

***Termofluidodinamica di Gocce
di Fluidi Complessi in Microgravità per lo
Sviluppo di Tecnologie per lo Spazio***

Patrizio Massoli

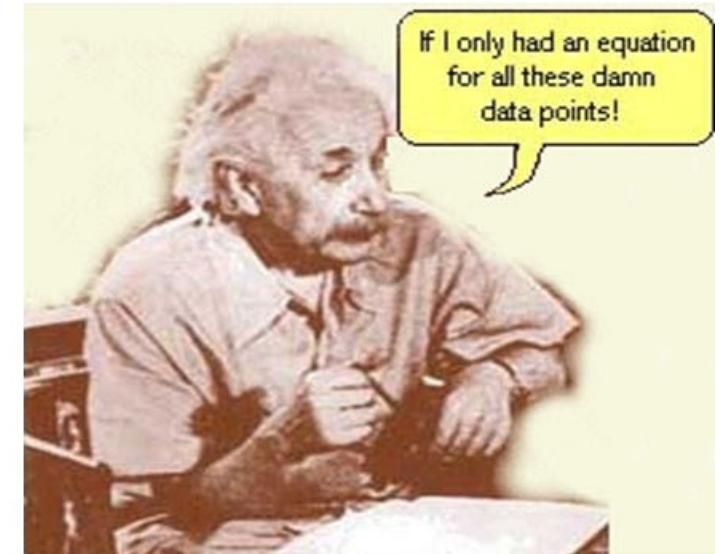
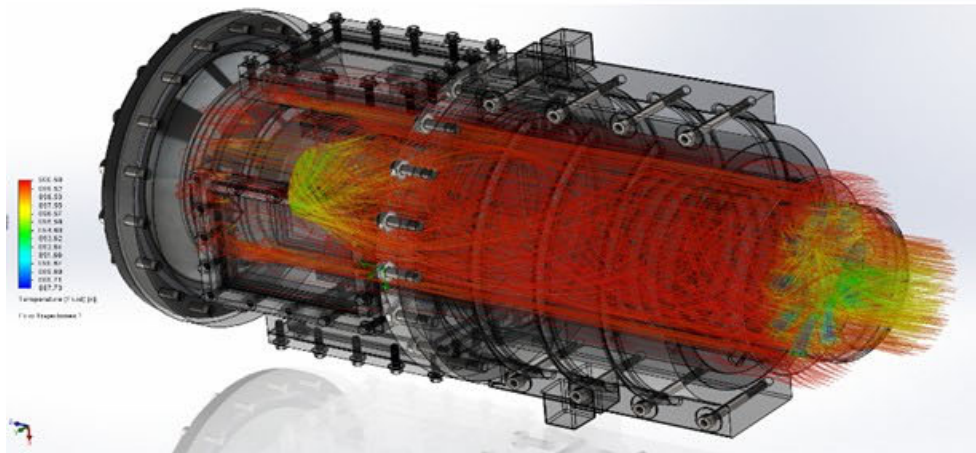
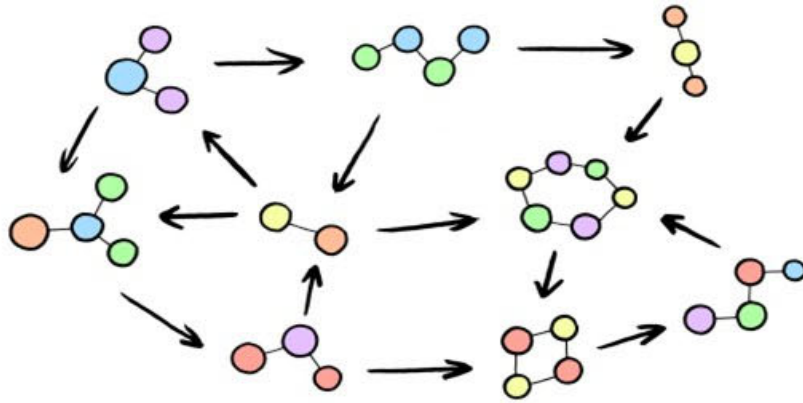
Institute of Sciences and Technologies for Sustainable Energy and Mobility

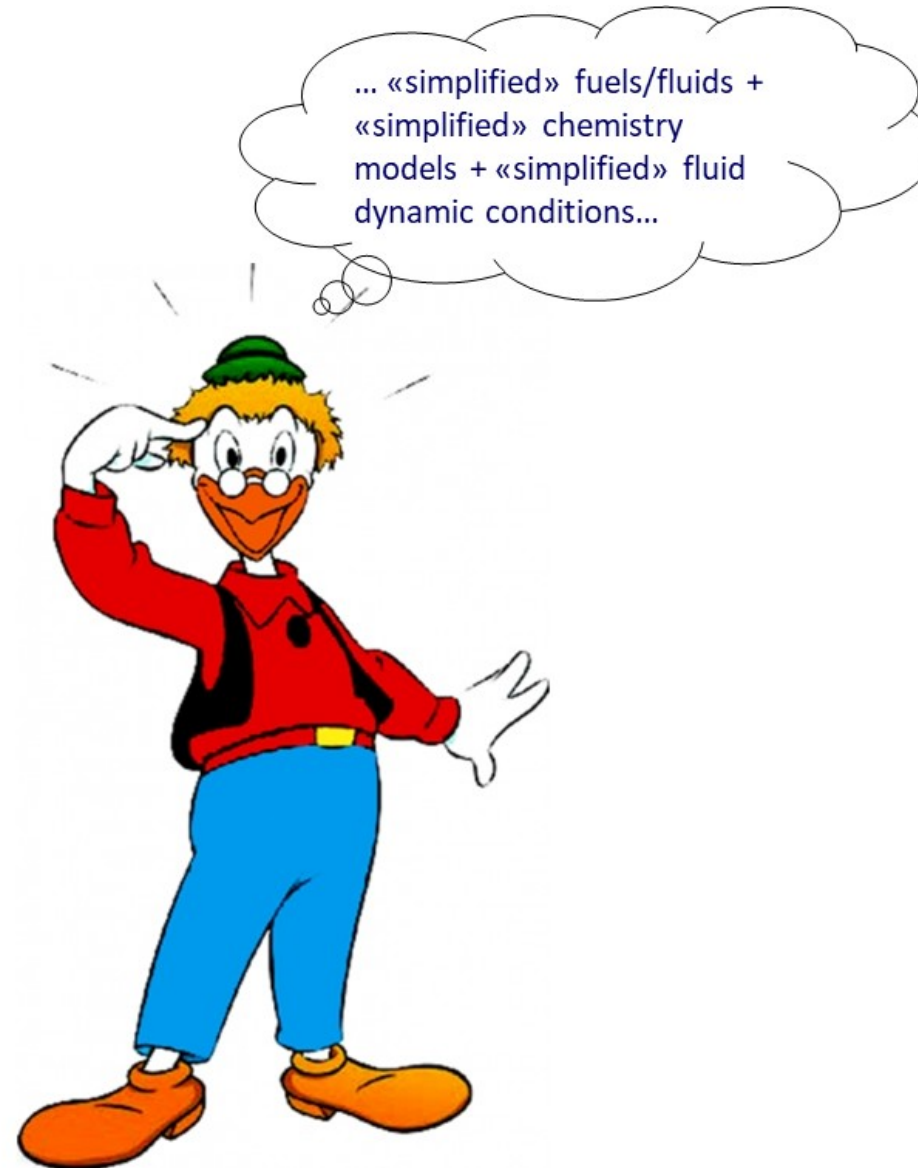
National Research Council of Italy

STEMS-CNR

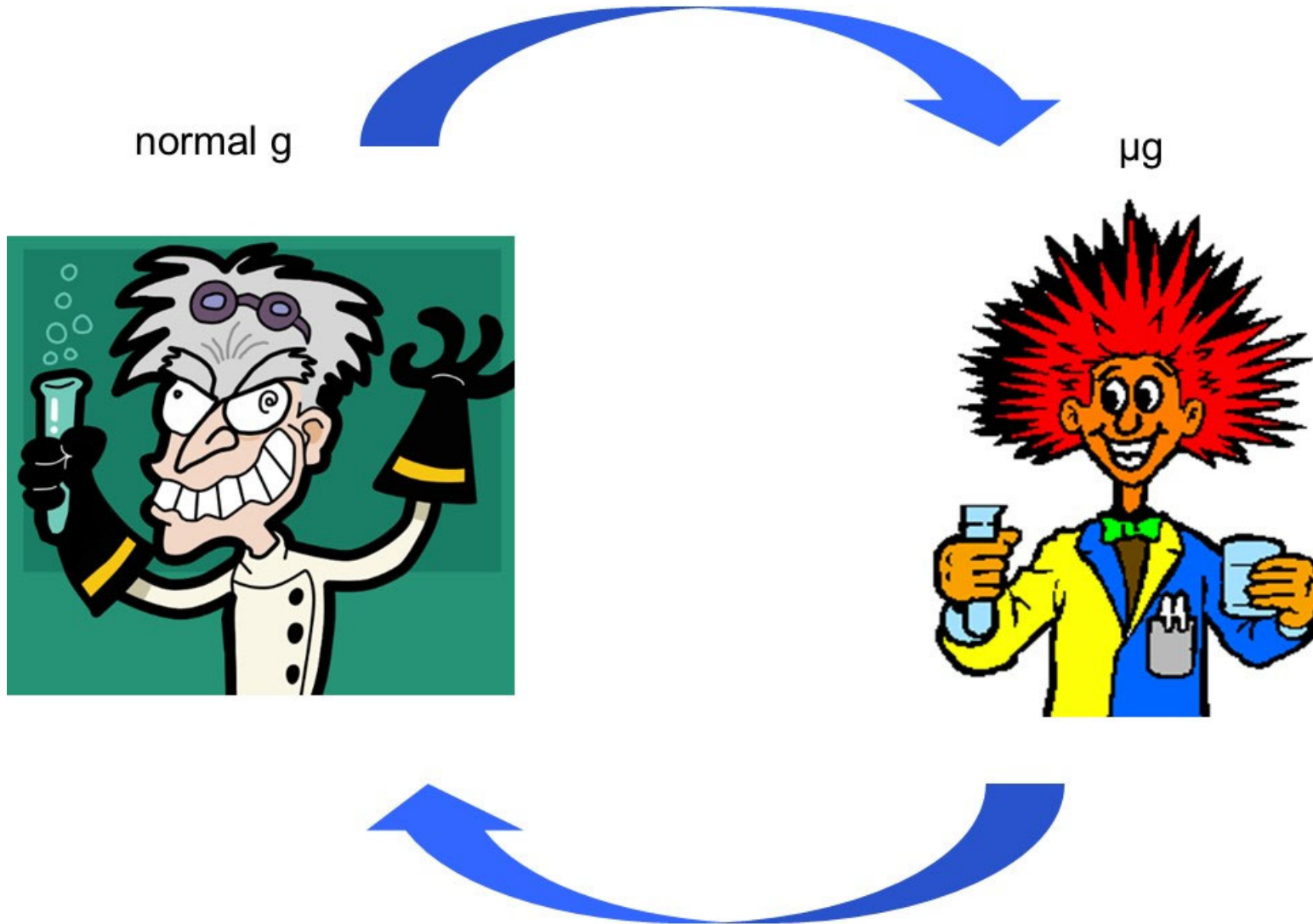
- **New combustion technologies**
 - **Rocket propellant**
 - **Fluids in Microchannels**
 - **Tools made of light**

