CENTRO INTERDIPARTIMENTALE DI RICERCA
«CENTRO STUDI DI ECONOMIA E
TECNICA DELL'ENERGIA
GIORGIO LEVI CASES"

PRESENTAZIONE PROGETTO DI RICERCA

A photobioreactor-on-a-chip technology for assessing and optimising photosynthetic activity in microalgae-based fuel production

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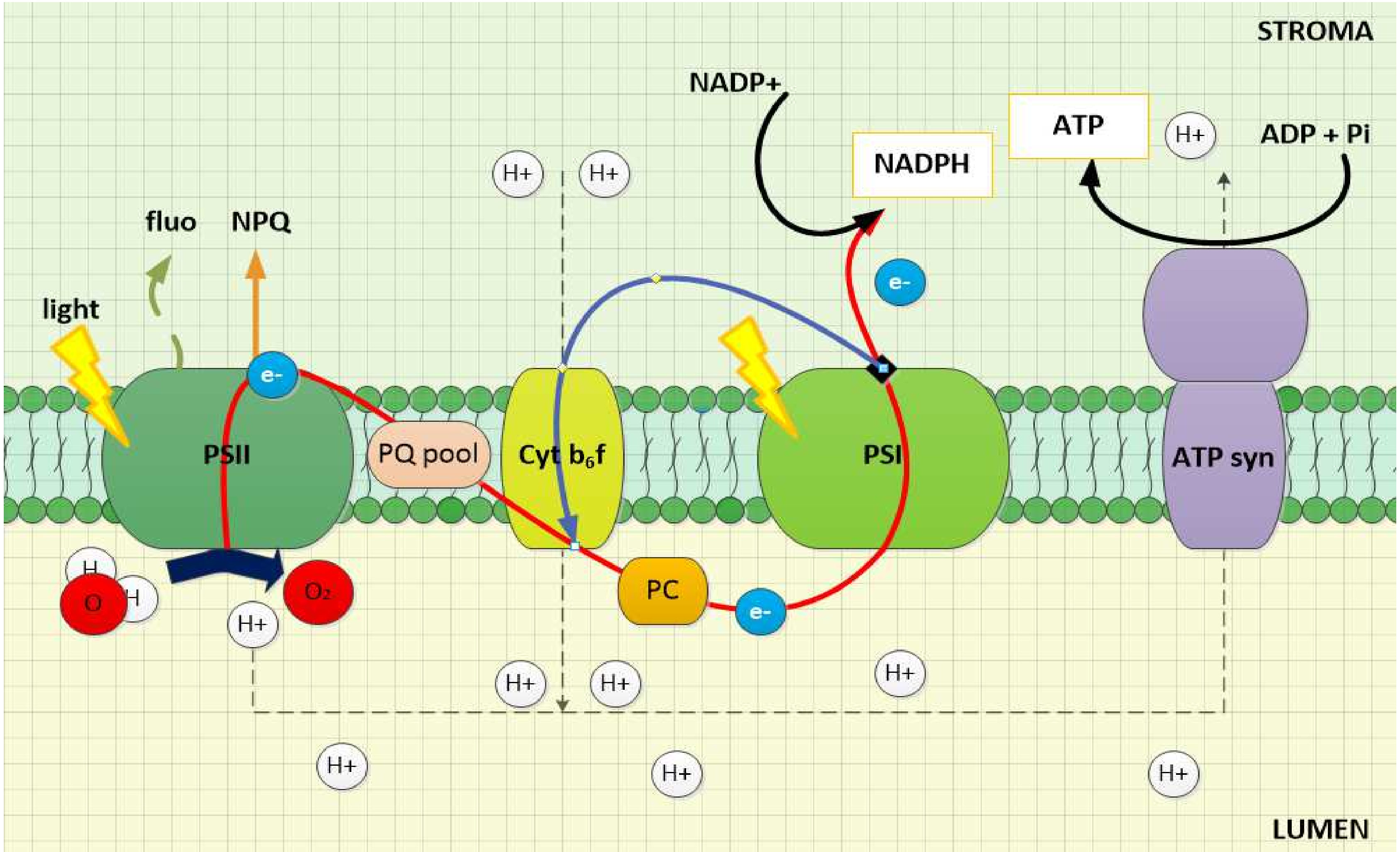
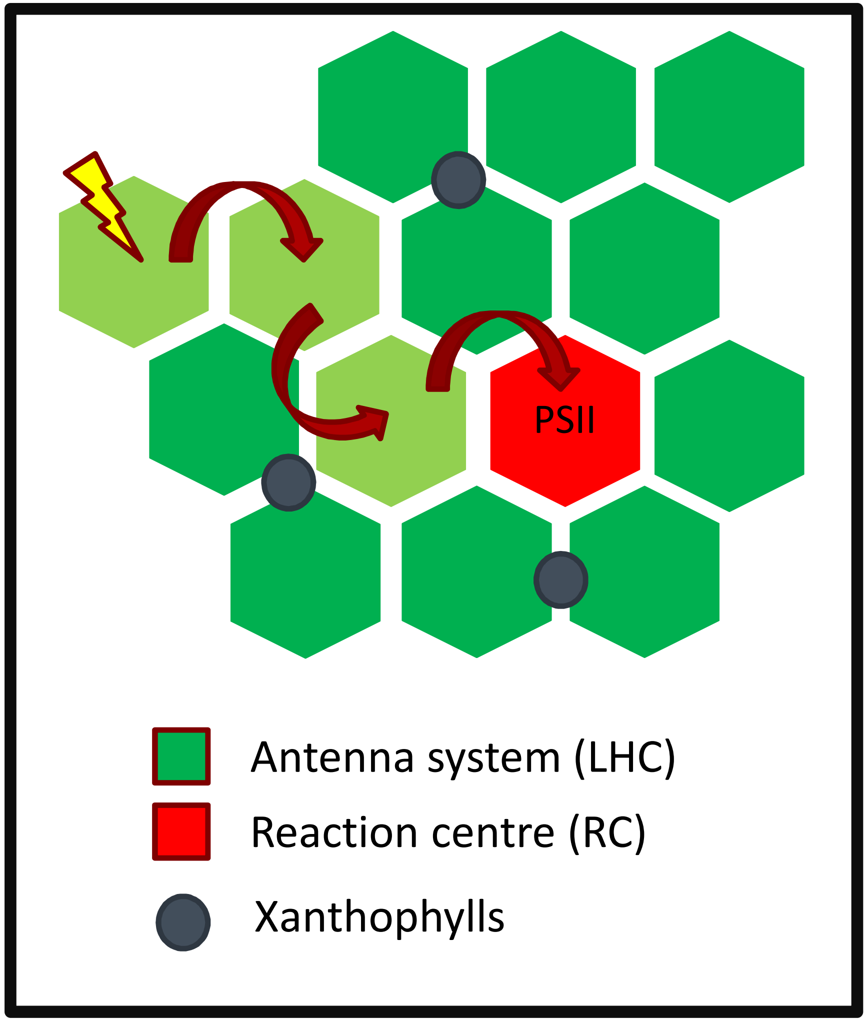
Aim of the work

