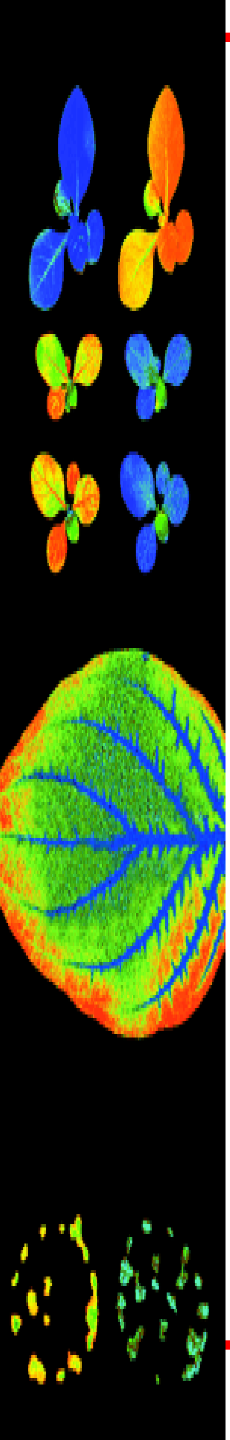

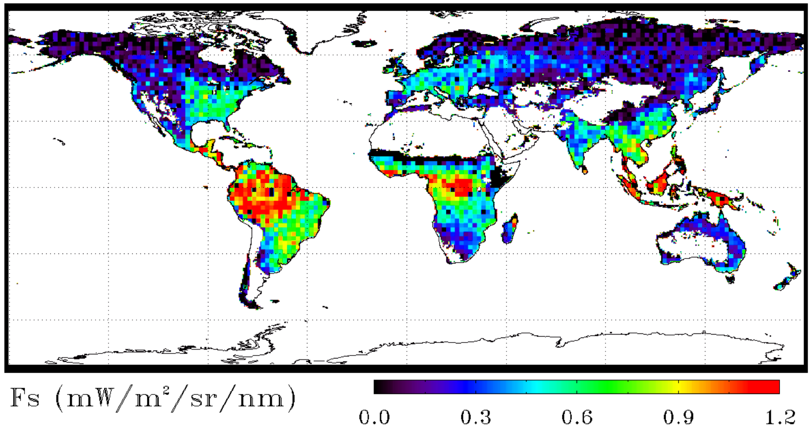

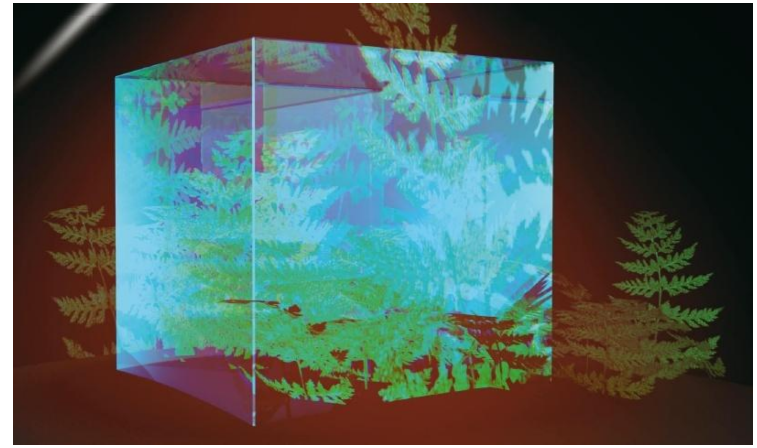

Recap of fluorescence retrieval techniques from ground and space (I/II)

Luis Guanter
Free University of Berlin, Germany

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NASA Goddard Space Flight Center, USA

Christian Frankenberg
NASA Jet Propulsion Laboratory, USA

KISS Workshop: New Methods to Measure Photosynthesis from Space, 26-31 Aug 2012, Pasadena, CA, USA

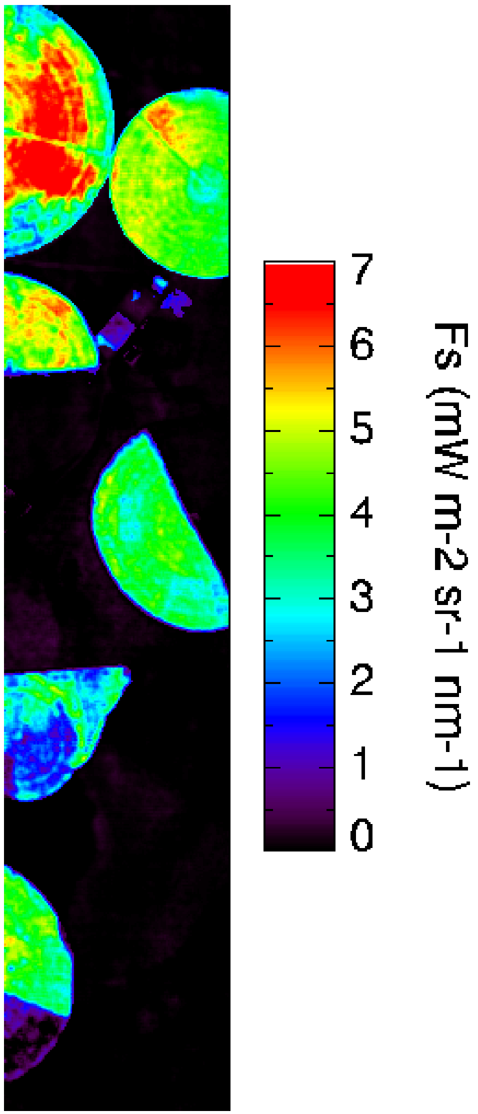
- **This talk: Retrieval of sun-induced chlorophyll fluorescence (Fs) from passive measurements under field conditions**

→ **Overview of Fs retrieval techniques at ground-, airborne and space-based scales provided**

→ Active (PAM-like) and lab-based experiments not covered!

→ Focus on Fs retrieval rather than on the "biophysical" lessons extracted from the measurements

→ Focus on retrieval techniques rather than on listing all experiments and measurements set-ups



First reference on the remote sensing of Fs: the FLD principle

306 IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. IM-24, NO. 4, DECEMBER 1975

The Fraunhofer Line Discriminator MKII—An Airborne Instrument for Precise and Standardized Ecological Luminescence Measurement

JAMES A. PLASCYK AND FRED C. GABRIEL, MEMBER, IEEE

***Abstract*—The Fraunhofer line discriminator Mark II (FLD-II) is an airborne photometric instrument for the remote measurement, on a precise and quantitative scale, of solar-stimulated luminescence. The luminescence may originate in such diverse sources as oil spills and chemical pollutants, the chlorophyll of normal or stressed vegetation, and fluorescent tracer dyes used to study current flow and dispersion in large bodies of**

strument is the precise quantitative distinction between reflected sunlight and luminescence, which may be orders of magnitude weaker.

