Overview of CHAFF: CubeSat Hyperspectral Application For Farming

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- Hyperspectral Imaging on CubeSats
  - Allows for cost effective constellations/more frequent revisit times.
  - Technology is in its infancy (HyperScout-1[1], AaSI (Aalto-1[2])).

•Applications:

  - **Agriculture.**
  - Mineral Mapping.
  - Disaster Relief.

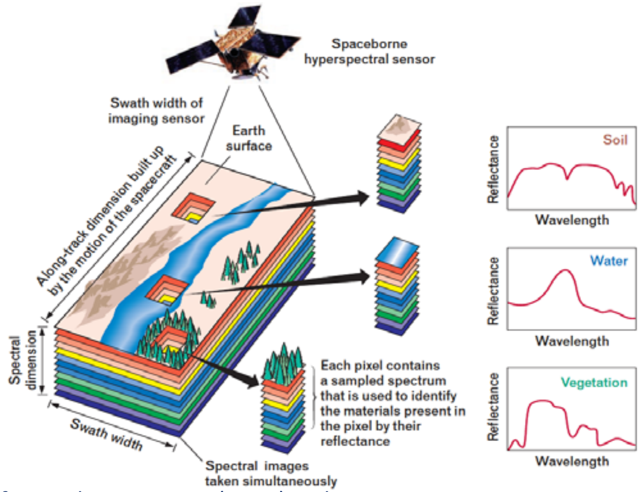


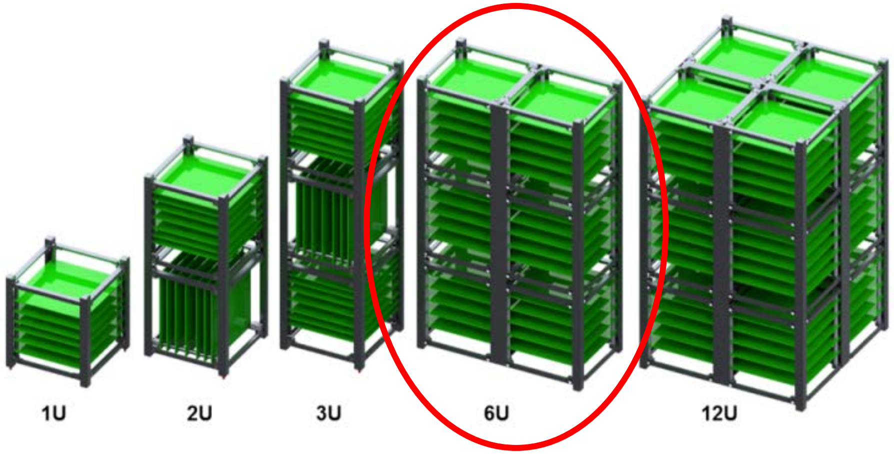
Image from Elowitz, R. M. (2018), What is imaging Spectroscopy (Hyperspectral Imaging)?. Available at: http://www.markelowitz.com/Hyperspectral.html Accessed 18/04/2018

[1]HyperScout-1 (2019), Available at: https://hyperscout.nl/ (Accessed 02/09/2019)

[2]Aalto-1 Spectral Imager (2019), Available at: https://www.aalto.fi/en/spacecraft (Accessed 02/09/2019)

Objective is to create:

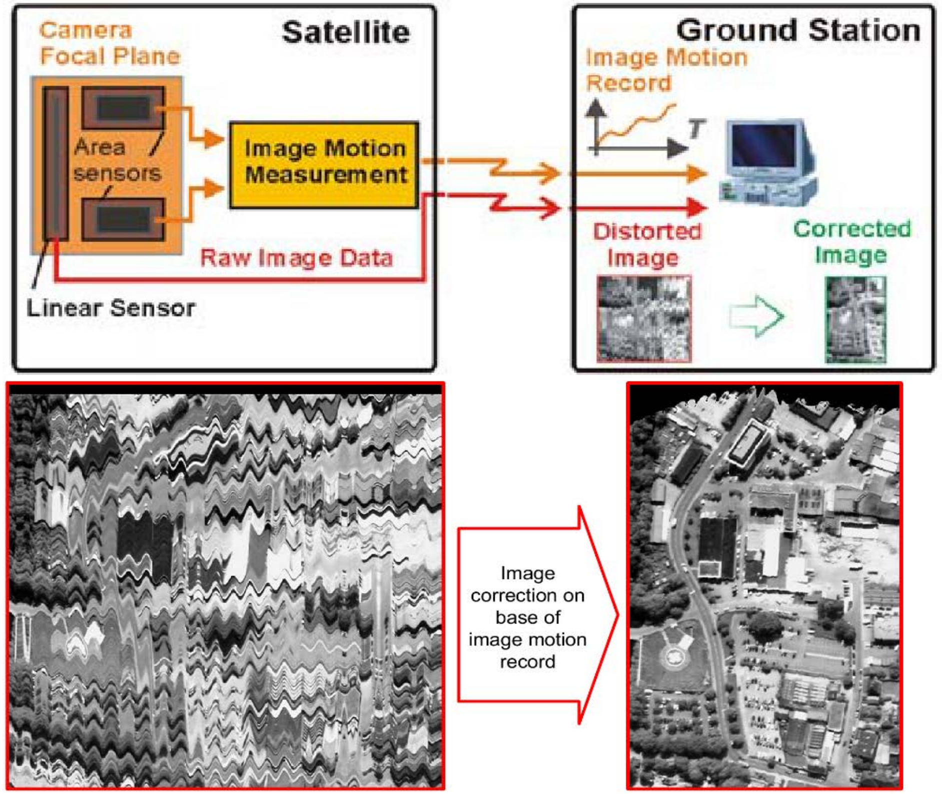
- **A holistically designed CHSI** capable of high spectral resolution/medium spatial resolution measurements.
- **Low-cost, compact design** able to operate within the constraints of the (CubeSat) platform.
- **High data fidelity** resulting from calibration to National Metrology Institute (NMI) Standards - i.e. NPL for the UK.
- **Mitigate CubeSat ADCS issues** via On-Board Processing/Auxiliary Imaging.
- **Mitigate CubeSat data link limitations** via advanced lossless data compression.



