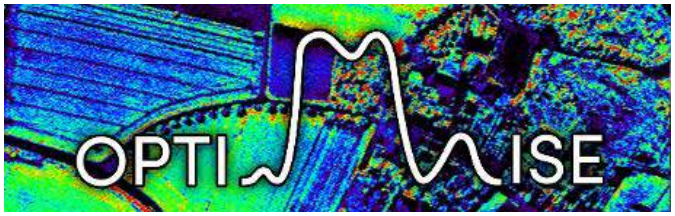

COST Action ES1309 OPTIMISE

Instrumental considerations for the measurement of sun induced fluorescence

Javier Pacheco-Labrador
Max Plank Institute for Biogeochemistry

Max Planck Institut
for Biogeochemistry

OVERVIEW

1. *F* & SPECTRORADIOMETRY

2. MODELING EXERCISE
   1. SPECTRAL DATASET
   2. MODELING APPROACH
   3. SPECTRAL CALIBRATION & ISRF
   4. RADIOMETRIC CALIBRATION
   5. TEMPERATURE SENSITIVITY
   6. NON-LINEARITY
   7. DIRECTIONAL RESPONSE

3. CONCLUSIONS

1. *F* & SPECTRORADIOMETRY

APPLICATION DETERMINES AFFORDABLE UNCERTAINTY

ARE OUR INSTRUMENTS / STANDARDS GOOD ENOUGH TO MEASURE SUN INDUCED CLOROPHYLL FLUORESCENCE (*F*)?

New sensors: improved spectral resolution, sensitivity, cooling systems…

Still, lack of uncertainty: Characterization / Propagation / Correction

1. *F* & SPECTRORADIOMETRY

1. *F* & SPECTRORADIOMETRY

- Considerations

Uncertainties (*u*)

- Radiometric calibration
- Spectral calibration
- Spectral Response Function
- …

Sources of error

- Temperature: Responsivity / Spectral changes
- Non-linearity
- Biased directional response of the optics / reference panels
- …

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Quantify?
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Quantify?
Correct?
Propagate?

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Characterize?

1. *F* & SPECTRORADIOMETRY

WHY IS THIS IMPORTANT?

- Top of the canopy *F* is very small (< 3 mW/m^2/sr/nm)

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What was the uncertainty of your last measurement?

1. *F* & SPECTRORADIOMETRY

WHY IS THIS IMPORTANT?

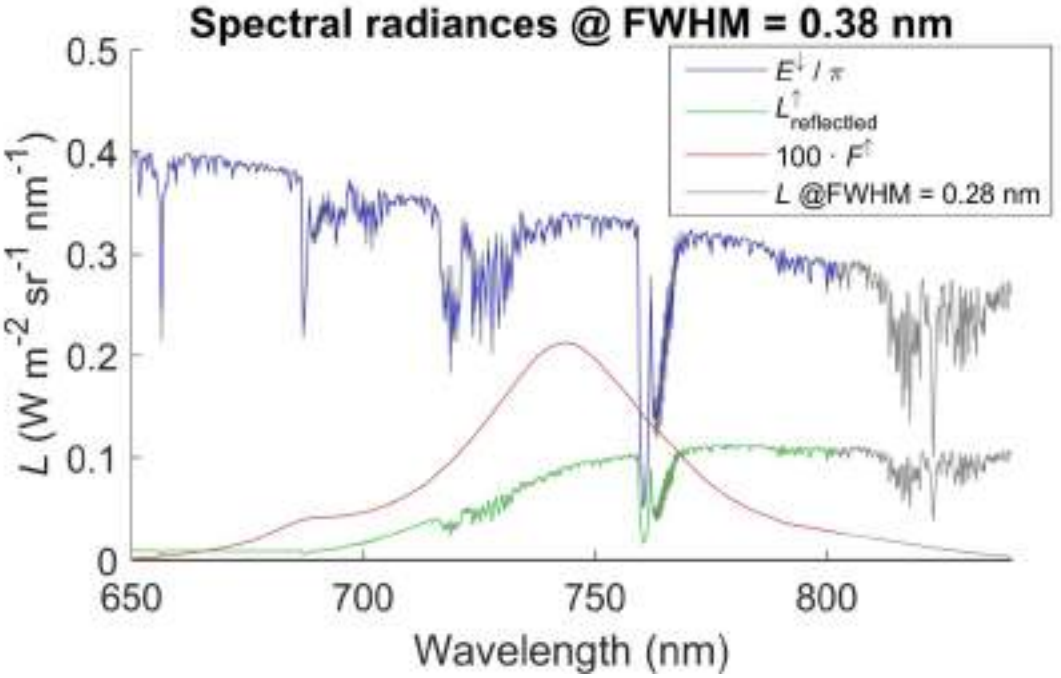
- Top of the canopy *F* is very small (< 3 mW/m^2/sr/nm)

What was the uncertainty of your last measurement?

How much it could bias your *F* estimates?

2. MODELING EXERCISE

- 1. SPECTRAL DATASET
  - MODTRAN Hi-Res Irradiance ($E^{\downarrow}$) @ FWHM = 0.28 nm
  - SCOPE simulated Radiance ($L^{\uparrow}$) and SIF ($F^{\uparrow}$)
  - Resampling to ~Ocean Optics QE *Pro* @ FWHM = 0.38 nm



