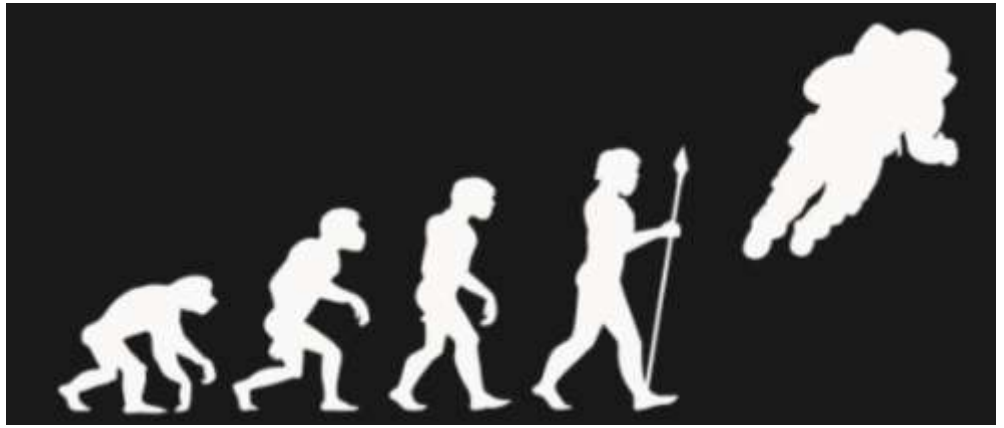
sck cen
Belgian Nuclear Research Centre



Space related health effects

Sarah Baatout

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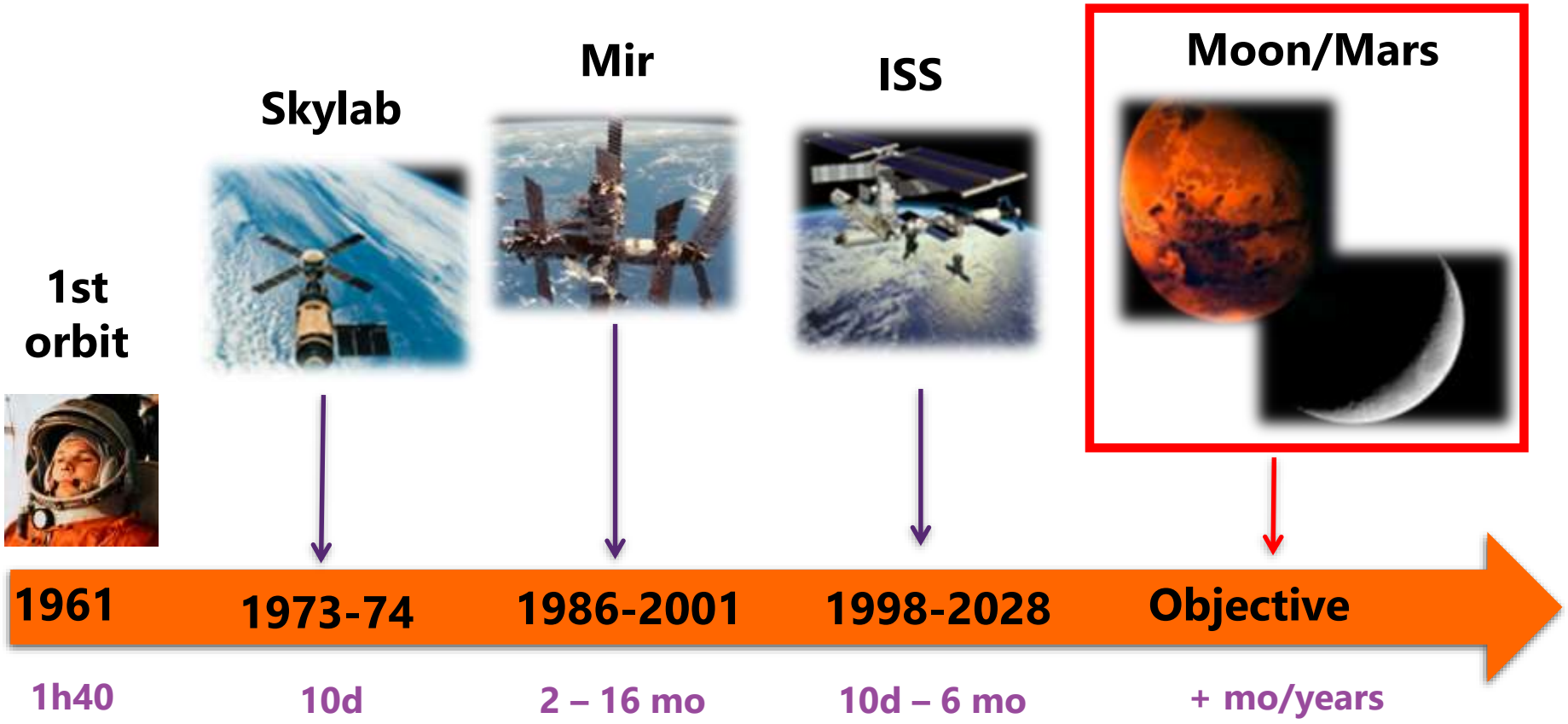
60 years of space missions



- Space flights have an **important impact** on the human body

  → Consequences for the health and behaviour **varies very much between astronauts**

- Space missions are becoming longer and longer: >6 months

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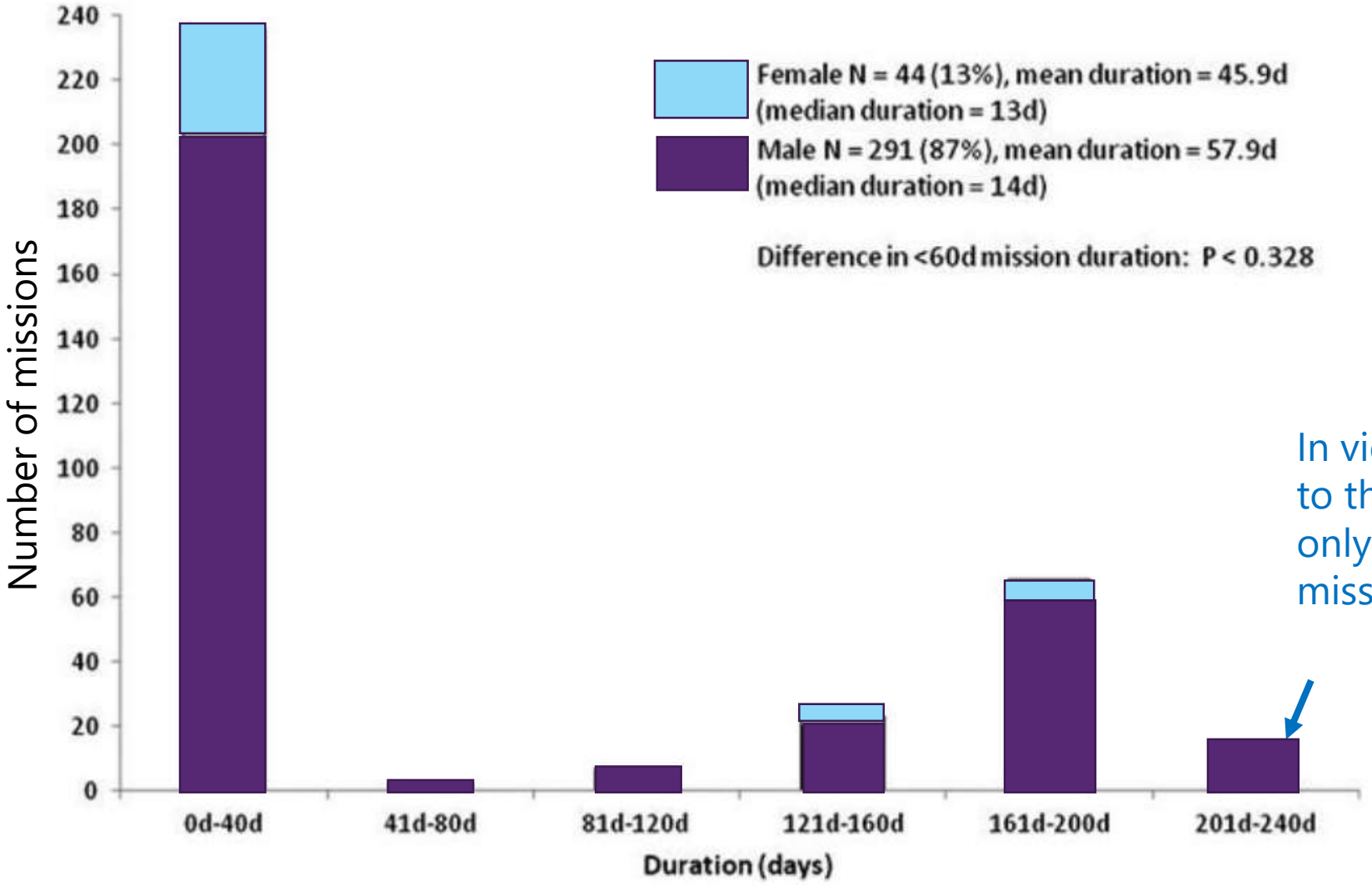
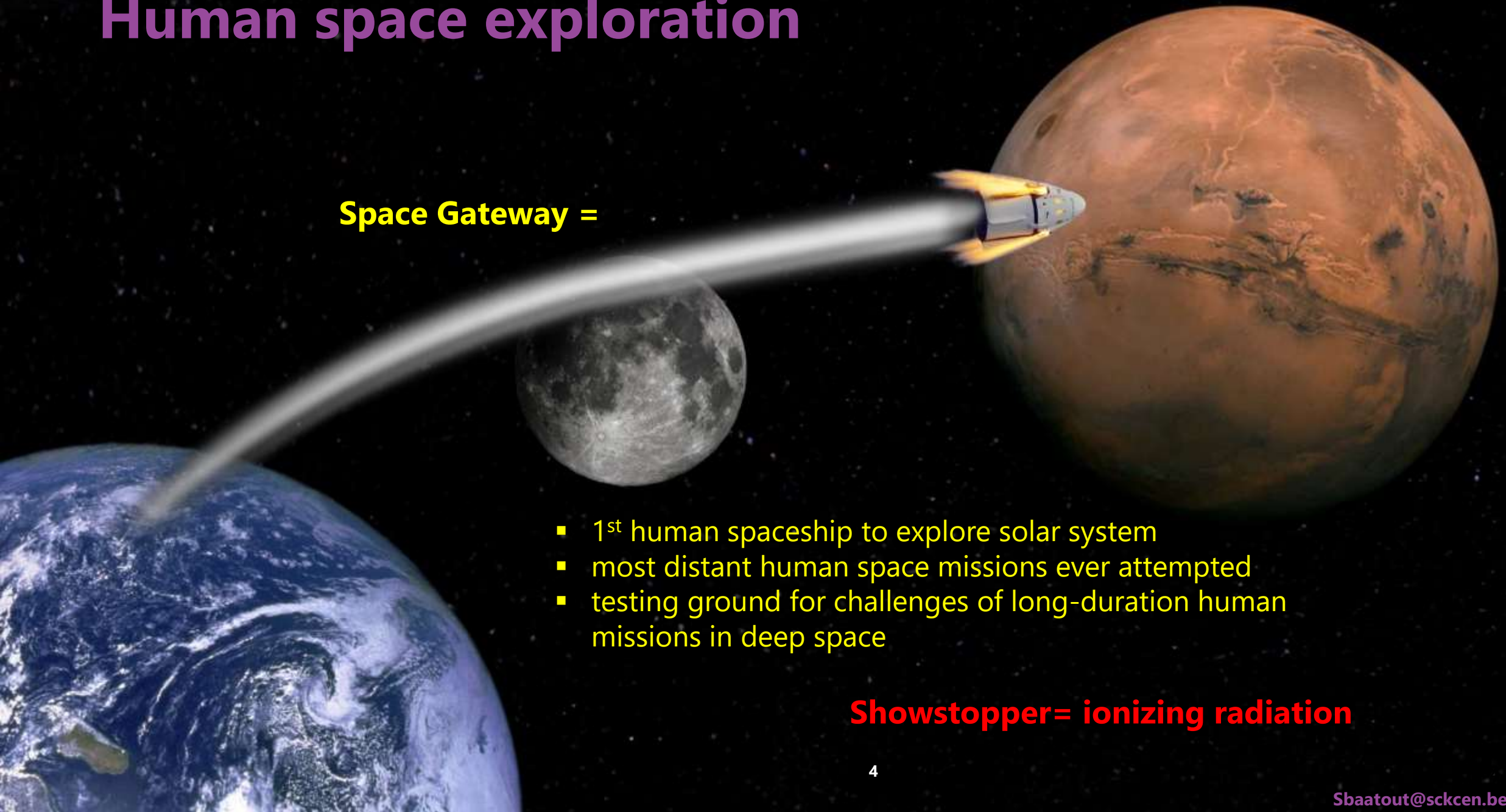
Space mission duration distribution for astronauts and cosmonauts (all nationalities)



