NEW WORLDS:
COLONIZING PLANETS, MOONS AND BEYOND

Dan Răzvan Popoviciu

Bentham Books

New Worlds: Colonizing Planets, Moons and Beyond

Authored by

Dan Răzvan Popoviciu

Natural Sciences
Ovidius University, Constanța,
Romania

New Worlds: Colonizing Planets, Moons and Beyond

Author: Dan Răzvan Popoviciu

ISBN (Online): 978-981-5080-71-1

ISBN (Print): 978-981-5080-72-8

ISBN (Paperback): 978-981-5080-73-5

First published in 2023.

need for a court order if at any point you breach any terms of this License Agreement. In no event will any delay or failure by Bentham Science Publishers in enforcing your compliance with this License Agreement constitute a waiver of any of its rights.

3. You acknowledge that you have read this License Agreement, and agree to be bound by its terms and conditions. To the extent that any other terms and conditions presented on any website of Bentham Science Publishers conflict with, or are inconsistent with, the terms and conditions set out in this License Agreement, you acknowledge that the terms and conditions set out in this License Agreement shall prevail.

Bentham Science Publishers Pte. Ltd.
80 Robinson Road #02-00
Singapore 068898
Singapore
Email: subscriptions@benthamscience.net

BENTHAM SCIENCE

CONTENTS

PREFACE

Be fruitful and increase in number; fill the earth and subdue it

Genesis, 1:28

Have you ever thought about what makes us, Homo sapiens, so special?

We are not particularly massive nor fast; we do not excel in terms of force or other natural features (claws, teeth, armor...). However, we are versatile, intelligent, and imaginative, with the unique ability to anticipate the future.

And there is more... We have a unique way of interacting with our environment. While any other animal would simply follow natural selection, living and evolving, breaking up into many new species, one for each environmental niche, or simply vanishing, leaving just some fossils, we chose another path. Our intelligence and versatility allow us to change the environment to suit us.

We ploughed the fields and grew livestock. We built villages and cities. Roads and irrigation canals. We ventured through the seas and atmosphere. We drilled into the depths of the Earth, to get useful resources. We created an industry, then, not long after, we stepped into the Post-Industrial Era: that of informatics and high technology. We wanted to know our environment, and we did it in order to tame it.

Maybe the most obvious consequence of these actions is that we are currently a planetary species. And this is not easy! Most species, microbial, vegetal or animal, are distributed only in a limited area here on Earth, with relatively homogenous living conditions. What other being do you know that is able to thrive from the frozen wastelands of Greenland to the Sahara and from the Tibetan Plateau to the Amazon rainforest? The few species close to this achievement are our parasites, crops and livestock!

Today, there is no corner of Earth where our traces are not visible. We are so "pro-eminent” that we even change the world’s climate. More and more call the current climatic era the Anthropocene – the Human Epoch. Is this a good thing? A bad one? Only time will tell...

What is quite clear is that our species is difficult to eradicate. I know that the mass media regularly comes up with catastrophic scenarios, and that (post)apocalyptic novels and movies are popular (I am quite fond of, I admit!). Global nuclear war, unprecedented plagues, asteroids, super-volcanoes, or simply our indifference towards environmental degradation. The sad thing is that all these scenarios are plausible.

The good thing is that no matter how many millions die, a Global species dies hard. We are no less than 7,902,594,207 individuals on Earth while I write this paragraph (at least this is what one of the many dedicated online applications tells me [1], surely other apps give other numbers). While I finished writing the phrase above, 300 new earthlings were born!

Let’s imagine extreme climate warming! Hey, but we can simply move towards the Poles, and we will survive! An ice age? We might just group together near the Equator. A super-pandemic? It would surely decimate urban and other densely-populated areas, but it is unlikely to reach isolated communities in the Arctic or Papua.

Certainly, this does not mean that we are invulnerable. A supernova in our "close” proximity would give us a shower of gamma rays, sterilizing all landmasses and surface waters. A black hole would swallow us, together with the whole planet. Even if we avoid such dangers, in about one billion years, the Sun will "swell”, as its hydrogen reserves get exhausted, turning our home into molten rock. The Universe is a dangerous place where anything can happen.

Do you think I look too far into the future? To much to anticipate when, maybe after a day of hard work, you get home and open this book? You feel that it does not concern you?

Well, you should know that even though extinction is not imminent, an unprecedented crisis is still at our gates! Because we have reached a limit.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The author confirms that he has no conflict of interest to declare for this publication.

ACKNOWLEDGEMENT

Declared none.

Dan Răzvan Popoviciu
Natural Sciences
Ovidius University,Constanța
Romania

CHAPTER 1

Crisis

Population, when unchecked, increases in a geometrical ratio.
Subsistence increases only in an arithmetical ratio.
Thomas Robert Malthus

Abstract:

More than 7.9 billion people currently inhabit Earth, and the population is growing. Halting this growth, although possible, would lead to Global economic and social collapse. Furthermore, the modern economy has a constantly growing demand for resources. Finally, demographic growth is inextricably linked to overall progress. Continuous growth *versus* a limited living space on Earth leads to an unavoidable crisis.

Keywords: Demography, Growth, Malthusianism, Progress, Resources.

1.1. A BIT OF DEMOGRAPHY

That Earth's human population constantly increases is surely no surprise for my readers. According to the current projections, there will be around 10 billion people by the end of this century (Fig. **1.1**).

Is it a big number? Many would say so, and overpopulation is a recurring theme in contemporary public discourse. Others would deny it. A popular meme plots the global population against its density. Briefly, a computer simulation shows that, at an overall density similar to that in New York City, all *Homo sapiens* individuals on Earth would easily fit in Texas (about three times the size of Romania), leaving the rest of the planet deserted [1]!

This is, surely, a valid point of view, just that our problem is not yet that of actual living space. This means we do not need to be afraid that we won't fit on Earth. The real problem concerns resources. No matter how we measure it, Earth's arable land is finite, to give just an example. As the population grows, its area per capita decreases. It is easy to imagine that, in a no so distant future, food production will become insufficient.

Dan Răzvan Popoviciu

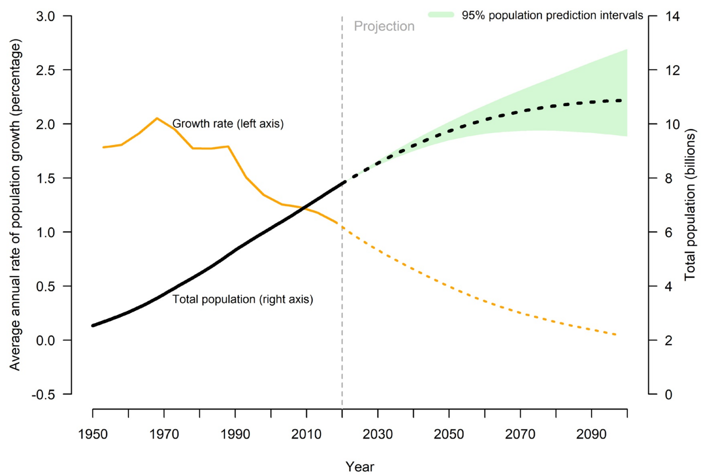

Fig. (1.1). Projected growth of Global human population until the end of the XXI[st] Century [2].

Other finite resources that will cause long-term problems are drinking water and mineral resources. When will they get depleted? Prognosing can be tricky, as the Club of Rome showed us (in 1972, they published a series of apocalyptic predictions for the next future; the next future became present and even past, and predictions did not come true). Still, the idea of finite resources *versus* a growing population is valid.

Throughout history, natural means of demographic regulation functioned. They include plagues, famine, wars *etc.*, basically, mass mortality events. How do you like those? Most contemporary people would consider such events unacceptable for an advanced society, and considering democratic and humanist values.

But the issue remains the same. Someone said that condemning humankind to a perpetual existence within the "borders" of this planet is a Fascist way of thinking. This because the next logical step is to decide who do we have to kill, for the rest of the population to continue living on the same resources.