The approach



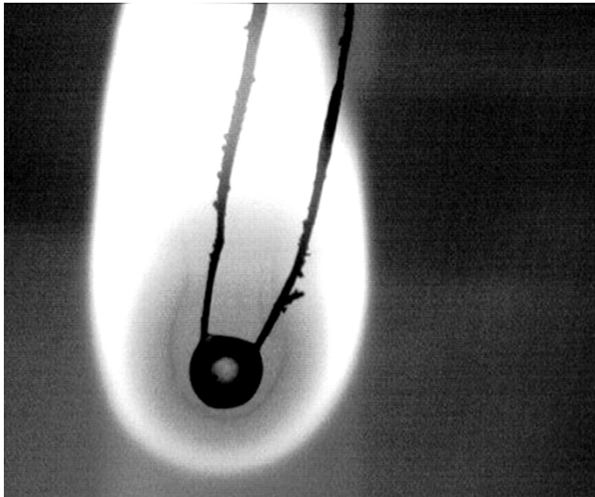


Why microgravity, why in the space

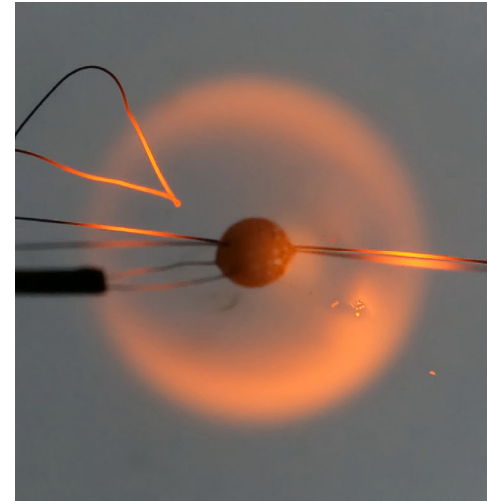


Why microgravity, why in the space

normal g

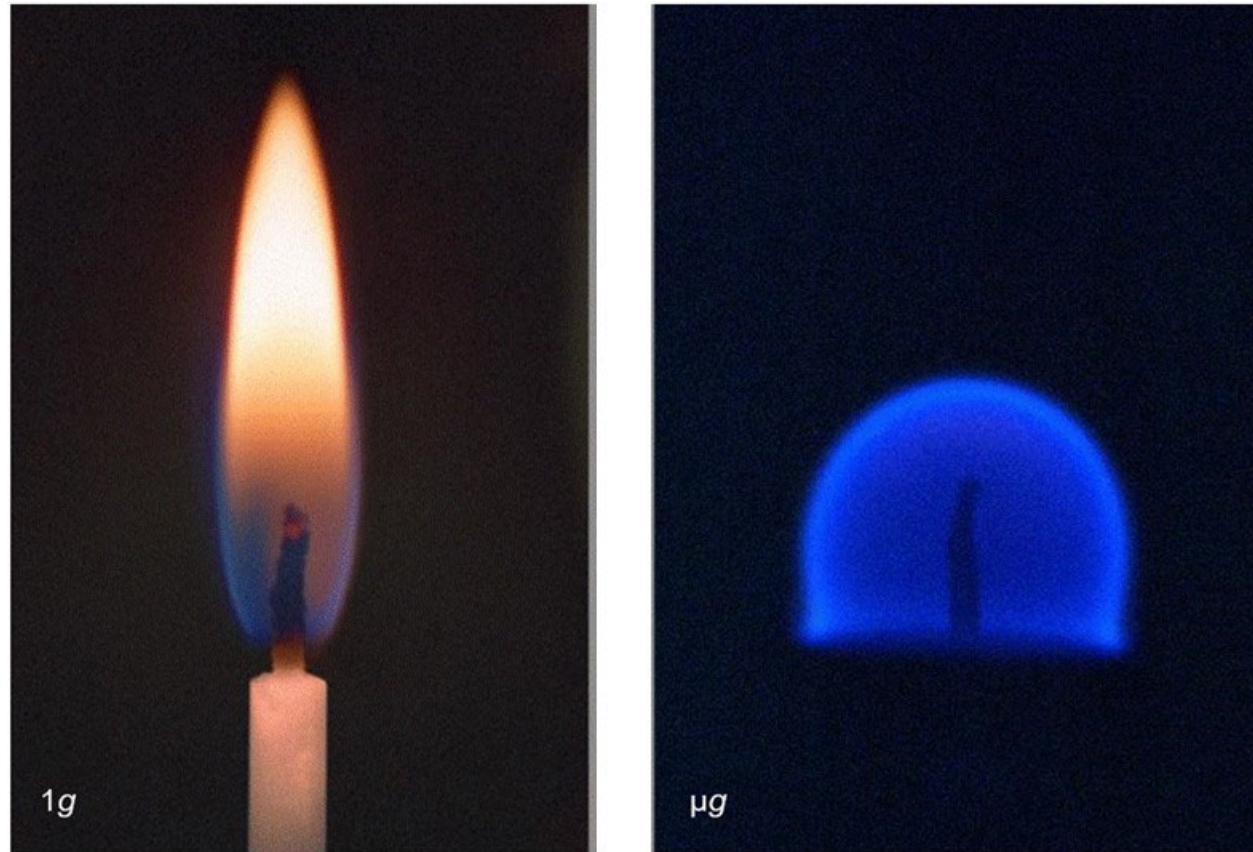


μg




Why microgravity, why in the space

A flame in the space

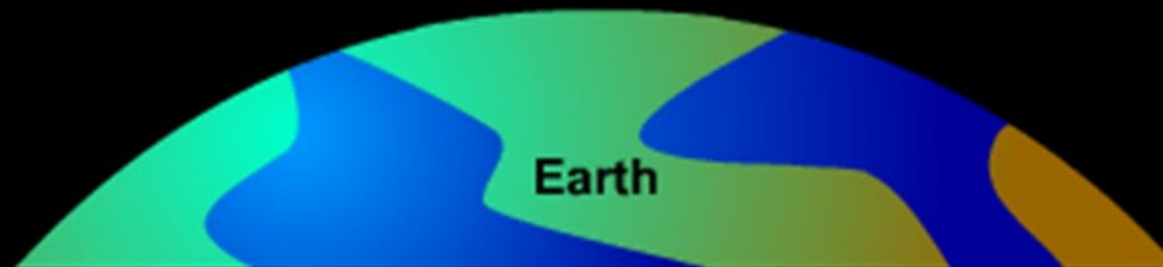


How to obtain 0-gravity

$$m \times 9.8 \text{ ms}^{-2}$$


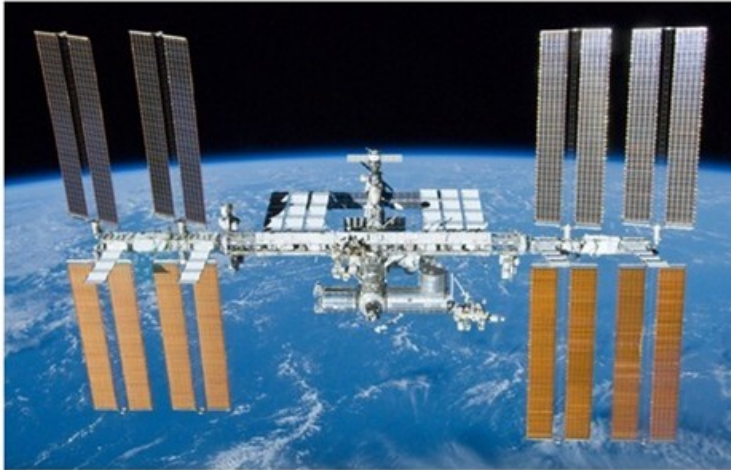


we can remove the effects of gravity on an object
either by placing it in freefall or by recreating freefall
conditions



Our experimentation in μg

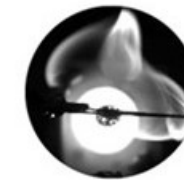
Experimentation in simplified boundary condition on simplified fluids: the key to link fundamental processes to real world



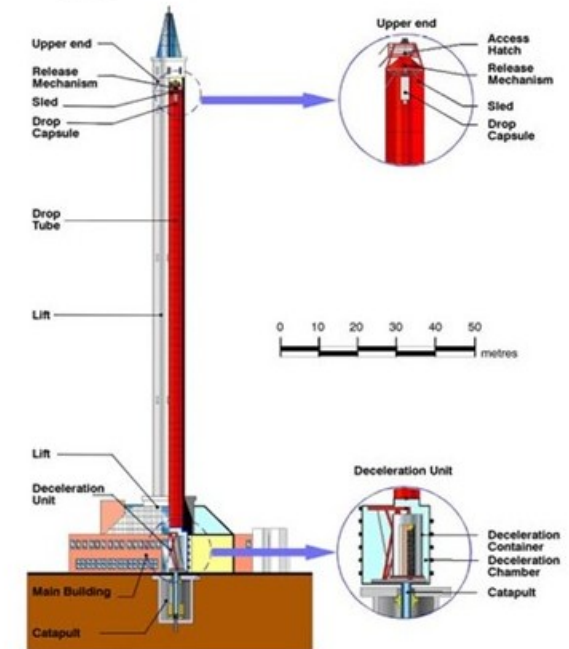
International Space Station
Mission *FLEX-ICE-GA* (Italian Combustion Experiment) (months @ $10^{-6} g$)



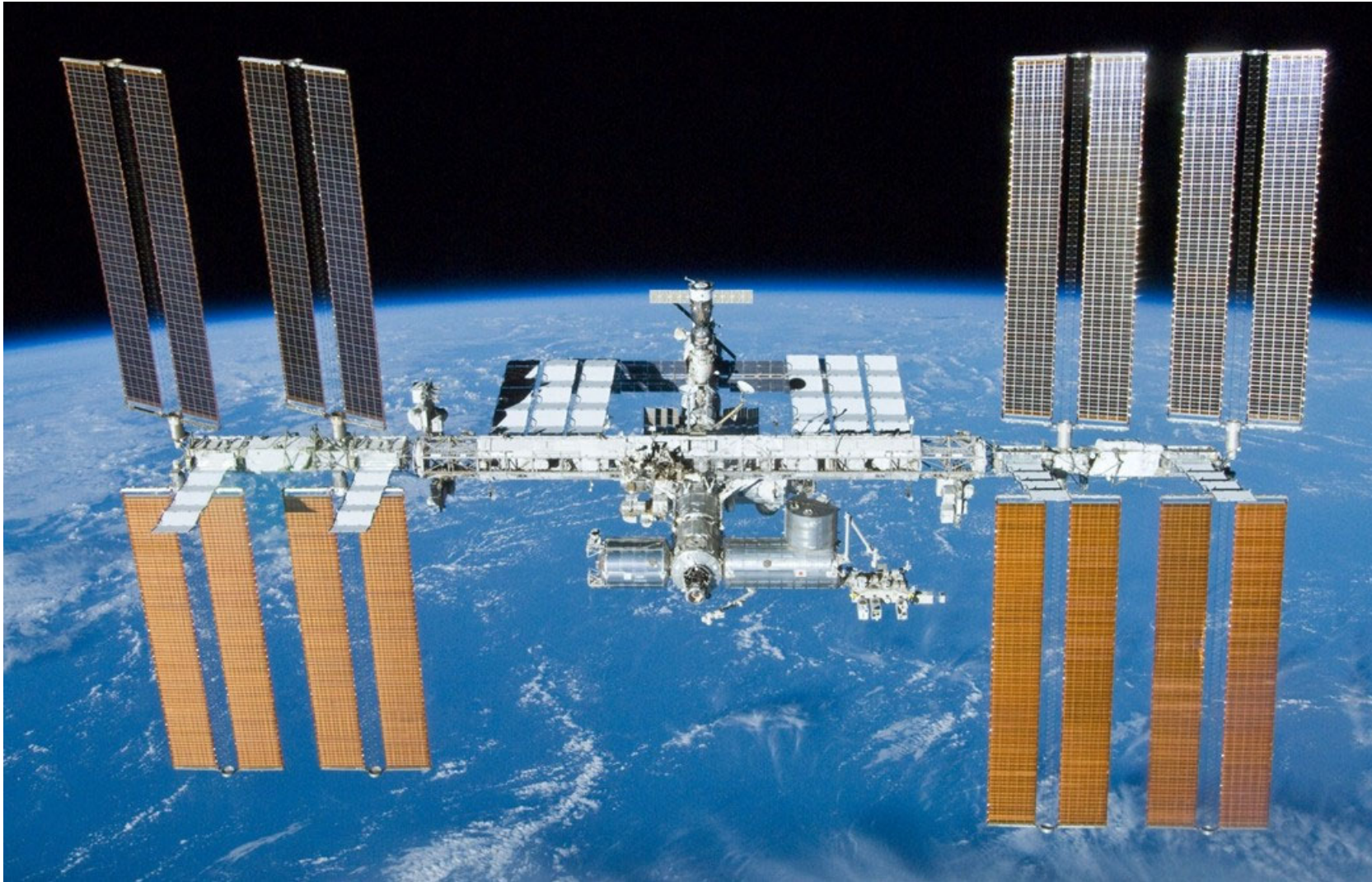
Sub-Orbital Spaceflight Virgin Galactic VSS
Mission *Virtude 1* (minutes @ $10^{-2} g - 10^{-3} g$)



ESA Project *STUDY-0g*
ZARM drop tower in Bremen
(9.48 s @ $10^{-3} - 10^{-5} g$)



Aboard the ISS (International Space Station)



Microgravity Duration: months

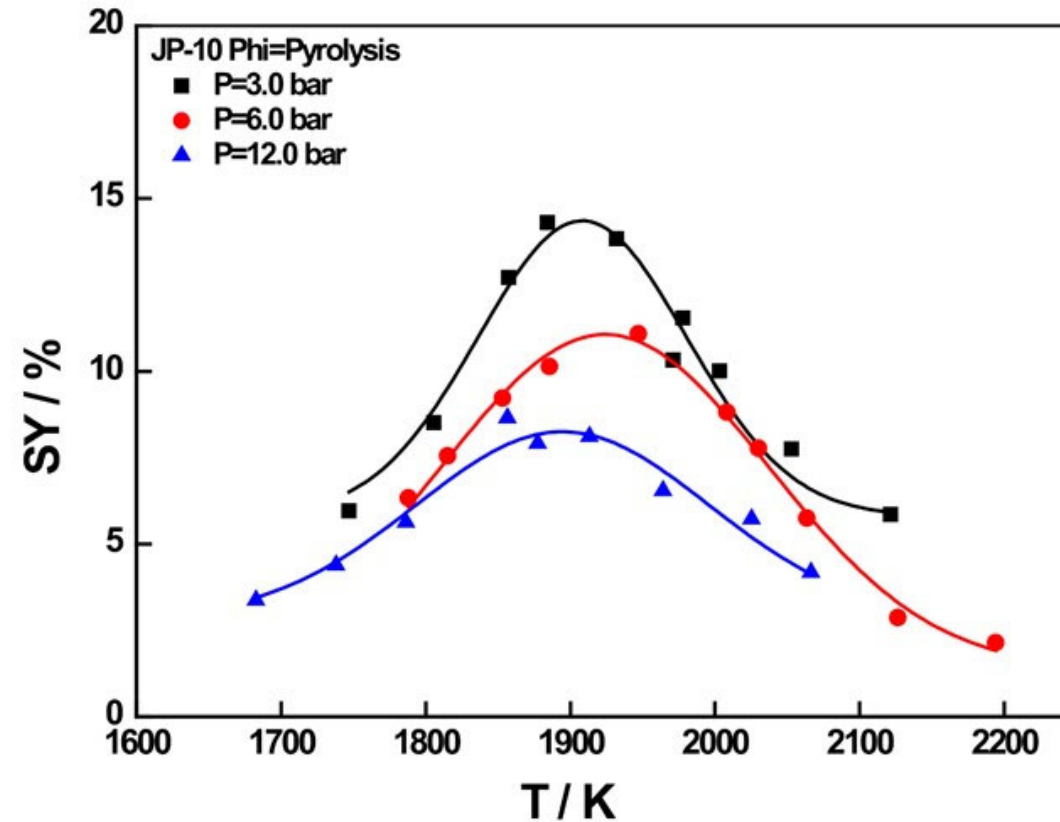
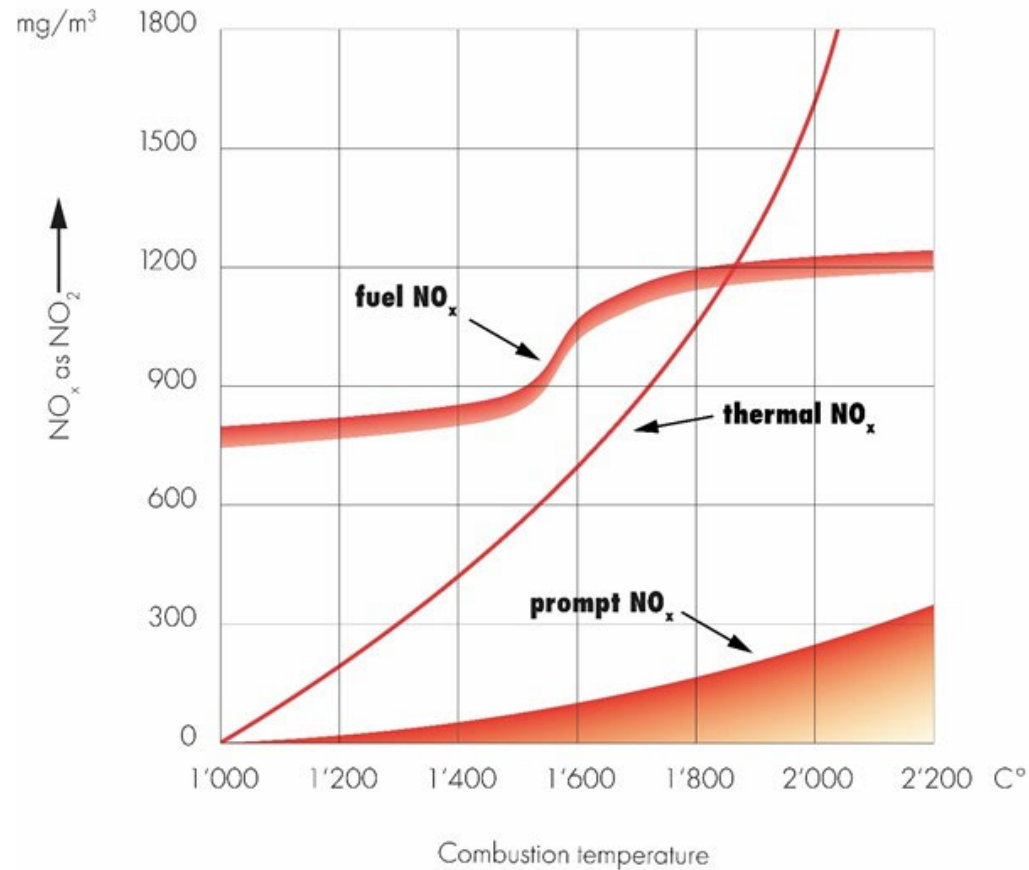
Microgravity Level: 10^{-6} g

