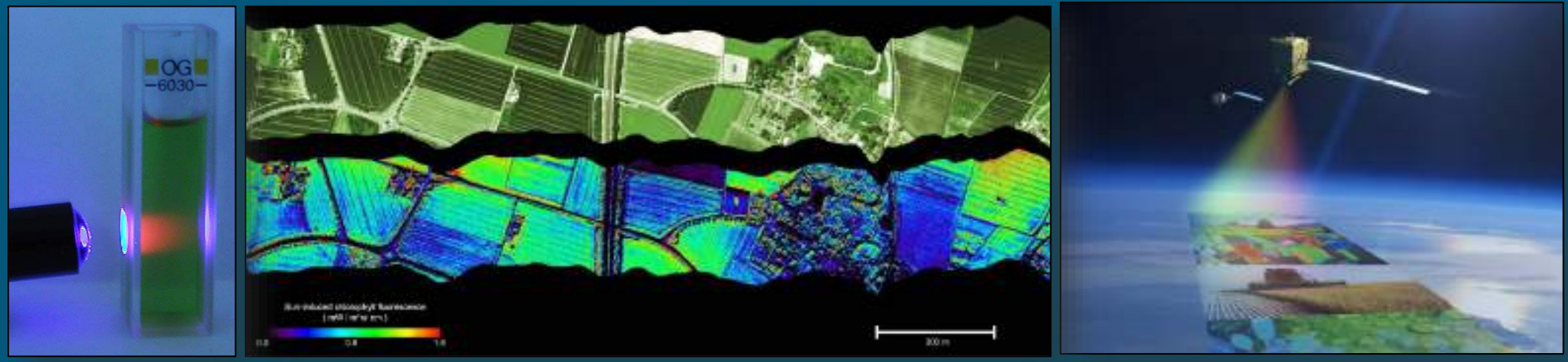
Institut für Bio- und Geowissenschaften
IBG-2: Pflanzenwissenschaften

FLEX (FLuorescence Explorer) and ground based approaches to map and better understand the dynamcis of sun-induced fluorescence and photosynthesis

Uwe Rascher, 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

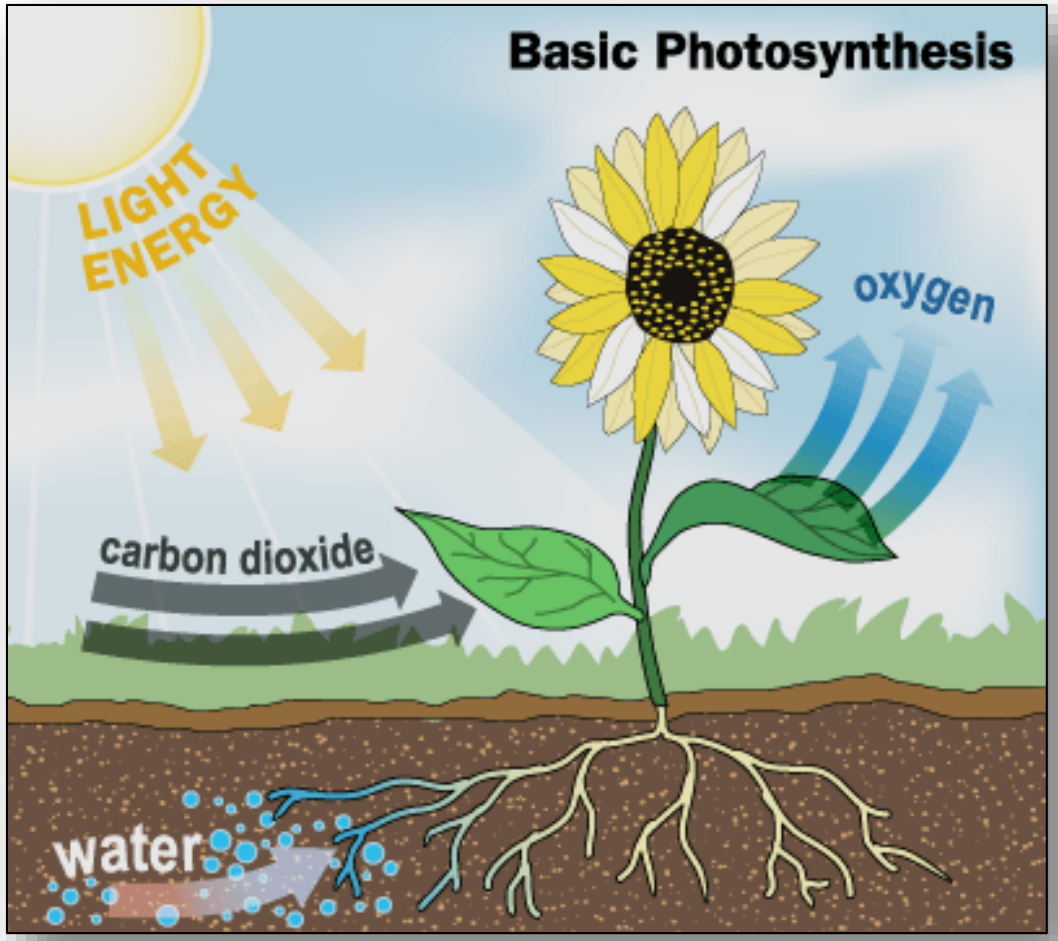


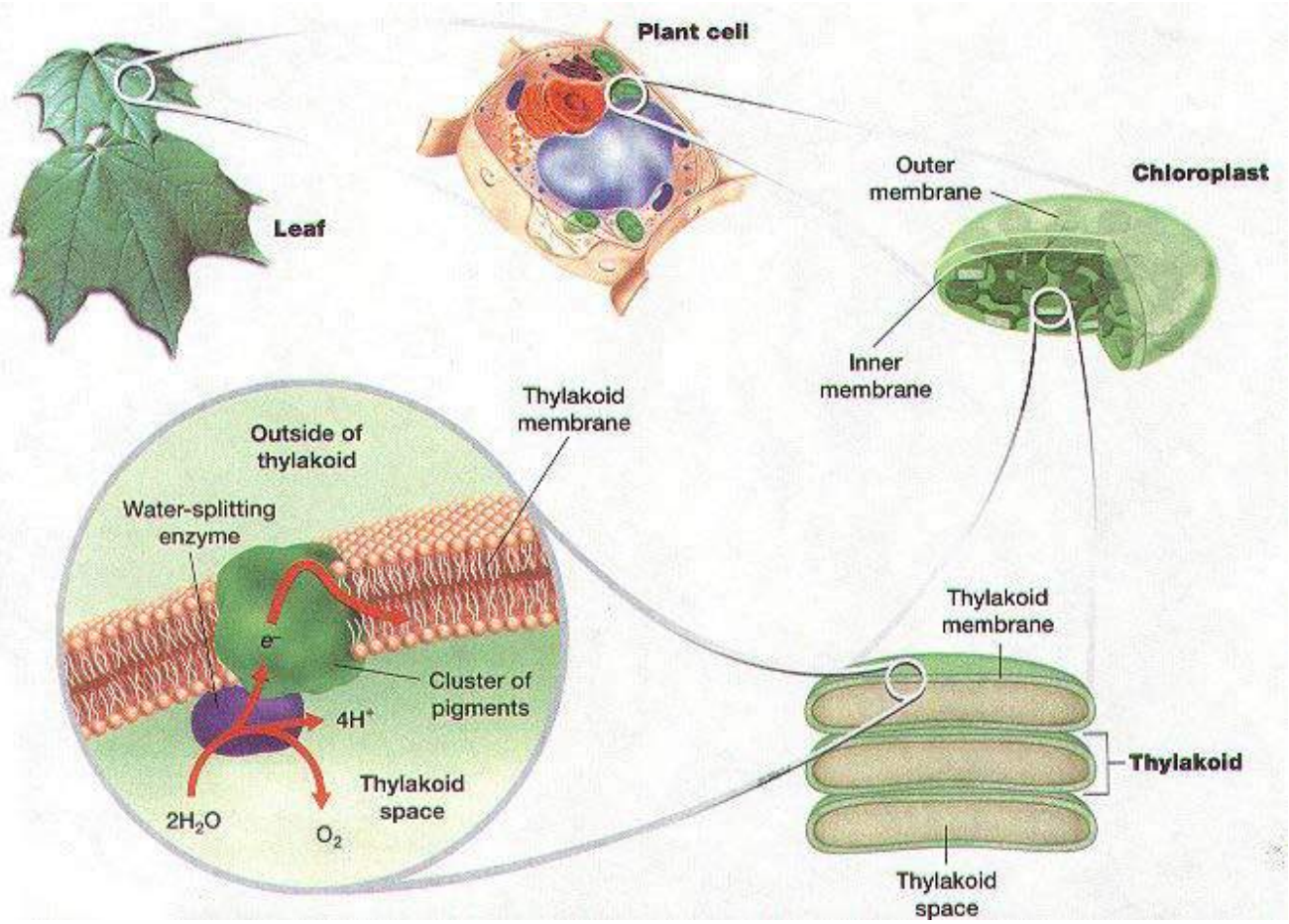
COST Fianl Conference – Sofia – 22. Feb 2018

Photosynthesis is the central metabolic process that is closely linked to plant productivity

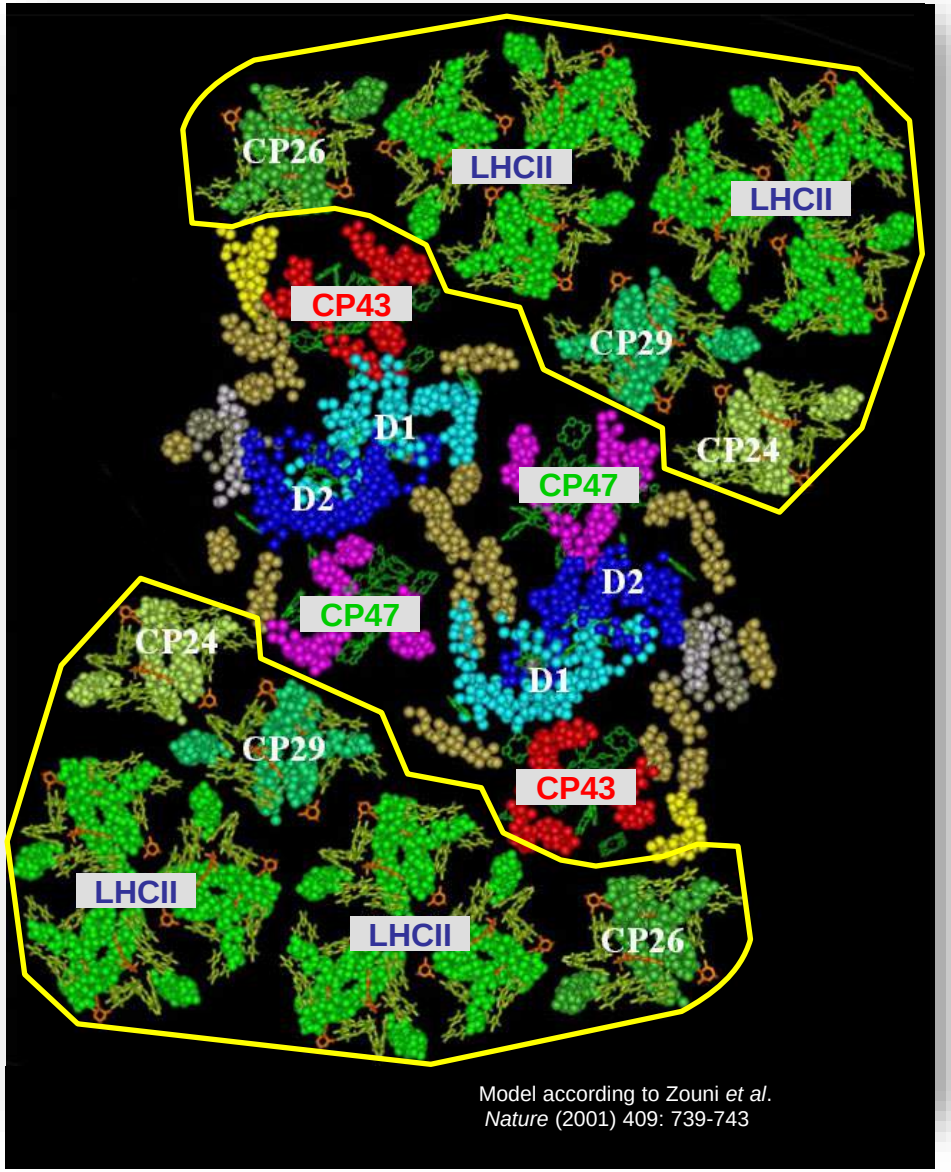
1) Photosynthesis in a nut-shell: the relevant aspect to put fluorescence into content
2) Propagation of the fluorescence signal from the chloroplasts to space
3) Status of the FLEX satellite

Photosynthesis: The fundamental biophysical and biochemical process to sustain life on earth

