Scuola Politecnica e delle Scienze di Base
Università Federico II, Napoli
12 ottobre 2019

Le nuove possibilità della combustione a gravità zero

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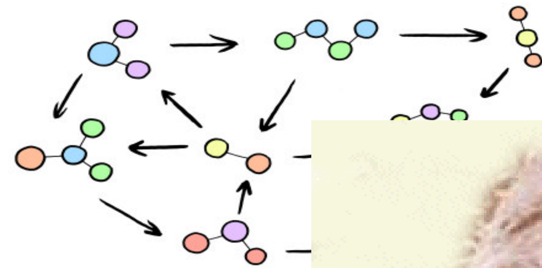
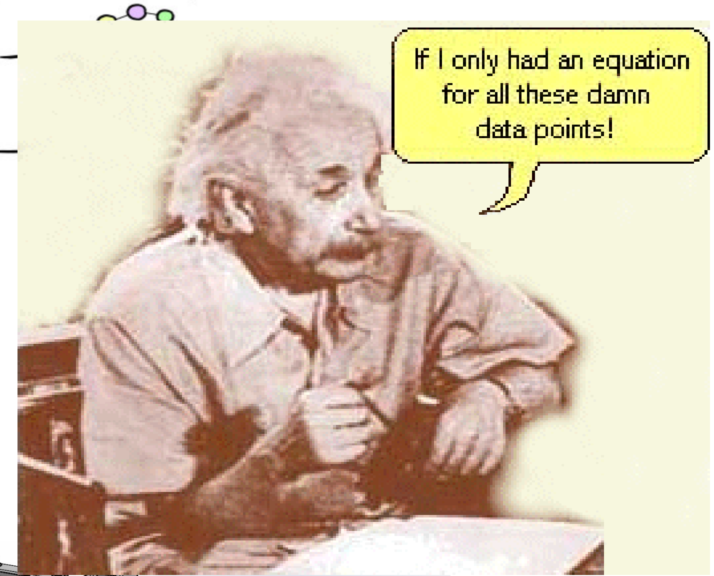
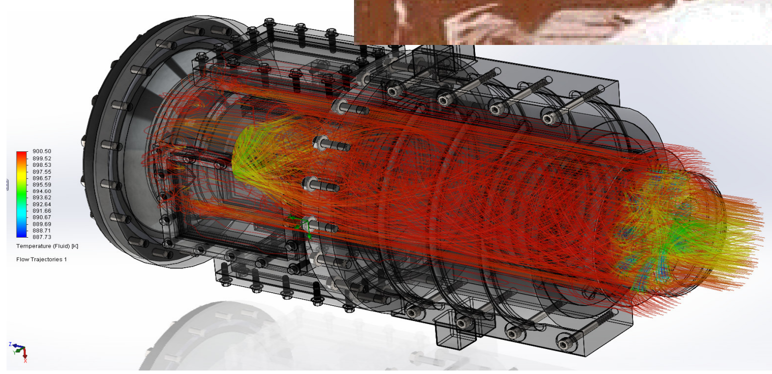
Istituto Motori – CNR , Napoli, Italy

Rationale: CFD and Chemical Kinetics

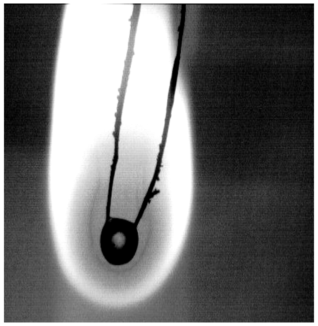
- The critical point is in the fact that the chemical models have to be used in connection with very heavy CFD simulations
- Also for single component fuels, models with thousands reactions are used to describe the evolution of matter. This approach becomes impracticable when practical fuels with hundreds 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.



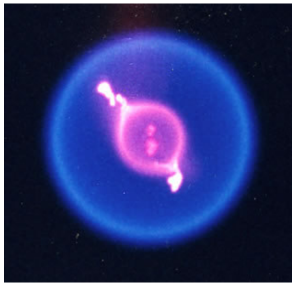




- Simplified fluid-dynamics, heat and mass transfer, to study the fundamental processes during heating and combustion of fuel droplets
- Simplified fuels, the surrogates, that well represent practical fuels in terms of composition, thermo-physical or combustion properties
  - Decane: jet A fuel surrogate;
  - 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

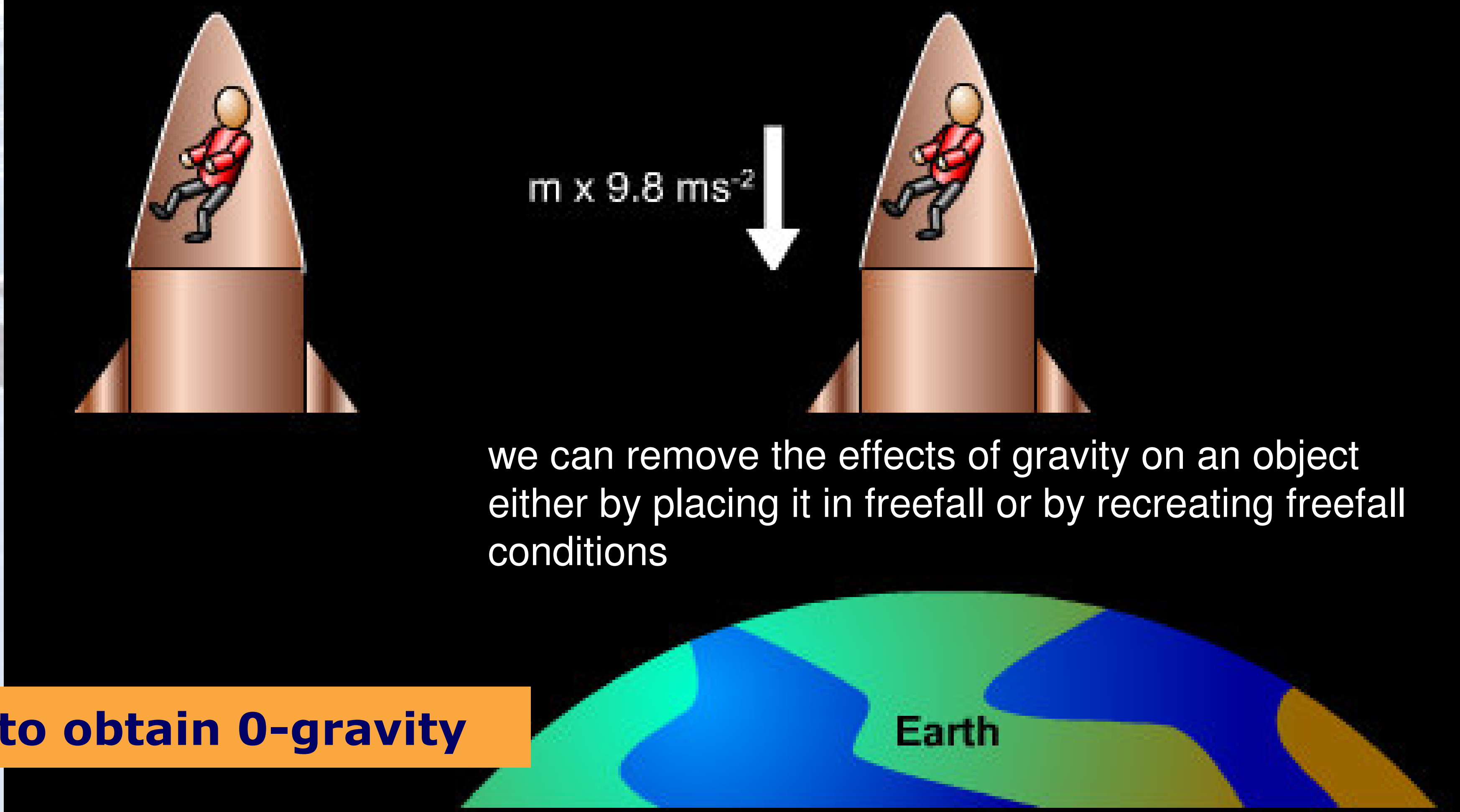
normal g

μg

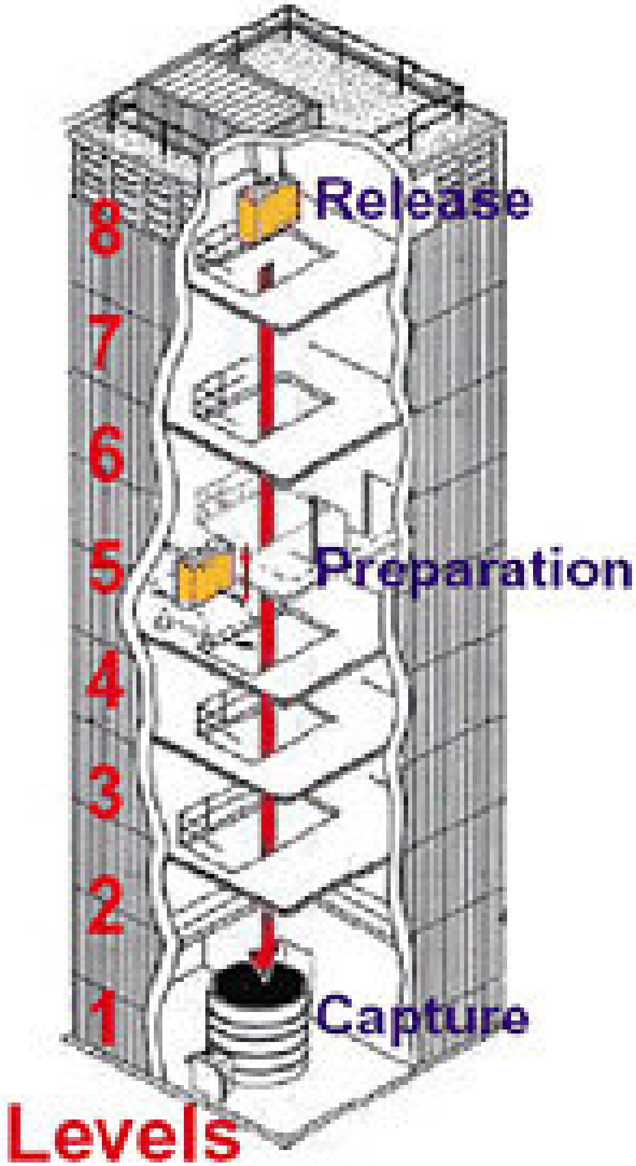
Rationale: Why μg?

