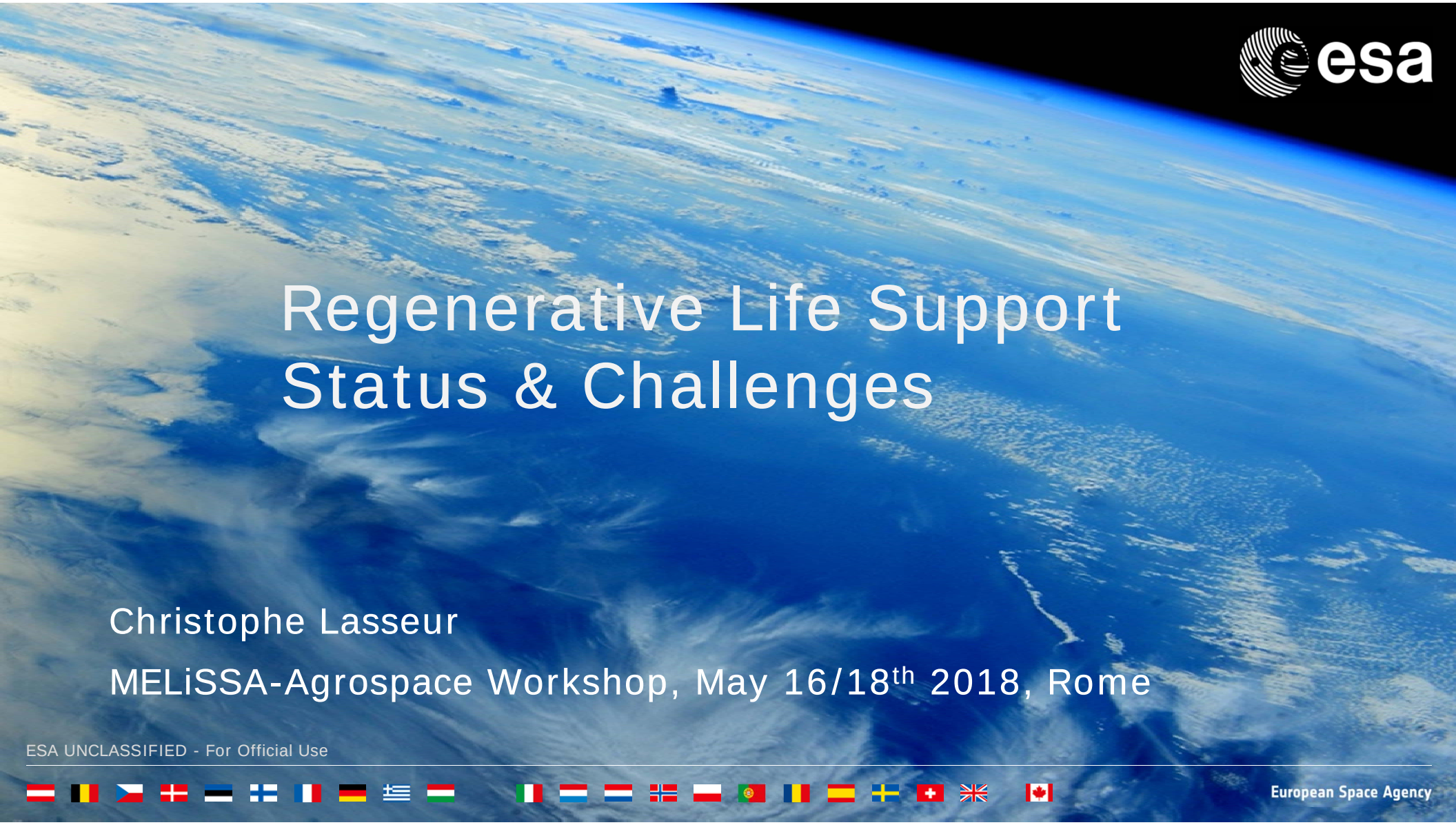


Regenerative Life Support Status & Challenges

Christophe Lasseur

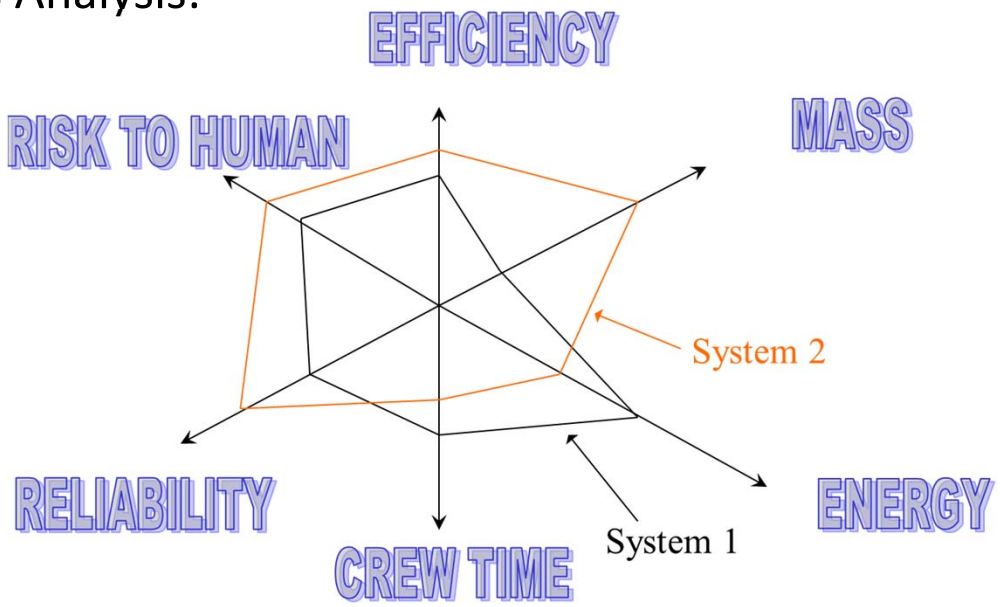
MELiSSA-Agrospace Workshop, May 16/18th 2018, Rome

