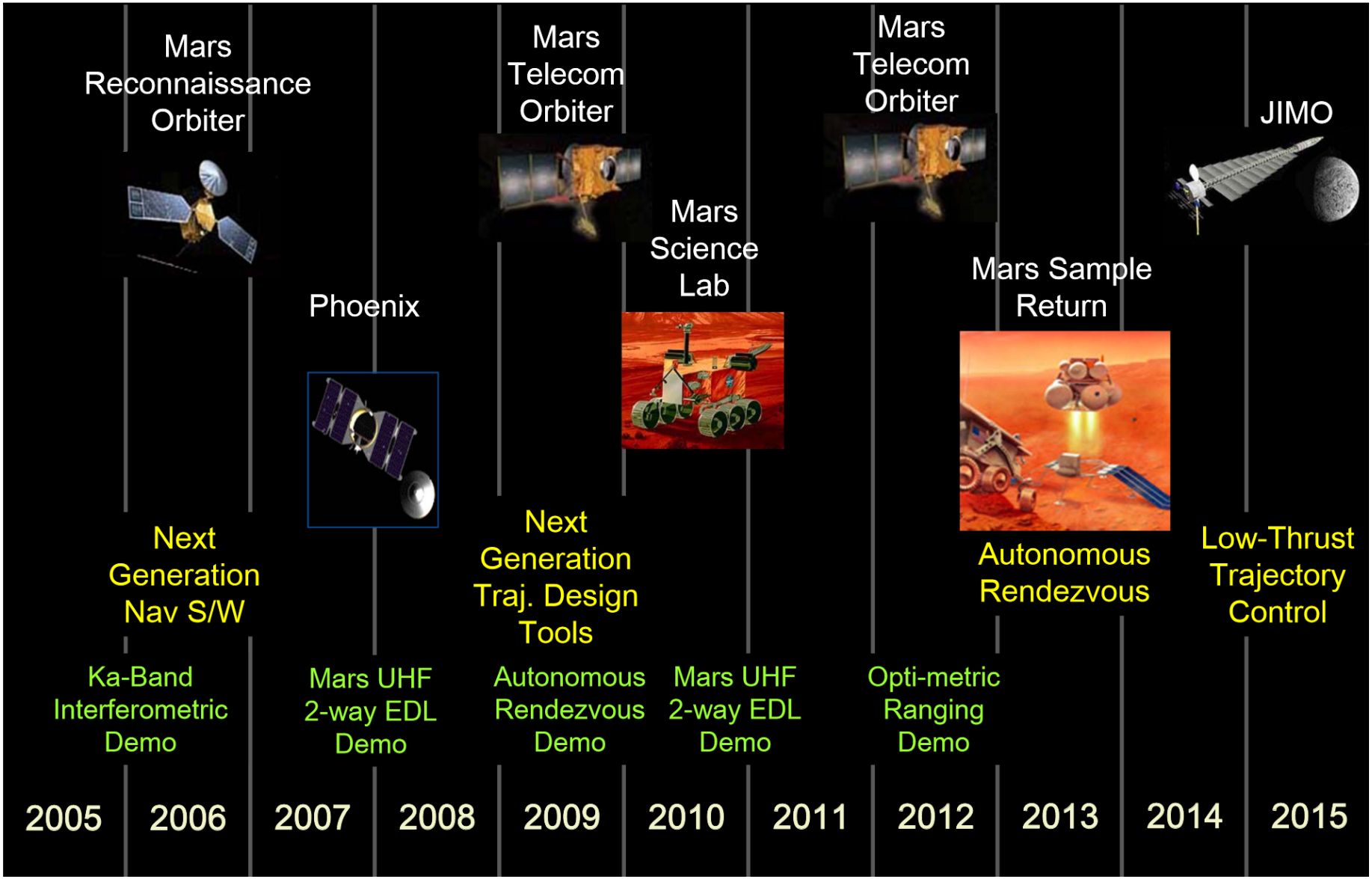
Metabolic Control Technology: Through the window of Space Exploration

Yuri Griko, Ph.D.
Laboratory of Countermeasures Development,
Life Sciences Division, NASA Ames Research Center


he survival of the human race is at risk as long as it is confined to a single
et. Sooner or later, disasters such as an asteroid collision or nuclear war
d wipe us all out.“
Stephen Hawking, 2006
The sky has—in all cultures—been a symbol of human aspiration
precisely because our future survival depends on going there.

A Timeline of Capabilities (as seen in 2005)



A Timeline of Capabilities (cont.)

Human Lunar Missions

Next Generation MTO

Aerorover

Planet Finder

Human Mars Missions

In-Situ Network-Based Navigation

Opti-Metric Ranging

Advanced Autonomous On-board Nav

Substantial Nav Infrastructure at Mars

2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030

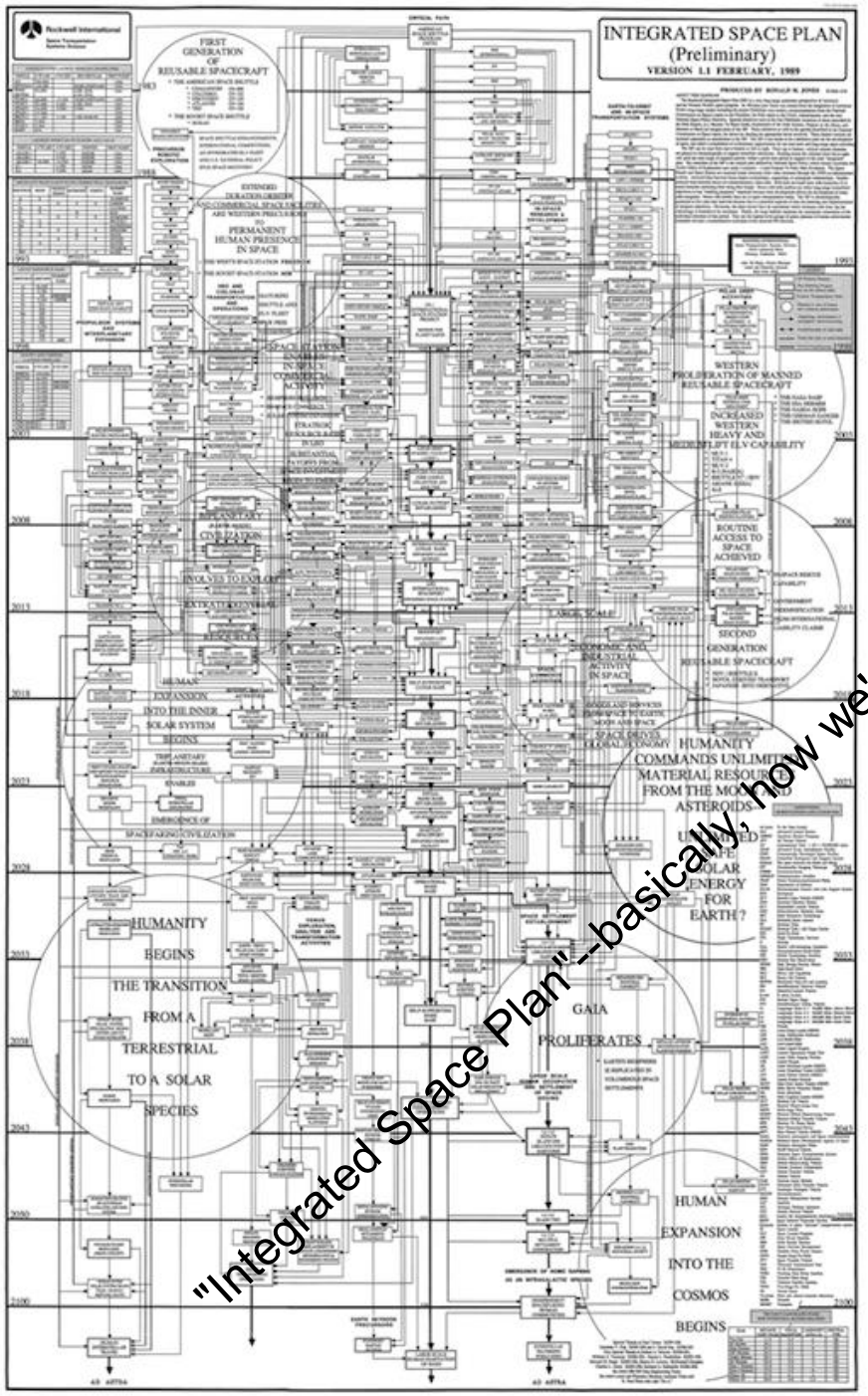
Does space exploration lost its hold on the public imagination, compared with a generation ago ….?

Yes: There's every reason for people to be disappointed with where we are now, particularly with regard to human space flight.

Eric Anderson co-founded Space Adventures in 1998, the leading entrepreneurs in the space industry.

"… While Mars is the goal, we recognize the capabilities of space-faring nations today are not sufficient to safely land and return humans from the surface of the Red Planet, as we know we have gaps in our scientific, engineering and technological knowledge".

Charles Bolden, NASA Administrator, 2014



"Integrated Space Plan"--basically, how we're all going to get off this rock we call home

NASA SP-413

Space Settlements

A Design Study

Edited by
Richard D. Johnson, NASA Ames Research Center
Charles Holbrow, Colgate University

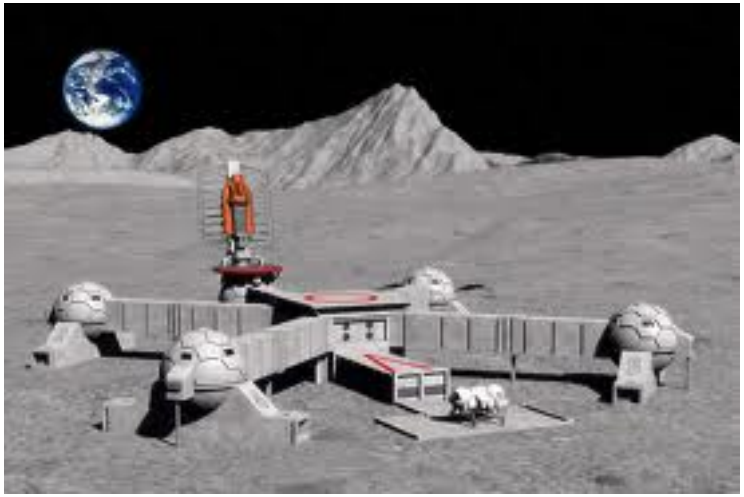
Scientific and Technical Information Office **1977**
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C

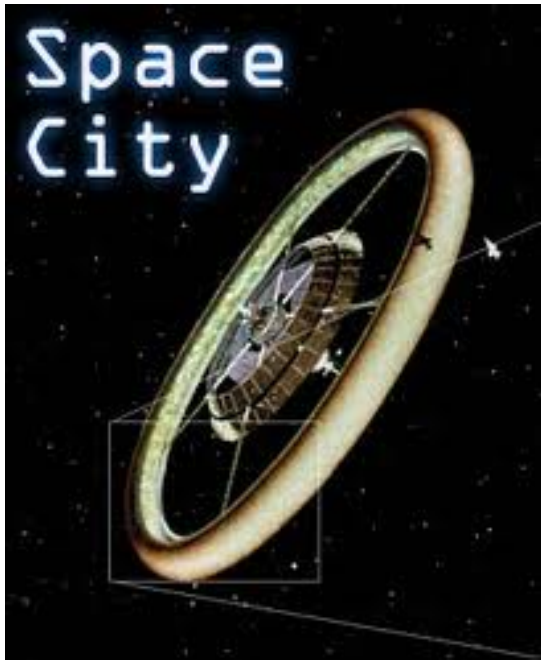
For sale by the Superintendent of Documents,
U.S. Government Printing Office, Washington, D.C. 20402
Stock No.033-000-00669-1
Library of Congress Catalog Card Number 76-600068

Authored by the Participants of
THE 1975 SUMMER FACULTY FELLOWSHIP PROGRAM IN ENGINEERING SYSTEMS DESIGN

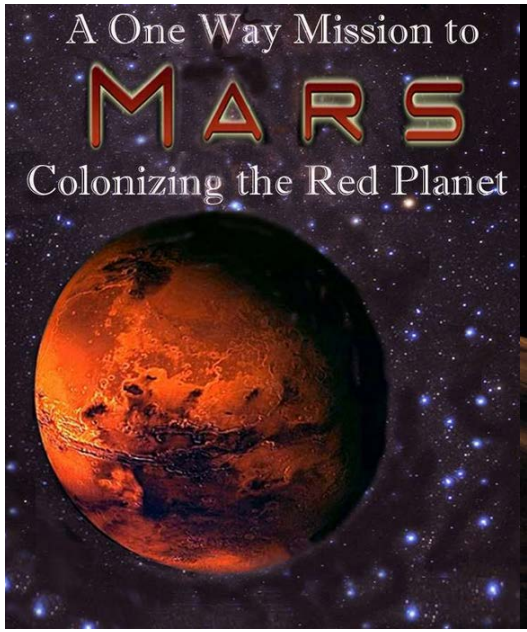
under the sponsorship of:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
and
AMERICAN SOCIETY FOR ENGINEERING EDUCATION

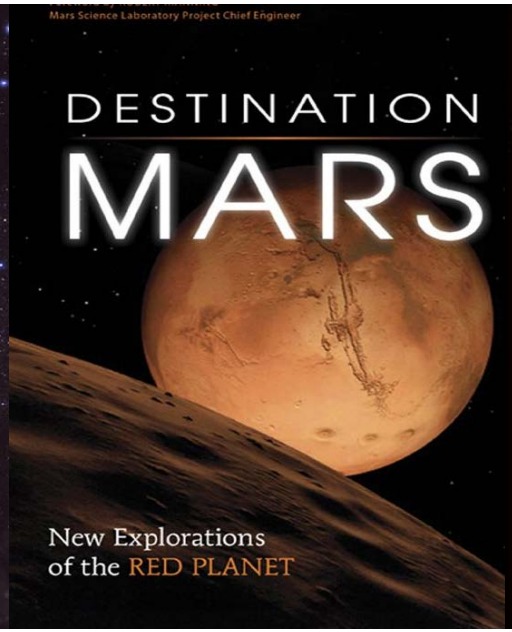
and directed by:
AMES RESEARCH CENTER
and
STANFORD UNIVERSITY

