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B2.02 FLEX
ESA's Photosynthesis Mission

The FLuorescence EXplorer (FLEX) mission: *scientific objectives and plans for data exploitation*

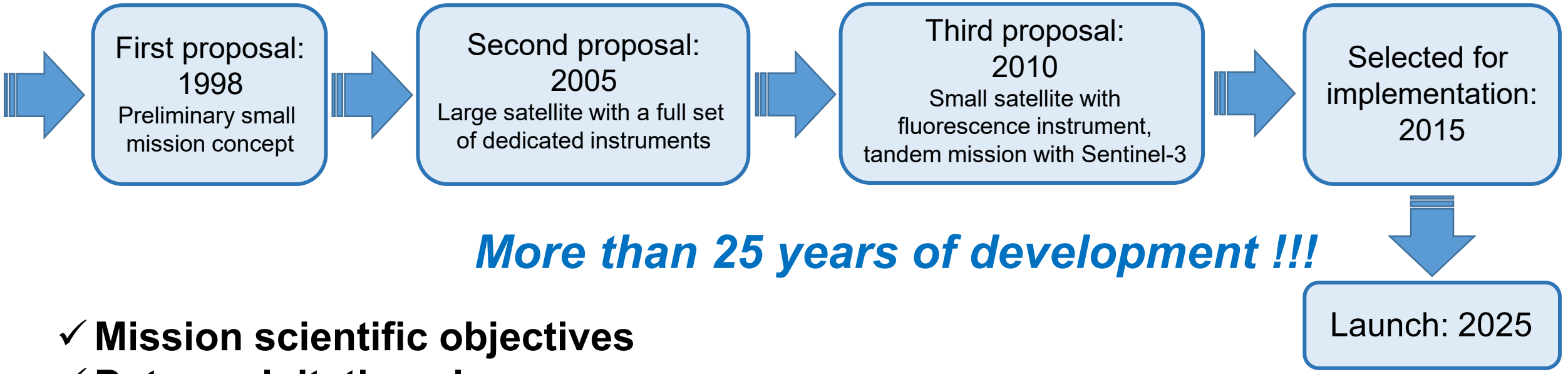
Jose Moreno (1) **Matthias Drusch** (2)

Jose.Moreno@uv.es *Matthias.Drusch@esa.int*

(1) Laboratory for Earth Observation, Dept. Earth Physics and Thermodynamics, University of Valencia, Spain

(2) Mission Science Division (EOP-SME), European Space Agency, ESTEC, Noordwijk, The Netherlands

Presentation outline



More than 25 years of development !!!

- ✓ **Mission scientific objectives**
- ✓ **Data exploitation plans**

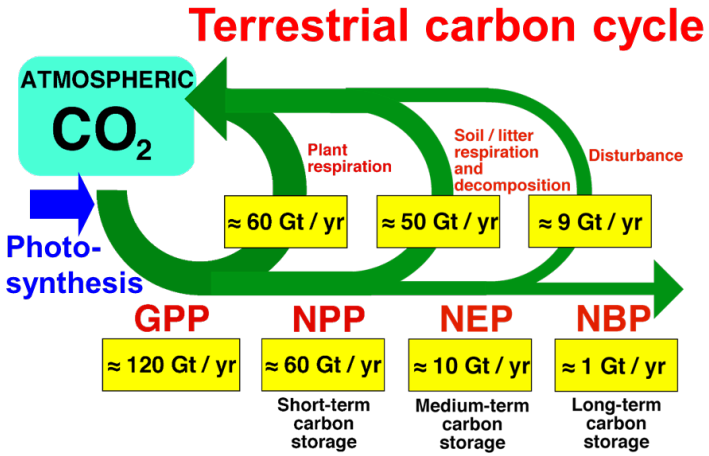
- Mission objectives
- Background on vegetation fluorescence
- Requirements and retrieval approach
- Mission products
- Data exploitation plans

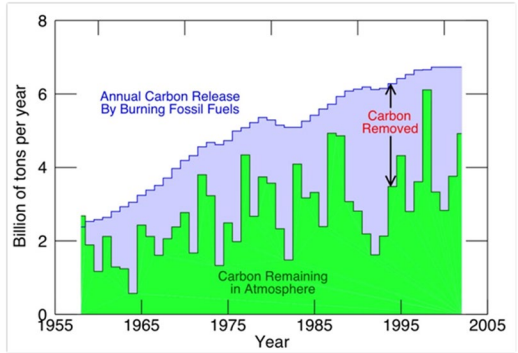
Mission objectives

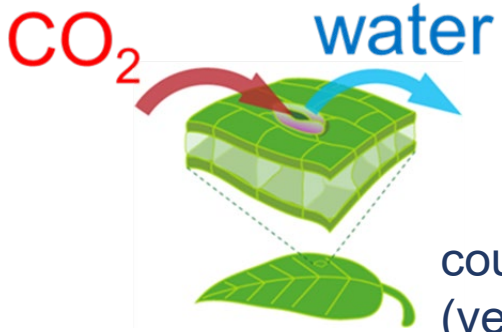
Quantitative global mapping of actual photosynthetic activity of terrestrial ecosystems, accounting for the spatial and temporal variability driven by environmental conditions

- Reduce uncertainty in global / regional estimates of carbon fluxes, in particular GPP (Gross Primary Productivity)
- Provide estimates of vegetation stress through variable photosynthesis rates (potential applications in agriculture / food security)

The goal is to quantitatively understand the observed dynamics, to develop predictive models (physical, mechanistic), and then be able to forecast climate trends and vegetation adaptations with reduced uncertainty.

