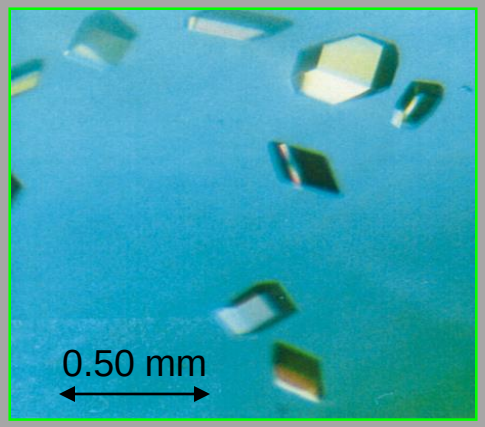
SD2905 Human Spaceflight

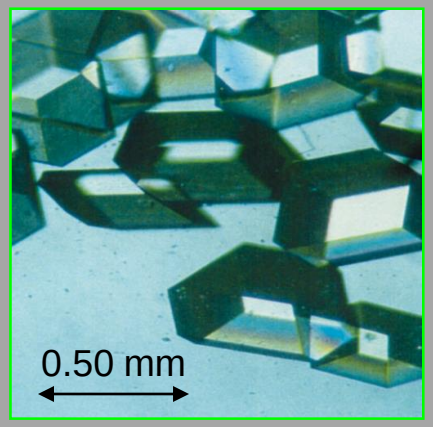
Lecture 9, 14-2-2014

Research on the International Space Station

Utilization areas on ISS

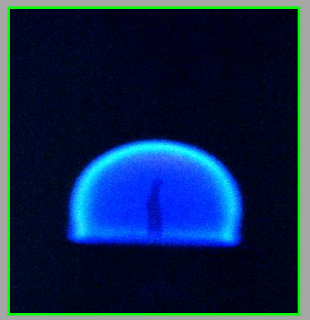
- Science
  - Weightlessness
  - Space view
  - Earth view
  - Space environment (radiation, vacuum, human isolation)
- Technology demonstrations / development
- Exploration preparation
- Education / outreach / inspiration





On Earth

In Space



Weightlessness (0G) is used for inumerable experiments in physics, medicine, biology, technology...

Weigtlessness (μG): Get rid of gravity-driven phenomena

- Falling objects
- Boyancy
- Sedimentation
- Convection in gases and fluids due to differences (gradients) in temp or density

Critical phenomena affected by or dominant in microgravity:

- Surface wetting & interfacial tension
- Multiphase flow & heat transfer
- Multiphase system dynamics
- Solidification
- Fire phenomena & combustion

Underlying processes on Earth emerge:

- Pressure-driven flows
- Capillary flows
- Diffusion
- Viscosity
- Electromagnetic forces
- Vibration

[Stratified flow, 1 g_0]

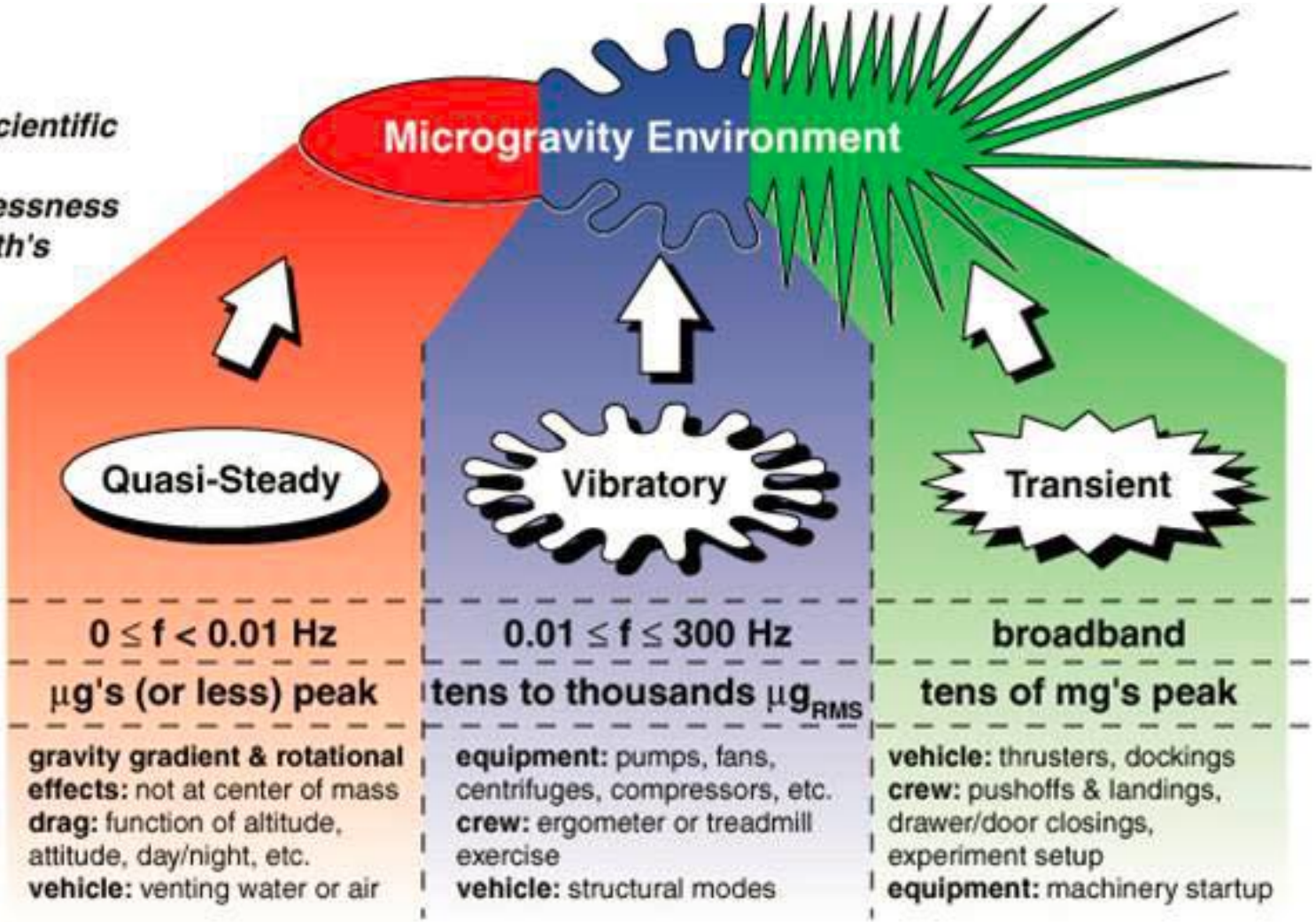
Multiphase Flow

[Annular flow, microgravity]

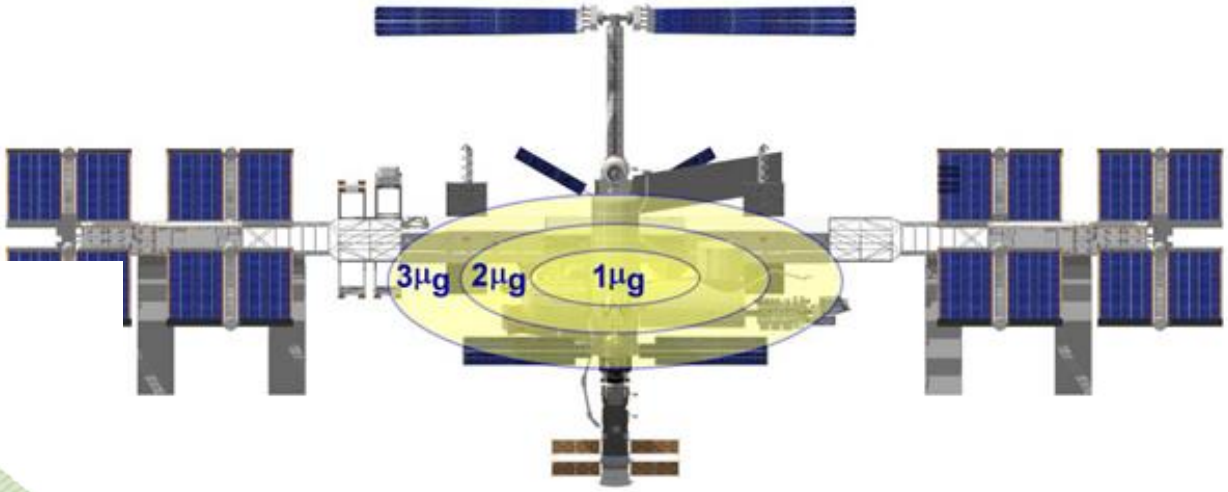
Verify models and calculations

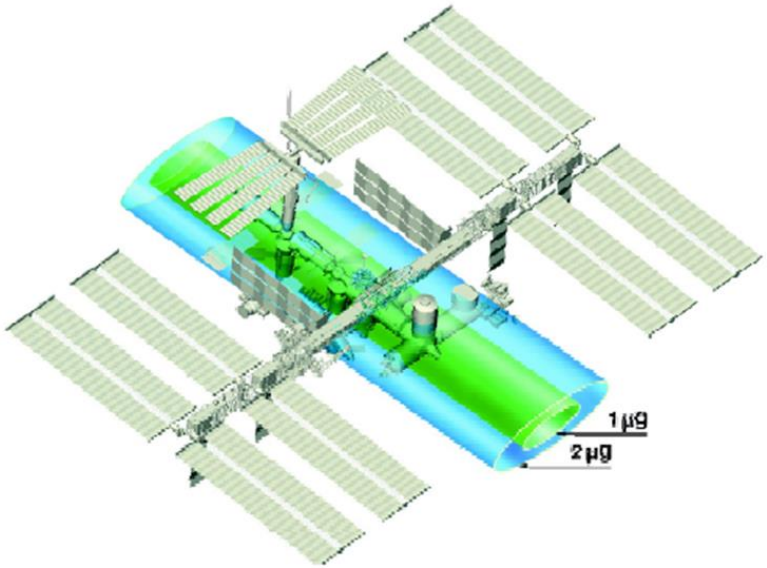
The Microgravity Environment

Microgravity is:
- *a general label for scientific investigations that exploit near-weightlessness*
- *one-millionth of Earth's normal gravity*
- *a reduced gravity environment*



