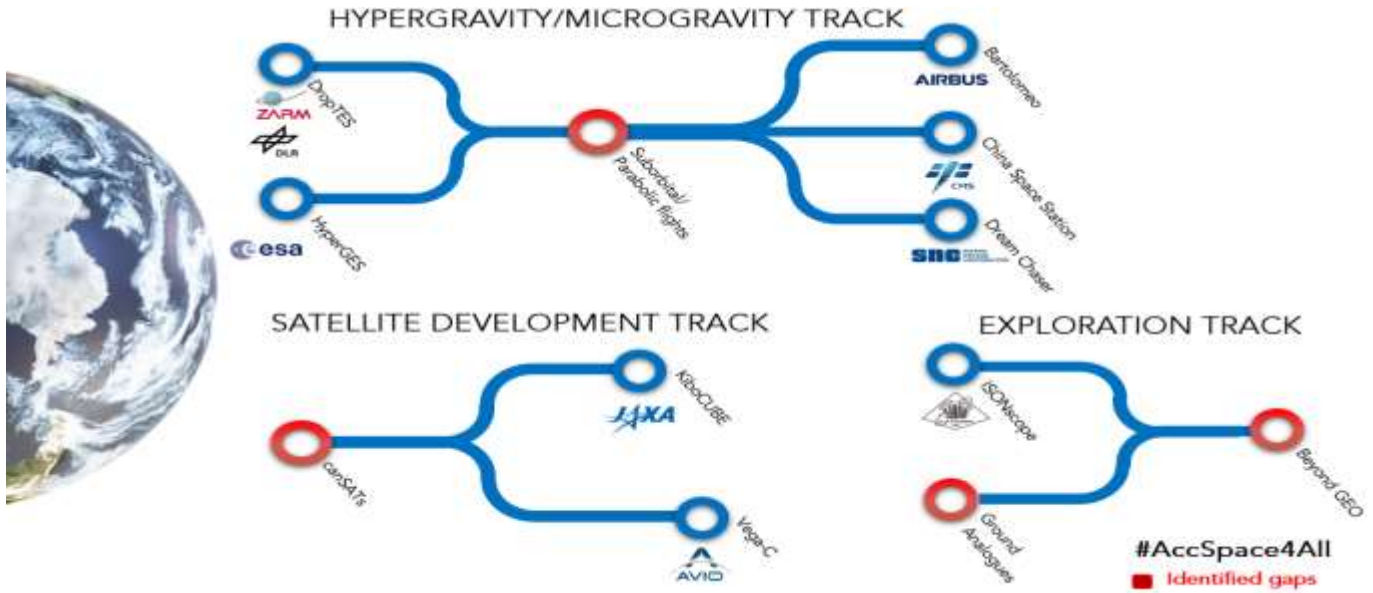


Introduction of fundamentals of R&D in Hypergravity / Microgravity environments

Dr.ing. Jack J.W.A. van Loon

Dept. Cranial-Facial Surgery, ACTA &
VU University Medical Center, Amsterdam, the Netherlands
&
Cooperate Scientist @ ESA-ESTEC-TEC-MMG Lab, Noordwijk, the Netherlands

21 April 2021, 10:30-10:50 CEST
Part of UNOOSA "Series of Webinars for the Hypergravity/Microgravity Track"

Gravity

Milky Way: ~$2.4 \cdot 10^{20}$ m

Solar system: $5.9 \cdot 10^{12}$ m (incl. Pluto?!)

Sun: $1.4 \cdot 10^{9}$ m

Earth: $1.3 \cdot 10^{7}$ m

Human: ~$2 \cdot 10^{0}$ m

Organs: ~$2 \cdot 10^{-1}$ m

Cell: $1 \cdot 10^{-5}$ m

Molecule (H): $7.4 \cdot 10^{-11}$ m

~10^{12}

~10^{12}

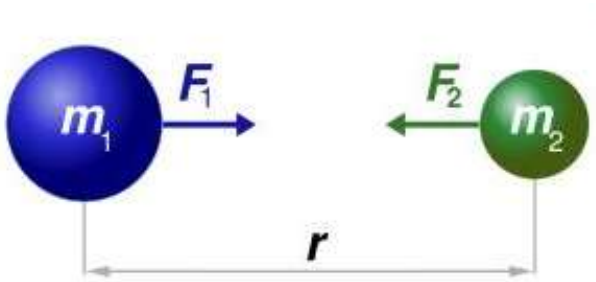
4 basic forces : weak nuclear force – strong nuclear force – electromagnetic force – **gravity**

Gravity has (mainly) impact on:

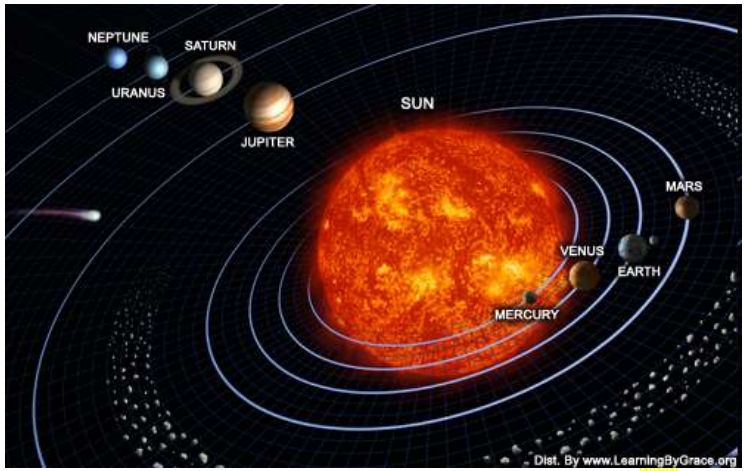
- Weight
- Hydrostatic Pressure
- Convection
- Buoyancy
- Sedimentation

NB: Spaceflight holds more variables: *e.g.* isolation, radiation, atmosphere (pressure, gas composition), stress, training, ……

Gravity and Mass - Weight



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$



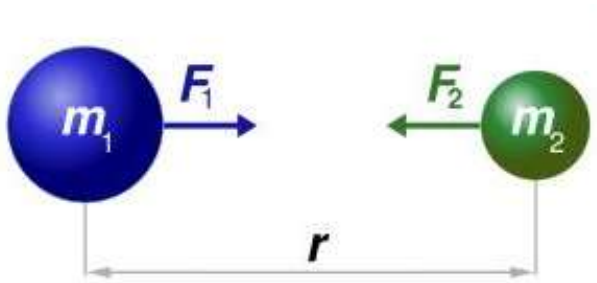
$$F = m \times a$$

i.e.

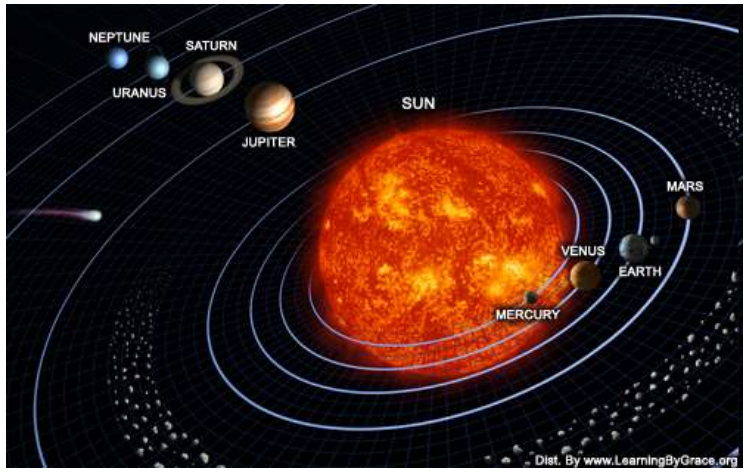
$$F = m \times g$$

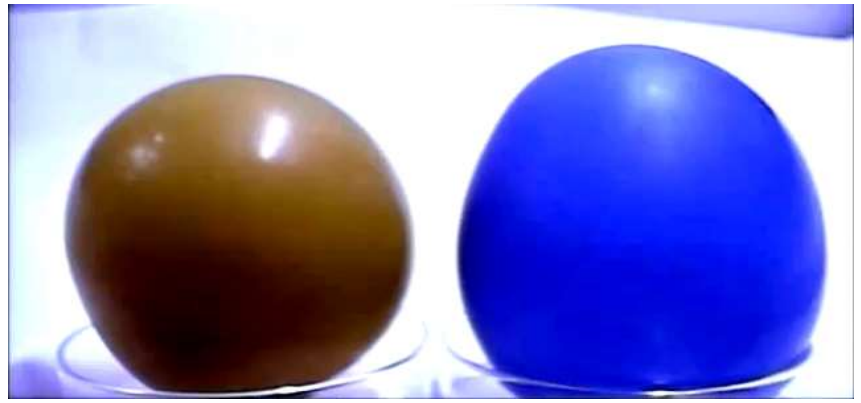
'g' no 'G' !!

Gravity and Mass - Weight



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

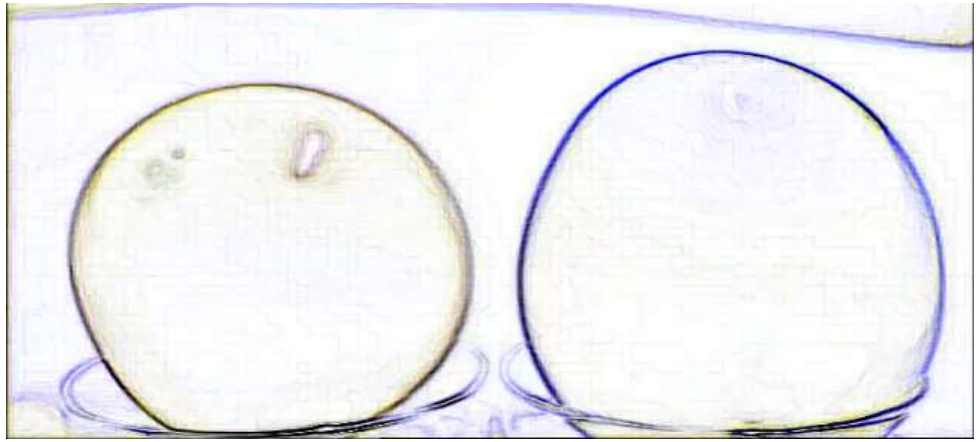




regular balloons

~15 cm

Large Diameter Centrifuge, LDC
ESA-ESTEC Noordwijk, NL



air (light) vs **water** (heavy) balloon

Hydrostatic pressure

$$P = F/A$$
$$= \rho A g h/A$$

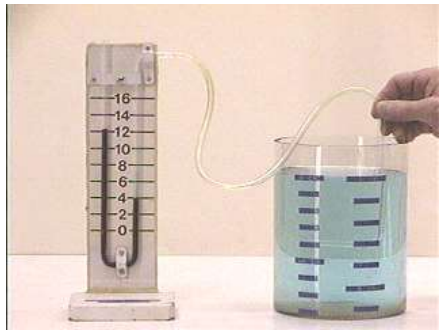
Where:
P = pressure (Pa)
F = force (N)
A = surface area (m^2)
ρ = density of the liquid or gas (g/cm^3)
***g* = unit gravity (m/s^2)**
h = height of the liquid (or gas) column (m)

www

Normally, the pressure exerted by a fluid column is additional to atmospheric pressure. The total pressure would be:

$P_{tot} = \rho g h + P_o$

Where:
P_o = atmospheric pressure (Pa)

