Plant gas exchange mechanistic modeling taking into account multiple timeframes and gravity levels

Lucie Poulet[1],

Gioia Massa[2], Raymond Wheeler[2], Claude-Gilles Dussap[3]

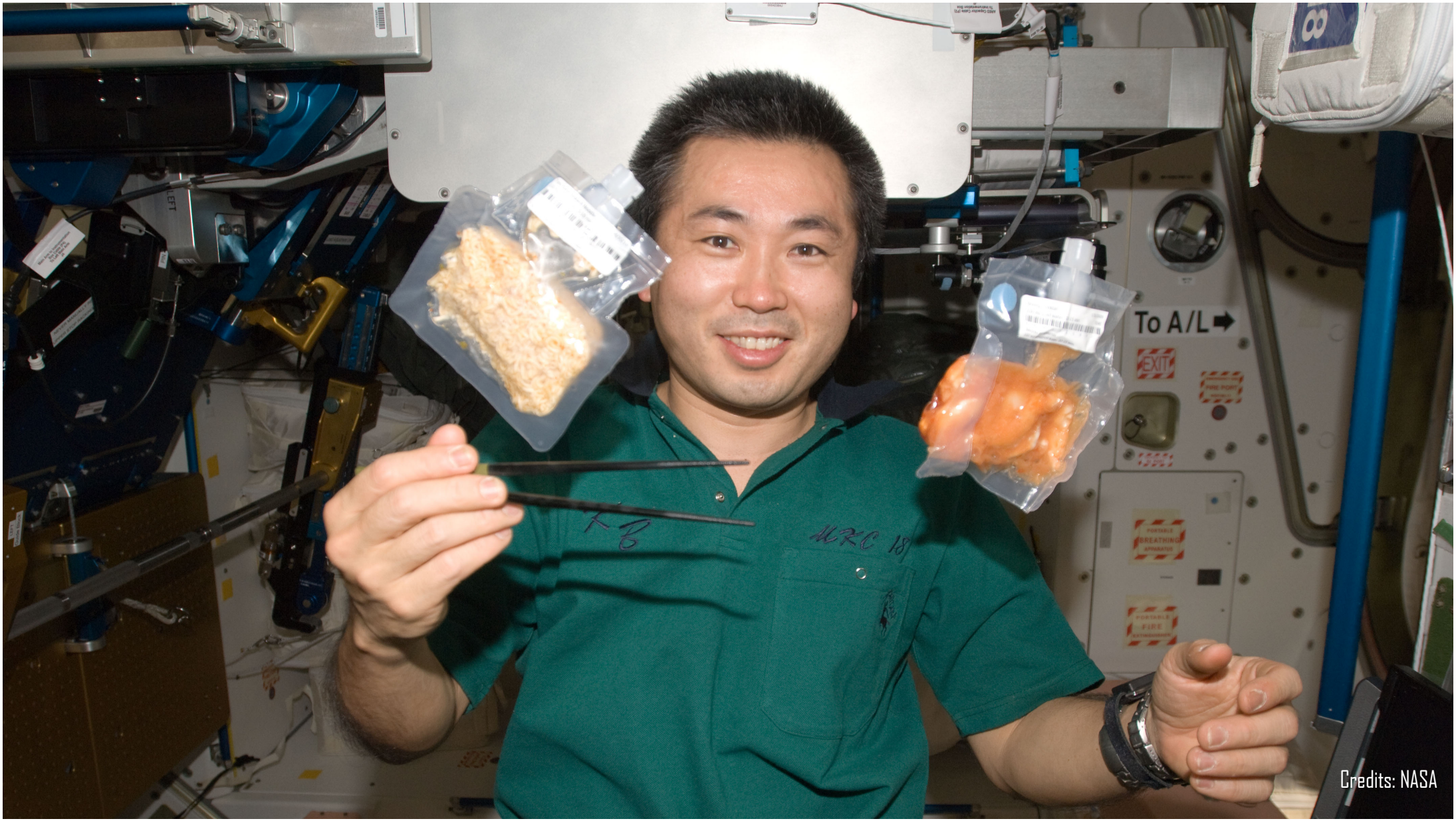
[1]NASA Postdoctoral Program, [2]NASA Kennedy Space Center, [3]University Clermont Auvergne

MELiSSA Conference - Edible Biomass Production

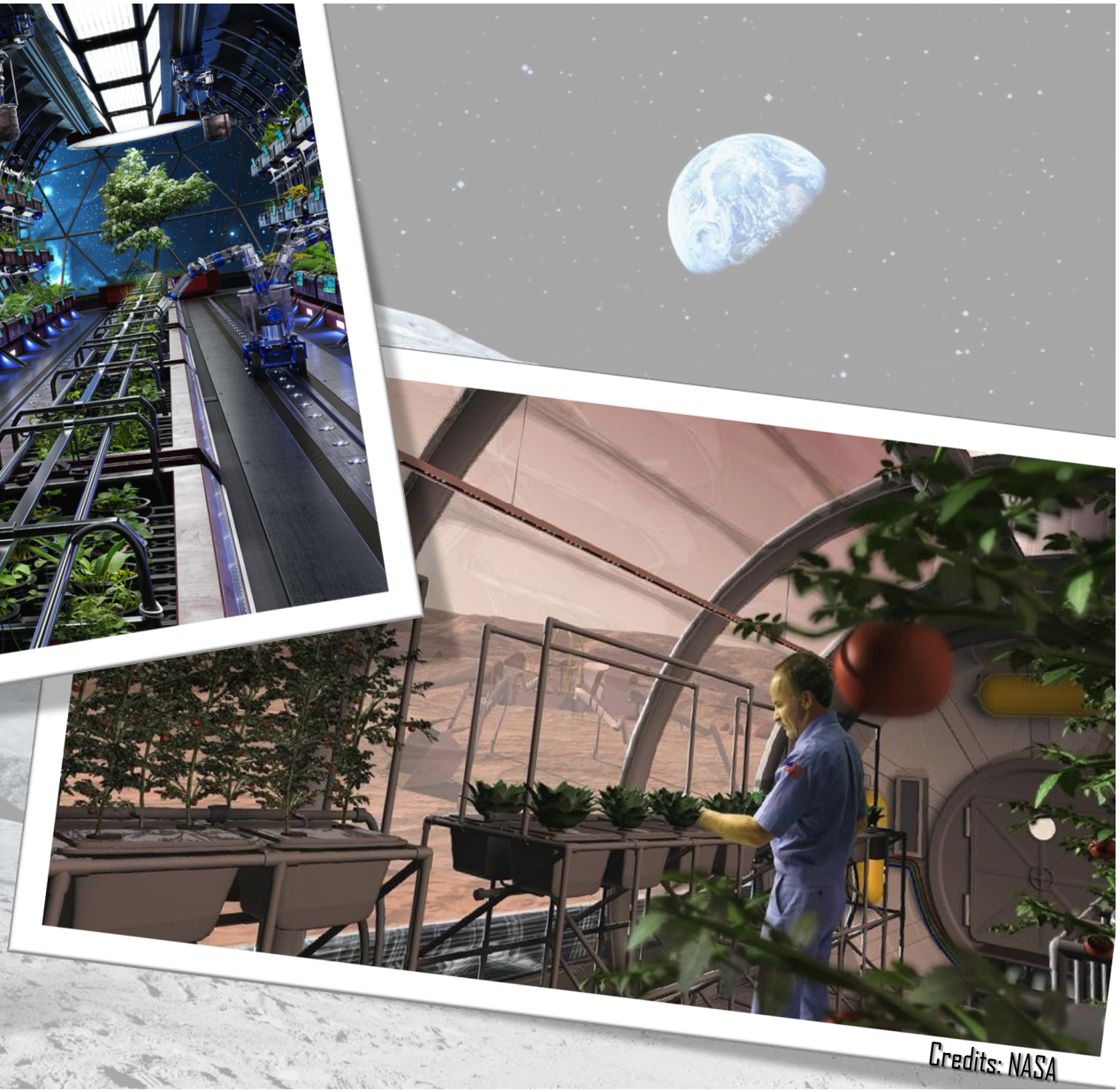
November 3rd 2020


SPACE PLANT BIOLOGY
Veggie
Food Production and Astronaut Nutrition
SPACE PLANT BIOLOGY
APH
ADVANCED PLANT HABITAT
Large Plant Research Facility
Credits: NASA

