Scuola Politecnica e delle Scienze di Base
Università Federico II, Napoli
12 giugno 2015

FLEX-ICE-GA
combustione di biocombustibili a gravità zero a bordo della Stazione Spaziale Internazionale

R. Calabria, D. Dietrich, P. Massoli
Istituto Motori – CNR , Napoli, Italy
NASA Glenn Research Center , Cleveland, USA

FLEX : Flame Extinguishment Experiment

ICE : Italian Combustion Experiment

GA : Green Air

Partnership ICE-GA:

AGT (small enterprise)

ASI (Italian Space Agency)

DTM (small enterprise)

IM-CNR (Istituto Motori of CNR)

Scientific Collaboration:

ASI

IM-CNR

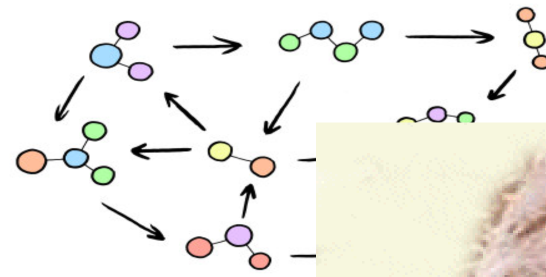
NASA

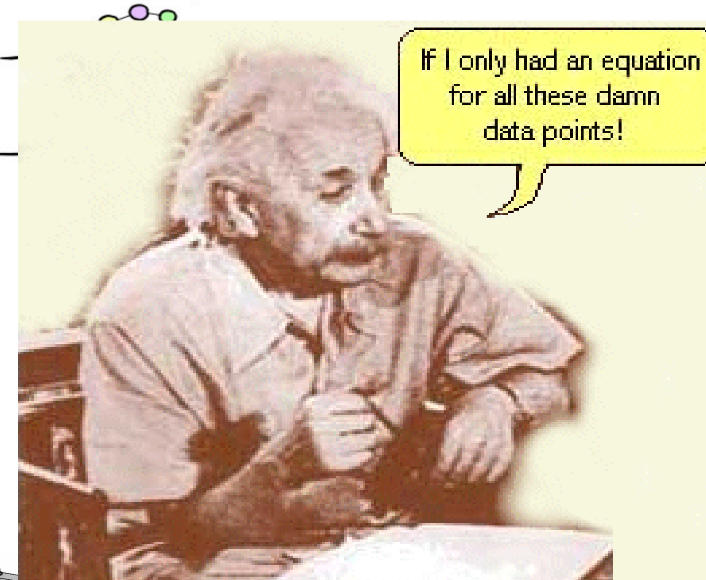
FLEX-ICE-GA

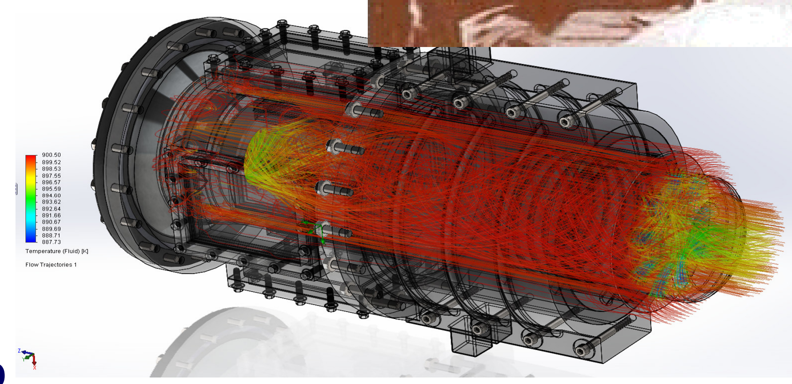
FLEX-ICE-GA
STICKER

Rationale: CFD and Chemical Kinetics

- **The critical point is in the fact that the chemical models have to be used in connection with very heavy CFD simulations**
- **Also for single component fuels, models with thousands reactions are used to describe the evolution of matter. This approach becomes impracticable when practical fuels with hundreds of compounds are investigated**
- **Surrogates are considered also for the evaporation phase to simplify the overall approach**
- **Lumped or reduced chemical schemes based on surrogate fuels are utilized to render acceptable the total computational cost.**



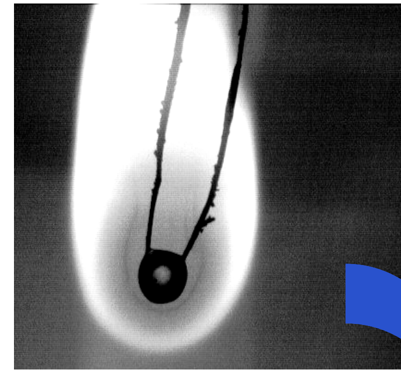




Rationale: Why μg?

- **Simplified fluid-dynamics, heat and mass transfer, to study the fundamental processes during heating and combustion of fuel droplets**
- **Simplified fuels, the surrogates, that well represent practical fuels in terms of composition, thermo-physical or combustion properties**
  - **Decane: jet A fuel surrogate;**
  - **1-hexanol: renewable long chain alcohol for conventional fuel blends or co-solvent for biodiesel mixtures;**
  - **heptane and ethanol: light sooting and non sooting fuels**

