Executive summary

Since the dawn of humanity, we've always been driven by curiosity, an incessant hunger for knowledge and discovery, occasionally even at the price of our own well-being. Space science is not an exception to this rule. Since its inception in the XX. century, we've made endless iterations to go up and beyond with our discoveries near our planet, in our solar system or as far as photons allow us to observe.

We've discovered, dreamed and invented new tools for remote sensing with remarkable, previously unthinkable accuracies such as Gaia for mapping our sky (ESA, 2013) not just as a static breathtaking canvas, but even recording changes over time or the mind-blowing achievement of visiting and sampling comets with Rosetta (ESA, 2004).

Yet, the desire for us, humans to be part of the journey has never stopped. The motivations are plenty, we can easily identify political rivalry between competing nations, businesses pushing the boundaries for new resources, scientists trying to understand our past, present and future better, trying to answer the most fundamental questions of every human whether that be where we came from, where we're heading, and of course, are we alone. Some even believe that becoming multi-planetary species is a matter of survival, as we're too fragile compared to the powers in nature, so it's just a matter of time before our time will end on our planet, Earth. To support this vision humanity is in the preparation phase of going back to the Moon with a crew, which aims to be a milestone towards establishing human based presence on Mars as well. This vision is led by the NASA's Moon to Mars program (NASA, 2024a) and one of its prominent manifestations of this multi-faceted effort is the currently ongoing, global Artemis program (NASA, 2025b).

This CubeSat report was inspired by the idea that one of the key obstacles ahead of extended manned space missions is low and no gravity environment changes. This is a very complex topic that's been continuously analysed by major space agencies like ESA’s Columbus laboratory (ESA, 2025), NASA's Human Research Program (NASA, 2025a) or the Canadian Space Agency's SANSORI program (Canadian Space Agency, 2025) and the symptoms are countless, they range from muscle loss (H Vandenburgh et al., 1999) to the even more fundamentally impacting vision loss (Savage, 2025) as well, some of these posing direct risk to manned space missions at its core.

This CubeSat report is proposing an affordable engineering solution to analyse the relationship of health degradation rates, for example, rate of osteopenia (bone density loss, bone demineralisation) and varying weightlessness levels (mechanical unloading, Walle et al. 2024) over time in deep space environments. We’re trying to answer whether this relationship is linear and whether we can find a pattern of adjustment levels over time that could slow, alleviate, maybe even resolve these challenges. To achieve different weightlessness levels, we’re utilising the physics of artificial gravity in a combination with simulating processes of the human body for observation using organ-on-a-chip (OOC) technologies, all in a 6U CubeSat form factor.

Science case

The challenge of manned space travel is that the human body has developed on Earth within its context for millions of years (Handwerk, 2021) and by leaving our planet we've encountered plenty of challenges questioning our body's functionality in the new environment, the space environment.

In this paper I'll focus on two of which in my opinion are the most critical ones: space radiation and gravity fields. My CubeSat report and my proposed science goal aim to add new data and conclusions to these fields of research from the human health point of view.

Space environment on human health

Space radiation is one of the challenging risks to astronauts' health. Exposure to Solar Particle Events (SPEs) and Galactic Cosmic Rays (GCRs) can increase the risk of cancer development, central nervous system decrements, degenerative tissue effects or developing acute radiation syndrome. Shielding can be an effective protection from SPEs, but they are ineffective against GCRs, highly charged galactic cosmic nuclei. A third type of radiation risk, energetic SPEs and heavy-charged GCR particles as interacting with the spacecraft can produce secondary intravehicular radiation as well. (Chancellor, Scott, Sutton, 2014)

The Earth's magnetic field protects us from the majority of these deleterious effects, mostly covering LEO gravity and biology experiments as well. Extending this research BLEO (Beyond Low Earth Orbit) is an obvious next step towards de-risking human space travel.

Low, micro or no gravity on human health

Lack of Earth-like gravity, or to be more precise, the lack of mechanical stress, load normally caused by Earth-like gravity changes our body and its capabilities. These changes vary from manageable through debilitating even to life and mission threatening. The primary areas of concern related to human health degradation in low or no gravity environments are (Fortescue, Swinerd, Stark, 2011, p. 45): Blood volume redistribution, Muscular atrophy, Vestibular systems, Locomotor systems

Science question

With the massive advancement in recent decades in cell biology, physiology and tissue engineering there are many aspects of human biology processes that can be observed in vitro in a miniaturized way. With minor modification, by replacing the bio payload we can also run neuro-vestibular with barrier-on-chip (Vetter *et al.*, 2025), immune with immunity-on-a-chip (Ramadan, Hazaymeh, Zourob, 2023), and many other OOC (organ-on-chip) variants once we standardize the integration of these components. A great review on the available OOC technologies offered by Farhang Doost, N. and Srivastava, S.K. (2024).