Experiments Number: 105

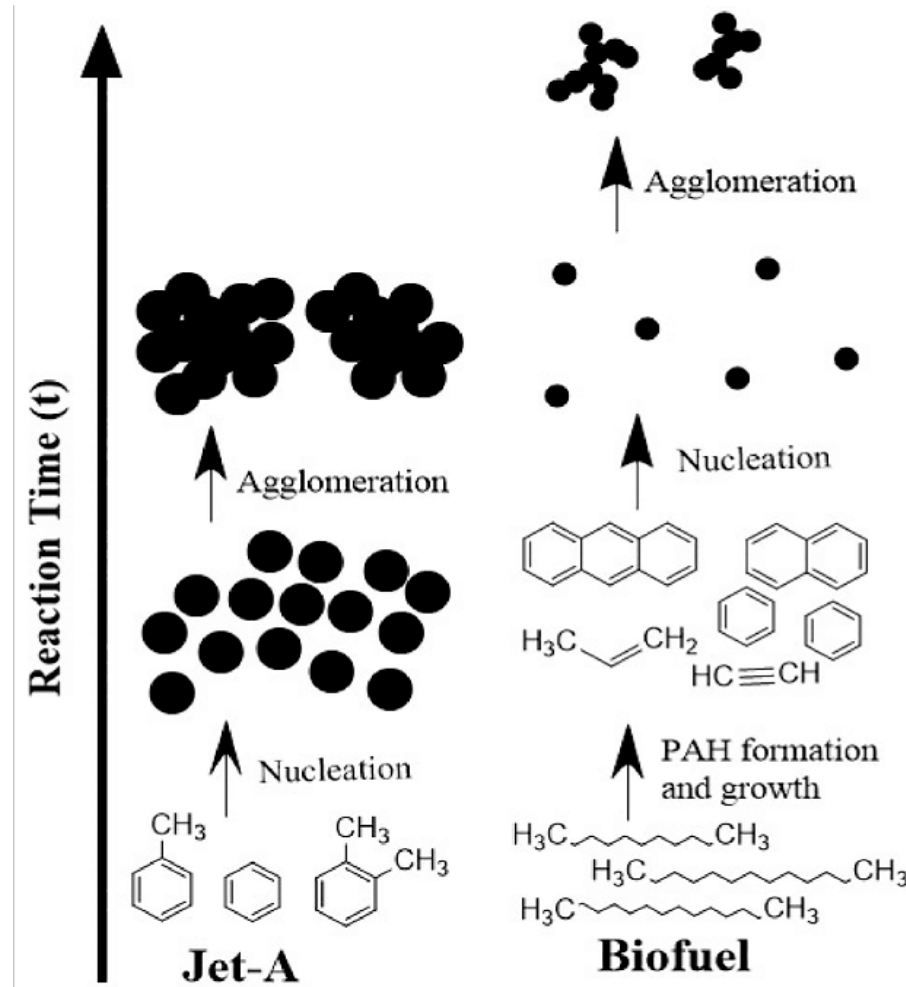
ICE-GA: un sostenitore molto speciale ...

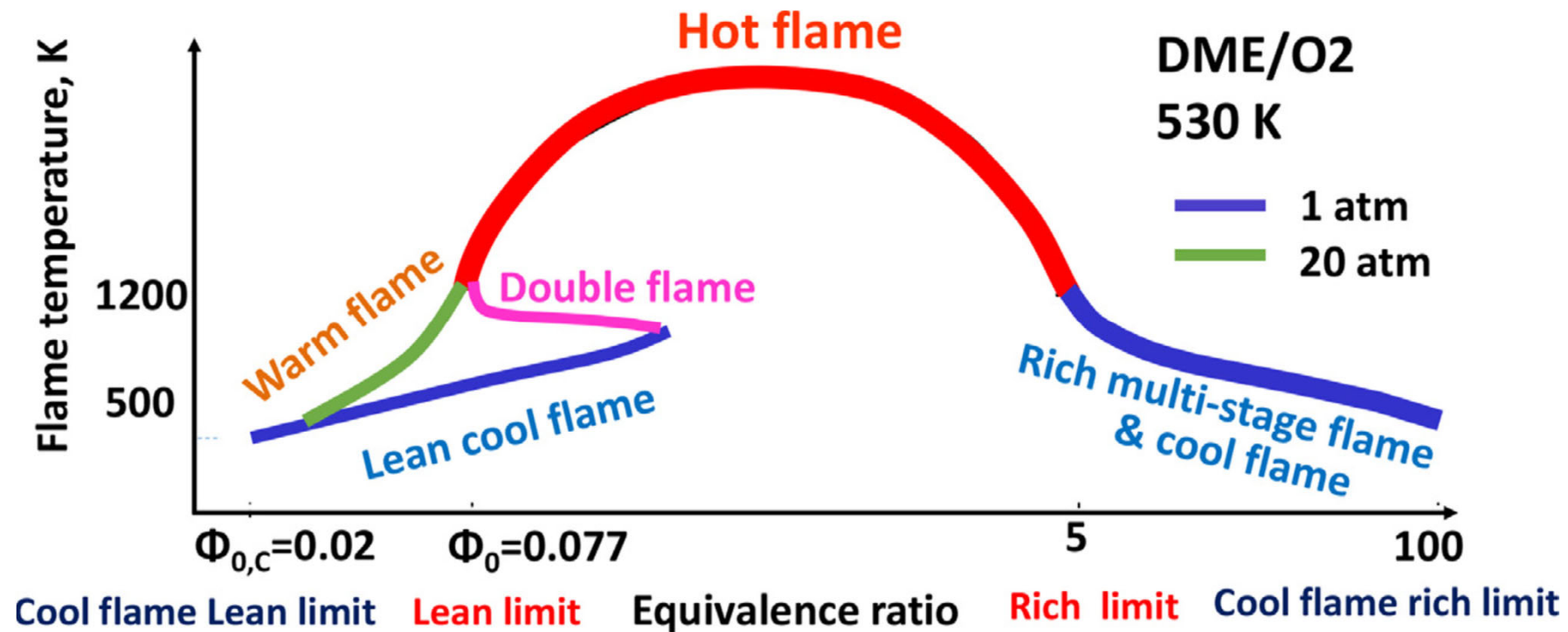


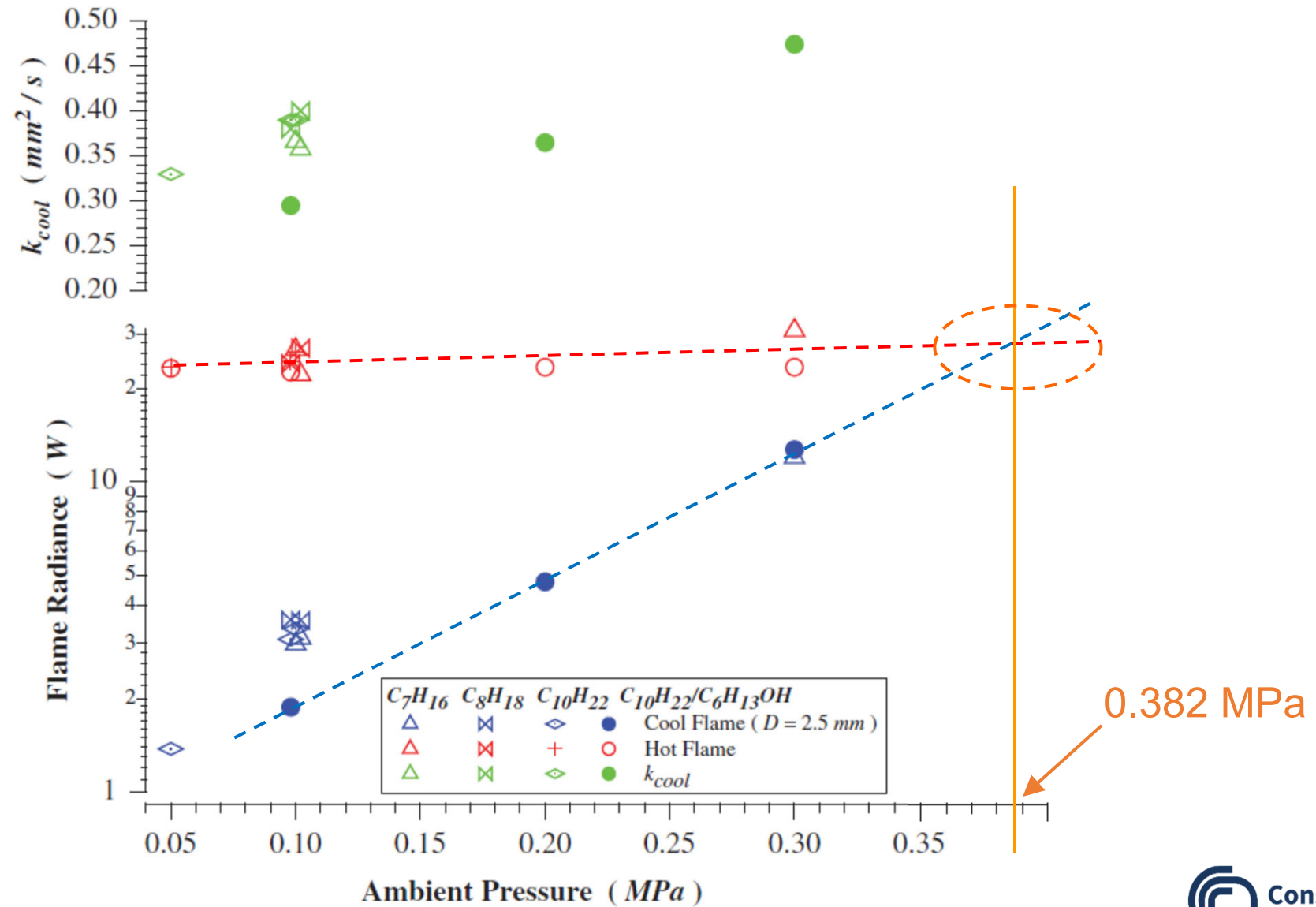
NO_x and Soot formation



Soot formation pathway





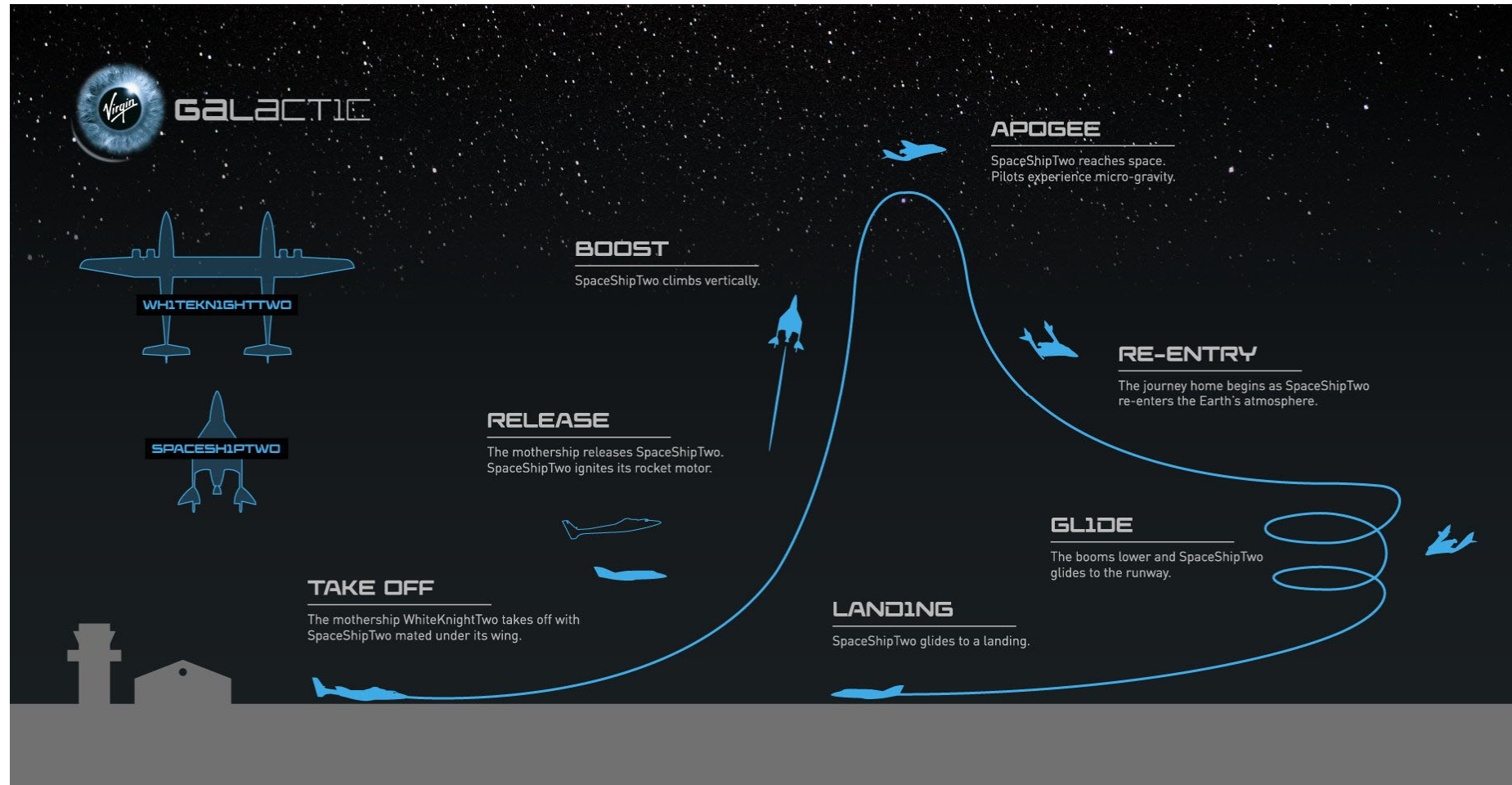


- **New combustion technologies (2° stage)**
 - **Rocket propellant**
 - **Fluids in Microchannels**
 - **Tools made of light**

