VIIRS On-orbit Optical Anomaly

Eugene Waluschka
NASA/Goddard Space Flight Center/551.0

Presented by Jack Xiong
NASA/GSFC 618.0

Folks who did the work

Ms. Diana Alaan Reflectance Measurements

Dr. Jim Barrie Optical Coatings

Dr. Martin Ciofalo Space Env. Effects

Dr. John Chaney TOF-SIMS

Dr. C.T. Chu Optical Coatings

Dr. Pete Fuqua Optical Coatings

Dr. Mike Meshishnek Space Env. Effects

Dr. Robert Moision TOF-SIMS

James Heaney,

John Lehan

Eric Johnson

Vijay Murgai

David Moyer

Larissa Graziani

Mark Ayers

Glenn Iona

Frank Deluccia

Jack Xiong

Brian Kennedy

Kibby Stovall

folks a NICST

Introduction

The NPOESS Preparatory Project (NPP) spacecraft was launched on Oct. 28, 2011, and began the commissioning phase of several of its instruments shortly thereafter. One of these instruments, VIIRS, was found to exhibit a gradual but persistent decrease in the optical throughput of several bands, with the near-infrared bands being more affected than those in the visible. This paper will discuss the sequence of events and activities which identified the cause of the optical degradation and the current and expected future state of the optics.

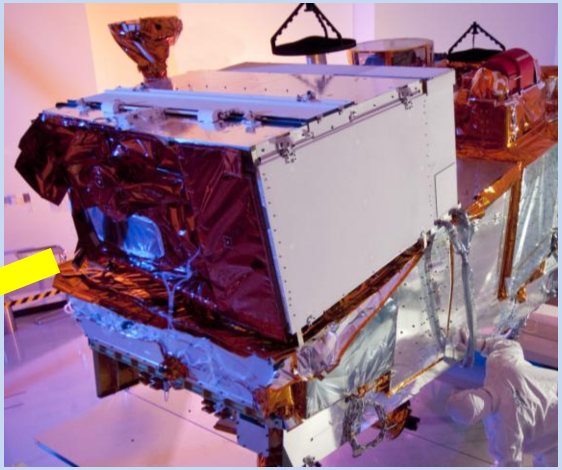
A year ago today

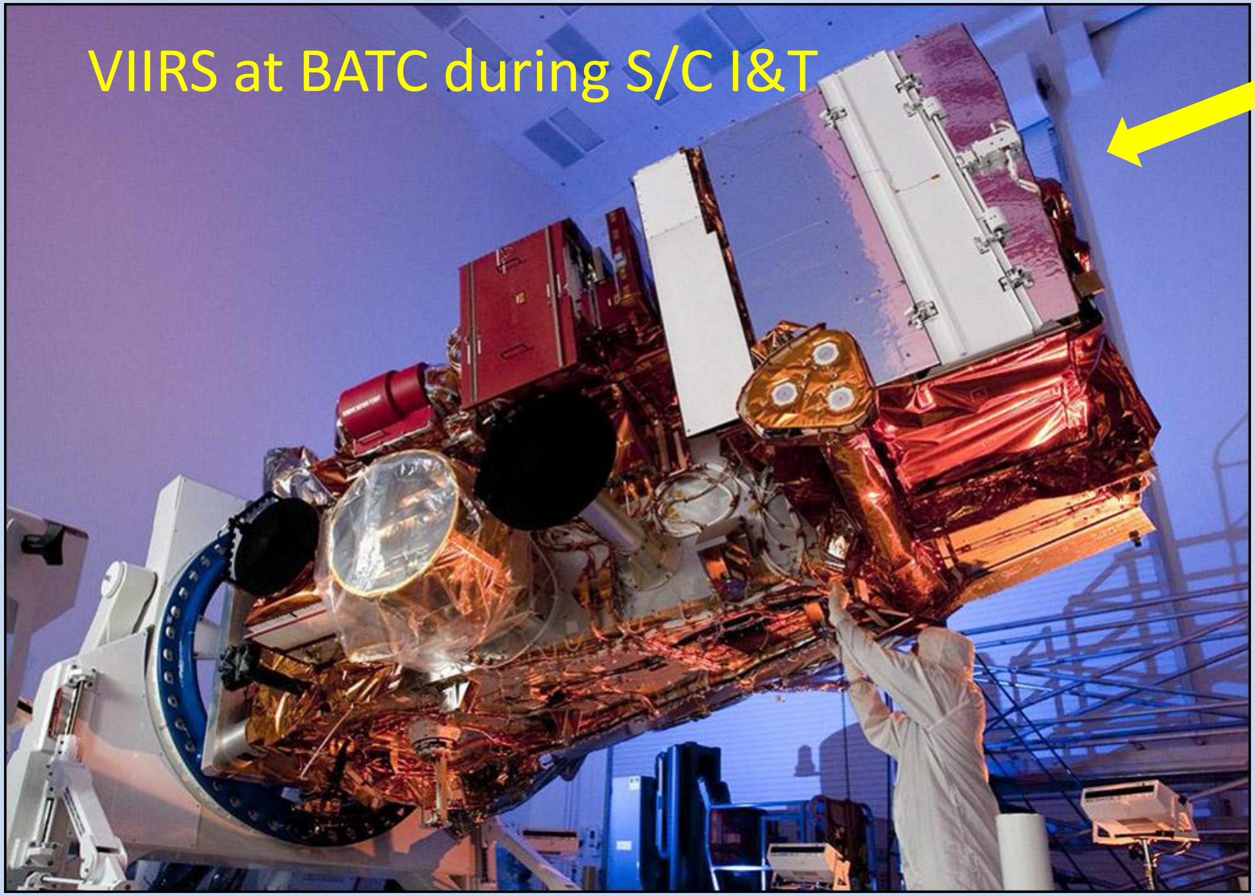
On Aug. 28, 2011, NPP was placed in a shipping container and loaded on a transport truck at Ball Aerospace & Technologies Corp.