It is only in the center of gravity you can get perfect 0G



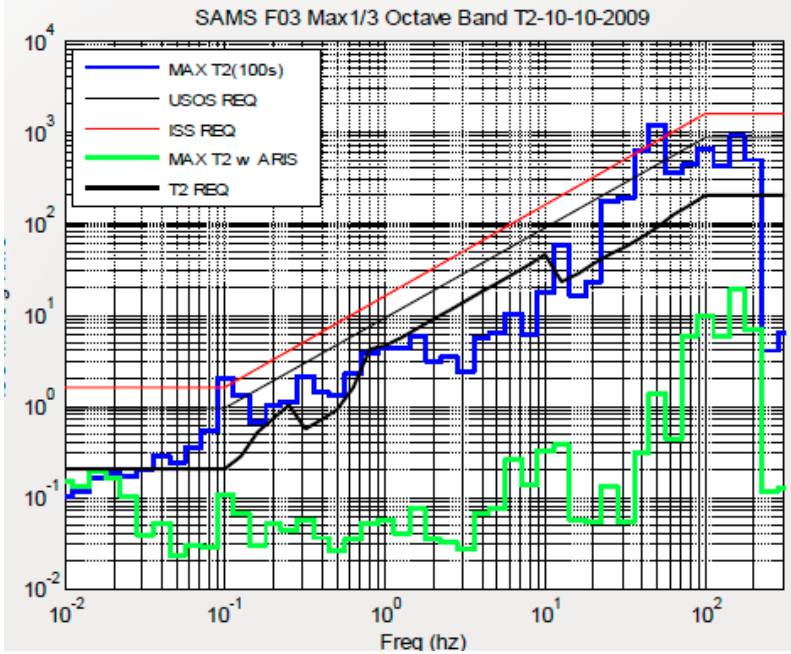


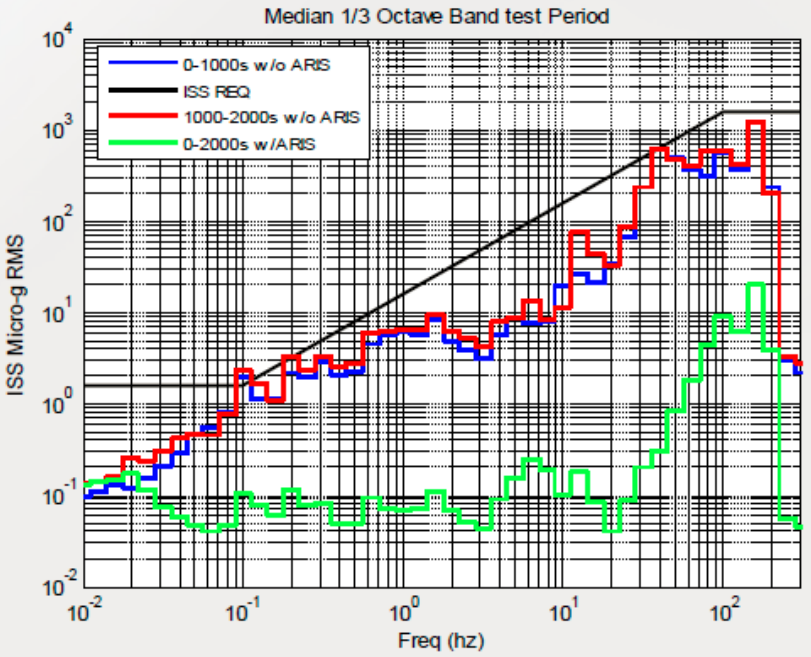
Want to know more about calculating the µG levels:
http://www.spaceflight.esa.int/impress/text/education/Microgravity/Question_Microgravity_008.html

Microgravity levels are measured on ISS

On-board sensors monitor perturbations to the microgravity state on the ISS.

Even without the Active Rack Isolation System, vibrations are typically within ISS requirements.





While the Station is at its most "quiet" during the eight hours of crew sleep, the Active Rack Isolation System can be effective even during crew exercise.

Interlude: Introducing ESA

European Space Agency
Agence spatiale européenne

European Space Agency

Established 1975 by 10 countries

Came out of two older organisations:

- ELDO (European Launch Development Organization)
- ESRO (European Space Research Organisation)

20 MEMBER STATES AND GROWING

ESA has 20 Member States: 18 states of the EU (AT, BE, CZ, DE, DK, ES, FI, FR, IT, GR, IE, LU, NL, PL, PT, RO, SE, UK) plus Norway and Switzerland.

Seven other EU states have Cooperation Agreements with ESA: Estonia, Slovenia, Hungary, Cyprus, Latvia, Lithuania and the Slovak Republic. Bulgaria and Malta are negotiating Cooperation Agreements.

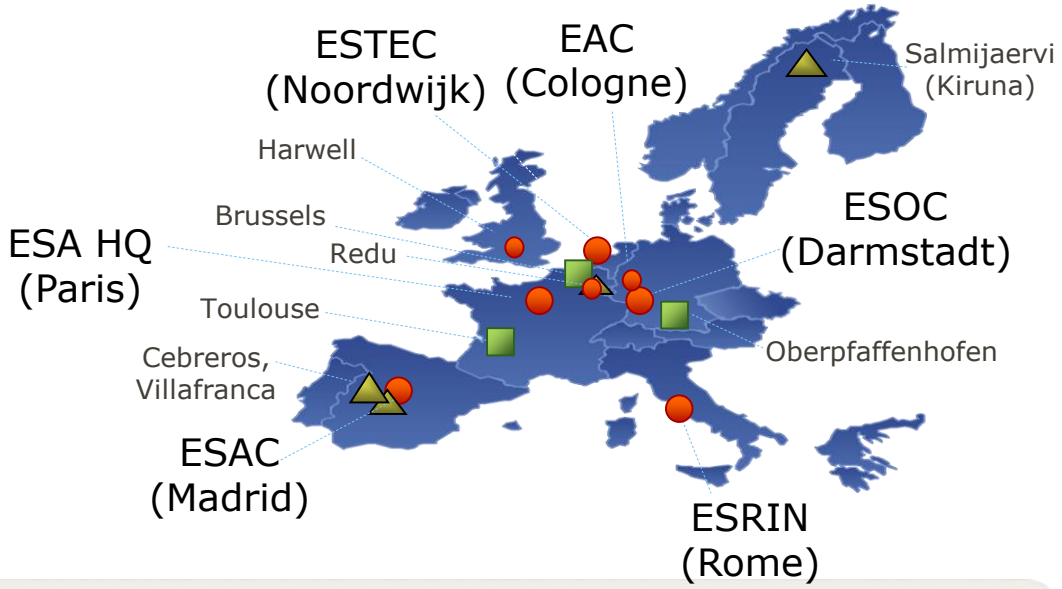
Canada takes part in some programmes under a Cooperation Agreement.

ESA'S LOCATIONS

ESA sites/facilities

Offices

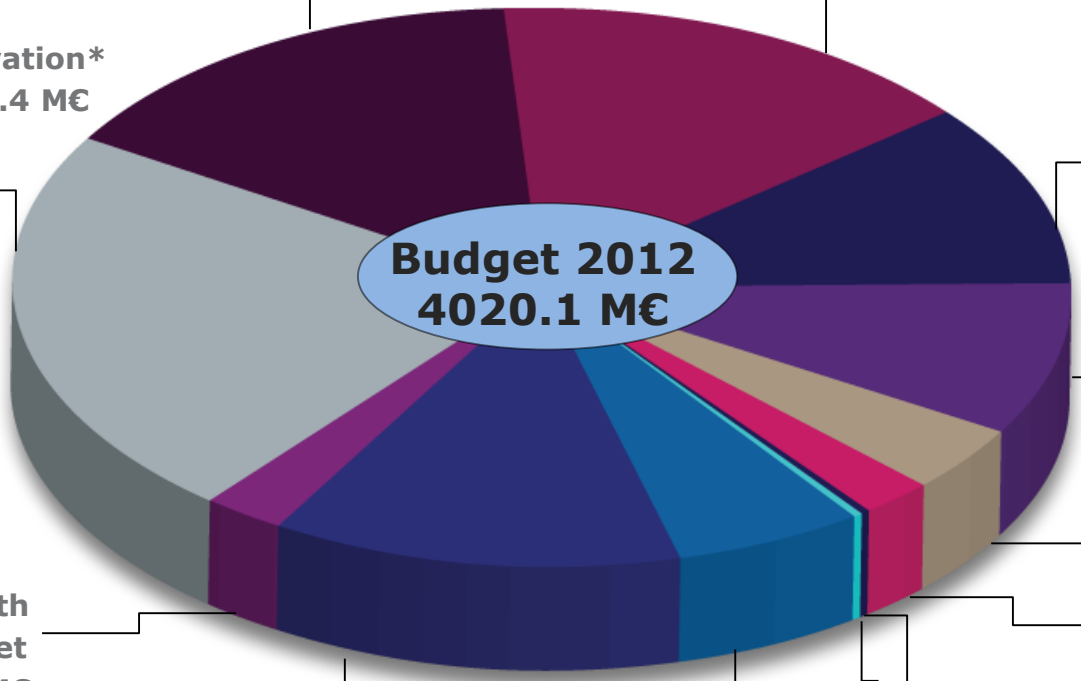
ESA ground stations



ESA 2012 BUDGET BY DOMAIN

M€: Million Euro

***includes Third Party Activities**



Launchers
14.4%, 578.0 M€

Navigation*
17.9%, 720.7 M€

Telecom & Integrated Applications*
8.2%, 330.0 M€

Earth Observation*
21.4%, 861.4 M€

Human Spaceflight*
10.3%, 413.3 M€

Robotic Exploration & Prodex
3.1%, 123.0 M€

Technology support*
2.0%, 81.0 M€

Space Situational Awareness
0.4%, 15.4 M€

Associated with General Budget
4.8%, 190.3 M€

Scientific Programme
11.9%, 479.7 M€

Basic Activities
5.5%, 221.5 M€

European Cooperating States Agreement (ECSA) 0.1%, 5.8 M€

ELIPS

European Life and Physical Science Research Program

* Since 2001 – Now ELIPS-4
- Funded for 3-4 years at Ministerial Councils
  210 M€ in 2012 (down from 285 in 2008)
* Separate funding from ISS Exploitation