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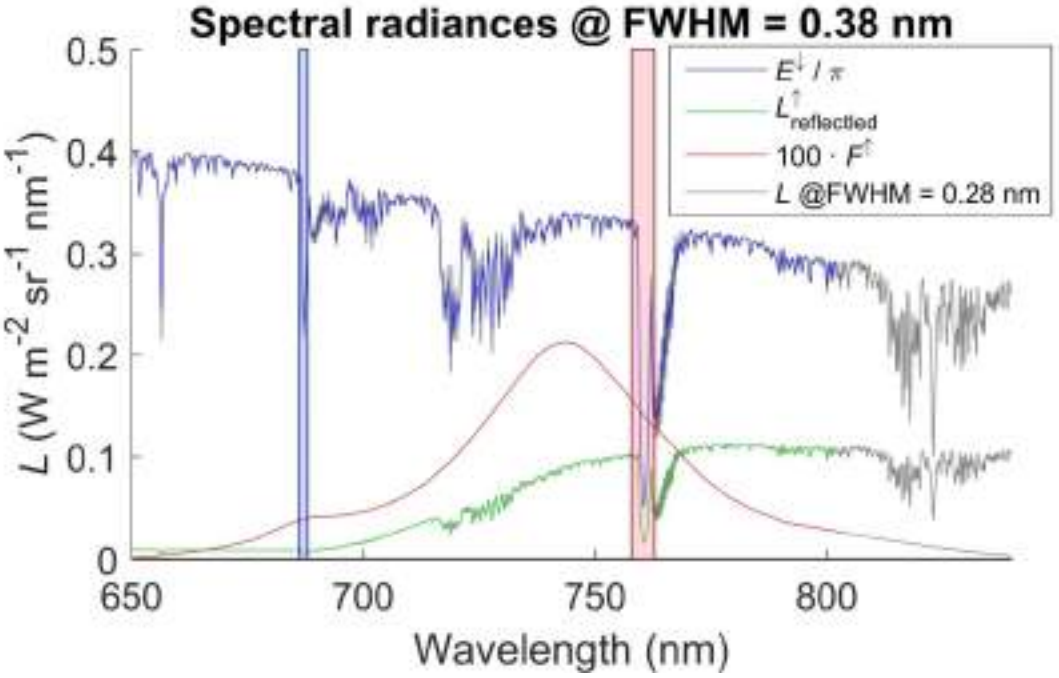
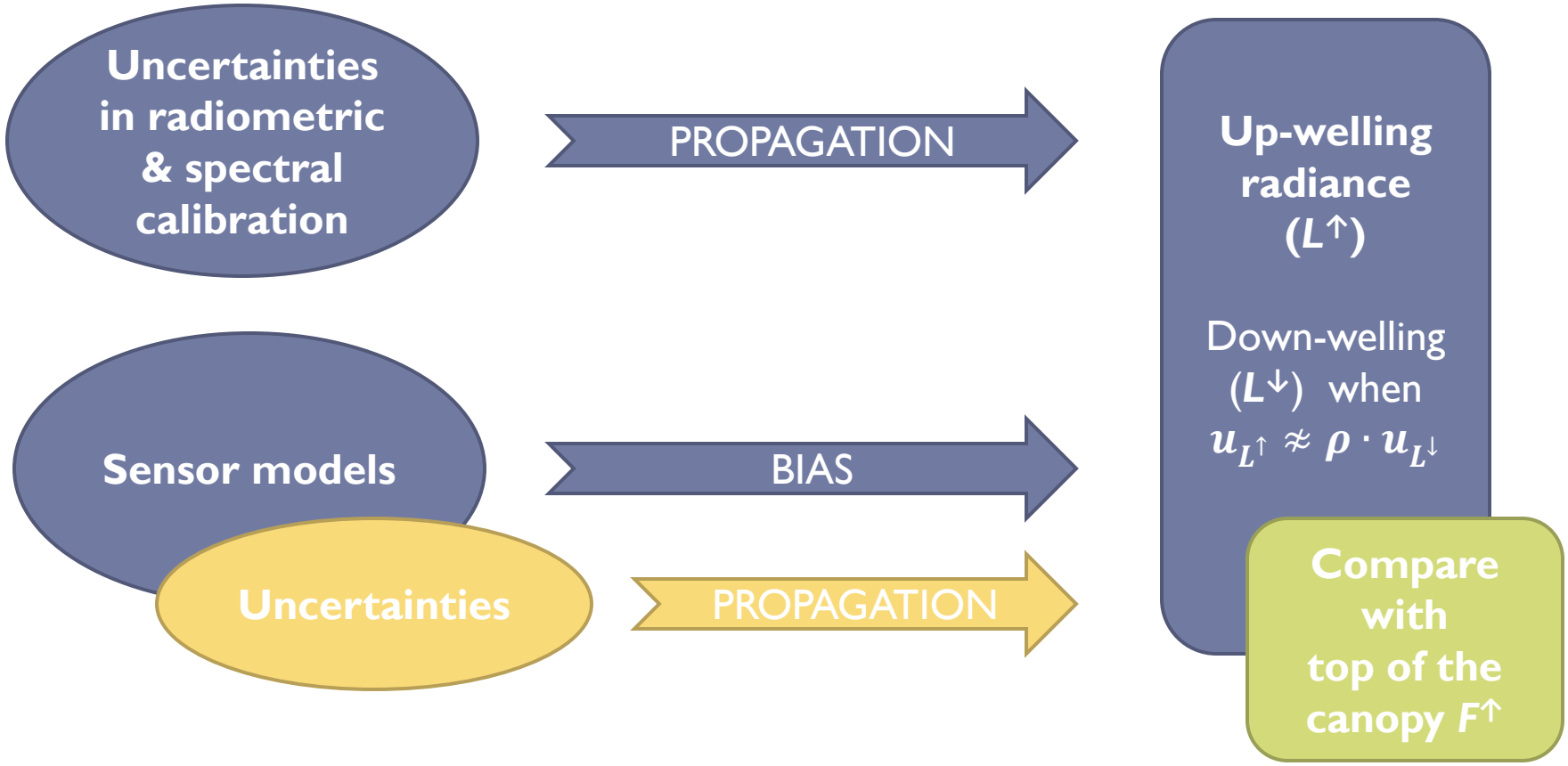


TOC $F^{\uparrow}$ (mW/m²/sr/nm)	O_2-A	O_2-B
Outside	1.57	0.38
Inside	1.41	0.39

F@757.99 = 1.57 | F@760.46 = 1.41 | F@686.23 = 0.38 | F@687.14= 0.39

2. MODELING EXERCISE

- 2. MODELING APPROACH



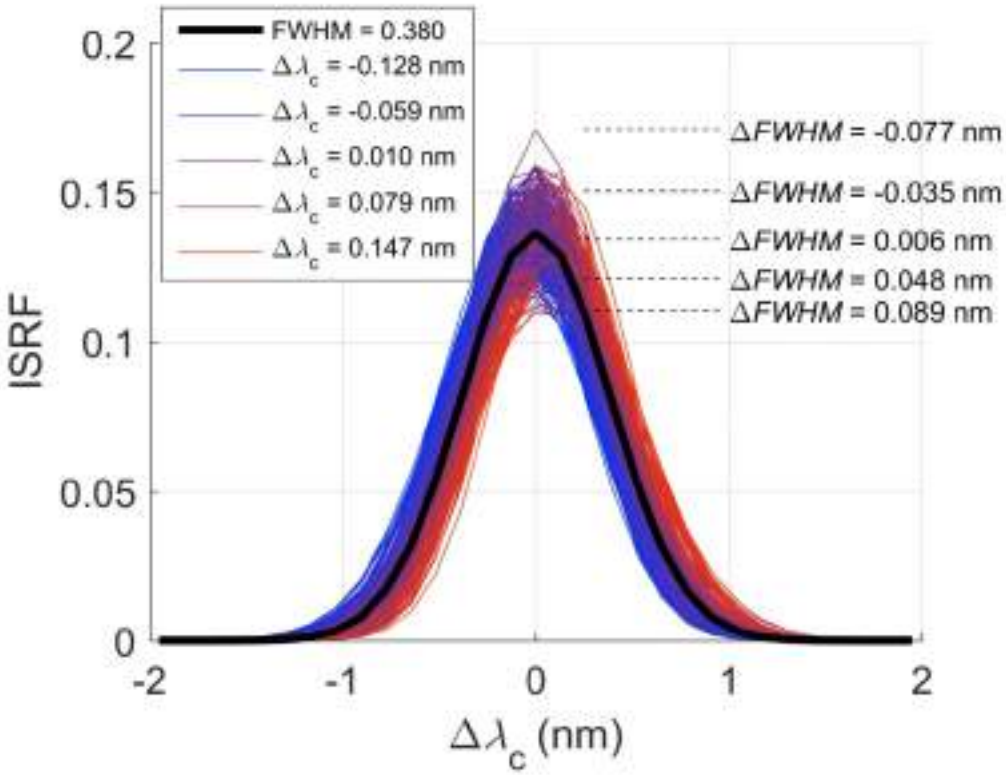
2. MODELING EXERCISE

- 3. SPECTRAL CALIBRATION & IRSF
  - **Spectral convolution of Hi-Res Irradiance**
  - **Uncertainties in center and FWHM of Gaussian ISRF**

500 realizations for:

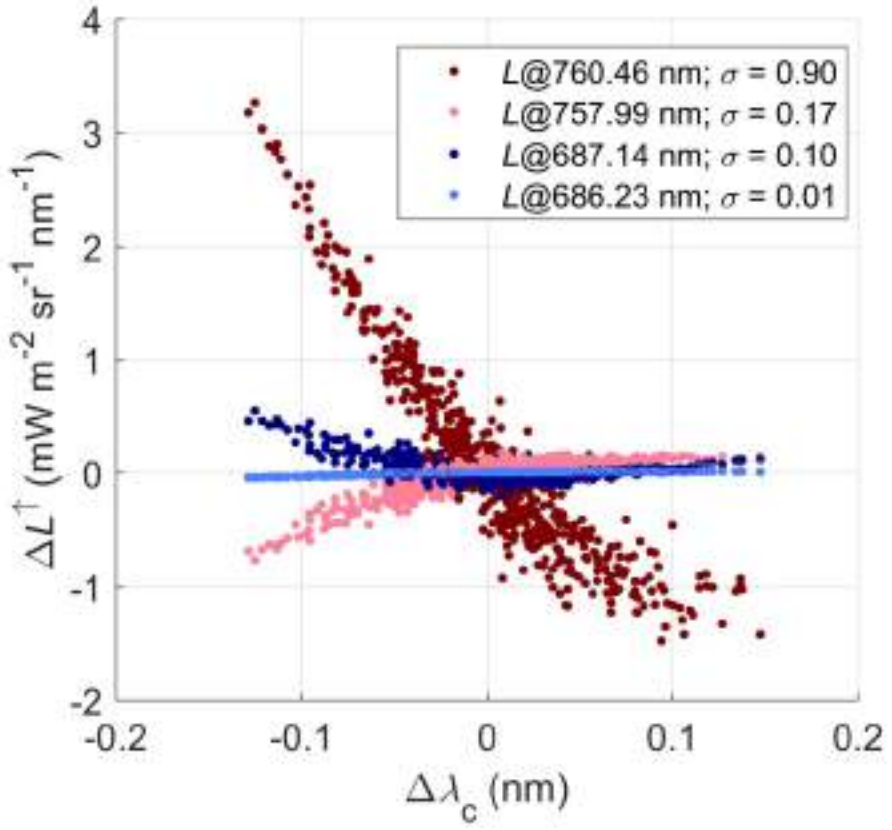
$$\sigma_{\lambda_c} = 0.050\ nm$$

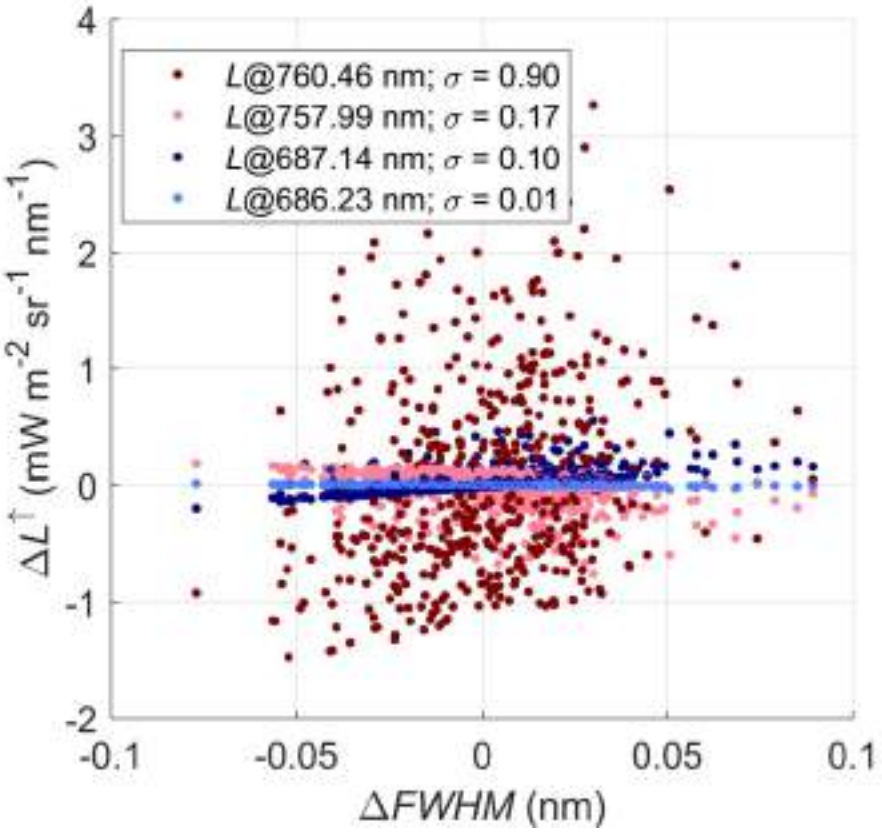
$$\sigma_{FWHM} = 0.025\ nm$$



2. MODELING EXERCISE

- 3. SPECTRAL CALIBRATION & IRSF
  - **Uncertainty Propagation: Up-welling Radiance ($L^{\uparrow}$)**





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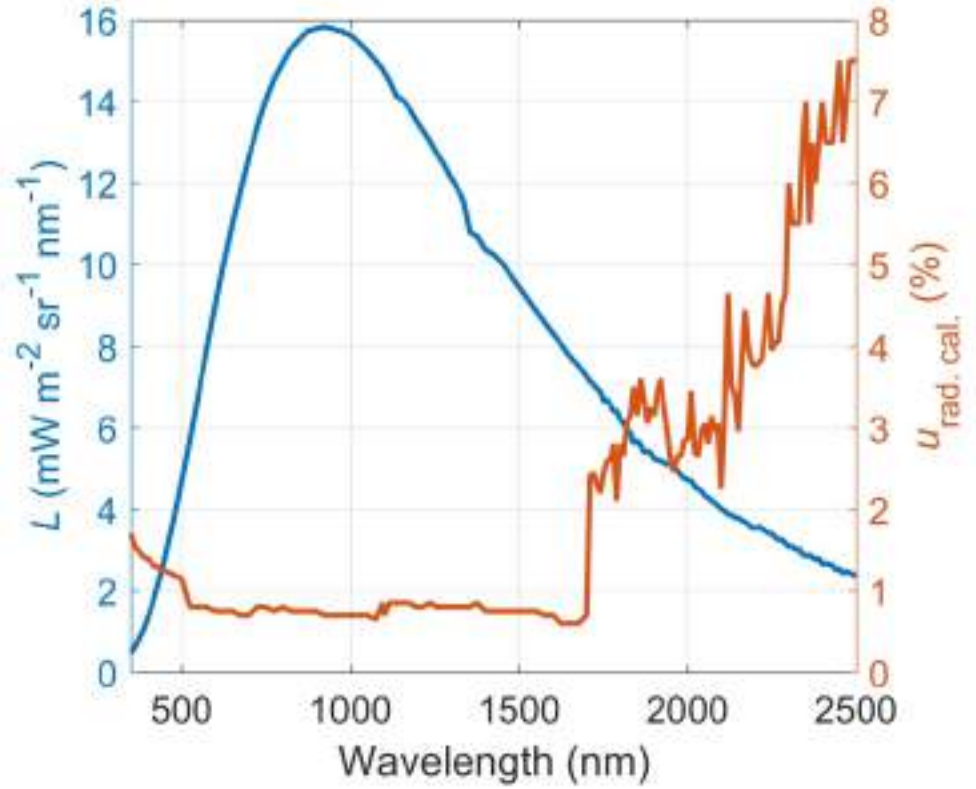
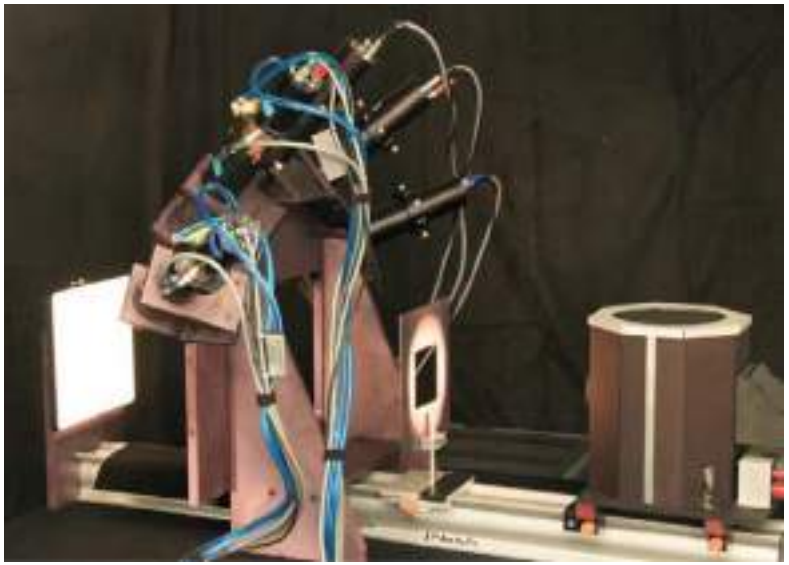
2. MODELING EXERCISE

- 4. RADIOMETRIC CALIBRATION
  - **RAdiance STAndard (RASTA)**
    - **Traceable Standard @ DLR Calibration Home Base**





