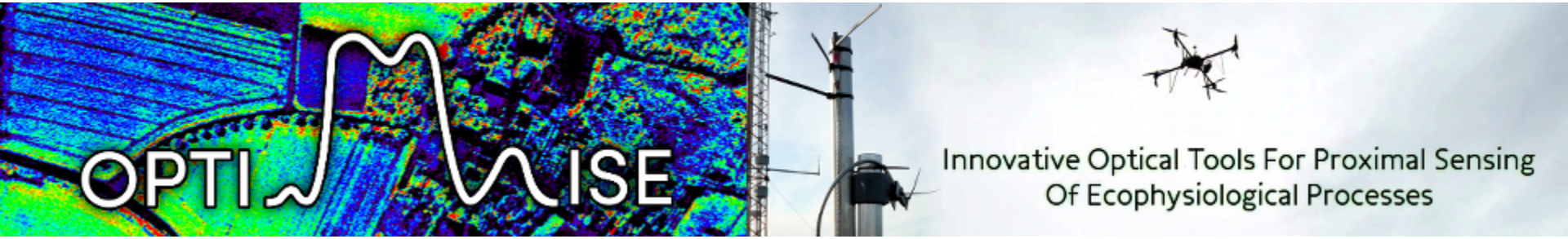


Impact of Instrument Characterization in the Retrieval of SIF: HyPlant Case Study

L. Alonso[1], J. Vicent[1], N. Sabater[1], S. Cogliati[2], F. Pinto[3], P. Rademske[4], U. Rascher[4], S. Kraft[5], J. Moreno[1]

1 IPL:LEO-Group, University of Valencia, Spain
2 Remote Sensing of Environmental Dynamics Lab., Dept. of Earth and Environmental Sciences, UNIMIB
3 Global Wheat Program, International Maize and Wheat Improvement Center (CIMMYT)
4 Institute of Bio- and Geosciences, Plant Science; Forschungszentrum Jülich
5 ESA/ESTEC

INTRODUCTION

- Chlorophyll fluorescence is a **very weak signal** that overlaps with reflected solar radiance.
- Spectrometers with very **fine spectral and radiometric resolution**, with **large dynamic range** are needed.
- Physical and manufacturing limitations alter the signal:
    - PSF, ISRF, stray-light, non-linear response
- The effect of these responses cannot be neglected for many applications where spatial or spectral high-contrast is present (in particular fluorescence)
- Totally avoiding these effects is not possible
- It might be mitigated by deconvolution, based on experimental characterization of instrument (not theoretical models)

Required Instrumental Characteristics

Instrumental Design

- Radiometric Resolution => need to resolve the signal
- Dynamic Range => need to measure high and low radiances

  IT must be set to cover the full DR without saturation
- Spectral Resolution and Sampling

