Radiometric Calibration and Performance of S-NPP and N-20 VIIRS Reflective Solar and Day-Night Bands

VIIRS Characterization Support Team (VCST)

November 18, 2019

We thank contributions from MCST

Objectives

1. Radiometric calibration improvements since last STM
2. RSB and DNB radiometric performance update
3. Future improvements

What Happened Since STM 2018

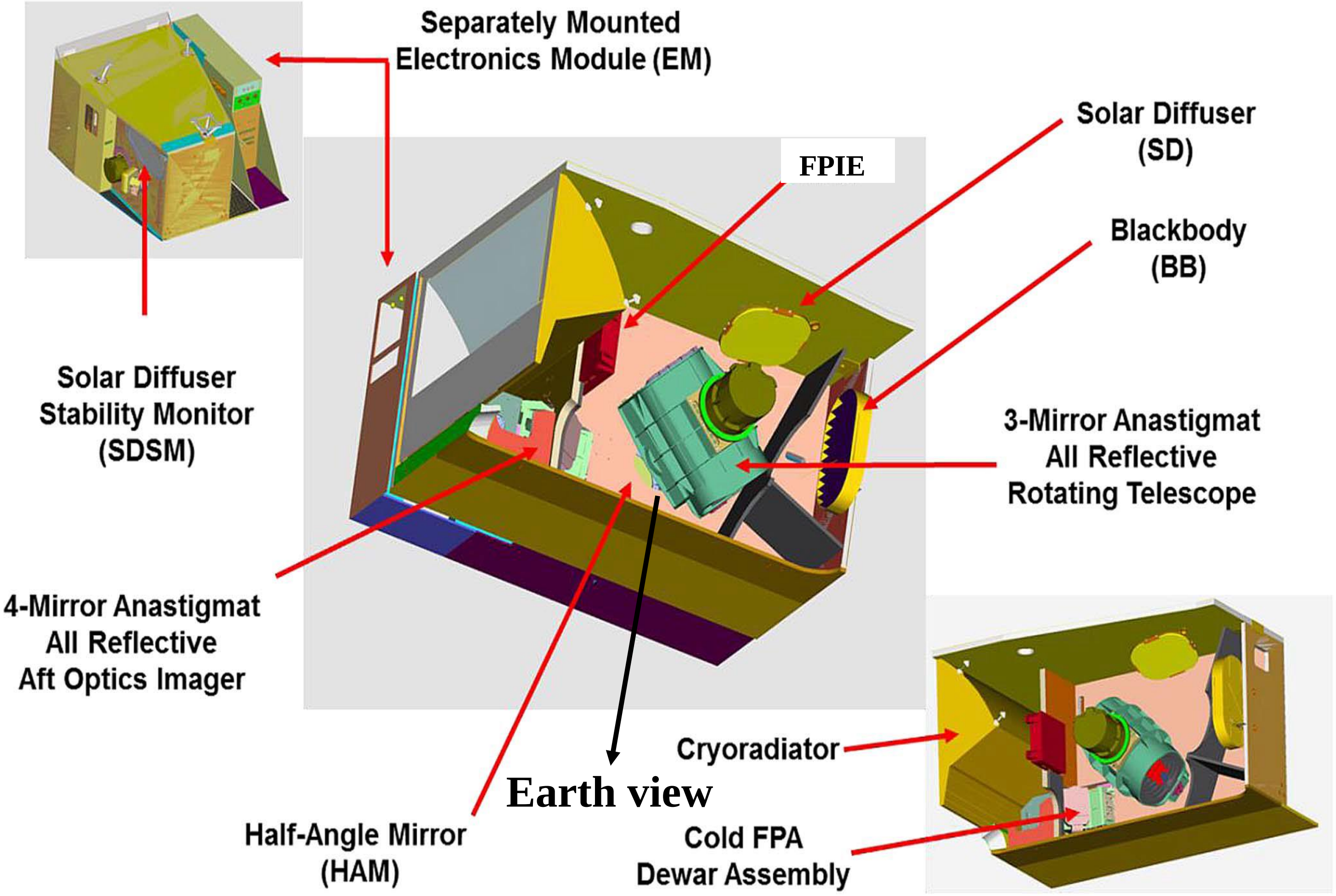
S-NPP

- Feb 24, 2019 event impacts resolved
- Updated prelaunch table (delta-C)
- H-factor solar angular dependence for all RSBs and DNB
- H-factor SD positional dependence
- Improved H-factor with 7-yr lunar results
- DNB dark count improved
- Other minor improvements (code, linear fit instead of mean)
- Mission-long LUTs delivered: C 2.0 (to early July 2019)

N-20

- Screen transmittance functions improved
- SD H-factor improved: updated screen functions and angular dependence
- DNB stray light correction improved: edge frames
- Mission-long LUTs delivered: C 2.0

VIIRS Physical Components



VIIRS RSB and DNB

Fourteen Reflective Solar Bands (RSBs)

- Narrow band widths: 15 – 80 nm
- Band central wavelengths: 0.412 – 2.25 μm
- Each band has an array of detectors
- M1-5, M7: dual-gain
- Three aggregation zones

One Day-Night band

- Wide band width: 0.5 – 0.9 μm
- Three gain stages, very high sensitivity
- 32 modes for SNPP, 22 modes for N20 (aggregations)
- 16 detectors bundled from pixels depending on mode

VIIRS RSB and DNB L1B Products

radiometrically as well as geometrically calibrated top-of-the-atmosphere (TOA) solar spectral radiance (RSB) and radiance (DNB)

RSB

$$\overline{L}_{EV}=\frac{\int_0^{\infty} RSR(\lambda)\,d\lambda\; L_{EV}(\lambda)}{\int_0^{\infty} RSR(\lambda)\,d\lambda}=\frac{F\times(c_0+c_1 dn+c_2 dn^2+c_3 dn^3)}{RVS(\lambda_B\,,t,\,\theta_{EV})}$$

C 1.0: c_3=0
C 2.0: c_0=0

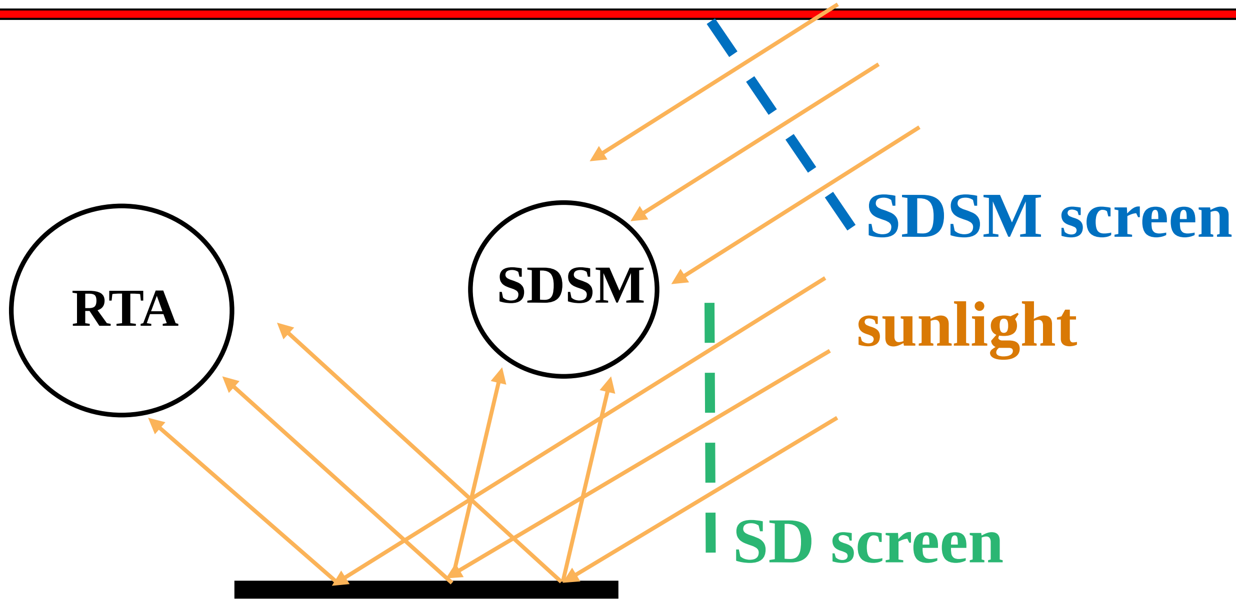
Relative HAM reflective over scan angle

on-orbit calibrated

DNB

$$L_{EV}=\int_0^{\infty} RSR(\lambda)\,d\lambda\; L_{EV}(\lambda)=\frac{F\times c_1 dn}{RVS(\lambda_{DNB}\,,t,\,\theta_{EV})}$$

VIIRS Radiometric Calibration



Solar Diffuser (SD): a calibration source
its BRDF change (H-factor) monitored by the SD stability monitor (SDSM)

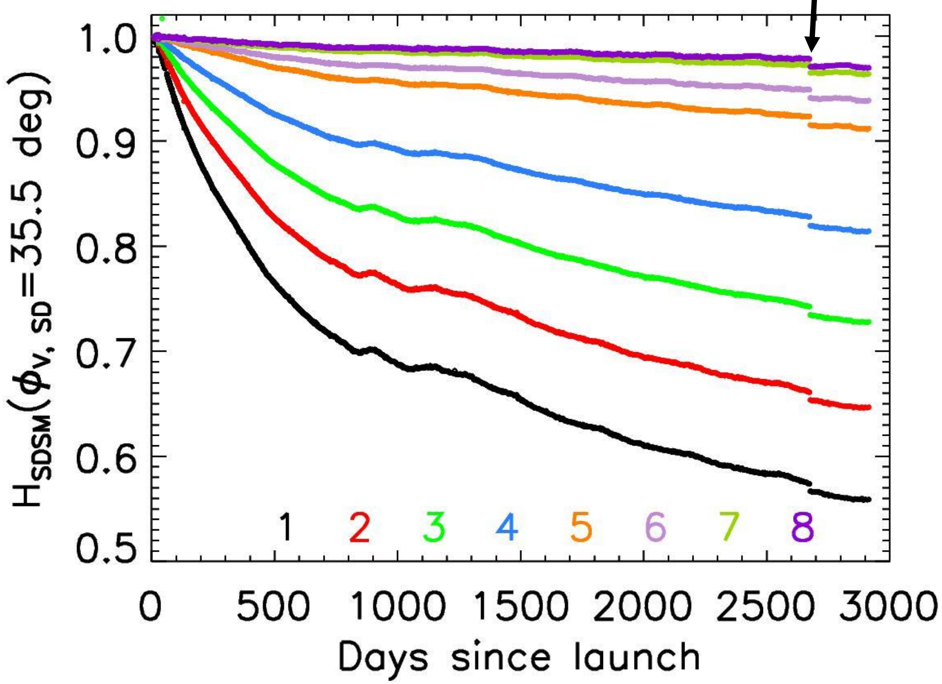
- τ_{SDSM} (relative)
- τ_{SD} BRDF(SDSM; relative)
- τ_{SD} BRDF(RTA; yaw)

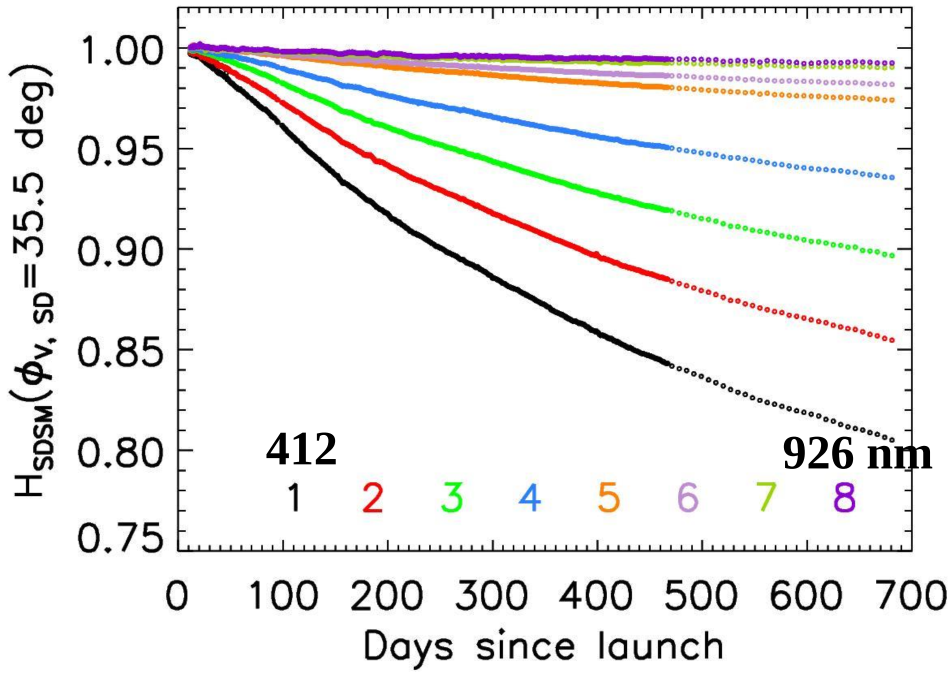
Improved with yaw and regular on-orbit data

For both S-NPP and N-20

VIIRS SD H-factor

S-NPP **Feb 24, 2019 event** **N-20**

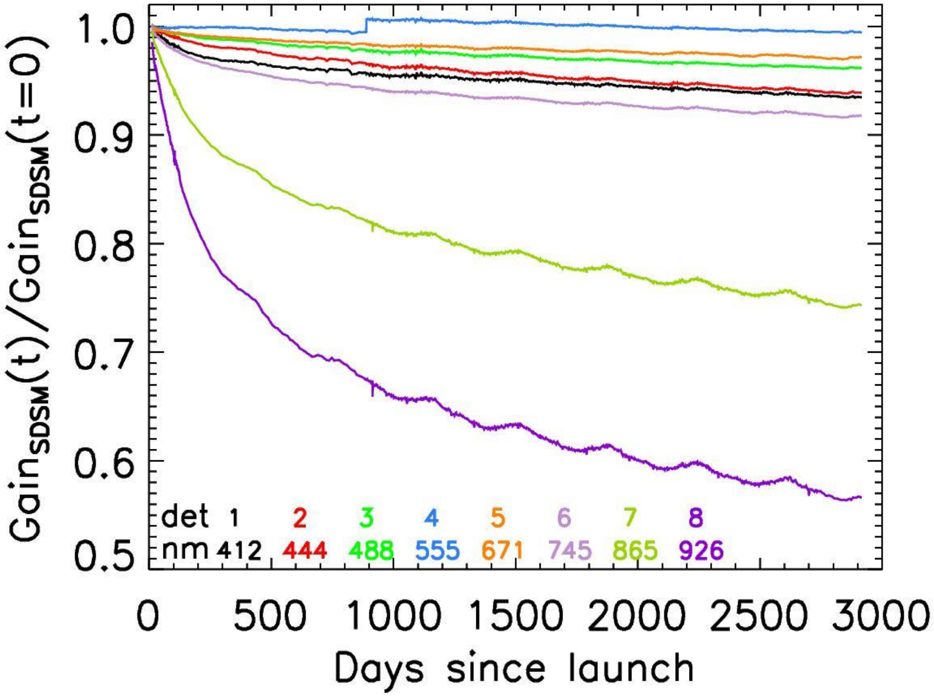




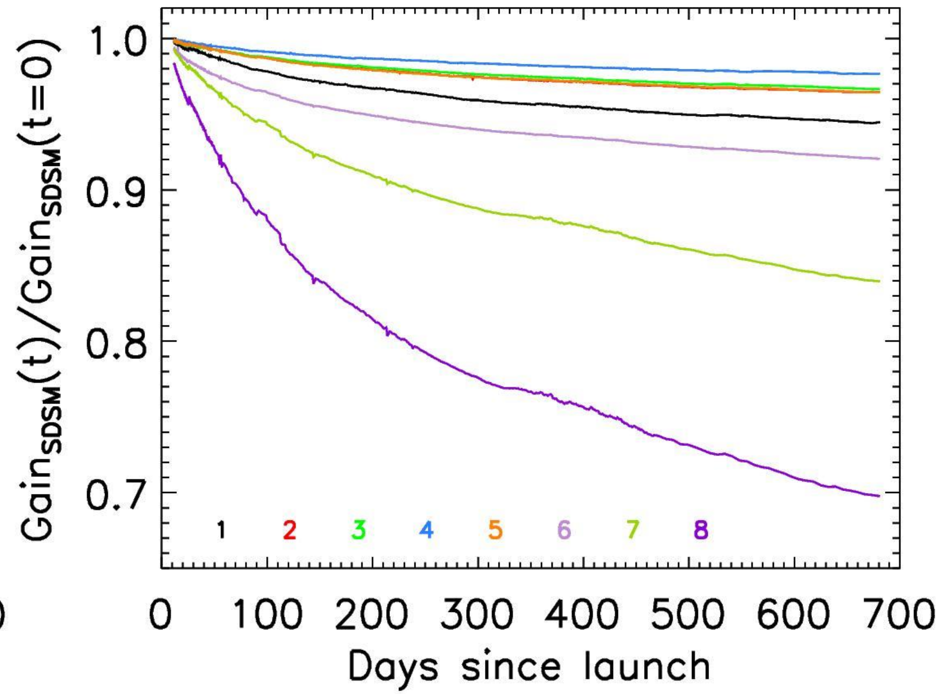
- **H-factors continue to decrease**
- **N-20 H-factor decreases at smaller rates**