2 months late

http://www.launchphotography.com/NPP.html

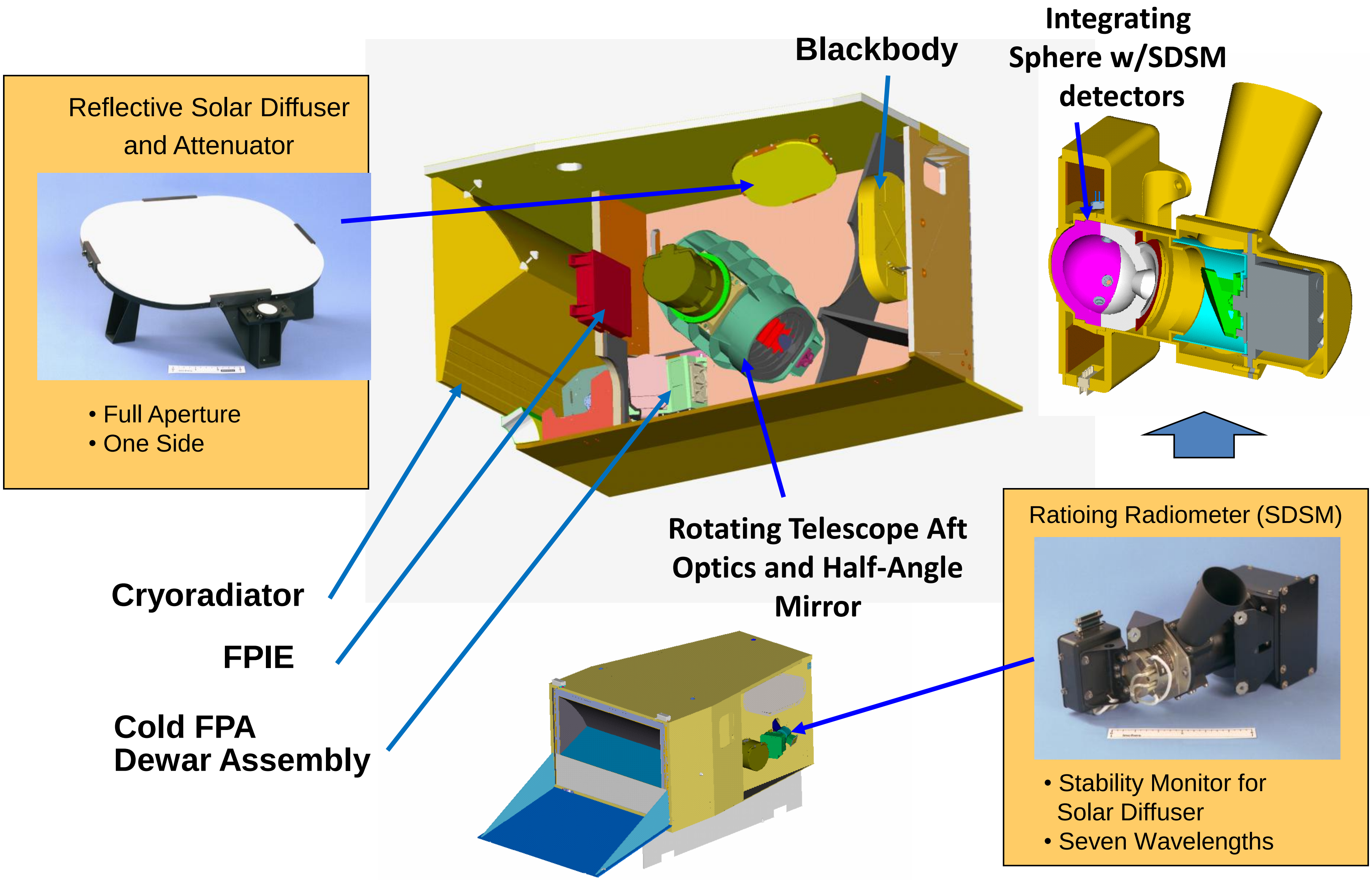
Visible/Infrared Imager Radiometer Suite (VIIRS)





22 bands: 0.4 to 12.5 μm

VIIRS OMM and SDSM Solar Calibration Components



Source/Credits: JPSS RTN VIIRS F2F Deep Dive –Data subject to RTN Proprietary and Sensitive Data Restrictions

Two things were noticed

VIIRS NIR detector response degrades much faster than expected.

SDSM detector response also degrades at NIR wavelengths.

Led to a series of reviews, investigations, tests, data analyses, ….

Major Events and Timeline

Event #	Description	Start-End DOY	Start Date_Time	End Date_Time	Start-End Orbit
1	NPP Launch	301-301	10/28/2011_09:48z	10/28/2011_09:48z	0-0
2	VIIRS Turned On	312-312	11/08/2011_05:44z	11/08/2011_05:44z	154-154
3	VIIRS Door Open	325-325	11/21/2011_16:03z	11/21/2011_16:03z	344-344
4	VIIRS 1394 Anomaly	329-330	11/25/2011_16:36z	11/26/2011_19:38z	401-417
5	Svalbard communication Loss (Cable cut)	331-336	11/28/2011_11:00z	12/02/2011_24:00z	441-505
6	RTA stowed for 3 days Sensor Test 1 (ST-1)	343-346	12/09/2011_22:47z	12/12/2011_19:33z	604-644
7	RTA rotating at night only, Sensor Test 2 (ST-2)	349-353	12/15/2011_16:32z	12/19/2011_19:37z	685-744
8	RTA Stowed for one week Sensor Test 3 (ST-3)	355-362	12/21/2011_17:14z	12/28/2011_14:55z	771-869
9	RTA Stowed for 4 days Sensor Test 4 (ST-4)	363-002	12/29/2011_14:36z	01/02/2012_20:18z	883-943

Event-5: This is just a data gap due to communicatio issue between Svalbard and IDPS. All RDRs are being processed and SDR gap will covered.

Anomaly Overview

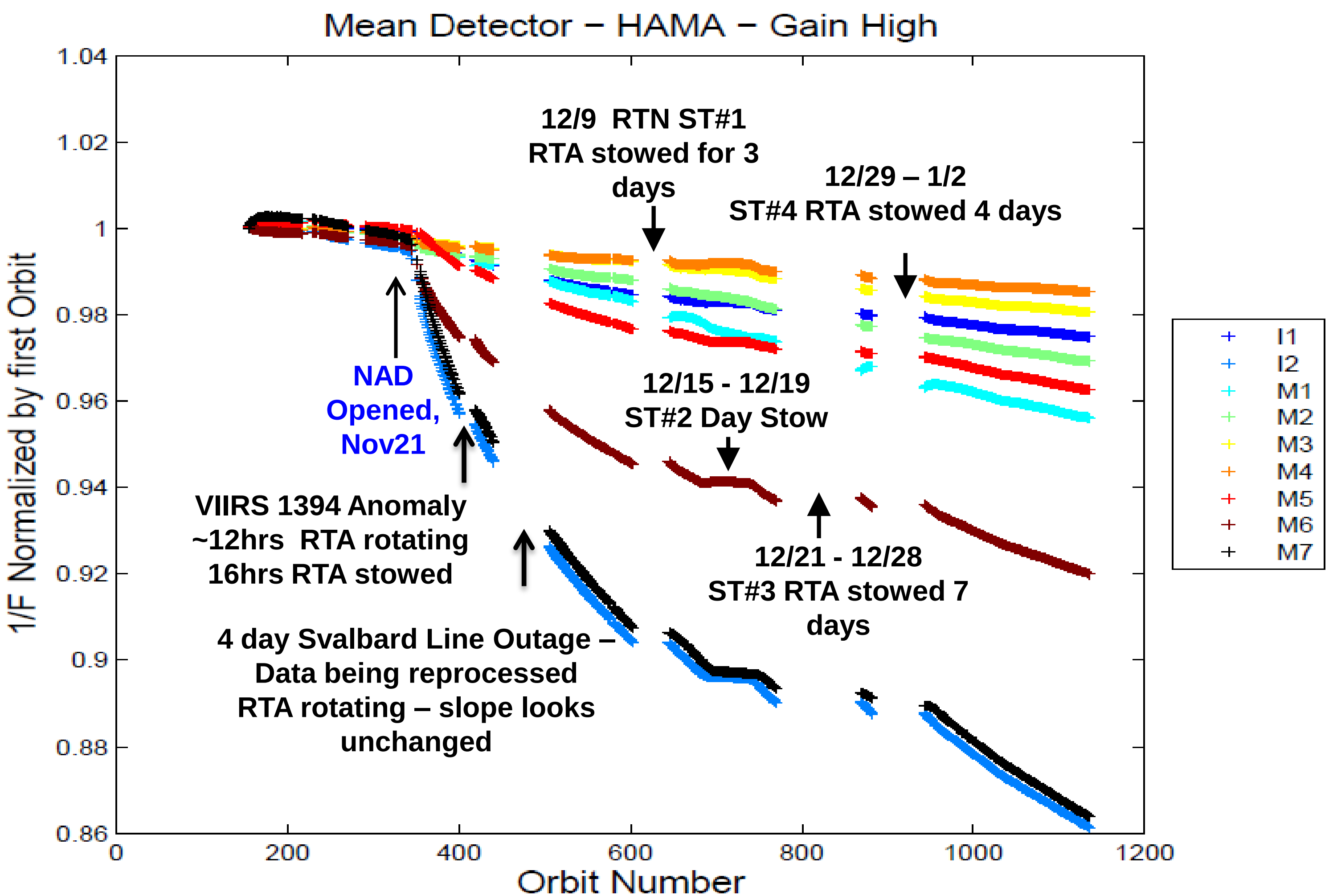
- VIIRS VisNIR degradation first reported 12/7/2011
  - Degradation rate increased sharply after nadir door opening on 11/21/11
  - Degradation essentially stops when stowed; sensitive to UV exposure
  - DNB response consistent with observed VisNIR degradation
- SDSM has a different optics path that shows similar spectral degradation
  - Degradation continues during stow period; insensitive to UV exposure
- VIIRS solar diffuser does not show this NIR spectral degradation
  - Showing nominal expected degradation in shorter wavelengths

