Making Terran's Interstellar

Jenna, Zero, Tristan, and Max

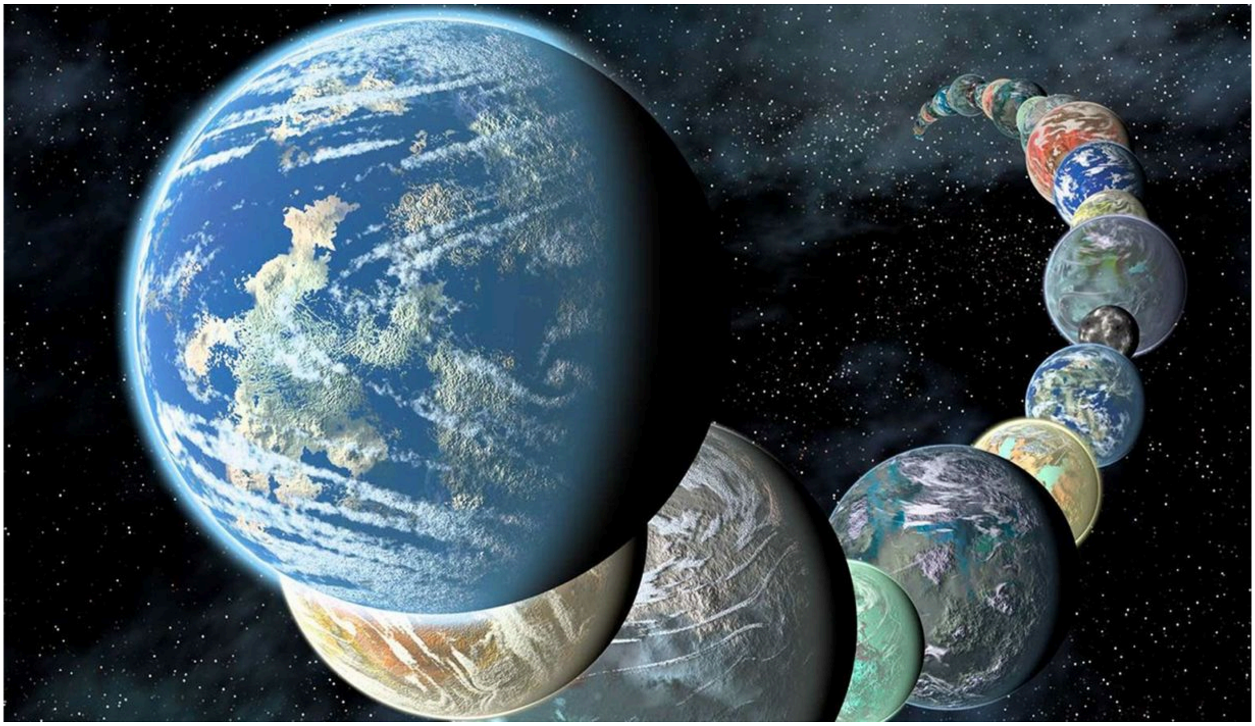


Figure 1-1: Artist's concept of potentially habitable rocky planets. Retrieved from https://science.nasa.gov/exoplanets/terrestrial/

Exoplanets

- To find a new home for Terrans, we need to first look at the different types of exoplanets.
- **Exoplanets** are any planet outside our solar system (NASA, 2024a).
- 4 types of exoplanets (NASA, 2025a):
    1. **Gas Giants:** large planets composed of mostly hydrogen and helium (Jupiter, Saturn).
    2. **Neptunian:** smaller than gas giants, hydrogen and helium atmospheres, metal cores (Neptune, Uranus).
    3. **Terrestrial:** Rocky planets, composed of rock/iron, solid/liquid surface, approx ½–2x size of Earth, may have atmospheres (Mercury, Venus, Earth, Mars).
    4. **Super-Earth:** Terrestrial planets >2x Earth mass but less than Neptune/Uranus.
- Currently 6000+ known exoplanets (NASA, 2024a).

- **Potentially habitable planets:** rocky planets between 0.5 and 1.6 Earth radii (or 0.1 to 3 Earth masses) that have the potential to harbour liquid water (orbit within habitable zone) (PHL @ UPR Arecibo, 2024).

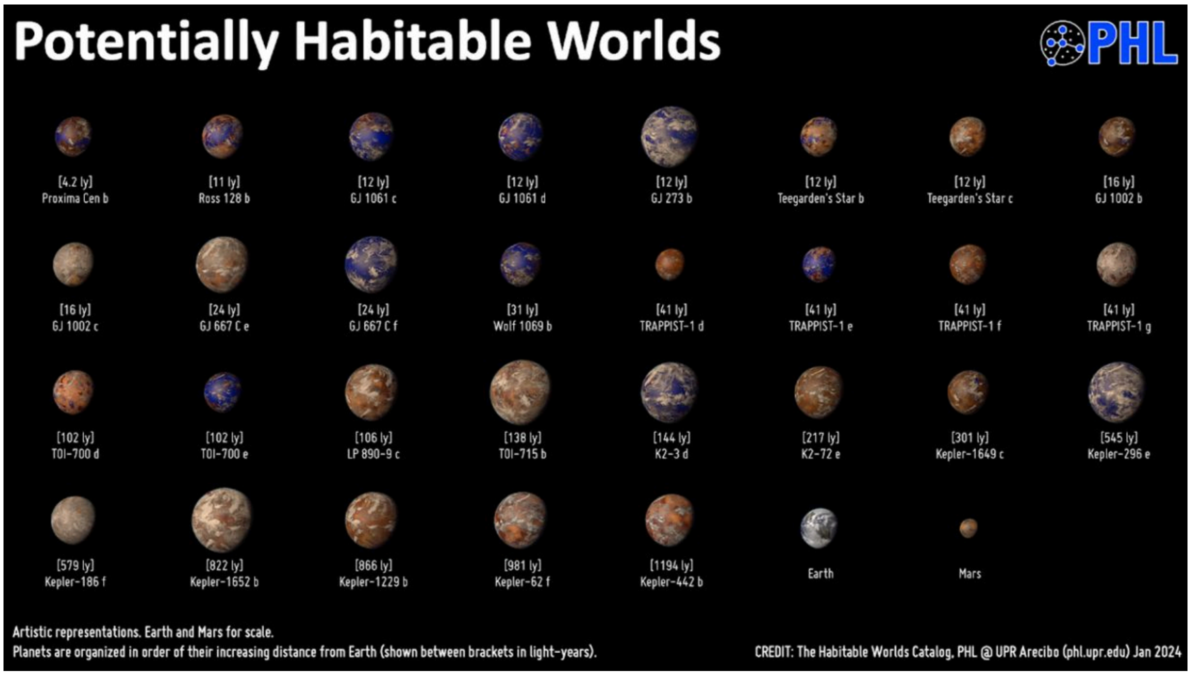


Figure 1-2: Potentially habitable worlds. Retrieved from https://phl.upr.edu/hwc

Stars Types

- Habitability of these planets depends also on the stars they orbit (NASA, 2024c).
- **Yellow-dwarfs** (NASA, 2024c):
  - Sun-like stars clearly have potential to host life.
  - Relatively rare in our galaxy.
  - Shorter-lived (~10 billion years) than other stars.
- **Red-dwarfs** (NASA, 2024c):
  - Most abundant stars in our galaxy.
    - 10 red-dwarfs for every 1 yellow-dwarf.
  - Live for ~100 billion years.
  - Smaller and cooler than Sun-like stars.

