Simulated Mars Environments

The evolution of the Martian magnetic field, the physical processes behind Recurring Slope Lineae and the possibility for microbial life on Mars.

Master Thesis

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Abstract

One subject that has interested people throughout time is the idea of finding life in places beyond Earth and one such place could be Mars. But could life survive on the red planet today? This is one of the questions the thesis focuses on. Separated into three major sections each section focuses on aspects that are crucial for life. The first section dives into the original Martian atmosphere and the time of the disappearance of the global magnetic field. Through simple calculations an estimated ratio of the original atmosphere of Earth and Mars, created either by outgassing or collisions, are found. From these calculations the estimated time for the disappearance of the Martian magnetic field is calculated. The calculations give a time of disappearance at either 2.96 Ga ago or at 3.74 Ga ago, depending on how the atmosphere was created. The second section focuses on the possibility of finding liquid water, in the form of recurring slope lineae (RSL) on the Martian surface today. Water is one possible explanation for RSL, that are dark lines traveling down slopes. The focus was to test the possibility for perchlorates to be a part of this explanation, and if they could lead to water vapor from the atmosphere condensing in the soil. The experiment consisted of a number of smaller experiments both testing soils with different concentrations of perchlorates measuring their reflectance as well as testing the slope. Liquid water is essential for all life known on Earth and this is why RSL is interesting and also leads to the third section which concentrates one the possibility for life on Mars. Through the use of a Mars simulation chamber, a Martian environment, consisting of a carbon dioxide atmosphere, a pressure of 1 % of Earth's and a low humidity around 17 % was created and bacteria was tested. The bacteria was exposed to the environmental changes over two weeks, with the interest in seeing how they reacted to a Mars-like environment. An additional experiment, testing how the bacteria coped with UV-radiation, was also conducted, exposing the bacteria to different intervals of UV-radiation. The common thread for all three sections is their focus on life. With the calculations estimating the time of disappearance of the magnetic field, the experiments surrounding recurring slope lineae, to the testing of bacteria under Mars-like conditions, all with the interest of better understanding the red planet and the possibility for life beyond Earth.

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Contents

1 Thoughts behind this thesis, the calculations and the experiments

The inspiration for this thesis is the enigma of life elsewhere in the universe. Are we alone or is life quite common? One of the interesting places to search for life beyond Earth is Mars, since the planet has some similarities with our own home. Though there are similarities, there are also a number of differences, among these, the composition of both soil and atmosphere, the surface pressure and the lack of water (in its liquid form). Especially water is an essential ingredient for life.

This thesis focuses on Mars and the possibility for water and life on the red planet. The thesis is made in collaboration with two other students and is consisting of three major parts: two experimental and one theoretical. The theoretical part is made in collaboration with a fellow astrophysics student Angeliki Christakopoulou, this means that though we have not written the section together, we have made the calculations in collaboration and discussed the best approaches. The reason for adding this part to the thesis was due to the corona lockdown, making it impossible to go to the lab. We also collaborated on Section 2, which we worked on together and the text in the section is therefore be the same, in both thesis. One of the two experimental parts was made in collaboration with both Angeliki Christakopoulou and (at the time) microbiology student Poul K. Madsen. This part is consisting of testing bacteria in a Mars like environment by using a Mars chamber. Here Poul K. Madsen, with his background in microbiology, has played a very important role in the preparation of the bacteria, as well as the experiment itself. I have participated in a number of the steps of the preparation as well as the extractions, but not all. After the experiments, the bacteria needed to be counted, which was done by Poul K. Madsen. The last experiment was an individual experiment. The purpose of this experiment was to test the possibility of liquid water on the Martian surface.

The common denominator for all of the sections is the possibility of water and life, as well as the evolution of the planet. The three parts therefore compliment each other well. The theoretical approach to the evolution of the atmosphere leads nicely to the lack of atmosphere today, which in turn leads to the question, can liquid water be found on the Martian surface? This again leads to the question if life can be found on Mars or can survive if sent there.

1.1 The structure of the thesis

This section serves as a brief introduction to each of the following sections.

Section 2 provides an overall background for the thesis. With an introduction to both the Big Bang, the creation of planets and Mars an its environment. It also takes a look at the requirements for life and the possibility of terraforming the planet as well as the ethical questions when exploring space.

Section 3 gives a more in-depth explanation for the possible mechanisms behind recurring slope lineae. It also provides a short introduction to the Gale crater and the Jezero crater which are the places the used soil analogs should imitate.

Section 4 is the first of the three major parts. It goes through simple calculations for the original mass of the Martian atmosphere as well as the time for the disappearance of the magnetic field.

Section 5 serve a short introduction to the Mars chamber which plays an important role in parts of the thesis.

Section 6 is the second of the three major sections, and describes the experiments conducted in regards to recurring slope lineae. The section is separated into minor sections explaining the different steps for the experiments, the data and ends with a sub-discussion.

Section 7 is the last of the three major sections and focuses on the experiments where bacteria were tested. It describes how both the UV-experiment and the Mars chamber experiment were prepared and made. It then looks into the data of the two experiments and ends with a sub-discussion about the results.

Section 8 discusses the three major sections overall and how they are connected with each other.

Section 9 is the conclusion and sums up the results.

2 Background for understanding the thesis and the experiments

Are we alone? Three small words, that implies an enormous question. A question that has sparked interest and baffled people throughout time. What if we are? What if we are not? The questions are many and the answers will most likely vary. In the last decades the search for clues has increased extremely in an attempt to try and answer the question "Are we alone?". Both ground and space based telescopes, rovers and satellites are trying to find clues to resolve this question. At the moment, one of the best suggestions for finding signs of life, either past or present, in our own solar system is Mars. In 1976 the first successful landing of a lander on the Martian surface took place, with Viking 1 and Viking 2 [Freedman et al., 2016]. From 1976 and up until today the examination of the planet is still ongoing. Though not every mission focuses of finding sings of life, other missions are still providing key information about the planet and its past.

The possibility of finding life or for life surviving on Mars is the main focus for the following sections. Before heading to the red planet, there is a short introduction going through the creation of the Universe. From the Big Bang to the creation of the elements, and from there to the creation of planetary systems (Section 2.1). This serves as a short introduction to the building blocks for the creation of everything, life included, ending with the creation of solar systems. The next section (Section 2.2) focus more in-depth on the Martian environment and the evolution of the planets through time. Focusing on the geology, the magnetic field, the atmosphere as well as the possibility of water both past and present on the surface, concluding with a section on the search for life on Mars. This leading to the third part (Section 2.3), a short introduction to biology and life with focus on bacteria. The last section (Section 2.4) takes a closer look at the possibility of terraforming Mars, as well as some of the ethical and possibly moral problems when it comes to space exploration.

2.1 From the Big Bang to the building blocks of life

In order to understand the physical processes in the Universe, including the physical principles that govern the rules of life we have to go back in time and see how the cosmos began.

2.1.1 The origin of elements

From a cosmic point of view, all of the observed matter was created during the first few minutes in the history of the Universe, in the Big Bang, 13.8 billion years ago [Ade et al., 2016]. During the first minutes, the Universe expanded extremely rapidly, with this phase being known as the inflationary epoch. After this time the Universe continued to expand with a slower expansion rate than previously, despite still being in a very high density and temperature state.
The Big Bang nucleosynthesis -primordial nucleosynthesis- took place during the first few minutes. This was while the temperature was very high and it refers to the production of hydrogen, helium, small amounts of deuterium, lithium and beryllium. At this point the

universe had a temperature low enough for deuterium to survive, but also high enough for fusion reactions to occur since there were still free neutrons available.

Biological life requires heavier elements, than the primordial, in order to be formed. The formation of these elements came by the result of thermonuclear reactions in the core of stars, and also during supernova and kilonova explosions. When a star's core runs out of hydrogen and expands into a red giant, it begins to produce carbon atoms by fusing helium atoms. Elements heavier than carbon are more complex to produce because the various reactions can lead to many nucleus in risk of being destroyed due to high temperatures. Stars with higher masses continue the nuclear burning. The elements formed in these stages range from oxygen through to iron. It has been noticed that nuclei with atomic mass multiple of 4 are more abundant (^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si, ^{32}S, ^{36}Ar, ^{40}Ca, ^{56}Fe). In total 98% of elements in the universe are hydrogen and helium and three quarters of the rest are made up of carbon and oxygen. Also, an overabundance for the elements around iron is observed, the reason is the strong binding energy of nuclei with a mass close to iron.

During the later phases of red giants, supernova or kilonova, the star releases great amounts of energy that leads to the formation of elements heavier than iron, such as uranium and gold. In these type of explosions, all the elements produced during the previous stages of life of the star are ejected into space.

The energy from these nuclear reactions is the high energy and it emits in the x-ray/gamma rays part of the spectrum. In the end, it is the nuclear reaction that drives the light emitted from the stars. And it is this light that heats the surface of the planet. This energy is responsible for warming the planet, influencing the weather and providing energy for life.

"The cosmos is within us. We are made of star-stuff. We are a way for the universe to know itself." — Carl Sagan

2.1.2 Interstellar Medium

The matter and radiation that exists in the space between the stellar systems in a galaxy, the interstellar medium or ISM, is an area where further reactions can occur and form more complex molecules. The interstellar medium consists of gas and dust. The gas phase dominates the medium (99% by mass [Boulanger et al., 2000]) with about 90% hydrogen, 10% helium (by number), and trace amounts of other elements, especially oxygen, carbon, and nitrogen [Ferriere, 2001]. The dust part consists of dust grains varying from millimeter to sub-millimeter size and having a carbonaceous or silicate-based core surrounded by an icy mantle of water (H_2O), carbon dioxide (CO_2), or ammonia (NH_3) [Srama et al., 2004]. The first diatomic molecules were discovered in the ISM almost a century ago. Today, more than one hundred species have been detected in the ISM [McGuire, 2018]. In this list of molecules, there are some related to the essential molecules of life, like glycine [Jiménez-Serra et al., 2014].
These molecules have been detected using atomic and molecular lines as tracers (e.g.

CO, HI 21cm, Hα). Analyzing the spectra observations makes it possible to estimate the different parameters (like temperature, abundance of elements, column density) that characterize such environments [Stahler and Palla, 2008]. Studying the densest regions of ISM, where stars are born and eventually planetary systems form, can tell a lot about the chemistry that takes place during star formation. This can lead to a better understanding of the origin of life and possibly elsewhere.

2.1.3 Planetary systems

Now knowing how these elements necessary for life were formed, the next step is to understand how they ended up in planetary systems. The standard theory that describes the way that solar systems formed, was first explained in 1796 by Pierre-Simon Laplace. This theory explains how rotating gas cloud collapse due its own gravity and as a result form a disk (Fig. 1). The solar system formed about 4.5 billion years ago from a dense cloud of interstellar gas and dust. The cloud collapsed, possibly due to a shockwave. The central parts of the cloud collapsed to form the Sun, and the remainder of the material created a flattened disk, the protoplanetary disk [Boss and Ciesla, 2014].

At the center of the disk, gravity accreted most of the surrounding material and the pressure in the core becomes so high that hydrogen atoms began to fuse and form helium. The mechanisms that lead to the formation of planets are still being a current topic in research across the world. One of the leading theories is that they formed due to accretion. After the dust particles had grown large enough, the Sun's gravity dragged them towards the mid-plane of the nebula. The dust began to collide and then grew until it reached a planet-sized body. As these planetesimals (solid objects exist in the protoplanetary disk) build up, some clumps were able to collide and build the final planets. More elliptical orbits would lead to collision of planetesimals and building up the planets.

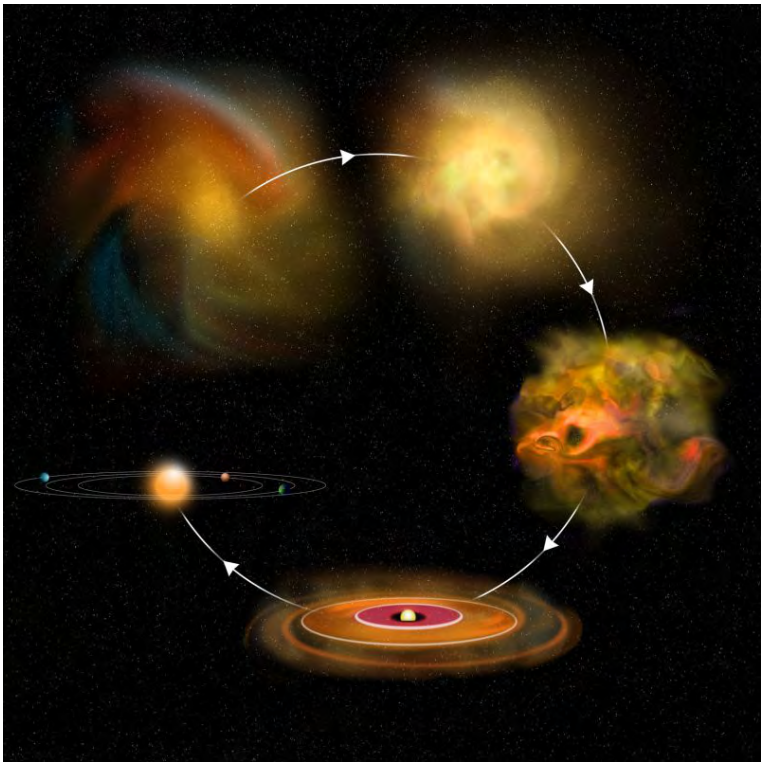


Figure 1: *Illustration of the planetary formation theory - image source Bill Saxton, NRAO/AUI/NSF.*

The theory for the solar systems is that the Sun and the planets formed around the same time, however there is no direct evidence supporting this. One can determine the age of a young cluster and then get an idea of the age of the Sun, but nothing about the age of the planets. The age of meteorites in the solar system having an estimated age of 4.5 Ga supports this age theory [Hedman, 2008]. Further support to the theory comes from looking at the direction of the orbits of the planets around the sun. If they had not been created from the disk at the early stages in the solar system, but rather been accreted from elsewhere in the Universe, we would see a large variety in the directions of the orbits.

Studying regions in which stars are born (like the famous M16 region), and running creating and examining simulations of the creation of solar systems could help to answer an elementary question. Is the solar system unique and different, or is it simply one out of many other solar systems created under the same initial conditions.

2.1.4 The snow-line and the water paradox

Early in the life of the solar system, before the star had fully accreted the surrounding materials and planetesimals were still accreting in the disk. Elements condense at different temperatures and some elements can only condense further out where the temperatures are sufficiently low. This leads to the planets growing bigger and when they reach approximately ten times the size of Earth, they tend to attract hydrogen and helium gases of the disk. If these gases are cold enough, then they can condense onto the planet. Further

in, closer to the Sun, elements which can condense at higher temperatures form the inner planets.

There is a specific distance from the Sun, the so-called snowline, which is estimated to be at approximately 2.7AU to 3.2AU[1], depending on the model used to calculate it [Hayashi, 1981, Martin and Livio, 2012, Podolak and Zucker, 2004]. At this distance it is cold enough for water molecules to be bound into a solid state. The lower temperature in the nebula beyond the snow-line makes a large number of solid grains available for accretion into planetesimals and eventually planets. The snow-line separates the terrestrial planets from the gas planets [Kaufmann, 1987].

Due to low pressure in space water can not exist in its liquid state. As a result water can only exist in the form of gaseous and solid state. The interesting thing with the solar system is that the terrestrial planets are closest to the Sun (within the snow-line) and the gas giants are further out (beyond the snow-line). When observing exoplanetary systems gas giants are usually found much closer to the host stars than in the Solar system. These gas giants are thought to have formed outside the snow-line and later migrated inwards to their current positions [Chambers, 2007] [D'Angelo et al., 2010]. The fact that Jupiter did not migrate closer to the Sun than it is today, may play a role in the existence of life and of Earth as known today. The planets beyond this line will have a core mainly of water. A remarkable point is that while water can only condense outside of the snow-line, all known life exists within the snowline and relies heavily on water. The origin of this water on the inner planets remains unknown. [Jørgensen, 2019].

Bearing in mind how all these mechanisms contribute to the creation of the planets and life as we know it, it would be strange if we were the only life form in the Universe.

2.2 Mars - Earth's smaller neighbour

Having gone briefly through the evolution of the universe, the Big Bang, the creation of elements, stars and planets the focus is now shifted onto one specific planet - Mars. Mars is the fourth planet from the Sun and is now one of the top candidates for the search for life within the Solar system. At the time of this thesis it is not known if life exists on Mars or if it ever has. But when looking at the possibility of life on a planet, the planet itself must first be understood. The following sections (Section 2.2.1-2.2.5) takes a deep dive into the red planet, the geology and its evolution through time. As well as taking a closer look at different planetary factors in order to understand the environment with the possibility of life in mind. A closer look at the magnetic field and atmosphere, the evolution of those and the possibility of liquid water both now but also in the past. The section ends with a short look at the investigations for life and habitability, from the past, the present and future.

[1] Astronomical units $1.5 \cdot 10^8$ km

2.2.1 The geological periods of Mars

Mars is believed to not always have been the dry wasteland that it is today. But to be a planet, where the environment and geological features have changed over time [Carr and Head III, 2009], much like seen on Earth. The geological history of Mars can roughly be separated in to three geological periods, the Noachian, the Hesperian and the Amazonian, each of them named after larger areas on the Martian surface [Carr and Head III, 2009]. The span of each period varies and the exact time for when one period changes to another are not completely defined. Throughout each period, the geological features as well as the environment of Mars has changed. Since the exact time of change from one period to the next is not entirely defined, the age might vary depending on where one look up the information. For the age and primary source of information on the geological periods, the paper by [Carr and Head III, 2009] is used. For any location references on Mars see Fig. 2.

One of the reasons why the areas can be hard to date is due to the lack of rock samples. When an area on the Martian surface is dated it can be done by crater count. An area or surface of a planet is initially barren (crater less), during time more and more craters will form on such surface. Simplified, a given number of craters on a surface therefore equals a specific age of the given area or surface. The number of craters forming will vary depending on the planet or moon (due to size, gravity, atmosphere etc.). It should however be noted that an age based on a crater count will vary depending on the model used. And also that it is just a model age until the age of actual rock samples can be determined and compared with the age from the model. This has been done with collected rock samples from the Lunar surface giving a more precise model age. At the moment since no Martian rock samples with a known origin has found they way to Earth, the models used for determining the age of the Martian surface and areas are made from extrapolated data from the Moon. This means that in the case of Mars (and any other extraterrestrial surface except for the Moon) the age found by using one of the models, will only be an estimate or a model age and will again vary depending on which model is chosen.

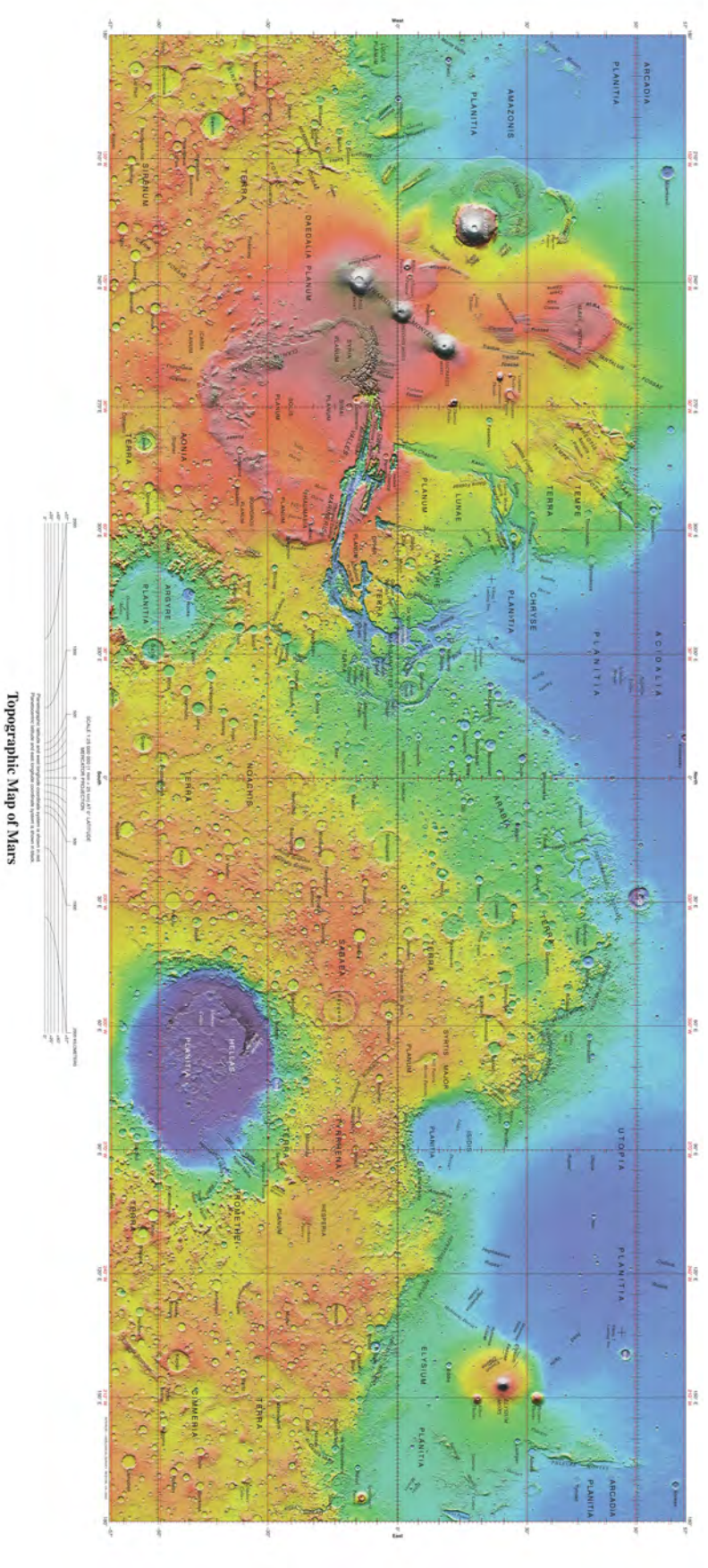


Figure 2: *Topographical Map of Mars [USGS, 2020].*

The Noachian period

The Noachian period is the first of the three periods, though a Pre-Noachian period is believed to have existed as well [Carr and Head III, 2009]. The Pre-Noachian period is believed to be from 4.5 – 4.1 Ga ago and not much is known about it, due to nearly non geological record. Periodically large basins and craters was created and as a result this, had a huge effect on the environment. During the Pre-Noachian period the planet also had a magnetic field [Carr and Head III, 2009].

The Noachian period is believed to stretch from 4.1 Ga ago till around 3.7 Ga ago [Carr and Head III, 2009] (overlapping with the Late Heavy Bombardment (LHB) stretching from around 4.1 - 3.8 Ga years ago [Freedman et al., 2016]). The Noachian period is named after the area found on the southern highlands, the Noachis Terra/region [Carr and Head III, 2009], located just west of the Hellas basin.

The period is recognized for its high number of valley formations and its large crater formation rate as well as erosion [Carr and Head III, 2009]. As mentioned the Noachian period overlaps with the LHB, and about 40 % of the Martian surface dates to the period. The largest impact craters also dates to the Noachian period [Solomon et al., 2005]. With the creation of Hellas marking the beginning of the Noachian period [Carr and Head III, 2009].

Volcanic activity was present on the Martian surface during the period, through most of it, likely took place in the Tharsis area [Carr and Head III, 2009]. When observing from planetary orbit (with a resolution of 100 meters) the Noachian landscape is, even though volcanic activity was present, influenced by impacts. [Carr and Head III, 2009].

Evidence suggest the possibility of having shorter periods of time with warmer conditions as well as rainfall during the Noachian period. There are however uncertainties as to if this phenomena was local or on a global scale due to the difficulties in maintaining the conditions that would be required. [Carr and Head III, 2009]. How these warmer conditions, during the Noachian period, came to be is still unknown. It is possible that it was due to impact or volcanic eruptions [Carr and Head III, 2009]. Parts of the valley systems are however believed to have been formed by water, indicating that water must have been present in some quantities, during the period [Jørgensen, 2019].

The end of the Noachian period overlaps with the earliest evidence of the first microbial cells on Earth, which might be as early as between 3.9 and 3.8 Ga ago. [Madigan et al., 2015]. The conditions on the Martian surface might have been similar to Earth and might have been present long enough, for the time it took life to emerge on Earth. The conditions on Mars might even have lasted longer, since the planet is smaller and as a result potentially cooled down to a suitable temperature before Earth [Jørgensen, 2019].

The Hesperian period

The Hesperian period is the second of the three periods and begins after the Noachian 3.7 Ga ago and stretched to 3 Ga ago. The period has gotten its name from the Hesperia Planum [Carr and Head III, 2009], which is located just north-east of the impact basin Hellas Planitia. The erosion, weather and the formation of valleys slowed down and were much lower than in the Noachian period. Despite this, there were still volcanic activity taking place throughout the period [Carr and Head III, 2009].

During the Hesperian period the valleys formation rate dropped, but did not stop completely. Episodically and locally the circumstances for formation of small valleys was present [Carr and Head III, 2009]. Despite the low rate of valley formation, especially in the later parts of the period, huge floods of water would occasionally form. In the northern lowlands bigger bodies of water might have been created as a result [Carr and Head III, 2009].

Sulfates are found on the Martian surface, though primarily detected in the western hemisphere and near the north pole. Observation has been made from both orbit and from landing sites, detecting deposits of sulfates from orbit and concentrations in the soil at different landing sites [Carr and Head III, 2009]. In some of the valley networks sulfates are present, suggesting that some water activity was still present during the period [Carr and Head III, 2009].

The Amazonian period

Following the Hesperian period, is the most recent and present period, the Amazonian. The period is named after the area Amazonia Planum [Carr and Head III, 2009] located in the northern part of Mars. The Amazonian period stretches from the end of the Hesperian at 3 Ga ago up until today and is the longest of the three periods [Carr and Head III, 2009].

During the Amazonian period any larger scale geological changes were mostly limited compared to the two previous periods [Carr and Head III, 2009]. Just like in the previous period volcanic activity was still present, though primarily in the Elysium and Tharsis area. The activity was also significantly lower (by a factor of ten) than previously. One, if not the most, notable mark for the period, might be the change in the landscape due to ice. Wind might also have played an important role [Carr and Head III, 2009].

Locally areas being covered by ice might have happened, in a number of places and small amount of floods might also have appeared occasionally. [Carr and Head III, 2009]. Another change due to water are gullies, most of those found on steep slopes was formed late in the Amazonian period [Carr and Head III, 2009].