VNIR Response vs Orbit Time Trends

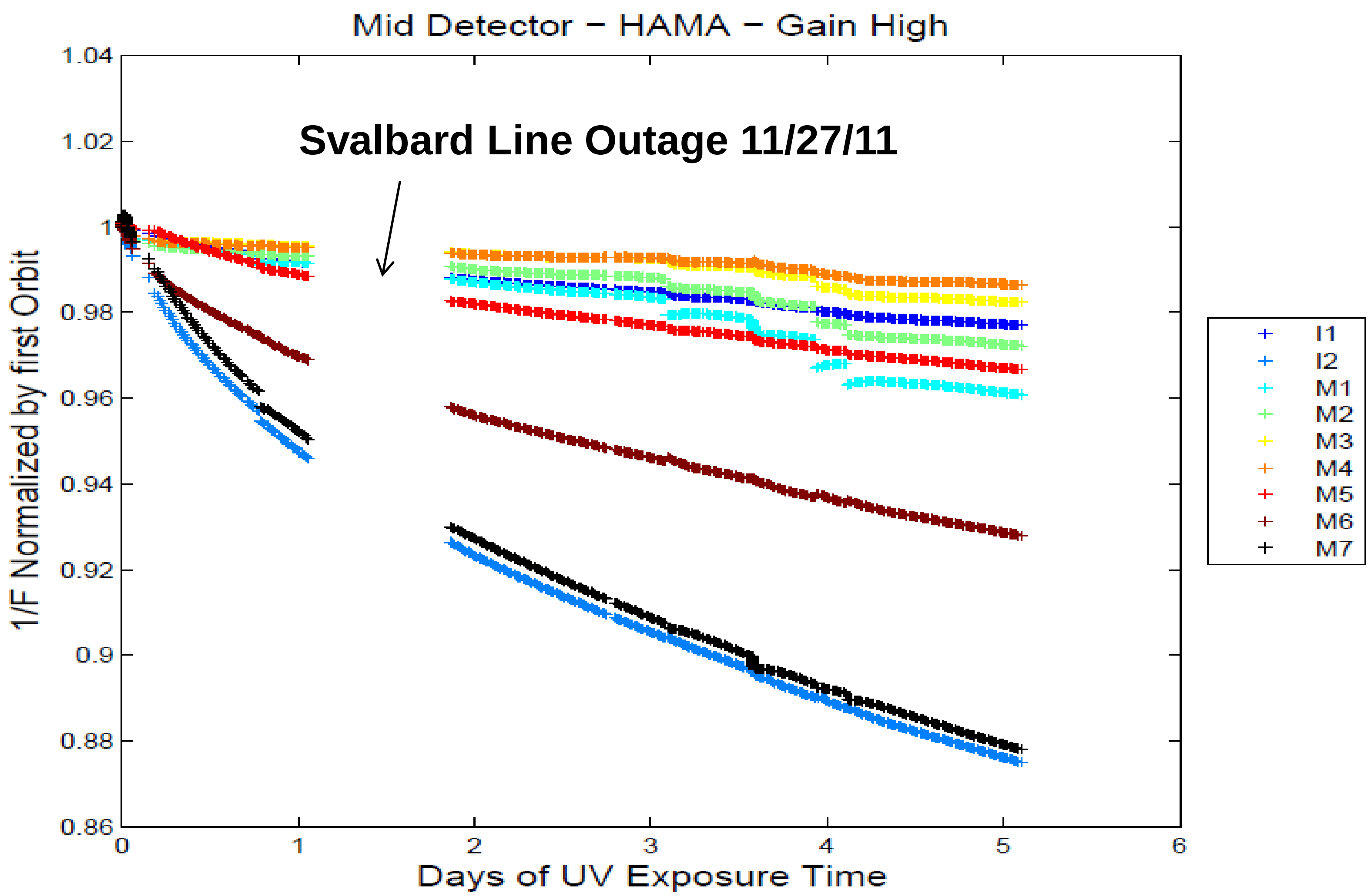
(Aerospace Data Plot)

Degradation is uniform across detectors within a band

- Rate of NIR response degradation significantly increased w/ NAD opening. Note discontinuity in trend for NIR bands (M7/I2, M6, M5)
- NIR Degradation paused when 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