Sub-Orbital Spaceflight VSS Mission Virtute 1



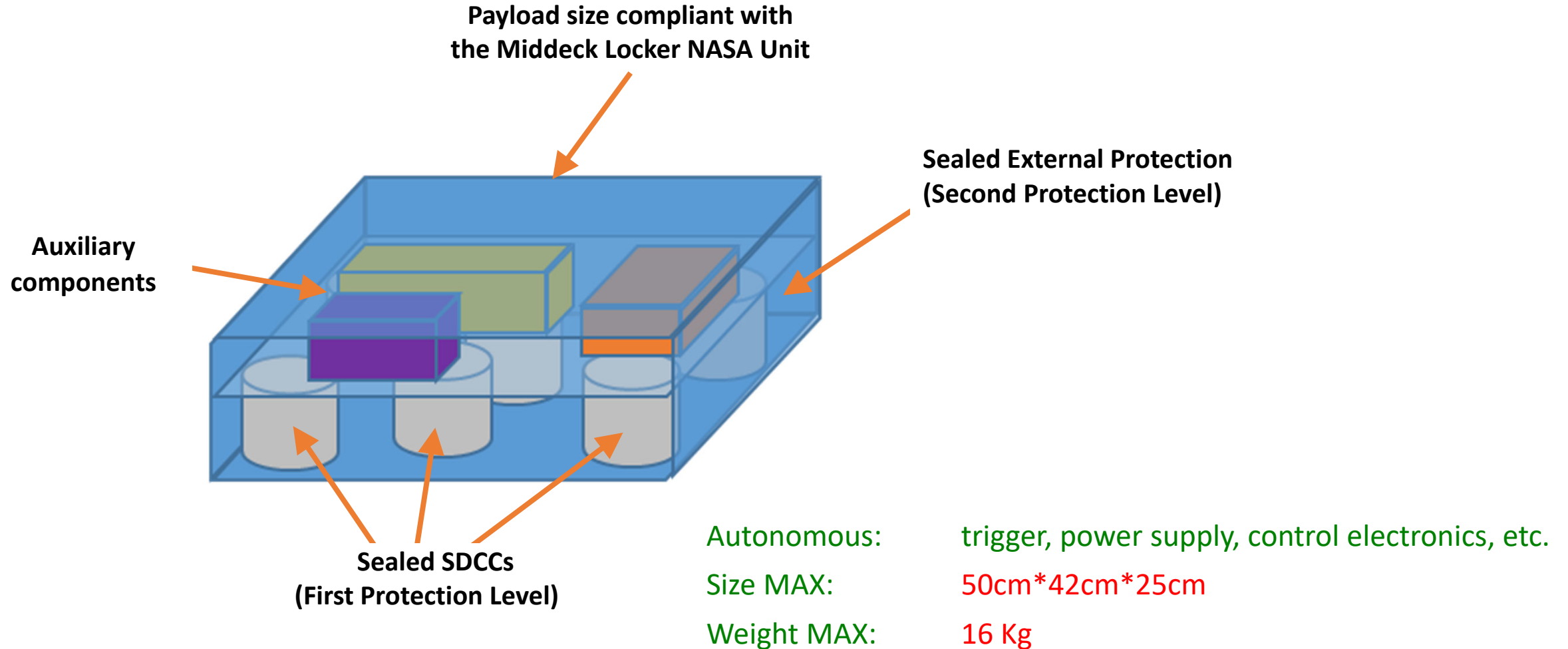
Virgin Galactic Parabolic Flight

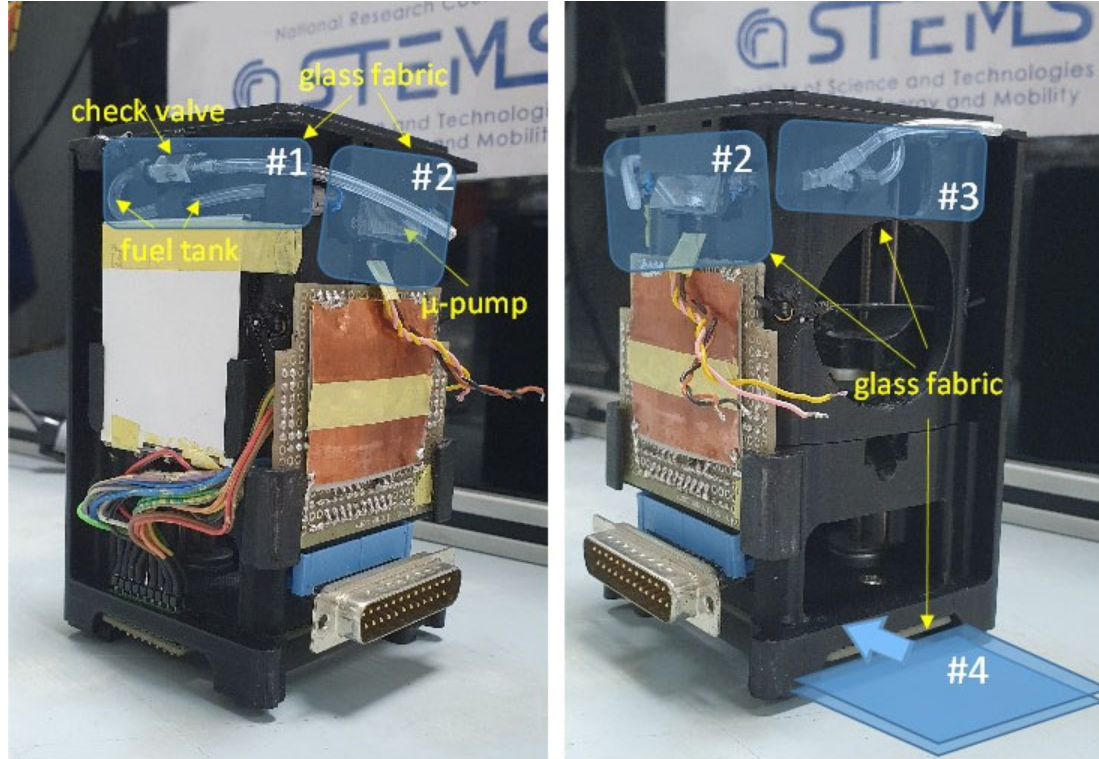




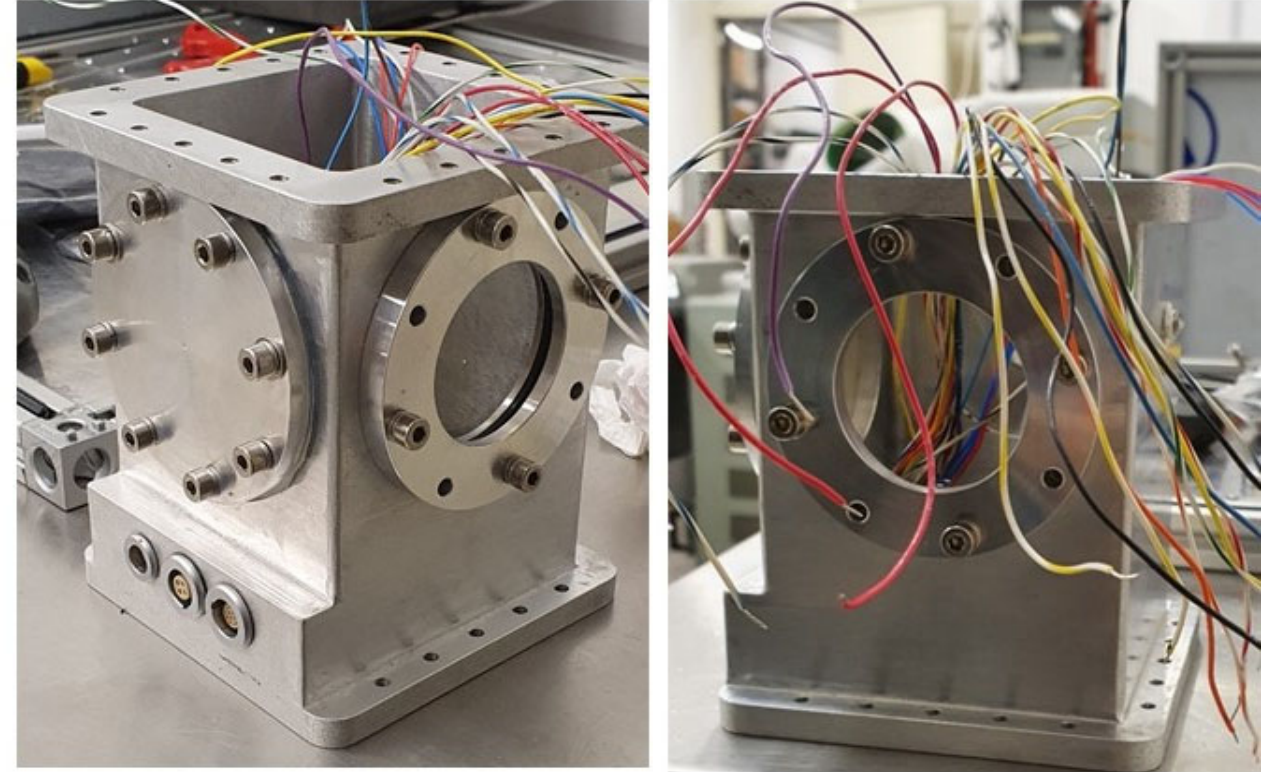
Spaceport America, Las Cruces, New Mexico (USA)

Payload structure



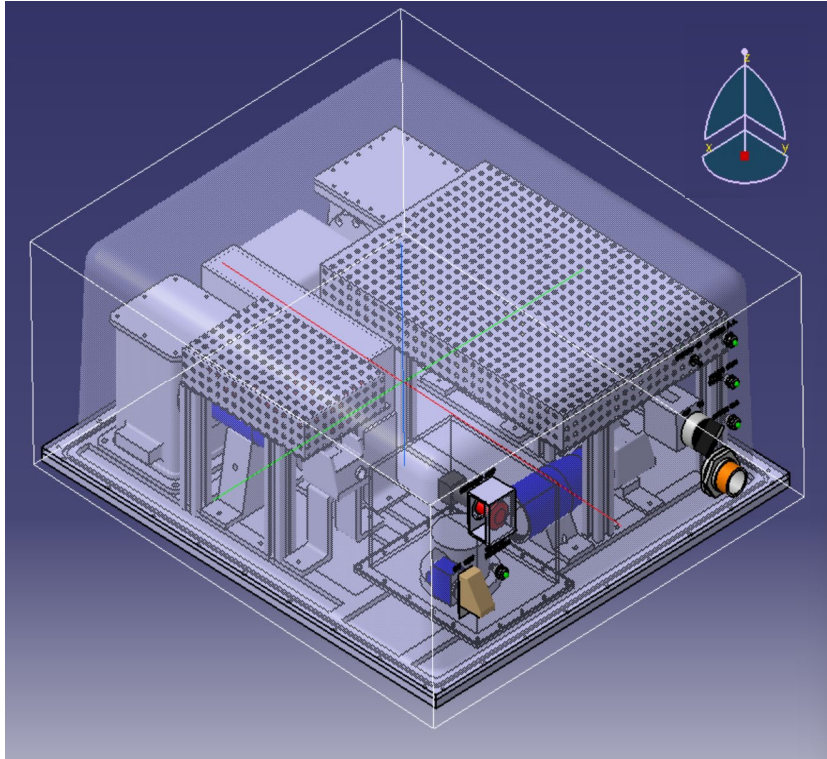


Atmospheric Pressure Combustion Cell: internal body structure



High Pressure Combustion Cell: central body and LEMO connectors (left);
view of the window flange (right)

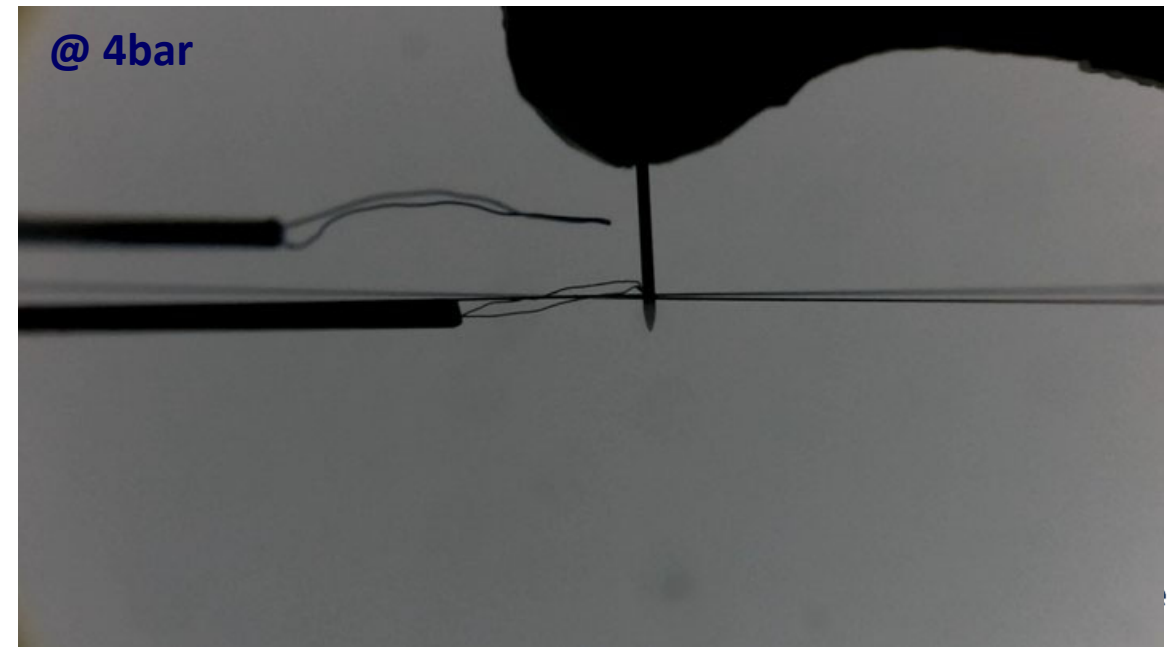
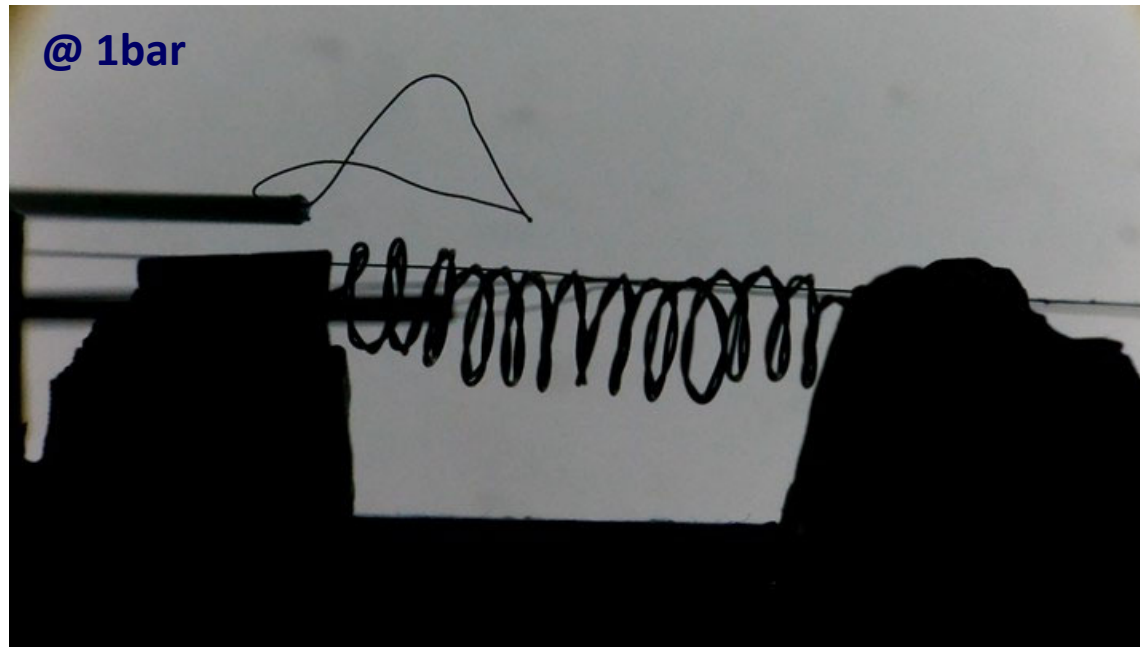
Payload structure



16 launches:

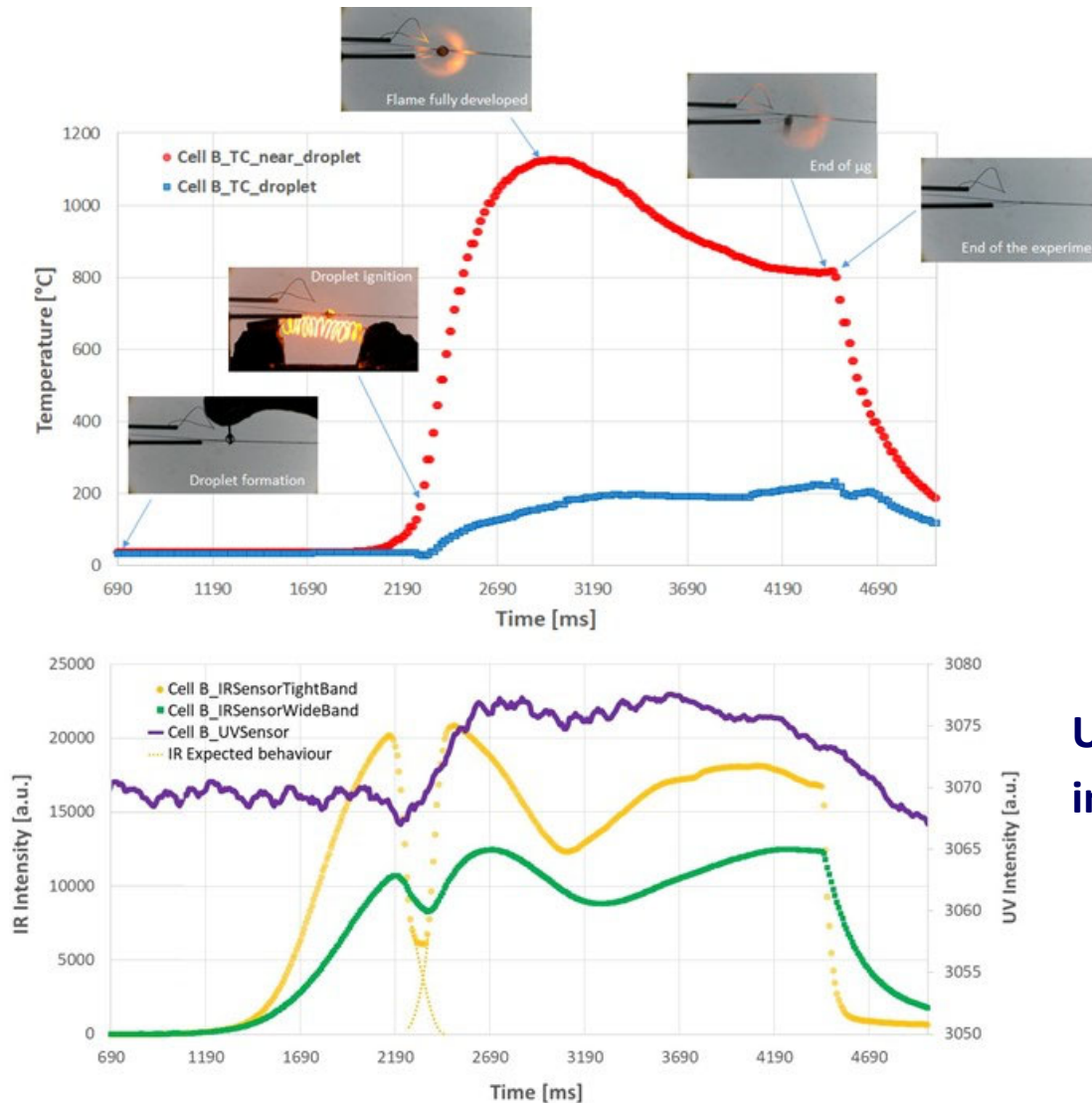
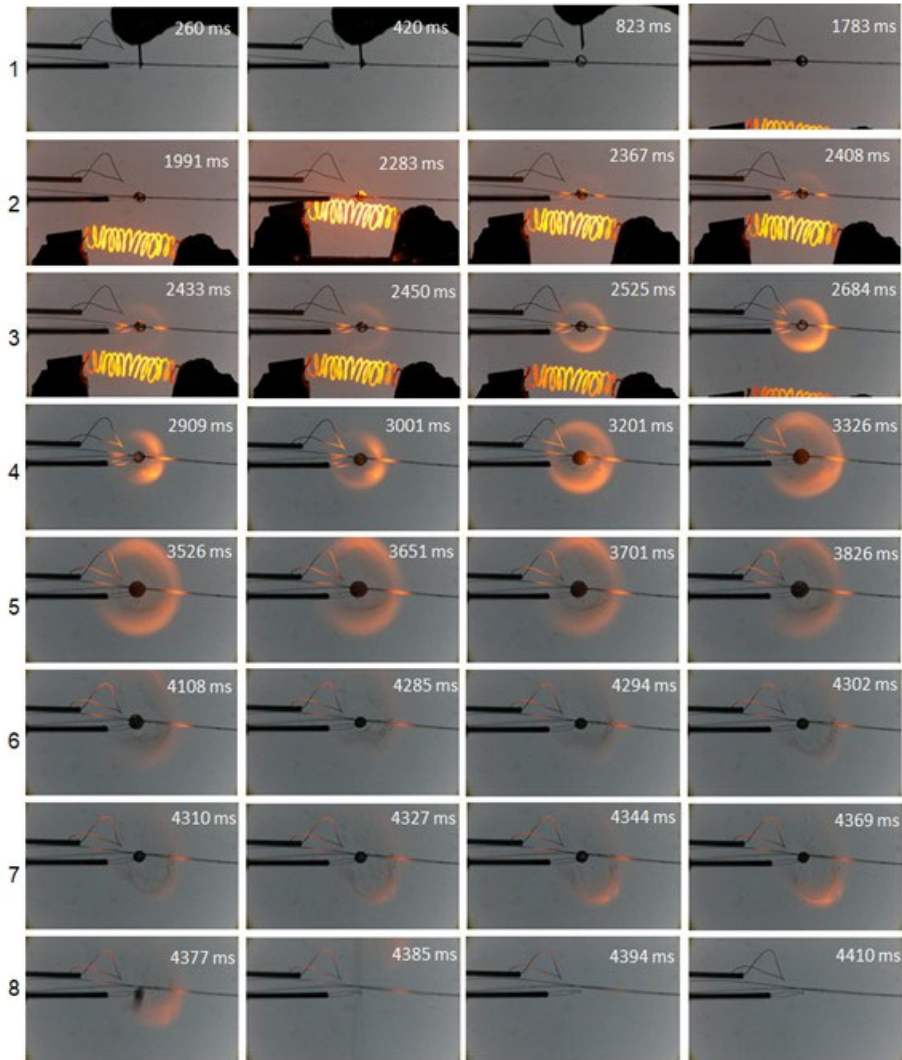
- 3 cells for droplet combustion studies (2 for low-viscosity fuels; 1 for high-viscosity fuels)
- 1 cell for radiative heating of soft matter (micro/nano colloidal suspensions of liquid or solid particles in a liquid matrix)
- Each cell is designed to perform a specific experiment on fuel droplets at a pressure of up to 30 bars in normal or syntethic atmosphere
- The payload is fully automated and autonomous: a computer embedded in the payload manages the payload and all subsystem procedures and experiments

combustion of n-decane/hexanol
50%/50% v/v



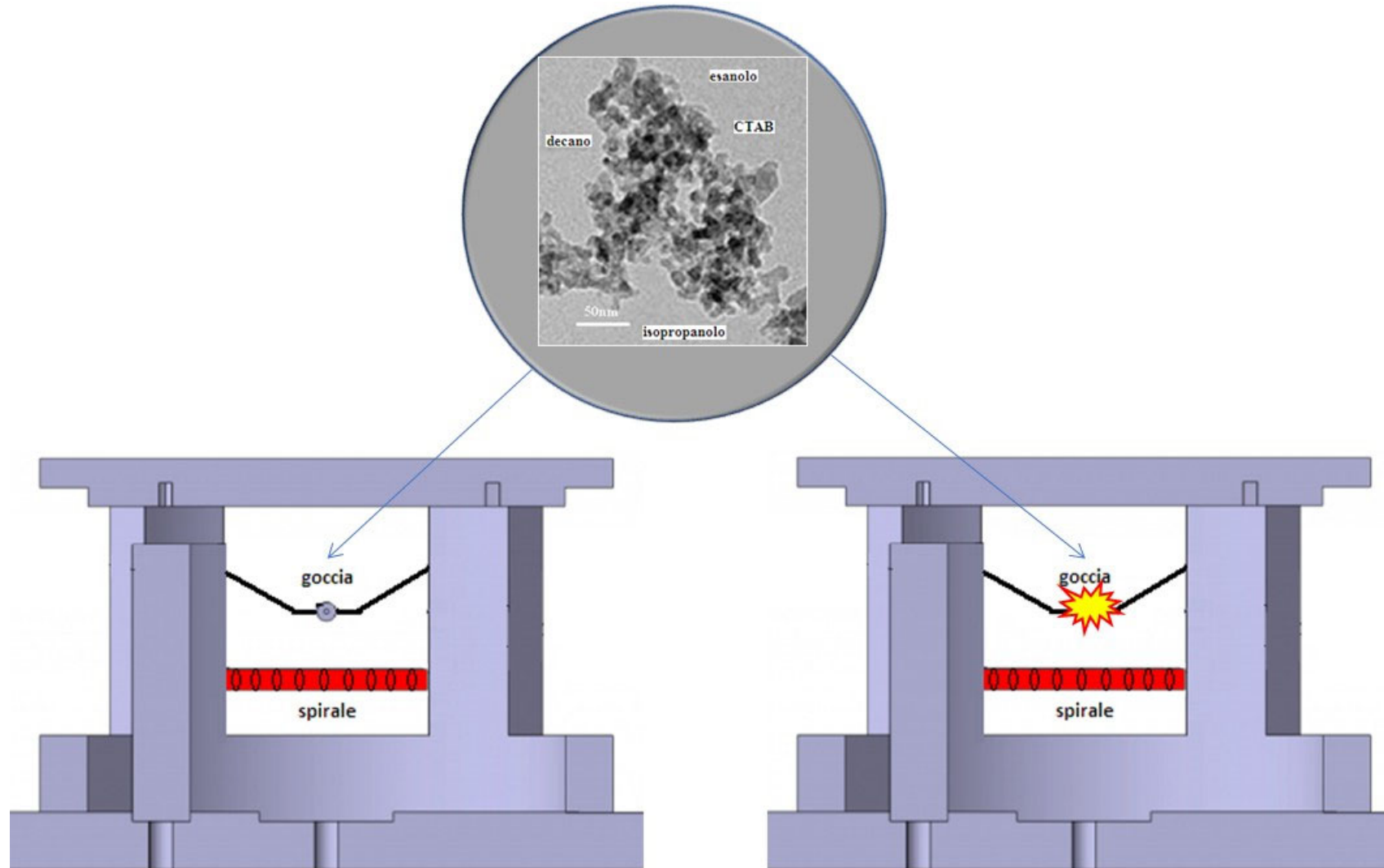
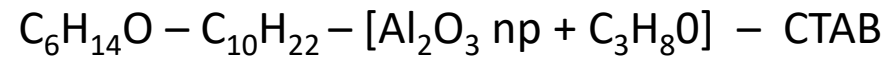
Experimentation @ ZARM – ESA μg Drop Tower

Thermo-optical analysis



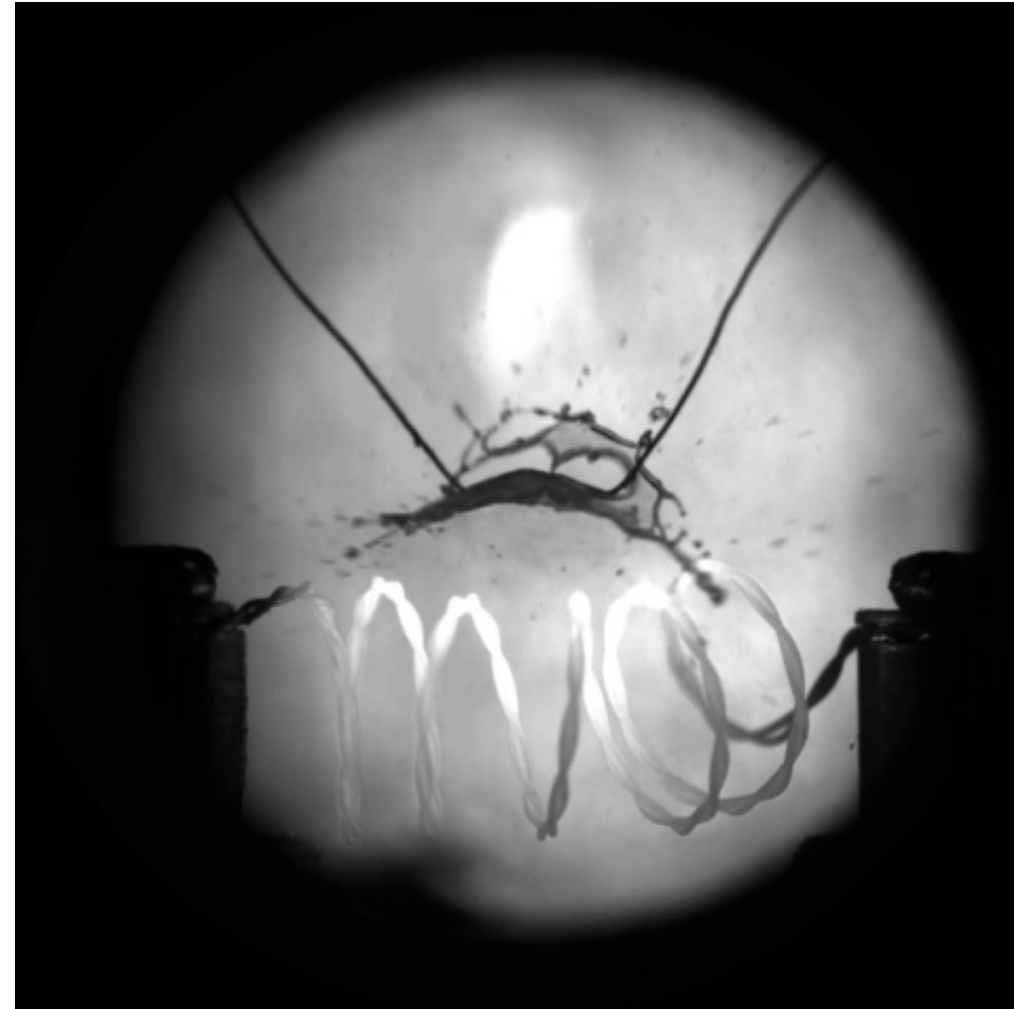
Ultraviolet and
infrared emissions

- New combustion technologies
 - Rocket propellant
 - Fluids in Microchannels
 - Tools made of light