2.2.2 The Martian magnetic field

The magnetic fields are commonly believed to be generated by the dynamo effect created inside the planetary core. The magnetic field arises as a result of the core alloys movement. In the solar system the terrestrial planets Mercury and Earth have magnetic fields but Venus and Mars does not. The presence and lack of magnetic fields for the planets are believed to depend on the composition of the alloys in the core and how quickly it cools down[2] [Ehlmann et al., 2016]. Even though Mars does not have a global magnetic field today, [Solomon et al., 2005] the planet is believed to once have had one, much like Earth has today. [Sakata et al., 2020]. Signs of remnants of a magnetic field are found in the Martian crust [Acuña et al., 1998][Solomon et al., 2005]. Magnetic remnants can appear when a magnetizable object has been exposed to a magnetic field, leaving the object slightly magnetized when the external field is removed [McElhinny and McFadden, 2000]. Weaker magnetic anomalies are found in some areas in the northern lowlands and stronger magnetic anomalies are found near the southern highlands/uplands [Solomon et al., 2005].

Data today indicate the Martian magnetic field disappeared (due to the halting of the dynamo) at around 3.9 Ga to 4.1 Ga ago [Ehlmann et al., 2016]. One of the arguments for this is the lack of magnetic anomalies found in the large impact basins (Argyre, Hellas, Isidis and Utopia) [Solomon et al., 2005]. The deficiency of magnetic anomalies in the impact basins could indicate that the dynamo had already stopped when the impact took place. [Ehlmann et al., 2016]. Hellas, is the oldest of the four impact basins, as mentioned above, and is dated to be somewhere between 3.9 Ga and 4.1 Ga old (estimated from crater counts) [Ehlmann et al., 2016]. Looking at basins with similar age, but where magnetic anomalies are found, and comparing these with the four basins mentioned above, suggest that the cease of the Martian dynamo might have been very sudden [Ehlmann et al., 2016].

As mentioned the Martian magnetic field is believed to have stopped somewhere between 3.9 and 4.1 Ga years ago. This is an estimate and the actual age for the ceasing of the magnetic field cannot be precisely determined until rock samples can be tested. The exact age of these samples also needs to be determined in order to get an age [Ehlmann et al., 2016].

It is thought that with the ceasing of the Martian magnetic field that the atmosphere was more vulnerable, allowing the solar winds and the Martian atmosphere to interact leading to the atmosphere being stripped away. The lack of the magnetic field not only led to the possible stripping of the atmosphere, but may also have led to a high number of charged particles (cosmic rays) reaching the Martian surface. The presence of charged particles can damage near surface materials chemical bonds, which in turn can create different oxidants (like perchlorates) [Ehlmann et al., 2016].

Though commonly believed that the magnetic field will protect against the interaction between the solar wind and the planetary atmosphere [Ehlmann et al., 2016], in some cases a weak magnetic field might lead to a greater loss of atmosphere [Sakata et al., 2020]. Some simulations made of the Martian magnetic field shows that a weak magnetic field

[2]This however, does not seem to be only depending on the rotational rate of the planets, since both Earth and Mars are rotating faster. Nor does it seem to be only depending on size, since both Earth and Venus are approximately the same size [Ehlmann et al., 2016]

might add to atmospheric loss. Which in turn leads to a greater loss of ions like O_2^+ when a weak magnetic field is present compared to no field at all [Sakata et al., 2020].

2.2.3 The Martian atmosphere

The study of the planetary atmospheres, the origin as well as the physical and chemical processes that occur and the mechanisms that determine their evolution, is crucial to determine a planet's habitability. The study of the terrestrial planets in the Solar system can lead one step closer to understanding if life could exist presently or previously. This could also help improve the expectations and conclusions in planets surveys beyond the solar systems, the exoplanets.

The exact mechanisms that caused the formation of the atmospheres which is seen today is still unknown and being studied. From proto planetary conditions and the proto atmosphere,[3] to the secondary atmospheres that evolve to the one seen today, the atmospheric conditions of the planets have been changed throughout their history. Two main scenarios for the origin of Earth's atmosphere, may also applied for other terrestrial planets. The first scenario is due to outgassing and the second for the creation of the atmosphere is due to accumulation by meteorite impacts events. For the outgassing scenario, volatiles [4] may have been produced through the interior of the planet (volcanic activity). The impact scenario describes the possibility that meteorites may carry elements which in turn could generate an atmosphere?.

At 4.1 Ga ago, the atmosphere of Venus, Earth and Mars would most likely have been a greenhouse atmosphere combined with liquid water surface areas. In the next million years a primitive form of life could maybe have be found on Earth. Along with potentially life-friendly environments on the other two planets (Venus and Mars) with atmospheres composed of carbon dioxide, nitrogen, and water [Baines et al., 2013].

During the next years, the planets' atmosphere most likely changed. These changes was a result of multiple potential factors. The solar flux, in terms of light and charged particle radiation, and the possibility of occasional bombardment by the asteroids and comets may have contributed to these changes. Explicitly for Mars, the effect of solar winds evolution was an important factor that affected the atmospheric loss of the planet, especially when the magnetic field was absent and therefore offered no protection from Sun's charged particles. All of the above reasons have left the planet with an atmospheric loss rate of $\sim$2-3 kg/s [Jakosky et al., 2018]. The Martian atmospheric loss is currently being studied through two missions, from The Indian Space Research Organisation with Mangalyaan (2013) [Sundararajan, 2013] and from NASA MAVEN mission (2013) [Jakosky et al., 2015].

The mass loss evolution of the Sun-like stars in the main sequence decreases exponentially with time (Eq.1). The same study suggests that the strength of the solar wind must have

[3]Proto atmosphere or early atmosphere of a planet is the one that was formed due to accretion of gaseous matter of the proto planetary disc

[4]Organic compounds with low boiling points and high vapour pressure at room temperature

been one thousand times stronger than it is today, when the Sun was at the first stages of its evolution [Wood et al., 2002].

$$\dot{M} \propto t^{-2\pm0.5} \tag{1}$$

For the case of Mars, it's climate differs from Earth's primarily because of its thin, dry atmosphere, combined with the greater distance from the Sun [Leovy, 2001].The last years a series of orbit and also surface explorers have taken place. The purpose of these missions are to explore the physical and chemical properties that contribute to the planet's climate, atmospheric composition, geology as well as to see if there are any sign of ancient water and any biologically related material.

One great instrument that provided information related to the martian atmosphere is the SMA (Sample Analysis at Mars) instrument. This set up, including the SAM Quadrupole Mass Spectrometer (QMS) of the Mars Science Laboratory (MSL) Curiosity rover, arrived on Mars in August 2012 [Mahaffy et al., 2012]. These instruments are equipped to analyze the Martian atmospheric gases and volatiles, studying the chemical and isotopic composition of the Martian atmosphere. The results was: carbon dioxide 0.96%, argon 0.02%, nitrogen 0.02%, oxygen $1.73 \cdot 10^{-3}$ % and carbon monoxide $7.94 \cdot 10^{-4}$ % [Franz et al., 2017].
An important gas, that is a potential bio-marker on planets is methane. This is based on the fact that 95% of Earth's methane is biologically derived [Formisano et al., 2004]. The Martian methane has been measured from satellite telescopes, Earth based telescopes and also in-situ from Curiosity rover. The measurements from ExoMars Trace Gas Orbiter (TGO) showed a maximum value of 0.05ppbv [Korablev et al., 2019]. The Canada–France–Hawaii ground based telescope measurements up to tens of ppbv [Krasnopolsky et al., 2004] and the Curiosity analysis at Gale crater values up to 7ppbv [Webster et al., 2015]. As seen from measurements, the menthane concentration has variations and depends on where one look on Mars and is equally dependant on time.
However, the origin of methane on Mars is still controversial and being research. Some potential sources are related to biological, geological and volcanic processes.

The temperature on Mars can fluctuate, depending on the time of the day, seasonality and location, from 183K to 268K according to the measurements made by Viking lander on the martian surface [Kieffer, 1976]. Amongst others, more recent studies based on the Phoenix mission show a temperature range from 181K to 253K in polar altitudes [Smith et al., 2004]. The seasonality is analog to Earth's due to the rotational axis to the orbital plane of Mars (25.2°) is very close to that on Earth (23.45°). But since the Martian year is longer than one Earth year ($\sim$1.9 of Earth's year), seasons are longer. Also, Mars' perihelion is 31 sols (sol = martian solar day) combined with the eccentricity of the martian orbit, this means that the southern winter is longer than the northern winter [Simon et al., 1994]

The Martian atmosphere always has some airborne dust resulting in the optical depth, to stay at τ $\sim$0.1-0.2 [Kahn et al., 1992]. The atmosphere is influenced by dust storms initiated by strong winds. These storms hit approximately 100 μm diameter particles

from the ground along the surface, this is called saltation [Greeley and Iversen, 1987]. The dust, also, absorbs sunlight and can reduce the daily temperature with up to 5K [Pollack, 1979].

2.2.4 Water on Mars - Past and present

Past Water on Mars
Parts of the Martian surface are covered by what appears to be a network of channels or valleys. This evidence along with the fact that the majority of the northern hemisphere, compared to the southern hemisphere is lower in altitude, strongly indicates the presence of liquid water in the Martian past. Looking at the number of impact craters and crater statistics, the northern hemisphere is also younger than the southern. The lack of craters in this area could indicate that there once was an ocean covering a larger part of the Martian surface [Jørgensen, 2019]. Signs of ancient water, along with clues to the evolution of the surface water, is found on the Martian surface today [Villanueva et al., 2015]/ [Williams et al., 2013].

During the Noachian period the erosion rates were much higher compared to later times, this indicating both the possibility of water and wind activity [Ehlmann et al., 2016]. There is also evidence pointing to water interaction with the surface [Solomon et al., 2005]. A large number of the networks of valleys (and smaller offshoots) created by rainfall or groundwater dates to this period as well [Solomon et al., 2005]. Branching valley networks became limited during the late Hesperian period and/or the early Amazonian period [Ehlmann et al., 2016]. Despite this, there were still, locally and occasionally, Paleolakes and other associated landforms created by water [Ehlmann et al., 2016]. In the Amazonian period water created landforms can still be found, though they are limited. This could be features like channels of water on glaciers or weak branching valley networks [Ehlmann et al., 2016]. More present features include gullies and recurring slope lineae, that could indicate water [Ehlmann et al., 2016].

The possibility of water on Mars today
Regardless of the amount of water present on Mars in the planet's past, water is found there today. Though mostly found in its solid state [Jørgensen, 2019] or as water vapor in the atmosphere [Whiteway et al., 2009], some evidence suggest the presence of liquid water on the Martian surface today [Martín-Torres et al., 2015]. Due to the low atmospheric pressure on Mars today, water cannot naturally exist in its liquid state. Because the atmospheric pressure is below the triple point of water, water ice will not "melt" but directly change to its gaseous state, water vapor. Today a large amount of water ice is found on the Martian poles and in permafrost [Jørgensen, 2019]. Even though water on Mars cannot naturally exist in its liquid form, there are observations that indicated liquid water might actually be found on the Martian surface anyway.

From both on-site and remote examinations, a number of different salts have been found on the Martian surface. [Ojha et al., 2015]. The salt might play an important role in finding liquid water as they can form brines. Different salts can in fact contribute to the lowering of water's freezing point, even by as much as 80 K [Ojha et al., 2015]. Beside the possibility of lowering the freezing point of water, the salt are also hygroscopic which

means that they among other things attract and absorb moisture found in the atmosphere [Ojha et al., 2015].

As already hinted in the above section, it might be possible to find liquid water on the Martian surface. One possible sign of liquid water on the surface is what is referred to as "recurring slope lineae" or RSL for short. Sometimes they are referred to as "Seasonal flows on warm slopes" as well [Vincendon et al., 2019]. They are found on slopes on the Martian surface, and are lines "traveling" downward [Ojha et al., 2015]. The lines are relatively narrow ranging from 0.5-5 m in width and have a low albedo [Stillman et al., 2019]. The RSL are observed on warm slopes, areas where the temperature of the slope normally surpasses a temperature of 250 K and more often 273 K [Ojha et al., 2015]. They have been observed in both the northern and southern mid latitudes as well as areas around the equator [Schaefer et al., 2018]. They are fading when inactive and are re-appearing over multiple Martian years [Ojha et al., 2015].

If recurring slope lineae are due to liquid water movement, this could be very interesting. Water is a crucial part for all life we know of today, [Ojha et al., 2015] which is also one of the reasons why the possibility of liquid water on the planet today is so interesting. But whether or not liquid water can be found on Mars, has not been determined yet. As well as the origin or origins of RSL which remains a mystery. [Schaefer et al., 2018]. One possible explanation is, as mentioned above, the presence of liquid water due to the salt concentration in the Martian soil. But another possible explanation is that the RSL are created due to dust movement and are of dry origin [Vincendon et al., 2019].

2.2.5 The search for life on Mars - Past, present and future

Are we alone? A question that has been asked through time and one that has still not been answered. This is not for the lack of trying, a number of missions and scientific studies have been taking place through a number of years in search for an answer. But space is big and there is more than one place to search. One of the closest places to search is Mars and the surface of the red planets has been investigated through time. The first successful lander to reach the surface was the Viking landers, (Viking 1 and Viking 2) [Freedman et al., 2016].

The Viking landers were made to test for life and one of the experiments could monitor for metabolism [Levin and Straat, 2016]. Both Viking lander 1 and Viking lander 2, which tested approximately 6440 km (4000 miles) apart had similar outcomes for the experiment, the results seamed to be positive. The results have however been questioned since and the conclusion is still debated today, believing that it might have been something non-biological the experiment detected [Levin and Straat, 2016]. One argument for why it was not biological, was that it could be a form of oxidants present in the soil, along with the Martian environment being too hostile for life [Levin and Straat, 2016]. With both arguments for and against detection of life on Mars, an answer to the question is still in the future.

At this moment no similar experiments have been carried out on Mars in the search for life [Levin and Straat, 2016]. But the exploration of Mars and search for sings of

life continued. A number of missions has been launched since, some with the focus on investigating the Martian environment and other in the search for potential life, but all with the goal of better understanding Mars.

Another mission which the focus of searching for habitability is the still operating Curiosity rover which launched in 2011. The main focus for the Curiosity rover was to investigate if Mars had ever been habitable or able to support microbial life [Curiosity, 2020]. The Curiosity rover landed in the Gale crater. A second mission is the more recently launched Perseverance rover (2020 Mission) which at the moment is on its way to Mars. The main focus for the Perseverance rover is to search for signs of ancient life on the red planet while also collecting rock samples (with the possibility of return them to Earth in the future). The landing site for the Perseverance rover is Jezero crater [Perseverance, 2020].

2.3 Understanding life

But why is it important to understand the Martian environment. As well as the evolution of the planet's surface, the magnetic field, the atmosphere along with the possibility of water, either past or present. The previous section 2.2, partially answers that question. Each of the sections go through radical environmental changes, leading to the barren planet seen today. The interest in regards to the the evolutionary changes is to better understand the environment and by extension the possibility of life. Not necessarily life as known from everyday life here on Earth, but life in more extreme environments or under more extreme conditions. However, to search for life in extreme conditions one does not have to go far, microbial life are found all over Earth and some even in places too extreme for macroorganisms [Madigan et al., 2015]. This is exactly the reason for interest in the Martian environment. Even though Mars is significantly different from Earth, areas on Earth similar to Mars are found. Places with very low temperature or high UV radiation or anaerobic systems. If life can be found in the most extreme places on Earth, then maybe life can be found elsewhere to.

2.3.1 Requirements for life

All life known here on Earth is made up of cells, some are made of only a single cell and other of trillions. To better understand the fundamental of the cell, what goes on inside the cell must be understood. Inside the cell a number of processes takes place, these are referred to as the metabolism. In order for the cell to work properly it needs two things, energy and material to work with. Life on Earth is said to be carbon based, the structure of the cell and the way it works is due to carbon. This is why the two important sources that the metabolism needs can be specified to an energy source and a carbon source [Bennett and Shostak, 2012].

The carbon source and the energy source can come from a range of different places. The carbon source serves as building blocks for the organic molecules in the cells. One way for the cells to get carbon is from eating something organic, something that contains carbon. Other cells can get carbon straight from there surroundings, for instance in the form of CO_2 from the atmosphere. But the cells also needs a way of getting energy an energy source. One way some cells are getting energy, which is much like the way of getting a

carbon source, is by eating. In this case the energy comes from chemical reactions which releases the energy. Other cells gets their energy from there environment, this could be in the form of sunlight (using photosynthesis) or from chemicals which does not contain any carbon [Bennett and Shostak, 2012].

For humans both our carbon source and our energy source comes from the food we eat. Some molecules, from the food that we eat, are used for cellular construction other molecules will instead go through chemical reactions which in turn releases energy. But as mentioned above, this is not the case for every organism, the sources can come from different places [Bennett and Shostak, 2012].

One last, but very essential thing required for any life form on Earth, is liquid water. Water is essential for all cell activity. Liquid water therefore plays a key role for life, and life on Earth, can only exist places where liquid water can be present. There are some organisms that can become dormant when no liquid water is present, but they cannot survive that way forever [Bennett and Shostak, 2012].

2.3.2 Life in extremes

When we talk about the limits of life we are referring to the known boundaries of life on Earth, where life as we know it can survive. These boundaries are referring to the physical and chemical conditions including radiation, temperature, water availability and toxicity of metals in the environment. On Earth all known organisms have different requirements to function. On regular basis, a human being needs a certain amount of water in order to maintain his or her functionality. But, there are some microorganisms that they can survive longer periods without water. These organisms can be extremely dry and as a result become dormant.

As already mentioned life comes in many forms and can be found in almost every corner of Earth. But not all organisms are as the life encountered in everyday life. And not all places on the Earth are suited for all lifeforms. Though humans are quite resilient, we are also very fragile when it comes to environmental differences. Things like changing the temperature either up or down or changing the concentration of different elements (like oxygen) in the atmosphere will have an extreme effect, and depending on how big the changes are, humans would only be able to survive it in a short period of time. This limits us in different places on Earth, but will also limit us in future exploration on other planets and moons, for instance a planet like Mars. But life comes in many forms and though humans would not be able to survive in these extreme environments, some organisms might be able to.

But are there any already existing organisms on Earth that could survive the Martian environment? The best candidates to survive such conditions would most likely be extremophiles. These kind of organisms can live on the physical, chemical and biological boundaries, at least as we define boundaries. For the extremely low temperatures on the martian surface there might be extremophiles like the psychrophiles that could survive [De Maayer et al., 2014]. These organisms have an optimal range of possible growth that lies in lower temperatures [Madigan et al., 2015].

2.3.3 The Martian Environment

Atmosphere
The environmental conditions on the surface of Mars makes it impossible for humans to survive there, at least without any form of protection gear. The atmospheric pressure ranges between 0,7% to 1% of that on Earth [Martínez et al., 2017] and is also considered lethal for organisms that need oxygen for surviving, due to the atmospheric composition. But some bacteria and archaea have found ways of substitute oxygen with an alternative source.
Most of the nutrients required for life on Earth have been found on Mars, like iron in the form of ferrous iron, manganese, sulfur, carbon, calcium, magnisium, phosphorus, potesium and sodium [Foley et al., 2003, Nachon et al., 2014]. These are some elements the cell needs in order to function. There are presently known bacteria that utilize carbon monoxide and dioxide on Earth [Bartholomew and Alexander, 1979].
As already hinted above, the surface pressure on Mars is very low, which in turn courses the boiling point of water to be extremely low as well. This does however contribute to relative humidity (RH) in the atmosphere with levels of (RH) been measured at 17-23%, sometimes reaching as high as 70% [Fischer et al., 2019].

Radiation
The low atmospheric pressure, the thin atmosphere and the absence of a magnetic field [Acuña et al., 1998], could lead DNA to be damaged by UV radiation [de Gruijl et al., 2001]. The UV spectrum consists of three sub-parts, UVA (315nm - 400nm), UVB (280nm-315nm) and UVC (200nm-280nm). With the third type (UVC) being the most harmfull for organisms [Cockell et al., 2008]. The daily measurements of radiation on Mars, have been found to vary from zero at night and can reach up to 20 W/m^2 at the day time [Gómez-Elvira et al., 2014]. There have been found organisms like *Bacillus subtilis Strain MW01* which were tested at the International Space Station and they show no preference to growing in UV exposure or not, vaccum space and Martian atmosphere [Wassmann et al., 2012].

Temperature
The fact that the temperature lies mostly in lower ranges (Section2.2.3) makes the Martian surface a cold environment and many organisms would have difficulty surviving. Also, because of the low temperatures, surface water will be in the state of ice, making it unavailable for organisms. But some organisms like it cold, and one of them is *Planococcus halocryophilus*. A specific strain of *Planococcus halocryophilus*, isolated from Artic region, has shown growth and metabolic activity at 258K and 248K respectively [Mykytczuk et al., 2013]. Today, the lowest temperature in which bacteria (*Sporosarcina*,*Chryseobacterium*) have shown metabolic activity is at temperature 240K [Bakermans and Skidmore, 2011].

Perchlorates
Another interesting factor when discussing the qualities and differences between Earth and Mars is the soil composition. And one compound is especially interesting, namely the perchlorates which plays a key role for the experiments in this thesis. The following

lines will take a closer look into this.

One of the substances found in the Martian soil is perchlorate, which is consisting of chlorine and oxygen (ClO_4^-). On Earth, perchlorates' origin can be both naturally and industrially. Naturally, the production can happen in the atmosphere, where chlorine oxides react with ozone [Catling et al., 2010]. The highest naturally occurring consecration of perchlorates are found in the Chilean desert, Atacama. The concentration of perchlorates varies, some sources say between 0.03 to 0.1 % [Sellers et al., 2006], other sources states the concentration can be as high as 0.6 % [Catling et al., 2010]. Experiments made by the Phoenix rover showed a concentration of perchlorates at that test site to be between 0.4 and 0.6 % in regards to mass [Hecht et al., 2009].

The main concern when it comes to perchlorates is their toxicity and their impact on humans. Low level exposure of perchlorates can interfere with the uptake of iodide by the thyroid gland, high consecrations can instead affect the endocrine system. [Sellers et al., 2006]. Beside the risk of affecting the endocrine system, perchlorate is considered a "likely human carcinogen" by the U.S. Environmental Protection Agency (EPA) [Council et al., 2005]. In contrast to humans, there are organisms that can use perchlorate during respiration. These bacteria have been shown to use a wide range of organic but also inorganic compounds like ferrous iron [Bruce et al., 1999] to produce energy. Organisms that are able to use perchlorates can do this in the absence of oxygen, but when oxygen is present it will in turn represses the transcription of the perchlorate reducing gene [Susan et al., 2010].

Today, it is still unclear if there are any terrestrial microorganisms that could cope with these biocidal factors and if they could, would they then be able to replicate on Mars [Nicholson et al., 2013]. Searching for organisms in places on Earth where the environmental conditions are considered as extreme, is the best way to find candidate organisms that may survive martian conditions.

2.3.4 Life in extremes on Earth

There are some places on Earth considered as extreme environments. Places like these are the highest in the mountains, deep lakes, dry desert etc. But, there are some organisms, that not only survive but thrive there. One such place is the Atacama desert in Chile, this place is considered a desert due to the lack of rainfall through the year [Azua-Bustos et al., 2018]. Due to the absence of clouds and the high altitude the UV exposure is extremely high, with annual doses of UVA and UVB at 3.5 kWh/m^2, which is almost double of what is seen on other places on Earth [Cordero et al., 2018]. Another contribution to the aridity of this place, is the perchlorates as already mentioned above. In this, not a biology friendly environment but there are bacteria, archae and fungi that seems to have gained tolerance in this kind of environment [Azua-Bustos et al., 2018].

2.4 Terraforming and the ethical problems of space exploration

One idea for the future of Mars is terraforming the planet, this might sound as science fiction, but it might very well become a reality in the future. But with the possibility of

terraforming Mars, ethical and moral questions arises. The following section takes a look at both terraforming of Mars and the ethics.

2.4.1 The idea of terraforming

The idea of terraforming the red planet is not new and has existed for some time. This idea was to make our neighbor planet, Mars, a sustainable second home for humans, and thereby making it possible to survive on the surface of the red planet without any kind of protection.

The habitability of the planet depends on its atmosphere. But how could one change an entire planetary atmosphere? This is not an easy task and it may lie somewhere between science fiction and a potential revolutionary epoch for humanity. In order to change the environmental parameters that has existed on a planet for a long time, the technological and engineering tools would have to evolve, and this may not necessarily be an easy task.

For all the reasons already discussed in previous sections, the Martian atmosphere is not hospitable for humans, as it is today. So the first step might be to change the atmosphere, and ideally making it as close to Earth's as possible. Since, as already mentioned, Mars once had a thicker atmosphere, some of this atmosphere might have been trapped into the ground [Jakosky and Edwards, 2018]. So, potentially releasing the carbon dioxide and the water vapour trapped in the sinks, a greenhouse effect might get created and this in turn could possibly lead to the creation of an atmosphere. But, since Mars has a weaker gravitational field than Earth, it is more likely to loss the atmosphere into space, rather than absorbing the most of it. The idea of using the existed carbon dioxide sinks in order to terraform the atmosphere was recently studied by Bruce M.Jakosky and C. Edwards [Jakosky and Edwards, 2018]. With the most accessible carbon dioxide sink being the one at the polar caps, the scientists found that if explosives are used to release the available gases then it would lead to an increase in the atmospheric pressure from $\sim$6 mbars to $\sim$15 mbars [Jakosky and Edwards, 2017]. And this is not anywhere close to Earth's atmospheric pressure.

Another relatively recent suggestion for terraforming Mars is by the use of microbes [Friedmann and Ocampo-Friedmann, 1995]. The idea is based on the fact that Earth for long periods of time was dominated by bacteria (e.g cyanobacteria) that were able to produce enormous amounts of gases (e.g oxygen) [Kulasooriya, 2011]. This lead to a build up of gasses in its atmosphere and after thousands of years the atmosphere changes. One possible way of achieving terraforming is by finding a way to produce greenhouse gasses that in turn might be able to change the atmosphere on the planet. But without a magnetic field, the atmosphere, will slowly be stripped away by solar winds. But one way of preventing this could be by the creation of a artificial magnetic field in a fixed point (lagrangian point), there will be able to protect planet [Nasa, 2020]. If this will be possible one day, it could potentially lead to the gradually thickening of the atmosphere, this will cause the temperature to rise and in turn lead to the melting of the polar caps, realising the trapped carbon dioxide [Nasa, 2020].

If this idea one day could become a reality, then Mars will most likely be the first colo-

nization of a terrestrial body beyond Earth, and that could lead to further terraforming and colonization in the galaxy.

