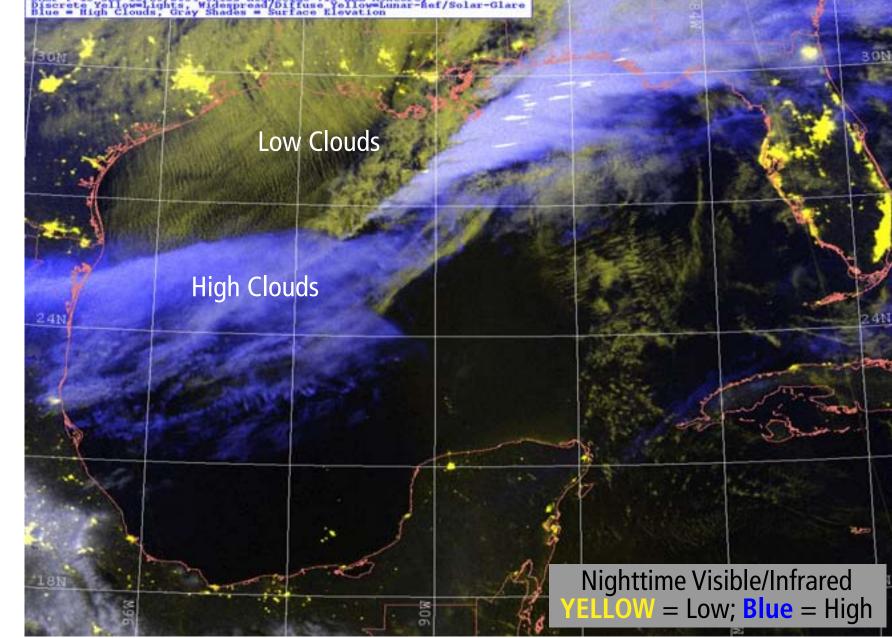# Operation and Characterization of the Day/Night Band for the NPP Visible/Infrared Radiometer Suite (VIIRS)

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Summary

- VIIRS F1 Instrument has successfully completed all sensor characterizations and verification

- Key Day/Night Band (DNB) performance requirements successfully demonstrated
  - SNR at EOL
  - Dynamic Range
  - Radiometric Cal. Uncertainty
  - Horizontal Sample Interval
  - Horizontal Spatial Resolution

VIIRS provides unprecedented ability to detect and derive information from clouds at night

Under adequate lunar illumination, the calibrated VIIRS DNB will provide quantitative cloud reflectance information, allowing markedly improved cloud characterization compared with IR-only approaches

VIIRS F1 Low Clouds High Clouds

Nighttime Visible/Infrared VIIRS = Low, Blue = High

Artwork provided courtesy of the U.S. Naval Research Laboratory-Monterey
Reference: Lee, T. F., Miller, S. D., Turk, F. J., Schueler, C., Julian, R., Deyo, S., Dills, P., and Wang, S., The NPOESS VIIRS Day/Night Visible Sensor. Bulletin American Meteorological Society, 87, 191-199 (2006).

VIIRS Introduction

- The Visible/Infrared Imager/Radiometer Suite (VIIRS) sensor is a nadir viewing, cross-track observing, continuously operating electro-optical imaging sensor for the National Polar-orbiting Operational Environmental Satellite System (NPOESS)

- Measures Earth and atmosphere scene spectral radiance in the visible and infrared spectrum from an altitude of 833 km

- Data used for retrieval of operational Environmental Data Records (EDRs)