In view of future missions to the Moon and Mars, only a small number of ong missions

Human space exploration



Space Gateway =

- 1st human spaceship to explore solar system
- most distant human space missions ever attempted
- testing ground for challenges of long-duration human missions in deep space

Showstopper= ionizing radiation

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Spaceflight stressors

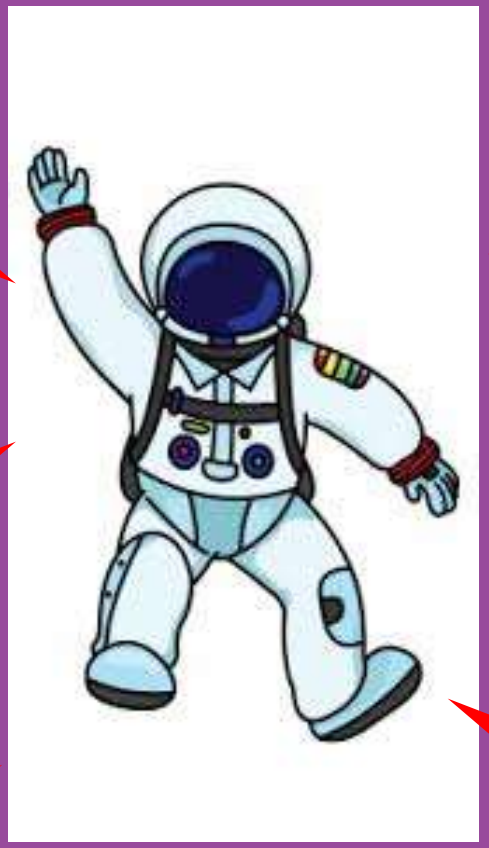
Physical stresses

Microgravity & change of gravity fields

Radiations

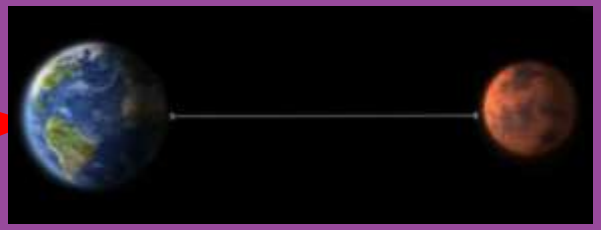
Microbes/Hostile environment

Lunar dust



Psychological stresses

Isolation & Confinement

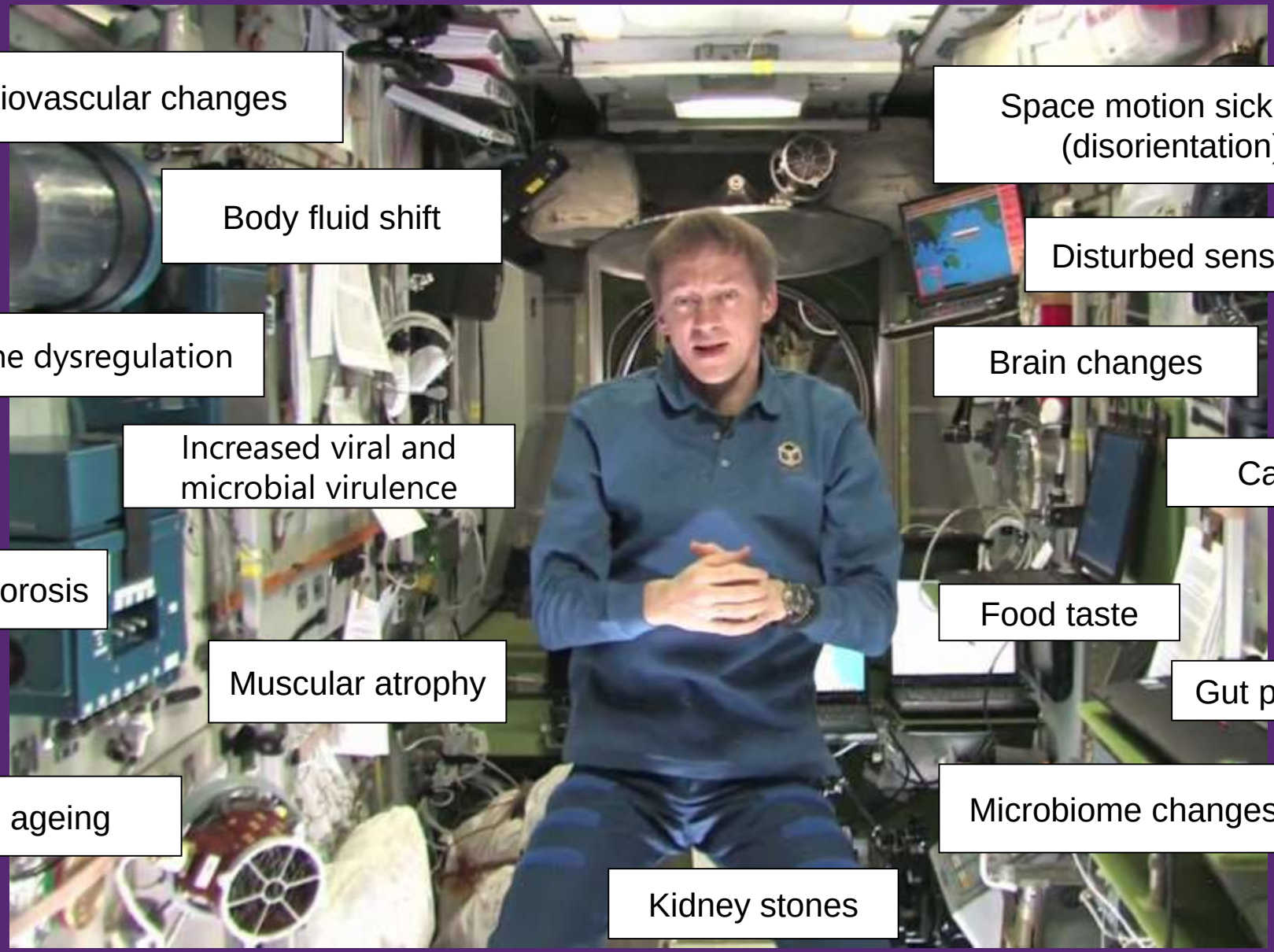


Distance from Earth

Workload

Sleep disturbances

Space health risks



- Cardiovascular changes
- Body fluid shift
- Immune dysregulation
- Increased viral and microbial virulence
- Osteoporosis
- Muscular atrophy
- Skin ageing
- Kidney stones
- Space motion sickness (disorientation)
- Disturbed sense of equilibrium
- Brain changes
- Cataract risk ↑
- Food taste
- Gut peristaltism
- Microbiome changes

Most effects are reversible when coming back on Earth

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The cardio-vascular system in space

- **On Earth**, the parts of the cardiovascular system (the heart, lungs, and blood vessels) work together in a stable state of equilibrium.
- **In weightlessness**, blood and other fluids are redistributed to the head and upper body.

  - Facial oedema (specially around the eyes)
  - Puffy face, stuffy nose, headache
  - Cranial veins dilate, interpreted by the body as an overall increase of the circulating volume which activates mechanisms which counteract hypervolemia, leading to a significant loss of water.
  - However, on return to Earth, the fluid shifts rapidly to the lower body again, which causes a tendency to develop orthostatic hypotension and syncope. Technically speaking, this is called "orthostatic intolerance." (comparable to shift from lying to standing position)

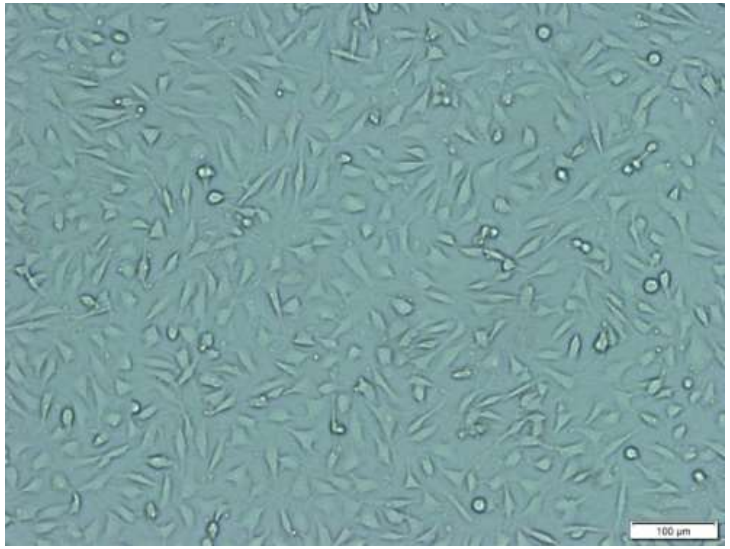
Understanding radiation tissue sensitivity: cardiovascular experiment in space