VNIR Response vs UV Exposure Time

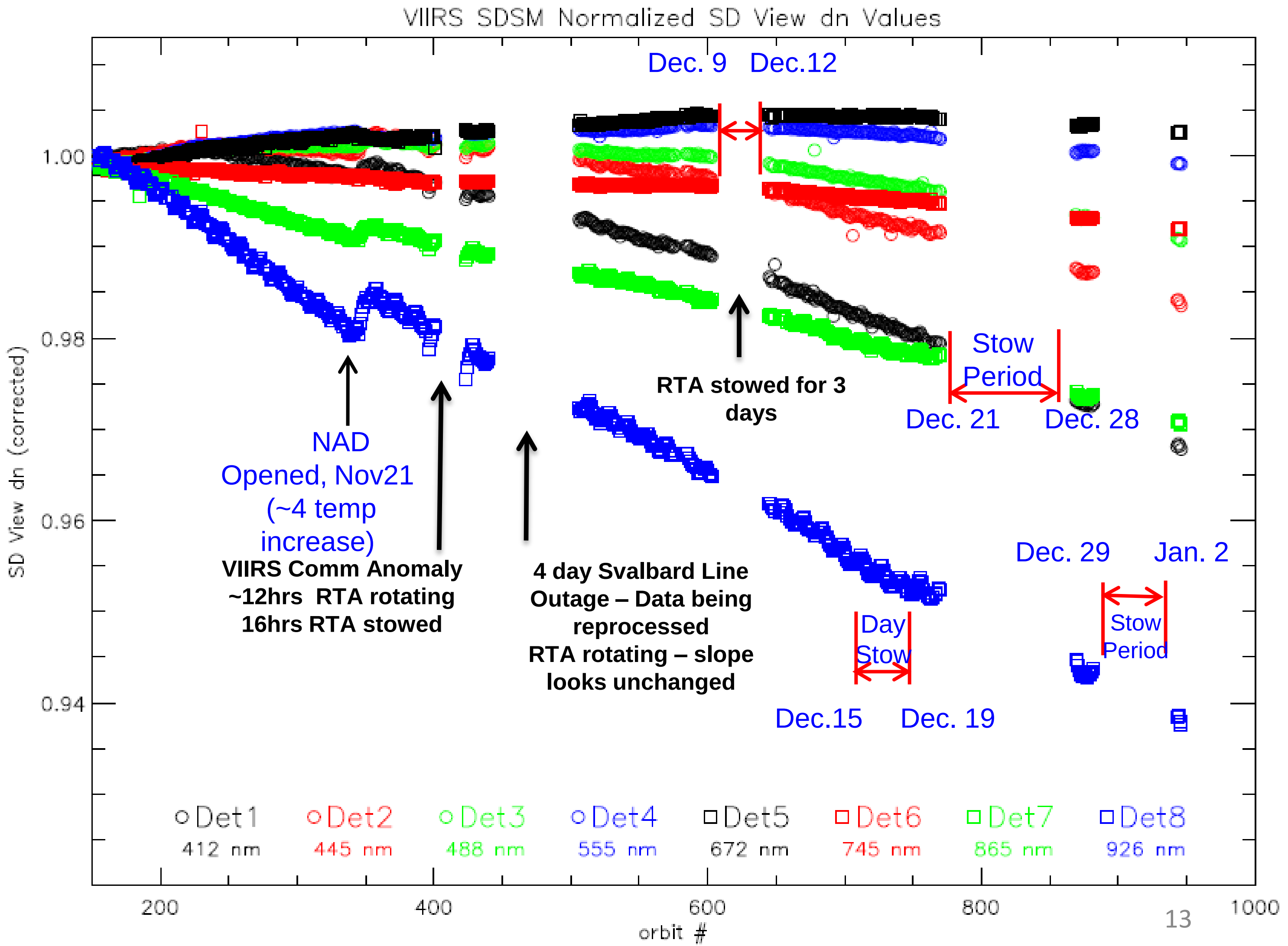


The degradation was correlated with UV exposure.

SDSM Normalized Response
(NASA Data Plot)

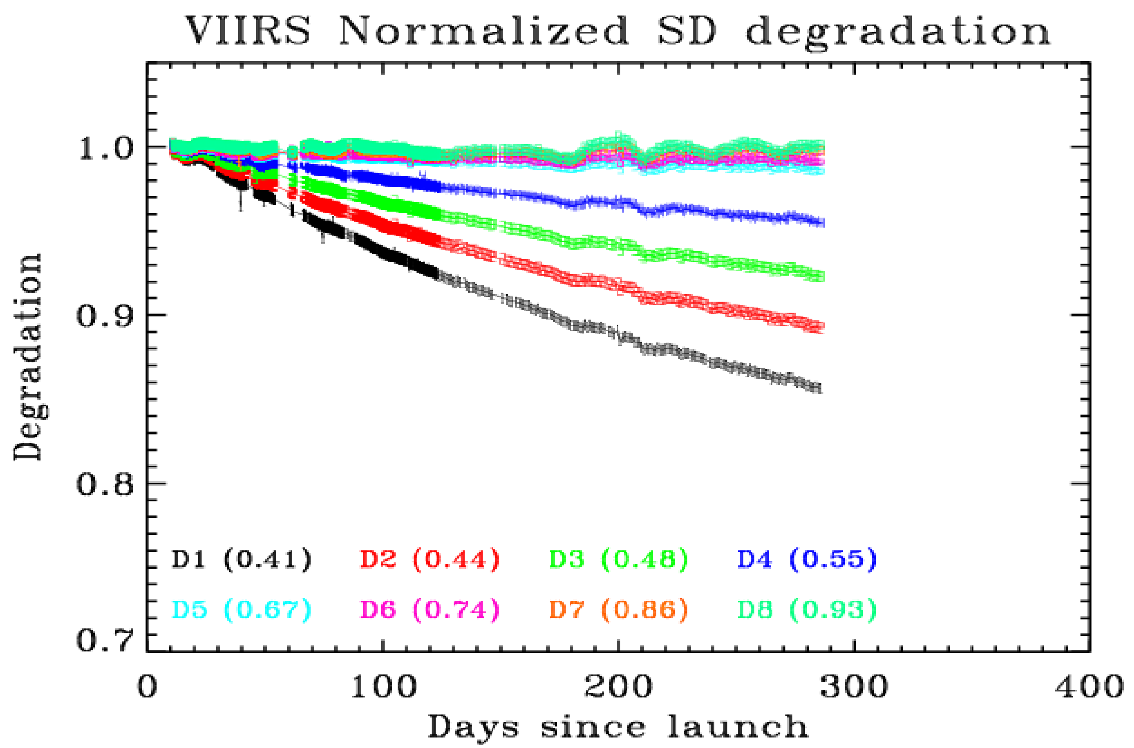
672, 870 & 926 nm Detectors show largest degradation

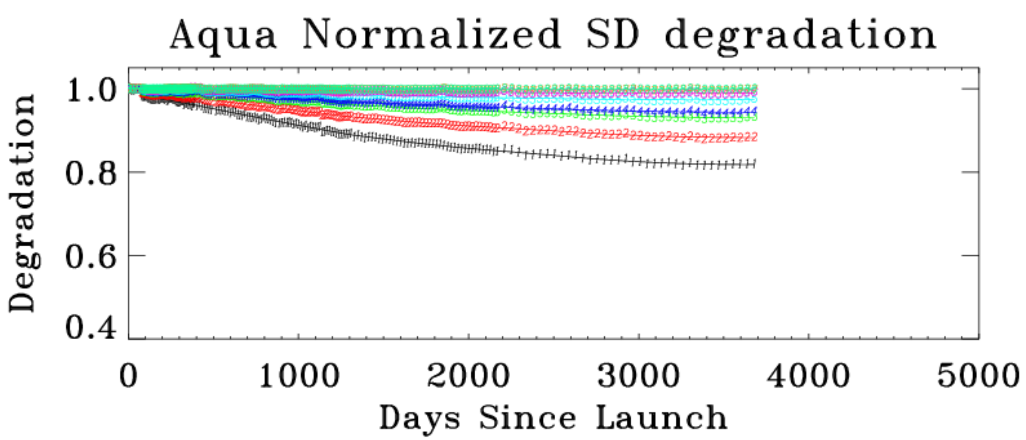
- SDSM NIR degradation appears to be unchanged through Stow period, contrary to VIIRS VNIR trend.
- SDSM exposed to light ~6 minutes per orbit during Solar Cal period and has been constant since Nov. 8th, except for 3 Stow periods:
- All other times during orbit, SDSM is off and mirror stowed (dark view inside SDSM scan cavity)



