# Use of Celestial Objects for VIIRS Day-Night Band On-orbit Calibration

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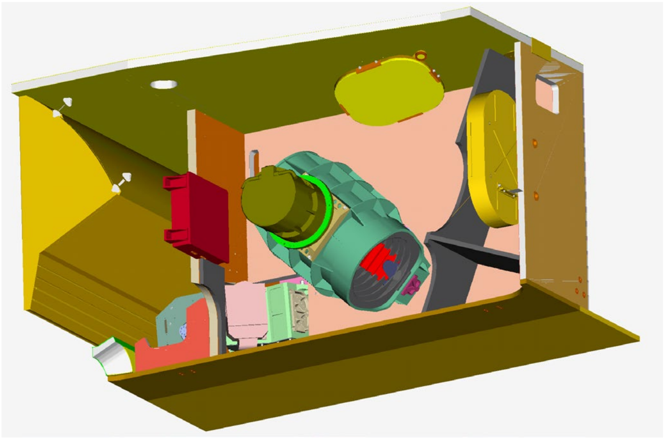
# Outline

- **VIIRS Day Night Band (DNB)**
- **DNB On-orbit Calibration**
  - Sun, Moon, **and Stars**
- **Results and Discussion**
  - On-orbit Gain Trending and Stability Monitoring
  - Calibration Inter-comparison (via Moon and Stars)
- **Summary and Future Efforts**

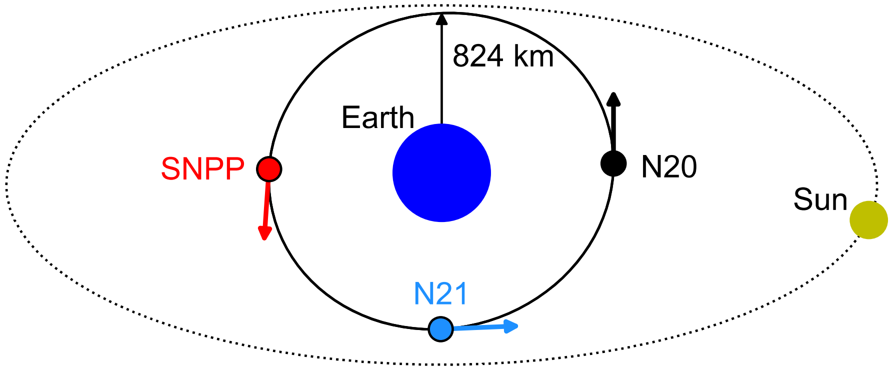
# VIIRS Instruments

- **Visible Infrared Imaging Radiometer Suite (VIIRS)**
  - A follow-on instrument to MODIS (on NASA's Terra and Aqua missions)
  - Currently on S-NPP, JPSS-1 (NOAA-20), and JPSS-2 (NOAA-21), launched in 2011, 2017, and 2022, respectively
  - Also to be onboard JPSS-3 (NOAA-23) and JPSS-4 (NOAA-22), scheduled for launch in 2033 and 2028, respectively
  - 22 spectral bands (0.41 to 12.2 μm): 14 reflective solar bands (RSB), 7 thermal emissive bands (TEB), **and 1 day night band (DNB)**



VIIRS

JPSS-2 launch on Nov 10, 2022

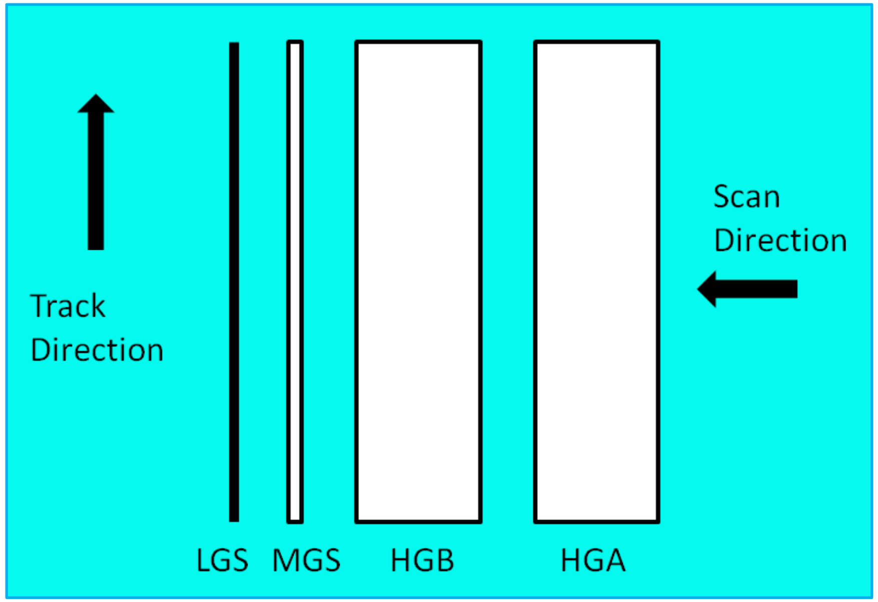



(before March 19, 2024)

N20 is now 180° separated with N21

# VIIRS Day Night Band (DNB)

- **Day and Night Band (DNB)**
  - 4 CCD detector arrays for low gain stage (LGS), mid gain stage (MGS), and high gain stages (HGA, HGB)
  - **16 detectors** along track and **32 aggregation modes** along scan with varying sub-pixel detectors to maintain near-constant spatial resolution on the ground
  - **ND filter for LGS**, TDI for MGS and HGS

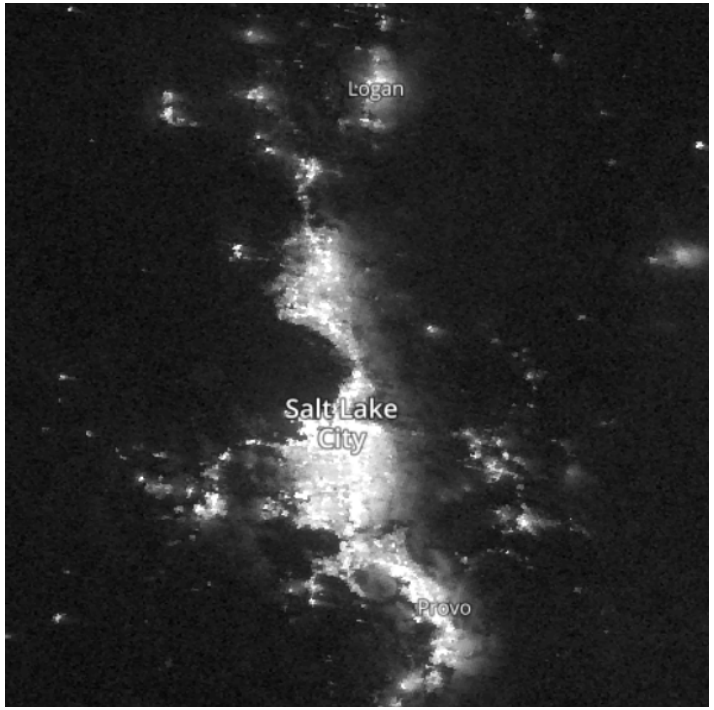



| | |
|---|---|
| Spectral Bandwidth | 0.5 - 0.9 μm |
| Lmin (HGS) - Lmax (LGS) | $3.0 \times 10^{-5}$ - $2.0 \times 10^{2}$ W/m²/sr |
| SNR at HGS Lmin and scan angle < 53° (≥ 53°) | 6 (5) |
| Uncertainty for LGS (Lmax - Lmin) | 5-10% |
| Uncertainty for MGS (Lmax - Lmin) | 10-30% |
| Uncertainty for HGS (Lmax - Lmin) | 30-100% |

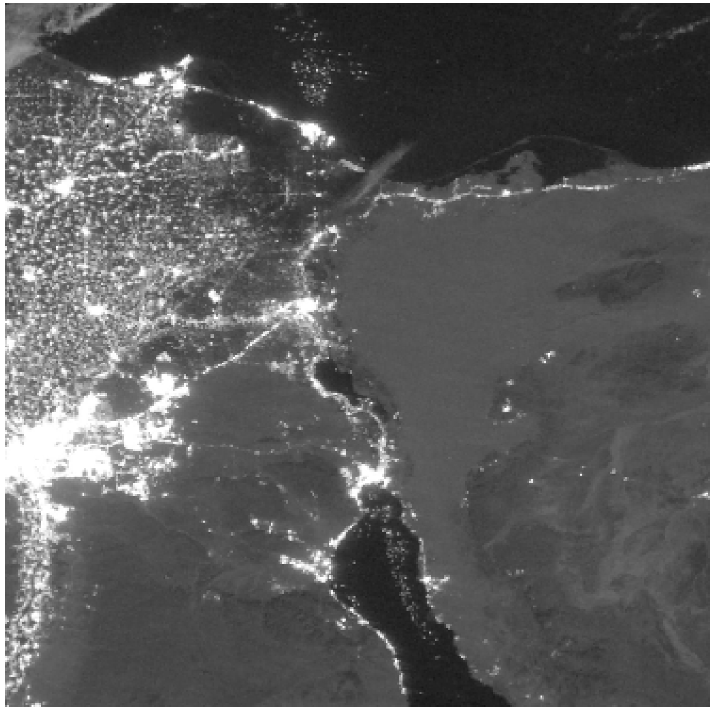
LGS: 1 x 672 (scan x track) sub-pixel detectors
MGS: 3 x 672
HGS A/B: 250 x 672