The chosen bio payload and mission subject for this CubeSat will be analysing the negative effects of variable gravity on bone structures. It's well documented that low gravity induces bone density loss suggested to be worse than osteopenia on Earth. Microgravity-induced osteopenia is a significant and unresolved risk for humans in space. Reduction in bone density in microgravity is due to imbalance of bone remodelling induced by changes in bone cells. Ground-based studies showed that functions and morphology of osteoblasts, osteoclasts, osteocytes and mesenchymal stem cells were all changed, suggesting that bone cells respond to altered gravity by changing their functions and morphology (Genah, Monici, Morbidelli, 2021).

This CubeSat mission is a technology demonstration mission, a design framework to draw the dose-response relationships between different gravity levels and human health degradation processes, osteopenia over time in deep space, Mars vicinity environments. The core science is done by a 1U custom built highly integrated science module, with a remotely adjustable centrifuge for adjusting gravity levels, bone-on-a-chip to simulate bone cell behaviours (Lee *et al*., 2024), microscope for observing, fluidic systems to keep the perfused culture alive. The CubeSat will provide data which will answer the following questions:

- Is the relationship between bone density loss rates and weightlessness levels linear?
- What rate the bone density loss and demineralisation happens in varying weightlessness levels?
- Can we find a non-linear weightlessness level pattern which can slow or avoid bone density loss?
- How our results compare from similar experiments in LEO?

Brief history and basic concepts of artificial gravity research

The first written record of artificial gravity concept took place in the late 19th century in 1883, way before we ever set foot in space in the middle of the 20th century by the famous visionary Russian philosopher scientist Konstantin Tsiolkovsky (Clement, G., Bukley, A., 2007, p. 60), the same person who independently published the chemical rocket equation (Fortescue, Swinerd, Stark, 2011, p. 180) in 1903.

Even though theoretically there are some options on how to generate artificial gravity (linear acceleration, mass) practically the only way known today feasibly is based on Newtonian mechanics and achieved by the centrifugal force generated by centripetal acceleration.

Circular motion is expressed by radius *r* and an angular velocity ω (in radians per second). Angular velocity represents simply how fast the object is spinning. Please note that we're using radians per second to describe angular velocity instead of rotation per second (or minute) since radians is an SI unit for the plane angle hence using r/s simplifies mathematics. The centripetal acceleration is a vector quantity by having a magnitude and associated direction. The magnitude of the centripetal force can be expressed as: $\mathrm{F_c = m\omega^2 r}$

Where F_c is the centripetal force in newtons (N), m is the mass of the object in kg, ω is the angular velocity in radians per second, and r is the radius from the rotation axis in meter. The centripetal acceleration (the gravity the object will experience in the centrifuge) is expressed as: $\mathrm{a_c = \omega^2 r}$. Where a_c is in meter per second, ω is the angular velocity in radians per second and r is the radius of the circular path (Clement, Bukley, 2007, p. 40).

It is important to highlight that the term artificial gravity is a bit misleading, as of today, humanity can't generate gravity. When we're talking about artificial gravity, we're talking about an inertial force that is indistinguishable from the normal gravity experience on Earth in terms of its action on any mass. A centrifugal force proportional to the mass being accelerated centripetally in a rotation is experienced rather than a gravitational pull. The easiest way of thinking about artificial gravity as the imposition of accelerations on the body to compensate for the lack of forces in microgravity during a spaceflight (Clement, Bukley, 2007, p. 34).

Orbit discussion

MMX Orbit

MMX after departing Earth, it'll enter an Earth to Mars direct transfer orbit and travel in a cruising orbit to Mars, where will apply a three stage Mars Orbit Insertion (MOI1, MOI2, and MOI3) maneuver (JAXA, no date). In MOI1 the spacecraft will be entering an elliptic orbit around Mars with a periapsis altitude of 500km and an apoapsis of around 40 Mars radii. After apoapsis, MOI2 will change the orbit inclination to around zero and to raise the periapsis up to the Phobos orbit. Finally, MOI3 at the periapsis will reduce to apoapsis to the Phobos orbit radius and inserting the spacecraft into the Phobos revolution orbit (JAXA, 2017, p. 13).

