On-orbit radiometric characterization of Suomi NPP Day/Night Band (DNB)

THE VALUE OF PERFORMANCE.

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JPSS Science Team Meeting, May 12-16, 2014

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Topics

- General DNB characteristics
- Radiometric sensitivity
  - Dynamic Range and saturation issues
  - SNR
  - Impact of airglow on offset
- Radiometric Accuracy
  - Radiometric accuracy
    - Low gain stage (LGS) radiometric accuracy from direct lunar observation
    - High gain stage (HGS) radiometric accuracy from lunar illuminated ground scenes
    - Mid gain stage (MGS) radiometric accuracy inferred from calibration transfer uncertainty
  - Stray light, stray light correction and remaining stray light issues.
- Recommendations

DNB Characteristics: meeting most performance requirements

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1. DNB Characteristics	Specification	Prelaunch Performance	On-orbit Performance
Spectral Passband center	700 ±14 nm	707 nm	Model estimate 694 nm [1]
Spectral Passband bandwidth	400 ±20 nm	379 nm	Model estimate 375 nm[1]
Horizontal Sampling Interval (HSI)	742 m (±5%)	742 m (±9%) scan 742 m (±7%) track	704-790 m (scan) 734-777 m (track)
Horizontal Spatial Resolution (HSR)	<= 800 m	< 820 m, scan < 670 m, track	< 770 m, <52^o < 750 m, <52^o
Geolocation uncertainty (3σ) on ellipsoid	400 m nadir 1500 m edge	N/A	249 m (nadir) 1041 m (edge)
Dynamic Range	$3x10^{-9}$ W·cm^{-2}·sr^{-1} – 0.02 W·cm^{-2}·sr^{-1}	$3x10^{-9}$ W·cm^{-2}·sr^{-1} – 0.021 W·cm^{-2}·sr^{-1}	$3x10^{-9}$ W·cm^{-2}·sr^{-1} – 0.0209 W·cm^{-2}·sr^{-1}
SNR @<53 deg SNR @ >= 53 deg	>=6 @ Lmin >=5 @ Lmin	>10 across scan	>9 across scan now >8 projected EOL
Calibration Uncertainty LGS[2]	5%/10% (0.5 Lmax/ transition to MGS)	3.5%	[4%,8%] (1 σ, ROLO); 8% [-4%,2%] (1 σ, Modis); 4%
Calibration Uncertainty MGS[2]	10%/30% (upper/ lower transition)	7.8%	[-7.7%, 5.7%] (1 σ) [4]; 7.7% [-9.6%, 7.6%] (1 σ) [4,5]; 10%
Calibration Uncertainty HGS[2]	30%/100% (transition from MGS/ Lmin)	11%	[-2.8%, 15%][3] ; [-10%, 8.2%][3,4] [0.8%, 18.6%] ; [-6.4%, 11.8%][4] [-9.7%, 14.3%]; [-16.9%, 7.5%][4,5]
Stray light	10% of minimum radiance	N/A	>100% Lmin ~15%-205 Lmin after stray light correction

In backup (Horizontal Sampling Interval through Geolocation uncertainty)

Covered in this talk (Dynamic Range through Stray light)

(1) Lei, N., Z. Wang, B. Guenther, X. Xiong, and J. Gleason (2012), Modeling the detector radiometric response gains of the Suomi NPP VIIRS reflective solar bands, *Proc. of SPIE* , **8533**, 853319.
(2) Radiometric uncertainty assumes signal with sufficient SNR. For per measurement uncertainty RSS with 1/SNR.
(3) Before Nov 16, 2012
(4) Inferred comparison with Modis
(5) Includes large scan angle data

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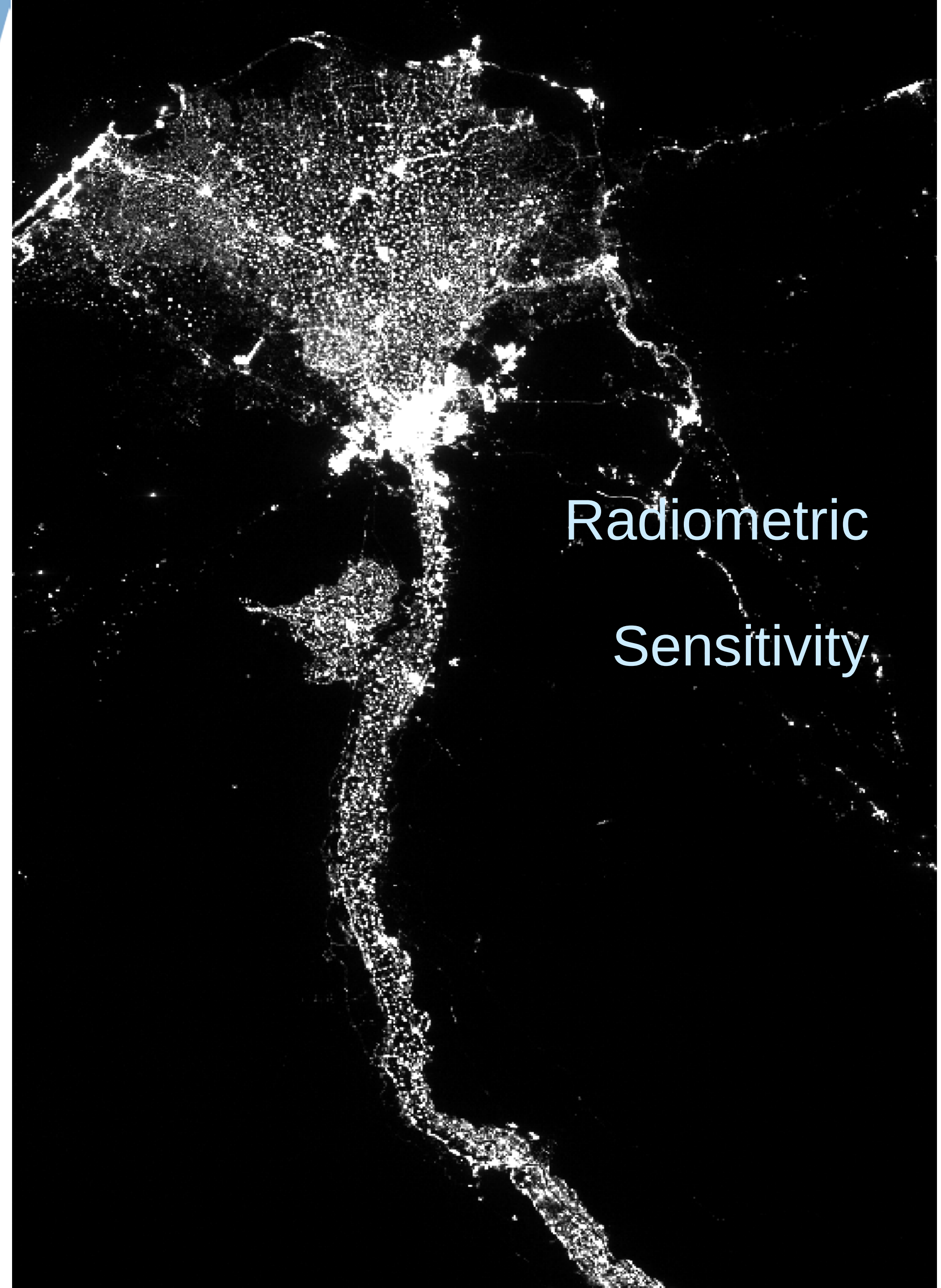
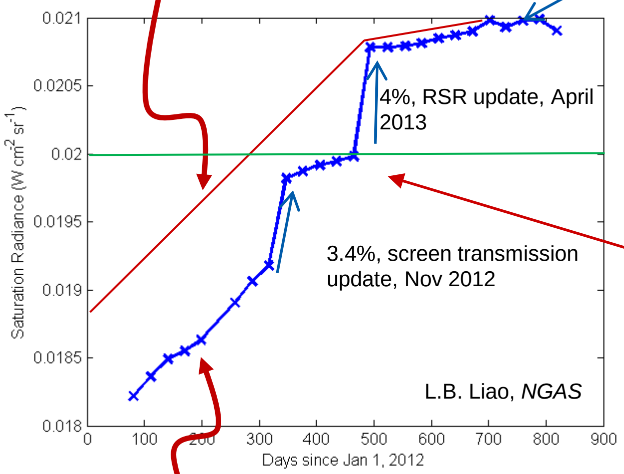


Radiometric Sensitivity

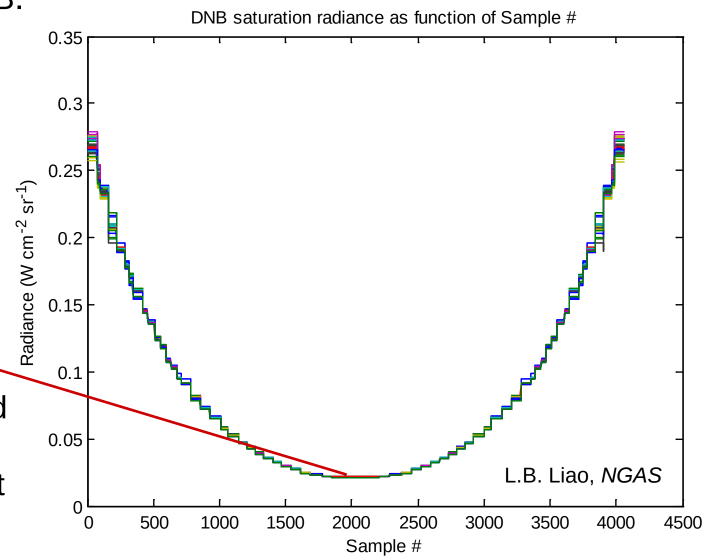
Dynamic Range

Approximate saturated radiance
if correct RSR and screen transmission
used at all times.

Saturation radiance rolling over, indicating
degradation in gain coefficient has stopped
for DNB.



Saturation radiance defined by aggregation zone with lowest saturation radiance value.



Gentle upslope due to RTA throughput degradation.

Due to aggregation scheme to keep a constant ground footprint, saturation radiance is a function of scan angle. As of May 2013, saturation radiance meets the requirement of 0.02 W·cm^{-2}·sr^{-1} .

Analog saturation (late transition, DR 4603) observed

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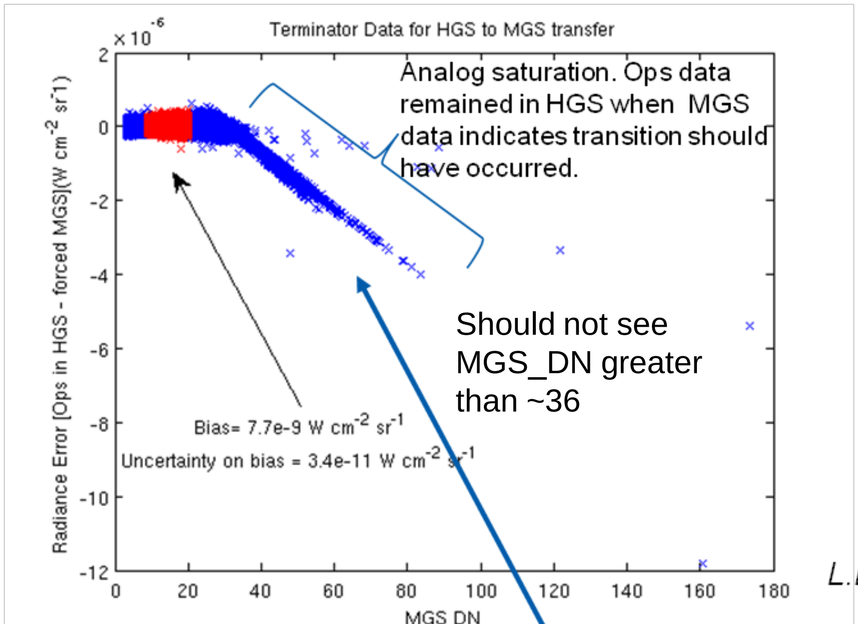

