

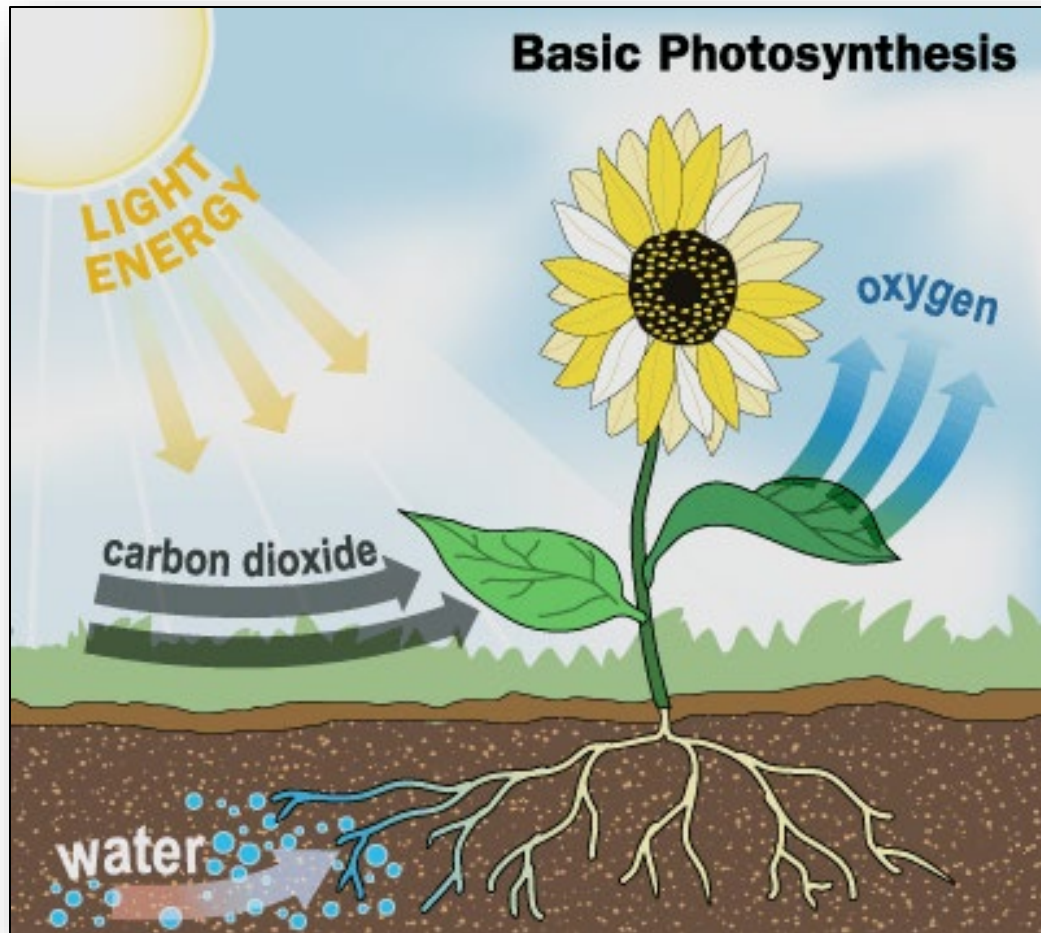
PHOTOSYNTHESIS IN A 5 MINUTE NUTSHELL – FROM THE MOLECULAR REGULATION OF PHOTOSYNTHETIC LIGHT CONVERSION TO THE GLOBAL CARBON FLUXES

Uwe Rascher – Forschungszentrum Jülich, IBG-2: Plant Sciences

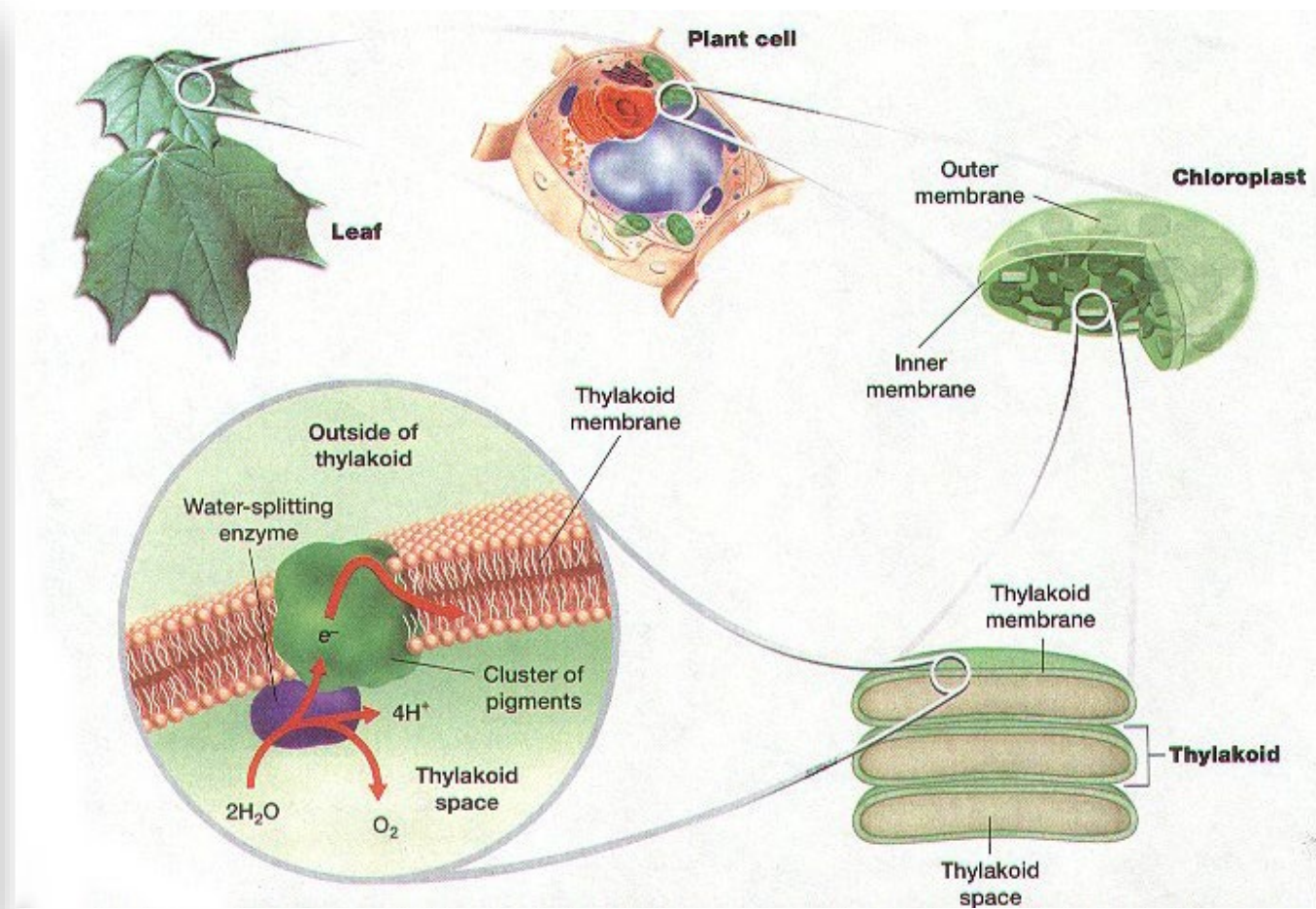
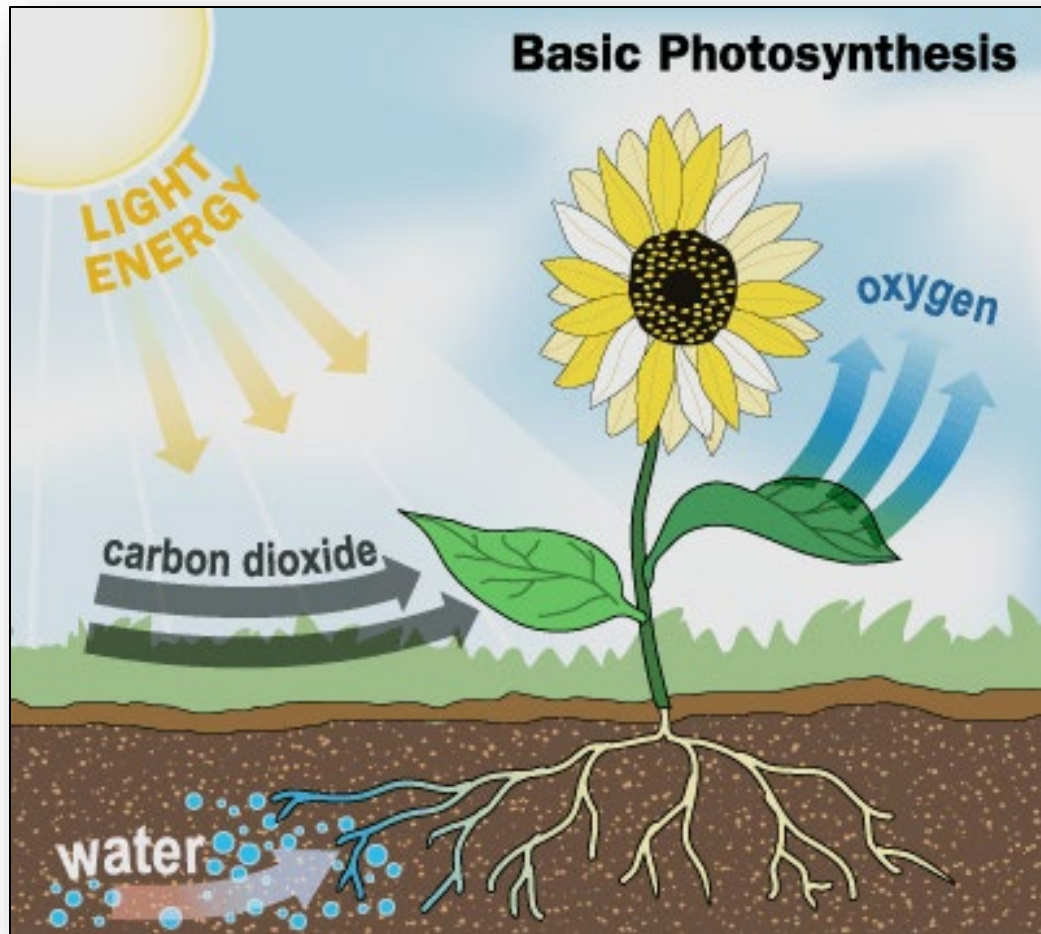
24. NOV 2022

Bastian Siegmann | Juliane Bendig | Caspar Kneer | Julie Krämer | Juan Quiros-Vargas | Ruonan Chen | Saja Salattna