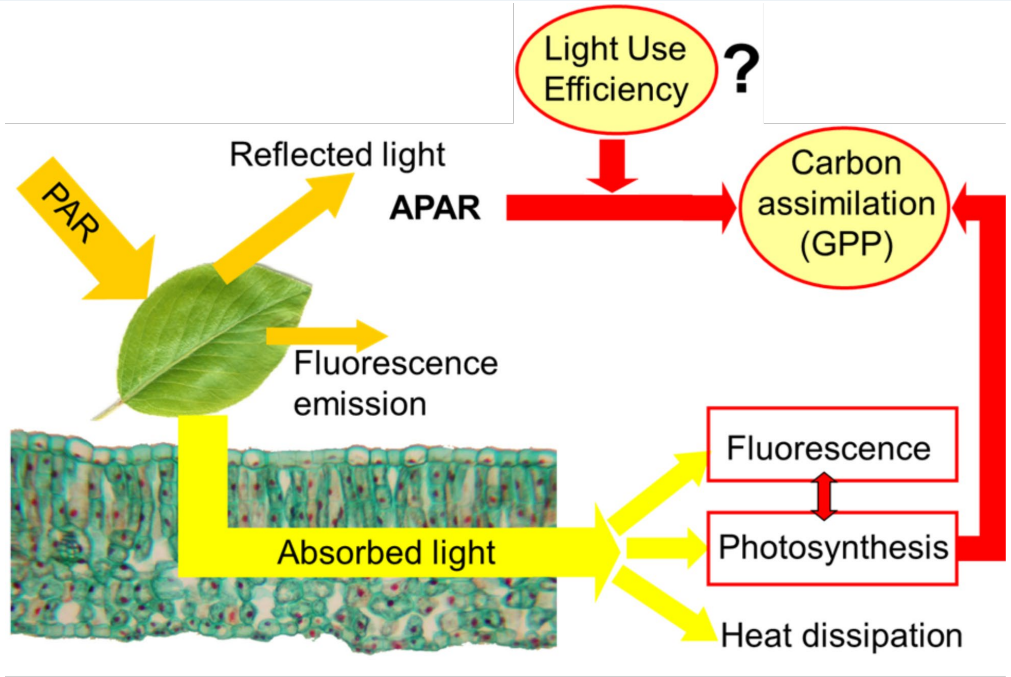




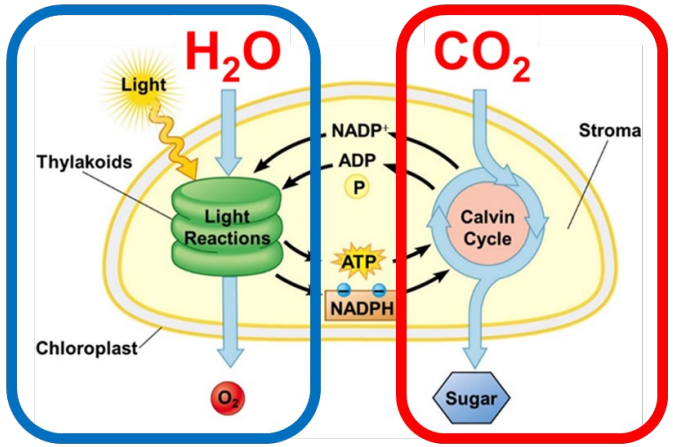


coupling of carbon and water cycles (vegetation stress)