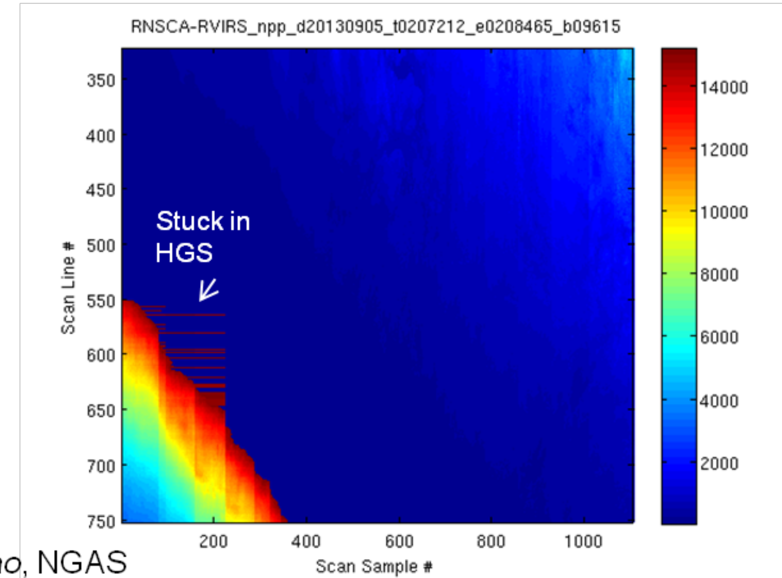

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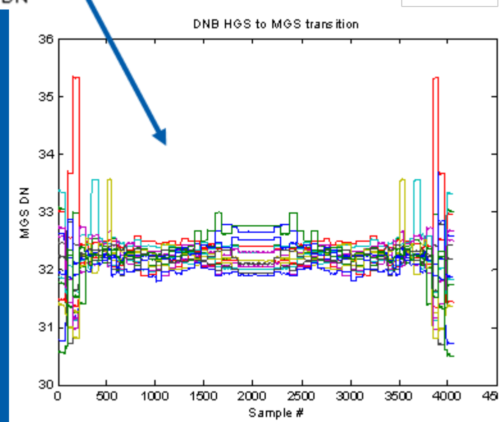
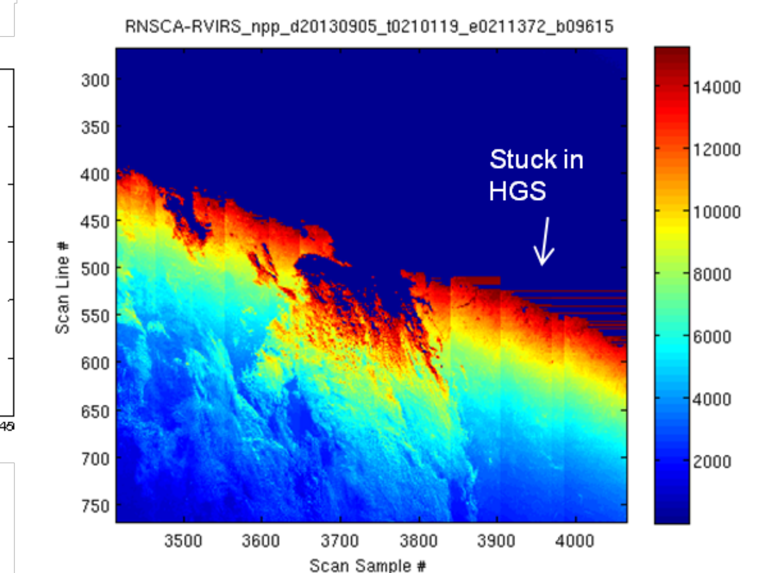
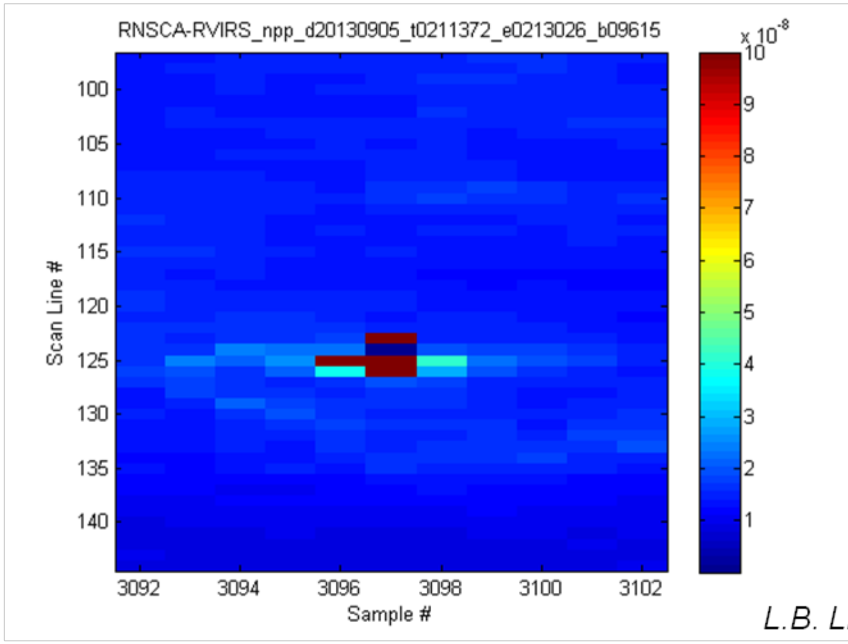
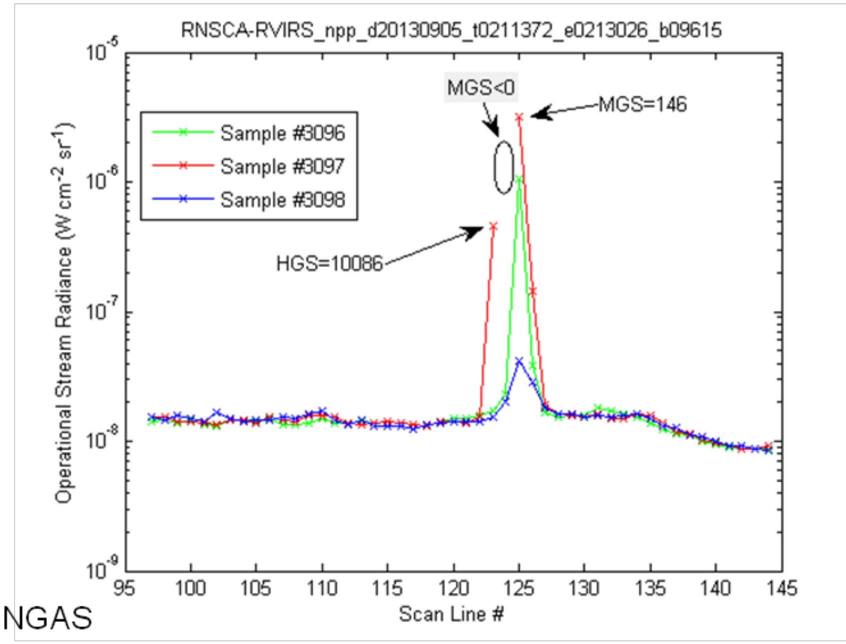




Analog saturation occurs mostly in aggregation zones 29-32. Some isolated pixels occur in other zones. If included in cross cal between stages, saturated pixels will bias c1 for higher sensitivity stages high. This results in higher retrieved radiance for all pixels in the affected aggregation zone. Furthermore, during normal ops, analog saturated pixels will retrieve lower radiance than actual radiance.

Early transition (DR 7364)





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Sudden negative or extremely low radiance pixels observed within a bright patch. This is due to early transition from HGS to MGS. In some instances, truncation of the data results in negative MGS_dn. Recall that base on digital saturation consideration, transition is supposed to occur around 20-30 dn's. This is a hardware issue that will impact future DNB units.

Scene based determination of SNR using photon transfer curve (PTC) (1/2)

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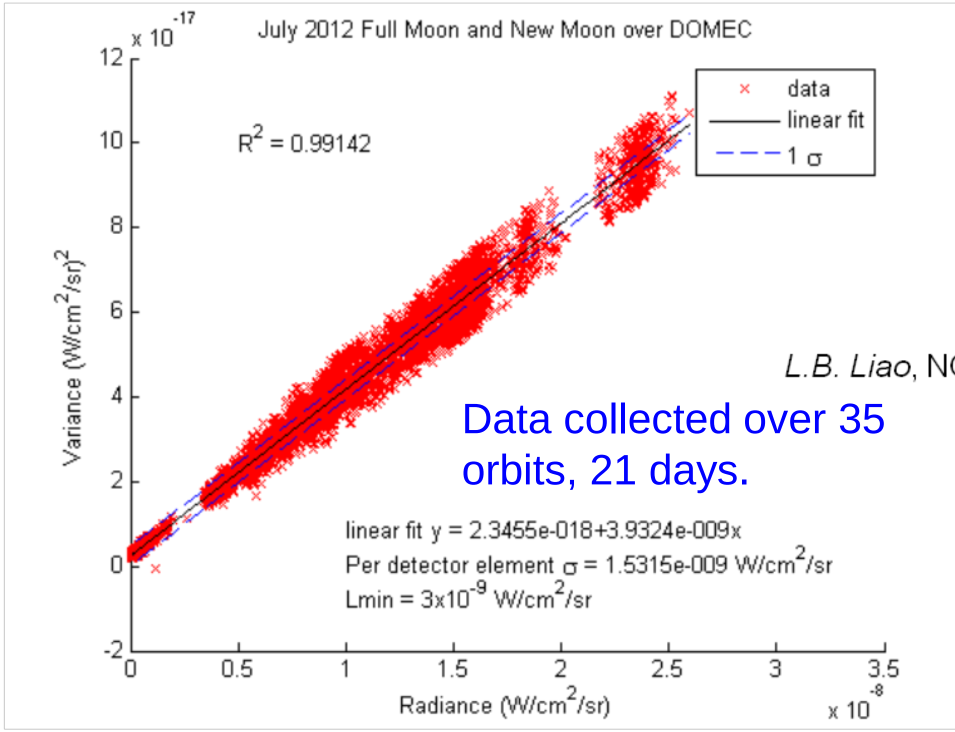

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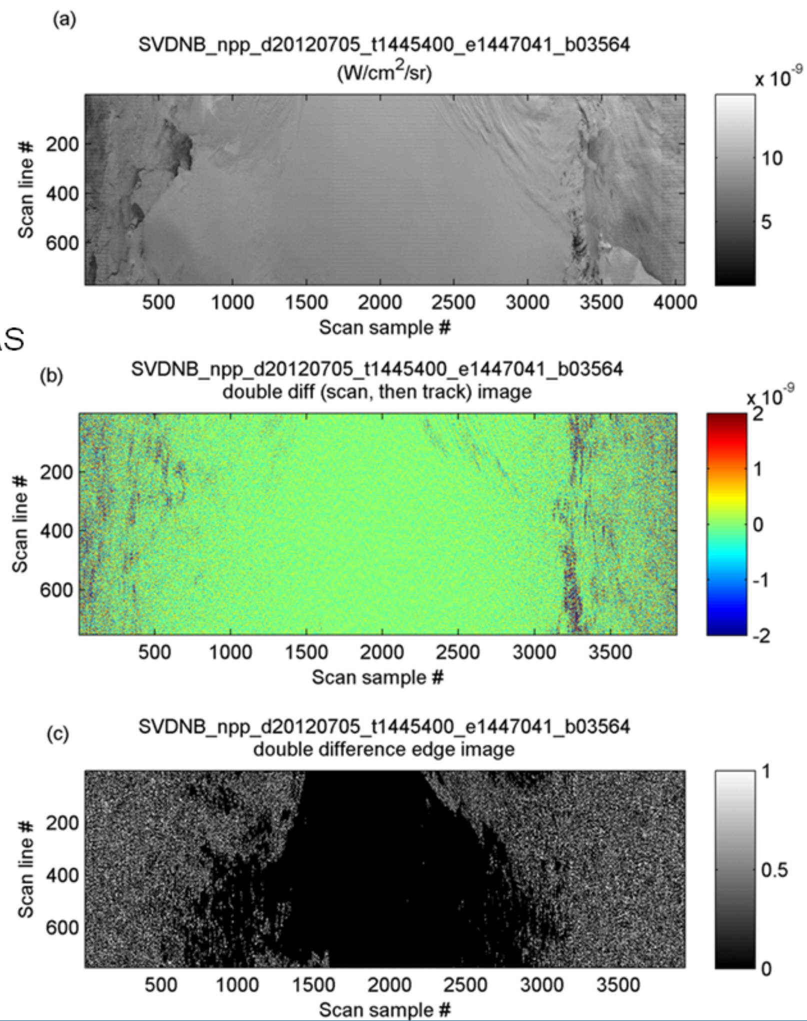
Data collected over 35 orbits, 21 days.



$$N_{agg} \times Var(L) - \left(\frac{1}{N_{agg}}\right)\left(\frac{G_e}{G_L}\sigma_{e^-,T}\right)^2 = \left(\frac{G_e}{G_L}\sigma_{e^-,S}\right)^2 + \left(\frac{G_e}{G_L}\langle L\rangle\right)$$

aggregated read-out noise

detector element dark current noise

In order for PTC to be valid, noise sources must add in quadrature and photon noise must obey Poisson distribution. Thus we must remove other sources of noise via signal processing and image processing.