**N-20 option 21: modified to minimize non-linearity at its higher aggregation modes**

# Examples of DNB Imagery




*City Light over Salt Lake City, UT*
*April 7, 2024*



*Ships queuing at the Suez Canal*
*April 1, 2021*

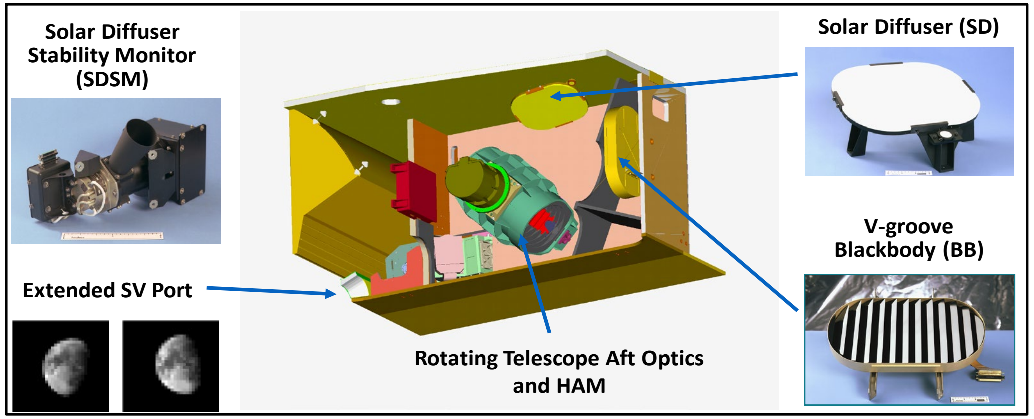
*Aurora Borealis seen over the United States*
*May 11, 2024*

(Imagery obtained from NASA Worldview)

**Applications:** City lights, Nighttime fires, Fishing boats (ship track), Aurora borealis, Hazard monitoring, and more, …

# DNB On-orbit Calibration - Sun

- **Solar Calibration (LGS, MGS, HGS)**
  - LGS calibration similar to RSB (via SD/SDSM)
  - MGS and HGS calibrated using ratios of LG/MG and MG/HG via partially illuminated SD (or VROP* data)
  - Initial on-orbit offsets derived using pitch maneuver data with changes monitored using OBC (or VROP* data)
  - Calibration performed for each detector, aggregation modes, and HAM (half angle mirror) side
  - HGS is averaged over HGA and HGB




$$F_{LGS} = L_{SD}/(dn_{SD})$$

$$F_{MGS} = F_{LGS} \cdot (dn_{LGS}/dn_{MGS})$$

$$F_{HGS} = F_{MGS} \cdot (dn_{MGS}/dn_{HGS})$$

F: calibration coefficient (1/gain)
$L_{SD}$: radiance from sunlit SD
dn: corrected detector responses

*** VROP - VIIRS Recommended Operating Procedure**

SD calibration is performed for each gain stage, detector, HAM side, and aggregation mode

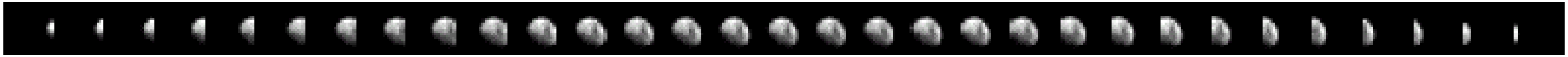
# DNB On-orbit Calibration - Moon

- **Lunar Calibration (LGS)**
  - Similar to DNB (and RSB) solar calibration
  - Calibration stability monitoring
  - Special considerations
    - Aggregation modes involved depend on data sector rotation
    - Use of all scans with correction for over-sampling effect
    - Some edge pixels could be recorded in MGS

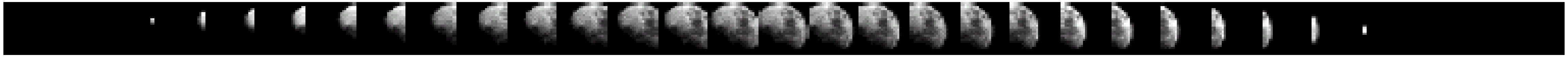
$$F_{LGS} = g \cdot I_{ROLO}/\Sigma(dn_i^{Moon})$$

g: a parameter related to solid angle and RSR

$I_{ROLO}$: integrated lunar irradiance from ROLO model



DNB LGS image from Feb, 2018 lunar roll for SNPP (aggregation mode 1)



DNB LGS image from Feb, 2018 lunar roll for N20 (aggregation mode 20)

# DNB On-orbit Calibration - Moon

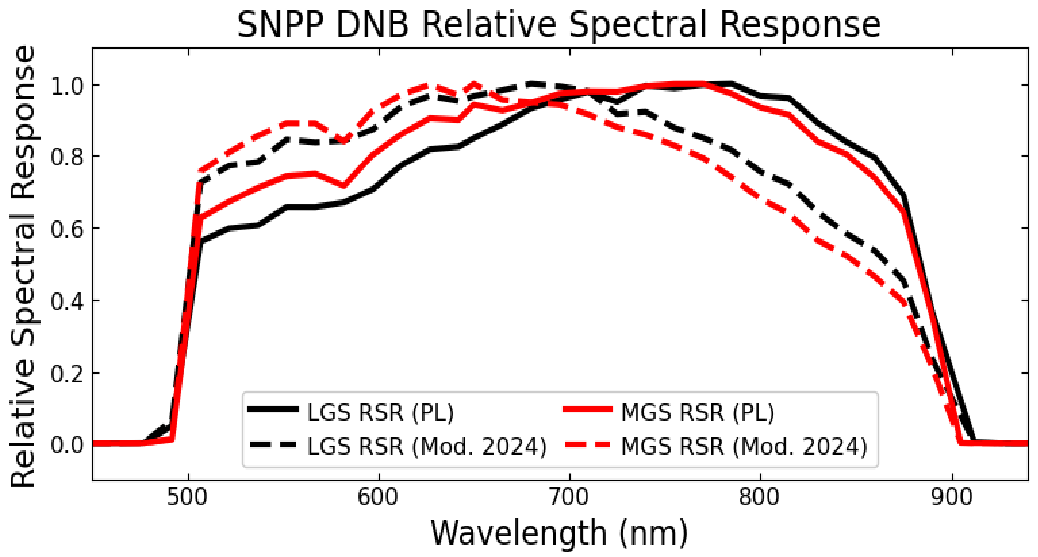
- **Lunar Calibration (LGS)**
  - Calibration inter-comparisons
    - Use lunar model predicted values to remove view geometry differences (impact) between lunar observations

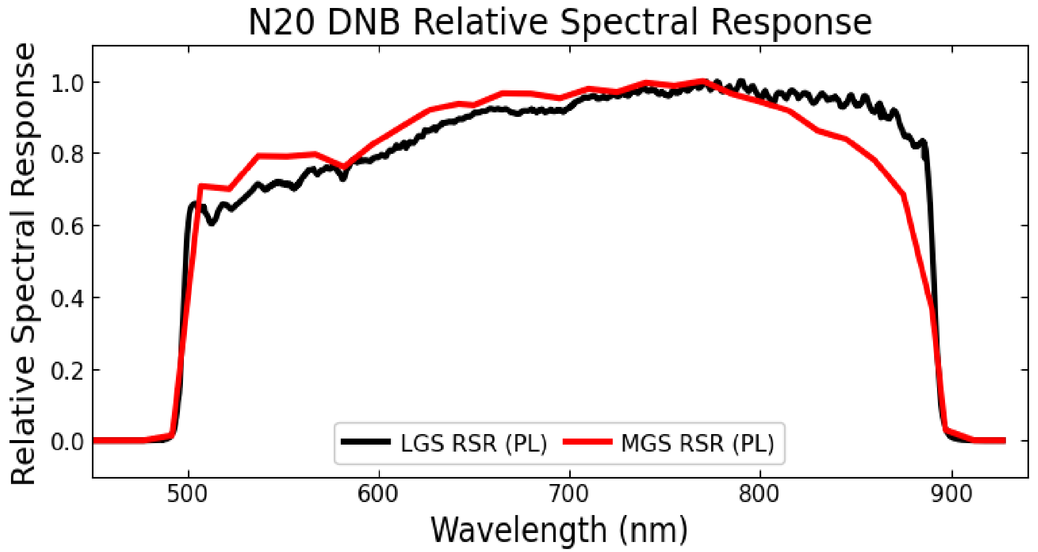
$$R_{A/B} = \frac{I_{meas,A}}{I_{model,A}} \Big/ \frac{I_{meas,B}}{I_{model,B}}$$

