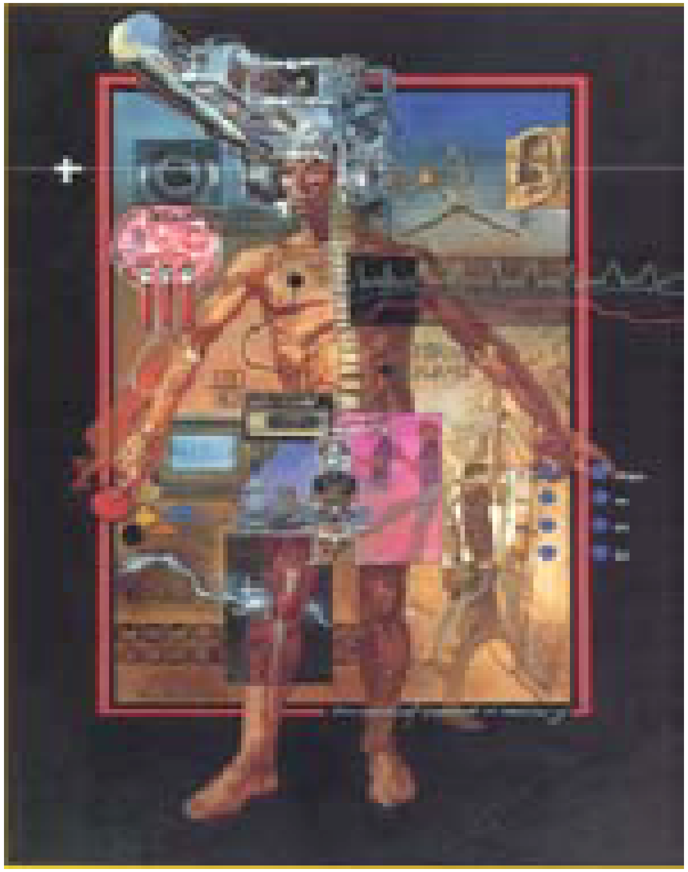
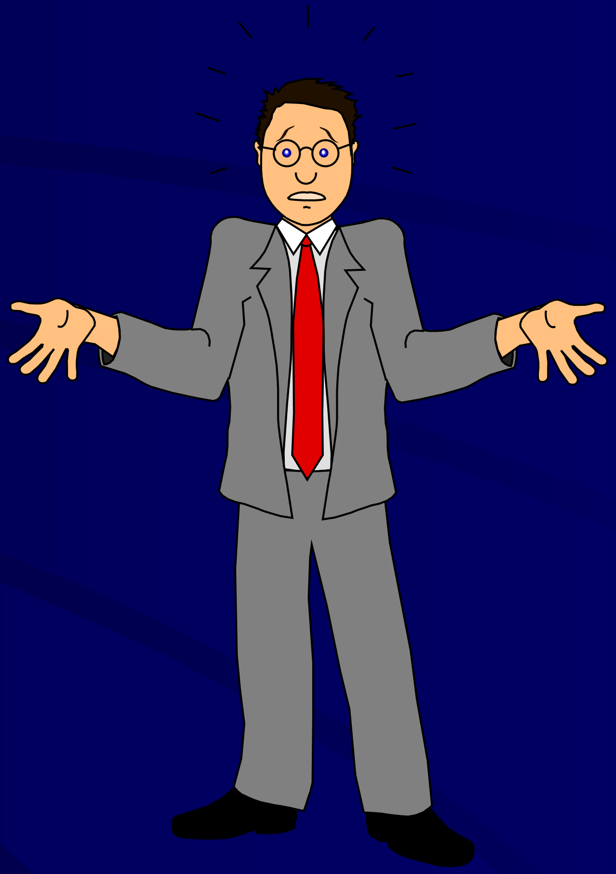
# Human Physiology in Space
## An Introduction

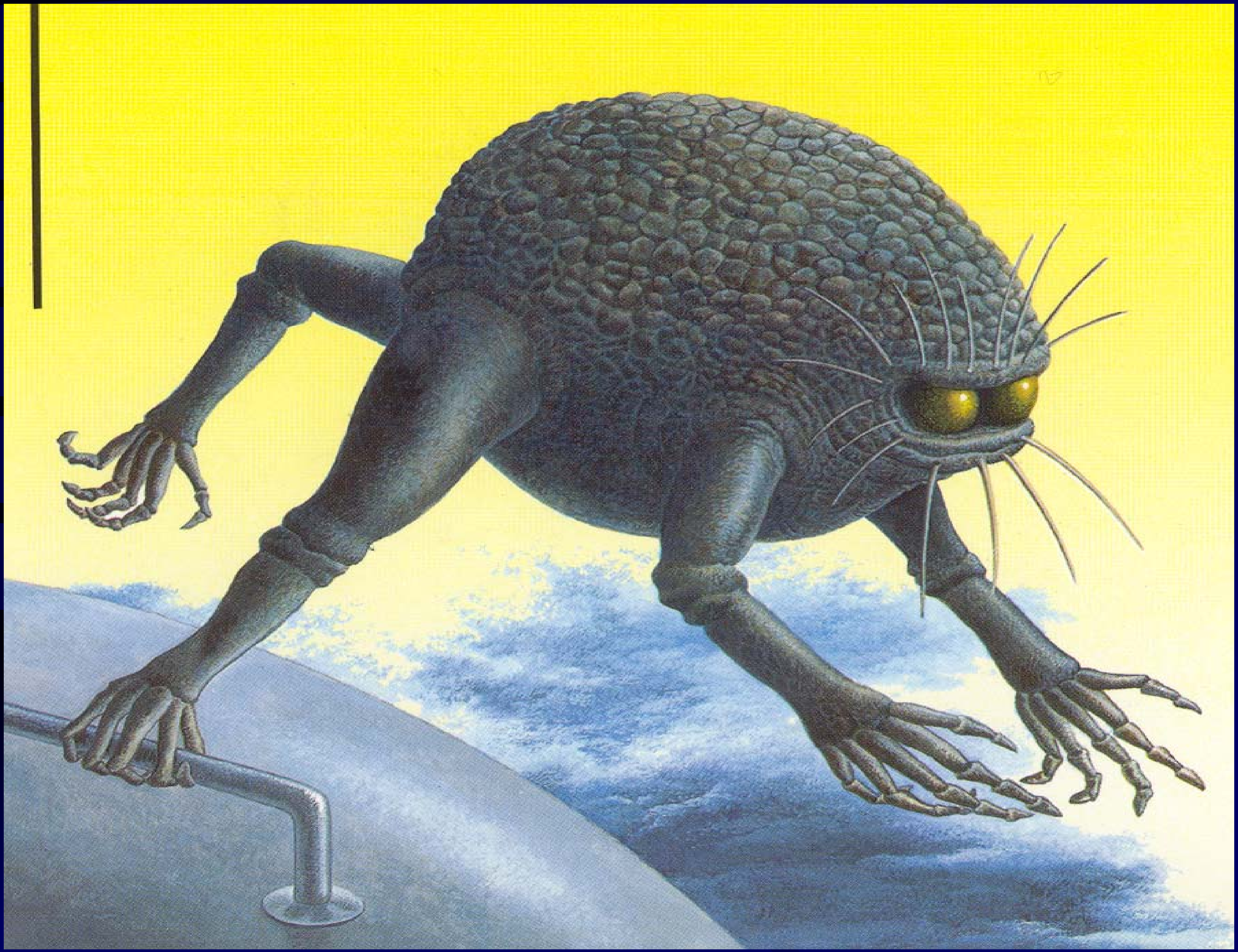
- First - (Gagarin 1961)
- Endurance - (Polyakov, 440 d)
- Farthest (Apollo)
- Oldest (Glenn, 77)



# Space Physiology

- Www.nsbri.org/human Physspace

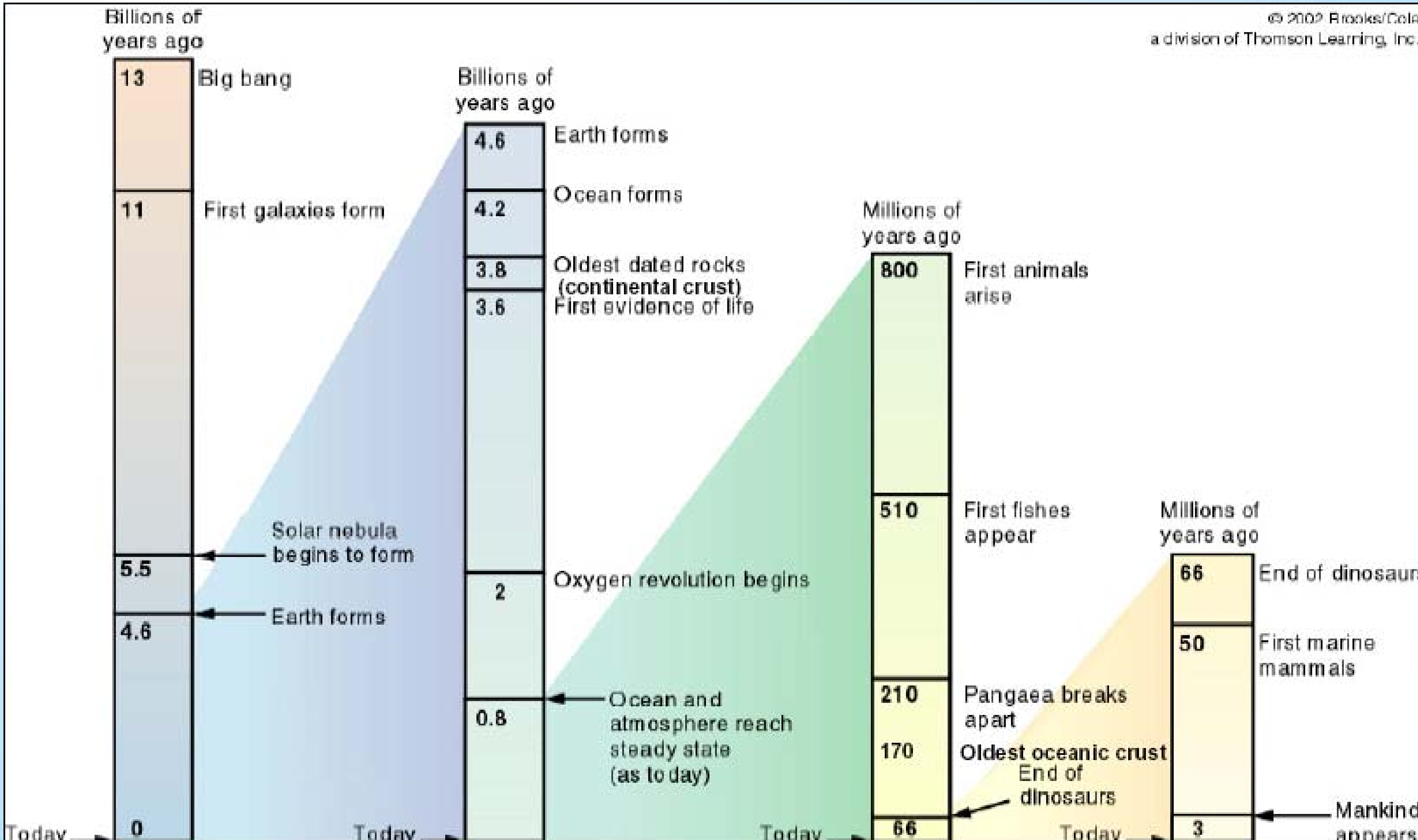


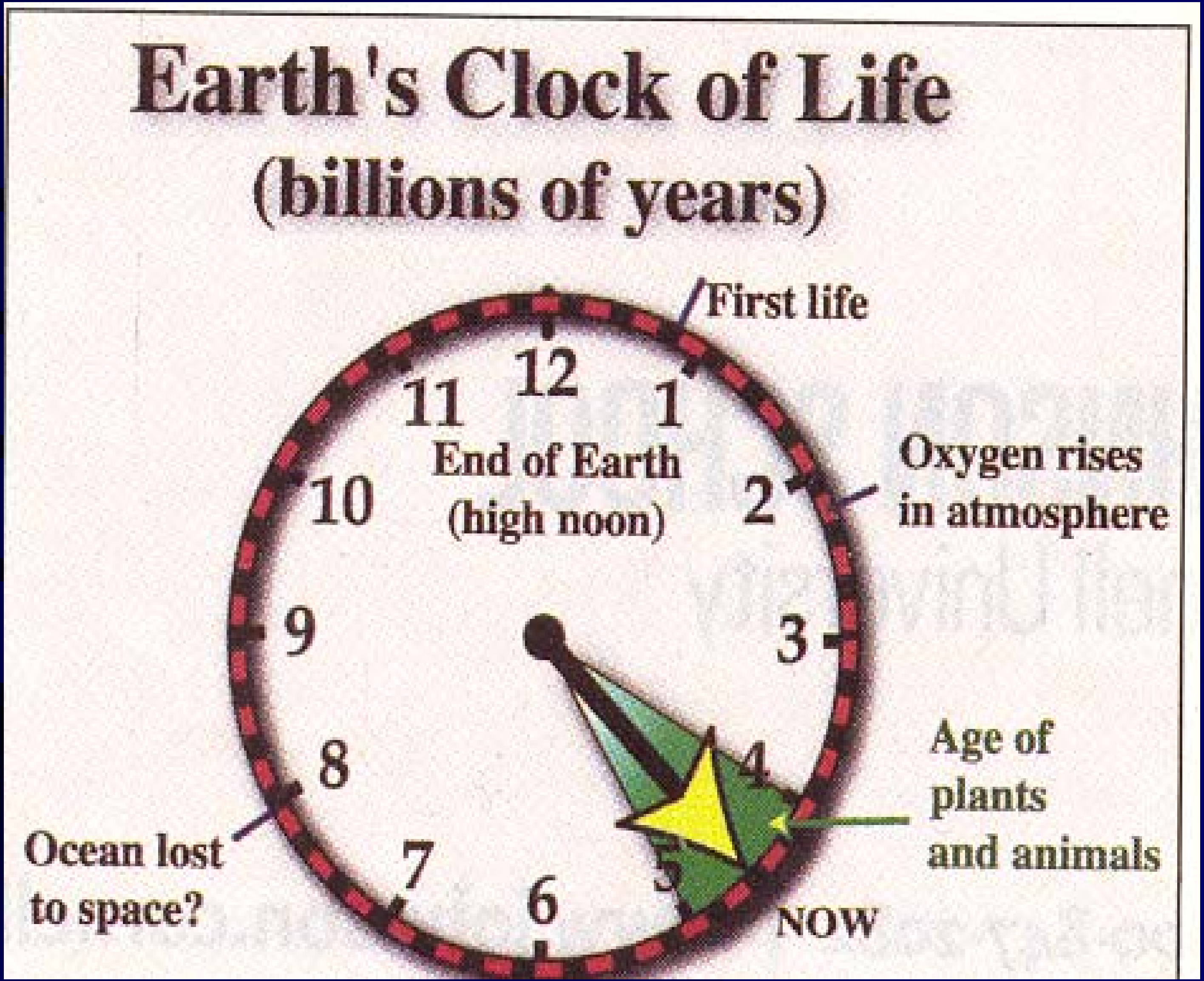


# Facts about the universe

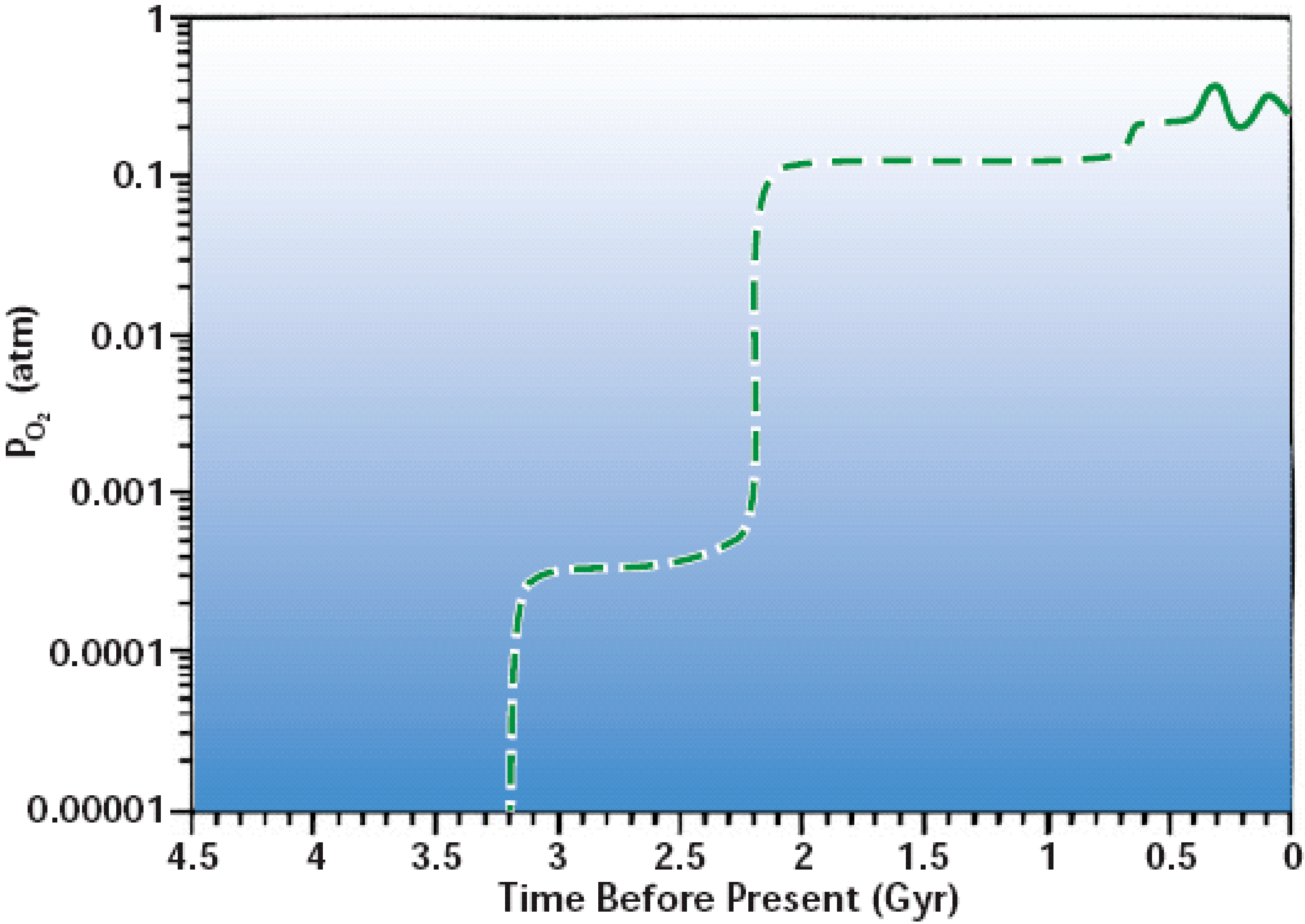
- Age
  - 13.7 Billion years
- Consists of
  - Measurable
    - 4% (atoms to energy)
  - ***Not measurable***
    - 23% dark matter
      - WIMP
    - 73% dark energy