The Challenge

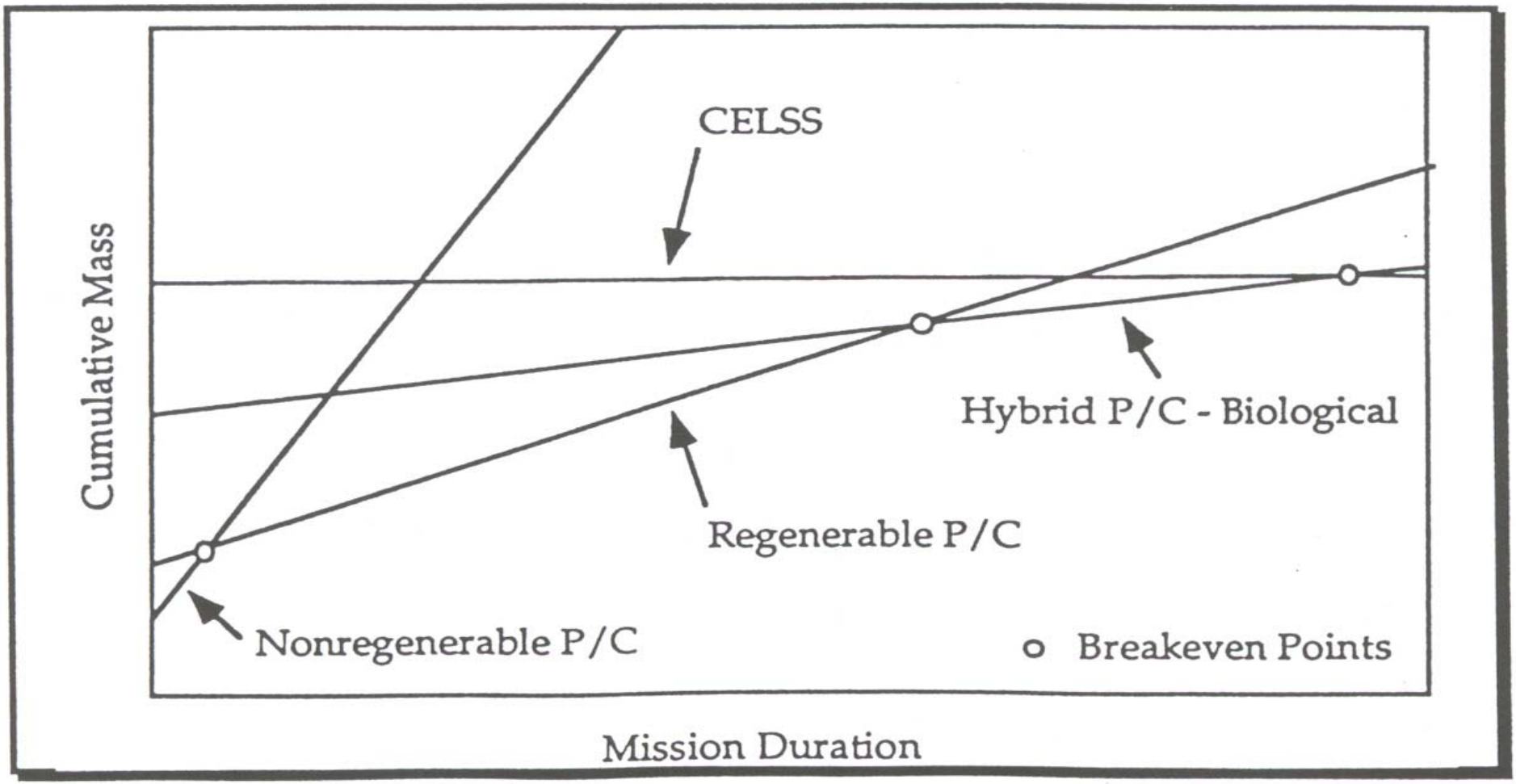
How to select and assemble processes and technologies to reach the highest level of closure and respect safety standards ?

ALiSSE/ESM Criteria

- Metric to evaluate and compare ECLSS:
  - Mono & Multi-parameters Analysis:
    - Mass,
    - Efficiency,
    - Energy,
    - Safety,
    - Crew time.



Mass


CELSS
Hybrid P/C - Biological
Regenerable P/C
Nonregenerable P/C
Breakeven Points
Cumulative Mass
Mission Duration

Food & Waste Diversity

- Main part of the waste are from human metabolism and of High Diversity,
- Food supply means high diversity,
- Only Biological processes can tackle the diversity of the waste transformation and food production, It is the direction but it is is far to be a product !
- Biological process means:
  - Very Complex molecule,
  - Complex metabolism understanding and prediction
  - Very high and very slow dynamics,
  - Potential nature changes,
  - …

Preparing the Future via past Experience ?

From 1733 to 2017…

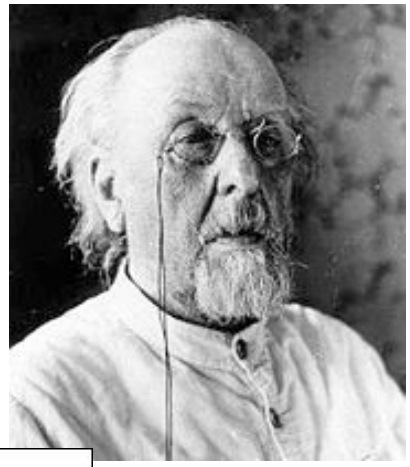
Joseph Priestley (1733-1804)

A "Patron Saint" of
Bioregenerative Systems !

Various Portraits of Joseph Priestley (courtesy Ray Wheeler)