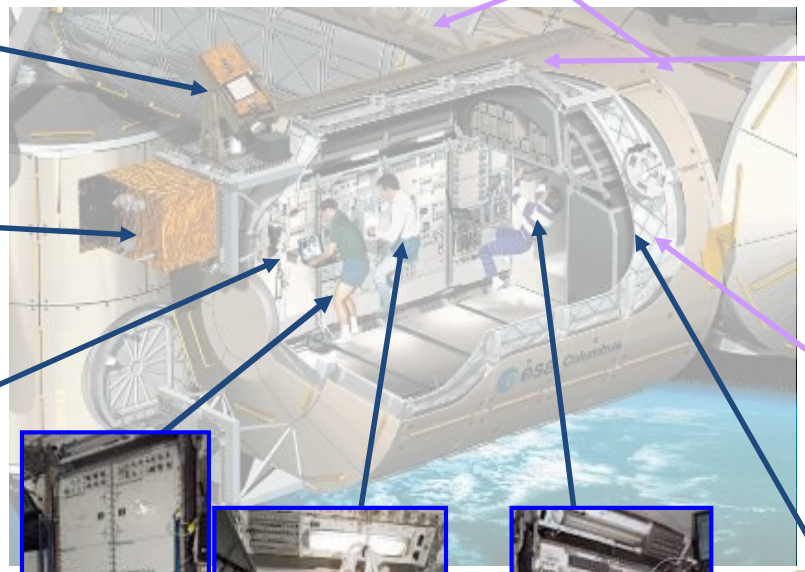
ESA's ISS Facilities

3x MELFI

Material Science Lab

SOLAR

EuTEF
(returned Sep-09)



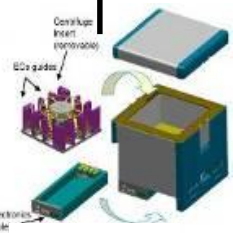
European Modular Cultivation System

European Drawer Rack

European Physiology Moddule

Microgravity Science Glovebox

PCDF



KUBIK

MEEMM + CardioLab

Fluid Science Lab

BIOLAB

European Transport Carrier

Many platforms for research

Short, medium, Long Duration Bed Rest

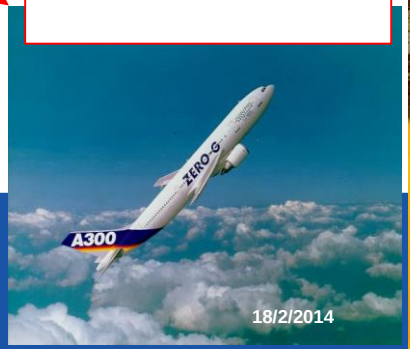
ISS (days, weeks, months, years)

Unmanned satellites (weeks)

Access to Ground Based Facilities

Sounding Rockets (6-13 min)

Parabolic Flight(20s)



Heavy Ion Radiation Biology (IBER - GSI)

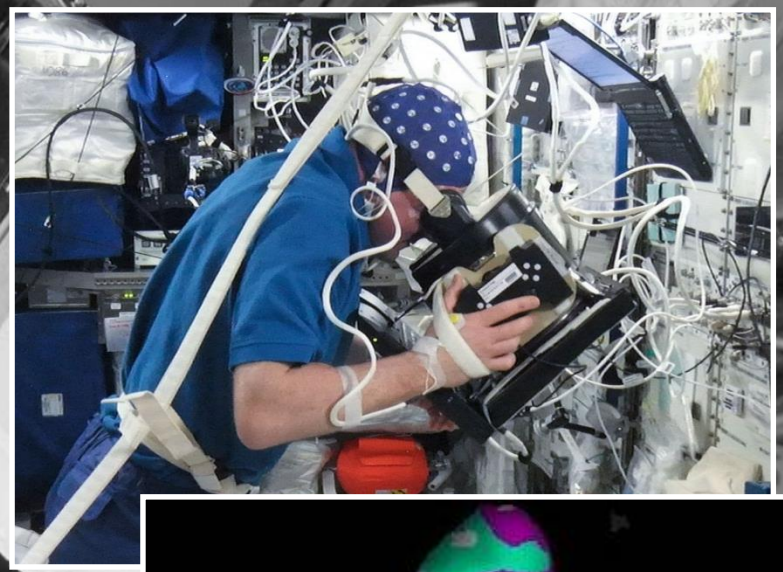
Drop tower (4-9s)

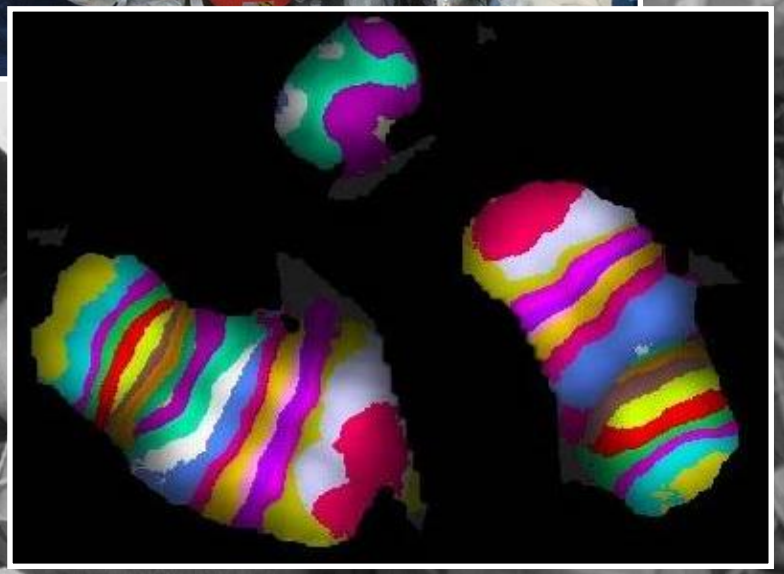
Isolation Studies

Key Research Topics

HUMAN PHYSIOLOGY AND PERFORMANCE

- Mechanisms orchestrating organ systems interaction and recovery under variable gravitational levels (system homeostasis)
- Factors impairing physical and cognitive performance
- Countermeasure strategies
- Radiation





EXAMPLES of HUMAN PHYSIOLOGY EXPERIMENTS

- **SOLO**
  - *Salt retention and effect on bone metabolism.*
  - *Sampling during high salt/Low salt diets.*
  - *Help assess optimal sodium intake.*
- **CARD**
  - *Understand how microgravity affects the regulation of blood pressure.*
  - *Establish how some of the hormones responsible for regulating the cardiovascular system are affected by long-term exposure to weightlessness.*

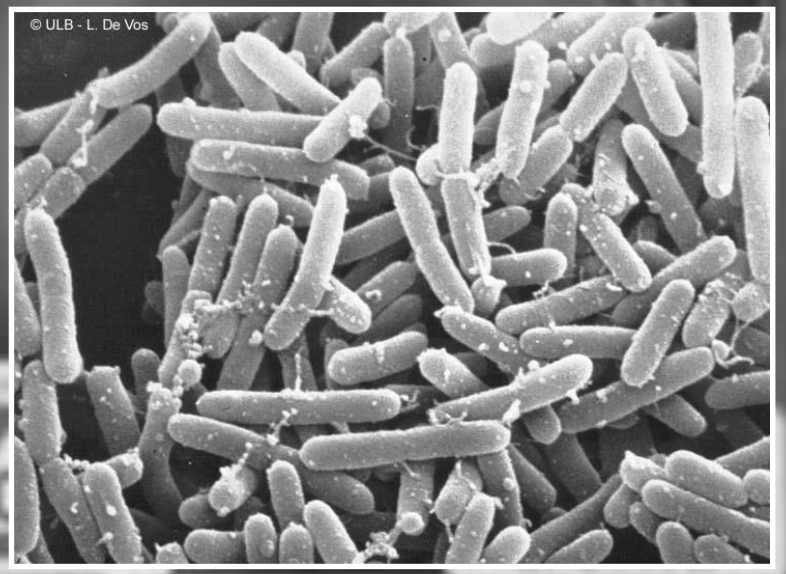
Vestibular experiment1818 performance

Astronaut = Guinea pig

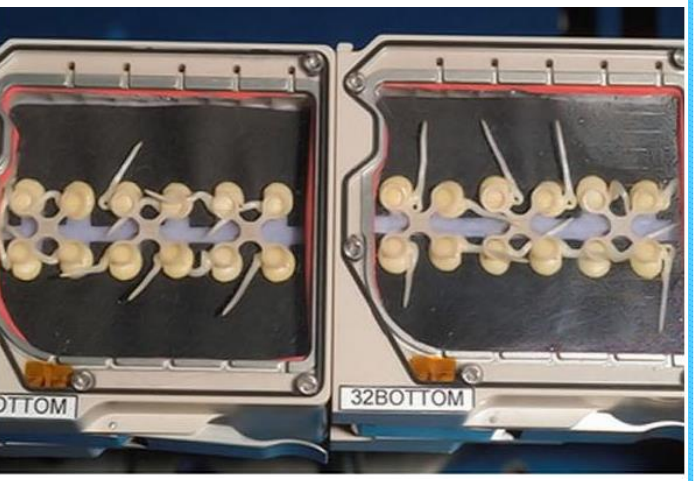
Key Research Topics

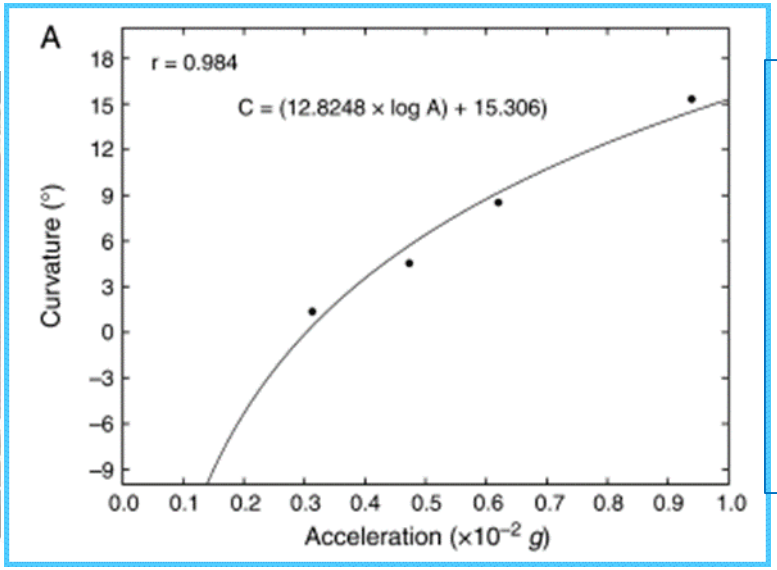
BIOLOGY

- **Sensitivity to Gravity of cells, plants and animals**
  - Molecular mechanisms for sensing and adaptation
  - Multicellular structure formation
  - Development and performance of organ systems
  - Lifecycle from embryonic development to senescence
- **Biological responses to multiple stressors**