II. OPERATING PRINCIPLES

An elegant technique, first devised by lunar astrono-

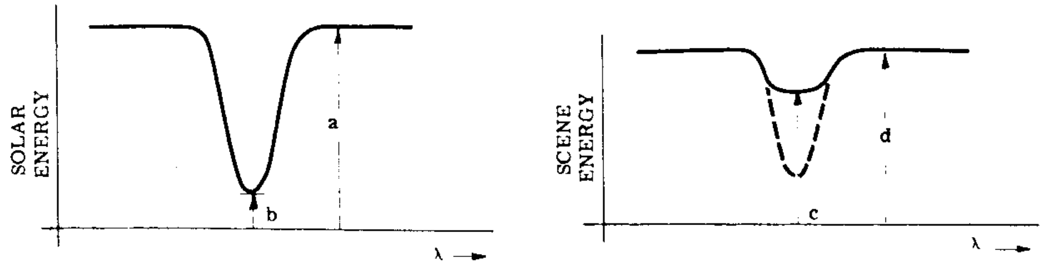
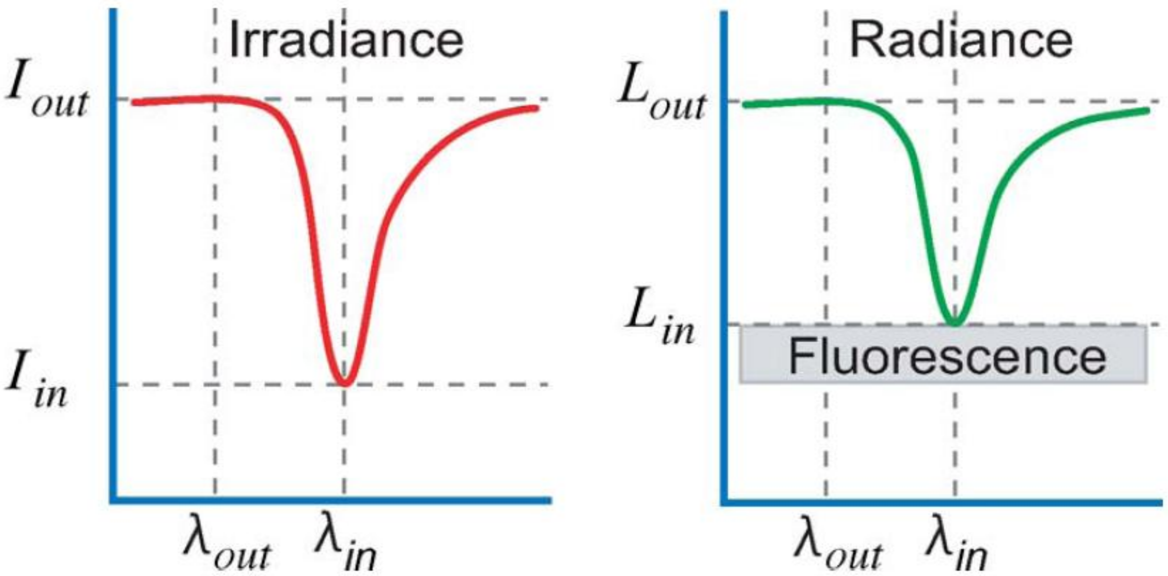


Fig. 1. Solar and scene spectral distribution.

The Fraunhofer Line Discriminator (FLD) principle

Alonso et al., IEEE GRSL, 2008



$$\left.\begin{aligned} L_{\mathrm{in}} &= R_{\mathrm{in}} \cdot I_{\mathrm{in}} + f_{\mathrm{in}} \\ L_{\mathrm{out}} &= R_{\mathrm{out}} \cdot I_{\mathrm{out}} + f_{\mathrm{out}} \end{aligned}\right\}$$

$$R_{\mathrm{in}} = R_{\mathrm{out}} \quad f_{\mathrm{in}} = f_{\mathrm{out}}$$

$$\Downarrow$$

$$f = \frac{I_{\mathrm{out}} \cdot L_{\mathrm{in}} - L_{\mathrm{out}} \cdot I_{\mathrm{in}}}{I_{\mathrm{out}} - I_{\mathrm{in}}}$$

- **Large family of FLD-like methods**, as a function of number of reference channels (e.g. 3FLD) or constraints in Rin/Rout and *f*in/*f*out (e.g. iFLD)
- **Field & airborne scales**: typically O2 A-band measurements & medium spectral resolution (ASD FieldSpec Spectroradiometer©, FWHM~3 nm, 1 only measuring channel)

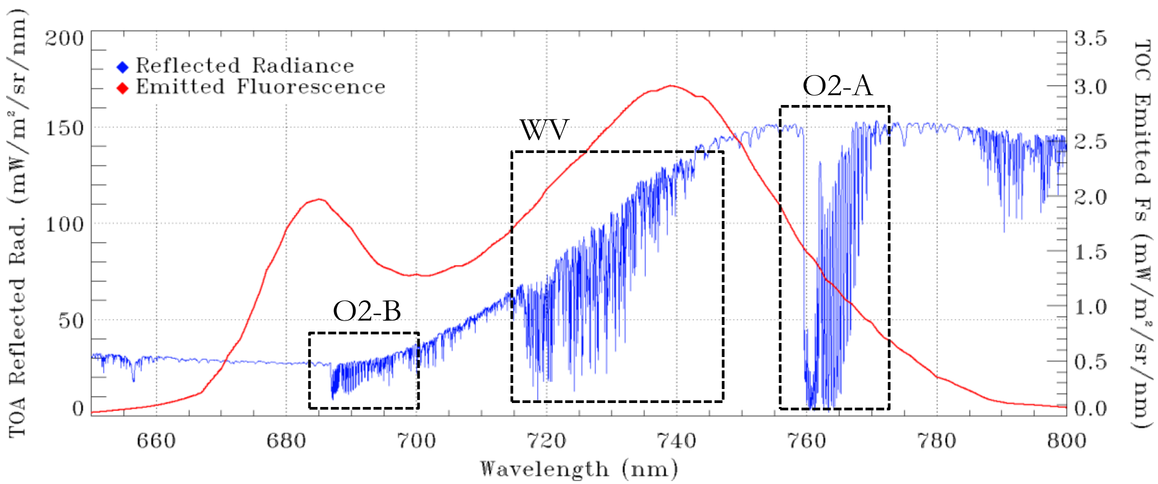
Absorption features for Fs retrieval: solar & atmospheric

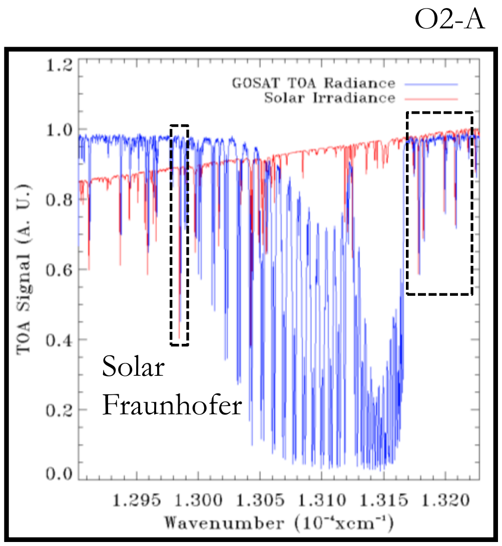
1. Retrieval with O2 bands (FWHM ~0.1-1.0 nm)

- **Pros:** able to sample the two Fs peaks (687 and 760 nm), high SNR, very convenient for ground-based measurements.
- **Cons:** for airborne/space retrievals, very complex atmospheric modelling, prone to systematic errors.