Some Names of Closed Loop …

Mel Averner

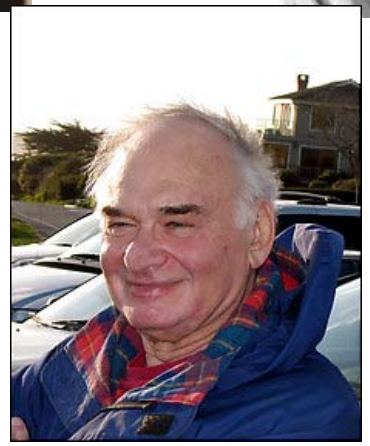


Constantin
Edouardovitch
Tsiolkovski

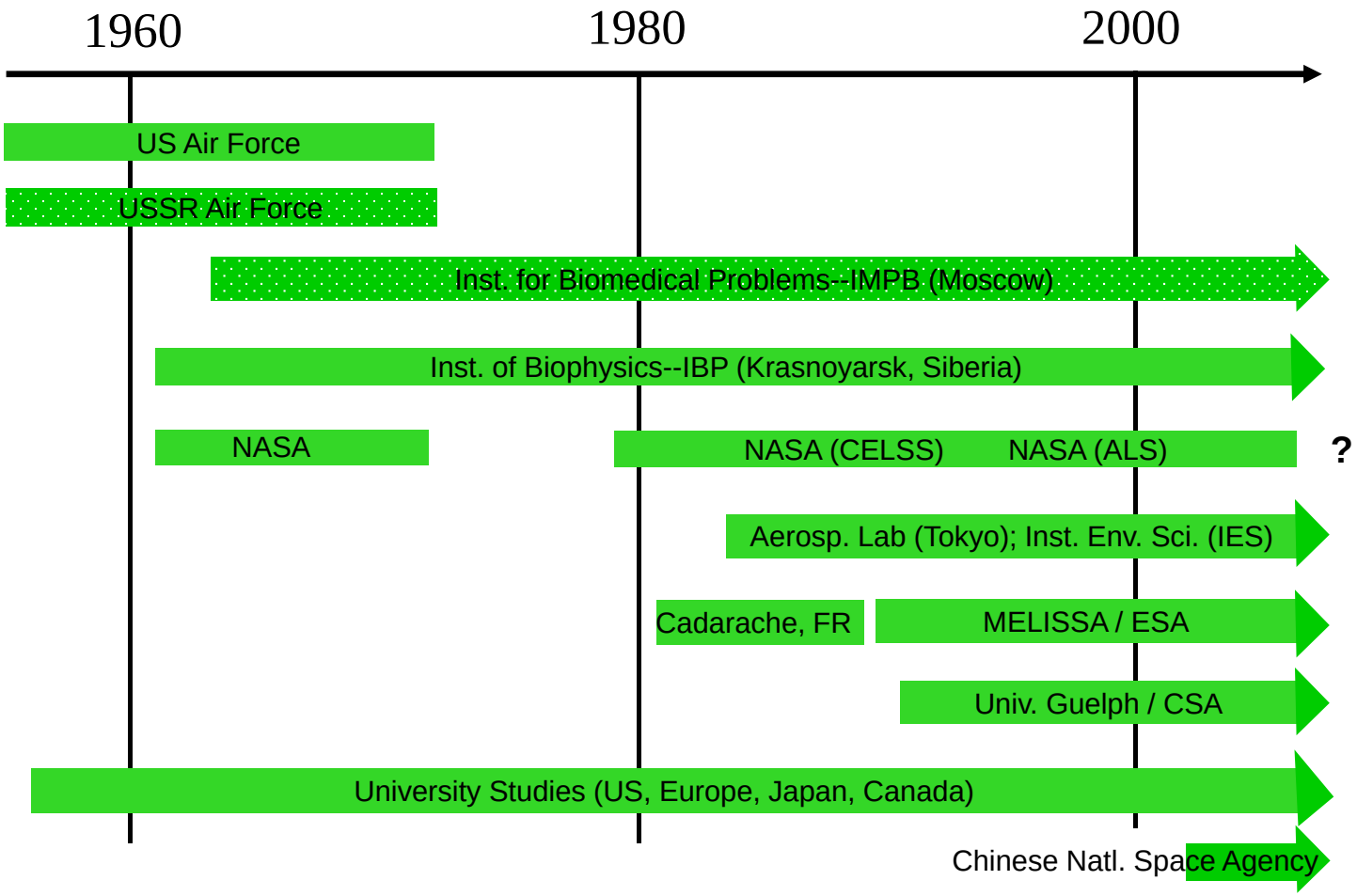
Bob
Mac Elroy

Korolev

Jack Myers



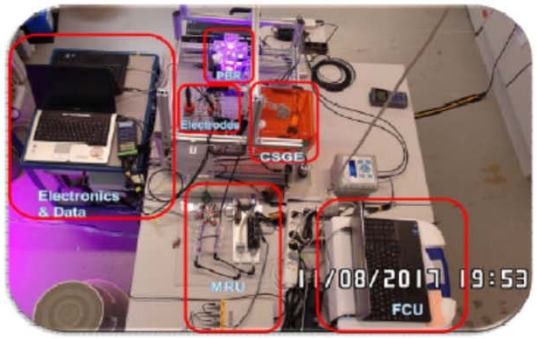
Regenerative Life Support around the World (Wheeler 2009)



Recent Flight Achievements

Sub-Modules:

- modular, stackable PBR, 50 ml volume each, new design
- illumination unit - new design
- Electrode Unit
- MRU – Media Recycling Unit
- CSGE – Cell Separation and Gas Exchange Unit
- FCU – Flow Cytometer Unit
- DCMU – Data Collection and Management Unit

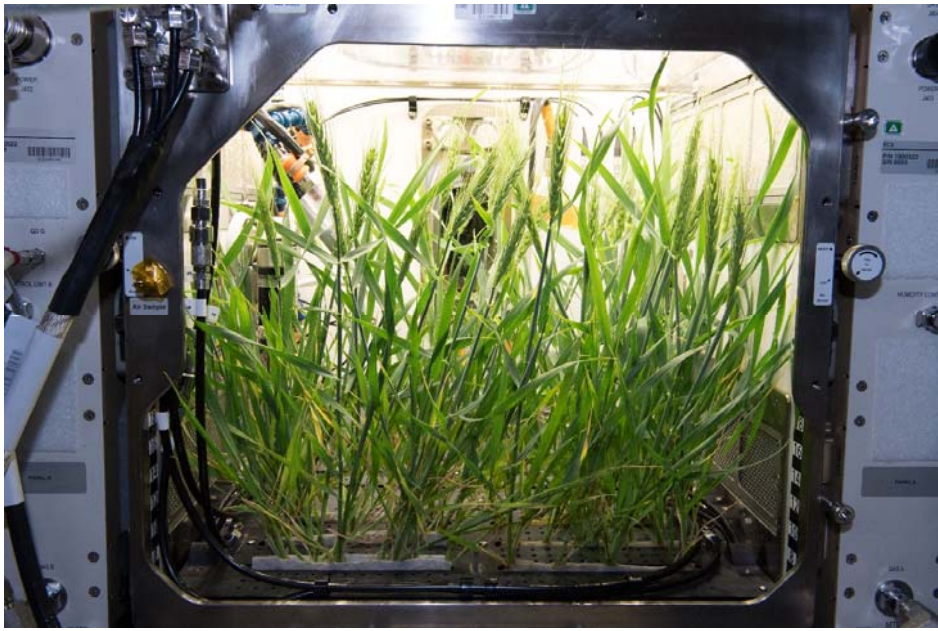


Results:

- 4 week long test runs succesfully completed (turbidostatic)
- micoralgae growth in a stabile community of bacteria and fungi
- media recycling successfull / biomass separated successfully transferred to consumer module
- lower and upper limits of nutrient concentrations determined
- gas exchange (removal of O_2, still insufficient)
- Electrode Unit revised – all optodes exchange to electrochemical electrodes
- etc.

This work is funded by the German Bundesministerium für Wirtschaft durch das DLR Raumfahrtmanagement, FKZ 50 WP 1711

VEGGIE/APH



Ground Demonstrators

Concordia Station

EDEN ISS

Ground Demonstration of Plant Cultivation Technologies for Safe Food Production in Space