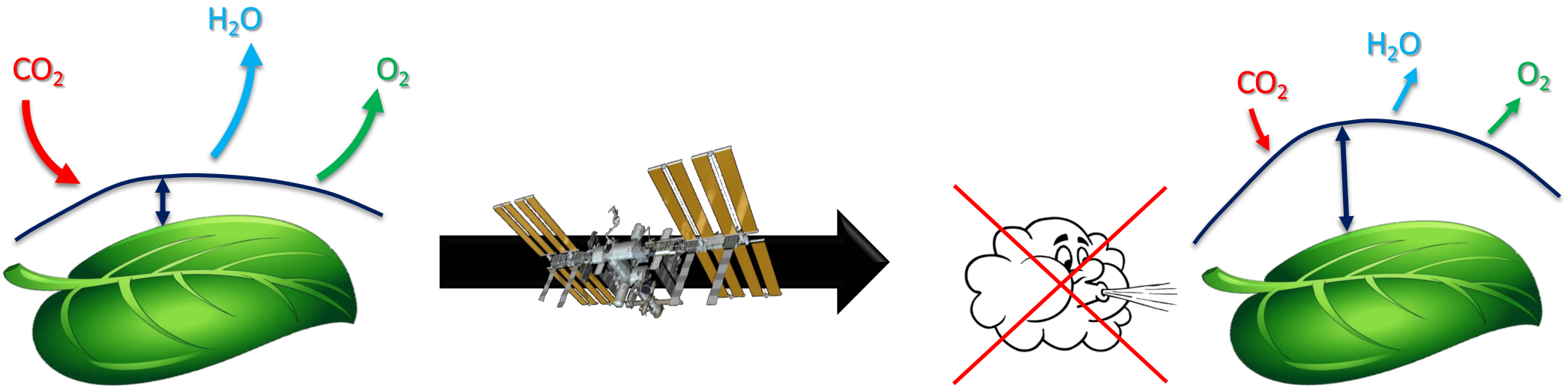

Credits: NASA

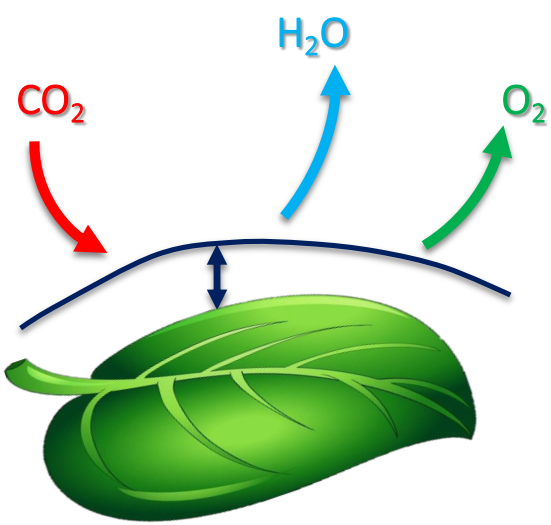

To A/L
EXIT
Credits: NASA

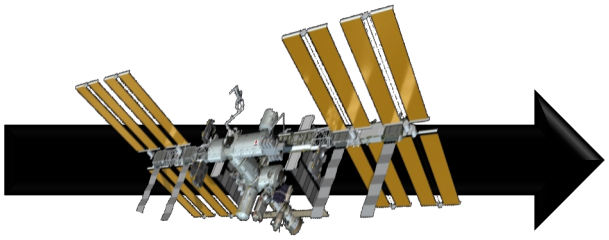
Credits: Kenji Aito

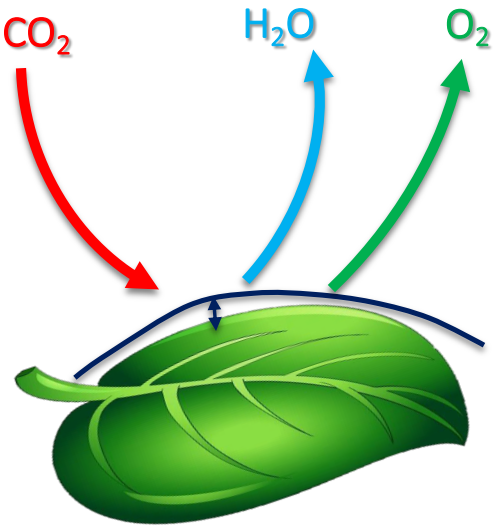


Credits: NASA

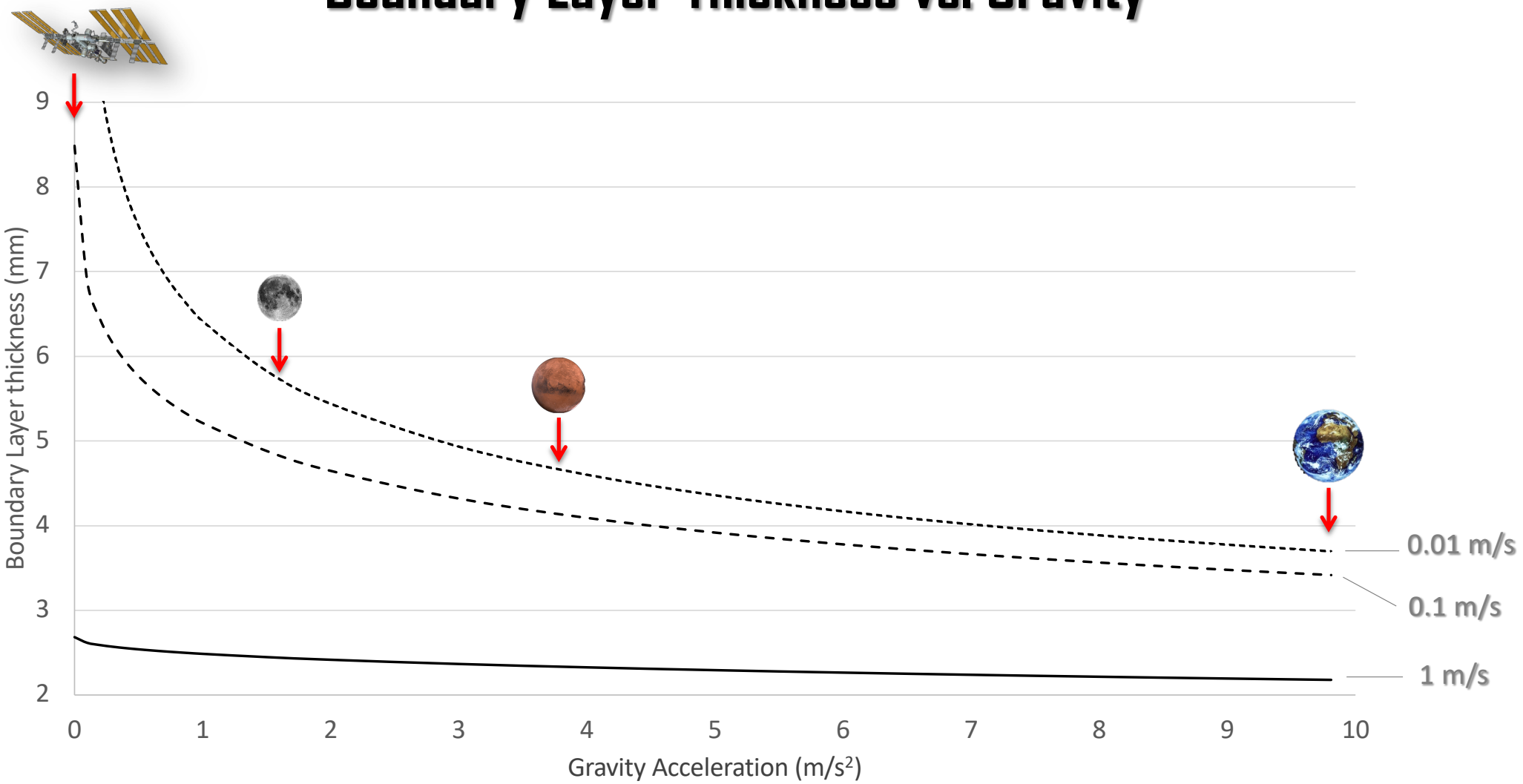

CO_2
H_2O
O_2
CO_2
H_2O
O_2

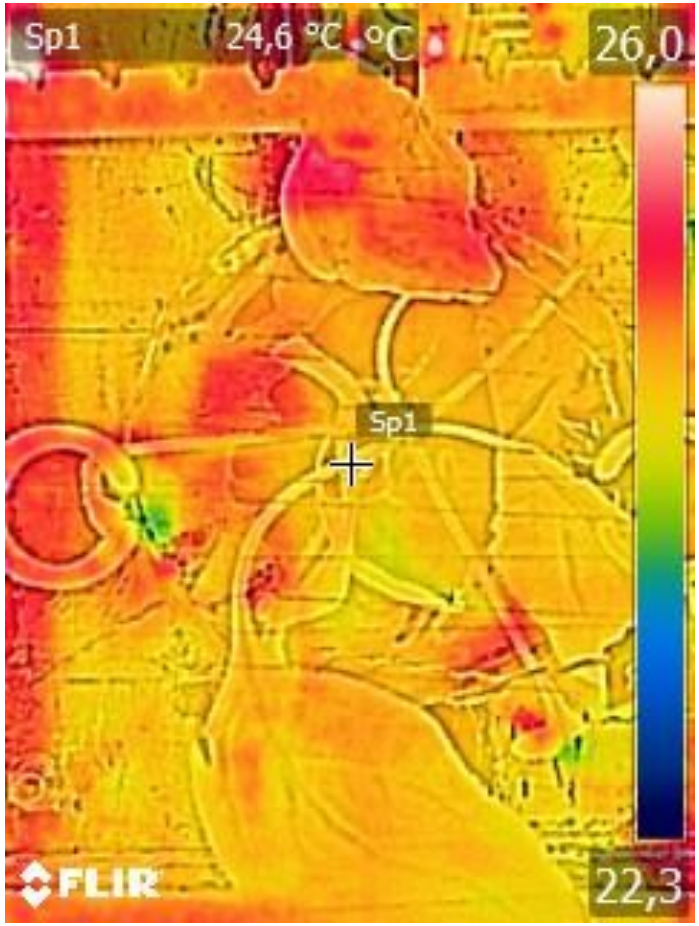

CO_2
H_2O
O_2



