Computational analysis of hydrodynamics and light distribution in photo-bioreactors for algae biomass production

Varun Loomba[1,2] , Eric von Lieres[1], Gregor Huber[2]

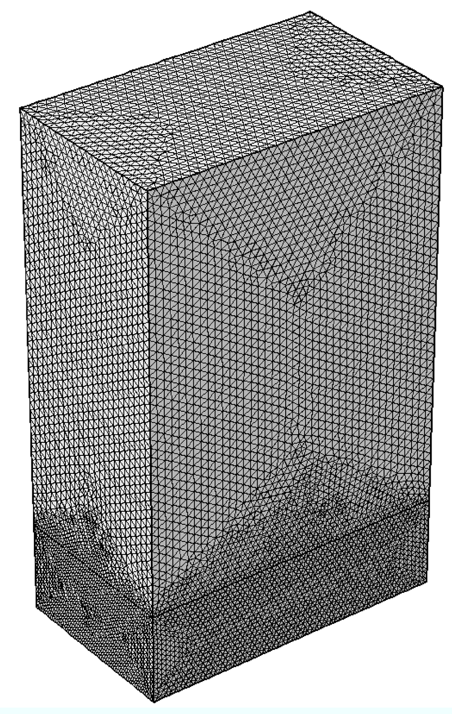
[1]IBG-1: Biotechnology, Forschungszentrum Jülich [2]IBG-2: Plant Science, Forschungszentrum Jülich

Introduction

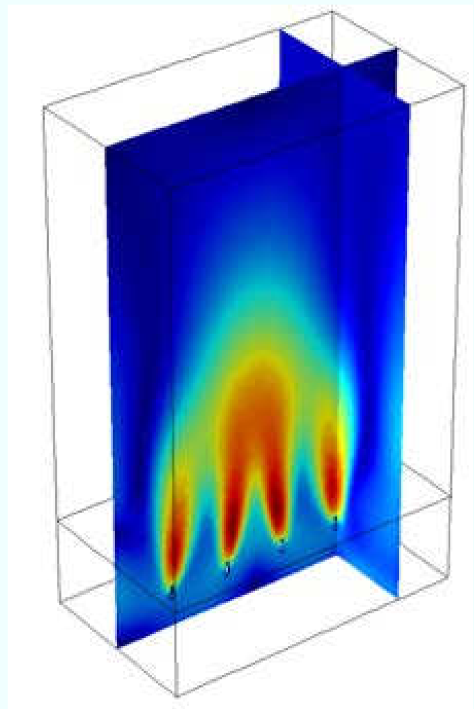
Microalgae are proven to have great potential in a variety of fields including commercial industry, water treatment, agriculture and source of biodiesel [1,2]. To realize the full potential of microalgae, optimal operating conditions for their cultivation in photo-bioreactors (PBR) need to be identified in order to maximize productivity, lipid content, and efficiency of photosynthesis. The most important parameters affecting PBR performance are reactor shape, light intensity distribution, algae growth and other metabolic properties. The presented study aims at optimizing these parameters using computational fluid dynamics (CFD) simulations with the COMSOL Multiphysics software.

1. Hydrodynamics

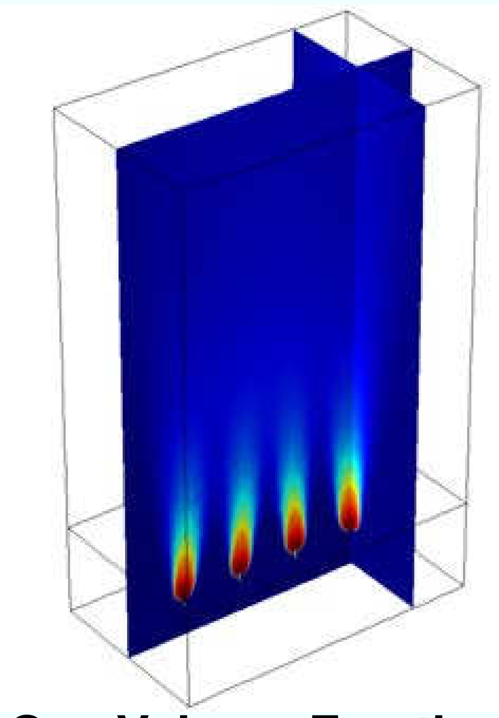
- Hydrodynamic studies using the turbulent bubbly flow model of COMSOL Multiphysics are performed.
- Liquid and gas phases, but not the microalgae cells, are considered in these simulations.
- The Navier-Stokes equations are solved using the Eulerian approach for both phases.
- The bioreactor model describes a lab scale flat panel reactor (10.34 x 6.1 x 20.83 cm) with a liquid holding capacity of 1 L.