Source: Radius Space
www.radiusspace.com

CHAFF Design Requirements

Parameter	Value	Notes
Volume	3U	Integration onto 6U CubeSat.
Spectral range	460 - 800 nm >80 bands	VNIR most suitable for application.
Cost	<£10,000	Commensurate with most CubeSat budgets. COTS optics.
Spatial Resolution (GSD@500 km altitude)	<40m	Across-track GSD.
Spectral Resolution	<5nm	Vegetation red edge sampling.
Swath width (@500 km altitude)	20-30km	Increase Likelihood of imaging target.
SNR	50 - 100	Adequate Radiometric accuracy.



- Tested aboard an aircraft to co-register a pushbroom image.
- Uses opto-electronic components
    - Unsuitable for CubeSats – we use GPUs
- Utilise the process as part of OBDH processing chain.
- Enable lossless compression schemes (CCSDS-123).

Images from: Janschek, K. Tchernykh, V. and Dyblenko, S. (2006), Smartscan – smart pushbroom imaging system for shaky space platforms, in *20th Annual AIAA/USU Conference on Small Satellites*, SSC06-VI-3

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NVIDIA Jetson Nano Developer Kit.
Image Credit: NVIDIA, https://developer.nvidia.com/embedded/jetson-nano-developer-kit (Accessed 29/08/2019)

Calibration and Traceability

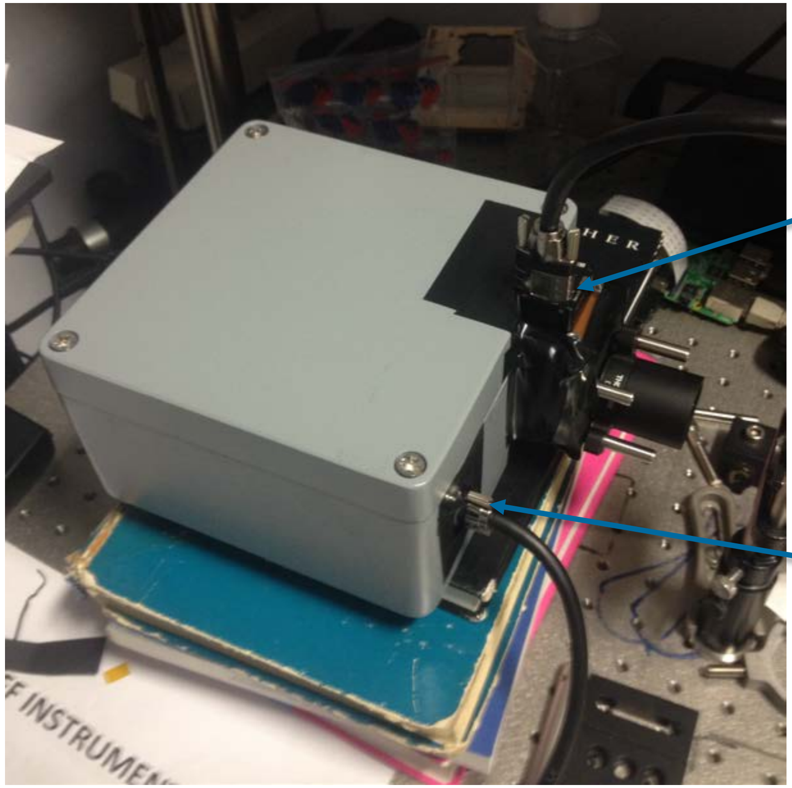
"If left unchecked and ungoverned without standards, HSI technology and the developing industry could be slow to reach its full potential due to disparate techniques and unbounded interpretation of instrument and application performance." – (Jablonski et. al., 2016)

- Calibration of a hyperspectral instrument is an arduous process (Instrument Profile for each spatial-spectral channel).
- Proposed use of tuneable laser systems to speed this up.
    - Spectral, radiometric and stray light characterisation from same source.
    - Expertise of the National Physical Laboratory.
- Allows calibration traceable to the standards of a National Metrology Institute (NMI), ensuring data fidelity.

Jablonski, J., Durell, C., Slonecker, T., Wong, K., Simon, B. Eichelberger, A. and Osterberg, J. (2016), Best Practices in Passive Remote Sensing VNIR Hyperspectral Hardware Calibrations, in "Proc.SPIE", Vol. 9860.

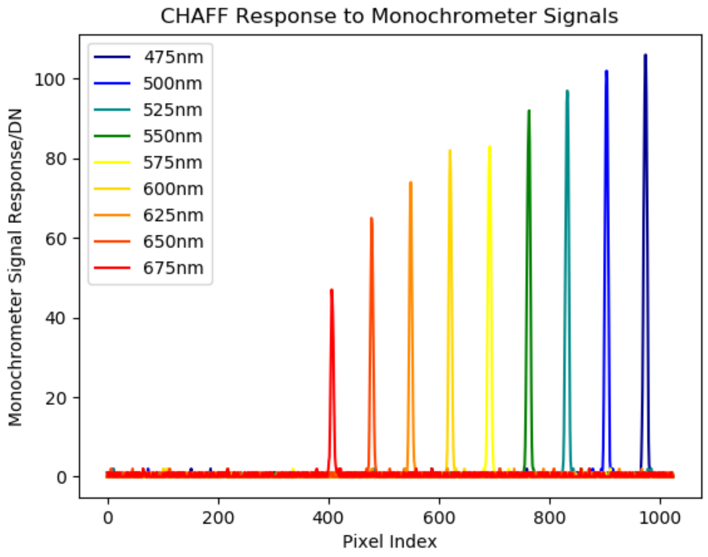
Portable Prototype

CHAFF: CubeSat Hyperspectral Application For Farming.

