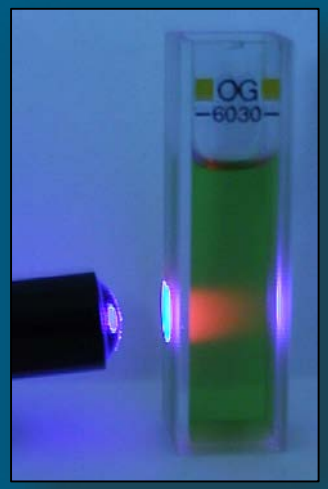
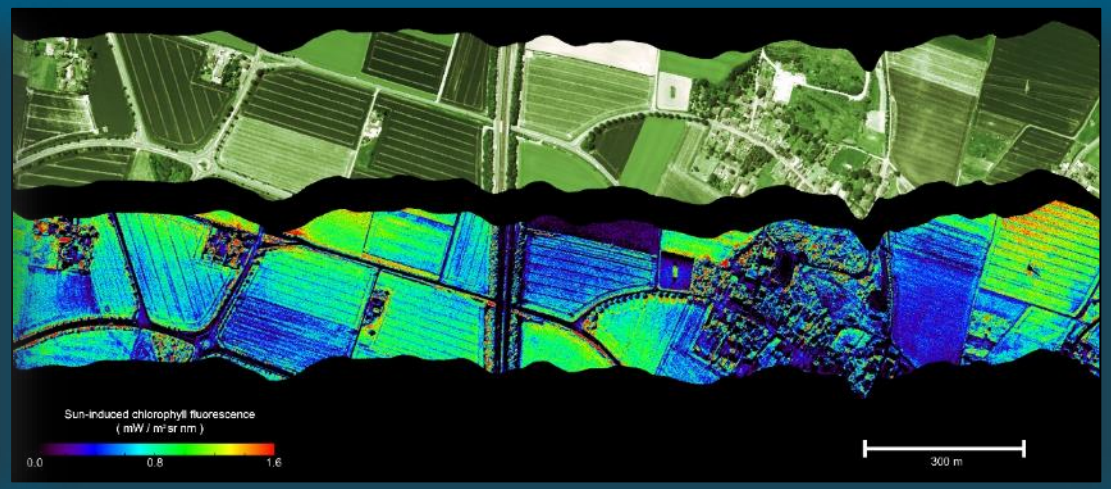
Institut für Bio- und Geowissenschaften
IBG-2: Pflanzenwissenschaften

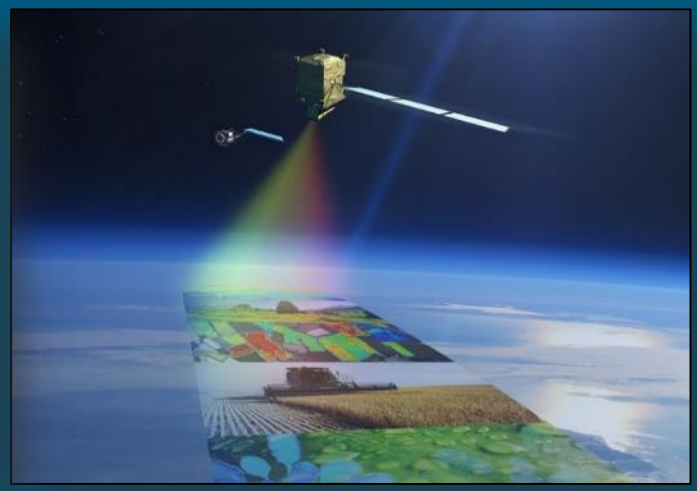
The airborne sensor *HyPlant* – the history of the first dedicated airborne fluorescence sensor (established 2012)

Uwe Ra<scher, Andreas Burkart, Maria-Pilar Cendrero, Maria Matveeva, Anke Schickling, Luis Alonso, Sergio Cogliati, Roberto Colombo, Alexander Damm, Matthias Drusch, Yves Goulas, Jan Hanus, Andreas Huth, Elizabeth Middleton, Franco Miglietta, Gina Mohammed, Micol Rossini, Dirk Schüttemeyer, Christiaan van der Tol, Wout Verhoef, Frantizcek Zemek

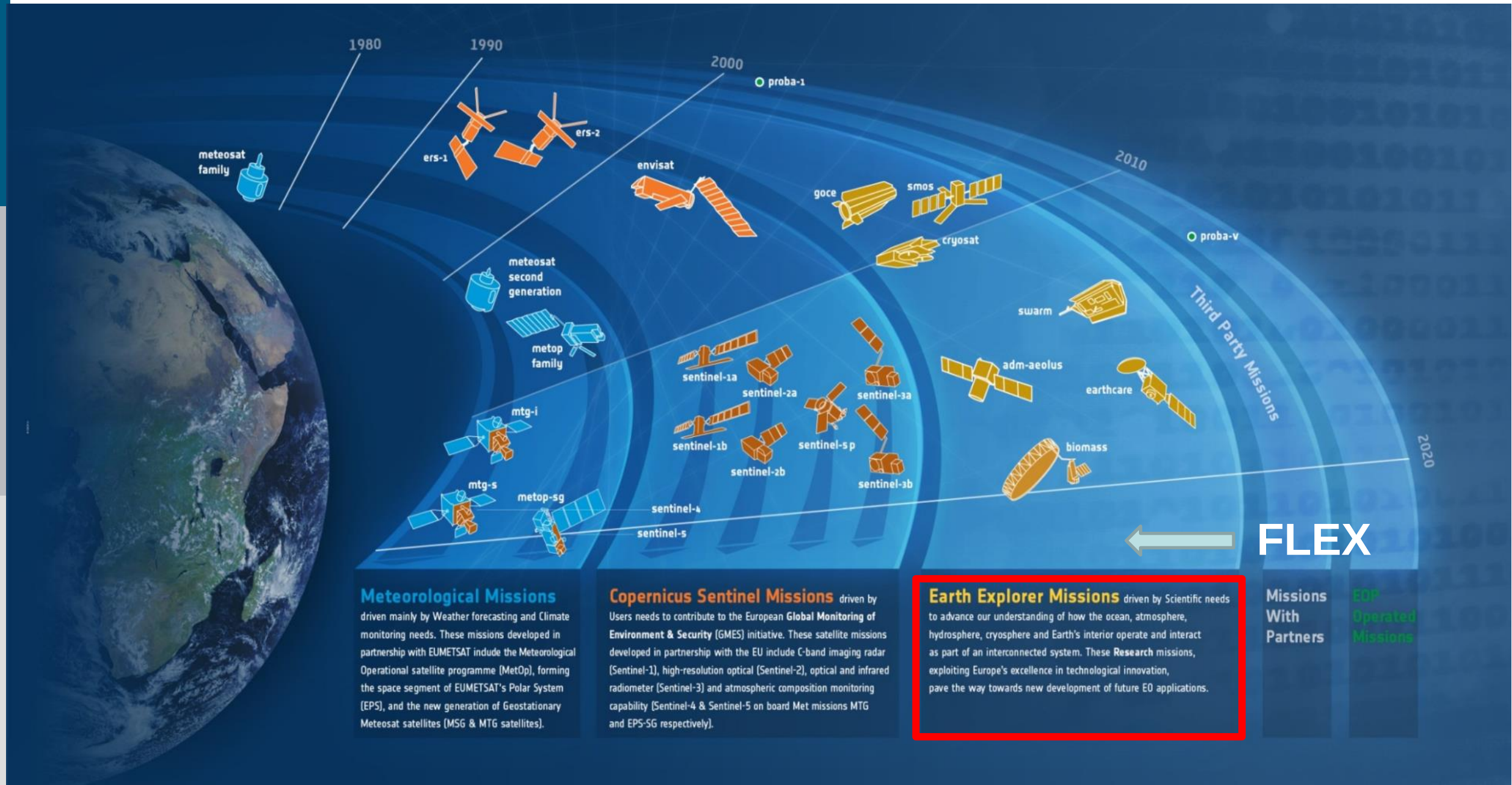
* Forschungszentrum Jülich, Institute of Bio- and Geosciences, IBG-2: Plant Sciences, Germany