Scene based determination of SNR using PTC (2/2)

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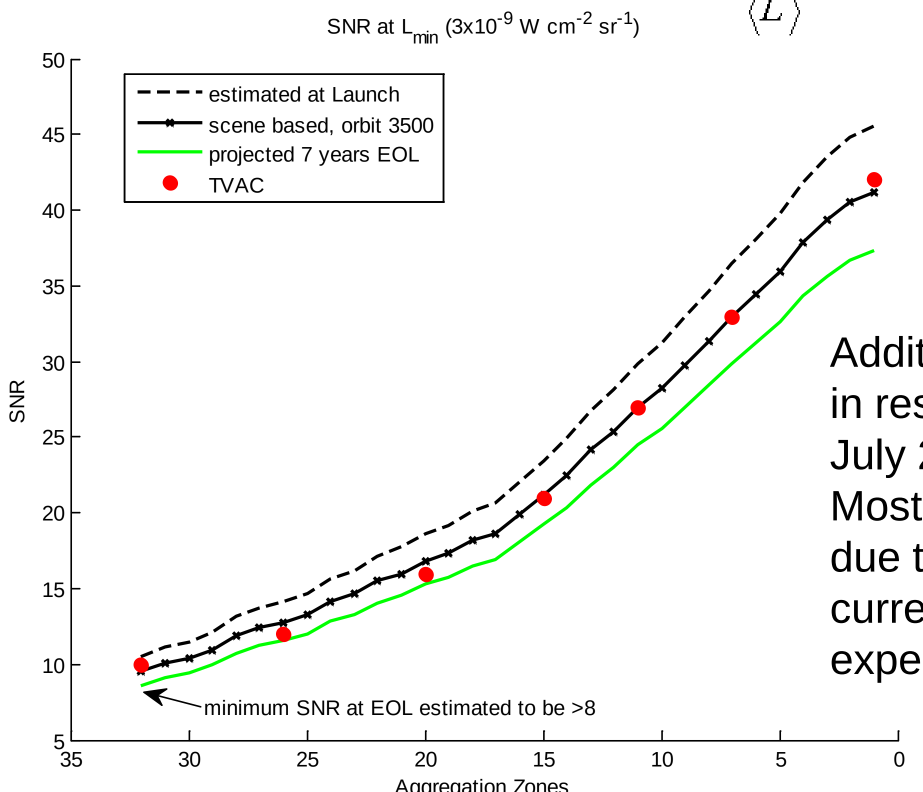
$$SNR = \frac{\sqrt{Var(L)}}{\langle L \rangle} = \frac{\sqrt{\left(\frac{1}{N_{agg}^2}\right)\left(\frac{G_e}{G_L}\sigma_{e^-,T}\right)^2 + \frac{1}{N_{agg}}\left(\frac{G_e}{G_L}\sigma_{e^-,S}\right)^2 + \frac{1}{N_{agg}}\left(\frac{G_e}{G_L}\langle L \rangle\right)}}{\langle L \rangle}$$

Total readout noise. Intercept of zero radiance PTC.

Detector element dark current noise. Intercept of scene based PTC and slope of zero radiance PTC.



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Additional 10% degradation in response expected from July 2012 to EOL in 2017. Most degradation in SNR due to increase in dark current noise. We still expect SNR > 8 EOL.

Once derived, PTC can be used to predict SNR at any time and any radiance (within the linear range), provided that one can derive the temporal evolution function of various noise sources other than the photon shot noise.

Zero signal PTC (from calibration views) can be used to derive dark current noise and readout noise

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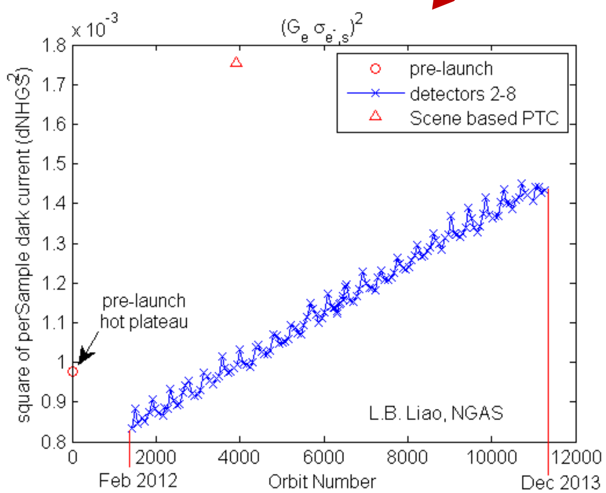
When observing a perfectly dark scene, the PTC for DNB can be written as,

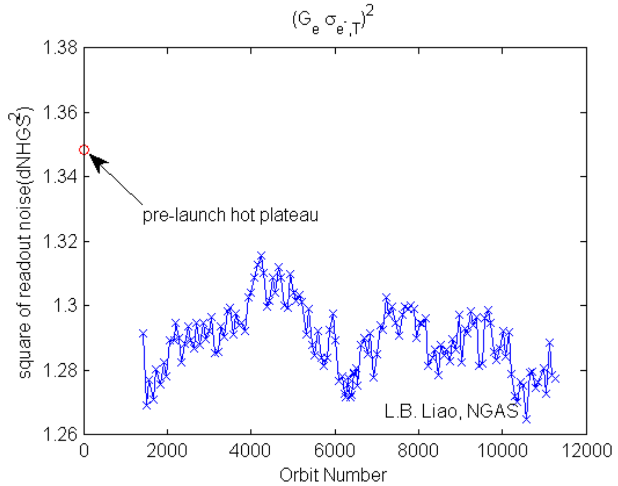
$$Var(HGSdN_s) = N_{agg} \times \left(G_e \sigma_{e^-,S}\right)^2 + \left(G_e \sigma_{e^-,T}\right)^2$$

Plot of variance of HGSDN versus N_{agg} results in intercept of read out noise and slope of detector element dark current noise.

detector element dark current noise

aggregated read-out noise





Dark current noise increasing with time (radiation exposure). We can use this time dependence to get EOL dark current noise. Interestingly, there is an oscillation which correlates with lunar phase variation.

Readout noise is relatively stable.

Variation in detector element dark current points to problem with radiometric offset

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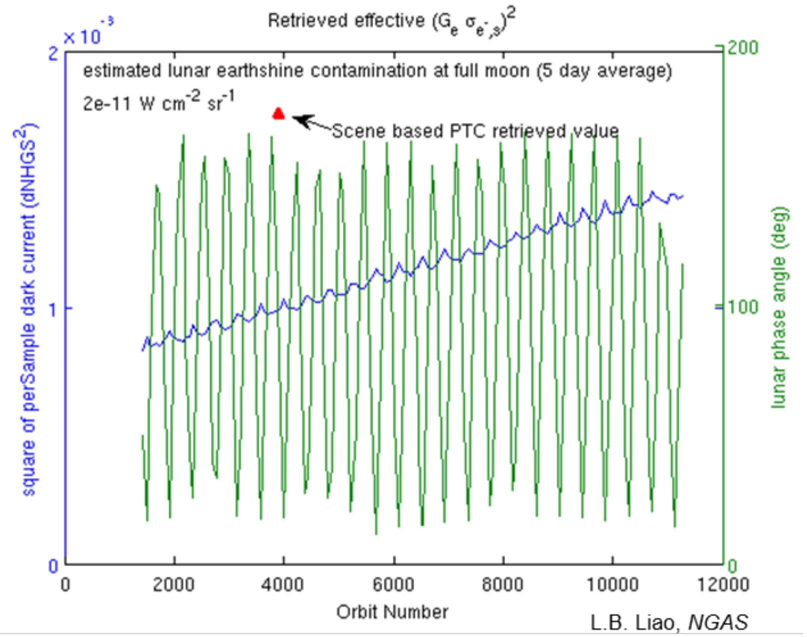


$$Var(HGSdN_s) = N_{agg} \times \left(G_e \sigma_{e^-,S}\right)^2 + \left(G_e \sigma_{e^-,T}\right)^2 + G_e G_L N_{agg} L$$

True dark (first two terms) — Contribution from external signal (last term)

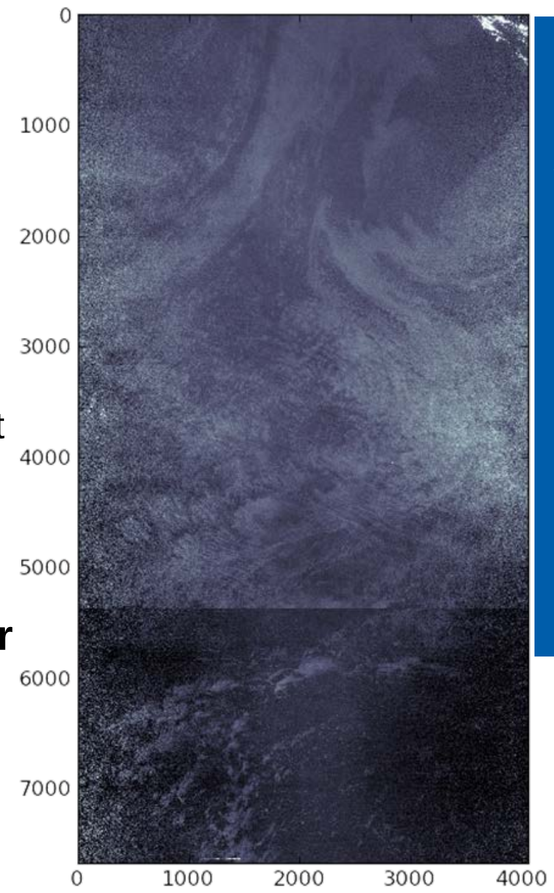
Slope of $Var(HGSdN_s)$ vs N_{agg} is $\left(G_e \sigma_{e^-,S}\right)^2 + G_e G_L L$

- Periodic structure in detector element dark current is correlated with lunar phase angle: peak at full moon and valley at new moon.
- This indicates that the signal from OBC Black Body is contaminated by lunar earthshine the magnitude of which is 2e-11 W cm^{-2} sr^{-1} , approximately 1% of L_{min}.
- The difference in value determined from two different PTC's indicates that the radiometric offset is 2.6e-10 cm^{-2} sr^{-1} . That is the SDR 'zero radiance' is really 2.6e-10 cm^{-2} sr^{-1} .

DNB offset is contaminated with airglow signal

- **DNB calibration is conceptually simple.**
  - Linear calibration means L = c1*(DN-DN0)/RVS.
  - c1 for low gain stage (LGS) is derived from solar diffuser data.
  - c1 for other gain stages (MGS and HGS) requires transfer from LGS using simultaneous observations around terminator region.
  - DN0 unfortunately can not be determined from the calibration views due to offsets between calibration view and earth view that are expected to change with FPA temperature and possibly amount of radiation damage.

- **DN0 determined for each detector, mirror side and sample number monthly.**
  - Assumes that new moon data over the ocean are completely dark.
  - There are two parts to the offset: on-board offset which is applied on-board and the ground offset which applied by the IDPS to the transmitted HGSdN.
  - Only the ground offset is updated monthly.



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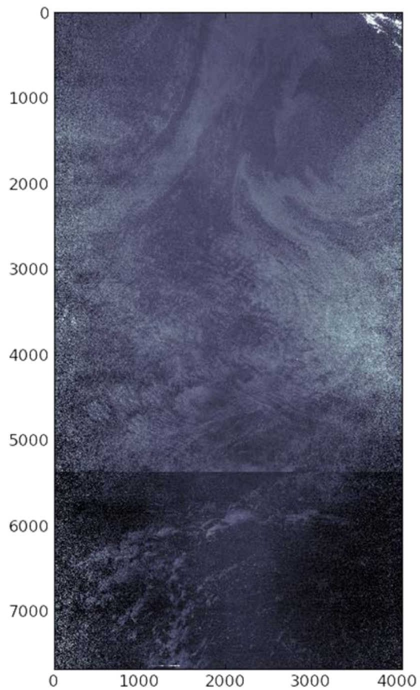
•Granules used in DN0 calculation for April 21, 2012.

•Obviously not dark. Contains signal from airglow.

•How to calculate the magnitude of this signal if we don't know the offset?

Combined PTC approach derives photon signal from variance values, eliminating the need to know the offset



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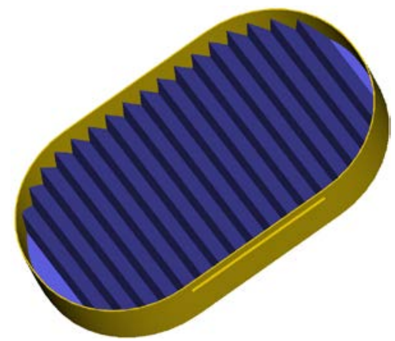
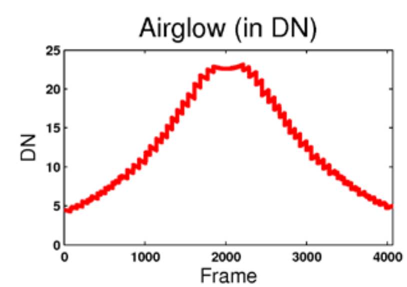
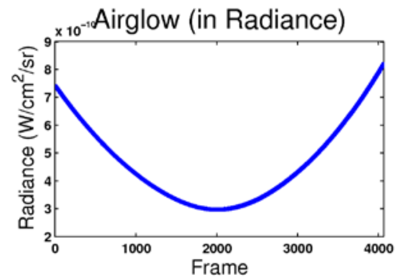
$$Var(HGSdN_{EV}) = N_{agg} \times \left(G_e \sigma_{e^-,S}\right)^2 + G_e \langle HGSdN_{EV} \rangle + \left(G_e \sigma_{e^-,T}\right)^2$$