RASTA, Schwarzmaier et al., 2012

2. MODELING EXERCISE

- 4. RADIOMETRIC CALIBRATION
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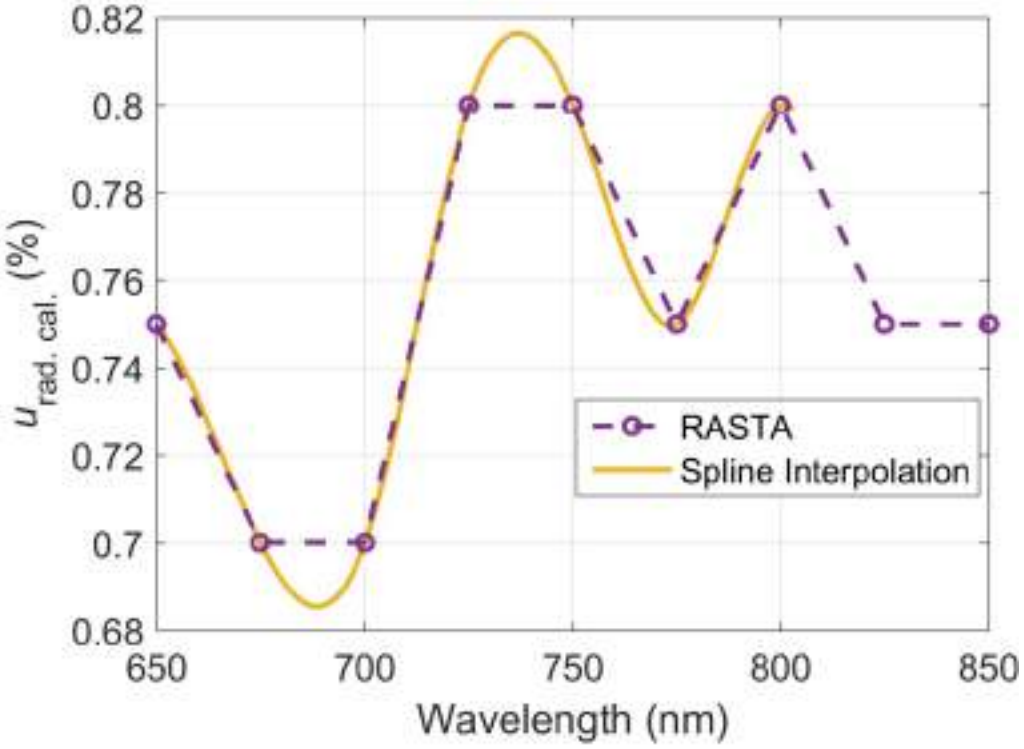
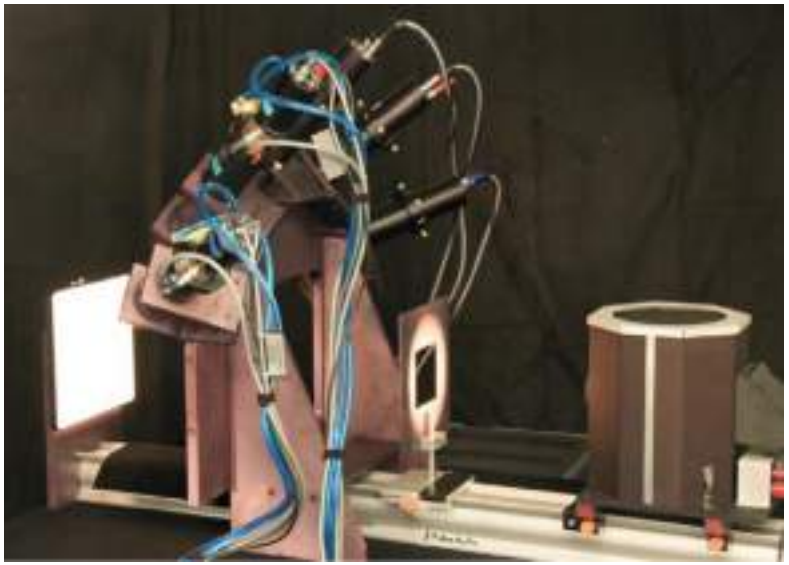
    - **Traceable Standard @ DLR Calibration Home Base**