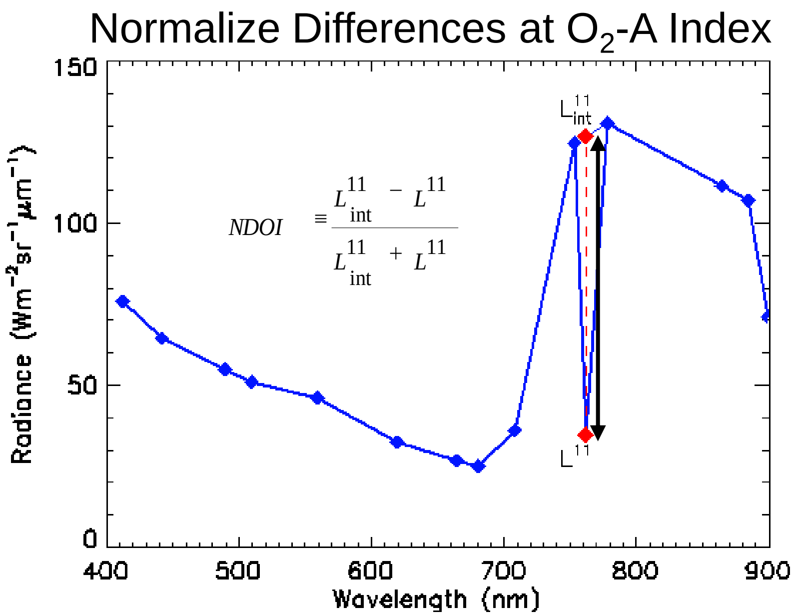
2. Retrieval with solar lines (FWHM~0.01-0.1 nm)

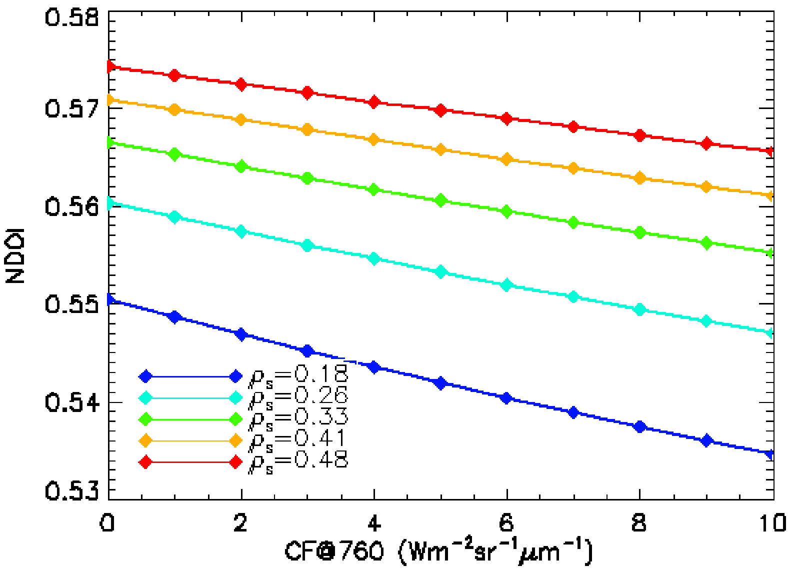
- **Pros:** simple modelling, insensitive to atmospheric scattering.
- **Cons:** high sensitivity to noise, and Fs sampled in one spectral point.

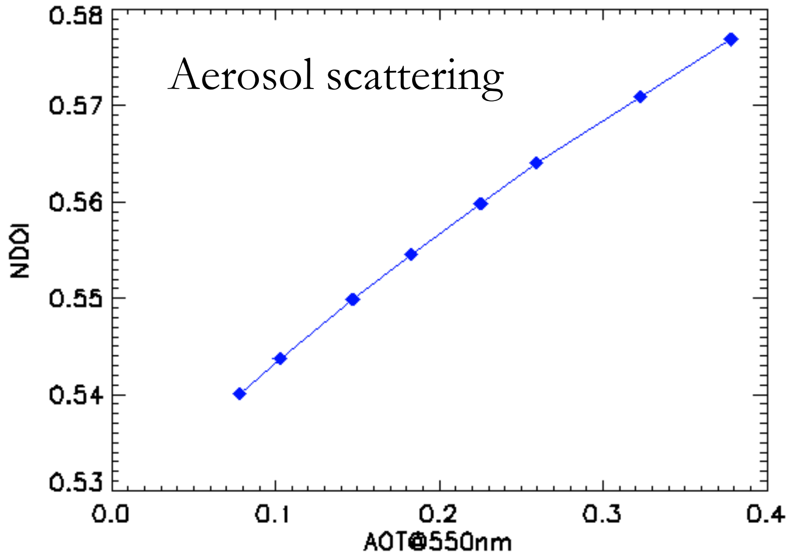


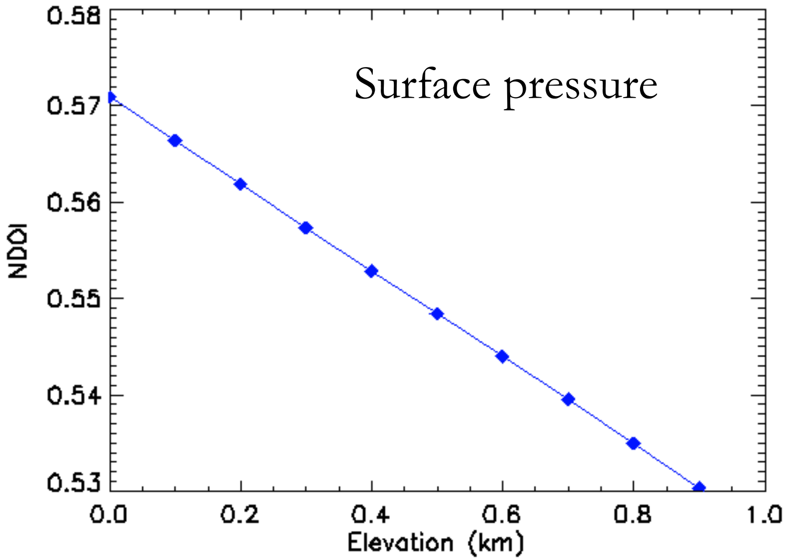


Uncertainty in O2-A in-filling due to atmospheric scattering









A reference work for ground & airborne Fs retrievals: Maier et al. (2003)

