5 December
2019

EXTRASOLAR CIVILIZATIONS & SPACE TRAVEL

Homework #8 due Monday by 7pm
Exam #3 on Tuesday – Review session Sunday

1

Exam #3

1 hr 15 min in-class exam, open book and open notes

- Things you should DEFINITELY bring with you:
  - Writing utensil (pencil or pen – blue or black ink)
  - Calculator
- Things you should PROBABLY bring with you:
  - Lecture notes
  - Laptop or tablet (so that you can access the WeBWorK homework problems)

REVIEW SESSION – Sunday, 12/8, at 7pm in B&L 203H

2

Extrasolar civilizations & Space travel

Issues of communication, visits, and exploration

The search for extraterrestrial intelligence (SETI)

The prospects for exploration in person:

- Conventional space flight: rockets and ion drives
- Nuclear propulsion and Project Orion
- Wormhole space travel using gravity
- The health problems faced by space-travelling human beings

The medical issues: humans in zero g, irradiated by high-energy cosmic rays

The grim assessment of human space flight

Score of the search: have other civilizations found us yet?

3

From how far away would we notice ourselves?

The Arecibo 305-m radio/radar telescope can broadcast about 2 MW at 2.4 GHz, which is equivalent to broadcasting about 20 TW (trillions of watts) in all directions (to those at which the signal is pointed).

Averaging this message for a period of 8 hours, we would adequately detect our own message from a distance of about **50 lyr**.

4

The search for extraterrestrial life

SETI is thus proceeding through targeted broadcasts and searches (mostly the latter) at radio frequencies. This is the main effort of the SETI Institute, the professional home of Frank Drake and Jill Tarter.

Most notable: observations with the Arecibo 305-m telescope in the direction of 800 sunlike stars with $r < 200$ lyr, 1998-2004.

Search through the data for signals by a vast array of PCs in the hands of amateurs: SETI@Home

No detections yet. We would have definitely heard about it if there had been.

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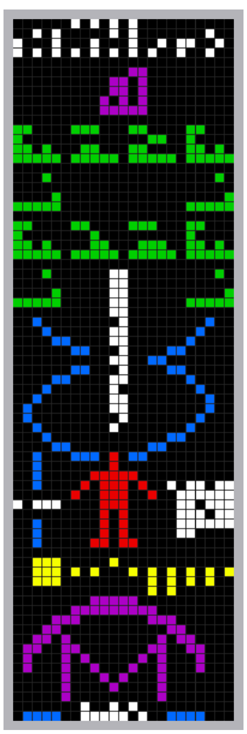

Numbers 1-10

Atomic numbers of H, C, N, O, P

Formulae for sugars and bases in DNA nucleotides

Number of nucleotides in DNA

Double helix of DNA

Human being
Height of human being
Human population of Earth

Solar system

Arecibo telescope transmitting message
Diameter of the telescope

Our first message

Sent in binary from Arecibo in 1974 by Drake.

There are 1679 bits in the message. 1679 is divisible by only two numbers (besides itself and 1): 23 & 73. These indicate the dimensions of the image.

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SETI

We are currently decently equipped to detect extraterrestrial signals at radio wavelengths, though the effort is traditionally underfunded and little appreciated.

Although the culture of radio astronomy is changing, most of the depiction of SETI in the movie *Contact* still applies: PhD thesis advisors do not like to see their students going into SETI.

The ongoing search for extrasolar planets – especially projects like NASA's *Kepler*, *K2*, and TESS, which search for habitable planets – will provide more and better targets to which to broadcast, and toward which to search for signals.

And sensitivity, bandwidth, and analysis power will continue to improve.

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Review question!

What is the ideal wavelength range for us to communicate with extraterrestrial life?