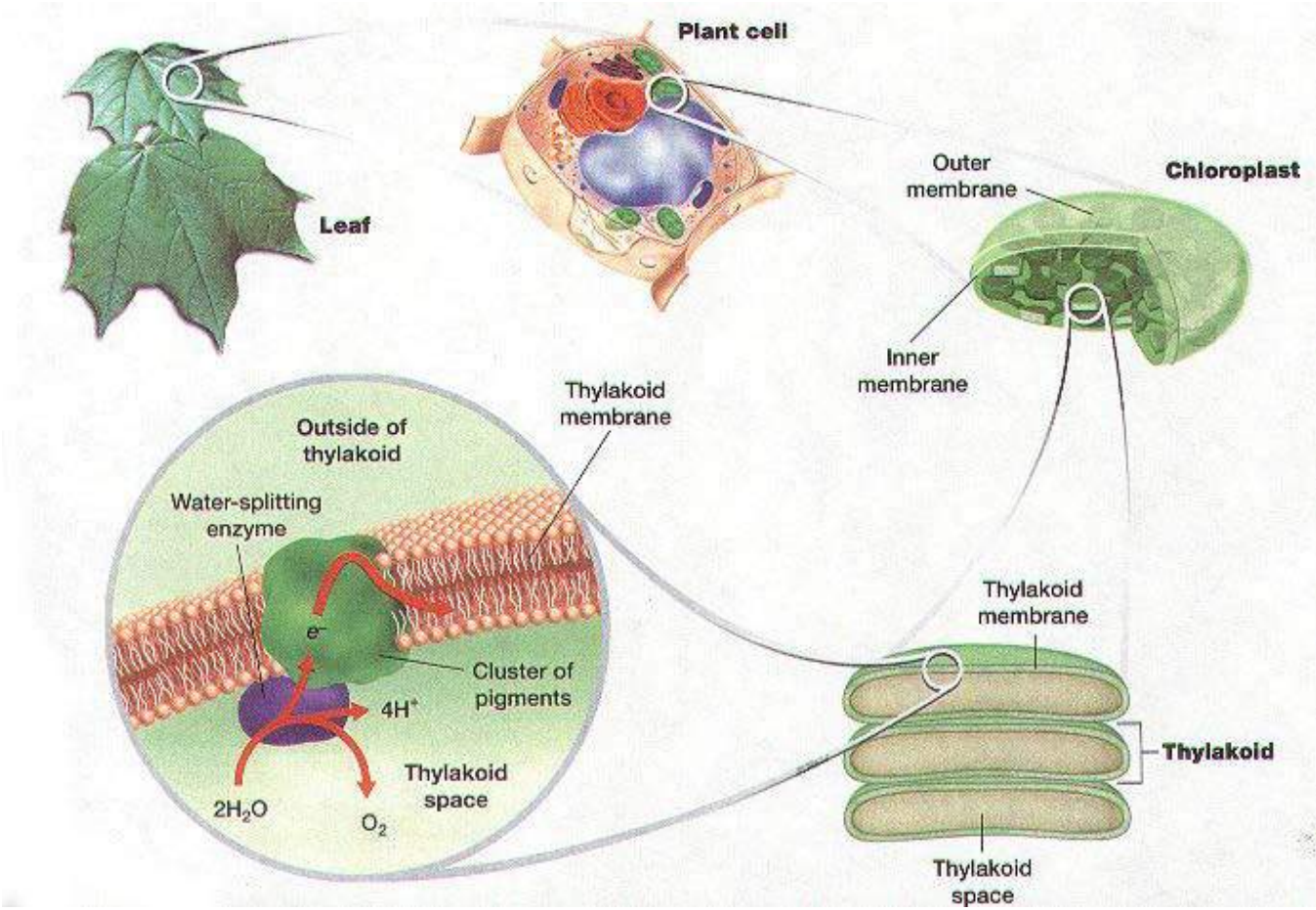




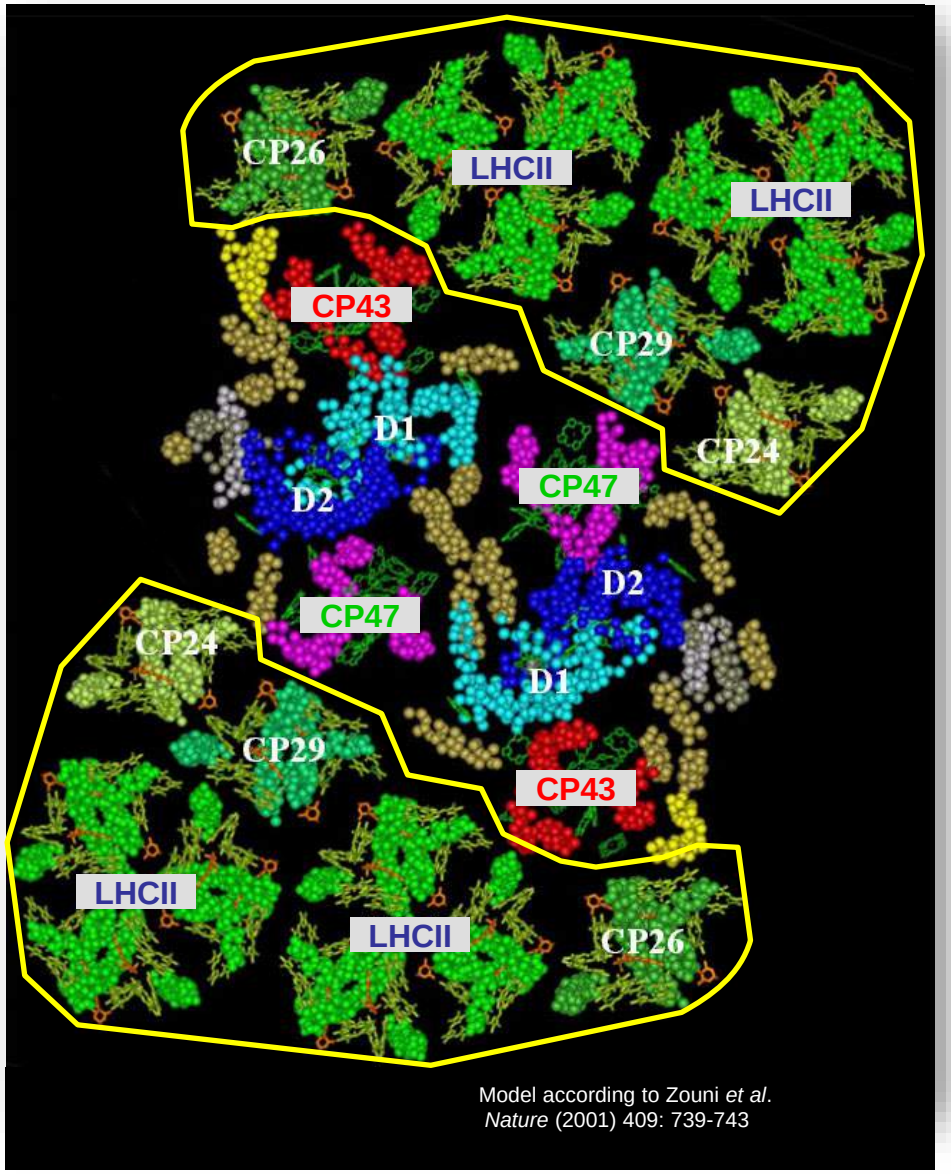
Pigments, photosystems and photosynthesis: a highly structured biological ‘super-complex’



Model according to Zouni *et al*.
Nature (2001) 409: 739-743



Photosynthesis step 1: Light reactions of photosynthesis converts light energy into electromagnetic forcing in the chloroplasts



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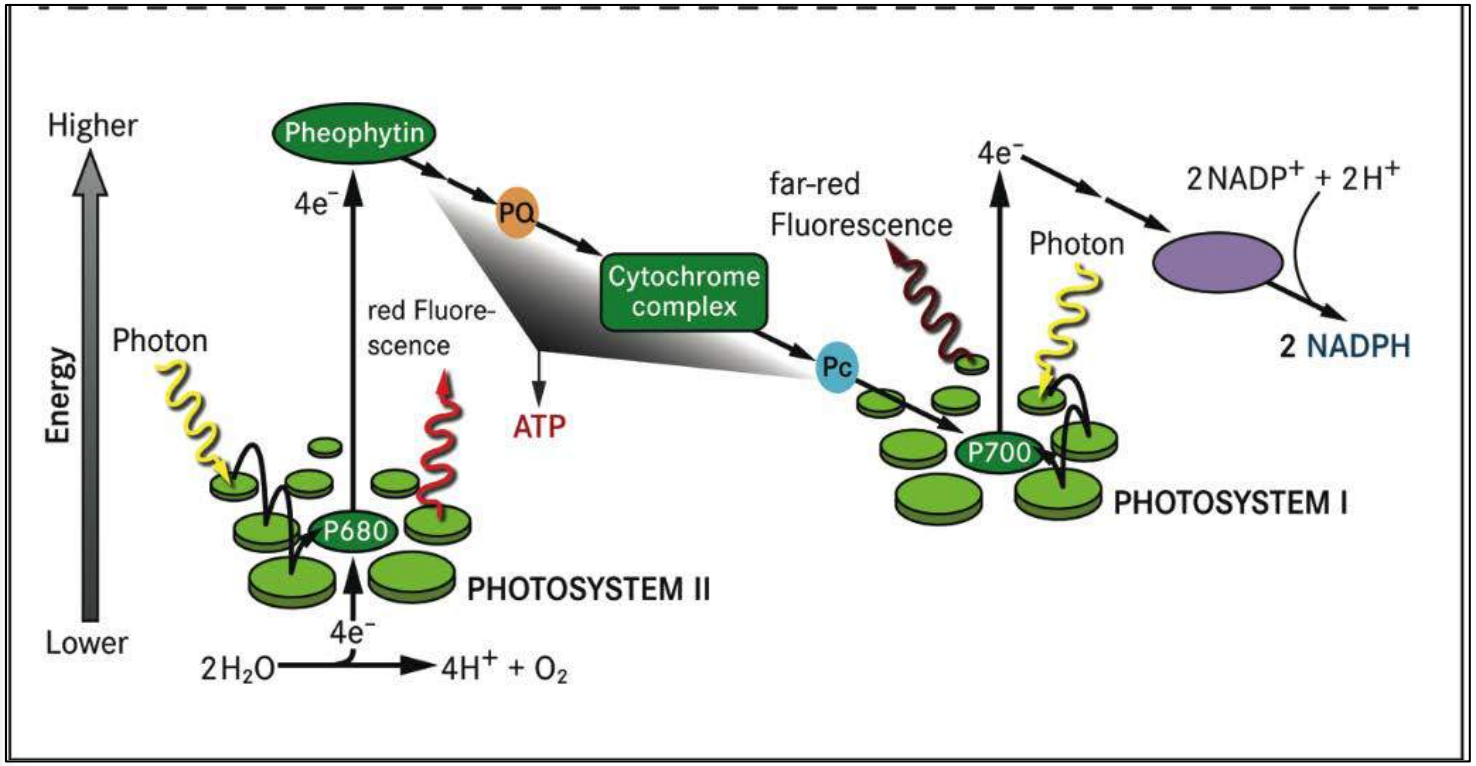
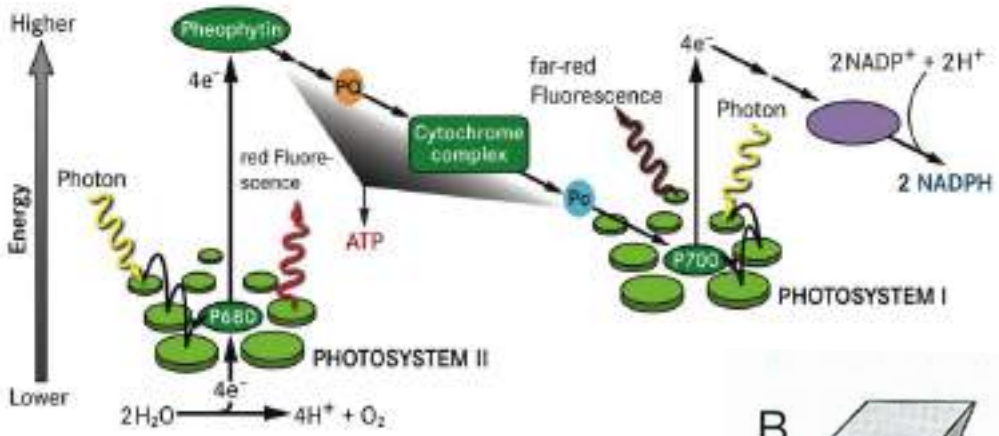
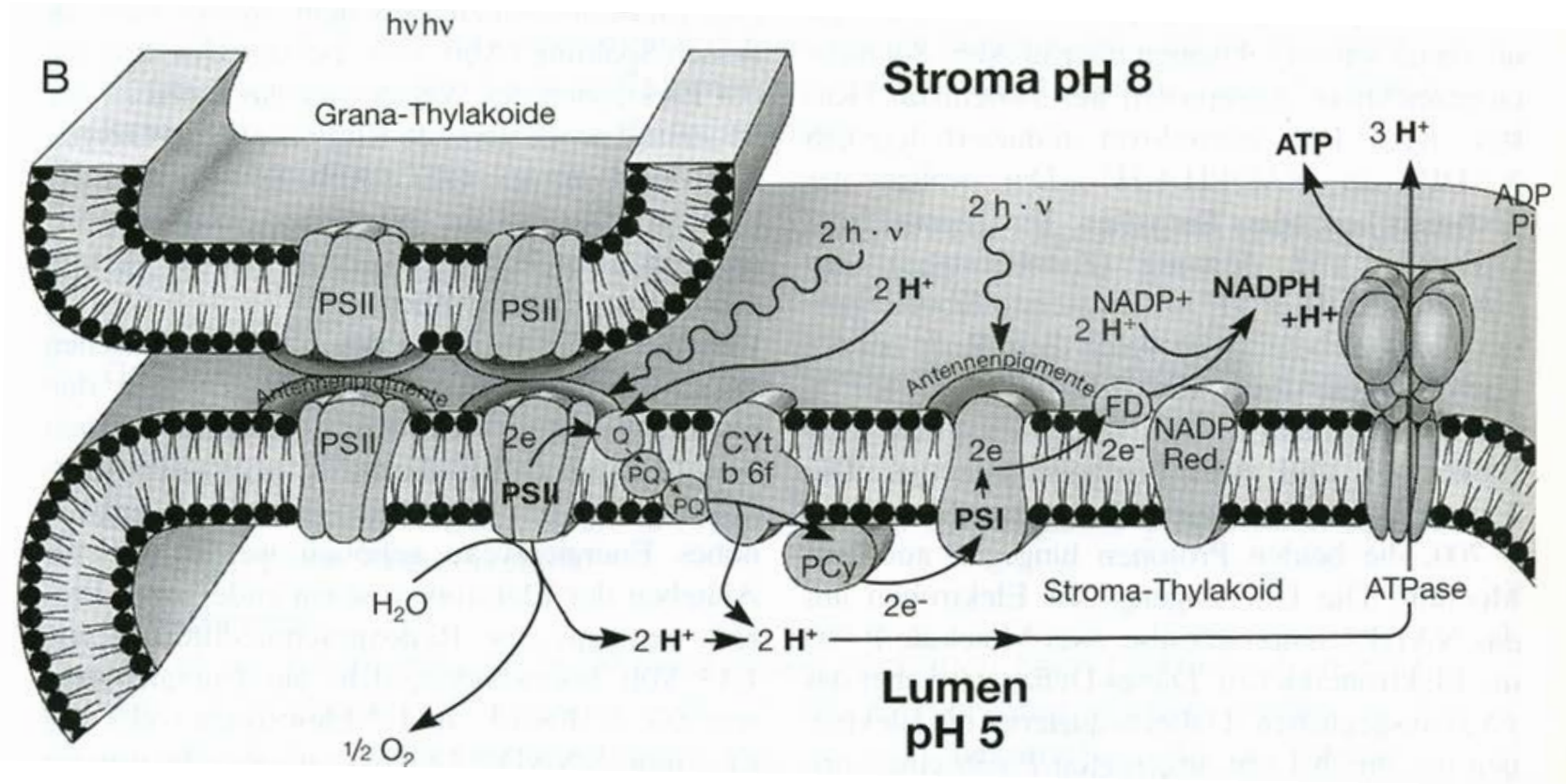
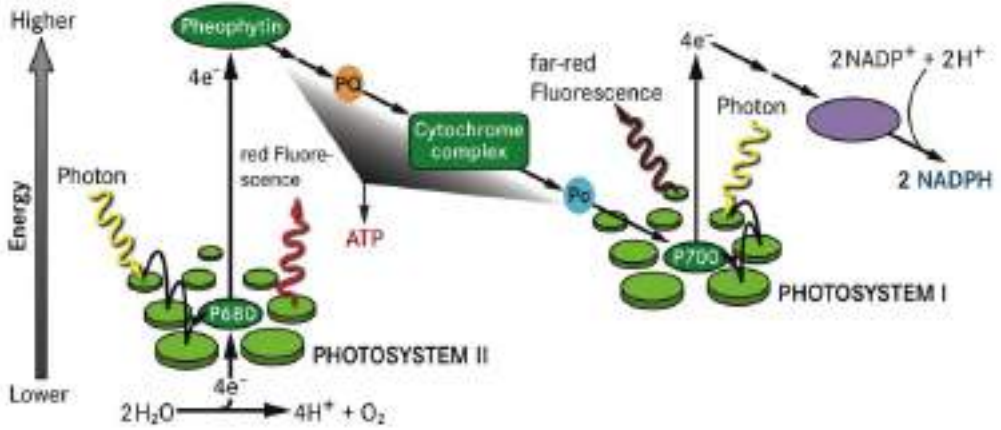


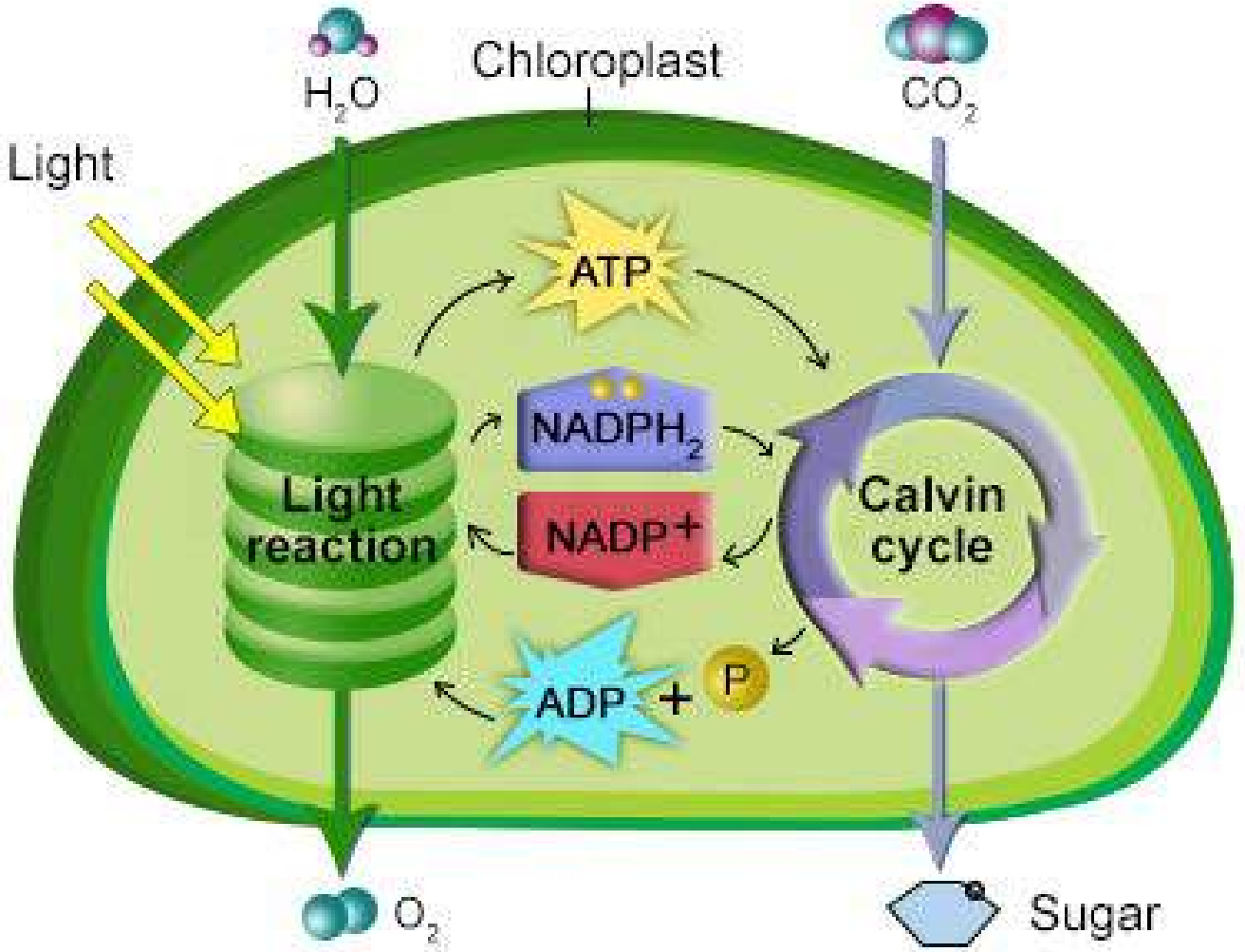
Photosynthesis step 2: Conversion of electromagnetic force to chemical enery (ATP)