- Twenty-two (22) spectral bands (0.41-12 μm)
  - 16 Moderate Resolution Bands (0.26 – 1.6 km)
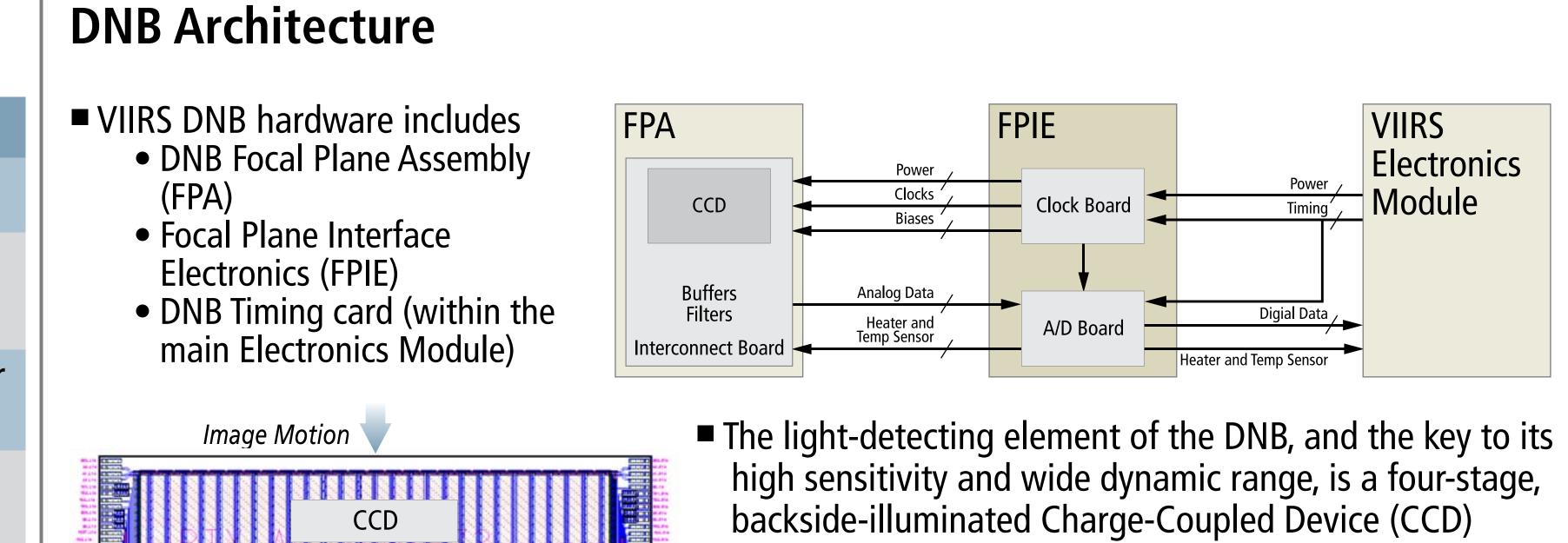 - 5 Imaging Resolution Bands (0.4-0.8 km)
  - 1 Visible Day/Night Band (0.742 km)

- Passive Cryoradiator to cool Emissive Band FPAs to 80 K

- On-board Blackbody Calibrator and Solar Diffuser/Solar Diffuser Monitor

- On-board lossless data compression
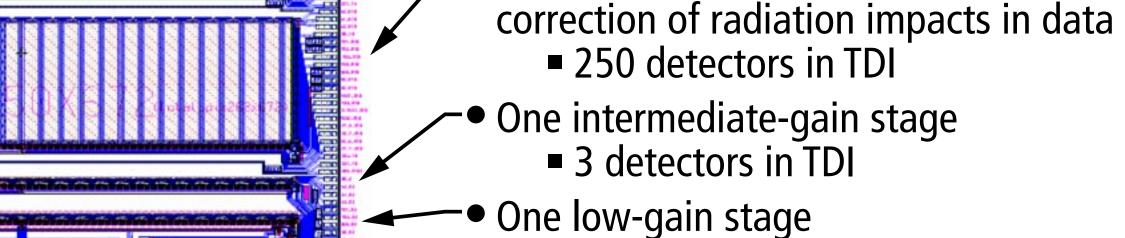
VIIRS Opto-Mech Module

VIIRS Electronics Module

Day/Night Band (DNB) Function

- The DNB addresses a top-priority requirement of the NPOESS VIIRS Specification: to provide visible through near-infrared spectral imagery of the Earth under illumination conditions ranging from full sunlight in daytime to quarter moon in nighttime

- DNB observations are performed by a dedicated focal plane assembly (FPA) and set of processing electronics within the VIIRS sensor

- The DNB is served by the same optics and scanning system as the other 21 VIIRS spectral bands

- Digitized DNB data is multiplexed with data from the other bands in the VIIRS output stream

Day/Night Band (DNB) Key Requirements

Rqmt No	Description	Value	Units
SRV0393	Spectral Passband	0.5 – 0.9	μm
SRV0569	Minimum SNR (At the Lmin radiance specified in SRV0646)	6 (0 – 53º) 5 (>53º)	– –
SRV0646	Dynamic Range – Lmin to Lmax (These are in-band FWHM radiances)	3e-5 to 200	W/m²/sr
SRV0614	Radiometric Calibration Uncertainty High Gain Stage: at Lmin for stage; at Lmax for stage Mid Gain Stage: at Lmin for stage; at Lmax for stage Low Gain Stage: at Lmin for stage; at 0.5 Lmax for stage	100, 30 30, 10 10, 5	% % %
SRV0564 SRV0565	Horizontal Sample Interval, Track & Scan Directions (Applies across full Earth scan)	742 ± 5%	meters
SRV0050	Horizontal Spatial Resolution, Track & Scan Directions (Half cycle of scene spatial frequency at which MTF = 0.5)	< 0.800	km

DNB Architecture

- VIIRS DNB hardware includes
  - DNB Focal Plane Assembly (FPA)
  - Focal Plane Interface Electronics (FPIE)
  - DNB Timing card (within the main Electronics Module)