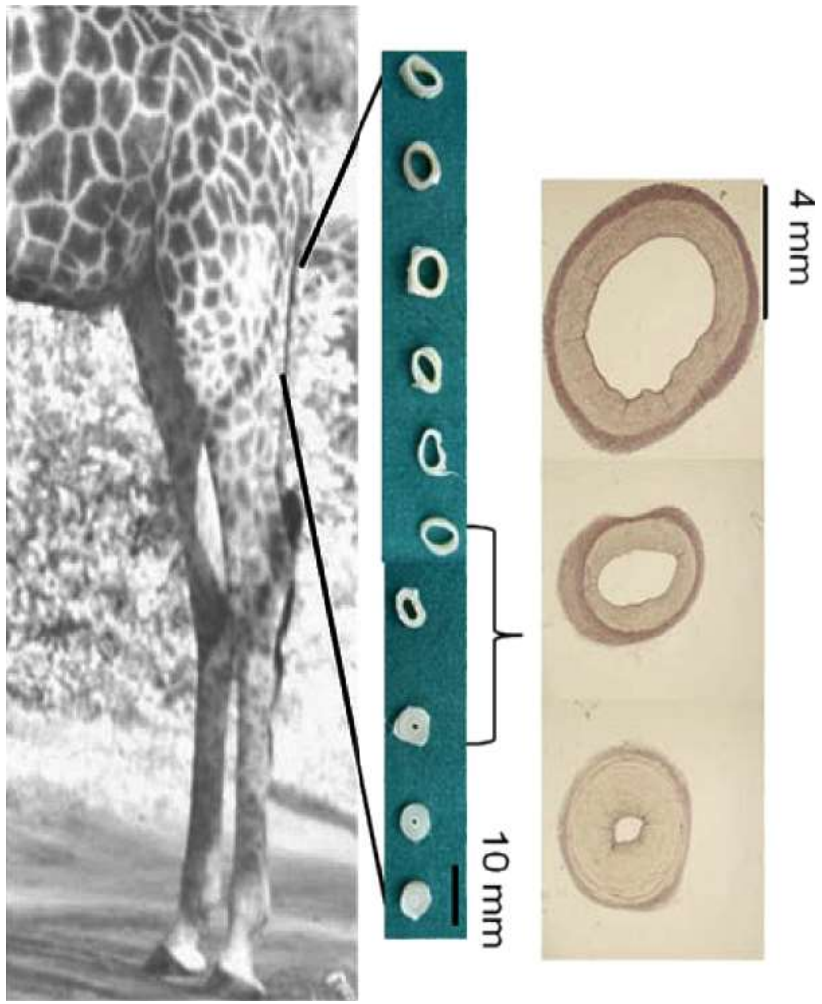


www

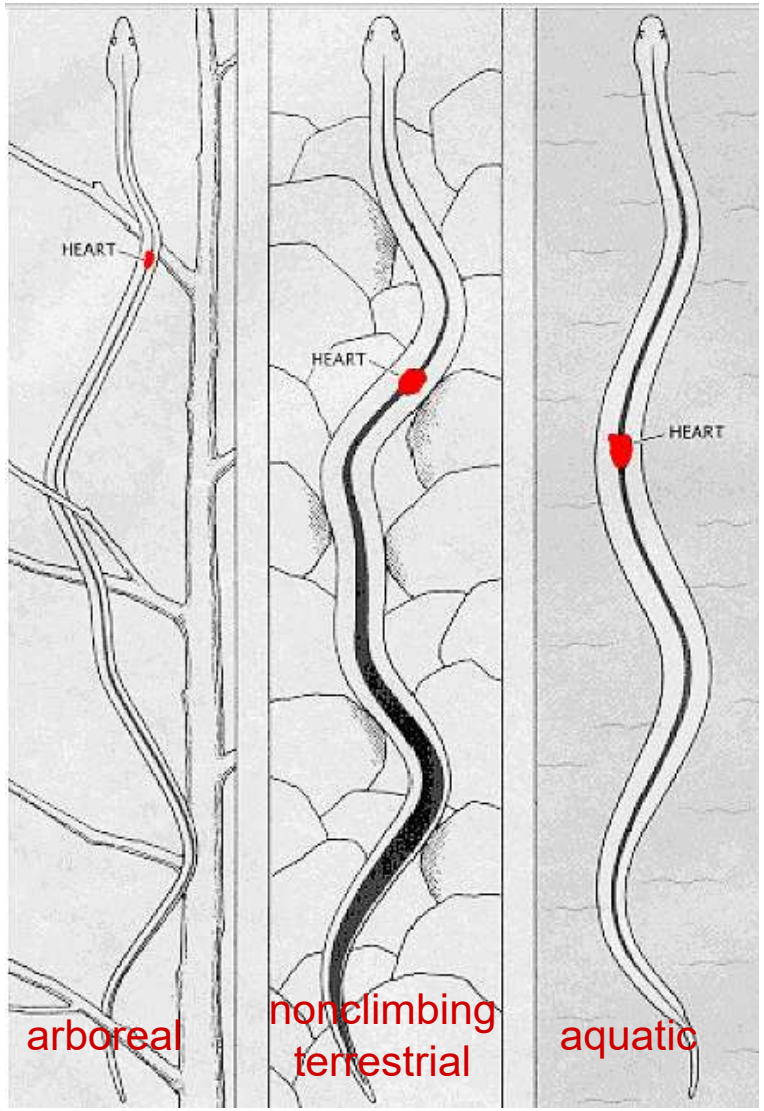
Hydrostatic pressure is linearly proportional to *g*. Under pure weightlessness conditions, hydrostatic pressure due to weight is zero.

Gravity and Hydrostatic Pressure

Norsk & Karemaker, Sci. Am. 2008



Hovkjær et al. J Comp Physiol B 2011



Lillywhite, J Exp. Zoology, 1996

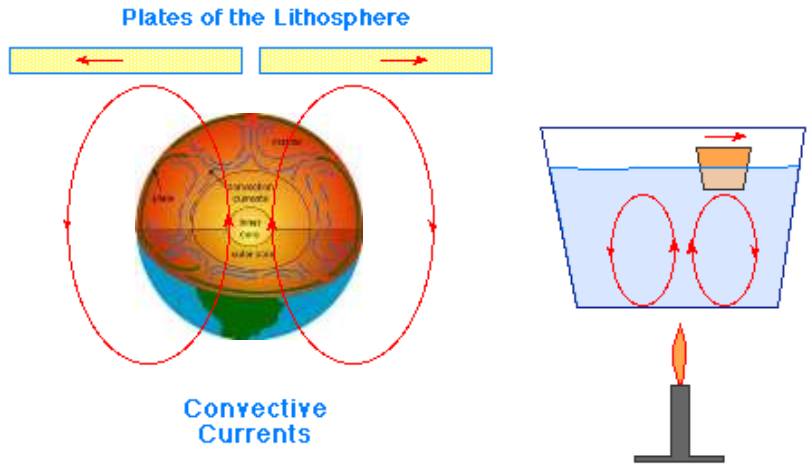
Convection

The general equation for convection: $q_c = \overline{h_c} A \Delta T$

Where:
q_c = the amount of heat transferred by convection
h_c = the average convection heat transfer coefficient
A = heat transfer area
ΔT = the difference between the surface temperature T_s and the ambient temperature of the fluid T_∞ far from the surface

Natural convection:

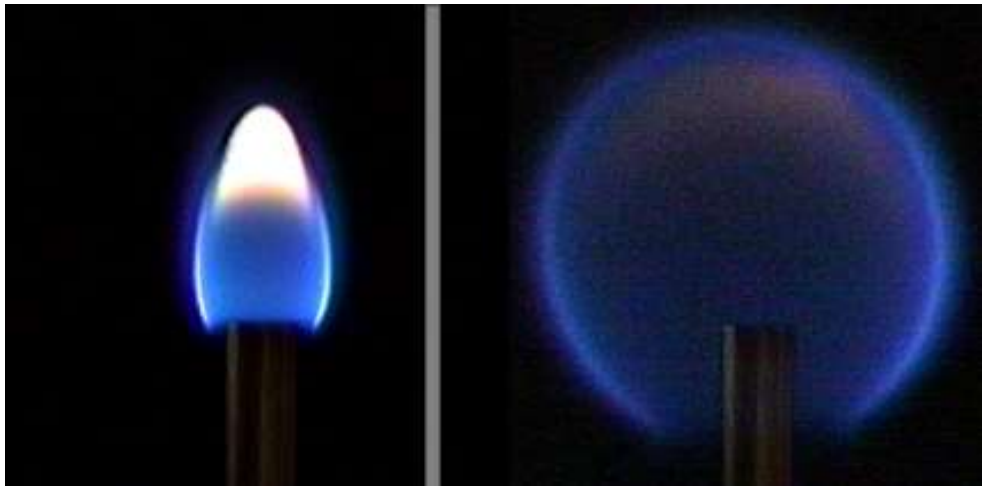
$$Gr = \frac{\mathbf{g}\beta(T - T_\infty)L^3}{\nu^3}$$



Where:
Gr = Grashof (Gr) number
g = acceleration due to gravity
β = the coefficient of expansion
($T - T_\infty$) = the temperature difference
L = the characteristic length
υ = the kinematic viscosity

Convection Examples – 1

Candle in 1 g



1g **µg**

(buoyancy)

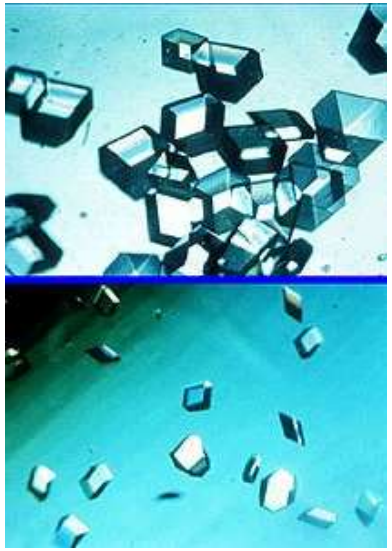
Sergey Krikalev, Mir

ESA-Kuipers EPO-Convection (on Earth!) ISS 2012

Rayleigh:
- body force
- global motion
- better mixing

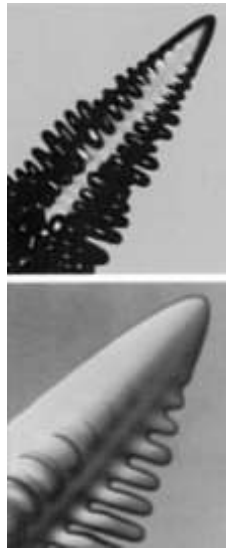
Marangoni (thermocapilary):
- surface force
- boundary layer
- intensified gradient

Crystal growth



µg

1g



Courtesy: NASA

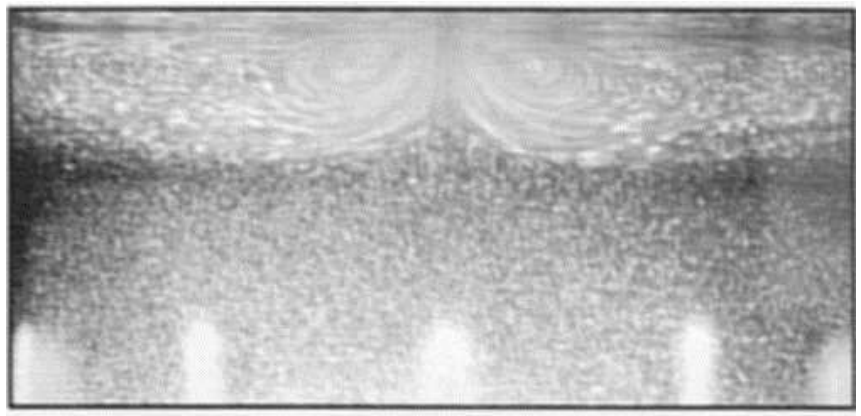
CaCl

1g **µg**

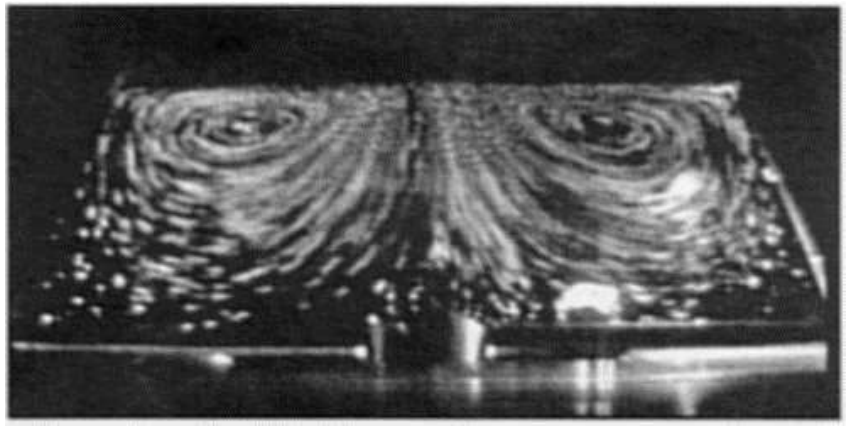
(buoyancy)