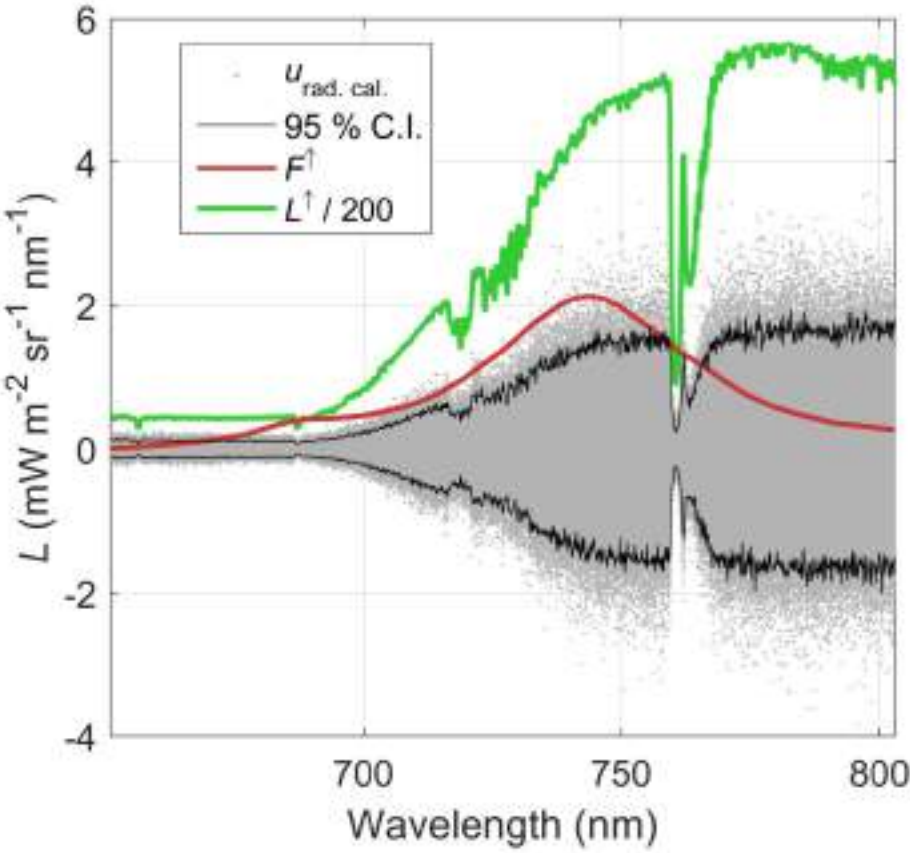


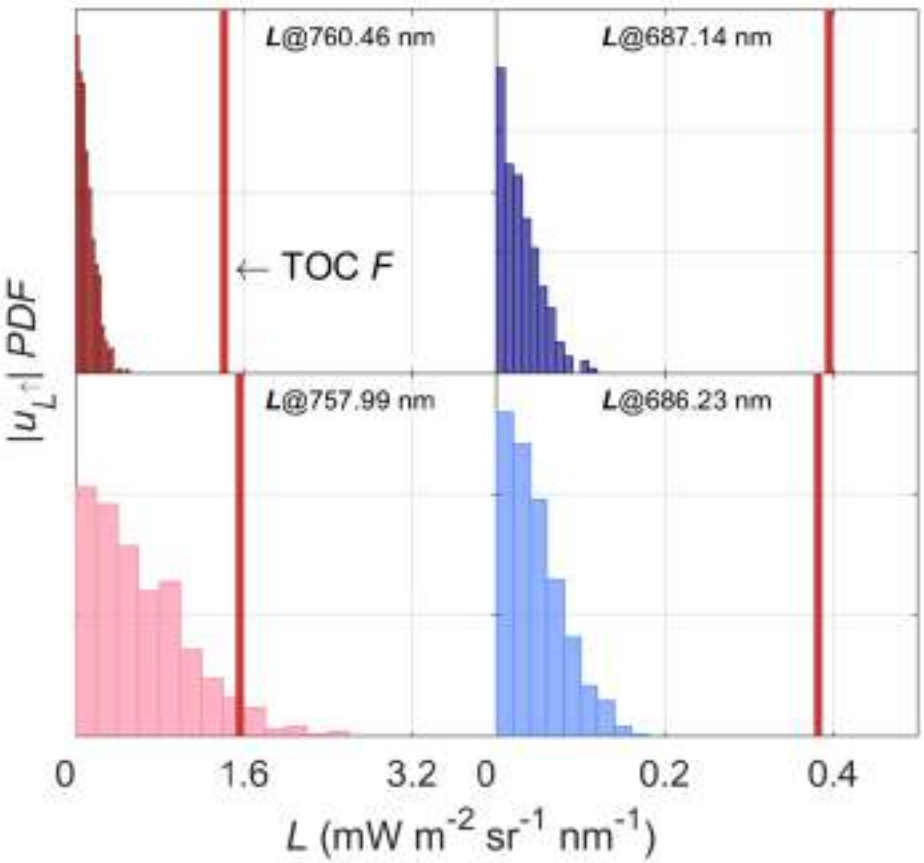


RASTA, Schwarzmaier et al., 2012

2. MODELING EXERCISE

- 4. RADIOMETRIC CALIBRATION
  - **Uncertainty Propagation**





F@757.99 = 1.57	F@760.46 = 1.41	F@686.23 = 0.38	F@687.14= 0.39

2. MODELING EXERCISE

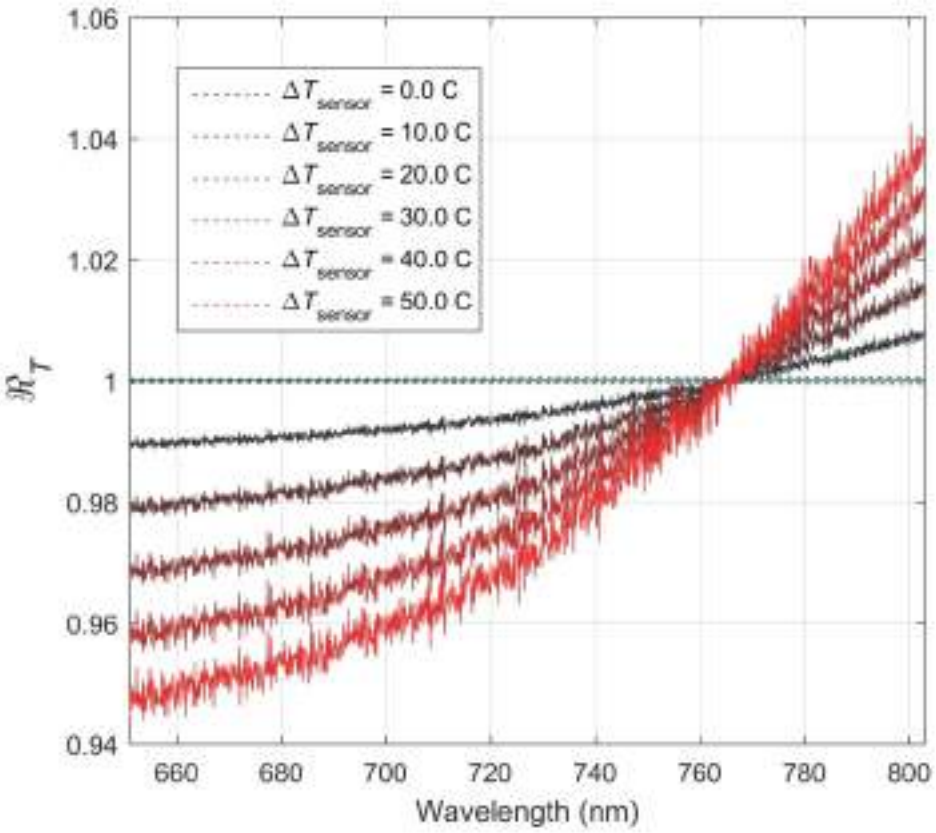
- 5. TEMPERATURE SENSITIVITY
  - **Simulation: $\mathcal{R}_T$ from ASD FieldSpec3® (Hueni & Bialek, 2017)**
    - **Si band gap reduction**
      - **Increased sensitivity**
    - **Effects on electronics**
      - **Less clear**
    - **Spectral calibration & ISRF**
      - **Low expansion coefficients**

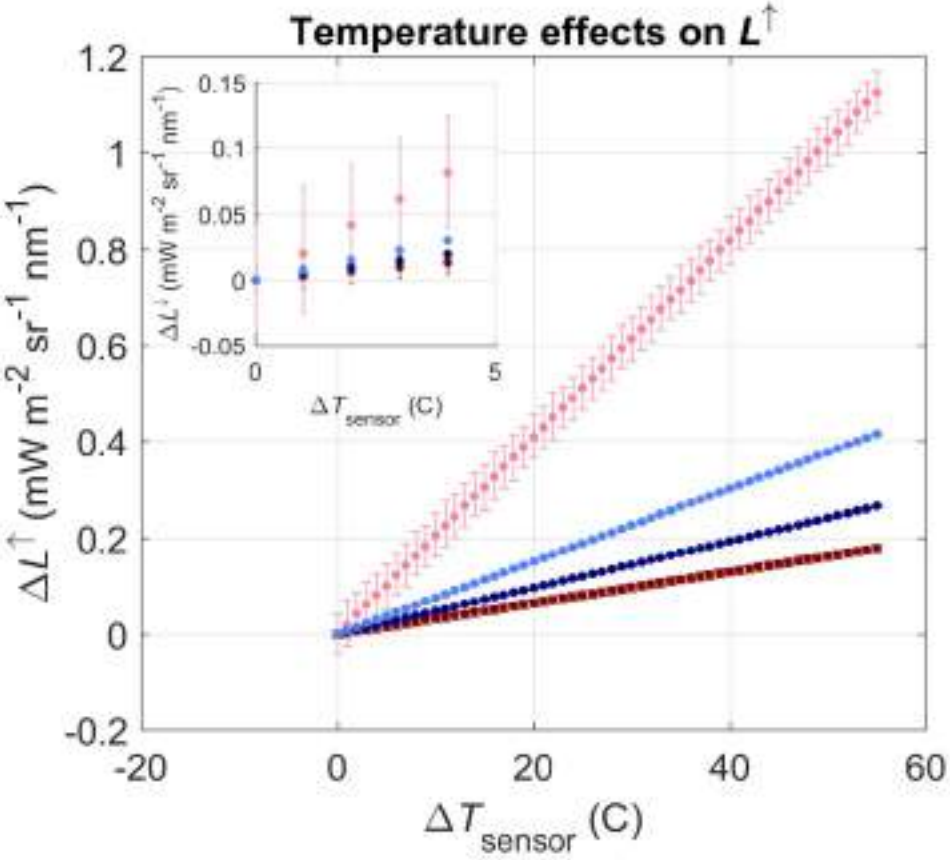
        Expansion ±0.17 pixel /°C

        Simulated QE *Pro* SSI: 0.13 nm
      - **$\Delta T \in$ ~[17 ,22] °C -> $\Delta\lambda_c$ ~ 0.1 nm in the O_2 bands**
    - **Simulation**
      - **RASTA uncertainty**
      - **u_T = 2 %**
    - **Sensor and system cooling is highly recommended**

2. MODELING EXERCISE

- 5. TEMPERATURE SENSITIVITY
  - **Simulation: $\mathcal{R}_T$ from ASD FieldSpec3® (Hueni & Bialek, 2017)**