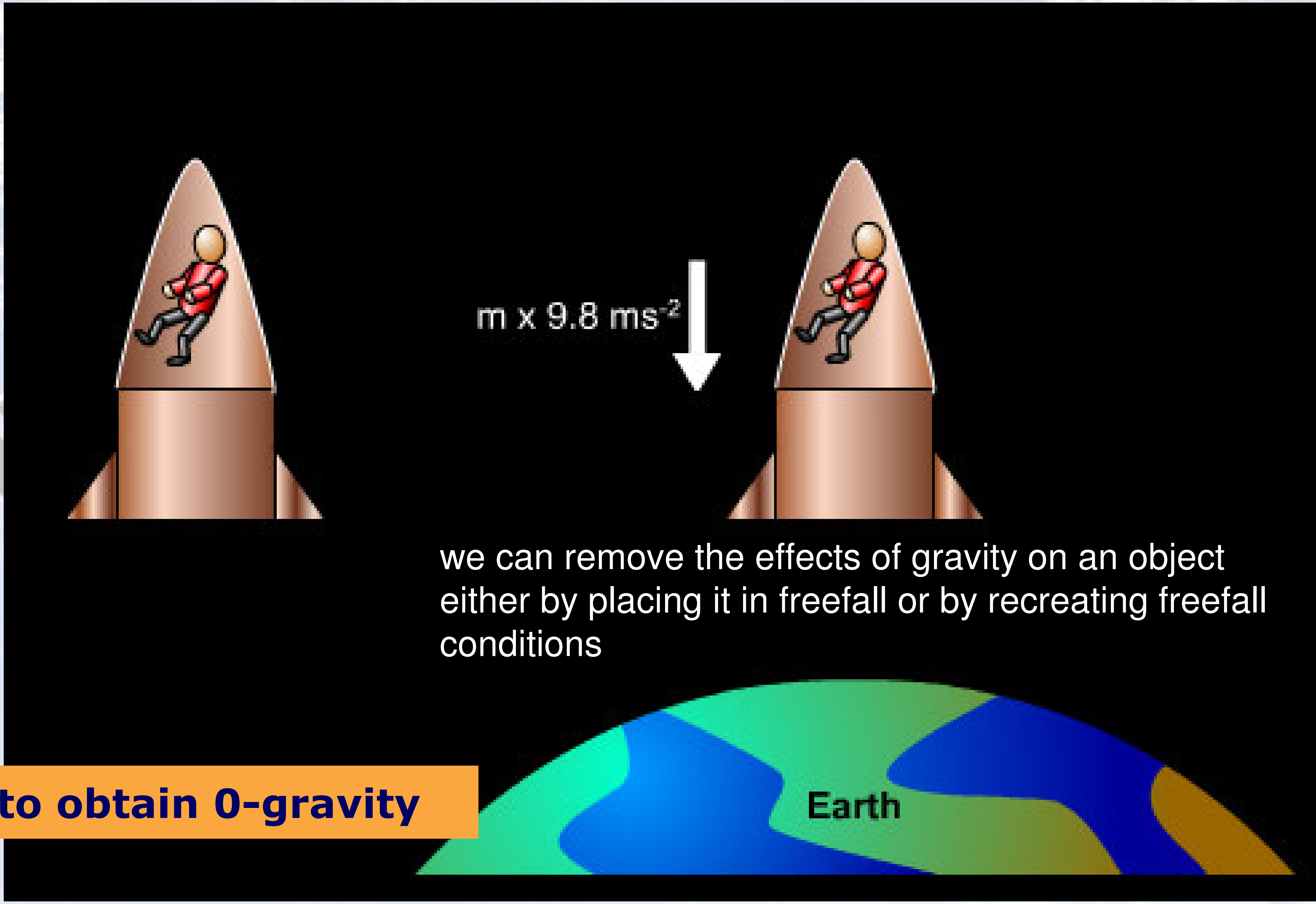
normal g



μg

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

How to obtain 0-gravity

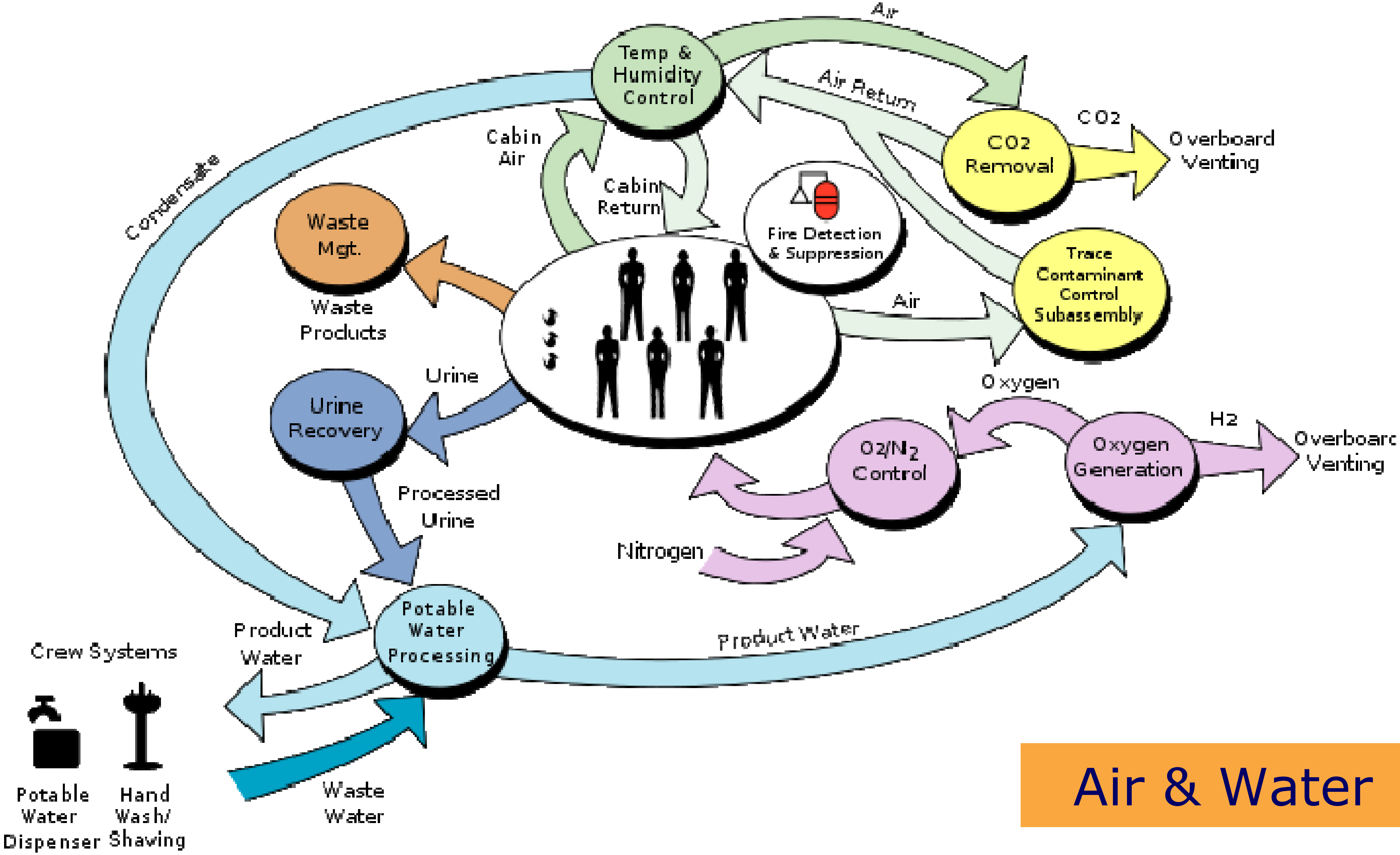


we can remove the effects of gravity on an object either by placing it in freefall or by recreating freefall conditions

ISS Facts and Figures

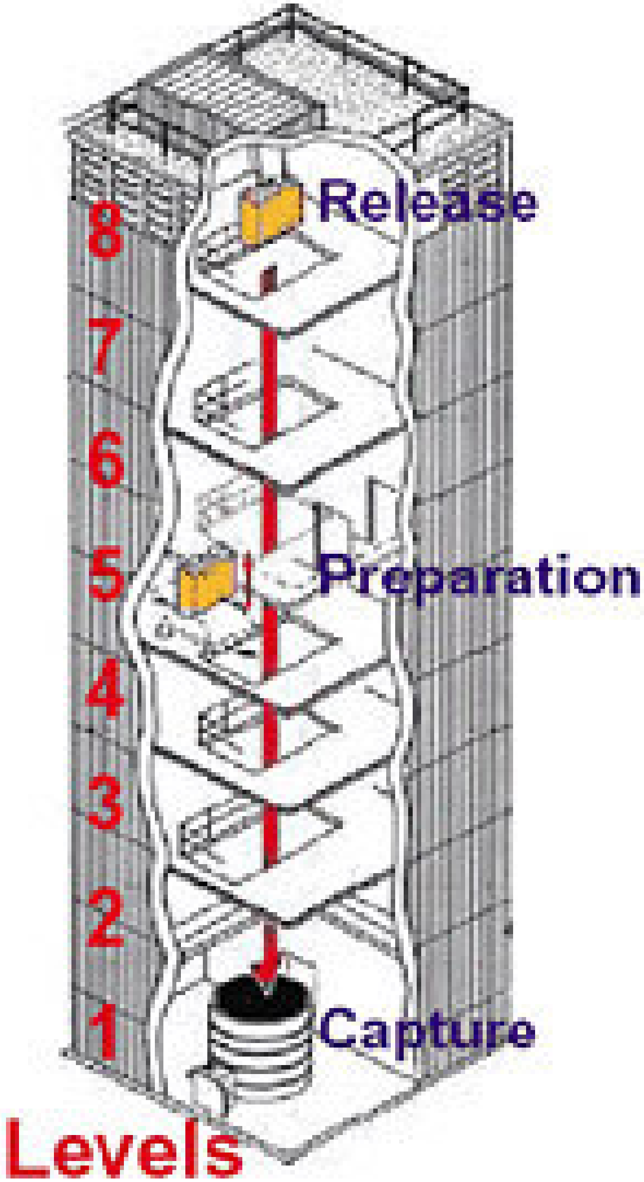
Call sign   Alpha, Station
Crew   Fully crewed 6
Currently aboard 6 (Expedition 42)
Launch   1998
Launch pad   Baikonur 1/5 and 81/23
Kennedy LC-39
Mass   approximately 450,000 kg
Length   72.8 m
Width   108.5 m
Height   ≈ 20 m
Pressurised volume 837 m3 (21/3/2011)

Atmospheric pressure   101.3 kPa
Perigee   416 km
Apogee   425 km
Orbital inclination   51.64 degrees
Average speed   7.66 km/s (27,600 km/h)
Orbital period   92.84 minutes
Orbit epoch   15 November 2014
Days in orbit   5851 (27 November)
Days occupied   5138 (27 November)
Number of orbits   91478
Orbital decay   2 km/month



Air
Temp & Humidity Control
Air Return
CO2
Overboard Venting
CO2 Removal
Cabin Air
Cabin Return
Condensate
Waste Mgt.
Fire Detection & Suppression
Trace Contaminant Control Subassembly
Waste Products
Air
Urine
Oxygen
Urine Recovery
H2
Overboard Venting
O2/N2 Control
Oxygen Generation
Processed Urine
Nitrogen
Product Water
Potable Water Processing
Product Water
Crew Systems
Potable Water Dispenser
Hand Wash/ Shaving
Waste Water

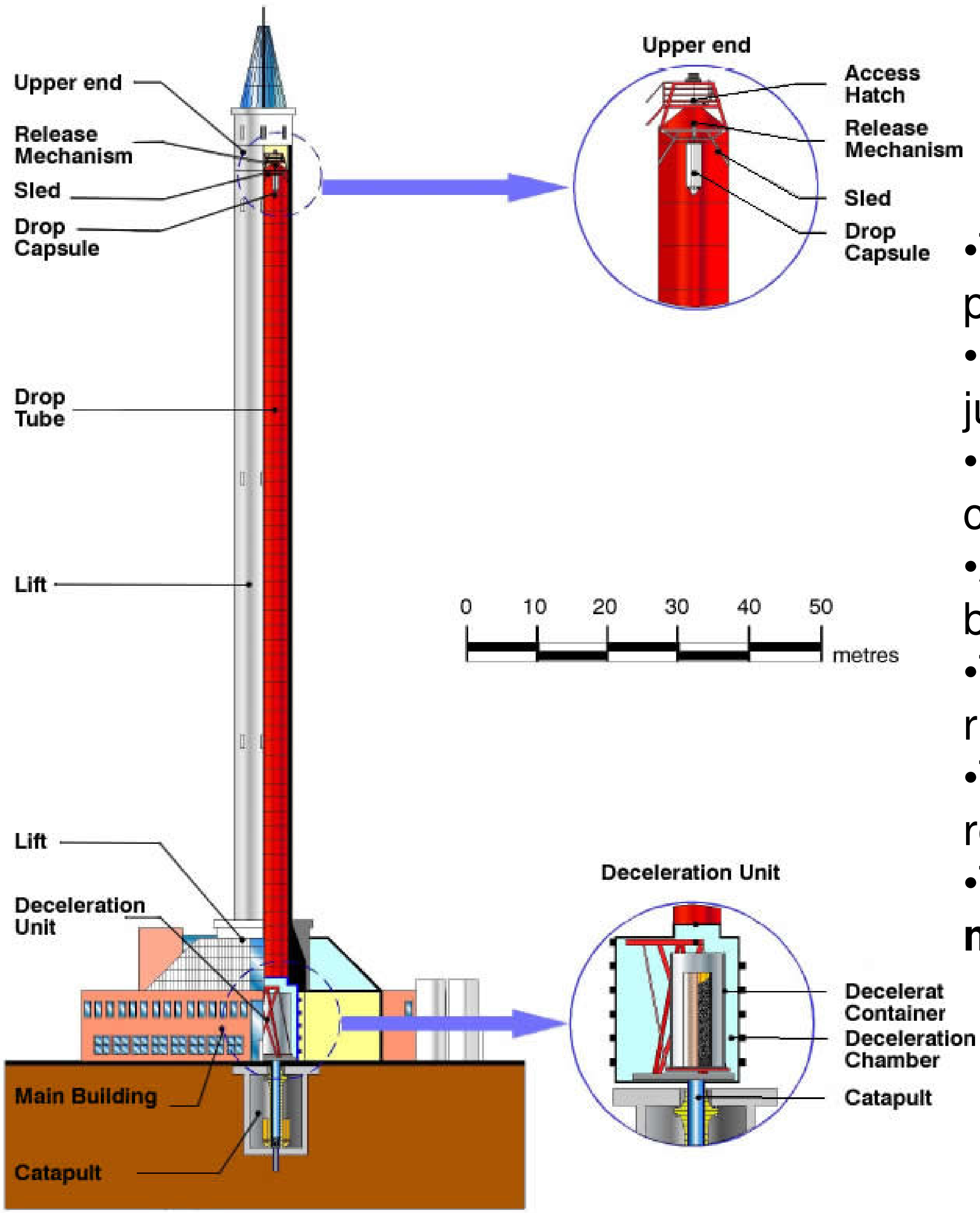
Air & Water



GRC NASA
2.2 seconds drop tower

- Microgravity Duration: 2.2 seconds
- Free Fall Distance: 79 feet (24 m)
- Gravitational Acceleration: < 0.001 g
- Mean Deceleration: 15 g
- Peak Deceleration: 30 g