A. Radio
B. Infrared
C. Visible
D. Ultraviolet
E. X-rays
F. Gamma rays

8

Space flight

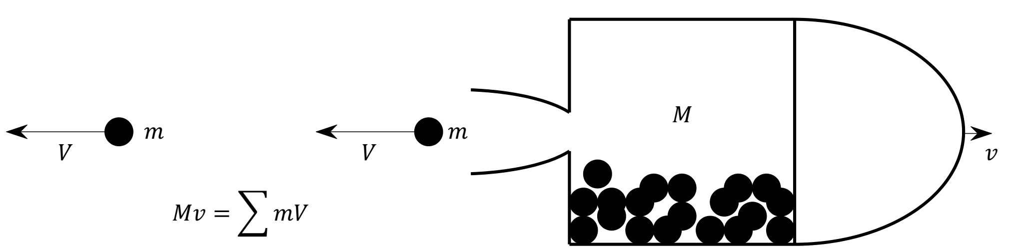
By contrast with communication, we are technologically far from being able to explore for extrasolar system civilizations both in person and robotically. The means that we can contemplate for travel are:

- Spacecraft which use thrust to accelerate up to near-light speed (c) and to decelerate at the end of the trip. We will call this conventional space flight.
- Thrust involves imparting the spacecraft with the momentum of molecules or particles in a propellant or external beam.
- Spacecraft which employ gravitational acceleration and specially-made shortcuts through spacetime called warp drive or wormholes.

Launch of the STS-92 mission to the ISS (Discovery, 11 October 2000)

Space flight

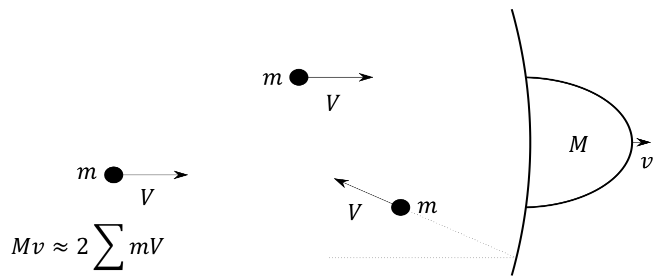
Thrust can be provided by ejection of onboard propellant, usually atoms (mass m) produced by burning molecular fuel and being expelled through a nozzle at some very high speed V.



The mass M of the spacecraft decreases with time if onboard propellant is used.

Space flight

In principle (i.e. has not yet been done), thrust can also be supplied externally in the form of a beam of light or high-speed (V) energetic particles (mass m), which bounce off the back side of the spacecraft.



Not obliged to pack fuel in this case, but can be very inefficient unless the beam can be kept from diverging (particles miss the spacecraft).

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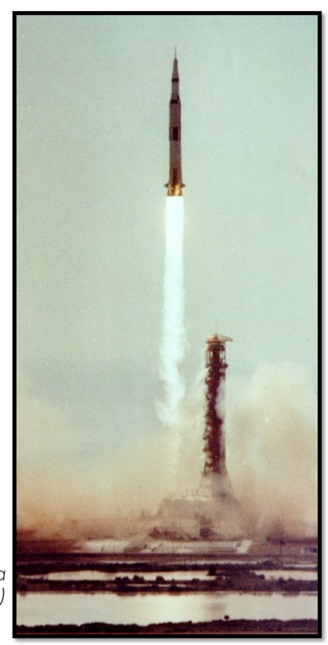
Space flight



Along with instruments, communication equipment, fuel, and gifts for the leaders of the civilizations that we expect to encounter, the spacecraft has to carry either

- Nothing, if it is unmanned
- Many years of food and life-support systems for human passengers, if it is manned

These life support systems must include artificial gravity and immense radiation shielding in order to keep the passengers alive.

Launch of Apollo 11 in 1969 on a mighty Saturn V booster (NASA)

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Space flight

When designing an interstellar spacecraft, two restrictions immediately apply:

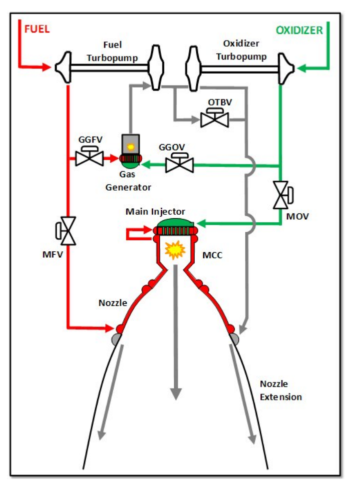
- Solar panels provide negligent power when the spacecraft is far from a star. Therefore, a long-lived power source needs to be packed.
  - Like NASA's SAFE-400 nuclear reactor: 100 kWe, 512 kg.
  - For similar reasons, the "beam" form of thrust is currently considered extremely impractical for long trips.
- The interstellar medium is very poor in material of any sort, particularly of anything that would make a good propellant. A sufficient supply of your own propellant must also be packed.
  - Some propellant schemes – the ion-drive sort – would demand additional onboard power generation.

