# matter, OUTER SPACE, structure

Master's Thesis in Architecture

*Spacecraft design from a health perspective*

*Matter, Outer Space, Structure*
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Chalmers School of Architecture:
Architecture and Urban Design

Healthcare direction
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## STUDENT BACKGROUND

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Chalmers University of Technology
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2013 - 2016
Architecture & Engineering, Bachelor's degree at Chalmers

2016 - 2017
Mparc Architecture Masters at Chalmers:
Material & Detail studio
Managing Design Projects course
Sustainable Building studio

2017 - 2018
Internship at Forum Arkitekter

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Language studies at language school in Tokyo, Japan

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Mparc Architecture Masters at Chalmers:
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Master's Thesis

## ABSTRACT

This thesis delves into spaceship design with a focus on the health and well-being of the people inhabiting it. A mission to Mars will take around six months, and if we send people to Jupiter's moons, that could take several years. Both of these trips would mean a long time spent in a small, microgravity environment with no possibility to leisurely step outside to get some fresh air. It affects the human body as well as the human mind in ways that we don't yet fully know, but studies made onboard the International Space Station indicates that the consequences can be severe. I have looked into these issues to see what solutions can be offered.

## THESIS QUESTION

*- How can a spacecraft carrying people to Mars, Jupiter's moons or beyond be designed to promote the physical and psychological well-being of the crew while still taking into account the strict technical requirements of the vessel?*

## PURPOSE AND AIM

**Space Architecture** is not a new profession, but has been emerging ever since the first long-term manned missions began - over 40 years ago. It is interdisciplinary, connecting aerospace engineering, architecture and design, space sciences, psychology etc. combining technical solutions with human needs for living and working. Just like "Earth Architects", Space Architects need to look at the "big picture" as well as every small detail of the designed environment.

The design of past and present spacecraft has been more heavily focused on the engineering side of the spectrum and solving the life sustaining systems in an efficient way. It is only recently that attention has been given to the actual perceived environment and its effect on the crew. The reason for this new attention is perhaps that we are about to become interplanetary travelers, spending months traversing deep space, enclosed in a small artificial environment.

**The purpose** of this thesis is to examine that environment from a health perspective - what are the physical and psychological challenges with living and working in isolation in deep space? And what solutions can be offered to meet the challenges, or mitigate the negative effects? I will not delve into technical details, but focus on the holistic design solutions of the interior. **The aim** is to create a catalogue of design guidelines to meet each challenge and then integrate them in to a design suggestion for a spacecraft habitat meant to be used for long-distance space traveling.

## VOCABULARY

In this thesis you will come across some "dry text" with technical terms and abbreviations. Return here if you want to get an explaination when it's not provided or to remind yourself of the meaning. The words/names/phrases marked in dark blue or light blue in text are listed here.

**Aeroponics,** a plant-cultivating technique in which the nutrients is delivered to the roots of the plant in the form of mist.

**Artificial Gravity,** refers to the centripetal force on an object that follows a curved path, which can create the illusion of being in a gravitational field.

**Avionics,** the electronic systems onboard an aircraft.

**Bios-3,** refers to a closed ecosystem experiment at the institute of Biophysics in Krasnoyarsk, Russia. It as an area of 315 $m^2$ and was designed to house three people.

**Chase-ways,** a dedicated logistical pathway for electrical cables and pipes.

**Circadian Rhythm,** an internal, biological process that regulates the sleep-wake cycle.

**Cislunar Space,** includes the space between the Earth and the Moon's orbit.

**Galactic Cosmic Rays (GCR),** high energy particles, mostly protons, traveling at the speed of light originating to a great extent from supernova explosions of stars.

**Low Earth Orbit (LOE),** an Earth centered orbit with an altitude of 2 000 km or less.

**Lux,** a logarithmic scale measuring light intensity.

**Microgravity/"Zero-G",** a minimal amount of gravitational force, creating a feeling of weightlessness.

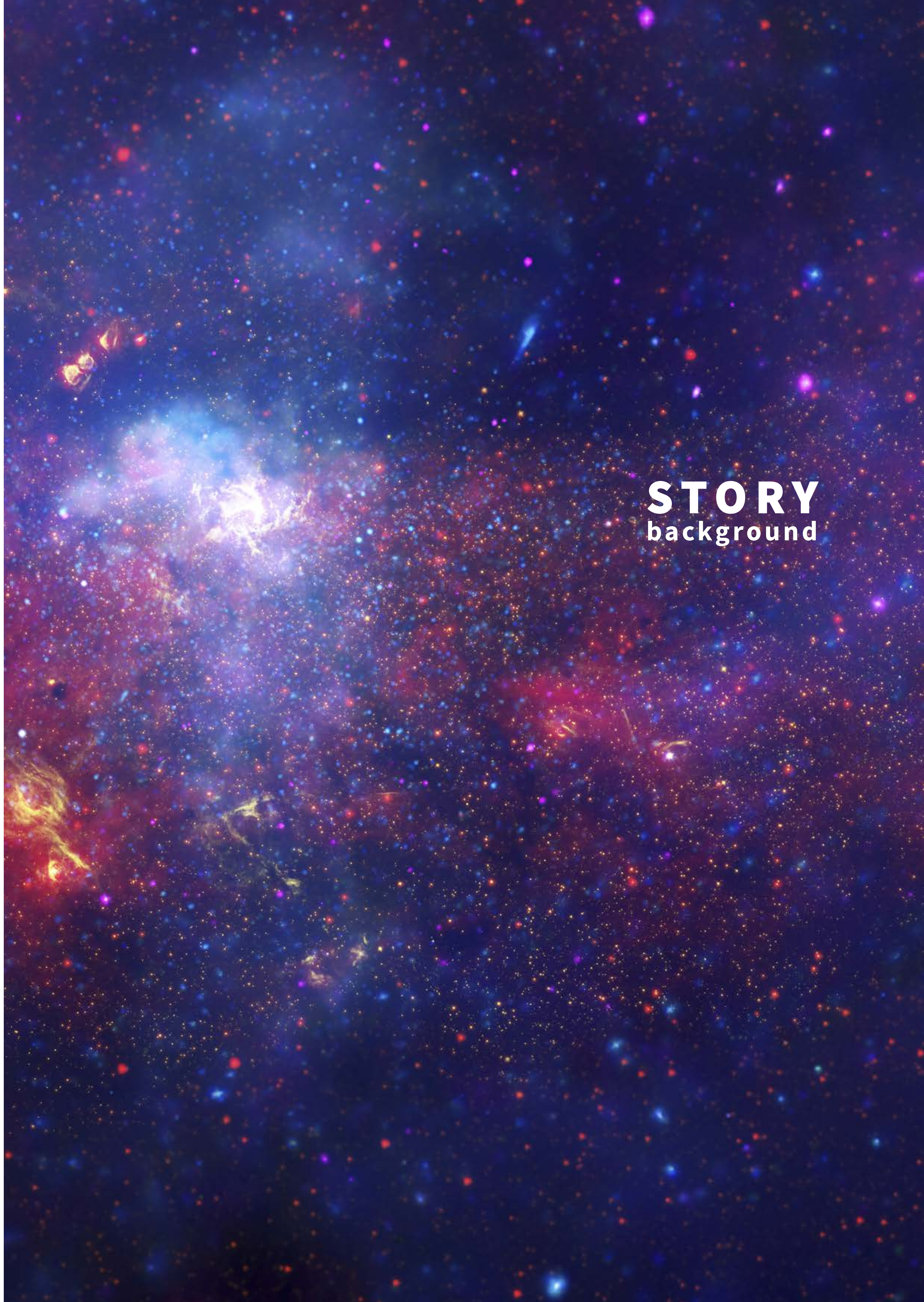
**Payload,** the amount or weight of the things or people that the spacecraft is carrying.

**Solar Electric Propulsion (SEP),** uses energy from the sun to accelerate ionized propellant to very high speeds.

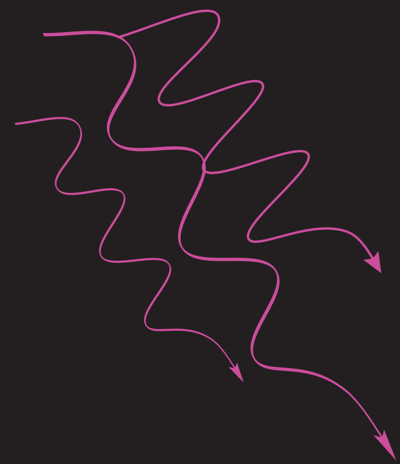
**Solar Particle Events (SPE),** high energy particles, mostly protons, shooting out from our sun as part of solar flares or coronal mass ejections.

# CONTENTS



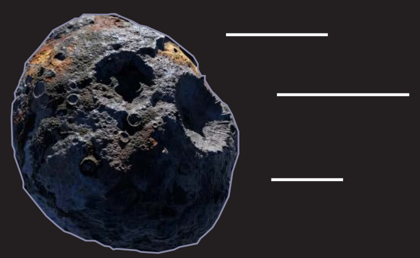


# SITE ANALYSIS: OUTER SPACE



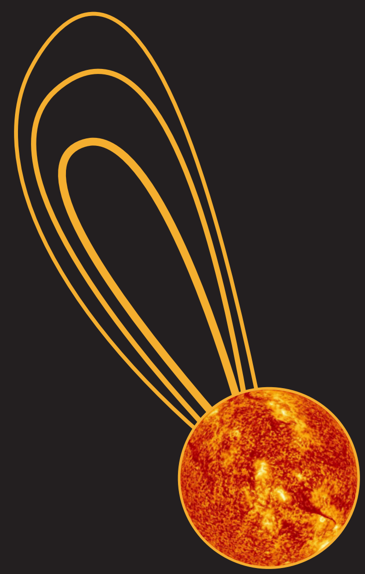
## TERRAIN

- There is no terrain, except for passing asteroids.
- It's a Microgravity environment (you are weightless). There is no "up" and no "down," unless created.



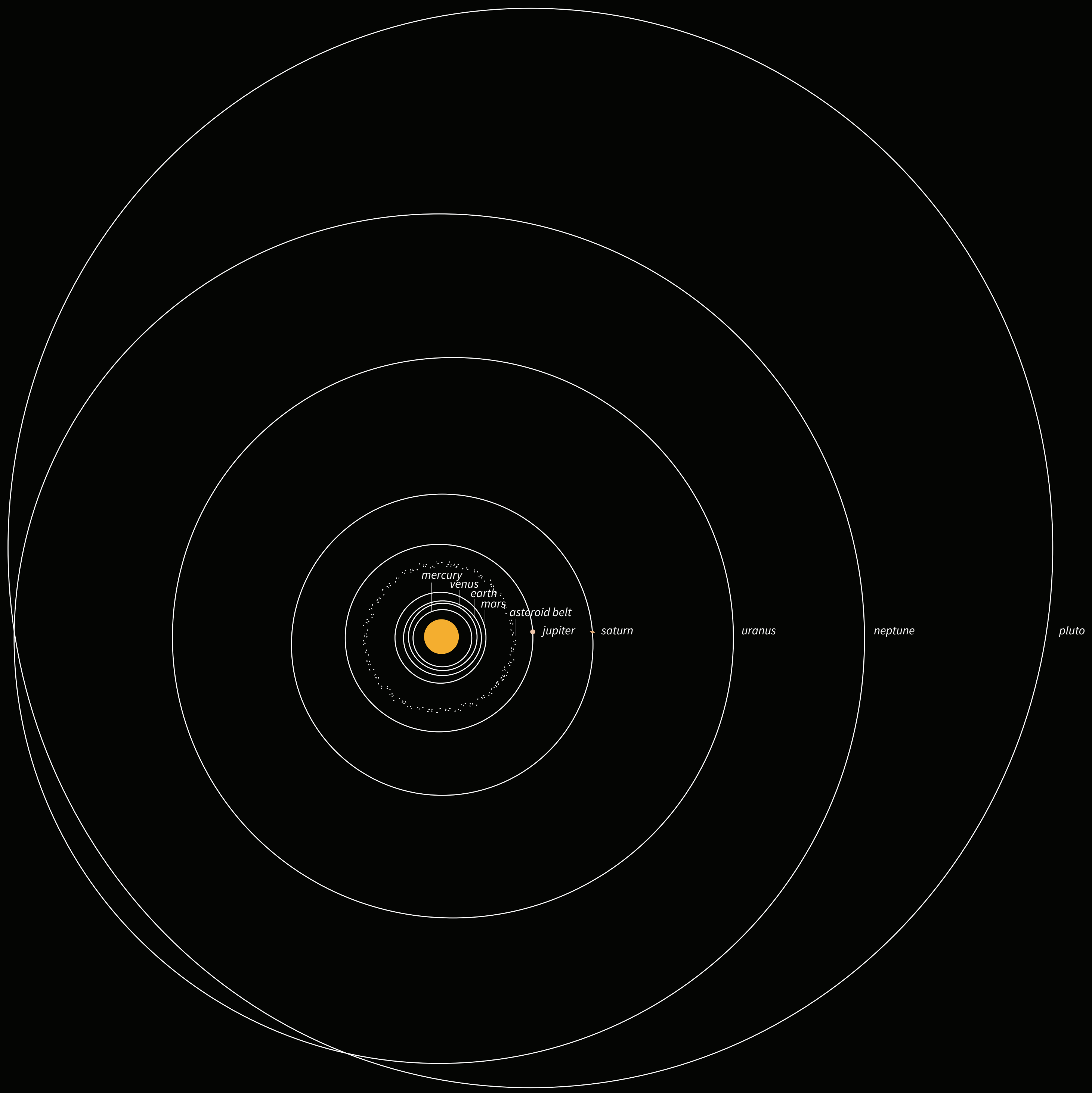
## WEATHER CONDITIONS

- The temperature ranges from a nice and warm **+200 ºC** down to a cool **-270 ºC**.
- There is no air to breath. There is no water. There is only **vacuum**. You will have to bring everything you need with you, unless you can catch an icy comet on the way.
- There is precipitation: constant showers of radiation, including Solar Particle Events (SPE) originating from our sun, and Galactic Cosmic Rays (GCR) coming from all direction. Both are extremely deadly to humans.
- The light from the sun is very bright and glaring. Where the sunlight doesn't reach, it's pitch black.

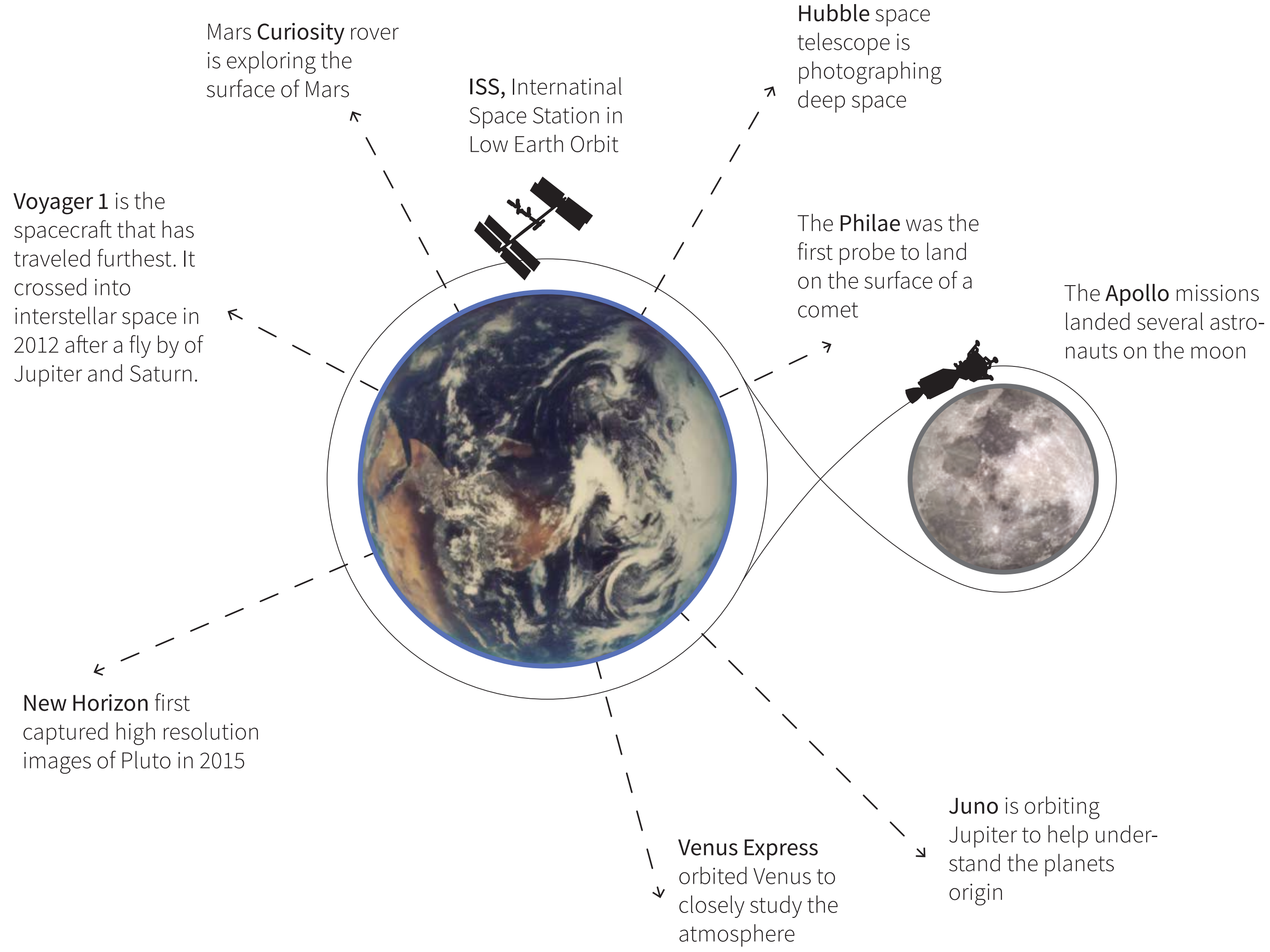


*I don't think the human race will survive the next thousand years, unless we spread into space. There are too many accidents that can befall life on a single planet. But I'm an optimist. We will reach out to the stars.*

**Stephen Hawking**




# WHERE HAVE WE BEEN?




## LOW EARTH ORBIT (LOE)

The first proper space station to orbit the Earth was called Skylab, which was assembled and outfitted on Earth. It was launched in May 1973 and occupied in succession by teams of three crewmember each time, who performed over 300 experiments in total. The longest stay on the station lasted 84 days.
The Russian space station Mir orbited the Earth for 15 years, with many international visitors. Unlike Skylab the Mir station consisted of modules that were assembled in space. Valeri Polyakov stayed on board for 437 days, which is the longest time anyone has ever spent in space. (Uri, 2020)
Currently the International Space station (ISS) is in orbit around Earth (see p. 17 for more)

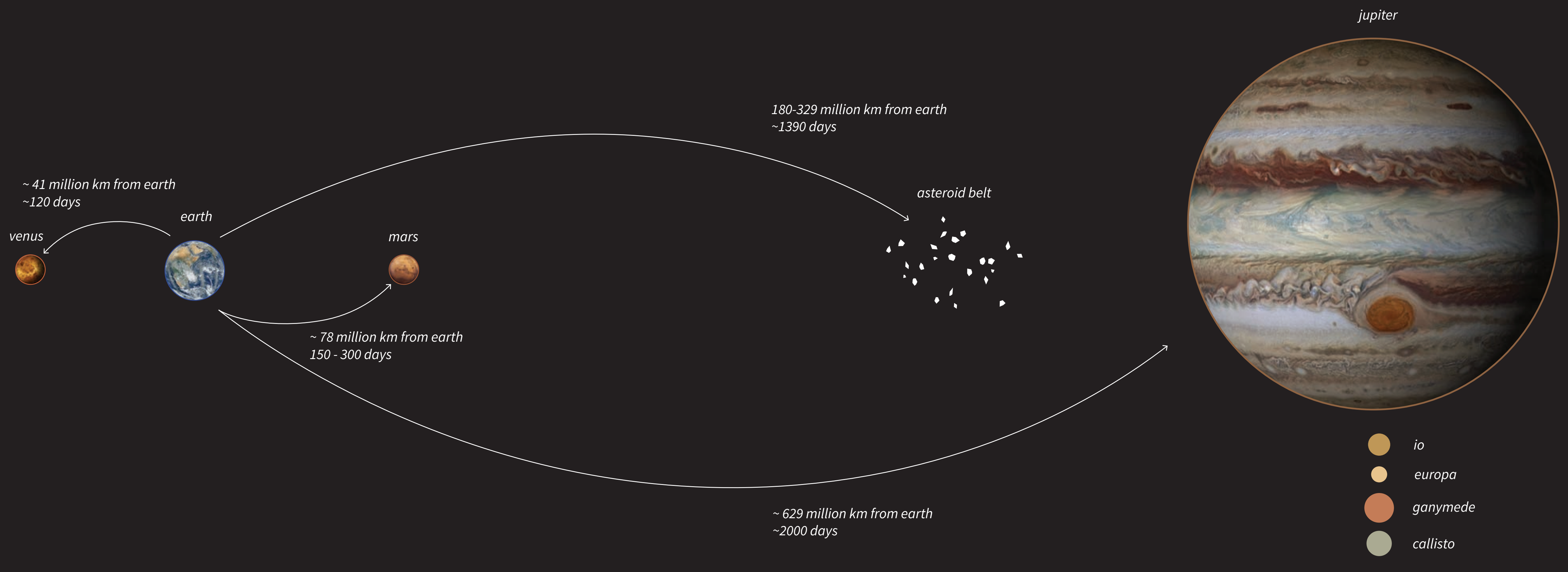
## THE MOON

With the Apollo program (specifically Apollo 11) NASA became the first organization to put people on the moon, in 1969.
The Apollo spacecraft were made up of three parts - the command module, the crew quarters and flight control section, and the lunar landing module.
In total a dozen people have visited and walked on the surface of the moon as part of the Apollo program, which ended in 1972. (NASA, 2019)

## UNMANNED SPACECRAFT

NASA has overseen over a 1,000 robotic missions into space since we first began to explore beyond Earth's atmosphere in 1958 (USA Today, 2019). Every planet in our solar system has been explored to some extent. Out of these Mars is the one that has been most thoroughly examined by various rovers (most recently the Curiosity rover). The farthest traveling spacecraft, Voyager1, has gone beyond our solar system and into interstellar space carrying with it a music collections (including music by Chuck Berry and Mozart) meant for anyone out there who wants to listen. (NASA, 2020)

# WHERE CAN WE GO?




## VENUS

Venus is the planet closest to Earth in the solar system (it only takes around 4 months to get there), and also the most similar in size. It has a thick, cloudy atmosphere that creates reflections that are easily seen from Earth. Because it is the second closest planet to the sun, it's extremely hot (the avarage surface temperature is 462 °C) which makes it nearly inhabitable. However, NASA has been looking into constructing floating cities 50 kilometers above the surface, where the environment is more Earth-like than any other place in our solar system. (Castro, 2015)

## MARS

Apart from maybe discovering life on Mars and developing new technologies that can be of use to us back on Earth, Mars could be our "Planet B". In the case that earth collides with a massive asteroid (which we know happened before, with devastating consequences), our species might still survive.
Mars is cold and the atmosphere is neither breathable nor capable of protecting us from deadly levels of radiation, but it is our best option for a planet colony within our solar system. The idea is to establish a base that can expand out and to slowly terraform the whole planet to make the conditions more friendly to life.

## ASTEROID BELT

Scientists believe that the asteroids contain mostly nickel and iron (nbcnews, 2019), but they could also contain far more valuable metals that are worth mining. This could start up a whole new kind of mining business. The work would probably be performed by robots, but since the asteroid belt is so far from earth it would take hours to issue commands from Earth. A number of humans could live there for certain periods of time to make the process more efficient. (Chow, 2019)

## JUPITER'S MOONS (JOVIAN SYSTEM)

Many of Jupiter's moons, which make up the Jovian system, hold water. The four largest of these (discovered by Galileo in the 17th century) are Io, Europa, Ganymede and Callisto, all of which are believed to have liquid water underneath the icy crust, and potentially life. Europa is the most likely contender. NASA is planning to send a spacecraft, the Europa Clipper, around the year 2025 to investigate closer (NASA, 2019). More unmanned investigating spacecraft will probably follow, and if signs of life are found, manned missions with scientists will follow, and possibly a research base be established.

# GENERAL REQUIREMENTS FOR LONG DISTANCE SPACE TRAVEL

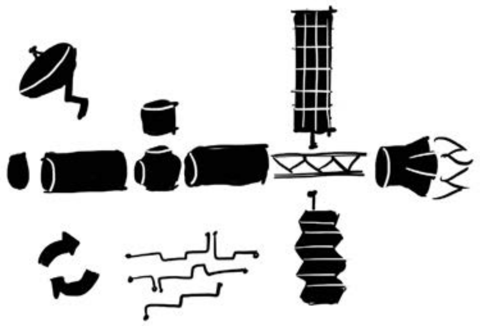
Every spacecraft that orbits the Earth or ventures into Outer Space has to fulfill certain requirements. If the craft is manned the interior has to be designed to meet the needs of the crew. The most basic needs are oxygen, water, food and protection from the harsh conditions outside. Depending on the length of the journey (most journeys in space are very long ones) it's relevant to start looking into long-term needs, such as keeping the body fit and clean, and the mind healthy. Here follows a short explanation of what generally needs to be present in a spacecraft.



# GENERAL SPACECRAFT DESIGN

GENERAL ARCHITECTURAL ELEMENTS:

- HABITAT - LIVING QUARTERS
- LAB - PERFORMING EXPERIMENTS
- NODE - TRANSITION ELEMENT
- STORAGE SYSTEM
- AIRLOCK - ENTERING AND EXITING
- DOCKING PORT
- POWER SYSTEM
- THERMAL SYSTEM
- LIFE SUPPORT SYSTEM
- COMMUNICATION SYSTEM
- PROPULSION SYSTEM
- (STRUCTURE)
- (OUTER SHELL/WALL)



CORE FUNCTIONS NEEDED TO SUSTAIN HUMAN PHYSIOLOGICAL NEEDS:

- FOOD
- WATER
- OXYGEN
- WASTE MANAGEMENT
- PERSONAL HYGIENE

CREW RELATED FUNCTIONS:

- PRIVATE QUARTERS
- HYGIENE & LAUNDRY
- TOILETS
- HEALTH MAINTENANCE
- WARDROOM/DINING SPACE
- GALLEY (KITCHEN)
- FOOD STORAGE
- GREEN HOUSE
- RECREATION
- EXERCISE
- LAB/WORK STATION
- EQUIPMENT STORAGE
- CONTROL PANELS (AVIONICS, ENVIRONMENTAL ETC.)
- EVA AIRLOCK

(Bannova & Häuplik-Meusburger, 2016)

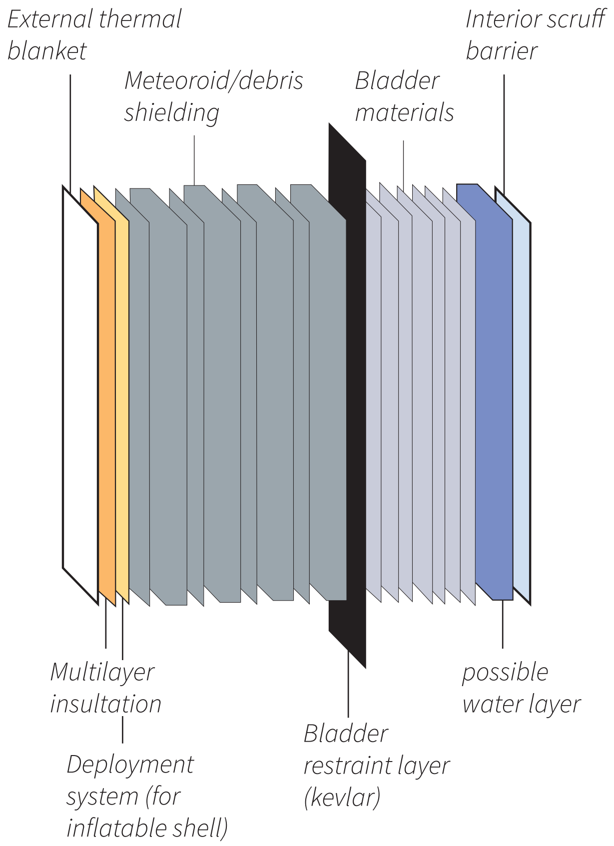
# CRITICAL SYSTEMS

## A PROTECTIVE SHELL

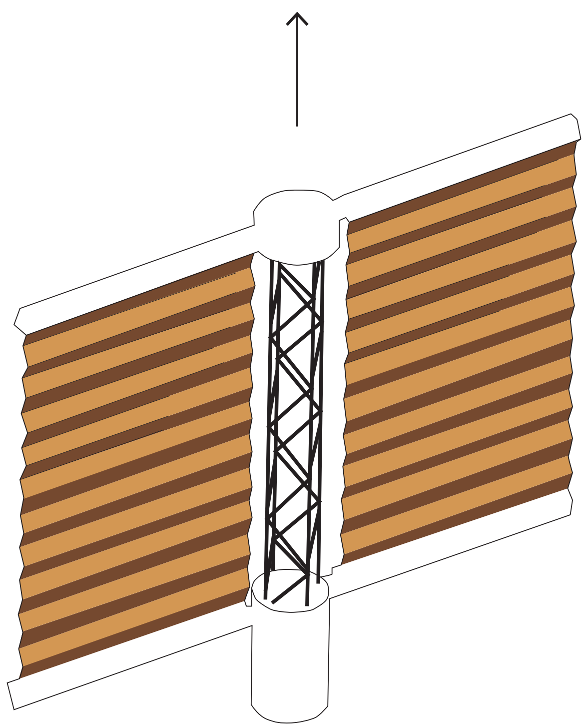
The most important function of the outer shell of a spacecraft is:

- Retaining the atmosphere
- Retaining heat/keeping out the cold (and vice versa)
- Protecting from meteoroid/space debris
- Shielding from radiation

This puts high demands on the material selection. **Kevlar** and fabrics with a **Ceramic/Aluminium/Glass fiber** base can be used for protection against impacts from small high-velocity objects.
An air-tight "bladder" made of layers of **Polyurethane/ Saran** can help retain the atmophere and layers of **Mylar** and **Dacron** provides heat insulation. (NASA)
Venturing beyond Low Earth Orbit and losing the protection that the Earth gives means extreme exposure to radiation. One way of shielding against it is to integrate a layer of water into the shell. A suggested thickness is ~80 mm. (Bannova & Häuplik-Meusburger, 2016)




(Pedley & Mayeaux, 2001)

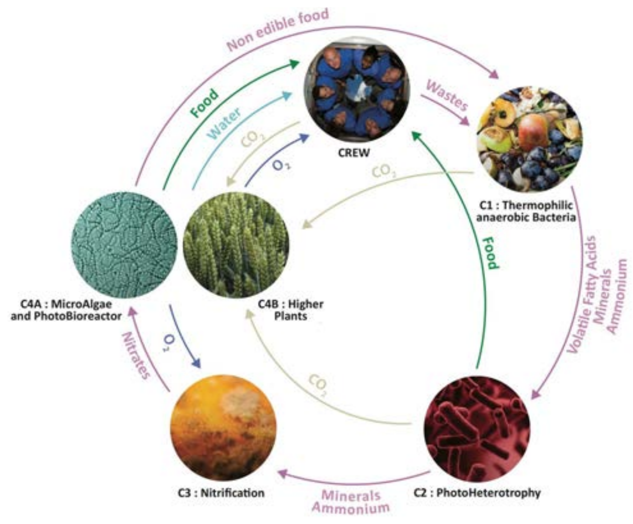


## POWER, HEATING AND COOLING

The easiest and most common way of producing electricity in space is through the use of Solar arrays. They would be launched into space folded up and then deployed when being installed. Batteries can provide temporary backup if in case of a solar eclipse.
If the spacecraft is properly heat insulated, then the problem is not staying warm, but keeping cool. This is because all the internal electrical equipment produces heat. Getting rid of the excess heat can be done through heat exchange. By letting water circulate in the interior, gathering heat, and then exchanging that heat with ammonia (with a lower freezing point at -77°C) which ciculates on the outside of the craft, releasing the heat as infrared radiation, the inner temperature can be kept at a comfortable level. (Price, Phillips & Knier, 2001)

## LIFE SUPPORT SYSTEMS

The survival of humans in space requires large quantities of oxygen, water and food, which costs a lot of money and effort to transport. For missions that reaches beyond Low Earth Orbit, it would even be risky to only rely on resupply from Earth. That is where a **circular life support system** comes in, making the spacecraft close to self-sufficient and able to meet the needs of the crew for long-duration missions.
There are many components to a life support system, and it can be done in different ways. It is possible to recreate the necessary chemical processes through artificial means, for example, using electrolyze to break apart water molecules, yielding oxygen and hydrogen as the byproducts. However, machines are prone to breaking. On the ISS the carbon dioxide removal system, CDRA or "Seedra", occationally stops working properly, sometimes leading to uncomfortably high levels of CO2 in the air (Kelly, 2017). Another way of doing it is to utilize the basic natural components of Earth's ecosystem - bacteria and plants (and humans) - and letting them "do their thing". This could be a much more reliable system if done correctly.