Is there any alternative? Sure! Even more of them...

Can we stop demographic growth? Can we reach a perfect balance between birthrate and deathrate, one that should stay constant forever? Yes, in theory. If you look at Fig. (**1.2**), you will see that not all of Earth's population grows at the same rate. How can we achieve this? Would it be a wise thing to do? Well, this is an entirely different discussion...

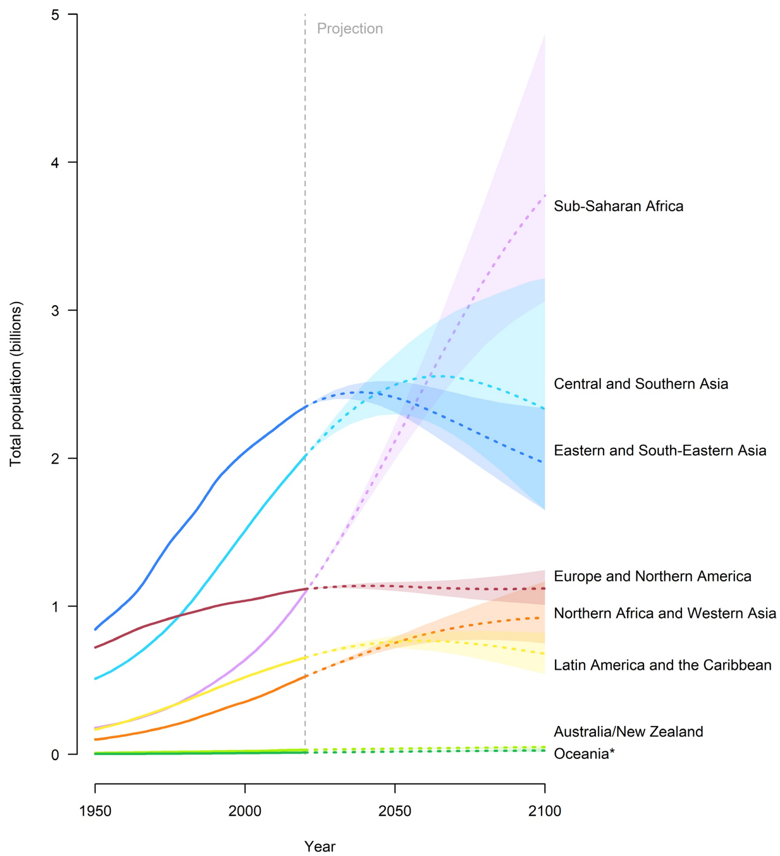

Fig. (1.2). Global population estimated growth, per major regions [1].

There are two ways: the peaceful and the totalitarian.

In the peaceful version, the birthrate steadily decreases due to socio-economic factors. The dissolution of the traditional family, decreasing fertility, raising the cost of living – which, on the one hand, raises the average age for starting a family and, on the other hand, decreases the average children number per couple – the easy access to contraceptive means and abortion, *etc.* All these have led to negative demographic growth in areas like Europe or Japan (even at alarming levels in Romania, for instance!).

The even worse alternative is that some governments enforced active measures to limit their population numbers. The most extreme example is the infamous "one child policy" in the People's Republic of China.

CHAPTER 2

Colonizing Earth

If you look the right way, you can see that the whole world is a garden.
Frances Hodgson Burnett

Abstract:

Currently, the human settlement of planet Earth is suboptimal, roughly covering some 15% of its surface. Remediating this problem involves several approaches. Inhospitable land areas can be "greened" by using modern technology, while the efficiency of current settlements can be improved. But humans could also take advantage of such new technologies to colonize the surface of still water bodies, underground and underwater environments. This enterprise would help us learn revolutionary new ways of providing food, light, heat and electricity to human populations, techniques that would also be applicable to other celestial bodies.

Keywords: Deserts, Green architecture, Seasteading, Settlement, Underground cities, Underwater colonies.

No, you do not hallucinate! No, this is not a typewriting error. And no, the author has not gone mad at least, I don't think so!

Surely, Earth has been our abode, as a species, for over 400,000 years. Fellow human beings live in all its corners. But do we really use it at its full potential?

Look at the image below (Fig. **2.1**).

This is how our planet looks at night. Such images offer a good clue about the global distribution of the human population. Bright areas host large amounts of people, with the most illuminated spots being urban centers. But we can also see almost dark areas. These regions are sparsely populated (or North Korea, for entirely different reasons).

Dan Răzvan Popoviciu

Fig. (2.1). One of the many images NASA offers to the public shows a night view of planet Earth [1].

Actually, of the entire Earth's surface, 71% are water bodies (oceans, seas, lakes *etc.*). Of the landmass surface, half is represented by rather hostile environments: extremely dry areas (deserts, semi-deserts, arid steppes), ice masses and tundras, mountain ranges and high, dry plateaus (Tibet, for instance), swamps and other wetlands, rainforests and dense boreal forests in cold regions of the world.

Simplifying all this, we could say that humankind piles up on around 15% of the planet's surface. What is to be done?

2.1. SETTLING LANDMASSES

Let's take, for instance, deserts – some of the most inhospitable and sparsely populated places on Earth. Environments continuously expand due to deforestation, intensive agriculture, overgrazing and climate changes.

Of course, there are many plans (some already under implementation) to halt this expansion, by creating forest barriers. Planting vast areas in Niger with *Faidherbia albida* (a tree similar to acacia) during the final decades of the last century already led to "re-greening" some 3 million hectares. Over a quarter of a million hectares were returned to agriculture. That means food, economic production and the possibility to populate regions that, in the 70s, were effectively turned into wastelands. For instance, the cereal production in these areas (millet, sorghum) increased by 20-85%, and horticultural production even quadrupled in some cases! And all these by “simply” replanting some trees [2]!

Can we do more? Of course! Especially in regions with natural water resources. One of the most grandiose such projects is the New Valley Project or, shorter, the Toshka Project.

Egypt is one of the countries most affected by the contradiction between sustained demographic growth and low habitable surface. Around 100 million citizens are forced to “crowd” on the narrow Nile Valley and in some other small and relatively wet areas (about 5% of the country!). The rest being, obviously, desert.

In 1997, the Egyptian government conceived a simple project with major consequences. In the southern part of the country lies Lake Nasser (a man-made reservoir created on the Nile). To the west, a rise in groundwater levels, due to water accumulation in Lake Nasser, created a row of new lakes, called Toshka Lakes (Fig. **2.2**). The idea is to drain their water, through irrigation canals, to the north, with the terminus point around Baris Oasis. The final purpose is to expand the country’s arable land by 40%, returning to public use vast areas west of the Nile, in the Southern Desert [3].

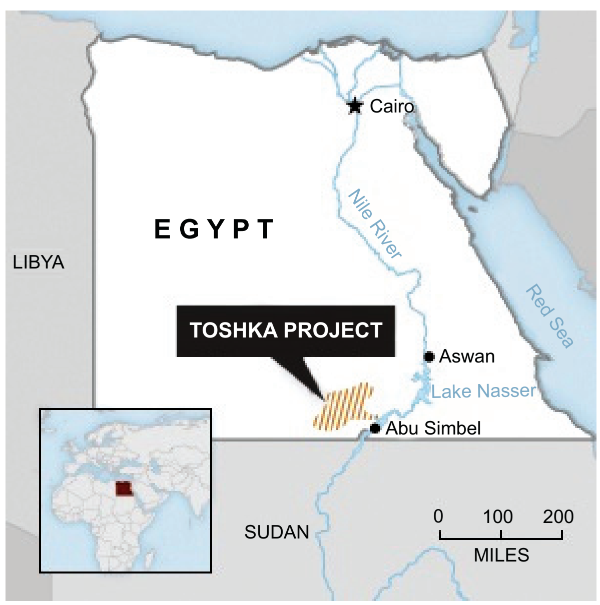

Fig. (2.2). The area to be irrigated and returned to agriculture through the Toshka Project [4].