Conventional space flight

There are two primary propulsion systems currently in use:

1. **Thermal impulsive thrust generation** (a.k.a. **rocket drive**), in which a fuel is ignited and the released heat accelerates the propellant.

- Pros of rocket drive:
  - Can generate a great deal of thrust and thereby launch substantial payloads from Earth
  - Power source and propellant are the same thing; no other power source needed
- Cons of rocket drive:
  - Rather low efficiency
  - Generation of large **specific impulse** (high speed) requires prohibitively large amounts of fuel



Schematic diagram of the J-2X rocket motor (NASA)

Conventional space flight

2. **Electrostatic or electromagnetic thrust generation** (a.k.a. **ion drive**), in which the propellant is accelerated by electric and/or magnetic fields.
   - Pros and cons of ion drives are the opposite those of rocket drives
     - Efficient relative to other propulsion mechanisms
     - Cannot generate much thrust, but can generate very large specific impulse, simply because they can run almost indefinitely on a reasonable supply of propellant

Hybrid approach: *Dawn* was launched with a rocket but maneuvers from orbit to orbit with an ion drive.

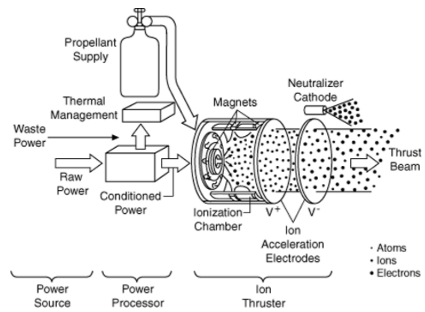


Diagram of Dawn's ion drive (JPL/NASA)

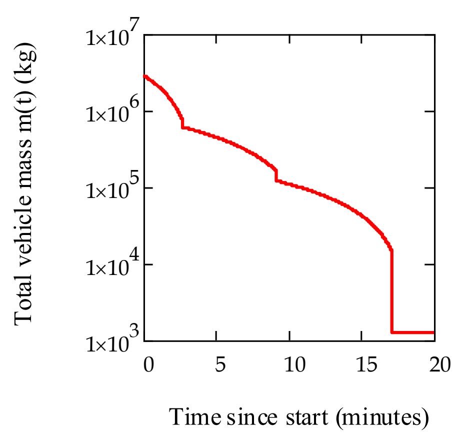
Ion drives v. rockets

Start the two vehicles with the same mass

- 43 NSTAR ion drives and a SAFE-400 reactor
- Saturn V rocket

Accelerate as long as they are producing thrust

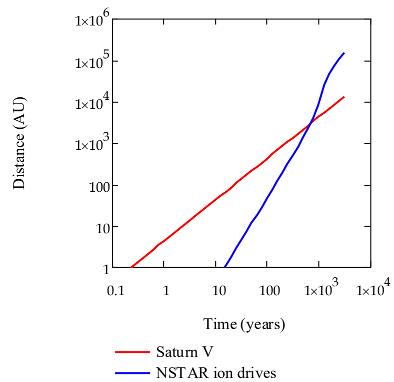
- Their masses decrease as they go and use up fuel, so the acceleration changes with time

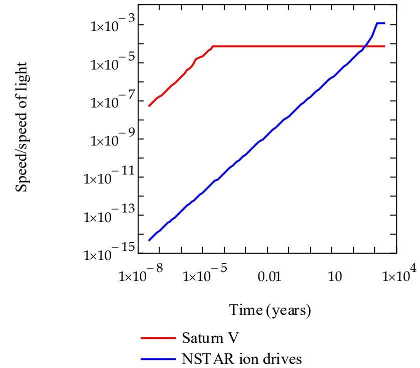


Mass of the rocket-powered vehicle, as the Saturn V expends and ejects its three stages

Ion drives v. rockets

Result: the Saturn V can get anywhere within the Solar System faster than the *current* NSTAR ion drives, but eventually the ion drive goes further and flies faster.