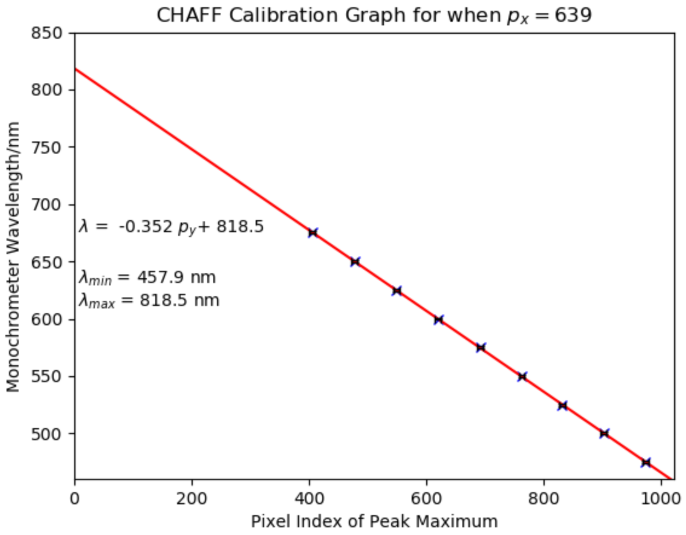


- Size ~ 230mm x 160mm x 90mm.
- Cost ~ £3500.
- Final Instrument ~3U volume (inc. GPU board) to fit 6U CubeSat.

Spectral Calibration



Monochrometer Signal Responses



Calibration Graph

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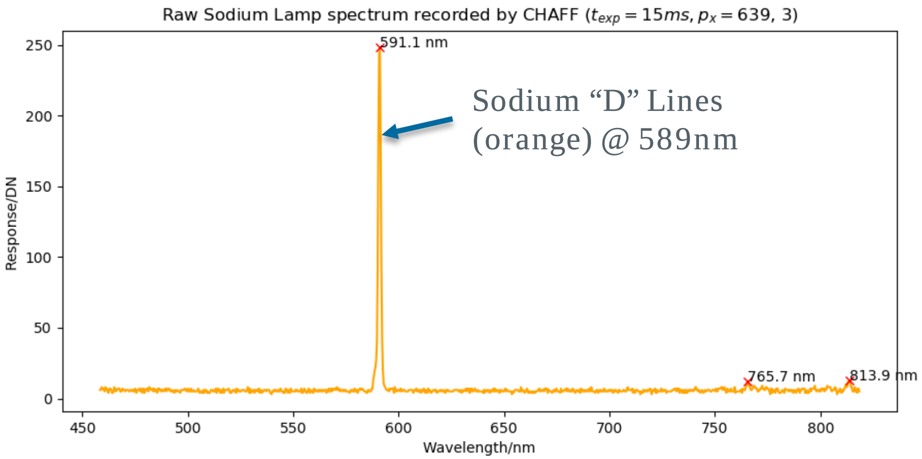
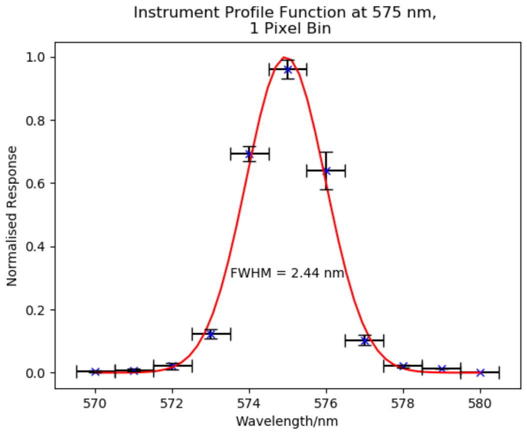
Sodium Lamp: Spectral Resolution



