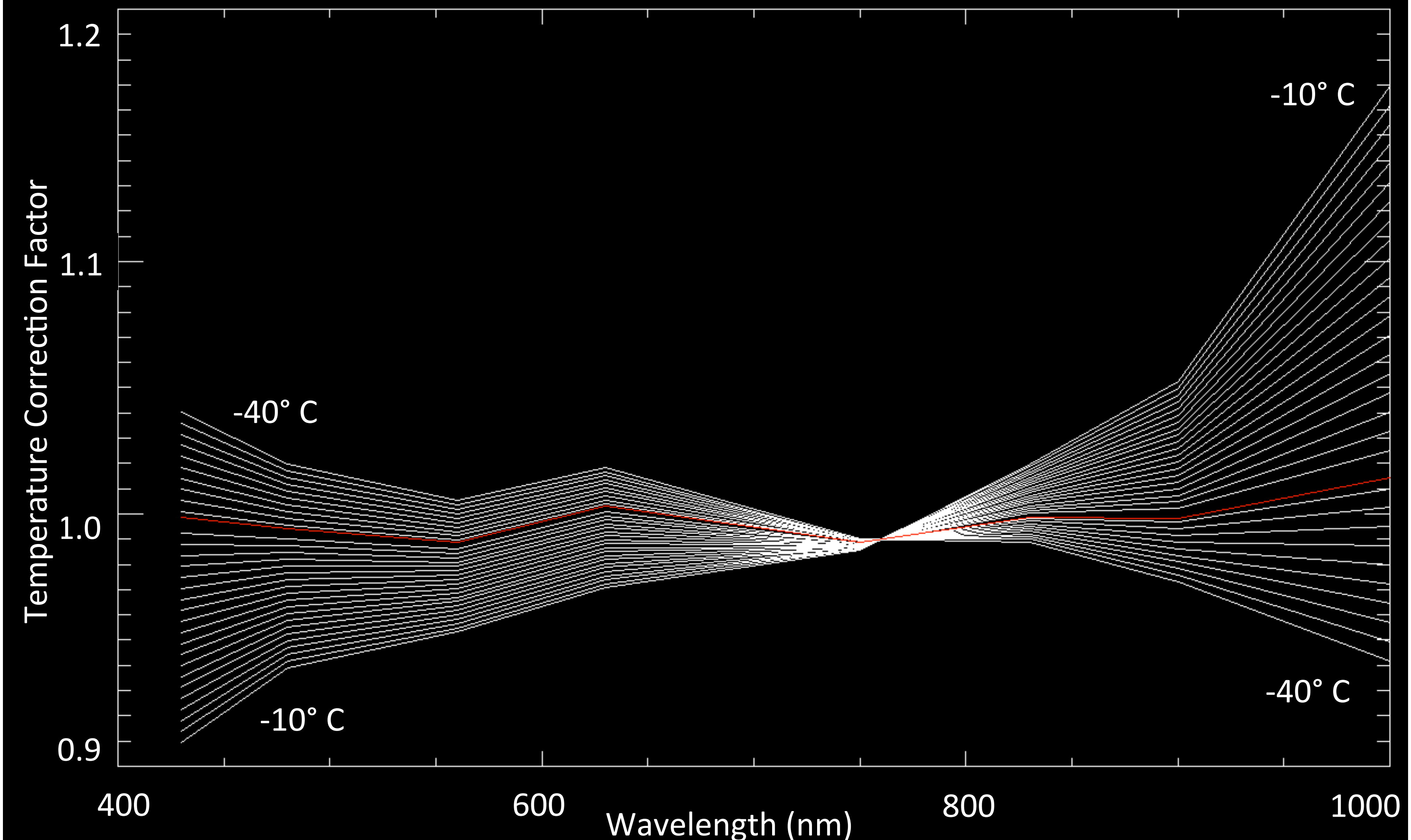
# Responsivity variation with temperature

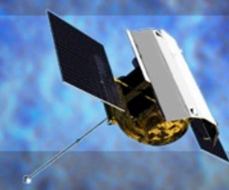
- MDIS has a wax buffer that keeps the CCD between -40 and -10° C
- Still, significant changes in responsivity of the CCD over this range
- Ground calibration did not do a great job of characterizing response over full range – updated from flyby and orbital data

  Resp(T,b) = R(t=-30.3C,b) *

  [correction_offset(b) + T(CCD) * correction_coef1(b) + T(CCD)^2 * correction_coef2(b)]




At longer wavelengths, relative responsivity increases with temperature
Hotter images → redder without correction



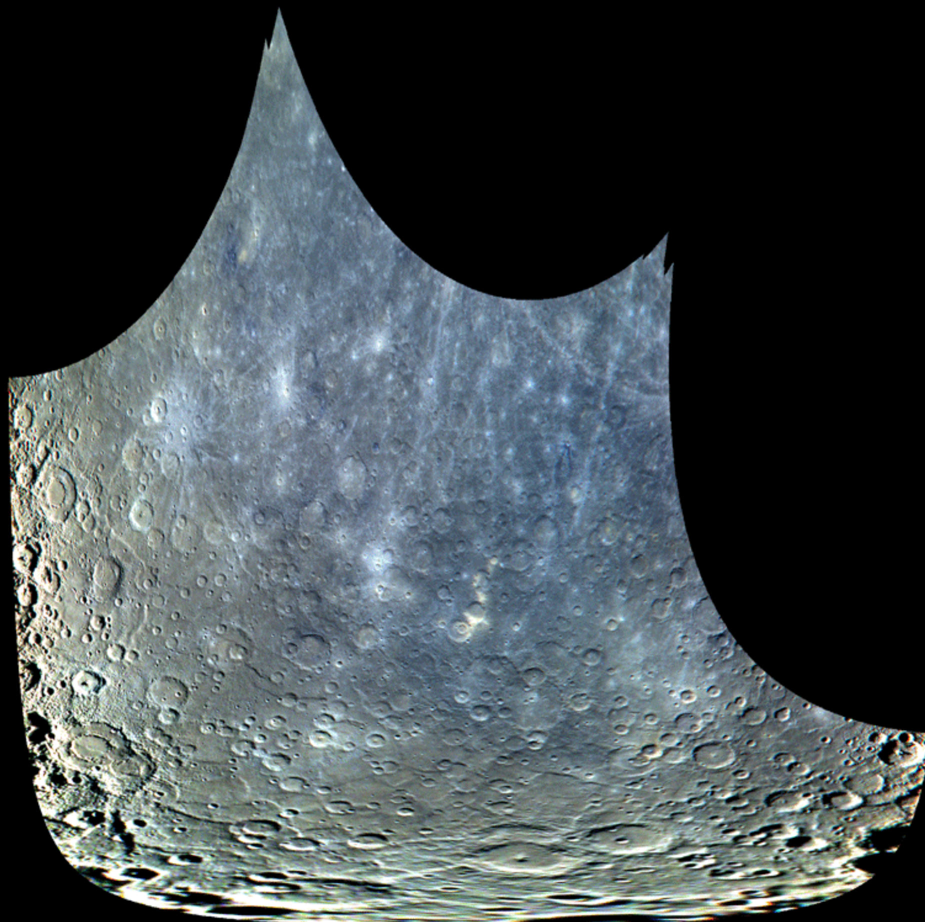
# Responsivity variation with temperature

- Temperature correction generally performing well under nominal operating conditions
  - Further improvements once other aspects of the calibration are refined
- However, a small number of images were acquired when CCD was hotter than -10°C (too red)
  - Only occurred in 8-hour orbit, after first year of primary mission
  - This data is in the PDS, but is not part of the advanced products
  - Affects images collected as part of 3-color mosaic campaign
- Correction not yet updated for higher temperatures
- Coming soon…

# Responsivity variation with time

- Unexpected complication:
- The first time the spacecraft reached peak temperatures during MDIS operations in orbit (~May 24, 2011), a contaminant from the spacecraft was deposited on the WAC optics (we suspect)
- Contamination caused wavelength dependent changes in the responsivity of the system
- Large initial drop in responsivity, followed by a slow recovery
- Does not appear to have fully recovered by the end of the first year of operations

DOY 100



Mosaics of images collected on individual days of year (DOY) 2011
Note changes that begin DOY 143 (May 24)

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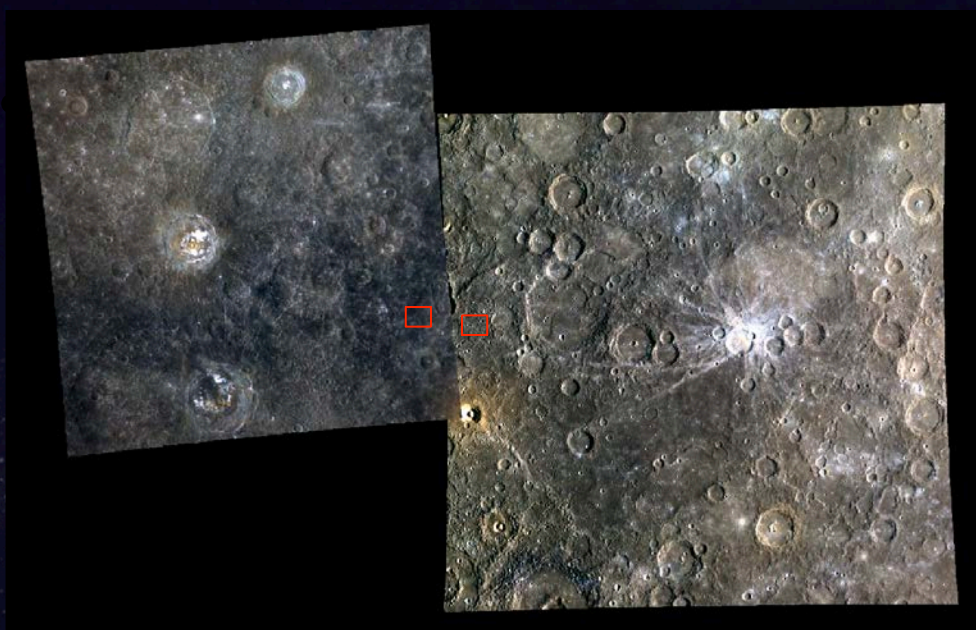
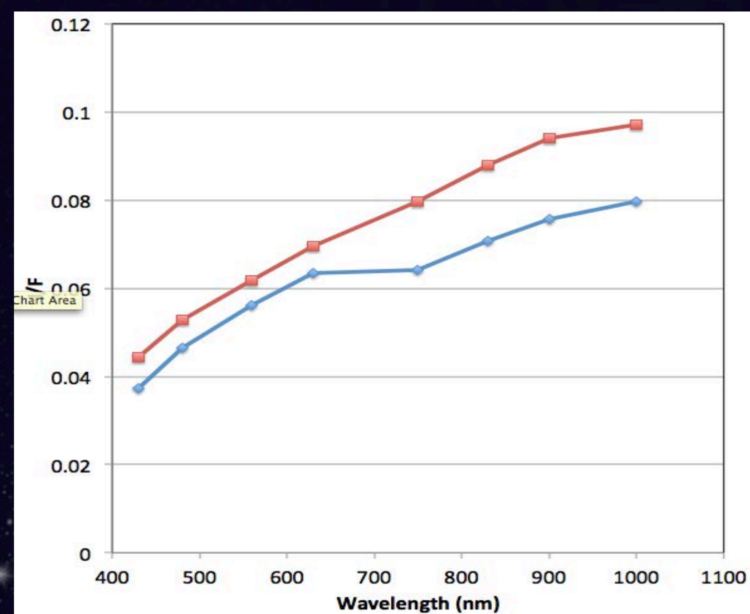
# Effects on spectra