Maier, S. W., Günther, K. P., & Stellmes, M. (2003). Sun-induced fluorescence: A new tool for precision farming. In T. VanToai, D. Major, M. McDonald, J. Schepers, & L. Tarpley (Eds.), *Digital imaging and spectral techniques: Applications to precision agriculture and crop physiology* (pp. 209–222). Madison: American Society of Agronomy.

$$L_\lambda = \frac{R\,E^0_\lambda}{\pi} + L^{\text{fluorescence}}$$

$$L^{\text{fluorescence}} = \frac{L_1 - \frac{E^0_1}{E^0_2} L_2}{1 - \frac{E^0_1}{E^0_2}}$$

Ground

16 Sun-Induced Fluorescence: A New Tool for Precision Farming

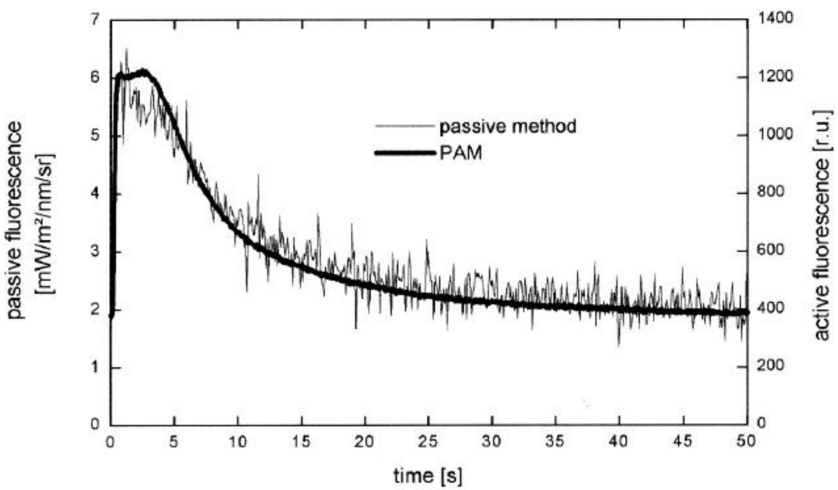
Stefan W. Maier
Department of Land Information
Wembley, Western Australia

Kurt P. Günther
German Aerospace Center
Wessling, Germany

Marion Stellmes
University Trier
Trier, Germany

ABSTRACT

Results of ground based experiments on spectral reflectance of dock leaves using a ZEISS spectrometer MCS501 UV-NIR with 2.5 nm resolution clearly show the well known induction kinetics of chlorophyll fluorescence when dark adapted leaves were exposed to

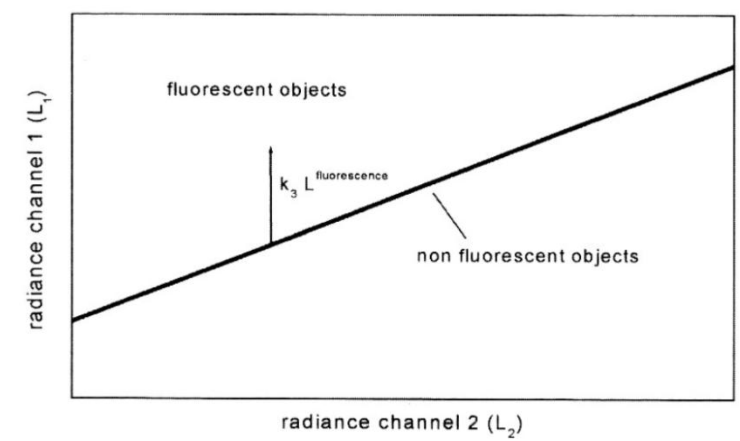


Airborne & Space

$$L_\lambda = \left(\frac{R\,E^0_\lambda}{\pi} + L^{\text{fluorescence}} \right) T_\lambda + L^{\text{path}}_\lambda$$

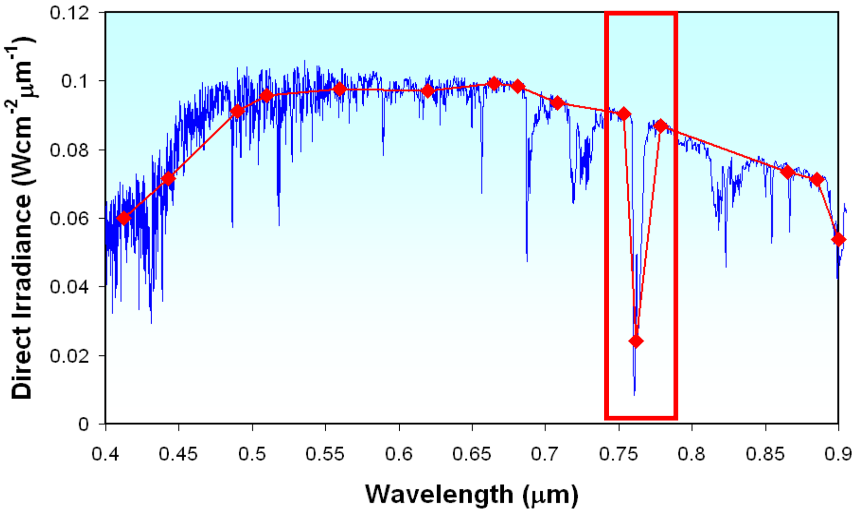
$$k_3\, L^{\text{fluorescence}} = L_1 - k_1\, L_2 - k_2$$

$$k_1 \equiv \frac{E^0_1\, T_1}{E^0_2\, T_2}\,;\; k_2 \equiv L^{\text{path}}_1 - k_1\, L^{\text{path}}_2;\; k_3 \equiv T_1 - k_1\, T_2$$



Experimental Retrievals with the FLD principle and the O_2-A band

SATELLITE – ENVISAT/MERIS



Adequate band configuration:

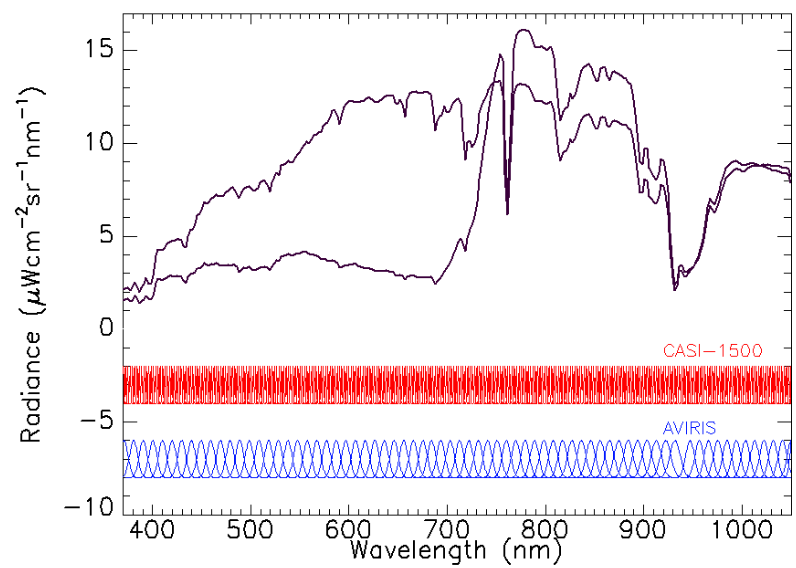
Band 10th: @753.5 nm, 7.50 nm width

Band 11th: @761.6 nm, 3.75 nm width

Accurate radiometric and spectral calibration.

