Challenges regarding the cross-validation of nighttime sensors

Martin Bachmann[(1)], Kevin Alonso[(1)], Emiliano Carmona[(1)], Tobias Storch[(1)] – with contributions by Mary Pagnutti[(2)]

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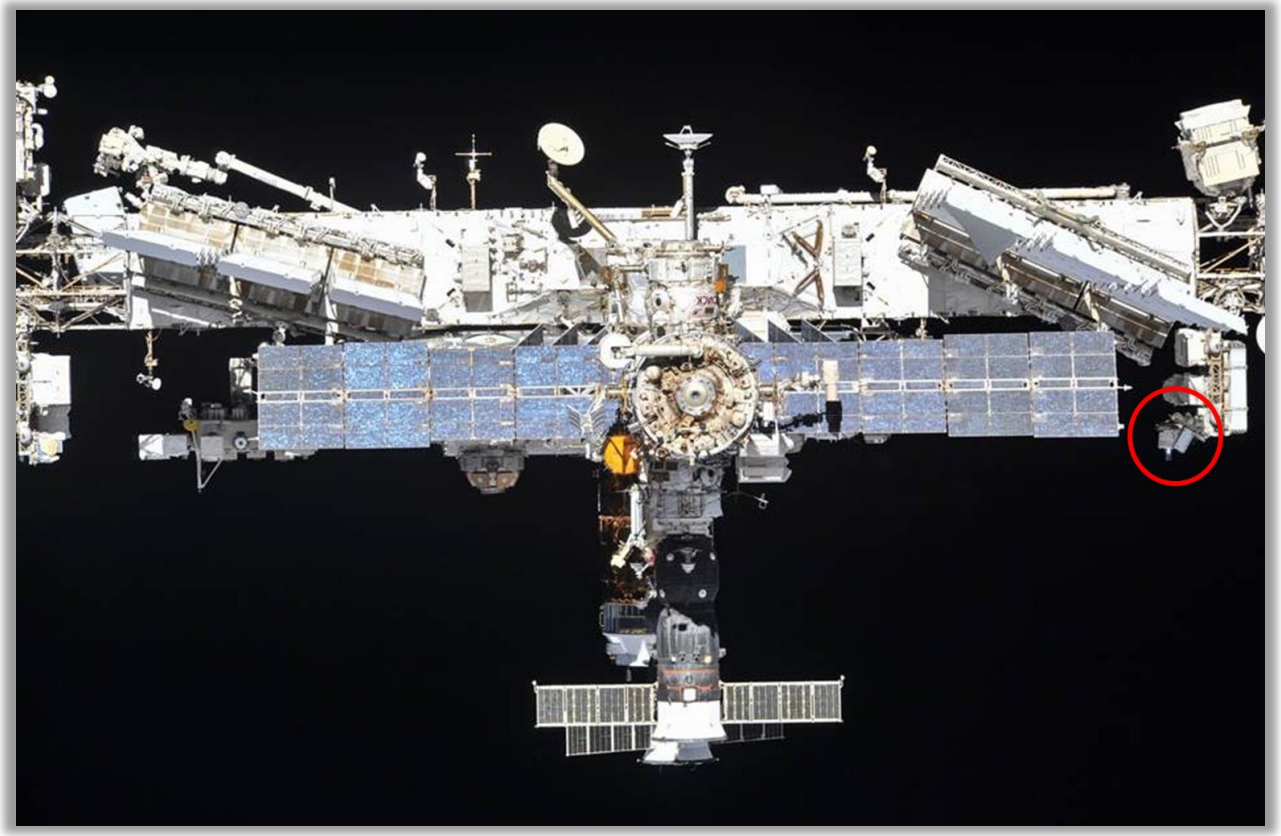
Content

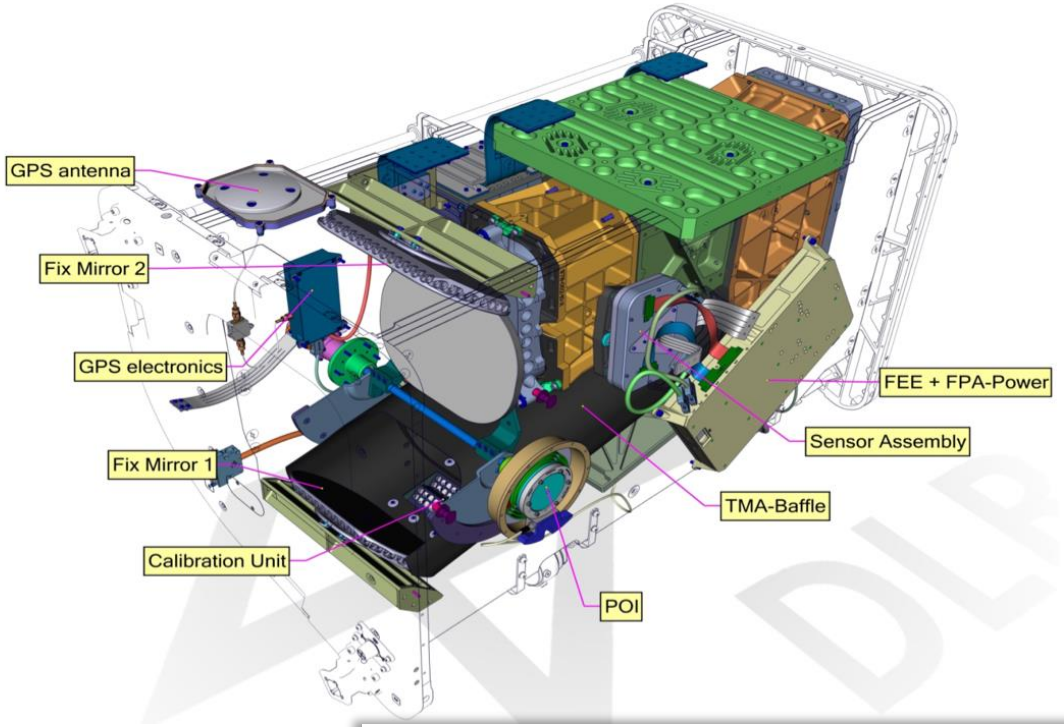
Within the following slides, common approaches for validation of airborne and spaceborne missions are presented w.r.t.

- geometry
- spectral characteristics
- radiometric characteristics

as examples for day- and nighttime missions.

… first a brief introduction to DESIS (DLR Earth Sensing Imaging Spectrometer)





sensors
MDPI
Article

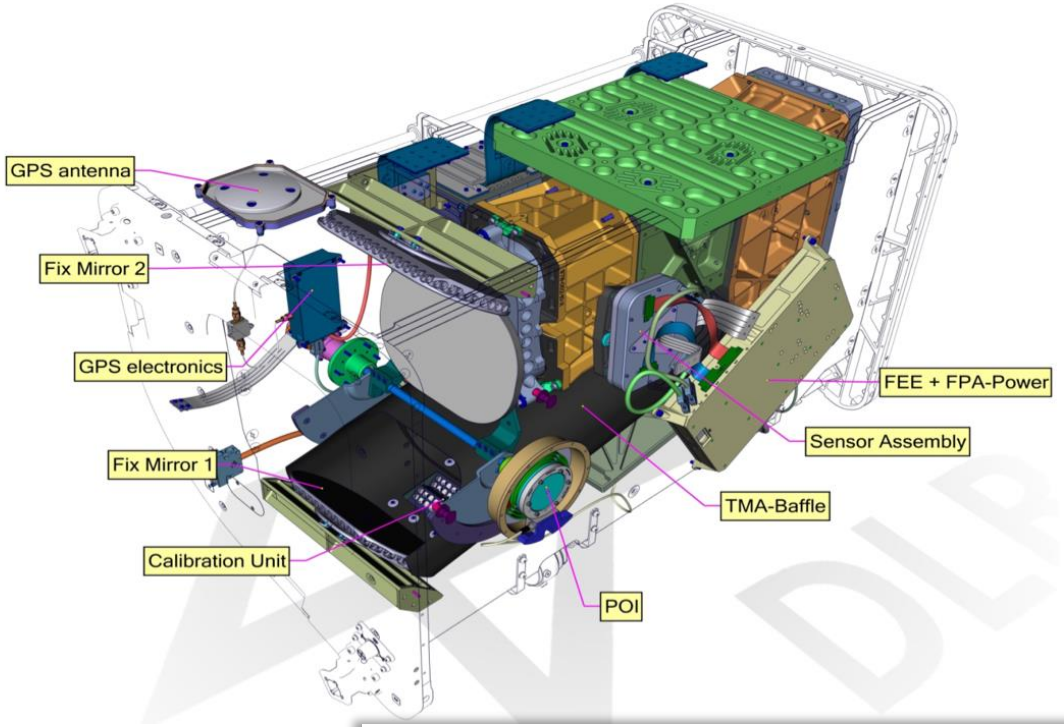
Data Products, Quality and Validation of the DLR Earth Sensing Imaging Spectrometer (DESIS)

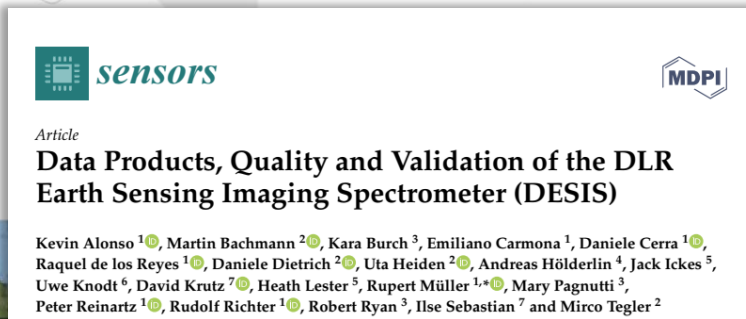
Kevin Alonso [1], Martin Bachmann [2], Kara Burch [3], Emiliano Carmona [1], Daniele Cerra [1], Raquel de los Reyes [1], Daniele Dietrich [2], Uta Heiden [2], Andreas Hölderlin [4], Jack Ickes [5], Uwe Knodt [6], David Krutz [7], Heath Lester [5], Rupert Müller [1,*], Mary Pagnutti [3], Peter Reinartz [1], Rudolf Richter [1], Robert Ryan [3], Ilse Sebastian [7] and Mirco Tegler [2]

… first a brief introduction to DESIS

- Hyperspectral instrument consisting of a Three-Mirror-Anastigmat (TMA) telescope combined with an Offner-type spectrometer

Mission Instrument	MUSES/DESIS
Target lifetime	2018-2023
Off-nadir tilting (across-track, along-track)	-45° (backboard) to +5° (starboard), -40° to +40° (by MUSES and DESIS)
Spectral range	**400 nm to 1000 nm**
Spectral Sampling (res., acc.,bands)	**2.55 nm,** 0.5 nm, 235 bands, 118 (bin 2), 79 (bin 3), 60 (bin 4)
Software Binning (sampling distance, number bands)	Binning 2 (5.1 nm, 118 bands) Binning 3 (7.6 nm, 79 bands) Binning 4 (10.1 nm, 60 bands)
Radiometry (res., acc.)	13 bits, ~10%
Spatial (res., swath)	**30 m,** 30 km (@ 400 km)
SNR (signal-to-noise)	**195** (w/o bin.) / 386 (4 bin.) @ 550 nm
Instrument (mass)	93 kg
Capacity (km, storage)	2360 km per day, 225 GBit

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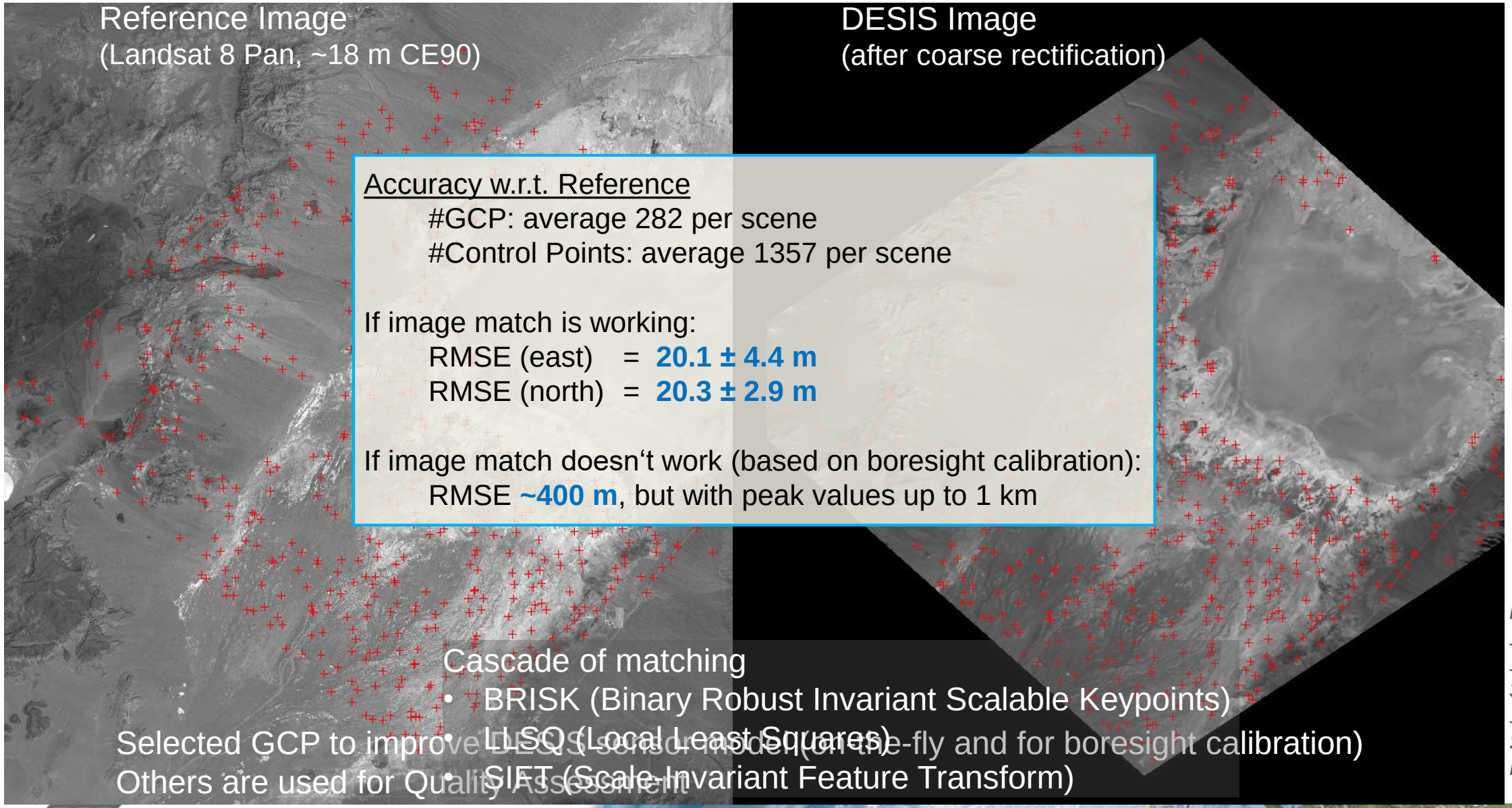
Geometric Calibration & Validation



Accuracy w.r.t. Reference

#GCP: average 282 per scene

#Control Points: average 1357 per scene

If image match is working:

RMSE (east) = **20.1 ± 4.4 m**

RMSE (north) = **20.3 ± 2.9 m**

If image match doesn‘t work (based on boresight calibration):

RMSE **~400 m**, but with peak values up to 1 km

Cascade of matching

- BRISK (Binary Robust Invariant Scalable Keypoints)
- LLSQ (Local Least Squares)
- SIFT (Scale-Invariant Feature Transform)

