INNOVATIVE
IMAGING & RESEARCH

Ground-based Artificial Light Source for Radiometric Calibration of the VIIRS Day-Night Band High Gain Stage

Early Results
NOAA SBIR Project

Robert E. Ryan (Presenter)

September 19, 2018

Team

- Robert Ryan (I2R)
- Mary Pagnutti (I2R)
- Timothy Ruggles (SDSU)
- Kara Burch (I2R)
- Larry Leigh (SDSU)
- Dennis Helder (SDSU)
- David Aaron (SDSU)

South Dakota State University
Image Processing Lab

INNOVATIVE
IMAGING & RESEARCH

Acknowledgements

- NOAA SBIR Program Phase I and Phase II Funding

- Changyong Cao NOAA COTR **Accurate Active Light Source** (AALS) Concept

  Satellite Meteorology and Climatology Division

  Satellite Calibration and Data Assimilation Branch

- Vince Garcia NOAA SBIR Program Manager

Nighttime Imaging

Imaging both day and night is challenging and quantitative night imaging is still in its infancy.

At any one time the Earth is half shadowed in darkness

VIIRS Overview

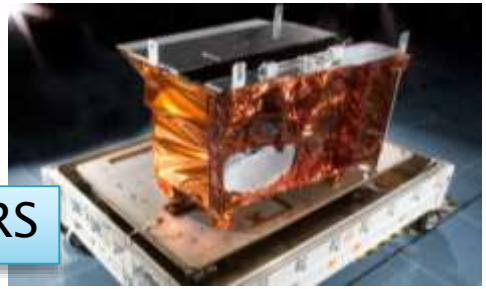
- Visible Infrared Imaging Radiometer Suite (VIIRS) is a scanning radiometer capable of measuring land, atmosphere and ocean properties
  - Provides MODIS and AVHRR Continuity
  - Swath: ±56°, 3040 km
  - Bands:5 high resolution bands (750 m), 16 moderate resolution bands (750 m), and a panchromatic DNB (750 m)
- Part of Suomi NPP and NOAA-20 (JPSS)

Suomi NPP

Image Source: http://npp.gsfc.nasa.gov/suomi_mission_details.html

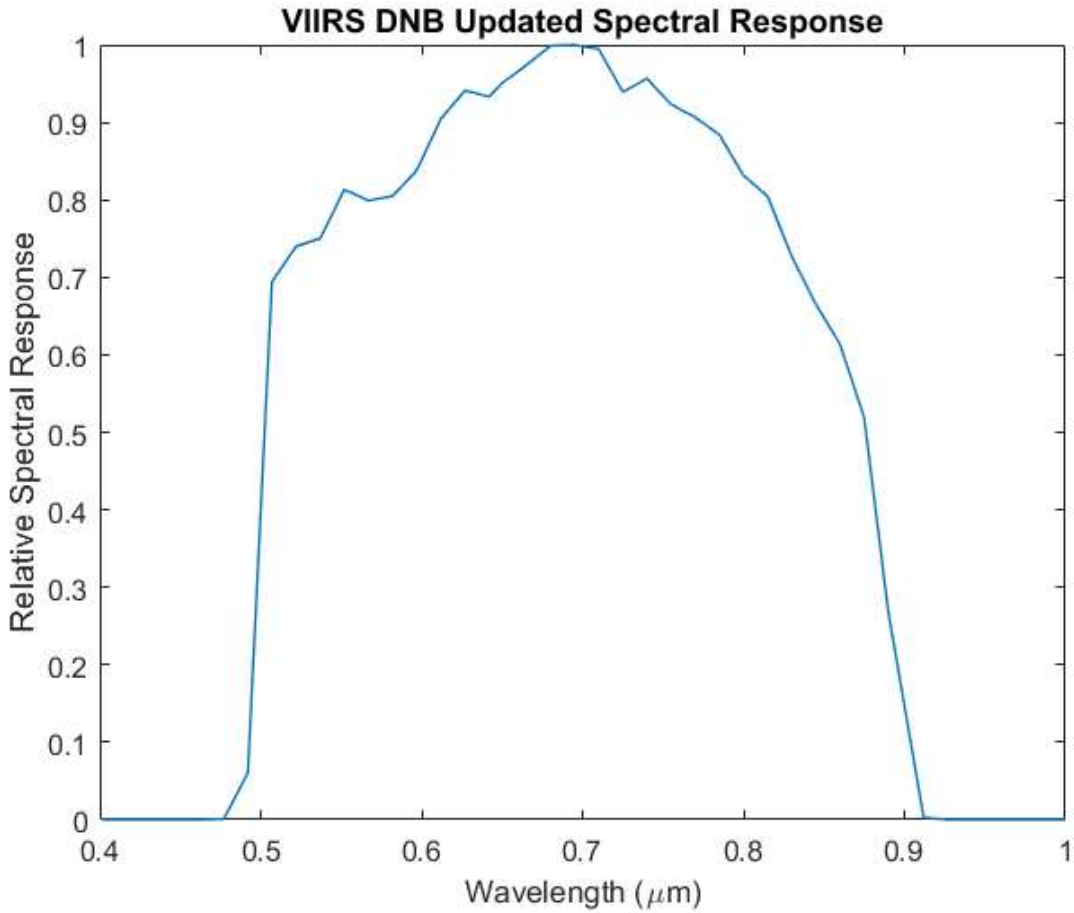
VIIRS DNB Characteristics

- Single Band (Spectral range: 0.5–0.9 μm)
- Quantization: 14 bits for high gain setting (HGS), 13 bits for other
- HGS L_{min}: 3e–9 [W cm^{-2} sr^{-1}]
  - Original design goal much lower but still used a reference
  - SNR >10 @ end of scan or ~40 at Nadir
- HGS stated calibration accuracy 15% (Spec: LGS 5%, MGS 10%, HGS 30%)
- Horizontal Sample Interval
  - ~750 m x ~750 m Nadir through end of scan

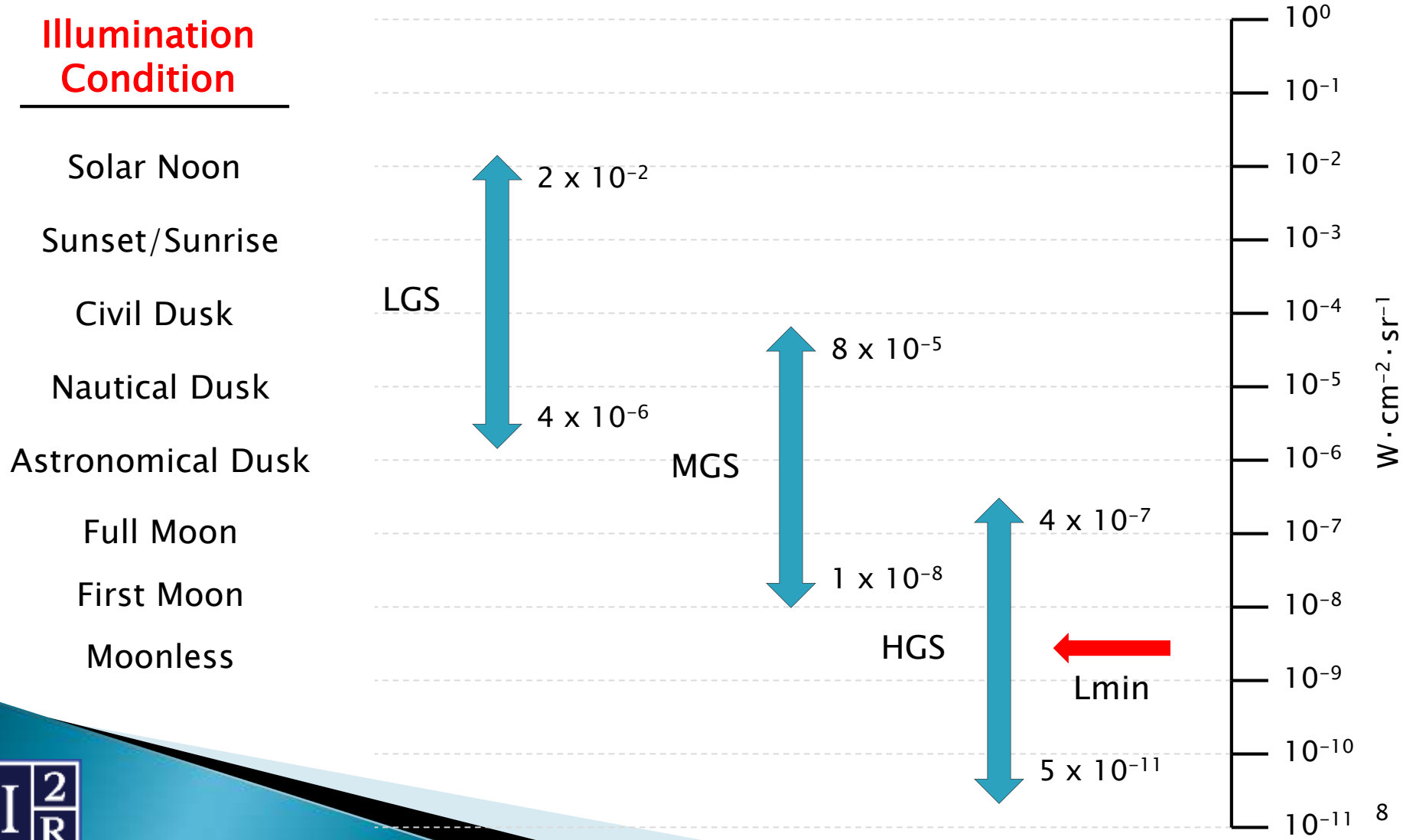


VIIRS Photo courtesy of Raytheon Space and Airborne Systems
Image Source: http://npp.gsfc.nasa.gov/viirs.html

VIIRS DNB Spectral Response

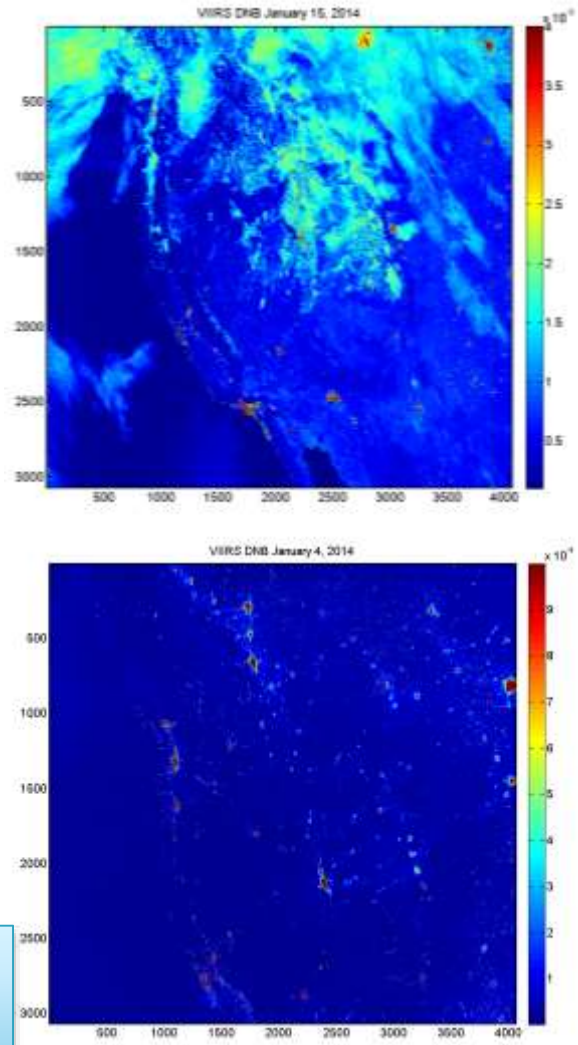


VIIRS DNB Dynamic Range



VIIRS DNB Overview and Application

- VIIRS Day/Night Band unprecedented sensitivity, revisit and resolution
- Applications
  - Emergency response
  - Search and rescue
  - Electrical power usage
  - Human activity (Socioeconomic)
  - Nighttime atmospheric monitoring
  - Light pollution



VIIRS DNB HGS night time images acquired over US West Coast, with lunar illumination (top) and without lunar illumination (bottom)