Cardiovascular system: (D. Grimm): growing blood vessels in space

ESA flight experiments (ISS):

On ISS, aboard Space X8

→ Behaviour of endothelial cells in space



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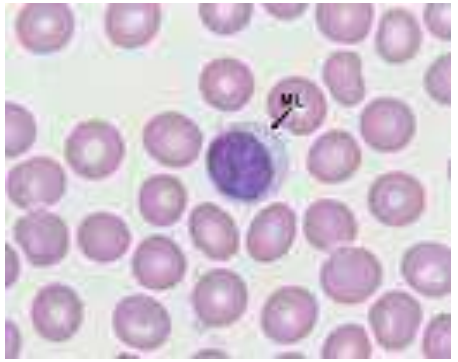
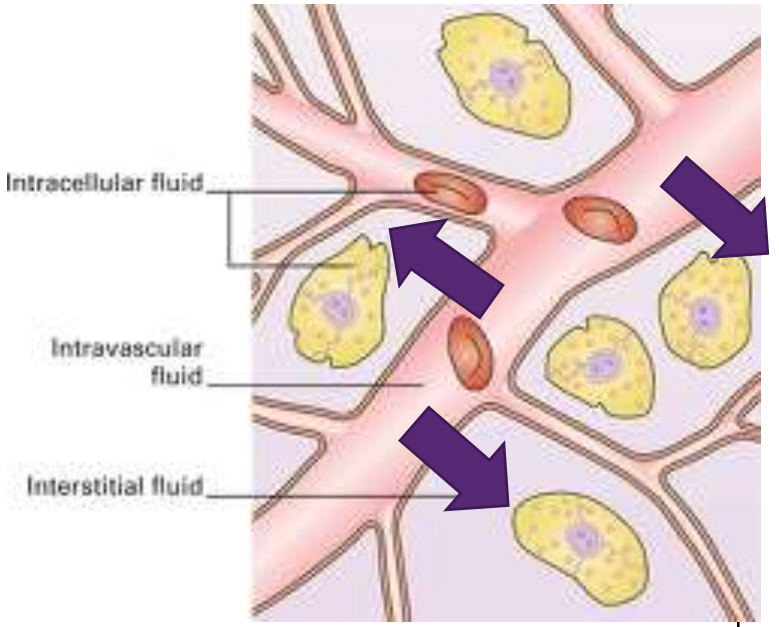
Immune system in space

- During early spaceflights, astronauts frequently suffered from otitis and skin infections



Immune system is dysregulated in space & the number of lymphocytes decreases.

- Do these blood cells decrease even more when a body stays longer in space?
- What are the implications for space voyages to Mars?
- Will the body able to fight infections which may occur?



Hygiene impaired (skin infection, dental infections)

ISS = confined environment like a hospital (resistant bacteria)

Monitoring of radiation sensitivity in space

SCK CEN participates in the long-term immune follow-up and individual radiation susceptibility of astronauts & cosmonauts on board the ISS

Anthropometric changes in microgravity

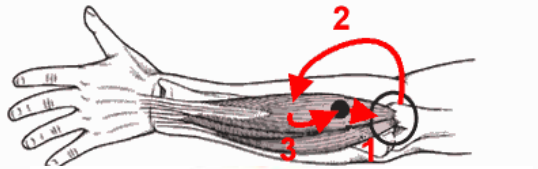
- Astronauts are 1-6 cm taller in space (the spine stretches more) due to swelling of the intervertebral discs and extension of the normal spine curvature. Increase height might present temporary fitting problems with the EVA space suits
- Free-floating astronauts tend to adopt a modified fetal posture.
- As much as 2 liters of body fluids move from the lower extremities early in space flight. Cephalad shift of body fluids is reported as 'fullness and nasal stuffiness' and can cause visual problems.

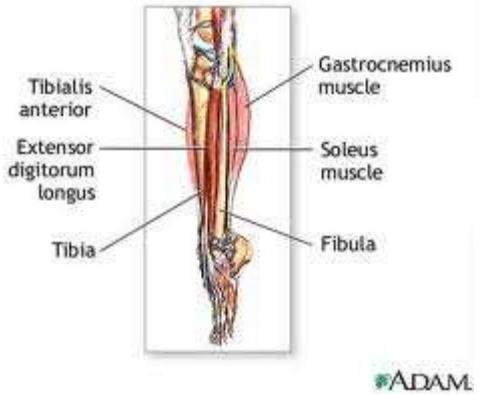
Motor Control in Space

- Effects of space flight include
  - **Short term**
    - Activation of extensor muscles is reduced
  - **Longer term**
    - **Reflexes** are affected – Achilles tendon tap
      - Magnitude of movement is reduced
      - Sensitivity to tap is reduced
      - Amplitude of induced electrical response is reduced
  - **Post-flight**
    - Increased rate of tremors*
    - Time to make postural changes increases 2-3 x

**Tremor : involuntary, somewhat rhythmic, muscle contraction and relaxation involving movements (oscillations or twitching) of one or more body parts*

Extensor muscles





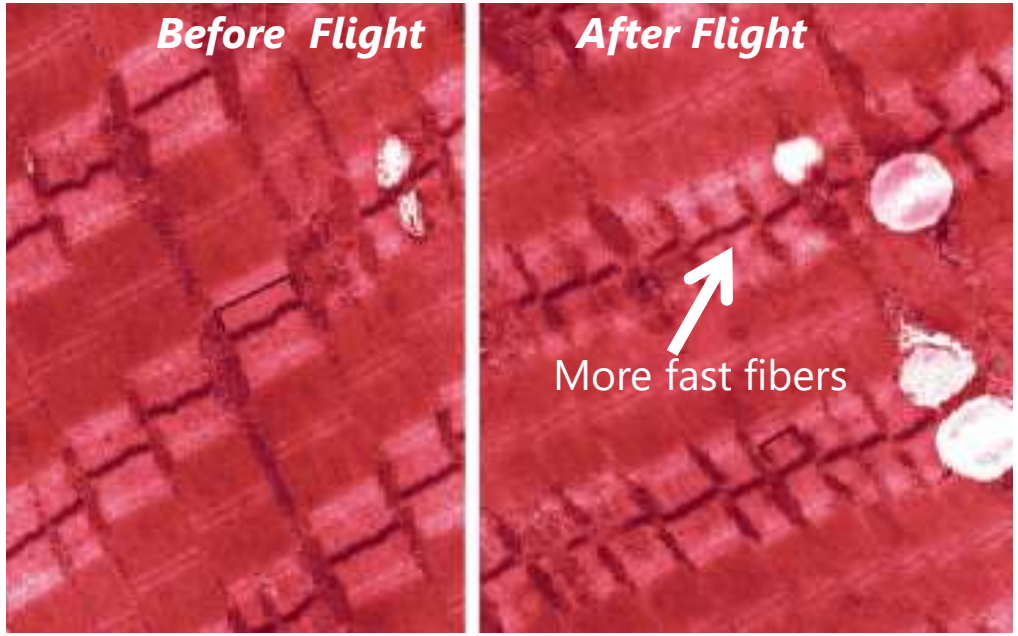
Achilles tendon tap

Muscle response to spaceflight

Without exercise for 2-3 months in space:

- Leg muscle cross-sectional area ↓ ~30%
- Leg strength ↓ ~50%
- **Shift occurs from slow to fast fiber types**
- Back muscles become weak, soft tissues at risk of injury

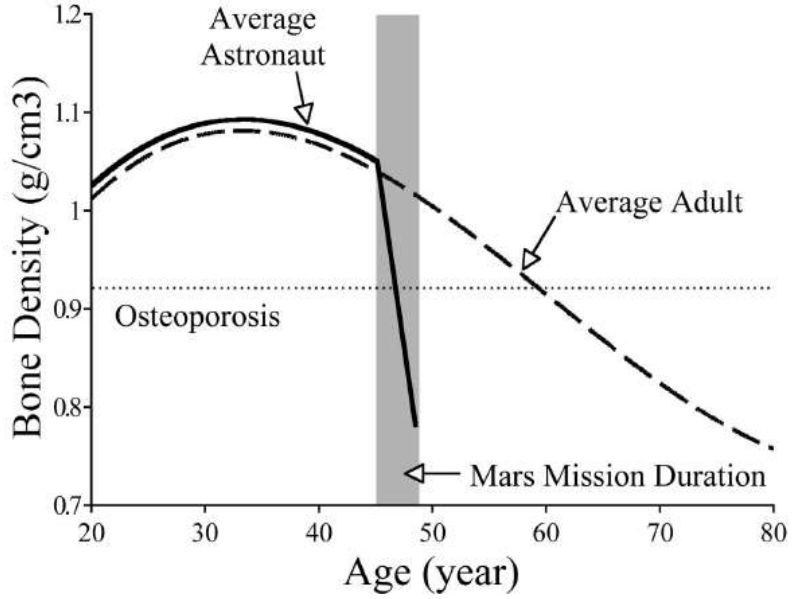
Astronaut muscle fiber cross sections



- **Muscle fibers** exist in two basic forms: slow and fast twitch.
- **Fast fibers** : dominant in sprinters and power athletes, contract quickly and powerfully but fatigue very rapidly.
- **Slow fibers** dominate in endurance athletes. They contract for long periods of time but with little force, resistant to fatigue.

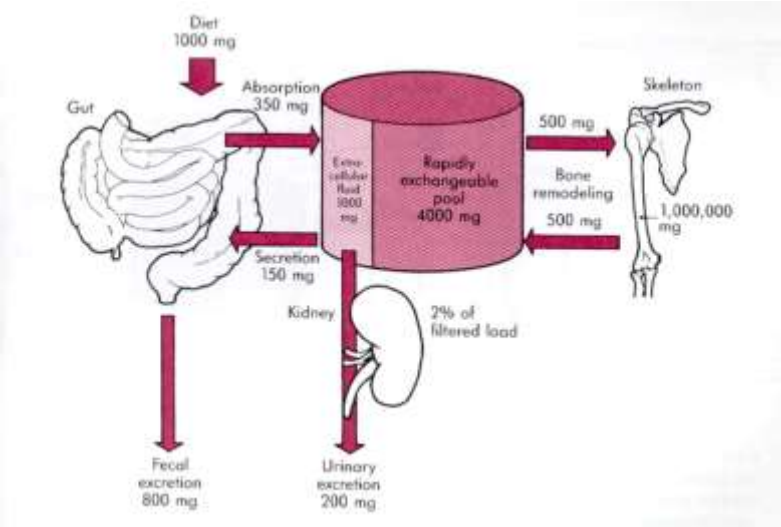
Bone loss in Space

- Spaceflight (Unloading): 0.5-2% per month= **6-24%/yr**
- **Type I Osteoporosis (or Post-Menopausal osteop.):**
  - **20% Tot, 3-4% per yr.**
  - when the amount of estrogen in the body greatly decreases.
  - leads to an increase in bone resorption (loses its substance).