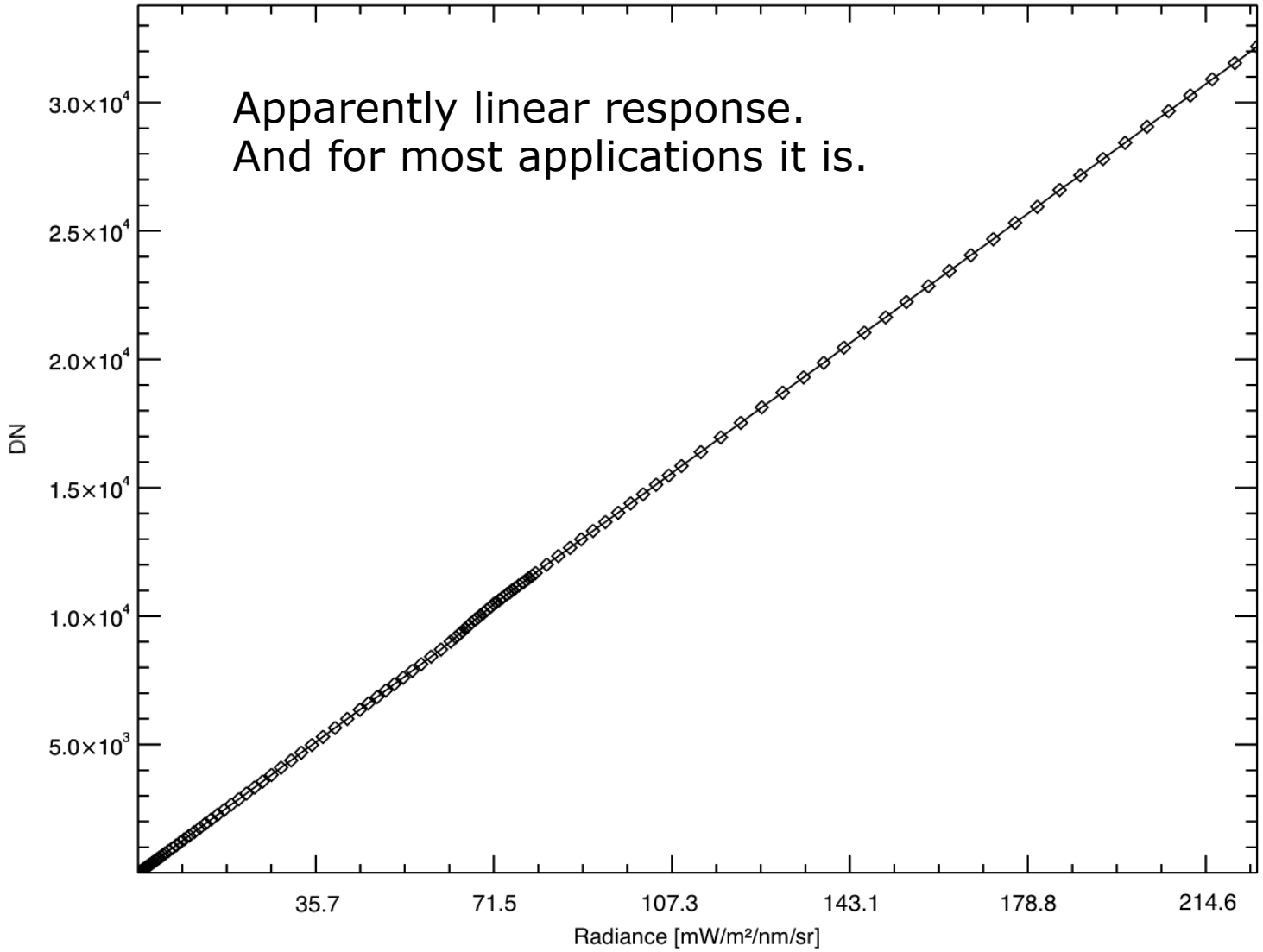
Instrumental Characterization

- Linearity in detector response to light intensity
- Radiometric Calibration

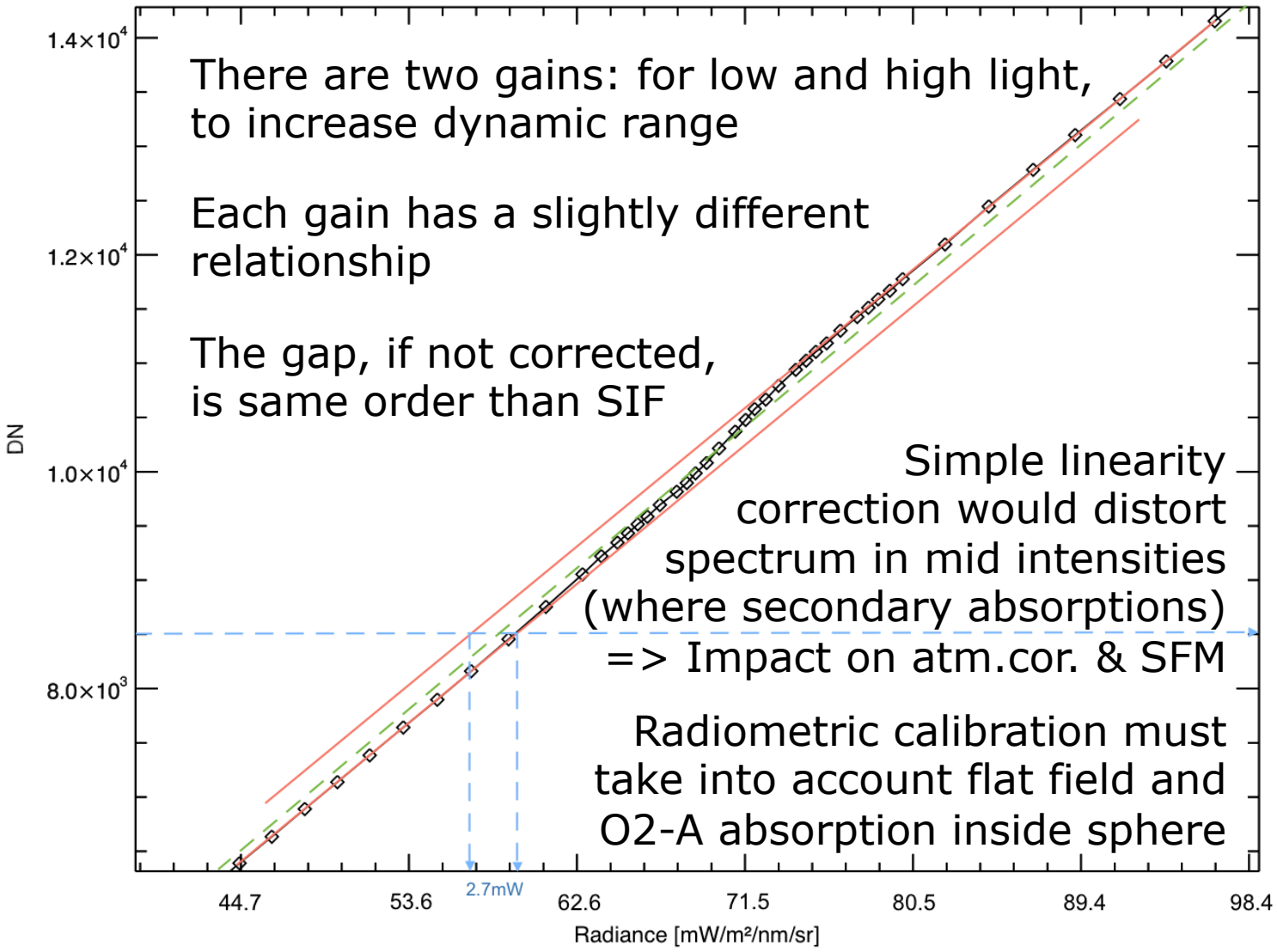
  Measurement in physical units

  Compensate quantum efficiency (flat field)
- MPSF: Response of the optical system to a monochromatic point source
- Straylight:

Linearity to light intensity



Linearity to light intensity



HyPlant Monochromatic PSF

HyPlant: Airborne imaging spectrometer for fluorescence (operating since 2012)

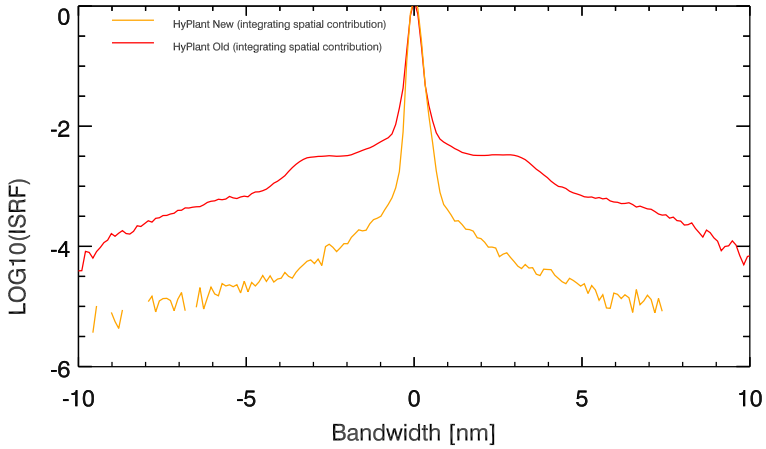
SSI=0.11 nm, FWHM=0.24 nm, GSI=0.9 m (@600m)

2D sensor: spatial x spectral

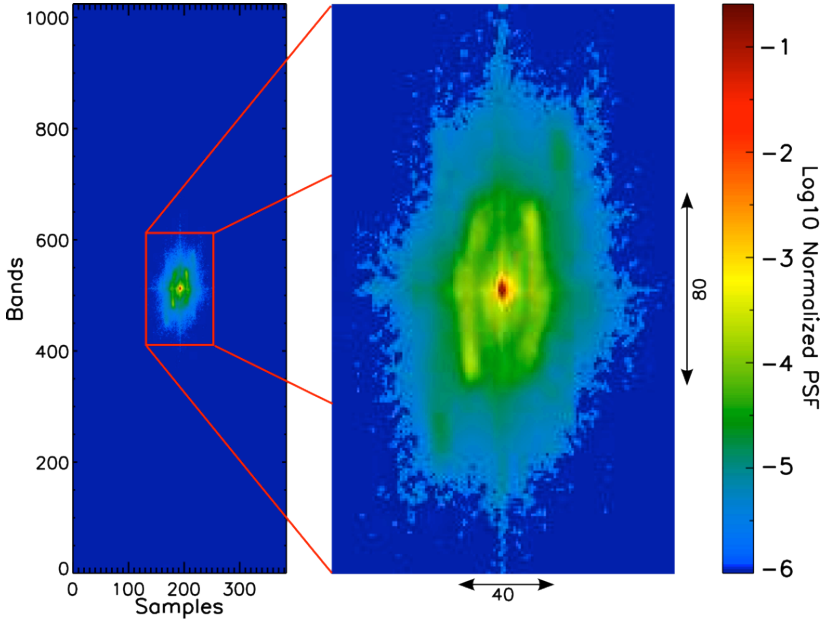
➪ PSF in spatial dimension, ISRF in spectral

Some diagonal contributions exist, so they cannot be treated independently.

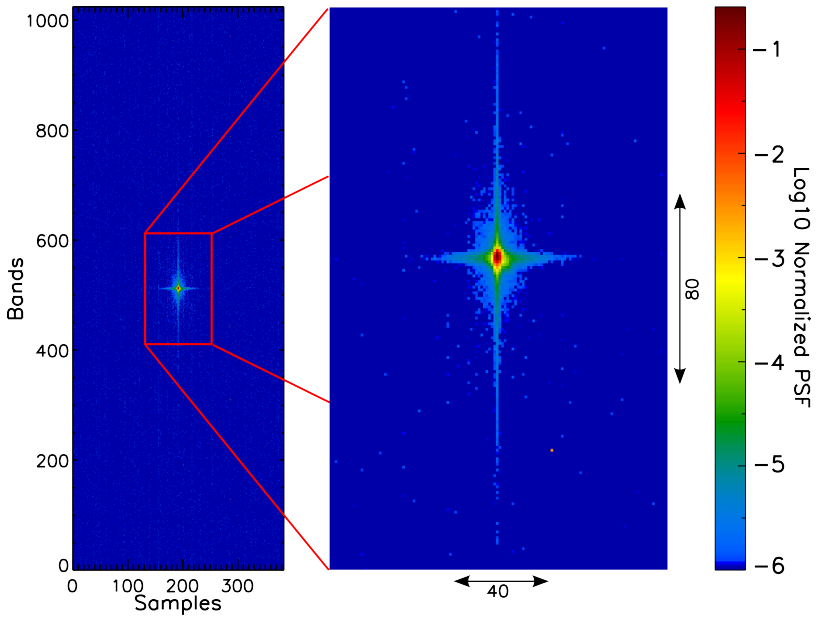
Monochromatic Point Spread Function (MPSF)



Blurring due to defective glue (2013)



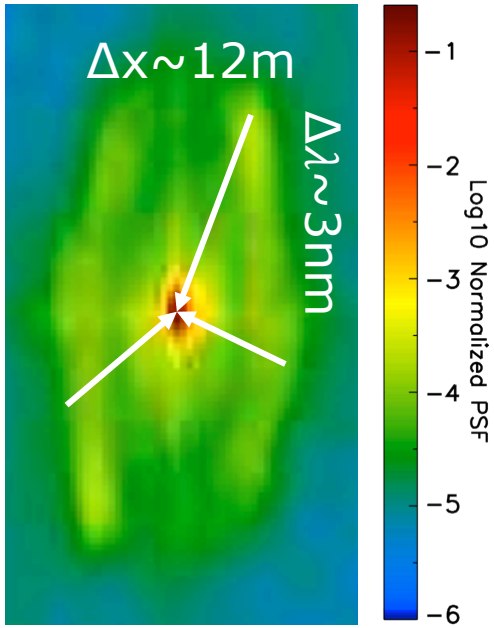
Corrected system (2015)

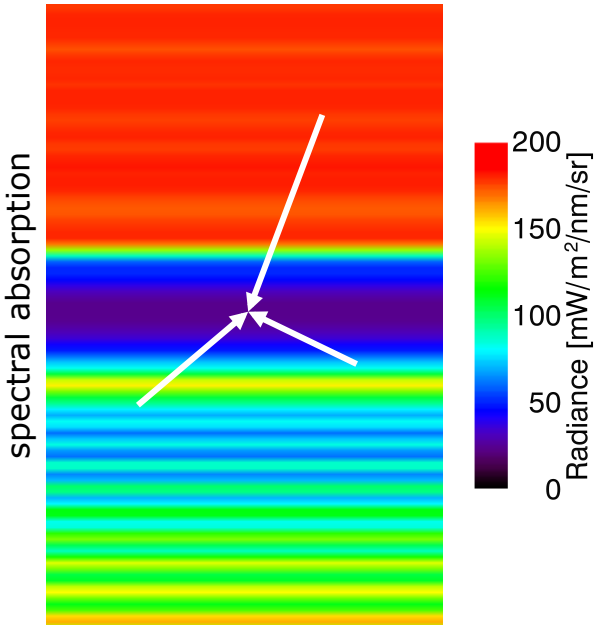


Effects On The Signal

A given pixel of the sensor is supposed to measure a point of light, but the arriving light-ray will disperse around it.

