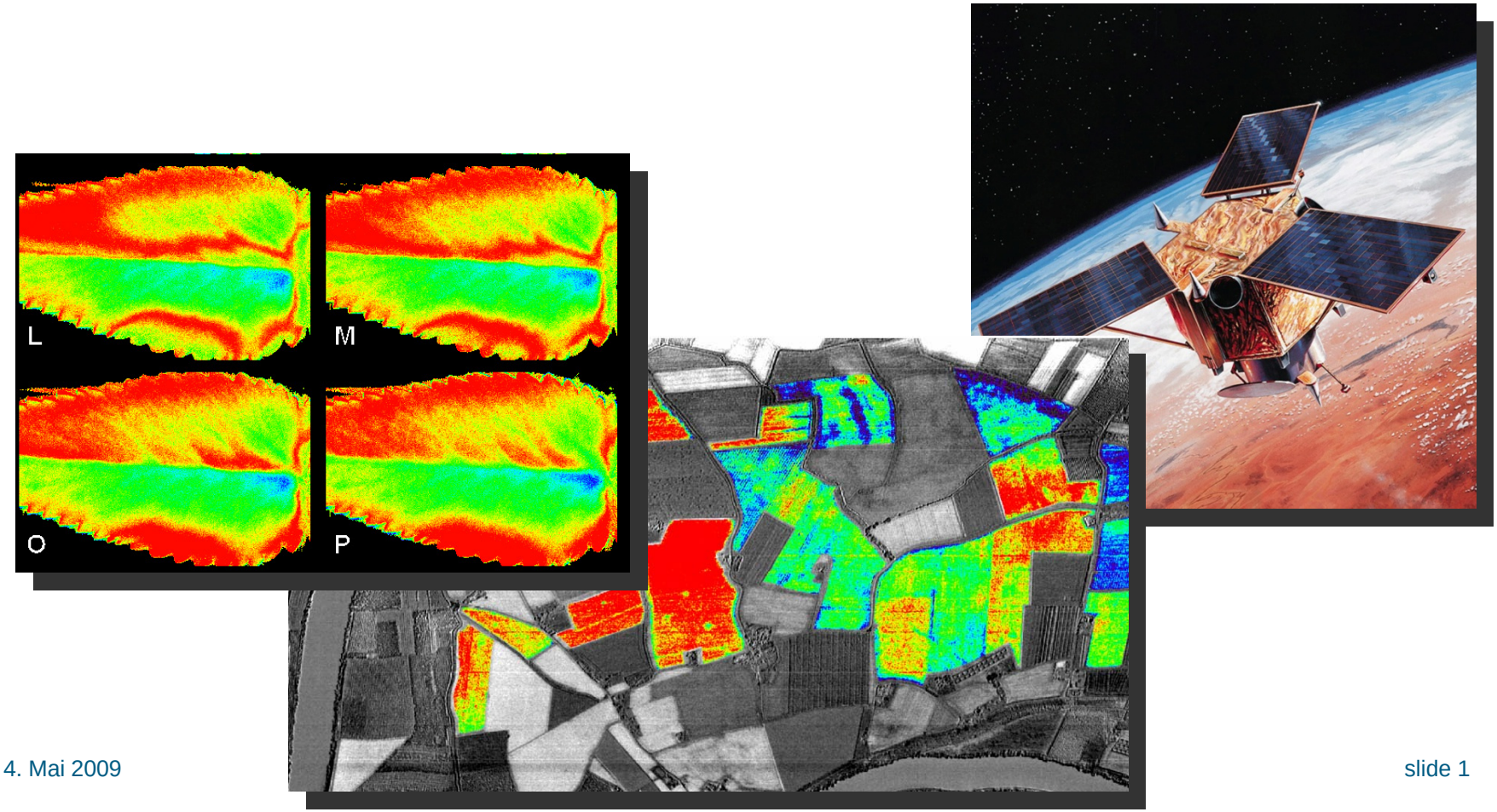
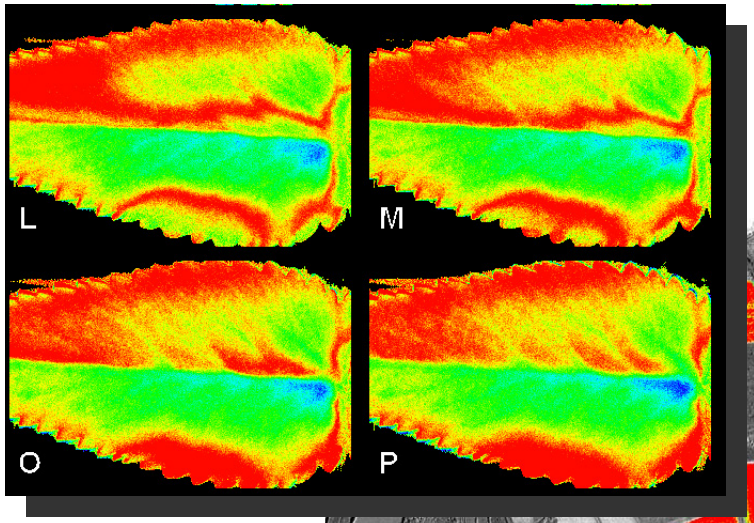
Imaging and Imagining the spatio-temporal variations of photosynthesis – optical remote sensing to scale physiological changes of the photosynthetic apparatus from the leaf to the globe

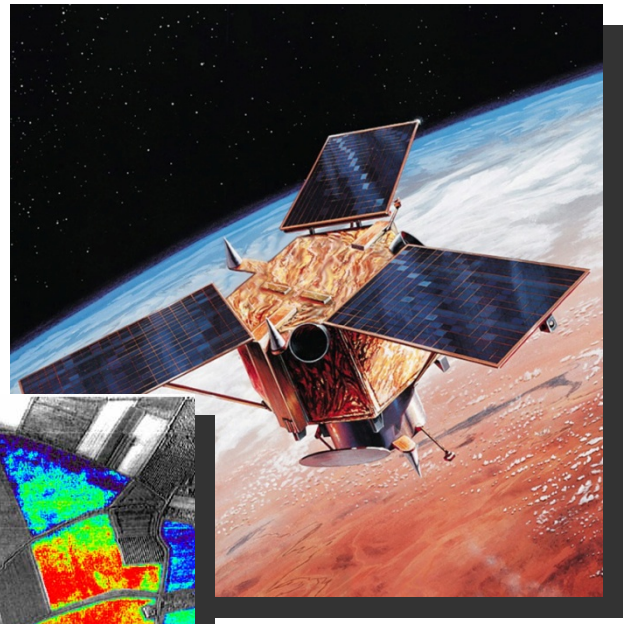
Uwe Rascher

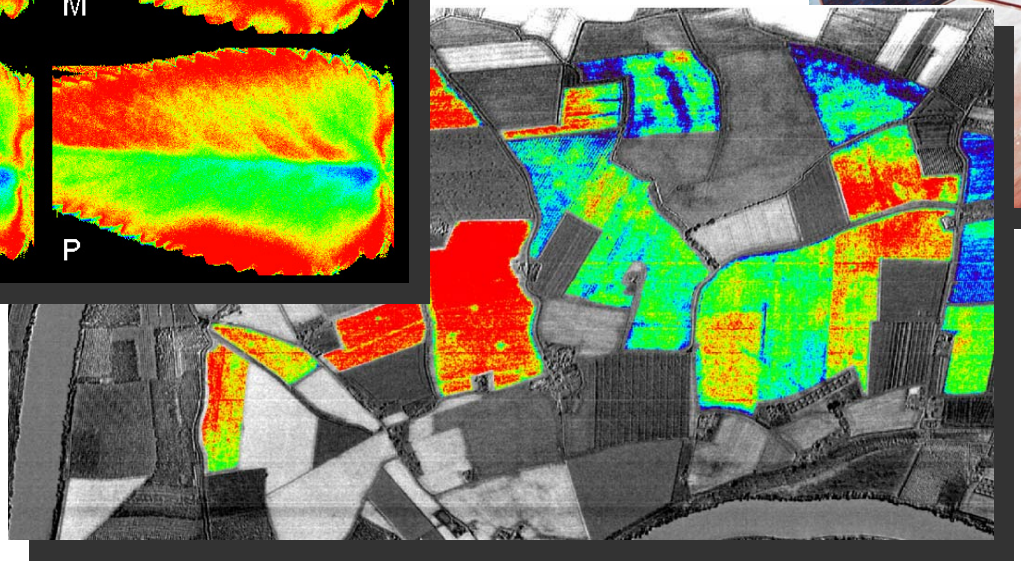


Imaging and Imagining the spatio-temporal variations of photosynthesis – optical remote sensing to scale physiological changes of the photosynthetic apparatus from the leaf to the globe

Joe Berry: ***"Remote Sensing of photosynthetic efficiency is the holy grail of plant physiology and remote sensing"***

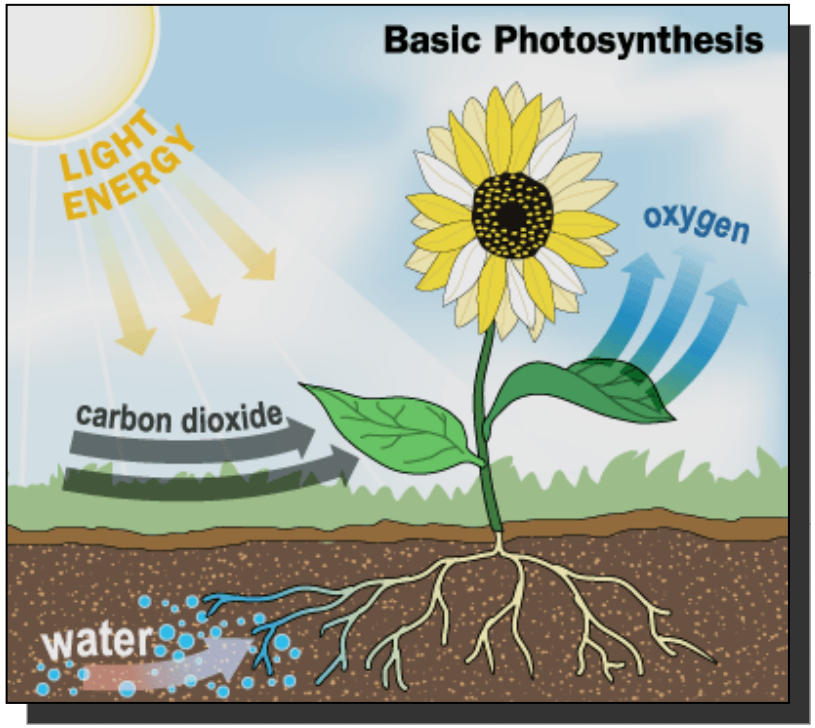


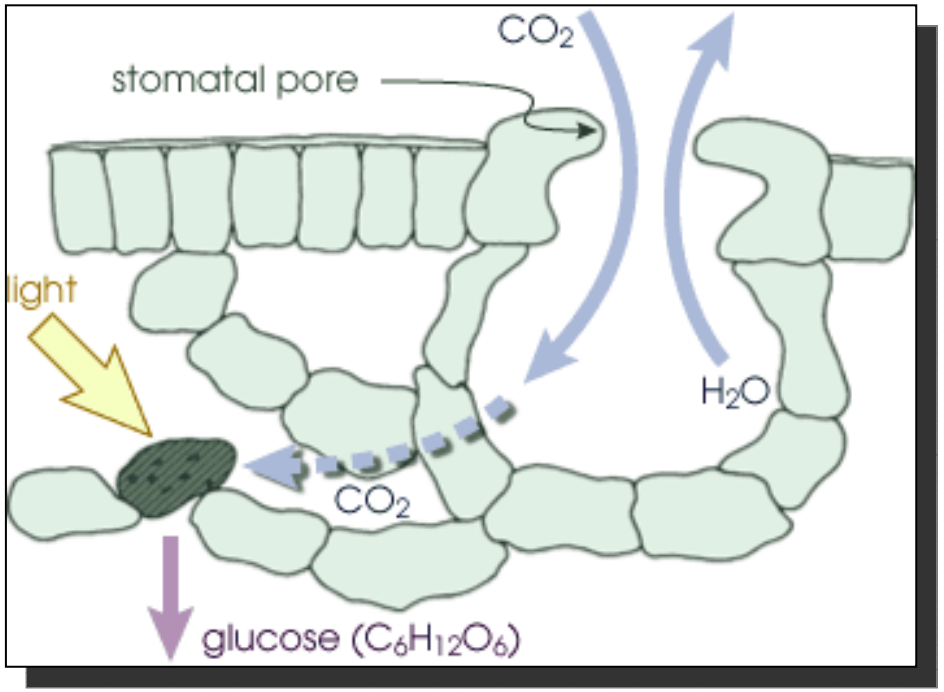




Scaling regulation of photosynthetic efficiency

Regulation of basic biophysical process of plant life





Scaling regulation of photosynthetic efficiency

Regulation of basic biophysical process of plant life

Determines biomass production in agrosystems

Scaling regulation of photosynthetic efficiency

Regulation of basic biophysical process of plant life

Determines biomass production in agrosystems

Governs plant mediated exchange in ecosystems

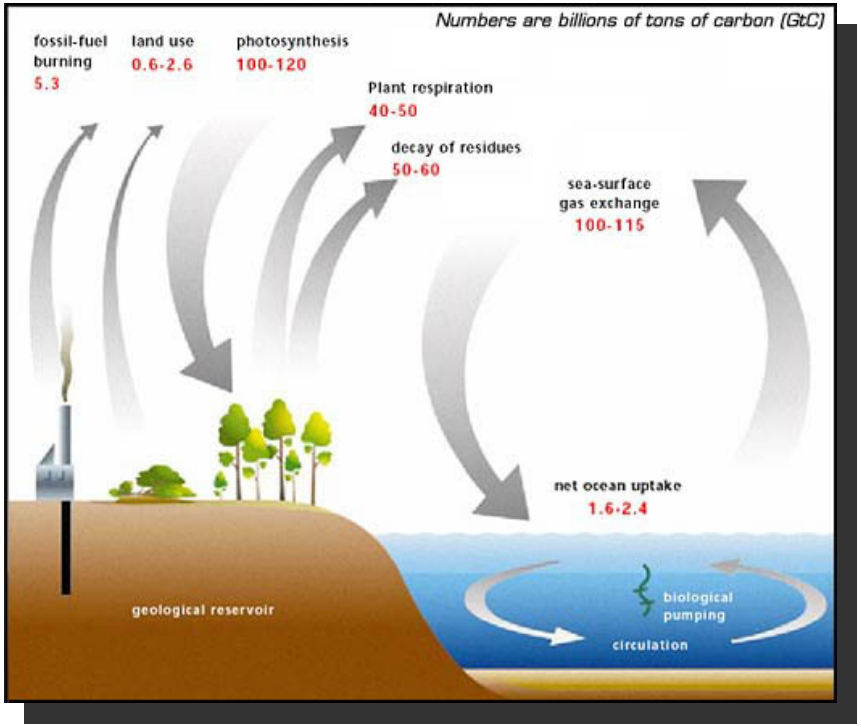
Scaling regulation of photosynthetic efficiency