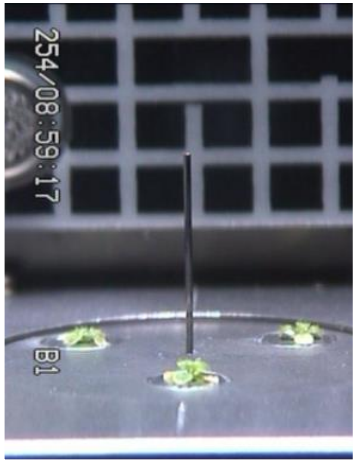
EXAMPLES of BIOLOGY EXPERIMENTS





GRAVI-1: Gravity perception thresholds established in Lentil seedlings. “Gravitropism”. The physical processes underlying the detection of the gravity vector by plants

MULTIGEN-1: The circumnutation (circular movement of stem) of Arabidopsis shoots occurs in microgravity, but with significantly lower amplitude than 1.g. Additionally the period of circumnutation under microgravity is altered in the presence of light. These unique observations showing how endogenous processes interact with light and gravity signals.



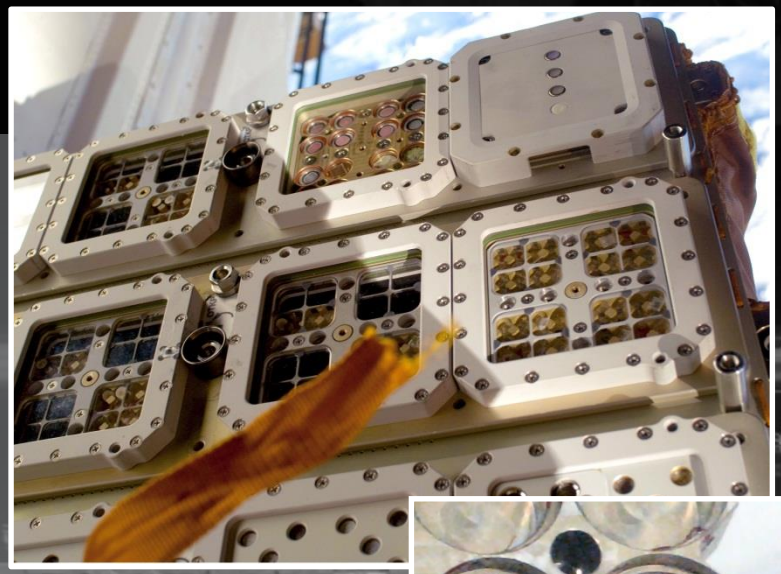
Left: just after germination
Right: 7 weeks later

ROALD on ISS in 2008. An enzyme, LOX-5, that regulates life expectancy becomes more active in micro-G.

Key Research Topics

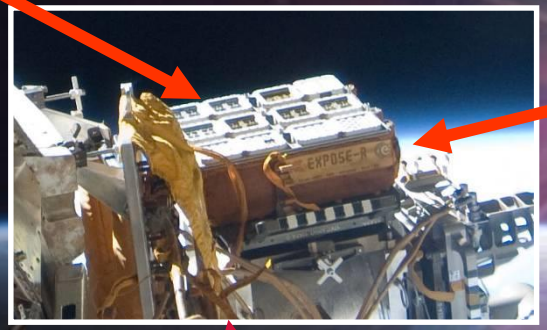
ASTROBIOLOGY

- Organic compounds and mineral interactions
- Polymerisation, stability and replication studies
- Response of pre-biotic building blocks to extra-terrestrial conditions
- Mechanisms of survival and adaptation of extremophiles



"Space Survivors"

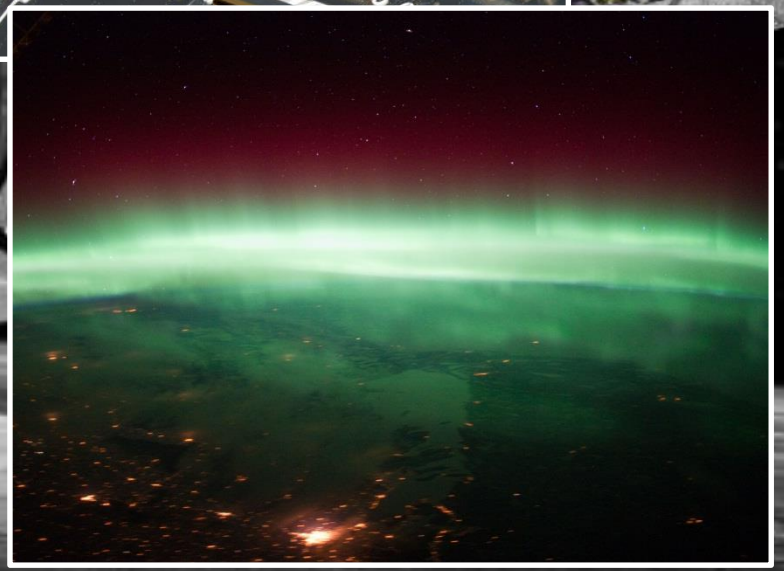
Cyanobacteri
Lichens
Tardigrades
Plant seeds



Key Research Topics

ATMOSPHERIC AND ENVIRONMENTAL RESEARCH

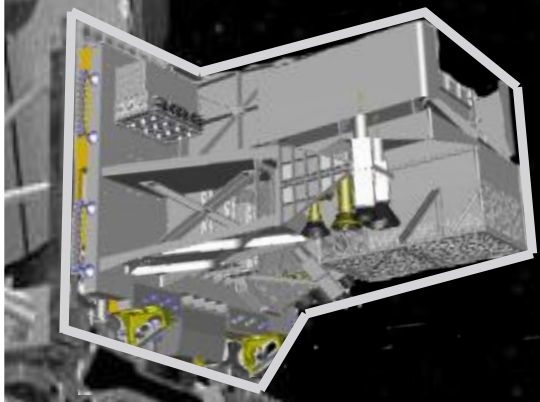
- Novel data understanding global climate change
- Space-atmosphere interactions
- Global animal migrations
- Solar spectral irradiance



EXAMPLE ATMOSPHERIC ENVIRONMENTAL RESEARCH

Atmosphere Space Interactions Monitor (ASIM)

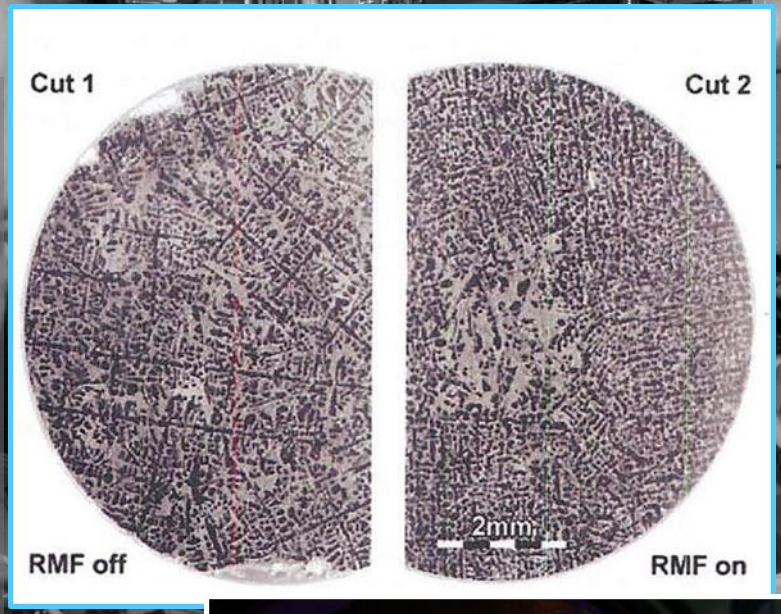
- **Will study recently discovered phenomena**
  - Transient Luminous Events (in 1989). Electric discharges between thunderstorms and the ionosphere
  - Terrestrial Gamma Flashes (in 1995). Flashes of X- and Gamma-rays from above thunderstorms Bremsstrahlung from relativistic electrons

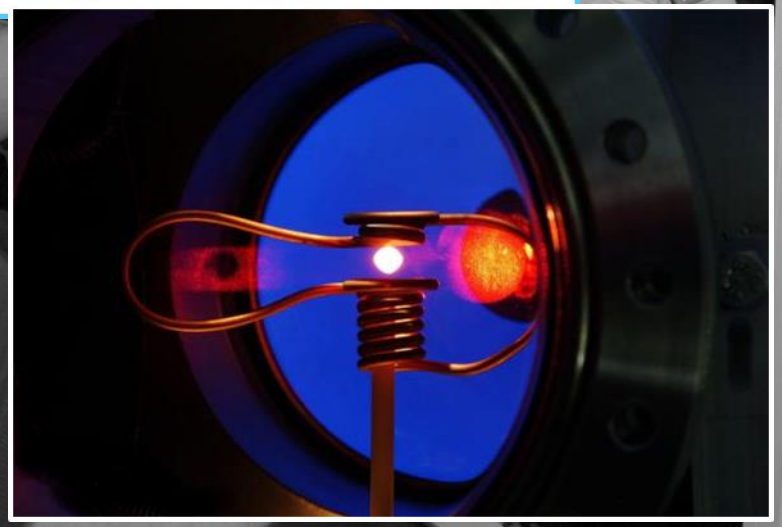


Key Research Topics

MATERIAL SCIENCES

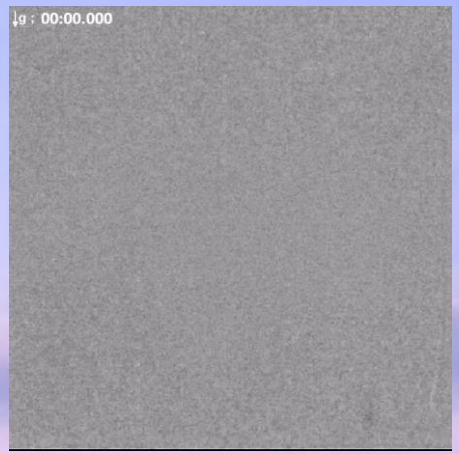
- Thermophysical properties
- Microstructures in alloys – convection influence
- Influence of the processing conditions on features of crystalline and amorphous phases and of biological, organic and inorganic materials.
- Links: materials processing - structure - properties of new light-weight structural metallic or intermetallic materials.