FPA   FPIE   VIIRS Electronics Module

Image Motion   CCD

672 Sub-pixel Detectors in Track Direction
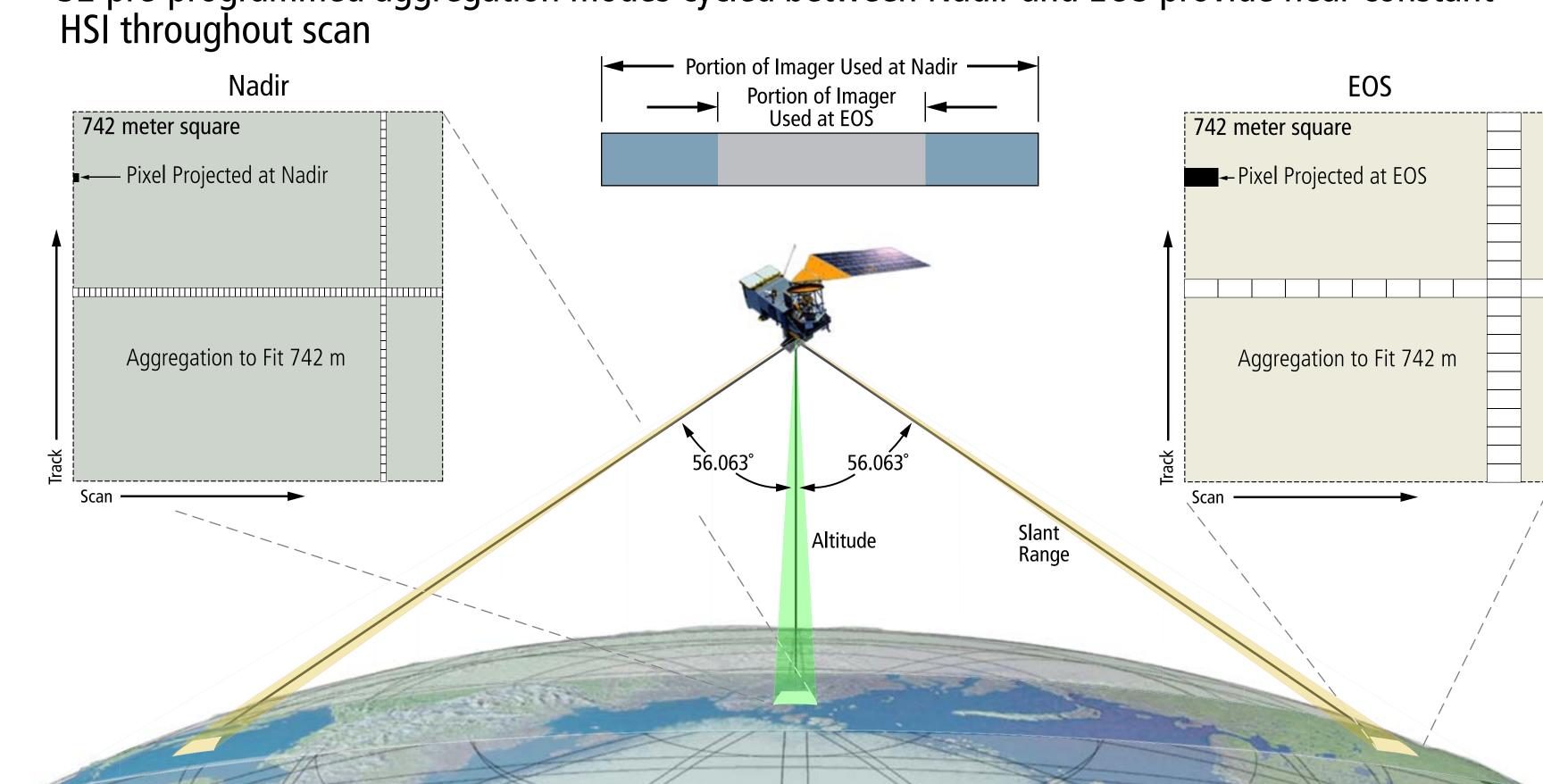
- The light-detecting element of the DNB, and the key to its high sensitivity and wide dynamic range, is a four-stage, backside-illuminated Charge-Coupled Device (CCD)
  - Two identical high-gain stages allow correction of radiation impacts in data
    - 250 detectors in TDI
  - One intermediate-gain stage
    - 3 detectors in TDI
  - One low-gain stage
    - No TDI, 45:1 ND Filter
  - Operating temperature -20°C