Regulation of basic biophysical process of plant life

Determines biomass production in agrosystems

Governs plant mediated exchange in ecosystems

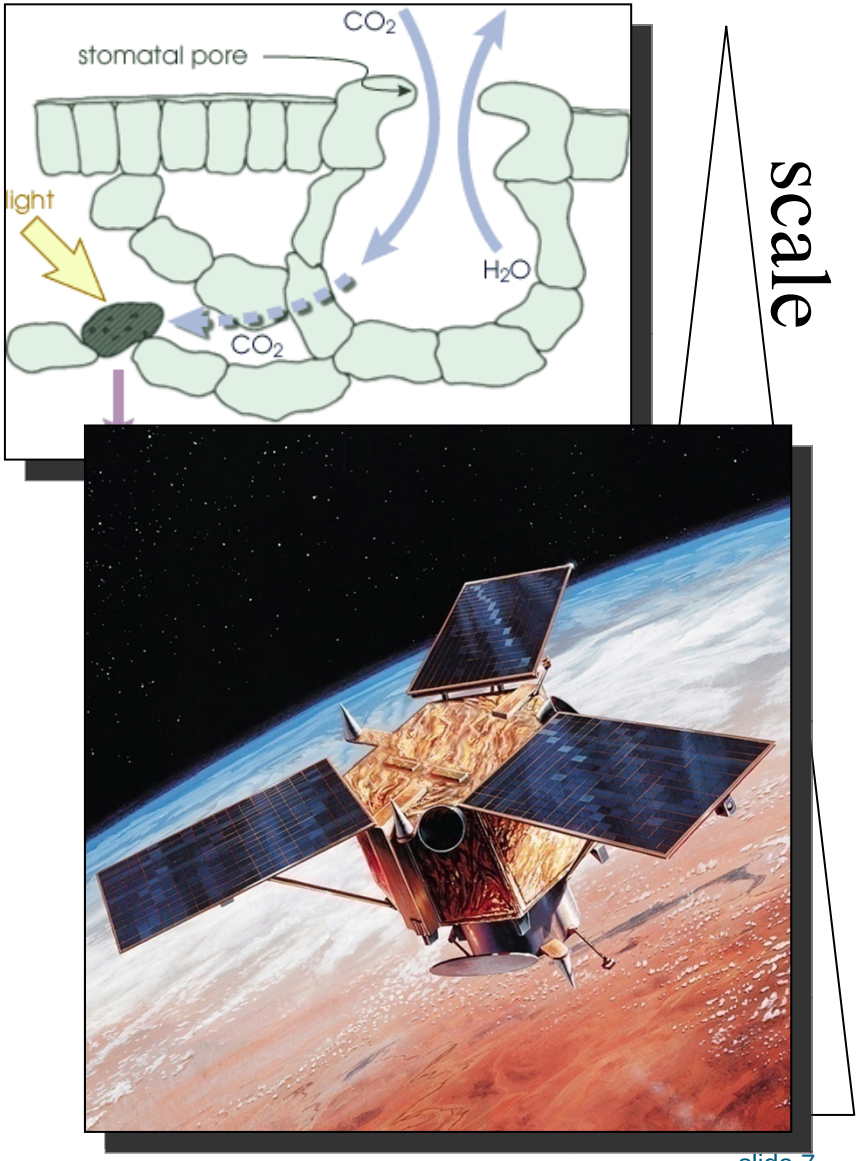
Essential to model global carbon and water cycle



Scaling regulation of photosynthetic efficiency

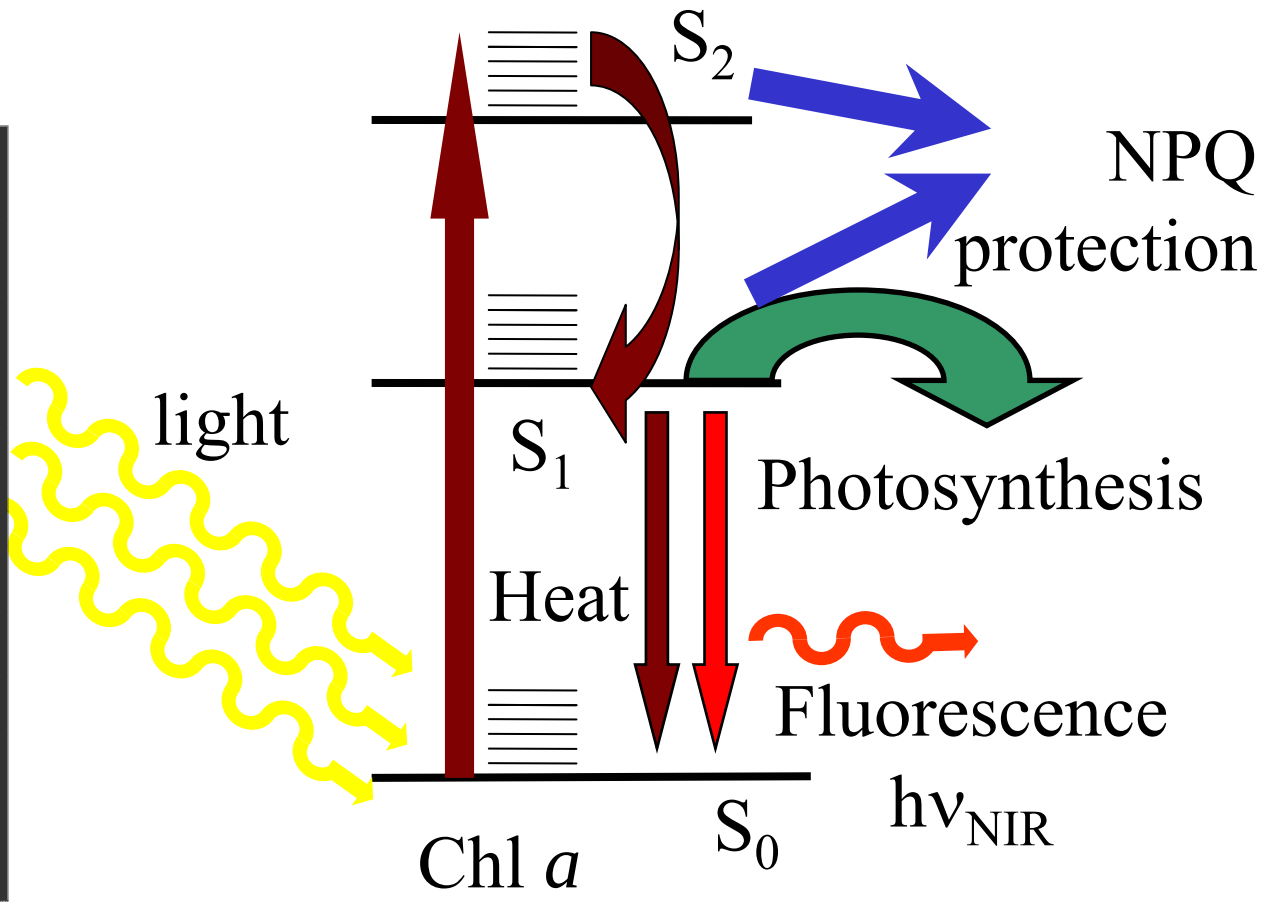
JÜLICH FORSCHUNGSZENTRUM

- Regulation of basic biophysical process of plant life
- Determines biomass production in agrosystems
- Governs plant mediated exchange in ecosystems
- Essential to model global carbon and water cycle



Chlorophyll Fluorescence

- Chlorophyll fluorescence is emitted from the core of the photosynthetic machinery and is directly correlated to efficiency of photosynthesis

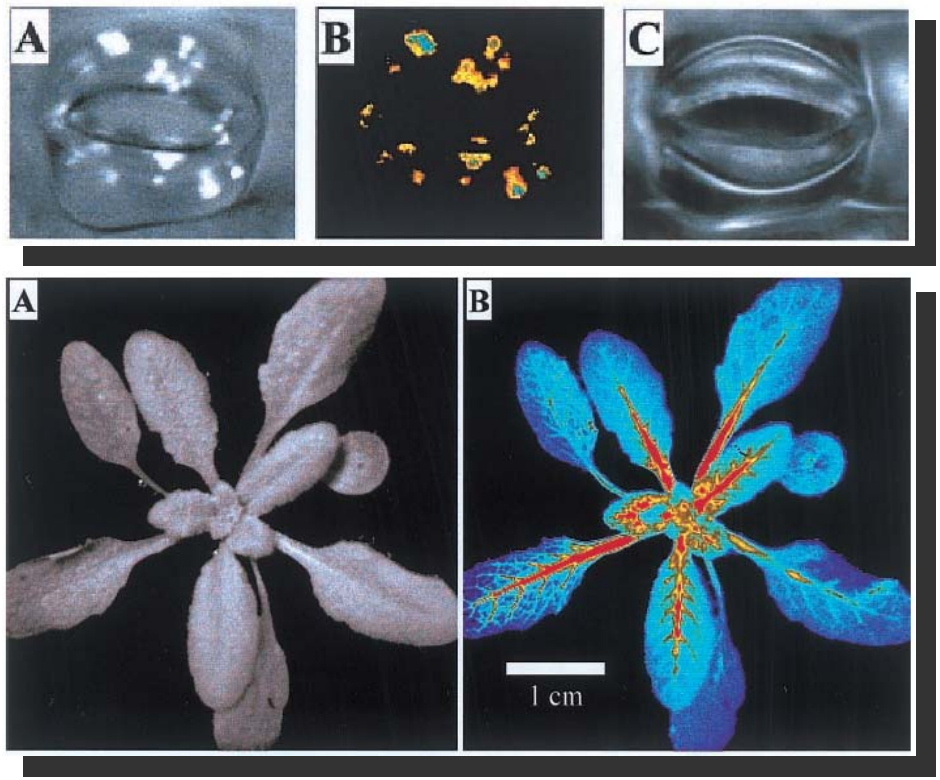


courtesy of L. Nedbal

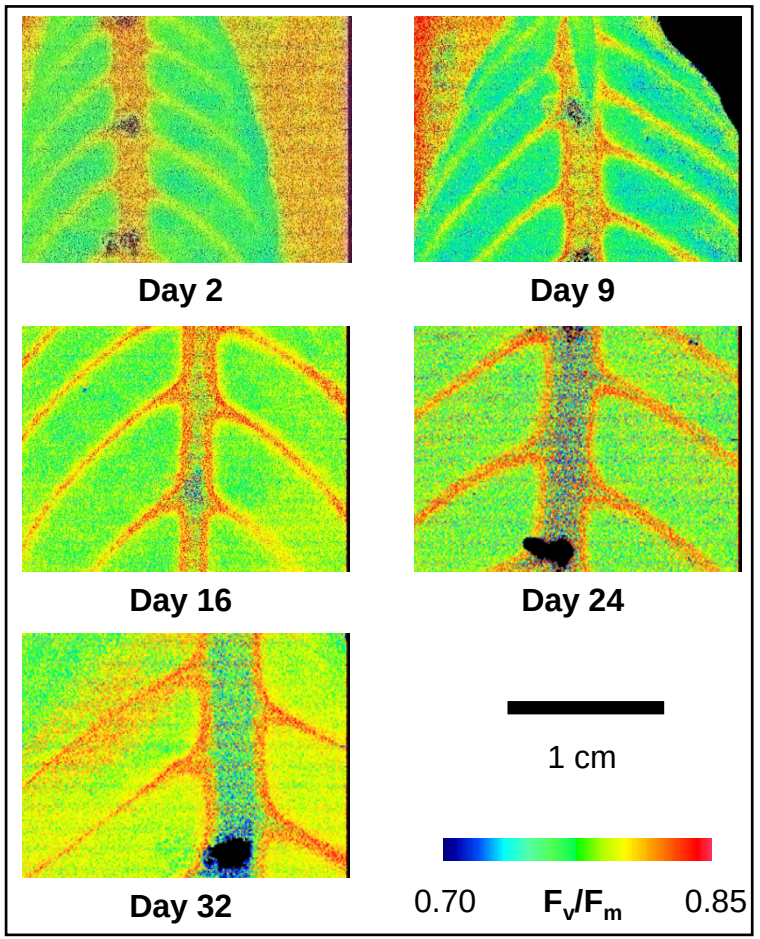
Fluorescence can be used to measure the spatio-temporal variations of photosynthesis

JÜLICH
FORSCHUNGSZENTRUM

Heterogeneity of photosynthesis I: Chloroplasts and anatomy

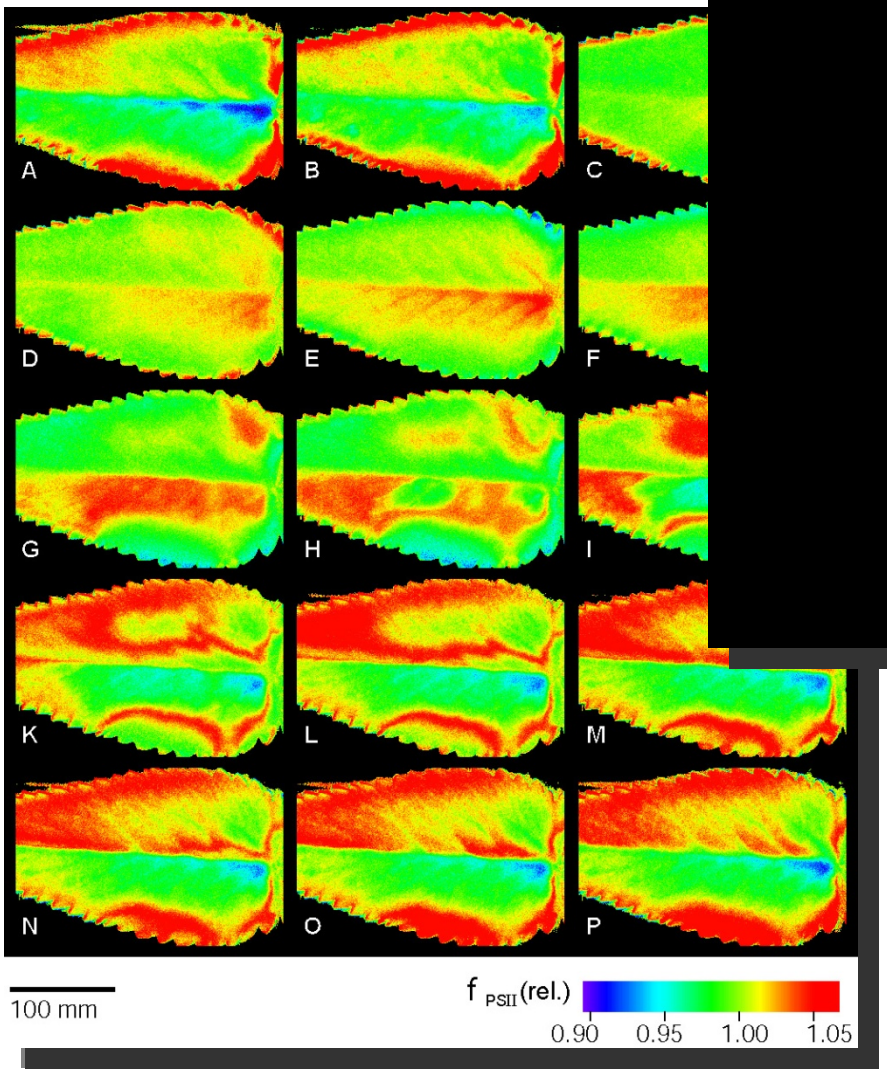


Baker et al. (2001) *J. Exp. Bot.* **52**, 615-621.



Walter, Rascher & Osmond (2004) *Plant Biol.* **6**, 184-191.