Selected GCP to improve DESIS sensor model (on-the-fly and for boresight calibration)
Others are used for Quality Assessment

Railroad Valley, USA
13-12-2018
18:23:11 UTC
38.4467°N
115.7512° W
Sun: 64.14°, 160.58°
Incident Angle: 0.8°

DLR

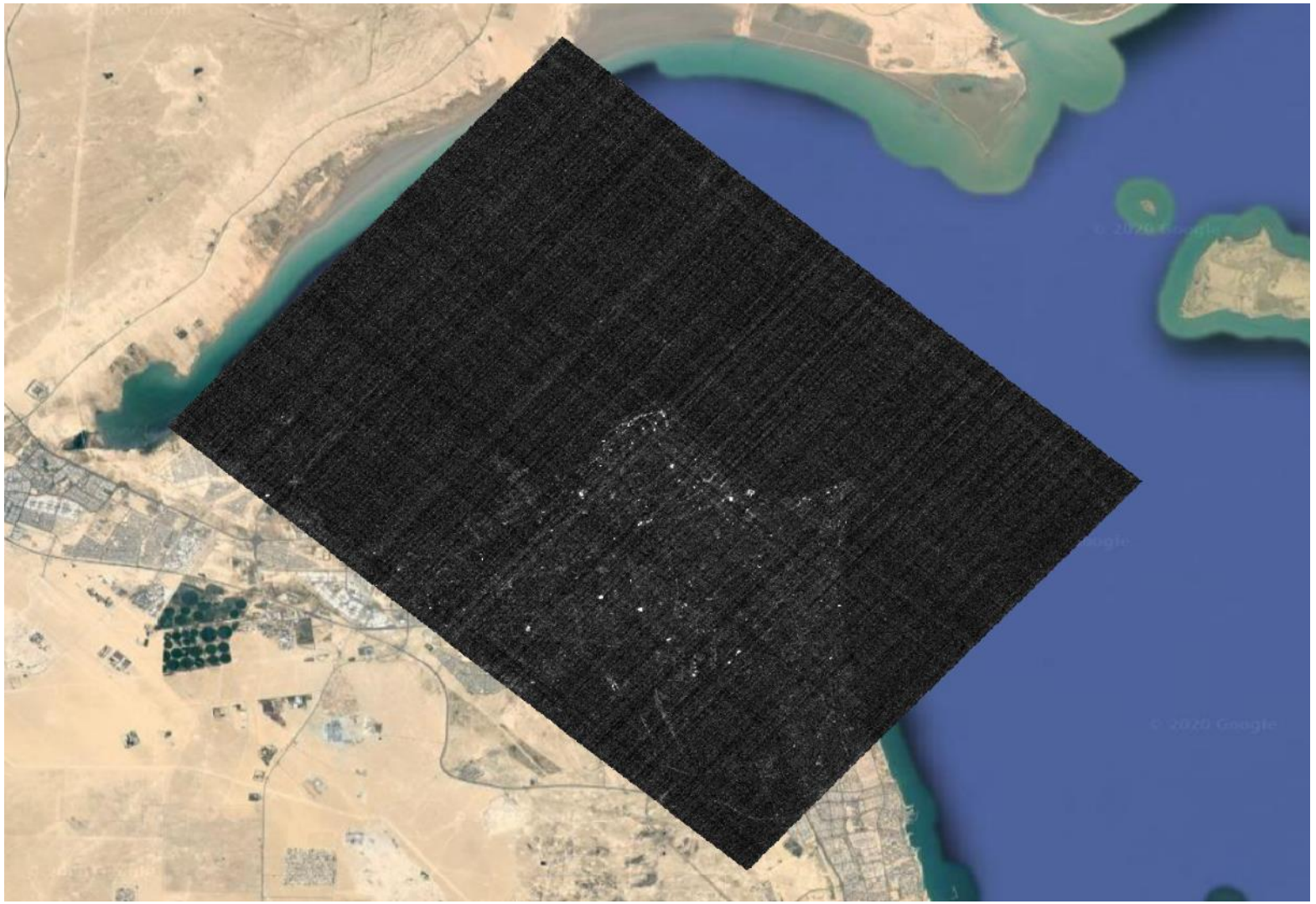
Geometry

Geometry

- Daytime:
  automatic ICP retrieved during image-to-image matching allows for scenewise position RMSE

- Nighttime:
  positioning error along track can’t be recovered because matching not working with dark scene

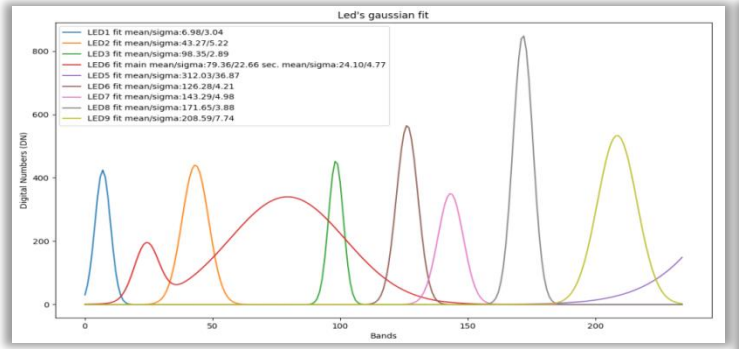
- Nevertheless, interactive checks for some locations are possible

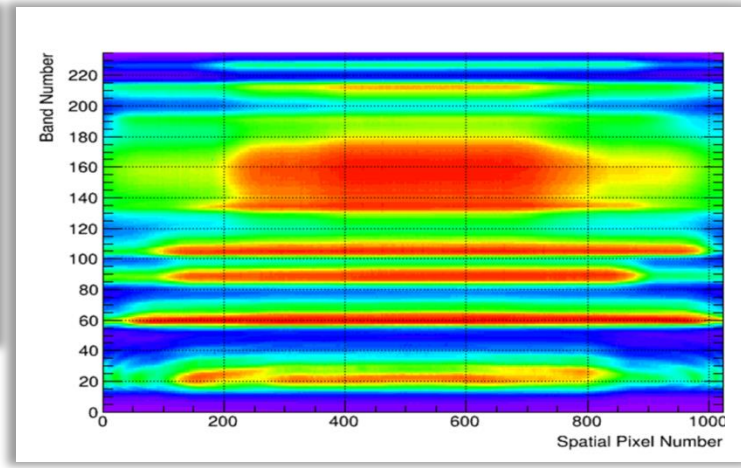


DESIS nighttime, Kuwait City, 14.09.2020

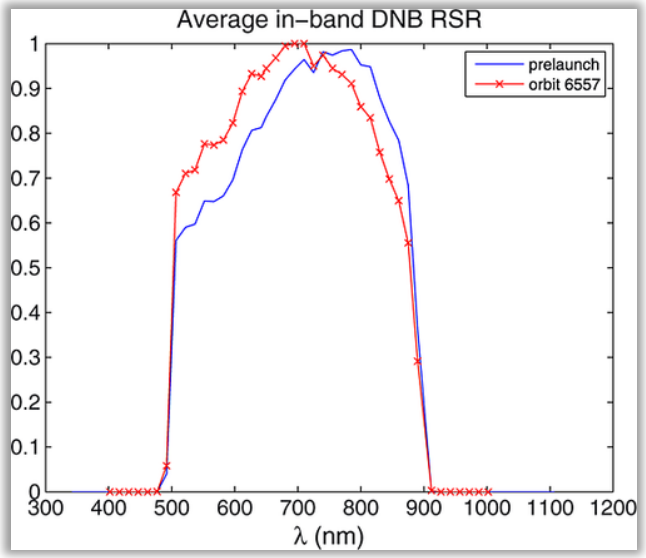
Spectral Characterization

- Using on-board calibration sources (LEDs)
  - Pre- and post-launch characteristics
  - Incl. temperature stability & other HK / telemetry data





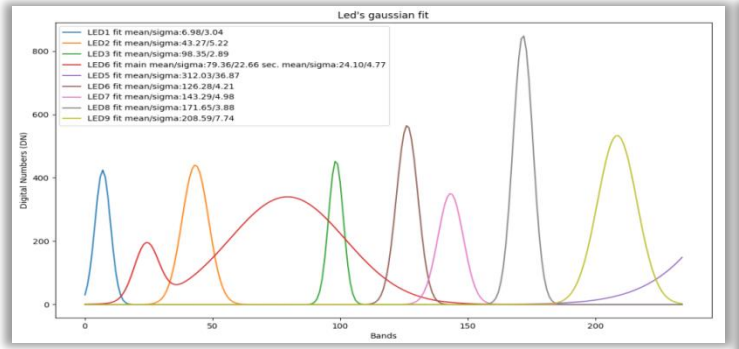
- Importance as Spectral Response Function (SRF) can change during mission
  Example: VIIRS DNB due to degradation of mirror coating

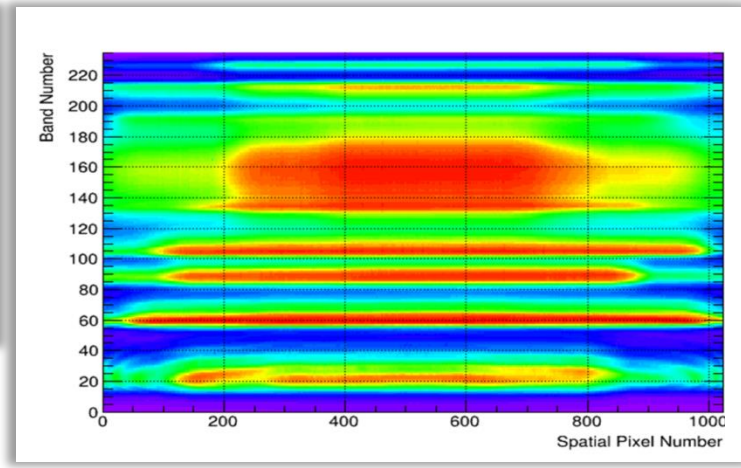


Liao et al., 2013,
https://doi.org/10.1002/2013JD020475
(based on model for mirror degradation)

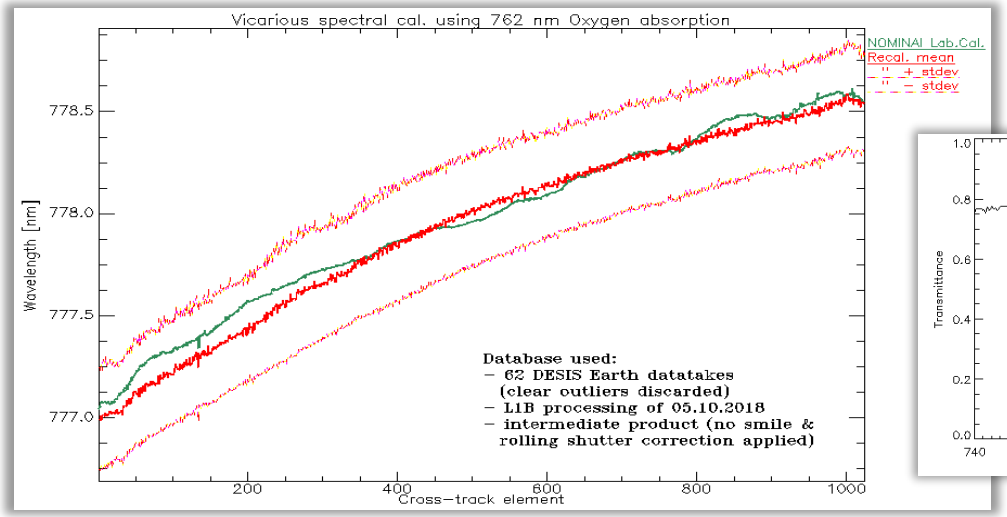
Spectral Characterization

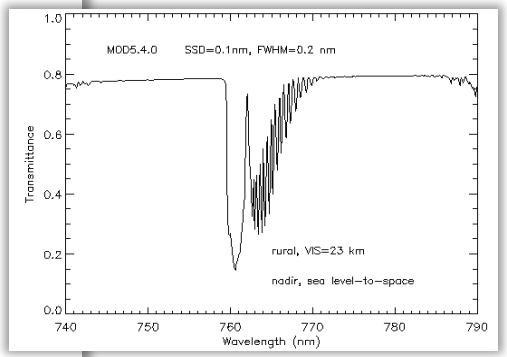
- Using on-board calibration sources (LEDs)
  - Pre- and post-launch characteristics
  - Incl. temperature stability & other HK / telemetry data



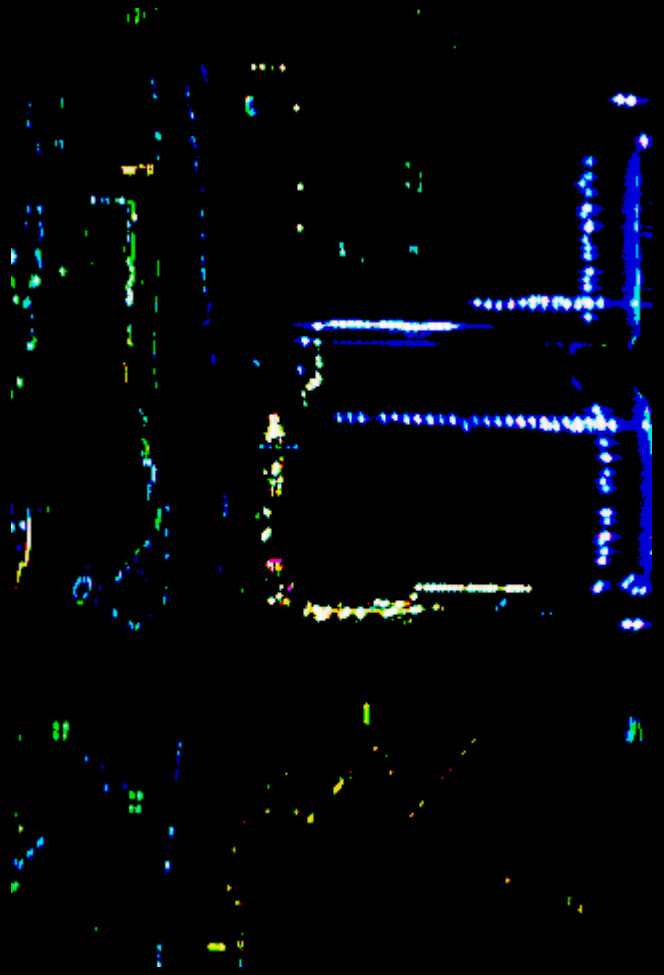


- Vicariously using atmospheric absorption features
  - Incl. smile pre- and post-launch
  - But: requires daytime imagery !