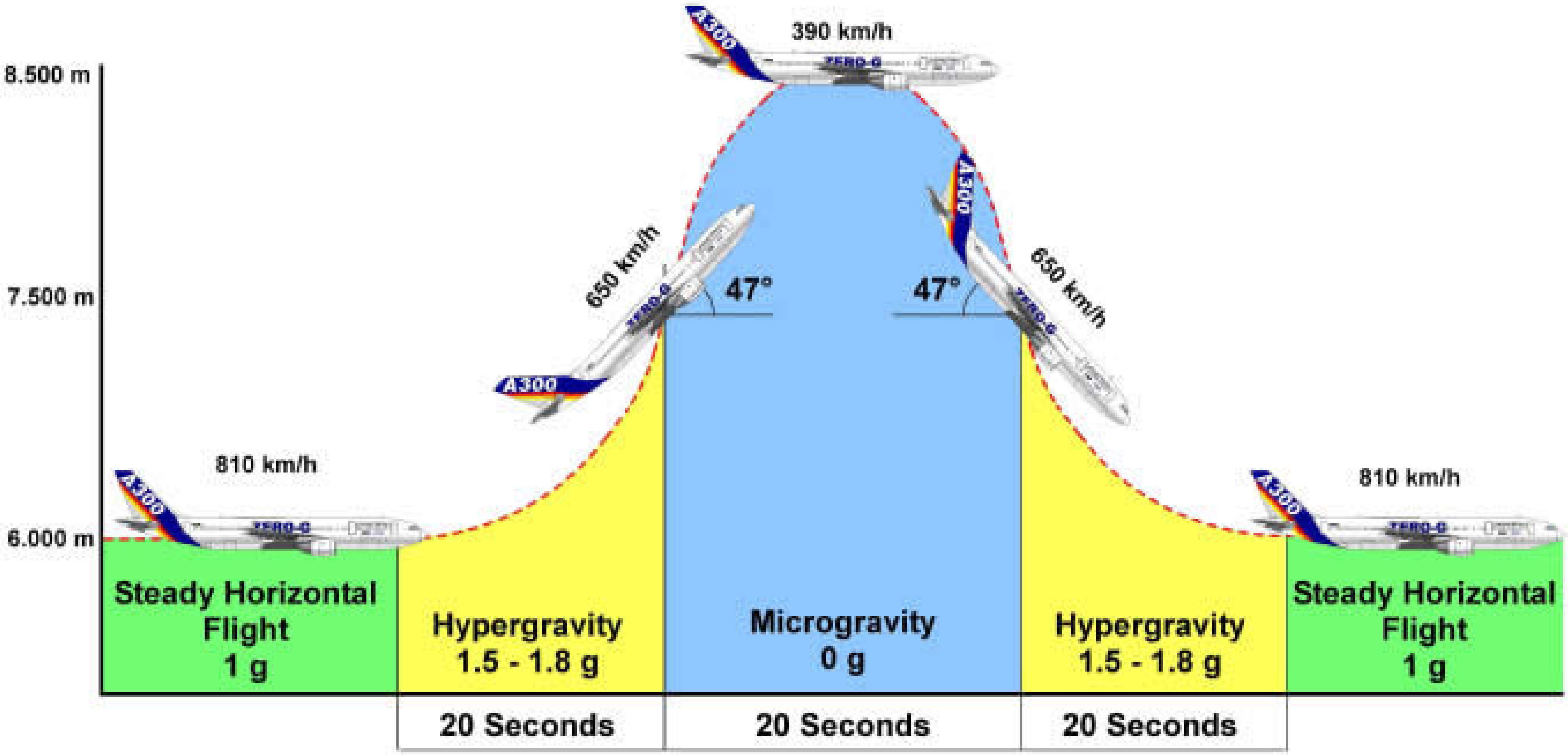
Drop Tower



- The time between an application and performing an experiment is short.
- Excellent standard of microgravity, just **10-5** g is considered standard.
- **4.74 seconds or 9.48 seconds** (with catapult: 30 g) of microgravity
- Access to the experiment shortly before and after the drop.
- Turnaround time is quick so several runs can be made in just a few days.
- There are minimal safety requirements.
- The **cost is low compared to other microgravity platforms**.

Drop Tower

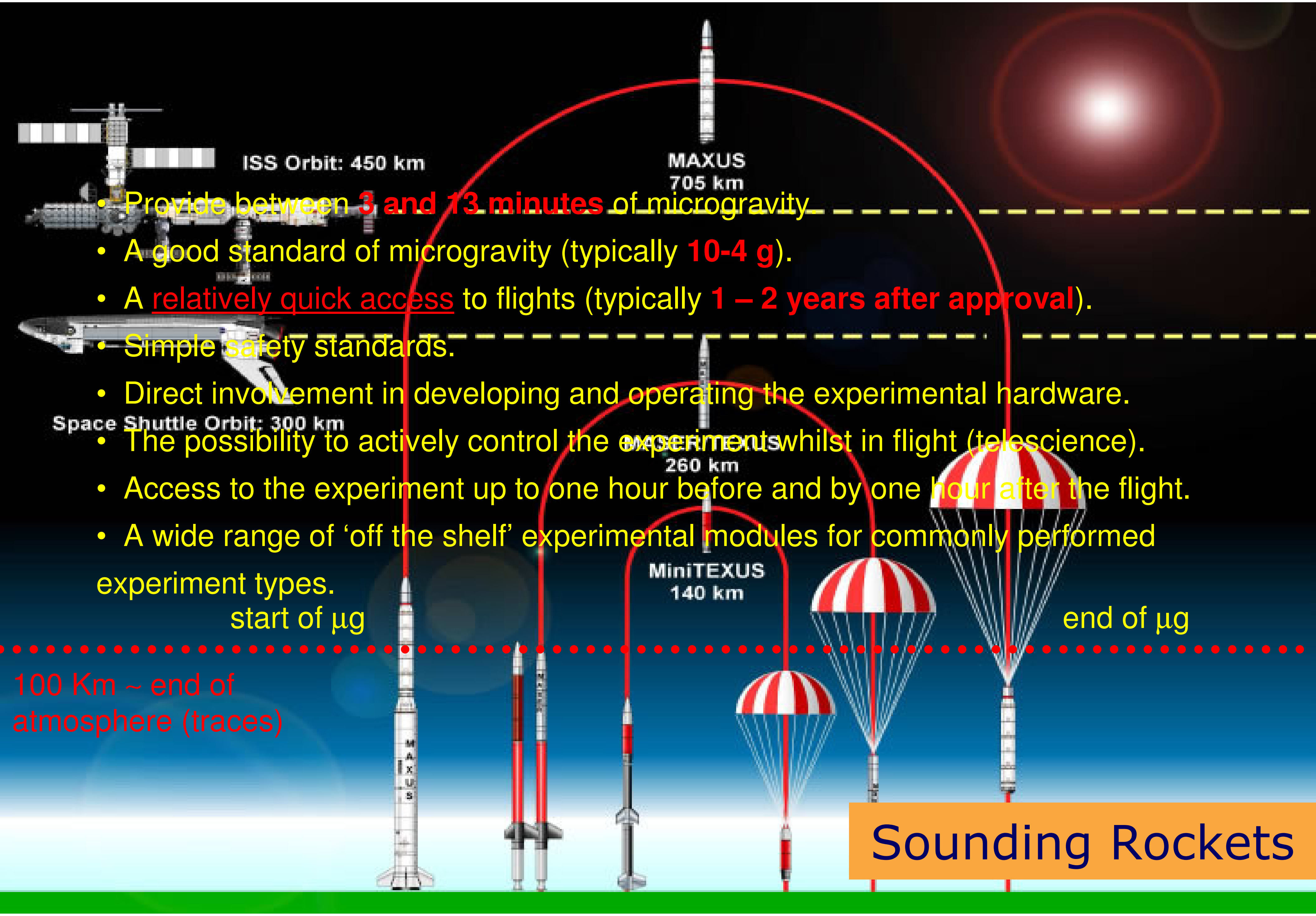
parabolic flight aircraft or “vomit comets”