MELiSSA (Micro Ecological Life Support System Alternative).
https://www.melissafoundation.org/page/melissa-pilot-plant

## MELiSSA

MELiSSA (Micro-Ecological Life Support System Alternative) is a **bioregenerative/circular life support system** that is aiming for complete self sufficiency. It mimicks the ecological processes of Earth's ecosystem by relying on plants and bacteria to produce oxygen and food, clean the water, and deal with the waste that is created. It is in development at the European Space Agency (ESA), where the main challenge is to make the system work in a highly controlled environment, with reduced mass and volume (as compared to Earth's ecosystems), higher kinetics (faster processes) and with extreme safety regulations. (MELiSSA Foundation, 2020) It also has to function well in an environment with no gravity, which changes the movements of masses and fluids.

## COMPONENTS OF MELiSSA

The MELiSSA includes a number of compartments, each with it's own function and biological reactions.

- **Compartment I : waste** compartment, the food waste, plant waste and feces are degraded to fatty acids, ammonium and minerals by bacteria.
- **Compartment II : light treatment** compartment, bacteria decompose fatty acids to ammonium using light
- **Compartment III : nitrification** compartment, bacteria turn ammonium into nitrate.
- **Compartment IV : higher plants & spirulina algae**, is divided into two parts. Both the Spirula (nutritious algae) and higher plants use carbon dioxide, nitrate and minerals to produce food and oxygen. The transpired water from the plants can be condensed and used as drinking water.
(Johansson, 2006)

# SPACECRAFT REFERENCES

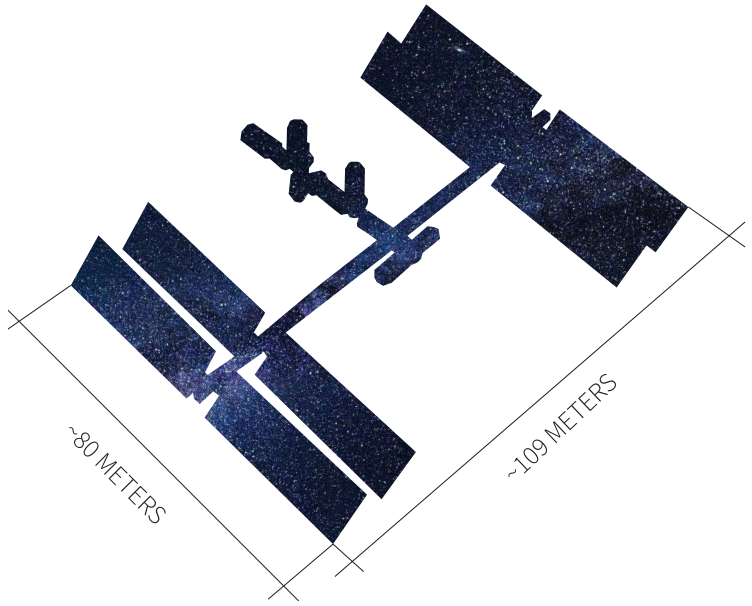
The number of spacecraft that have been manned in space for a long time are not many. The space stations Skylab, Mir and the International Space Station (see p. 9) are the ones where people have spent the most time. Here you can find more information on the International Space Station (ISS) and spacecraft designed for long-distance space travel that are or have been in development.

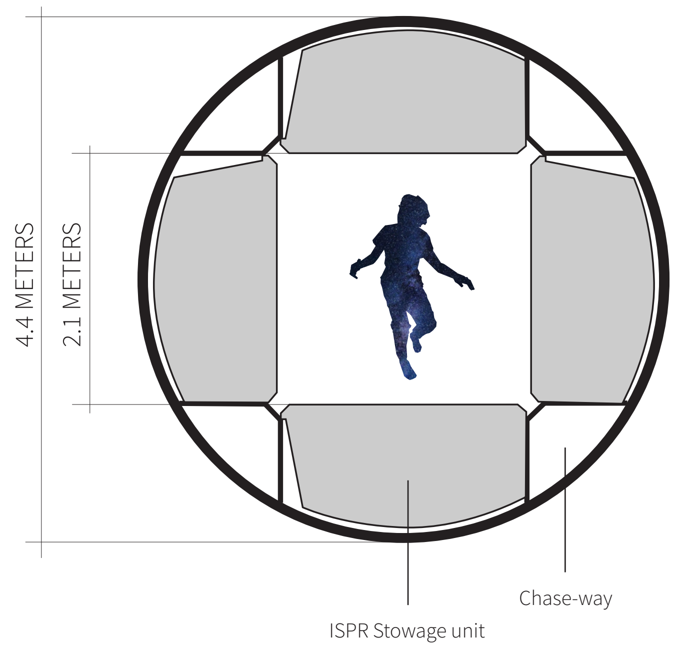


# THE INTERNATIONAL SPACE STATION (ISS)

## ISS

The ISS is a modular space station with a truss backbone that provides "multipurpose elements attachment", meaning that modules with different functions can be attached. The first parts were sent up in 1998 and it has orbited our planet and been continuously manned since November, 2000. It is owned and serviced by many countries (Russia, the U.S., Canada, Japan and a number of European countries) and different spacecraft. It is a project that is held together by the collaboration of former enemies, who have continously been launching rockets with crew, resupplies and new modules to be attached. Building and sustaining the ISS requires approximately 80 launches over a 12 year period.
The people manning the station usually spend around six months at a time there, to carry out experiments and maintenance, and they are usually six in number. One of the experiments that are carried out involves finding out the long term effects of being in space on the human body and mind, which is crucial knowledge needed to be able to prepare for longer journeys in space. (Howell, 2018)

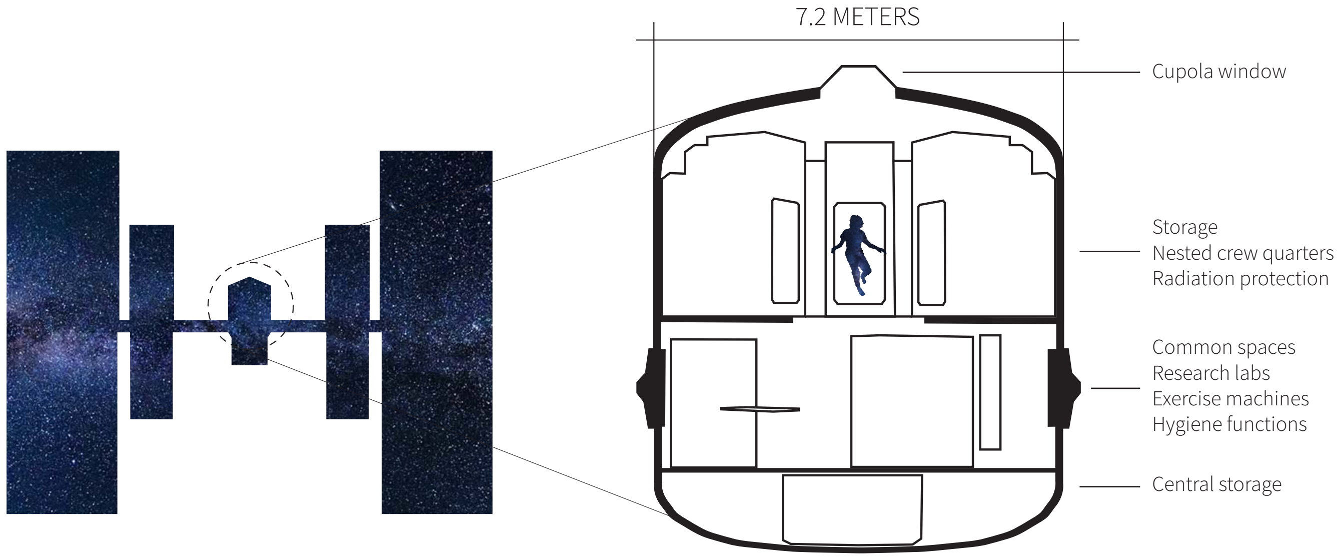



## ISS MODULE DESIGN

The modules of the ISS are shaped like canisters or spheres to be able to hold the pressurized air inside. The standard habitat/laboratory module has an outer diameter of 4.4 meters. On the interior walls four chase-ways (for cables and pipes) run along it's length, and in-between them the so called *International standard payload racks (ISPR)* are placed, where the majority of the stowage is accommodated. One such rack provides a volume of 1.6 $m^3$ and measured approx. 2 x 1 x 0.85 meters. It can store 700 kg of payload equipment (the rack itself weighs 14 kg). The ISPR has a standard power interface of a 3kW feed.
The free space that is left for circulation and equipment measures approximately 2.1 meters.
The modules hold different functions, such as laboratories, crew quarters and galley, life support systems etc. but the structure is similar. (Bannova & Häuplik-Meusburger, 2016)

# NASA'S DEEP SPACE TRANSPORT




## DEEP SPACE TRANSPORT (DST)

The **DTS** is NASA's latest idea of a spacecraft meant to carry people into deep space, to Mars for example. The whole structure will be prefabricated and launched on an SLS 1B cargo flight (a launch vehicle with a payload diameter of 8.5 meters), and when in space resupply and minimal outfitting will be done in cislunar space by the crew on the so called **Deep Space Gateway** (**DSG**) that will be stationed between Earth and the Moon.

## HABITAT

The habitat is split into two levels where the "upper" part contains a core of storage with nested crew quarters and a strong radiation protection, and the "lower" part contains the common spaces, research labs, exercise machines, hygiene functions etc.

- Crew of 4
- Minimun 25 m$^3$ habitable volume per person

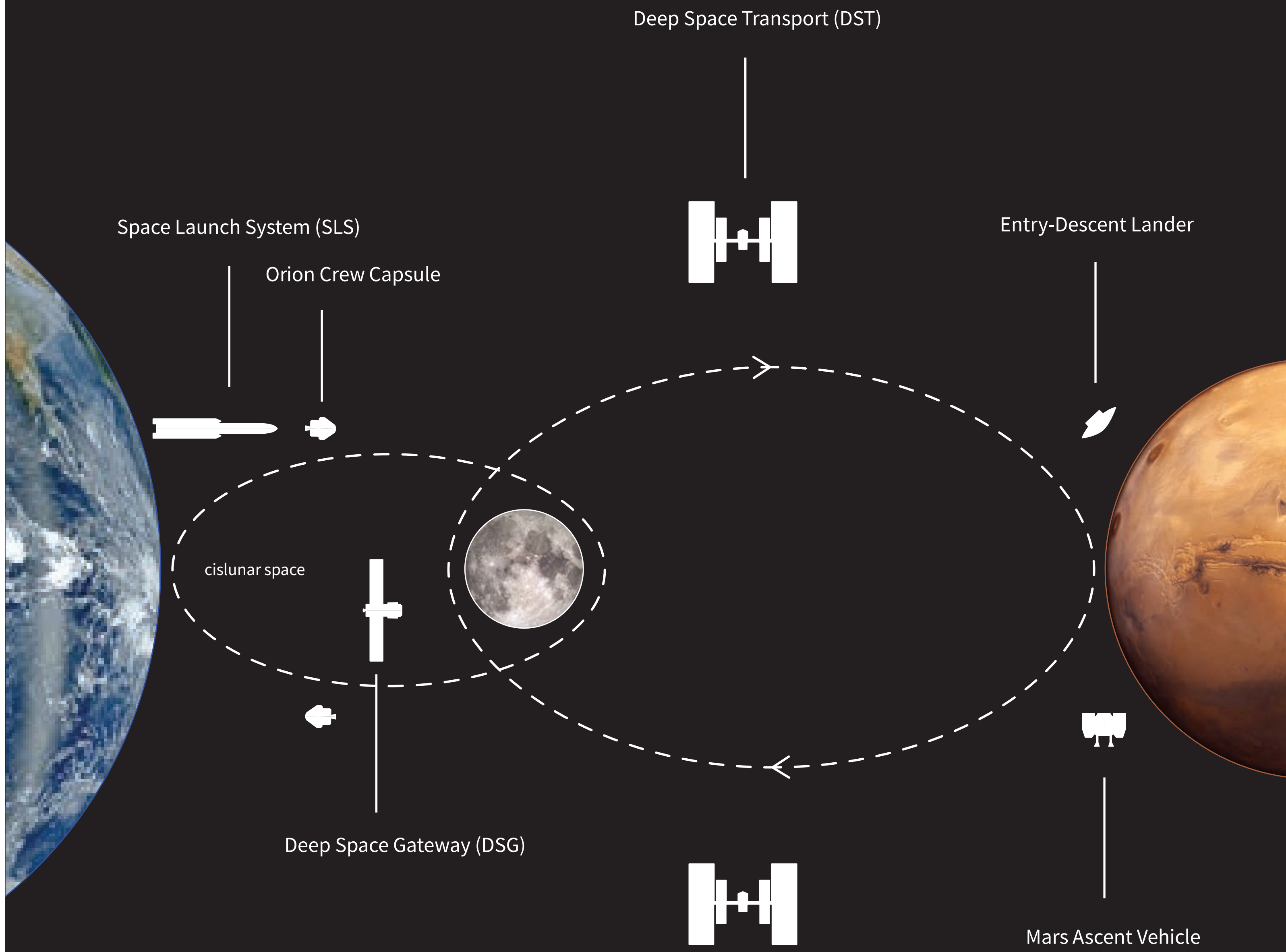
## THE PLAN

Phase 0 (now): “Use the ISS as a test bed to demonstrate key exploration capabilities and operations, and foster an emerging commercial space industry in LEO”.
Phase 1: Buildup of the Deep Space Gateway.
Phase 2: (starting in the mid 2020s): Buildup of the Deep Space Transport ending with a one year crewed cruise in space
Phase 3: Crewed missions beyond Earth-Moon system
Phase 4a: Development and robotic preparatory missions
Phase 4b: Mars human landing missions

(Gerstenmaier, 2017)



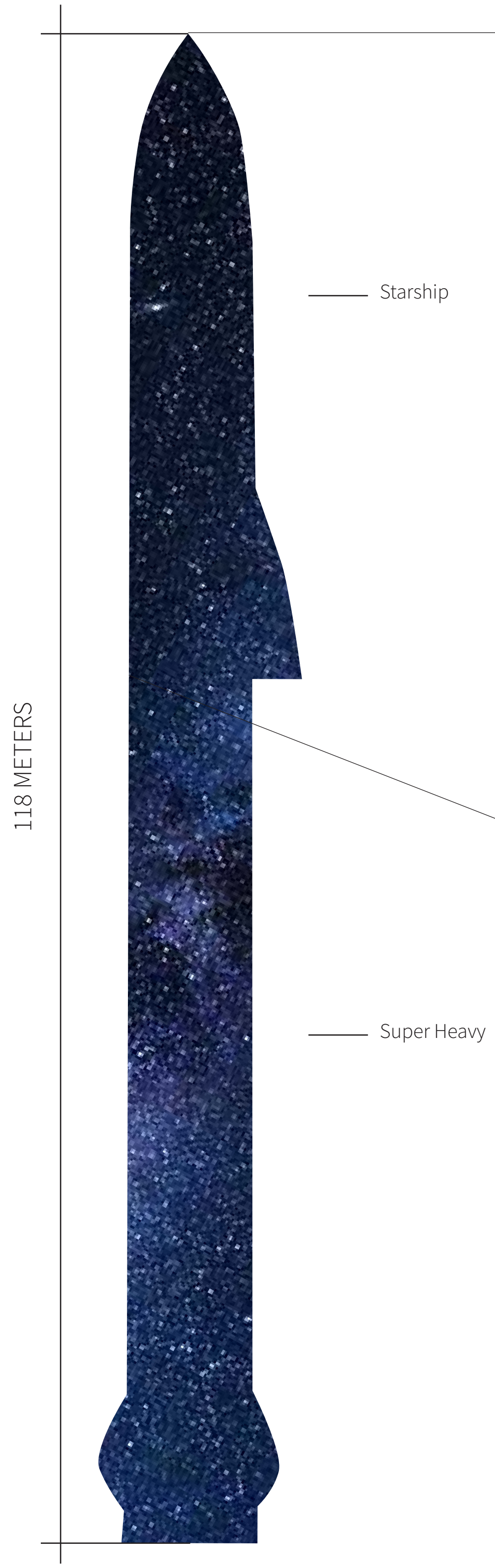
# NASA'S WAY TO MARS

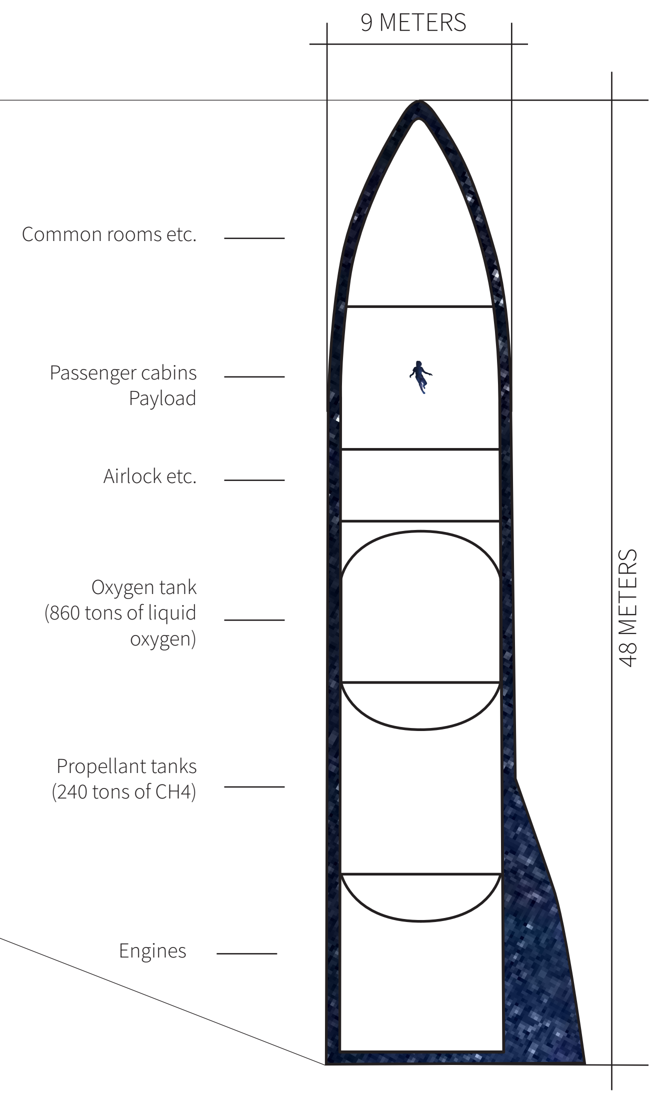



## PROCEDURES

On a crewed mission to Mars the crew module called Orion would dock with the Deep Space Gateway (DSG), that is stationed in cislunar space. When the Deep Space Transport (DST) has docked with the DSG the crew can then walk through the airlock, detach and accelerate towards Mars, using Solar Electric Propulsion (SEP). In Mars orbit the DST will rendezvous with a lander and the crew will descend to the surface, leaving the DTS in orbit. For Mars ascent a special Mars Ascent Vehicle will be used to bring the crew back to the DST.
(Gerstenmaier, 2017)

# SPACEX'S BFR (BIG FALCON ROCKET) - STARSHIP & FALCON HEAVY



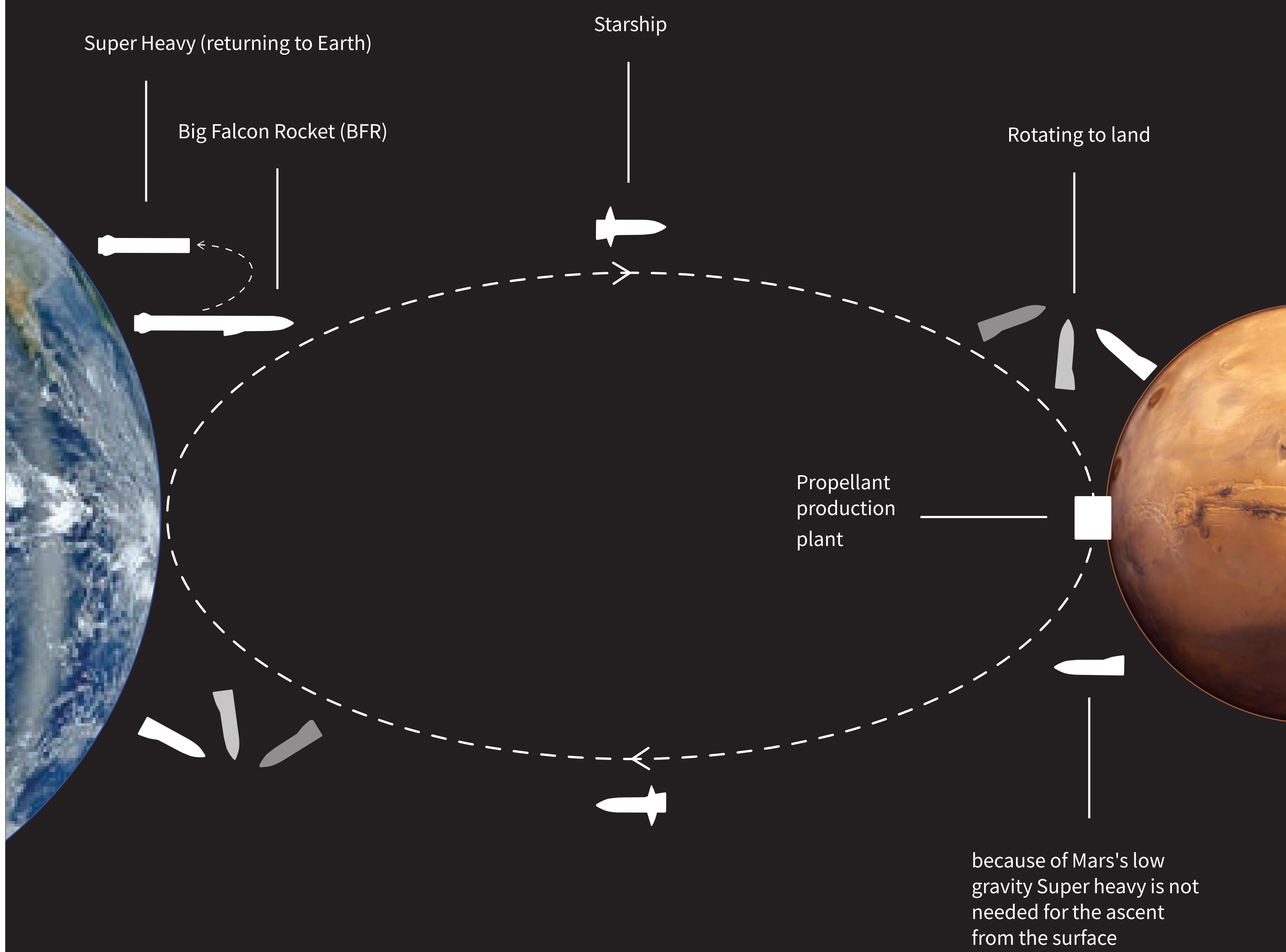

## STARSHIP

SpaceX's vision for how humans will travel in space in the near future (as well as between far away places on Earth) involve the **Starship** and **Super Heavy Rocket**. They are part of the same reusable transportation system (two-stage vehicle) called the **Big Falcon Rocket** (**BFR**) where Super Heavy is the booster required to enter Earth orbit, and Starship is the ship that will travel beyond Low Earth Orbit. When Starship detaches from Super Heavy, the booster will return to earth and land, ready to be refueled and reused.

- 40 cabins, 2-3 people in each ≈ 100 passengers
- Ships dry mass is 85 tons
- Propellant mass 1,100 tons
- Max ascent payload 150 tons, typical return 50 tons

SpaceX (2020)

# SPACEX'S WAY TO MARS

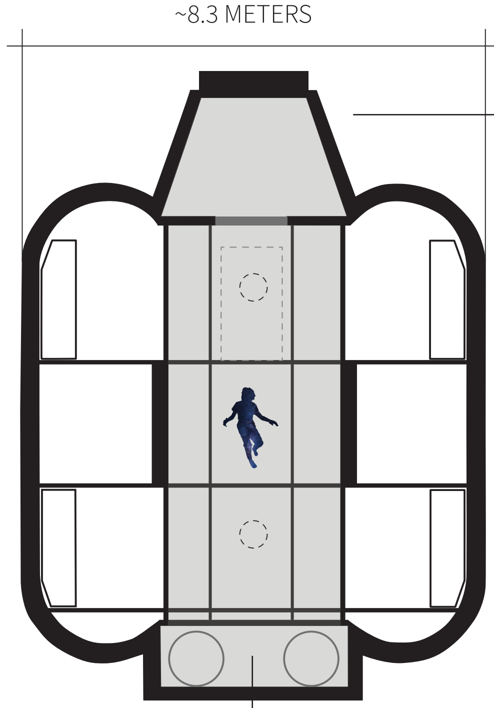



## PROCEDURE

When Starship has reached Earth orbit it will be fueled by another Starship by "mating" tail to tail. It could then make the trip to the Moon and back without refueling, and a one-way trip to Mars. To refuel on Mars local resources would have to be used - turning water and carbon dioxide into fuel ($CH_4$) and oxygen - by setting up a propellant production plant. This could be done by the first crew to reach Mars, after a few cargo ships have delivered power, mining and life support equipment to set up an infrastructure.

SpaceX (2020)

# THE TRANSIT HABITAT (TRANSHAB)



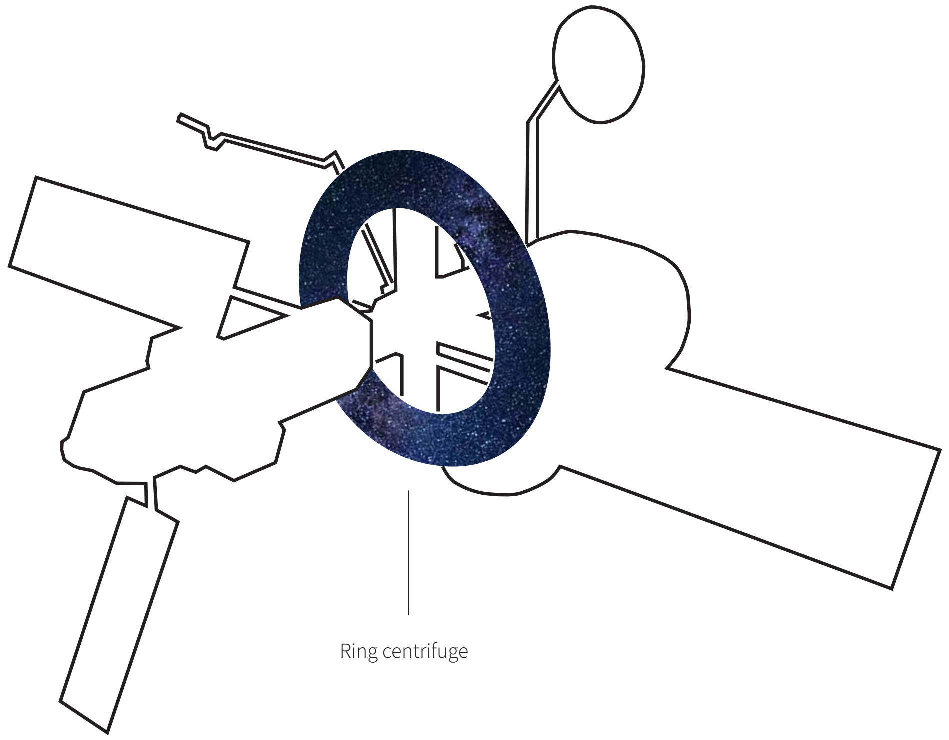

## TRANSHAB

TransHab is an inflatable module that was developed by a team at NASA in the end of the 1990s. Its initial purpose was to function as a transportation vehicle for a manned mission to Mars. Later it was redeveloped as a possible alternative to the current ISS habitat. Unfortunately the project was cancelled in 2001.
The challenge was to deliver the module to space using existing launch vehicles (the STS Orbiter). The requirements of sufficient volume per crew member forced the team to work with an inflatable structure that could increase the usable space while still fitting into the payload bay of the launch vehicle. The hab consists of a metal core approximately 3 meters in diameter, which houses a central passageway, a chase-way for power, data, and coolant runs, as well as crew quarters which are located behind a protective water tank (against radiation).

During a launch the folded fabric that makes up the outer shell would also be gathered around this core. The architecture of the TransHab module creates a separation of private and social spaces while still maintaining an integrated environment - achieving a “home-like design”. Some of the important design features are to establish a local vertical, separate the dining area from the exercise area and provide large crew quarters.
(Bannova & Häuplik-Meusburger, 2016)



# NAUTILUS-X




## NAUTILUS -X

In 2011 NASA announced that it was working on a deep space vessel for manned missions. It was a suggestion for a reusable spacecraft with room for six people and enough supplies for a two-year voyage. It would be assembled from expandable structures, such as inflatable living quarters that was being developed by a company called *Bigelow Aerospace*. One of its main features is a ring centrifuge that would be able to provide artificial gravity to some extent. A radiation protection system using water or liquid hydrogen slush was also proposed. According to Edward Henderson working at NASA’s Johnson Space Center the vessel would be a *Multi-Mission Space Exploration Vehicle* (MMSEV) that could expand to incorporate mission-specific propulsion units, i.e. it would be possible to attach more engines depending on the length of the trip.
(Messina, 2011)

## METHOD

This project has two different design parts: the Design Guidelines, which have been divided into five different Focus Areas that each represent a health challenge and guidelines to solve the challenge or mitigate the negative effects; and the Design Proposal, which is my attempt at following the guidelines and integrating them into the design of a space habitat for long-distance space traveling.
The selection of focus areas is based on studies of literature on the subject of spacecraft design. The design guidelines are also based on the suggested solutions from this literature, as well as literature and research papers on more specific and non-space related topics, such as claustrophobia and the spacial effects of colors. My personal experiences and knowledge as an architect has also contributed to the guide to some extent.