Convection Examples – 2 (NOT gravity dependent)

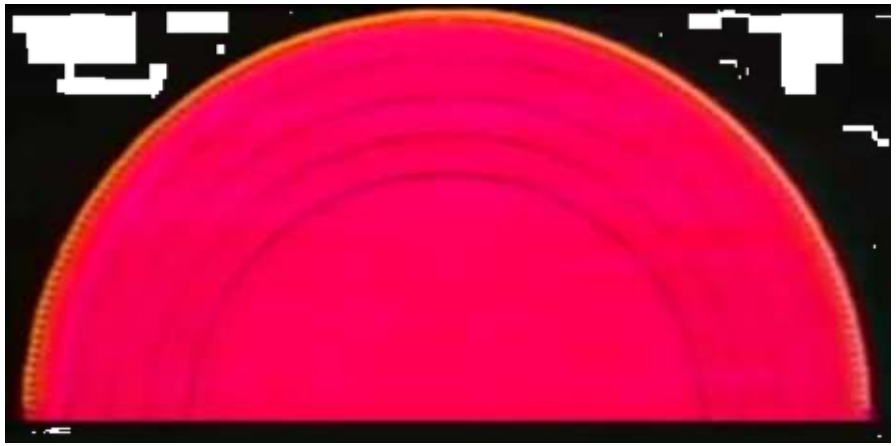
thermo-capillary / Bénard–Marangoni convection



1g



µg



Courtesy: NASA

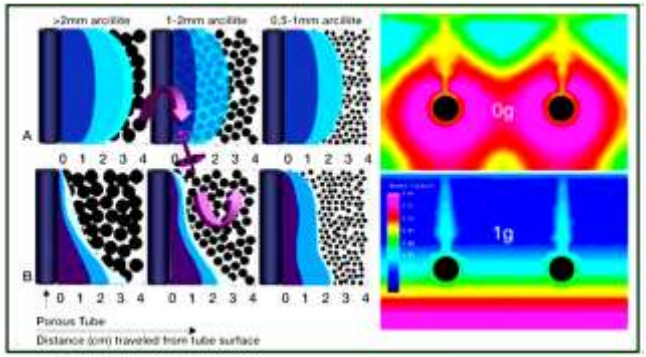
thermo (C. Buffone, ULB, BE)

surface tension-dominated convection (Gibbs/Marangoni)

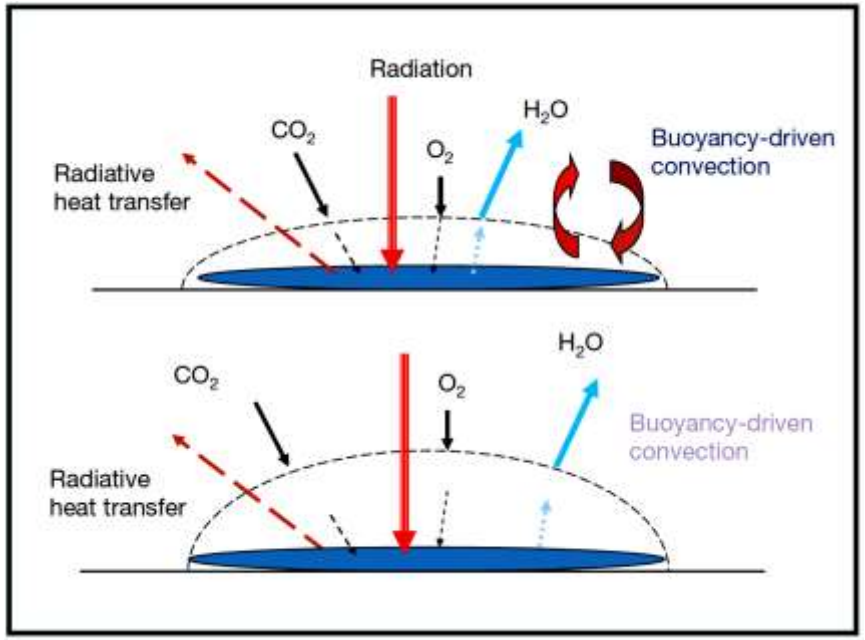
Plants and Convection

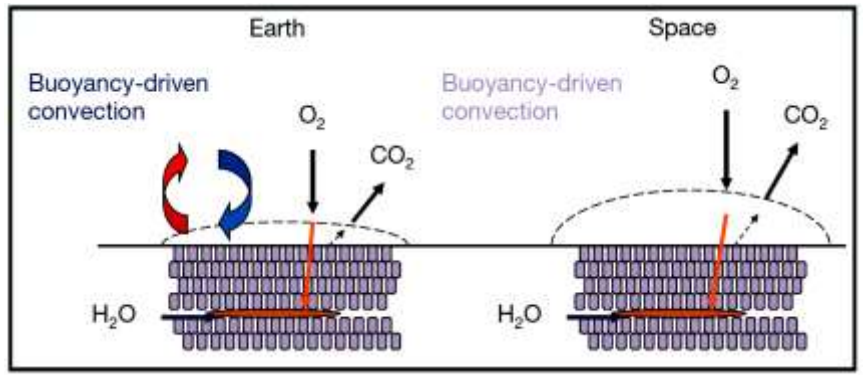
Biomass Production System, ISS (Orbitec)

Root Zone Fluid Dynamics



Moisture distribution in media is different in microgravity than at 1g. The picture on the left shows the effect of particle size on moisture distribution between the 0 and 1.8 g during a parabolic flight. The image on the right shows the distribution of water around a porous tube under 0-g (upper) and 1-g (lower) conditions





A Researcher's Guide to: Plant Science. NASA, 2015

pea leaf grown in Lada chamber on ISS.

Absence of buoyancy-driven convection in microgravity results in a barrier at the soil/atmosphere interface that limits the diffusion of O_2 into the root zone

see also: L Poulet et al. Astrobiology, 2018

Sedimentation

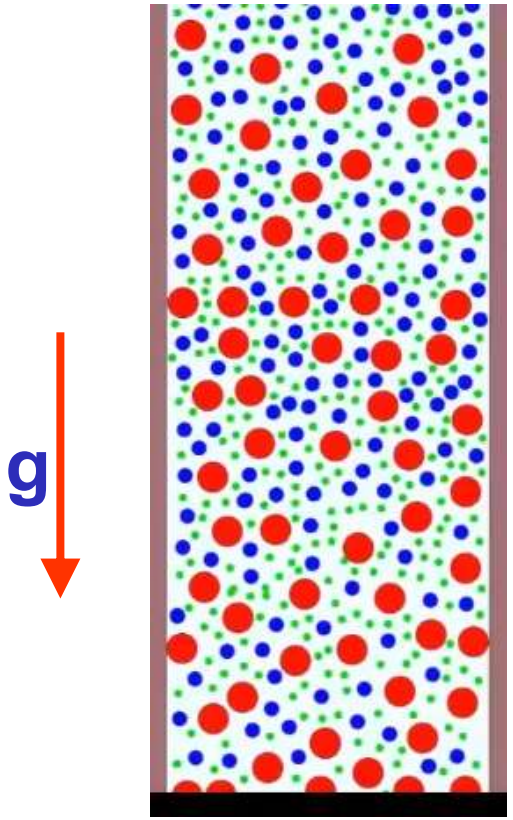
$$F_S = mg - F_B - F_F$$

$$F_S = mg - (\rho f V g) - (6\pi r \eta v)$$

Where:
m = mass of the object (kg)
g = the gravity acceleration (m/s^2)
FB = buoyant force (see below) = ρf*V*g
ρf = specific density of the fluid (g/cm^3)
V = volume of the displaced fluid (= volume of the object) (m^3)
F_F = frictional force = kv

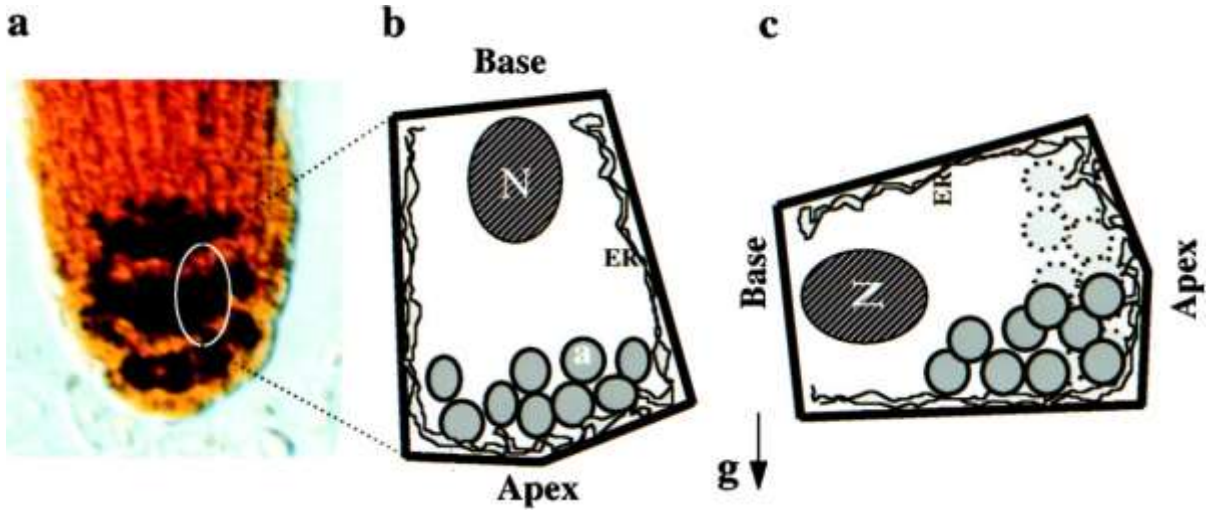
k = the Stokes equation: 6πrηv (v for a spherical object)

Where:
r = radius of the object (m)
η = viscosity constant ($N \cdot s/m^2$ or, Pa·s)
v = object's velocity relative to the fluid (m/s)

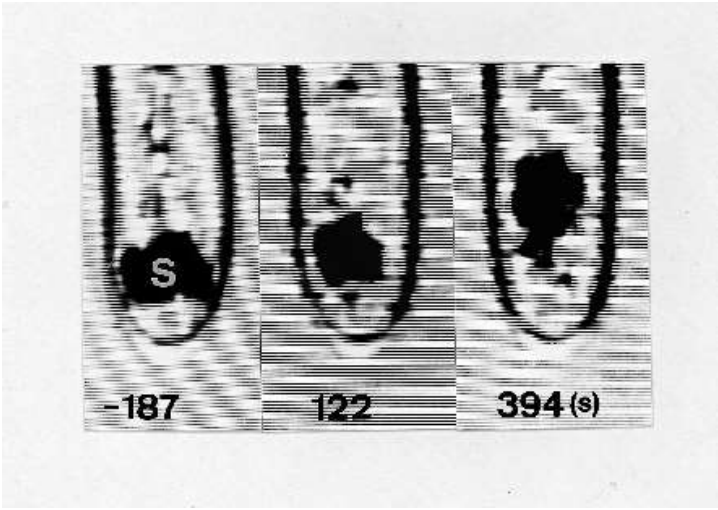


By definition, sedimentation force (F_S) is the downward force of weight due to linear acceleration (m*g*) minus buoyancy (F_B) minus frictional forces opposing downward motion (F_F).