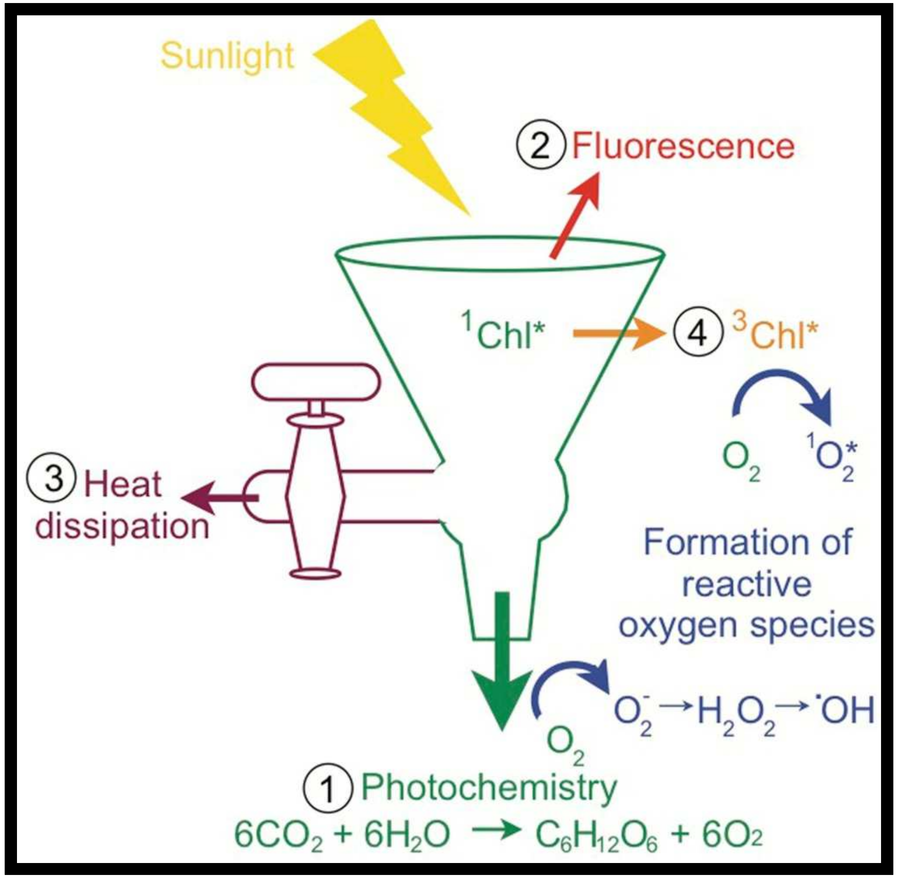
- Develop reliable dynamic model photosynthetic phenomena
- Propose an effective investigation tool through microscale devices