Spectrally Calibrated Sodium Lamp Response



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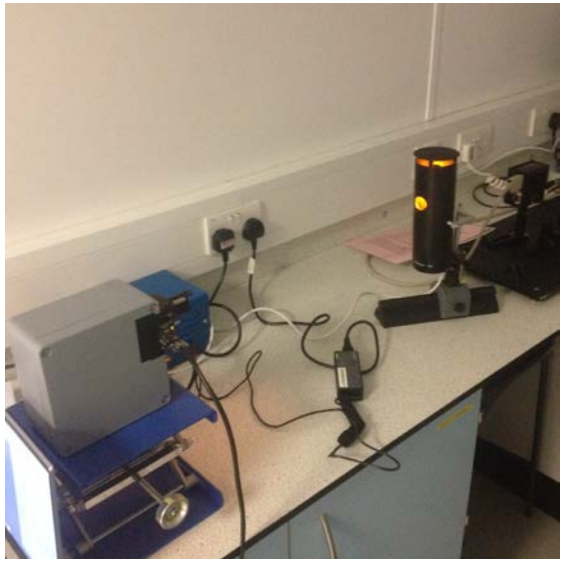
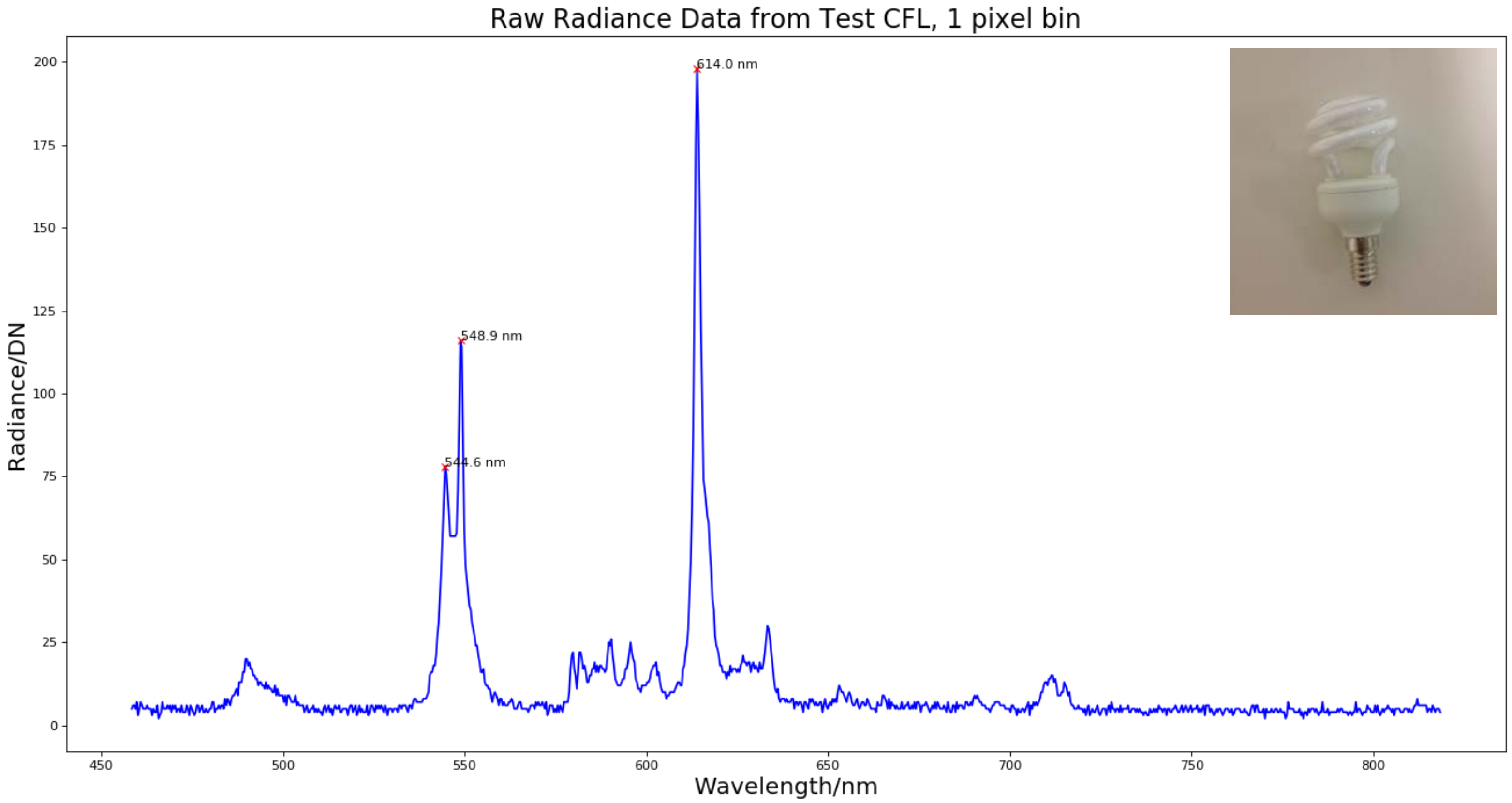
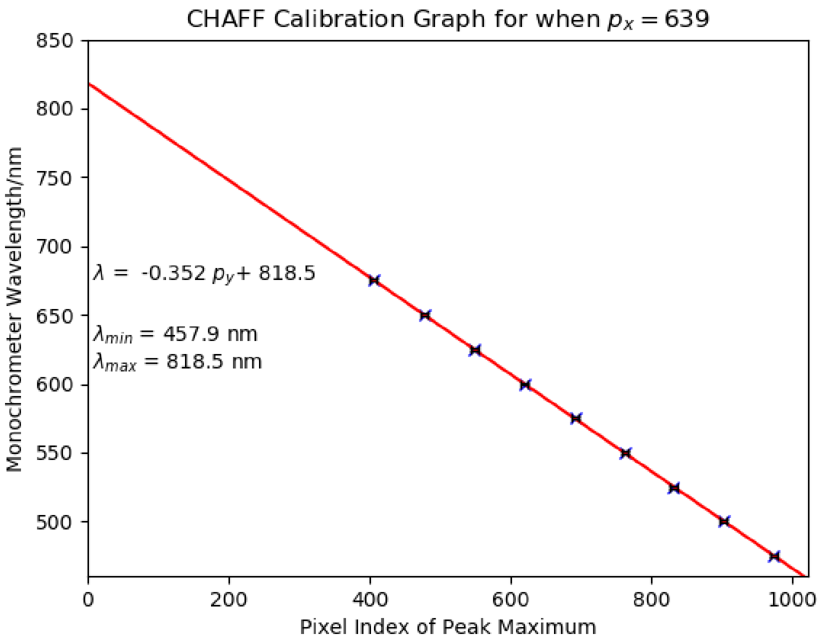
- Channel width ~7 pixels @ FWHM.
- => ~2.5±0.2nm spectral resolution.
- Confirmed by monochrometer instrument profile function measurement.