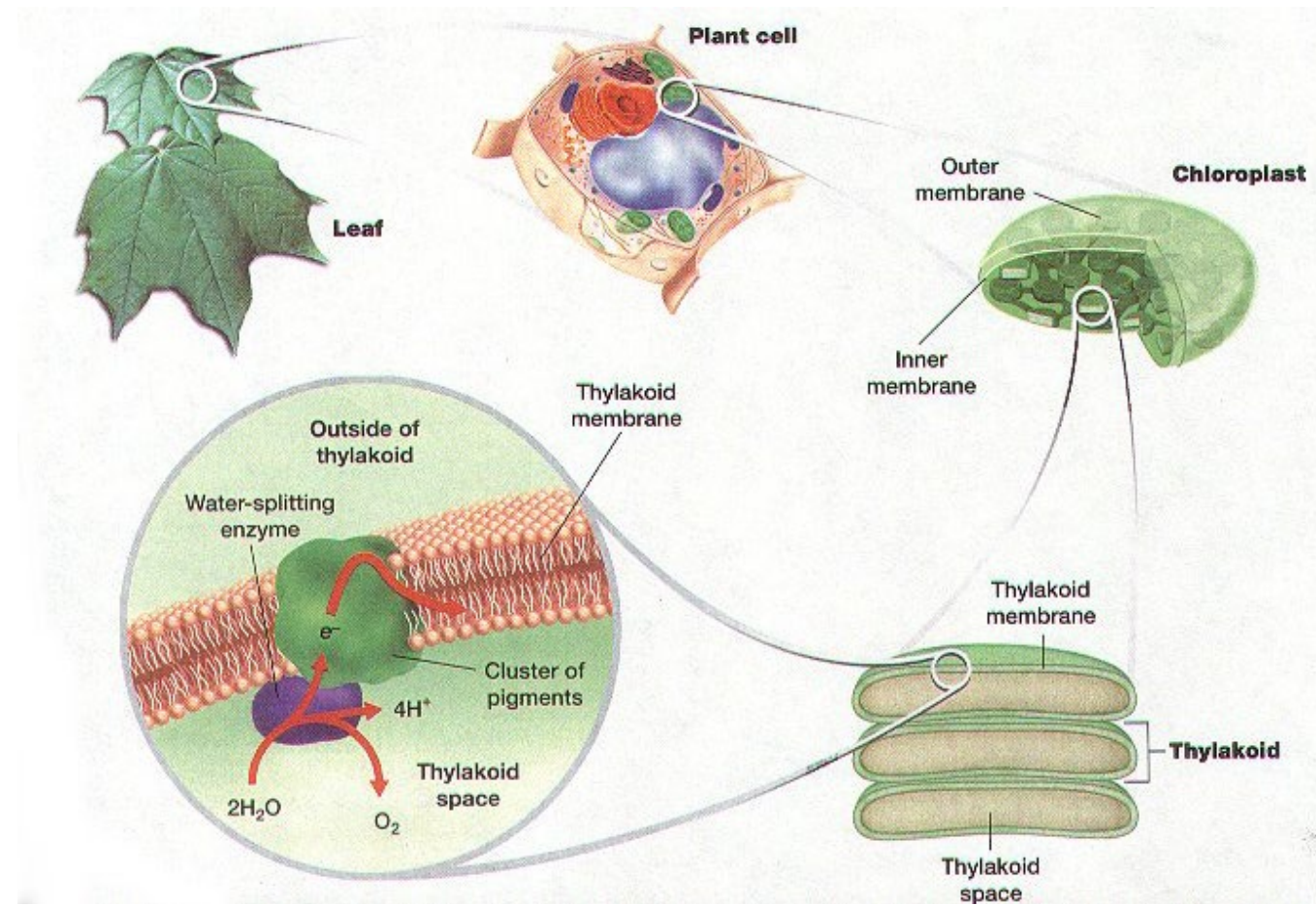
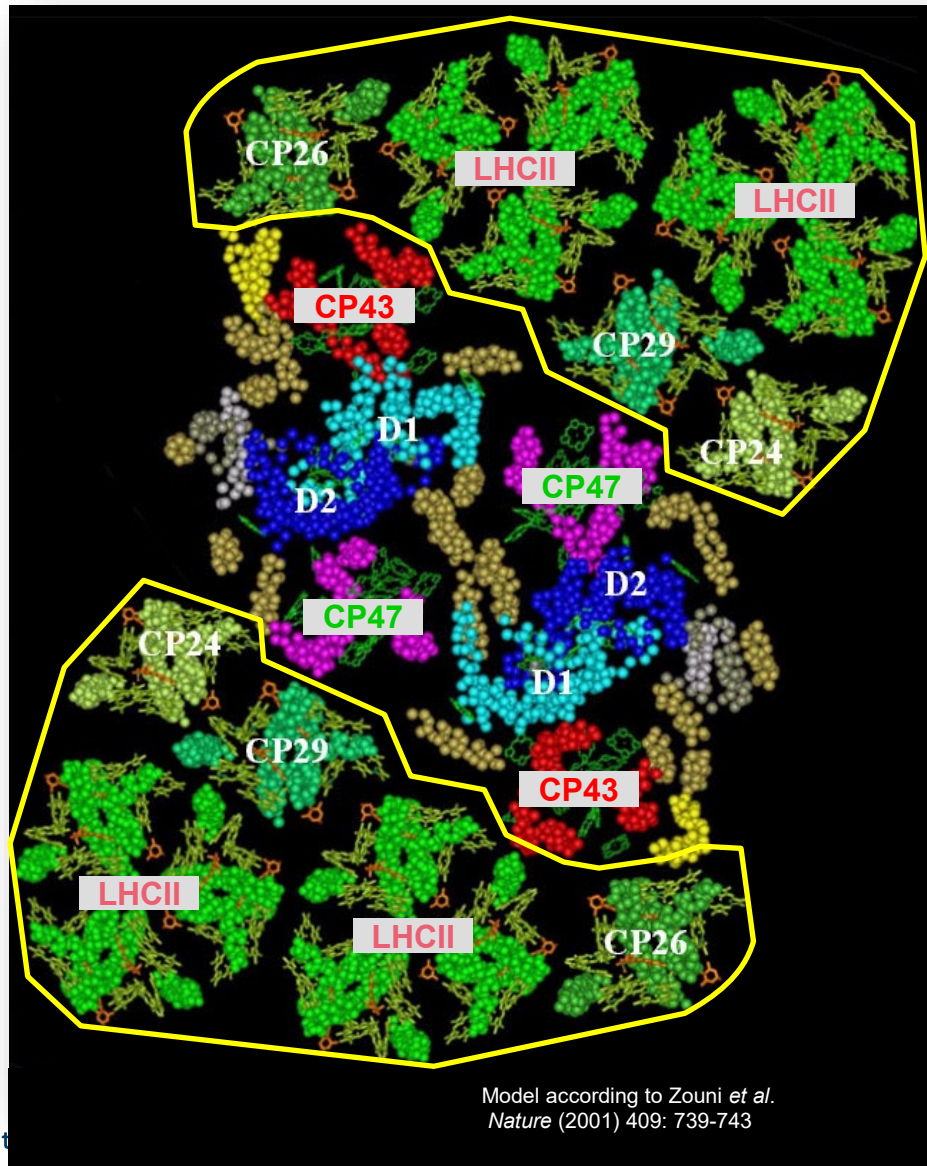
Photosynthesis is the central metabolic process that is closely linked to plant productivity



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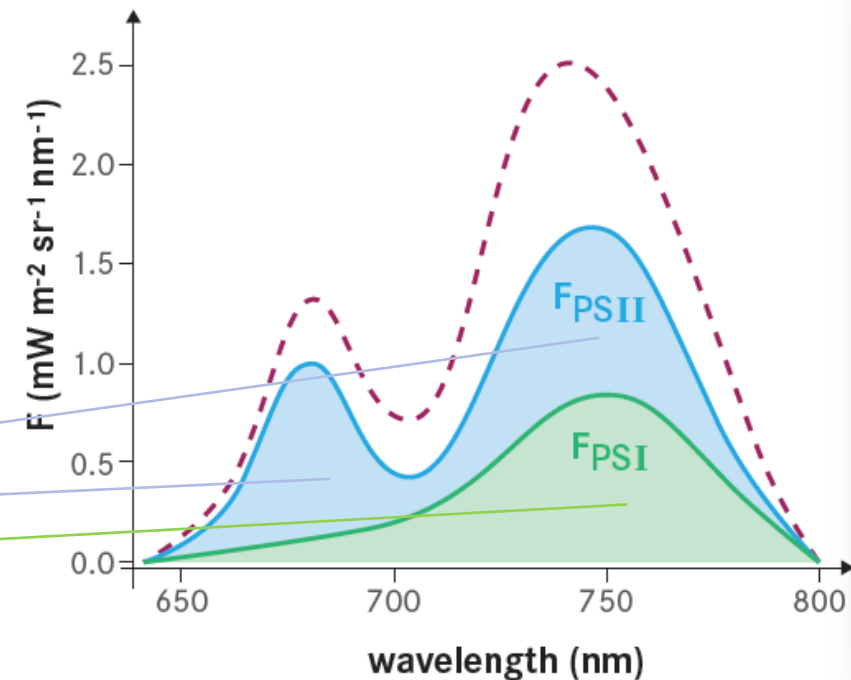
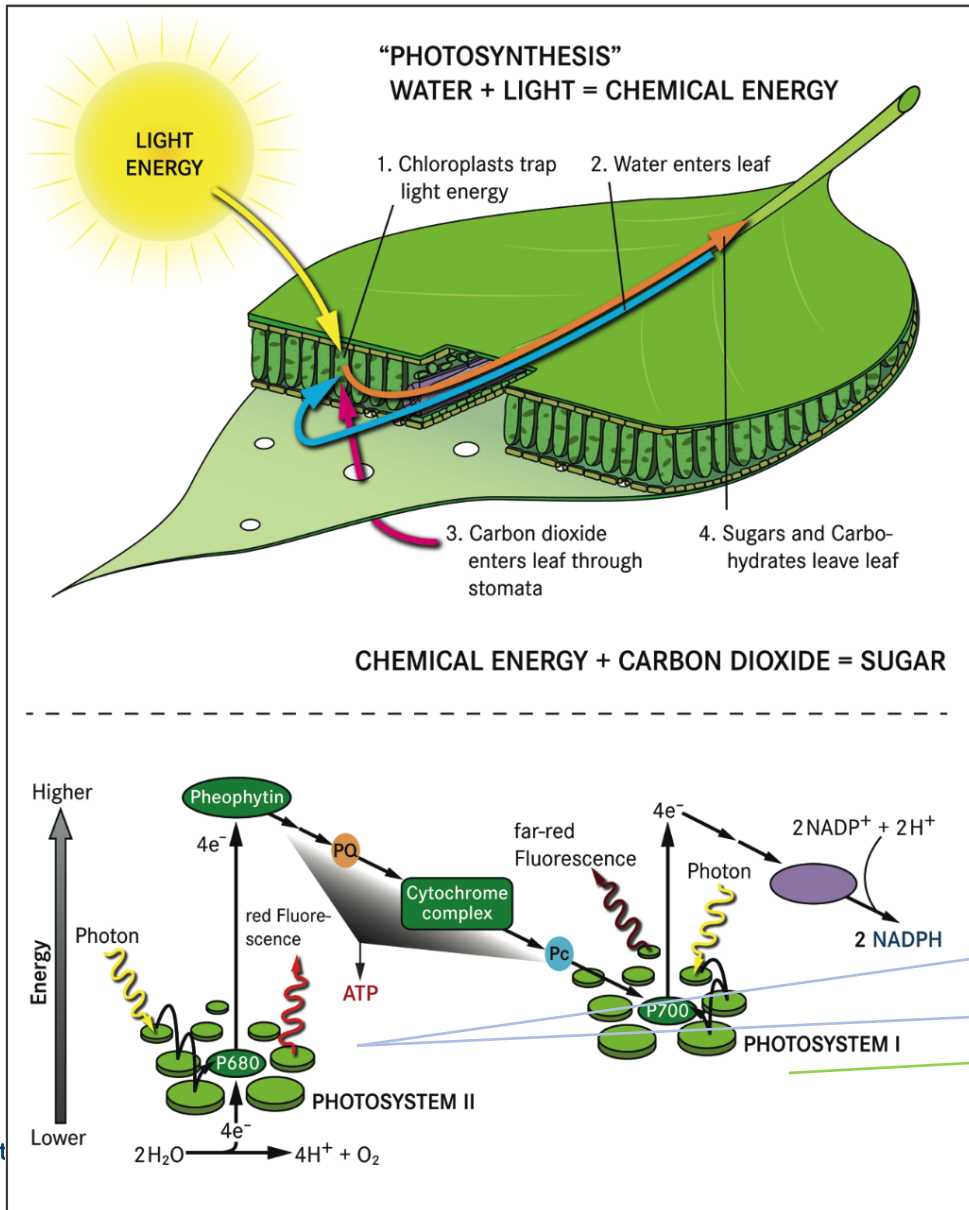