Conventional space flight

The fastest we have been able to travel so far is $8\times10^{-5}c$ via a combination of impulsive thrust and gravity boost on a small unmanned spacecraft.

This is the NASA *New Horizons* mission to Pluto, Charon, and a random Kuiper belt object, 2014 MU69. This spacecraft weighs about 1,000 lb in total.

- Thrusters are insufficiently powerful to insert the spacecraft into orbit around Pluto; it merely conducted a flyby.

Of course, much more energy (and thrust) per gram of fuel would be liberated by using the fuel's **nuclear energy** instead of its chemical energy.

Several proposals for nuclear-blast-propelled spacecraft have been fleshed out.

Nuclear-propelled space flight

Example: Liberate energy in the form of either heat or light from 1000 kg (1 metric ton) of anthracite coal.

- Chemical energy: burn it (turns it all into CO_2 and H_2O):
$$\Delta E = 4.3 \times 10^{17}\ \mathrm{erg} = 10\ \mathrm{t}$$
- Nuclear energy: maximum-efficiency fusion in the core of a star (turns it all into iron):
$$\Delta E = 4.1 \times 10^{24}\ \mathrm{erg} = 100\ \mathrm{Mt}$$

This point has not been lost on scientists trying to invent better means of propulsion.

- The ultimate means of impulsive thrust: controlled explosion of nuclear weapons, specifically high-yield H bombs.

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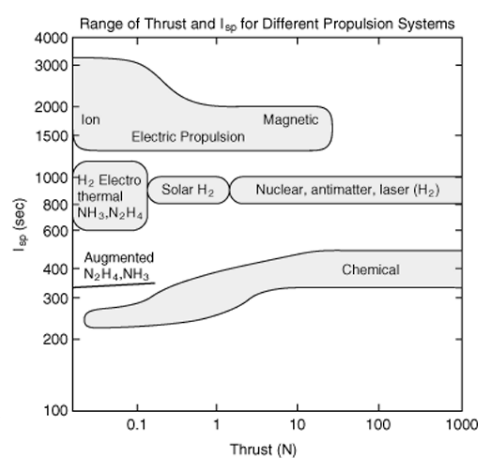
Conventional space flight

If we had to do it tomorrow, we would use

- Rocket-powered launch vehicles to assemble spacecraft in orbit
- Nuclear-blast propulsion to escape solar system
- Ion drive, powered by an onboard nuclear reactor, to accelerate up to a fair fraction of the speed of light



Thrust and specific impulse for various propulsion schemes (JPL/NASA).

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Unconventional space flight

Even if all of this works, it takes many years to even get to the nearest stars. What of the bold ideas proposed by science-fiction writers for faster-than-light travel, like warp drive and wormholes? Are they plausible?

No. But, if you insist…

In principle they work and provide a means to travel the Galaxy on the time scale of human lives.

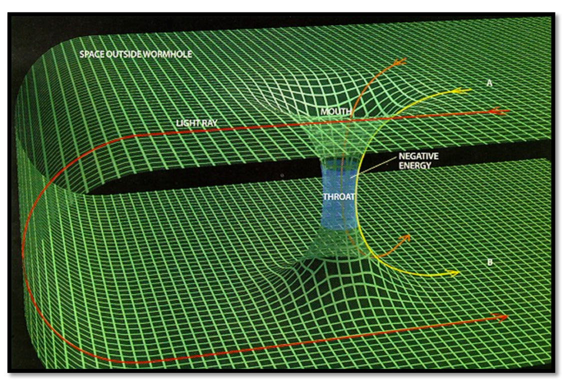
They hinge upon warping space-time to provide shortcuts through space-time, with acceleration and deceleration provided by gravity: no propulsion required.

Unfortunately, they all require **exotic matter** – matter with negative energy density – and we have no idea how to make this unless we have a black hole in hand.

Wormholes

Wormholes are the solutions to the Einstein field equations of general relativity that (potentially) involve shortcuts through spacetime.

- If a wormhole has mouths in two locations, traveling between these locations through the wormhole can be **orders of magnitudes faster** than traveling “beside” the wormhole at the speed of light.
- One way to think of wormholes: a special overlap between the interiors of widely-spaced black holes.
- We cannot manipulate black holes – for which masses start at a few solar masses – and thus have no empirical evidence that this is possible.