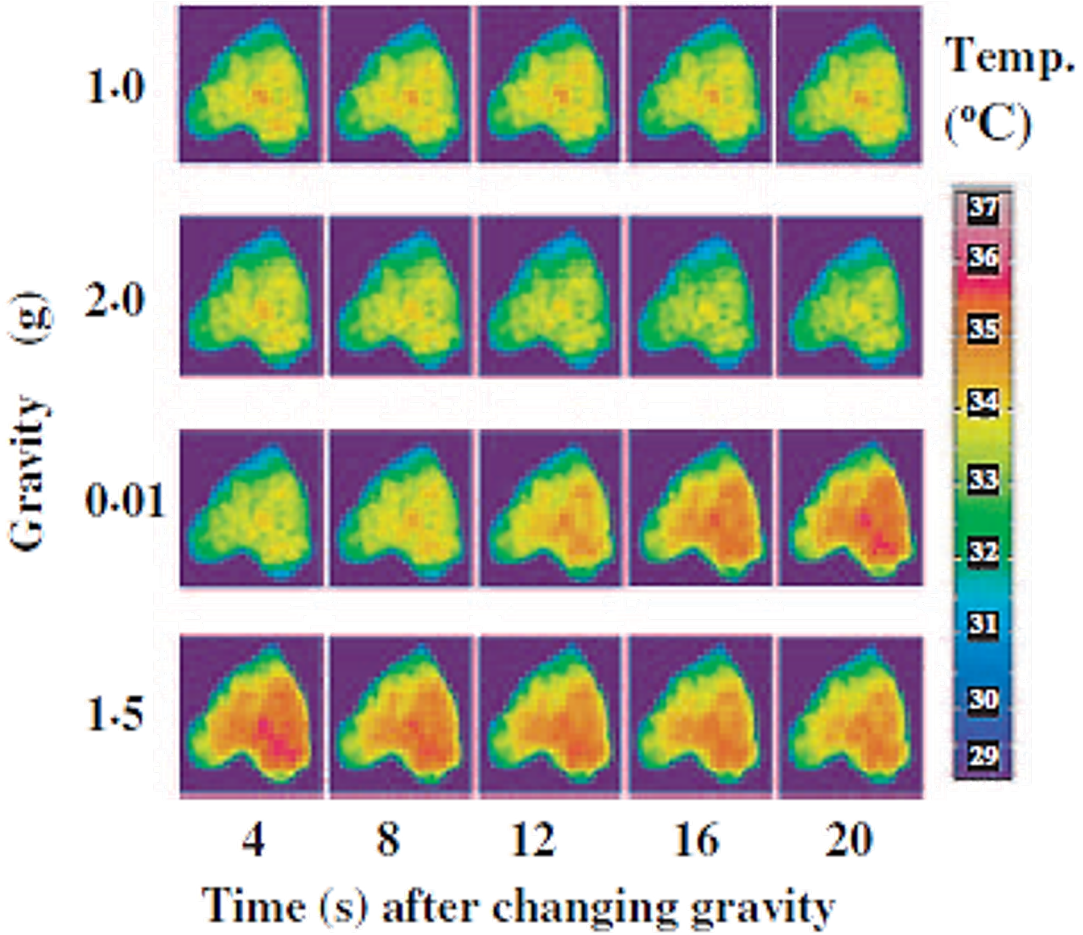

CO_2
H_2O
O_2

Boundary Layer Thickness vs. Gravity





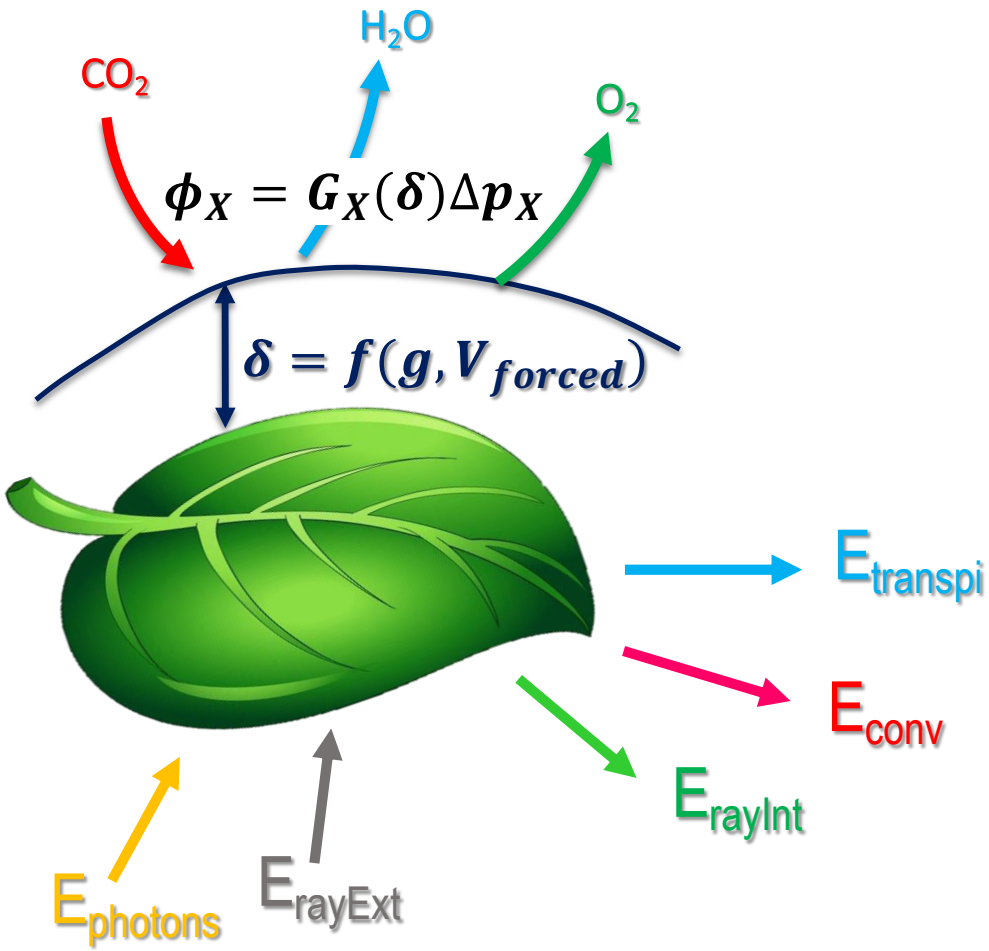
Poulet, Vernay, Sharif, Kondyli, CNES Parabolic Flight Campaign 2017 (unpublished)



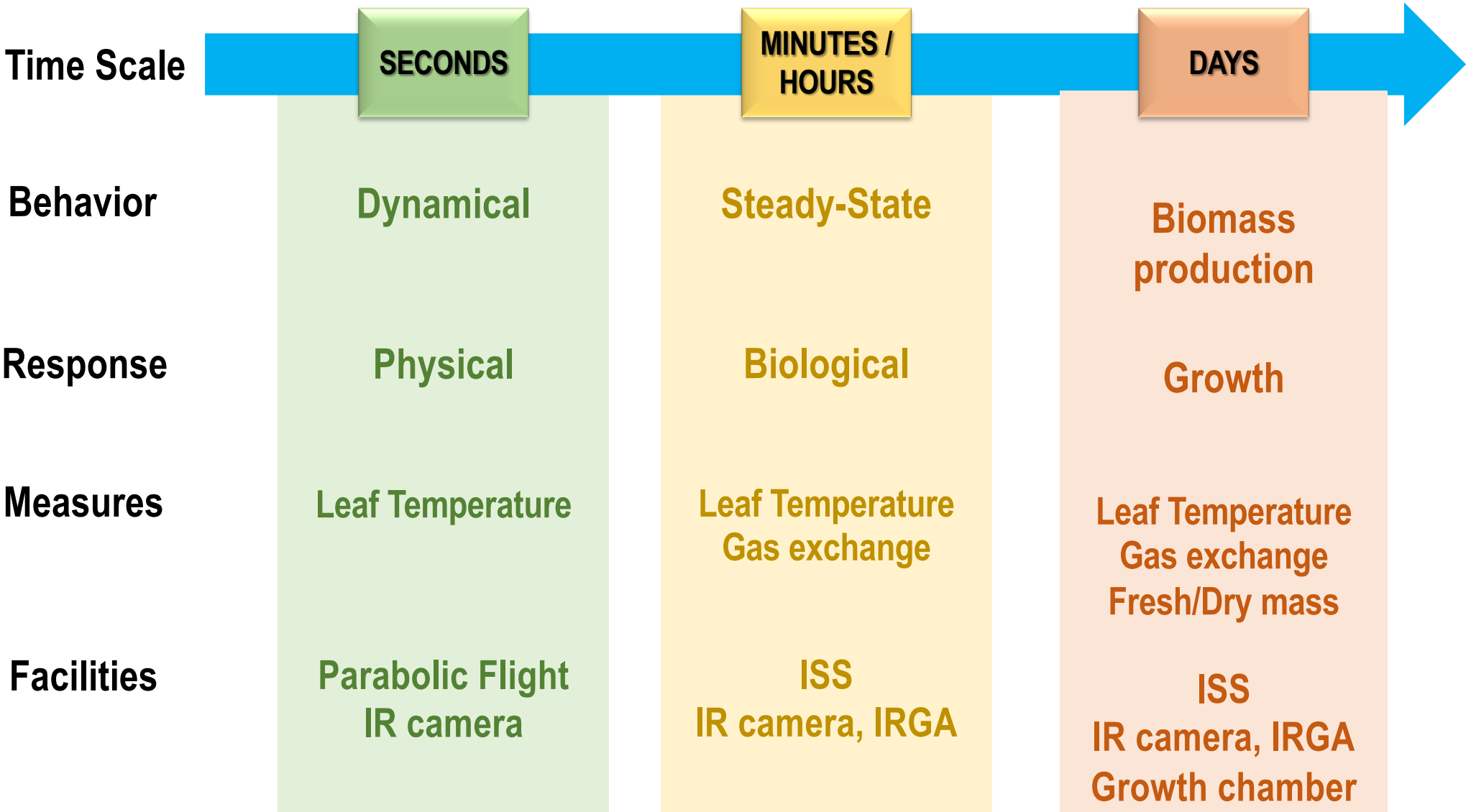
Kitaya et al., The effect of gravity on surface temperatures of plant leaves, Plant, Cell and Environment, (2003), 26, 497–503.

