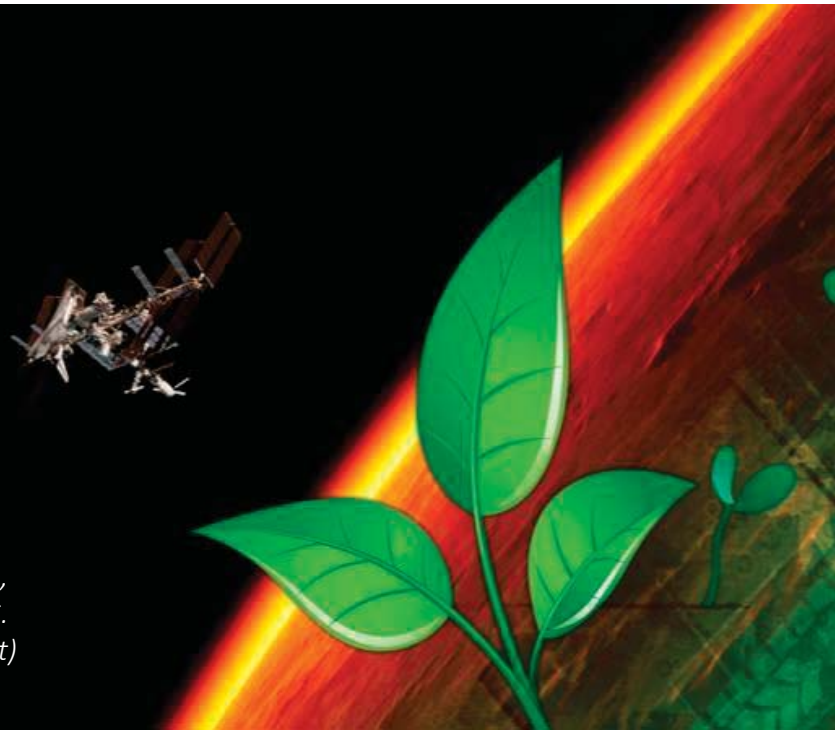
TIME SCALE

The Horizon 2020 Programme

1st Joint AgroSpace-MELiSSA Workshop, Rome, 2018

Plant cultivation experiments for design and testing of TIME SCALE Crop Cultivation System



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cmr Prototech

WAGENINGEN UNIVERSITY WAGENINGEN UR

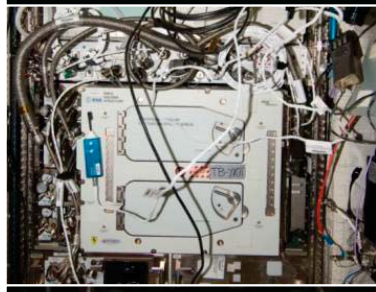
DTM TECHNOLOGIES

UNIVERSITEIT GENT

Interscience

Motivation (Space)