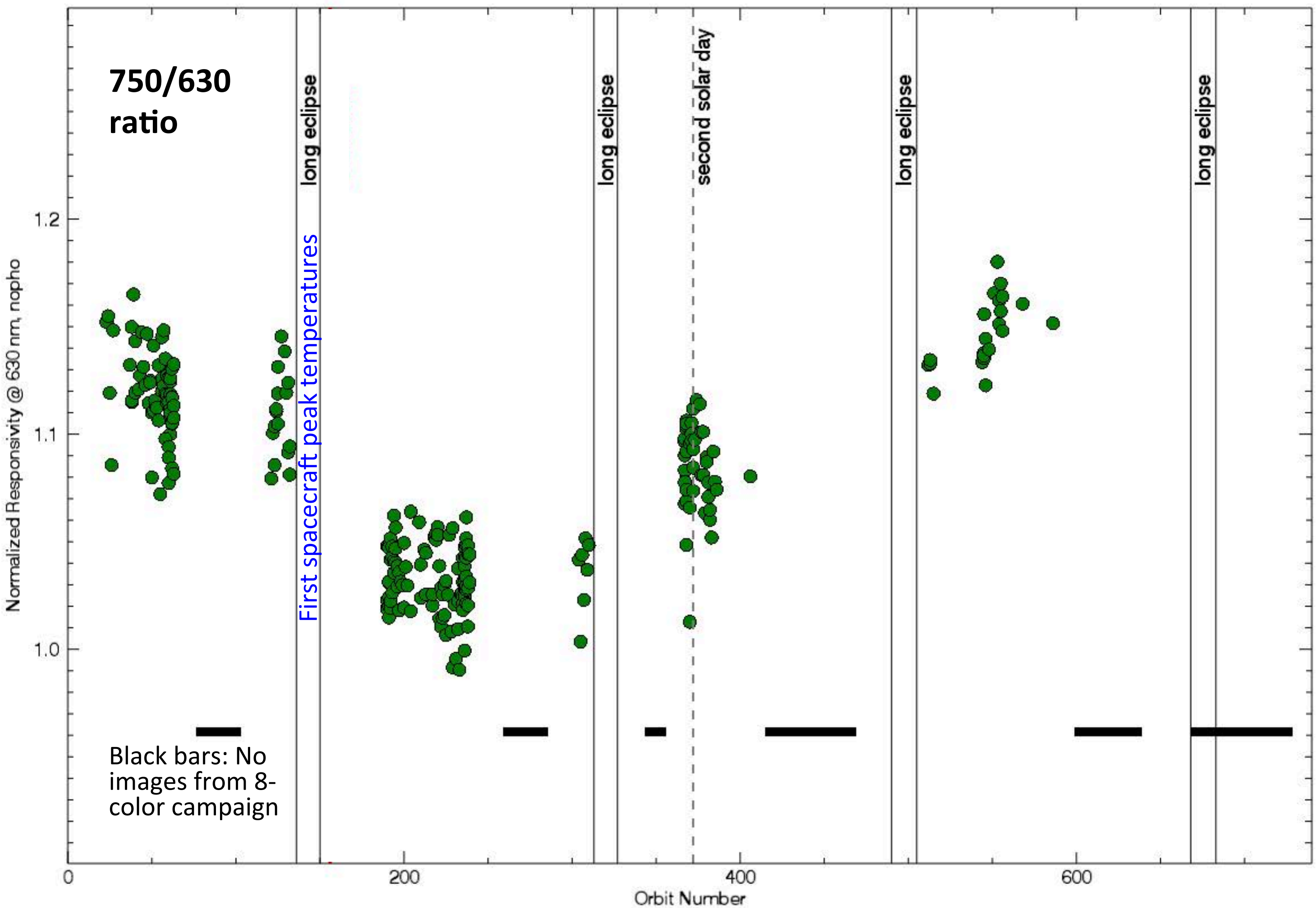
- Same region of the planet imaged early after orbit insertion (right image, red spectrum) and at a later date (left image, blue spectrum)

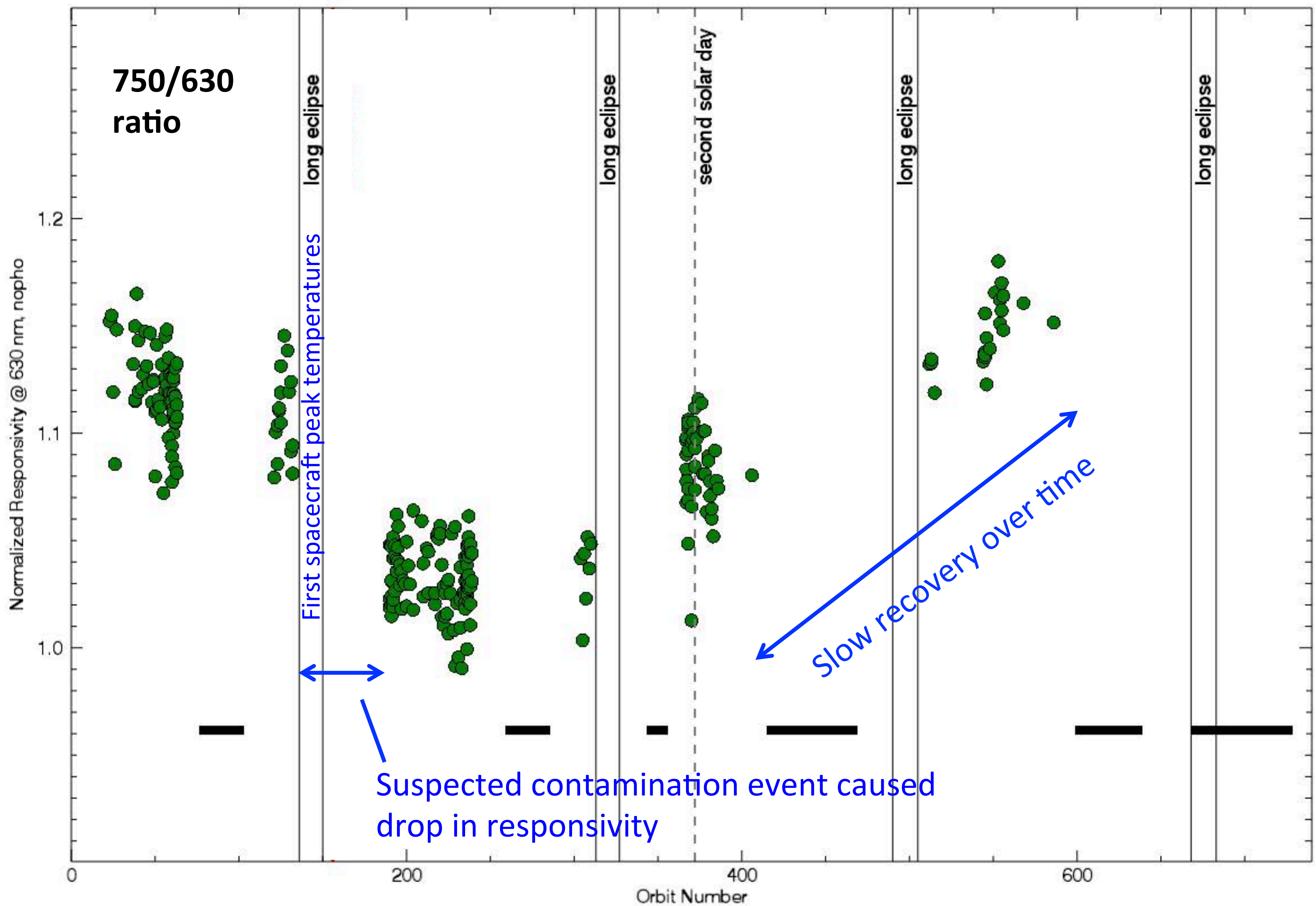




# Characterizing responsivity over time

- Selected 8-color sets over a narrow range of photometric angles and a broad range in time
- 630-nm filter appears to have smallest change – normalize other filters to 630 nm

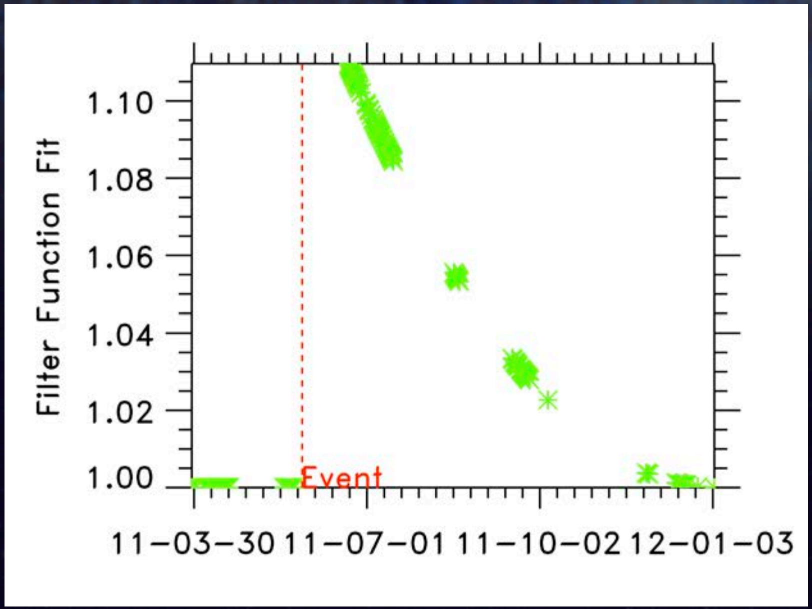

750/630
ratio
long eclipse
First spacecraft peak temperatures
long eclipse
second solar day
long eclipse
long eclipse
1.2
1.1
1.0
Normalized Responsivity @ 630 nm, nopho
0
200
400
600
Orbit Number
Black bars: No
images from 8-
color campaign



750/630
ratio
long eclipse
long eclipse
second solar day
long eclipse
long eclipse
First spacecraft peak temperatures
Slow recovery over time
Suspected contamination event caused drop in responsivity
Normalized Responsivity @ 630 nm, nopho
1.2
1.1
1.0
0
200
400
600
Orbit Number

# Correcting for the contamination event

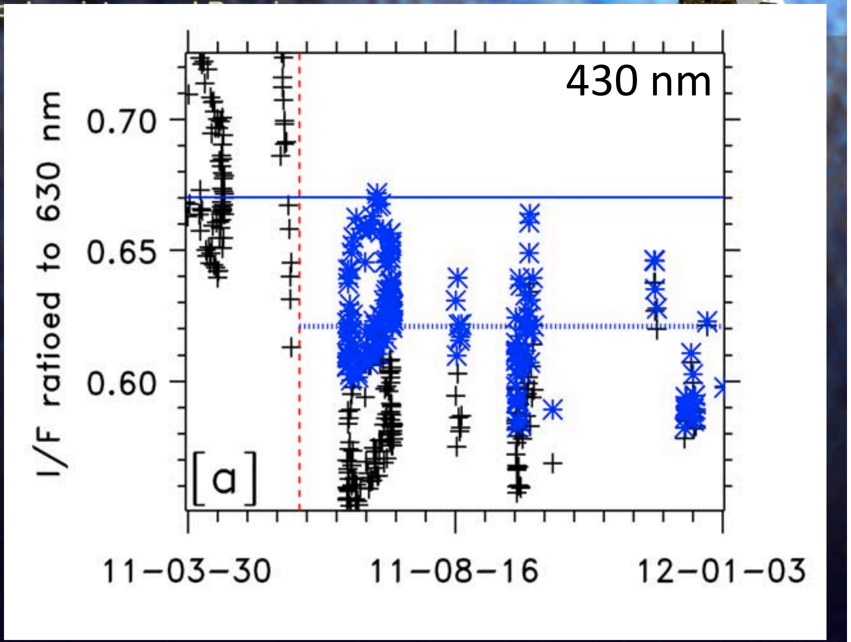
- Step 1 of initial correction (used in the PDS-delivered MDR mosaic):
  - Exponential function with time
  - Set to 1 (no correction) before June 23, 2011
    - Don't use data from ~May 24 - June 23, 2011
    - Data from this time not included in PDS released mosaic
  - All bands assumed to have the same time constant, returning to pre-event median by Feb. 2012
  - Step 1 correction not derived for 1000 nm band