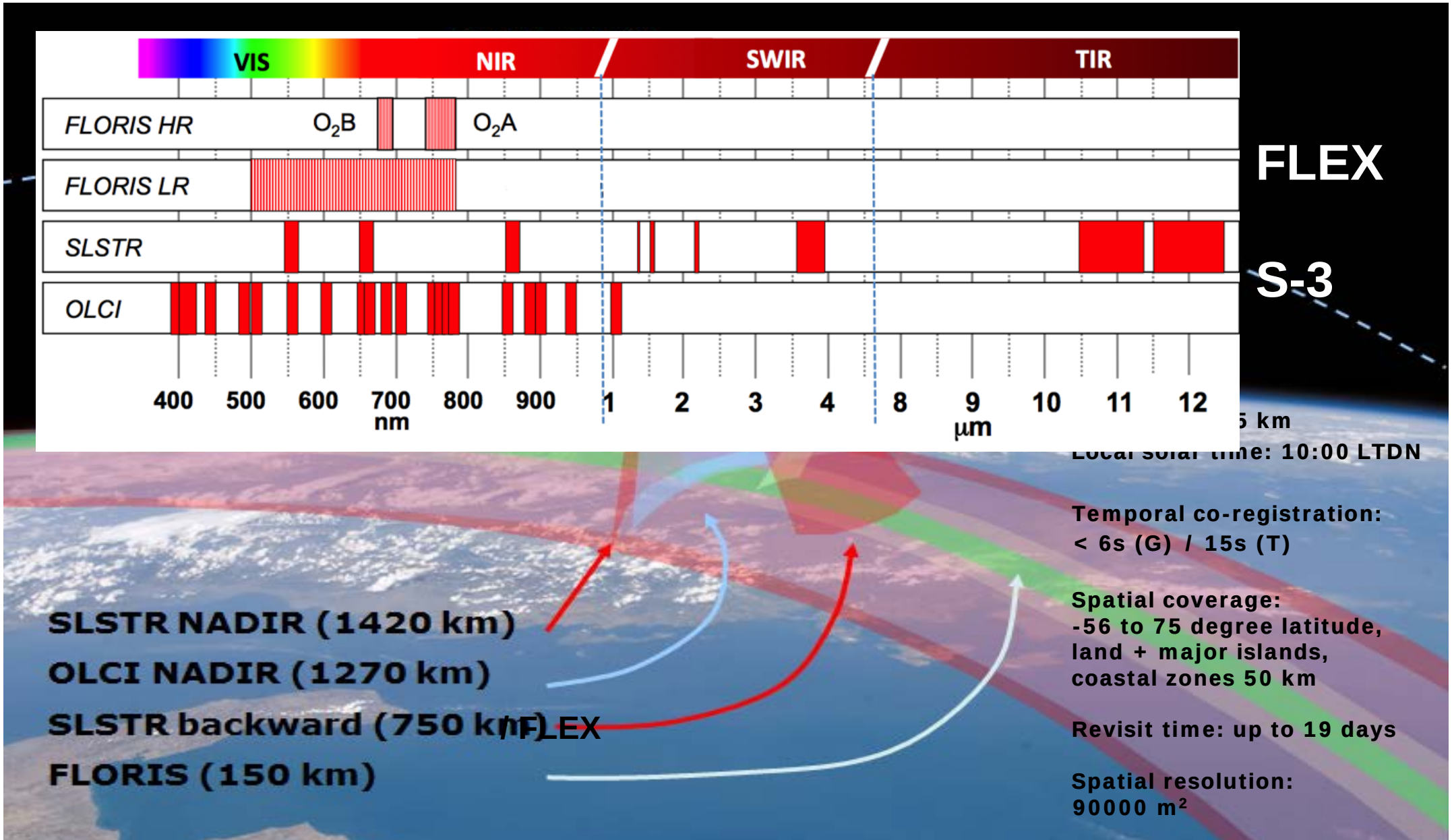




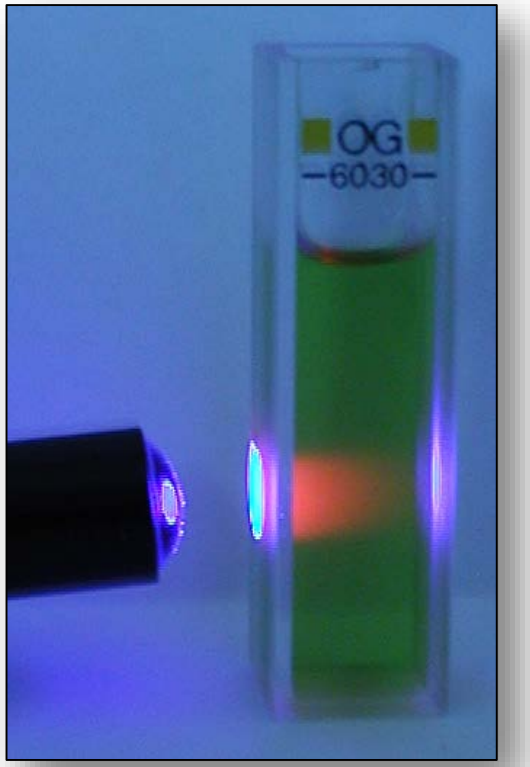
ESA’s Earth Observation satellites

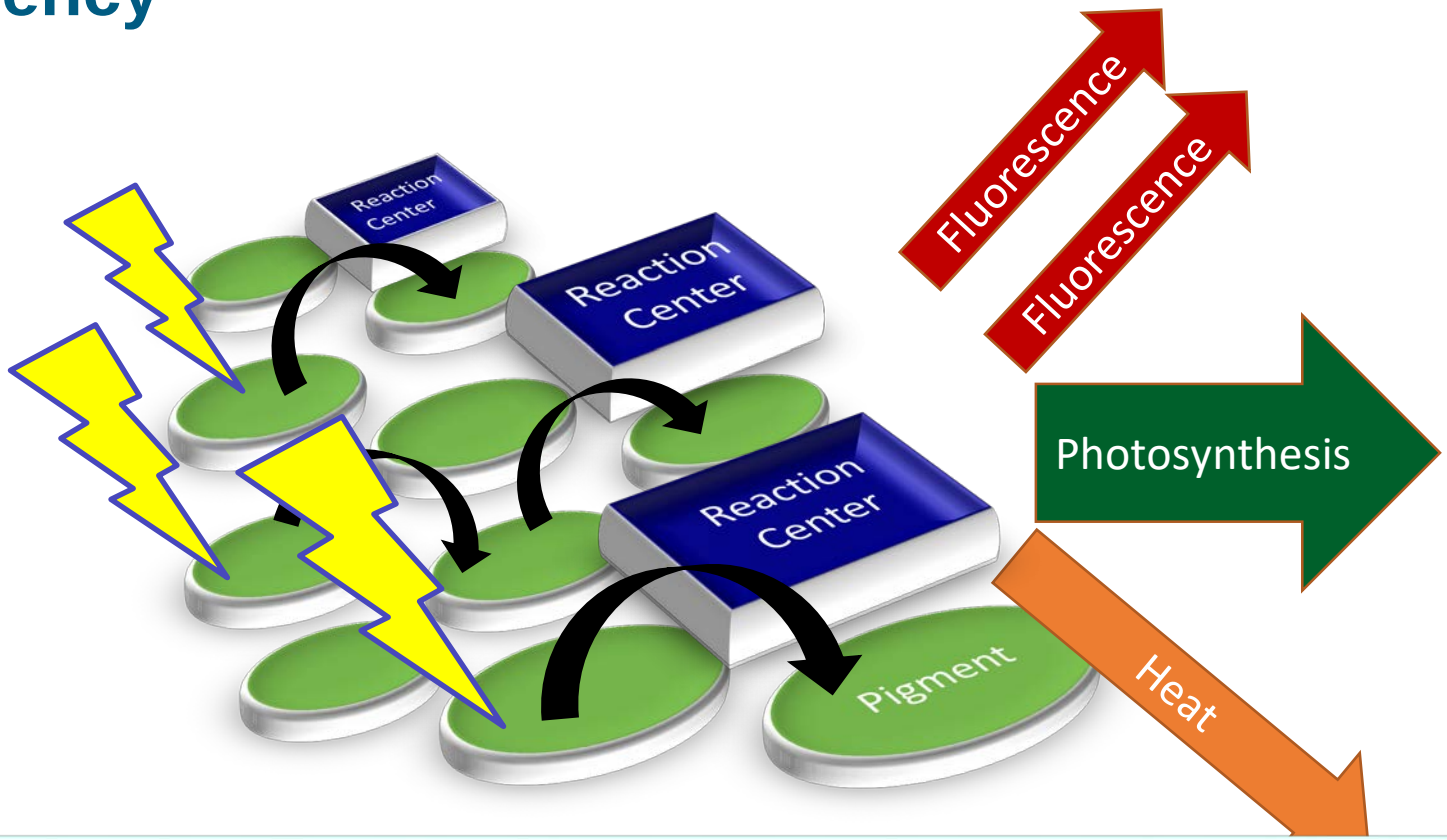


FLEX Satellite Mission – a tandem concept with Sentinel-3



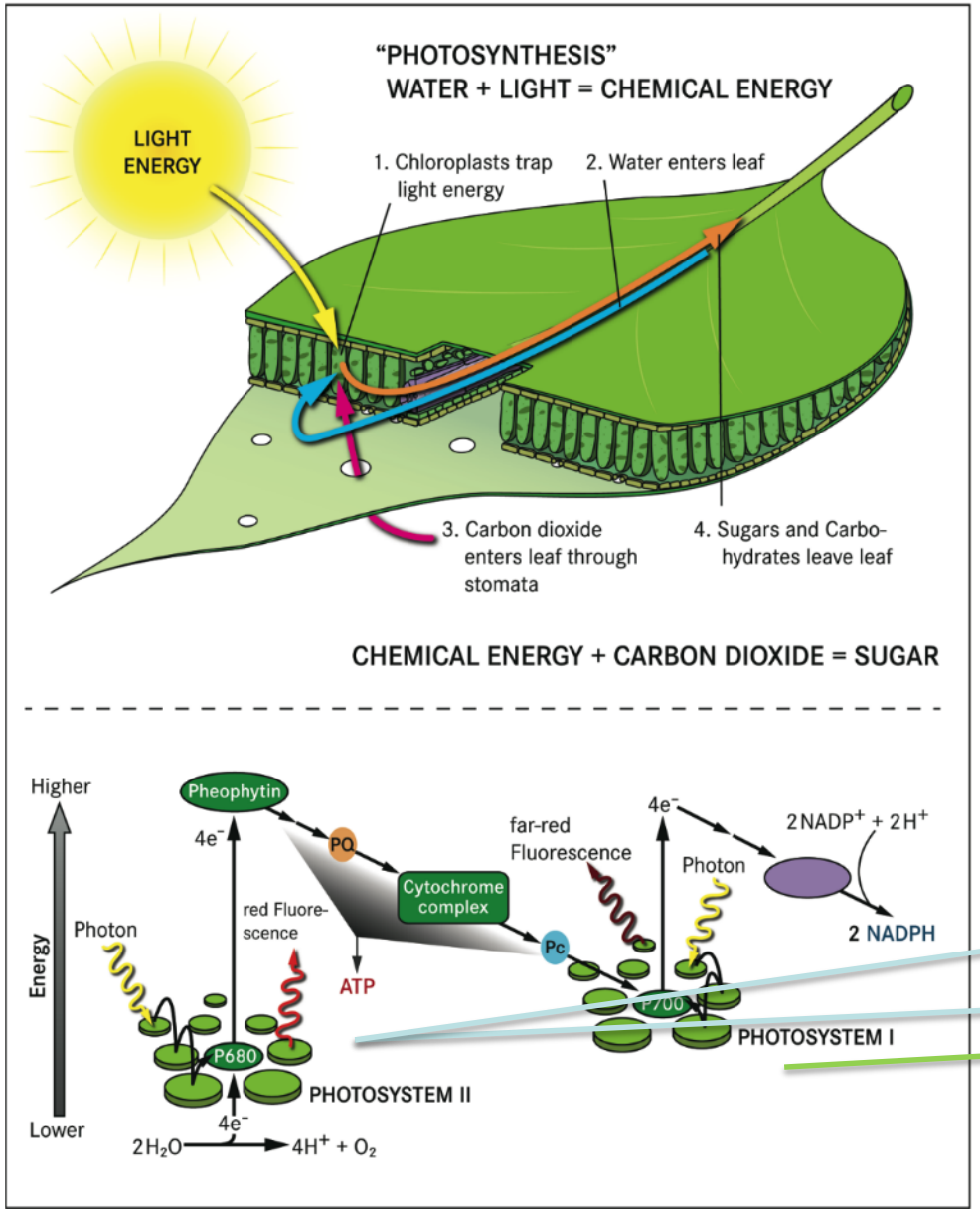
The origin of fluorescence – an indicator for photosynthetic efficiency



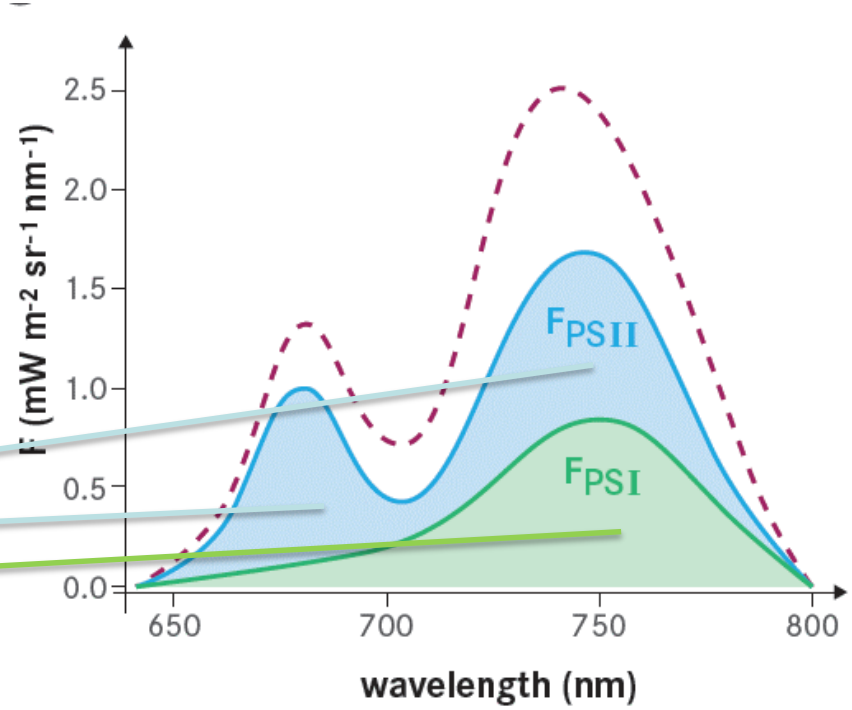


1. Chlorophyll molecules emit fluorescence. The intensity of the fluorescence signal depends on light intensity, the concentration of chlorophyll (LAI) and the functional status of photosynthesis
2. The fluorescence signal is rather weak (2-5 % of intensity of reflected light in this spectral region)

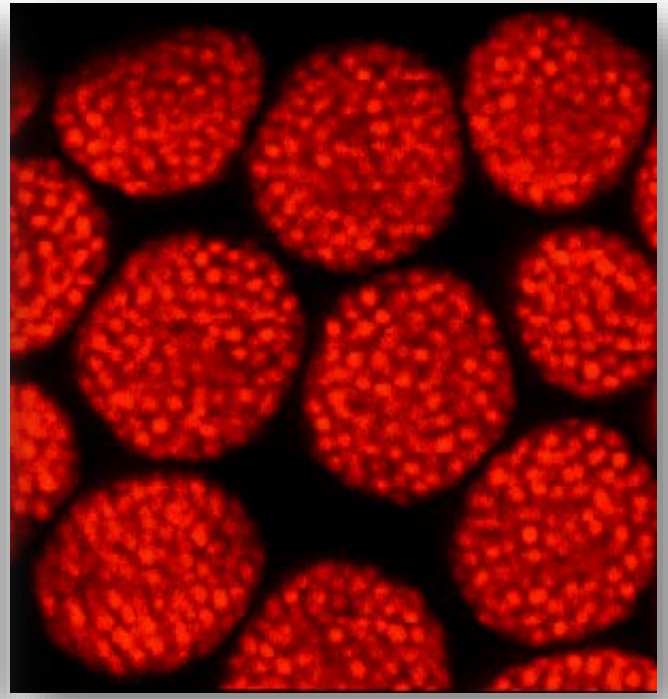
The origin of fluorescence – an indicator for photosynthetic efficiency

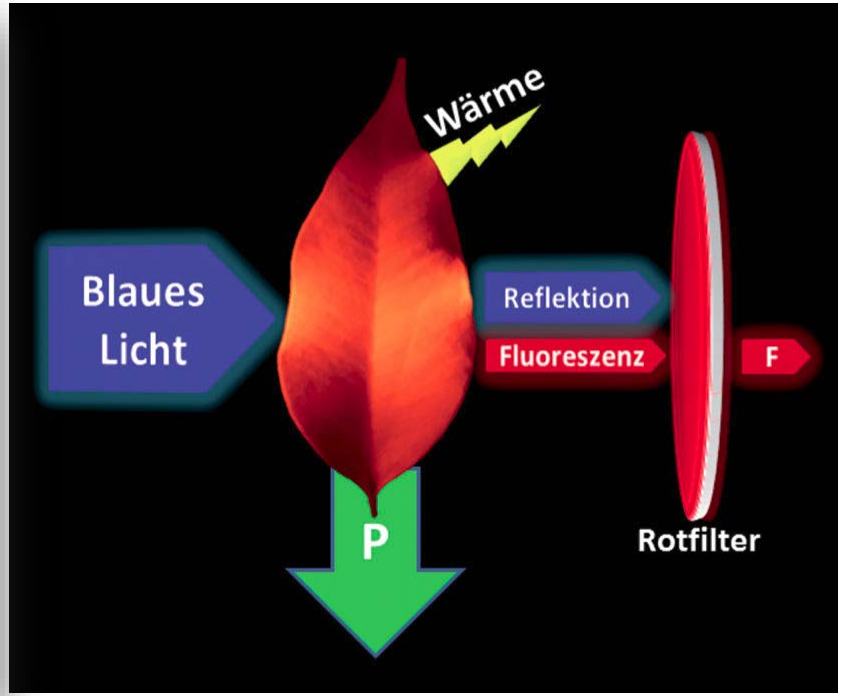


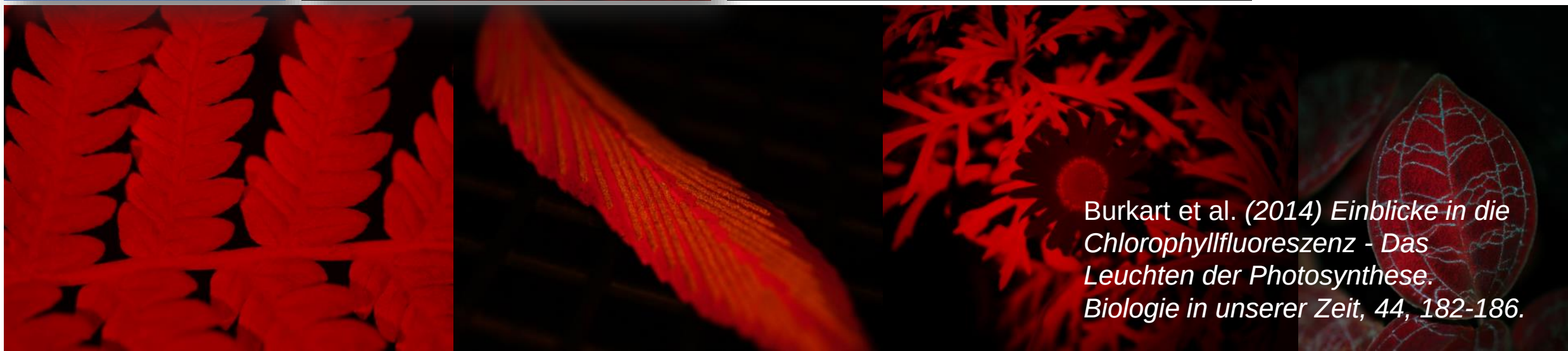
- Photosynthesis is a highly regulated process that involves a cascade of electron transfers (*Light reaction*) to fuel carbon fixation (*Calvin cycle*)
- Fluorescence is emitted from the cores of the photosynthetic machinery: Photosystems I and II
- Two-peak feature of fluorescence



Pigments, photosystems and photosynthesis: a highly structured biological ‘super-complex’ that emits fluorescence