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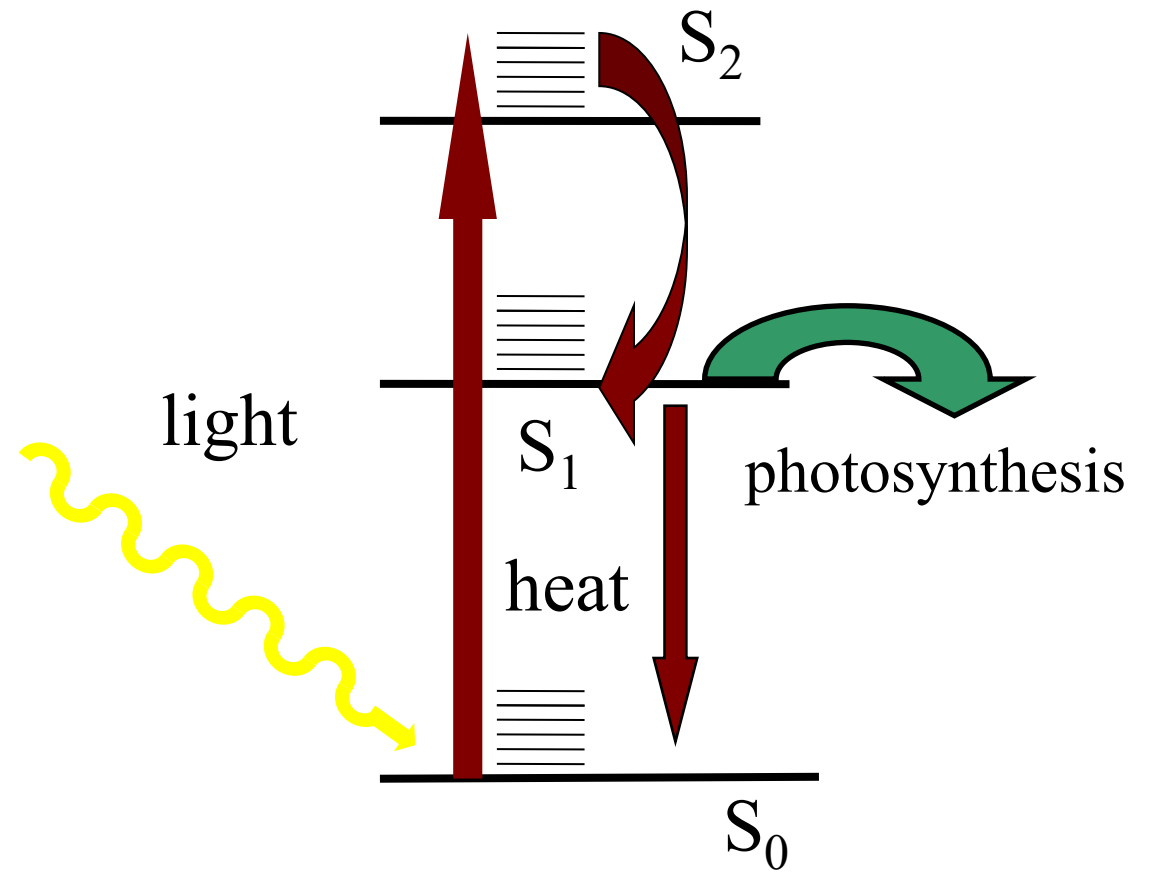
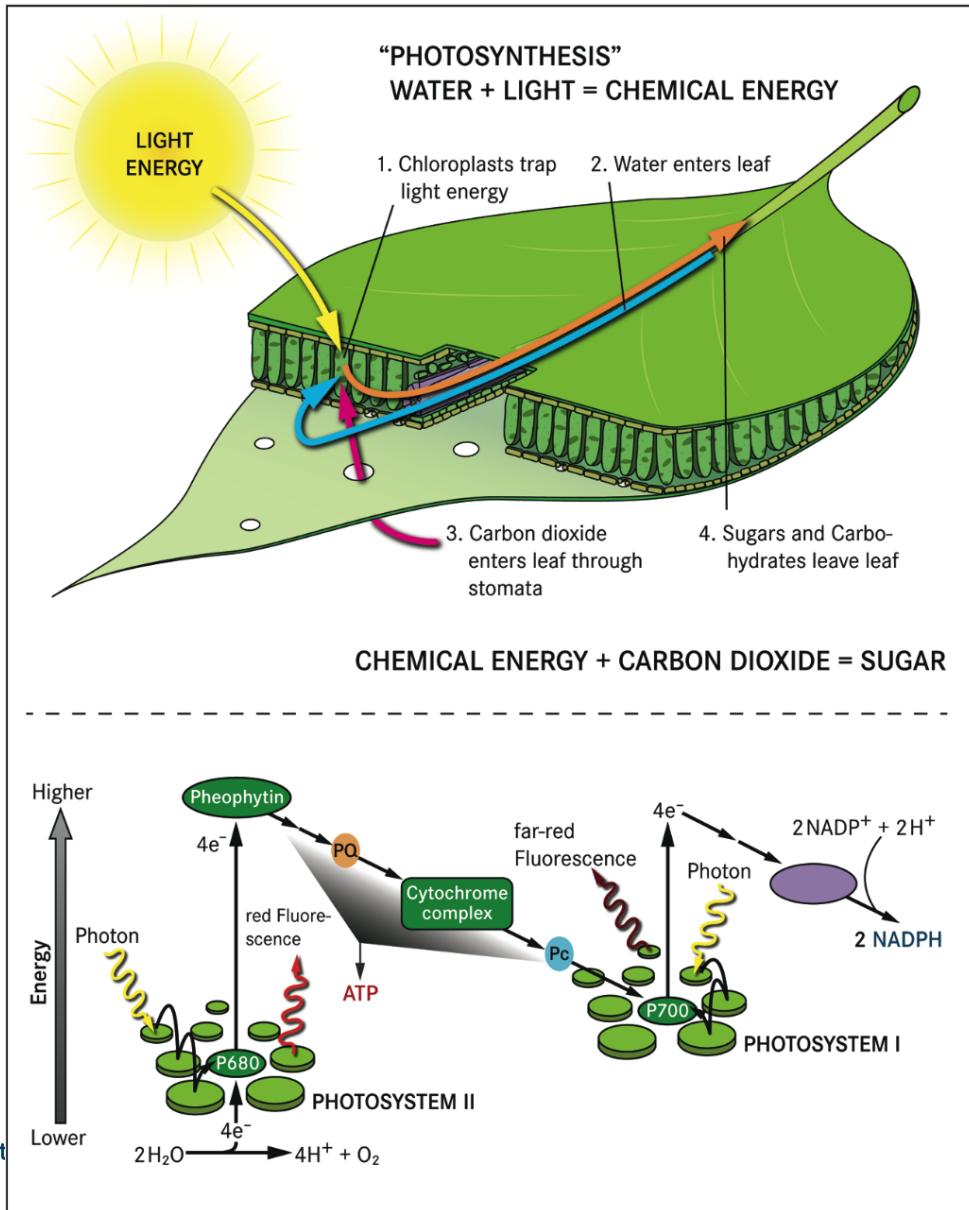
Chlorophyll fluorescence – an indicator for photosynthetic efficiency