Computational Domain



Velocity Field



Gas Volume Fraction

2. Light Intensity Distribution

- The light intensity distribution is computed using MATLAB by solving the radiative transfer equation (RTE).

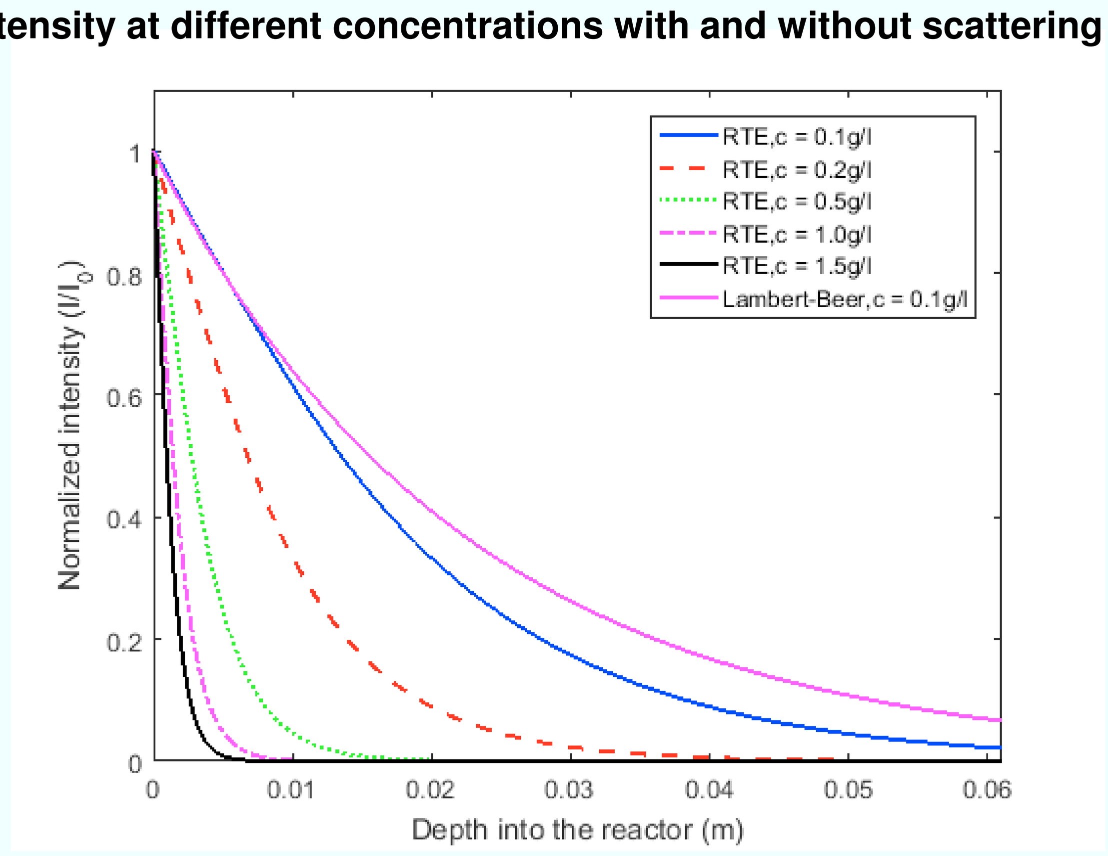
$$\frac{dI}{ds} = -\kappa I - \sigma_s I + \frac{\sigma_s}{4\pi}\int I(\bar{s}_i)\Phi(\bar{s}_i,\bar{s})d\Omega_i$$

- The HG approximation is used for the scattering phase function Φ.

