

VIIRS on-orbit optical anomaly – lessons learned

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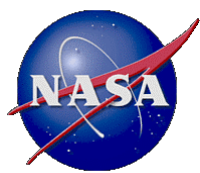
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Topics



- Introduction
- Anomaly and Commissioning Challenges
- Anomaly Investigation
- Fishbone Development and Disposition
- Discovery of the Smoking Guns and Root Cause Analysis
- Corrective Actions
- Lessons Learned
- Conclusions

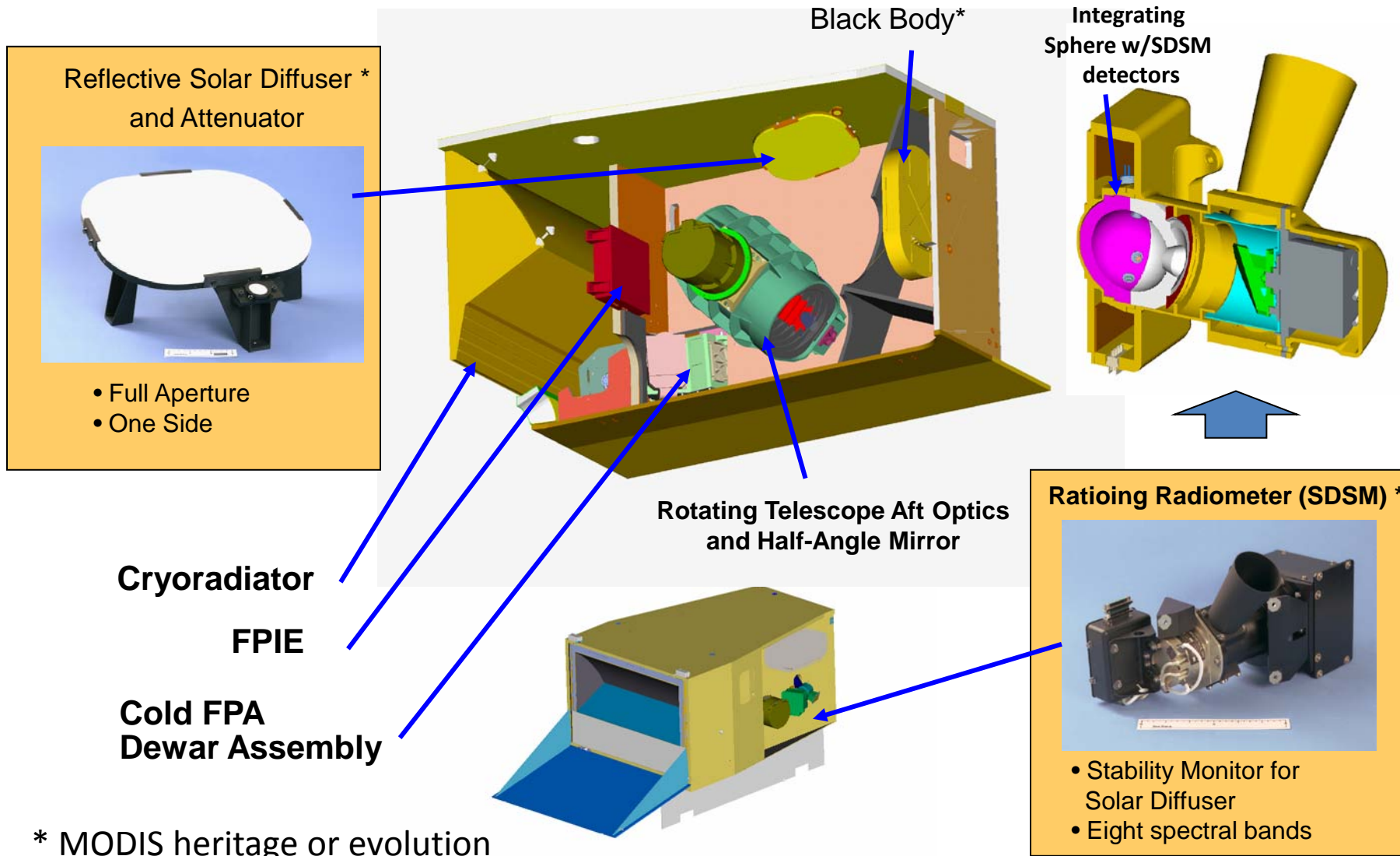


Introduction

- Over the last dozen years, NASA has launched a series of satellites – known collectively as the Earth Observing System (EOS) – that has provided critical insights into the dynamics of the entire Earth system: clouds, oceans, vegetation, ice, solid Earth and atmosphere.
- Suomi-NPP is the first satellite in the series of Joint Polar-Orbiting Satellite System (JPSS) to extend and improve upon the Earth system data records and weather prediction capability.
 - SNPP provides risk reduction for future JPSS sensors, ground system and operations
 - Continuity of EOS sensor data sets is another significant objective
 - Visible Infrared Imager Radiometer Suite (VIIRS) provides continuity from the NASA MODIS sensor on Terra (1999 launch) and Aqua (2004 launch) missions.

Introduction (2)

VIIRS Opto-Mechanical Module (OMM) and Solar Diffuser Stability Monitor (SDSM)

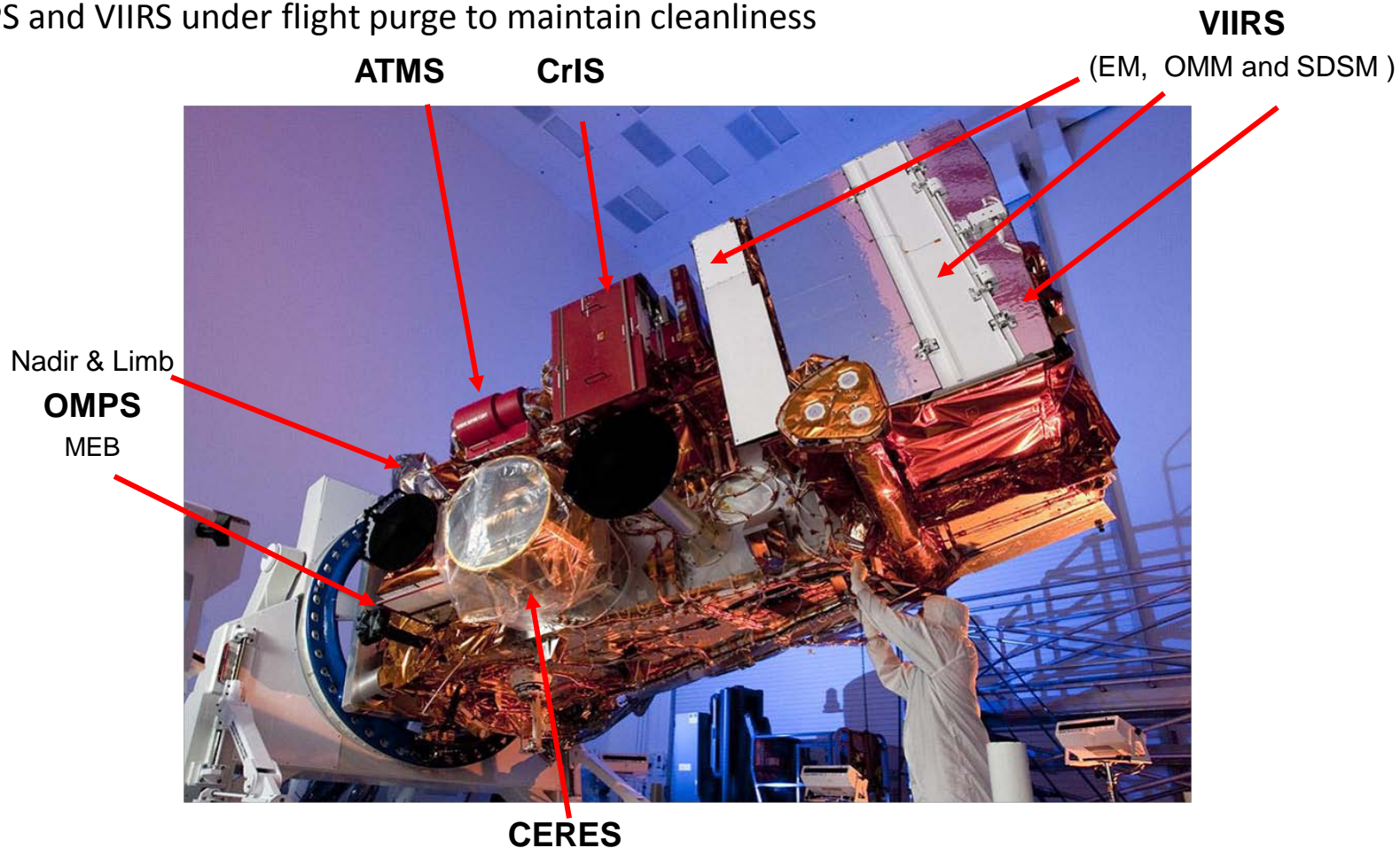


* MODIS heritage or evolution

Introduction (2)

Suomi-NPP Earth Pointing Sensor Deck

- Photo from satellite in cleanroom.
- Sensors in close proximity given Nadir deck dimensions of 1.346 meters x 3.622 meters
- Remove before flight protective covers installed for ATMS and CrIS
- CERES protective bonnet installed and sensor under test purge to maintain cleanliness
- OMPS and VIIRS under flight purge to maintain cleanliness