# Earth's History



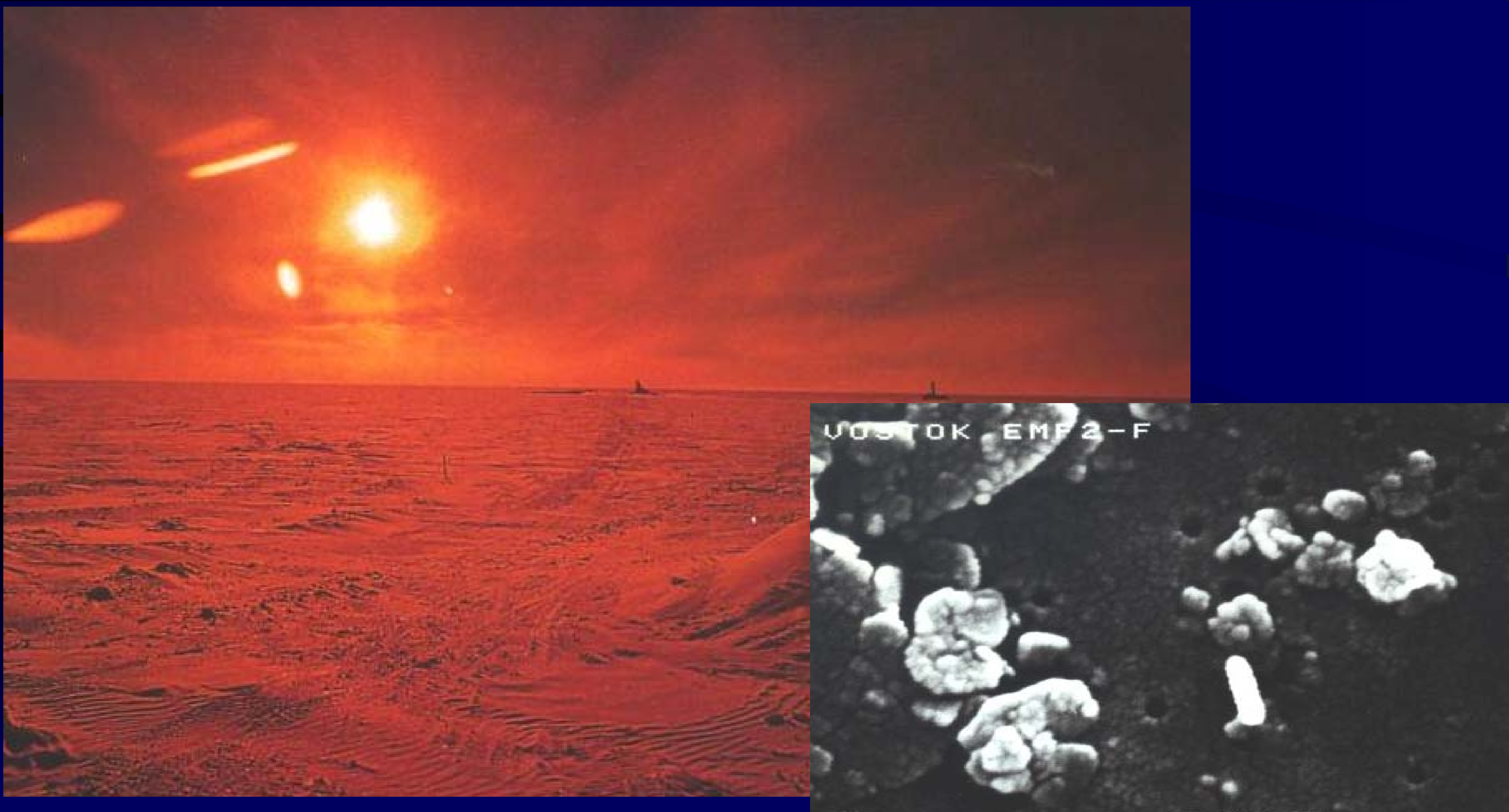


Earth's Clock of Life
(billions of years)
First life
12
11
1
End of Earth
(high noon)
10
2
Oxygen rises
in atmosphere
9
3
8
4
Age of
plants
and animals
Ocean lost
to space?
7
6
5
NOW



1
0.1
0.01
0.001
0.0001
0.00001
$P_{O_2}$ (atm)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Time Before Present (Gyr)

# Microbes from 4000 m in ice.




350°C
3.500 msw

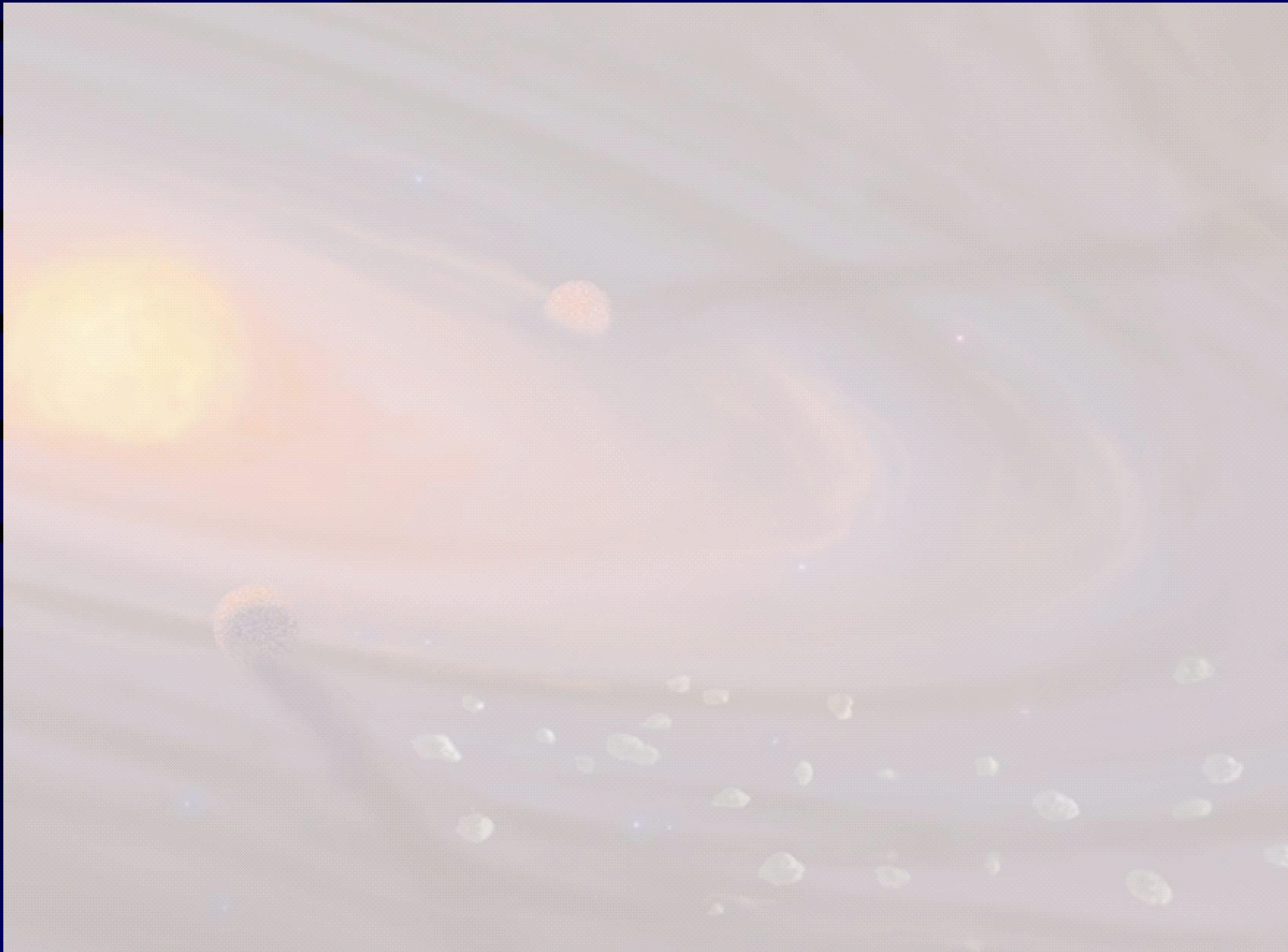
# What are extremophiles?

- EXTREMOPHILES are organisms that require extreme environments for growth.
- Extremophiles are organisms that are "fond of" or "love" (-phile) environments including high temperature, pH, pressure and salt concentration, or low temperature, pH, nutrient concentration, or water availability.
- Extremophiles are also organisms that can tolerate extreme conditions including high levels of radiation or toxic compounds, or those living in conditions that we consider unusual.
- Most extremophiles are microorganisms that thrive under conditions that from a human perspective are clearly extreme

- **Alkaliphile**: An organism with optimal growth at pH values above 10.
- **Barophile**: An organism that lives optimally at high hydrostatic pressure.
- **Endolith**: An organism that lives in rocks.
- **Extreme Acidophile**: An organism with a pH optimum for growth at, or below, pH 3.
- **Extremophile**: An organism that is isolated from an extreme environment and often requires the extreme condition for growth. Extreme is anthropocentrically derived.
- **Halophile**: An organism requiring at least 0.2M salt for growth.
- **Hyperthermophile**: An organism having a growth temperature optimum of 80 C or higher.
- **Psychrophile**: An organism having a growth temperature optimum of 15 C or lower, and a maximum temperature of 20 C.
- **Toxitolerant**: An organism able to withstand high levels of damaging agents. For example, living in water saturated with benzene, or in the water-core of a nuclear reactor.
- **Xerotolerant**: An organism capable of growth at low water activity. For example, extreme halophile or endolith.

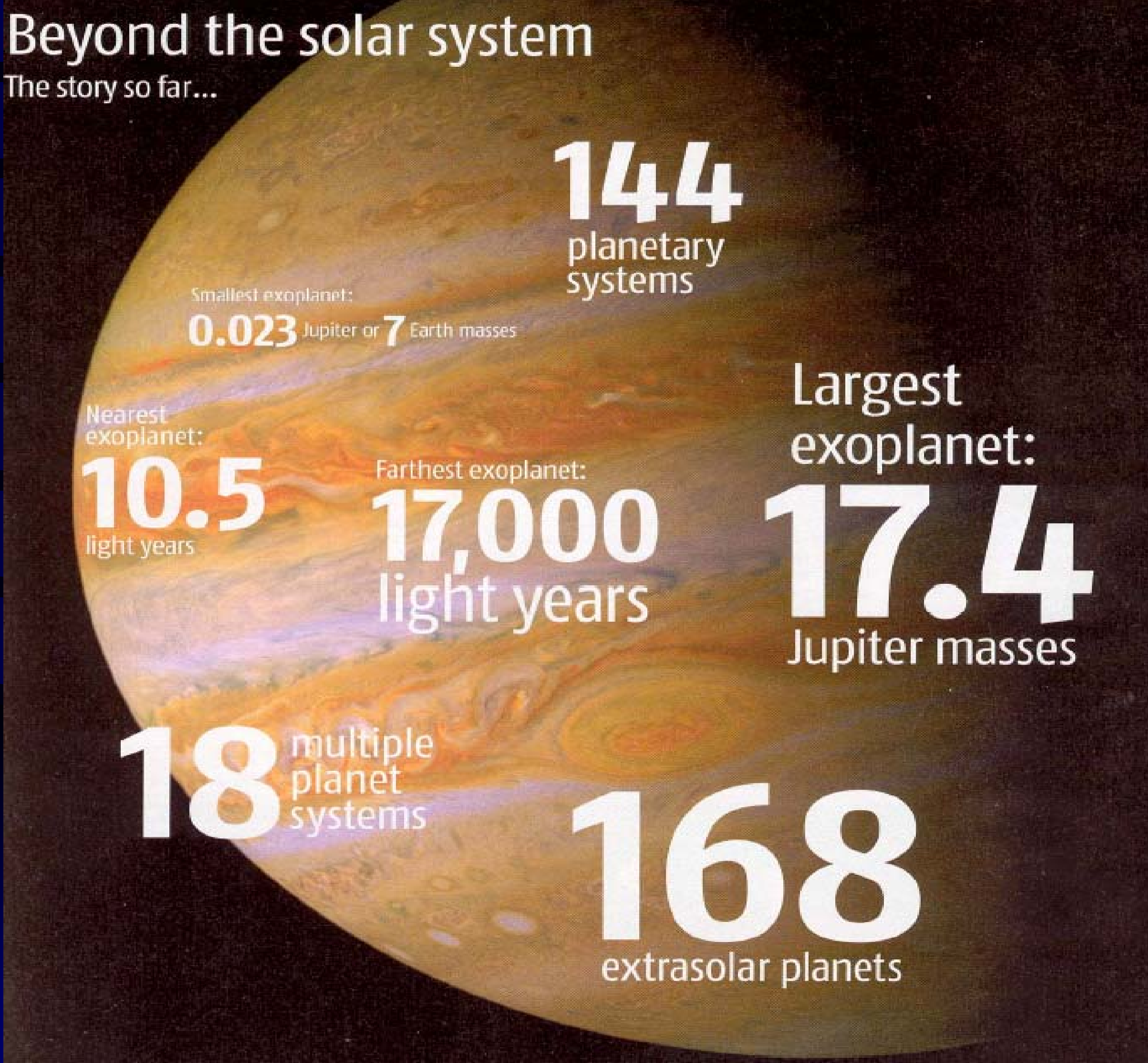
# How is this possible ?

- How can macromolecular structure such as proteins be stable at temperatures higher than 100℃ (<160 °C)?
- How is it possible to display appropriate metabolic fluxes at temperatures as low as –2℃ ?

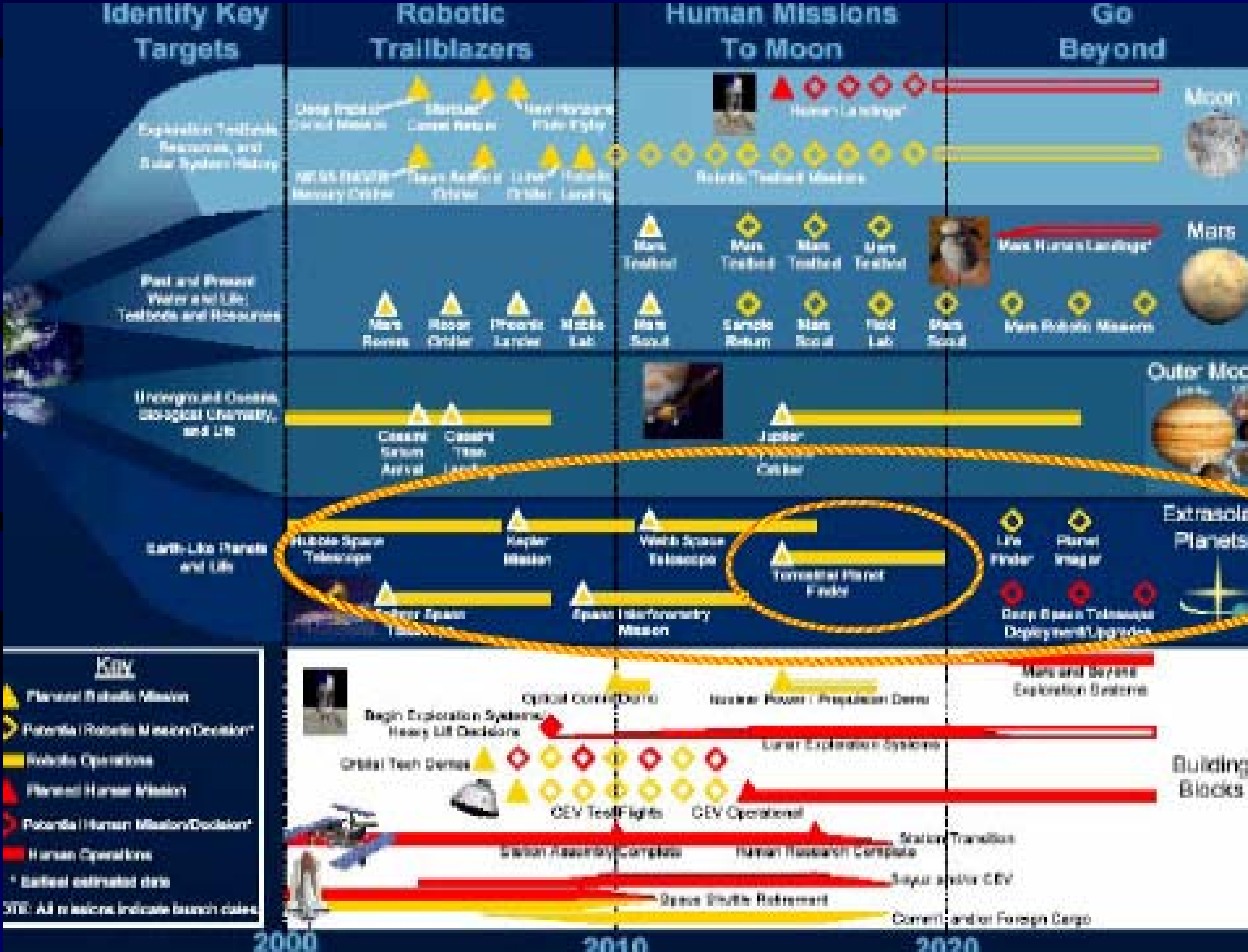


| Planet | Gravity Constant [m/s²] | Gravity Relative to Earth's Gravity |
|---|---|---|
| Mercury | 3.53 | 0.36 |
| Venus | 8.83 | 0.9 |
| Earth | 9.81 | 1 |
| Mars | 3.73 | 0.38 |
| Jupiter | 26 | 2.65 |
| Saturn | 11.18 | 1.14 |
| Uranus | 10.5 | 1.07 |
| Neptune | 13.24 | 1.35 |
| Pluto | 2.16 | 0.22 |
| Earth's Moon | 1.67 | 0.17 |
| Mars' Moon (Phobos) | 0.02 | 0.002 |
| Large Asteroids | 0.02 | 0.002 |

***Table III.6:*** **Gravity on Other Planets of the Solar System [17]**



Beyond the solar system
The story so far...
144
planetary systems
Smallest exoplanet:
0.023 Jupiter or 7 Earth masses
Largest exoplanet:
17.4
Jupiter masses
Nearest exoplanet:
10.5
light years
Farthest exoplanet:
17,000
light years
18
multiple planet systems
168
extrasolar planets



Identify Key Targets
Robotic Trailblazers
Human Missions To Moon
Go Beyond
Moon
Human Landings*
Robotic Testbed Missions
Mars
Mars Testbed
Mars Human Landings*
Mars Robotic Missions
Outer Moons
Jupiter
Orbiter
Extrasolar Planets
Hubble Space Telescope
Kepler Mission
Webb Space Telescope
Terrestrial Planet Finder
Life Finder
Planet Imager
Space Interferometry Mission
Deep Space Telescope Deployment/Upgrades
Earth-Like Planets and Life
Key
Planned Robotic Mission
Potential Robotic Mission/Decision*
Robotic Operations
Planned Human Mission
Potential Human Mission/Decision*
Human Operations
* Earliest estimated date
Optical Comm Demo
Nuclear Power / Propulsion Demo
Mars and Beyond Exploration Systems
Begin Exploration Systems/Heavy Lift Decisions
Lunar Exploration Systems
Orbital Tech Demos
CEV Test Flights
CEV Operational
Building Blocks
Station Transition
Station Assembly Complete
Human Research Complete
Soyuz and/or CEV
Space Shuttle Retirement
Commercial and/or Foreign Cargo
2000
2010
2020

# Human Capabilities/Limitations

- Capabilities
  - Creativity
  - Adaptability
  - Multi-sensory perception
  - Manual dexterity
  - Physical flexibility
  - Physical strength
  - Physical-mental feedback loop
  - Reason/logic
  - Cognitive processing
  - Data interpretation
- Limitations
  - Strange environment
  - Limited resources
  - Distance from support network
  - Reduced-gravity impacts force application
  - Cannot work outside without bulky, cumbersome spacesuit

# The space environment

**- Radiation**
All kinds of particle and wave radiation with a wide spectrum, different from those on Earth, exist in outer space and on the other planets of the solar system.

**- Gravity**
In free space basically no gravitational loads act upon free-flying space vehicles. The gravitational acceleration on other planets varies by a great margin.

**- Atmosphere**
In free space there is a vacuum, i.e. practically no atmosphere. The structure and behavior of the atmosphere of other planets are physically and chemically different from Earth's atmosphere.

**- Magnetic Fields**
The magnetosphere of every planet in the solar system is different in orientation and strength. Also there exists an interplanetary magnetic
field (IMF).