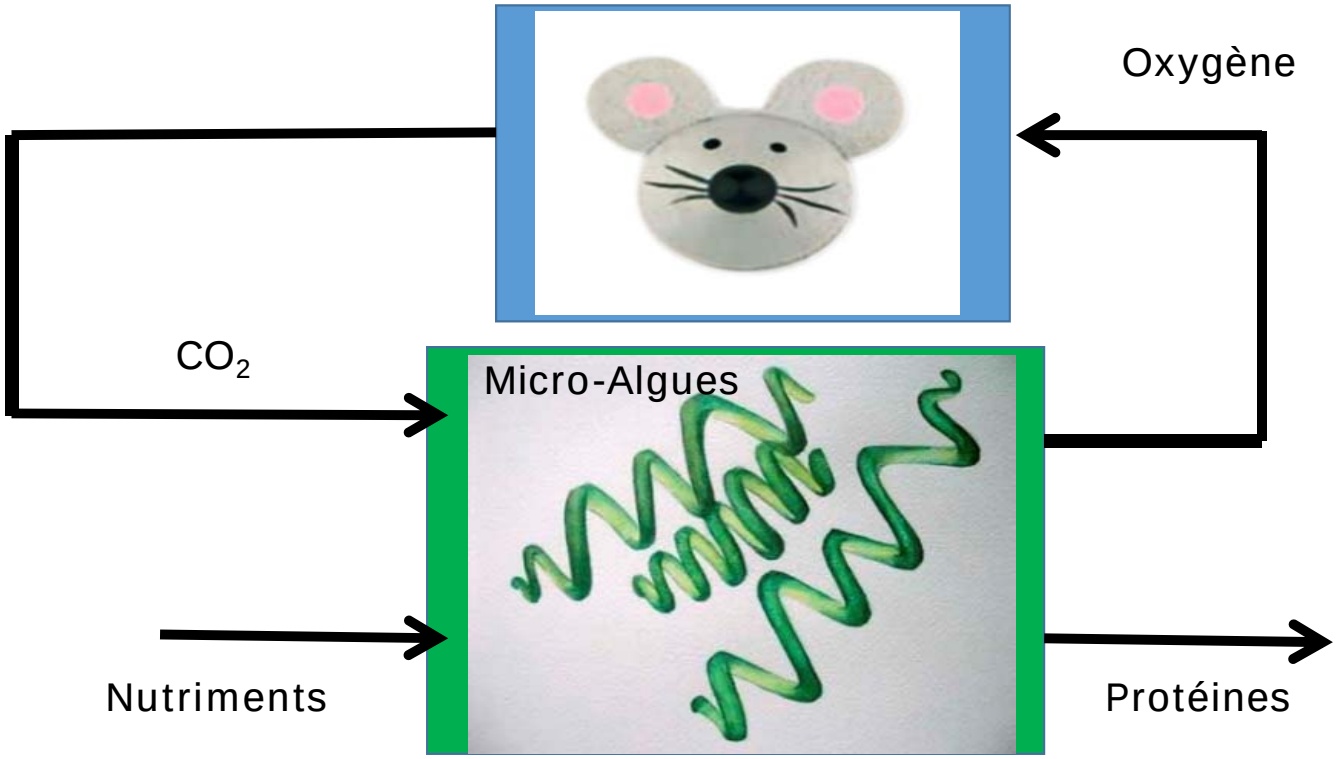
- COMPET 7 - 2014: Space exploration - Life support
- EU Contribution ~4.5 M€ (total over 5.5 M€)
- 14 Partners from Industry, Academia and research Institutes
- Germany, Ireland, Italy, Netherlands, Sweden, Austria, Canada, and USA
- 12-month analogue mission to Antarctica

HORIZON 2020

DLR · ThalesAlenia Space · University of Guelph · Liquifer Systems Group · Airbus Defence & Space · heliospectra · ENGINSOFT · UF University of Florida · ARESCOSMO · Consiglio Nazionale delle Ricerche · AWI · Wageningen University · Limerick Institute of Technology · Telespazio