    - Apply correction if necessary to remove differences due to sensor specific RSR and solar spectrum used in sensor calibration

$$C_{A/B} = \frac{\int RSR_A(\lambda) E_{Sun_B}(\lambda) d\lambda}{\int RSR_A(\lambda) E_{Sun_A}(\lambda) d\lambda}$$

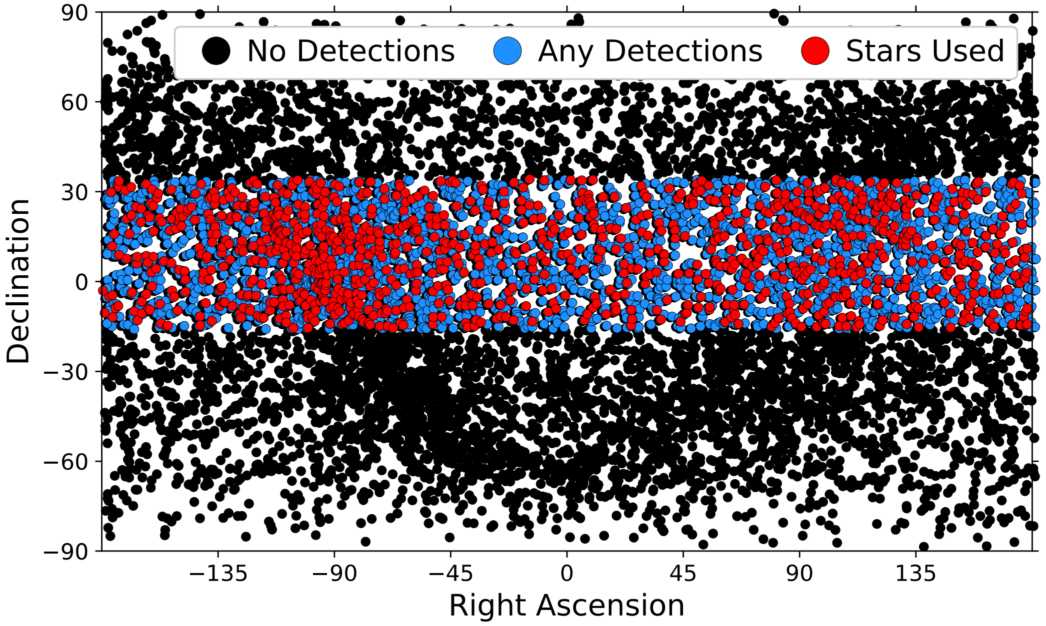
Xiong, X., J. Sun, A. Angal, T. Wilson, "Calibration Inter-Comparison of MODIS and VIIRS Reflective Solar Bands Using Lunar Observations," Remote Sens. 2022, 14(19), 4754



# DNB On-orbit Calibration - Stars

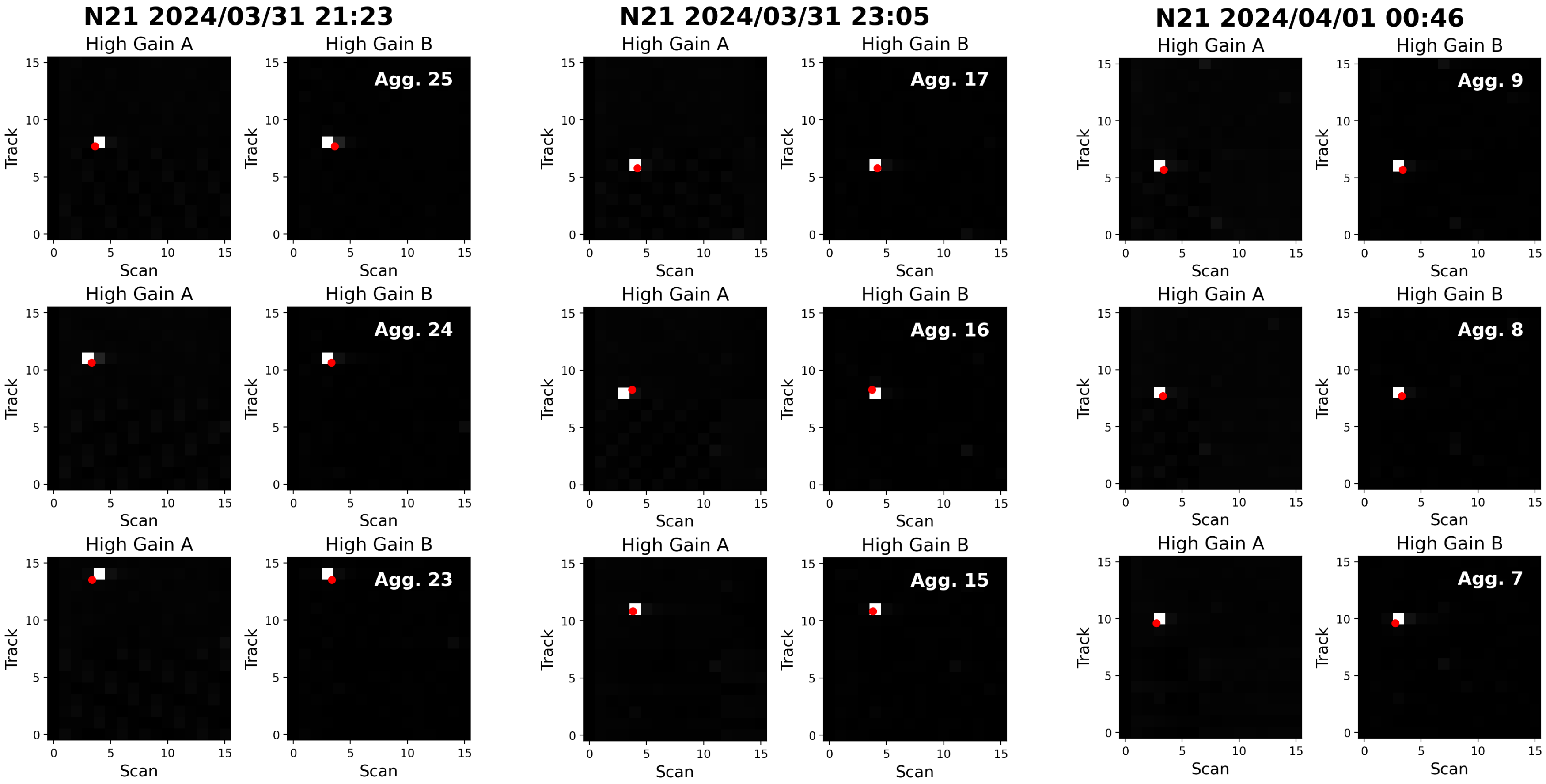
- **Star Calibration (HGS)**
  - SV port geometry limits star observations (declination range)
  - Select stars of temperature class A, B, and K brighter than magnitude +6 are used in this study
  - Stars can be viewed from SV port in orbit cycles, consecutive orbits, and multiple scans (stability monitoring)
  - Same stars could be viewed by all 3 VIIRS and at the “same” time (calibration inter-comparison)
  - Orbit and instrument pointing data is used to determine when and where stars will be in the SV FOV. A spatial map of each aggregation mode was derived using bright isolated stars



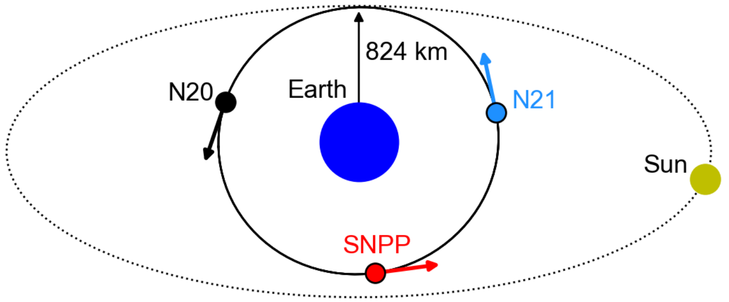

| Instrument | # of Stars |
|---|---|
| S-NPP Detected Stars | 3435 |
| Used Stars | 1145 |
| N20 Detected Stars | 3435 |
| Used Stars | 1153 |
| N21 Detected Stars | 3335 |
| Used Stars | 1136 |