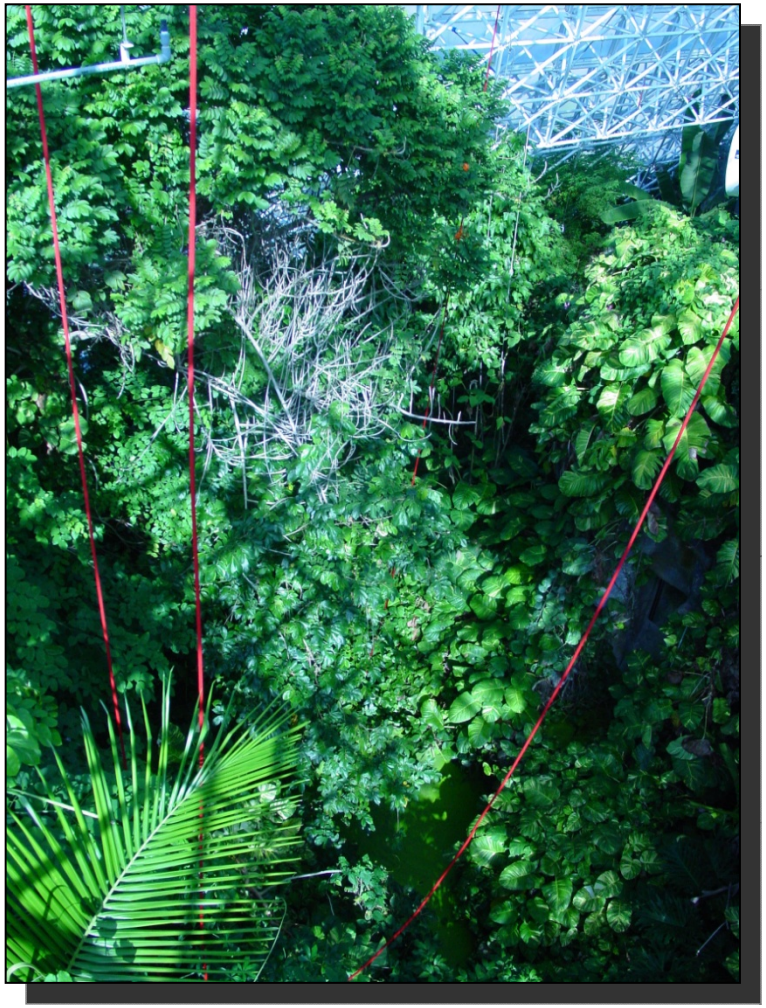
Heterogeneity of photosynthesis II: Physiology

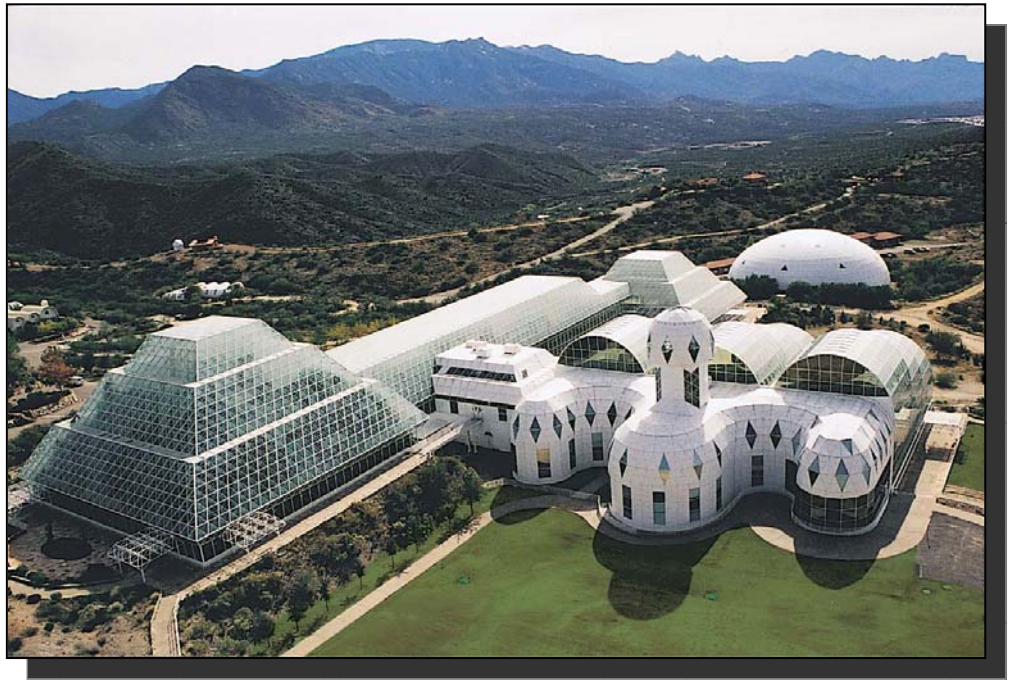


Rascher et al. (2001) *Proc. Natl. Acad. Sci. USA* **98**, 11801-11805.

Heterogeneity on anatomically uniform leaves

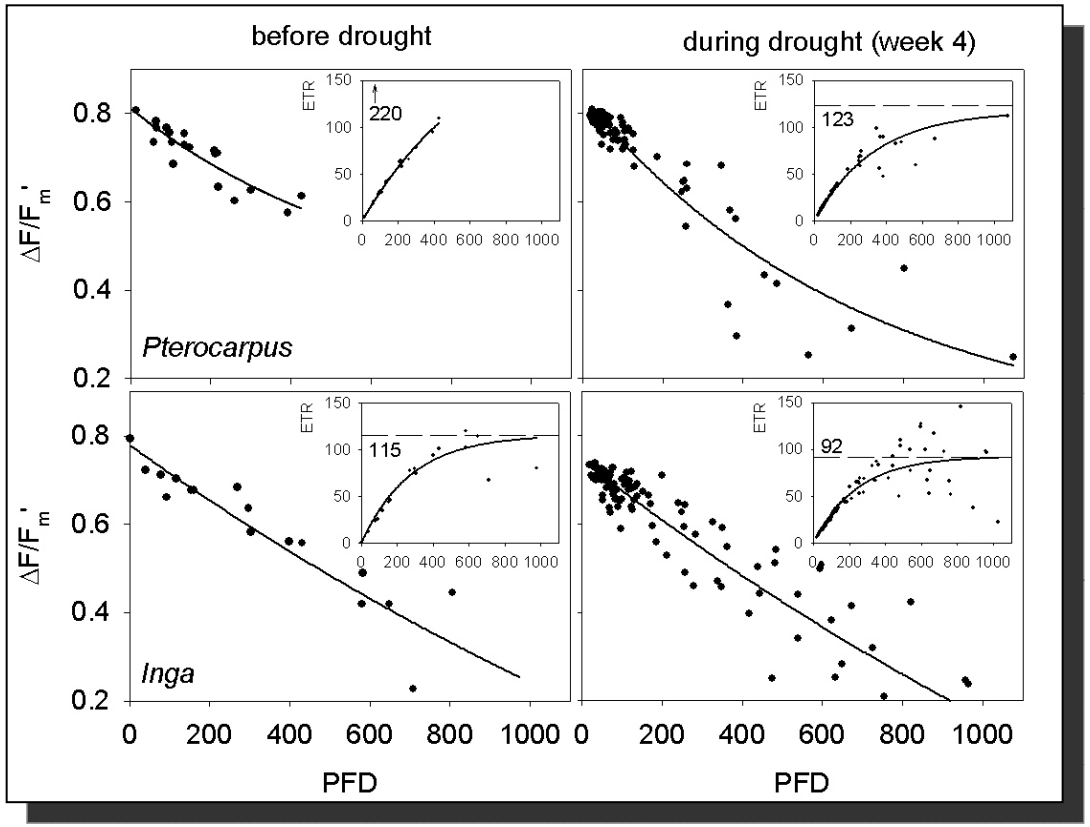
Example: tropical rainforest of Biosphere 2: Drought effects from the leaf to the ecosystem





Closed system on 42m x 42m with 15m tall canopy, about 110 species

drought reversibly reduced maximum electron transport rate at photosystem II: functional diversity on the leaf level

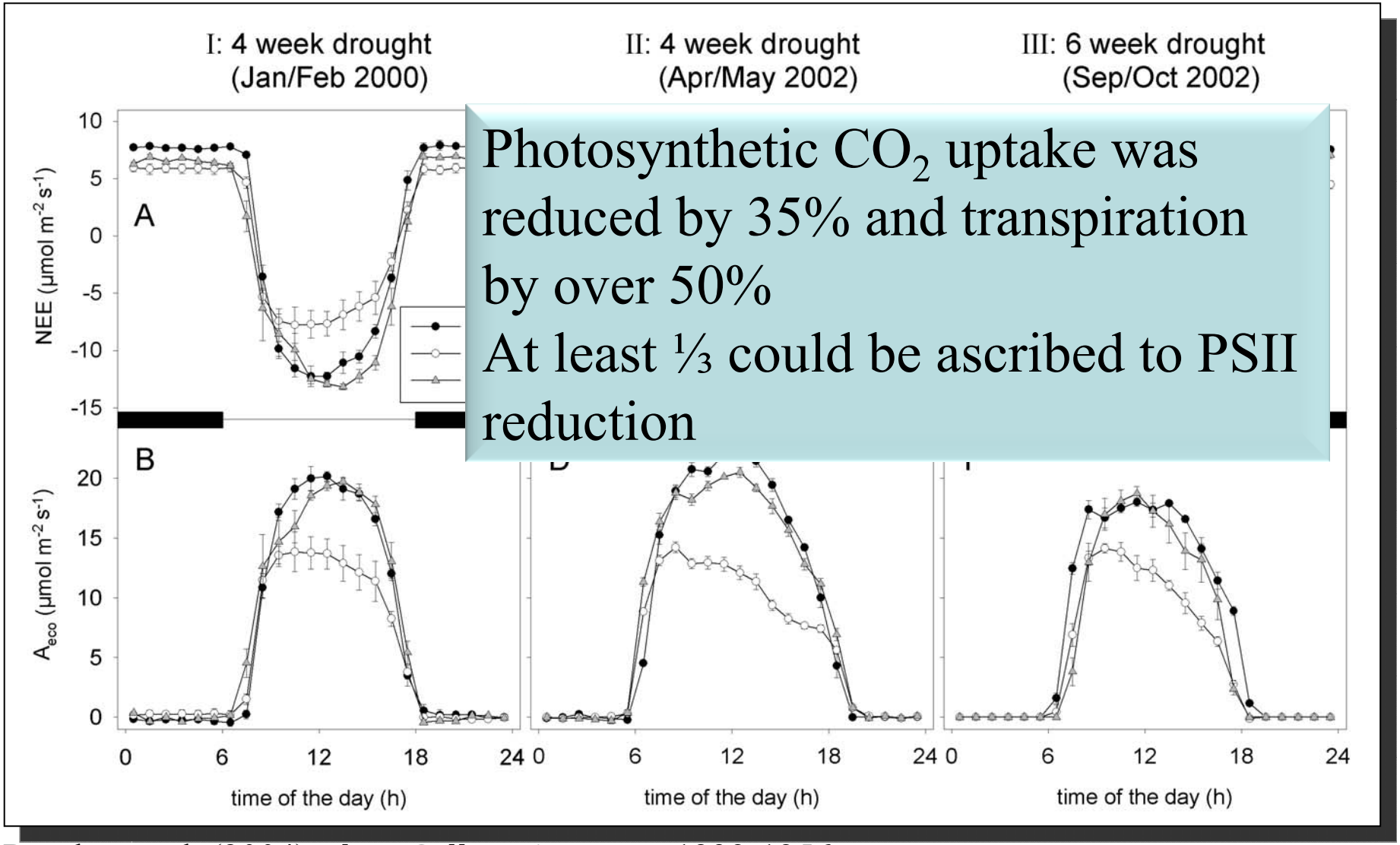


Pterocarpus indicus

Inga cf. sapindoides

Rascher et al. (2000) *Plant Cell Environ. 23*, 1397-1405.
Rascher et al. (2004) *Plant Cell Environ.*, *27*, 1239-1256.

drought reversibly reduced ecosystem CO_2 uptake

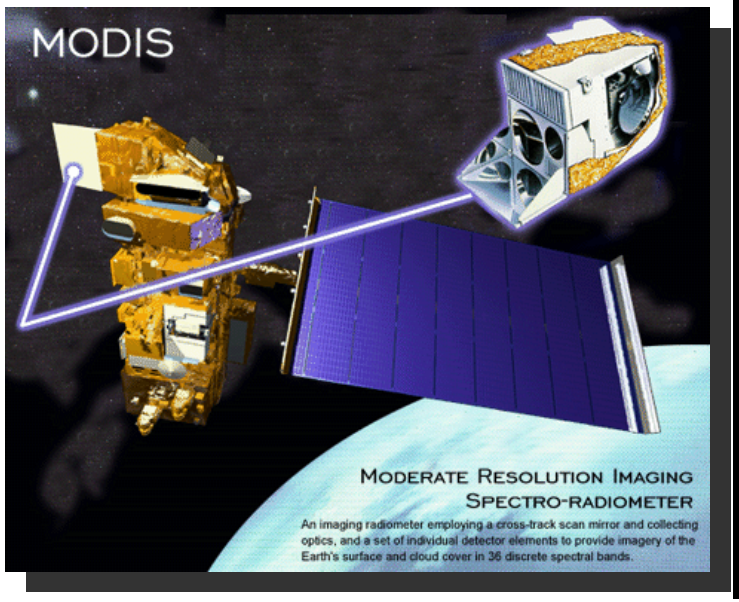


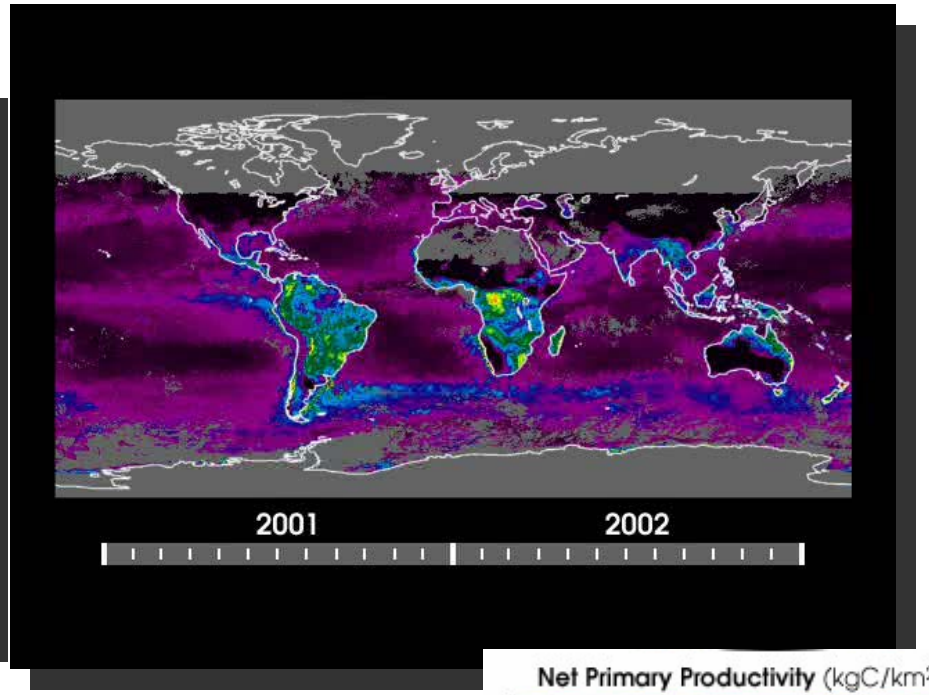
Photosynthetic CO_2 uptake was reduced by 35% and transpiration by over 50%

At least ⅓ could be ascribed to PSII reduction

Rascher et al. (2004) *Plant Cell Environ.*, *27*, 1239-1256.