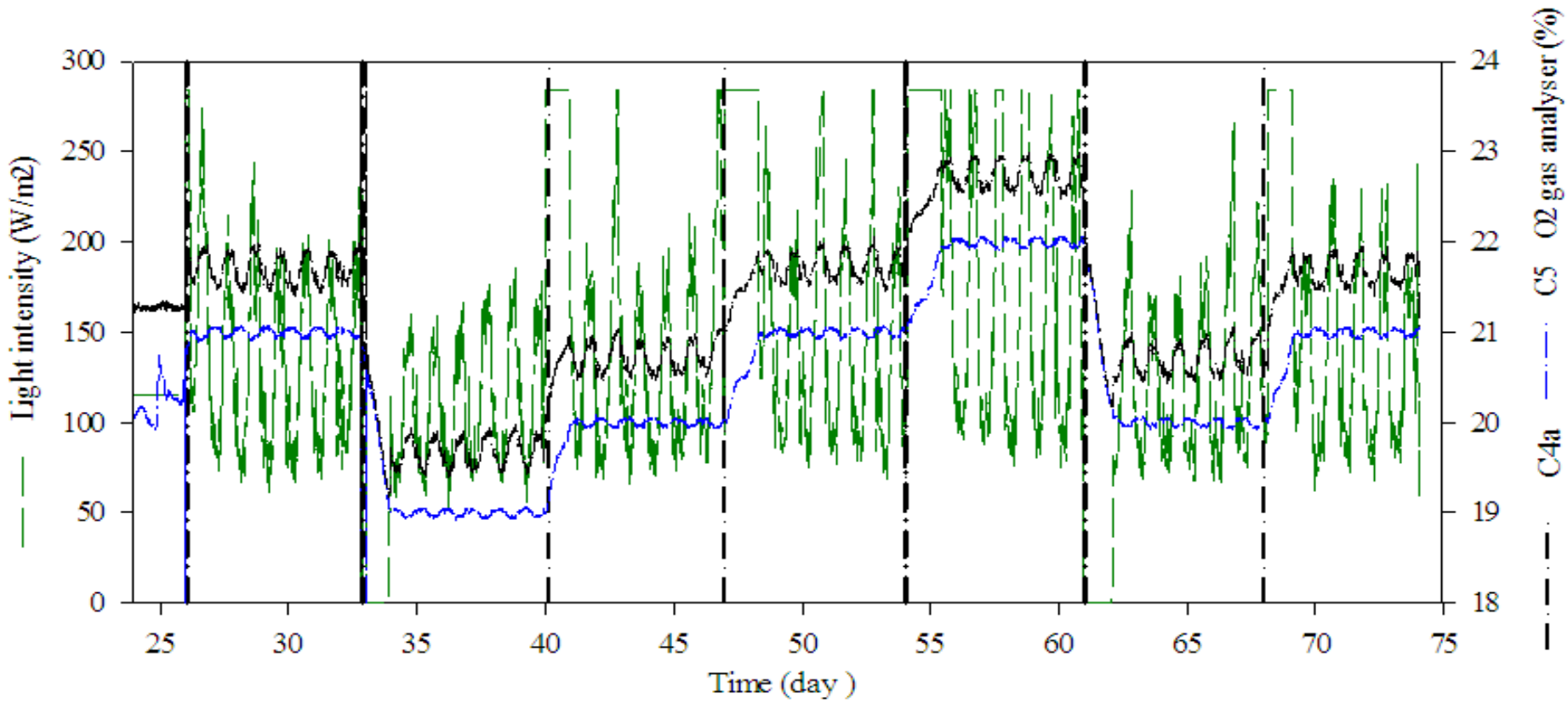
MELiSSA Pilot Plant

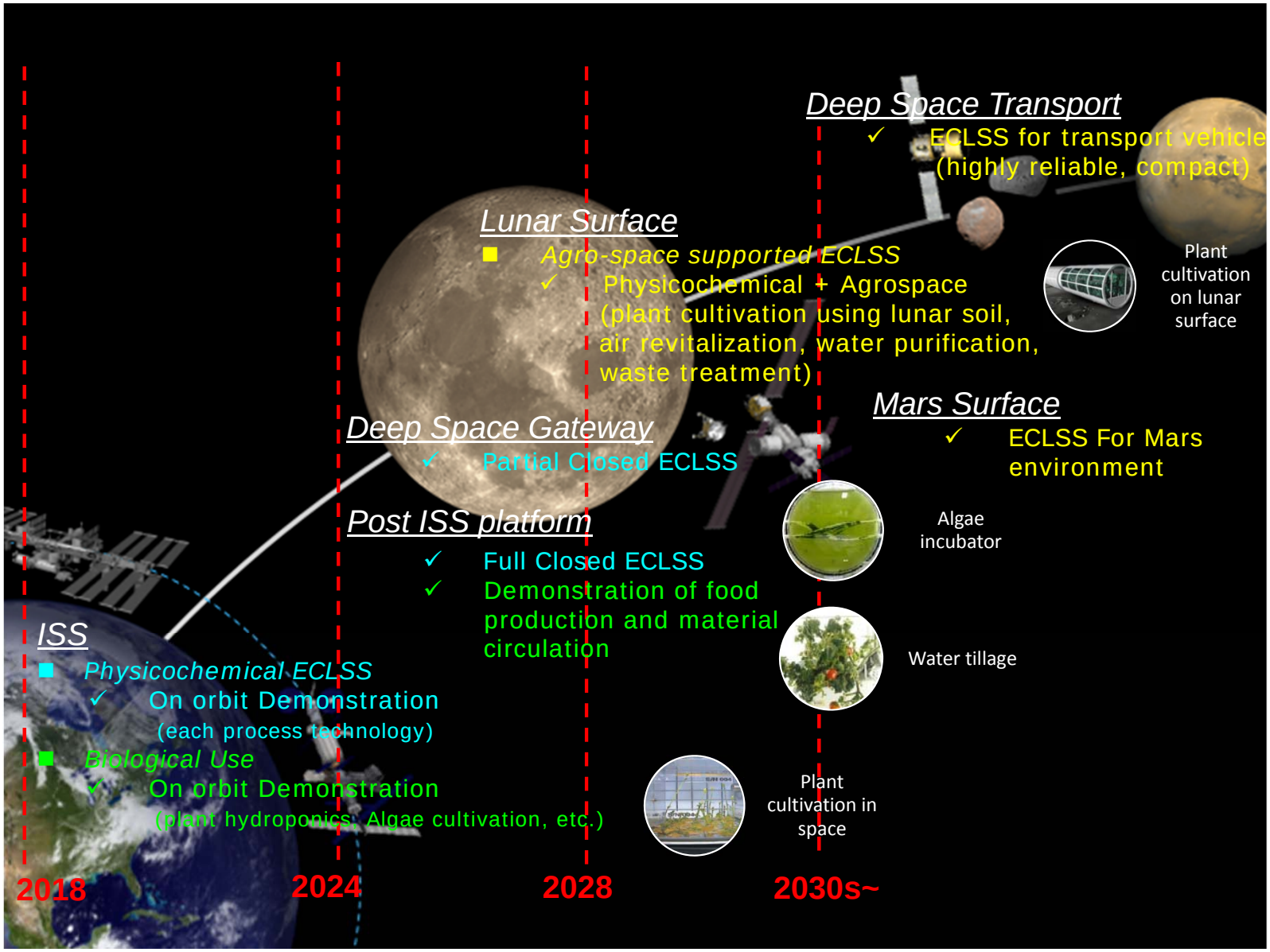
Oxygène/CO_2



The "Crew"

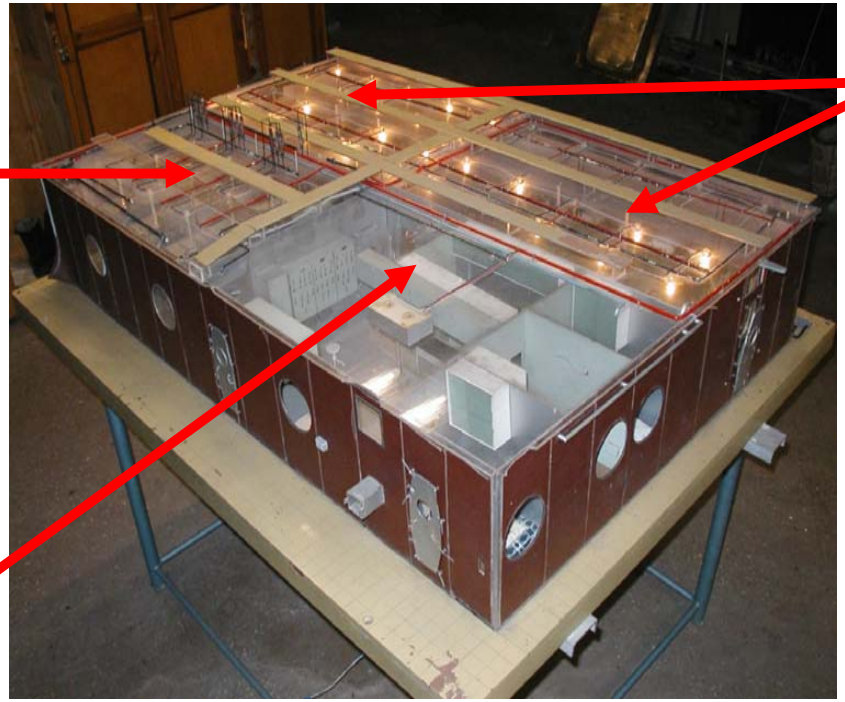
High Control Strategy

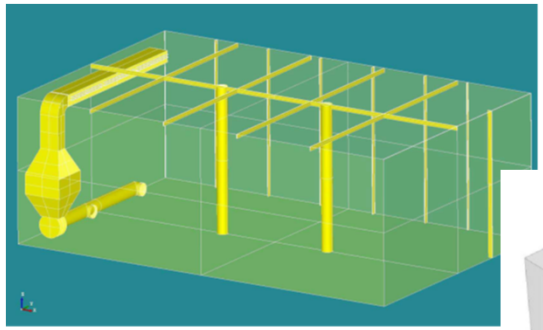


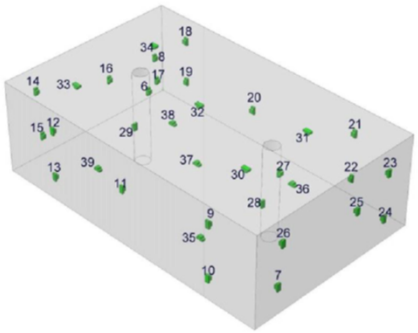

Deep Space Transport
✓ ECLSS for transport vehicle (highly reliable, compact)
Lunar Surface
■ Agro-space supported ECLSS
✓ Physicochemical + Agrospace (plant cultivation using lunar soil, air revitalization, water purification, waste treatment)
Plant cultivation on lunar surface
Mars Surface
✓ ECLSS For Mars environment
Deep Space Gateway
✓ Partial Closed ECLSS
Post ISS platform
✓ Full Closed ECLSS
✓ Demonstration of food production and material circulation
Algae incubator
Water tillage
ISS
■ Physicochemical ECLSS
✓ On orbit Demonstration (each process technology)
■ Biological Use
✓ On orbit Demonstration (plant hydroponics, Algae cultivation, etc.)
Plant cultivation in space
2018
2024
2028
2030s~

BIOS Krasnoyarsk

- The Facility
  - Devoted mainly to Life Support issues (still the best on the world)
  - 300 m3 total volume, up to 3 persons for 6 months