        - Planets must orbit much closer to be within the habitable zone.
            - The surface can receive 400x more radiation than Earth.
    - Very active stars (frequent, powerful flares).
- **Orange-dwarfs** (NASA, 2024c):
    - Best stars for habitability.
    - Wider habitable zone than red-dwarfs.
    - More common than yellow-dwarfs (3:1) and live longer (~40 billion years).
    - Only 2 potentially habitable planets orbit orange-dwarfs, both around 1000 ly away (PHL @ UPR Arecibo, 2024).
- To prioritize proximity over certainty, we look at the closest star system to Earth that just so happens to host all 3 of these star types.

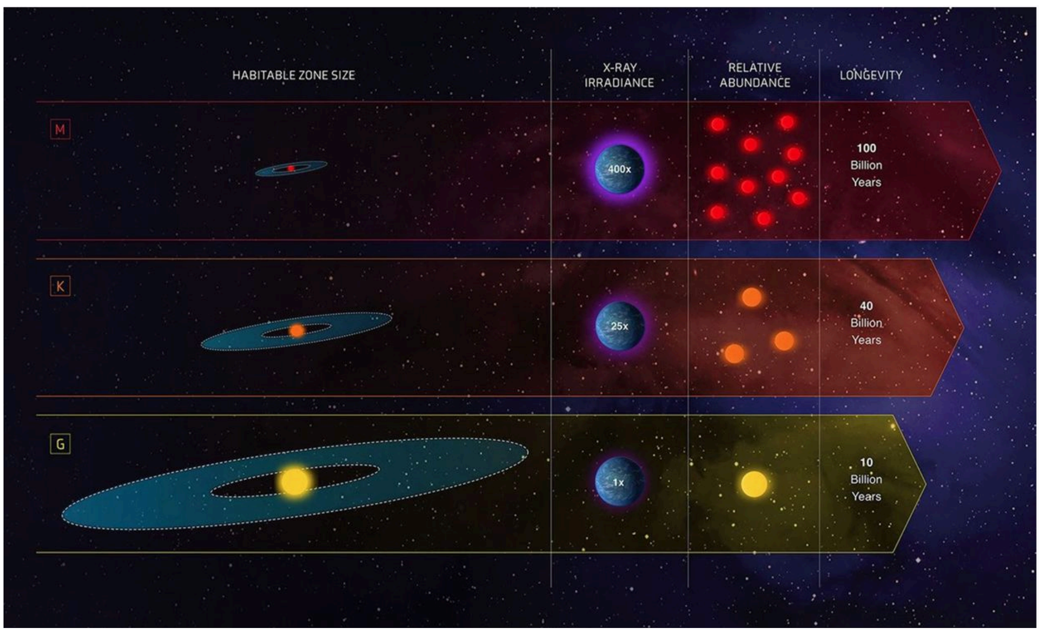


Figure 1-3: Characteristics of red, orange, and yellow-dwarfs. Retrieved from https://science.nasa.gov/exoplanets/habitable-zone/

The Alpha Centauri Stellar System

- ~4.3 ly away (NASA, 2018).
- Visible in the constellation Centaurus (Southern sky) (Andreoli, 2013).

- **Alpha Centauri A:** yellow-dwarf, $1.1M_{\odot}$ (NASA, 2023).
    - $M_{\odot}$ is 1 solar mass (the mass of the Sun)
- **Alpha Centauri B:** orange-dwarf, $0.9M_{\odot}$(NASA, 2023).
- **Proxima Centauri**: red-dwarf, $0.125M_{\odot}$ (NASA, 2018; Andreoli, 2013).
    - Closest star to Earth (Andreoli, 2013).

Alpha Centauri AB

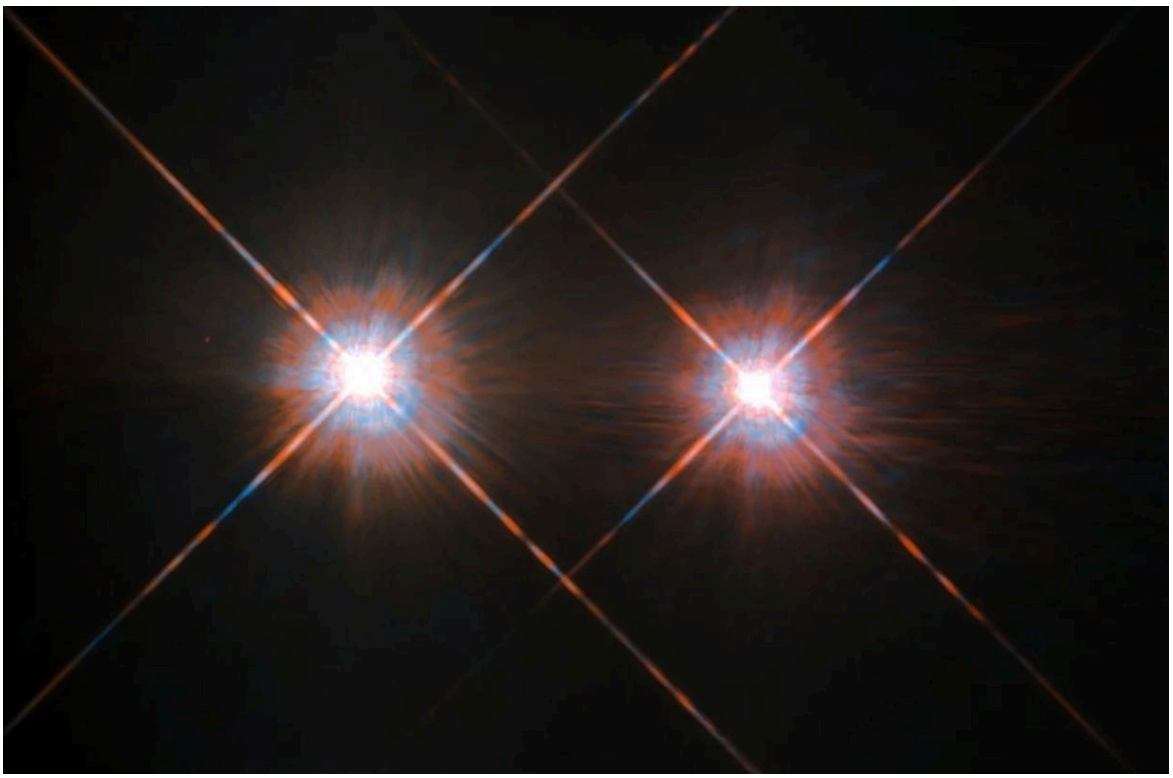


Figure 1-4: Alpha Centauri A (left) and Alpha Centauri B (right). Retrieved from https://science.nasa.gov/missions/hubble/hubbles-best-image-of-alpha-centauri-a-and-b/

- Alpha Centauri A and B are our primary targets.
- Binary pair: orbit a common centre of mass every 80 years (Brennan, 2025).