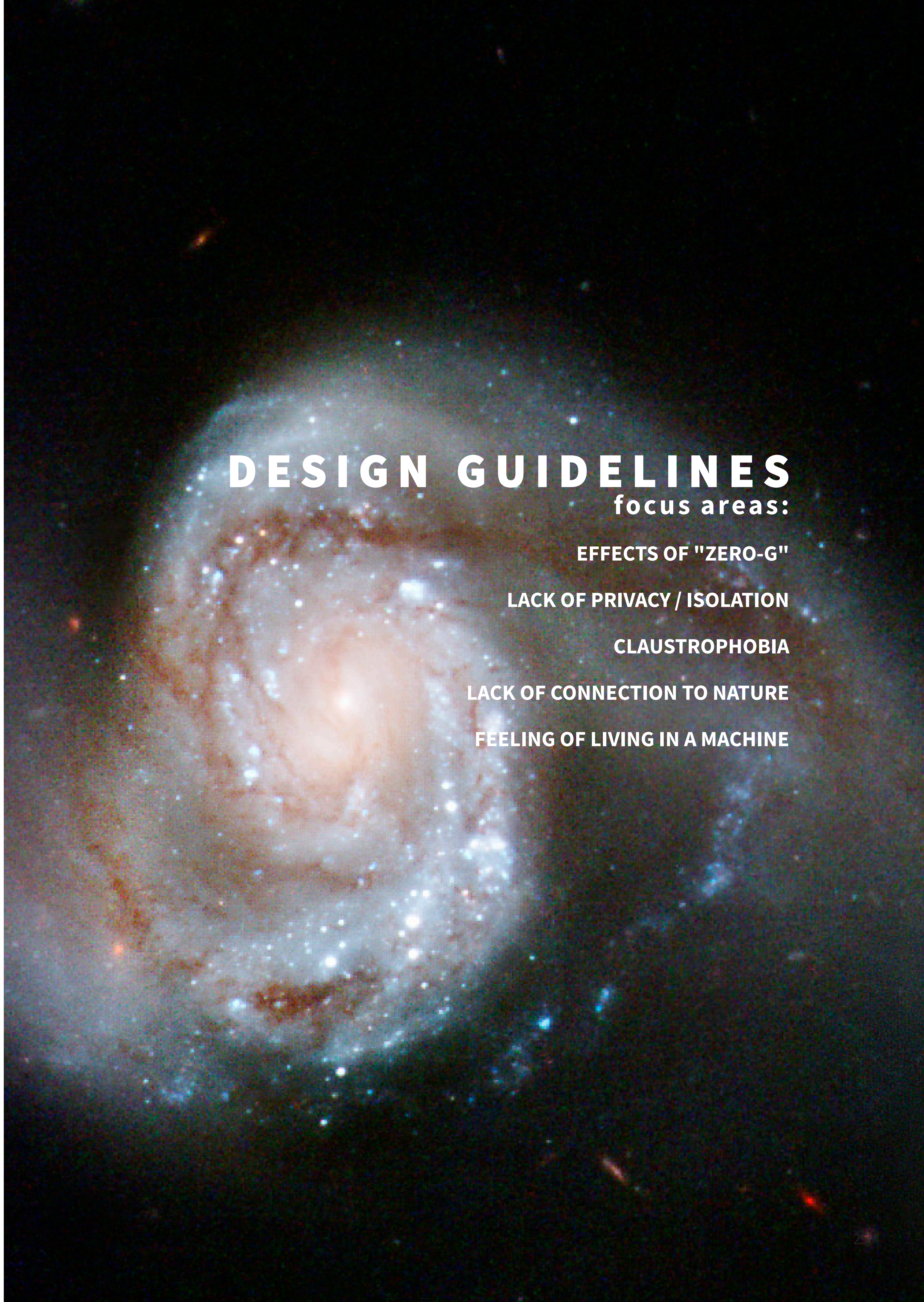
*Larry Toups*

An open discussion and workshop about designing for extreme environments (which took place in February, 2020) with former NASA employee Larry Toups (who has experience in working with the design of manned interplanetary spacecraft and the implementation of circular life support systems) contributed to the shaping of the scope of the project and focusing it into something manageable.
He stressed the importance of focusing on the design aspects first and foremost, and to not go too deep into the detailed technical solutions that are not part of the architectural profession. Making basic assumptions and design choices early to create a foundation for delving deeper into certain design areas he also suggested as an important strategy. The most important takeaway from the workshop was that asking the right questions, so called “guiding questions” can help in leading the design forward. By identifying the issues/problems and special circumstances of the subject, design solutions can be easier to find.

Physical models were made in order to understand the 3-dimensional layout of the structure, connections between different areas and how they relate to the human scale.

A digital model together with a VR-headset has been used to explore the spatial perception from a crew members perspective. Sightlines between areas, spaciousness and how it feels to move around within the habitat are some of the things that one can experience in a unique way by using this tool.





# EFFECTS OF "ZERO-G"

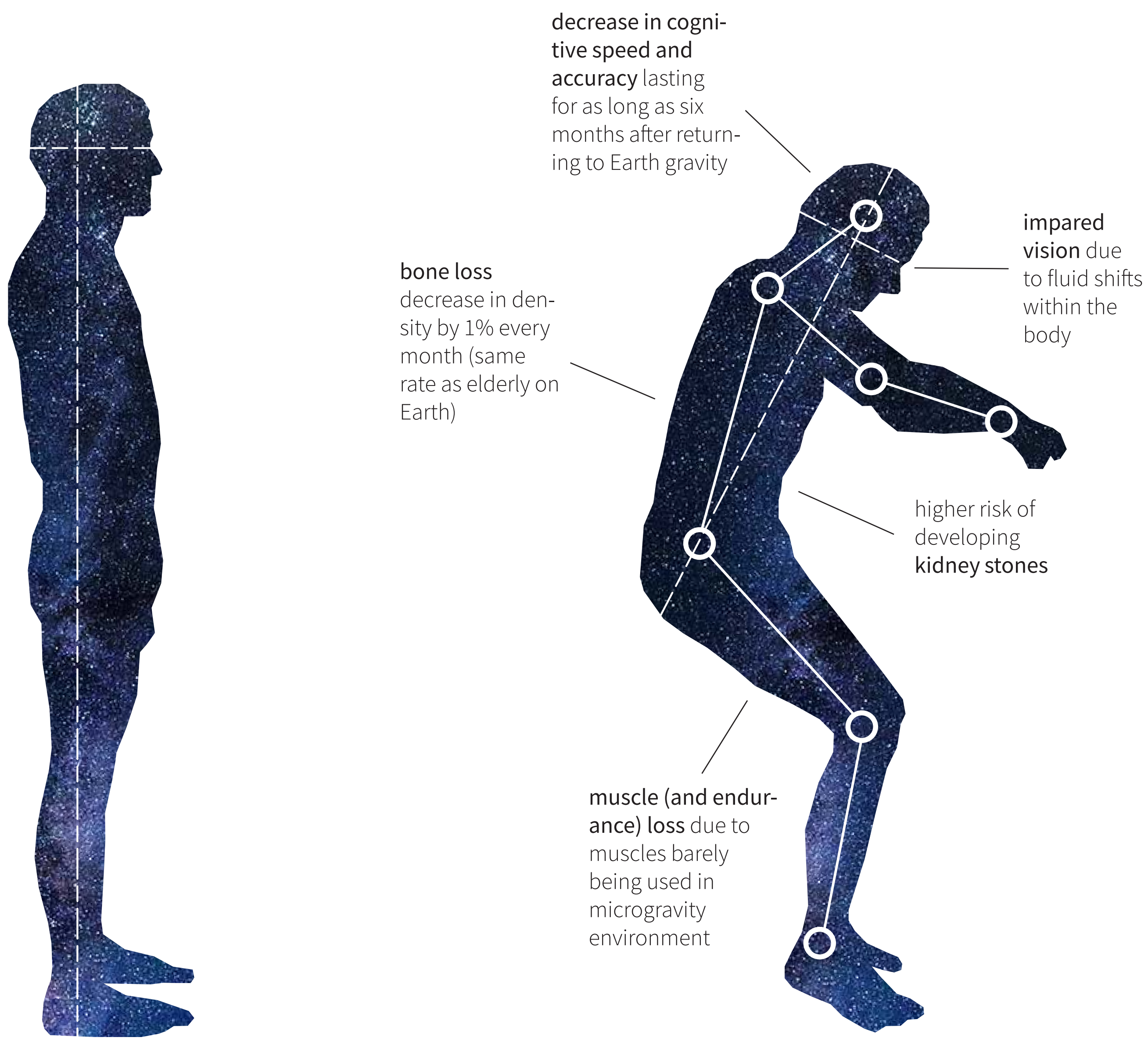
GUIDING QUESTIONS:

- *What are the long-term effects of Microgravity on the human body?*
- *What are the benefits of living in a Microgravity environment?*
- *What are the design implications of Microgravity?*
- *How can you create an environment with Artificial Gravity?*
- *What are the characteristics (pros and cons) of either environment?*



## PHYSICAL CHANGES

Some of the observed/measured effects after having been in space for more than 3 months.




EARTH GRAVITY

MICROGRAVITY / "ZERO-G"

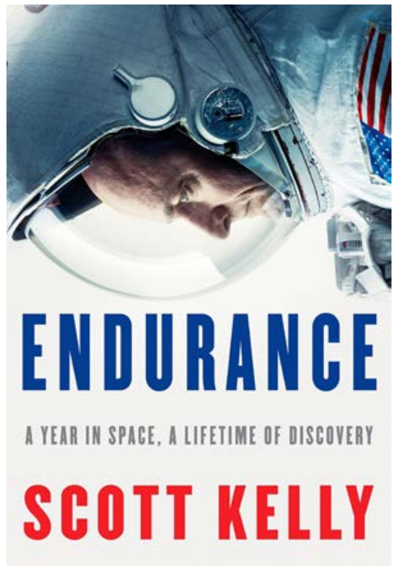
(NASA, 2020)

## SCOTT KELLY'S ONE YEAR IN SPACE, AND THE TWIN STUDY

Reflections right after mission end and touchdown on Earth:

*If I were on the first crew to reach the surface of Mars, just now touching down on the red planet after a yearlong journey and a wild-hot descent through it's atmosphere, I feel like I would be able to do what needed to be done. One of the most important questions of my mission has been a simple yes or no: could you get to work on Mars? I wouldn't want to have to build a habitat or hike ten miles, but I know I could take care of myself and others in an emergency, and that feels like a triumph.*

Scott Kelly, 2017




### One year mission on the ISS

At the time (2016) Scott Kelly was the first person (together with Russian cosmonaut Misha Kornienko) to have spent one whole continuous year in space on the International Space Station. The purpose of his stay was to study how his body was affected physically and psychologically by experiencing microgravity for a long period of time. Previous to this mission astronauts would spend up to six months on the station at a time, and side effects such as bone and muscle loss and changes to the structure of the eye was discovered. This experiment took it a step further, to see how well or bad people would fare on a mission to Mars.

### The Twin Study

Scott happens to have a genetic twin called Mark, which proved to be a great opportunity for the scientists at NASA to perform a true comparison between the two. Eyes, heart, blood vessels, sleep and nutrition was being studied, and his DNA was analyzed and compared with Mark's to see the effects of spaceflight on a genetic level. He was also asked to reflect on the effects of long-term isolation and confinement.
He continously took blood samples and performed ultrasounds on bloodvessels, heart, eyes and muscles, and kept logs of everything from the contents of his meals to his mood.
Ten research teams down on Earth analyzed the data.

### Important findings

Scott's cognitive performance ramained mostly unchanged during his time on the space station, however

a noticeable descrease in speed and accuracy was observed after his landing and lasted for six months,

inflammation and carotid artery wall thickening was discovered,

and his body mass decreased by 7% during flight (but this was likely partly because of increased exercise and controlled nutrituional intake).

(Edwards & Abadie, 2019)

## BENEFITS OF "ZERO-G"?

*On this mission I learned the differences between visiting space and living there. On a long-duration flight, you work at a different pace, you get more comfortable moving around, sleep better, digest better. As my first long-duration mission went on, what surprised me the most was how little force it actually took to move around and to hold myself still. With just a slight push of a finger or a toe, I could travel across a module and wind up exactly where I wanted to be.*

Scott Kelly, 2017

### Ease of movement

As described by Scott Kelly in his book *Endurance*, it is possible to get used to living in a microgravity environment, and when that happens it can be faster and easier to get around in the spacecraft than it would be in Earth gravity or artificial gravity.
Heavy objects are also easier to handle. When equipment needs to be unpacked, moved or repaired working in microgravity can make the process easier.

### It's not about **$m^2$**, but **$m^3$**

Microgravity is a challenge, but it can provide great opportunities due to the elimination of any "up" and "down", making it possible to use volume rather than area when designing. However, even in this environment it is recommended that a local vertical be established to make it easier for the crew to orient themselves. Lighting, airflow and colors can be used to to accomplish this. (Kennedy, 2002)
Even if a local verticial is established the space that can be reached and thus used is much greater than in a gravity environment. This enables the use of all surfaces and the design of spaces with greater dimensions where ladders and stairs don't have to be included.

### The alternative is not Gravity

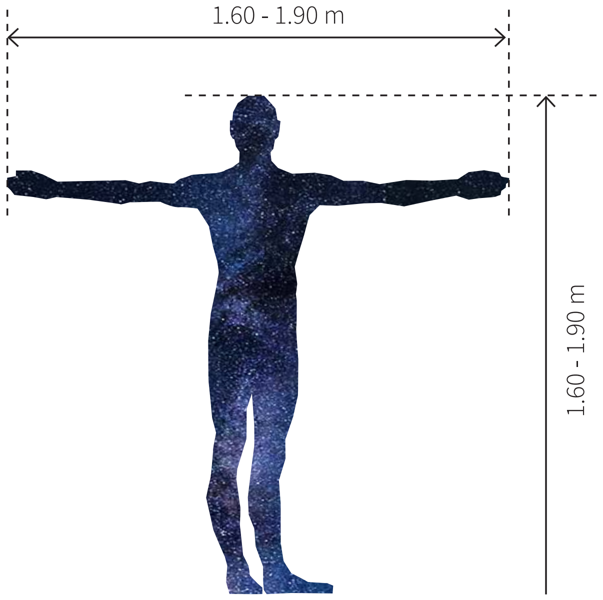
The alternative to microgravity is not normal Earth gravity. It is possible to simulate a credible gravity environment if the spacecraft is very large, a radius of approximately 10 kilometers would do it. But that kind of megastructure is not relevant for near future space transportation vehicles.
With a smaller radius artificial gravity comes with a set of quirks and difficulties, which are explained in the following pages.
Additionallt artificial gravity can incur 5-15% mass penalties over a microgravity system depending on chosen propulsion system and configuration, which roughly translates to 5-15% additional development costs. (Kennedy, 2002)

# DIMENSIONS

## THE RULES OF MICROGRAVITY

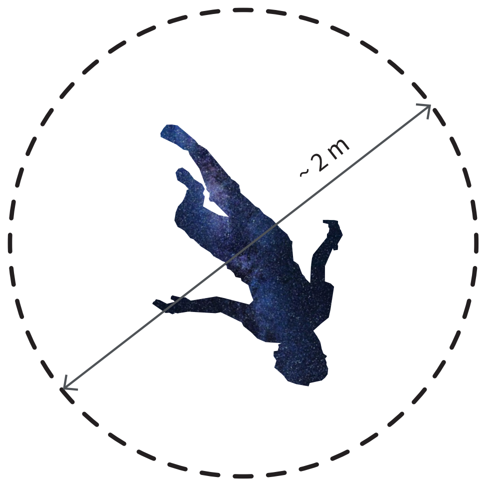
In a microgravity environment there is no force pulling you "down" to a surface that you can walk on. Your body appears to be weightless, and so does every object around you. All surfaces are equal, and none of them will be made to walk on. Simply moving in mid-air will have no effect on your forward momentum. According to the laws of physics, in order to move in one direction you have to throw or push something in the opposite direction. Movement is usually initiated by pushing or pulling with the hands. Changing the direction and stopping is also usually done by using the hands, but keeping yourself in place can be done by using your feet. This helps to free up the hands so that they can perform other necessary tasks.

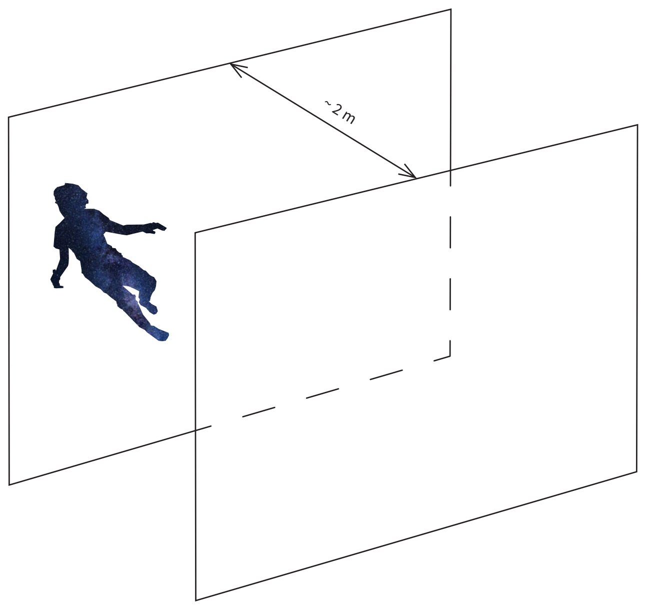
The height of the crew can vary between approximately 1.60 - 1.90 meters (NASA), which needs to be taken into account when deciding the distances between e.g. surfaces and handlebars.




## WITHIN REACH

In order not to find oneself suspened in mid-air, having drifted away an inch from anything to grasp, there should always be something to grab hold of within 1 meter of one's position.
This could be a handle attached to a surface for example. But in spaces where the surfaces of the room are further apart than 2 meters a different system has to be designed. This could be some kind of railing network spanning these larger sized spaces.



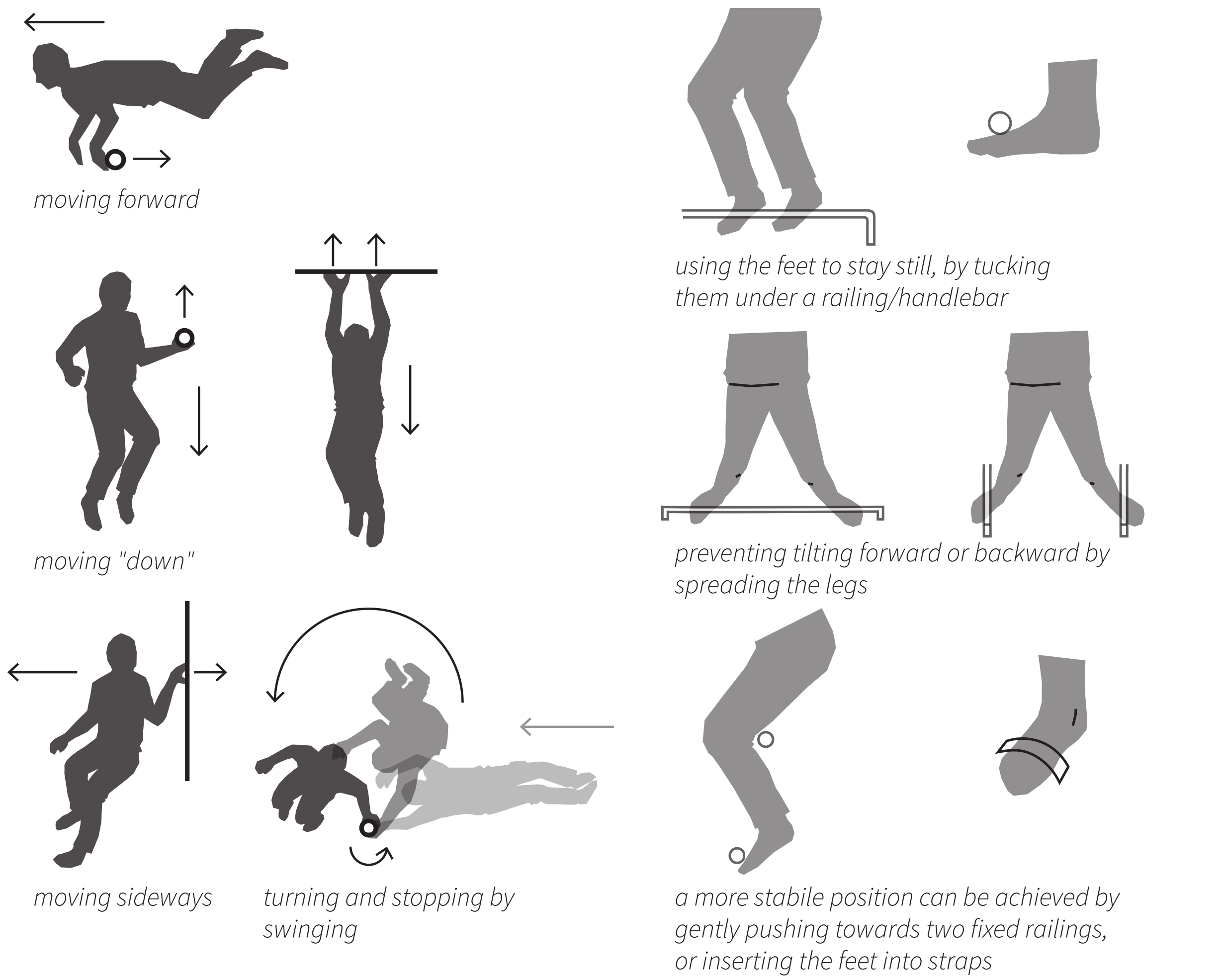






# MOVEMENT

*So here in space, obviously, in microgravity, we have to use our hands to get ourselves around, to float around the modules, because our feet, we don't necessarily walk around, we just grab hand holds and move ourselves around, which means that we need our hands free to do just that.*

Christina Koch, 2019



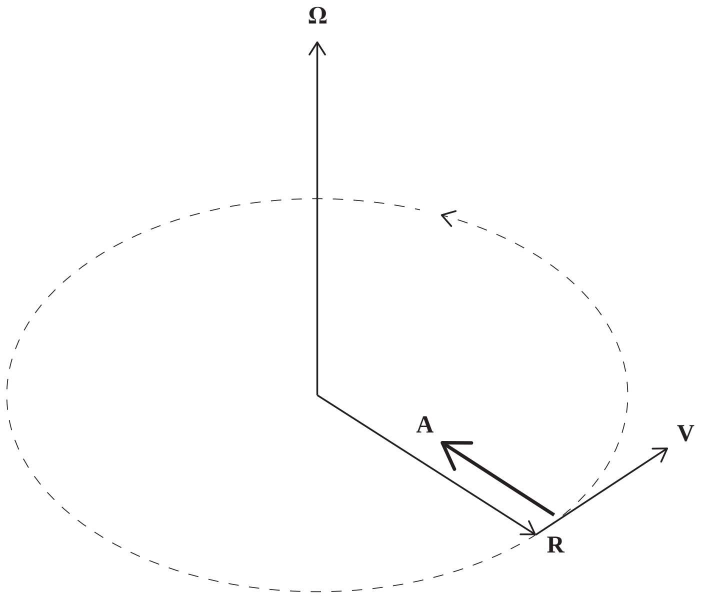

## GETTING AROUND WITH EASE

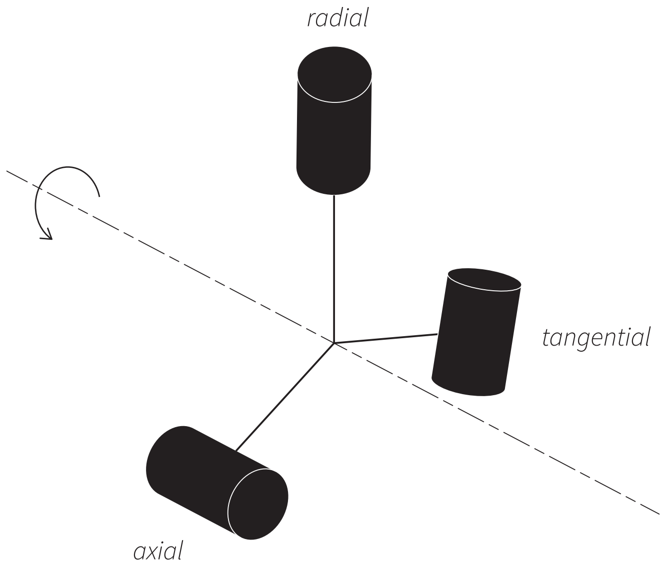
By studying how the crew of the ISS moves around in the space station, certain movement patterns become clear. As Christina Koch says in the quote above, the astronauts mainly use theirs hands to move in different directions, to turn and to stop. Sometimes the push of a toe will suffice in getting you where you want to go (this is a more advanced level of movement, performed by experienced astronauts only), and in some cases it's possible to shuffle your feet sideways underneath the railing to move short distances, but these are exceptions. It is clear that railings/handlebars with different orientations will be necessary to install. For example, a handlebar that is perpendicular to the body and going from left to right is most efficient for moving foward, whereas turning and stopping is done easiest with a handlebar that is perpendicular but going from "underneath" to "above" in relation to the body. Movement for longer distances along a handlebar that is parallell with the body was not observed.
Staying in place is done with the feet by tucking them under a handlebar or into straps (straps being more stabile). It was observed that to prevent the body from tilting forward or backward, the legs are spread wider or the feet tucked under different handlebars.
To further stabilize ones position two parallel railings could be installed close together to fixate against.

# INVESTIGATION INTO ARTIFICIAL GRAVITY

## CENTRIPETAL FORCE

The centripetal force makes an object follow a curved path. For this to happen an object is positioned in or fastened to a rotating structure that keeps the object from simply continuing it's movement in the direction (V) of the motion. This preventative force (A) is what accelerates the object towards the center of rotation, which is always perpendicular to the motion of the object. The acceleration is what is in this case referred to as Artificial Gravity. It differes from Earth Gravity in that there is a direction of movement. This direction changes constantly due to the rotational spin, which leads to some peculiarities of relative motion. (Hall, 2006)



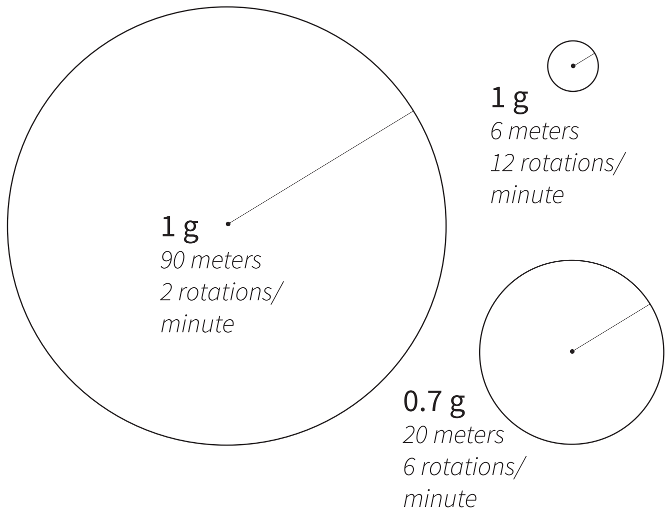




## CHOOSING AN ORIENTATION

The illustration to the left shows the principal orientation of modules: axial, radial and tangential. The surface that is facing out from the center of rotation will be the "floor" of the spacecraft.
In the axial orientation, most crew movement will be parallel to the axis of rotation with minimal side effects due to the direction of movement.
The radial orientation implies a lot of "vertical" movement, which requires ladders that involve risks and inconvenience even on Earth, but that would pose even greater risks in a spinning structure.
In the tangential orientation, the crew would move mostly perpendicular with the axis of rotation, and thus fully experience the side effects of the directional spin. The floor would also have to be curved to prevent it from appearing to slope downhill. (Bannova & Häuplik-Meusburger, 2016)

## ROTATIONS/MINUTE, RADIUS AND THE CORIOLIS EFFECT

In designing for artificial gravity, the architect must first acknowledge that the gravity will not be Earth-normal (1 g) even if the acceleration is 1 g, unless the radius of the rotating structure is very large. With a radius of around 10 kilometers, one would achieve a complete illusion. Anything much smaller than that will require a period of adaptation for the crew. By changing the variables **Radius** and **Rotations/minute** one can achieve different artificial gravity environments. A larger radius requires less rpm (rotations/minute) to achieve 1 g, wheras a smaller radius requires more. What is considered comfortable differs, but experiements indicate that most people adapt to 3 rpm quickly, and the upper limit is around 6 rpm. (Bannova & Häuplik-Meusburger, 2016)



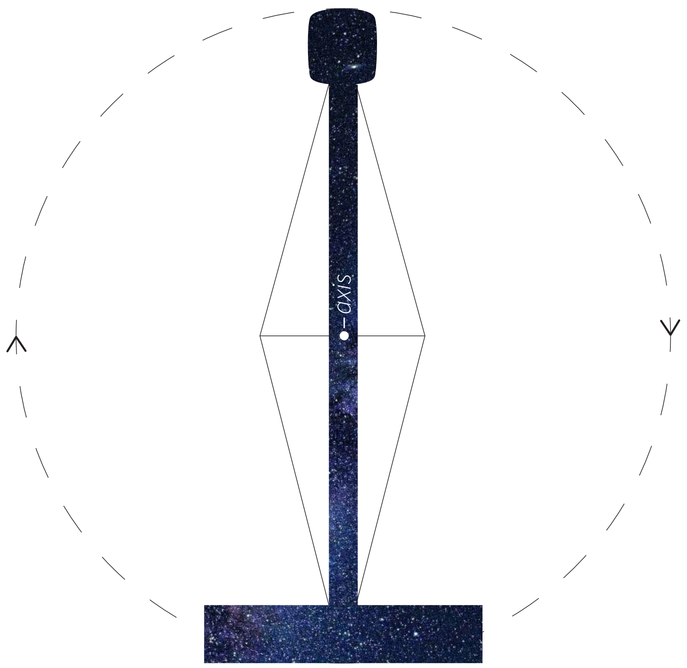


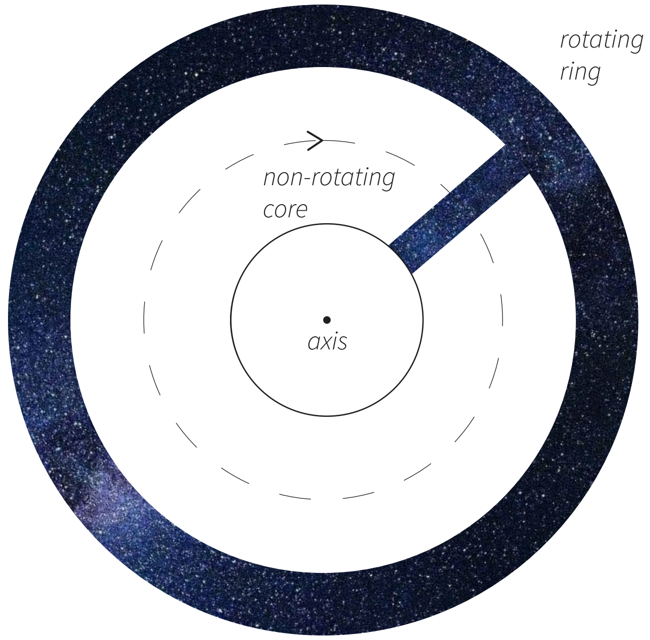

# DESIGNING FOR ARTIFICIAL GRAVITY

## TOTAL ROTATION

The whole vessel rotates around an axis extending in the direction of travel. The structure can be large, connected with trusses, without being too expensive. The habitat is located on one end and can be counter-wighted with e.g. power conversion/reactor system on the other end.

| pros: | cons: |
|---|---|
| Comfortable 1g environment possible | Hard to reach all parts of the vessel for maintenance<br>Rotation needs to be stopped for docking and undocking procedures |




## ROTATING RING MODULE

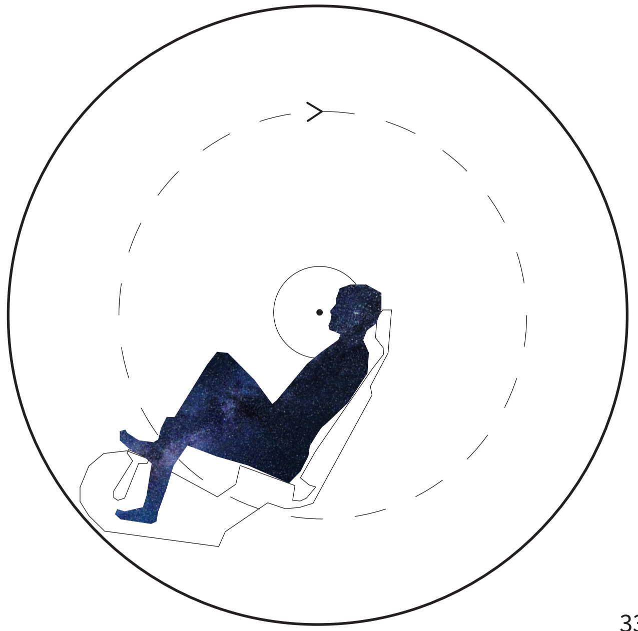
A part of the vessel is dedicated as an Artificial Gravity Environment, where functions that are best suited to this environment is located. The central part of the vessel is still in microgravity, which can also be taken advantage of (by maximizing used volume).

| pros: | cons: |
|---|---|
| Two different kinds of environments are created with their own advantages | Radius of rotation is limited, requiring a faster spin rate to achieve 1g<br>Structural connection between spinning and non-spinning part |

## ON-BOARD CENTRIFUGE

Only a small part of the vessel is dedicated to a centrifuge big enough to fit one person at a time. It would be used for daily exercise by all crew members.

| pros: | cons: |
|---|---|
| Takes up little space (can be a module attached to the side of the core habitat) | Does it make enough difference to the physical health of the crew? |



## PROS AND CONS

| CONSIDERATIONS | ZERO-G | ARTIFICIAL GRAVITY |
|---|---|---|
| HUMAN MOBILITY | + Mobility is effortless, and managing heavy objects is easy<br>– Restraints are needed for both people and objects | +<br>– Movement can be severly handicapped by Coriolis forces. |
| PHYSICAL ADAPTION | +<br>– Loss of bone and muscle mass, and a shift of fluids within the body will have a negative effect on the performance of the crew when exposed to a gravity environment | + The physical condition of the body is easy to maintain<br>– The transition from Earth gravity to Artifical Gravity might cause nasea and a sense on imbalance, depending in the rate of spin |
| PSYCHOLOGICAL ADAPTION | +<br>– There is a need to establish a local vertical, using visual cues, to avoid spatial orientation confusion | +<br>– Visual cues are needed to show the direction of the spacecraft rotation, to avoid imbalance |
| SPACECRAFT DESIGN CHALLENGES | +<br>– Fluid systems design will be influenced by microgravity, and heat convection is negated | + Fluid systems can work in much the same way as on Earth, making it easier to use familiar equipment<br>– The rotation required to achieve artificial gravity might complicate docking procedures and cause vibrations, as well as add structural mass |
| MAINTAINENCE | +<br>– Dust and other particles float freely, which makes them difficult to control and sometimes easy to lose. | + Maintainence is similar to what it is on Earth<br>– |

(Bannova & Häuplik-Meusburger, 2016)



## SUMMARY

I will try to use these design strategies in my design:

- Due to the benefits of efficient use of space, ease of movement and moving things around, and the substantial knowledge about the physics of microgravity and it's effects of the human body, the spacecraft will be a microgravity environment. The decision is further strenghtened by Scott Kelly's confidence in his physical condition after having spent almost a year aboard the ISS.
- It's possible that a module of the spacecraft will contain a small rotating centrifuge to improve the physical health of the crew.
- Utilize volume and surfaces as much as possible.
- Use the 2 meter rule when deciding the width of spaces.
- Create a railing/handlebar system that is intuitive to use by taking into account the "natural" movement of humans in microgravity.
- Establish a "local vertical", using colors and light, to help with orientation.