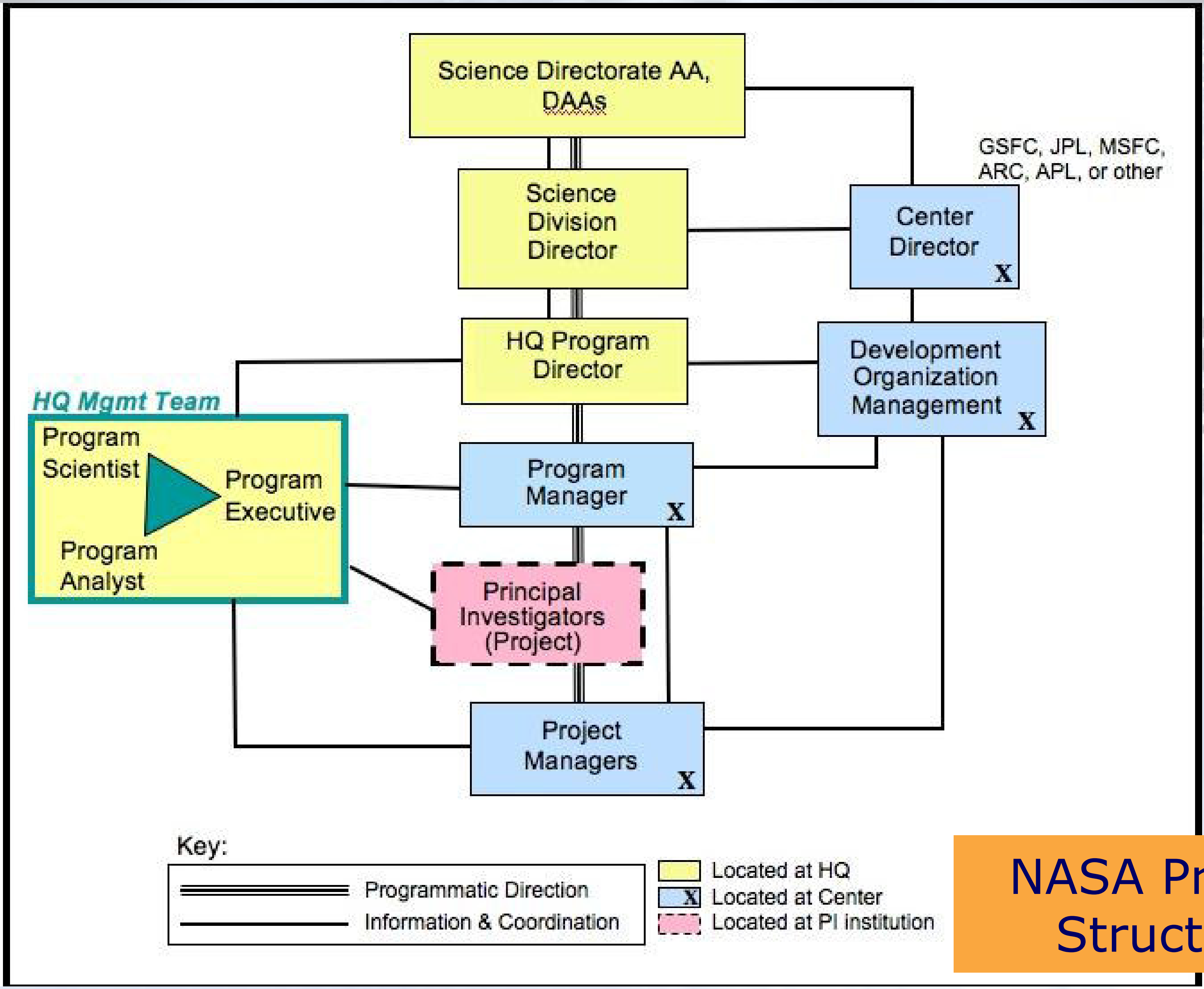


Parabolic flights

Sounding Rockets

- Provide between **3 and 13 minutes** of microgravity.
- A good standard of microgravity (typically **10-4 g**).
- A relatively quick access to flights (typically **1 – 2 years after approval**).
- Simple safety standards.
- Direct involvement in developing and operating the experimental hardware.
- The possibility to actively control the experiment whilst in flight (telescience).
- Access to the experiment up to one hour before and by one hour after the flight.
- A wide range of ‘off the shelf’ experimental modules for commonly performed experiment types.





NASA Project Structure

Increment 35/36 Investigation Locations

Investigation Locations

SpX-2 Investigations included

Facility Acronyms

CB – Clean Bench
CBEF – Cell Biology Experiment Facility
CGBA – Commercial Generic Biology Apparatus
CIR - Combustion Integrated Rack
EDR - European Drawer Rack
EMCS - European Modular Cultivation System
EPM - European Physiology Module
FIR – Fluids Integrated Rack
FPEF – Fluid Physics Experiment Facility
FSL – Fluid Sciences Lab
HRF – Human Research Facility
KUBIK - Incubator
LMM – Light Microscopy Module
MARES – Muscle Atrophy Research and Ex Sys
MDCA – Multi-Drop Combustion Apparatus
MELFI – Minus Eighty deg. Laboratory Freezer
MSG – Microgravity Sciences Glove box
MSL – Material Science Lab
MSPR – Multi purpose Small Payload Rack
MSRR - Materials Science Research Rack
MVIS – Microgravity Vibration Isolation System
PCRF – Protein Crystallization Research Facility
WORF - Window Observation Research Facility

External Facility / Payload

U.S. Lab

S3Truss – AMS-02
ELC2 – MISSE-8
ELC4
ELC3 – STP-H3, SCAN Testbed
ELC1 – STP-H4

WORF
EarthKAM, ISERV

MSG
CSLM-3, CCF, BASS

CIR
MDCA/FLEX-2, ICE-GA

FIR
LMM/ACE-1, CVB

MSRR
MSL/Batch2a-Set2

MELFI-3

EXPRESS Rack-1
CGBA-4/
MAMS, SAMS-II

EXPRESS Rack-2A
CGBA-6/CSI-06, ABRS
GLACIER1, Platereader
Microflow

Express Rack-6
GLACIER2, MERLIN

EXPRESS Rack 7
GLACIER4
Robonaut

EXPRESS Rack-8
Robonaut-Teleops,
Amine Swingbed,
CGBA-2/NLP Vaccine21

AMS laptop, BCAT (3, 4, 6), BCAT-C1, BRIC-17, **CARA**, Cell Bio Tech Demo, CEO, CFE-2, Comm&Outreach-2, DTN, EPO Demos, Hi Eff Bact Filt, HiMassSEE, RADI-N2, REM, Robonaut, SNFM, SPHERES-RINGS / Zero Robotics / Interact / HET Smartphone, Surface Telerobotics, TomatosphereIII, UBNT

FGB

VIABLE

Columbus

Solar
Vessel ID

EXPRESS Rack 3A
GLACIER3,
EMCS/SeedlingGrowth
ISS Ham, Veggie

HRF-1
SLAMMD/
ICV, Ocular Health,
Spinal USND,
Vessel Imaging

HRF-2
PFM/PAM, RF
BP Reg, ENERGY,
Microbiome,
Nutrition, ProK,
Repository,
Vascular

MARES
SARCOLAB

FSL
MVIS/ FASES

EDR
KUBIK/

BioLab

EPM
BP Reg,
DOSIS-3D, ENERGY

BCAT (3, 4, 6), BCAT-C1, Circadian Rhythms, Comm&Outreach-2, DIAPASON, DOSIS-3D, ENERGY, EPO-Parmitano, Journals, RADI-N2, Reaction Self Test, Reversible Figures, Space Headaches, Skin-B, TRITEL, Vessel ID

JEM - KIBO

EXPRESS Rack-4
NanoRacks Platforms/
Modules-19, 20, 21, 22
DECLIC/DSI-R, ALI

EXPRESS Rack-5
SpaceDRUMS

MELFI-1
Space Pup**

MELFI-2

SAIBO
CB/
CBEF/

RYUTAI
FPEF/
PCRF/JAXA PCG

KOBAIRO

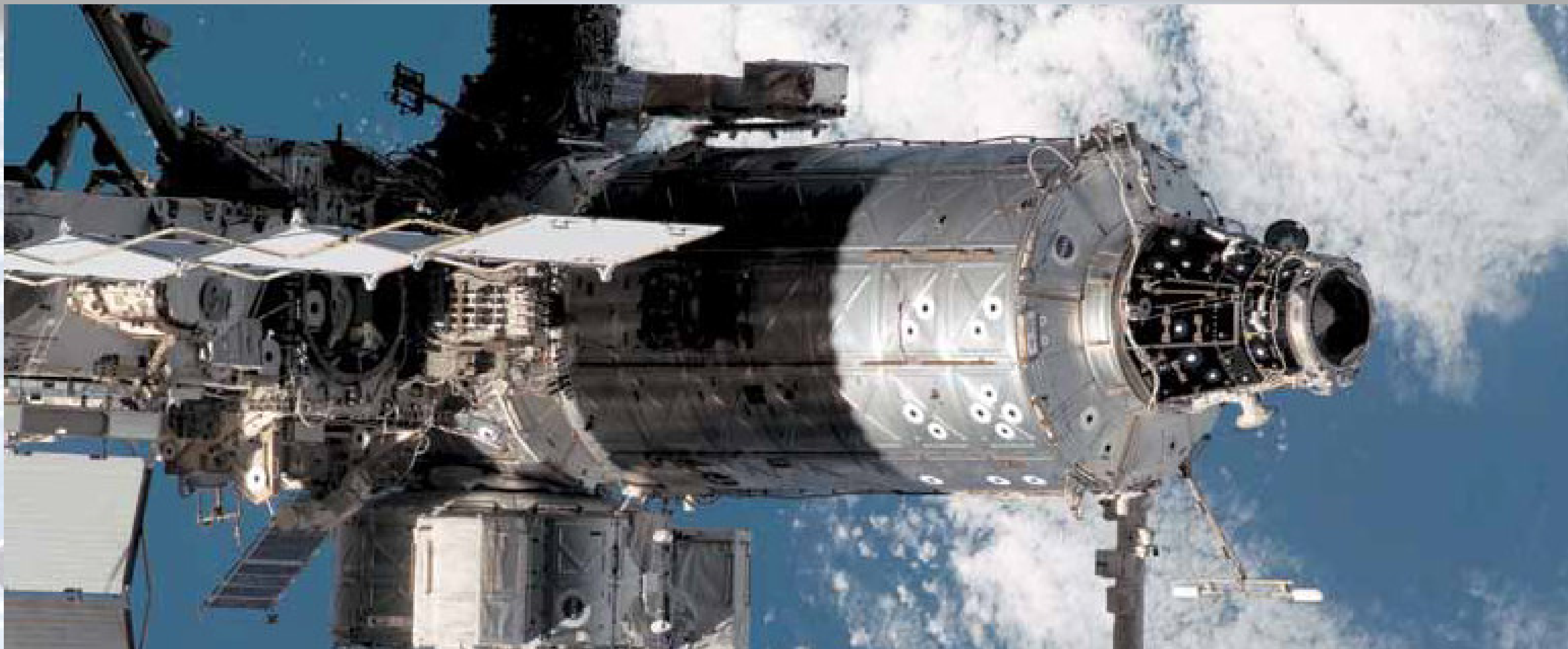
MSPR
AQH/Medaka
Osteoclast-2

Area PADLES-10, Asian Seed 2013, Bio Rhythms-48h, BCAT (3, 4, 6), BCAT-C1, RADI-N2, CFE-2, Commercial, CubeSats, DIAPASON, Microbe-A1, SNFM, SPHERES-RINGS / Zero Robotics / Interact / HET Smartphone, ~~Tanpopo~~**, TEM

HREP/HICO, RAIDS

SMILES, SEDA-AP, MAXI, MCE

Destiny Racks



Fluids Integrated Rack (FIR)

A complementary fluid physics research facility designed to accommodate a wide variety of microgravity experiments.