- 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



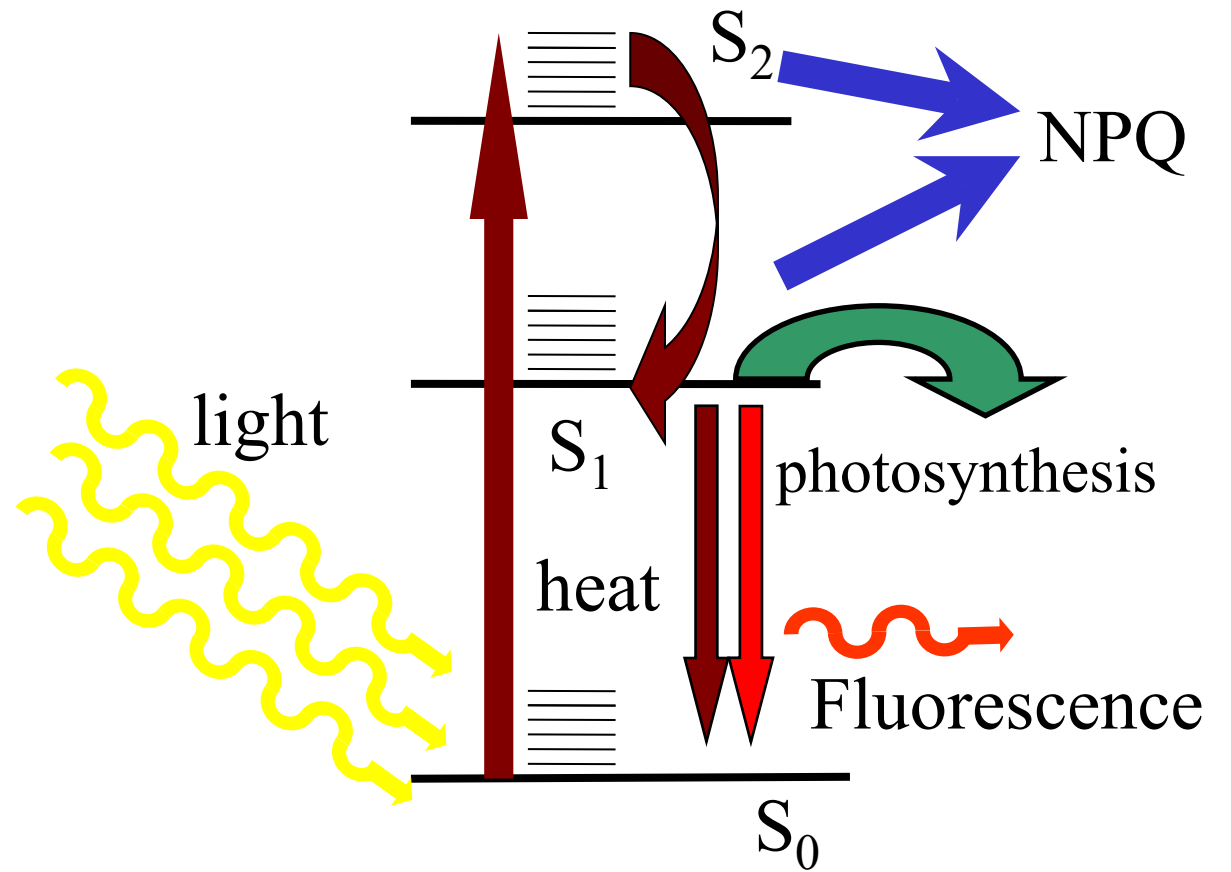
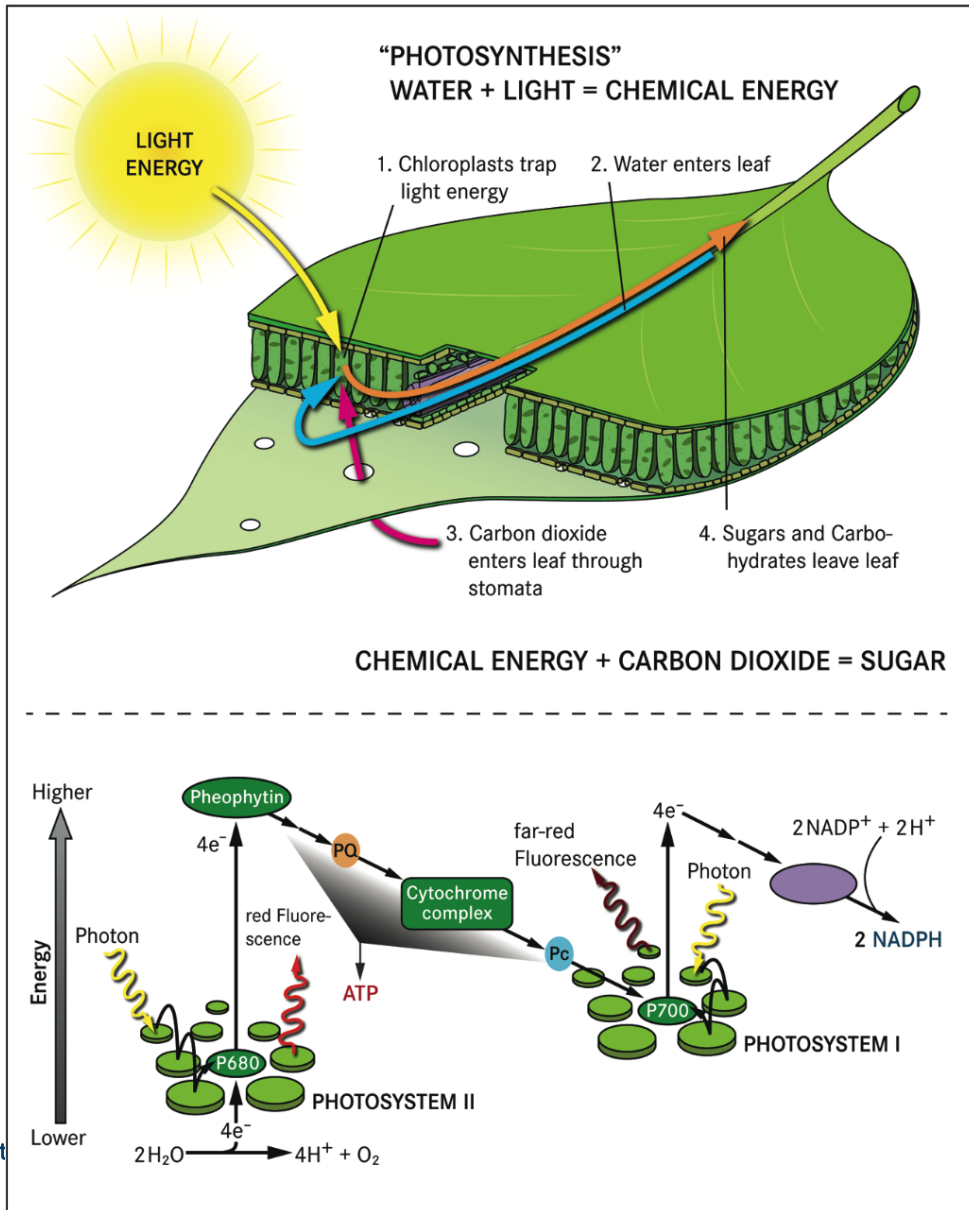
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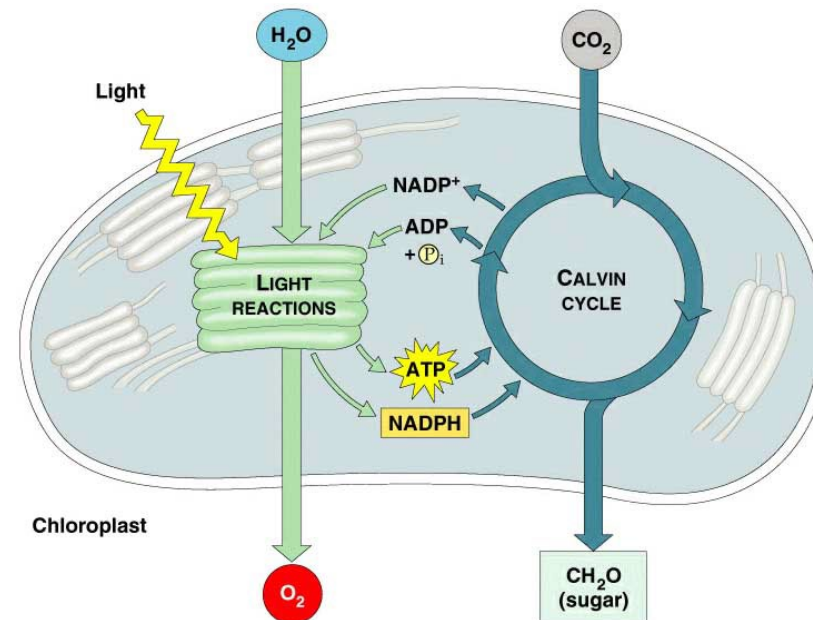
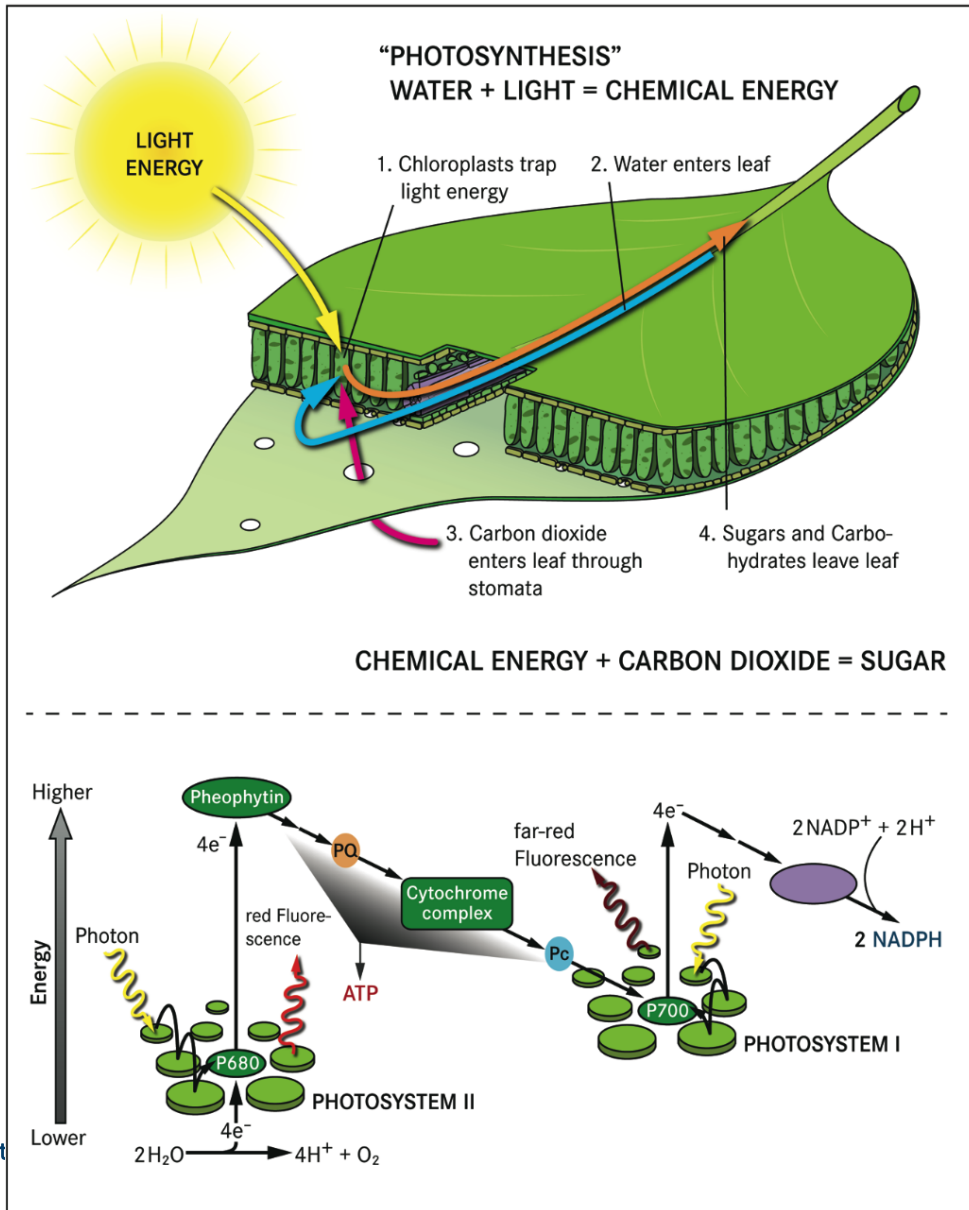
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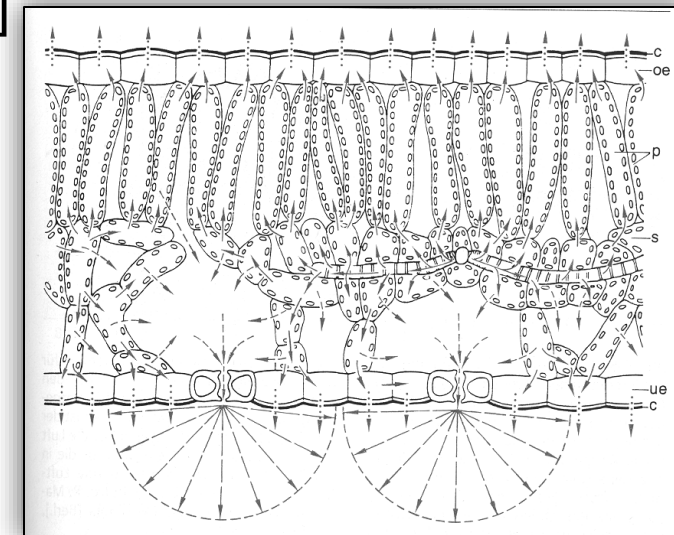
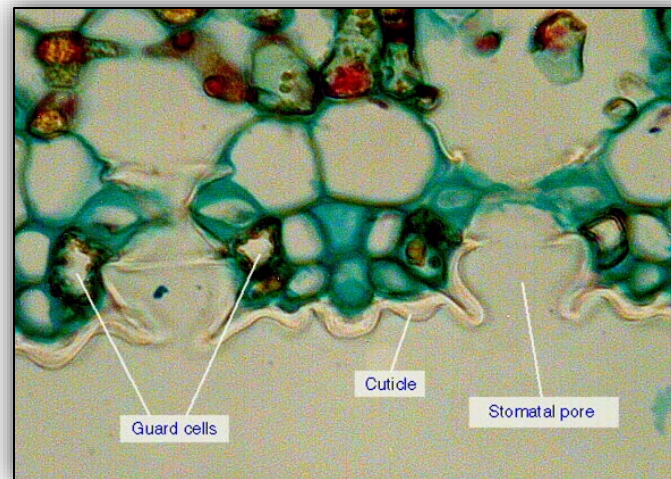
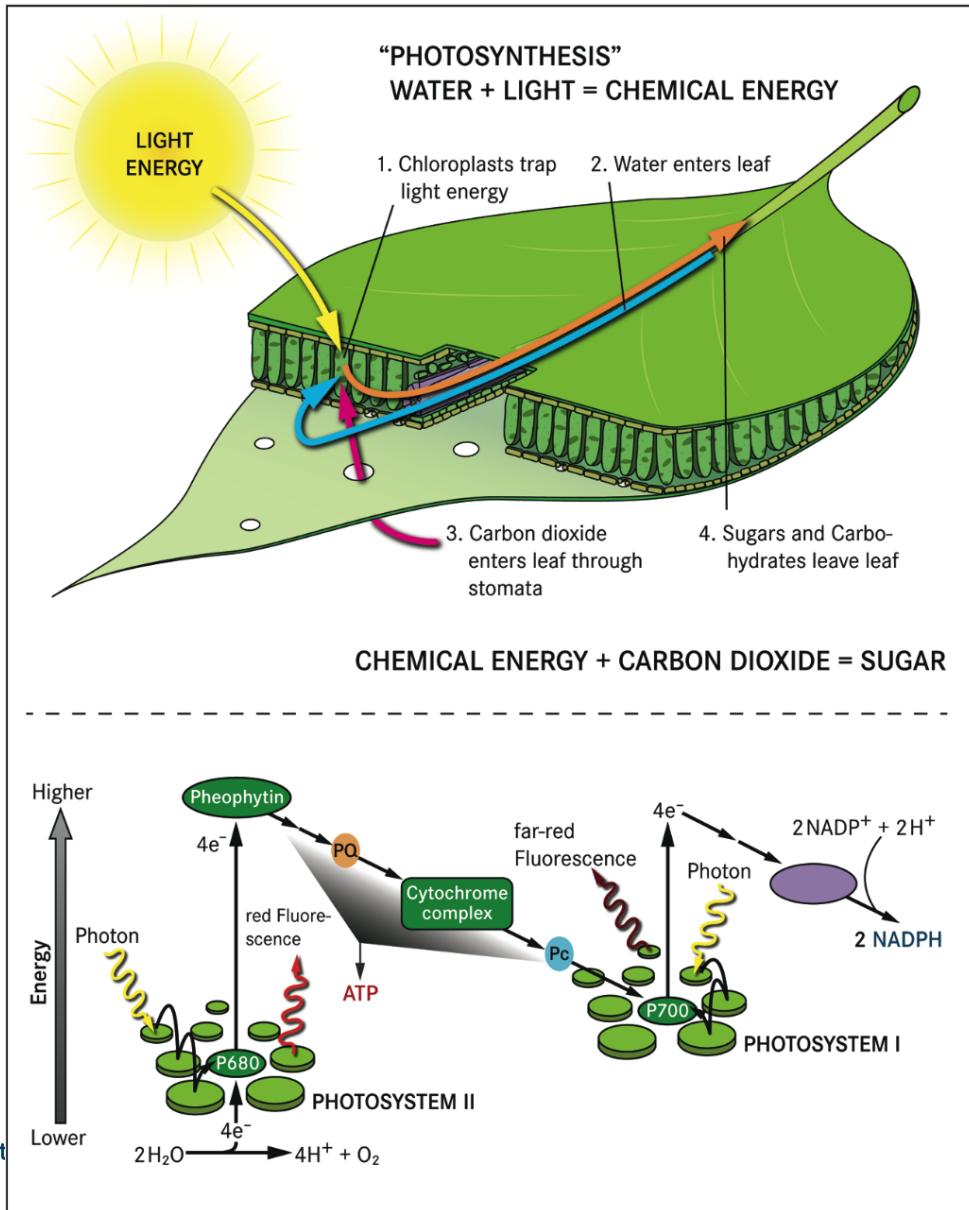
The origin of fluorescence – an indicator for photosynthetic efficiency