For more information, consult the relevant parts of AST 102, available next semester.

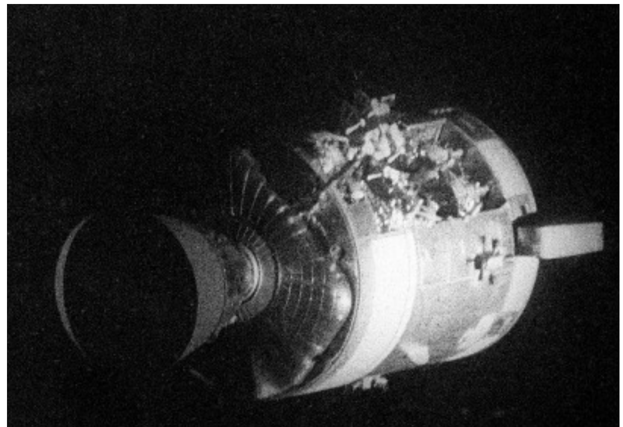
Space is a hostile environment

574 humans, from 38 countries, have been in outer space:

- 12 suborbital, 562 in Earth orbit
- 24 beyond low Earth orbit
- 12 walked on the Moon
- 150.3+ person-years in space
- 191 person-days of spacewalks

This has led to at least 22 deaths, and a large and incompletely-recorded number of injuries and illnesses.

- 98% of astro/cosmonauts have reported "medical events."



Apollo 13's damaged service module, after jettisoning (NASA JSC)

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Space is a hostile environment

The relevant concerns of space medicine:

- **Environmental** →
- Physiological
- Psychological
- Occupational
- Social/cultural
- Communicational

Microgravity
Oxygen requirements
Hypothermia/hyperthermia
Water requirements
Nutritional requirements
Waste disposal – trash management
Radiation

Ureles (2010)

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Space is a hostile environment

The relevant concerns of space medicine:

- Environmental
- **Physiological** →
- Psychological
- Occupational
- Social/cultural
- Communicational

Acceleration, vibratory, acoustic
Weight loss
Fluid shifts
Vestibular
Loss of muscle mass
Osteopenia-osteoporosis
Slow wound healing
Hematologic changes
Immunological
Microbiological
Endocrine

Ureles (2010)

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Space is a hostile environment

The relevant concerns of space medicine:

- Environmental
- Physiological
- **Psychological** →
- Occupational
- Social/cultural
- Communicational

Stress
Anxiety
Fear
Lack of privacy
Depression
Sleep disorders →
Maladaptation
Psychosexual

Sunrise/sunset *q* 90 minutes (Shuttle)
Excitement
Position
Mechanical & human noise
Circadian rhythms – light/dark – cortisol
Insomnia – cognitive impairment
Sedatives v. melatonin

Ureles (2010)

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Space is a hostile environment

The relevant concerns of space medicine:

- Environmental
- Physiological
- Psychological
- **Occupational**
- Social/cultural
- Communicational

Trauma: in-cabin crowding, floatation

Work overload: fatique

Space walking: art, balance, dangers

Competition: numbers v. opportunities

Suit puncture: loss of consciousness in 9-12 s, death within 2 min

Ureles (2010)

Launch

Vibration (sub-audio frequencies):

- Humans are most sensitive to vibration frequencies of 4-10 cycles per second, as this is the range of natural resonance frequencies of the major internal organs.
- Brief experience: pain, nausea, headache, and dizziness
- Prolonged exposure: organs begin tearing away from the mesentery

Noise at audio frequencies:

- Maximum tolerance for noise is 140-150 dB (> for longer than a minute = permanent deafness)
- Space boosters generate 145-175 dB during lift-off.

Immediate post-launch

Deep space is reached in 3-8 minutes. Immediately, you begin to experience the effects of the dreaded Space Motion Sickness (SMS).