MODIS: “moderate resolution imaging spectro-radiometer”



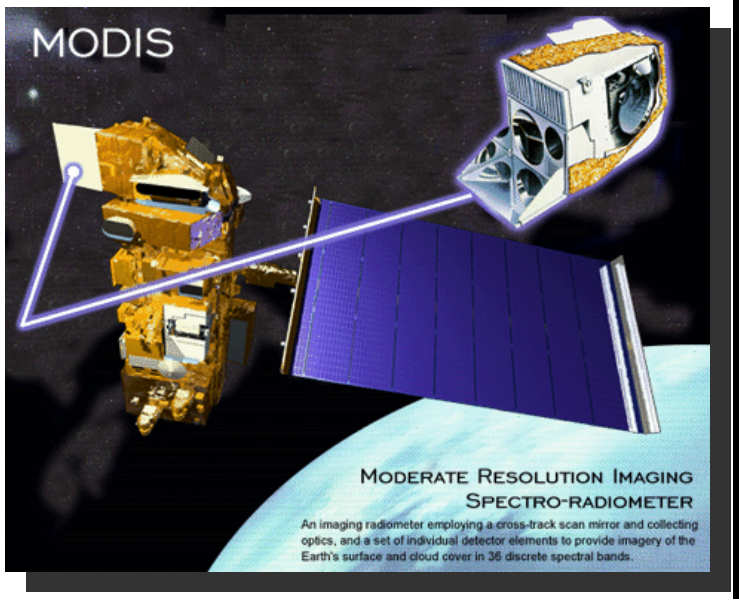


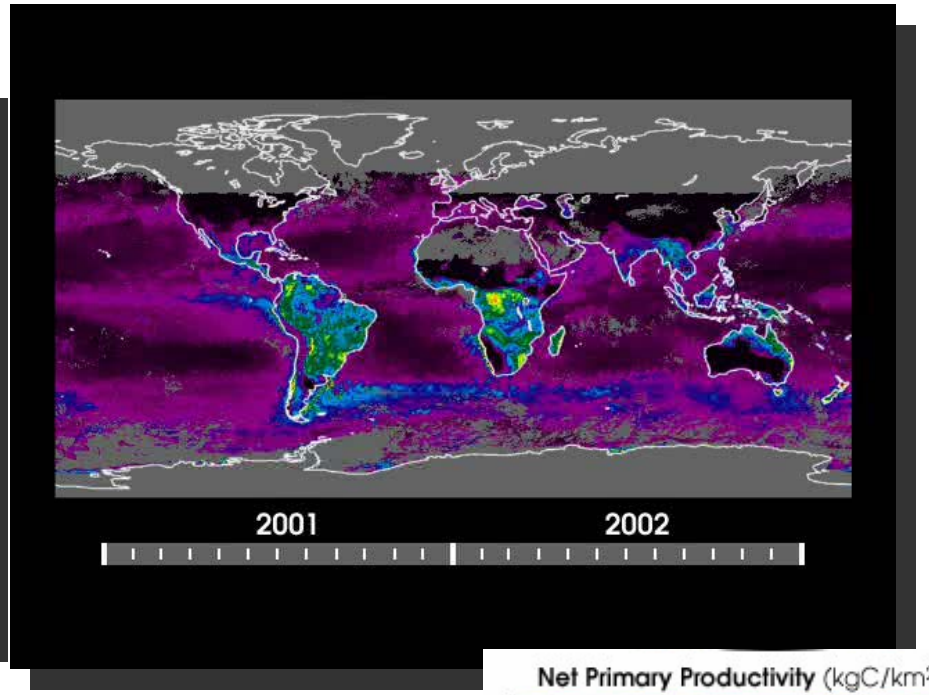
http://earthobservatory.nasa.gov/Newsroom/NPP/npp.html

Table 2-1. Canopy Structural Attributes of Global Land Covers From the Viewpoint of Radiative Transfer Modeling

	Grasses and Cereal Crops	Shrubs	Broadleaf Crops	Savannas	Broadleaf Forests	Needle Forests
Horizontal heterogeneity	no	yes	variable	yes	yes	yes
Ground cover	100%	20-60%	10-100%	20-40%	> 70%	> 70%
Vertical heterogeneity						
(leaf optics and LAD)	no	no	no	yes	yes	yes

MODIS: “moderate resolution imaging spectro-radiometer”





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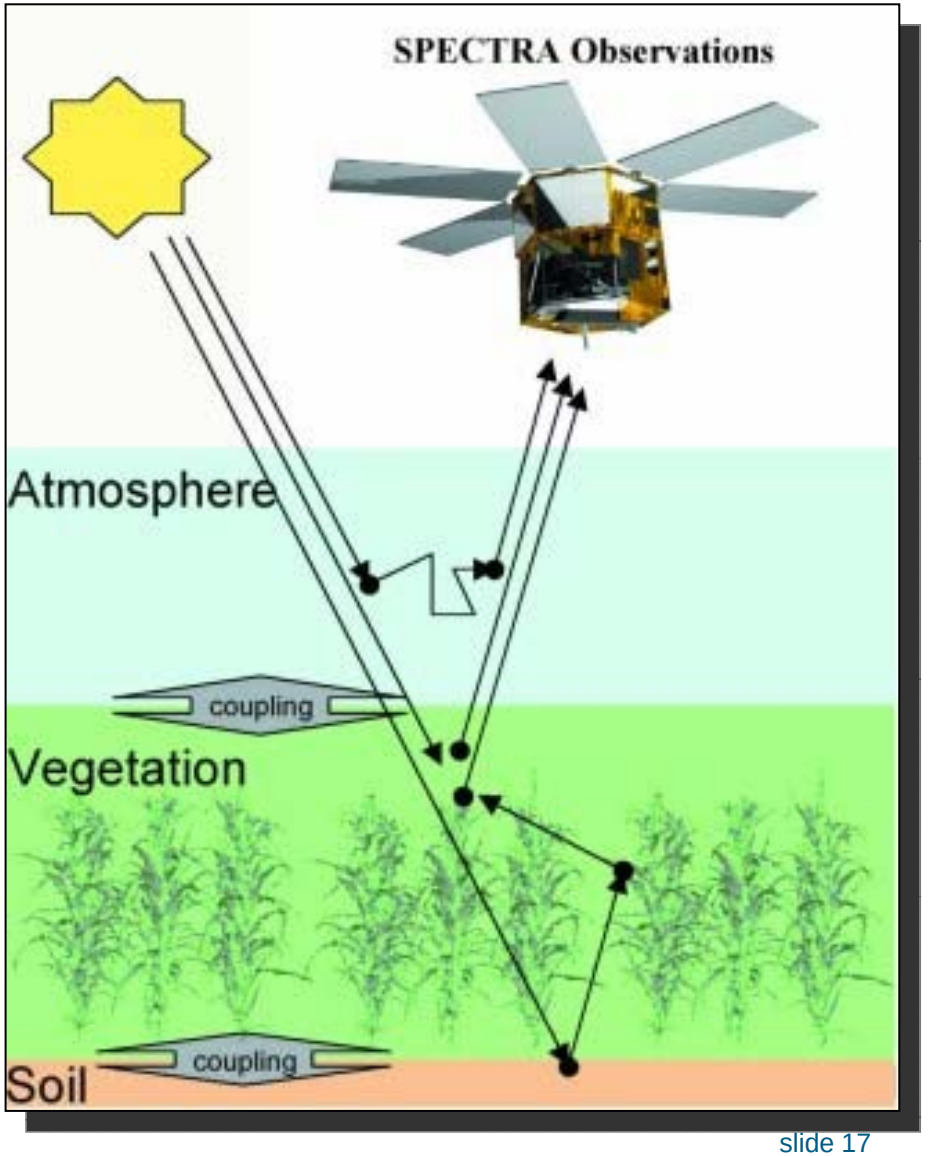
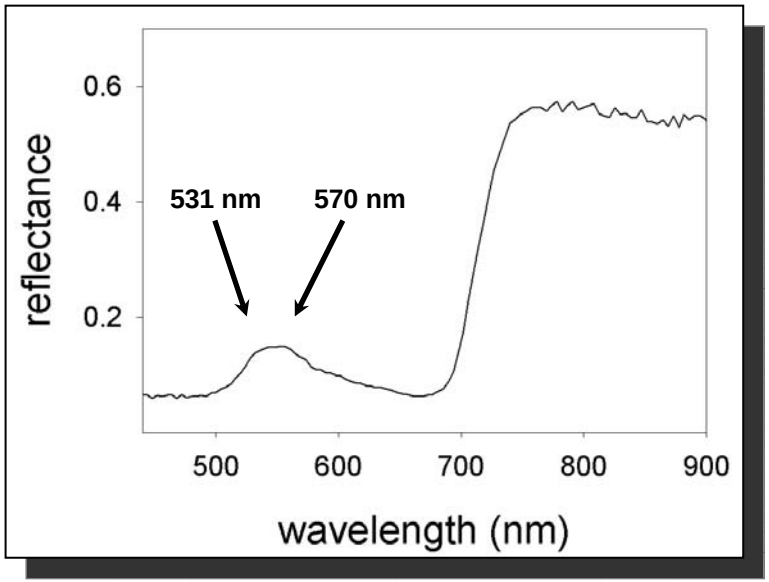
	Grasses and Cereal Crops	Shrubs	Broadleaf Crops	Savannas	Broadleaf Forests	Needle Forests
Hor						yes
Gro						> 70%
Ver						
(						yes

Great uncertainties as NPP is driven by changes in greenness (NDVI) and empirically modulated by maximum and minimum temperature

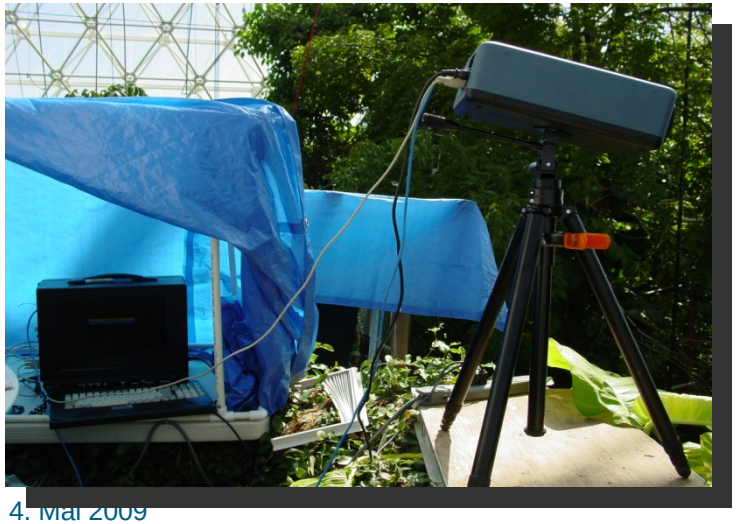
Mapping photosynthesis from space: hyperspectral reflectance - fluorescence

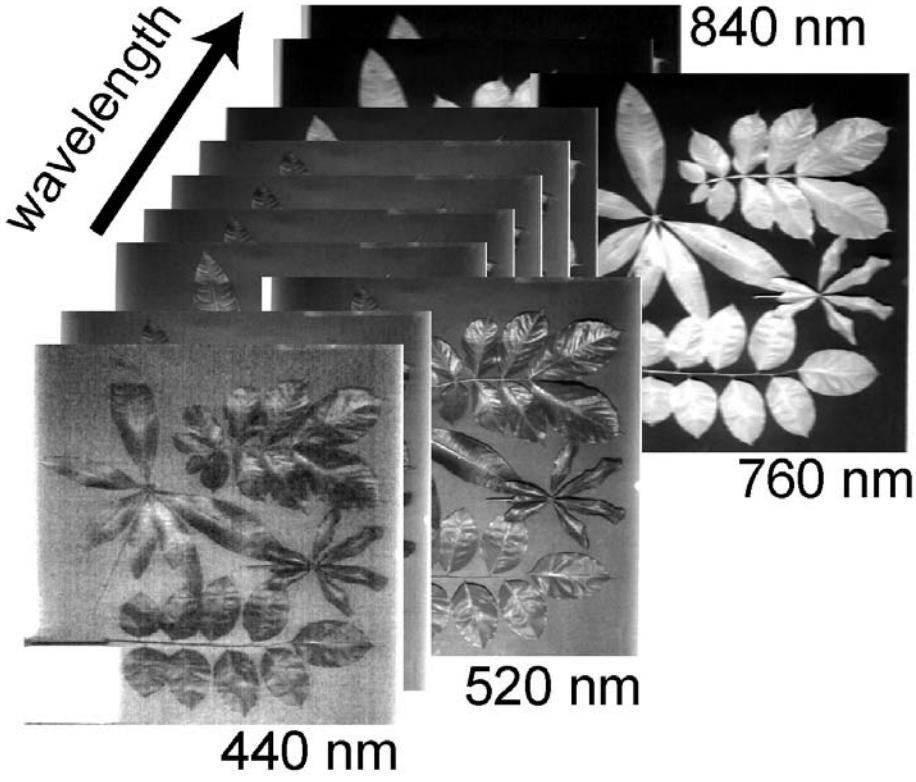


Hyperspectral reflectance: Photochemical Reflectance Index (PRI)



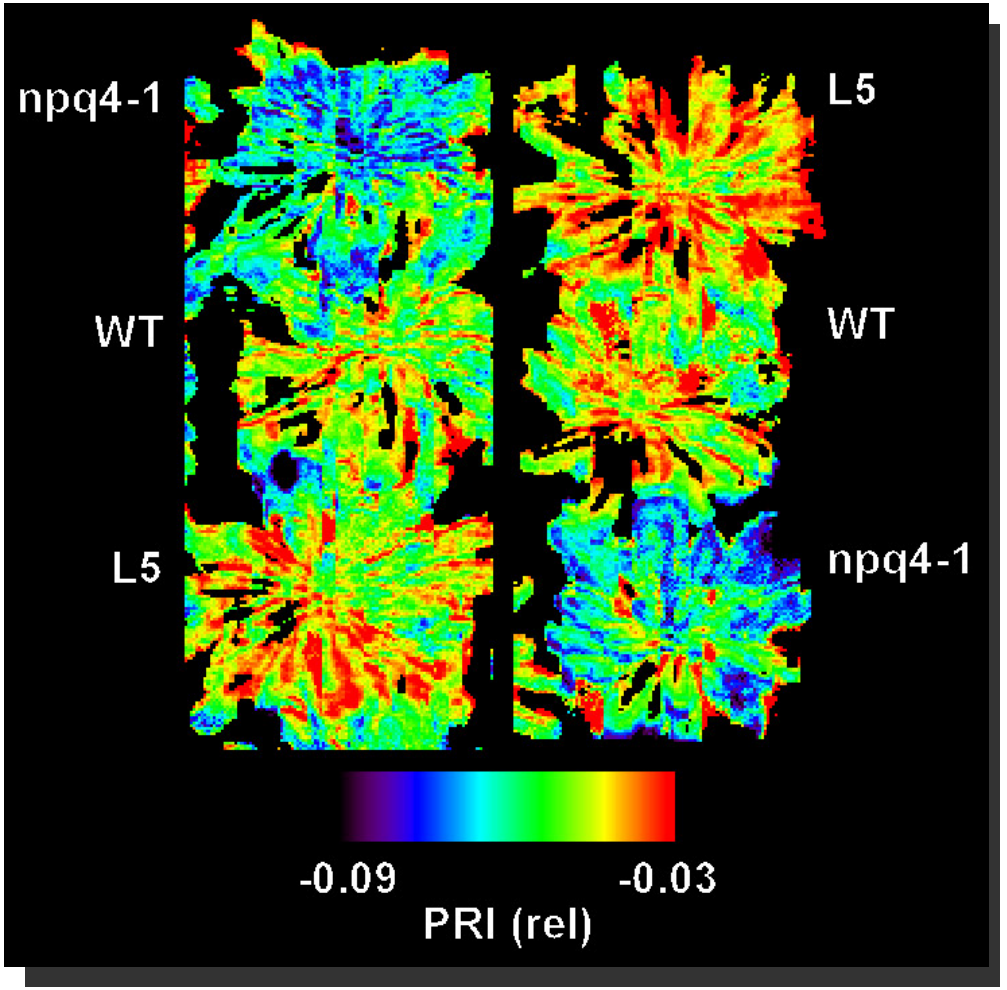
$$PRI = \frac{R_{570} - R_{531}}{R_{570} + R_{531}}$$





Gamon et al. (1990) *Oecologia* **85**, 1-7.