CHAPTER 3

Baby Steps

Earth is the cradle of humanity, but one cannot remain in the cradle forever.
Konstantin Tsiolkovsky

Abstract:

The first obstacle to overcome in large-scale space colonization is represented by the elevated costs of launching payloads into Earth's orbit. The main reasonable solution is using non-rocket space launch methods, which are rather numerous. In the long term, an even more efficient approach is investing in megastructures, such as stratospheric towers, space elevators or orbital rings, that would dramatically ease our access to space, while also allowing us to harness the energy in Earth's atmosphere. Another strategy to support the space race is to make it profitable through space mining. Asteroids and planets host huge deposits of valuable ores, water and fuels, while technical solutions for extraction are already at our ease.

Keywords: Asteroids, Magnetic levitation, Megastructures, Non-rocket space launch, Space mining.

3.1. BREAKING OUT OF THE EGGSHELL BREAKING OUT OF THE EGGSHELL

The moment has come to look above us! Our planet's atmosphere and the extraterrestrial spaces are neither barriers nor mere research targets, but an ensemble of practically infinite resources.

Earth's orbit is a somewhat familiar environment: more than two thousand artificial satellites are in continuous revolution around the planet, one of them being the International Space Station. Plus a lot of "space junk", of course.

Yet, space launches are not really at our ease. They are not part of our current life. From this point of view, we are in the same situation as our Stone Age ancestors when they started exploring the sea. Some did adventure, but rarely and not far from shore. And there is a reason for all this costs.

Dan Răzvan Popoviciu

Currently, the entire aerospace fleet of humankind is based on thermo-chemical propulsion engines. Basically, the violent oxidation of a certain fuel produces hot gases with a fast dilation, whose ejection generates thrust. However, there is a problem: Earth has a gravitational force that tends to slow down and pull down any vehicle launched from its surface. And there is more: the atmosphere has its own friction force that also brakes spacecraft.

The current solution is to add some extra fuel, in order to compensate for the two hostile forces. But this extra fuel has extra mass, making the vehicle heavier. To propel the supplemental fuel, a new amount of fuel is necessary. This fuel also has its own mass.

You have surely seen images of space rockets. In reality, only their "tip”, the capsule, is the one carrying the payload. The rest are detachable stages filled with fuel. Similarly, for space shuttles, only the shuttle itself and the side boosters are reusable, not the huge external tank.

The overall costs of necessary fuel and building materials are enormous. Launching one kilogram of payload into Earth’s orbit costs at least $12-15,000!

Obviously, there is some recent progress in the field, mostly through SpaceX's reusable rocket technology. For the moment, launch costs have decreased to some $5,000/kg and even $2,000/kg, with the new Falcon Heavy model, and the company leadership aims to a further drop to around $1.000/kg, in the next few years [1, 2].

However, if we really want to become a multi-planetary species, we should probably find a more convenient alternative to classic rocketry. And there are a few useful ideas.

One that Jules Verne would surely find appealing is the ballistic space launch. Basically, we should call in the heavy artillery! The advantage of a cannon is that combustible materials, those creating thrust, are to be found at the ground site, inside the launching device. They do not need to be carried by the projectile, thus no more of that bothering progressive weight increase effect described above.

By "cannon” we could, obviously, mean any explosive ejection device. In 1961, a team of researchers from McGill University, Montreal, led by Dr. Gerald Bull, in collaboration with the US Army’s Ballistic Research Laboratory, initiated Project HARP (*High Altitude Research Project*). Three huge cannons were tested, with calibers of 406-410 mm and 20-41 m barrel lengths. One of them managed to send a 180 kg projectile at 180 km altitude, before the project was cancelled in 1967 [3].

Although HARP was never resumed (the unfortunate collaboration of Dr. Bull with Saddam Hussein was, probably, one of the reasons), there was a second version: SHARP (*Super High Altitude Research Project*), initiated in 1985. In this case, a mixed system, with chemical (methane) ignition and compressed gas (namely, hydrogen), was employed. The projectile was propelled through a 47 m barrel (the primary barrel and the compression pump attached had a total of 82 m!) and launched up to 130 km, at an impressive speed of 3,000 m/s. Only small-sized projectiles (5 kg) were used, SHARP being only intended as the first step towards larger launchers (unfortunately, this project also got "stuck", due to financial reasons, in 1995) [4].

SHARP's "father", Dr. John Hunter, unsuccessfully tried to resume the program as a private venture. Quicklaunch company designed a 1-km-long compression launcher, for massive projectiles. This would have ensured a launch velocity of 6,000 m/s, which would have been supplemented by triggering a rocket engine at a high altitude (11,000 m/s is the escape velocity needed for the escape Earth's gravity). Due to the intense 5.000 g acceleration, this method could be only used for inert materials – satellites, building materials, supplies *etc.* – 9 g being the maximum value our body can withstand.

Still, such a launcher would decrease payload costs to $125-250/kg! But only if its designers manage to raise the initial funding needed [5].

During the same period, scientists in the Soviet Union also researched the possibility of using mega-cannons as orbital launchers. In 1976, T. Bakirov and V. Mitrofanov imagined a *blast wave accelerator* – a cannon bearing circular explosive charges, at regular intervals along the barrel. These would be able to progressively accelerate a projectile, up to incredible speeds. An 861-m-long and 576 mm caliber cannon could launch 1,000 kg vehicles (250 kg being their payload), up to 8,000 m/s.

There is also the possibility of using "mechanical", sling-style acceleration. The *Slingatron*, imagined by D. Tidman in 1995, would be composed of a spiral barrel, subjected to circular oscillations due to engines placed at regular intervals (Fig. **3.1**). There is no need for major oscillation amplitudes for the projectiles to be accelerated at each curve of the spiral. For accelerating a 1,000 kg projectile to an 8,000 m/s launch velocity, a 45-km-long barrel (the resulting spiral would reach 500 m in diameter), 330 mm caliber, oscillating at 75 m/s would be enough. With absolutely no need for any fuel [6]!

CHAPTER 4

The Red Planet

Certain harmonies could be set up here along self-sustaining lines.
You merely have to understand the limits of the planet and its pressures.
Liet Kynes (character of the Dune series, by Frank Herbert)

Abstract:

Among the planets in our Solar System, Mars is the closest to Earth in terms of distance and similarity. However, current environmental conditions on its surface are hostile to any life form. While it provides enough space for sheltered, enclosed settlements, the final goal should be terraforming the Red Planet, which is perfectly achievable at our current technological level.

Terraformation consists of two stages. Ecosynthesis (creating conditions for microbial life) can be accomplished within a century, by a synergistic approach using nuclear blasts, greenhouse gasses, orbital mirrors, thermal aquifer drilling, directed asteroidal impacts, *etc.,* Caeliformation (creating a breathable atmosphere for humans) would take several centuries, involving the controlled introduction of terrestrial life forms and atmospheric conversion through photosynthesis. Even after that, a continuous effort would be required to ensure habitability in the long term.

Keywords: Caeliforming, Ecosynthesis, Mars, Microbial colonization, Photosynthesis, Terraforming, Warming.

Mars has always captivated the imagination of humans and, especially, scientists (Fig. **4.1**). Located at 1.52 astronomical units from the Sun (AU; where an astronomical unit is equivalent to the distance between the Sun and Earth), with a lower mass than Earth and an adequate gravity (0.38 g – 38% of the terrestrial one), having a year of 687 Earth days, with each day surprisingly similar to ours (one terrestrial day and 37 minutes!), Mars is considered to be the most "habitable" planet besides ours.

Dan Răzvan Popoviciu

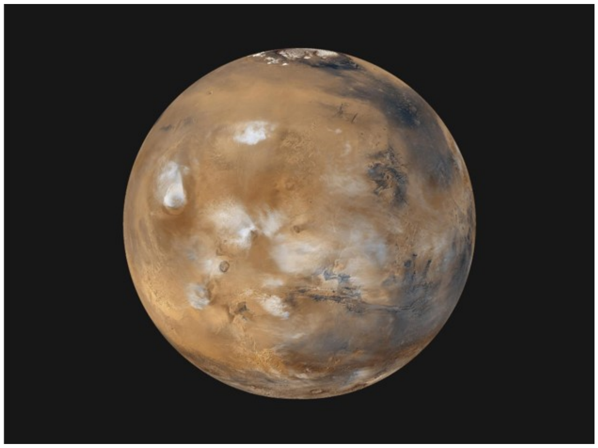

Fig. (4.1). Mars seen from space; the northern polar cap and the huge Valles Marineris canyon are visible [1].