Spectral Characterization



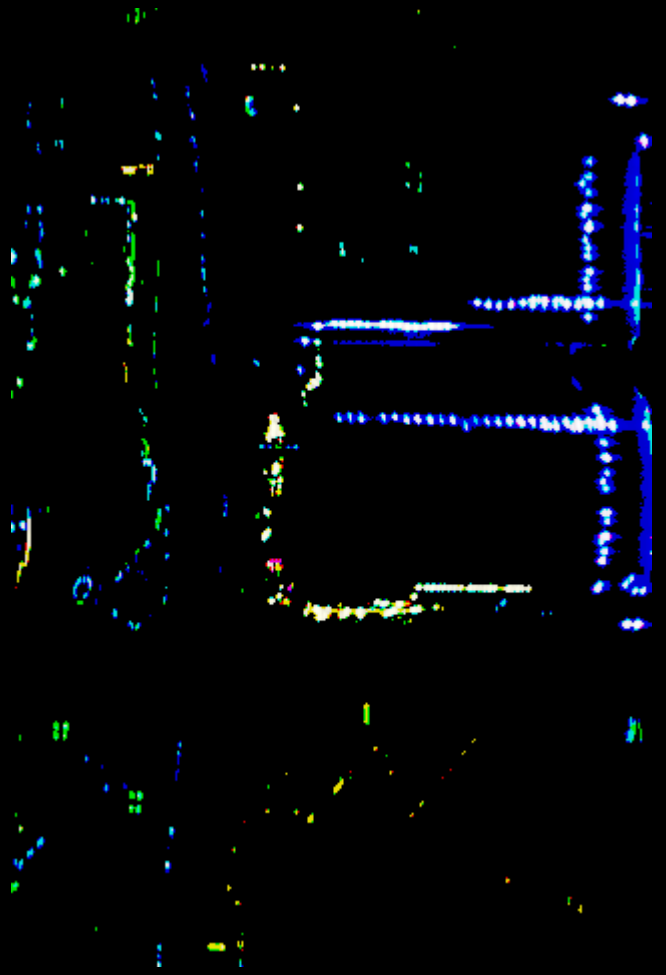
RGB: 535nm, 651nm, 859nm

For nighttime imagery:

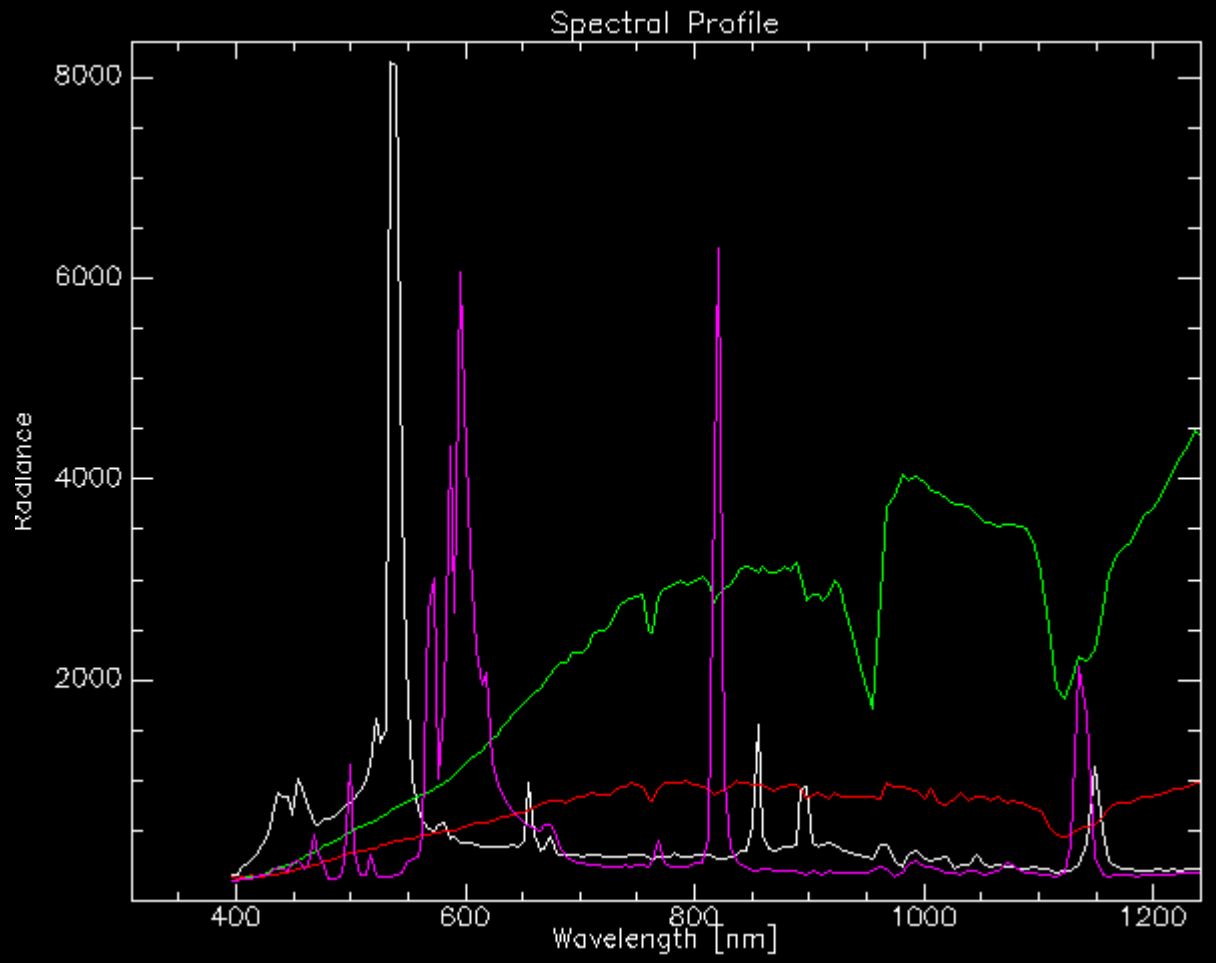
- Vicarious val. using emissive lights
- Example: airborne ProSpecTIR-VS data for Las Vegas (1998) plus reference measurements by Kruse & Elvidge et al.