# LACK OF PRIVACY /FEELING OF ISOLATION

GUIDING QUESTIONS:

- *What is a comfortable amount of privacy?*
- *What kind of activities does one want to perform in private?*
- *What is the volume requirement for these activities?*
- *Furniture, objects, tools required?*
- *What causes the feeling of isolation?*
- *How can one create a feeling of community?*
- *How can one achieve social balance?*
- *In what way can one communicate with friends and family on Earth?*

# THE SOCIAL ASPECT

## PERSONAL SPACE

Everyone feels the need to be alone sometimes - to get away from all social interaction and all judgement. The smaller the shared space is and the greater the number of people sharing it, the greater is the need for it.
For long duration flights lasting six months or more, each crewmember will need a private "room" with access to personal storage, dressing area and a private recreation area to ensure that he/she can get enough privacy. Similar to the ISS, a long duration habitat should offer multiple volumes or divided rooms to properly separate activities. (Kennedy, 2002)

In the constrained environment of a spacecraft, maintaining a desired privacy level can be a challenge, putting a lot of demands on the layout design. However, social interaction is also very important for maintaining psychological health and should also influence the design. (Bannova & Häuplik-Meusburger, 2016)

## COMMUNITY

During a deep space mission the crew will be physically separated from the rest of humanity for the duration of the mission, and the other crewmembers are the only people that it's possible to interact with. On Earth it's possible to find a new social context if things don't work out in a relationship, but on a spacecraft the alternative is social isolation, which would most likely lead to depression. Therefore, good relationships amongst crewmembers is crucial to maintaining a good social life and psychological health.
A human mission to Mars will include a travel time of 6-9- months each direction, and a stay on the surface lasting between 3 months to 2 years. During this long-term mission the degree of crew isolation, social monotony and autonomy will be very high. It is documented that the isolation and external environment in Polar Regions affect an individual's consciousness and somatic and mental health.

Personalizing a private space is one of the important contributing factors for mitigating extreme feelings of isolation and loneliness. It can establish a sense of belonging, a temporary home. (Bannova & Häuplik-Meusburger, 2016)

# "ANALOG MISSIONS"

## REPRODUCING A SPACE ENVRIONMENT

An **Analog** is a reproduction of the conditions experienced by the human mind and body in space in an Earth setting. NASA is currently associated with at least 14 analog missions spread out on different locations, such as Antarctica, the Arizona desert and inside the Johnson Space Center, to name a few.
These missions are essentially field tests where new technologies and equipment are tested, as well as behavioral effects on the crew, such as isolation and team dynamics. (NASA, 2019)

An example of an analog missions is the "Hawaii Space Exploration Analog and Simulation" (HI-SEAS), which is run by the University of Hawaii and funded by NASA. The first mission started in 2013 and was scheduled to run for a year, with a crew of six (three men and three women). To gather information on the well-being of the habitants, monthly questionnaires were distributed and post mission interviews performed.

## HI-SEAS MISSION IV:

The design of the habitat is based on a dome-like structure with half of the space being open and double height and smaller rooms with different ceiling heights in a semicircle in the other half. The openness increases the sense of space but limits the opportunities for privacy.
Examples of **Enjoyable Social Situations** include:

- Cooking
- Group work outs (e.g. running together)
- Games (the crew organized special game nights once a week)

In general the enjoyable social activities took place in the most volumous parts of the habitat in the evening, or in one of the private rooms.

Examples of the opposite, **Unpleasant Social Situations** are:

- Dining (in contrast with research done on other analog missions dinner could be unpleasant due to social tentions or the work that needed to be reviewed during the meal).
- Other group activities involving the whole crew (they were forced or avoided)
- Personal Hygene activies (including showers and toilet use)

During the mission work related activities were of great importance to the crew, which could at times disrupt those who wanted to relax because the two activities shared the same space.
Privacy became more and more valuable to the crew as the mission progressed, resulting in people often spending 3-8 hours in their private room during the day to avoid social interaction. Sound proofing was very low, which negatively impacted the time spent alone. The crew reported that there was a "sense of observation which was difficult to escape from", and a lack of semi-private spaces.
Social rifts and splitting into smaller groups happened early due to social tensions.

The design of this particular habitat can be said to be unbalanced, with more space and attention given to the great social spaces, and not enough to the private and semi-private ones.
This is just one example of many designs, but it showes the importance of a good balance of private and social. (Häuplik-Meusburger, Binsted, Bassingthwaighte & Petrov, 2017)



# CO-LIVING ON EARTH


Included here is information from studies made in Sweden of what spaces people would like to share and in what way, in the form of Master's Thesis projects produced at Chalmers University of Technology.

These investigations are catered more towards the designers of "normal" co-living communities on Earth, but some situations and feelings can also exist in a space habitat environment. For example, how does one show that one desires privacy? And how can one encourage more spontaneous meetings and not force people together to participate in mandatory activities? The issue of making the common space feel welcoming for all inhabitants is also very relevant.

## FULL HOUSE
### Master's Thesis by Tove Wennberg & Maria Wikström

There is an increased interest in co-living (Ungbo, 2012, as cited in Wennberg, 2016), and it was written in 2014 that 47% of young people in Stockholm want to live together with friends or others who are not part of their family (United Minds, 2014, as cited in Wennberg, 2016). Important reasons for co-living are to save resources, for both economical and environmental reasons. In a survey done in connection with the thesis project it was discovered that for shared homes to work it is crucial to share not just the physical space but also responsibilities, such as housework, and to be respectful of each other.
It was also found that one of the most important reasons for not wanting to live together with others is lack of privacy, which is normally strongly connected with the concept of home.
In shared environments, such as a co-living community or in a family home, the door can be considered the most obvious tool for manifesting the need for privacy. It is referred to as the "door language". A closed door is usually a sign of the need for privacy, and a door that is ajar can be taken to mean that the person inside the room wants to be alone but still take part in a small way in the activities that are going on outside. A completely open door is a sign that socialization is welcome and the room becomes an extension of the common space outside.
In the workshops that were held together with people living in a co-living community, flows and communication were stated to be important - which rooms are accessible from where and how one gets there. The possibility for each person to influence the shared environment and add their personal touch was also discussed and identified as important. (Wennberg & Wikström, 2016)

## A-PART-MENT
### Master's Thesis by Felicia Davidsson

To understand why there is a resistance towards sharing your living space with others one has to differentiate between the types of activities done in the home. The resistance to sharing spaces is usually greater when it comes to performing necessary tasks, such as cooking or using the bathroom. These tasks need to be done several times a day, even when you don't feel like socializing. if, on the other hand, you aren't forced to do something or use a specific space it is more likely to happen. This means that the freedom that comes with option is a very important psychological factor when it comes to using common spaces. This requires careful designing of these spaces.
To encourage social interaction in general amongst neighbors their shared spaces also have to be carefully designed, otherwise nothing will happen - as Jan Gehl puts it: "Nothing happens because nothing happens" (Gehl, 2011, as cited by Davidsson, 2017). In an apartment building for example, the starwell can be an important place where spontaneous meetings occur. (Davidsson, 2017)

# THE CREW QUARTERS

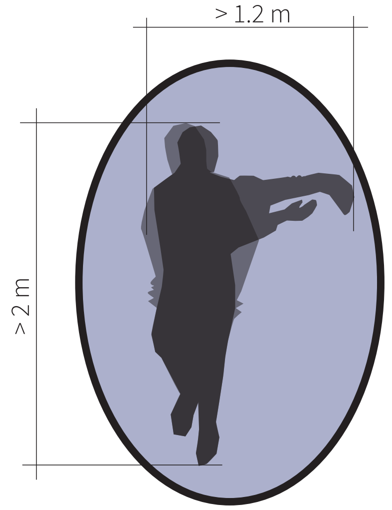
## PERSONAL ACTIVITIES

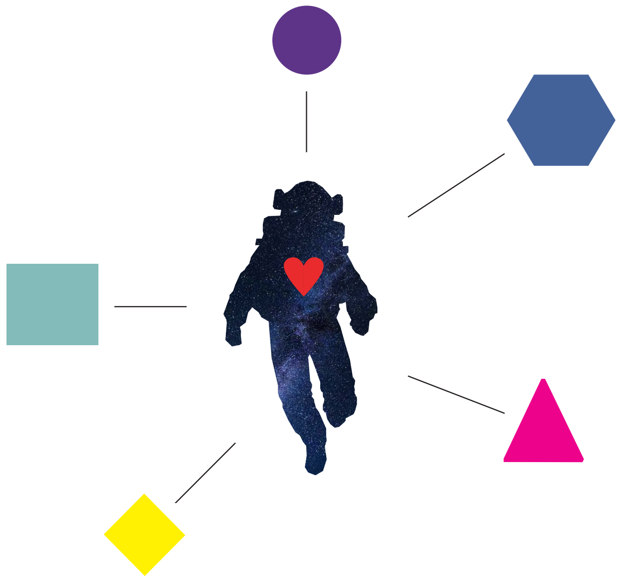
What are activities that we usually or occationally want to do in a private space?

- Sleeping
- Dressing and undressing
- Relaxing, e.g. with a book, a movie/tv-series or a personal diary
- Contacting friends or family
- Working on personal projects

## GENERAL CONSIDERATIONS

In a confined and at the same time exposed (to the other crew members) environment such as a spacecraft it is important to provide each person with an environment that supports quality sleep and where it's possible to relax in private, unexposed.
In the first American space station, Skylab, crew members were provided with their individual quarters. They commented that the main problems where disturbance due to noise, light and other crew members. They also wished for a more customizable personal space regarding use and personalization.
(Fairburn, 2001)



## SIZE

Any long distance spacecraft will likely (and hopefully) be reused many times by a different set of crew, which puts demands on the flexibility of the private compartment - it needs to fit both the size and difference in values and interests of several individuals.
The activities that would be performed in the private crew quarters don't require a large volume. Most of the activities can be done simply by remaining in the same neutral body posture (the posture that the body naturally takes in a microgravity environment), and moving the arms. Dressing and undressing are the most volume demanding activities, requiring enough space to fully stretch out the limbs. This means providing the space corresponding to the full length of the crew member, from head to toe, in one direction and the space corresponding to the fingertips of one hand to the opposite shoulder. This is the absolute minimun measurement, but if possible a small margin should be added to increase the comfort of movement.
The crew must also be given enough personal storage.

Some items should be visible (for personalization) and easily accessable (clothes and equipment that is used often), while items that are used less can be stored outside of the personal compartment.

## PERSONALIZATION

The design and asthetics of an environment can have an impact on an individuals comfort and productivity (Stuster, 1996, as cited in Fairburn, 2001). Providing a crew member with a space that they can turn into their own by customizing it in some way, can create a sense of "home" in space - a secure base where it's possible to relax and be reminded of the things they like and the people that they love. The degree of customization can vary from e.g. displaying personal belongings openly (such as photos or books) to being able to change the layout, materials, colors and light intensity of the compartment.



# THE COMMON SPACE

## SOCIAL ACTIVITIES

What are activities that we usually or occationally want to do together with others?

- Meetings
- Cooking
- Eating
- Playing games
- Watching movies
- Exercising

## GENERAL CONSIDERATIONS

In general, larger spaces should be provided for common areas to encourage positive social interactions (Toups & Simon, 2014). Creating vizual connections between different activity zones could help mitigate feelings of isolation - always being able to see someone and wave or call out to them can be comforting and strengthen the social connections between the crew.

Astronaut: Having dinner together is an important social activity. "At dinner at night, we have a time, even if you are busy; you set this time to make jokes and to have fun".
(Bannova & Häuplik-Meusburger, 2016)

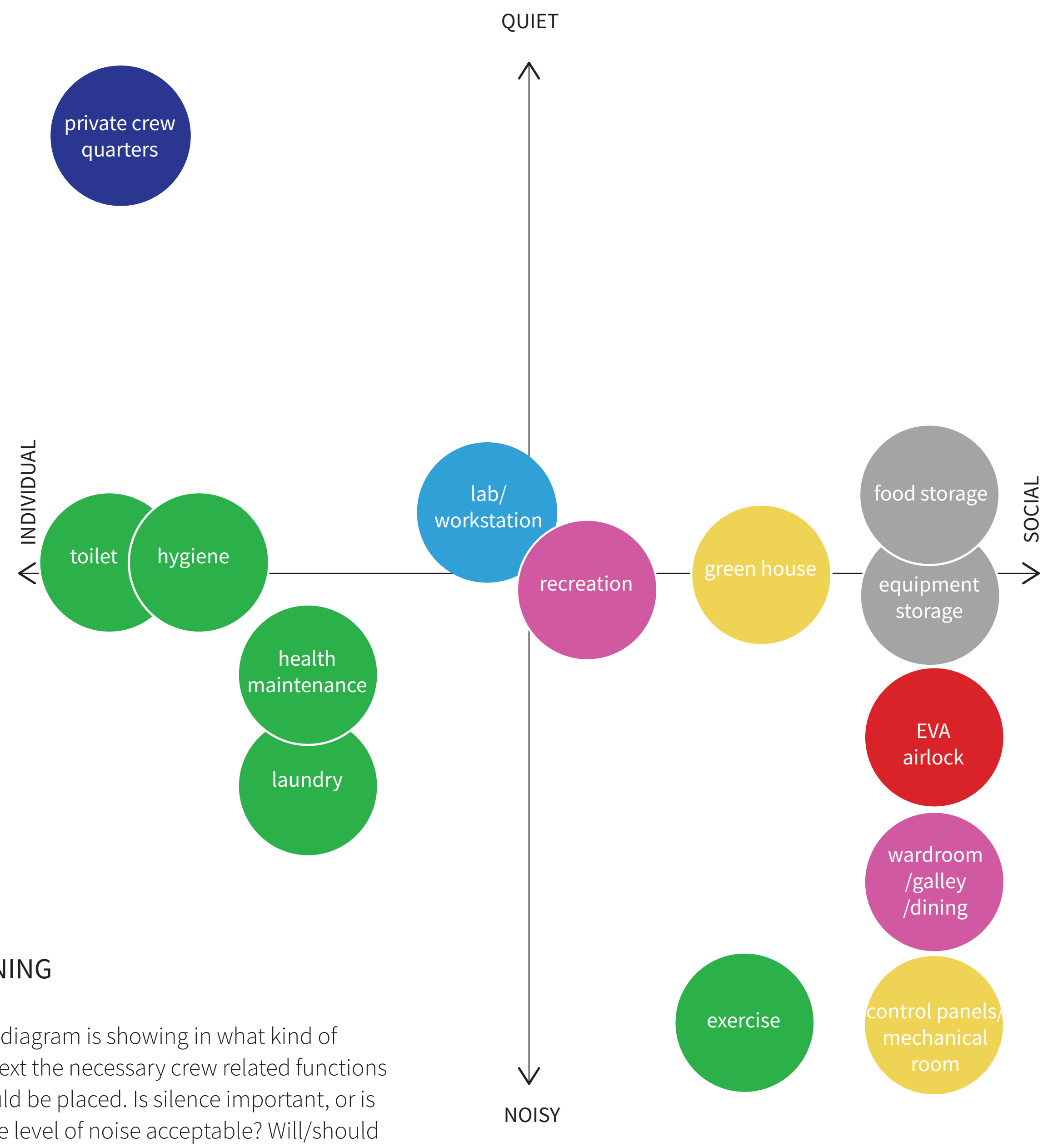
## SEMI-PRIVATE SPACES - NOOKS

Outside of the smaller crew compartment and within the shared space, it should be possible to find a more open environment where one can seek relaxation or concentration. Here one is a part of the social sphere without necessarily being in the center of it. These spaces can be called "Nooks". They are small bubbles of semi-privacy in the larger common space. If translated into "door language" (as mentioned previously in FULL HOUSE), these nooks can be likened to a door left ajar.
As described in the reports from the HI-SEAS mission IV, the lack of semi-private spaces was part of the reason for the social rifts. It is easy to become tired of and irritated with each other when forced to be in the same company whenever one leaves one's own private quarters.
These spaces can be created by adding partial visual obstructions or furniture/equipment that is places at a distance to gathering spots.

## PERSONALIZATION

Even in the shared spaces personalization can be important. By letting each crew member have their own personal work space and perhaps their own kitchen cabinet and seat at the dining table, everyone can feel a sense of belonging to the group.
Just as each family member in most families has their own seat at the table, part of the couch and place for their toothbrush, personalization of and thereby occupation of a space can help strengthen the feeling of being in a family. It would be a family where everyone is grown up and have equal responsibility for the mission.

# LAYOUT




## ZONING

This diagram is showing in what kind of context the necessary crew related functions should be placed. Is silence important, or is some level of noise acceptable? Will/should the function be used privately or by many people at once? The chart is based on a recommendaton from *Space Architecture Education for Engineers and Architects.* (Bannova & Häuplik-Meusburger, 2016)
The most important division of space, regarding sight and sound, is between the Private Crew Quarters and every other function. Personal hygiene is also tended to individually. The wardroom/dining space and exercise area are the most social and can be exposed to more noisy surroundings. The lab/workstations should be positioned in a relatively undisturbed space with the possiblity for crewmembers to work on individual projects. Recreation is done socially, as well as individually in the private quarters.



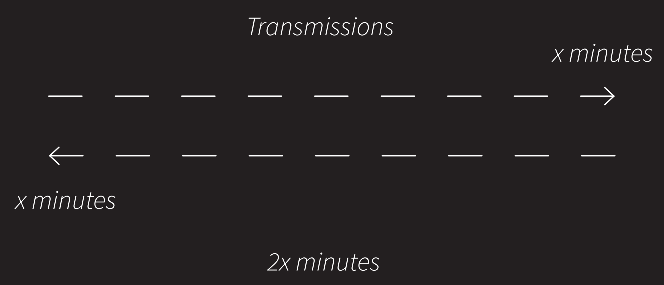
## "ROOMS"

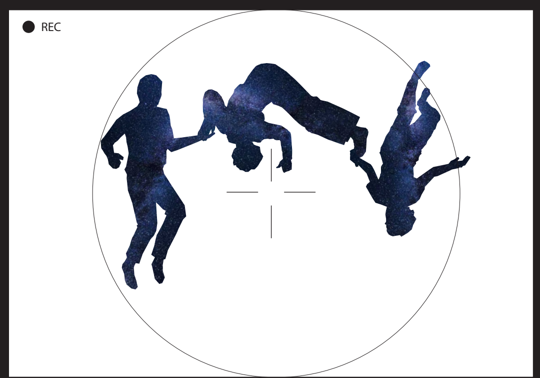
In order to save space functions can overlap each other in the same "room". The private crew quarters need to be kept seperate, but in the common area several functions can share the same space. The meeting room can also be where the crew dines and meet to play games for example, and the green house can advantageously be placed close to all activities to promote well-being through exposure to the plants.
Exercise and lab/workstation functions can both be used socially, but should be kept at some distance to each other, both visually and audibly, so as not to distract or disturb.

# CONNECTING WITH EARTHLINGS...

## THE TIME GAP

As the mission into deep space progresses the distance to Earth will grow longer and longer. The consequence of this is a time lag that will start as seconds and grow into minutes. On Mars for example, the time is takes for a transmission to travel to Earth is approximately 20 minutes (NASA), which means waiting at least 40 minutes for a reply. Direct communication with NASA will become harder and harder, and the crew will have to be able to handle more urgent issues on their own. But it also becomes harder to communicate with loved ones, which can have a greater psychological effect on the crew. After a few weeks of traveling the communication will turn into messages and recordings.




## SPACES FOR COMMUNICATION

How do you make this slow communication fulfilling? First of all every crew member needs to be able to create and receive transmissions in private. But there could also be camera setups in the common space, showing friends and family what the habitat looks like and providing more space for creating more interesting recordings (showcasing microgravity acrobatics, explaining the progress of experiments/personal projects, sharing food preparation, creating lectures etc.). Having several cameras could also help when communicating with NASA.

# SUMMARY

I will try to use these design strategies in my design:

- Design the private crew quarters in a way that provides a relaxed and quiet space to retreat into when in need of privacy, with enough room for personal belongings, a computer setup, a "bed", changing one's clothes and communicating with friends and family.
- Provide a generous amount of space for group activities, so as to promote socialization.
- But not forgetting to leave room for semi-private zones.
- Create sighlines that make the crew feel connected even when they are in different "rooms" doing different things.
- Make personalization possible in both the crew quarters and common spaces to promote a feeling of "home" and "family".
- Add distance or sound insulation between activities that are noisy and activities that require more quiet concentration.

# CLAUSTROPHOBIA

GUIDING QUESTIONS:

- *What are the causes of Claustrophobia?*
- *What kind of reactions does it lead to?*
- *How can one prevent it?*
- *Or, provide a means of mitigating the effects?*



## ENCLOSED

### CAUSES AND REACTIONS OF CLAUSTROBHOBIA

The term *Claustrophobia* was introduced in 1871, which litterally means a fear of being enclosed. (Lewin, 1935)
It is a form of anxiety disorder, where the irrational fear of having no escape, running out of oxygen or of the walls closing in can lead to a panic attack. Triggers include being inside a small space (confined by some kind of wall or even other humans) with seemingly no way to exit or no view towards the outside, wearing clothes that are too tight, or simply being confined to a certain space (willingly or unwillingly) for a long time. (Paddock, 2017) Claustrophobia can be connected to having a dysfunctional amygdala (the part of the brain that controls our reaction to fear), but it is often caused by a traumatic experience, such as being stuck in a small space for a long time. (Scaccia, 2016)
The symptoms are similar to other kinds of panic attacks: sweating and chills, dizziness, dry mouth, hypervantilation, accelerated heart rate, chest pains, general confusion and disorientation, an urge to run away etc. (Paddock, 2017) The reaction is usually to try to get out of the situation and find a more open space. People who suffer from the phobia in their every day life usually avoid small, enclosed or crowded spaces and compulsivly look for the nearest exit in every situation. (Scaccia, 2016)

### WAYS OF PREVENTION / MITIGATION

Firsly, how can one prevent the feeling of being in a space that feels too small, crowded or confined?

- Design/choose a structure that allows for relatively large open spaces to exist.
- If a certain space is restricted in size for some reason, try to make it *appear* larger than it actually is, using colors and natural light illusion (natural light can help give the impression that a larger space is waiting outside.
- Include generous openings towards other "rooms" to allow for easy movement, long sightlines and diagonal views.
- Partition a space into separate areas with different identities in order to make the environment feel varied and not part of one larger "room" that one cannot escape from.
- Keep areas as clean and uncluttered as possible. (Toups & Simon, 2014)

If a crewmember where to  experience a panic attack due to claustrophobia, the way to cope with the attack is to:

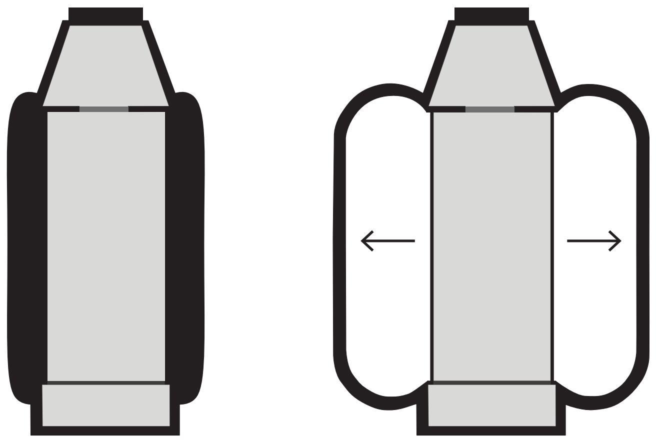
- Breath slowly
- Focus on something safe or visualize a place or moment that makes you calm
- Question the trigger of the attack and remind yourself that the fear is irrational (Scaccia, 2016)

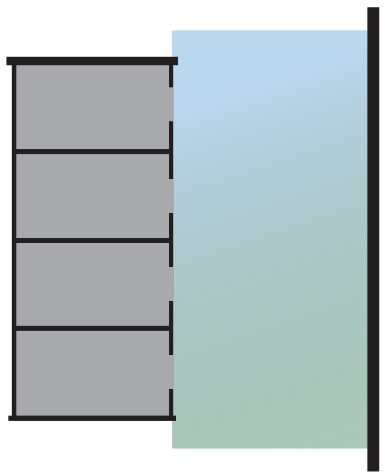
It is up to the crewmember to carry out these actions, but the interior design could help by providing calm spaces that could bring forth calming memories and thus slowing down the heart rate and breathing.

# STRUCTURE AND LIGHT

## THE TRANSHAB PRINCIPLE: INFLATABLE SHELL

How can one design a structure that can feel expansive and allow for larger spaces while still being able to fit into the payload space of one launch vehicle? One answer lies in the design principle behind the TransHab module (see p. 22) - using an inflatable outer shell that can more than double the usable volume.





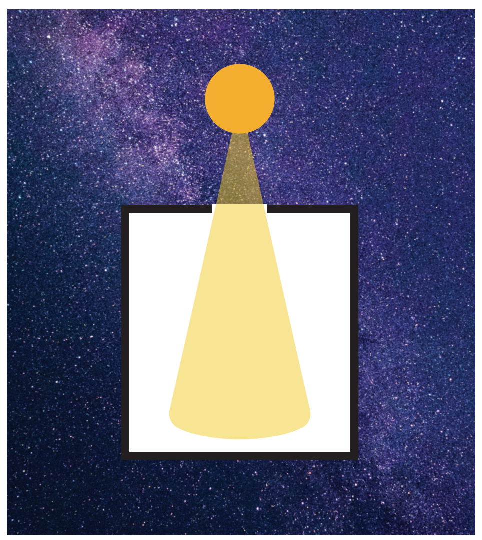
## INSIDE - OUTSIDE FEELING

Is it possible to create a space inside the spacecraft that posesses many of the characteristics of the outdoors, making it feel as if you're stepping outside when emerging from another smaller space? This space should be filled with bright daylight, greenery, sounds of nature, and a breeze if possible. Entering this outdoor space by emerging from a smaller space could give psychological relief simply by giving you the illusion of being in the free oudoors.

The inflatable type of construction consisiting of a core structure and an inflatable outer layer could work well with this design strategy - the space between the core and the outer shell being slighly larger than the inner rooms, and providing a continuous circular space.

## SUNLIGHT

Simulating sunlight reaching into the structure can give a feeling of a larger space existing outside of the confined space, further adding volume.
With a bright overhead light simulating the sunlight, this can be achieved. It also helps establish a clear sense of up and down in the microgravity environment.