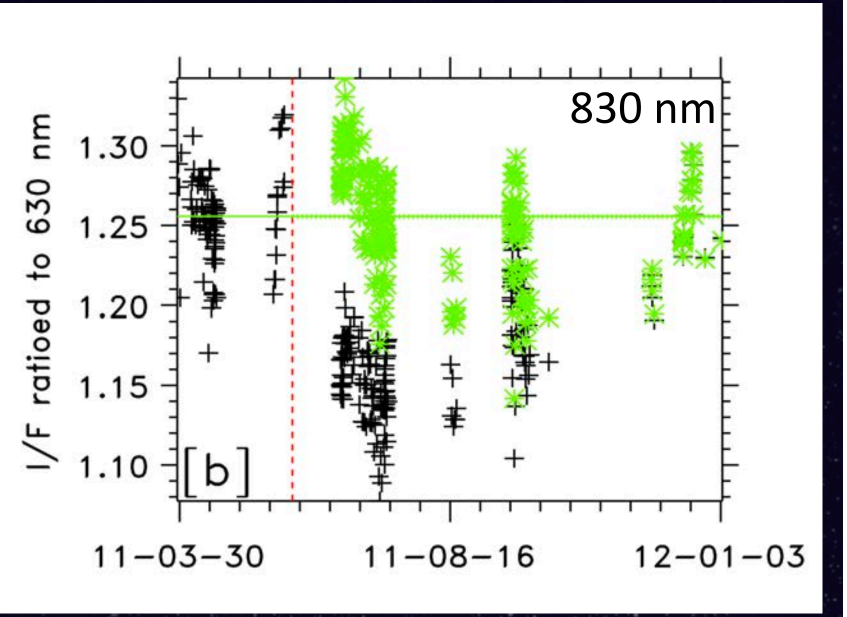



Fit to 830 nm filter
Shows only data post May 24 2011

# Example corrections

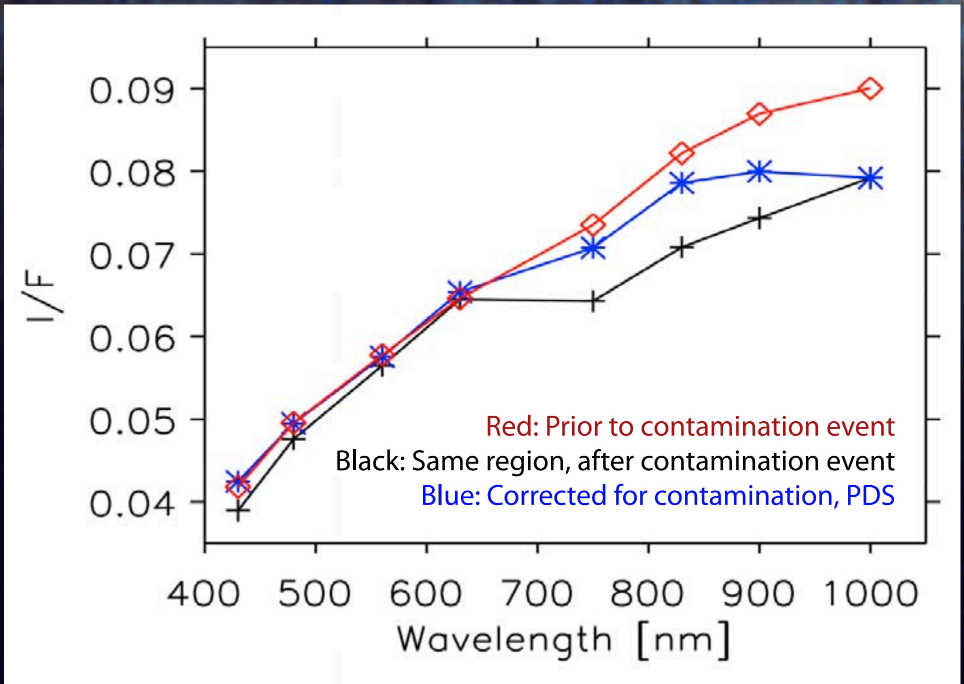
- Plots at right show uncorrected data (black points) pre-event (to the left of red line), and post-event (to the right of red line)
- Median of pre-event data is solid horizontal line
- Colored points show data with correction applied
- Correction was more successful for some bands (e.g., 830 nm) than others (e.g., 430 nm) in returning data to the pre-event median



# Results of step 1 correction

- Initial correction made substantial improvements, but some spectral artifacts remained, clear color differences for images collected in different time periods



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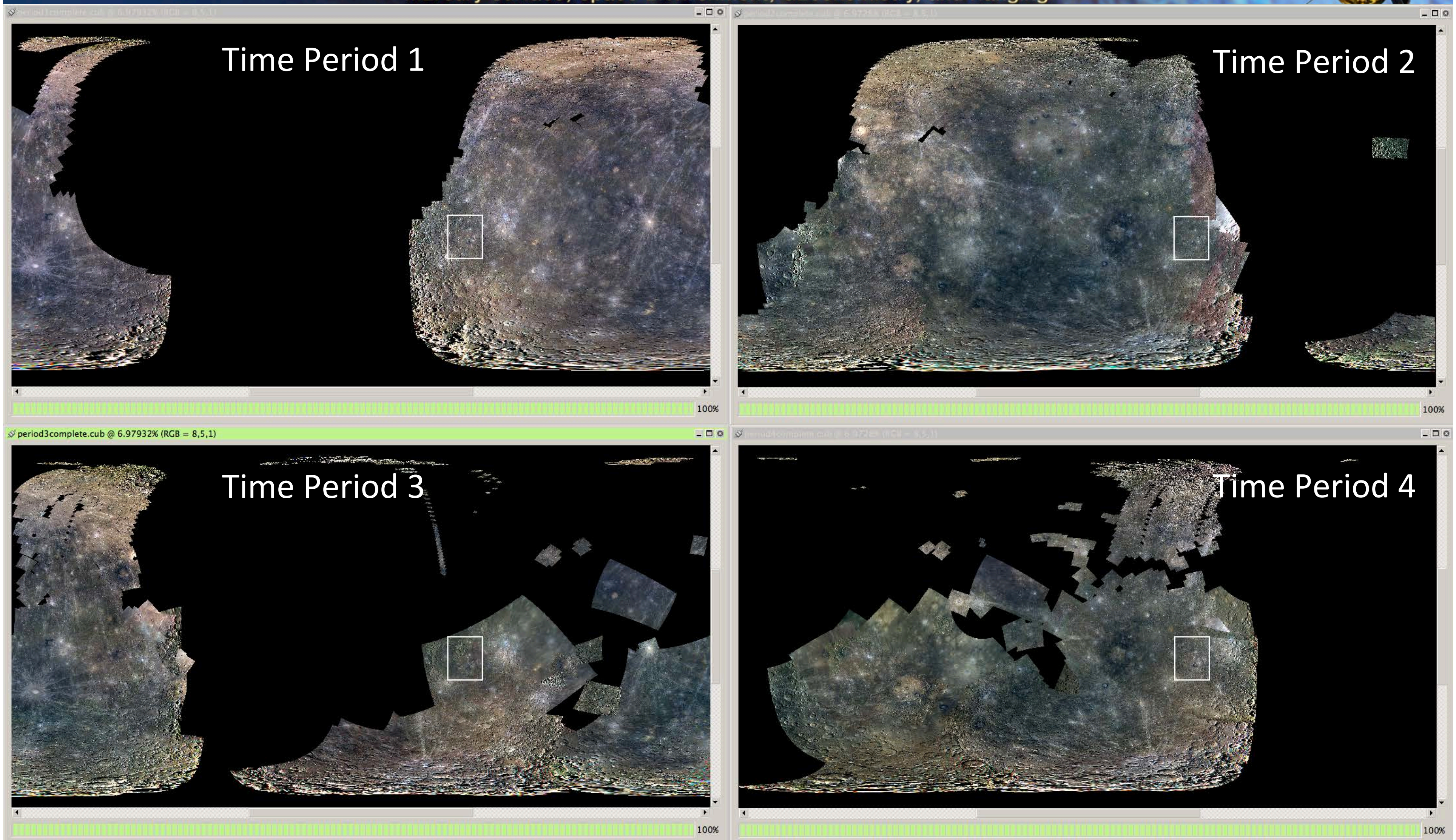


Time-dependent changes in color still observed
Use overlapping areas to produce an extra correction factor in Step 2

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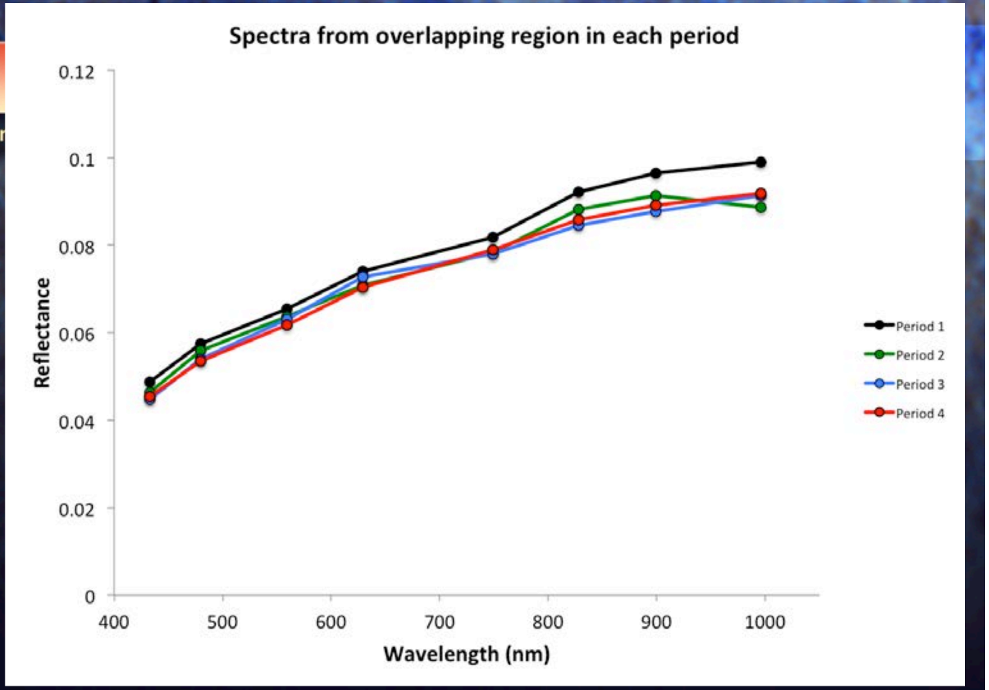
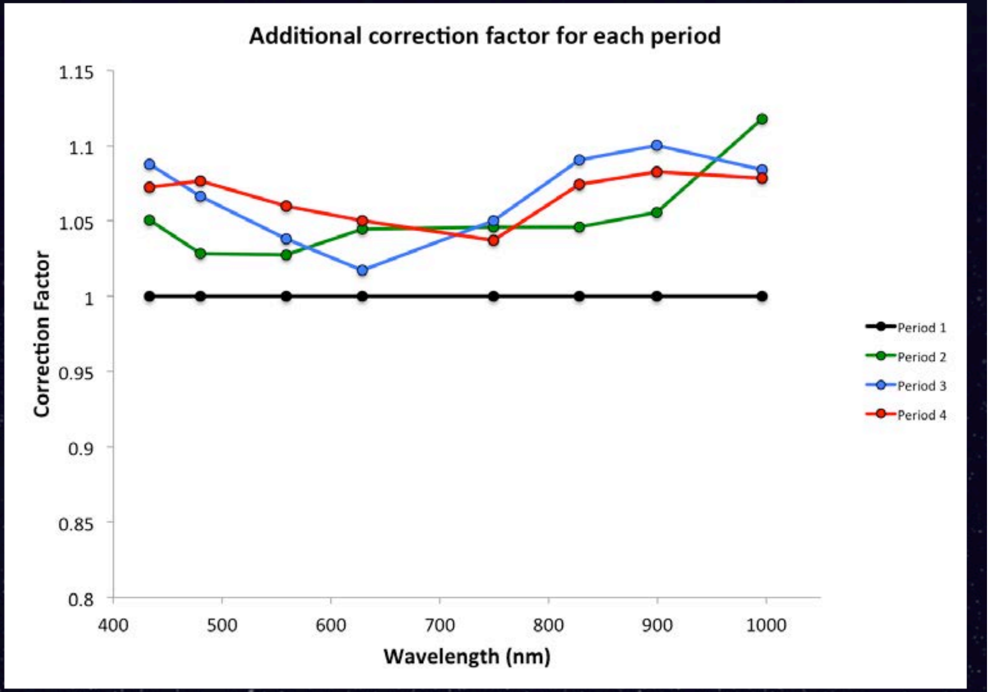
# Step 2 of Contamination Correction