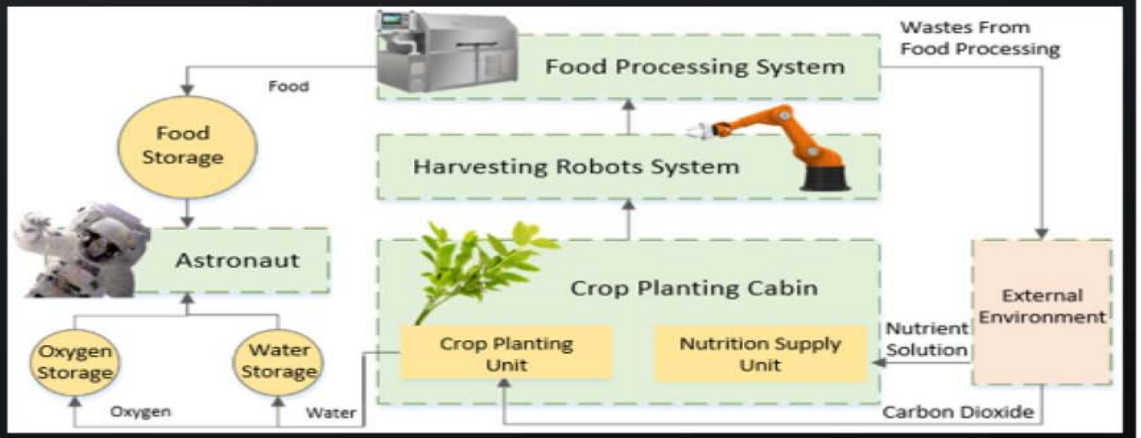




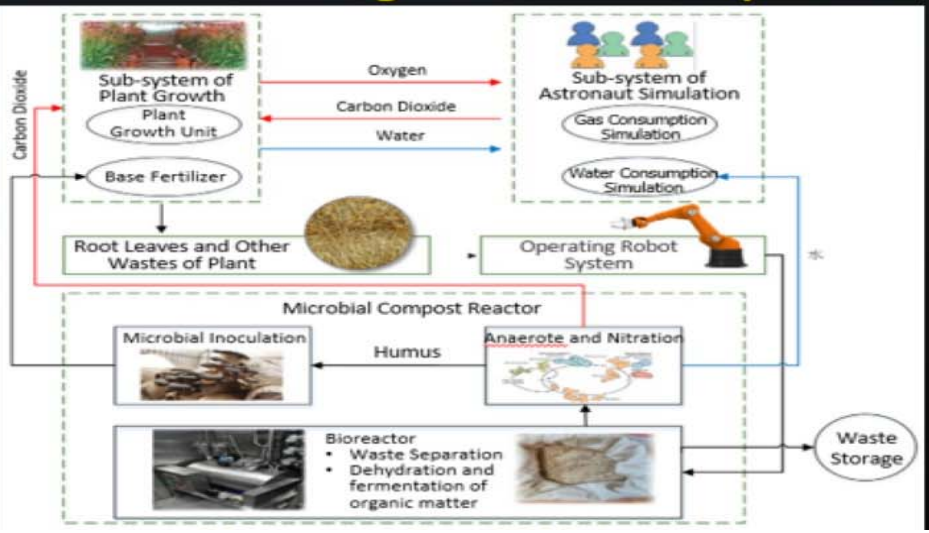
Chinese Space Laboratory Ground Experiment Center

- **Area: 30000 m²**
- **Project investment: ¥351 million CNY (≈$55 million)**
- **Support international cooperation research of life science and biotechnology, material science, fundamental physics, fluid physics and combustion, astronomy etc.**
- **The first phase will support the international cooperation projects of Bioregenerative Life Support System**

Controlled Biological Life Support System



Closed Bio-Ecological Circulation System



Societal Impact

Some PhDs

MULTI-TROP

MULTIple-TROPisms: interactions for root orientation in microgravity

University Team*:
Giovanna Aronne (Project Leader and Principal Investigator)
Veronica De Micco and Stefania De Pascale (Scientific Team)
Luigi Gennaro Izzo, Leone Ermes Romano, Sara De Francesco (Students)

**Dept. Agricultural Sciences, University of Naples Federico II*

School Team**:
Pina Russo and Giovanni Ciaravolo (School Team Leader)
Chiara Buonanno, Claudia Cosenza, Roberta Cosenza, Daniela D'acunzo, Mario Ferre, Ilaria Giordano, Giada Giuliano, Francesco Saverio Marrano, Simone Punzo (School students)

***Liceo Scientifico Statale L. Silvestri, Portici (NA)*

Overall Status

Known Status….

FUNCTION	Status	Ground	Flight
CO2 to O2	Partially at Payload level	Photobioreactor, ACLS, MODULES, PBR@LSR	ARTEMISS,
Condensate	~100%	/	ISS, MIR,
Urine	Water recovery only, preliminary Payload	Nitrification (Pilot)	VCD
Waste	Partially	Bench Hardware	/
Food	Some Payloads	Engineering Model	VEGGIE, SVET, LADA
Complete Loop Closure	Partially	MPP, EDEN ISS, Concordia, BIOS, CEEF, Lunar Palace,..	/
System Prediction	Control	MPP	ARTEMISS (e.g Oxygen)

Why Not More ?