Since every pixel will do so, it is possible to assume that the MPSF also can be interpreted as the contribution to a given element from the surrounding ones.





homogeneous target

Actual signal **20mW**

Central pixel contribute with ~80% =**16mW**

Surrounding pixels contribute with 10^{-4}

but there are
30s x 60b = 1800
and 50% with 200mW
=**18mW**

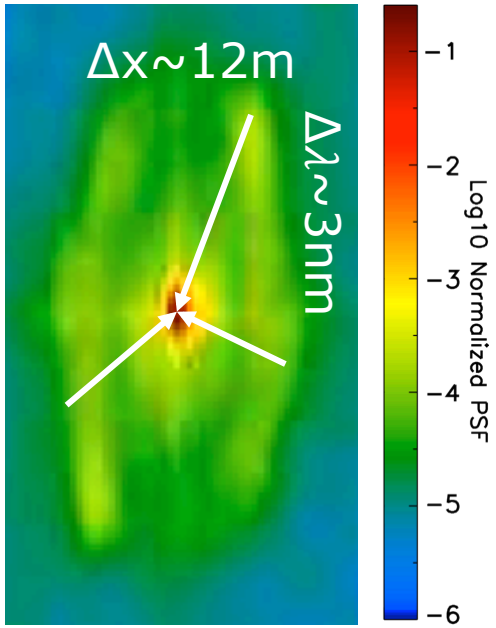
Resulting measurement
=**34mW**

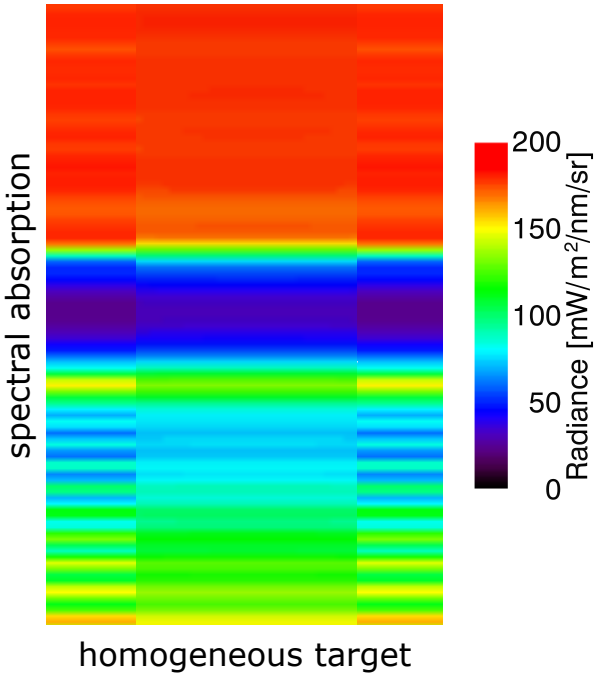
And fluorescence is just 1-2mW!!!

Effects On The Signal

A given pixel of the sensor is supposed to measure a point of light, but the arriving light-ray will disperse around it.

Since every pixel will do so, it is possible to assume that the MPSF also can be interpreted as the contribution to a given element from the surrounding ones.





Actual signal **20mW**

Central pixel contribute with ~80% =**16mW**

Surrounding pixels contribute with 10^{-4}

but there are
30s x 60b = 1800
and 50% with 200mW
=**18mW**

Resulting measurement
=**34mW**

And fluorescence is just 1-2mW!!!

Deconvolution: Solving The Problem

Van-Cittert Deconvolution

The measured image is the result of convolving the real image by the PSF

$$i_{sens} = i_{orig} * PSF$$

The deconvolution tries to **reconstruct the original signal**.

We follow an iterative process defined by

$$g_0 = i_{sens}$$

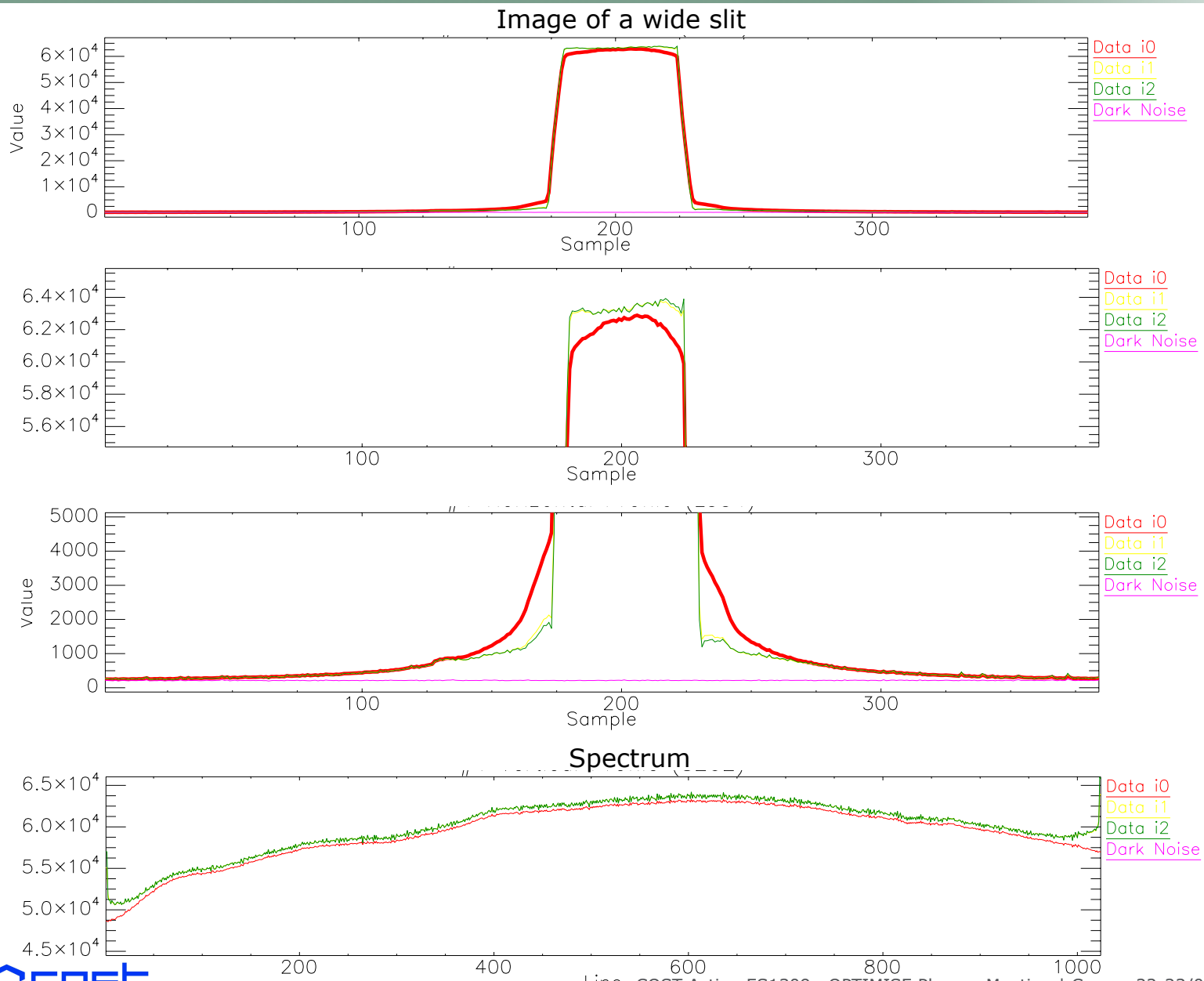
$$g_{k+1} = i_{sens} + (I - PSF) * g_k$$

Deconvolution removes dispersed-light but also **amplifies noise**.

Finding the number of iterations is a compromise between both.

Other **more sophisticated** approaches are currently being explored.