Photosynthetic process scheme (1)

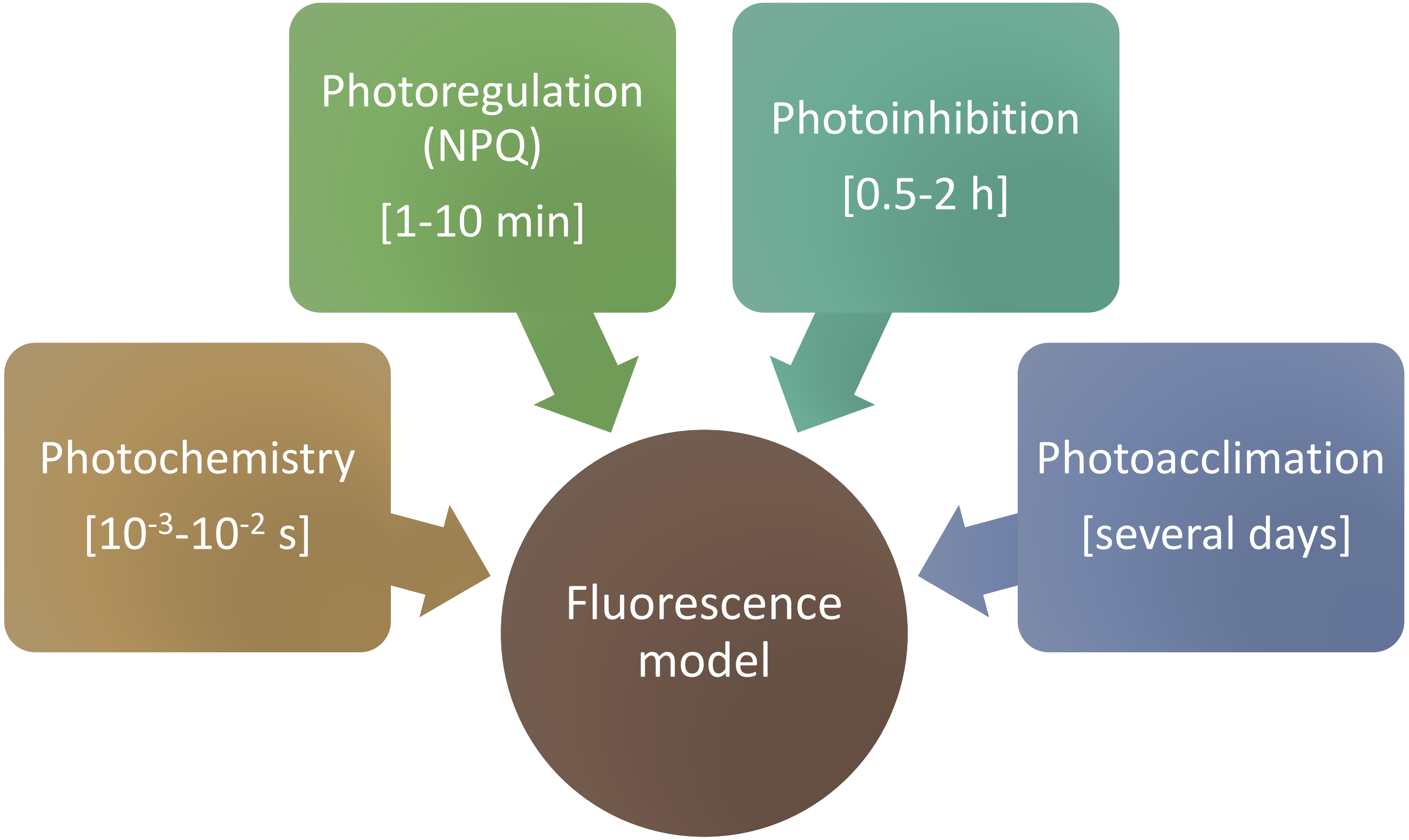


Photosynthetic process scheme (2)