Sedimentation Examples



Settling amyloplasts (starch)



Chara Rhizoids : micro-g (SR)

(Buchen, Braun & Sievers)

Coleoptile emergence www

Shoot gravitropism www

(Britanica)

Waves

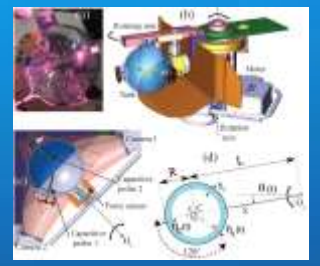
Capillary

ISS-51 Thomas Pesquet

ISS

(courtesy E. Falcon)

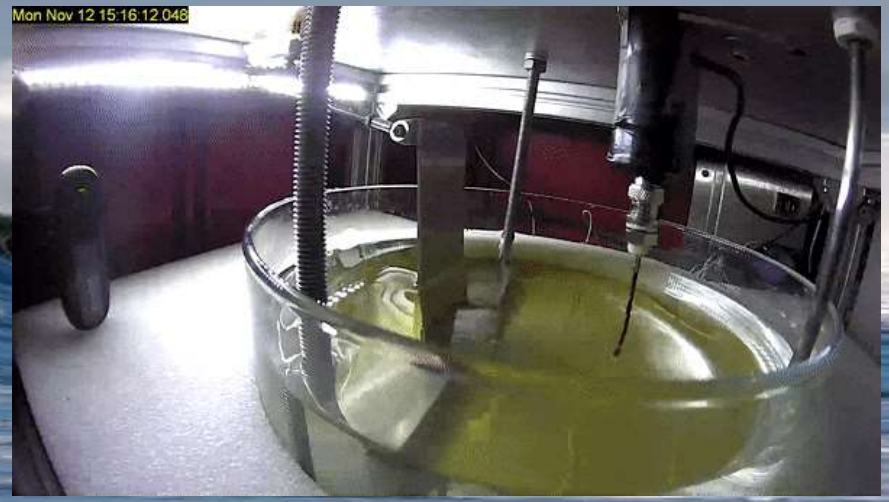
PF



Berhanu et al. EPL (Europhysics Letters), 2020

Gravity

LDC



LDC

Cazaubiel et al. Phys Rev Lett. 2019

Gravity Machines

Facilities for Weight Research

hyper

centrifuges (magnets)

USE as MANY as POSSIBLE ! !

hypo

simulators real micro-weight

MidiCAR (cell/ tissue)

LDC (animal/ plant, fluids …)

:Envihab Human

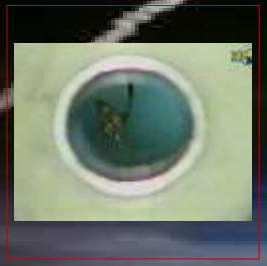
- gel cultures
- tail suspension
- water immersion
- bed-rest
- head down tilt