- **Type II Osteoporosis (Senile osteop.):**
  - **age related (from age 75)**
  - **occurs both to men and women in ratio 2:1**
  - **~1% per year, ongoing**
  - involves thinning of both the trabecular bone (the spongy bone inside of the hard cortical bone) and the hard cortical bone.
  - often leads to hip and vertebral body (in the spine) fractures.

Calcium loss in Space

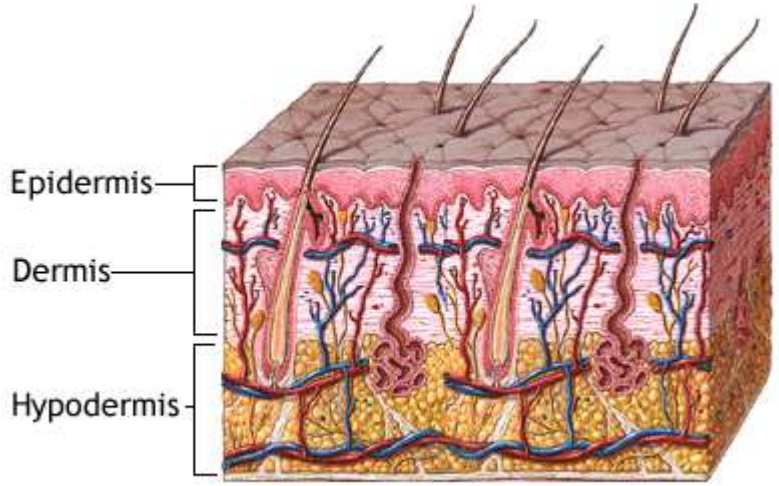


- Calcium salts provide structural integrity of **skeleton**
- Calcium in extracellular and cellular fluids is essential :
  - Neuromuscular excitability
  - Blood coagulation
  - Hormonal secretion
  - Enzymatic regulation
- Calcium **concentration**, both extracellularly and intracellularly, be maintained within a very narrow range: $[Ca^{2+}]_{cyt}$ is approximately 1/1000th of extracellular concentration.
- When extracellular calcium falls below normal, the **nervous system** becomes progressively more **excitable** because of increase permeability of neuronal membranes to sodium.
- Hyperexcitability causes tetanic contractions.

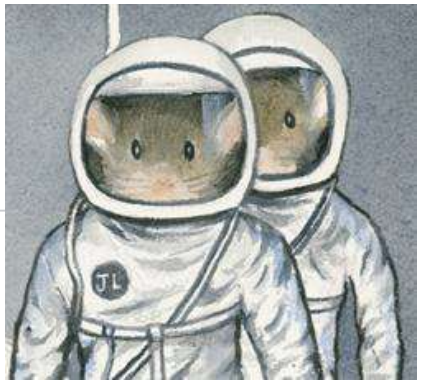
- **In space, calcium lost in urine -** ~200mg/day
- **Less calcium absorbed –** lost in feces
  - May be at greater risk for kidney stones

Why the skin?

- Largest organ of the body
- Vital functions:
  - Barrier function, immune defense, protection, thermoregulation, sensory function, endocrine function
- Most frequent medical incidents reported by astronauts:
  - Small injuries of the skin, dryness, itching, delayed wound healing



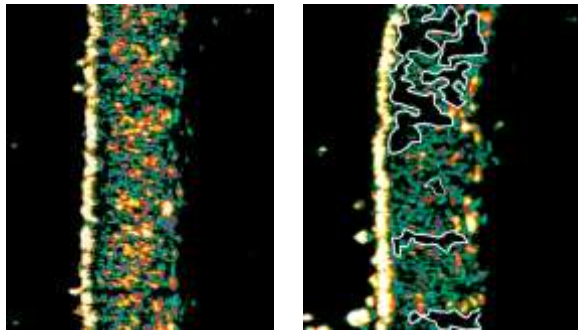
What happens to the skin in space?



Human

- Thinning of the epidermis up to 20%
- Increase in collagen to elastin ration
- Loss of elasticity of the dermis
- Atrophy of dermal matrix
- Related to skin aging

Tronnier et al. 2008

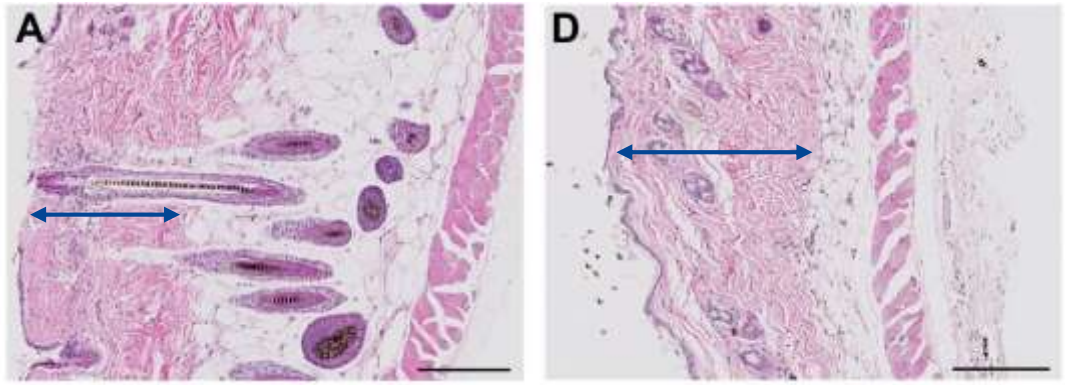


Pre-Flight Post-Flight

Mice

- Three months in orbit
- Reduced thickness of dermis → increased collagen turn-over
- Disturbed hair follicle cycle → depending on silencing of hair stem cycle

Neutelings et al. 2015



Space Ground

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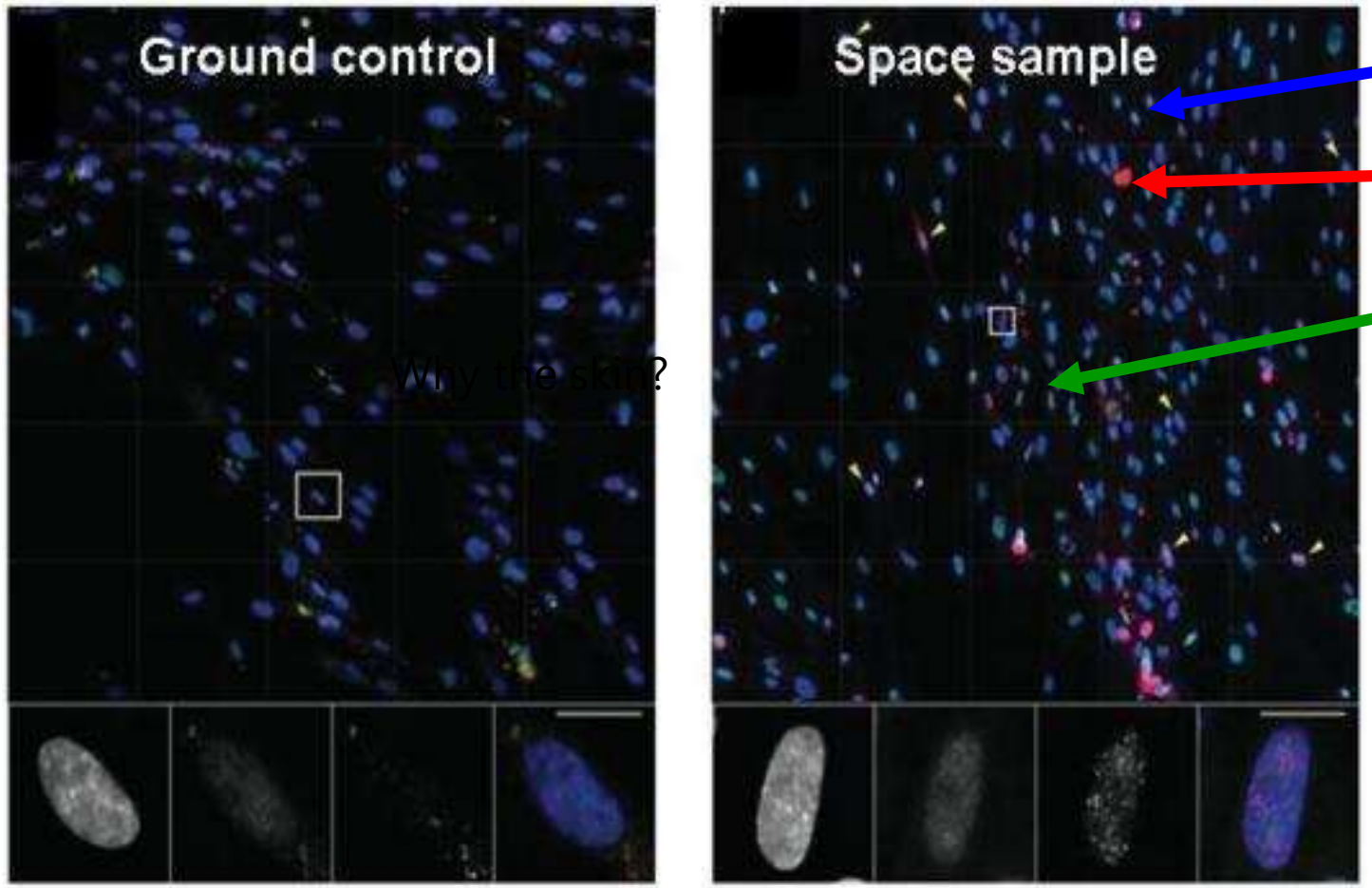
Understanding radiation tissue sensitivity
SCK CEN skin experiment in space



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MHRPE Exploration Risk Ratings

Multilateral Human Research Panel for Exploration

Multilateral Human Research Panel for Exploration

MHRPE Risk	MHRPE Risk Rating					
	ISS (≤1 year)	Lunar Orbit (≤30 days)	Lunar Orbit (30d-1yr)	Lunar Surface (≤30 days)	Lunar Surface (30d - 1yr)	Mars (3 yrs)
Musculoskeletal: Mission risk of reduced muscle strength, aerobic capacity. Long-Term health risk of Early Onset Osteoporosis and degenerative tissue disease.						
Sensorimotor: Mission risk of sensory changes/dysfunction						
Autonomous Medical Care: Mission and long-term health effects due to an inability to provide adequate medical care throughout a mission. (Includes Pharm stability, PK/PD)						
Behavioral Health and Performance: Mission and long-term adverse behavioral health effects associated with extended duration missions, particularly in isolated, extreme and confined environments						
Ocular Syndrome: Vision alterations and other health effects due to intracranial pressure changes due to fluid shifts						
Nutrition: Mission risk to behavioral and nutritional health due to an inability to provide appropriate quantity, quality and variety of food						
Hypogravity: Long-term risk associated with adaptation during IVA and EVA on the Moon, Mars (physiological adaptation of cardiovascular and immune systems, the microbiome, as well as physiological demands during EVAs) and postflight rehabilitation						
Dust Exposure: Cardiovascular, pulmonary, etc) associated with exposure, particularly during surface operations						
Environmental Exposure: Mission and long term health effects associated with exposure to toxic substances or virulent microorganisms, including immunology						
Radiation: Long-term risk of carcinogenesis due to radiation exposure – ***Largely addressed with ground-based research***						