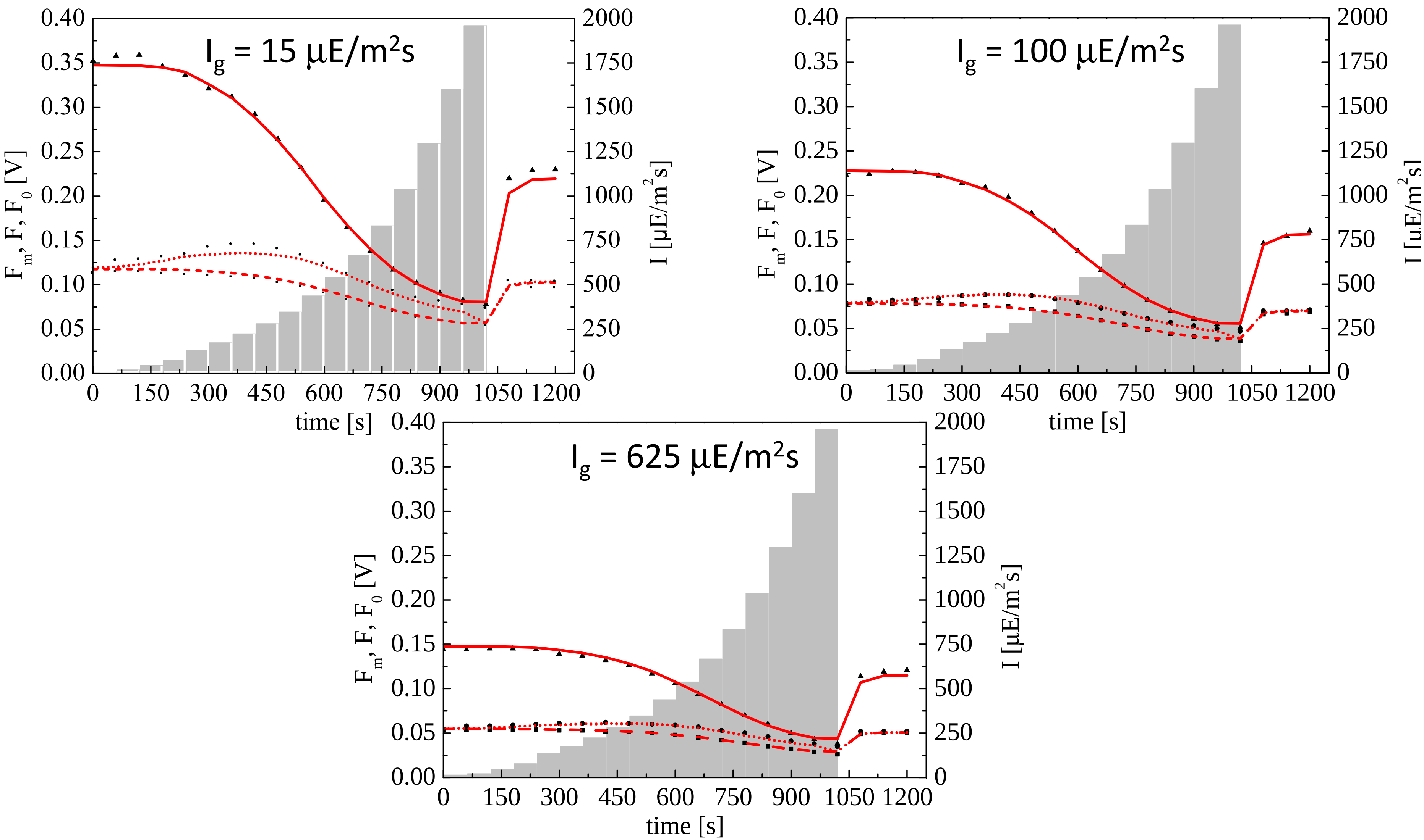




Dynamic model of fluorescence



Model results

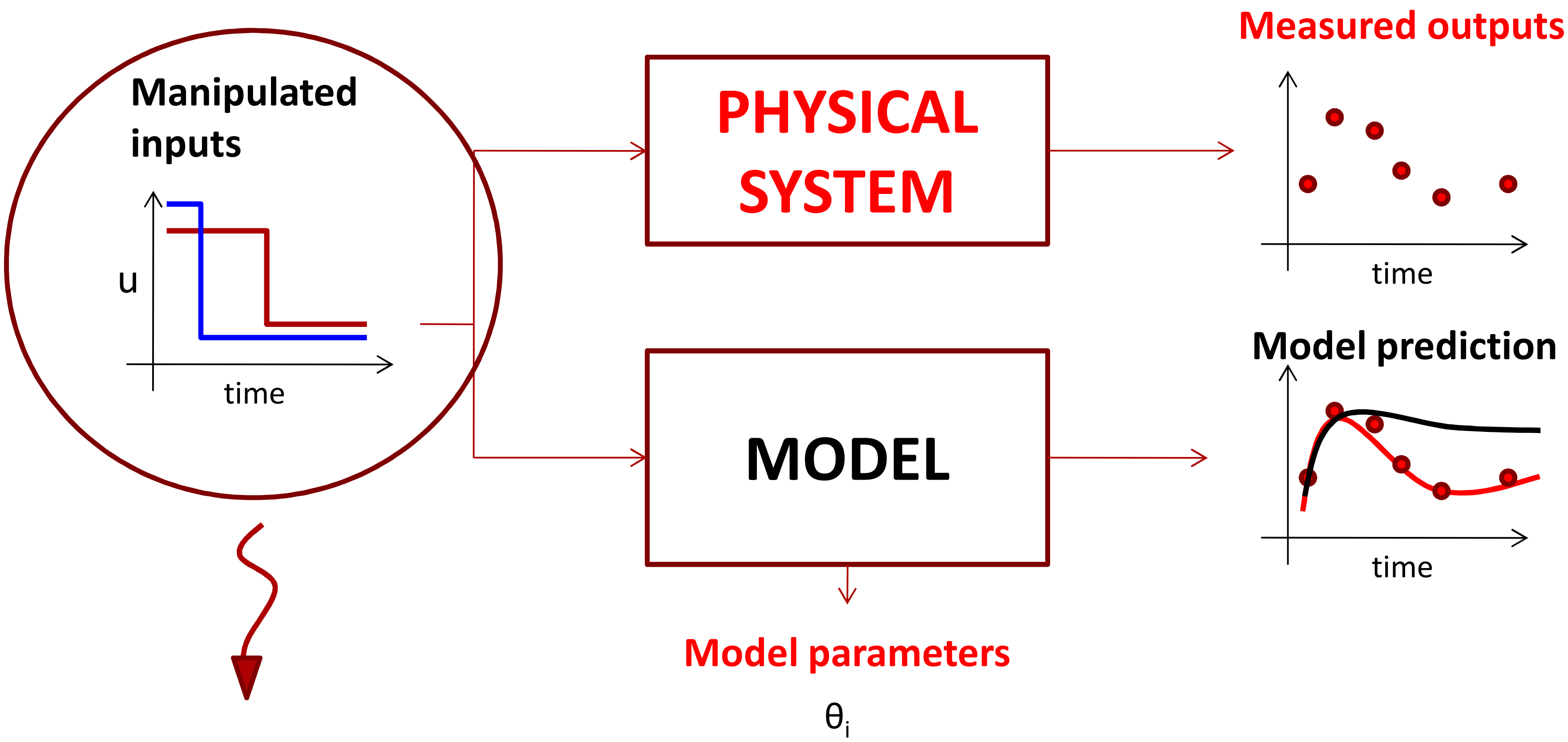


Issues

- Several issues at stake:
  - modelling hypotheses require experiments for discrimination and parametric validation
  - experiments are time consuming and costly and often blurred by:
    - intrinsic biological variability
    - limited number of measurements
    - concurrent phenomena happening at the same time (e.g. "interference" of biomass concentration and equipment design on light effects)

Propose more effective experimental devices coupled with advanced experimetal design techniques

Model-Based Design of Experiments



Optimal input design

MBDoE

Optimal design problem

$$\boldsymbol{\varphi}^{opt} = \arg\min_{\boldsymbol{\varphi}} \left\{ \psi\left[\mathbf{V}_{\theta}\left(\boldsymbol{\theta},\boldsymbol{\varphi}\right) \right] \right\} = \arg\min_{\boldsymbol{\varphi}} \left\{ \psi\left[\mathbf{H}_{\theta}^{-1}\left(\boldsymbol{\theta},\boldsymbol{\varphi}\right) \right] \right\}$$

DESIGN OPTIMALITY

subject to

$$f\left(\dot{\mathbf{x}},\mathbf{x},\mathbf{u},\mathbf{w},\boldsymbol{\theta},t\right)=0 \qquad \hat{\mathbf{y}}=h\left(\mathbf{x}\right)$$

DETERMINISTIC MODEL

$$\tilde{\mathbf{C}} = z\left(\dot{\mathbf{x}}(t),\mathbf{x}(t),\dot{\mathbf{u}}(t),\mathbf{u}(t),\mathbf{w},\boldsymbol{\theta}\right) \le 0$$

FEASIBILITY CONDITIONS

(Constraints on State Variables)