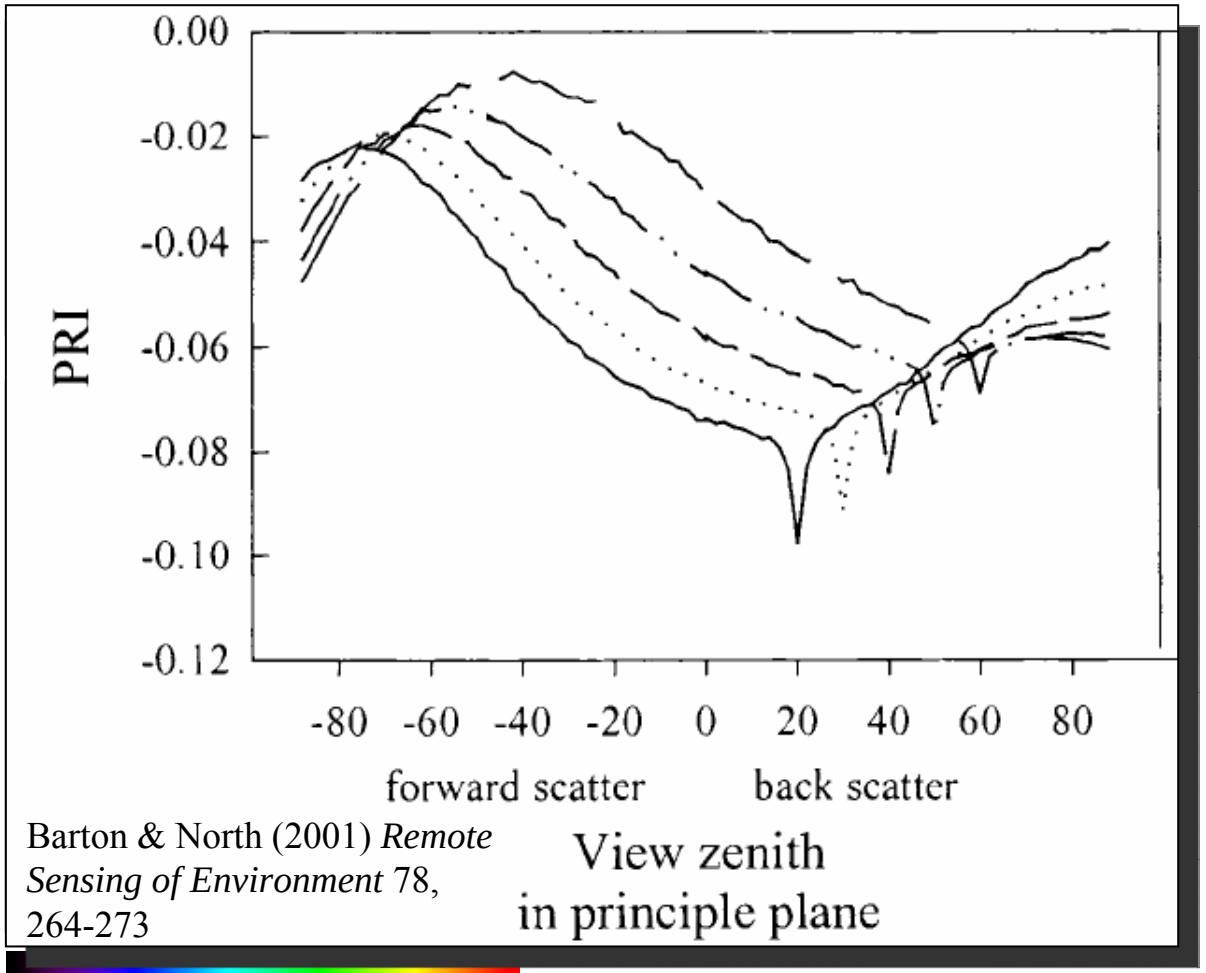
PRI: test case, genetically modified *Arabidopsis thaliana*



npq4-1: reduced NPQ
L5: over-expressed NPQ

Rascher et al. (2007) *Photogrammetric Engineering and Remote Sensing*, **73**, 45-56

Soyface: Remote Sensing of structure and function

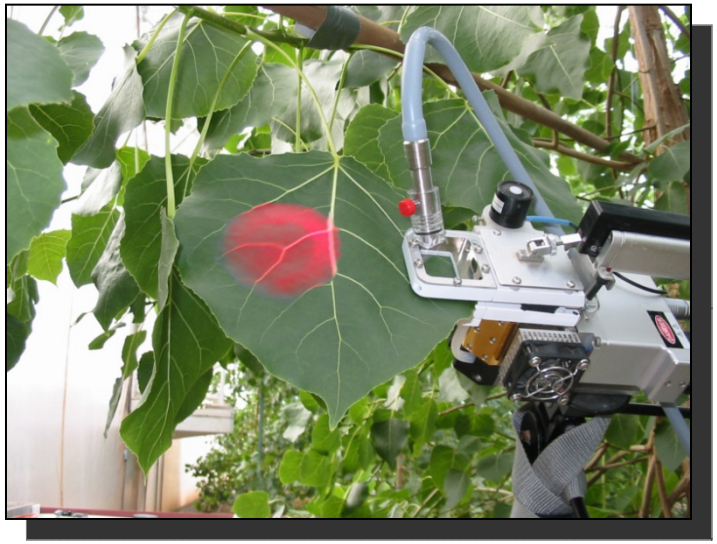


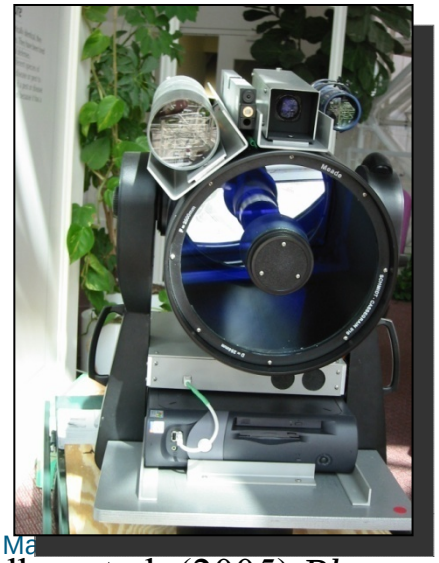
Barton & North (2001) *Remote Sensing of Environment* 78, 264-273

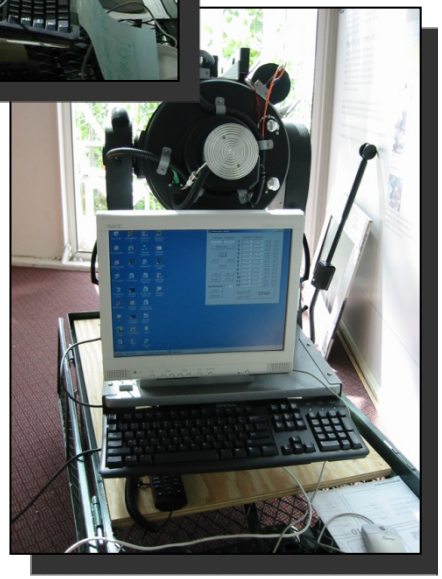
Rascher and Pieruschka (2008) *Precision Agriculture*, **9**, *355-366*

SOYFACE
UNIVERSITY OF ILLINOIS at Urbana-Champaign

Fluorescence: active laser induced fluorescence transients, LIFT







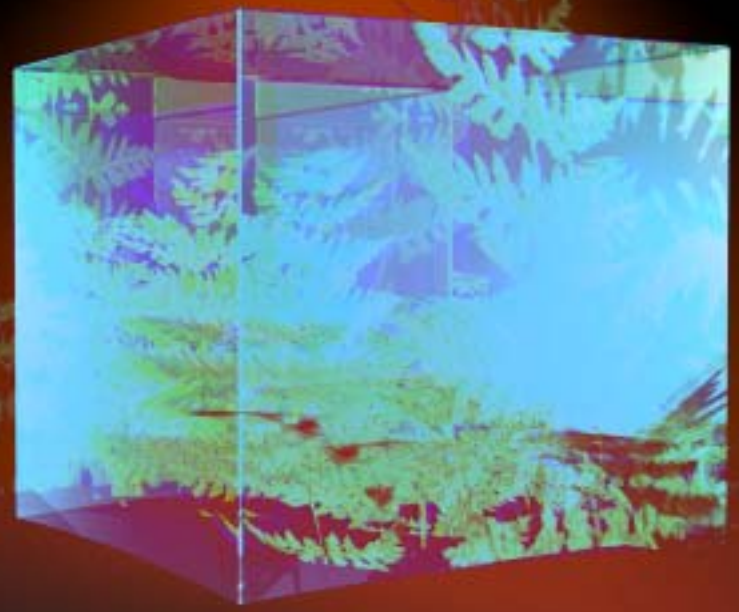
Quantification of photosynthetic efficiency of up to 50 meters

Kolber et al. (2005) *Photosynthesis Research*, *84*, 121-129

LIFT can be used to map distribution of photosynthesis within the canopy

Rascher & Pieruschka (2009) *Precision Agriculture*, DOI 10.1007/s11119-008-9074-0

FLEX - FLuorescence EXplorer:
a remote sensing approach to quantify spatio-temporal variations of photosynthetic efficiency from space



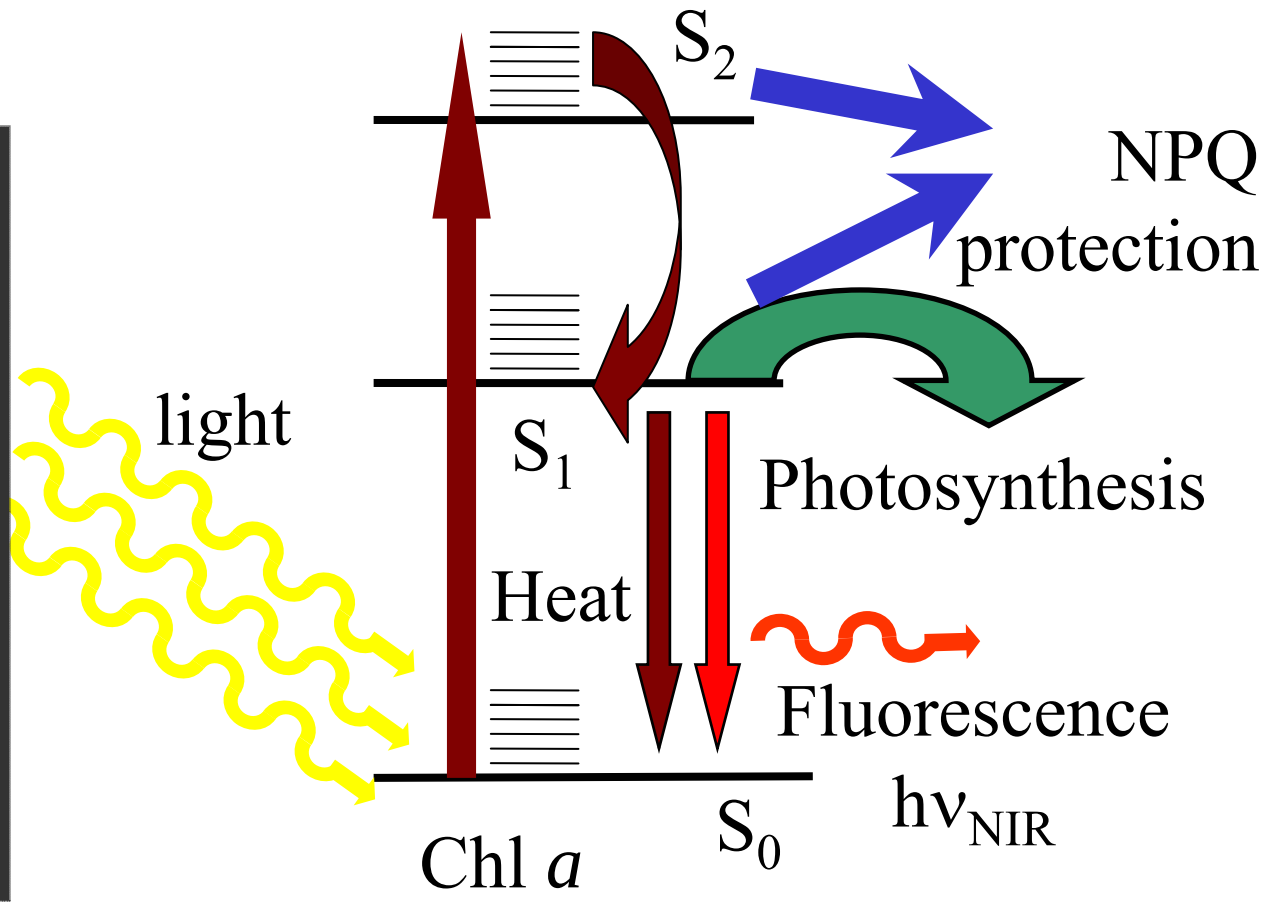
A proposed mission to observe photosynthetic activity from space

U. Rascher

on behalf of the FLEX Team and
ESA's Mission Assessment Group

Chlorophyll Fluorescence (1)

- Chlorophyll fluorescence is emitted from the core of the photosynthetic machinery and is directly correlated to efficiency of photosynthesis