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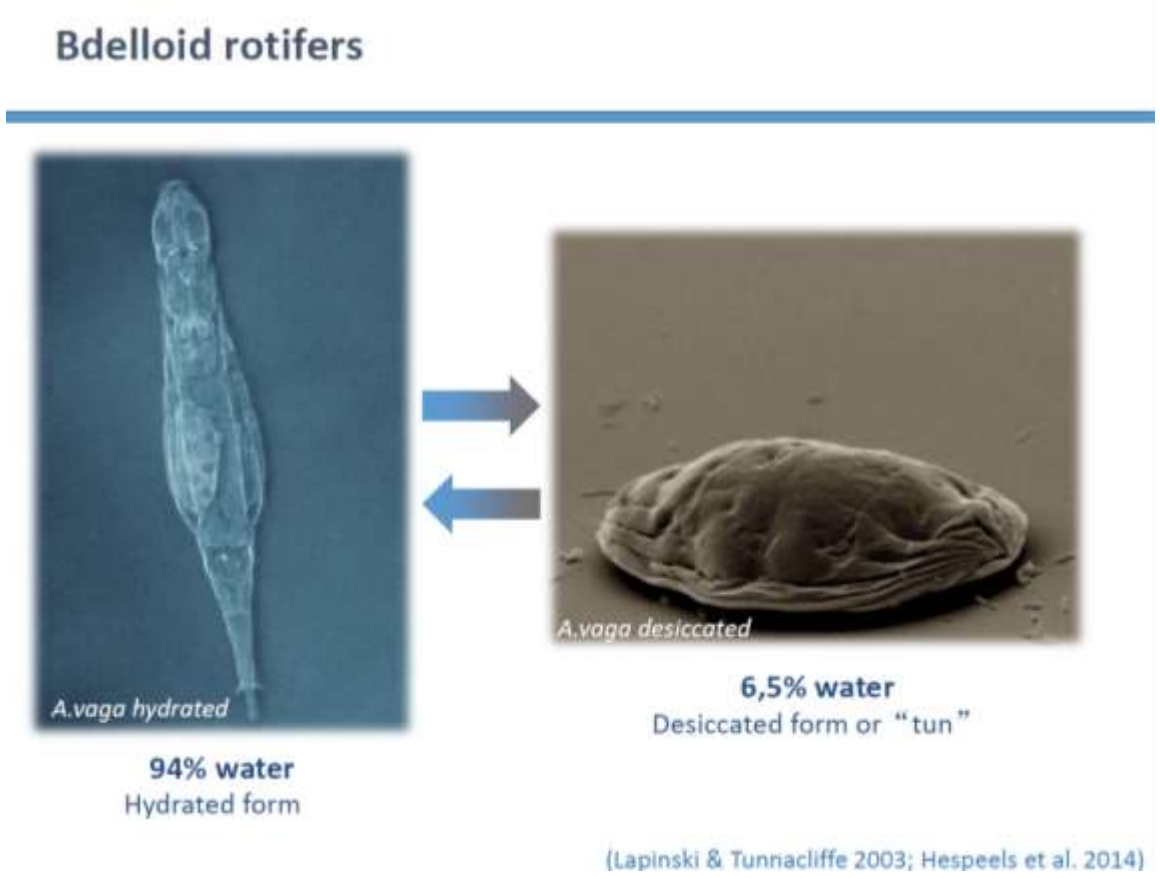
low/very low consequence | low to medium consequence | high consequence (requires mitigation)

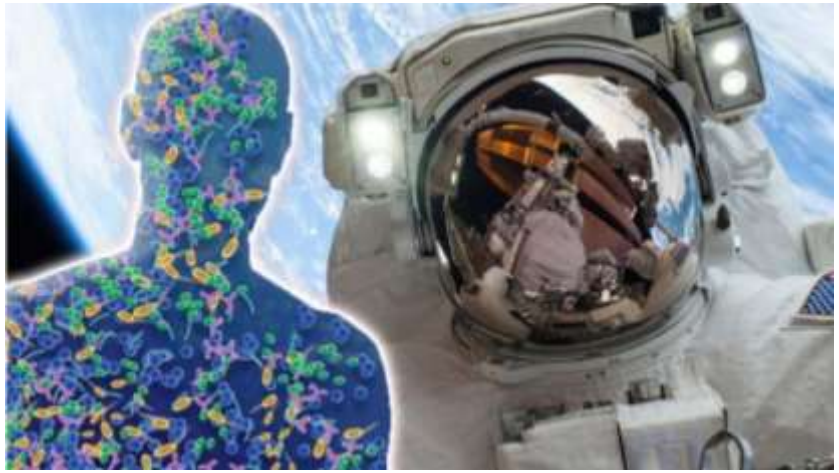
Understanding radiation resistance in organisms
Rotifers in ISS

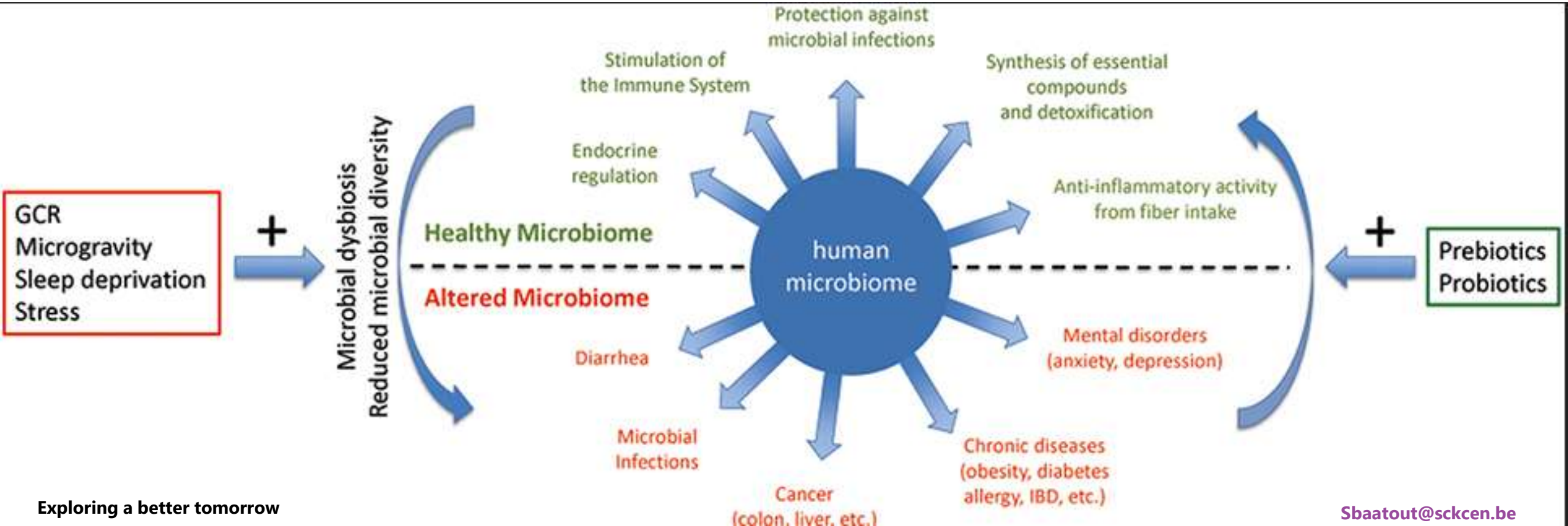


Rotifers = One of the most radiation resistant organisms on Earth
SCK CEN participates in 3 flight experiments with Space -X

A healthy gut microbiome

- SCK CEN investigates how:
  - Microbial composition is altered in space environment
  - Decrease of diversity in gut microbiome





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Towards precision medicine in astronauts

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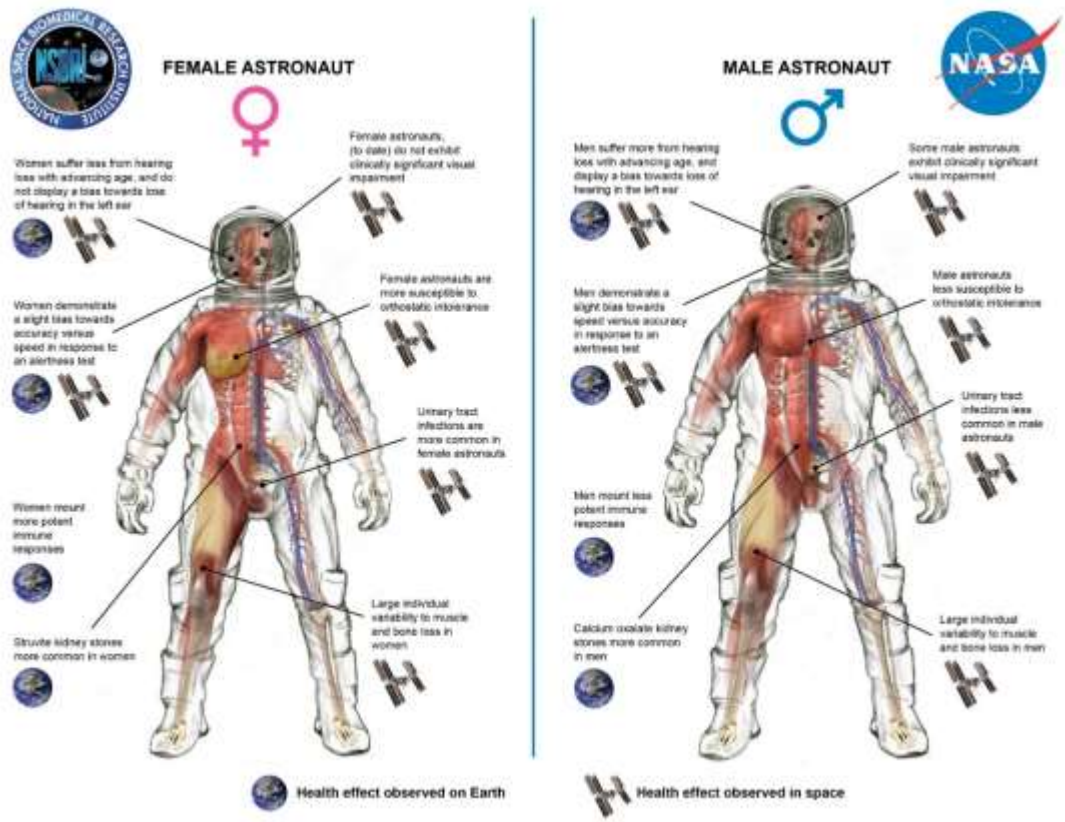
Astronaut gender differences in space health impact

1. Women have greater loss of plasma volume & respond to physical stress by an increase in heart rate
2. The visual impairment/intracranial pressure syndrome (VIIP) affects 82% of men as compared to 62% of women astronauts.
3. Women report a higher incidence of in-flight space motion sickness (SMS) while more men experience SMS symptoms upon return to Earth.
4. Hearing thresholds decline with age much more rapidly in male than in female astronauts.
5. Extrapolated data from ground-based studies suggests that in space, women are more susceptible to radiation-induced cancer than their male counterparts; and permissible exposure levels are lower for women than men astronauts.
6. Women have more urinary tract infections.