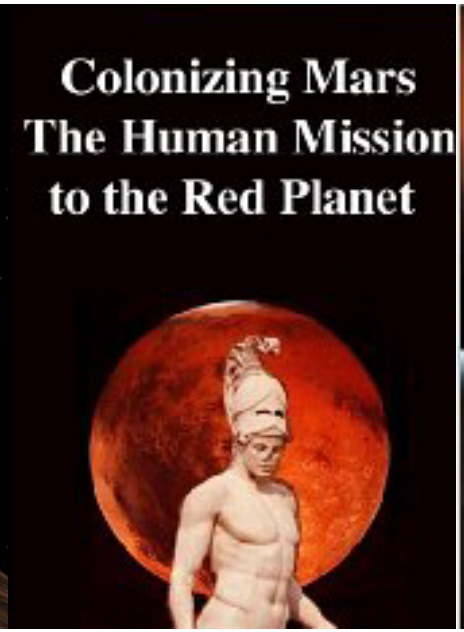


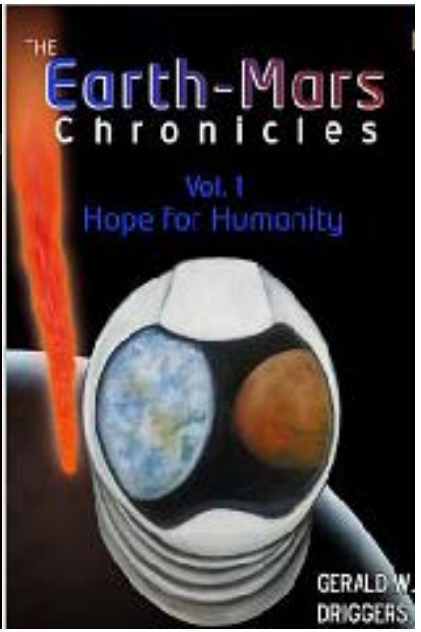

Space
City

/

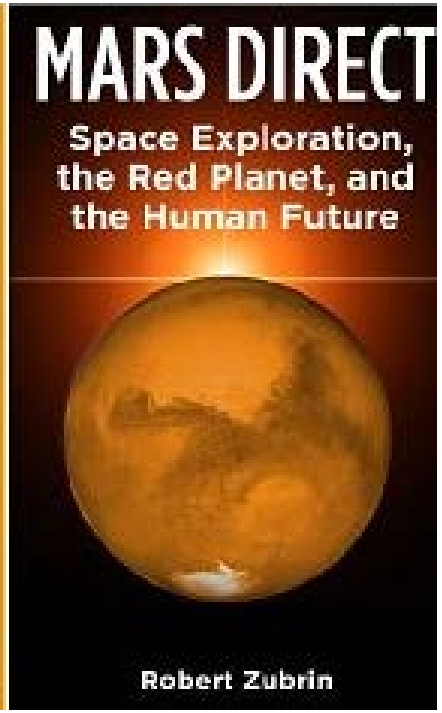

A One Way Mission to
MARS
Colonizing the Red Planet

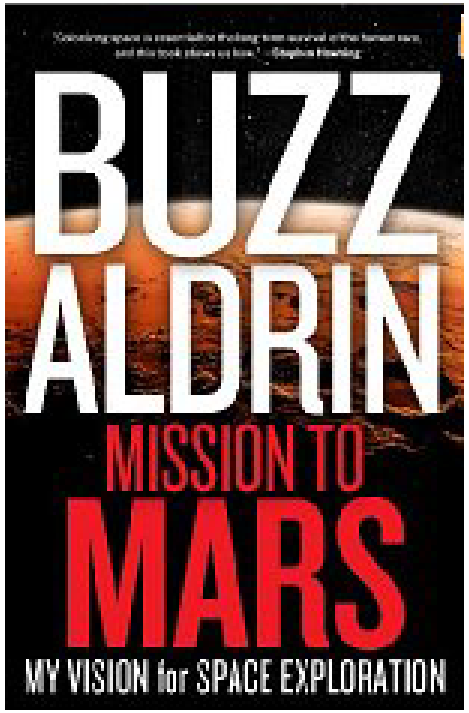

Mars Science Laboratory Project Chief Engineer
DESTINATION
MARS
New Explorations
of the RED PLANET

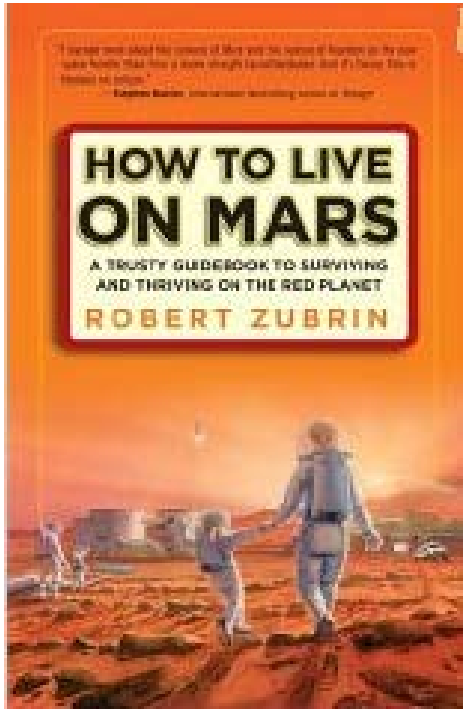

Colonizing Mars
The Human Mission
to the Red Planet

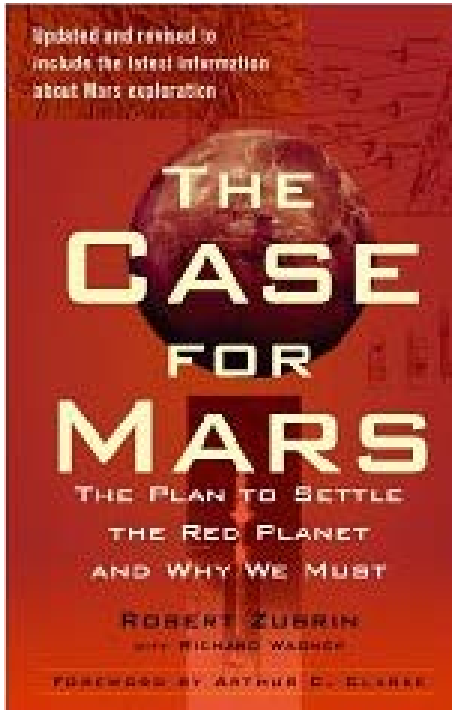

THE
Earth-Mars
Chronicles
Vol. 1
Hope for Humanity
GERALD W.
DRIGGERS


A PENGUIN SPECIAL


MARS DIRECT
Space Exploration,
the Red Planet, and
the Human Future
Robert Zubrin


BUZZ
ALDRIN
MISSION TO
MARS
MY VISION for SPACE EXPLORATION


HOW TO LIVE
ON MARS
A TRUSTY GUIDEBOOK TO SURVIVING
AND THRIVING ON THE RED PLANET
ROBERT ZUBRIN

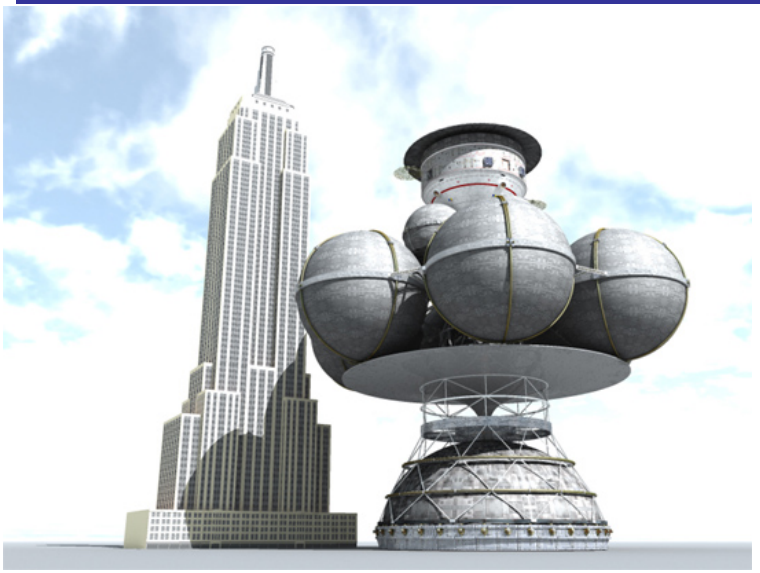

Updated and revised to
include the latest information
about Mars exploration
THE
CASE
FOR
MARS
THE PLAN TO SETTLE
THE RED PLANET
AND WHY WE MUST
ROBERT ZUBRIN

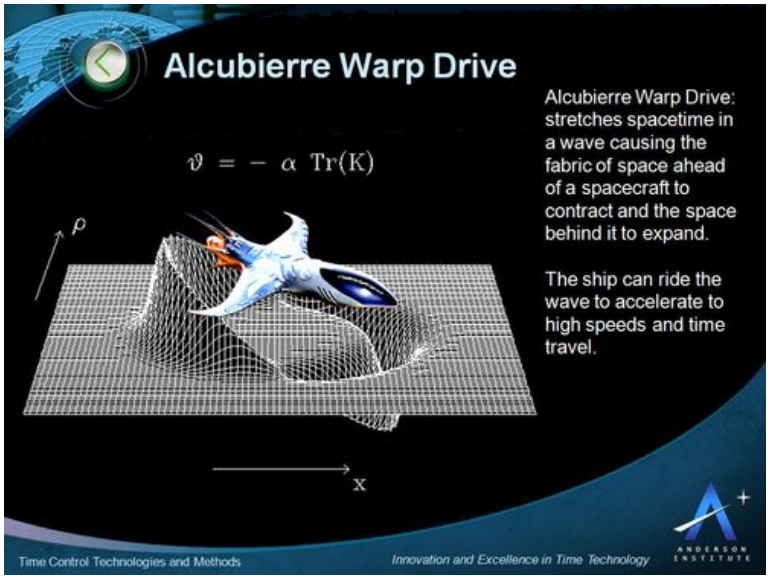
However, there are many largely unaddressed questions, both moral and practical that have not been presented alongside the space colonization platform.

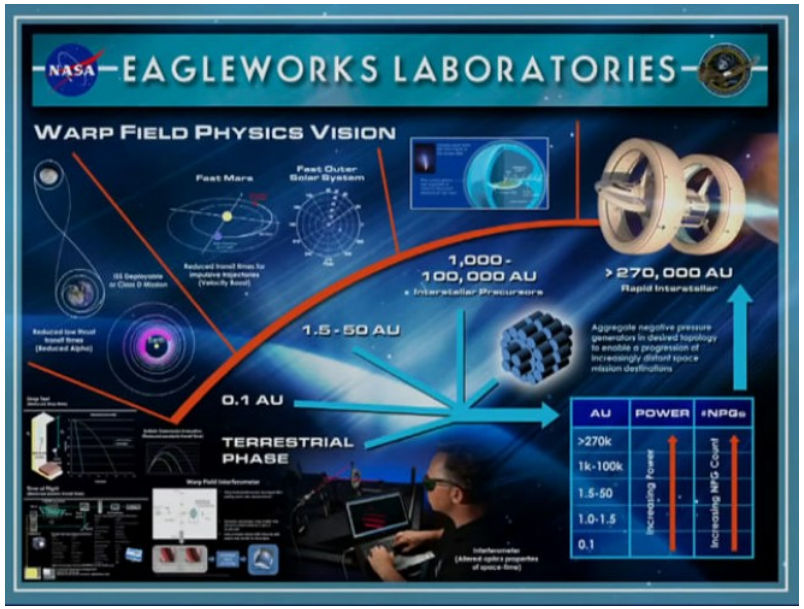
It's called "reality" and it's not nearly as rosy as the dream

… The biggest reality is that we, humans, evolutionary adopted to leave under conditions of earth gravity and acceptable level of radiation, cannot adopt to permanently leave in space without significant alteration in our physiology which may make us not humans at the end

Alcubierre Warp Drive

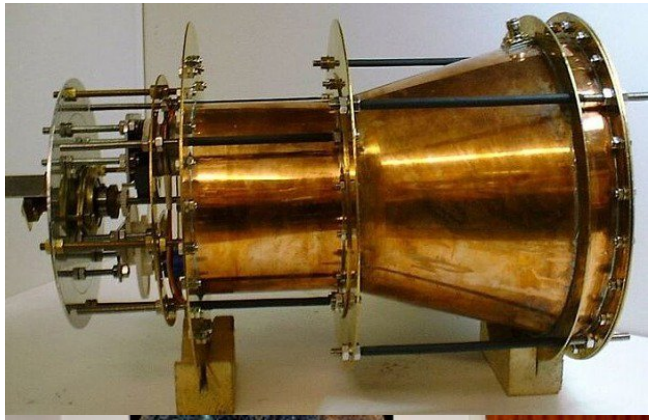


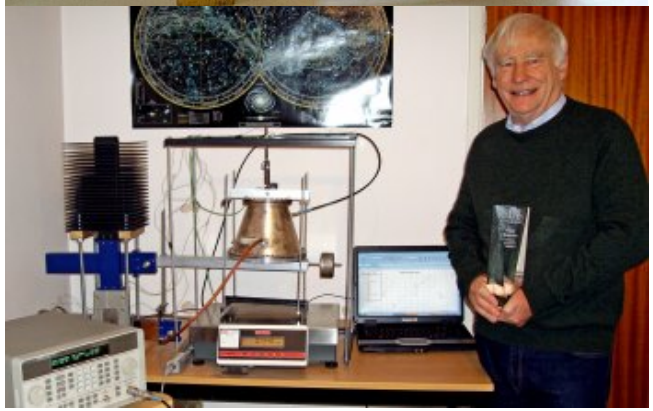




EM – Drive could revolutionize space travel

- would be able to power a spacecraft without the need for heavy rocket fuel on board
- Would be able to carry humans great distances in incredibly short periods of time





English researcher Roger Shawyer

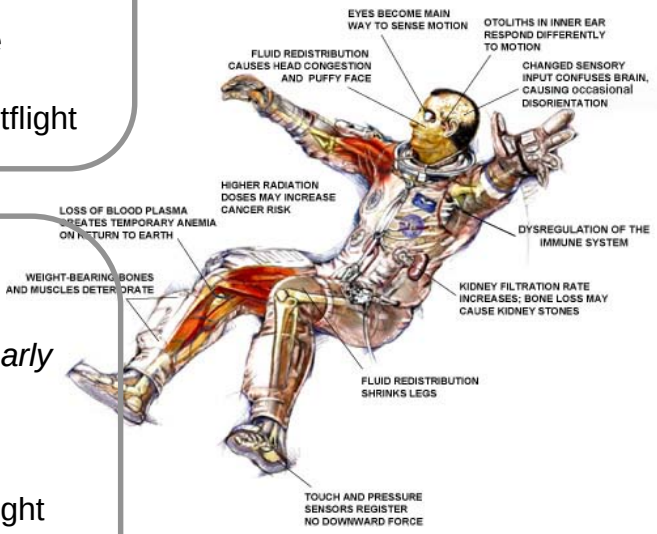
NASA confirms ‘impossible’ thruster actually works

There's been a whole lot of hype, controversy, and debate the past few months about the EM Drive – an "impossible" engine that, if functional, could supposedly power a spacecraft to Mars in just 10 weeks, without any rocket fuel.