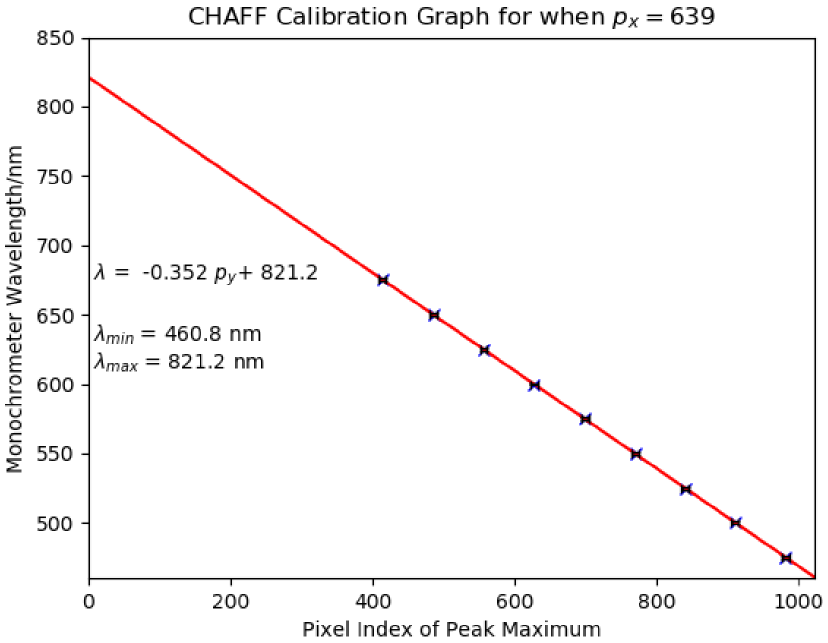
CFL spectrum



Spectral Re-calibration

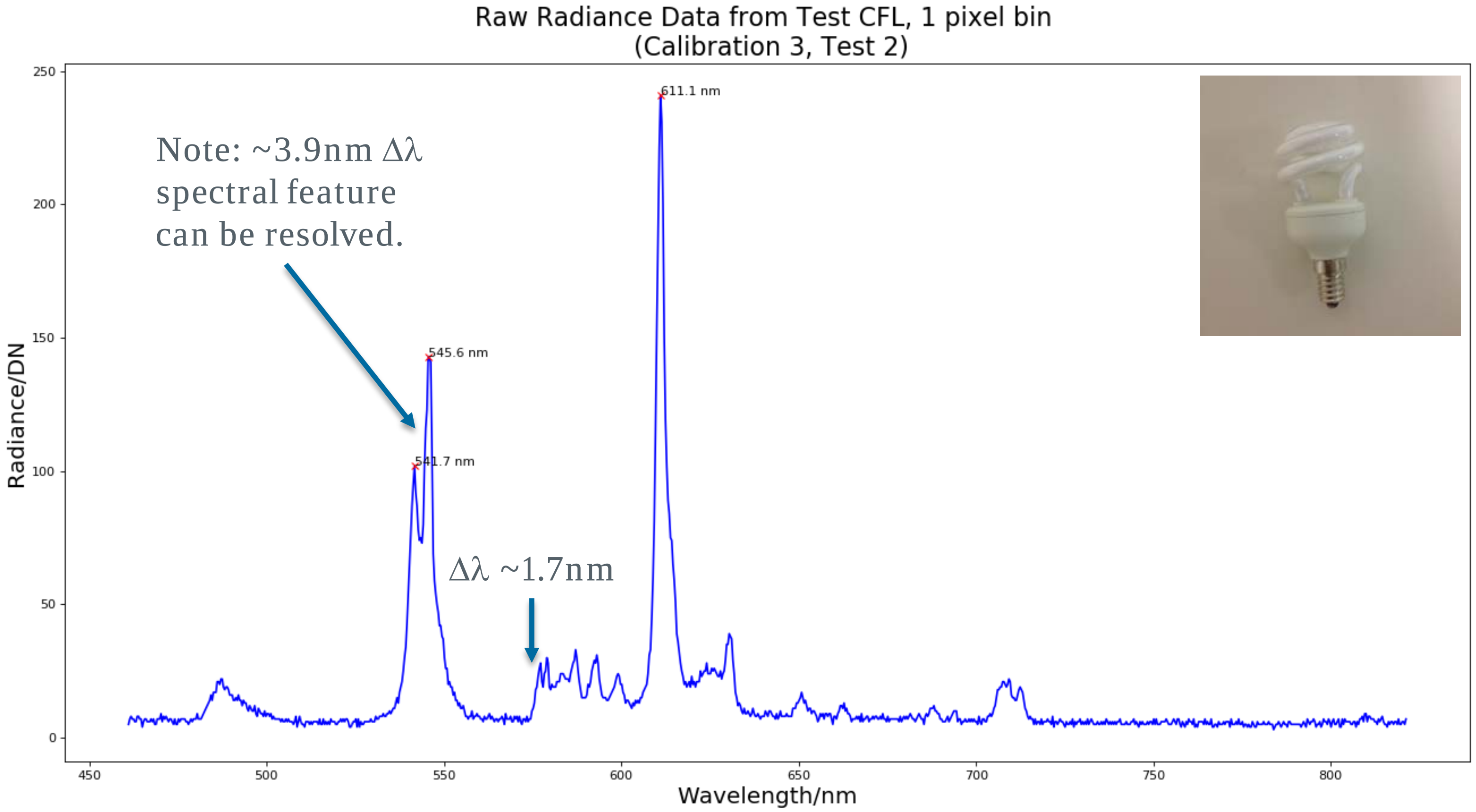


Before Movement



After Movement Again!

CFL spectrum after Re-calibration



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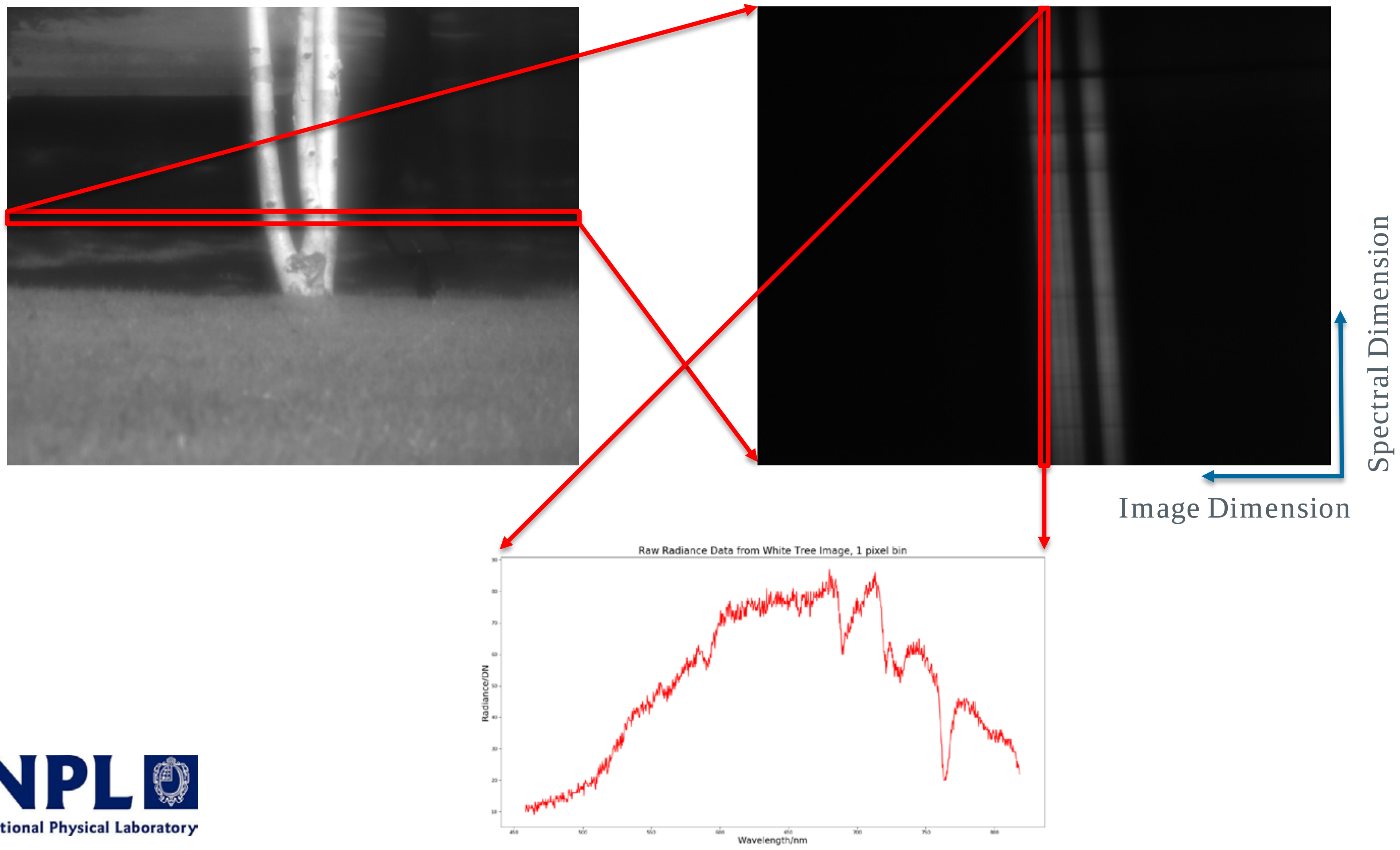
Field Trials