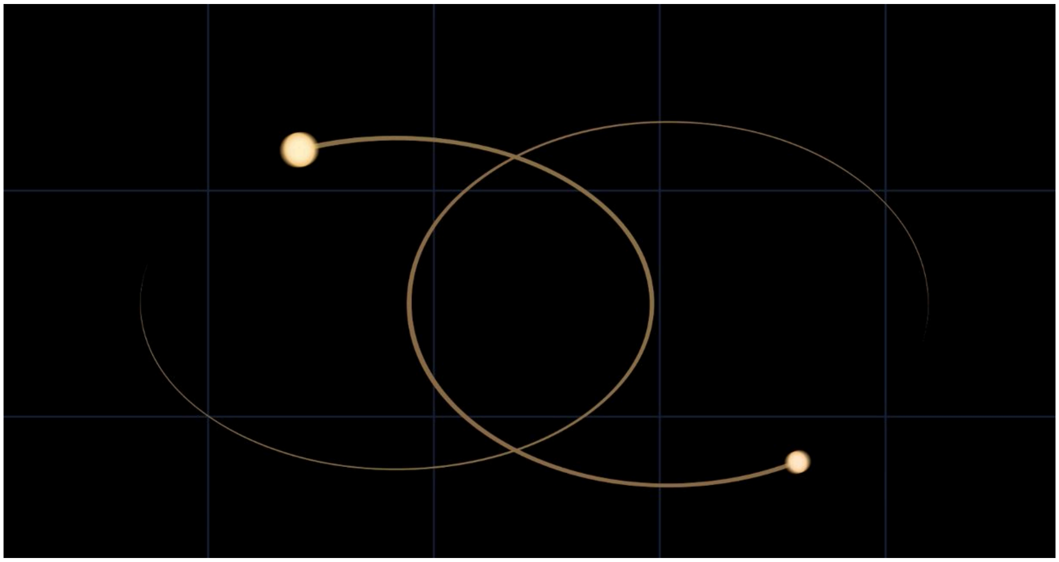


Figure 1-5: Alpha Centauri A and B orbiting each other. Retrieved from https://science.nasa.gov/exoplanets/other-stars-other-worlds/our-nearest-celestial-neighbor-an-exotic-3-star-system/

- Planets within the habitable zone of either of these stars likely receive similar amounts of radiation as Earth (NASA, 2018).
- Problem: their combined light essentially blinds telescopes from Earth, and they move across the sky quickly (NASA, 2018).
- No planets orbiting either star have been **confirmed** (NASA, 2018), but the JWST recently found strong evidence of a gas giant orbiting within Alpha Centauri A's habitable zone (NASA, 2025b).
- This planet is around the mass of Saturn, which has 274 moons (NASA, 2025b; NASA, 2024b).
- A gas giant within Alpha A's habitable zone potentially means hundreds of exomoons within the habitable zone.

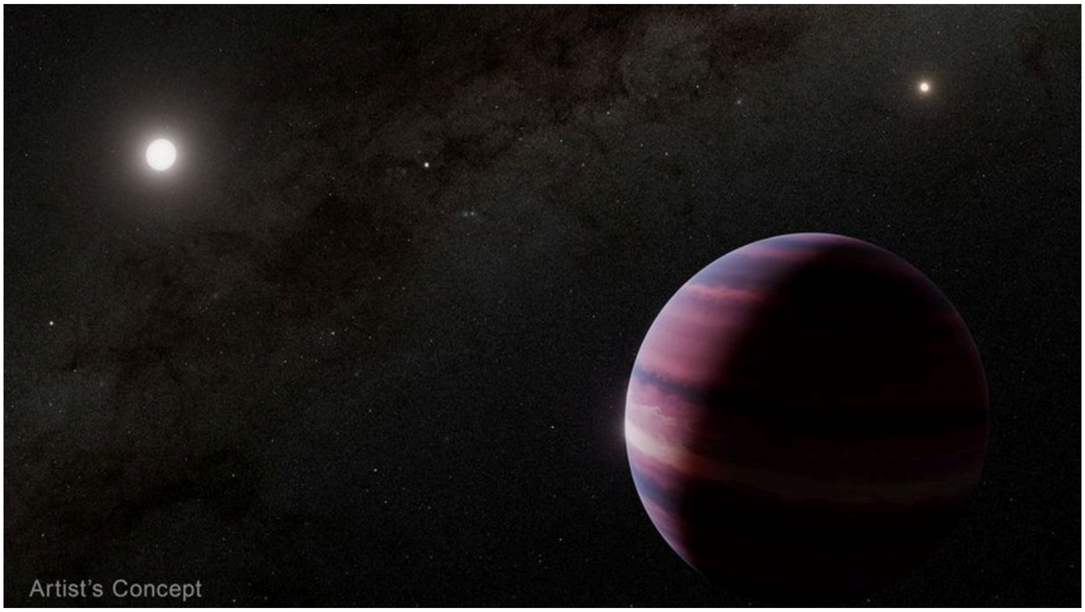


Figure 1-6: Artist concept of gas giant orbiting Alpha Centauri A. Retrieved from https://science.nasa.gov/missions/webb/nasas-webb-finds-new-evidence-for-planet-around-closest-solar-twin/

Exomoons

- 5 moons in our solar system have strong evidence of subsurface oceans (Hill, 2018). A moon within the habitable zone allows liquid water to exist right on the surface.
- Exomoons orbiting gas giants can potentially be more habitable than exoplanets (Hill, 2018).
- 3 different energy sources (Hill, 2018):
  1. Sunlight from their star.
  2. The gas giant reflects that sunlight and radiates its own heat onto the moon.
  3. The planet's gravity pulls on the moon's crust and heats it from within.
  ➔ This gives a more stable environment over a longer period of time.
- Gas giants have a large magnetosphere that can protect their moon's atmosphere from stellar winds (Hill, 2018).
  - If the moon has a magnetic field and atmosphere, this increases the chance that it isn't stripped away.

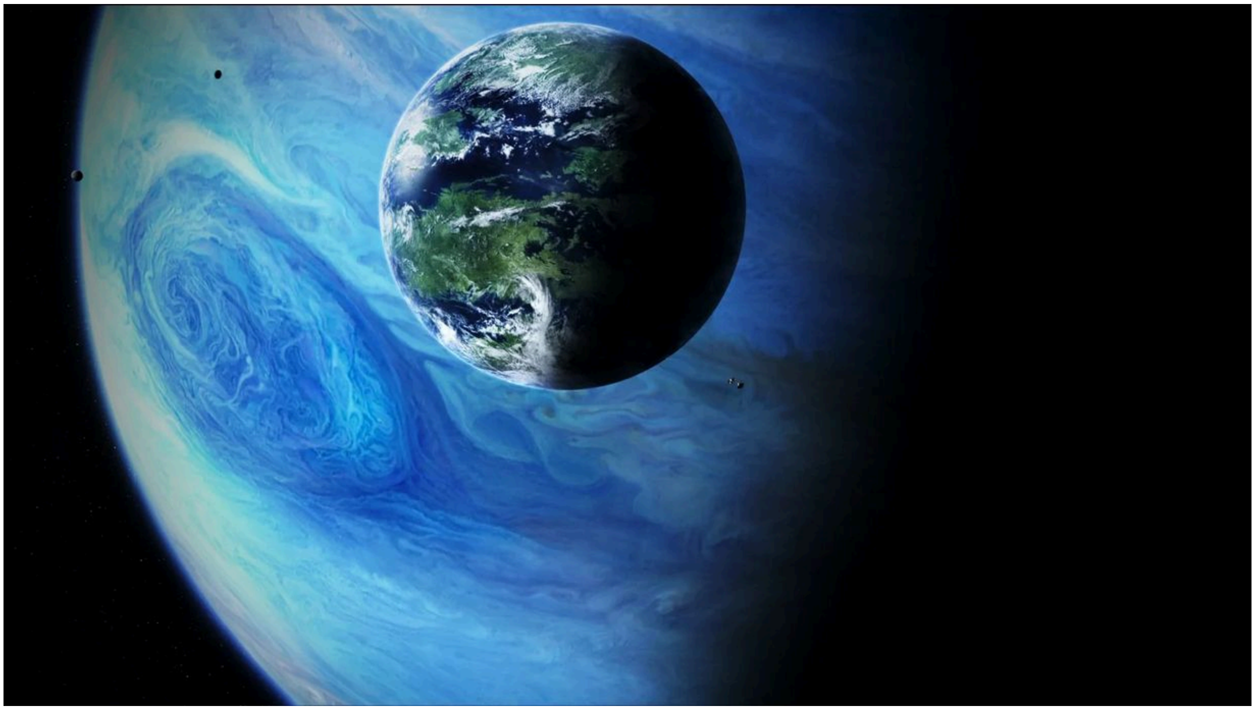


Figure 1-7: Habitable exomoon orbiting gas giant. Retrieved from https://screenrant.com/avatar-movie-franchise-future-earth-details/

- What if we don't find any planets around Alpha A or B?