2.4.2 Ethics and possible moral complications in space exploration

Humans are curious by nature and the exploration of space is rather unpreventable. But there are a number of possible complications as well as ethical questions that should be kept in mind when it comes to exploring the vast expanse. In 1967, the *United Nations Outer Space Treaty* came to be and with it, a policy in regards to microbes and space [Lopez et al., 2019]. Along with the treaty is also the Planetary Protection Guidelines (COSPAR) that works to prevent contamination. Essentially it means that one have to make sure that there does not exist any type of life before the first human contact [Lopez et al., 2019]. To try an ensure that no contamination happens, a key policy for the majority of exploration was implemented, it had to make sure that everything was sterilized [Lopez et al., 2019]. When using the word sterilize in a biological context this means that all types of living organisms will be eliminated completely. This in turn means that there will be limitations as to what can be sent to extraterrestrial locations [Lopez et al., 2019]. But why is there a fear of contaminating, sure one does not wish to conduct tests on the Martian surface getting a positive result only to realize that the organism detected was brought along from Earth. But the risk of disrupting emerging life should also be taken into account. When and if the first humans explores are send to Mars new microbial organisms will regardless of preparation be introduced to the Martian environment [Lopez et al., 2019]. And this raises the question of ethics and if there should be any limitations to future space exploration. Ethics plays an important role in everyday life - what is right and what is wrong. Some actions are pretty well defined, where other are not as black and white in terms of morality and the question “is it right or wrong?” will vary depending on the person asked. When it comes to ethics, space exploration and possibly colonization, a number of questions arise and the answers will most likely vary again depending on who is asked. An example of such a question emerge when diving in to the topic of exploration of Mars could be ”can we colonization?” But also the ethical question “should we colonize Mars and do we have the right to so?”. There are no simple answer to this type of question and many similar questions will arise when topics like these are discussed.

3 Theory behind experiments.

The previous section served as an explanation for the background of the thesis, going through both the Universe, Mars and its environment as well as an introduction to life. The next section serves as a thorough, in-depth explanation to mechanisms behind Recurring Slope Lineae, which a larger part of the thesis will focus on. Some of the possible mechanisms behind their creation is therefore explained in more detail. It also provides a short introduction to two different, but very important, locations on Mars - Gale Crater and Jezero Crater. The two areas are important for both experiments carried out through this thesis.

3.1 RSL - What could they be and how can they form

As mentioned, one of the possible explanations for recurring slope lineae is liquid water. The concentrations of salts in the soil can possibly shift the freezing point and thereby the triple point of liquid water. This in turn makes it possible for liquid water to exist on the Martian surface even with the lack of atmospheric pressure. The salts are also hygroscopic and as a result will attract moisture present in the atmosphere. The lowering of the freezing point of water, is therefore also one of the ways of explaining recurring slope lineae, but it is not the only one, as briefly mentioned in the section above. Another possible explanation for the dark lines found on slopes are due to dust movement [Stillman et al., 2019]. In the following section both of the possibilities, wet and dry, will be explained more in detail.

3.1.1 Theory behind dry origin of Recurring Slope Lineae

As just mentioned above, one of the theories for the creation of RSL is that they are of a dry origin. The theory is that RSL occur as a result of dust and/or sand movement down a slope. The slopes are steeper than the angle of repose, leading the sand and/or dust to slide down. The majority of RSL are found on slopes steeper than 28°. It is however not known what initiates the movement of the sand, but there are different ideas, one of which is that it is caused by wind. One explanation for the dark color of the RSL, could be due to the movement of the grains of the sand when sliding down. This could be by removing smaller grains of sand only leaving larger grains when moving down. Another but similar explanation could be, the separation of the sand grains when the sand is sliding down the slope, having the bigger grains at the top and the smaller underneath[5]. These are possibilities for the darkening of the RSL. One explanation for why the RSL appears like to be fading, could be the darkening of the surroundings relative to the RSL albedo. One potential problem with the dry RSL theory is that the sand would need to be replaced each year [Stillman et al., 2019].

3.1.2 Theory behind wet origin of Recurring Slope Lineae

Another theory behind the formation of RSL it that they are of a wet origin. The main idea behind this theory are brines[6] traveling downhill through sand or silty sand. The water causing the RSL might originate from a spring. The spring would then in turn be linked to an aquifer[7] which is pressurized with a pervious rupture. During the colder parts of the year the spring would form an ice dam. In order for the rapture not to freeze, the freezing point of the brine would have to be close to the mean temperature during the year. During the warmest months the spring would flow. The brine will travel downward when released and darken the ground. Depending on how quick the rate of sublimation and/or evaporation are, compared to the rate of release, the length of the RSL will vary. The RSL will decrease or stop if the sublimation/evaporation rate is higher or the same as the rate it is released with. Whatever amount of water lost through either evaporation or sublimation has to be replaced every year. A number of different factors will make the

[5]Like inverse grading
[6]Salt rich water
[7]A penetrable rock, which can transmit or contain groundwater

loss rate grow bigger. This could be factors like the melting point for the RSL as well as the surface area where it is located, but also factors like the temperature plays a role. A factor like the temperature is also controlling how long the RSL will keep being liquid. The period of which the brine can stay liquid drops when the temperature declines till it has reached the point where it freezes. When the temperature decreases the dam could possibly refreeze, this would then lead to the RSL gradually fading. This theory explains how the RSL are darkening and fading without any material being moved, at least to any measurable extent, during six Mars years. It also explains both the darkening and the lengthening of the RSL with warmer temperatures [Stillman et al., 2019].

Large amounts of water is needed to drive the processes, which is why it is believed it is created in aquifer-driven systems. It is therefore also not believed that the humidity in the atmosphere or any subsurface water vapor would be sufficient enough. What happens to the salts left in the soil is also uncertain. Each year salts would be left and thereby possibly forming salt deposits which in turn would slow the possibility for flow of future RSL. But with the use of thermal data there has not been found any evidence for such layers. But with that said, no similar layers have been found in Antarctica where briny wet tracks, which might be the most accurate earthly analog to RSL, have been found [Stillman et al., 2019].

3.1.3 Hybrid theory of Recurring Slope Lineae

A third theory combines the two, creating a hybrid theory with a combination of dry and wet RSL behavior. The flow of sand is caused by a wet mechanism where the water stars boiling/evaporating leading to a sand flow. With a higher amount of water present allowing a larger rate of flowing water, the sand would float on top of the water vapor, this would in turn increase the downhill movement. But like the two other theories, the hybrid theory also has limits. As a combination of the dry and wet theories, it has restrictions from both. Like for the dry theory, the sand will need to be reset or replaced every year, and like the wet theory the water source will also have to be restored each year [Stillman et al., 2019].

Neither the wet nor dry theory can explain all RSL sightings. Each of the theories offer an explanation to RSL but each does also have limitations [Stillman et al., 2019].

3.2 Places on the Martian surface and soil analogs

Just like on Earth, the Martian surface is diverse and varies. Not only in appearance, like the differences between the cratered highlands and the more flattened lowland, but also in the composition of the soil found on the surface. Two locations on Mars that are somewhat apart and of importance for this thesis are the Gale Crater and the Jezero crater. The reason for the interest in these two locations are the soil analogs used in the experiments.

3.2.1 Gale Crater

In 2012 the rover Curiosity landed in the Gale crater, located on the line between the lowland and the uplands [Grotzinger et al., 2014], close to the equatorial plane. The crater is 154 km [8] and dates to around 3.7 Ga ago [Grotzinger et al., 2014]. The inside of the crater shows signs of geological activity with a range of different relative ages, with the oldest parts maybe dating to the Early Hesperian period [Grotzinger et al., 2014].

Gale crater was chosen as the landing side for the Curiosity rover due to the many and various ancient water-like environments [Grotzinger et al., 2014]. With the already possible signs of ancient water, this improved the chance of finding a place where the other needed components, for maintaining a habitable environment, were present [Grotzinger et al., 2014].

3.2.2 Jezero Crater

Jezero crater is located a little further north than Gale crater near the large Isidis basin and is approximately 45 km in diameter [Goudge et al., 2015]. Jezero crater serves as the landing side for the NASA 2020 mission containing the Perseverance rover which is set to land in February 2021. One of the central jobs for the Perseverance rover is to search for signs of ancient life. (As well as gathering soil and rock samples that can be returned to Earth at a later time) [Perseverance, 2020].

Jezero crater contains signs of a valley network and paleolakes, as well as containing two inlets and one outlet. All three located on the crater rim, the two inlets, west and north, and the outlet east [Goudge et al., 2015]. This is interesting since this indicates that the basin must have held water [Goudge et al., 2015].

3.2.3 Why the interest in Gale crater and Jezero crater

Both craters are interesting in their own way, but the common denominator, that both holds signs of ancient water activity, are of special interest. Both missions hold the objective of searching for habitability in one way or the other, and the possibility of ancient water activity definitely makes this more interesting.

The reason for mentioning these two specific locations on Mars is due to their role in the experiments carried out through this thesis. For both the biological experiment and for the RSL experiment, Martian soil analogs were used. A total of three different analogs were used, two Gala crater analogs, one of which contains sulfates as well as a Jezero analog.

[8] Making the diameter the approximate distance between Copenhagen and Odense

4 Theoretical approach for the evolution of the Martian atmosphere and the loss of the magnetic field

The main interest in the thesis is, as mentioned, the possibility of life on Mars. This relates both to the possibility of ancient life and the possibly of present life, as well as the potential of life from Earth surviving on the Martian surface today. The following sections serve as a point of interest in this discussion. If life did exist on Mars, how long did it have to evolve? With simple calculations I find a suggestion for the mass of the original Martian atmosphere as well as a idea of when the magnetic field might have disappeared from Mars. I would like to point out that the calculations are rather simple and therefore only give an approximation.

4.1 Calculating the ratio of the original atmospheres

In addition to the physical experiments carried out in this thesis, a theoretical approach for the Martian atmosphere was made. Only little is know about the early atmosphere of the planets in our solar system, Earth included. The main theory for the atmospheric creation is that the atmosphere either came from outgassing or was brought to the planet by impacts. In the following calculations, the estimated ratio between the mass of Earth's original atmosphere and the mass of Mars' original atmosphere is found. The ratio is found for both assumptions (outgassing and impact) with the possibility of the impacts originating either from the Asteroid belt or the Kuiper belt. The ratios for each of the two possibilities are found by the following assumption and the use of the equations for the mass and surface area of a sphere.

$$M = \rho \cdot V \tag{2}$$

Where M is the mass, ρ is the density and V is the volume given by Eq.3.

$$V = \frac{4}{3}\pi r^3 \tag{3}$$

Where r is the radius. The surface area is given by Eq. 4.

$$S = 4\pi r^2 \tag{4}$$

The mass from outgassing is proportional to the radius of the planet, see Eq. 5. The outgassing can originate from any part of the planets' volume but it should also be noted that the two planets (Earth and Mars) have different mean densities. The collision is proportional to the distance l, of the effective area, see Eq.6.

$$out \propto \rho \ r^3 \tag{5}$$

$$coll \propto l^2 \tag{6}$$

Finding the ratio of the original atmosphere from outgassing is rather simple, using Eq. 5. But finding the ratio of the atmosphere from collision takes a few more steps, since it is depending on the distance of the effective area. This distance again also depends on the velocity of the incoming object. Depending on, where the object is traveling from, the Asteroid belt or the Kuiper belt, the velocity for when it travels past Mars and Earth will vary. The velocity for the different scenarios can be found from the conservation of energy. The object traveling from either the Asteroid belt or the Kuiper belt will be drawn in towards the Sun, due to its gravity. When the object is at rest either in the Asteroid belt or the Kuiper belt they have a gravitational potential energy, as described by Eq. 7. As the object starts to travel in towards the Sun, the potential energy will be converted to kinetic energy, for kinetic energy see Eq. 8.

$$U = -\frac{GMm}{r} \tag{7}$$

$$E_{kin} = \frac{1}{2}mv^2 \tag{8}$$

Here m is the mass of the object, v is the velocity, G is the gravitational constant, M is the mass of the Sun and r is the distance from the Sun to the object. The total energy (E_{kin}+U) of the object at rest equals the total energy of the object at its final destination due to the conservation of energy. This can be written as

$$\frac{1}{2}mv_{in}^2 - \frac{GMm}{r_{in}} = \frac{1}{2}mv_{end}^2 - \frac{GMm}{r_{end}} \tag{9}$$

The object is assumed to initially be at rest when it is located in the Asteroid/Kuiper belt. Which means that $v_{in} = 0$

$$-\frac{GMm}{r_{in}} = \frac{1}{2}mv_{end}^2 - \frac{GMm}{r_{end}} \tag{10}$$

From this expression, the velocity at the final destination can be found.

$$-\frac{GMm}{r_{in}} = \frac{1}{2}mv_{end}^2 - \frac{GMm}{r_{end}} \Rightarrow -\frac{GMm}{r_{in}} = GMm\left(\frac{mv_{end}^2}{2GMm} - \frac{1}{r_{end}}\right) \Rightarrow -\frac{1}{r_{in}} = \frac{v_{end}^2}{2GM} - \frac{1}{r_{end}} \tag{11}$$

From here the velocity is easily found

$$-\frac{1}{r_{in}} = \frac{v_{end}^2}{2GM} - \frac{1}{r_{end}} \Rightarrow v_{end}^2 = 2GM\left(\frac{1}{r_{end}} - \frac{1}{r_{in}}\right) \tag{12}$$

Taking the square root on both sides gives the final expression for the velocity

$$v_{end} = \sqrt{2GM\left(\frac{1}{r_{end}} - \frac{1}{r_{in}}\right)} \tag{13}$$

From Eq. 13 the velocity of the objects when passing by Earth or Mars can be calculated. The mass and radius of the Sun, Earth and Mars can be found in Table 1 [Freedman et al., 2016].

Value/Object	**Sun**	**Earth**	**Mars**
Mass [kg]	$1.989 \cdot 10^{30}$	$5.974 \cdot 10^{24}$	$6.418 \cdot 10^{23}$
Radius [m]	$6.96 \cdot 10^{8}$	$6.378 \cdot 10^{6}$	$3.397 \cdot 10^{6}$

Table 1: *Mass and radius of the Sun, Earth and Mars.*

Other constants and values used for the calculations are the gravitational constant, the distance from the Sun to both Earth and Mars as well as the Asteroid belt [9] and the Kuiper belt. The distance for the Kuiper belt is assumed to be infinite, which of course is not the case, but since the distance the object would have to travel is huge, infinity is used as the distance. These can be found in Table 2.

G $[\frac{m^3}{kgs^2}]$	$6.67 \cdot 10^{-11}$
Distance to Earth [m]	$1.496 \cdot 10^{11}$
Distance to Mars [m]	$2.279 \cdot 10^{11}$
Distance to Asteroid belt [m]	$4.144 \cdot 10^{11}$
Distance to Kuiper belt [m]	∞

Table 2: *Other values and constants used for calculations.*

From Eq. 13 and the constants and values in Table 1 and 2, the velocity is calculated. This velocity is however that of the object when it is passing by either Earth or Mars, traveling from the Asteroid belt or the Kuiper belt. But in order to find the velocity an object would have, when it reaches Earth or Mars, the escape velocity for each of the planets must be added to the velocity found by Eq. 13. The escape velocity is found by using Eq. 14. Where m is the mass of the planet, R the radius and G the gravitational constant.

$$v_{esc} = \sqrt{\frac{2Gm_{planet}}{R}} \tag{14}$$

The escape velocities are calculated to be the following.

Escape velocity of Earth	11182 $\frac{m}{s}$
Escape velocity of Mars	5022 $\frac{m}{s}$

Table 3: *The escape velocities calculated for Earth and Mars.*

[9] Distance to Ceres is chosen

Using the velocities found by Eq. 13 and adding the escape velocities, see Table 3, the velocities, needed to calculate the radius of the effective area, are found. They can be found in Table 4.

Velocity of object from Asteroid belt passing Earth	44856.8 $\frac{m}{s}$
Velocity of object from Kuiper belt passing Earth	53308.7 $\frac{m}{s}$
Velocity of object from Asteroid belt passing Mars	27919.2 $\frac{m}{s}$
Velocity of object from Kuiper belt passing Mars	39153.4 $\frac{m}{s}$

Table 4: *The maximum velocities of objects from the Asteroid belt or Kuiper belt when passing by Earth or Mars.*

With the needed velocities found, the radius of the effective areas are now calculated, by Eq. 15 [Jørgensen, 2019]

$$l = \sqrt{R^2 \cdot \left(1 + \frac{2Gm_{planet}}{Rv^2}\right)} \tag{15}$$

The calculations are made for objects passing Earth and Mars from both the Asteroid belt and the Kuiper belt. The calculated radii for the effective area can be found in Table 5.

Radius effective area of Earth for object from Asteroid belt	$6.57 \cdot 10^6\ m$
Radius effective area of Earth for object from Kuiper belt	$6.52 \cdot 10^6\ m$
Radius effective area of Mars for object from Asteroid belt	$3.45 \cdot 10^6\ m$
Radius effective area of Mars for object from Kuiper belt	$3.42 \cdot 10^6\ m$

Table 5: *The radii of the effective areas for Earth and Mars.*

Now all of the needed variables for calculating the ratio between the original atmosphere of Earth and Mars have been found. Calculating first the ratio under the assumption of collision. This will be two calculations, one for objects from the Asteroid belt and one for the Kuiper belt.

$$coll_{ast} \propto \left(\frac{6.57 \cdot 10^6\ m}{3.45 \cdot 10^6\ m}\right)^2 = 3.627 \tag{16}$$

$$coll_{kuiper} \propto \left(\frac{6.52 \cdot 10^6\ m}{3.42 \cdot 10^6\ m}\right)^2 = 3.621 \tag{17}$$

From Eq. 16 and Eq. 17 the ratios between the original atmosphere on Earth and on Mars is found to be very similar, 3.627 or 3.621 depending on the place of origin for the objects colliding with Earth and Mars. Now calculating the ratio under the assumption that the atmospheres were created by outgassing.

$$out \propto \left(\frac{5.515 \cdot 10^3 \ \frac{kg}{m^3}}{3.934 \cdot 10^3 \ \frac{kg}{m^3}} \right) \cdot \left(\frac{6.378 \cdot 10^6 \ m}{3.397 \cdot 10^6 \ m} \right)^3 = 9.279 \tag{18}$$

The ratio between the original atmosphere of Earth and Mars from outgassing is 9.279.

4.2 An estimate of the mass of Martian atmosphere, when it was created

By using the ratios between the two original atmospheres, an estimated mass of the Martian atmosphere can be calculated. This is done under the assumption that Earth's magnetic field protects the atmosphere and as a result, the mass of the atmosphere is the same today as it was 4.5 Ga ago. This is most likely not entirely true, since Earth has probably lost a small part of its atmosphere during those 4.5 Ga.

With the mass of Earth's atmosphere, $5.1 \cdot 10^{18} \ kg$ [Williams, 2020a], the mass of the original Martian atmosphere can be found. This is done in two different ways: first is by using the ratios, see Eq. 19 and second by using the current mass loss rate for Mars, calculating backwards. This will give a total of four different masses.

$$M_{OMR} = \frac{5.1 \cdot 10^{18} \ kg}{ratio} \tag{19}$$

From this calculation, the estimated mass of the Martian atmosphere found by ratios can be seen in Table 6.

Ratio	**Atmosphere mass [kg]**
3.627	$1.41 \cdot 10^{18}$
3.621	$1.41 \cdot 10^{18}$
9.279	$5.5 \cdot 10^{17}$

Table 6: *The calculated mass of the Martian atmosphere. The ratios for the collision from the Asteroid belt, the Kuiper belt and from outgassing respectively.*

The second way of calculating the mass of the atmosphere is by using the mass loss rate for the Martian atmosphere today and assuming that it has been constant over time. This gives the fourth estimate of the atmospheric mass, see Eq. 20. The mass of the Martian atmosphere today is $2.5 \cdot 10^{16} \ kg$ [Williams, 2020b] and the mass loss of the Martian atmosphere is, as mentioned in Section 2.2.3 somewhere between 2 and 3 $\frac{kg}{s}$, for the calculation, the mass loss rate used will be 2 $\frac{kg}{s}$.

$$M_{OMmlr} = 2.5 \cdot 10^{16} \ kg + \left(2 \ \frac{kg}{s} \cdot 4.5 \ Ga \cdot 3.2 \cdot 10^{16} \ \frac{s}{Ga} \right) = 3.094 \cdot 10^{17} \ kg \tag{20}$$

Comparing the four numbers of the atmospheric masses, shows that all three masses found by using the ratios, scaling between Earth and Mars, are larger than the mass found by calculating backwards. This suggest that the mass loss rate for the Martian atmosphere might have been higher at some point earlier in the planet's history. Next part is therefore to see from the calculations, when Mars approximately lost its magnetic field.

4.3 When did the magnetic field disappear

After having calculated the mass of the original atmosphere, an estimate of when the magnetic field disappeared is found. This is done by using Eq. 21, which was also mentioned in Section 2.2.3 and finding the coherency between the mass loss of the Sun and the mass loss of the Martian atmosphere. The mass loss of the sun can be described by the following equation, Eq. 21.

$$\dot{M}_{sun} \propto \frac{1}{t^2} \tag{21}$$

The equation is used under the assumption that the mass loss for the Sun is coherent with the strength of the Solar wind. The larger the mass loss from the Sun the greater the strength of the Solar wind. The mass loss rate of the Martian atmosphere is depending on the strength of the Solar wind, there is therefore the following coherency between the mass loss of the Sun and the mass loss rate of Mars. These two are proportional, with a constant k in the expression for Mars. The estimated mass loss of the Martian atmosphere can therefore be calculated using Eq. 22.

$$\frac{dM}{dt} = k \cdot \frac{1}{t^2} \tag{22}$$

From this expression the constant k can be found using Eq. 23.

$$\frac{dM}{dt}(t_{now}) = x_{now} \tag{23}$$

Here x_{now} is the mass loss rate today at t_{now}, the time today. Using this expression and isolating, the constant, k, becomes (see Eq. 24)

$$k = t_{now}^2 \cdot \left(\frac{dM}{dt}\right)_{now} = t_{now}^2 \cdot x_{now} \tag{24}$$

Now the expression for k can be placed in Eq. 22 and an expression for the change in mass loss over time, can be found.

$$\frac{dM}{dt} = t_{now}^2 \cdot x_{now} \cdot \frac{1}{t^2} \tag{25}$$

Finding the mass loss rate over time, the expression in Eq. 25 is integrated from t_0 till today, t_{now}.

$$\int_{t_0}^{t_{now}} \frac{dM}{dt} dt = t_{now}^2 \cdot x_{now} \int_{t_0}^{t_{now}} \frac{1}{t^2} dt \tag{26}$$

Solving the integral.

$$M_{atm} = t_{now}^2 \cdot x_{now} \int_{t_0}^{t_{now}} \frac{1}{t^2} dt \ = -t_{now}^2 \cdot x_{now} \cdot \left[\frac{1}{t}\right]_{t_0}^{t_{now}} \tag{27}$$

Which will be

$$M_{atm} = -t_{now}^2 \cdot x_{now} \cdot \left[\frac{1}{t}\right]_{t_0}^{t_{now}} = t_{now}^2 \cdot x_{now} \left(\frac{1}{t_0} - \frac{1}{t_{now}}\right) \tag{28}$$

Knowing both the mass of the original atmosphere, the mass loss rate today and the time today, Eq. 27 can be solved for t_0 finding the time, the mass loss of the Martian atmosphere started. This is under the same assumption, as for Earth, that the mass loss of the atmosphere did not start until the magnetic field disappeared [10]. Solving for t_0 the following expression is found.

$$M_{atm} = t_{now}^2 \cdot x_{now} \left(\frac{1}{t_0} - \frac{1}{t_{now}}\right) \Rightarrow t_0 = \frac{t_{now}^2 \cdot x_{now}}{x_{now} \cdot t_{now} + M_{atm}} \tag{29}$$

Using the different numbers from the original Martian atmosphere (collision and outgassing), a time t_0 can be found. The time found, is the time after the creation 4.5 Ga ago. So to find out how long ago it disappeared, t_0 is subtracted from 4.5 Ga. The estimated times for when the magnetic field disappeared can be found in Table 7.

Creation	**Time ago [Ga]**
Collision from Asteroid belt	3.74
Collision from Kuiper belt	3.74
Outgassing	2.96

Table 7: *How long ago did Mars lose its magnetic field.*

4.4 Sub-discussion on the calculations and results

The above calculations are approximations for both the mass of the original atmosphere, created by two different scenarios, as well as an estimate of when Mars lost its magnetic field. This should be kept in mind when looking over the results. In other words the results found are not definitive true values. Having said this the calculations do offer up some interesting suggestions for the creation of the planetary atmospheres in regards to the disappearance of the magnetic field. The calculations suggest, that if the atmosphere was created as a result of outgassing, then the magnetic field might have disappeared as late as around 3 Ga ago. Whereas, was it created by collision, either with objects from the Asteroid or Kuiper belt, then the magnetic field might have disappeared earlier at around

[10] Which may not be entirely true

3.74 Ga ago. If these number should be compared to disappearing times found in literature then the calculations indicate that the creation by collision seems more reasonable. In literature the disappearance of the Martian magnetic field is set to be between 3.9 Ga ago and 4.1 Ga ago, comparing this to the number found by the calculations, the disappearance of the magnetic field, if the atmosphere was created by collisions, is much closer, than if created by outgassing. The calculations also show that even though there is a difference in the velocities for object traveling from the Asteroid belt and the Kuiper belt, when the effective area is calculated, that difference only plays a very small part. This means that the radius of the effective area, and later the ratios, become very similar (it is not until the third decimal, that they vary). From the calculations, it therefore looks like the origin of the object does not matter much in regards to the mass of the atmosphere, if created by collision.

One of the interesting ideas that arises, looking at the calculations and the numbers found, are the ratios. The ratio for collision is 3.62 or approximately 4. Meaning that approximately 4 times more material hit Earth than Mars. The surface area of Earth is also approximately 4 times larger than the surface area of Mars. This means that from the perspective of the calculations, the same amount of material hit Earth and Mars per surface area. From this, it could be argued that the amount of atmosphere per surface area of the two planets would also be the same, leading to the atmosphere being equally thick and as a result equally protective against radiation. It should be noted that if this was the case, the pressure on Mars would still be lower than on Earth, due to the Martian gravity being lower.