VIIRS SD degradation

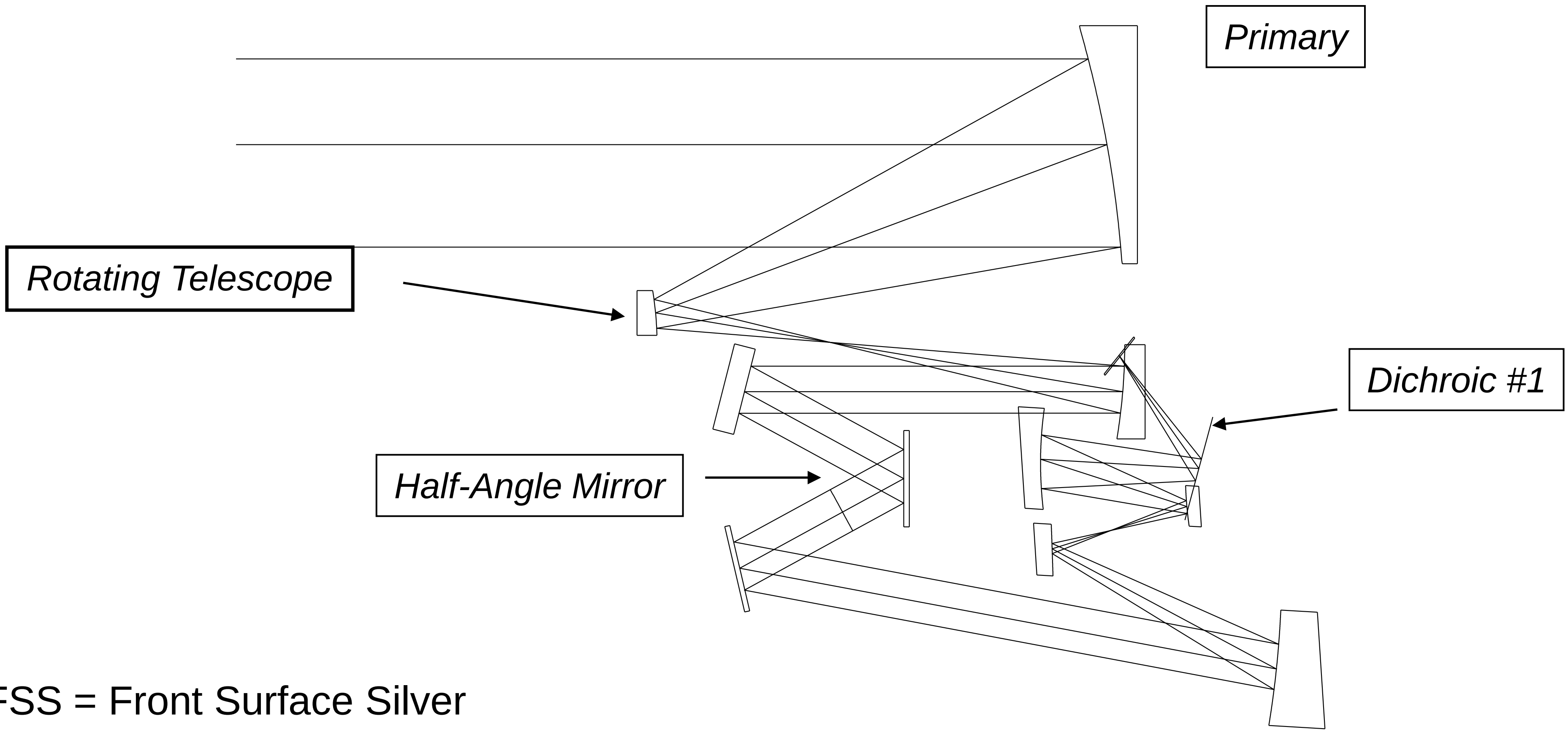
SD degradation: expected





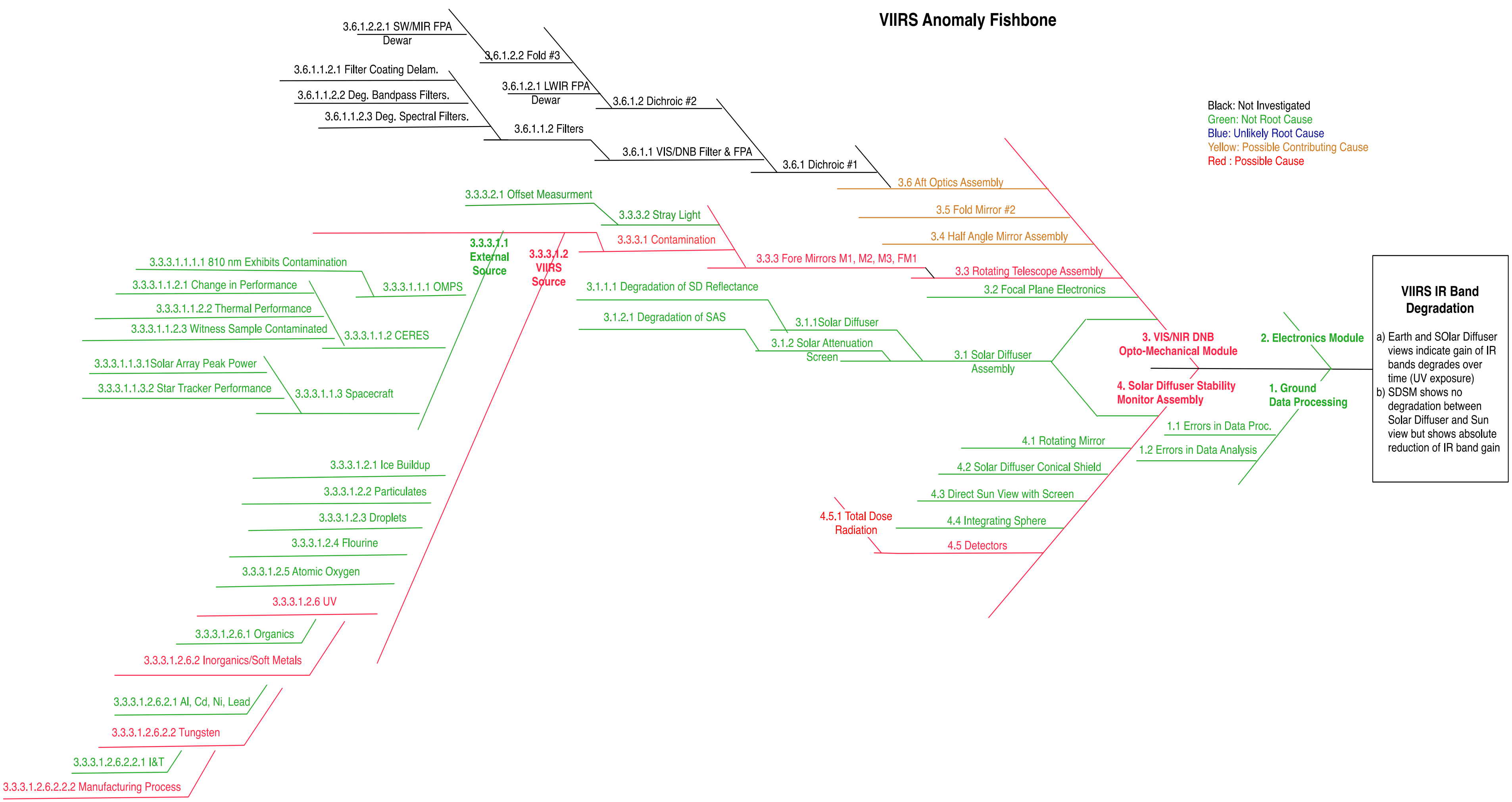
Possible culprits in VIIRS Visible Light Path