Here MMX will spend around 3 years in a Quasi-Satellite Orbit (QSO) around Phobos, which is very similar to Phobos orbit around Mars: almost equatorial and circular, with an altitude of 9,376km (Ogohara, K. *et al.*, 2022, p. 14).

Target orbit

For the orbit selection process, I had to think through the requirements for my mission. My primary requirement for the orbit was to have as much view on the Sun as possible, to operate the centrifuge and to provide thermal stability for my biology payload. For this, a dawn/dusk Sun-Synchronous Orbit (SSO) appears to be the most ideal (Fortescue, Swinerd, Stark, 2011, p. 125) which provides the most sunlight to my mission.

To achieve SSO around Mars we're aiming to identify an orbital tilt that uses Mars' equatorial bulge to make our orbit precess in sync with the Sun. To achieve this, we're identifying the target precession rate, the altitude, the mean motion and with the help of certain constants we'll use the nodal precession formula to get the inclination which satisfies our precession rate goal. We're aiming for eccentricity close to zero (circular) and altitude of 400km, and we we're calculating the inclination (Vuckovic, 2010).

First, we need to know the speed our orbit precess. An SSO orbit must complete one full 360° rotation in one Martian year. A Martian year is 1.881 Earth years (Fortescue, Swinerd, Stark 2011, p. 37) which is 686.565 Earth days, which is 59,319,216 Earth seconds. The angular velocity in radians per second

$$\Omega = \frac{2\pi\, rad}{59319216s} = 1.059 \, * \, 10^{-7} rad/s$$

The orbit's altitude (h) is 400km which is 400,000m, the Mars' equatorial radius (R) 3.40 * 10^6 m (Fortescue, Swinerd, Stark, 2011, p. 37). Semi-major axis (a) will be $a = R + h = 3400000m + 400000m = 3800000m$. Next, we need to calculate the average angular speed, the mean motion (n). Mars' gravitational parameter (μ) is 4.283 x 10^{13} m^3/s^2 (Fortescue, Swinerd, Stark, 2011, p. 83), so mean motion (n) is, using Fortescue, Swinerd, Stark, 2011, p. 87, eq. 4.17:

$$n = \sqrt{\frac{\mu}{a^3}} = \sqrt{\frac{4.283 * 10^{13}}{3800000^3}} = 8.834 * 10^{-4} rad/s$$

Finally, we're using the nodal precession equation to express the inclination (i)

$$\Omega = -\frac{3}{2} J_2 \left(\frac{R}{a}\right)^2 n\, cos(i), \text{ where } cos(i) = -\frac{2\Omega}{3 J_2 \left(\frac{R}{a}\right)^2 n}$$

Using our variables, plus J_2 (oblateness) for Mars from Fortescue, Swinerd, Stark, 2011, p. 83., we get cos(i) = -0.0508 and arccos(-0.0508) = 1.61 rad = 92.913°, which will be the orbit's inclination.

Transfer maneuver

We'd request the CubeSat to be released from MMX once it ends up at its Quasi-Satellite Orbit at altitude 9,376km, when we'll have to apply an orbit transfer maneuver to get to our destination SSO orbit, altitude of 400km. I considered asking for a release at stage MOI1 when MMX is at 500km altitude, but I'm worried that the calculations of an orbit transfer given the context of being in a middle of an orbit insertion would be significantly more complex compared to completing an orbit transfer from starting from a stable orbit, even if the altitude is significantly higher.

I've spent time trying to calculate the required orbit transfer here based on Fortescue, P., Swinerd, G., Stark, J. (2011, pp. 114-116) and our first TMA, but I must admit I can't figure it out. As I understand, in this case a Hohmann transfer wouldn't work as that requires the two orbits to be coplanar, which in this case isn't true.

Space environment, space weather

The CubeSat is planned to stay in Mars' SSO Orbit, which is way harsher space environment than LEO (where most similar experiments are done), and it's closer to what we'll encounter in deep space. This mean higher dose of cosmic and solar radiation from GCRs and SPEs (Neukart, 2024). Additionally, the spacecraft will experience extreme temperature swings as well, which are expected at perihelion/aphelion. For further details about the CubeSat's atmosphere in orbit we can use NASA's Mars Global Reference Atmospheric Model by Justh, H. L., Cianciolo, A. M. D. and Hoffman, J. (2021).