RPM

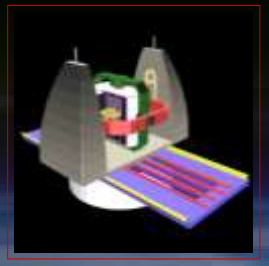
FFM

Magnet

Clinostat

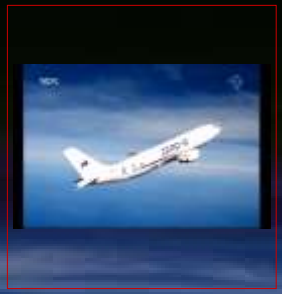


Magnet

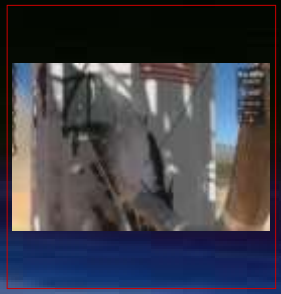


DESDEMONA

- (weight) excersise



zero-g Airbus



sub-orbital

DragonLab

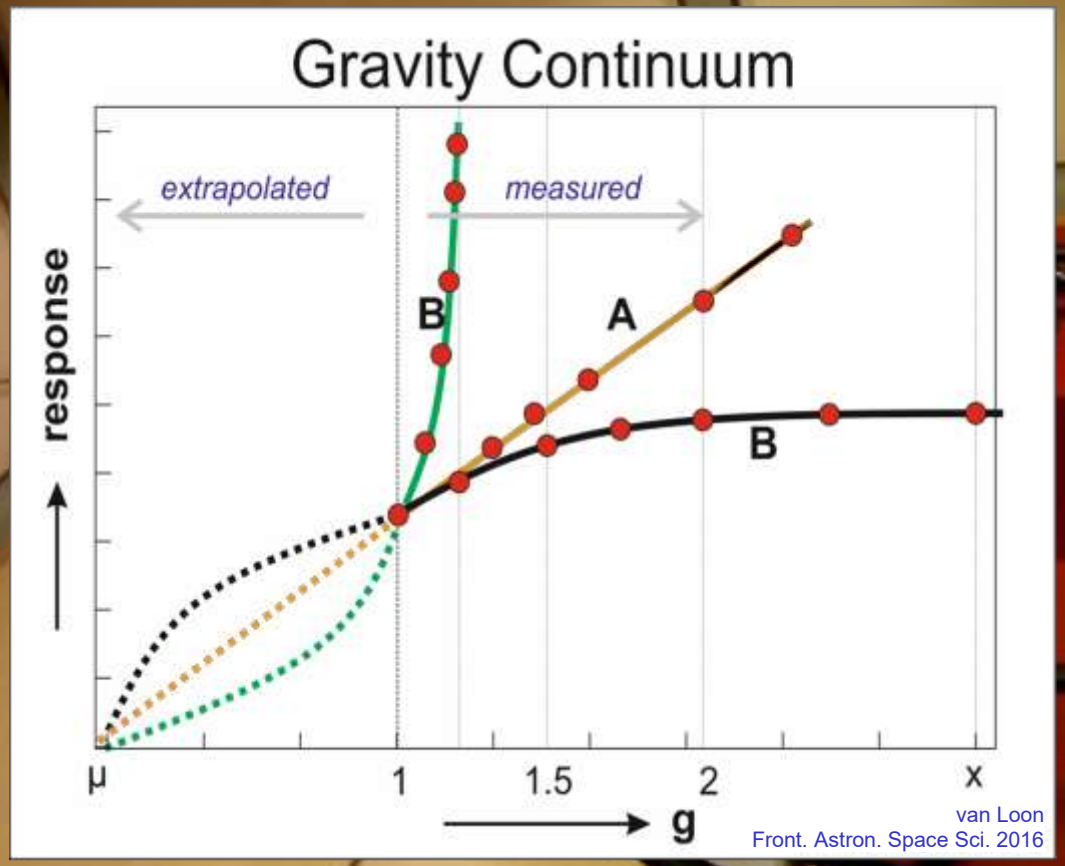
ISS

Soyuz

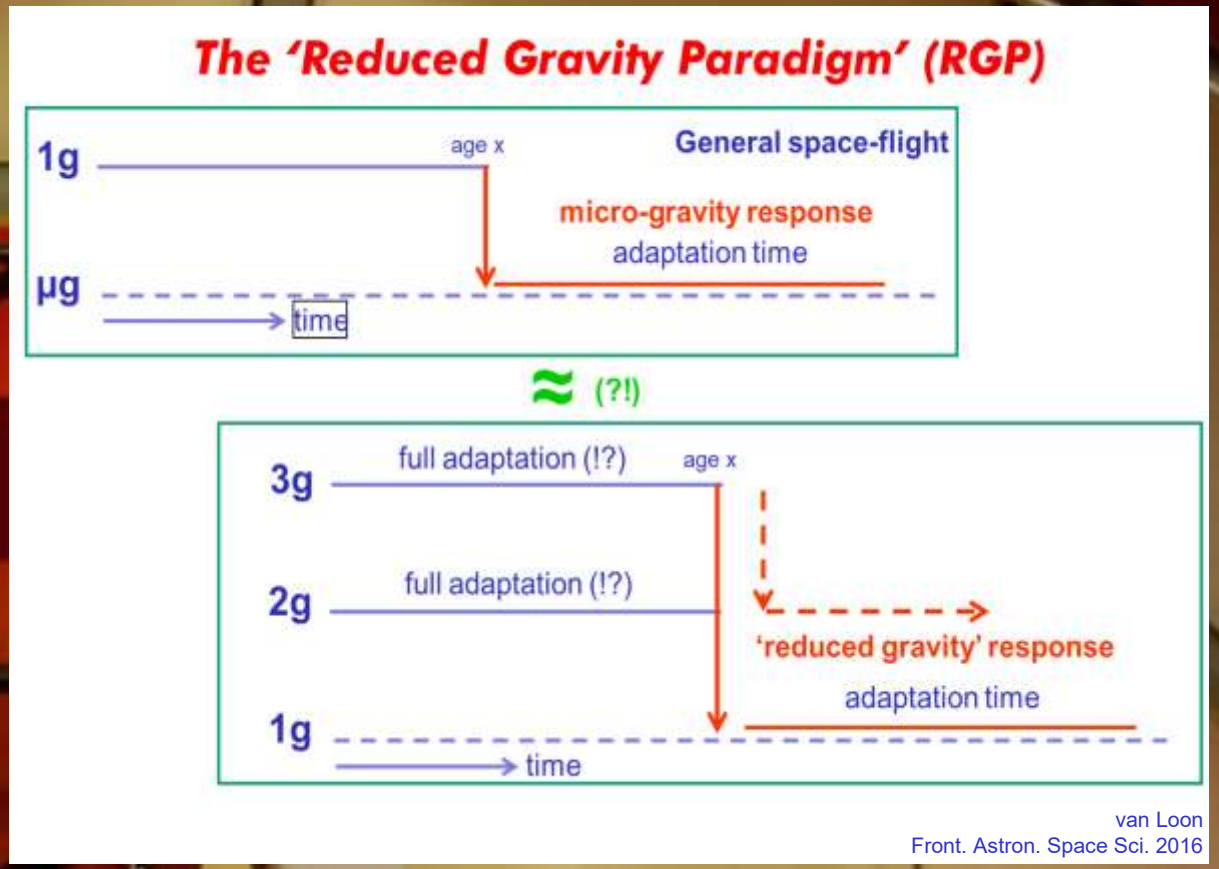
CSS


NO SPACE
– flight research
WITHOUT GROUND
– based research

Application of Ground-Based Centrifuges



van Loon
Front. Astron. Space Sci. 2016



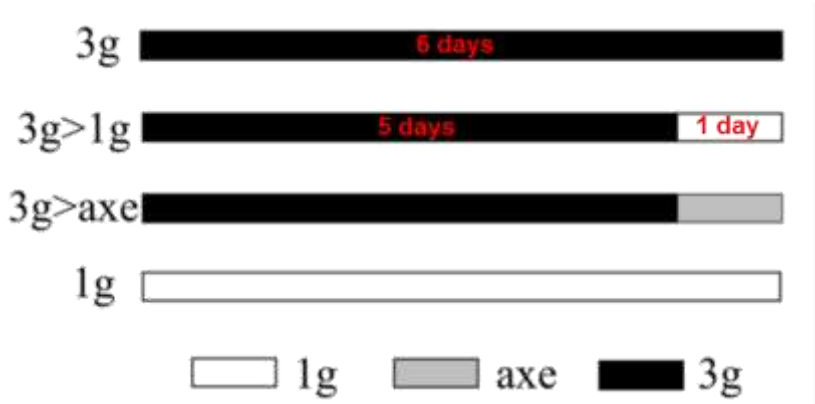
van Loon
Front. Astron. Space Sci. 2016

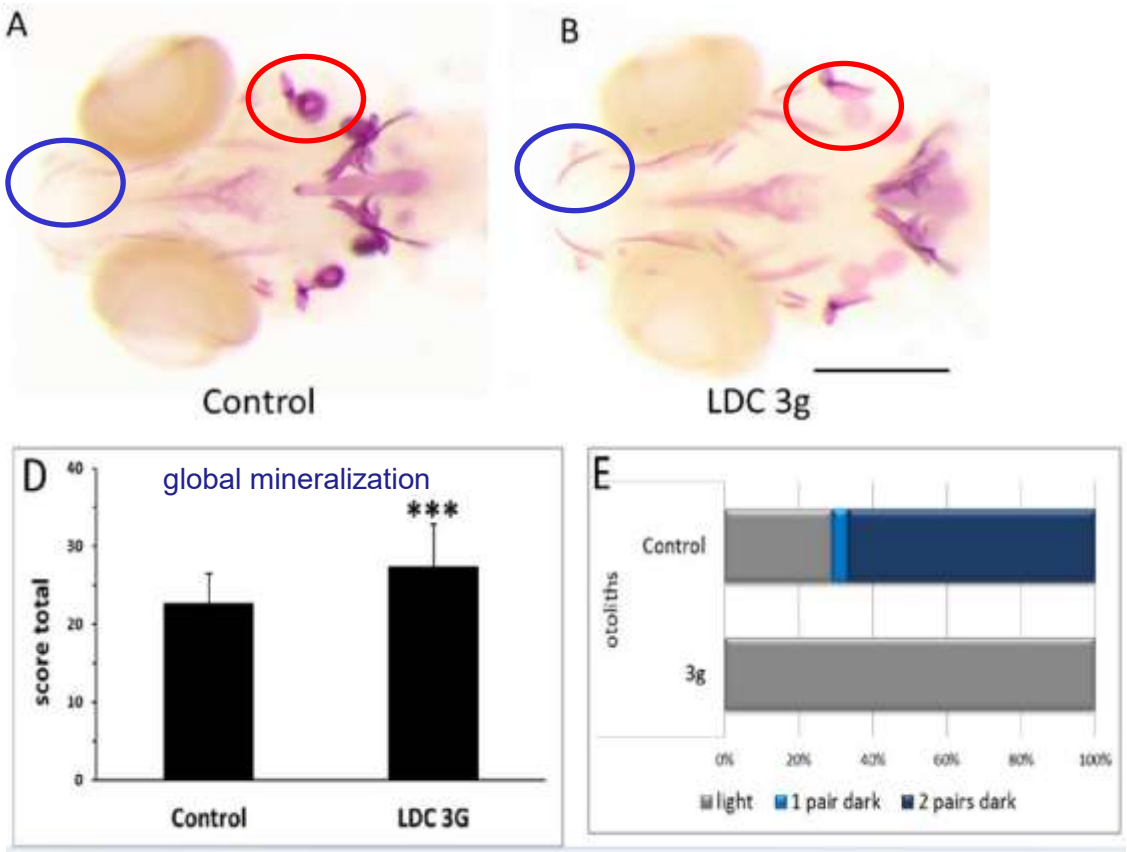
Background: ESA-ESTEC LDC centrifuge

Gravity otoliths & bone development

zebrafish *(Danio rerio)*

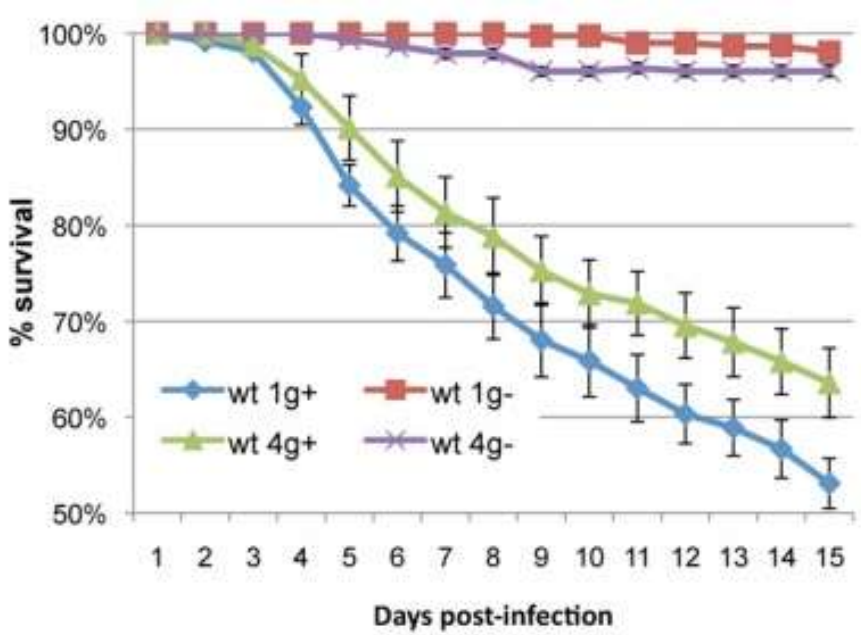
LDC (ESTEC, Noordwijk)

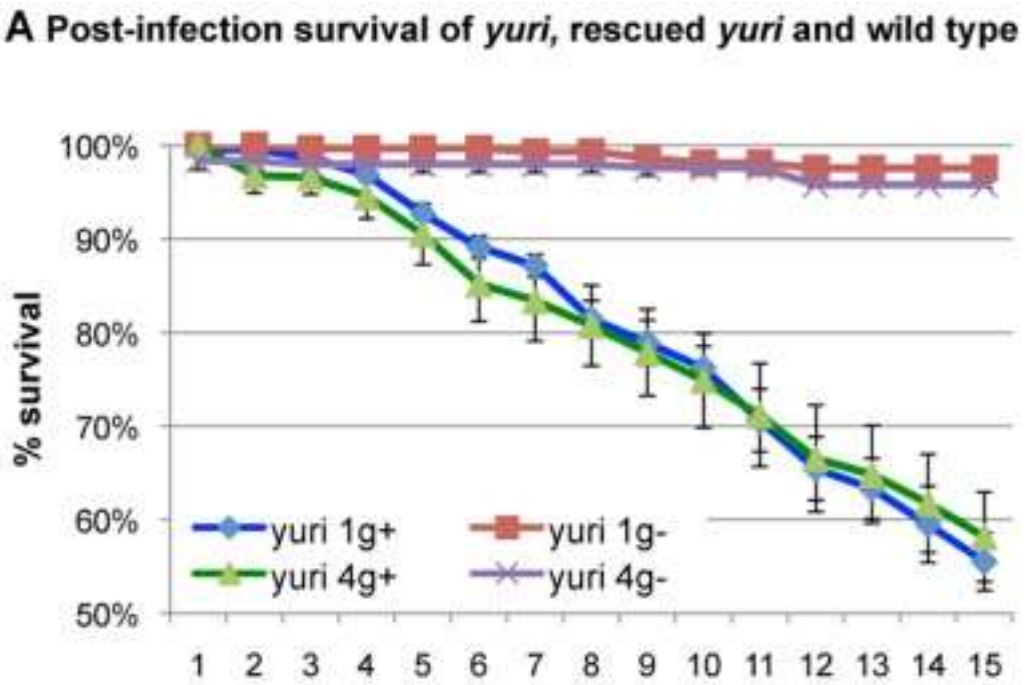




Aceto, van Loon, Muller et al. PLOS One, 2015

Drosophila Effects of hyper g on post-infection survival



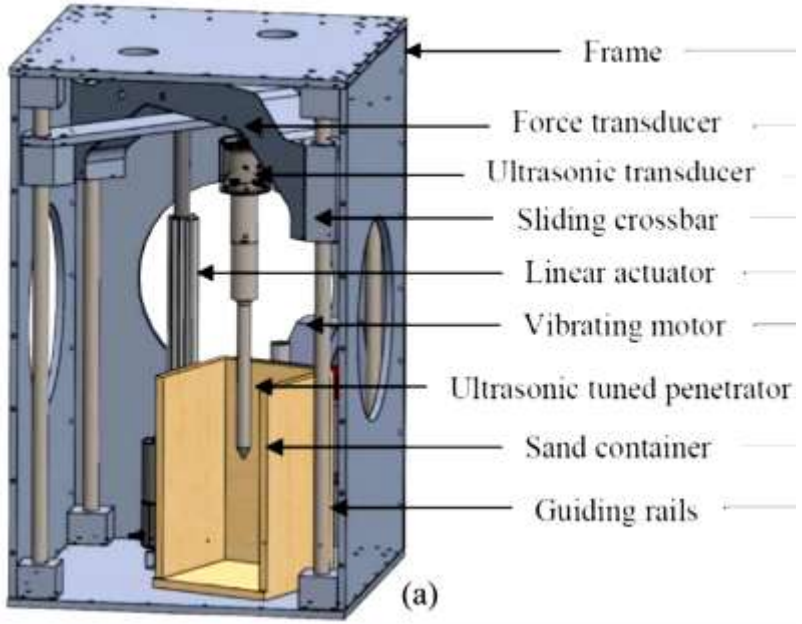


\+ infected (fungal)
\- uninfected

gravitaxis mutant of the yuri gagarin gene.

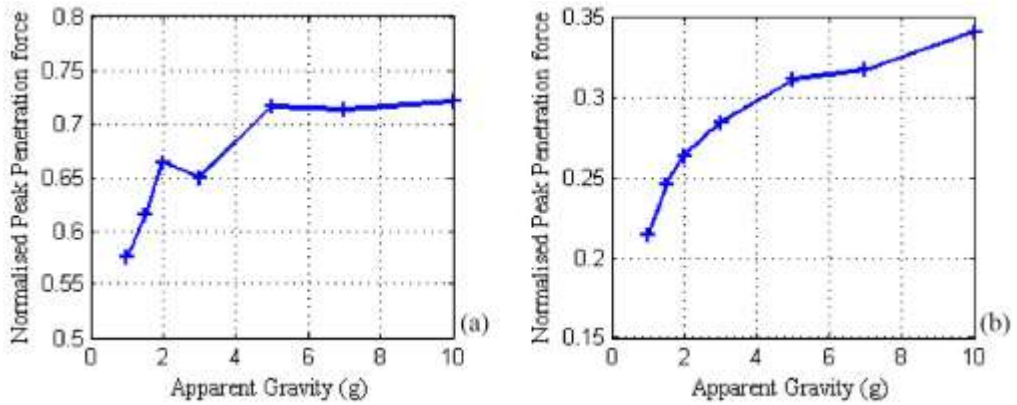
Taylor et al. PlosOne, 2014

Penetration Tests Ultrasonic Drill in High Gravity



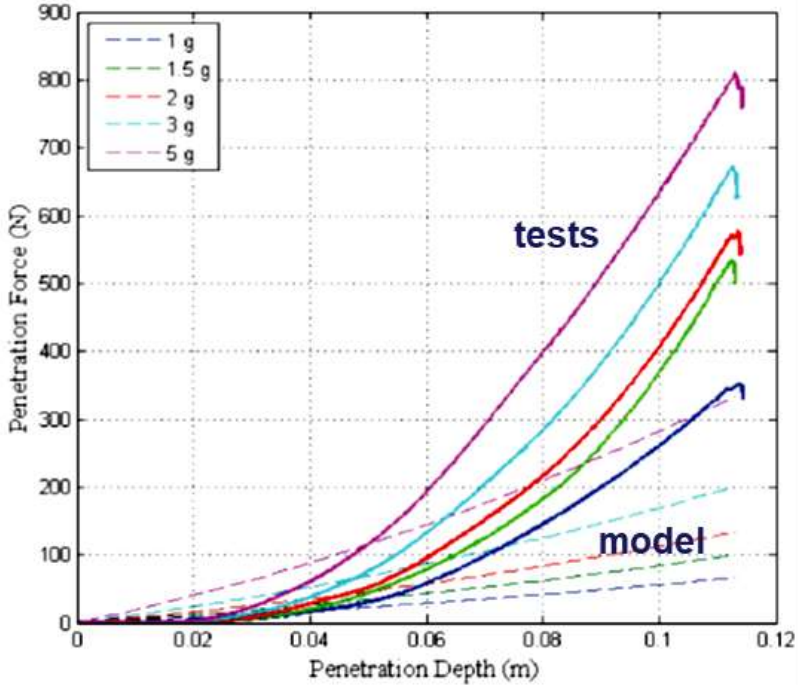
ultrasonic drill in
ESA-LDC gondola

normalized peak penetration forces



Normalised peak penetration profiles with respect to increasing gravity at (a) 0.4 μm, and (b) 1.6 μm ultrasonic excitation amplitude.

Surface drill peak penetration force



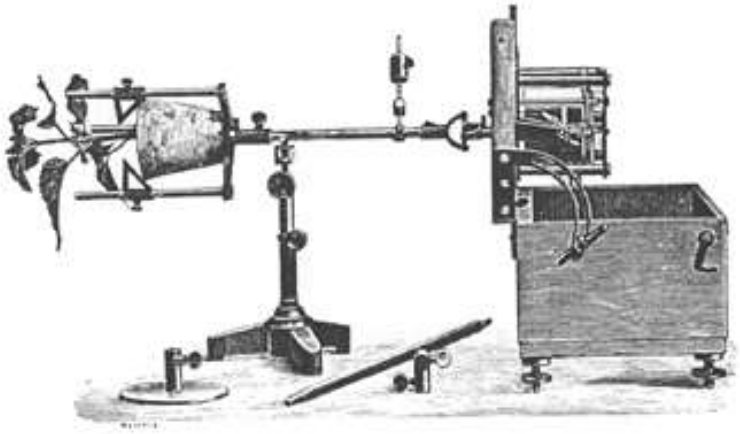
Peak penetration forces for all gravity levels as a function of ultrasonic excitation amplitude. The circled values were not experimentally acquired due to over-loading concerns, and indicate anticipated values based on trends.