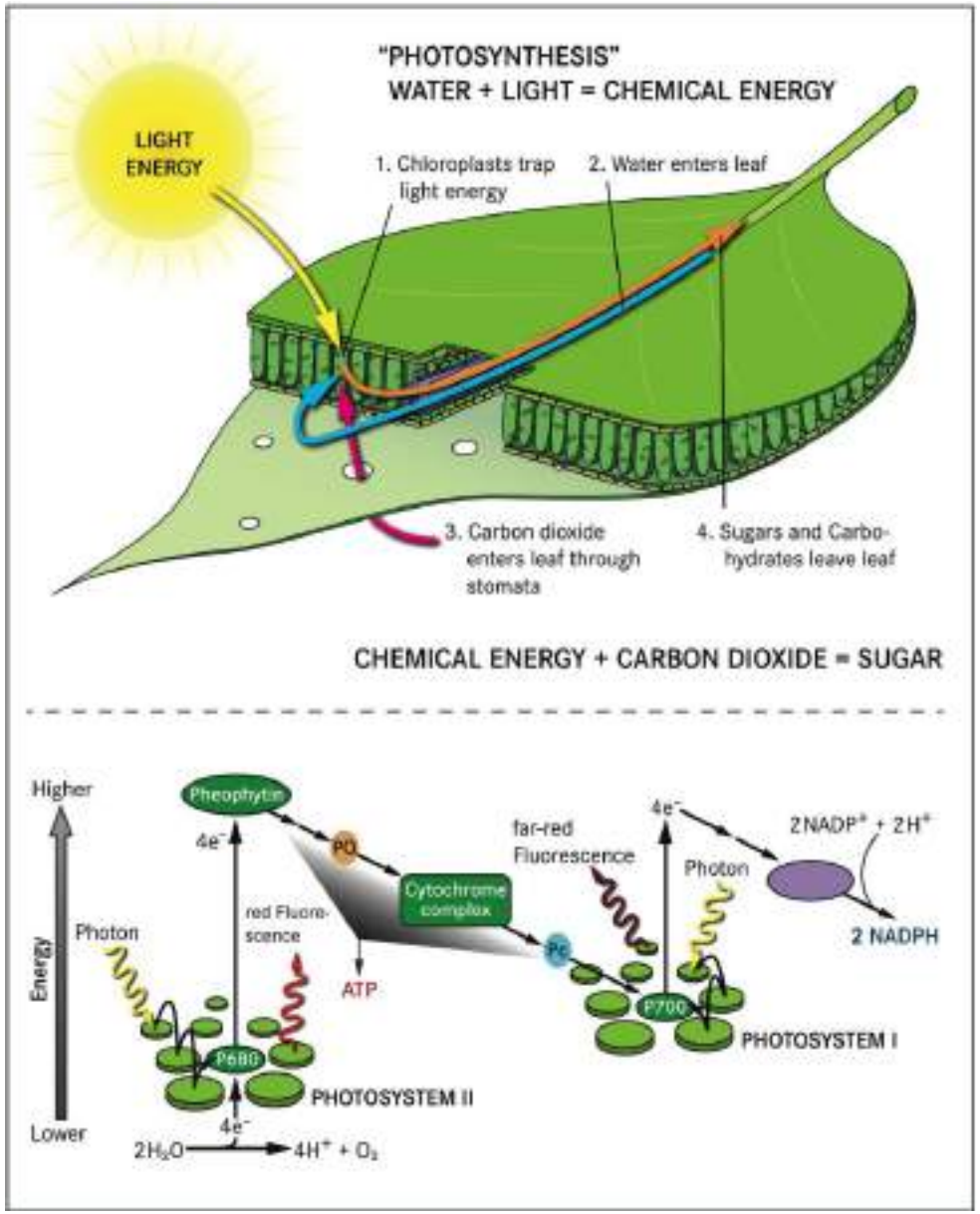


Photosynthesis step 3: Dark reactions (Calvin Cycle) uses the chemically stored energy to fix CO_2



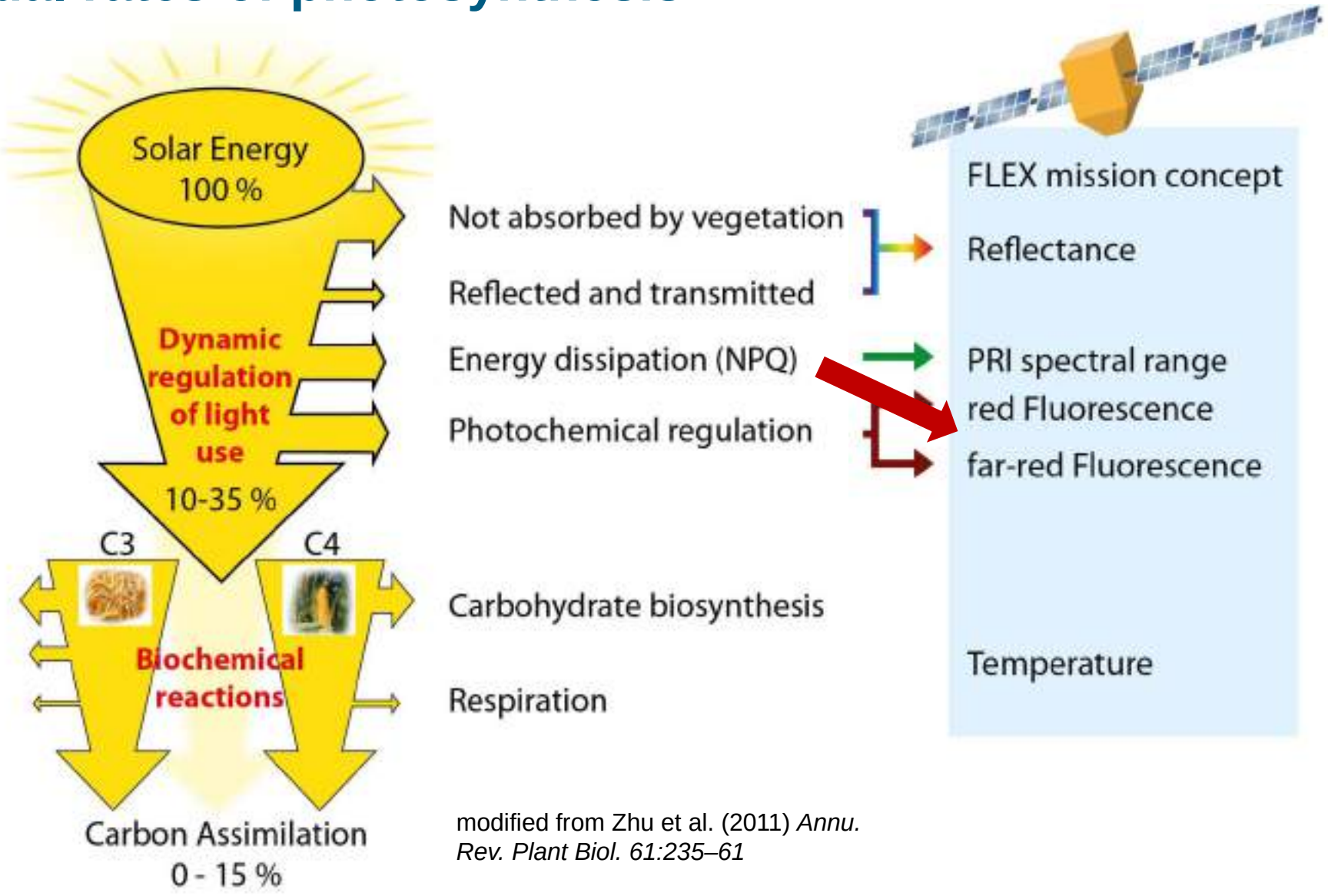


The origin of fluorescence – an indicator for photosynthetic efficiency



- Photosynthesis is a highly regulated process that involves a cascade of electron transfers (*Light reaction*) to fuel carbon fixation (*Calvin cycle*)
- Fluorescence is emitted during the first steps of photosynthesis
- To translate fluorescence to carbon fixation (or even biomass accumulation / plant growth / yield) requires an understanding of all the relevant mechanistic steps
- Lets stop to find easy correlations between fluorescence and carbon uptake, GPP or other plant traits
- The art is to find the right balance between
  - ‚Not being lost in complexity' (Plant Biologist)
  - Not naively oversimplifying

Concept to translate sun-induced fluorescence to actual rates of photosynthesis

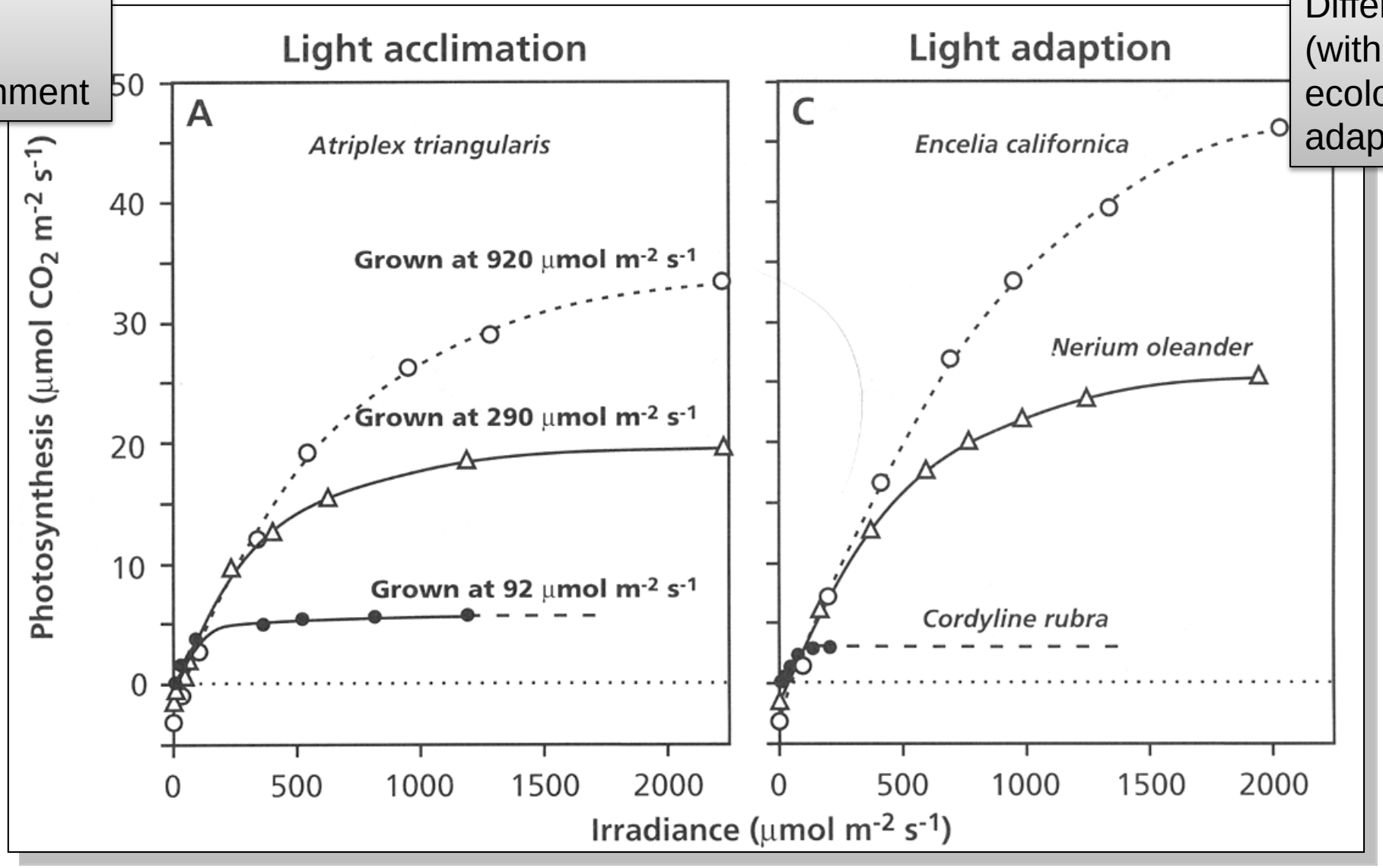


modified from Zhu et al. (2011) *Annu. Rev. Plant Biol. 61:235–61*

Example: The dynamic nature of photosynthetic carbon fixation

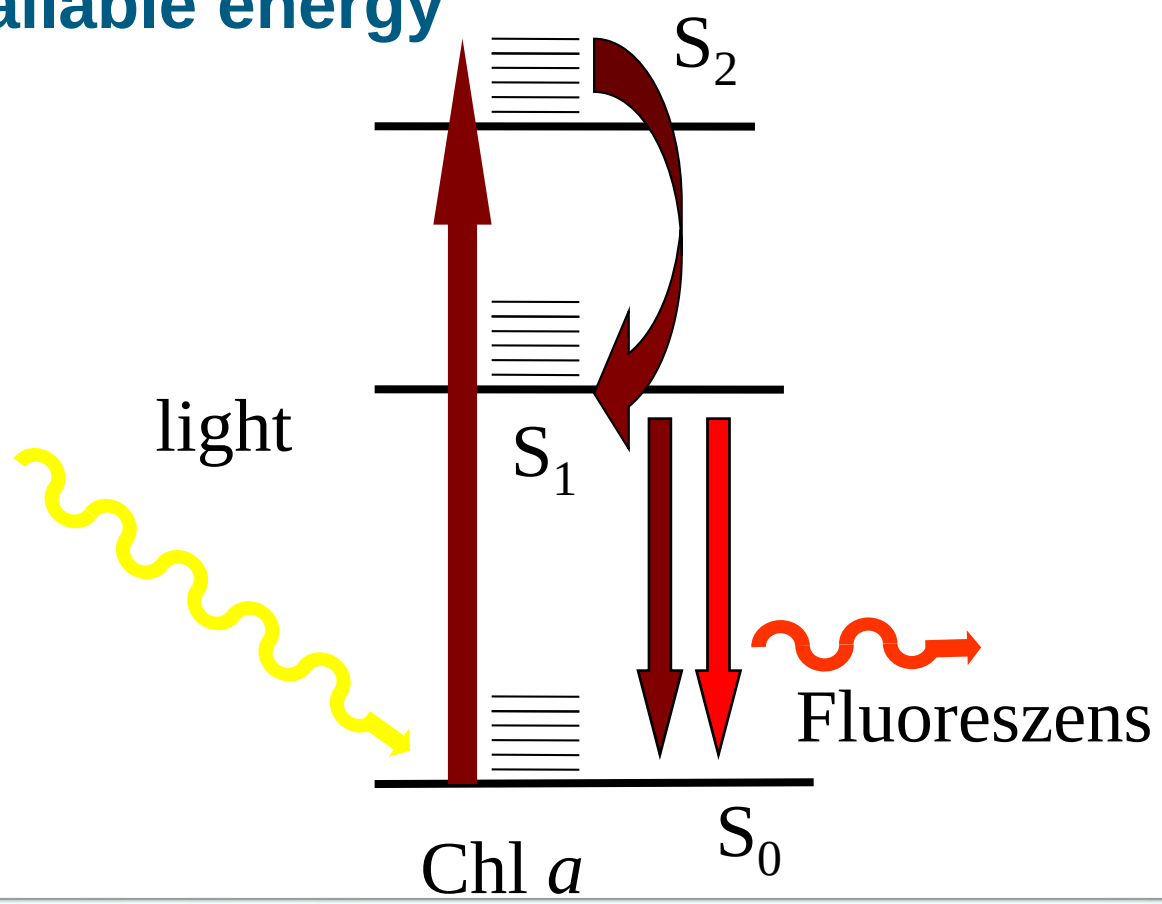
Same species acclimated to different environment

Different species (with different ecological adaptation)