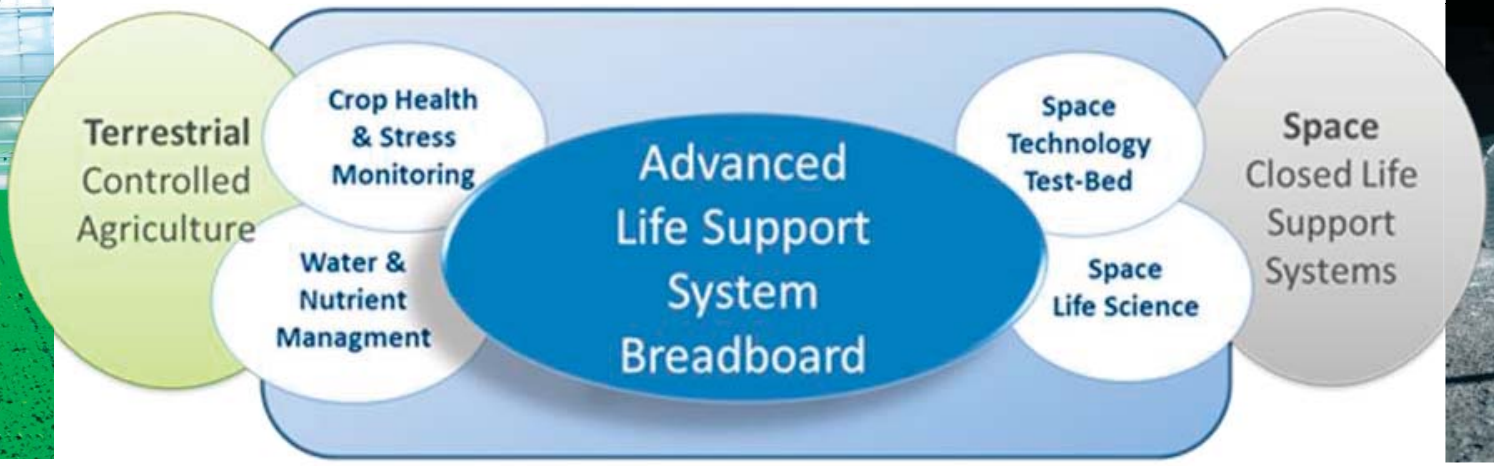
- Regenerative life support systems
  - Need for fundamental knowledge on plant physiology and biological processes under fractional gravity conditions
- Rotor-based plant cultivation facilities have for more than 10 years generated valuable life science results on ISS
  - European Modular Cultivation System (EMCS), installed 2006
  - Biolab, installed 2008
- Improvement potentials of current cultivation facilities



TIME SCALE strategy (Space and Earth)

*Based on EMCS on ISS, develop a **life support system concept** for future life science **research** and **technology demonstrations** under fractional gravity conditions*

Solutions for Human Spaceflight and Earth Applications



BACKGROUND and OVERVIEW

Concepts and design

Crop Cultivation System
- Plant Cultivation Chamber (PCC)
- Algae Cultivation Chamber (ACC)

Water and Nutrient Management (WNM) system

Plant Health Monitoring (PHM) system

Breadboard

Functionality testing

Life testing

Emphasis on PCC and WNM

Generic technology

VOC analysis by SIFT-MS and CompactGC

Imaging techniques

Automated nutrient analyzer

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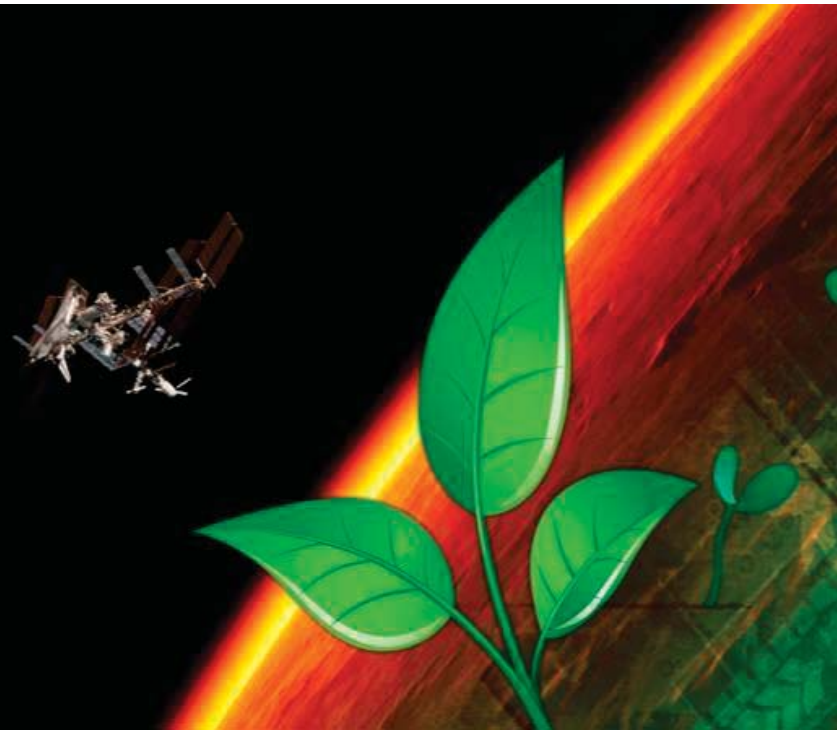
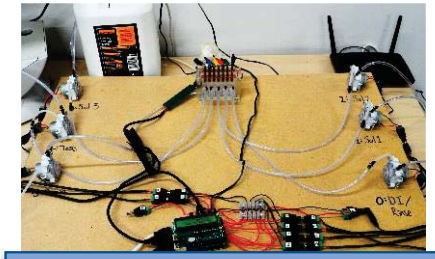
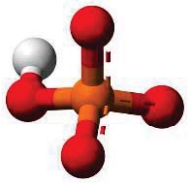
Generic technology with Earth Applications

