IAC-21-A3.1.3-65095

"WHY SPACE EXPLORATION WILL BE SOON UNSUSTAINABLE, WITHOUT A SERIOUS CIVILIAN SPACE SETTLEMENT PROGRAMME"

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Abstract

Space exploration was born since the first satellite launch – Sputnik, October 4th 1957 – and developed for more than 60 years. A huge investment of public money was devoted to space agencies, however the high frontier was not yet opened to civilian development.

The cost of Earth to Orbit transportation was artificially kept very high for more than 40 years, to second the lobbies of spendable rockets producers. And it is now only thanks to the Elon Musk's visionary and pragmatic strategy – the rockets reusability – that such cost is finally decreasing, allowing private enterprises to enter the space market area.

Notwithstanding the great success and impetuous growth of the new space industry and market segment, that is paving the path for commercial space activities and eventually space settlement, the whole space agencies' strategy is still mainly based upon space exploration. And the enabling technologies to allow untrained civilians to travel, work and live in space, are still not having the due priority in the research programmes, according to a misconception – that civilian space flight pertains to private industry only.

However, protection from cosmic radiations is a scientific challenge, artificial gravity includes scientific research and experimentation aspects, green environments in space habitats require research by exo-biology and exo-agriculture sciences, just to name a few key examples.

This paper discusses why the advocates of a further space exploration should become the best advocates of space settlement. No doubts that space exploration will always have its importance: what we want to promote is to give proper importance to civilian space settlement, finally.

The differences between exploration and expansion, in terms of feasibility, sustainability, opportunity and social needs will be analysed.

The main rationale is socio-economic: should our civilization remain closed within the boundaries of our mother planet, the multiple crises that are already jeopardizing our economy and culture will likely close the "launch window" sooner than what we could expect until a few years ago. The dramatic climate change, the COVID19 pandemics, and the subsequent deep economic crisis, are a clear demonstration.

In a few years, should the space economy not be vigorously on its road to reverse the multi-crises and relaunch the global economy and cultural renaissance, how can we think there will be funds and enthusiasm for a further self-targeted space exploration?

HUMANITY MODERATELY INVESTED IN SPACE, SINCE 60 YEARS, WHAT'S THE RETURN?

Space exploration was born since the first satellite launch – Sputnik, October 4th 1957 – and developed for more than 60 years. A huge investment of public money was devoted to space agencies, however only during the last years we are witnessing the first sights of the high frontier to be opened to civilian development.

The major space agencies spent about $1.7 trillion, during their history so far. Adding the expenditure of the rest of the space agencies of the world, we can estimate a total of $2 trillions globally invested by Planet Earth governments in space[1]. This is much smaller than space commercial activities, dominated by telecommunication applications.

Such an investment is ludicrous, compared to the insane military global expense, which totals up to 2 trillion per year[2]. However, it represents a meaningful figure, when we compare it to other voices of public expense, such as school, public health and public transport systems.

Did such investment repay the taxpayers? For sure the fallouts on our daily life were paramount important:

not a single aspect of our daily life is unaffected by space technologies.

agency	total expense ($B)	average yearly budget ($B)
NASA	1313,00	20.83
ESA	200,00	4.16
ROSCOSMOS	68,00	2.52
CNSA	66,32	2.65
JAXA	30,00	1.81
ISRO	16,52	0.66
total	1693,84	32.63

Table 1. Total public expenditure in space in history

Yet, is the goal of the space programme only to improve our life on the surface of our mother planet? The requirements of the main stakeholder – the civilization – include another major goal, even more important: to help a sustainable expansion of civilization beyond the limits of the Earth's atmosphere, since 8 billion Earthers can no longer survive and keep on developing on one only planet. As demonstrated by the dramatic effects of the multiple crisis we are facing – pandemics, climate changes, environmental decay, resources shortage and ensuing conflicts, mass migrations – we definitely need one or more "planets B". We are dramatically learning, over our skin, that the only sustainable development is outside our planet, i.e. we need to start expanding into the Solar System, asap.[3]

Respect the above requirement, space agencies are late, and such delay is only in part due to technology constrains.