Mass Balance

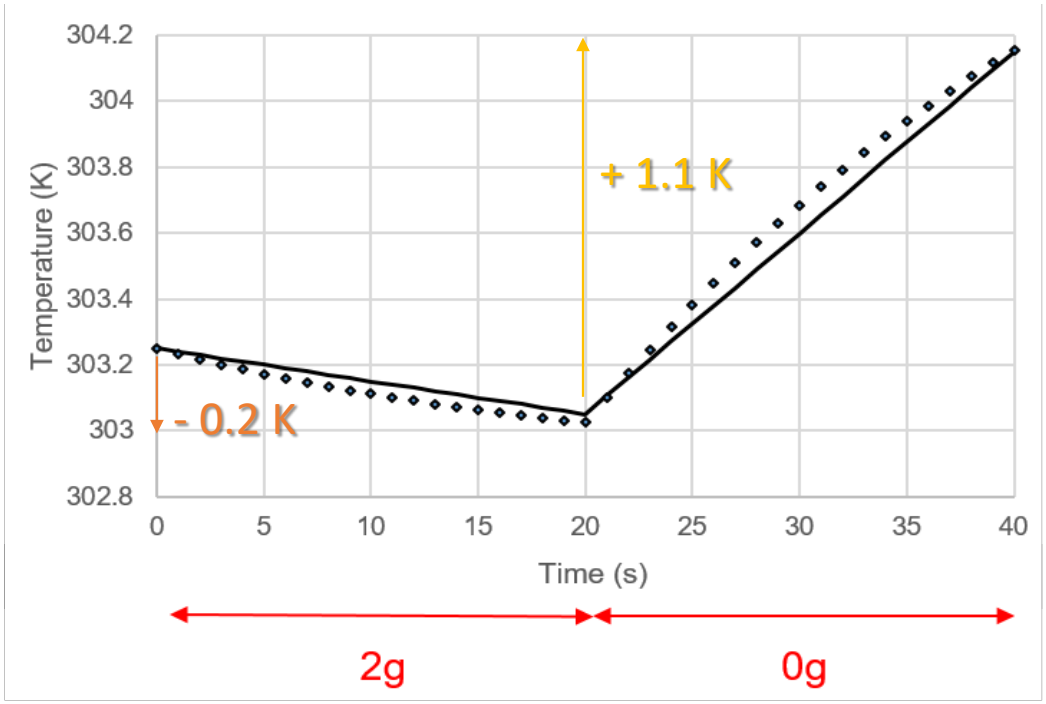
Energy Balance



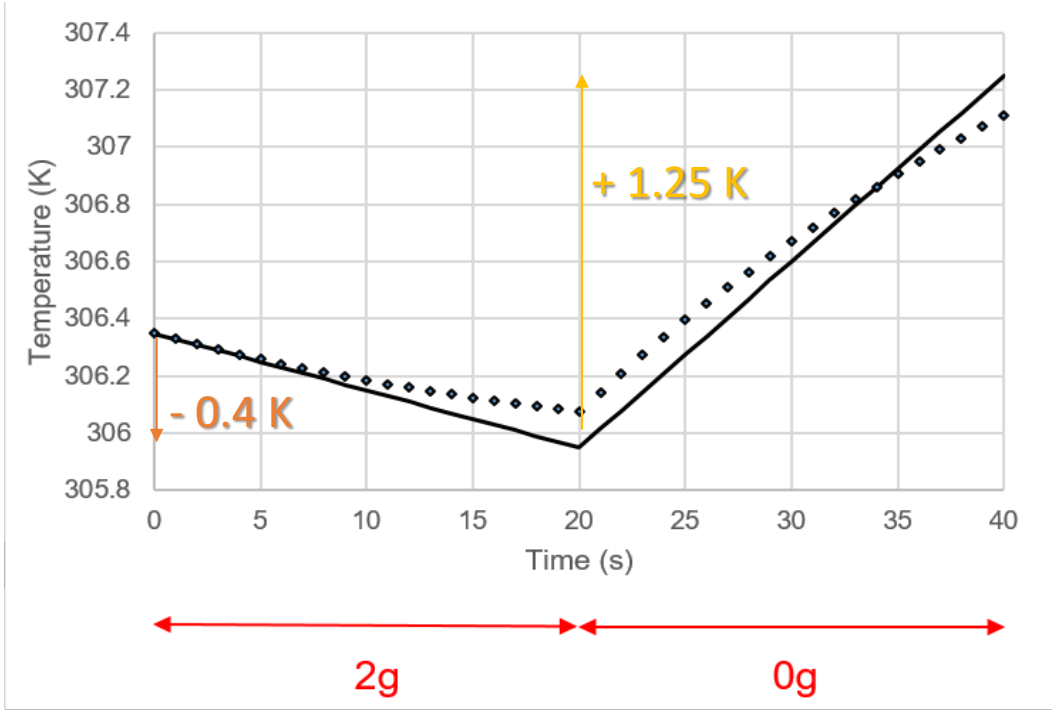
$$T_{leaf} = f(\phi_{H_2O}, m_{H_2O}, I_0, \delta)$$


Time Scale
SECONDS
MINUTES / HOURS
DAYS
Behavior
Dynamical
Steady-State
Biomass production
Response
Physical
Biological
Growth
Measures
Leaf Temperature
Leaf Temperature
Gas exchange
Leaf Temperature
Gas exchange
Fresh/Dry mass
Facilities
Parabolic Flight
IR camera
ISS
IR camera, IRGA
ISS
IR camera, IRGA
Growth chamber