- Photosynthesis is a highly regulated process that involves a cascade of electron transfers (*Light reaction*) to fuel carbon fixation (*Calvin cycle*)
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- Energy of light-reactions is used to biochemically fix CO₂ from the atmosphere



The origin of fluorescence – an indicator for photosynthetic efficiency

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- Fluorescence is emitted from the cores of the photosynthetic machinery: Photosystems I and II
- Energy of light-reactions is used to biochemically fix CO₂ from the atmosphere.
- And there are stomata... the maybe ,most important cells on earth' [Joe Berery]



CHLOROPHYLL FLUORESCENCE DETECTION

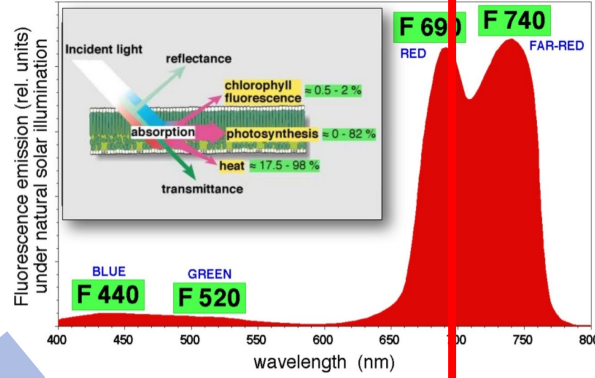


~1985-
PAM, WALZ

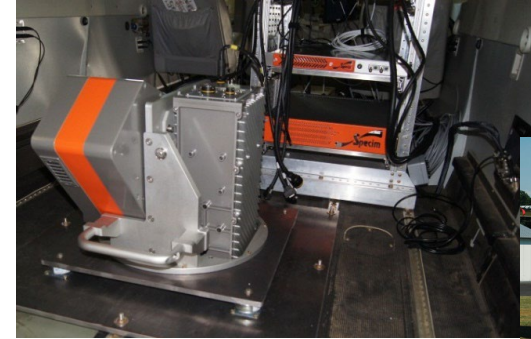


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**ATTACHED TO LEAF
ACTIVE**



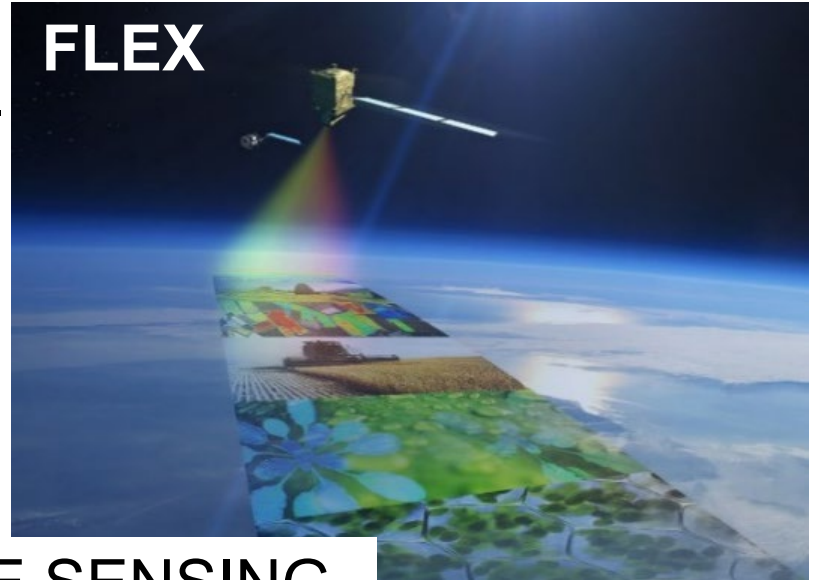
2012-



HYPLANT

Rascher et al. 2015 Global Change Biology

2023-

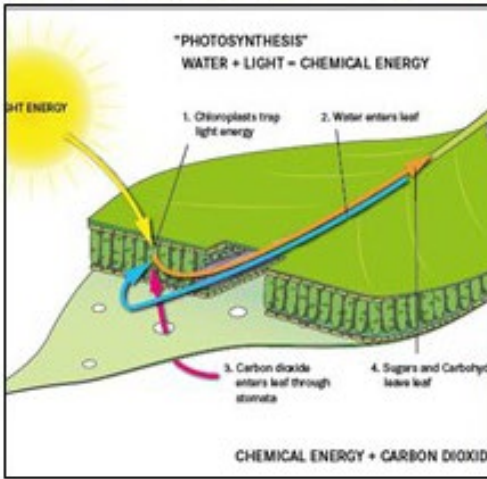


**REMOTE SENSING
PASSIVE**

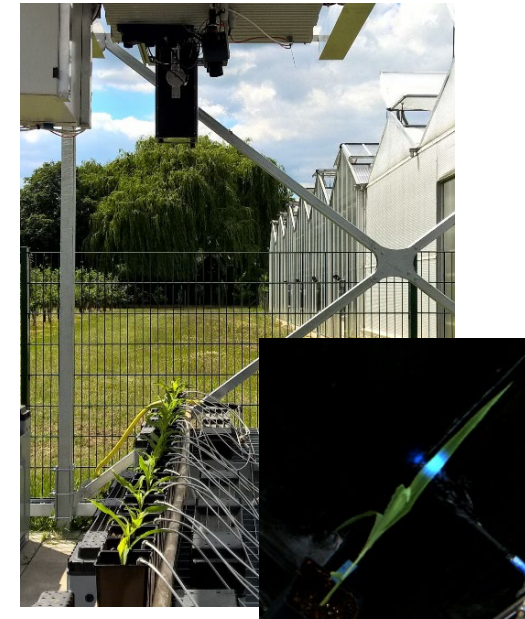
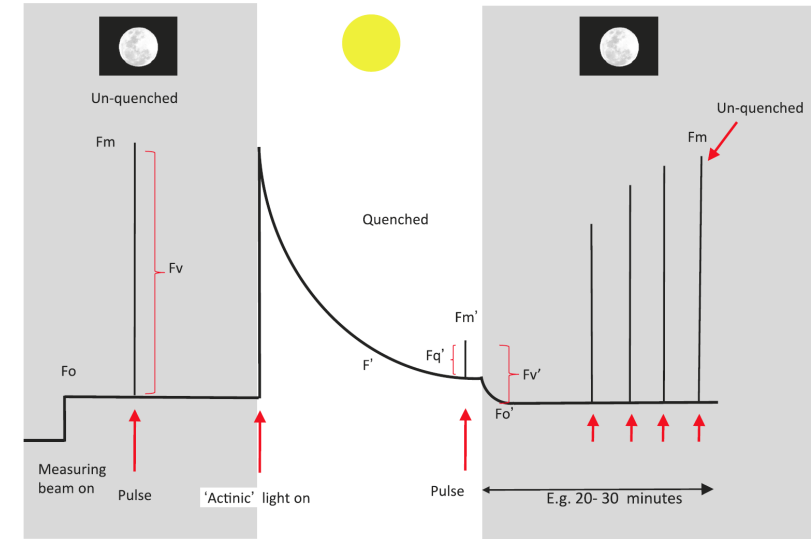
PROXIMAL SENSING, ACTIVE

PROXIMAL SENSING, PASSIVE

Fluorescence techniques are the most widely used approaches to investigate photosynthesis



- Leaf level measurements to understand the functional link between photosynthetic regulation and fluorescence emission
- Various instruments available and currently ~750 Papers published per year (ISI core collection).
- Most of these methods use active approaches, such as PAM, saturating light pulses or lasers induced fluorescence transients



Murchie & Lawson (2013) Chlorophyll fluorescence analysis: a guide to good practice and understanding some new applications. *Journal of Experimental Botany*, Vol. 64, No. 13, pp. 3983–3998,

Rascher et al. (2010) Sensing of photosynthetic activity of crops. In *Precision Crop Protection - the Challenge and Use of Heterogeneity*. Springer Science+Business Media B.V., doi 10.1007/978-90-481-9277-9_6.