# Examples of DNB HGS Star Observations

## DNB Star Images (HR 740)




Orbit N → Orbit N+1 → Orbit N+2

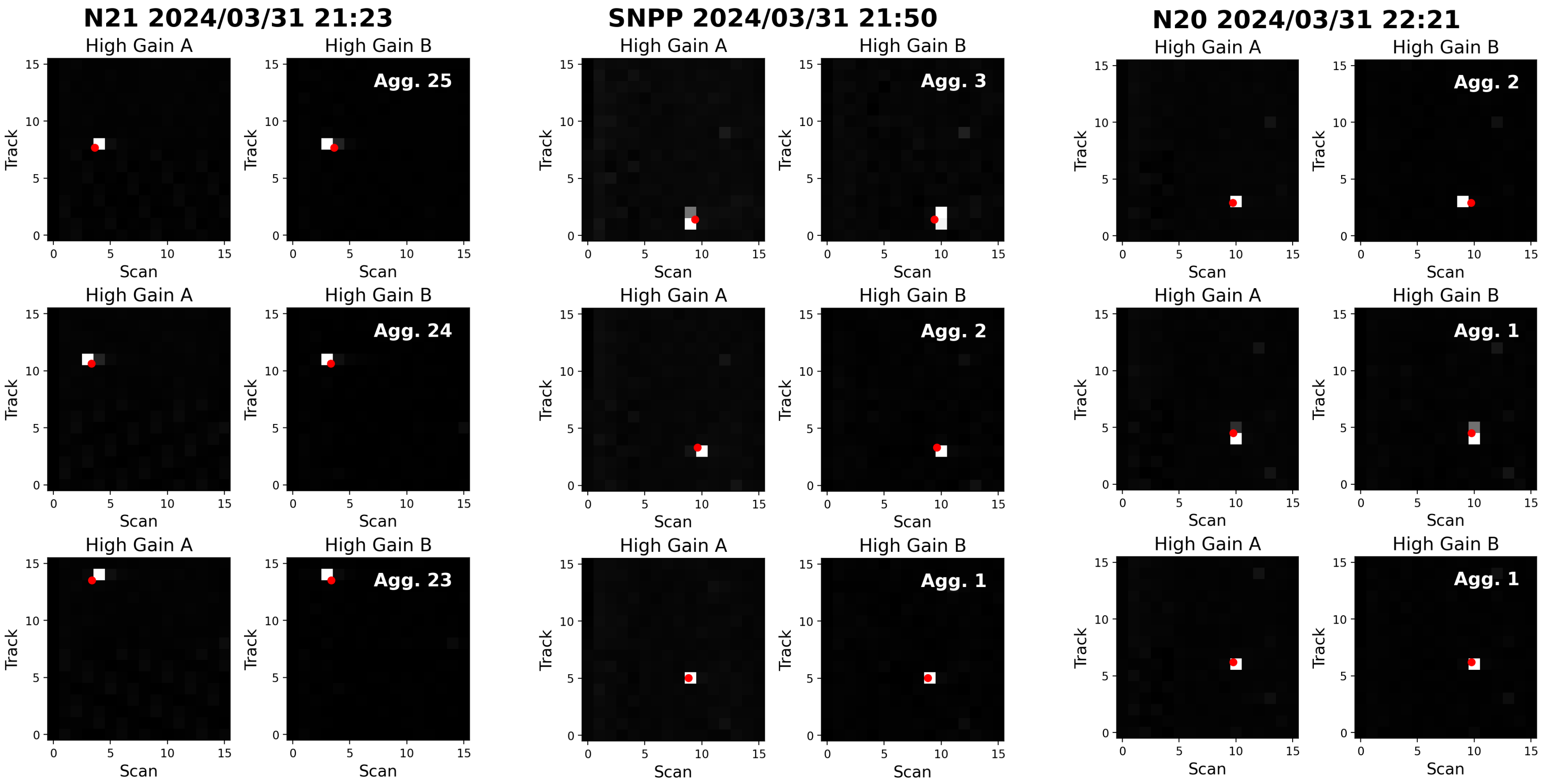



*Relative orbital positions on 2024/03/31

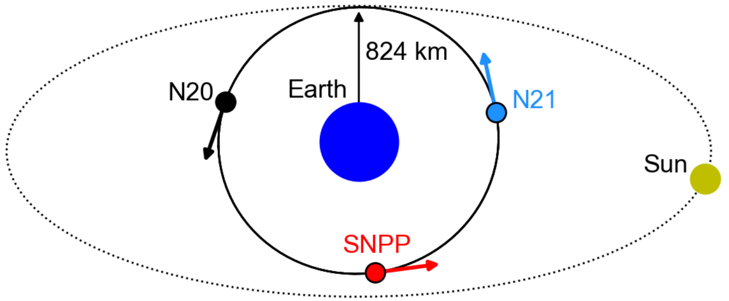
The red dot shows the predicted star location in each image.

# Examples of DNB HGS Star Observations

## DNB Star Images (HR 740)




N21 → SNPP → N20




*Relative orbital positions on 2024/03/31

The red dot shows the predicted star location in each image.

# DNB On-orbit Calibration - Stars

- **Star Calibration (HGS)**
  - Special considerations in data processing:
    - Exclude images with any saturated pixels, which can occur for the brightest stars and also during satellite daytime due to stray light (large in S-NPP, small in N20, and smaller in N21).
    - Locations of the stars match with the predicted positions using spatial mapping data (within 1.2 pixels).
    - Same star is detected in both HGA and HGB and appears within 1 pixel of each other; their signal ratio is within 30% of unity.
  - Stability monitoring with multiple stars: correction for star spectral differences due to modulated RSR (S-NPP only)
  - Calibration inter-comparison using the same stars: correction for sensor specific RSR

$$R_{SNPP/N20} = (I_{SNPP}/I_{N20}) \cdot (\gamma_{N20}/\gamma_{SNPP})$$

$$I = F_{HGS} \cdot dn \cdot \Omega$$

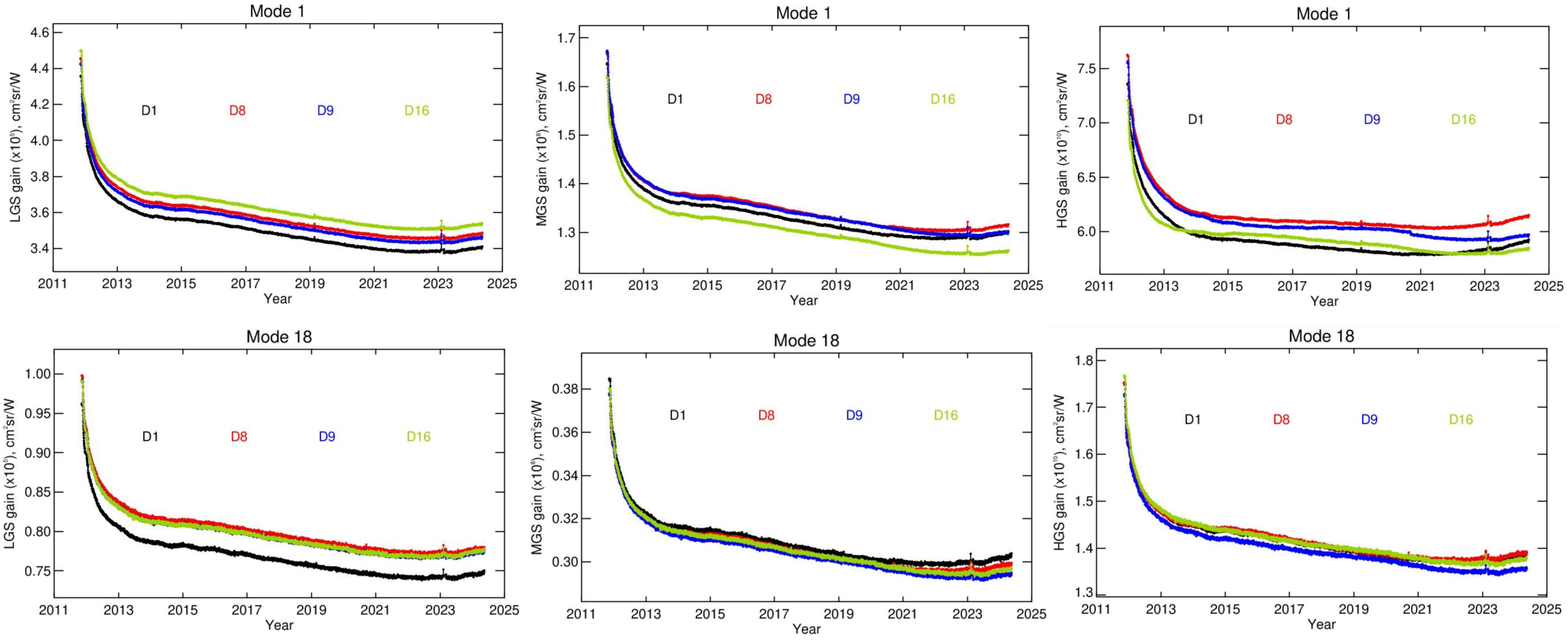
$$\gamma_i = \int E^*(\lambda) \cdot RSR_i(\lambda) d\lambda$$

$\Omega$: pixel solid angle (aggregation mode dependent)
I: measured star irradiance
$E^*(\lambda)$: star irradiance spectrum