10 “FSS99” and one dichroic and bandpass filters

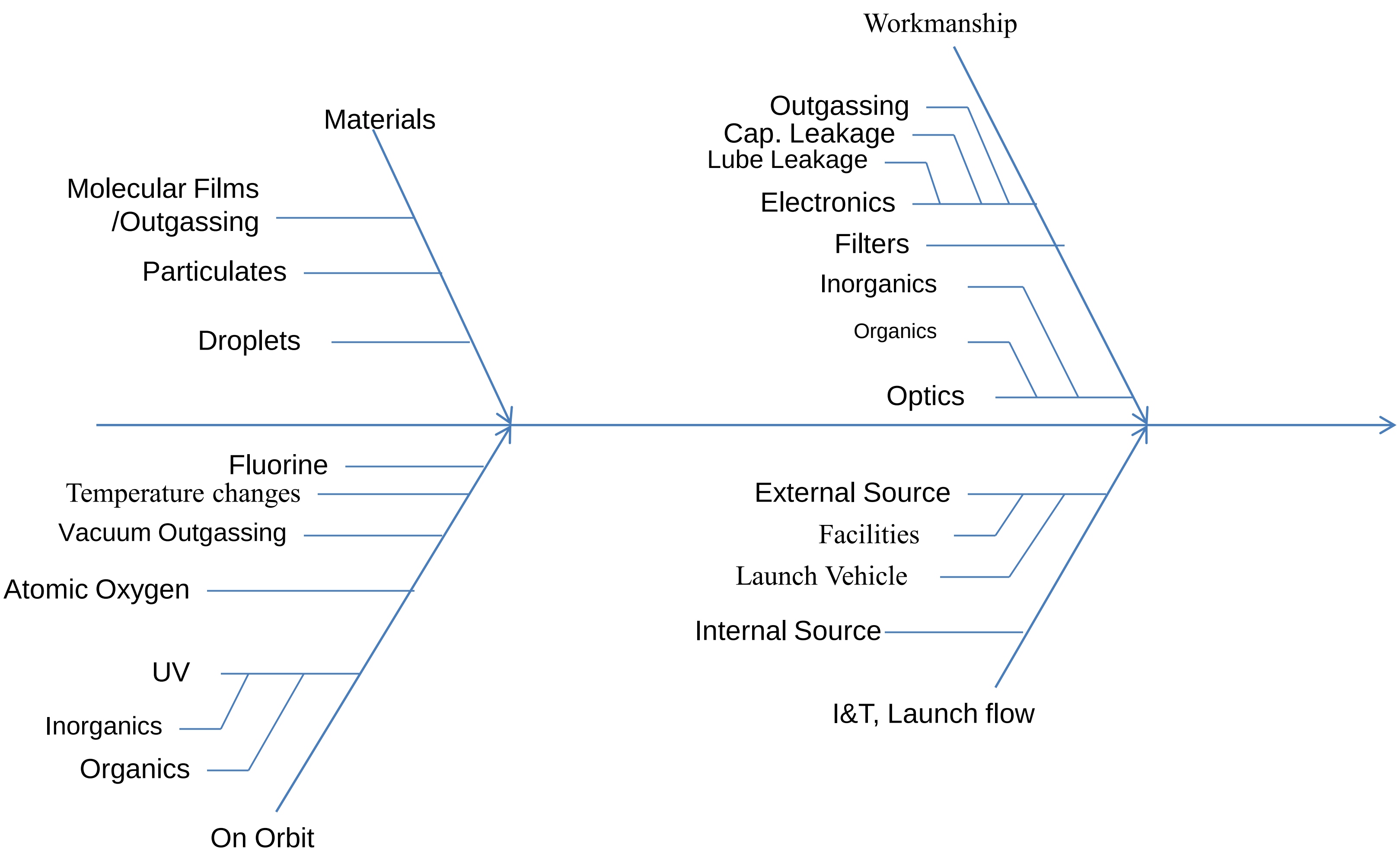


FSS = Front Surface Silver

NPP VIIRS Hardware Fishbone



Contamination Fishbone



First correct hint

- -----Original Message-----
  From: Peter D Fuqua [mailto:Peter.D.Fuqua@aero.org]
  Sent: Friday, December 16, 2011 12:11 AM
  To: Frank J DeLuccia
  Cc: Bruce Guenther; Waluschka, Eugene (GSFC-5510); Kennedy, Brian C. (GSFC-590.0)[ASRC MANAGEMENT SERVICES INC]; James.D.Barrie@aero.org; Chung-Tse Chu
  Subject: Contamination on silver mirrors
-
- Hi Frank,
- Enclosed please find charts that show that properly manufactured
- FSS99 should be robust to space exposure, that show the change in reflectivity of a protected silver mirror due to addition of a variety of hypothetical contaminants, and that addition of a tiny amount of a material with a refractive index similar to a grey metal (Cr, Ni, Ti, or Cd) can produce losses that are very similar to what is observed on orbit.
- Lastly, the SDSM mirror has a completely different design. We should not assume it will behave the same way.
-
- Following up on your earlier questions, if we pursue this contamination hypothesis, we would expect that the contamination source is directional and that the primary mirror is only exposed to the source when the telescope is rotating. When the telescope is stowed, the source might
- deposit on the outside of the telescope housing. Furthermore, to explain
- the observations, we would also need the contamination rate when the Nadir Aperture Door opened. This might occur if the source gets warmer due to solar exposure or Earthshine.
-
- We're looking solarization hypotheses as well, but that didn't make it into these charts. The same logic will apply. Thin-film Interference effects may have a strong influence on the wavelengths were absorptive loss is realized.
-
- Please distribute as you feel appropriate.
-
- Best Regards,
- Pete
-
- (See attached file: Fuqua Contam effects on protected silver v3.pptx)

Tungsten?

- Tungsten oxide found on surface of VIIRS follow-along mirror via TOF-SIMS. Estimated thickness 15-30Å
- Spectral loss on UV exposure of telescope follow along witness mirror closely matches observed VIIRS loss.
- Literature indicates tungsten oxides are photochromic in UV.
- Very few sources available to deposit tungsten or its oxide
- Very high temperature (>1000^{o}C) needed to sublimate tungsten or an oxide.
- Volatile tungsten compounds do exist, but none are part of the spacecraft build. Deposition from these sources is also typically an elevated temperature process.
- Potential external sources:
  - Tungsten counterweight in ATMS. No line-of-sight and no mechanism.
  - Lubricants:
    - No evidence that tungsten disulfide was substituted for molybdenum disulfide in any spacecraft lubricants. Temperatures too low. No sulfides evident.
    - Vacuum roughing pumps did not use lubricants containing tungsten
  - CERES witness sample did not degrade in test, suggesting source outside of I&T.
- Potential internal sources:
  - Dry lubricant in RTA launch locks: no mechanism to convert from particles to film
  - FOD: no mechanism
  - Radiation shield on VIS-NIR detectors: too cold
- Potential workmanship sources:
  - Machining: Tungsten carbide cutting surfaces do not transfer the material to surfaces.
  - Optical coating process: Discussions with Quantum ongoing.

Tungsten source

- VisNIR 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

QUANTUM Coating Incorporated

BSI
ISO 9001:2008
FM 514425

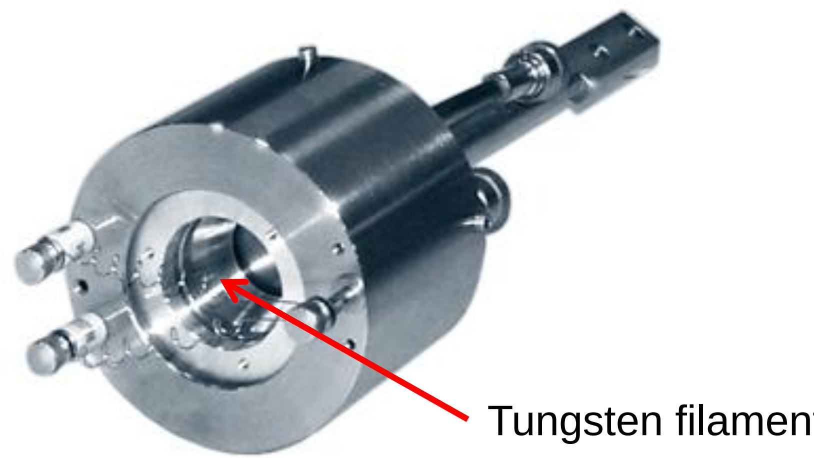
3/5/12

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.