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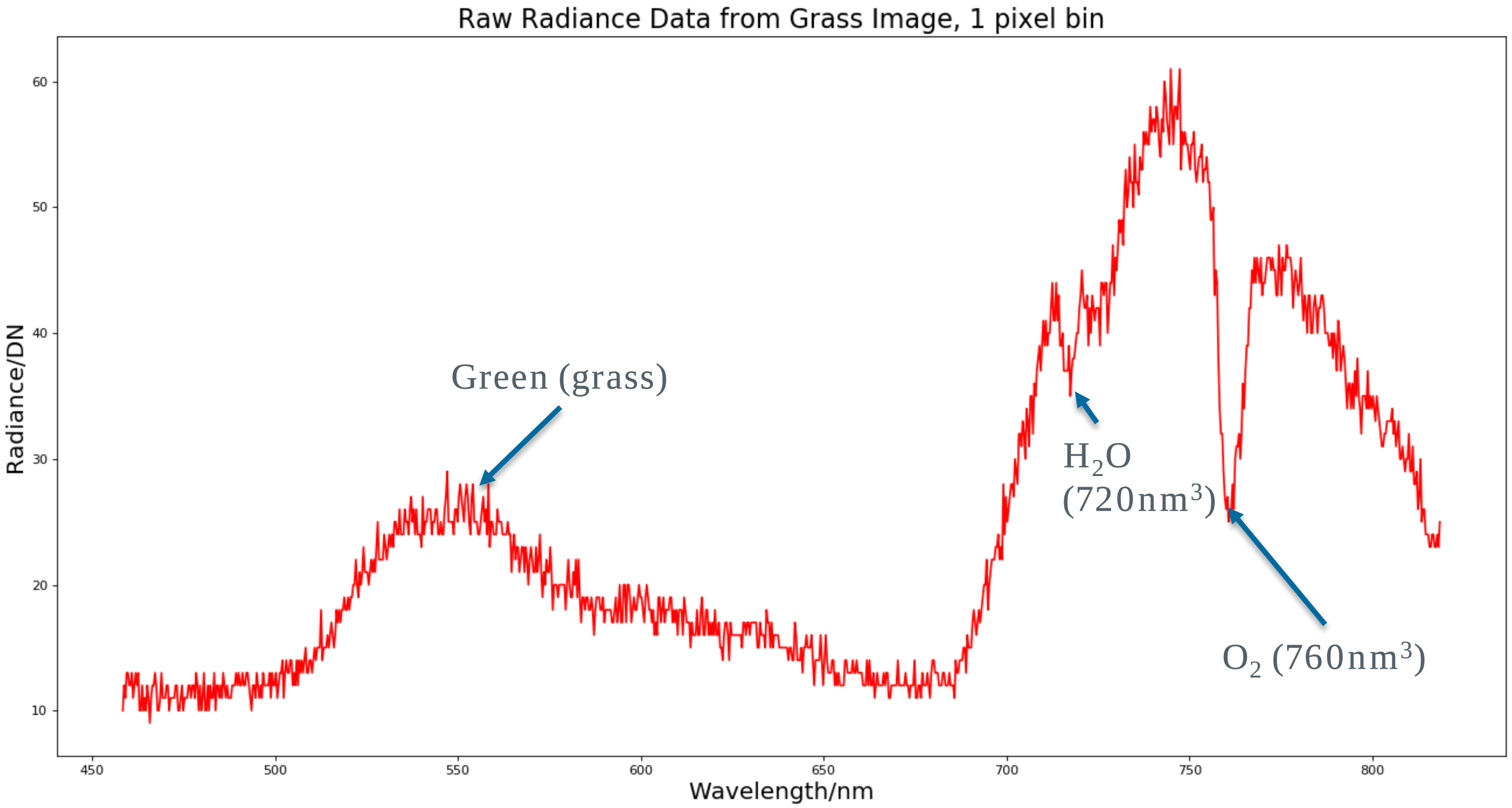
Field Trials – Radiance Spectrum

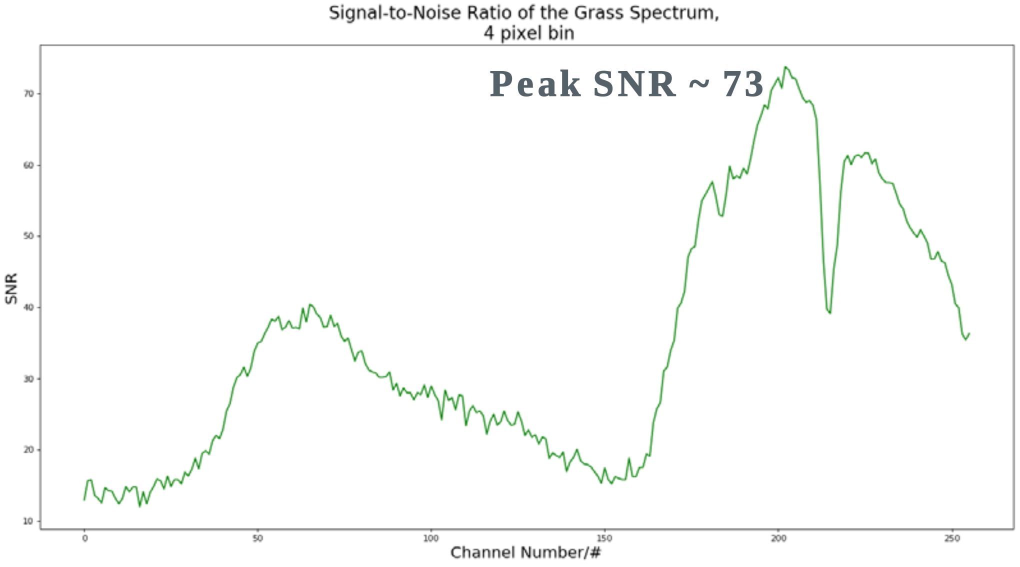
Radiance Spectrum of Grass.