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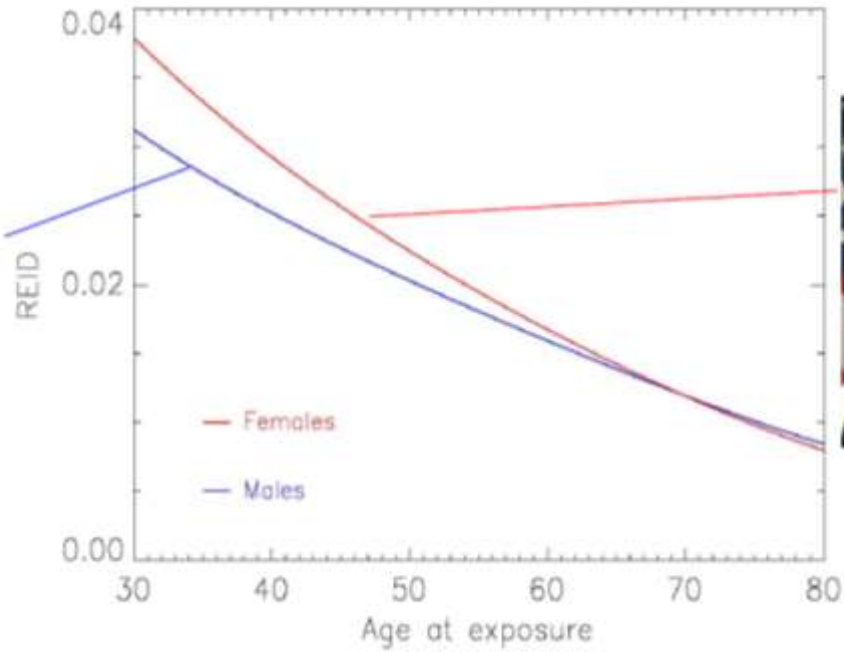
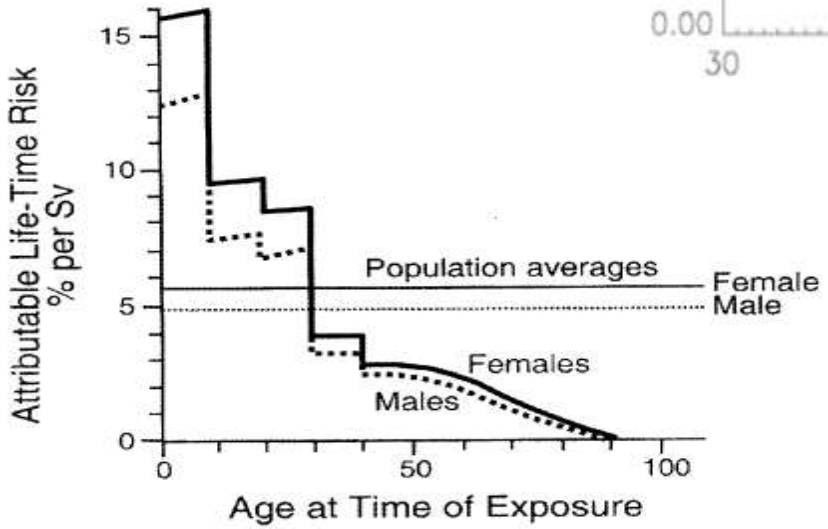
Radiation sensitivity varies with age & gender

Risk of stochastic effects

in relation to age & gender



Age (years)	Multiplication factor for risk
< 10	**3.0**
10 – 20	**2.0**
20 – 30	**1.5**
30	**1.0**
30 – 50	0.5
50 – 80	0.3
> 80	**Negligible risk**



Relative attributable lifetime risk, according to ICRP 1990

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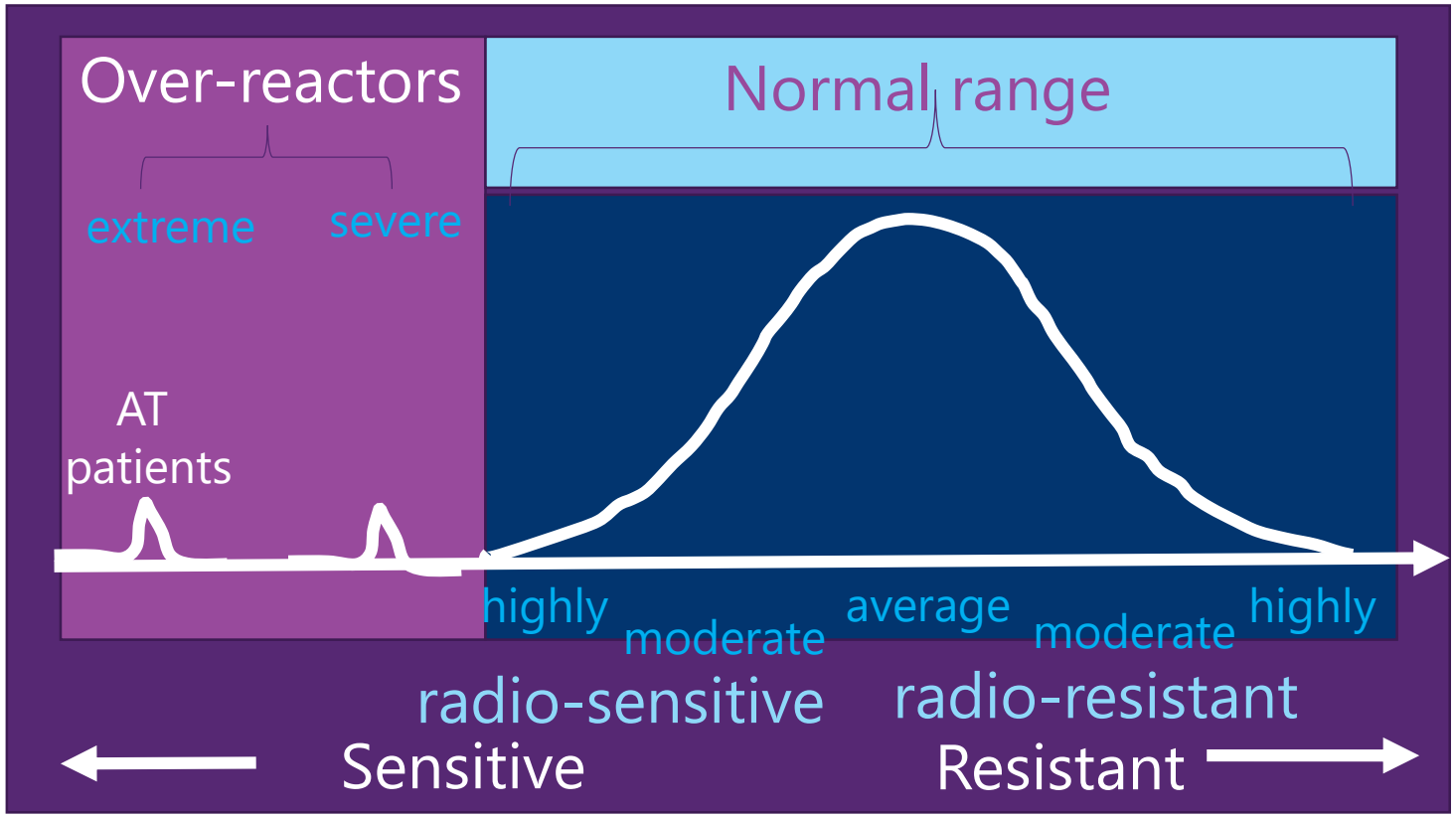
Variable interindividual radiation sensitivity to IR

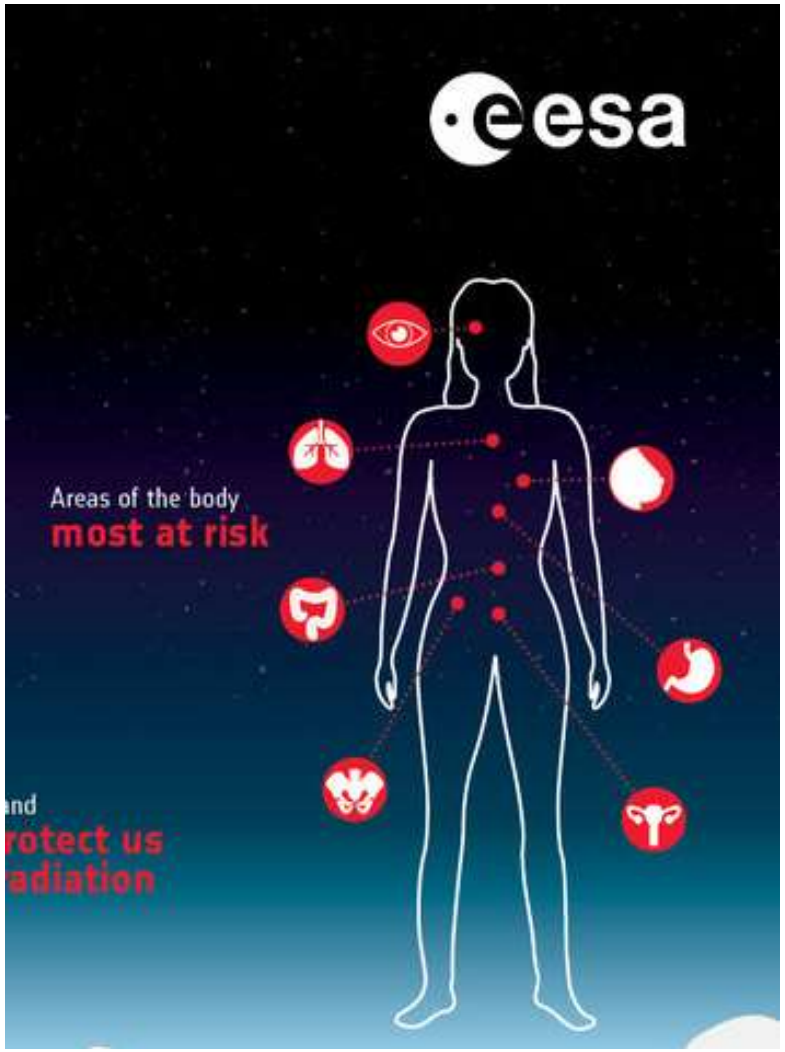
- In terms of sensitivity to radiation, all *humans* are created equal,...but some *humans* are more equal than others"
- Radiation sensitivity/susceptibility is not distributed equally within the population -> need for biomarkers of radiation sensitivity (radiobiology)