Firstbrook et al. Univ. Glasgow, UK

‘Classical’ Clinostat

A Clinostat as Invented by Julius von Sachs. A clockwork (at the right side of the picture) has weights and a pendulum that start a slow movement of the axis. A mounting is fixed at the axis inside a protecting case (dark chamber), upon which a fungus is growing (*Phycomycetes*). The middle part of the axis is enclosed by a glass case that is standing upon a water-filled dish that helps to keep the air in the surrounding of the test object humid (J. v. Sachs, 1887).

Sachs 1887



Pfeffer ~ 1892

Random Positioning Machine (RPM)

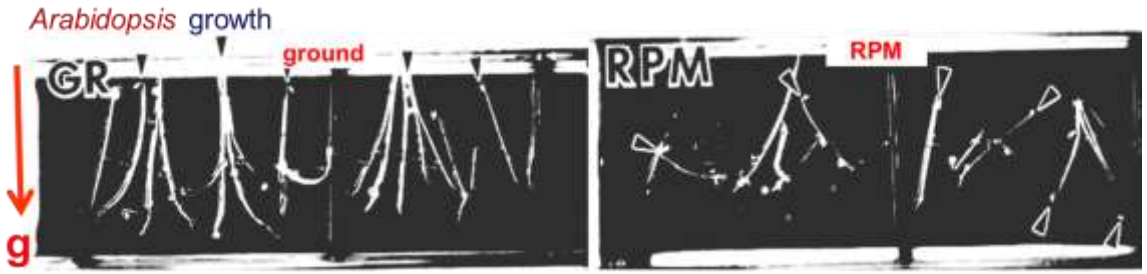
Results with *Arabidopsis* & *Drosophila*

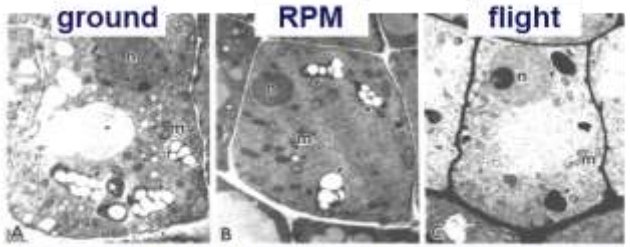
Principle:
The RPM is a machine for micro-weight simulation through a random change, in 3D, of the direction of the gravity vector.

Dik Mesland, ESA

Large RPM at DESC / ESA Noordwijk, NL

NASA Mercury program



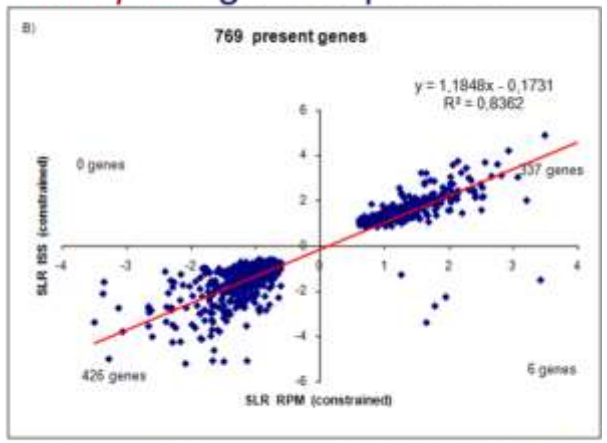


EM micrographs of columella cells : arrowhead = amyloplasts

Krafft, van Loon, Kiss, Planta 2000

Desktop RPM

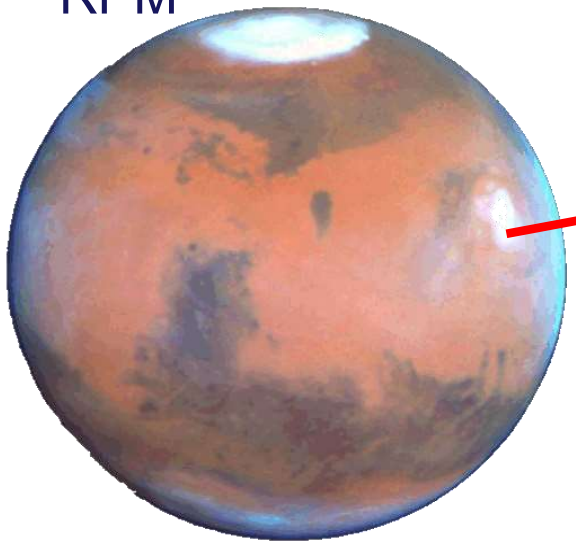
Drosophila gene expression

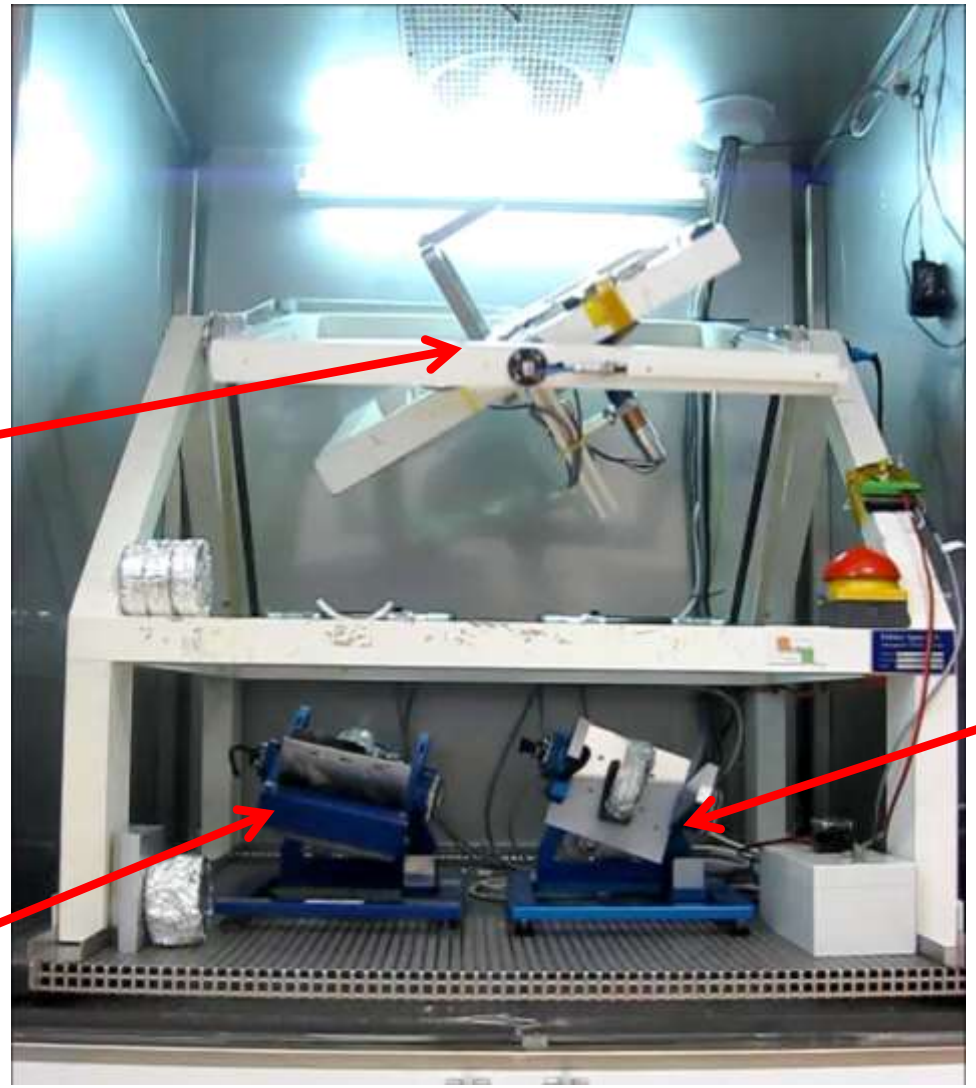


R. Marco, R. Herranz et al. Univ. Madrid, ES

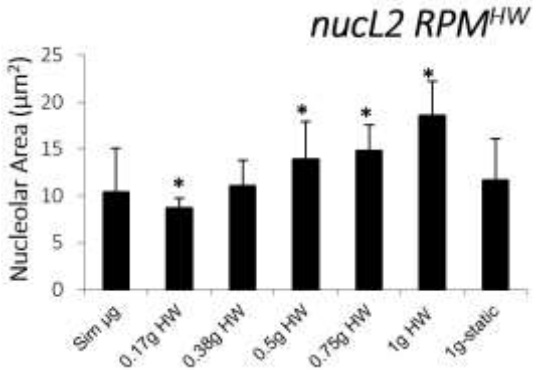
Our RPM 'Play Ground'

Hardware Partial-g RPM





DESC RPM's @ ESA-ESTEC Noodwijk, NL



first pilot data

Software Partial-g RPM

Regular RPM

Manzano et al.
npj Microgravity, 2018

Some Cell Mechano-Biology: … Mechanomics … Physicomics

Gravitational Cell Biology

Direct / primary effects of gravity acceleration onto a cell

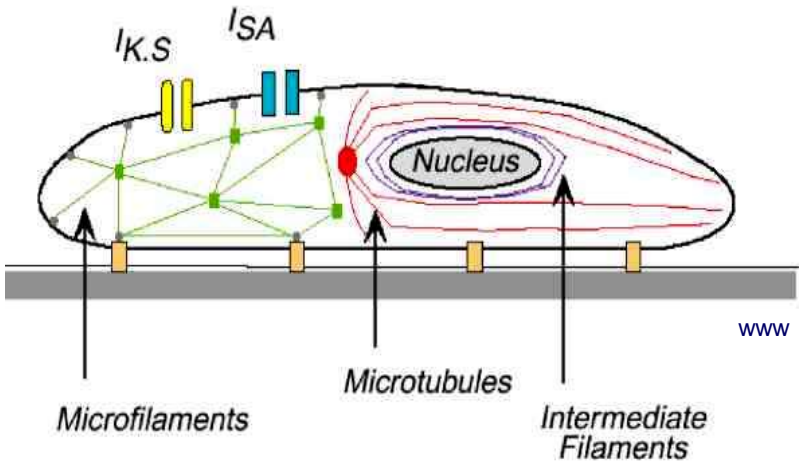
apply or remove a mechanical load

biochemical messengers

mechanotransduction

changes in structural, mechanical and functional properties

gene expression
protein synthesis

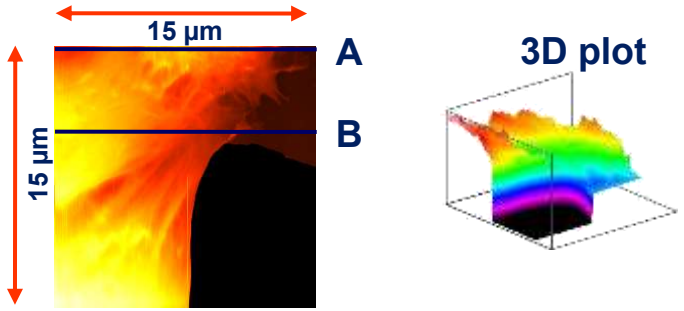


adaptation or injury

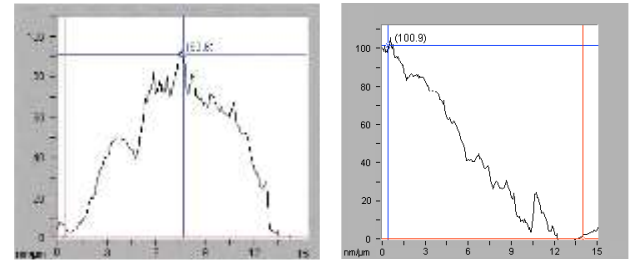
A cellular response to mechanical loads requires 'mechanosensors' and 'mechanotransducers'.