Concept of Operation
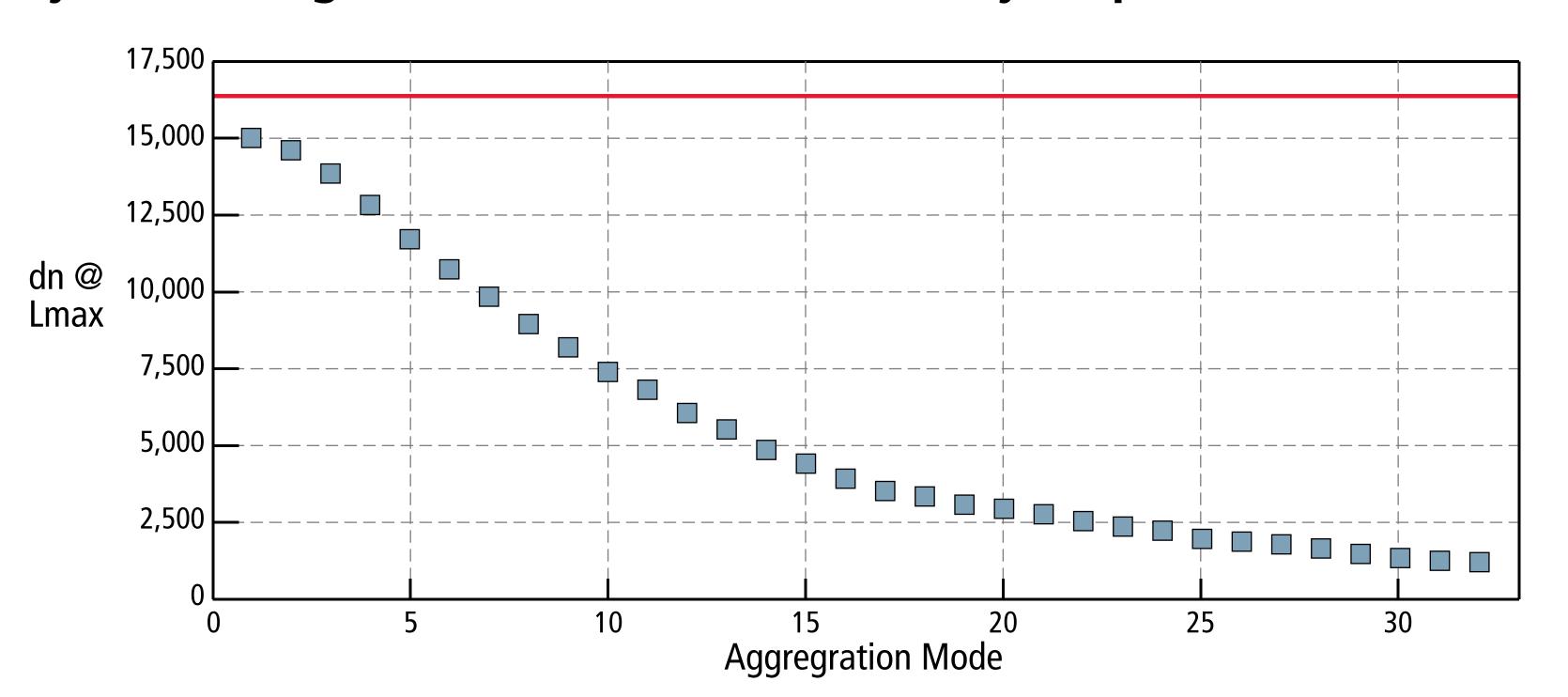
- 32 pre-programmed aggregation modes cycled between Nadir and EOS provide near constant HSI throughout scan

Nadir   EOS

742 meter square   742 meter square
Pixel Projected at Nadir   Pixel Projected at EOS

Portion of Imager Used at Nadir
Portion of Imager Used at EOS

Aggregation to Fit 742 m   Aggregation to Fit 742 m

56.063º 56.063º   Altitude   Slant Range

Verification Approach to Dynamic Range and Signal-to-Noise Ratio

- Verification for the DNB Dynamic Range and SNR requirements relies on a validated Radiometric Model to predict end-of-life performance under worst-case on-orbit conditions

- The Radiometric Model is based on component and subassembly measurements and nominal design parameters that are correlated with measurements of end-to-end signal, noise and gain made at the sensor level during ambient and thermal vacuum testing

- On-orbit/end-of-life conditions modeled include: (1) optical transmission degradation, (2) worst-case on-orbit temperatures and (3) increases in detector dark current

- The Radiometric Model spectrally integrates the following inputs:
  - Lunar spectral radiance computed using MODTRAN (0.4 – 1.0 μm) for Lmin
  - Spectrally flat reference radiance for Lmax at 5.00e-5 W/cm²/sr/nm
  - Measured mirror reflectance vs λ
  - Measured bandpass filter data vs λ
  - Measured dichroic reflectance vs λ
  - Measured ND filter transmission data for low-gain stage vs λ
  - Measured detector QE vs λ

- Performance requirements are verified with two model settings
  - SNR requirement for HG stages: Lmin reference radiance at EOL
  - Saturation requirement for LG stage: Lmax reference radiance at BOL