There are a few basic assumptions made throughout the calculations that at a closer look may not hold up entirely. However, these are approximations and for the purpose they serve, they are okay throughout the calculations. They will nevertheless be mentioned and shortly discussed. The first is, that with a magnetic field present, the planets are not losing any atmosphere. This is, as already mentioned above, probably not entirely true. Earth has a magnetic field, but is still losing atmosphere to space. Which means that if/when Mars had a magnetic field, though it would have protected the planet, it would most likely also have lost some of its atmosphere to space. Next is that the velocities for objects traveling from either the Asteroid belt or the Kuiper belt are calculated under the assumption that they are in free fall. This may not be the case entirely. One last assumption or mechanism not taken in to account, is the possibility of material reentering space after a collision. If an object traveling towards either Earth or Mars, has a high enough velocity when hitting the surface, material might be flung back out to space. This in turn would result in lesser material actually hitting the surface and leading to a slightly lighter atmosphere. These are basic assumptions used throughout the calculation, which is an approximation, but are also important to keep in mind when viewing the results.

All in all, the calculations give a suggestion for mass of the original atmosphere as well as when the magnetic field might have disappeared. This is very interesting for the prospects of emerging life that is a main part of this thesis. Did life ever emerge on Mars and if it did, did it have time to evolve? Understanding the planet's past might very well be a part of answering that question.

5 Introduction to the chamber

As mentioned in the introduction, the thesis is consisting of three parts, the first is the calculations for an estimate of the original Martian atmosphere, as well as an idea of when the magnetic field might have disappeared. The second and third part are both experimental in nature, and was initially both thought to be carried out inside the Mars simulation chamber. This, as seen further in the thesis, was however not possible due to time limitations. The following section serves as an introduction to the experiments and the Mars simulation chamber. The first experiment focuses on the possibility of liquid water on the Martian surface in the form of recurring slope lineae (RSL). The potential presence of liquid water on the Martian surface is interesting since liquid water is a universal requirement for life as we know it here on Earth. This leads to the second experiment which focuses on the possibility of life on Mars, in terms of both the possibility of finding signs of life but also the possibility of sending or bringing life to Mars. A key component for the experiments was the Mars simulation chamber. A chamber that can simulate some of the conditions found on Mars, such as the low pressure, the atmosphere composition and the temperature[11] . The chamber itself is placed inside a glove box in order to better control the surrounding atmosphere, see Fig. 3. The Mars chamber was used for part of the bacterial experiment.

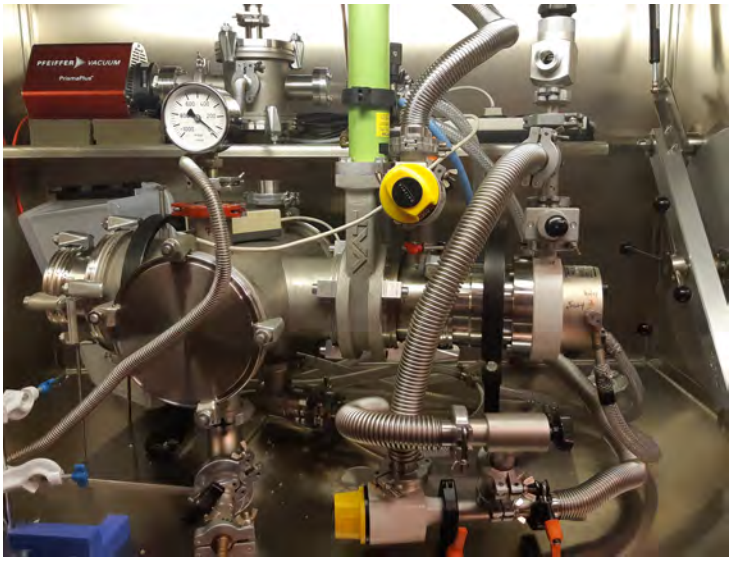


Figure 3: *Image of the Mars simulation chamber inside the glow box. The chamber itself is the cylinder, which is sealed in the left side of the image.*

6 Recurring Slope Lineae Experiment

The idea behind the *Recurring slope lineae* (RSL) experiment was to test and see if water could be a possible explanation for the RSL. As already mentioned one of the explanations for the occurrence of the RSL is water movement. This however should not be possible since water cannot exist in its liquid state due to the low pressure and temperature on the

[11] We did not make use of of the possibility of changing the temperature

Martian surface. There are however the possibility that the high concentrations of salts in the soil can lower the freezing point of water enough that it would be able to exist in its liquid form. If this is the case and liquid water can be found on the surface of Mars, the possibility for life just increased. It has not been possible to make any onsite investigations of RSL and the exact source is therefore not known at the moment. The intention at the beginning of the thesis was to use the Mars simulation chamber. Using the chamber, some of the environmental conditions which the RSL are found under, can be replicated and some can be omitted (like the wind movement which is another possible explanation). The Mars simulation chamber can simulate both the low pressure, the temperature and the humidity. And soil analogs from locations on Mars as well as additional salts can be added, simulating the Martian surface. The hope was that with the combination of these, the environment at which the RSL are formed, could be replicated. The experiment inside the chamber was however not made.

6.1 Preparation and execution of RSL experiment

In order to prepare for the RSL experiment, a number of alterations had to be made. To begin with, the chamber had a small shelf or rack that could be moved in and out of the chamber. At the bottom of the rack was attached a Pielte element in order to cool the samples down. This had to be removed since the rack had to be changed. The idea was that the rack could be tilted at different angles in order to change the slope of the samples. On the rack small plastic boxes that contain Mars analog soil would be placed. On some of the boxes would be placed a lid, these boxes also had holes drilled in the bottom. Other boxes, without holes, would have no lid. The reason for the change were to see if there could potentially be a difference (if it is water) in where it originates from.

As mentioned in the in-depth description of the wet mechanism behind RSL, there might not be sufficient amounts of water in the atmosphere to actually create the down slope movement. RSL, possibly created by groundwater or a deposit of water, can however not be simulated, therefore the test for the RSL is done with the possibility of the humidity being high enough for water to condense.

Now, when starting out with the thesis and the experiments, the plan was to conduct the tests inside the chamber under Martian conditions. This was however not possible due to the lack of time (partially due to the lockdown). In the section below there are a thorough explanation on how it would have been conducted, had the time been there. One of the other reasons for the lack of time was the testing outside the chamber. The reason for testing outside the chamber was to see if anything would happen with a higher humidity and a sufficient pressure to sustain liquid water.

6.1.1 Testing the perchlorates

The first experiment was made to see if there were any reaction between the perchlorates and the atmospheric humidity. Using petri dishes, a fixed amount of Martian soil analog was placed in each dish with a different concentration of perchlorates. I used the concentrations of 50 % and 25 % perchlorates to soil, as well as one without any perchlorates as a control. This is a very high concentration, especially compared with the previously

used 1 %, this was simply to see if there was a reaction or not. For all of the experiments regarding RSL, the Jezero soil analog was used, the reason for choosing this was due to its lighter color compared to the Gale soil analogs. With the soil having a lighter color, any darkening would be easier to spot. The Jezero soil analog was mixed with sodium perchlorate in the two concentrations. Each of the different concentrations were placed in two petri dishes with a total of 6 samples. Since the perchlorates are hygroscopic the goal was to see a change in color of the sand or any other indication that water has condensed in the soil. Therefore a weather station that could monitor both humidity and temperature was placed in each of the boxes in order to see if the humidity changed during the experiment. In one of the boxes, an extra humidity sensor and thermometer was placed, as well as a control, this led to the box having a small crack in one side, due to the wire from the humidity sensor.

As will be discussed later on, the results from the experiment were positive. Though the humidity fluctuated quite a bit, first dropping then slowly increasing to a higher humidity, at the end of the experiment, water did condense in the soils. It was clear, both in the color of the sand but also from the texture. With the positive results, the experiment was expanded in order to get a more quantitative measure for the changes. The testing of the perchlorates therefore continued, this time with a larger number of concentrations and with an initial spectroscopic measurement, measuring the reflectance of the sand.

6.1.2 Testing the RSL and measuring the reflectance

After having conducted the first experiment, testing to see if there were simply any reaction due to the perchlorates, the experiment was redone adding more steps in order to get a more quantitative measurement of the testing. Adding additional concentrations to the test, testing for 50 %, 25 %, 10 %, 5 % and 1 % perchlorates in the soil and one control without perchlorates. The previous samples were reused, but slowly heated in order for any water present to evaporate, then grinded and new concentrations were mixed. Before initiating the experiment, the color of the samples were measured using a spectrometer, measuring the reflectance of the samples. The spectrometer was coupled to a computer running the program Ava-

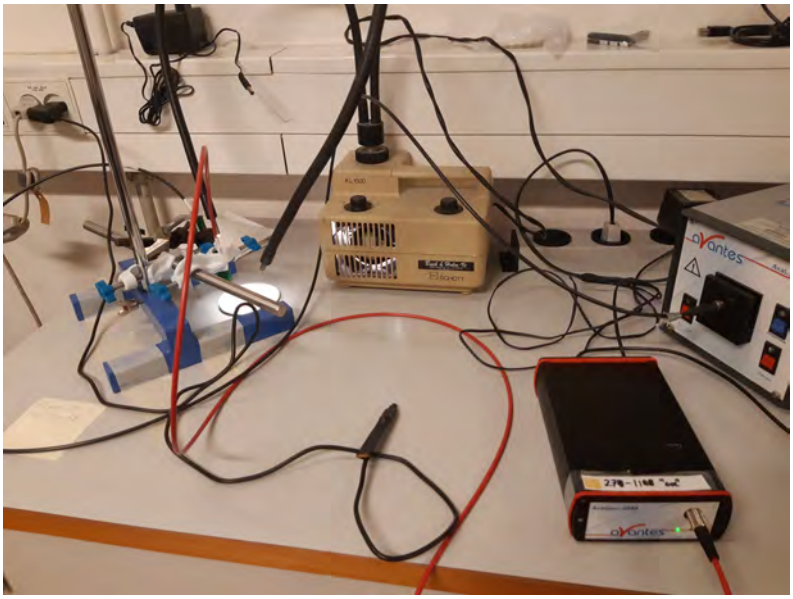


Figure 4: *Image showing the setup for testing the reflectance of the different soils containing perchlorates. Light source is on, illuminating the white reference plate.*

soft (Avaspec60), where the measurements were taken. A lamp generating a white light and a white reference point were used as well. To the spectrometer was also attached a fiber, that was used when taking the measurements. Angling the light and positioning it, so a nice homogeneous spot was present under the fiber. See Fig. 4 for the setup. Before any measurements of the soils could be started a "dark" and a "white" spectrum were measured. The "dark" describes the noise from the spectrometer itself and the "white" is a reference, defining what is white. The program Avasoft automatically corrected for both the "dark" and the "white" after they were measured. The measurements were then initiated, the samples were filled in petri dishes and then placed on a white paper towel that was then positioned under the light source. The integration time was set to be 30 ms and the reflectance for each of the samples was measured.

After the reflectance for each of the samples was measured, they were weighed to see the precise amount of soil in each, see Table 8 for measurements. This was also a change from the first experiment, where the goal only were to see if there was a change in the color (by eye measure). As a result, when the mass of the samples were measured it was only to make sure, that approximately the same amount of soil were in each sample. This time, the precise amount of soil was found, in order to be able to compare it after the experiment. The idea were to see, if the amount of water that would condense in the soil could be measured from the mass of the samples. The samples were placed in a plastic box, like in the first experiment, and left waiting.

Concentration of sample	**Initial mass [g]**	**End mass [g]**
Control	14.9382	14.9271
1 %	15.0363	15.0670
5 %	14.6816	14.6743
10 %	14.6364	14.6297
25 %	15.0025	14.9764
50 %	15.2258	15.2293

Table 8: *Table showing the weight for each of the samples with different concentrations of perchlorates, at initiation and end of the experiment.*

After 13 days, the samples were taken out of the box, and weighed again, to see if there were any changes in the weight. Having weighed them, the reflectance was measured in a similar fashion as to when the experiment was initiated.

6.1.3 Testing the setup of RSL

Along with the second testing of perchlorates, a third experiment, testing the setup outside the chamber, was carried out. Using the rack created especially for the chamber, eight small plastic boxes were placed at a fixed angel of 28°. As described in Section 3.1.2, the structure behind the occurrence of RSL if caused by water movement, might be a subsurface spring, and not moisture from the atmosphere. The experiments I conducted, focused on water vapor in the atmosphere as the source of darkening of the soils. This was due to the difficulties of simulating a subsurface spring. From my initial experiment, I did

however see a visible indication that the water in the atmosphere would condense in the soils containing perchlorates. But I did not see any patterns form in the samples. This made me think, that if RSL potentially could be caused by moisture in the atmosphere, then the lines formed, might be due to preexisting concentrations of perchlorates in these lines. This idea was the reason for the different patterns created during this experiment. In four of the plastic boxes, four holes were drilled in the bottom and these boxes were closed with lids. The reason for this was to see, if atmospheric moisture could create the patterns in a similar fashion as the spring. The four other boxes were left open, without any holes. At the bottom of all eight boxes was a piece of sand paper, to make sure the soil did not just slip, but also that it did not fall through the holes. A similar setup of soil and perchlorates was made both for the boxes with holes and without. From the first experiment it was clear that the water from the air condensed in the soil, but no patterns or lines were formed. Therefore, arrangement of soil containing 50% perchlorates was made on the soil with no added perchlorates. The different arrangements can be seen in Fig. 5. The boxes were arranged so the pattern in box number 1 from the left is the same as for box number 5 etc. The thoughts behind the first pattern was to see if the perchlorate rich soil placed in vertical lines would grow darker over time, creating the downhill lines. For box number 2 and 6 I wanted to see if it could cause the soil to move, as more and more water condensed in it. The same was the idea behind box 3 and 7, box 4 and 8 was made as controls and are only containing the Jezero soil analog.

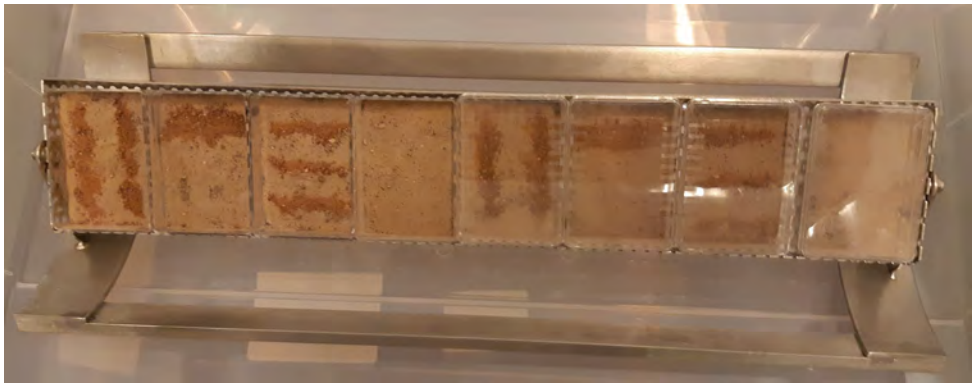


Figure 5: *Image showing the arrangement of perchlorate rich soil at initiation of experiment, testing the setup. From the left, the first four boxes are without holes, box five to eight are with holes and lids on.*

After preparation of the boxes, they were placed on the rack as seen in Fig. 4, the angle of the rack was measured to be 28°. This, to simulate an angle close to the minimum angle the recurring slope lineae are detected at, as mentioned in Section 3.1.1.

Like for the second testing of perchlorates, the samples on the rack were left for 13 days, though at day eight the lid was lifted to see if anything had changed. Their reflectance was not measured since the setup could not measure the reflectance on a slope. The risk of causing movement to the samples meant that they could not be moved around. Images were taken at initiation, at day eight and at the end of the experiment.

6.1.4 The setup of the experiment inside the Mars chamber, had time allowed it

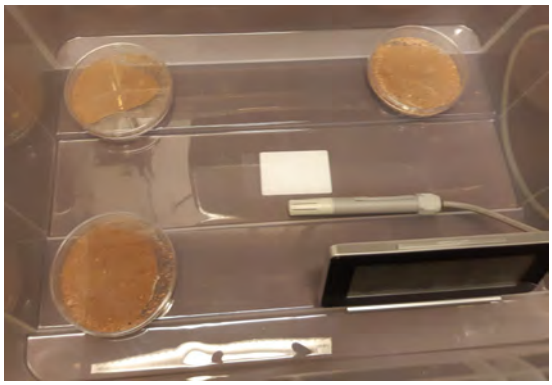
The idea was to see if Recurring slope lineae could be due to water movement, using the Mars simulation chamber to simulate the Martian environment. This was, as mentioned, however not possible due to the lack of time. The following sections describe the idea for the setup and execution for the experiment inside the chamber had there been time. The environmental changes would have been lowering of the pressure to 1% of Earths atmospheric pressure or 0.01 *bar*, lowering the temperature below the freezing point of water, somewhere between 0℃ and −10℃ and the humidity to be around 17%.

The setup of the samples would be equivalent to the setup of the experiment conducted outside the chamber. The soils and perchlorate rich soil would be placed in a similar fashion and the angle would be the same. The humidity would be lowered using silica gel to the desired humidity and the temperature would be lowered using the Peltier element. The rack would be placed in the chamber, which would be sealed, and the pressure lowered slowly as to not cause any sand movement. The experiment would then be left for weeks. When the chamber is sealed, it can not be seen what goes on inside, the period of waiting would therefore be an estimate found from the experiments conducted outside the chamber. Additional experiments could be carried out afterwards for either shorter or longer periods.

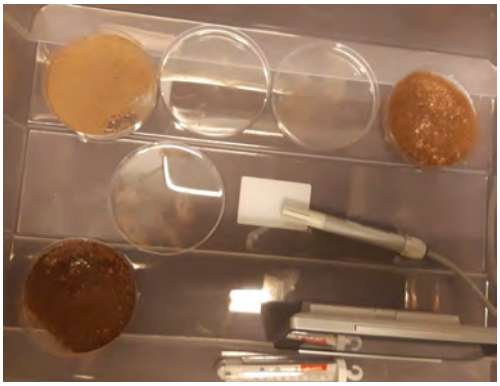
6.2 Data for the RSL experiment

6.2.1 First experiment testing the perchlorates

The first experiment was consisting of six plates with two of each, having the same concentration of 50%, 25% as well as the control with no perchlorates. This experiment was made as a kind of pilot study simply to see if anything happened. The measurement was only done by taking pictures at initiation, during and at the end of the experiment and from these seeing if there were any visible differences. After a little under two weeks, the change in the samples were visible for both the 25 % and the 50 % and no visible change for the control without perchlorates. The soil had gotten a lot darker, and for some of the samples the sand had even started to get slightly "muddy", indicating that a lot of water had condensed in the soil. Throughout the run of the experiment the humidity was measured in order to see if it changed in any way. The idea at the beginning of the experiment was that if water condensed in the soil, the humidity would drop, this was however not the case. The humidity started out being 37/38 % in each box respectively. The second day it dropped to 30/32 % and then slowly started to increase again all the way up to 49/49 % at the end of the experiment. Please note that I did however make an error in forgetting to write down which petri dish contained the 25 % and which contained the 50 %. I am however almost entirely certain that the petri dish at the bottom left corner contained the 50 % and the one in the upper right corner is the 25 %. But despite this I did see a visible reaction, see Fig. 6 and the experiment was therefore conducted again, this time with more concentrations as well as a measurement of the reflectance of the soils and the weight.



(a) *Image showing the samples at the initiation of the experiment. From upper left corner (as remembered): Sample without perchlorates, samples with 25 % and 50 %.*



(b) *Image showing the samples at the end of the experiment. From upper left corner (as remembered): Sample without perchlorates, samples with 25 % and 50 %.*

Figure 6: Image of samples at initiation and ending of experiment. Samples are in the box with a small crack in it due to humidity sensor.

6.2.2 Second test of the perchlorates and spectral data

For the second experiment testing the perchlorates, both the mass and the reflections for each sample was measured. The mass of the samples both before and after can be found in the section above. The difference between the mass before and after can be found in Table 9. It should be kept in mind that the mass of the samples was measured before the reflectance was measured, the movement of the samples can have caused the soil to move a little within the petri dish.

Concentration of sample	**Initial mass [g]**	**End mass [g]**	**Difference in mass [g]**
Control	14.9382	14.9271	-0.0111
1 %	15.0363	15.0670	0.0307
5 %	14.6816	14.6743	-0.0073
10 %	14.6364	14.6297	-0.0067
25 %	15.0025	14.9764	-0.0261
50 %	15.2258	15.2293	0.0035

Table 9: *The mass of the samples at initiation of the experiment and again at the ending as well as difference in the mass of the samples after 13 days.*

Using the program Avasoft for measuring each of the samples, a data file containing the wavelength, the counts for the dark, the reference and the sample as well as the reflectance was created. In Fig. 7 an example of the raw spectrum can be seen, the range of the wavelengths reaches beyond the visible spectra.

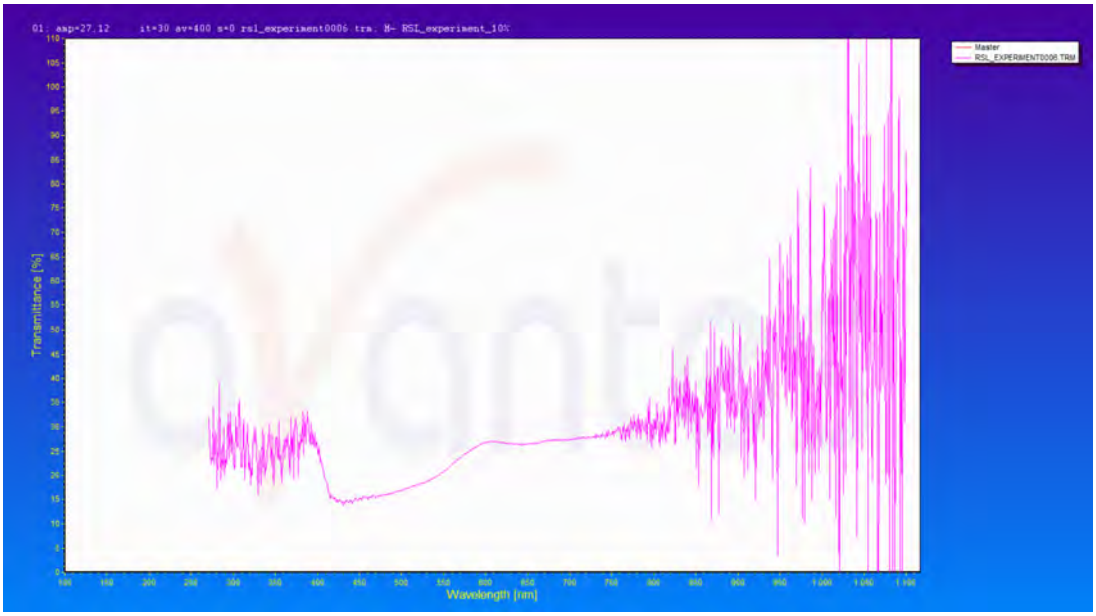


Figure 7: *Raw data spectra showing the reflectance of the soil samples with 10 % perchlorates. Please note, that even though the image says transmittance, it was the reflectance that was measured.*

Since the interest was whether or not the sample changes in color, only parts of the spectra was looked at. The data was loaded and the spectra was plotted (wavelength above 430 nm and below 721 nm).

After having made the second measurements of the samples, the spectra was put up against each other in order to see if there was any difference in the reflectance between the two samples see Fig. 8 and appendix 11.1. For all of the plots made from the end data, two distinctive bumps can be seen just before the 550 nm and just after the 600 nm as well a few lesser bumps. Generally when looking over the end data, the curve is slightly more uneven or not as smooth as the measurements taken at initiation of the experiment. At first glance it seemed weird and might have been caused by a mistake. It was suggested that it might be absorption lines for hydrated perchlorates, which could be an explanation, since the bumps are consistent throughout all of the measurements, but do vary in appearance with the different concentrations. One thing that however should be noted, is that the bumps are seen on every measurement including the control, which does not contain any perchlorates. This again could potentially indicates that it is some sort of measuring error, possibly from the second measurement. Another thing that could indicate that it might be an error in measuring is the white/reflectance measurements. After the reflectance was measured an initial measurements containing data, was taken it can be seen in Fig. 9. Note here that it shows the counts and not the reflectance since this is a measurement for the white. Here the two bumps are present again for the end measurements. Looking over the data it might have been a good idea to redo the end measurements. But do to the circumstances with the initiation of the second lockdown as well as time these measurements was not done. The hope is that it will be possible to take an initial set of measurements. This will however, if possible, not be until after the

thesis is handed in.