# Results and Discussion

- **Detector gains (stability monitoring)**
  - LGS, MGS, and HGS from SD calibration
  - LGS from lunar calibration
  - HGS from star calibration
- **Calibration inter-comparison**
  - Lunar observations (LGS)
  - Star observations (HGS, MGS)

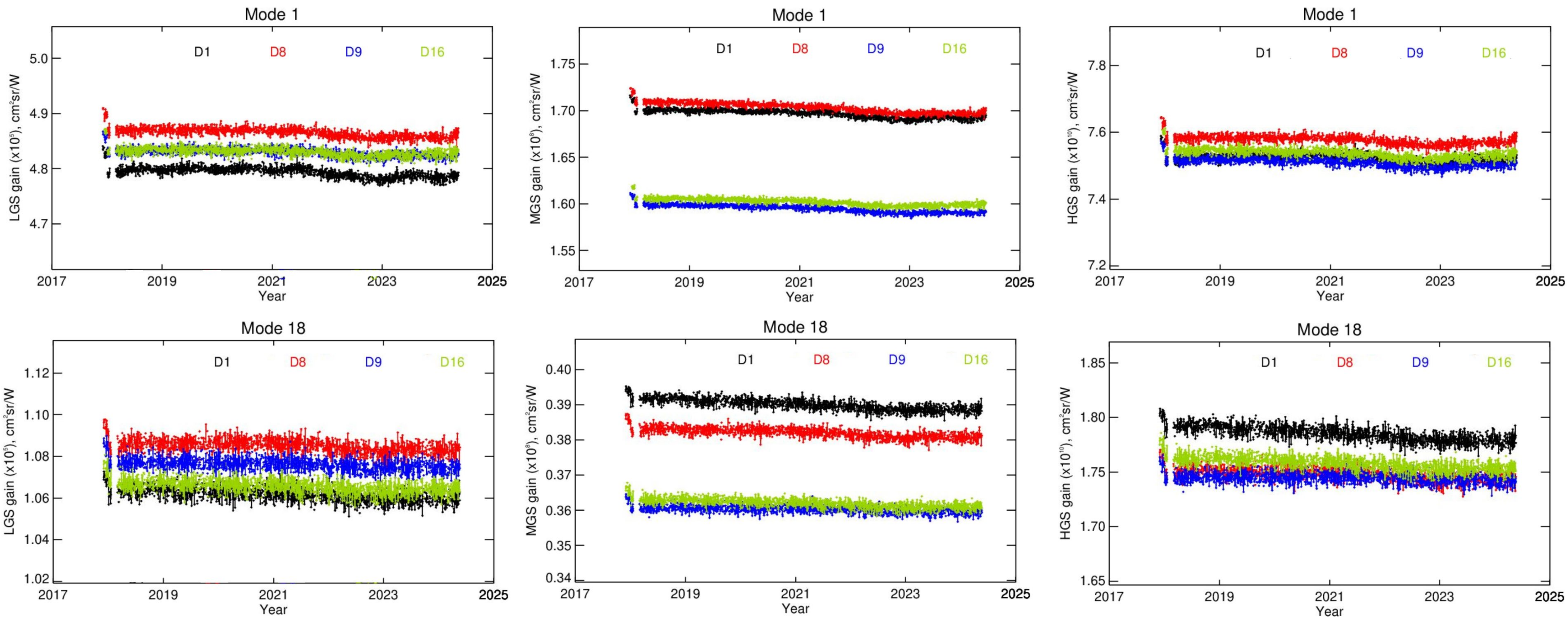
# DNB Gains from SD Calibration (S-NPP)




HGS calibration is extremely sensitive to instrument events (small changes of DN offsets)

HGA and HGB data are averaged for noise reduction

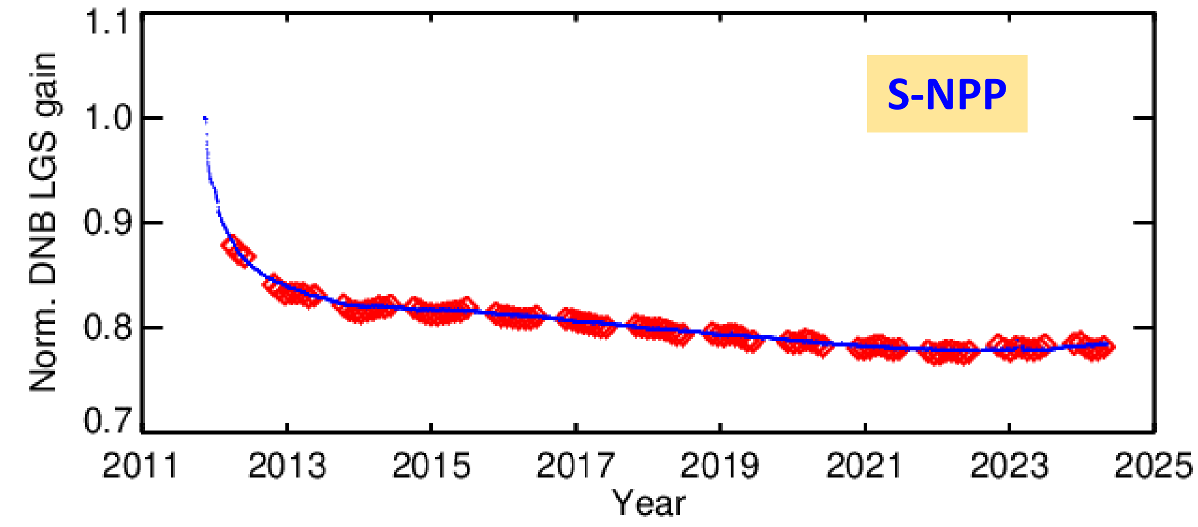
# DNB Gains from SD Calibration (N-20)

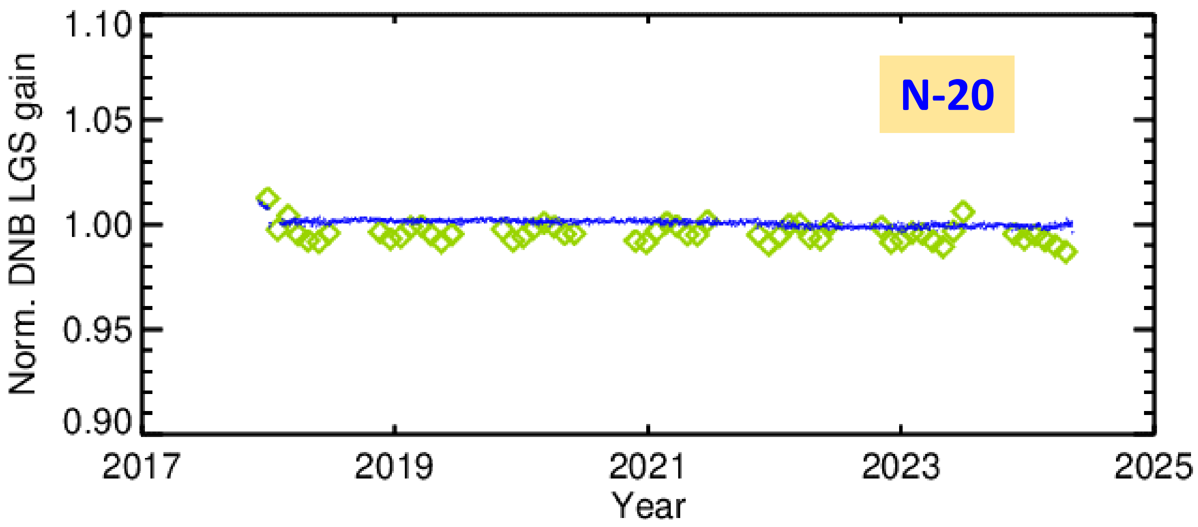



HGS calibration is extremely sensitive to instrument events (small changes of DN offsets)