- > 70% of crew members get SMS.
- Onset in first 48-72 hours of the mission
- Greater in larger space vehicles (known in part to the experiences of John Glenn)
- Head fixation and eye control help avoid it, as does dramamine
- May recur on return to Earth ☹

Early in the flight

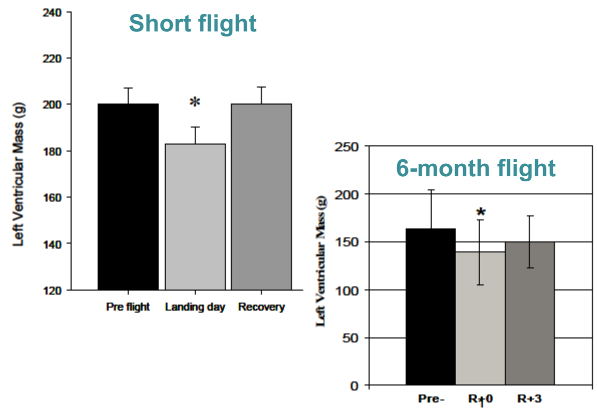
Possibly connected to the causes of SMS, **fluid shifts** soon occur as the circulatory system responds to microgravity (Leach Huntoon et al. 1996, *Humans in Spaceflight, book 2*).

- "Wet brain" encephalopathy reminiscent of thiamine deficiency in chronic alcoholics
- Cephalad fluid shifts: visual impairment, intracranial pressure (see also Otto et al. 2011)
- Nasal and sinus congestion; general facial swelling
- Blood-plasma hypovolemia (relative dehydration): promotes kidney-stone formation (see also Sibonga et al. 2008), reduces red-cell mass (anemia)
- Cardiac and jugular-vein distension which, over longer terms, may be expressed as **congestive heart failure**
- **Orthostatic intolerance** – inability to maintain blood pressure while standing – during re-exposure to gravity. This gets worse the longer the exposure to microgravity, and it seems to be worse for women than men.

Early in the flight

Muscle loss also starts up right away…
- 10-20% of muscle mass is lost on short flight missions
- Loss of muscle tone and strength; deconditioning within 5 days and is progressive with time in space
- Loss of muscle volume – atrophy rate of 5% per month

…even cardiac muscle!
- At right: left ventricular mass in six astronauts before flight, at landing, and 3 days later (Platts et al. 2010)



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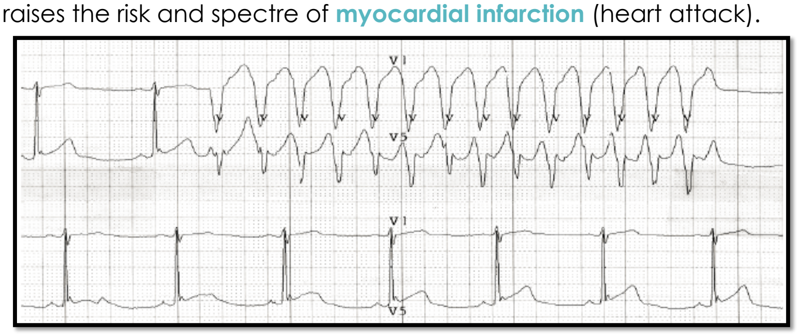
Early in the flight

The microgravity effects on the autonomic nervous system combine with those of plasma hypovolemia and cardiac muscle loss to produce **cardiac arrhythmia** (atrial fibrillation, tachycardia…)

This, in turn, raises the risk and spectre of **myocardial infarction** (heart attack).



Record of a brief interval of ventricular tachycardia in a Mir crewmember (Fritsch-Yelle et al. 1998)

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Early in the flight

Microgravity's effects on joints and bones:

Spinal unloading: the spine elongates when gravity is not compressing it, usually by 1-2 inches.

- Astronauts first notice this early in missions when their space suits feel as if they have suddenly shrunk.
- Moderate to severe back pain in flight experienced by 68% of astronauts (Sibonga et al. 2008a)
- Has led to herniated intervertebral disks and spinal cord compression

Bone loss due to unloading: bone mass decreases at the rate of about 1% per month in microgravity. (Not to be confused with the loss of bone *density*.)