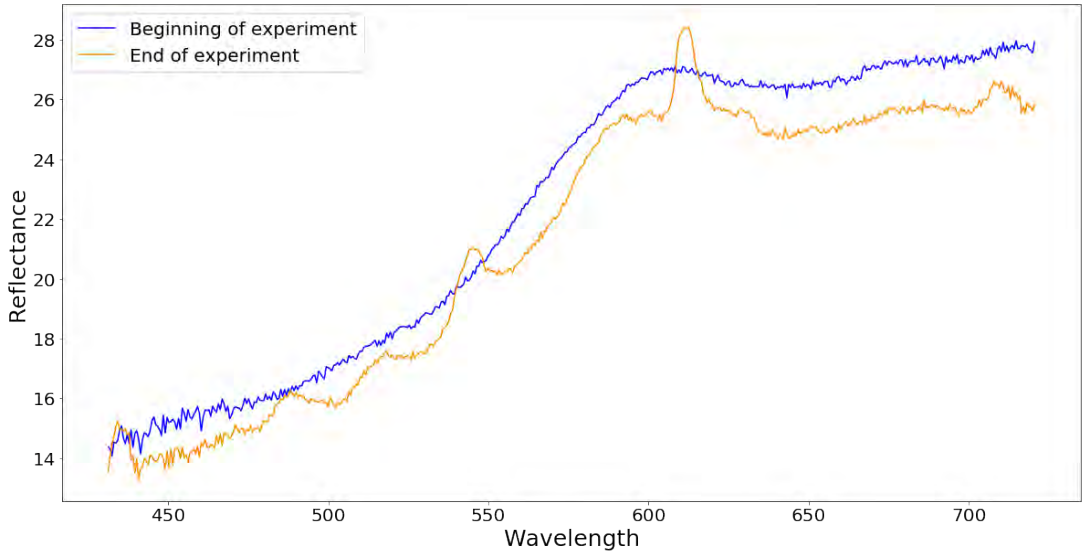


Figure 8: *Spectra showing the reflectance of the soil samples with 10 % perchlorates both at initiation and end of experiment.*

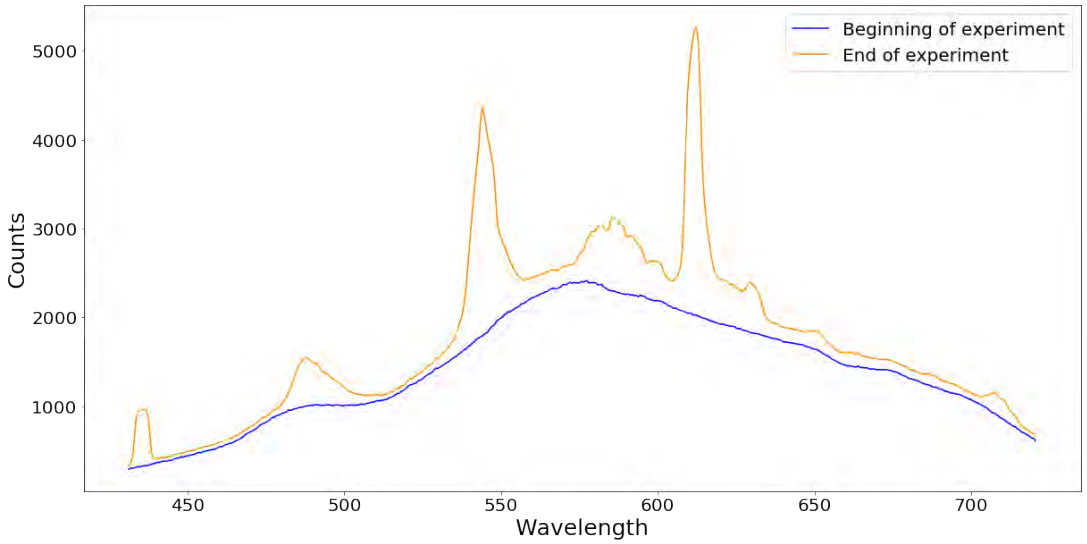


Figure 9: *Spectra showing the counts for the measurements of the white at initiation and end of experiment.*

Please note that the next section looks at the data but with a correction. This correction is made under the assumption that the bumps are due to a measuring error as well as the assumption that the control sample did not change during the course of the experiment. In other words, the control did not suck out any moisture from the atmosphere nor did it loss any. From this assumption, the spectra for initiation and end should be the same, this is not the case due to the these bumps just mentioned. Under this assumption, the

difference between these two should therefore be due to a measuring mistake. Therefore I find the ratio between these two. Having found the ratio, this can now be multiplied with the reflectance values for the end measurement, trying to correct for the possible measuring error. Doing this corrects for the distinctive bumps, note here that the corrected plots are labeled *End of experiment co* see Fig. 10 and appendix 11.2. This assumption may not hold up entirely, since the control samples might still have sucked some atmospheric moisture making the sample look darker. At the same time, water could also have evaporated from the control sample after the 13 days, leading to it getting slightly lighter. But for this section the assumption is that the sample did not change over time.

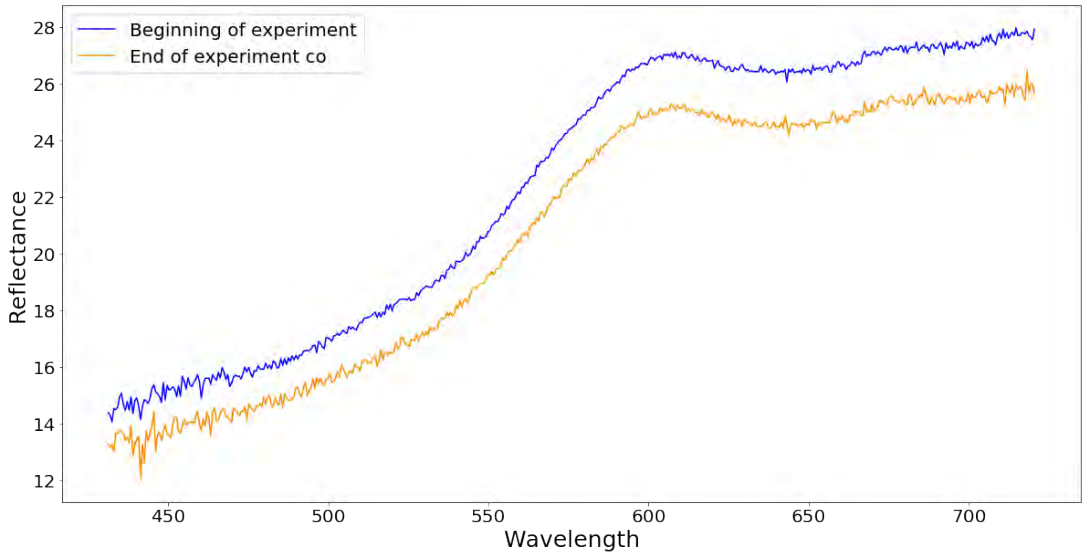


Figure 10: *Spectra showing the reflectance of the soil samples with 10 % perchlorates. The end data has here been corrected.*

6.2.3 The testing of the setup of RSL

The third experiment conducted in regards to RSL was the experiment of the setup. The setup is described in details in Section 6.1.3, here it is also mentioned that images were taken at initiation, during and at the end of the experiment. I initially intended to measure the mass for each of the boxes as well, and did measure the mass of the soil without perchlorates and the soil with perchlorates. I did however make the mistake of not measuring the box with the sandpaper in, which meant that when I wanted to measure the experiment after the 13 days had passed, the mass measured was the total mass of the box, sandpaper and soil, both with and without perchlorates. I did think of measuring the boxes with sandpaper after. But due to the sensitivity of the scale and the fact that the size of the sandpaper was not the exact same for all of the samples, I decided that this was not a good approach. At the same time, the spectrum was not measured either, the reason for this was as mentioned, due to the risk of moving the patterns created with the perchlorate rich soil. The data from this experiment is therefore not as precise, since part of it again relies on the visible difference. The images of the samples at the initiation can be seen in Fig. 4, and in Fig. 11 the samples at the end of the experiment can be seen.

(a) *Image showing the samples without lids for RSL setup at the end of experiment.*

(b) *Image showing the samples with lids for RSL setup at the end of experiment.*

Figure 11: Images showing the samples at the end of the experiment.

6.3 Sub-discussion for RSL experiment

The first experiment testing the perchlorates showed signs that water from the atmosphere condensed in the soils which contained perchlorates. Some of the samples even became slightly "muddy", it should be noticed that the box containing these samples had a slight crack, due to the wire from the humidity censor. A change in color was also seen in the other box without a crack, though this change was not as extreme. After seeing that the soils that contained perchlorates did in fact become darker over time due to water, the second part of the experiment was conducted. In the second experiment, no visible change in color as clear as in the first experiment was detected. One possible explanation to this could be that more samples were placed in the same box for the second experiment than for the first. For the first experiment, three petri dishes was placed in one box, whereas for the second experiment, six petri dishes was placed in the same box. For the first experiment, the box which had a small crack, was also the one to show the clearest visible changes, whereas for the second experiment, the box was closed completely (like the other box in the first experiment). The combination of the closed box and the higher numbers

of samples from the first to the second experiment, could be one possible explanation. Another possibility could be due to the reusing of the perchlorates as mentioned in the section above. Both possibilities would be taken into account if the experiment was redone.

Additional measures were also taken to see if there would be any changes for the second experiment, from Table 9 as well as Fig. 12 the differences in mass, from the initiation of the experiment to the end of the experiment, can be found. From these measurements, there does not seem to be any consistency with the mass loss or gain from each of the samples. Only the sample containing 1 % and 50 % perchlorate show an increase in mass after 13 days, whereas the rest of the samples show a drop in mass. There is no definitive connection between the loss or gain of mass through the samples. From the measurements, the 1 % concentration seems to have gained more mass than the 50 % did, and at the same time, the sample containing a 25 % concentration seems to be the one with the greatest mass loss. So no coherency between the samples' change in mass was found. One thing that was noted during the last mass measurements was that though the scale used was precise, when the petri dishes was placed on it, it did seem to fluctuate a bit. When the dishes was placed on the scale, it almost covered the plate, with only a few mm on each side, placing smaller objects the scale did not seem to give fluctuations on the same level. Due to these fluctuations, I therefore believe that the uncertainty for the samples are at the second decimal [12], since the fluctuations varied for the fourth and sometimes the third decimal. Looking at the differences between the samples most of them are very small and for half of them, the difference is not visible until the third decimal and for the other half, it is on the second. With the fluctuations, the lack of systematicness and coherency in the differences, as well as the uncertainty, nothing definitive can be said about the mass measurements for the second experiment. Should the experiment be replicated, smaller petri dishes would be used to insure better precision along with maybe a new scale.

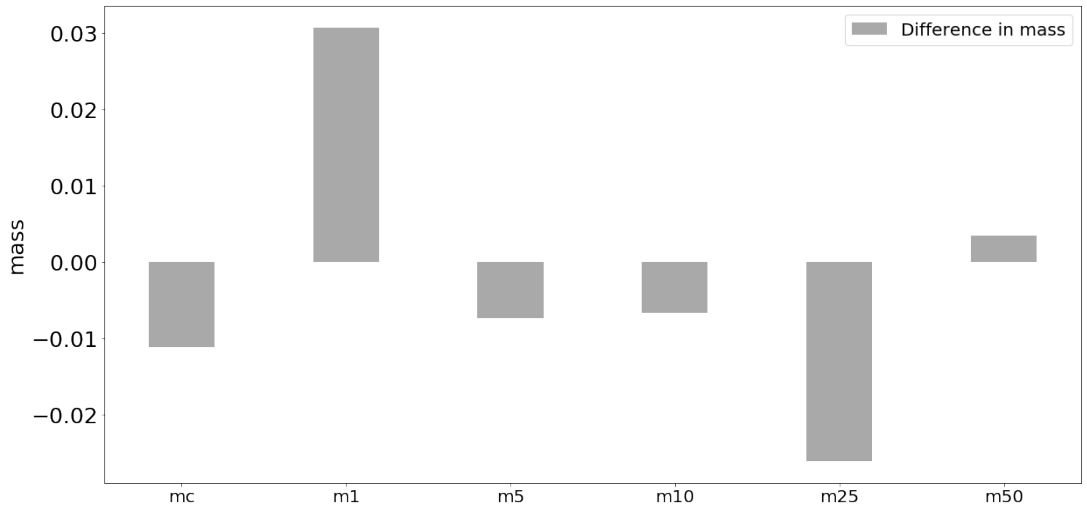


Figure 12: *Bar plot showing the difference in mass from the initiation of the experiment to the end of the experiment.*

[12]The scale measures down to the fourth decimal

The mass was however, as mentioned, not the only measurement taken for the second part of the experiment. For each of the samples the reflectance was also measured. When the data for the visible part of the spectra was plotted, it looked very different from the reflectance measured at the initiation of the experiment, see Section 6.2.2 for further explanation. The bumps visible on the spectrum taken at the end of the experiment, are believed to possibly be due to a measuring error during the end experiment. I did however, as stated in Section 6.2.2, try and make a possible correction under the assumption that the control had not changed. But regardless of viewing through the original end spectra or the spectra corrected, no systematic connection between the spectra and concentrations can be seen. For instance, the 5 % concentration shows sings of darkening, whereas the 50 % shows signs of having gotten lighter. Comparing the changes in mass differences and the changes in the spectra, no consistency between the two are found either. In general, nothing consistent can be said of the measurements for the second experiment, either from the mass measurements, the spectra data or the images taken. The tendency seen in the first experiment with the samples getting darker over time, was not really visible in this experiment. Two possible explanations for this could be, as mentioned above, the closed box and the reuse of the perchlorate rich soil. Another possibility could also be their placement in the room the experiment was done in. For the first experiment, the samples were placed in a box on the floor, for the second experiment the samples were placed in a box on top of another box. The lab is located in the basement and the floor is cold. In each of the boxes, a weather station was placed and the temperature measured by these did not vary between the two experiments. An additional thermometer was placed in the box with the crack during the first experiment. This thermometer was placed in the box close to the floor and did measure a slightly lower temperature. This could be a simple difference between the two, or it could be due to the fact that the additional thermometer was closer to the floor.

There was, as seen in Fig. 6 in Section 6.2.1, a clear visible difference between the samples at initiation and ending of the first experiment. This difference was not clear in the second experiment, neither from the measurements or the images taken. Redoing the experiment from the beginning would give the possibility of ensuring or looking in to some of the uncertainties and had time not been a factor, a new experiment would have been conducted. If the experiment were conducted again, new soils would be mixed, two petri dishes for each concentration would be used and placed in two different boxes. One of the boxes would contain an additional water source and the other would not, this to see if the crack in one of the boxes could have had an effect. As mentioned above the petri dishes used would be smaller. The experiment would also be left for a longer period of time than the approximately two weeks to see if this changed anything.

One last experiment was made to test the slope, this experiment was made only to see if there was any visible changes to the patterns created on the slopes. The box was open twice during the run of the experiment, the first time after a week and the second time at the end of the experiment, 13 days after the initiation. No real visible changes were noted during this time, except for one of the lines in box number 1, which seemed like

it might have been a little moist and then dried up[13]. A possible explanations for not seeing any clear changes could be the same as mentioned for the second experiment, the number of samples, the closed box and the reusing of the perchlorates. And as for the second experiment, one way of figuring out, would be to redo the experiment as well. If redone the mass of the samples would also be measured.

It should be noted that there are a slight difference in the color of the soil before the experiment was started. This can especially be seen in Fig. 11a, one potential explanation could be due to the reusing of the perchlorate rich soil, which might not have been as dry as initially thought, leading to the difference in color. It could also be due to the size of the sand grains, if the experiment was redone the soil both with and without perchlorates would be grounded to make sure they had a consistent consistency.

7 Experiment with bacteria

The third and last part of the thesis, dives in to the possibility of life surviving on Mars today and is consisting of two experiments, where bacteria suvival was tested. One experiment focused on testing how well they coped with UV-radiation, exposing them to UV-radiation in different time intervals. The other experiment focused on testing bacteria to see how they reacted to Mars-like environment. They were tested with the use of the Mars simulation chamber mentioned in Section 5.

7.1 Important terms

Before going into any further details about the experiments is as short introduction and explanation to some of the terms used in the following sections.

7.1.1 Media and buffer - TSB and PBS

One of the things used throughout the experiments is media. Media is a liquid or solid solution used for supporting bacterial growth, this can for instance be TSB. Another concentration also used is a buffer, this could be PBS, this is a solution which contains salts and water. In other words TSB contains "food" for the bacteria and supports bacterial growth, where as PBS does not contain any of those neutrinos. PBS can be used for making dilutions.

7.1.2 Dilution

When working with bacteria one might need to dilute the sample a number of times. The reason for dilution is to make sure that it is possible to count the colonies when the microorganisms in the samples have had time to grow, preventing overgrowth. The dilution is marked by a number that describes the number of times it has been diluted, so -1 means diluted once, -2 means two times etc. It is done by having a number of containers that matches the desired number of dilutions. The containers are filled with a specific amount of PBS, for example 900 μl and taking 100 μl of media containing

[13]This was from looking at it. It looked like I might have been a little humid

bacteria, adding this to the first container, shaking it and then taking a 100 μl from that adding to the next etc. This way a smaller amount of bacteria will be present the higher the dilution.

7.1.3 OD - The optical density

A part of preparing the bacteria is measuring the OD or optical density. The OD is a number that describes how many bacteria there approximately are in a given sample. It shares similarities with the optical depth known from astrophysics. The OD is described by Eq. 30, where I_0 is the initial intensity and I is the transmitted intensity. This is very similar to the expression for the optical depth which is also described by the difference in intensity at the incident and the intensity that are being transmitted.

$$OD = log_{10}\left(\frac{I_0}{I}\right) \tag{30}$$

Placing a small amount of liquid media without bacteria and shooting a light beam through it, measures the media it self, and gives a calibrating point. From here the OD of the media containing bacteria can be measured in the same way, placing a small concentration, shooting a light beam through it. The higher the OD the more bacteria are present in the sample. For our experiments we wanted an OD at around 0.3, if the OD for the bacteria was higher then they needed to be diluted. This was done by adding a specific amount of media to a specific amount of media containing bacteria. These numbers depend on the measured OD and can be calculated by using Eq. 31.

$$\frac{desired\ OD}{measured\ OD} \cdot wanted\ total\ volume = media\ containing\ bacteria \tag{31}$$

Subtracting the *media containing bacteria* from *wanted total volume* gives the amount of media which needs to be added. When both media with and without bacteria has been mixed, the OD is measured again.

7.2 Method for testing the bacteria

The interest behind the bacteria experiment was to see if lifeforms found on Earth could potentially survive a Mars like environment. For the thesis, bacteria from the Atacama desert was used, this was due to some similarities between the Atacama desert and Mars. Similarities like the higher concentration of UV radiation, the thinner atmosphere, the lower humidity as well as the presence of perchlorates in the soil. As mentioned the atmospheric pressure on Mars is approximately 1 % of Earth's at sea level and the humidity (RH) lies somewhere between 17 % and 23 %. With soil from the Atacama dessert a number of different bacteria were isolated, this step was done by Poul K. Madsen, but will be explained quickly in the following section. It was done the following way: Taking a small amount of the soil and adding it to PBS mixing it well. When it was mixed well, a small amount was then extracted and added to an agar plate. The plates contain solidified media (media mixed with agar) that the bacteria could grow on. The growth varies and the next step was to wait till the colonies became visible. On the agar plates a number of

colonies became visible, and therefore needed to be separated. Identifying each individual colony a sample of that colony was taken and added to a new agar plate waiting again for growth, this step and the following I partook in. This step was repeated, if there were still more visibly different colonies present on one plate. After having isolated each of the bacteria (isolates) they were transferred back to liquid media and placed in a room with a fixed temperature. A vial that only contained media was also prepared and placed together with the isolates, as a control. As time, passed each of the liquid media then changed appearance, becoming slightly murky, this should however not be the case for the control. If the control became murky, as well the transfer needed to be redone to make sure no contamination had happened. We had to redo this step due to contamination the first time we did it.
Each of the vials contains one isolate and are referred to by a number throughout the experiment and this thesis.

7.3 The experiments and reevaluation

When the transferring of bacteria was done and we were ready to begin our experiment, at first 16 different isolates were used. Our first round of experiments were then conducted with each of the 16 isolates both in the chamber itself and under different conditions like low temperature, an anaerobic atmosphere and UV-radiation. We did however run in to an unforeseen obstacle in the form of the Lockdown due to COVID-19. Our initial experiments where therefore prolonged. From the experiments we had conducted that had been running during Lockdown, a smaller number of isolates where chosen to move forward with. A total number of six isolates was selected for a more thorough test, due to both their reaction to low pressure and low humidity inside the chamber. The six isolates chosen were labeled the following numbers *5, 6, 9, 10, 201* and *202-1*.

The experiment inside the Mars simulation chamber and the UV experiment was repeated with the chosen six isolates. Some alterations were made from the initial experiment to the second experiment, these are mentioned in the sections below.

7.3.1 UV-experiment

In the original experiment the 16 isolates were exposed to short intervals of UV-radiation from a UV-source, in a distance of around 40-50 cm in intervals of 5 seconds, 10 seconds, 15 seconds and 20 seconds. We saw no real effect, with the short UV-exposure (this experiment was conducted only days before the lockdown was initiated). The experiment was therefore redone, using longer intervals and a shorter distance between the source and the sample. The new setup had the bacteria at a distance of 20 cm, and the exposure time was changed to be 30 seconds, 1 minute, 1.5 minutes and 2 minutes. The UV-light source that was used, had two sources with different wavelengths (254 nm and 366 nm) and each of them with a power of 4 watts. The irradiance the samples were exposed to can be calculated using Eq.32

$$E = \frac{P}{A} = \frac{P}{4\pi r^2} \tag{32}$$

Where P is the power of the source measured in watt and A is the area or in this case the surface area and r is the distance from the source to the object being exposed to the radiation. The irradiance is given in watts per square metre. This equation does however describe the irradiance of a point source, which irradiates in all directions. This I believed not to be the case for the source used in the experiment, since this light source only emits light in one direction. The equation therefore becomes

$$E = \frac{P}{C4\pi r^2} \tag{33}$$

Here C describes how big of an area light is emitted in to.

For each of the different bacteria a total number of 9×5 plates were prepared. Having a dilution series from -1 to -9 for each of the four exposure times as well as a control, becomes 45 plates per bacteria and a total number of 270 plates for the UV-experiment. Due to the very large number of plates the experiment was done over two days, with three isolates a day.

The first isolates to be tested, were 5, 6 and 9. The second day, isolates 10, 201 and 202-1, along with an *ϵ-coli* was tested. The *ϵ-coli* was tested, to be able to compare the six bacteria, with a bacteria which is known not to cope well with UV-radiation. The steps of the actual testing was different from day one and day two. But the preparation was the same. The first step was to measure the OD. The OD was measured for each of the bacteria and the values can be found in Table 10.

Bacteria	*5*	*6*	*9*	*10*	*201*	*202-1*	*ϵ-coli*
OD	0.5141	0.788	0.4212	0.3802	1.5801	0.314	1.7913

Table 10: *OD measured for the isolates tested.*

For our experiment the desired value was around 0.3 and since not all of our samples were around the desired value, some had to be diluted as described in Section 7.1.3. For both isolate 10 and 202-1 no dilution was made, since the value was very close to the desired 0.3. After diluting, the OD for the isolates were remeasured, this too make sure that the value was around 0.3. With the new measured OD the dilution from -1 to -9 could begin, we poured a small (fixed amount) on each agar plate distributing it using little glass beads.

After diluting and plating of the isolates we then exposed them to the UV-radiation. The bacteria 5, 6 and 9 was tested first. They were placed in a box lined with tin foil with a small hole in the top where the UV-lamp were placed. For the first experiment the distance between the lamp and the sample were 20 cm. Each of the three bacteria were exposed to the UV-light for 30, seconds, 1 minute, 1.5 minute and 2 minutes as well as a sample not exposed to any UV-light as a control. The setup for bacteria 10, 201 and 202-1 as well as the *ϵ-coli*, was the same. We did however change both the distance and the exposure time. The distance was changed to 17.5 cm and the exposure time changed

to 1.5 minute, 2.5 minutes, 3.5 minutes and 4.5 minutes. The changes were made due to the fact that we saw very little after bacteria 5, 6 and 9 where exposed to UV-radiation. After the UV-exposure all of the isolates were left waiting for growth and then counted.

7.3.2 Mars Chamber experiment

One of the main interest of this thesis was to introduce the different isolates to environmental changes inside the Mars chamber. The purpose was to see how they would react to the low humidity, pressure and change in atmospheric composition. But also to see how they coped with different Martian soil analogs and with perchlorates, which is, as mentioned above, found in the Martian soil. Perchlorates are in general toxic to a broad number of organisms on Earth, humans included, but the interest for adding perchlorates to the Martian soil analogs was to see if the organisms we used could cope with it. As already mentioned we used bacteria from the Atacama desert which hold a high concentration of perchlorates. Two larger experiments were conducted inside the chamber, one with the original 16 isolates and one with the six selected isolates. Just like the steps taken for the UV-experiment, the OD for this experiment was measured as well. The overall preparation for the two chamber experiments were the same, but we did find a number of changes necessary.

Preparation and adjustments
As already mentioned a number of environmental changes can be simulated using the Mars chamber. The bacteria were placed in liquid media and then added to small "wells" in a plate containing a number of wells, see Fig. 13. In each of the wells a small amount of Martian soil analog was placed. The soil analogs used were analogs from two different places on the Martian surface, Jezero crater and Gale crater, an extra soil analog from Gale crater containing sulfates was used as well. Perchlorates were added to a small amount of each of the soil analogs making the concentration of perchlorate 1% in mass. We then had soils both with and without perchlorates. For each of the 16 bacteria a total of 9 wells were filled, one for each of the three different soil analogs and for each of them, one containing food, one without and one with perchlorate added soil. One of the reasons for redoing the experiment was that the preparations were made only two days before the Lockdown. The intention was for the bacteria to be in the chamber for two weeks, but due to the Lockdown this ended up being much longer. Furthermore as a control, some of the wells were filled with soil, but no isolates were added. When the samples were taken out of the chamber wells that were only supposed to contain soil, then showed sign of bacteria/growth. When the wells were filled with soil and isolates later added, it was done out in the open, though done carefully, contamination most likely happened. The mistakes from the first experiment was corrected for the second, where for both safety and to reduce the chance of contamination, the soil and bacteria were filled in the openings inside a glove box with suction.

Most of the steps in preparation for the experiment were the same, except for some corrections as mentioned above. To make sure that there were no cross-contamination an empty well was left between each of the filled ones. During the first experiment no fixed amount of soil had been added, this was corrected during the second experiment. Using a scale, an amount of around 16 g was added to each of the chosen wells. After having filled all of the wells, media containing the bacteria was added. The bacteria was contained in TSB which holds food, in order to get bacteria without food, a small sample was placed in a centrifuged in order to separate the "food" from the rest. The bacteria added in the perchlorate rich soil did also receive food. After having added all of the bacteria in the nine different wells, they were placed inside the chamber. For each isolate and each of the soil analogs one well containing soil with 1 % perchlorate was made. This was to test how the bacteria would react to the perchlorates. The concentration was higher than the 0.6 % found on Mars, but the idea were that if they could cope with concentration of 1 % then they would also be able to cope with a concentration of 0.6 %.

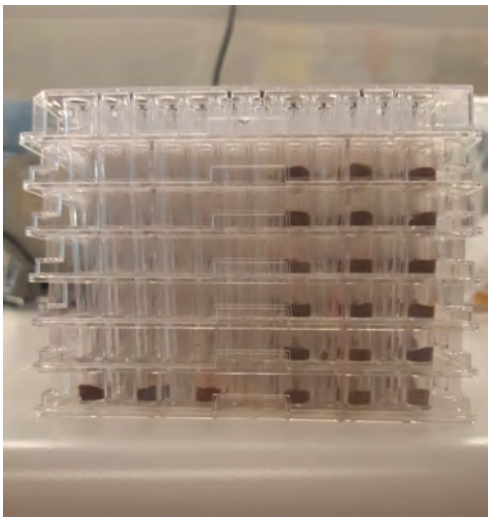


Figure 13: *Image showing the samples ready for entering the chamber.*

Entering the chamber

The goal for testing them inside the Mars chamber was to see how they would react to low humidity around 17 %, low pressure around 0.01 bar and an anaerobic atmosphere. For the first experiment we flushed the glove-box and chamber with nitrogen, to see how they would react to a different atmosphere not containing oxygen. For the second experiment we used carbon dioxide (CO_2) instead since it was a better analog for the Martian atmosphere. To make sure that the humidity was low enough, the glove-box, with the chamber open inside, was flushed. This did however not bring the humidity down to the desired percentage, so petri dishes containing silica gel was added to suck out any extra moisture from the air. This was not an exact science and the humidity when testing the six bacteria was therefore at 14 %. Placing the samples inside the chamber see Fig. 14 and sealing it off, waiting. For both the first and the second experiment the samples were left in the chamber in the afternoon/evening until the next day, without any change in the pressure. This was to give the bacteria time to adjust to the environmental change. The following day we would start lowering the pressure. This was done in small steps in intervals of about 45 minutes to an hour, again to ensure the bacteria had some time to adjust. (And to prevent the cells from exploding due to the extreme changes in the pressure).