HGA and HGB data are averaged for noise reduction

# DNB Lunar Calibration Stability Monitoring



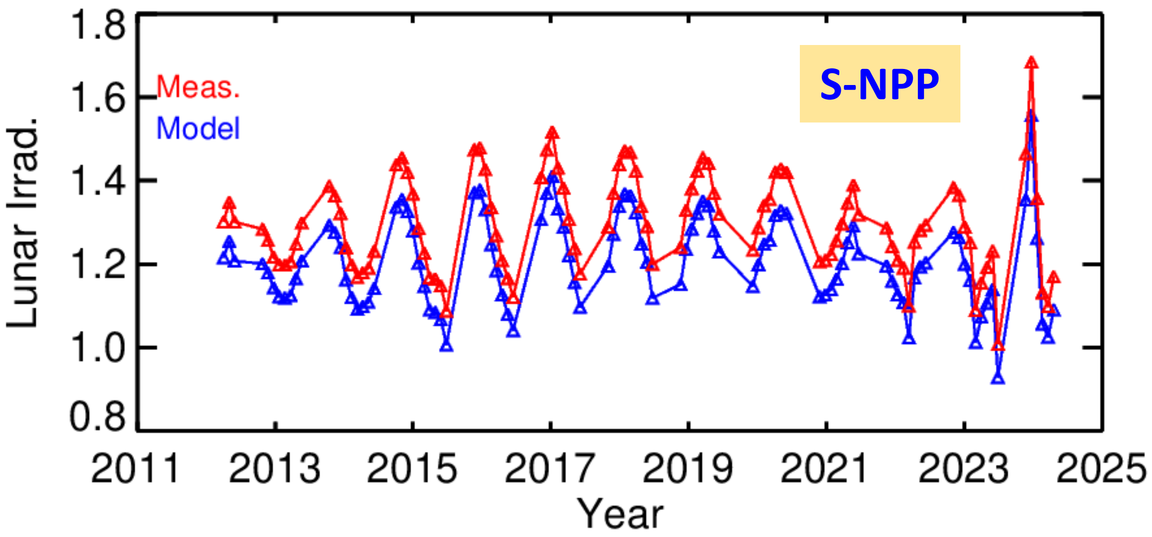



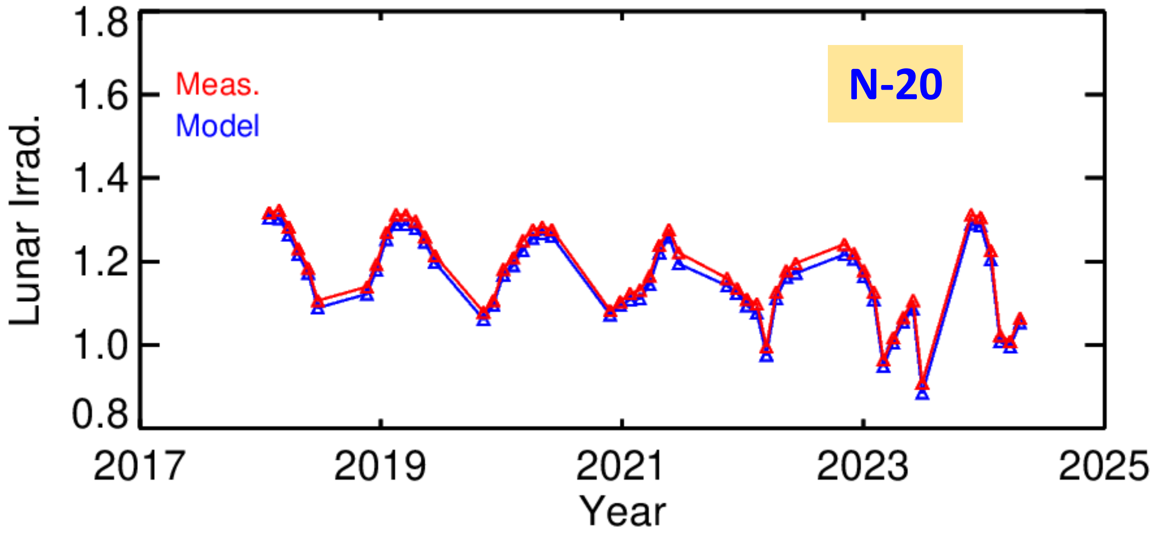

Blue dotted line: normalized SD calibration gains of select aggregation mode

Diamond symbols: normalized lunar calibration gains

Good agreement between SD and lunar calibration

# DNB Lunar Calibration Inter-comparison




Using lunar observations made over the same period and calibration coefficients derived with TSIS spectrum

$$R_{SNPP/N20} = \left(\frac{I_{meas}}{I_{model}}\right)_{SNPP} \Big/ \left(\frac{I_{meas}}{I_{model}}\right)_{N20} = 1.048\ (+/-0.006)$$

[R = 1.027 for the RSB within DNB(λ)]

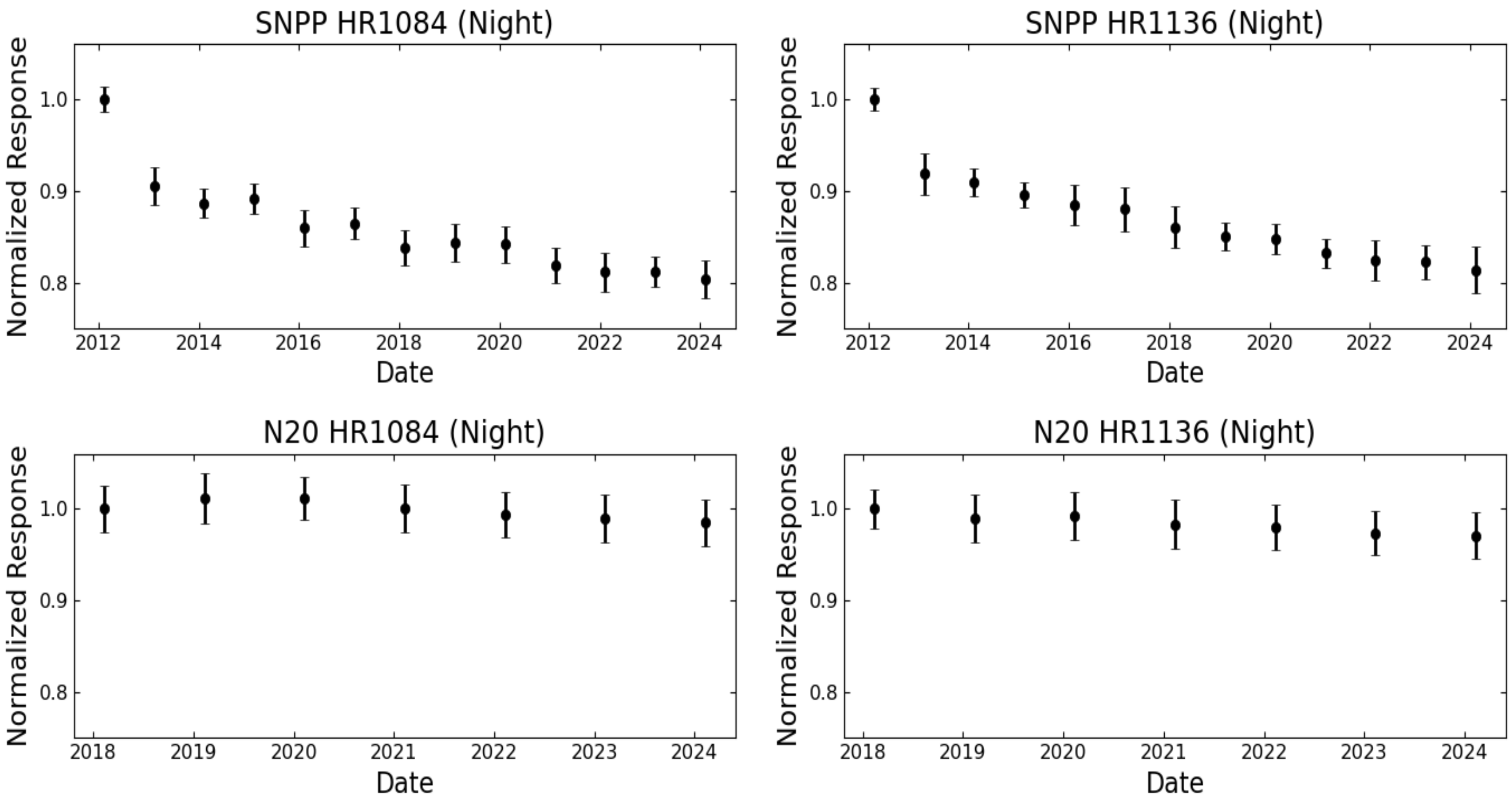
$$R_{N21/N20} = \left(\frac{I_{meas}}{I_{model}}\right)_{N21} \Big/ \left(\frac{I_{meas}}{I_{model}}\right)_{N20} = 1.006\ (+/-0.006)$$

[R = 1.005 for the RSB within DNB(λ)]

# DNB HGS Stability Monitoring Using Stars

- **Trending "corrected" detector responses**
  - Background subtracted detector responses multiplied by a calibration LUT (t=0) to remove initial gain differences among detectors, aggregation modes, and HAM sides
  - Data averaged over each orbital cycle, which has sufficient scans after 3-sigma outlier rejection
  - Nighttime data