VIIRS SDSM Detector Gains

S-NPP



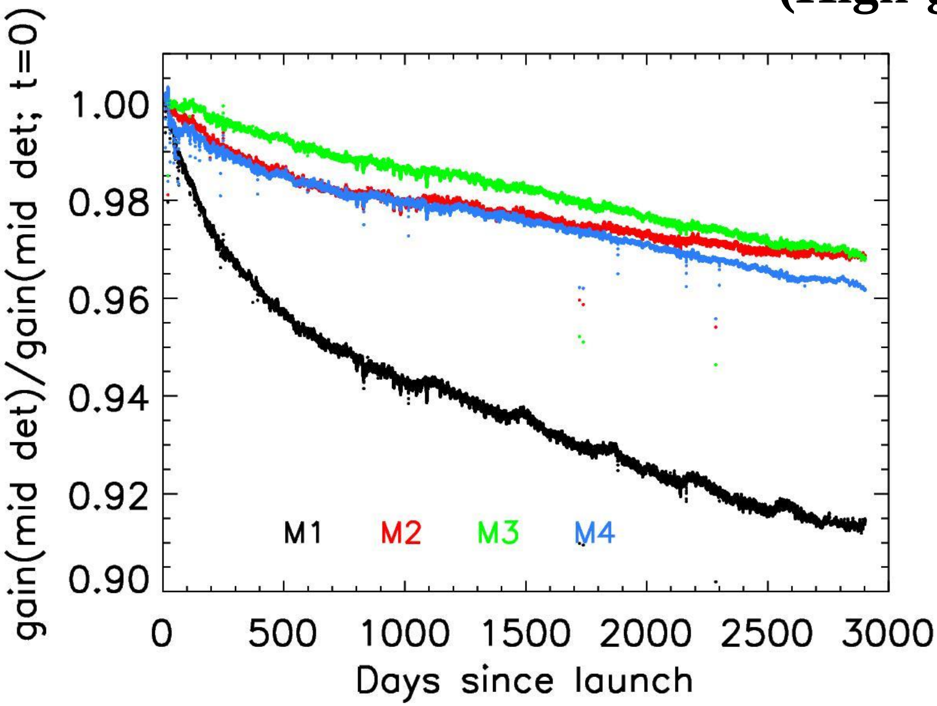
N-20

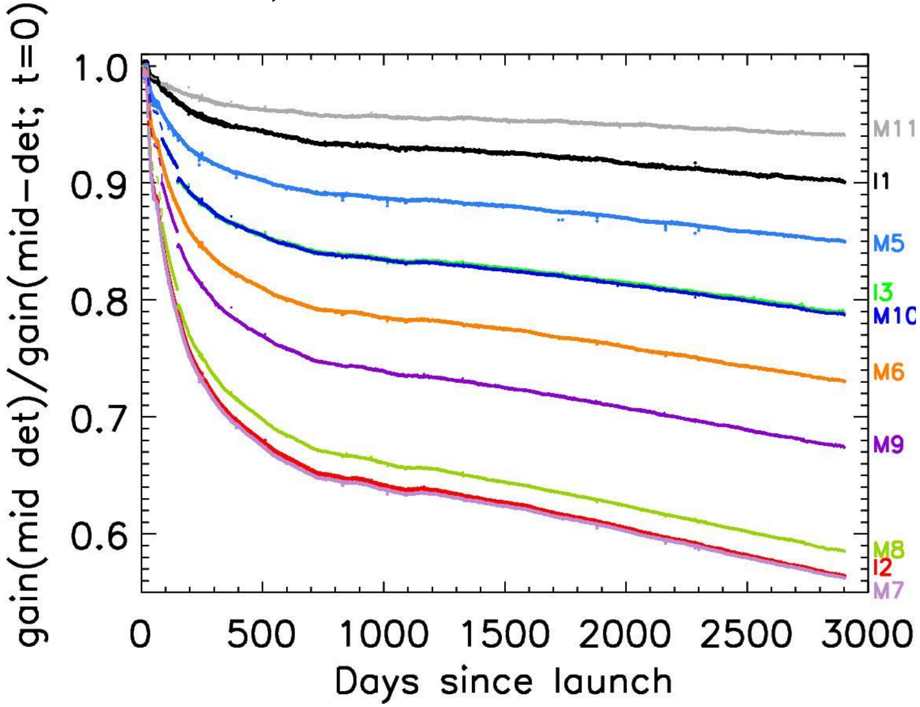


- **Detectors 2, 7 and 8 gains decrease at nearly identical respective rates**
- **Other detectors: N-20 decreases faster than S-NPP**

S-NPP VIIRS RSB Gains

(High-gain, HAM A)

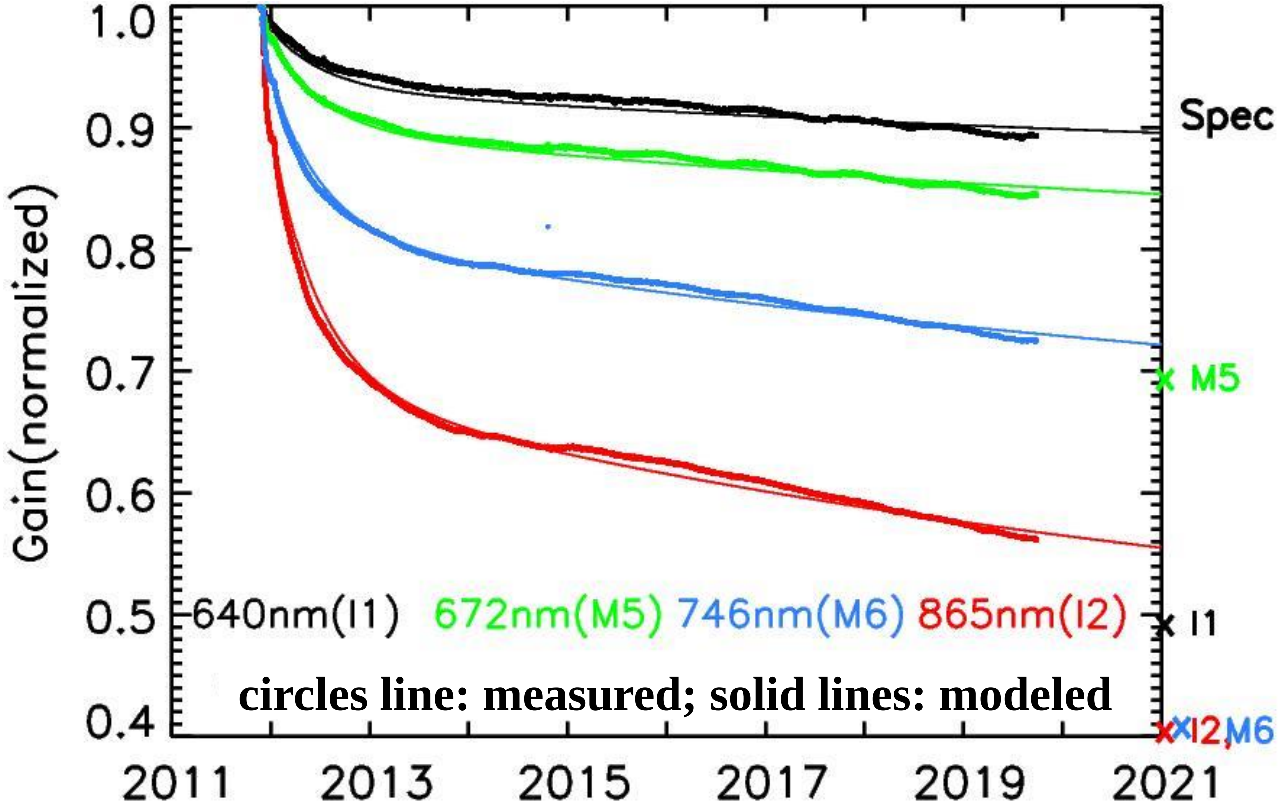




(Gain:=1/F)

Gain decreases the most for I2 and M7 bands: down ~ 44%

S-NPP VIIRS Gains: Modeled vs Measured

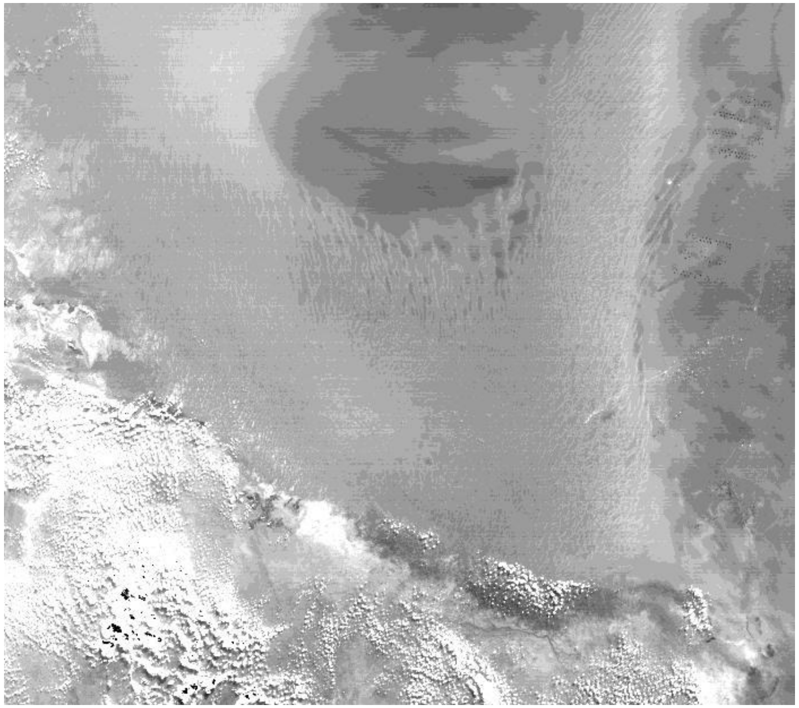


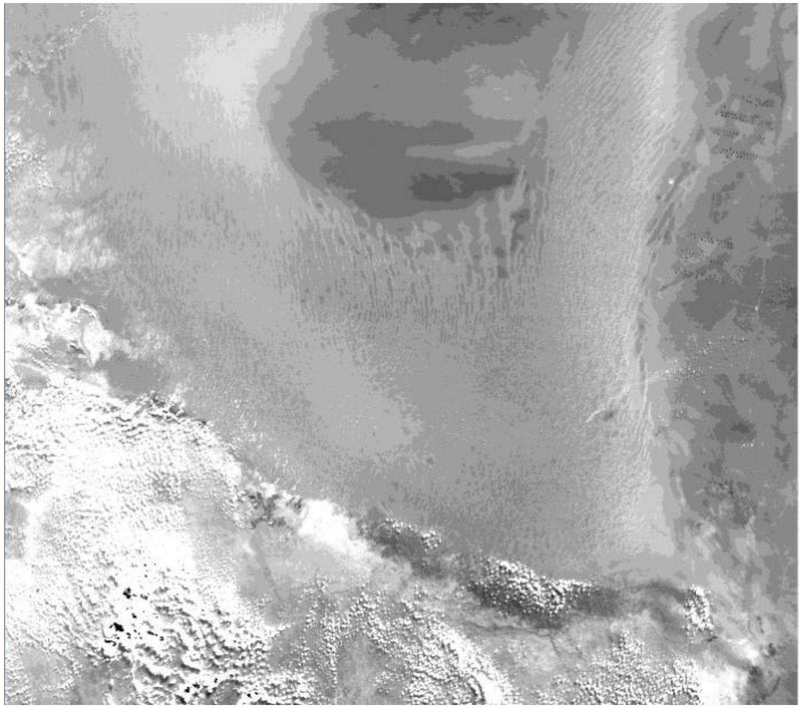
Gain decrease is due to RTA mirror contamination

Lei, et al, SPIE Proc. Vol 8533, Art-ID: 8533-19 (2012)

S-NPP VIIRS Image Striping Removed in C 2.0 (Very Early Time)

M1 light striping (C 1.0) **2011335** **M1 striping gone (C 2.0)**

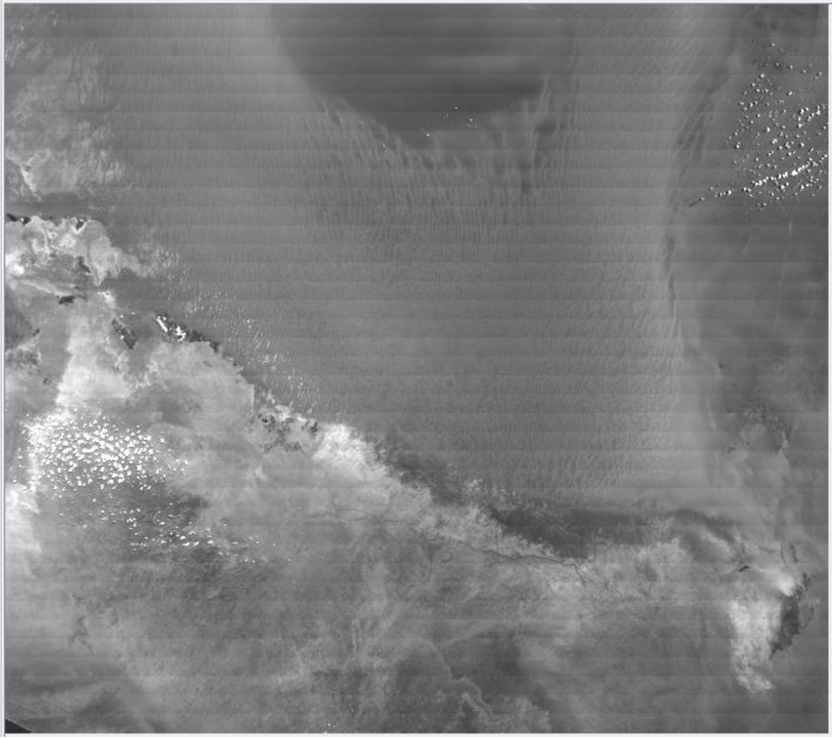


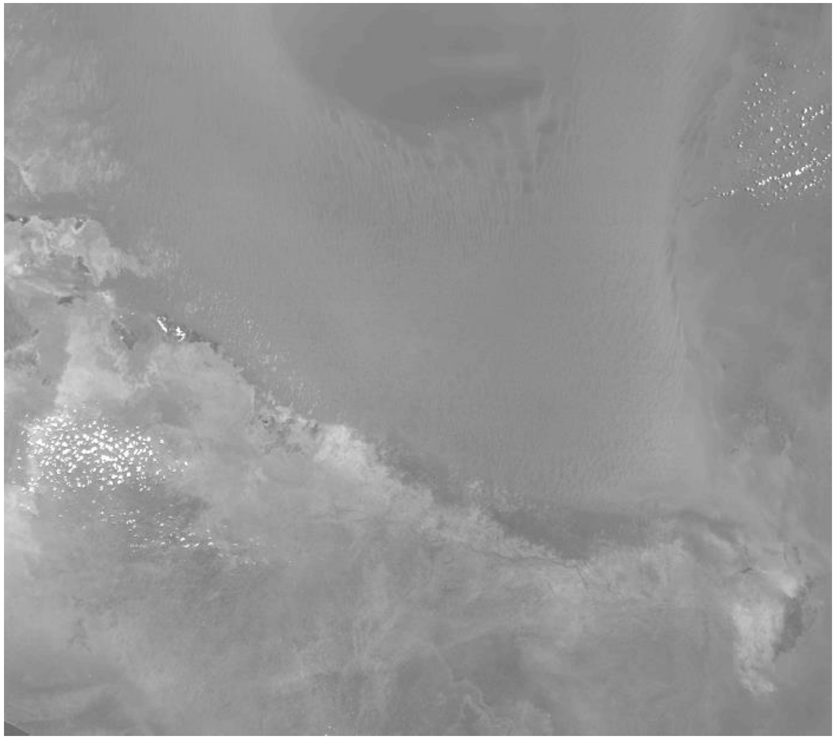


Libya4 images show better quality with C 2.0 LUTs (striping is gone; small improvement)

S-NPP VIIRS Scene Striping Removed in C2.0 (Recent Time)