# Earth

Africa

Antartica

Apollo 17 (1972)

# Earth Rising on the Moon

Apollo 11

Lunar Phases

# Mars

Fourth planet from the Sun at 1.5 AU

7 times smaller than the Earth

Temperatures range from –140 °C to 20 °C

Polar caps of frozen carbon dioxide and water

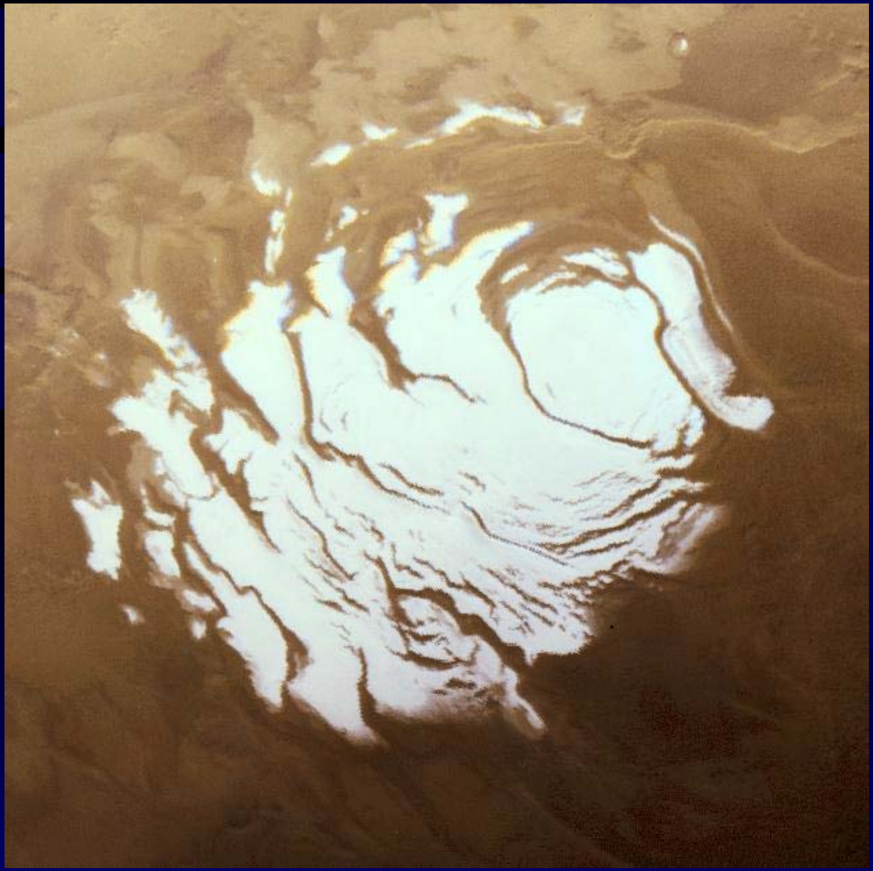
Thin atmosphere that is 95 percent carbon dioxide

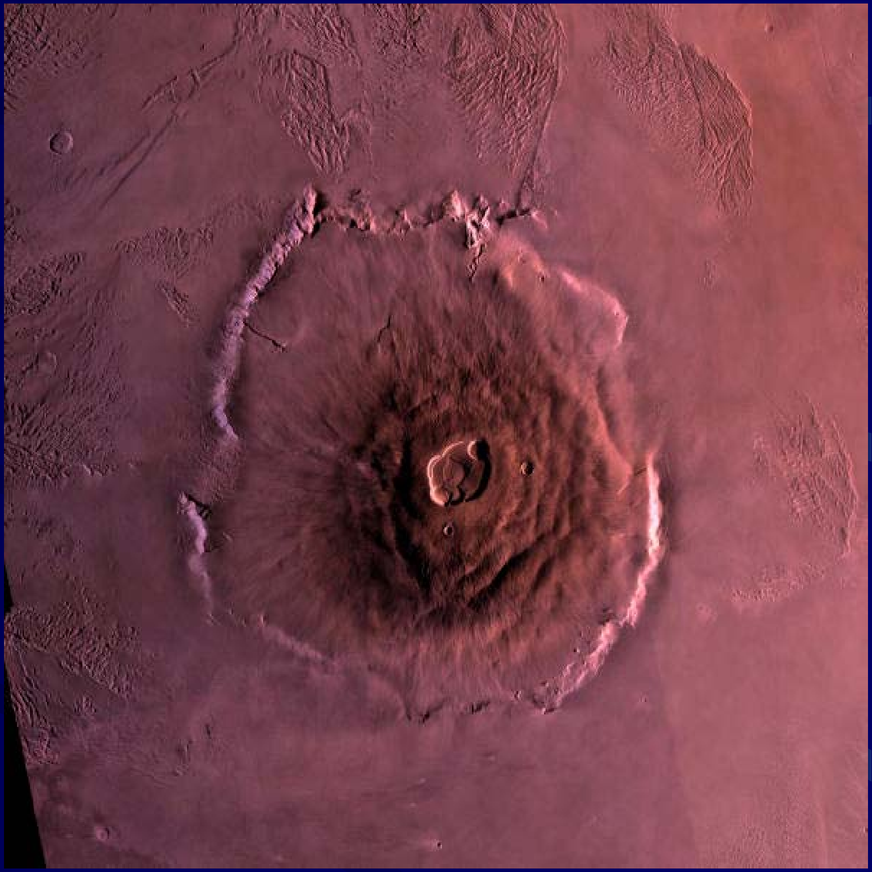
Hubble Space Telescope

# Martian Surface

South polar cap

400 km in diameter





Olympus Mons

24 km in height

Viking Orbiter


Mission Scenario*
Outbound - 150 d
Stay - 619 d
Return - 110 d
Total - 879 d
*2009 Reference Mission / ARC

# Planetary Science on the Web

NASA – Space Science

http://spacescience.nasa.gov/

NASA's Planetary Photojournal

http://photojournal.jpl.nasa.gov/

National Space Science Photo Gallery

http://nssdc.gsfc.nasa.gov/photo_gallery/

Views of the Solar System

http://www.solarviews.com/

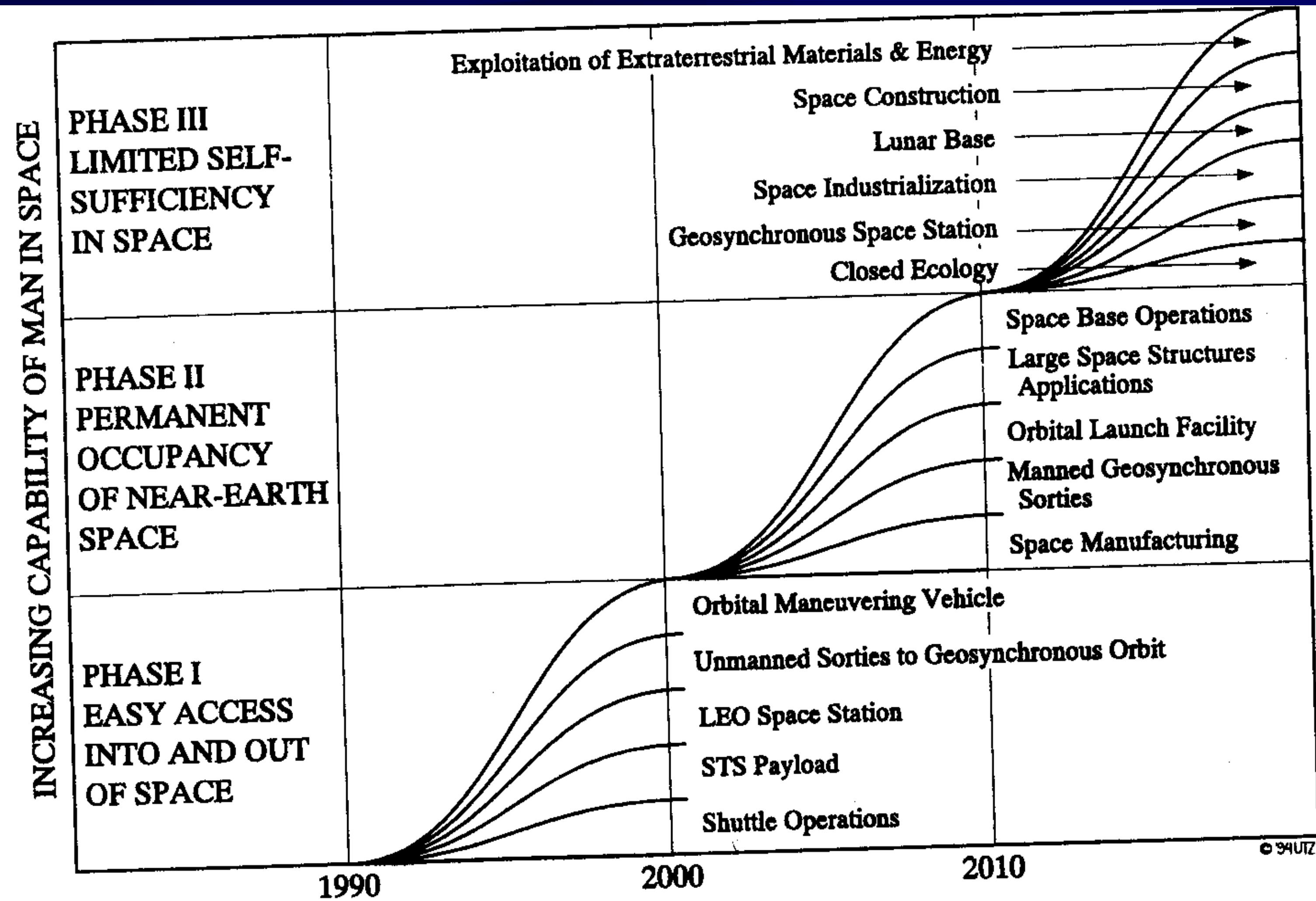
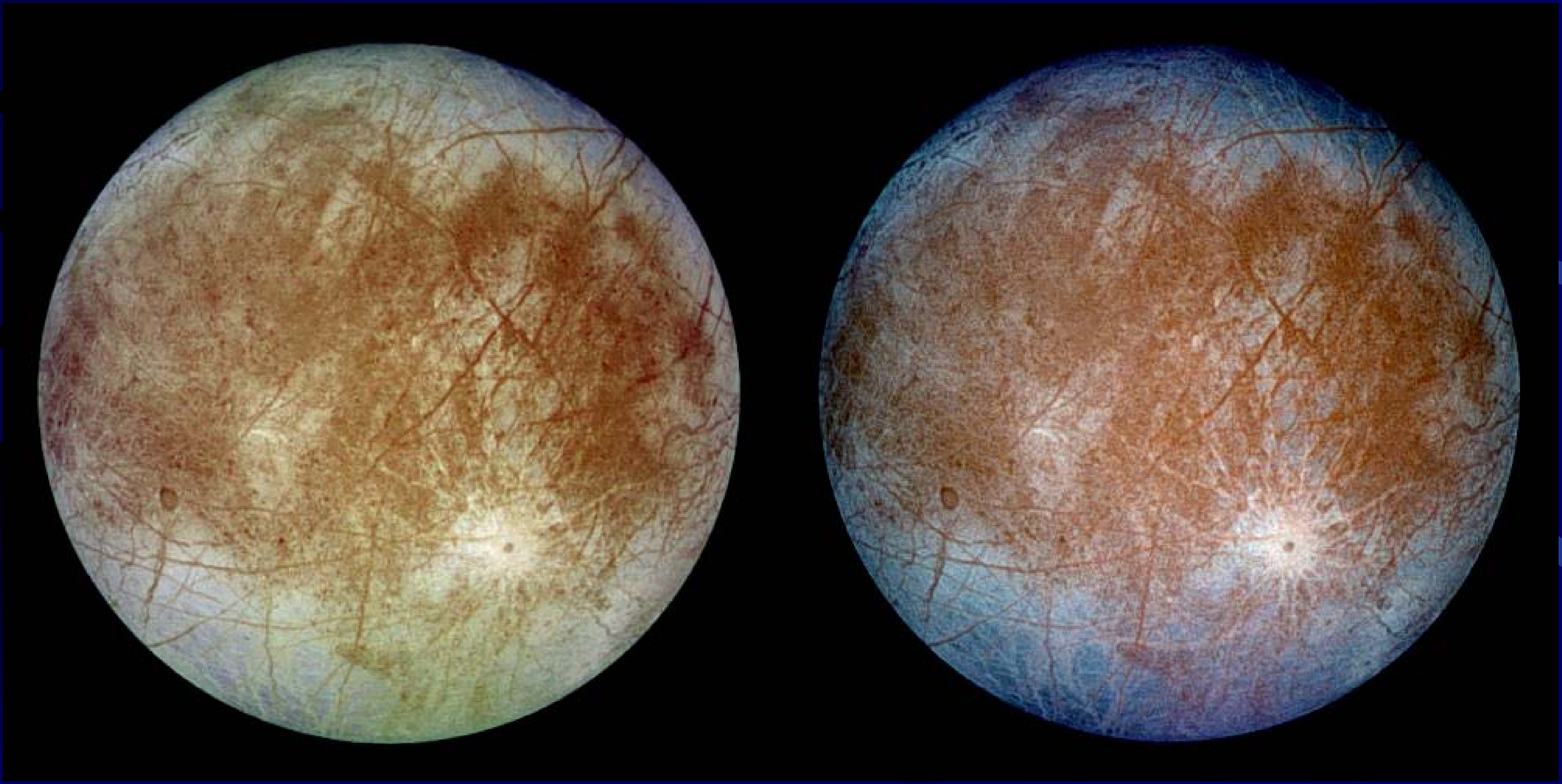
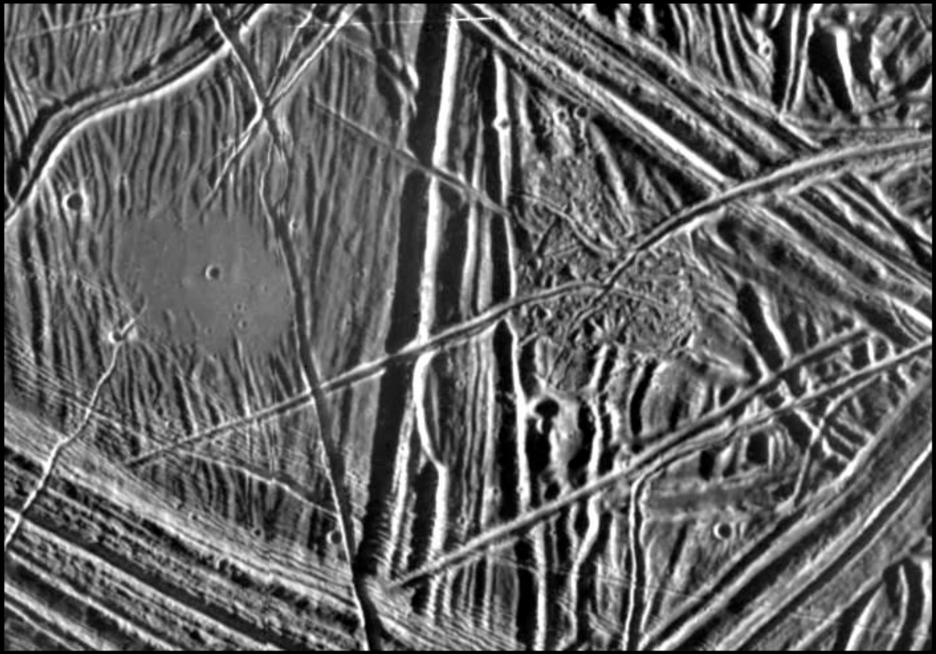



*Figure I.3:* **Progress in Spaceflight [6]**

| Classes of Potential Benefits | Comments |
|---|---|
| Intellectual | Derived from science - new knowledge and new technologies |
| Utilitarian / Materialistic | Industrial products, terrestrial applications, commercialization |
| Humanistic | Communications and informations from space, e.g., social and health services, international cooperation, cultural and spiritual effects |

# Europa





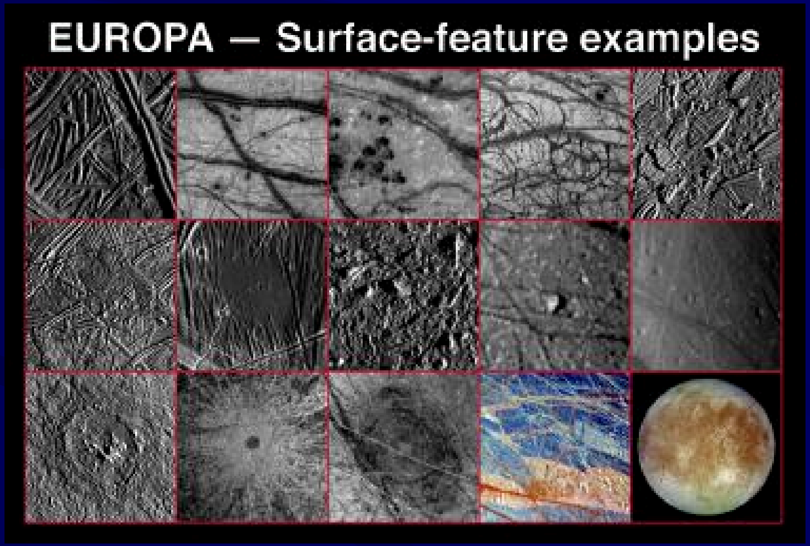
# Europa Features

# Why go to Europa?

Evidence of Liquid Water

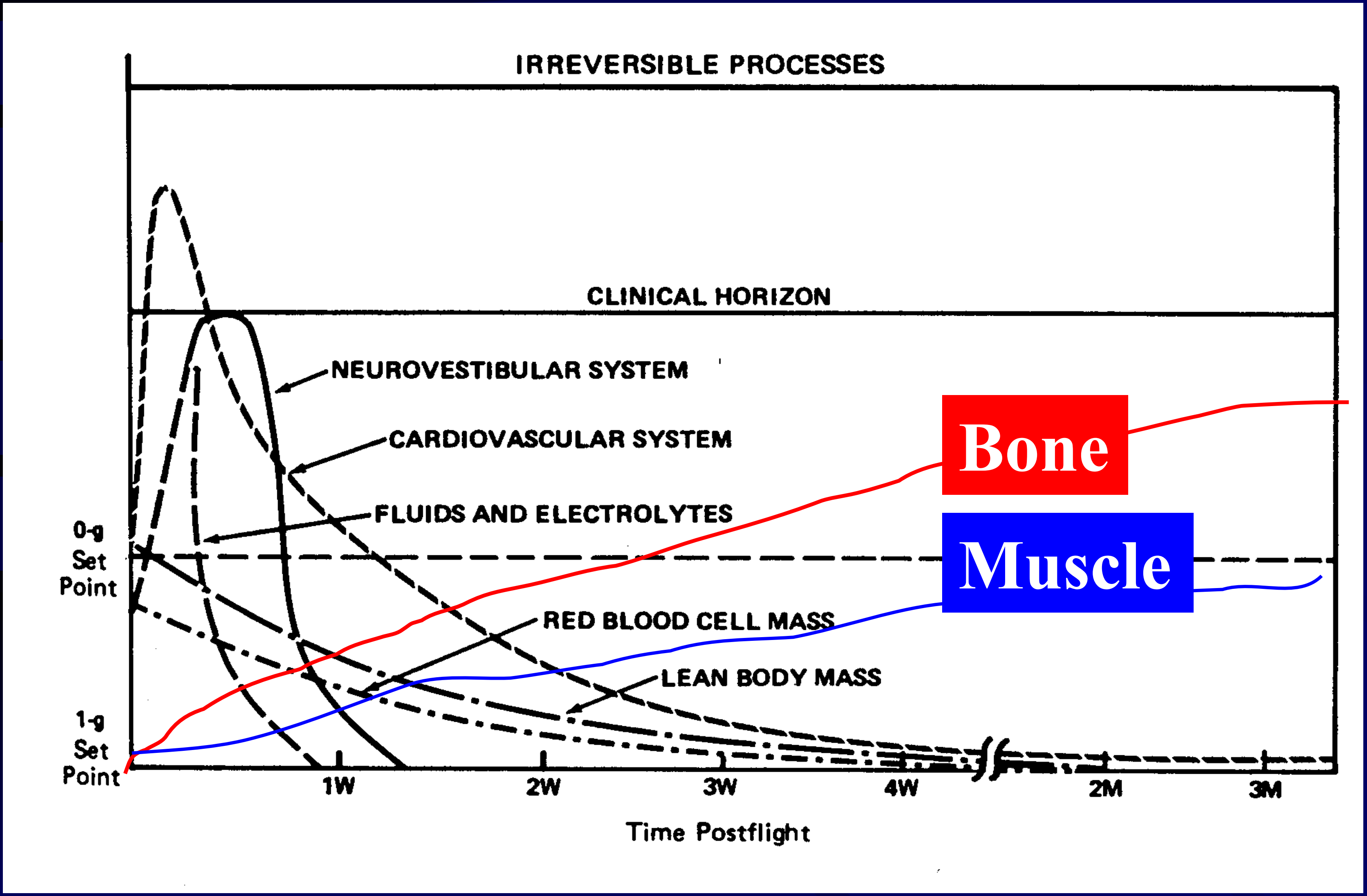
- Water leads to life?