Human Physiological Adaptations to Long-Duration Weightlessness in Space Flight

Cardiovascular
↑ resting heart rate
↑ stroke volume early in flight
↑ PACs & PVCs
↓ fluid volume
↓ orthostatic tolerance
↓ aerobic & anaerobic capacity
↓ resting blood pressure postflight
↓ central venous pressure (indirect)
↓ cardio/thoracic ratio postflight

Immunology
↑ viral reactivation & shedding
↓ DTH skin test response
↓ Cell mediated immunity
↓ lymphocyte function
-- unchanged humoral immunity



Sensory-motor
↑ vestibular disturbances
↑ space motion sickness *early in flight*
↓ postural stability
↓ sensorimotor function
↑ intraocular pressure in flight
↑ retinal blood vessel constriction postflight
↓ visual motor task performance
↓ contrast discrimination
↓ visual field postflight

Muscle & Bone
↓ muscle mass
↓ muscle endurance & strength
↓ bone mineral content
↓ bone integrity

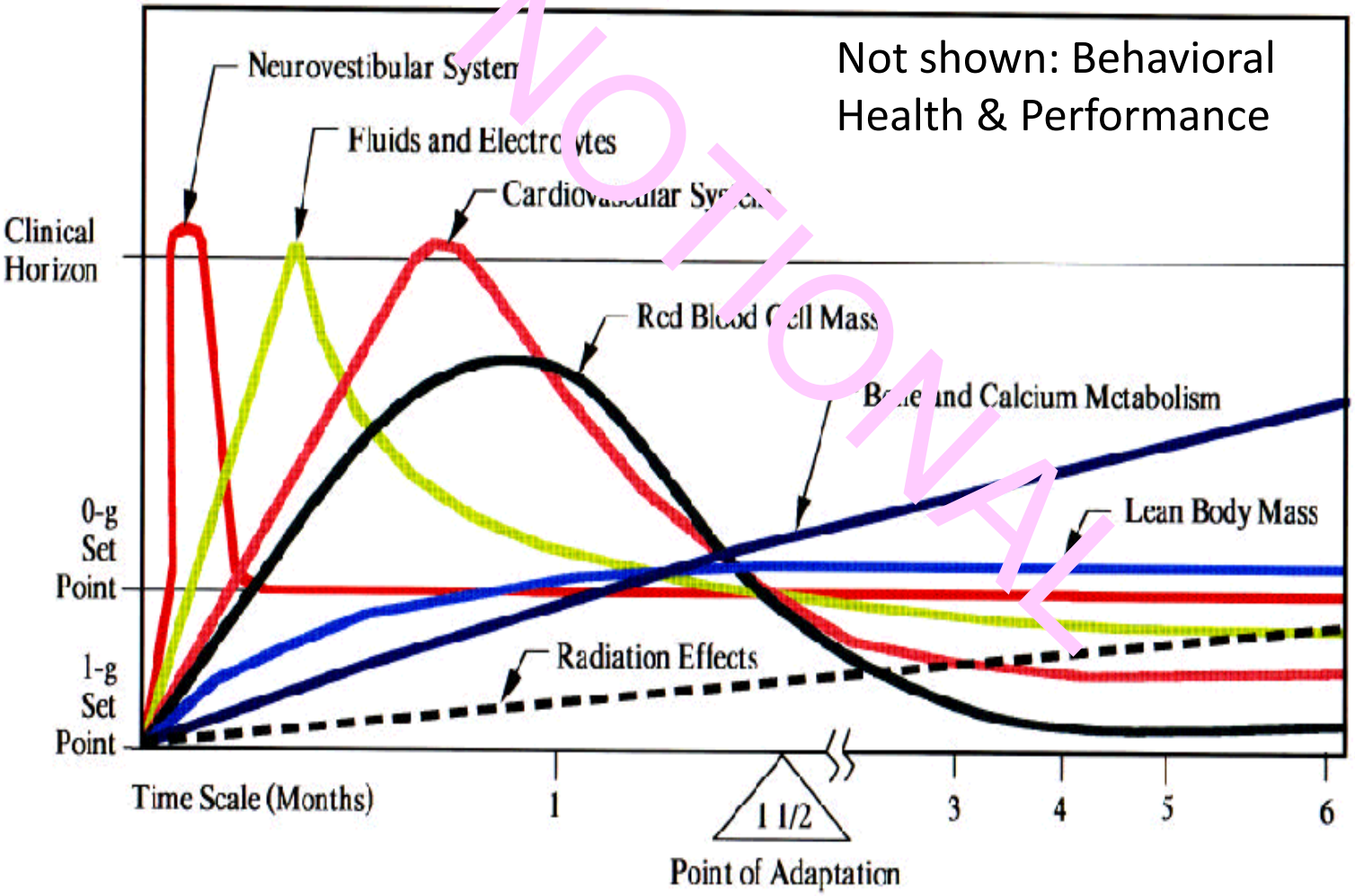
Body Fluids
↑ hemoglobin & hematocrit postflight
↓ total body water
↓ plasma & urine volumes postflight

Electrolytes
↑ urinary Ca, PO_4 postflight
↓ plasma K & Mg postflight
↓ urinary Na, K, Cl, Mg

Hormones
↑ plasma ADH, ANF
↑ urinary aldosterone
↑ urinary ADH, cortisol postflight
↓ urinary epinephrine, androsterone postflight
↓ plasma ACTH, aldosterone, cortisol

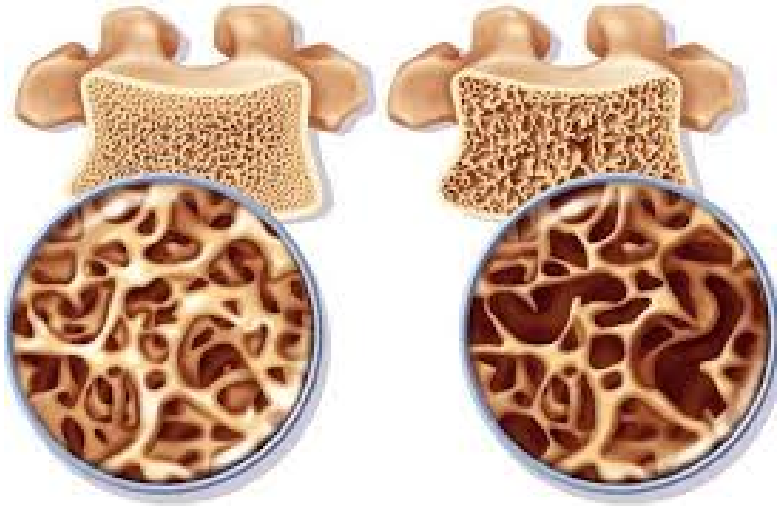
Metabolites
↑ plasma glucose, creatinine, BUN postflight
↓ albumin, cholesterol, triglycerides, uric acid

Time course of physiological changes in long-duration weightlessness (notional) based on Skylab data



Crew Recovery Status: *Mir* & ISS

Observed post-landing conditions of *Mir* & ISS crewmembers may be predictive for just-arrived Mars crewmembers



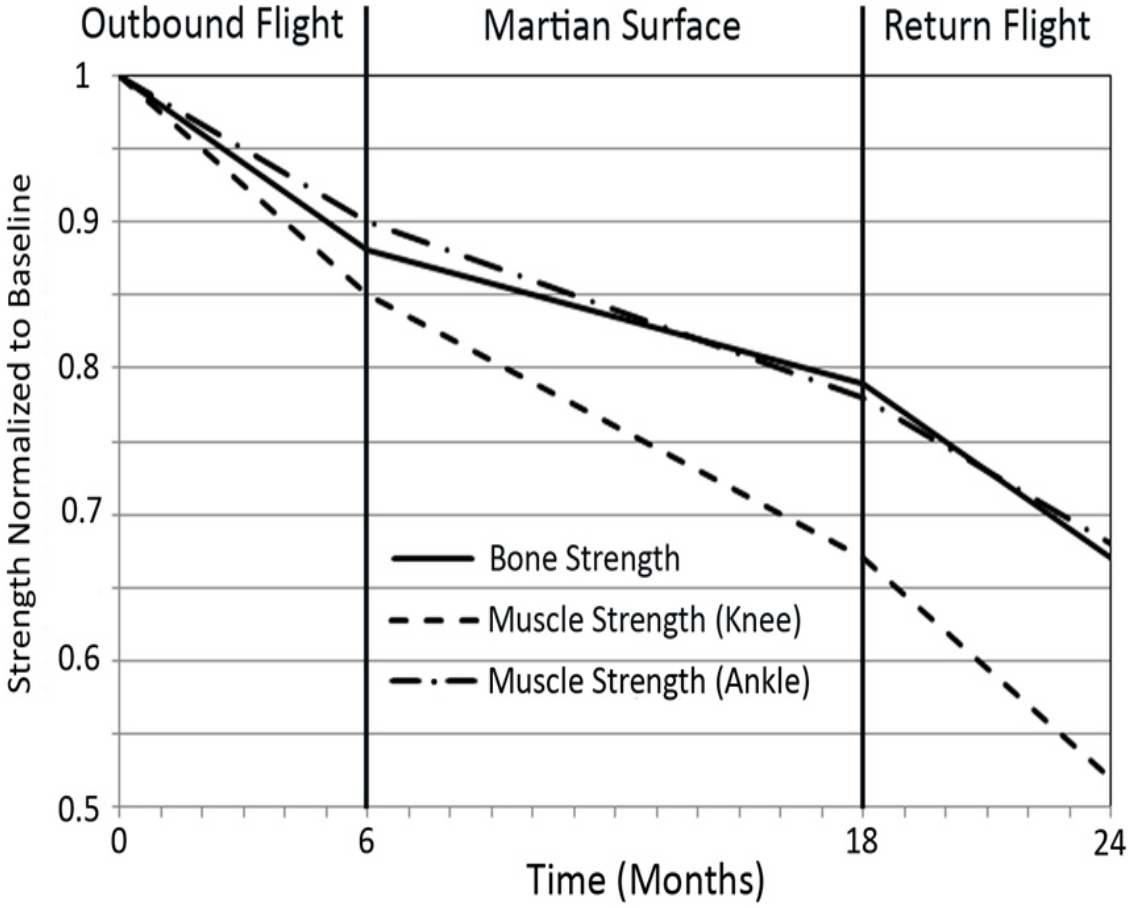
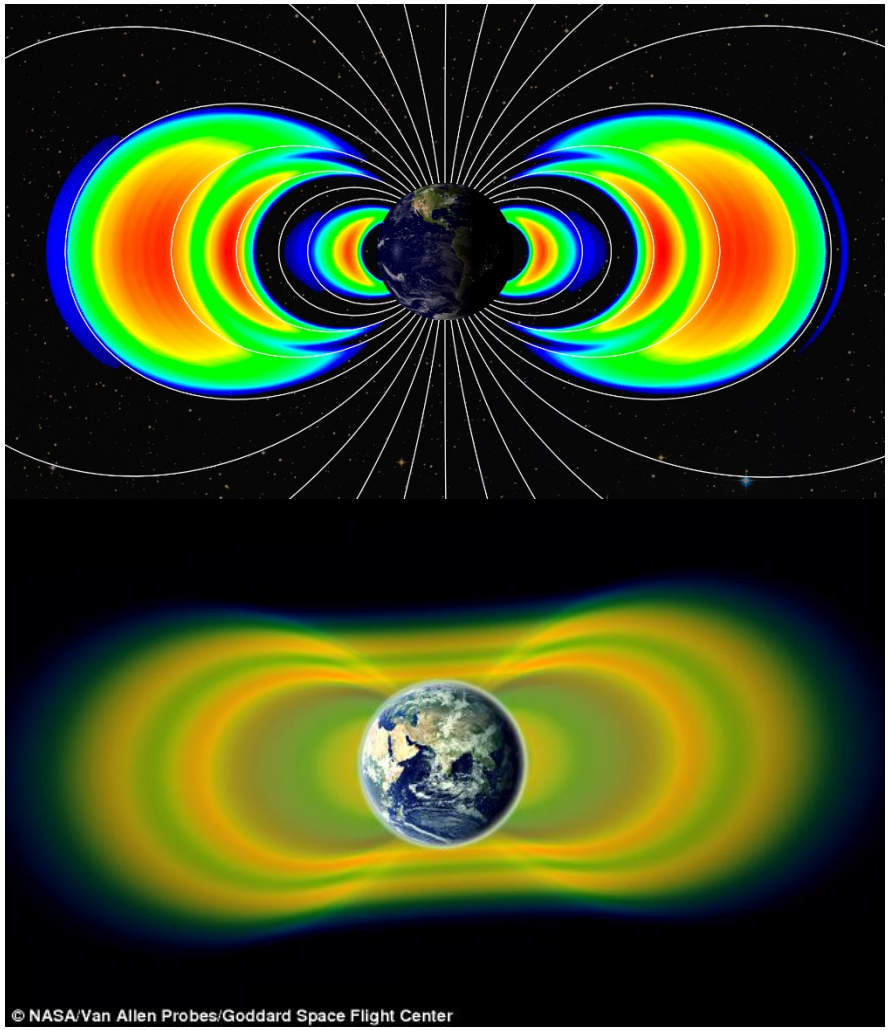