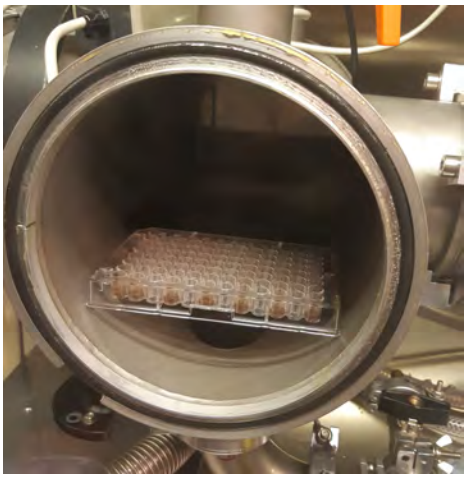


Figure 14: *Image showing the samples placed inside the chamber, before it was sealed.*

One of the corrections made from the first experiment, testing all 16 isolates, to the second, testing the 6 isolates, were the sealing of the glove-box. During the first experiment after sealing the chamber we opened the glove-box again. The pressure had to be changed using a vacuum pump, that had to be plugged in and a valve on the chamber had to be turned. The turning of the valve was much easier and more precise without the gloves on the glove-box, which is why we decided to remove them. We did however find out that the chamber itself had a small leak, which over time slowly increased the pressure inside the chamber. To prevent any "regular" air from entering the chamber, when doing the second experiment the glove-box stayed sealed. We did try to repair the small leak by using grease, this however did not fix the problem (but did make it a tiny bit better). As a way of correcting the pressure making sure it did not increase too much, the vacuum pump was turned on for a few seconds every day or every other day. After two weeks had passed, the time to decrease the pressure had come again. Unfortunately we did run in to a small obstacle a few days before we were planing on increasing the pressure, the computer showing the current pressure had stopped working. This meant that increasing the pressure was done without knowing the exact amount it was increased. Despite this, it was done in a similar way as when lowering the pressure in steps of about 45 minuets to an hour. The pressure was increased some, the day before the bacteria was extracted. The following morning the pressure was increased the last bit and the bacteria was taken out.

Along with the samples inside the chamber, samples with identical setup, was placed outside the chamber as a control. In order to see how the different bacteria would react to "normal" non Mars-like conditions. Along with the two tests, one inside the chamber and one outside, a control for the amount of bacteria in a sample was also created. A dilution series from -1 to -9 for each of the isolates was made as well, these were plated right away and left for growth. When the colonies were present on the plates they were counted, but only for plates containing somewhere between 20-30 and 200-300 colonies. From these plates a number of bacteria in 1 ml could be found, the procedure is described in detail in section 7.4 and the averacke number of bacteria in 1 ml for each of the isolates was then found. These are referred to as C.CFU (control culture forming units).

Our of the chamber

As already mentioned, when we initiated the first experiment it was right before the lockdown which lead to some restrictions. Since we were not allowed on campus, the two weeks initially planed for the experiment could not be followed. This meant that the samples were left inside the chamber for much longer than the two weeks. At this time I was still not allowed back on campus, but Poul K. Madsen however was. He therefore did the rest of the examination of the initial experiment on his own. During the second experiment I had been allowed to return back, and therefore participated in the second experiment. After taking the samples out from the chamber, the next part of the testing could take place. Adding media to each of the wells containing samples, letting the soil get moist. In another tray with larger wells, a $900\mu l$ of media was filled in each opening. Taking $100\mu l$ from each of the soil samples adding this to the new tray with wells, mixing it well. This was done to ensure that we had the bacteria (if any survived) in liquid form. Having moved and mixed all of the samples, they were then diluted, 9 times and ready to be plated. This was done by adding $100\mu l$ to agar plates and using glass-beads to spread out the liquid. This was repeated for each of the six bacteria, in each of the nine cases (different soil, food, no food and perchlorate) for each dilutions. After having plated all of them the next thing to do was wait, to see if any of them grew, so they could be counted. An example of the count of one of the isolates can be found in Table 12 and all of them can be found in appendix 11.5. An image shoving the plated isolates after a few days can also be seen in Fig. 15.

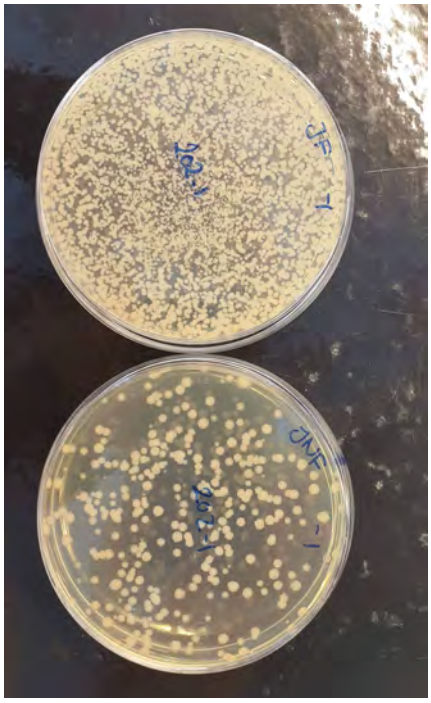


Figure 15: *Image showing the plated, first dilution of Jezero soil analog with (top) and without food (bottom).*

7.4 Data analysis

The following steps were made for both major experiments, the UV-experiment and the Mars chamber experiment. As mentioned in Section 7.2, before plating the bacteria they were diluted, the reason for the dilution was to make them easier to count. For each of the dilutions in the dilution series, the concentration of bacteria decrease by a factor of 10. See Table 11. As a result less bacteria would grow on plates with higher dilution and therefore make them easier to count.

Dilution number	-1	-2	-3	-4	-5	-6	-7	-8	-9
Concentration	$\frac{1}{10}$	$\frac{1}{100}$	$\frac{1}{1000}$	$\frac{1}{10^4}$	$\frac{1}{10^5}$	$\frac{1}{10^6}$	$\frac{1}{10^7}$	$\frac{1}{10^8}$	$\frac{1}{10^9}$

Table 11: *Concentration for the dilutions.*

For both experiments the plates used for counting the colonies vary, and for some, dilution -2 was used, for others -4, etc. In order to be able to compare them, a point of reference or a common criteria for all of the dilutions was needed. This point was found by calculating backwards from the different dilutions to the concentrations in $1ml$, which again can be compared with the C.CFU. for the Mars chamber experiment. An example could be Isolate 5 GSF, here 45 colonies was counted on the plate with dilution -3. Calculating backwards giving the concentration of bacteria in $1ml$ (of Isolate 5 GSF) would then be $45 \cdot 10^4$. An example of the counts for the different dilutions can be found in Table 12 and all of them can be found in appendix 11.3 and appendix 11.5.

Soil/Isolate 5	**Count**	**Dilution**
GSF	45	-3
GSNF	200	-2
GSP	-	-
GF	18	-2
GNF	-	-
GP	-	-
JF	23	-2
JNF	259	-2
JP	-	-

Table 12: *Count and given dilution for the control of Isolate 5.*

7.4.1 UV-experiment

After having calculated backwards and having found the concentration in $1ml$ a bar plot for each of the samples were made, containing the counts for each of the exposure times as well as a control. An example of the bar plot for one of the isolates, Isolate 10, can be seen in Fig. 16 and the rest of them can be found in appendix 11.4.

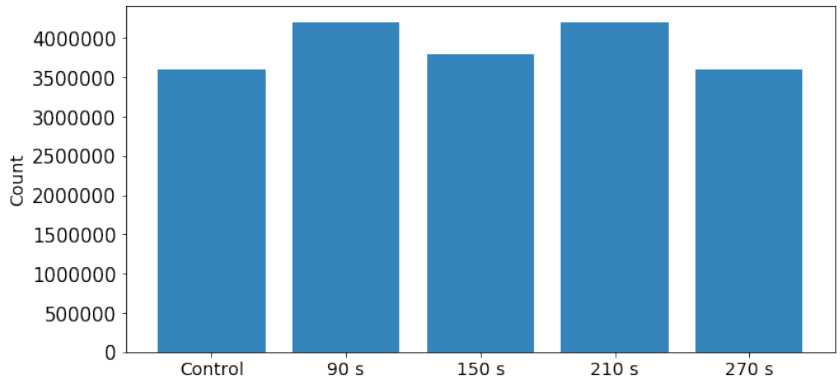


Figure 16: *Bar plot of UV-experiment of Isolate 10, showing the number of bacteria surviving the different exposure times, as well as a control.*

In order to have an idea of the exposure the bacteria were exposed to, the irradiance of the two distances was calculated as well, using Eq. 33, described in section 7.3.1.

Calculating the irradiance for the two distances give the following exposure for the samples. The distances were 20 cm and 17.5 cm and the power of each of the two sources was 4 watts. The area the UV-lamp is emitting light in is not known, but it is assumed that it is approximately equivalent to $\frac{1}{2}$ of the sphere, which means that in this case $C = \frac{1}{2}$ and the equation describing the irradiance therefore becomes

$$E = \frac{P}{2\pi r^2} \tag{34}$$

First for the distance of Isolate 5, 6 and 9, which was 20 cm.

$$E_{20} = \frac{8\ W}{2\pi\ 0.2^2\ m} = 31.83\ \frac{W}{m^2} \tag{35}$$

And then calculating it for Isolate 10, 201 and 202-1 as well as the ϵ-*coli* at a distance of 17.5 cm.

$$E_{17.5} = \frac{8\ W}{2\pi\ 0.175^2\ m} = 41.58\ \frac{W}{m^2} \tag{36}$$

So the estimated exposure of UV-radiation the isolates was exposed to was 31.83 $\frac{W}{m^2}$ for Isolate 5, 6 and 9. For Isolate 10, 201, 202-1 and the ϵ-*coli* the irradiance was 41.58 $\frac{W}{m^2}$.

7.4.2 Data from the Mars Chamber experiment

Using the count and calculating the concentration in $1ml$ a number of bar plots was made for each of the isolates (Mars chamber count and control). The bar plots for the individual isolates tested with food, without food and perchlorates in the three different soils can be found in appendix 11.6.

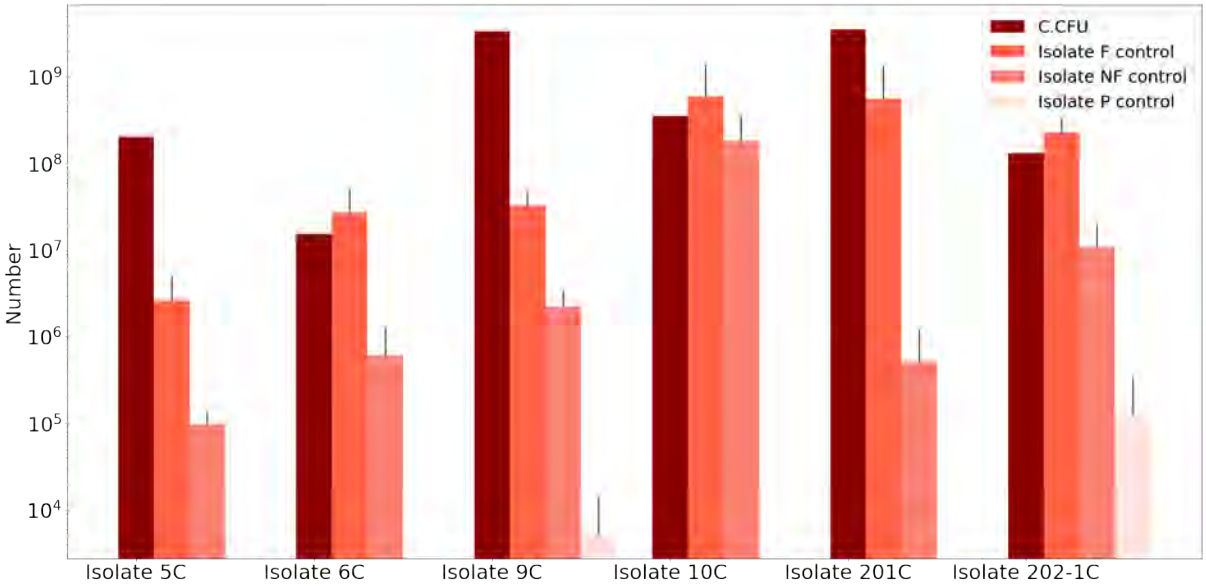
The experiment was initiated with an interest in the different soil analogs and if they

would play a role for the bacteria tested. When looking at the bar plot in appendix 11.6, it is in the following section assumed that the soils do not play any important role for the bacteria. It can however not be disproved entirely since there was only one experiment per isolate for each of the soils making it had to say anything definitively.
As just mentioned there was only conducted one experiment, meaning only one data set per isolate with food/no food/perchlorates in each of the three different soils. With the assumption that the soils did not play any role for the bacteria, the data can now be seen as three data sets for each isolate with food/no food/perchlorates. Therefore in order to get a better idea of how the bacteria are doing, the mean for all three food for each isolate was found, as well as for no food and perchlorates. Along with calculating the mean, the standard deviation was also calculated. The mean for each isolate with food, no food and perchlorates as well as the standard deviation can be seen in Fig.17. Bar plots for the three scenarios food, no food and perchlorates for control and the samples inside the chamber, was made as well, to better see the difference between the two, they can be found in Fig. 21, 22 and 23.

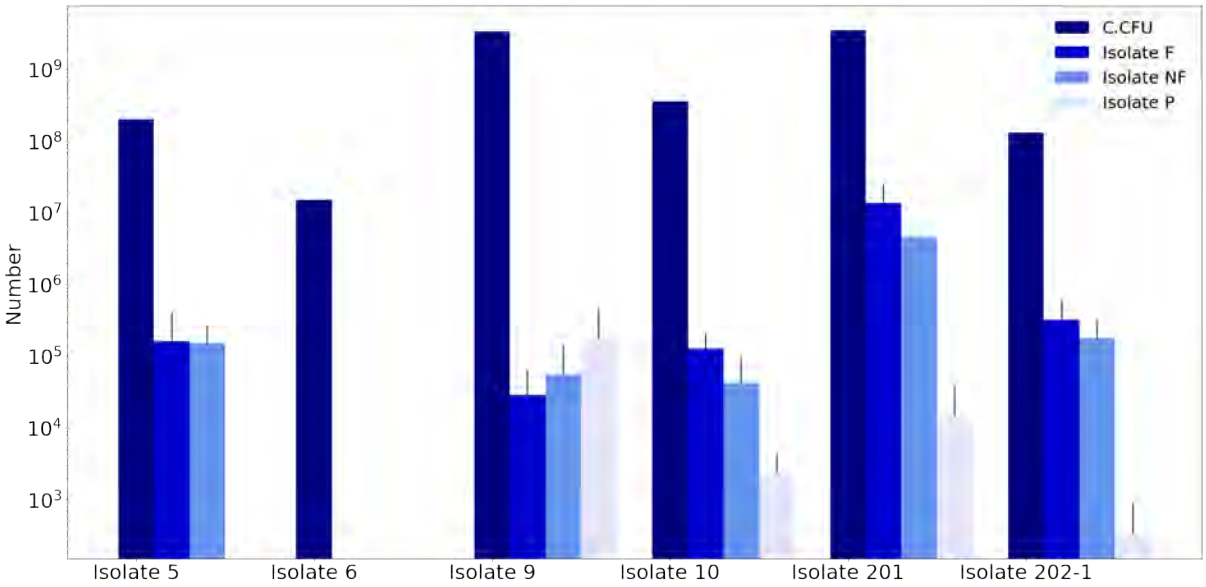
Throughout the hole experiment the samples was referred to as isolates since we at the time of initiation did not know what kind bacteria they were. After the experiments Poul K. Madsen send the samples to be sequencing in order to know what kind of bacteria we had been working with. In Table 13 the different isolates can be seen along with the genus and species they match as well as the percentage they match.

Isolate	**Genus and Species**	**Similarity**
5	Bacillus heynesii/paralicheniformis	97 % for both species
6	Bacillus sp. Strain JDMASC59	97 %
9	Pseudomonal songnenensis	97.02 %
10	Bacillus halotolerans	96.1 %
201	Staphylococcus capitis	97.29 %
202-1	Bacillus mojavensis	97.34 %

Table 13: *The genus and the species for each of the isolates used in the experiment. The first name describes the genus and the second describes the species. The column marked as similarity shows the percentages of how close the isolate is to the noted genus and species.*



(a) *Bar plot of mean with standard deviation for the control outside the chamber for each of the isolates. C.CFU (control colony forming units) showing the estimated initial number of bacteria in 1 ml, for each isolate. Isolate F control are bacteria that received food during the experiment. Isolate NF control are bacteria without food during the experiment. Isolate P control are bacteria introduced to soils containing 1% perchlorates.*



(b) *Bar plot of mean with standard deviation for the test inside the chamber. C.CFU (control colony forming units) showing the estimated initial number of bacteria in 1 ml, for each isolate. Isolate F are bacteria that received food during the experiment. Isolate NF are bacteria without food during the experiment. Isolate P are bacteria introduced to soils containing 1% perchlorates.*

Figure 17: Bar plots showing count for the different isolates both for control and for tested inside the chamber.

7.5 Sub-discussion bacteria experiment

7.5.1 UV-experiment

The wavelengths of the two sources were 254 nm and 366 nm which means that they are UVC and UVA respectively. This is interesting since UVC are the most dangerous part of the UV spectrum, and the bacteria seem to cope rather well with the exposure. In general when looking through the bar plots for the UV-experiment, the time the different isolates were exposed, does not seem to have any greater effect. The count continues to be high throughout the increasing exposure time, with only a few exceptions one of which is Isolate 201, see Fig. 18, which drops drastically after an exposure time of 2.5 minutes indicating that being exposed to 3.5 minutes and 4.5 minutes is too harsh for it to cope with. Other than Isolate 201 a few others, show signs of not coping well with specific exposure time periods for example see Fig. 19. Here the bacteria cope well, with a high count for the first 1.5 minutes and 2.5 minutes but drops for 3.5 minutes only to increase again at 4.5 minutes. In this case and similar cases found in the appendix, the reason for that one drop is most likely due to an error when the experiment was performed or an error during plating

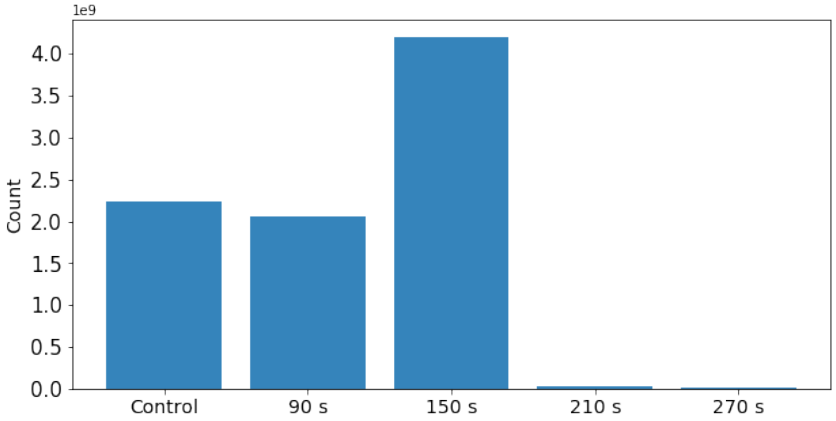


Figure 18: *Bar plot of UV-experiment of Isolate 201, showing the number of bacteria surviving the different exposure times, as well as a control.*

In Section 2.3.3 it is mentioned that the amount of UV radiation that reaches the surface of Mars is approximately 20 $\frac{W}{m^2}$ during the day. Comparing this to the numbers calculated for the irradiance of the samples in our experiment, it seems like the samples might have been exposed to a higher concentration. For the first part of experiment, with the distance at 20 cm, the exposure was 31.83 $\frac{W}{m^2}$ and for the second part of the experiment, which was made at a distance of 17.5 cm, the irradiance changes to 41.58 $\frac{W}{m^2}$. And if the numbers found by Eq. 34 are correct, then the exposure from the UV-lamp are about double the exposure on Mars. It should be mentioned that this is only the exposure for UVA and UVC and not UVB. But the concentration of UVA, UVB and UVC of irradiance on the Martian surface is not defined in the number 20 $\frac{W}{m^2}$.

Keeping this in mind it should also be noted that the UV-source potentially could have

lost some of its strength during its time, making it less powerful than first believed. This was also one of the reasons for adding the ϵ-*coli* and exposing it to the UV-radiation. ϵ-*coli* bacteria are found inside the human body and should therefore as a result not be able to cope well with the exposure to the UV-radiation. We do see a drop from the control to the samples exposed, but the drop is not that extreme. It seems like the UV-radiation did affect the ϵ-*coli*, see Fig. 20, but not extremely, except for one drop at 2.5 minutes in a similar way to Isolate 202-1. One other thing to note is that only the power of the laps are known, they are 4 W each, but if they act like point source or if the light is concentrated/reflected in one direction is not known. I made the assumption that the light from the laps were reflected, meaning that the light was only sent out in on direction equivalent to $\frac{1}{2}$ of the sphere. But this may not be the case, if my assumption was wrong and the lamps act like a point source, the calculated number drop to half, becoming 15.92 $\frac{W}{m^2}$ and 20.79 $\frac{W}{m^2}$.

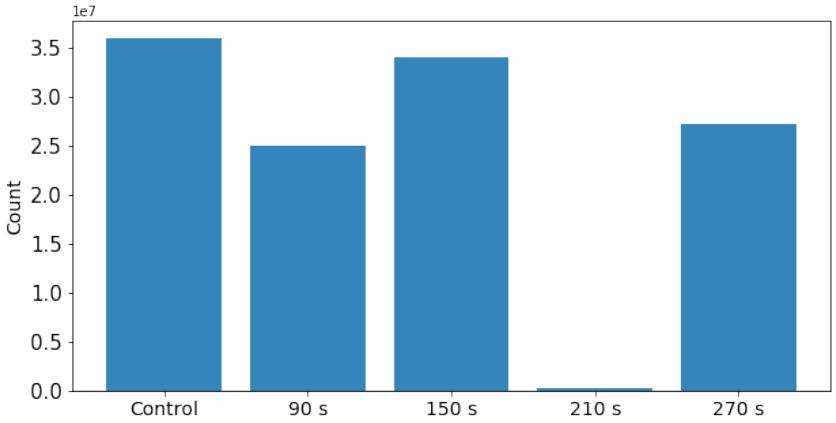


Figure 19: *Bar plot of UV-experiment of Isolate 202-1, showing the number of bacteria surviving the different exposure times, as well as a control.*

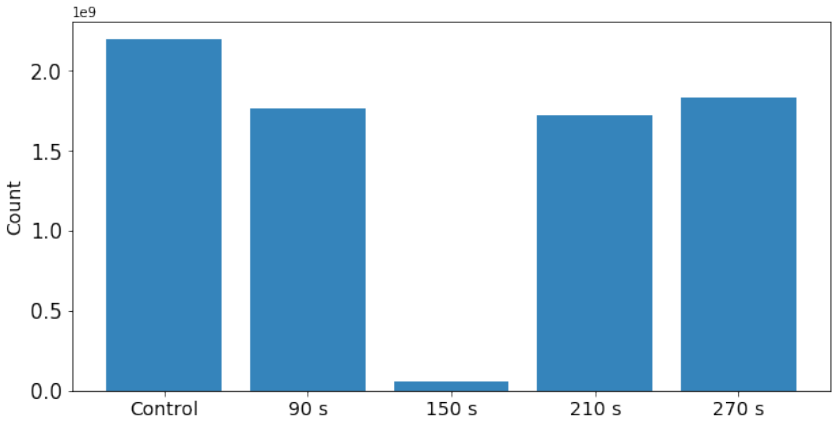


Figure 20: *Bar plot of UV-experiment of the ϵ-coli, showing the number of bacteria surviving the different exposure times, as well as a control.*

With all of this said, the sources the bacteria originate from are the Atacama desert.

The Atacama desert is located at a higher altitude and as a result may very well receive a higher amount of UV-radiation, this is after all one of the reasons for choosing this location.

In truth the best way to know, would be to conduct the experiment again, potentially using a new UV-source, to see if it would yield the same result. Redoing the experiment would also give the possibility of getting measurements without drops for specific exposure times. It would also give the possibility of making triplets and as a result have more data set. The reason for not making triplets in our experiment was due to time and the number of plates needed for doing so. Each of our plates were plated by hand which takes time. For our UV-experiment a number of 315 plates were used, this number would of course have been tripled, had we made triplets which we did not have to time to do.

7.5.2 Mars chamber experiment

Looking at Fig. 17a and Fig. 17b and comparing the two, it is seen that the bacteria in general do not like being inside the chamber. The count for bacteria inside the chamber are in general, though there are exceptions, lower than for the bacteria left outside the chamber. In order to better see the difference for the control and the ones inside the chamber see Fig. 21, Fig. 22 and Fig. 23. It is for instance clear that Isolate 6 does not like the changes imposed on it inside the chamber regardless if food is present or not. The samples do in general cope better with the environment inside the chamber with food present than without, which of course makes sense. Having said that, two samples do actually seem to do slightly better without food inside the Mars chamber than outside, See Fig. 22. Here the count for Isolate 5 and 201 is higher for the samples inside the chamber than for the control outside the chamber. Though there is a visible difference for Isolate 201, nothing definitive can be concluded since the experiment was only conducted once. It could be that they cope better inside the chamber without food, but it could also simply be due to uncertainty since there is both growth inside and out side the chamber. Repeating the experiment would be the best way of saying something more definitively. Comparing the two with their counterparts who received food, the changes for both Isolate 5 and 201 inside the chamber for food and no food are almost non-existent. Whereas the change for the samples outside the chamber is clear as seen in Fig. 17a and Fig. 17b.