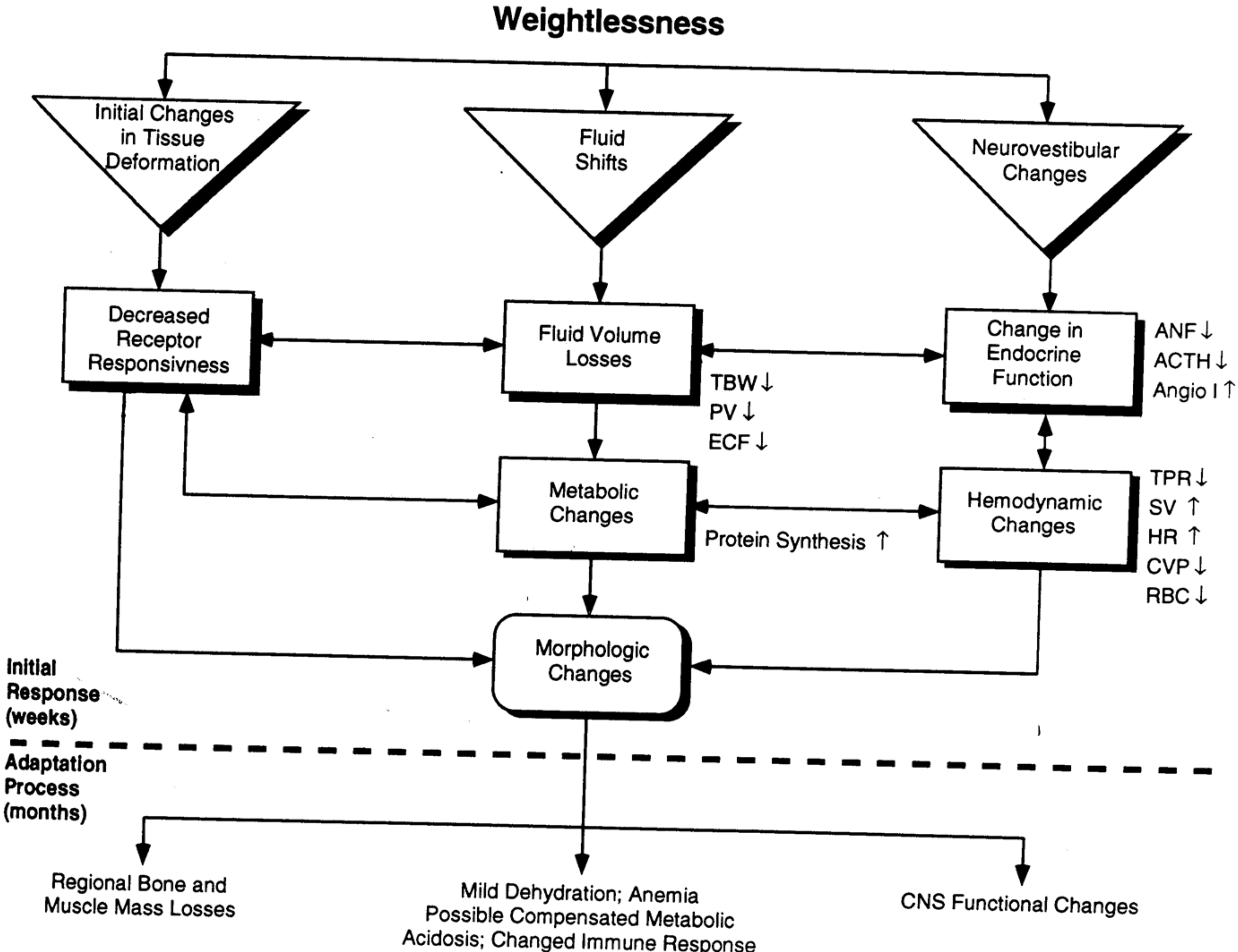
Extremophiles



# Things (and people) float!

# Adaptation to space

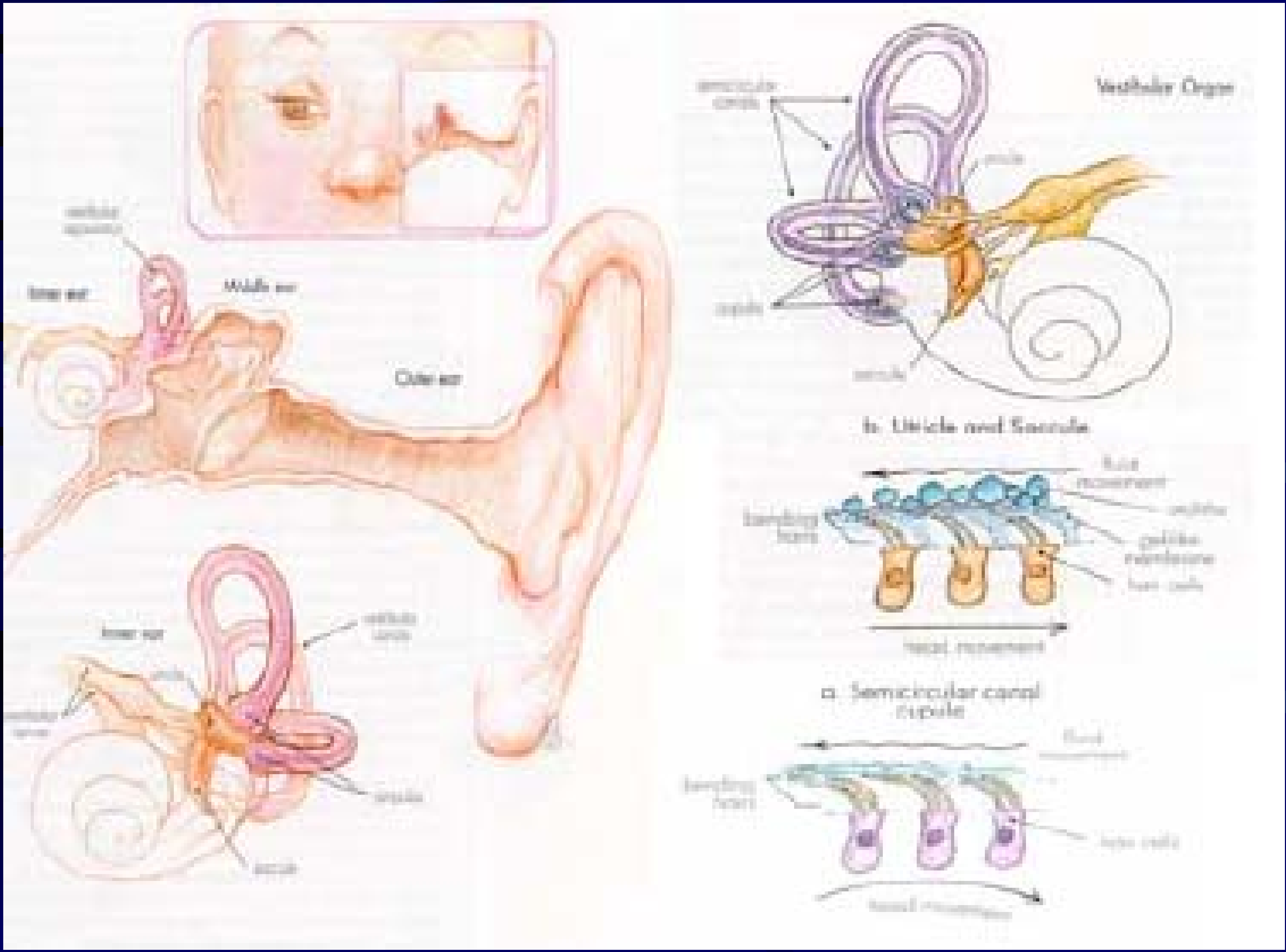



Weightlessness
Initial Changes in Tissue Deformation
Fluid Shifts
Neurovestibular Changes
Decreased Receptor Responsivness
Fluid Volume Losses
Change in Endocrine Function
ANF ↓
ACTH ↓
Angio I ↑
TBW ↓
PV ↓
ECF ↓
Metabolic Changes
Protein Synthesis ↑
Hemodynamic Changes
TPR ↓
SV ↑
HR ↑
CVP ↓
RBC ↓
Morphologic Changes
Initial Response (weeks)
Adaptation Process (months)
Regional Bone and Muscle Mass Losses
Mild Dehydration; Anemia
Possible Compensated Metabolic Acidosis; Changed Immune Response
CNS Functional Changes

# Balance / Neurovestibular

Components

- Vestibular - Inner ear
- Visual - Eyes
- Proprioceptive - Joints, muscles, tendons
- Neuro - Brain and nervous system



Vestibular Organ
Inner ear
Middle ear
Outer ear
b. Utricle and Saccule
a. Semicircular canal
cupula

# Sensory and Balance System

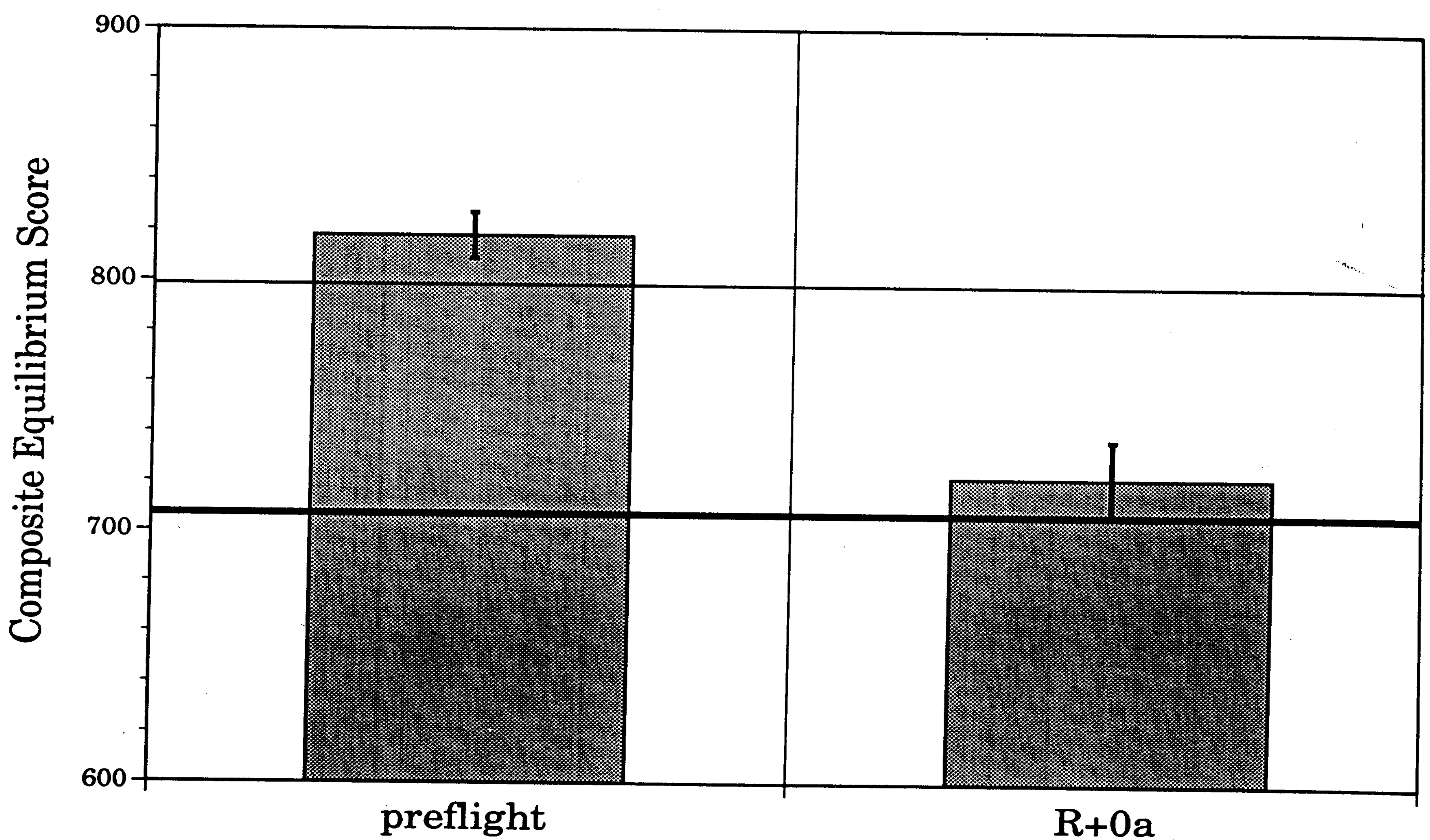
- Signal conflict
- Space Motion Sickness
  - 66%
  - Adapt quickly
- Postural changes
  - Inflight
  - Postflight

## INCIDENCE AND SEVERITY OF SPACE MOTION SICKNESS DURING 36 SPACE SHUTTLE FLIGHTS

| | Number of Crewmembers | | |
|---|---|---|---|
| Motion-Sickness Rating | First Shuttle Flight | Later Shuttle Flight | Totals |
| None | 32 (29%) | 28 (45%) | 60 (35%) |
| Mild | 36 (33%) | 24 (39%) | 60 (35%) |
| Moderate | 29 (27%) | 10 (16%) | 39 (23%) |
| Severe | 12 (11%) | 0 (0%) | 12 (7%) |
| Totals | 109 (64%) | 62 (36%) | 171 (100%) |

(Adapted from Davis et al [1988] and Beck [personal communication, 1991].)

# Postural stability



# Countermeasures for SMS

- Motion sickness drugs
- Accupuncture
- Biofeedback training
- Adaptation (patience)

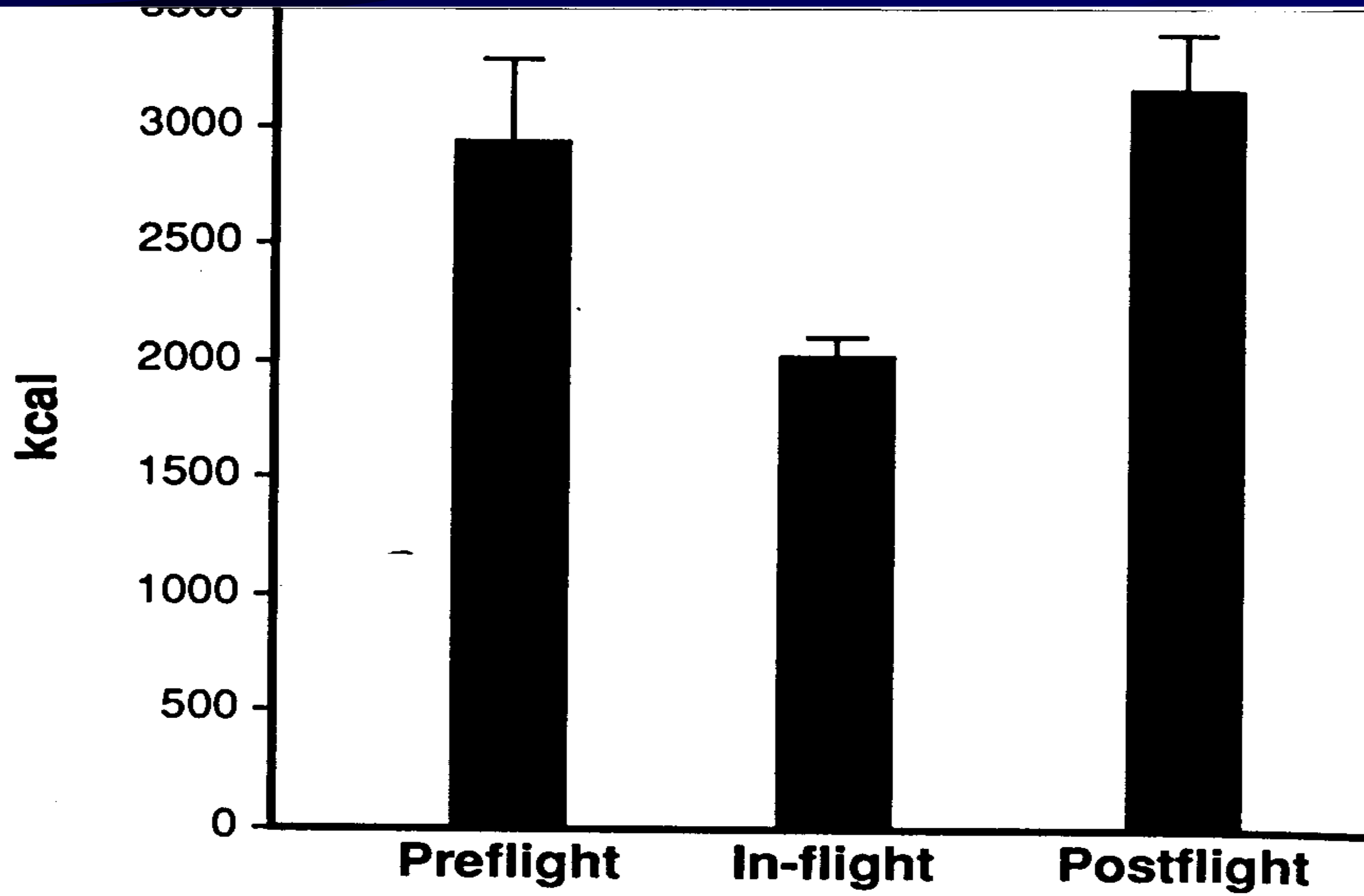
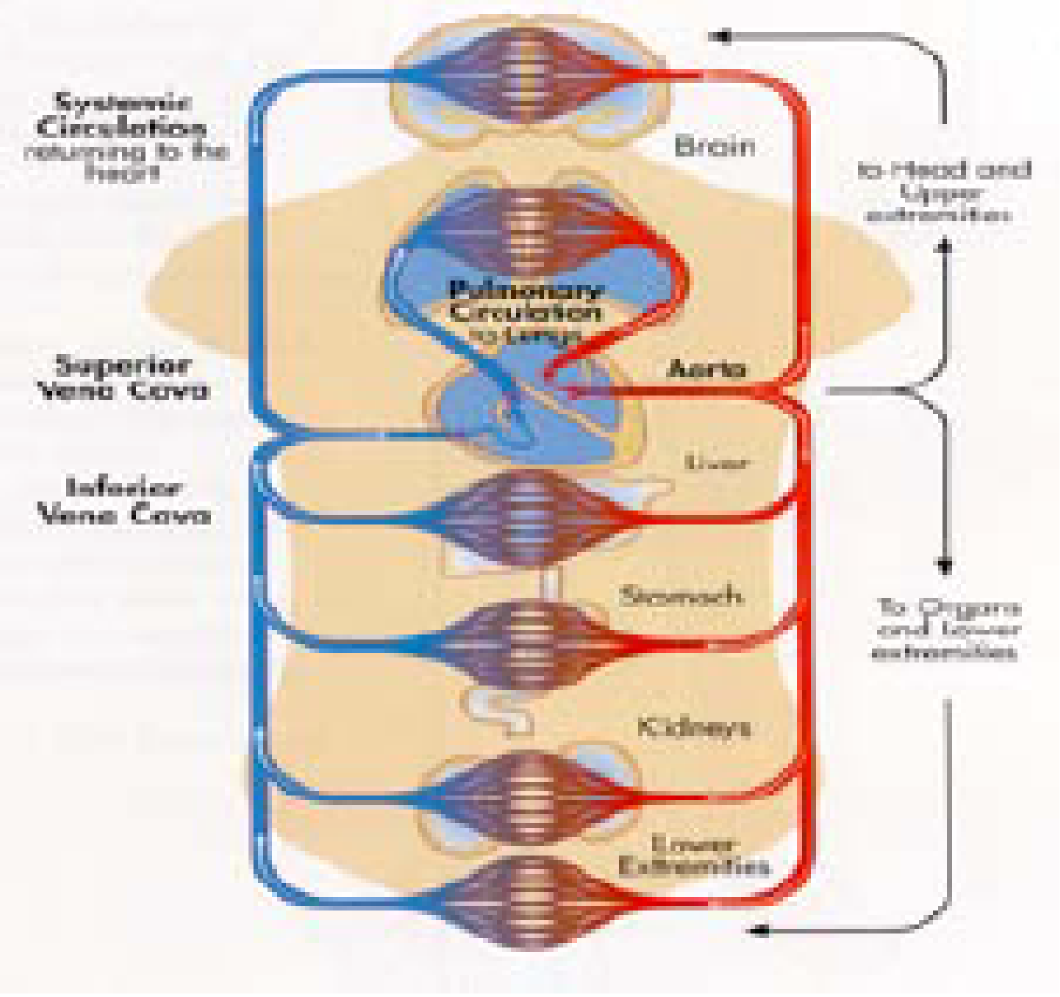
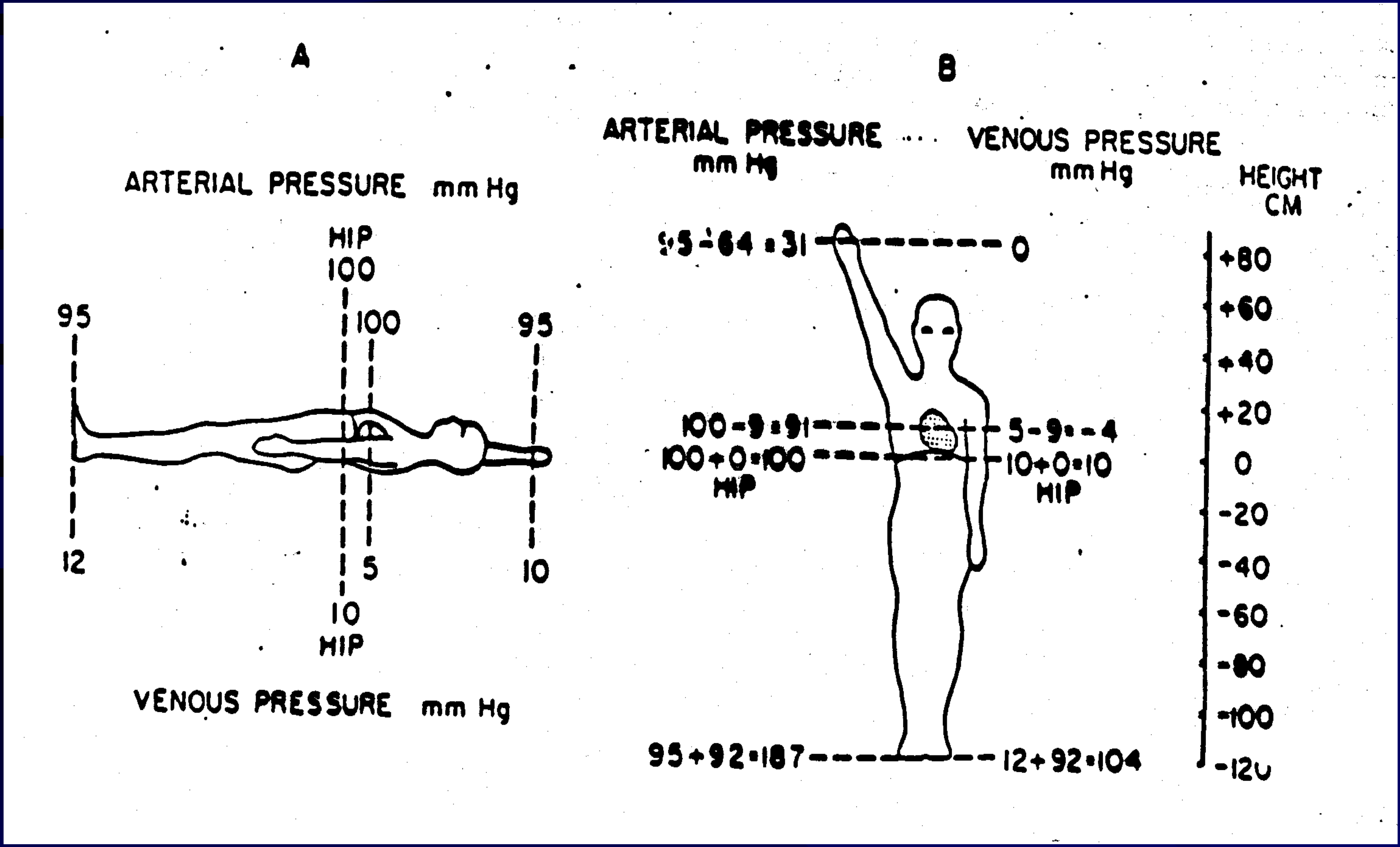