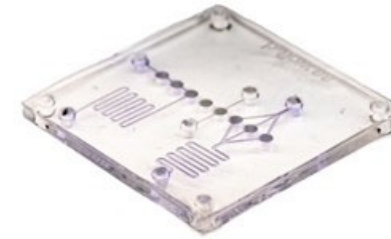
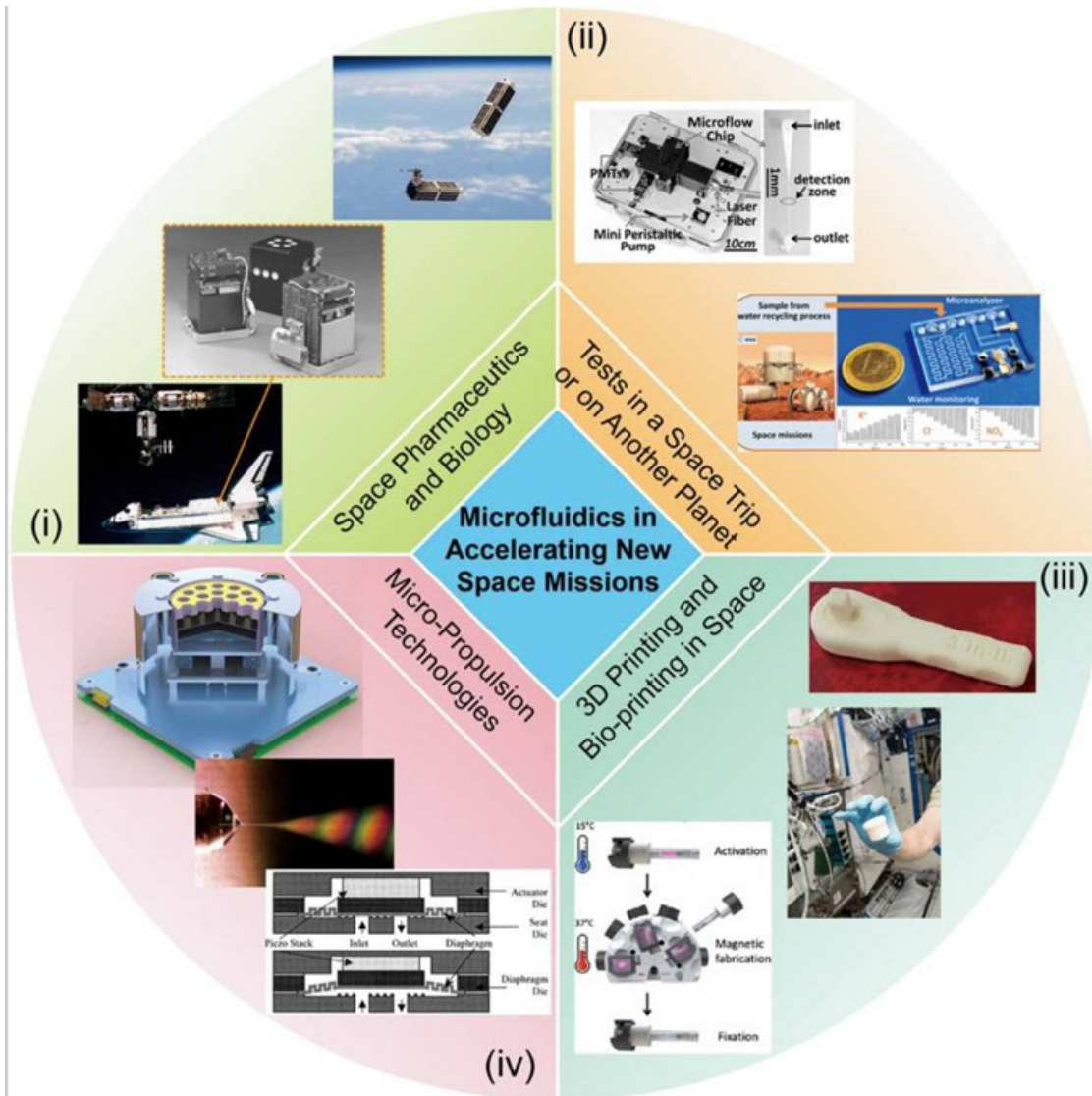
Puffing & Sputtering



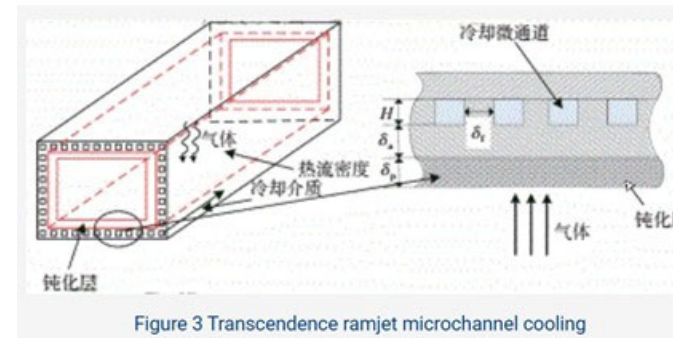
Microexplosion

- New combustion technologies
 - Rocket propellant
 - **Fluids in Microchannels**
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Role of microfluidics in aerospace applications

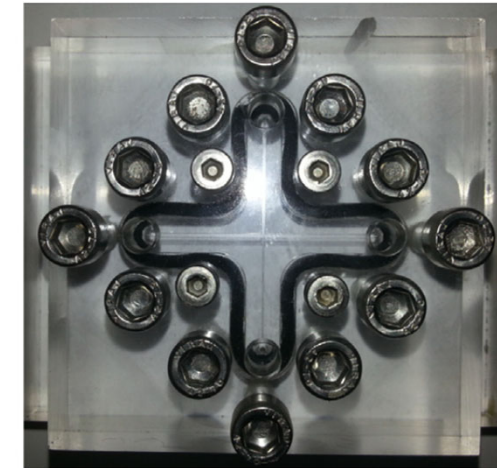
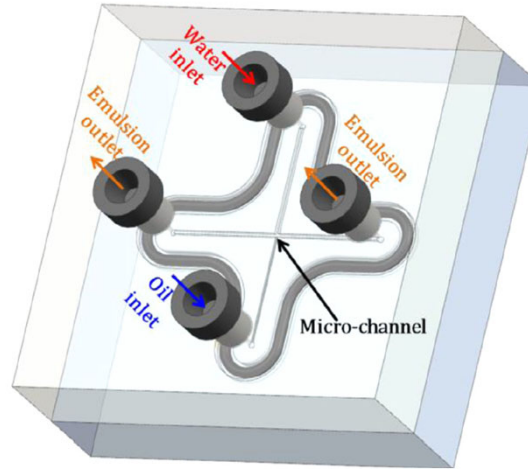
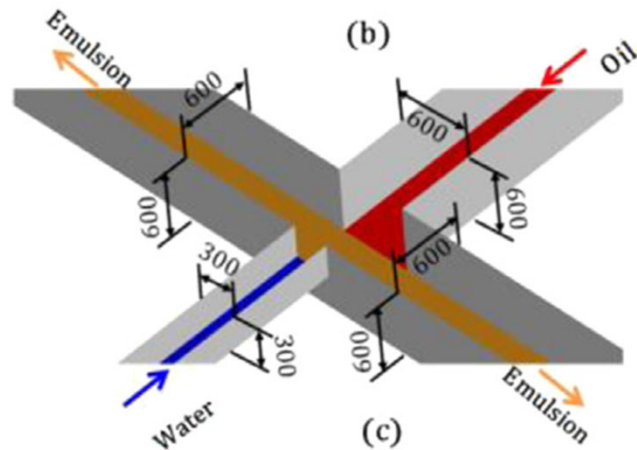


Microfluidic systems in CubeSats
Microfluidic chip

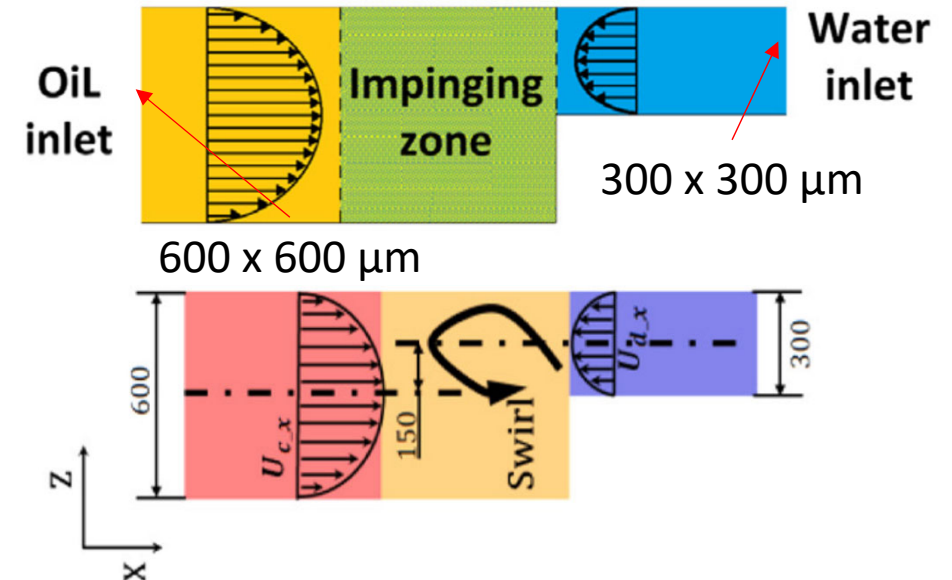


Ramjet microchannel cooling

Generation of micro suspensions liq/liq (W/O) in microchannels



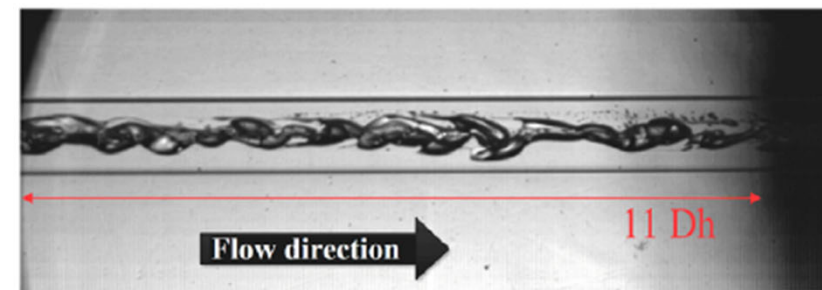
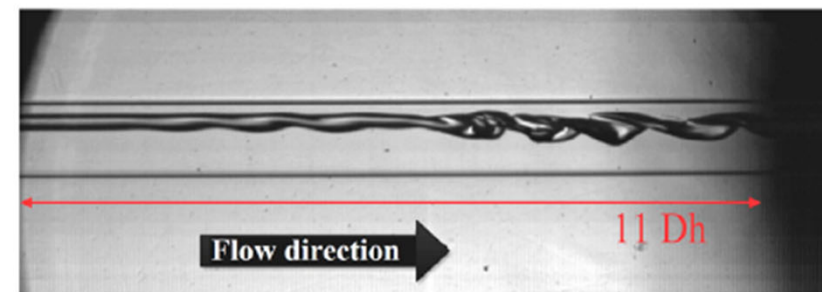
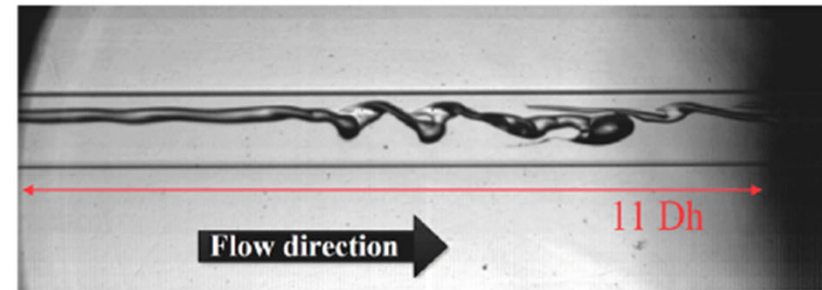
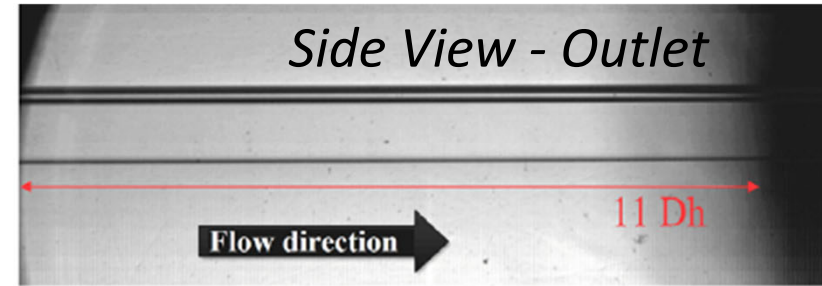
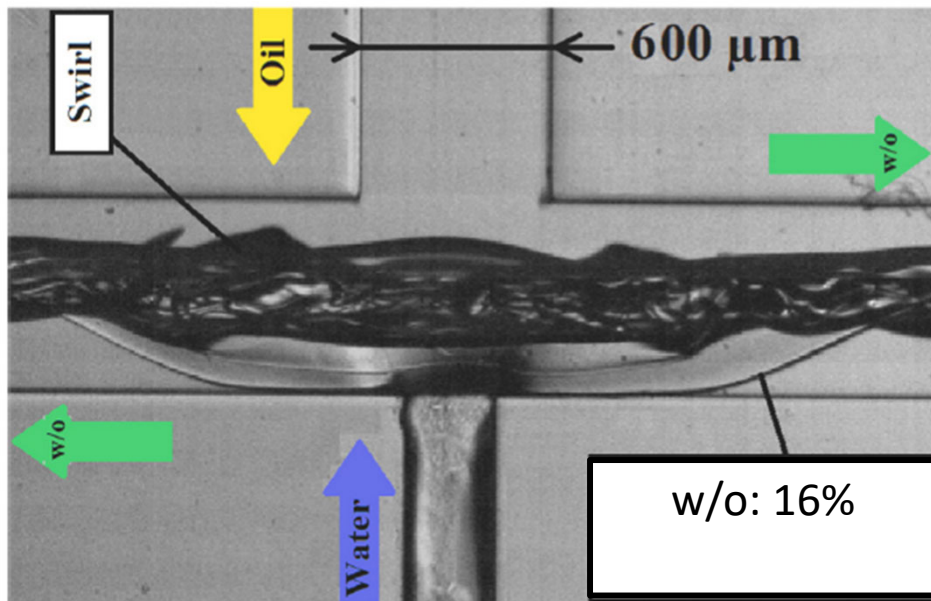
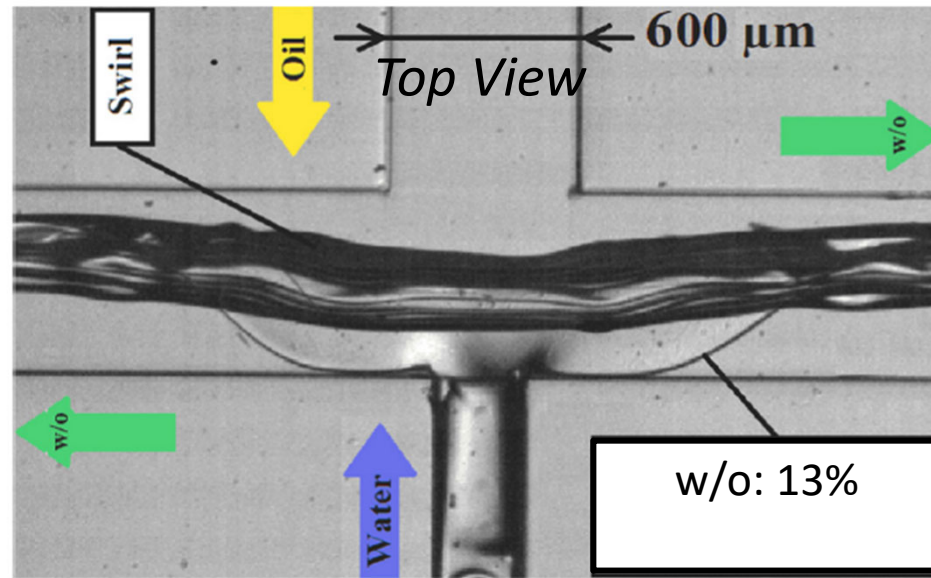
Property	Water	Oil
Density [kg/m ³]	998	865
Cp [J/kg*K]	4185,5	1820
Thermal Conductivity [W/m*K]	0,6	0,105
Viscosity [kg/m*s]	0,01	0,052
Molecular Weight [kg/kmol]	18,02	869,16



- Belkadi, A., Tarlet, D., Montillet, A., Bellettre, J., & Massoli, P. (2016). Study of two impinging flow microsystems arranged in series. Application to emulsified biofuel production. *Fuel*, 170, 185-196.

- Ji, Y., Bellettre, J., Montillet, A., & Massoli, P. (2020). Fast oil-in-water emulsification in microchannel using head-on impinging configuration: Effect of swirl motion. *International Journal of Multiphase Flow*, 131, 103402.