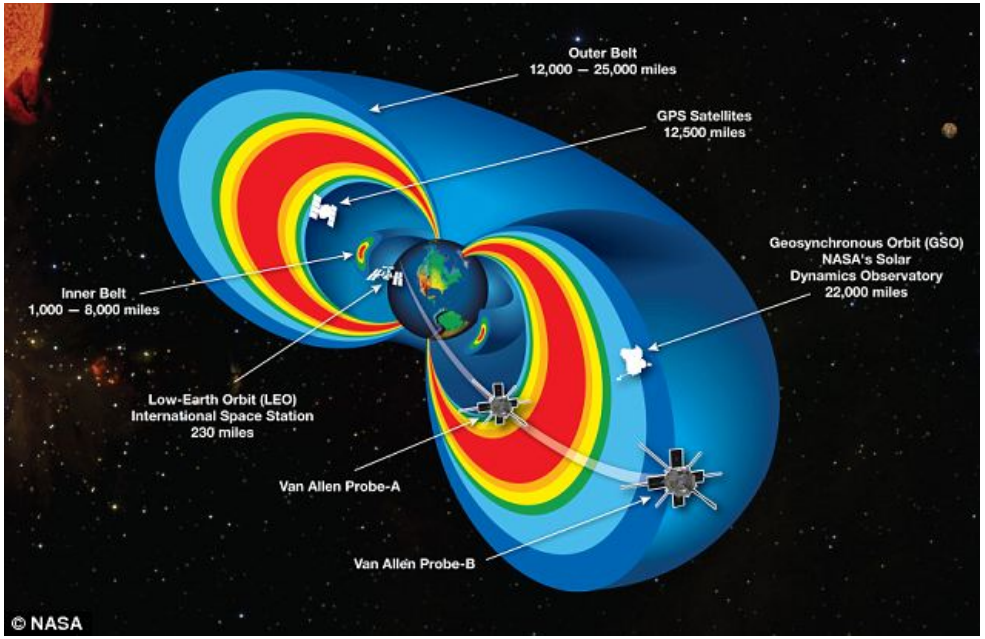
Figure 3. Hypothesized changes in bone and muscle strength that would occur on a manned mission to Mars. These predictions, which are based on rates of change in bone and muscle measured in long-duration, low-Earth orbit missions, are a worst-case scenario for a mission comprised of a 6-month flight to Mars, a 1-Earth-year stay on the Martian surface, and a 6-month return flight.

Journal of Cosmology, 2010, Vol 12, 3778-3780.

/

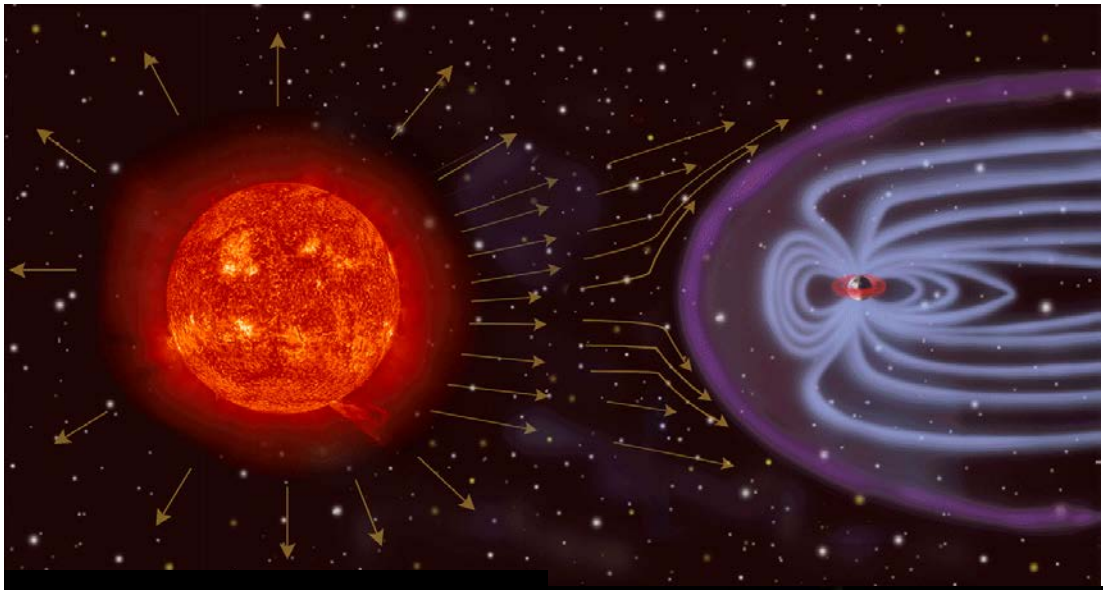
Space radiation



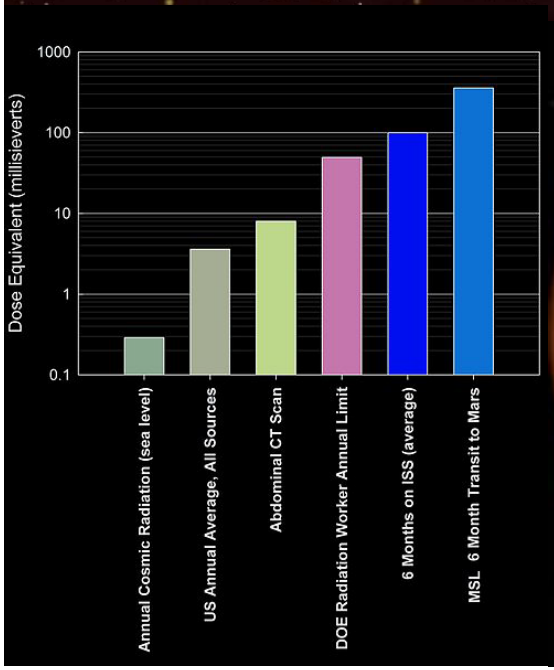


/

Space radiation Risks



Outside the earth's magnetic field, the fluency rates of the GCR are:
~ 4 protons/cm2/sec
~ 0.4 helium ions/cm2/sec
~ 0.04 HZE particles/cm2/sec

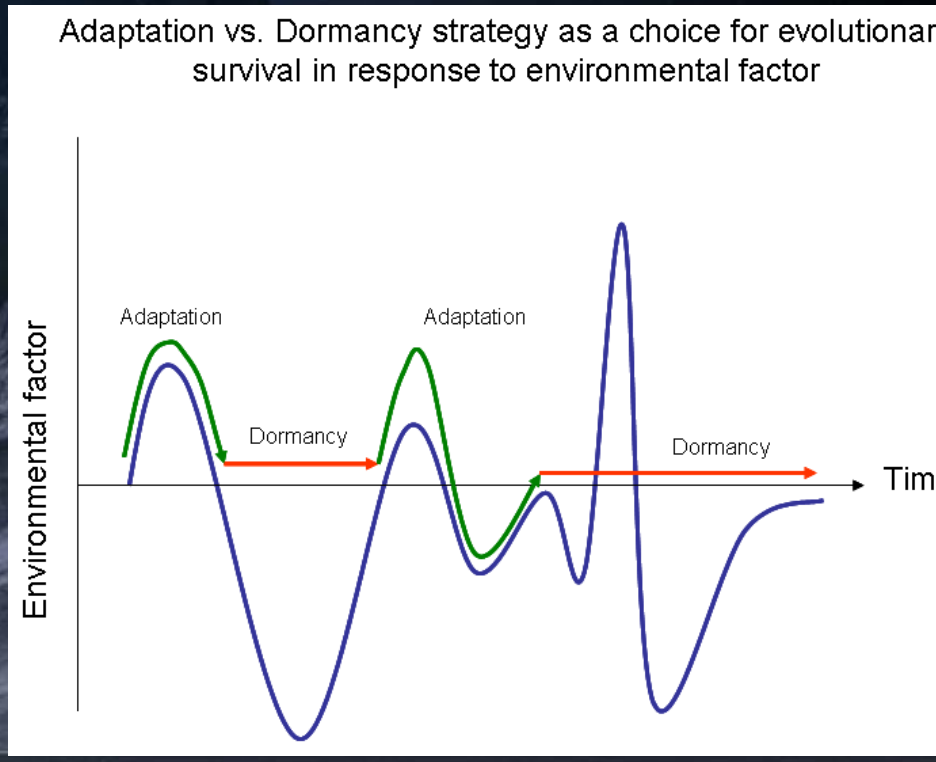


For a 100 µm2 nucleus, each cell nucleus in the body would be hit by
- a proton once every 3 days
- a helium ion once every month
- a HZE particle once per year

HRP Risks & Criticality

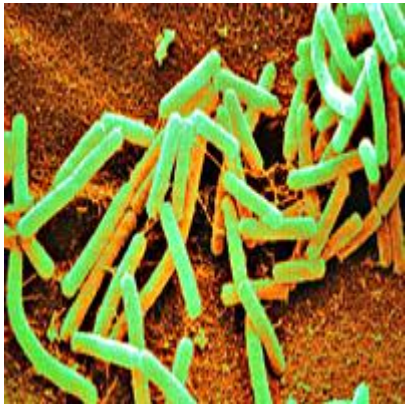
HRP Element	Risk Title (Short Title)	Criticality		
		Lunar	NEA	Mars
HHC	Risk of Orthostatic Intolerance During Re-Exposure to Gravity (Short Title: OI)	C	A	A
HHC	Risk of Early Onset Osteoporosis Due to Spaceflight (Short Title: Osteo)	C	A	A
HHC	Risk Factor of Inadequate Nutrition (Short Title: Nutrition)	C	A	U
HHC	Risk of Compromised EVA Performance and CrewHealth Due to Inadequate EVA Suit Systems (Short Title: EVA) - *Pending HSRB RMAT Approval*	A	A	A
HHC	Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance (Short Title: Muscle)	A	A	U
HHC	Risk of Renal Stone Formation (Short Title: Renal)	C	C	C
HHC	Risk of Bone Fracture (Short Title: Fracture)	C	C	C
HHC	Risk of Intervertebral Disc Damage (Short Title: IVD)	C	I	I
HHC	Risk of Cardiac Rhythm Problems (Short Title: Arrhythmia) - *Pending HSRB RMAT Approval*	C	I	i
HHC	Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity (Short Title: Aerobic)	A	A	U
HHC	Risk of Crew Adverse Health Event Due to Altered Immune Response (Short Title: Immune)	C	C	I
HHC	Risk of Impaired Control of Spacecraft, Associated Systems and Immediate Vehicle Egress due to Vestibular / Sensorimotor Alterations Associated with Space Flight (Short Title: Sensorimotor)	C	A	A
HHC	Risk of Therapeutic Failure Due to Ineffectiveness of Medication (Short Title: Pharm) - *Pending HSRB RMAT Approval*	C	C	I
HHC	Risk of Microgravity-Induced Visual Impairment/Intracranial Pressure (Short Title: VIIP) - *Pending HSRB RMAT Approval*	I	I	I
HHC	Risk of Injury from Dynamic Loads (Short Title: Occupant Protection)	U	U	I
SHFH	Risk of Performance Decrement and CrewIllness Due to an Inadequate Food System (Short Title: Food)	C	C	U
SHFH	Risk of Inadequate Human-Computer Interaction (Short Title: HCI) - *Pending HSRB RMAT Approval*	C	C	A
SHFH	Risk of Performance Errors Due to Training Deficiencies (Short Title: Train) - *Pending HSRB RMAT Approval*	C	C	A
SHFH	Risk of Inadequate Design of Human and Automation/Robotic Integration (Short Title: HARI) - *Pending HSRB RMAT Approv*	C	C	A
SHFH	Risk of Poor Critical Task Design (Short Title: Task) - *Pending HSRB RMAT Approval*	C	C	A
SHFH	Risk of Adverse Health Effects of Exposure to Dust and Volatiles During Exploration of Celestial Bodies (Short Title: Dust) – *Pending HSRB RMAT Approval*	A	I	I
SHFH	Risk of an Incompatible Vehicle/Habitat Design (Short Title: Hab) - *Pending HSRB RMAT Approval*	C	C	A
SHFH	Risk of Adverse Health Effects Due to Alterations in Host-Microorganism Interactions (Short Title: Microhost)	A	I	I
ExMC	Inability to Adequately Recognize or Treat an Ill or Injured CrewMember (Short Title: ExMC)	A	A	U
BHP	Risk of Adverse Behavioral Conditions and Psychiatric Disorders (Short Title: Bmed) - Reference RMATs for Risk of Adverse Behavioral Conditions, and Risk of Psychiatric Disorders	C	A	U
BHP	Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness, and Work Overload (Short Title: Sleep)	C	C	C
BHP	Risk of Performance Decrements due to Inadequate Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team (Short Title: Team)	C	A	A
SR	Risk of Radiation Carcinogenesis (Short Title: Cancer)	A	U	U
SR	Risk of Acute Radiation Syndromes Due to Solar Particle Events (Short Title: ARS)	A	A	A
SR	Risk of Acute or Late Central Nervous System Effects from Radiation Exposure (Short Title: CNS)	A	I	I
SR	Risk of Degenerative Tissue or other Health Effects from Radiation Exposure (Short Title: Degen)	A	I	I

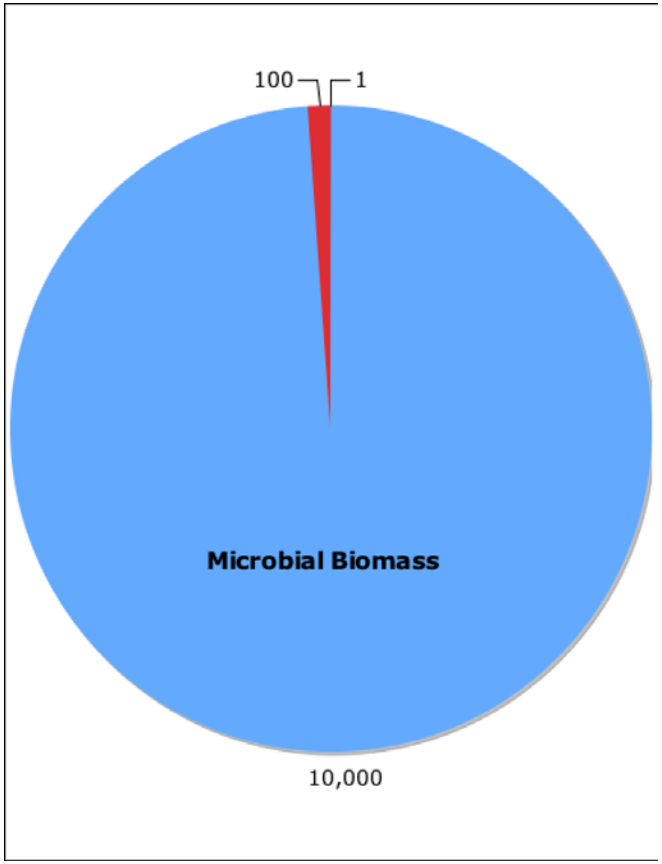
Hypometabolic Stasis as Evolutionary Component for Adaptation and Survival of Species.