  DOI: 10.1109/AERO.2011.5747396

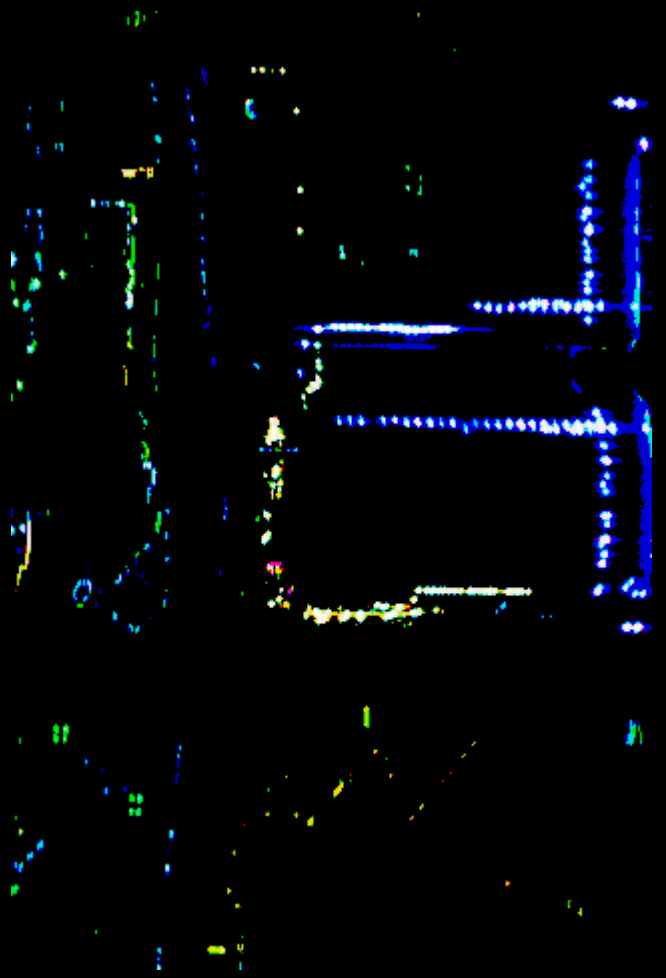
Spectral Characterization



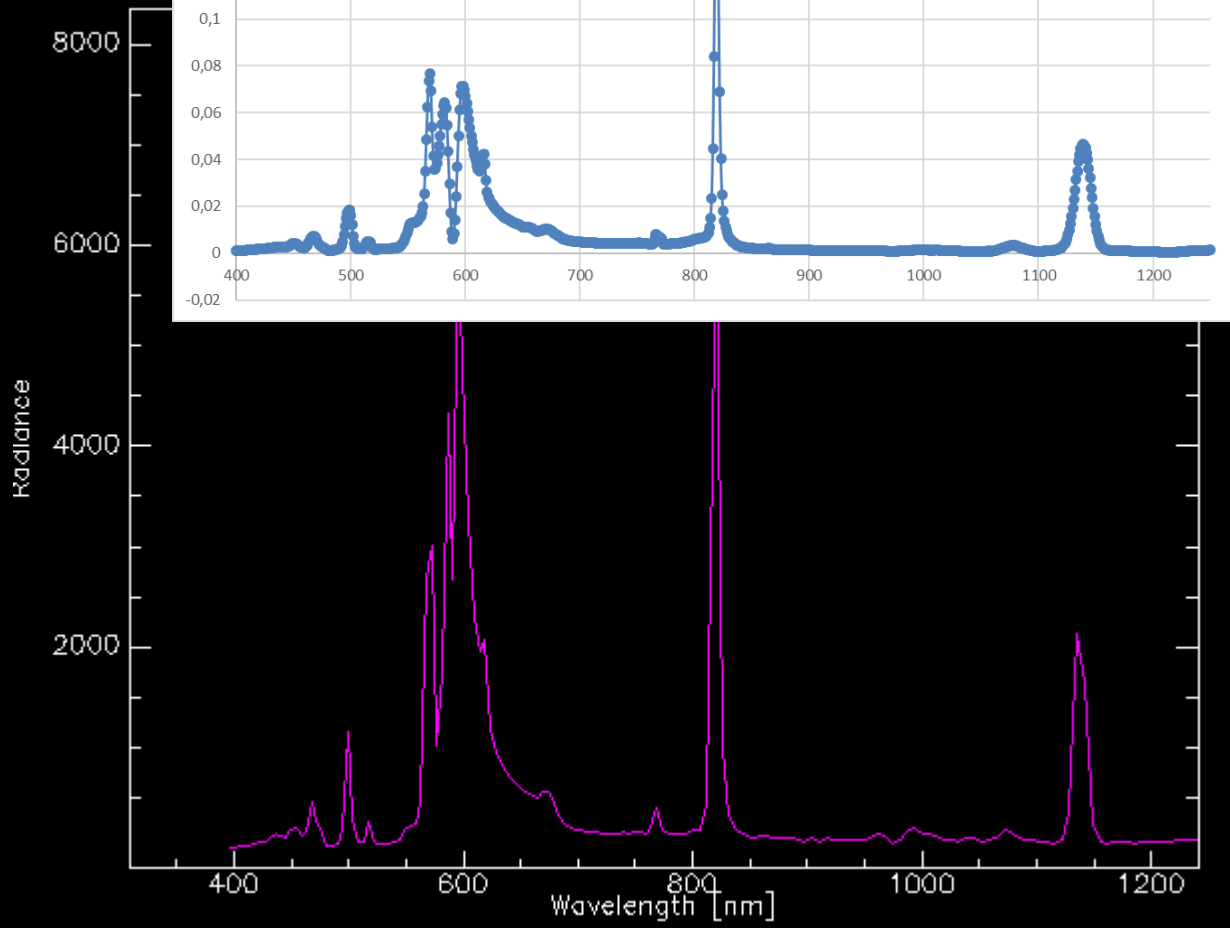
RGB: 535nm, 651nm, 859nm



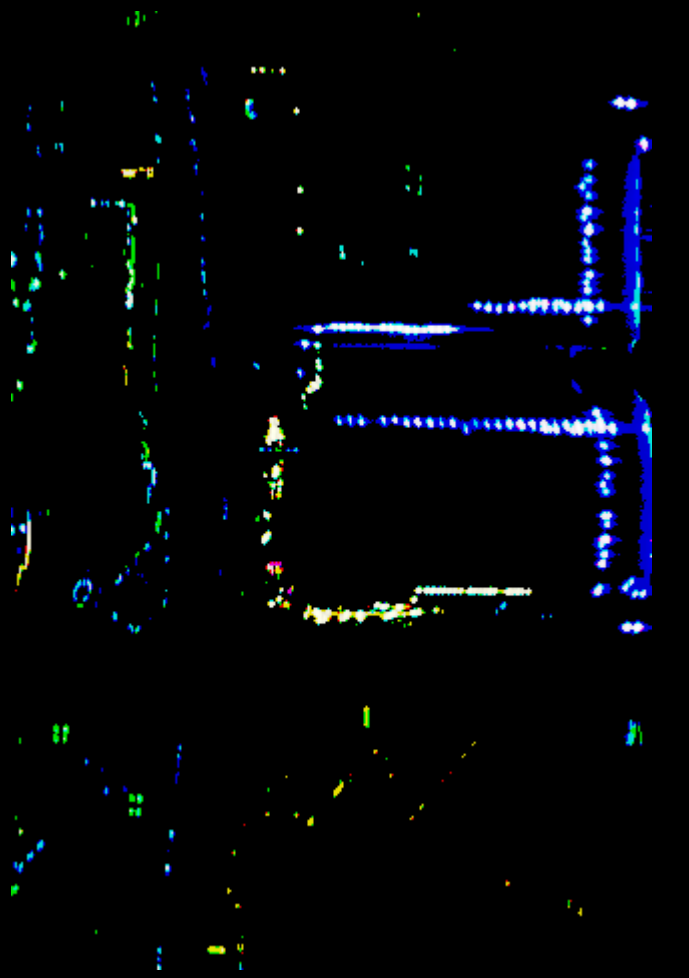
Spectral Characterization



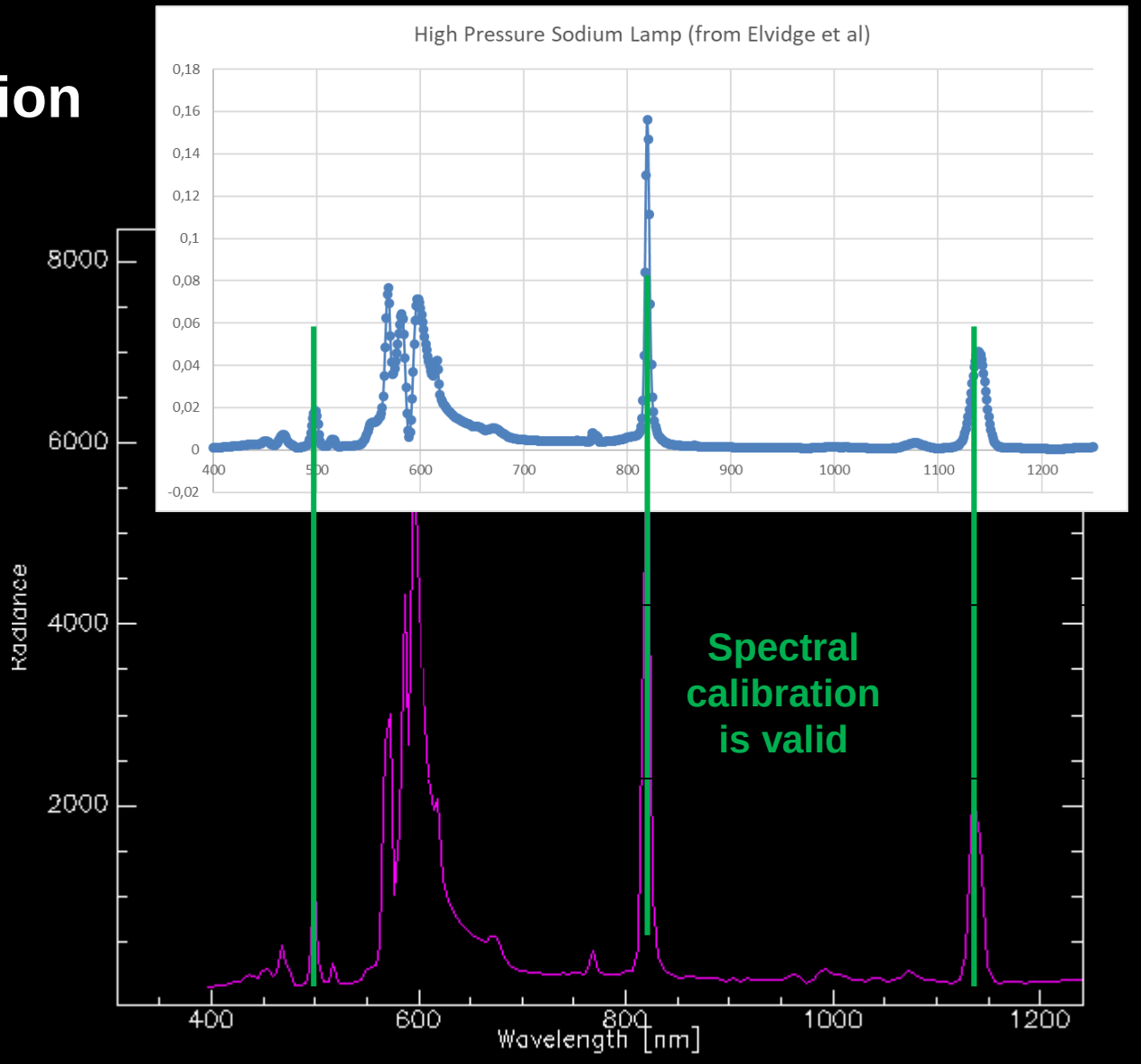
RGB: 535nm, 651nm, 859nm



Spectral Characterization



RGB: 535nm, 651nm, 859nm



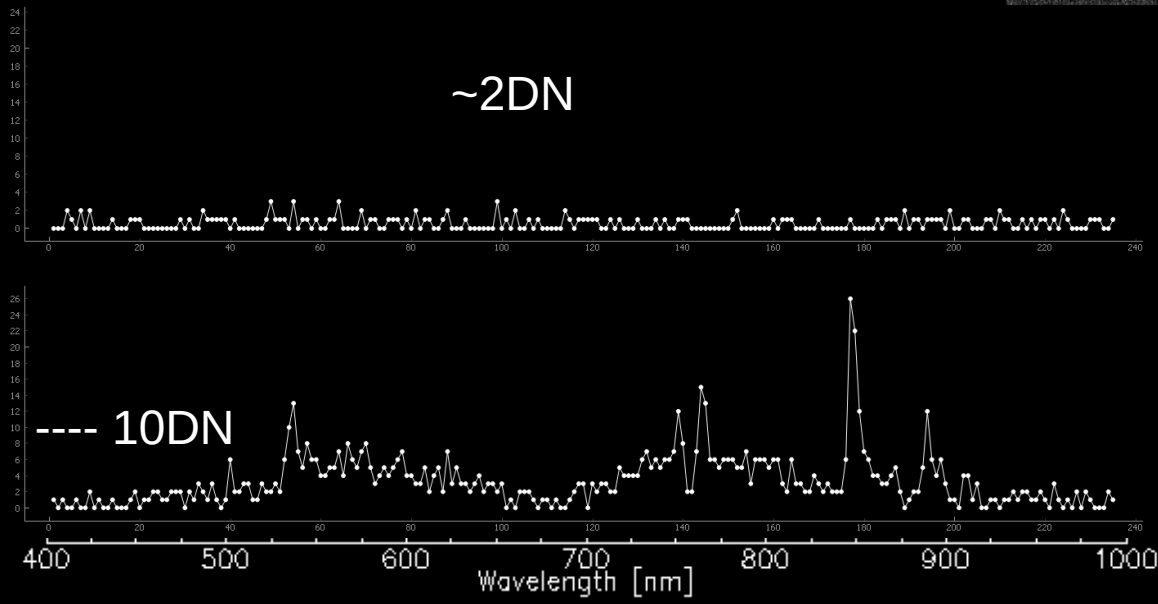
Spectral Characterization

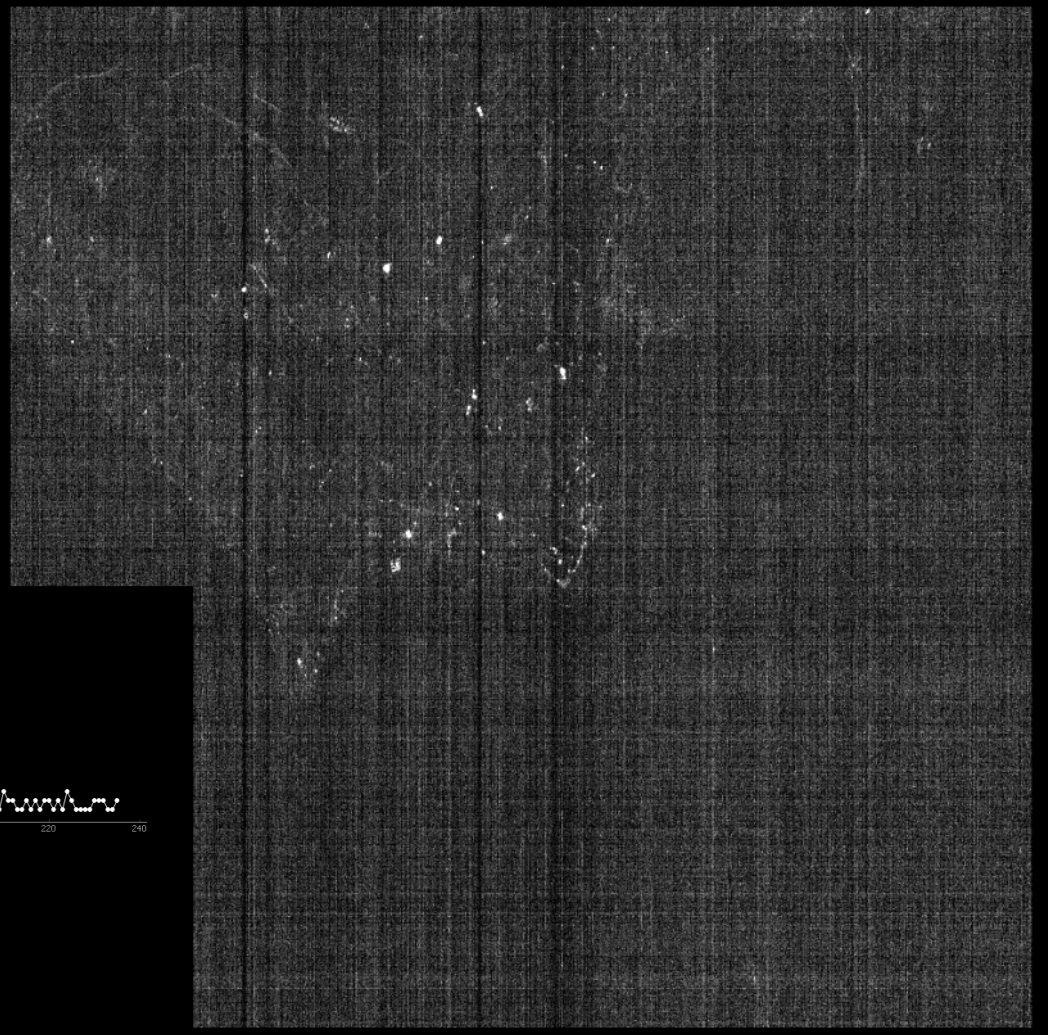
- DESIS L1B,
  statistical enhancement
  (work in progress)

Spectral Characterization

- DESIS L1B,
  statistical enhancement
  (work in progress)