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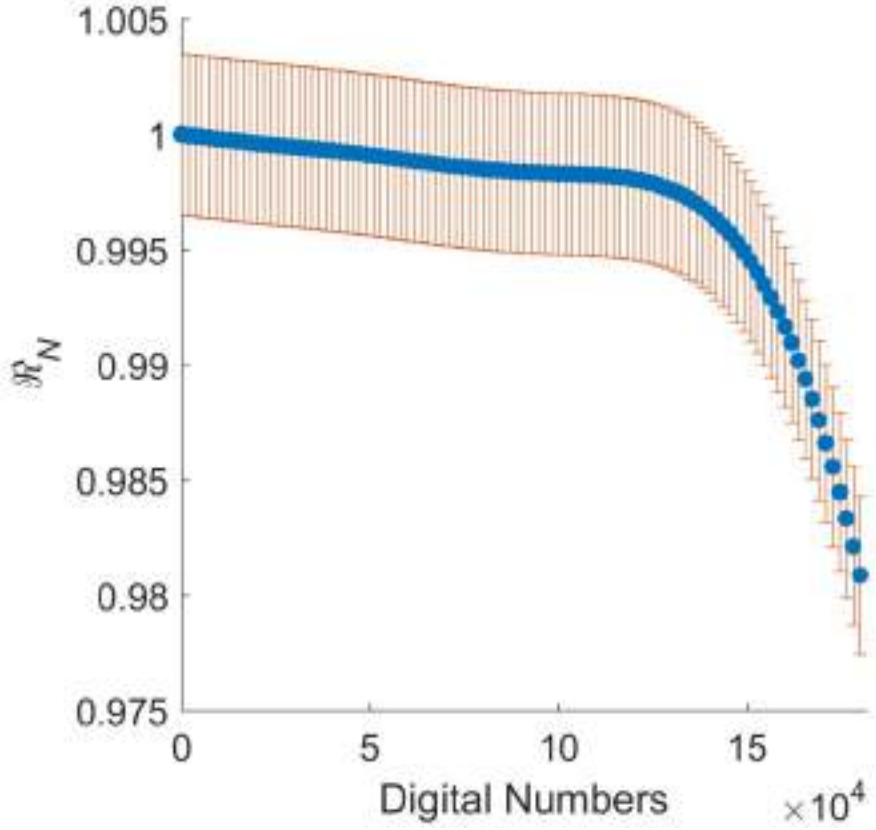
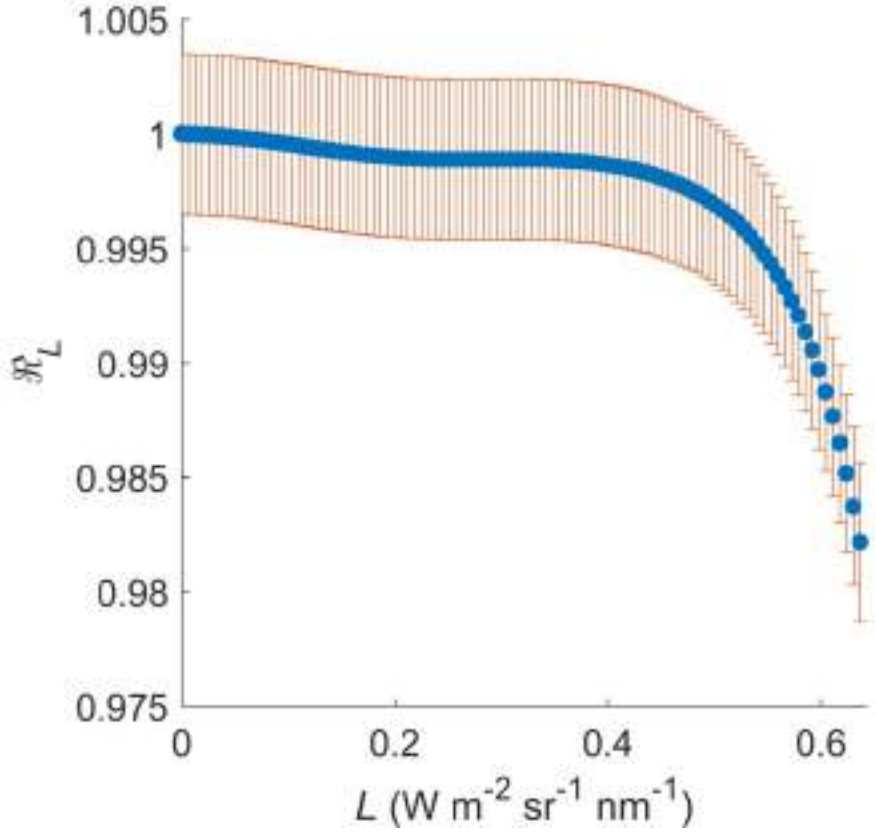
2. MODELING EXERCISE

- 6. NON-LINEARITY
  - **Simulation: $\mathcal{R}_N$ and $\mathcal{R}_L$ from several experiments**





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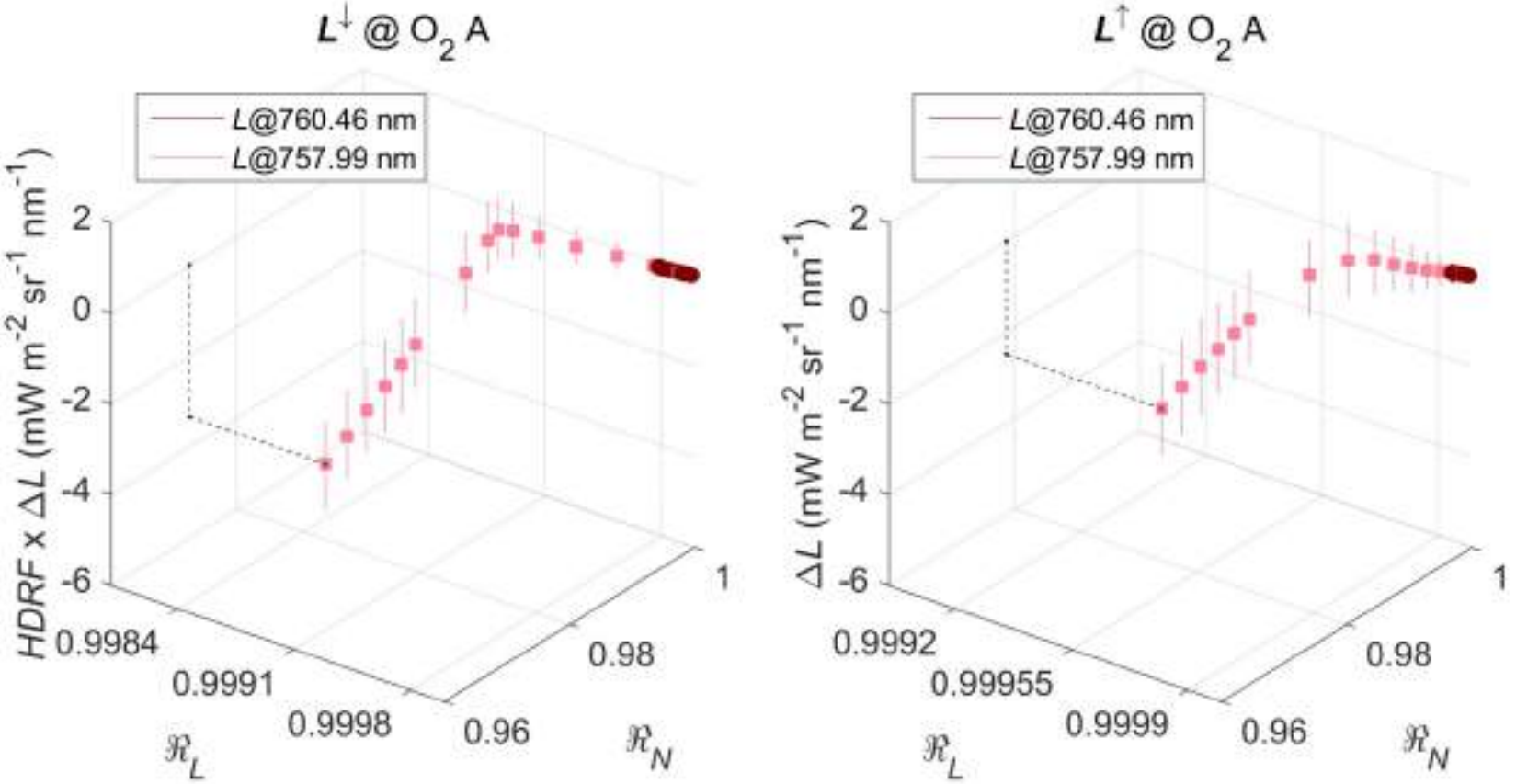

