I2R Innovative Imaging & Research

Radiometric Calibration/Validation of the VIIRS Day-Night Band High Gain Stage Using Ground-based Artificial Light Sources

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- Vince Garcia SBIR Program Manager

VIIRS Overview

- Visible Infrared Imaging Radiometer Suite (VIIRS) is a scanning radiometer capable of measuring land, atmosphere and ocean properties
  - Continues and extends measurements made by the Moderate-resolution Imaging Spectrometer (MODIS) and the Advanced Very High Resolution Radiometer (AVHRR)
- Launched on Suomi NPP on Oct. 28, 2011
  - National Polar-orbiting Partnership (NPP) satellite
  - Planned to launch on Joint Polar Satellite System satellites JPSS-1 and JPSS-2

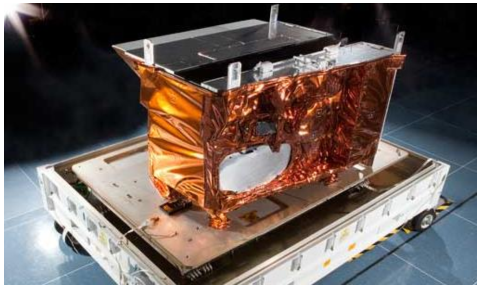
Suomi NPP

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

VIIRS Overview

- Suomi NPP is in an 824-km sun-synchronous orbit with 101.44 minute period and 98.69 inclination
- The VIIRS sensor has the following instrument specifications:
  - Swath: ±56°, 3040 km
  - Bands:5 high resolution bands, 16 Moderate resolution bands, and a day-night band (DNB) (~750-m spatial resolution)
- The Suomi NPP VIIRS DNB is enabling new nighttime imaging applications because of its high resolution and the extreme low light sensitivity in its HGS mode

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



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

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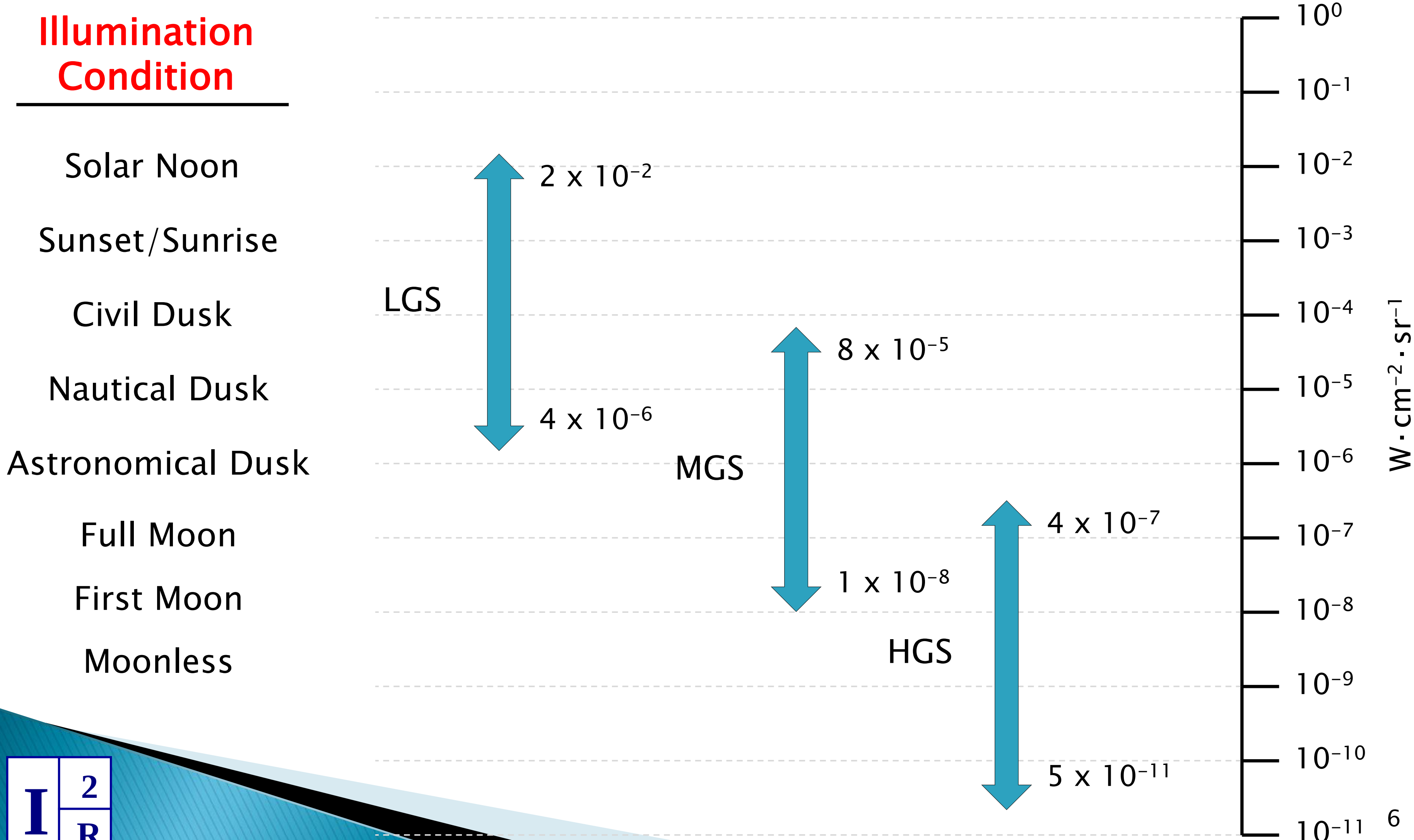
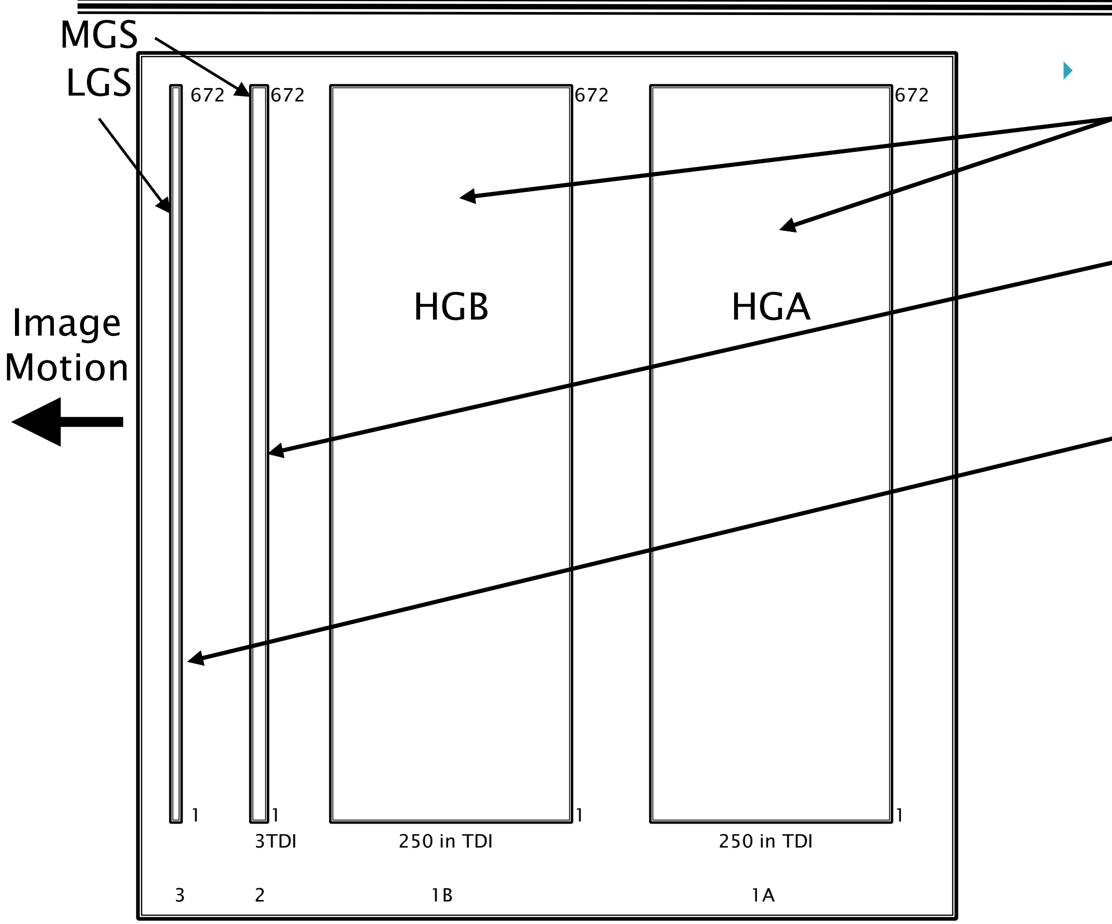
VIIRS DNB Characteristics

- Spectral range: 0.5–0.9 microns
- Quantization: 14 bits for high gain setting, 13 bits for other
- HGS L_{min}: 3e–9 [W cm^{-2} sr^{-1}]
- SNR >10 @ end of scan or ~40 at Nadir
- HGS stated calibration accuracy 15% (Spec: LGS 5%, MGS 10%, HGS 30%)
- Horizontal Sample Interval
  - ~0.75 km x ~0.75 km Nadir through end of scan

VIIRS DNB Dynamic Range



DNB Array Design



Operating Temperature = -20 C

- One CCD array sectored into 4 parts
  - Two identical high-gain stages (HGS)
    - Allows filtering of radiation impacts
    - 250 detectors in TDI
  - One mid-gain stage (MGS)
    - 3 detector TDI
    - No filter
    - 200 times less gain than HGS
  - One low-gain stage (LGS)
    - No TDI
    - 35x Neutral Density Filter
    - 475 times less gain than MGS
  - 672 detectors in-track aggregated to 16 virtual detectors with variable aggregation for constant footprint
  - Aggregation in-scan and in-track performed electronically as part of the read-out circuit using 32 aggregation modes
  - Ground resolution ~ 750x750 m across entire swath