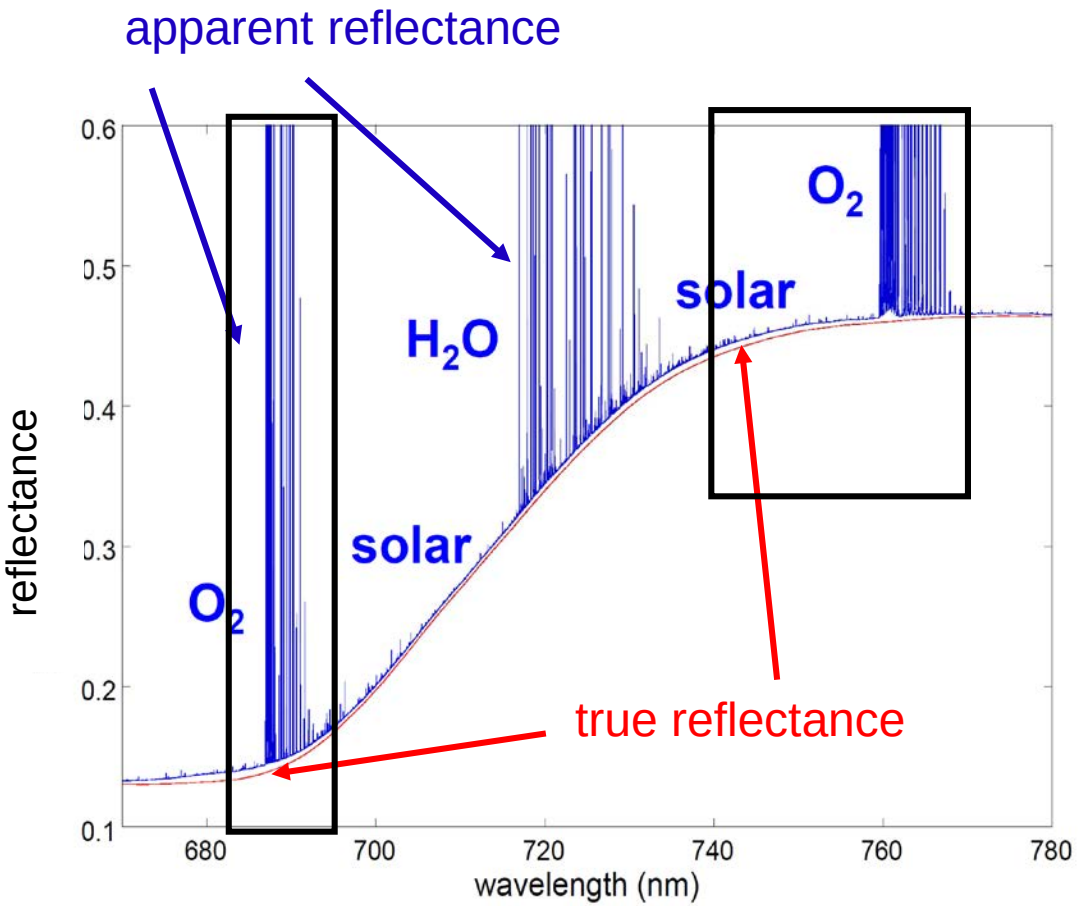




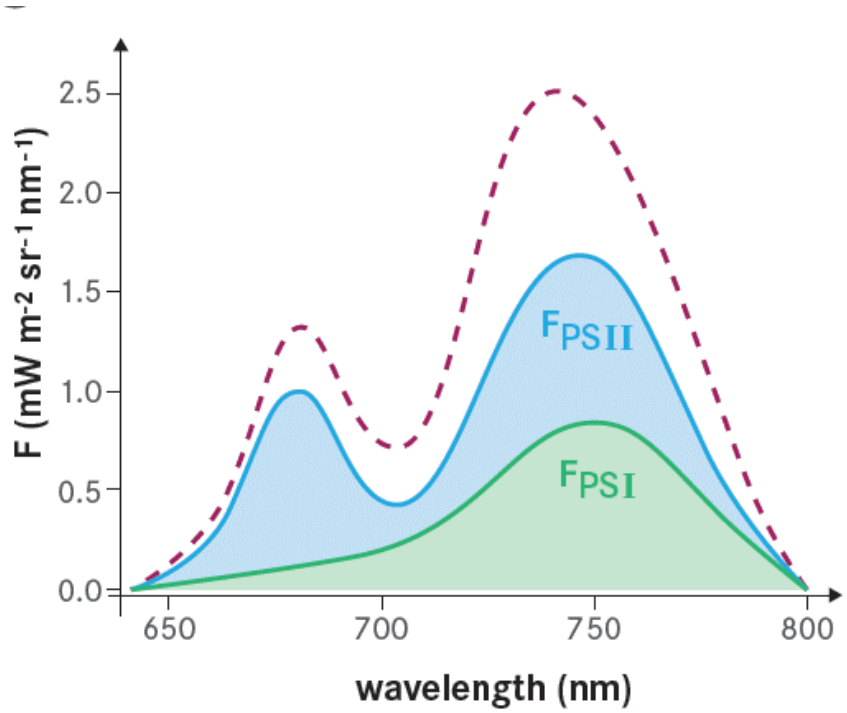


Burkart et al. *(2014) Einblicke in die Chlorophyllfluoreszenz - Das Leuchten der Photosynthese. Biologie in unserer Zeit, 44, 182-186.*

Sun-induced fluorescence can be measured in the solar and atmospheric absorption lines



Atmospheric oxygen and solar absorption lines can be used to retrieve the fluorescence signal from the surface reflectance (under

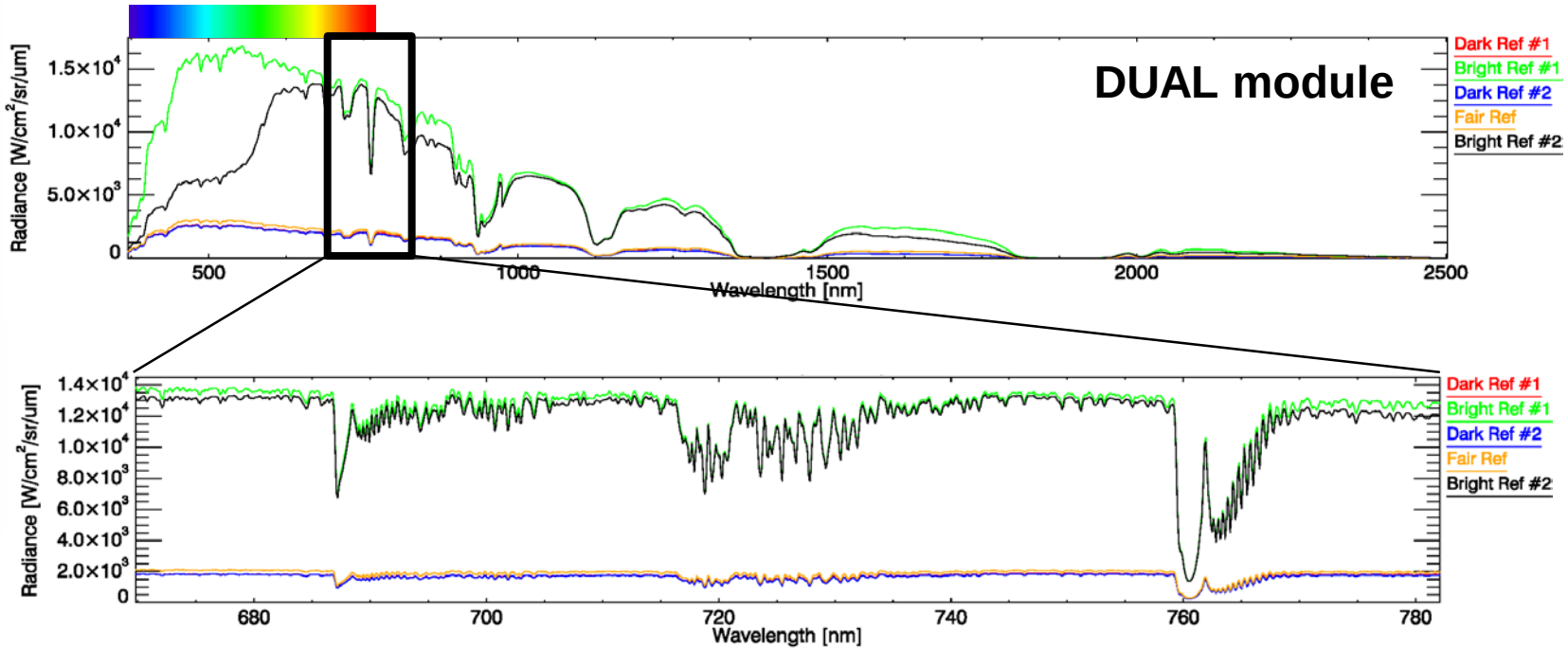


Plascyk (1975) *Optical Engineering 14*, 339–346
Carter et al. (1996) Remote Sensing of Environment 55, 89–92
Moya et al. (2004) Remote Sensing of Environment 91, 186–197
Meroni et al. (2009) *Remote Sensing of Environment, 113,* 2037-2051

HyPlant: A high-resolution airborne imaging spectrometer with FLEX like measurement characteristics

Rascher et al. (2015) *Global Change Biology, 21*, 4673–4684

- **DUAL module** (380 – 2500 nm)
  VIS/NIR: 3-4 nm FWHM, 1.7 nm SSI, SNR 510
  SWIR: 13 nm FWHM, 5.5 nm SSI, SNR 1100
- **FLUO module** (670 – 780 nm)
  0.25 nm FWHM, 0.11 nm SSI, SNR 210



HyPlant: modelling the importance of sensor characteristics

Remote Sensing of Environment 115 (2011) 1882–1892

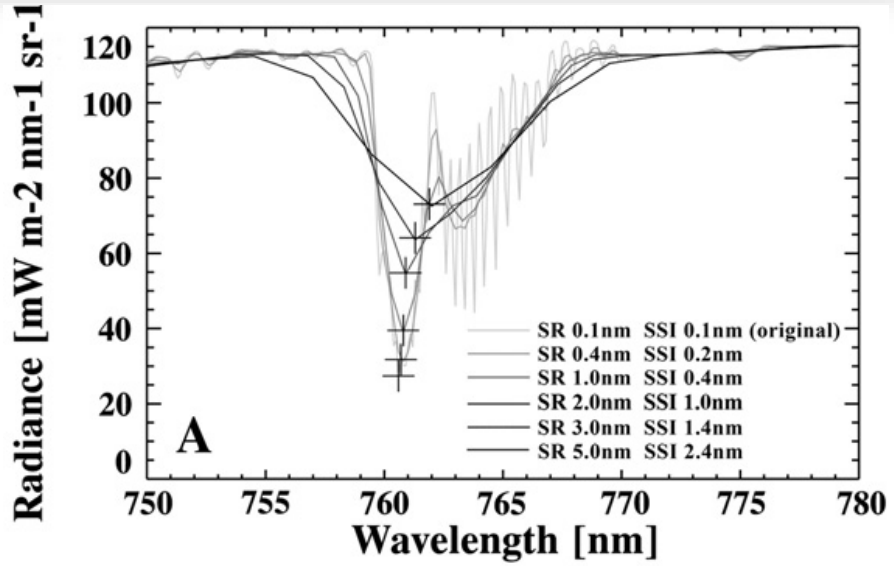
Contents lists available at ScienceDirect

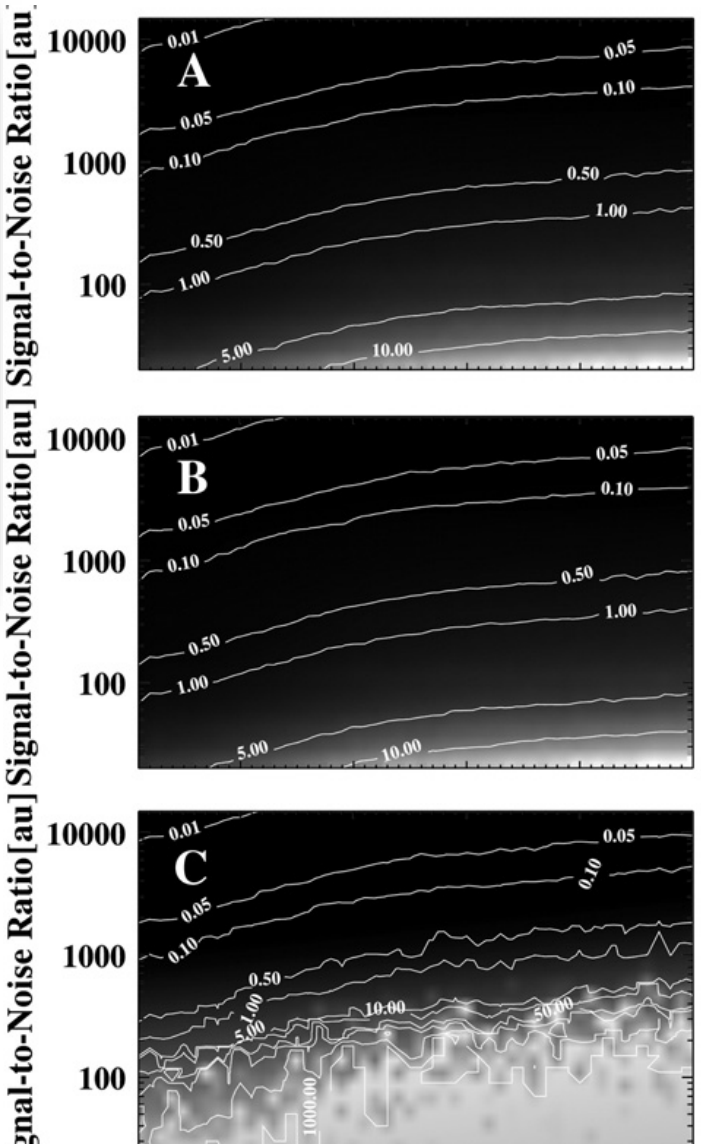
Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

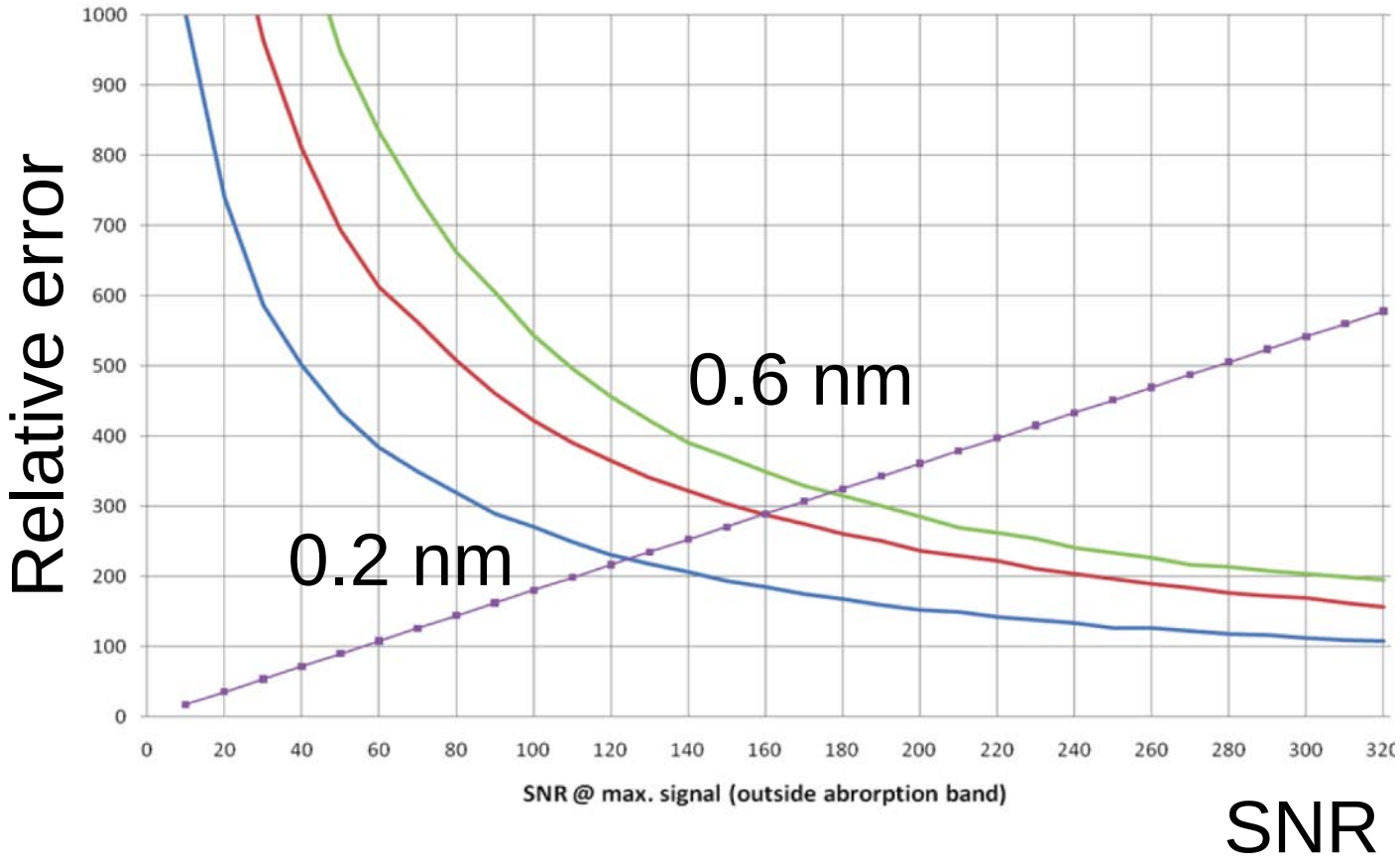
Modeling the impact of spectral sensor configurations on the FLD retrieval accuracy of sun-induced chlorophyll fluorescence