Anomaly and Commissioning Challenges Overview

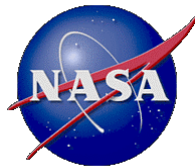


- VIIRS Visible – Near-Infrared (VisNIR) degradation first reported to SNPP Project on December 7th
 - Degradation rate increased sharply after nadir door opening on 11/21
 - Degradation essentially stops when stowed
 - DNB response consistent with observed VisNIR degradation
- SDSM has a different optics path that show similar spectral degradation
 - Degradation continues during stow period; insensitive to UV exposure
- VIIRS solar diffuser does not show this Near-Infrared (NIR) spectral degradation
 - Showing nominal expected degradation in shorter wavelengths
- Degradation is not characteristic of hydrocarbon or silicone based contaminant given the spectral signature is selective to NIR bands in both the SDSM and VIIRS optical systems
- Unclear if other sensors could be at risk given an unknown contamination source and the close proximity on the nadir sensor deck



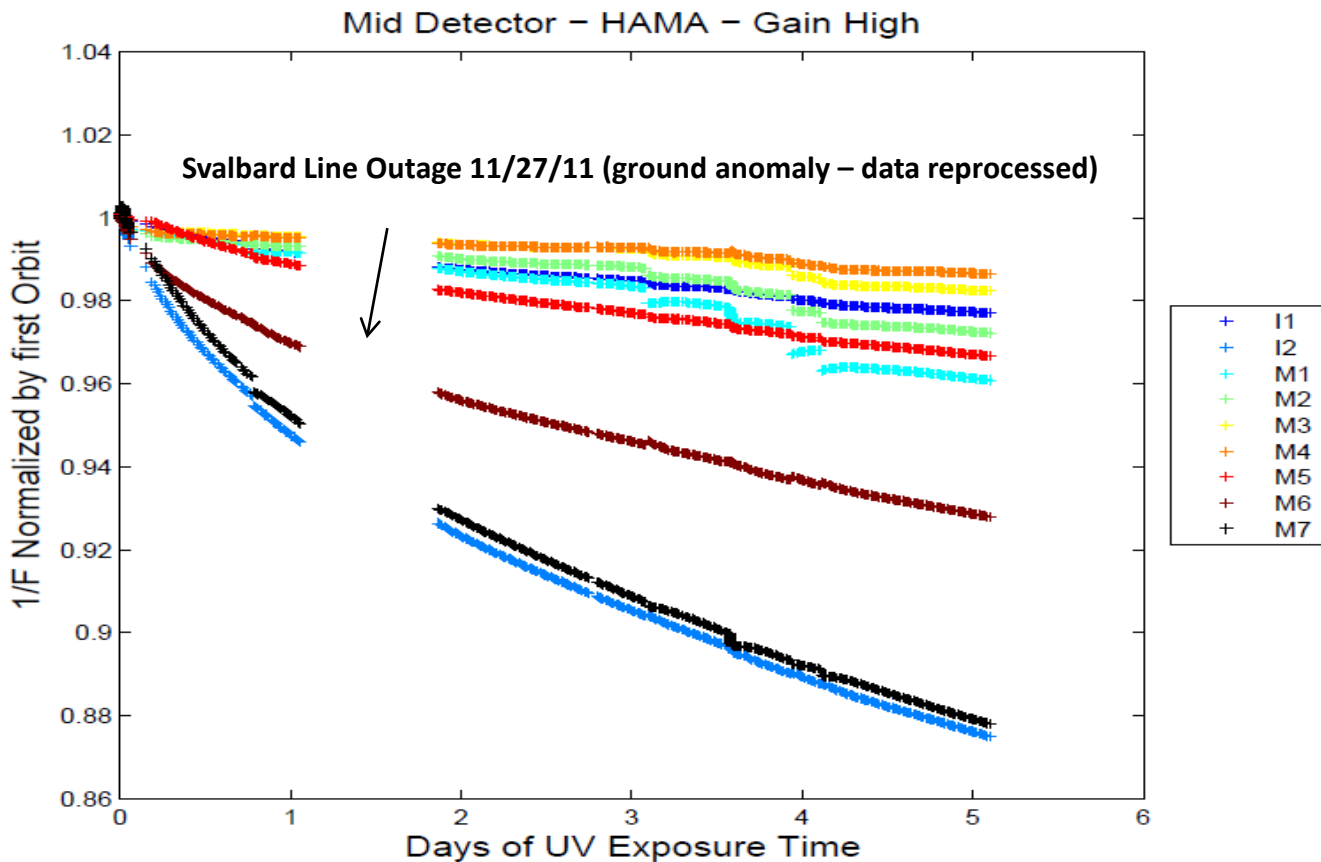
Anomaly and Commissioning Challenges (2)

Problem



- Upon opening the SNPP VIIRS Nadir doors on-orbit, analysis of VIIRS data revealed accelerated and continued degradation of Visible/Near Infrared (VisNIR) bands throughput. The degradation was correlated with UV exposure.

- VIIRS optics are exposed to UV in earthshine is $0.5 * (124.2^\circ / 360^\circ) = 0.18$ UV day/calendar day
- For additional information refer to the "Discovery and characterization of on-orbit degradation of the Visible Infrared Imaging Radiometer Suite (VIIRS) Rotating Telescope Assembly (RTA)", SPIE proceedings – Earth Observing Systems XVII, Session 10: VIIRS III Paper 8510-46

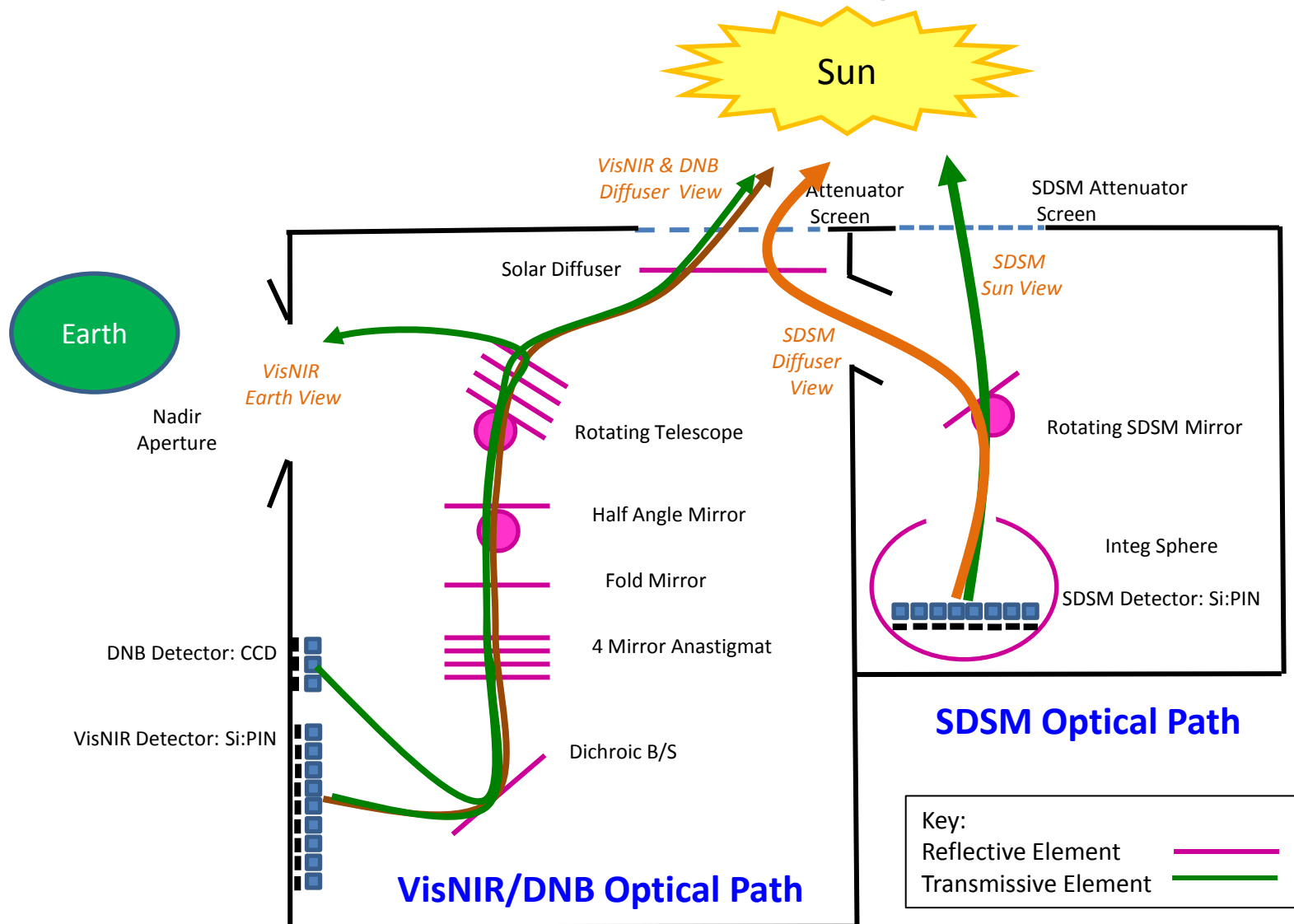
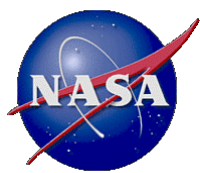


Degradation is measured from value first observed upon sensor activation



Anomaly and Commissioning Challenges (3)

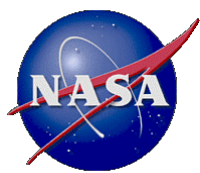
VIIRS VisNIR/DNB SDSM Optical Paths



Note: reflective elements shown as transmissive elements for simplicity



Anomaly Investigation



- With few hard facts, there was much speculation about possible causes and consequences of the degradation.
- At the time of the anomaly, CERES, CrIS and OMPS were powered, but not operational. All apertures were closed as they were for the outgassing phase.
- ATMS was operational and scanning but it is relatively insensitive to molecular contamination
- VIIRS nadir doors were open but the cryoradiator cooler door was closed.
- Next step in the sensor commissioning plan was to open the VIIRS and CrIS cooler apertures to cold space. This was suspended to avoid potentially impacting the cooler performance and compromising mission science performance.
- With these restrictions and limited insight to understand the observed degradation the Anomaly Resolution Team (ART) needed to find other ways to discriminate between possible causes.