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



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

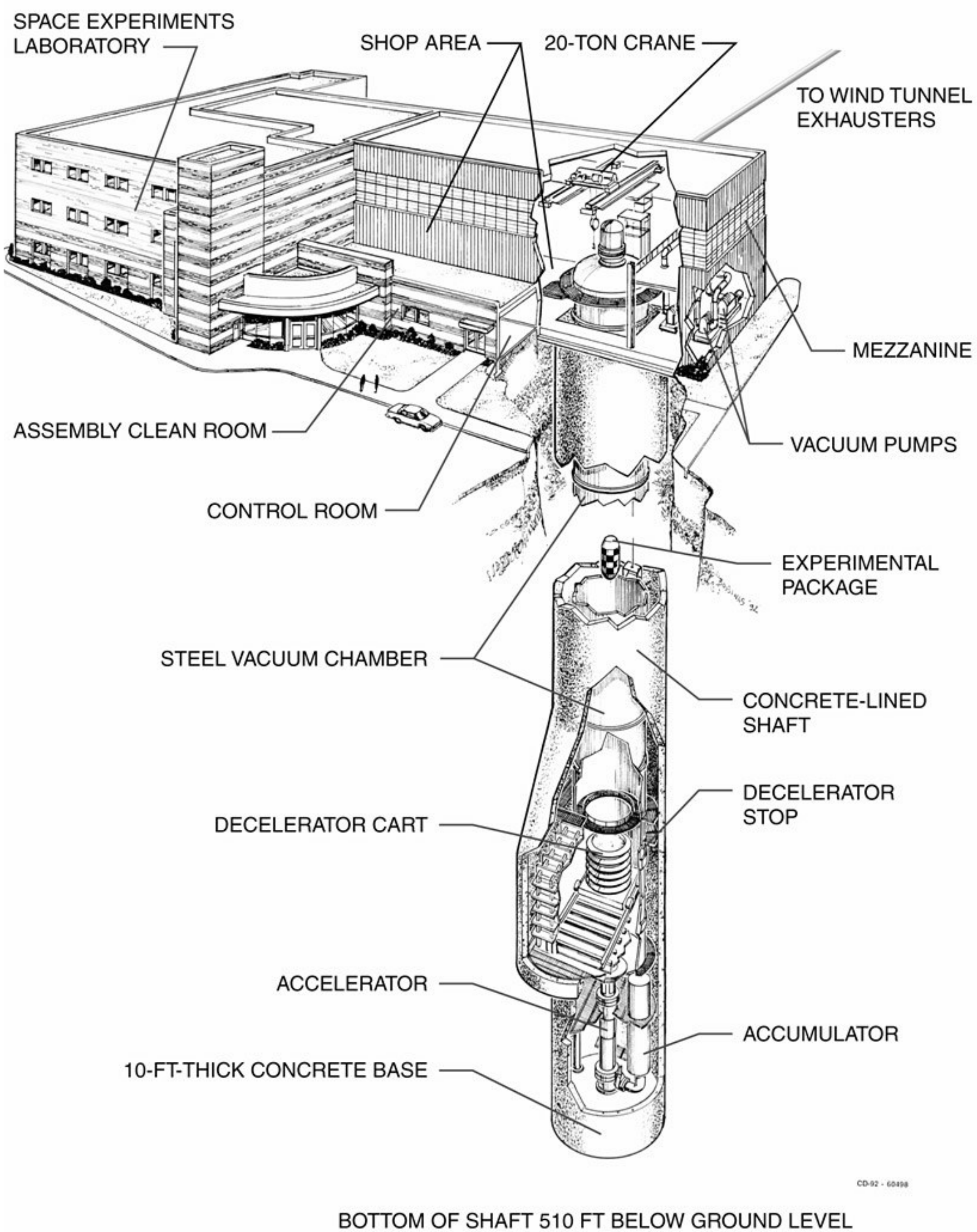
How to obtain 0-gravity



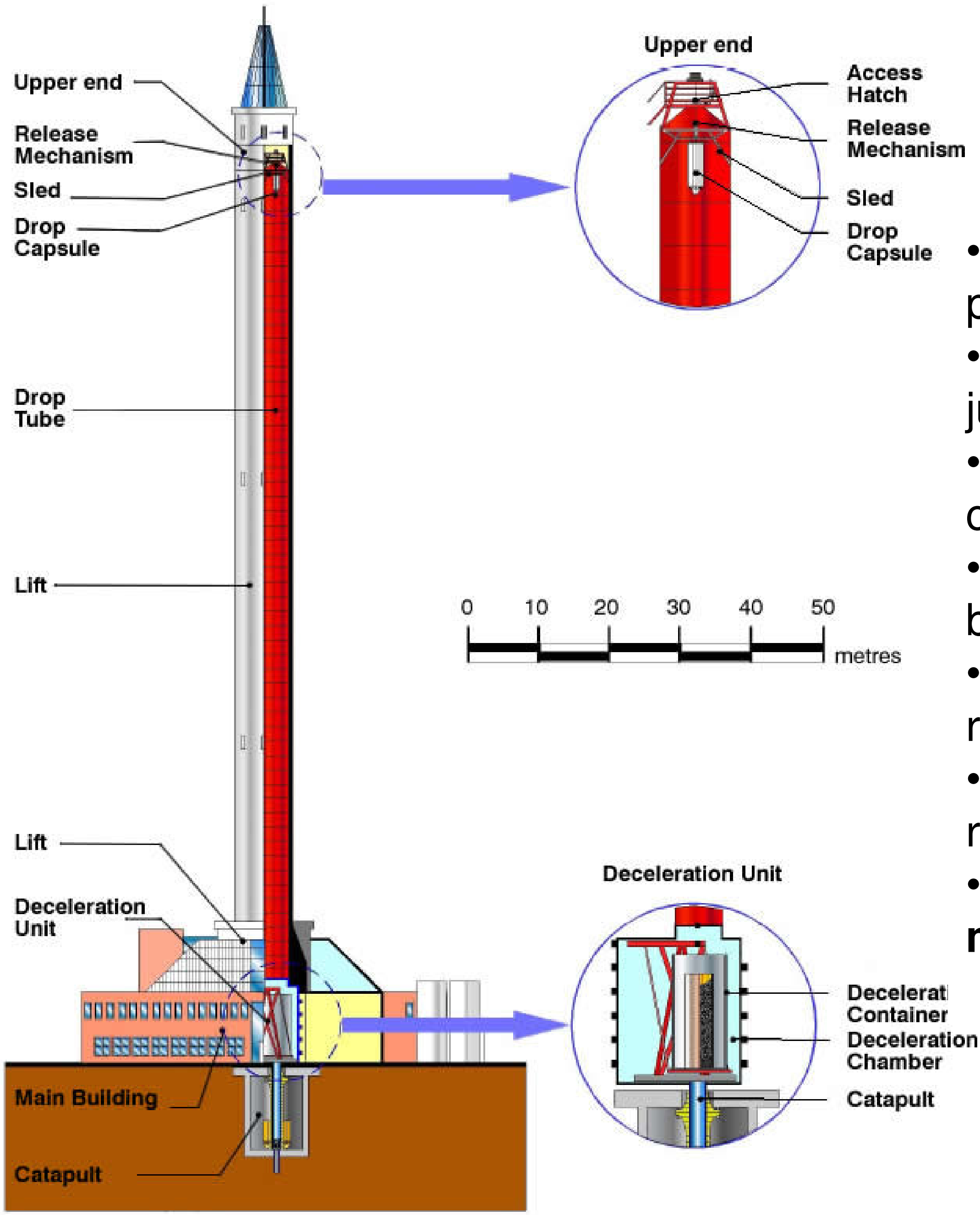
GRC NASA
2.2 seconds drop tower

- **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**

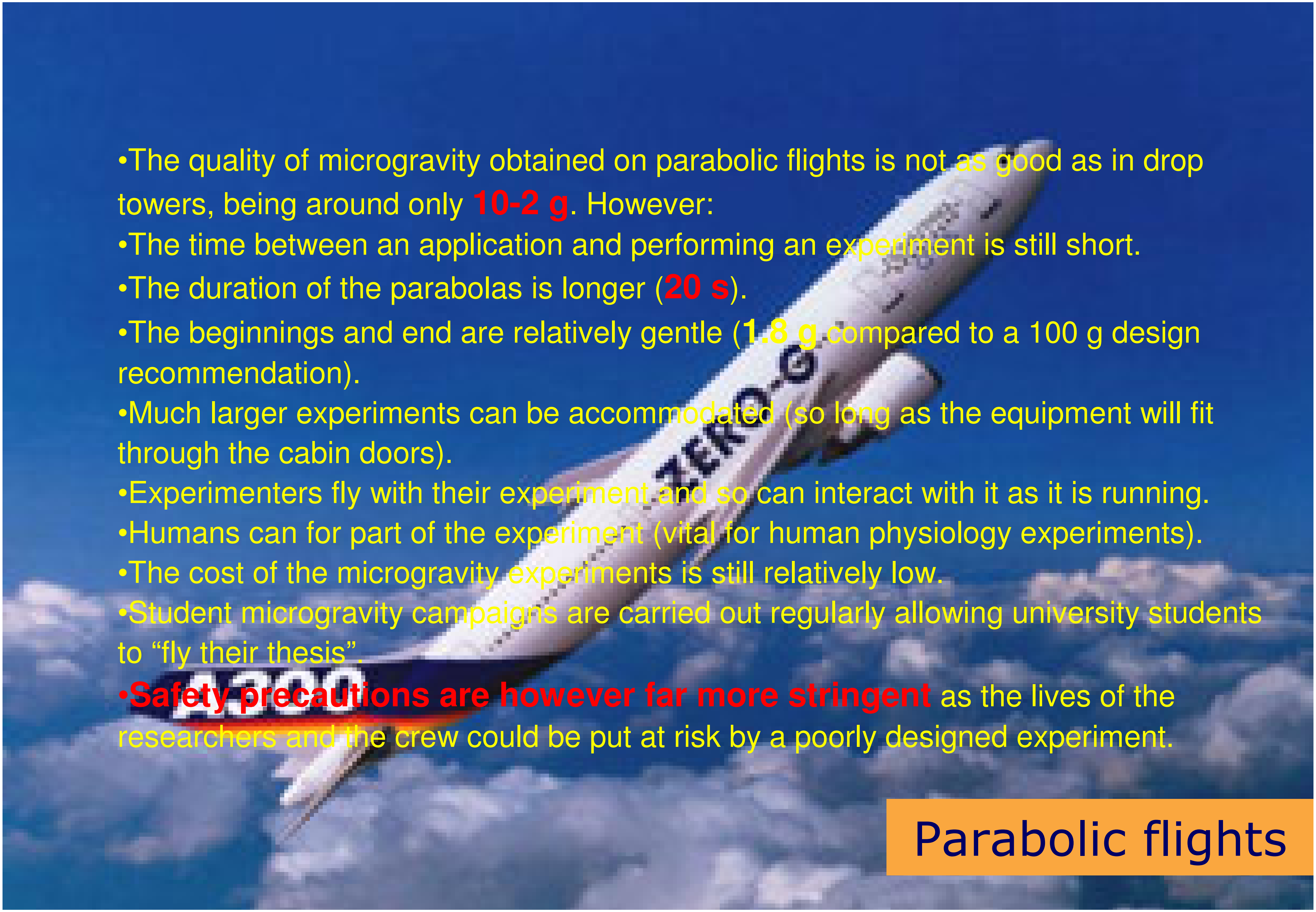
Drop Tower



Zero Gravity Research Facility (Zero-G)	
Operational Parameters	
Microgravity Duration:	**5.18 seconds**
Free Fall Distance:	**432 feet (132 m)**
Gravitational Accelleration:	**<0.00001 g**
Mean Deceleration:	**35 g**
Peak Deceleration:	**65 g**
Vacuum Level:	**0.05 torr**



- 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**.

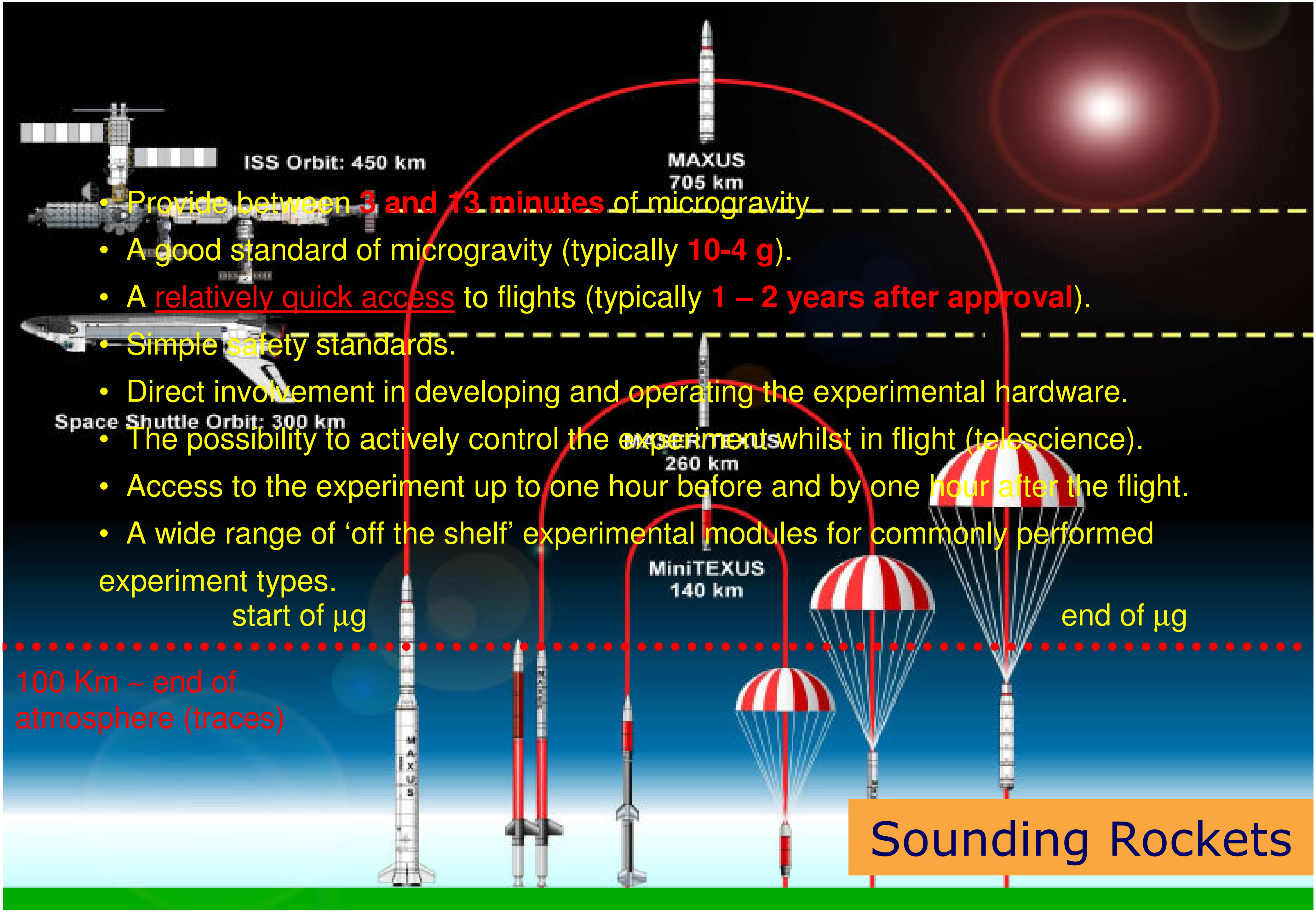


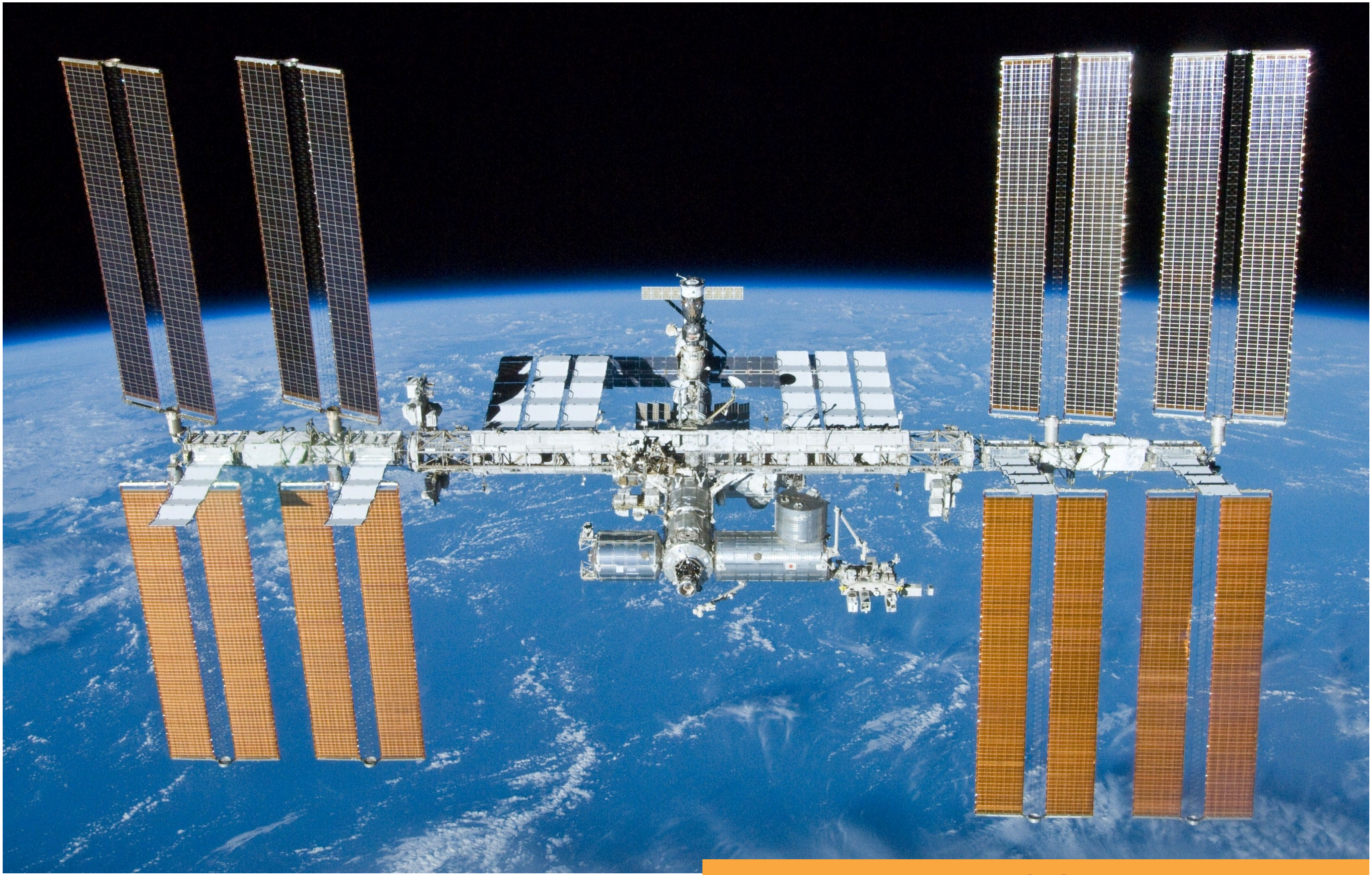
Parabolic flights

- The quality of microgravity obtained on parabolic flights is not as good as in drop towers, being around only **10-2 g**. However:
- The time between an application and performing an experiment is still short.
- The duration of the parabolas is longer (**20 s**).
- The beginnings and end are relatively gentle (**1.8 g** compared to a 100 g design recommendation).
- Much larger experiments can be accommodated (so long as the equipment will fit through the cabin doors).
- Experimenters fly with their experiment and so can interact with it as it is running.
- Humans can for part of the experiment (vital for human physiology experiments).
- The cost of the microgravity experiments is still relatively low.
- Student microgravity campaigns are carried out regularly allowing university students to “fly their thesis”.
- **Safety precautions are however far more stringent** as the lives of the researchers and the crew could be put at risk by a poorly designed experiment.