Enough spatial resolution in FR mode (300m/pixel).

AIRBORNE – CASI 1500



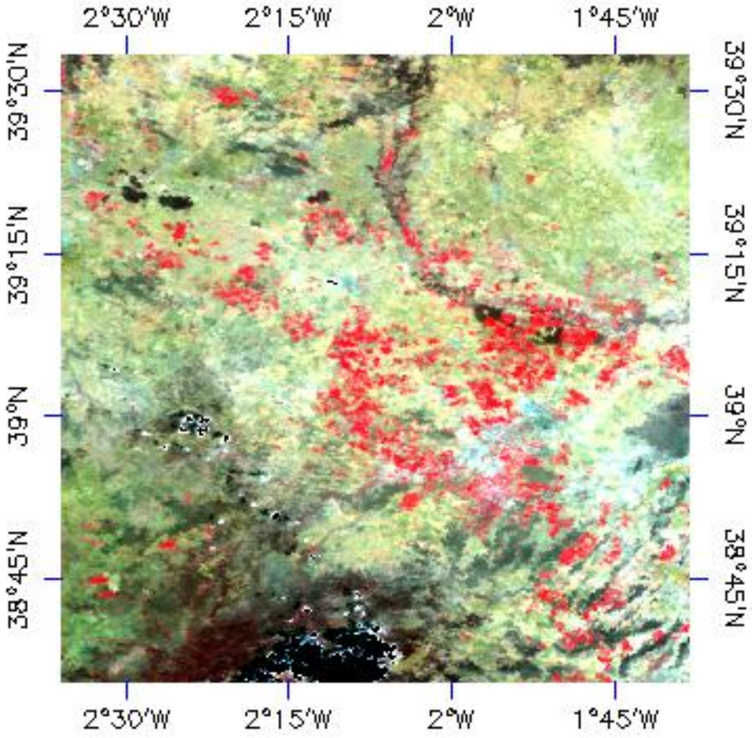
Spectral resolution:

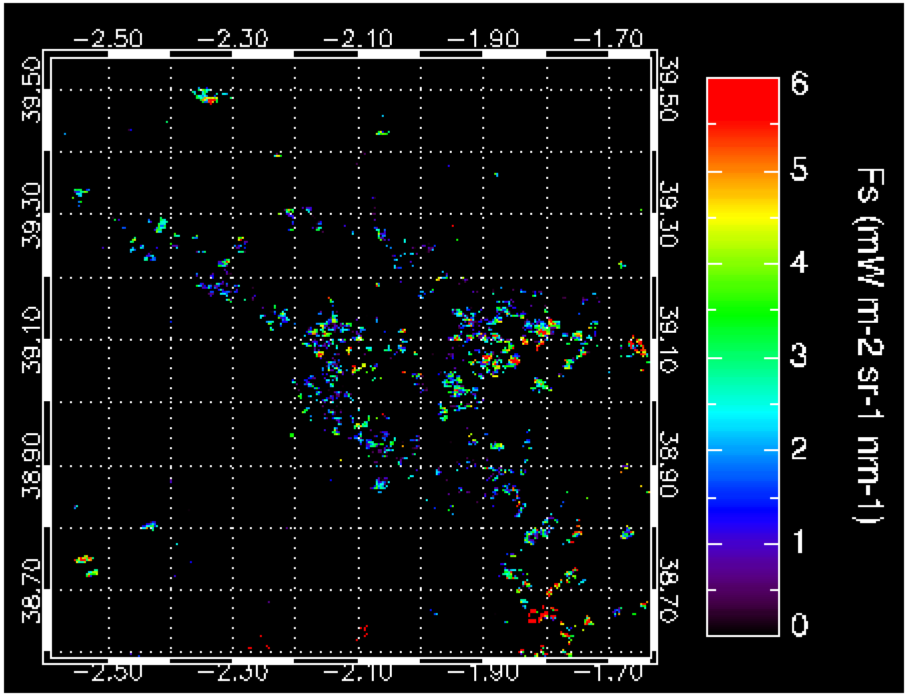
288 bands from 370 to 1050 nm, bandwidth 2.2 nm

Spatial resolution: 3m/pixel

Fs Retrieval in O2-A with "reference surfaces"