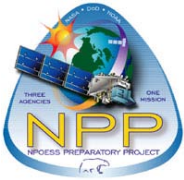


Anomaly Investigation (2)

Anomaly Resolution Team



- The ART defined a multifaceted approach to gain additional insight to quantify the risk to all sensors and to outline a revised plan for completing the remaining sensor commissioning activities. This plan included
 - Round up of additional project and non-project government and contractor experts for VIIRS, optics, detectors, contamination, radiation, materials, data analysis, science, mission assurance, and systems
 - Forming VIIRS technical anomaly team to focus on special tests to better characterize of the VIIRS on-orbit degradation along each optical path. They also performed data analysis and action item tracking
 - Forming contamination team to coordinate witness sample testing and to research possible contamination sources that matched spectral signature.
 - Aerospace team lead witness sample testing for VIIRS, CERES, and control samples; including VIIRS samples from the flight sensor RTA mirror coating run
 - Forming a satellite and sensor special test team to evaluate sensor / spacecraft special tests and review of pre-launch documentation for any possible signs or causes
 - Involving various science team members from Raytheon, NASA, NOAA, Aerospace, and others for data analysis and trending
 - Hold a VIIRS Deep Dive Face to Face meeting to review the optical design, materials, process, testing, and build history. This also allowed those unfamiliar with VIIRS to understand the design
 - Perform a site visit to the mirror coating manufacturer Denton (now Quantum)

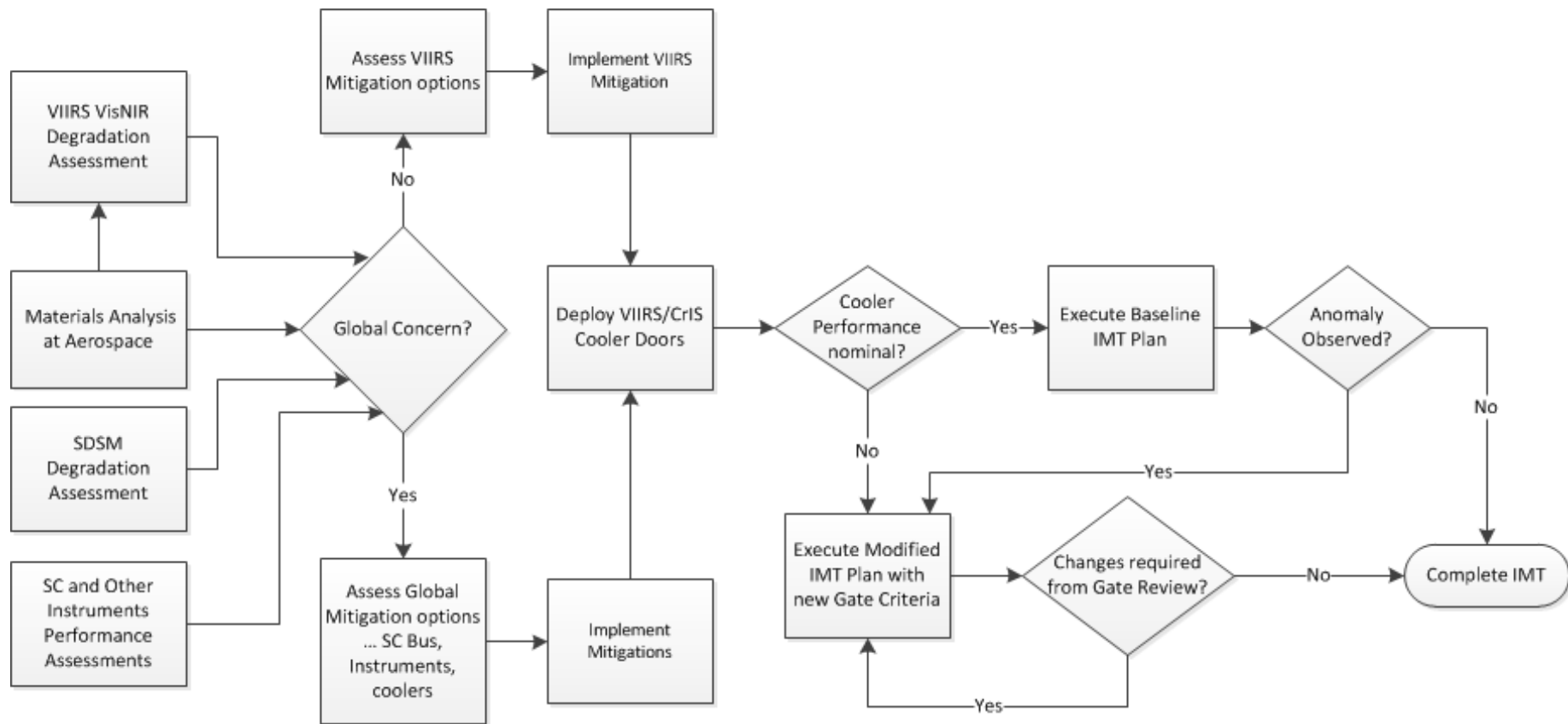


Anomaly Investigation (3)



Decision process to assess commissioning risk

- The primary focus early on was to find discriminators to address the question of whether this is a localized VIIRS event or global contamination concern. In either case, could a mitigation be found or prevent further spreading or degradation.
- Once we could rationalize the risk as minimal, opening the VIIRS/CrIS cooler doors would provide key performance data to bound the risk.



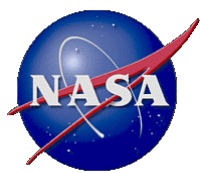
IMT – Integrated Mission Timeline for satellite commissioning activities

SPIE Optics + Photonics San Diego, CA 12 - 16 August 2012



Anomaly Investigation(4)

VIIRS Events and Special Tests (ST)



- The Raytheon anomaly team outlined four VIIRS special tests to discriminate between the VisNIR/DNB and SDSM optical path degradation. The timeline, data and results are shown in the next few charts.

Test Activities	Objective	Conclusions / Findings
VIIRS Special Tests #1 – RTA and SDSM stowed 3 days (12/9 – 12/12)	<ul style="list-style-type: none"> Evaluate rate of degradation for VIIRS/SDSM (RTA stowed eliminating optics UV exposure) 	<ul style="list-style-type: none"> VIIRS NIR degradation returned to slower decay SDSM NIR degradation continued at same rate
VIIRS Special Tests #2 - RTA stowed in daylight, Night Obs with Solar Cals (12/15 – 12/19)	<ul style="list-style-type: none"> Minimize light on VIIRS optics to discriminate between solar and other contamination effects while providing trend data 	<ul style="list-style-type: none"> VIIRS NIR degradation returned to slower decay SDSM NIR degradation continued at same rate Active contamination source unlikely to be the cause
VIIRS Special Tests #3 – Long stow of RTA/SDSM ~ 1 week (12/21 – 12/28)	<ul style="list-style-type: none"> Confirm SDSM degradation rates are relatively insensitive to solar exposure Stow 12/21 – 12/28, 1-day OP_D/OP_N mode to measure rate of decay 	<ul style="list-style-type: none"> VIIRS NIR degradation returned to slower decay SDSM NIR degradation confirmed not to be UV related as it continued to decay at the same rate
VIIRS Special Tests #4 - Short stow of RTA/SDSM not operating ~ 4 days (12/29 – 1/2)	<ul style="list-style-type: none"> Stow 12/29 – 1/2 to halt degradation while we awaited the Aerospace witness sample results 	<ul style="list-style-type: none"> VIIRS NIR degradation returned to slower decay SDSM NIR degradation continued at same rate

- For additional information on how these special tests supported the investigation refer to the SPIE proceedings – Earth Observing Systems XVII, Session 10: VIIRS III Paper 8510-46 and the Raytheon Program Data Archive - Mirror Degradation due to UV Exposure: Root Cause”, Raytheon Engineering Notebook (ENB) 3-10-J1-015