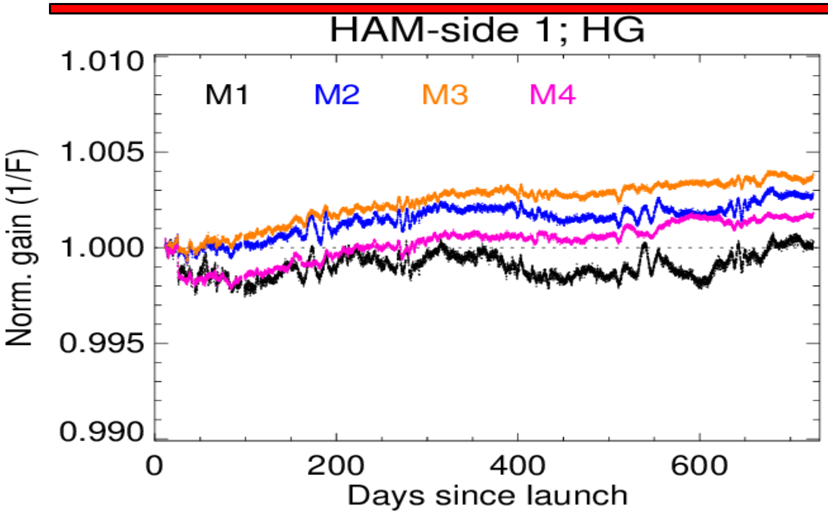
M1 striping (C 1.0) **2019229** **M1 striping gone (C 2.0)**

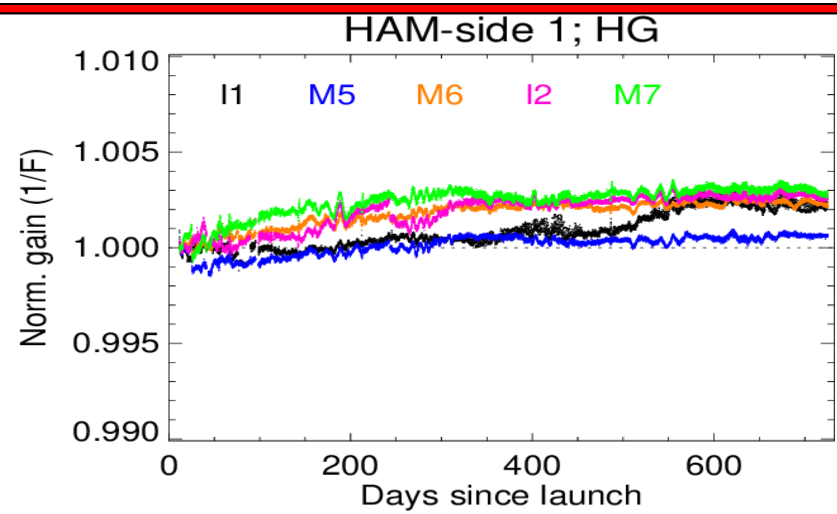


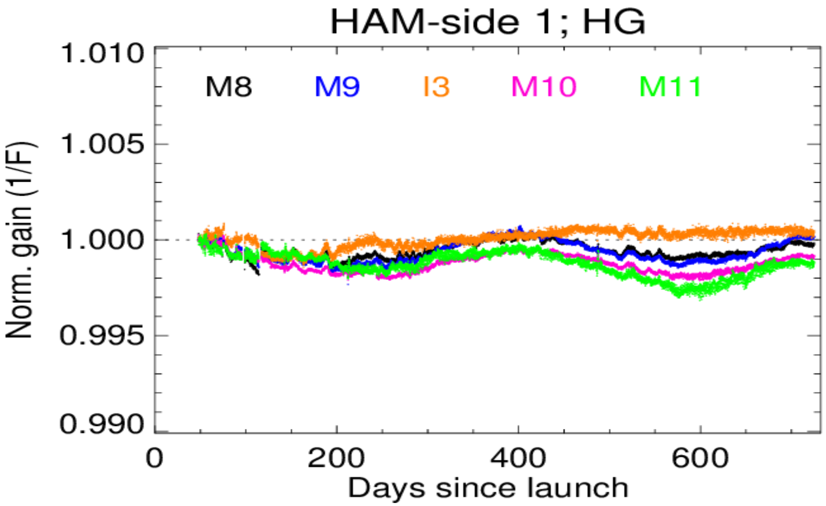


Libya4 images show better quality with the new LUTs (striping is gone; largest improvement ~ 1.0%)

N-20 VIIRS Gains (C2.0)





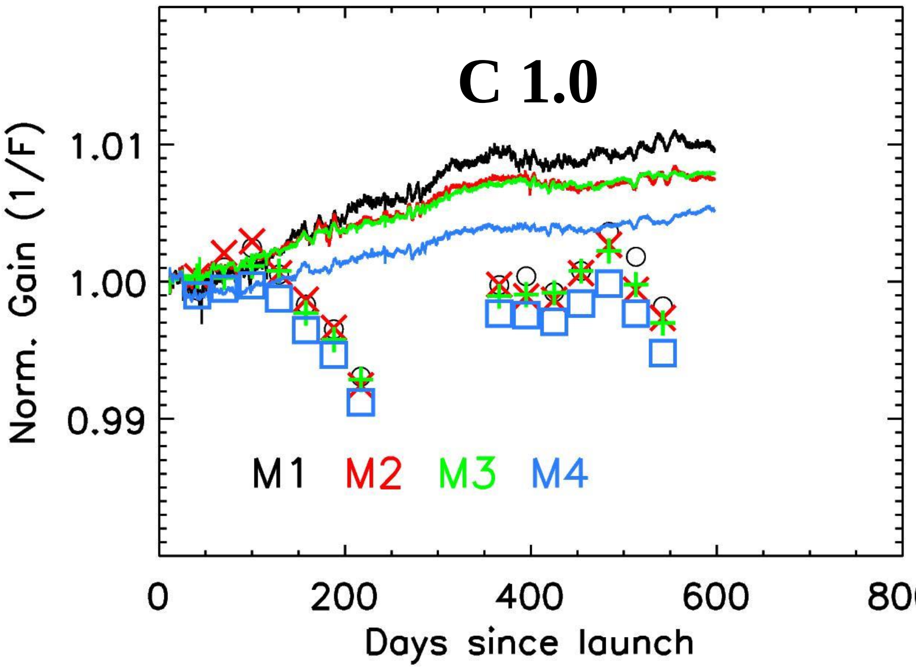


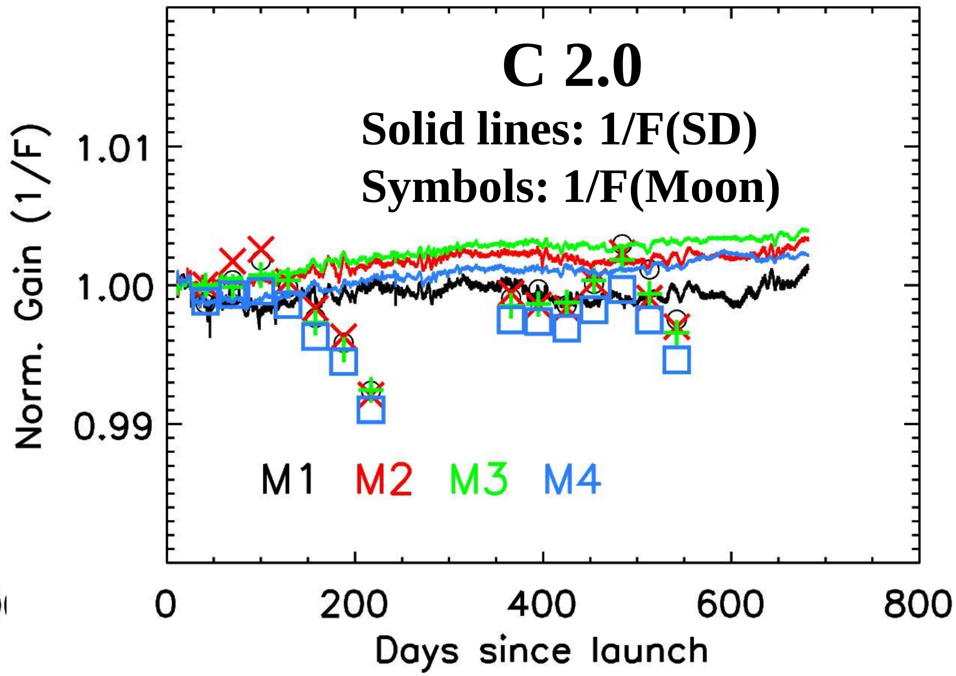
F-factors (1/gains) are extremely stable

No RTA mirror contamination

C 2.0 LUTs delivered in March-April 2019

N-20 VIIRS Gain(SD) vs Gain(Moon)





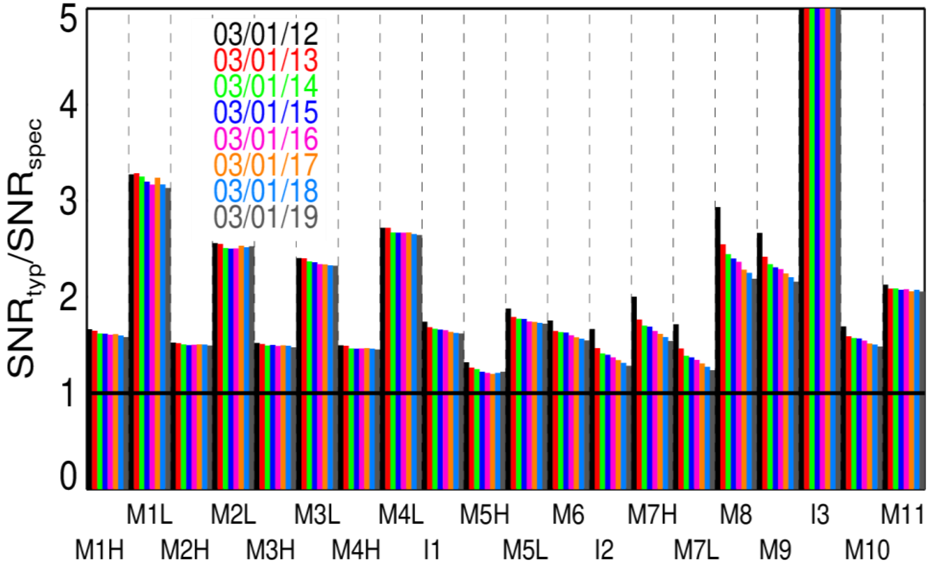
- **Gains (C 2.0) agree much better with lunar results than C 1.0**
- **Improvements as large as ~ 1.2%**

$$H_{\mathrm{RTA}} = H_{\mathrm{SDSM}} \times \frac{1 + \alpha_{\mathrm{RTA}}(\lambda)(1 - H_{\mathrm{SDSM}})}{1 + \alpha_{\mathrm{H}}(\lambda)(1 - H_{\mathrm{SDSM}}) \times (\phi_{\mathrm{H,SD}} - \phi_0)}$$

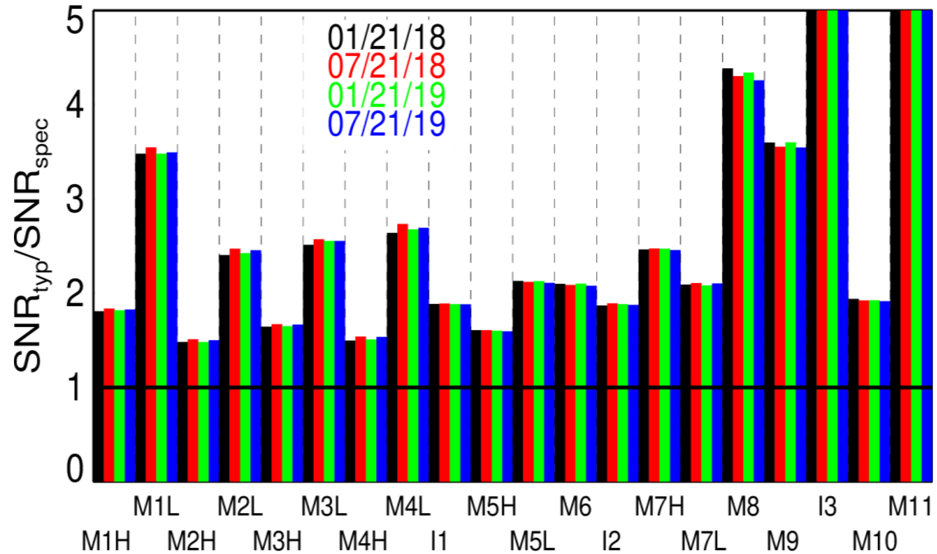
C 2.0

VIIRS RSB Signal-to-Noise Ratio

S-NPP

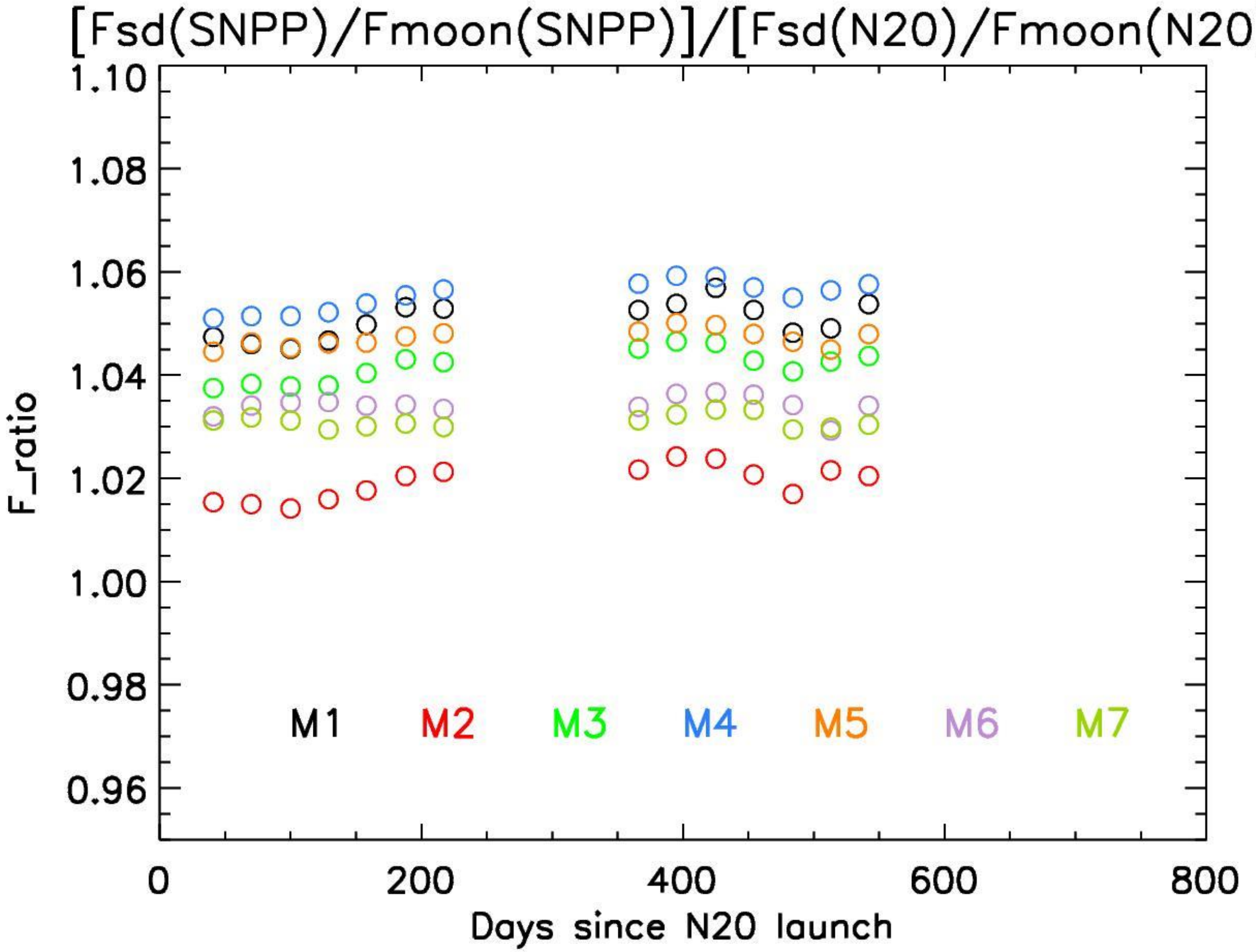


N-20



SNRs are well above requirements and will remain so for the foreseeable future

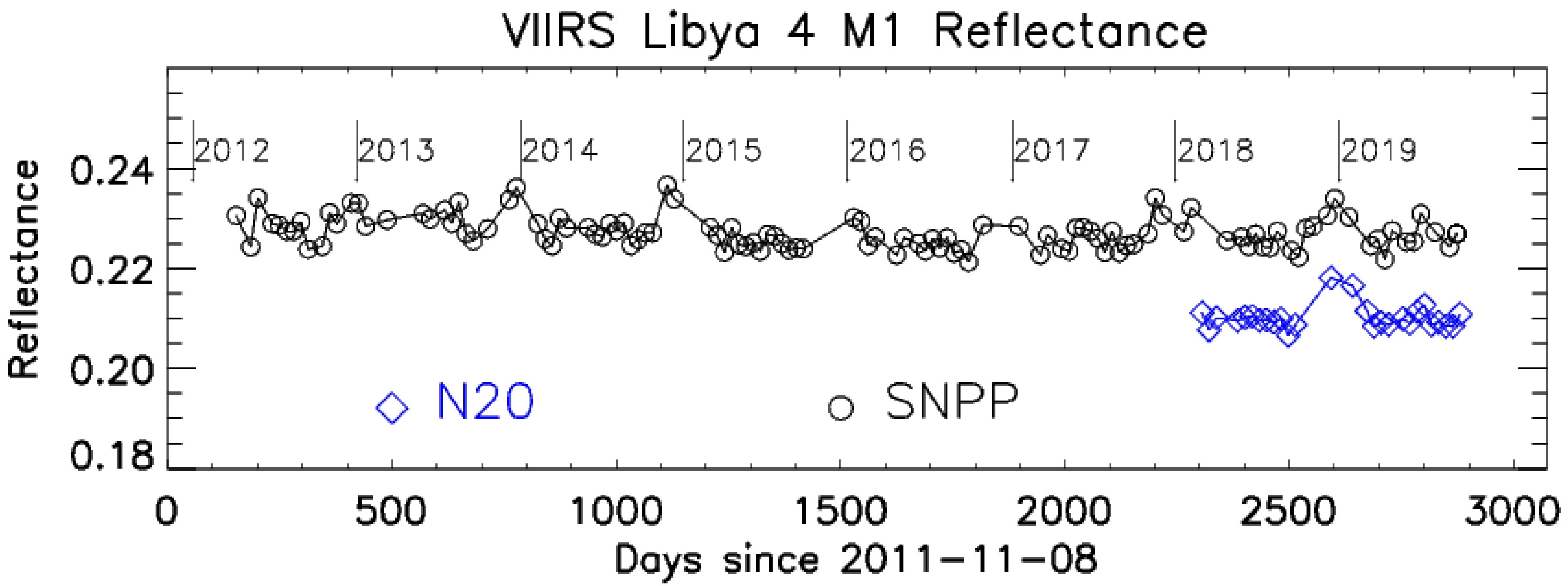
VIIRS F-factors SNPP vs. N20 using Moon



S-NPP (C 1.0)
N-20 (C 2.0)