Dynamic Range On-Orbit Predictions Satisfy Requirements

dn @ Lmax vs Aggregation Mode

- DNB model was run at Lmax for BOL at a FPA temperature of 251 K

- Model uncertainty estimated from correlation errors is very small (~1%)
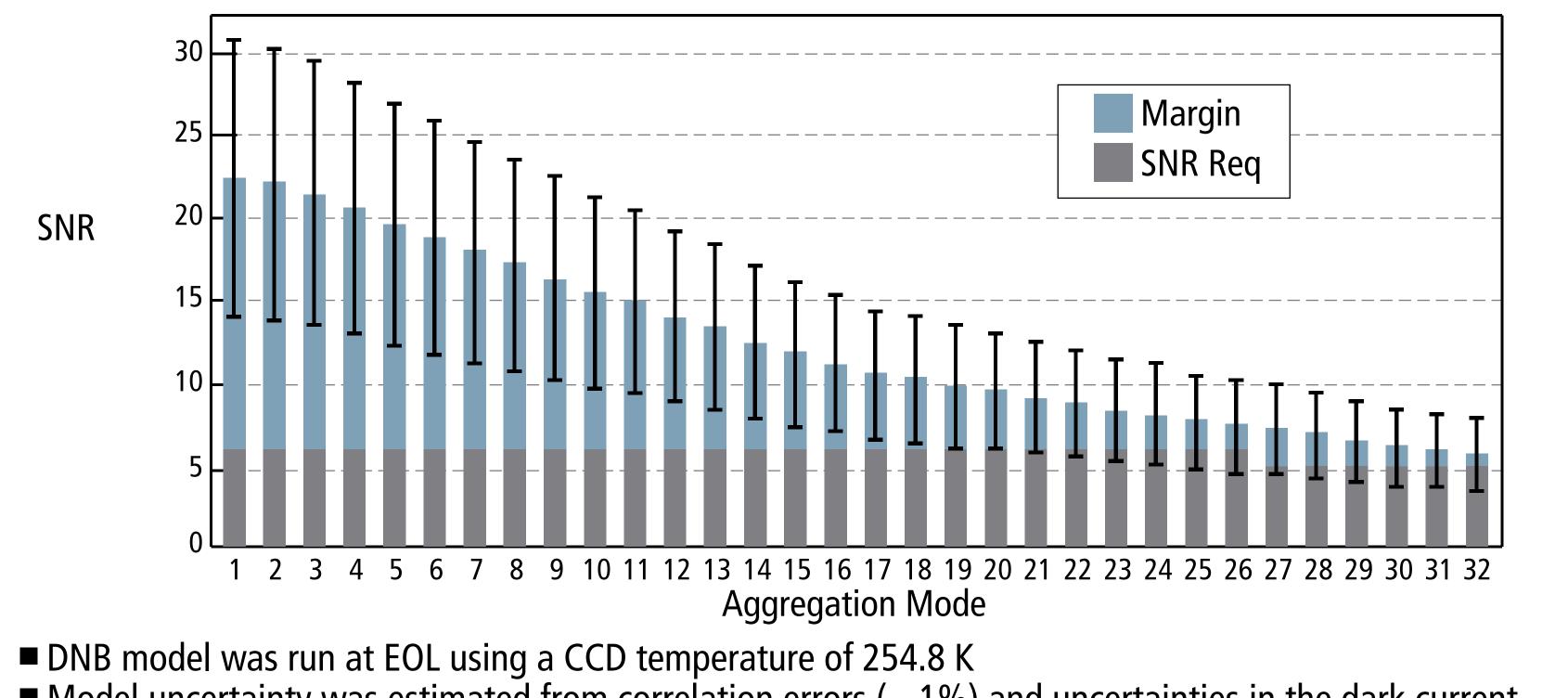
Lmin SNR On-Orbit Predictions

- The SNR at Lmin is predicted using the lunar reference spectrum for Lmin and the EOL optical transmission

- SNR is given by the following equation:

$$SNR = \frac{N_{TDI}N_{agg}S}{\sqrt{N_{TDI}N_{agg}S + N_{TDI}N_{agg}\sigma_{dark}^2 + \sigma_{read}^2 + \sigma_{elec}^2}}$$

where,
S = Signal (e-/pixel)
N_{TDI} = # of TDI stages
N_{AGG} = # of aggregated detectors
σ_{dark}^2 = Dark noise (e-/pixel)
σ_{read}^2 = Readout noise (e-/pixel)
σ_{elec}^2 = Electronics noise (e-/pixel)

- SNR margin is given by the following equation:

$$\%SNRmargin = 100 \cdot \left(\left(\frac{SNR}{SNR_{reqmt}} \right) - 1 \right)$$

- SNR margin is computed for all 32 aggregation modes which correspond to scan angles from 0 to 56.063 degrees from nadir