Alexander Damm [a,*], André Erler [b], Walter Hillen [c], Michele Meroni [d], Michael E. Schaepman [a], Wout Verhoef [e], Uwe Rascher [b]





HyPlant: modelling the importance of sensor characteristics



- Optimized imaging spectrometer for fluorescence retrieval having
  - High spectral resolution
  - good SNR
  - Low stray light
  - Stable sensor configuration

Damm et al. (2011) *Remote Sensing of Environment, 115*, 1882-1892
Rascher et al. (2015) *Global Change Biology, 21*, 4673–4684

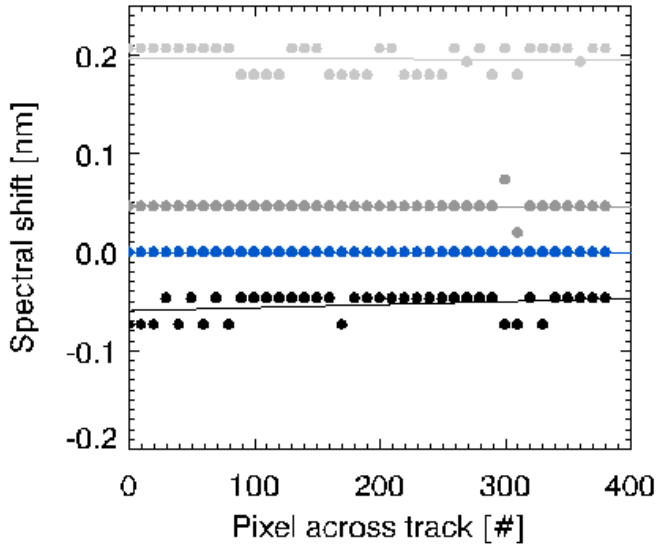
HyPlant: real sensor characteristics

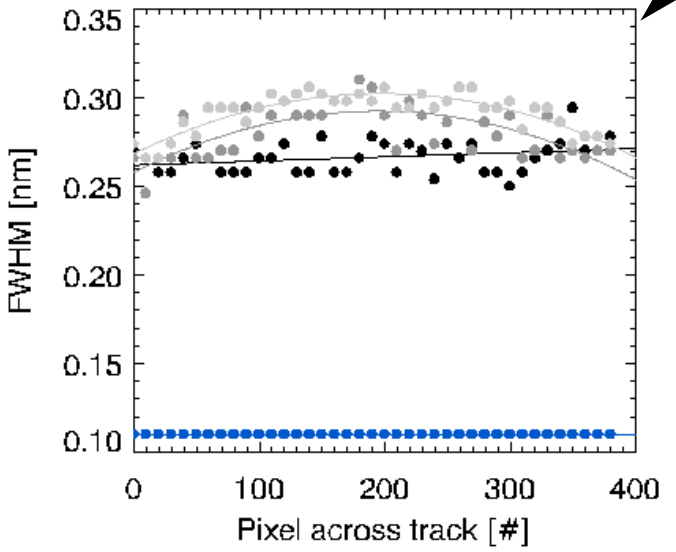
Sensor	Dual-channel module		Fluorescence module
Spectral performance			
Wavelength range [nm]	380–970	970–2500	670–780
Bands	350	272	1024
Wavelength sampling interval [nm]	1.7	5.5	0.11
Wavelength resolution (FWHM) [nm]	4.0	13.3	0.25 at O_2-A 0.23 at O_2-B
Band broadening [nm]	0.2	0.2	0.01 at O_2-A 0.03 at O_2-B
Spectral shift [nm]	1.2	2.4	<0.04
Smiling [nm]	0.4	1.2	<0.01 at O_2-A 0.01 at O_2-B
Radiometric performance			
SNR with full-scale signal	(510)	(1100)	(240)
Stay light and pixel cross talk [%]			<0.5
Spatial performance			
Spatial pixels	384	384	384
Field of view [deg]	32.3		32.3
Instantaneous field of view [deg]	0.0832		0.0832
Swath [m]	380 at 600 m agl* 1140 at 1780 m agl		380 at 600 m agl 1140 at 1780 m agl
Spatial sampling interval (across track) [m]	0.98 at 600 m agl 2.94 at 1780 m agl		0.98 at 600 m agl 2.94 at 1780 m agl
Sensor type			
Type	CMOS	MCT	sCMOS†
Dynamic range [bit]	12	14	16

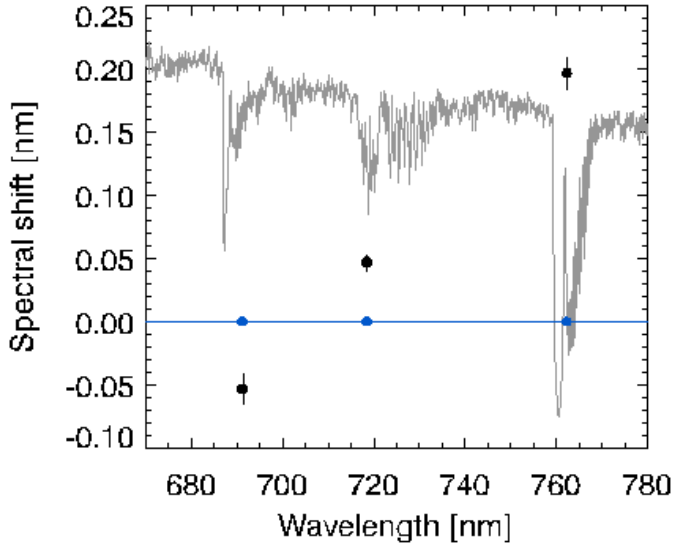
Optimized imaging spectrometer for fluorescence retrieval having

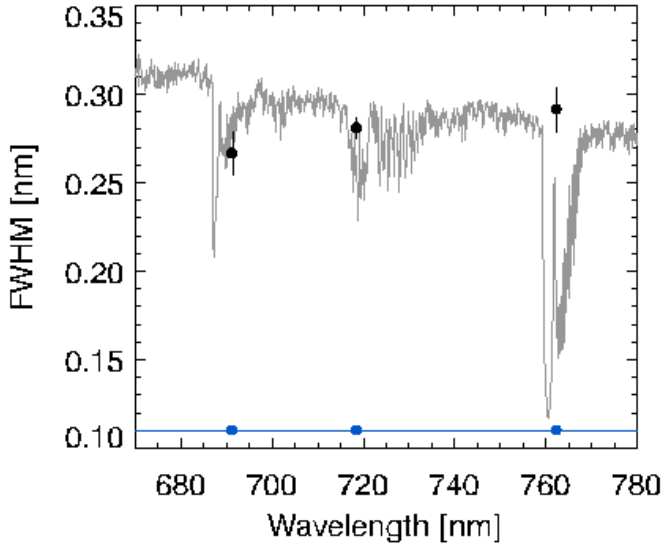
- High spectral resolution
- good SNR
- Low stray light
- Stable sensor configuration

HyPlant: real sensor characteristics





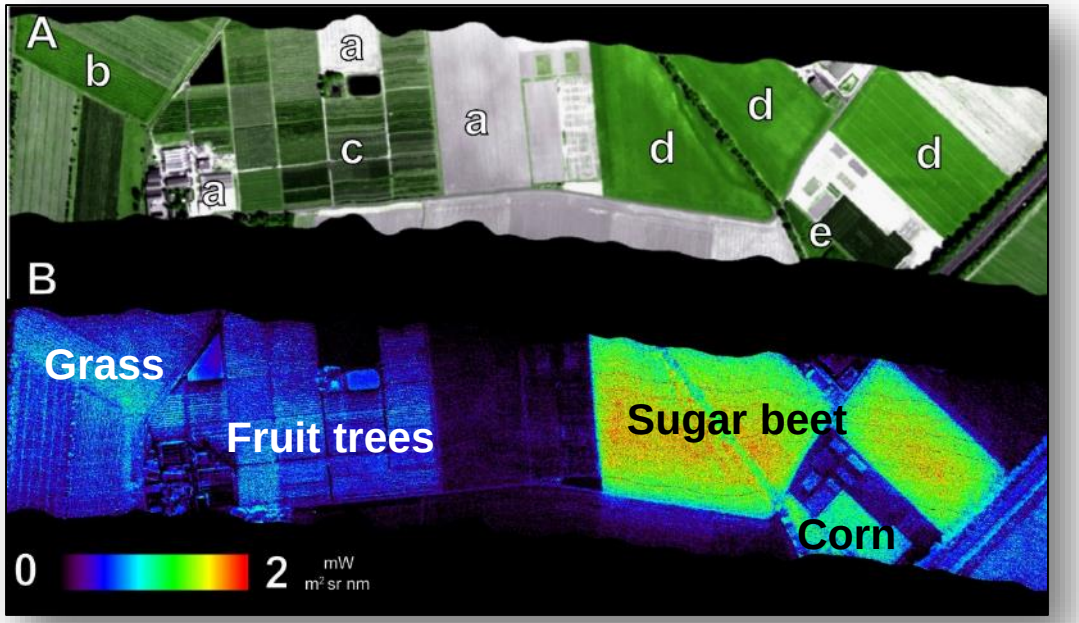


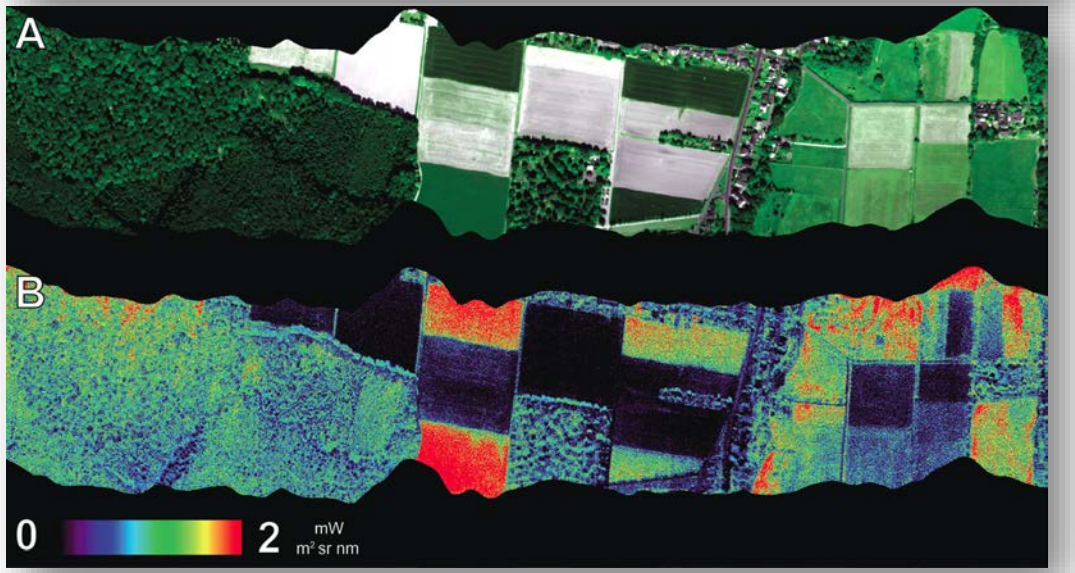


- Optimized imaging spectrometer for fluorescence retrieval having
  - High spectral resolution
  - good SNR
  - Low stray light
  - Stable sensor configuration

HyPlant: 2012 campaigns

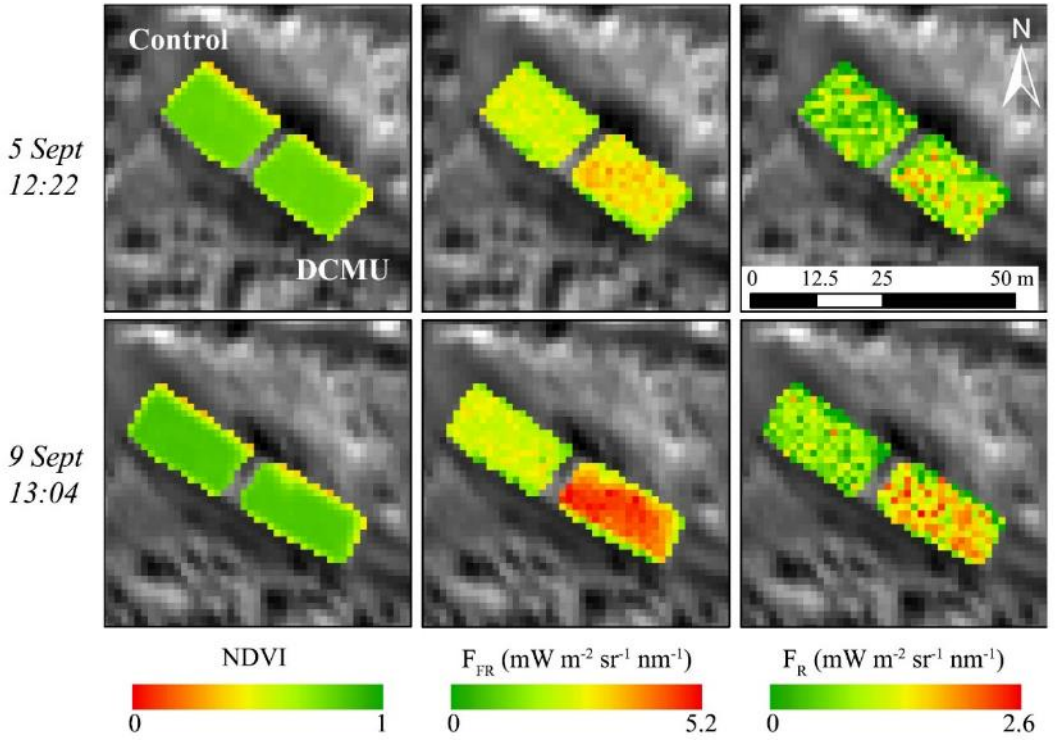
- Used to demonstrate the uncoupling of ‘greenness’ and fluorescence
  [Rascher et al (2015) Global Change Biol., 21, 4673-4684]
  [Simmer et al (2015) BAMS – Bulletin of the American Meteorological Society, 96, 1765-1787]