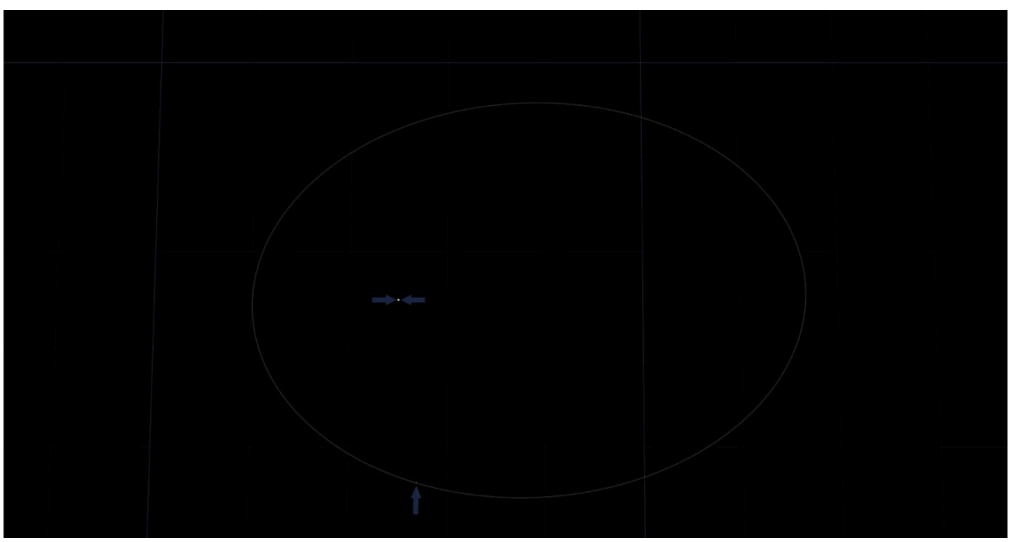


Figure 1-8: Proxima Centauri’s orbit around Alpha Centauri AB. Retrieved from https://science.nasa.gov/exoplanets/other-stars-other-worlds/our-nearest-celestial-neighbor-an-exotic-3-star-system/

Proxima Centauri

Figure 1-9: Proxima Centauri. Retrieved from https://science.nasa.gov/asset/hubble/proxima-centauri/

- Proxima Centauri hosts the closest potentially habitable planet to Earth: Proxima Centauri b (NASA, 2024d).
- **Proxima Centauri b:**
  - Super-Earth (approximately 1.02 Earth Radius and 1.055 Earth mass) (NASA, 2024d)
  - Assumed to be 86% similar to Earth (PHL @ UPR Arecibo, 2024)
  - Because Proxima is a red-dwarf, Proxima b orbits only 0.04 AU from its star. This means the surface of this planet likely receives high amounts of radiation (NASA, 2024d)
  - How do we survive this kind of radiation?

How Human Can Survive in Outer Space -Zero

(Slide 1)

Figure 2-1: Astronauts exercising inside the Space Shuttle Retrieved from https://www.nasa.gov/missions/station/iss-research/counteracting-bone-and-muscle-loss-in-microgravity/

Human body vs Outer space environment
(Human concerns in outer space)

Loss of muscle mass and bone density

●For every month in space, bones become roughly 1% less dense if they don’t take precautions to counter this loss.

- % difference in bone density: lumbar spine/pelvis −6.2%, lower limbs, −5.4% ,the rate of bone loss −0.8% per month

●Muscle loss of 10 to 20 % has been observed on short missions and, if no countermeasures were applied, this could go up to 50% on long duration missions.

Air/Oxygen (Vacuum space)

●"Humans, of course, cannot survive more than a few seconds while exposed to the vacuum of space" (Launius, 2010)

Following state when human go outer space without spacesuits

- Oxygen deficiency:low blood oxygen levels, become unconscious within seconds.
- Body swelling:swells up to about twice its body size.
- Boiling of body fluids (ebullism):damage to tissues

Radiation and Cosmic Rays

●DNA damage (mutation/cell death)

●Increased risk of cancer

(Slide 2)

Suggested Solutions

●Artificial Hibernation—purpose is longer survival human body: protect organs, tissues and nervous system+saving resources such as food, water, other supplies that maintain

●Cyborgization—replacing the human body components that are necessary for humanity to survive (e.g. the organs such as esophagus, lungs)in outer space with the corresponding parts as an idea.

(Slide 3)

Artificial Hibernation/Cryostasis

Hibernating Animal:Frogs freezing during hibernation - cryostasis.

- The brown tree frogs have reliably survived for 12 hours at -1 °C and withstand having up to 47.5% of their body water frozen.

There are 2 ways:

・Chemicals in the body that act as "antifreeze," usually glucose or glycerol.

- The substances lower the freezing point of water in the body, preventing freezing even when the temperature drops below 0°C.
- Rexer-Huber's team found that as the frogs were chilled, they produced extra glycerol, suggesting that glycerol is their antifreeze. They think that is to ensure their damage repair mechanisms had enough energy.

・ "Ice-nucleating agent (INA)", which requires the formation of an internal iced crystal in a controlled way so they don't damage the cells. The frog can both produce INAs in its skin and take them in from the soil. It's not clear what INAs the brown tree frog is producing.

How do INA and antifreeze have potential applications for humans?

Utilizing INA in artificial hibernation prevents "random ice formation" = "destruction of important cells during hibernation." This could potentially create a safe hypothermic state without completely freezing the body.

Regarding antifreeze, there are antifreeze proteins found in Antarctic fish, hibernating insects, and frogs that can revive even after freezing. These prevent cells from freezing, which could be extremely useful for long-term preservation of organs, blood, and cells.

However, at present, it is only applicable to organs and some human body components, making it a little unrealistic to protect the entire human body for long periods of time. So I think the next method has more potential.↓

・Three methods were proposed in a paper on the application of artificial hibernation to the treatment of spinal cord injuries.

Methods of using artificial hibernation in humans

① Hypothermia therapy: A method of lowering a person's body temperature to 32-34°C

- drugs and physical cooling→may cause complications
- Endogenous hibernation inducers and hibernation-related central neuromodulation

② Substances that induce hibernation (hibernation inducers)

- H_2S (hydrogen sulfide)
- Adenosine
- A substance found in the blood of hibernating animals
  →May potentially induce a state close to hibernation even in non-hibernating animals

③ Methods to directly control the brain

- Animal experiments have confirmed that stimulating the part of the brain that determines body temperature lowers body temperature and lowers metabolism.