In-band Radiance and Relative Spectral Response

- The spectral radiance is integrated by the VIIRS relative spectral response to produce a single value

$$L = \int L(\lambda) * RSR(\lambda)\, d\lambda$$

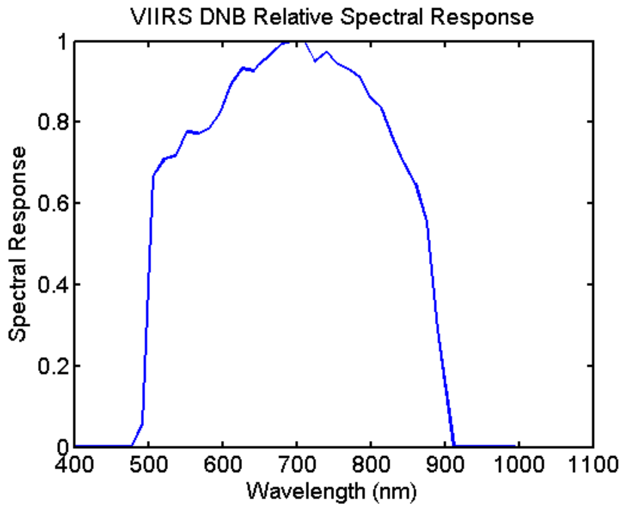
Where,

$L(\lambda)$ = spectral radiance [W cm^{-2} sr^{-1} nm^{-1}])]

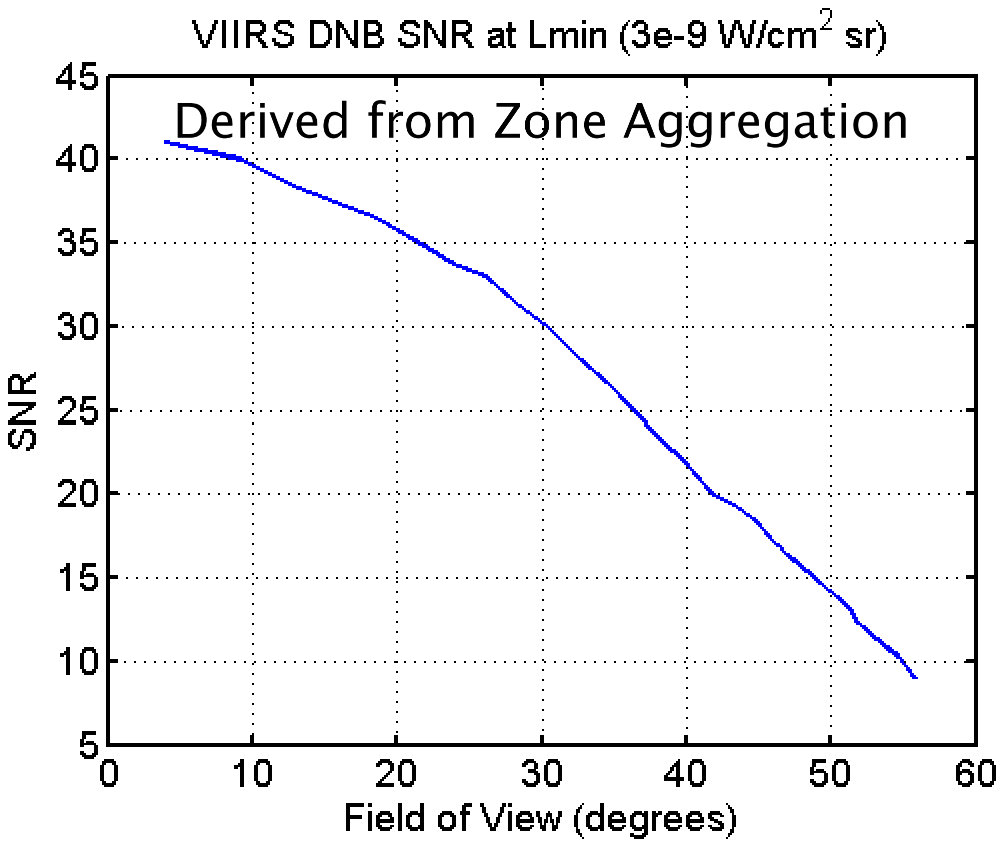
$RSR(\lambda)$ = VIIRS DNB relative spectral response

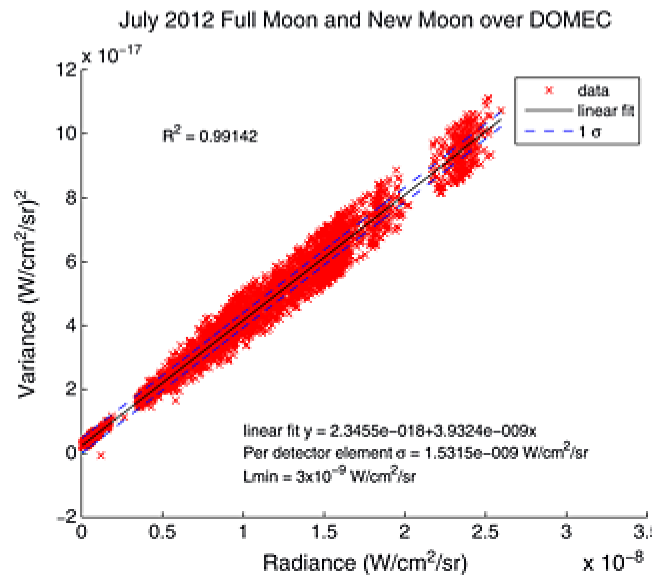
λ = wavelength

L = integrated radiance [W cm^{-2} sr^{-1}]



VIIRS DNB SNR





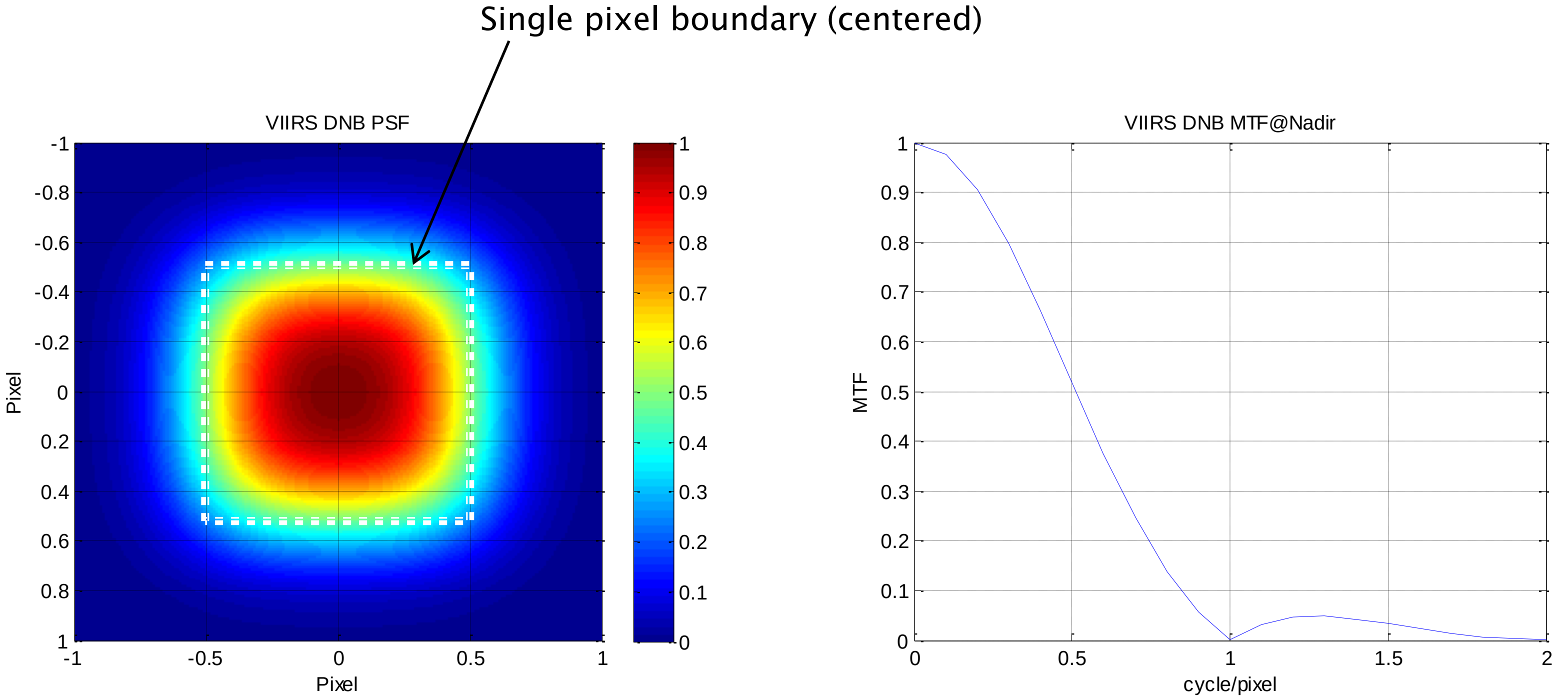
Photon noise limited!