VIIRS DNB Calibration Problem

- Currently there are limited ways to radiometrically calibrate the VIIRS Day/Night Band (DNB) High Gain Setting (HGS) (Cao and Bai, 2014)
  - Low Gain Setting (LGS)
    - Solar diffuser
  - Medium Gain Setting (MGS)
    - Overlap of LGS and MGS in terminator collections
    - Cannot use solar diffuser
  - High Gain Setting (HGS)
    - Overlap of MGS and HGS (less confidence)

Lunar illuminated scenes can be used for vicarious calibrations but are not point sources

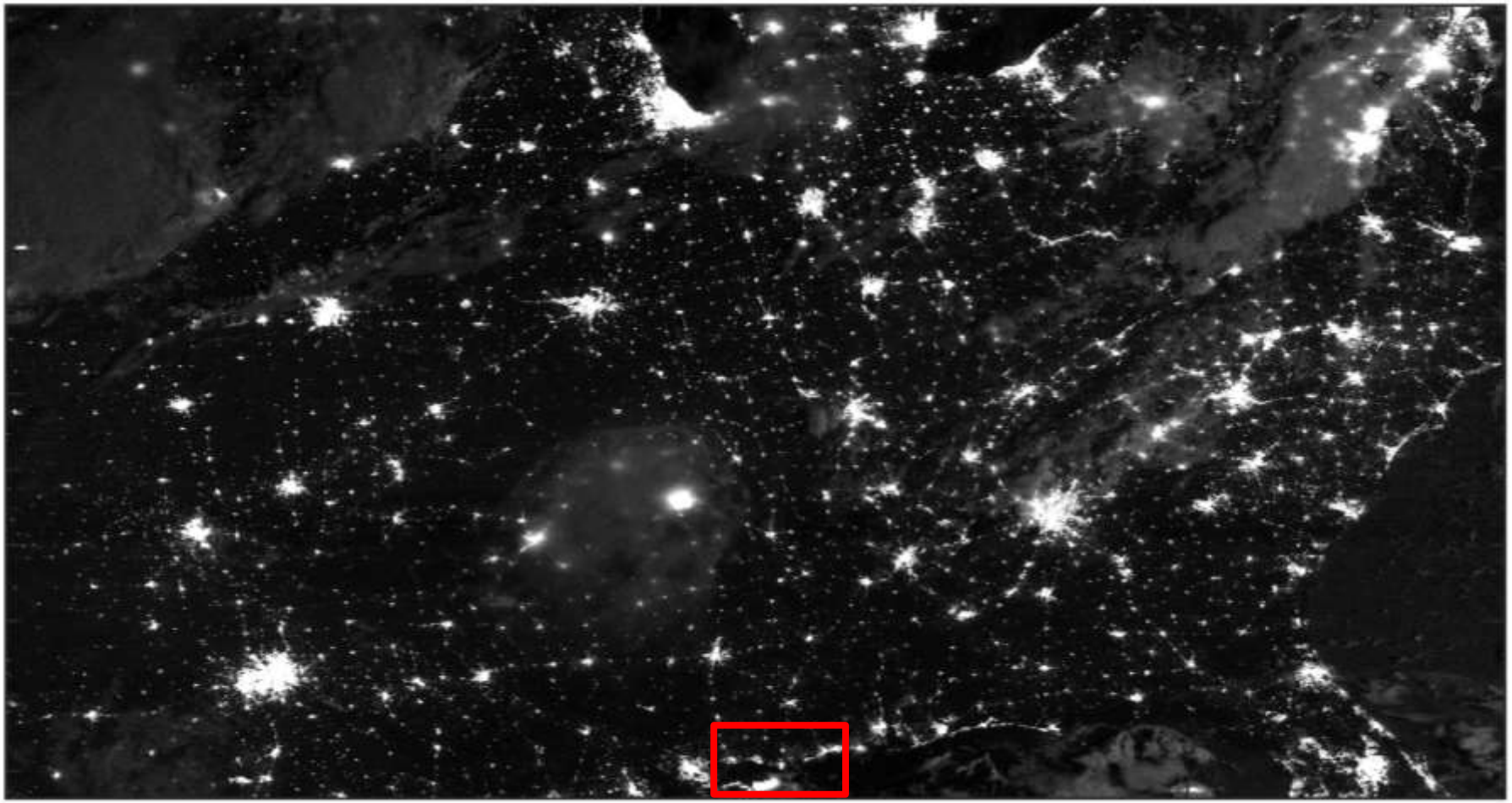
Application Time Series (Problem Statement Restated)

- Time series and change detection quality depends on
  - Sensor radiometric stability
  - Knowledge of the atmospheric conditions
  - **Artificial light source characteristics**
  - **Sensor PSF**
  - **Sensor pointing**
  - Lunar illumination and BRDF correction
  - Straylight