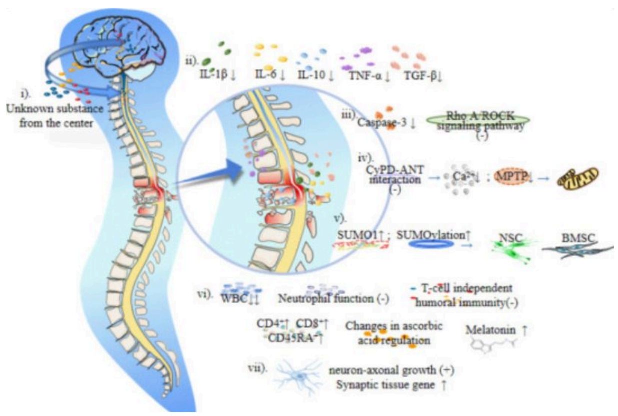
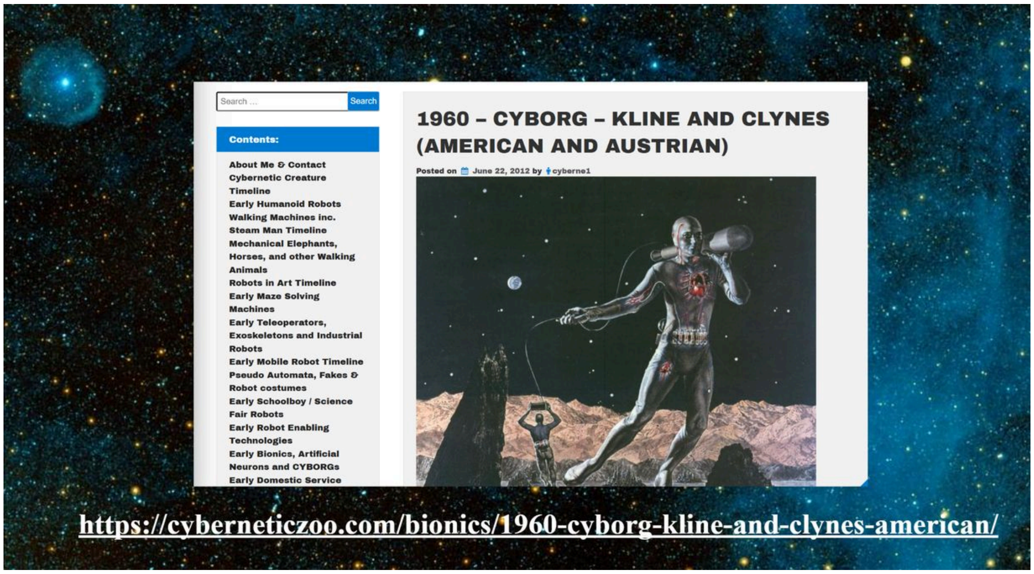
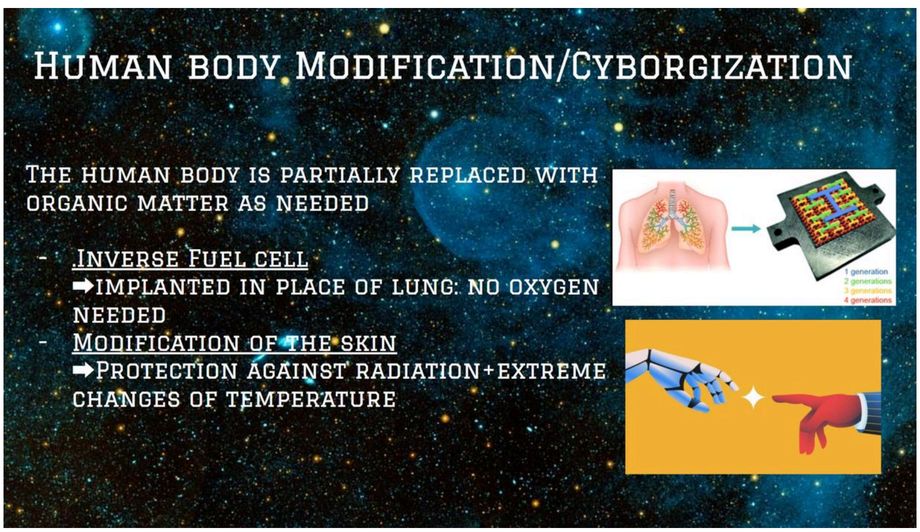


Figure 2-2:Mechanism of the artificial hibernation-induced neuroprotection after spinal cord injury. Retrieved from https://doi.org/10.4103/1673-5374.375305



(Slide 4)

-The idea of turning the human body into a cyborg has been around since the 1960s.



(Slide 5)

Human Body Modification/Cyborgization

●use of an inverse fuel cell, implanted in place of the lung, which would make conventional breathing unnecessary. →No need for oxygen.

●modification of the skin: adaptive response to extremes of temperature and increased exposure to radiation→Protecting the body from radiation and cosmic rays

Challenge
・Money→NASA choose not invest more funds in cyborg studies and keep distance from the concept since late 1960s
・Resources→As everyone considered, technical issues are a huge obstacle, so I can not assume the amount of resources required to make humans turn into cyborgs.

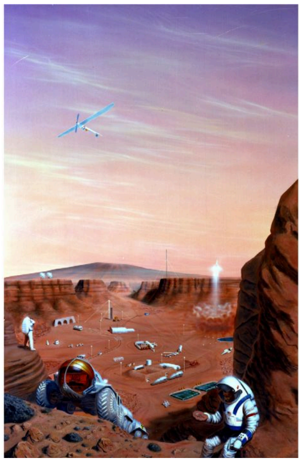


Figure 2-3: NASA has created a vision of space exploration in which humans would colonize the solar system. Retrieved from https://doi.org/10.1016/j.endeavour.2010.07.001

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Visual Effect of Light Speed Travel

Once in interstellar space, let's discuss what the journey will look like from the view of the spacecraft. When travelling at high speeds, special relativity along with how the human eye perceives wavelengths, provide an interesting phenomenon that can be split into two effects: aberration, and Doppler shift.

Aberration

This geometric effect describes how the photons emitted from distant stars appear to one moving at relativistic speeds. As one accelerates, the direction from which the photons are emitted appear to shift relative to the direction in which the traveler is moving. Below is a figure to help display this effect.

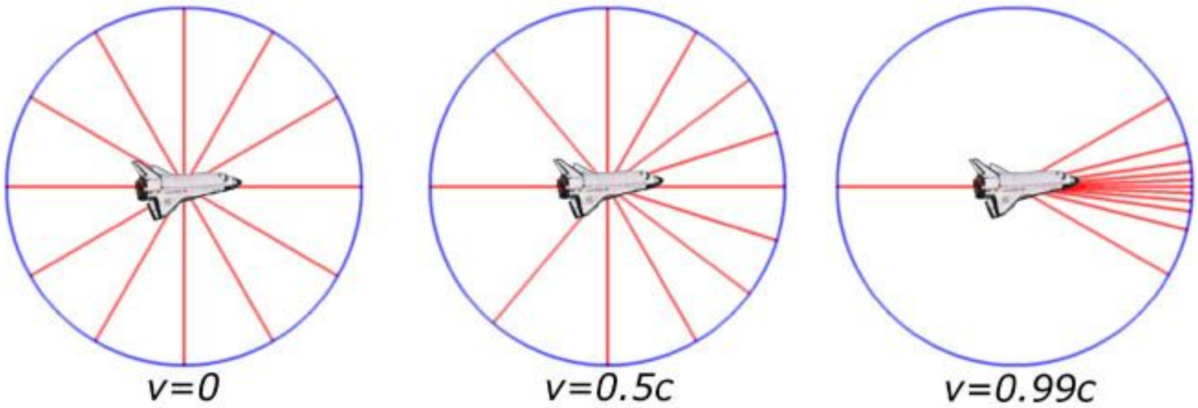

Figure 3-1: Effect of aberration at different speeds. Retrieved from https://math.ucr.edu/home/baez/physics/Relativity/SR/Spaceship/spaceship.html

On the far left, we are shown a spacecraft at rest with photons from 12 fixed stars surrounding it. Since the spacecraft has no velocity, the photons act as expected. The middle figure shows the same situation, but with the spacecraft moving at half the speed of light. The direction of the photons appear slightly skewed and coming from the forward direction. The effect is minimal since the Lorentz factor has an exponential graph (see above), with the strength of the relativistic effects only first appearing at 0.5 c (Arkos, lesson on Relativity).