CHLOROPHYLL FLUORESCENCE DETECTION

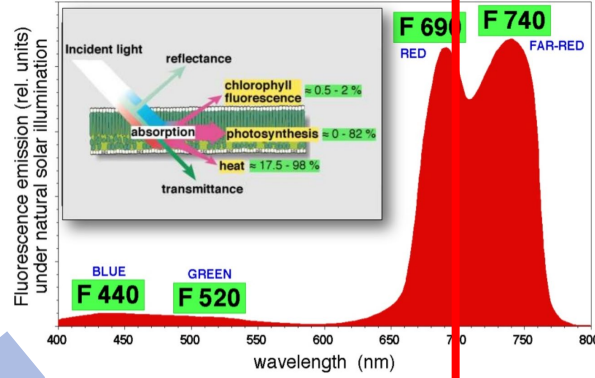


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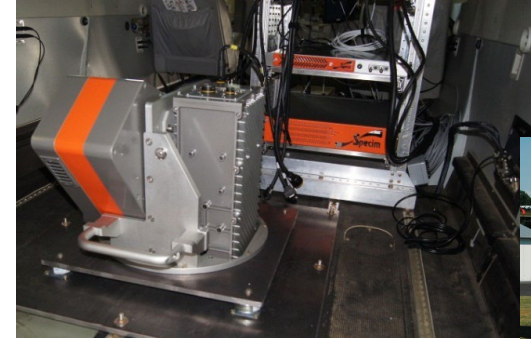
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ACTIVE**



PROXIMAL SENSING, ACTIVE

PROXIMAL SENSING, PASSIVE

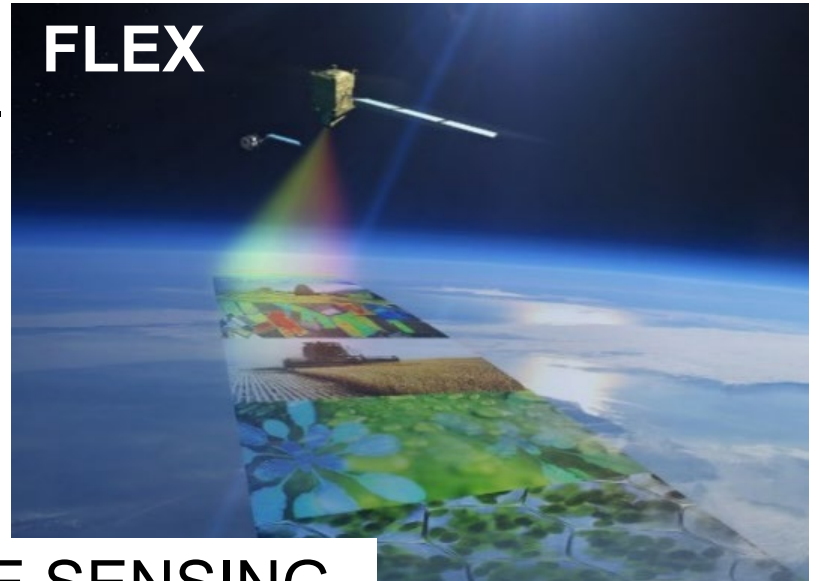


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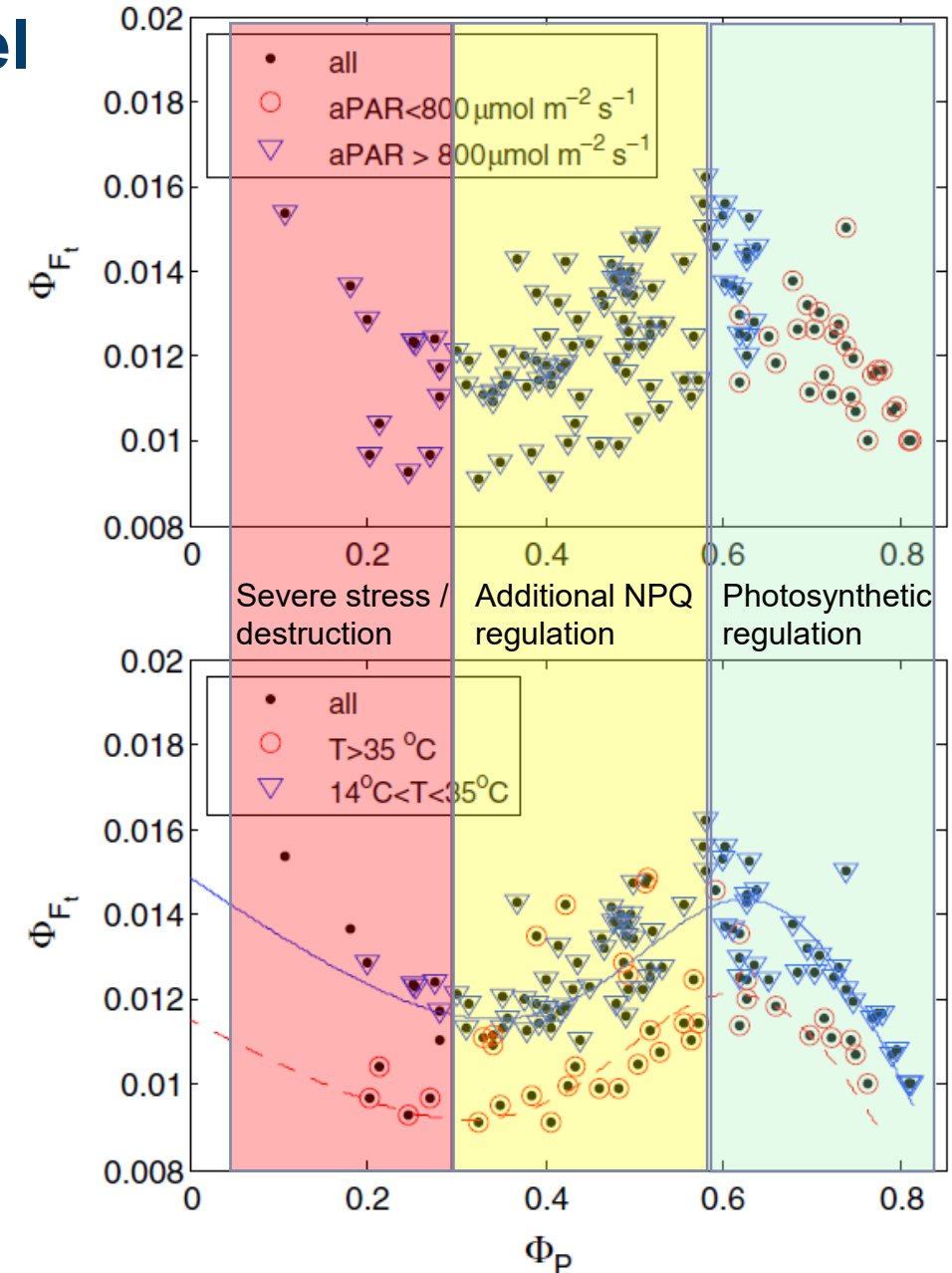


FLEX

**REMOTE SENSING
PASSIVE**

Steady-state fluorescence and photosynthetic efficiency are non-linearly related – leaf level

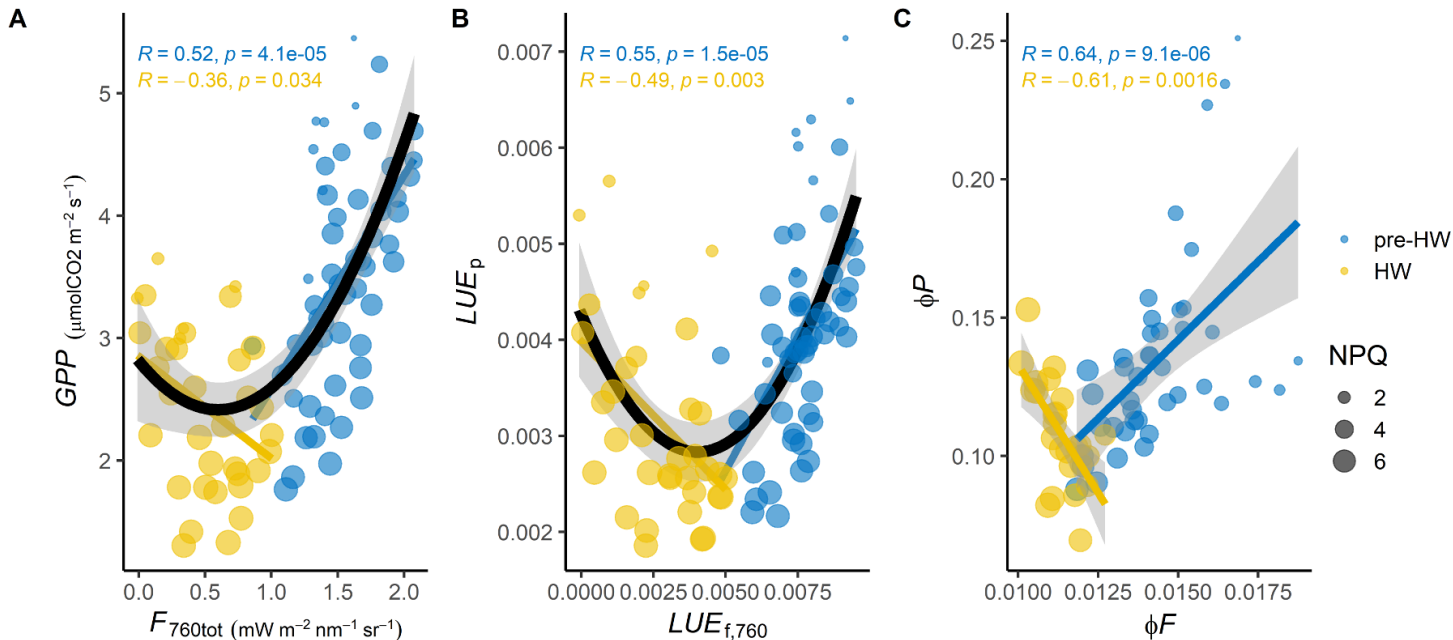
- The relationship between solar-induced fluorescence and efficiency of photosynthesis is not linear
- Light intensity and the degree of non-photochemical energy dissipation influence the relation between solar-induced fluorescence and photosynthesis



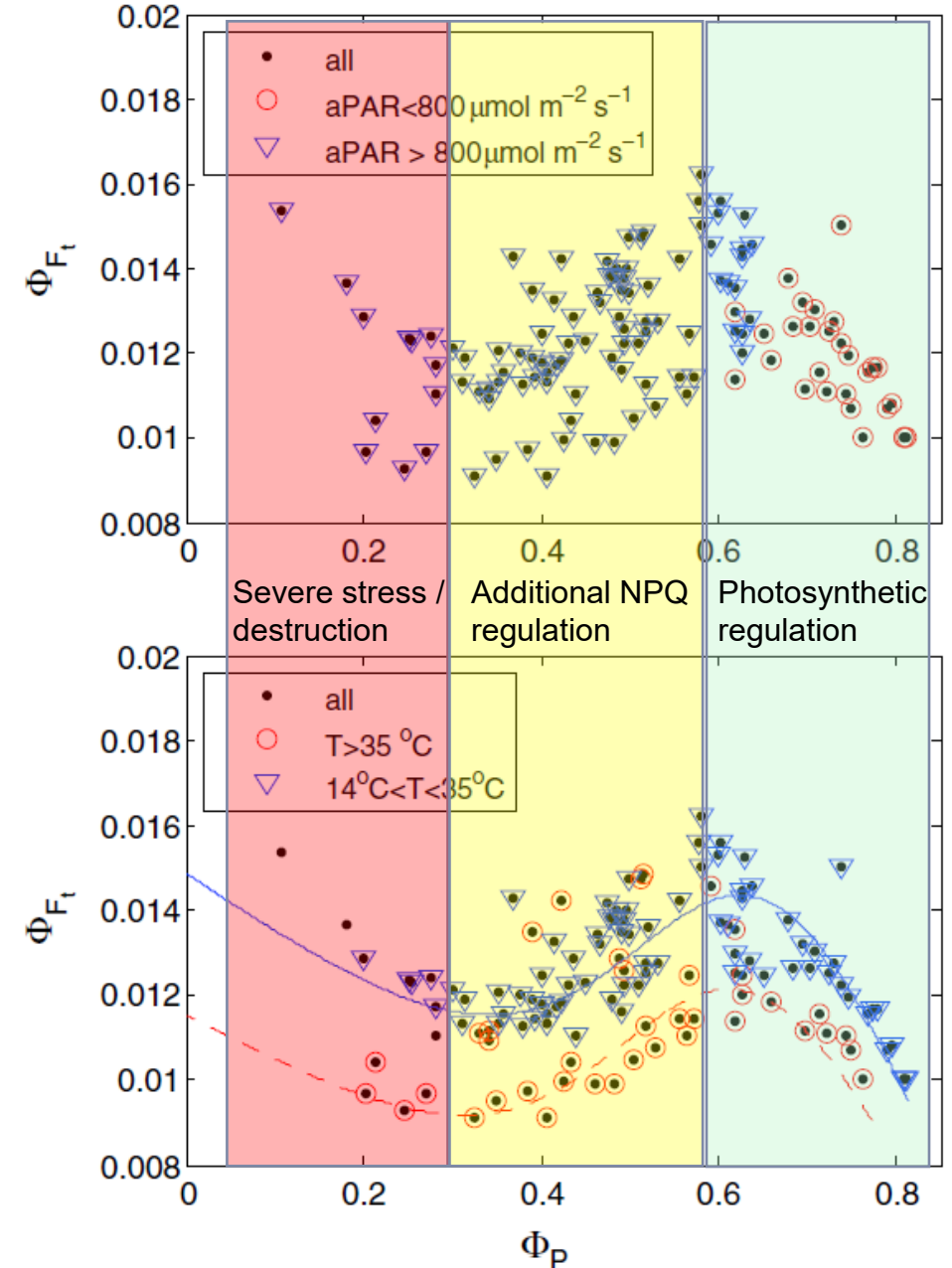
van der Tol C., Berry J.A., Campbell P.K.E. & Rascher U. (2014) Models of fluorescence and photosynthesis for interpreting measurements of solar-induced chlorophyll fluorescence. *Journal of Geophysical Research - Biogeosciences*, 119, 2312-2327.