[3]Hill, C., and Jones, R. L. (2000), Absorption of solar radiation by water vapor in clear and cloudy skies: Implications for anomalous absorption, *J. Geophys. Res.*, 105(D7), 9421– 9428, doi:10.1029/1999JD901153.

Pixel Binning

SNR of Grass Radiance Spectrum.



$$SNR = \frac{S}{\sqrt{S + N_d^2 + N_r^2 + (nN_q)^2}}$$ [1]

$$S = binned\ signal$$

$$n = no.of\ pixels\ binned$$

$$N_d = \sqrt{nS_d}$$

$$N_r = \sqrt{S_r}$$

$$S_d = Dark\ signal^*$$

$$S_r = Binned\ Read\ Signal^\dagger$$

$$N_q = \frac{w}{2^m\sqrt{12}} = \text{Quantisation Noise}$$

$$w = well\ depth$$

$$m = bit\ depth$$

*Calculated from data sheet of sensor and integration time

†Measured from Sensor

[1]. All equations adapted from Manolakis, D., Lockwood, R. and Cooley, T. (2016) *Hyperspectral Imaging Remote Sensing: Physics, Sensors and Algorithms*, Cambridge: Cambridge University Press

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Field Trials – Remote Sensing Reflectance

$$L_{ref} = \frac{E_i \rho_{ref}}{\pi} \qquad [2]$$

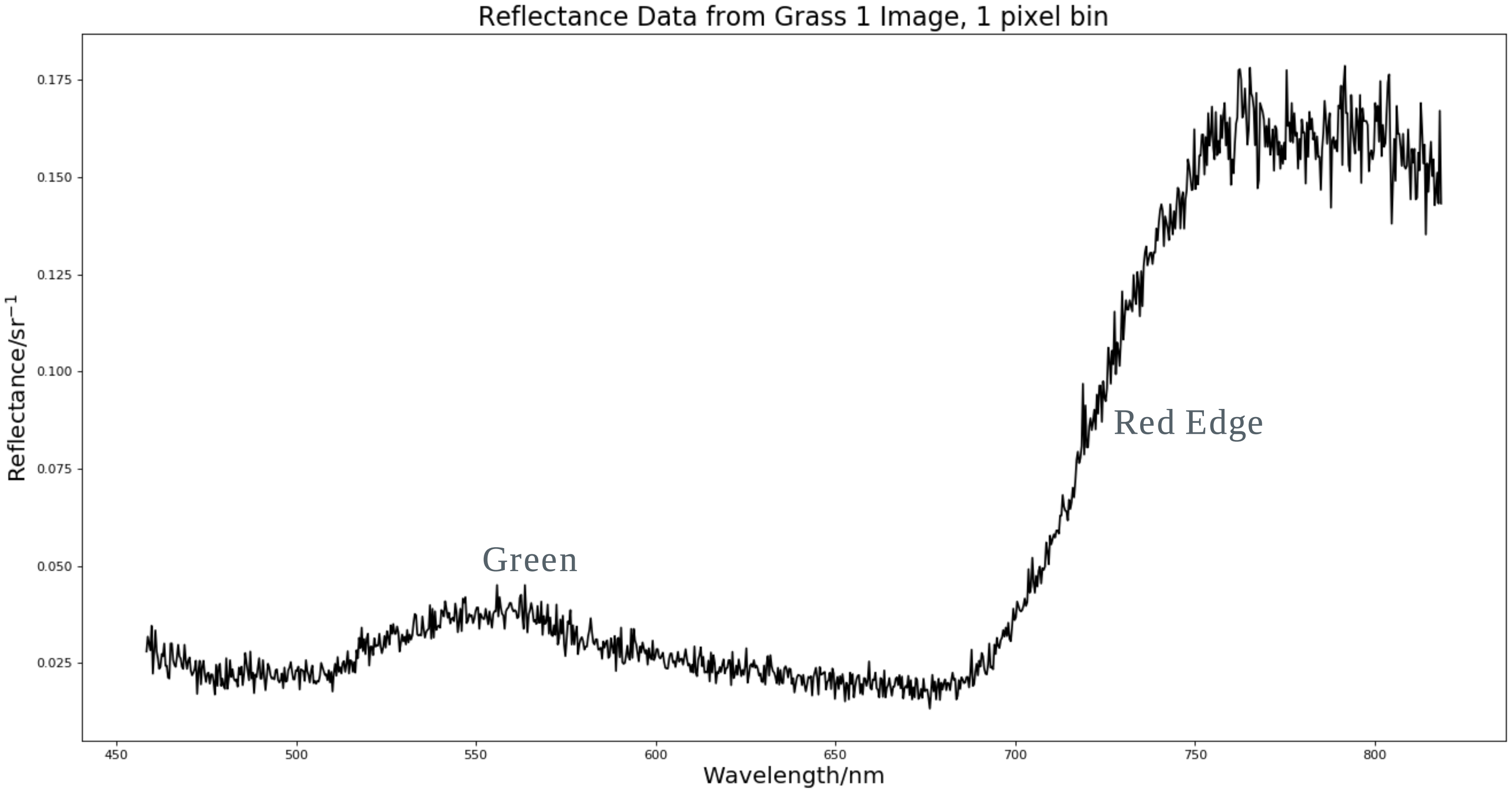
$$\rho_{rs} = \frac{L_{grass}}{E_i} = \frac{L_{grass}}{\pi L_{ref}} \rho_{ref} \qquad [3]$$

[2]. From Manolakis, D., Lockwood, R. and Cooley, T. (2016) *Hyperspectral Imaging Remote Sensing: Physics, Sensors and Algorithms,* Cambridge: Cambridge University Press.