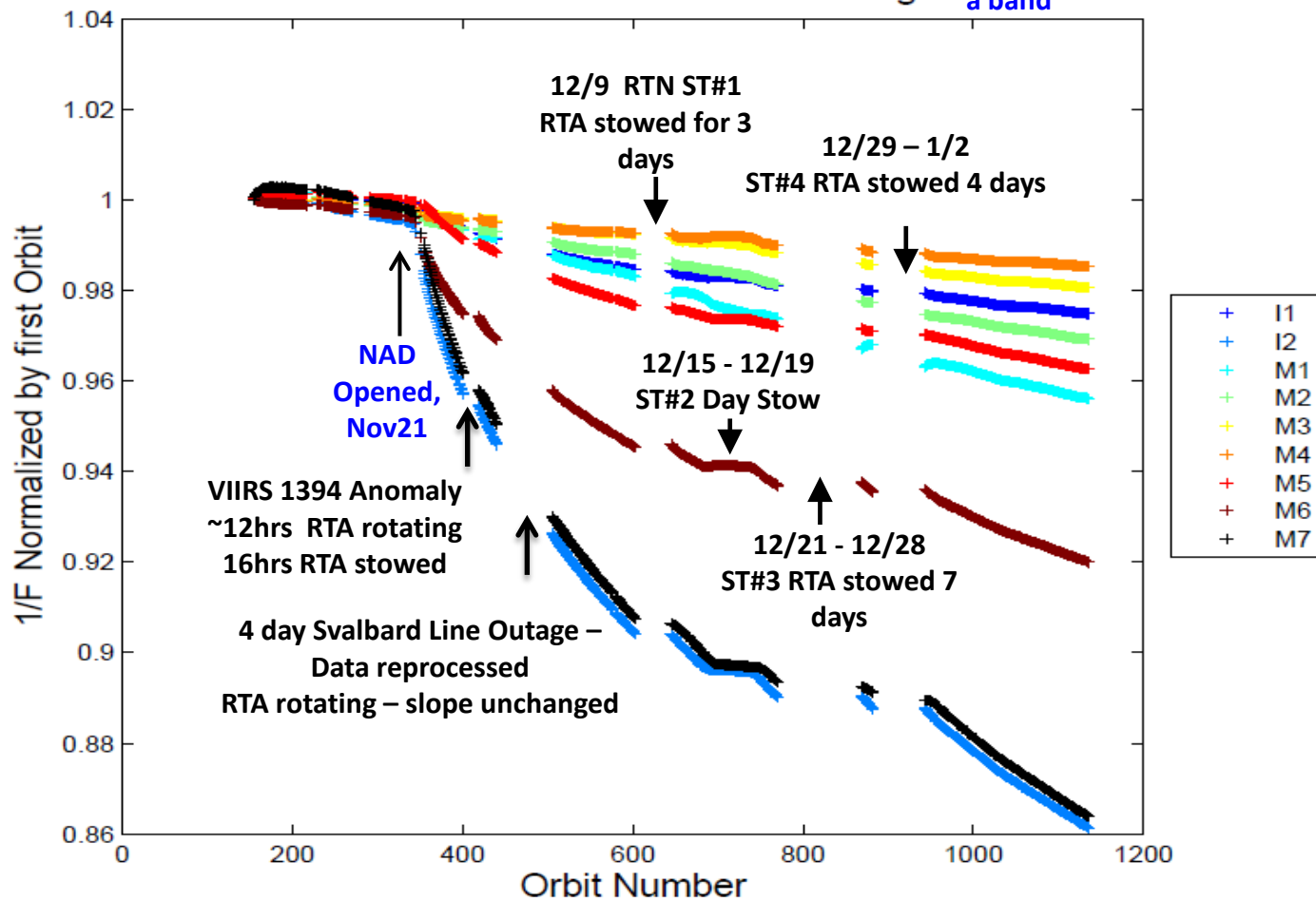
Anomaly Investigation(5)



VisNIR Response vs Orbit Time Trends

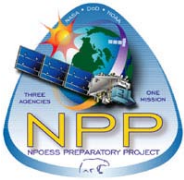
Degradation is uniform across detectors within a band

Mean Detector – HAMA – Gain High



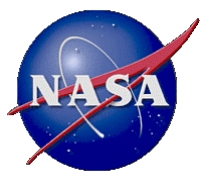
NOTE: For additional information refer to the “Discovery and characterization of on-orbit degradation of the Visible Infrared Imaging Radiometer Suite (VIIRS) Rotating Telescope Assembly (RTA)”, SPIE proceedings – Earth Observing Systems XVII, Session 10: VIIRS III Paper 8510-46

- Rate of NIR response degradation significantly increased with nadir door opening. Note discontinuity in trend for NIR bands (M7/I2, M6, M5)
- NIR Degradation paused when in darkness or stowing telescope, stopping UV exposure.
- Degradation of short wavelength bands (M1-M3) relatively constant through stows and strongly correlated w/ drop in SD reflectance measured by SDSM.
- Data shows 1/F-factor for solar observations. Should be 1 for new sensor.
- VIIRS optics are exposed to UV in earthshine is $0.5 \cdot (124.2^\circ / 360^\circ) = 0.18$ UV day/calendar day



Anomaly Investigation(6)

Other Sensor Special Tests and Findings



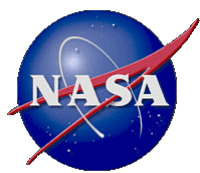
- In parallel with the VIIRS Special tests, other tests or data evaluation were performed by the OMPS and CERES team. Results do not support a global contamination theory.
- However, CERES observed similar degradation on the SiPIN photodiodes consistent with higher 2x radiation environment and effects observed on prior CERES sensors.

Test Activities	Objective	Conclusions / Findings
OMPS Special Tests On-orbit	<ol style="list-style-type: none"> 1. OMPS LED Lamp (at 810nm - trending with door 2. Solar Cals with diffuser in place to evaluate performance trending (3m, 50m, 3m) 3. Limb Earth view 2 consecutive orbits; 1 orbit includes lunar view 4. Nadir first series of 11 solar cals each 6 min planned for 1/10 5. Series of Limb/Nadir solar and earth view collects planned to evaluate performance 	<ol style="list-style-type: none"> 1. LED lamp 2% change highly correlated with temperature variations 2. Significant, wavelength-independent changes observed correlated with calendar time. High probability changes are goniometry errors. Based on comparable exposure of the Limb diffuser, OMPS is no longer concerned about excessive UV degradation 3 & 4 – no degradation seen 5. – no degradation seen
CERES Special Tests On-orbit	<ol style="list-style-type: none"> 1. Evaluate Sun Presence Sensors (SPS) and radiator trending data for any changes. SPSs oriented with 1 cold and 1 viewing sun 2. Evaluate Thermal performance of radiators 3. Evaluate CERES internal calibrations for differences from prior CERES sensors 4. CERES lifetime (Mar 2009 – Sept 11) witness sample contamination analysis (ToF-SIM, Solar UV tests) 	<ol style="list-style-type: none"> 1. Higher change in SPS response is likely attributable to the increased radiation environment (~2x Total Ionizing Dose) 2. No evidence of degraded thermal radiator performance 3. Internal calibration results are consistent with prior flight sensors. CERES SW SiPD decay consistent with expectations based on high energy particles 4. CERES lifetime witness sample does not show UV sensitivity or contamination



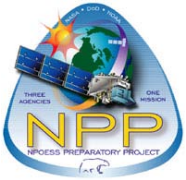
Anomaly Investigation(7)

Spacecraft Investigation Results



- In parallel with the VIIRS Special tests, the spacecraft contractor reviewed on-orbit performance and pre-launch documentation. Results do not support a global contamination theory or an identified source of contamination .

Test Activities	Objective	Conclusions / Findings
Solar array peak power	<ul style="list-style-type: none"> Evaluate changes in peak power out of eclipse 	<ul style="list-style-type: none"> Solar array output increase is accounted for in the changes in beta angle and solar factor
Star tracker trending	<ul style="list-style-type: none"> Evaluate star tracker telemetry trending performance 	<ul style="list-style-type: none"> ADCS does not see anything in the number of stars tracked, the background level, or the temperatures that might indicate a change in the tracker performance due to contamination
Satellite Review of Post TVAC activities	<ul style="list-style-type: none"> Identify materials and processes used for post TVAC activities 	<ul style="list-style-type: none"> No indication activities could be source of contamination
SC thermal trending (Heater duty cycle and radiator temps)	<ul style="list-style-type: none"> Evaluate changes in heater duty cycles and radiator temperatures 	<ul style="list-style-type: none"> Reviewed flight thermal data through December and there was no evidence of thermal degradation attributable to contamination. This was based on four flight thermistors measuring fin temperatures. Locations were selected because they are most likely to observe degradation because of the large surfaces and are directly exposed to the surrounding environment. After the first 10 days of commissioning, we haven't measured any real temperature change on these surfaces.
Solar Array Cert Log History	<ul style="list-style-type: none"> Look of any source of outgassing materials 	<ul style="list-style-type: none"> No indication activities could be source of contamination



Anomaly Investigation (8)