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.





By NASA/Crew of STS-132 - http://spaceflight.nasa.gov/gallery/images/shuttle/sts-132/hires/s132e012208.jpg(http://spaceflight.nasa.gov/gallery/images/shuttle/sts-132/html/s132e012208.html), Public Domain, https://commons.wikimedia.org/w/index.php?curid=10561008

ISS

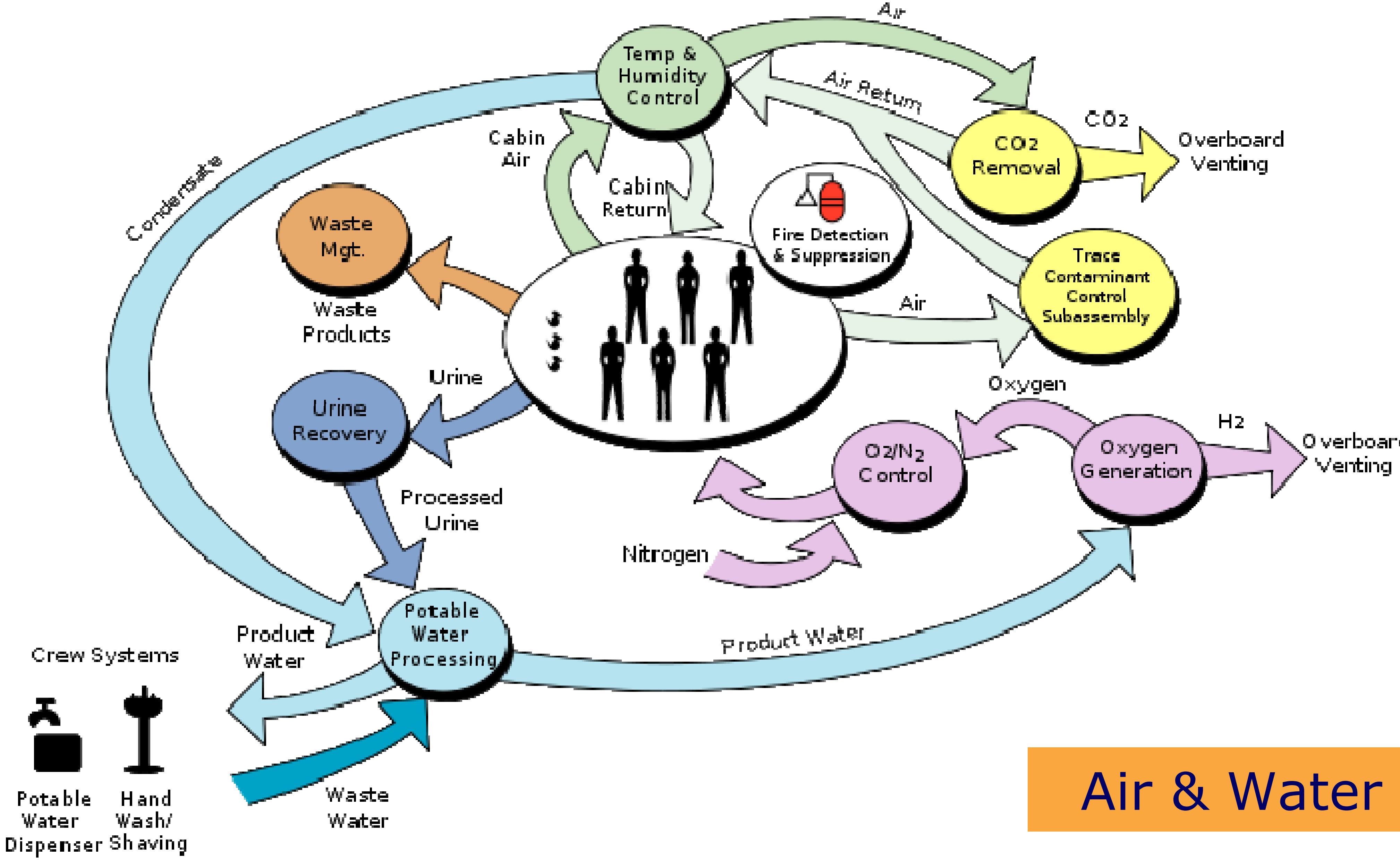
International Space Station

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

Energy & al.
Solar Array Length: 73 meters
Habitable Volume: 388 cubic meters
Power Generation: 8 solar arrays = 84 kilowatts
Lines of Computer Code: approximately 2.3 million
Last updated in November 3, 2014

ISS Facts and Figures


Air
Temp & Humidity Control
Air Return
CO_2
Overboard Venting
CO_2 Removal
Cabin Air
Cabin Return
Condensate
Fire Detection & Suppression
Waste Mgt.
Waste Products
Trace Contaminant Control Subassembly
Air
Urine
Oxygen
Urine Recovery
H_2
Oxygen Generation
Overboard Venting
O_2/N_2 Control
Processed Urine
Nitrogen
Potable Water Processing
Product Water
Product Water
Crew Systems
Potable Water Dispenser
Hand Wash/ Shaving
Waste Water

Air & Water

FLEX-ICE-GA
STICKER


OK, now you are ready to participate in a mission on the ISS .... but first you have to be trained on a particular experiment will be carried on board ...
FLEX-ICE-GA

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:

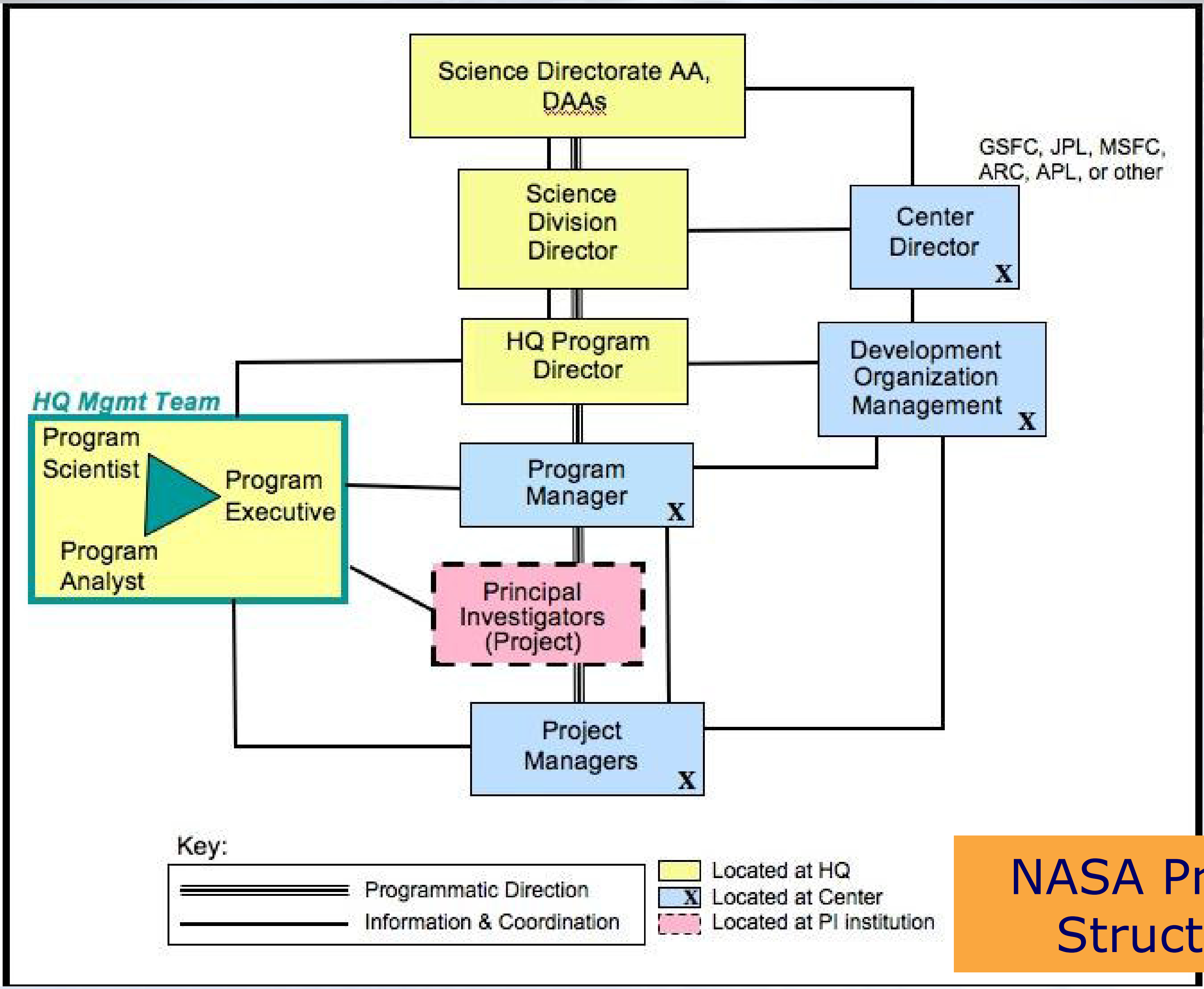
ASI

IM-CNR

NASA

FLEX-ICE-GA

NASA Project Structure



SCIENCE CONCEPT REVIEW OUTLINE

i. Welcome (NASA GRC Division Chief or Program Manager)

ii. Instructions to Science Panel (NASA Enterprise Discipline Scientist)