Materials Science Research Rack-1 (MSRR-1)

Accommodates studies of many different types of materials.

Window Observational Research Facility (WORF)

Provides a facility for Earth science research using the Destiny science window on the ISS.

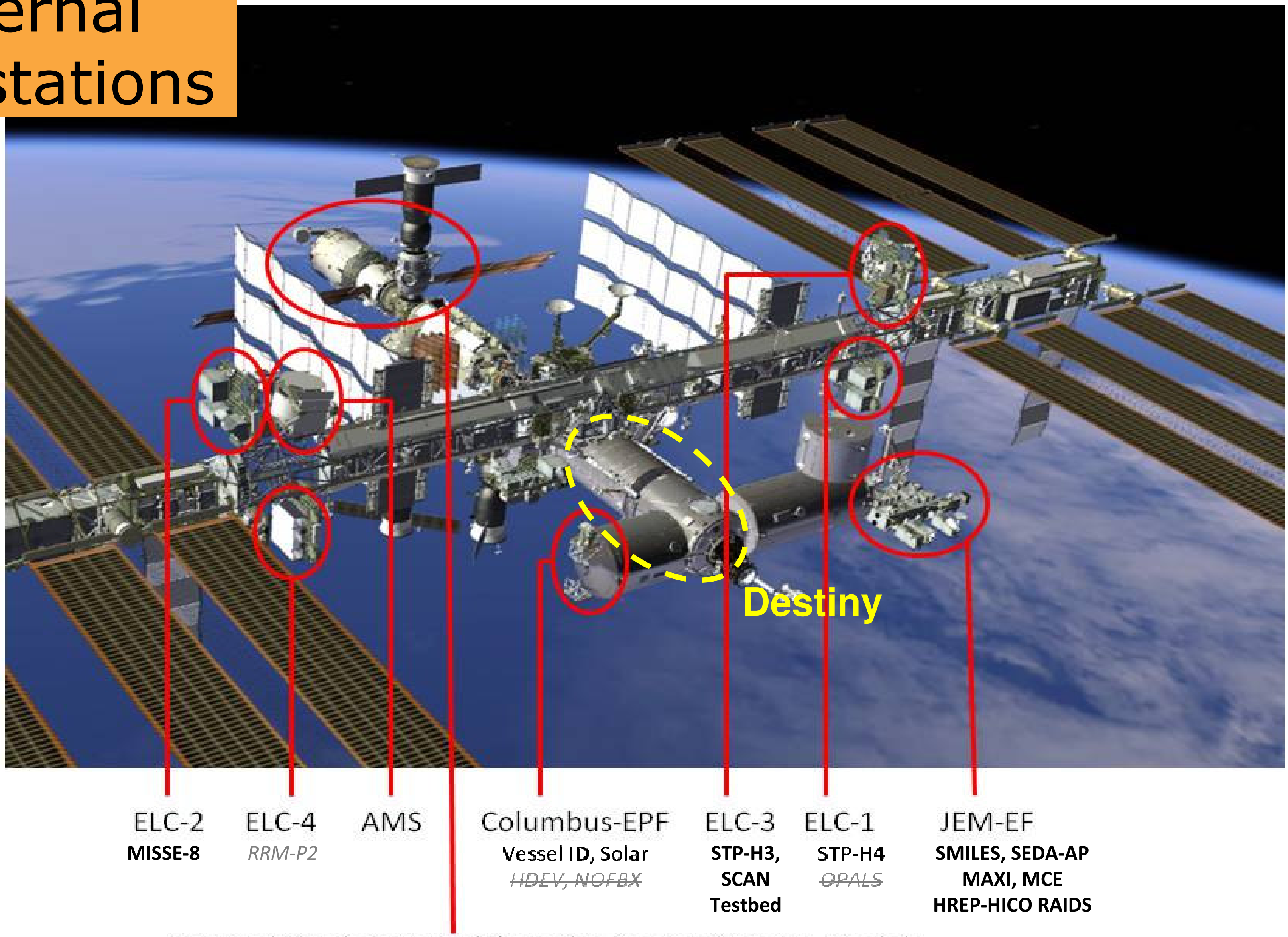
Minus Eighty-Degree Laboratory Freezer fo ISS (MELFI-2)

A refrigerator/freezer for biological and life science samples.

Combustion Integrated Rack (CIR)

Used to perform sustained, systematic combustion experiments in microgravity.

External Workstations

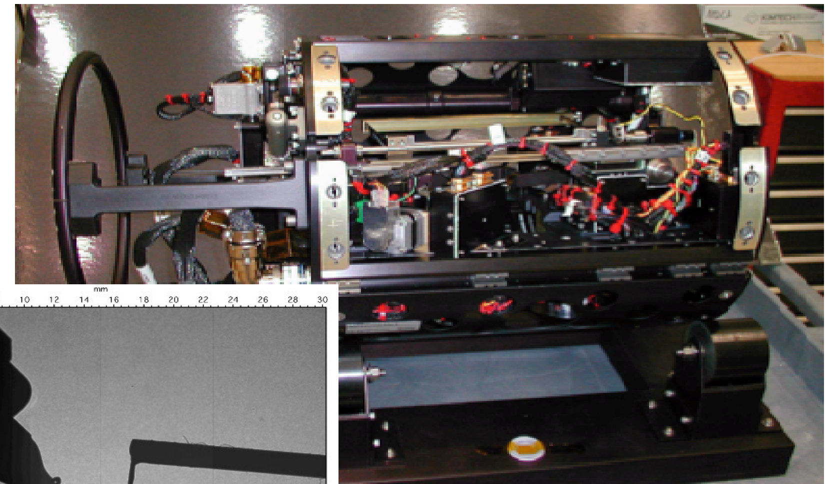


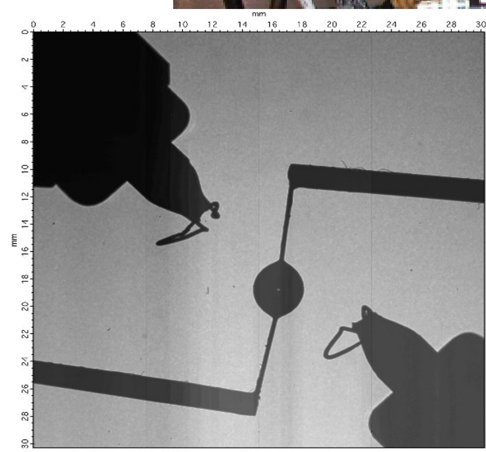
- Launched to ISS in Nov 2008 (Shuttle Endeavor)
- Operational since Mar 2009
- Multi-purpose facility for housing a range of fundamental science and spacecraft fire safety experiments
- CIR consists of:
  - 90 liter combustion chamber
  - Fuel Oxidizer Mixing Apparatus (FOMA)
  - Passive Rack Acceleration System
- Experiment-specific hardware inserted into the CIR combustion chamber
  - Multi-User Droplet Combustion Apparatus (MDCA)
- Flame Extinguishment Experiment (FLEX) is the first experiment
  - Droplet combustion experiment
  - FLEX-2
  - FLEX-2J: NASA/JAXA/Nihon Univ./Yamaguchi Univ. collaboration
  - FLEX-ICE-GA: NASA/ASI/Istituto Motori-CNR collaboration

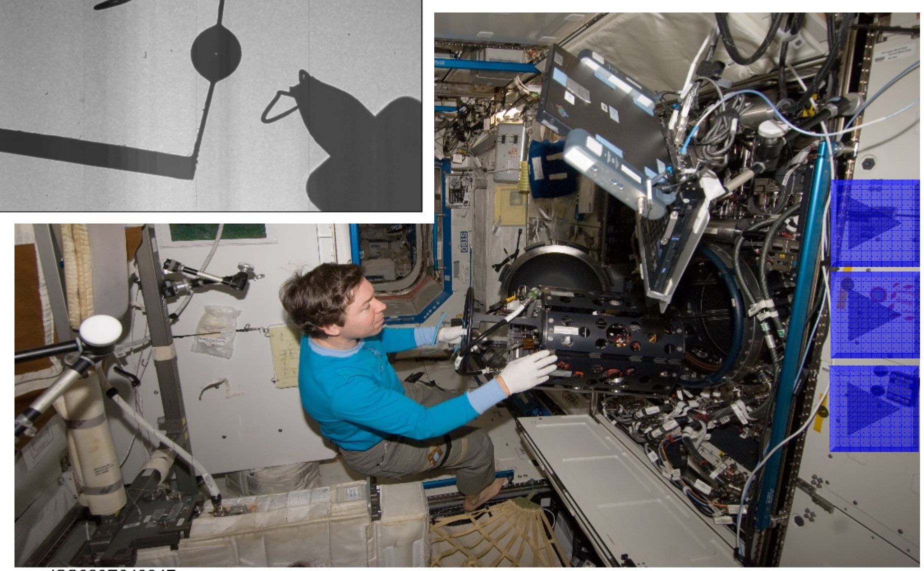
The Combustion Integrated Rack (CIR)