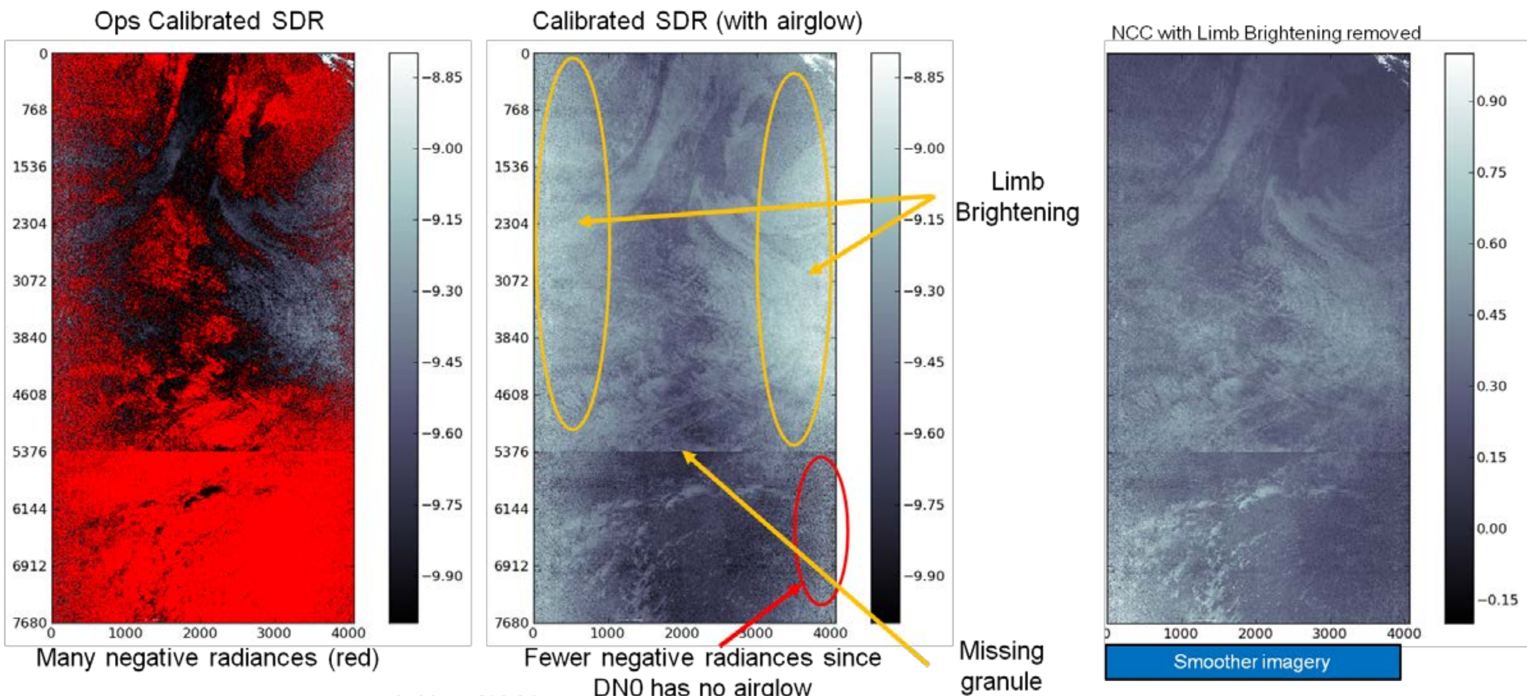
$$Var(HGSdN_{OBCBB}) = N_{agg} \times \left(G_e \sigma_{e^-,S}\right)^2 + \left(G_e \sigma_{e^-,T}\right)^2$$





$$HGSdN_{EV} = \frac{Var(HGSdN_{EV}) - Var(HGSdN_{OBCBB})}{G_e}$$

Airglow corrected SDR shows limb brightening which can be corrected for NCC with the derived airglow curve



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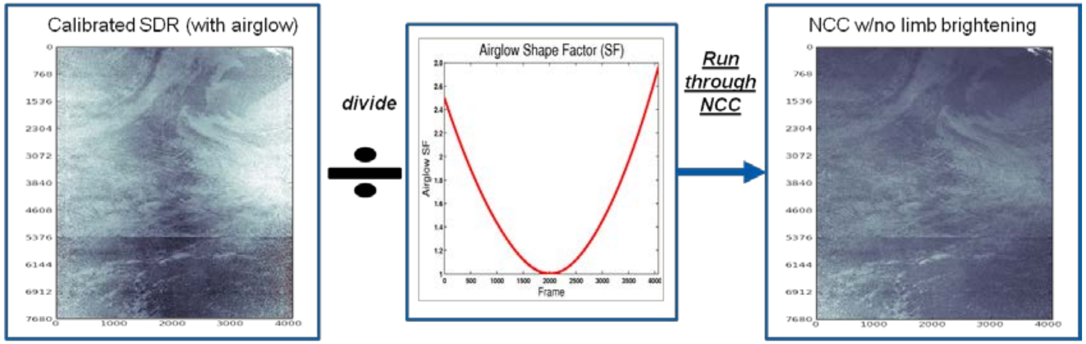

Example application from April 21,2012

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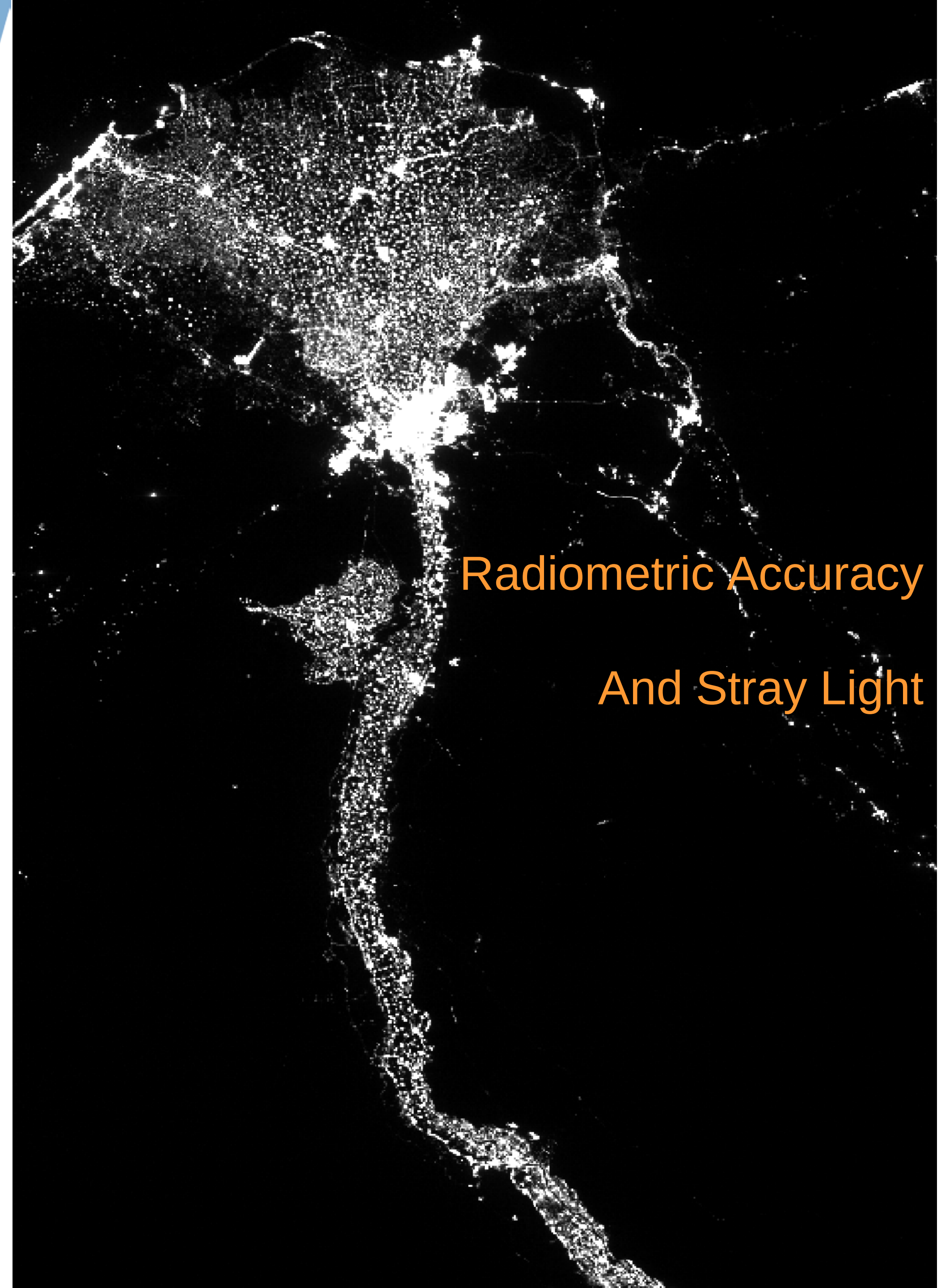
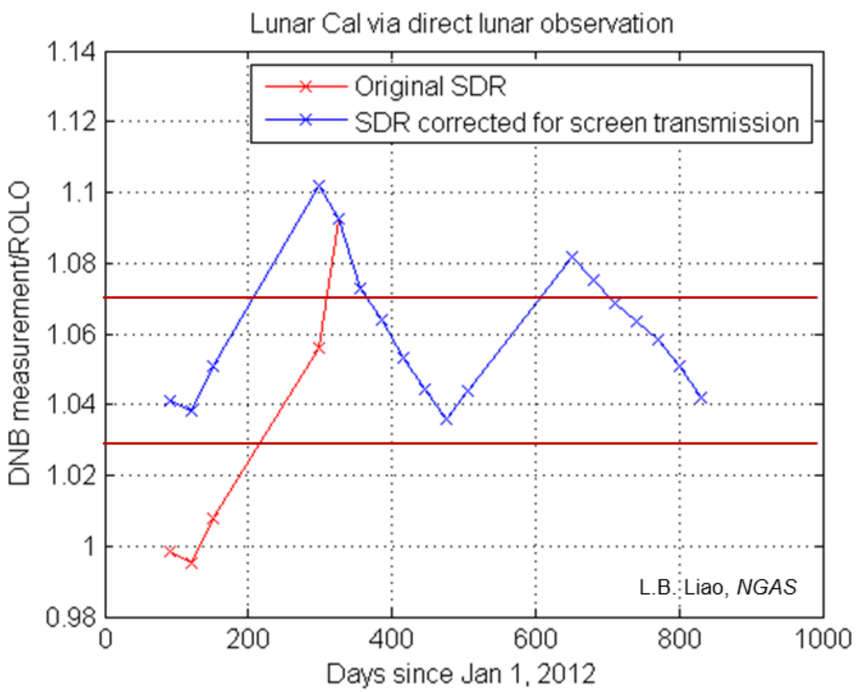
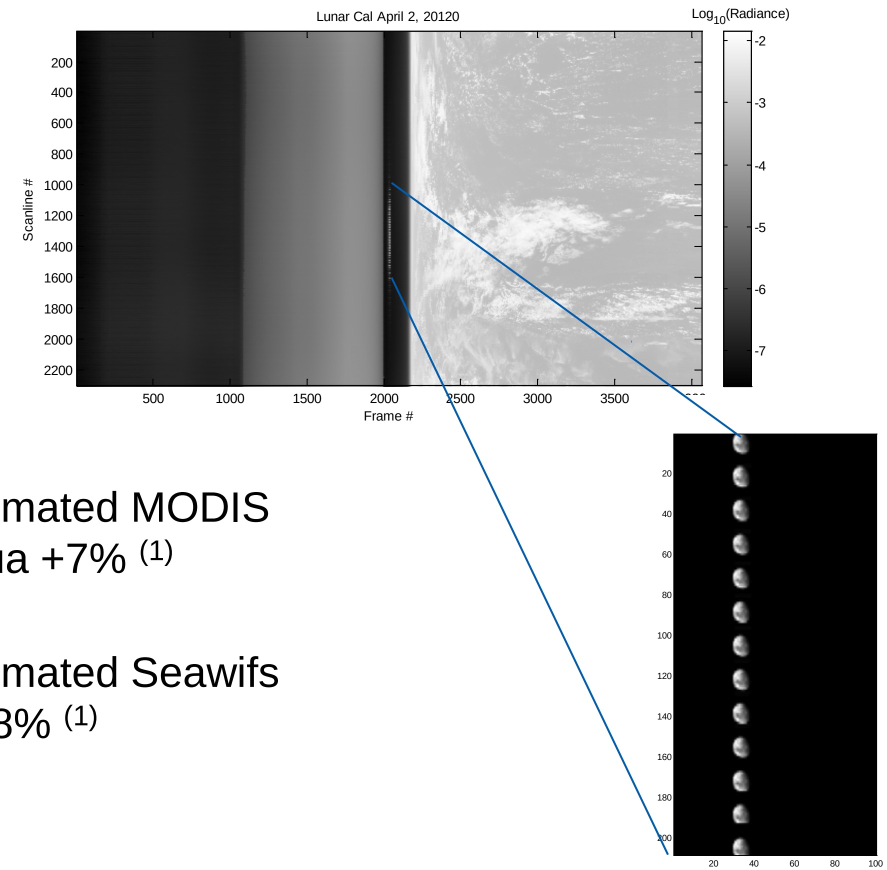


Radiometric Accuracy And Stray Light

Lunar Cal for Low Gain Stage (LGS)





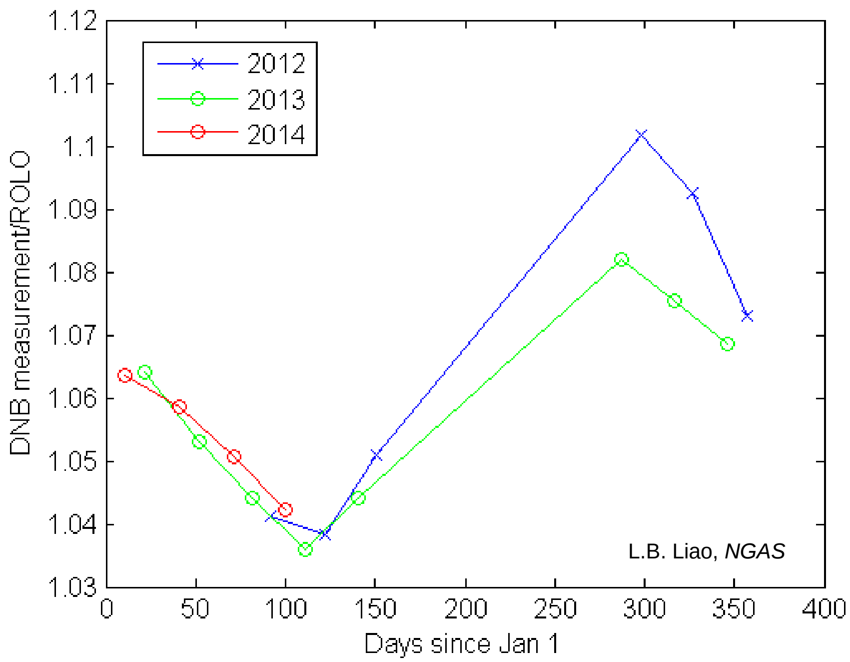
Estimated MODIS Aqua +7% (1)

Estimated Seawifs +2.8% (1)

Radiometric uncertainty relative to ROLO (lunar model from USGS) is (6 ± 2) %.
Relative to MODIS, this would translate to (-1% ± 3) %.
For a given scene, this implies DNB retrieves slightly lower radiance than MODIS.