The figure on the right shows the spacecraft at a velocity of 0.99c, and almost all the photons appear to be arriving from the front, despite originating from stars that are located beside or behind the ship. This is due to the fact that the photons get an added velocity component in the ship's inertial frame. This velocity component is in the opposite direction of the spacecraft's movement, which shifts the photons to appear to be coming from closer to the forward direction (Brandeker, 2002).

Doppler Shift and Beaming

Doppler shift refers to the light itself that is produced by stars. This effect was discovered by an Austrian physicist Christian Doppler in 1842, who found that this phenomenon occurs when a receiver of waves is in a different frame of reference than the emitter. As we have already learned, the light emitted from stars has to travel a vast distance to reach across our expanding universe, and when the light eventually reaches us, its wavelength is stretched and appears weaker (redshift). But how does this phenomenon apply to a relativistic interstellar traveller?

Since the spacecraft is heading towards the light source, rather than the light source being inflated away, the light emitted appears in shorter wavelengths, or blueshifted. Next , let's discuss beaming. This is related to aberration, and how the flux intensity is increased in the forward direction due to the spacecraft's velocity. As the spacecraft heads towards the stars, more photons are arriving, which results in a higher flux intensity. This causes the stars in front of the spacecraft to appear brighter, whereas the stars behind the ship get fainter as the ship moves away from them. Below is an example of what a traveller aboard this ship might see when approaching Orion, without taking aberration into account.

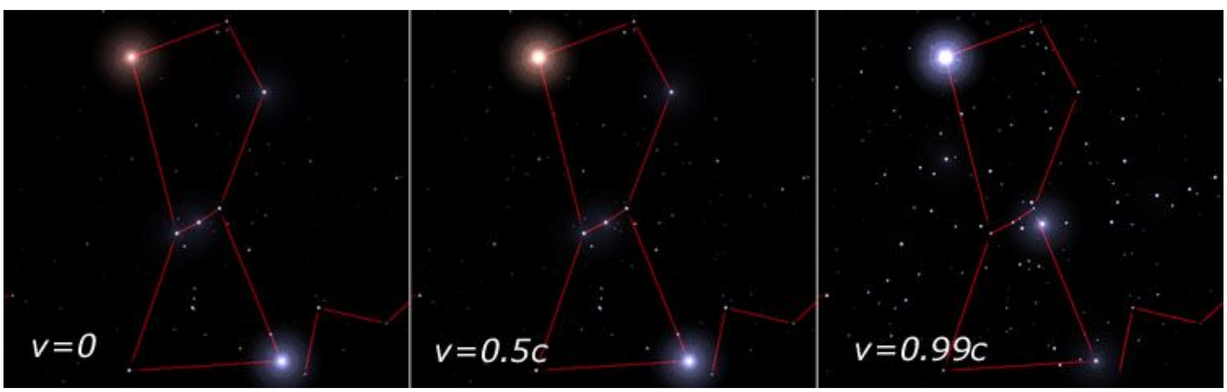

Figure 3-2: Doppler shift and beaming at different speeds. Retrieved from https://math.ucr.edu/home/baez/physics/Relativity/SR/Spaceship/spaceship.html

As the ship approaches the speed of light, the star's light intensity changes. This is highlighted when comparing the red supergiant Betelgeuse (upper left) with the blue supergiant Rigel (lower right). In the far left image, the stars appear of the same brightness, whereas in the far right image, Rigel is significantly dimmer than Betelgeuse. We can also see that the faint star on the lower right of Orion's Belt, the red giant star 31 Orionis, brightens as the velocity of the ship increases. What was originally a dim star now appears as the second brightest as we approach light speed.

Uniting the Geometric and Radiative Relativistic Effects

Combining both Doppler shift and aberration, the resulting image of the space surrounding our ship is much different that it is at rest. Below is an image of how the constellation Orion would be perceived while aboard a spacecraft travelling at different fractions of the speed of light.

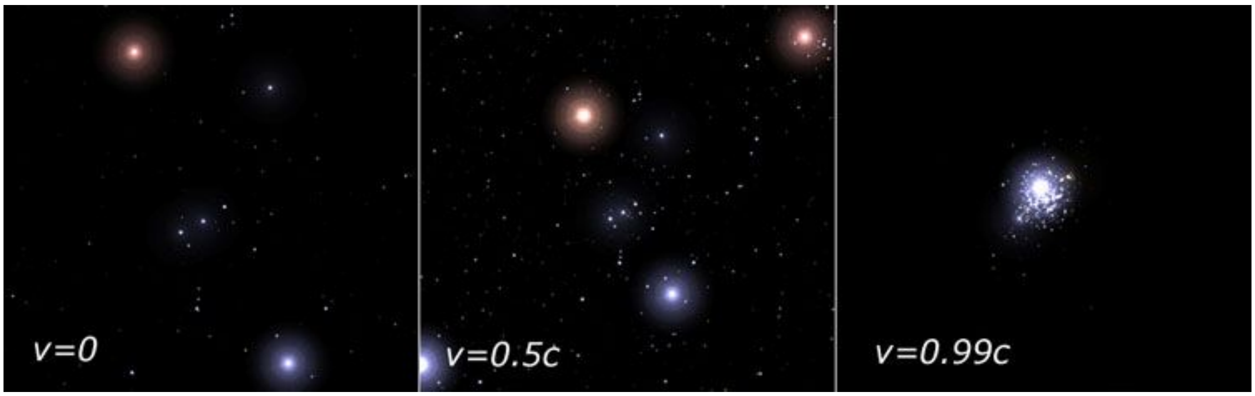

Figure 3-3: Both aberration and Doppler shifting at different speeds. Retrieved from https://math.ucr.edu/home/baez/physics/Relativity/SR/Spaceship/spaceship.html

Voyager Interstellar Mission

The Voyager Interstellar Mission (VIM) consists of two probes, Voyager 1 and Voyager 2, the only spacecraft in history to travel outside of the heliosphere. This mission began as a planetary mission, with flybys past Jupiter and Saturn, and eventually Voyager 2 extending its path to Uranus and Neptune. VIM began 12 years after the initial launch of the spacecraft in 1977. At this point, Voyager 1 was roughly 40 AU from the sun, with Voyager 2 about 9 AU's behind (NASA, 2025).

In order to reach interstellar space, the probes took advantage of the planetary alignment in order to use the gravitation assist of each planet to further propel itself outwards. This alignment occurs about every 176 years, and provides the probes with enough velocity to fling itself to the next planet, and therefore, further away from the sun's gravitational pull.

Once past the gas planets, and nearly twice as far as Pluto's orbit, the probes eventually made it to the final hurdle before interstellar space: The Heliosphere.

The Heliosphere

Termination Shock

- Boundary of the outer solar system, roughly 84 - 94 AU from the sun
- Innermost edge of the heliosheath
- Due to the abrupt change in solar wind speed, as well as the pressure of the interstellar medium, a compressed boundary is formed
- At this point the solar magnetic field, which is in the east-west orientation, is colliding with the interstellar magnetic field, which appears to have a north-south component based on observations from Voyager 1 (Burlaga, 2013).