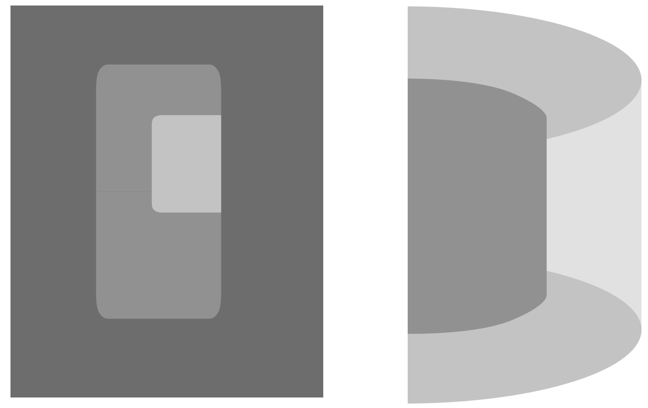




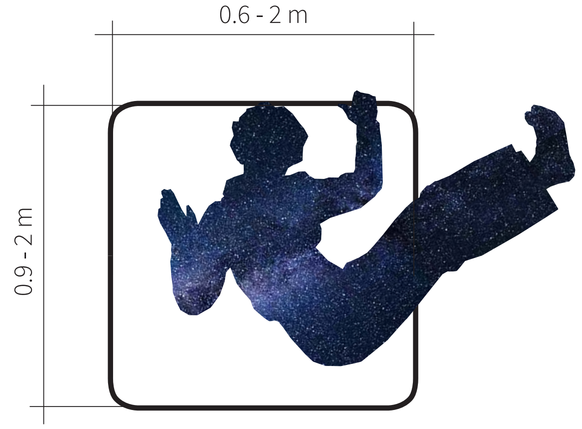
# SIGHTLINES AND IDENTITY

## SIGHTLINES

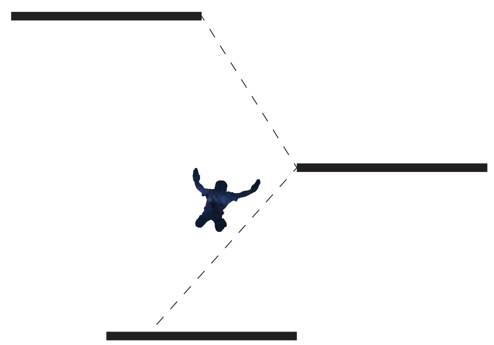
Designing for clear views towards adjacent "rooms" in the spaces that are used often provides easy wayfinding. The crew would of course learn how to get around no matter what the design of the circulation system was like, but it can give an ease of mind to almost never have to be in a small space with seemingly no exits. Particularly important would be the view to the possible "outdoor space".



A continous space that hints at something behind the bend can also give a sense of being in a larger space, and make it seem more dynamic and interesting even though one knows what supposedly awaits around the "corner".



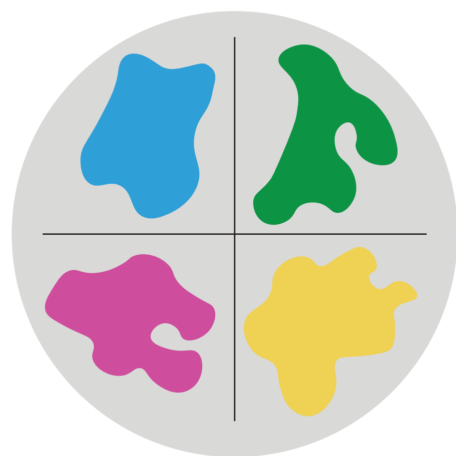

What is a good size for openings between "rooms"? Some openings might be more like normal doorways, while others are smaller for privacy reasons and seem more like windows. However, even windows are possible passageways in microgravity, which means that the size has to be comfortable enough to pass through with ease. The way of passing though is of course also different in a microgravity environment - head-first or feat-first (this is clear if one observes how the crew of the ISS move around). This means that it's mainly the space beside the shoulders that must feel wide enough. The average shoulder width for an man (in the U.S.) is 41 cm (and 36 cm for women) (healthline, 2018). A comfortable minimum width would then be > 0.6 meters. The width of inner doors range from 0.7-1 meters and a normal outer door has a measurement of 0.9-1 meter, which should suffice in both "width" and "height".



If possible, creating open "rooms" and greater visual connections between different activity areas can also have a positive effect. It can, as stated previously regarding the common space, give a greater sense of connection to the rest of the crew by seeing them more often.

## DISTINCT SPACES

Giving different areas their own identity and thereby giving the mind more information to process about them can make the mental map of the habitat grow in size.
However, it is important to still keep some spaces larger and uniform, and not subdivide them into smaller areas. Otherwise the whole habitat might start to feel like a maze and all spaces will feel cramped.



# THE COLOR PALETTE

## "SPACIOUS COLORS"

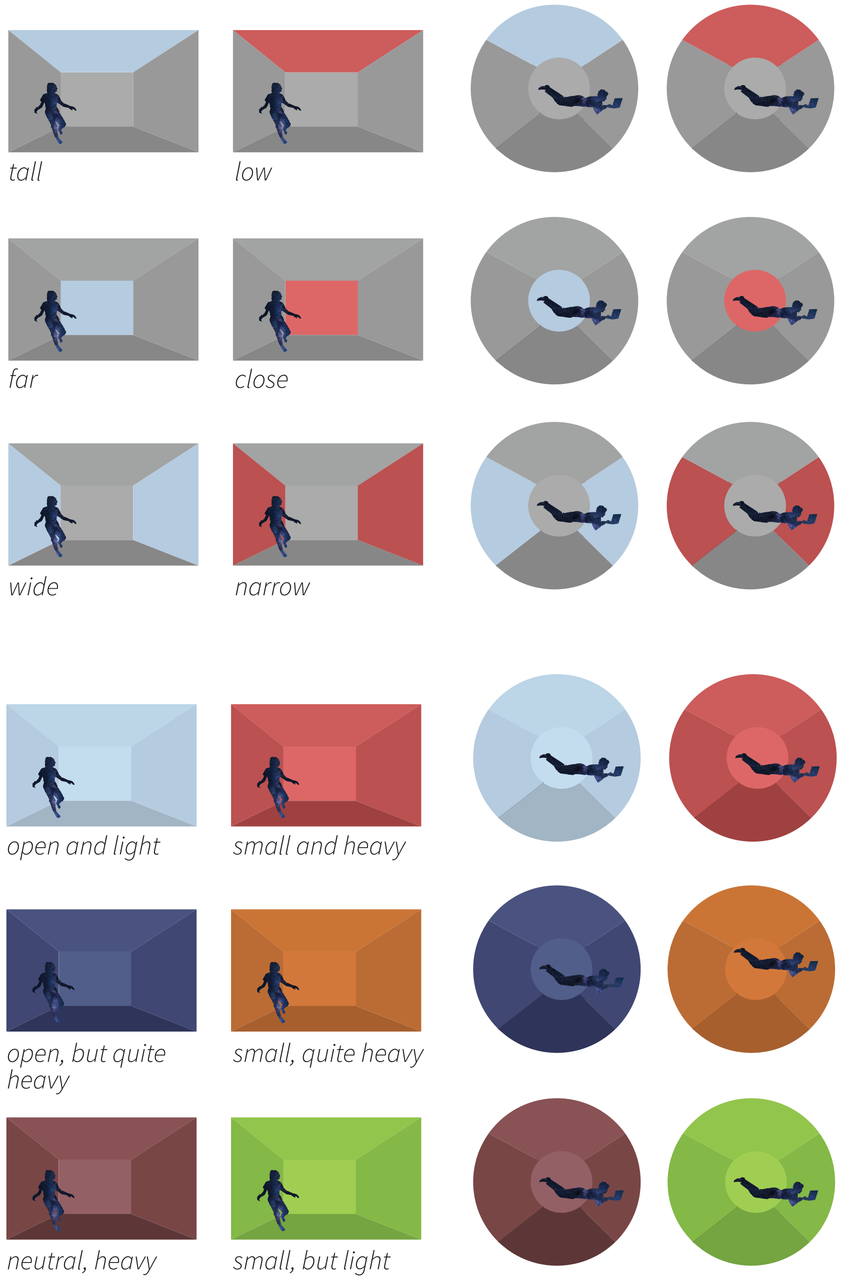
In architectural space the following can be perceived:

- Warm, saturated and bright colors advance to the foreground.
- Colors with no apparent "termperature" appear to be located in intermediate ground.
- Cool and bright colors, as well as dark warm and dark cool colors recede into the background. (Merwein, 2007)

And concerning hues of equal brightness the following can be perceived:

- So called *Passive Colors*, such as green and green-blue, seem lighter in weight
- And so called *Active Colors*, such as red, seem heavier

The effect that a color has in architectural space always depend on it's brightness and saturation, as well as the relation to the surrounding colors. (Meerwein, Rodeck & Mahnke, 2007)




*By adding "advancing" colors and "receding" colors into a neutral grey environment the effect becomes immediately apparent. Even in a setting with a more unusual geometry it is noticable.*

*In experimenting with using the same color throughout one space, it can be made to feel open and light or small and heavy.*



# SUMMARY

I will try to use these design strategies in my design:

- Work with an inflatable structure, similar to the TransHab.
- Create the feeling of there being both an inside space and an outside space with simulated sunlight.
- Include generous openings between "rooms" to allow for easy passage and sightlines.
- Differentiate between spaces by giving them their own identity.
- Use bright, cool colors in the "outdoor" space to make it appear larger, and use dark, cool and dark warm colors in the crew quarters to create a receding effect, as well as to help with sleeping.

# LACK OF CONNECTION TO NATURE

GUIDING QUESTIONS:

- *Why is our connection to nature important?*
- *What amount and what form of nature can make a difference?*
- *How can it be integrated into the design?*



## LONGING

*Oh, how I miss the wind on my face, the feeling of raindrops, sand on my feet and the sound of the surf crashing on the Galveston beach, we take daily sensory inputs for granted until they are absent. The environmental inputs on the space station consist mostly of the constant hum of the ventilation system. It stirs the air, allowing the purification system to scrub and clean our atmosphere so it's breathable. While some places on the space station are as loud as a lawn mower, others are as quiet as the vacuum of space. I can not wait to feel and hear Earth again.*

Christina Koch, 2020

*It's hard to explain to people who haven't lived here how much we start to miss nature. In the future there will be a word for the specific kind of nostalgia we feel for living things.*
*We all like to listen to recodings of nature - rainforests, birdcalls, wind in the trees. (Misha even has a recoding of mosquitoes, which I think goes a bit too far).*

Scott Kelly, 2017

# PSYCHOLOGICAL BENEFITS OF NATURE

## OUR CONNECTION TO OTHER LIVING THINGS

Being surrounded by an environment in which life is abundant and thriving, filled with plants and animals, the air fresh and water easy to be found, means that it is an environment that is ideal for life. Here is a good place to stay and live.
If, on the other hand, other lifeforms are scarce or not to be found at all, this indicates that the environment is most likely hostile, or simply doesn't contain the necessary substances for life, and that we should move on. This is the thought process that might be going on subconsciously whenever we enter into a new environment. Our subconscious mind might tell us to stay or to leave, and our emotions will automatically respond to that "command" or "suggestion". This means that prolonged stay in an environment that seem unfit for life, e.g. due to the absence of other living organisms, will most likely lead to negative psychological effects.

It is argued that humans possess an innate need to establish a connection with other living things. We only recently started living in man-made cities separated from nature, and Kellert and Wilson (authors of the *Biophilia Hypothesis* which aims to explain our desire to relate to nature) argue that it is unlikely that we have lost the sense of nature's value which has long been a part of our biology. Evidence of the biophilia hypothesis can be found everywhere: in our fondness for natural scenery, love towards animals as well as plants and the popularity of parks and wilderness actitivities etc. (Nisbet, Zelenski & Murphy, 2008)

There is also evidence that nature has a positive effect on our health and healing. Roger Ulrich is one of the most prominent figures when it comes to providing evidence for the health-benefits of exposure to nature in the healing process at e.g. hospitals.
Studies show that patients who are exposed to real or simulated nature can reduce the feeling of pain and stress, lead to an increase in positive emotions and a reduction in negative ones such as fear and anger. Even nature in the form of art, such as paintings, can have a pain and stress reducing effect.
This effect could also be observed in the caregivers. (Ulrich, 2012)

## REAL NATURE: PLANTS IN SPACE

Plants, in the form of rice, were first grown in space in 1973 in the American space station Skylab, where experiments were conducted to see how they would grow in a microgravity environment. It was also tested on the Russian space station Mir and the spacecraft Salyut 7. (Bureau, 2019)
On the ISS the space garden called Veggie (Vegetable Production System) helps NASA makes detailed studies, while providing the crew with fresh food to enhance their diet and general well-being. For now it can hold six plants, each of which grows in a "pillow" that contains clay-based growth media and fertilizer. (NASA, 2020)
In the 1990s NASA began experimenting with using aeroponics (see p. 58 for more) as an efficient growing system in space, which was demonstrated to work by the researcher Richard Stoner, who developed a self-contained inflatable system that could be deflated and easily stored away when not in use. (Spinoff, 2006)

## SIMULATED NATURE?

In the natural environment many senses are stimulated - sight, hearing, touch and smell. In what ways can they be stimulated in a similar way using other means?

- Photographs/Paintings
- Videoscreen/Projection
- Light and color movement (e.g. light shining though moving branches or scattered clouds, slow sunrises and sunsets)
- Virtual Reality
- Sound recordings (wind through leaves, rain, birdsong, insects etc.)
- Generated air turbulance (breeze)



# DIFFERENT FORMS OF NATURE

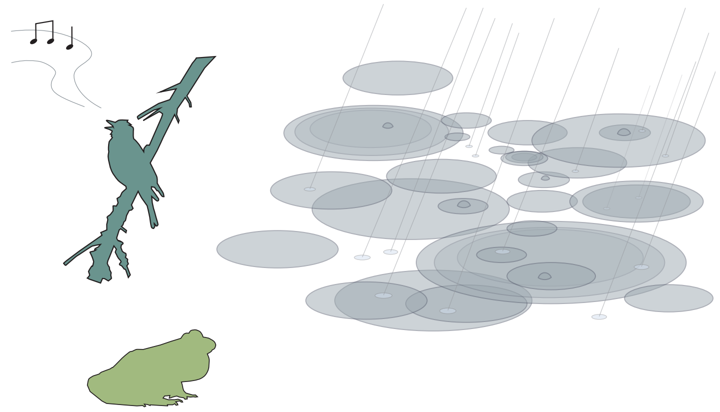
## MOVING PROJECTIONS

Special video recordings (probably hundreds) made in natural environments around the world can be stored on a hard drive on the spacecraft and then played continuously throughout the day. One such recording can capture one specific place for one day, from dawn to dusk, or for several days displaying different weather phenomena.
In order to strengthen the illusion of the habitat being grounded on Earth, and the projections being "windows" towards the surroundings, more than one projection can be running at once, showing a different view from the same place. The crew themselves will have to decide how often the recordings will shift from one place to the next, i.e. how realistic they want the illusion to be.

## ADDING SOUND (AND MOVEMENT?)

Accompanying the video recordings (or as a stand alone feature) can be sound recordings from the same place. These can be recordings of rain falling on the surface of a lake or on leaves in a forest, or of the birdsongs and insect buzzes around a summer meadow.

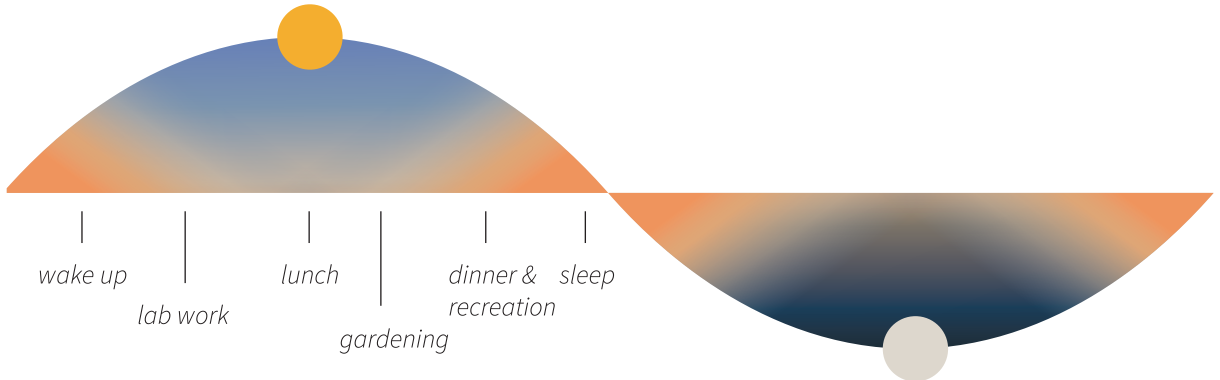
If the recording includes a breeze/wind, could this be simulated with specially programmed fans that create air movement that can be felt on the skin and create a sway in the plants?



## VIRTUAL REALITY HEADSETS

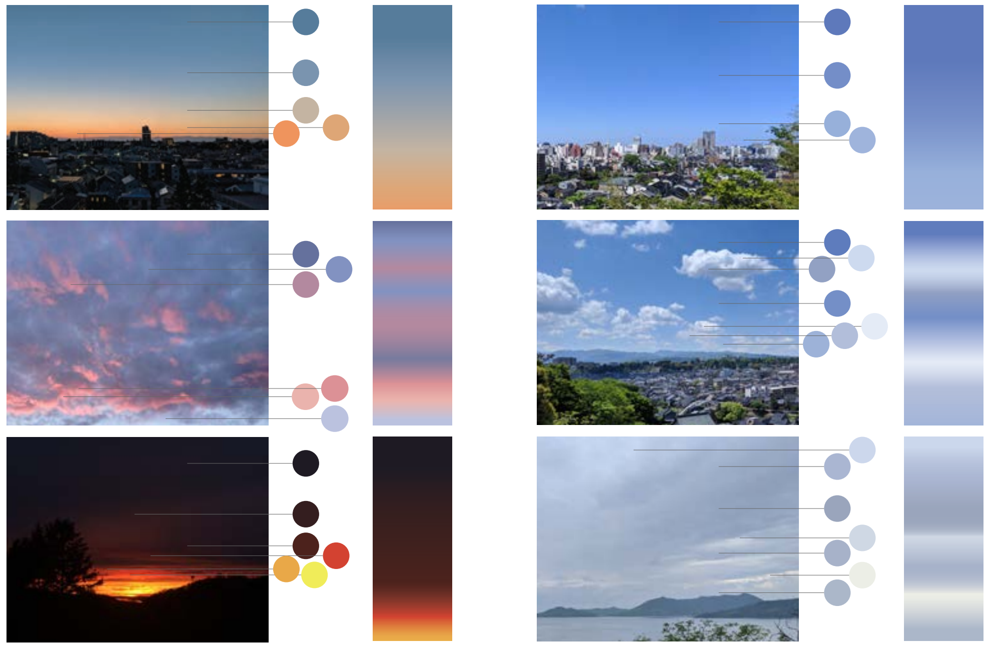
Virtual reality is a simpler way of creating an immersive experience that includes sight and sound. This could be something that every crew member owns and can use in their own quarters. It is however more of an individual experience and cannot be shared in the same way as something external, e.g. a projection.

# LIGHTING: THE CIRCADIAN RHYTHM

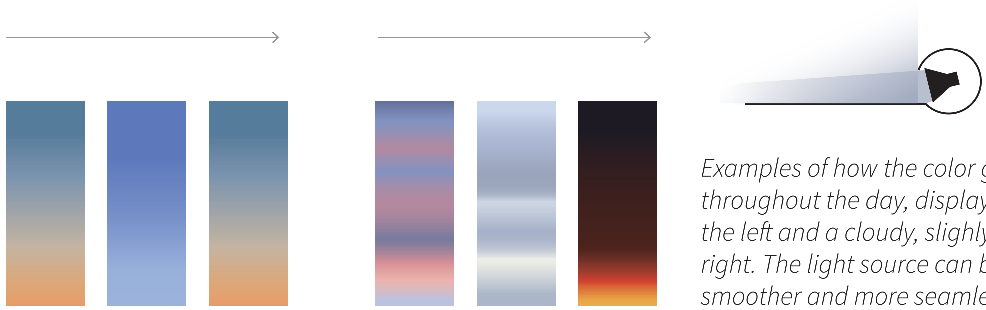



## EARTH TIME AND WEATHER

In order to establish a clear sense of day and night, which helps with keeping up the bodies Circadian Rhythm (an internal process that regulates the sleep-wake cycle) and to provide a sense of connection with Earth and it's natural cycles, lighting can be used in various ways. Light sources can shift through different intensities, depending on the "time of day", and be placed in a way that could simulate the light of the sun as it moves over the "sky".
To further play with the concept of time and also weather as it is experienced on Earth, colored light can be made to slowly shift thorugh different color gradients to simulate sunrise and sunset in different weather conditions. This system can be constructed in different scales and be used differently depending on the place.



*Sampling different weather conditions during different times of the day, and creating a color gradient that can be displayed on some kind of surface.*



*Examples of how the color gradient can change throughout the day, displaying a clear day on the left and a cloudy, slighly rainy day on the right. The light source can be hidden to create a smoother and more seamless effect.*



# THE MATERIAL PALETTE

## MATERIAL REQUIREMENTS

### FIRE SAFETY

In the first spacecrafts to leave Earths atmosphere the atmospheric composition inside was made up of pure oxygen at a pressure of ~5.0 psi. This was chosen because of it's simplicity and to prevent decompression sickness, but it increased the risk of starting a fire. Today the International Space Station is aiming to use sea-level atmosphere: 78 % nitrogen, 21 % oxygen, 1 % other gasses and a pressure kept at ~15.0 psi. In future spacecraft the percent of oxygen might be slightly higher, at around 34 %, which presents a small but increased risk of fire. The consequence of a fire outbreak would be severe, since fire can consume oxygen at a high rate, and the amount of oxygen is very limited in a small spacecraft. To further minimize the risk the materials used should be non-combustible or have extremely low flammability.
(Thomsen, Fernandez-Pello, Urban & Olson, 2018)

### LOW OUT-GASSING

It is important that the materials chosen do not release any volatile chemicals into the air over time. They could cause headaches, nausea, dizziness and allergy issues.

### LIGHTNESS

In order to keep within the payload weight limit, the materials should be as light as possible.

## METALS

The most common structural material used in spacecraft is metal, which can be both strong and light, as well as non-combustible.

ALUMINUM
Non-combustible
(melting point at 660°C)
No out-gassing
Low density: 2,70 g/cm³
(Royal Society of Chemistry, 2020)

TITANIUM
Non-combustible
(melting point at 1670°C)
No out-gassing
Low density: 4,50 g/cm³
(Royal Society of Chemistry, 2020)

STAINLESS STEEL
There are many different compositions of stainless steel, but generally this applies:
Non-combustible
(melting point between 1371°-1426°C)
No out-gassing
Density: ~8 g/m³
(Euro Inox, 2007)

## OTHER MATERIALS

Other materials commonly used includes non-organic textiles (clothing, storage containers, sleeping compartments etc.).

NON-ORGANIC TEXTILES
Such as Durette, PBI (Polybenzimidazole fiber) and Carbon fiber.
Non-flammable
Low out-gassing
Low density
(Tang, 2017)

## INTRODUCING ORGANIC MATERIAL: CORK

Cork is a slow combustion material, which means that it burns, but very slowly and without flame. The smoke that is released in the case of fire is non toxic. It is a material that is pleasant to touch, and can act as an excellent thermal, acoustic and anti-vibration insulation material.

CORK
Fire restardant (slowly combustible)
No out-gassing
Low density: 0,24 g/cm³

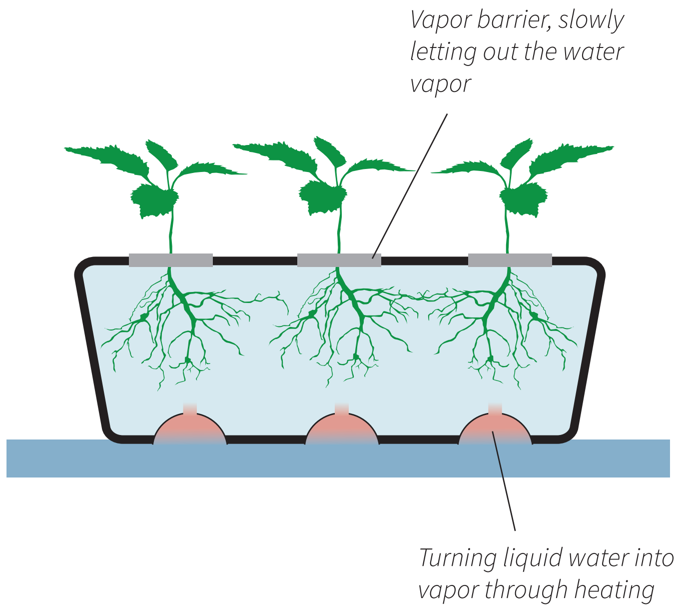
(Silva et al., 2005)

# LIFE SUPPORT INTEGRATION (PLANTS)

## AEROPONICS

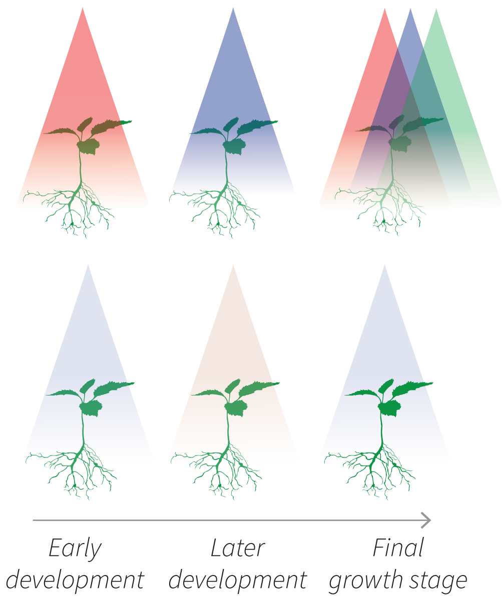
In order to save space and reduce weight, an aeroponics based system should be used. Providing the plants with moisture and nutrients through water vapor instead of using soil or liquid water as conduit. There would need to be a semi-closed moisture barrier between the stem and roots of the plants to contain the vapor and let is spread evenly around the root system. Using a few different sources that touch on aeroponics and circular life support systems, mainly an article about the Bios-3 closed system experiment in Siberia (Salisbury, Gitelson & Lisovsky, 1997), a theoretical calculation of the space required to grow food on a "generation ship" (Marin, Beluffi, Taylor & Grau, 2019) and an article on closed ecological systems (Nelson, Pechurkin, Allen, Somova & Gitelson, 2009), a theoretical square meter requirement for self sufficiency regarding food has been landed on:

- Minimun 40 $m^2$ of food required per person. (Us-




## WHAT PLANTS?

Higher plant (plants with vascular tissues and veins) that work well in a limited amount of space and contain lots of nutrition include **wheat, tomato, potato, soybean, rise, spinach, onion and lettuce.** In MELiSSA (see p. 15) algae are also used for producing oxygen and food, but processing it into an edible form is difficult and large quantities of algae in the diet can lead to nutrient deficiencies and illness. The higher plants on their own could produce enough oxygen for the crew while at the same time providing for a varied diet. (Salisbury, Gitelson & Lisovsky, 1997).




## WHERE AND HOW TO GROW?

The plants should be the most visible part of the life support system, since they have been proven to have a positive psychological effect. If possible, the plants should be present in the daily lives of the crew, as something that they pass by or are enveloped by while doing other activities.
The other compartments that are part of the life support system don't require much human interaction, and can be hidden away. It would make it easier logistically if they were placed close together.

## COLOR OF PLANT LIGHTING?

**Red**, and in particular, **blue** wavelengths are most efficiently absorbed by the plants, however, the combination of the two produces a puplish-gray image of the plants for the eye, making it harder to evaluate plant health and notice injuries. A small flux of **green** light can solve this problem. White LEDs with red, blue and green wavelengths have been tested as a human vision-friendly light source. Cool white light is superior than warm and neutral in that it is more electrically efficient, but the combination of both cool and warm light should be used during different stages of plant development. (Virsilè, Olle & Duchovskis, 2017)



# SUMMARY

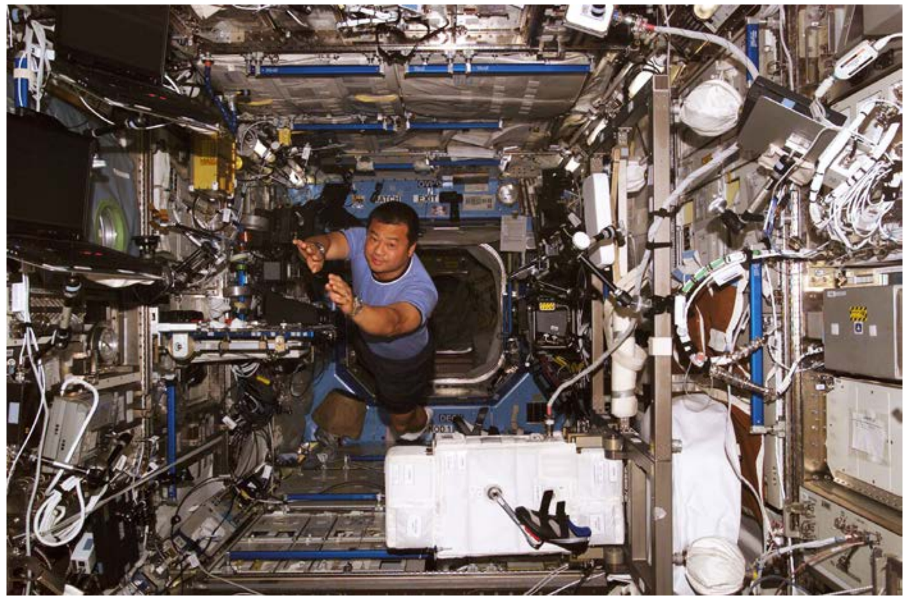
I will try to use these design strategies in my design:

- Integrate projections and accompanying sound recordings into specific spaces.
- Work with lighting placement, intensity, color and movement to simulate the passing of time and weather conditions.
- use Cork as a cladding material on surfaces that are often touched.
- The bioregenerative life support system MELiSSA will be used as a model, with the exception that only higher plants will be used and not algae.
- Integrate aeroponic plant units into the structure and alternate between using cool white and warm white LED lighting.

# FEELING OF LIVING IN A MACHINE

GUIDING QUESTIONS:

- *Why do past and present day space habitats create this feeling?*
- *What are the psychological effects?*
- *How can the interior be designed to instead create a feeling of being in a "home"?*



Interior of the Destiny lab module (ISS)

## AN ARTIFICIAL ENVIRONMENT

*Most of the spaces where I spend my time have no windows and no natural light but rather bright fluorescent lights and clinical white walls. Devoid of any earthly color, the modules seem cold and utilitarian, like a prison of sorts. Because the sun rises and sets every ninety minutes, we can't use it to keep track of time. So without my watch keeping me on Greenwich Mean Time and a schedule tightly structuring my days, I'd be completely lost.*

Scott Kelly, 2017

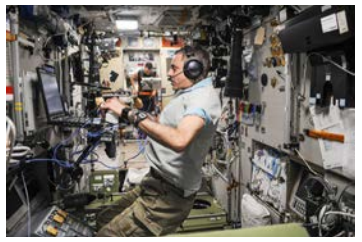
# A LIFE OF RESEARCH

## THE MESS ON THE ISS

On the International Space Station a "highly organized chaos reigns" (Samantha Cristoforetti, Il Sore 24 Ore). When a new module is delivered the interior surfaces are relatively uncluttered, with only handlebars jutting out into the passage. However, over time the "walls", "ceiling" and "floor" get filled up with equipment, cables and storage units to meet the needs of the crew and support various scientific experiments. It might be an organized mess, but it is non the less a mess, and it can be difficult to find a sense of peace and focus in such an environment.