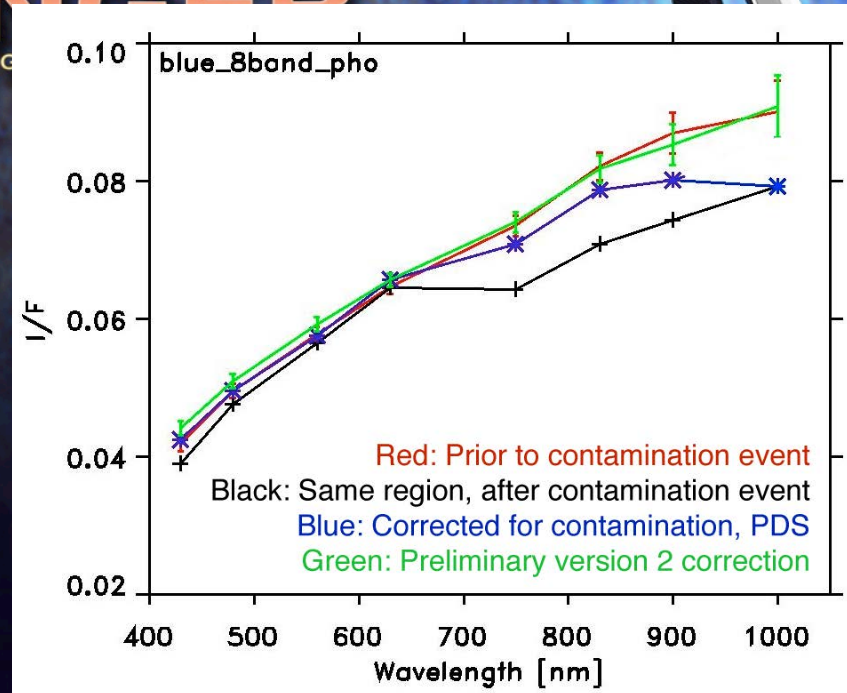
- For PDS delivery, a secondary correction was applied (used in MDR mosaic, WAC CDRs)
- Derived by pulling average of a large region observed multiple times, correcting all data within a time period by that factor

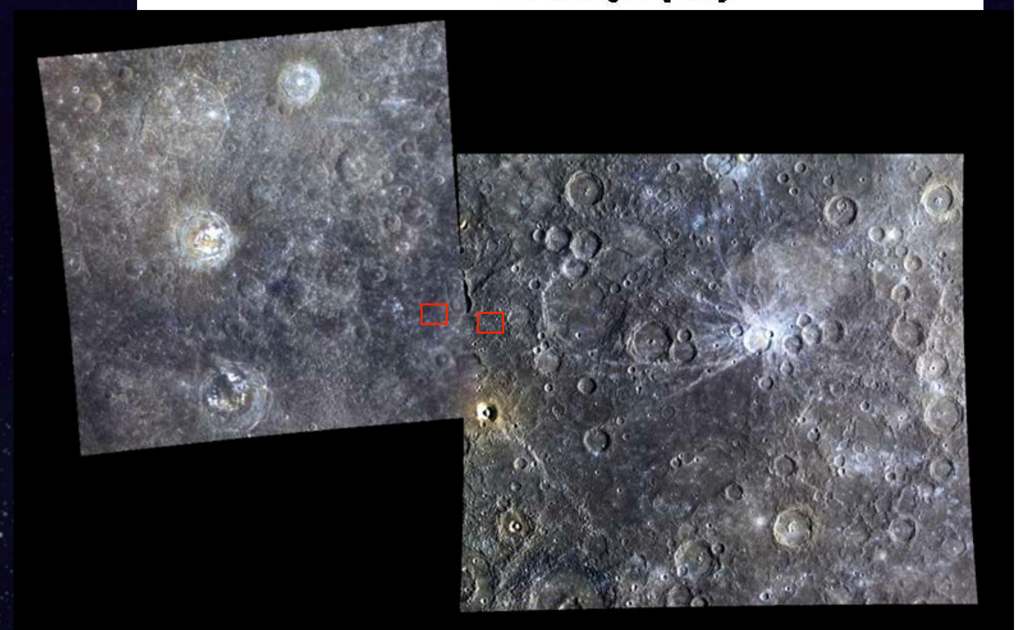


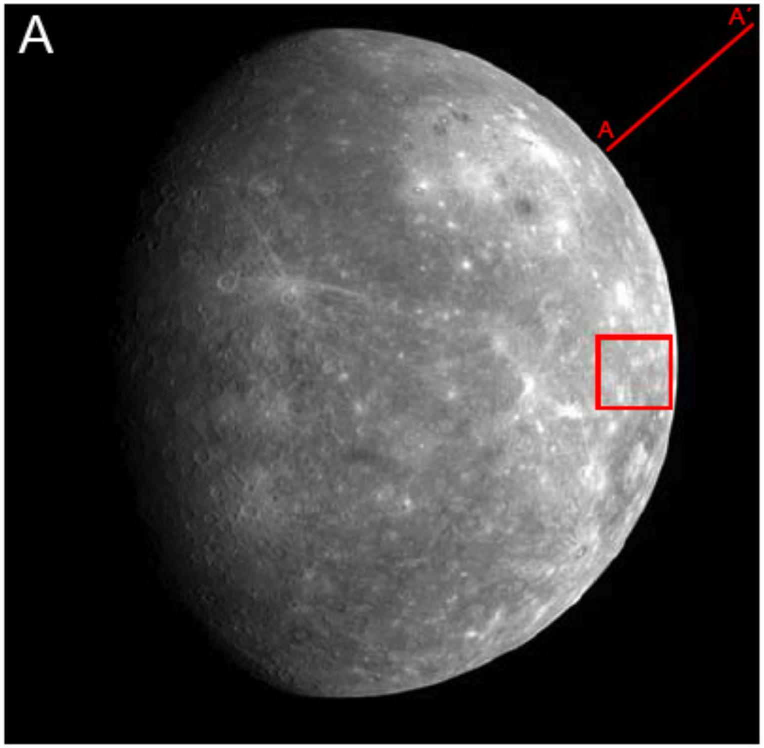
# Ongoing work

- Improved correction is being developed – high priority, will be available through ISIS rsync
- See Keller et al. poster on Tuesday evening, LPSC 44 Abstract #2489
- For now: be most wary of data May 24-June 23, 2011 (worst period)
- "Absorption bands" at 750 nm are suspect
- If you are searching for small spectral features or trends, safest data is prior to May 24, 2011 until next correction is developed

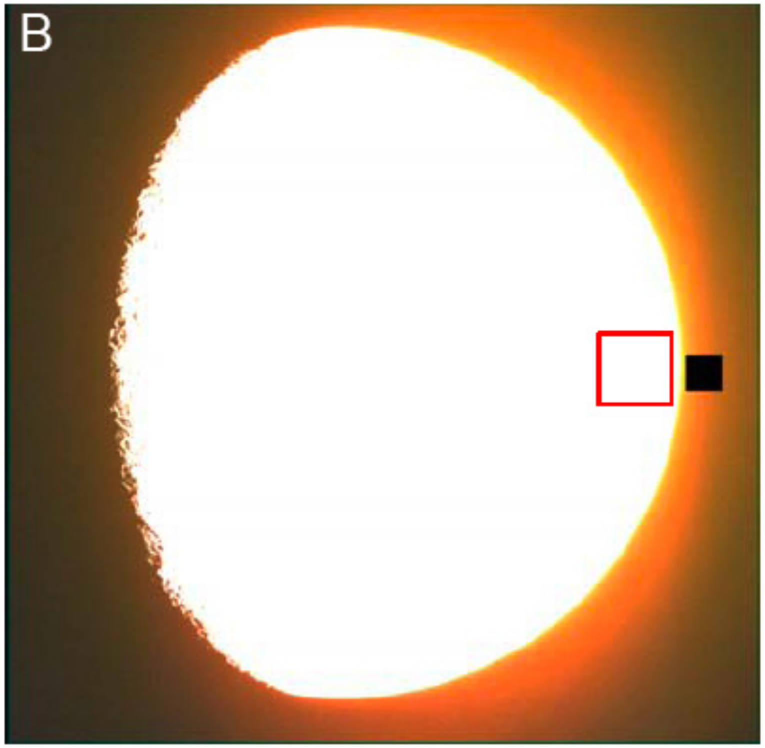


# Scattered Light Complicates Interpreting Small Color Features




Flyby 1 Departure Color




Stretched

- In all filters in the WAC light is scattered from a source across the field-of-view (FOV)
- Scatter in an image like this is ~2% in the violet filter increasing with wavelength to ~7% in the near-IR
- "Redder" light is scattered out of small bright features, into small dark ones