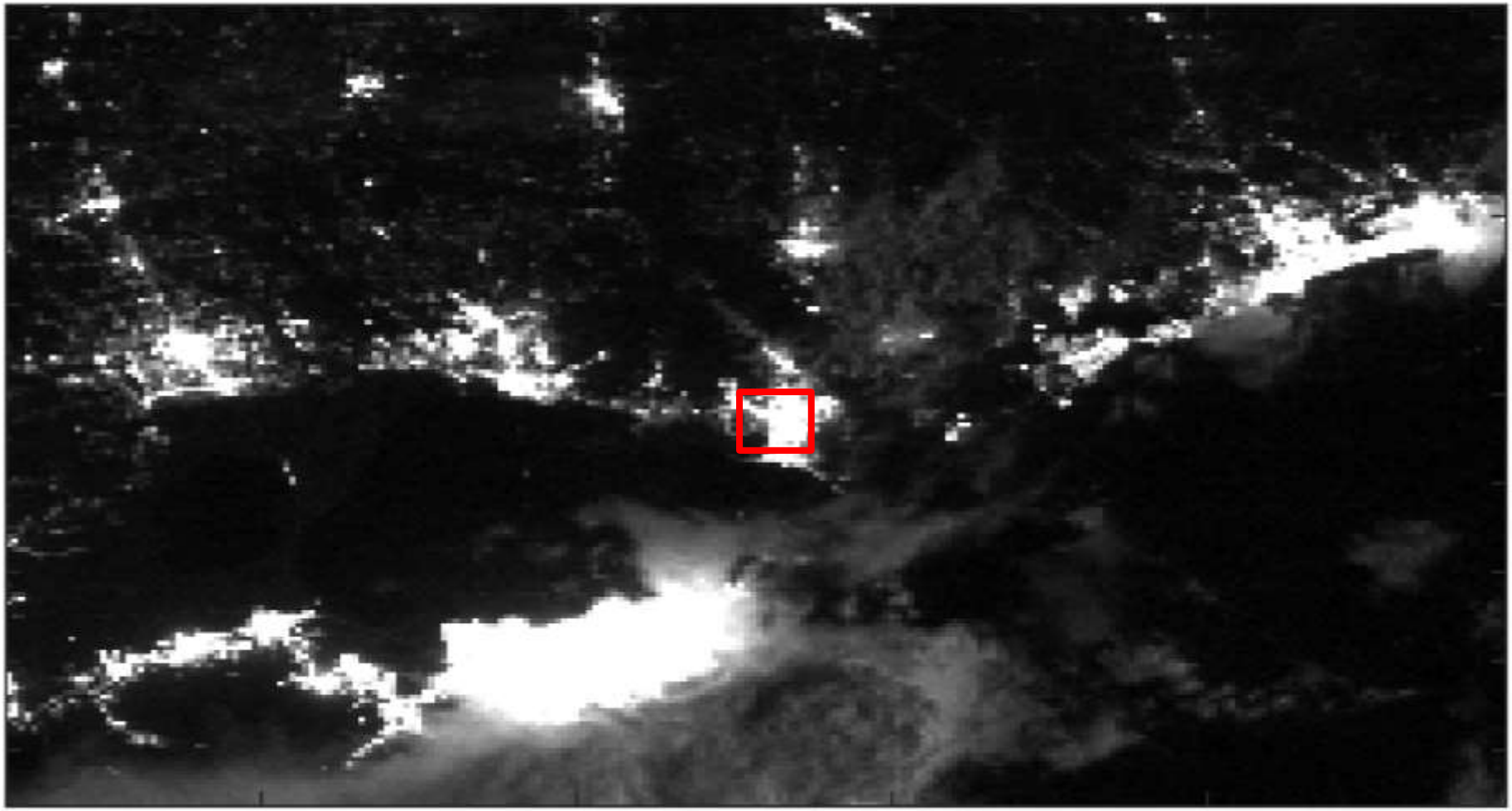
Example Time Series

Slidell, LA July 2018

VIIRS DNB Image
Eastern US, July 5, 2018

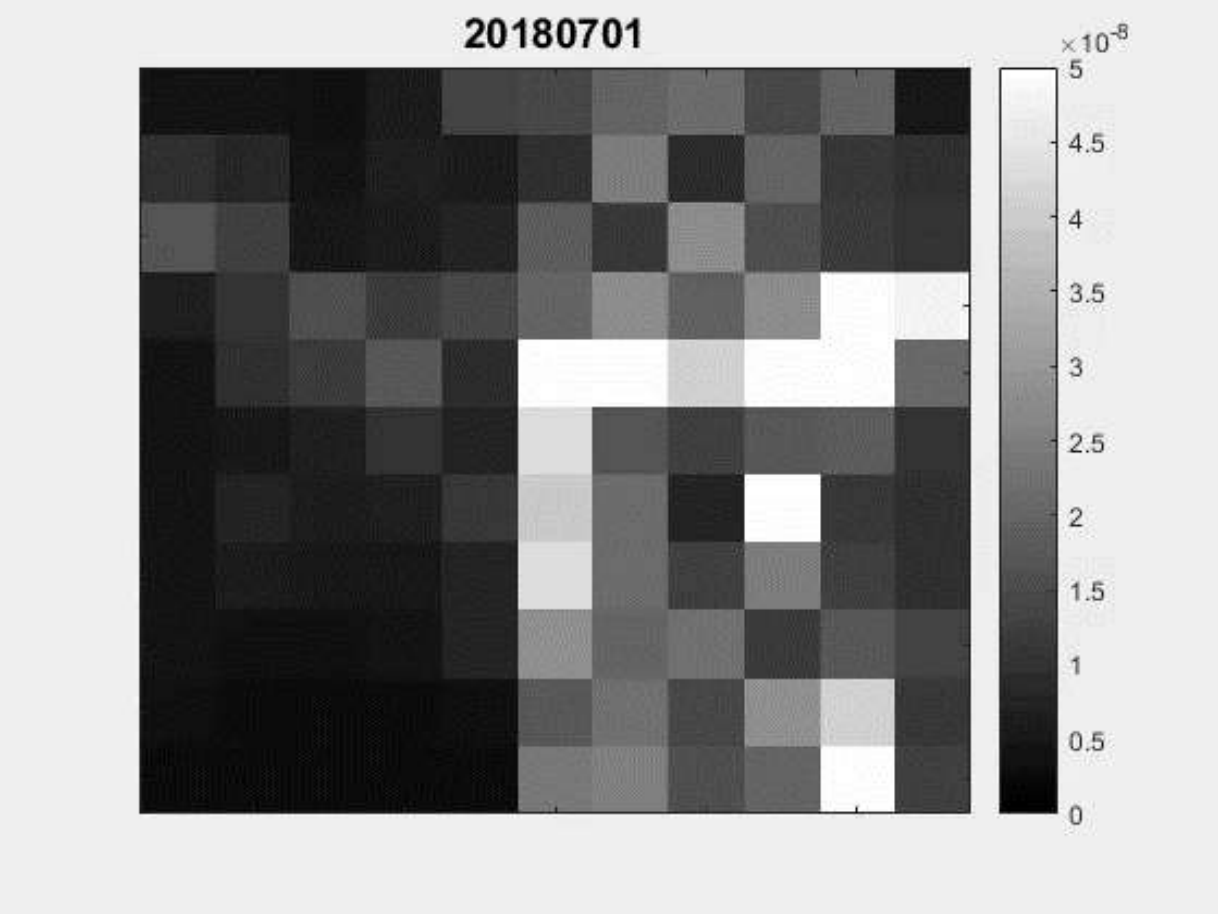


VIIRS DNB Image, Louisiana – Mississippi Zoom Area, July 5, 2018



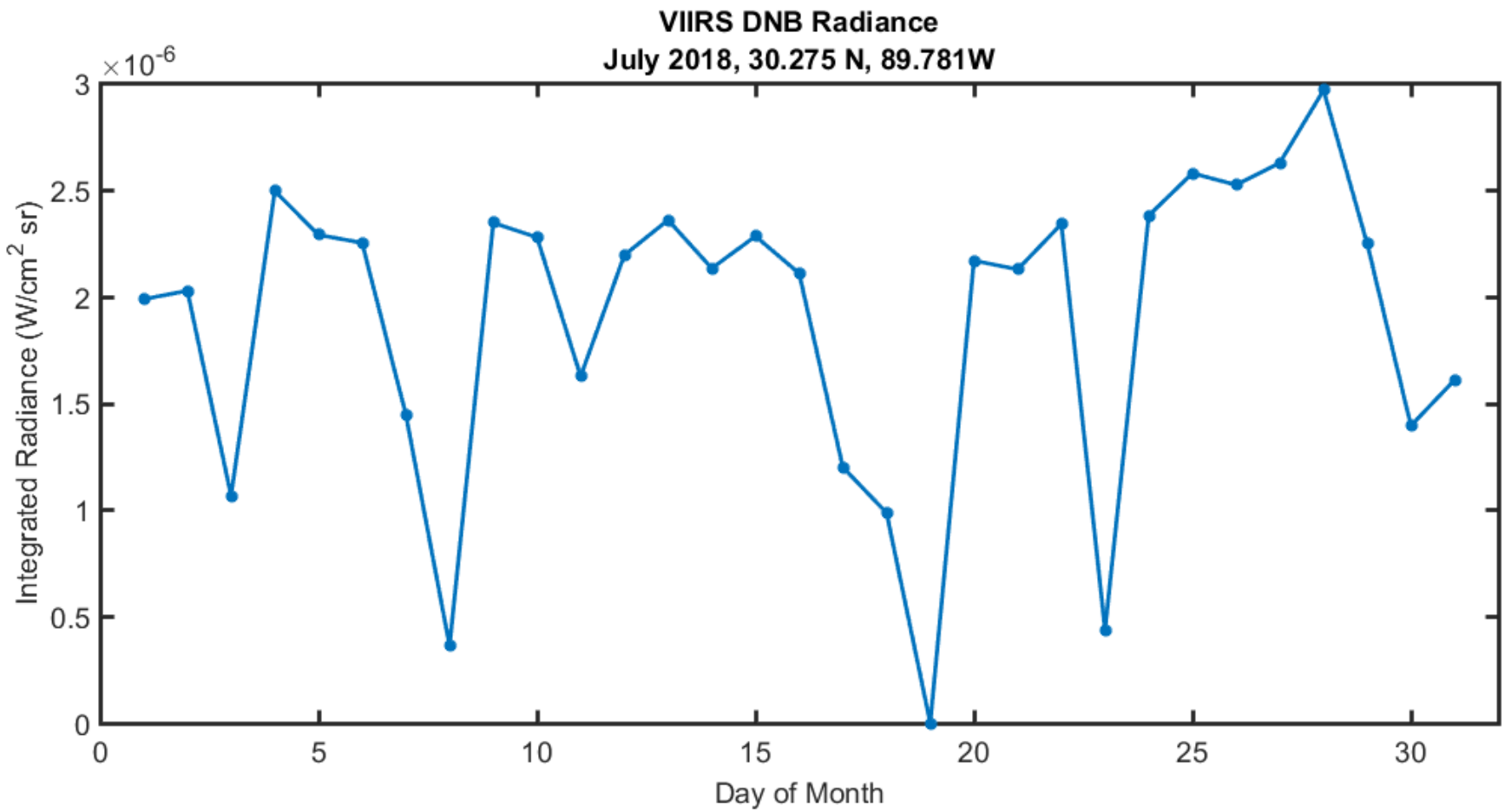
Time series movie area of interest outlined red

Slidell Time Series VIIRS (MOVIE)



Time Series Integrated Radiance

Note large variability



SBIR Project Objectives

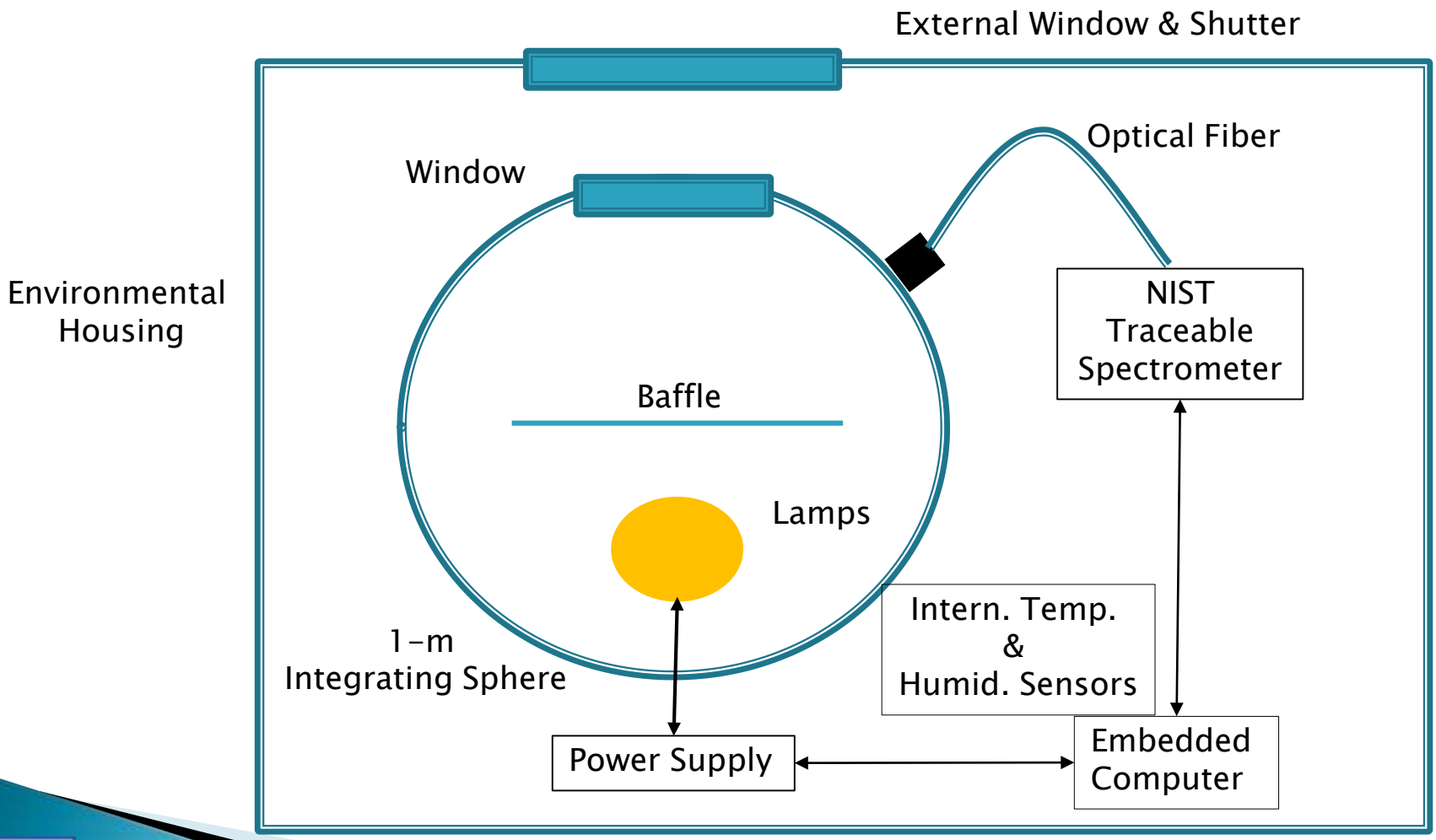
- Develop and test an **Accurate Active Light Source** (AALS) at selected calibration sites to compliment the calibration/validation of the VIIRS DNB under low light level conditions

Performance Parameter	Performance Goal
Effective radiance output	$> 3\times10^{-9}$ W cm^{-2} sr^{-1}
Corrected systematic drift	$< 1\%$
TOA absolute radiometric accuracy (SI traceable)	Accurate to within 5%
Viewing angle	$\pm 30^{\circ}$ Updated from $\pm 10^{\circ}$

Proposed VIIRS DNB HGS Calibration Concept

- Use a well calibrated active source to produce a known radiance
  - Operate under low illumination conditions (moon rises after or sets before overpass)
  - Measure illumination source and other light sources
  - Provide means for local atmospheric correction
    - Supports algorithm development

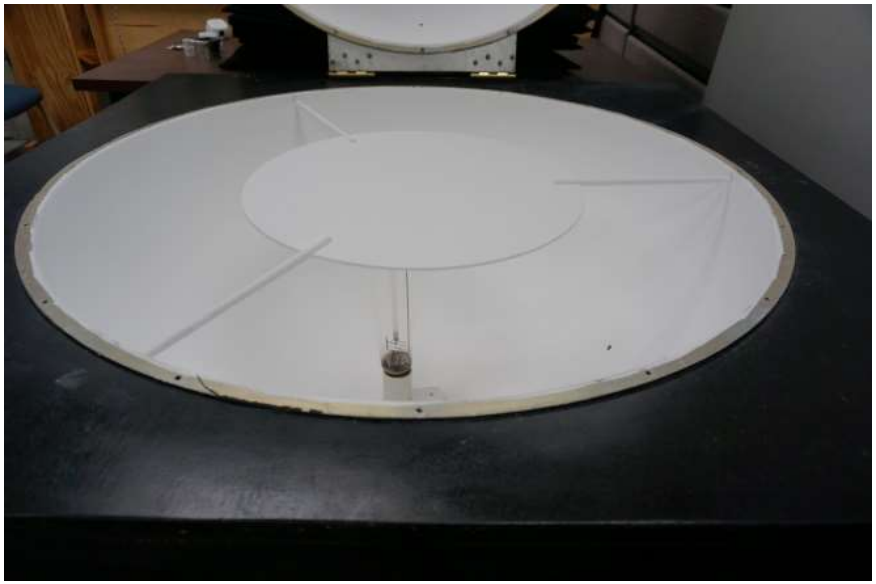
AALS Principle of Operations



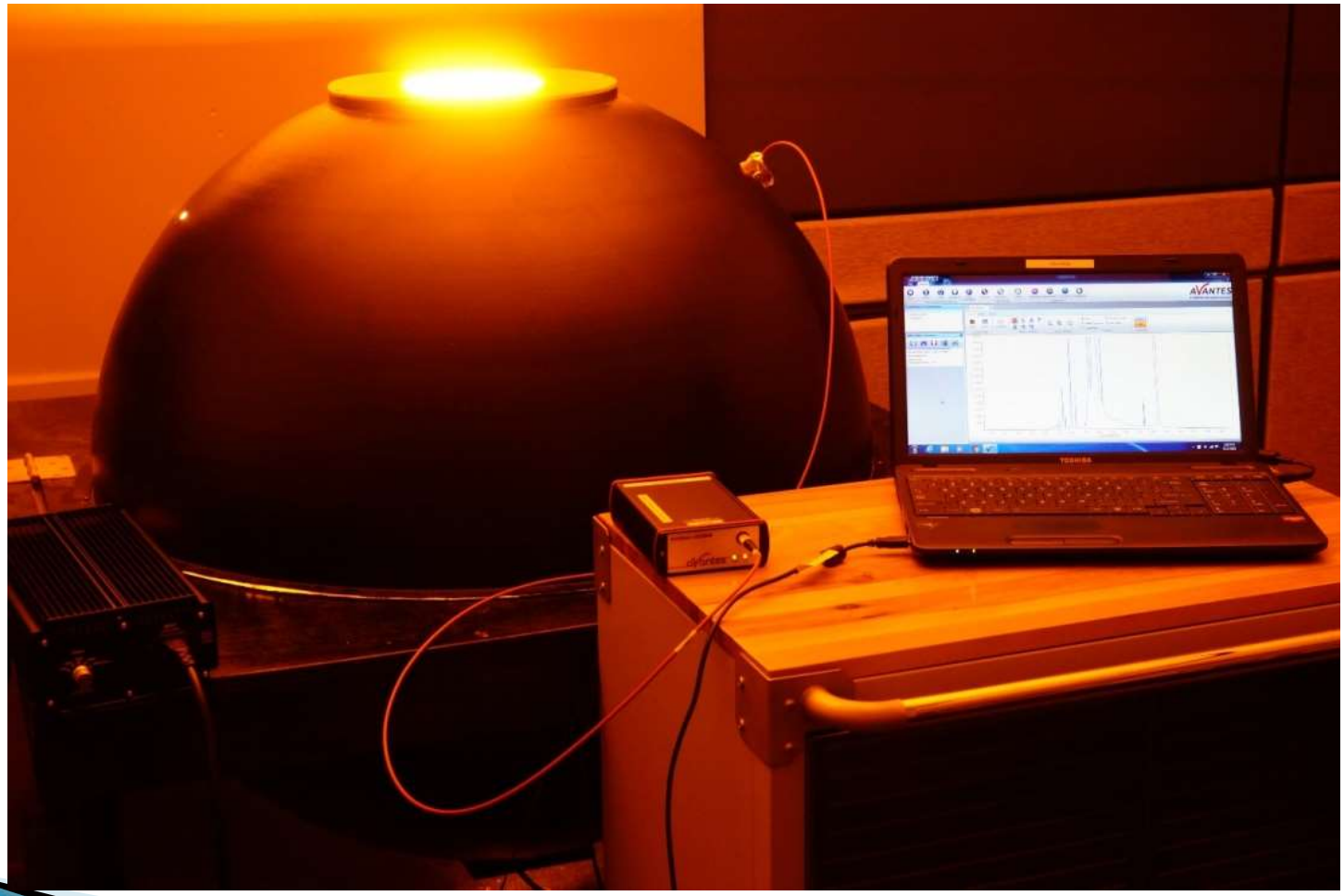
First Generation AALS

- Large Integrating sphere with 4 KW of High Pressure Sodium Lamps
  - Far field angular dependence is well-known, easily modeled and characterized.
  - Source radiance monitoring built into the sphere (Expected to better than 3-5% in field)
  - Radiance level ~8x Lmin many times larger than most moonless backgrounds and even moon lit backgrounds