0. **Executive Summary (PI)**
    1. Goals/Objectives
    2. Proposed Space Experiment (concept diagram)
    3. Benefits (potential application)

1. **Introduction and Background (PI)**
    1. Description of Science
    2. Brief Historical Overview of Science
    3. Currently Active Research
    4. Current Status of Understanding
    5. Gaps in Understanding this Experiment Plans to Fill

2. **PI Research Related to Proposed Space Experiment (PI)**
    1. Experiments - 1g Laboratories, Drop Towers, and Aircraft
    2. Models - Numerical and Analytical

3. **Proposed Space Experiment (PI)**
    1. Objective and Hypothesis of Proposed Investigation
    2. Benefit to Science and Technology
    3. Flight Experiment Description
    4. Science Requirements
    5. Test Matrix
    6. Success Criteria (minimum and complete)
    7. Anticipated Results

4. **Justification for Extended Duration Microgravity Environment (PI)**
    1. Limitations of Terrestrial (1-g laboratory) Testing
    2. Limitations of Drop Towers and Aircraft
    3. Need for Accommodations in the ISS, Space Shuttle or Sounding Rocket
    4. Limitations of Modeling Approaches

5. **Use of Data Obtained from Proposed Space Experiment (PI)**
    1. Data Reduction and Analysis
    2. Model or Hypothesis Verification

6. **Proposed Space Experiment Concept (PS or PI)**
    1. Description of Experiment Concept (cartoon and block diagrams)
    2. Measurements and Diagnostics Required
    3. Experiment Procedure

7. **Science Plan to RDR (PI)**
    1. Identify Critical Tasks and Plans for Resolution
    2. Other Science Activities

8. **Summary (PI)**

9. **Engineering Plan to RDR (PM)**
    1. Identify Critical Engineering Feasibility Issues
    2. Develop Plan for Resolution of Engineering Feasibility Issues
    3. Develop Schedule and Costs

10. **Rough Order of Magnitude Schedule and Costs to Flight (PM)**

11. **Science Panel Caucus (PS to attend as an observer and answer questions)**

12. **Science Panel Feedback to PI**

13. **Concluding Remarks (NASA Enterprise Discipline Scientist)**

SCIENCE REQUIREMENTS DOCUMENT OUTLINE

i SIGNATURE PAGE
ii NOMENCLATURE
iii ACRONYMS
iv TABLE OF CONTENTS
v LIST OF TABLES
vi LIST OF FIGURES
0.0 EXECUTIVE SUMMARY
1.0 INTRODUCTION AND BACKGROUND
- 1.1 Brief Overview of Scientific Topic
- 1.2 Brief Literature Survey
- 1.3 Current Status of Understand
- 1.4 Knowledge Still Lacking

2.0 PI'S RELATED RESEARCH AND PROPOSED SPACE EXPERIMENT
- 2.1 Experiments - 1g Laboratories, Drop Towers, and Aircraft
- 2.2 Models - Numerical and Analytical
- 2.3 Objective and Hypothesis of Proposed Investigation
- 2.4 Flight Experiment Description and Concept
- 2.5 Anticipated Knowledge to be Gained, Value, and Application

3.0 JUSTIFICATION FOR EXTENDED DURATION MICROGRAVITY ENVIRONMENT
- 3.1 Limitations of Terrestrial (1g laboratory) Testing
- 3.2 Limitations of Drop Towers and Aircraft
- 3.3 Need for Accommodations in the ISS, Space Shuttle or Sounding Rocket
- 3.4 Limitations of Modeling Approaches

4.0 EXPERIMENT PLAN
- 4.1 Flight Experiment Procedure
- 4.2 Flight Experiment Plan and Test Matrix
- 4.3 Postflight Data Handling and Analysis
- 4.4 Ground Test Plan
- 4.5 Mathematical Modeling

5.0 EXPERIMENT REQUIREMENTS
- 5.1 Science Requirements Summary Table
- 5.2 Test Sample
- 5.3 Experiment Chamber
- 5.4 Temperature Measurement and Control
  - 5.4.1 Range, Accuracy and Response Rate
  - 5.4.2 Location and Number of Sensors
  - 5.4.3 Sampling Rate
- 5.5 Pressure Measurement and Control
- 5.6 Flow Rate
- 5.7 Imaging
  - 5.7.1 Type
  - 5.7.2 Frame Rate
  - 5.7.3 Field of View and Resolution

Increment 35/36 Investigation Locations

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

Investigation Locations

SpX-2 Investigations included

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, HiMasSEE, 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 micro-gravity 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.

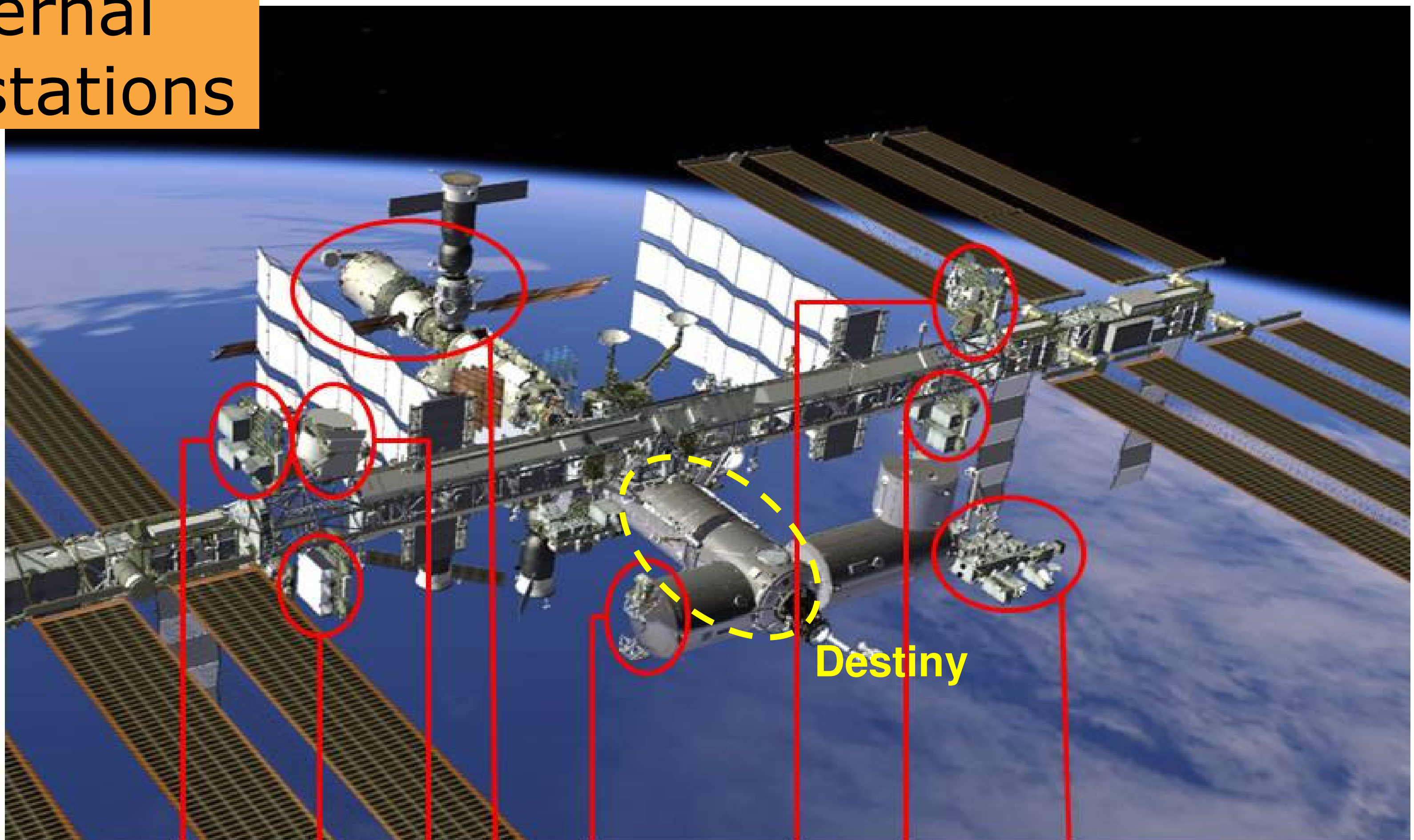
Minus Eighty-Degree Laboratory Freezer fo ISS (MELFI-2)

A refrigerator/freezer for biological and life science samples.

Combustion Integrated Rack (CIR)

Used to perform sustained, systematic combustion experiments in microgravity.