[3]. From Mobley, C. and Taylor, L. (2018), Reflectances in *Ocean Optics Web Book,* Available at: http://www.oceanopticsbook.info/view/overview_of_optical_oceanography/reflectances (Accessed 28/08/2019)

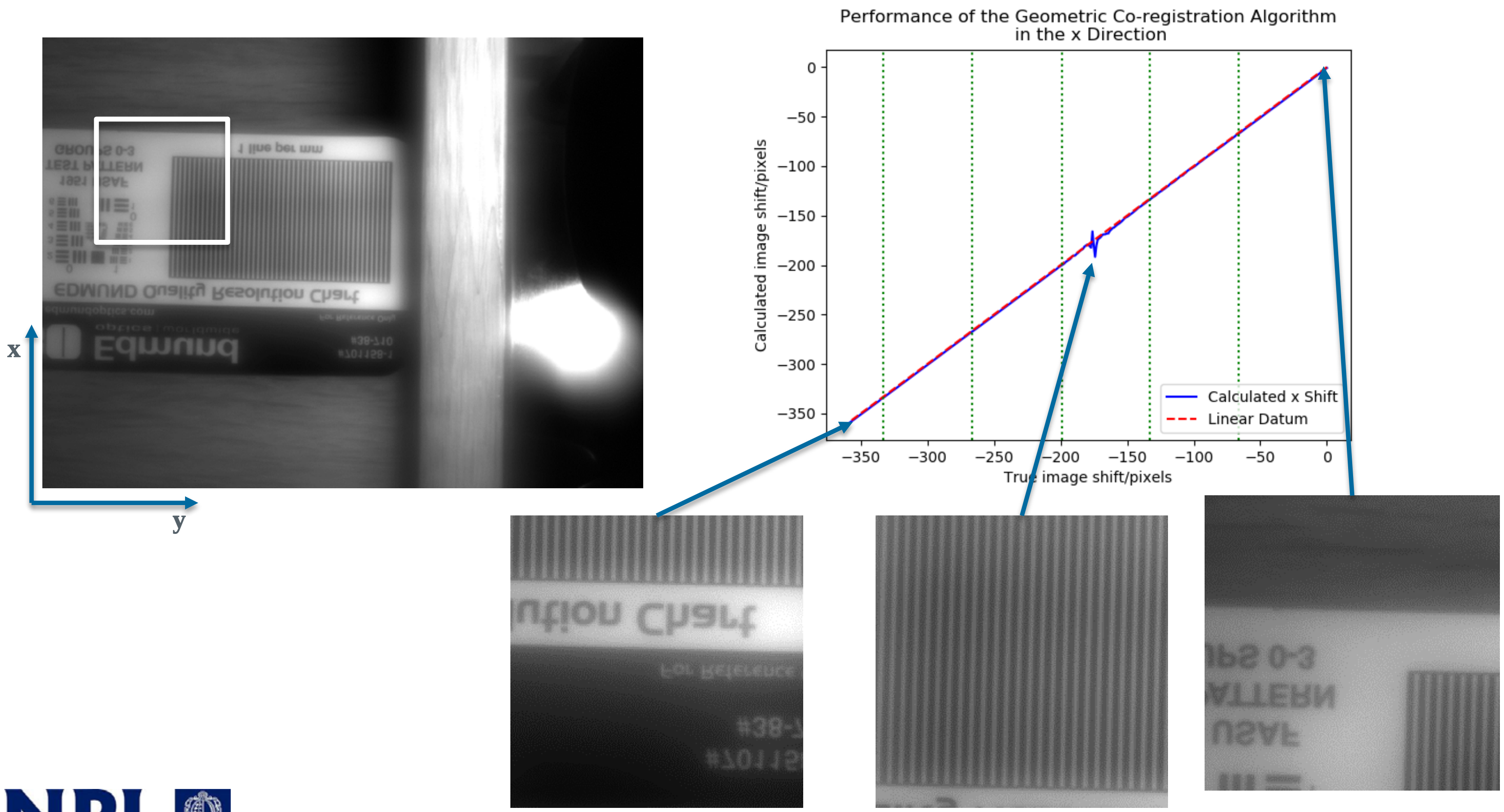
Field Trials – Remote Sensing Reflectance

Radiance Spectrum of Grass processed to Remote Sensing Reflectance

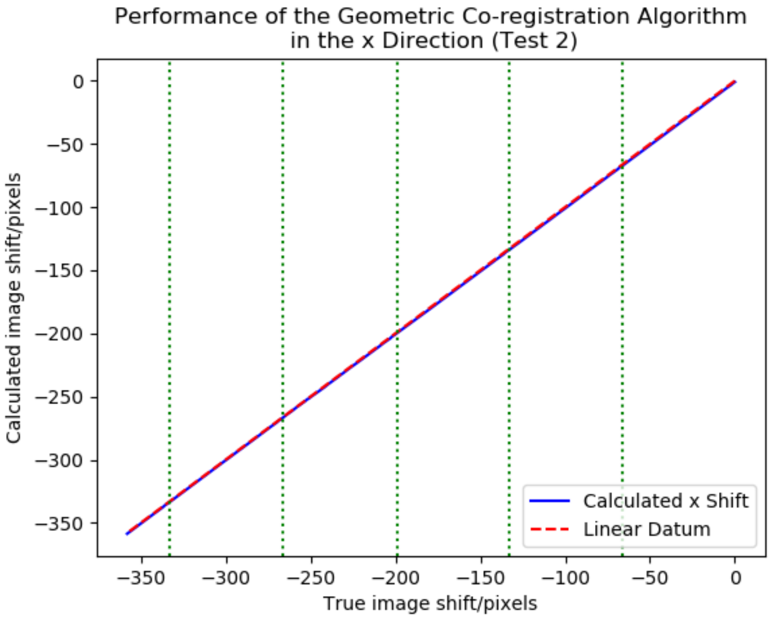


$$NDVI = \frac{\rho_{760nm} - \rho_{630nm}}{\rho_{760nm} + \rho_{630nm}} = \mathbf{0.75}$$

Prototype Processing Chain



Prototype Processing Chain



Conclusions

- Portable prototype constructed, preliminary spectral calibration achieved.
- Excellent spectral resolution (~2.5nm).
- Optical component of geometric co-registration shown to function.
- Preliminary Field Trials performed with reflectance curve achieved.

Future Work

- Radiometric Calibration of Prototype at NPL.
- Implement GPU On-Board Processing (co-registration algorithm, CCSDS-123) and achieve data cube.
- Field Trials on ground Vehicle/UAV.
- Flight on CubeSat?

Thank-You

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