Relevance of chlorophyll fluorescence emission for vegetation studies



Look at the whole photosynthesis processes from the side of light reactions

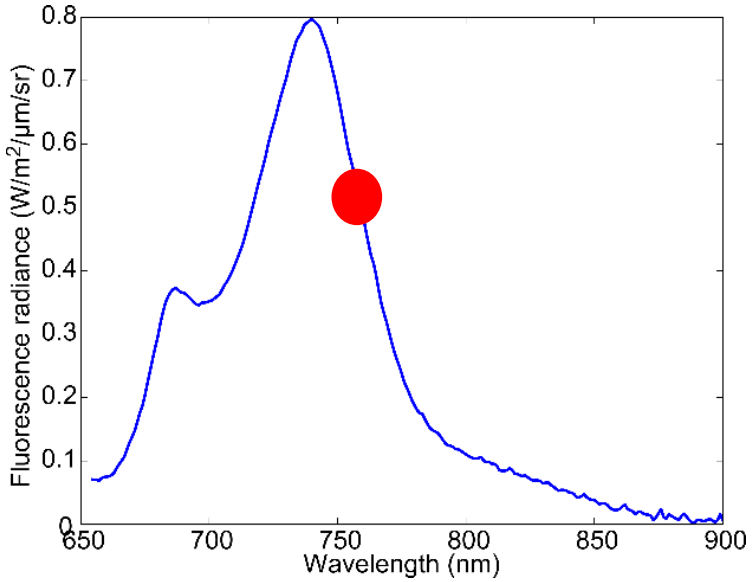


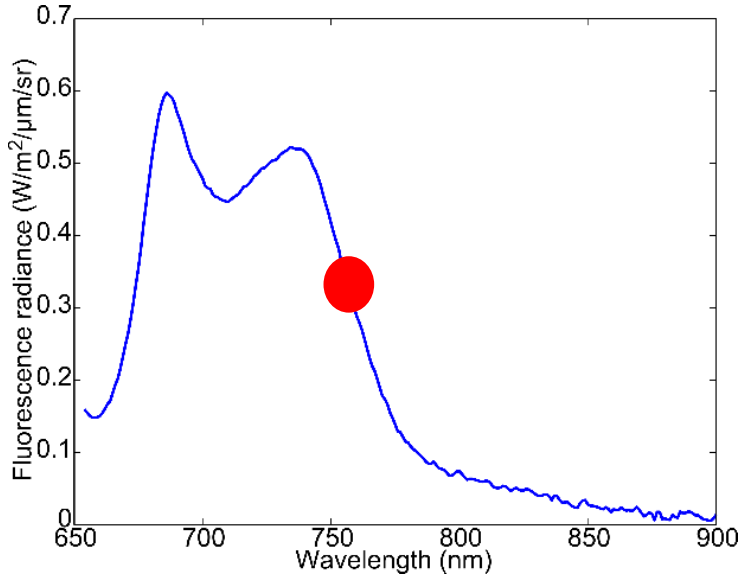
"light reactions" side "dark reactions" side

large variability in the shape and amplitude of fluorescence emission

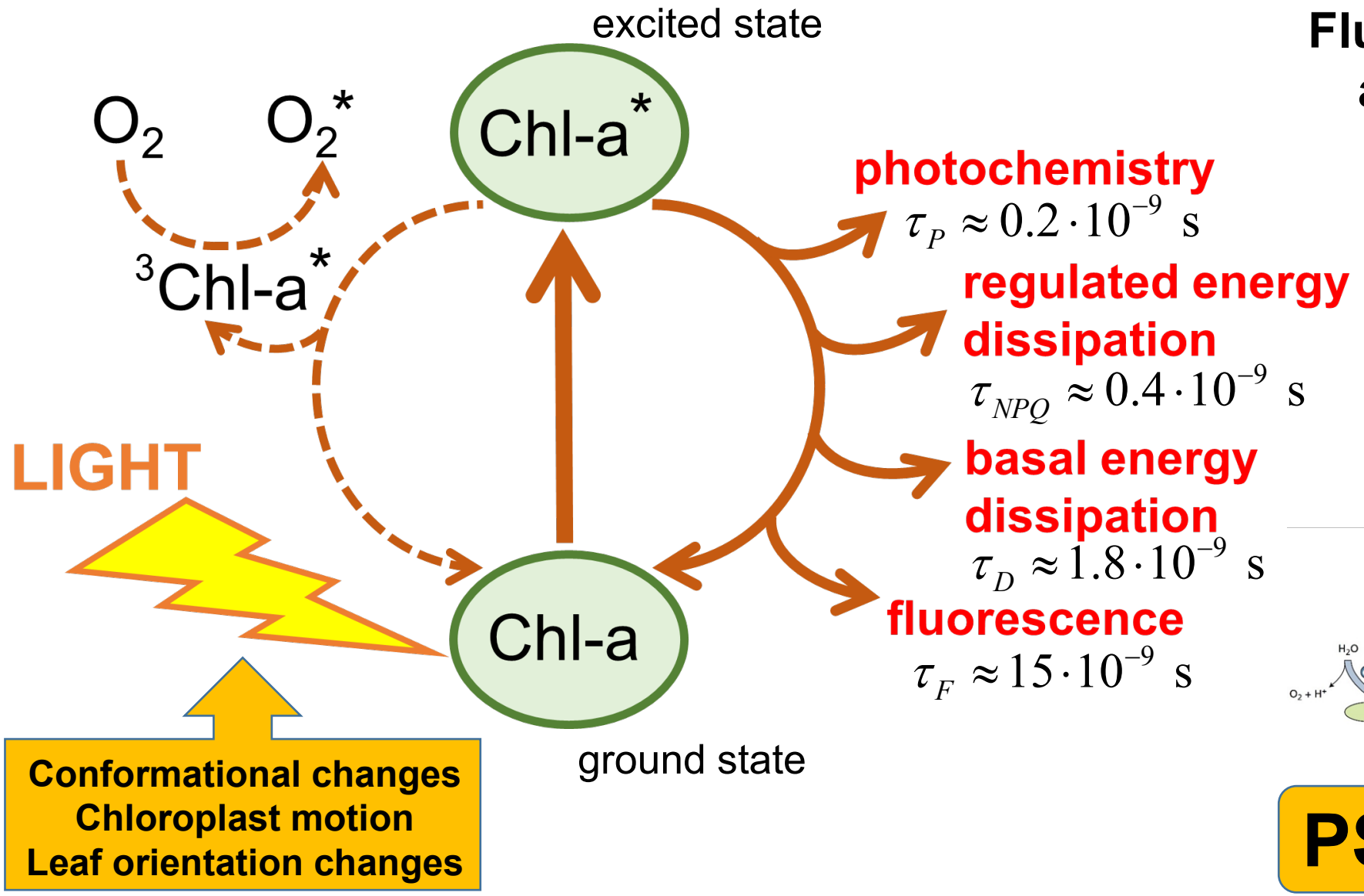
$$\int_{\lambda} F(\lambda)\, d\lambda$$

total spectral integral of whole fluorescence emission is what can be related to photosynthesis