And there is more and more proof showing that hundreds of millions of years ago, the planet had a dense atmosphere, a mild climate and vast water bodies, both still and moving. Maybe even life, who knows? After which things went crazy. We do not know the cause, maybe a major asteroid impact, the loss of the planet's magnetosphere, causing the slow atmospheric erosion due to solar wind. Either way, Mars entered an extreme ice age: the remaining atmosphere froze or got "lost" somewhere in the crust or space, surface water disappeared, and average temperatures dropped to around -60°C (+15°C being the average value on Earth).

Today, Mars is a cold, sterile world, with an atmospheric pressure of 0.8 kPa (compared to 101 kPa on Earth), covered by a red regolith („soil" analogue plus surface rocks), rich in iron oxides but continuously showered by cosmic radiation and unwelcoming to any life form due to high amounts of peroxides. Yet, we know there is groundwater, periodically bursting though the surface (last flow traces are less than one million year old!), water, and carbon dioxide ice in the polar caps and regolith [1, 2].

Although many scientific probes were sent there, the effort to reach Mars never went past this level. Even though there have been years of discussion about possible human missions on the Red Planet, for scientific exploration, exploiting its quite remarkable mineral resources (iron, vanadium *etc.*) and, most of all, colonization.

And one of the main issues here is, again, propulsion. Sending people into space, on a trip that lasts for months, with the chemically-propelled vehicles currently in use, is not really efficient, let's admit!

Fortunately, there are solutions. Ion thrusters, for instance, work by heating an inert gas (usually xenon) using microwaves, until electrons leave their orbits around the atoms, forming ionized plasma, that can be rapidly ejected using electrodes. Such engines were already used by NASA (NSTAR and NEXT projects). They work exclusively outside the atmosphere and allow groundbreaking accelerations, but are more suitable for the small-sized craft.

The main solution to efficient interplanetary transport is VASIMR (*Variable Specific Impulse Magnetoplasma Rocket*), an idea belonging to a former astronaut, Frank Chang Diaz. Its principle is similar but using instead electromagnetic fields for plasma ejection. Such engines are more durable and allow for transporting larger payloads. There are some drawbacks, including relatively low efficiency and issues with purging excess heat. For these reasons (and also political-bureaucratic ones), it never went past the laboratory phase. However, such a technology would allow travelling to Mars in just 39 days, instead of over half a year [3, 4]!

Either way, perspectives look promising enough that private companies, like SpaceX, began planning future Martian settlements [5].

Of course, the first colonies will probably be small mining and industrial settlements. Although many of you have in mind the classic space city under a transparent dome, that was made so popular by SF literature and cinematography, it is more likely for the first colonists to go underground.

Due to the intense volcanic activity in the planet's past, we have enough space at our disposal. We are talking about lava tubes, formed by differential cooling of lava flows: outer layers cool fast, turning into solid rock, while the interior keeps flowing away. We can find such formations on our planet, too, on the Moon and, maybe, on other planets.

Some are really huge: on Mars, such tubes were found to span 250 m in width (it seems a lot, but on the Moon, equivalent structures can be more than 1 km wide, being able to host entire cities the size of Philadelphia!). Their advantage is that they provide constant temperature conditions and radiation shielding (Fig. **4.2**) [6].

CHAPTER 5

New Stars are Born

A big enough hammer fixes anything.
Anonymous (Murphy's Laws)

Abstract:

Another valuable target is at our ease. The two gas giants of the Solar System, Jupiter and Saturn, host their mini-systems of various-sized moons. Among these, the four Galilean moons (Io, Europa, Ganymede and Callisto) and Titan are the largest.

While all these moons can be settled, they do not have enough light and heat to allow terraformation. The way to change this is by helioforming the two gas giants. Turning Jupiter and Saturn into mini-stars would efficiently thaw the major moons, creating atmospheres, hydrospheres and landmasses needed for life seeding.

Once triggered, the process might be even faster than on Mars. At the same time, some engineering effort is needed to correct the rotation rate of these tidally-locked worlds and ensure full human habitability.

Keywords: Galilean moons, Helioformation, Jupiter, Planetary spin, Saturn, Titan, Terraforming.

Considering the Martian example, let's go even farther from Earth!

At over 5 astronomical units (778,000,000 km) from the Sun, the realm of the giants starts. We are talking about the enormous gas planets: Jupiter, Saturn, Uranus and Neptune.

Jupiter has one-thousandth of the Sun's mass (and almost 318 times Earth's). Actually, it is 2.5 times heavier than all the other celestial bodies in the System (except for the Sun, obviously) together! Saturn (located at some 9.6 astronomical units from the Sun) has around a third of Jupiter's mass, while Uranus and Neptune are much smaller (we will put them aside for now).

So, huge and made of gas. Actually, each one has a core the size of Earth, made of rocks and ice. Yet, when the Solar System formed, these planets accumulated eno

Dan Răzvan Popoviciu

enormous amounts of gas, mostly hydrogen and helium, forming successive layers dominated by solid, "metallic", then liquid and gaseous hydrogen (Fig. **5.1**) [1, 2].

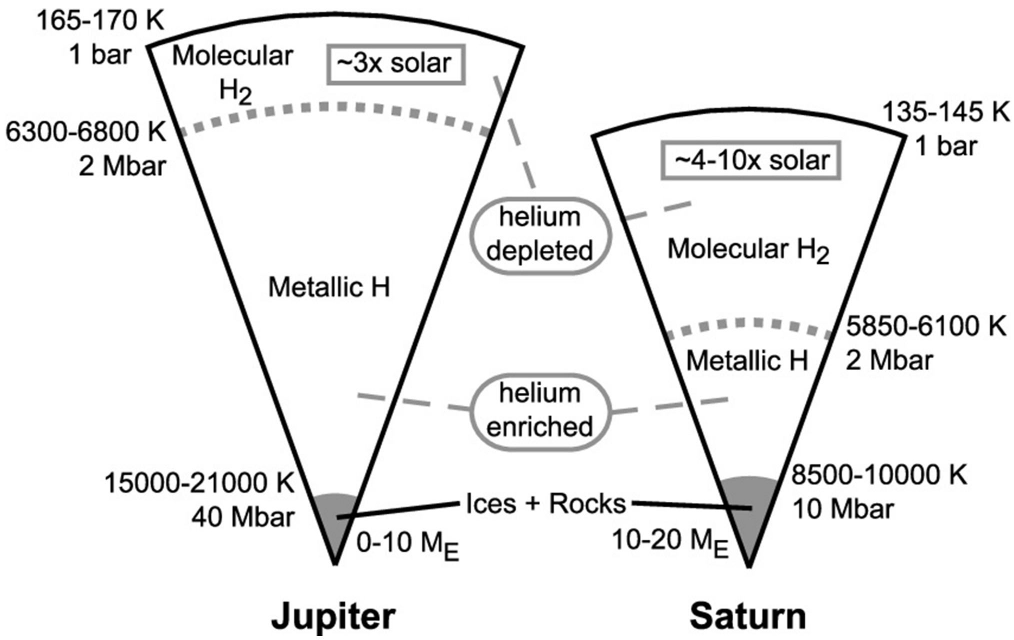

Fig. (5.1). The internal structure of Jupiter and Saturn [1].

These are surely not places where you would want to live! However, each gas giant has its system of satellites, some having impressive sizes. Practically, mini-systems within the Solar System (Figs. **5.2** and **5.3**).

79 natural satellites are orbiting Jupiter, most of them the size of usual asteroids. Four of them, on the other hand, have a remarkable potential for colonization. They are the moons called "Galilean" (named in honor of their discoverer, Galileo Galilei): Io, Europa, Ganymede and Callisto.