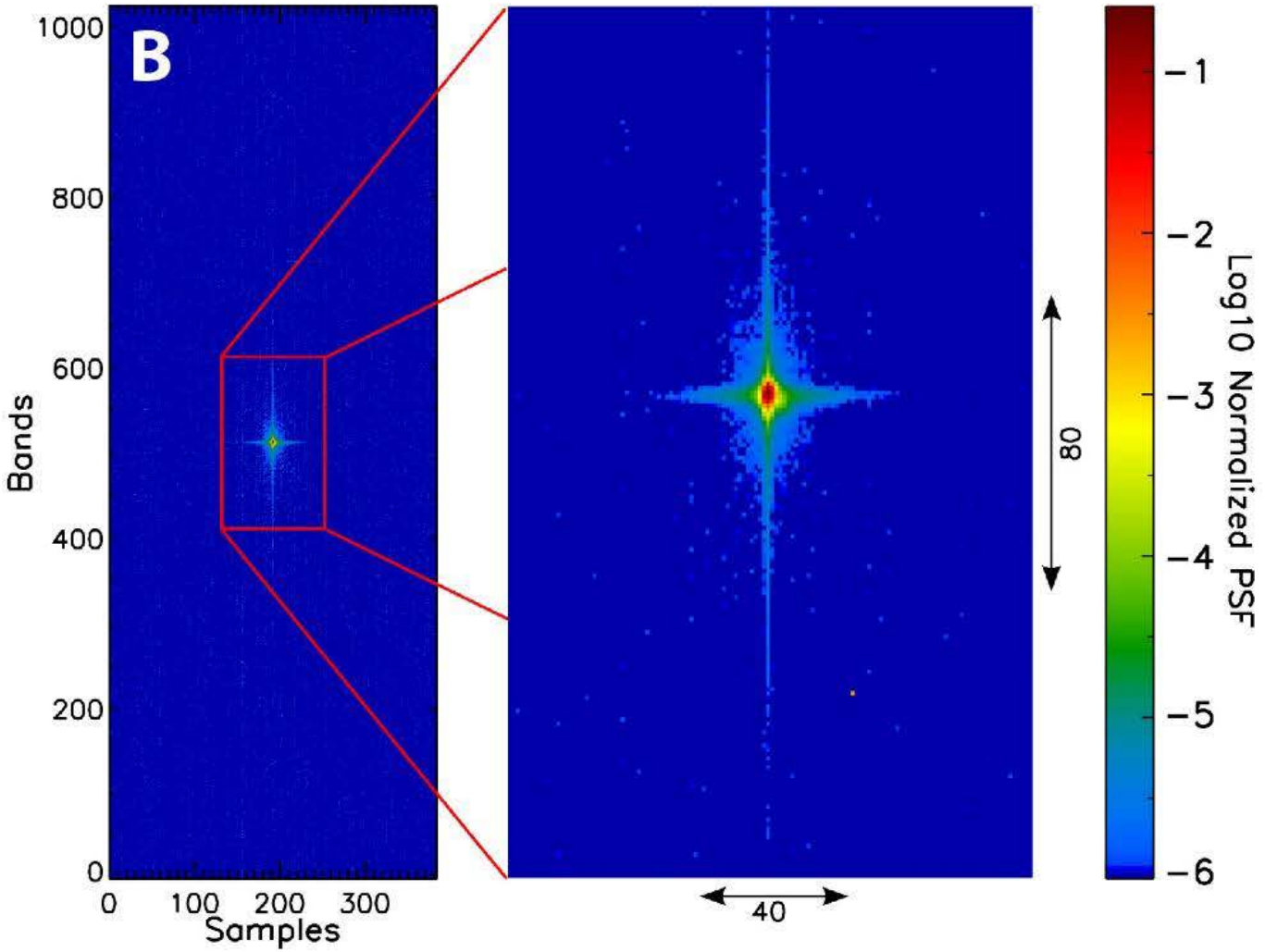


HyPlant: 2012 campaigns

- Used to demonstrate the uncoupling of ‘greenness’ and fluorescence
  [Rascher et al (2015) Global Change Biol., 21, 4673-4684]
  [Simmer et al (2015) BAMS – Bulletin of the American Meteorological Society, 96, 1765-1787]
- First demonstration that functional blockage of photosynthesis can be mapped from aircraft
  [Rossini et al (2015) Geophys. Res. Lett., 42, 1632-1639]



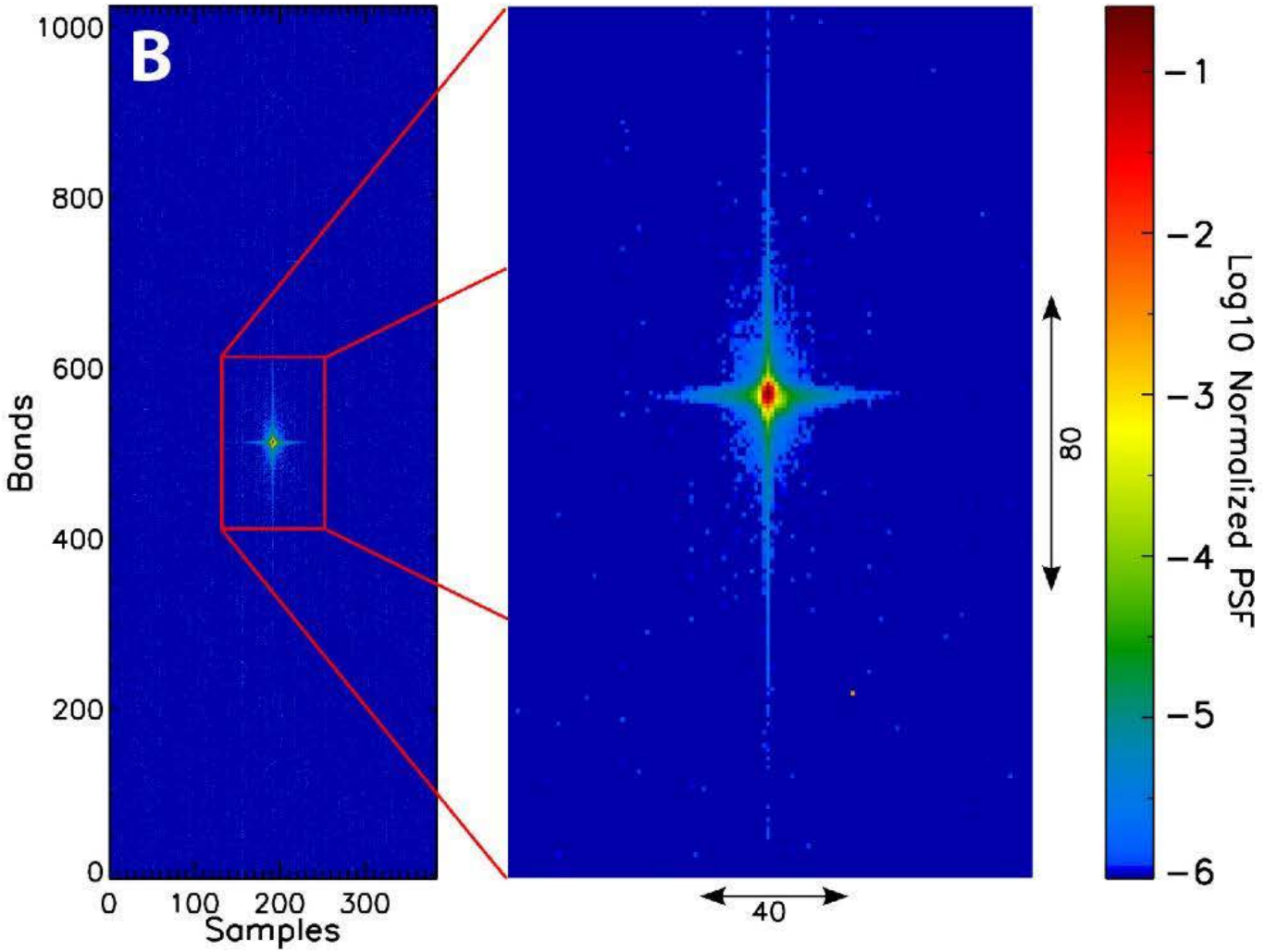
HyPlant: Having a closer look at radiometric performance. Point spread function and stray light



- Optical path and detector was exchanged / upgraded
  - SNR improved 4 times
  - Point spread function greatly improved

Since 2014

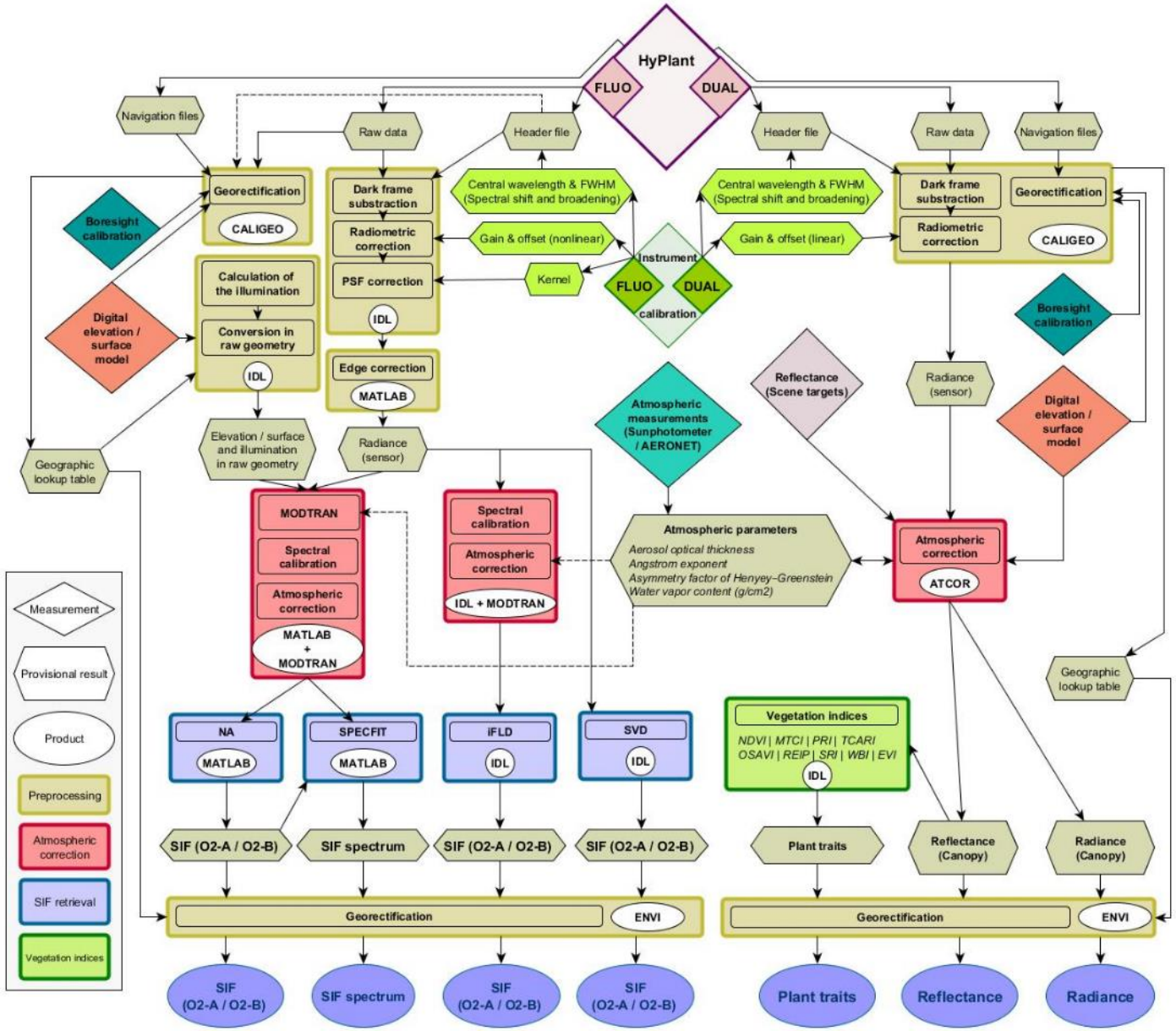
HyPlant: Having a closer look at radiometric performance. Point spread function and stray light



- Optical path and detector was exchanged / upgraded
  - SNR improved 4 times
  - Point spread function greatly improved
- Additional deconvolution algorithm developed and now routinely applied to all flight lines of *HyPlant*