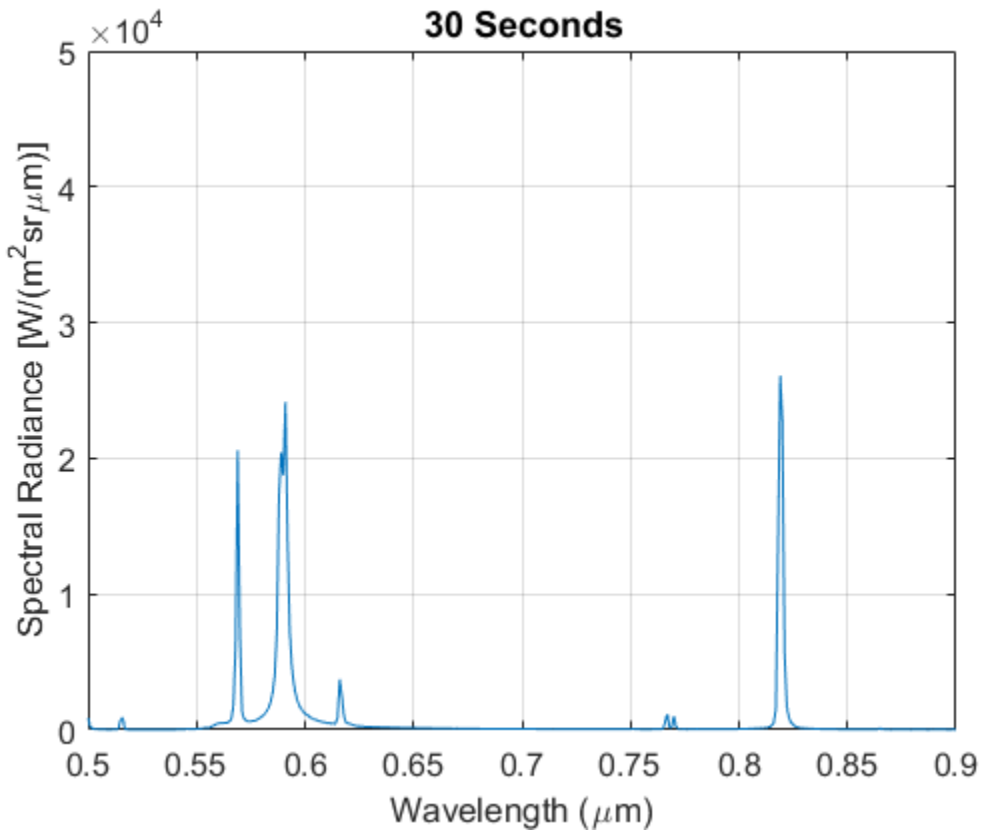
1000 W HPS Lamp Installed within 1-m Diameter Integrating Sphere



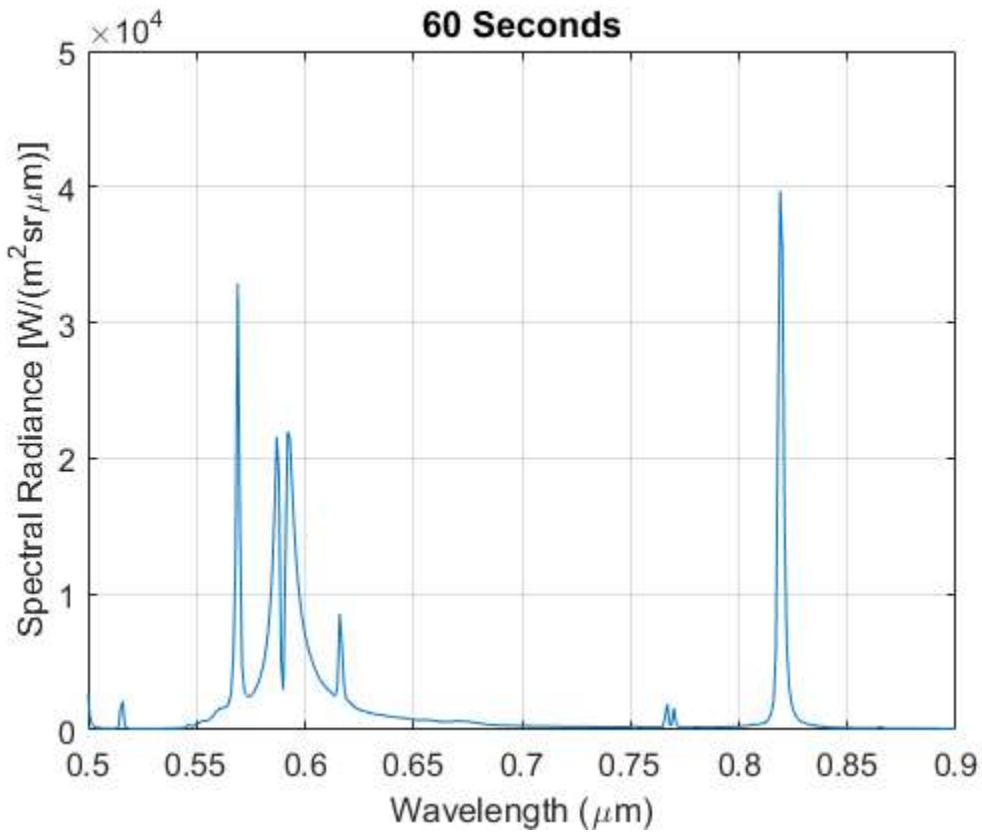
Proof of Concept: 1-m Diameter Integrating Sphere and HPS Lamp On