Interior of Kibo, Japanese experiment module

Interior of the Denstiny lab module



Interior of the Russian Zvezda Service Module

## LIVING IN A LAB

Everywhere on the ISS machines and cables are present, even in the sleeping area and the kitchen/dining space. This can give a feeling of constantly being in a work/lab environment, and thus the feeling of relaxation that comes with leaving work for the day and returning home to deal with other areas of life, such as hobbies and socializing with one's family, never surfaces.

## WHAT WILL THE ASTRONAUTS BE DOING ON A LONG DISTANCE SPACECRAFT?

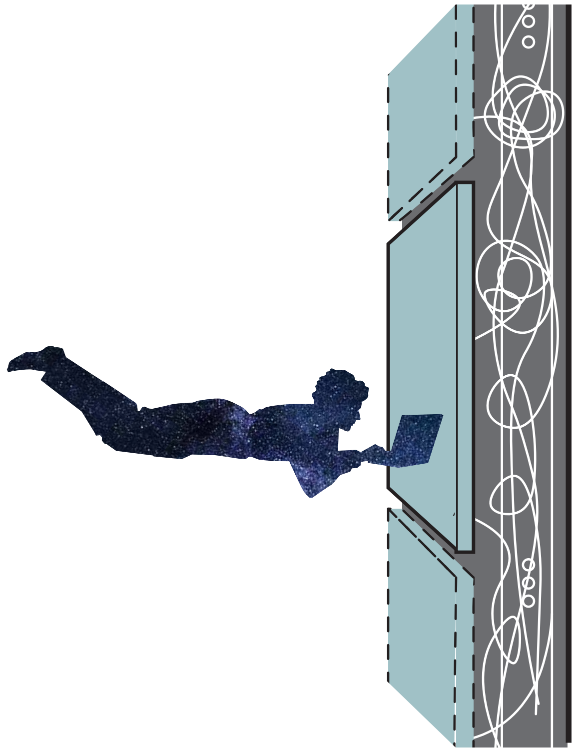
On the ISS, as on previous space stations (Skylab and Mir), the focus of the crew's mission is/was to run experiments, and secondarily to see to their own personal health (sleep, exercise, food intake etc.).
The design of the space habitats were based mainly on engineering and structural requirements, and not centered around the lives of the inhabitants.
In future long-duration spaceflight the crew will instead be assigned vital roles in the system, and the needs and wants of the crew must be adressed in a greater way. (Bannova & Häuplik-Meusburger, 2016)
On these long-duration flights there will be lab work and other experiments to perform, but since the main target of exploration is still ahead, the crew will most likely have more "free time" to fill with their personal projects, hobbies, exercise and recreation. The design of the spaces that surround these activities should support the activities physically and psychologically.

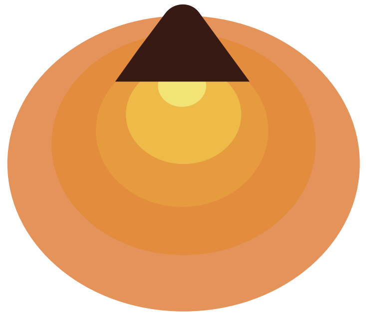


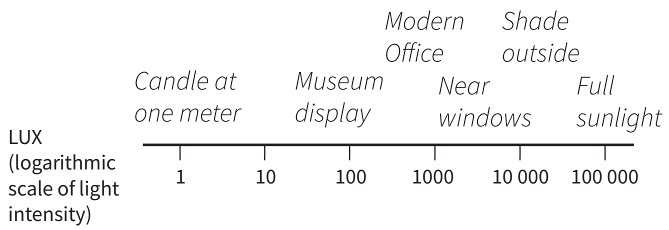
# A SENSE OF HOME IN SPACE

## HIDING TECHNOLOGY

The electrical equipment onboard a spacecraft is essential to manouvering and keeping the crew alive. There is no avoiding it, but it can be planned, gathered up and hidden in a clean way. In a normal home or office building the walls contain any number of cables and pipes , but they are ussually not seen. They only manifest themselves in the form of taps and toilets, ventilation intakes or power sockets.
Can the organization be done in a similar way in a spacecraft? Hiding the parts that are not part of the interface or scientific experiment (e.g. cables). There could be a standardized way of doing it, with clean panels that are simple to attach to, keeping the equipment in place and providing power outlets.








## COZY LIGHTING

There is a difference in light intensity and hue between say living room lighting in a home and the bright overhead lighting at a supermarket or in an office. The reason is that the pupose of the spaces are completely different.
In a work environment it's important to be able to work efficiently, read text and make out details without having to strain one's eyes. Bright white light increases contrast and thus legibility. However, being exposed to this strong light for long periods can cause eye fatigue and also lead to headaches.
In a home environment, such as in the living room, at the kitchen table or in the bedroom the focus in more on rest and relaxation. This means that a softer light is prevalent, allowing the eyes to relax. The color hue and temperature that is prefered in this kind of setting diferes between cultures, but to give a feeling of warmth and envelopment lighting that is warmer and closer to the red and orange hues should be used.

Recommended Lux levels:

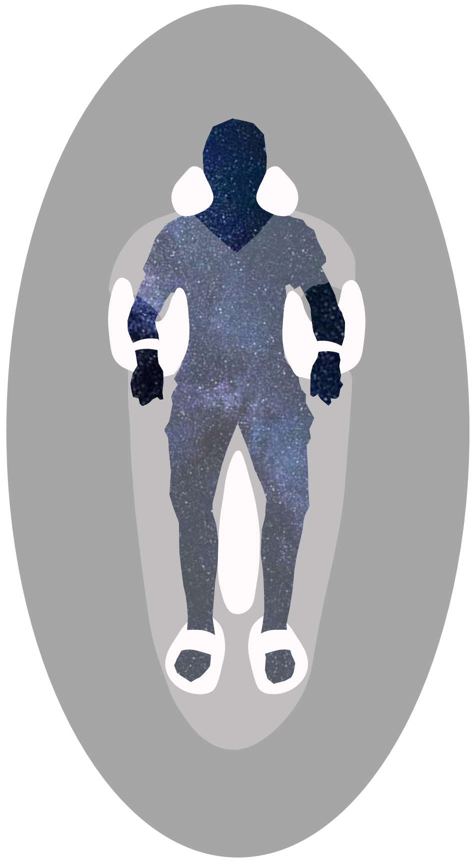
- **dining space** ~ 200 lux
- **kitchen** ~ 300 lux, **above countertop** ~ 750 lux
- **bedroom** 100 - 300 lux depending on task
- **office** ~ 500 lux, **above workspace** ~ 800 lux

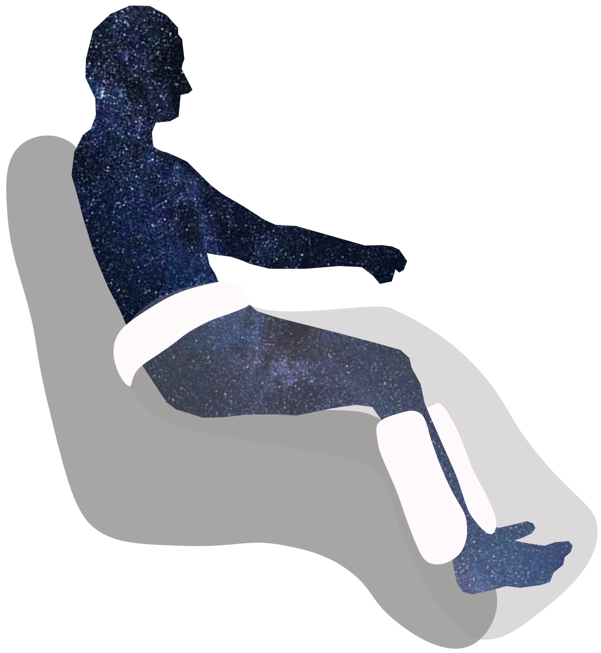
(Adams, 2019)

## FAMILIAR FURNITURE

"SITTING" IN A SOFA AND "LYING" IN A BED

In a gravity environment, relaxing at home is often strongly associated with sitting or lying down on a piece of furniture, letting one's weight be held by it.
In a microgravity environment resting on or towards something is impossible, since these is no active pulling force. When floating freely in an open space the body is in a state of relaxation, requring only restrictions to keep it in place.
Since there is this strong link between relaxation and a comfortable piece of furniture, a pillow or blankets, it's hard to enter into the mental state of relaxation without these being present. On the ISS for example, during a movie night the crew would automatically lean backwards as if lying down in a sofa, even though it physically made no difference (Kelly , 2017). Astronaut Marsha Ivins said that she attached a block of foam to the back of her head to make her neck relax (Devine, 2015), and a researcher at Nasa is looking at ways to design a "space pillow system" to provide psychological comfort and a sense of coziness.





In order introduce furniture into the interior of the spacecraft in a useful way and provide mental comfort and relaxation, the standard "Earth furniture" has to be redesigned slightly. Firstly it has to have an integrated restraining system that feels comfortable and is placed anatomically correct to keep the body stable. Secondly a number of soft cushioning "pillows" has to be distributed close to the body in places where they would feel supportive. The restraints would help push the body against these soft "pillows" creating the illusion of being held. The restrainst and the "pillows" can be designed in many ways - they could even be one and the same if designed correctly.

## SUMMARY

I will try to use these design strategies in my design:

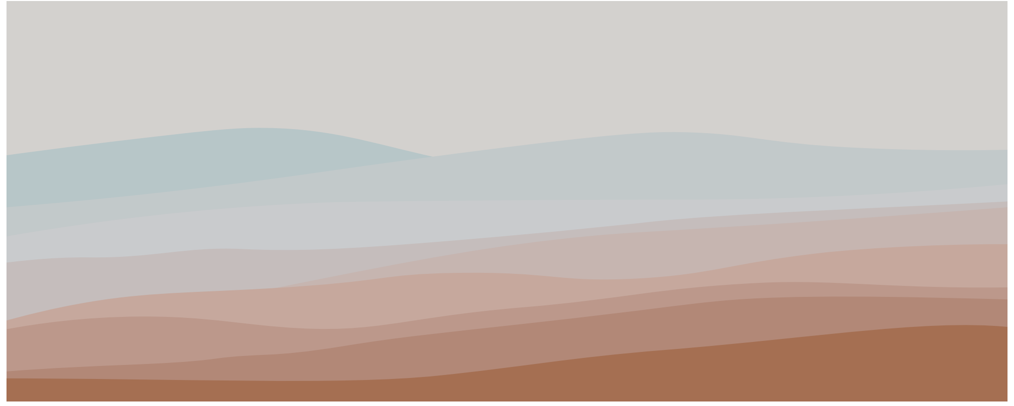
- Hiding the parts of technological equipment that don't need to be seen or interracted with.
- Using appropriate brightness and hue for the lighting, depending on location and activity.
- Integrate furniture into the interior of the spacecraft that can give a familiar sense of support and relaxation.

*Often when I do interviews and press events from space, I'm asked what I miss about Earth. I have a few answers I always reach for that make sense in any context: I mention rain, spending time with my family, relaxing at home. Those are always true. But throughout the day, from moment to moment, I'm aware of missing all sorts of random things that don't even necessarily rise to the surface of my consciousness.*
*(...)*
*I also think about what I'll miss about this place when I'm back on Earth. It's a strange feeling, this nostalgia in advance, nostalgia for things I'm still experiencing every day and that often, right now, annoy me. I know I will miss the friendship and camaraderie of the fourteen people I have flown with on this yearlong mission. I'll miss the view of Earth from the Cupola. I know I will miss the sense that I'm surviving by my wits, the sense that life-threatening challenges could come along and that I will rise to meet them, that every single thing I do is important, that every day could be my last.*

Scott Kelly



# DESIGN
## assumptions & design proposal



# DESTINATION / OBJECTIVE

## DESTINATION : MARS (for now)

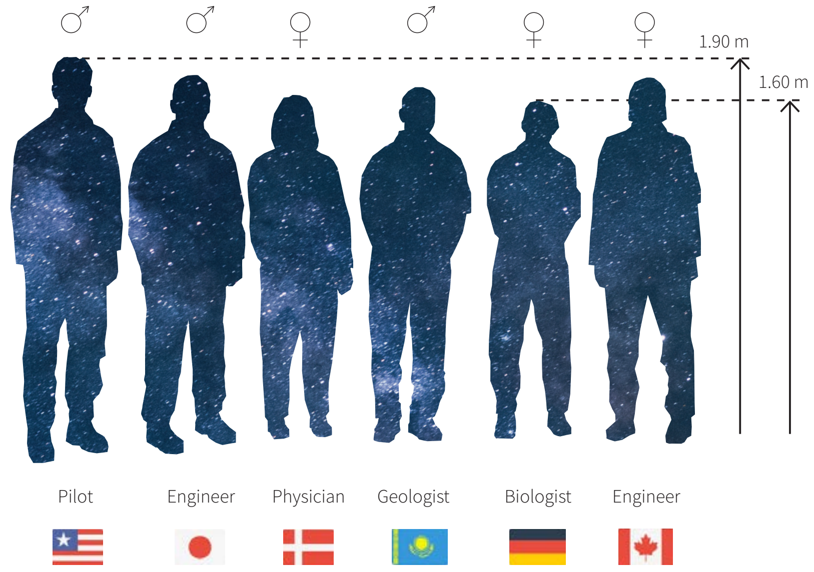
The design of the spacecraft that has been developed for this thesis is meant to function well for journeys to different destinations and of varying duration, with a circular life support system and considerations taken for both physical and psychological well-being. However, currently our eyes are focused on Mars and being able to send a manned mission to orbit the planet and eventually land on it's surface. Mention of Mars and the time it takes to travel there, as well as the transmission lag between Earth and Mars has hinted at the red planet being the first destination for this long-distance space habitat.

## MISSION OBJECTIVE

The crew onboard the spacecraft are scientists and engineers within their fields, and their main mission objective will be to set foot on the planet, examine it's soil and atmosphere, and to set up a base for future visits. The craft is meant to be part of the first stages of planetary exploration, hence the small size and limited number of crew.



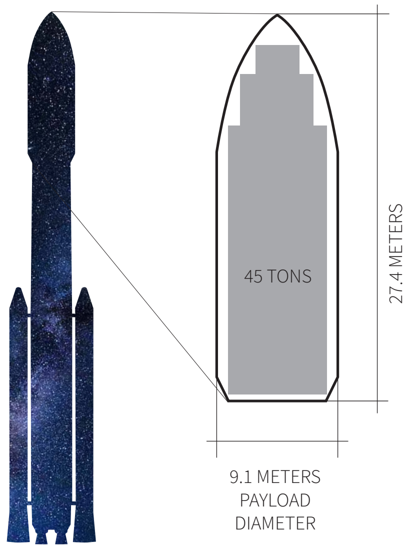
# ASSUMPTIONS




## A CREW OF 6 PEOPLE

- 6 crew members, 3 men and 3 women
- Various nationalities and skills
- Pilot, physician, geologist, biologist & engineers
- General knowledge and overlapping skills are necessary in case one person gets injured or sick and can't perform their appointed tasks
- Their height might range from 1.60 m to 1.90 m (NASA 's approved height interval)

Prior to the mission to Mars the crew has undergone extensive training together, which means that they have a close relation and there are no indications of personal conflicts arising during the voyage.



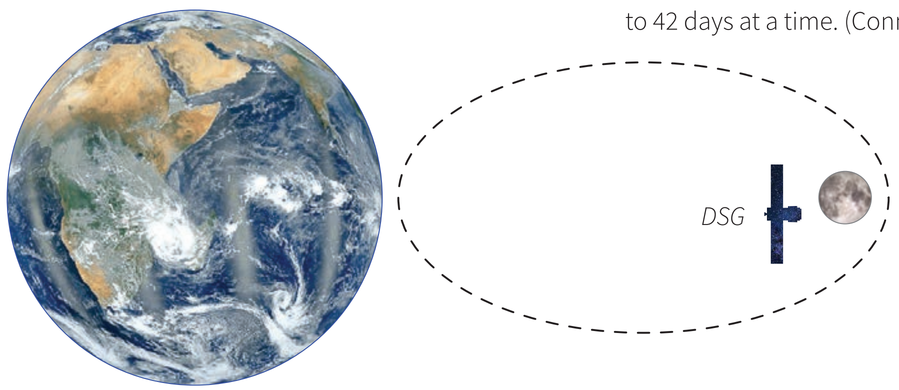

## LAUNCH SYSTEM: SLS Block 2

The SLS Block 2 is in development at NASA and could start launching into space as early as year 2028 (Creech, 2017).

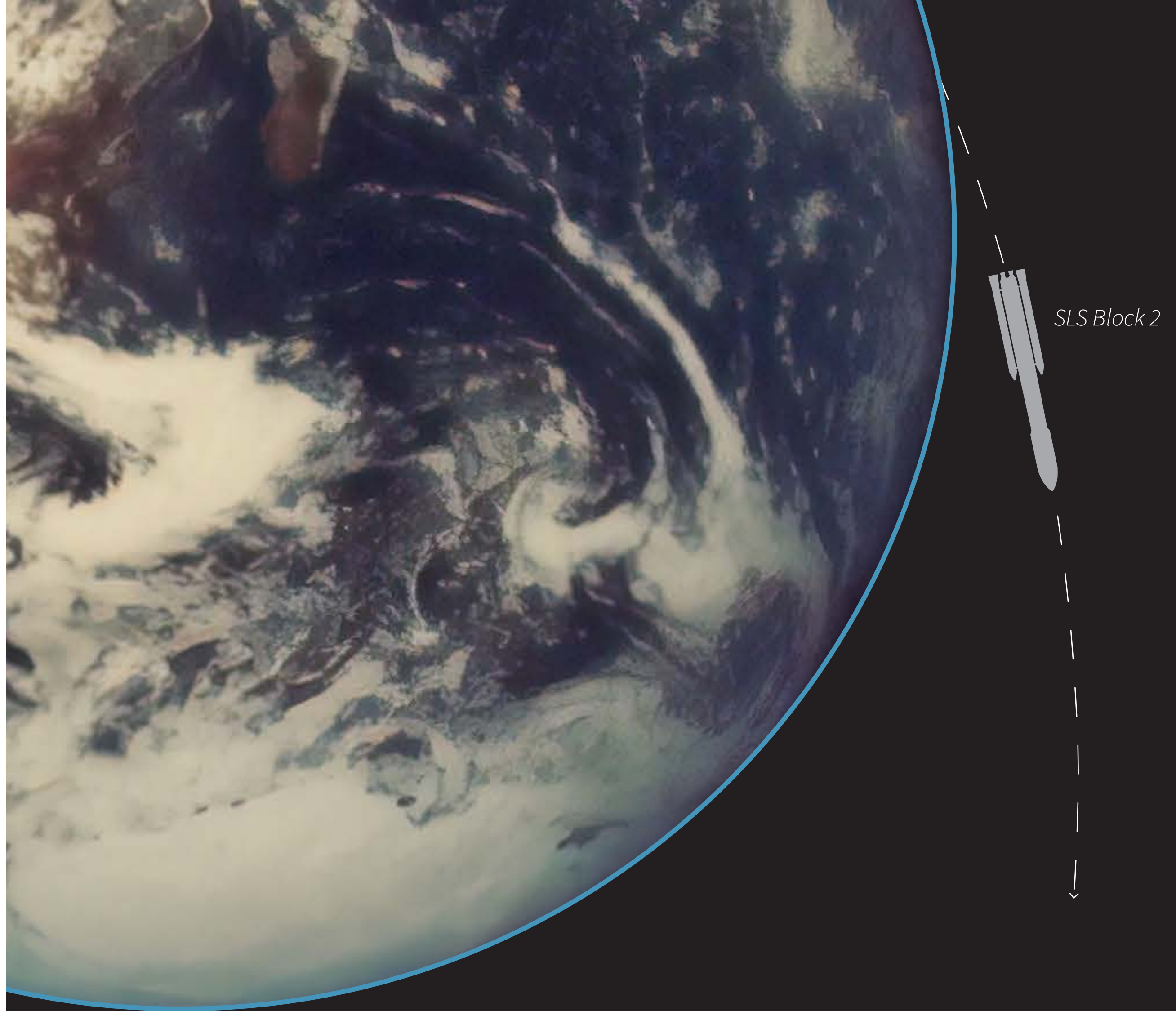
- 9.1 meters of internal payload diameter
- 27.4 meters in height
- 45 tons cargo mass capacity

## ASSEMBLY / DEPLOYMENT AT DSG

The SLS Block 2 will launch several times and bring parts into cislunar space, in range of the **Deep Space Gateway** (DSG) space station, where the parts can be assembled and/or deployed by the current crew.
The DSG space station will support future missions beyond Low Earth Orbit. With the crew capsule Orion docked it can be manned by a crew of 4 people for up to 42 days at a time. (Connolly, 2017)

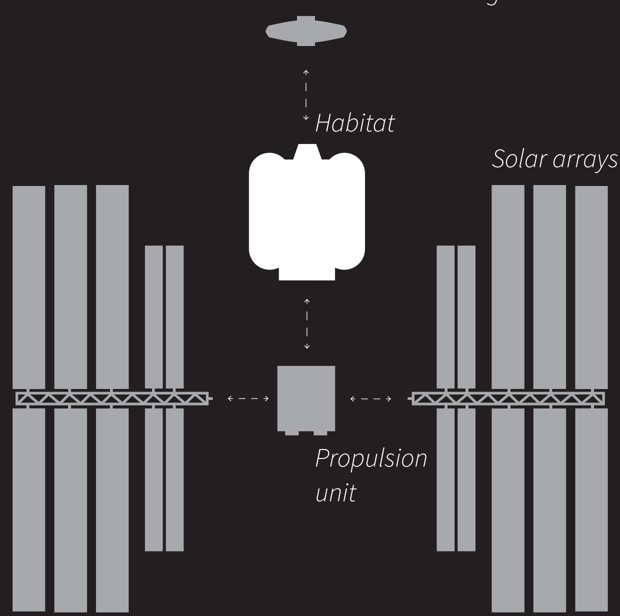


# DESIGN PROPOSAL

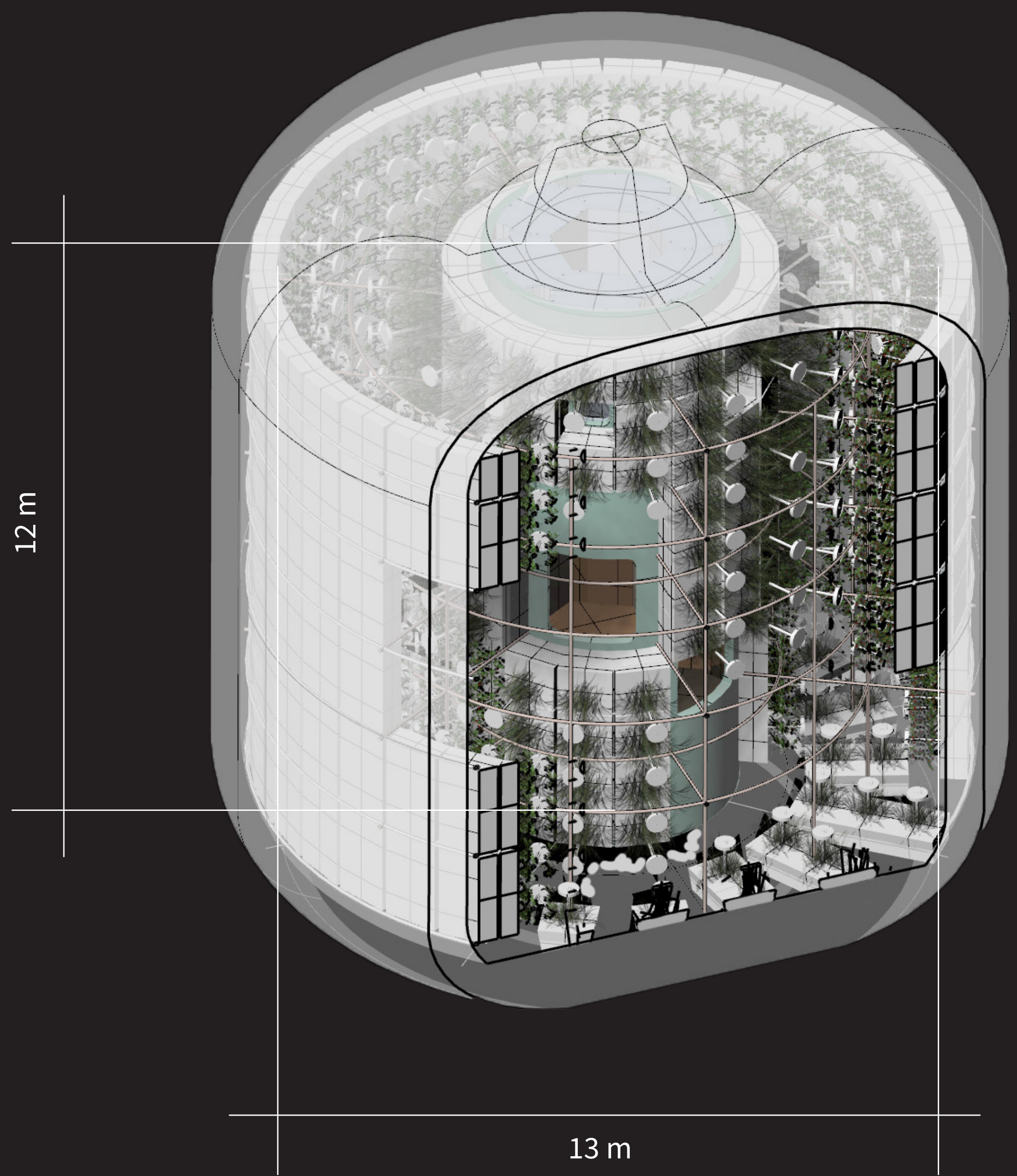



## ASSEMBLY

I have focused on the livable part of the Spacecraft - the Habitat - but there are of course several other modules and components that are needed for interplanetary traveling. Some of these parts could be launched together with the launch vehicle, but more than one launch will be needed to assemble the whole spacecraft.
The solar arrays provide power and the propulsion unit is what propells the craft forward. The centrifuge module could potentially be attached to the nose of the habitat and provide artificial gravity for exercise puposes.

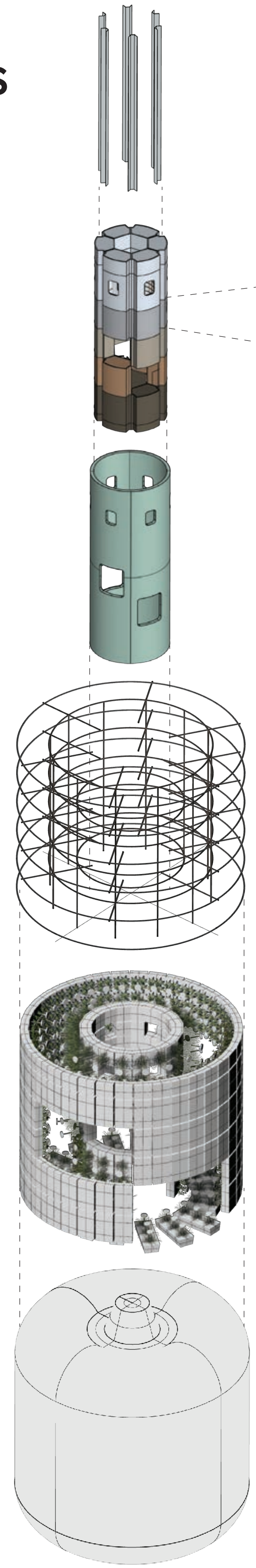


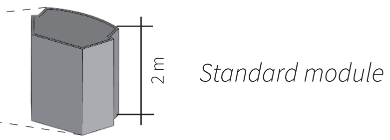

# TRANSHAB 2.0




The design of the TransHab 2.0 is based on the *TransHab* concept (see p.22) that was developed by a team at NASA at the end of the 1990s. They share the same cylindrical core and inflatable shell structure. The most important differences are in size and life support system integration - TransHab 2.0 is more than twice as volumous and contains an integrated circular life support system.

# MAIN ELEMENTS






CHASE WAYS
In between the modules and against the wall of the core cables and pipes run in dedicated chase-ways. Water for the plants is transported in these, and led through the walls of the core and then further distributed via the railing system.

MODULES
Inside of the core the layout is reminiscent of the modules of the International Space Station. Standard modules with a height of 2 meters surround the central passageway which has a diameter of ~ 2 meters. The modules will have different designs (one module might be a kitchen, and another is used as a shower), but they take up the same volume.
The modules shift in color in such a way as to give a feeling of up and down, with darker colors in the bottom and lighter towards the top.

CORE
The cylindrical core is the structural backbone of the habitat, and during launch the inflatable shell will be gathered flush against it. It's punctured in a few places to allow for passage and sightlines, which also helps to create an openness and give views towards the greenery.

RAILING SYSTEM
In the open space created between the inner cylindrical core and the inflatable shell, a system with handlebars in both the "vertical" and "horizontal" direction are installed to make movement in all directions easy. A surface or handlebar is always within one meters reach. Sheets of cork cover the bars to make them more pleasant to touch.

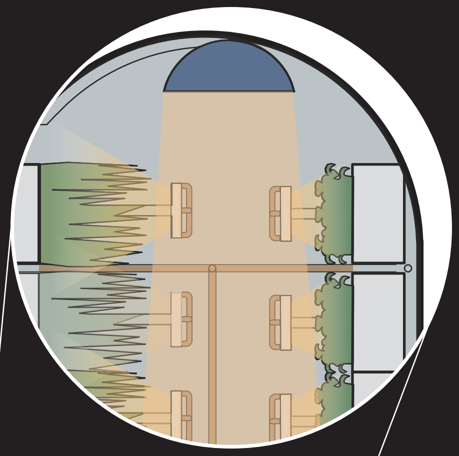
PLANTS
Edible plants that are part of the circular life support system onboard have been integrated into the outer room of the habitat. Sections have been left empty to make space for activities, but the plants are a part of and visible from almost everywhere as a backdrop, including the private crew quarters that have windows looking out towards a green wall.