External Workstations



ELC-2
MISSE-8

ELC-4
RRM-P2

AMS

Columbus-EPF
Vessel ID, Solar
~~HDEV, NOFBX~~

ELC-3
STP-H3, SCAN Testbed

ELC-1
STP-H4
~~OPALS~~

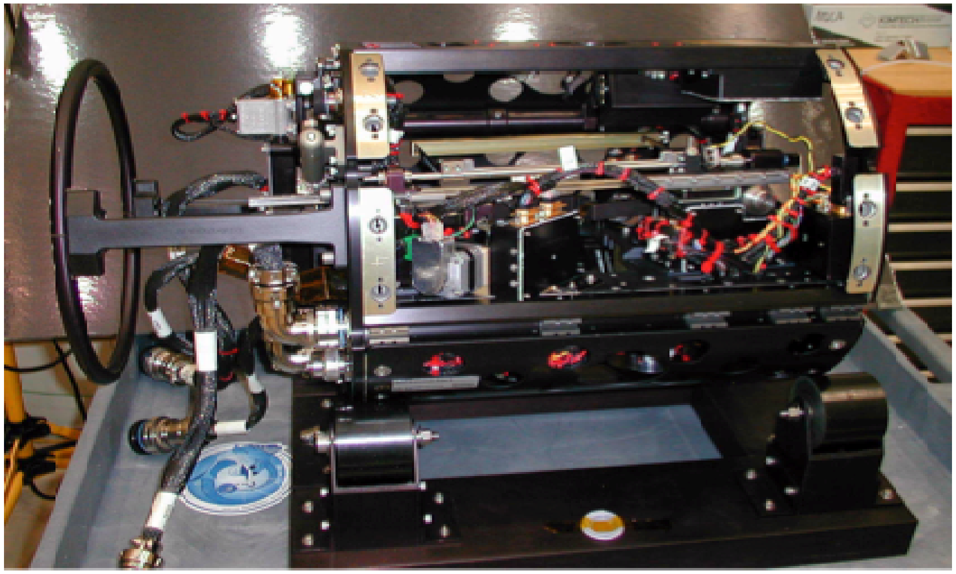
JEM-EF
SMILES, SEDA-AP MAXI, MCE HREP-HICO RAIDS

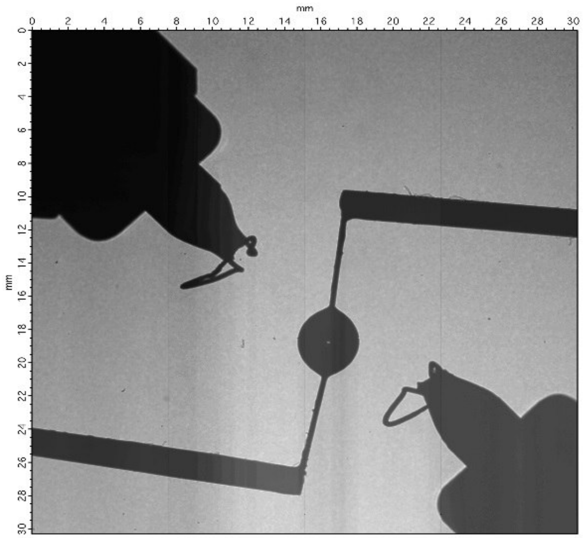
External Workstations (9) on the Russian Service Module
EXPOSE-R2 on Zvezda

- 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)

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

Experiment Sequence

- **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.**

Research Goals of FLEX-ICE-GA

Experiment Diagnostics

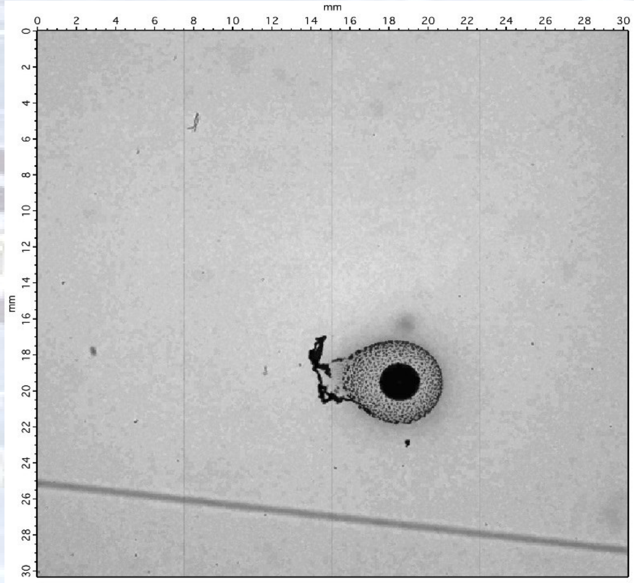
<u>Backlit view of droplet</u>:
- Droplet size, soot shell dynamics, soot volume fraction

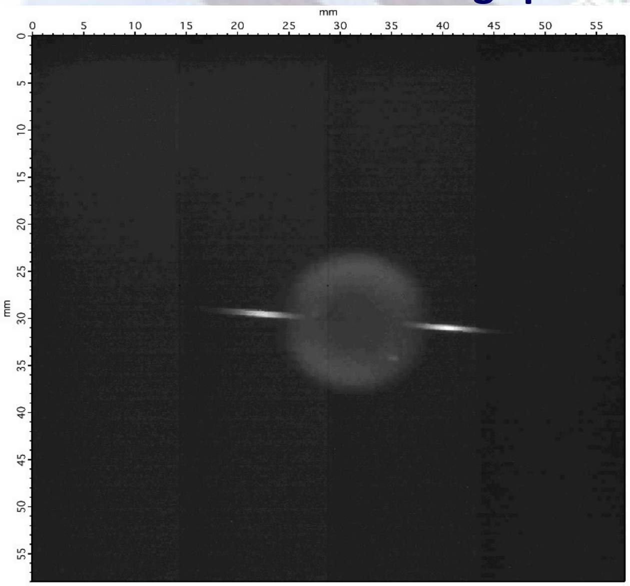
<u>Flame luminosity filtered for *OH** (308 nm)</u>
- Flame size, relative intensity, flame dynamics

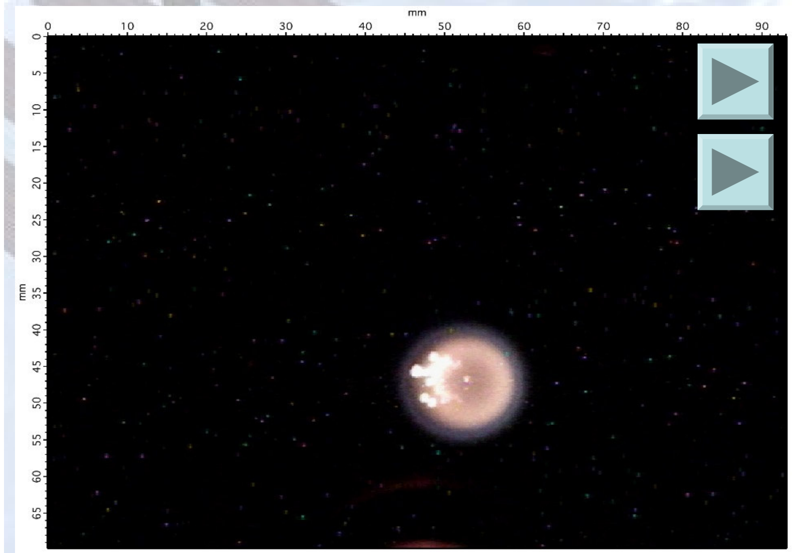
<u>Color camera view of flame</u>
- What the eye would see
- Flame size, flame dynamics, flame color (yellow, blue)

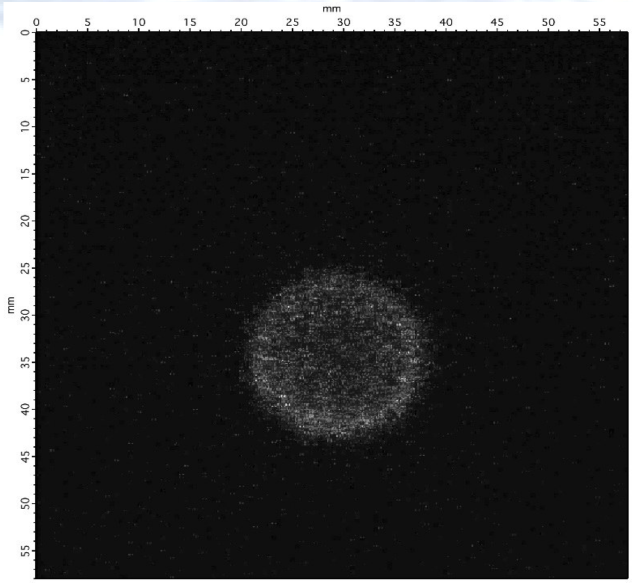
<u>IR-filtered view of flame/fiber</u>
- Estimate of flame temperature (for fiber-supported tests)
- Estimate of soot temperature (in combination with soot volume fraction)

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









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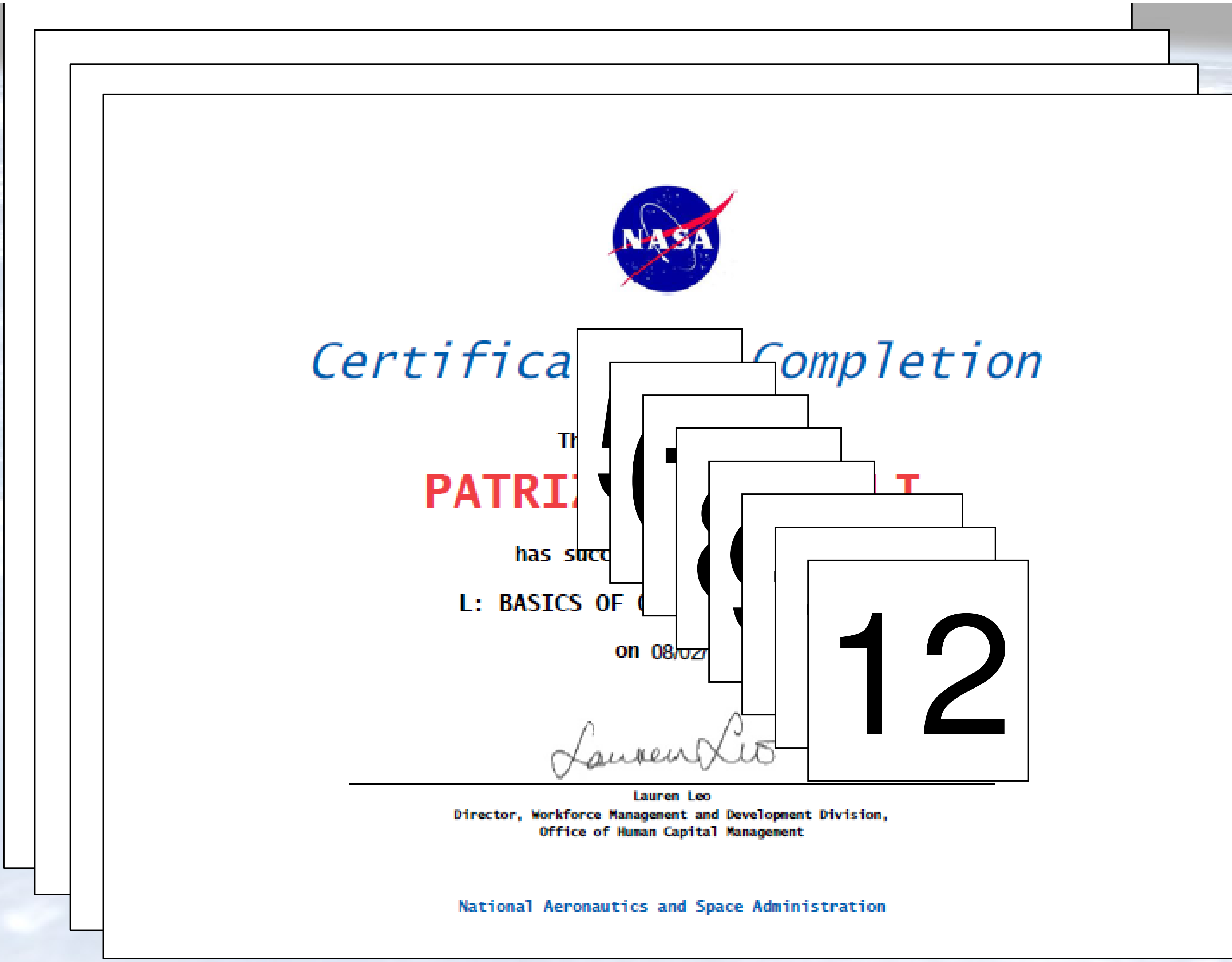
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on 08/02/