Impact on RadCal and Linearity Measurements

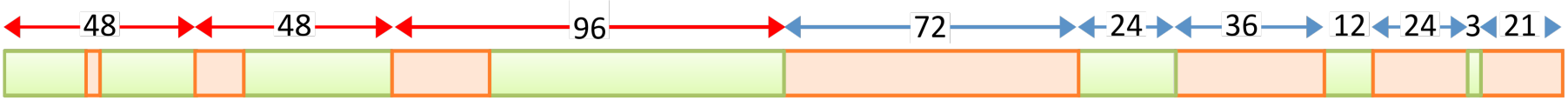


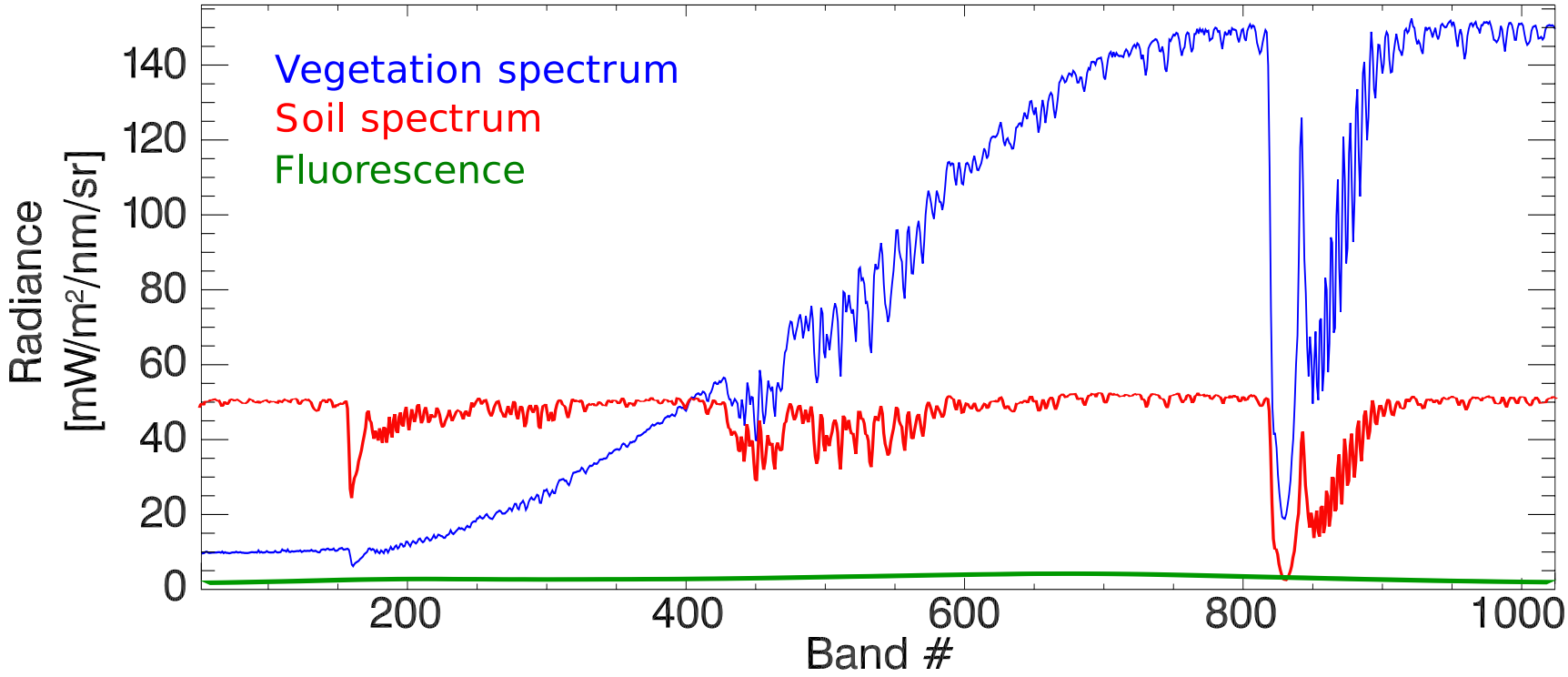
Simulated Scene

Synthetic target to test effect of MPSF

Two targets: Vegetation and bare soil

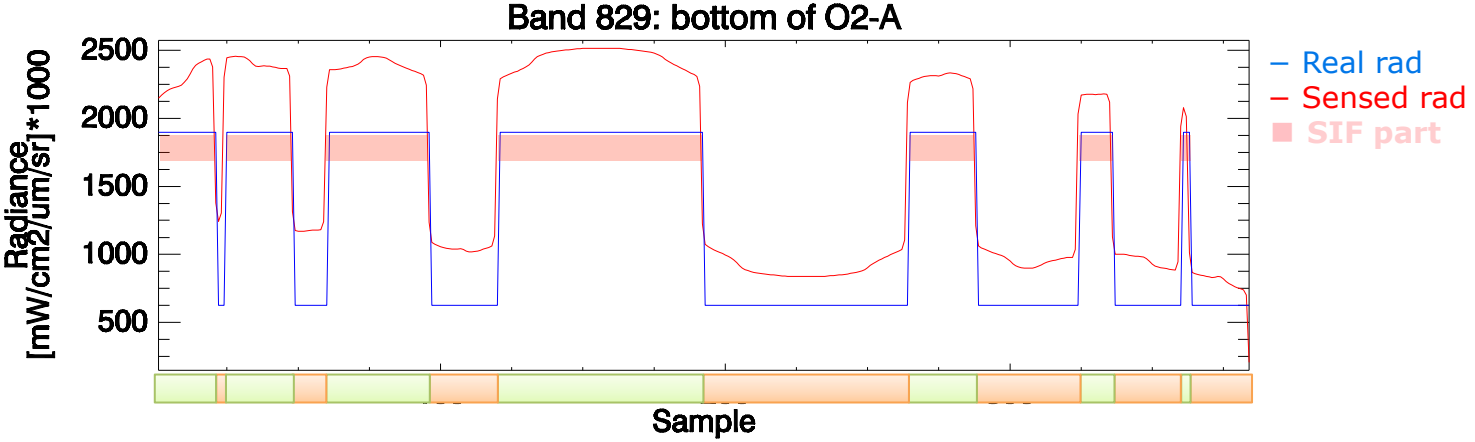
Distributed alternating surfaces with different spatial extension