SNR at Stressing Lmin Shows Positive Margin at all Agg Modes

SNR vs Aggregation Mode
Margin / SNR Req

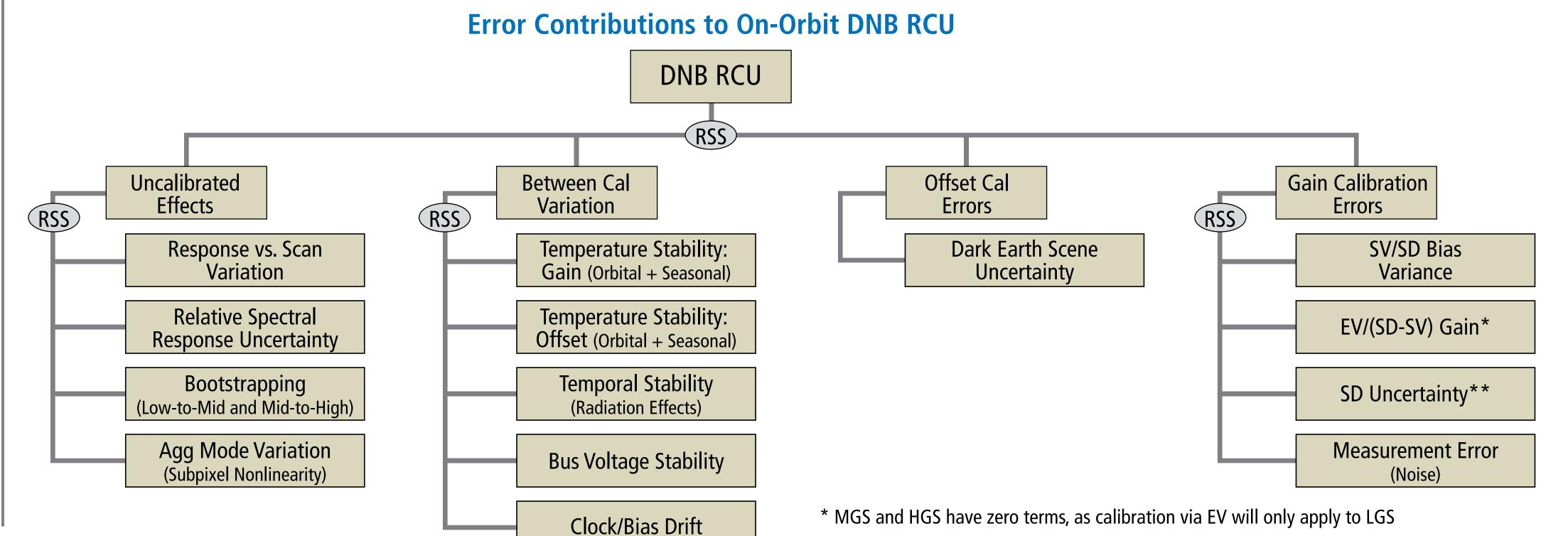- DNB model was run at EOL using a CCD temperature of 254.8 K
- Model uncertainty was estimated from correlation errors (~ 1%) and uncertainties in the dark current increase at EOL due to radiation effects
  - Uncertainties in the magnitude of the radiation effects are large due to limited availability of relevant data and accelerated radiation dosing of tested parts

DNB Radiometric Calibration Uncertainty

- Absolute radiometric calibration uncertainty (RCU) is determined by a combination of test, analysis and engineering assessment
  - Reported at the one-sigma level

Error Contributions to On-Orbit DNB RCU

DNB RCU
RSS

Uncalibrated Effects
- Response vs. Scan Variation
- Relative Spectral Response Uncertainty
- Bootstrapping (Low-to-Mid and Mid-to-High)
- Agg Mode Variation (Subpixel Nonlinearity)

Between Cal Variation
- Temperature Stability: Gain (Orbital + Seasonal)
- Temperature Stability: Offset (Orbital + Seasonal)
- Temporal Stability (Radiation Effects)
- Bus Voltage Stability
- Clock/Bias Drift

Offset Cal Errors
- Dark Earth Scene Uncertainty

Gain Calibration Errors
- SV/SD Bias Variance
- EV/(SD-SV) Gain*
- SD Uncertainty**
- Measurement Error (Noise)

* MGS and HGS have zero terms, as calibration via EV will only apply to LGS
** MGS and HGS errors do not apply except through bootstrap