From 1959 to 1968 NASA developed and tested X-15, the first fully reusable space vehicle, two stages, both reusable. X-15 made 199 flights, of which 18 at suborbital quote: the same concept of the ScaledComposites SpaceShipOne, and the Virgin Galactic SpaceShipTwo, that recently carried 2 pilots and 4 passengers at 86 km. The X-15 spaceplane project was closed. Few years later, the first design of the Space Shuttle (by Krafft Ehricke) was based upon the same concept, but the implemented machine was only partially reusable, as we know.

Should the X-15 philosophy had been continued, we could have reusable launch vehicles since 40 years, at least.

Civilization could be well on its way of expansion in the solar system: Earth orbit industries, cislunar economy, use of lunar and asteroid materials, producing fuel in space. Technology was not an obstacle (as Branson and Musk finally demonstrated), while short-sighted policies and lobbies were huge and heavy burdens for human progress. The cost of Earth to Orbit transportation was artificially kept very high for more than 40 years, to second the lobbies of spendable rockets producers.[4]

During the last years, following the disruptive advent of Space X's reusable rockets, things have begun to change.

In 2018, the total global space budget was $72.18 billion, $72.34 billion in 2019. Over the last three years, governments spent a combined total of $216.27 billion on space activities.[5] Statistics also witness that space civil budgets are overcoming the defence spending. Published in December 2020. Global government space budgets totaled $82.5 billion: civil budgets $50.2 billion, 61 percent of total spending, defence space programs $32.4 billion in 2020. Even more interesting, human spaceflight is the highest-funded space application by governments worldwide at $13.2 billion, overtaking the $11.7 billion invested in Earth Observation (EO) and meteorology, which have been the most popular applications since 2012. Space science and exploration came in third, with a total value of $9 billion.[6]

THE COST TO ORBIT IS FINALLY DECREASING, CIVILIAN SPACE DEVELOPMENT SHOULD GROW ACCORDINGLY

And it is now only thanks to the Elon Musk's visionary and pragmatic strategy – the rockets reusability – that such cost is finally decreasing, allowing private enterprises to enter the space market area.

The cost of transport from Earth to LEO had a first substantial reduction after 2016, from $54,500/Kg. (Space Shuttle) to $2,720/kg (SpaceX's Falcon 9)[7].

With the development of Starship[8], the first fully reusable orbital system, the cost to orbit will be further meaningfully reduced, making the geo-lunar space industrialization and settlement finally feasible and sustainable.

The goal declared by Elon Musk, when Starship will profit of economies of scale, is that Super Heavy will cost under $1 million/launch. Over the years, Starship will cost buyers roughly $20/kg to $30/kg for delivering lunar payloads.[9] It is also easy to understand what such a cost means, when transporting people, as tourists, workers, business men.

The above perspective is fully not understood – if they consider it at all – by the economists.

Notwithstanding the great success and impetuous growth of the new space industry and market segment, that is paving the path for commercial space activities and eventually space settlement, the whole space agencies' strategy is still mainly based upon space exploration. And the enabling technologies to allow untrained civilians to travel, work and live in space, are still not having the due priority in the research programmes, according to a misconception – that civilian

space flight – or commercial space activities, as they are mainly called – pertain to private industry only.

However, there is a number of technologies that should benefit of a higher priority, to prepare the advent of manned space industry and settlement. Protection from cosmic radiations is a scientific challenge, artificial gravity includes scientific research and experimentation aspects, green environments in space habitats require research by exo-biology and exo-agriculture sciences, just to name a few key examples. Commercial space keeps on needing the support of (public funded) scientific research, i.e. space agencies.

The huge potential of the (new) space economy is far from being understood, in terms of its capability to reverse the global multiple crises and kick-off an age of unprecedented growth. Added to the poor understanding, several ideological wings are trying to obstacle, hinder and delay the civilian space development, likely fearing that, with the restart of the global economy, may be missing an opportunity to rethink its strategy of development. Yet, each year we keep on laying on passive strategies, the crisis keeps on destroying the economy and the social environment, paving the way to mafia, neo-feudalism despotic regimes, and all of these without assuring any progress on the ground of protecting the environment. And nobody knows where is the break-event point, where the crisis becomes irreversible, and the "launch window" for the space development will be closed forever[10].