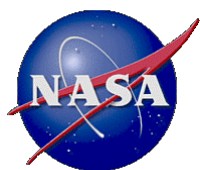


VIIRS Witness Sample Testing and Meeting Findings

Test Activities	Objective	Conclusions / Findings
<p>VIIRS RTA witness sample testing #1 witness followed sensor I&T, #2 pristine in dry storage</p>	<ul style="list-style-type: none"> Perform molecular evaluation and Solar radiation tests to determine potential contaminants VIIRS only (FTIR, GC-MS), CERES/Control Samples (TOF-SIM, Solar UV tests) 	<ul style="list-style-type: none"> VIIRS RTA #1 & #2 shows surface Tungsten in ToF-SIMS (~15-30 Angstroms), #1 UV exposure matches on-orbit signature, #1 Depth profile shows tungsten on surface and in outermost layer VIIRS 2nd RTA sample showed UV saturation levels comparable to RTA#1 sample. The VIIRS FMA witness sample was unchanged after 96 hours of UV exposure. For additional information reference “Root cause determination of on-orbit degradation of the VIIRS rotating telescope assembly”, Proceedings of SPIE – Earth Observing Systems XVII, Session 10: VIIRS III. Paper 8510-47
<p>VIIRS Deep dive (1/9 – 1/10)</p>	<ul style="list-style-type: none"> Communicate information on VIIRS design, manufacture, test, and operation to allow ART to accurately interpret on-orbit data. Gather in-depth information on potential causes. Brainstorm causes, additional testing, plan forward, and risks Continue to develop fishbone 	<ul style="list-style-type: none"> F2F held January 9 – 10. Build history review 1/11 – 1/13/2012 Quantum reported deviation from coating process for RTA mirrors coat run L4G12 (source of tungsten). MODIS SDSM & VIIRS SDSM degradation have similar signature. Both use the same Si PIN PD (part # & manufacturer match). The proximate cause was degradation attributed to radiation. This was confirmed based on NPP/J1 part testing, spectral signature and analysis
<p>Quantum / Denton Site Visit 1/31/12</p>	<ul style="list-style-type: none"> Brief Quantum on NPP VIIRS Flight 1 Degradation Status and Investigation into root cause Review the SNPP VIIRS RTA mirror coating build documentation for any indications of contamination source Discuss potential applicability for other JPSS or NASA mission mirrors. Discuss generation of GIDEP by Quantum, Raytheon or NASA 	<ul style="list-style-type: none"> Site visit on January 31. SNPP VIIRS RTA mirrors coated by Denton in 2004 prior to Quantum purchased and ISO certification in 2007. Toured facility coating chamber and reviewed FSS99-500 process used by Denton Reviewed Quantum/Denton’s proprietary FSS99-500 process for a 3-year period. The root cause was a process deviation for the VIIRS RTA mirror coating run; which resulted in tungsten & tungsten oxide deposition on the outer mirror surface. Tungsten is known to have chromogenic properties, which clear up in atmosphere.



Anomaly Investigation (9)



VIIRS Jan 9 – 10 Deep Dive Scope & Key Questions

- Scope limited to SNPP VIIRS so we can move forward with remaining commissioning activities safely
 - VIIRS FM2 impacts, root cause source identification and corrective action for future designs can occur in parallel with SNPP commissioning
- Key Questions
 - **Do we have sufficient information to understand causes for VIIRS VisNIR and SDSM degradation?**
 - Are there other possible contributing causes?
 - Do we agree VIIRS and SDSM degradation are due to different causes?
 - **Does data and analysis match on-orbit signature for VIIRS and SDSM?**
 - **How should we proceed with VIIRS commissioning?**
 - What is risk to VIIRS Cryo cooler performance?
 - **Is there a global satellite risk or is the anomaly local to VIIRS?**
 - What else can be done to assess the risk to other sensors



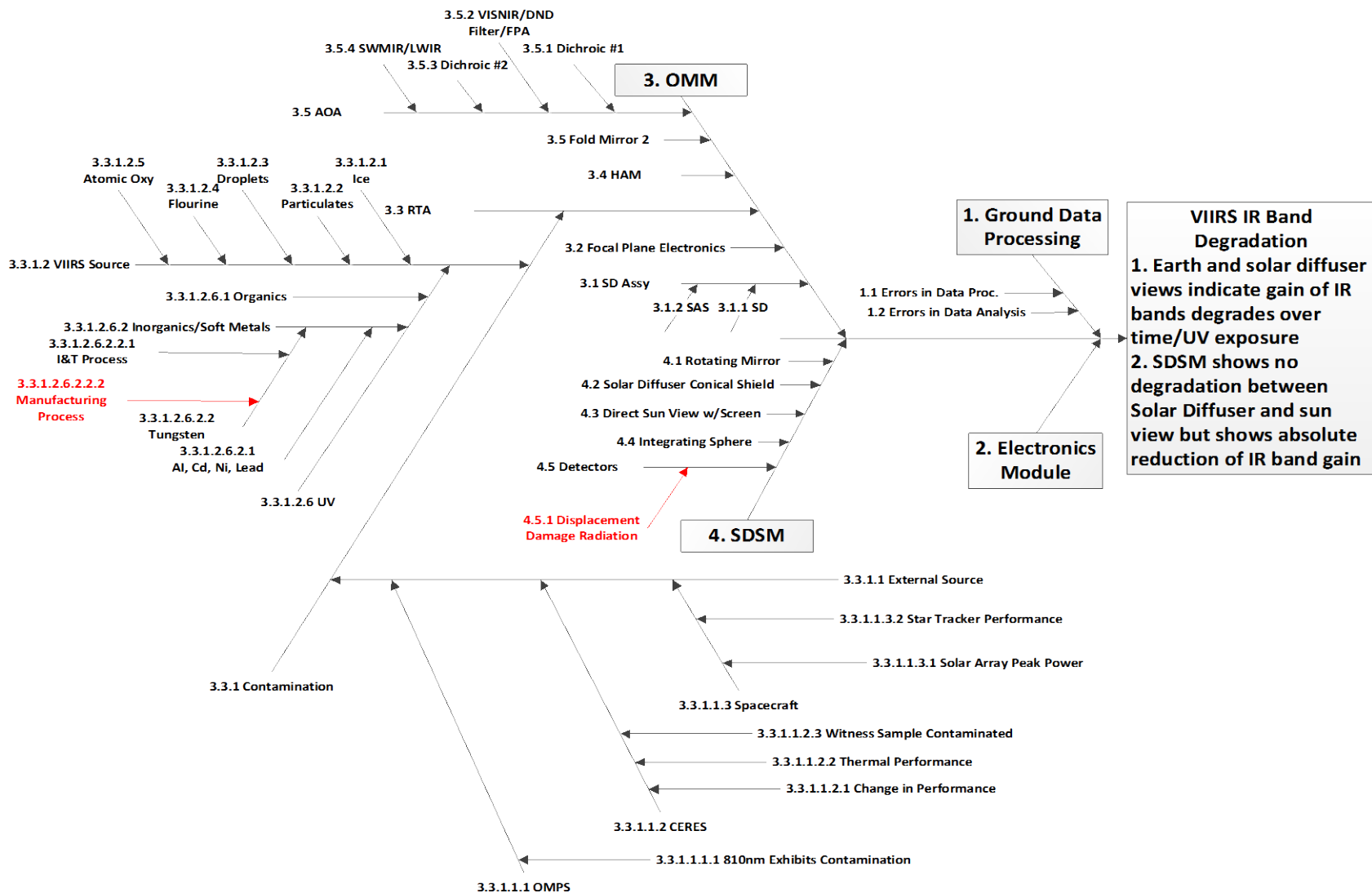
Fishbone Development and Disposition

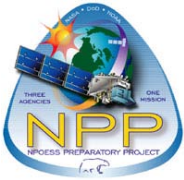


- The fishbone illustrates the various bones that were investigated to varying degrees based on what we learned incrementally through the anomaly investigation.
- The final fishbone identifies the proximate causes
 - tungsten film contamination on the VisNIR/DNB RTA mirrors and
 - displacement damage for the SDSM in Silicon PIN photodiode.
- There was a significant amount of effort expended by the team, that is not discussed in this or other papers, on how the various possible causes were discounted.



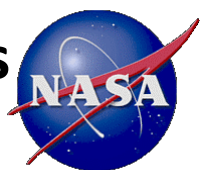
Fishbone Development and Disposition





Discovery of the Smoking Guns and Root Cause Analysis

VisNIR Degradation Root Cause Analysis Summary

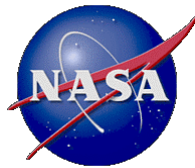


- Signal degradation observed on SNPP on orbit for VisNIR bands is correlated with UV exposure
 - UV exposure of two witness samples coated in the same coating run of FSS99-500 (L4G12) as the RTA mirrors results in degradation with the same spectral signature as seen on SNPP
 - Both witness samples show presence of tungsten oxides on the surface unlike other FSS99-500 samples which do not show a darkening or the presence of tungsten oxides
 - Literature shows that tungsten oxides can darken on exposure to UV under vacuum
 - Quantum Coatings records show process deviations that resulted in the deposition of tungsten: not normally present
 - Combination of one time presence of tungsten oxide combined with UV exposure darkening and literature indicates that tungsten oxide is mechanism of darkening
 - Root cause was determined to be a process deviation that resulted in tungsten oxide deposition
 - Unlikely to recur due to lessons learned at Quantum and subsequent Quantum certification 100-0001
- Root cause: process deviation resulting in tungsten oxide deposition

- Root cause determination of on-orbit degradation of the VIIRS rotating telescope assembly”, Proceedings of SPIE – Earth Observing Systems XVII, Session 10: VIIRS III. Paper 8510-47
- Murgai V., “Program Data Archive - Mirror Degradation due to UV Exposure: Root Cause”, Raytheon Engineering Notebook (ENB) 3-10-J1-015 revision dash April 4, 2012



Discovery of the Smoking Guns and Root Cause Analysis (2) Why was VisNIR Degradation Undetected Pre-launch?