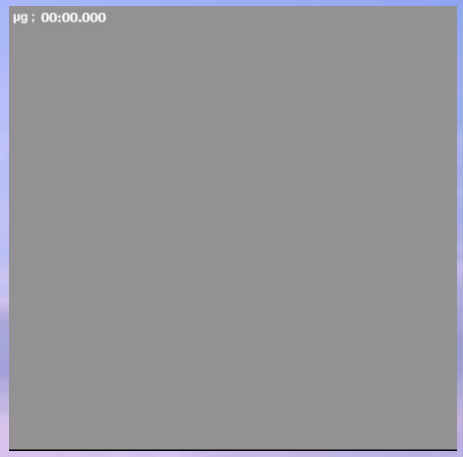


Material Science

In-situ Solidification

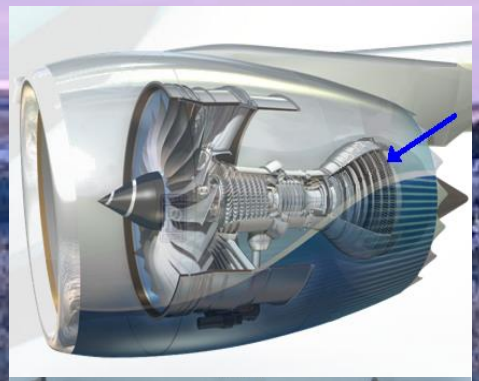


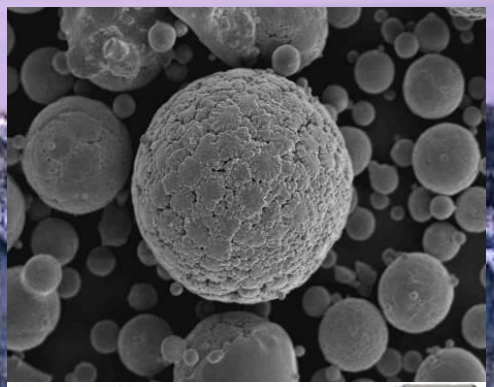
Ground



Space

MASER-12





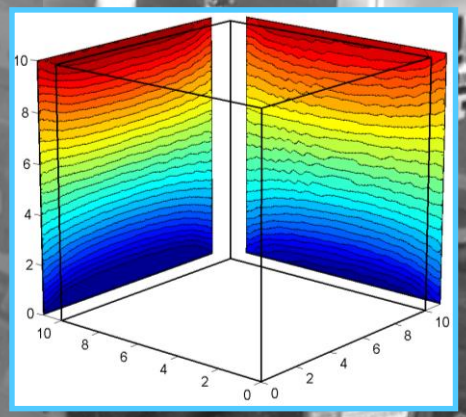
- New lightweight TiAl turbine blades for jet engines and gas

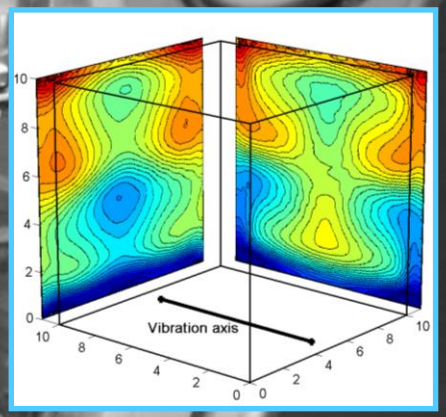
-New NiAl catalytic powders for hydrogen fuel cells and other chemical processes

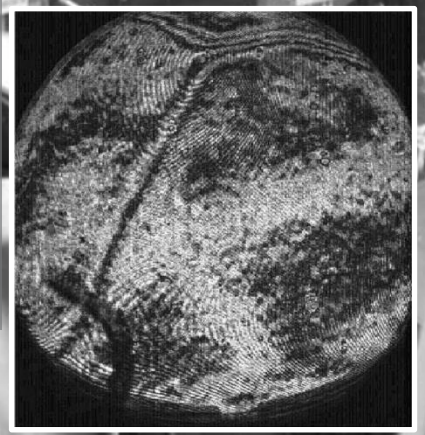
Key Research Topics

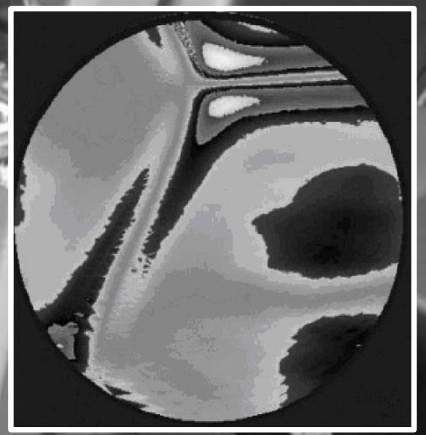
PHYSICS OF FLUIDS AND COMBUSTION

- Dynamics and properties of interfaces
- Convective instabilities under conditions not realisable on Earth
- Phase separation, evaporation and heat transfer
- Complex fluids: coarsening and stability
- Combustion processes of dispersed systems





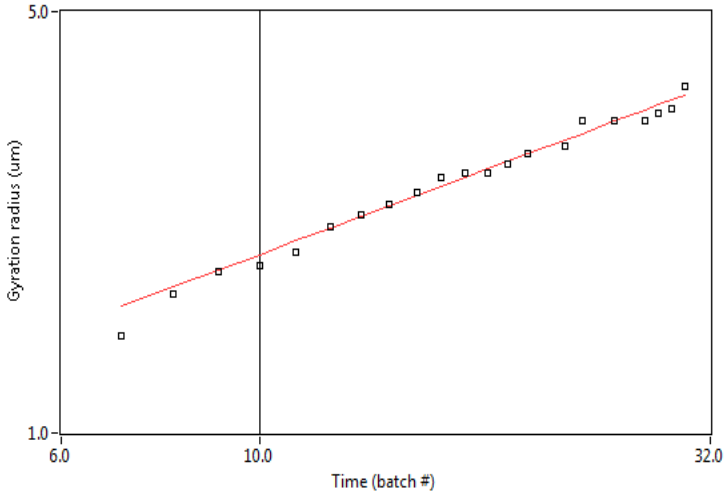




EXAMPLE FLUIDS: *SODI COLLOID*

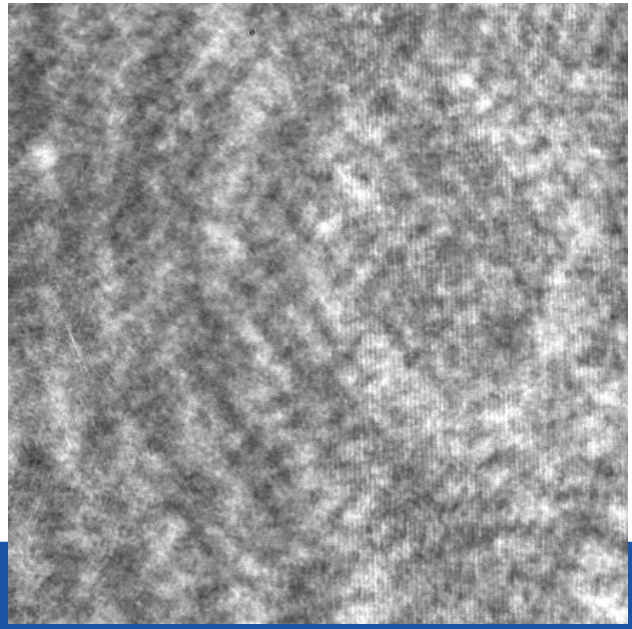
- Aggregation of nanoparticles.
- Aims at measuring the weak critical Casimir forces (caused by density fluctuations), and control the growth of nano-structured material by temperature

Astronaut Furukawa installing SODI COLLOID In the MSG



Evolution of aggregates size as a function of time

Aggregation of nanoparicles over approx 1 hour (video)

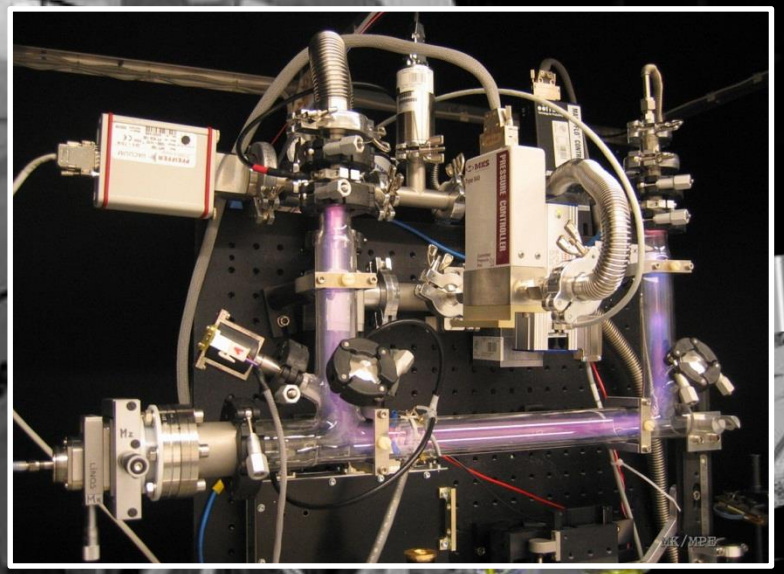


References:
D. Bonn et al. Phys. Rev. Lett. **103**, 156101 (2009)
F. Ferri et al. Phys. Rev. E **70**, 041405 (2004)