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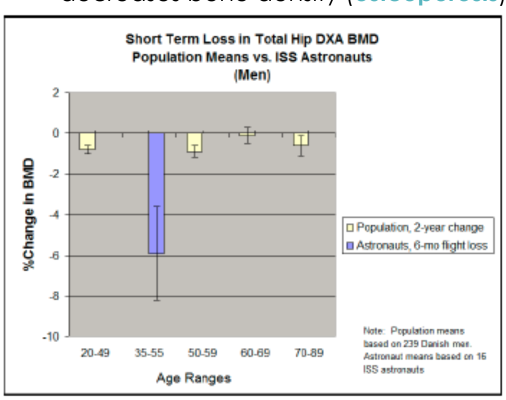
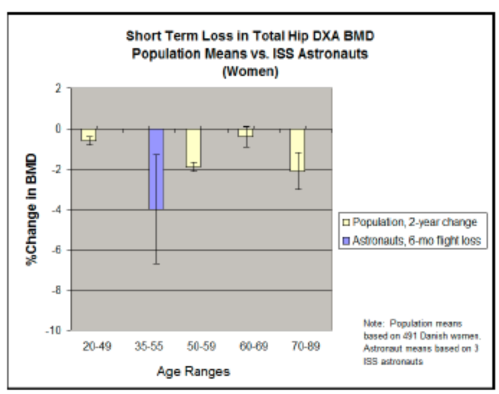
Early in the flight

Bone weakening: Microgravity induces an increased loss of calcium, which in turn decreases bone density (**osteoporosis**) and bone strength.





Bone mineral density change in six months for ISS astronauts compared to that in two years for the general population (Sibonga et al. 2008b)

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Later in the flight, and accumulating

Perhaps the most dangerous effects are those of high-energy, ionizing, and atom-displacing radiation: **cosmic rays**.

- Most GeV radiation is the Solar System:
  - Protons 90%
  - Alpha particles 9%
  - HZEs (heavy nuclei) 1%

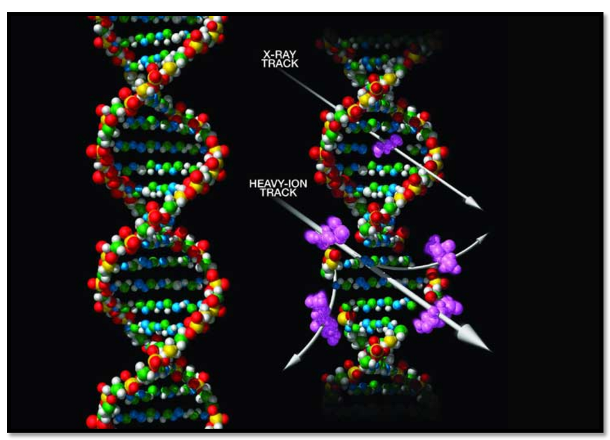
The HZE cosmic rays are the worst.

- No place in deep space is free of this cosmic radiation.
- Travel at near-light speed – as required for exploratory trips either propelled or mediated by wormholes – increases the energies involved and makes the shielding problems practically insurmountable.

Later in flight

If you were on your way to Mars (which would currently take about 9 months),

- About 30% of the cells in your body would be traversed by HZE cosmic rays with Z between 10 and 28.
- To say nothing of the coronal-mass-ejection photons!
- Much worse than X-rays
- The biological effects of HZE nuclei on cancer induction, the central nervous system, and the eyes are even worse in microgravity than otherwise.

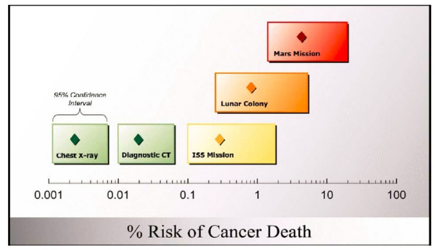


Later in the flight

Risks from Galactic cosmic rays and stellar storms:

- Acute central nervous system (CNS) effects: reduced cognitive and motor function, behavioral changes
- Late CNS effects: dementia, such as early-onset Alzheimer's disease
- Degeneration of tissue with low blood circulation, prominently in the eye's lenses (cataract formation)
- Degeneration of cardiac and vascular tissue, leading to such things as atherosclerosis.
- Acute radiation syndrome: nausea, anorexia, and fatigue, followed by shut-down of the blood-forming organs.
- Acceleration of all aging effects: digestive, respiratory, endocrine, and immune system
- And, probably most famously, carcinogenesis

(Cucinotta et al. 2009, Huff & Cucinotta 2009, Wu et al. 2009)



Risk of death from cancer in Solar System space flight (Cucinotta & Durante 2009)