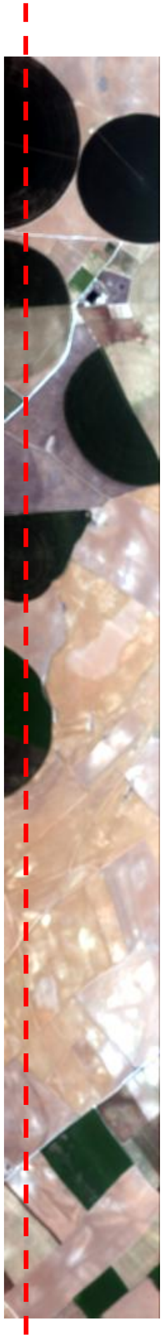
SPARC Campaign
Barrax (Spain) 14/7/04

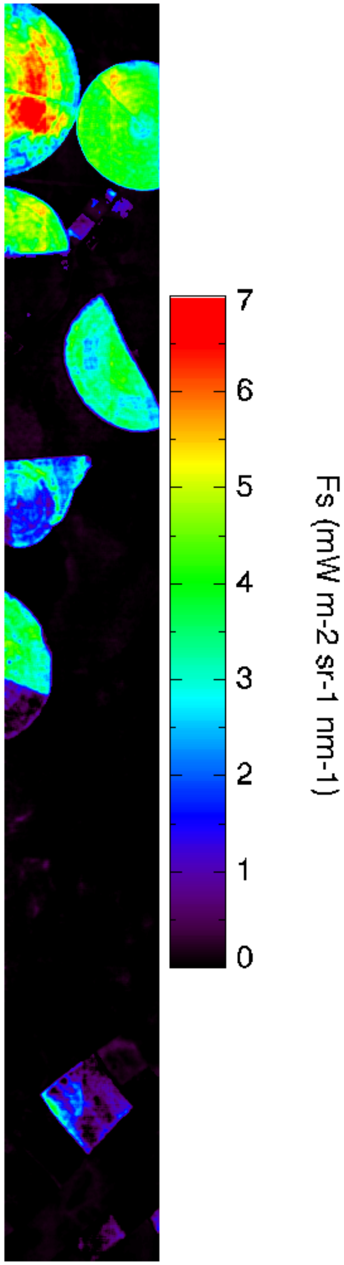


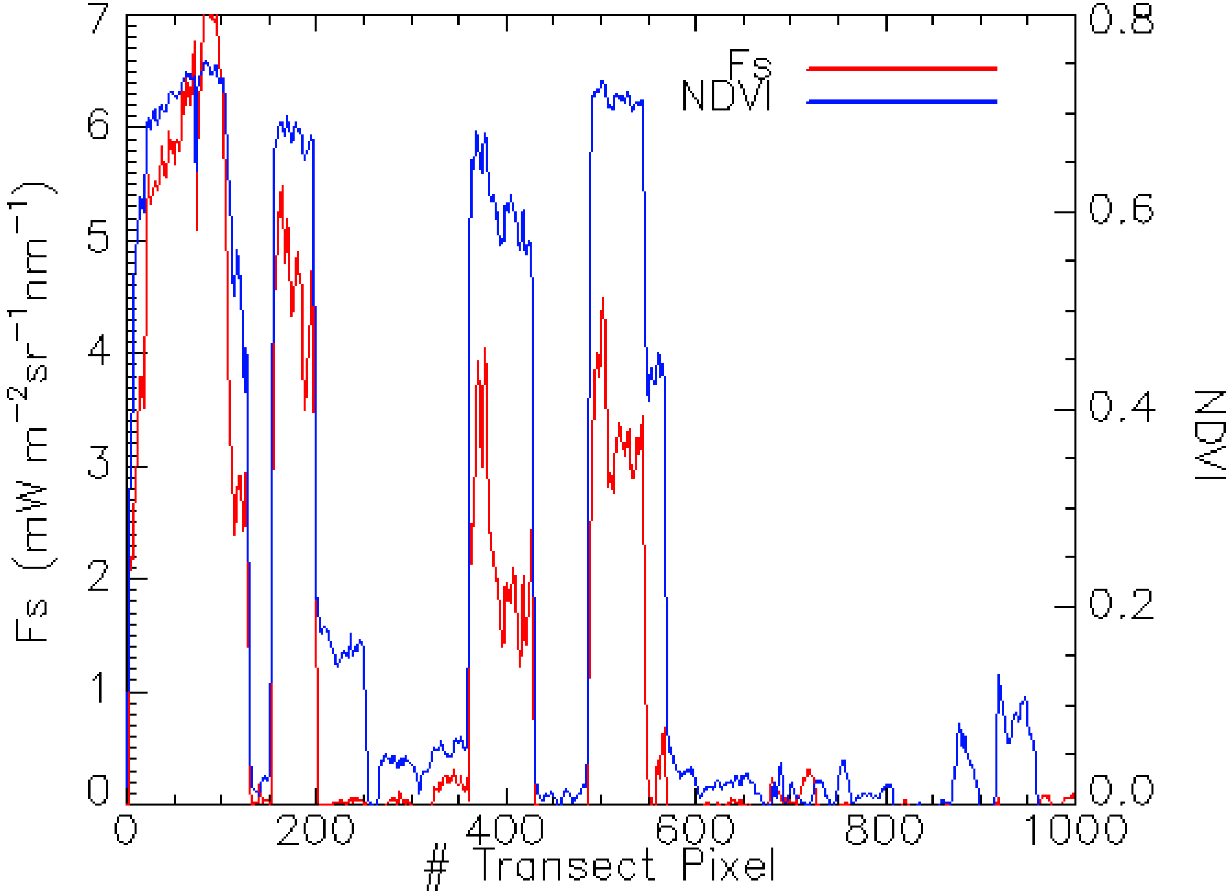


Guanter et al., GRL, 2007

Comparison of Fs and “greenness”