- **Provides capability to store, dispense and deploy free-floating and fiber-supported droplets in microgravity.**
- **Fuel stored in two (crew-replaceable) syringe connected to the two fuel needles**
- **Ignition from two horizontally opposed hot-wire igniters**

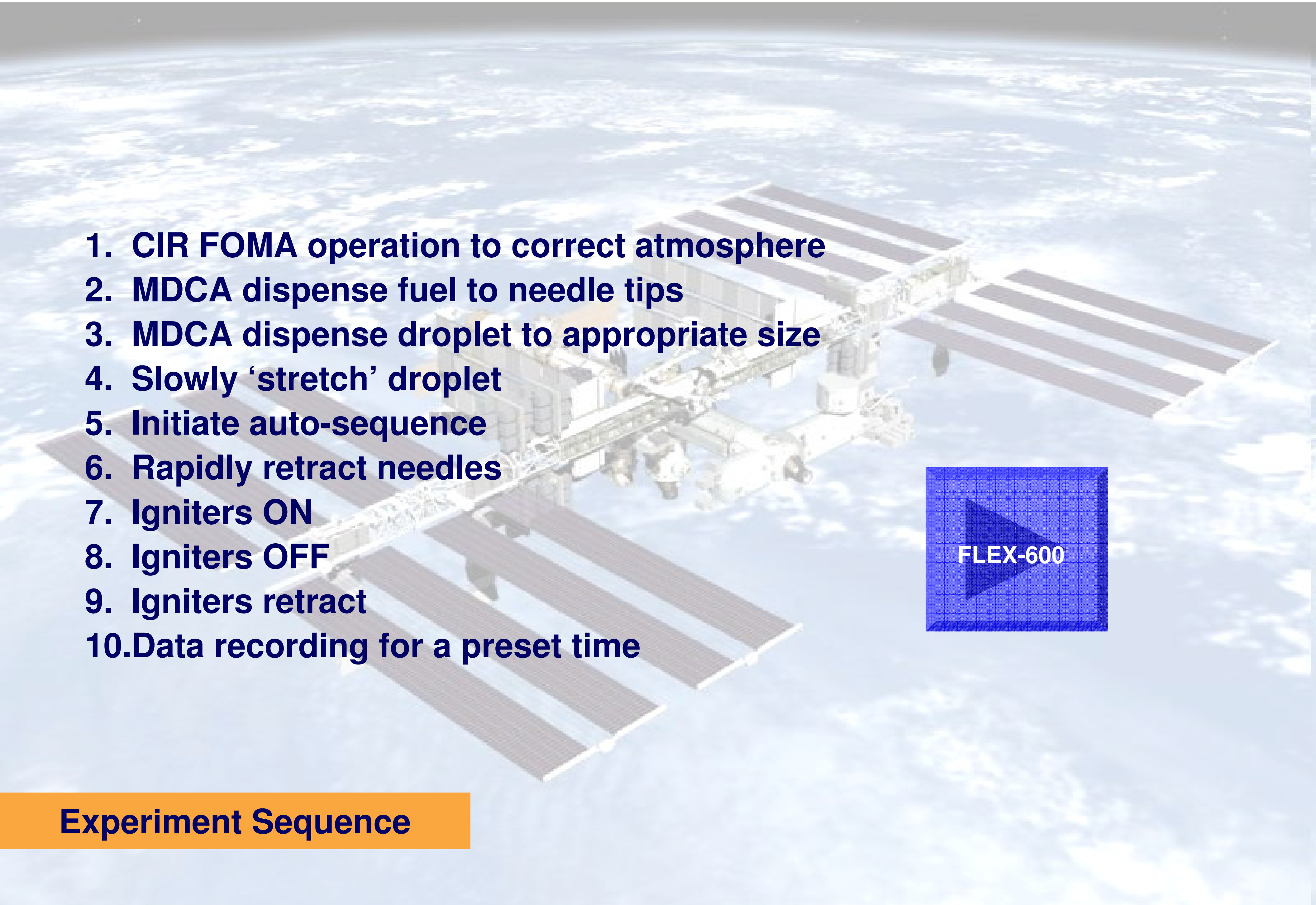
Multi-User Droplet Combustion Apparatus (MDCA)







ISS020E043347



1. CIR FOMA operation to correct atmosphere
2. MDCA dispense fuel to needle tips
3. MDCA dispense droplet to appropriate size
4. Slowly ‘stretch’ droplet
5. Initiate auto-sequence
6. Rapidly retract needles
7. Igniters ON
8. Igniters OFF
9. Igniters retract
10. Data recording for a preset time

FLEX-600

Experiment Sequence

Experiment Diagnostics

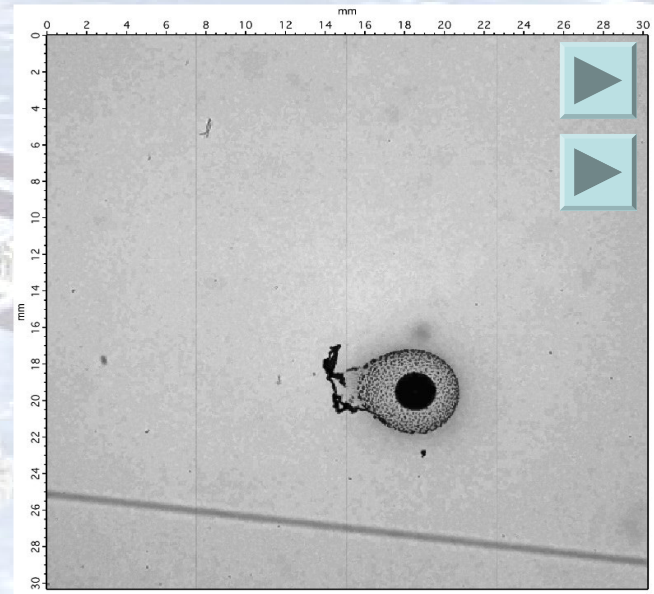
<u>Backlit view of droplet</u>:
- Droplet size, soot shell dynamics, soot volume fraction

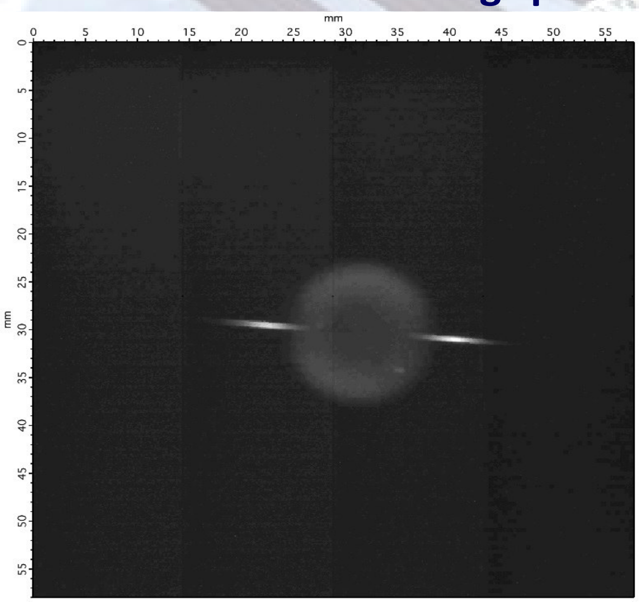
<u>Flame luminosity filtered for *OH** (308 nm)</u>
- Flame size, relative intensity, flame dynamics

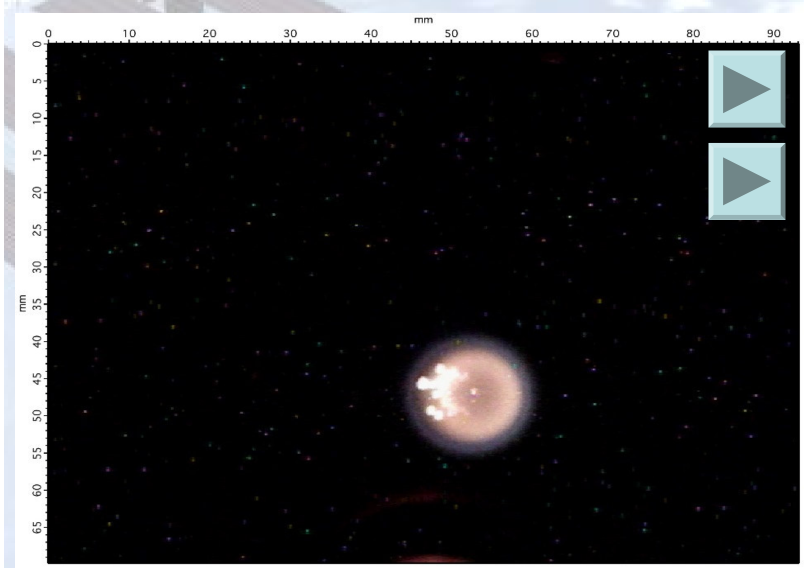
<u>Color camera view of flame</u>
- What the eye would see
- Flame size, flame dynamics, flame color (yellow, blue)