Saturn has 82 moons, of which only Titan has reasonable mass and gravity (Fig. **5.3**).

Yet, before initiating any terraforming process, there is a big issue: light. Jupiter and its moons receive flux of sunlight below 4% of the one reaching Earth, and there is not the slightest chance for photosynthesis to occur.

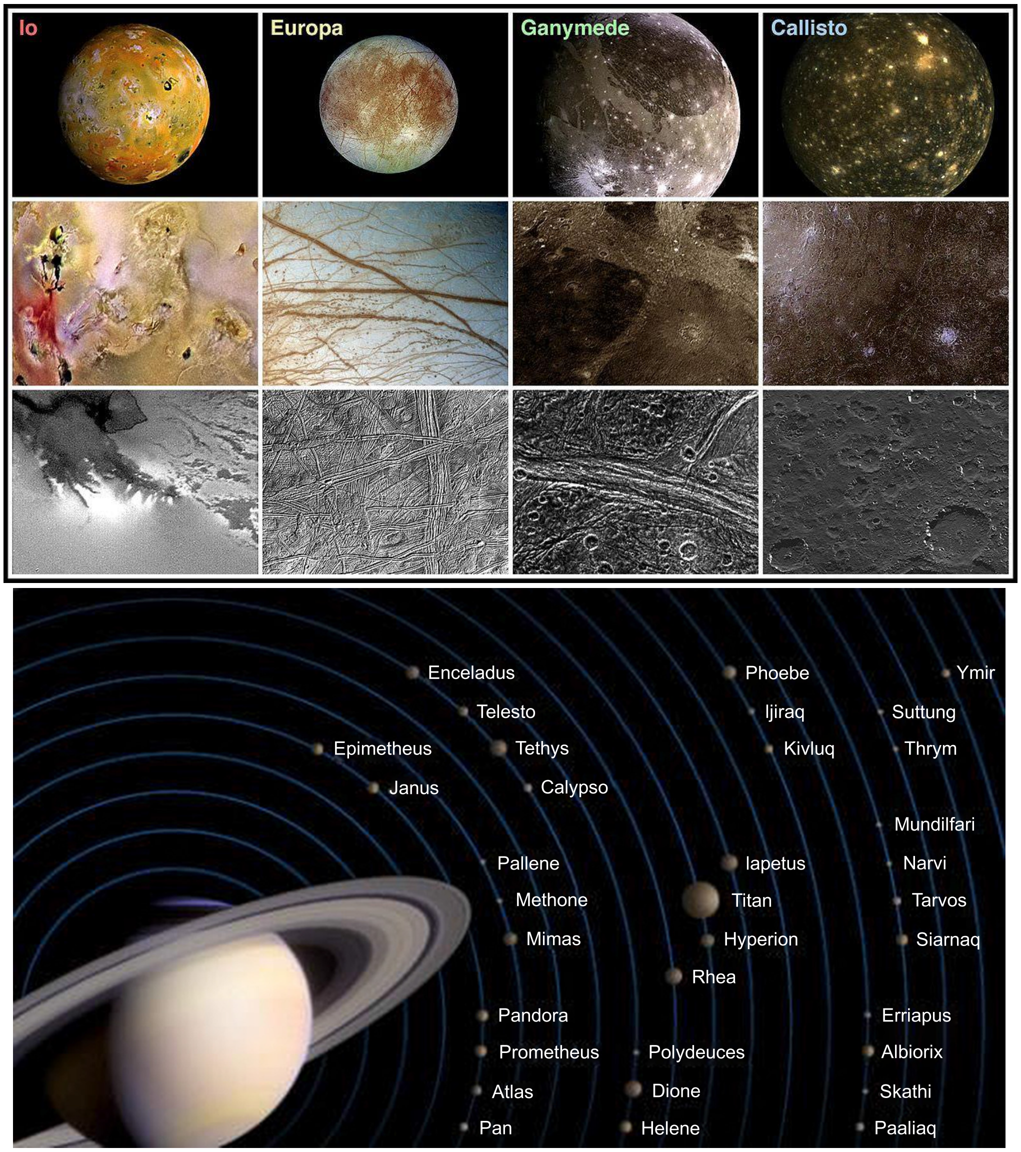

Fig. (5.2). Galilean Moons (the main satellites of Jupiter; with surface images) [3]; the moons of Saturn [4].

There are various proposed means to increase the amount of light, by using permanent orbital reflectors, similar to those used for terraforming Mars [3 - 5]. The problem, in this case, is that we would need some mirrors 12-15,000 km in diameter (wider than each moon itself). And this would be extremely difficult for obvious technical reasons [6].

CHAPTER 6

Close Neighborhood

The face of the Mahdi shall shine upon the surface of the Moon.
Prophet Muhammad
(hadith narrated by M.I. at-Tirmidhi and J. as-Sadiq)

Abstract:

The Inner Solar System hosts several valuable planet-sized objects, that should be targeted by human colonization.

The Moon has the major advantage of being close to Earth, plus also having several useful features, such as low gravity (perfect for space launch) and useful mineral resources. It hosts vast areas suitable for enclosed settlements of limited terraformation. However, there are clues that, in time, it could be fully terraformed.

Mercury is a small, hot and dry planet, a tough target for future colonists. Planetary engineering could also work in these conditions, eventually allowing terraforming, or at least large-scale paraterraformation, under a planetary "shell".

Finally, in the Main Asteroid belt, Ceres could be the easiest terraformable object in the whole System. There are also technical solutions that could turn other planetoids and small moons into new homeworlds for humankind.

Keywords: Ceres, Moon, Mercury, Moons, O'Neill habitats, Parraterraformation, Planetoids, Terraformation.

Seven worlds are undoubtedly better than one. But it would be a pity if we settled for just that.

Towards the center of our Solar System, two telluric planets, similar to ours and well-lightened by the Sun, await us. Even closer, obviously, lays the Moon. An apparently deserted and unhospitable body, but having great economic value.

And it is so accessible to us that it would be really shameful if we did not take advantage and colonize it. The whole Universe would laugh at us!

Dan Răzvan Popoviciu

So, three big worlds. And, let's not ignore more problematic bodies: the large asteroids, like Ceres and Vesta, almost the size of small planets. Or small-sized Jovian and Saturnian moons: Rhea, Dione, Enceladus, *etc.,* There are obvious difficulties concerning their low gravity, but this does not mean that we cannot find suitable solutions.

Until now, Mars and the moons of Jupiter and Saturn taught us how to bring icy worlds to life, how to build up atmospheres, how to create a planetary magnetic field or to accelerate a planetary rotation to a day-night cycle similar to that on Earth.

These methods are partially applicable to the warmer region of the System, together with other specific techniques. For now, we will put aside the "jewel in the crown", Venus, and we will focus on our little neighbors.

6.1. GREEN MOON

At "just" 384,000 km from us lays an orb that has lightened our nights and captivated our imagination since the dawn of time. It is our only natural satellite, the Moon (Fig. **6.1**).

Fig. (6.1). The Moon as seen from Earth [1].

Its diameter is a bit larger than a quarter of Earth's, its mass is eight times lower, while the gravitational acceleration is one-sixth of the terrestrial one (and half of the Martian one). The atmosphere, mostly composed of noble gases, is negligible in terms of mass and pressure.

The average temperature is somewhere around -50°C, but don't be deceived! Extremes reach really unpleasant values: -170°C, respectively 120°C. The revolution period around Earth is 27 days and 7 hours, during which it shows us the same hemisphere. This also means that the daylight cycle of the Moon has the same duration.

Its structure and composition largely resemble that of Earth, out of which it was formed 4.6 billion years ago. The magnetosphere is extremely weak. The surface is arid, with small amounts of ice in the circumpolar regolith, some shaded craters (1.6 billion tons), and other amounts chemically bound to the regolith (up to 0.1% of the total mass). It will have quite an economic potential, in the future, due to ^{3}He reserves [1, 2].