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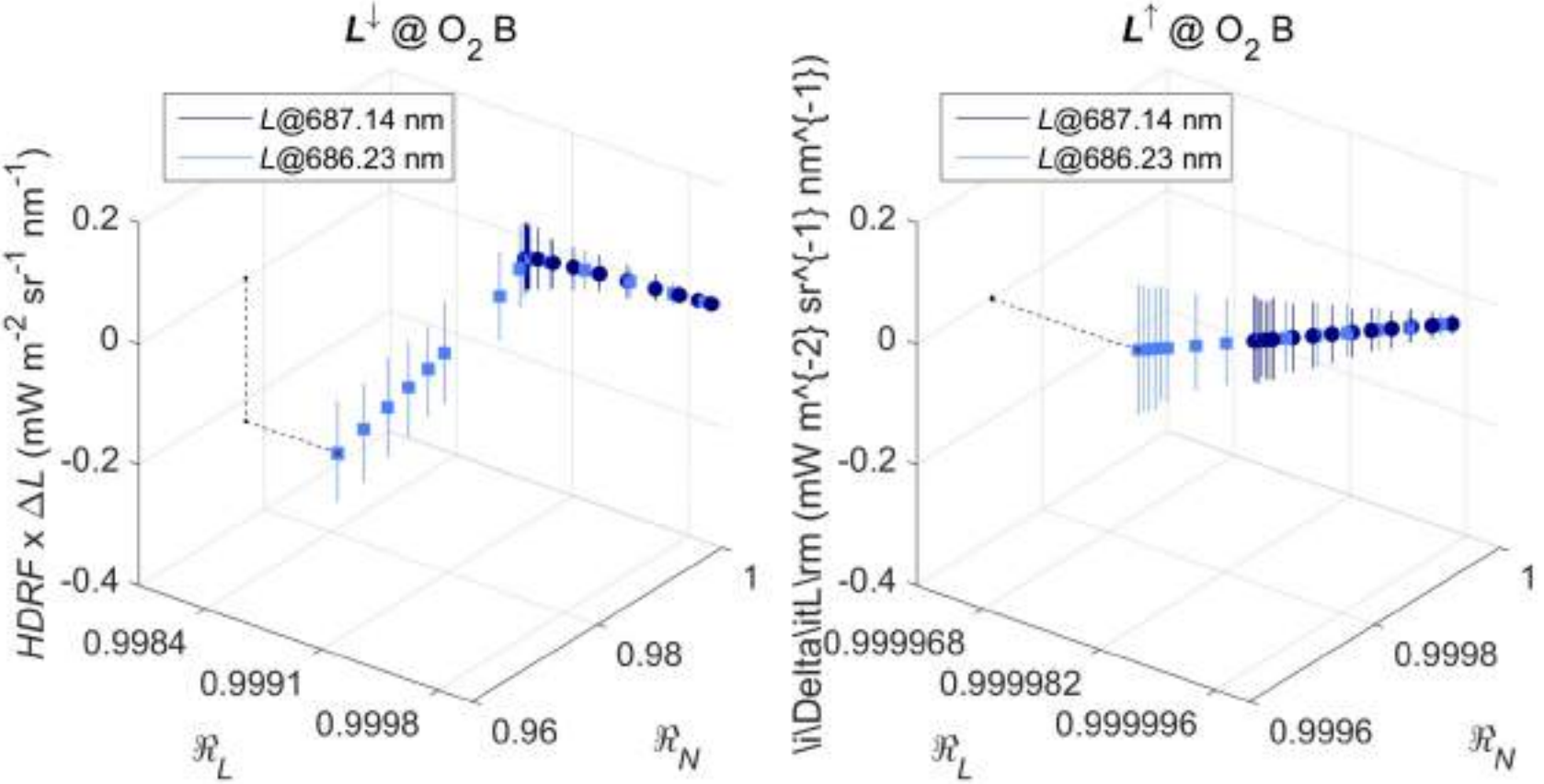

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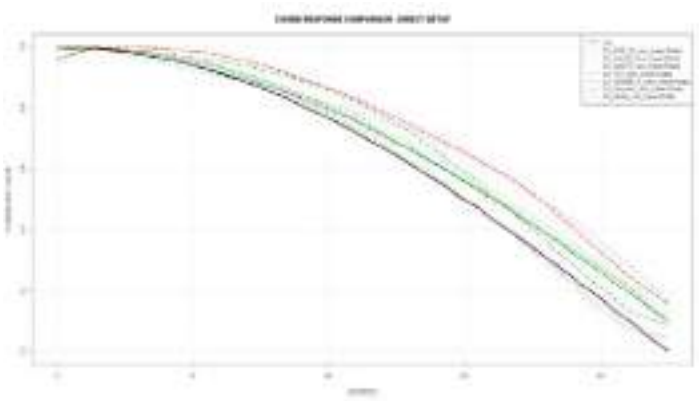
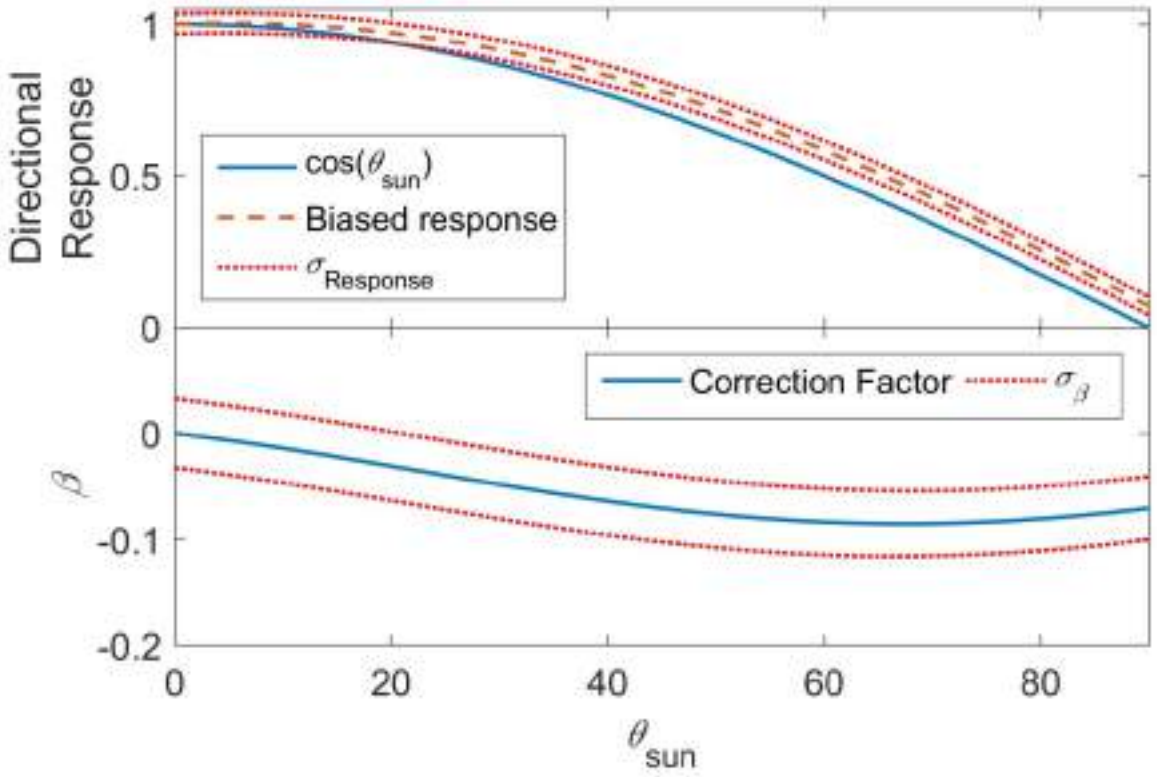
2. MODELING EXERCISE

- 7. DIRECTIONAL RESPONSE
  - **Deviation from cosine of illmination angle (Julitta, 2015)**
    - **Hemispherical diffuser and Lambertian reference panels**