Radiometric Calibration Uncertainty Shows Positive Margin

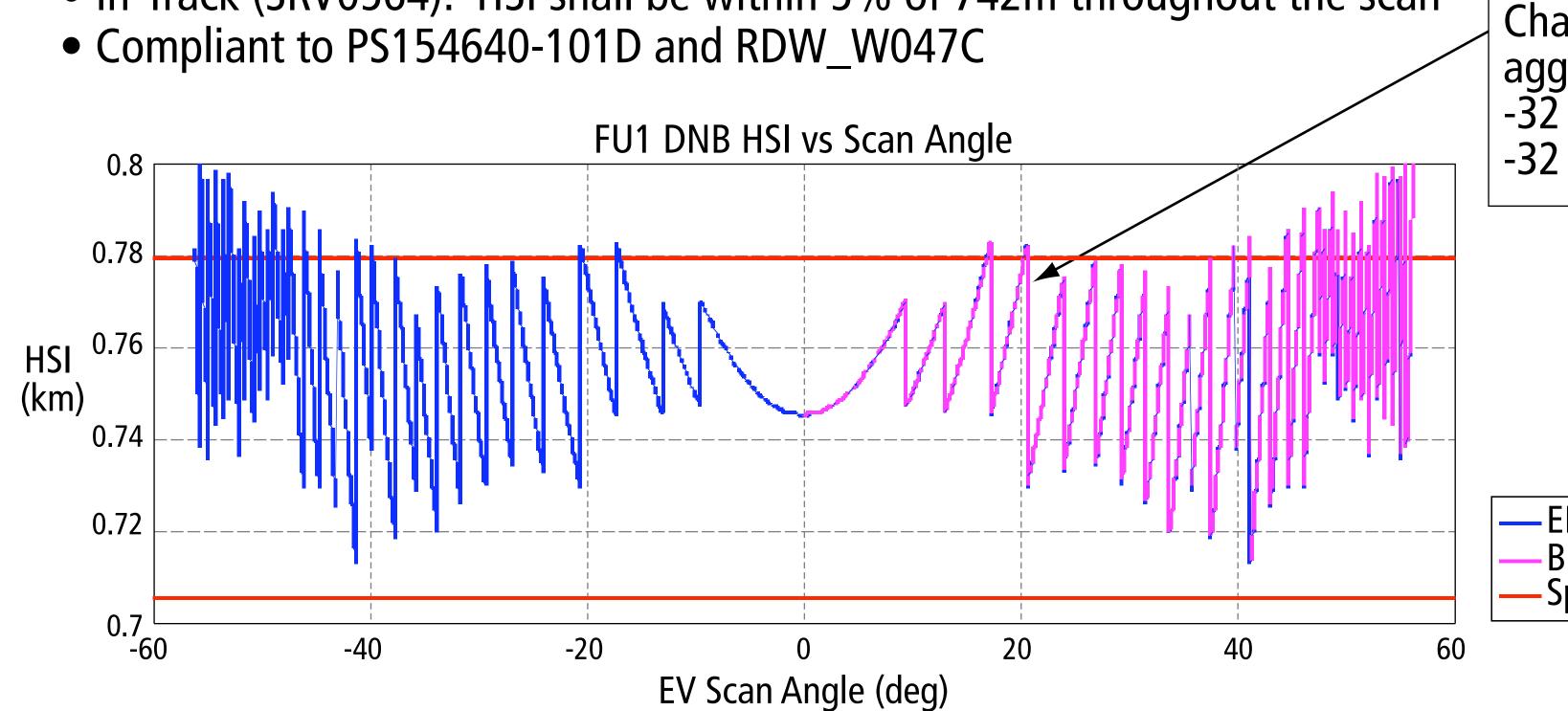| Gain Stage	Radiance Level	Performance	Requirement
LGS	0.5*Lmax	3.5%	5%
LGS	Lmin	3.5%	10%
MGS	Lmax	7.8%	10%
MGS	Lmin	7.8%	30%
HGS	Lmax	11%	30%
HGS	Lmin	11%	100%

Dominant Error Sources:
LGS: 1.5% Solar Diffuser Radiance, 2% SIS100 Radiance, 2% Agg Mode Variation
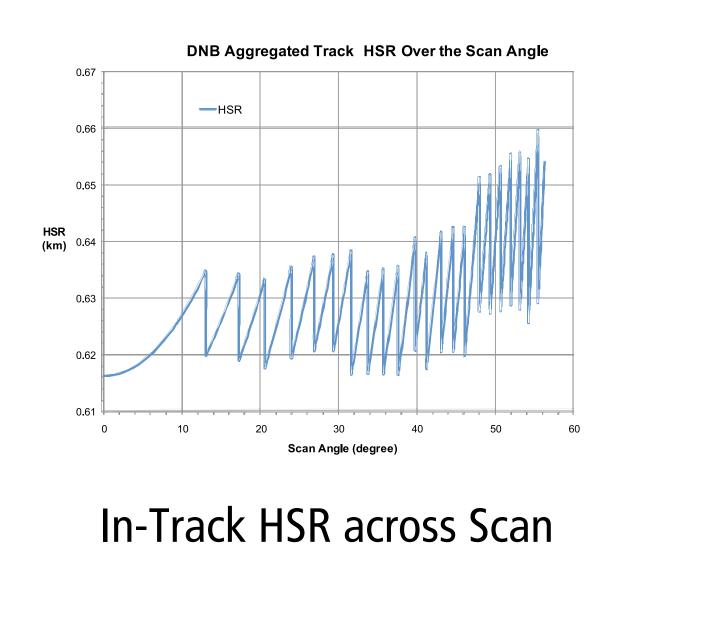MGS: Additional 7% for Bootstrap Gain Calibration
HGS: Additional 10% for Bootstrap Gain Calibration