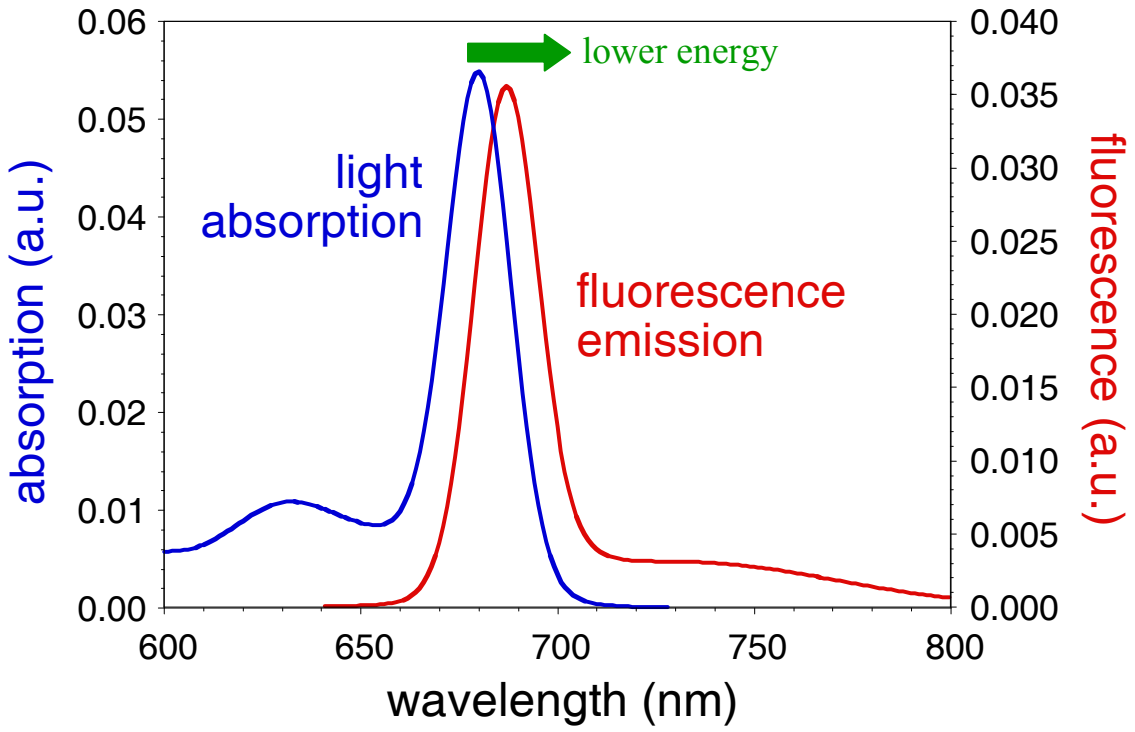


courtesy of L. Nedbal

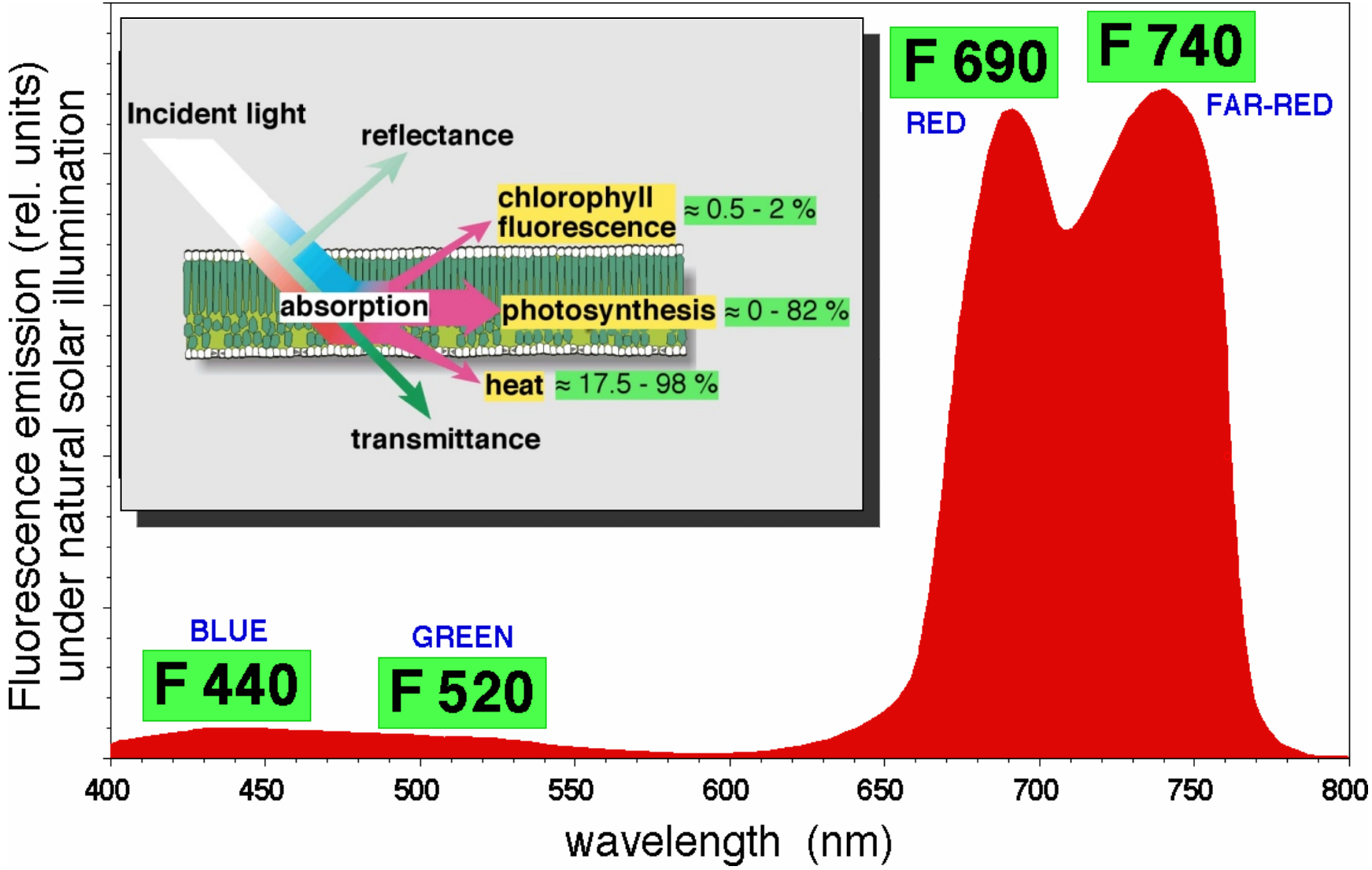
Chlorophyll Fluorescence (2)

- Chlorophyll fluorescence is emitted from the core of the photosynthetic machinery and is directly correlated to efficiency of photosynthesis

- The fluorescence signal is shifted to longer wavelengths

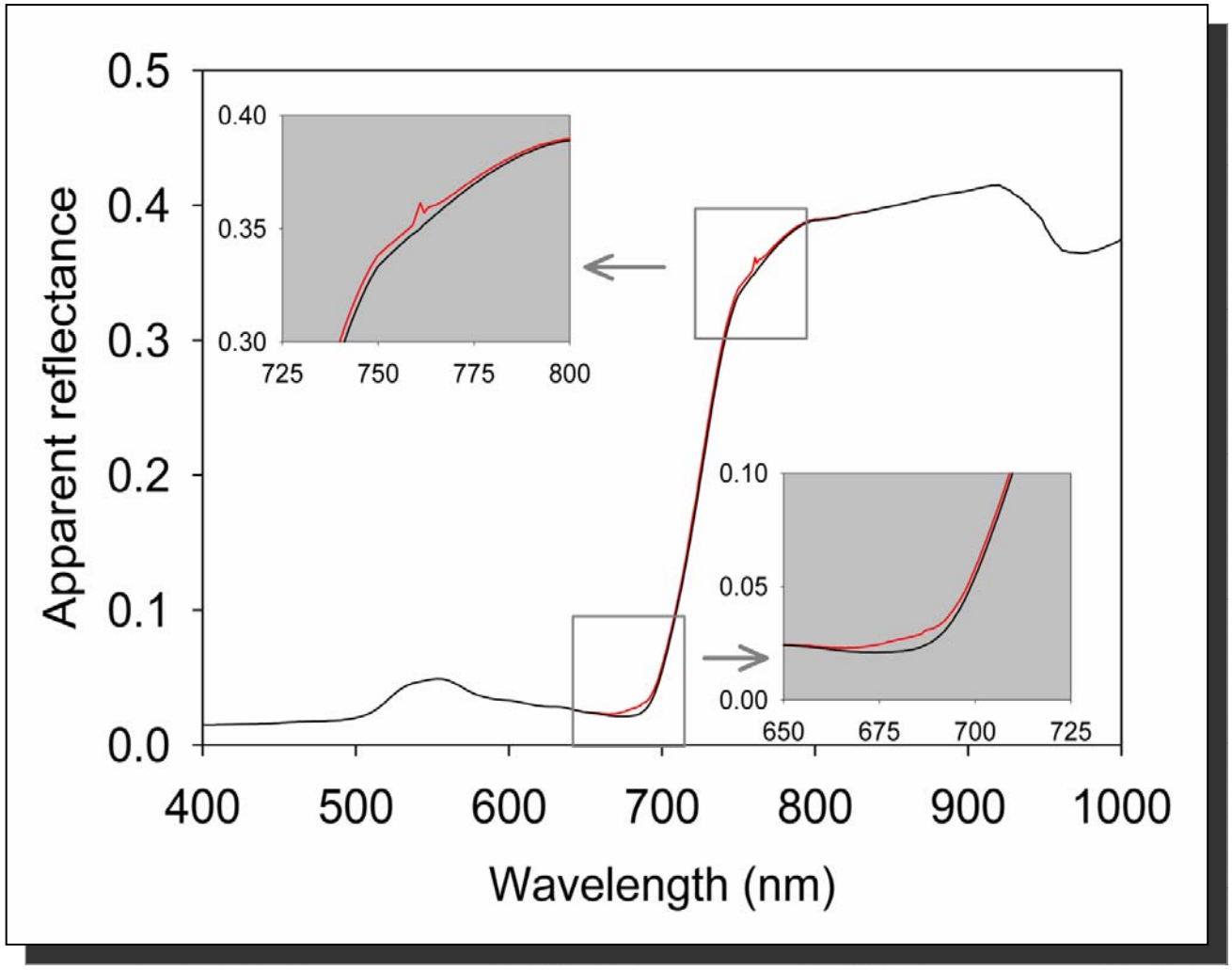


Chlorophyll Fluorescence (3)

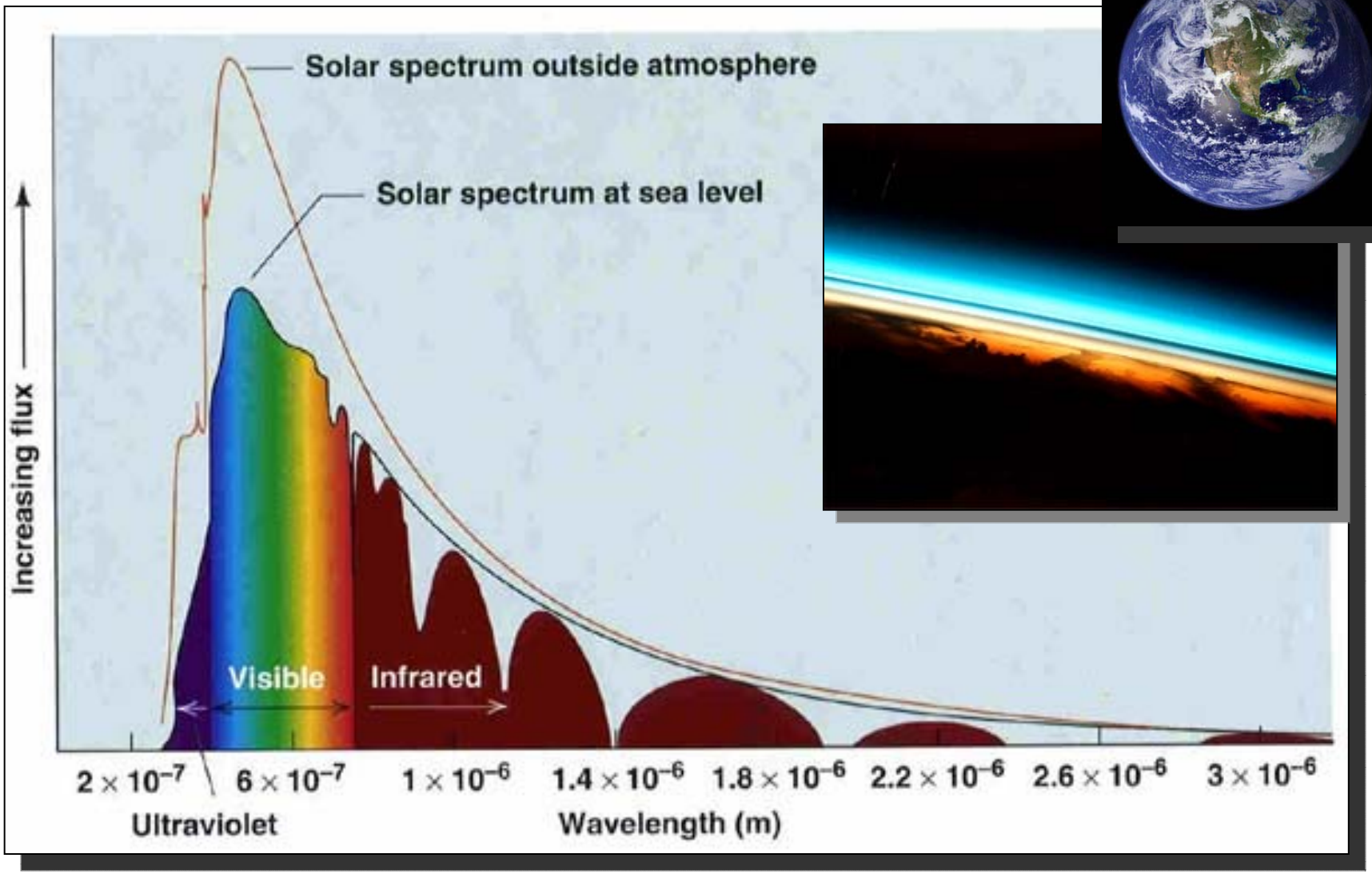


Chlorophyll Fluorescence (4)

- However, the fluorescence signal is only 2-5 % of the reflected light and thus cannot not be measured with classic spectroscopy