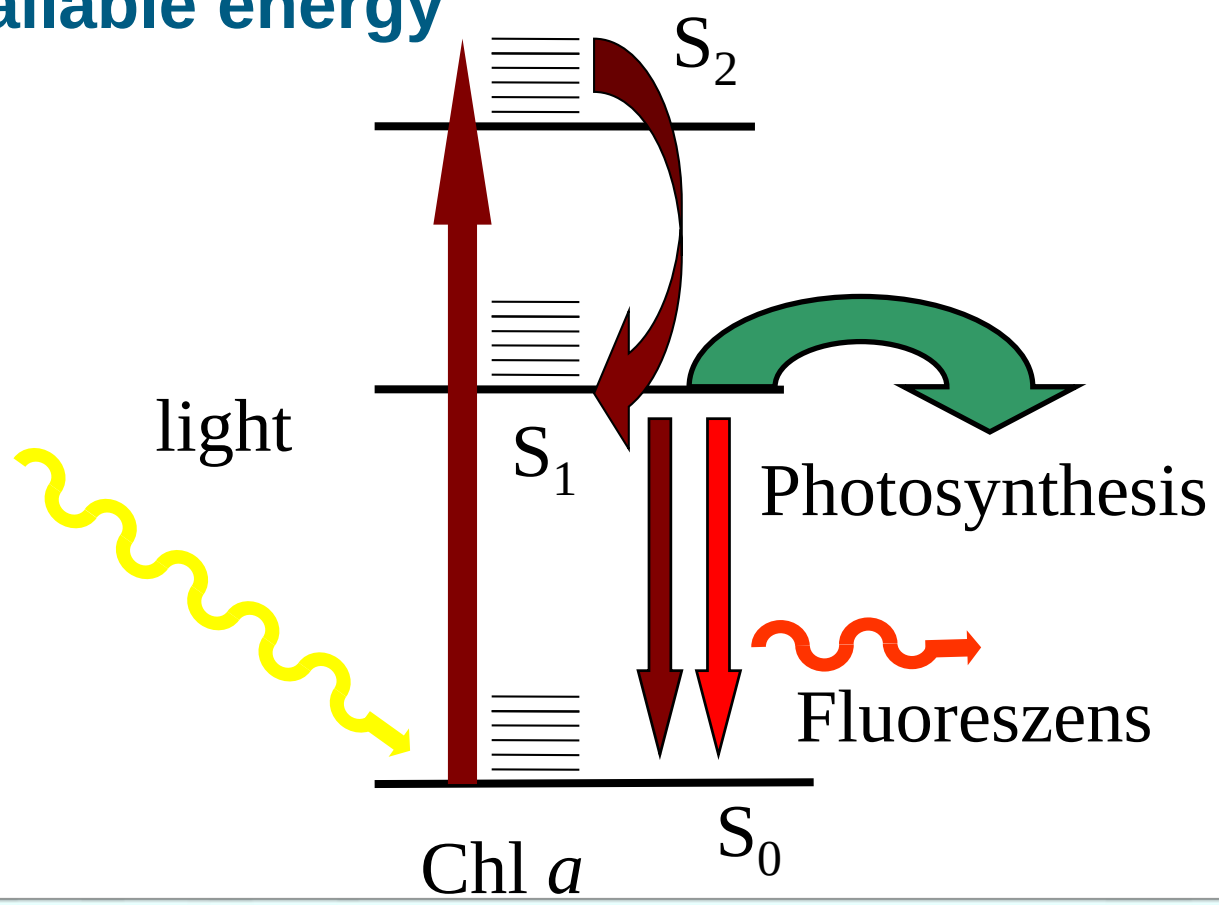
aus: Lambers, Chapin III & Pons 2000

The origin of fluorescence – an indicator for photosynthetically available energy



1. Chlorophyll molecules absorb light energy and emit fluorescence (pure biophysic). The more light the higher the fluorescence emission per molecule

The origin of fluorescence – an indicator for photosynthetically available energy



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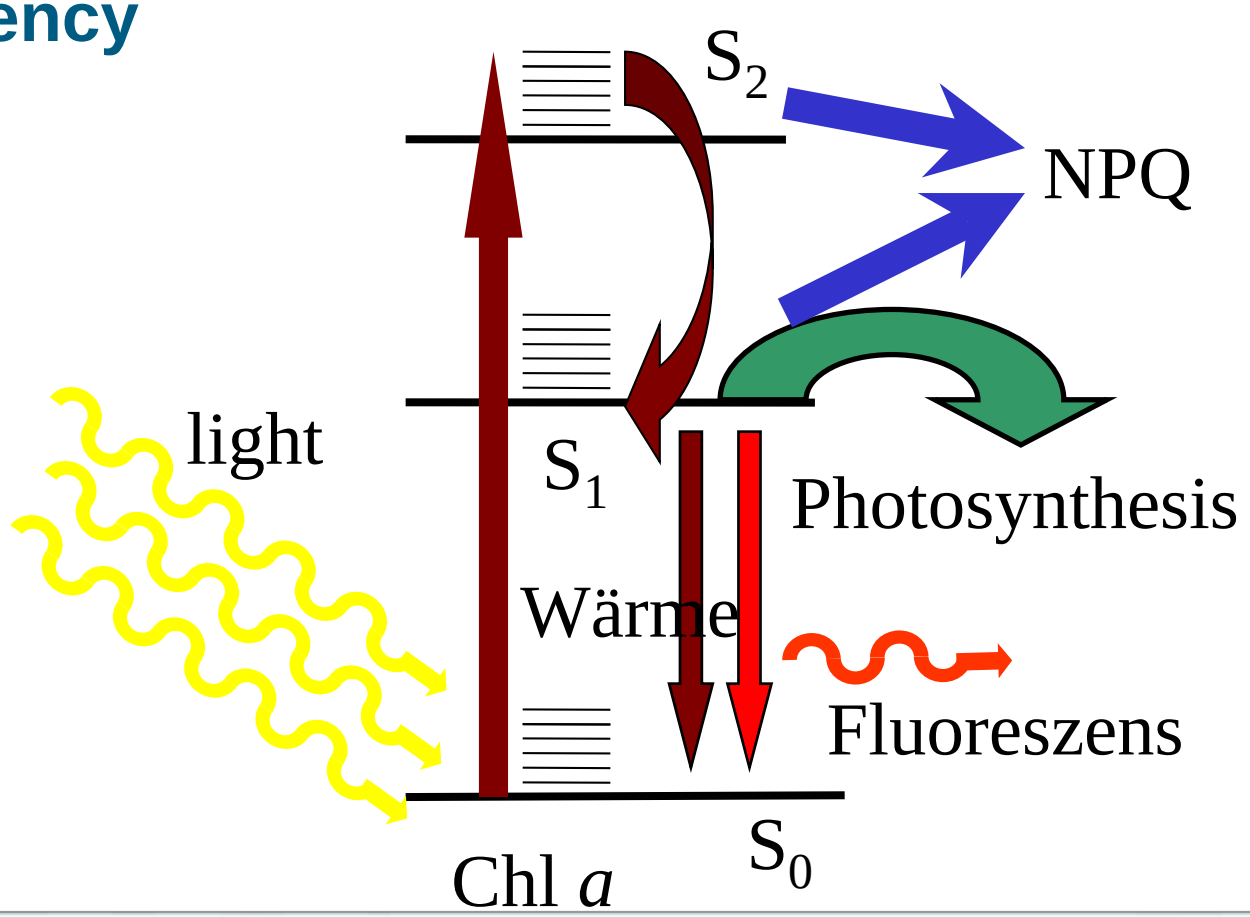
2. In natural photosystems the energy of chlorophyll molecules is quenched and partly transferred to light reaction of photosynthesis

The origin of fluorescence – an indicator for photosynthetic efficiency



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The origin of fluorescence – two photosystems: two different fluorescence emission spectra

Biochimica et Biophysica Acta, 462 (1977) 307–313

BBA 47380

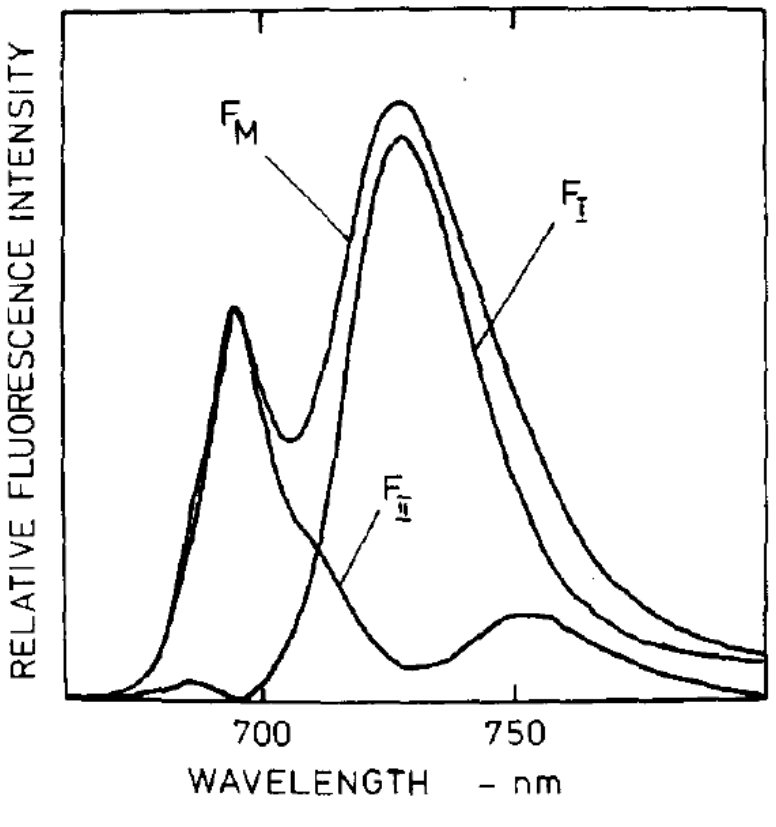
FLUORESCENCE EMISSION SPECTRA OF PHOTOSYSTEM I, PHOTOSYSTEM II AND THE LIGHT-HARVESTING CHLOROPHYLL *a*/*b* COMPLEX OF HIGHER PLANTS

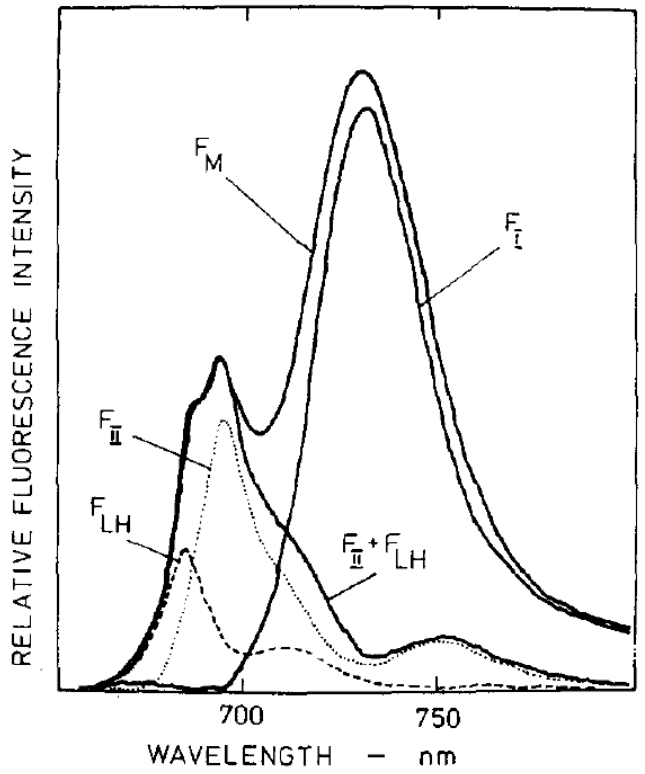
RETO J. STRASSER and WARREN L. BUTLER

Department of Biology, University of California, San Diego, La Jolla, Calif. 92093 (U.S.A.)

Several more papers are available from the pioneers of fluorescence working in the past millennium

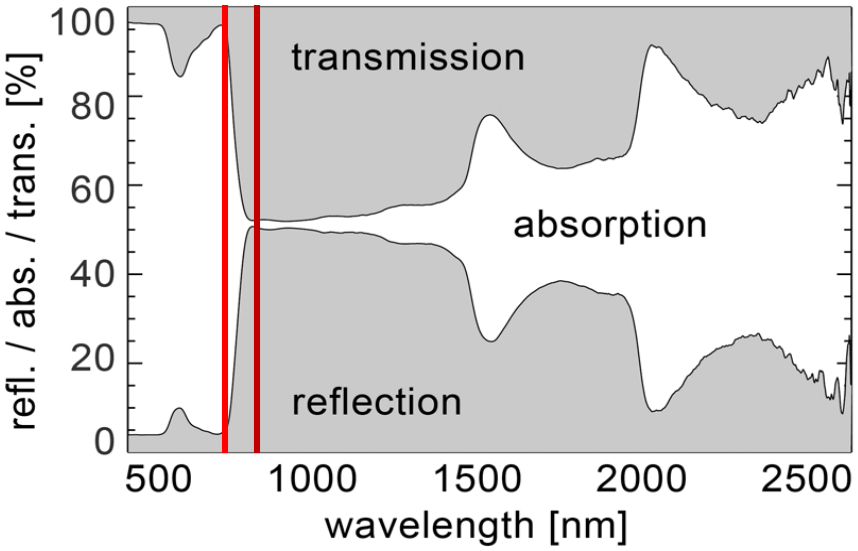
The origin of fluorescence – two photosystems: two different fluorescence emission spectra



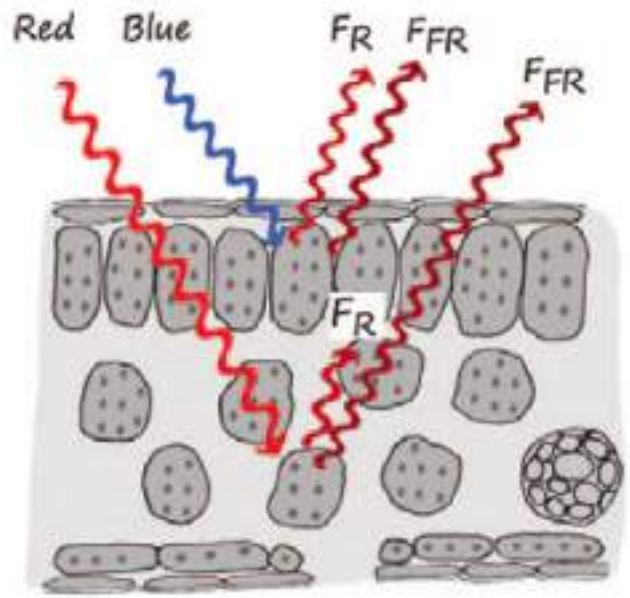


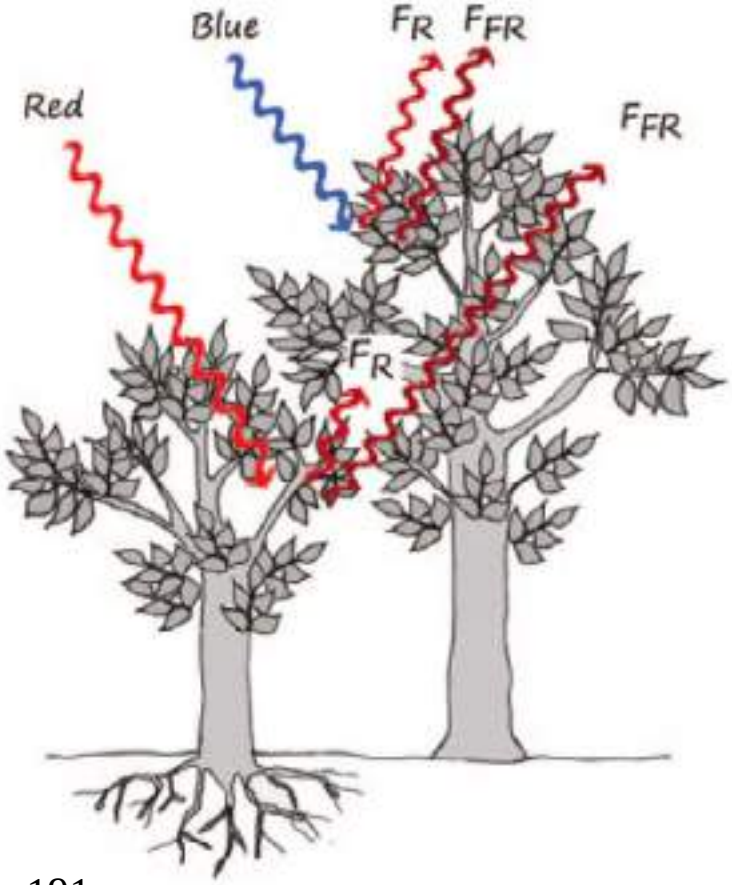
- Photosystem I: One peak in the far-red
- Photosystem II: Two peaks in the red and far-red
- **BUT**!!! Photosystem I fluorescence is 10-30 fold weaker than Photosystem II fluorescence (upper figure is scaled!)