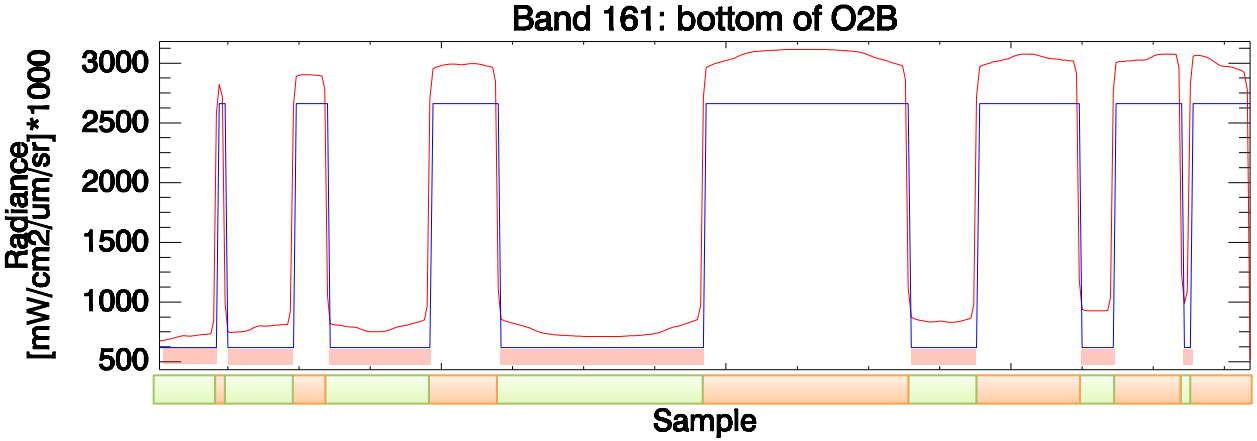


Effect On The Inside Of O2 Absorptions

At O2-A infilling is stronger in large homogeneous vegetation targets



At O2-B infilling effect is larger in bare soils even when in small patches

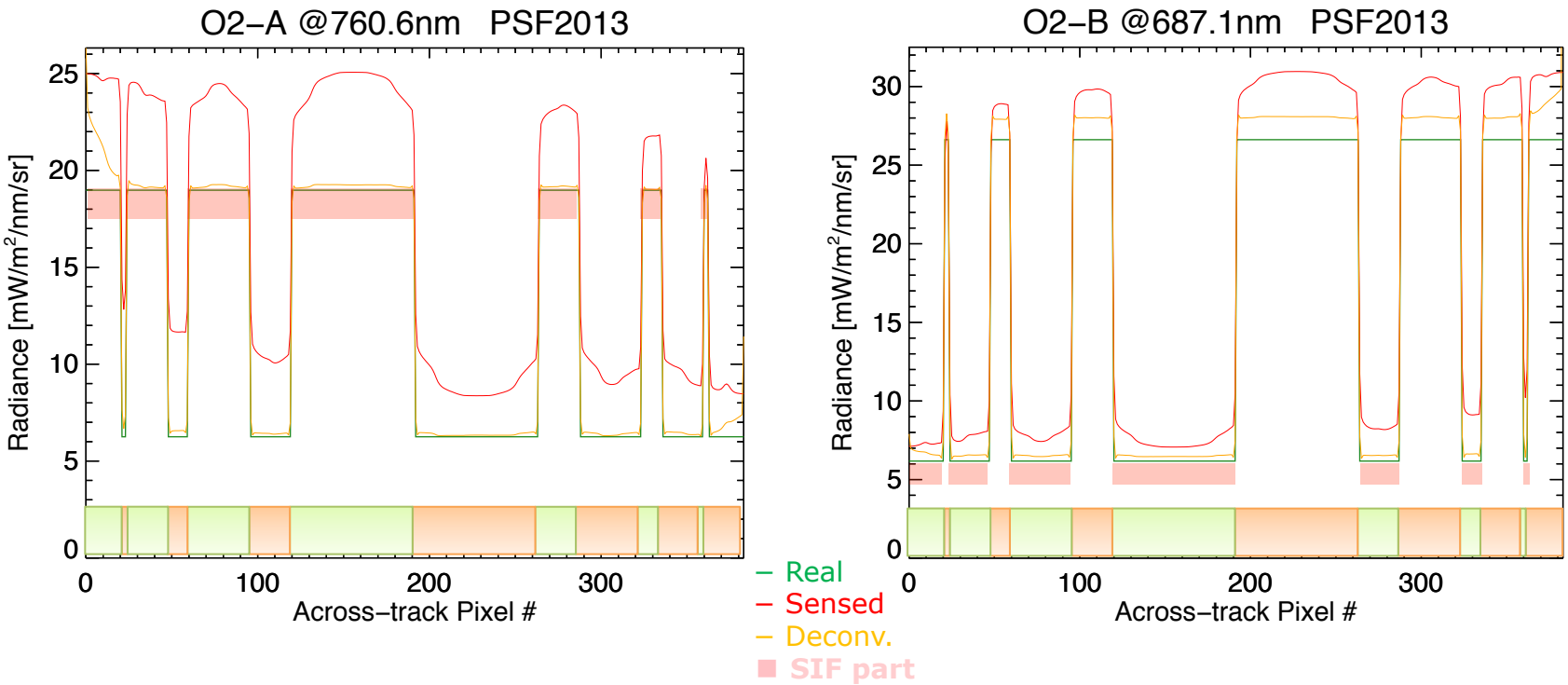


There is a strong edge effect

Correcting for zero-fluorescence at soil (non-fluorescent) targets does not solve the problem: O2-A will still overestimates, and O2-B will underestimate.

Deconvolution: Solving The Problem

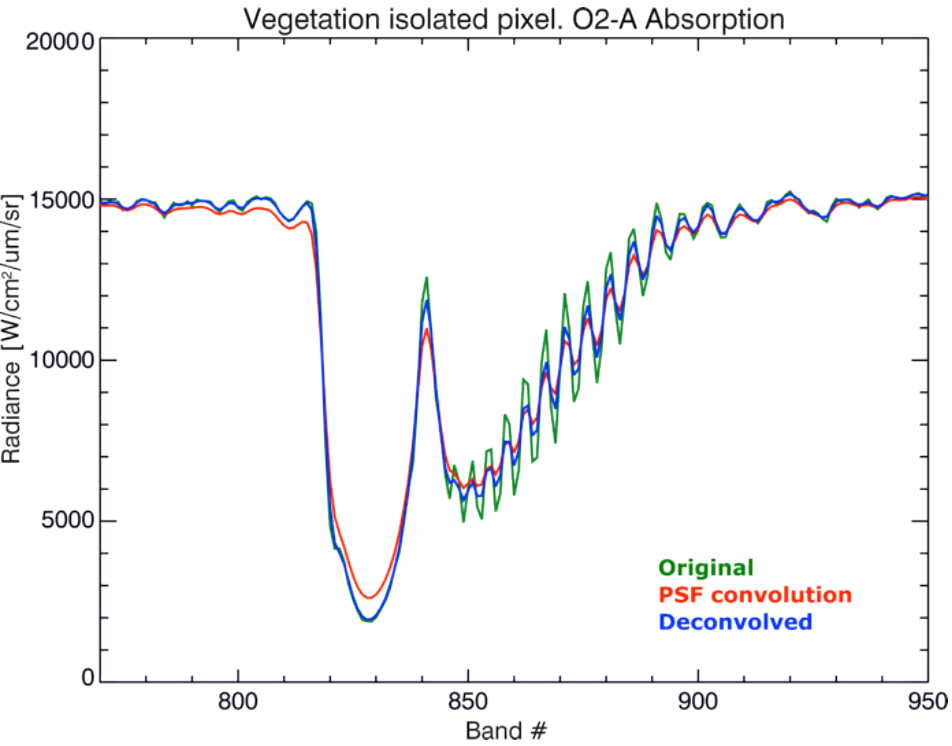
1st iteration of deconvolution (blue) removes most of the injected radiance into the absorption bands to a level smaller than expected fluorescence (red area)