Steady-state fluorescence and photosynthetic efficiency are non-linearly related

- Models predicted a three-phase relationship between SIF and photosynthetic efficiency
- Heat wave in Spain (summer 2018) demonstrated the tipping point between dynamically regulated photosynthesis and severe stress (canopy level)

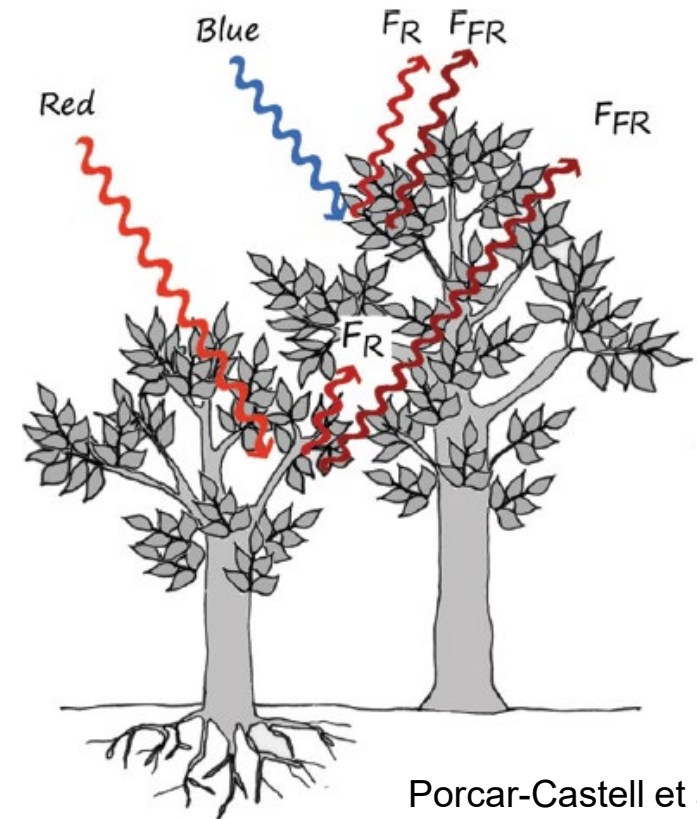


Martini et al. (2022) Heatwave breaks down the linearity between sun-induced fluorescence and gross primary production. *New Phytologist*, 233, 2415–2428



Correction of scattering and re-absorption of SIF within the canopy

- Several approaches are currently being discussed to normalize the top-of-canopy signal to leaf fluorescence
 - Radiative Transfer model inversion
 - Calculation of SIF escape fraction
 - Fluorescence correction vegetation index (FCVI) (Yang et al. 2020)
 - Near-infrared reflectance of vegetation (NIRv) index (Badgley et al., 2017)
 - NIRvH1 and NIRvH2 (Zeng et al. 2021)

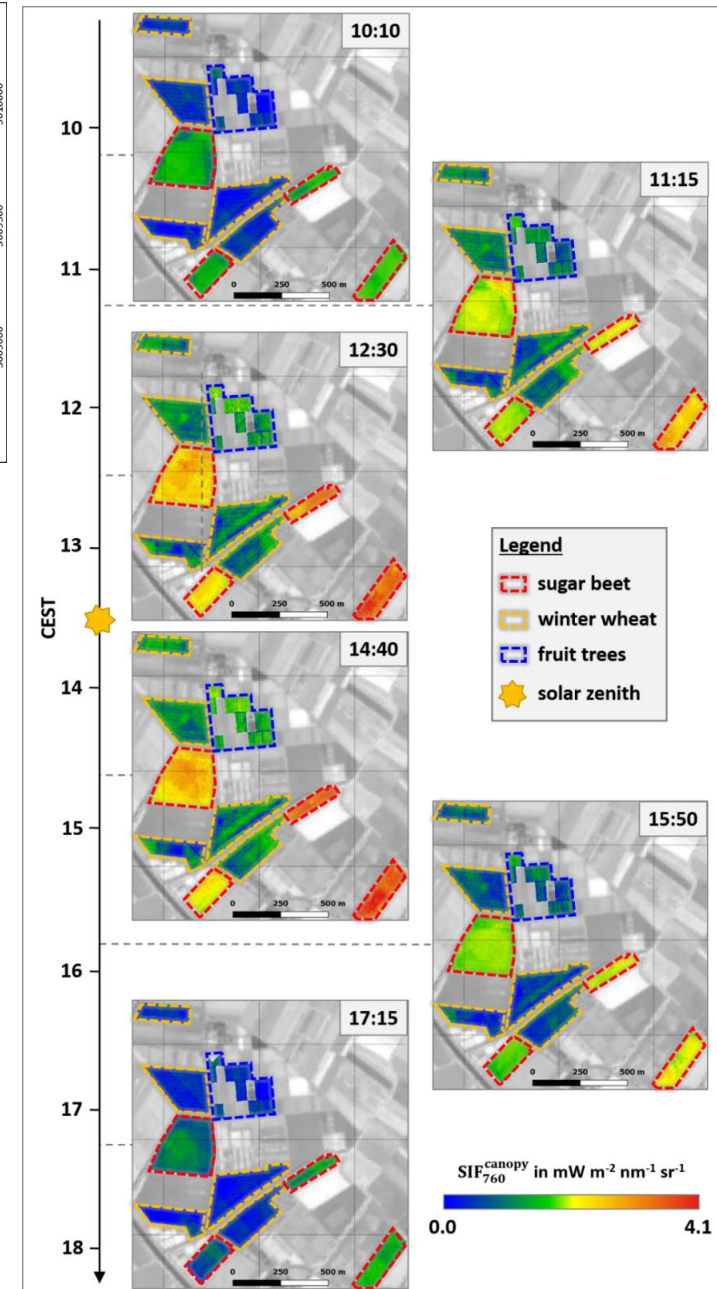
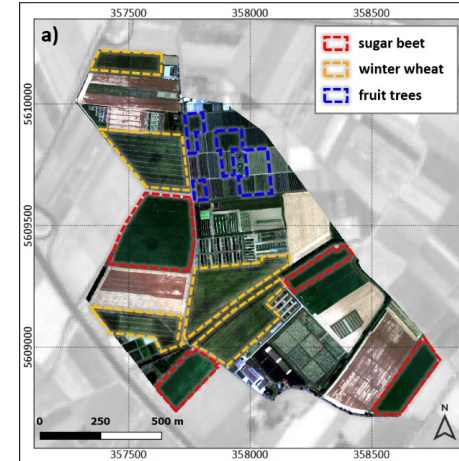
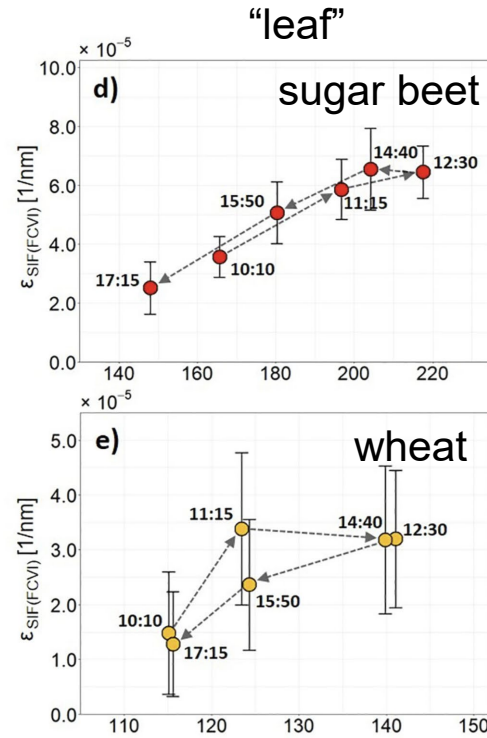
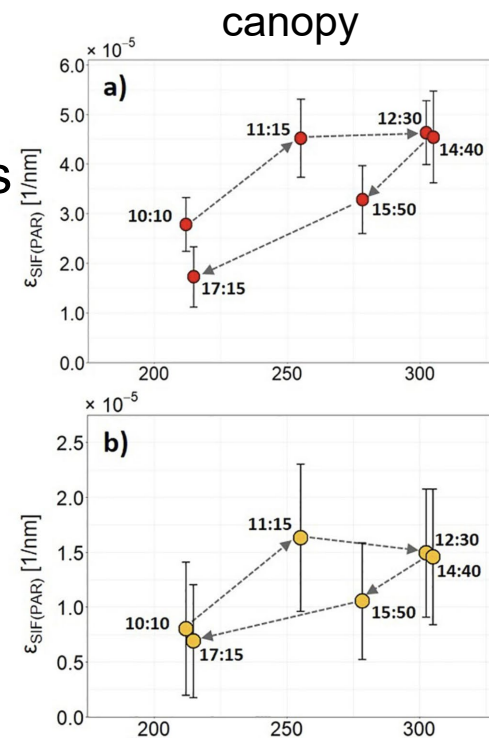


f_{esc} = SIF escape fraction
index = FCVI, NIRv, NIRvH1 or NIRvH2
 f_{APAR} = fraction of photosynthetically active radiation