**Figure 15–3.** Energy consumed by the STS-4 payload crew before, during, and after flight.

# Cardiovascular System

- Heart
- Lungs
- Blood vessels
- Blood





A
ARTERIAL PRESSURE mm Hg
HIP
100
95
100
95
12
5
10
10
HIP
VENOUS PRESSURE mm Hg
B
ARTERIAL PRESSURE
mm Hg
VENOUS PRESSURE
mm Hg
HEIGHT
CM
95-64=31
0
100-9=91
5-9=-4
100+0=100
HIP
10+0=10
HIP
95+92=187
12+92=104
+80
+60
+40
+20
0
-20
-40
-60
-80
-100
-120

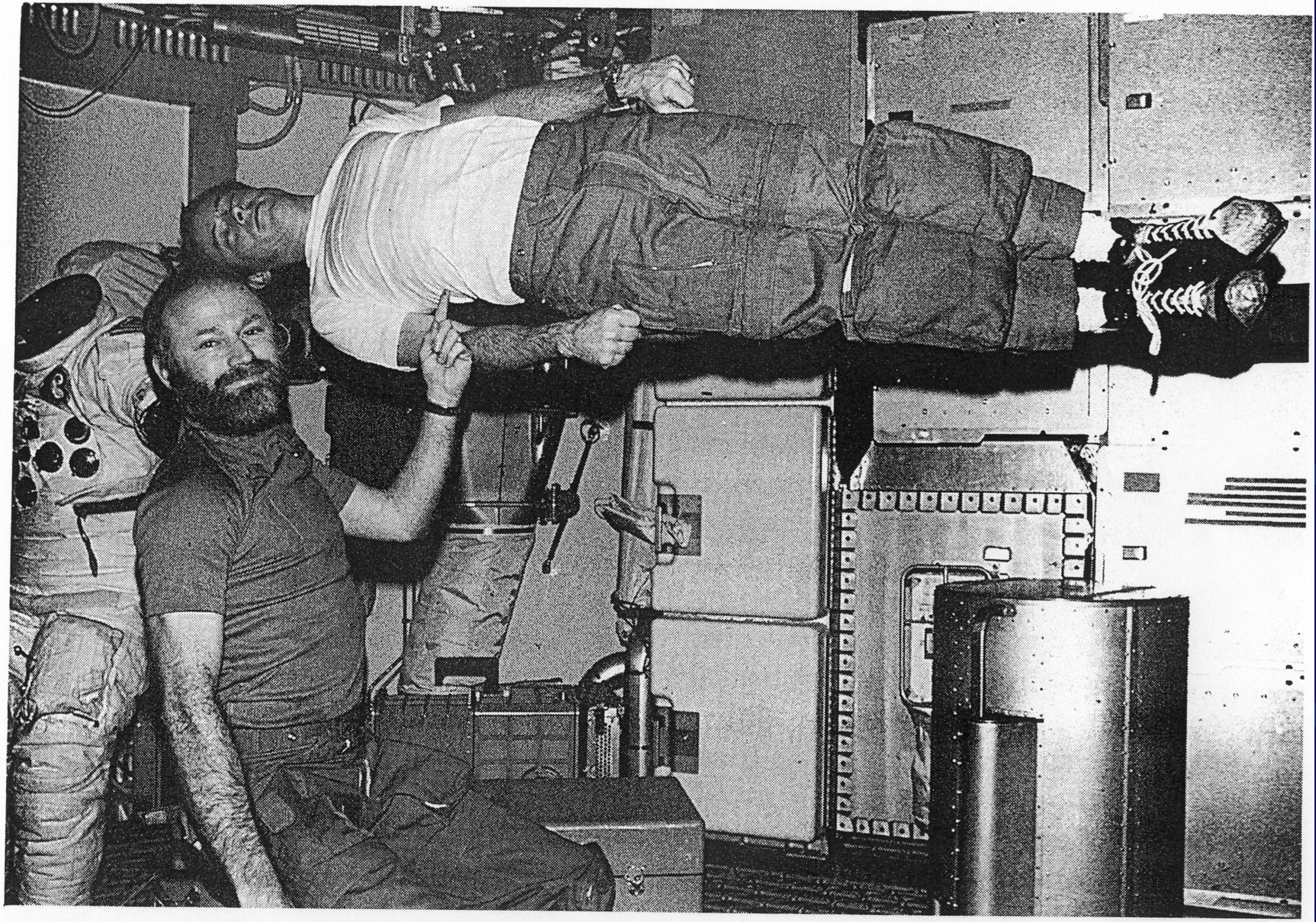
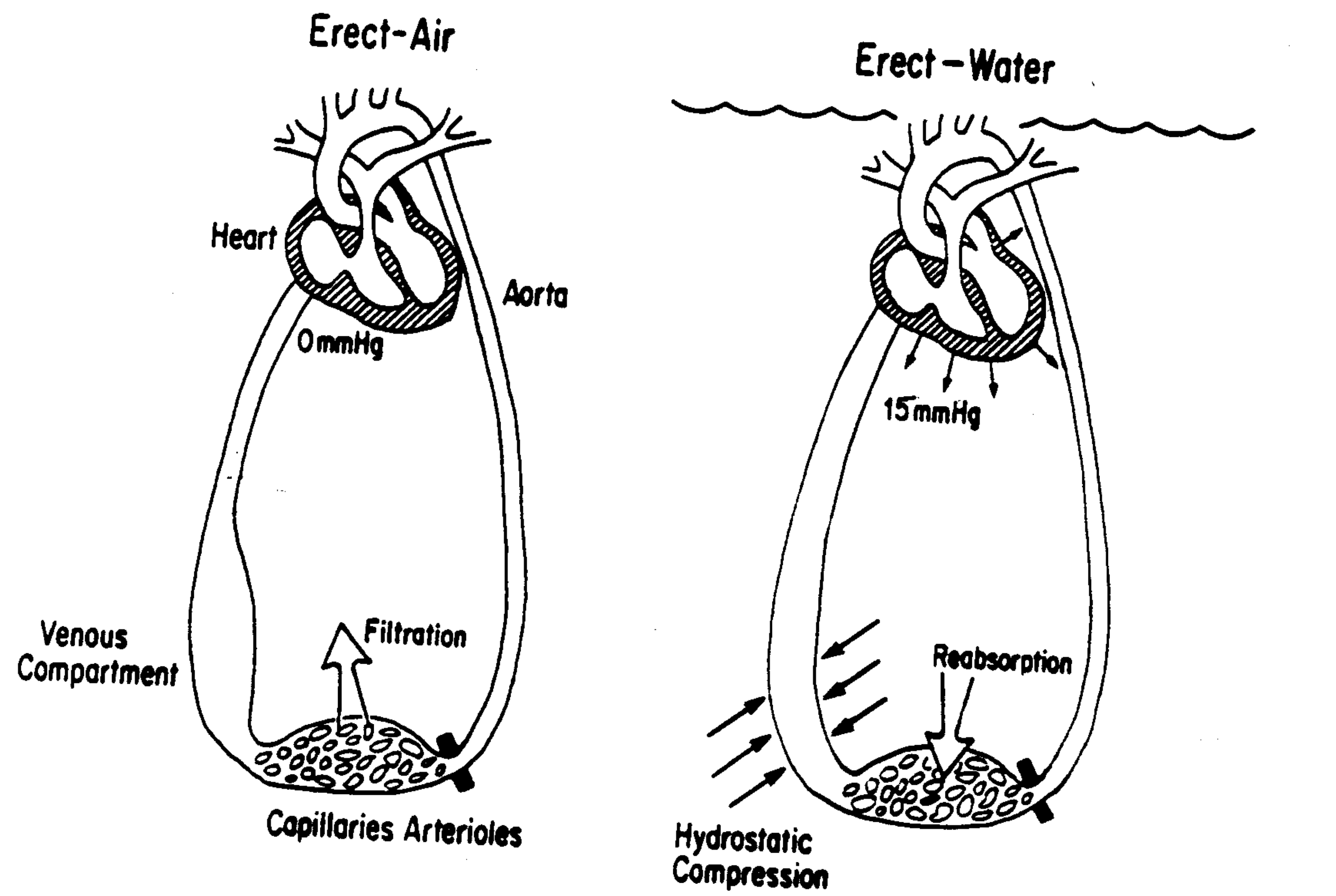
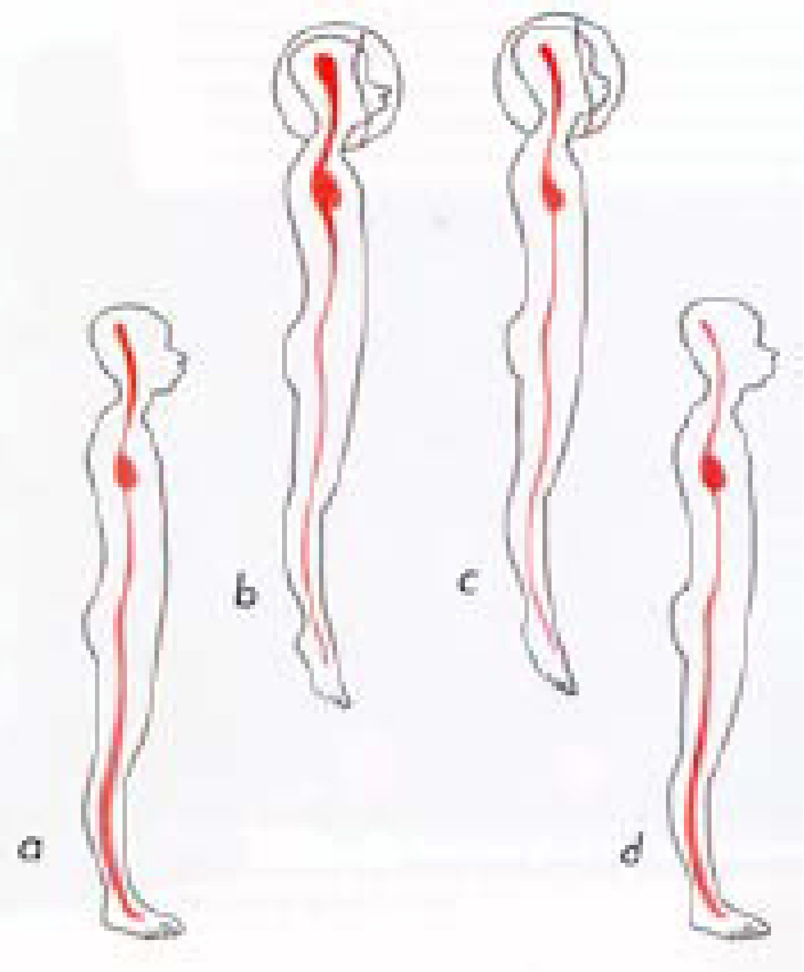


**Figure 2–4.** Skylab-4 astronauts demonstrate the effect of microgravity on weight.


Erect-Air
Erect-Water
Heart
Aorta
0 mmHg
15 mmHg
Venous
Compartment
Filtration
Reabsorption
Capillaries Arterioles
Hydrostatic
Compression

# Cephalid (Headward) Fluid Shift




Assignment

# CV problems

- Puffy face (skinny legs)
- Fluid loss
- Anemia (RBC)
- Postflight orthostatic intolerance (fainting)

# Countermeasures

- Fluid loading
- Electrolytes
- Lower body negative pressure (LBNP) suit
- G suits

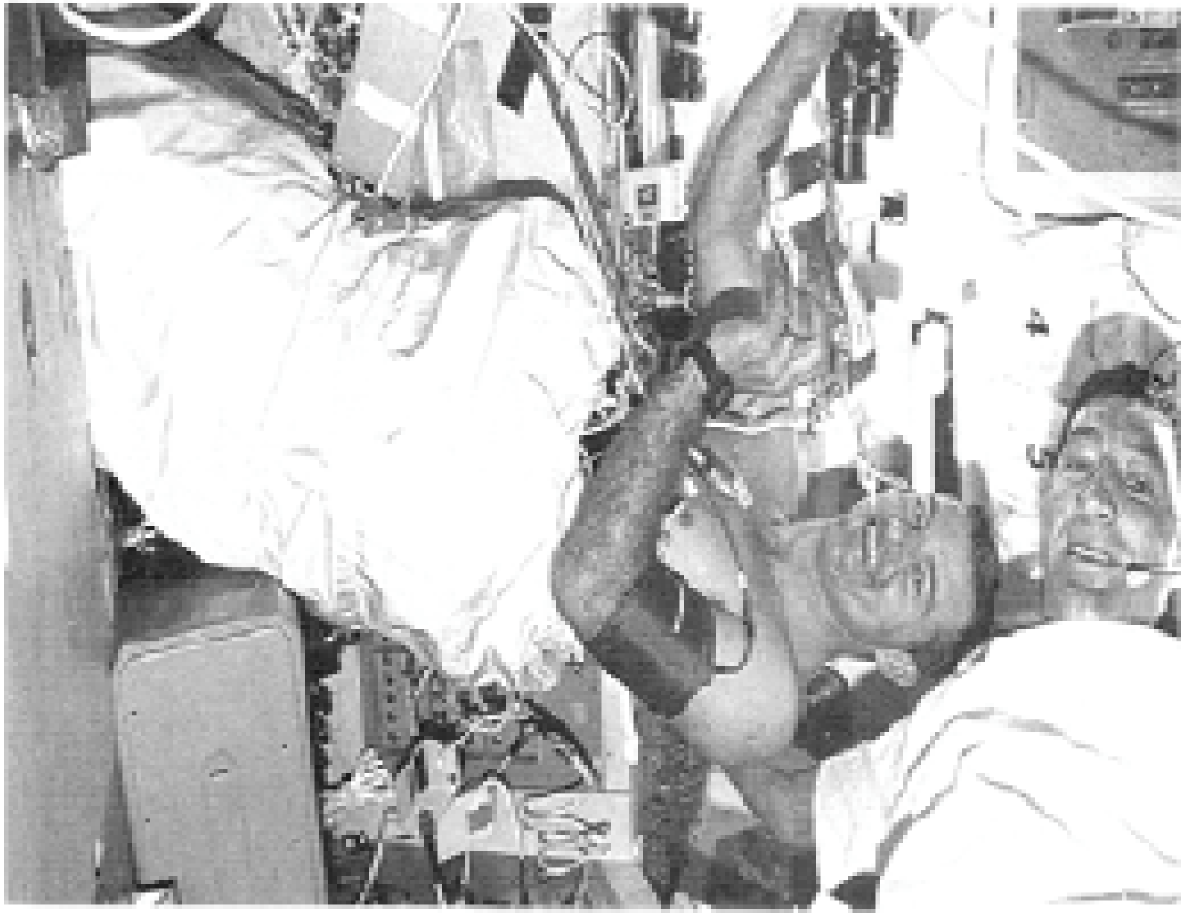
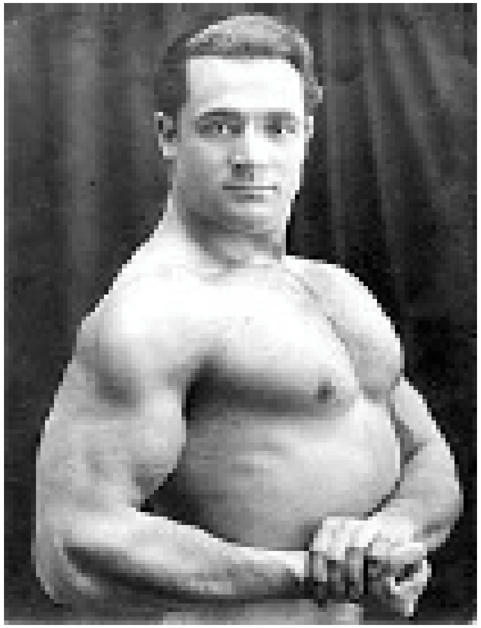


Figure 14–5. Astronaut James Voss uses the mobile in-flight LBNP device on STS-44 while Mario Runco observes.