Key Research Topics

FUNDAMENTAL PHYSICS

- Fundamental Constants of Nature
- Universal time scales and clock comparison at global scale
- Dynamics of degenerate quantum gases
- Test Einstein's Weak Equivalence Principle
- Mimic molecular interactions

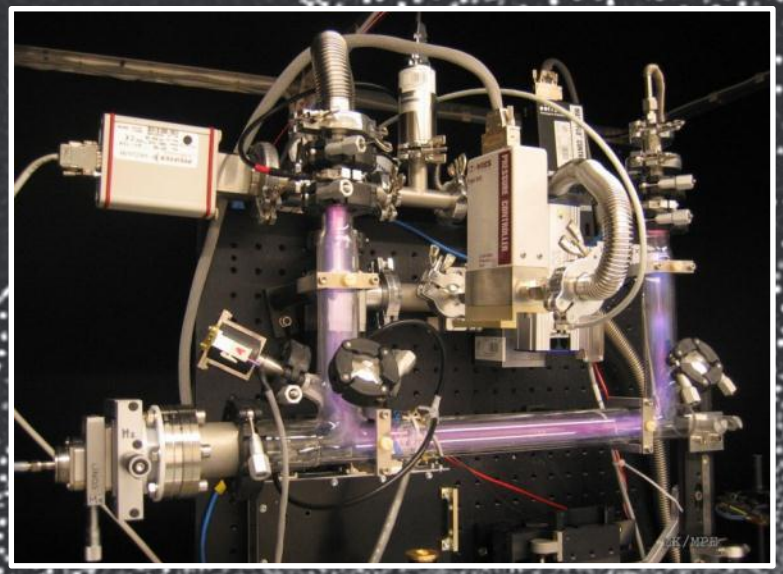


EXAMPLE FUNDAMENTAL PHYSICS

COMPLEX PLASMAS

Complex Plasmas are low temperature ionised gases into which dust particles have been injected. The dust particles accumulate charge and adopt a behaviour which can "mimic" that of atoms in a crystal, liquid or gas.
This particularity makes them interesting, as one can study and actually observe with microscopes phenomena which, in the case of atoms, are too small and too fast to observe.

The gases used for the plasma are e.g. Argon or Neon. The ionization is produced by electric discharges (DC or RF).
PK-4 will be a DC discharge chamber, particularly well adapted for the study of flows in the liquid phase.

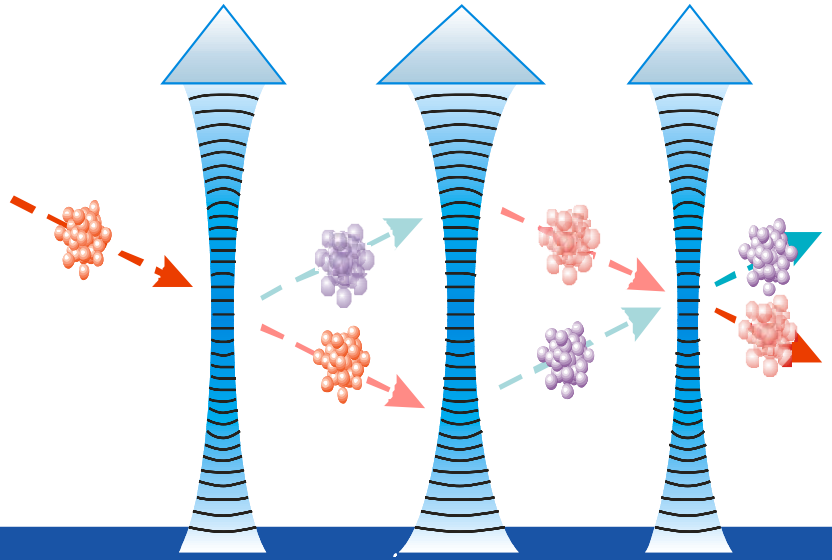


EXAMPLE FUNDAMENTAL PHYSICS

Quantum test of the Weak Equivalence Principle - QWEP

Space Atom Interferometer: Atom interferometer for fundamental physics studies in space

Objective: Atom interferometry test of the Weak Equivalence Principle on quantum object at 10^{-15} level for a mission opportunity on the ISS in 2018-2020. (Today's limit is $5 \cdot 10^{-13}$)

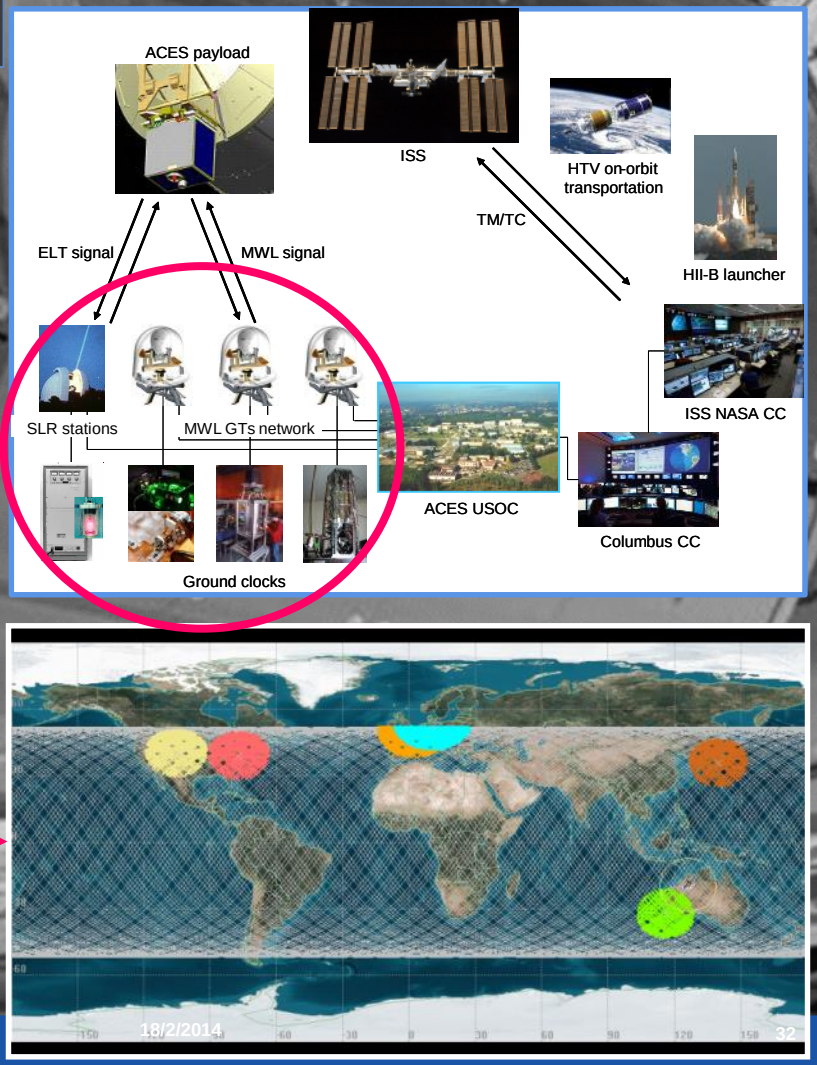


Trajectories of two different atom clouds aboard the ISS are monitored as they fall around the Earth.