- $\mathbf{x}(t)$ n_s- dimensional vector of state variables
- $\mathbf{u}(t)$ n_u- dimensional vector of manipulated inputs
- $\mathbf{w}$ n_w- dimensional vector of time-invariant inputs
- $\hat{\boldsymbol{\theta}}$ n_ϑ- dimensional vector of model parameters
- $\hat{\mathbf{y}}(t)$ M – dimensional vector of measured variables

Design vector

$$\boldsymbol{\varphi} = \left[\mathbf{y}\left(t_0\right),\mathbf{u}\left(t\right),\mathbf{w},\mathbf{t}^{sp},\tau\right]$$

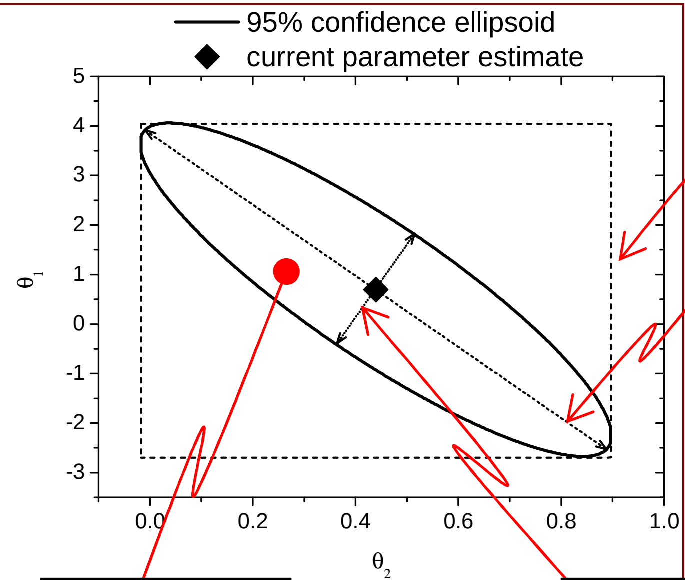
MBDoE

DESIGN OPTIMALITY CONDITION

$$\varphi = \arg\min \psi\left\{\left[\mathbf{V}_\theta(\theta,\varphi)\right]\right\} = \arg\min \psi\left\{\left[\mathbf{H}_\theta(\theta,\varphi)\right]^{-1}\right\}$$

Dynamic Information Matrix

Design Criteria



A-Optimal

E-Optimal

D-Optimal

SV-Optimal

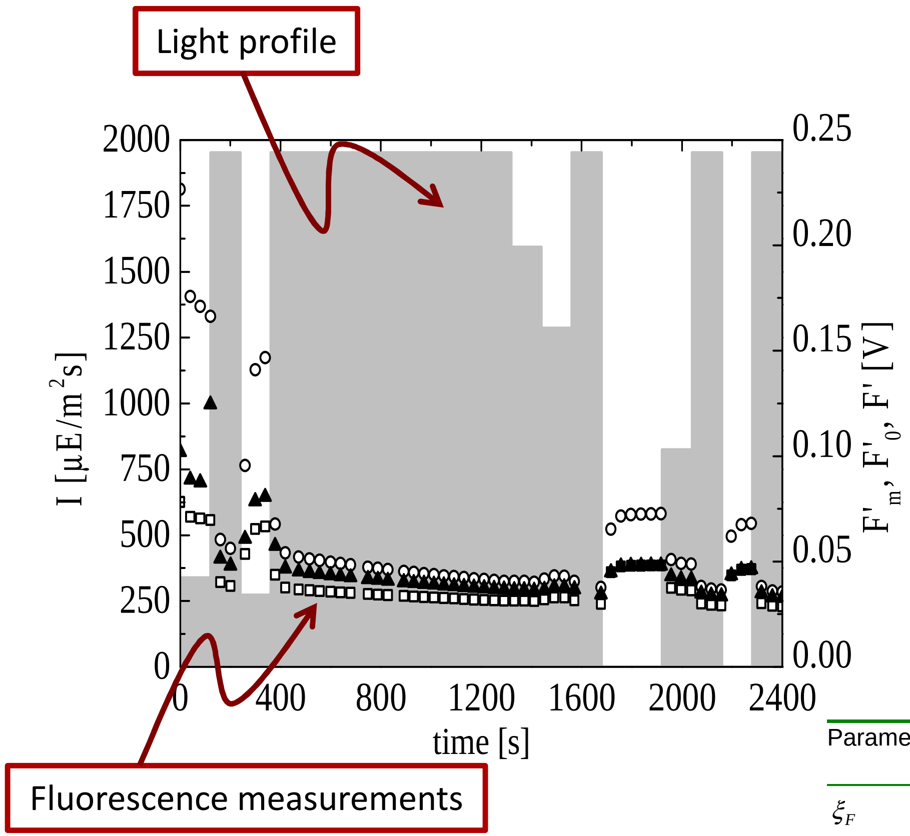
Preliminary Information Matrix

$$\mathbf{H}_\theta(\theta,\varphi) = \left[\sum_{k=1}^{n_{sp}}\sum_{i=1}^{N_y}\sum_{j=1}^{N_y} s_{ijk}\mathbf{Q}_{ik}^T\mathbf{Q}_{jk} + \mathbf{H}_\theta^0\right]$$