Validation in short-term: leaf temperature at 0.2 m/s



Barley



Sweet Potato

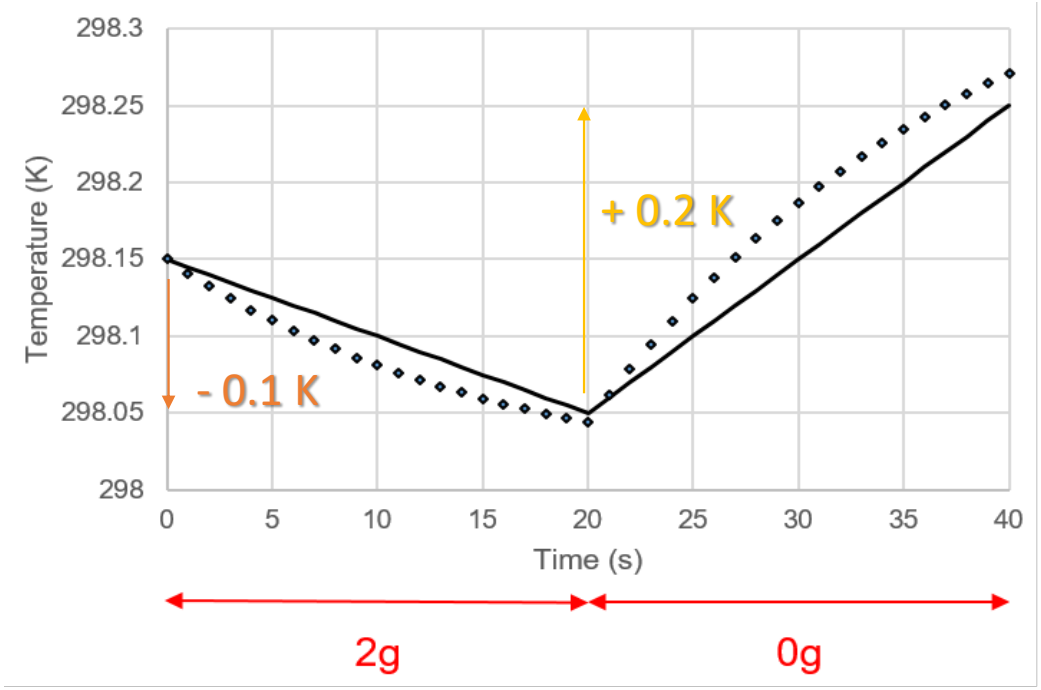
Model

Experimental*

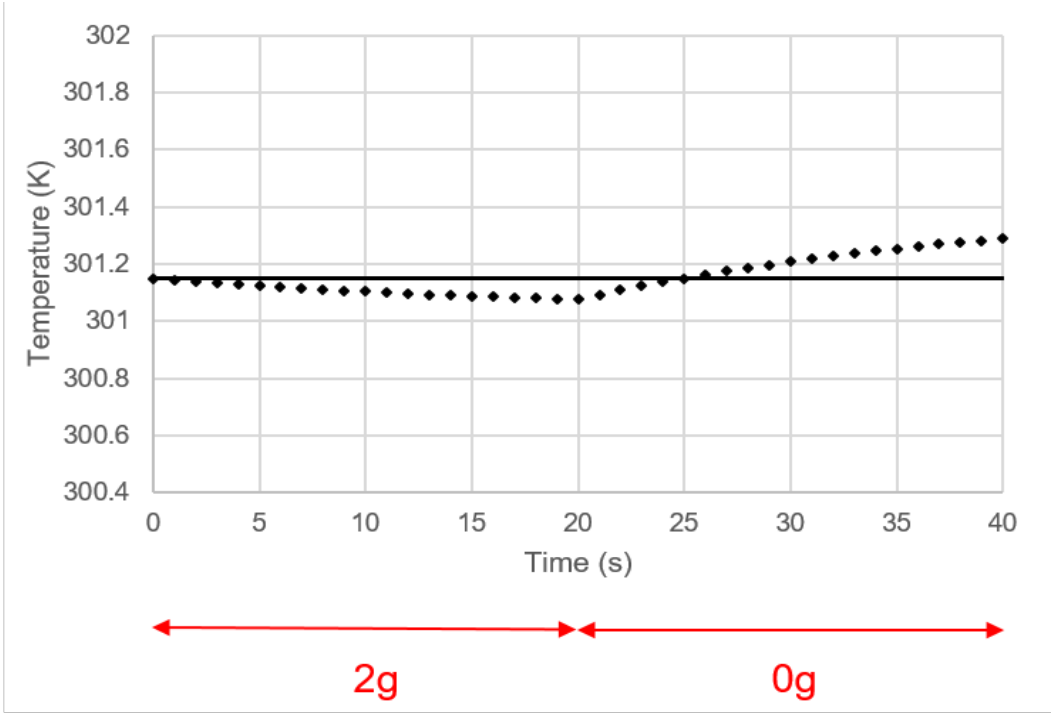
* Referencing data: Y. Kitaya, M. Kawai, J. Tsuruyama, H. Takahashi, A. Tani, E. Goto, T. Saito, M. Kiyota, The effect of gravity on surface temperatures of plant leaves, Plant Cell Environ. 26 (4) (2003) 497–503

Poulet L, Dussap C-G & Fontaine J-P. Development of a mechanistic model of leaf surface gas exchange coupling mass and energy balances for life-support systems applications. Acta Astronautica,175:517-530, 2020

Validation in short-term: leaf temperature at 1 m/s



Barley



Sweet Potato

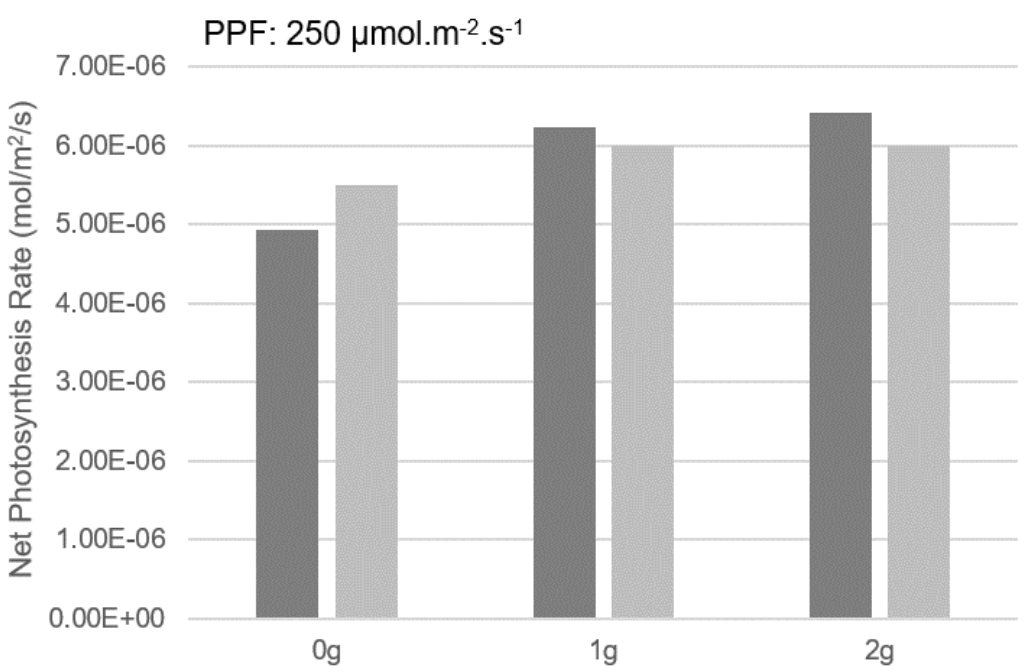
Model

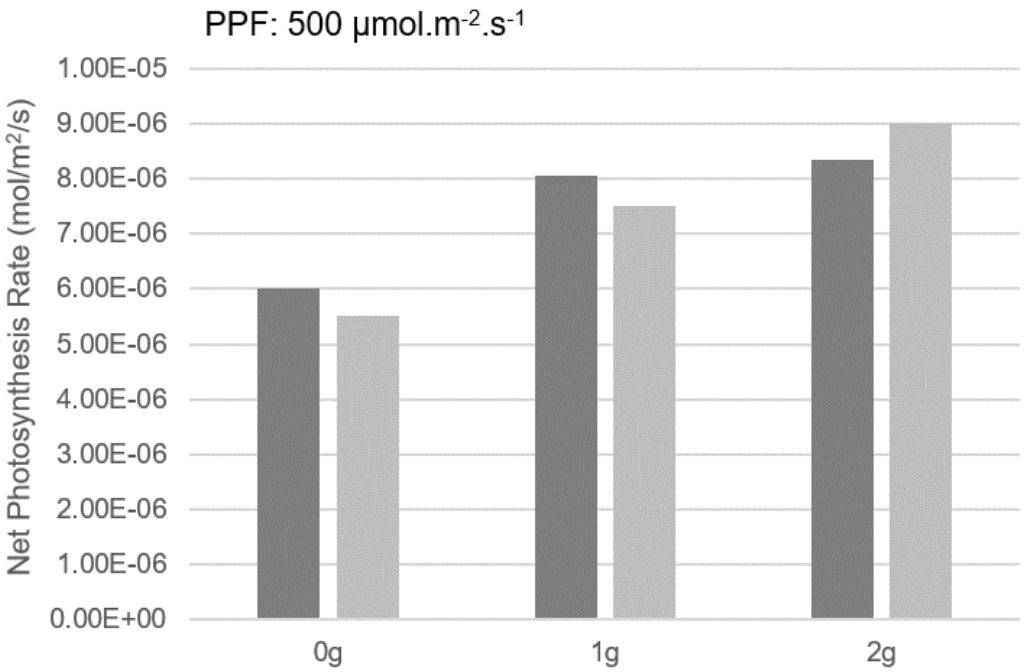
Experimental*

* Referencing data: Y. Kitaya, M. Kawai, J. Tsuruyama, H. Takahashi, A. Tani, E. Goto, T. Saito, M. Kiyota, The effect of gravity on surface temperatures of plant leaves, Plant Cell Environ. 26 (4) (2003) 497–503

Poulet L, Dussap C-G & Fontaine J-P. Development of a mechanistic model of leaf surface gas exchange coupling mass and energy balances for life-support systems applications. Acta Astronautica,175:517-530, 2020