- **S-NPP RSBs yield larger scene spectral radiance**

Libya 4 Nadir Reflectance

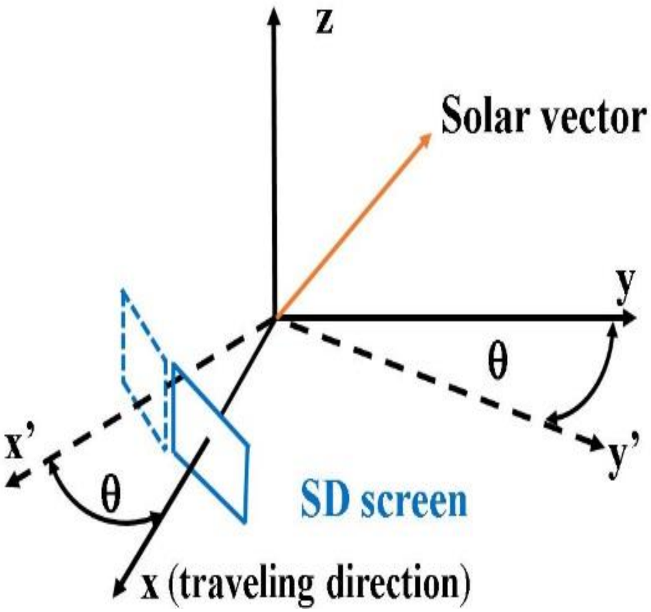


8.0% (M1), 6% (M2), 5% (M3), 2% (M4), 5% (M5), 3% (M7), 2% (M8, 10, 11) with Libya 4 L1B results (nadir)

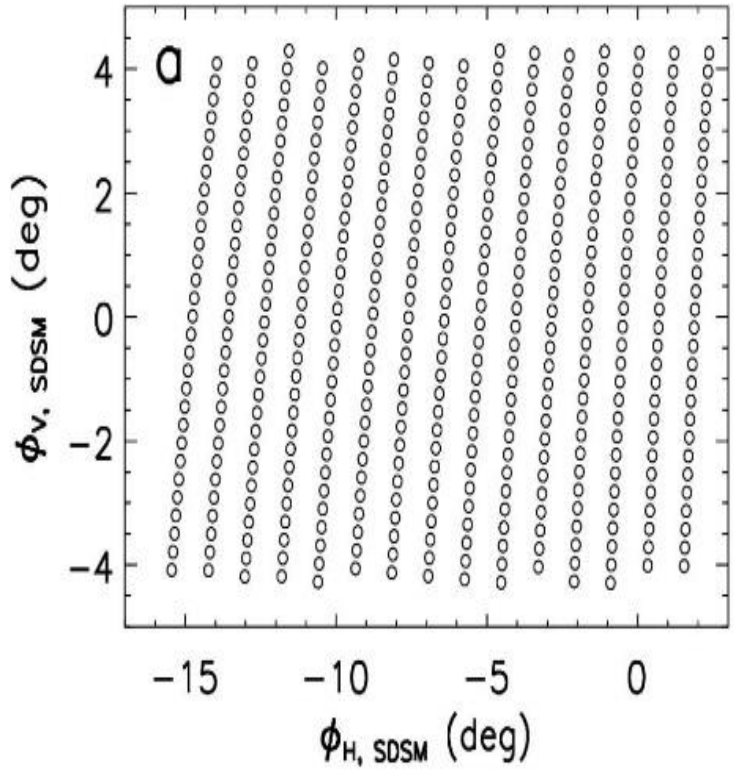
VIIRS RSB Performance Summary

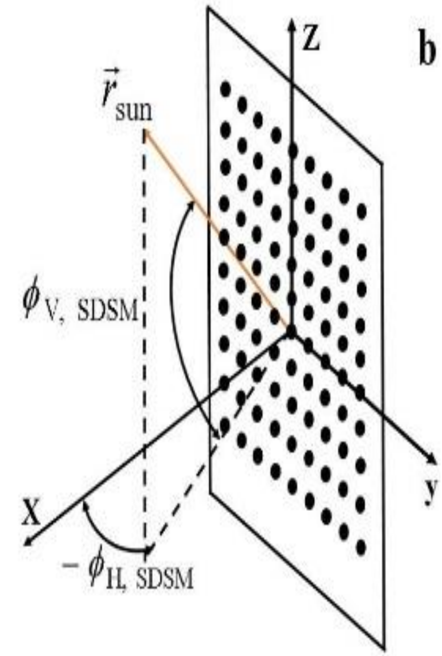
- **SDSM detector gains continue to decrease with time**
- **SD H-factors are very smooth functions of time and continue to decrease with time with reducing rates**
- **H(λ, t; N-20) > H(λ, t; S-NPP)**
- **S-NPP Gains (1/F) decrease with time with reducing rates, mainly due to RTA mirror contamination**
- **S-NPP RSB Earth scene striping removed in C 2.0**
- **S-NPP VISNIR band gain yearly undulations removed/reduced**
- **N-20 gains are quite stable over time, no RTA mirror issue**
- **SNRs are well above requirements**
- **Scene reflectance: ρ(S-NPP) > ρ(N-20) by ~ 5%**

Improvement #1: N-20 VIIRS Screen Functions



15 yaw maneuvers

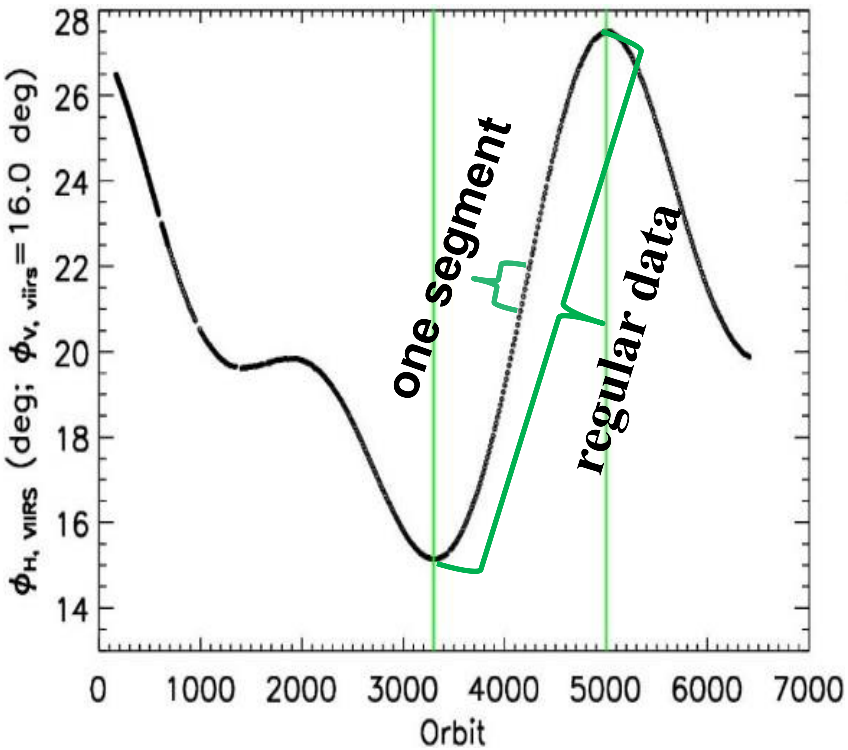


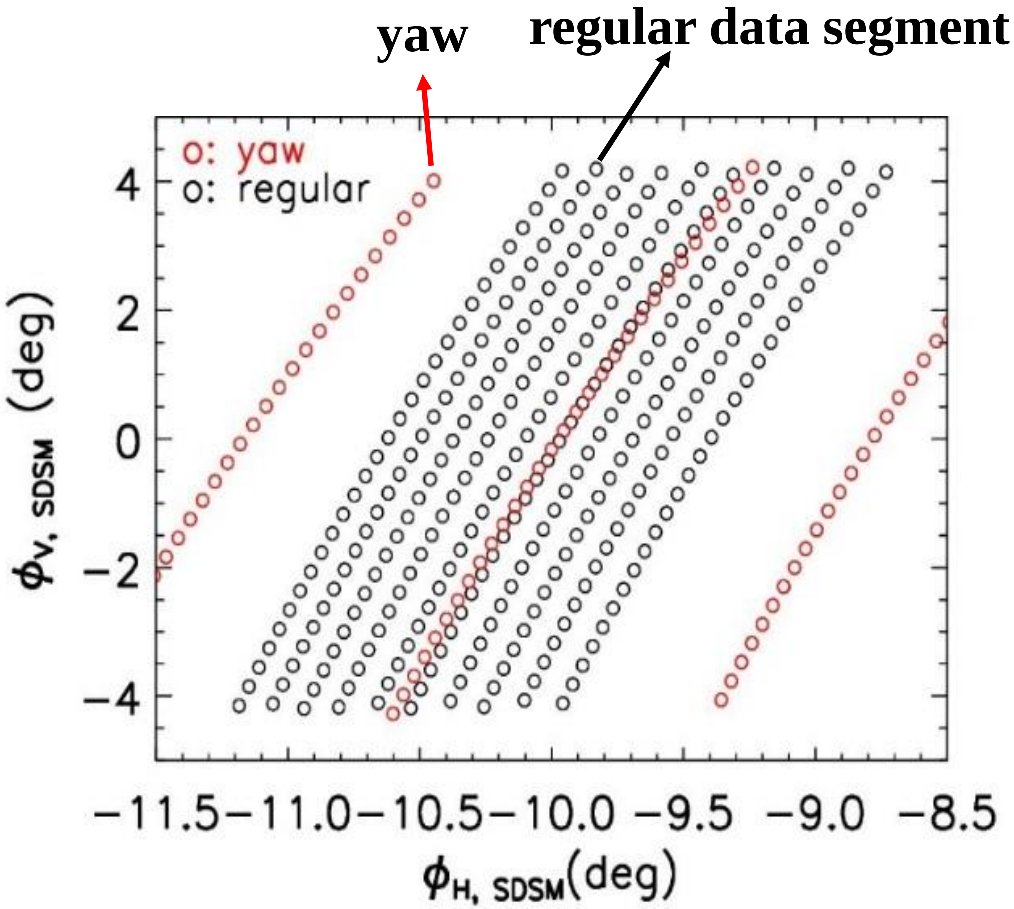


SDSM screen

- **Yaws maneuvers were performed to improve the screen functions**
- **But solar azimuth angular step size is too large**