Two peak feature of fluorescence is affected by reabsorption in the leaf and the canopy



Rascher et al. (2010) *Precision Crop Protection, Springer, ISBN: 978-90-481-9276-2*, pp 87-100





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

Strong absorption of the red peak, weak absorption of the far-red peak

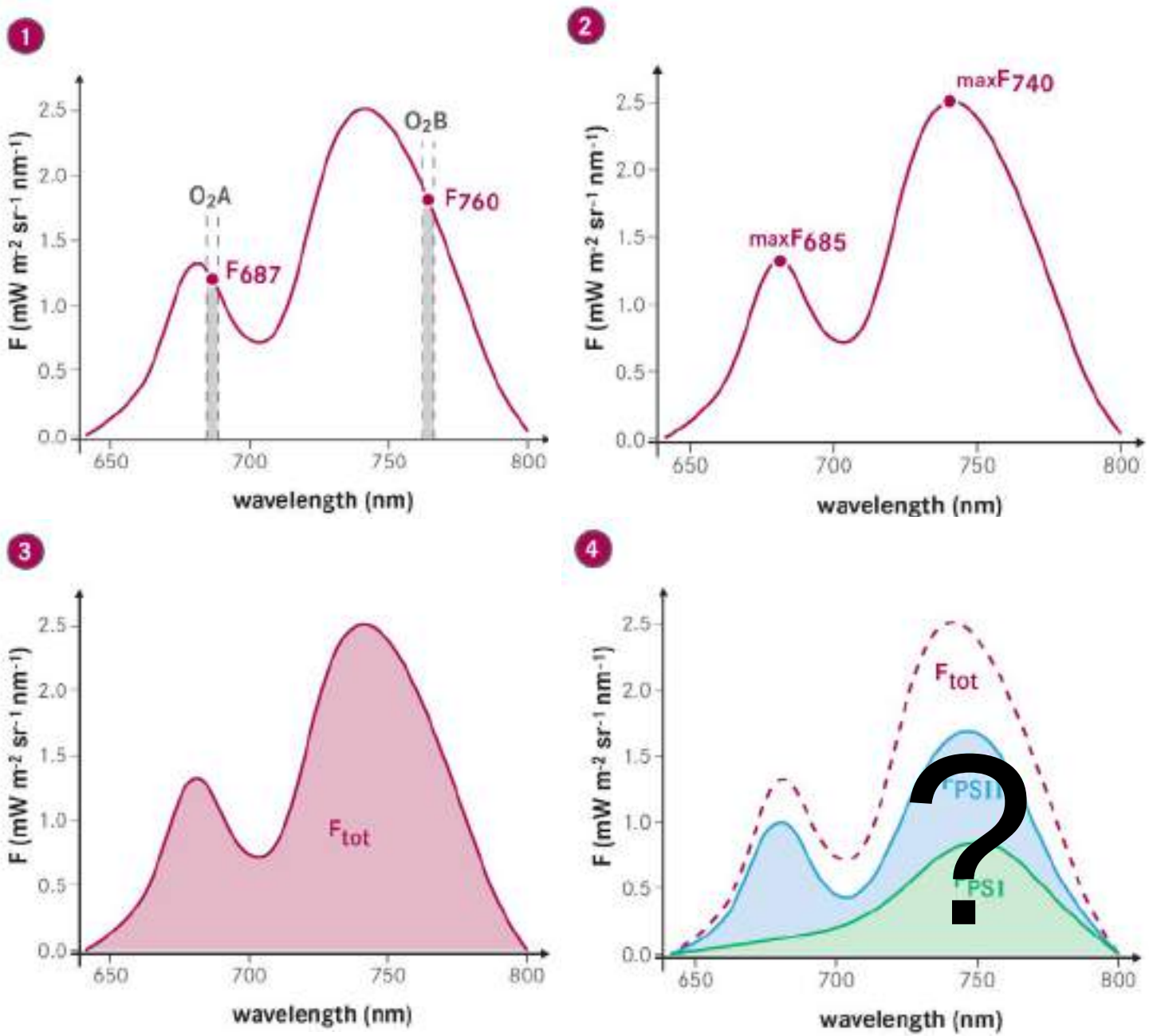
FLEX L2 product 1: Fluorescence emission

(1) Fluorescence emission at the oxygen absorption bands (O_2-A & O_2-B) (**F_{687}** and **F_{760}**)

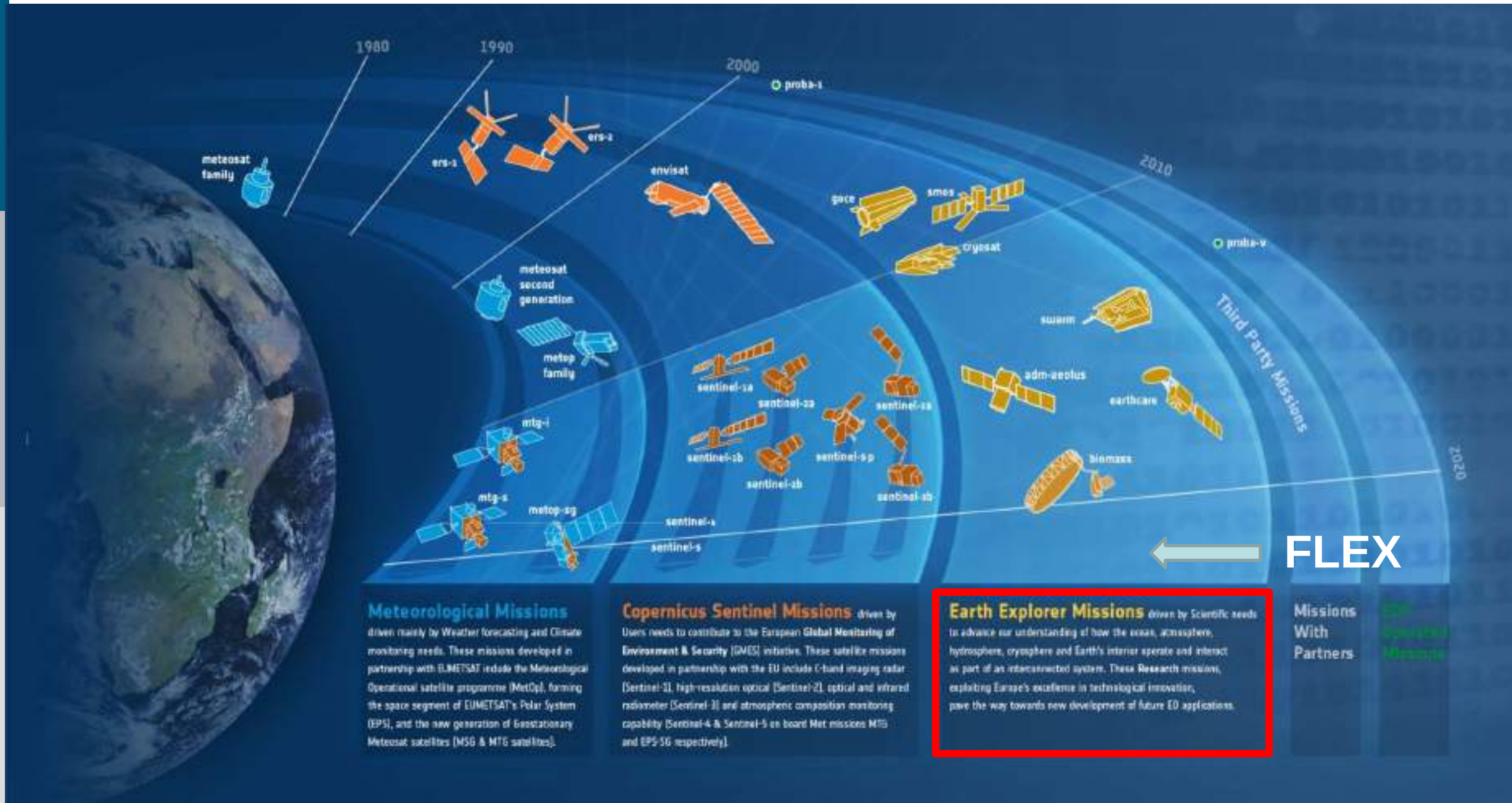
(2) Fluorescence emission at two peaks and the position of the peaks (**$\lambda_{<680>}$**, **$F_{<680>}$**, **$\lambda_{<740>}$**, **$F_{<740>}$**)

(3) Total, integrated fluorescence emission (**F_{tot}**)

(4) Fluorescence emission from the two photosystems (PSI & PSII) (**F_{PSI}** and **F_{PSII}**)



ESA’s Earth Observation satellites

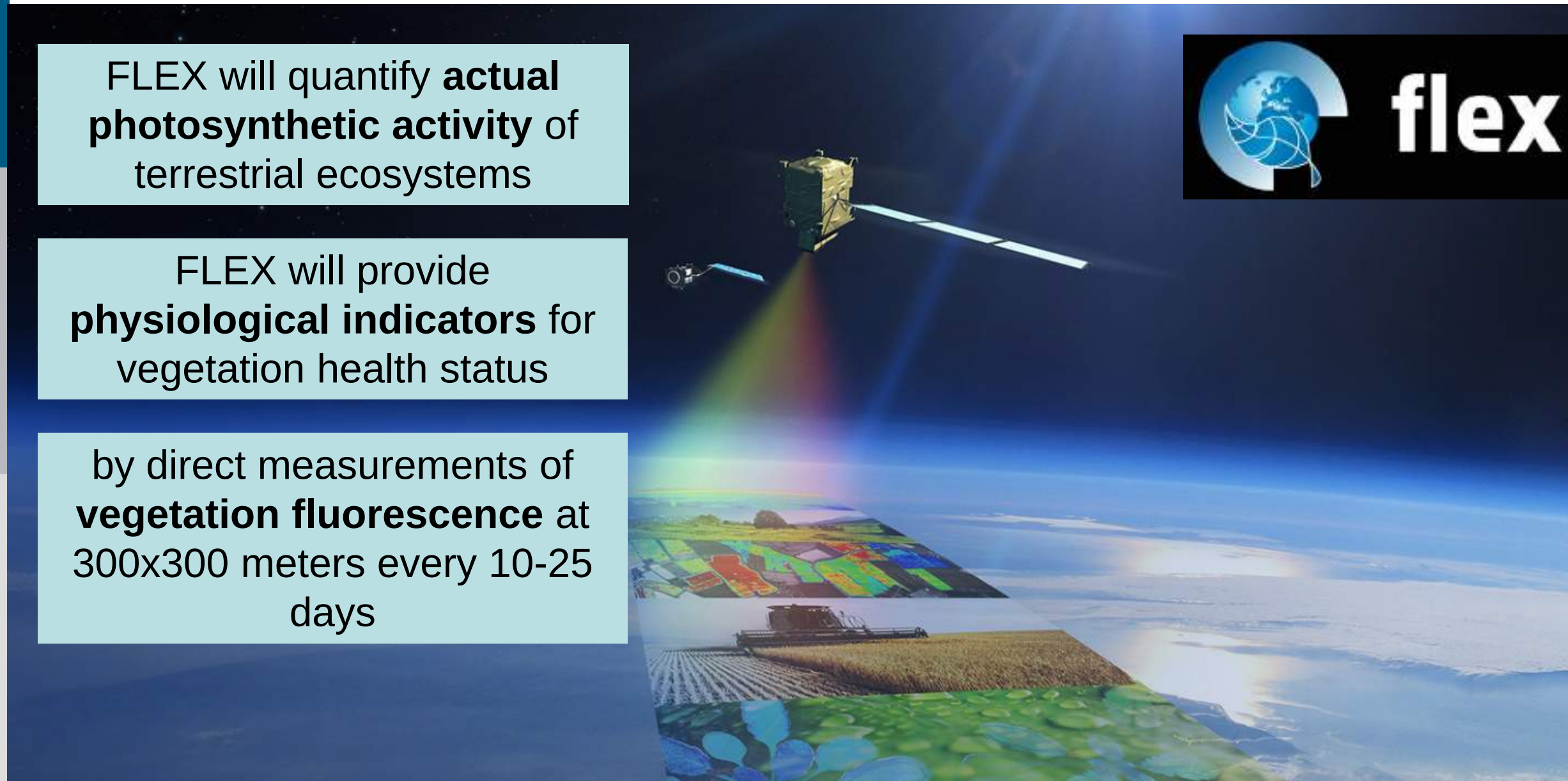


FLEX Satellite Mission will become the 8th Earth Explorer of ESA

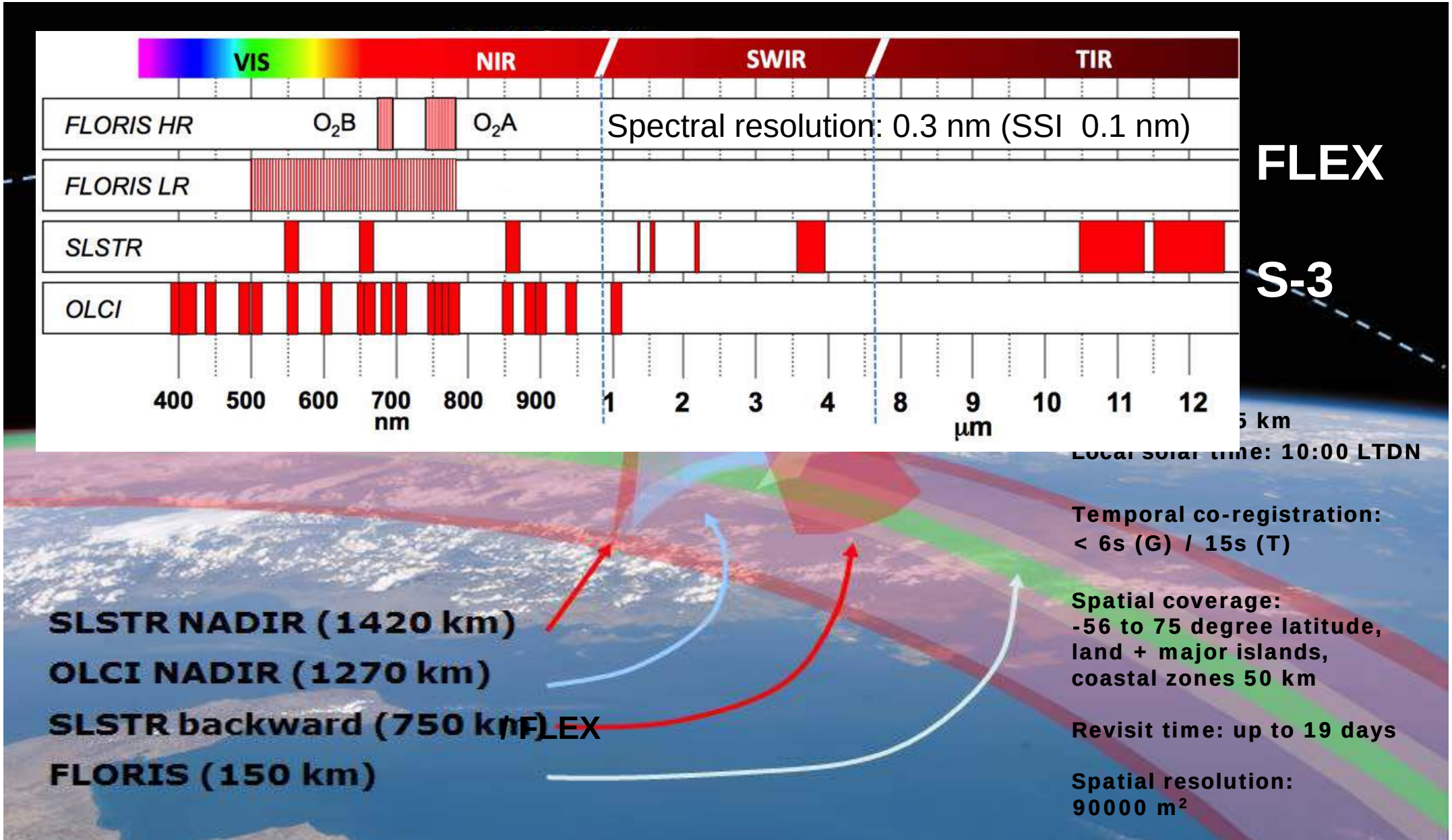
FLEX will quantify **actual photosynthetic activity** of terrestrial ecosystems

FLEX will provide **physiological indicators** for vegetation health status

by direct measurements of **vegetation fluorescence** at 300x300 meters every 10-25 days