Liao, L.B., S.Weiss, S.Mills, and B.Hauss, 2013. Suomi NPP VIIRS day-night band on-orbit performance.
Journal of Geophysical Research: Atmospheres
Volume 118, Issue 22, pages 12,705-12,718, 27 NOV 2013 DOI: 10.1002/2013JD020475
http://onlinelibrary.wiley.com/doi/10.1002/2013JD020475/full#jgrd50927-fig-0008

VIIRS DNB Characteristics (continued)

- Point Spread Function (Delivered Data)
  - Approximately a convolution of Top Hat with a Gaussian Blur
  - Horizontal Sampling Resolution (HSR) is at half the spatial wavelength for which the MTF=0.5
    - MTF(1/(2*HSR)) = 0.5
    - Measured HSR ~ 750 m in Scan and Track directions except for far off Nadir (model is 50-100 m smaller) (*Liao et al, 2013)*
- Geolocation Accuracy RMSE <100 m (~80 m)

VIIRS DNB HGS Active Calibration Source MTF and PSF Model

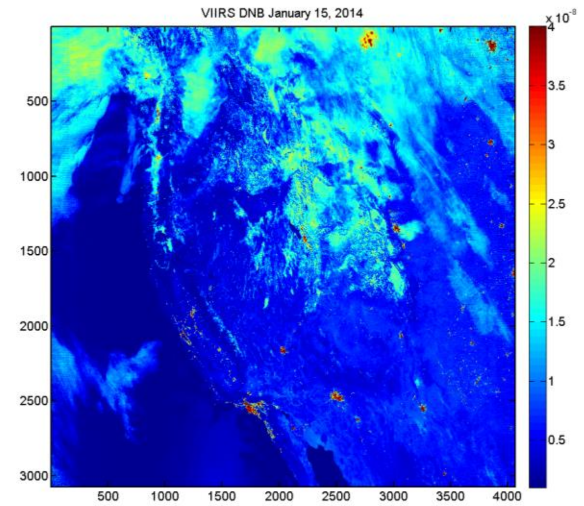


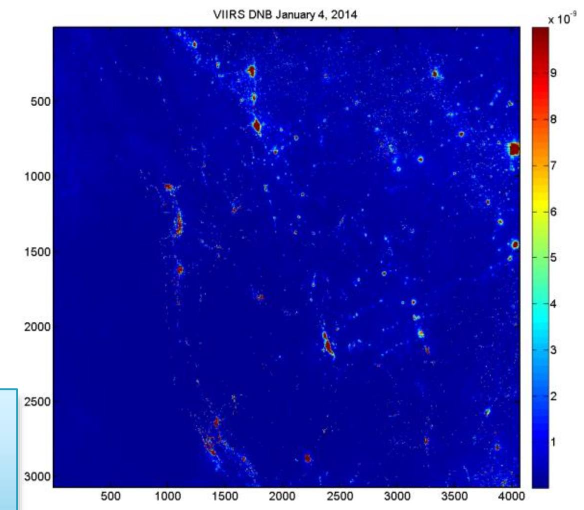
MTF at Nyquist ~ 0.52

Derived from:
Liao, L.B., S.Weiss, S.Mills, and B.Hauss, 2013. Suomi NPP VIIRS day-night band on-orbit performance. **Journal of Geophysical Research: Atmospheres**
Volume 118, Issue 22, pages 12,705-12,718, 27 NOV 2013 DOI: 10.1002/2013JD020475
http://onlinelibrary.wiley.com/doi/10.1002/2013JD020475/full#jgrd50927-fig-0008

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
  - 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 – Night Time Imaging to Aid Hurricane Sandy Response

Image credit NASA SPoRT
http://www.nasa.gov/mission_pages/hurricanes/missions/sport/blackout1.html

NASA Short-term Prediction Research and Transition Center (SPoRT) VIIRS maps Hurricane Sandy Blackout

RGB composite for Nov. 1, 2012

Yellow regions indicate urban regions with power before Hurricane Sandy, but not after.

Blue regions are the result of clouds.

"This imagery has allowed emergency response teams to expedite their response to hurricane-ravaged areas," said Dr. Gary Jedlovec, SPoRT project lead at NASA's Marshall Space Flight Center in Huntsville, Ala.

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VIIRS – Night Time Imaging to Monitor Power Outages

Power Outage Washington/Baltimore

Normal Image

http://earthobservatory.nasa.gov/IOTD/view.php?id=78445

These before and after images show the power outages over Washington, DC and Baltimore that occurred as a result of a rare, fast-moving thunderstorm system on 29 June 2012.

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)
    - Limited tests to validate
      - Northrop Grumman has used vicarious calibration at Railroad Valley but not necessarily reliable
      - Recent efforts used lunar illumination of deep convective clouds for vicarious calibration (*Ma et al, 2015)*
    - Cannot use solar diffuser
- Improved HGS calibration could open up new applications

SBIR Project Objectives

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

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

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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
  - Mitigate stray light
    - Operate further south in northern latitudes or further north in southern latitudes
    - Measure and correct

Why Care? Part I

- Remote sensing of night time artificial light sources is valuable and relatively unexplored
- Traditional remote sensing applications are based on extended targets illuminated by solar/lunar natural sources
  - Limited calibration experience with artificial active point sources
    - Schiller SPARC approach is an artificial point source based method based on solar illumination

Why Care? Part II

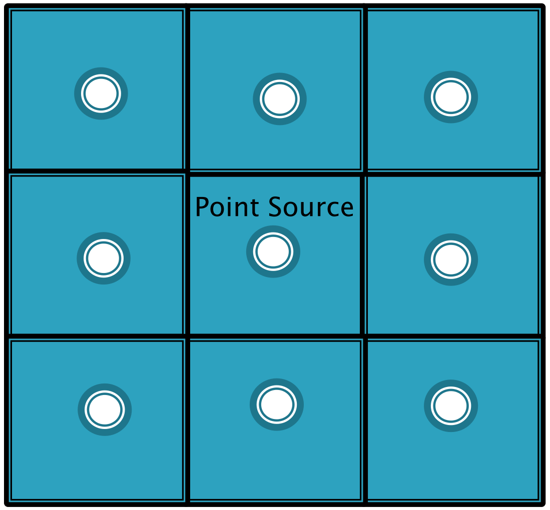
- Reference active point source would be valuable to develop new applications
  - Removes uncertainty in light source
  - Emulates other sources
  - Facilitates development of time series of artificial sources
- New vicarious calibration approach

VIIRS DNB Light Sources

- Many light sources including AALS will be point sources
- VIIRS radiometric calibration is in radiance L (W cm^{-2} sr^{-1})and defined for extended sources
  - Moonlight, Airglow
  - High density of artificial light sources with spacing less than PSF extent
- Point sources are defined in intensity J (W sr^{-1})
  - Sparsely spaced artificial light sources with spacing much greater than PSF

Point Source and Extended Source

- Extended source emulated with an array of point sources



- Effective radiance equivalent will be

$$L_{TOA} \approx \frac{J_{Source}\, T^{\uparrow}}{A_{Pixel}}$$

- Generalization: Area of pixel replaced with Area of source cell

First Order VIIRS DNB HGS Active Calibration Source Brightness

- Assumptions
  - One way transmission to space = 0.85
  - Lmin= 3e-9 [W cm-2 sr-1]
    - Calculations are performed for 1e-8 [W cm-2 sr-1]
    - Pixel Area ~ 750 m x 750 m
  - Surrounding area assumed dark and low reflectance (ignore spherical albedo and background reflectance contribution)
- Ground Source Intensity 65 [W sr-1]
  - Required peak electrical power for each source will need to be ~0.7 – 3.3 KW for simple Lambertian source (no optics)

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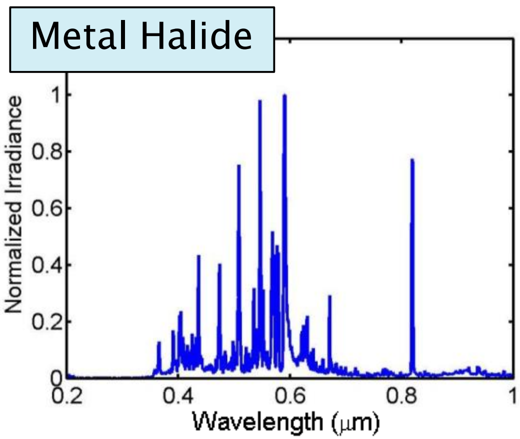
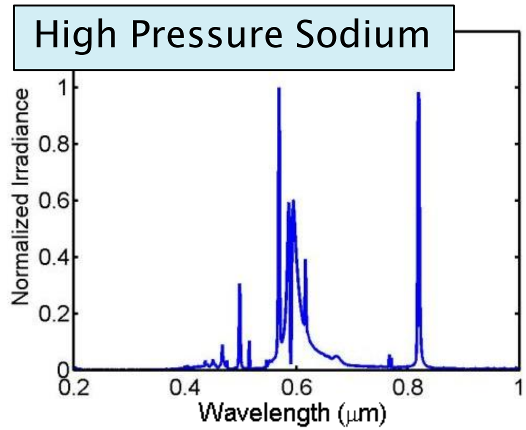
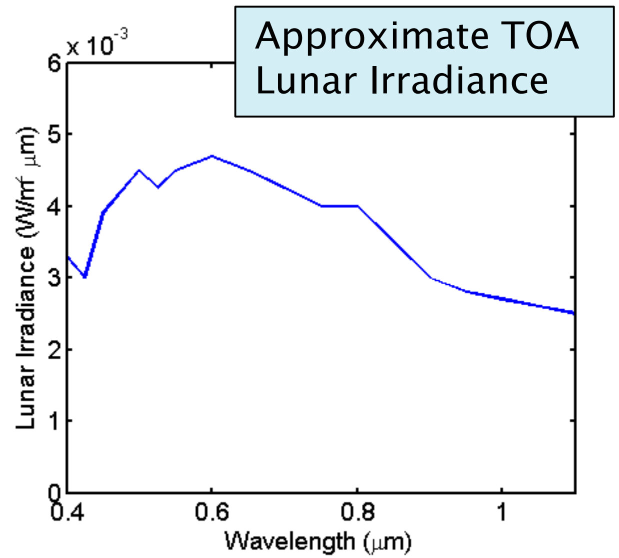
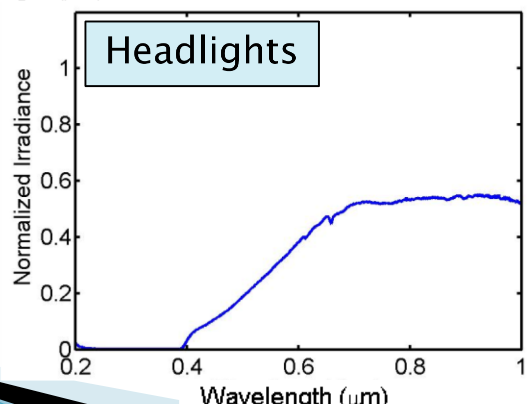
Spectral Shape