# Muscular System in Space

- Muscle functions
  - motion and locomotion
  - movement of substrates in body
  - postural maintenance
  - heat production (85%)



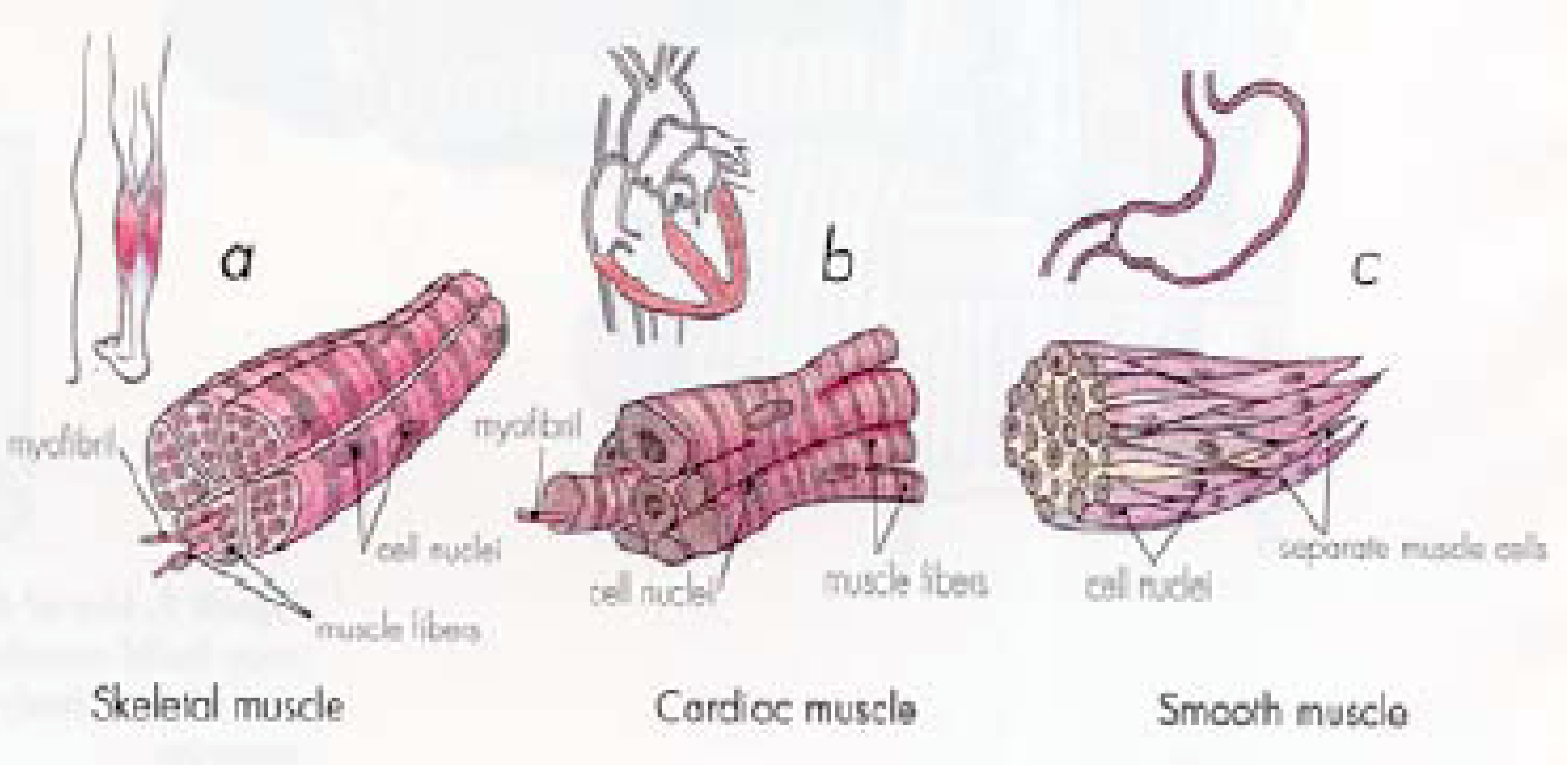
# Muscle function in space

## Force

- Skylab astronauts who exercised maintained muscle force
- Leg volume reduced, exercise or not
- Proximal antigravity muscles (torso, posture) deconditioned after 5 days

# Types of Muscle

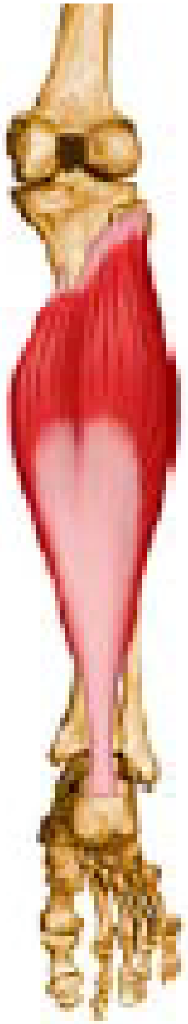
skeletal, cardiac, smooth
fast and slow twitch



# Muscle Atrophy

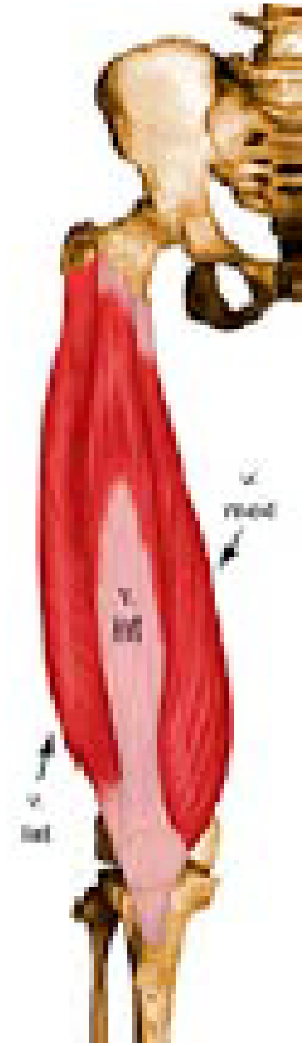
- Wasting away of muscle.  Individual fibers decrease in size due to progressive loss of myofibrils (actin and myosin)
- Caused by:
  - Disuse
  - Denervation
  - Disease

# Muscular structure in space



- Using MRI, found soleus volume reduced. No significant recovery after 7 days postflight.

- Using biopsy, found vastus lateralis xs area reduced. Due to loss of fast twitch fibers. Capillary density reduced (decreased oxidative potential).



# Muscle function in space

## Force

- Skylab astronauts who exercised maintained muscle force
- Leg volume reduced, exercise or not
- Proximal antigravity muscles (torso, posture) deconditioned after 5 days

# Muscle function in space (cont)

- Fatigue
  - Greater fatiguing (Skylab)
  - Recovery (9 d mission) of muscle conditioning complete after 2 d postflight exercise
- Control
  - Achilles reflex duration (time between tap on heel and cessation of movement)
  - ARD decreased in flight, but increased postflight (suggests proprioceptive inputs is sensitive to microgravity)

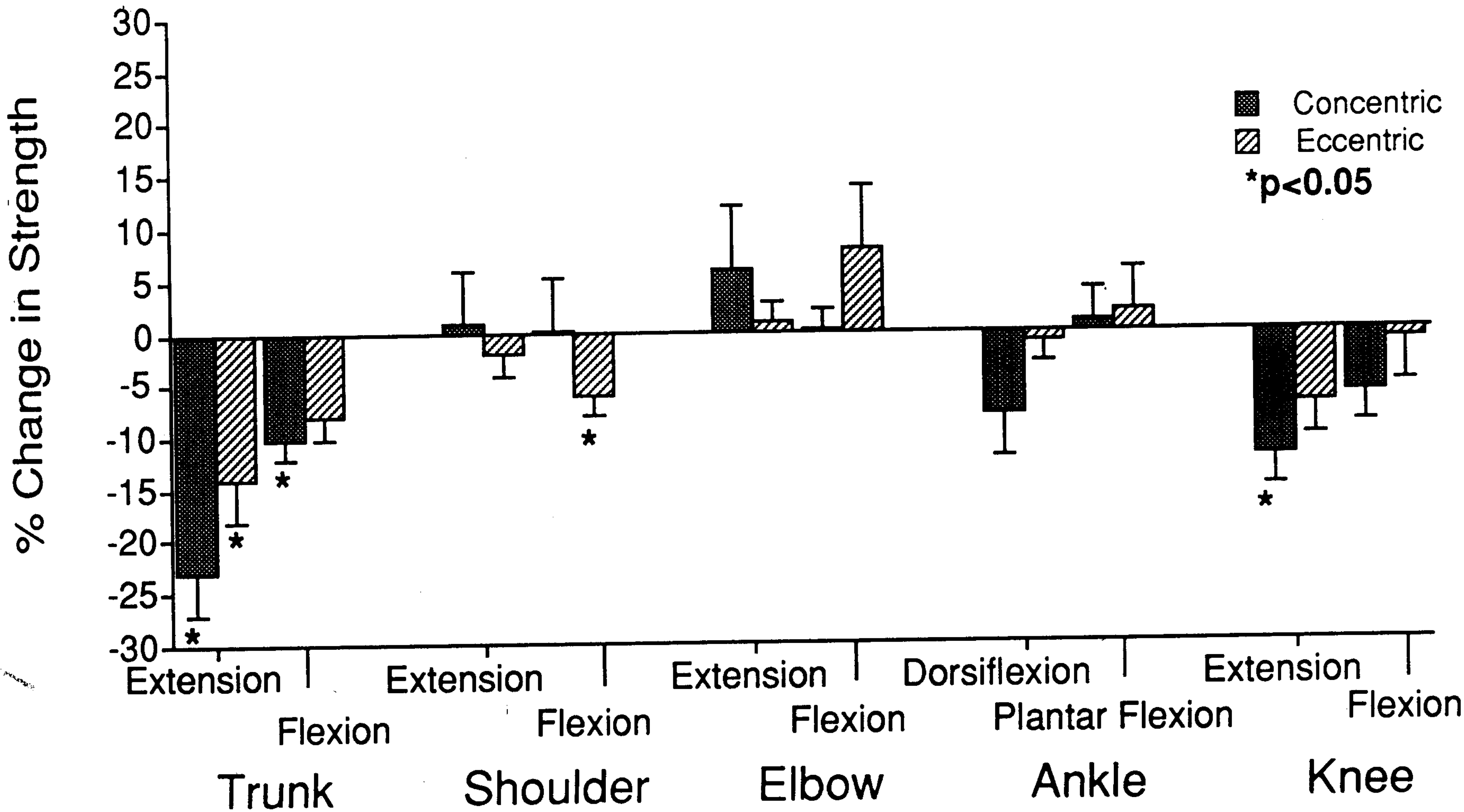



**Figure 10–10.** Summary of changes in strength in 19 astronauts tested before launch and after 4 to 11 days of space flight.

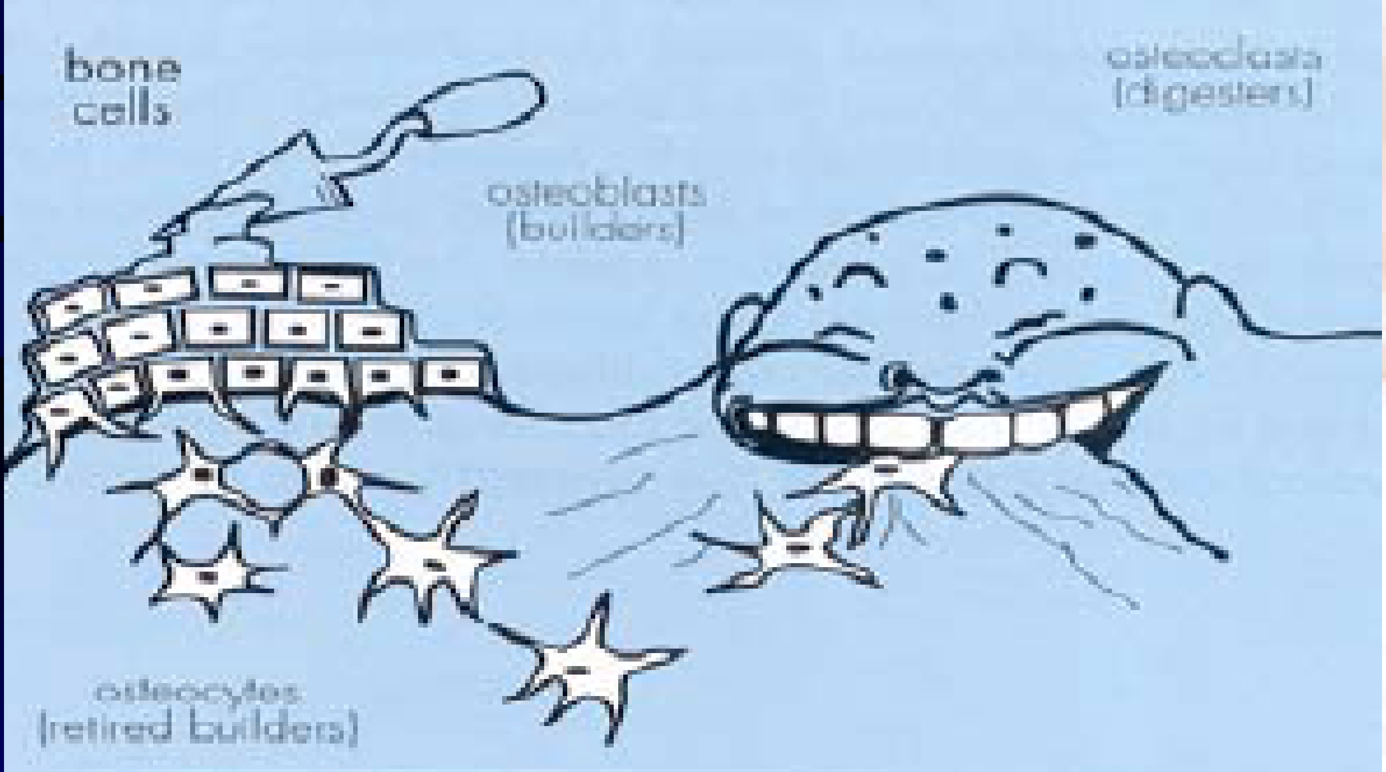
# Countermeasures

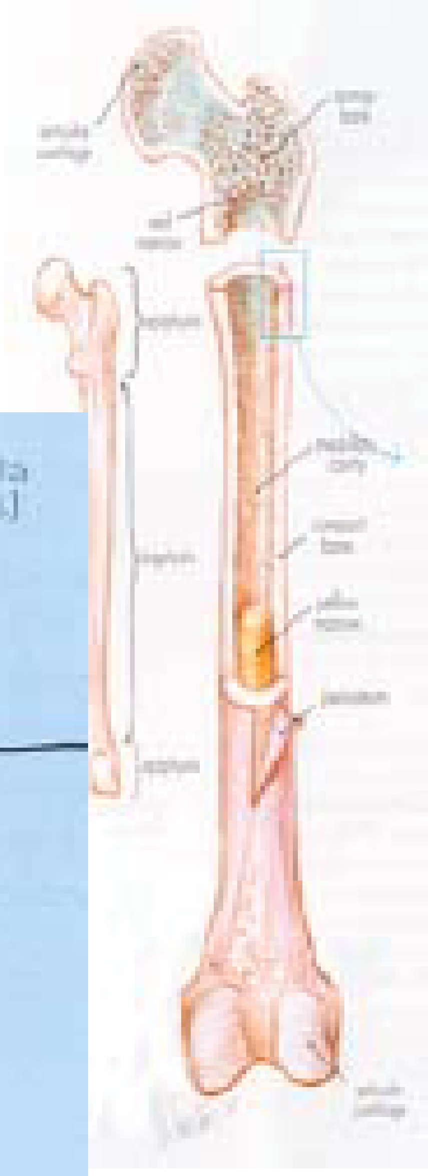
- Exercise
- Passive stretch
- Electrical stimulation
- Anabolic drugs
- Proprioceptive neuromuscular facilitation

# Skeletal System – Functions

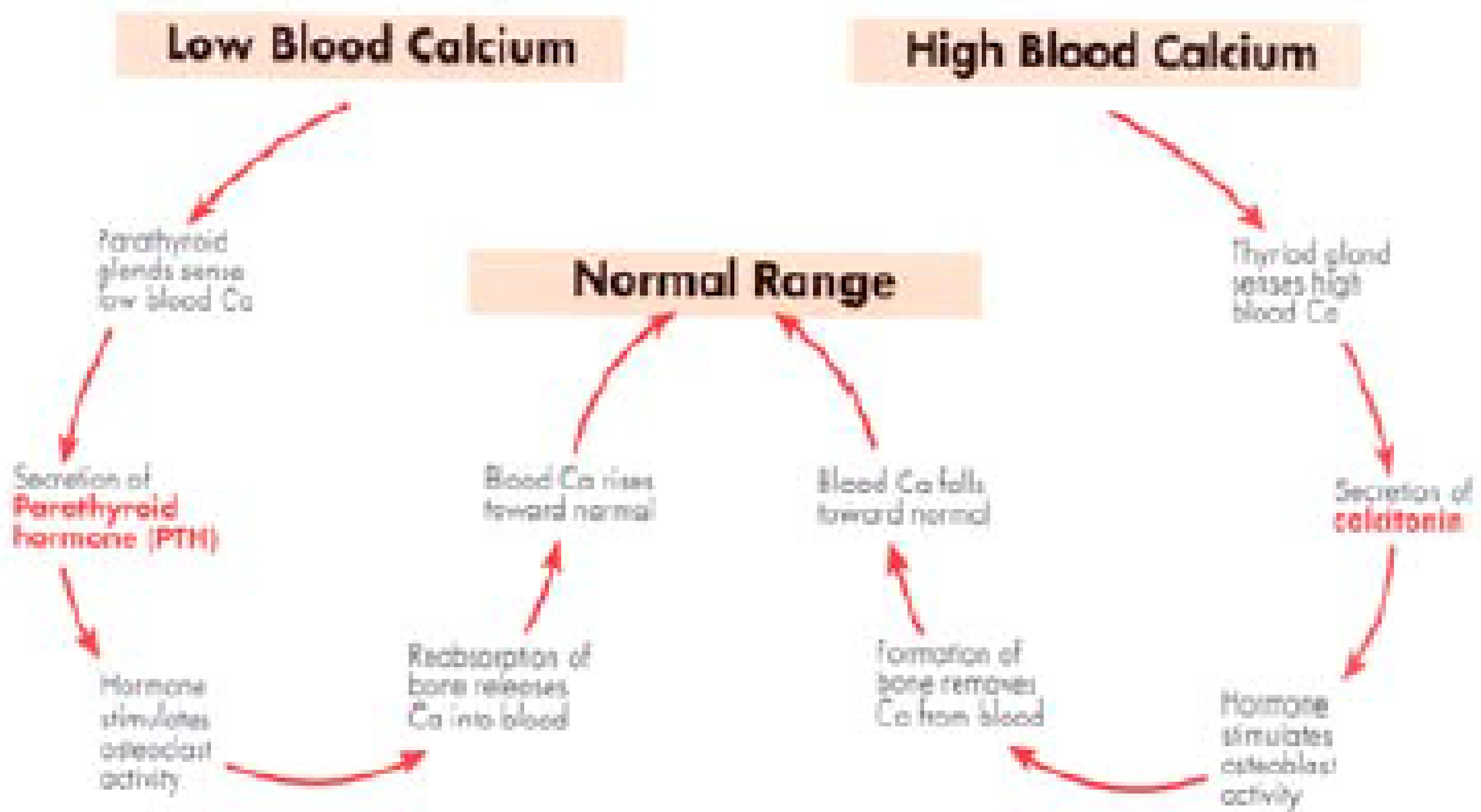
- Support
- Protection
- Movement
- Mineral storage and homeostasis
- Site of blood production (red bone marrow)
- Energy storage (yellow bone marrow)

- Bone in constant turnover (osteoblasts make and osteoclasts resorb)
- Bone strengthens with mechanical stress