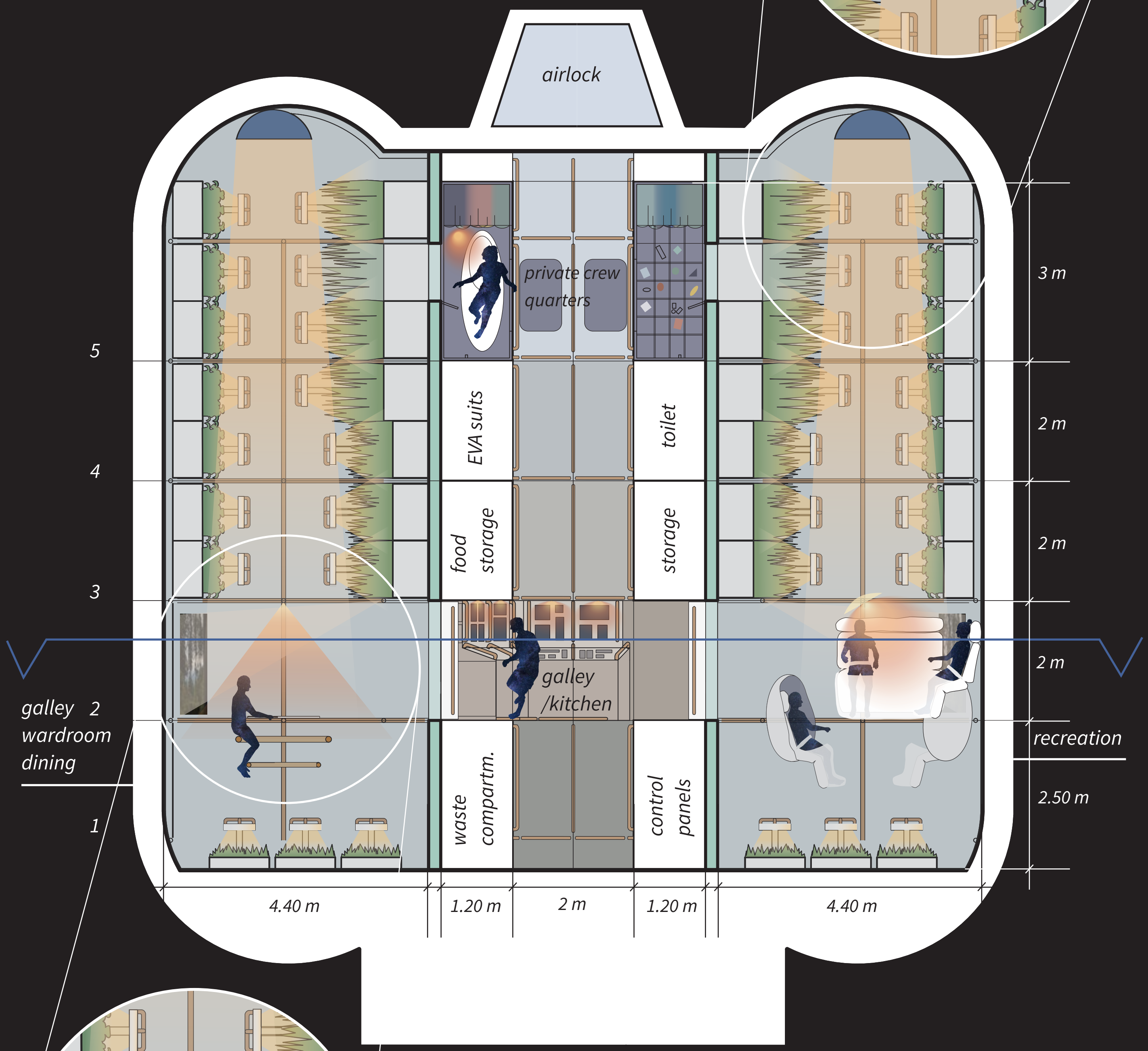
SHELL
The shell of the habitat is designed to be inflatable and add more than 5x more volume.
In order to protect the crew from strong radiation there are no windows, and an 8 cm thick layer of water has been integrated into the shell.

# SECTION 1:100

SKYLIGHT

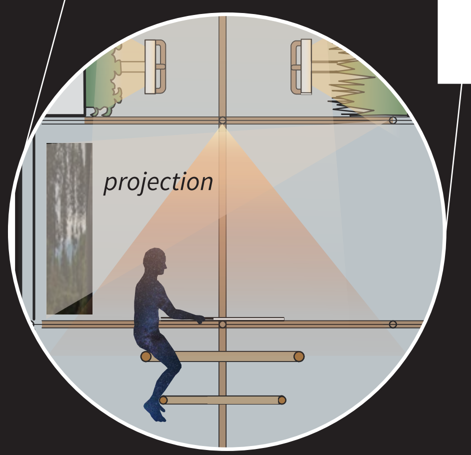
The overhead light simulates sunlight, shifting in color and intensity depending on the time of day.



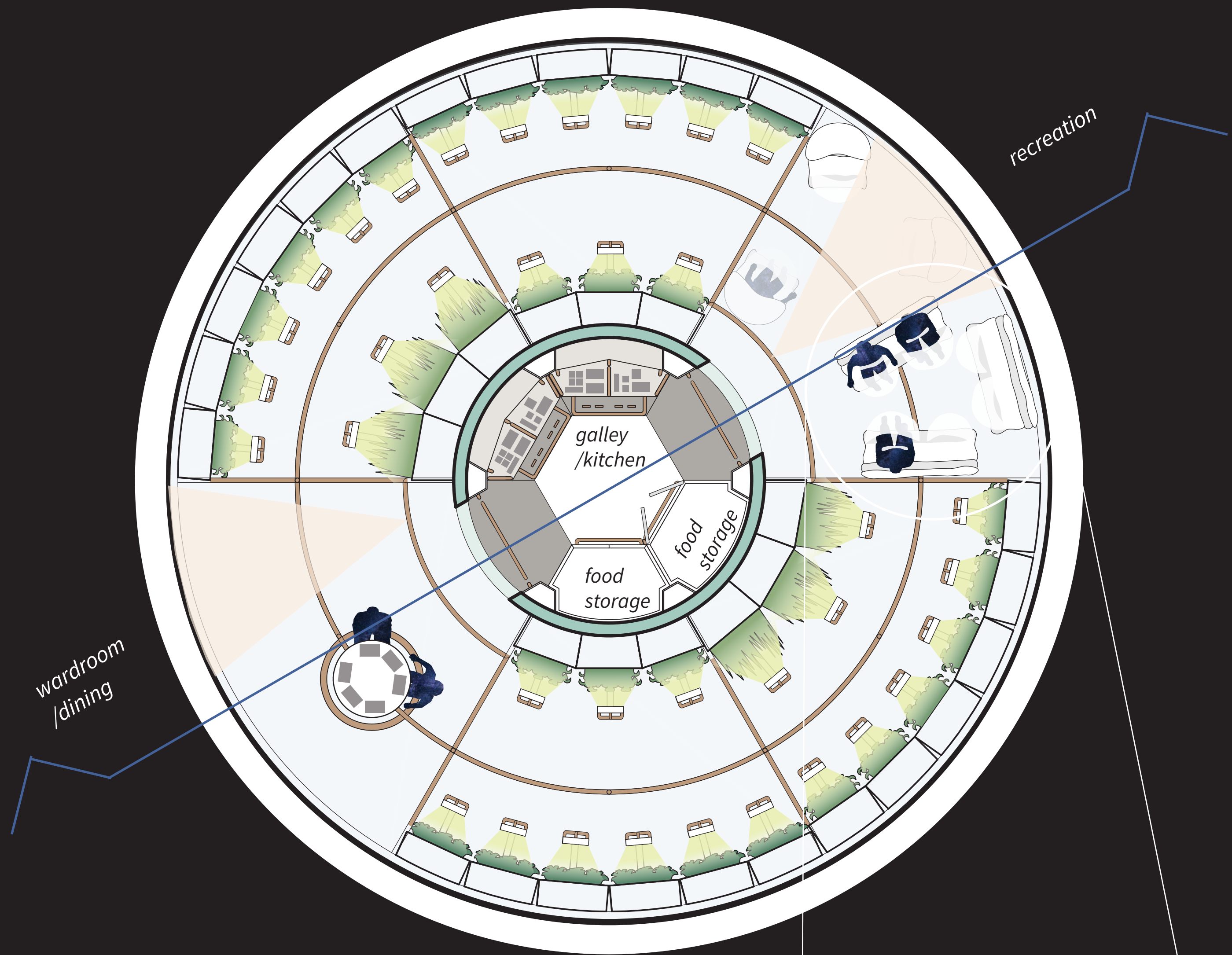



DINING

The dining/meeting area is a social and including space, with soft, homey lighting and a video projection of nature resembling a view through a window.




# PLAN 1:100

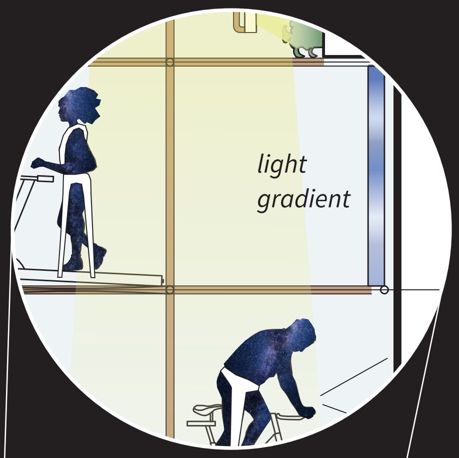


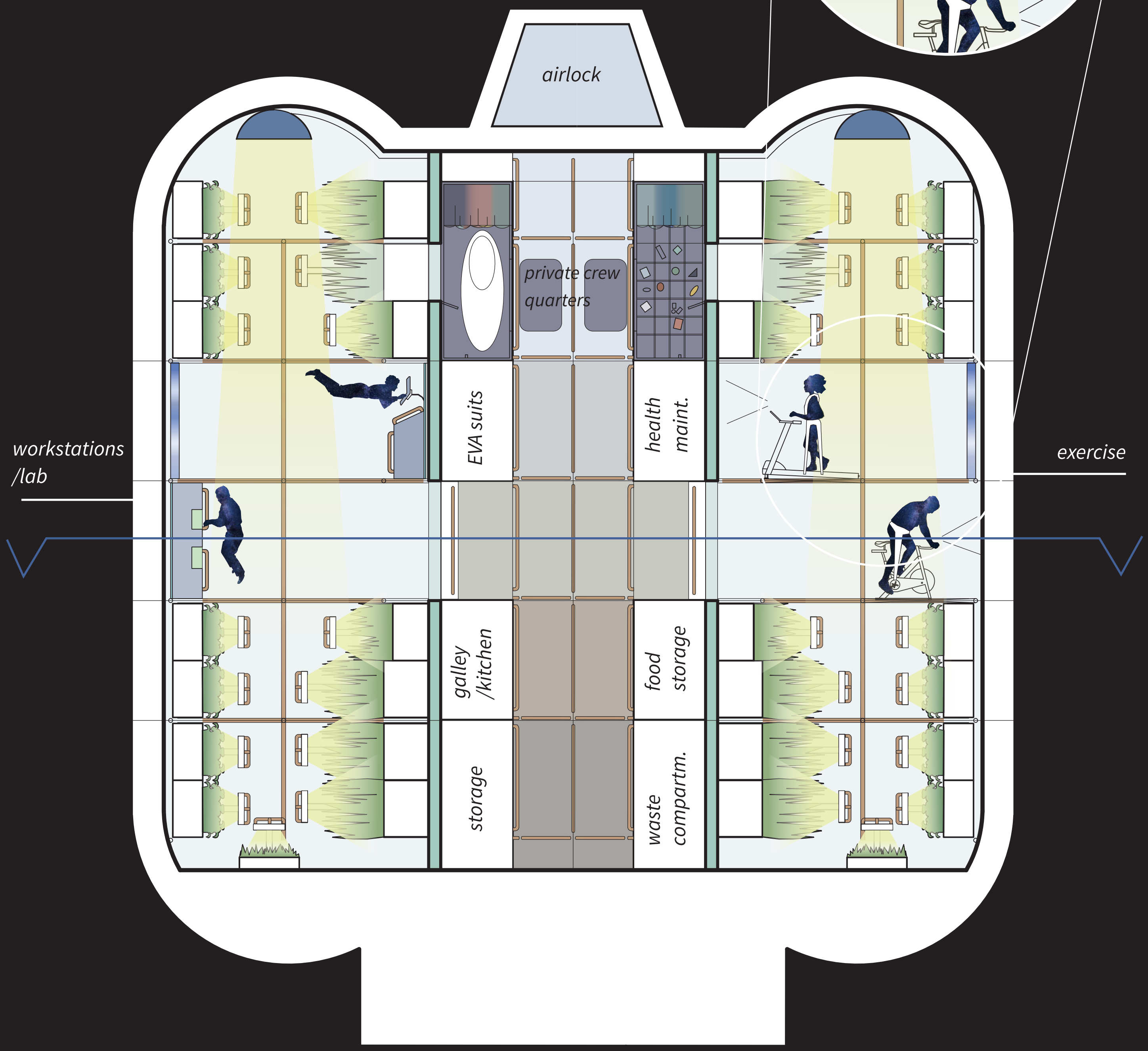

RECREATION

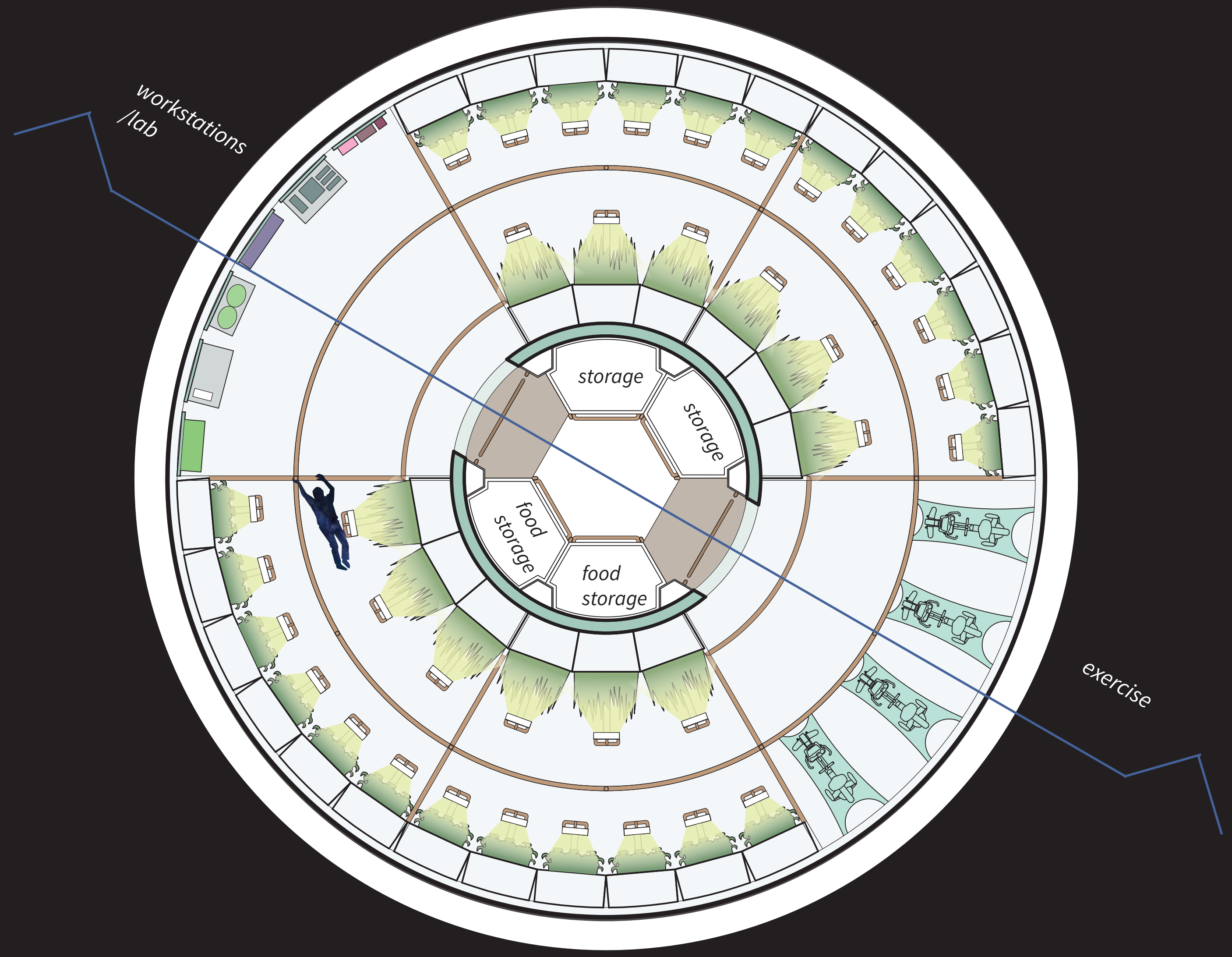
The recreational space includes both social zones where the whole crew can gather and socialize, and semi-private zones with special furniture that allows for more privacy.

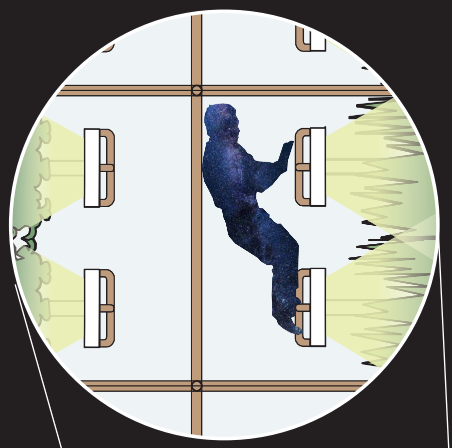
## LIGHT GRADIENT

Colored light is reflected onto a surface, shifting depending on the time of day and different weather phenomena, making the days feel more varied.



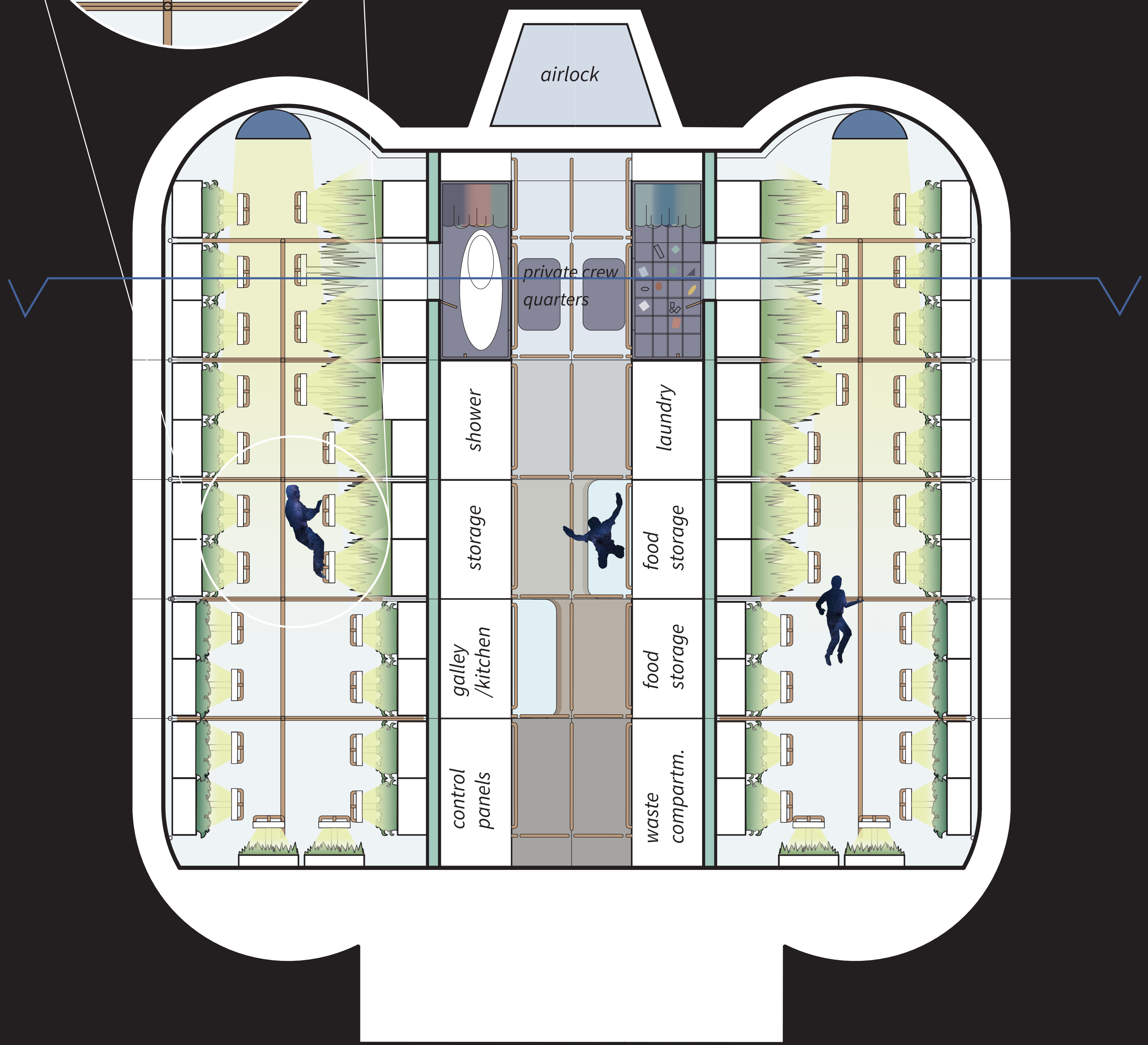





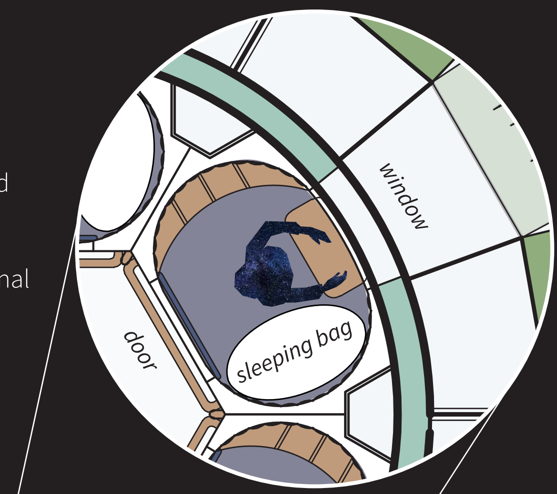
## AMONG PLANTS

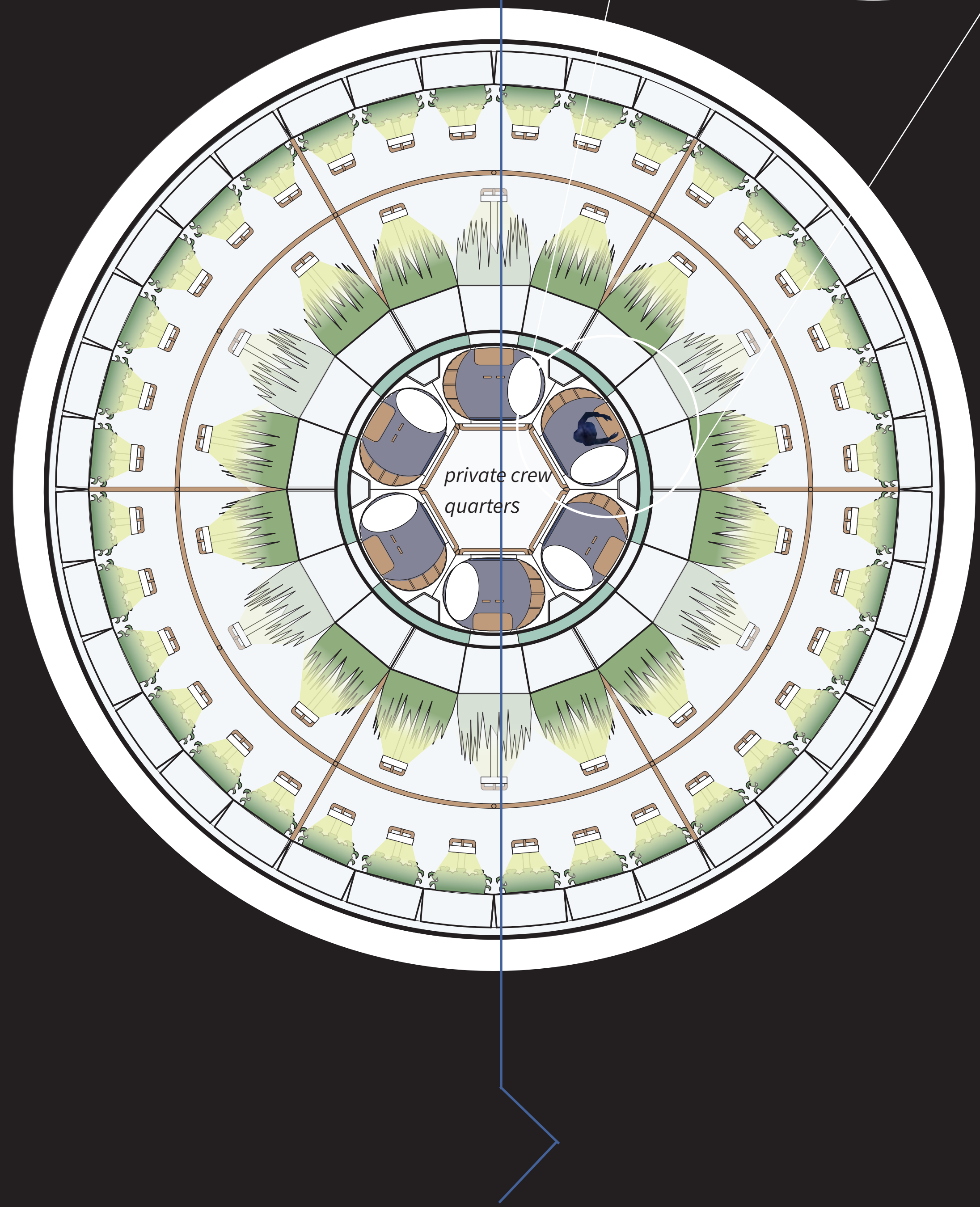
The aeroponic plant system is present in the larger part of the spacecraft. A daily task is to harvest the crops, which can be done by moving the plant lamp to the side and tucking one's feet into the handlebar on the adjacent lamp.
Apart from harvesting, time can be spent among the plants for the sake of finding relaxation in a semi-private space.




## CREW QUARTERS

The private crew quarters is a private zone than be accessed from the inner cylinder or through the "window" facing the outer room and the plants. It can be made quiet by closing the sound absorbing fabric in the openings. Personal belongings can be stored it the see-through shelf opposite the sleeping bag, and a cork "desk" underneath the window, with attached velcro, can be a place for one's personal computer.

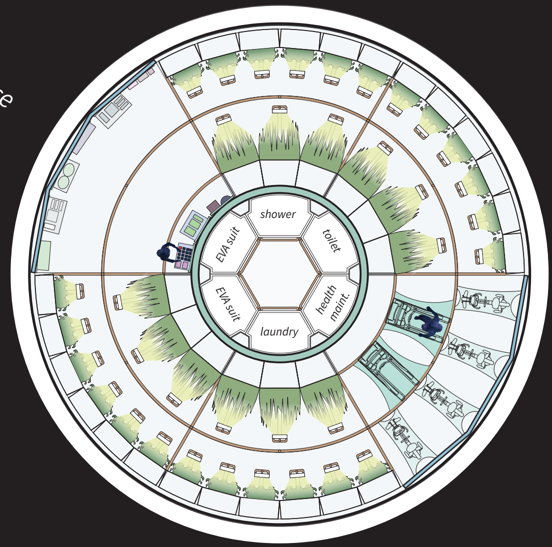


# PLANS 1:200

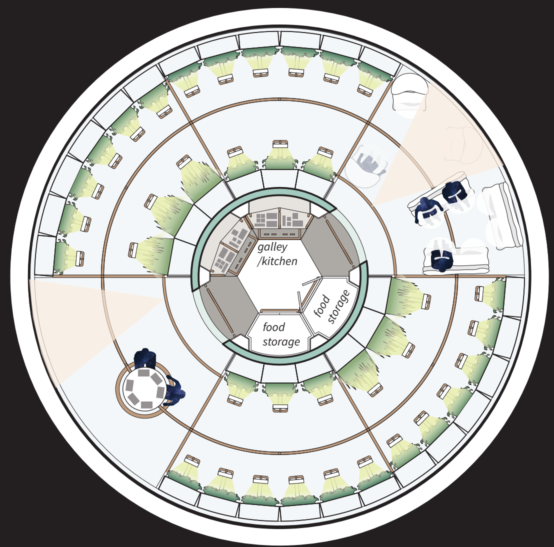
## 4

Workspace/lab
Exercise
EVA suits
Health management
Shower
Toilet
Laundry



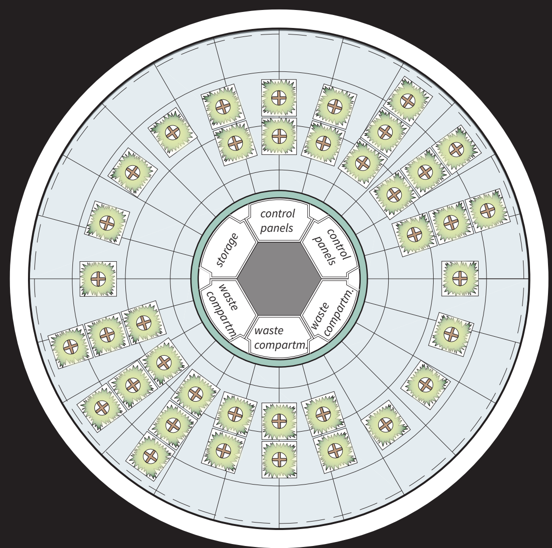

## 2

Wardroom/dining
Recreation
Galley/kitchen
Food storage



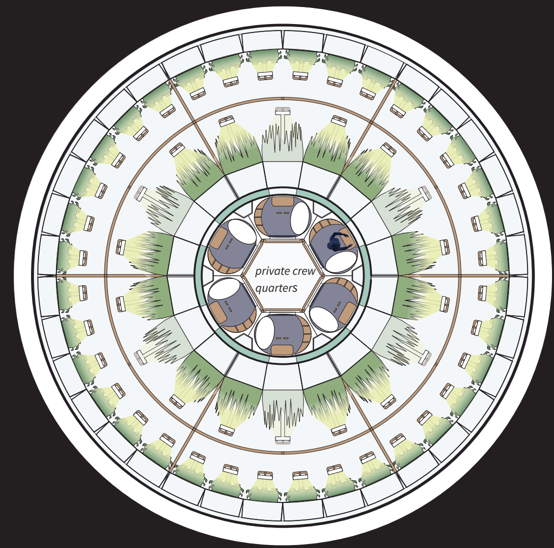

## 0

View of plant arrangement on the "floor"