- Artificial light source spectral distributions differ from natural light sources









Current calibration approaches use lunar spectra

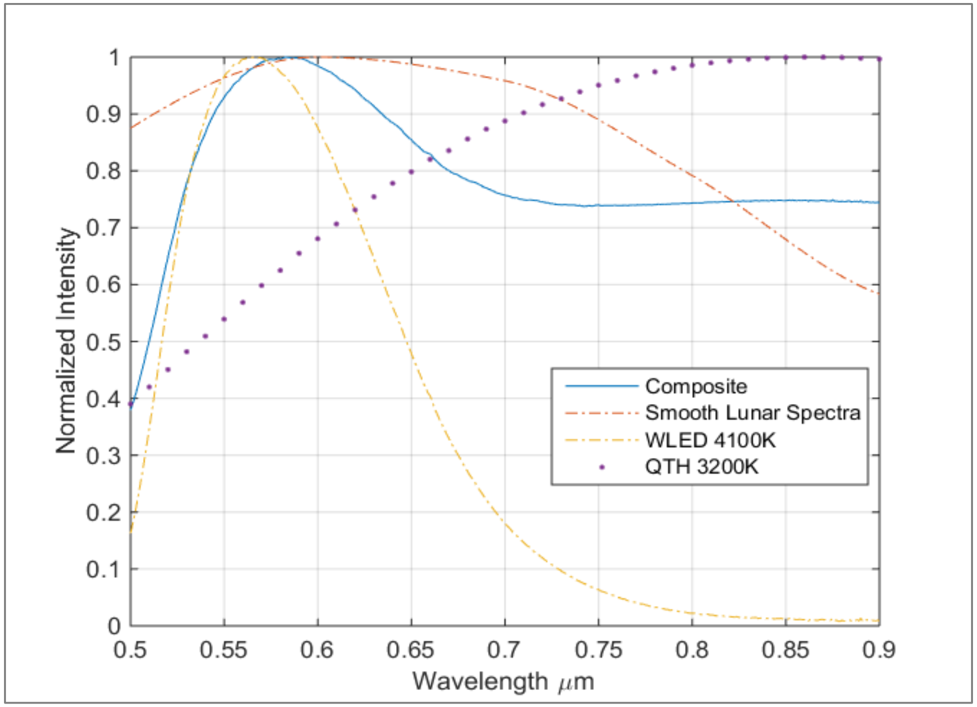
Potential AALS Lamp/Bulb Types

Lamp/Bulb Type	Spectral Distribution	Power Type	Comment	Stability
White Light LED	Continuum in visible w/ 450 nm spike limited NIR	Typically DC	Extremely long life, ~16-18 % efficient over VIIRS DNB bandpass	Excellent with precision power supply and temp stabilization
Quartz Tungsten Halogen (QTH)	Continuum with mostly NIR	DC or AC	Regularly used as a calibration sources; Few KW sources available (Low Cost); Relatively short lifetime (50-300 hrs.); ~18 % efficient over VIIRS DNB bandpass @3200 K Color Temp	Excellent stability over 50-100 hrs. in a lab environment with precision power supply
Color LEDs	Narrow spectrum; Colors available visible – NIR	Typically DC	Extremely long life, potentially very efficient; NIR LED limited availability compared to other colors	Excellent w/precision power supply and temp stabilization
Sulfur Lamps	Broadband continuum Color Temp ~6000 K	Typically microwave	Very Bright, Limited commercial sources	TBD. Considered for use in lab integrating spheres
High Intensity Discharge	Atomic emission lines	Typically AC	High Power Available	TBD. Typically contain spectral spikes w/AC power
High-Pressure Sodium	Continuum in the visible with spectral spikes	Typically AC	High power available. Largest ~ 1.5 KW	TBD. Typically contain spectral spikes w/AC power
Xenon Arc	Broadband continuum w/ spikes	DC	Plasma noise, warmup	Spectral spikes and some plasma noise

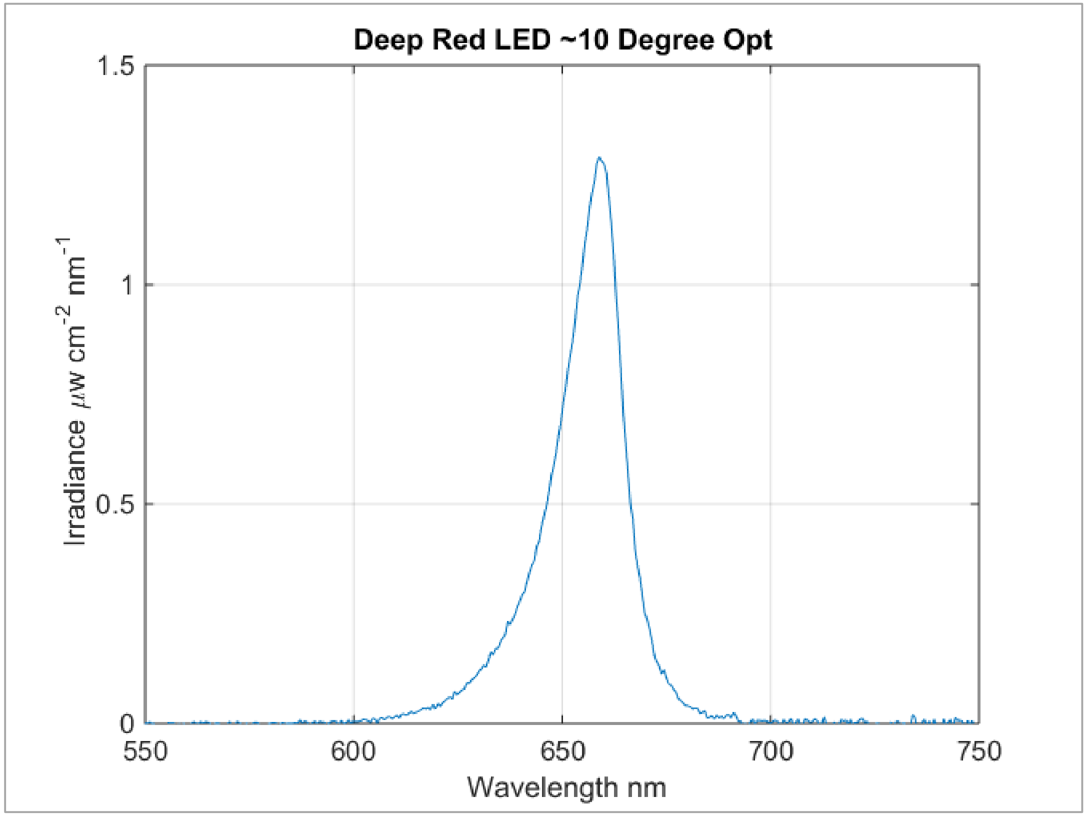
Spectral Shape

- Lunar-like spectra preferred to minimize differences between current calibration approaches
  - Expensive to create
- Other source, such as narrow band LEDs simplify implementation

Lunar Like Composite Spectra



Deep Red LED Spectra



Point Source(s)–Spatial Distribution

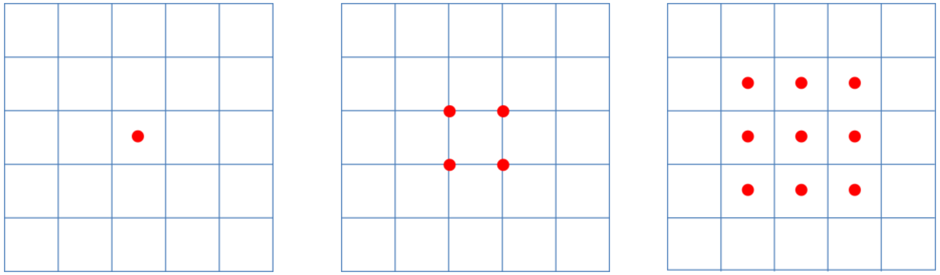
- Simplest configuration is to use a single point source and then aggregate pixels to estimate the total power from the source (Stellar Method)
  - Pixel aggregation however lowers the SNR of the measurement (by the approximately square root of the number of pixels aggregated) (2 – 3x)

Point Source Radiance Conversions

- Method 1 (Stellar Method)
  - Convert a single point intensity to radiance
  - Simple, but lowers SNR of measurement (2 – 3x)
  - Similar stellar calibrations
    - Schiller et al, 2012A
    - Schiller et al, 2012B
    - Arnold et al, 2013
    - Rudy et al, 2015
- Method 2 (Extended Source Approximation)
  - Use point sources and create an array that emulates an extended source

Point Source(s) – Spatial Distribution

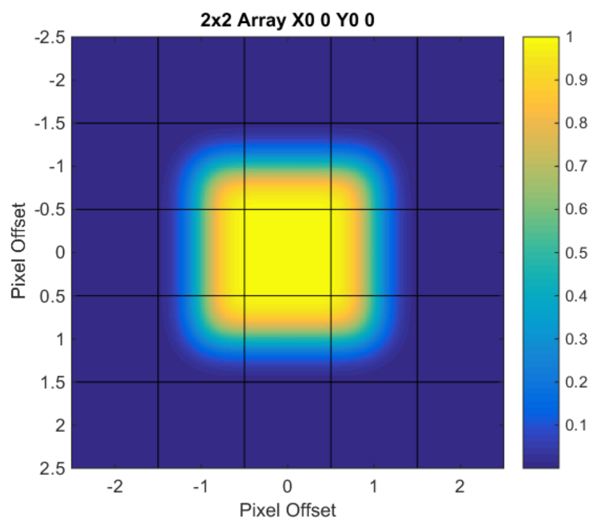
- Trades performed show that multiple point source light fixtures fielded in particular ways and produce an effective radiance relatively insensitive to the sensor pixel spacing or location and emulate an extended source (Extended Source Approximation)