As for the compounds necessary for life, it seems that Lunar regolith is not really rich in carbon (0.001-0.028%, generally as small calcium carbonate inclusions) and nitrogen (0.001-0.016%),[3] even if some findings suggest somewhat higher quantities, under the form of nitrates and ammonium salts. Briefly, it is a poor "soil", when considering nutrient and volatile resources. Instead, it is dominated by oxygen compounds (41-45%), silica, aluminium, iron, magnesium and titanium; free aluminium concentration is actually high enough to induce phytotoxic/inhibitory effects in plant growth experiments on Lunar regolith simulant [3 - 5].

The bottom line is that the Moon is an unpleasant and hostile place. What is to be done?

To start with, the Moon already offers huge sheltered spaces, adequate for early colonization. We are talking about lava tubes, already mentioned in Chapter 4. Unlike their terrestrial and Martian equivalents, low gravity causes Lunar tubes to reach absolutely astonishing sizes. Kilometer-wide ones seem to be widespread, while some even reach tens and even hundreds of kilometers in length [6, 7].

Many of the ones detected until now have collapsed ceilings, but there are clues that such natural megastructures can be stable and keep their initial shape [8].

Such formations could provide an environment sheltered from extreme temperatures and radiation, where the first permanent settlements should be built. And as you can observe (Fig. **6.2**), they would also provide enormous spaces, enough for the future colonists to build entire cities and all the needed infrastructure.

But what about the surface? Considering the differences in gravitational acceleration, respectively in area, in order to have the same atmospheric pressure

CHAPTER 7

A World of Fire

Sometimes, to win you must know how to wait.
Getúlio Dornelles Vargas

Abstract:

Although our planet's "twin" in any other aspect and object of several terraformation scenarios, Venus is a very difficult target for human settlement. Due to its extreme atmospheric pressure and temperature, it is the most inhospitable celestial body in our Solar System.

This does not mean that terraforming it cannot be done, but in order to do it in a reasonable time, some technologies that are currently out of our reach need to be applied. Wormholes are the best option, coupled with some large-scale megastructure buildings, plus "regular" planetary engineering means. Fortunately, even if it seems like SF, scientists are currently making serious advances towards achieving such technologies.

At the end of the process, Venus could be transformed into the most habitable world in our System, a true paradise.

Keywords: Atmosphere removal, Planetary cooling, Sunshades, Terraformation, Venus, Wormholes.

The Latin goddess of beauty, love, fertility and abundance, represented as a gorgeous, but also difficult and moody woman; neither less beautiful nor less difficult is the planet christened after her. We are, of course, talking about Venus, Earth's "twin sister" (Fig. **7.1**) [1].

It has a diameter equivalent to 94% of Earth's, a mass of 81.5% and a gravitational acceleration of 0.9 g. It is located at 0.7 AU from the Sun, and a Venusian year lasts for 224 terrestrial days [2].

It seems that the planet had a pleasant climate for over two billion years, with a reasonable atmosphere and, maybe, oceans and other bodies of liquid water. Then, 715 million years ago, Venus underwent dramatic changes.

Dan Răzvan Popoviciu

There are various explanations: the Sun-Venus relation, crust and mantle features, that prevent CO_2 sequestration, tidal phenomena or a major impact (maybe with its own moon), melting part of the crust and causing chaotic volcanism [3 - 6].

Fig. (7.1). Venus as seen from orbit; in reality, the planets's surface is difficult to observe, due to its dense atmosphere and opaque clouds [1].

No matter what the actual mechanism was, it led to an accumulation of huge amounts of gas in the atmosphere, and the planet literally turned into hell! The atmosphere reached a pressure of 9.2-9.3 MPa (92-93 times higher than the terrestrial one, of which 3.5% is nitrogen and the rest CO_2). The average temperature on the ground currently reaches 464°C! It is quite reliable proof that carbon dioxide has a greenhouse effect and that maybe we should refrain from raising its concentration in Earth's atmosphere!

All water bodies on the planet boiled a long time ago, generating, by reaction with sulfur oxides, bizarre clouds made of sulfuric acid, reflecting around 75% of the incident sunlight but without managing to quench the greenhouse effect [7].

The same apocalyptic event probably changed the rotation speed and direction: Venus has a retrograde spin, lasting for 243 Earth days (a Venusian day is, literally, longer than the year!).

Maybe you wonder why I never mentioned this planet until Chapter 7. Usually, in all terraforming papers, it comes second. But considering the environmental conditions (extreme temperature and pressure, no water, rotation rate), you will agree that Venus is a hard nut to crack.

7.1. HOW TO GET RID OF AN ATMOSPHERE?

It is obvious that the main obstacle preventing habitability on Venus is its enormous atmosphere. Contrary to the Martian case, less atmospheric gas would help us cool the planet, thus allowing life to settle.

There are several proposals, though many are technically challenging.

Paul Birch, for instance, envisions shading the planet, by using a huge space sunshade" (25,000,000 km^2), coupled with enormous vertical atmospheric pipes, to accelerate convection between the upper atmosphere and planetary surface.

Once cooled, carbon dioxide would liquefy under its own pressure, and resulting oceans should be covered by an artificial crust, over which an atmosphere, hydrosphere and biosphere would be built from scratch by importing materials from other regions of the Solar System [8].

It is a rational option, but the resource requirements to build the sunshade (although we might alternatively place swarms of smaller, light-reflecting satellites or asteroidal fragments in the Lagrange L1 point), to hide" the old atmosphere and create a new one are of unimaginable magnitude. Add the risk of permanently living with the equivalent of 9.3 MPa of lethal gas beneath your feet.

There are some other ideas, involving the mechanical removal of the atmosphere. We could trigger controlled impacts, with large-sized asteroids. The energy of each impact would eject some of the atmosphere into space. The problem here is that a large number of impacts are needed. At an average diameter of 16 km, assuming 100% efficiency, 2,000 such objects would be required. But, since efficiency cannot be anywhere near 100%, in the worst-case scenario, we would need two million asteroids to bring the atmosphere to 0.1 MPa [9, 10]!

A related version would involve some major impacts, with objects weighing around 10^{18} kg or more. Practically, about 200 Sycorax-sized objects are used the same way as on Mercury. The volcanism triggered would lead to carbon dioxide sequestration in lithospheric minerals [10].

Then, there is the option of atmospheric mining". We saw, in previous chapters, how a complex of orbital rings and mass drivers can be used to deliver CO_2 and N_2 to other celestial bodies. But we also saw the quantitative drawbacks (Subchapter **4.1**).

CHAPTER 8

The Edges of the System

Never say "it's impossible", but start with, "let's see."
Nicolae Iorga

Abstract:

The Outer Solar System is an enormous region, offering plenty of potential living space and valuable resources for humankind. It comprises Uranus and Neptune with their moon systems, myriads of trans-Neptunian dwarf planets and planetoids including Pluto, Charon, Eris *etc.* and putative planetary or substellar-sized objects.

The most feasible approach for ice giant planets seems to be helioformation, followed by terraforming and colonizing their moons, using methods similar to those that should be employed on Jupiter and Saturn.

Since many other celestial bodies are too far from any light source, turning them into habitable worlds requires altering their orbit. While such a process requires a carefully-planned and sustained effort, it would be made easier by the low mass of these planetoids.

Keywords: Changing orbits, Helioformation, Moons, Nemesis, Neptune, Terraformation, Trans-Neptunian objects, Tyche, Uranus.

Until now, we have studied nine main terraformable and habitable worlds (besides Earth, of course). And at least the same number of secondary terraformable or paraterraformable bodies, plus the plethora of asteroids and small-sized moons suitable for paraterraformation, hosting underground habitats, or O'Neill colonies.

Ten worlds are open to human colonization. At a quite reasonable average of five billion inhabitants for the main planets and secondary ones (like Ceres, Rhea *etc.*), we get a total population of 100 billion people! And, with a bit of effort, we can even increase this number.