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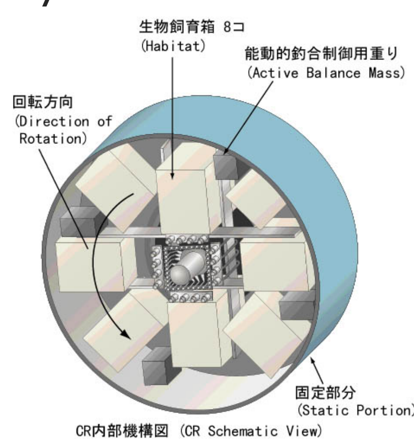
Basic requirements for human space flight to Mars and beyond

1. **Artificial gravity**, full time:
   - Can do with the classic centrifuge concept, but this is bulky, heavy, and expensive (~10 m radius, ~100 tons all by itself)
2. **Radiation shielding**, especially in the forward direction
   - Probably **kilotons** of high-Z shield (e.g. lead), as magnetic shields would need fields both difficult to generate and dangerous to humans (Parker 2005)

It currently costs about $1M to launch a 1 kg brick into space. More, if more complex.



Small centrifuge designed for life science experiments on ISS: would have been 1.25 m in radius and weighed about one ton (JAXA)

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Have we been visited or contacted?

If cost is the main issue: it is possible that other civilizations have solved that problem by now.

So, have extra-solar civilizations contacted or visited us?

Easy answer: **NO**

- In fifty years of SETI, we have yet to receive our first signal from intelligent civilizations on other planets. You will hear about it loud and clear as soon as we do.
- We expect communication to be more frequent than visits, of course.
- There are no credible reports of visits by extraterrestrial space travelers to Earth, nor credible evidence that this happened at any point in our past.

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"But scientists may be concealing evidence of communication by extraterrestrials!"

Scientists – especially astronomers and those involved in SETI – would be the first to detect signals from extraterrestrials…

- Not the military! They are looking down, not up.

…and would publicize confirmed communications.

- No scientist is obligated by contractual terms to conceal such information or place it first at any government's disposal, at least here and in western Europe.
- The culture of science is such that correct results are *very* hard to conceal, and scientists are provided a great incentive to be the first to reveal important results. And to check each other's results for correctness and completeness.

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"But all those reports of UFOs cannot be wrong!"

Just because a flying object is unidentified does not mean it comes from outer space and carries intelligent beings.

A cautionary tale:

- Before WWII, reports of mysterious flying objects were infrequent and essentially always explicable in terms of natural phenomena.
  - Notably comets and meteors, which do come from outer space but are not carrying or concealing intelligent beings from outer space.
- During WWII, the number of aircraft and balloons in the air increased by many orders of magnitude. This led to a greater notice of flying objects by people.

Comet 1P/Halley, in 1066 (left, Queen Mathilde) and 1986 (below, Giotto/ESA)

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"But all those reports of UFOs cannot be wrong!"

The US Air Force conducted a study of the reports (Project Blue Book, 1948-1968) to see if there was credible evidence of visits by aliens, which would have been a security risk.

- In 21 years, they investigated almost 13,000 reports, plausibly identifying all but about 700 as natural phenomena or known aircraft.
- The others involve shaky evidence, not mysteries.
- Thus, the Air Force concluded that there was no evidence of either alien visits or a security risk.

This was not enough for the UFO zealots, who pestered the Air Force and Congress with tales of cover-ups and conspiracies.

So, the Air Force recommended, and Congress approved, an independent research-university study of Blue Book and other evidence. The lead was taken by famous atomic physicist Edward Condon (U. Colorado) and the results go by the name of the Condon Report (1969).

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"But all those reports of UFOs cannot be wrong!"

Summary of the Condon Report:

- No credible evidence of visits to Earth by extraterrestrials
- Not even any reports sufficiently mysterious that there could be other scientific interest in their further study
- In essentially all of the cases, the sightings were of aircraft, human-deployed spacecraft, or natural phenomena.

This was still not good enough for some, so the Condon Report was referred to the National Academy of Sciences for a review.

- The eleven members of the NAS panel reviewed the Condon Report – the study's methods and results – and found themselves unanimously in complete agreement with the report and its conclusions.

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