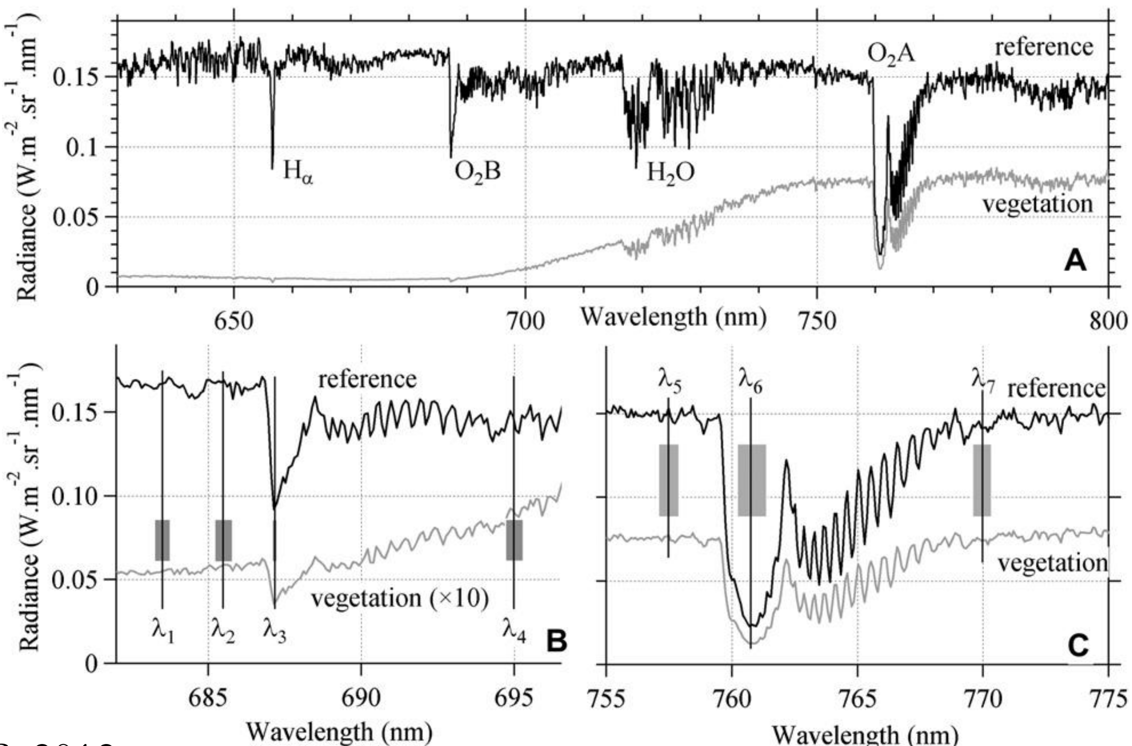






High spectral resolution measurements: resolving the O2 bands

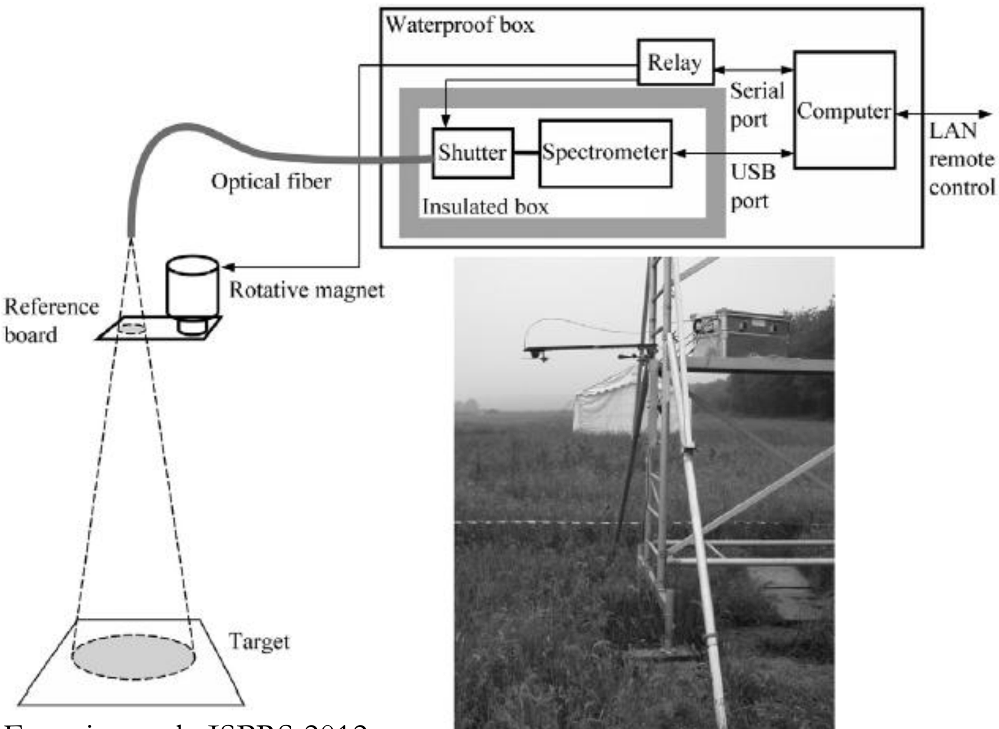
- **High resolution (FWHM~0.1nm) measurements for Fs retrieval in the field:**
  - Better characterization of the background reflectance (spectrally non-linear in 600-800 nm)
  - Enables retrieval in O2-B, which is very difficult with FLD techniques
  - Less sensitivity to instrumental noise



Fournier et al., ISPRS, 2012

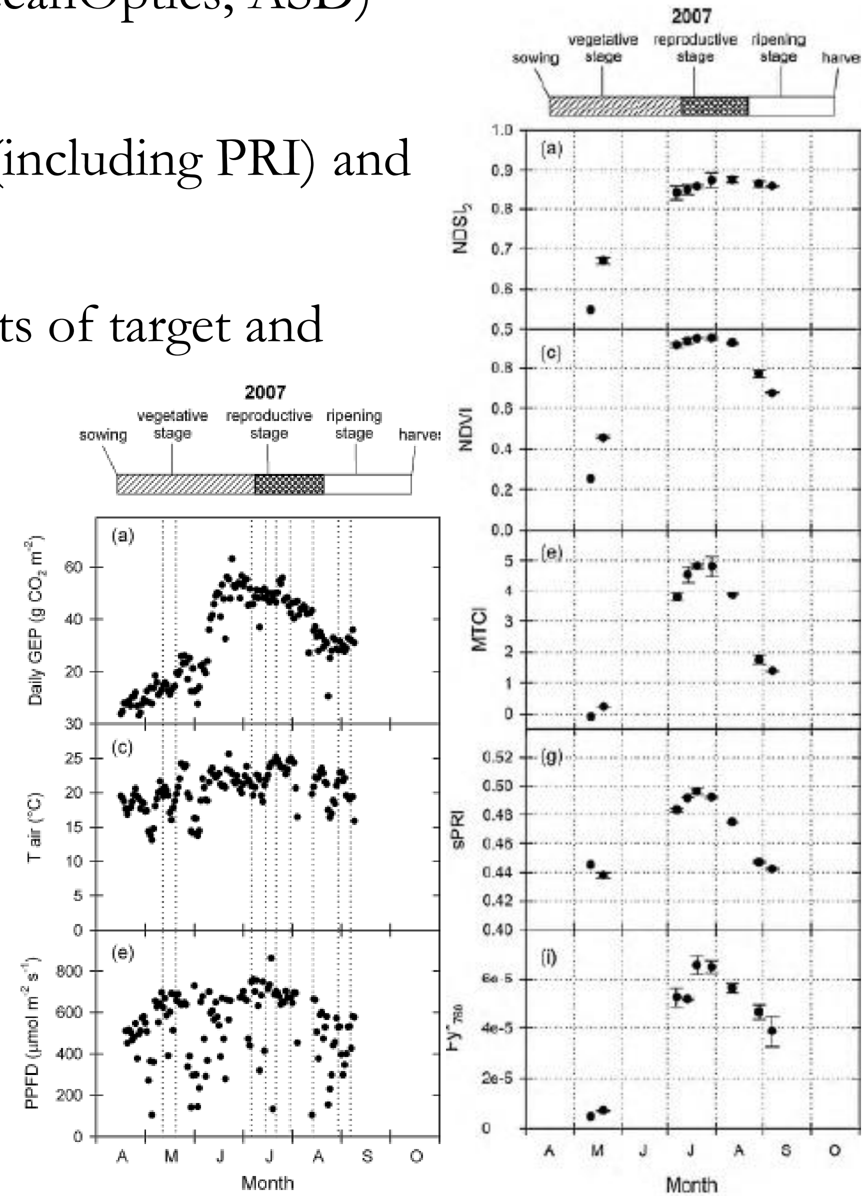
Towards automatic measurements of Fs at the ground level

- Flux towers + different spectrometers (OceanOptics, ASD) to measure TOC Fs and reflectance
- Temporal series of Fs, reflectance indices (including PRI) and GPP
- Fs retrieval from consecutive measurements of target and reference panel