Does this mean that we should stop here? Definitely not! The Universe does not just mean the Inner Solar System. At more than 19 astronomical units from the Sun, towards the cold and dark edges of the System, new worlds await us,

Dan Răzvan Popoviciu

offering new resources and new promises. There are the two giants made up of gas and ice, Uranus and Neptune, with lots of moons, larger or smaller. Then, there is a multitude of dwarf planets, including Pluto and Charon, Eris, Sedna or Haumea. Plus, countless tiny and icy objects form the Kuiper Belt and Oort Cloud. And there might be something bigger and more spectacular lurking in the shadows.

Beyond these edges, there is the infinite Universe! So, come along with me on a journey toward new, strange and wonderful realms!

8.1. A KEY DECISION

Besides Jupiter and Saturn, our star system possesses two other giant planets. Once considered *gas giants* and, nowadays, *ice giants*, Uranus and Neptune are two "twin" planets with extremely similar sizes and structures (Fig. **8.1**).

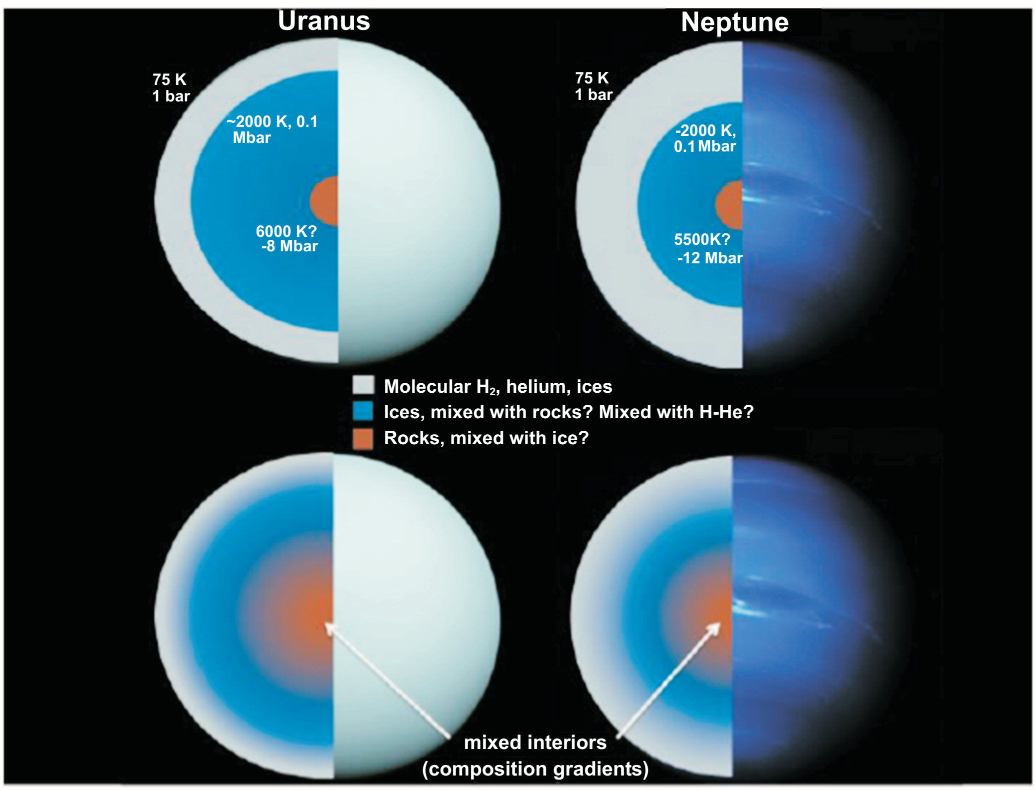

Fig. (8.1). The internal structure of Uranus and Neptune: the layered version and that of density gradients [1].

Located at 19, 30 astronomical units from the Sun, having masses 14.5, 17 times larger than Earth's and colored in different tones of blue, the two enormous planets are somehow different from their larger "neighbors" in terms of mass and composition.

Outside is an atmosphere made of hydrogen (over 70% of its mass) and helium, with an unknown depth. This is because there are several concurrent models of the possible internal structure: atmosphere, "mantle" made of ice and a rocky and metallic core, all of them clearly separate; undemarcated atmosphere and mantle, with separate core; separate atmosphere with undemarcated mantle and core; finally, a continuous density gradient, from the gaseous atmosphere to the solid core, without any clear boundaries (Fig. **8.1**).

Thus, we may either have an atmosphere hundreds of kilometers thick (around 300 km, on Uranus), followed by thick layers of ice (where "ice" is the term used by astronomers for layers dominated by water, methane, ammonia *etc.*, no matter what their state of matter is), or a continuous atmosphere, extending, as far as 80-85% of the planets' radii [1, 2].

And here we have uncertainty and a decision that our descendants will have to make at one point. Are Uranus and Neptune helioformable? So, can we transform them into mini-stars and terraform/colonize their moons? If so, is this the optimal choice, or can we use the two giants in another way?

To start with, the amount of hydrogen in each of them equals just twice Earth's mass. Of course, this means an impressive amount, but compare it to the hydrogen equivalent of 300 Earth's masses, in the Jovian atmosphere [2]!

But the fuel required by nuclear fusion does not necessarily need to be molecular hydrogen! Water and methane can work as well, especially where there is a high enough concentration of deuterium or tritium (^{2}H or ^{3}H). A ratio between deuterium and protium of 1:300 seems to be enough to help propagate an explosive chain reaction [3].

Furthermore, there are current proposals to use methane pellets as a fuel for future fusion power plants [4], including a form called *methane diamond* (crystallized methane) [5], a type of material that seems to naturally occur in the deeper layers of both planets.

As for the ratio of deuterium and protium, it is even higher on Uranus and Neptune than on the other giant planets (where, again, it is anywhere between 10^{-4}-10^{-5}), but lower than in cometary nuclei and even Earth's oceans [6, 7].

CHAPTER 9

Beyond Edges

Indeed, We established him upon the earth, and We gave him to everything a way.
Qur'an, 18:84 [on Prophet Zulkarnain]

Abstract:

Our Solar System represents just a tiny fraction of the Galaxy and the whole Universe. Now we know for sure that many stars host planetary systems, starting with our close "neighbor", Alpha Centauri.

However, the first problem on the way to our Universe-wide expansion is getting there in reasonable amounts of time. This can only be done by faster-than-light travel, which, in turn, needs "bypassing" normal space-time.

There are some ideas on how we could accomplish these, even if research is still at its beginnings.

Until then, thousands of exoplanets were already discovered. Some of them seem to be rather easy to terraform and settle, while others could also be colonized, by using synergistic means of planetary engineering.

Keywords: Alcubierre drive, Exoplanets, Faster-than-light travel, Habitability, Terraforming, Wormholes.

In our journey through the Solar System, we saw that, despite appearances, there are plenty of celestial bodies that could become new homes for humankind. And we do not only mean colonization, but actual terraformation, worlds where our descendants will be able to live, work and dream under the bare sky, together with other countless life forms brought from our homeworld (Fig. **9.1**).

Of course, this is not really a piece of cake, but nor impossible, even with our current state of technico-scientific knowledge. We saw that this task would be easier for some planets and much more difficult for others. With a little will, we could start right tomorrow and finish terraforming processes in a few millennia. But even small asteroids and moons can be turned, with some effort, into habitable spaces.

Dan Răzvan Popoviciu

Fig. (9.1). Artistic vision of a fully-terraformed Solar System (most objects above 320 km in diameter were taken into consideration) [1].

The reward is huge-tens of major worlds and maybe thousands or thousands of minor ones. Enough to host human populations ranging up to thousands of billions!

Should we stop there? We have already discussed, in Chapter 1, the demographic and economic consequences of stagnation. Furthermore, we would not be safe! Here, we depend on the Sun and the few helioformable planets. What happens when their life cycle closes to an end, turning them into enormous, killer fireballs?

Fortunately, the edges of our Solar System do not represent an end, but just a frontier toward a new phase. Because beyond them, billions and billions of stars await us, each with its own system of planets, moons, planetoids and asteroids. An infinite array of homeworlds for *Homo sapiens*!