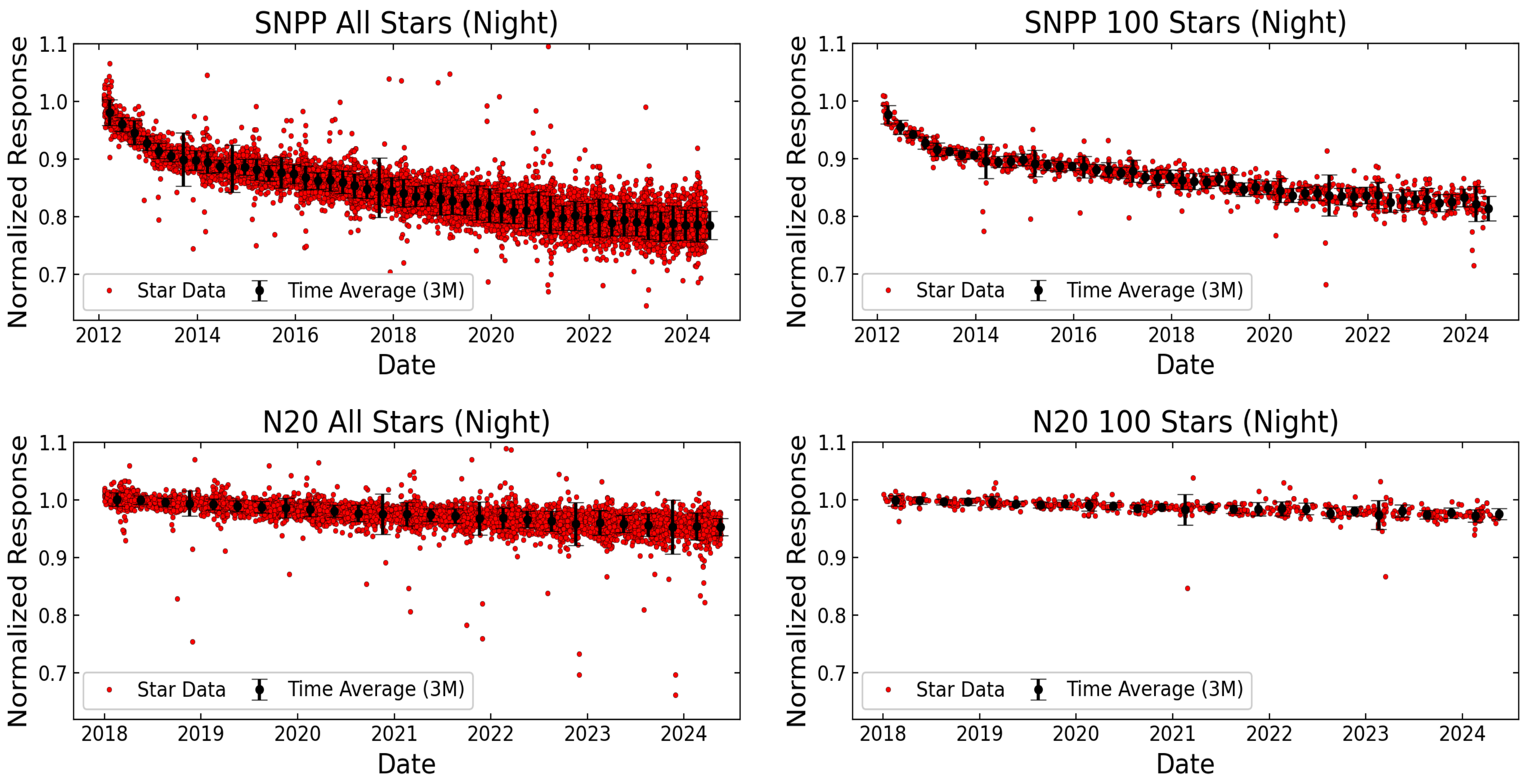
**Individual Stars**



# DNB HGS Stability Monitoring Using Stars

## All Selected Stars

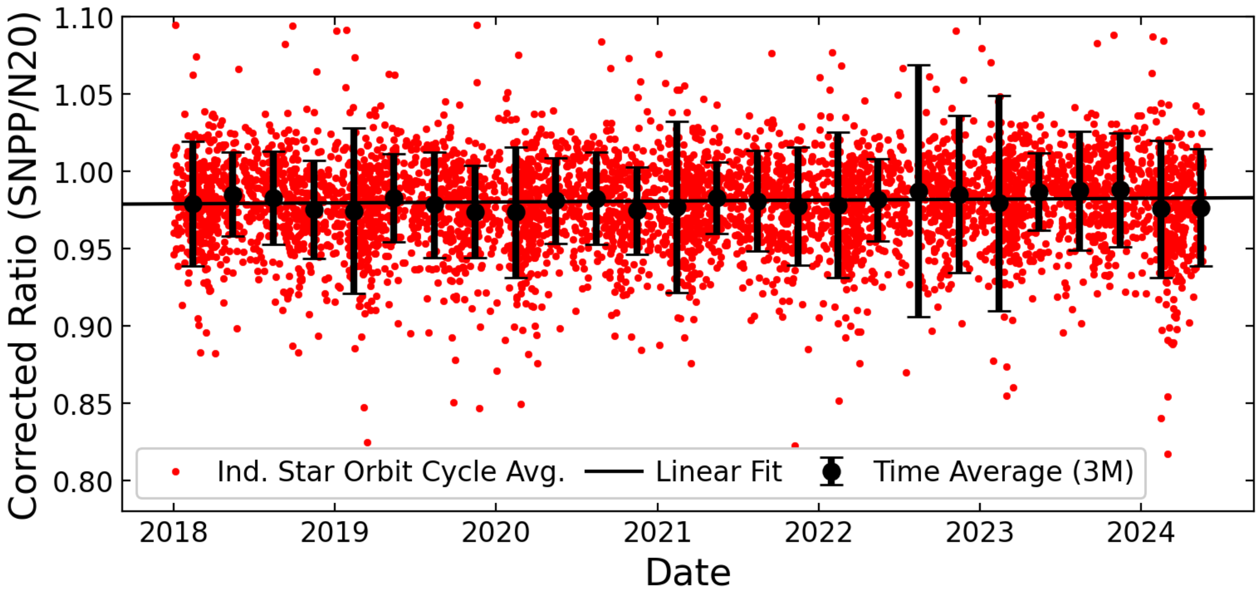
## 100 Stars (brightest)