Burnett et al

Radiation sensitivity varies between organs

Organs of the body most at risk from radiation



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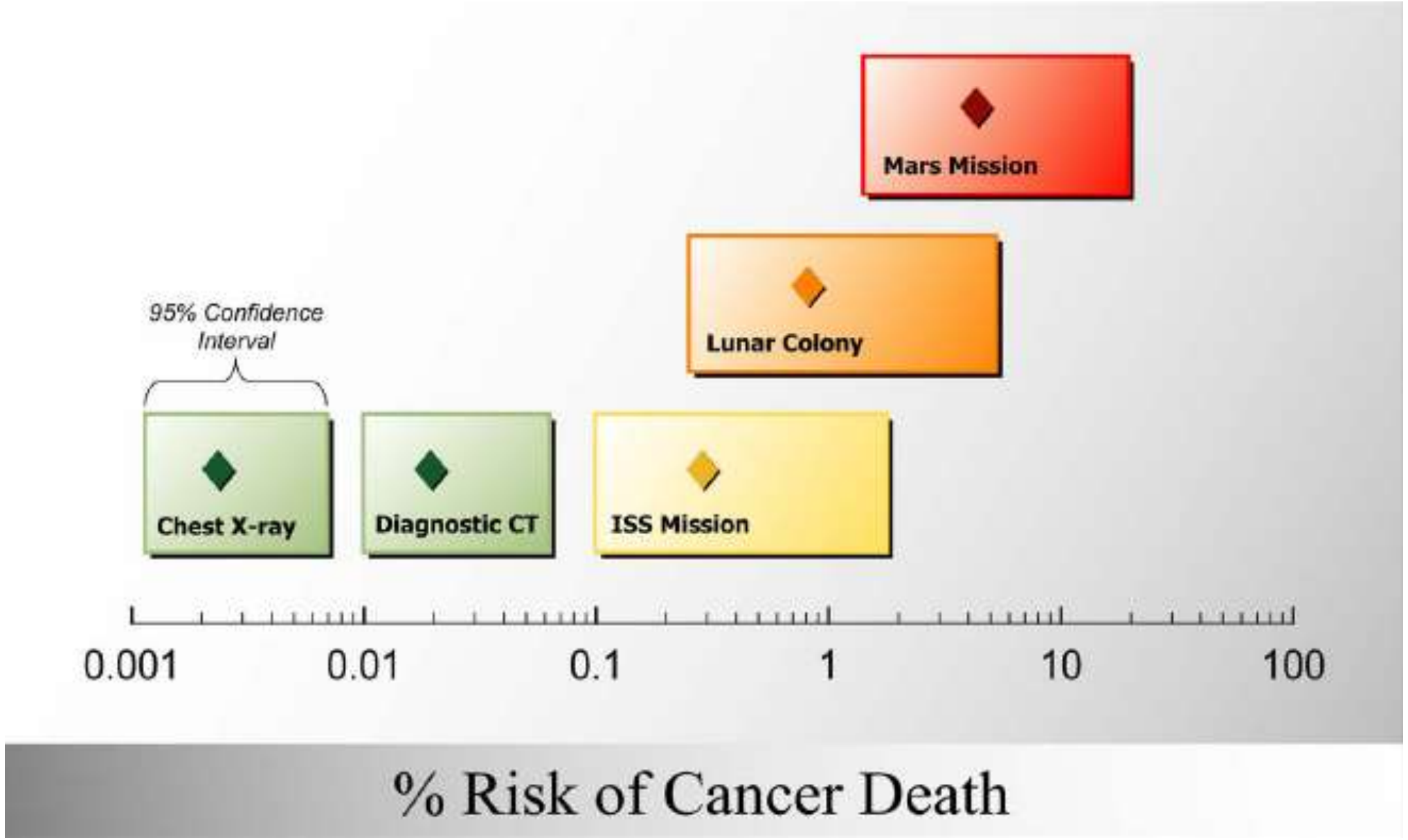
Cancer risk variation expected between astronauts



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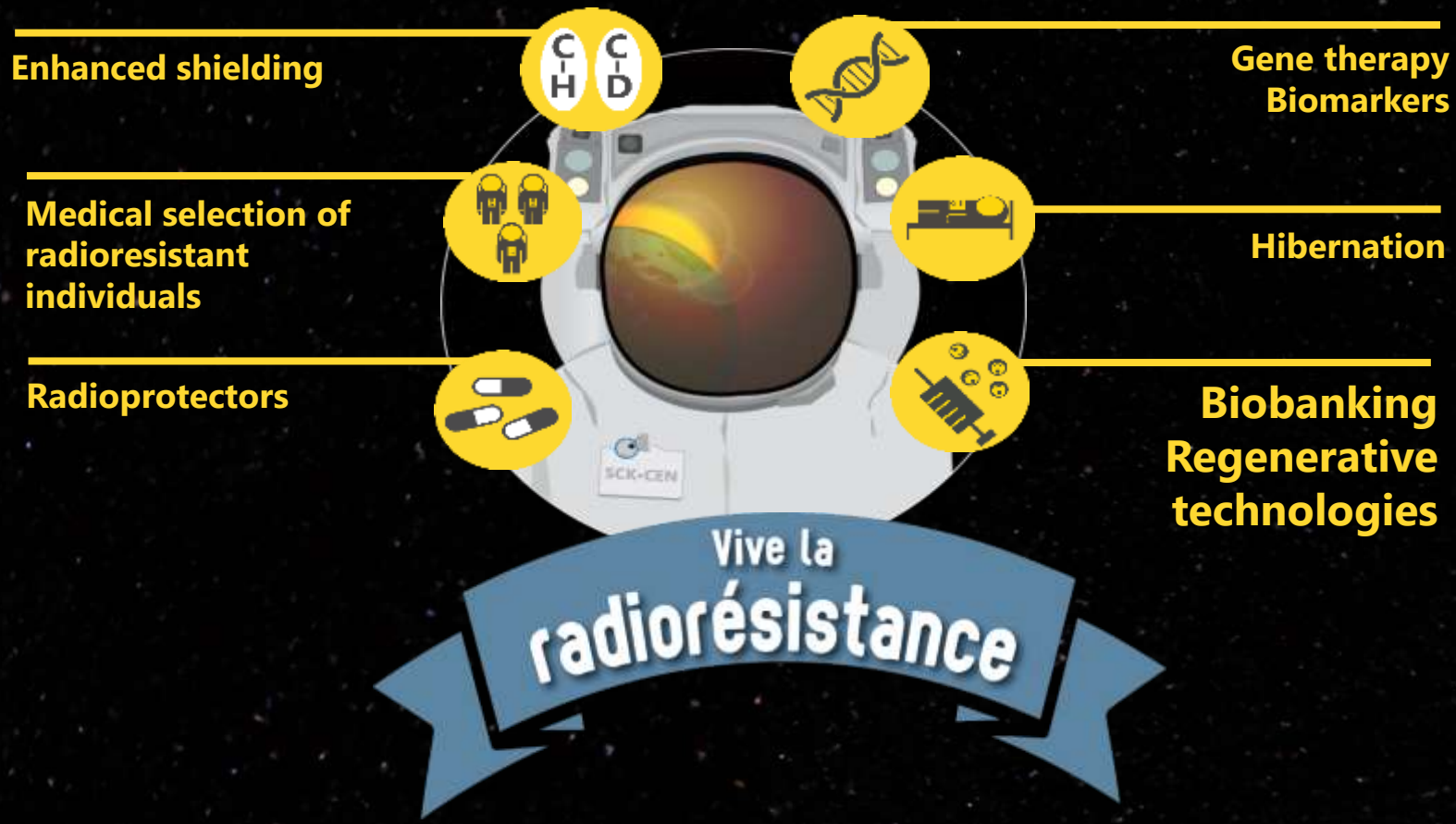
How to improve radiation resistance of astronauts

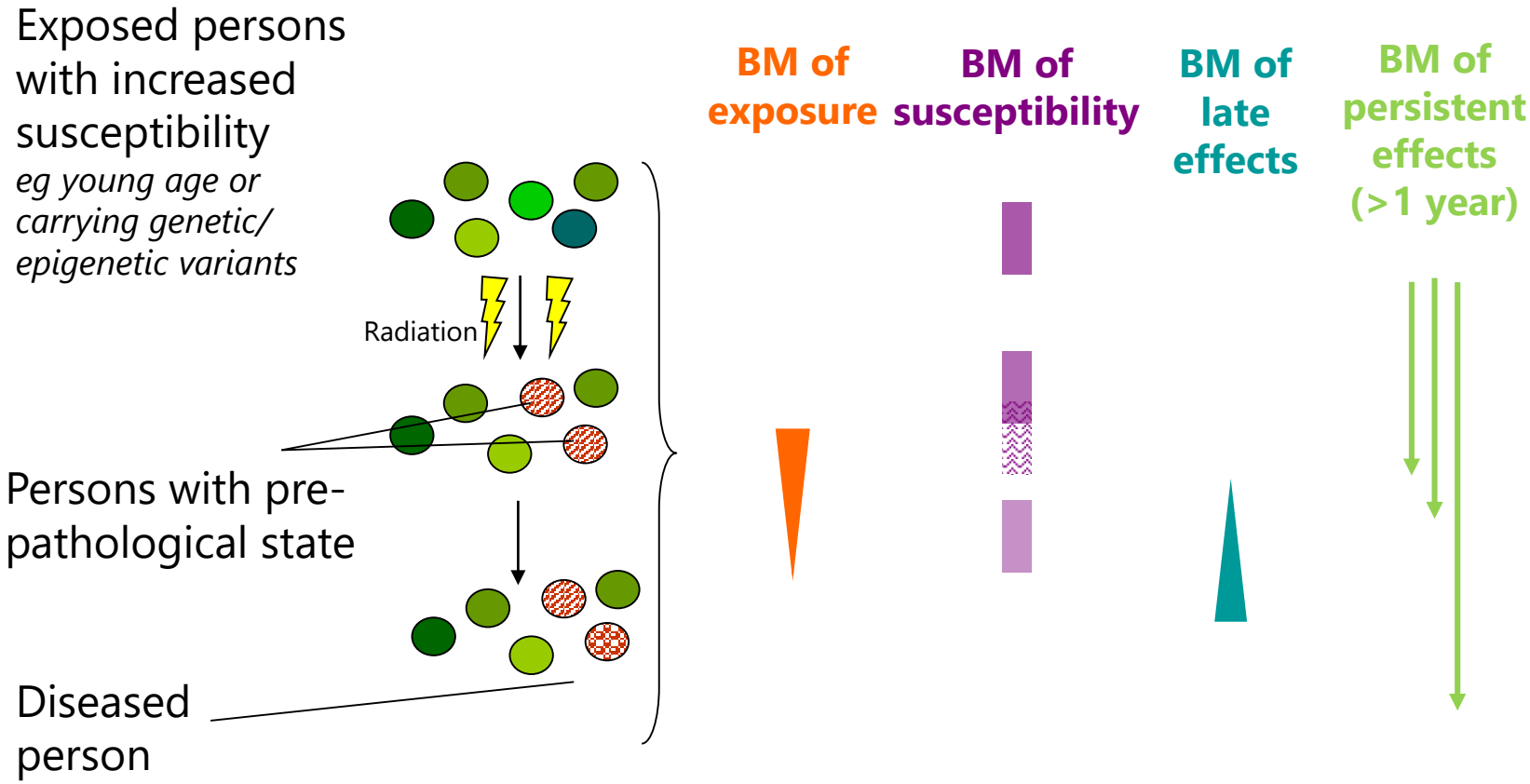


Vive la radiorésistance!: converging research in radiobiology and biogerontology to enhance human radioresistance for deep space exploration and colonization