Quantum Ion Gun

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

Aerospace comes to the rescue

- Chemical analysis of witness samples using Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS)
- Vacuum testing (UV exposure) of witness samples
- Thin film modeling of FSS99 + WOx

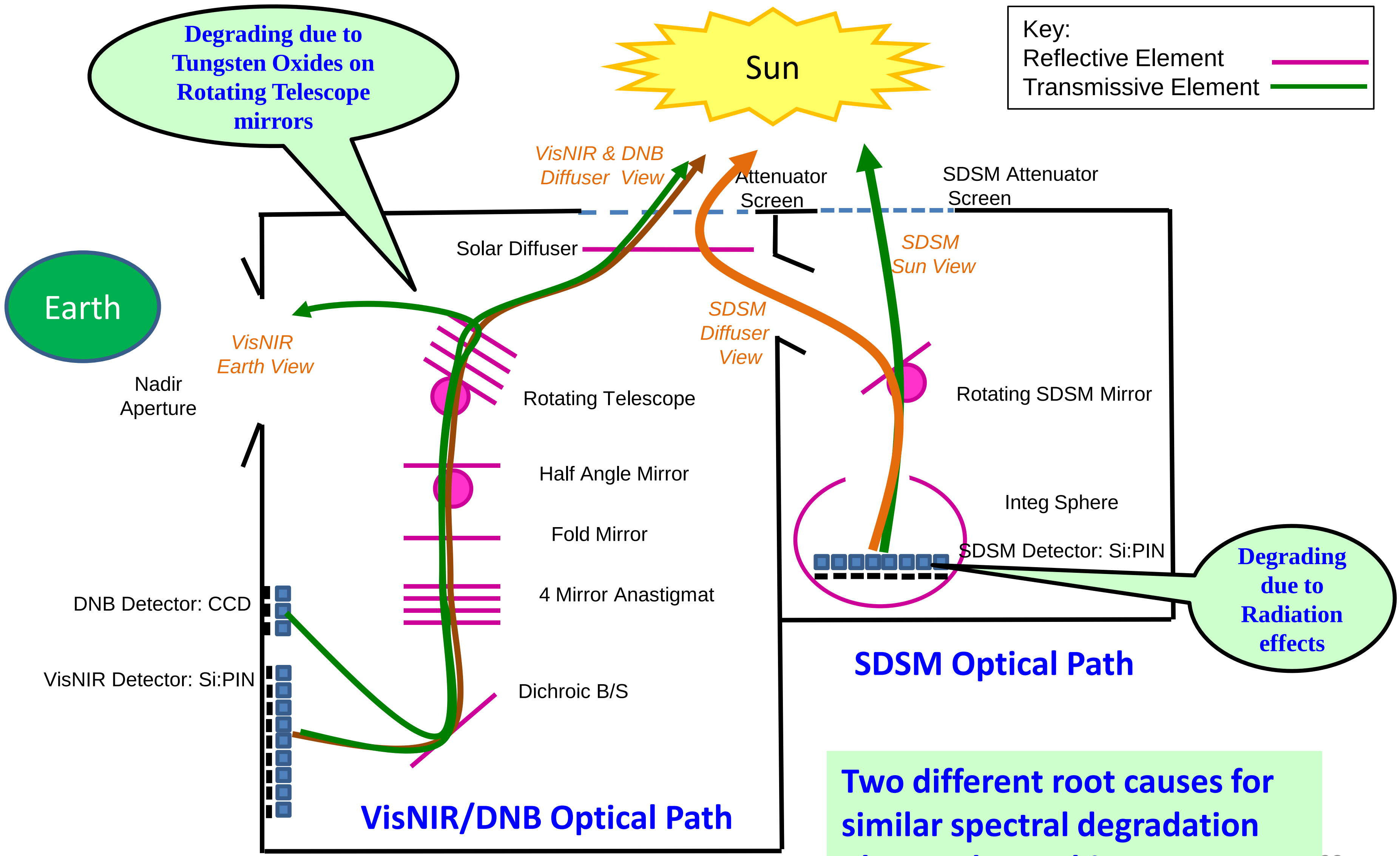
Aerospace presentation later in week.

Executive Summary

- Problem - Upon opening the SNPP Visible Infrared Imager Radiometer Suite (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 ultraviolet (UV) exposure. A secondary degradation was observed in the same spectral region within the VIIRS Solar Diffuser Stability Monitor (SDSM).
- Cause - Quantum (previously Denton) deviated from their qualified mirror coating process that resulted in tungsten oxides being deposited on the SNPP Rotating Telescope Assembly (RTA) mirrors. The SDSM degradation was traced to detector:SiPN sensitivity to high energy particles.
- Corrective action - The SNPP predictions show that all bands will stay within specification. The science team will continue trending and perform calibration table adjustments to normalize the product. JPSS-1 witness samples have been tested and the results showed no spectral degradation and therefore no additional corrective action is required.
- Residual risk – The residual risk is considered low as the predictions indicate the instrument will continue to perform within specifications through the life of the SNPP mission. There is no risk to JPSS-1 VIIRS.

VIIRS VisNIR/DNB & Solar Diffuser Optics

Note: reflective elements shown as transmissive elements for simplicity



Two different root causes for similar spectral degradation observed on-orbit

Lessons learned

- Don’t rush – Maintaining schedule required a Friday pump down for Saturday coating run.
- Question consequences of deviations from established procedure.
- Test as you fly. Expose optics to solar spectrum in vacuum and, while still in vacuum, measure reflection in vacuum.

Backup

VIIRS Degradation
ART Panel Status
January 4, 2012

Key ART Personnel

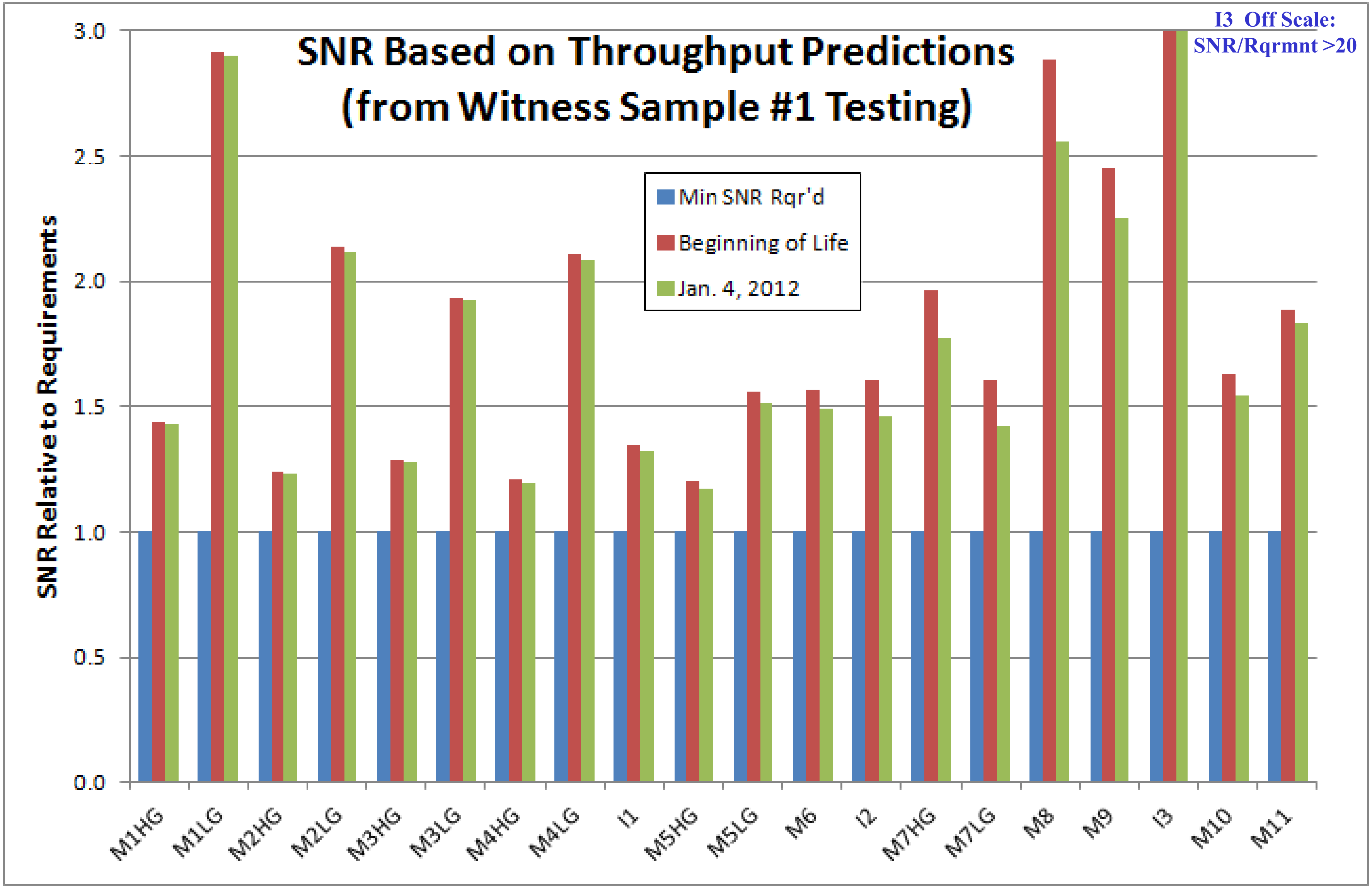
- **ART Lead – G. Iona**
- **Code 500 – M. Hagopian**
- **RTN Lead – Eric Johnson**
- **Data Analysis -** F. DeLuccia V. Chiang
- **Contamination – L. Graziani,** M. Secunda, J. Triolo, R. Hedgeland,
- **Instrument/SC CCE -** K. Stoval, C. Maag, M. Crowder, B. Fluegeman
- **Detectors – S. Babu,** K. Ando,
- **Optics** – J. Heaney, C. Kent, G. Waluschka,
- **Radiation – Paul Marshall**
- **Materials** – **S. Sours,**
- **Systems** – **B. Lambeck,** S. Glockner, M. Bay
- **JPSS Instrument Systems** – M. Ayers, B. Kennedy
- **Science – J. Gleason,** J. Butler, J. Xiong, B. Guenther,
- **Mission Assurance** – **M. Born,** T. Robertson,
- **JPSS Flight Project Lead – P. Sullivan**
- **JPSS VIIRS IM – P. Driggers**
- **NOAA JPSS - J. Morris**
- **JPSS Instruments – B. Park,** M. Jurotich,
- **OMPS – Glen Jaross**
- **CERES –G. Fleming,** K. Priestley
- **CrIS – M. Poling**
- **Spacecraft** – **R. Baltrum**/R. Brewster
- **Instrument IMT – T. Gentry**