Background „noise“ spectra
magnitude typically <8 DNs

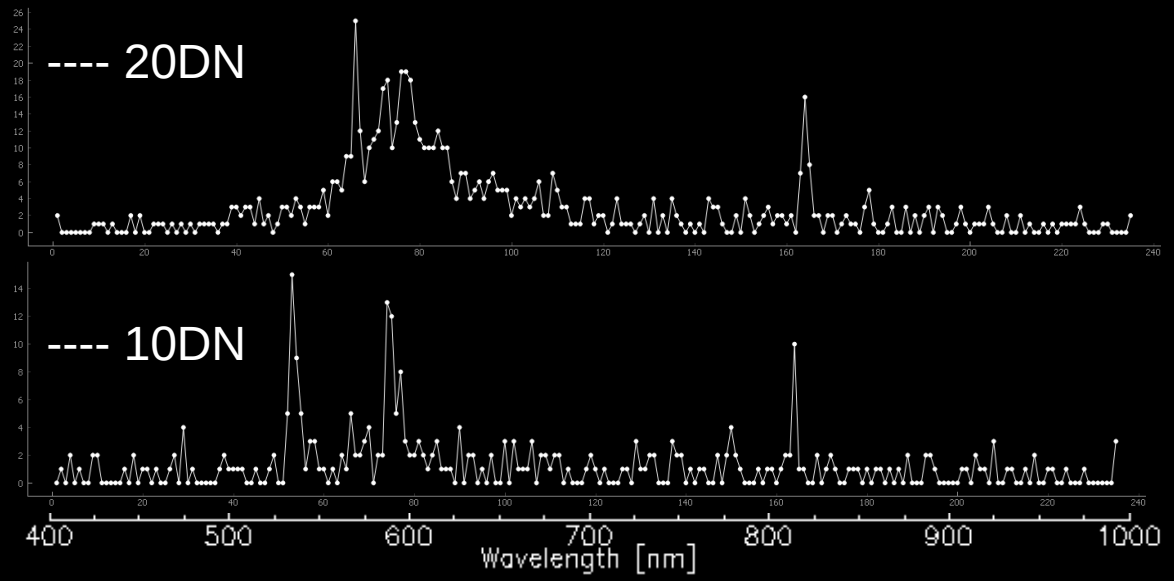


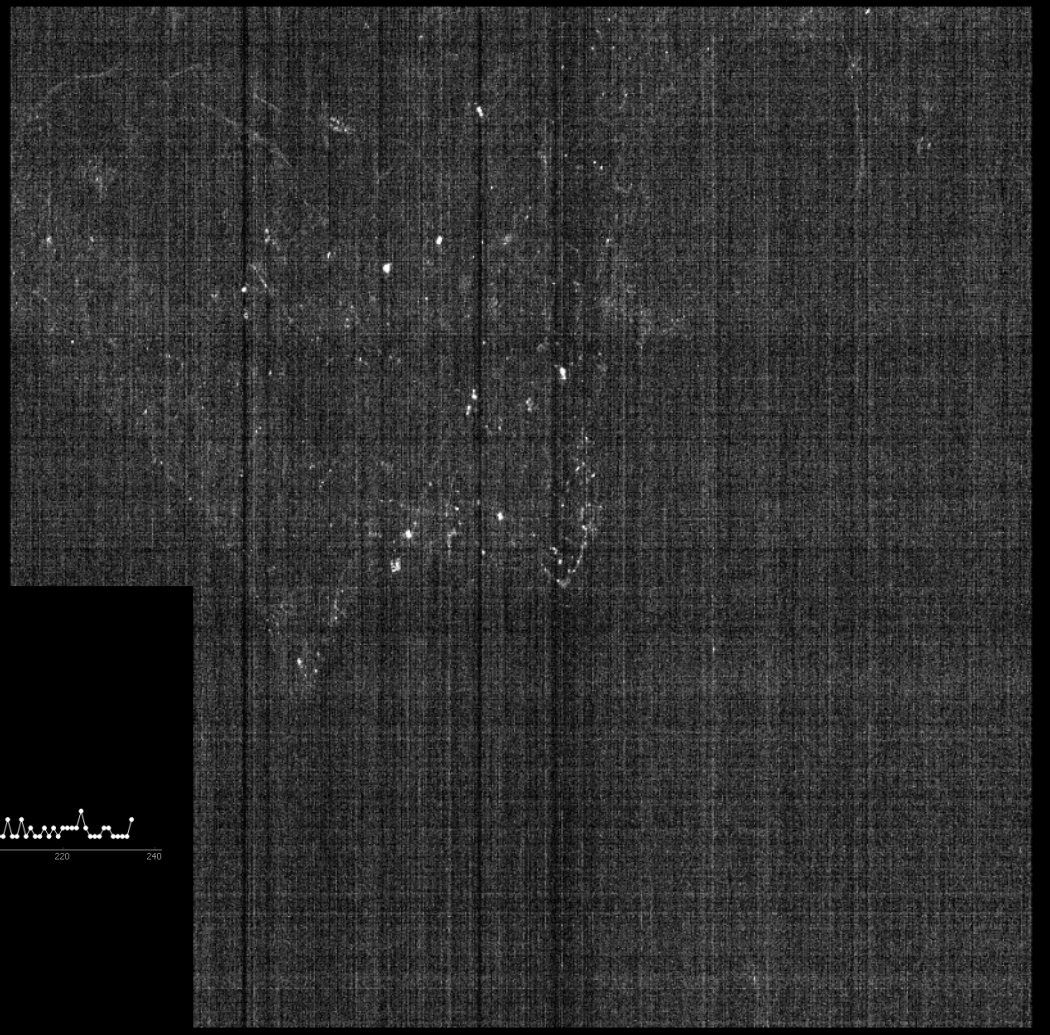


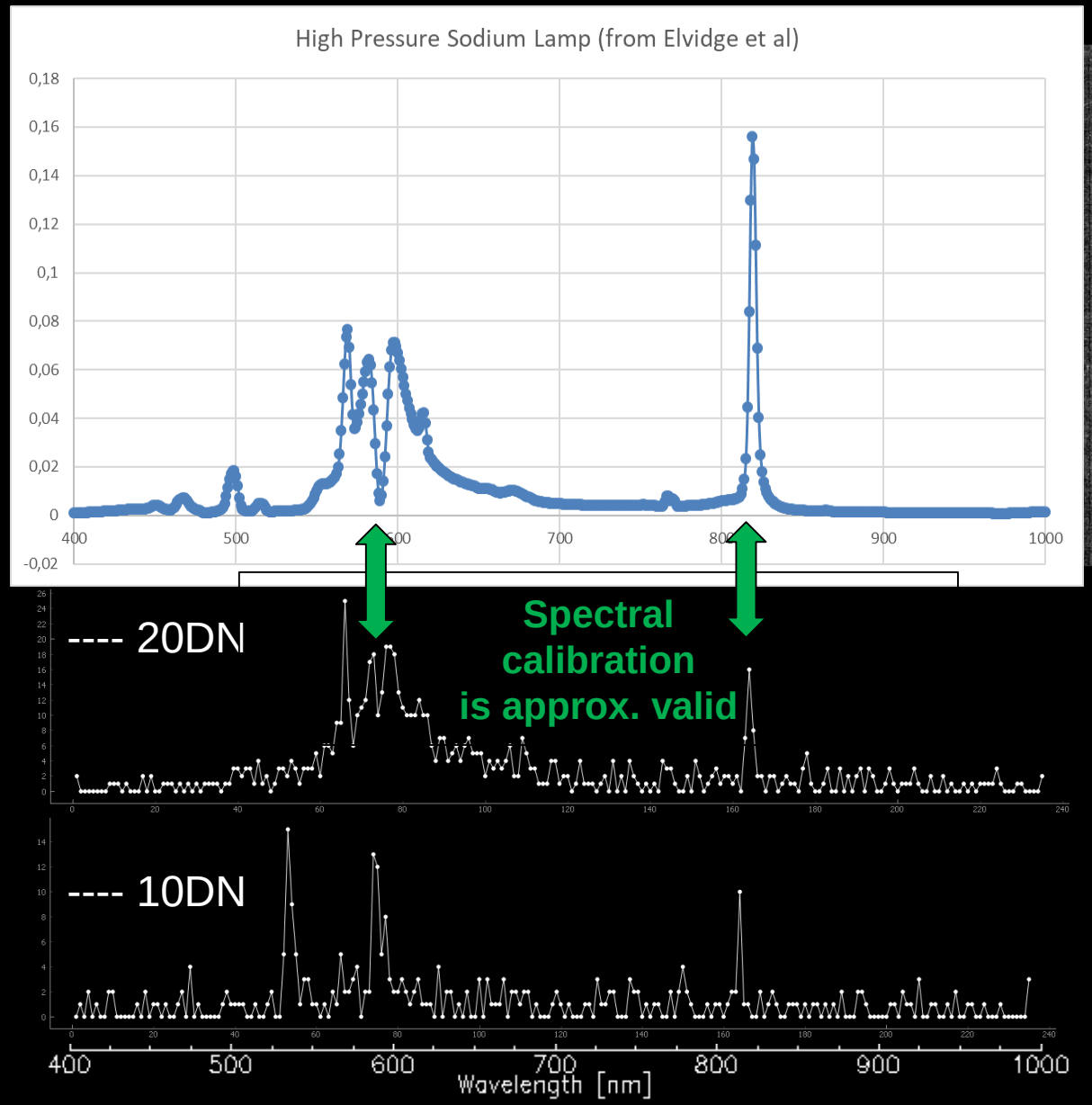
Spectral Characterization

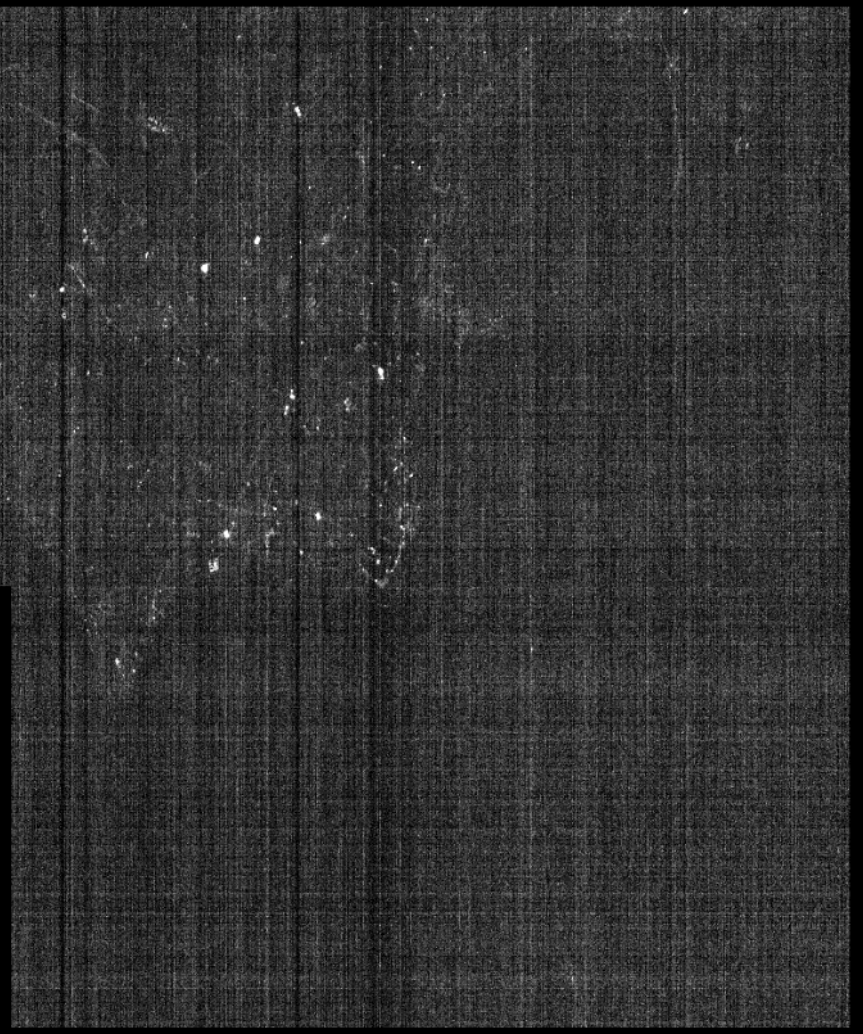
- DESIS L1B,
  statistical enhancement
  (work in progress)

Night time lights
peak typically 12 - 20 DNs

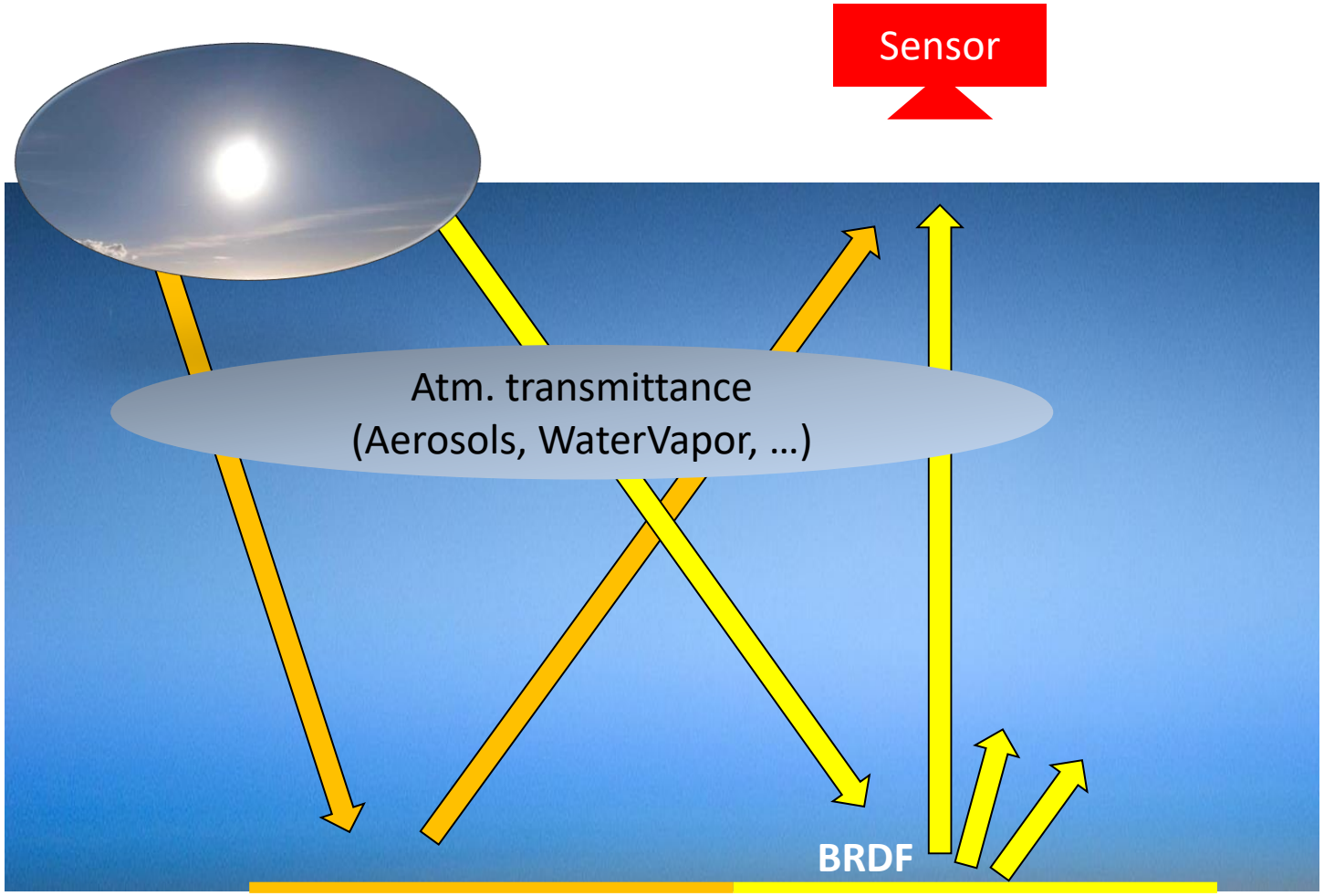




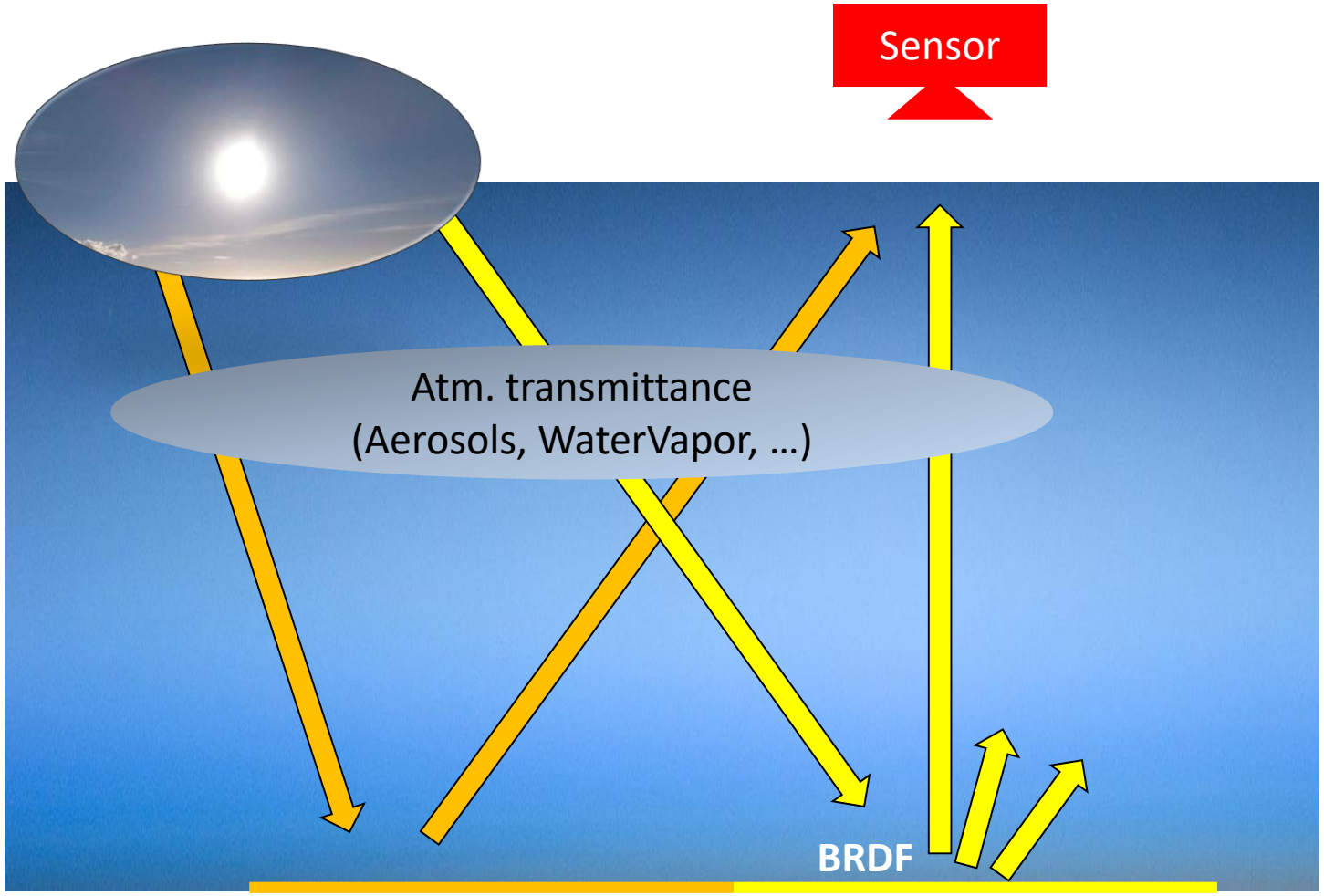

High Pressure Sodium Lamp (from Elvidge et al)
0,18
0,16
0,14
0,12
0,1
0,08
0,06
0,04
0,02
0
-0,02
400
500
700
900
1000
---- 20DN
Spectral calibration is approx. valid
---- 10DN
400
500
600
700
800
900
1000
Wavelength [nm]



Radiometry


Sensor
Atm. transmittance
(Aerosols, WaterVapor, …)
BRDF
adjacency
Target reflectance

Radiometry



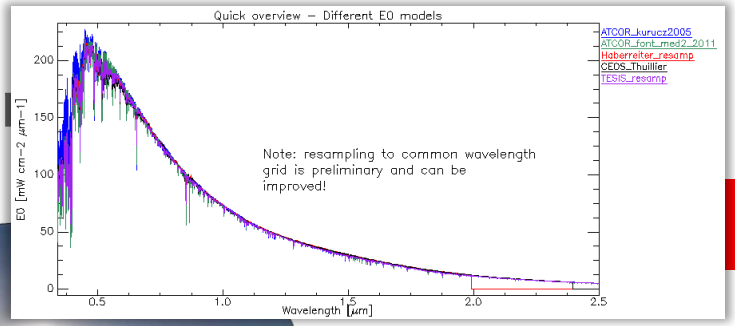
Aspects:

- Known illumination (Sun)
- Measured atm. composition (Aeronet, Sun photometer, …)
- Measured target reflectance @ BOA
- Tagets being (best):
  - bright and spectrally homogeneous
  - Lambertian surface or with characterized BRDF
- Reduced adjacency effects by using large targets