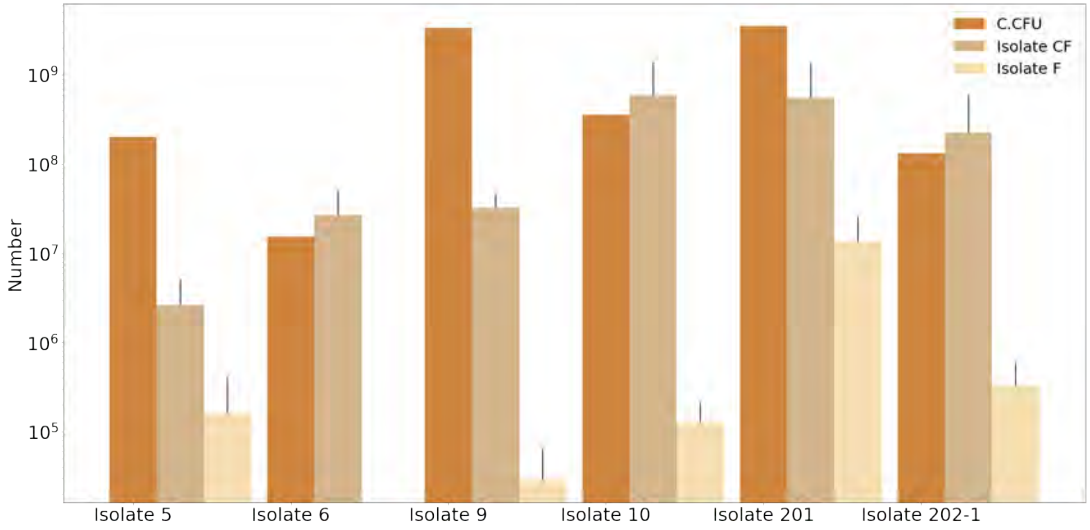


Figure 21: *Bar plot showing the C.CFU (control culture forming unit) as well as the mean with standard deviation for samples both inside the chamber and outside that received food. Isolate F are samples inside the chamber with food, Isolate CF are the samples outside the chamber with food.*

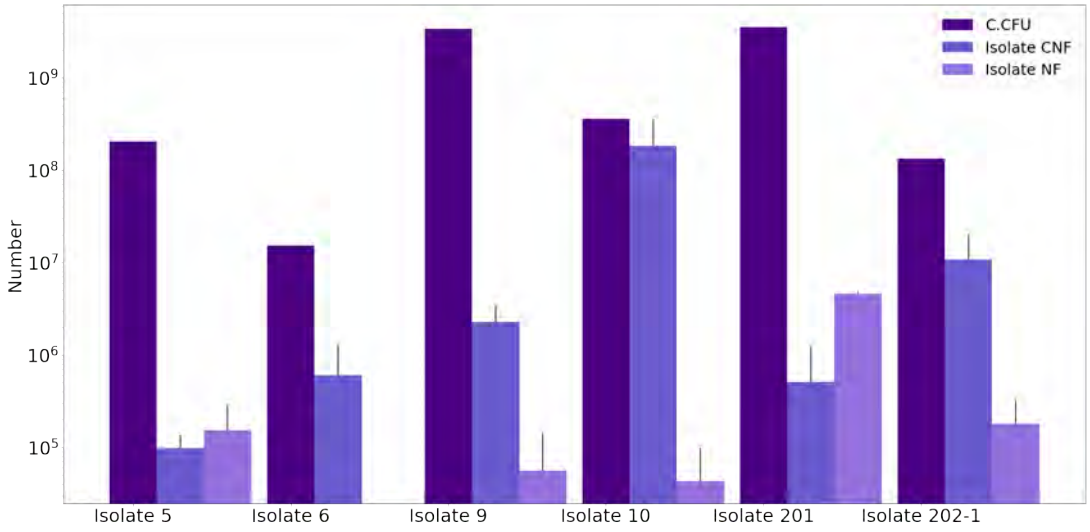


Figure 22: *Bar plot showing the C.CFU (control culture forming unit) as well as the mean with standard deviation for samples both inside the chamber and outside which did not receive food. Isolate NF are samples inside the chamber without food, Isolate CNF are the samples outside the chamber without food.*

One thing that however is very interesting is Isolate 9, 10 and 201, which all cope better with the perchlorates inside the chamber than outside, and for Isolate 10 and 201 the samples containing perchlorates outside the chamber show no sign of growth, where as the ones inside the chamber did. This is interesting since this could indicate that there are something in the simulated environment that is needed for the bacteria to survive with the perchlorates. There can however not be said anything definitively as to why they cope

better inside that out. One suggestion could be that the atmosphere which was CO_2 plays a role. In these cases the concentration of perchlorates in the soils are also interesting. The perchlorates was added to the different soil analogs and mixed giving a concentration of 1%. When the perchlorates were added it is not unlikely that there might have been some water attached to the perchlorates. Some of that water attached to the perchlorates would likely have evaporated when the pressure was lowered inside the chamber, which in turn would give a slightly higher concentration of perchlorates in the soil inside the chamber than outside. The increase would be very very small, but for the bacteria in the samples, this tiny increase would seem more extreme. It should also be noted that the mixed concentrations of perchlorates both inside and outside the chamber were higher than the concentrations found on Mars. For our experiments we used a concentration of 1 % perchlorate, which is higher than the high concentrations found on Mars which lies around 0.6 %.

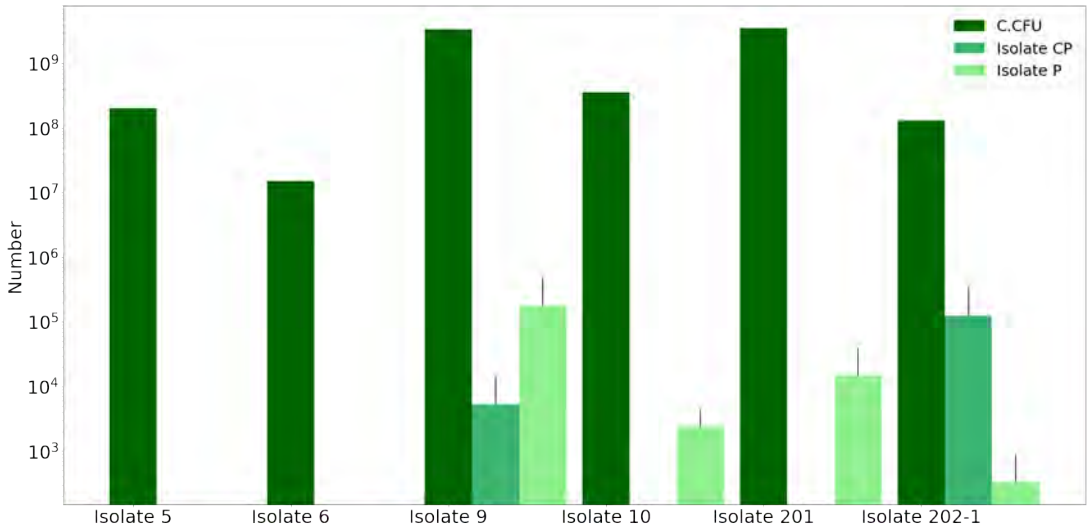


Figure 23: *Bar plot showing the C.CFU (control culture forming unit) as well as the mean with standard deviation for samples both inside the chamber and outside that was tested in the* 1% *perchlorate rich soil. Isolate P are samples inside the chamber in soil with perchlorate, Isolate CP are the samples outside in soil with perchlorate.*

In general the majority of the bacteria cope with the environmental changes, with the exception of Isolate 6. Some cope better than other, in general Isolate 10 and Isolate 201 are the ones that over all do best through the tests conducted inside the chamber. It is interesting to note that Isolate 201 most like was a contamination since Staphylococcus capitis is a bacteria commonly found on the skin.

The fact that the experiment was rather time consuming, both in preparation and in testing time as well as the initiation of the lockdown, lead to the experiment only being conducted once. Normally each of the isolates would have been tested more than once, preferably something like three identical set-ups (triplicates) for each isolate. Which would give three counts for each of the different conditions with the possibility of finding a mean. With triplicates a more definitive conclusion to whether or not the soils play a

role would also be possible. This would however have left us to only test one or two of the isolates instead of all six chosen. The reason for choosing to test the six isolates instead of just two were to see if anything could survive under Mars like conditions. This was the whole purpose of the experiment to begin with, to see if it was even possible to get bacteria that survived.
This also means that had time not been a factor or should the work continue the six bacteria would be put through similar test with triplicates in order to get a broader and more quantitative measure.

Another possibility would also have been to make triplicates when plating the isolates after the experiment. This would have given a better mean for the number of surviving bacteria. This was however again not possible due to time restrictions. There were for the experiment 9 different combinations per isolate. For each combination a dilution series from -1 to -9 was required, meaning the total number of plates per isolate would be 81. With 6 isolates this would bring the number to 486 plates just for the samples inside the chamber, the same number was needed for the control outside. In the end if we were to have plated triplicates for each of the combinations we would have had to plate a little under 3000 plates, which was not durable by hand.

8 Discussion

The three sections each serve as an investigation of Mars and the possibility of life surviving on the planet. In each section the results have been discussed and in the following section, these will be discussed as a whole. The evolution of the atmosphere and the magnetic field is important for understanding the possibility for life on Mars. From the calculations it is seen that the mass of the original atmosphere vary, depending on the creation and with that the time of the disappearance of the magnetic field. As mentioned, the time of disappearance from the two scenarios were 2.96 Ga ago for outgassing and 3.74 Ga for collision, giving a rather big difference between the two. From the perspective of the calculations, this means that if life ever originated on Mars, then it potentially would have had a longer time to evolve under the outgassing scenario than under the collision scenario, since the magnetic field disappeared later. As already mentioned, these numbers can be compared to disappearing times found in literature (4.1 Ga ago to 3.9 Ga ago). If the numbers are compared, the collision scenario seems to be the best explanation for the creation of the atmosphere, since the disappearance of the magnetic field under this scenario is closer to the times found in literature. The number found by the calculations would also be interesting to compare to the time found when Mars samples in the future might be returned to Earth.

But finding out when the magnetic field disappeared would potentially be key to finding out how long life, if it ever originated on Mars, would have had to evolve. This leads nicely on to the search for water today, with the disappearance of the magnetic field and probably not that long after the atmospheric pressure, water would slowly have started to evaporate. Over periods of time this would have led to the planet seen today, where liquid water in its pure form cannot exist. In the second part, I look into the possibility of water vapor from the atmosphere condensing in the soil due to the concentrations

of perchlorates. The experiments showed some signs that water from the atmosphere could indeed condense in the soil, but there were also some uncertainties in the second measurements. It should also be kept in mind that even if moisture from the atmosphere is being attracted by the perchlorates, then this might not be the best idea for explaining recurring slope lineae.

The importance of water for life is no secret and this is also why it would be incredibly interesting if recurring slope lineae are caused by liquid water in a concentration with salts like perchlorates. This leads to the last part, could life found on Earth possibly survive in an environment similar to that of Mars? Testing bacteria found in one of the places on Earth that shares some similarities with Mars, the Atacama desert, we tried to dive into this question. The experiments were very extensive, which led to them only being conducted once and as a consequence, our results are not definitive. For the reasons discussed in the sub-discussion, repeating the experiment would have yielded better results, but as also mentioned, this was not possible due to time limitations. Having said that, we did have results from our experiments. Though the different isolates did not like to be introduced to the Mars like environment, the majority of them survived the test. One of the interests was to see if the bacteria could cope with perchlorates in the soil. The reason for during this, other than the presences of perchlorates on the Martian surface, was due to the interest of liquid water on Mars. As mentioned above, the presence of perchlorates might be an explanation for the recurring slope lineae. If RSL are liquid water with a concentration of perchlorates, then maybe bacteria could live in these brines. Testing the bacteria in the Mars chamber was done for two reasons. First, could life found on Earth potentially survive a Mars like environment and if so, could this then mean that life potentially could be present on Mars today? Second, could bacteria from Earth be brought to Mars and possibly help make the planet a little less dangerous for future human explorers? This was one of the interests in testing the bacteria in soil with 1 % of perchlorates in them, could these bacteria potentially use the perchlorates. If the bacteria could utilize the perchlorates in the soil, could they then help terraform the planet for future generations, making the soil less dangerous? Part of this might sound like science fiction, but the truth is that it might very well be a part of the future. And if terraforming is in the future it might also lead to the question, should it be done?

9 Conclusion and results

Through three different examinations, the possibility for life surviving on Mars has been investigated. The results from each of the major sections have been discussed in their individual sub-discussions and as a whole in the discussion. First, I found an estimate of the mass of the original atmosphere of Mars for three different scenarios of creation. The three scenarios for creation was outgassing and collision, but where the objects either originated from the Asteroid belt or the Kuiper belt. By making a number of assumptions, I then found an estimated time for the disappearance of the magnetic field. The time of disappearance might play a very important role in the possibility of potential emerging life on the Martian surface. Without a global magnetic field, the atmosphere was most likely striped from the planet not that long after, leading to not only a lower pressure, but also a thinner atmosphere, which in turn might very well lead to a greater exposure of

radiation and a harsher environment. The interest in when the magnetic field disappeared, gives an estimate of how long life (if it ever existed) would have had to evolve. This also means that the calculations suggested the magnetic field disappeared much later for the calculated atmosphere created by outgassing, giving potential life longer time to emerge. However, as mentioned in the sub-discussion, if the calculated values are compared to literature, which states the disappearance of the magnetic field most likely happened 3.9 Ga to 4.1 Ga ago, then collision is the closest in time.

In the second part, the focus is on the possibility of water on Mars, with the experiments testing perchlorates and the probability of them sucking out moisture from the air. The first part of the experiment showed that samples with high concentrations of perchlorates 25 % and 50 %, did get darker over time due to water. The experiment was conducted again and here the results were not as consistent, neither for the spectral data, the mass measurements or the visible data. Possibilities for the difference between the two experiments are discussed in the sub-discussion. An additional experiment was also conducted testing the setup of the experiment adding a slope. The experiment did not show any clear signs of water condensation either, except for what seemed to be a small visible change in the one of the lines.

The last of the three parts looked at the possibility of life from Earth surviving a Mars like environment. We tested six different isolates, exposing them to different intervals of UV-radiation, for most of the samples we did not see any greater change with the increased time. For isolate 201 we did see a drop after 3.5 minutes, but for the majority of the samples, no greater change over time was seen. We also tested the six different isolates in the Mars simulation chamber, we found that even though they overall did not like the environmental changes, 5 out of 6 survived the conditions. From the experiment we also saw that some coped better with the concentration of perchlorates especially Isolate number 10 and 201.

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11 Appendix

11.1 RSL-Experiment Spectra

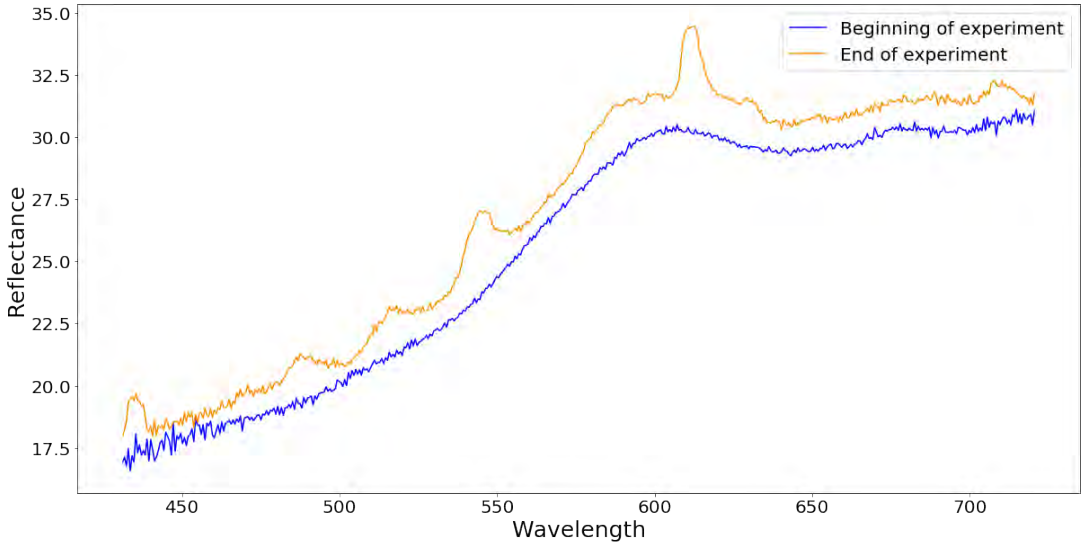

Figure 24: *Spectra showing the reflectance of the soil samples with 1 % perchlorates. Both at initiation and end of experiment.*

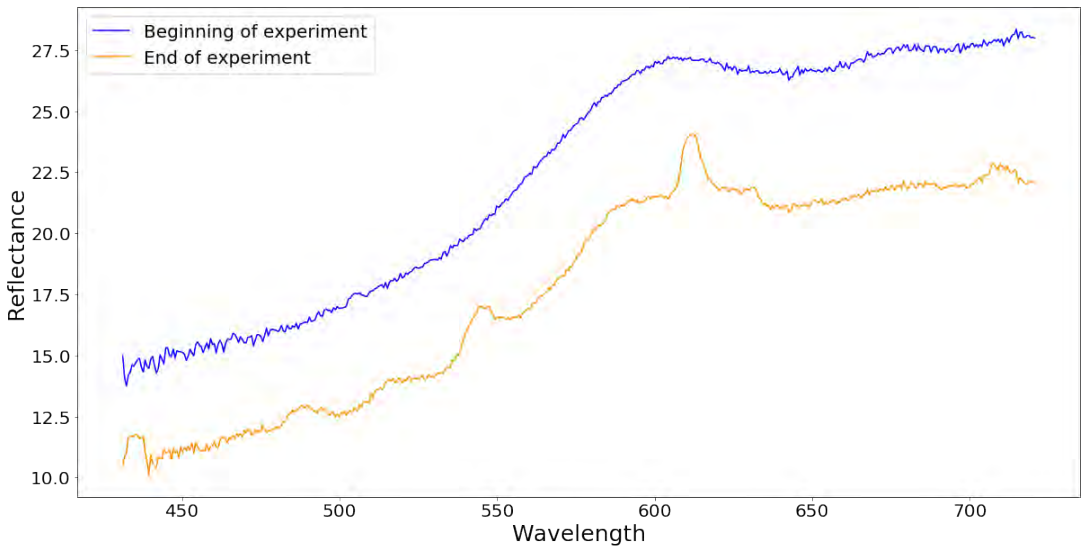

Figure 25: *Spectra showing the reflectance of the soil samples with 5 % perchlorates. Both at initiation and end of experiment.*

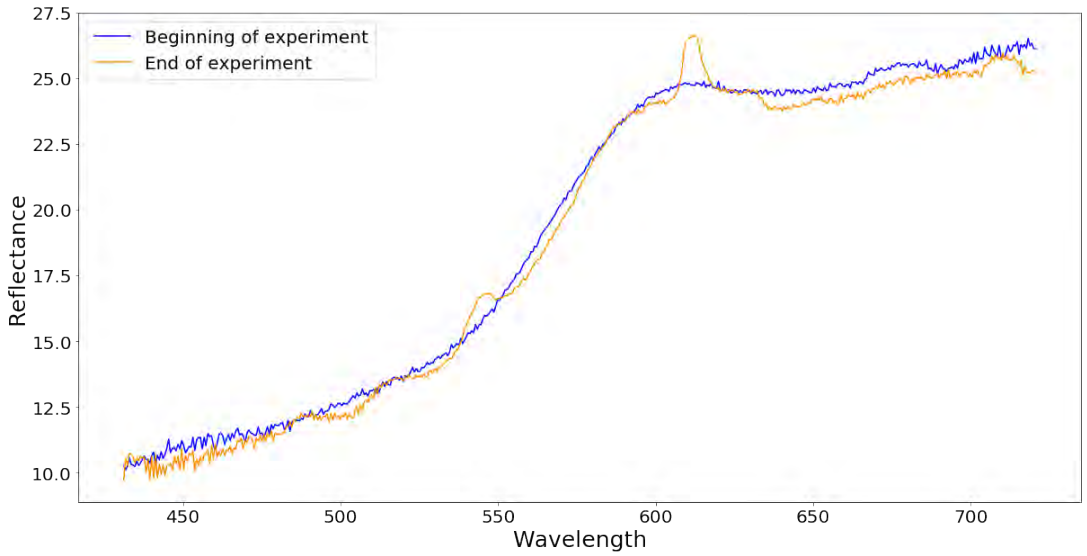

Figure 26: *Spectra showing the reflectance of the soil samples with 25 % perchlorates. Both at initiation and end of experiment.*

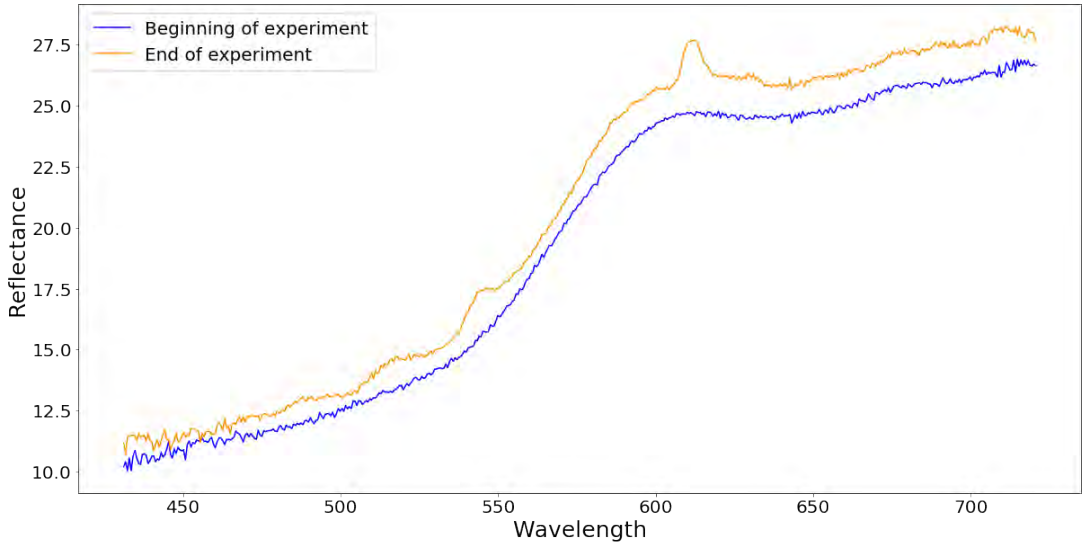

Figure 27: *Spectra showing the reflectance of the soil samples with 50 % perchlorates. Both at initiation and end of experiment.*

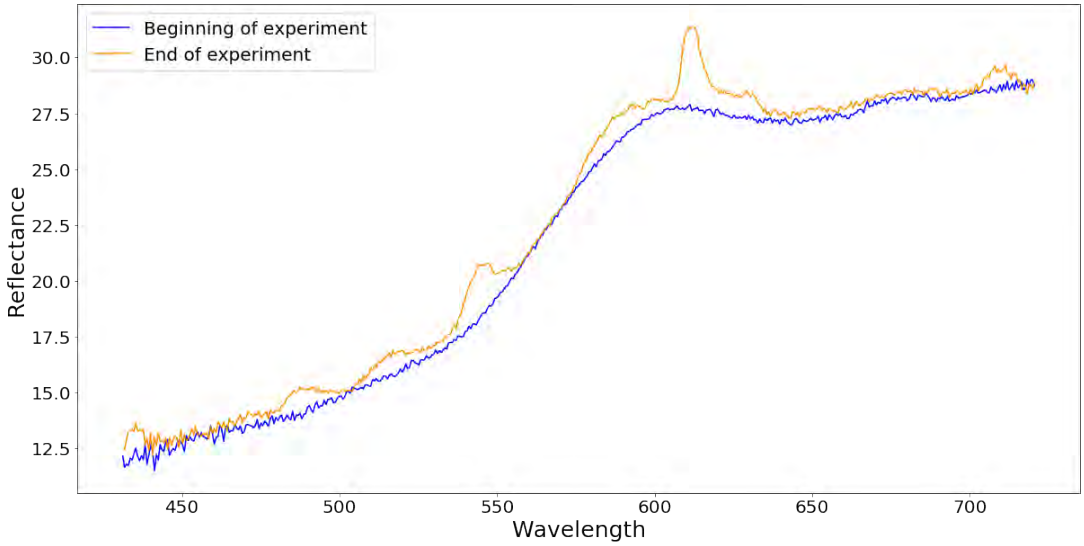

Figure 28: *Spectra showing the reflectance of the control soil samples. Both at initiation and end of experiment.*

11.2 RSL-Experiment corrected Spectra

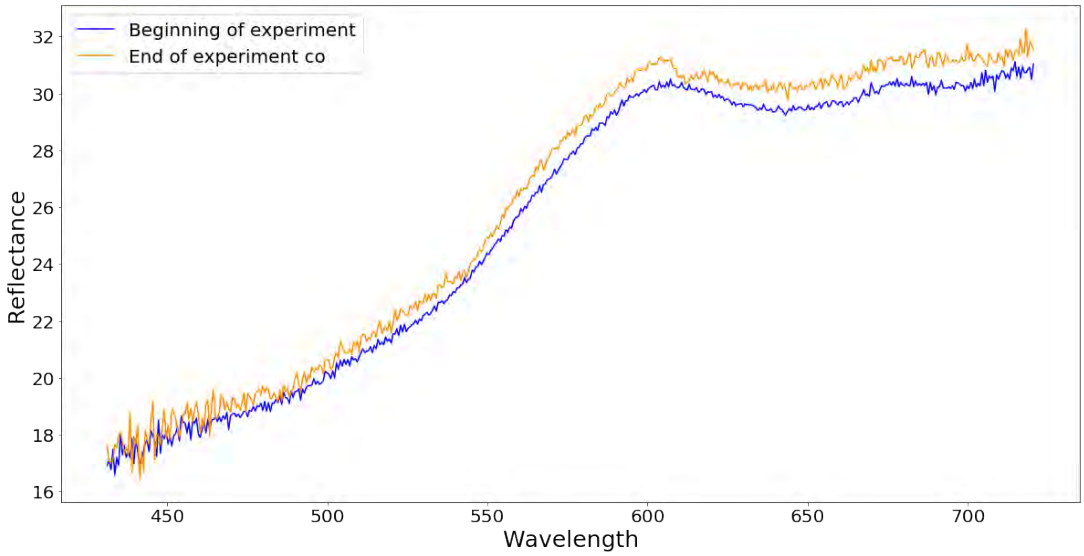

Figure 29: *Spectra showing the reflectance of the soil samples with 1 % perchlorates, where end data has been corrected.*