The multiple crises shall be defeated and reversed as soon as possible. Civilian space development is, at the same time, a strategic mean and a goal.

SPACE EXPLORATION VS. SPACE EXPANSION

As evidenced in this comparative table (Table **2**), space expansion will not kill space exploration, while self-targeted space exploration can delay and even hinder space expansion, in the context of a space program void of proper strategy[11].

Several factors are determining the persistence of the space exploration paradigm over its age, and hinder the shift to a space settlement paradigm. The main factor was the aim to protect the bureaucratic privileges of the space agencies: space exploration, as well as space science, can be "sold" to taxpayers forever (that's not true, and we will see why), without any duty to give a return of investment. Space settlement, since it will necessarily involve private initiative and enterprises, will deal with investments, the related return of investment and commercial activities, as it happens on Earth surface. Legitime concerns about environmental issues and the need to setup a legal framework to avoid abuses and "far-west" behaviors can easily end in a delay in the bootstrap of civilian space development. The most aware and pragmatic dealers understood that legal and environmental concerns should better to accompany the settlement, more than preceding it. Settlement should be seen as a historical social progressive process, that cannot and should not be hindered.

Jeff Greason said it clear, in several speeches at ISDC: everybody in the space community agree that we need a change of paradigm, but nobody dares to draw the required need of designing a proper strategy, to set the goal, the milestones and the technological and financial means. In other words, there's a gap, between the current status and the desired space settlement context, and none strategic decisions were taken, to fill it.

As Jeff Greason proposed in a famous speech at NSS's ISDC 2017[12], progressively mining the Moon[13], the Near Earth Asteroids, the Mars Moons and the Asteroid Belt, we can produce fuel in space[14], to be supplied in Earth Orbit, Cislunar Space and so on. Each global infrastructural level we will build, thanks to space fuel, will reduce the cost of missions and investments, making space more and more affordable for private enterprises. All of the stakeholders, the whole civilization in first place, will immensely benefit of such a cosmic renaissance. That's why the advocates of a further space exploration should become the best advocates of space settlement. No doubts that space exploration will always have its importance: what need is to give proper importance to civilian space settlement, finally.

Space Exploration	Space Expansion
Exploration can exist without expansion	Expansion requires more advanced exploration
Exploration is a military concept	Expansion is a civilian concept
Exploration does not require industrialization or the construction of infrastructure	Expansion requires industrialization and construction of infrastructure
Exploration can be done by robots	Expansion requires a coherent enlargement of human settlement, from Earth to nearby space, and progressively beyond
Exploration is done with public money	Expansion requires private investors and companies
Exploration is made of round trip short missions	Expansion is built upon permanent settlements
Exploration doesn't imply growth	Expansion is a global progressive civilization growth
Exploration only gives technological payback to Earth	Expansion assures a continuous structural and infrastructural growth in space
Exploration is based on human life expendability	Expansion requires a continuous evolution of technologies for life and health protection
Exploration allows technology transfer from space to Earth	Expansion requires moving/evolving Earthly jobs to space

Table 2. Space Exploration vs. Space Expansion paradigms, main differences

THE ECONOMY ISSUE, AND THE ENERGY DILEMMA.

The main rationale, in support of kicking off civilian space development as soon as possible, is socio-economic: should our civilization remain closed within the boundaries of our mother planet for other 10 or 20 years, the multiple crises[15] that are already jeopardizing our economy and culture will likely close the "launch window" sooner than what we could expect until a few years ago. The dramatic climate change, the COVID19 pandemics, and the subsequent deep economic crisis, are a clear demonstration. In a few years, should the space economy not be vigorously on its road to reverse the multi-crises and relaunch the global economy and cultural renaissance, how can we think there will be funds and enthusiasm for a further self-targeted space exploration?

The Morgan Stanley unlikely forecast

Morgan Stanley envisages the space economy will be worth 1 Trillion by 2040: as the space economy accesses the next giant leap.[16]

As amply argued in the 2021 Space Renaissance Congress Thesis 1[17], it seems that space tourism has become the most interesting new space activity, proposing access to space for private citizen, space explorers, space adventure programs and others. A big potential is attributed to extracting water, rare minerals and metals from near-Earth asteroids as well.