Emulsification of water-in-oil (W/O) in microchannels: effect of dilution ratio



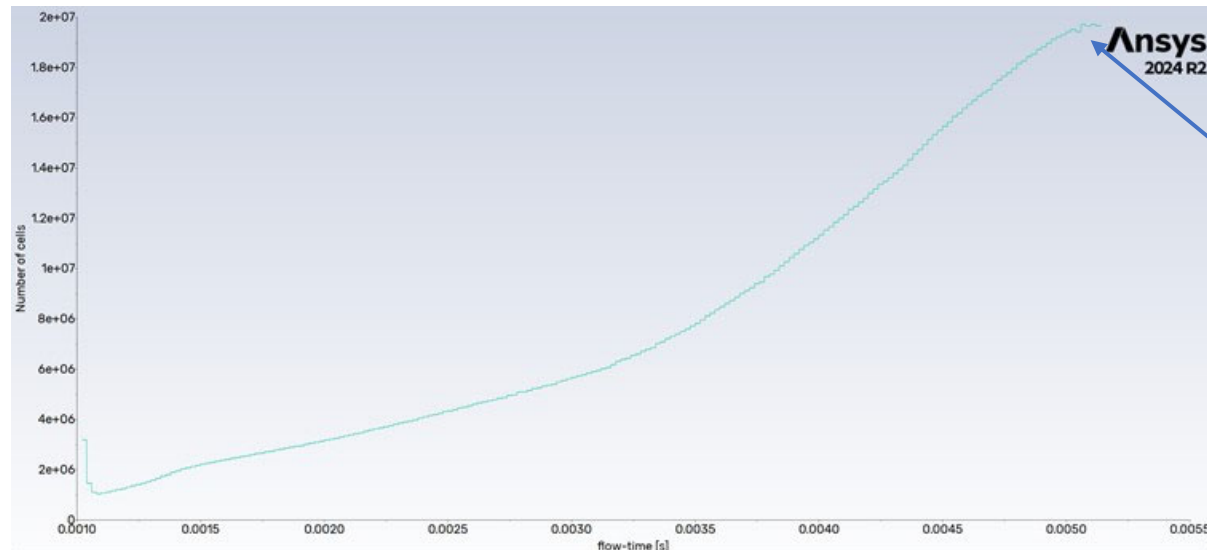
Emulsification of water-in-oil (W/O) in microchannels: CFD Simulation – model definition

Software: ANSYS Fluent 2024 R2

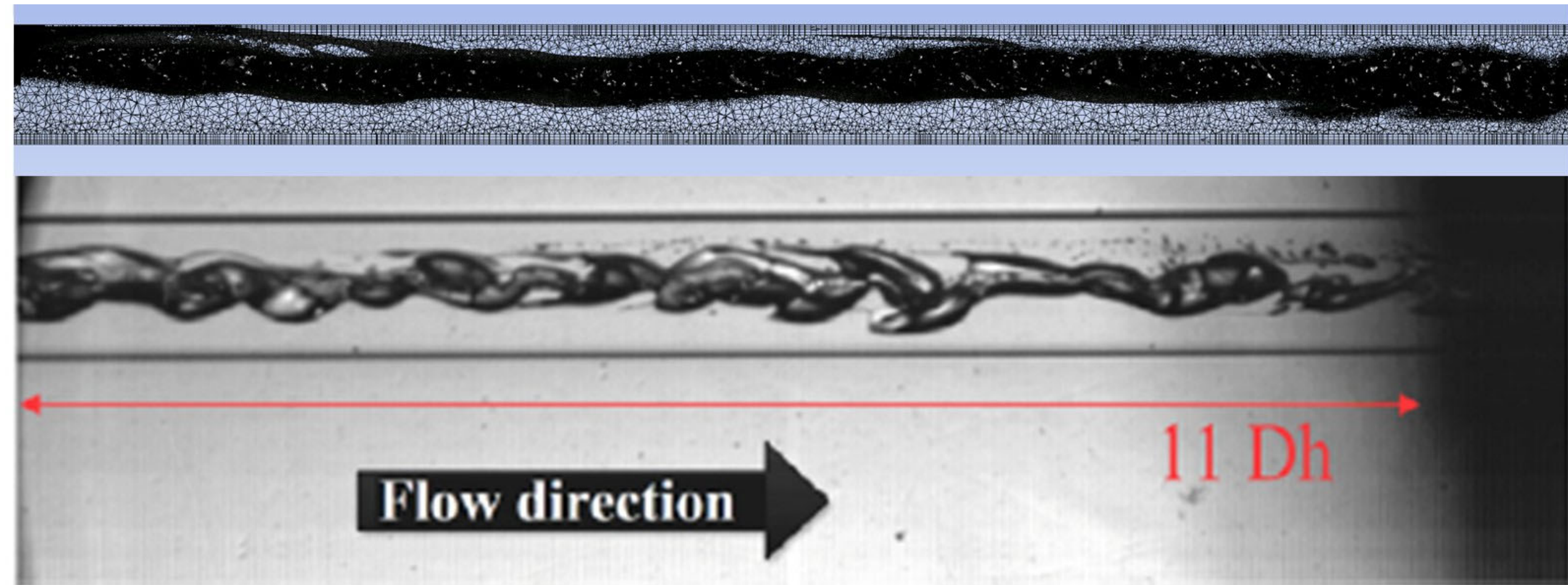
Unsteady simulation – Timestep **1 μ s**

Volume of Fluid (**VOF**) method; turbulence model: $k - \omega$ SST

Type of mesh	Mean Cell dimension	Boundary Layer	Number of cells
Starting mesh	25 μ m	5 layers on 60 μ m	$1.08 \cdot 10^6$
Adaptive Mesh Refinement	Refinement – Phase Oil Volume Fraction Higher than 0.06		



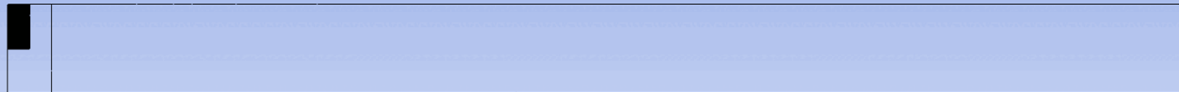
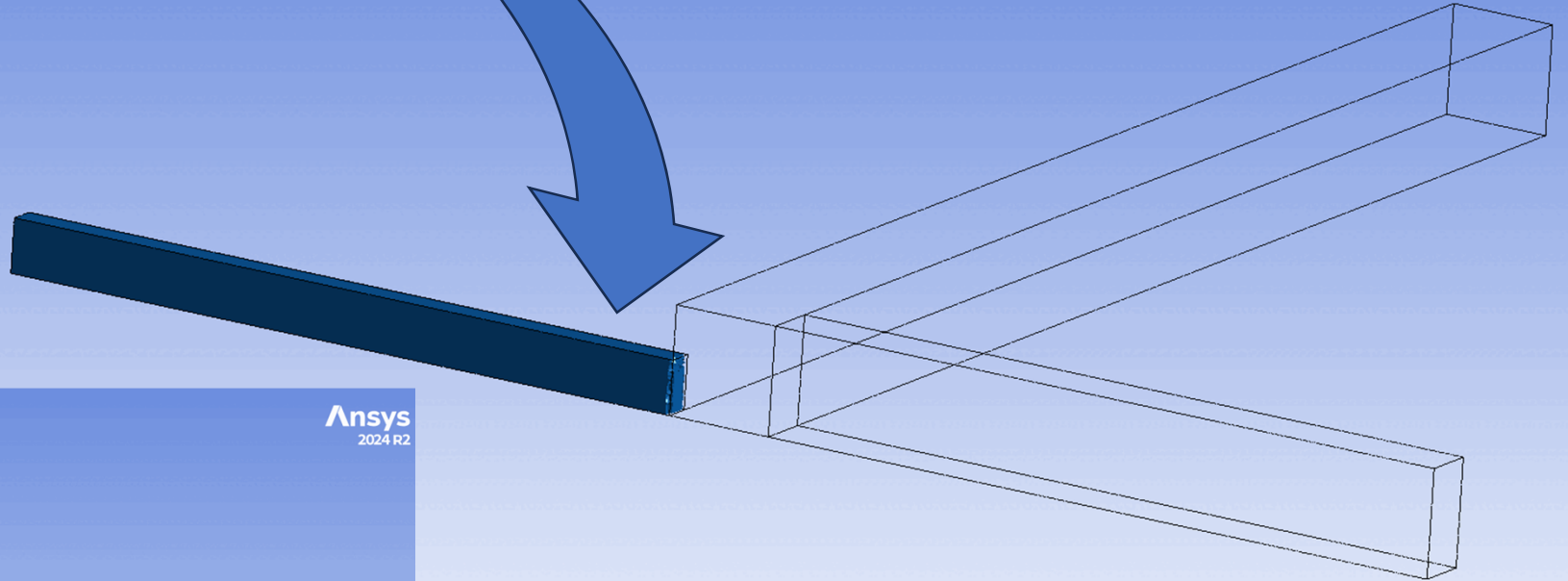
Emulsification of water-in-oil (W/O) in microchannels: Results of CFD simulations



Side View - Outlet

w/o: 22,5%

Emulsification of water-in-oil (W/O) in microchannels: Results of CFD simulations



0 0.001 0.002 (m)
0.0005 0.0015

0 0.001 0.002 (m)
0.0005 0.0015



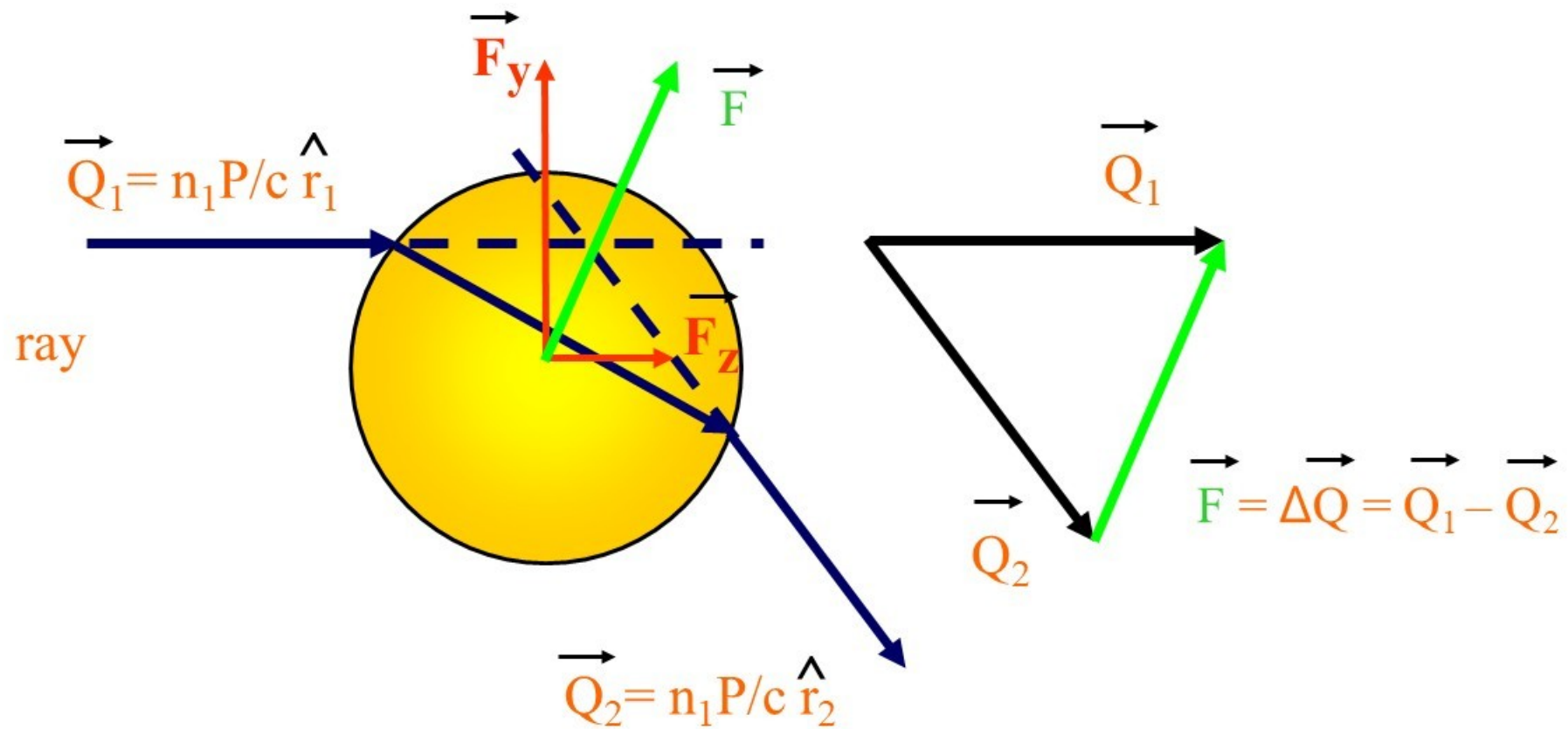
Isovolume – water in oil
Time: 0 → 5 ms
w/o: 22,5%

- **New combustion technologies**
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The Tractor Beam: science or fiction?