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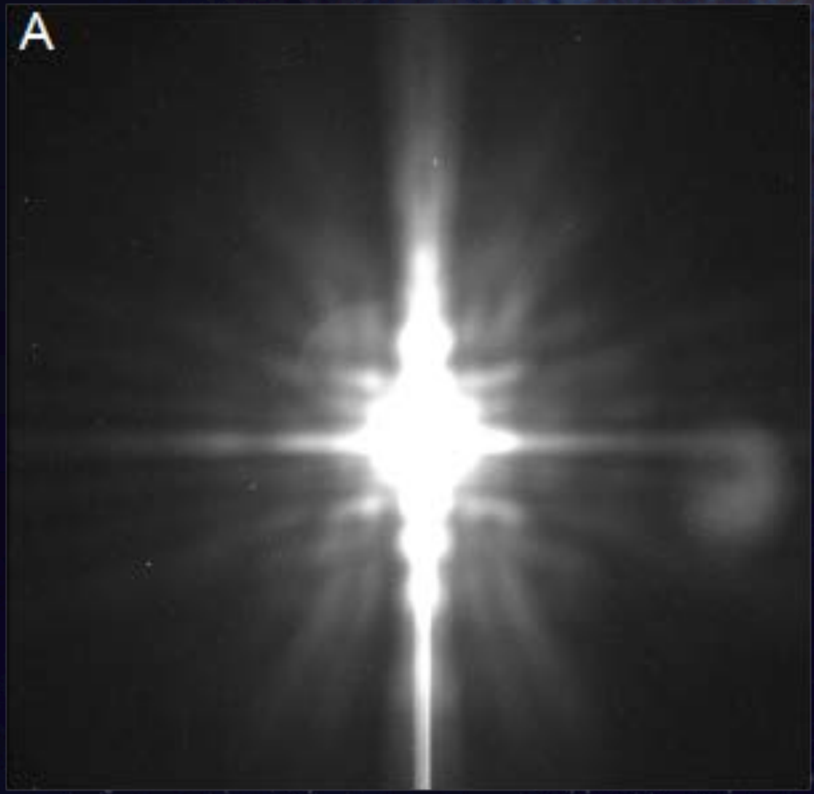
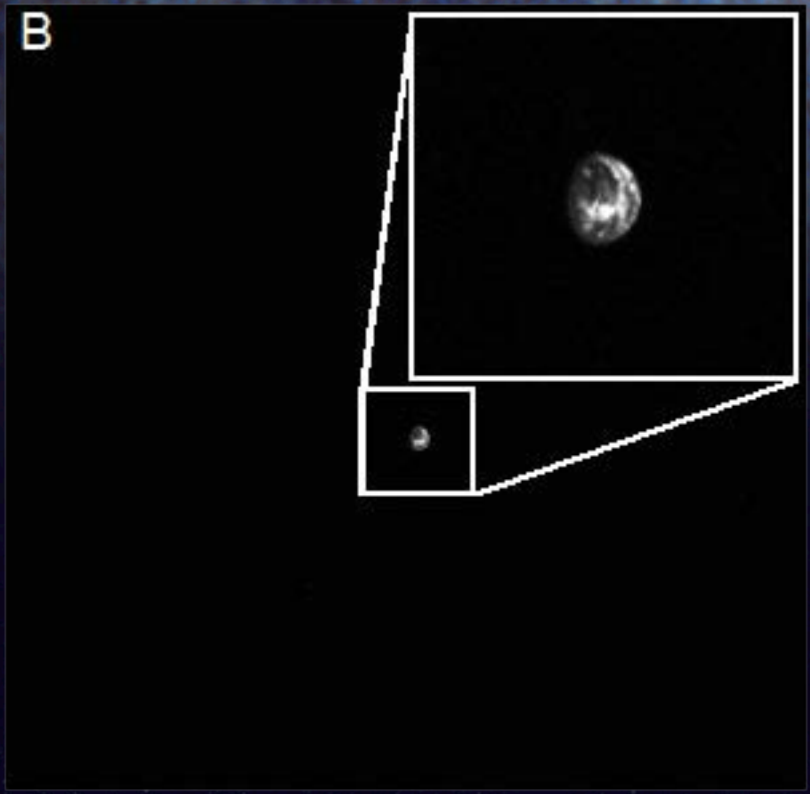
# WAC Scattered Light: Some Originates Inside the FOV



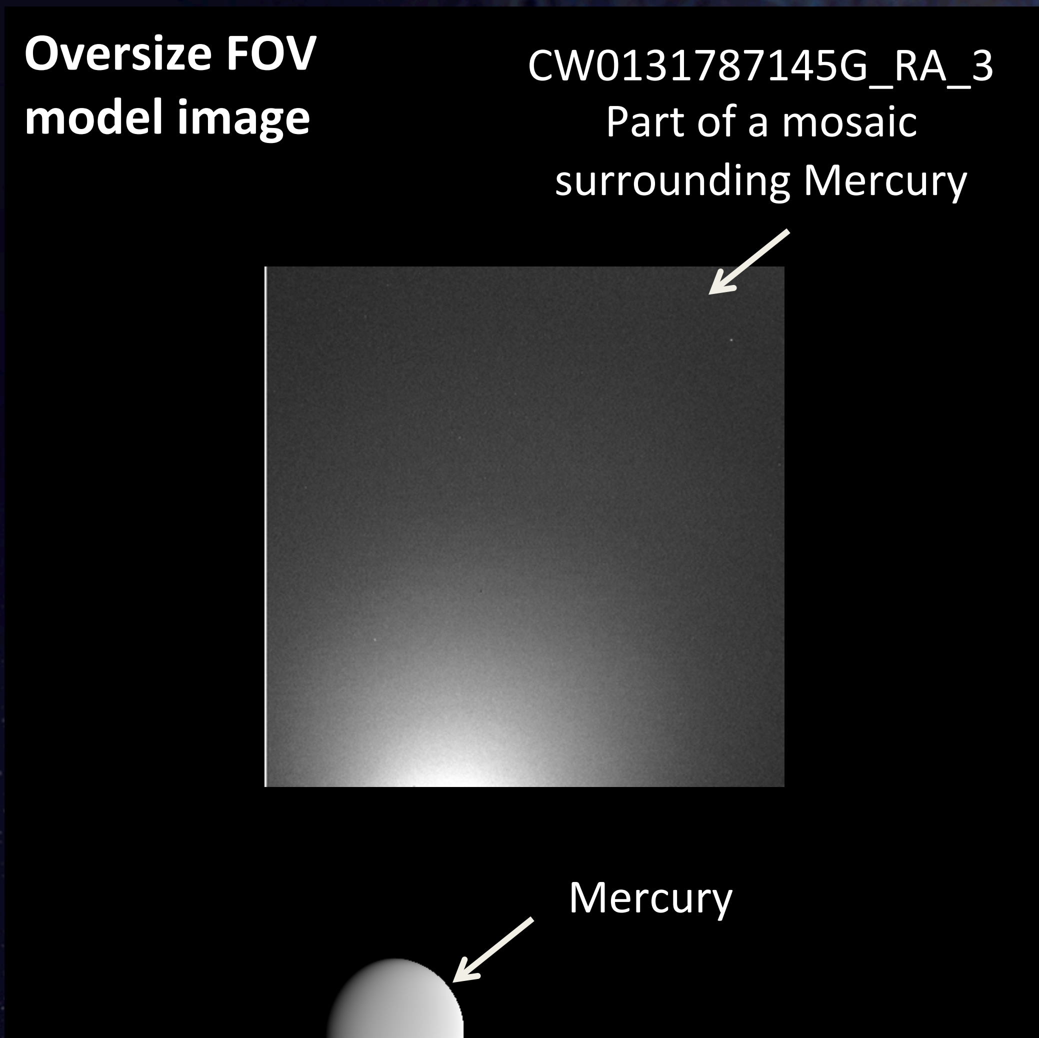

CW0030974616B_RA_1
Highly saturated distant image of Earth




CW0030974606A_RA_1
Companion unsaturated image

- Quasi-rectilinear pattern of spots arising from an object imaged onto the CCD
- Originates from diffraction off periodic structures on the CCD surface, reflected back onto the CCD from a cover glass
- For a large or field-filling source this merges into a diffuse blur

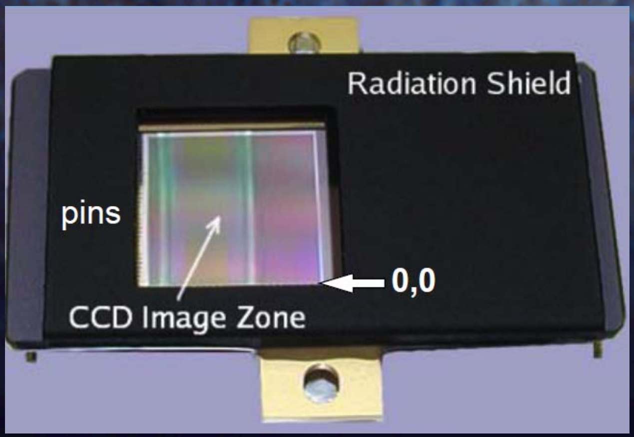
# WAC Scattered Light: More Originates Outside the FOV

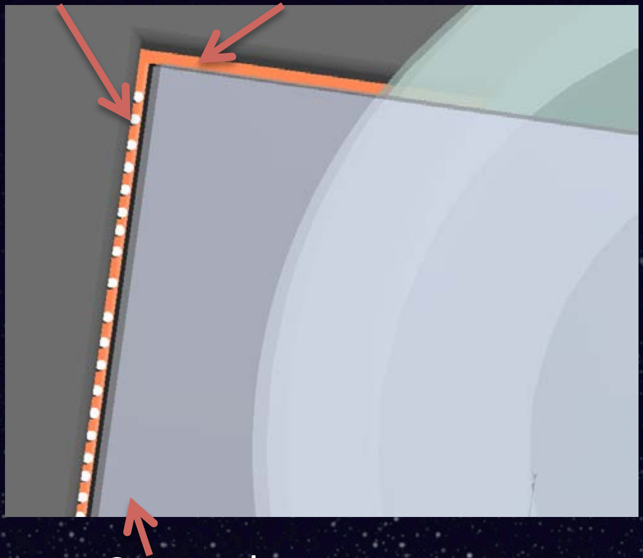



- Diffuse gradients across an image original from out-of-field sources
- Some images with out-of-field sources have weak jet-like structures in them
- These effects originate from reflections off structures inside the camera

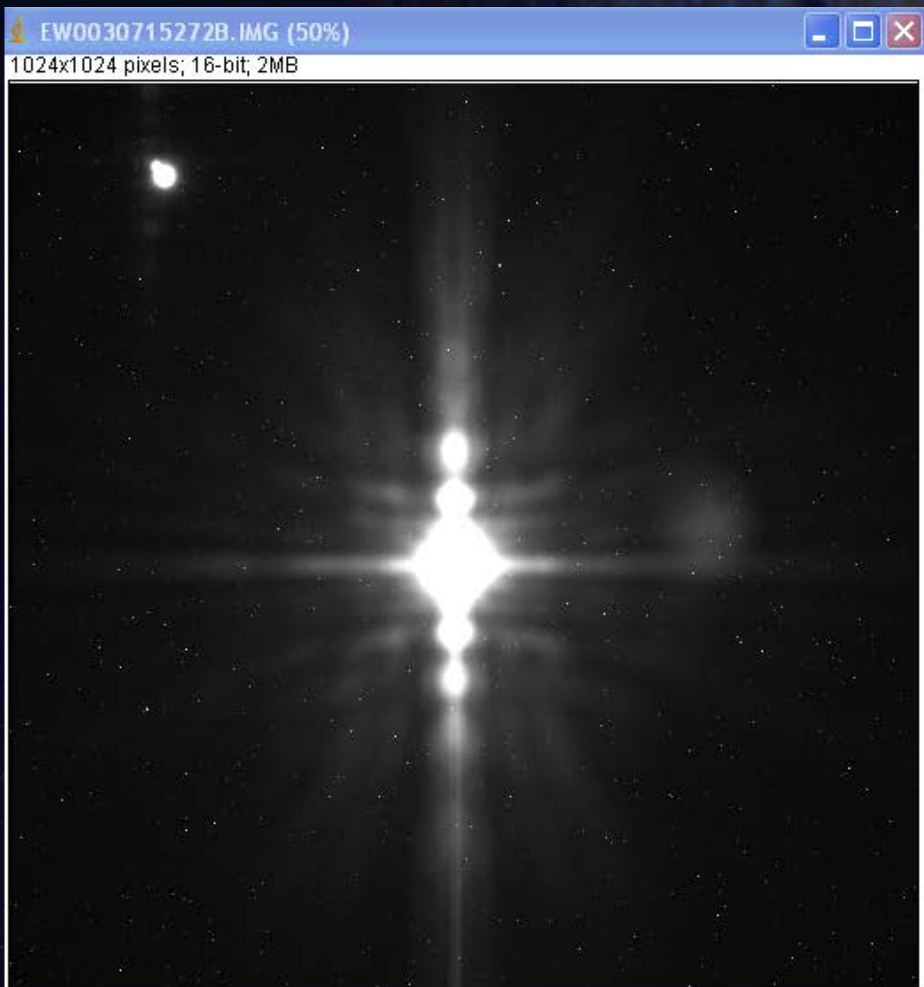
# Approach to Correcting Scattered Light