Justification in context of MMX

There were some notable CubeSat missions in the astrobiology category before, usually they aim to observe biological processes in microgravity, so far all of them took place in LEO. The first CubeSat with biology experiment payload beyond LEO is the BioSentinel (Massaro *et al.* 2023) from NASA launched to space in 2022. Astrobiology related CubeSats with adjustable artificial gravity level is even more rare, so far SporeSat (Kanapskyte *et al.* 2021) by NASA and Eu:CROPIS (Jens *et al.* 2018) by German Aerospace Center are the sole participants launched in 2014 and 2017 targeting LEO, both observing plant cells. The category we're aiming at is rare even in LEO but based on my research no CubeSat launched to this day beyond LEO with the science mission of observing biological processes in relation to variable gravity levels in deep space environment. We would be the first in this category.

Specification of satellite and instrumentation

Foundations

CubeSat's name is HMS Dreamer, its size is 6U (specified by the EMA).

Please note that in the specification I prioritized reasoning over specific component selection. In my opinion within context of this report, understanding why I would pick a component is more important than the actual component selection.

Considerations

The primary constraints for component selection are power, mass and size. For most components COTS modules can work, one key exception is the science unit, centrifuge, lab/organ-on-chip payload, which will be custom designed. Please note that in the history of CubeSats the majority went to LEO, it's a fairly recent development that both NASA (Harbaugh, 2021) and ESA (ESA, no date) are sending CubeSats to deep space, hence there are only a few selected COTS that we can choose from that are tested in deep space and viable for our mission as well.

Observing bone cell changes and behaviours takes time. Another key factor from an engineering point of view is the planned mission length as that'll determine the overall lifecycle of the spacecraft and multiple factors in the components themselves. One such obvious bottleneck is the propellant required to stay in orbit. We're aiming and designing for a mission length of one year. The base plan would be to adjust gravity levels every two weeks which should be enough to observe meaningful effects (Fournier, Harrison, 2020), starting from 1g and ending with 0, record observation every hour, which will allow us to have ~24 adjustment steps, each responsible for ~4.1% of adjustment. Please note that this experiment aims to use 1g as a baseline hence requires that we're protecting the cells from microgravity on the way to our destination orbit, which may require artificial gravity even during the trip or freezing the payload which could pose additional engineering challenge.

Science payload (Centrifuge + bone-on-a-chip)

This component is custom built for two reasons hence providing an accurate design specification in this document would be an unrealistic expectation, but I'll go through the concepts and components with reasonings on what this custom-built device should achieve.

The two reasons are the form factor (the components must be highly integrated, purpose-built to make sure it fits 1U) and the space environment (must be space certified, and requires mission specific mechanisms, like hydrating/freezing for the duration of the travel to the target orbit).

Based on my research the only complete solution in this form factor that satisfies both criteria is the 1U centrifuge + lab-on-a-chip integration device in SporaSat, called BioCDs. The BioCD design and manufacturing process are public and well documented by Park, J. et al. (2017) so it served as a major inspiration and guidance on how I'd design the mission 1U for this CubeSat as well.

Centrifuge

The centrifuge isn't anything special, the only requirement is that it has to support adjustable speed, remote control and the capacity to read the current speed. The material selection should take into account that it'll operate in space, should be power efficient and preferably space flight tested. The centrifuge, organ-on-a-chip (cell culture), detector (microscope), pumps, valves should all be custom designed, built and tightly integrated.

Bone-on-a-chip

This biological payload (a size of a glass microscope slide) will provide a miniaturized version of bone development processes over time, which my CubeSat will observe in relation to varying gravity levels in Mars orbit. Depending on the integration level possible, we'll have weeks or months for our observations, the minimum observation time worth is at least 3 months.

Observation of the chip is visual, requires a fluorescent microscopy (Development of an Organ-on-a-Chip for Correlative Microscopy: Visualizing Early Osteogenesis in 3D with High Resolution, 2024). For the reference, SAGE (ARIS, 2025) a Swiss CubeSat design in progress using (IDS, 2025) a Sony CMOS camera model U3-38J1XLE Rev.1.2 (IDS, no date) for a very similar purpose, observing microfluidic chip.

We'll need to prepare for on-board analysis with purpose-built software as well, depending on the communication bandwidth we can achieve to Earth. Ideally, we want to transfer images for deeper analysis but have to prepare the software for doing some level of autonomy, in-space diagnosis, abstraction which would require transfer way less data back to Earth.