Heliosheath

- Region between the termination shock and the heliopause
- Solar winds slow down after interacting with dust, material, and gas scattered in space (Interstellar Medium)
- Voyager 1 took 8 years to pass through this region

Heliopause

- Outermost part of the boundary
- Boundary where the solar wind is no longer strong enough to push against the stellar wind
- Solar wind is stopped by interstellar medium

Bow Shock

- Solar winds push against stellar winds
- Forms a bow shock in front of the heliosphere
- Similar to what occurs in front of a supersonic jet

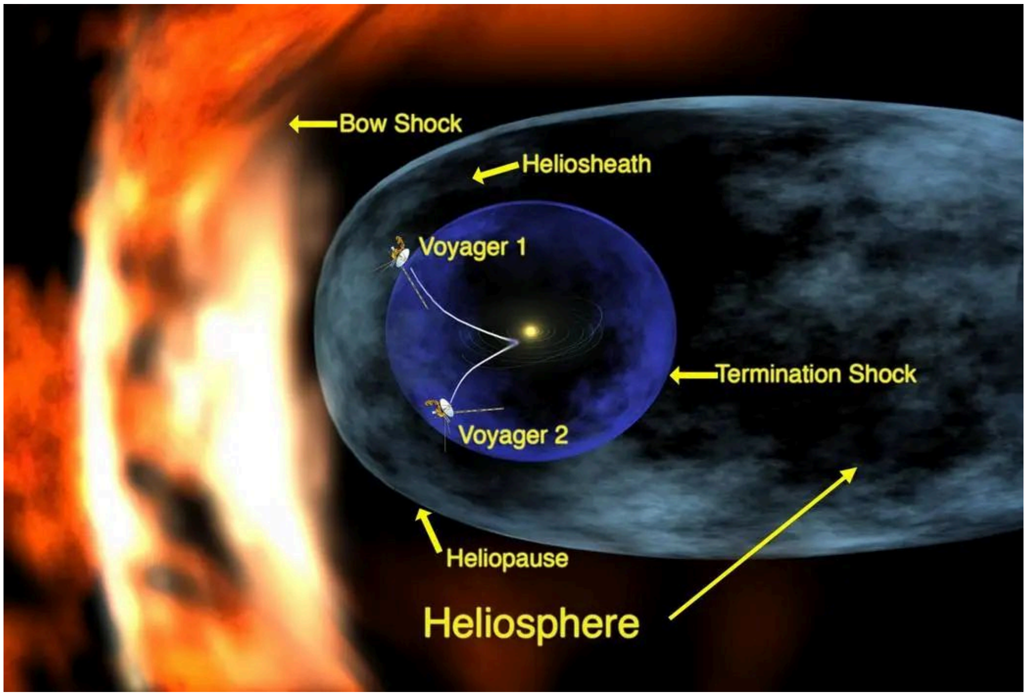

Figure 3-4: Artist's concept of our Heliosphere, labelled. Retrieved from https://www.nasa.gov/image-article/heliosphere-4/

Anti Matter

Electron -Positron Annihilation $e^- + e^+ \rightarrow 2\gamma$ ($E_\gamma = O.511 MeV$)" (Lapointe, 2020)

It would be difficult to use this energy for thrust.

Proton anti-proton annihilation or full hydrogen atom annihilation is likely the way to go. (Lapointe, 2020)

A significant fraction of the energy produced is converted into neutrinos which carry energy away without interacting. So, while it does convert momentarily into 100% energy, much of the energy is not useable, and an even larger portion of the energy than the energy lost by neutrinos is not useable without significant innovation in methods of harnessing this energy.

$E_\nu / E_0 = (276 \text{ MeV} + 594 \text{ MeV}) / 1880 \text{ MeV} = 870 / 1880 \approx 0.4628 \approx 46.3\%$

According to this article about 46% of the mass energy is converted into neutrinos which will not be usable. (Lapointe, 2020)

Rough estimate based on FermiLab values:

- k_{grid} = wall plug power ≈ **\$0.10/kW-hr (\$2.8x10^{-8}/J)**
- M_a = antimatter rest mass collected (kg)
- η_{grid} = electrical efficiency of the accelerator system ≈ **5x10^{-3}**
  14 MW of power required to deliver 5x10^{12} 120-GeV proton beam every 1.5 s onto production target → power in beam ≈ 6.4x10^{4} W; 6.4x10^{4}/14x10^{6} ≈ 5x10^{-3}
- η_{conv} = efficiency of production and collection process≈ **7.8x10^{-8}**
  Rest mass energy of $\bar{p}$ = 938 MeV = 9.38x10^{8}/$\bar{p}$. Energy to create and collect one $\bar{p}$ = 120 GeV/proton x 10^{5} p/$\bar{p}$ = 1.2x10^{16} eV/$\bar{p}$; 9.38x10^{8}/1.2x10^{16} = 7.8x10^{-8}

$$\frac{K}{M_a} = \frac{k_{grid}\, c^2}{\eta_{conv}\eta_{grid}} = \frac{(\$2.8\times10^{-8}/J)(3\times10^{8} m/s)^2}{(5\times10^{-3})(7.8\times10^{-8})} \approx \frac{\$6.4\times10^{18}}{kg} = \boxed{\frac{\$6.4\times10^{12}}{mg}}$$

Figure 4-1: Antimatter propulsion concept. Retrieved from https://ntrs.nasa.gov/api/citations/20200001904/downloads/20200001904.pdf

A small number of picograms of anti matter can be stored indefinitely. (Lapointe, 2020)

However, a portable anti matter storage designed by nasa can only hold pico grams for up to 18 days. (Lapointe, 2020)

Storage for solid antihydrogen using magnets or electrostatic levitation. (Lapointe, 2020)

Spaceships will need to account for gamma ray shielding which could significantly increase the mass. (Lapointe, 2020)

There are no practical methods for high density anti matter storage. (Lapointe, 2020)

Project Orion

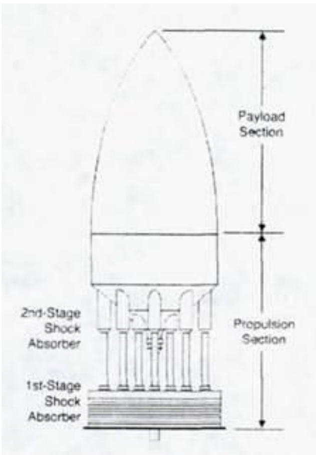

Figure 4-2: *Nuclear Pulse Propulsion - Orion and Beyond*. Retrieved from https://ntrs.nasa.gov/api/citations/20000096503/downloads/20000096503.pdf

Project Orion was a research project from 1958-65 and it had very strong scientific backing, the only reason it was shut down is political. It proposed propelling rockets vie nukes. It remains perhaps the most viable option today. (Schmidt et al., 2000)

Fusion

Tritium is a rare and radioactive material which is a bi product of nuclear power plants, or fission reactors, making accumulating large quantities for an interstellar mission difficult. (*FAQs | Nuclear Regulatory Commission*, 2024)

Large quantities of He3 have been found on the moon. While it has significantly higher temperature/pressure requirements to start, and is more difficult to contain. (*FAQs | Nuclear Regulatory Commission*, 2024)

Tritium can also be produced from lithium. Lithium also needs to be used in batteries though.

He3 can also be mined on the outer gas planets. This would cost 1.5 M$ - 6000 $ per Kg. (Hein, Tziolas, & Crowl, 2010)

A fission rocket is proposed for this mission. While fission has large energy per Kg, it is not practical interplanetary missions due to having a relatively low exhaust velocity. It is limited by material. Unlike for fusion where most heat is contained in the plasma by magnetic field, a fission rocket heats hydrogen in a container, and those contained walls would melt if anyone attempted to heat it to the point that it’s exhaust could propel a ship at relativistic speeds.