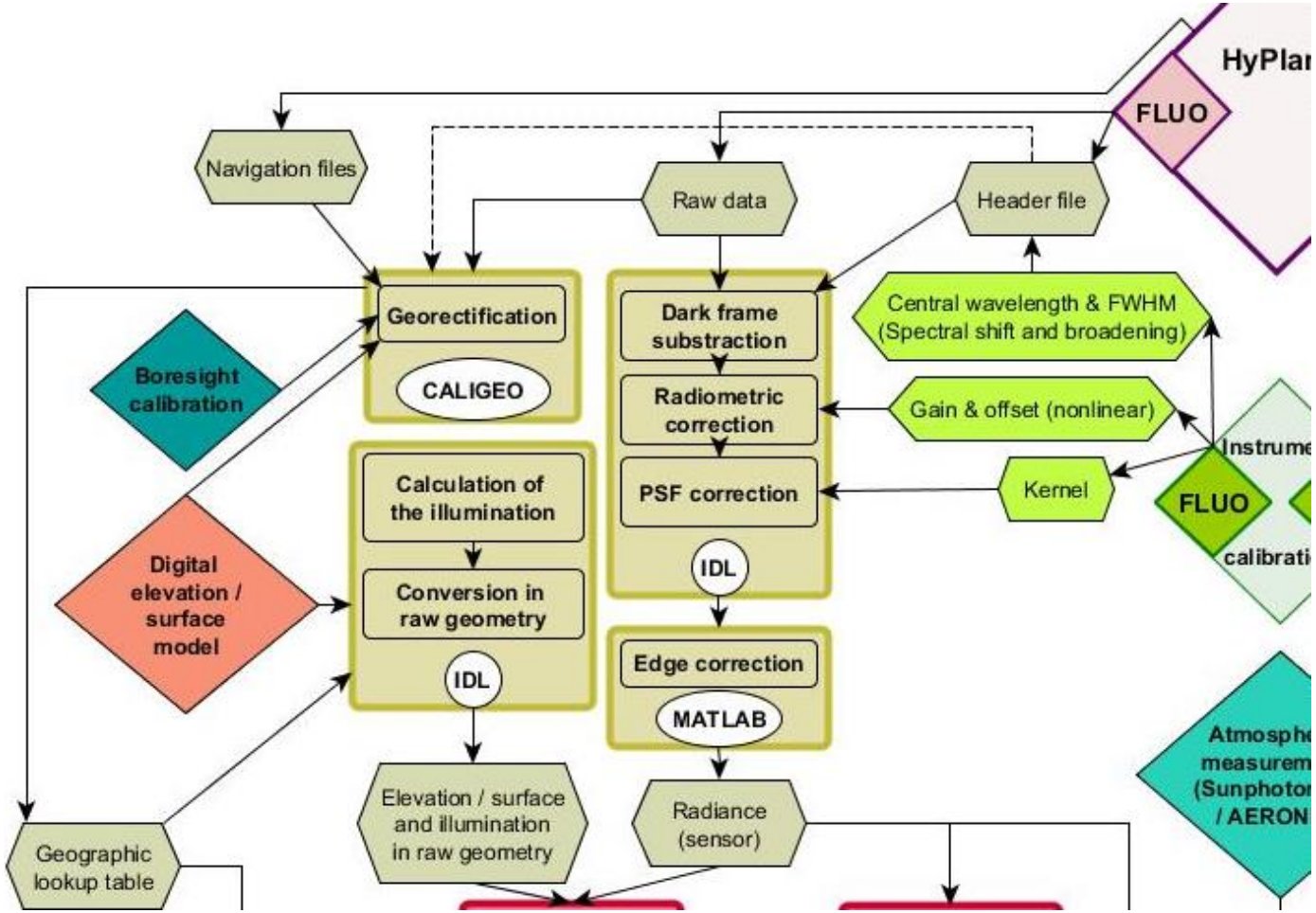
Since 2014

HyPlant: processing becomes consolidated



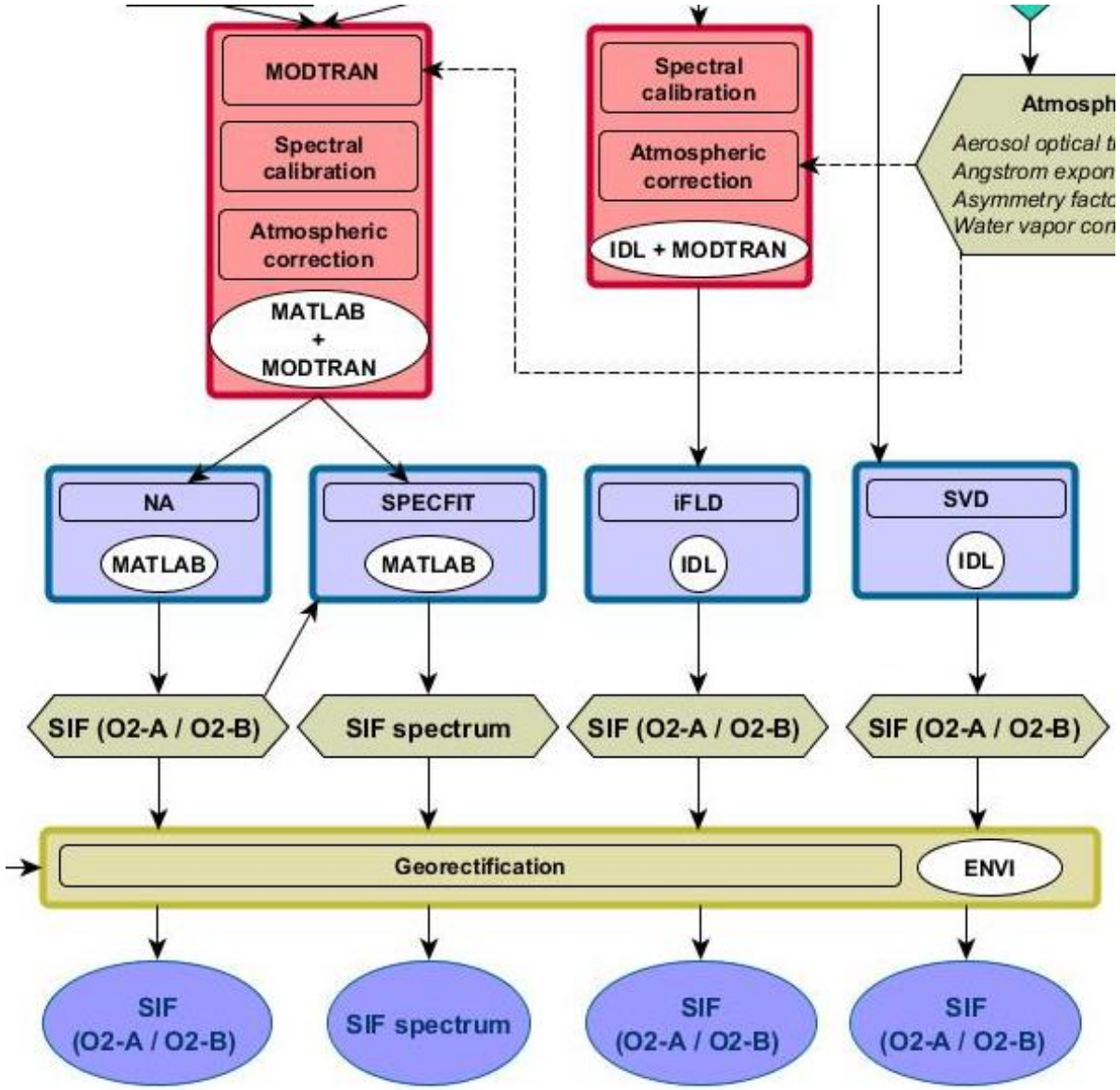
- Optimized imaging spectrometer for fluorescence retrieval
- Processing pipeline developed that includes

HyPlant: processing becomes consolidated



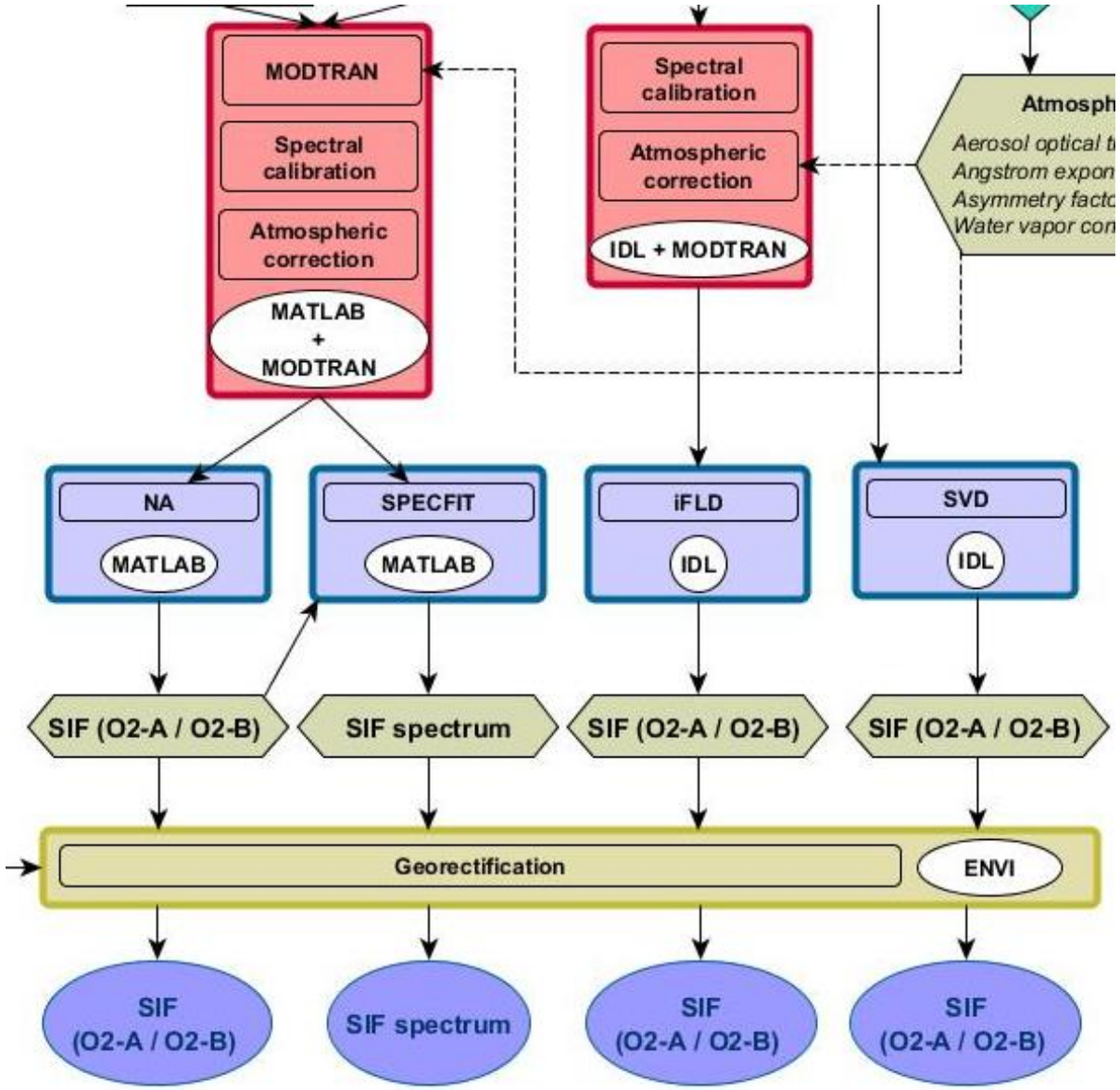
- Optimized imaging spectrometer for fluorescence retrieval
- Processing pipeline developed that includes
  - Advanced and careful pre-processing including deconvolution for point-spead function (PSF)

HyPlant: processing becomes consolidated



- Optimized imaging spectrometer for fluorescence retrieval
- Processing pipeline developed that includes
  - Advanced and careful pre-processing including deconvolution for point-spead function (PSF)
  - Three way to retrieve fluorescence (both peaks and total fluorescence)

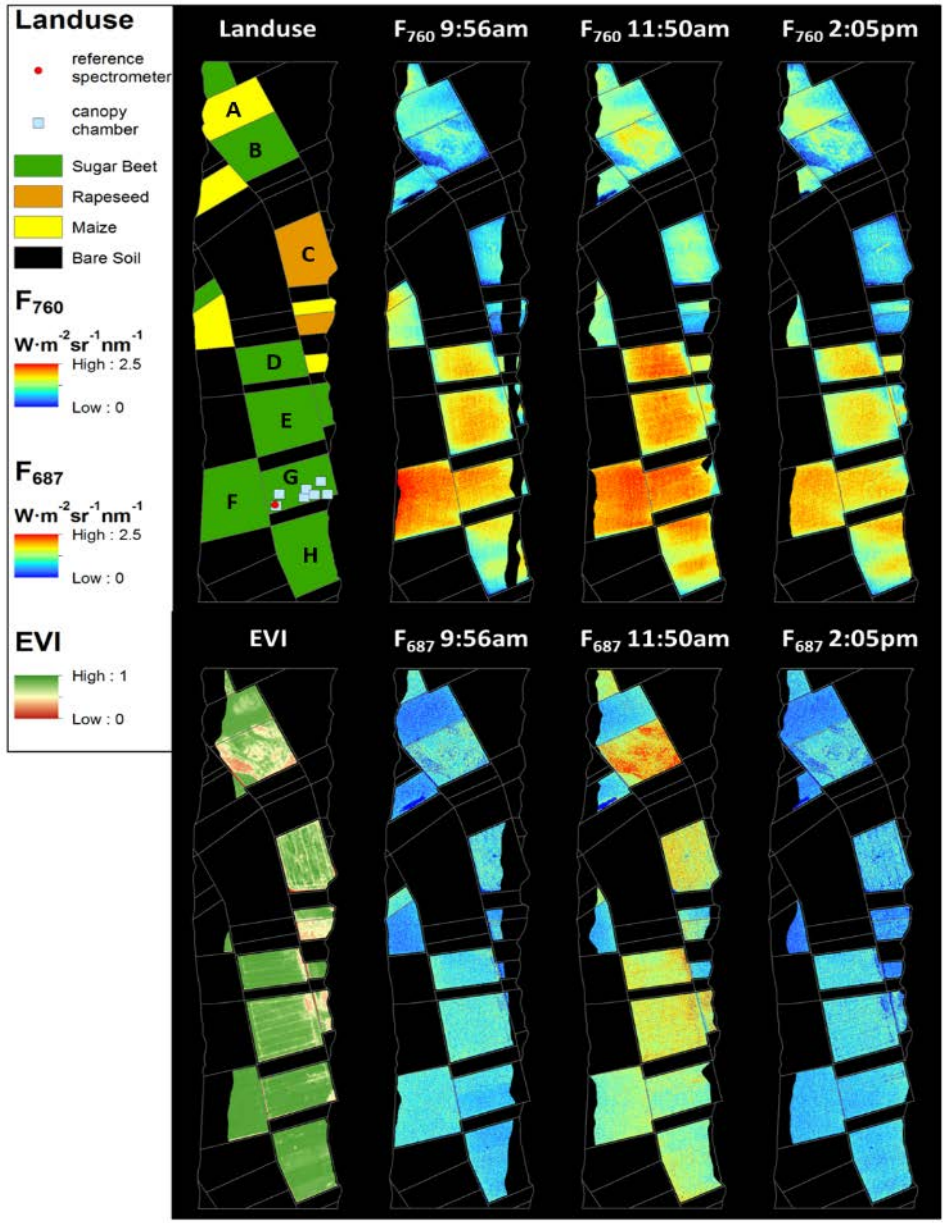
HyPlant: processing becomes consolidated



- SVD: good first estimate that works in about 70% of the cases
- 3-FLD: not usable because of strong dependency of surface reflectance
- iFLD: 'working retrieval' as long as we have non-vegetated reference targets in the scene
- Spectral fitting: method of choise that was recently adapted also for *HyPlant*. (need for good characterization of atmospheric parameters)