(1) Eplee, et al Proc. of SPIE Vol. 8866 88661L-1

Lunar observations oscillates on an annual cycle



DNB observation of the moon is higher in radiance than predicted by ROLO. There is an average offset of approximately 6%. However, there is also an unexpected annual cycle in the observed radiance ratio of DNB observation measurement relative to ROLO prediction. The cycle appears to be repeatable but the peak value for 2013 was 2% lower than 2012. In fact, all late fall measurements (Oct –Dec) were lower in 2013 than 2012.

Vicarious Cal of High Gain Stage (HGS) data with lunar illuminated playa

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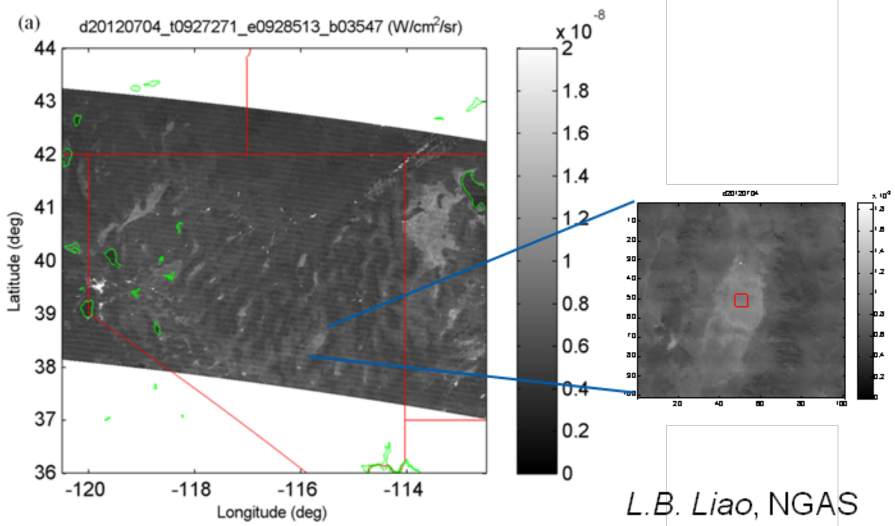
Before stray light removal



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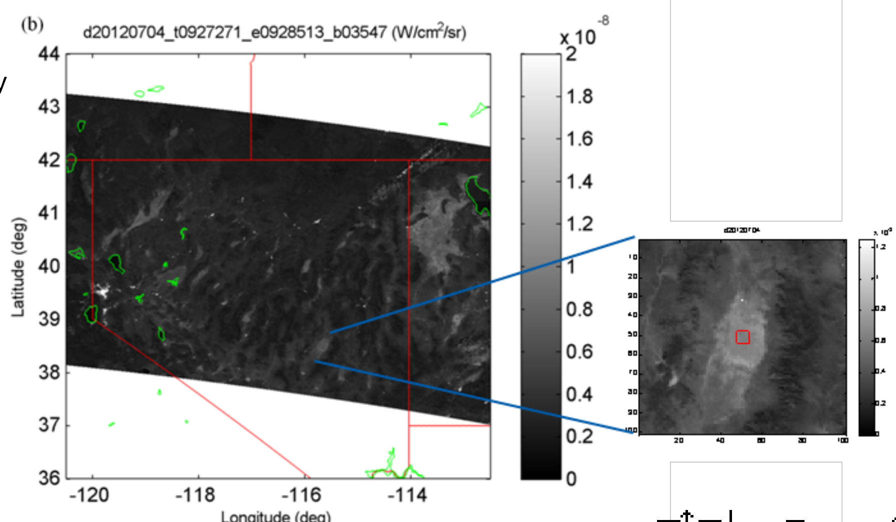
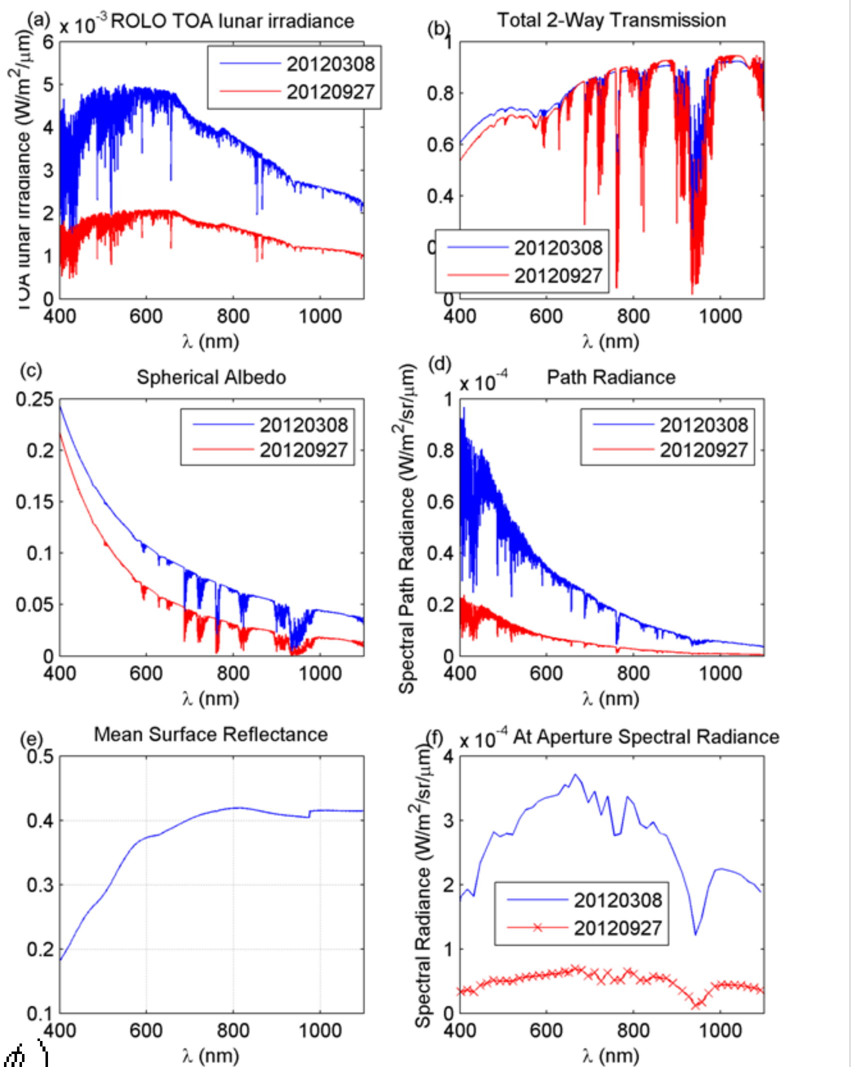
After stray light removal





$$L = L_{path} + \frac{T^{\uparrow}T^{\downarrow}\rho_s E_I \cos(\phi_z)}{\pi \times (1 - A_{spherical}\,\rho_s)}$$

Results of 2012 HGS vicarious calibrations

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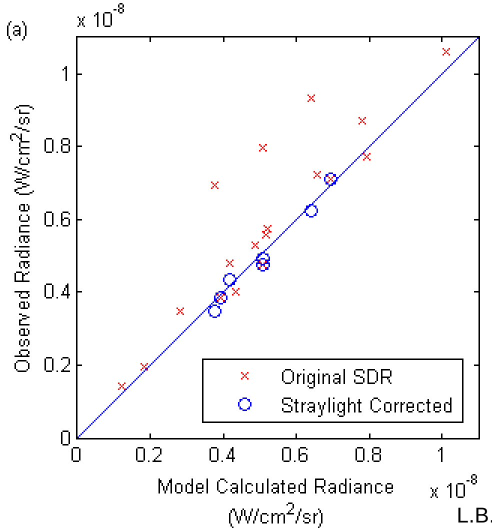

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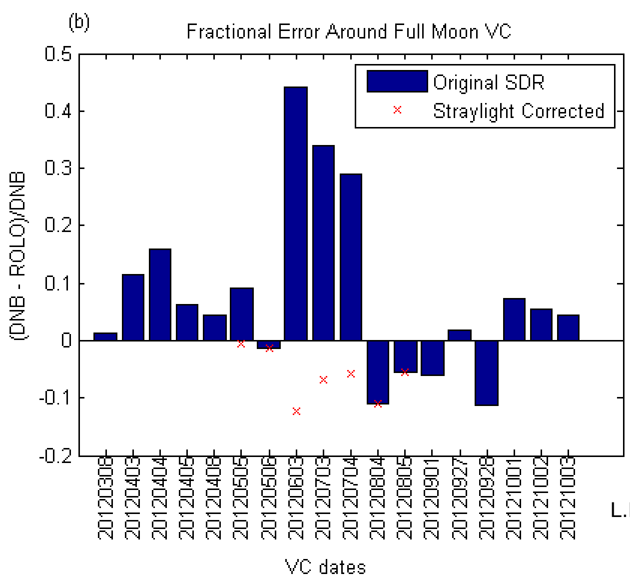

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HGS Radiometric Uncertainty (1 σ)		
	Before Nov 16, 2012	After Nov 16, 2012
Relative to ROLO (DNB-ROLO)/DNB	6.1 ± 8.9 %	9.7± 8.9 %
Relative to MODIS (DNB-MODIS)/DNB	-0.9 ± 9.1 %	2.7± 9.1 %

Estimated calibration transfer uncertainty is 6.4% per transfer, implying MGS uncertainty of -1%± 6.7%. (MGS uncertainty is quoted with same sign as LGS)

	Stray light contamination
Before Correction	2.4×10^{-9} W·cm^{-2}·sr^{-1} (~100% L_{min})
After Correction	4.5×10^{-10} W·cm^{-2}·sr^{-1} (~15% L_{min})

Results of 2013 HGS vicarious calibrations

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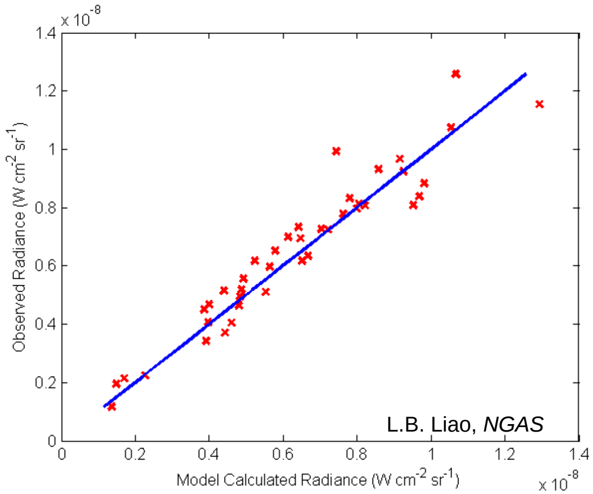
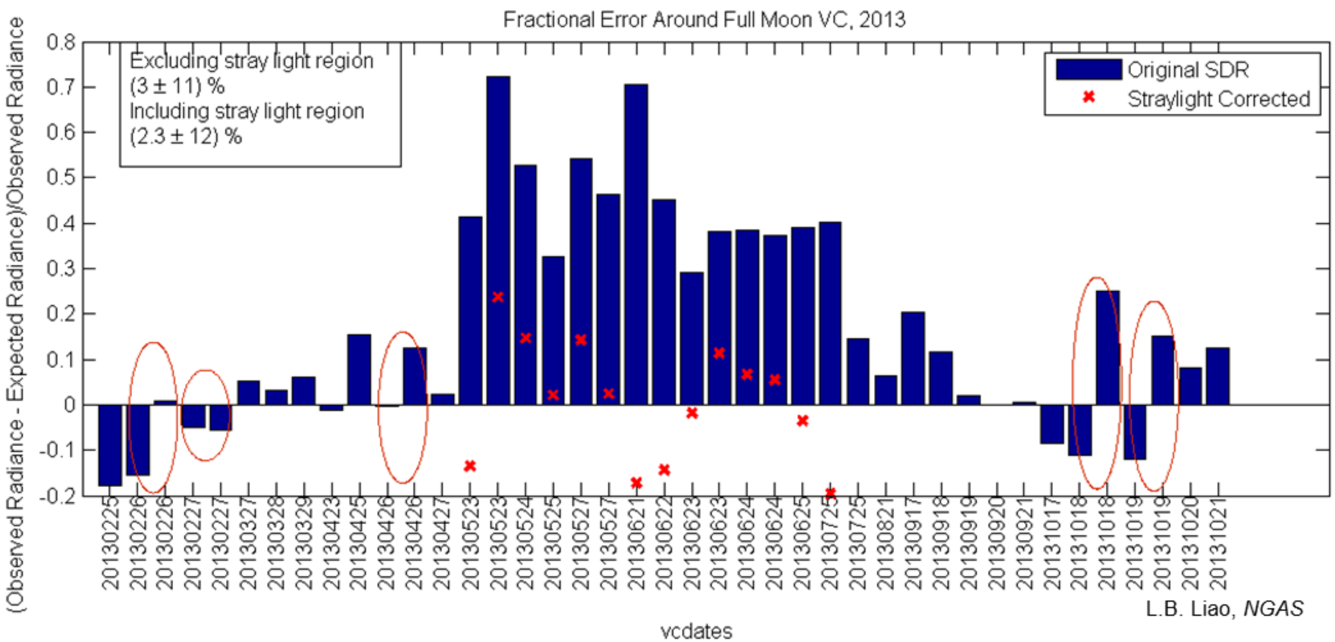