CEOS Tuz Golu 2009

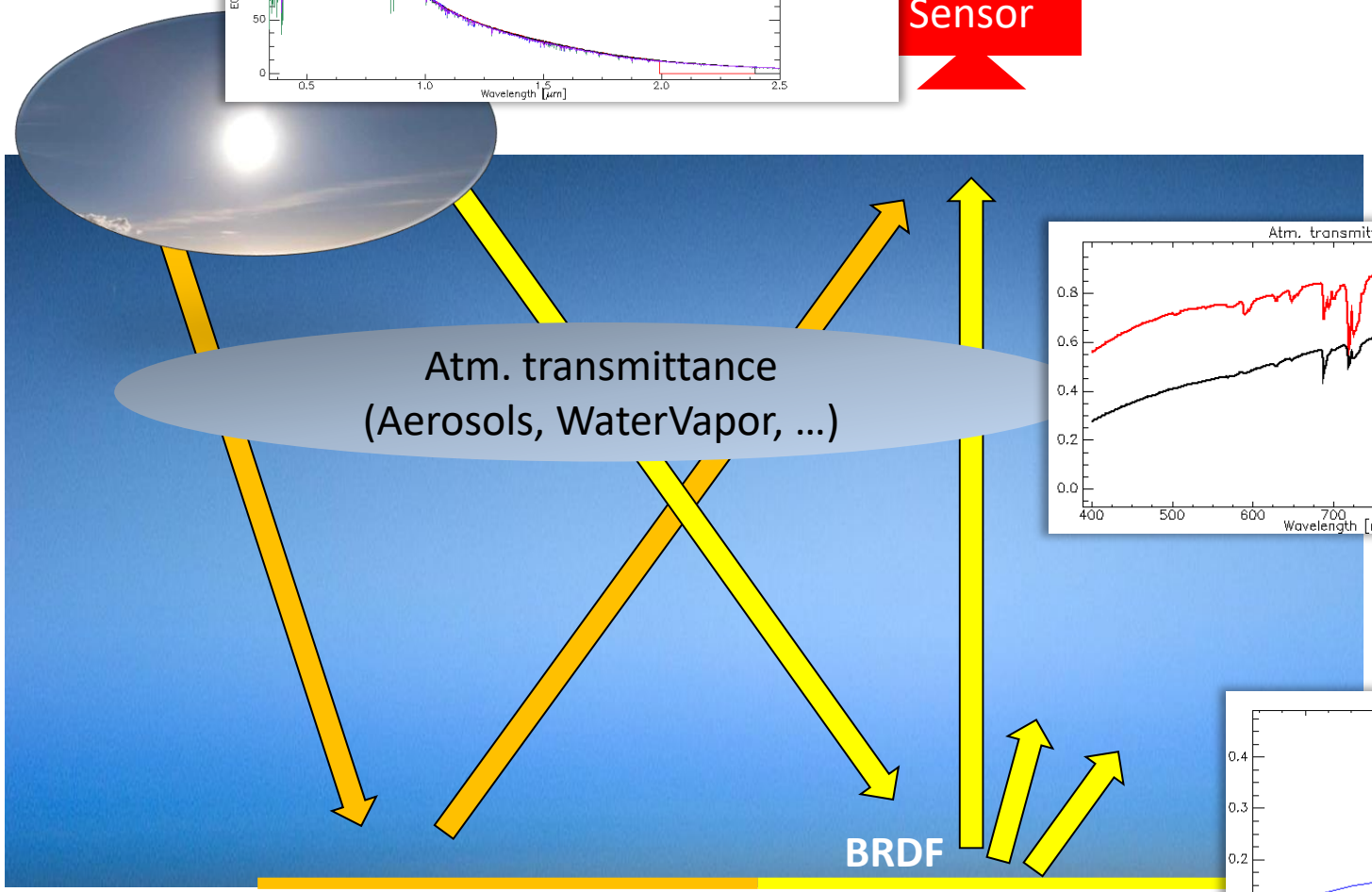
DLR

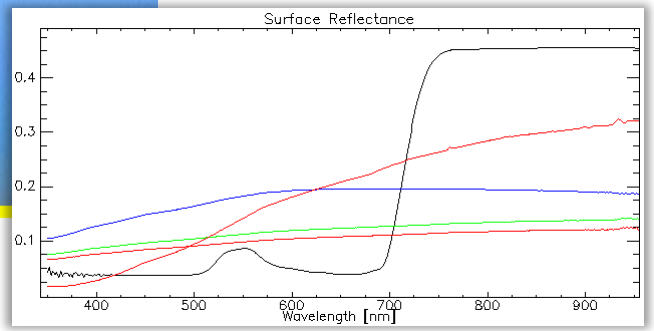
Radiom



Sensor

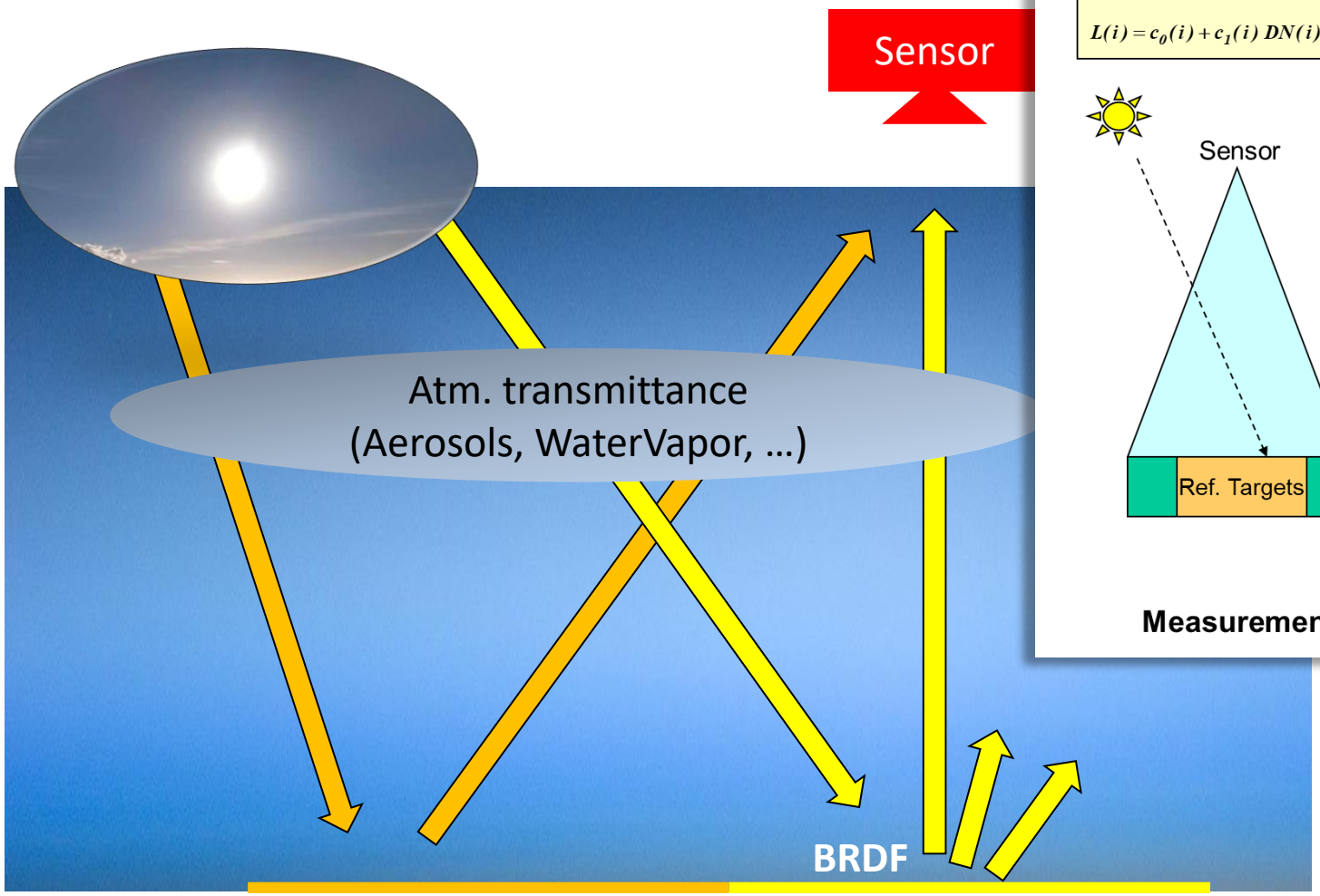
… but still many uncertainties exist



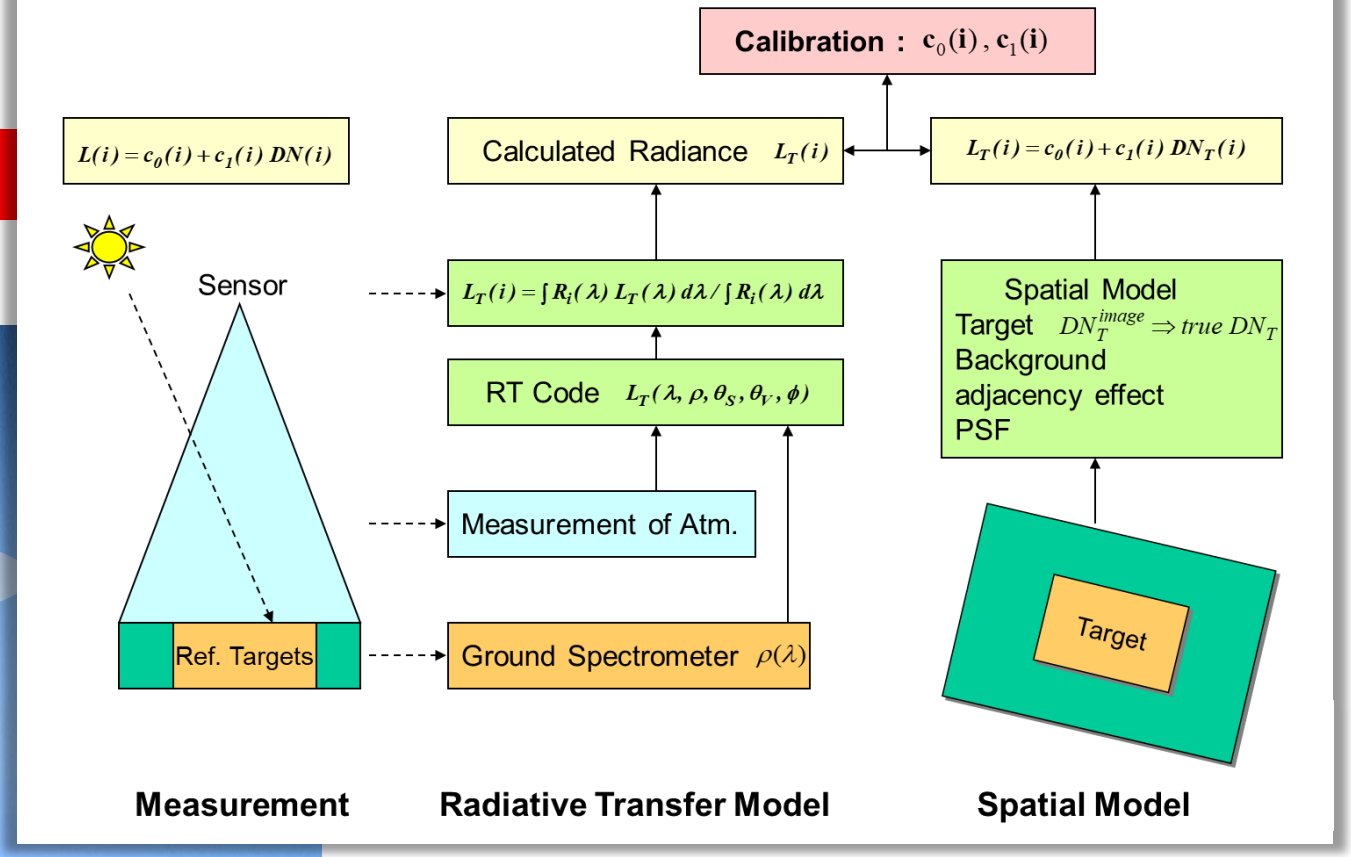


DLR

Radiometry



Radiometric In-Flight Calibration using ATCOR

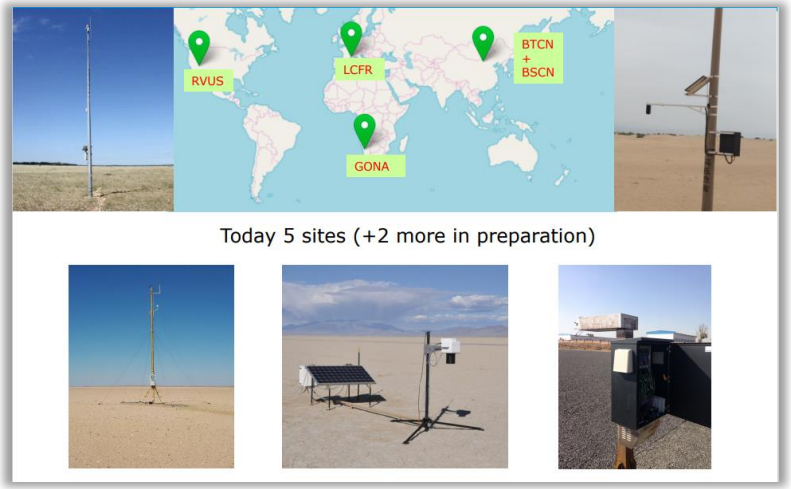


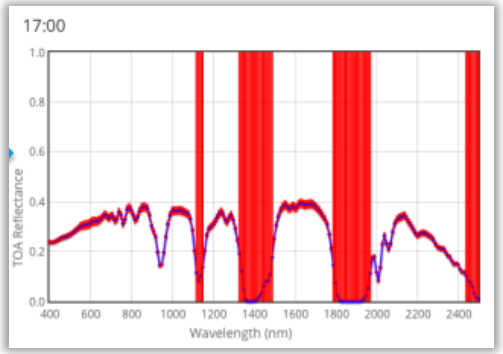
Radiometry (operational Cal/Val for daytime imagery)

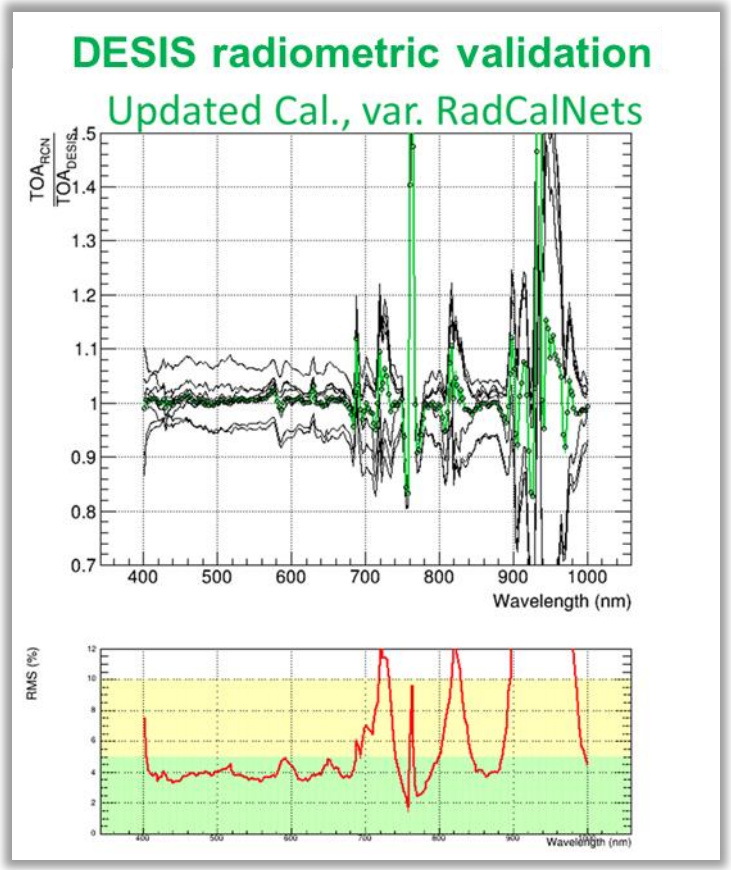
- Established automated network
  CEOS Radiometric Calibration Network
  www.radcalnet.org

- Automated provision of
  BOA_ref
  modeled TOA_ref
  and atm. parameters (AOT, WV)
  for 5 sites each 30 minutes
  incl. uncertainties