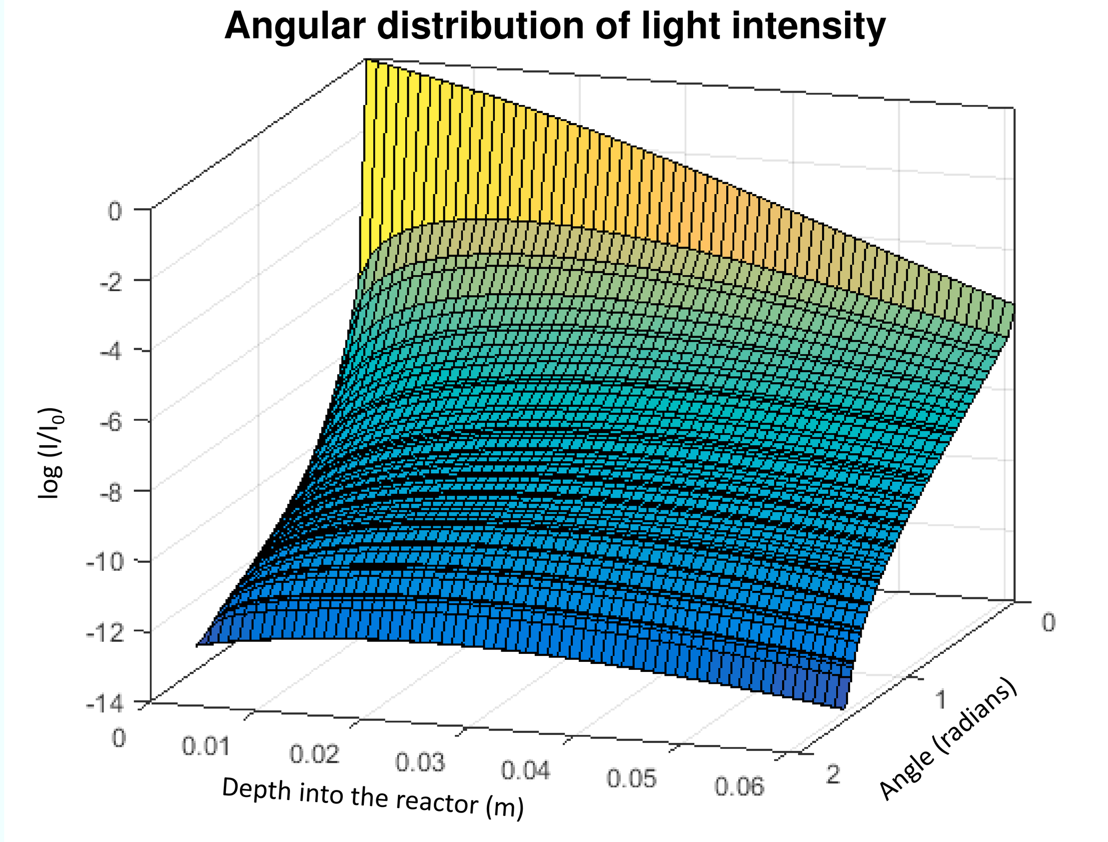
$$\Phi = \frac{1-g^2}{(1+g^2-2g\cos\theta)^{1.5}}$$

- The absorption and scattering coefficients are used as reported by Kandilian et. al.[3]