N-20 VIIRS Screen Improvements: Yaw + Regular Data

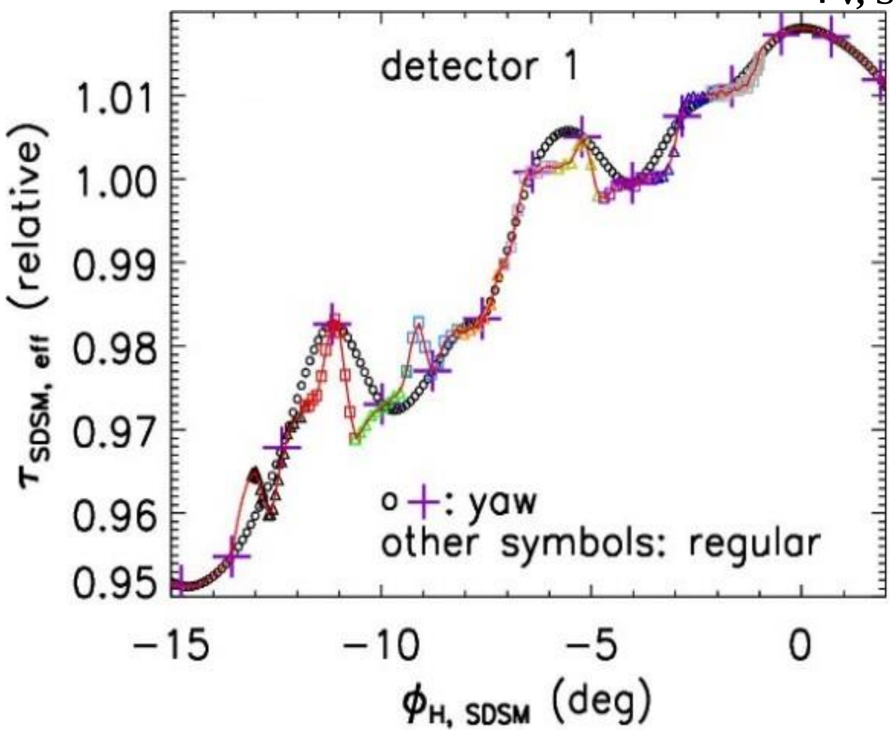


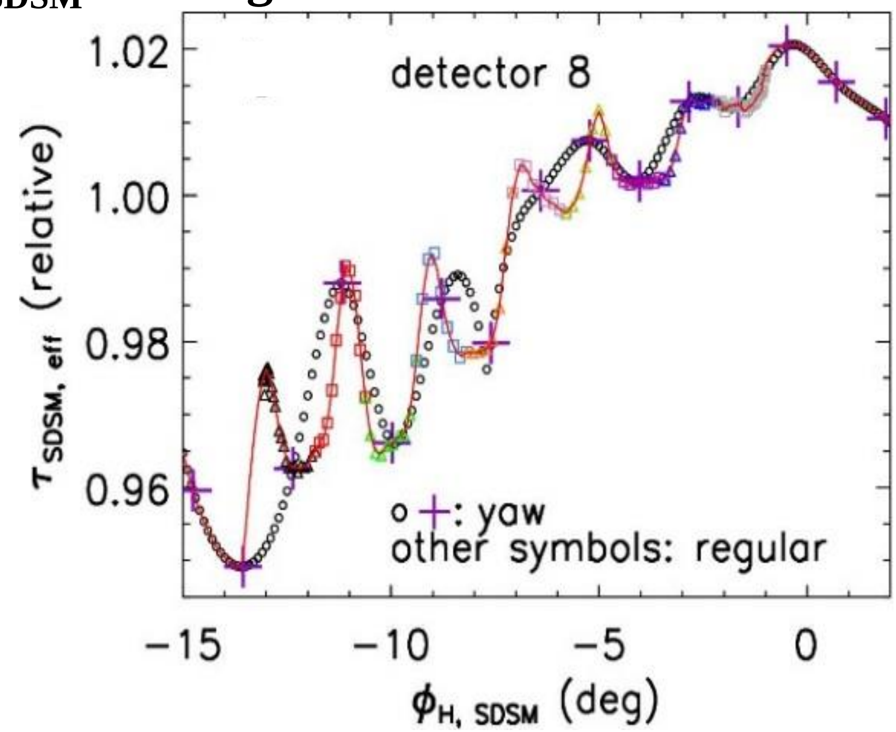


Handle linear as well as nonlinear detector gain(t)+solar power(t) change

N-20 VIIRS Screen Improvements: SDSM screen

$\phi_{V,\ SDSM}$=0.0 deg



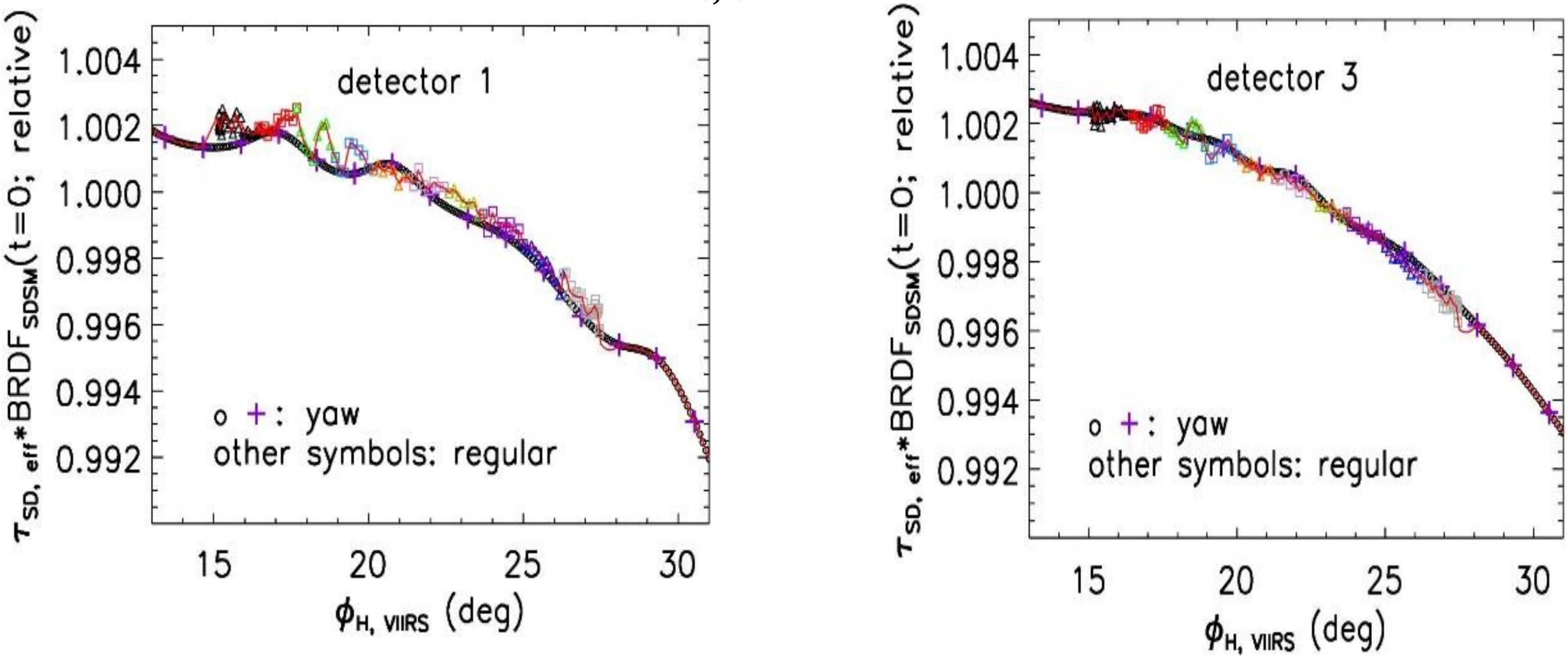


Large improvements for SDSM screen transmittance ~ 2.0% for detector 8, ~ 1.0% for detector 1

(largest slope ~ 3.0%/per degree)

N-20 VIIRS Screen Improvements: SD screen SDSM view

$\phi_{V,\,VIIRS}$=16.0 deg

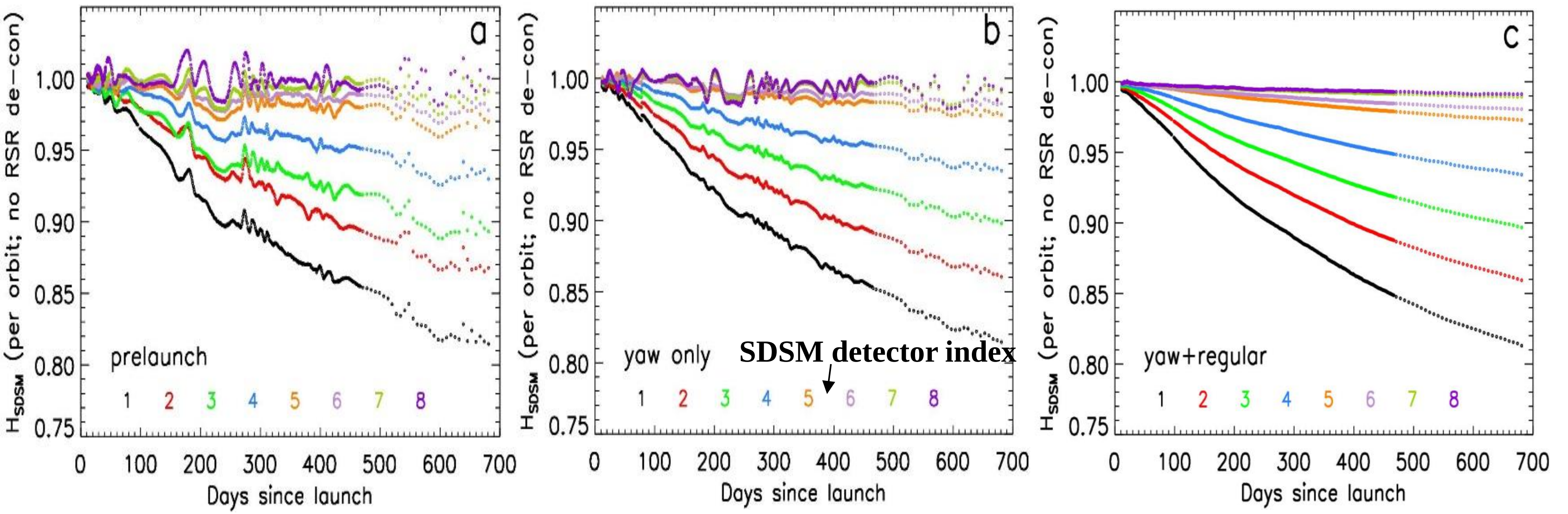


Minor improvements for N-20 SD screen

~ 0.15% for detector 1, ~ 0.05% for detector 3

(largest slope ~ 0.3%/per degree along ϕ_H)

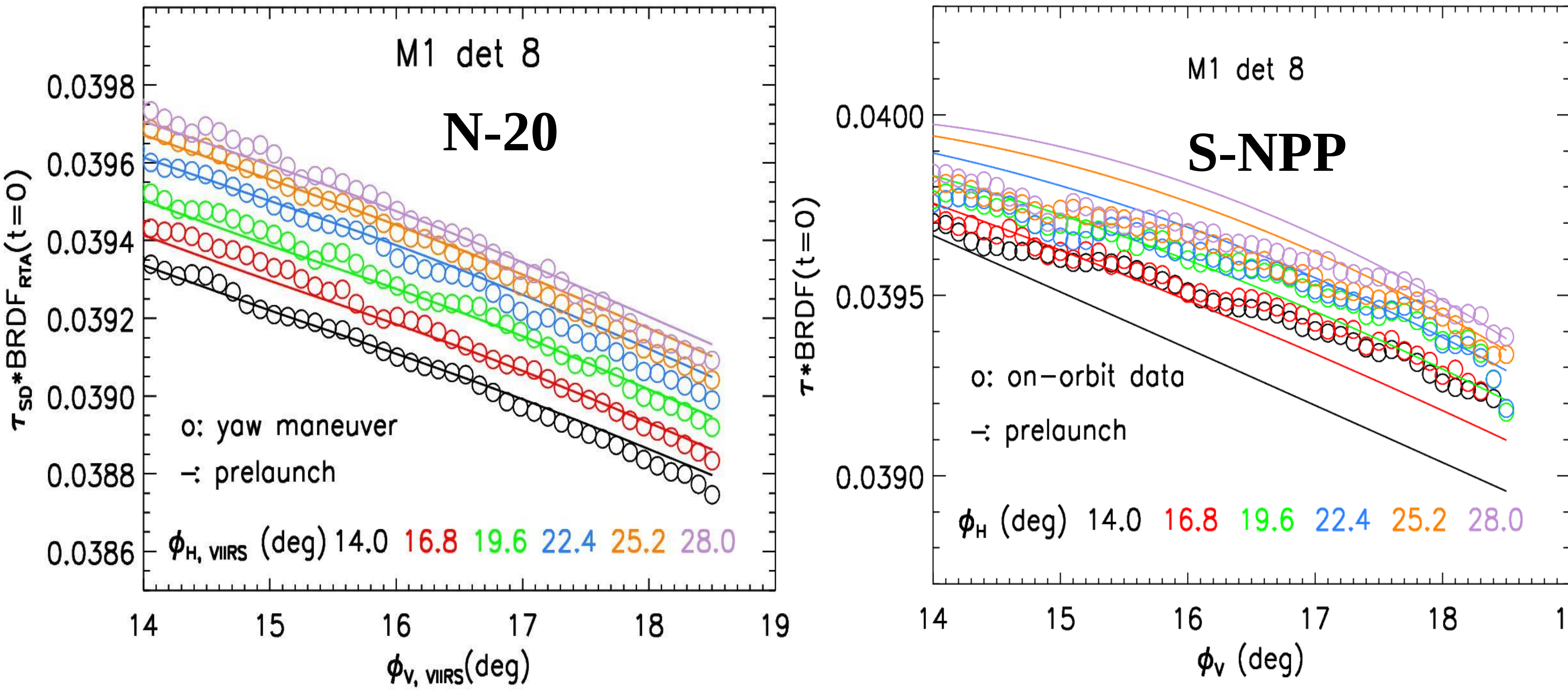
N-20 VIIRS Screen Improvements: Validation



Large unrealistic undulations in the N-20 SD H-factors removed

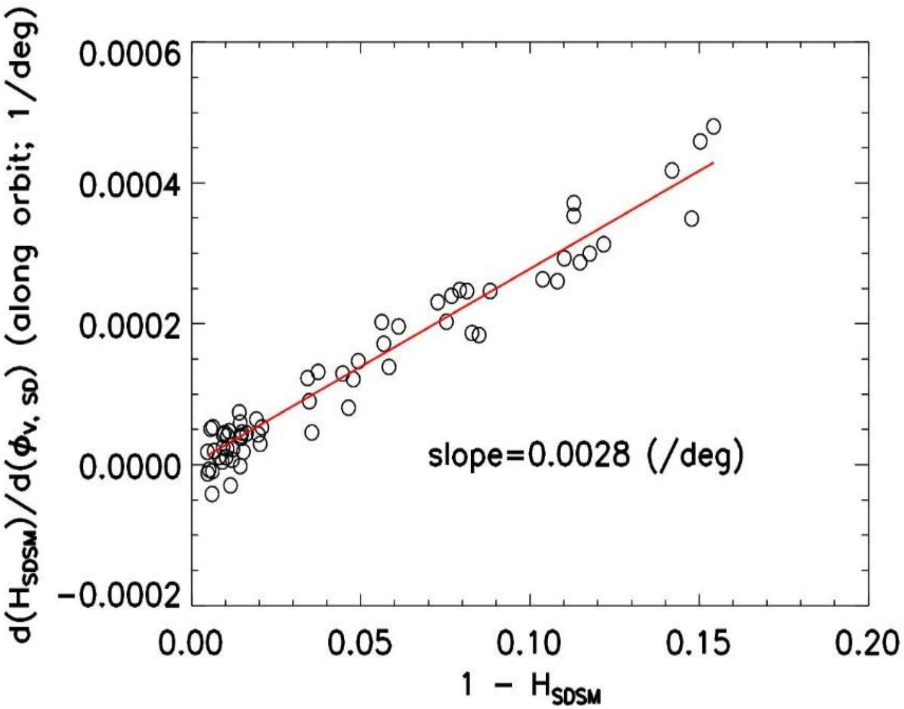
N-20 screen functions for SDSM are very good

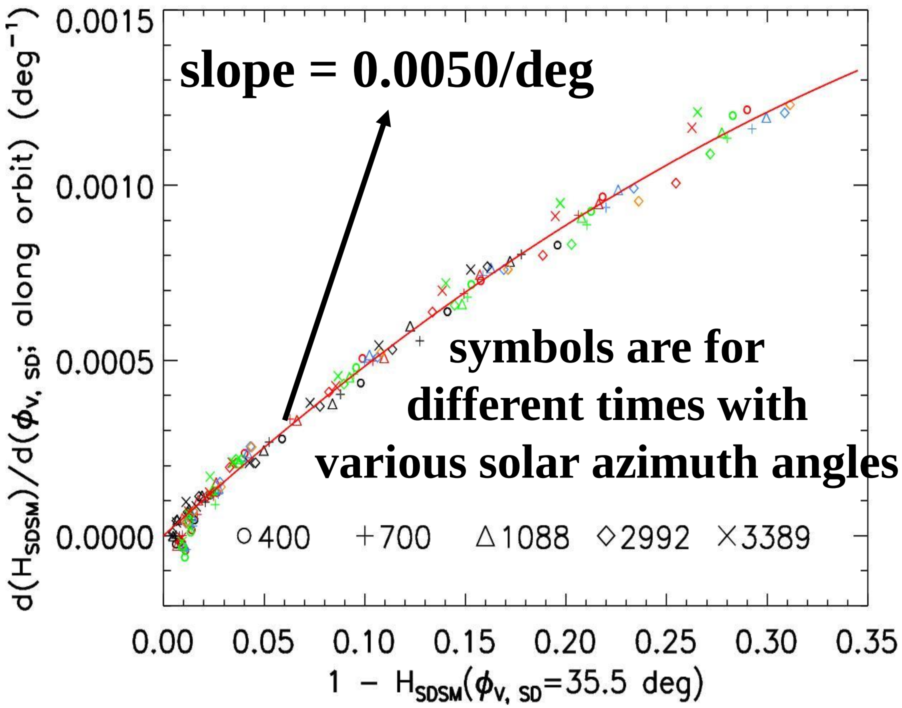
VIIRS SD Screen Function at RTA View



N-20 τ_{SD}BRDF(RTA; yaw) agrees much better with τ_{SD}BRDF(RTA; prelaunch) than S-NPP

Improvement #2: N-20 H_{RTA}

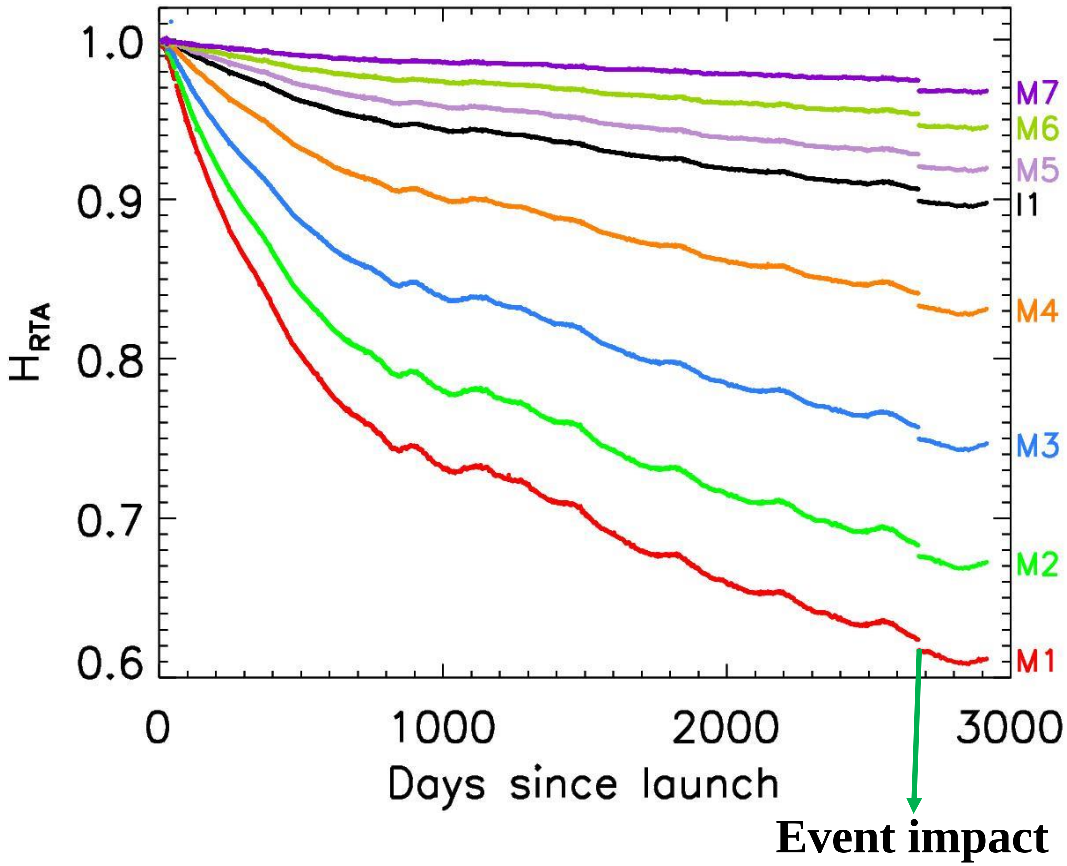




$$H_{\mathrm{RTA}} = H_{\mathrm{SDSM}} \times \frac{1 + \alpha_{\mathrm{RTA}}(\lambda)(1 - H_{\mathrm{SDSM}})}{1 + \alpha_{\mathrm{H}}(\lambda)(1 - H_{\mathrm{SDSM}}) \times (\phi_{\mathrm{H,SD}} - \phi_0)}$$