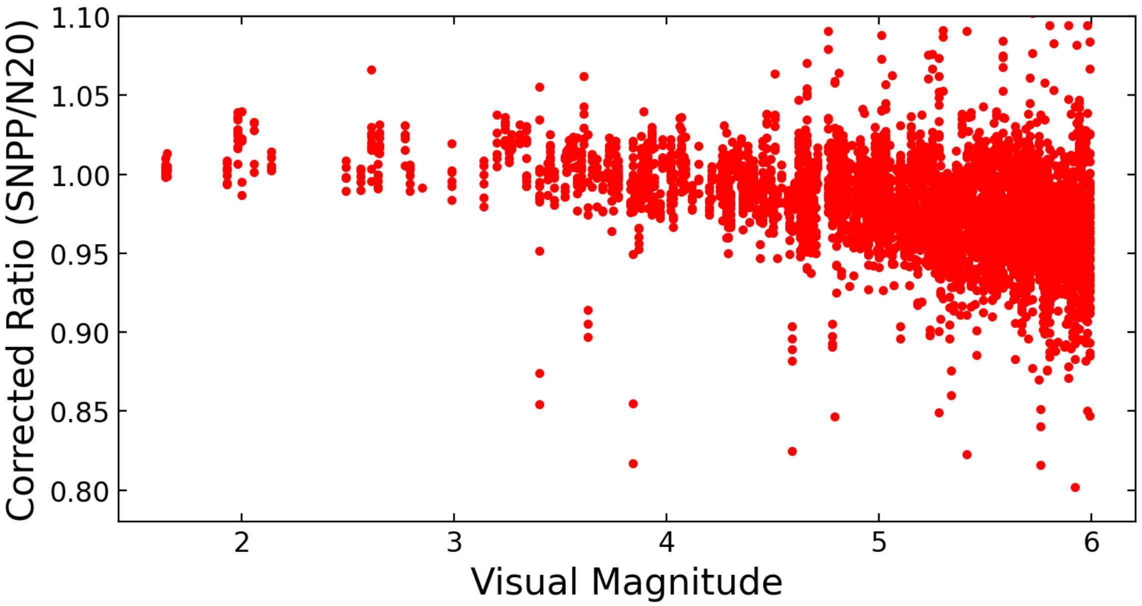


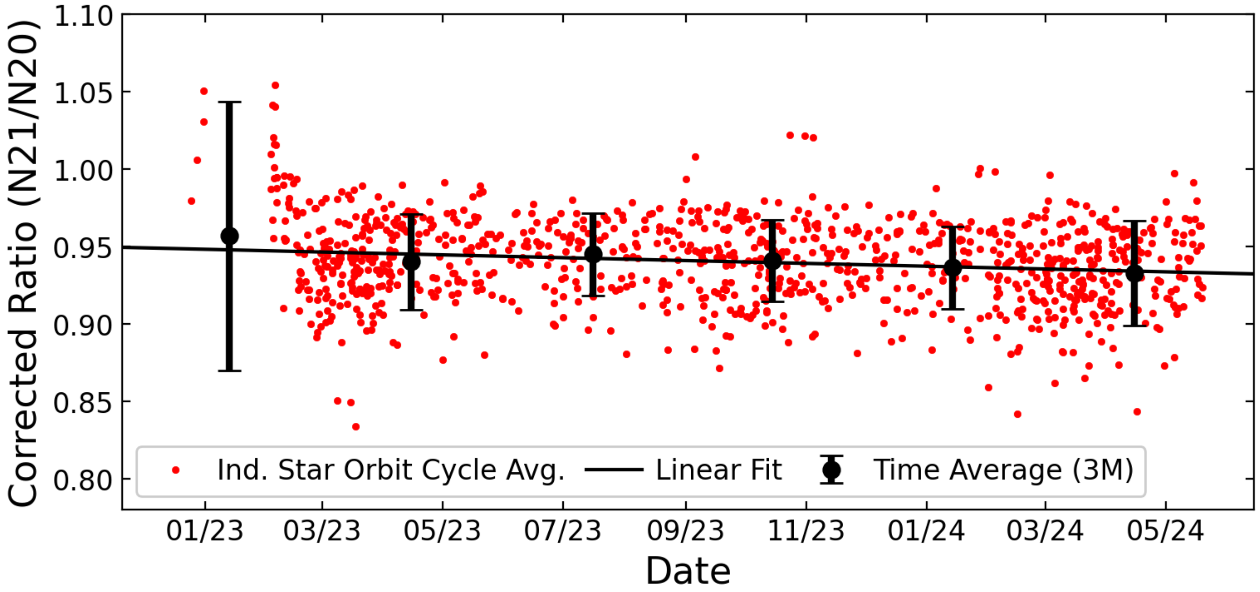

- **Variations among all stars:**
  - SNR (stars with low signals)
  - Nonlinearity (more in S-NPP)
  - Source spectral differences with modulated RSR (S-NPP)
  - Initial normalization among all stars

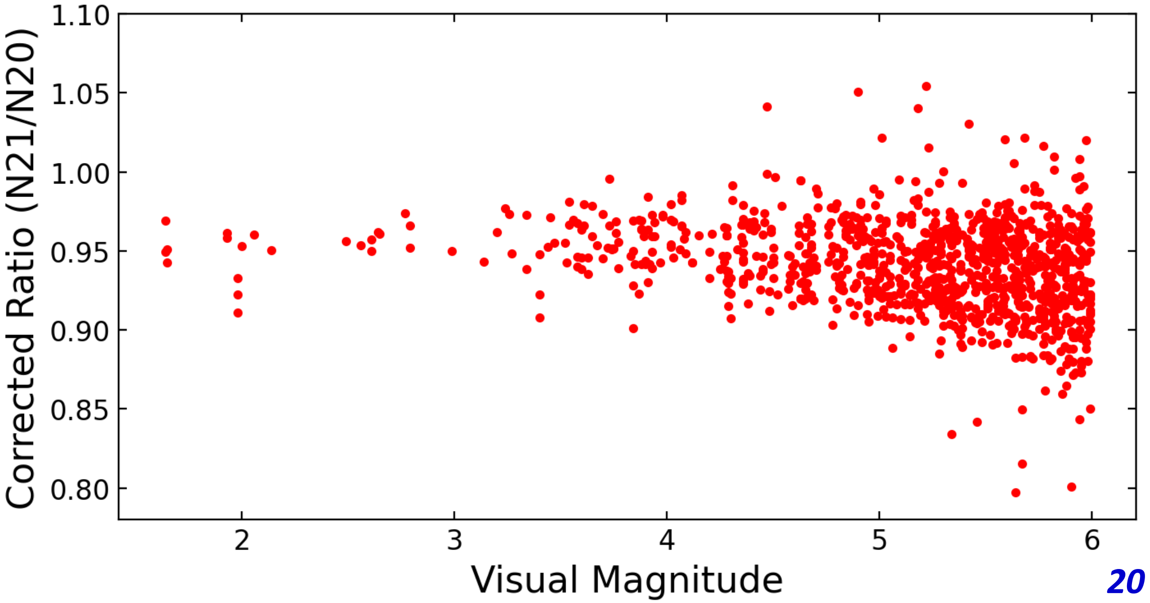
**The N21 needs to have more data for long-term stability monitoring**

# DNB HGS Calibration Inter-comparison Using Stars

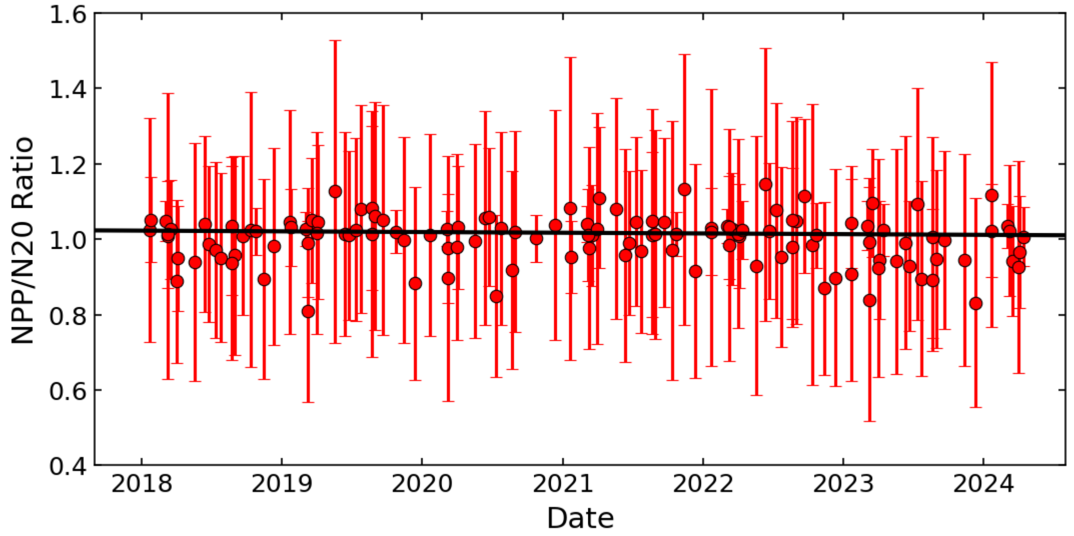


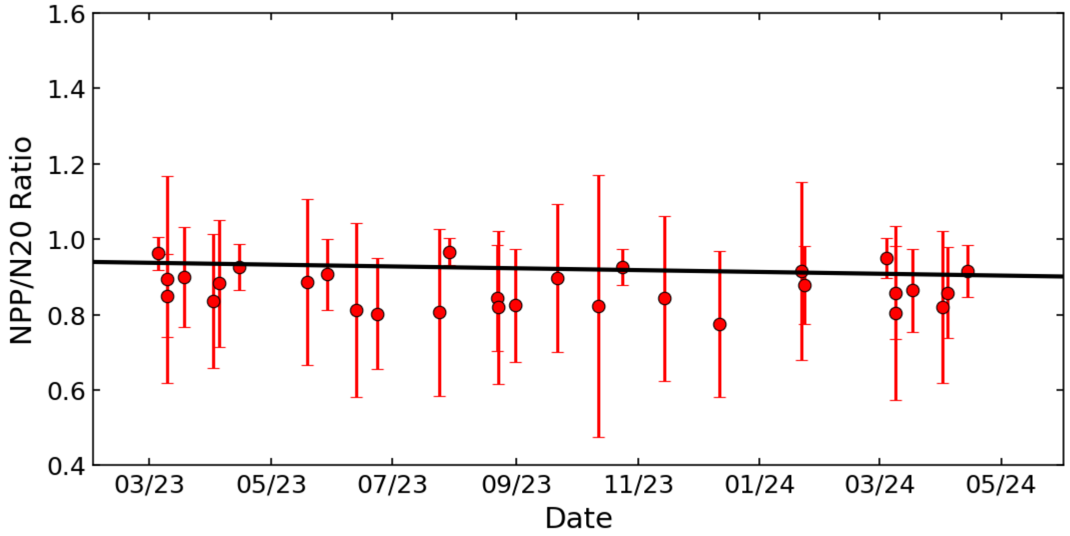



# DNB MGS Calibration Inter-comparison Using Stars




SNPP/N20 MGS Difference (%): 1.8053 +/- 1.2425

N21/N20 MGS Difference (%): -7.2294 +/- 1.8302

# Summary and Future Efforts

- **In addition to solar calibration (via on-board SD), both lunar and star observations can be used for the VIIRS DNB on-orbit calibration**
  - Calibration stability monitoring (Moon for LGS, stars for MGS and HGS)
  - Calibration inter-comparisons (especially for the MGS and HGS)
- **Results show good calibration stability and calibration consistency between S-NPP, N20, and N21 VIIRS DNB**

  LGS: SNPP/N20 = 4.8%     N21/N20 = 0.6%

  MGS: SNPP/20 = 1.8%     N21/N20 = - 7.2%

  HGS: SNPP/20 = - 2.2%     N21/N20 = - 5.8%
- **Special tools (and procedures) developed for star calibration have been demonstrated to be effective and flexible for future missions**
- **Future efforts**
  - Small differences between solar and star calibration stability monitoring
  - Absolute calibration using stars with accurate spectral irradiance
  - Night time EV based trending and inter-comparison