Will elaborate on this topic deeper in the engineering challenges section, as this is the heart and soul of the mission and deserves more details even on the considerations, but these are the main, high-level criteria for the 1U mission device within this 6U CubeSat.

We must make sure that this 1U science payload passes TRL 6 (Fortescue, Swinerd, Stark, 2011, p. 641), including but not limited to shock and vibration tests, heat control. Besides the standard flight readiness checks, we also have to make sure the biology payload is protected from the Van Allen Belts radiation and inactive until we reach our destination orbit.

From a computer science point of view, all components must be remotely readable and controllable.

Guidance, Navigation, Control / Attitude Determination and Control System

Deep space navigation is performed using radio transponders in conjunction with the Deep Space Network (DSN). For deep space navigation as of 2020 in a CubeSat there are only a handful options have flight heritage. IRISv2 designed by JPL, and which derived from the Low Mass Radio Science Transponder (LMRTS) has flown on the MarCO CubeSat in 2018 and six other Artemis 1 secondary payloads (Weston *et al.*, 2025, p. 162). The CubeSat should be able to maintain a stable view to support a deployable solar array facing the Sun, which can be achieved with miniaturized reaction wheels and a Sun sensor.

I chose IRISv2 deep space transponder, it is 1.1kg, 10.3W supporting X, Ka, S, or UHF Bands with 25 radiation tolerance.

Based on my research I couldn't find a CubeSat around Mars which used the MRN (Mars Relay Network) for ADCS as well, even most spacecrafts and landers that use the MRN are using it as a high performant downlink option while still keeping a direct channel to Earth for ADCS, the only exception to this was the Phoenix lander (Gladden *et al.,* 2021). This could further simplify the design, although it's not available today.

In-space propulsion

To reach our target orbit defined earlier, we must add a propulsion system to the CubeSat. Additionally, once we arrive to our orbit, at Mars SSO we'll still experience atmospheric drag, which means we'll need some propulsion for orbit maintenance as well.

The three standard spacecraft propulsion systems are categorized as chemical, electric or propellant-less. After careful consideration, I'd select chemical hybrid propellants for the orbit transfer and Hall-effect (HET) electric thruster for orbit maintenance. The reasoning is, for orbit transfer we're more likely to need higher thrust or rapid maneuvers where the chemical propulsion systems thrive. Out of the chemical propulsion systems I selected the hybrid as they provide the best trade-off combination for thrust capacity and improved safety. Electric propulsion devices are great for small scale adjustments. (Weston *et al.*, 2025, pp. 68-82) We have to pay attention during thermal design of the potential thermal soak-back from the electric propulsion within the spaceship to ensure it won't corrupt the science unit, which is highly sensitive to temperature.

Would like to note that while propellant-less technologies like solar sail (Weston *et al.*, 2025, p. 102) are fascinating, they're not a viable option for orbit maintenance because if directionality.

Communications

For communication, we have two options. Either solely direct communication with Earth as proven viable by the MarCO CubeSat (Helvajian *et al.,* 2023) or use the Mars Relay Network (MRN) as well which is a communication relay network in cooperation with NASA and ESA.

The requirement is that we have to be able to have low capacity upstream for command and control, while at least medium capacity for downstream, to collect science result data in the form of images. To clarify, in this document upstream means communication direction towards the spaceship, while downlink means communication direction from the spaceship.

We have the option to use radio frequency (RF) or free space optical communication (FSO). RF is the standard, while FSO is the challenger communication technology. By reviewing both, despite FCO having unequivocal advantages in smaller size and higher bandwidth, the precise pointing requirement and that all demonstration took place only in Earth orbit (Weston *et al.*, 2025, pp. 249-276), hence along risk mitigation chose RF over FCO. Communication component selection is constrained by power, mass and directionality (Weston *et al.*, 2025, p. 252). The communication link is characterized by frequency and data rate, hence the antenna selection is crucial to achieve our goals.

The history and massive success of the Mars Relay Network proved that off-loading certain functions to a purpose-designed, shared infrastructure can boost scientific research, 99% of the science data generated on Mars had been relayed through the MRN (Gladden *et al.,* 2021). Even though MarCO CubeSat proved that the form factor is capable of direct communication with Earth, the bandwidth increase and simplified antenna and communication device and power requirements are great points to go with MRN. This CubeSat would be the first to use the MRN, which could count as a secondary technology demonstration goal as well.

CubeSat will communicate directly with Earth for command and control while using the MRN for downlink, transferring science data via UHF and the exact protocol is described in The Mars Network (MRN) Participation Guide (NASA, 2025d, p. 19).