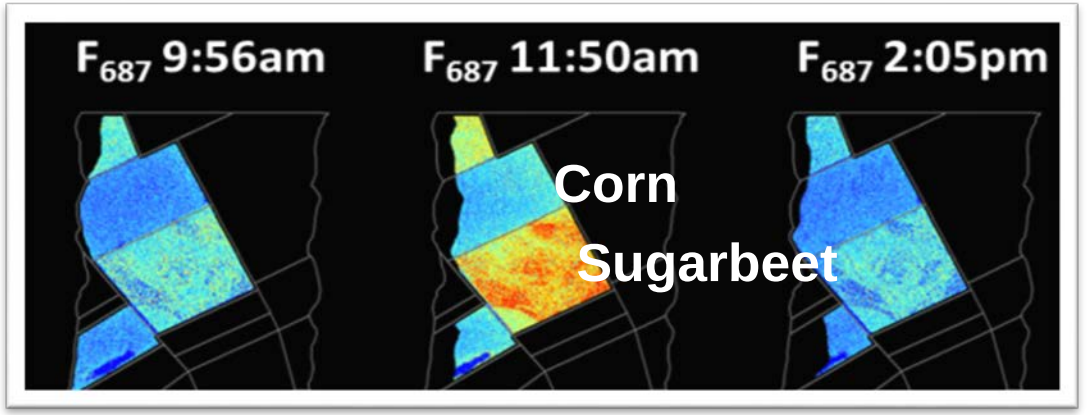
HyPlant: 2014 campaigns

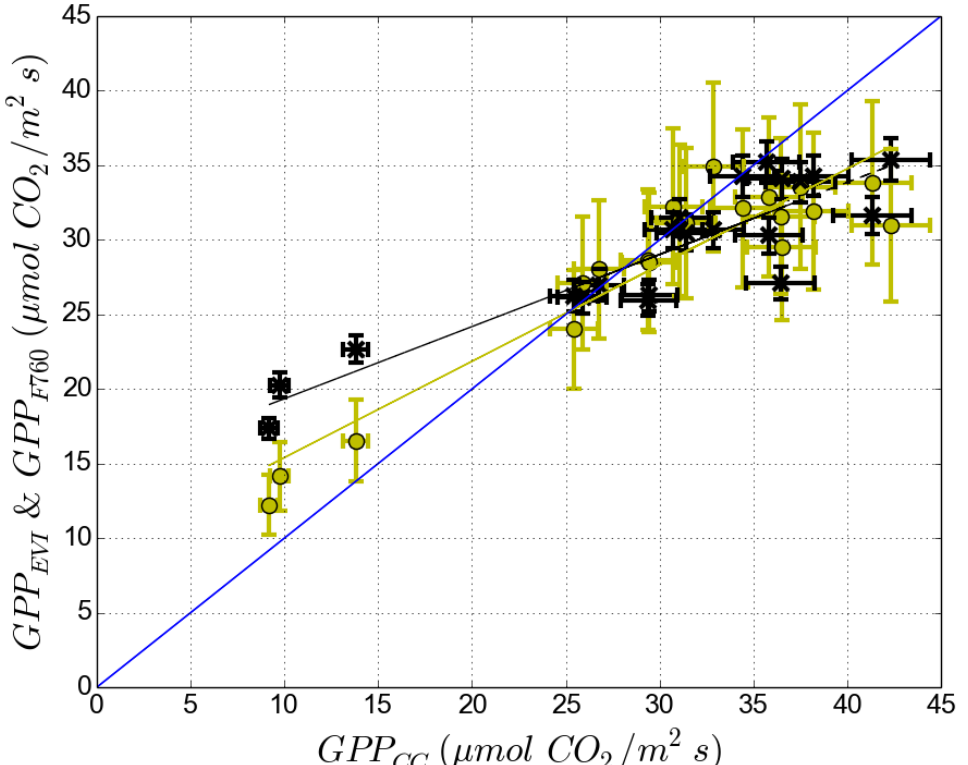
- Used to demonstrate the uncoupling of ‘greenness’ and fluorescence
  [Rascher et al (2015) Global Change Biol., 21, 4673-4684]
  [Simmer et al (2015) BAMS – Bulletin of the American Meteorological Society, 96, 1765-1787]
- First demonstration that functional blockage of photosynthesis can be mapped from aircraft
  [Rossini et al (2015) Geophys. Res. Lett., 42, 1632-1639]
- Fluorescence improves modelling of diurnal changes in GPP
  [Wieneke et al (2016) Rem Sens Environ, 184, 654-667]



HyPlant: 2014 campaigns

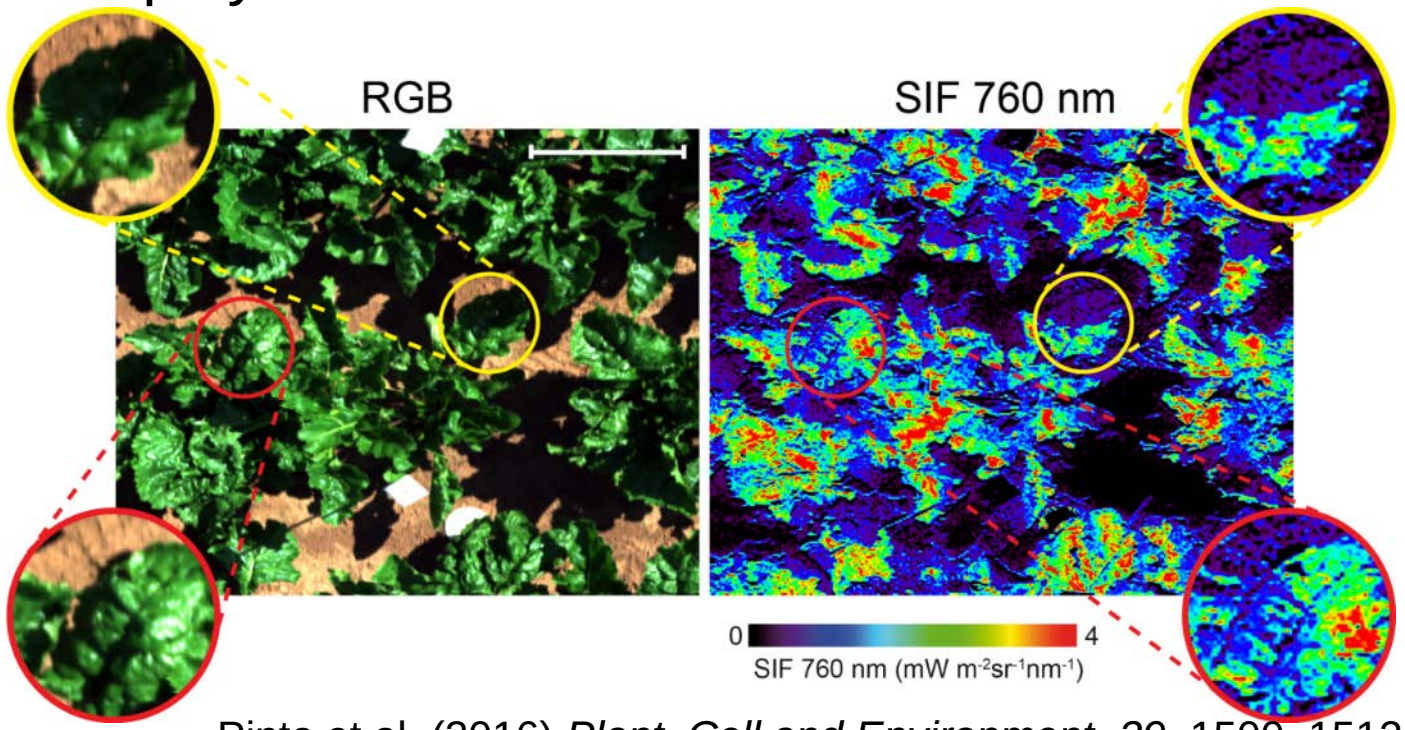
- Used to demonstrate the uncoupling of ‘greenness’ and fluorescence
  [Rascher et al (2015) Global Change Biol., 21, 4673-4684]
  [Simmer et al (2015) BAMS – Bulletin of the American Meteorological Society, 96, 1765-1787]
- First demonstration that functional blockage of photosynthesis can be mapped from aircraft
  [Rossini et al (2015) Geophys. Res. Lett., 42, 1632-1639]
- Fluorescence improves modelling of diurnal changes in GPP
  [Wieneke et al (2015) Rem Sens Environ, 184, 654-667]

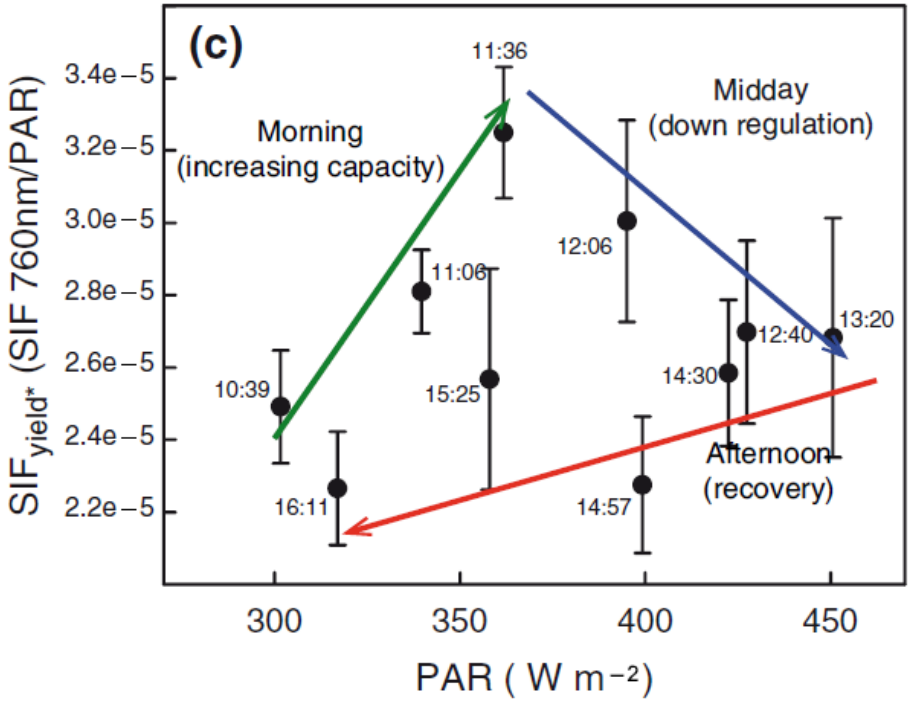




What are we doing to complement airborne mapping of fluorescence?

- Mapping of sun-induced fluorescence on the ground to understand interplay of the variations of light intensity within natural canopies and the three dimensional leaf display



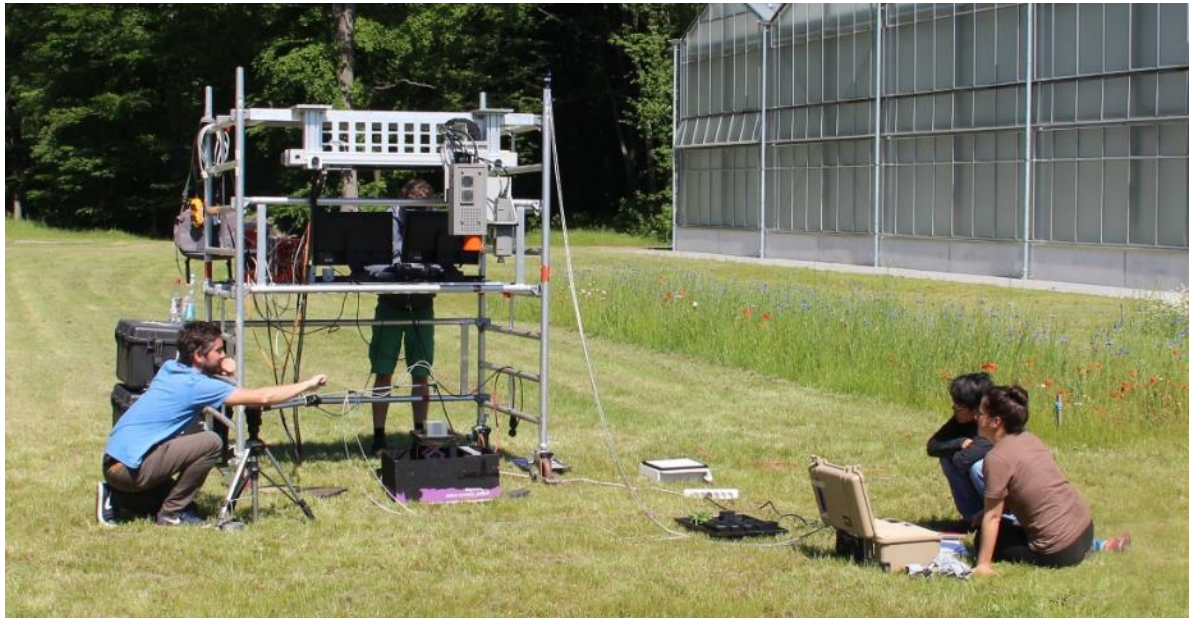


Pinto et al. (2016) *Plant, Cell and Environment, 39*, 1500–1512

Pinto et al. (2017) *Remote Sensing, 9, article no. 415, doi: 10.339(*

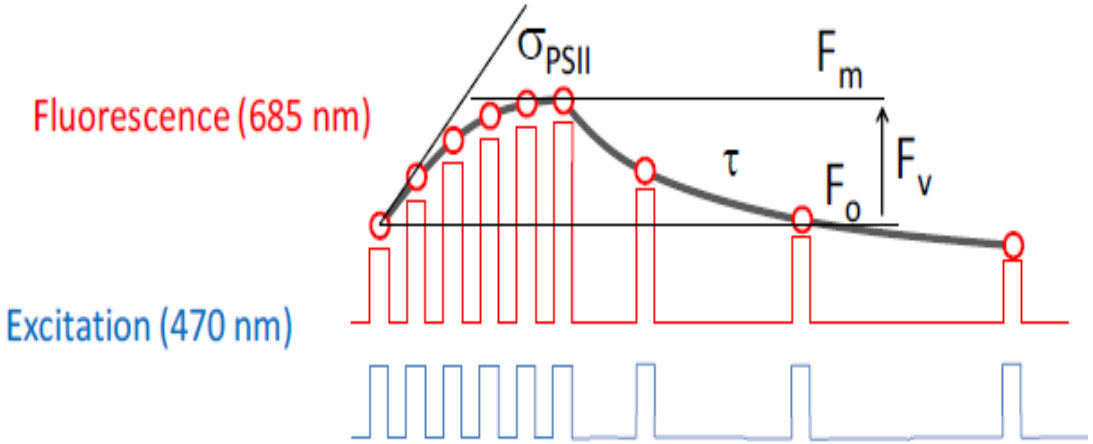
What are we doing to complement airborne mapping of fluorescence?