- Ingest a CAD model of the focal plane and camera structure and optics
- Develop a scattering model of illuminated surfaces of the CCD and surrounding structures, using optical ray trace software tuned by scattering properties of coatings
- Pre-generate images of scatter (magnitude, distribution) from each cell of a matrix of locations inside and surrounding the WAC FOV
- To correct an image
  - Inset it into an oversize FOV
  - Synthesize a model image of Mercury in the oversized FOV using constant reflectivity and the Domingue et al. [this meeting] photometric function
  - Scale the pre-generated scatter images by the brightness of fake Mercury at each matrix position
  - Subtract

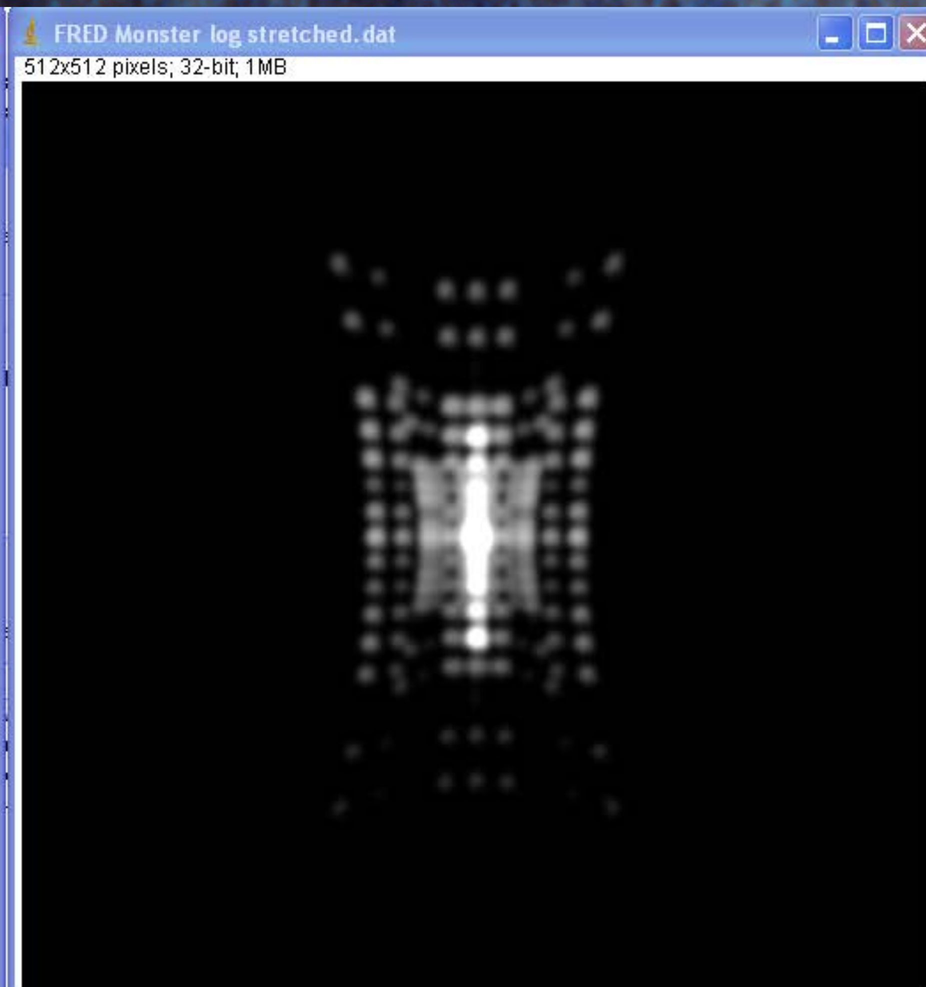


# Comparison of Actual and Simulated In-field Scattering




Earth flyby distant long-exposure image (moon in upper left)




Simulation of Earth (excluding moon)

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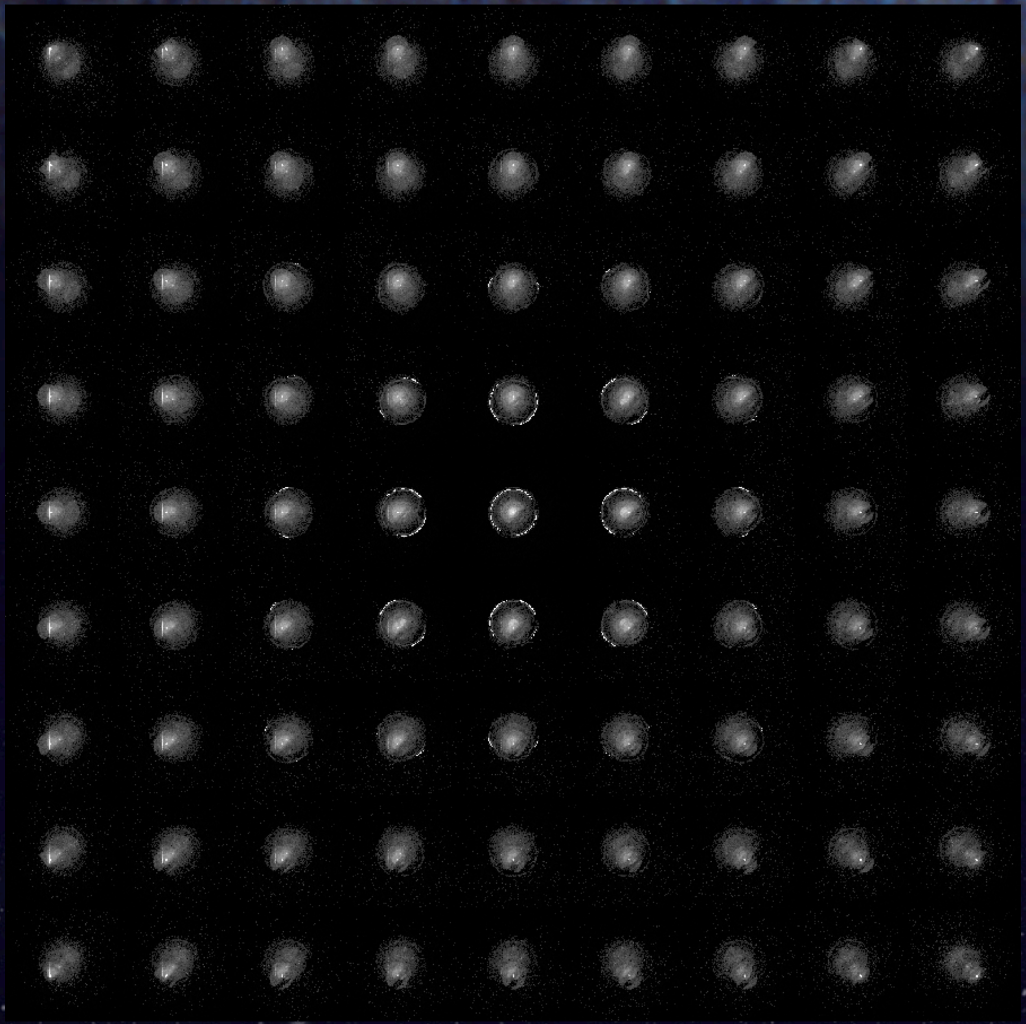
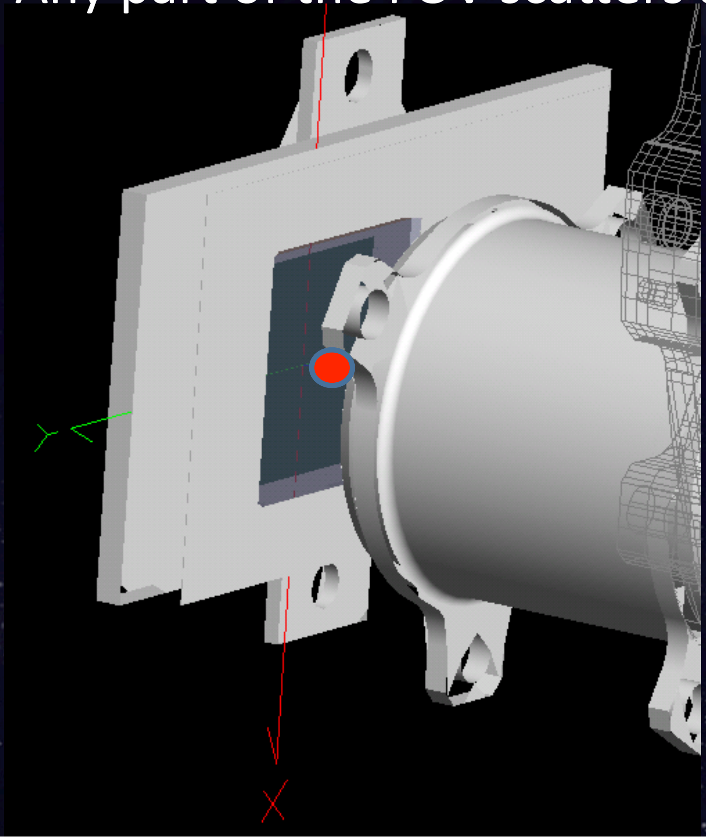
# Non-Uniform Scatter Pattern Across the Field-of-View

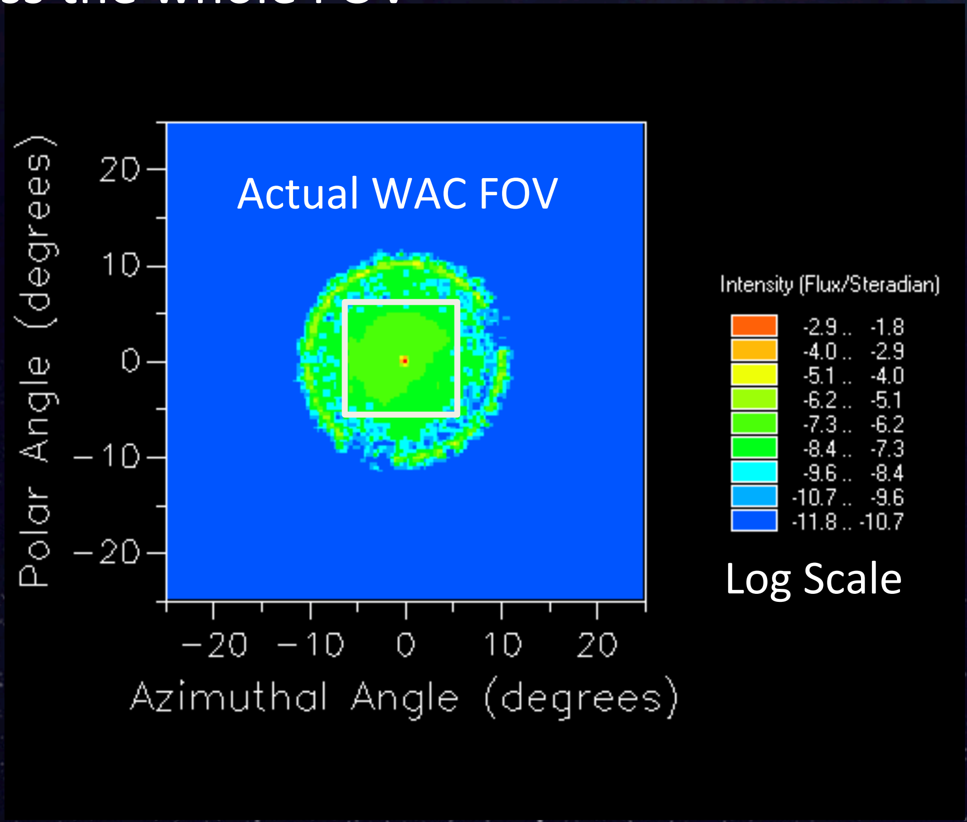
- This shows the central parts of the scatter pattern for a sample of sources inside the FOV
- Note that the scattering pattern varies across the FOV
- This is because converging rays of light near the center of the FOV are centered near-normal to the CCD, but at the edges and corner of the FOV come in at an angle
- Fourier image restoration can’t easily model this