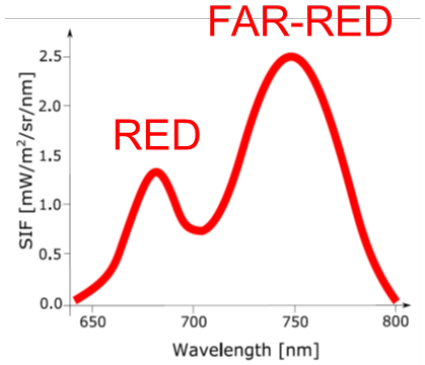


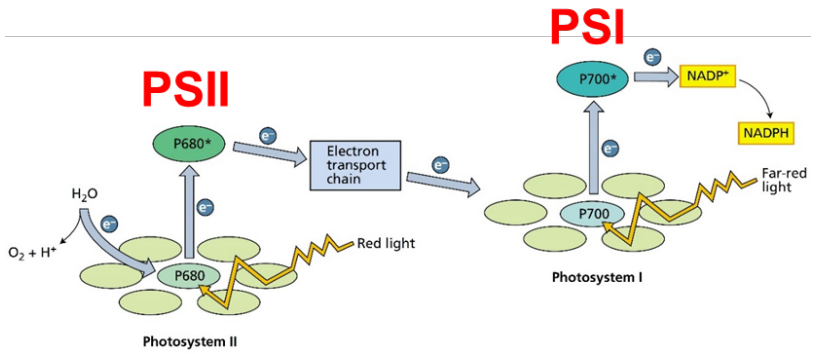


Information content of chlorophyll fluorescence



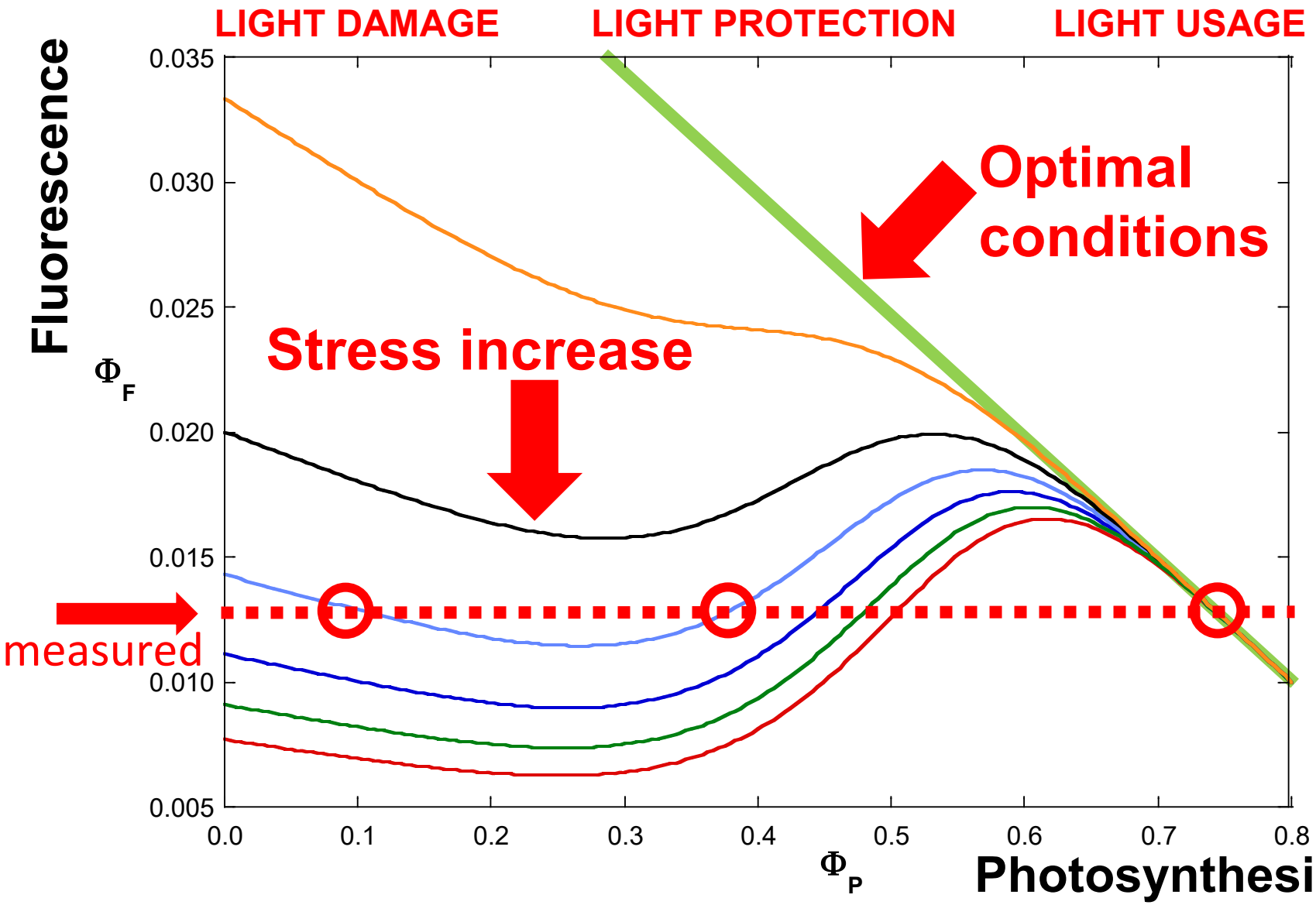
Fluorescence emission is a kind of residual effect for the unused energy