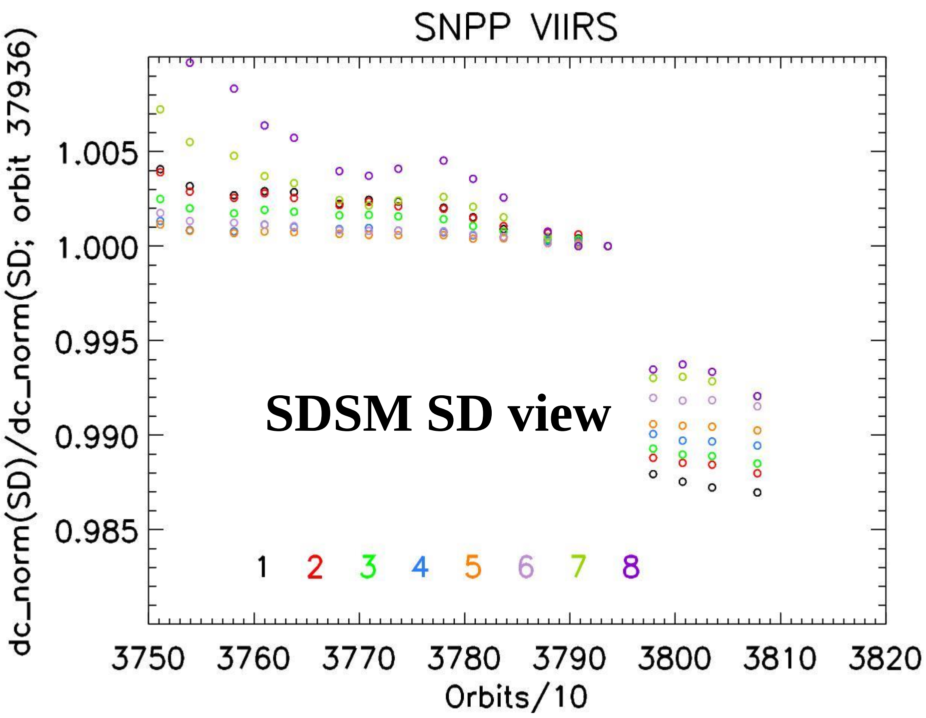
- **Model parameter values: 0.56 of S-NPP's**
- **F(SD; N20) agrees with F(moon; N20) much better**

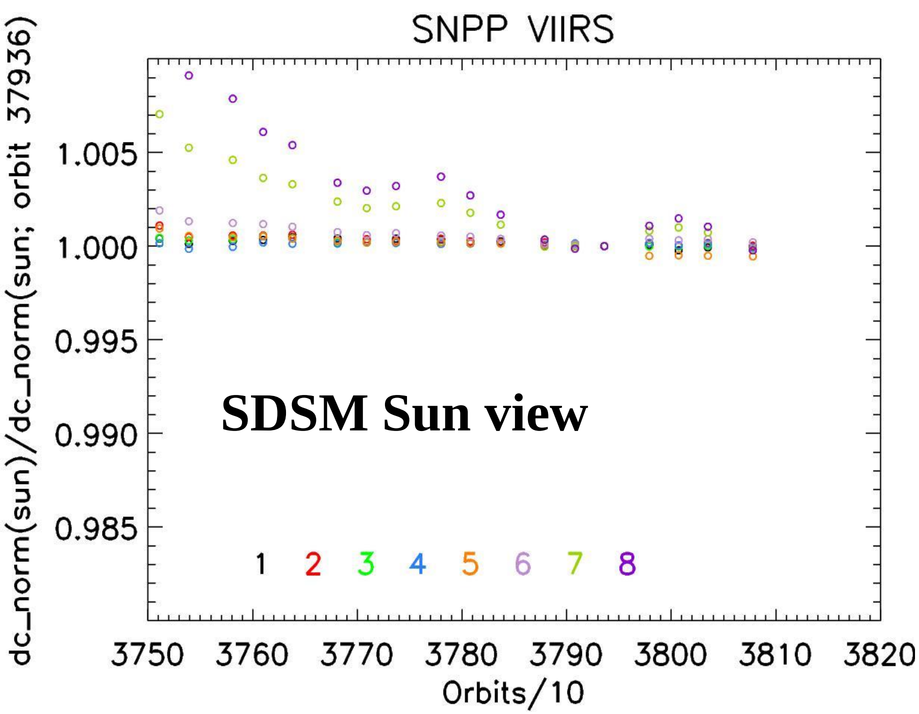
Improvement #3: S-NPP Feb. 24, 2019 Event Impact



- **H-factor gaps down right after the event**

S-NPP Feb 24, 2019 Event Impacts

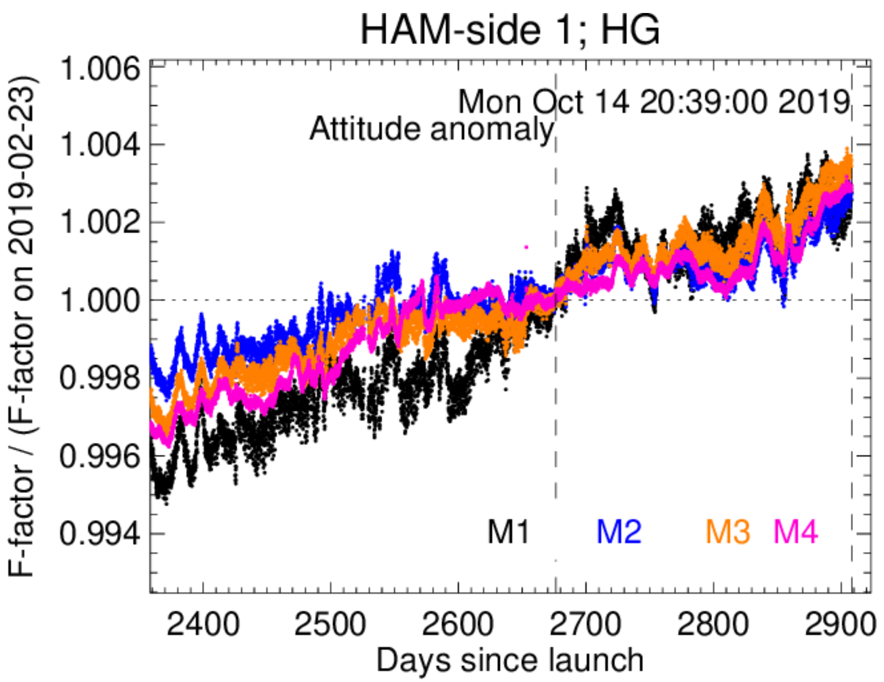


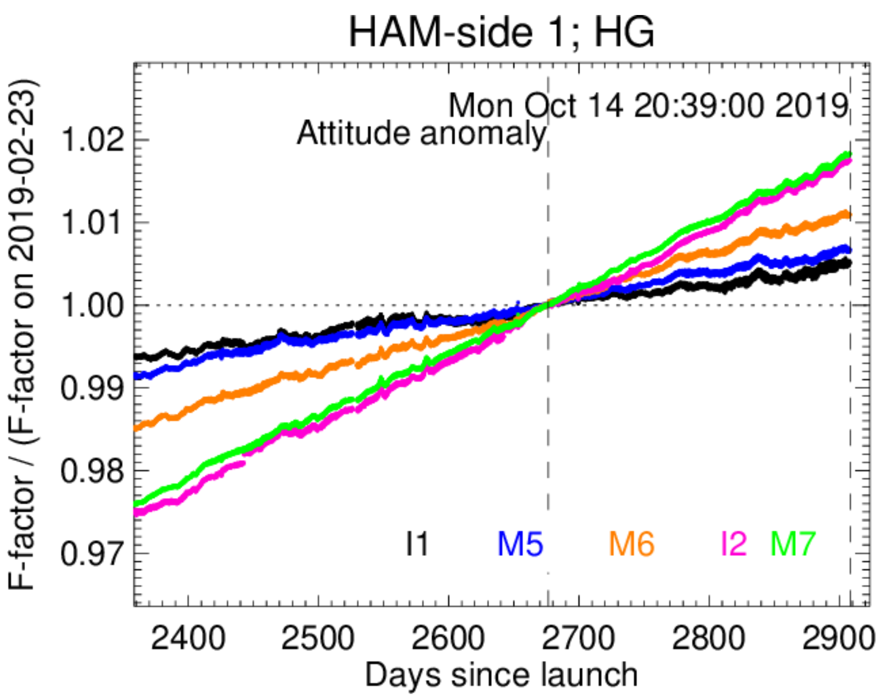


SDSM detector gain and SDSM screen not changed much

Change is on the SD and/or SD screen

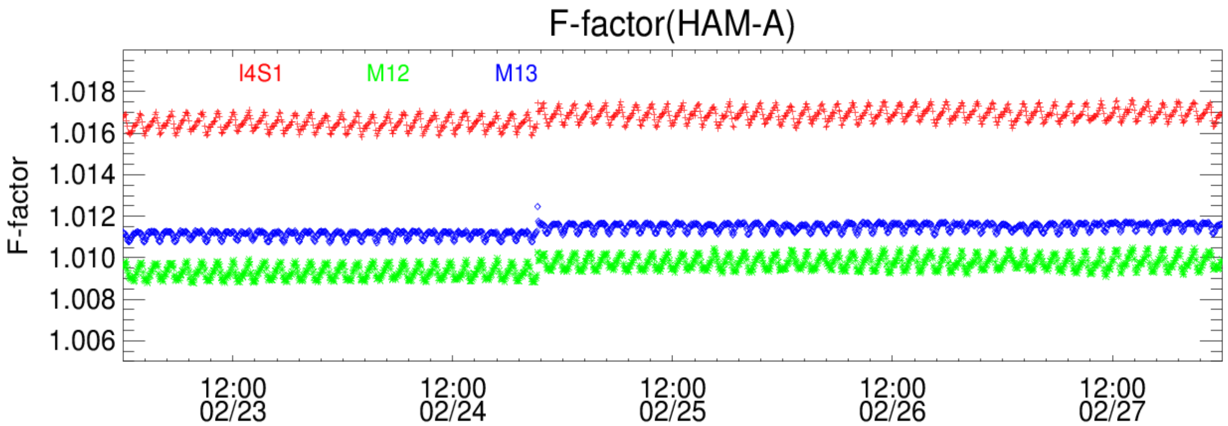
S-NPP Feb 24, 2019 Event Impacts

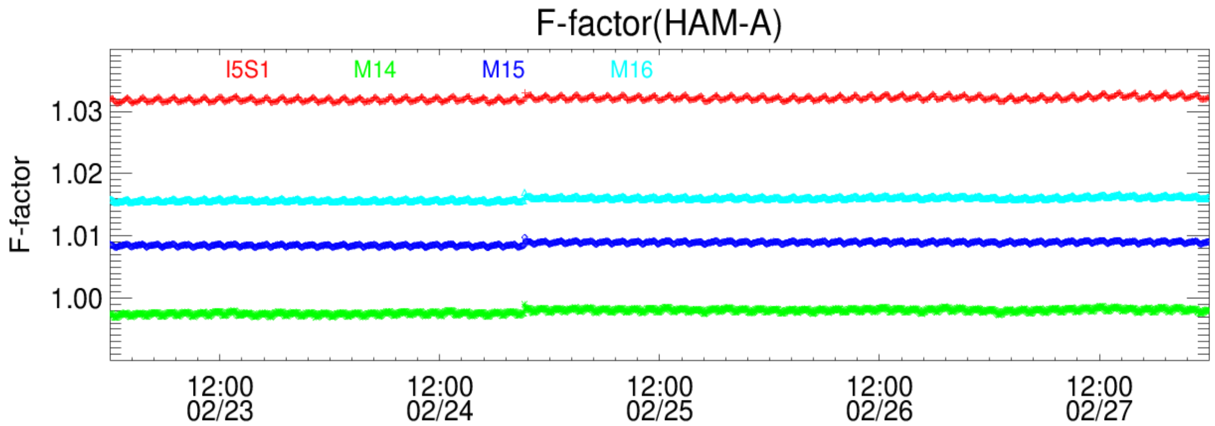




VISNIR band gains are continuous across event time

S-NPP Feb 24, 2019 Event Impacts

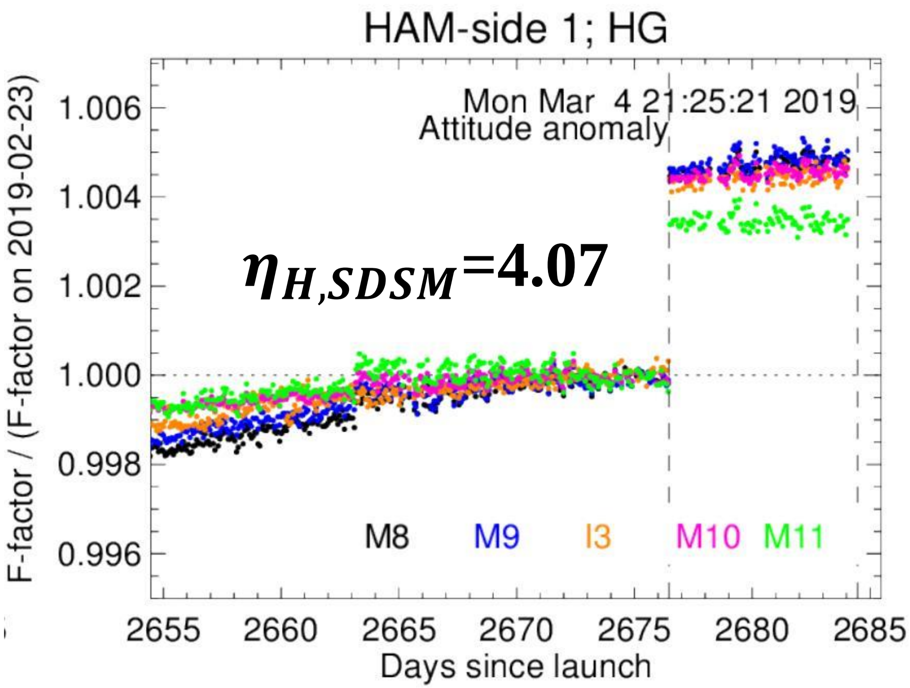


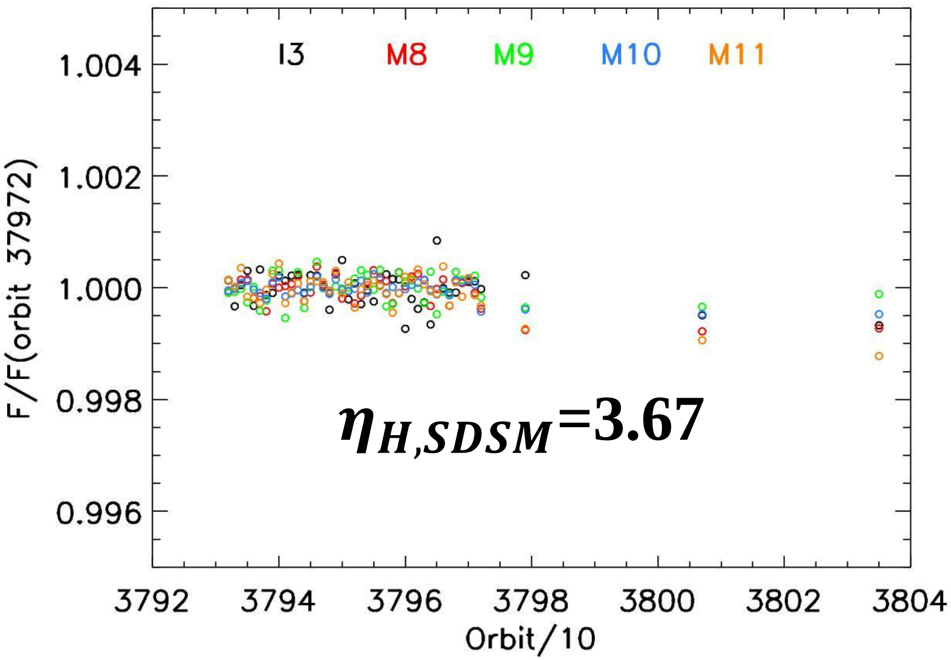


TEB F-factors across event time is nearly continuous.