RadCalNet

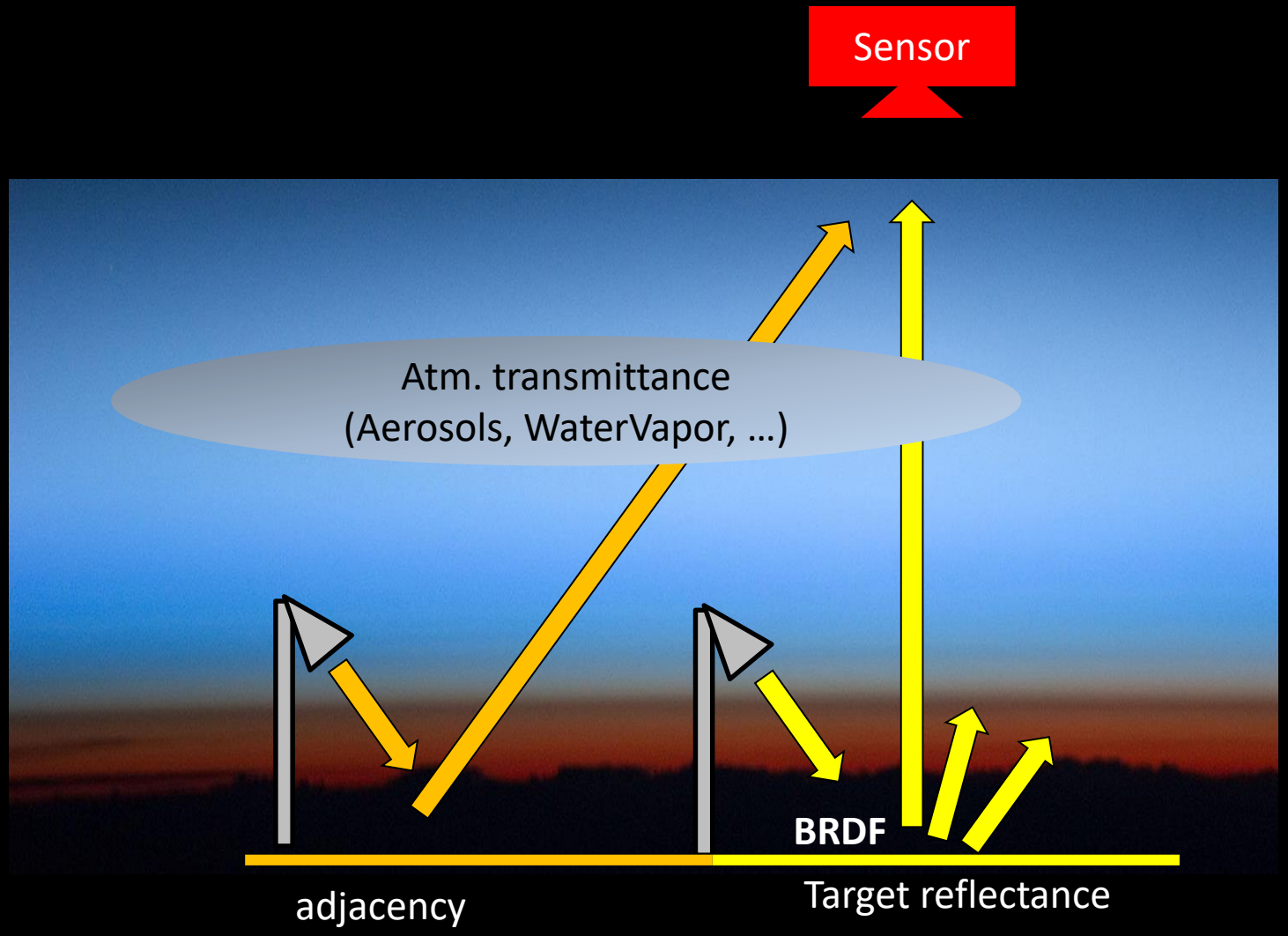






RadCalNet Images from Buvet et al., 2020

Radiometry

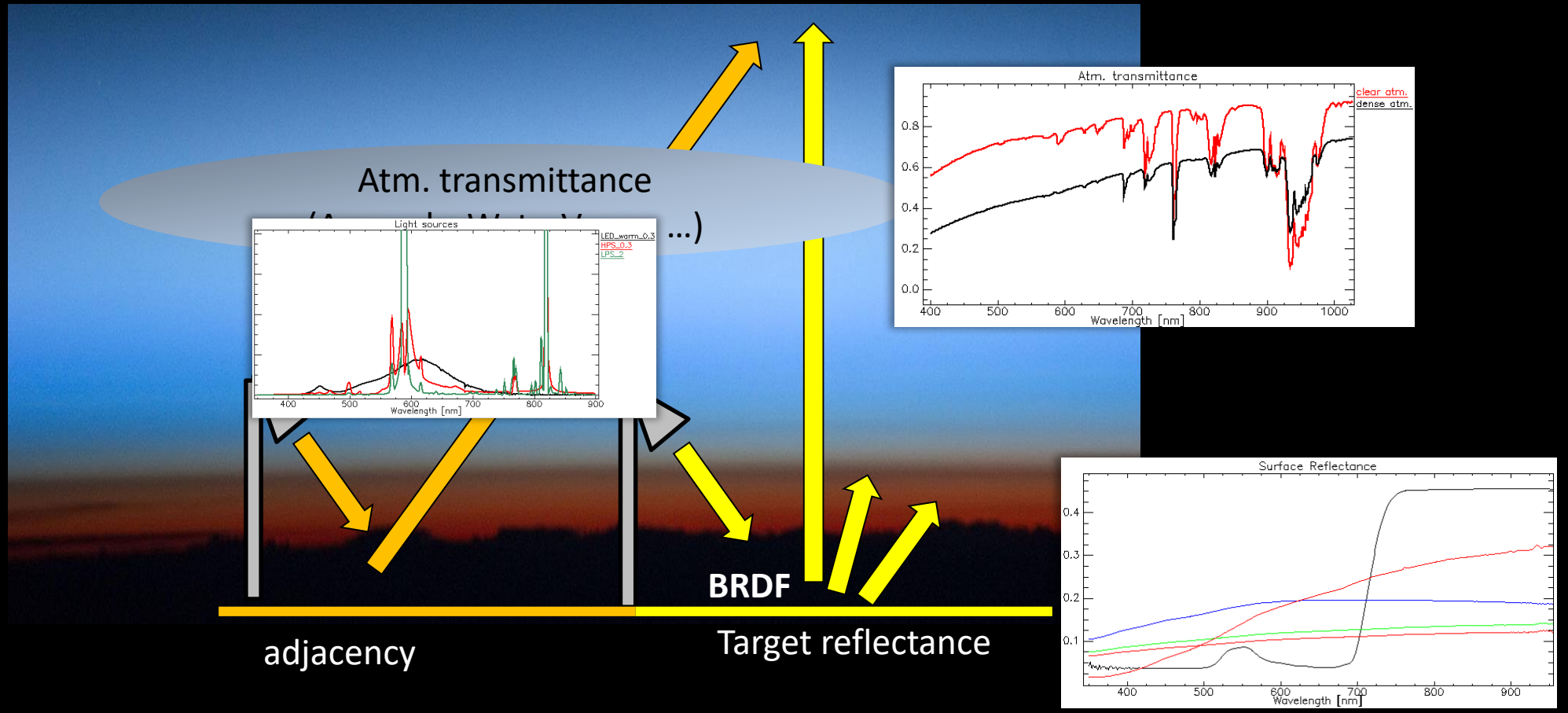


Aspects:

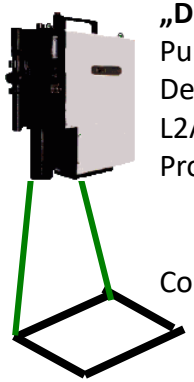
- Unknown illuminations (var. lamps, Moon)
- ~~Measured atm. composition (Aeronet, Sun photometer, …)~~
  (Most often) unknown atmosphere
- Measured target reflectance @ BOA
- Tagets being (best):
  - homogeneously illuminated
  - bright and spectrally homogeneous
  - Lambertian surface
    or with characterized BRDF
- Reduced adjacency effects by using large targets or dark surroundings

Radiometry

… even more uncertainties exist

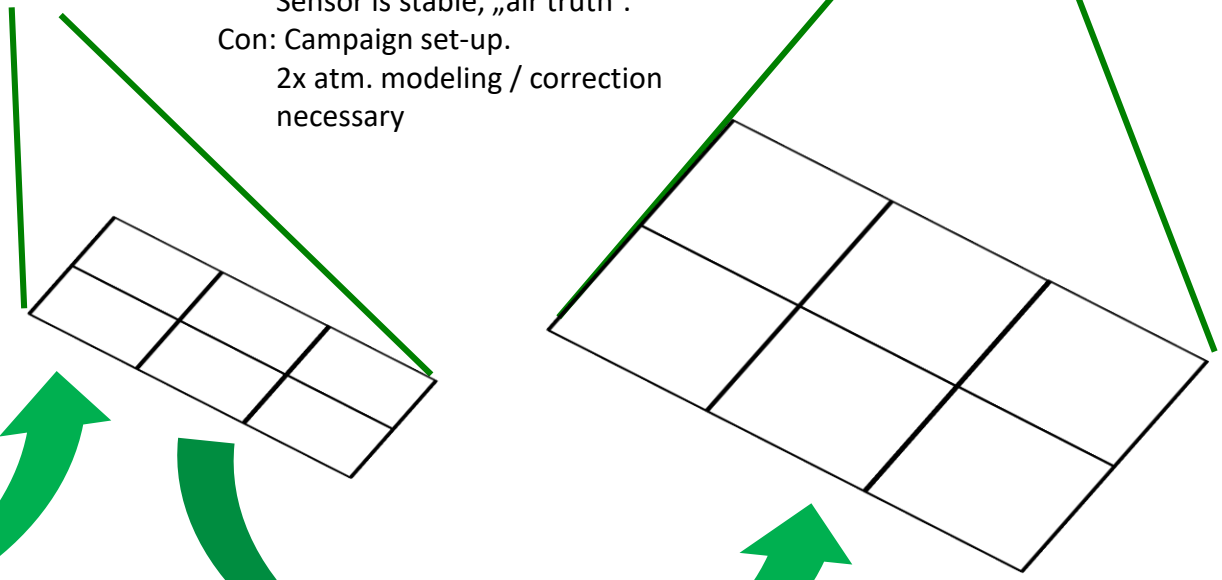


Scaled validation approach



„Direct“ BOA-ref measurement
Purpose:
Demonstration that airborne L2A data is indeed valid
Pro: Only small (but suitable) reference targets needed.
Method well understood.
Con: Only few pixels possible

Upscale airborne - spaceborne
Purpose:
„Mitigate“ non-homogeneous sites
Pro: Full scene / larger areas can be used => better statistics!
Sensor is stable, „air truth“.
Con: Campaign set-up.
2x atm. modeling / correction necessary



Field <=> spaceborne
Purpose:
Pro: Method well understood & proven for spatially invariant sites.
Only 1x atm modelling / correction required
Con: No PICs near OP.
Statistics for only 2-3 pix can be dubious (site standard deviation @ 30m GSD)

In-situ spectrometer measurements

- Examples from Munich campaign (07/2019) using ASD and OceanOptics spectrometer

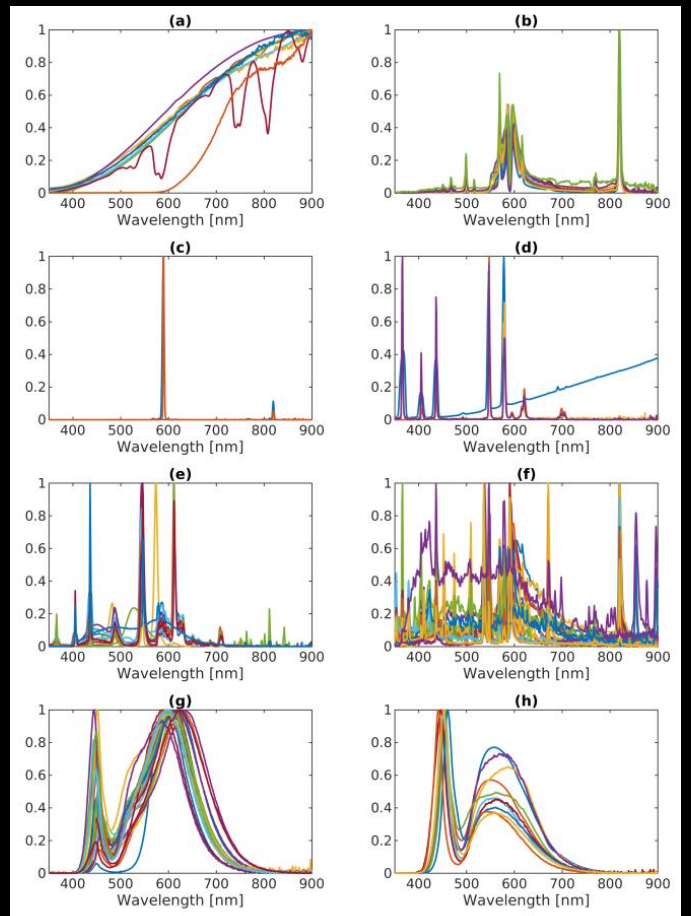


Figure 3.1: Variation in emission spectra for different lamp types with (a) incandescent lamps; (b) high-pressure sodium lamps; (c) low-pressure sodium lamps; (d) mercury vapour lamps; (e) metal halide lamps; (f) fluorescent lamps; (g) warm LED lamps (CCT ≤ 4000 K); and (h) cool LED (CCT > 4000 K). Note that the y-axis represents relative irradiance values.

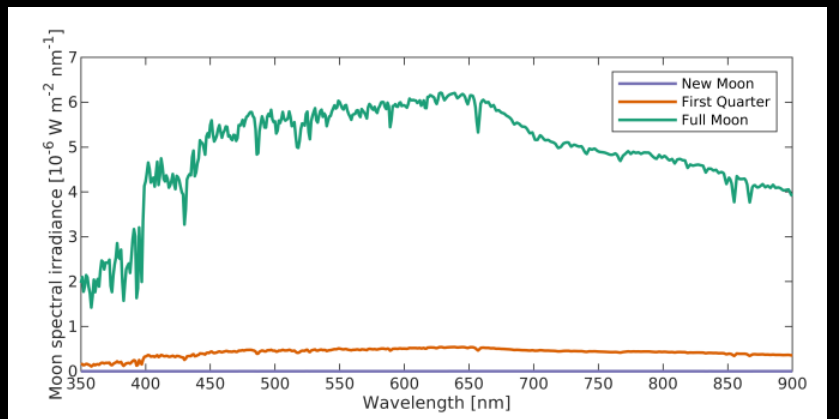


Figure 3.3: Moon spectral irradiance values for lunation 1194 in Munich, Germany. New moon on 2 July 2019, 19:16 UTC, first quarter on 9 July 2019, 10:54 UTC, and full moon on 16 July 2019, 21:38 UTC.