- Mapping of sun-induced fluorescence on the ground to understand interplay of the variations of light intensity within natural canopies and the three dimensional leaf display
- New ‘HyPlant light’ [*HySceen*] is operational



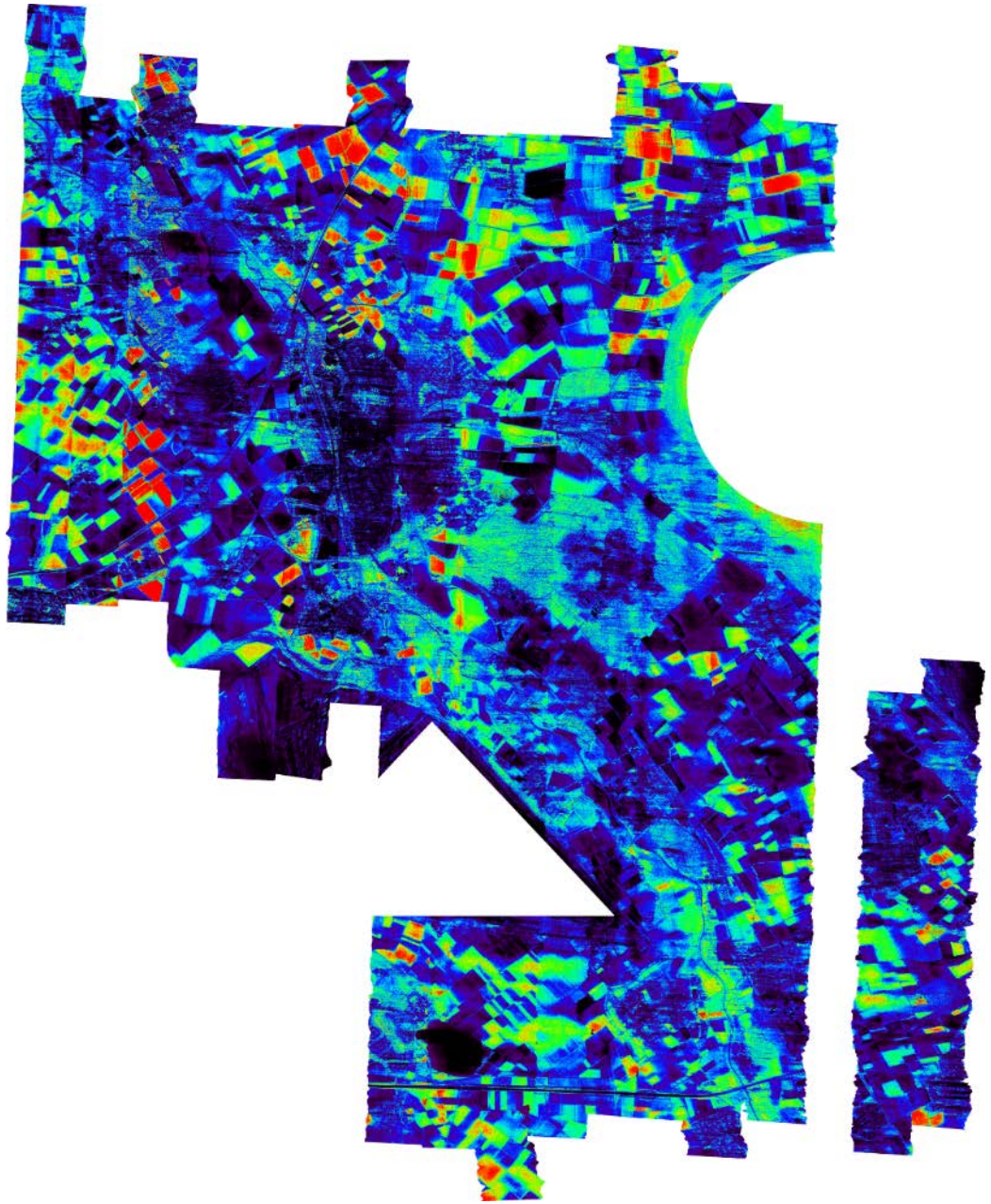
What are we doing to complement airborne mapping of fluorescence?

- Mapping of sun-induced fluorescence on the ground to understand interplay of the variations of light intensity within natural canopies and the three dimensional leaf display
- New ‘HyPlant light’ [*HySceen*] is operational
- Link passive sun-induced fluorescence measurements with active fluorescence approaches that allow deeper insight into the photosynthetic machinery



What are we doing to complement airborne mapping of fluorescence?

- Mapping of sun-induced fluorescence on the ground to understand interplay of the variations of light intensity within natural canopies and the three dimensional leaf display
- New ‘HyPlant light’ [*HySceen*] is operational
- Link passive sun-induced fluorescence measurements with active fluorescence approaches that allow deeper insight into the photosynthetic machinery
- Aggregate flight lines to produce FLEX like data and understand fluorescence on the 300 x 300 meter pixel



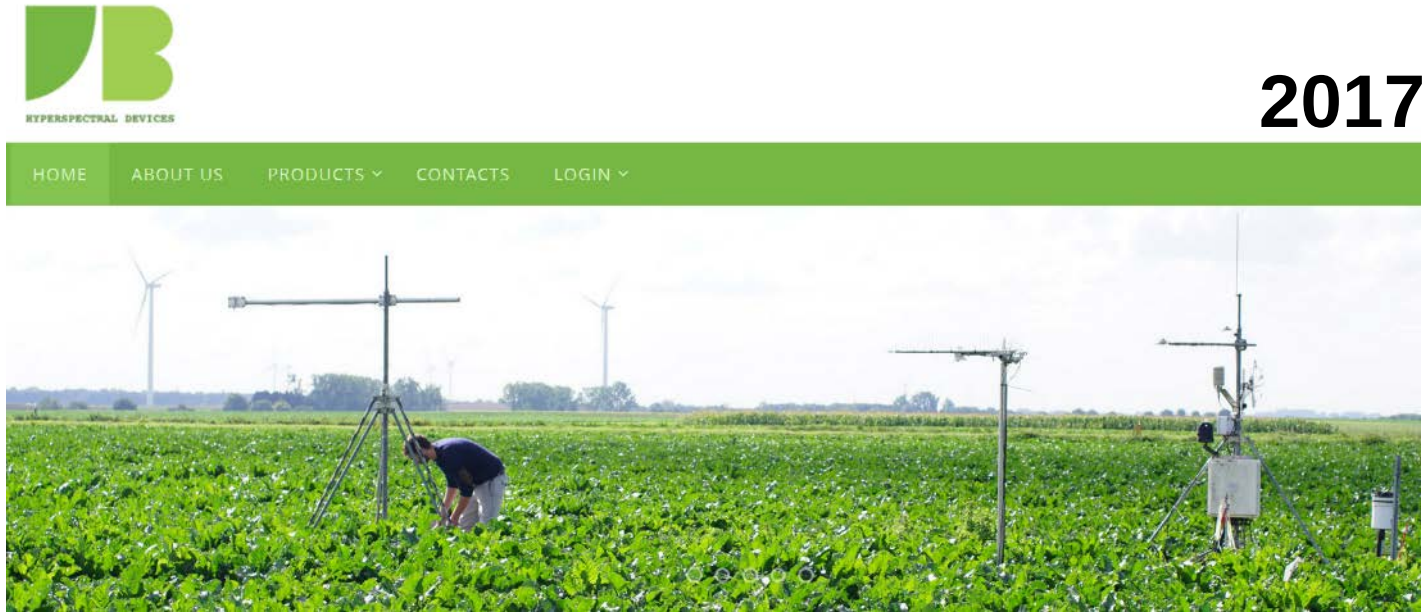
What are we doing to complement airborne mapping of fluorescence?

- High-resolution point spectrometer developed, optimized and standardized system available
- ~10 systems have been employed and are operational

2012

2016

2017

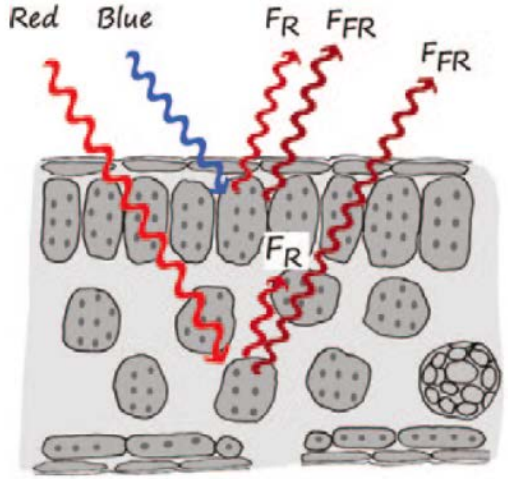


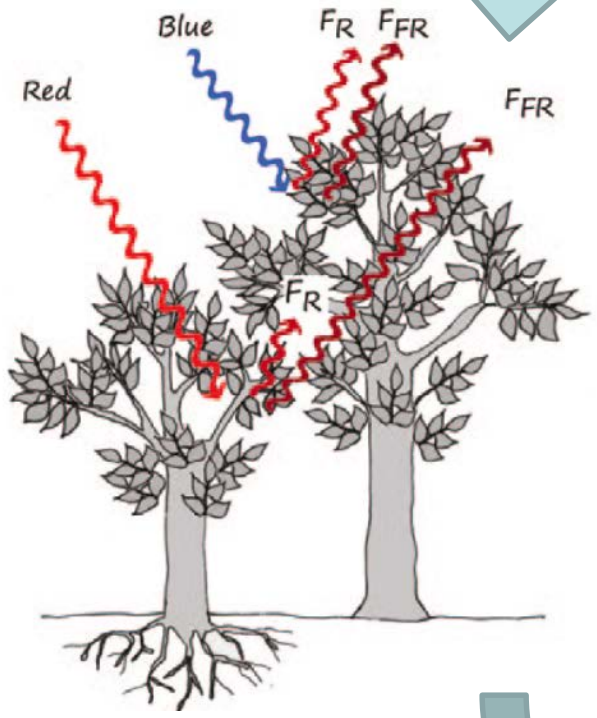
Burkart et al. (2015) *IEEE Sensors, 15,* 4603-4611

Cogliati et al. (2015) *Remote Sensing of Environment, 164, 270-281*

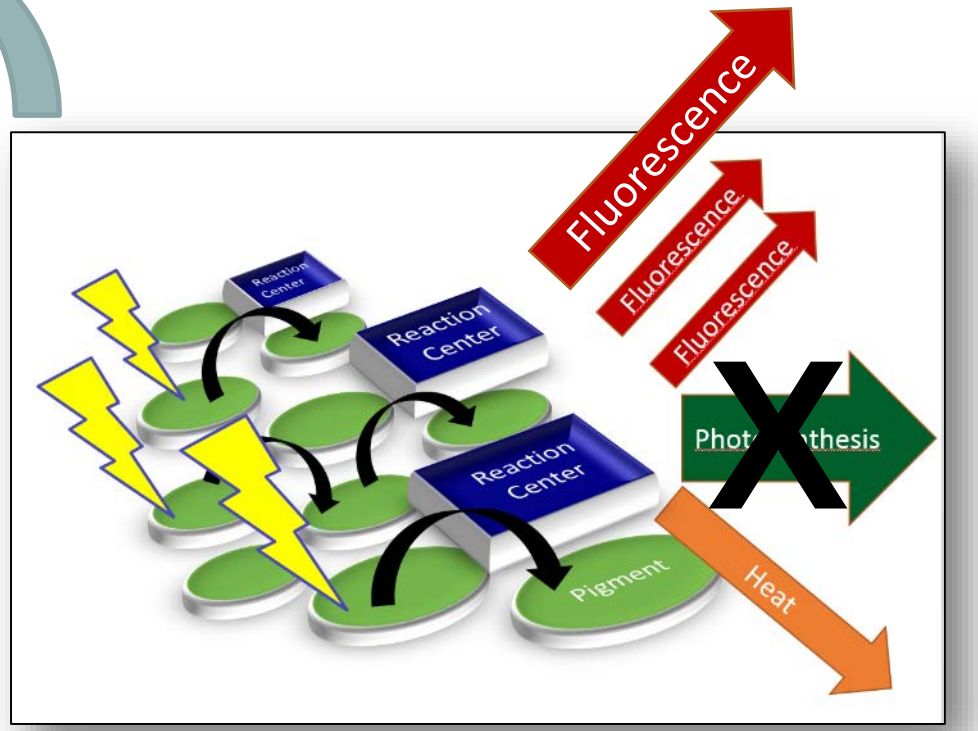
Understanding sun-induced fluorescence:
A matter to understand Structure / Function Relations

Structure



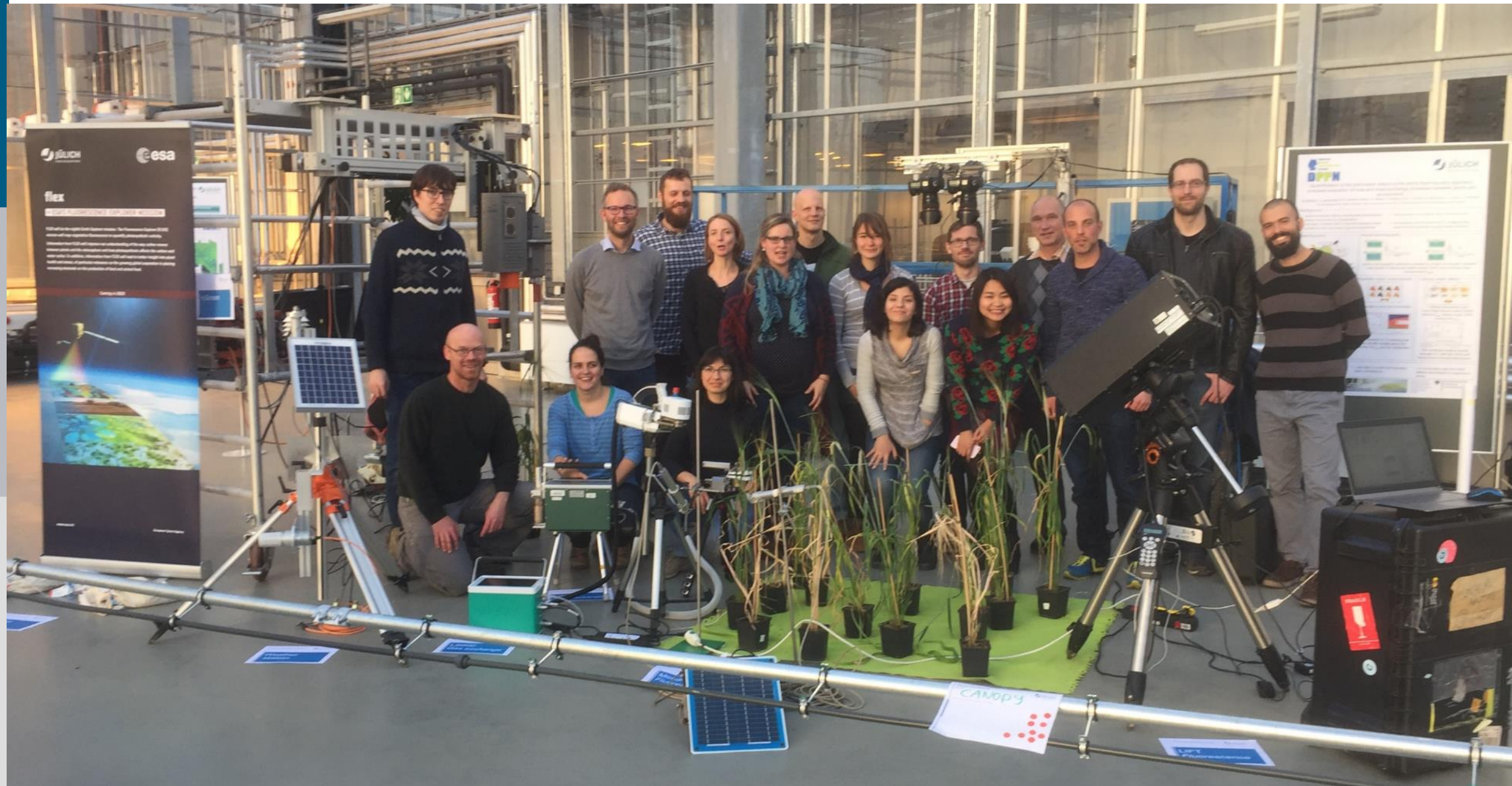


Function



Porcar-Castell et al. (2014) *Journal of Exp. Botany, doi:10.1093/jxb/eru191*

Many thanks to my group



Many thanks to the numerous partners