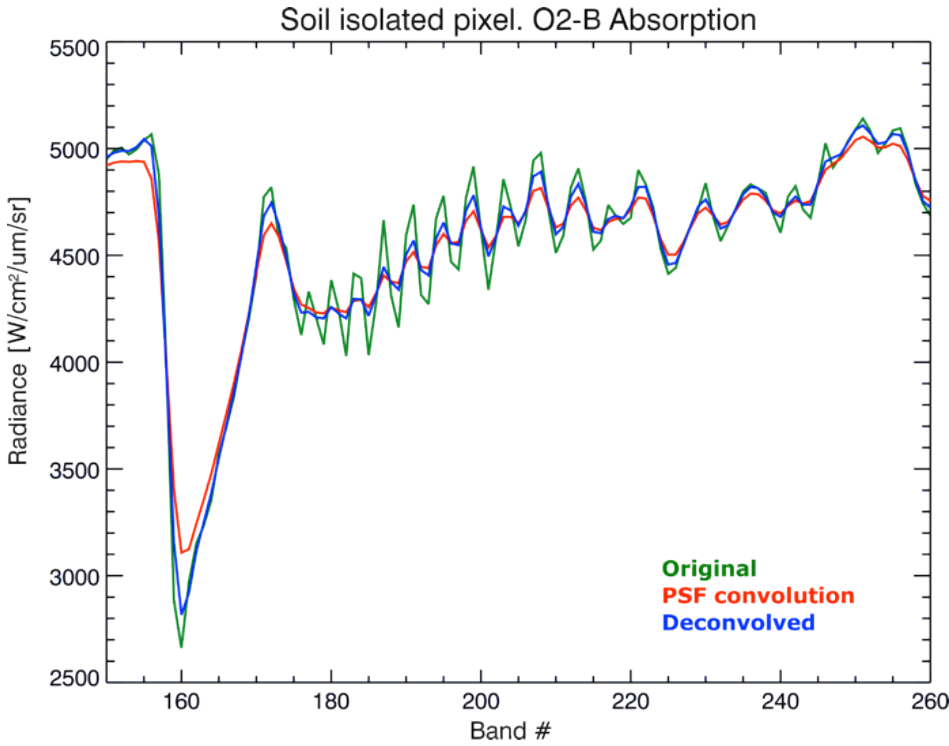


Only soils at O2-B retain a significant residual

Deconvolution: Solving The Problem

Spectrally the MPSF softens high-frequency features

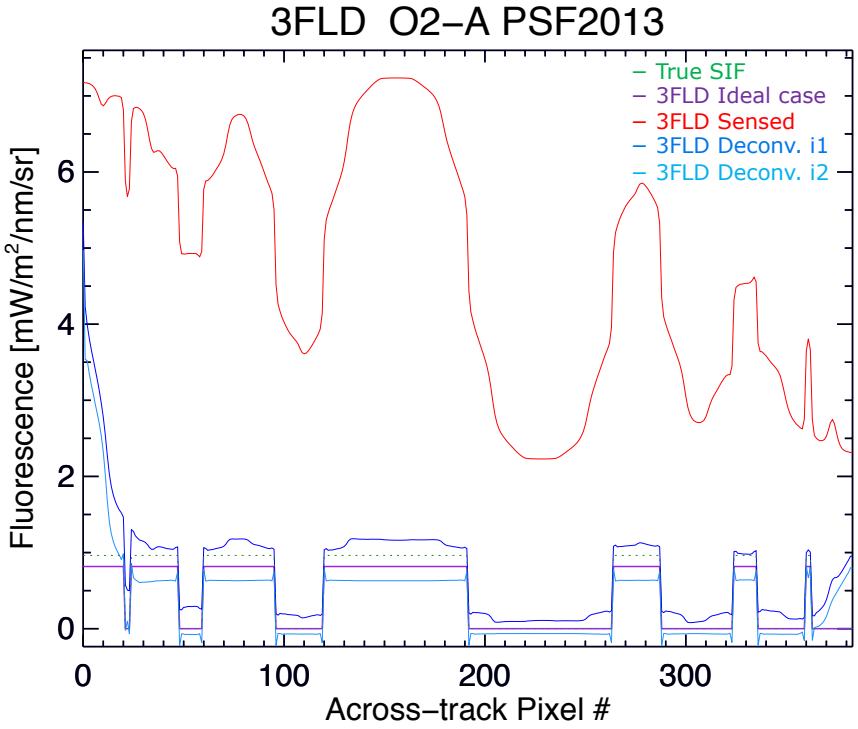


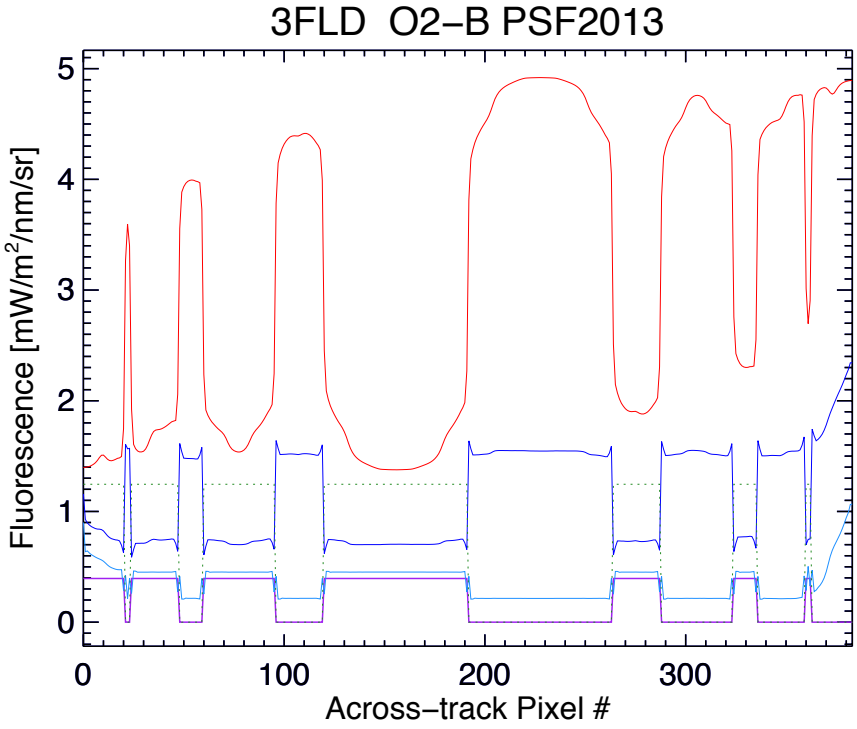


After deconvolution absorptions recover their depth (to some extent) and shoulders get their proper height.
However, after one single iteration high frequency peaks remain smoothed.

Effect On SIF Retrieval

We tested the 3FLD retrieval, assuming perfect knowledge of solar irradiance.



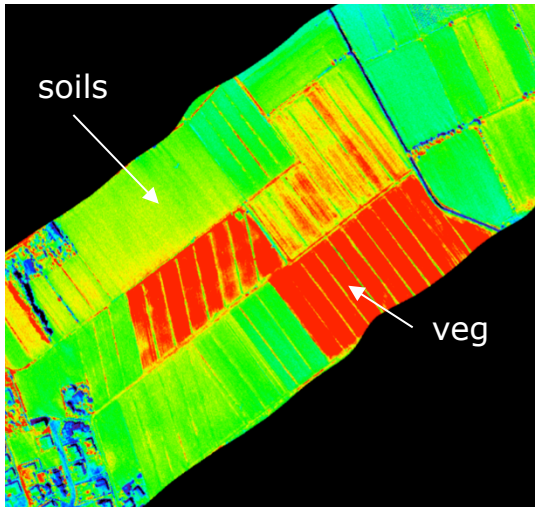


The first iteration (i1) removes most of the in-filling effect, but the edge-effects remain. The second iteration (i2) flattens out the spatial variance, but overcorrects at O2-A.

Note that 3FLD underestimates SIF even in the Ideal case, since it does not take into account the reflectance curvature, especially at O2-B.

HyPlant Real Data

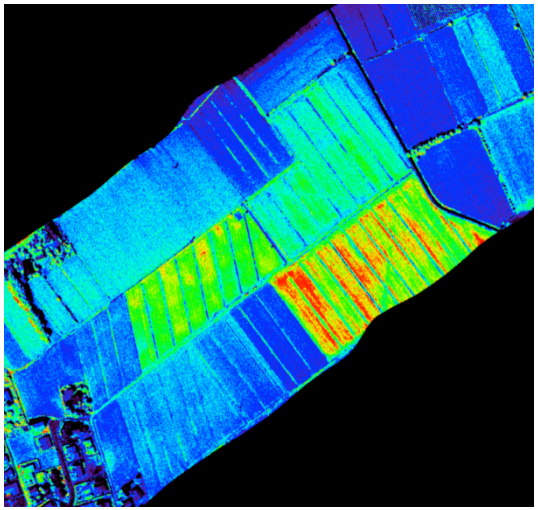
MPDF (i0)



Across-track gradient

Higher values

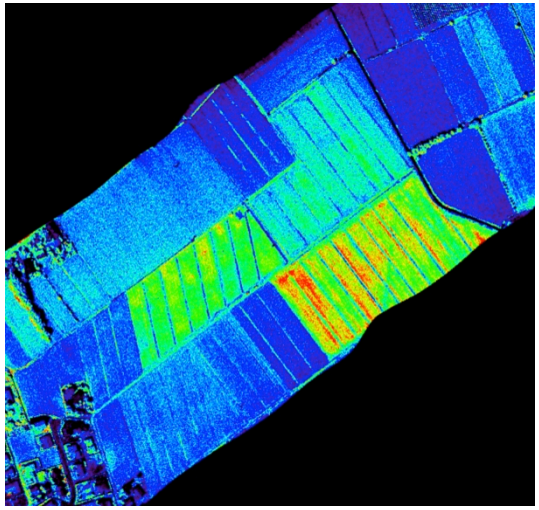
Deconvolution (i1)



Residual across-track gradient

Values already close to final

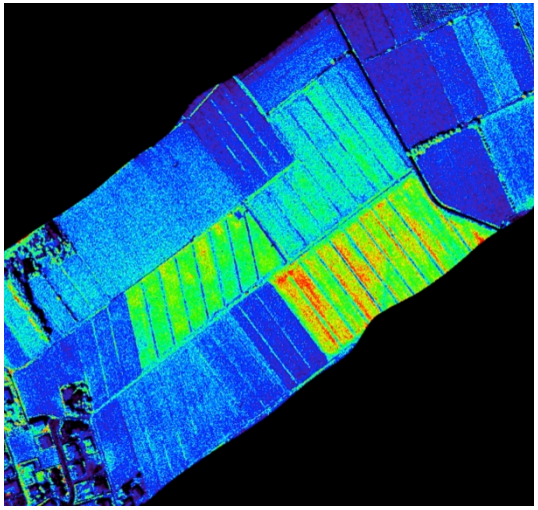
Deconvolution (i2)



Gradient greatly mitigated

Amplified noise

Deconvolution (i3)