Validation in short-term: photosynthesis





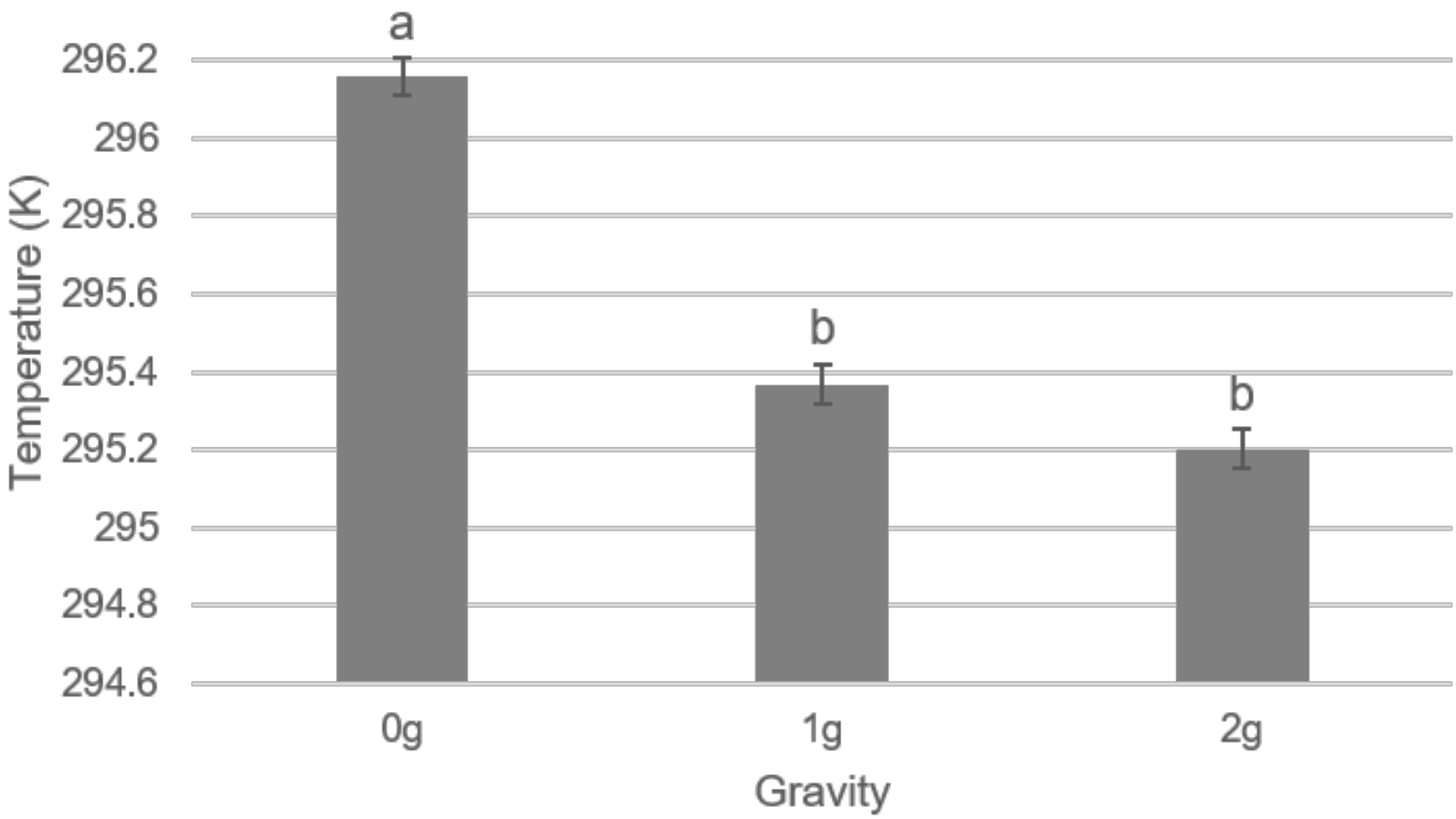
Model

Experimental*

* Referencing data: Y. Kitaya, M. Kawai, J. Tsuruyama, H. Takahashi, A. Tani, E. Goto, T. Saito, M. Kiyota, The effect of gravity on surface temperatures of plant leaves, Plant Cell Environ. 26 (4) (2003) 497–503

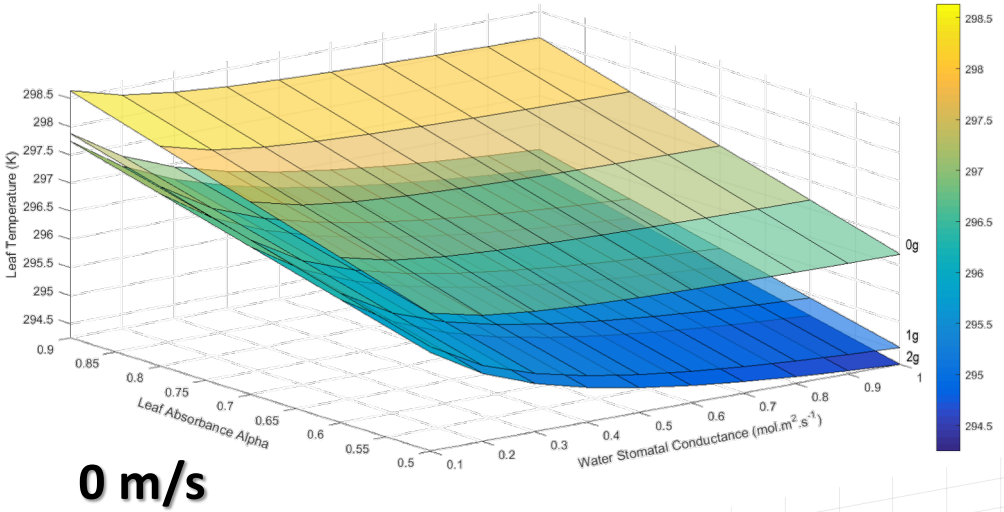
Poulet L, Dussap C-G & Fontaine J-P. Development of a mechanistic model of leaf surface gas exchange coupling mass and energy balances for life-support systems applications. Acta Astronautica,175:517-530, 2020

Gravity influence on leaf surface temperature after 20 s

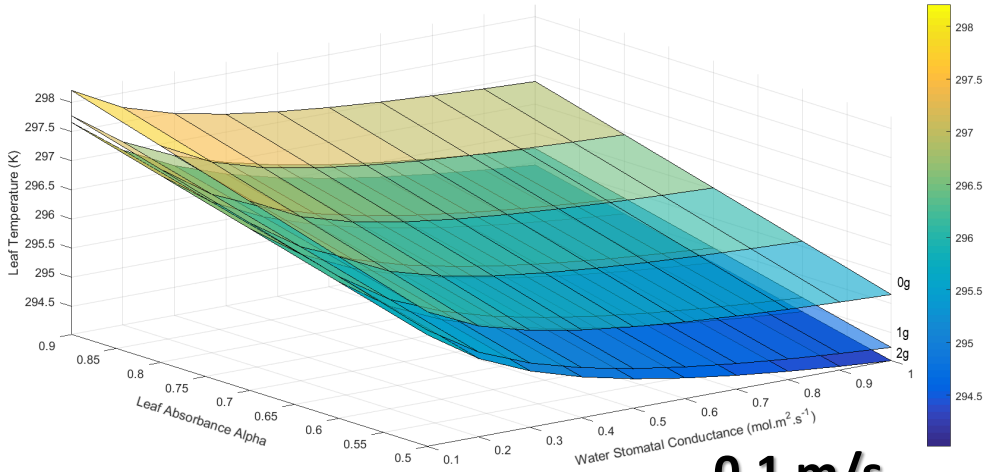


Poulet L, Dussap C-G & Fontaine J-P. Development of a mechanistic model of leaf surface gas exchange coupling mass and energy balances for life-support systems applications. Acta Astronautica,175:517-530, 2020

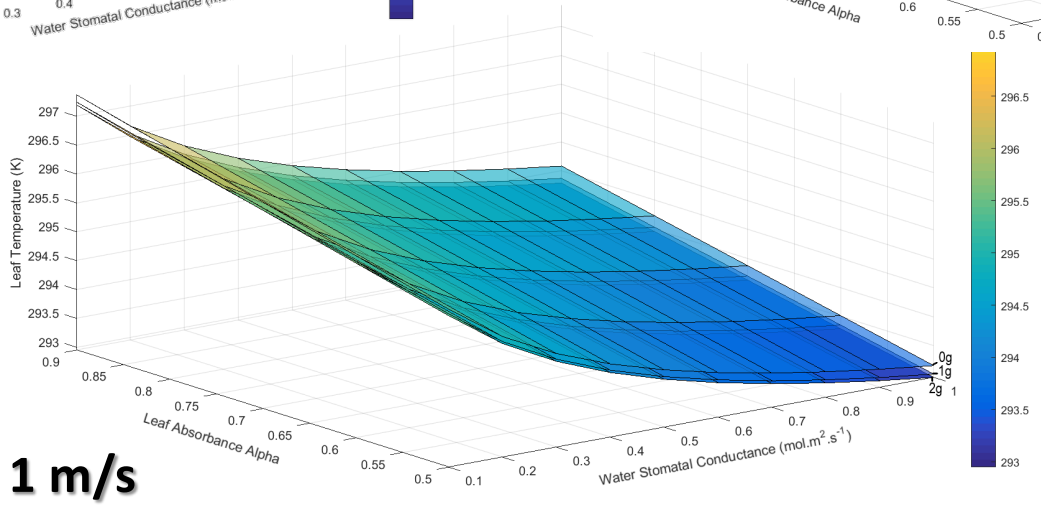
Leaf absorbance and stomatal conductance influence on leaf surface temperature after 20 s