Airborne measurements

Munich central, sensor: airborne 3K camera,
RGB composite - radiometrically *uncalibrated*
Not simultaneous with field campaign

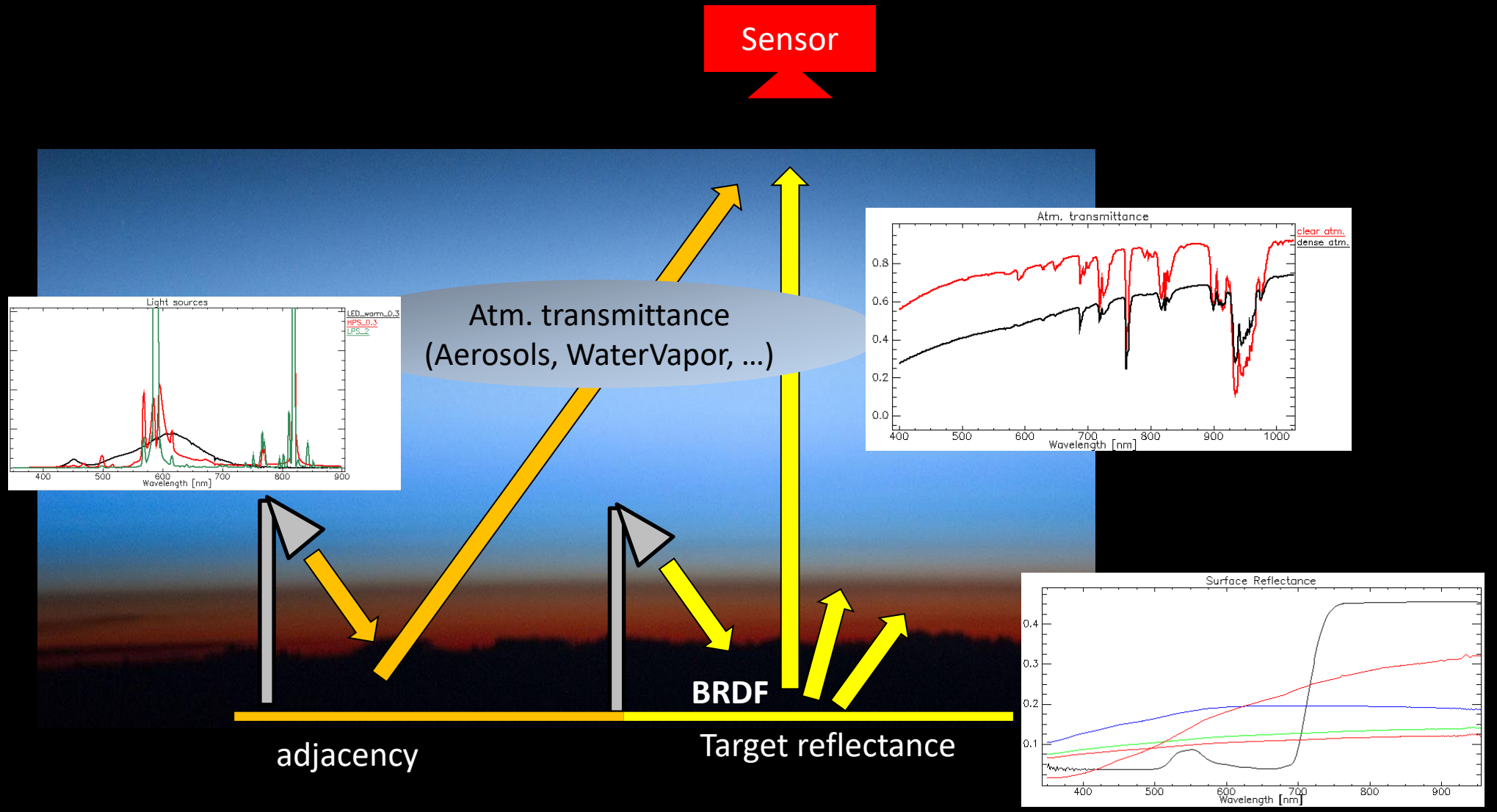
Radiometry

- Problems using Daytime approaches
  - Largely different radiance levels
    (e.g., VIIRS Day/NightBand: difference up to 7 orders of magnitude resp.
    TDI setttings of 3 (low gain) to 250 pix (high gain))

- Cross-talk, echo, straylight
  - Lab. Characterization for straylight

  - Validation using point sources
    offshore gas flares, bridges & boats (CAO & BAI 2016 doi:10.3390/rs61211915)
    or
    high-contrast scenes (VIIRS DNB @ Antarctic Dome C, QUI et al., doi:10.1080/01431161.2017.1338786)

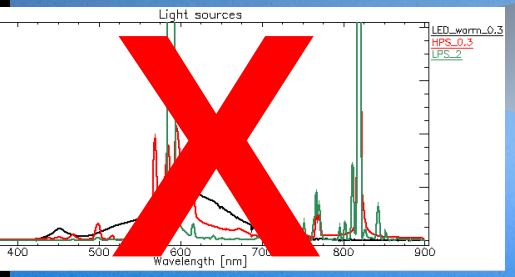
Radiometry

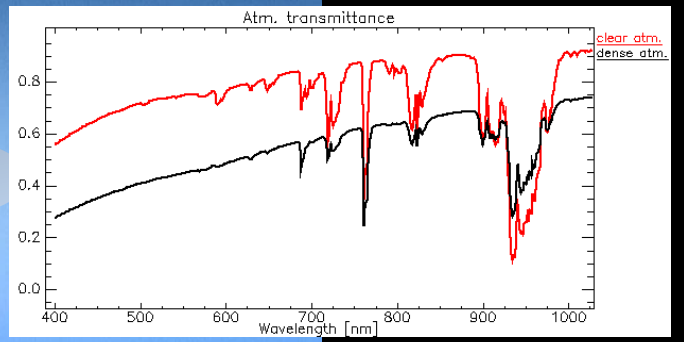

Sensor
Atm. transmittance
(Aerosols, WaterVapor, …)
Light sources
LED_warm_0.3
HPS_0.3
LPS_2
Wavelength [nm]
Atm. transmittance
clear atm.
dense atm.
Wavelength [nm]
BRDF
adjacency
Target reflectance
Surface Reflectance
Wavelength [nm]

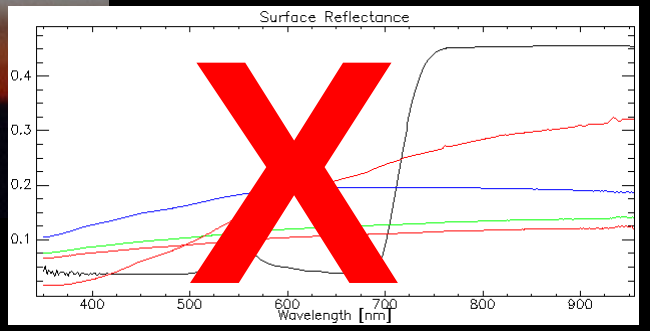
Radiometry

Simplified:

- Upward-pointing light source with known spectral / radiometric properties
- Site with dark surrounding, avoiding adjacency
- New moon phase
- Only atmosphere is (often) unknown

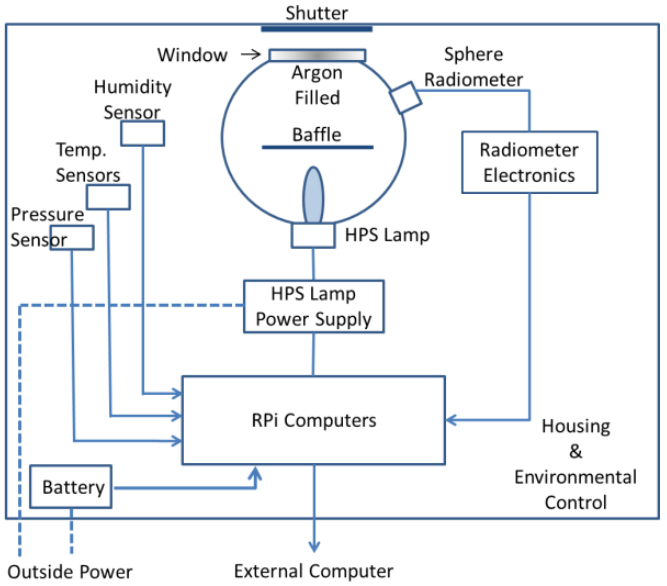






Terra Vega Calibration Source

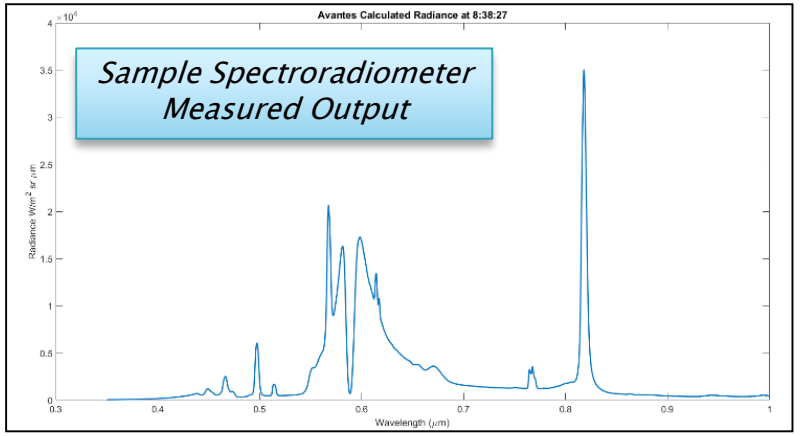
- I2R developed a field deployable NIST-traceable active light source under a NOAA-funded SBIR research grant
  - Integrating sphere (1m diam-$BaSO_4$)
  - Four 1KW High Pressure Sodium Lamps
- Compliments the calibration/validation of the VIIRS DNB under low light level conditions
- Provides expanded capability
  - Validate night imaging products
  - Enable time series assessments



Terra Vega Proof of Concept (Battery Pack Operation)

Parameter	Performance
Effective radiance output	> $3x10^{-9}$ W cm^{-2} sr^{-1}
Corrected systematic drift	< 1%
TOA absolute radiometric accuracy (SI traceable)	Accurate to within 5%
Viewing angle	± 30°

Trailer Mounted with Retractable Roof

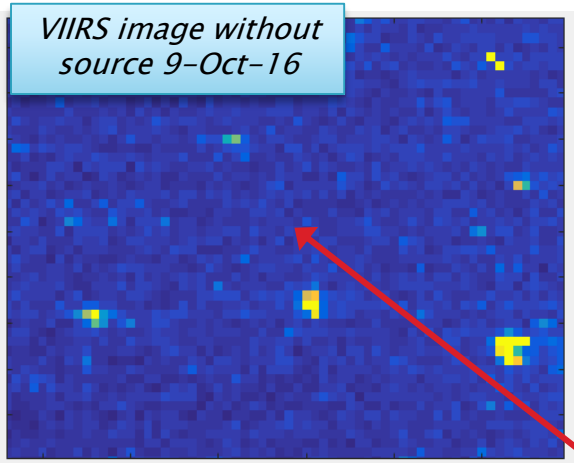


Sample Spectroradiometer Measured Output

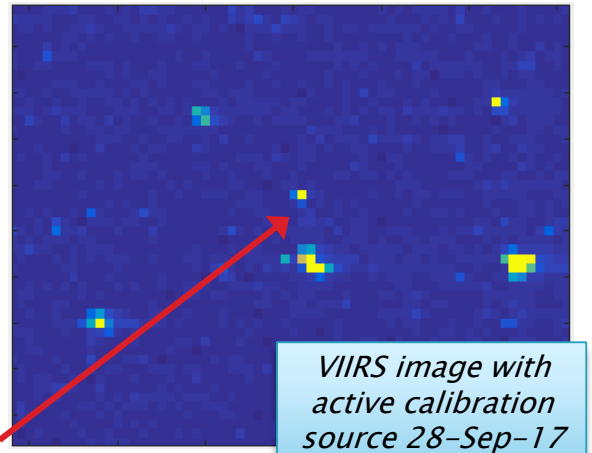
Terra Vega Deployment Sites/Different Dates

Farm near Arlington SD

- Lat/Long: 44.41 N/97.125 W
- Avg. Background Radiance: 2.43×10^{-10} $Wcm^{-2}sr^{-1}$



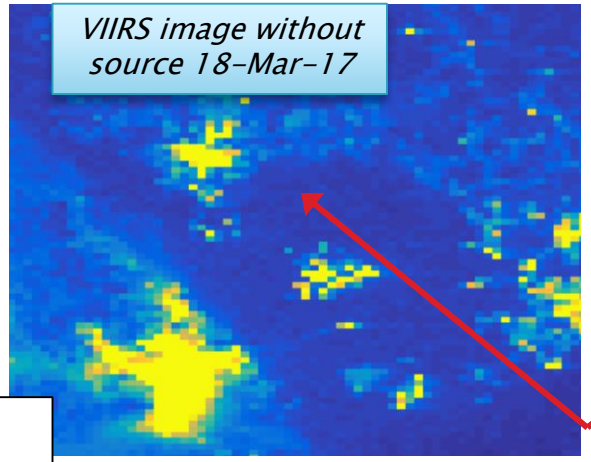
VIIRS image without source 9-Oct-16



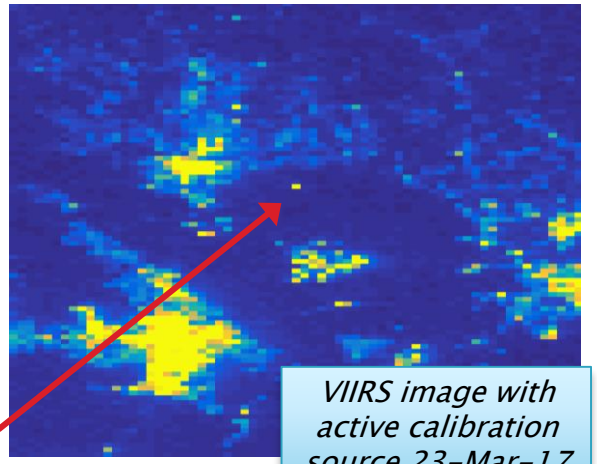
VIIRS image with active calibration source 28-Sep-17

near Picayune MS

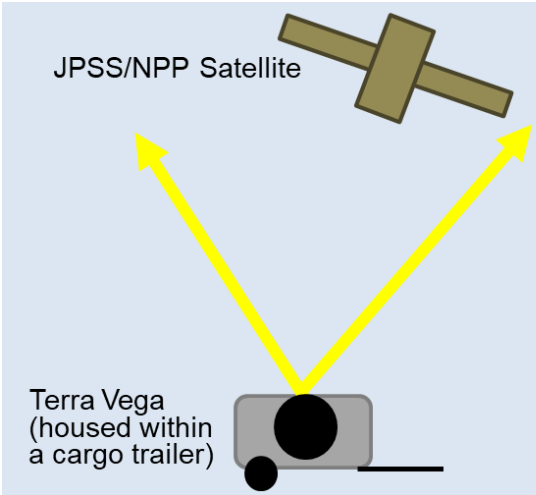
- Lat / Long: 30.48 N/ 89.60 W
- Avg. Background Radiance: 5.38×10^{-10} $Wcm^{-2}sr^{-1}$



VIIRS image without source 18-Mar-17



VIIRS image with active calibration source 23-Mar-17



Terra Vega VIIRS DNB TOA Radiance Comparisons

- In-band radiance generated by Terra Vega is propagated through the atmosphere using a MODTRAN modeled atmosphere
  - Aerosol measurements taken using a nearby AERONET CIMEL sun photometer (average of two daytime measurements taken 1-day before and 1-day after overpass)
  - Series of MODTRAN measurements made varying visibility, water vapor, ozone, with either a MLW of MLS model atmosphere
  - Least squares approach taken to spectrally best match AERONET measurements

Satellite	Date & Time	VIIRS Measured Radiance	Terra Vega TOA Radiance	% Diff
NOAA-20	8/11/18 8:43:37 UTC	1.41 $x10^{-8}$	1.50 $x10^{-8}$	-6.4%
NOAA-20	8/17/18 8:31:08 UTC	2.08 $x10^{-8}$	2.06 $x10^{-8}$	1.0%
NOAA-20	8/22/18 8:37:25 UTC	2.40 $x10^{-8}$	2.24 $x10^{-8}$	6.7%
			NOAA-20 Mean	0.4%
Suomi NPP	9/28/17 8:38:28 UTC	2.49 $x10^{-8}$	2.42 $x10^{-8}$	2.8%
Suomi NPP	10/20/17 8:25:59 UTC	2.20 $x10^{-8}$	2.44 $x10^{-8}$	-10.9%
			Suomi NPP Mean	-4.1%

Ryan, Robert E., Mary Pagnutti, Kara Burch, Larry Leigh, Timothy Ruggles, Changyong Cao, David Aaron, Slawomir Blonski, and Dennis Helder. "The Terra Vega Active Light Source: A First Step in a New Approach to Perform Nighttime Absolute Radiometric Calibrations and Early Results Calibrating the VIIRS DNB." *Remote Sensing* 11, no. 6 (2019): 710.

Some conclusions…

Validation of

- **Geometry**
  - for nighttime imagery not automated

- **Spectral** characteristics:
  - using established on-board sources
  - vicariously using artificial light sources (if spectral resolution is sufficient)

- **Radiometric** characteristics
  - daytime calibration approaches hardly usable as large differences in radiation levels plus: different gain settings / integration times, linearity issues, …
  - nevertheless, similar field measurement approaches as for daytime possible
  - calibrated active light sources (Terra Vega) can further improve this
  - better knowledge on atm. characteristics during nighttime needed

Thank you for your attention!

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