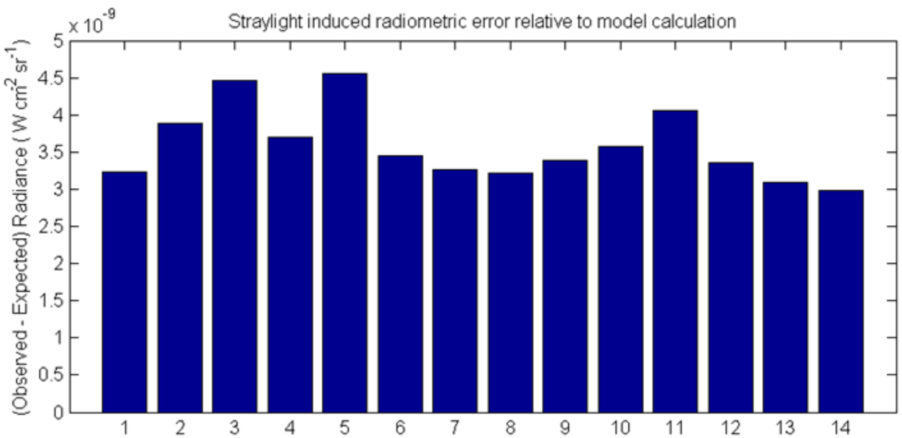
HGS Radiometric Uncertainty (1 σ)		
	2013	Expected, based on 2012 data
Relative to ROLO (DNB-ROLO)/DNB	2.3 ± 12 %	9.7± 8.9 %
Relative to MODIS (DNB-MODIS)/DNB	-4.7 ± 12.2 %	2.7± 9.1 %

Estimated calibration transfer uncertainty is 8.6% per transfer, implying MGS uncertainty of -1%± 8.6%. (MGS uncertainty is quoted with same sign as LGS)



Additional scatter caused by inclusion of large angle data. Overlap observations indicate that retrieved radiance at start of scan is lower than retrieved radiance at end of scan.

Stray light correction improves the radiometric quality of the data from 2013 VC



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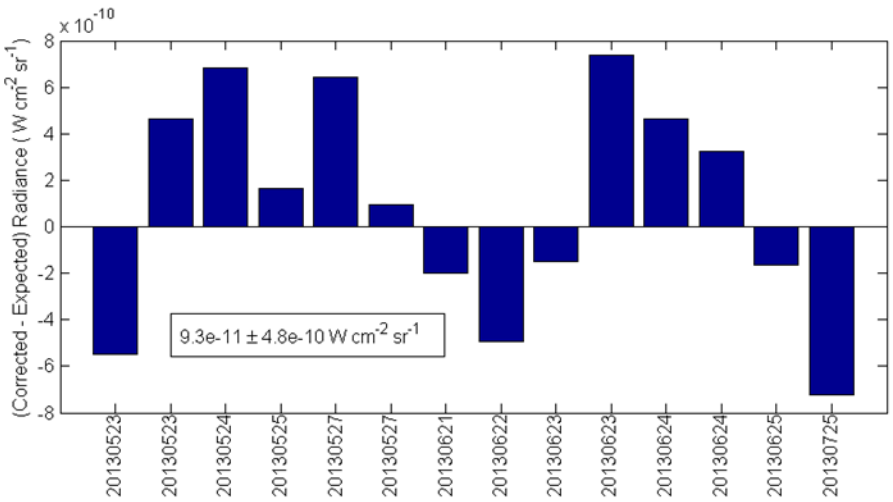
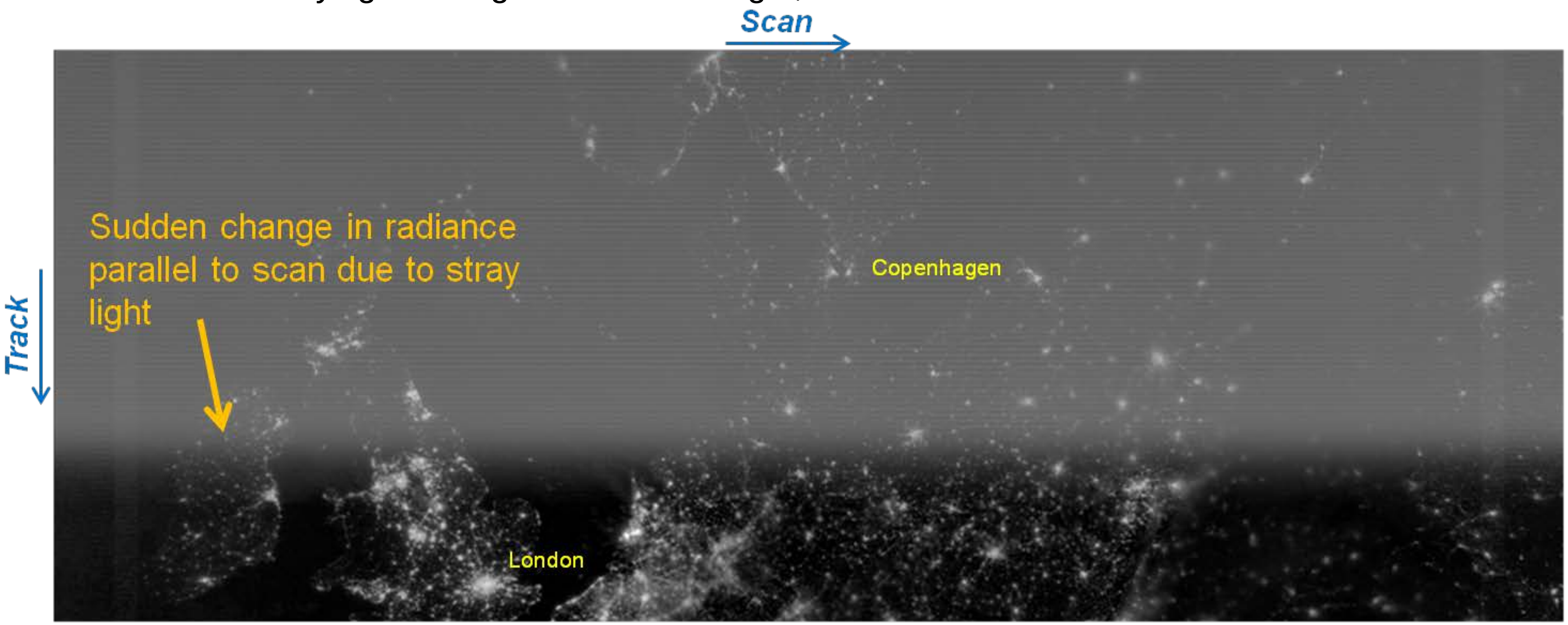


	Stray light contamination
Before Correction	4×10^{-9} W·cm^{-2}·sr^{-1} (~100% L_{min})
After Correction	6×10^{-10} W·cm^{-2}·sr^{-1} (~20% L_{min})

DNB Stray Light Description

- Stray light appears on the night side of the terminator
  - Occurs for both the northern & southern terminator crossing
    - Ends when sun is eclipsed by the earth relative to the spacecraft, indicating it is caused by direct path from the sun.
  - Affects different segments of the orbit in the Northern and Southern hemispheres
    - Sun shining into EV port
    - Sun shining into both SD and EV ports (southern hemisphere only)
  - Stray light has detector dependence
  - Level of stray light changes with scan angle, but extends across the entire scan



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Northern Hemisphere (log scale)

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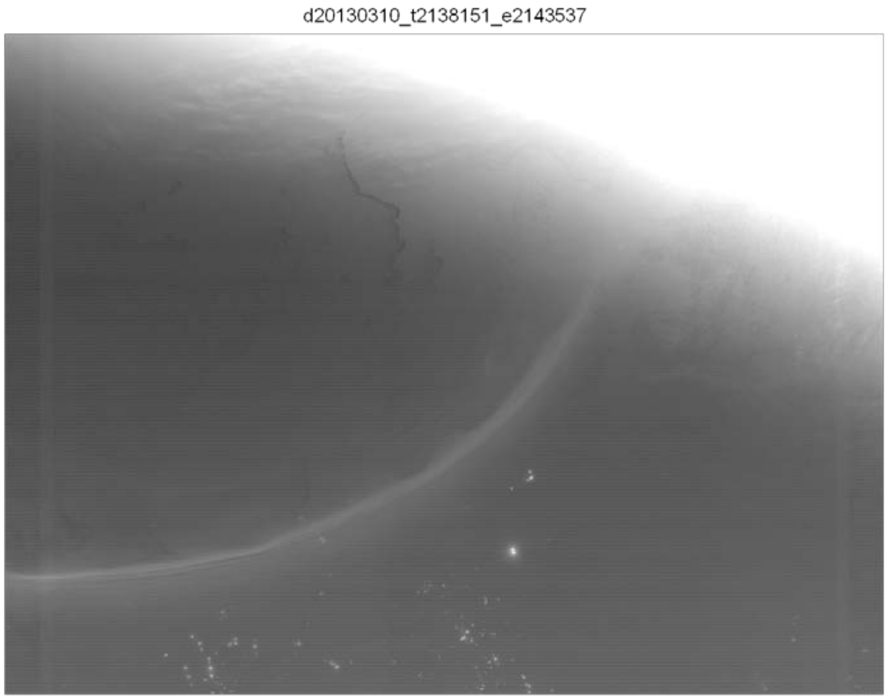
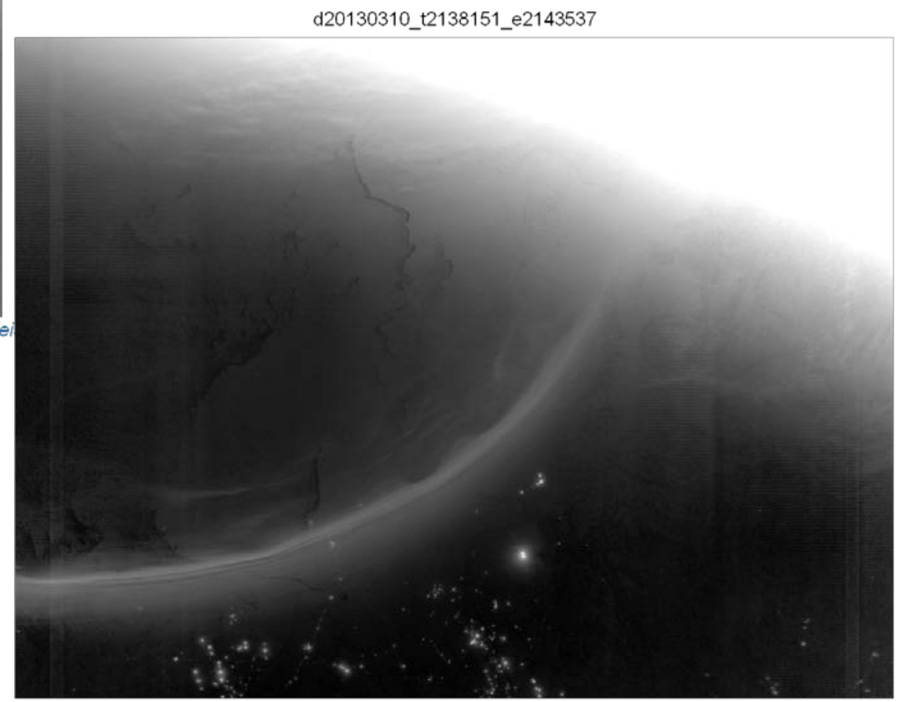


S. Wei

The stray light correction enhances the dynamic range of the scene and allows users to extract details that were previously washed out due to the stray light.