Plasma is contained via magnetic fields and if an out of control reaction occurs it will hit the physical walls of it’s containment vessel and cool. (Princeton Plasma Physics Laboratory, 2011)

D + D	→	^{3}He	+	n	+	3.2 MeV*
D + D	→	T	+	p	+	4.0 MeV
D + T	→	^{4}He	+	n	+	17.6 MeV
D + ^{3}He	→	^{4}He	+	p	+	18.5 MeV

Figure 4-3: *Fusion power*. Retrieved from https://www.pppl.gov/document/2206

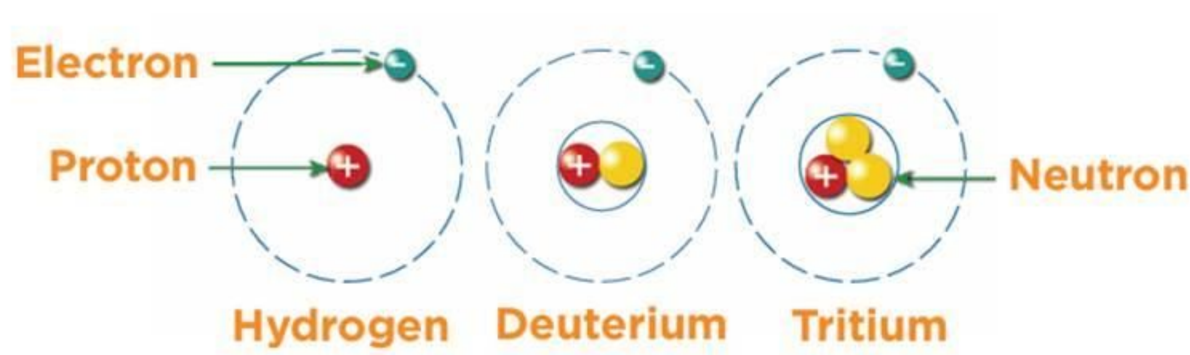

Figure 4-4: *Fusion power*. Retrieved from https://www.pppl.gov/document/2206

D-He3 fusion requires about an order of magnitude more energy than D-T fusion about 10^8 degrees Celsius for D-T and about 10^9 degrees Celsius for H-He3 (J Chaerani et al., 2024)

D-He3 could be safer because the way that the energy is extracted from the fusion process is different, in D-T, high energy neutrons with roughly 80% of the energy from the process hit the 'blanket' this energy is extracted via heat. Part of the function of this blanket in many designs is for the neutrons to react with lithium and produce trillium. This is considered an important part of the design by many nuclear physicists across sources because of trilliums scarcity. It also produces energy: n + Li → T + He + energy. (J Chaerani et al., 2024)

For a He3-D reaction, most of the energy goes into protons. There are two advantages to having most of the energy in charged particles: 1, it can be contained and released in a controlled way, 2, since it is a charged particle, it can be converted directly into current. So conceptually, it has a higher efficiency. (J Chaerani et al., 2024)

The 80% energy that the neutrons carry is not lost, it is the energy production. It hits the blanket and heats it, part of the function of this blanket in many designs is for the neutrons to react with lithium and produce trillium. This is considered an important part of the design by many nuclear physicists across sources because of triticums scarcity. (J Chaerani et al., 2024)

types of fusion:

(50%)D+D−−→He3 (0.82MeV) + n (2.45MeV)

(50%)D+D−−→T (4.04MeV) + p (14.67MeV)

D+T−−→He4 (3.52MeV) + n (14.06MeV)

D+He3 −−→He4 (3.67MeV) + p (14.67MeV)

$p + B11 \longrightarrow 3He4$ (8.68MeV)

(Lutz, 2025)

Anti matter can be used to initiate fusion reactors. The extremely high initial temperature requirements for a fusion reactor are a major limiting factor. If anti matter could be stored larger amounts than they can be for long periods of time today, but for less time than would be required for interstellar travel, it would be an excellent (maybe) lightweight solution to fusion ignition. (Lutz, 2025)

Fusion reactors which produce charged particles are preferred for space travel because it is much simpler to convert them into useable energy, by either electric energy by blasting them at an already positively charged plate (for protons) and thereby increasing the electric potential in that circuit, or by directly ejecting them. The shielding requirements for fusion with neutral by products add a large amount of weight, even for an unmanned spacecraft. (Lutz, 2025)

A D-He3 fusion reactor still have D-D reactions which produce neutron radiation and therefore still require shielding. However, significantly less than a D-D or a D-T reactor. (Lutz, 2025)

Tritium production via neutron absorption into blanket and reaction with Lithium. ‘breeding blanket’.

$Li6 + n \longrightarrow T + He4 + (4.8MeV)$

$Li7 + n \longrightarrow T + He4 + n - (2.8MeV)$

(Lutz, 2025)

This is a cool way to keep the communication device small and not overly complex. Gravitational lensing increases the apparent intensity of the signal which has been dispersed throughout space and focuses it onto a receiver.

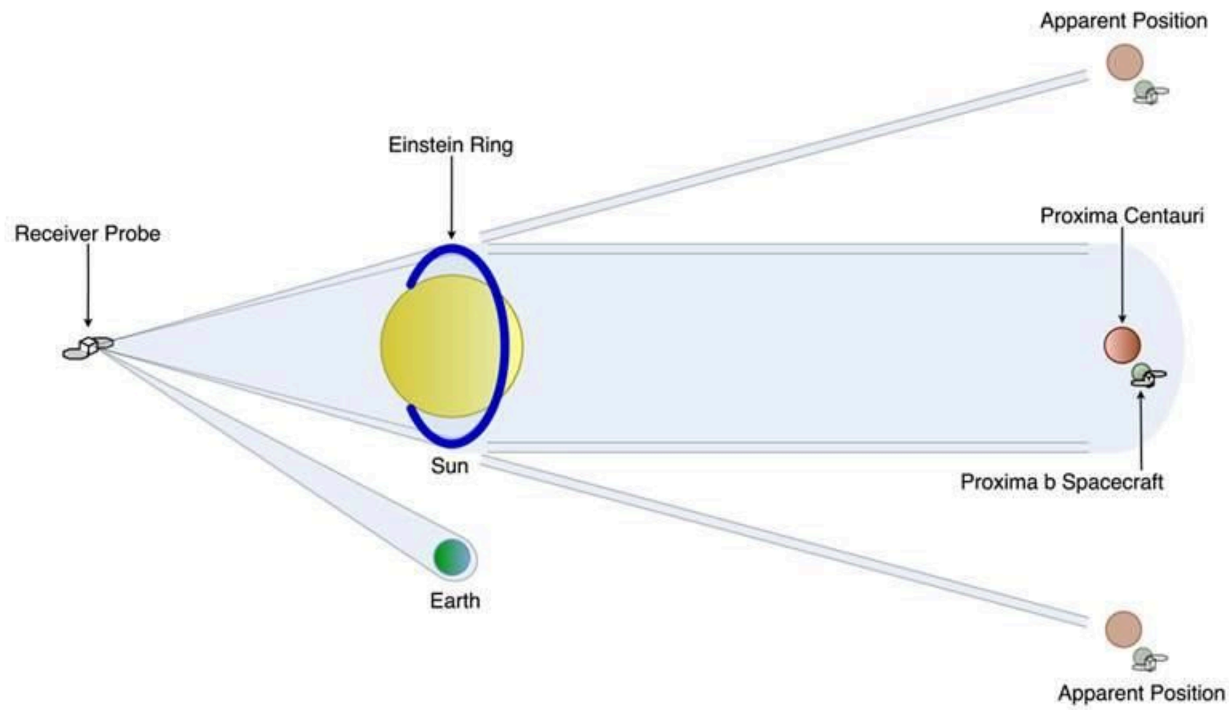

Figure 4-5: *Interstellar mission design of a fusion-powered spacecraft to Proxima b*. Retrieved from https://vtechworks.lib.vt.edu/server/api/core/bitstreams/df416ee7-df98-4839-8801-039eaddd1aeb/content?utm_source=Securitylab.ru