Results from single cell AFM in hypergravity

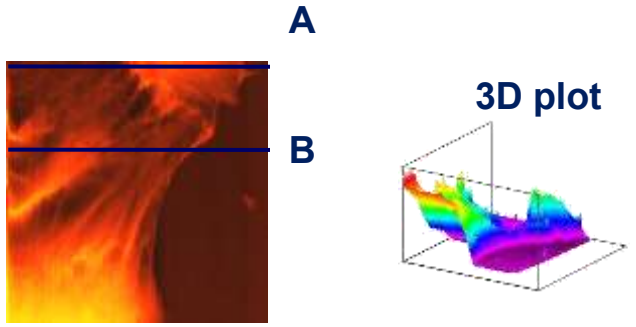
(Atomic Force Microscope)



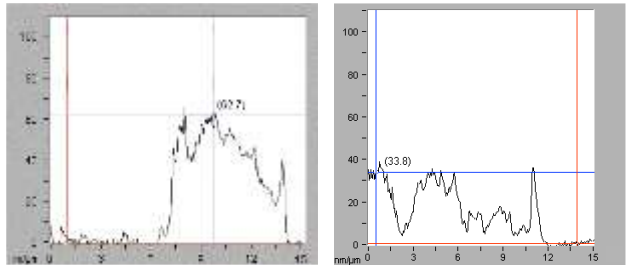
Cell surface at 1g

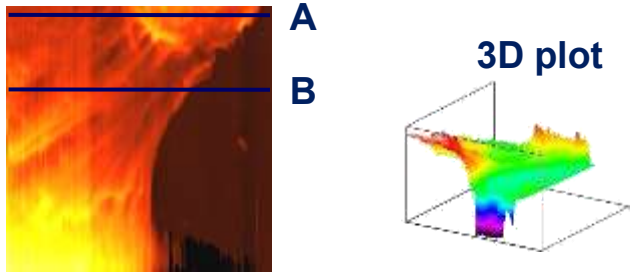


AMC Amsterdam

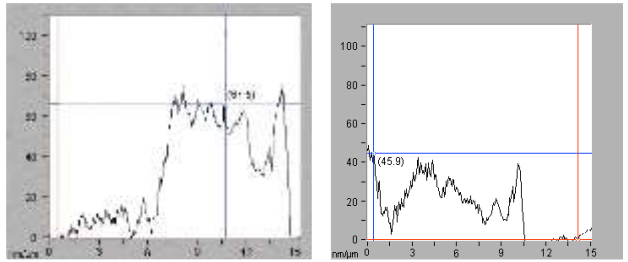


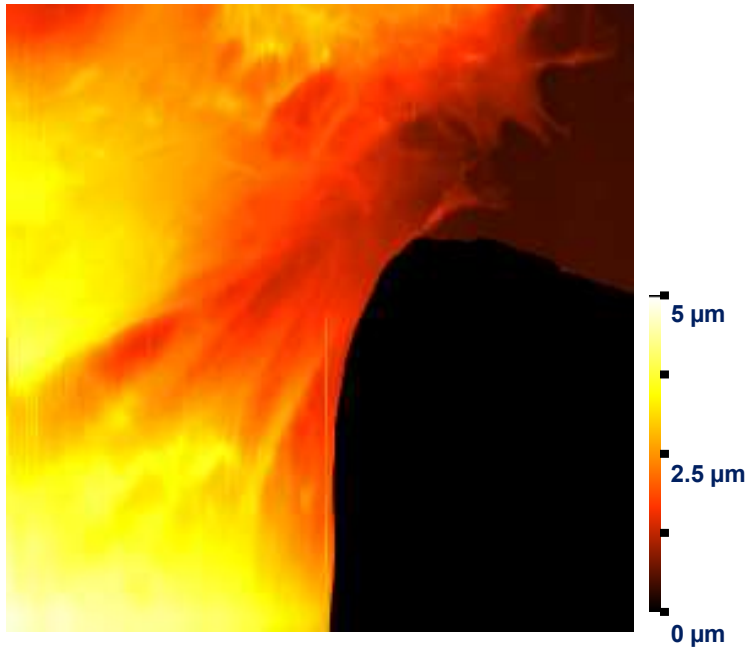
Cell surface at 2g





Cell surface at 3g



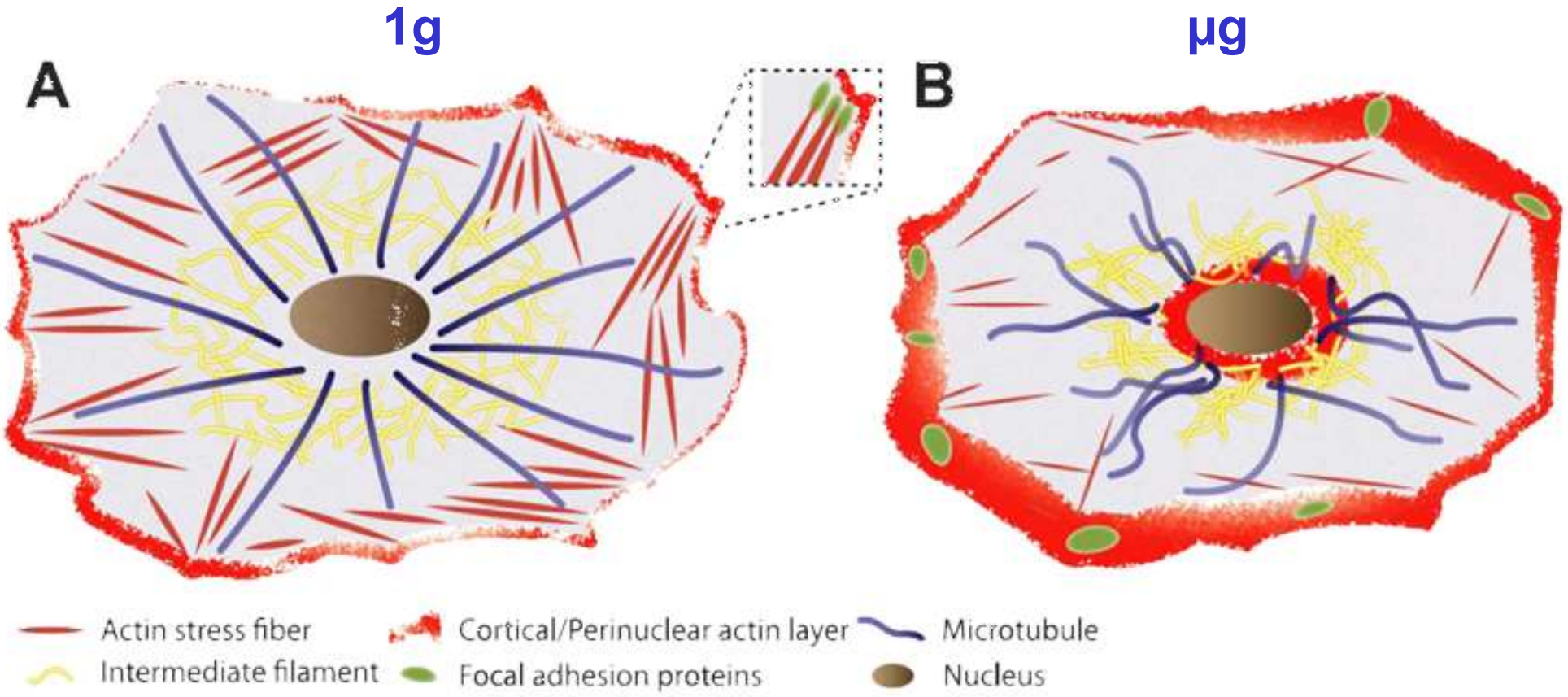


loop 1-2-3-1 x g

van Loon et al. J. Microsc. 2009

Micro-Gravity and Cytoskeleton

overall general findings

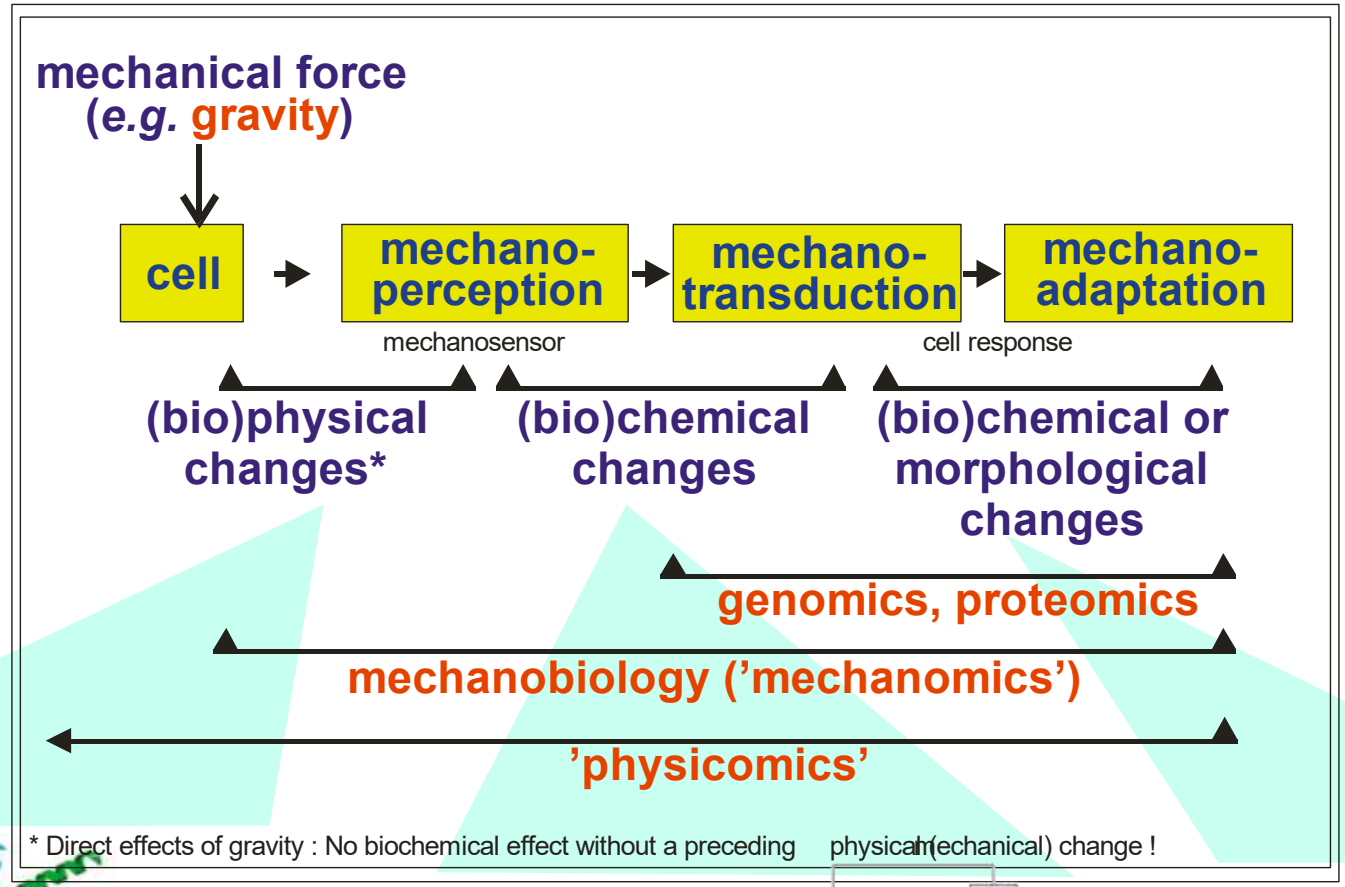


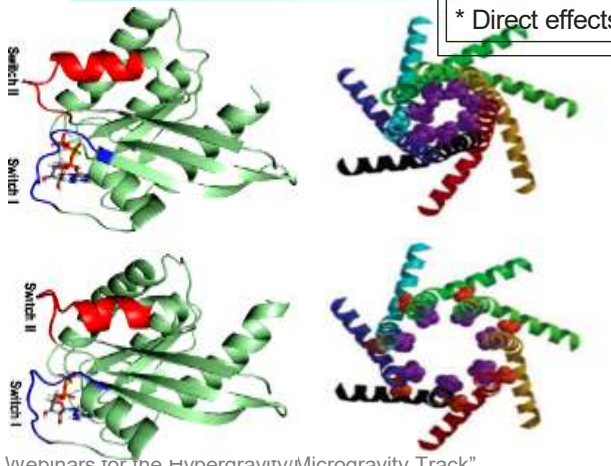
- Possible release of mechanical pre-stress of cyoskeleton of the weight of all organelles ?!?
- More systemics in-flight and ground based studies required !