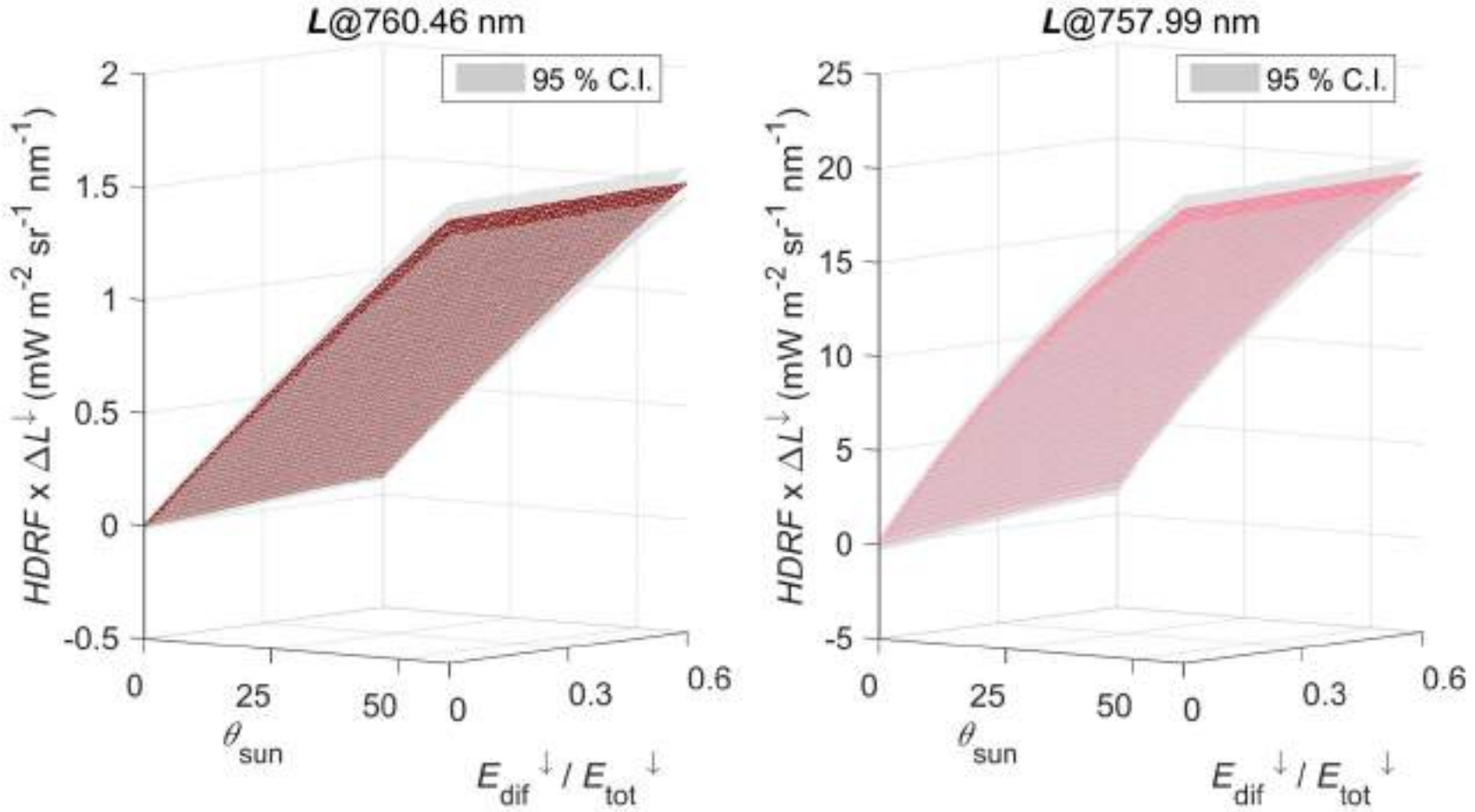


Julitta, 2015. PhD Thesis



2. MODELING EXERCISE

- 7. DIRECTIONAL RESPONSE – O_2A band



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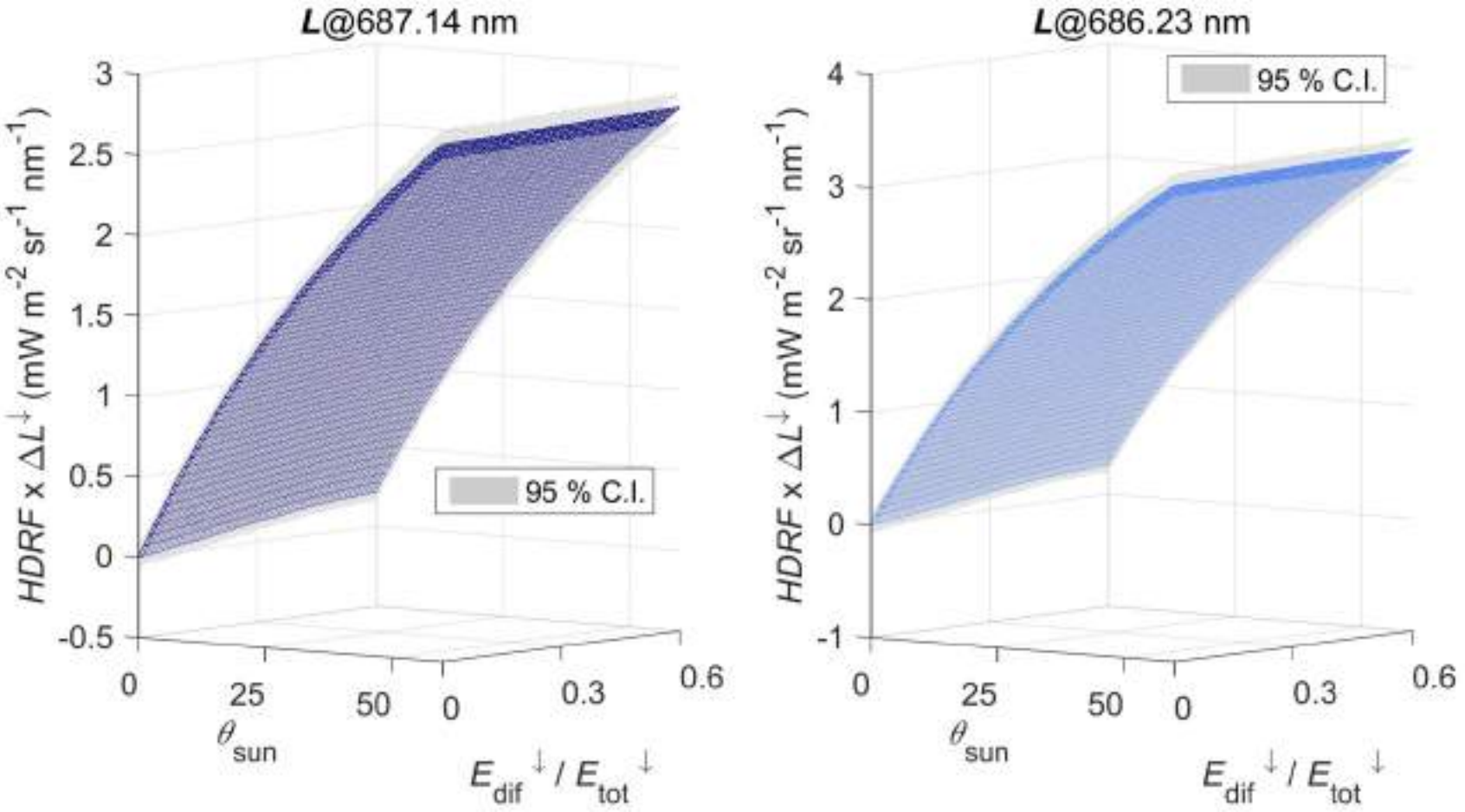
- 7. DIRECTIONAL RESPONSE – O_2B band



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3. CONCLUSIONS

- Easily: $u_L \geq F^{\uparrow}$
  - Global budget unknown
  - Effects on SIF retrieval also unknown
  - Multiplicative uncertainties

} Case-specific

    - Larger uncertainties outside absorption bands but ~ *HDRF*
    - Others (Linearity, Directional Response) might not (bias)

- Characterization of new spectrometers is needed
  - Need of Hi-res traceable standards?
  - Is the Standards certitude (radiometric and spectral) enough?

3. CONCLUSIONS

- Uncertainty quantification and propagation is needed
  - Quantify trust in radiometric data
  - Some corrections might increase incertitude
  - Some phenomena cannot be avoided (directional responses)
    - Difficult to correct (e.g. quantify diffuse irradiance distribution)
  - Additional uncertainties (e.g. atmosphere, protocols) might be later bigger?

- Impact of uncertainties in the retrieval is unclear
  - Depends on data and retrieval method
  - Need for validation methods and devices

3. CONCLUSIONS

MEASURING REFLECTANCE FACTORS IS NOT THE SAME THAN MEASURING SUN INDUCED FLUORESCENCE

QUESTION OUR MEASUREMENTS BEFORE MAKING CONCLUSIONS ABOUT PHYSIOLOGY?

DO WE GET A RELATIVE OR AN ABOSULUTE METRIC?

THANKS FOR YOR ATTENTION

QUESTIONS / REMARKS