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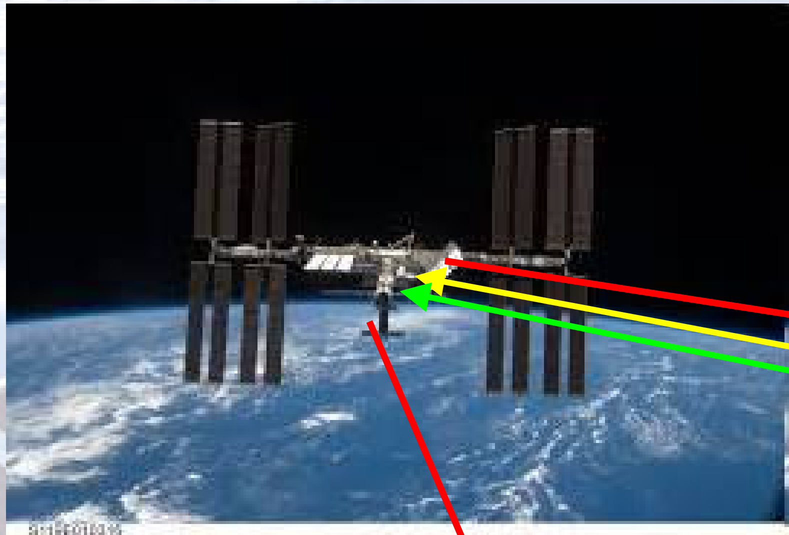
Lauren Leo
Director, Workforce Management and Development Division,
Office of Human Capital Management

National Aeronautics and Space Administration

Experiment Operation

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

- Video/audio link to external PI



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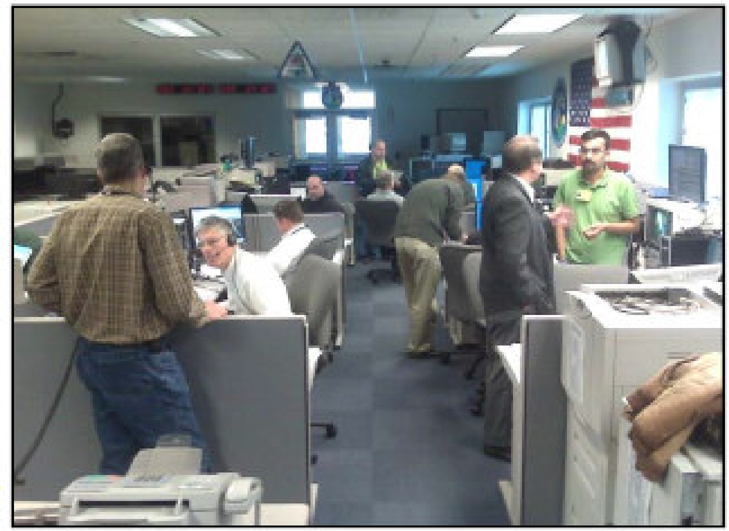

Fluids & Combustion Facility Mission Operations at TSC, Building 333


23 Voice Channel
1 dedicated to FLEX-ICE-GA
4 Webcam
2 (at least) internal
1-2 external
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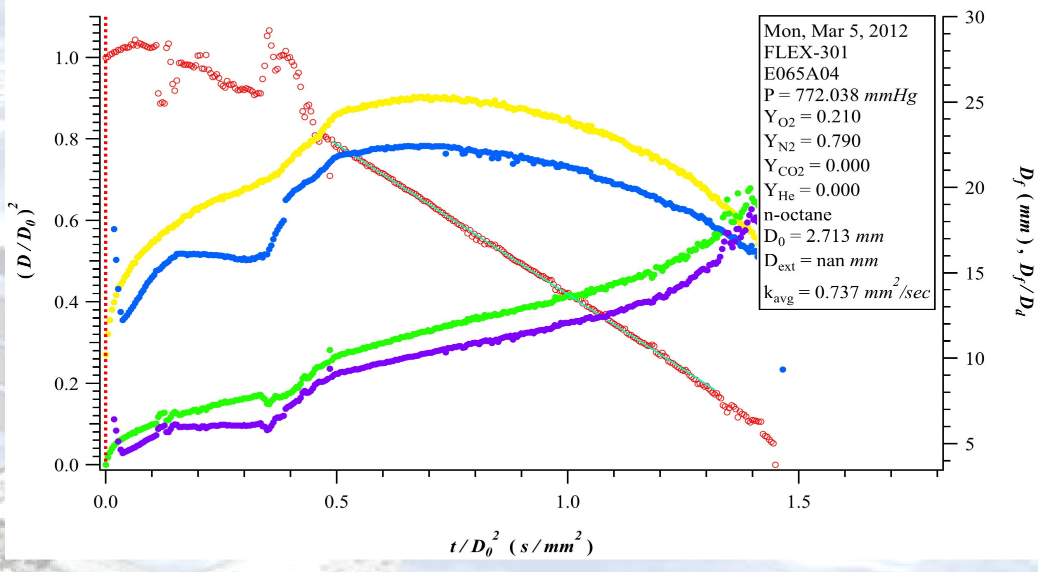
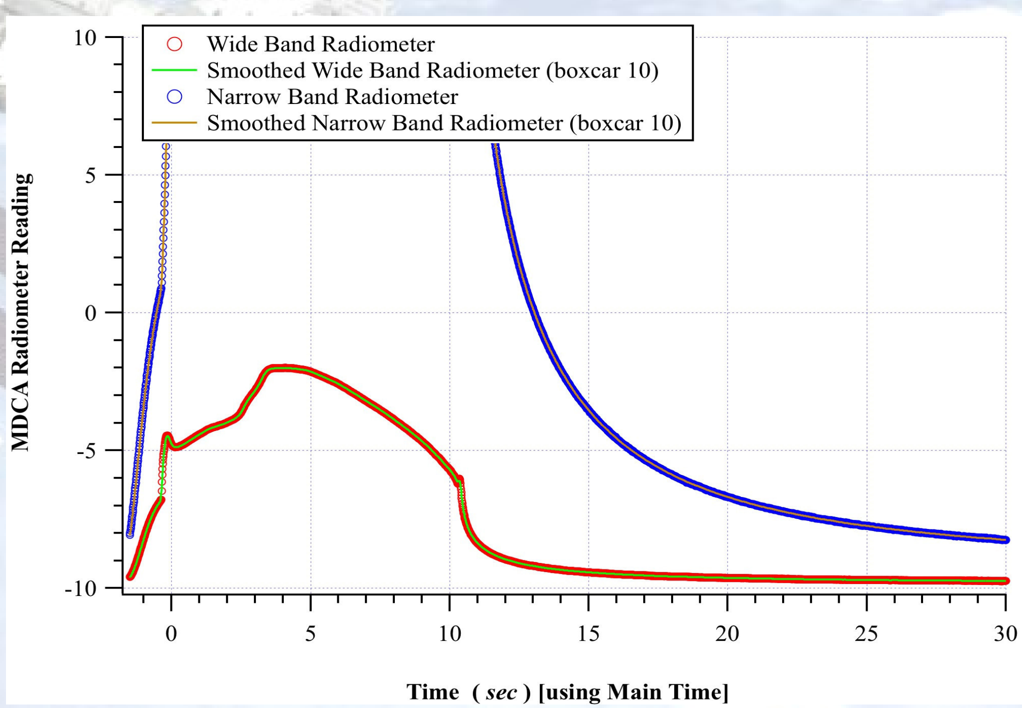
Experiment Methodology