PSI / PSII effects

The link between fluorescence and photosynthesis



constant

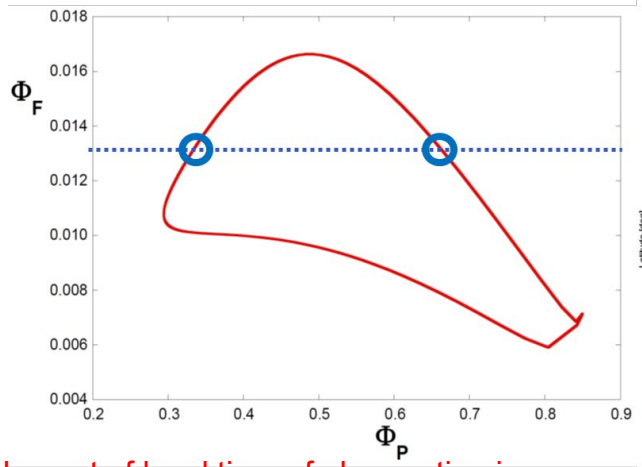
$$\Phi_F \approx \frac{k_F}{k_F + k_D}\left(1 - \Phi_P\right)$$

$$\Phi_F = \frac{k_F}{k_F + k_D}\,\frac{1 - \Phi_P}{1 + NPQ}$$

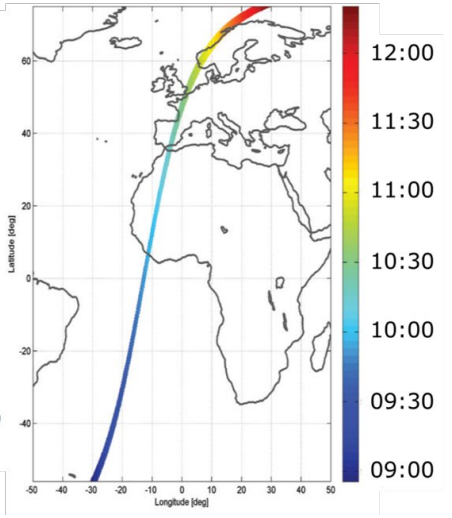
Additional information needed to disentangle the ambiguity