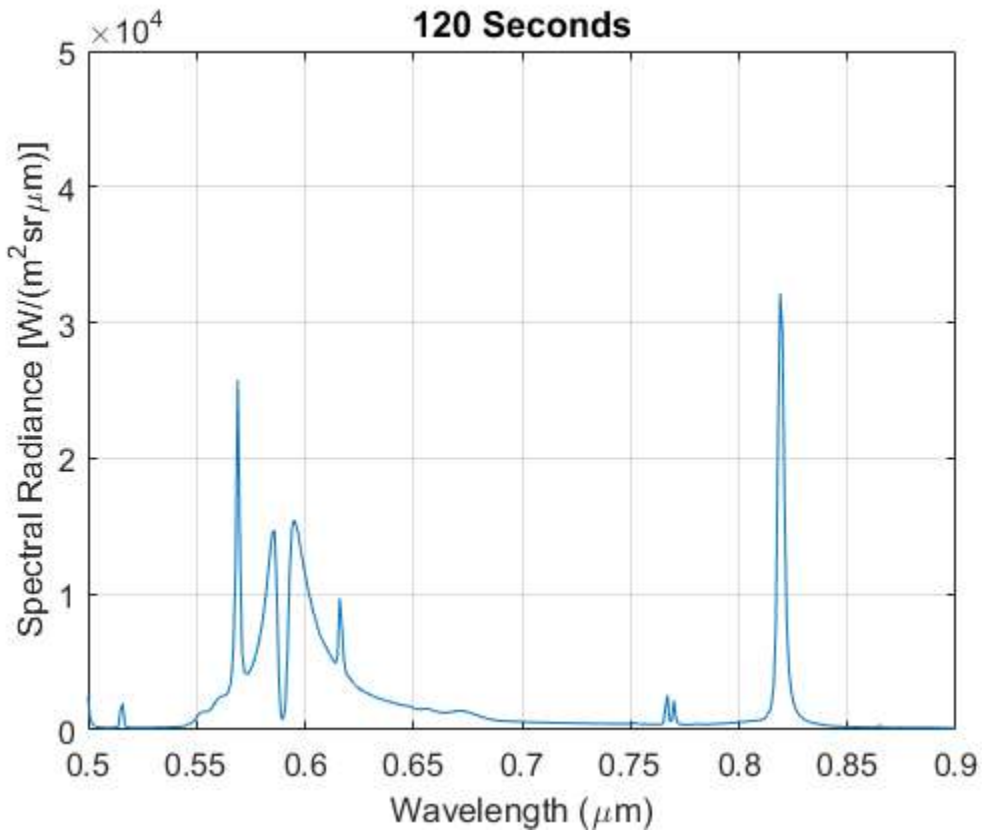
1000 W HPS Warmup @ 30 Sec



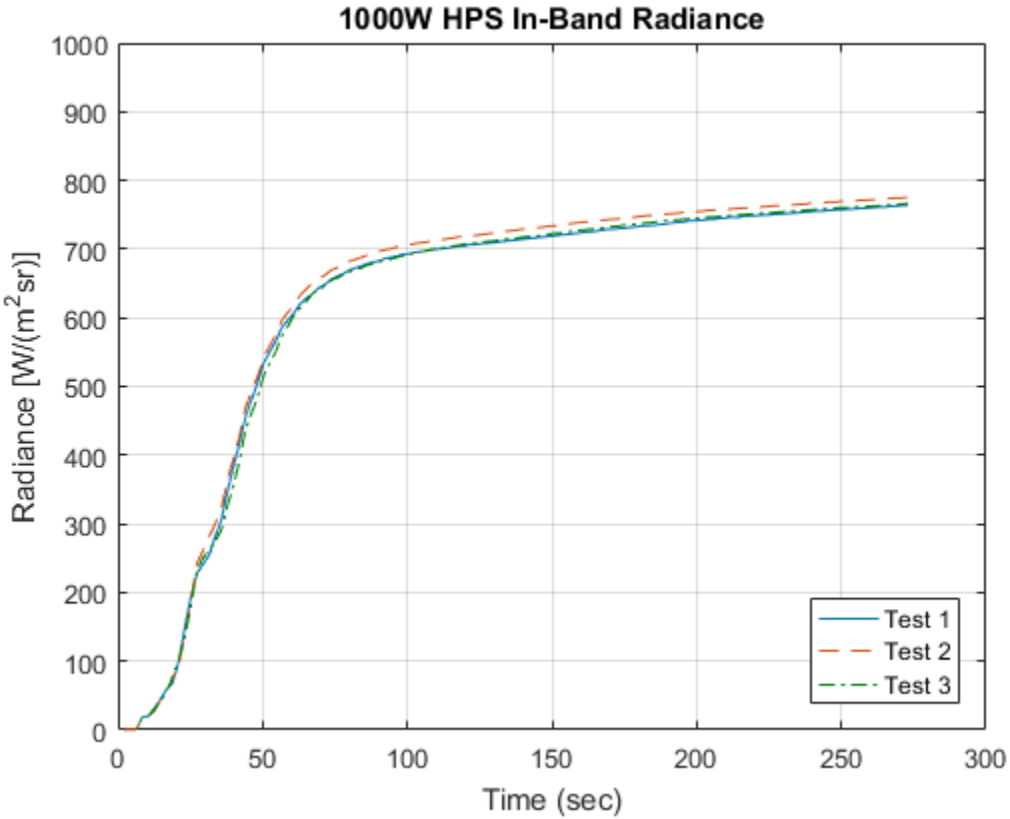
1000 W HPS Warmup @ 60 Sec



1000 W HPS Warmup @ 120 Sec



1000 W HPS Warmup



AALS Deployment

Spring-Fall, 2017

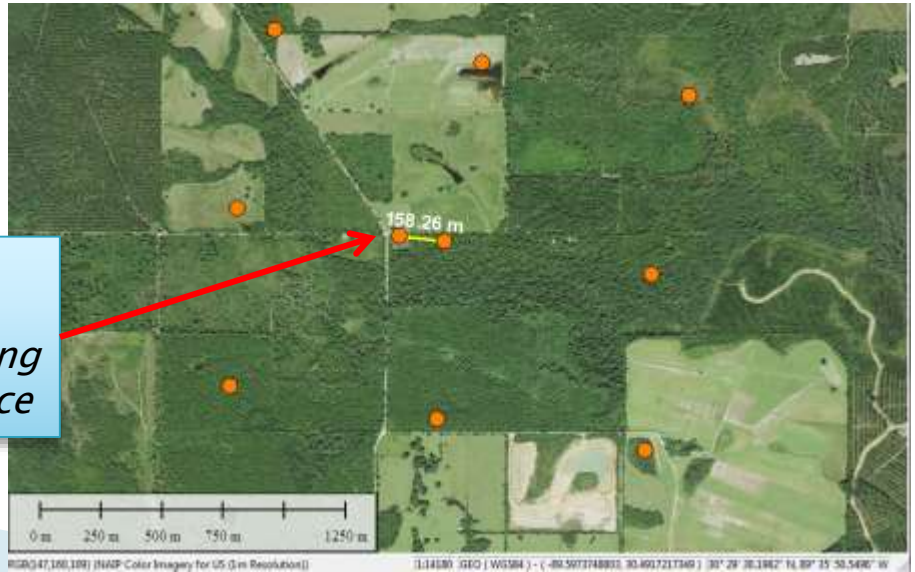
Deployment Overview

- I2R developed an active radiometric calibration for the VIIRS DNB HGS
  - ~ 160-180 W/sr at the surface
  - Calibration source powered using a gas generator, battery bank or wall power
  - Radiance output monitored using a NIST traceable spectrometer
- AALS deployed in spring 2017 in the SSC BUFFER Zone
  - Functionality test and verification that VIIRS could see light
- AALS deployed in September-October 2017 near Brookings South Dakota

AALS Proof of Concept SSC Building 1103 (Battery Pack Operation)

First Acquisition Summary

- I2R radiometric calibration source deployed at a location within the Stennis Space Center buffer zone with little to no background illumination
  - Typical background radiance < 1e-9 W/cm^{2}sr
- VIIRS overpass occurred on March 23, 2017 at 07:44:38 UTC (2:55:38 AM CDT)
  - Target location ~ 158 m east of pixel center for this collect



Pixel center locations from 3/23/17 image marked with orange circles; arrow is pointing to location of calibration source

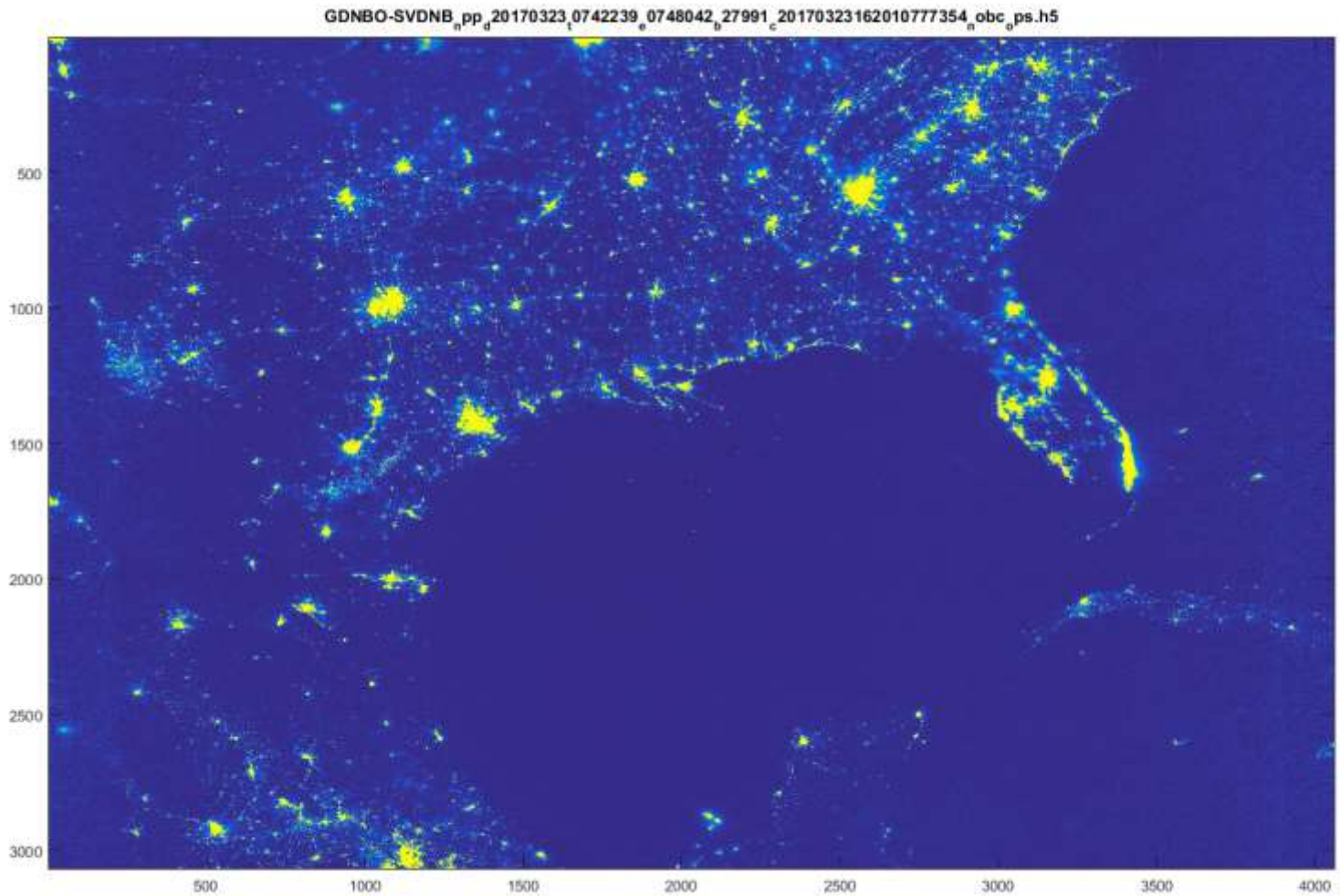
Calibration Source Field Test

Calibration source tested ~1.5 hours before overpass; All 4 bulbs illuminated

Calibration Source at Overpass

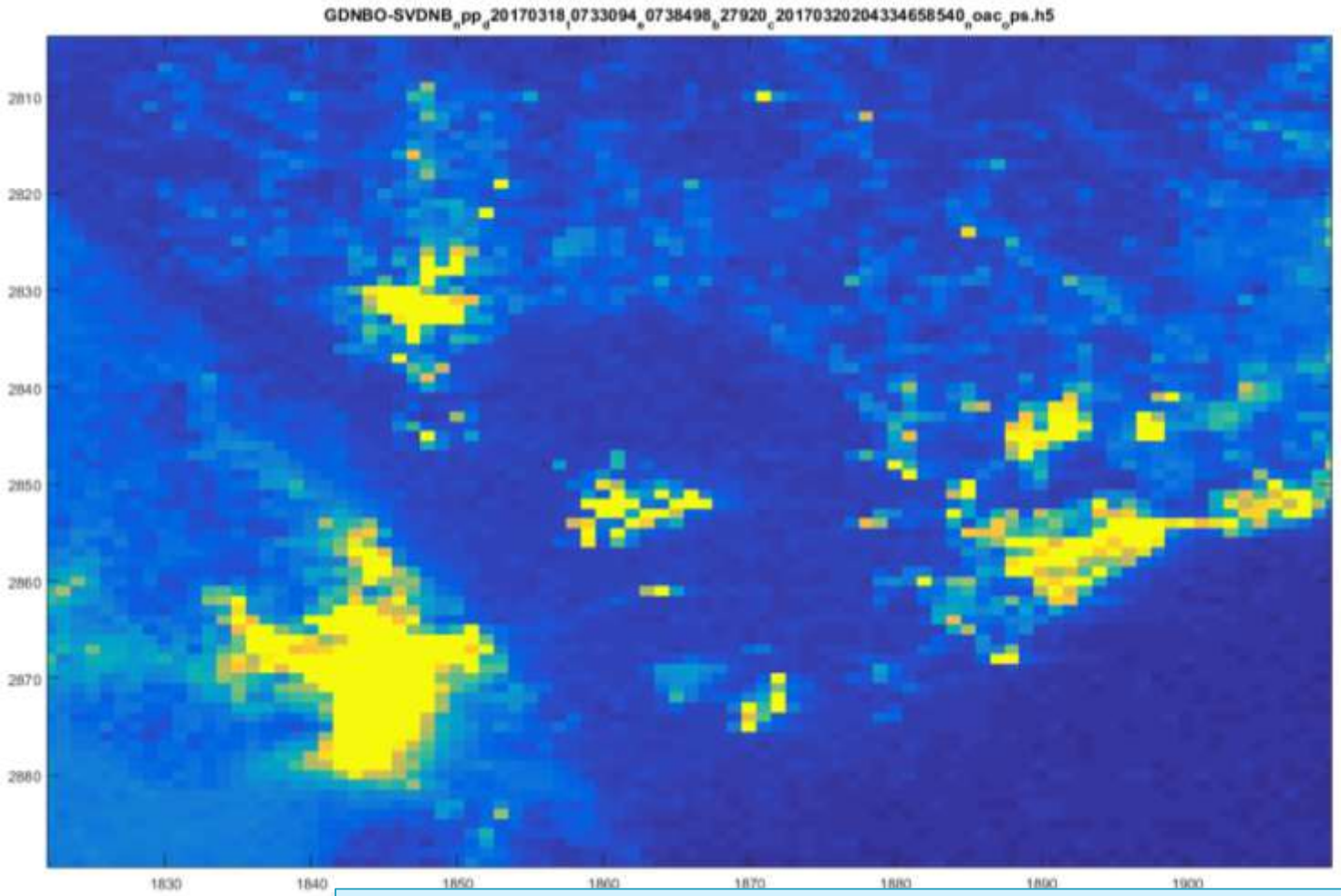
Calibration source illuminated ~20 minutes prior through ~5 minutes after; Only 2 bulbs illuminated