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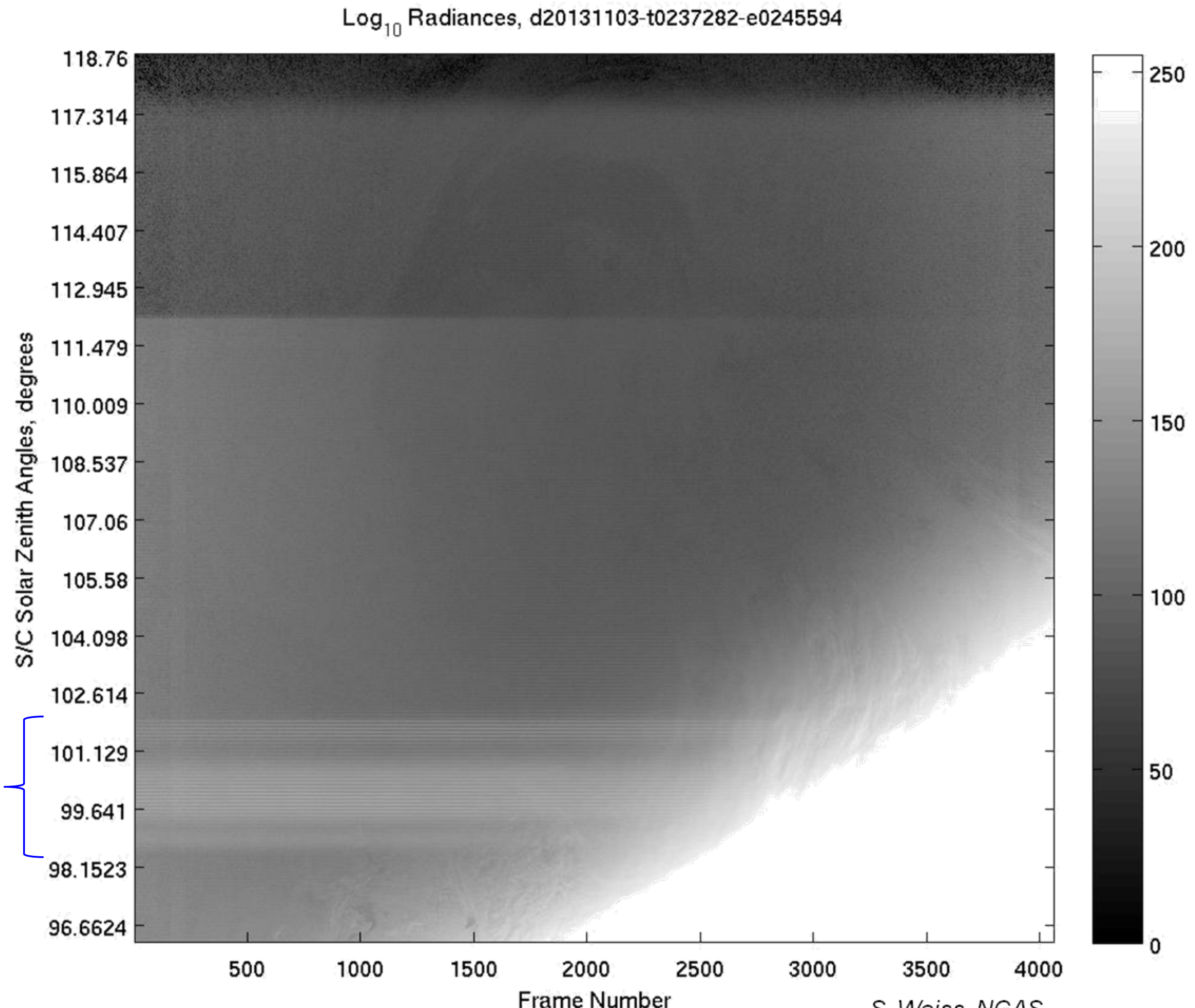
Stray light Correction Issues

- Additional stray light region shows up from October through December in the southern hemisphere
  - Ranges from about ~102.4 to ~98.8 degrees, depending on the month
  - Has a dependence on S/C solar zenith angle and detector
- Existing stray light correction scheme does not correct for this additional stray light region
  - Pattern shifts between the months, making it difficult to model and correct

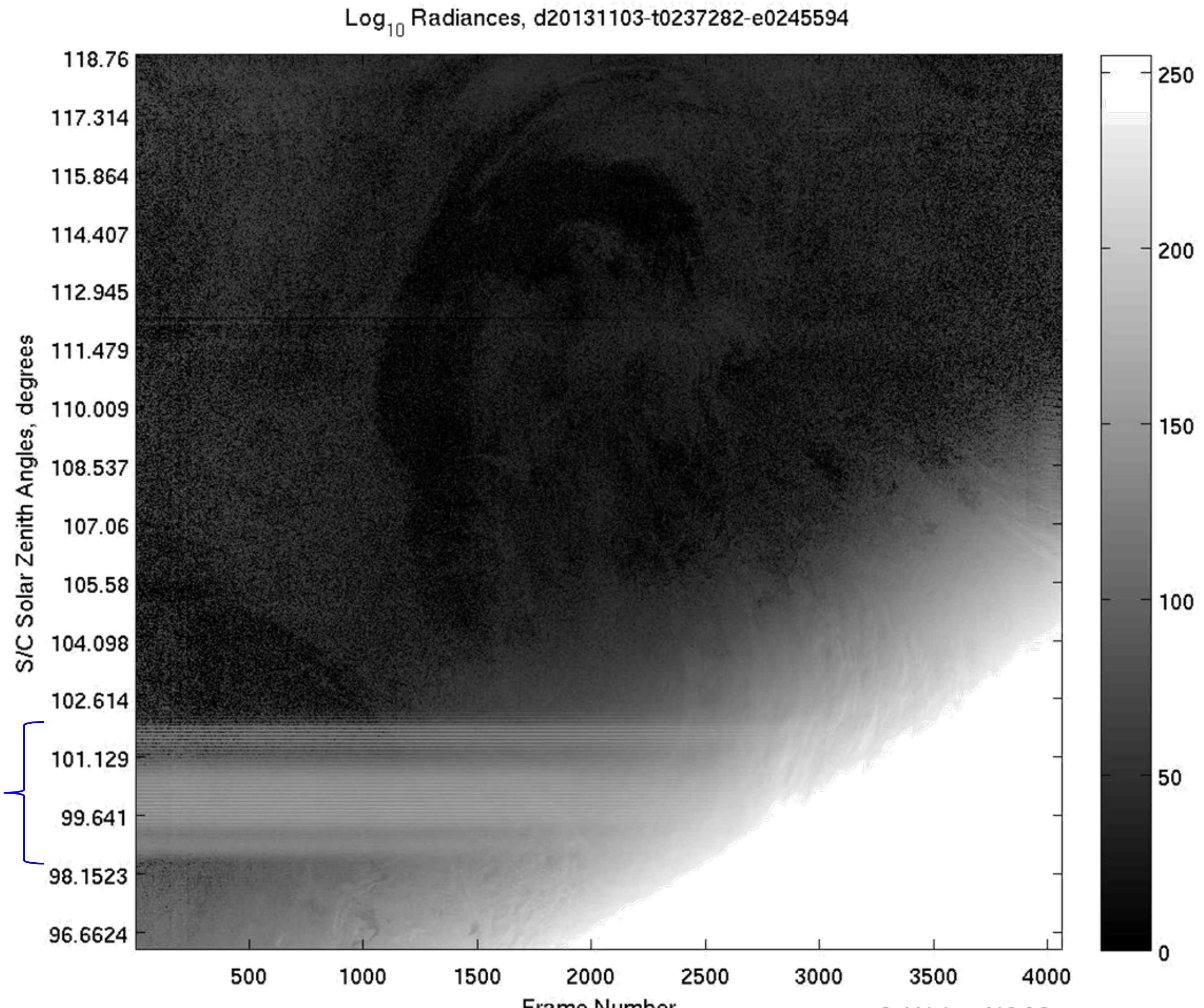
Uncorrected Radiances for Nov 2013 - Additional Stray Light Region Near Terminator



Additional stray light region ranges from S/C Solar Zenith Angles of about 102.3° to 98.6° for Nov 2013

S. Weiss, NGAS

Corrected Radiances for Nov 2013 - Additional Stray Light Region Not Corrected



Additional stray light is not corrected by the stray light correction since this region is not modeled.

S. Weiss, NGAS

Conclusions and Potential Improvements (1/2)

- **DNB is performing well on-orbit**
  - Exceeding most radiometric performance requirements
  - LGS radiometric uncertainty of 4%, MGS radiometric uncertainty of 10%, HGS radiometric uncertainty of 17%
  - Projected SNR >8 at end of life.
    - Minor decrease due to response degradation. Majority of SNR decrease due to increase in dark current noise.
  - Stray light correction enhances the contrast and radiometric accuracy of the scene and allows users to extract details that were previously washed out.

- **New technique using Photon Transfer Curve (PTC) was developed to retrieve noise and signal in the presence of unknown offset**
  - PTC allows for retrieval of various noise sources, depending on the source of input data. zero signal PTC can be used to monitor change in dark current noise and SNR throughout the life of the mission. (As well as monitoring possible change in electronic gain and read out noise all of which should be fed back to JPSS-1.)
  - Combining PTC data of both calibration and earthview allowed us to remove the airglow signal, which is ALWAYS present, from the DNB offset data. This allows us to produce more accurate radiance data and eliminates the large fraction of negative radiance data around new moon.
  - Periodic variation in retrieved effective dark current signal is due to presence of lunar earthshine.
    - Technique can be used to calculate earthshine contamination in calview ports and its implication for calibration of other RSB.

- **It has been shown that Combined PTC scheme has been demonstrated to retrieve accurate airglow signal for data from the time period near the pitch maneuver.**

Conclusions and Potential Improvements (2/2)

- **Some performance issues and potential improvements:**
  - Analyze the additional small stray light region appearing from October to December in the southern hemisphere. The stray light pattern for this region changes from month to month and may be difficult to model and correct.
  - More vicarious calibration data to quantify residual radiometric error after DNB stray light removal.
  - Develop a scheme for flagging ‘dark’ pixels described in DR7364. Detailed analysis showing frequency of occurrence as function of detector # and aggregation zones will help JPSS-1 DNB build.
  - Develop a scheme for flagging analog saturation (DR 4603) and verify that these points are not included in cross calibration. If designed properly, this should not have occurred. JPSS-1 DNB build should optimize its gains for different stages so that this does not happen.
  - Use combined PTC scheme to validate the assumption that the offsets between earth view samples and black body view samples are constant.
  - Use combined PTC approach to estimate the contamination of SD and SV ports by earthshine.
  - Combined PTC can be used to remove limb brightening in NCC products once RSB_autocal is operational.