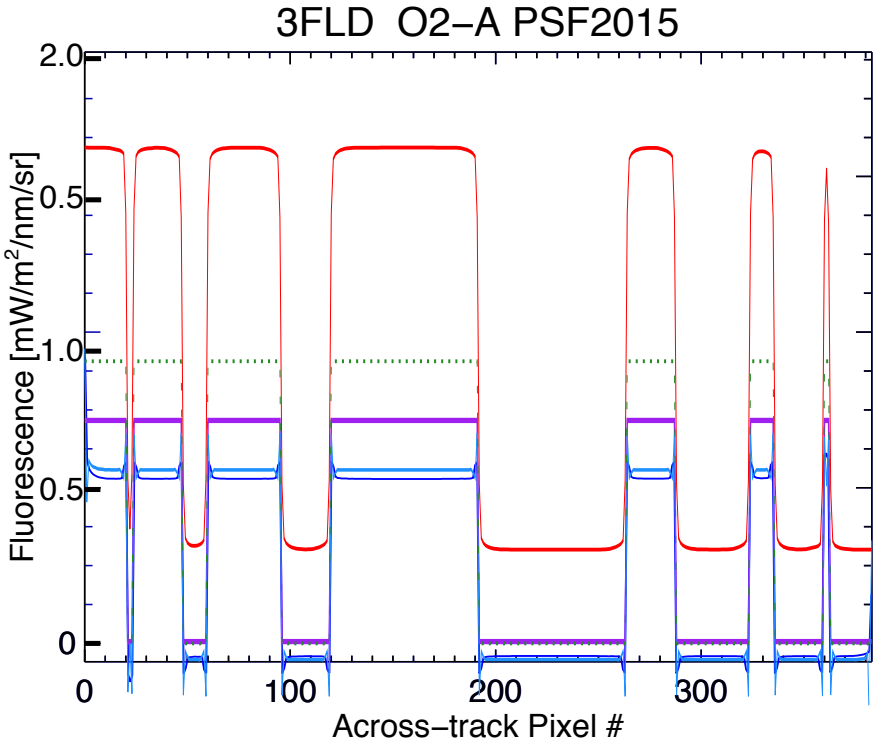


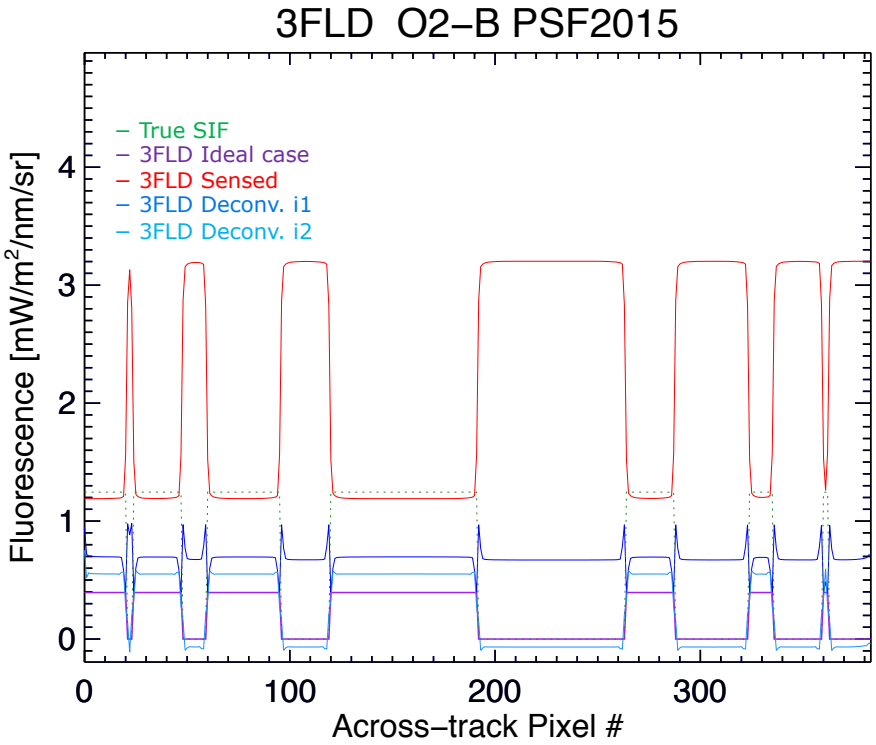
Minor radiance variations

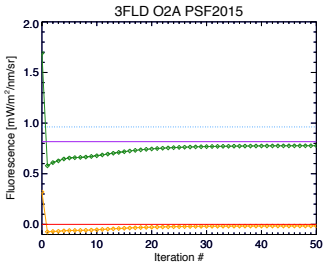
Amplified noise

Effect On SIF Retrieval

Performance with the corrected instrument







The extent of the MPSF is much smaller, thus does not have a strong spatial variation even on the measured data.
At O2-A many iterations are needed to reach the expected value.

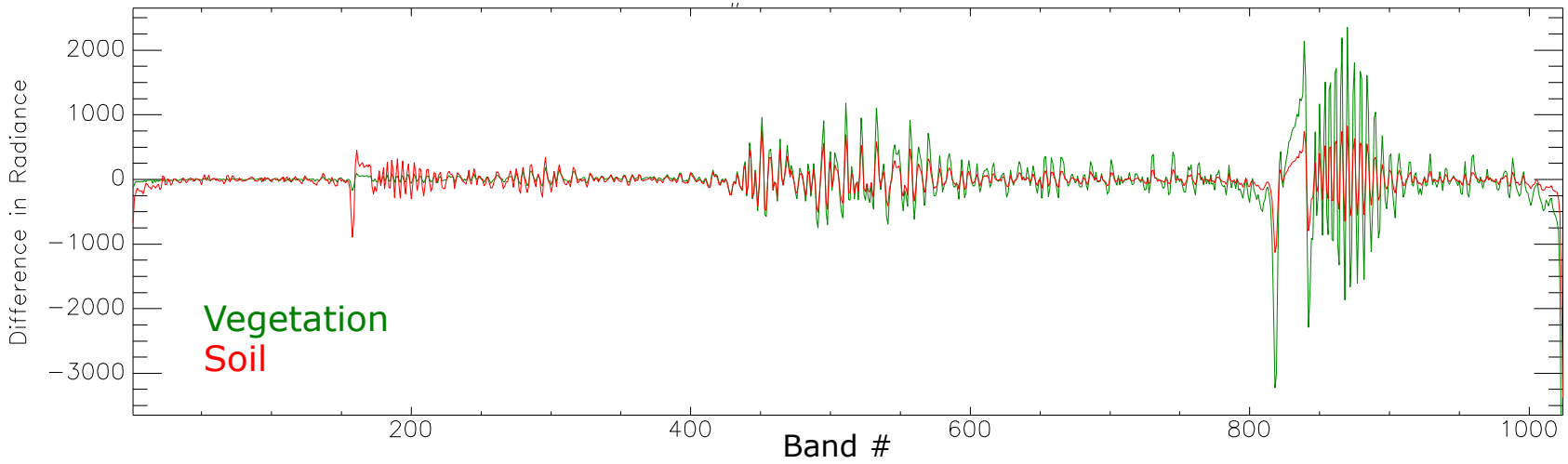
Summary

- Non-linear response must be carefully corrected, effect of same order than SIF signal
- Simple non-linearity correction distorts spectral shape
- Light scattering also 2D: PSF (spatial) and ISRF (spectral) are entangled (diagonal terms).
- Distortions depend on spatial distribution and spectral shape
  - Spectral shape (contrast) is intrinsic and unavoidable
  - homogeneous fields are not “immune”
- Deconvolution removes the stray-light, but amplifies noise
- Requires good knowledge of MPSF in order to work
- More sophisticated deconvolution approaches need to be tested: robust to noise, cope with changing MPSF across sensor, auto-determination of effective MPSF, …
- Field spectrometers should also be characterized, they are not free of these effects.

Spatially isolated pixels

MPSF has ~30 pixels of spatial extension

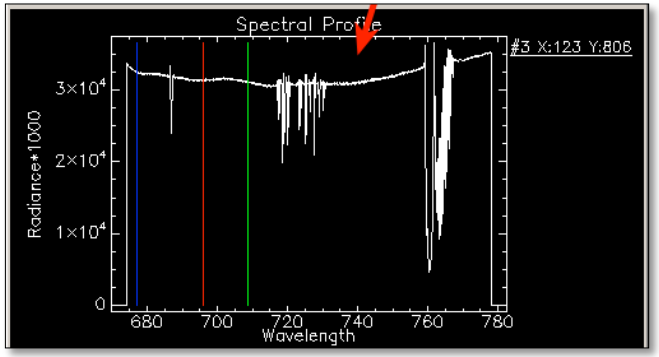
Differences found in pixels spatially surrounded by 40 identical target on each side



Effect also due to spectrally contrasting bands (high signal next to low signal)

Infilling inside band AND decrease in outside bands

One problem with deconvolution appears with saturated pixels, since they propagate erroneous values.

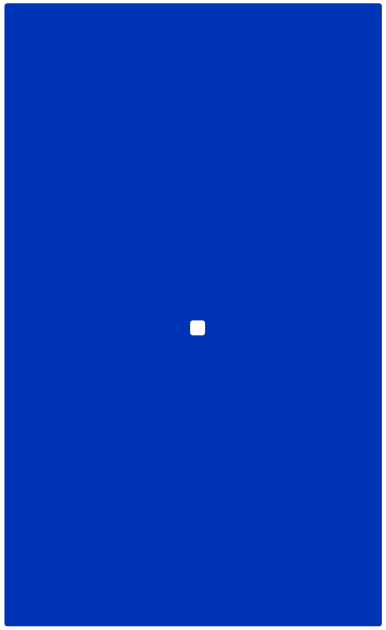


Effects On The Signal

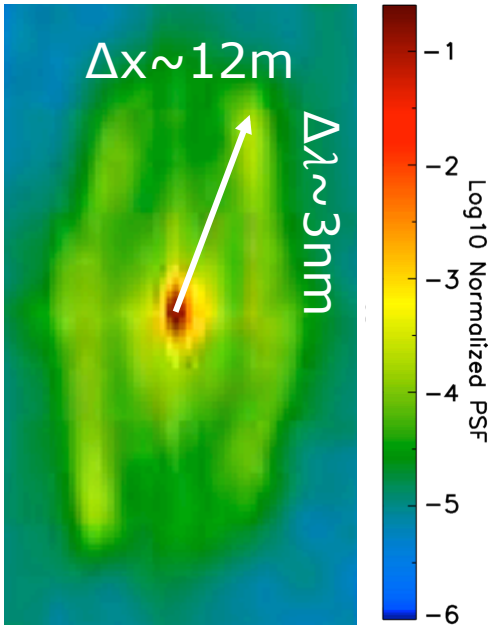
Laboratory instrument characterization in 2013 showed a wide MPSF

- 30 spatial pixels x 60 spectral pixels
- Strong diagonal components, i.e. one band from one sample is affected by a far band (~3nm) of a neighbouring target (~13m)
  (provided that SSI=0.11nm and GSI=0.9m)

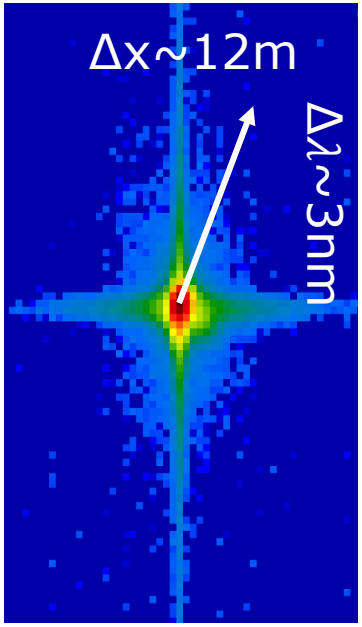
In 2015 the affected optical elements were fixed



Ideal sensor

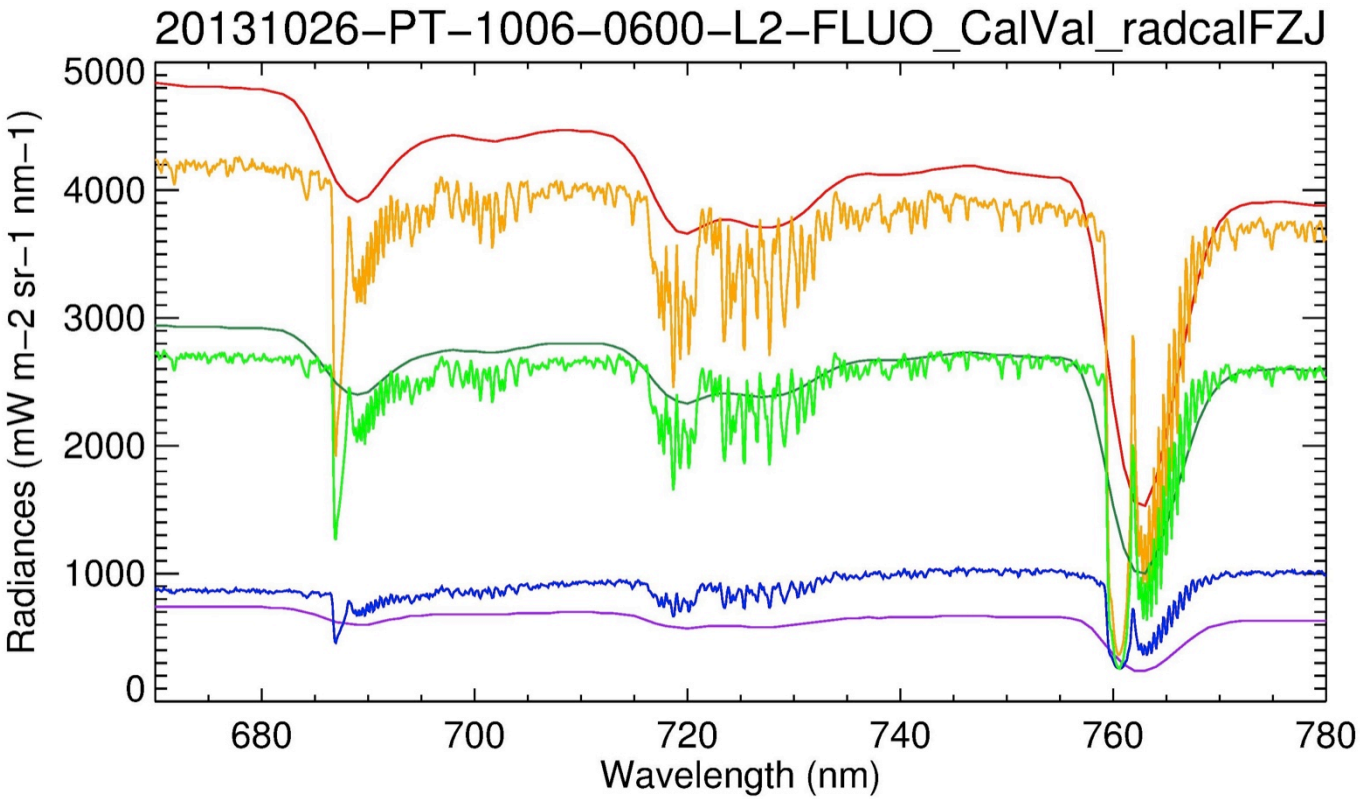


Defective sensor



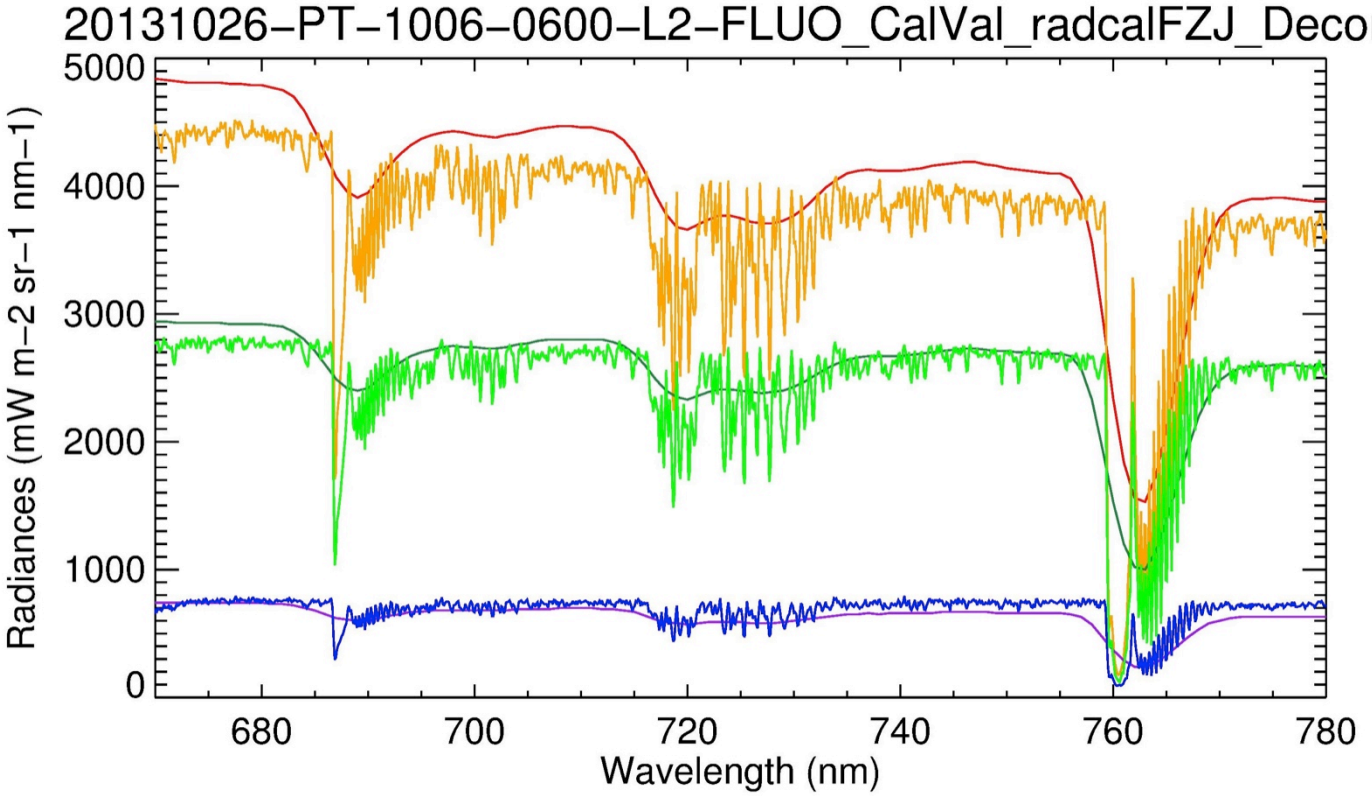
Corrected sensor

HyPlant vs Ground Truth



Radiance levels close to ground truth
but not quite

HyPlant vs Ground Truth



After deconvolution spectral shape is closer to reference spectra and absorption features are deeper.
However noise has been amplified.