# Extended Scatter from an In-Field Source

- This shows on a log scale the extended scatter from a source near the center of the FOV
- After the rapid falloff over a fraction of a degree, a more uniform glare extends out >10°
- Any part of the FOV scatters across the whole FOV



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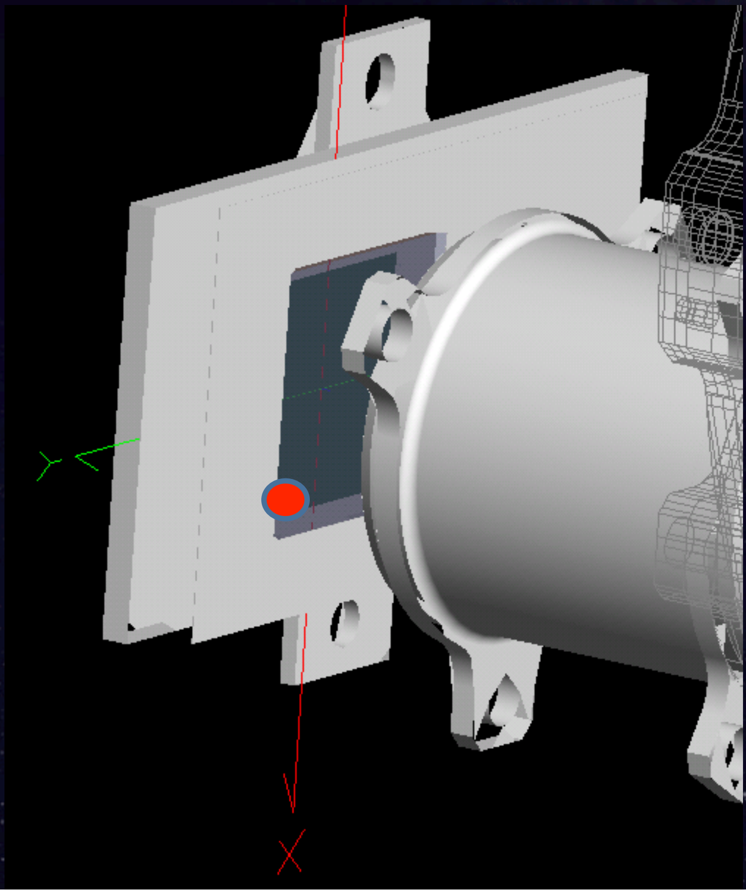
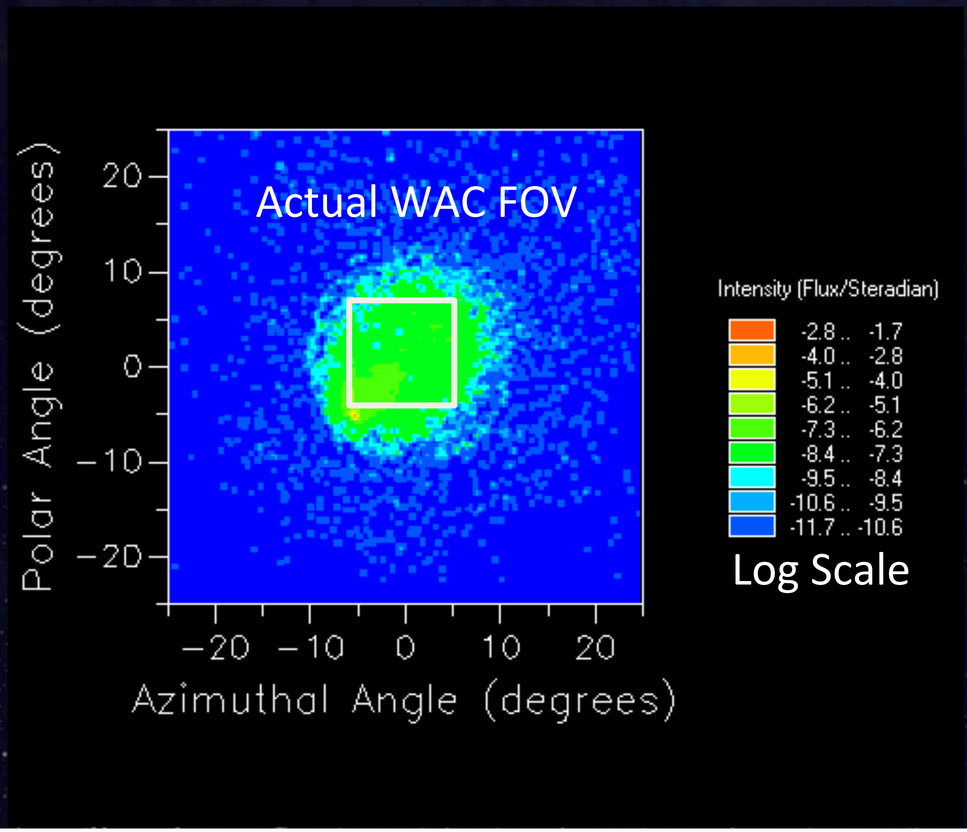
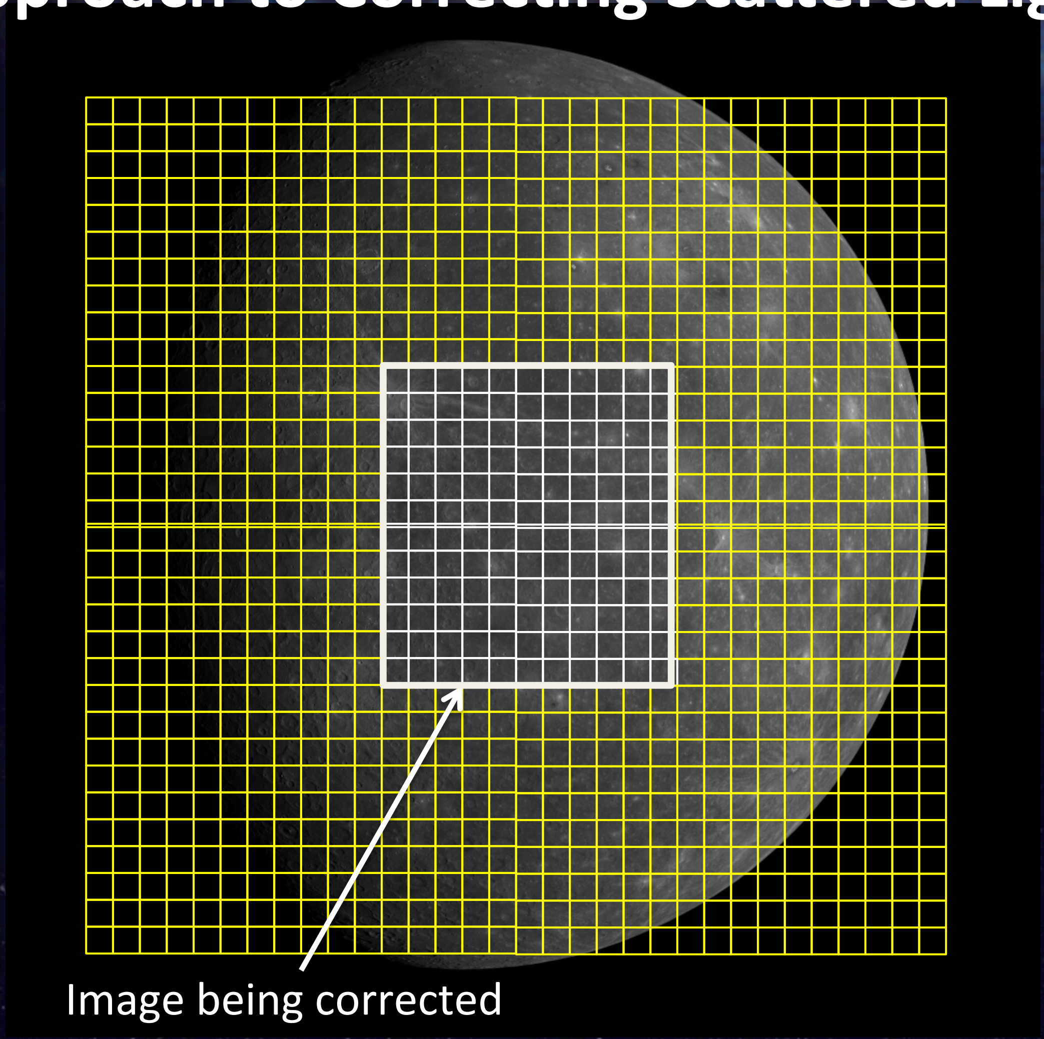
## Extended Scatter from a Corner-of-Field Source

- This shows on a log scale the extended scatter from light falling at one corner of the FOV
- Light scatters in a different pattern but still affects the whole field
- There are thousands more views like this, but you see the pattern…



# Approach to Correcting Scattered Light



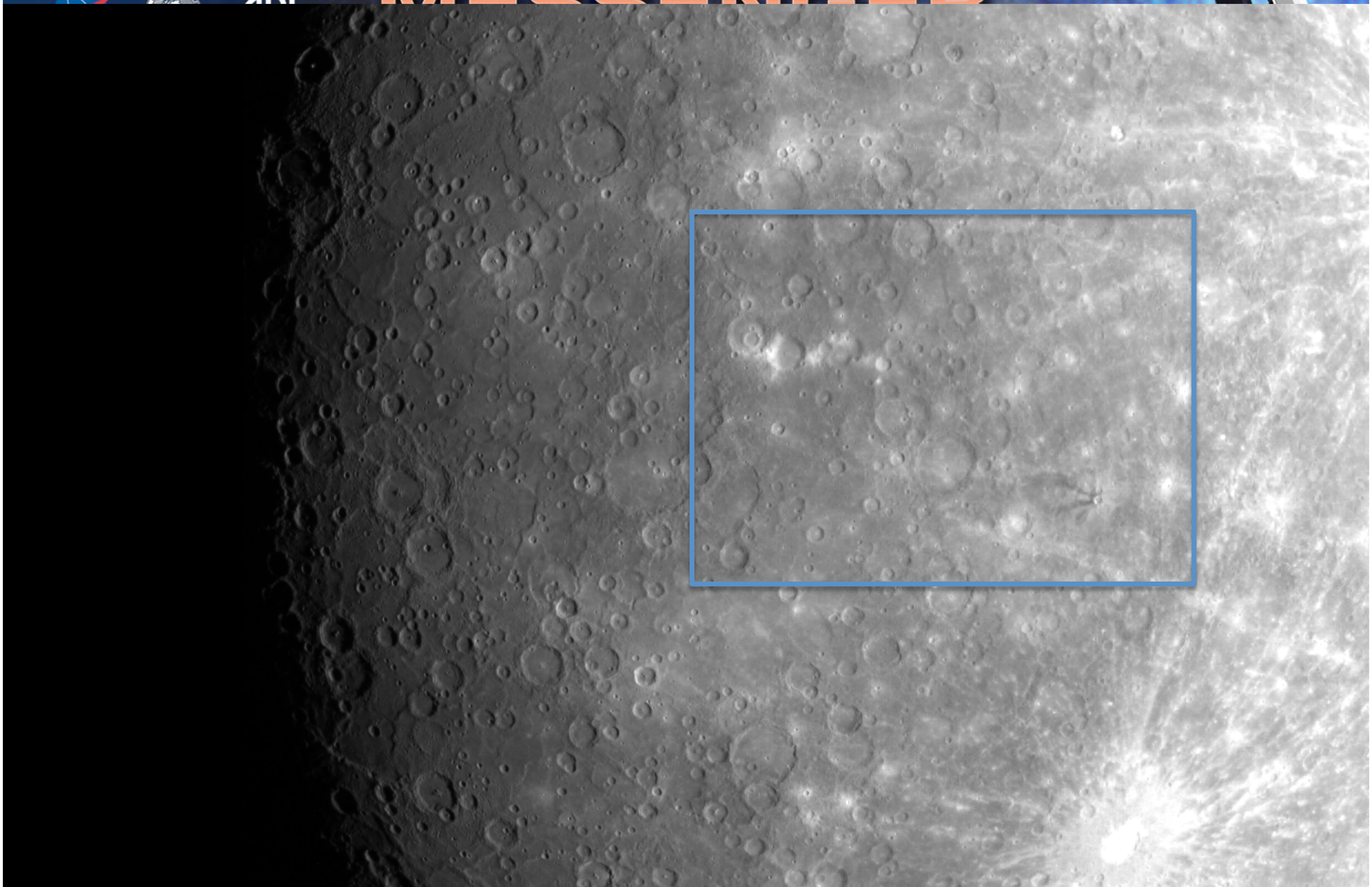

$$Lc_{i,j} = L_{i,j} - \sum_{i} \sum_{j} L_{i,j} * f_{i,j}$$ where $f_{i,j}$ is the scatter image