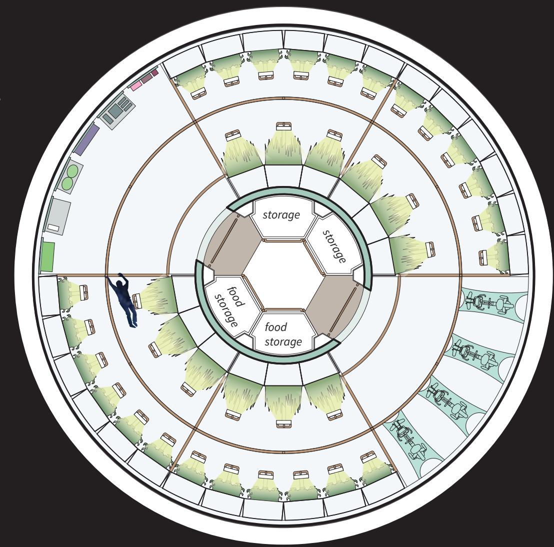

## 5

Private crew quarters



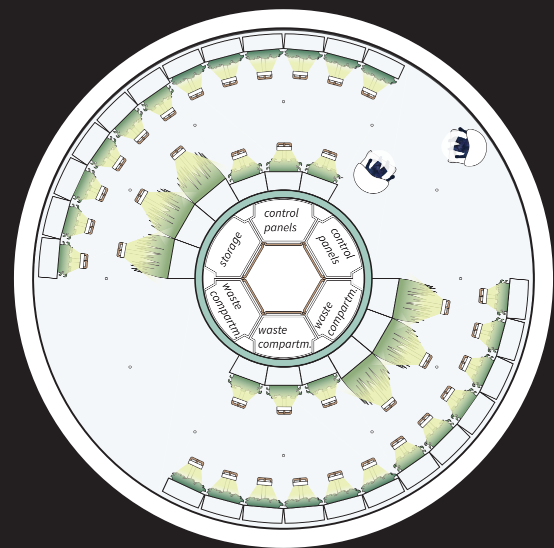

## 3

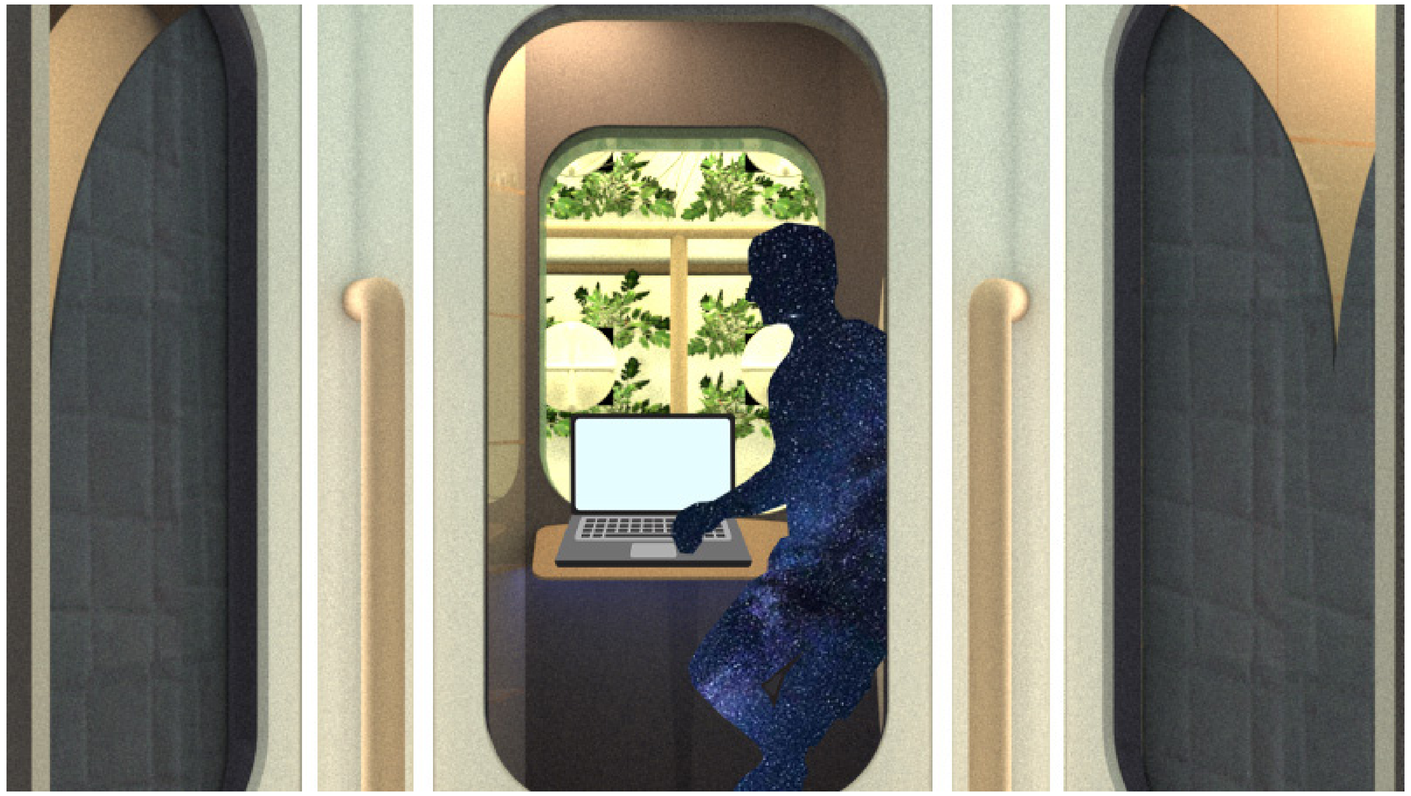
Workspace/lab
Exercise
Storage
Food storage



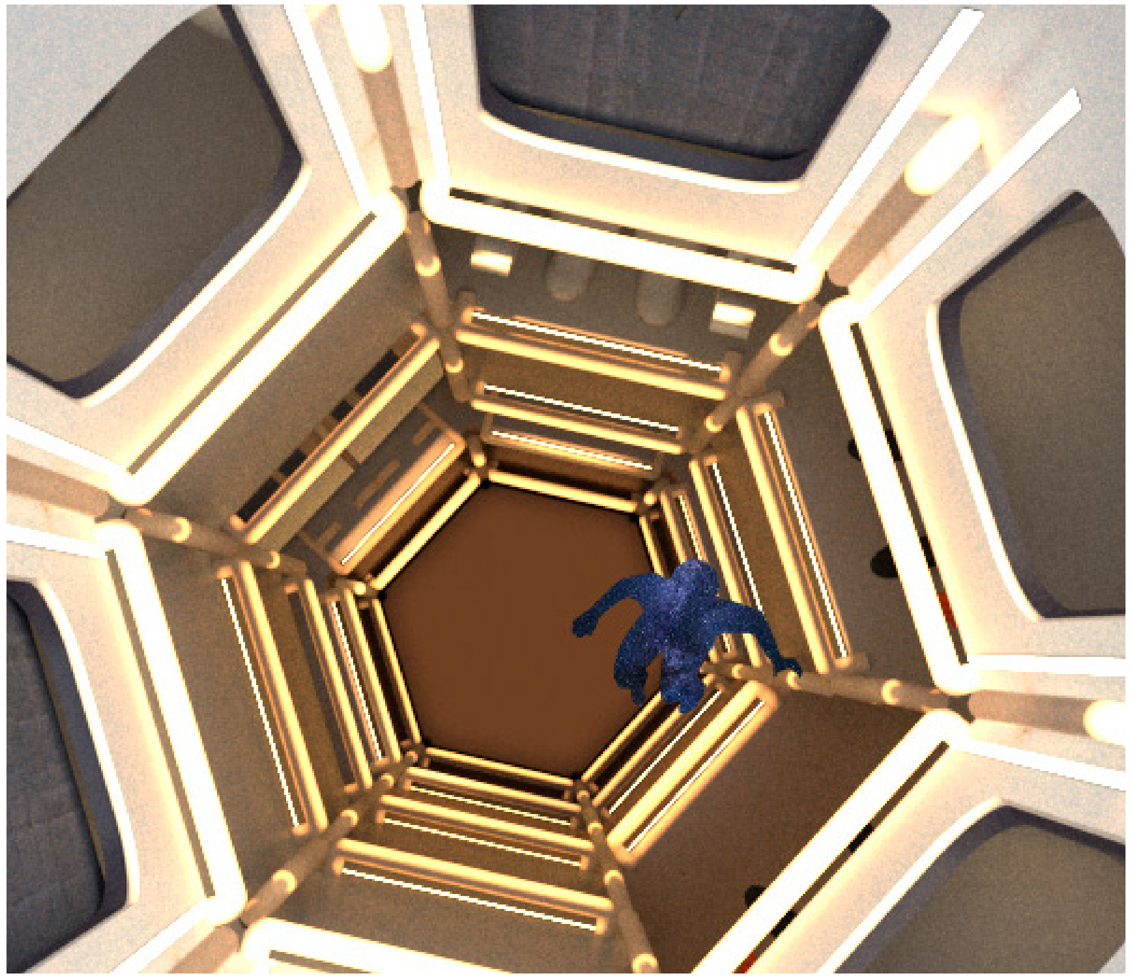

## 1

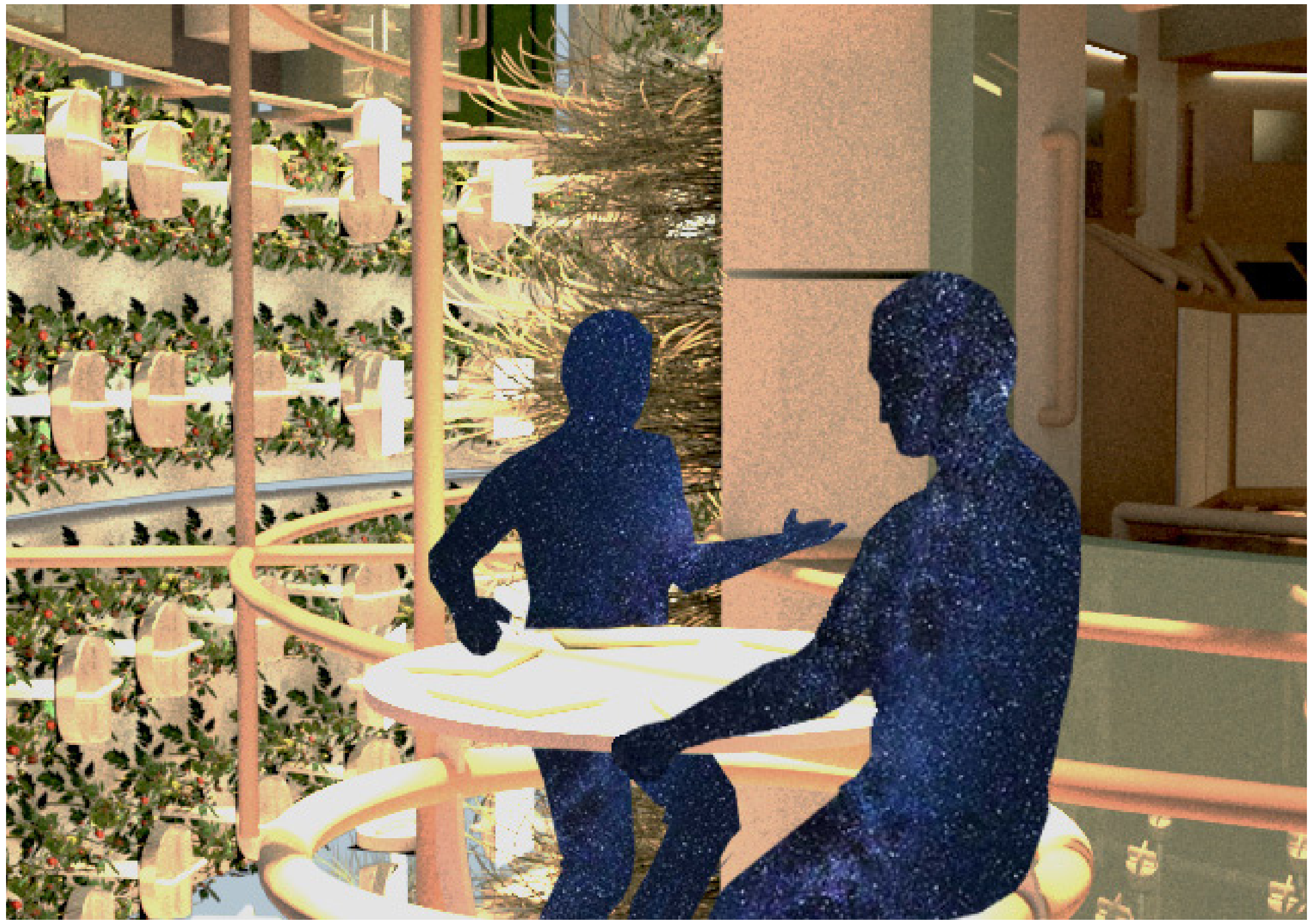
Galley
Wardroom/dining
Recreation
Storage
Control panels (avionic & life control)
Waste compartments

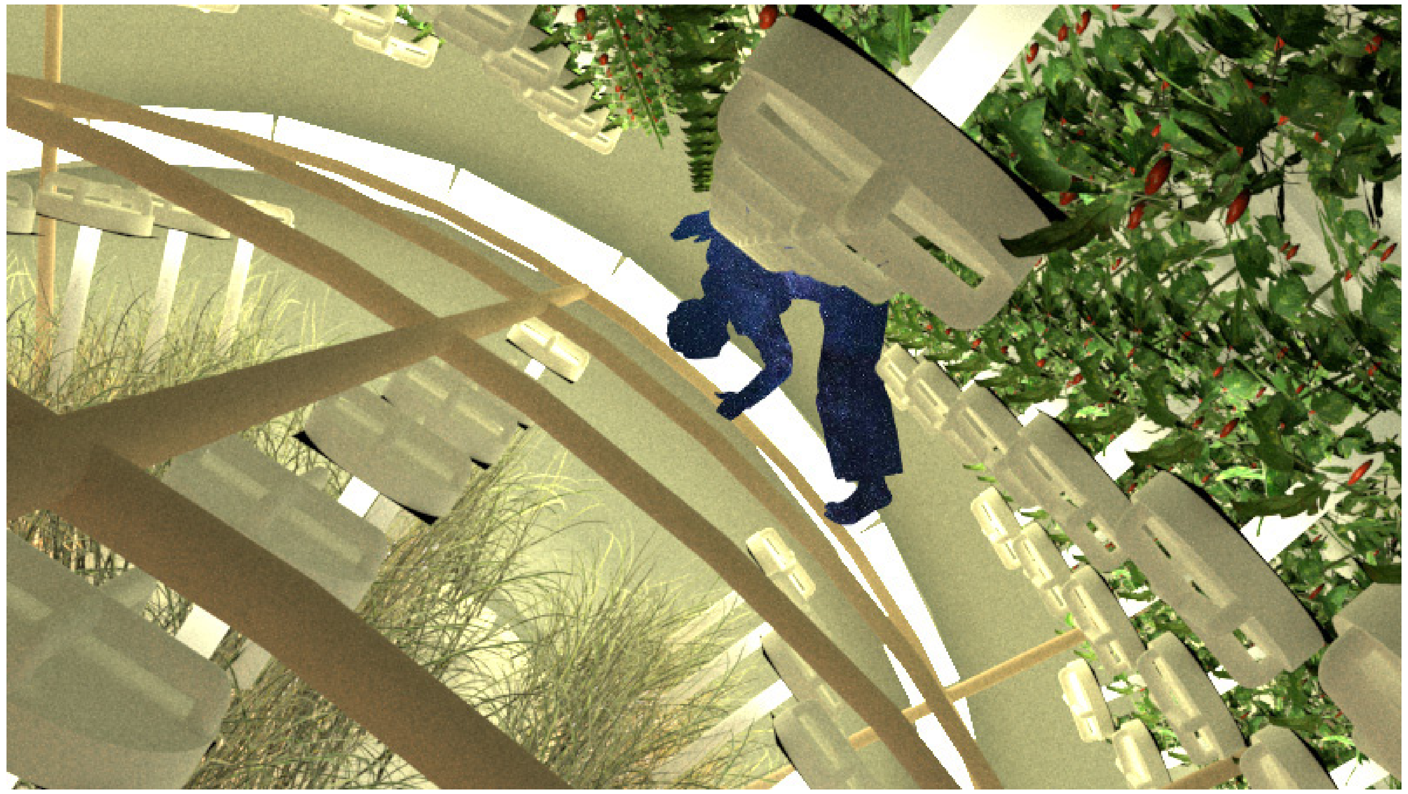


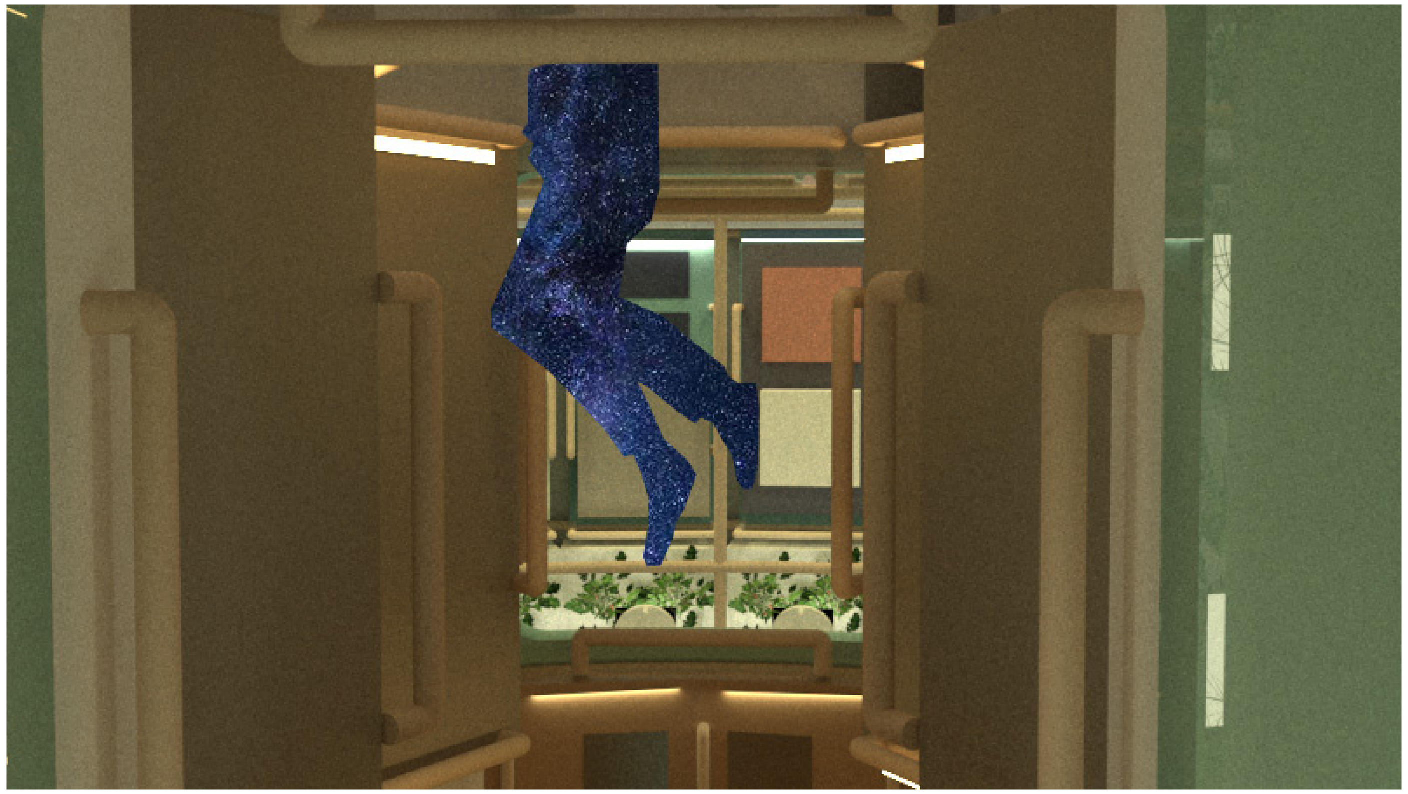


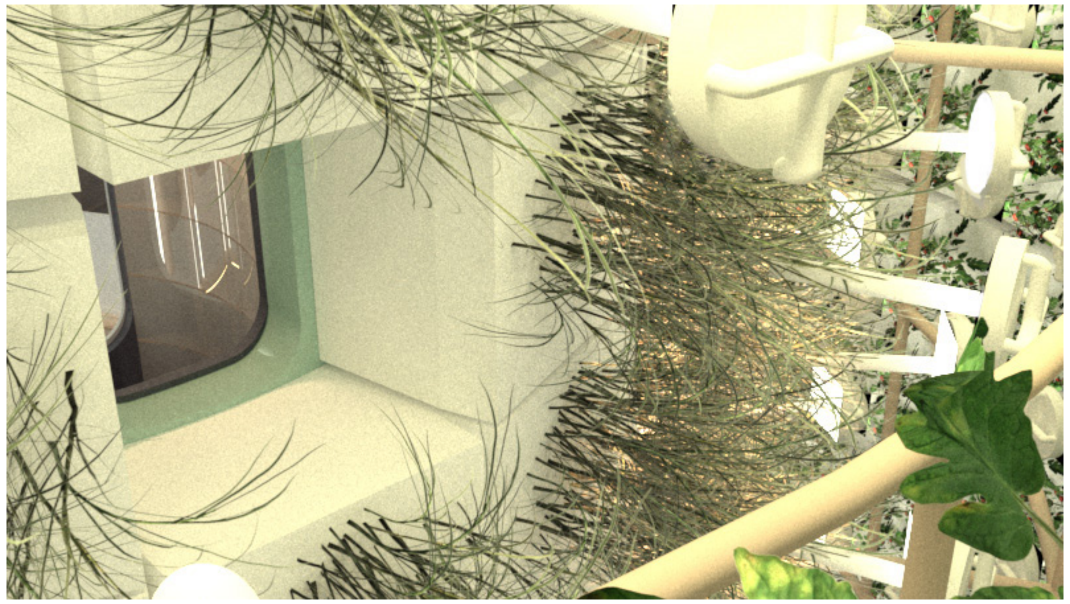
RENDERINGS





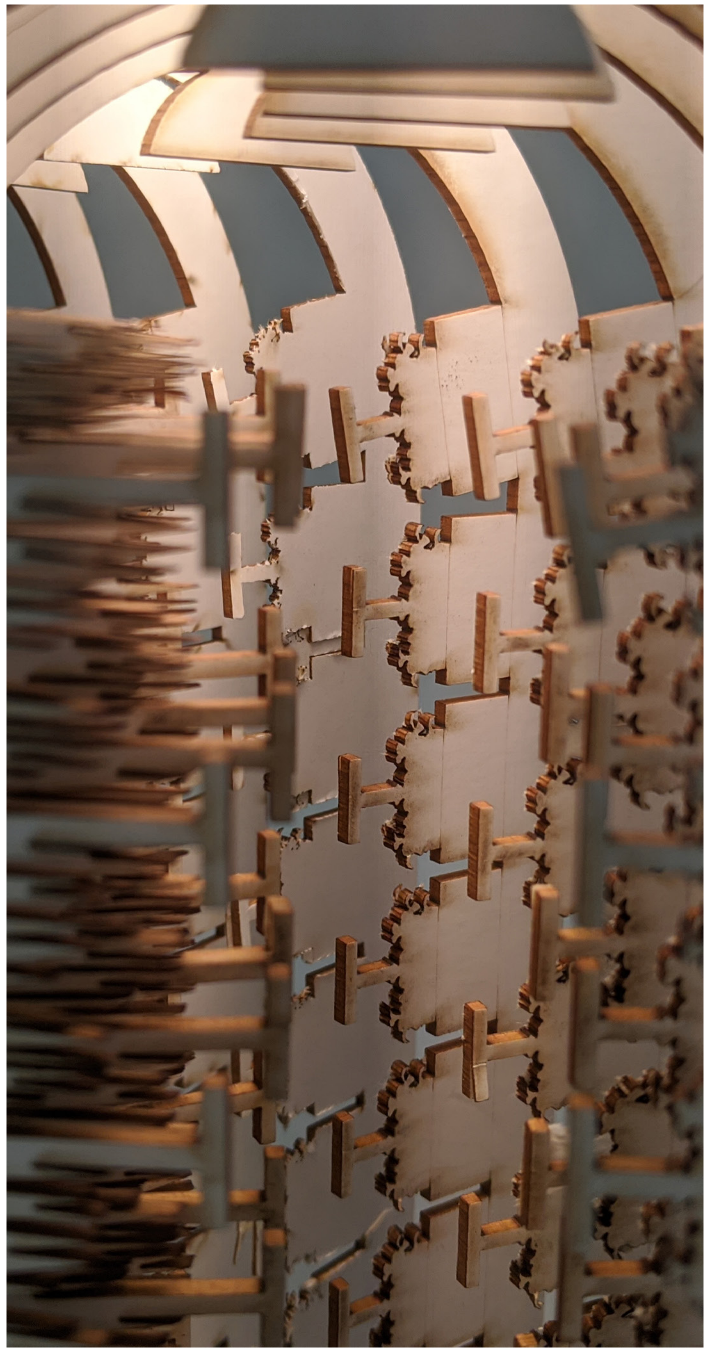






*Video of Walkthrough of TransHab 2.0*

## PHYSICAL MODEL





## CORK RAILING PROTOTYPES

## THANK YOU,

Lin Tan, for being such an encouraging and engaging supervisor

Mattias Roupé and Mikael Johansson, for helping me to use Virtual Reality as a tool in my work process

Larry Toups, for giving me thoughful advice early in the design process

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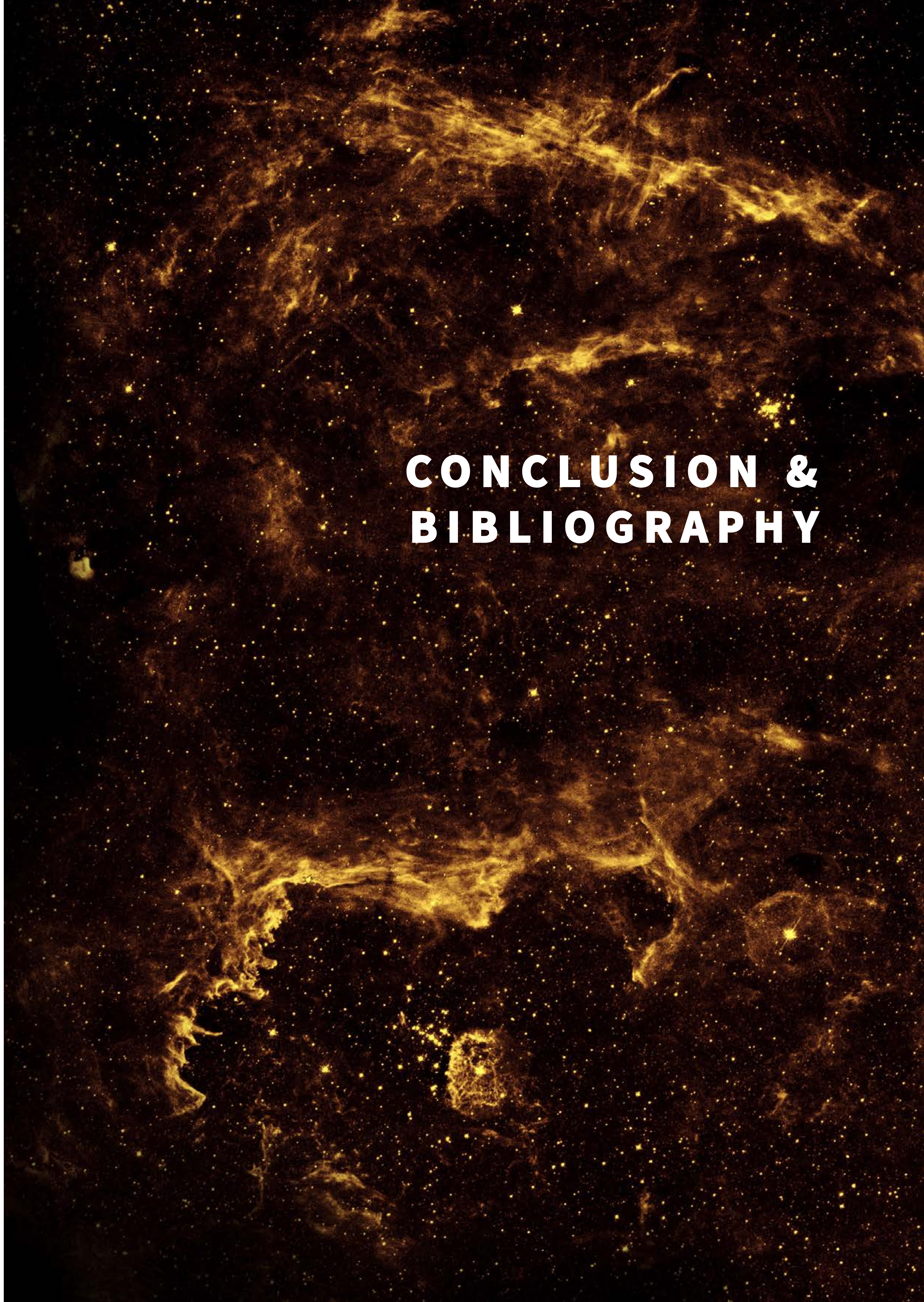
Karin Eckerdal, for participating in our weekly zoom-meetings and giving me helpful critique

Grandma, for keeping me company on the phone when the lack of people at campus (due to the Corona virus) made me feel miserable

Mum, for your general support





# CONCLUSION

## ANSWERING THE THESIS QUESTION

*- How can a spacecraft carrying people to Mars, Jupiter's moons or beyond be designed to promote the physical and psychological well-being of the crew while still taking into account the strict technical requirements of the vessel?*

The answer to my thesis question has resulted in a catalogue of design guidelines and an example of how they can be implemented. The ways of promoting well-being and mitigating the negative effects of long-distance space traveling are many. I chose to focus on what I considered to be the five most relevant challenges from a health perspective (mostly *mental* health perspective), and the offered guidelines are also merely a selection of all the different ways that one can approach each challenge.

The diversity of the fields in which one can find good solutions is fantastic. Lighting, colors, material selection, spatial layout and greenery are some of the areas that have been relevant to look into. I have tried to integrate all the suggested solutions into my design to test them out and see how they work together, but in this limited amount of time it's impossible to give all the parts equal care and attention. The ones that I was able to integrate works well together, and the only conflict that has arisen is perhaps between the desire for a sense of openness and the need to provide enough handholds in a microgravity environment.

Technical requirements and limitations, such as the size limitation (due to available payload space in the launch vehicle), the high demands put on materials, the need to protect against radiation by adding a water barrier and completely excluding windows have been taken into account. Doing so has added to the difficulty of creating a pleasant space, but perhaps forced the project into more interesting areas - if it's too dangerous to add windows, how can one create the illusion of being in or looking out at an outdoor space?

## GAINED KNOWLEDGE

My contribution to the field of architecture (more specifically, space architecture) is perhaps trying to design the spacecraft habitat as a home rather than a vessel for getting from one place to another. Because of the extreme distances between Earth and most other destinations in space the time spent on board the spacecraft will be counted in months and years. That is a large part of a human life. For the sake of the mission, but also for the sake of being at peace with spending such a large part of one's life isolated in a spacecraft far away from Earth, the possibility to feel at home (i.e. comfort, security, contentment) is crucial in the long run. My suggested design is still very different from a traditional Earth home, but the similarities lies in the details.

## REFLECTIONS ON RESEARCH AND METHOD

Choosing to divide the design part of the thesis into different areas has worked well - a general design vs. my specific suggestion. Since I had very little prior knowledge about space architecture and about many of the fields that I've chosen to base my design guidelines on, an enormous amount of time has gone into research (e.g. reading). By selecting such an unusual topic I was forced to go through this. But I wish that I could have put more time into working on my implementation of my research.

Contacting and discussing my project with the former NASA employee Larry Toups, who has worked with the design of long-distance spacecraft, was a great help in the beginning, since the number of people who has knowledge on this subject at my university and within the architecture department are very few.

I had planned from the start to use a **VR-headset** as a tool during the design process. Admittedly I began using it later than I had intended to, but when I did use it the experience was incredible. Perhaps that tool is particularly valuable in projects that deal with small and confined spaces, but I would recommend every architect, really *everyone*, to start using Virtual Reality. Not only to make sure that the design looks OK in the end, but to let it be part of the early stages of the design process. This enables the designer to see things and experience spaces in a way that is not possible when working in only two dimensions. Even working with a 3d model, observing it from an exterior view and perhaps trying to find some good perspective views in the interior, cannot compare to the feeling of actually being in the structure. What Virtual Reality adds specifically, is a broader peripheral view (which results in a more realistic perception of volumes) and the possiblity of realistically moving around in the designed space. To me, working with movement in microgravity, this tool has been invaluable.

## FURTHER RESEARCH

There are, as mentioned, more challenges related to physcial and mental health to look into when it comes to space traveling, and there is no lack of interesting solutions. However, if I would continue with the project I would spend more time trying to perfect the implementation of the guidelines that have been presented in this thesis.

One of the choices that I made in my design was to work with a microgravity environment. It would have been interesting to also try to work on a project that went the other way - looking into artificial gravity and it's particular quirks. The physical health benefits are potentially greater, but the structural and design challenges are probably harder.

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