1) Downscaling of SIF from TOC to leaf level – normalizing for canopy structure

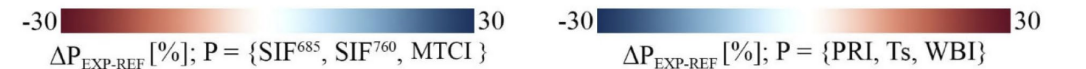
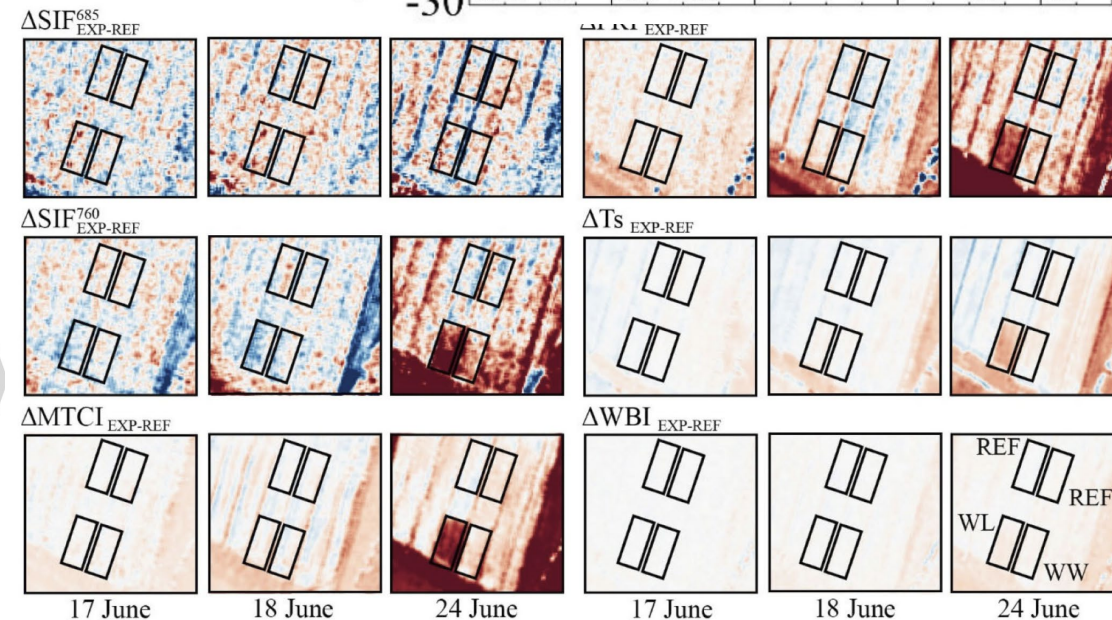
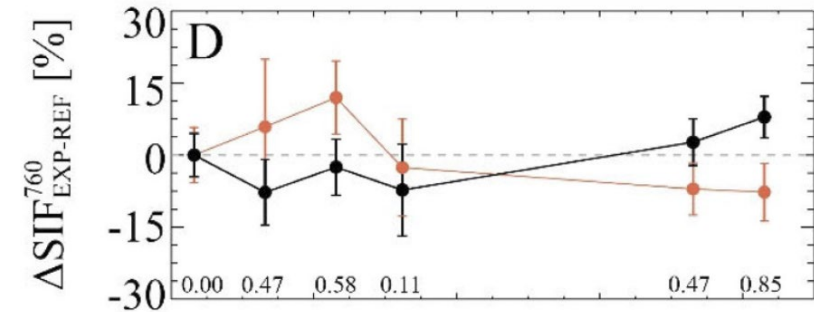
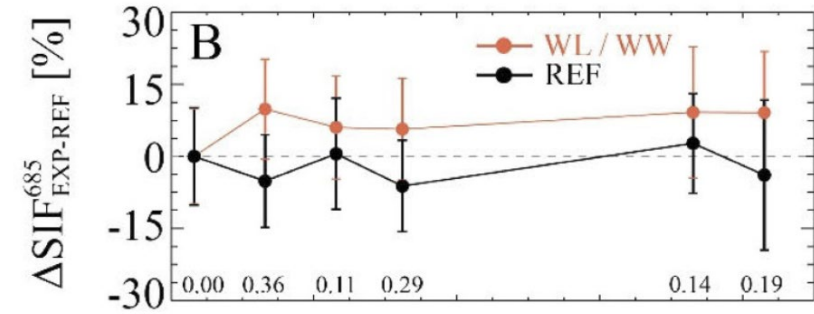
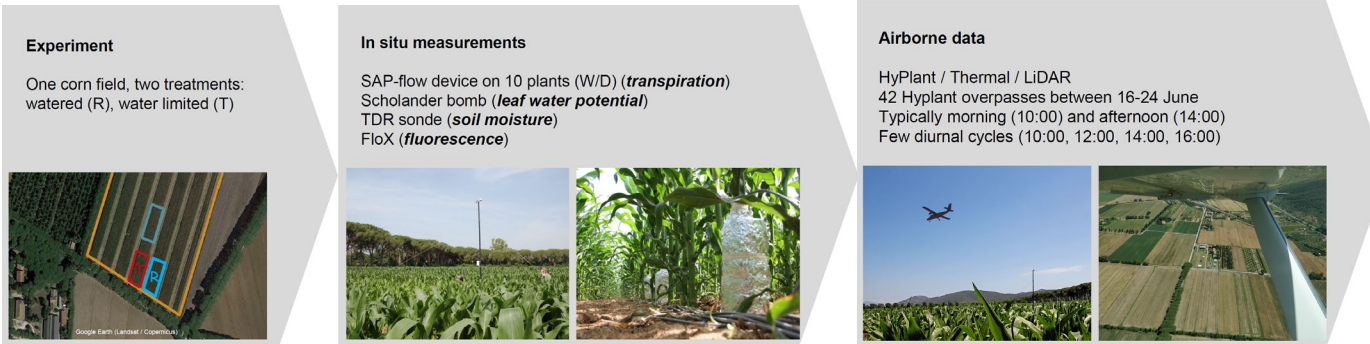
- Diurnal course over heterogeneous fields of experimental research campus (Campus Klein-Altendorf, Uni Bonn)
- Normalization with escape fraction or FCVI reveals leaf-level processes and the dynamic regulation of photosynthesis
- Separating canopy structural from leaf functional processes

Siegmann et al. (2021) Downscaling of far-red solar-induced chlorophyll fluorescence of different crops from canopy to leaf level using a diurnal data set acquired by the airborne imaging spectrometer *HyPlant*. *Rem. Sens. Environ.*, 264, article no. 112609



2) SIF to early detect vegetation drought

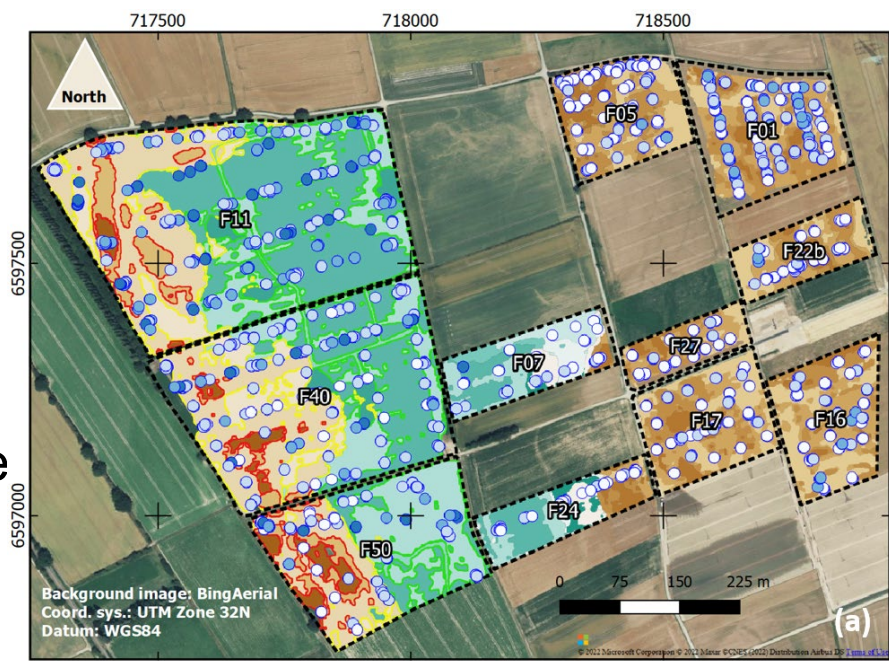
- Controlled drought experiment in Italy with quantitative measurements during the continuous development of drought response
- Complete data set using the full potential of the *HyPlant* airborne package (SIF, hyperspectral reflectance, thermal & LiDAR)
- SIF has the potential to detect early, 'pre-visual' signs of drought stress (complementing thermal and hyperspectral data)



Damm A., et al. (2022) Response times of remote sensing measured sun-induced chlorophyll fluorescence, surface temperature and vegetation indices to evolving soil water limitation in a crop canopy. *Rem. Sens. Environ.*, 273, article no. 112957

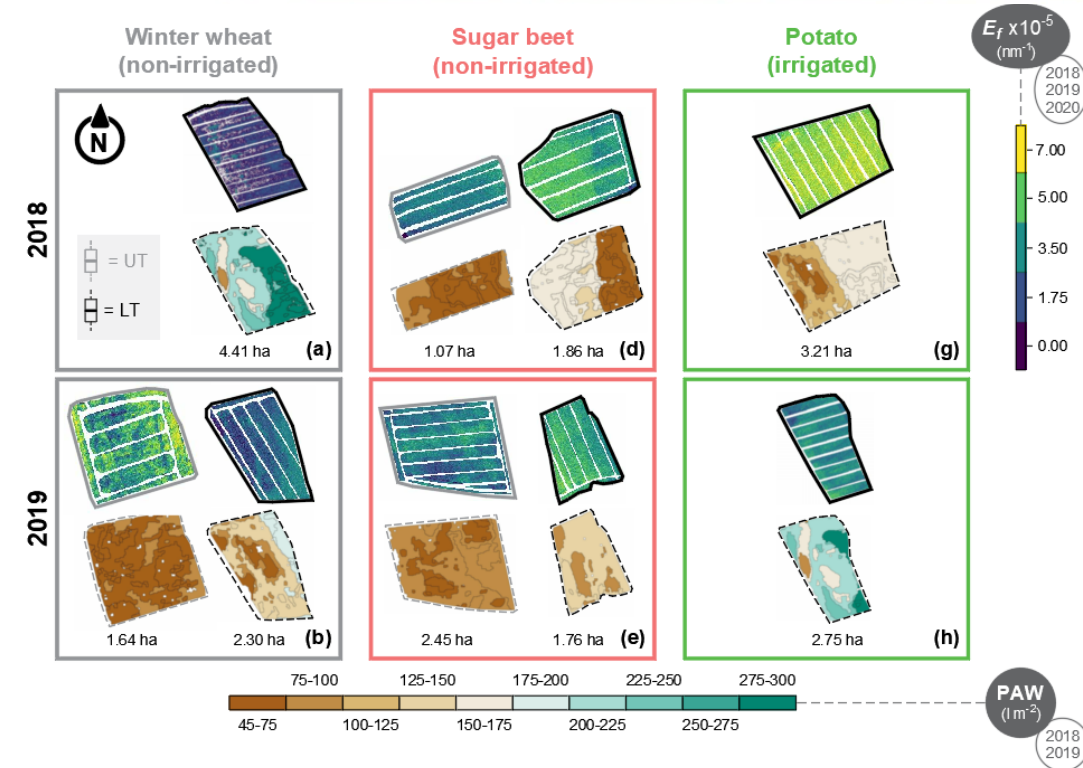
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- SIF has the potential to detect early, 'pre-visual' signs of drought stress (complementing thermal and hyperspectral data)
- SIF emission efficiency (ϵ_{SIF}) is related to plant available water (PAW) in the root zone, demonstrating the functional mechanism of early drought sensitivity



von Hebel C et al. (2018) Understanding soil and plant interaction by combining ground-based quantitative electromagnetic induction and airborne hyperspectral data. *Geophysical Research Letters*, 45, 7571-7579, doi: 10.1029/2018GL078658.

Quirós-Vargas et al. Spatial relation between solar-induced chlorophyll fluorescence and plant available water in the root zone. *PNAS Nexus*, re-submitted



Four new faces from our side working with the LIASE data



(Dr.) Juan Quiros:
expert in
understanding the
link between plant
available soil water
and SIF



Saja Salatna: PhD
student – better
understand the
quantitative relation
between drought and
SIF



Dr. Juliane Bendig:
expert in using UAVs
for crop measure-
ments & UAV based
SIF quantifications



Ruonan Chen:
PhD student with a
solid background on
how to model GPP
using satellite SIF
data

Many thanks to the numerous partners



University of Zurich ^{UZH}



FINNISH METEOROLOGICAL INSTITUTE



Joint Research Centre



UNIVERSITAT DE VALÈNCIA



Max-Planck-Institut für Biogeochemie