Accounting for regulated energy dissipation (NPQ) along diurnal cycle

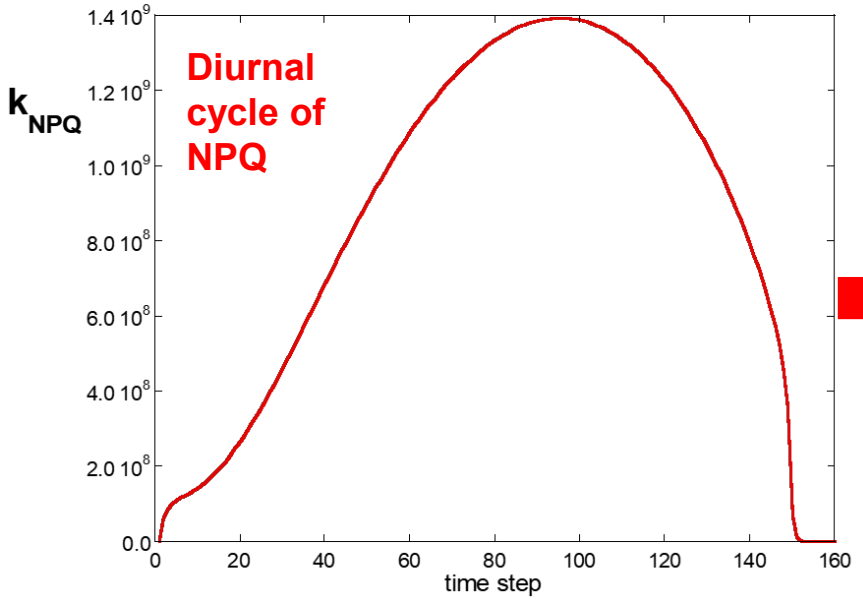
Diurnal cycle of Φ_P, Φ_F

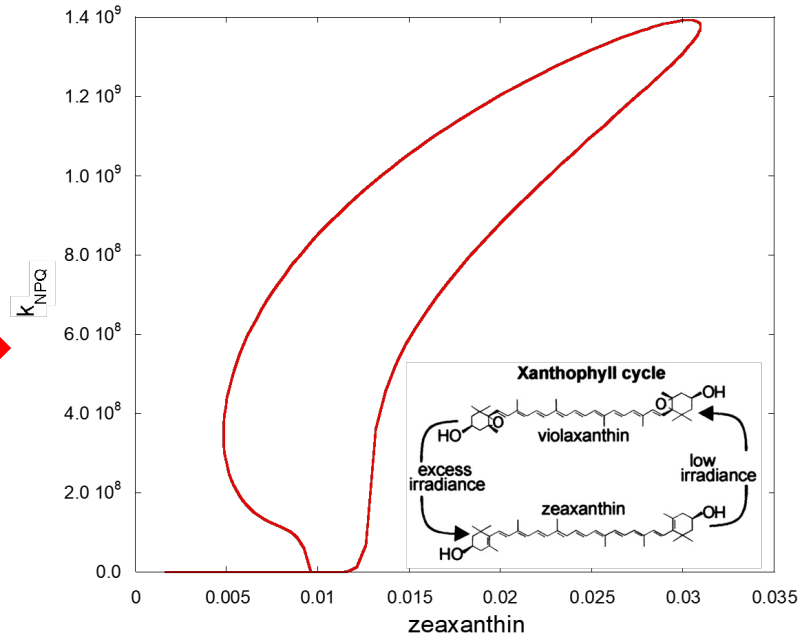


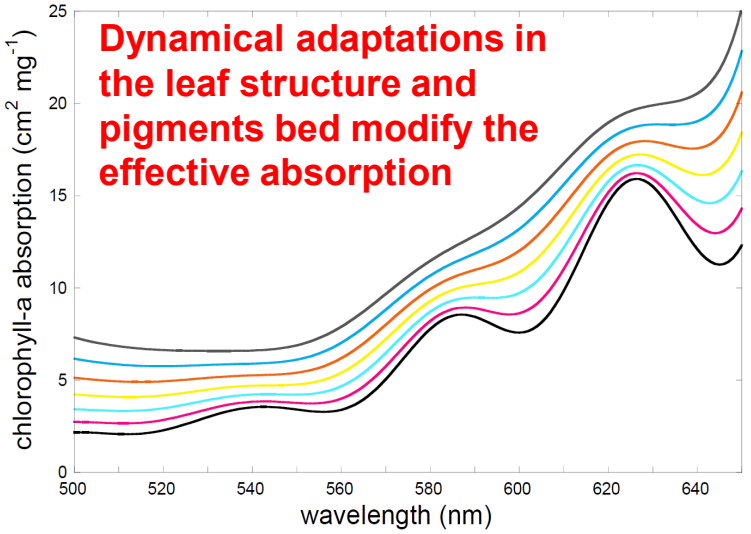
FLEX observation time

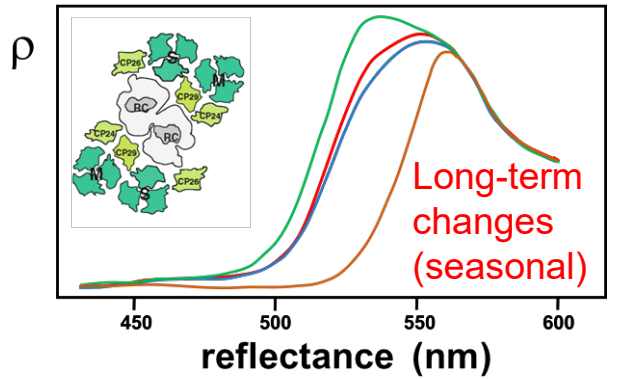


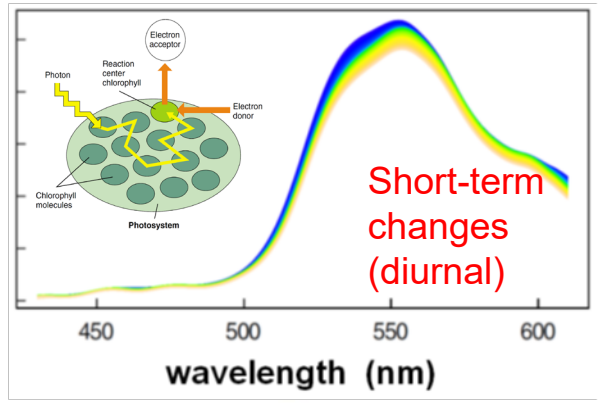
Impact of local time of observation in the retrieval of dynamical variables

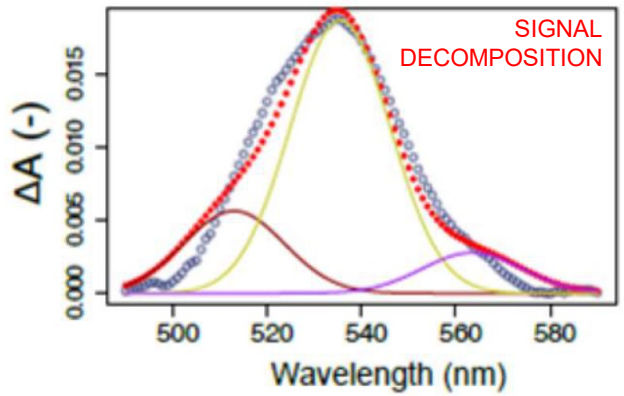












Key information provided by FLEX

Main FLEX product:

for all wavelengths (spectral integratiom), for all emission angles (angular integration), corrected for reabsorption and scattering through canopy structure

$$\Phi_F = \frac{\text{total number of photons emitted as fluorescence}}{\text{number of photons absorbed by chlorophyll}}$$

total number of excited states (photons actually absorbed by chlorophyll and not by other material)

$$\Phi_F = \frac{k_F}{k_F + k_D + k_{NPQ}}\left(1 - \Phi_P\right)$$

$\Phi_D \approx$ energy lost as basal (constitutive) heat dissipation

$\Phi_{NPQ} \approx$ energy lost as regulated heat dissipation (NPQ)

Accuracy requirements in final output products and retrieval strategy

PHOTOSYNTHETIC ELECTRON TRANSPORT RATE

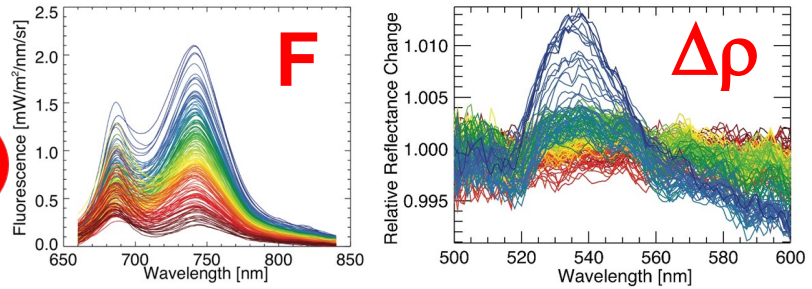
$\Phi_P \rightarrow J^{PSII \rightarrow PSI}_{electron}$