S-NPP Feb 24, 2019 Event Impacts

SWIR band F-factors across event time should be continuous



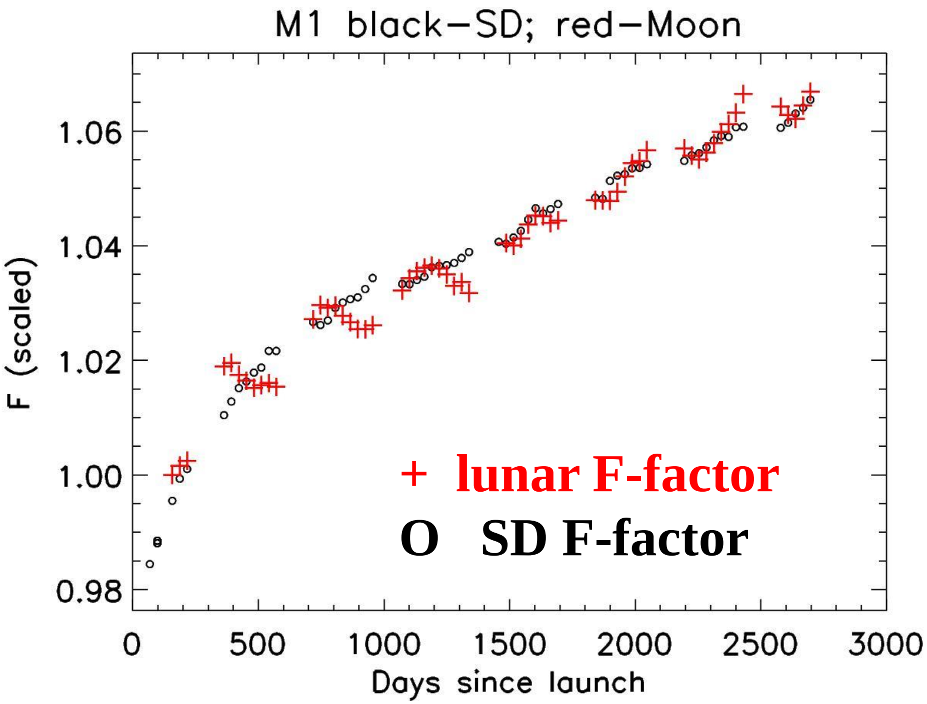


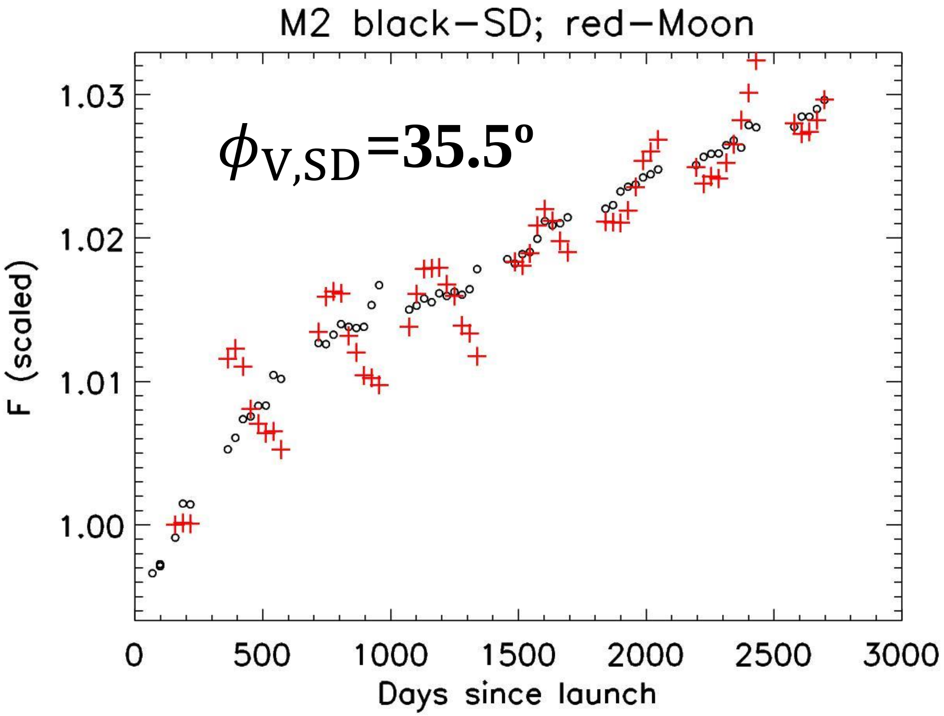
- $H_{\mathrm{SDSM}}(\lambda, t) = 1 - \beta(t)/\lambda^{\eta_{\mathrm{H,SDSM}}(t)}$ **(SDSM det5-8 &SWIR wavelengths)**
- $\boldsymbol{\eta_{H,SDSM}}$**=3.67**

Improvement #4: S-NPP VIIRS SD H-factors

Determined from comparison with 7-year lunar F-factor

$$H_{\mathrm{RTA}} = H_{\mathrm{SDSM}} \times \frac{1+\alpha_{\mathrm{RTA}}(\lambda)(1-H_{\mathrm{SDSM}})}{1+\alpha_{\mathrm{H}}(\lambda)(1-H_{\mathrm{SDSM}})\times(\phi_{\mathrm{H,SD}}-\phi_0)}$$





Lunar results from Amit Angal of SSAI

Other Improvements

 # 5: H-factor SD positional dependence

- remove L1B image striping, using deep convective cloud results provided by MCST and Libya 4 results

 # 6: H-factor solar azimuth angular dependence applied to all RSBs

 # 7: Minor code improvements

S-NPP VIIRS L1B Improvements C2.0 upon C1.0

1. **Up to 1.0% due to applications of 7-year lunar data**
2. **Up to 1.0% due to H-factor SD positional dependence**
3. **Up to 0.25% due to H-factor solar azimuth angular dep.**
4. **Up to 0.25% due to code improvements**

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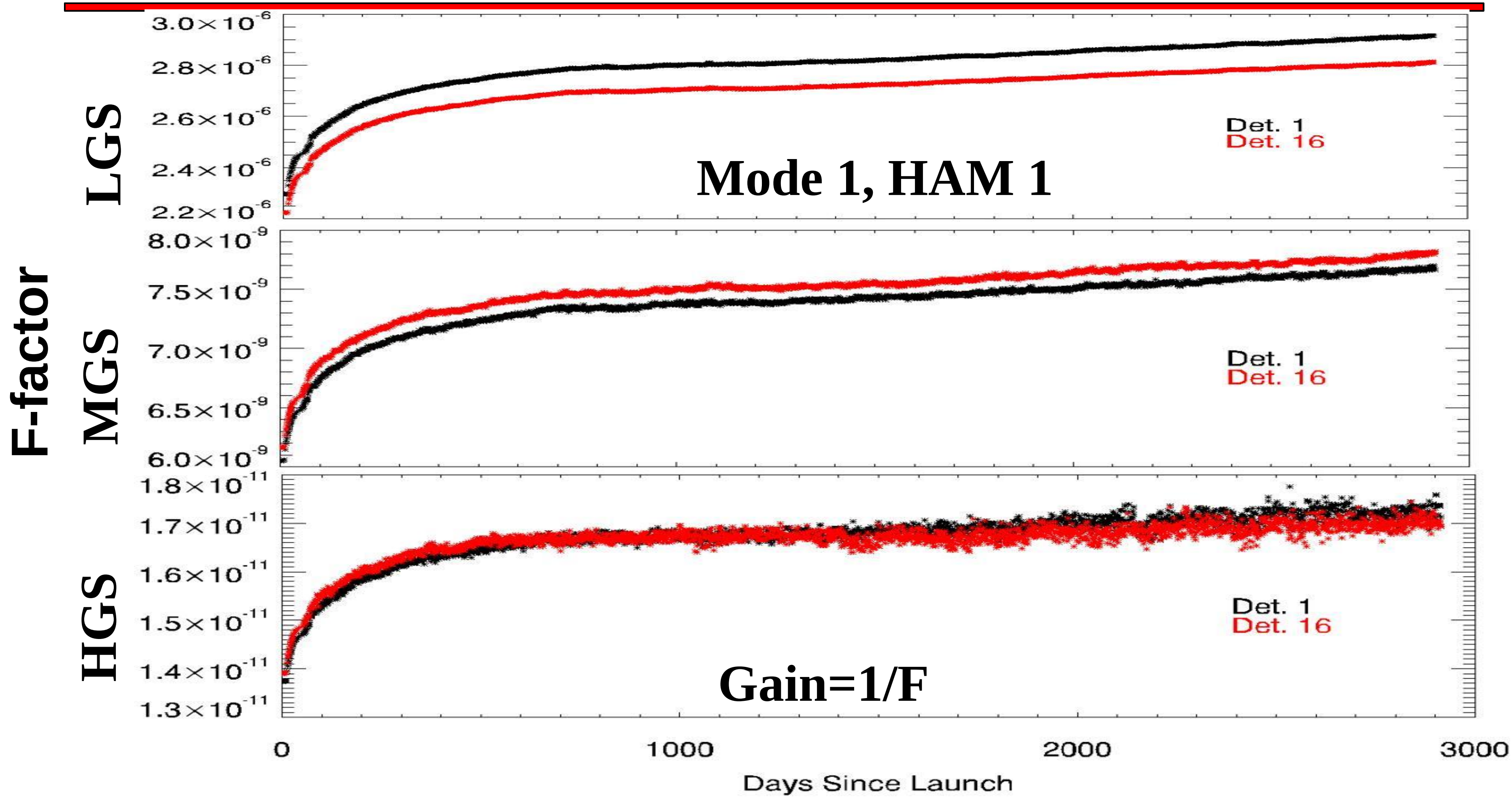
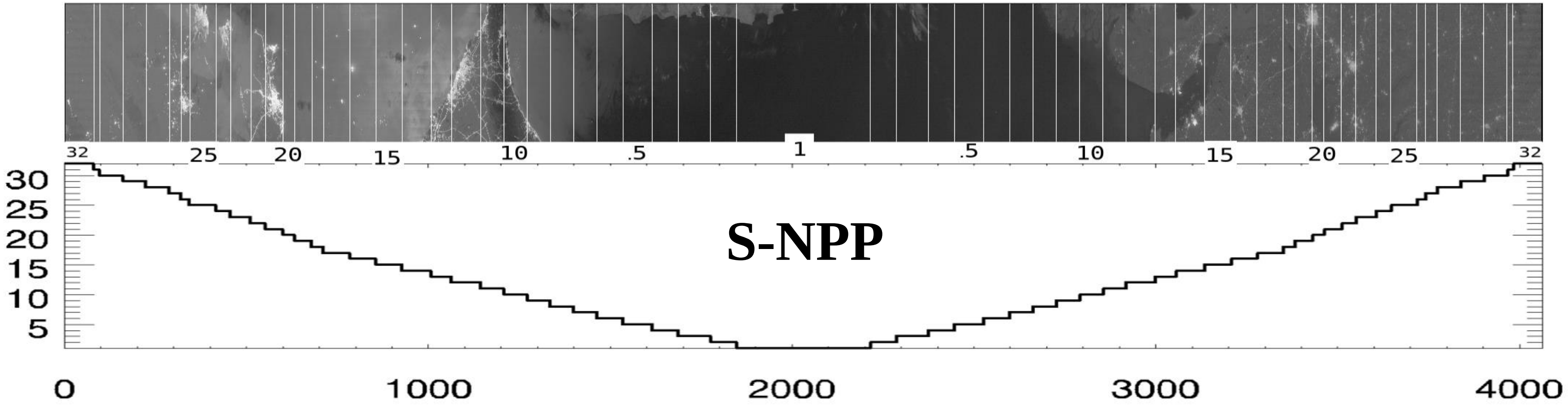
Total: approximately up to 1.3% improvement