Dormancy a reversible state of low metabolic activity

“I always thought the most significant thing that we ever found on the whole x Moon was that little bacteria who came back and lived and nobody ever said x about it”.
— Pete Conrad (NASA's annotated Apollo Lunar Surface Journal.)





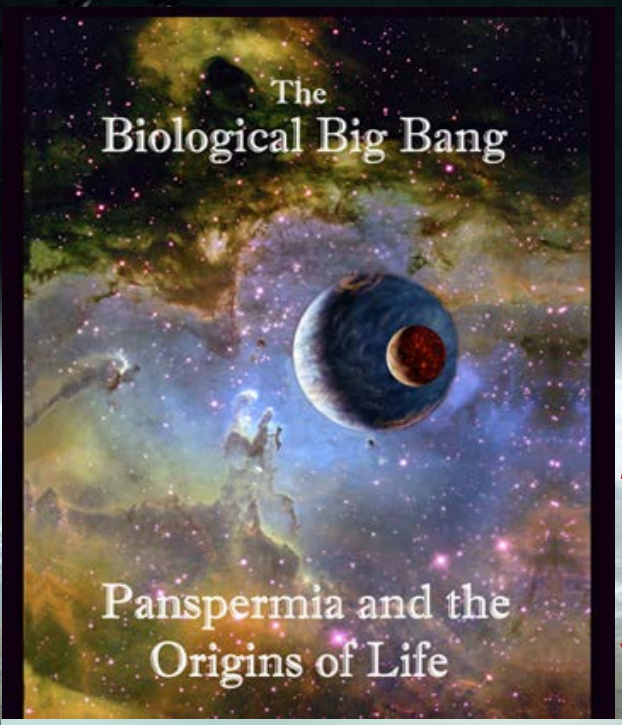
Thirty Million-Year Sleep: Germ Is Declared Alive!

Ancient bee in amber (May 19, 1995)

Alive...after 250 million years !

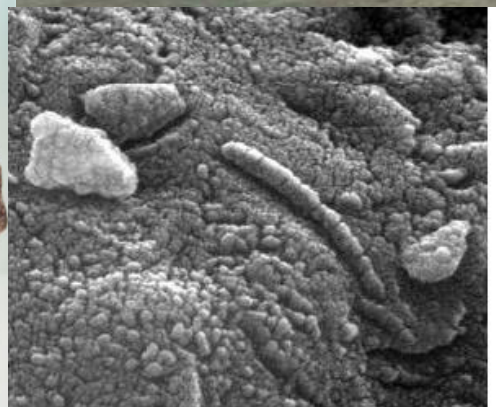
South-east New Mexico, US, 2000

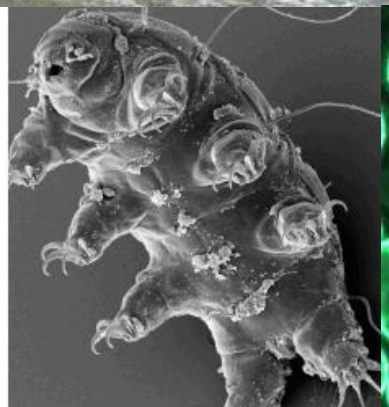
… it is very likely that many life forms in Universe can be found in a state of metabolic stasis accommodated to some certain habitable planets or being in transitional state as a result of spreading for colonization utilizing asteroid or small comets

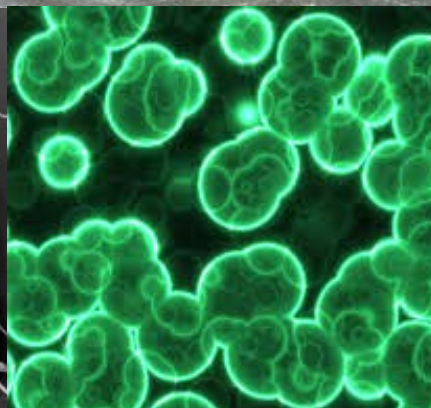


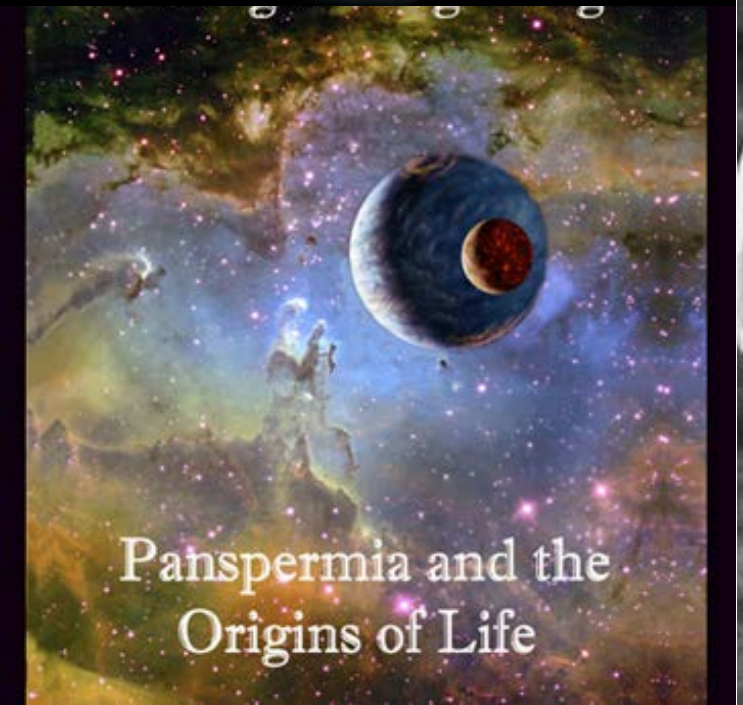
Directed panspermia" missions can be accomplished wit present technology.

Suspension of life for purpose of delivery is realistic strategy









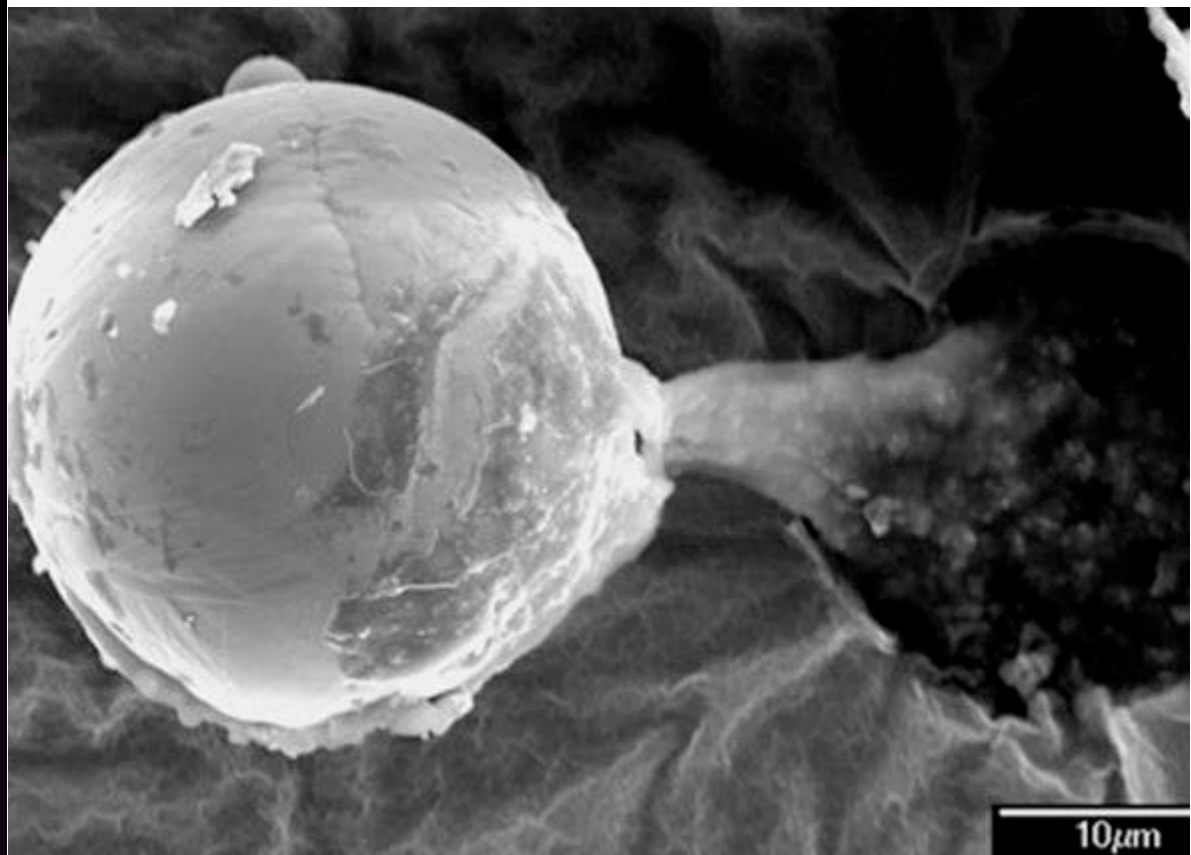
Was life on Earth started with alien space seeds?

February 18, 2015

Astrobiologist Milton Wainwright and a team of researchers at the University of Buckingham, UK recently discovered a microscopic metal sphere in the dust from the team's atmospheric balloon. Specifically, the hair-length ball is made of titanium and vanadium with a viscous liquid, and most intriguingly, a biological core

"… One theory is it was sent to Earth by some unknown civilization in order to continue seeding the planet with life".

Dr. M. Wainwright




The Earth is in a constant exchange of matter
with the larger cosmos

Metabolic rate depression is an important survival strategy for many animal species

- Extended space flight duration logistics
- Lower payloads (reduce the required life-support resources)
- Eliminate psychological stressors associated with the space environment
- Provide emergency rescue in long-duration missions
- Protection against radiation

Hypometabolic STASIS

for NASA needs

Laboratory of Countermeasures Development, Dr. Yuri Griko
Life Sciences Division NASA Ames Research Center

The Stasis Project

Carnegie Mellon Innovations Lab

Metabolic Control:
a game-changing technology for future long-term space exploration

Big Idea: Induce “hibernation” in humans by reducing metabolism in various ways.

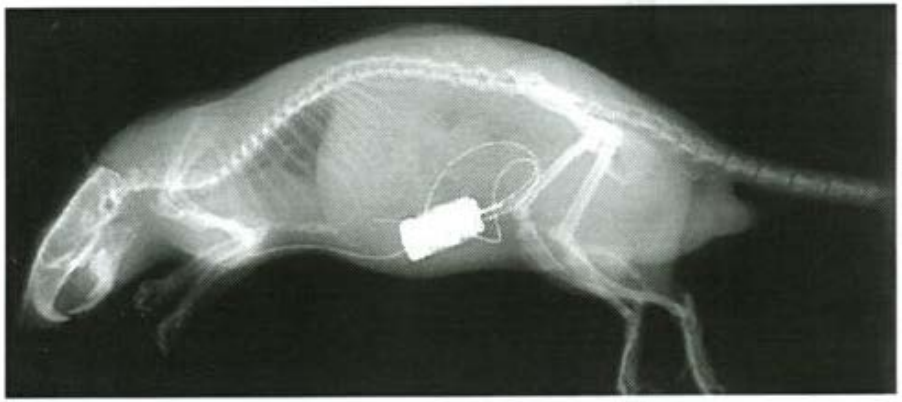
Concept: Demonstrate feasibility of integrating metabolic control technology into a space flight architecture and its abilities to solve many problems associated with payload cost reduction, space flight duration logistics, and influence of multiple damaging space environmental factors including radiation and microgravity on human health.

Approach: We have induced “hibernation” in a small animal system (mouse) with 90% metabolic reduction. The next steps require scaling-up to human-size animals and, eventually, to humans.

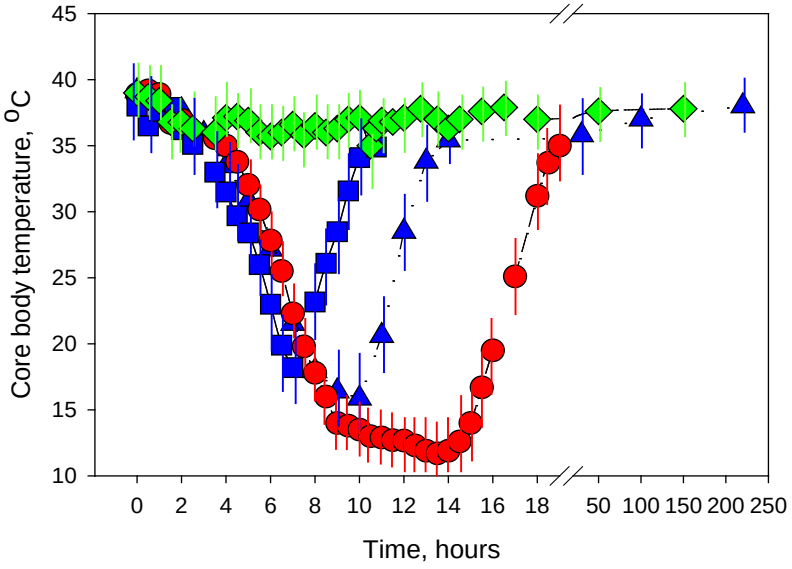
Goal: Advance metabolic control technology from its current TRL-1 all the way to practical mission applications over the next 10-20 years.