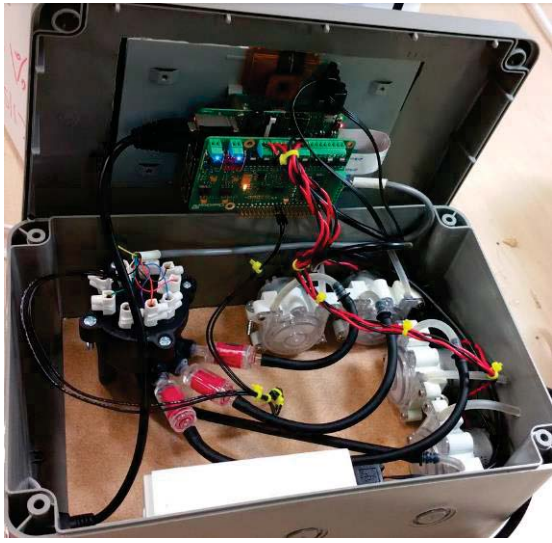
Nutrient analyzer
Imaging
VOC analysis



From manual sampling to automated at-line measurement







Starting point: Hand-held probe based on multiple ion-selective electrodes

Requirements and requests for Space and Earth applications: Automation, miniaturization, phosphate

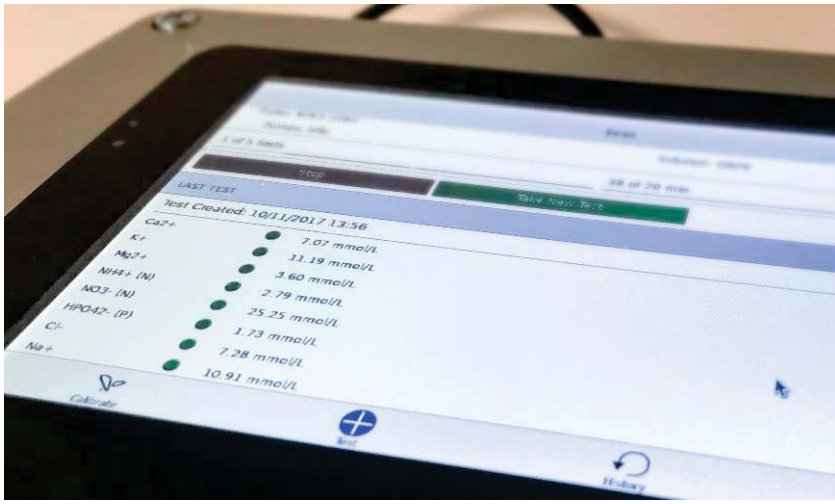
NUTRIENT ANALYZER

Refinement

- Auto-calibration
- Auto-sampling
- Phosphate ISE (HPO_4^{2-})

Commercialization

- Recently launched as commercial product: Automated, at-line analyzer for monitoring of Ca^{2+}, K^+, Mg^{2+}, NH_4^+, NO_3^-, HPO_4^{2-}, Cl^-, Na^+ in solution.