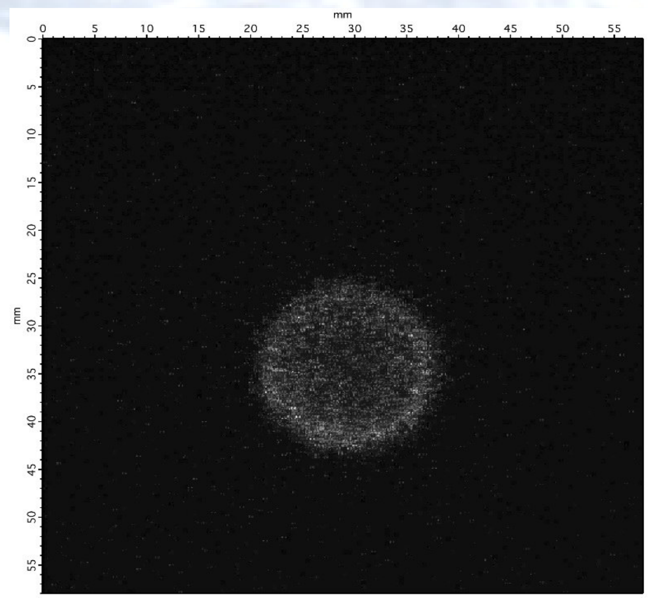
<u>IR-filtered view of flame/fiber</u>
- Estimate of flame temperature (for fiber-supported tests)
- Estimate of soot temperature (in combination with soot volume fraction)

<u>Radiometric views of flame</u>
- Wide band radiometer
- Narrow band looking specifically at H_2O emission



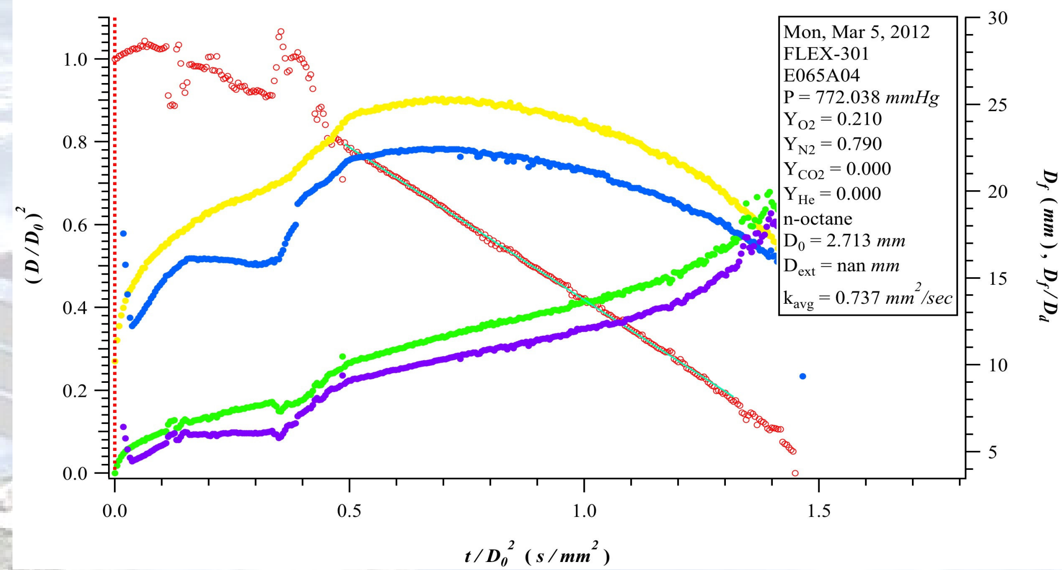


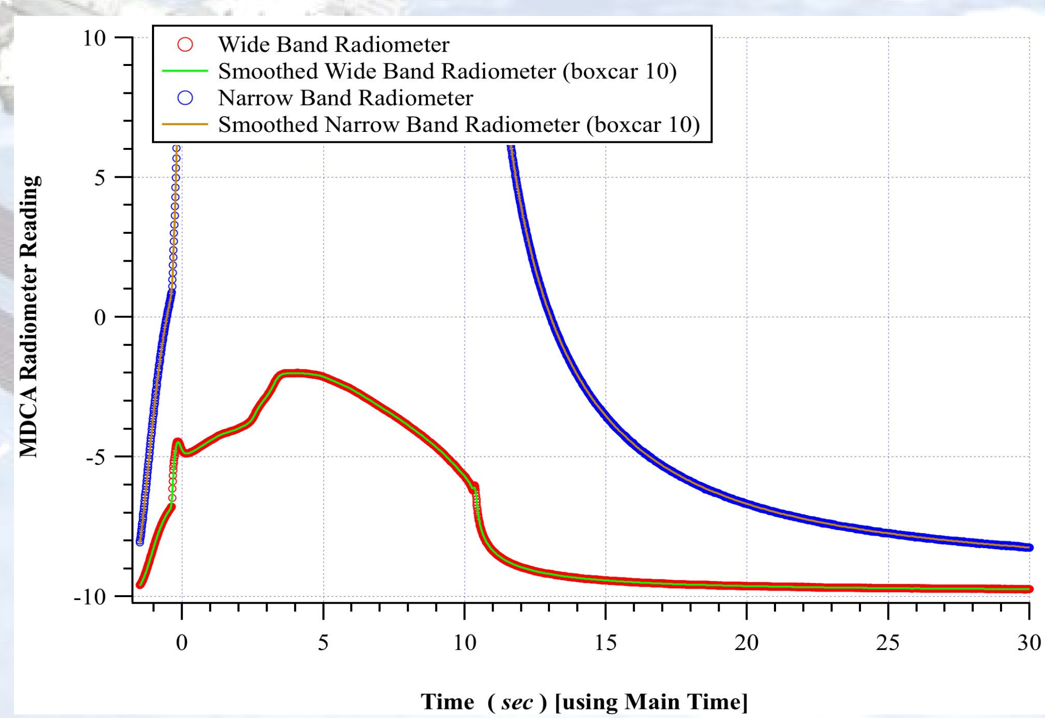


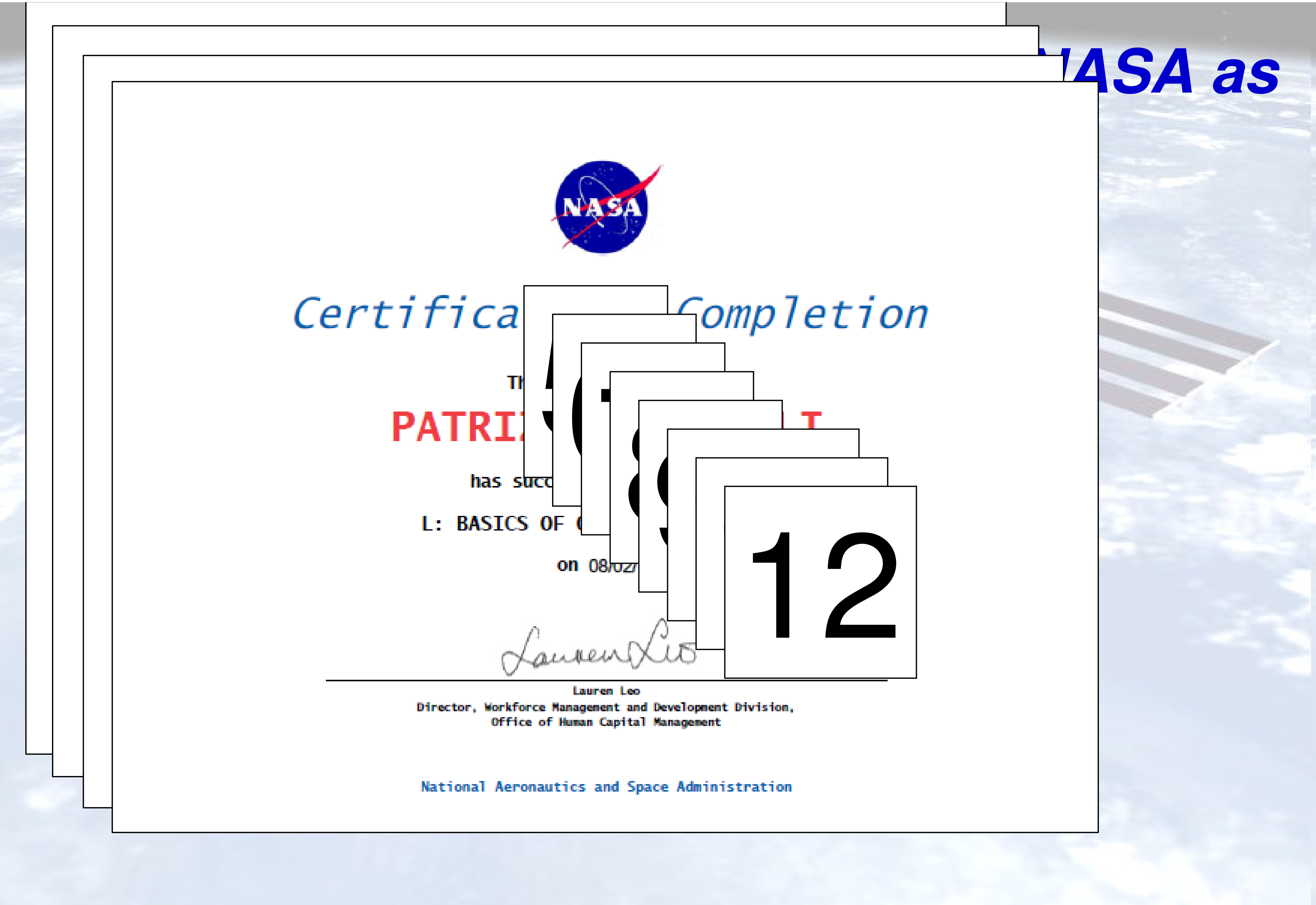


Experiment Methodology

- 4 – 10 Test points (droplet combustion tests per day)
- 1 or 2 ambient atmospheric conditions per test day
- Approximately 1-2 test day per week
- Real time experiment control at NASA GRC TSC
- Real-time audio/video feed to ASI/Istituto-Motori
- Approximately 1 day required for data downlink
- Approximately 1 week for data decompression/formatting
- Collaborative data analysis between Istituto-Motori and NASA
- 1,5 months of experiment operations
- Schedule allows for modification of test matrix between test point days
- Examine parameter space of interest based on previous results