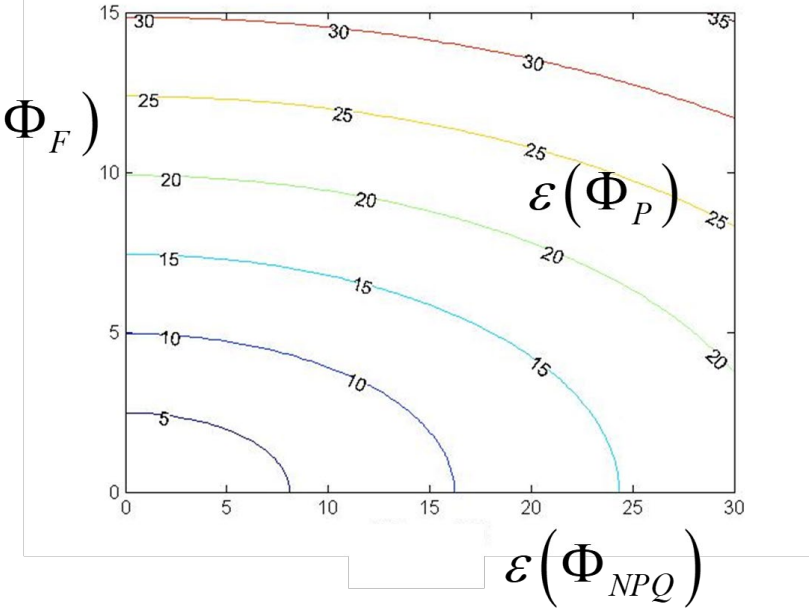
CARBON ASSIMILATION:

gross primary productivity (GPP)

STRESS INDICATORS:

actual / potential photosynthesis





Φ_D | NPQ | $\Phi_F^{(PSI)}$ | $\Phi_F^{(PSII)}$

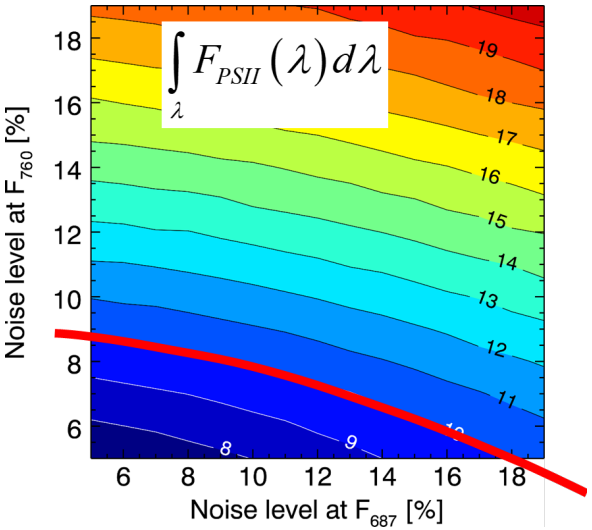
- temperature
- Illumination conditions
- zeaxanthin, antheraxanthin, violaxanthin
- carotenoids pool