PLANT HEALTH MONITORING

Growth, photosynthetic performance and leaf temperature by non-destructive imaging at different wavelengths

- Automated, rapid throughput, time lapse with 1 min resolution.

Stress parameters (multiple VOCs) by SIFT-MS

- Up to 20 VOCs simultaneously with 5 min resolution.
- Particularly useful to identify and monitor low MW and oxygenated VOCs (methanol, ethanol, acetone, etc.).

Ultrafast gas chromatography and dynamic sampling for ethylene monitoring

- Development of improved Compact-GC prototype with new modules:
  - Thermal Desorption (TD) module, which releases sample to analytical column after in-line absorption trap
  - Programmable Oven (PO) module, which allows controlled elution and use of standard detection technology
- TD- and PO-modules commercialized and offered as part of custom-made, turn-key CompactGCs

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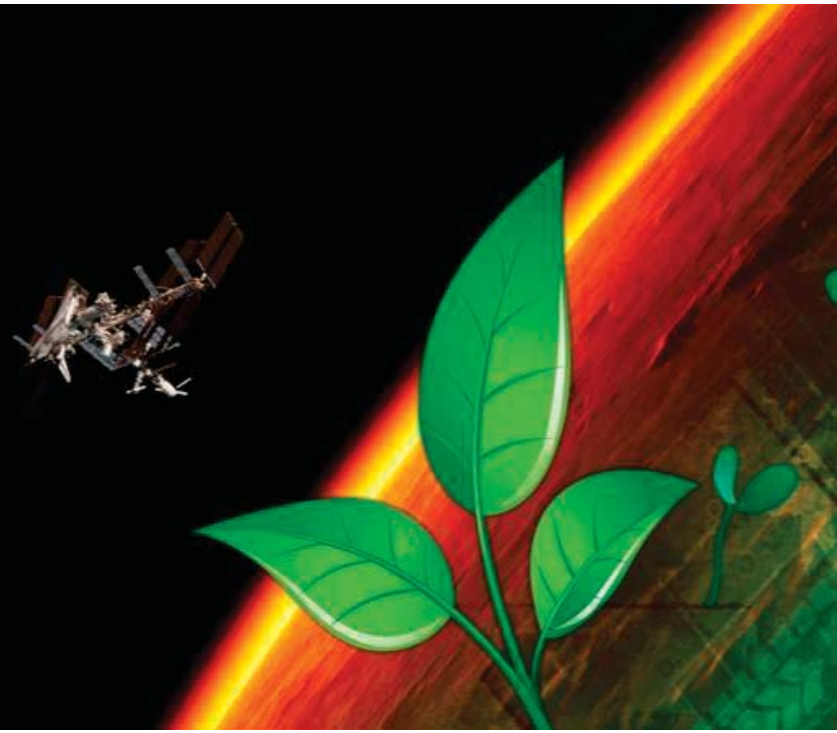
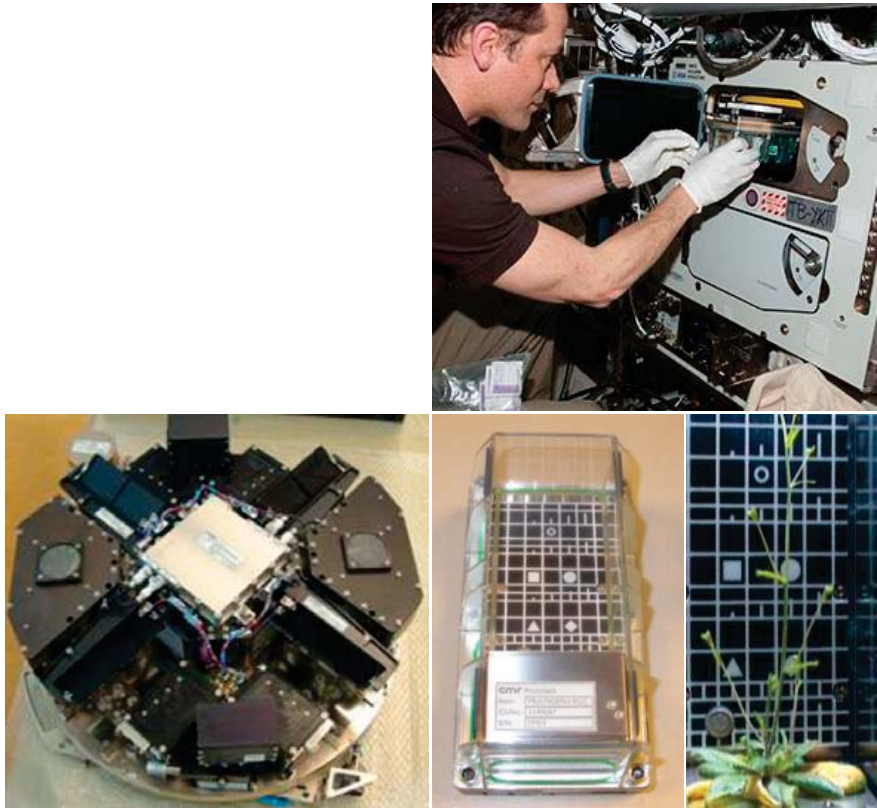
Concepts for Crop Cultivation System