0 m/s



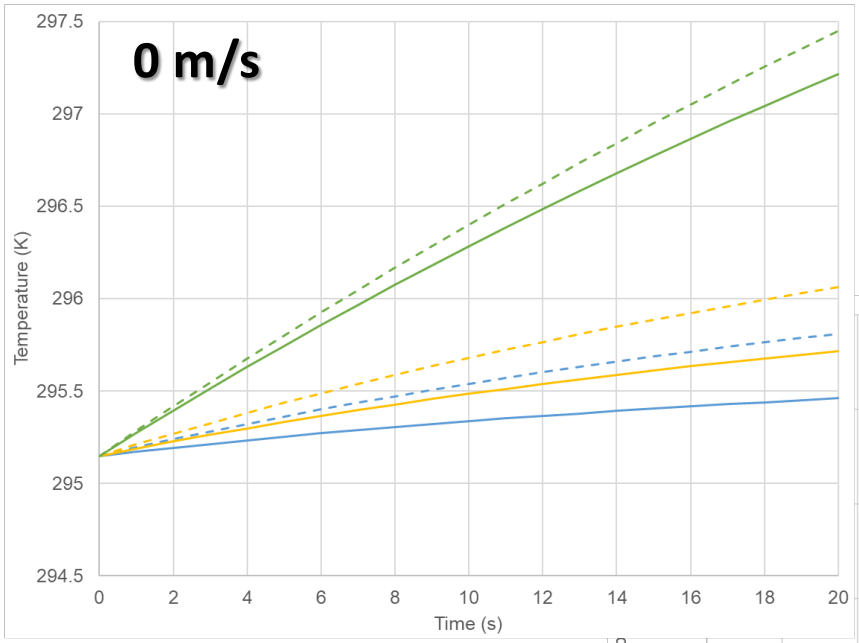
0.1 m/s

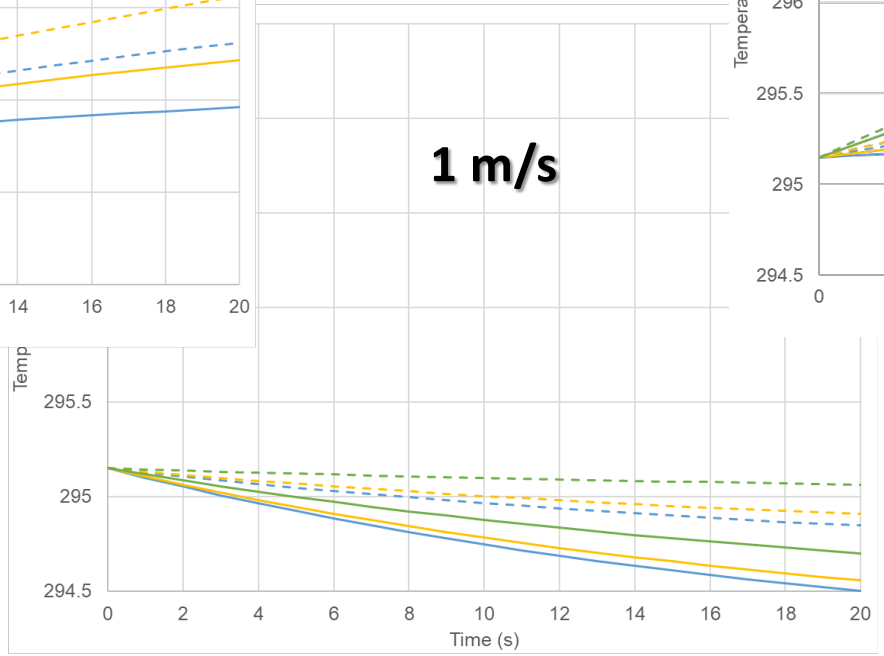


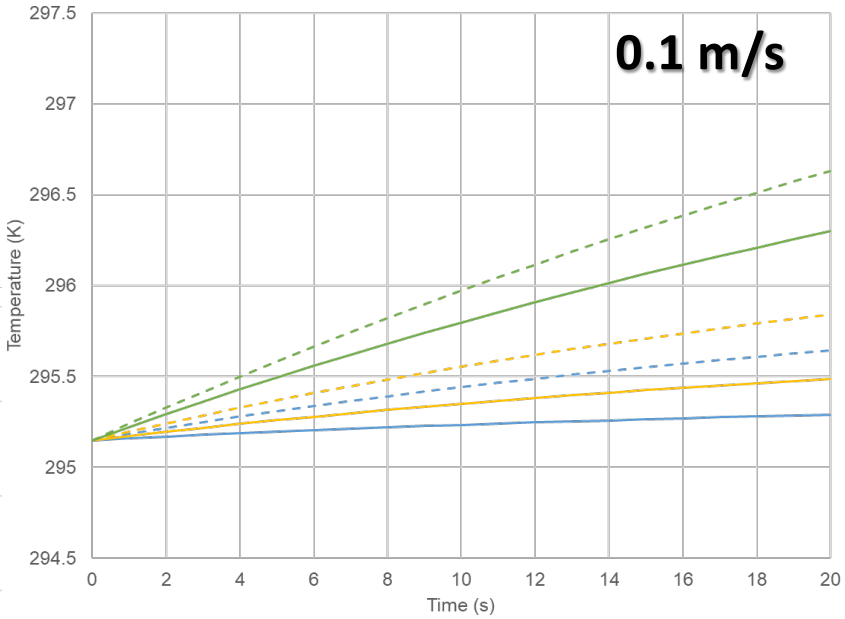
1 m/s

Poulet L, Dussap C-G & Fontaine J-P. Development of a mechanistic model of leaf surface gas exchange coupling mass and energy balances for life-support systems applications. Acta Astronautica,175:517-530, 2020

Leaf shape influence on leaf surface temperature after 20 s







0g
1g
2g

Circular
Rectangular

Poulet L, Dussap C-G & Fontaine J-P. Development of a mechanistic model of leaf surface gas exchange coupling mass and energy balances for life-support systems applications. Acta Astronautica,175:517-530, 2020

Acta Astronautica 175 (2020) 517–530

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

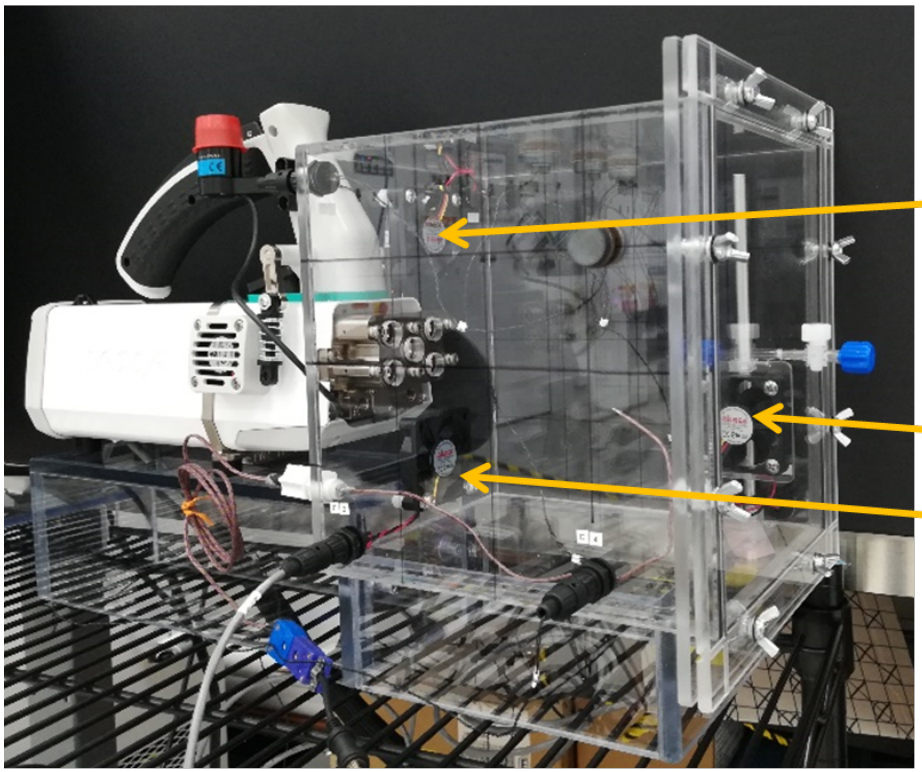
Development of a mechanistic model of leaf surface gas exchange coupling mass and energy balances for life-support systems applications

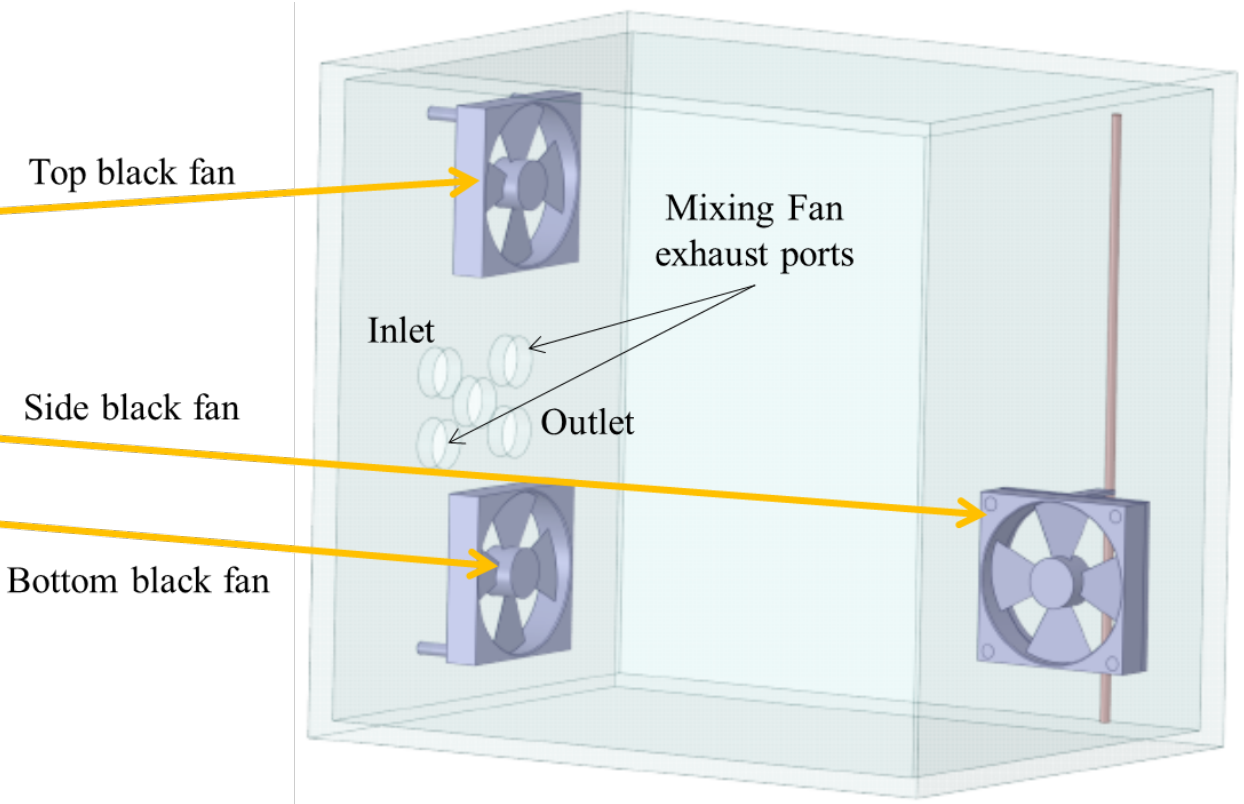
Lucie Poulet[1,*], Claude-Gilles Dussap, Jean-Pierre Fontaine