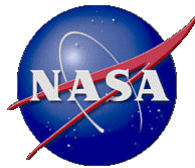


- Research has been done as cited in the Bechinger paper “On the fundamental role of oxygen for the photochromic effect of WO₃”. This paper cites the following
 - “Coloration can be obtained, for example, by an electrochemical process (electrochromic effect) using an external voltage and a proton source, or by irradiation, e.g., with ultraviolet light (photochromic effect).
 - “Thin amorphous WO₃ films can be switched reversibly from transparent to a blue colored state which has a broad absorption band at 1000 nm, with a shoulder towards the visible range”.
- This matches the observed degradation on-orbit and, through Aerospace testing, the RTA witness mirror samples. In both cases the M7/I2 bands showed the greatest rate of decay. The spectral range for these bands are 846 – 885 nm.
- Given Tungsten chromogenic properties and no VIIRS pre-launch testing with a UV source in vacuum the contamination went undetected

- Bechinger C., “On the fundamental role of oxygen for the photochromic effect of WO₃”, Journal of Applied Physics, Citation: J. Appl. Phys. **74**, 4527 (1993); doi: 10.1063/1.354370. View online: <http://dx.doi.org/10.1063/1.354370>



Discovery of the Smoking Guns and Root Cause Analysis (3) VIIRS SDSM Investigation Summary

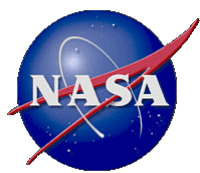


- VIIRS SDSM Spectral degradation signature similar to VIIRS VisNIR degradation but not driven by solar exposure
 - Similar VIIRS SDSM and MODIS SDSM degradation signatures
 - MODIS & VIIRS designs similar; both use same SiPIN photodiodes part and manufacturer
 - NPP and J1 detector radiation testing was performed at three levels. Degradation at 900 nm response similar to that observed on-orbit.
 - NPP Radiation environment roughly 2x over MODIS/Aqua orbit for both ionizing dose and proton fluence
- CERES observed similar degradation on the SiPIN photodiodes consistent with higher 2x radiation environment and effects observed on prior CERES sensors

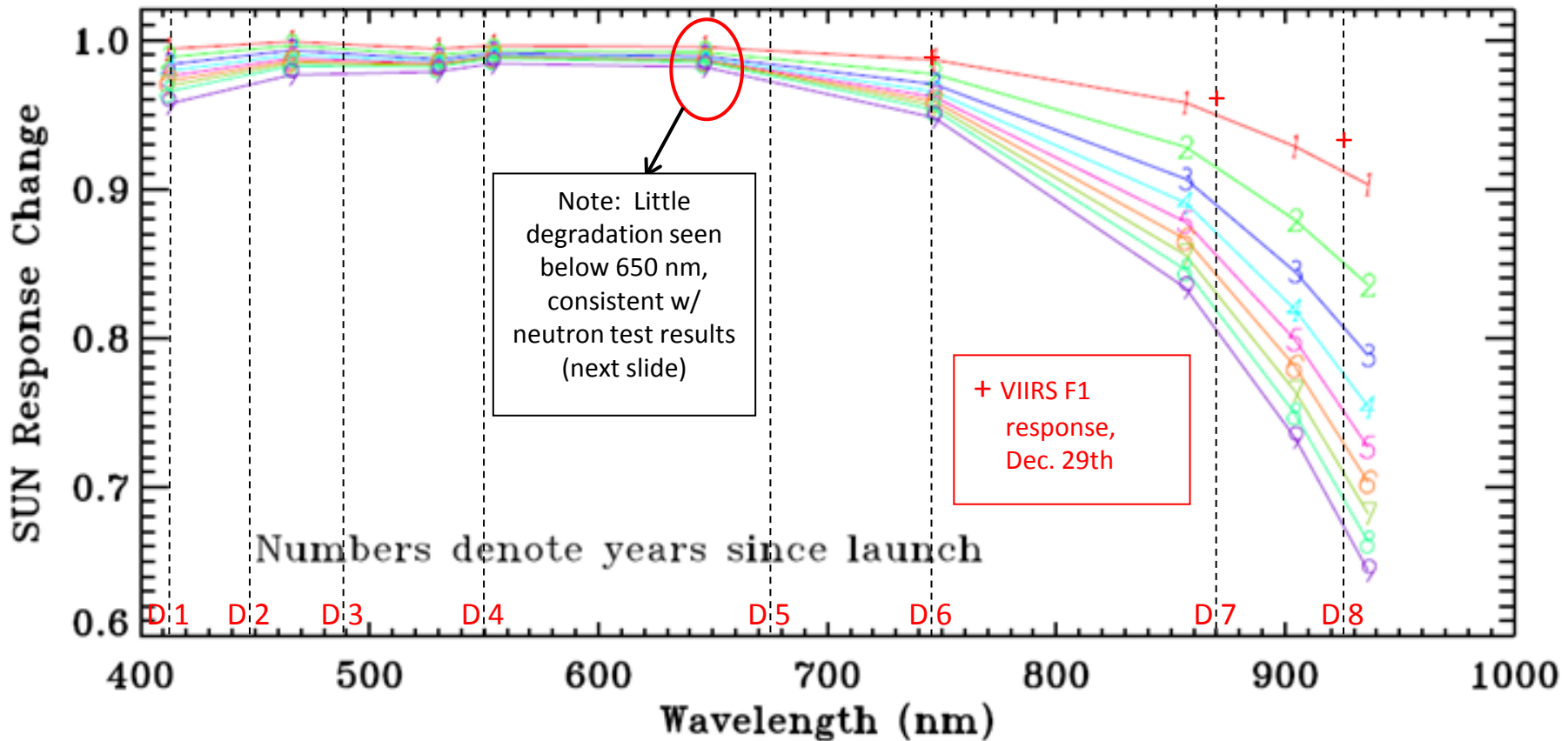


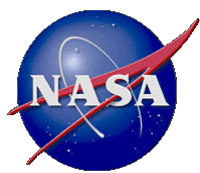
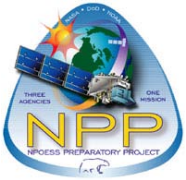
Discovery of the Smoking Guns and Root Cause Analysis (4)

VIIRS vs MODIS Aqua SDSM Response Degradations:



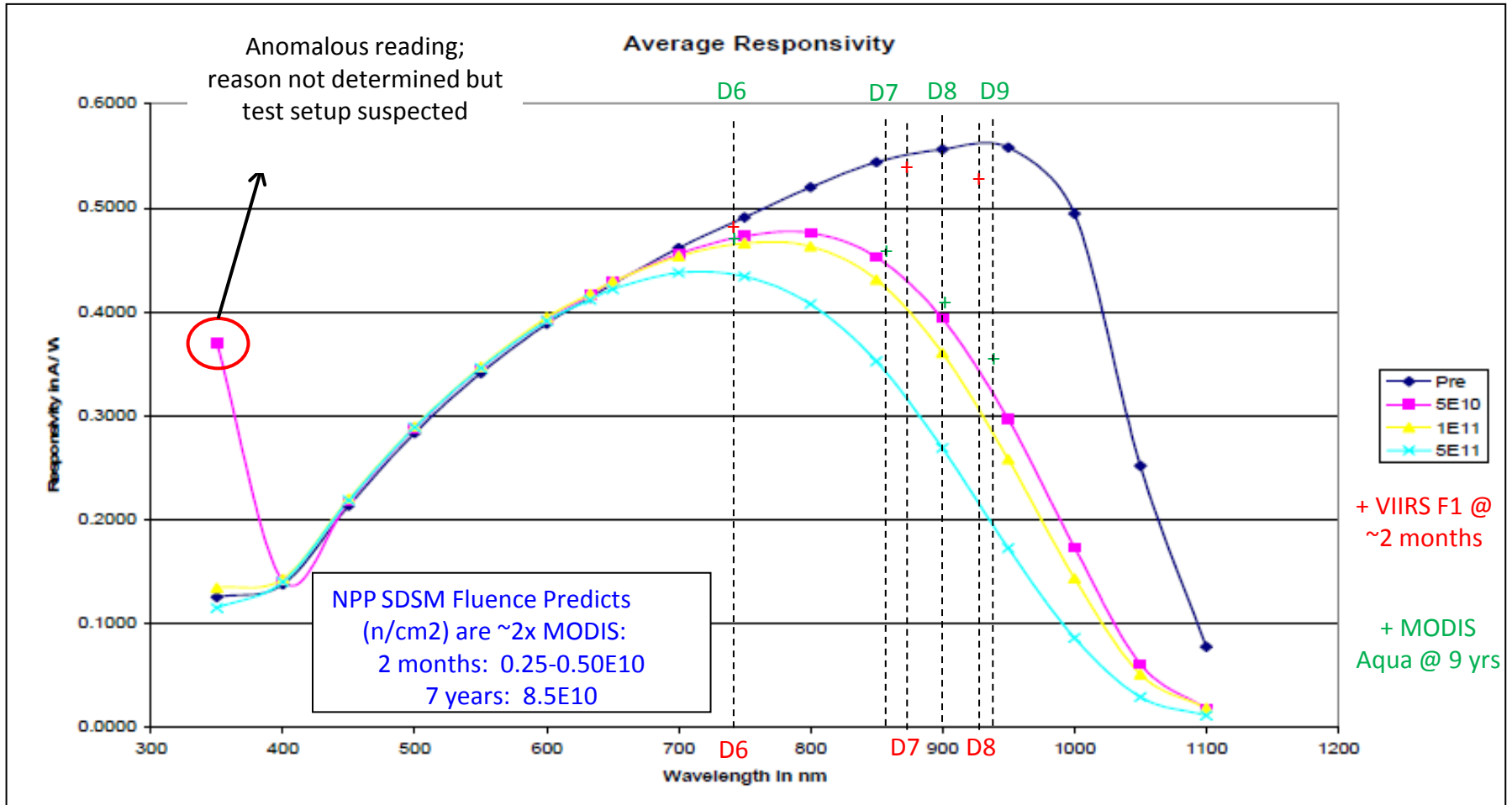
- MODIS Aqua trend data courtesy of Jack Xiong and Amit Angal (MCST)
 - Similar degradation also seen for MODIS Terra
- Values for VIIRS detectors D6, D7 & D8 measured on Dec. 29th overlaid (~ 2 months since launch)
 - Est. degradation in response is <1% for D1-D5 (412-676 nm) after correction for SD degradation, not shown
- The SDSM detector vendor and part number are identical across all missions