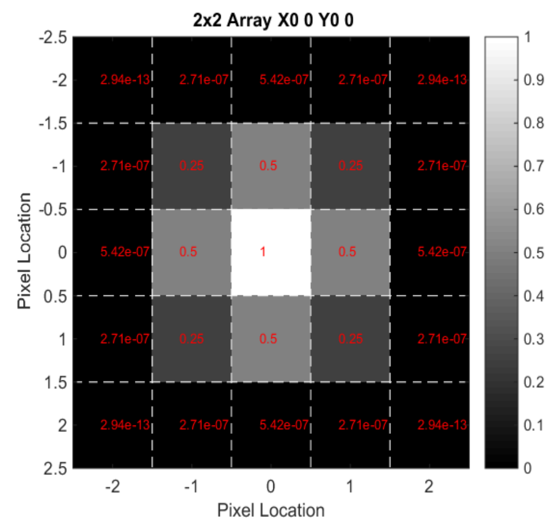


AALS configurations: single point source (left), four lamp 2x2 point source (center), and nine lamp 3x3 point source (right)

2x2 Arrangement

- Single light source arrangement was capable of capturing 97% of the illumination only when light source was centered within the pixel
- In the 2x2 arrangement, even when offset by 0.5 pixel in both the x and y direction, at least 98.5% of the illumination is captured
  - If the VIIRS pixel is centered in between the four light sources, 100% of the illumination would be captured (figures shown below)
- With this configuration, no pixel aggregation is required, so there is no SNR penalty





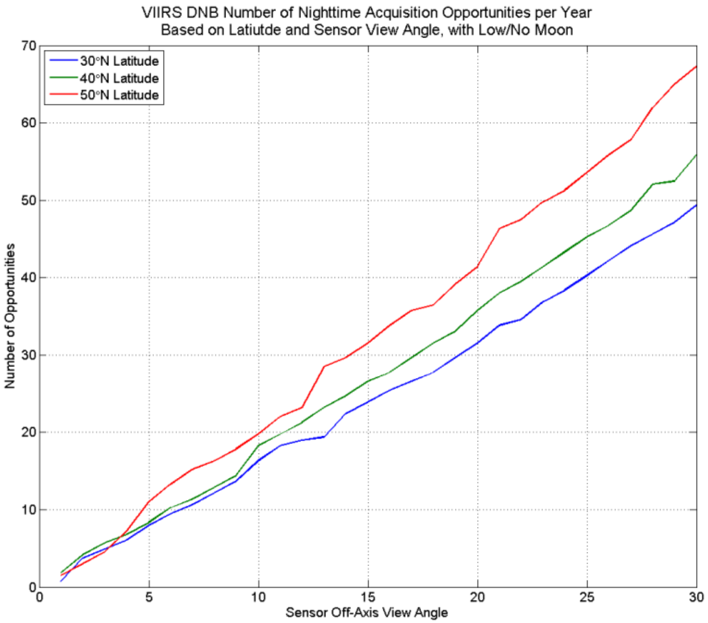
2x2 arrangement with VIIRS pixel centered between lights (percentage of illumination captured shown on the right)

View angle

- SBIR stated goal of ± 10 degrees will have very few chances for observations
  - Limits averaging opportunities
- Suggest increasing to about ± 30 degrees
  - Nearly triples opportunities
  - Larger view angles start to have large SNR degradation
  - Atmospheric modeling uncertainty increases at large angles
  - Many point sources intensity rolls off with angle
- Drives source to be a wide field-of-view source in the cross-track direction

Revisits Dependence on View Angle

- Ignoring cloud cover and high visibility constraints but including Low/No Moon night collects
  - ± 10 degrees ~20 per year
  - ± 30 degrees ~55 per year



± 10 degrees view angle might only have a few good collects per year, while ± 30 degrees should have 10 or more (assuming 0.2 are good)

Optical Considerations

- Lambertian source cosine response well understood and simple to deploy (pointing error small)
  - Power inefficient
  - Radiation not where needed and can complicate multiple scattering
- Narrow directed light sources
  - Lower power
  - Increase TOA radiance uncertainty due to knowledge of angular distribution

Light Source Type I

- Using hermetically sealed integrating spheres as the active light sources simplifies SI traceability (also increase expense)
  - Mixing QTH lamps and a white Light LED allows for simple spectral mixing and enables emulation of a lunar like spectra
    - Simplifies intercomparison with other calibration/validation methods based on lunar illumination?
  - Far field angular dependence is well-known, easily modeled and characterized.
  - Source monitoring can be built into the sphere
  - Power hungry (18% wall plug efficiency; ~45% optical loss)

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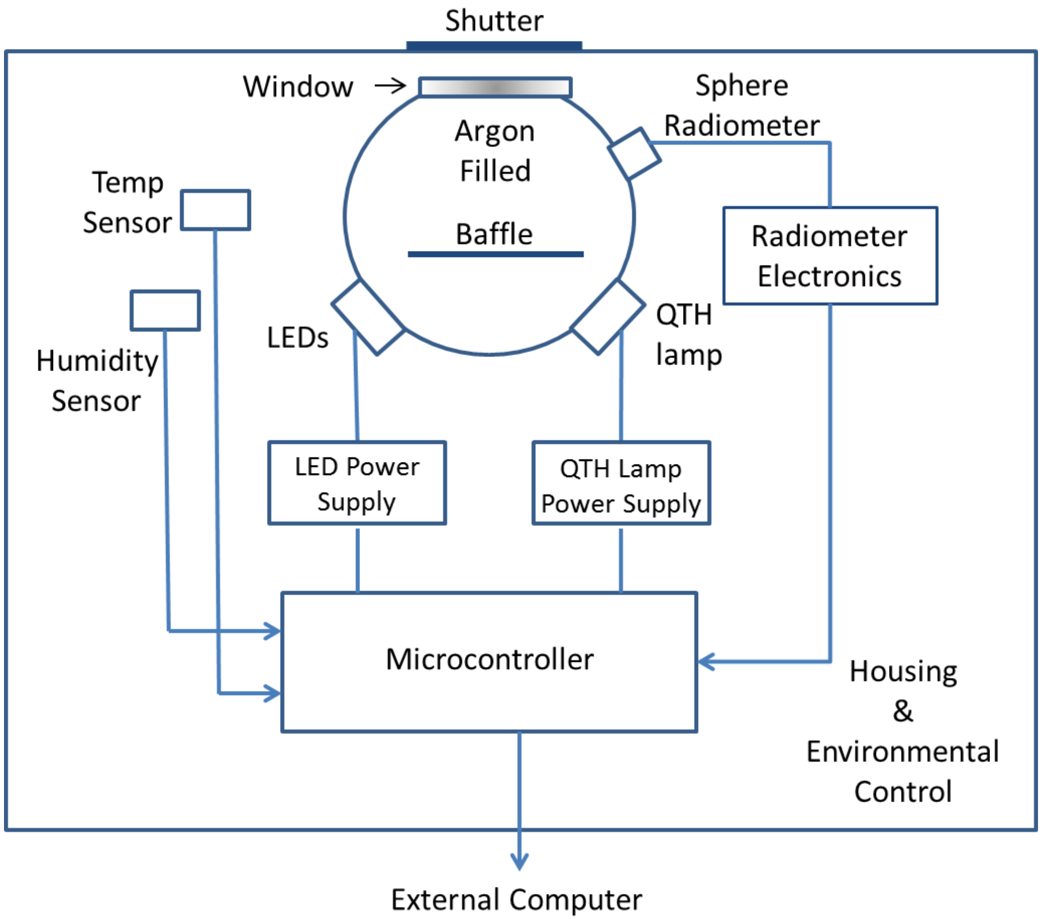
Integrating Sphere Approach



Optical Power With Different Light Fixtures

Fixture Type	Optical Power	Typical Optical Value at $\theta = 0$
Integrating Sphere	$\Phi = \frac{\pi J}{M f_e \cos(\theta)}$	$\Phi = 5.72\, J$
Narrow beam Direct Illumination	$\Phi = \Omega_{source} T_{Diff}\, J$	$\Phi = \Omega_{source} J$ (T_{Diff} included in spec sheet)
Direct Illumination with sources following Lambert's Law	$\Phi = T_{Diff} \pi\, J$	$\Phi = 3.14\, J$ (T_{Diff} included in spec sheet)
Bare Bulb Direct Illumination Source (against a black target)	$\Phi = 4\pi\, J$	$\Phi = 12.56\, J$
Single Panel Reflective Source	$\Phi = \frac{\pi J}{\rho \cos(\theta)}$	For Spectralon (ρ <0.98) $\Phi = 3.21\, J$ For Playa (ρ <0.4) $\Phi > 7.85\, J$

Electrical Power Requirements

$$P_{Peak} = \frac{P_{Optical}}{\eta_{Lamp}(1 - Opt_{Loss})\eta_{PS}}$$

P_{Peak}= Peak electrical power to operate lamps [W]

$P_{Optical}$= Optical power needed to achieve target intensity [W]

η_{Lamp} = Lamp wall−plug efficiency []

Opt_{Loss}= Optical loss coupling to light fixture []

η_{PS} = Power supply efficiency []