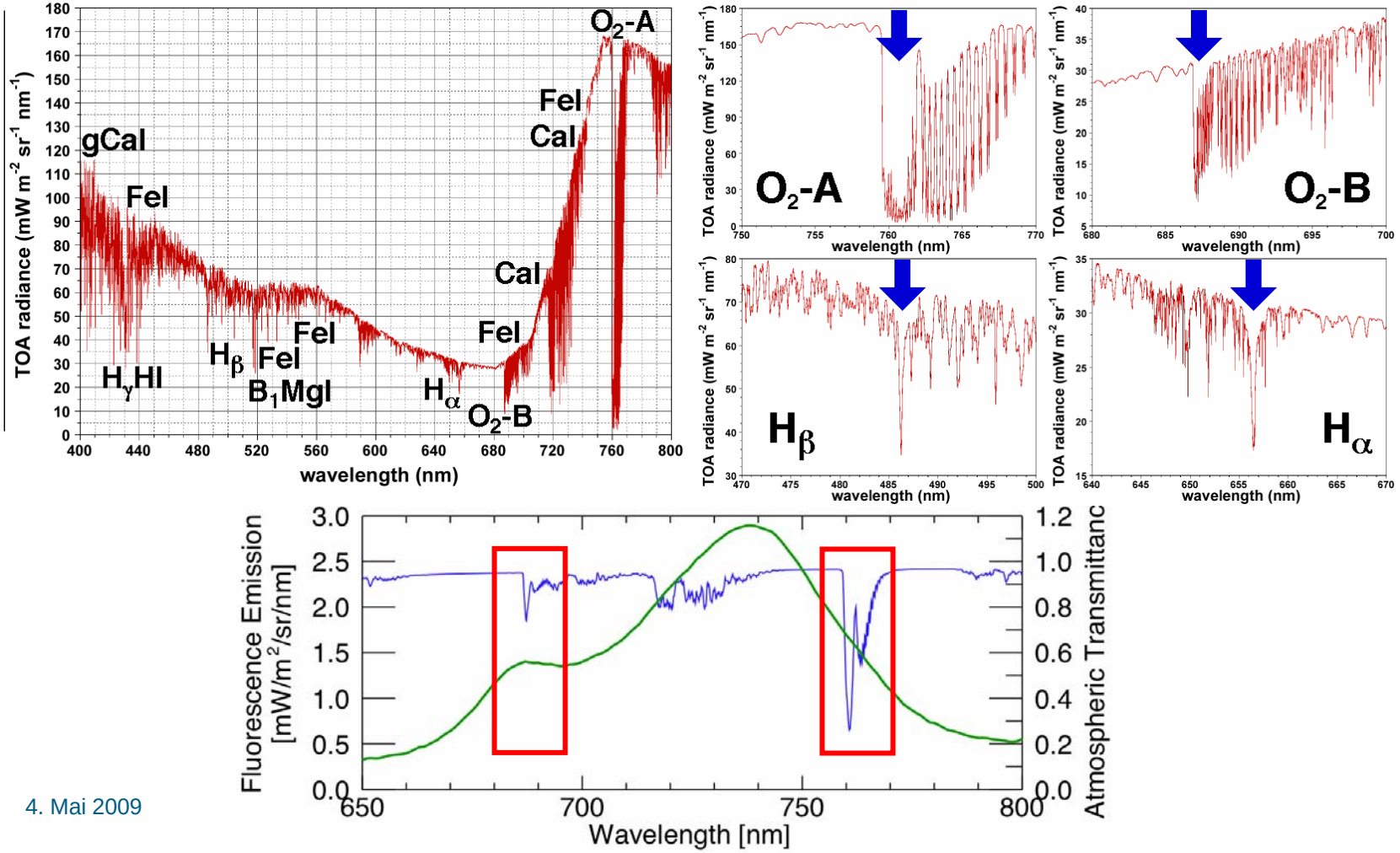


Earth atmosphere: a wavelength selective filter



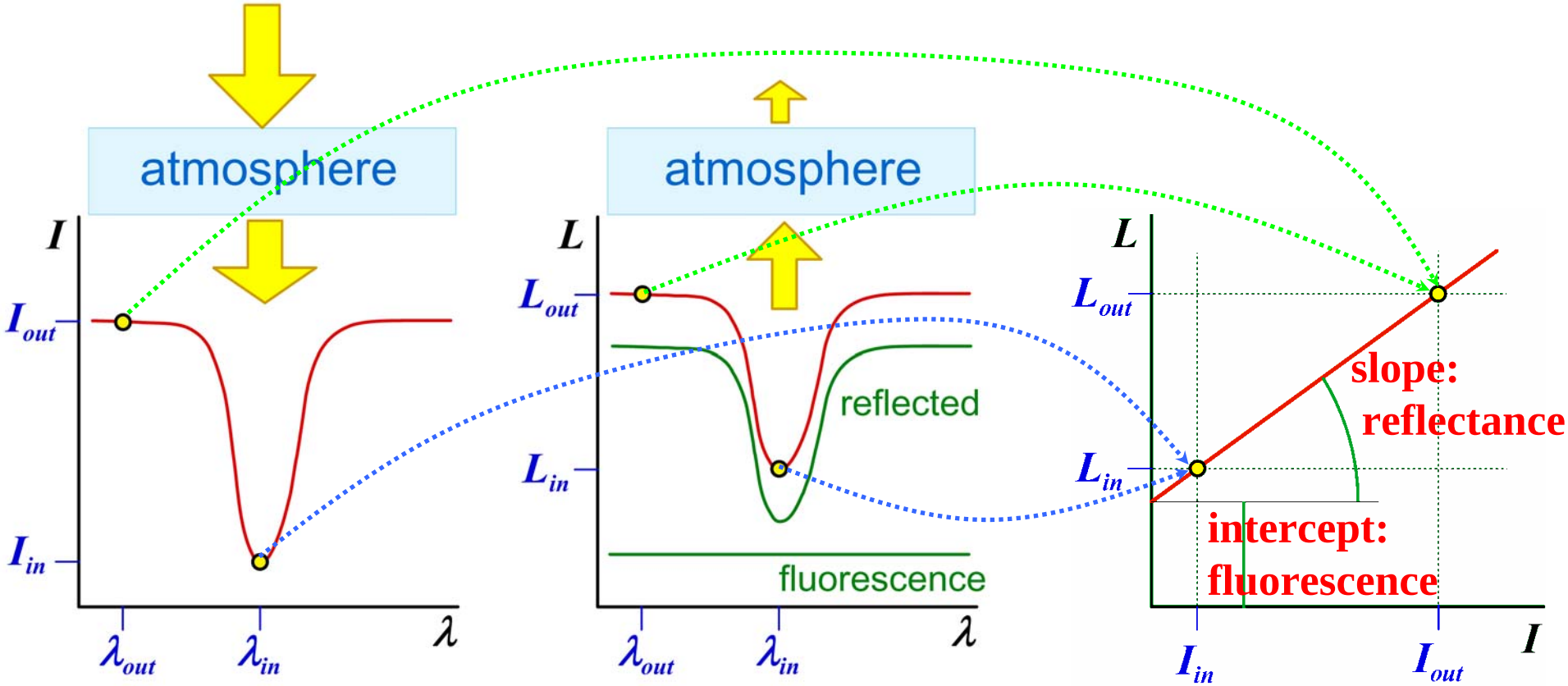
Retrieval concept: Fraunhofer line discrimination (FLD)

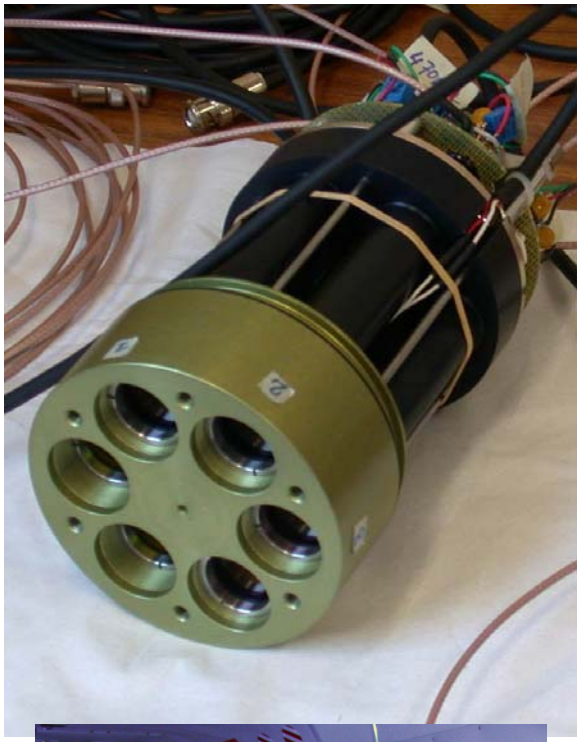
- Solar and earth atmosphere is a spectrally selective filter
- Two oxygen absorption bands (O_2-A and O_2-B) are at the right spectral region for fluorescence retrieval

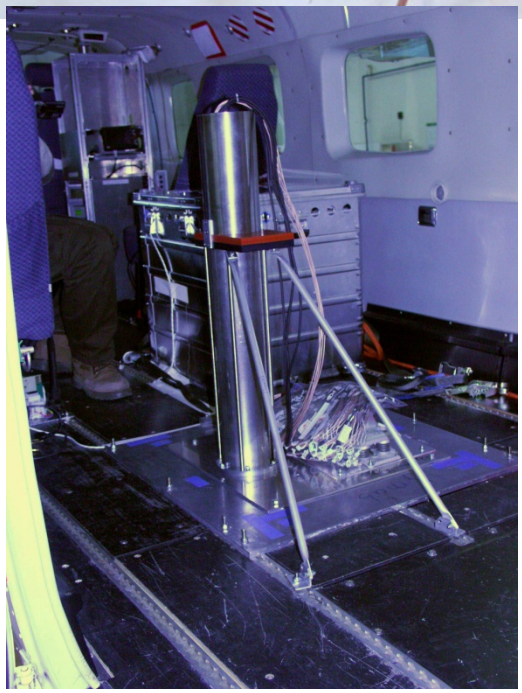


Retrieval concept: Fraunhofer line discrimination (FLD)

- Fluorescence can be retrieved in the relative dark atmospheric absorption bands according to the Fraunhofer Line Depth (FLD) method.



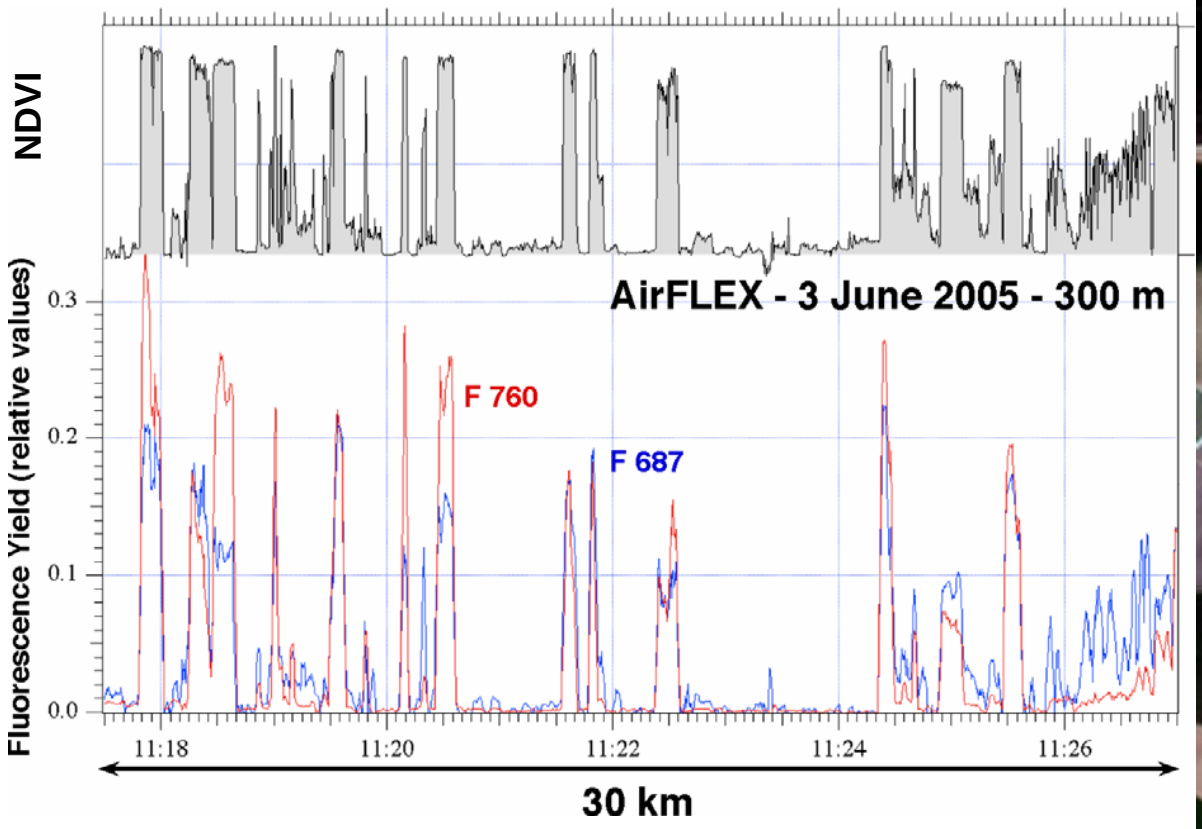


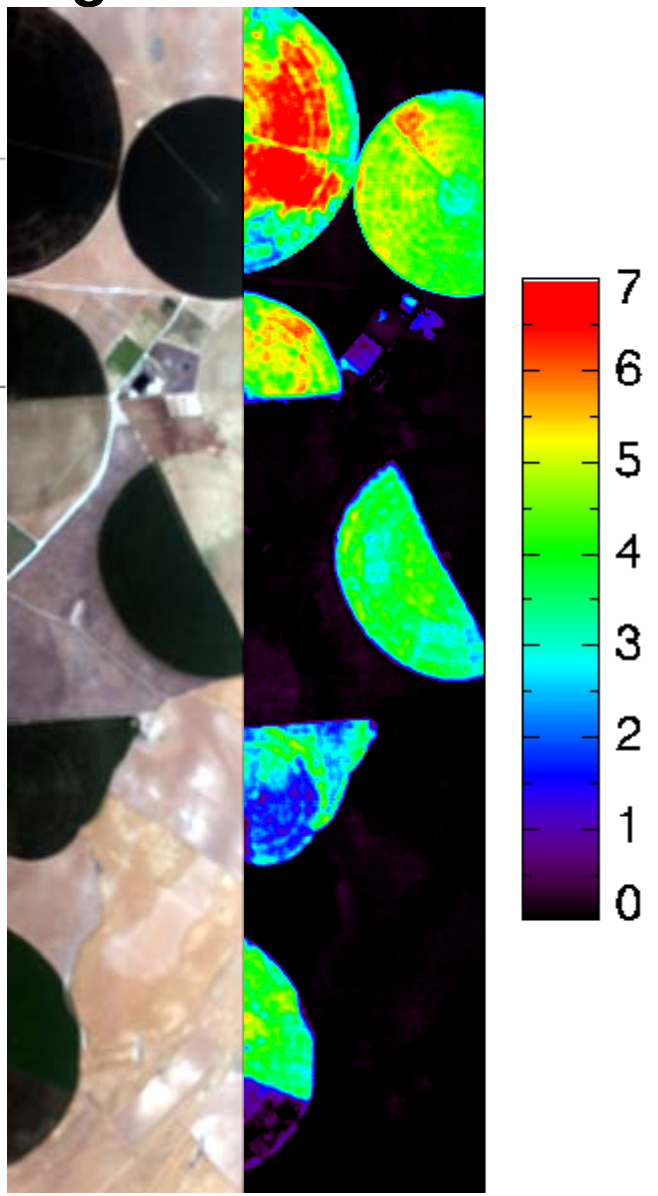


AIRFLEX
Airborne FLEX Simulator

4. Mai 2009

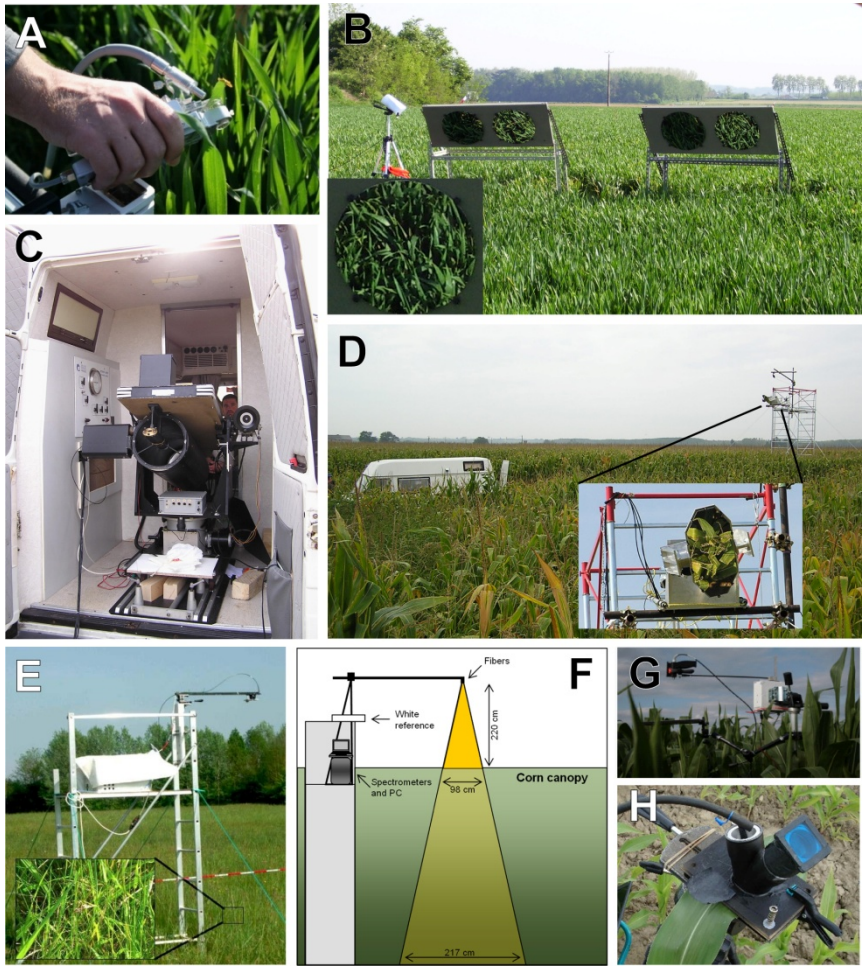
SEN2FLEX campaign: Air-FLEX detects information that is not accessible through classical remote sensing