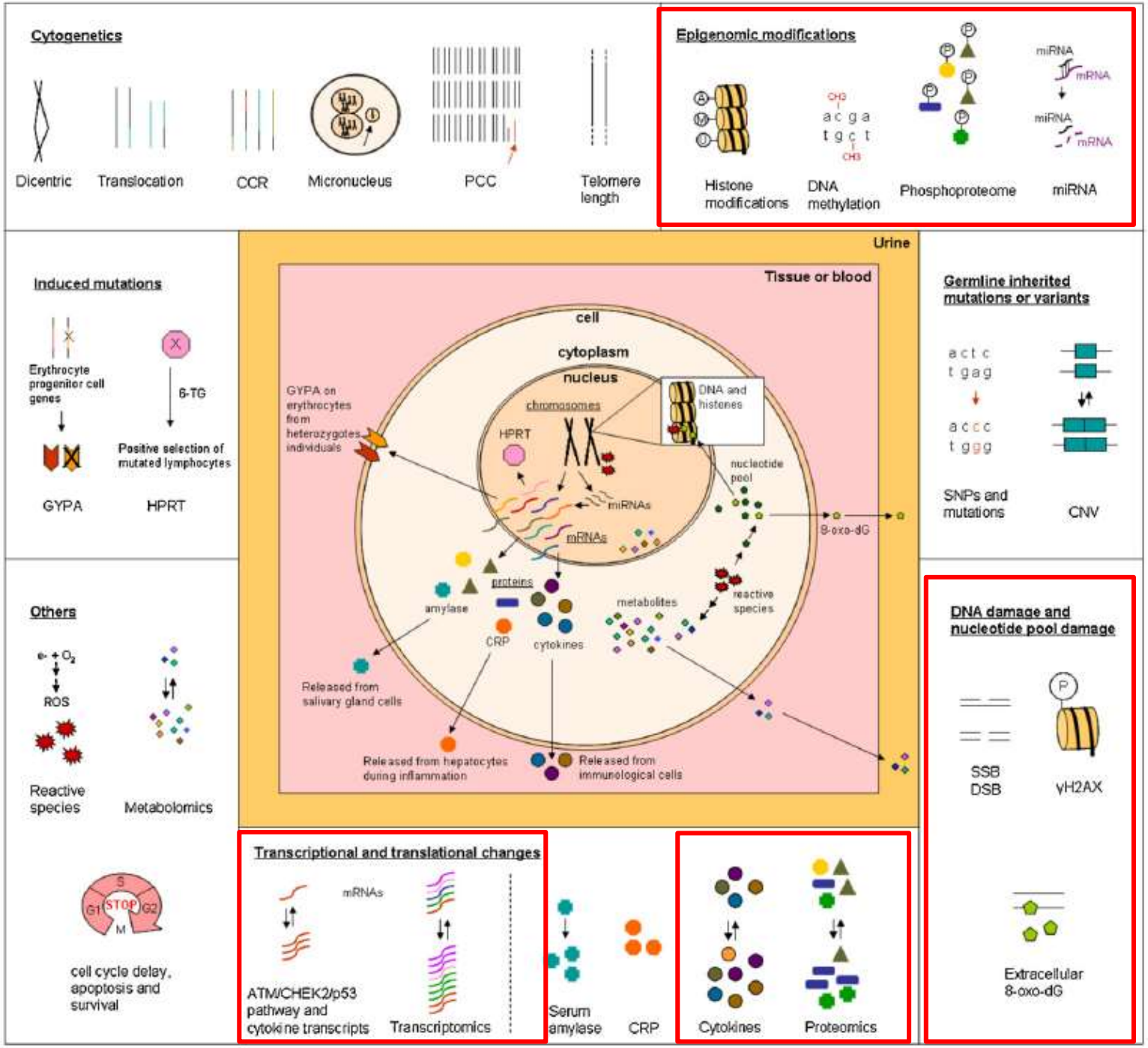
Oncotarget, 2018

Biomarkers for precision medicine in astronauts

Classification of biomarkers: A biomarker is any measurement reflecting an interaction between a biological system and an environmental agent, which may be chemical, physical or biological.



Pernot et al., Mut Res 2012; Hall, 2017



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Pernot et al., Mut Res 2012
Hall, Mut Res, 2017

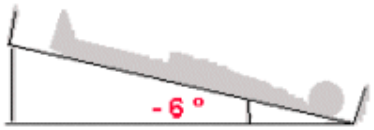
SCK CEN human space research programme

Ground based simulation

µg – radiation

stress hormones

Microgravity



Bed Rest study

(France, Germany)

Confinement – Isolation

ESA Concordia Station (Antarctica)

Princess Elisabeth station (Antarctica)

Parabolic flights

ISS & FOTON experiments

blood vessels in space

Skin cells in space

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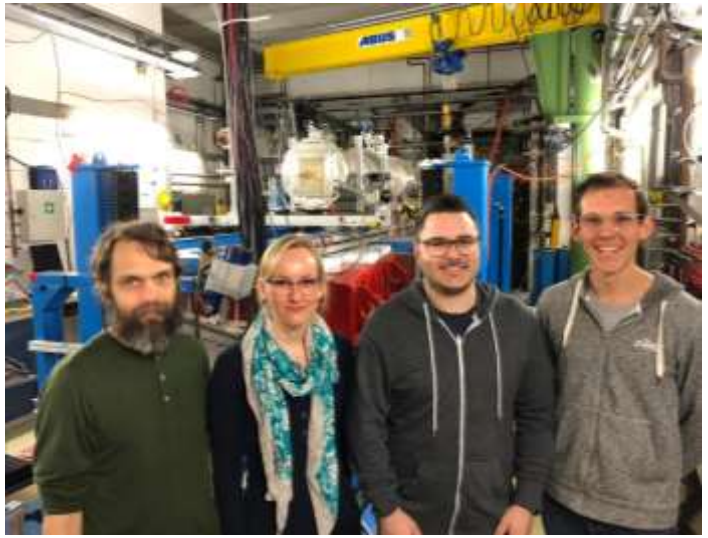
ESA Radiation Research Programme: IBER, GSI

- Programme for conducting research into radiation and how to protect astronauts from space radiation
- SCK CEN has various biological and dosimetric experiments to irradiation with heavy ions at GSI



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ESA Research using bedrest model

- Head tilt 6°: musculoskeletal, cardiovascular deconditioning, body fluid changes, optic nerve and psychological effects of long-term confinement.
- SCK CEN participates in sampling collection & analysis

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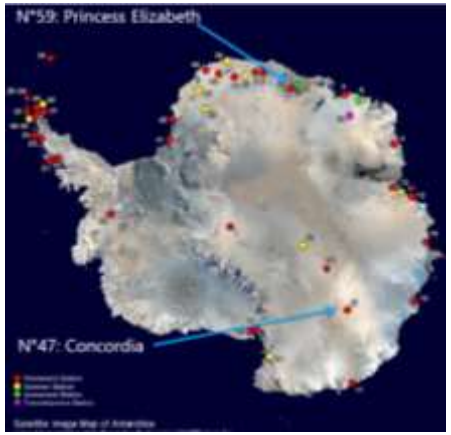
Antarctica: highest fidelity ‘real life’ analogues for future lunar and Martian habitats.



Space Environment

- Naturally hostile environment, day/night
- Monotonous landscape
- No vegetation (plants, grass, woods)

Mission

- Workload
- Mission duration
- Emergency/evacuation
- Limited medical support (telemedicine)
- Isolation for many months
- Unique technical as well as scientific research tasks performed

Space Habitat

- Same confined environment (same food, same air, same water, same germs for the whole crew)
- Limited resupply of food
- Life support system for organic recycling

Social Situation

- Itnl crew size with complementary/overlapping competence
- Restricted communication with outside
- Participation of everyone in housekeeping
- High level of solidarity
- Same age range & psychological profile as space crew
  - general inclination in pushing boundaries further
- Crew in good health and good physical conditions

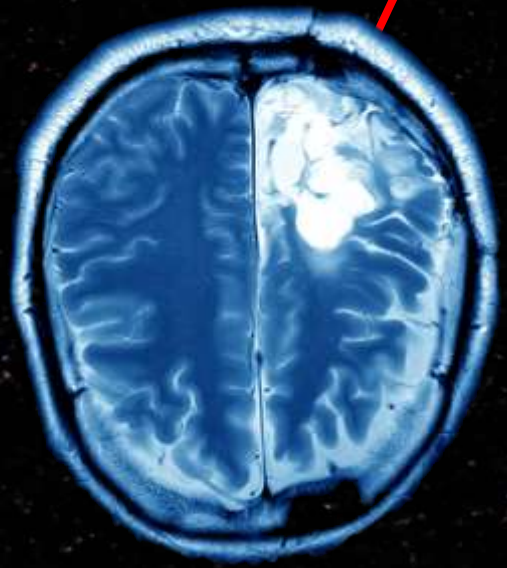
Antarctica: highest fidelity ‘real life’ analogues for future lunar and Martian habitats.

Zero emission station

Belgian Princess Elisabeth station in Antarctica

Space research benefits to patients

Cancer = n°1 killer



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Health benefits on Earth

- Specific Examples of Potential Earth Benefits

  - Advanced measurement devices for early and more precise diagnosis of osteoporosis
  - Improved treatment options for bone-wasting diseases
  - Noninvasive technologies to detect and treat bone loss and muscle atrophy
  - Development of new drug delivery techniques
  - Improved health and safety measures for industrial and clinical radiation workers
  - Better radiation therapies for cancer patients
  - Pharmacological intervention strategies for radiation and oxidative stress damage
  - New materials to shield hazardous materials workers and first responders from radiation exposure

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Your way to space

#SpaceCare

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