Bold names are lead for that discipline

VIIRS Anomaly Investigation

January 17, 2012

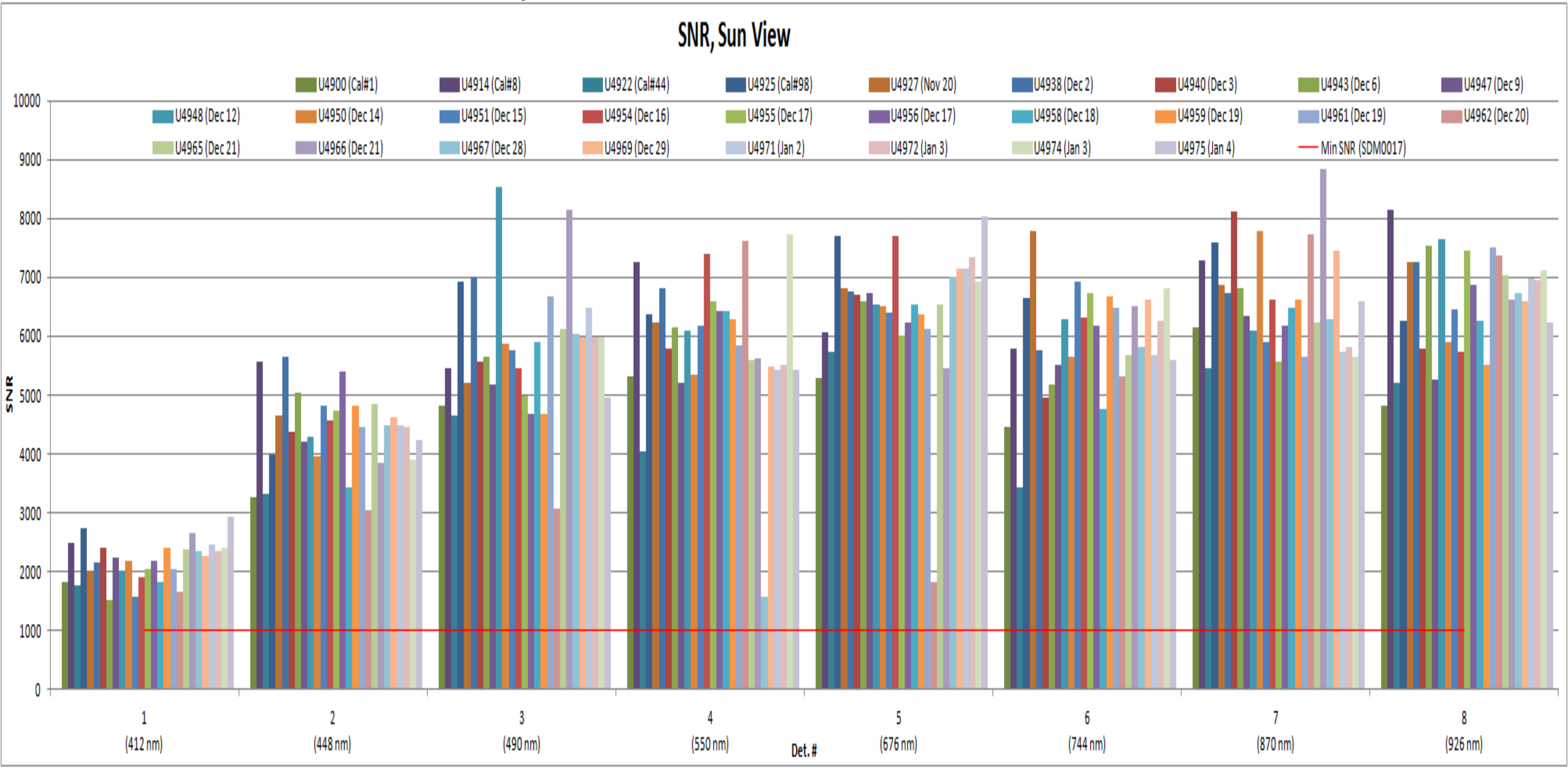
VNIR and SWIR Bands Still Have Healthy SNR Margins



SDSM SNR Margins Healthy, Especially in NIR

- Minimum SNR requirement is 1000:1
- Sun view provides lower signal than SD view, thus lowest SNR
- SNR calculated as: $$SNR = \frac{Signal}{\sqrt{DarkNoise^2 + SignalNoise^2}}$$

SNR measure noisy. Varying signal in SD view allows few samples (5) in Signal_Noise calc that is avg'd over 14 cycles



Closure Approval for Suomi National Polar-orbiting Partnership (SNPP) VIIRS Degradation Anomaly Root Cause/ Corrective Action Investigation Report

6/14/2012

6/14/2012
Gregory Ayers Date
Lead Instruments Systems Engineer

6/15/2012
Martin Born Date
Instruments CSO

6/19/12
Glenn Iona Date
SNPP Flight Segment Engineer/
Deputy Flight Segment Manager

6-14-2012
For Elizabeth Park Date
Instruments Systems Manager

6-19-12
James Butler Date
Project Scientist

6/14/12
Bryan Fafaul Date
Flight Project Manager