- 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



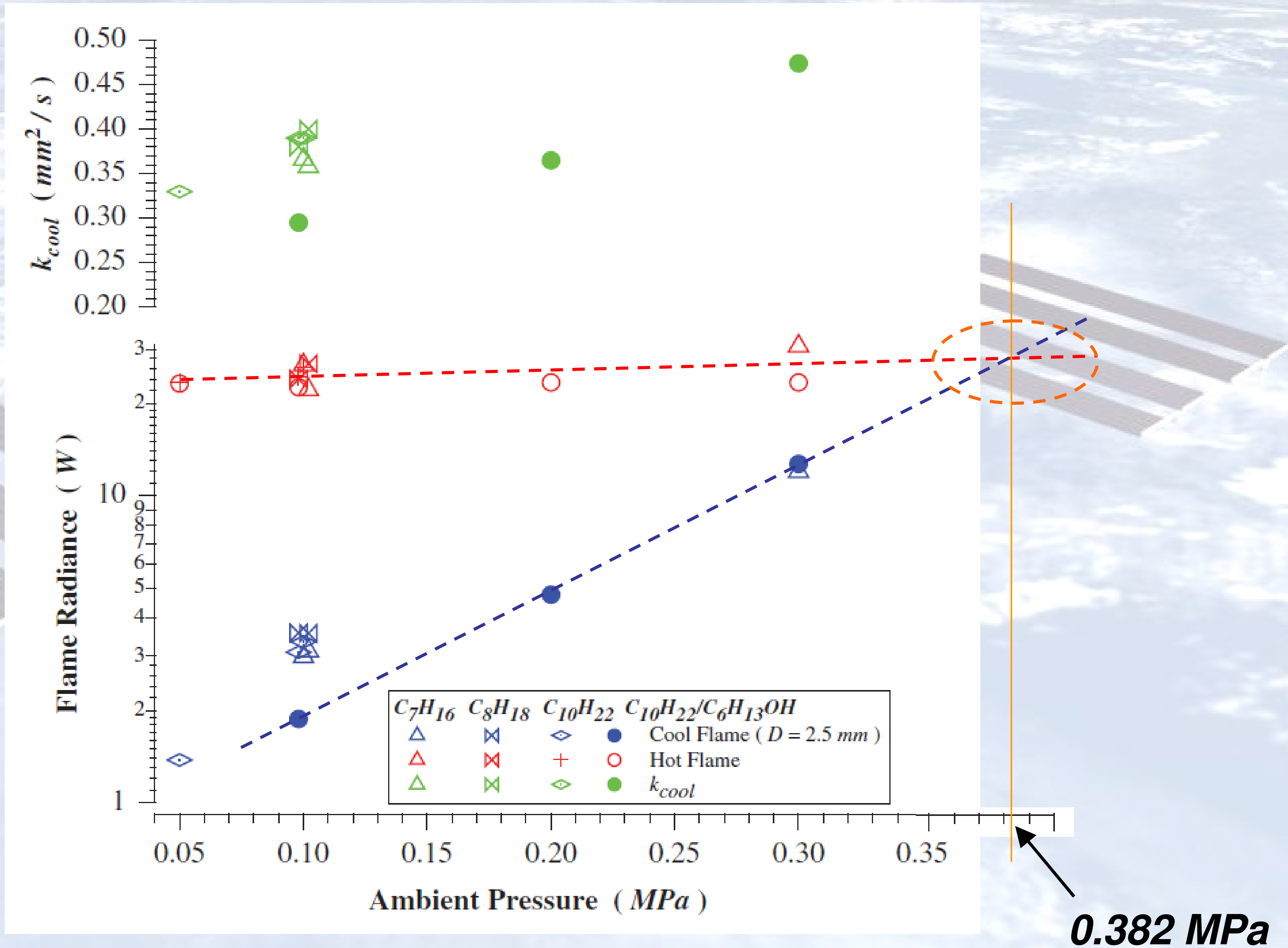


- Determination of fundamental combustion characteristics (burning rates; flame front as a function of time; droplet lifetimes) of blends 50%/50% vol of n-decane/1-hexanol and 50%/50% vol of n-heptane/ethanol.
- Analysis of soot tendency of the blends in terms of soot volume fraction and soot temperature 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



D. L. Dietrich, R. Calabria, P. Massoli, V. Nayagam & F. A. Williams (2017) Experimental Observations of the Low-Temperature Burning of Decane/Hexanol Droplets in Microgravity, Combustion Science and Technology, 189:3, 520-554, DOI: 10.1080/00102202.2016.1225730

Thank you for your attention …..

….. first part …..

now…. the future …

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Tre italiani nello spazio con Virgin Galactic nel 2020

Faranno esperimenti su corpo umano e carburanti verdi

Redazione ANSA 04 ottobre 2019 08:58 Scrivi alla redazione Stampa

http://www.ansa.it/canale_scienza_tecnica/notizie/spazio_astronomia/2019/10/02/tre-italiani-nello-spazio-con-virgin-galactic-nel-2020-_f8f3b382-dee9-4a56-8d10-8639ff7dbe40.html

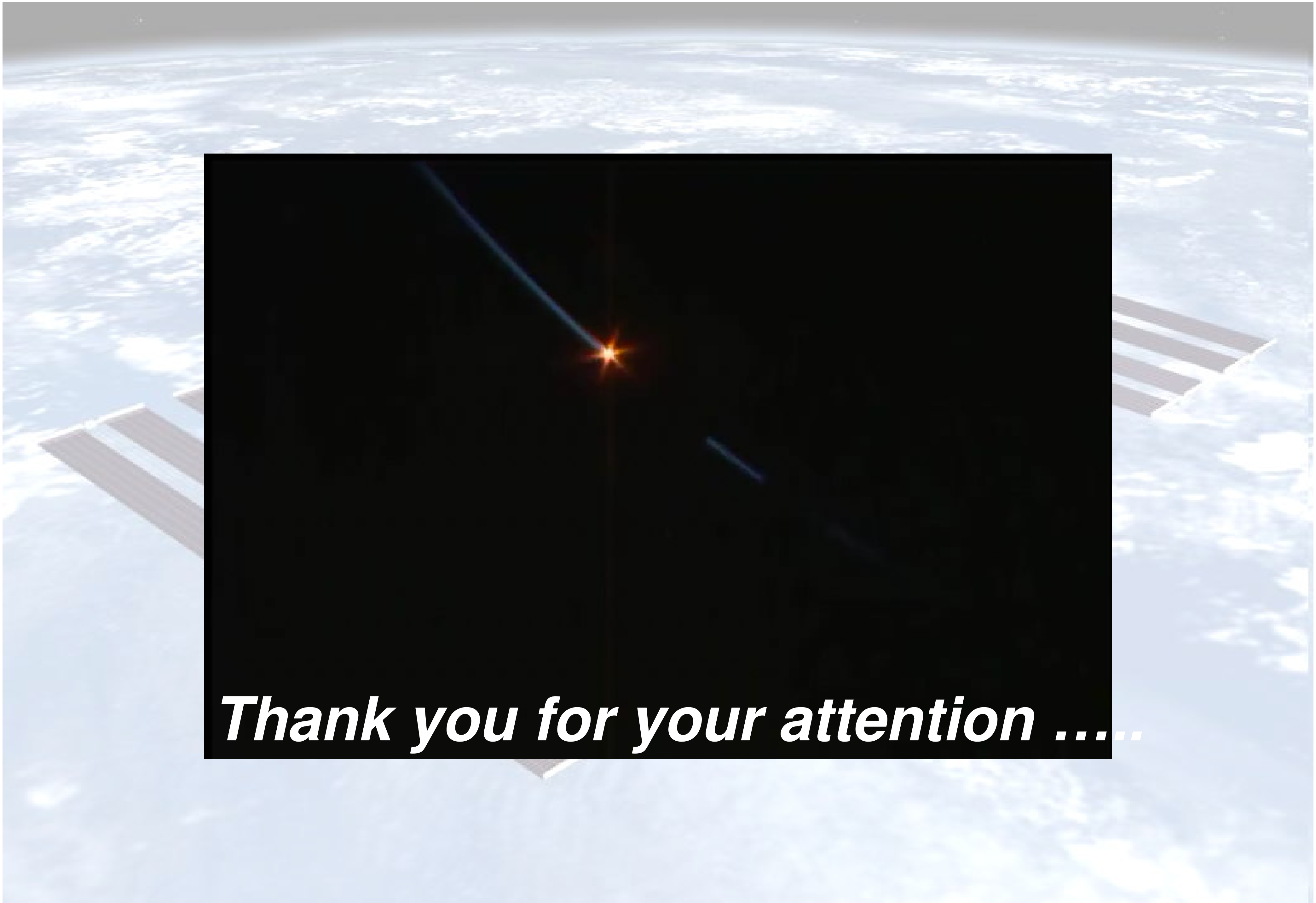

V1RG1N SPACESH1P UN1TY
SECOND SPACEFL1GHT

Comunicato Ansa 3 ottobre 2019

Nel 2020 tre ricercatori italiani avranno la possibilità di condurre esperimenti nello spazio durante un volo suborbitale a bordo dello spazioplano SpaceShipTwo di Virgin Galactic: lo stabilisce l'accordo siglato nella sede dell'ambasciata italiana a Washington dalla compagnia del magnate Richard Branson con l'Aeronautica Militare Italiana. E' la prima volta che un dipartimento governativo finanzia un volo umano a scopo di ricerca scientifica su un veicolo spaziale commerciale.

La missione porterà nello spazio tre specialisti di carico italiani e uno 'scaffale' di esperimenti scientifici. L'Aeronautica militare e il team della Virgin Galactic stanno già lavorando con il Consiglio nazionale delle ricerche (Cnr) per progettare i carichi degli esperimenti.

"Durante il volo, dopo lo spegnimento del motore del razzo, i ricercatori si sganceranno dai sedili ed eseguiranno le azioni necessarie per completare ciascun esperimento nel giro di alcuni minuti a gravità zero", si legge in una nota congiunta. "La compagnia si occuperà dell'addestramento e della preparazione dei ricercatori, in modo che siano pienamente equipaggiati per compiere il loro lavoro come specialisti della missione sul volo, e fornirà in loco il supporto pre-volo per ciascuno dei carichi sperimentali". Tra questi saranno inclusi strumenti per misurare gli effetti biologici sul corpo umano della transizione dalla gravità alla microgravità. Altre attrezzature potrebbero essere usate per studiare meglio la chimica dei carburanti verdi.


Thank you for your attention …..