Plant Cultivation Chamber
Algae Cultivation Chamber



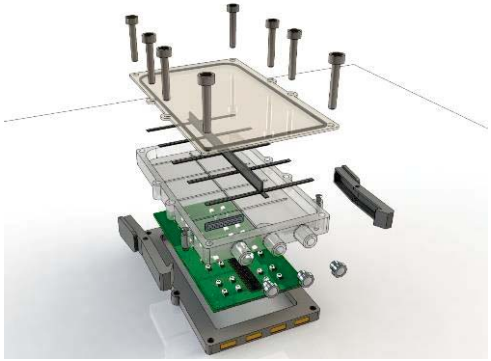
Crop Cultivation System

- Improvement potentials beyond today's EMCS
  - Water and Nutrient Management system
    - Recirculating water/nutrient solution
    - Pure water substrate and nutrient monitoring to allow study of nutrient dynamics
  - Plant Health Monitoring system
  - Larger cultivation chambers, for both algae and higher plants



The current EMCS on ISS, with a 60-cm rotor holding four Experiment Containers

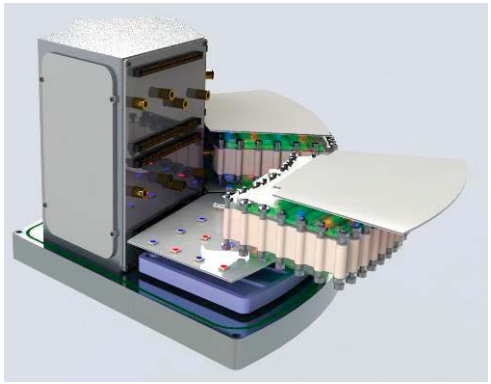
Algae Cultivation Chamber (ACC) concepts

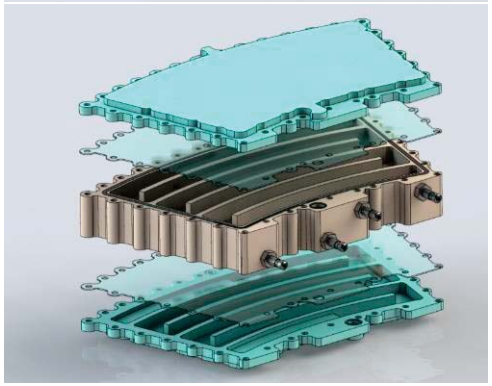


Algae photobioreactor concepts:

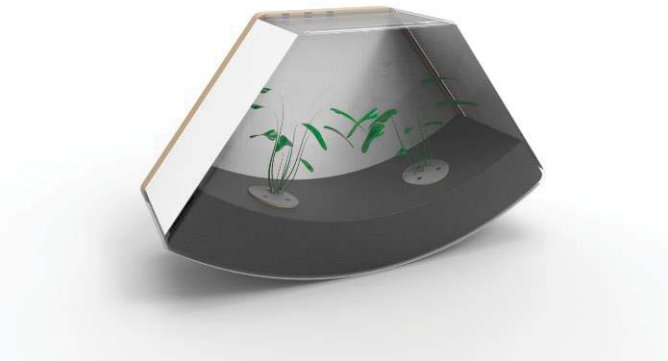
Design A (right) for technology demonstrations, e.g. test reactor design

Design B (left) for biological research, e.g. cell responses, photosynthesis





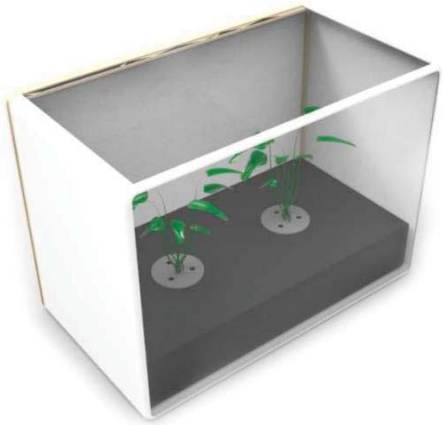
Plant Cultivation Chamber (PCC) concepts



PCC concepts:

Flight version (left)

Breadboard version (right)



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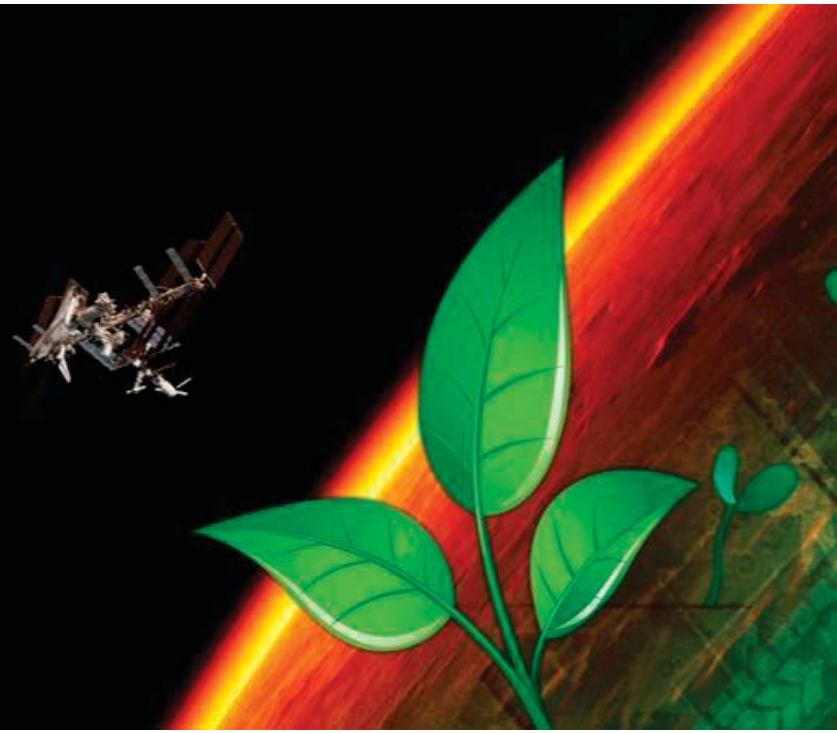
Plant cultivation experiments as input for the design of the Plant Cultivation Chamber

Functional and advanced,
but still possible to make small and simple?
- Selected results -



Effects of root compartment size on lettuce cultivation (single plants)