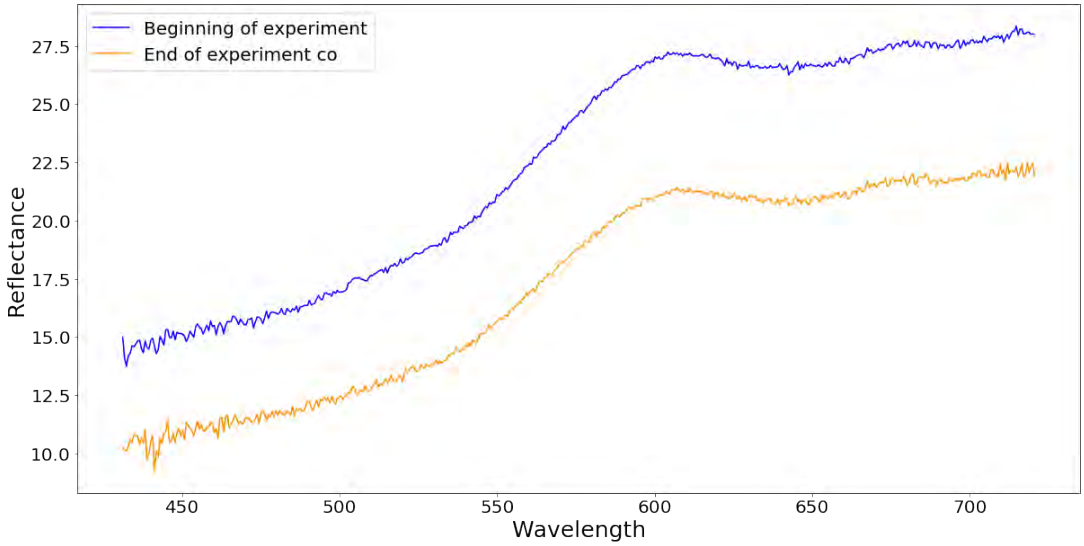

Figure 30: *Spectra showing the reflectance of the soil samples with 5 % perchlorates, where end data has been corrected.*

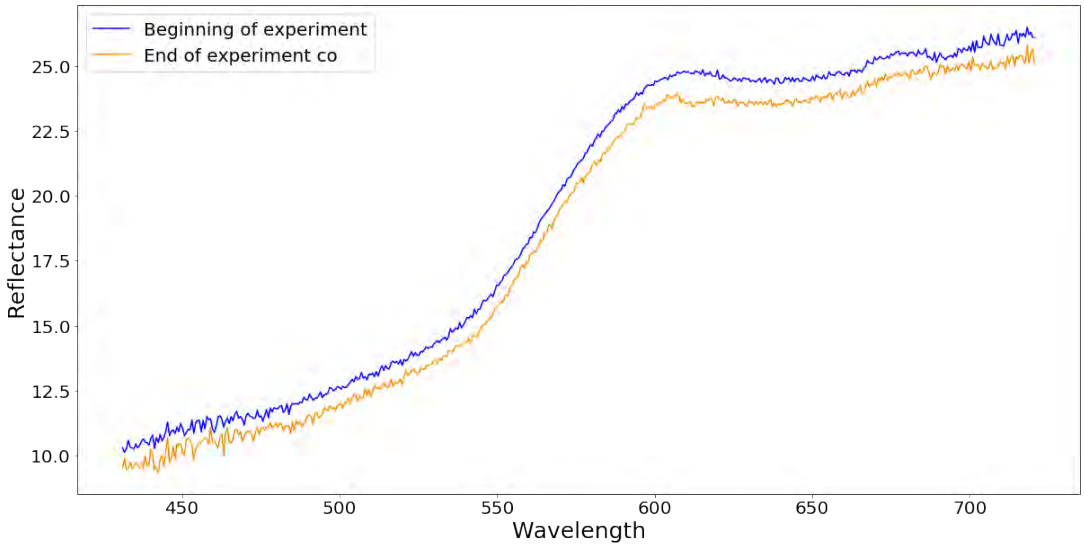

Figure 31: *Spectra showing the reflectance of the soil samples with 25 % perchlorates, where end data has been corrected.*

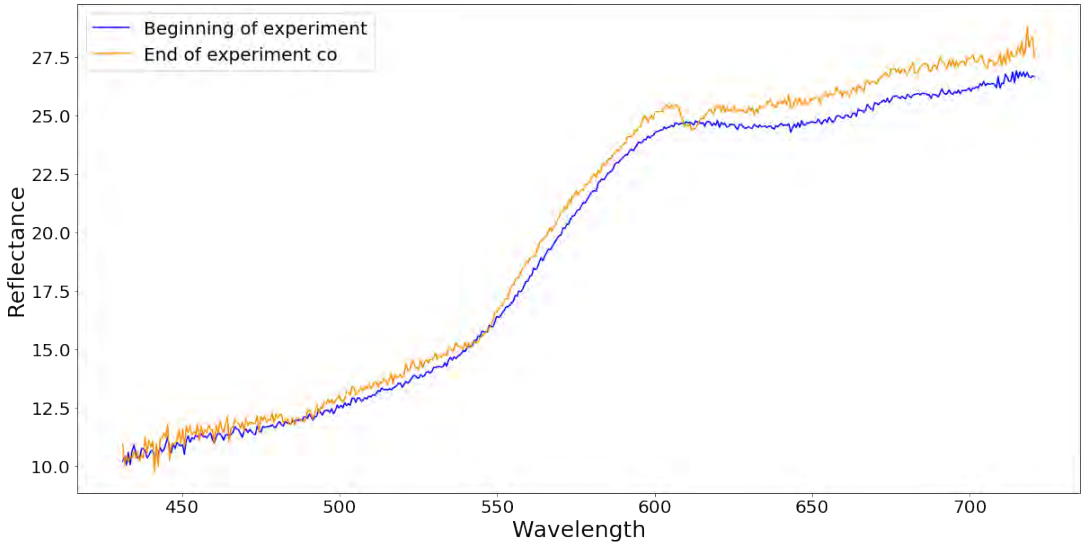

Figure 32: *Spectra showing the reflectance of the soil samples with 50 % perchlorates, where end data has been corrected.*

11.3 Counts for UV-experiment

Isolate 5		
Exposure time [sec]	**Count**	**Dilution**
Control	111	-5
30	135	-5
60	47	-5
90	121	-5
120	23	-4

Table 14: *Exposure time, counts and dilution for Isolate 5.*

Isolate 6		
Exposure time [sec]	**Count**	**Dilution**
Control	93	-4
30	114	-4
60	191	-4
90	195	-4
120	132	-4

Table 15: *Exposure time, counts and dilution for Isolate 6.*

Isolate 9		
Exposure time [sec]	**Count**	**Dilution**
Control	232	-4
30	246	-4
60	355	-4
90	216	-4
120	261	-4

Table 16: *Exposure time, counts and dilution for Isolate 9.*

Isolate 10		
Exposure time [sec]	**Count**	**Dilution**
Control	36	-4
90	42	-4
150	38	-4
210	42	-4
270	36	-4

Table 17: *Exposure time, counts and dilution for Isolate 10.*

Isolate 201		
Exposure time [sec]	**Count**	**Dilution**
Control	223	-6
90	205	-6
150	42	-7
210	36	-5
270	21	-5

Table 18: *Exposure time, counts and dilution for Isolate 201.*

Isolate 202-1		
Exposure time [sec]	**Count**	**Dilution**
Control	36	-5
90	25	-5
150	34	-5
210	258	-2
270	272	-4

Table 19: *Exposure time, counts and dilution for Isolate 202-1.*

Isolate E.Coli		
Exposure time [sec]	**Count**	**Dilution**
Control	220	-6
90	177	-6
150	57	-5
210	172	-6
270	183	-6

Table 20: *Exposure time, counts and dilution for Isolate E.Coli.*

11.4 Bar plots for UV-experiment

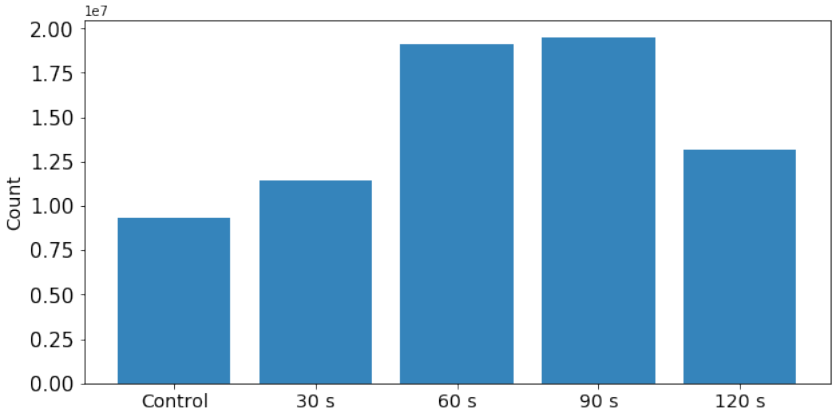

Figure 33: *Bar plot of UV-experiment of Isolate 6, showing the number of bacteria surviving the different exposure times, as well as a control.*

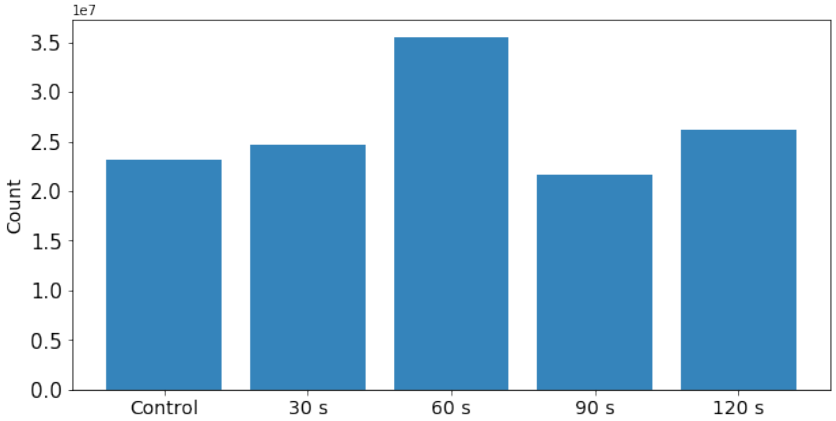

Figure 34: *Bar plot of UV-experiment of the 9, showing the number of bacteria surviving the different exposure times, as well as a control.*

11.5 Counts for each isolates Mars chamber experiment

Isolate 5

Soil/Isolate 5C	Count	Dilution
GSF	47	-3
GSNF	60	-2
GSP	-	-
GF	202	-3
GNF	135	-2
GP	-	-
JF	54	-4
JNF	99	-2
JP	-	-

Table 21: *Count and given dilution for the control of isolate 5C.*

Isolate 6

Soil/Isolate 6C	Count	Dilution
GSF	44	-5
GSNF	241	-2
GSP	-	-
GF	37	-5
GNF	14	-4
GP	-	-
JF	29	-2
JNF	17	-3
JP	-	-

Table 22: *Count and given dilution for the control of isolate 6C.*

Soil/Isolate 6	Count	Dilution
GSF	-	-
GSNF	-	-
GSP	-	-
GF	-	-
GNF	-	-
GP	-	-
JF	-	-
JNF	-	-
JP	-	-

Table 23: *Count and given dilution for the control of isolate 6.*

Isolate 9

Soil/Isolate 9C	Count	Dilution
GSF	40	-5
GSNF	36	-4
GSP	-	-
GF	163	-4
GNF	192	-3
GP	-	-
JF	42	-5
JNF	128	-3
JP	16	-2

Table 24: *Count and given dilution for the control of isolate 9C.*

Soil/Isolate 9	Count	Dilution
GSF	68	-2
GSNF	157	-2
GSP	536	-2
GF	548	1
GNF	8	-2
GP	-	-
JF	18	-2
JNF	2	-2
JP	-	-

Table 25: *Count and given dilution for the control of isolate 9.*

Isolate 10

Soil/Isolate 10C	Count	Dilution
GSF	193	-5
GSNF	35	-6
GSP	-	-
GF	151	-6
GNF	202	-5
GP	-	-
JF	90	-5
JNF	15	-4
JP	-	-

Table 26: *Count and given dilution for the control of isolate 10C.*

Soil/Isolate 10	Count	Dilution
GSF	81	-2
GSNF	24	-2
GSP	4	-2
GF	226	-2
GNF	106	-2
GP	3	-2
JF	75	-2
JNF	-	-
JP	10	-2

Table 27: *Count and given dilution for the control of isolate 10.*

Isolate 201

Soil/Isolate 201C	Count	Dilution
GSF	95	-5
GSNF	135	-3
GSP	-	-
GF	84	-5
GNF	-	-
GP	-	-
JF	150	-6
JNF	189	-2
JP	-	-

Table 28: *Count and given dilution for the control of isolate 201C.*

Soil/Isolate 201	Count	Dilution
GSF	-	-
GSNF	43	-4
GSP	43	-2
GF	242	-4
GNF	45	-4
GP	-	-
JF	164	-4
JNF	495	-3
JP	32	-2

Table 29: *Count and given dilution for the control of isolate 201.*

Isolate 202-1

Soil/Isolate 202-1C	Count	Dilution
GSF	66	-6
GSNF	93	-4
GSP	-	-
GF	171	-4
GNF	208	-4
GP	38	-3
JF	212	-3
JNF	218	-3
JP	-	-

Table 30: *Count and given dilution for the control of isolate 202-1C.*

Soil/Isolate 202-1	Count	Dilution
GSF	18	-3
GSNF	15	-3
GSP	-	-
GF	64	-3
GNF	56	-2
GP	-	-
JF	17	-3
JNF	34	-3
JP	1	-2

Table 31: *Count and given dilution for the control of isolate 202-1.*

11.6 Bar plots for Mars chamber experiment

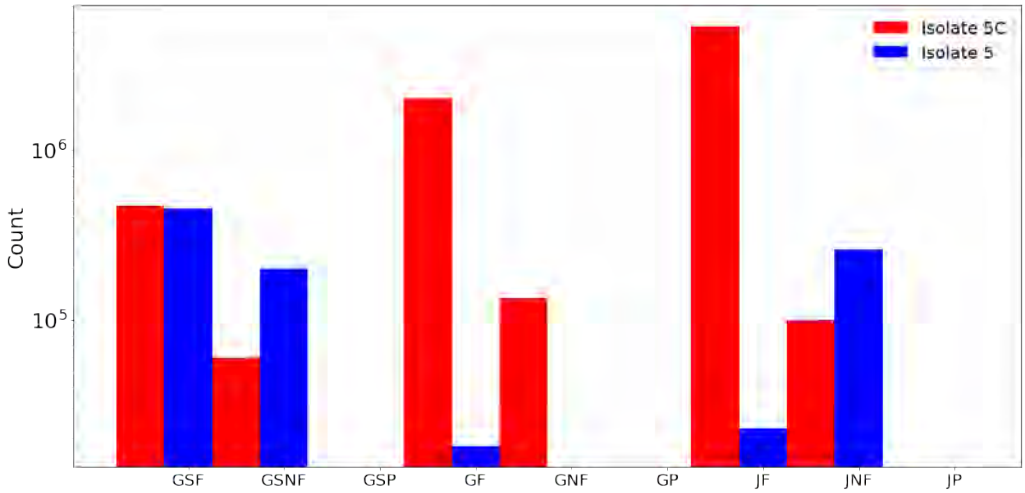

Figure 35: *Counts for both control outside the chamber (C.Isolate 5) and for the experiment conducted inside the Mars chamber (Isolate 5) for each of the soil. GF is test for Gale soil analog with food, GNF is Gale soil analog with no food and GP is Gale soil analog with 1 % perchlorates. GSF is test for Gale soil analog containing sulfates with food, GNF is Gale soil analog containing sulfates with no food and GP is Gale soil analog containing sulfates with 1 % perchlorates. JF is Jezero soil analog with food, JNF is Jezero soil analog with no food and GP is Jezero soil analog with 1 % perchlorates.*

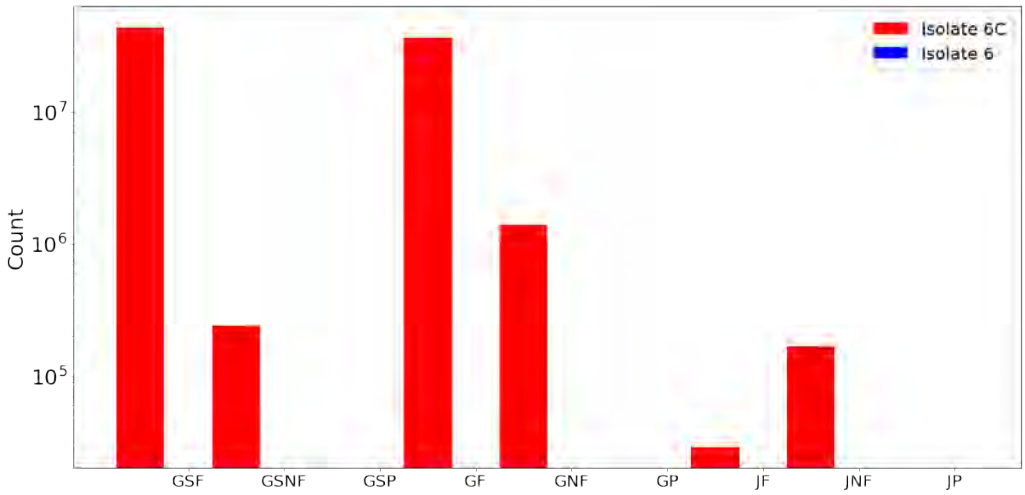

Figure 36: *Counts for both control outside the chamber (C.Isolate 6) and for the experiment conducted inside the Mars chamber (Isolate 6) for each of the soil. GF is test for Gale soil analog with food, GNF is Gale soil analog with no food and GP is Gale soil analog with 1 % perchlorates. GSF is test for Gale soil analog containing sulfates with food, GNF is Gale soil analog containing sulfates with no food and GP is Gale soil analog containing sulfates with 1 % perchlorates. JF is Jezero soil analog with food, JNF is Jezero soil analog with no food and GP is Jezero soil analog with 1 % perchlorates.*

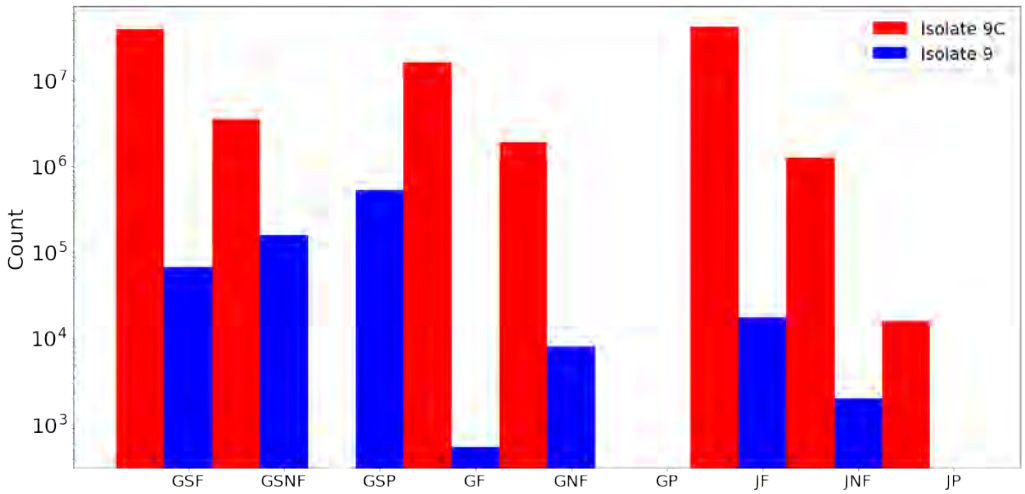

Figure 37: *Counts for both control outside the chamber (C.Isolate 9) and for the experiment conducted inside the Mars chamber (Isolate 9) for each of the soil. GF is test for Gale soil analog with food, GNF is Gale soil analog with no food and GP is Gale soil analog with 1 % perchlorates. GSF is test for Gale soil analog containing sulfates with food, GNF is Gale soil analog containing sulfates with no food and GP is Gale soil analog containing sulfates with 1 % perchlorates. JF is Jezero soil analog with food, JNF is Jezero soil analog with no food and GP is Jezero soil analog with 1 % perchlorates.*

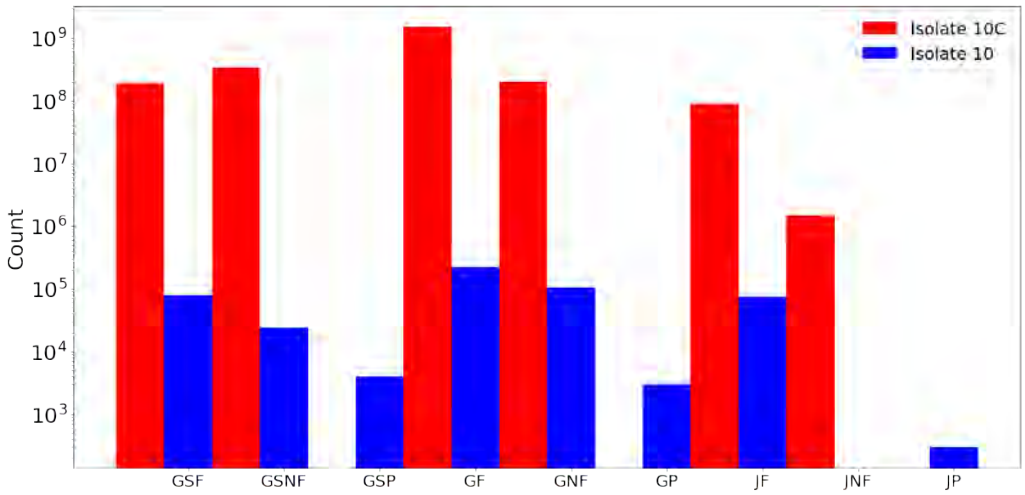

Figure 38: *Counts for both control outside the chamber (C.Isolate 10) and for the experiment conducted inside the Mars chamber (Isolate 10) for each of the soil. GF is test for Gale soil analog with food, GNF is Gale soil analog with no food and GP is Gale soil analog with 1 % perchlorates. GSF is test for Gale soil analog containing sulfates with food, GNF is Gale soil analog containing sulfates with no food and GP is Gale soil analog containing sulfates with 1 % perchlorates. JF is Jezero soil analog with food, JNF is Jezero soil analog with no food and GP is Jezero soil analog with 1 % perchlorates.*

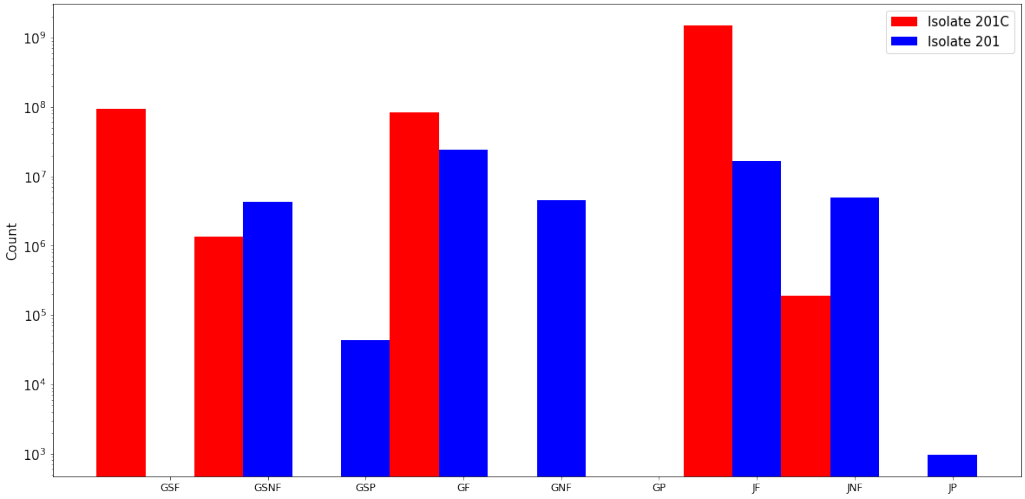

Figure 39: *Counts for both control outside the chamber (C.Isolate 201) and for the experiment conducted inside the Mars chamber (Isolate 201) for each of the soil. GF is test for Gale soil analog with food, GNF is Gale soil analog with no food and GP is Gale soil analog with 1 % perchlorates. GSF is test for Gale soil analog containing sulfates with food, GNF is Gale soil analog containing sulfates with no food and GP is Gale soil analog containing sulfates with 1 % perchlorates. JF is Jezero soil analog with food, JNF is Jezero soil analog with no food and GP is Jezero soil analog with 1 % perchlorates.*

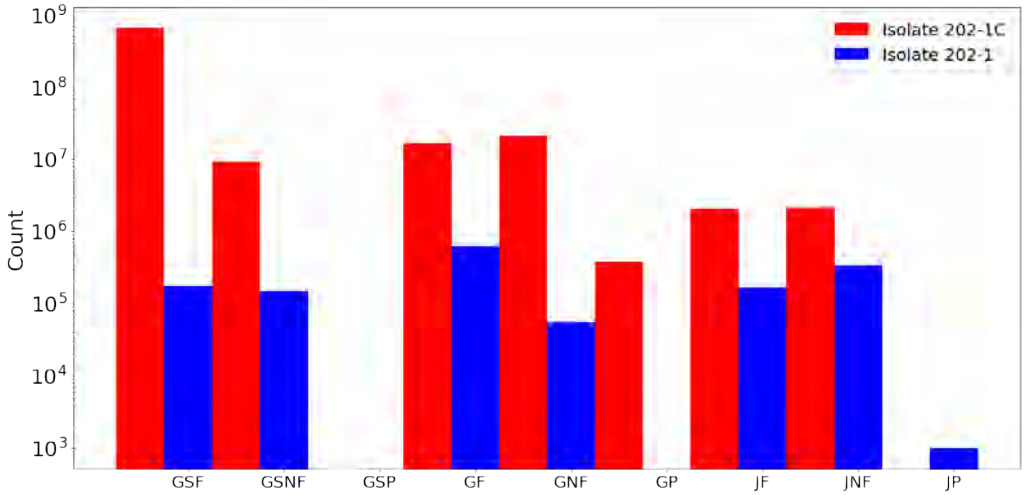

Figure 40: *Counts for both control outside the chamber (C.Isolate 202-1) and for the experiment conducted inside the Mars chamber (Isolate 202-1) for each of the soil. GF is test for Gale soil analog with food, GNF is Gale soil analog with no food and GP is Gale soil analog with 1 % perchlorates. GSF is test for Gale soil analog containing sulfates with food, GNF is Gale soil analog containing sulfates with no food and GP is Gale soil analog containing sulfates with 1 % perchlorates. JF is Jezero soil analog with food, JNF is Jezero soil analog with no food and GP is Jezero soil analog with 1 % perchlorates.*