Spatial Performance: Horizontal Sample Interval

- HSI (horizontal sampling interval) is the distance, as measured on the ground, between adjacent samples reported by the VIIRS sensor
  - In-Scan (SRV0565): HSI shall be within 5% of 742m throughout the scan
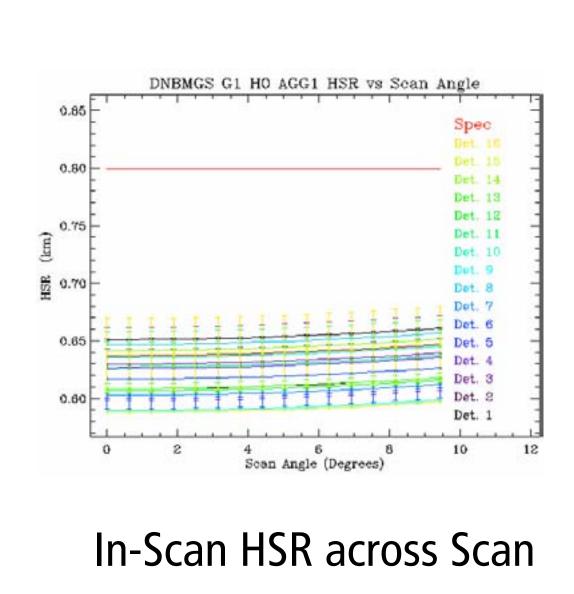 - In-Track (SRV0564): HSI shall be within 5% of 742m throughout the scan
  - Compliant to PS154640-101D and RDW_W047C

Changes in HSI are due to aggregation mode switching
-32 pre-Nadir (< 0 deg)
-32 post-Nadir (> 0 deg)

FU1 DNB HSI vs Scan Angle
HSI (km) vs EV Scan Angle (deg)
EHJCalc / BHRCalc / Spec

Spatial Performance: Horizontal Spatial Resolution
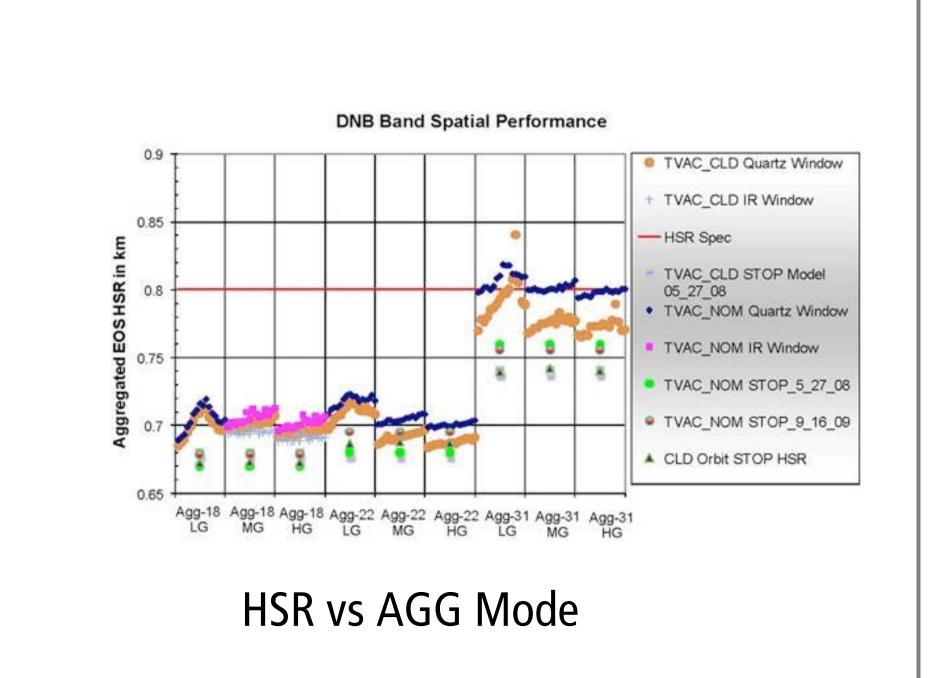
- HSR (horizontal spatial resolution) is the distance, on the Earth's surface, corresponding to one-half the longest spatial wavelength at which the sensor MTF has dropped to 0.5

- SRV0050: HSR in track and cross-track direction shall achieve less than 0.800 km throughout the scan
  - Compliant to PS154640-101D and RDW W114

DNB Band Spatial Performance

In-Track HSR across Scan   In-Scan HSR across Scan   HSR vs AGG Mode

Raytheon