Intensity at different concentrations with and without scattering

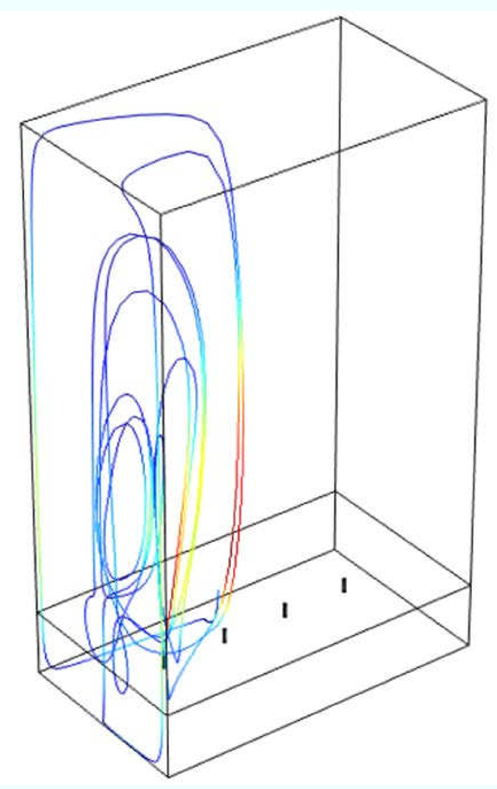


Angular distribution of light intensity

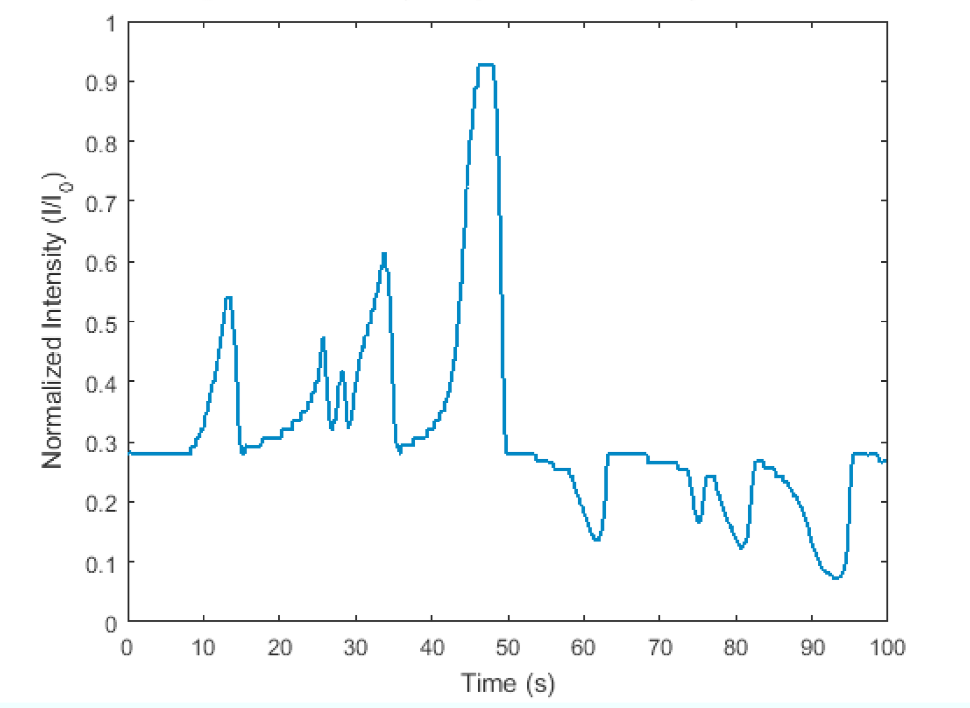


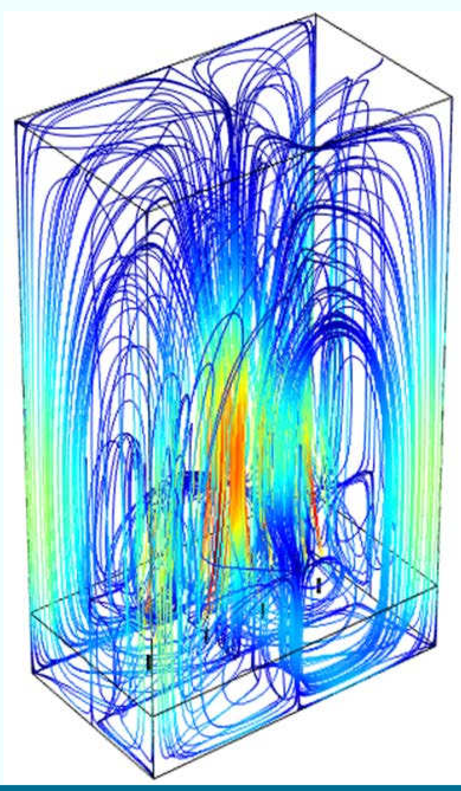
3. Particle tracing and combination with light intensity distribution

- Paths of single and multiple microalgae cells are traced over time using the liquid phase velocity profiles from the hydrodynamic study.
- Light observed by the algae cells is determined by combining particle tracing data with light intensity distribution and the paths of the cells are statistically analyzed