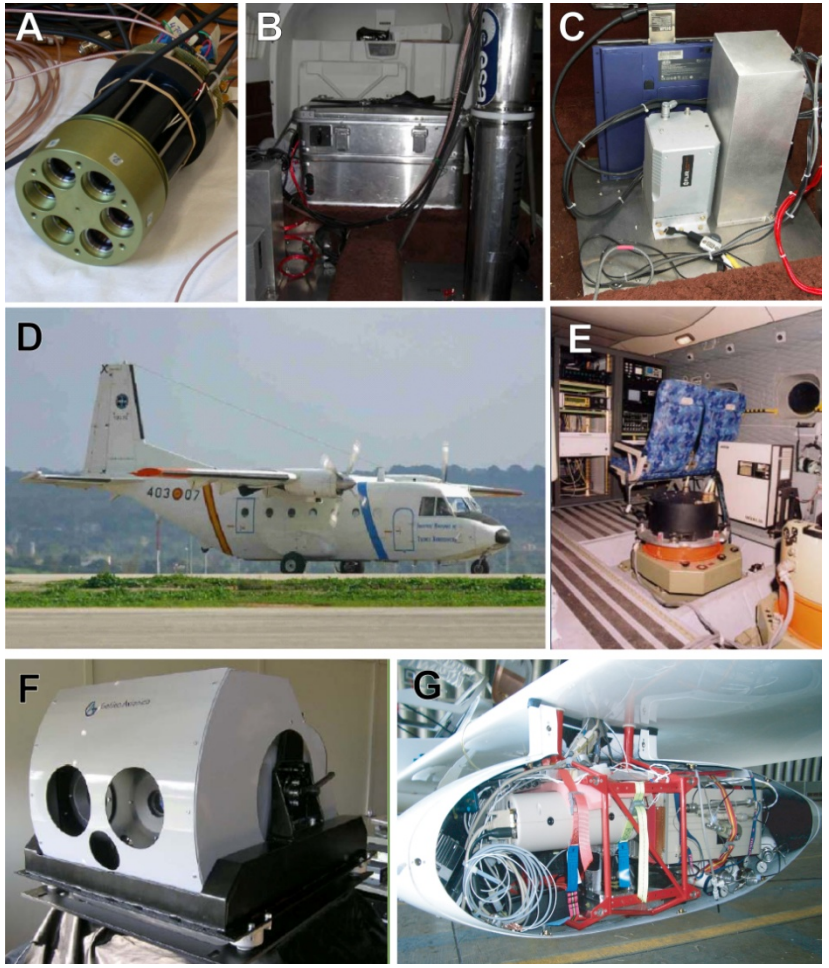




First Results from CEFLES 2 campaign (leaf to region)

- This multinational campaigns focused in quantitative understanding of photosynthetic efficiency and fluorescence from the leaf to the ecosystem (CEFLES2)

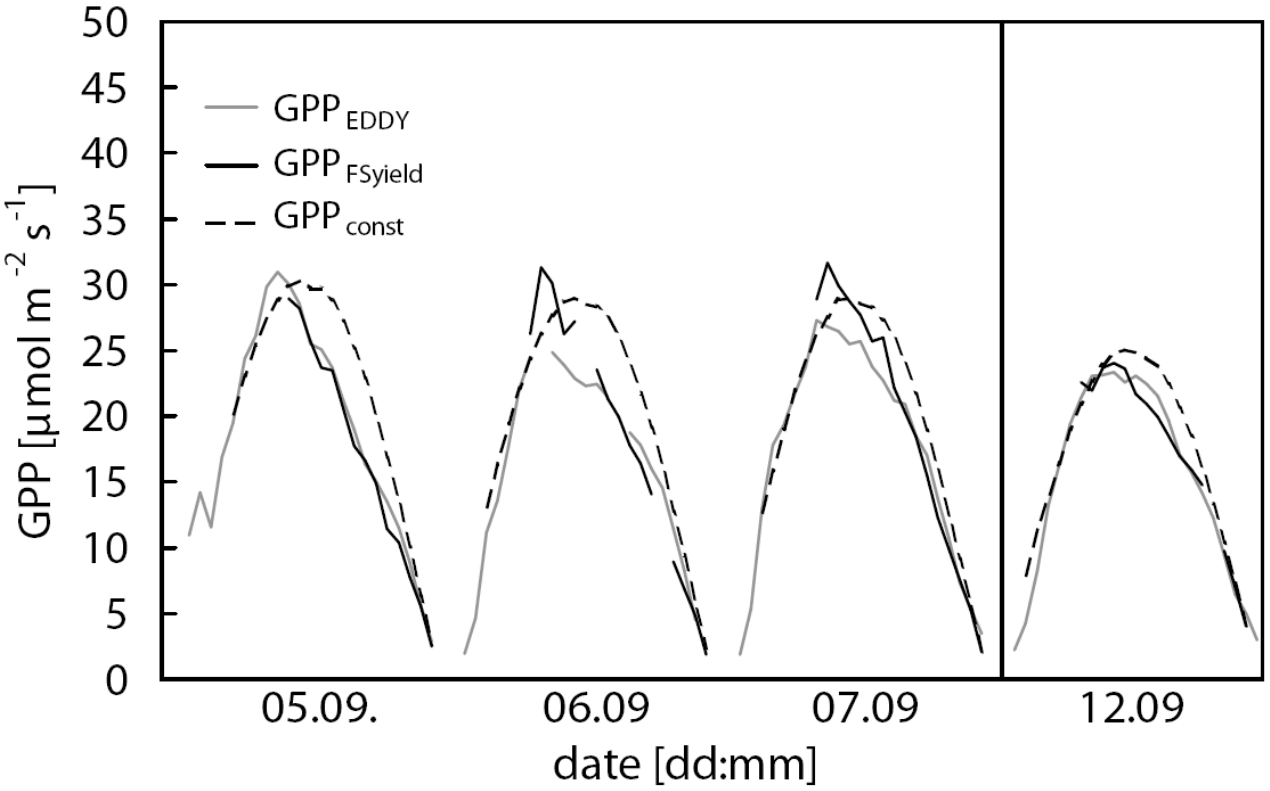


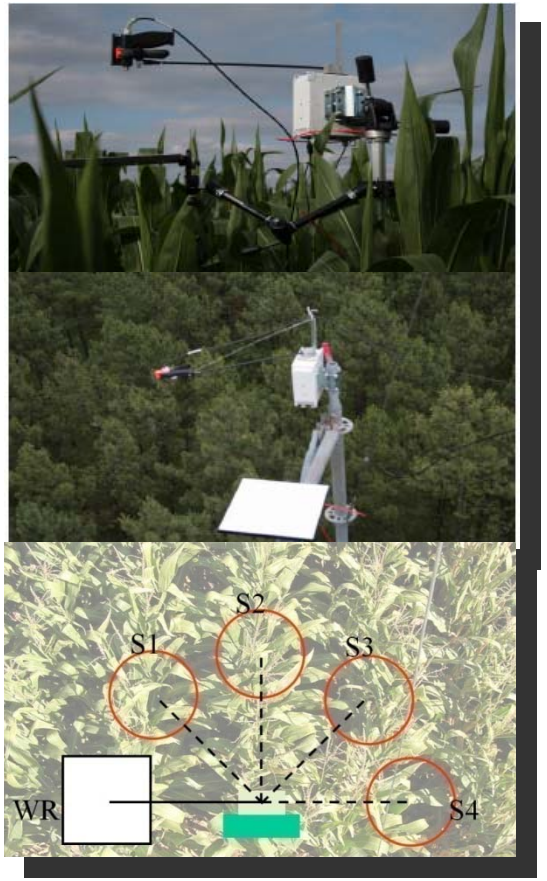


Rascher et al. (2009) *Biogeosciences Discussion*, 6, 2217–2266.

CEFLES2: First results on the correlation of canopy fluorescence and CO_2 exchange of fields

$$GPP = APAR \cdot LUE$$

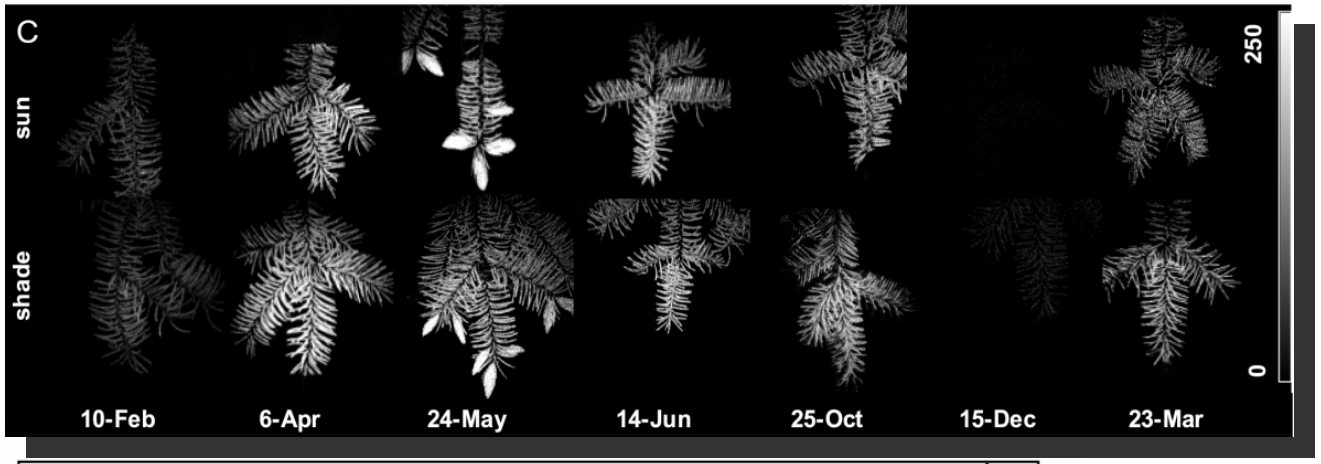


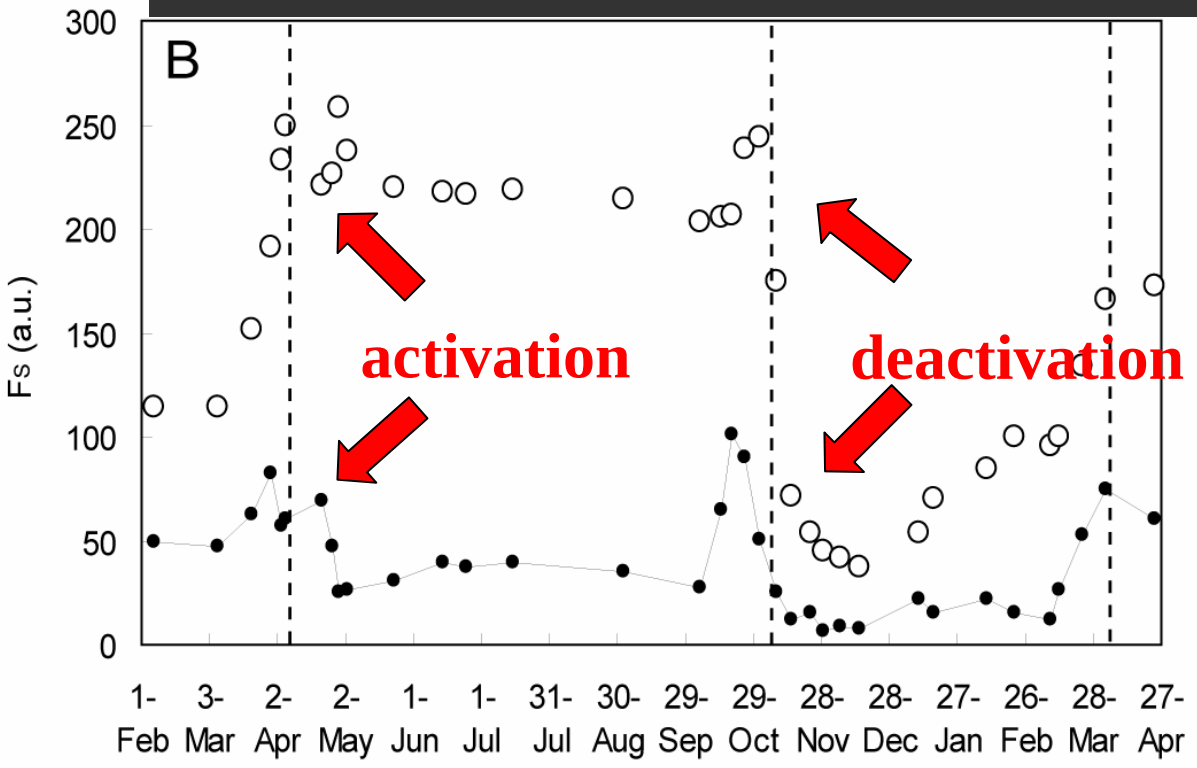


Dynamic modeling of GPP improves day courses of photosynthetic CO_2 uptake

Damm and 15 others, *Global Change Biol., DOI: 10.1111/j.1365-2486.2009.01908.x.*

Fluorescence tracks the seasonal activity of actual photosynthesis (annual cycle)





boreal forest
(Nove Hrady, Czech Republic)

steady-state fluorescence
● standard deviation of fluorescence

Soukupová et al. (2008)
Functional Plant Biology, 35, 63-76

Conclusions and outlook

Spatio-temporal heterogeneity of photosynthetic efficiency scales from the leaf to the ecosystem

Sun-induced fluorescence (and hyperspectral reflectance) have the potential to quantify photosynthesis from space

Challenges:

- Understand the interplay of structural and functional properties of plant canopies
- Mixing of fluorescence in complex canopies – scaling fluorescence from leaf to ecosystem
- Better process understanding to translate fluorescence to GPP and specific plant stress

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Thanks to:

Thomas Udelhoven

Barry Osmond
Edward Bobich
Guanghui Lin

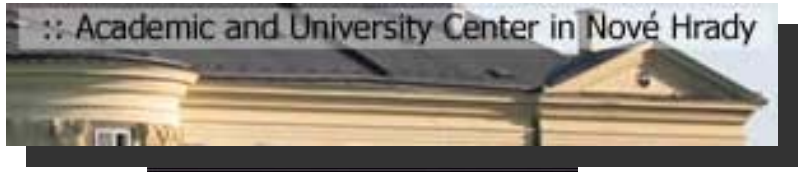
Patrick Hostert
Sebastian van der Linden

Ulrich Schurr
Vicky Temperton
Achim Walter
Anke Schickling
Andre Moersch
Alexander Damm
and a lot more

Christoph Gerbig
Han Dolman
Ronald Hutjes
Franco Miglietta

Joe Berry
Roland Pieruschka

Julie Soukupová & Lada Nedbal



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