Composite Spectra Lamp Power Comparisons Lambert's Law

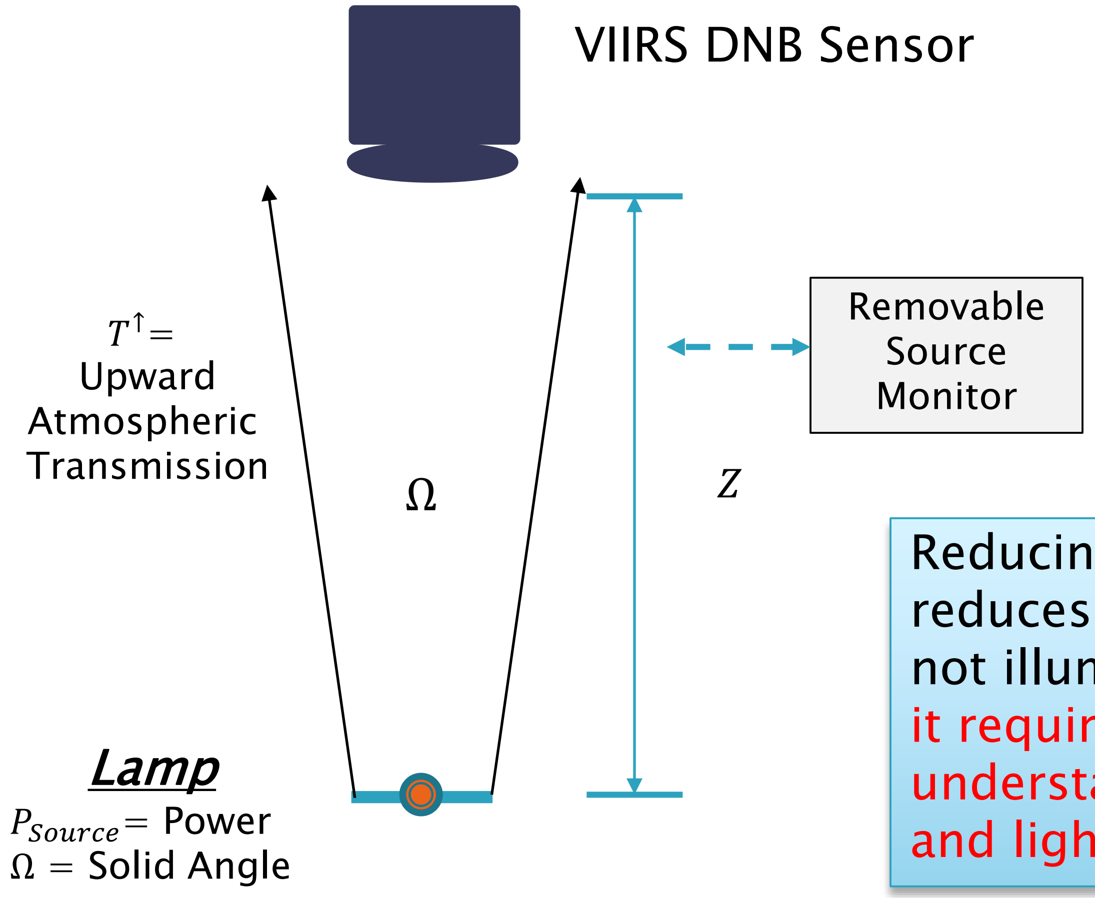
	Optical Power [W] $P_{Optical}$	Electrical Power (18% Efficiency) [W]	Optical Loss Opt_{Loss}	Electrical Power with Optical Loss [W]	Power Supply Efficiency η_{PS}	Electrical Power with Optical & Power Supply Loss [W]
Integrating Sphere (baseline concept)	372	2082	0.2	2603	0.8	3253
Direct Illumination with sources following Lambert's Law	204	1143	0.1	1270	0.8	1587
Single Panel Reflective Source (using Spectralon)	209	1168	0.2	1461	0.8	1826
Single Panel Reflective Source (using a reflective natural surface ~40%)	510	2857	0.1	3175	0.8	3969
Bare Bulb Direct Illumination Source	817	4574	0.1	5082	0.8	6353

Low Wall Plug Efficiency and Wide Angle Emission Requires Large Power

Light Source Type II

- Upward pointing Deep Red LED
  - Wall plug efficiency greater than 40%
  - Optical loss minimal
  - Red light less attractive to insects
  - Angular distribution calibration possibly a challenge
  - Narrow band light source has drastically different spectral shape than lunar source
  - Fairly strong temperature dependence that must be understood

Active Source with Direct Illumination

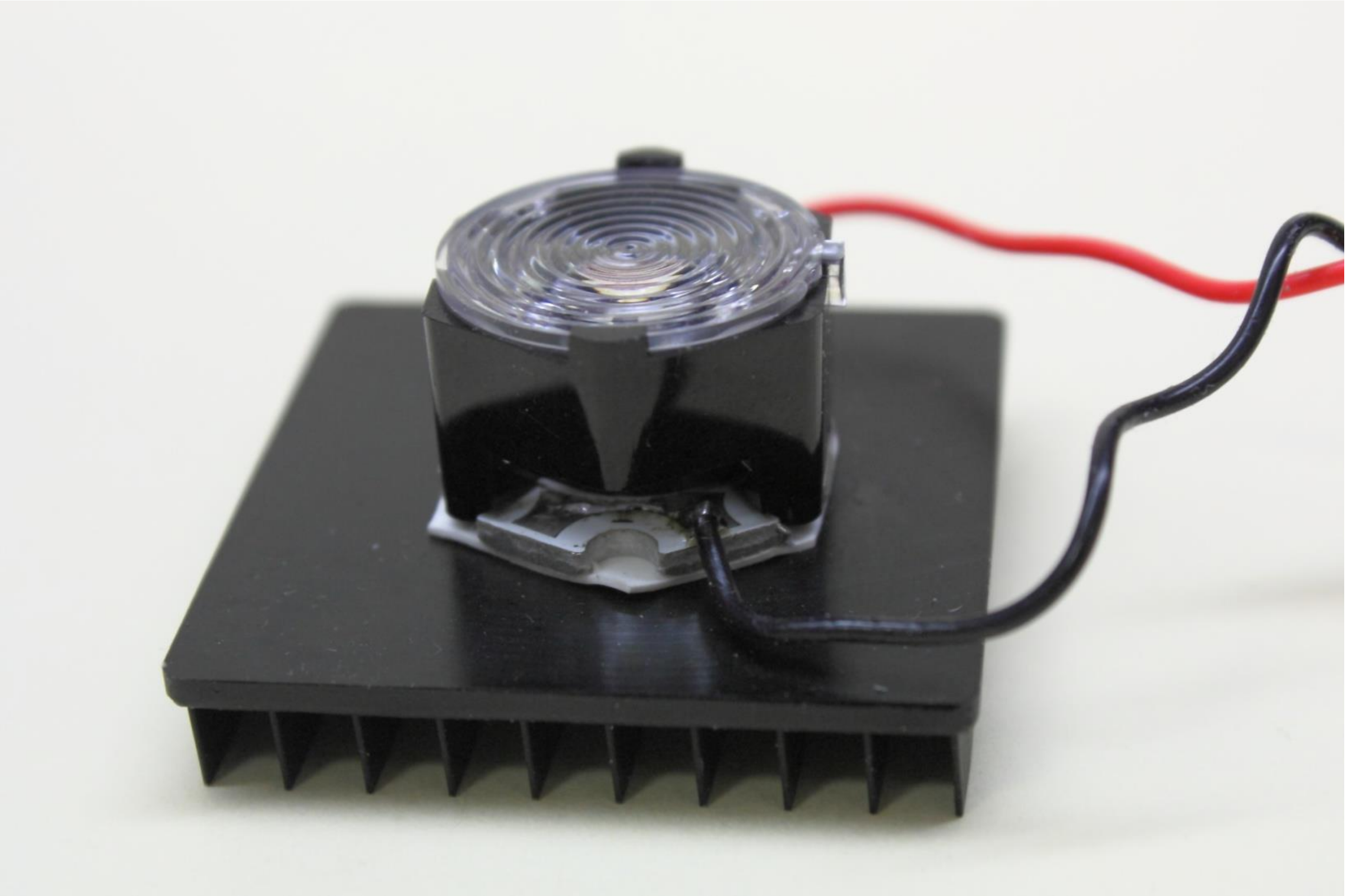


TOA Radiance

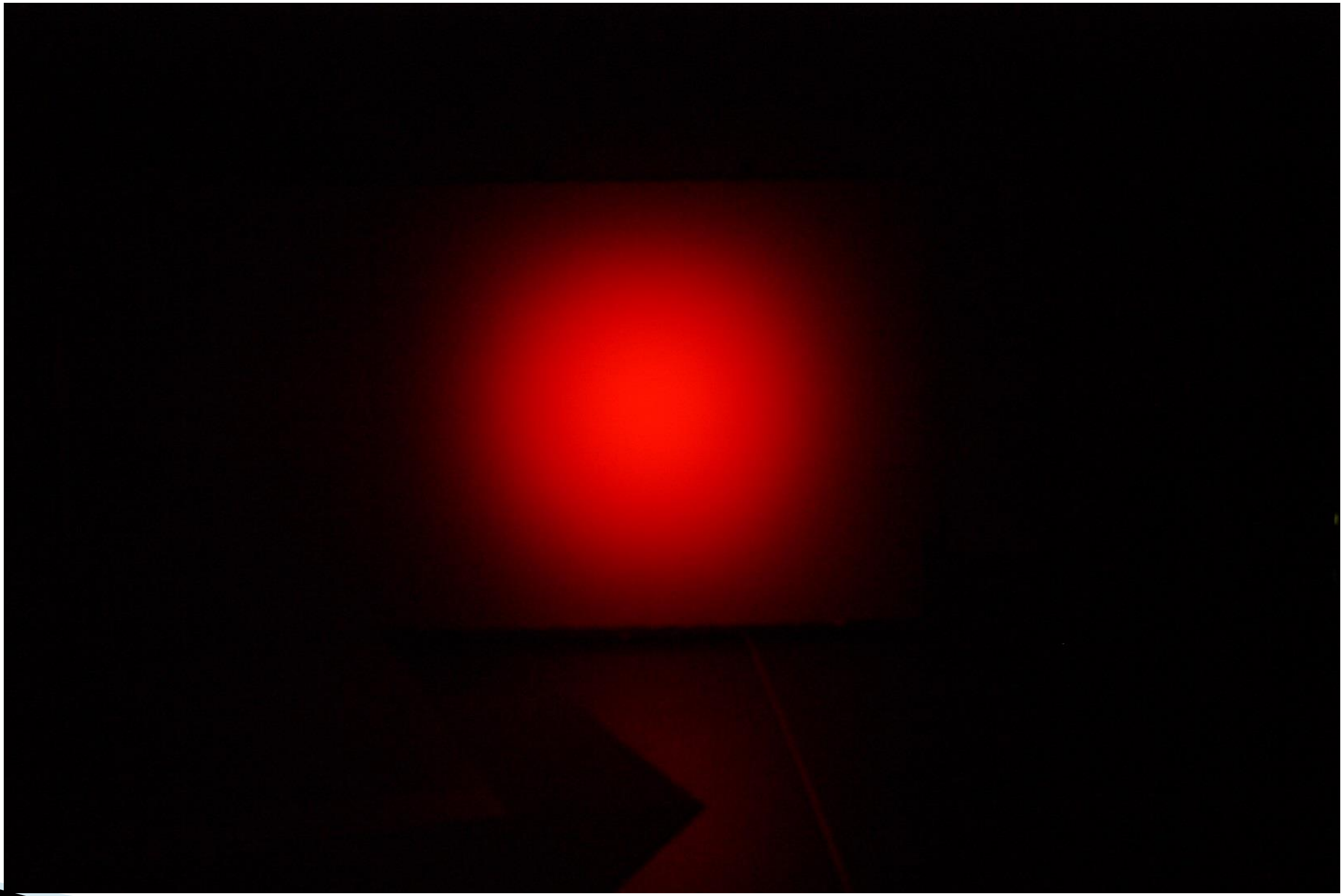
$$L_{TOA} = \frac{P_{Source}\,T^{\uparrow}}{\Omega_{Source}A_{Pixel}}$$