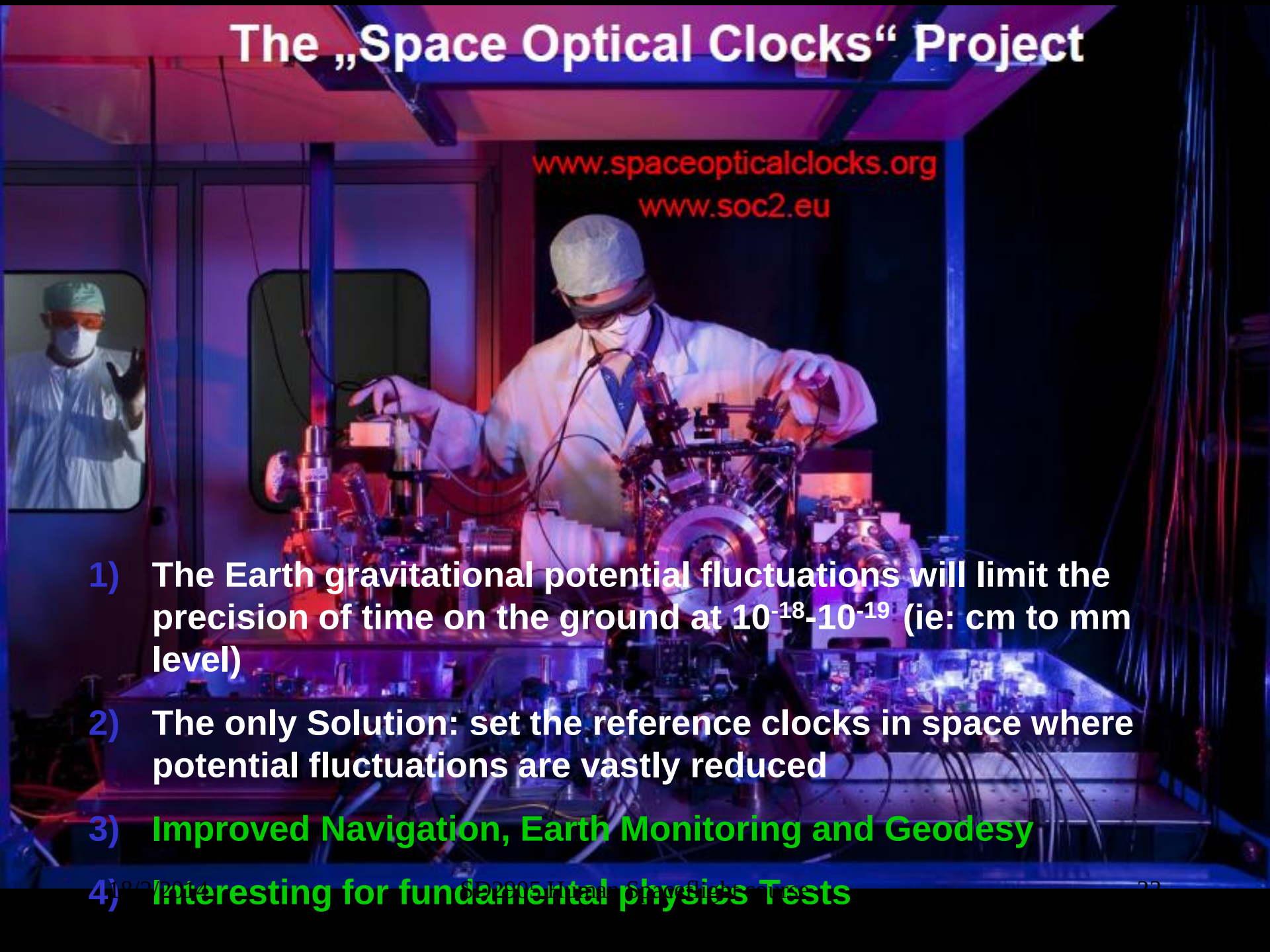
EXAMPLE FUNDAMENTAL PHYSICS

ACES: The Atomic Clock Ensemble in Space

- Two high-performance atomic clocks for the most precise measurement of time in space. (Stability 10^{-15} - 10^{-16})
- Benefit different research areas including testing Einstein's general relativity and alternative theories of gravitation.



The „Space Optical Clocks“ Project



1) The Earth gravitational potential fluctuations will limit the precision of time on the ground at 10^{-18}-10^{-19} (ie: cm to mm level)

2) The only Solution: set the reference clocks in space where potential fluctuations are vastly reduced

3) Improved Navigation, Earth Monitoring and Geodesy

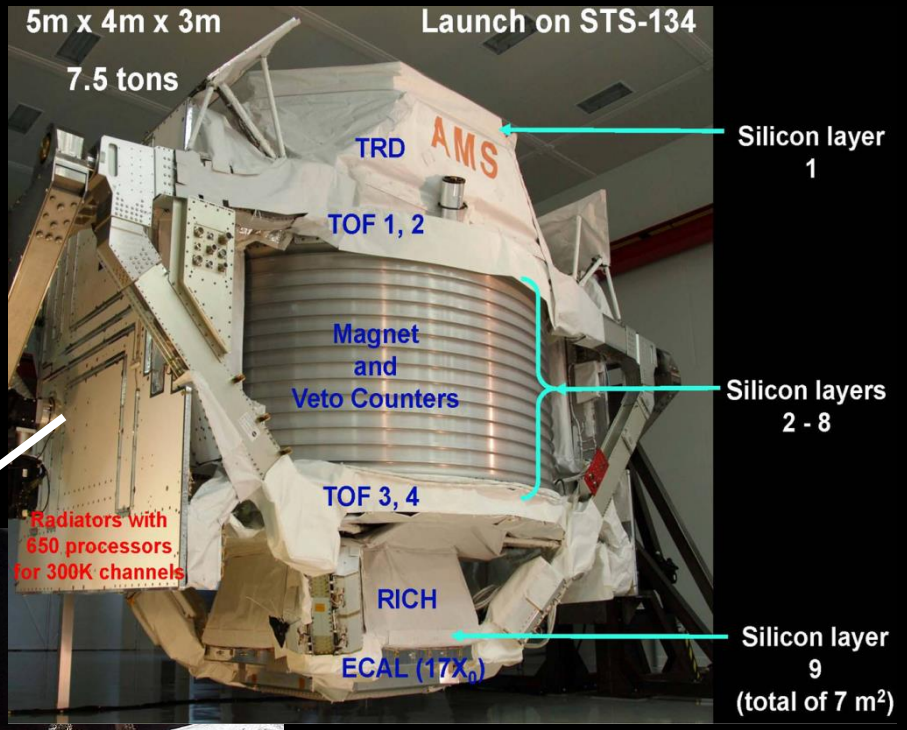
4) Interesting for fundamental physics Tests

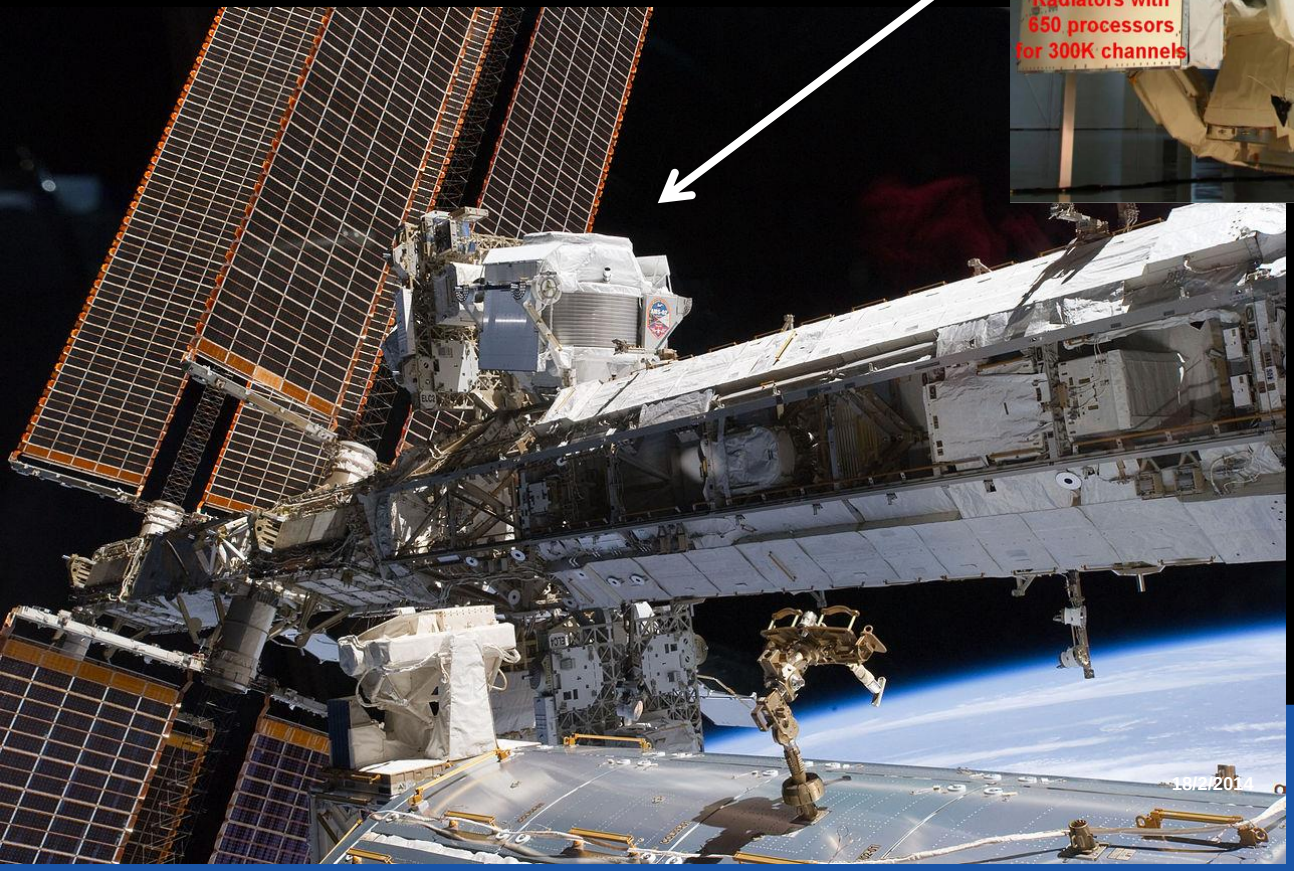
You DO get younger in LEO – or rather you age slower

- During my total 26.7 days in LEO I "gained" 0.75 ms from high velocity
- But I "lost" 0.08 ms from the gravitational field being 10% less! ("redshift" effect)