Calcium loss - women begin at 30 y (30% loss by 70 y), men begin at 60 y

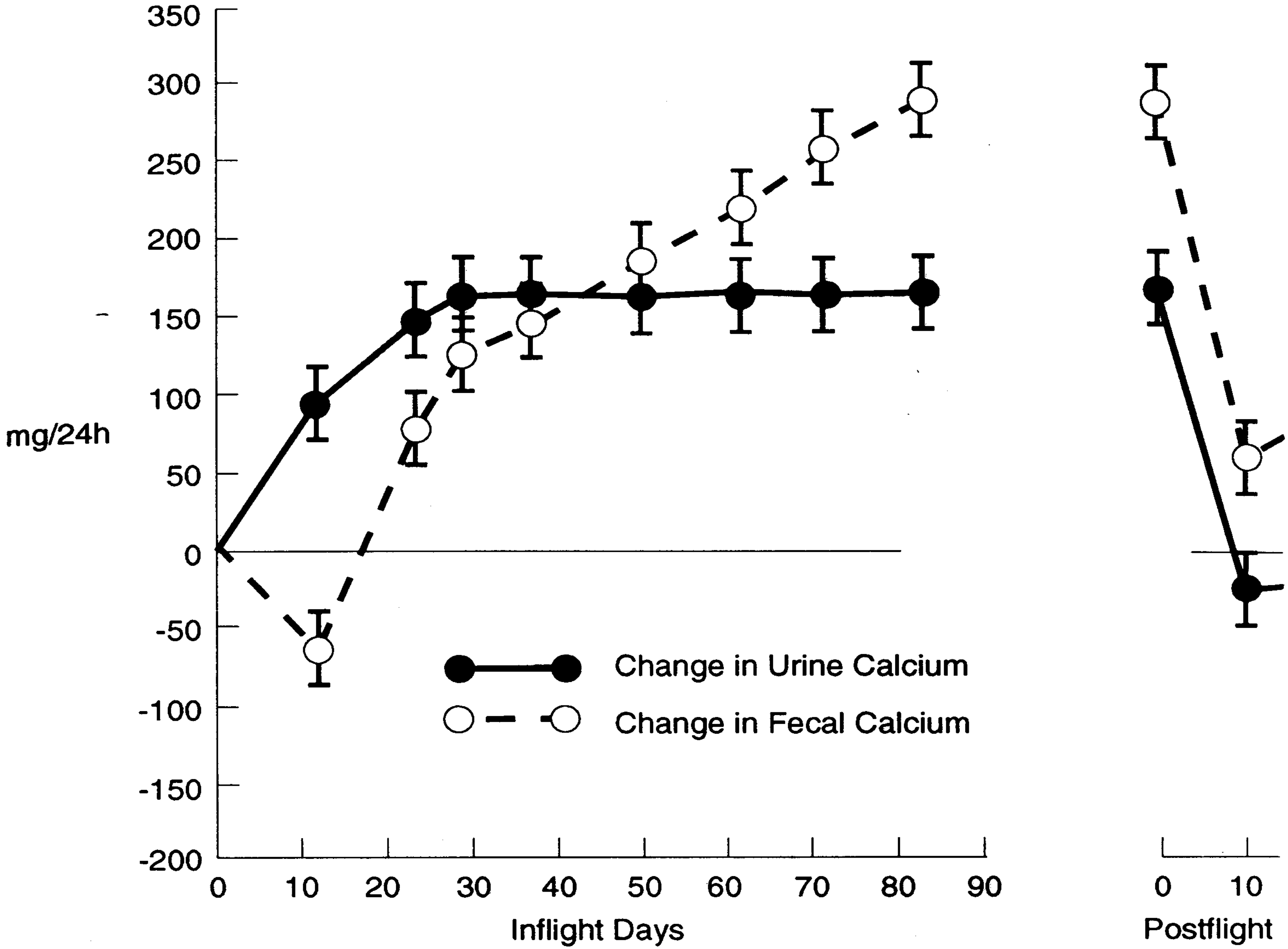


# Calcium Balance in Space

- **Skylab (84 d) - Increased Ca output in urine and feces**
- **Calculated that after 1 y in space that 25% of Ca would be lost**
- **Recovery of Ca balance (urine/fecal) begins soon after return.**

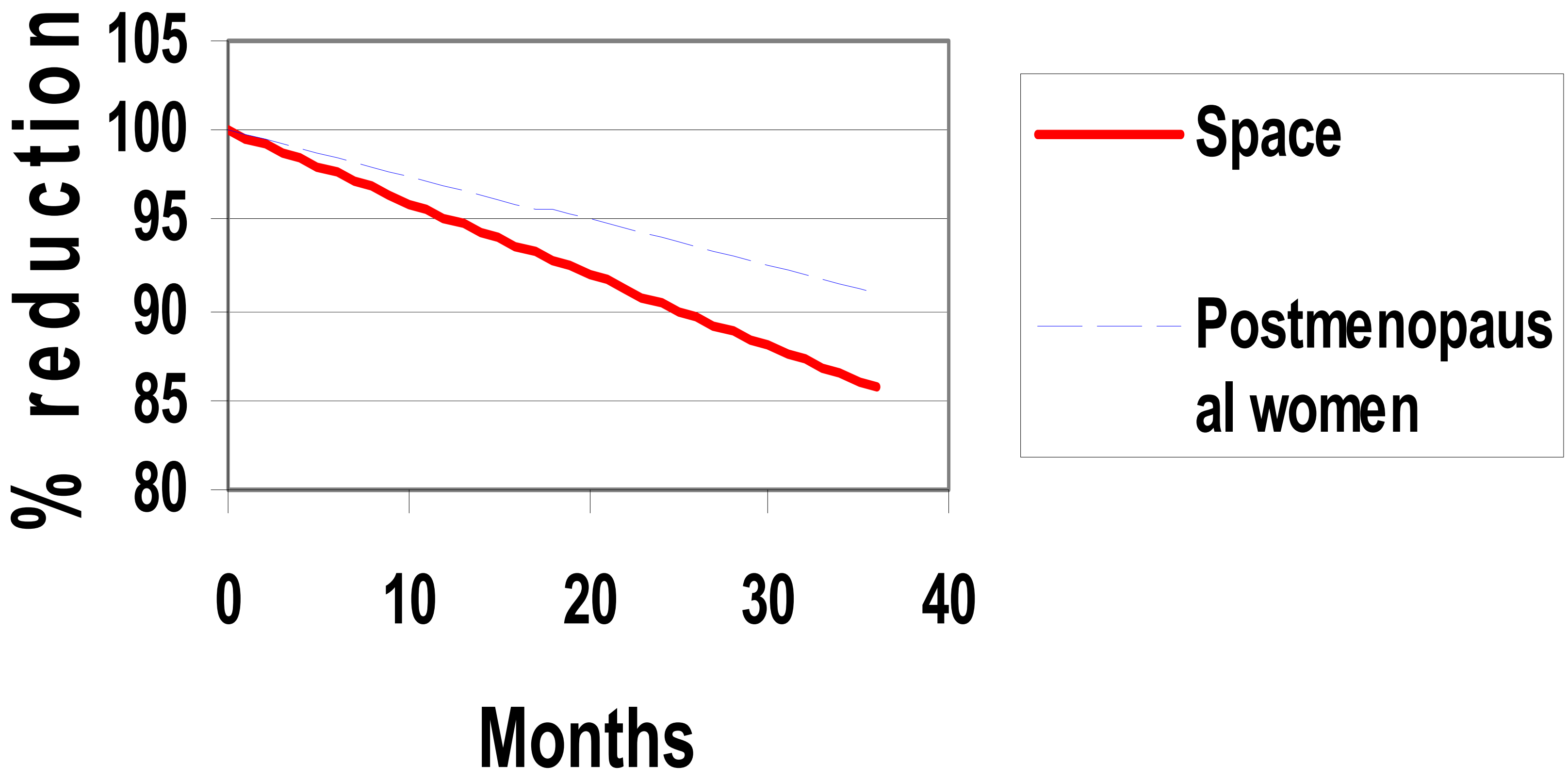
***This could be a problem - Why?***

Because bone is in a constant state of turnover.
If the Ca balance returns to normal quickly,
the bone density (strength) may never recover
or recover very slowly.



350
300
250
200
150
100
50
0
-50
-100
-150
-200
mg/24h
0
10
20
30
40
50
60
70
80
90
Inflight Days
0
10
Postflight
Change in Urine Calcium
Change in Fecal Calcium

# Decrease in Bone mass



# Bone strength

- Young rats, 7 d in space, decrease in:
  - bone growth
  - mineralization
  - mechanical bending strength
  - weight of lumbar spine
  - bone cell size
- No change in levels of calcitrol in kidney (involved in bone resorption)

  *What does this suggest about the mechanism?*

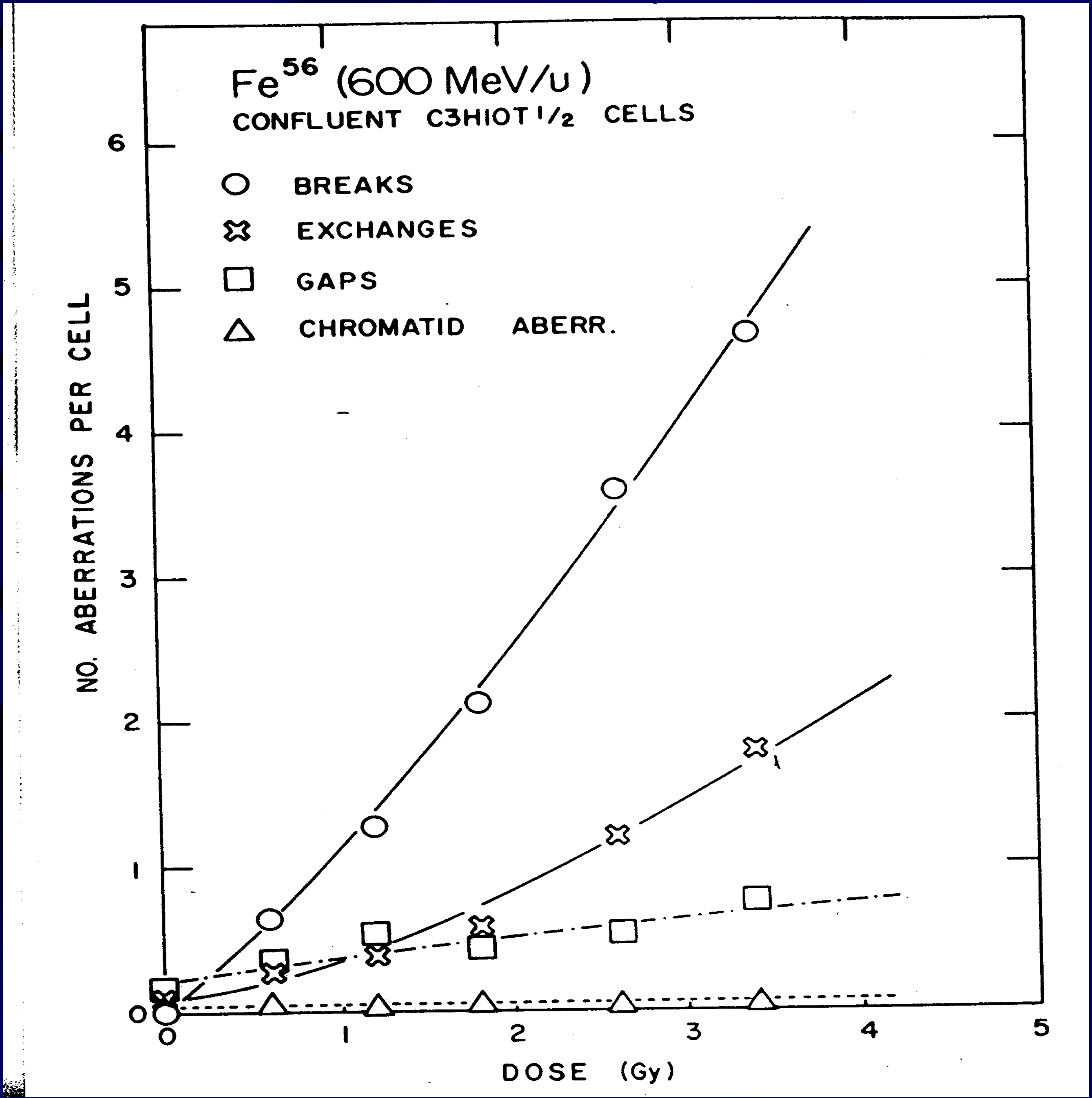
**Probably caused by inhibited bone formation (osteoblast), not to increased bone resorption (osteoclast).**

# Countermeasures

- Weight loading exercises (still will be bone loss)
- Centrifugation (reduces Ca and P losses from rat long bones)
- Nutrition (supplement diet with Ca and P - *would this cause other problems?)*
- Drugs (fluoride and Clodronate have been effective in bed rest studies)

| Radiation | RBE | Occurrence |
|---|---|---|
| X-rays | 1 | Radiation belts, Solar radiation, Bremsstrahlung |
| 5 MeV $\gamma$-rays | 0.5 | Radiation belts, Solar radiation, Bremsstrahlung |
| 1 MeV $\gamma$-rays | 0.7 | Radiation belts, Solar radiation, Bremsstrahlung |
| 200 keV $\gamma$-rays | 1.0 | Radiation belts, Solar radiation, Bremsstrahlung |
| Electrons | 1.0 | Radiation belts |
| Protons | 2.0 - 10.0 | Cosmic radiation, Inner radiation belt |
| Neutrons | 2-10 | Close to the Earth, the Sun and any matter |
| $\alpha$-particles | 10-20 | Cosmic radiation |
| Heavy particles | | Cosmic radiation |

*Table III.3:* **RBE and Occurrence of Different Kinds of Radiation [26, 29]**

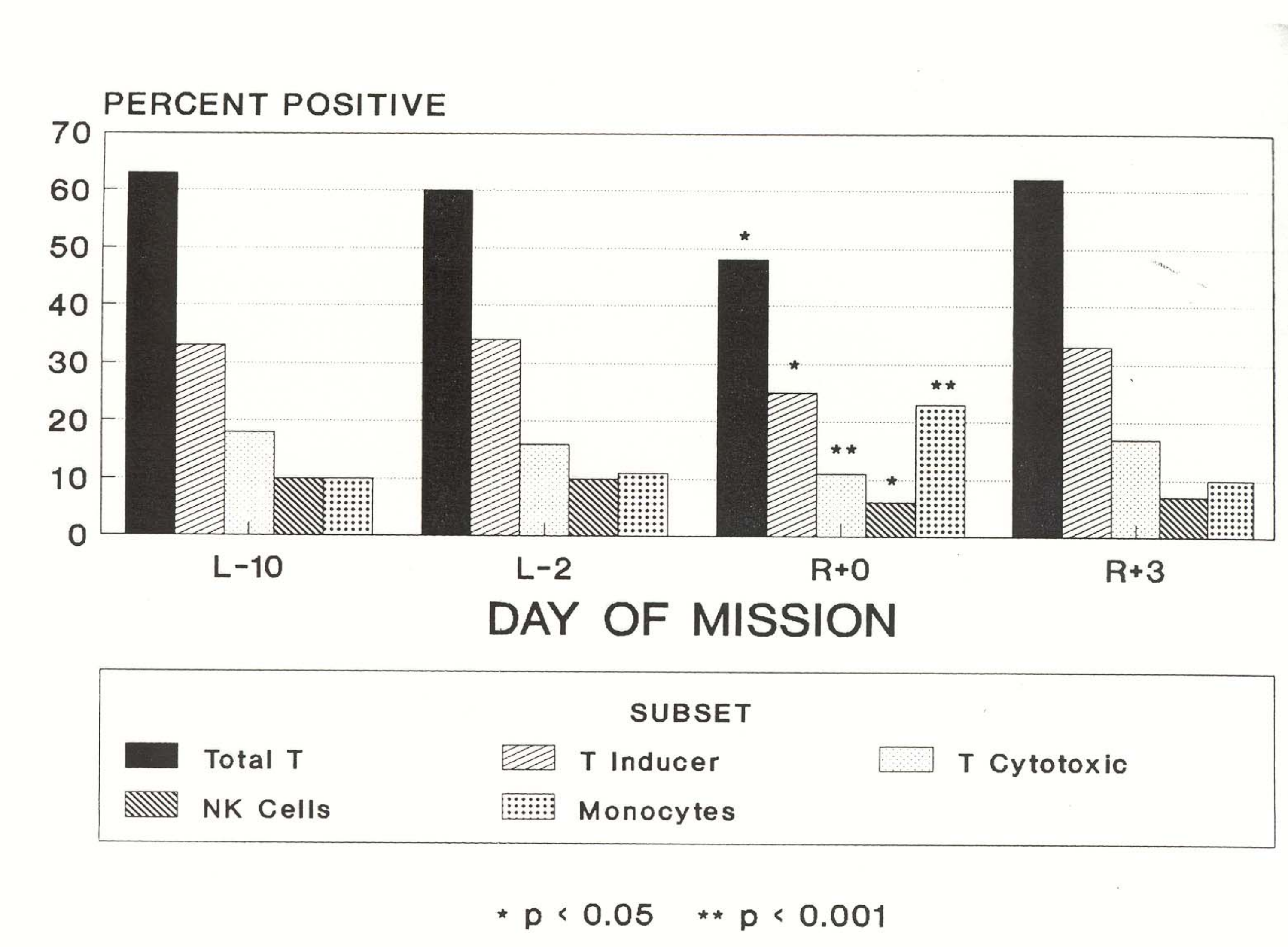


Fe56 (600 MeV/u)
CONFLUENT C3H10T1/2 CELLS
BREAKS
EXCHANGES
GAPS
CHROMATID ABERR.
NO. ABERRATIONS PER CELL
DOSE (Gy)
0
1
2
3
4
5
6

## Immune System

- Human immune response may be attenuated during spaceflight
- Results point to a decrease in the cell-mediated immune response
- Must understand the effects of spaceflight on the microbial agents of disease as well as the human immune response

# Immunological effects of space flight



## CREW DISPLAYS AND CONTROLS

| Program | Panels | Work Stations | Control Display Elements | Computers No./Modes |
|---|---|---|---|---|
| Mercury | 3 | 1 | 143 | 0 |
| Gemini | 7 | 2 | 354 | 1 |
| Apollo | 40 | 7 | 1374 | 4/50 |
| Skylab | 189 | 20 | 2980 | 4 |
| Shuttle | 97 | 9 | 2300 | 5/140 |
| Space Station* | 200 | 40 | 3000 | 8/200 |

*Assuming real-time control on board, database management from the ground.