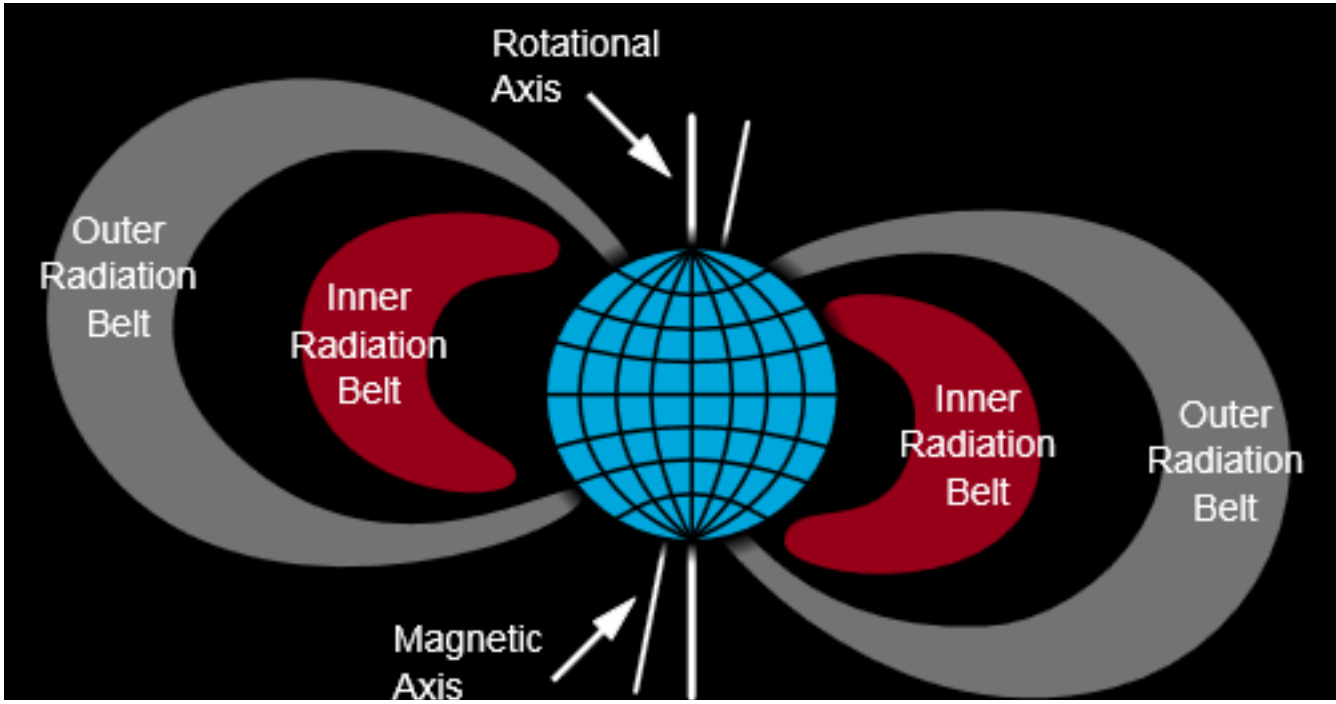

CIS LUNAR ORBITER

2) Are we not resisting ?

Robustness

- We will not escape the Safety Boards,
- In other words we need to demonstrate the engineering performances of our biological processes,
  - Prediction,
  - Performances,
  - Robustness,
  - Energy,..
- Any resistance is a lost of time, and by the way, of Innovation, Creativity and competitiveness,

3) Radiations ?



Radiations Effects

- Plants and bacteria are radiation sensitive but CREW too…
- Can we predict radiation breakage effects and model reconstruction phenomena ?
- How critical will it be ? (Spirulina known to resist very well to radiation !)

4) Terrestrial Synergy

Earth of the Future

- For the last ~5 years, there is a huge booming in circular system :
  - Circular economy
  - Smart cities
  - Vertical farming,
  - Organic Food.
- Although we are active in the field for more than 50 years, Why are we not leading and some times even not involved ?

5) Are we organized ?

Diverse Community

- Why today there is no International Exchange platform and/or collaborations for Regenerative life Support:
  - IALSWG 2000-2012,
  - COSPAR, almost no engineering,
  - ICES, no really international, and almost no scientists,
  - Even within Europe there are duplications,

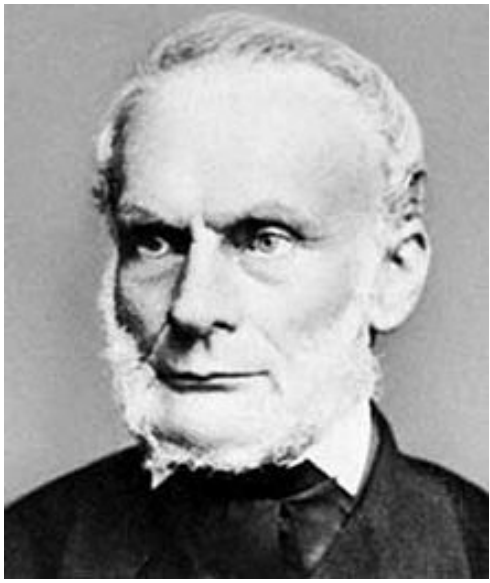
I have some Dreams…

My Dream List

- Clear, Harmonized and Robust European Strategy,
- High quality of the Scientific and Engineering approach ,
- Multidisciplinary exchanges, (e.g human physiology),
- Easier and Faster Access to Space,
- Easier and Stable financial source,
- Economical : Terrestrial spin-in/Spin-out
- Societal:
  - Education,
  - Citizen participation, and support,
- I have more…..!!!

Modelling and Simulation

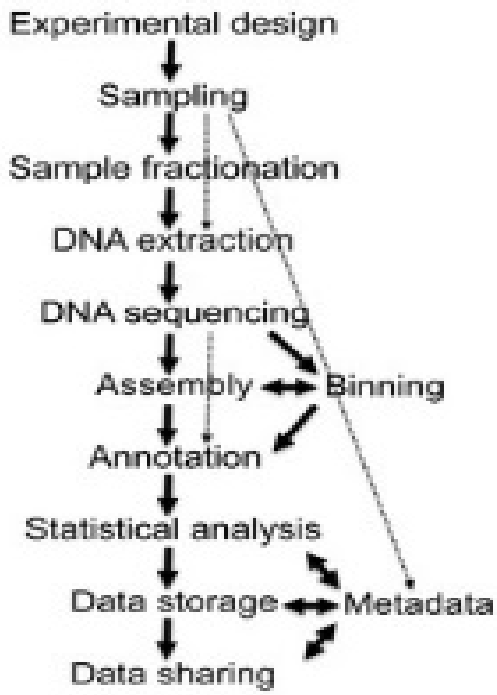
- From one organism/plant modelling to a functional community modelling,
- From CHNOSP elements to the complete Mendeleev table,
- From Mass balance/Monod to Thermodynamical models (i.e R. Clausius),
- Modelling of genetic/transcriptomic evolution,



Microbiology

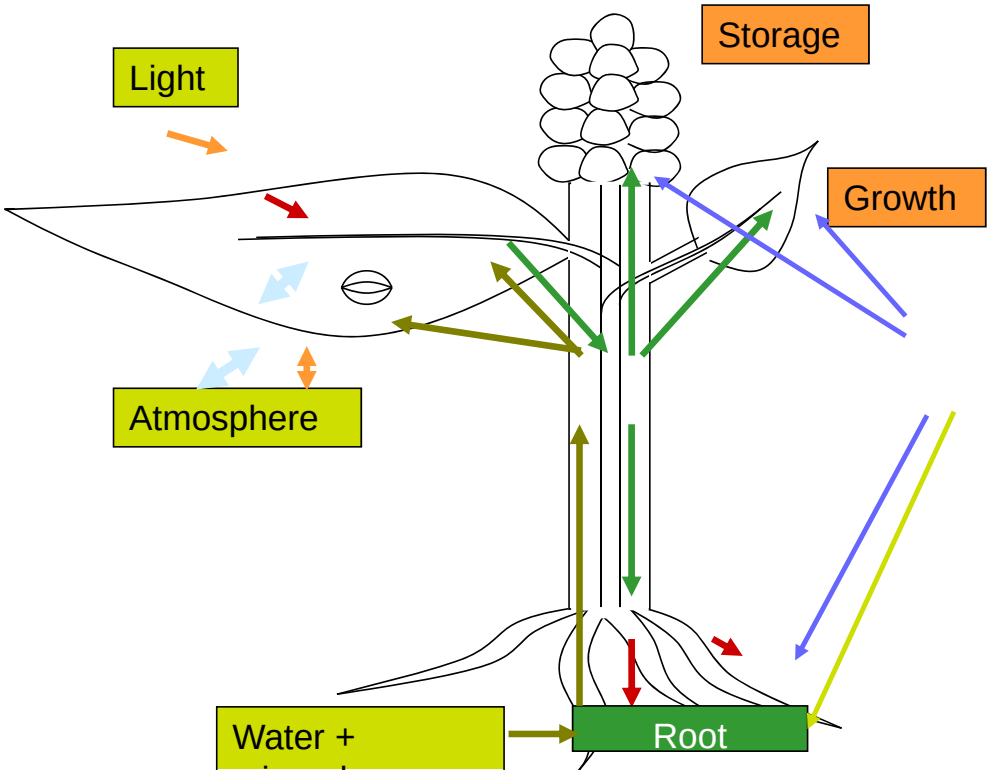
- On-line and real time microbial identification and quantification,
- Genetic Stability,
- Food Engineering.