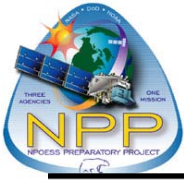




Discovery of the Smoking Guns and Root Cause Analysis (5) VIIRS & MODIS SDSM Degradation vs. Neutron Test Results

- Results provided by E. Johnson/Raytheon are for average of 4 detectors radiation tested
- Values for VIIRS D6-D8, as measured on Dec. 29th and MODIS Aqua D6-D9 @ 9 yrs overlaid on plot assuming initial on-orbit responsivity = "Pre" values
 - Est. degradation response is negligible for D1-D5 (412-676 nm) after correction for SD degradation





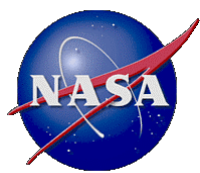
Lessons Learned and Corrective Actions



No.	Lesson Learned	VIIRS Applicability
1	Understand Test As You Fly (TAYF) exceptions and potential risks	<ul style="list-style-type: none">• TAYF exception for UV testing and measurement in vacuum of VIIRS mirror reflectance could have identified contamination prior to launch• For SNPP, the witness mirrors were repeatedly measured in atmosphere. Given tungsten oxide is chromogenic the anomaly went undetected prior to launch.• Special test equipment required was available at the Aerospace corporation; which accelerated confirmation of root cause during the anomaly investigation
2	Process changes should be thoroughly evaluated for possible undesired secondary effects	<ul style="list-style-type: none">• After the low reflectance readings on the mirrors were attributed to oxygen deficiency from lower pressure due to overnight pumping, the practice of pumping the chamber overnight was no longer performed³.• Reflectance improved by ion bombardment with oxygen to increase oxidation of silica and densification of protective layers. This introduced tungsten oxides on the mirror surface.• Improved process controls were implemented at Quantum; including ISO certification.
3	Use of travelers, certification logs, and build documentation can provides valuable insight for investigations	<ul style="list-style-type: none">• Denton build documentation provided confirmation of process deviation that led to use of oxidation of outer mirror coating using tungsten gun• For Quantum it provided valuable information to state this was isolated to SNPP VIIRS and not other coating runs
4	Anomaly resolution should include appropriate documentation and notification based on severity and contract requirements	<ul style="list-style-type: none">• FSS99-500 standard process deviation was not sufficiently elevated through subcontracts to government. Nor was it sufficiently documented in delivery documentation• JPSS contract changes put in place to elevate deviations to government for awareness and/or disposition depending on severity
5	Where heritage designs are used for future designs understand differences in application and environment	<ul style="list-style-type: none">• SDSM degradation existed on EOS MODIS (same manufacturer and part as VIIRS SDSM) but degradation was slower given lower radiation environment in EOS mission orbit.



Lessons Learned and Corrective Actions (2)



- SNPP Flight Project
 - No corrective actions possible; problem isolated to VIIRS only
 - Raytheon completed modeling of degradation and results compare with observed on orbit performance. For additional information reference Murgai V., “Program Data Archive - Mirror Degradation due to UV Exposure: Root Cause”, Raytheon Engineering Notebook (ENB) 3-10-J1-015 revision dash April 4, 2012
 - Science team will continue to trend on-orbit NPP VIIRS and SDSM performance and predict future performance for the life of the mission
 - Ground system algorithms changes have been implemented to accommodate the changing VIIRS response
- JPSS Flight Project
 - Raytheon Root Cause/Corrective Action investigation is complete and the results have been provided to government
 - Fishbone analysis and documentation are now completed
 - Contract changes to improve notification for deviations from qualified process
 - JPSS-1 VIIRS has conducted UV exposure testing to JPSS-1 mirror witness samples – No degradation observed
- Industry
 - GIDEP Lessons Learned Report (LL-U-12_001) issued by Quantum 3/5/2012. Report indicates this was a one time process exception to improve surface reflectance.
- GSFC Optics Branch working to develop and publish information summary and guidance (test, process control, etc) for missions that have or will use silver reflective mirrors.



Lessons Learned and Corrective Actions (3) Quantum GIDEP Lesson Learned Memo



- VisNIR root cause: Quantum deviated from the qualified FSS99 coating process (on the four SNPP RTA mirrors) that resulted in the deposition of tungsten on the mirrors, with a consequence of spectral degradation on-orbit

LL-U-12-001



ISO 9001:2008
FM 514425

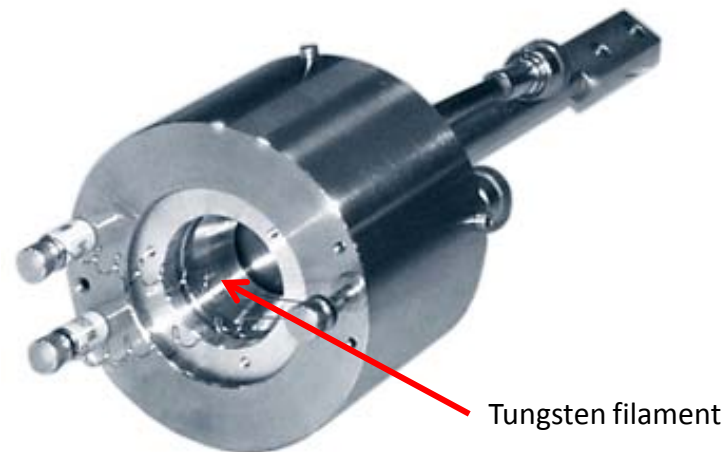
3/5/12

Government Industry Data Exchange Program (GIDEP)
PO Box 8000
Corona CA 92878-8000

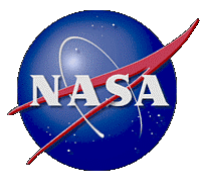
Re: Lessons Learned for Ion Bombardment of FSS99 Silver Coating

Issue Description: There was a FSS99 silver coated mirror reflection degradation issue. The root cause was determined to be Tungsten Oxide film on the surface of the FSS99 coated mirrors that was introduced after the coating was applied in an attempt to increase reflection.

Containment Action: Upon original notification of the anomaly, records of the coating run were reviewed to determine if tungsten oxide could have been deposited during the standard FSS99 process. Additional records for other FSS99 coating runs for other programs were also located in order to determine if there were any coating deficiencies or anomalies present during these events. It was determined that there were no issues with subsequent coating runs for any specific program.

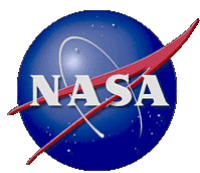


- Ion gun used for substrate deposition per normal FSS99 process
- Deviation: gun used for oxygen ion bombardment to improve reflectivity



Conclusion

- Identification or detection of the proximate causes may have been possible, pre-launch, if additional effort was applied to perform testing or analysis in a flight like manner closer to what SNPP is experiencing
 - For VisNIR/DNB degradation it would have required additional testing with special test equipment to simulate UV exposure in vacuum; including measurement of reflectance before returning back to atmosphere
 - For SDSM it would have required extrapolation of radiation testing or comparison to EOS performance with adjustments for the higher radiation dose environment that SNPP