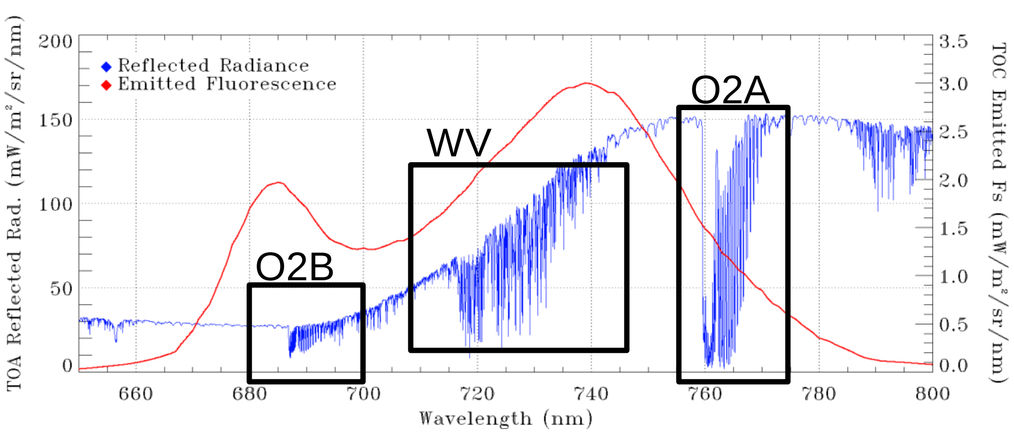


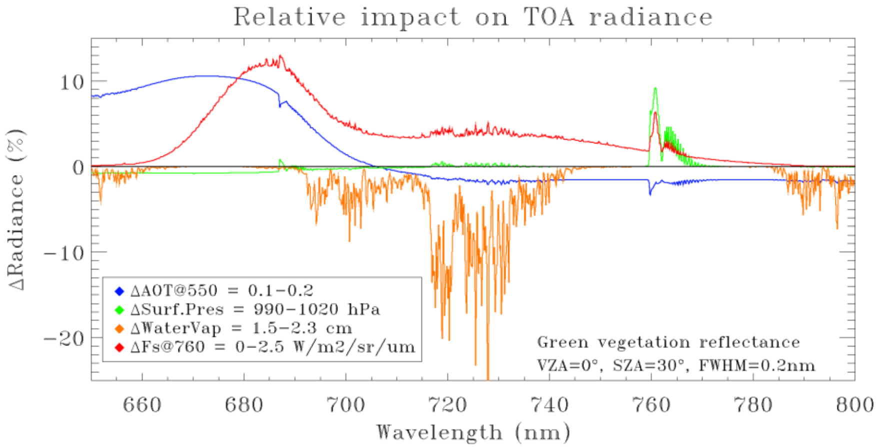
Fournier et al., ISPRS 2012

Rossini et al., AFM 2010

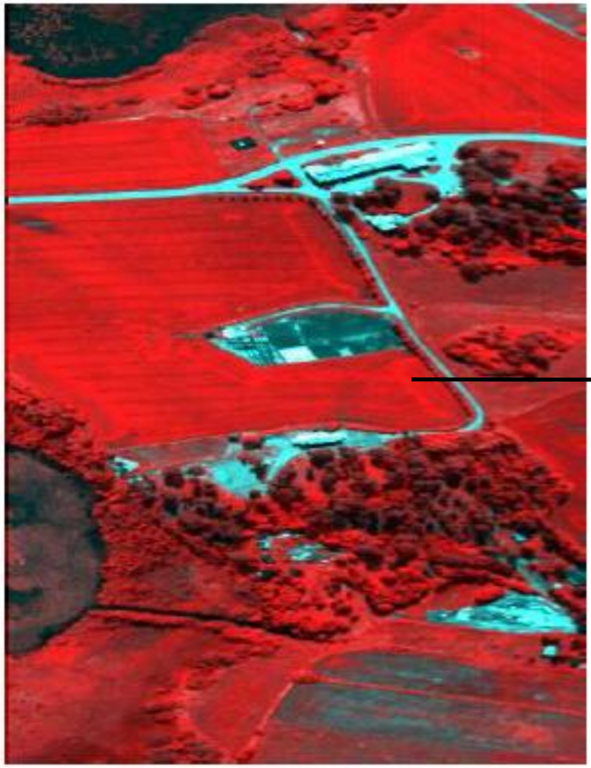


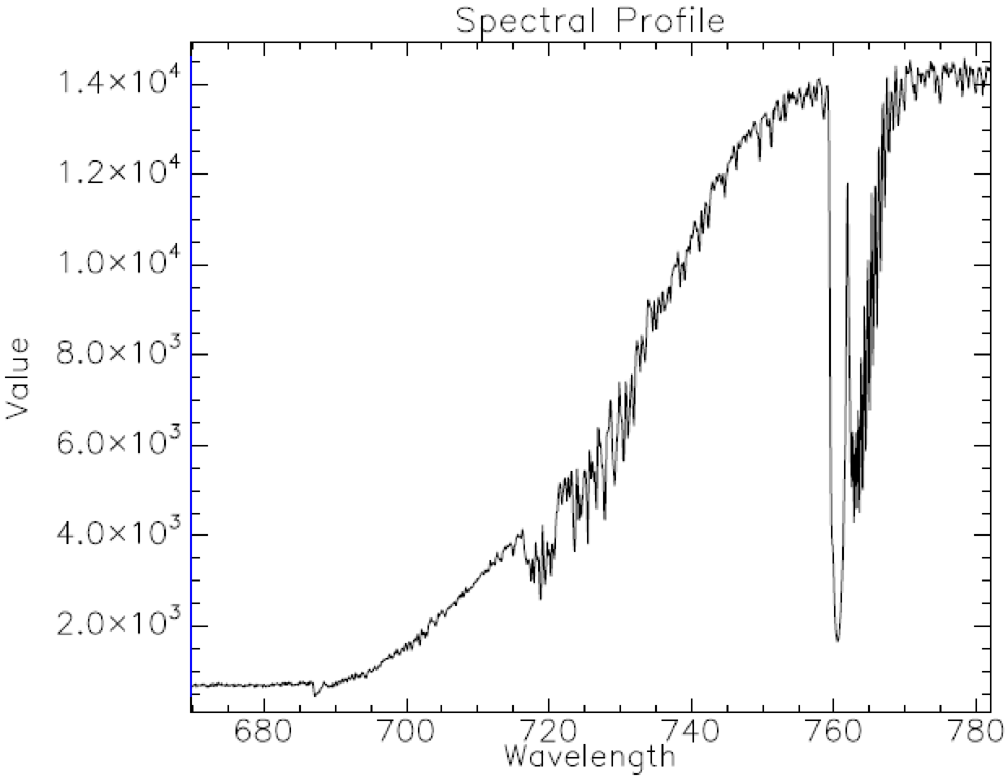
- **FLEX-FLORIS:** spectrally-continuous measurements in 650-800nm with FWHM~0.2nm → samping O2-A, O2-B
- **Multi-parameter retrieval approach**:
  - Atmospheric absorption features to disentangle solar-reflected from fluorescence signals
  - Consistent inversion of atmospheric/vegetation/instrument parameters:
    - Atmosphere: AOD, aerosol model (SSA & ph. function), aerosol height, surface pressure, water vapour…
    - Surface reflectance: Cab, LAI, soil background, BRDF
  - **Pros:** sampling the entire Fs spectrum, consistent inversion of Fs and LAI/Cab
  - **Cons:** Very complicated inversion scheme, prone to biases





- **FLEX-FLORIS airborne simulator ("HyPlant", U. Rascher, ForschungsZentrum Juelich) made available very recently**





- First field campaigns including concurrent field measurements of Fs and other vegetation parameters being carried out