# Scattered Light

- Both in-field and out-of-field scattered light, worse for longer wavelengths
- Worst for small dark region surrounded by bright, vice versa
- Correction being developed but not yet implemented

# Photometric Normalization

- Update from published flyby model (Domingue et al., 2010)
- Used orbital data bounded by 47-49°S, 334-336°E (next slide)
  - Used only data prior to probable contamination event
- Hapke photometric function that uses double-lobed Henyey-Greenstein single particle scattering function



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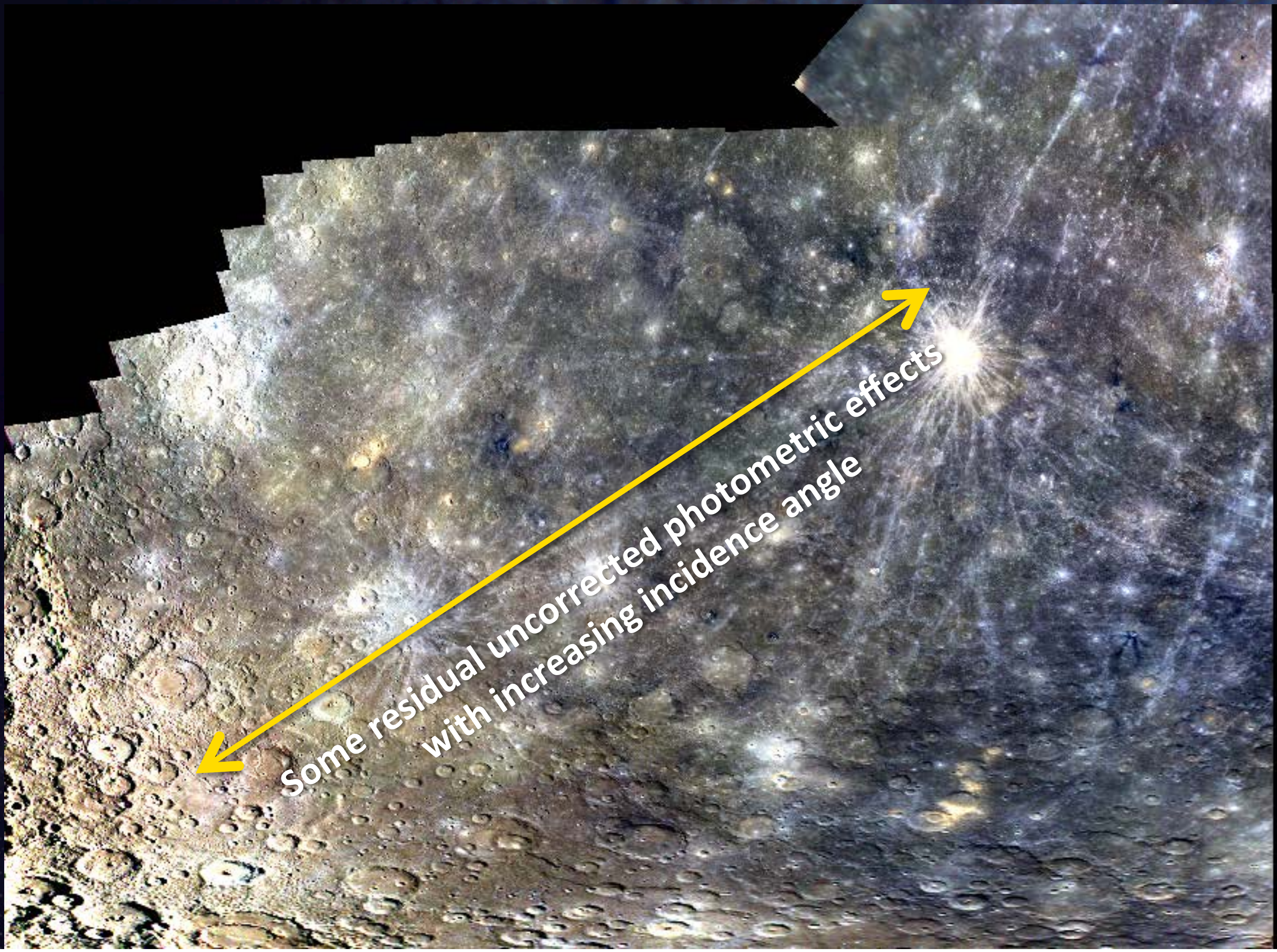
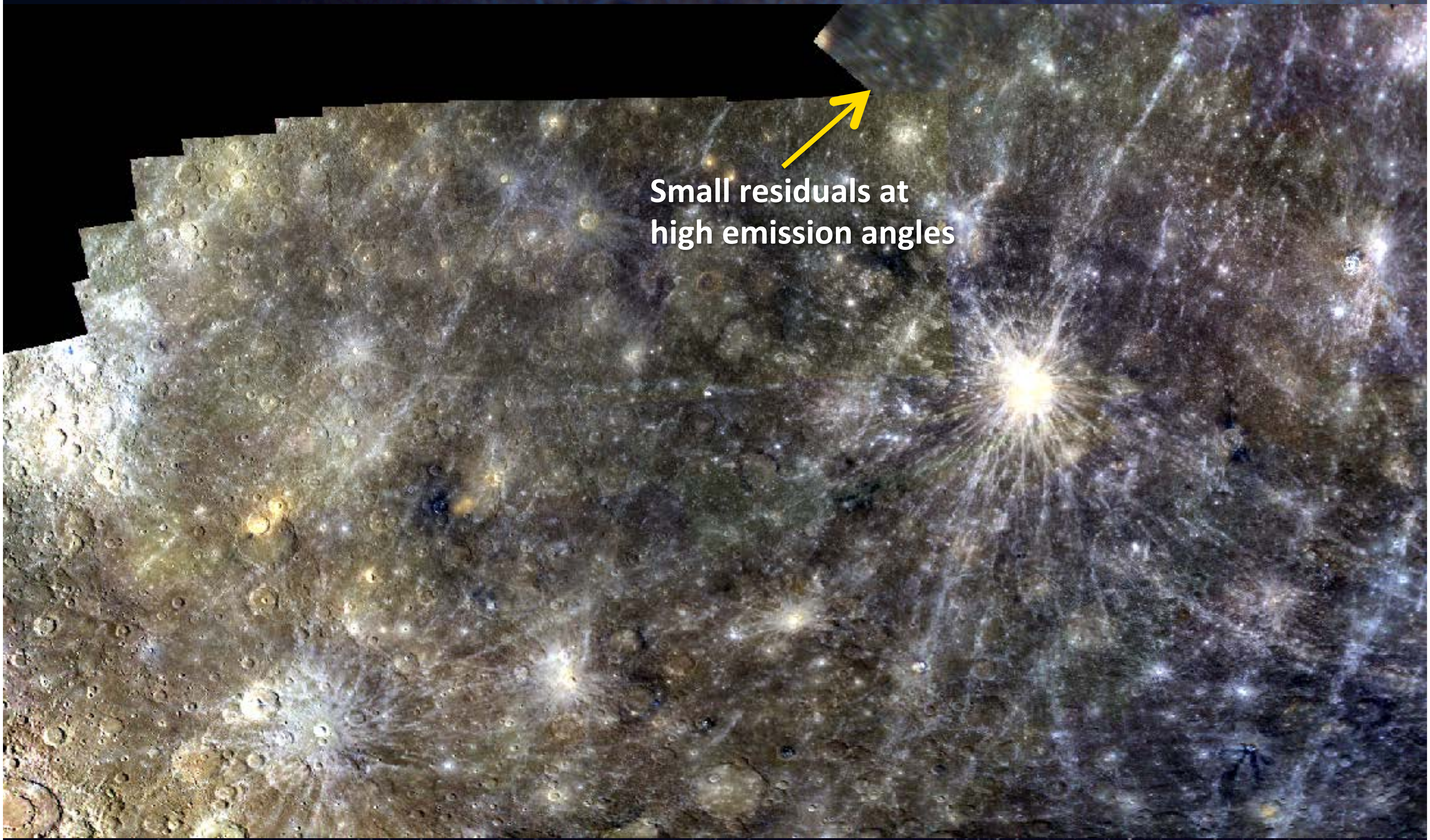
# Photometric correction used in PDS-delivered mosaic



# Photometric correction used in PDS-delivered mosaic



# Photometric Normalization

- Ongoing work to update and improve
- See Domingue et al. poster Tuesday night, LPSC 44 abstract #1324
- Discussion of how to apply photometric correction during ISIS tutorial

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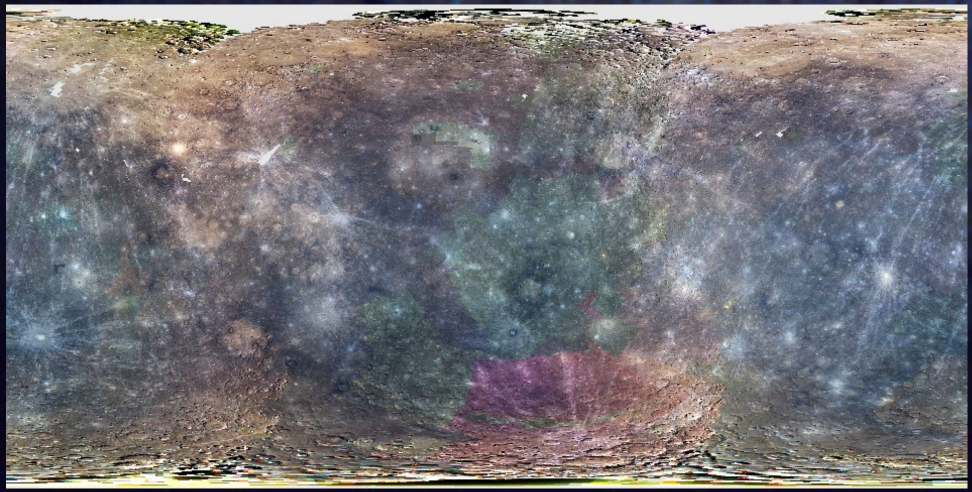
## Pre-orbit calibration, photometry



## Delivered to PDS