Reducing the source solid angle reduces the required source power by not illuminating the hemisphere, but it requires better pointing and understanding of the alignment and light source angular distribution

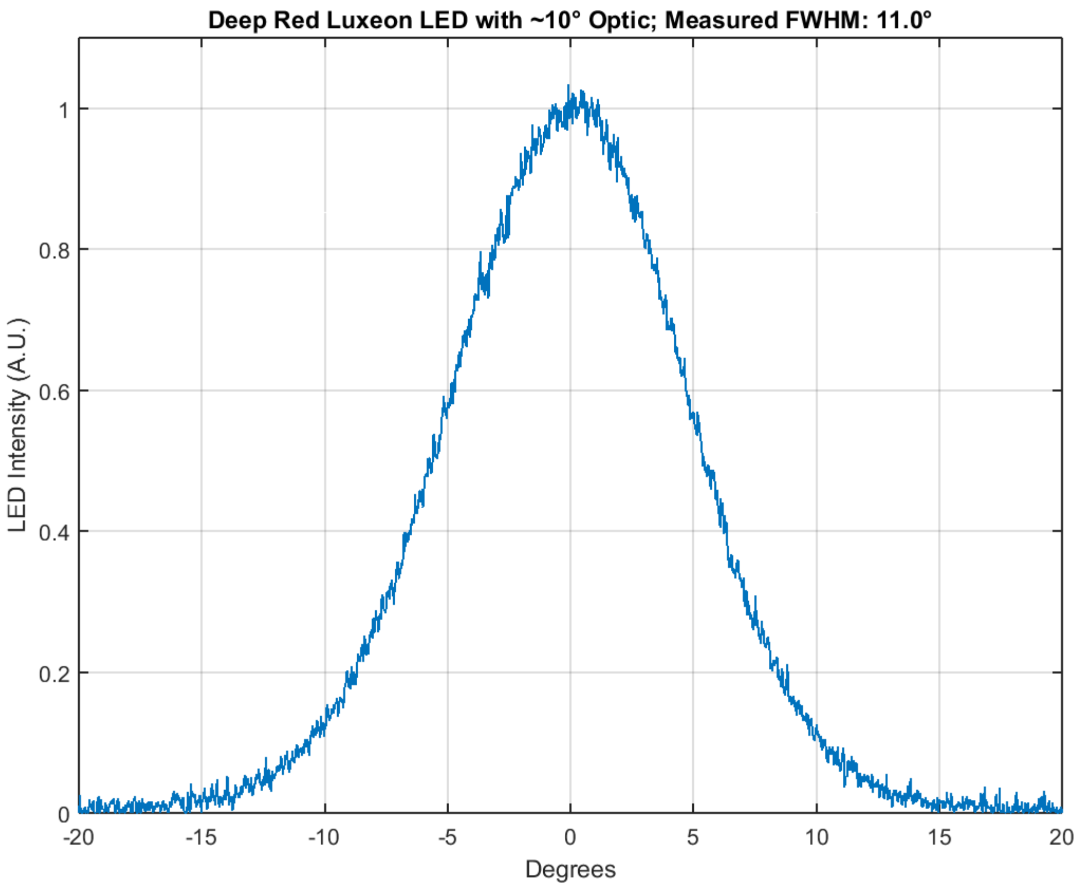
Prototype LED with Collimating Optics



Intensity Distribution



Deep Red LED with 10 Deg Optics



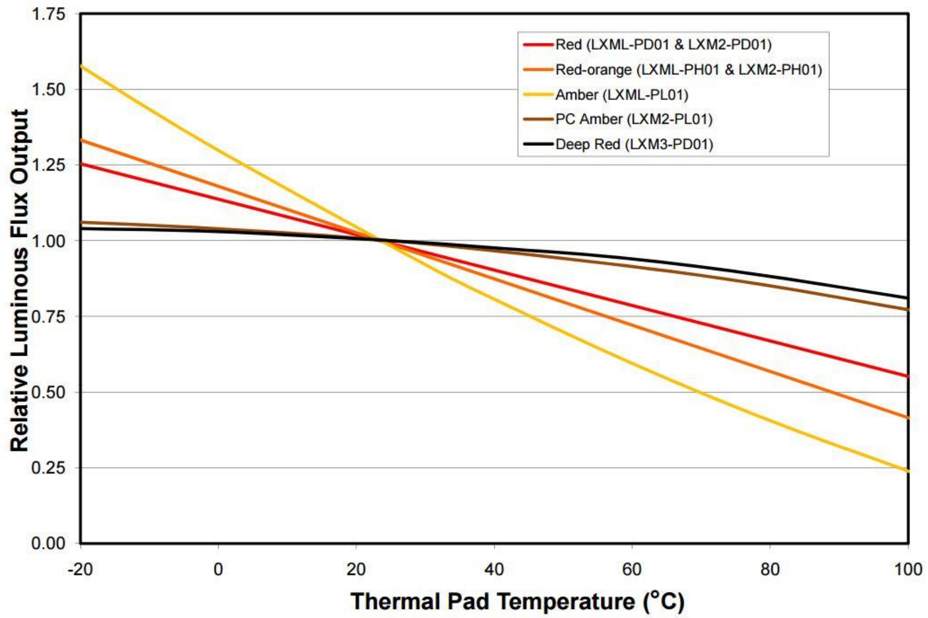
Single RED LED Intensity

Parameter	Value	Comment
Optical Power	0.58 W	Data sheet specifies 640 mW at 700 mA at 25 °C. Since the LEDs will be operated at an elevated temperature, a more conservative value was used (10% lower).
Lens Coupling Efficiency	0.8	Data sheet 0.87 (~10% lower)
RSR	0.93	Estimated from RSR curve at 655 nm
Solid Angle	0.0344 sr	Beam width 12° FWHM.
Single Deep Red LED Source Intensity (on Axis)	13.4 W sr^{-1}	2 W equivalent electrical power (0.8 power supply and 0.36 wall plug efficiency (0.29 effective)

Depending on the number of LEDs used to reduce pointing errors expect the electrical power to be less than 60 W to exceed 65 W sr^{-1}

LED Stability

- Deep Red LEDs (λ_o 655 nm FWHM 20nm) AlInGaP



Maximum Slope $\approx \frac{0.3\%}{^oC}$

- Junction temperature knowledge or control to approx 1˚C critical

Source: Lumileds 2015, LUXEON Rebel & LUXEON Rebel ES Colors, http://www.lumileds.com/uploads/265/DS68-pdf