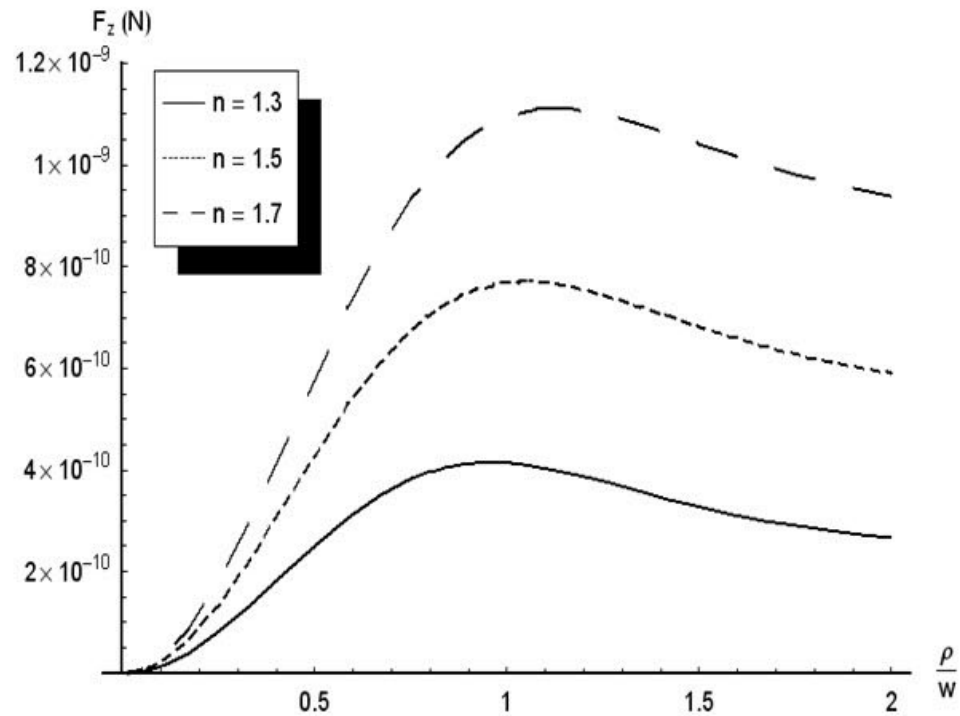


Momentum vector analysis

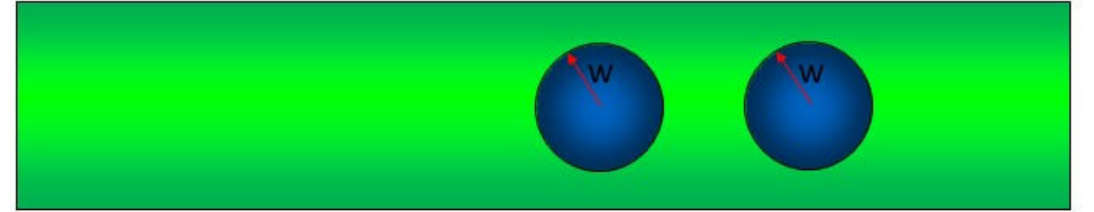
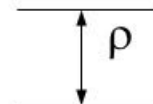
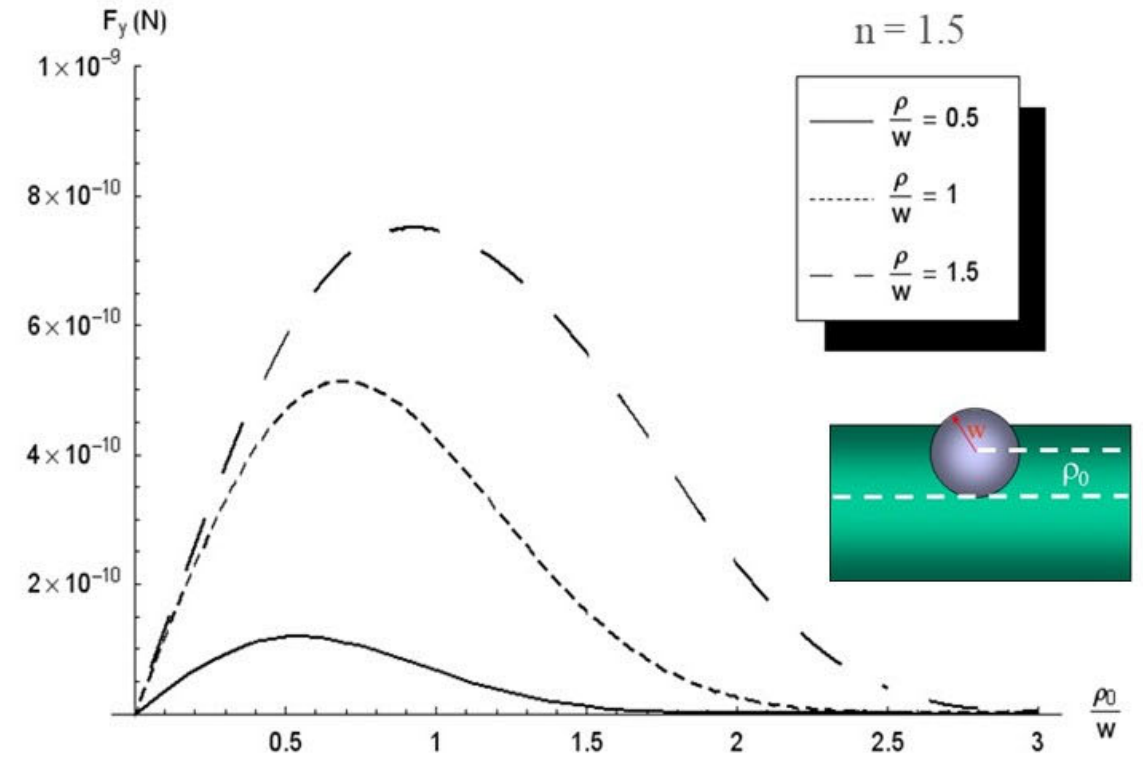


The Tractor Beam: forces analysis

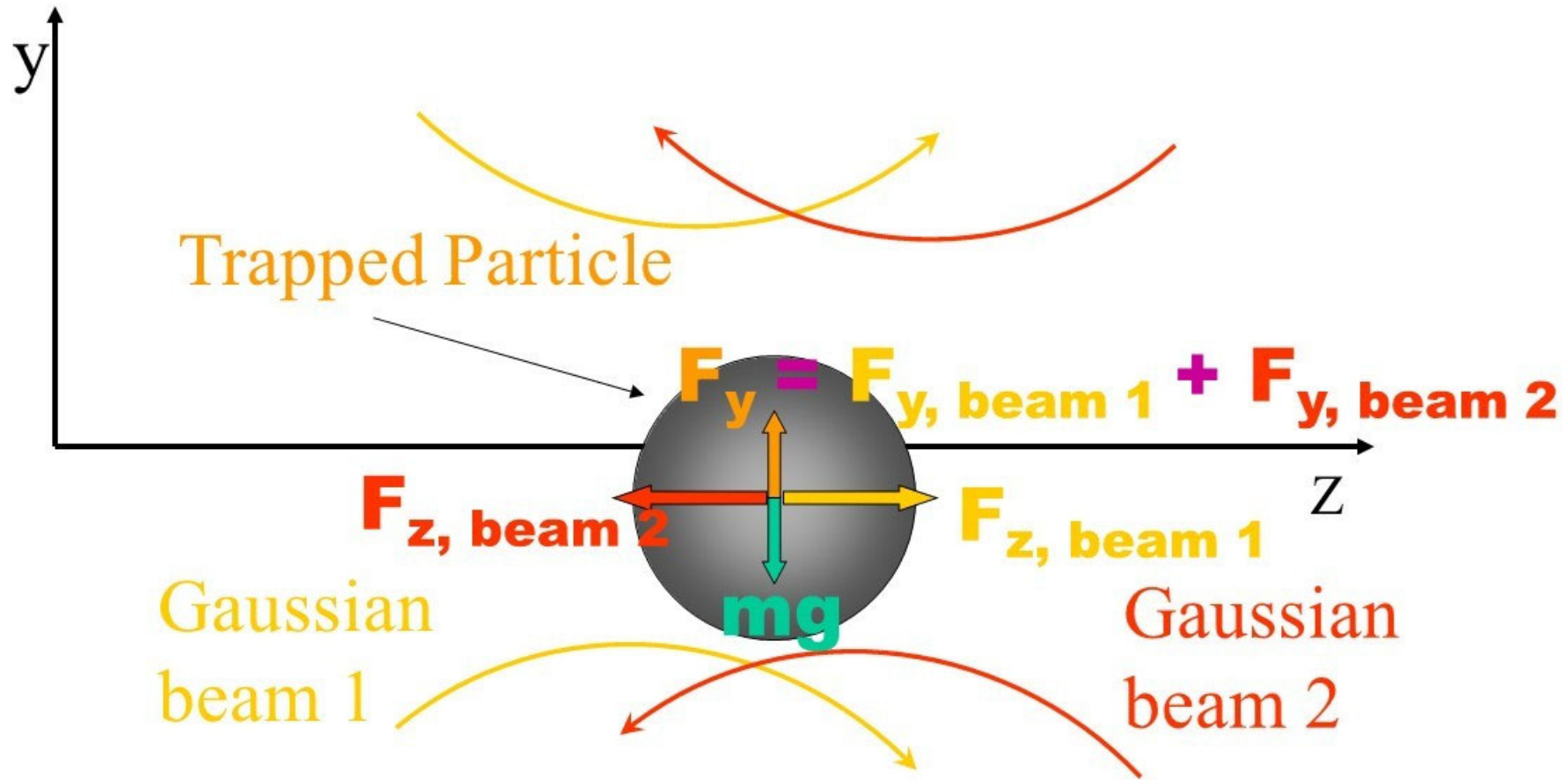
Longitudinal Force: a pushing force



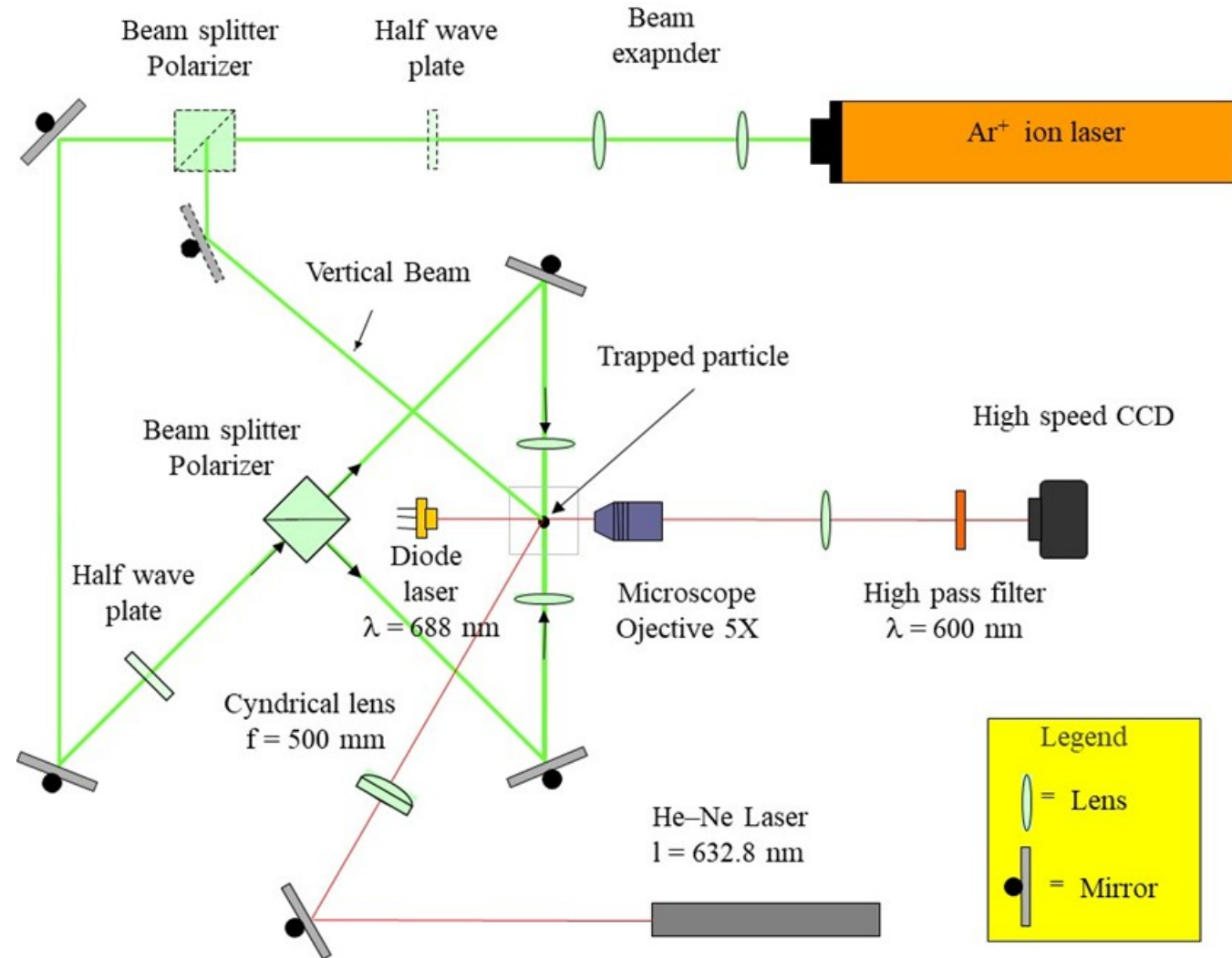
Transversal Force: a restoring force

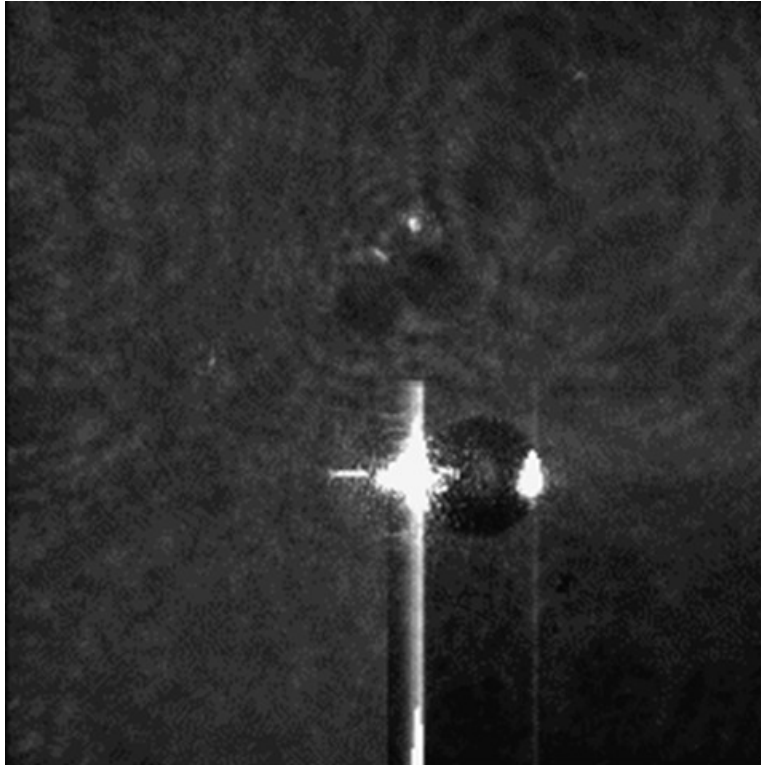


Optical Tweezers: 2 beams forces analysis

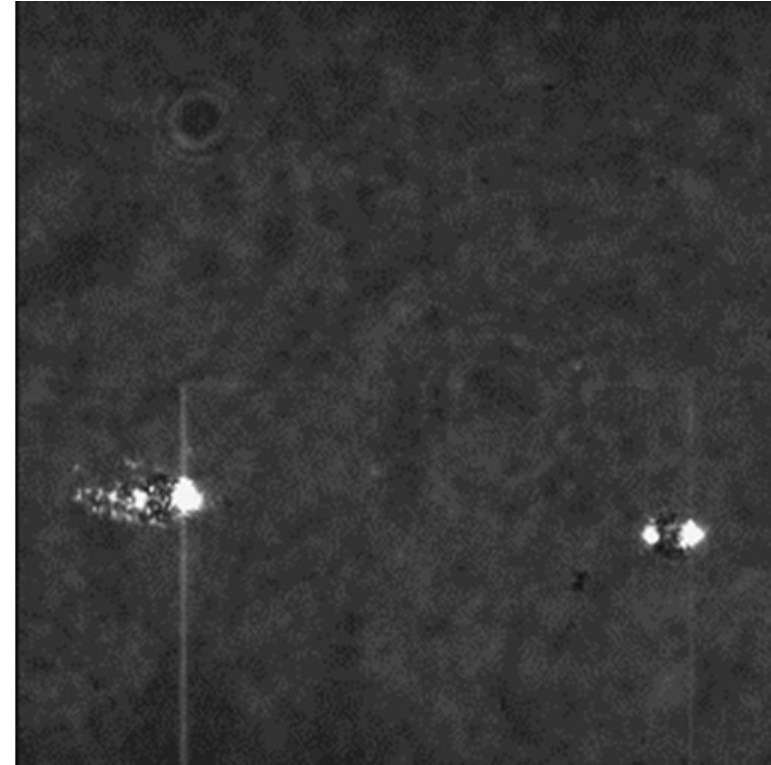


Optical Tweezers : experimental system





Particle of 90 μm trapped in the optical tweezers



Two particles of 20 μm simultaneously trapped in the optical tweezers

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Pietro Capaldi, STEMS-CNR

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Thank you for your attention

...really it is the end !