FLEX Satellite Mission – a tandem concept with Sentinel-3



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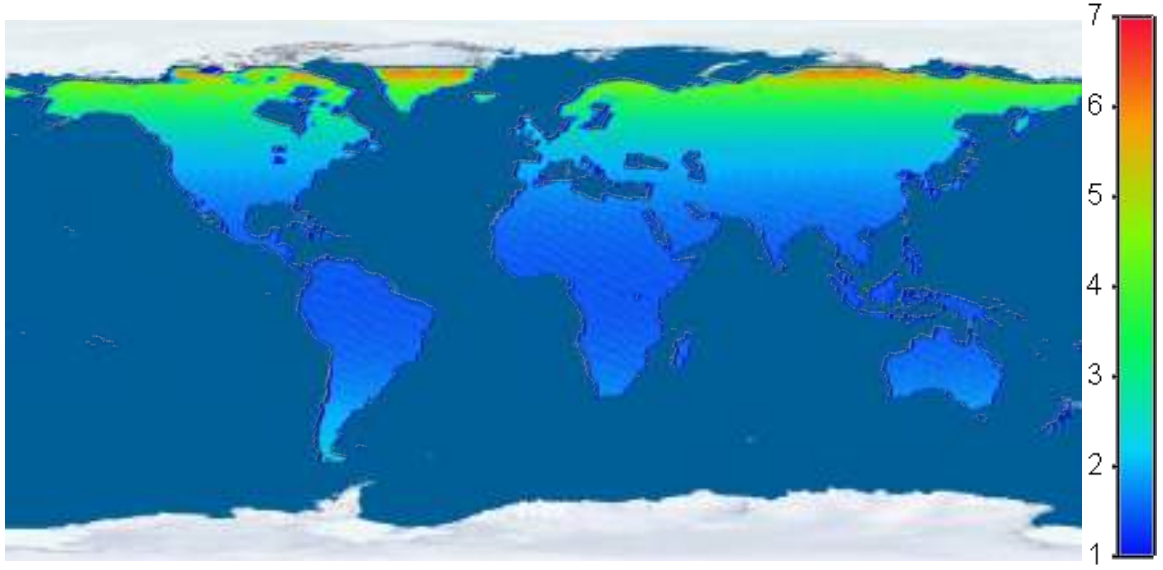
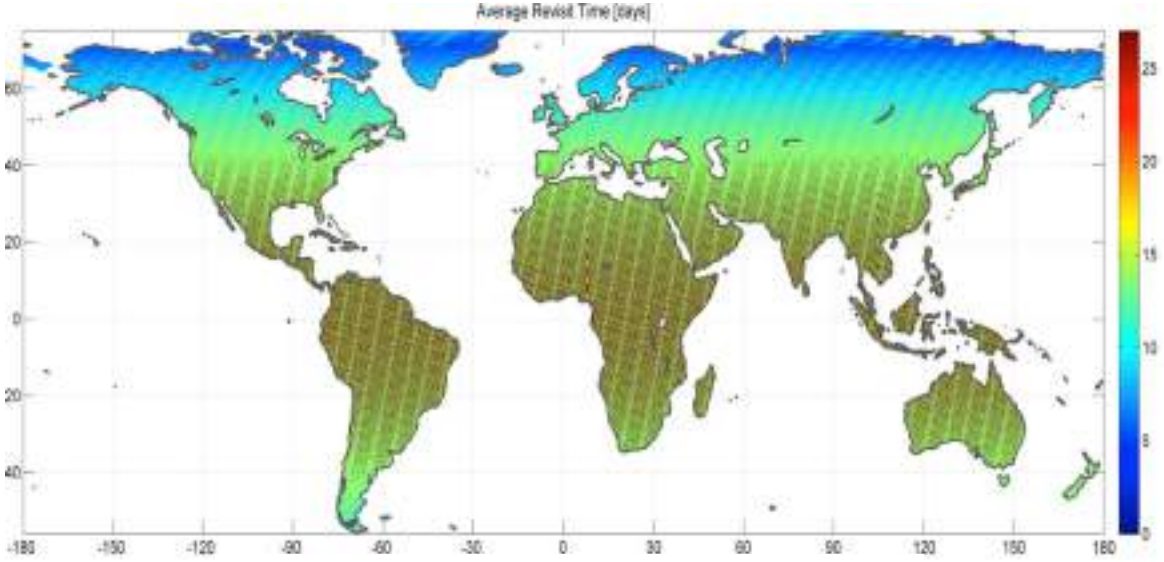


Number of acquisitions within a repeat cycle

Average revisit time (days)

- FLEX will acquire images of all land between 56° S to 75° N, including major islands and coastal areas
- 300 x 300 meter pixels
- Launch is scheduled for 2022
- Full coverage every 27 days



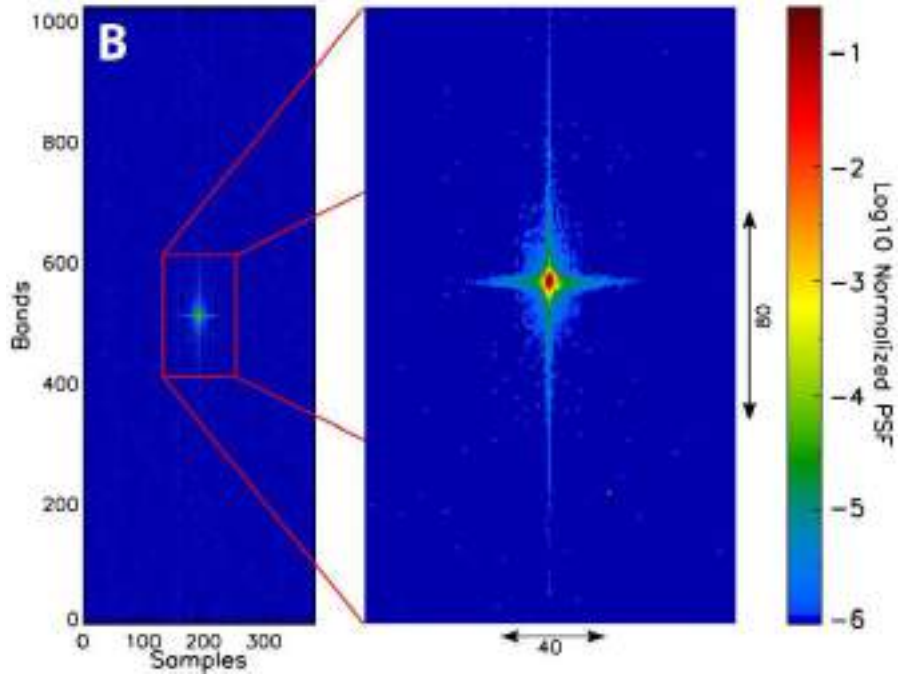
Longitude

Average revisit time:

- 27 days at Equator
- ~ 20 days at Tropics
- ~ 10 to 15 days over Europe and Canada
- ~ 5 to 10 days over boreal forests

Elements of the FLEX Satellite Mission are produced, assembled and tested

- Industrial contracts are in place and components of the instrument are produced
- Special care is given to spectral performance with the point spread function and stray light being a driving factor for instrument design
- Elements are assembled in a clean room at ESA and performance testings are ongoing



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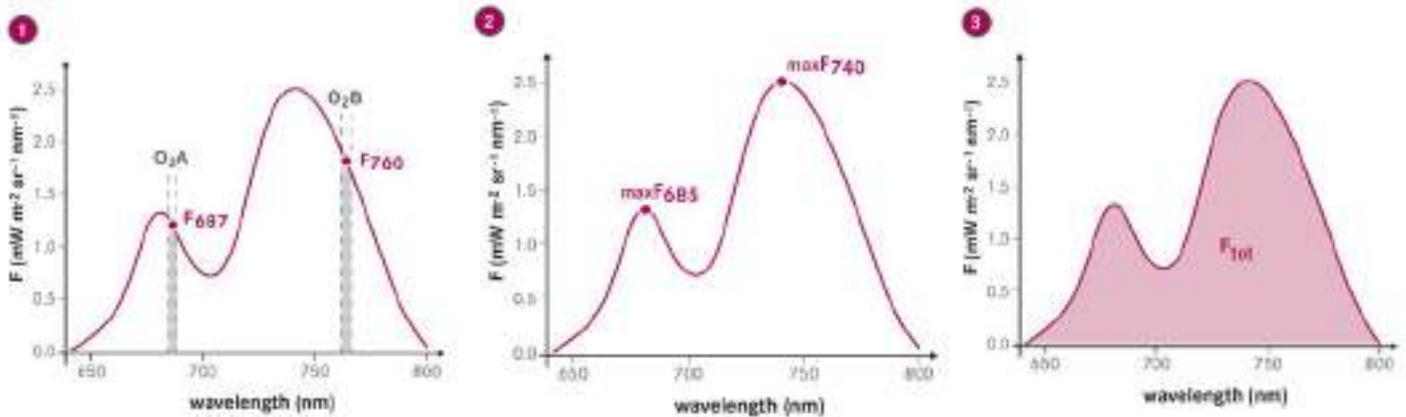

Level 2a TOA radiances

Level 2b TOC irradiance and apparent reflectance

Level 2c O_2-A and O_2-B TOC fluorescence emission values (F_{687} and F_{760})

Level 2c Peak values and peak position of TOC fluorescence emission ($maxF_{red}$, λ_{red}, $maxF_{far\text{-}red}$ and $\lambda_{far\text{-}red}$)

Level 2c Total TOC fluorescence emission (F_{tot})

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- Product development has started and ESA will develop products up to lvl 2
- Preparation for ground segment and Cal / Val has started and various activities are ongoing there (large campaign to obtain reference data set in 2018)