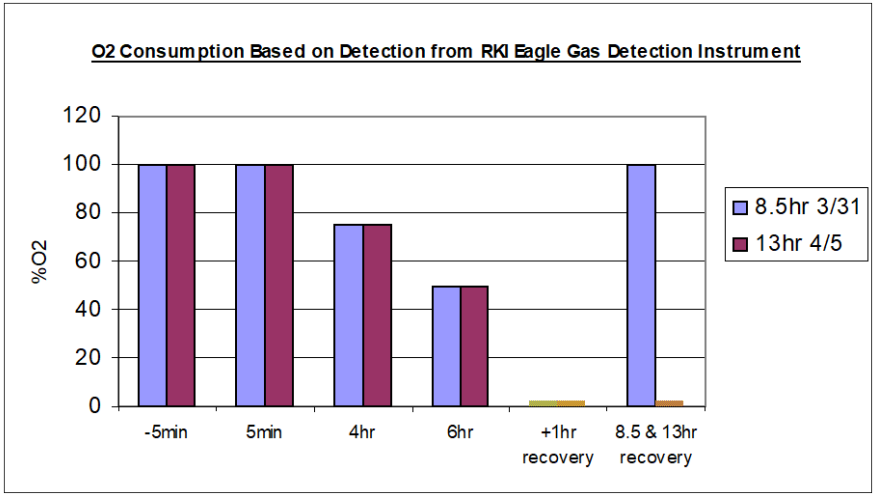
Yuri Griko
NASA ARC/SCR
(650)-604-0519
Yuri.V.Griko@nasa.gov

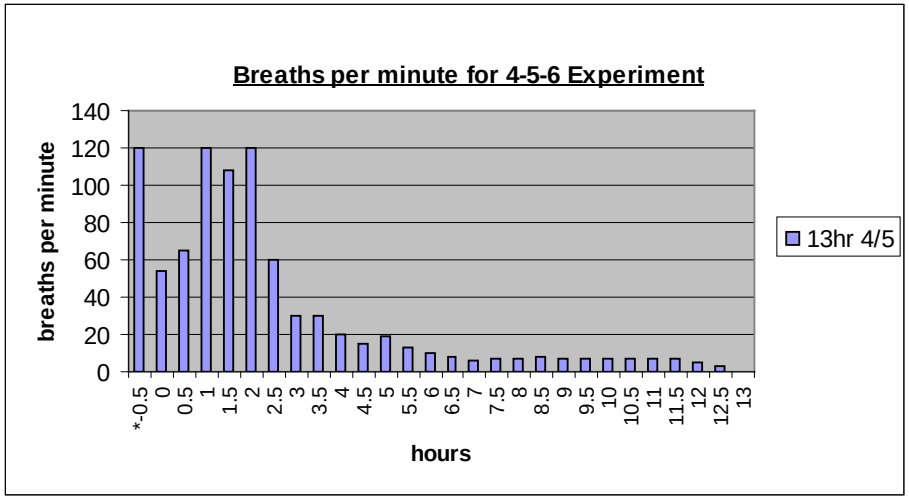
ECG lead II configuration

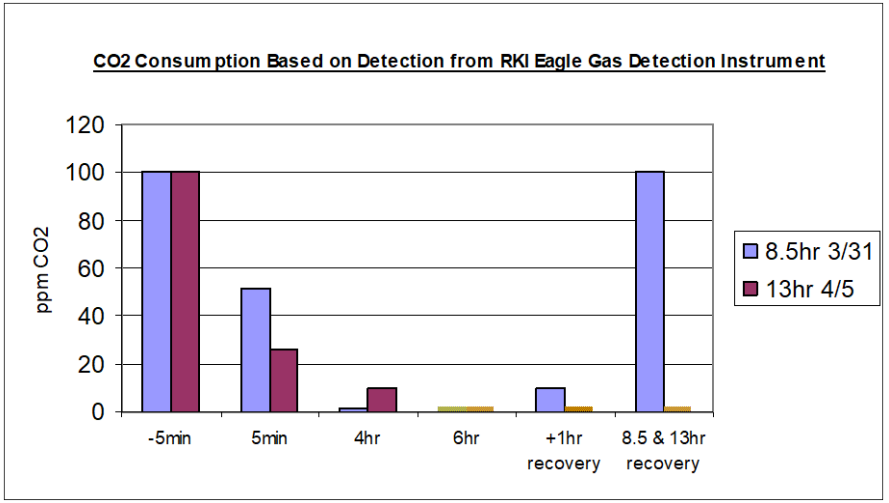


Metabolic parameters

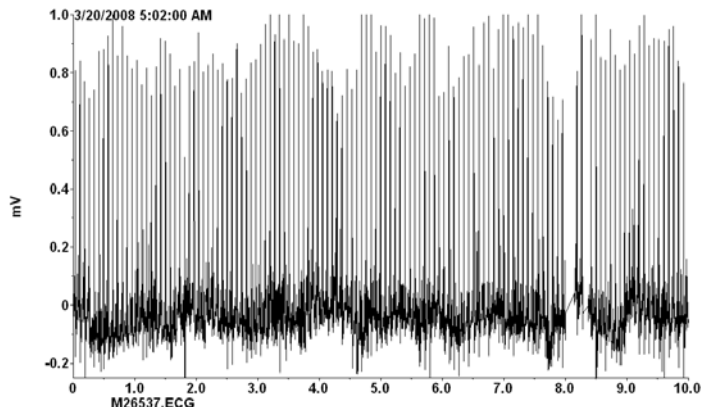


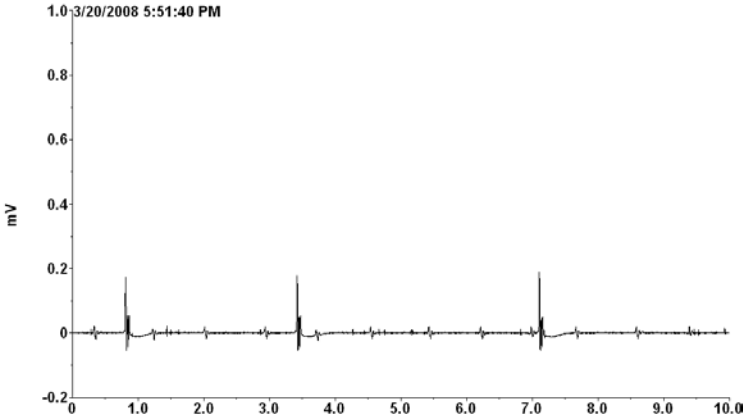


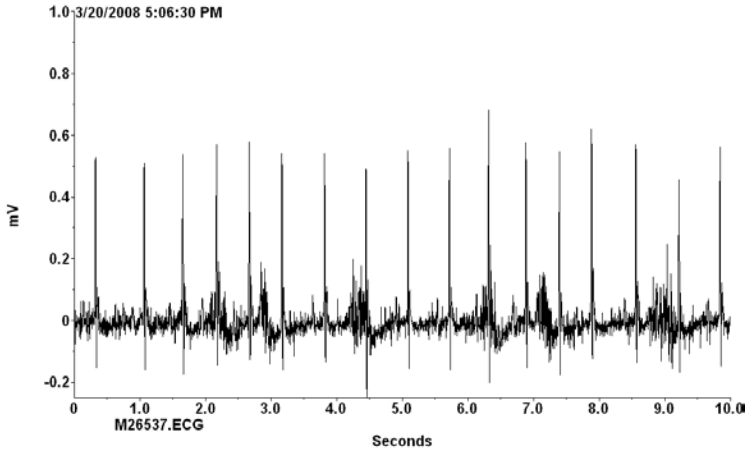


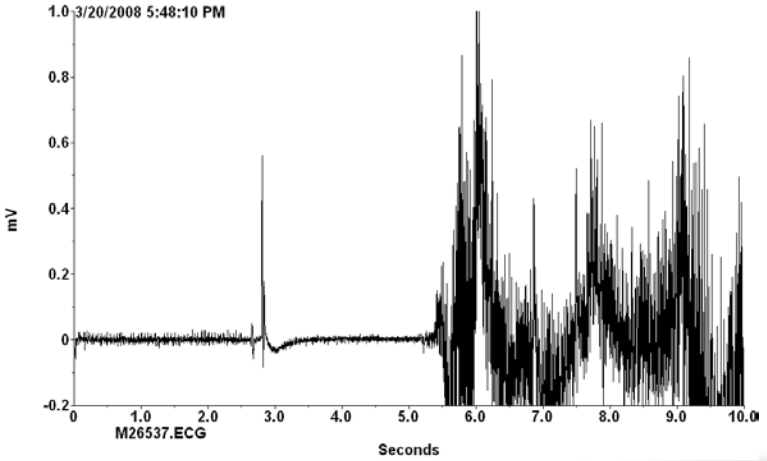


Mice electrocardiographic changes

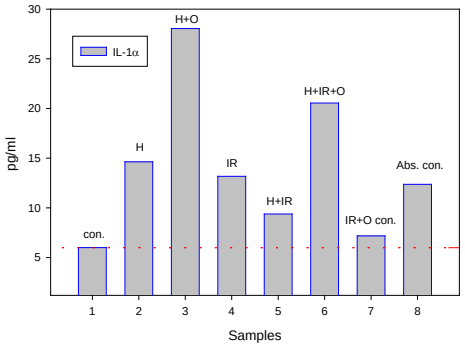


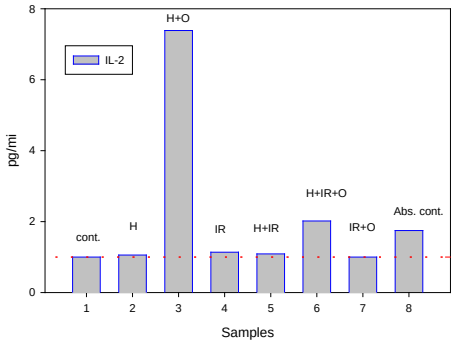


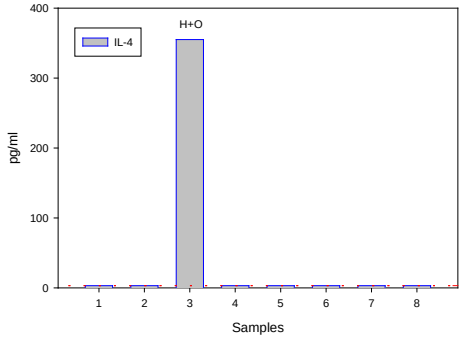


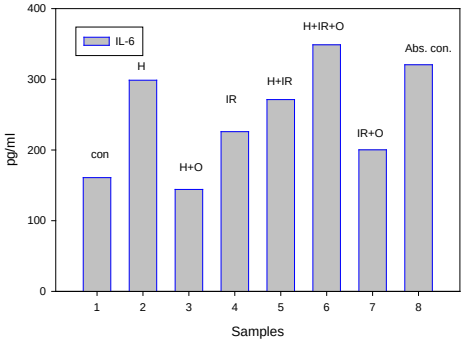


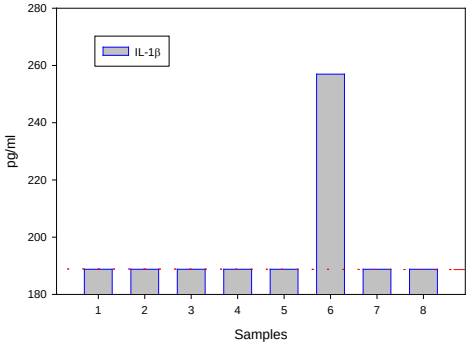
Enzyme-linked immunosorbent assay (ELISA) of inflammatory cytokines