**TABLE 10–2**

## SPACE SYSTEM INFORMATION

| Program | Displayed to Crew | Measurements Displayed at Mission Control | Totals* |
|---|---|---|---|
| Mercury | 53 | 85 | 100 |
| Gemini | 75 | 202 | 225 |
| Apollo | | | |
| Command Module | 280 | 336 | 475 |
| Lunar Module | 214 | 279 | 473 |
| Skylab | | | |
| Command Module | 289 | 365 | 521 |
| Air Lock Module | 326 | 1,669 | 1,720 |
| Shuttle | 2,170 | 3,826 | 7,831 |
| Space Station† | 4,000 | 4,000 | 10,000 |

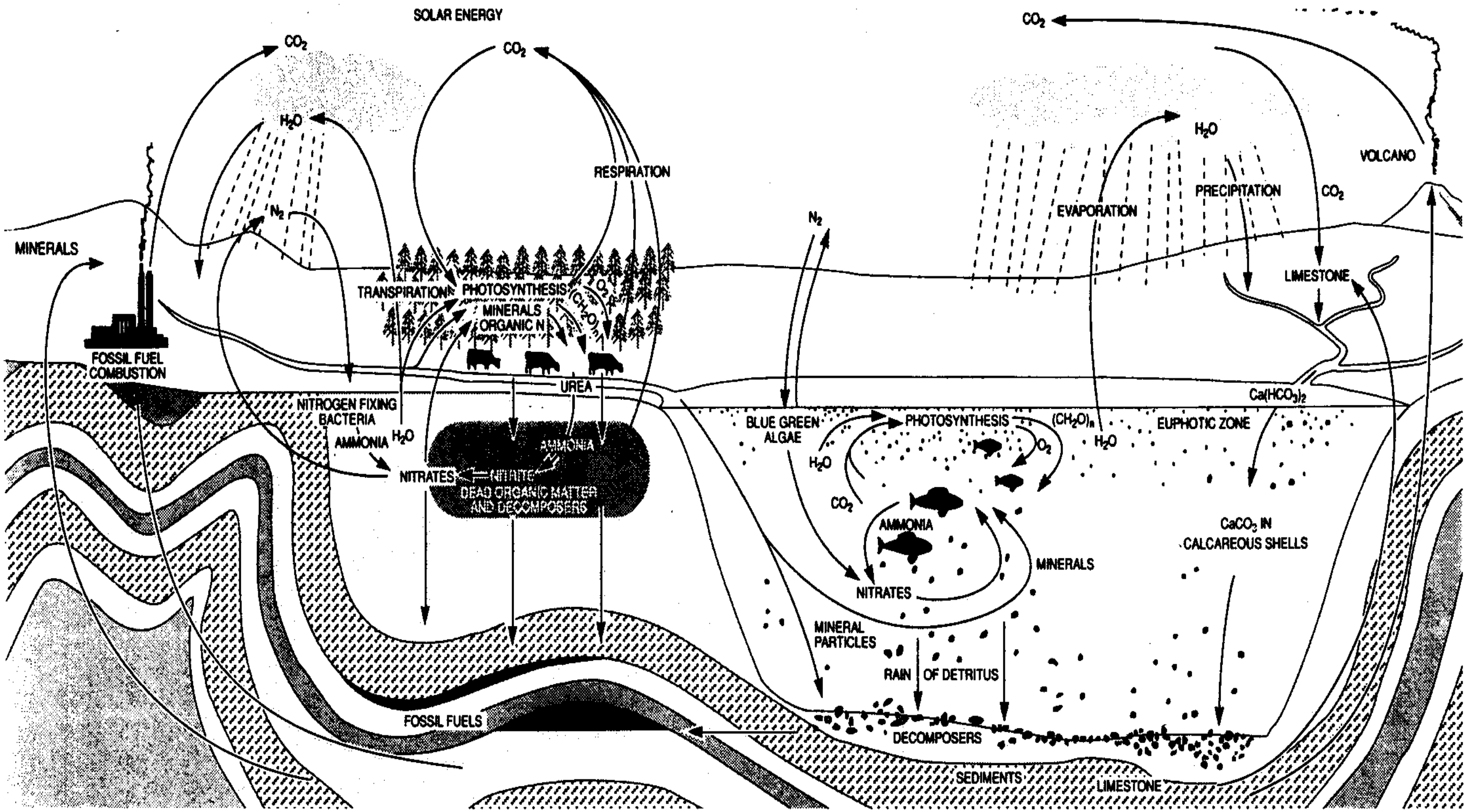



***Figure II.13:*** **The Major Cycles of the Biosphere [1]**

**TABLE 20–1**

## CLINICAL FINDINGS DURING AND AFTER BED REST AND SPACE FLIGHT

| Findings | Bed Rest Position 0° | –4° | –8° | –12° | Space Flight |
|---|---|---|---|---|---|
| **During Bed Rest or Space Flight** | | | | | |
| Increased taste and olfactory sensitivity | – | + | + | ++ | + |
| Sensation of blood rushing to and heaviness in head | – | + | + | ++ | ++ |
| Nasal congestion | – | + | ++ | +++ | ++ |
| Uncomfortable feeling in the nose and throat, hoarse voice | – | + | + | ++ | – |
| Increased intranasal resistance | + | + | ++ | +++ | NM |
| Nausea, stomach awareness | – | – | R | R | +++ |
| Spatial illusions | – | – | + | ++ | ++ |
| Nystagmus | – | – | + | ++ | ++ |
| Facial puffiness, overfilling of sclera and conjunctival vessels | – | + | ++ | ++ | ++ |
| Sensation of fullness in the eyes, fatigue in eyes during reading, decline in acuity | – | + | ++ | ++ | + |
| **After Bed Rest or Space Flight** | | | | | |
| Orthostatic intolerance | ++ | ++ | ++ | ++ | ++ |
| Decreased muscle strength | ++ | ++ | ++ | ++ | ++ |
| Loss of bone mineral | ++ | ++ | ++ | ++ | ++ |
| Ataxia | – | – | – | – | ++ |

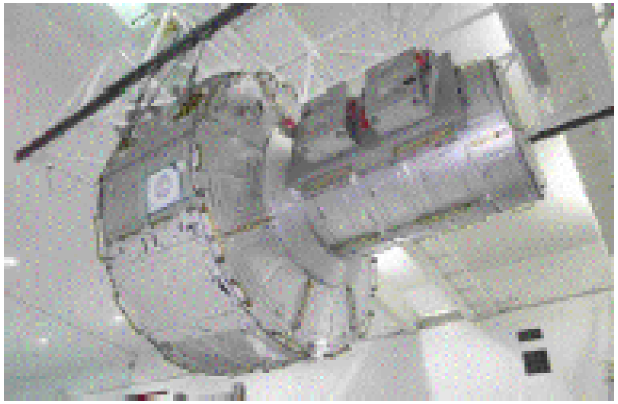
– = symptoms absent.
+ = symptoms present (++, +++ = pronounced symptoms).
R = symptoms rarely present.
NM = not measured.

(Adapted from Kakurin et al., 1976.)


# Current State of EVA

Existing NASA EVA architecture is over 24 years old (1977) and has evolved from Apollo, Skylab and Shuttle technology and operations.

All current EVA systems are only compatible with low earth orbit zero-G activities and require costly regular ground based maintenance, resupply and monitoring.



# Space Fatalities

- Soviet Space Program
  - 1 Fatality – Soyuz 1 (1967) parachute entanglement during reentry
  - 3 Fatalities – Soyuz 11 (1971) cabin decompression during reentry
- U.S. Space Program
  - 3 Fatalities – Apollo 1 pad fire
  - 7 Fatalities – Challenger STS 51L (1986) launch breakup

# Medical Evacuation from Space

- Salyut 5 (1976) station abandoned 49 days into 54 day mission for intractable headaches
- Salyut 7 (1985) evacuation at 56 days into 216 day mission for sepsis/ prostatitis
- Mir (1987) evacuation at 6 months into 11 month mission for cardiac dysrhythmia

# Medical events in Russian Space Program

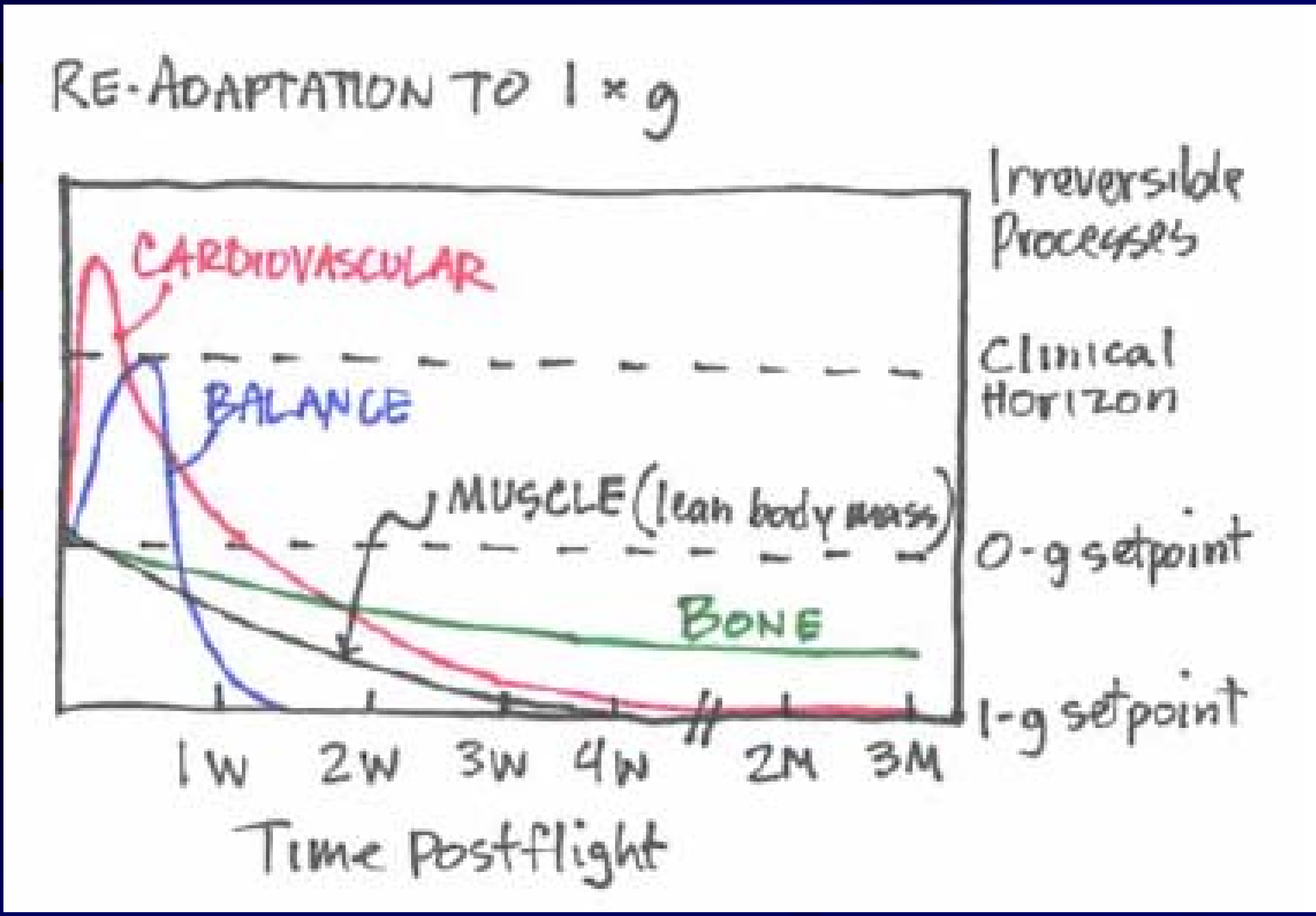
- Events not resulting in mission termination or early return
  - Spacecraft fires - 1971, 1977, 1988, 1997
  - Kidney Stone - 1982
  - Hypothermia during EVA - 1985
  - Psychological stress reaction - 1988
  - Spacecraft depressurization -1997
  - Toxic atmosphere - 1997

# Medical events in U.S. Space Program

- Apollo 8 crew – 1st Americans to report SMS
- Apollo 9 - SMS caused EVA to be rescheduled (1st timeline change due to medical cause)
- Apollo 11 – Type 1 DCS in command module pilot
- Apollo 13 – Kidney infection during mission
- Apollo 15 – Cardiac disrhythmia
- (PVC, PAC, bigeminy) during lunar EVA

# Medical symptoms in U.S. Space Program

- Shuttle program (89 shuttle missions) 1981-1998
- 508 crew (439 men, 69 women)/ 4443 flight days
  - 79% reported Space Motion Sickness
  - 98% reported some medical symptom
    - 67% reported headache
    - 64% reported respiratory complaints
    - 59% reported facial fullness
    - 32% reported gastrointestinal complaints
    - 26% reported musculoskeletal complaints


RE-ADAPTATION TO 1 × g
Irreversible Processes
CARDIOVASCULAR
Clinical Horizon
BALANCE
MUSCLE (lean body mass)
0-g setpoint
BONE
1-g setpoint
1W
2W
3W
4W
2M
3M
Time Postflight

## SIGNIFICANT BIOMEDICAL FINDINGS IN THE APOLLO PROGRAM (PRE- VS. POSTFLIGHT)

Vestibular disturbances

Less than optimal food consumption (1260–2903 kcal/day)

Postflight dehydration and weight loss (recovery within 1 week)

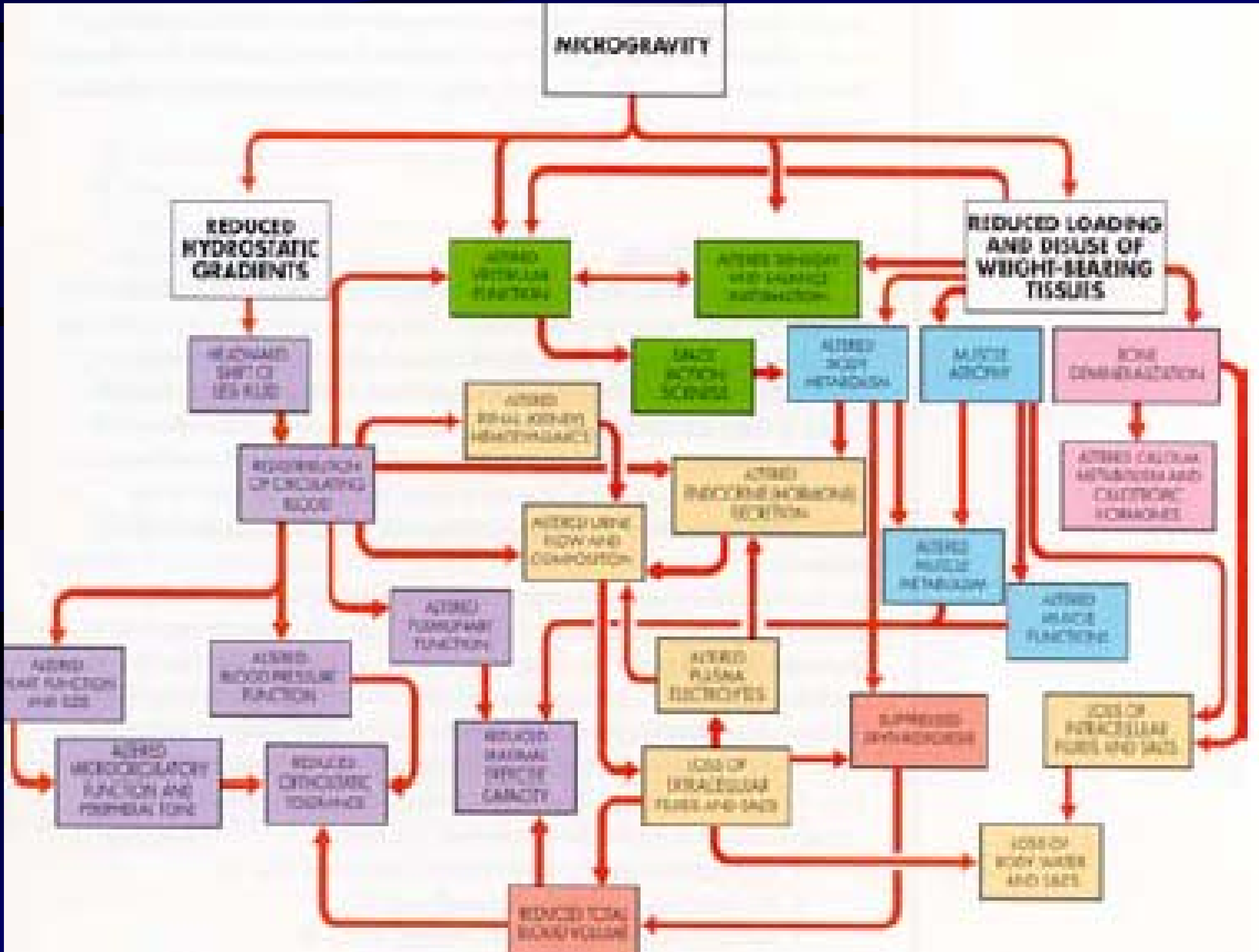
Decreased postflight orthostatic tolerance (tilt/LBNP tests)

Reduced postflight exercise tolerance (first 3 days)

Apollo 15 cardiac arrhythmias (frequent bigemini)

Decreased red cell mass (2–10%) and plasma volume (4–9%)

LBNP = Lower-body negative pressure.


MICROGRAVITY
REDUCED HYDROSTATIC GRADIENTS
REDUCED LOADING AND DISUSE OF WEIGHT-BEARING TISSUES

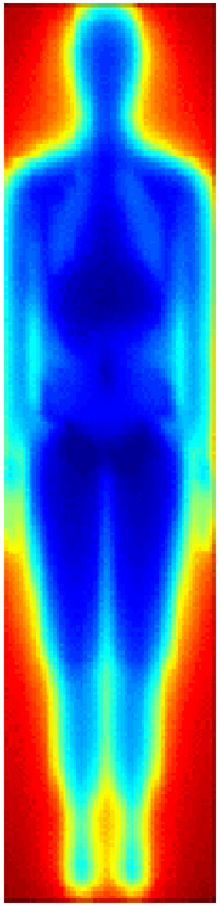
# Human Research Initiative:
## Enabling Longer Duration Human Spaceflight

SpaceResearch.nasa.gov

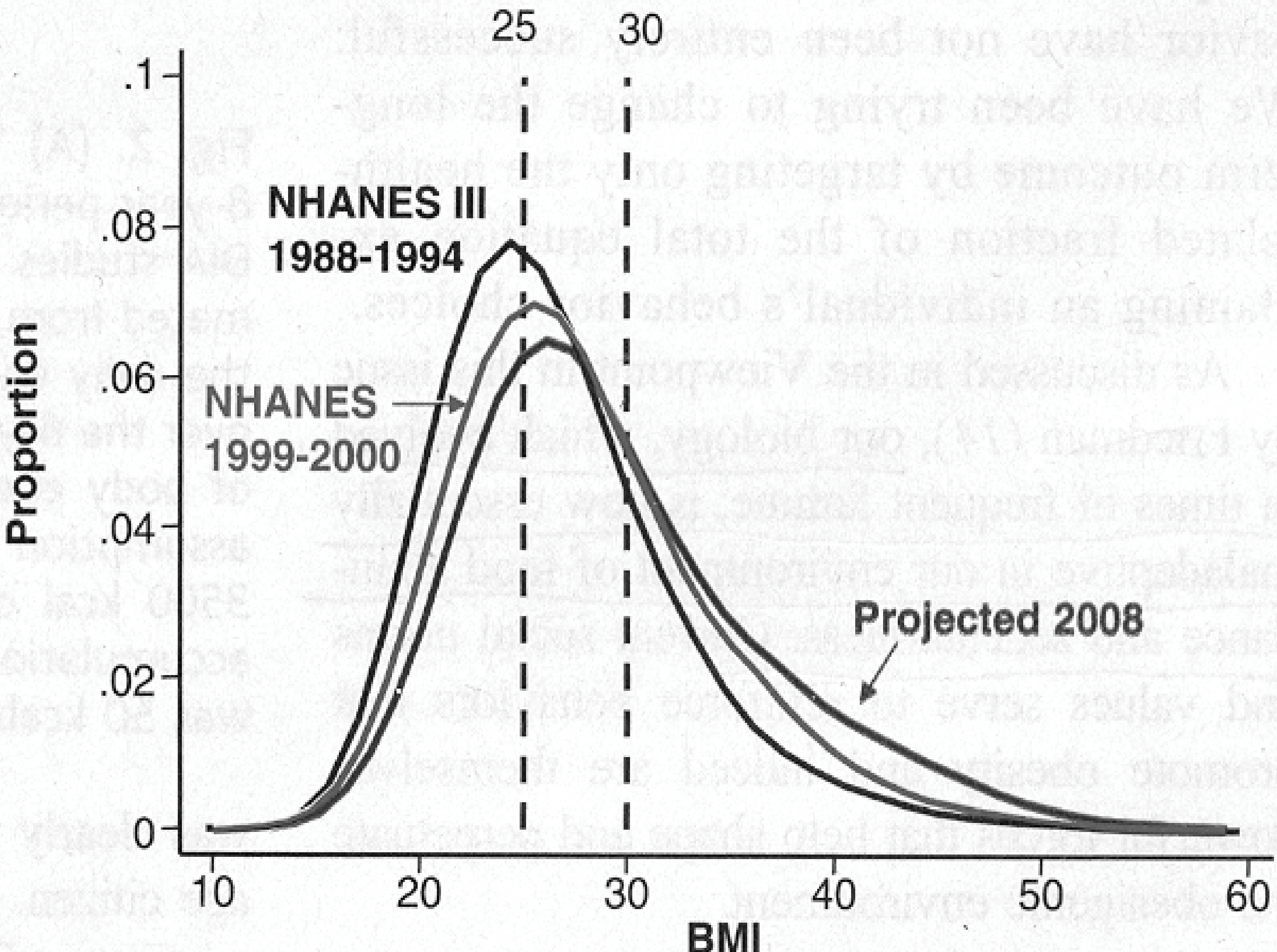
OBPR

Office of Biological & Physical Research

- **For future missions beyond low Earth orbit**
  - Improved therapies to prevent bone and muscle loss in space
  - New technology for quickly and accurately monitoring crew health
  - Improved performance and reliability of microgravity systems for power, propulsion, and environmental control
  - Reduce, by a factor of three, the time to conduct critical research to certify crew safety for missions beyond low Earth orbit over 100 days
  - Results from space will have applications for improved health care on Earth



- **For efficiency of life support in space**
  - Enables knowledge and technology to reduce mass to orbit and beyond for life support by a factor of 3 by 2010
  - Improve fire prevention, detection and suppression in space
  - Research can be translated into methods for monitoring and identification of biological and chemical agents


25
30
.1
.08
.06
.04
.02
0
Proportion
NHANES III
1988-1994
NHANES
1999-2000
Projected 2008
10
20
30
40
50
60
BMI