- Treatment
  - Small Root Compartment (0,7 liter, same as PCC flight and breadboard version)
  - Big Root Compartment (3,5 liter)
- Results
  - Up to 20 days: No significant differences in total dry weight or shoot/root ratio
  - At prolonged cultivation periods, small root compartment cause
    - Higher root dry weight
    - Tendency of lower shoot dry weight

Recirculating nutrient solution for two lettuce heads

- Treatment
  - Limited nutrient solution budget (3,4 liter)
  - Unlimited budget (100 liter, refreshed weekly)
- Results
  - No significant impacts up to 24 days of cultivation
    - Shoots, roots, leaf area
    - Stomatal conductance, chlorophyll surface content
    - Index of epidermal flavonoids and anthocyanins
  - Need for pH control can be minimized by NO_3^-/NH_4^+-ratio and use of pH buffer

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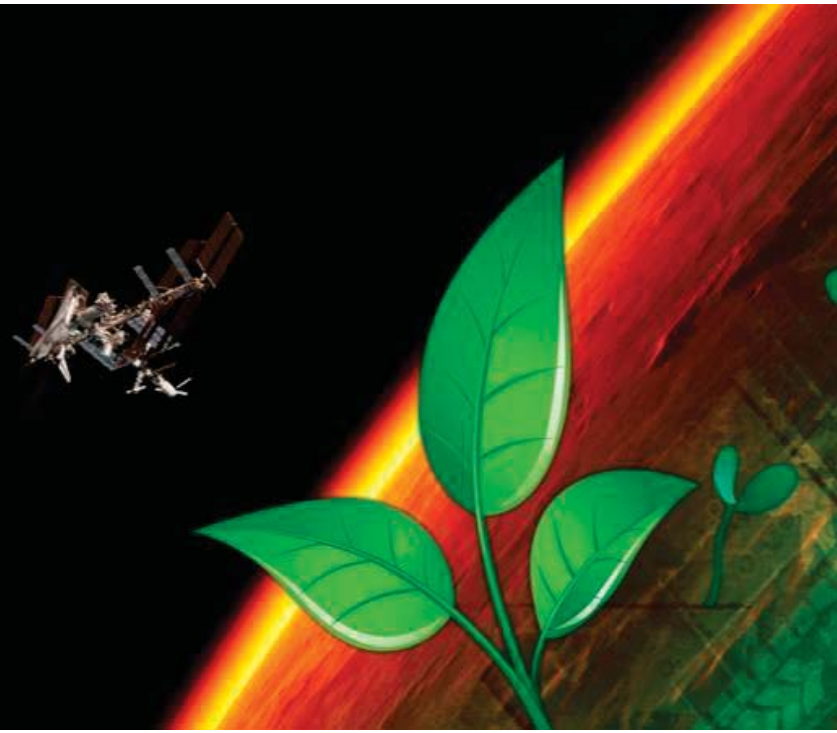
Crop Cultivation System breadboard



BREADBOARD TESTING

Modular Test Bed

Plant Cultivation Chamber

Water and Nutrient Management

TIME SCALE breadboard

BREADBOARD TESTING

A first step in a line of developmental models towards flight system

- Functionality testing
  - Individual parts, overall system and operational modes
- Life testing
  - Germination
  - Continued growth for 20 days
  - Normal plant development
- Two runs (lettuce cultivation, 20 days)

Breadboard results

Objective	Evaluation
Germination	OK
Continuous growth for 20 days	OK, second run
Normal plant development	Partly

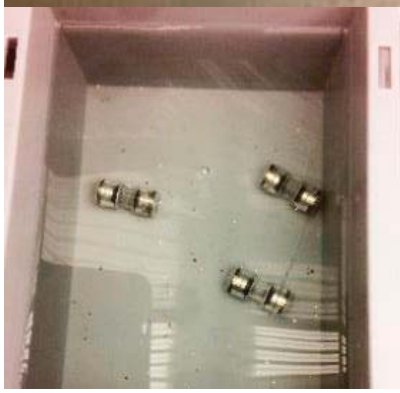
Breadboard valuable for improving functionalities and components

- Issues including air bubbles, flooding and suboptimal growth conditions were addressed: Proposed improvements for future models and for future technology demonstrations on ISS, including gas/liquid interphase, improved operational capabilities, improved material testing/purity.