Université Clermont Auvergne, CNRS, SIGMA Clermont, Institut Pascal, Clermont Ferrand, France

Validation in steady-state: Gas exchange

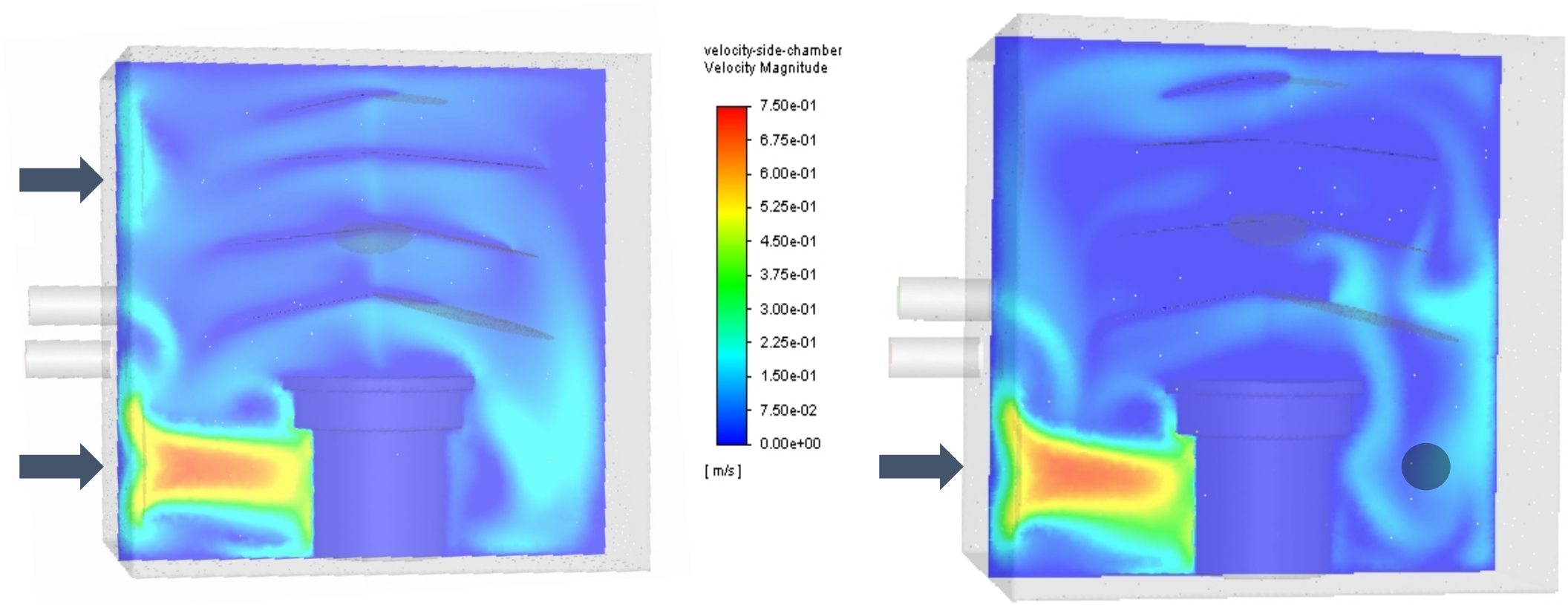
Custom-made photosynthesis measurement chamber





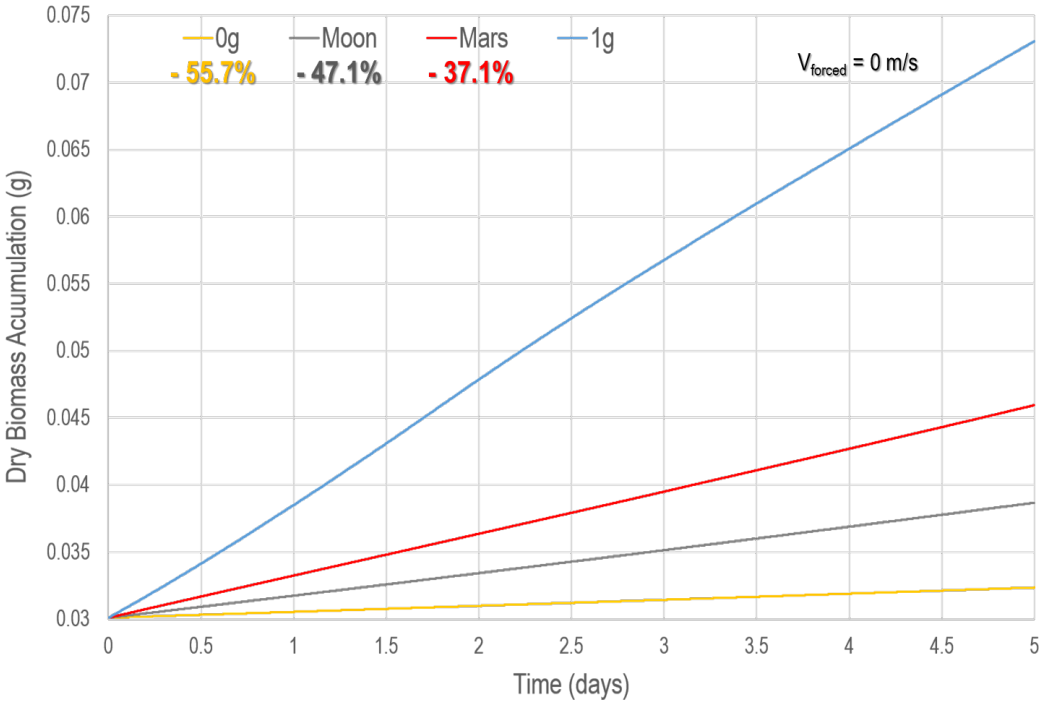
Poulet L, Gildersleeve M K, Koss L L, Massa G D, Wheeler R M. Development of a photosynthesis measurement chamber under different airspeeds for applications in future space crop-production facilities. Proceedings of the International Conference on Environmental Systems, 2020 (cancelled conference but published proceedings).

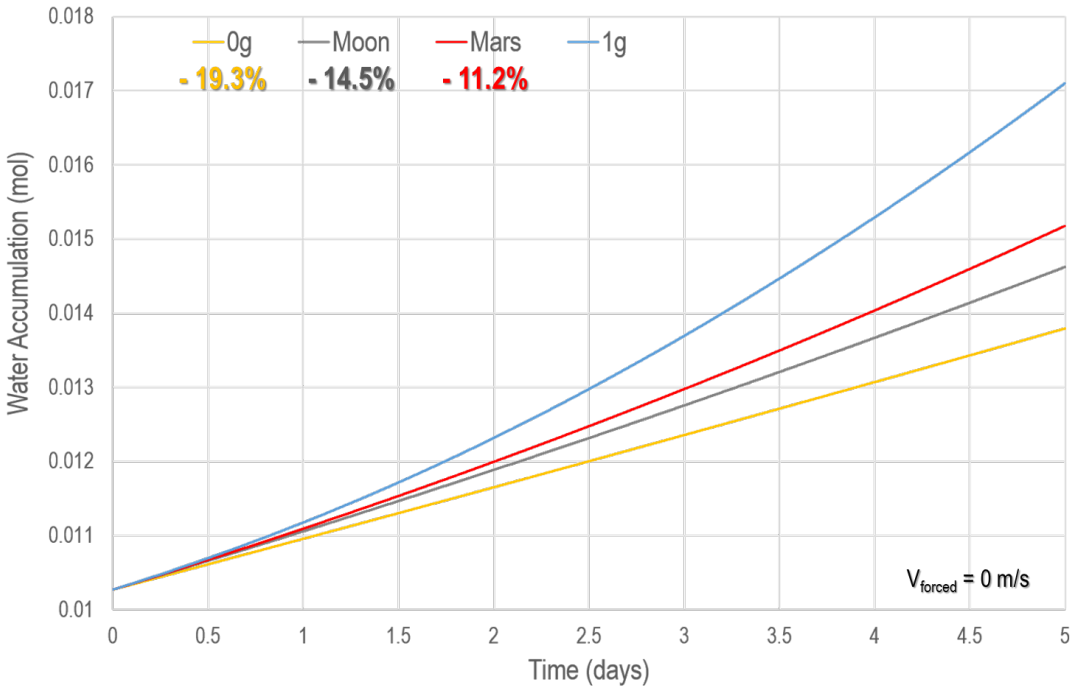
Computational Fluid Dynamics



Poulet L, Gildersleeve M K, Koss L L, Massa G D, Wheeler R M. Development of a photosynthesis measurement chamber under different airspeeds for applications in future space crop-production facilities. Proceedings of the International Conference on Environmental Systems, 2020 (cancelled conference but published proceedings).

Long-term predictions: Biomass accumulation





Conclusion

- This mechanistic model
  - Robustness for a wide range of environmental parameters
  - Prediction with good accuracy order of magnitude of photosynthesis rate
- Importance of mechanistic models for bioregenerative LSS design
  - Can be used for predictions in lower gravity environments
- Custom photosynthesis measurement chamber with LI-6800
  - CSTR assumption
  - Low airspeeds (<0.1 m/s) can be maintained on top of the chamber
  - Used for 1g model validation / calibration

Special thanks to:
NASA Postdoctoral Program
Institut Pascal
Université Clermont Auvergne
Clermont Auvergne Metropole
Space Farmers
CNES
CNRS
ESA
INRA/PIAF