On Board Computer

The on-board computer is crucial for the mission and the primary aspect defining our requirement here is that we're operating in deep space, high radiation space environment affected by both cumulative and single events effects (SEEs) as well. That means we must use a resilient architecture with all components (CPU, Memory, etc.) being radiation hardened or radiation tolerant with a standard real time operating system, like VxWorks or RTEMS (Weston *et al.*, 2025, p. 240).

Thermal Control System

The science unit will force us to be stricter in range and more cognizant with our thermal control design hence exceptional heat modelling is required. We have to apply both passive (material selection, circuit board design, component alignments), and active heat control methods to deal with external (solar flux, albedo, planetary radiation, radiation) and internal heat sources as well (Weston *et al.*, 2025, pp. 206-223).

Electrical Power System

Power generation

We have to take into account that even though we'll be in a high Sun exposure SSO orbit, solar irradiance is a function of distance from the Sun hence our 1.5AU distance will impact our solar power efficiency. Consequently, we recommend using multi-junction solar cells with deployable solar arrays to maximise projected surface area, which will increase spacecraft complexity and risk yet will allow us to support the spacecraft's science goal. (Weston *et al.*, 2025, pp. 31-42) Also recommend for one of the panels to be built with organic solar cells as the new promising photovoltaic technology in development, yet there was no test in space to date (Weston *et al.*, 2025, p. 42). This experimental panel is optional and should be allowed only if we get enough solar capacity required with a generous error margin (+20%) from our multi-junction solar cells so its potential malfunction wouldn't risk our overall science goal.

Power storage

Our mission length suggests that we're going to use standard lithium-ion rechargeable batteries (Weston *et al.*, 2025, pp. 43-49) for our CubeSat. There is no special requirement for batteries in this CubeSat besides being able to support the spacecraft during brief periods of lacking exposure to Sun, especially around the aphelion periods when our distance will result lower power generation in general.

Discussion of engineering challenges

Even though there are many technical challenges, the most crucial part is the science module, which makes the whole mission worthy for sponsorship. As a result, I'll briefly summarise the key areas of challenge and then dedicate the rest of the page to the science module's challenges.

- One of the first design consideration and trade-off I had to make is whether to rotate the whole spaceship or just use a centrifuge inside of a 1U. Rotating the spaceship could've increased the radius of the rotation but brought many additional problems around directionality which then affects power and communication that I decided to use an internal, integrated centrifuge.
- Planning mission length was a challenge, as it is directly related to how much science value we can provide, yet working with biological components in space for an extended time brings an enormous amount of challenge, environmental constraints, radiation protection, perfused culture brings new set of equipment with new requirements.
- Van Allen belts cause a great headache as it's a direct danger to biological payload.
- Adding biology to my mission increased its complexity exponentially to the already challenging task of sending a CubeSat to deep space.
- Coming up with the specification is absolutely a challenge as many things (power requirements, size constraints) would only be calculable once I get the final decision of all components, which appears to be impossible given the page count limit and the fact that I want to include justification to my choices, which in my opinion is more important, higher priority than the chosen specific component.

Science module challenges

We have a relatively long history of observing human biological processes in microgravity on the ISS (Fournier, Harrison, 2020). In my case, I'll observe bone density loss, osteopenia which is symptom caused by the imbalance of osteoblasts which is responsible for building new bone cells and osteoclasts, responsible for breaking down old cells (Chen *et al.,* 2018). The challenge is that observing these processes requires many components: a fluidic system that keeps the cells alive (cell maintenance), a detector/observer just to name the bare minimum. True though we could use self-contained microfluidic cassettes which are static cell cultures (Chen *et al.,* 2010), but their lifetime is extremely limited and don't fit our use case.

Even though organ-on-a-chip is a marvellous technology for shrinking and isolating human organ behaviour, the ecosystem around, the whole circulation system was not designed for space research, let alone shrink it down to 1U form factor. It appears this wasn't a priority so far, so my science goal is to through an example of osteopenia analysis in low gravity deep space environment, also to motivate and push towards a standardization and miniaturization of the whole ecosystem around organ-on-a-chip as well, to enable this fantastic innovation to be used in space research efficiently. Based on my experience, standardization usually leads to increased adoption, sometimes even opening new avenues of research as well. Thank you for taking the time reading my proposal and I'm hoping to get your support in selecting HMS Dreamer as a worthy beacon of nano-light of human health studies in deep space!

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