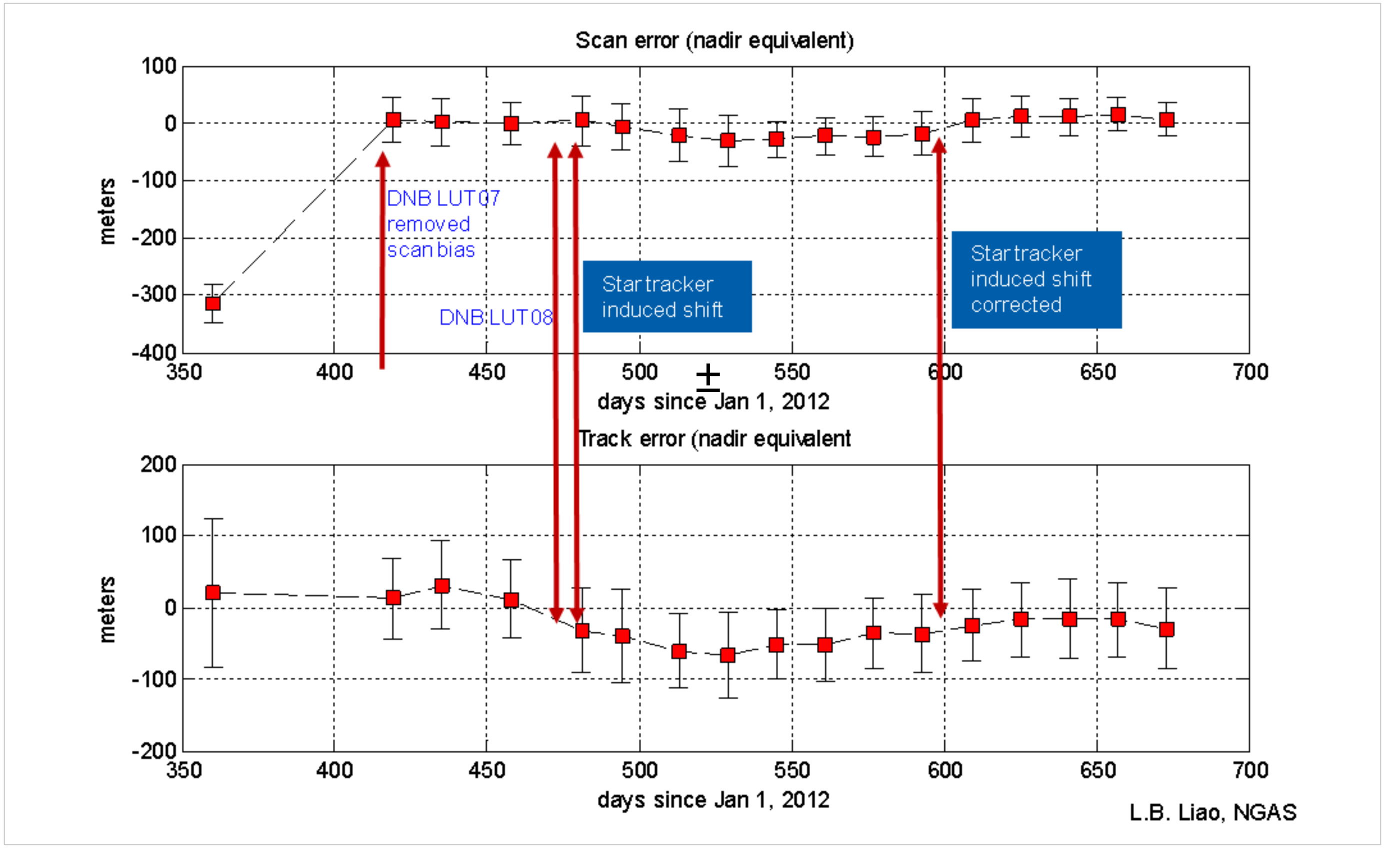
Back up

THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN

DNB Geolocation

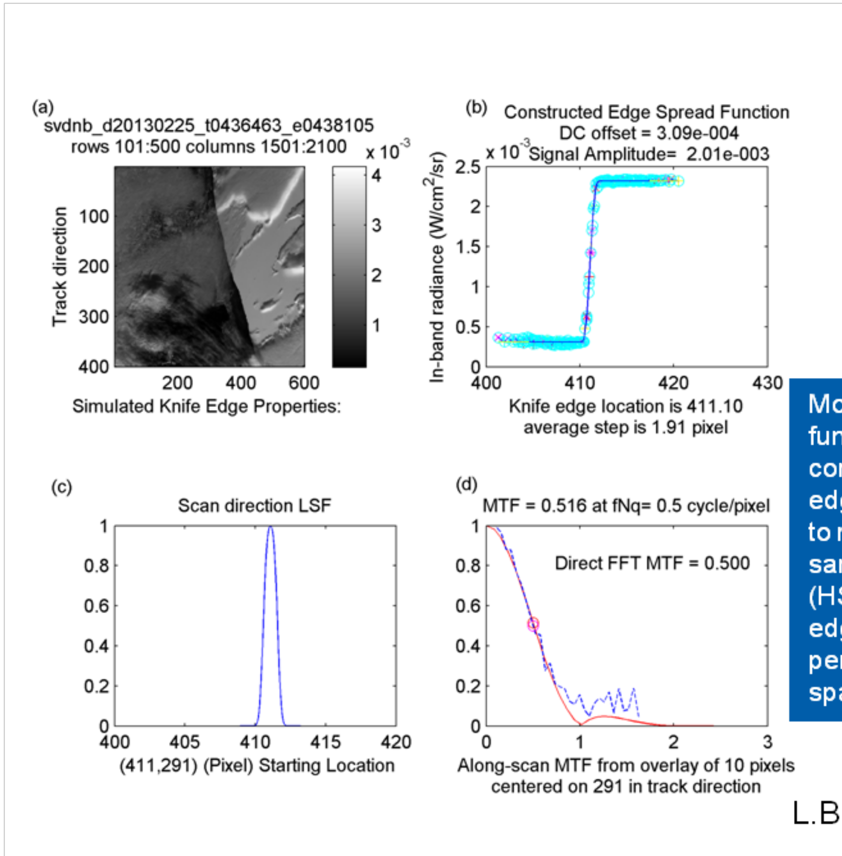
NORTHROP GRUMMAN



As of Nov 4, 2013, the DNB geolocation accuracy is,
Scan : 8 ± 33 μrad ; Track : -35 ± 68 μrad

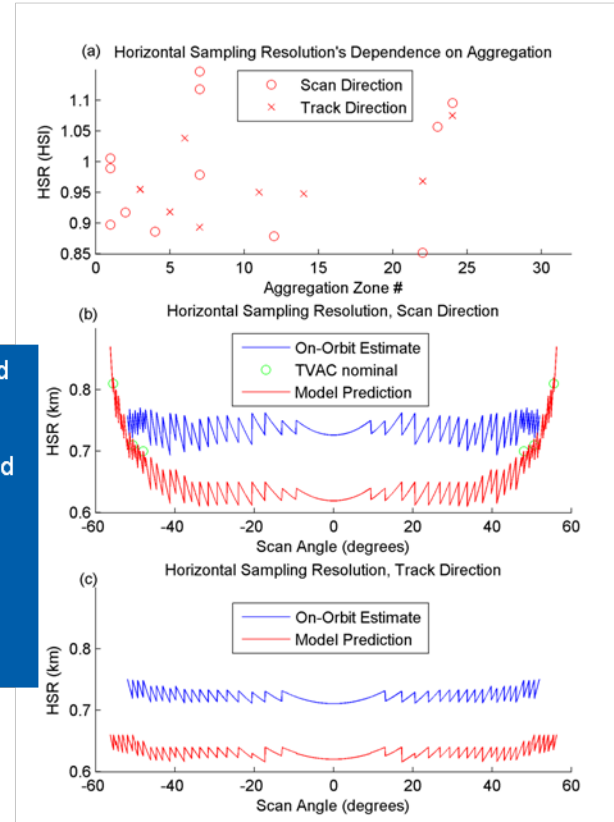
DNB spatial characteristics

NORTHROP GRUMMAN



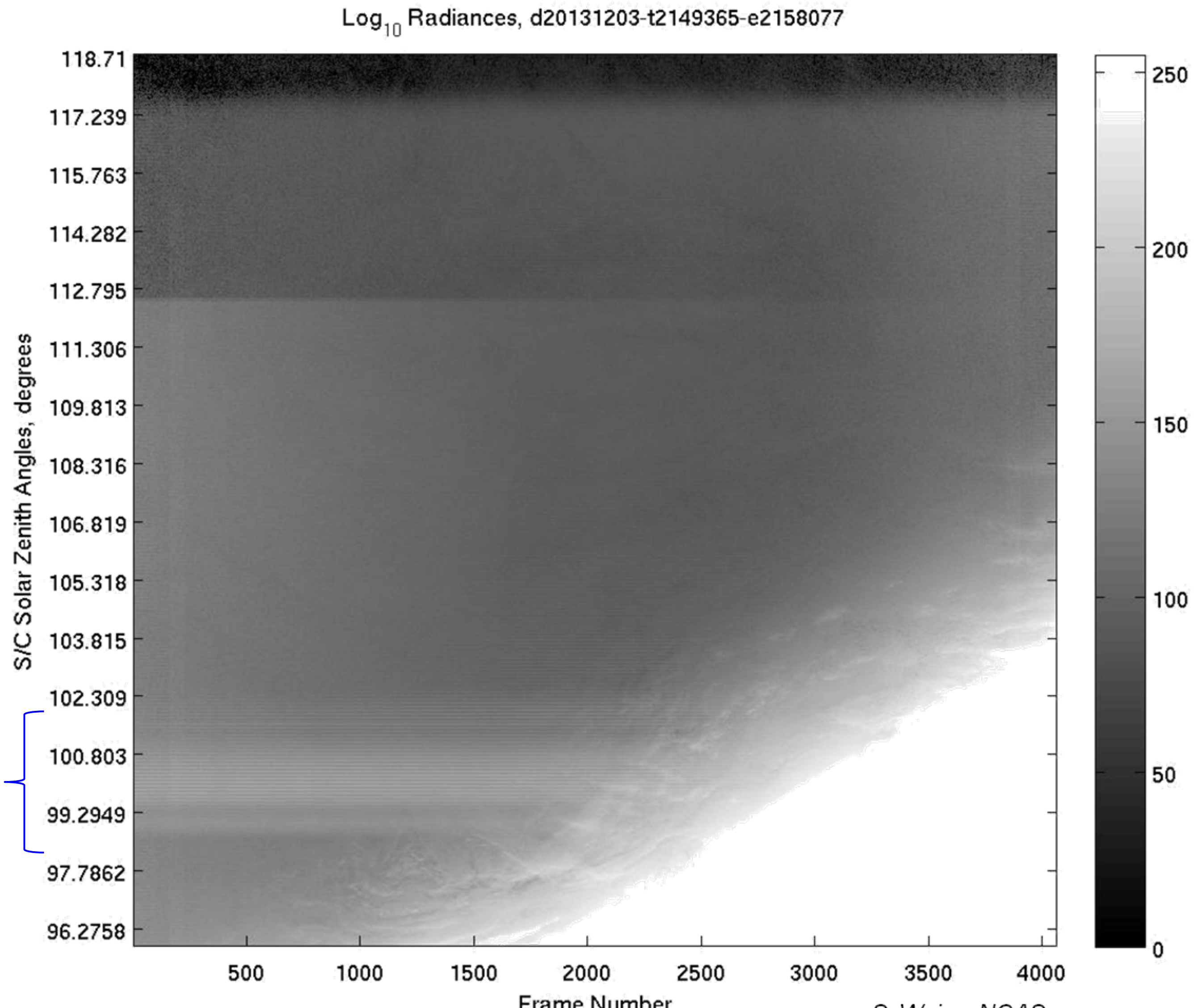
Model based line spread function (LSF) construction using ice edge scenes was utilized to retrieve horizontal sampling resolution (HSR). Correction for edge slant was performed in Fourier space.

L.B. Liao, NGAS



DNB HSR is approximately a constant multiple of the horizontal sampling interval (HSI) for aggregation zones 1-24. This results in approximately constant HSR in units of ground distance, with saw tooth pattern that is inherent in the ground HSI. HSR meets the requirement of 800 meters upto scan angle of 52 degrees.

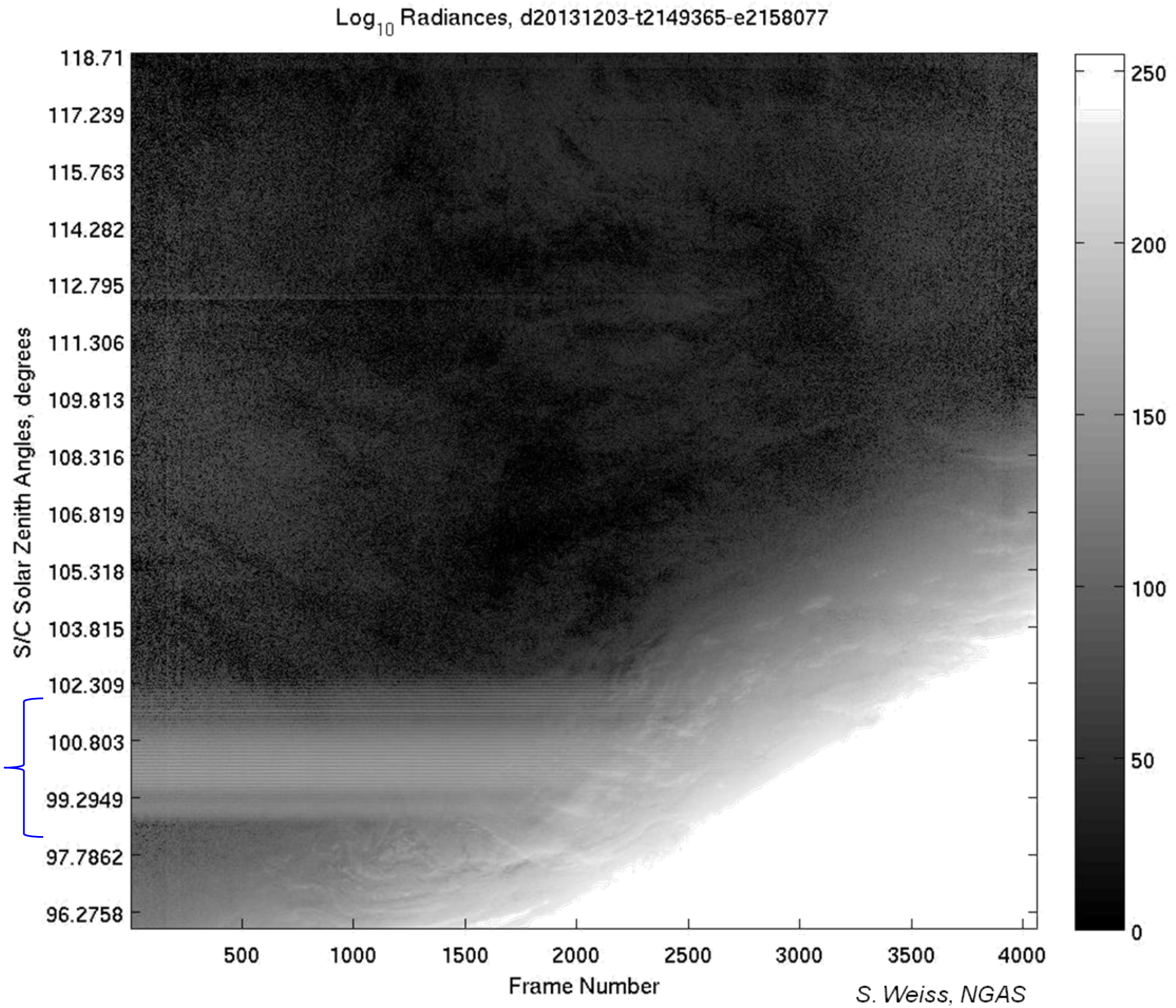
Uncorrected Radiances for Dec 2013 - Additional Stray Light Region Near Terminator



Additional stray light region ranges from S/C Solar Zenith Angles of about 102.5° to 98.9° for Dec 2013

S. Weiss, NGAS

Corrected Radiances for Dec 2013 - Additional Stray Light Region Not Corrected



Additional stray light is not corrected by the stray light correction since this region is not modeled.

THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN