Radiometric Characterization and Calibration of the Marine Optical System (MOS) for the Marine Optical Buoy (MOBY) Project

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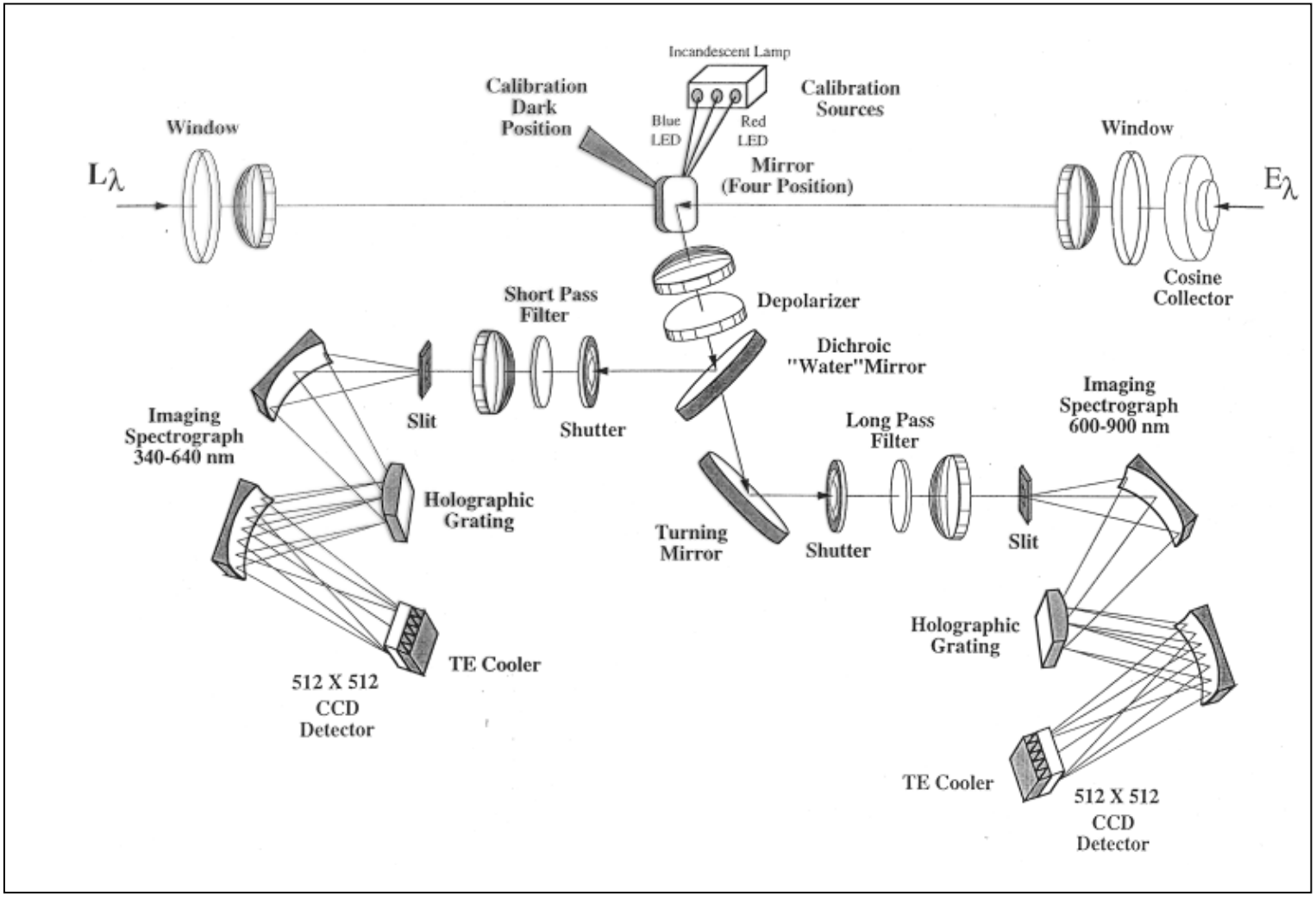
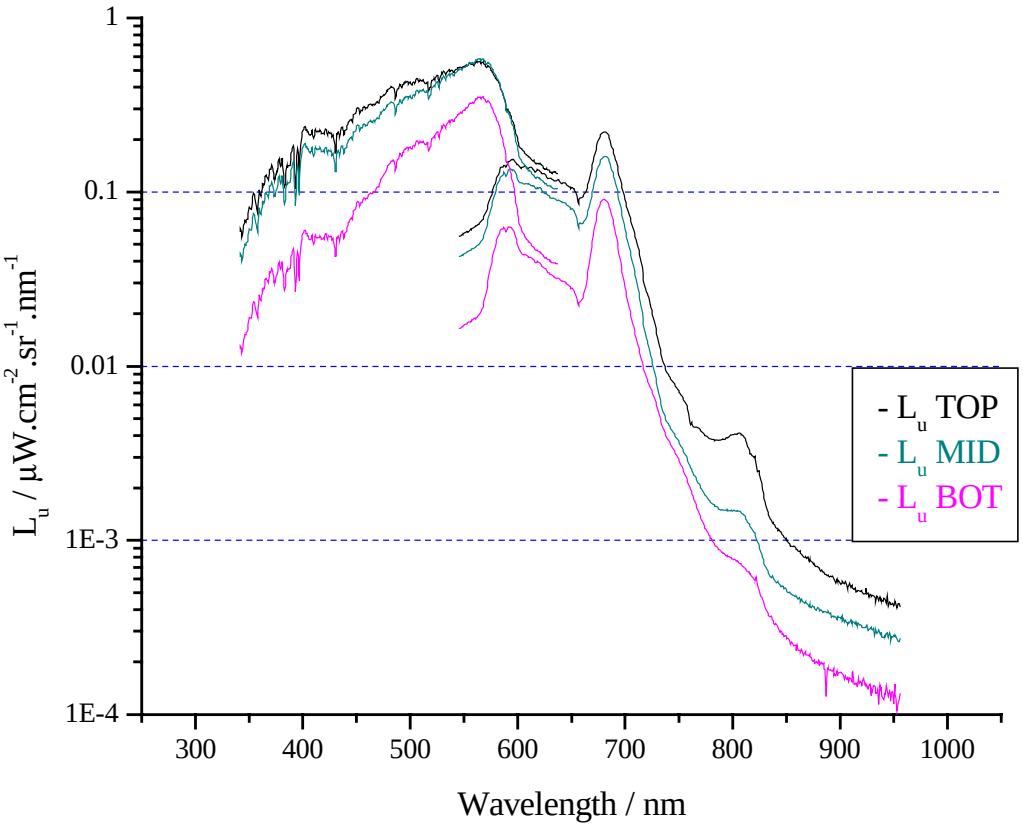
- Marine Optical Buoy (MOBY) deployed in support of the Earth Observing System (EOS)
- Calibration reference station for ocean color satellite instruments such as SeaWiFs, MODIS and OCTS
- MOBY's scientific objective : measure the down-welling spectral irradiance, E_d and the up-welling spectral radiance, L_u

Marine Optical Spectrograph (MOS)



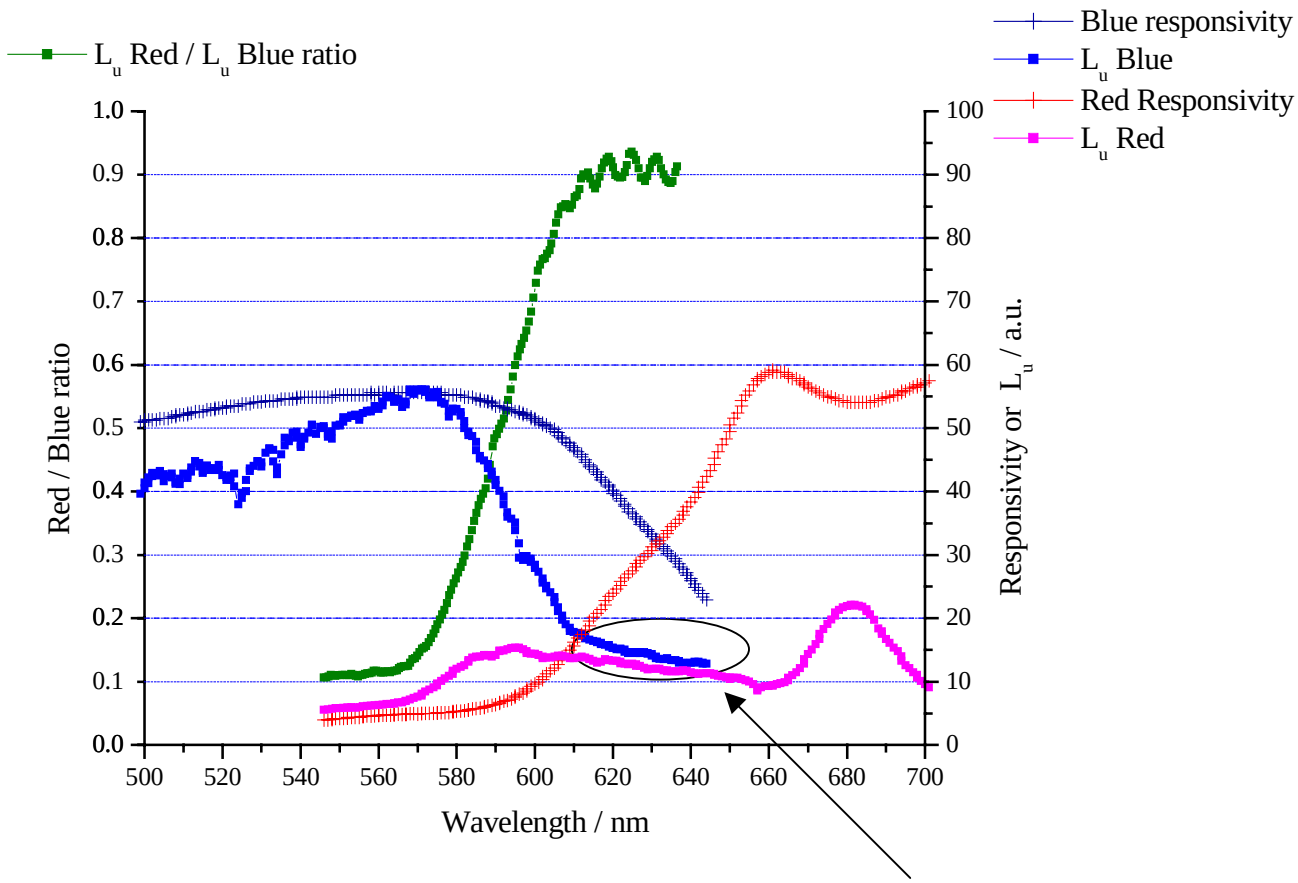
Upwelling Radiance Measurements with MOBY

Measurements with the red and the blue spectrographs disagree in the spectral overlap region



Largest Difference Occurs in Region of Low Red Responsivity

Low transmittance through dichroic beamsplitter



MOBY is calibrated against an incandescent lamp source that contains IR radiation
Then measures upwelling radiance that has very little radiation in the IR

L_u Blue > L_u Red

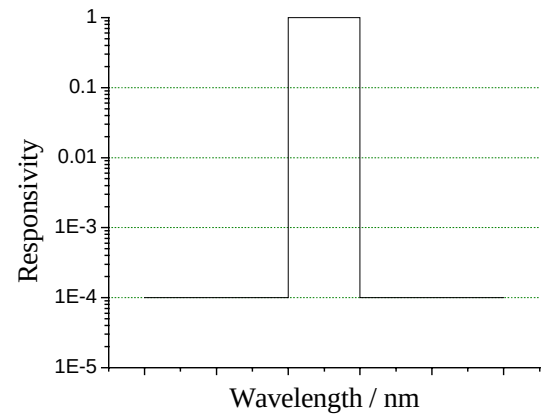
Consideration of Stray Light

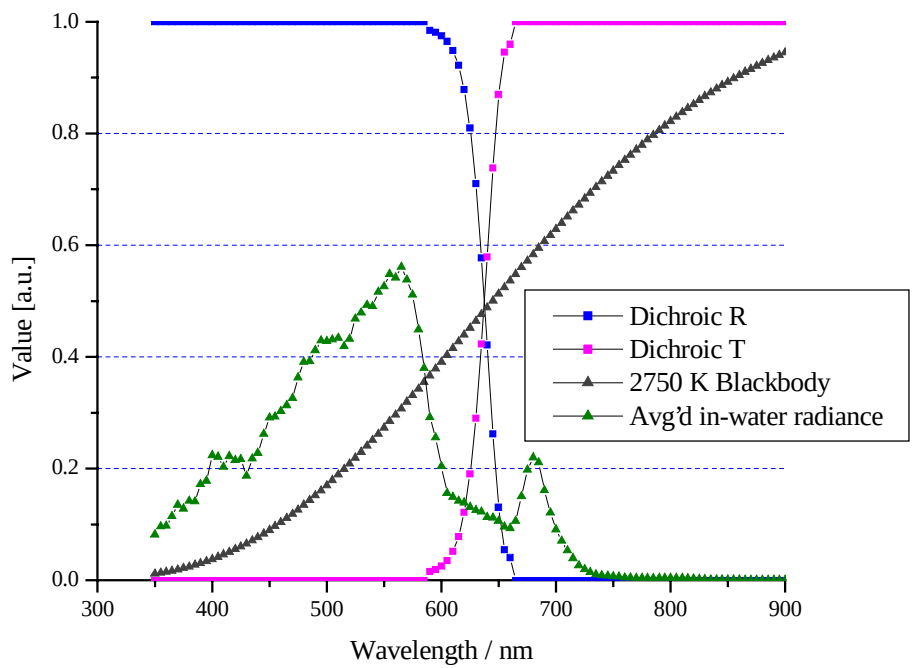
Model :

$$S = \sum R(\lambda) L(\lambda) \Delta\lambda$$

$$S_{in-band} = \sum_{in-band} R_{in-band}(\lambda) L(\lambda) \Delta\lambda$$

$$S_{out-of-band} = \sum_{out-of-band} R_{out-of-band}(\lambda) L(\lambda) \Delta\lambda$$





Plot shows difference in spectral shapes in region of dichroic

Simulation :

- Take flat CCD response = 1

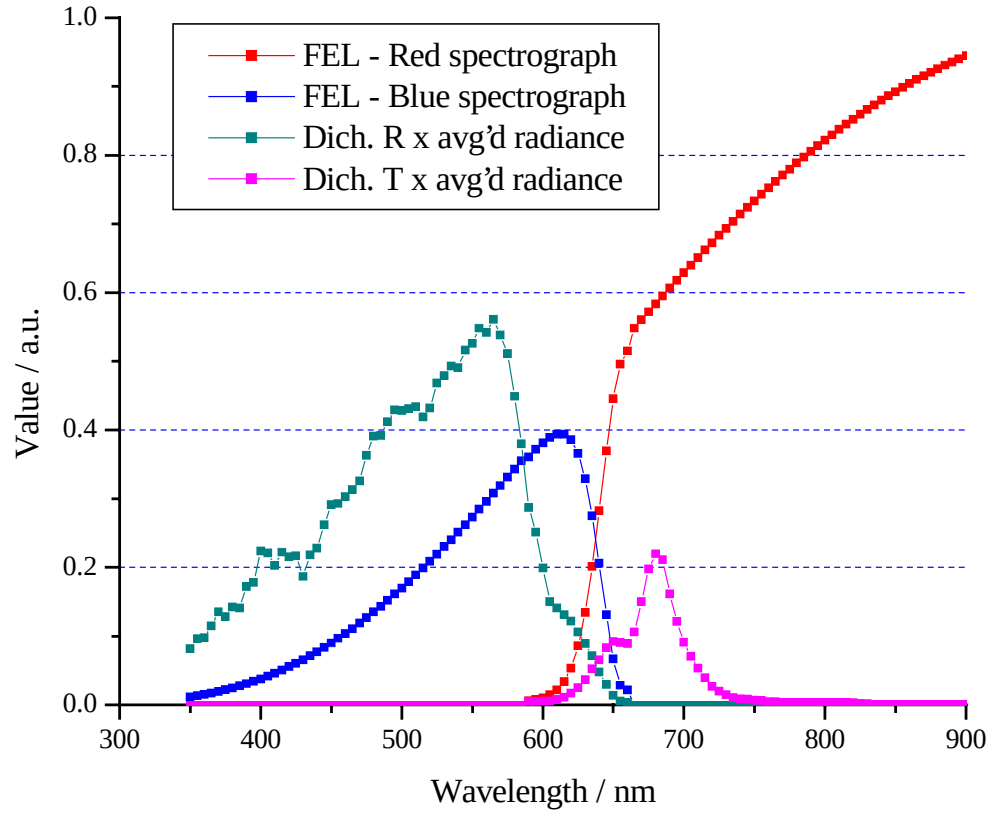
$$S_{inband} = 1 \times T(\lambda) L(\lambda) \Delta\lambda$$

T(λ) = Dichroic Transmittance or Reflectance

- Take stray light factor = 10^{-4}

$$S_{out of band} = 10^{-4} \sum_{\lambda} T(\lambda) L(\lambda) \Delta\lambda$$

- Take light falling on the CCD to be the source spectral distribution times the dichroic beamsplitter Transmittance (Red) or Reflectance (Blue)



What CCD sees

During calibration :

$$R_C(\lambda) = \frac{S_C(\lambda) + S_C^{SL}(\lambda)}{L_C(\lambda)}$$

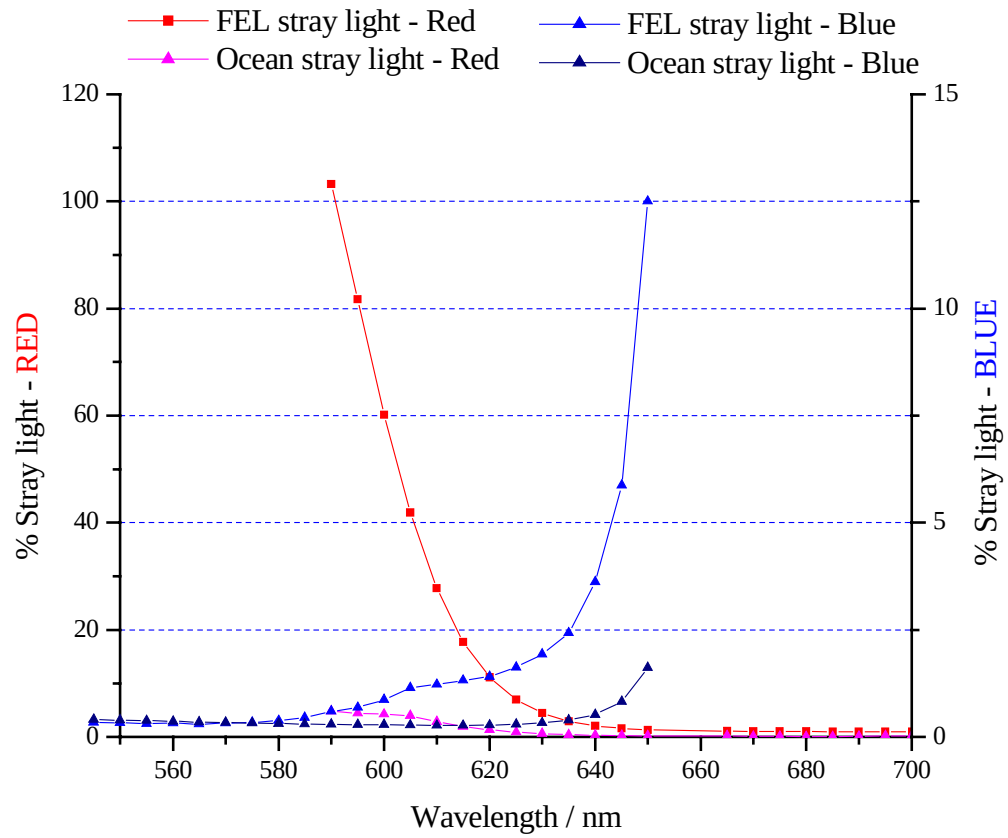
$R_C(\lambda) = responsivity$

$S_C(\lambda) = in-band\ signal$

$S_C^{SL}(\lambda) = out-of-band\ signal$

$L_C(\lambda) = radiance\ of\ calibration\ source$

$$Stray_light = 100 \times \frac{10^{-4} \times \sum L(\lambda)}{L(\lambda)}$$



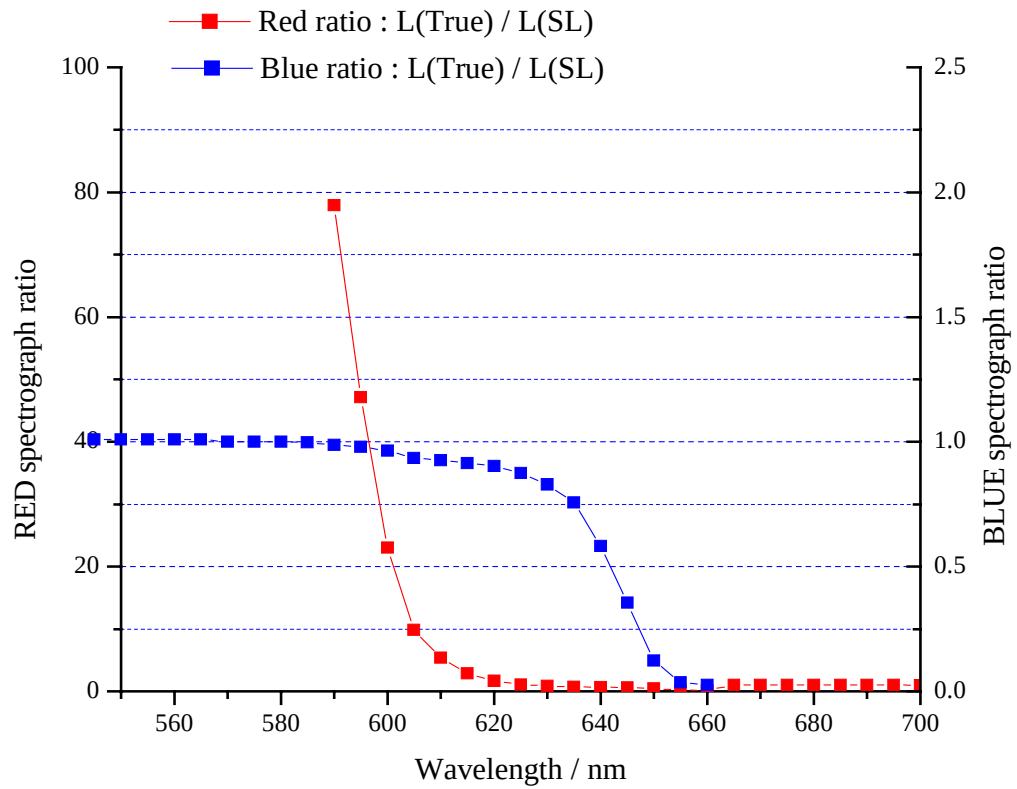
Stray light has a large effect on the Red Spectrograph
(where the transmitted radiance is small)

For measurements of radiance :

$$L_M(\lambda) = \frac{S_M(\lambda) + S_M^{SL}(\lambda)}{R_C(\lambda)}$$

$$L_M(\lambda) = \frac{S_M(\lambda) + S_M^{SL}(\lambda)}{S_C(\lambda) + S_C^{SL}(\lambda)} L_C(\lambda)$$

$$\frac{L_M^{True}}{L_M^{SL}} = \left[1 + S_C^{SL} / S_C\right] \Big/ \left[1 + S_M^{SL} / S_M\right]$$



The Blue spectrograph needs to be corrected a small amount.

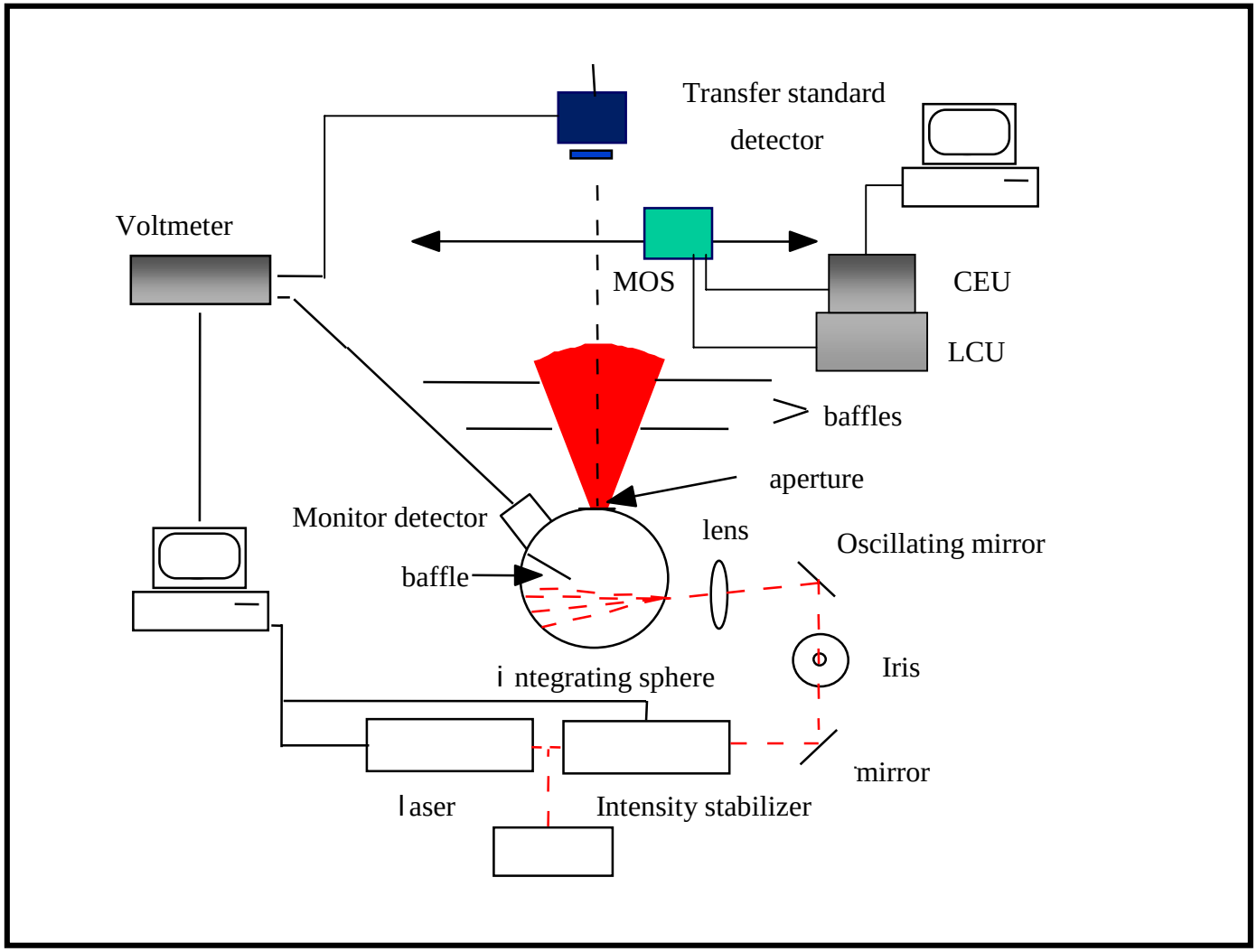
The Red spectrograph needs to be corrected significantly.

Approach

- Calibrate a MOS Bench Unit against a spectrally tunable, narrow-band source on SIRCUS
  - Linearity, exposure time correction
  - Single pixel responsivity
  - Directly measure stray light

- Calibrate the MOS Bench Unit against a broad-band source with a distribution similar to the one used to calibrate the Field Units and compare the results with those from SIRCUS

MOS Calibration on SIRCUS



MOS Bench Unit

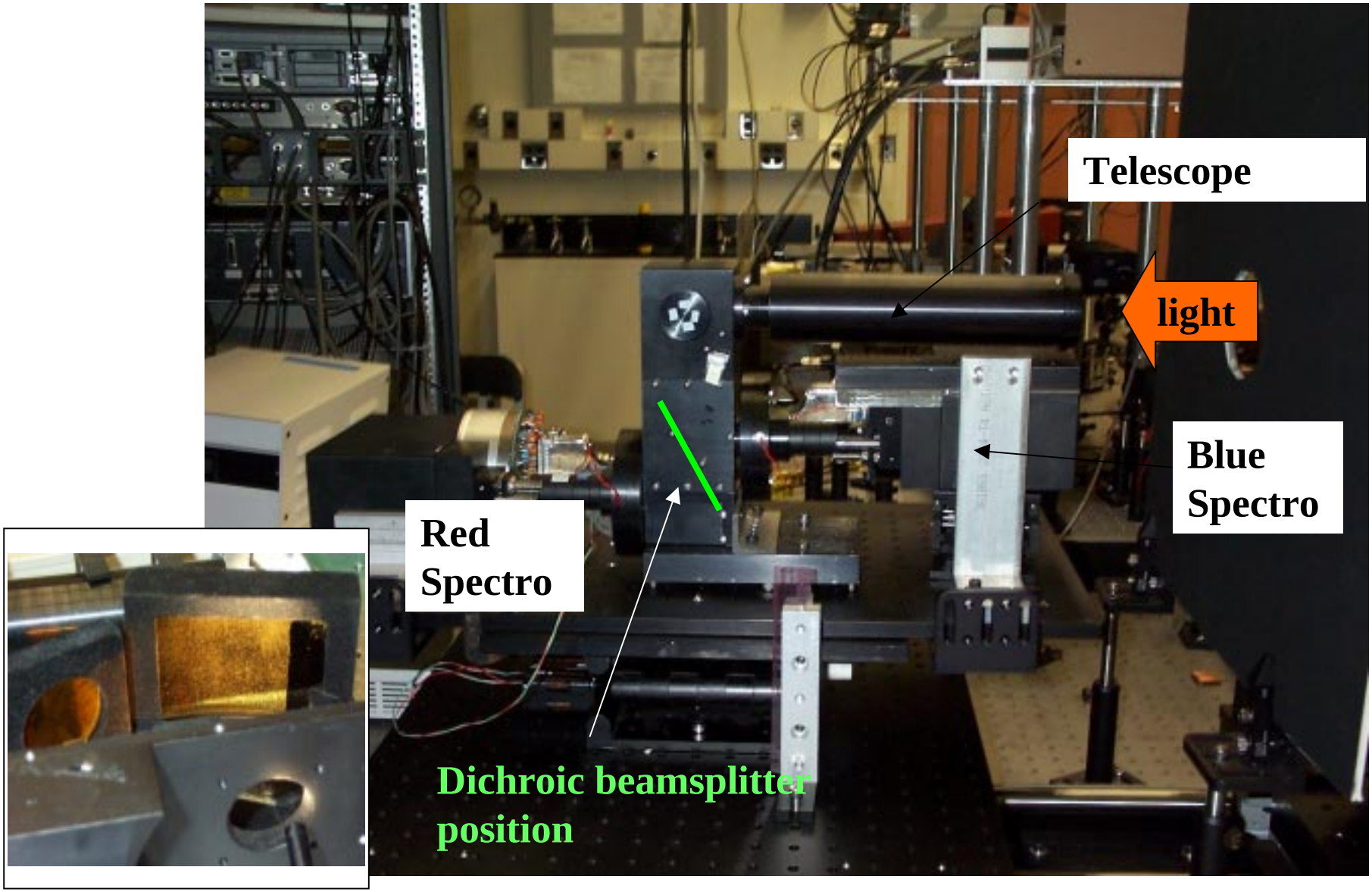
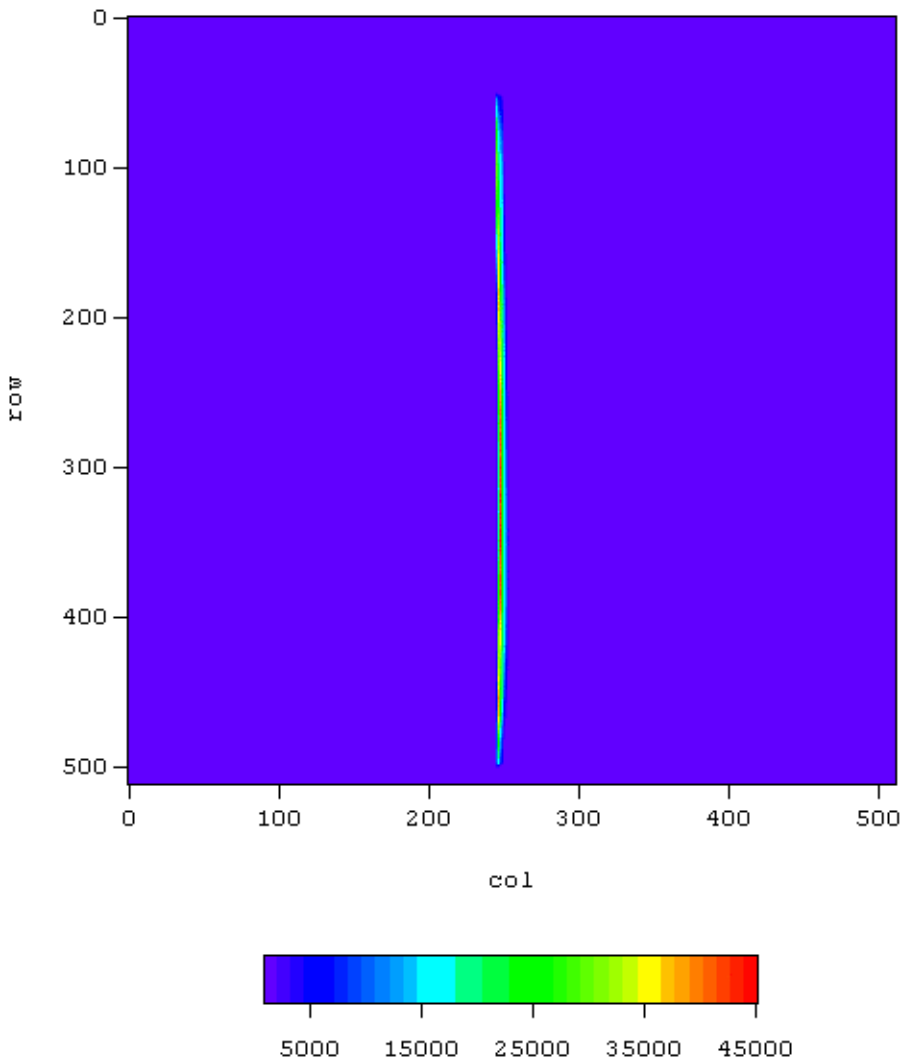
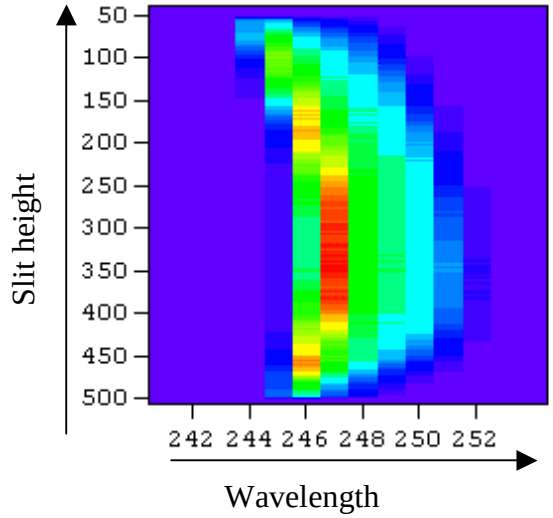
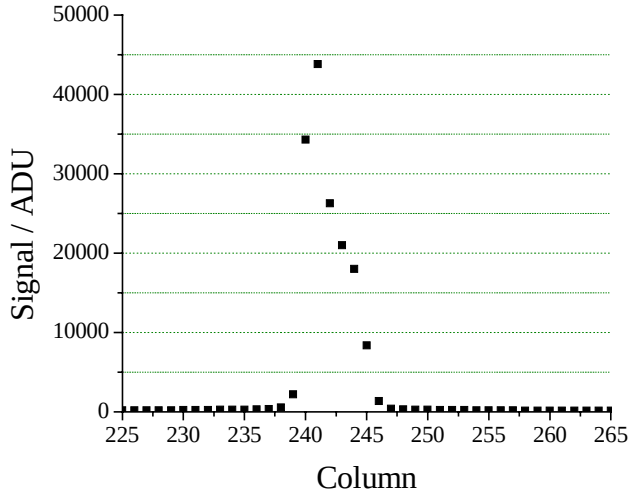


Image from Red Spectrograph with 745 nm Excitation

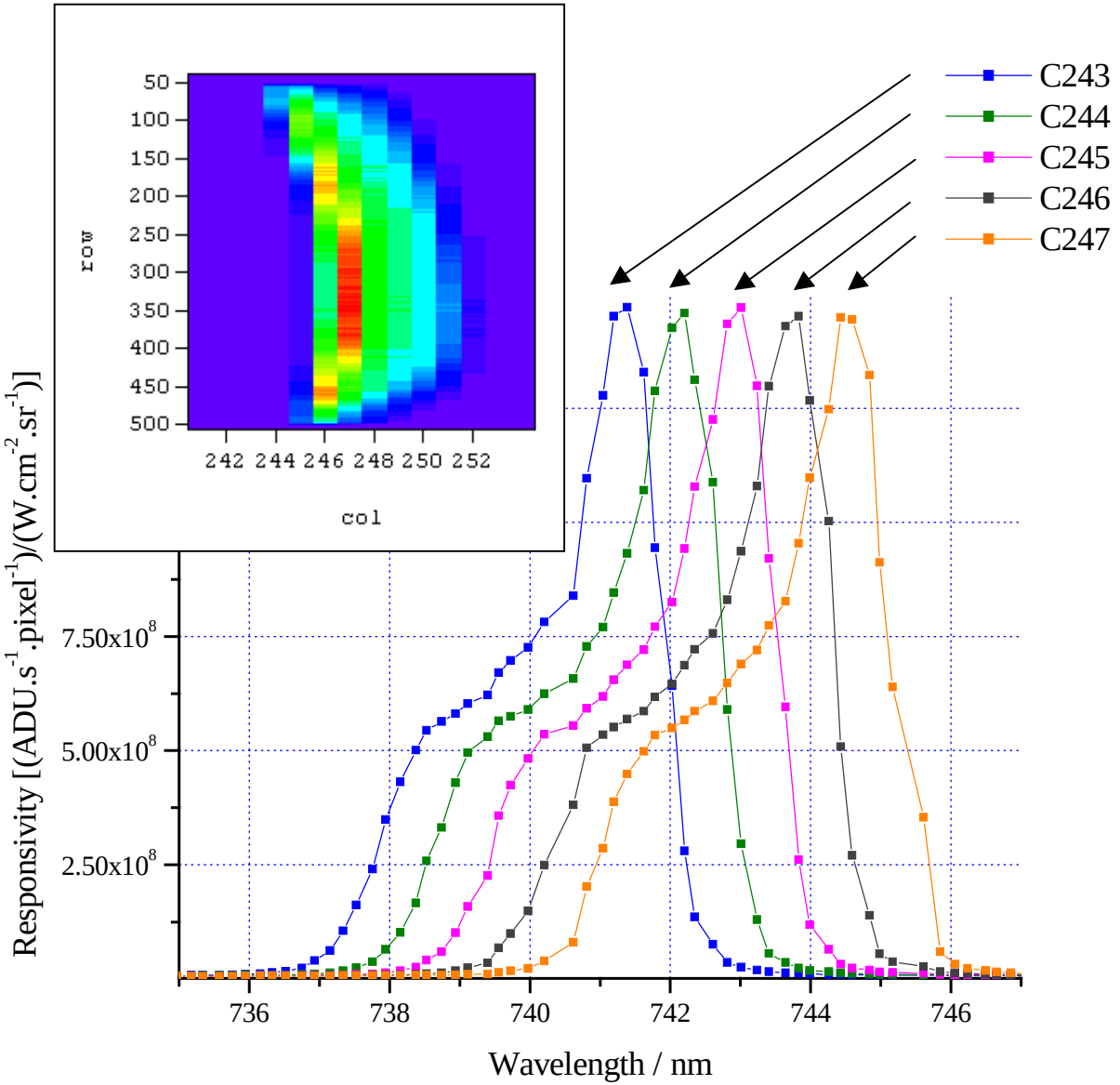




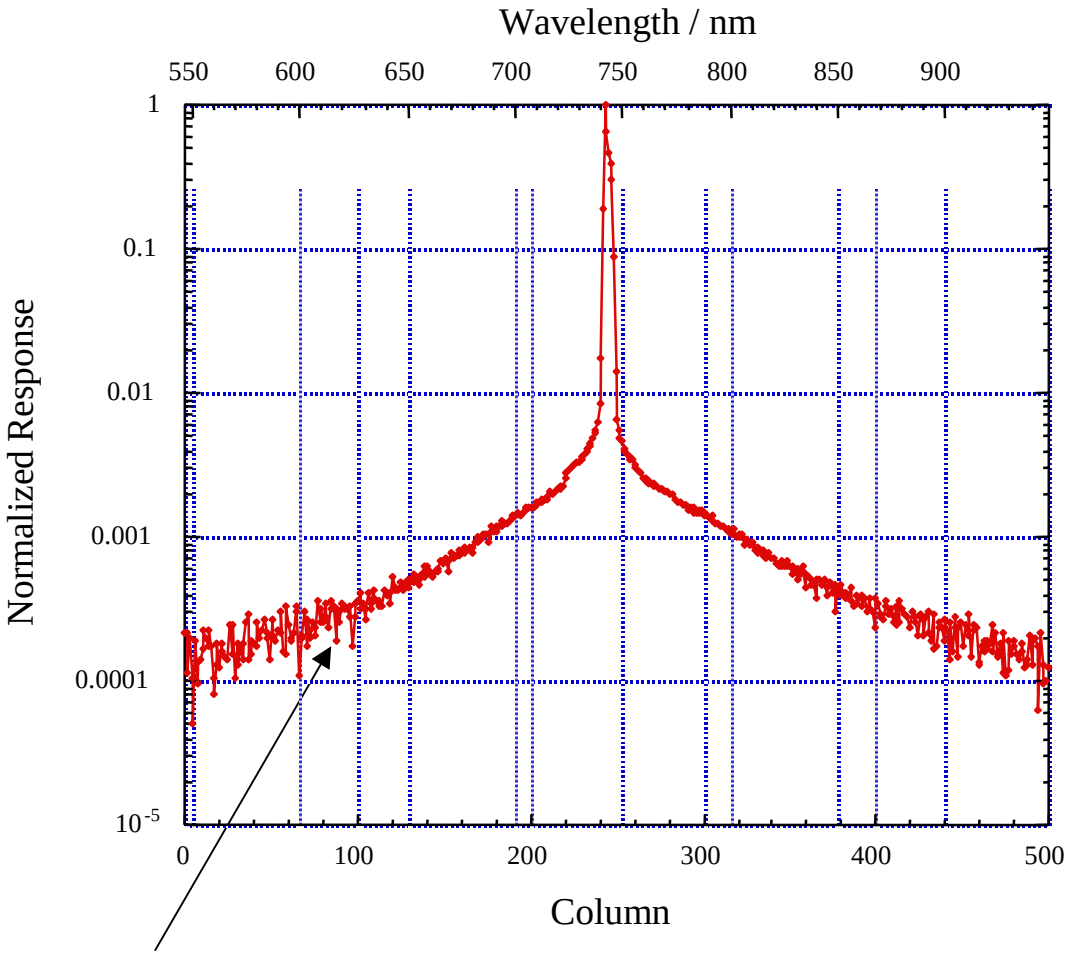
Column response at 742 nm excitation



Single Column Averaged Responsivity

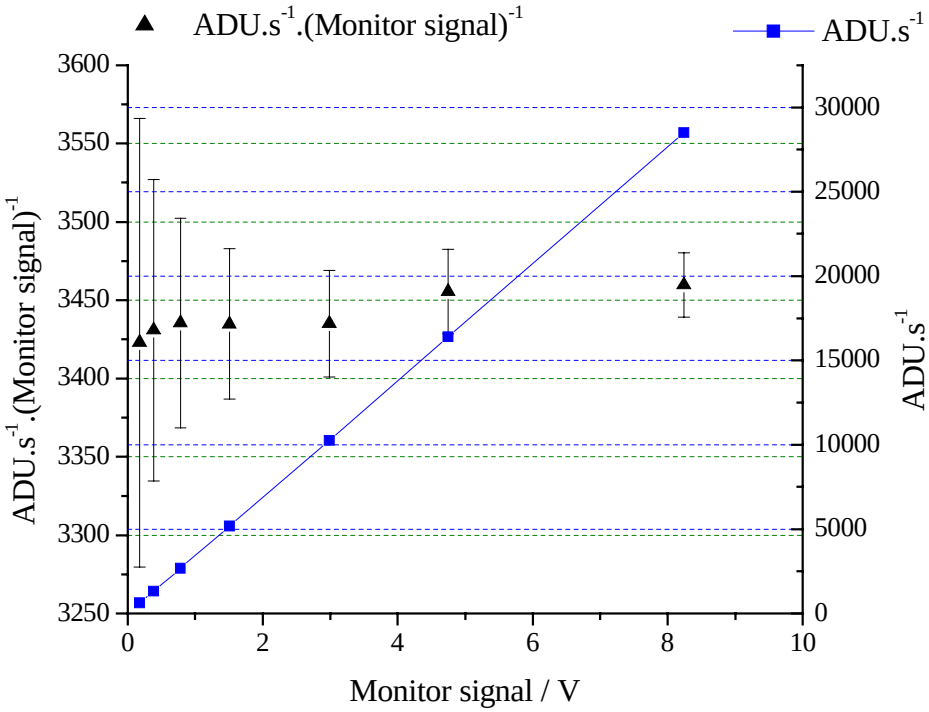


System Response to Monochromatic Excitation



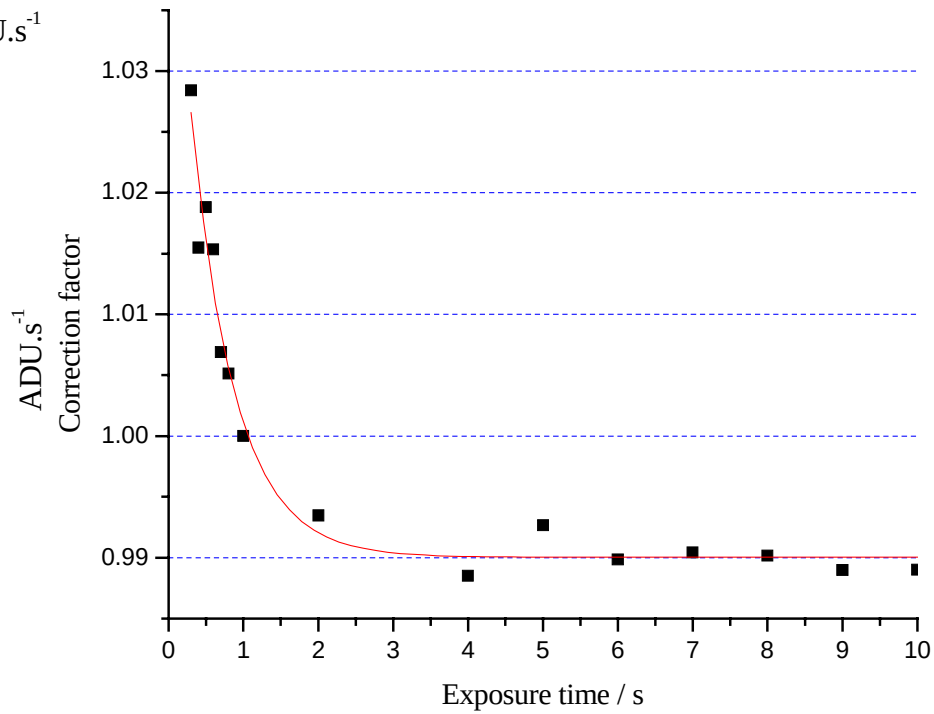
Finite response at pixel 100 (~625 nm)

Linearity



CCD System Response is linear to within the uncertainty. The vertical lines represent the standard uncertainty.

Exposure Time



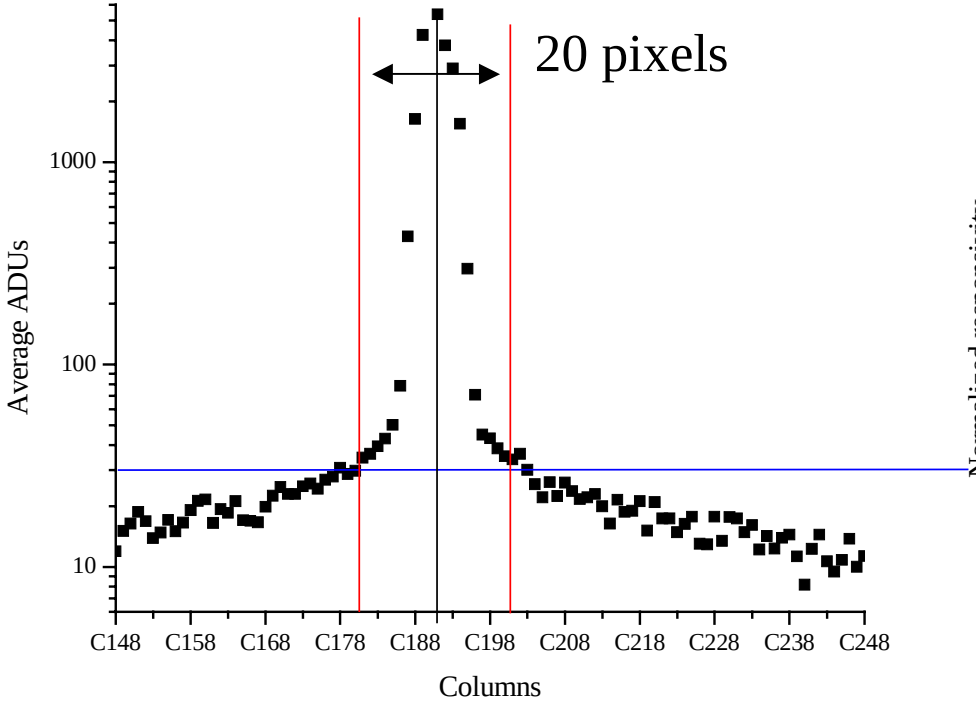
Fit to exponential decay : $y_0 + A_1 \exp\left(\frac{-x}{t_1}\right)$

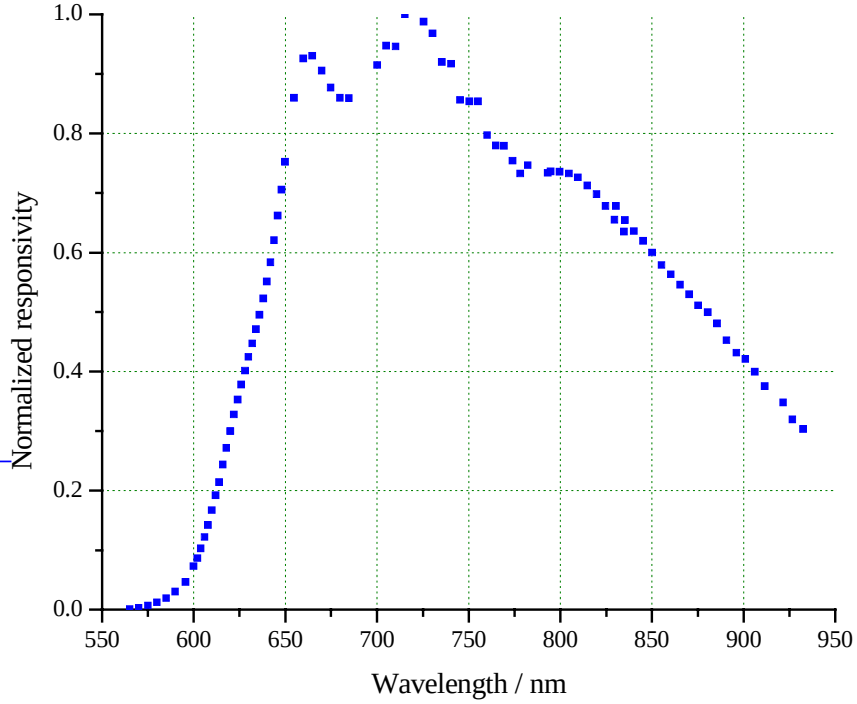
$y_0 = 1.0002$

$A_1 = 0.06159$

$t_1 = 0.58657$

Absolute Spectral Responsivity



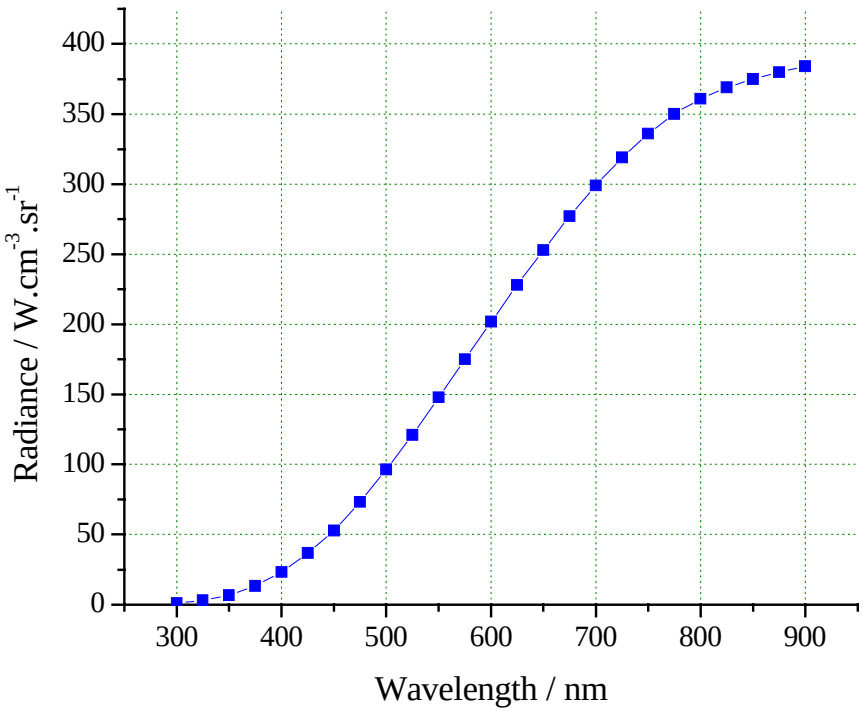


In-band signal = 20 pixels

Consider in-band signal to calculate responsivity

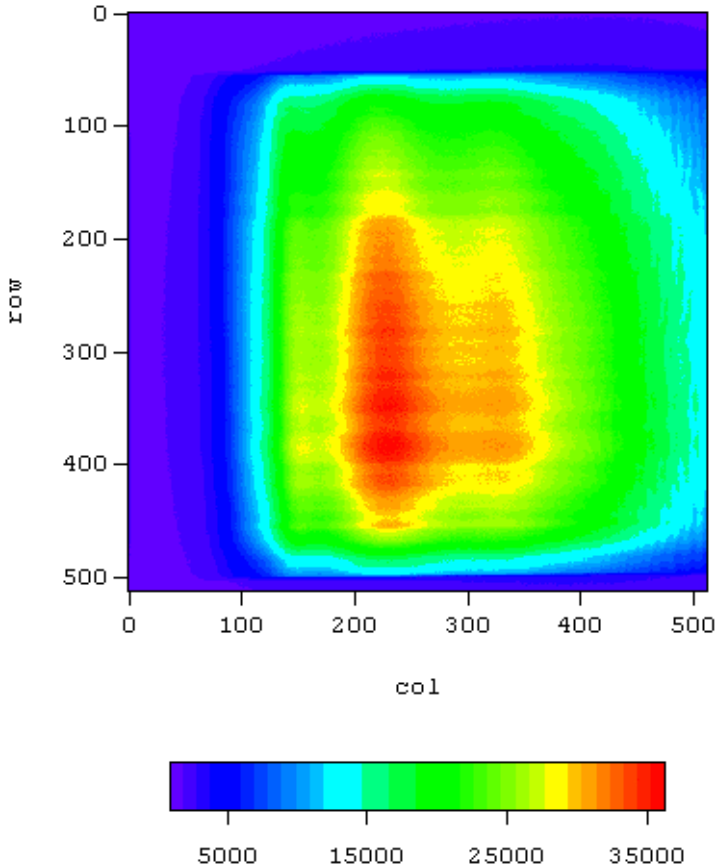
Calibration vs. a Broad-band Integrating Sphere Source

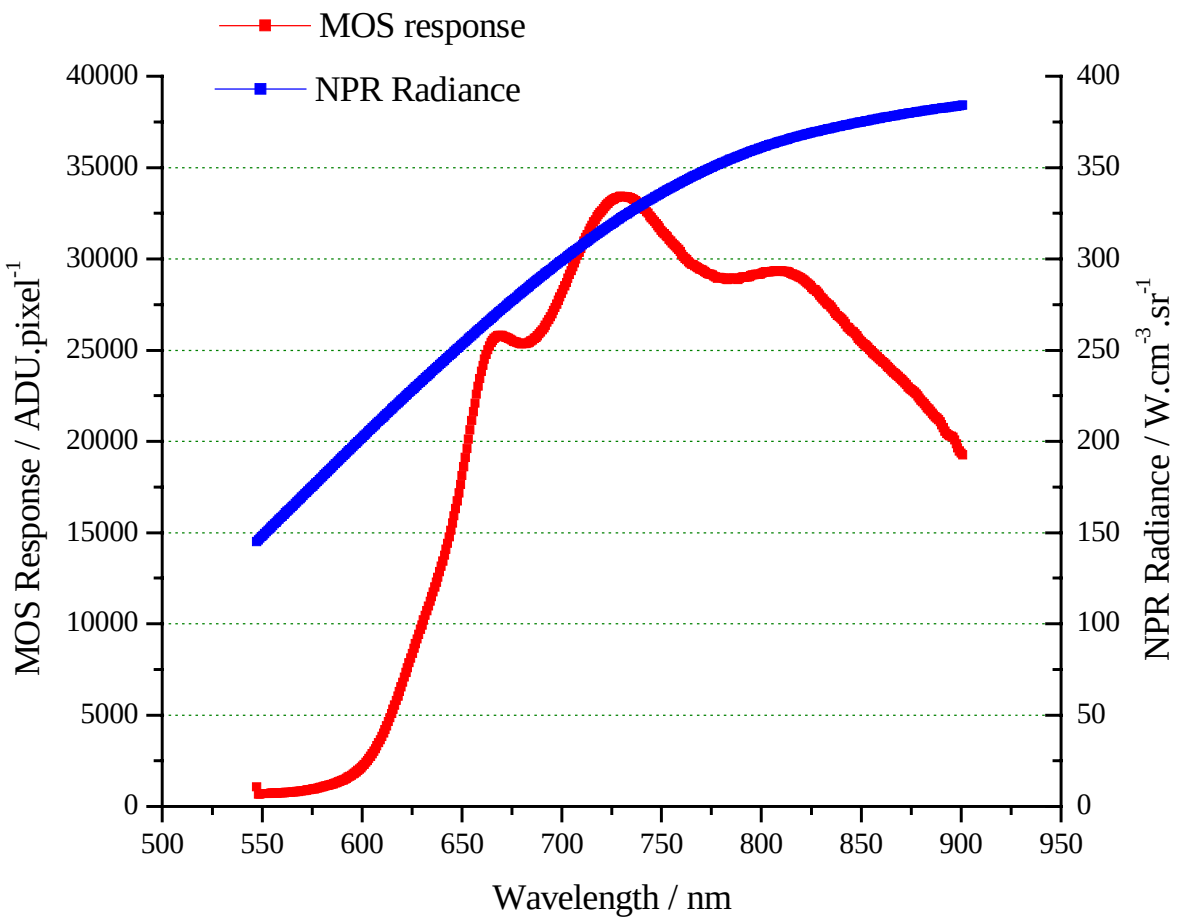
ISS Spectral Radiance



Spectrograph Image

(0.5 s exposure)

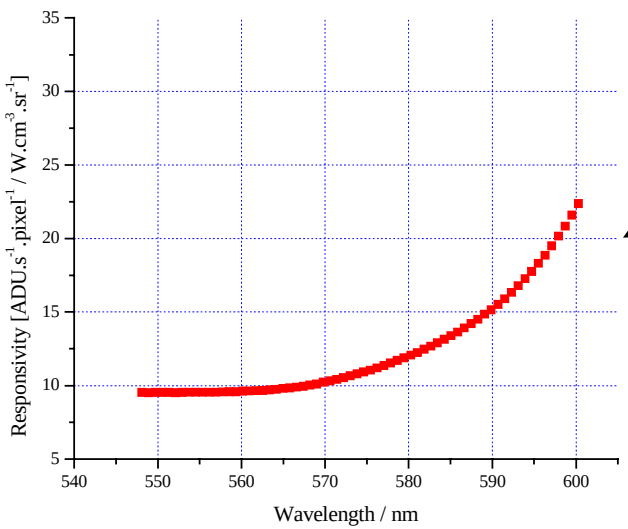


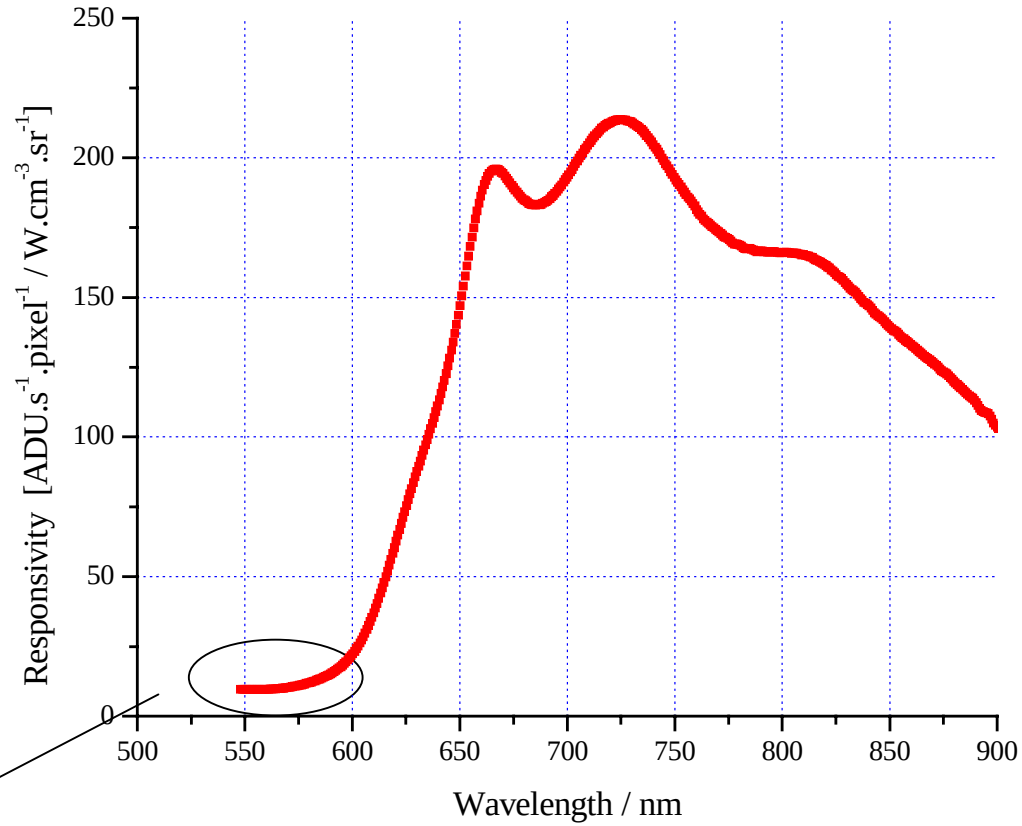


Response shape due to dichroic beamsplitter

Responsivity :

$$R_\lambda = \frac{MOS \quad response}{NPR \quad radiance}$$

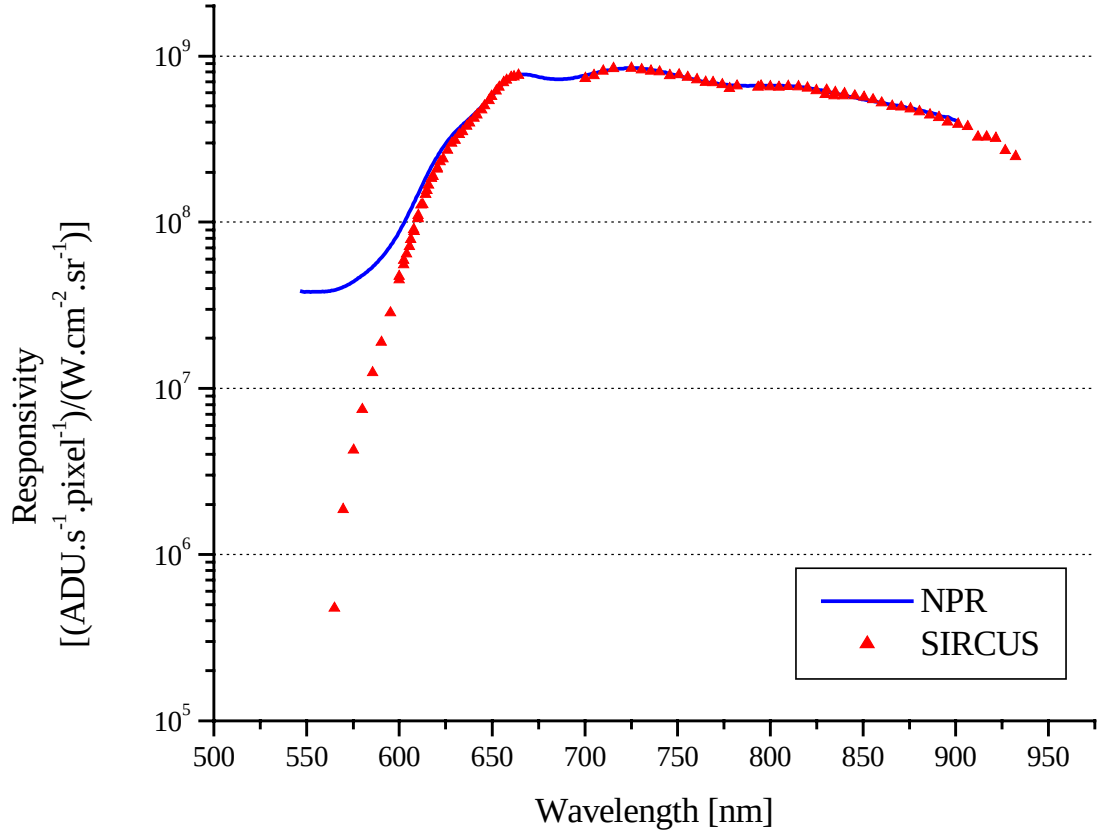




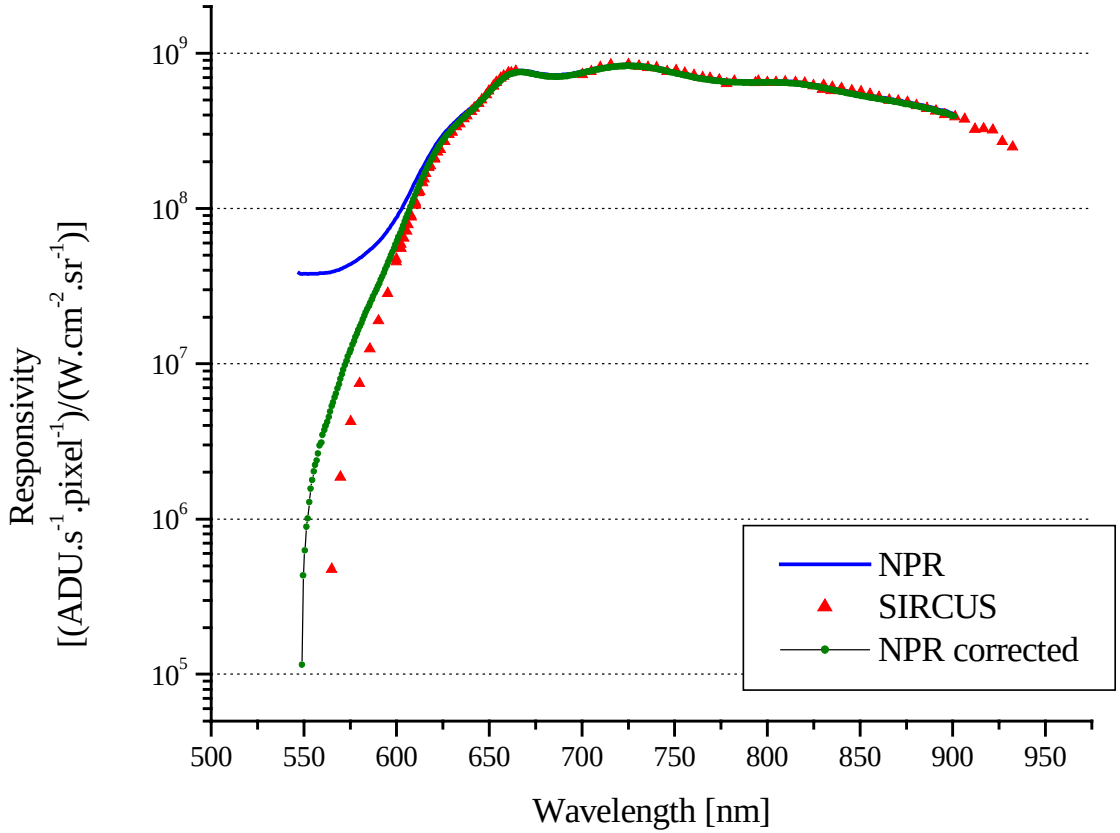
Responsivity should go down to zero in this region.

This is the effect of stray light.

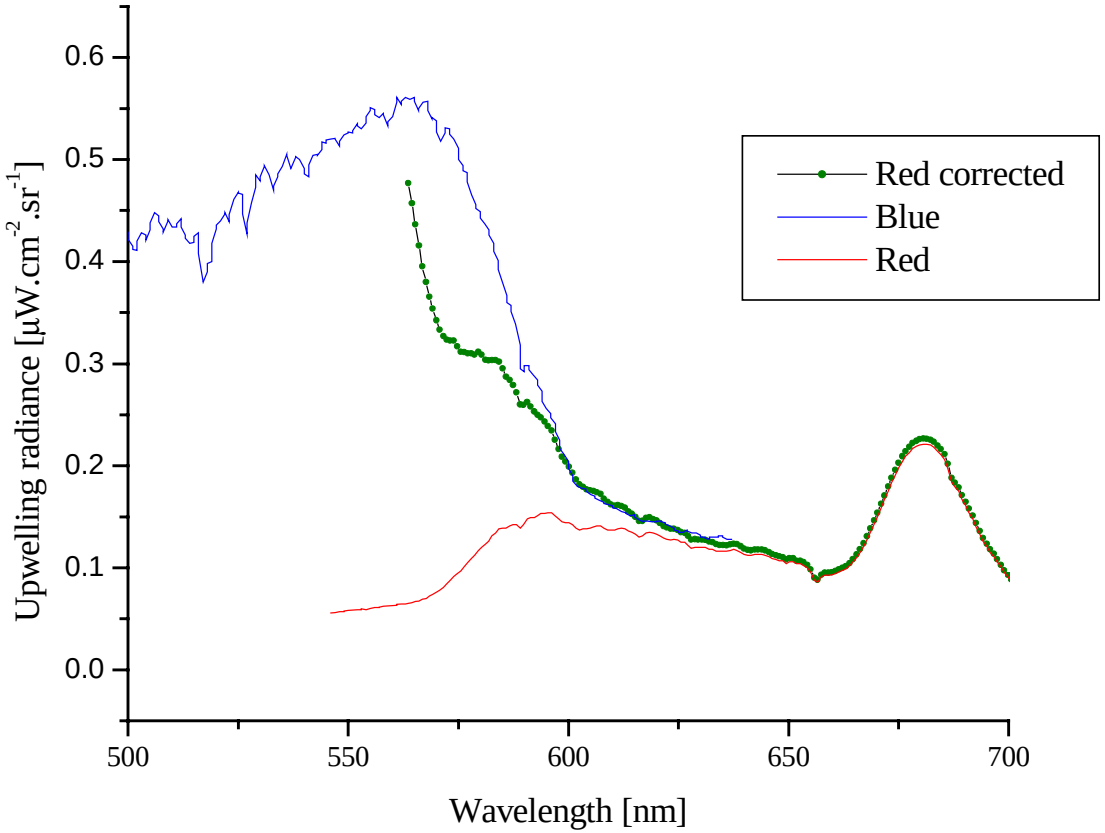
Column averaged responsivity for both techniques



Simple correction to the NPR measurements



Stray light correction to MOBY data



Conclusion

- First time that a laser based approach is used to calibrate a CCD spectrograph.

- Discrepancies strongly reduced in overlap region

- Will result in more accurate water-leaving radiance :
  - Give confidence in measurements of important Red spectral region
  - Impact satellites data :
    - Atmosphere algorithms
    - Atmospheric models