In the economic forecast (see Figure **1**), the above two activities are worth a small part of the 'Other' segment of the 2040 pie: 52 billions, less than 5%.

The largest slices will go to satellite launch, satellite internet, Government programs for Earth observation, monitoring the weather climate, maritime data GPS. The Government slice, since the 1960's, also includes deep space exploration, Moon, Mars and beyond, Lunar landing, missions to the Moon, building products and infrastructures for Moon missions.

Is it a plausible estimation that the space economy will be worth 1 trillion in 2040?

Is it a practical estimation that satellites and Earth oriented space activities will represent the largest percentage of the space economy in 2040?

Should the space economy figure in 2040 turn out to be the one sketched by Morgan Stainley, we could say that Civilian Space Development will not really have deployed at all. The only effective result would be for the suppliers of satellites and related space services. Humankind would not have had advanced into outer space, the high frontier will remain closed to humans, only to be inhabited by automated machines.

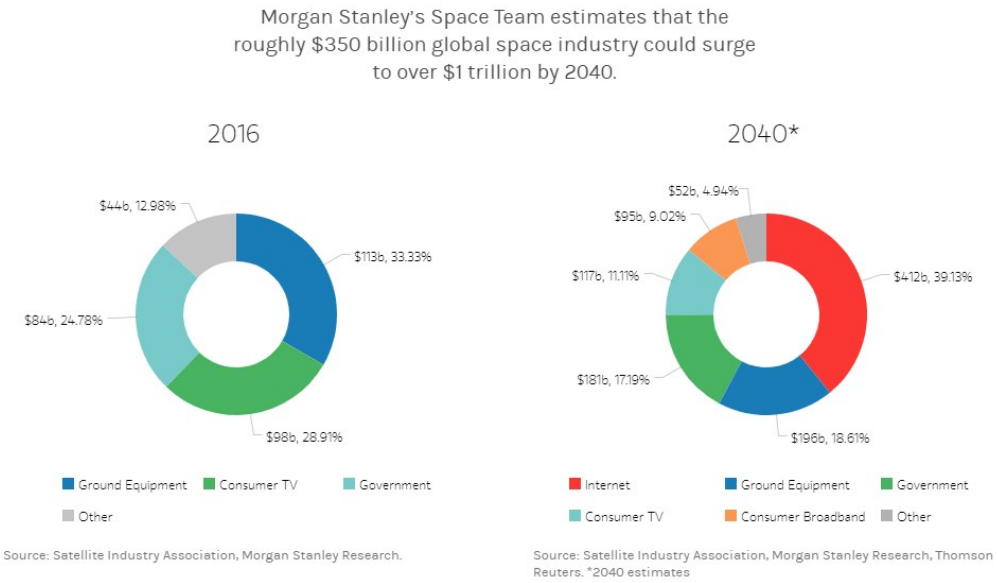

Figure 1. Morgan Stanley Space Team estimation of space industry development to 2040

Should this trend prove to be realistic, it is quite probable that the space economy will never reach 1 trillion, because the Earthly economy will collapse far earlier, before 2030.

Such a forecast makes evident the dimension of our mission: to turn most of the space economy figure, during next 10 years, towards civilian space activities, industry, tourism, health.

If and when a paradigm for Civilian Space Development will lead out the earthly global economy, we will grow in manifold accordingly: this is the greatest opportunity at stake, to initiate such a formative process during next 10 years.

The space economy will not reach the 1 trillion benchmark without being guided by the impetus for Civilian Space Development. The global economy cannot grow anymore within such limited constraints, it will implode, unless it is led by the innovative space economy.

2040: a 3.5 $trillion space economy

If we want to say it in a simple and easy to understand way, we could say "the New Space Economy will save our ass!"

In other words, should the development of the new space economy be hindered or derailed, the global earthly economy will collapse, including all of the previously leading segments.

Alternatively, should the new space economy be allowed to develop according to its great potential, it will lead out the global economy, and all of the earthly traditional segments will be driven and dragged into the renaissance, including telecommunication, tv, broadband, and space exploration. In this perspective, the space economy in 2040 could be worth 3 or more $trillions! (See Figure **2**).

The energy issue

The main killer of the global economy, should the civilization remain closed inside the boundaries of planet Earth, will likely be the energy issue, together with the extreme climate events.