Variance-covariance of measurements errors

Sensitivity Matrix

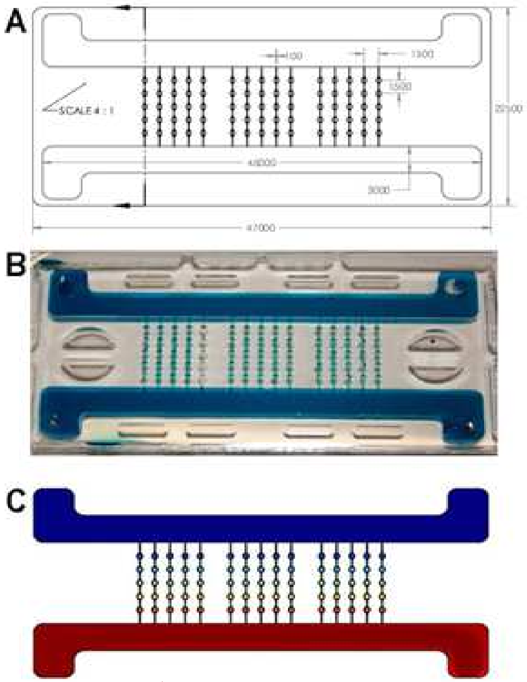
Implementing MBDoE

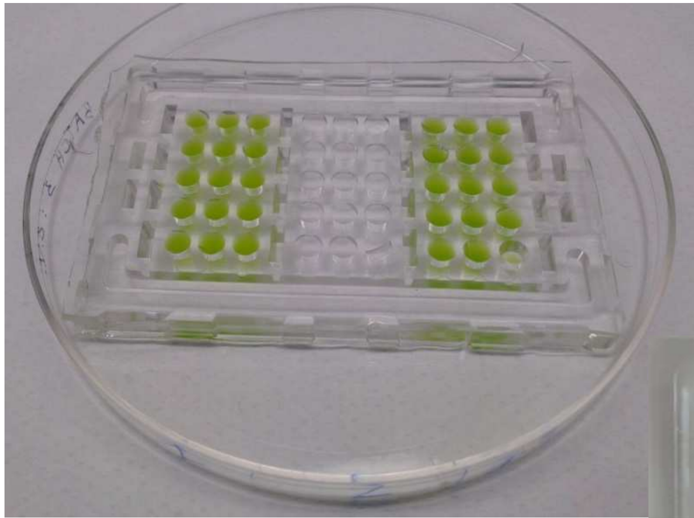


Demonstrated effectivess of MBDoE to **identify** model parameters

	Standard experiment			**Designed experiment**		
Parameter	Par. Value	95% Conf.Int.	t-val 95%	Par. Value	95% Conf.Int.	t-val 95%
	Non designed experiment			Optimally designed experiment		
ξ_F	$5.76\ 10^{-2}$	$1.38\ 10^{-2}$	4.07	$5.64\ 10^{-2}$	$5.34\ 10^{-3}$	10.82
I_{qE}	$8.13\ 10^{2}$	$9.43\ 10^{1}$	8.32	$9.49\ 10^{2}$	$6.16\ 10^{1}$	4.32
k_d	$7.06\ 10^{-7}$	$1.76\ 10^{-6}$	0.48*	$8.19\ 10^{-7}$	$3.31\ 10^{-7}$	2.18
n	$2.39\ 10^{0}$	$2.31\ 10^{0}$	10.71	$2.23\ 10^{0}$	$1.74\ 10^{-1}$	5.91
η_I	$7.84\ 10^{1}$	$1.21\ 10^{2}$	0.49*	$6.36\ 10^{1}$	$3.29\ 10^{1}$	2.53
$\overline{\eta}_{qE}$	$1.87\ 10^{1}$	$1.79\ 10^{1}$	7.89	$2.07\ 10^{1}$	$1.16\ 10^{0}$	6.84
η_p	$1.12\ 10^{1}$	$3.12\ 10^{-1}$	28.05	$1.15\ 10^{1}$	$3.08\ 10^{-1}$	16.55
S_f	$1.68\ 10^{0}$	$2.82\ 10^{-1}$	4.99	$1.55\ 10^{0}$	$9.66\ 10^{-2}$	6.07
σ	$8.13\ 10^{-1}$	$1.52\ 10^{-1}$	4.99	$8.82\ 10^{-1}$	$1.85\ 10^{-1}$	6.19