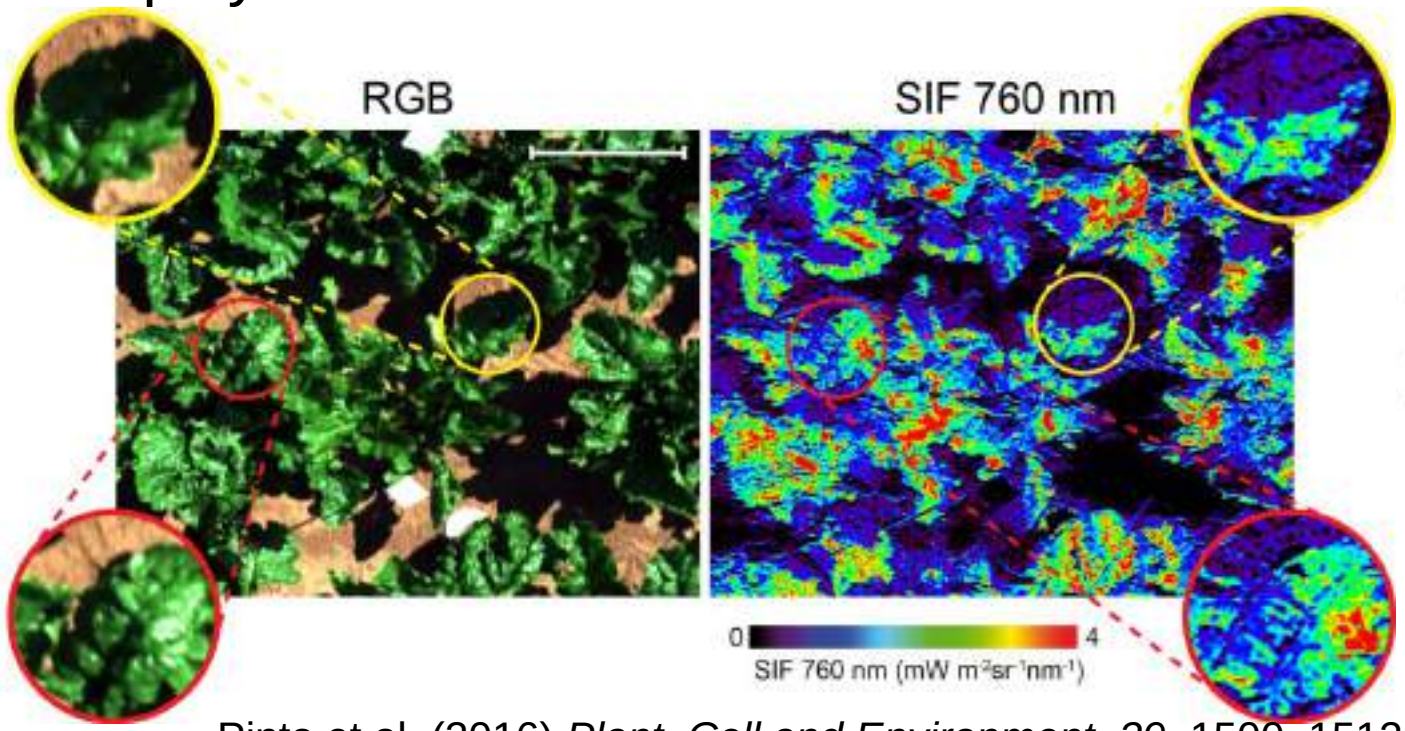
2012

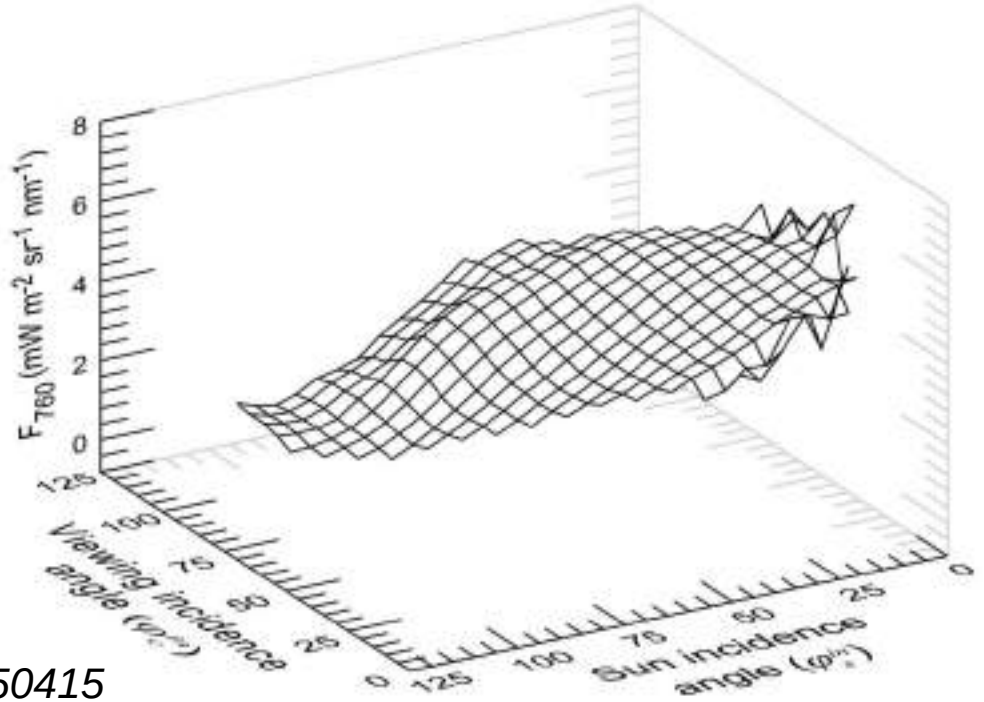
2016

To complement space and 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

First estimate of BRDF characteristics of fluorescence





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

Pinto et al. (2017) *Remote Sensing, 9, 415, doi: 10.3390/rs9050415*

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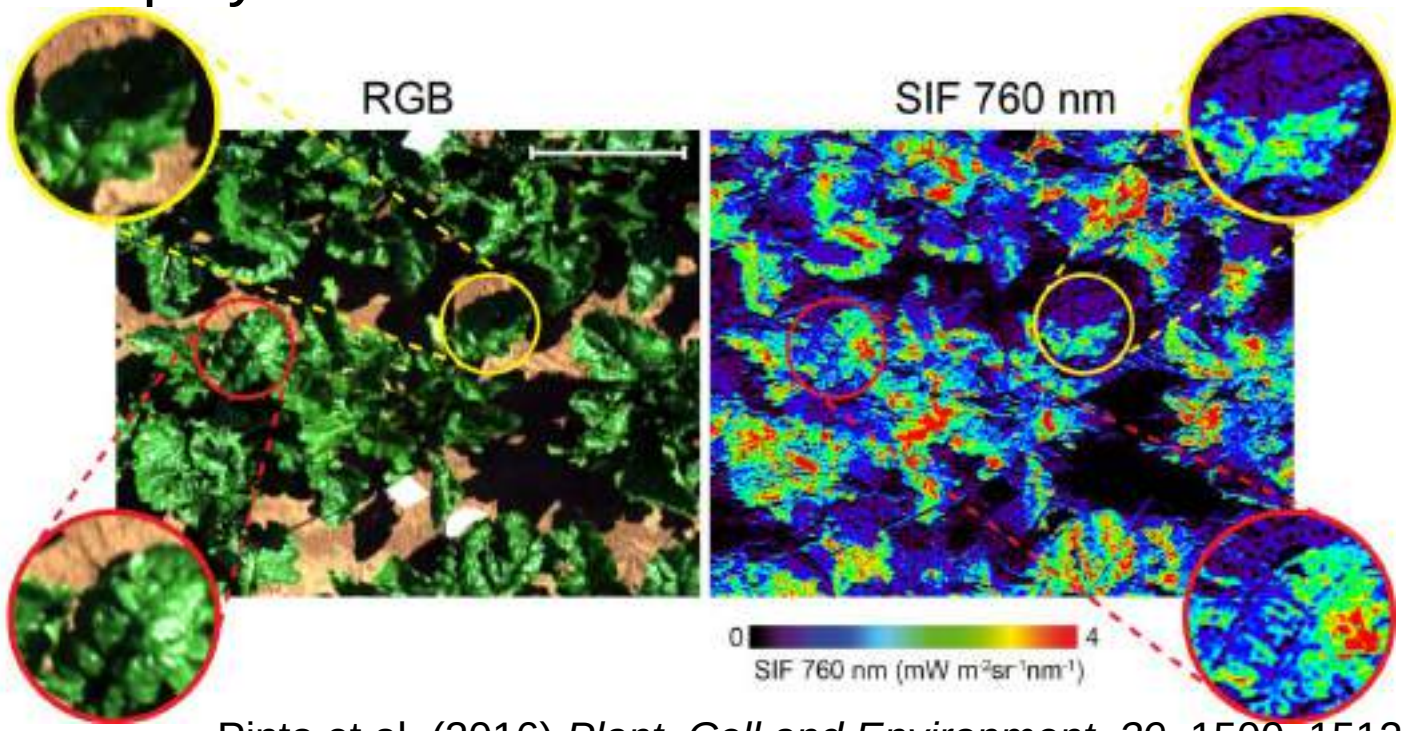
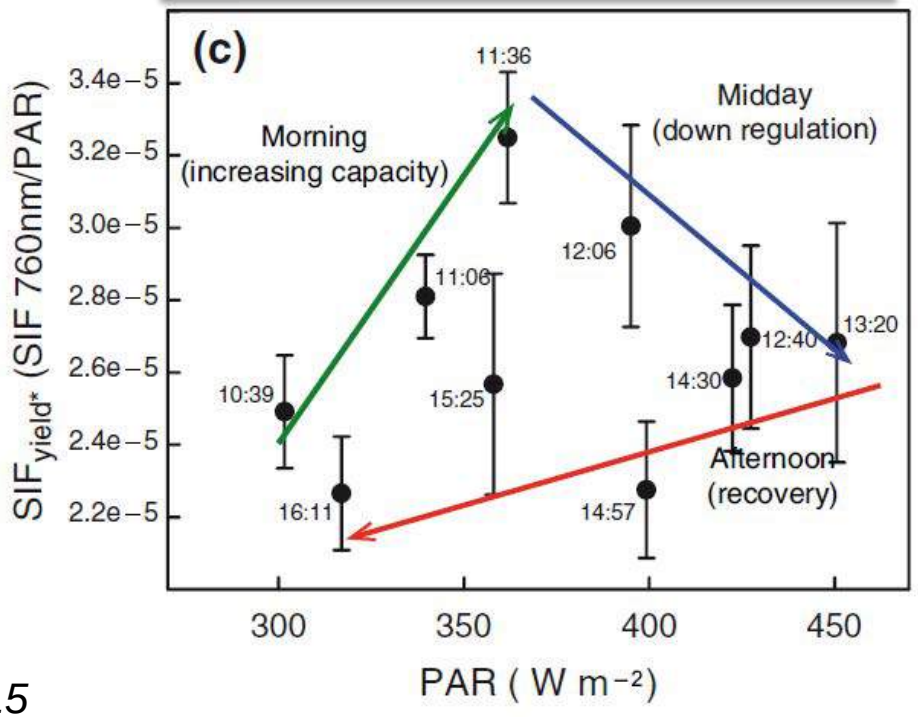


Diurnal course of sun-lit leaves of upper canopy



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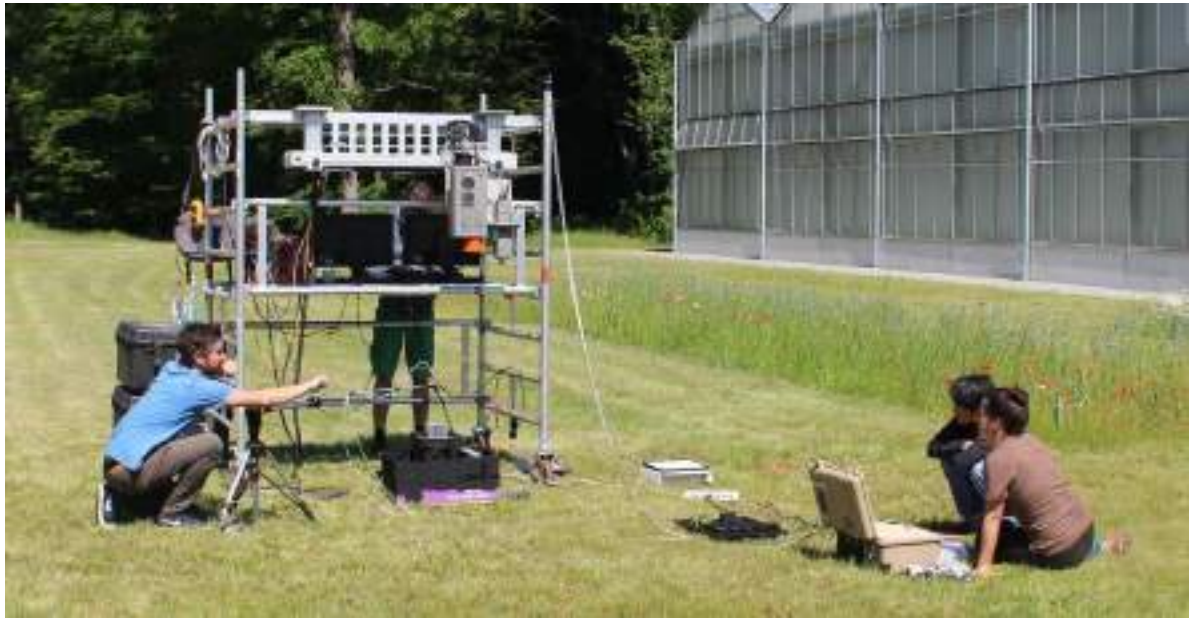
What are we doing to complement airborne mapping of fluorescence?

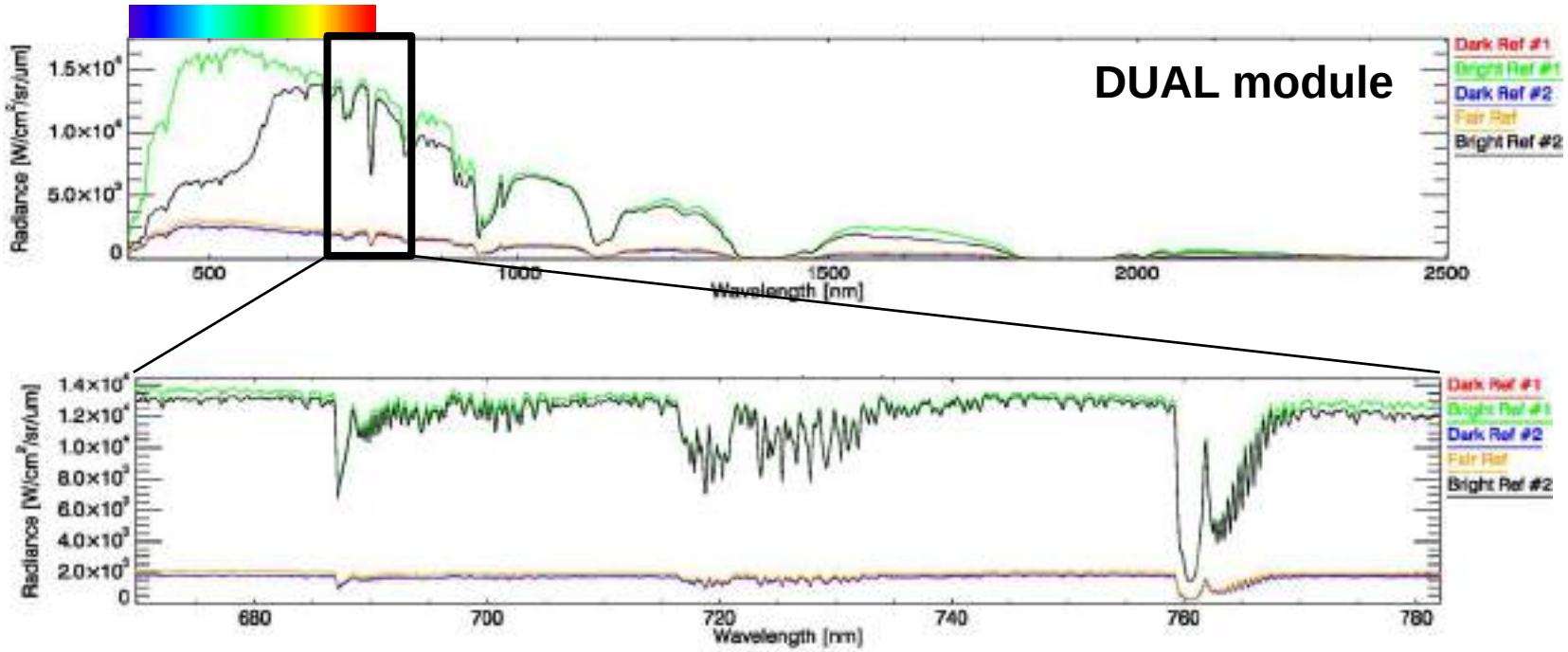
- Mapping of sun-induced fluorescence on the ground to understand interplay of the variations of light intensity within natural canopies and the three dimensional leaf display
- New ‘HyPlant light’ [*HySceen*] is becoming operational



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

- Used to demonstrate the uncoupling of ‘greenness’ and fluorescence
  [Rascher et al (2015) Global Change Biol., 21, 4673-4684]
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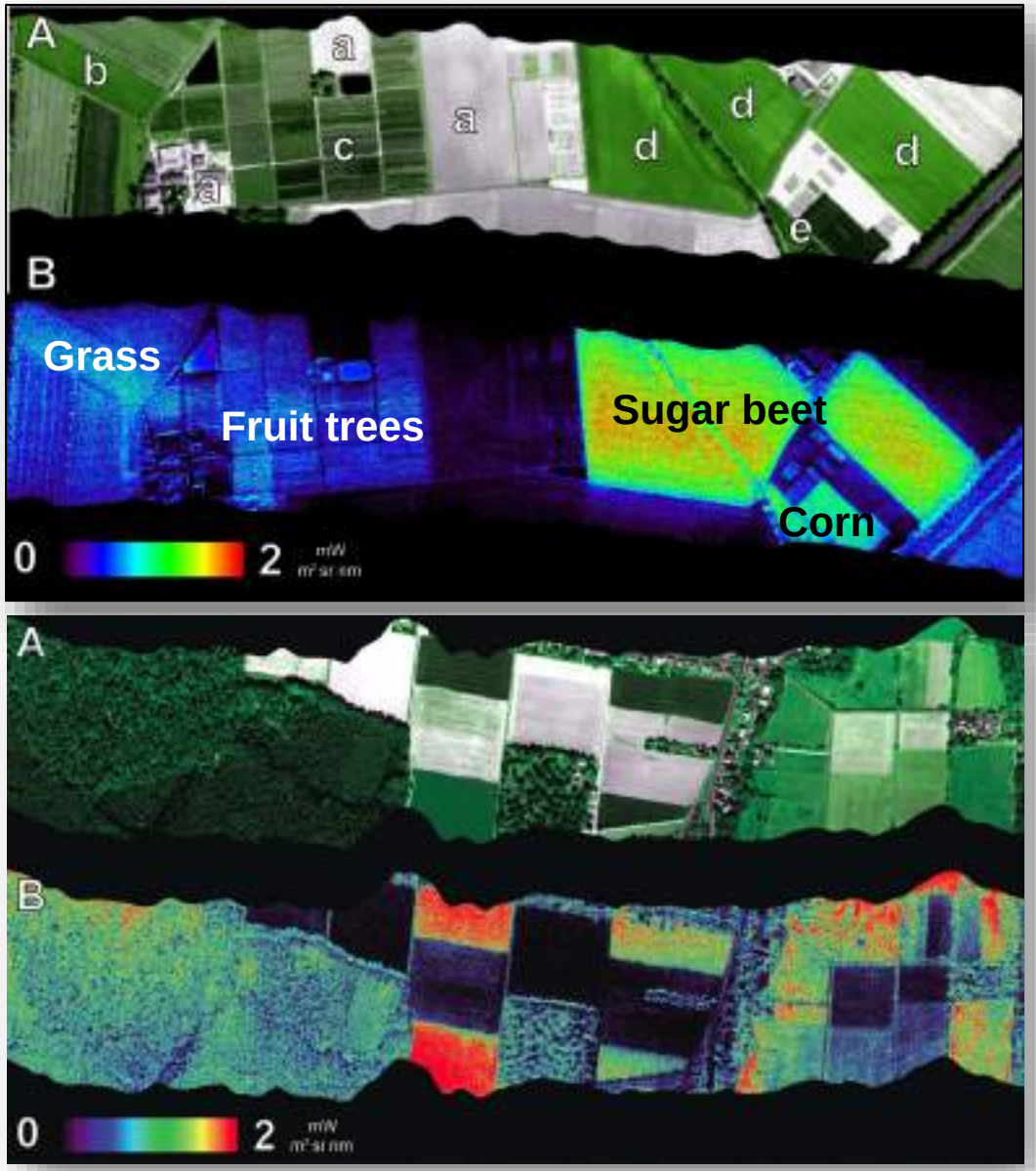

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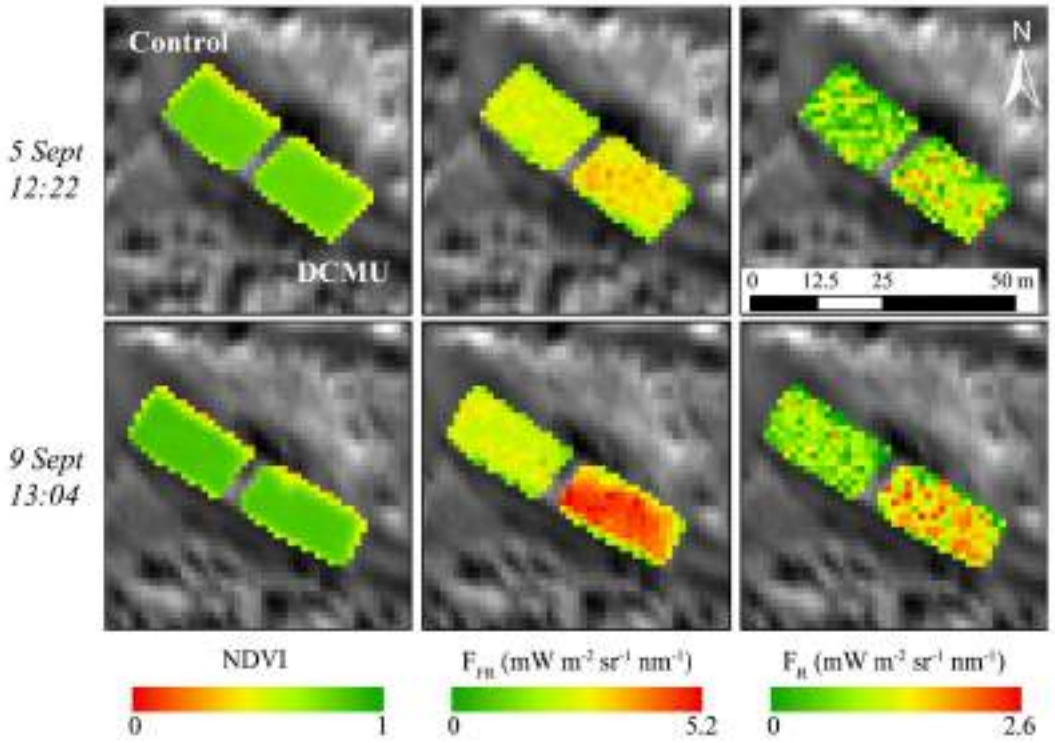