Performance of S-NPP DNB

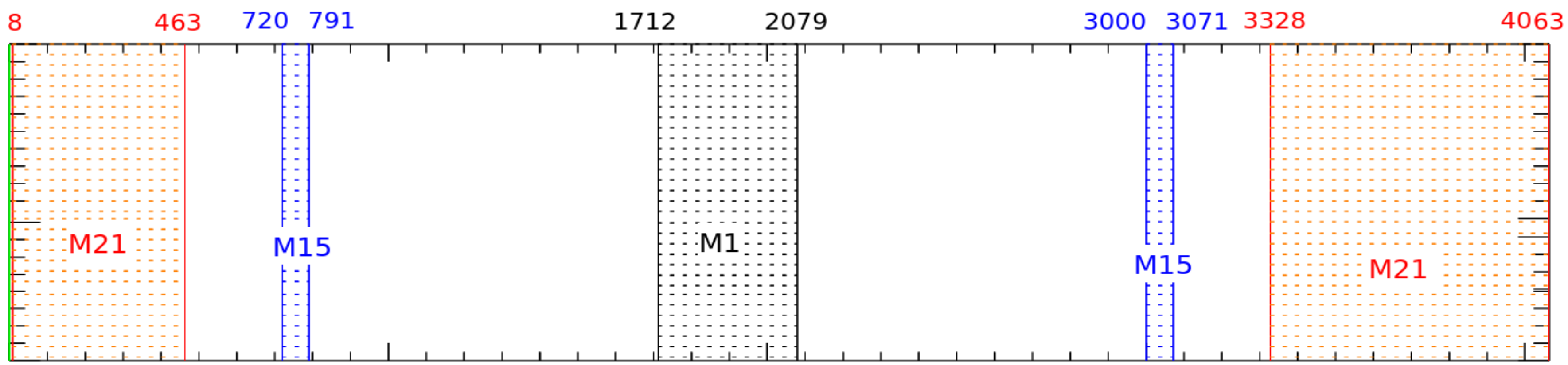


S-NPP DNB F-factors trend up due to RTA mirror contamination

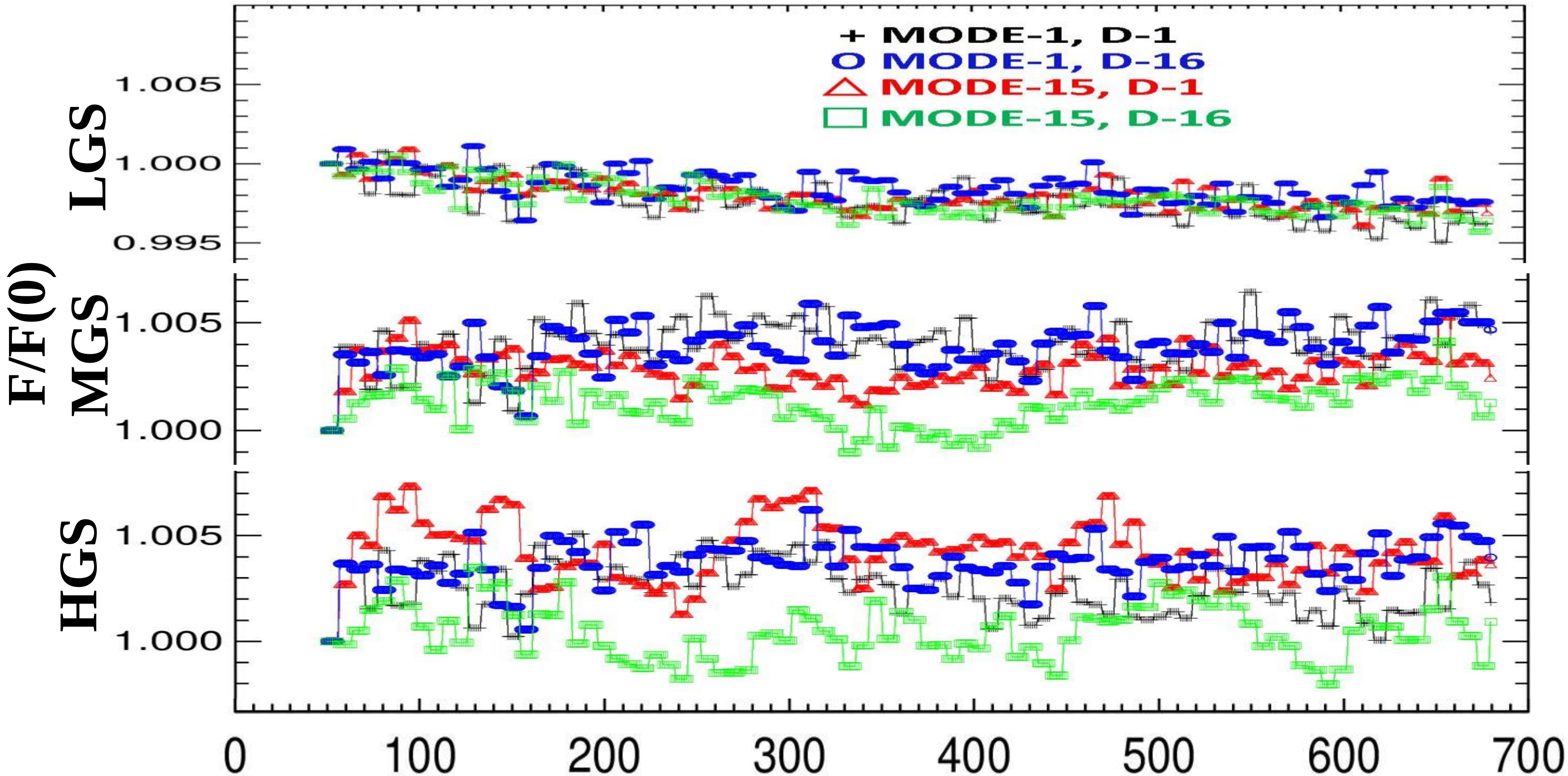
DNB Modes vs Frame Numbers



N-20

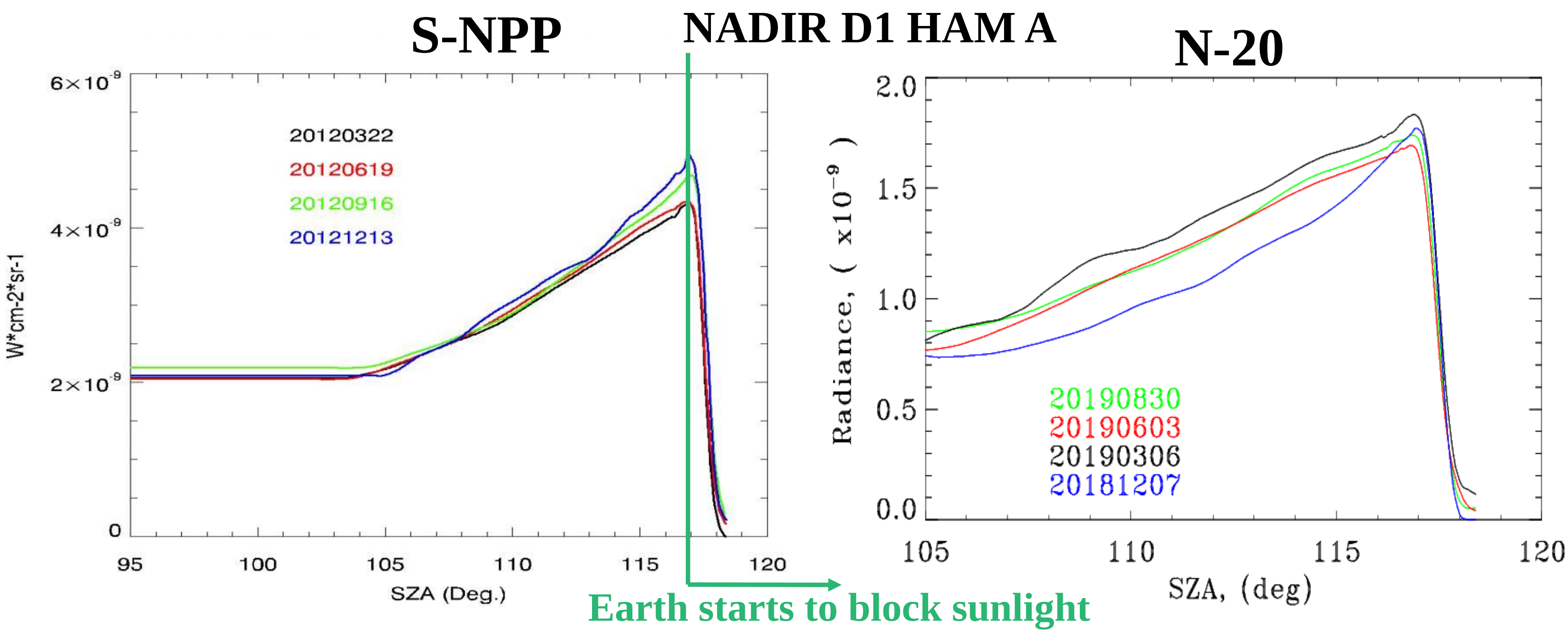


Performance of N-20 DNB



N-20 DNB gains are very stable, no RTA mirror contamination

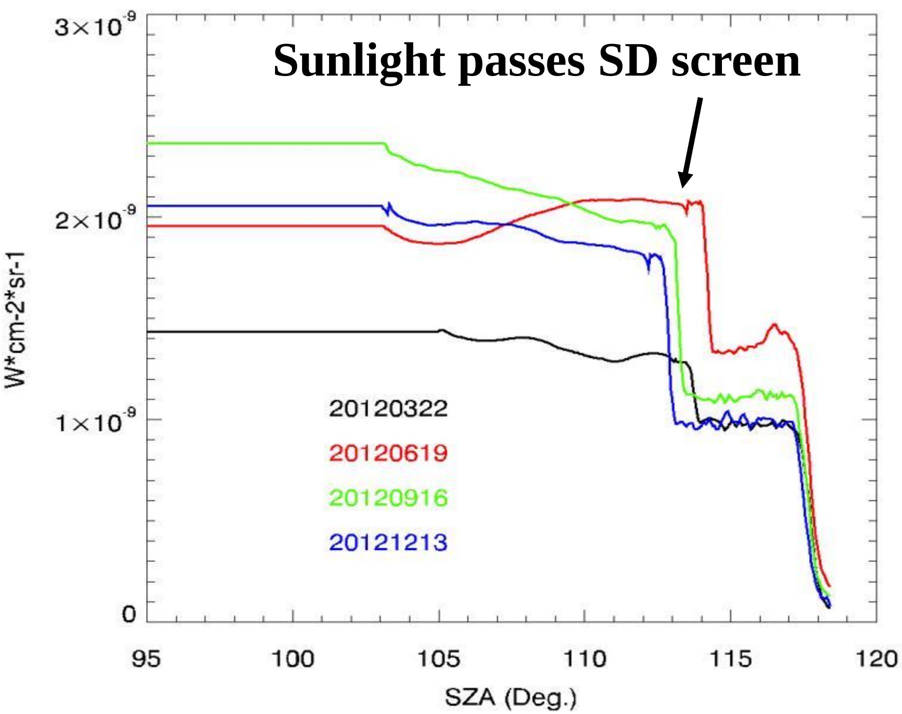
DNB Stray Light over Northern Hemisphere

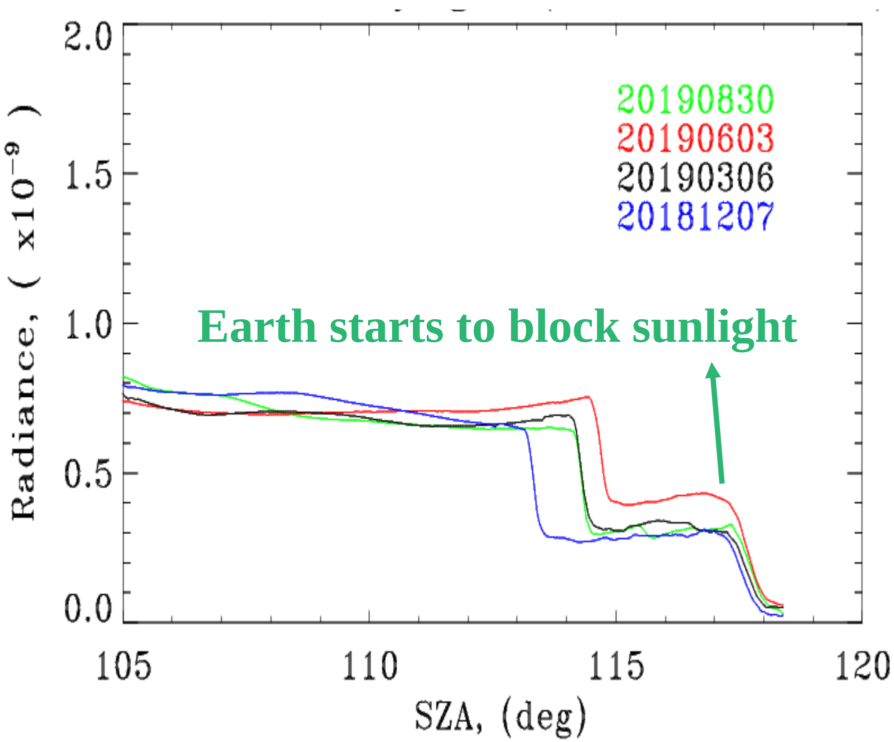


- Stray light comes from sunlight and/or Earth reflected sunlight hitting instrument
- N-20 VIIRS has much weaker stray light contamination

DNB Stray Light over Southern Hemisphere

S-NPP NADIR D1 HAM A N-20





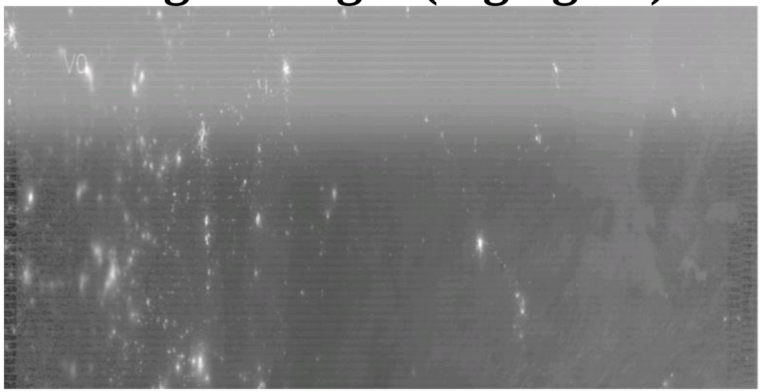
- Stray light is weaker over Southern Hemisphere
- Stray light patterns are different over the two hemispheres

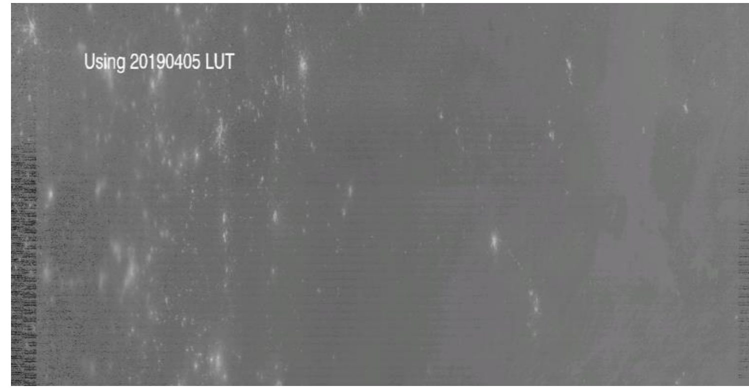
DNB Stray Light Removal

Stray light contaminated night images (high gain)

Stray light removed

S-NPP 20190327

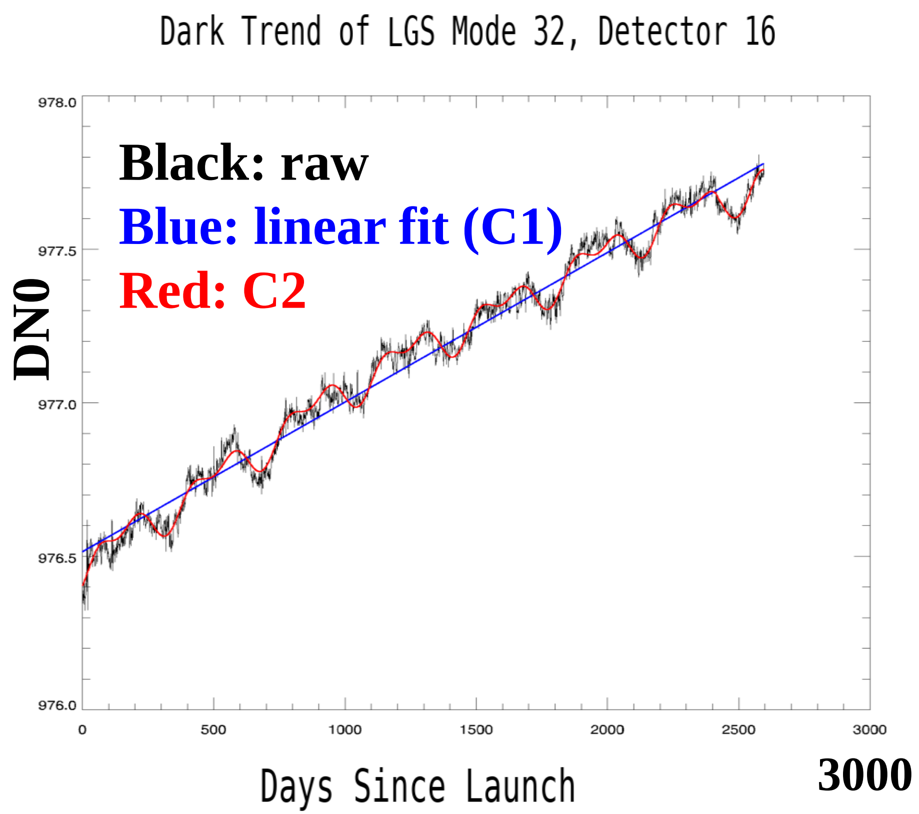


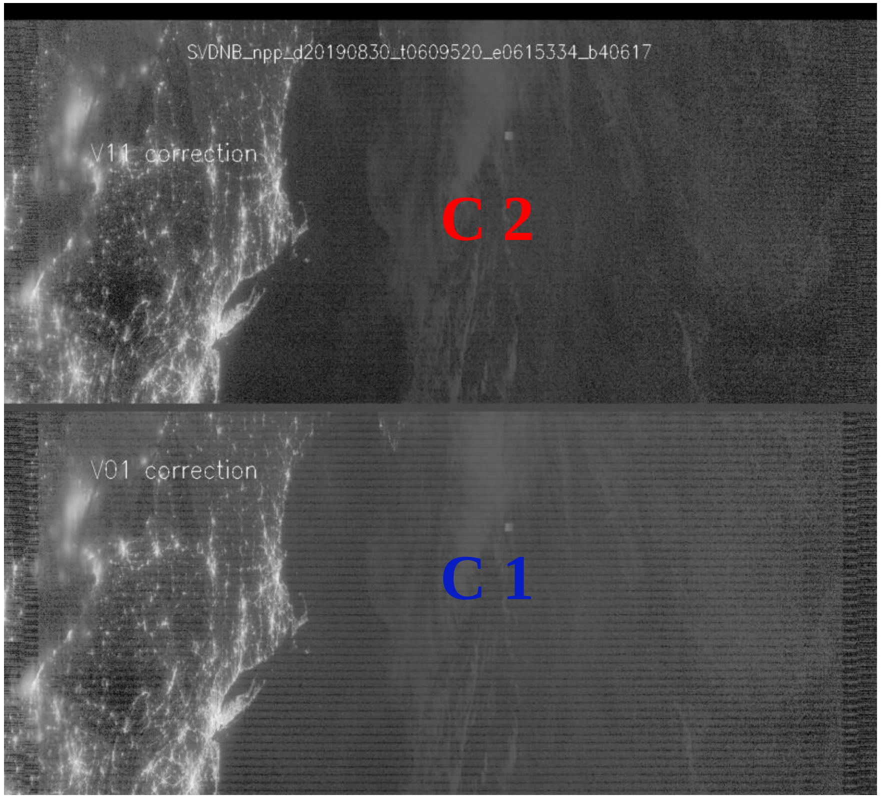


N-20 20190730

Stray light successfully removed

S-NPP DNB Dark Improvement





More accurate DN0 removes/reduces striping

VIIRS DNB Improvements and Performance Summary

S-NPP

- Gain (1/F) trends lower with time with decreasing rates
- Improved dark count accuracy: remove/reduce night image striping

N-20

- Gains are very stable over time
- Improved stray light accuracy over edge frames

Future Improvements

S-NPP

1. Examine prelaunch calibration coefficients
2. Find potential changes in VIIRS RVS vs AOI
3. Improve SD F-factors for RSB low-gain stages
4. Yield more accurate DN saturation flagging
5. Study polarization induced Earth view striping
6. DNB stray light weekly LUTs

N-20

1. Examine prelaunch calibration coefficients
2. Study SD positional dependence of the H-factor
3. Find DNB stray light pattern more accurately

Summary

- Both S-NPP and N-20 RSB and DNB detector gains perform as expected with SNRs well above specifications
- S-NPP VISNIR M-bands reflectance greater than N-20's by 4-5%, except for M2 (1.5%) with lunar results; 8.0% (M1), 6% (M2), 5% (M3), 2% (M4), 5% (M5), 3% (M7) with Libya 4 L1B results (nadir)
- Performed a number of improvements for S-NPP VIIRS RSBs with the largest improvement at 1.3%
- S-NPP SD screen transmittance times prelaunch BRDF has biases larger than 0.6% whereas the difference is less than 0.3% for N-20, comparing with results from on-orbit data
- Obtained more accurate dark counts for S-NPP DNB: removed/reduced striping in night images
- N-20 screen transmittance functions improved: much smoother H-factor curves
- Obtained more accurate stray light pattern for edge frames for N-20