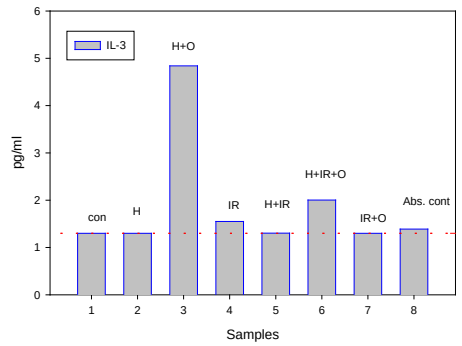


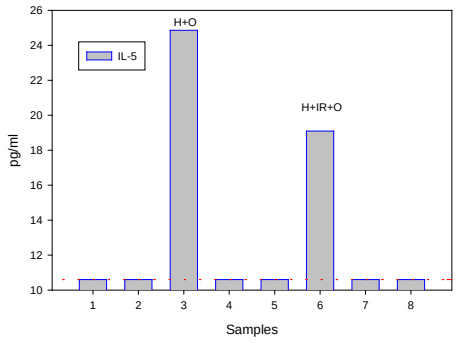


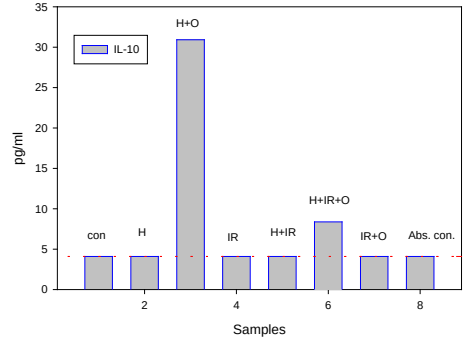






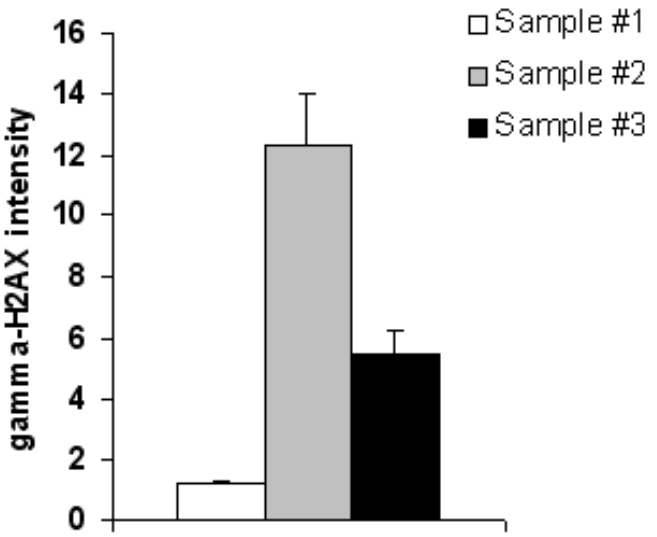


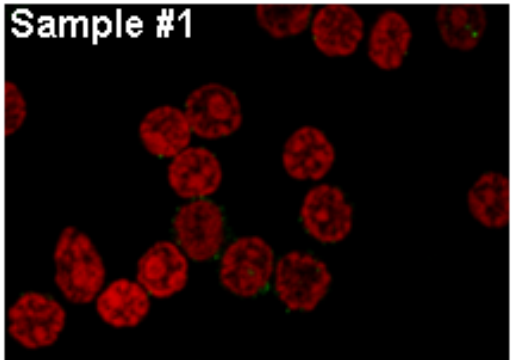


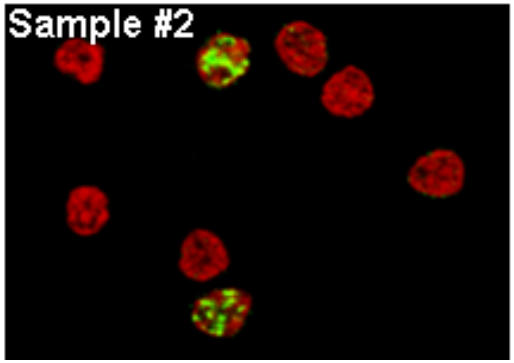


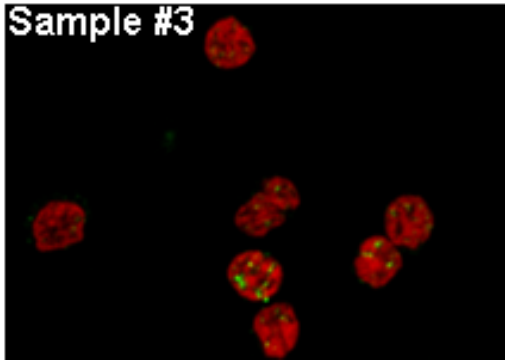
Protection against radiation

Carnegie Mellon Innovations Lab



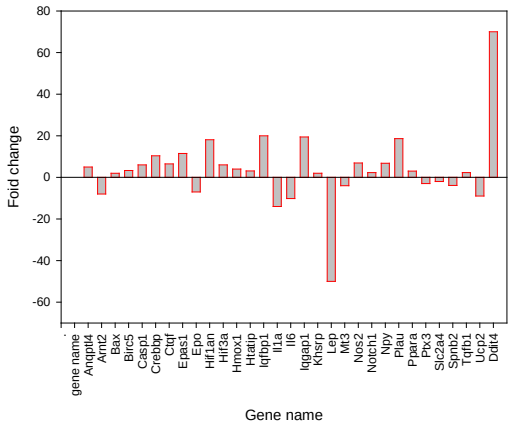




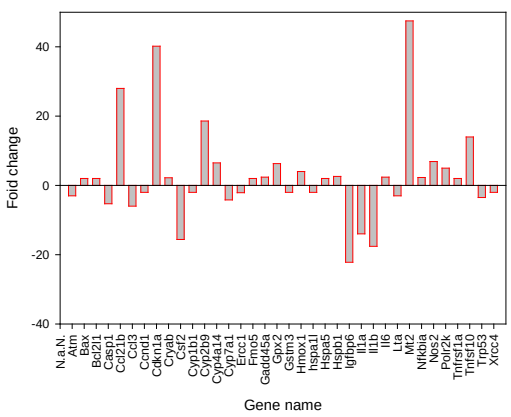


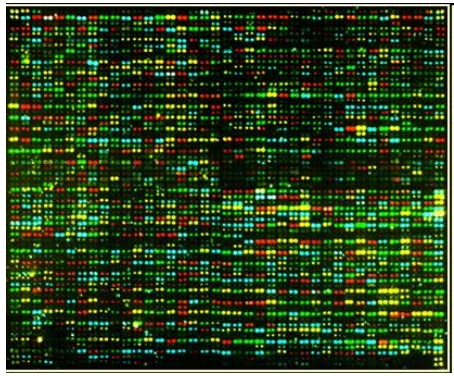
Differential gene expression in hypometabolic mice

Differential expression of the hypoxia pathway -related genes in hypometabolic state of mice vs. normal state

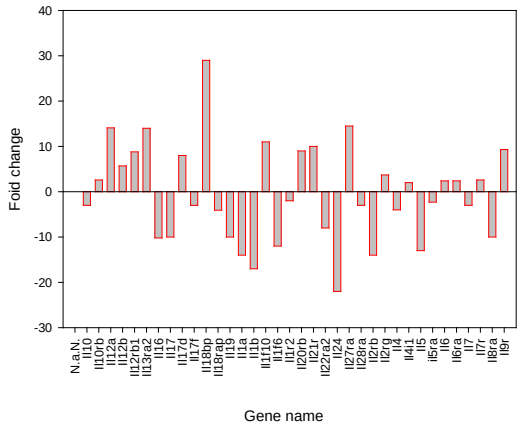


Differential expression of the Stress/Toxicity pathway - related genes in hypometabolic state of mice vs. normal state

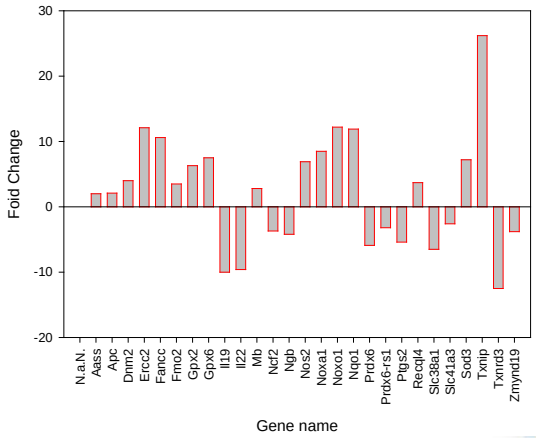




Differential expression of the Interleukins genes in hypometabolic state of mice vs. normal state



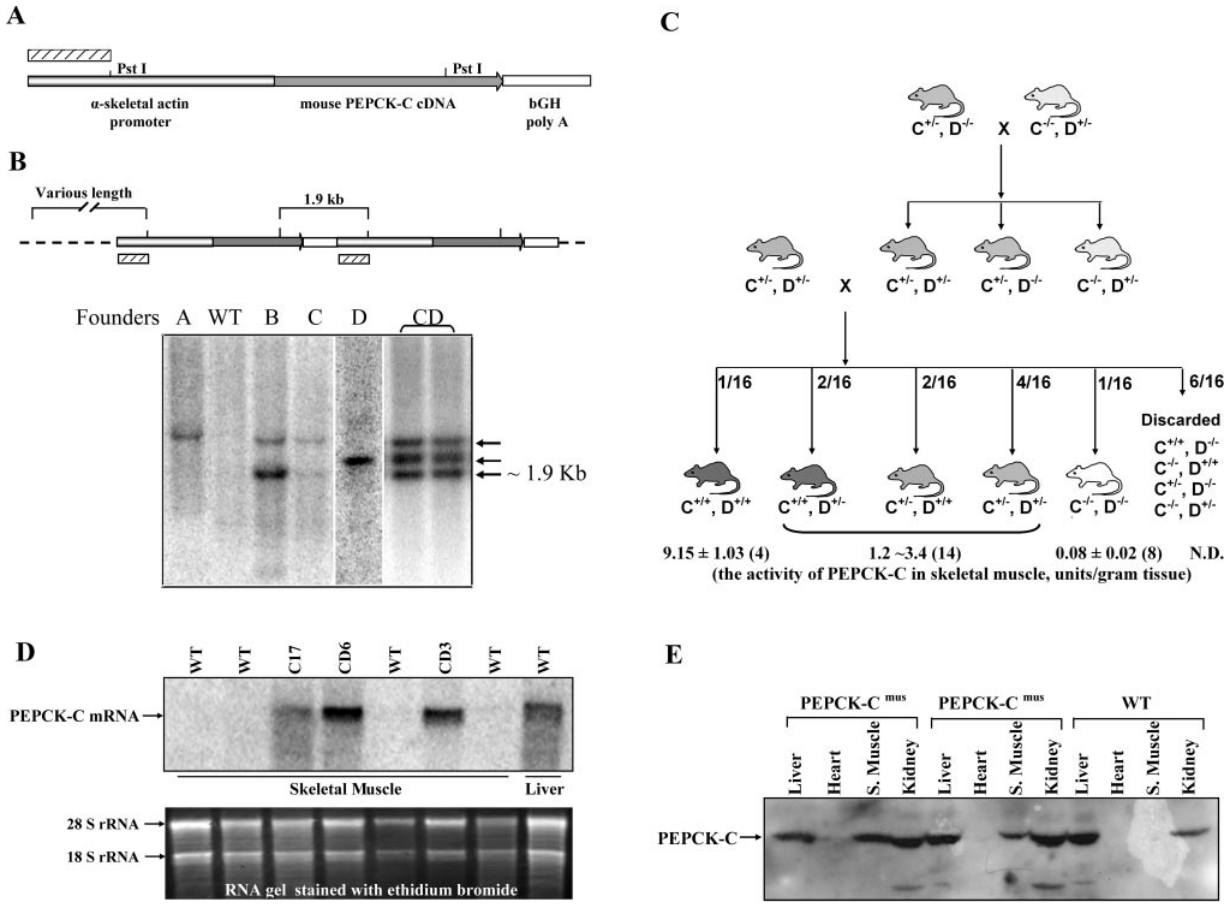
Differential expression of the Oxidative Pathway genes in hypometabolic state of mice vs. normal state



Metabolic role of PEPCK-C

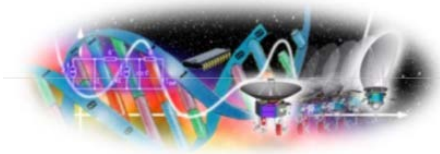
Genetic key to super-humans capabilities

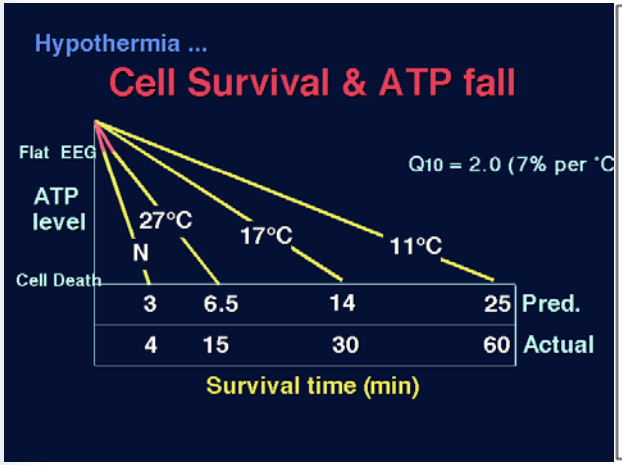
Dr. Richard Hanson (Case Western Reserve University)

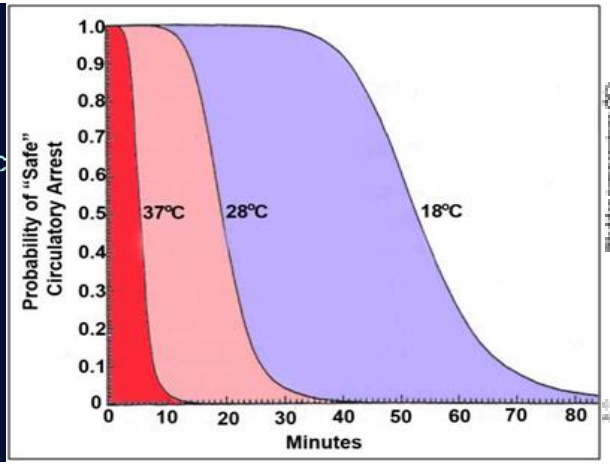


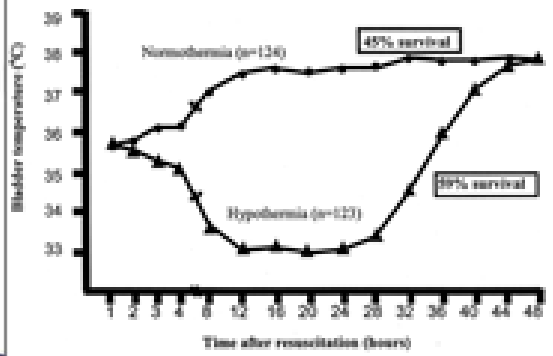
The genetic alteration to a gene involved in glucose metabolism appears to stimulate the efficient use of body fat for energy production

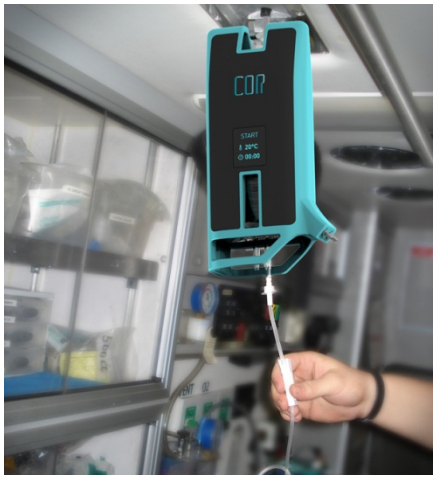
Therapeutic hypothermia











The *RhinoChill System*

New York City paramedics are initiating a policy of delivering many of their cardiac arrest patients only to hospitals equipped with therapeutic hypothermia capabilities.