VIIRS DNB Image



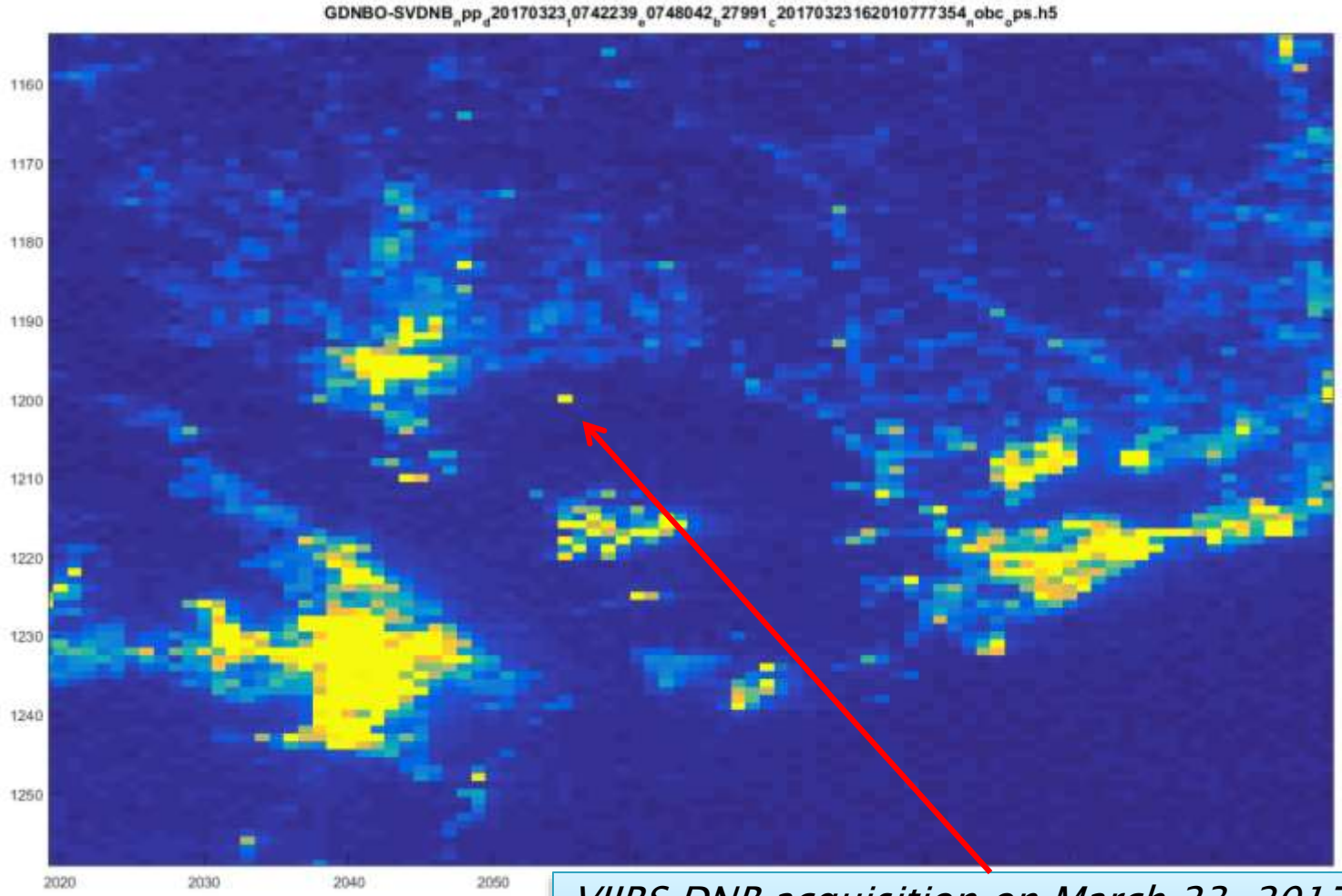
VIIRS DNB acquisition on March 23, 2017

VIIRS DNB Image without Source



For comparison, VIIRS DNB acquisition from March 18, 2017, without source (pixel same as background)

VIIRS DNB Image with Source



VIIRS DNB acquisition on March 23, 2017 (arrow pointing to source-illuminated pixel)

AALS on at SDSU

AALS Being Crated and Shipped to Local Farm

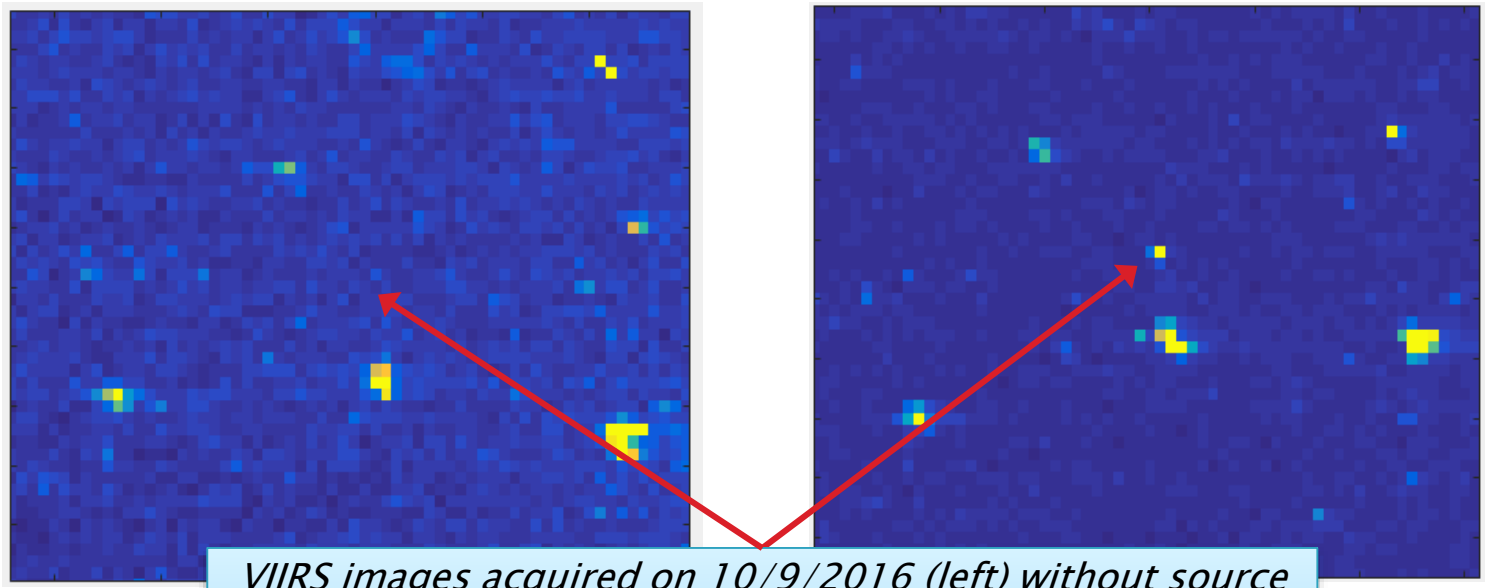
AALS at Local Farm

AALS Being Operated at Farm

AALS Being Operated at Farm

Site Information

- Farm Location: 44.41N, 97.13W
  - Approximate elevation 0.49 km
- Typical site background radiance measured over 3 acquisitions in 2016 ~ $2.43e^{-10}$ W/cm^{2}sr



VIIRS images acquired on 10/9/2016 (left) without source and 9/28/2017 (right) with active calibration source. Red arrow pointing to Farm Site in both images

Processing Overview

- VIIRS DNB calibration performed by comparing VIIRS measured target radiance to top-of-atmosphere (TOA) radiance estimated from ground truth
- Ground truth components of the TOA radiance estimate:
  - Calibration source output radiance measured with NIST traceable spectrometer
  - Daytime Aeronet optical depth used to estimate atmospheric transmission in MODTRAN and determine MODTRAN parameters

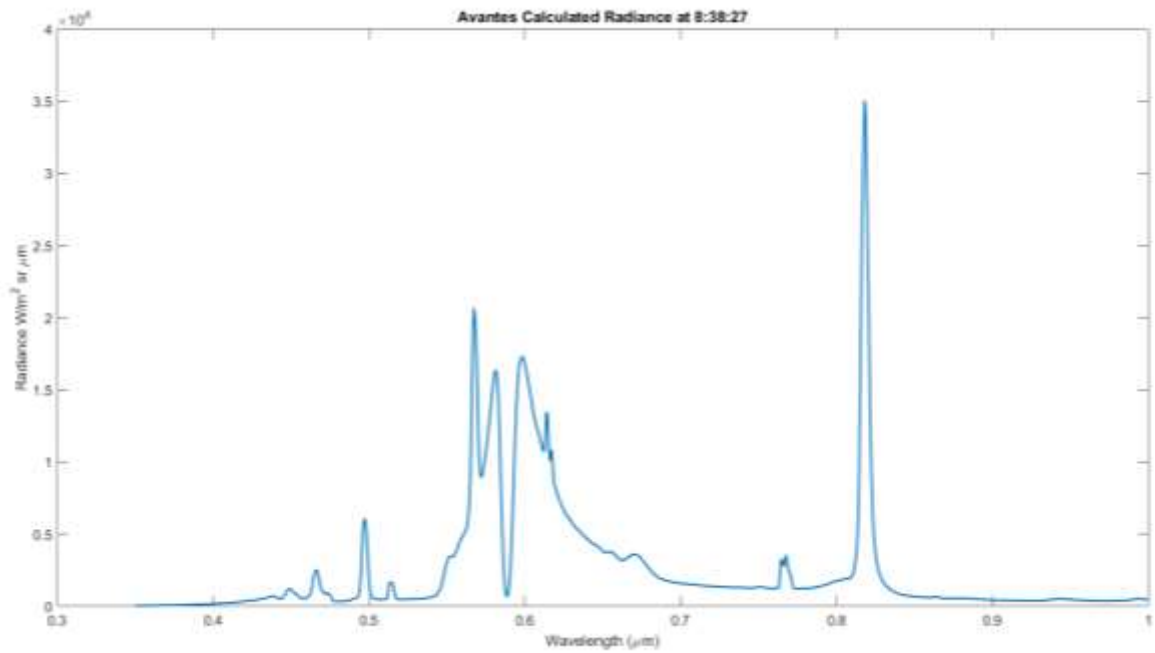
VIIRS Measured Radiance

- VIIRS radiance calculated from downloaded imagery
- Target pixel containing the calibration source located using latitude/longitude
  - 3x3 area around target pixel extracted
- Average background radiance estimated
  - Mean of the 16 pixels around the 3x3 target area
- Total target radiance is background corrected
  - Each 3x3 pixel is background subtracted
  - Corrected 3x3 pixels are summed to give the total calibration source radiance

$$Total\ Radiance = \left(\sum_{i=1}^{3}\sum_{j=1}^{3} Tgt\ Pixel_{ij}\right) - 9 * Avg\ Bg\ Radiance$$

Spectrometer Radiance

- Calibrated spectroradiometer used to monitor sphere radiance every 5 seconds
  - Spectra from +/- 30 seconds of overpass time are converted to radiance
  - Radiance spectra are averaged and stored for TOA Radiance calculation



Radiance spectra from Sept. 28, 2017 acquisition

2017 Overpass Summary

- Fall 2017 had 3 VIIRS acquisitions coincident with the active calibration source

Date	Time (UTC)	Satellite	View Zenith Angle	Atmospheric Conditions	Lunar Conditions
9/28/17	08:38:28	NPP	14.737°	Clear	No Moon
9/29/17	08:19:41	NPP	13.236°	Haze or Fog at Overpass	No Moon
10/20/17	08:25:59	NPP	3.319°	Clear	No Moon

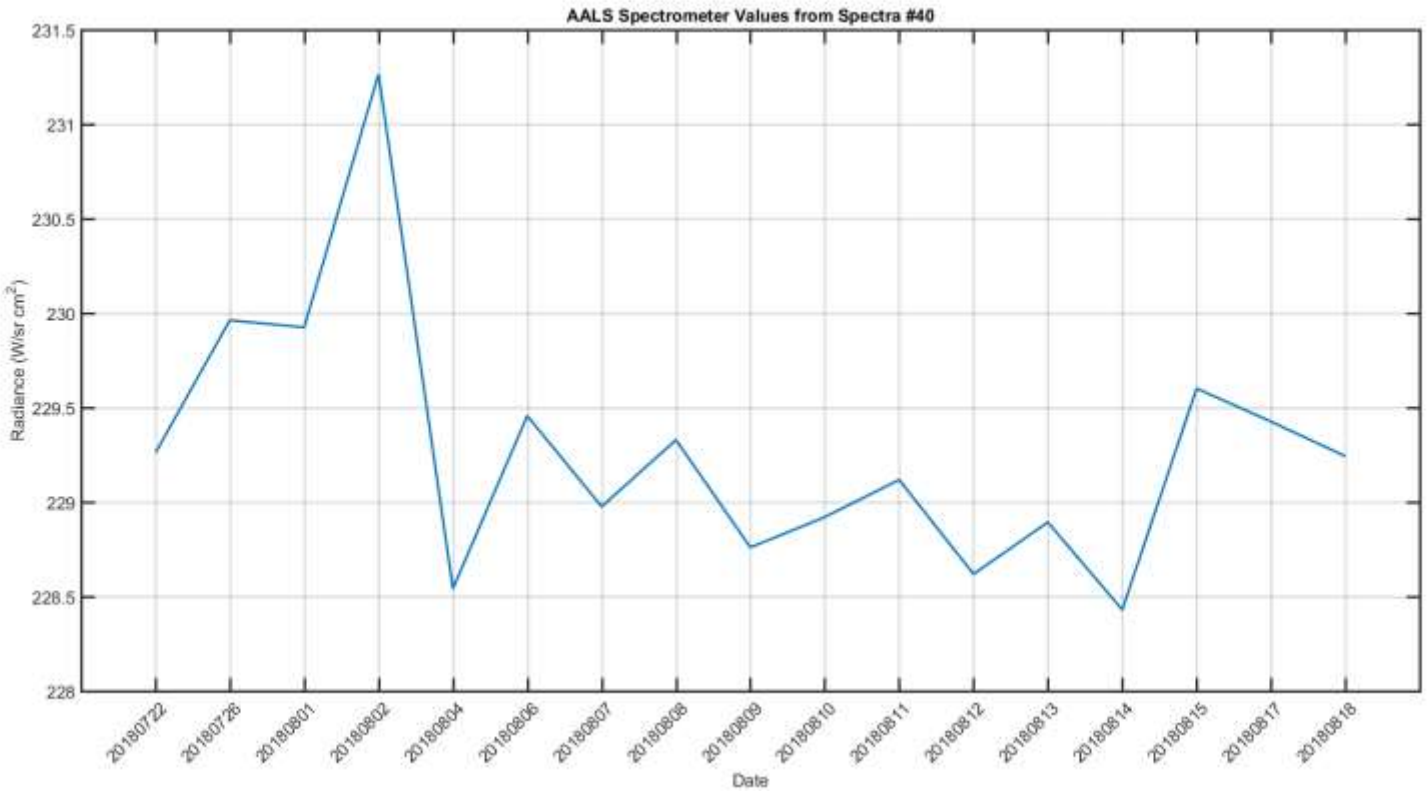
2018 VIIRS Overpass Summary

- The active calibration source was operated for 19 VIIRS overpasses during July – August 2018
  - AALS stability over these days better than 1%
- Of these, 6 dates were determined to have clear atmospheres (determined by visual inspection at time of overpass)