Prototyping the idea



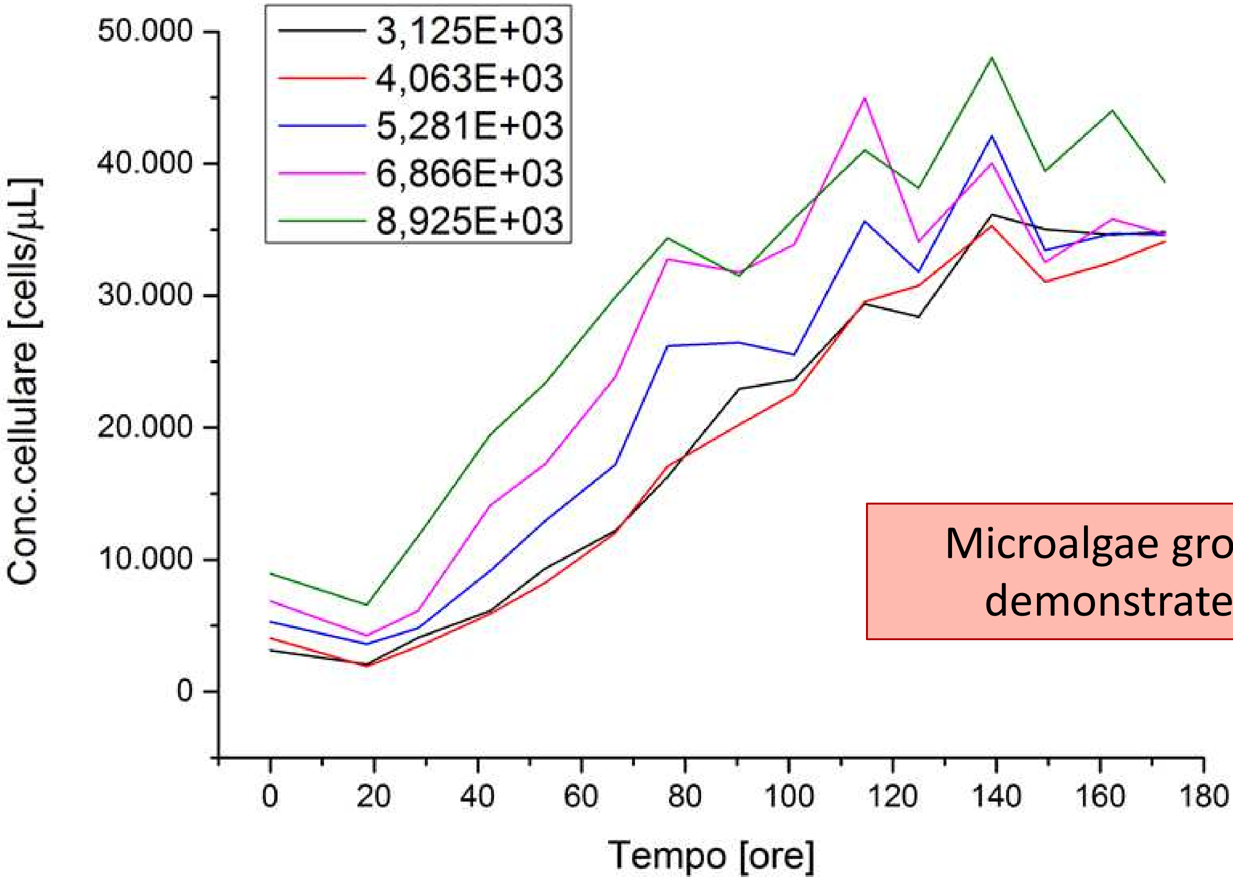


First prototype platforms already realised

Arrays of micro-photobioreactor on a microfluidic platform

- stable concentration gradients over a large number of cell samples
- possibility to generate multiple gradients of nutrients,
- possibility to apply fast dynamic changes of environmental signals (light)
- complex sequences of time- and space- resolved gradients
- continuous operation
- support of long-term culture of algae cells in a no-shear environment,
- high-throughput studies with large numbers of replicates
- compatibility with on-line imaging and standard analytics

Preliminary results



Microalgae growth in microPBRs demonstrated (batch-mode)

Future work

- Consolidate experimental and analytical techniques in microPBRs
- Move from batch to continuous operations
- Enhance model structure and validate it

Thank you for your attention