Toward Human Hibernation

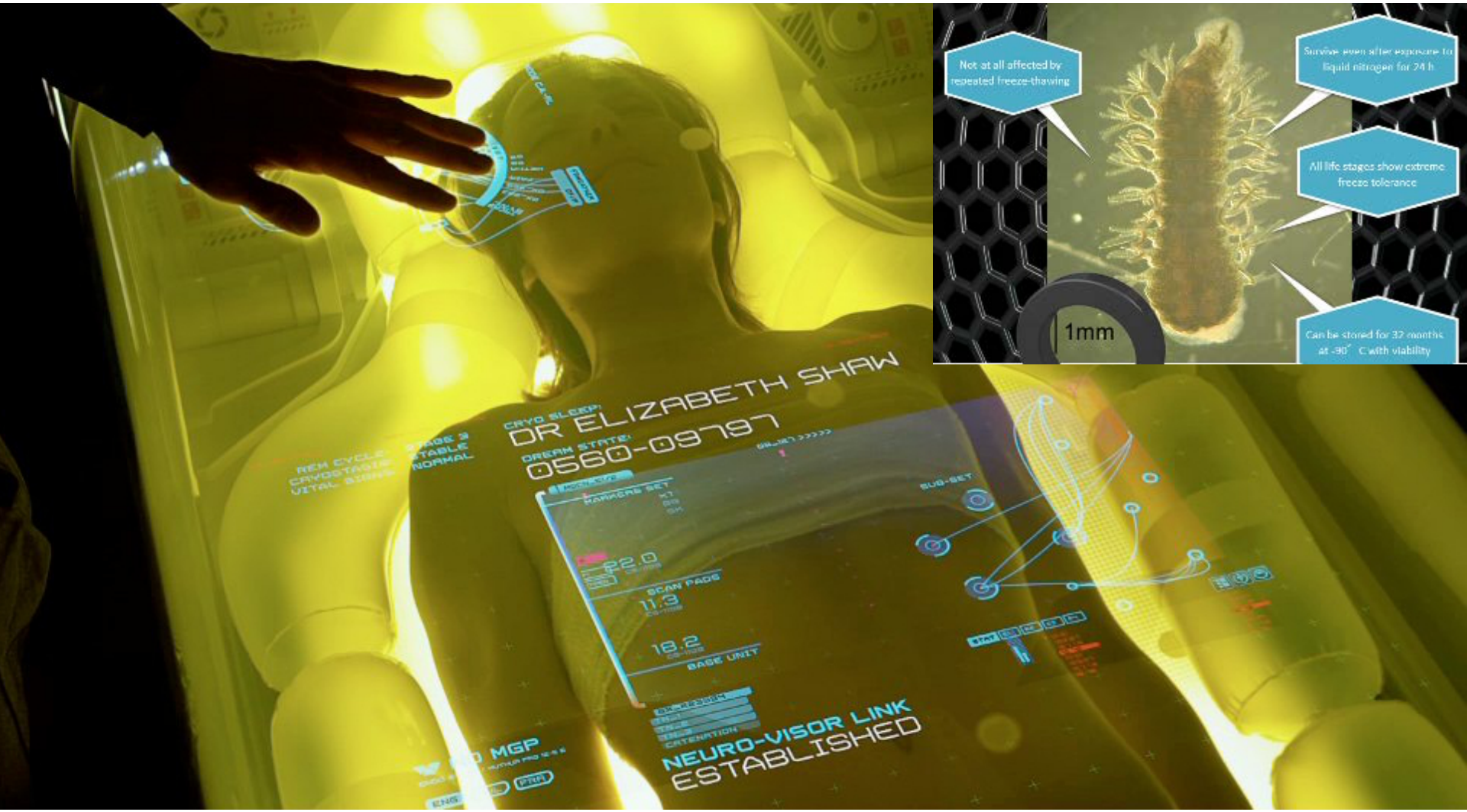
- **Proof of principle that living organisms can be reversibly frozen**

  (Dai Suzuki et al., PLOS One, January 2015)

- **Demonstration of the metabolic plasticity in human-size animals**

  (Dai Suzuki et al., PLOS One, January 2015)

Cryobiosis


DR ELIZABETH SHAW
0560-09797
NEURO-VISOR LINK
ESTABLISHED
Not at all affected by repeated freeze-thawing
All life stages show extreme freeze tolerance
1mm

Metabolic plasticity in human-size animals

Bamboo now makes up about 99 percent of giant panda food. How panda survive on a diet almost exclusively of a low-nutrient food like bamboo?

Giant Pandas Have Exceptionally Low Metabolic Rate (38%) !
similar to those of black bears during their seasonal hibernation

Potential applications:

TORPOR INDUCING TRANSFER HABITAT FOR HUMAN STASIS TO MARS

NIAC

Advanced Hypothermia Therapy

Body Thermal Management
- Reduction in core body temperature of only 10° F required to obtain 50-70% reduction in metabolic rate
- Cooling via non-invasive pads -or- ambient temperature reduction with warm-up cycle

Sedation
- Neuromuscular blockade to suppress shiver reflex and prevent movement

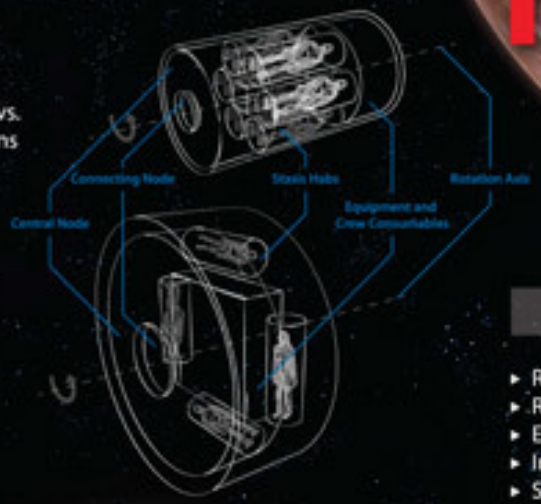
Nutrition and Hydration
- Total Parenteral Nutrition (TPN) aqueous solution containing all vitamins, amino acids, minerals needed for sustainment

Key Questions and Challenges

Architectural
- Quantify system mass savings compared to current Mars reference architectures
- Impact to Opposition-class missions vs. longer-stay Conjunction-class missions
- Protocols for "emergency wake"

Medical
- Potential onset of pneumonia
- Muscle atrophy and bone loss
- Long term sedation on organs

Habitat Concepts

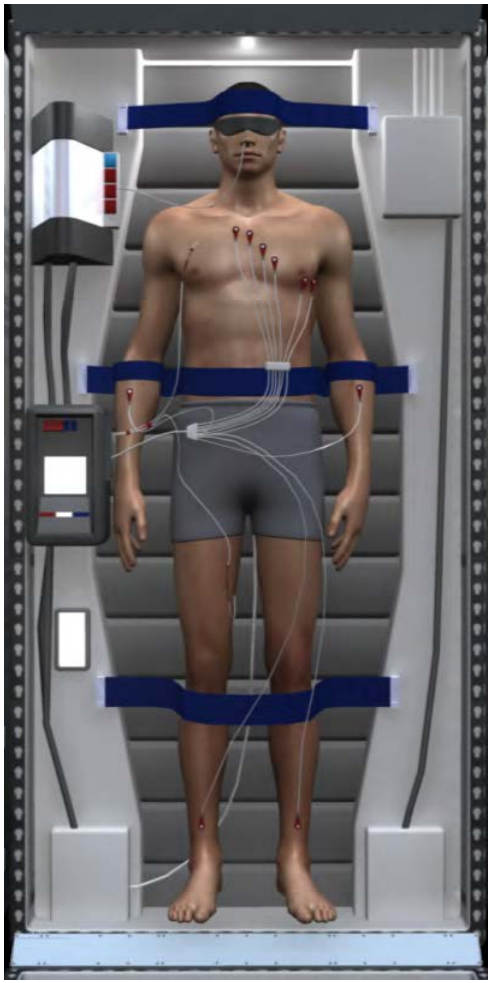


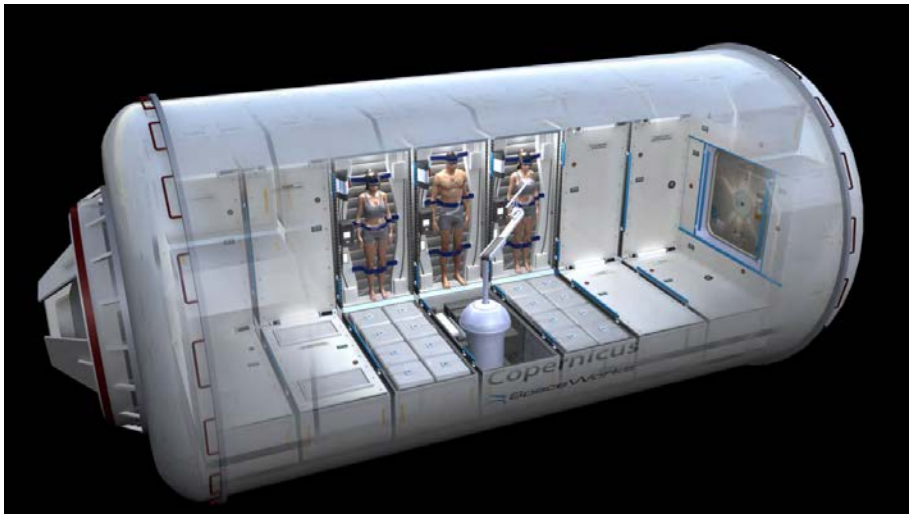
Mars Exploration Benefits

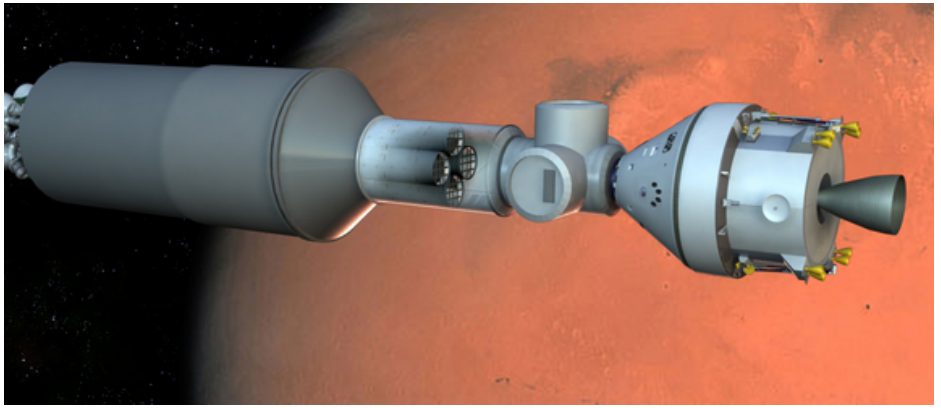
- Reduction in habitat mass and volume
- Reduced crew consumables
- Elimination of psych-social aspects
- Increased mission margin
- Simplified artificial gravity systems
- Viability possible due to other government funding efforts (NIH, DoD)
- Scalable solution for ultimately achieving Mars colonization

SLEEPING YOUR WAY TO MARS!

INCREDIBLE TECHNOLOGY







Artist's concept of a manned Mars spacecraft containing a stasis habitat for hibernating astronauts (in tubes at center). Credit: Copyright SpaceWorks Enterprises, Inc. (SEI)

Suspended animation toward organ preservation

Development of better organ preservation methods remains a major target and deserves scientific consideration

Identification of metabolic regulatory mechanisms during intentionally-induce reversible “suspended animation” state similar to the natural hibernation will allow the development of applied strategies that can be used to impose metabolic rate depression upon organs explants to improve their long-term preservation

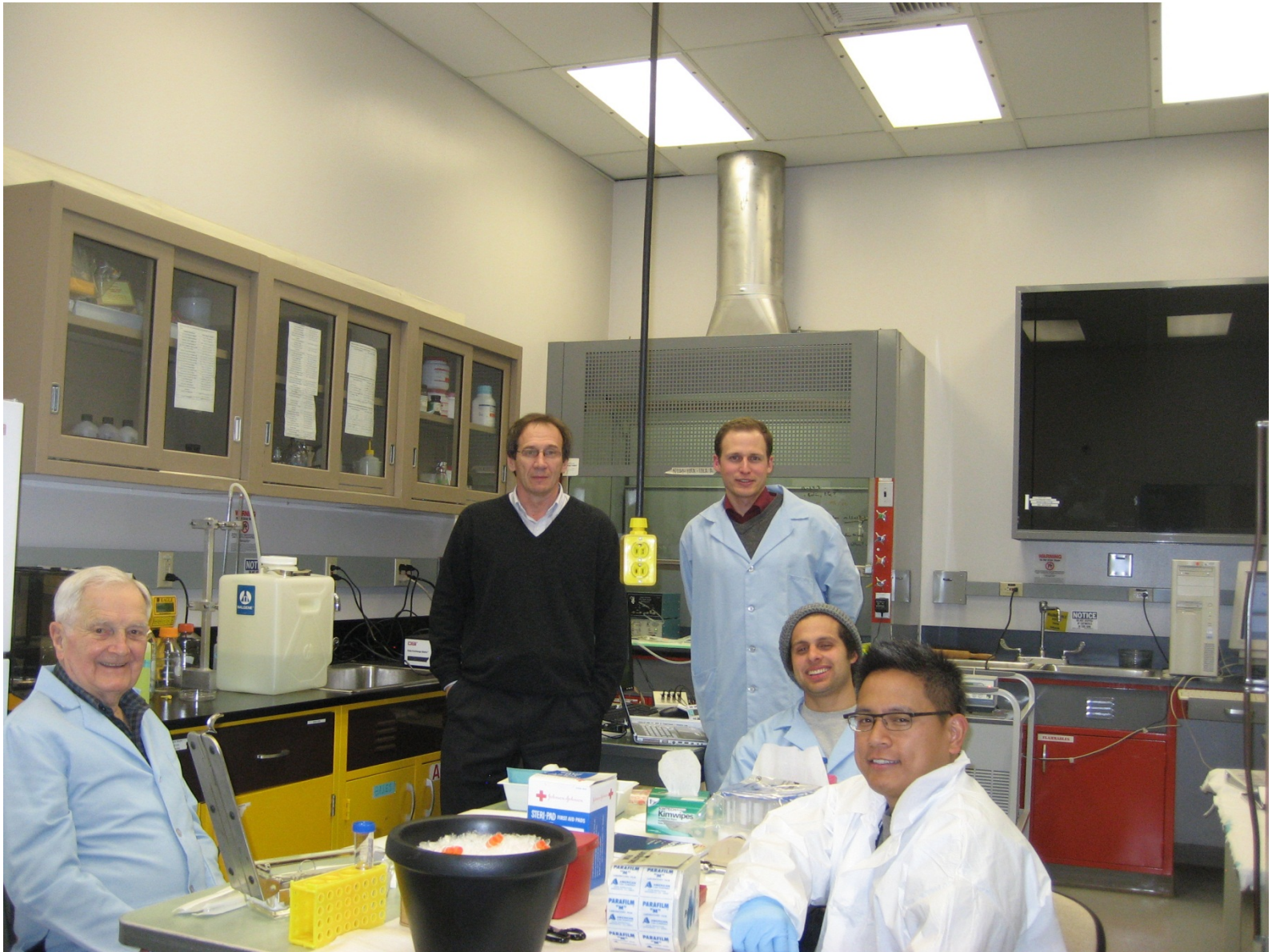
Current technologies allow systemic hypothermia to be maintained for periods as long as 5 hours with consistently satisfactory recovery after warming.

Challenges

Will human consciousness ever be transferable?

Lab photos

Lab photos



The Stasis Project

Carnegie Mellon Innovations Lab