Date	Time (UTC)	Satellite	View Zenith Angle	Atmospheric Conditions	Lunar Conditions
8/2/18	08:12:16	NOAA-20	21.979°	Clear	Full moon
8/9/18	08:31:41	NPP	5.041°	Clear	Rising (within 0.5 hour)
8/11/18	**08:43:37**	**NOAA-20**	**23.451°**	**Clear**	**No moon**
8/17/18	**08:31:08**	**NOAA-20**	**5.811°**	**Clear**	**No moon**
8/22/18	**08:37:25**	**NOAA-20**	**15.011°**	**Clear**	**No moon**
8/23/18	08:18:39	NOAA-20	12.956°	Clear	Setting (within 0.5 hour)

- For the 2018 preliminary calibration, only dates with no lunar illumination (bolded) were included
  - Corrections for lunar illumination are being developed and tested

AALS Stability



MODTRAN Parameters

Date	Atmosphere	Aerosol Model	Water Vapor Scaling	Ozone Scaling	Asymmetry	Visibility
9/28/17	Mid-Latitude Winter	Rural	1x	1x	G = 0	150 km
9/29/17	Mid-Latitude Winter	Rural	2x	1x	G = 0	150 km
10/20/17	Mid-Latitude Winter	Rural	2x	1x	G = 0	75 km
8/2/18	Mid-Latitude Summer	Tropospheric	1x	1x	G = 0	27 km
8/9/18	Mid-Latitude Summer	Rural	1x	1x	G = 0	32 km
8/11/18	Mid-Latitude Summer	Tropospheric	1x	1x	G = -1	11 km
8/17/18	Mid-Latitude Summer	Rural	2x	2x	G = 0	27 km
8/22/18	Mid-Latitude Summer	Tropospheric	1x	1x	G = 0	33 km
8/23/18	Mid-Latitude Summer	Rural	1x	1x	G = 0	33 km

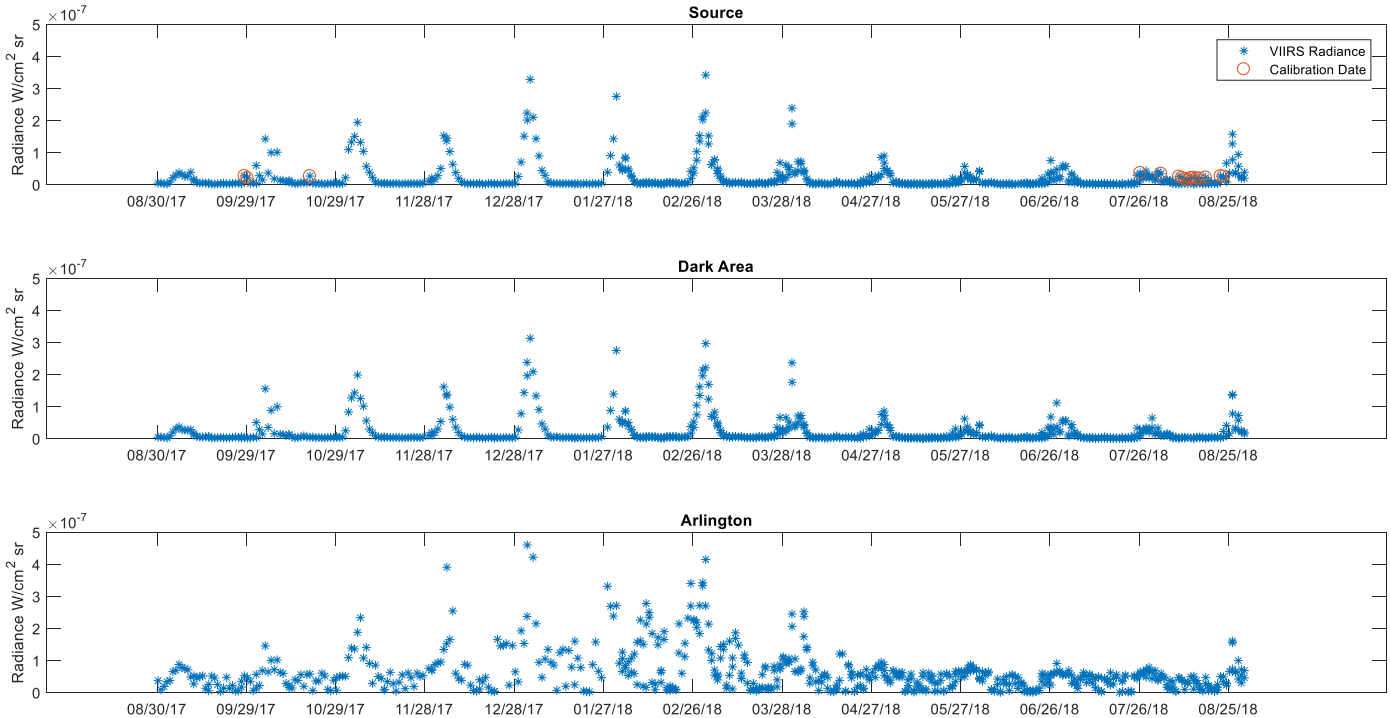
Preliminary Results Summary

(Days with No Moon)

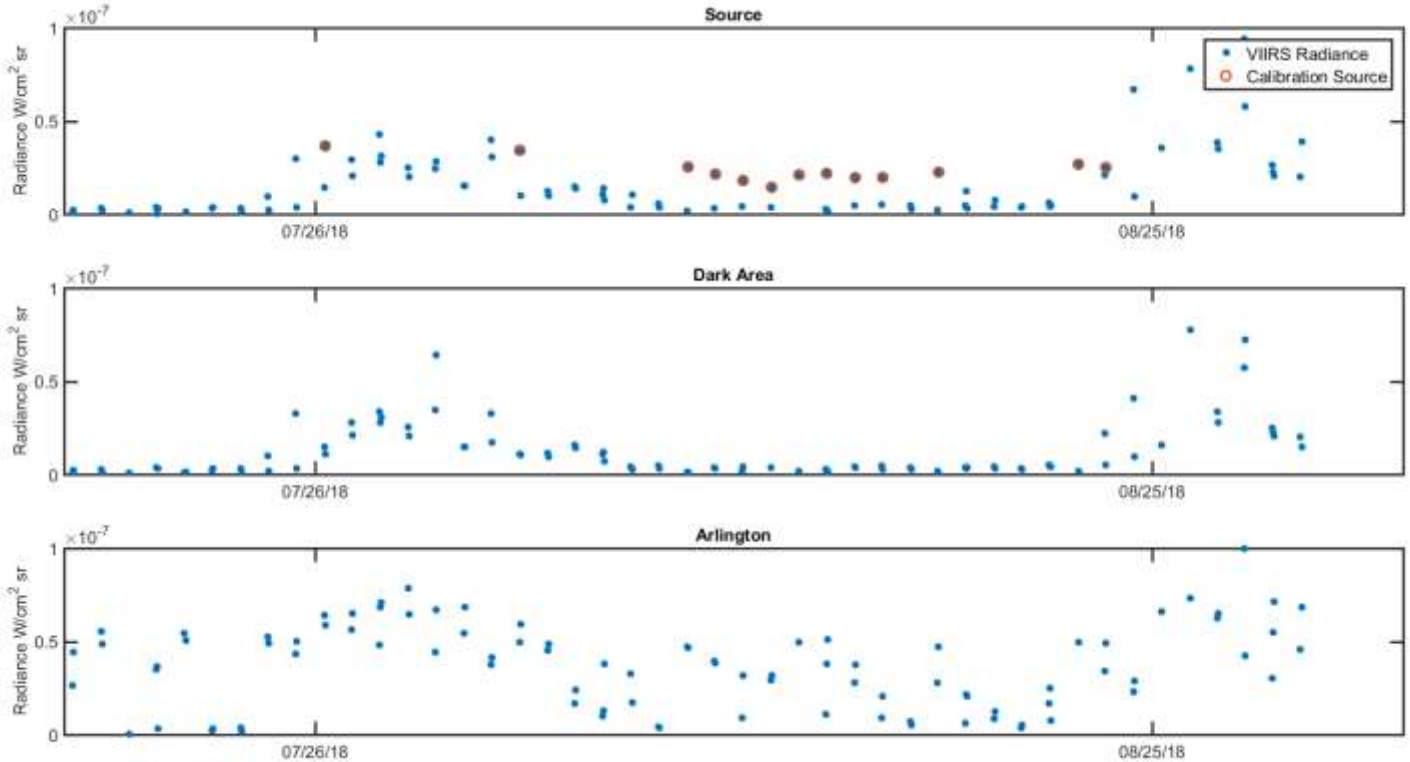
Date	Satellite	Estimated TOA Radiance using MODTRAN (W/cm^2 sr)	VIIRS Background Radiance (W/cm^2 sr)	VIIRS Target Radiance (W/cm^2 sr)	Percent Difference 100*(1 – TOA/VIIRS)	Reason for Rejection
9/28/17	NPP	$2.371e^{-8}$	$3.323e^{-10}$	$2.486e^{-8}$	4.6 %	N/A
9/29/17	NPP	$2.406e^{-8}$	$3.761e^{-10}$	$1.741e^{-8}$	-38.2 %	Haze or Fog
10/20/17	NPP	$2.391e^{-8}$	$5.422e^{-10}$	$2.201e^{-8}$	-8.6 %	N/A
8/2/18	NOAA-20	$1.957e^{-8}$	$1.214e^{-9}$	$2.291e^{-8}$	14.6 %	Full Moon
8/9/18	NPP	$2.184e^{-8}$	$3.575e^{-10}$	$1.861e^{-8}$	-17.4 %	Rising Moon
8/11/18	NOAA-20	$1.467e^{-8}$	$9.385e^{-11}$	$1.408e^{-8}$	-4.2 %	N/A
8/17/18	NOAA-20	$2.028e^{-8}$	$1.809e^{-10}$	$2.084e^{-8}$	2.7 %	N/A
8/22/18	NOAA-20	$2.202e^{-8}$	$3.04e^{-10}$	$2.396e^{-8}$	8.1 %	N/A
8/23/18	NOAA-20	$2.15e^{-8}$	$6.339e^{-10}$	$1.937e^{-8}$	-11.0 %	Setting Moon
				Average Difference (without rejected dates)	**0.52 %**	

Note that the Aeronet assumption (nighttime aerosols ~average of surrounding days) does not hold for the 9/29/17 data set. An improved method of determining visibility is required.