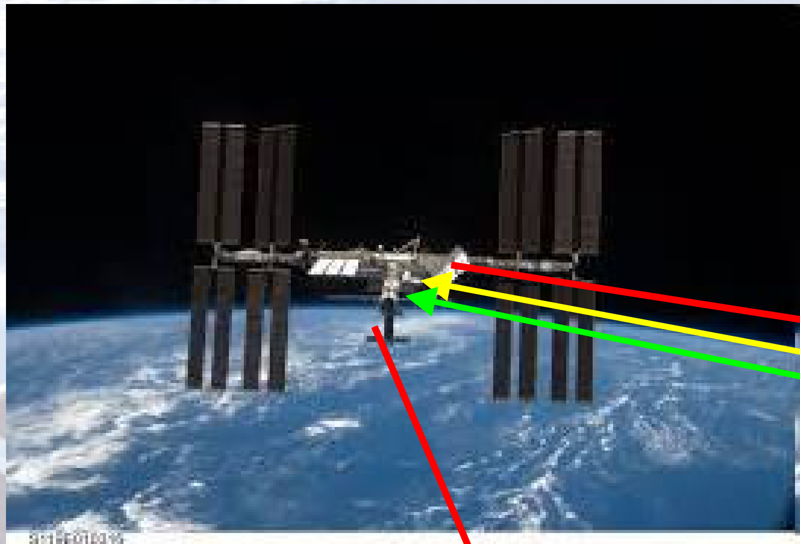


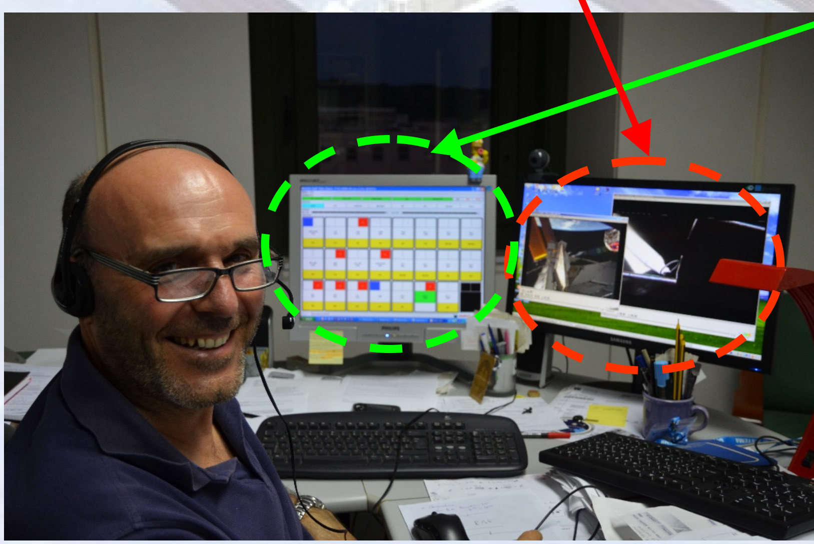



Completion
12
Lauren Leo
Director, Workforce Management and Development Division,
Office of Human Capital Management
National Aeronautics and Space Administration

All experiment operations controlled at *John H. Glenn Research Center* (GRC*) Telescience Support Center* (TSC) Cleveland, Ohio.

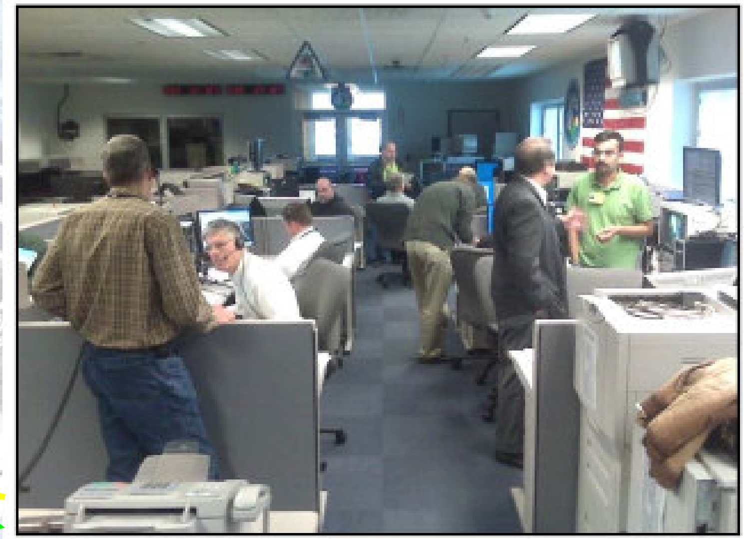
- Video/audio link to external PI





Istituto Motori – CNR, Napoli 30/7/2013 00:12

Experiment Operation



Fluids & Combustion Facility Mission Operations at TSC, Building 333

- Determination of fundamental combustion characteristics (burning rates; flame front as a function of time; droplet lifetimes) of blends 50%/50% vol of n-decane/1-hexanol and 50%/50% vol of n-heptane/ethanol.
- Analysis of soot tendency of the blends in terms of soot volume fraction and soot temperature as a function of time
- Characterization of flame extinguishment as function of droplet diameter and ambient pressure and oxygen concentration.
- Evaluation of the stability of the blends and their ideal/non-ideal behavior.
- Formation of a database and comparison with experimental data at normal gravity.
- Comparison of the experimental data with numerical models.

BUT ALSO

New Combustion Behaviors

Expected Results

Ing. Filippo Ugolini, ***President AGT Engineering***
Dr.ssa Silvia Ciccarelli, ***Project Manager***

Dr.ssa Delfina Bertolotto, ***Responsible ASI Microgravity Unit***
Ing. Salvatore Pignataro, ***Responsible ASI ISS Utilizzation***
Ing. Gabriele Mascetti, ***Program Manager ASI***

Dr. J. Mark Hickman, ***Project Manager, NASA GRC***
Dr. Marty O'Toole, ***Engineering Team Lead, ZIN Technologies, Inc.***

Acknowledgements

Thank you for your attention …..

….. first part


Backstage

the meeting at the headquarter of ASI

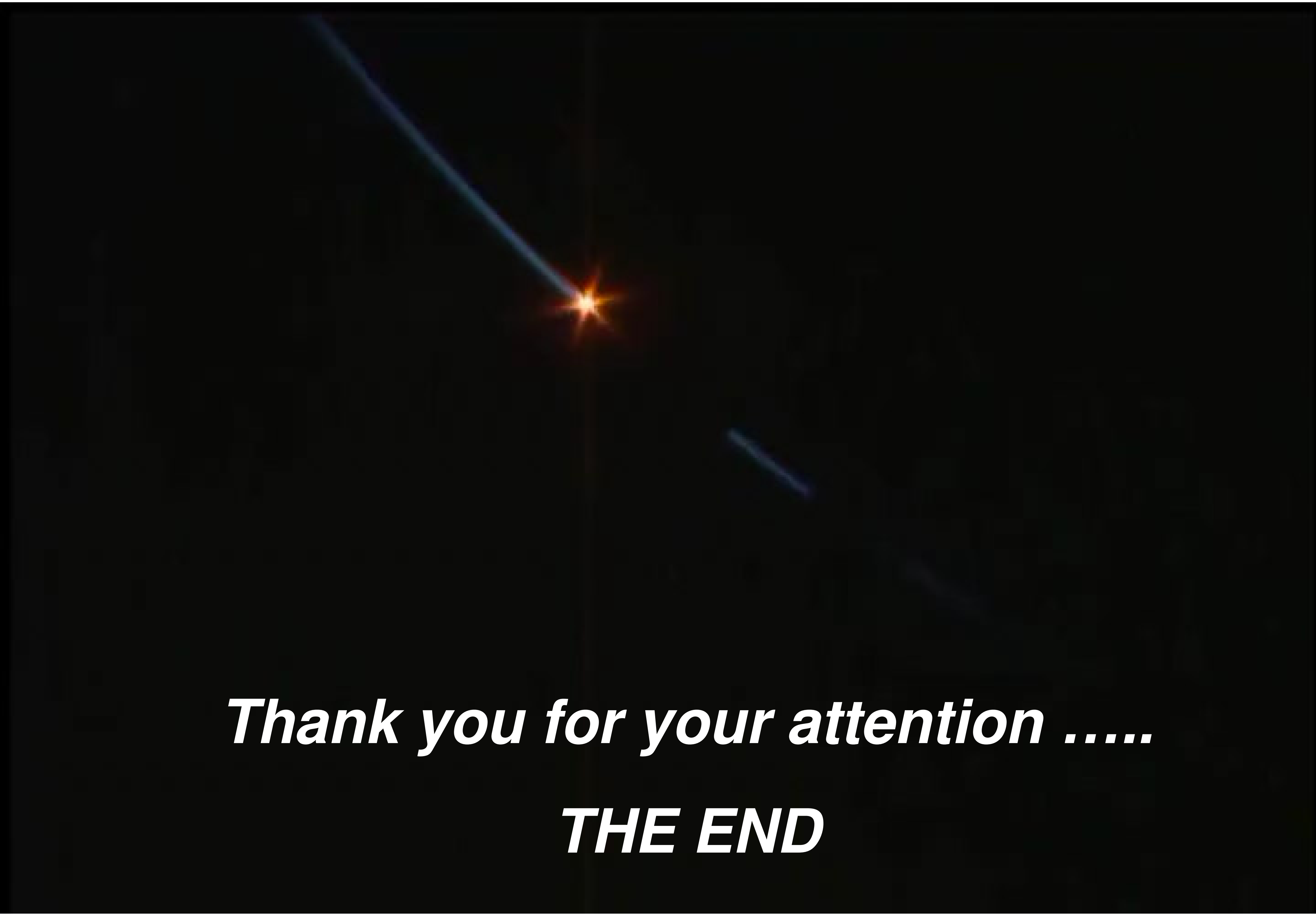
with the astronaut

Luca Parmitano

after the return to Earth

Mickey Mouse (in Italian: Topolino) n.3006 del 9 Luglio 2013

Our first very impressive PUBLICATION with huge **IMPACT FACTOR**


Thank you for your attention …..
THE END