$F_{tot}^{(PSII)}$, $F_{tot}^{(PSI)}$, A_{chl}

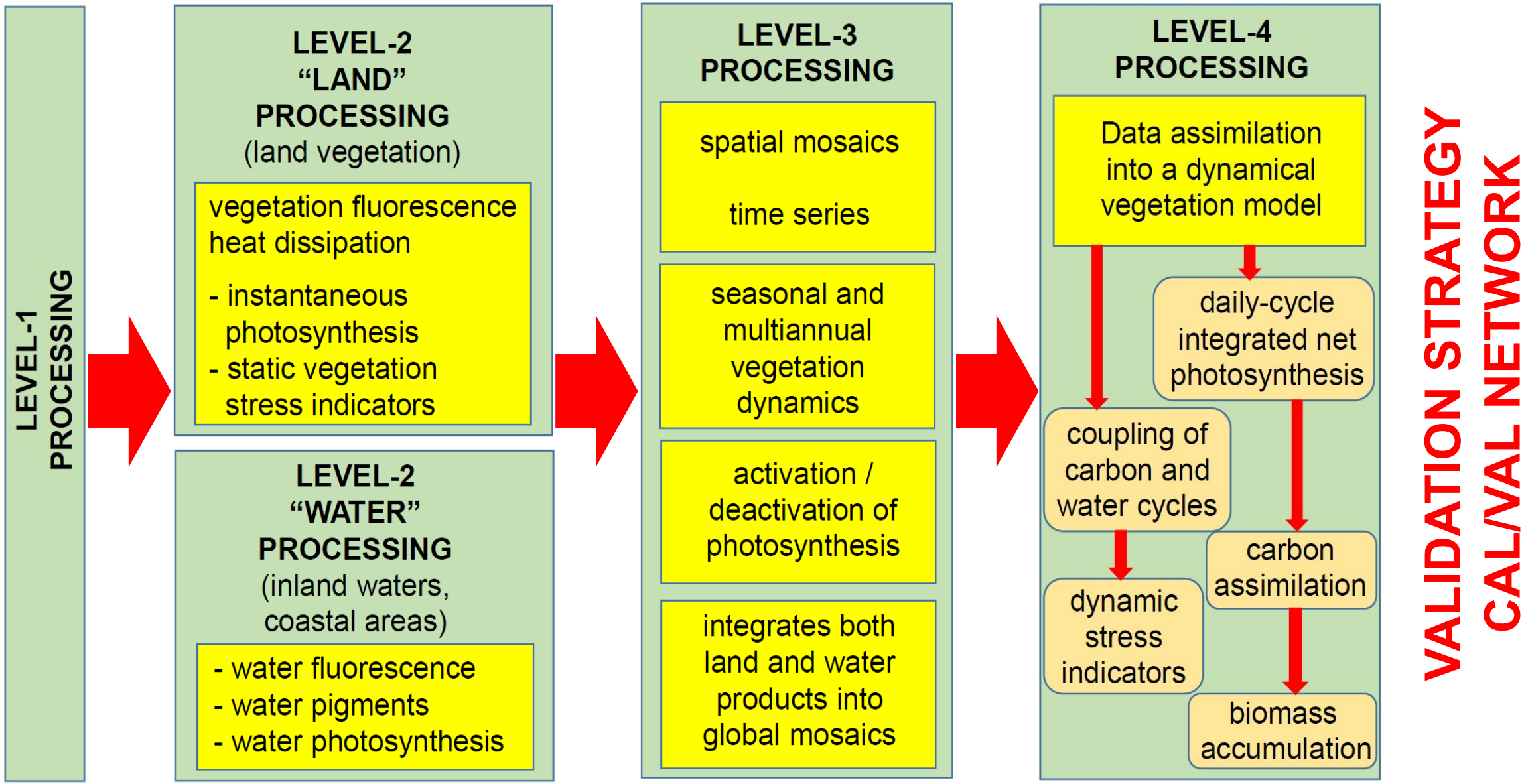
- chlorophyll-a / b
- effective leaf area
- fractional cover
- anthocyanin
- structural reabsorption

$$\varepsilon(\Phi_F) \leq 0.14$$

$$\varepsilon(\Phi_{NPQ}) \leq 0.2 / 0.3$$



FLEX data processing strategy: from raw data to high-level products



FLEX data exploitation plans

Full set of final high-level products available for end users
(ready to be incorporated in models and applications)

Analysis Ready Data (ARD)

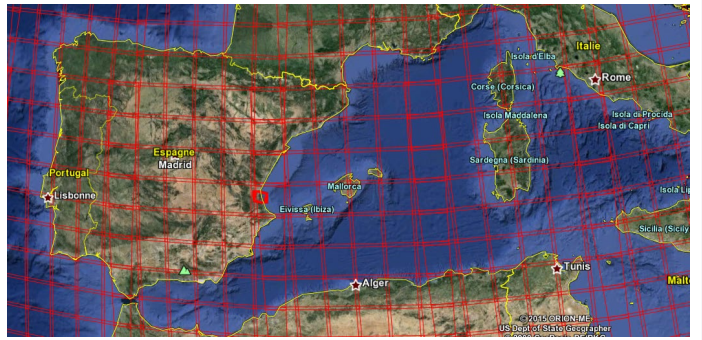
Initial set of TOA radiances and intermediate / raw products available for remote sensing specialists
(development of new algorithms, enhanced products, new applications)

Multimission data exploitation:

- ✓ FLEX / Sentinel-3 by default in nominal L2 products
- ✓ Sentinel-2 for surface heterogeneity and scale analysis (L3/L4 products)

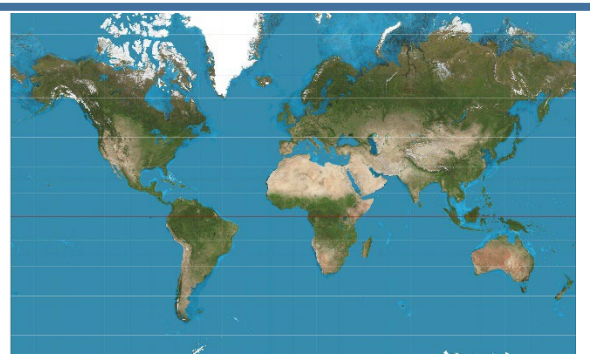
Level-2 products

Provided in Sentinel-2 UTM Tiling Grid to facilitate combined exploitation with other missions



Level-3 /-4 products:

Provided in Adapted Mercator projection to optimize global data analysis and assimilation into global models



Product uncertainty (confidence interval)

- ✓ Full **covariance matrices**, rather than single product uncertainty
- ✓ **Montecarlo** error propagation
- ✓ **Statistical distribution** associated to each product

random

systematic

$$\mu_F = \left\langle \overline{F} \right\rangle_{-\delta_\alpha^{(-)}}^{+\delta_\alpha^{(+)}} \pm \Delta_{sys}^{(F)}$$

Confidence interval for each product

Final remarks

- ✓ Well defined objectives, quantification the role of vegetation in the carbon cycle
- ✓ Advanced retrievals methods to separate the small signal from the background
- ✓ High-level science products, ready to be used in models and applications: robust uncertainty estimates, quantitative product validation
- ✓ Multi-mission exploitation (FLEX / Sentinel-3, Sentinel-2, +other sources)
- ✓ Availability of open-source free-access data exploitation tools to promote further usage of the data

…getting ready for launch in 2025.