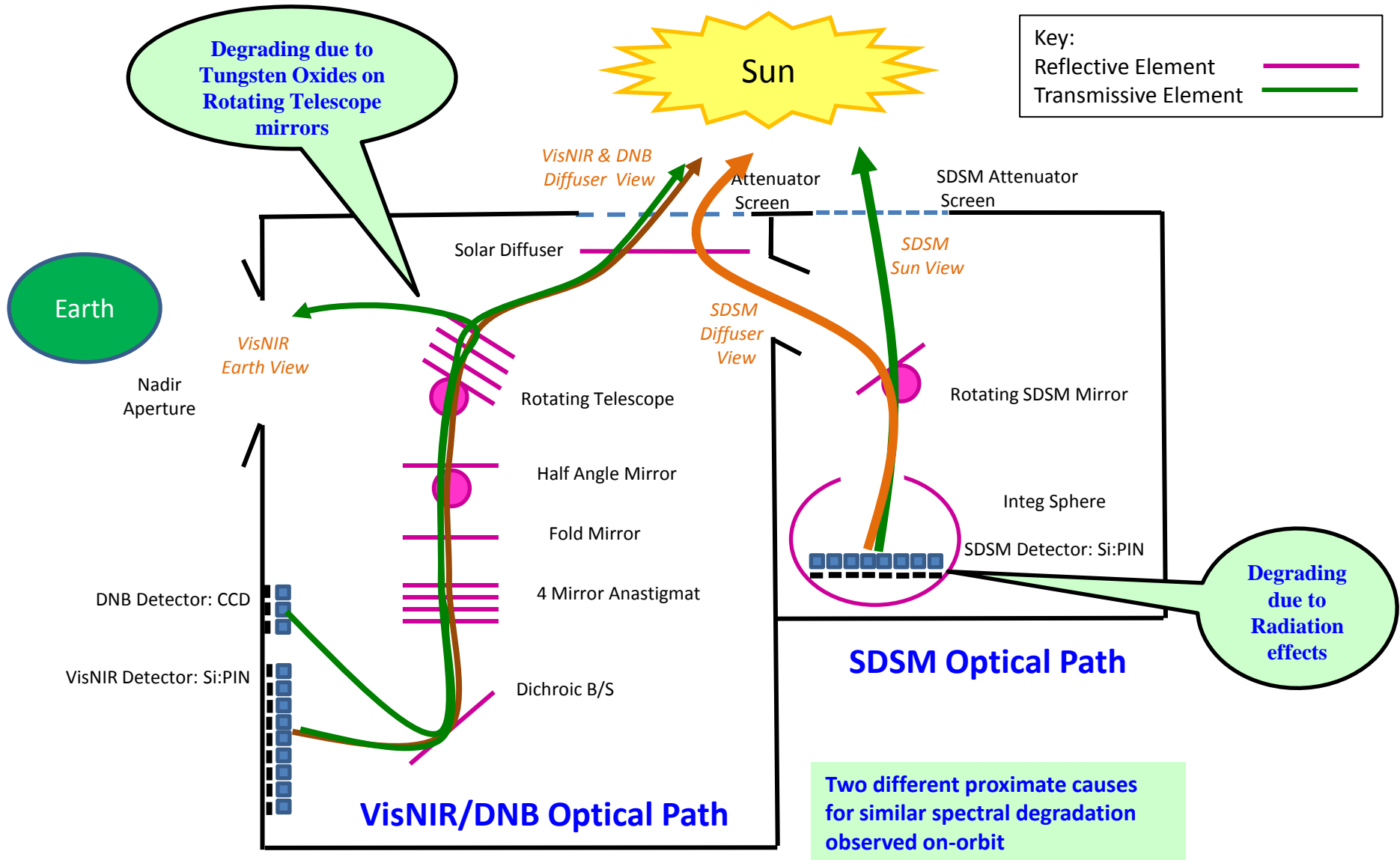
Conclusion (2)

- VIIRS degradation traced to two different proximate causes
 1. VisNIR/DNB degradation was conclusively traced to the photochromic effects of tungsten on SNPP VIIRS RTA mirror surfaces. Through inspection of Denton (now Quantum) build documentation it was isolated to a 1-time process deviation (i.e. root cause) to improve surface reflectance during the mirror coating process.
 - Raytheon has modeled the degradation and it compares well with the VIIRS on-orbit performance
 - Science team will continue to trend performance for the mission life
 - JPSS-1 VIIRS RTA mirror tested and are unaffected
 2. The VIIRS SDSM proximate cause was degradation due to displacement damage in the Silicon PIN photodiodes induced by the ~2-times radiation environment, both ionizing dose & equivalent neutron fluence, when compared to the MODIS/Aqua orbit.
 - Margins are extremely healthy (e.g. greater than 200% at 7 years)
 - Similar degradation observed with MODIS SDSM photodiodes (i.e., same manufacturer and part number) but to lesser extent given lower radiation environment
 - CERES uses similar silicon PIN photodiodes that have exhibited this behavior on prior EOS missions
- VIIRS will experience reduced optical throughput but it will continue to meet science performance needs beyond the SNPP mission life.
 - The Science team measured and predictions show the normalized gain will remain above specifications beyond 2019

Conclusion (3)

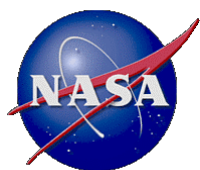
Two Proximate Causes Identified

Note: reflective elements shown as transmissive elements for simplicity

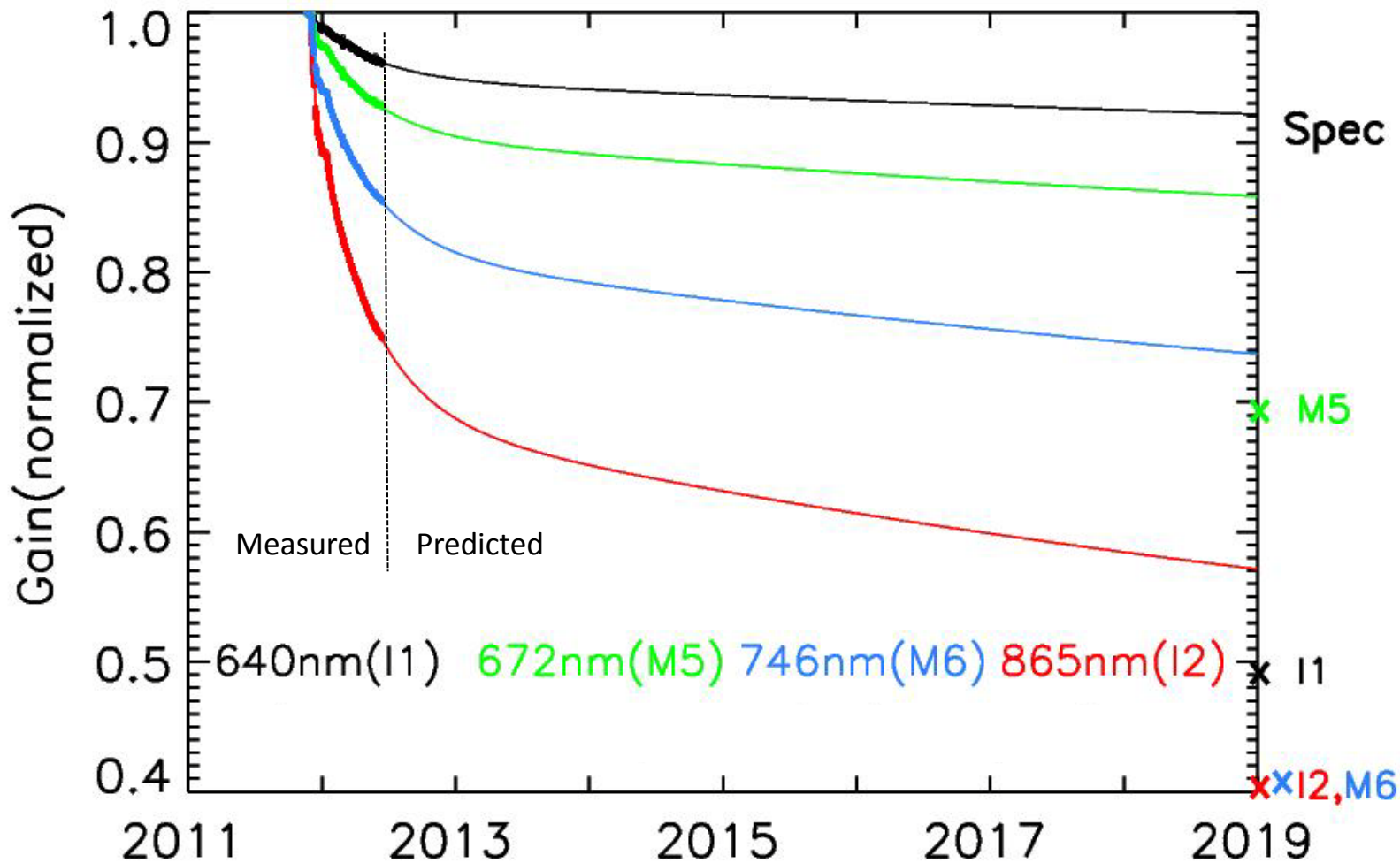




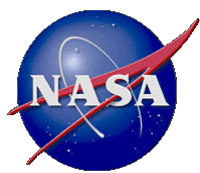
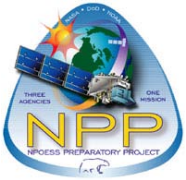
Conclusion (4)



VIIRS measured and degradation prediction



Predictions all within specifications



Acknowledgements

- This investigation was very complex with the possibility for numerous outcomes. It required the extended mission team, suppliers and invited experts to
 - Work together to stabilize the situation
 - Full disclosure of information to carefully analyze the situation with an open mind
 - In-Depth evaluation of possible causes
 - Methodical coordination of on-orbit activities with out jeopardizing any of the instruments
- So Kudo's to the extended team for their support; which has been recognized by a NASA Agency Group Achievement Award