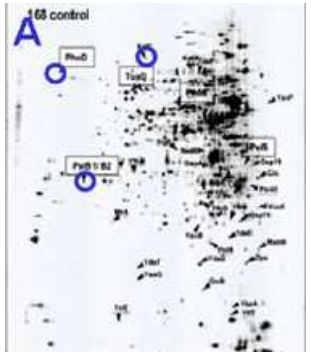
Vorselen, van Loon et al. FASEB J, 2014

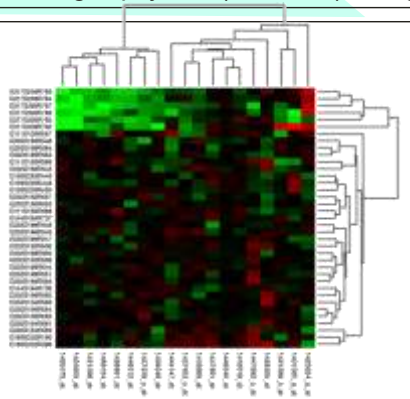
Gravitational Biology / Mechanomics – Physicomics

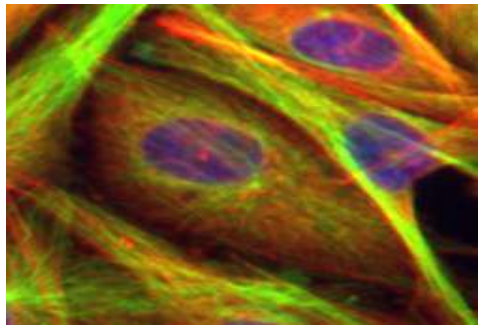
Explore:
- organelle reposition (e.g. nucle(o)lus, ribosomes)
- cytoskeleton conformation
- ion channel
- whole cell shape (membrane (wall)+cytoplasm)
- potentials (electrical currents)
- convection (fluid mechanics)
- .....











van Loon, Gravitat. Space Biology, 2007
van Loon, Microgr. Sci. Technol. 2009

Space Related Sciences

Basic Science

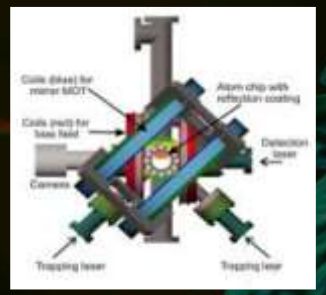
blood draw

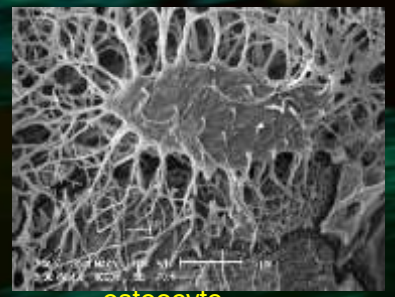

plant growth


melts

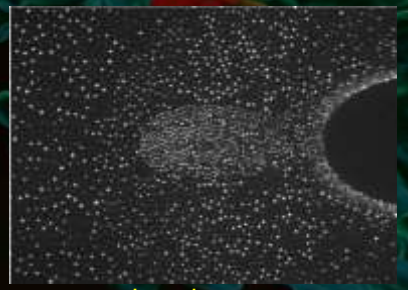
LMM

prep. colloid exp.


Bose-Einstein Cond.


osteocyte


developmental


complex plasma

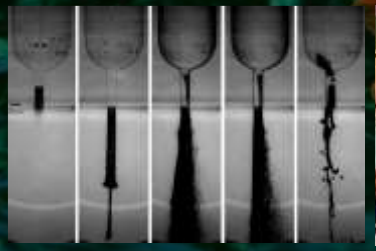
Operational Science

Ocular Health (OH)
Fundoscope exam

Muscle / Bone loss

Blood draw


Plant (food) growth


Technology / two phase flow


Radiation Matroshka

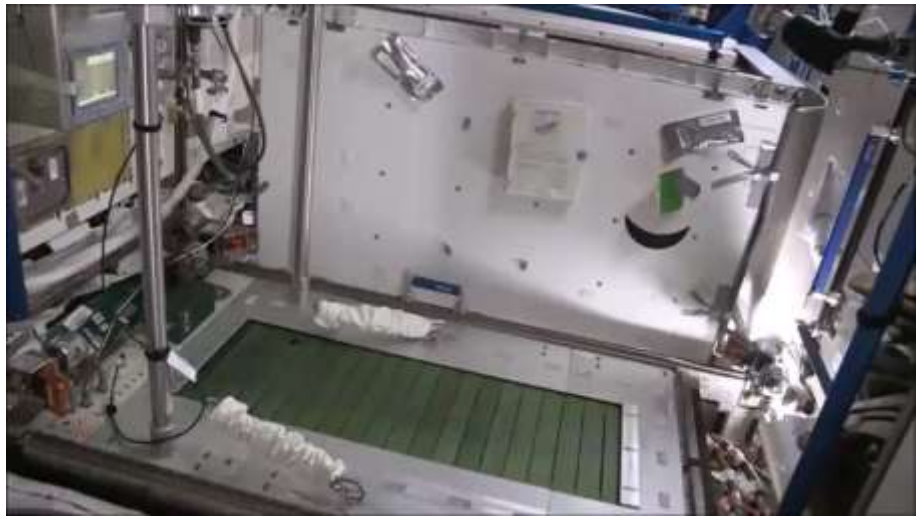

Exploration

ISS Inflight 'Daily' Exercise

Interim Resistive Exercise Device (iRED, 2003)

The Pathology and Ethics of Microgravity !

Chibis LBNP



T2 treadmill (2009)

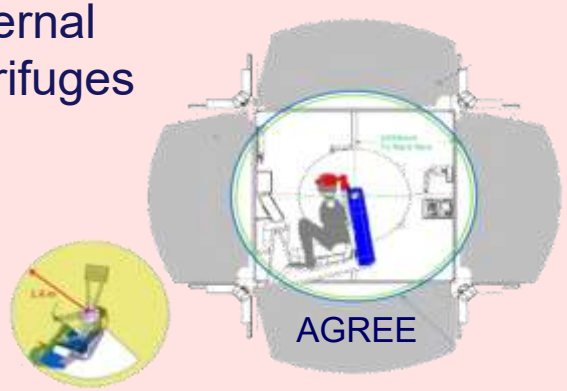
aRED system (2009)

van Loon et al. Frontiers in Physiology 2020

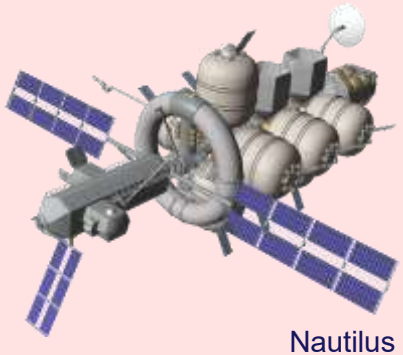
Artificial Gravity Concepts – Ground Research

FLIGHT

internal centrifuges



AGREE



Nautilus

Delta-Utech

Fire Baton

cis-lunar

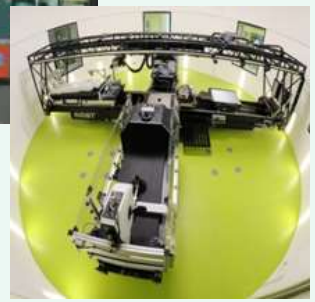
GROUND

Antwerp / Toulouse / Cologne / Planica (EU)

Nagoya, JP

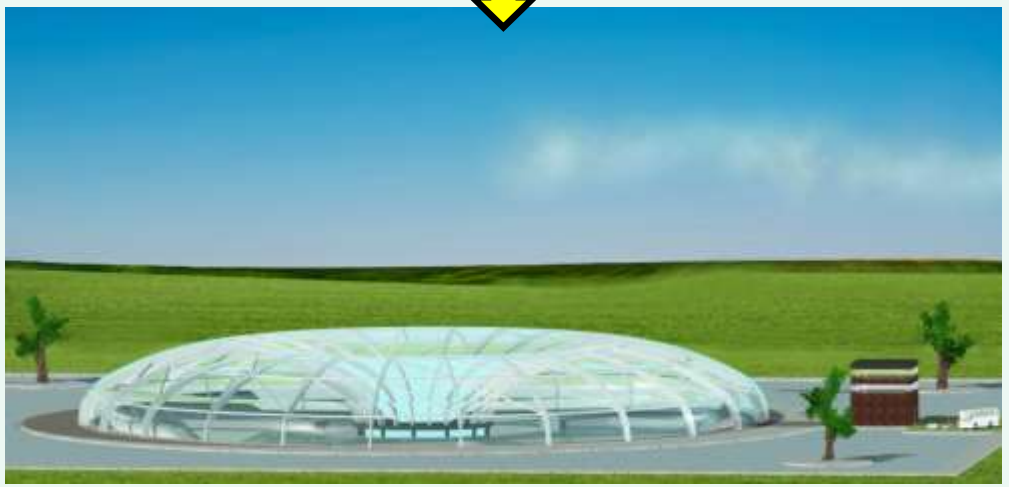
Galveston / Houston, US

Xi'an, China



Cologne, DE

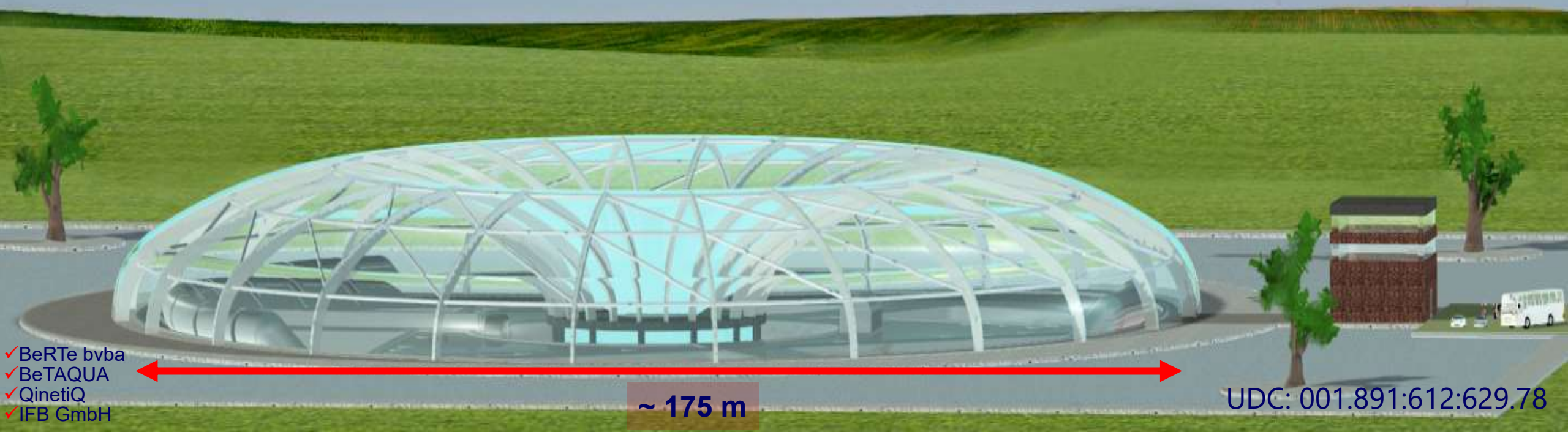
no 'present' solution



Human Hypergravity Habitat, H³

The Human Hypergravity Habitat, H^3

A Possible (??!!) Future Ground-Based Altered Gravity Platform



✓BeRTe bvba
✓BeTAQUA
✓QinetiQ
✓IFB GmbH

UDC: 001.891:612:629.78

Acknowledgements

to all who have provided information and data for this presentation . . .

Thank you for listening !

Jack J.W.A. van Loon
VU - University Amsterdam, NL
j.vanloon@AmsterdamUMC.nl