Raw Time Series (AALS Source Near Arlington SD)



Background Time Series (AALS Source Near Arlington SD) (Temporal Zoom)



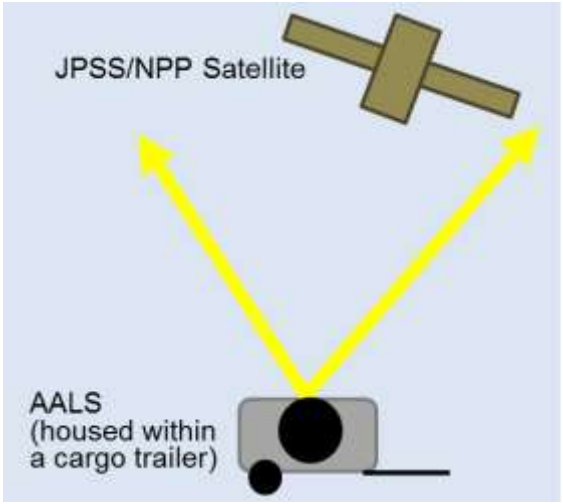
Evidence that the source can be used for validation of the NASA Black Marble Product and other time series work.

Summary

- Early Ground-based Artificial Light Source Radiometric Calibration has been deployed in both Mississippi and South Dakota
- Expected Ground Integrating Sphere Radiance uncertainty 3-5% (Work in progress)
- Atmosphere knowledge is largest uncertainty in TOA radiance
  - Early measurement differences (AALS/VIIRS) < 10% on clear nights

Current Project State

- NOAA is providing funding to test this fall
- Light source is being moved into a trailer with movable roof to protect unit



Future Directions

- AALS is a near ideal point source which could be used to bound the accuracy and uncertainty in artificial light source time series

Backup

VIIRS DNB Overview and Application

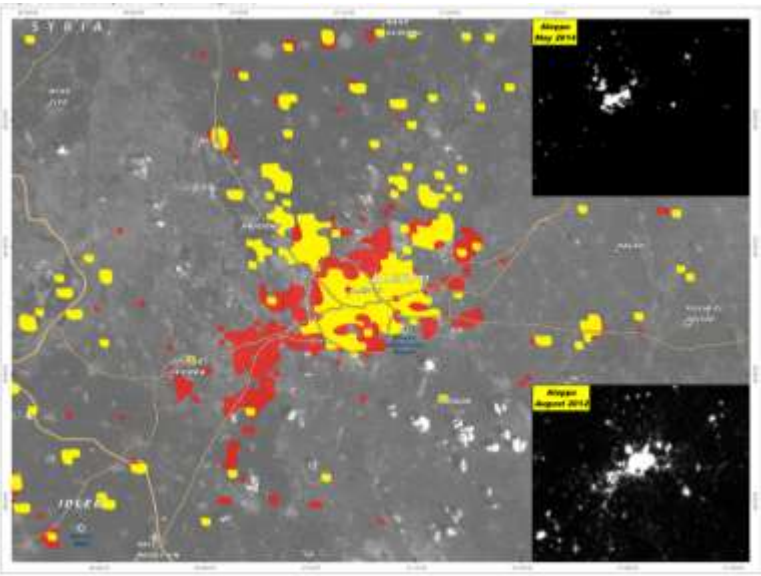
- Defense/Intelligence
- Energy Use and Power Consumption
- Commercial Development/Property Management
- Air Quality and Visibility

"Night-time light can be used as a proxy for…urbanization, density, and economic growth"

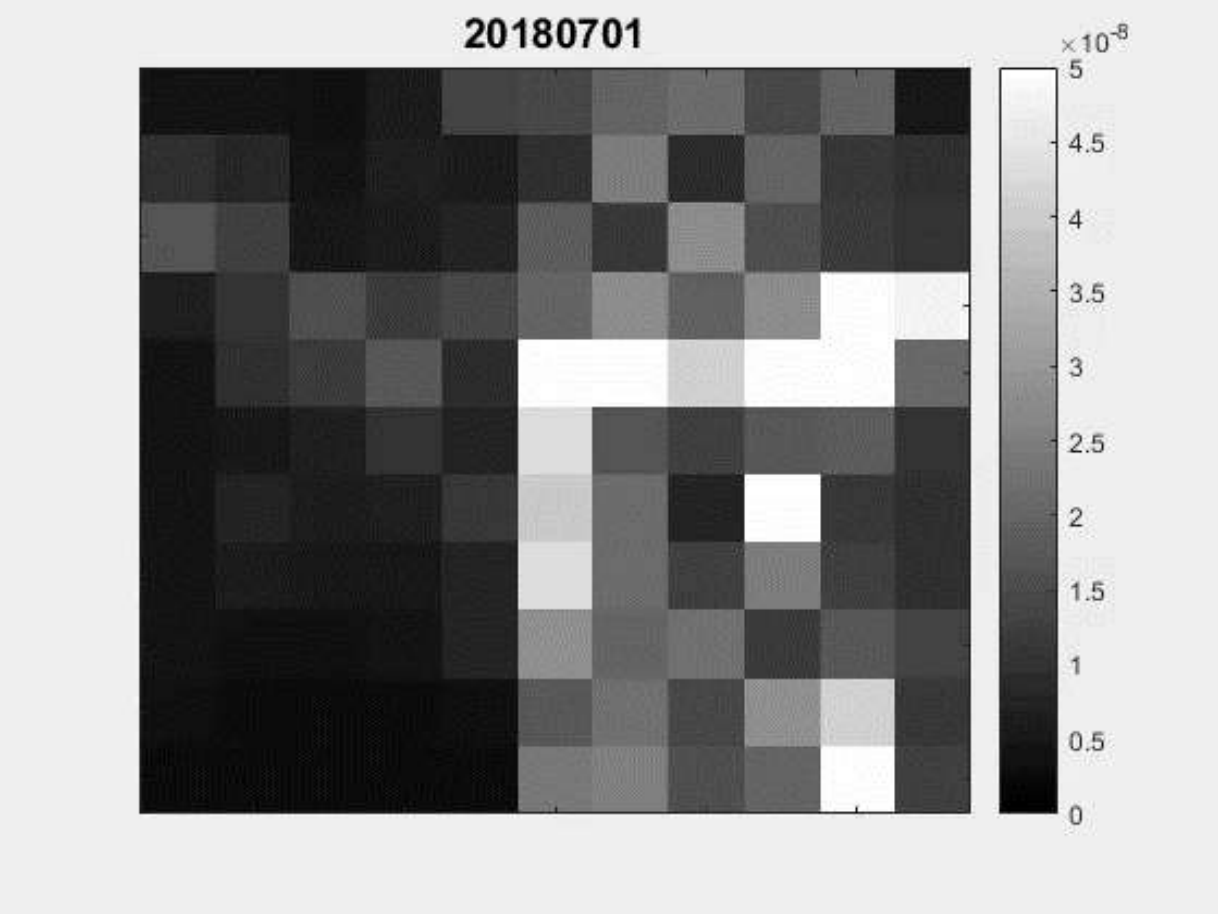
"The costs associated with street lighting accounts for up to 66% of all energy costs for a city."

Night-time light is more important in areas with reduced census information

VIIRS Aleppo Syria 2012/2014



Slidell Time Series VIIRS (MOVIE)



AALS –Turns Night Imagery into Valuable Quantifiable Information

Solution: AALS – Accurate Active Light Source

Innovative sphere-based technology that brings optical laboratory calibration techniques to the field enabling never-before nighttime information

NOAA-funded Phase II SBIR (VIIRS)

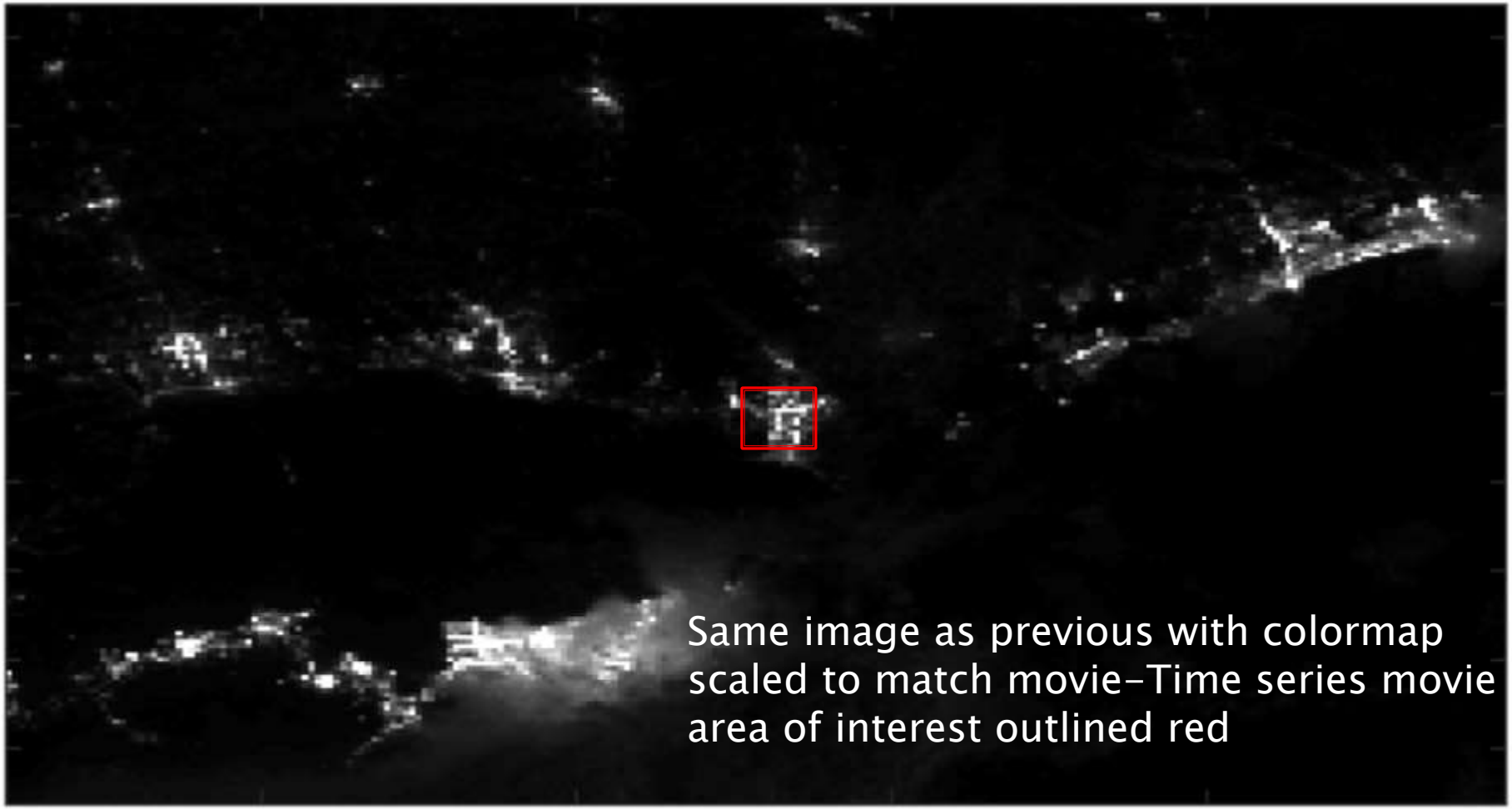
Dual Use

Application Time Series (Problem Statement Restated)

- Time series and change detection quality depends on
  - Sensor radiometric stability
  - Knowledge of the atmospheric conditions
  - Artificial light source characteristics
  - Lunar illumination and BRDF correction
  - Straylight

- Improved HGS calibration could open up new applications

VIIRS DNB Image (scaled)
Louisiana – Mississippi Zoom Area, July 5, 2018



Atmospheric Transmission

- Atmospheric transmission is estimated using Aeronet data
  - Aeronet version 3 data used (if available)
  - L1.5 total optical depth used (L2 data not yet available)
- Total optical depth at 6 wavelengths converted to transmission
  - Air mass corresponding to the sensor elevation angle used
  - Transmission values at each wavelength from the day prior and day after the overpass are averaged
- MODTRAN transmission is estimated for sensor elevation angle and a series of visibilities
  - MODTRAN transmission at 6 wavelengths compared to Aeronet transmission
  - Least squares used to determine the best visibility that matches Aeronet transmission
    - Model atmosphere, ozone, and water vapor values may be modified to improve visibility match

TOA Radiance

- TOA Radiance estimated by combining spectrometer measured radiance with estimated transmission to space
  - Average radiance spectra scaled by:
    - Exit port area
    - MODTRAN estimated atmospheric transmission
    - Cover glass transmission
    - 1/(VIIRS pixel area)
    - Cosine of the view zenith angle to sensor
  - Scaled radiance spectra integrated over the VIIRS DNB
- Single TOA Radiance value produced for each VIIRS overpass