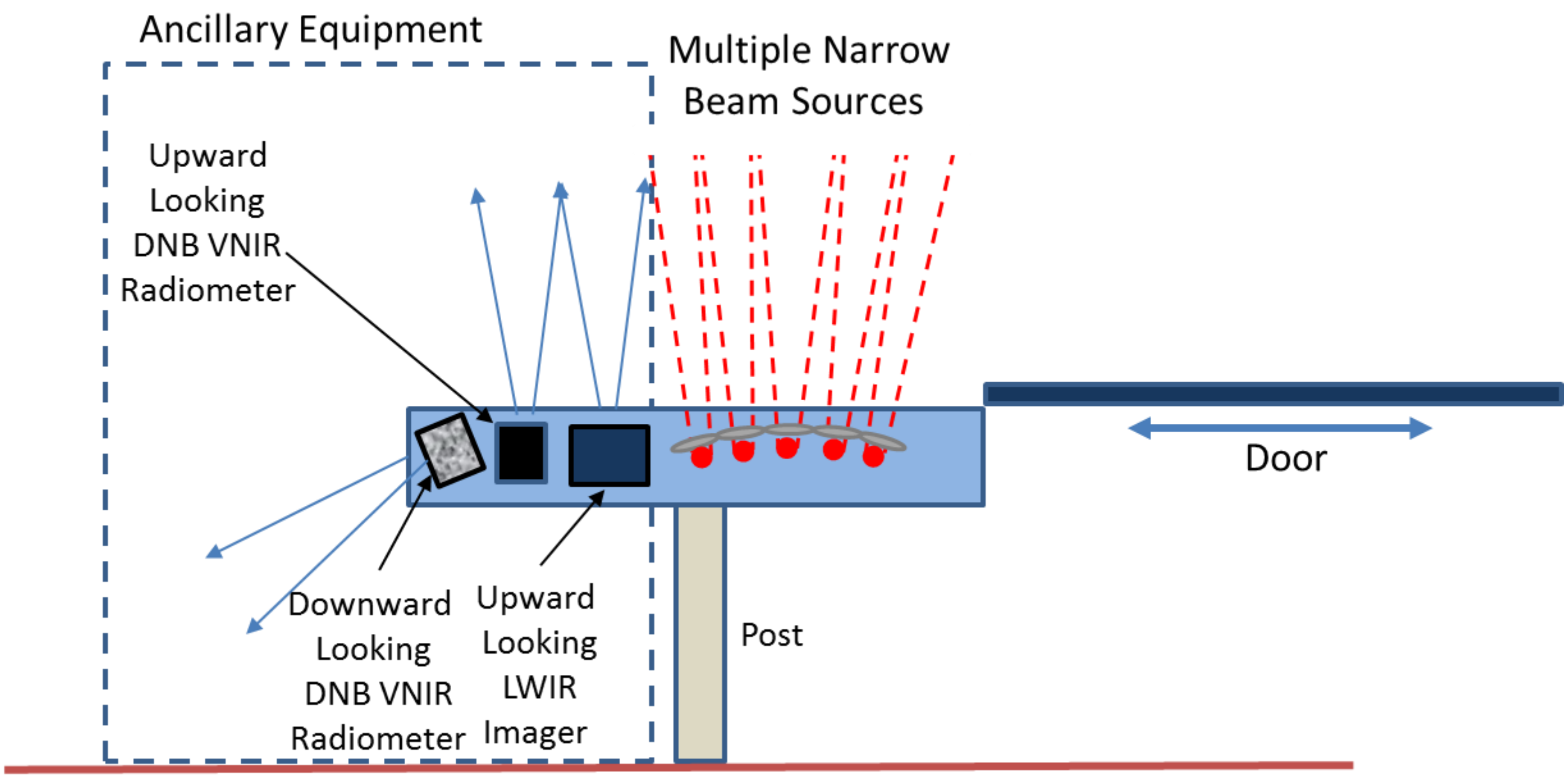
Comparison of Integrating Sphere and Narrow Beam Approach

Feature	Upward Looking LED Calibration Source (Narrow Beam)	Integrating Sphere Calibration Source
Power Requirements	Direct illumination-requires less power.	Requires more power due to reflectance losses within sphere and Lambertian.
Spectral Shape	Does not support spectral mixing, but white light LEDs emit within visible spectrum.	Multiple illumination sources can be integrated which enables spectral tailoring including simulated lunar illumination.
Maintenance	Easy to maintain.	More effort to maintain.
Deployment	Easy to deploy.	More difficult to deploy.
Source Type	Narrow beam-Illumination angular distribution may require calibration data to be taken from multiple angles.	Lambertian source-nearly ideal. Calibration techniques well understood.
Calibration Implication	Narrow beam-may be difficult to align and point	Wide angular illumination with multiple scattering can complicate calibration for high reflectance land cover.

Stability Maintenance Concept

- The light source needs to be observable by a satellite for only a few minutes a month, which can allow for reduced duty cycle and maintenance.
  - Placing a shutter in front of the light source will minimize insect attraction and reduce contamination of the source window from particulates, rain residue, and insects
  - Open shutter when conditions are favorable
    - Good visibility, dark, cloud free line-of-sight
  - Reduced duty cycle reduces size of power system

Conceptual Deployment of a Single Source



Ancillary equipment will also include a local Meteorological Station

Site Selection

- Site requirements for VIIRS DNB active calibration source deployment
  - No or minimal light pollution
  - Clear conditions (low aerosol/clouds) for much of the year to maximize calibration opportunities
  - Low latitude to minimize impact of stray light during summer months (northern hemisphere)
- Railroad Valley is a commonly used CEOS calibration site, with high elevation and minimal light pollution
  - Used to generate initial time series to estimate number of calibration opportunities expected in a year

Radiative Transfer

- Atmospheric, irradiance and radiance measurements associated with the vicarious calibration approach would be beneficial in reducing the uncertainty of the active source approach
- Low reflectance background reduces influence of background (spherical albedo)
- However, largest atmospheric uncertainty is knowledge of the aerosol
  - Goal is to know atmospheric transmission to $\pm 2\%$

AALS Radiative Transfer

$$L_{TOA} = [M_s L_s(\theta,\varphi) + M_d \frac{E_d \rho_h}{\pi}] T^{\uparrow} + L_u$$

$L_s(\theta,\varphi)$ = AALS surface (at source) radiance [W cm^{-2} sr^{-1}]

θ = zenith angle [radians]

φ = azimuth angle [radians]

L_u= path radiance [W cm^{-2} sr^{-1}]

$T^{\uparrow}$= total transmittance from the surface to the satellite [ ]

E_d= diffuse irradiance [W cm^{-2}]

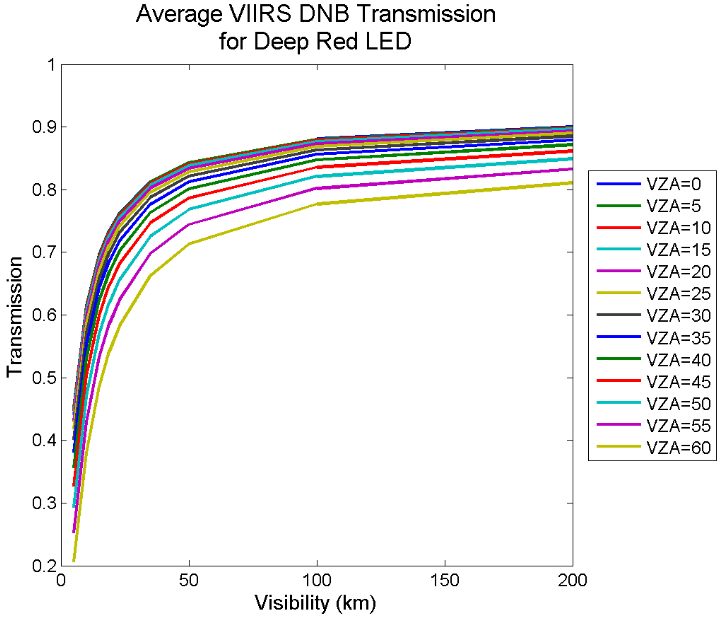
ρ_h = hemispherical reflectance [ ]

M_s = multiple scattering factor; active source [ ]

M_d = multiple scattering factor; diffuse source [ ]

DNB Average Deep Red LED Transmission

- Spectral transmission scaled by deep red LED irradiance and averaged over VIIRS DNB spectral response



Zenith Angle (Degree)	Visibility (km)								
	5	10	15	19	23	35	50	100	200
0	0.453	0.616	0.696	0.735	0.763	0.813	0.843	0.880	0.900
5	0.452	0.614	0.695	0.734	0.762	0.812	0.843	0.880	0.899
10	0.448	0.611	0.692	0.732	0.760	0.810	0.841	0.879	0.898
15	0.441	0.605	0.687	0.727	0.755	0.807	0.838	0.877	0.896
20	0.431	0.597	0.680	0.721	0.750	0.802	0.834	0.873	0.894
25	0.418	0.585	0.671	0.712	0.742	0.796	0.829	0.869	0.890
30	0.401	0.571	0.658	0.701	0.732	0.787	0.822	0.863	0.885
35	0.381	0.553	0.643	0.687	0.719	0.777	0.812	0.856	0.879
40	0.356	0.531	0.624	0.669	0.702	0.763	0.801	0.847	0.871
45	0.327	0.504	0.600	0.647	0.682	0.746	0.786	0.836	0.862
50	0.293	0.470	0.570	0.620	0.657	0.725	0.768	0.821	0.849
55	0.252	0.430	0.533	0.585	0.624	0.698	0.744	0.802	0.833
60	0.206	0.380	0.486	0.541	0.583	0.662	0.713	0.777	0.811

High Visibility and Zenith Angle Desired

Aerosols

- Estimating aerosol at night is problematic
- Possible night time aerosol sources
  - Models (Navy Aerosol Analysis and Prediction System) Global Aerosol Model)
  - Stellar photometers (analogous to sun photometers)
    - Expensive and rare
  - Visibility sensors
  - Micropulse lidars
    - Expensive and rare (DOE ARM sites)

Source radiance L_{TOA} uncertainty contributions

$$\left(\frac{\sigma_{L_{TOA}}}{L_{TOA}}\right)^2 = \left(\frac{\sigma_{M_s}}{M_s}\right)^2 + \left(\frac{\sigma_{L_s}}{L_s}\right)^2 + \left(\frac{\sigma_{T^\uparrow}}{T^\uparrow}\right)^2 + \left(\frac{\sigma_{L_{Background}}}{L_{TOA}}\right)^2$$

Term	Estimated Uncertainty (%)	Comment/Justification
$\frac{\sigma_{L_s}}{L_s}$	3.6	Depends on good characterization of intensity distribution
$\frac{\sigma_{M_s}}{M_s}$	0.6	Assumed narrow beam case reduces multiples scattering to a negligible contribution
$\frac{\sigma_{T^\uparrow}}{T^\uparrow}$	2	Assumes that we can use clear conditions based on models and predictions.
$\frac{\sigma_{L_{Background}}}{L_{TOA}}$	1	Active source much larger than background radiance, When background is measured and subtracted expect to be small.
$\frac{\sigma_{L_{TOA}}}{L_{TOA}}$	4.3	RMS

Initial analysis indicates we can meet the 5% goal

Summary

- AALS concept using RED LEDs looks promising and feasible for calibrating VIIRS DNB since it only requires a few tens of watts

- Use of an array of emulates an extended source and maintains SNR and minimizes geolocation errors

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