The green transition[18] [19] – largely adopted now by the main powers in the world – is betting all of its fishes on three factors: i) reduction of the CO2 emissions ii) reduction of energy consumption iii) transition to renewable technologies. It is showing more and more evident that such a mostly passive plan is based on a meaningful reduction of the freedom of movement and a supposed further development of the communication via web. See, in Figure 3, the forecast of global energy demand in 2030 and 2040, where, in the scenario of "sustainable development" the energy demand is decreasing.

However, assuming that limitations to freedom of movement were acceptable, the "promise" of a greater availability of network communication is a fairy tail.[20]

The network communication – namely with the higher use of video-communication features – is requiring a huge energy consumption[21]. The same can be said about the use of electronic money, such as credit cards, bitcoin, blockchain, e-commerce[22]. Our future, in the scenario of the world remaining closed, is clearly a future of remaining closed in our homes, and avoiding any "unnecessary" consume of energy: who will decide which are the necessary uses of energy? Who will decide which will be the necessary, proofed, needs to travel?

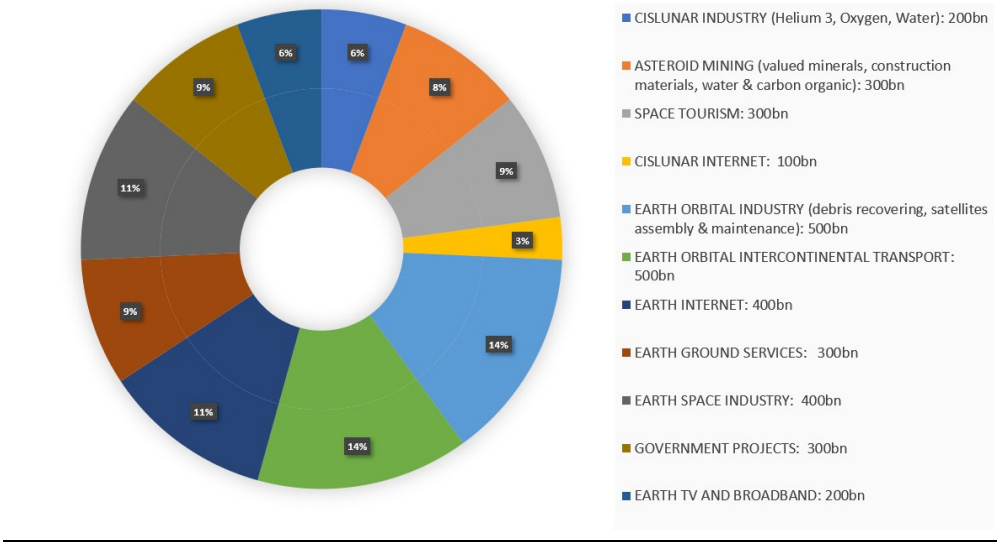

Figure 2. Space Economy 2040, whit Civilian Space leading global economy

Terrestrial renewable energy sources and mobility are controversial[23]. Photovoltaic requires a huge consumption of soil, to be subtracted to cultivation, and leading to desertification of the ground[24]. Electric cars, far from pairing the efficiency of the combustion engines, are all but neutral to the environment, since batteries make a large use of rare elements, and the disposal represent another big environmental issue[25].

We are not saying that the green transition is useless: it can help, at least assuring a few more years of survival to our terrestrial environment. However, civilization will not be safe if we will not take profit of such a grace period by bootstrapping the civilian space development during next 10 years, before 2030.

The sole sustainable solution, to win over the energy issue and many other issues of the closed world, is to start moving industries in space[26]. When the main industries will be off world, the only energy needs to be satisfied on Earth will be the ones of the Earth citizen, roughly a half of the current global energy demand.