Phytotoxicity in small and closed recirculating systems

- Analyses prior to detailed design and manufacturing
  - Building materials and parts tested by plant cultivation (indicator species) and VOC analyses

  → Some parts (*e.g.* specific cable glands, pumps and tubing) identified as questionable with respect to phytotoxicity, and therefore not used
- Still, abnormal growth observed in some experiments
  - Preliminary test-hardware not used for further plant experiments: Selection of new materials for breadboard
  - Abnormal growth in first breadboard experiment
- Small and closed recirculating systems require great emphasis on material testing and verification with respect to phytotoxicity



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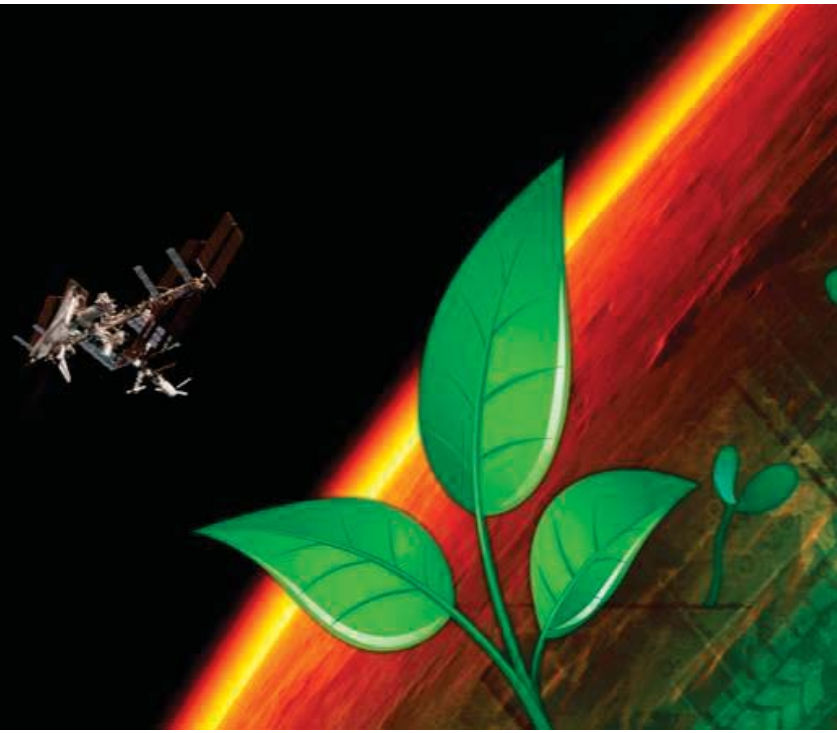
Highlights and outlook



Highlights

- Development of commercial products and generic technology for Space and Earth applications
  - Automated multi-ion nutrient analyzer including phosphate
  - Advanced imaging technology and VOC analysis for plant health monitoring
- Concepts for Algae and (higher) Plant Cultivation Chambers (flight and breadboard) were developed
- Crop Cultivation Chambers for life science research in fractional gravity can be made relatively small and simple even with advanced Water and Nutrient Management system, including capabilities for recirculation and nutrient monitoring
- Breadboard emphasizing on Plant Cultivation Chamber and Water and Nutrient Management System tested functionality and gave important input to future models

Outlook

- ESA has recently selected EMCS for decommissioning in 2018
- TIME SCALE results applicable also to ESA Biolab payload (comparable: modular, incubator, rotor)
- ISS technology demonstrations proposed (system and sub-systems, all adaptable to Biolab), including
  - Gas/liquid interphase plate
  - Multi-ion nutrient analyzer
  - Complete Crop Cultivation System
- Further Earth applications of generic knowledge and technology including Plant Health Monitoring and Water and Nutrient Management