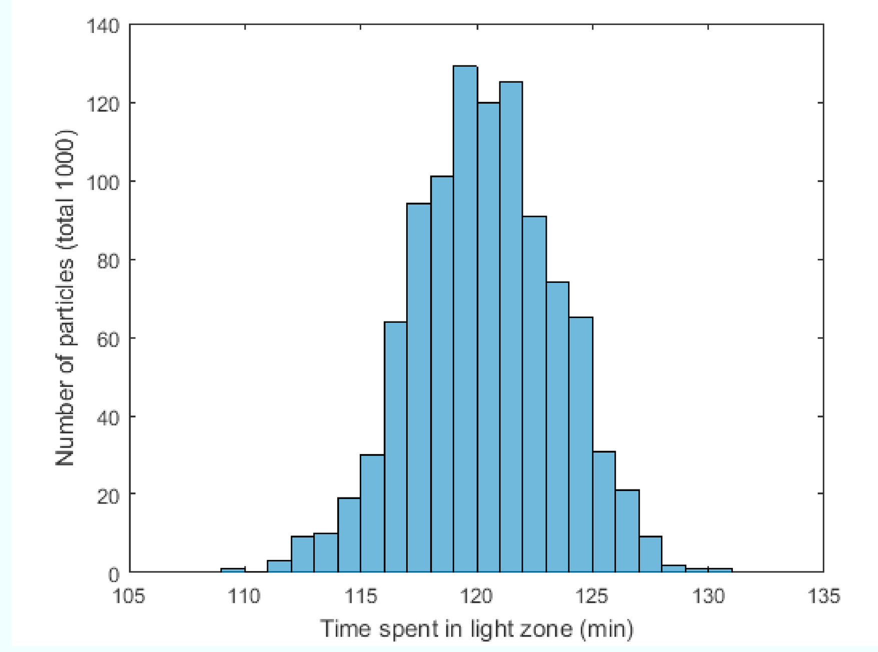


Light Intensity experienced by 1 cell





Time spent by 1000 cells in Light zone



Light zone defined as the region with light intensity more than 10% of incident light

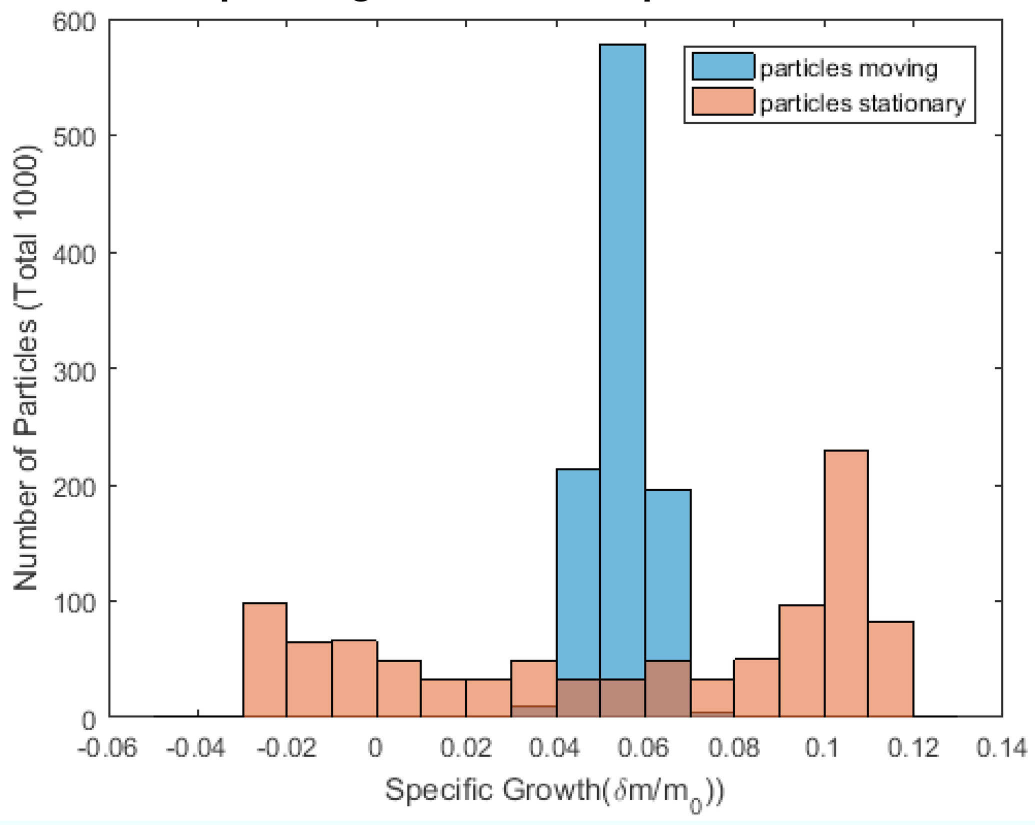
4. Light dependent growth modeling

- Based on the available light intensity I calculated using the RTE, the specific growth rate can be calculated as [4] :