			Stated Policies		Sustainable Development		Current Policies	
	2000	2018	2030	2040	2030	2040	2030	2040
Coal	2 317	3 821	3 848	3 779	2 430	1 470	4 154	4 479
Oil	3 665	4 501	4 872	4 921	3 995	3 041	5 174	5 626
Natural gas	2 083	3 273	3 889	4 445	3 513	3 162	4 070	4 847
Nuclear	675	709	801	906	895	1 149	811	937
Renewables	659	1 391	2 287	3 127	2 776	4 381	2 138	2 741
Hydro	225	361	452	524	489	596	445	509
Modern bioenergy	374	737	1 058	1 282	1 179	1 554	1 013	1 190
Other	60	293	777	1 320	1 109	2 231	681	1 042
Solid biomass	638	620	613	546	140	75	613	546
Total	**10 037**	**14 314**	**16 311**	**17 723**	**13 750**	**13 279**	**16 960**	**19 177**
Fossil fuel share	*80%*	*81%*	*77%*	*74%*	*72%*	*58%*	*79%*	*78%*
CO_2 emissions (Gt)	**23.1**	**33.2**	**34.9**	**35.6**	**25.2**	**15.8**	**37.4**	**41.3**

Notes: Mtoe = million tonnes of oil equivalent; Gt = gigatonnes. Other includes wind, solar PV, geothermal, concentrating solar power and marine. Solid biomass includes its traditional use in three-stone fires and in improved cookstoves.

Figure 3. World primary energy demand by fuel and scenario (Mtoe) by IEA

In other words, we need to develop the Jeff Bezos's plan, to progressively move heavy industry in the geo-lunar space, and "terraform" planet Earth as a beautiful natural garden. To do that, we need to assure the Elon

Musk's agenda: developing fully reusable starships, to assure low cost, safe and reliable space transport systems. At the same time, the space tourism venture should not be neglected: this is the sole segment, so far, that is approaching the issue of civilian passengers transportation and accommodation in space, leveraging the civil aeronautic experience to meet the requirements of protecting human life and health, warranting the human rights in space.

THE CHALLENGES BEFORE US

Assuming a large agreement on the need to move quickly toward a change of paradigm, from space exploration to space expansion, which are the needed initial steps? The recently closed 2021 Space Renaissance Congress gave some clear indications[27]. From the Final Resolution, approved by the Congress, June 30th 2021:

- Not going back, but going forward to the Moon[28]: develop proper industrial infrastructure to produce fuel in space, from lunar and asteroid materials, also mining resources such as water, rare earths, precious metals and Helium-3.
- Space debris recovery and reuse[29]. It is not only a necessary and overdue cleaning action. Starting the reuse of space debris is a bootstrapping point for Earth orbit industry, signaling the transition from a worthy public environmental initiative to the first orbital industrial business.
- Enhance life protection in space. Radiation from our sun and deep galactic cosmic rays represent a big threat to health and reproduction[30]. Humans cannot travel and live in space for long time and distances without proper protection.
- Start experimenting with simulated gravity[31]. It can be done by rotating connected modules, as an initial method: we need to learn a great deal about the effects of different diameters and rotation speeds on human perception, psychology and physical conditions.
- Target younger generations to empower their growth and inspire them on their path to space.
- Keep on supporting the development of 100% reusable space vehicles. Low cost, safe and reliable passenger space transportation vehicles.
- Produce food in space. Boost exo-agriculture study and experimentation[32]. Start experimenting with large space habitats and lunar habitats, cultivating food and producing oxygen.
- Space Safety[33]. Protection from asteroids impacts[34] and strong solar storms[35]. Develop radiation protection shields for space vehicles and habitats, in space, on the Moon and Mars. The same concept could apply to Earth protection.
- Support the space tourism industries and their effort to develop civilian space travel and accommodations (hotels), turning the aeronautic experience into profit[36].
- Space Based Solar Power. Inexhaustible energy collected in space, to feed the space industrial infrastructures and to study how to supply energy to Earth surface, as a contribution to clean energy[37].
- Support space related art and bring art into space[38].
- To add an 18th SDG, bootstrap the civilian space development[39], to UN 17 Sustainable Development Goals.[40] In order to make the 17 SDG feasible and sustainable.

Acronyms

acronym	description
CNSA	China National Space Administration
ESA	European Space Agency
IEA	International Energy Agency
ISDC	International Space Development Conference
ISRO	Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
MMAARS	Mars-Moon Astronautics Academy & Research Science
NASA	National Aeronautic and Space Administration
NSS	National Space Society
ROSCOSMOS	Russian Federal Space Agency
SGAC	Space Generation Advisory Council
SDG	Sustainable Development Goals

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