But first, let's get there...

9.1. Faster Than Thought

It is rather hard for a human being to understand, in an intuitive manner, the distances in outer space. Imagine lying on the beach at Mamaia! Down on a beach chair, watching the sea. And now you take a small melon in your hand.

Somewhere in its center, small as a pinhead lies our Sun. And on the fruit's skin, invisible to the bare eye, is orbiting Earth. Uranus lies in the arms of the neighbor on the beach chair in front of you, while Neptune is one row farther.

The closest star system, Alpha Centauri, is another pinhead, very likely having planetary orbits around. But it is located in Eforie-Sud, some 40 km away!

It seems obvious that we need entirely different means of propulsion to cope with distances of an entirely different order of magnitude. Conventional means even the hypothetical Nemesis/Tyche would be impossible to reach in due time. Ion thrusters or VASIMR technology are of little use: traveling for millennia to reach the closest star is not reasonable.

And no idea involving increased acceleration can work. The Universe does not allow speeds higher than the light's (299,792 km/s). And a body having mass cannot be accelerated up to such speeds, and we should not even try it. Why?

Because it would be inefficient – fuel requirements would increase exponentially, and nobody wants to build spacecraft with fuel tanks the size of Earth! Because it is dangerous – interstellar spaces are not completely void and, at relativistic velocities, even the impact with a dust particle or a tiny group of molecules could result in a memorable explosion. And because it lacks finality – once the target reached, the colonists would find themselves completely isolated from their homeworld; a simple bidirectional message exchange with Earth would take more than eight and a half years! And this is from the closest stellar system!

The only way to solve this problem is to completely "bypass" space. To take a shortcut [1].

An interesting concept in Muslim mysticism is *Tay al-Ardh/al-Makan* ("folding up the earth/space"), while Judaism mentions *Kefitzat HaDerekh* ("shortening the way") [2, 3]. A way of travelling without effectively traversing space, by Divine power and that of one's own mind. Are they just legends or long-lost science? Either way, this would be the path to follow, this time in a more technological manner.

We discussed, in (Subchapter **7.2**), wormholes, as a means to transport things over long distances. Yet, to create a wormhole, we should likely control both ends. So, interstellar travel might require a different solution.

In 1994, Miguel Alcubierre published an article putting forward a revolutionary idea: faster-than-light travel is possible, without breaking the laws of physics. This is because the method he imagined does not imply moving an object through space, but distorting space itself.

More precisely, applying a certain form of energy allows creating a distortion wave that contracts space in front of the object while dilating that behind. Thus, the object would permanently travel enclosed in a space-time bubble, in which its actual movement would not surpass the speed of light in fact, it could not even move at all; (Fig. **9.2**). Velocities (in regard to the universe outside the bubble)

CHAPTER 10

Ethical Issues

We'll never be anyone here. We won't be human here. We won't do anything new. We won't grow. We get sick here. We're degenerating. There's no air.There's no room here. It's cramped in here.

Artyom "Dark" (character of the Metro 2033-35 series, by Dmitry Glukhovsky)

Abstract:

Space settlement, while drawing much support from public opinion, also has its critics. They bring various counterarguments, from the need to "fix" Earth's problems first to the use of nuclear explosives and military devices, which might go against international treaties. However, the main argument is the desire to preserve eventual life forms, including microscopic ones, that might be encountered in the C.

Here, we argue that the highest likelihood is that of life scarcity in our Universe. Life forms are, most probably, rare, usually microbial and living in environmental niches which would not be affected by terraforming. Intelligent life should be even much scarcer.

Furthermore, we argue that space expansion is not just a desire but an imperative for preserving and growing our species and our entire Biosphere.

Keywords: Alien life, Conservationism, Ethics, Intelligent life, Extremophiles, Terraforming, Transpermia.

Beyond this endless Universe, there is nothing. Or is it? Anyway, we have no idea yet. So that this book may well end here.

And I would end it if I did not know that human expansion into space has its critics. Even if, instinctively, the perspective of our descendants creating thousands and thousands of worlds teeming with life, settling them and expanding indefinitely, probably charms the minds and hearts of most readers, we must accept that there are also opposing views.

Dan Răzvan Popoviciu

From the first moment *Homo sapiens* left his ancestral land, wherever that is, spreading all over the Globe and radically altering his environment and his way of life, he had this thought: shouldn't he rather "clumped" in his native homeland?

Of course, it's a joke! No, for millennia, humans did not have such dilemmas. Fortunately, I say, since otherwise, there would have been no progress. You would not read this book, which would have never been written (like no other book would have been written or read, in general). We would be living in an eternal Paleolithic!

The issue of "slowing down" or "temperating" human progress and expansion, as an intellectual solution to the problems of humankind, is a radical response to the sometimes reckless actions of contemporary civilization: pollution, destruction of natural habitats, altering atmospheric composition and climate, war, nuclear weapons testing. It is mostly connected to "Green" politics and thought.

And this environmentalist criticism also extended to human activities in space. You have surely noticed this kind of discourse, in offline or online media.

We discussed, in Chapter 1, the negative and damaging consequences of stagnation, be it demographical or economical. And the solutions put forward for "colonizing Earth" in Chapter 2 always mean a durable development that harmoniously integrates urban, agricultural and natural ecosystems. A planet that is populous and economically exploited at its maximum potential, but is still "green". This is because a chaotic and destructive development, such as that in the last decades, threatens not only wild species, the result of millions and millions of years of evolution, but also the actual health, wellness and prosperity of our own kind of our descendants.

If these ideas will probably not cause much controversy, the situation dramatically changes when we discuss space colonization.

A rather frequently heard but easy-to-respond counterargument is the following: our planet already has plenty of problems; why not solve them first, and then think of other worlds?

The answers are pretty obvious. First, solving social, economic and ecological issues here on Earth does not contradict our cosmic expansion.

Second, as we saw in Chapter 1, colonizing their worlds is essential to the future and even the continuity of humankind! Focusing on one planet only makes us vulnerable and leads to certain extinction. The farthest point reachable is the catastrophic dilation of the Sun, in about one billion years: humans will definitely not survive such an event. But other cosmic cataclysms are lurking around the corner and threatening to send our entire species into oblivion.

Unfortunately, the Universe does not wait for us to solve our problems, and, as we also saw, the process of rendering other worlds truly habitable could take entire millennia!

Yet, the most important and widely-debated argument is that of our interaction with other possible life forms in the Universe. Is there life outside Earth? This is a brief and simple question that is impossible to answer in a precise manner for now.

It can be subdivided into two secondary questions. Are there life forms (of any kind, including microbial ones) outside Earth? But is there intelligent life outside our planet?

Furthermore, there is another way to subdivide each of these questions. Is there life (intelligent or not) independently evolved from the terrestrial one? Is there life (intelligent or not) of terrestrial origin (or sharing a common origin with the one on Earth) on other celestial bodies?

Let's start with the first of these four questions! Is it possible that, somewhere in this Universe, life appeared independently from that on Earth? Since the Cosmos is huge, this is very likely. However, the main issue here is its frequency, which is how likely it is to find alien life, at least within our close neighborhood.

The trouble here is that we only have one example to start with: life as we know it here, on Earth, with its specific biochemistry.

We can just imagine alternative forms of life chemistry. Some researchers already did! For instance, organic structures are based on silicon (or, at least, a mixture of carbon and silicon as a skeletal formula), or ammonia as an intracellular solvent, instead of water [1, 2].

Yet, there is a constant here: organic chemistry, mainly based on light elements, is the only one able to ensure the complexity and plasticity indispensable to life. And there is one more constant: thermodynamics. Towards absolute zero (-273.15°C), thermal agitation progressively slows down, until it completely ceases. And at high temperatures, a high thermal agitation causes various compounds to dissipate, evaporate or melt.

SUBJECT INDEX

A

B

C

D

E

Dan Răzvan Popoviciu

F

G

H

I

J

K

L

R

U

V

W