- Why :
  - Understanding AND Modelling of semi-complex community,
  - Better Robustness, and probably better efficiency,



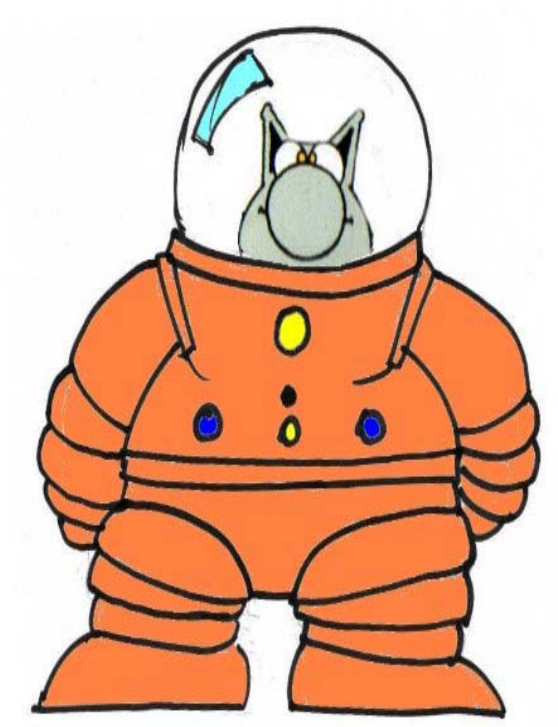
Plant Physiology

- Characterisation and quantification of flux within the plant body (roots, stem, leaves,..)
- Morphological Development models,
- Intensive plants characterisation,
- Halophilic resistance,
- Understanding of reduced gravity,
- Radiation effect,

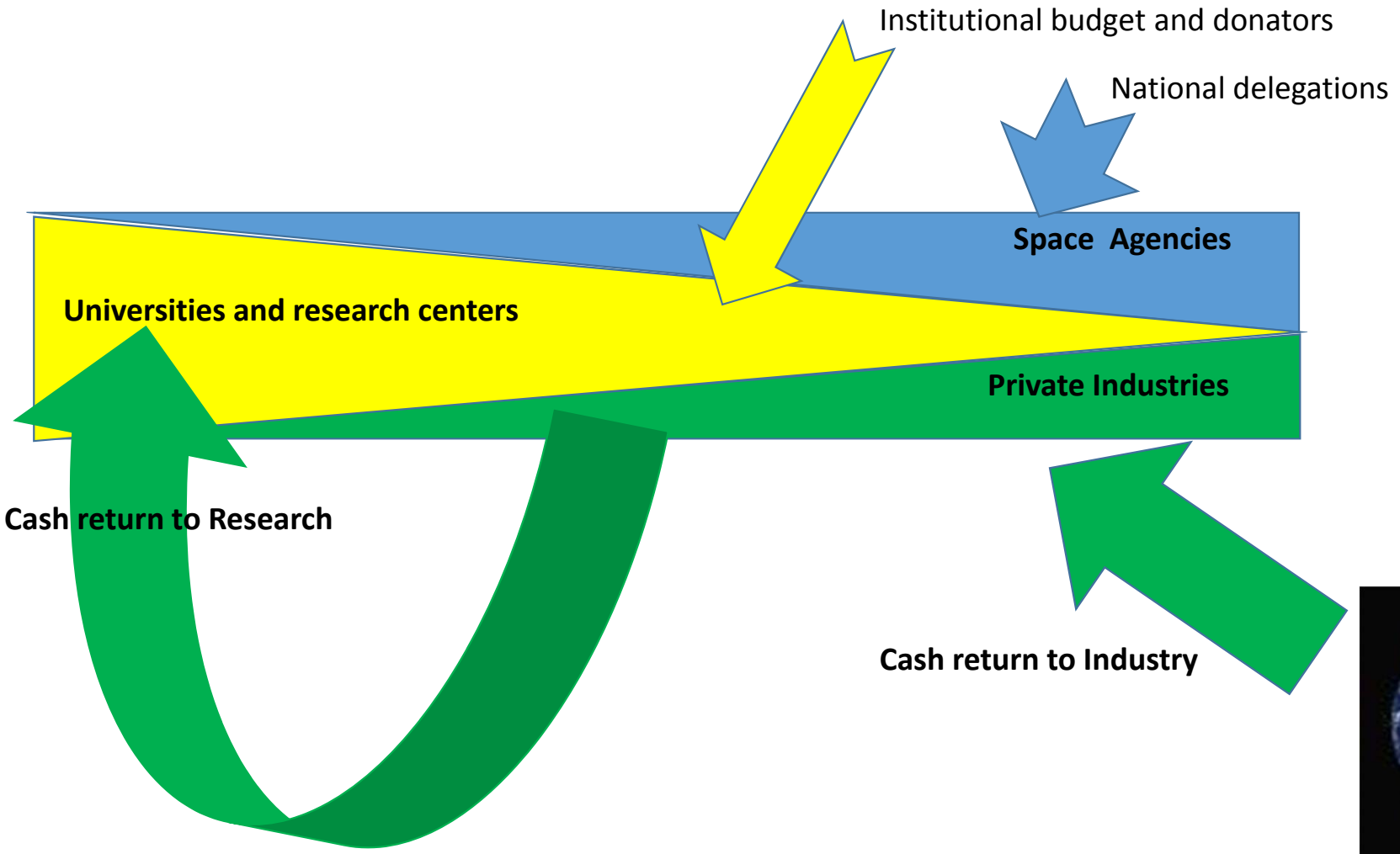


Human Physiology

- Waste/Urine Quality Prediction,
- Food perception and acceptance
- Microgravity effects,
- Radiation Countermeasures (?),
- Psychological effects

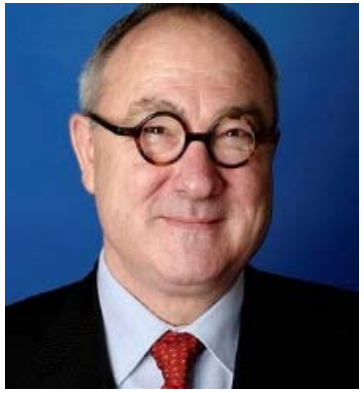


Additional Financial Pathways ?



Conclusion

- For the first we had Biological Life Support payloads on board ISS,
- The Participation of this Workshop confirms the high motivation,
- Short term will not be easy….
- On Friday afternoon, recognized experts will share their comments and recommendations with us.



GRAZIE