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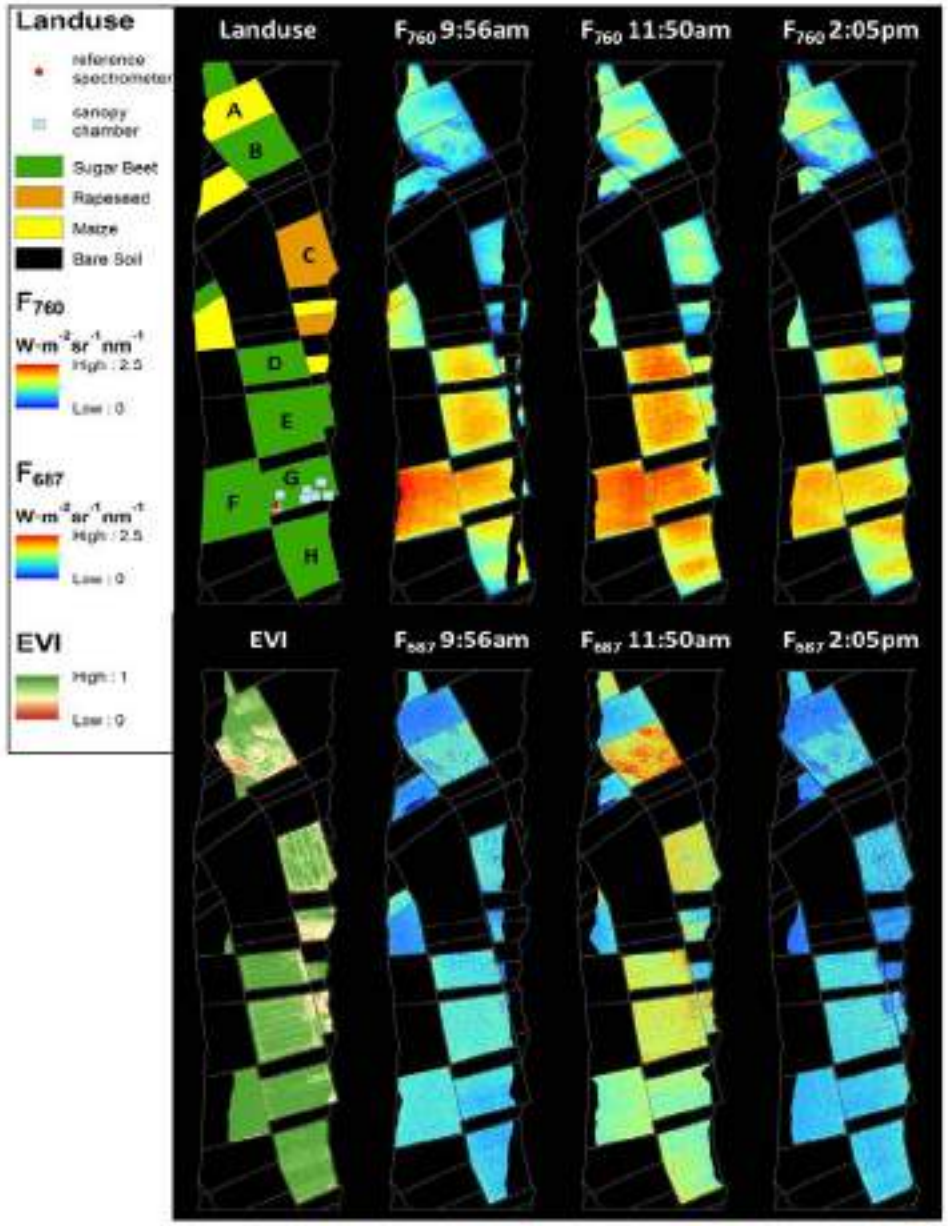

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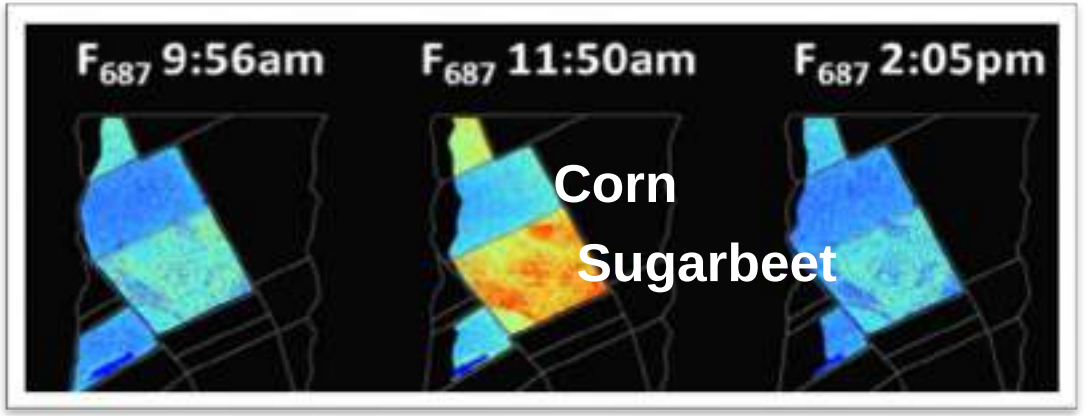
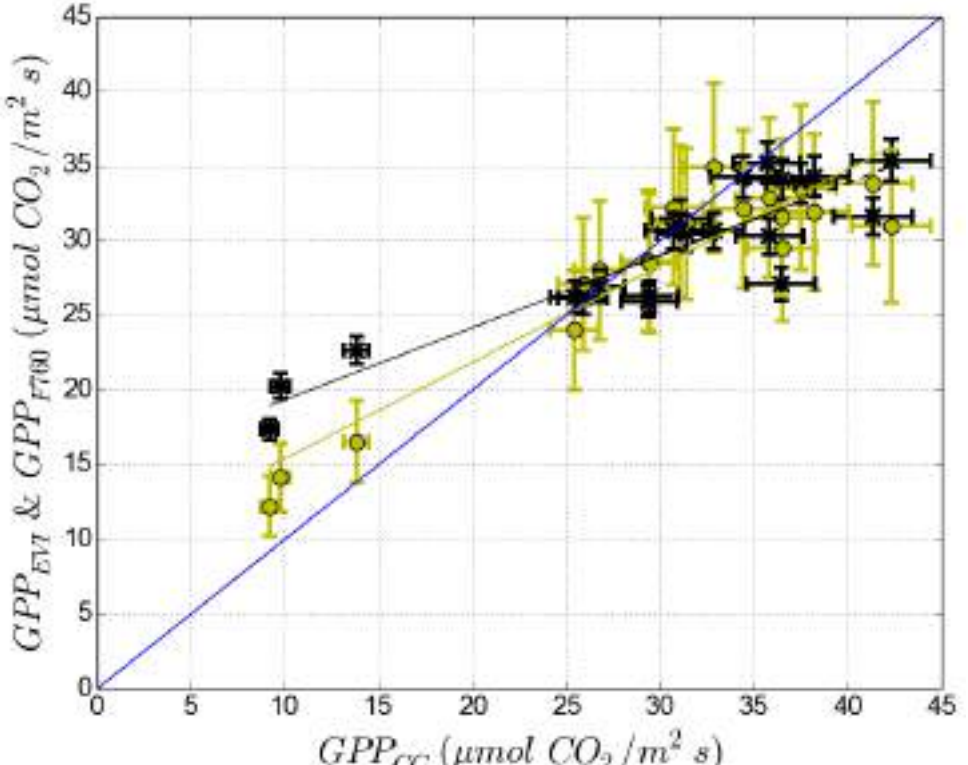
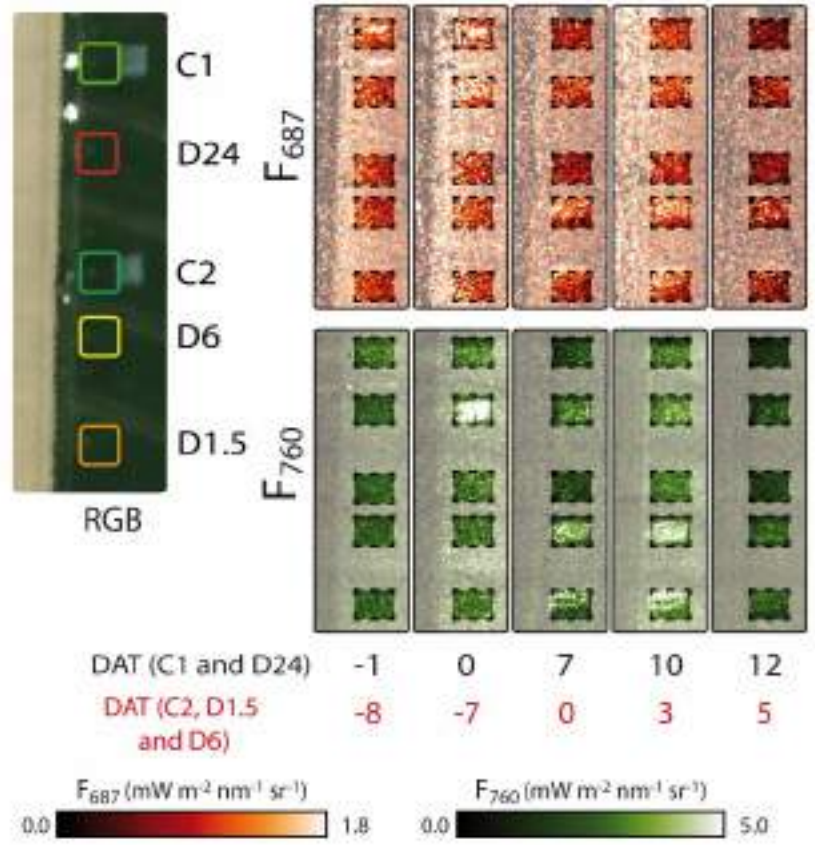


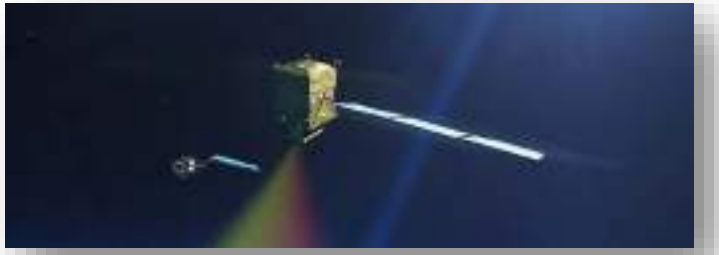


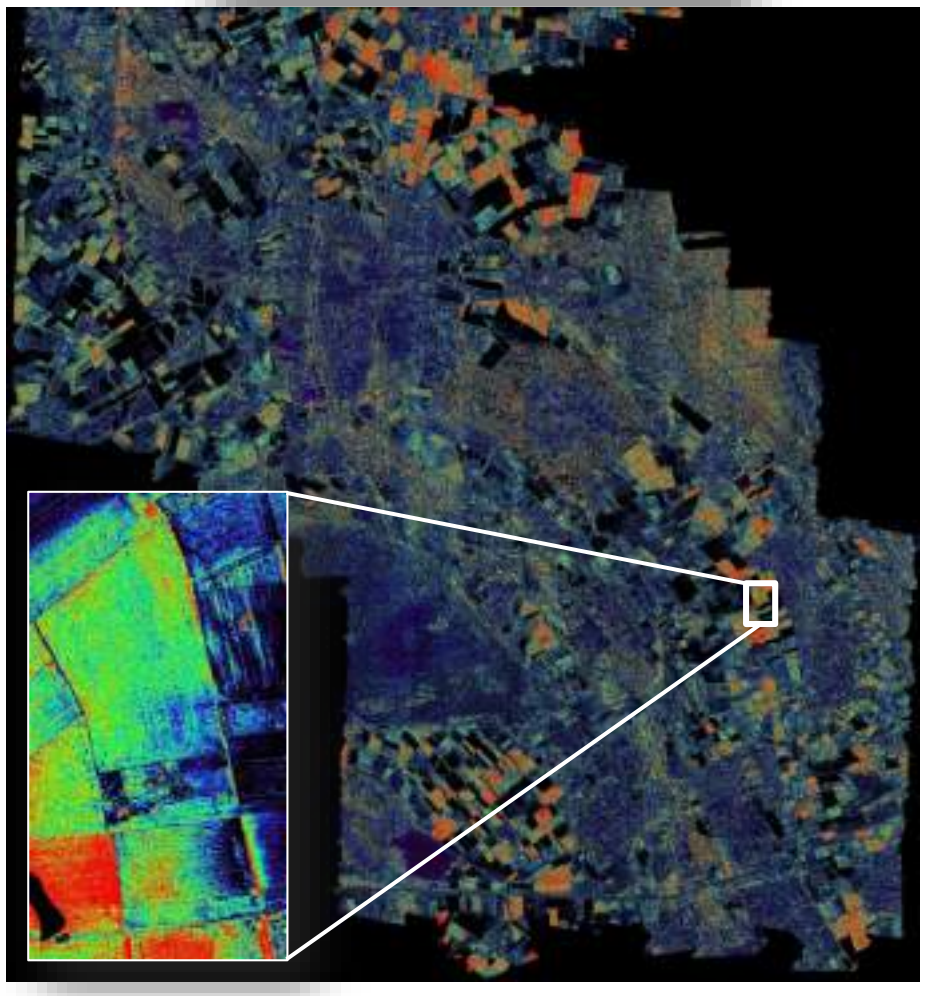
HyPlant: A high-resolution airborne spectrometer with FLEX like measurement characteristics

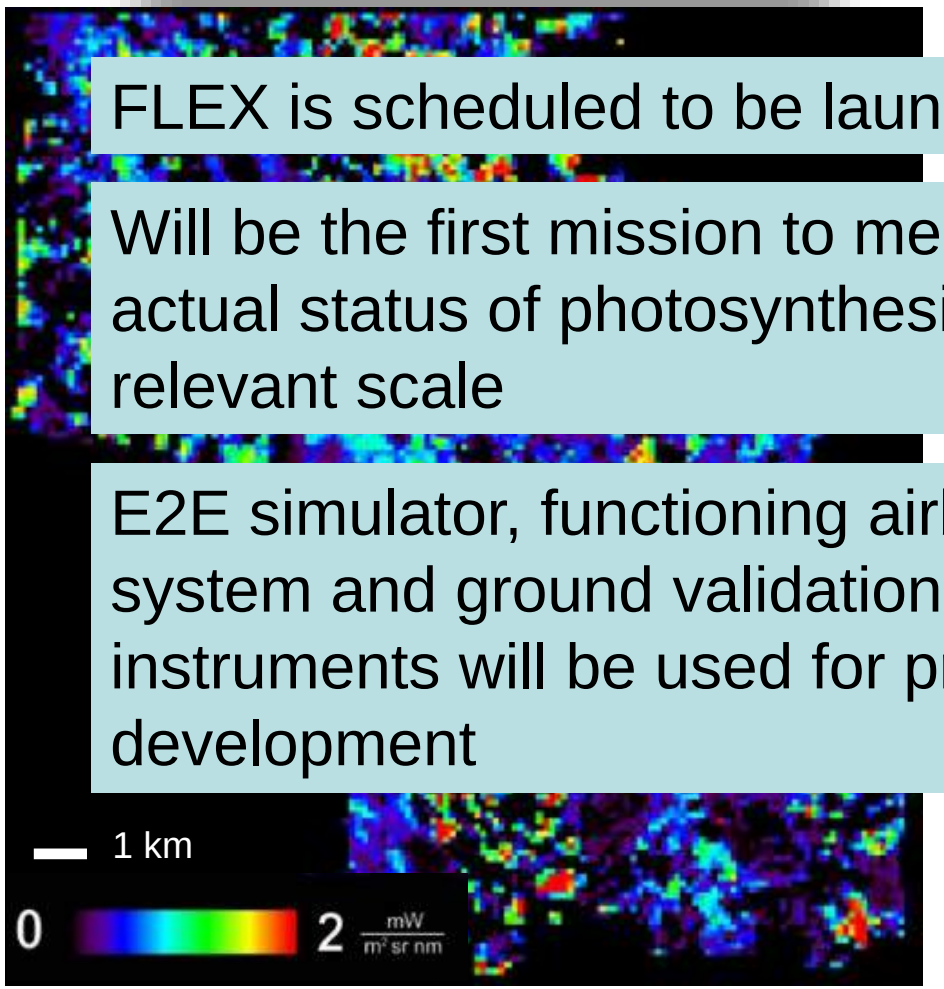
- Used to demonstrate the uncoupling of ‘greenness’ and fluorescence
  [Rascher et al (2015) Global Change Biol., 21, 4673-4684]
  [Simmer et al (2015) BAMS – Bulletin of the American Meteorological Society, 96, 1765-1787]
- First demonstration that functional blockage of photosynthesis can be mapped 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]
- Experimental studies to better understand the mechanisms of photosynthetic regulation on the canopy scale
  [Pinto et al (to be submitted)]



Scaling the processes from single leaves to the 300 x 300 m FLEX pixel





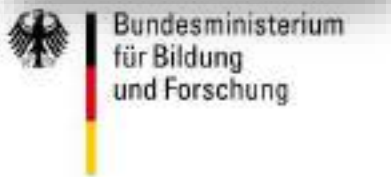


FLEX is scheduled to be launched 2022

Will be the first mission to measure the actual status of photosynthesis on relevant scale

E2E simulator, functioning airborne system and ground validation instruments will be used for product development

Many thanks to the numerous partners



Many thanks to my group