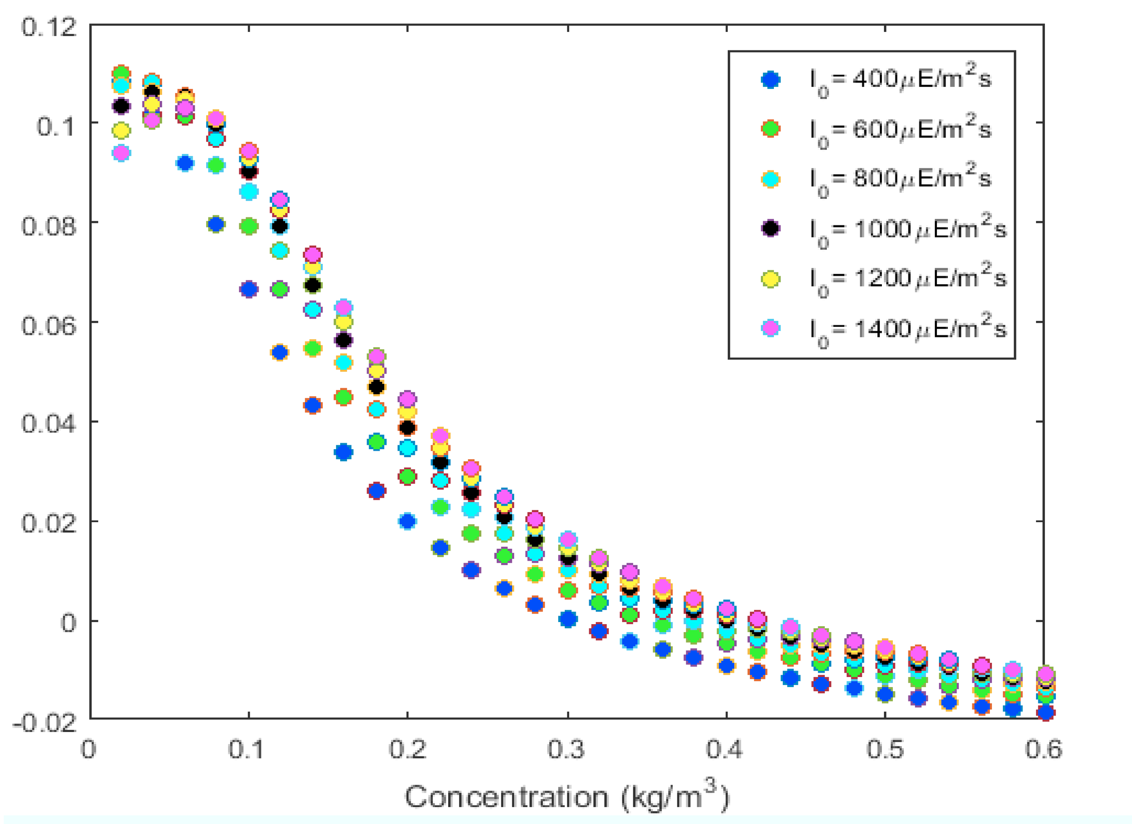
$$\mu = \mu_s \frac{I}{K + I + \frac{I^2}{K'}} - \lambda$$

- Specific growth for 1000 particles calculated for 3000 seconds, algae concentration C = 0.2 kg/m^3 and incident light intensity I_0 = 1000 μE/m^{2}s.

Specific growth for 1000 particles



Average specific growth for different algae concentrations



Mitglied der Helmholtz-Gemeinschaft

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

Projektträger Jülich Forschungszentrum Jülich

5. References

[1] Spolaore et al., (2006) *J. Biosci. Bioeng.* **101**: 87-96.
[2] Bitog et al., (2011) *Comput. Electron. Agr.* **76**: 131-147.
[3] Kandilian et. al (2016) *J. Quant. Spect. & Radiative Transfer.* **175**: 30-45
[4] Pruvost et.al. (2008) *Chem. Engg. Science.* **63**: 3679-3694

Varun Loomba
IBG-1/IBG-2
Forschungszentrum Jülich
v.loomba@fz-juelich.de