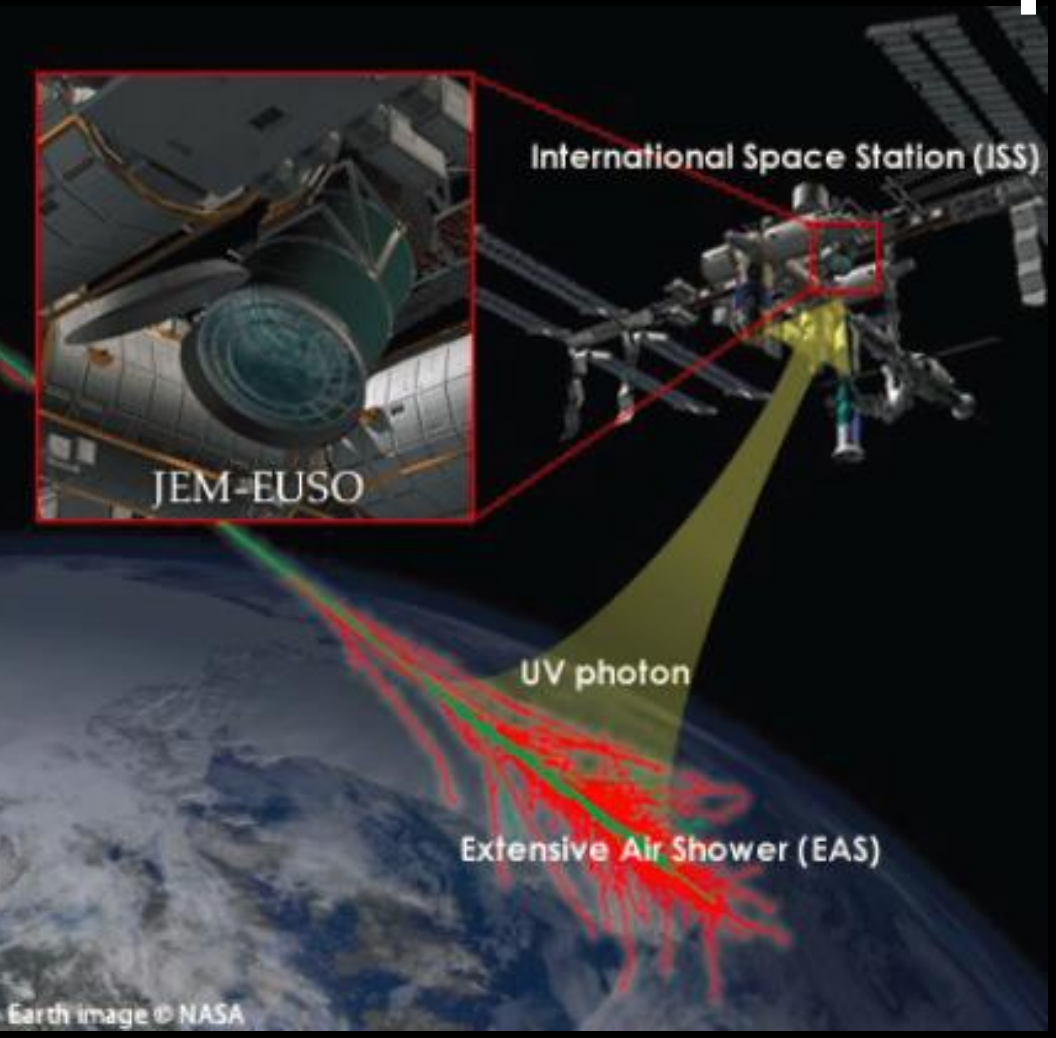
Important effects to correct for in GPS signals – otherwise position error would grow with ≈10 km/day!

The Alpha Magnetic Spectrometer on ISS

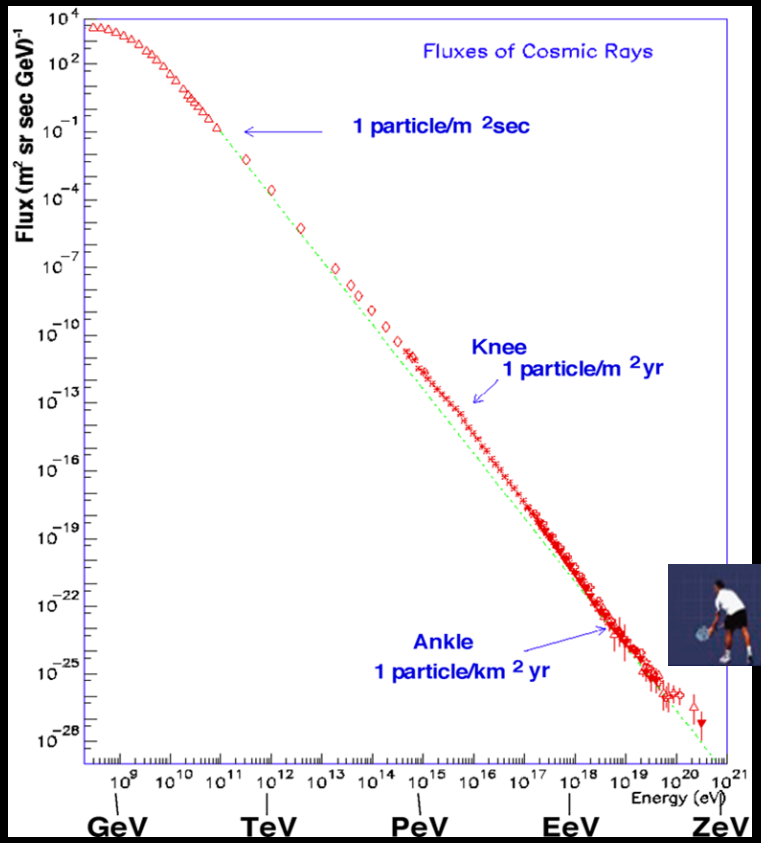




Extreme Universe Space Observatory



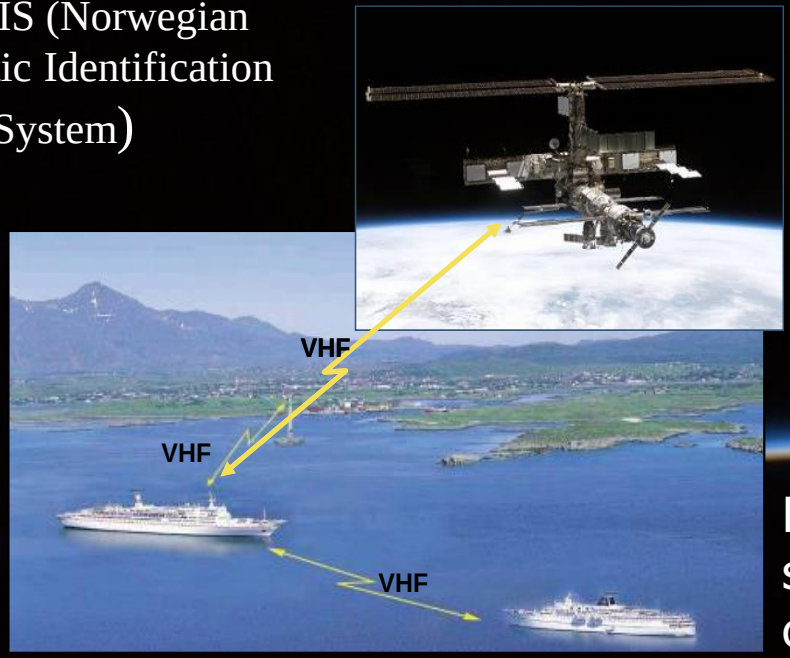
- Ultra-high energy Cosmic Rays E: > 3×10^{19} eV
- Earth atmoshere as detector
- Measure produced UV and Chrenkov light from ISS



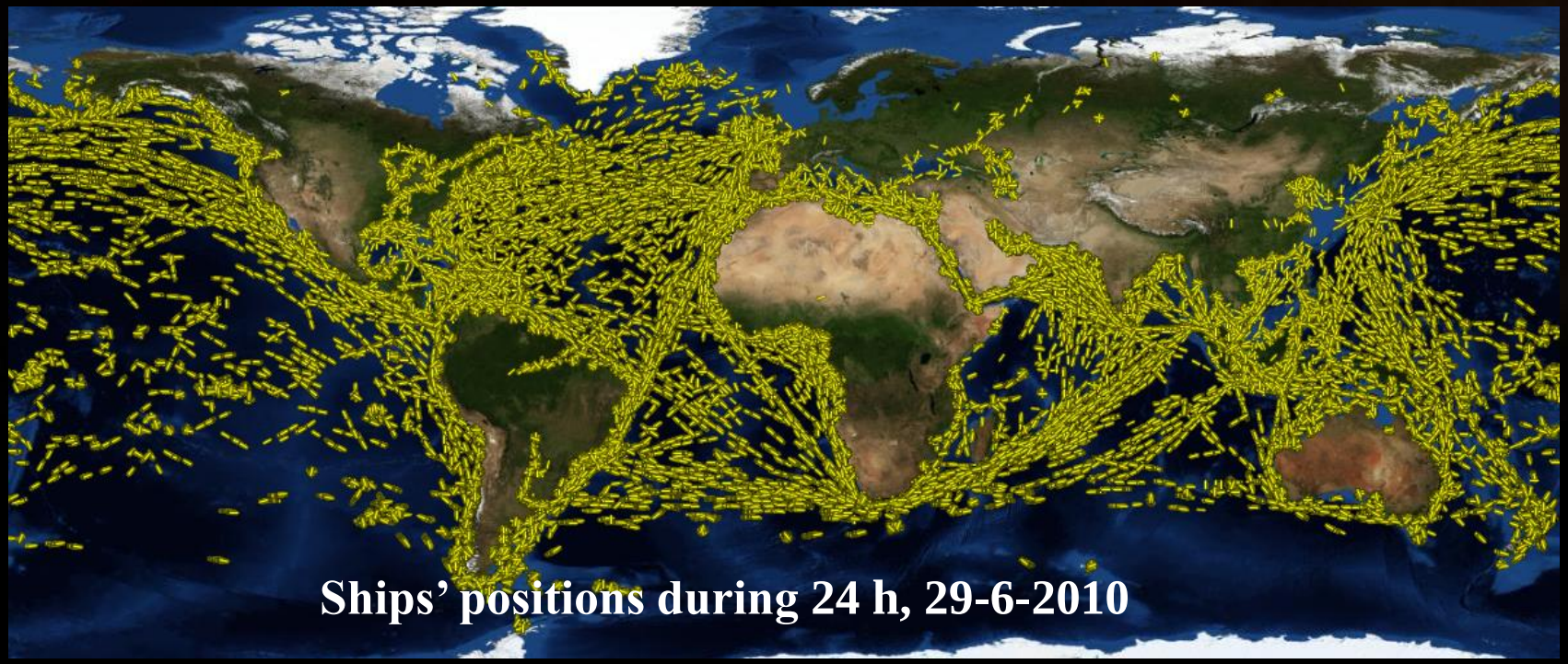
Launch ca 2018;
min 5 yr ops.

TECHNOLOGY DEMONSTRATIONS

NORAIS (Norwegian Automatic Identification System)



Developing a global satellite-based shipping control system



Ships' positions during 24 h, 29-6-2010

Deploying cubesats from ISS

Summary

Space offers some unique opportnities for various fields of science.
In particular those that can benefit of weightlessness (0G or more properly µG) or the views of the Earth and towards space.

ESA has a specific scientific program for this: ELIPS

The main areas of research are in the fields of

- Human Physiology
  - Almost every physiological system is affected by µG
- Biology (and astrobiology)
  - From gene expressions to and cellular level to full plants and animal (e.g. mice)
- Atmospheric and environmental physics
- Fluid physics
- Combustion Sciences
- Material Sciences
- Fundamental Physics
- Technological demonstrations

References

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