Exploring the nearest destinations in the Milky Way

Basil Evangelidis[1]

[1]Affiliation not available

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Abstract

The present paper examines the possibility of a smart grid to the nearest destinations in the Milky Way, incorporating research data of astrobiology, biosignatures, habitability criteria, proposals for terraforming terrestrial planets, and innovations in interplanetary robotic exploration, energy production and spacecraft motion. We focus on the dynamics of modelling and experimentation, with projects such as interstellar chemical engineering, bio-manufacturing, space sails, fusion, ion thrusters and antimatter propulsion, into the surrounding environments ranging from Kuiper Belt and Oort Cloud to Proxima and Alpha Centauri. The research task is the experimental modelling of current real-world situations in alignment with the past, the present and the future of space exploration.

Dr Basil Evangelidis
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Since time is often the only independent variable in such problems, we must develop strategies for discovery of hospitable places and utilization of energy resources in extraterrestrial level. This purpose recalls research questions of Space Exploration in the fields of second-generation biofuels, fusion, biosignatures, techno-signatures, atomic abundances curve, nucleosynthesis (namely burning of H, He, C, Ne, O, Si, Fe) etc. Nucleosynthesis of helium, oxygen and neon from hydrogen, as well as nucleosynthesis of iron from capture of the overabundant atmospheric carbon and methane could provide precious material resources and promote technoscientific know-how for space exploration. Fusion, anyway, in combination with other efficient means, is a promising technological project for interstellar travel, whereas ethical problems regarding control of nuclear proliferation must also be addressed under this perspective. Utilitarianism, therefore, should be assisted by responsibility and combinatorics.

To handle these problems, we should start building continuities, from the perspective of bridging the distances between destinations in the Solar System and its neighbouring stars. We can distinguish two extreme instances of the maximum and minimum levels of habitability: respectively, naturally habitable environments, such as the Earth, and innovative artificial environments, such as the International Space Station. We could start planning the construction of a smart interplanetary and interstellar grid through an international forum on the thematics of a) robotic space reconnaissance and communication (Davies, 2022), firstly with micro-probes, b) terraforming terrestrial planets and satellites, and c) building wholly artificial habitable stations at interstellar level. In this way, some intriguing and very tricky problems, such as distant communication, or the availability of fuel and appropriate infrastructure for the first return journey(s) from a potential interplanetary or interstellar habitat, could be thoroughly sorted out, examined and solved.

Uranus' distance is 19.8 AU from the Sun and light travels there in 2 hours and 40 min. Neptune is placed around 30.4 AU far from the Sun. Pluto is 39.5 AU from the Sun and light travels in Pluto in 5 hours and 28 min. At 43.3 AU from the Sun, we find Haumea and at 45.8 AU Makemake. At an average distance of 67.7 AU we find Eris, where light travels in 9 hours and 40 min. At inner heliosheath, 122 AU (18 billion km) from the Sun, Voyager 1 mission observed the termination shock boundary, where sun particles are pushed backwards, because of the interaction between heliopause and interstellar medium. Exiguous worlds like Sedna deviate from 76 AU at perihelion to 937 AU at aphelion, since the gravitational influence of the Sun extends beyond its magnetic one, as Ashworth (2015) remarks.

Between 550 AU and 1000 AU we find the incredibly important gravitational lensing point, where a reconnaissance spacecraft can choose an appropriate position to use the Sun as a gravitational lens that magnifies the light of nearby stars and planetary systems. Travelling further away, 63,241 AU equal to one light year (ly). The outer edge of the hypothetical Oort Comet Cloud may be 100,000 AU far away from the Sun; therefore, the Solar System may obtain a diameter of 200,000 AU.[1] Between the outer boundary of the Oort Cloud and visible nearby stars we may expect to discover free-floating unbound planets, nomadic worlds and brown dwarf systems, as Long (2015) supposes. Proxima Centauri is 4.25 ly away, Sirius 8.6 ly, Epsilon Eridani 10.5 ly, Teegarden's Star 12.5 ly away, while the diameter of the Milky Way is 105,700 ly and our Solar System is placed 26,000 ly from its center. Nonetheless, in the center of the Milky Way, radiation would not permit biological life to exist, while on the opposite side of the habitable zone, the planets forming around the stars tend to be gas giants (Czysz et al. 2018).

Within 15 ly around the Sun, travelling a 100-years journey, with a velocity of fifteen percent of light, we could reach at least 58 stars in 39 stellar systems, as Crawford (2015) supports. Potential habitable destinations would be hypothetical planets at Alpha Centauri A and B located 4,37 ly afar, Teegarden's Star b located 12.5 ly far away, Luyten b at 12 ly, Ross 128b, GJ 1061d etc. Further away, Gliese 876 d at 15.2 light-years, given its enormously high temperature, could become habitable only within future technological structures, but Trappist-1d about 41 ly away, may be habitable, while the exoplanet K2-18 b probably contains a molecule (dimethyl sulphide) in its atmosphere, which on Earth is only produced by life.

Among the indispensable parts of the dynamics of habitability we should focus on liquid water, source(s) of energy, like tides and radiolysis, and biologically important chemical elements (C, H, N, O, P, and S or CHNOPS). The principal habitability criteria are the presence of liquid water, conditions favorable for the assembly of complex organic molecules at some time during the planet's history, and energy sources to sustain metabolism (National Academies, 2019). Habitability depends, to a certain

[1] Light travels 1 AU between the Sun and the Earth, in 8 min and 17 s. Jupiter's distance from the Sun is 5.2 AU and light travels there in 43 min and 17 s.

extent, on the large thermal inertia of the oceans and liquid water reservoirs, which mitigate stellar irradiance (Wolf et al., 2020). Furthermore, habitability depends on the presence of a magnetic field, atmosphere and plate tectonics (outgassing and recycling of the atmosphere driven by plate tectonics).

The current fact that we estimate 300 million habitable planets, in our galaxy alone, makes it justified to implement research plans that investigate energy resources, biosignatures and potentially continuous paths across the Milky Way galaxy. From the observational point of view, JWST currently performs spectroscopy on the atmosphere of exoplanets and detects various elements present in their atmosphere. From the theoretical point of view, dynamical systems theory introduces the concepts of manifolds, state space and phase space, fitting better to random elements of observation.

On regard of detectability, the luminosity and the mass of stars are very significant parameters. For main sequence stars, the star luminosity depends to the 3rd-4th power of the star mass, i.e. $L/L_0 = (M/M_0)^a$ with a=3-4 and the suffix 0 referring to our Sun. Red dwarfs, the most abundant type of stars in the Milky Way, are too dim to be seen with the naked eye from Earth. They give off less energy, having cooler temperatures and red light, since their biggest instance reaches only partly the size of our Sun. They are much cooler than our Sun and they are the coolest main sequence stars (they actively fuse hydrogen into helium).

The Hubble Volume is the most convenient measure of the observable universe. While parameters as the light delay play a role in our perception of the universe, we estimate its magnitude as 93 billion light years, with reference only to the observable universe and the Hubble Volume. Redshift, the decrease in wavelength, and the respective redshift value z, provide further evidence for distances into universe. The local universe includes firstly the Local Group, more than thirty galaxies and hundreds satellite and dwarf galaxies, extending around 10 million ly in average. The Local Volume corresponds to redshift value z: 0.002. About 11-30 million ly from the Earth, there are more than five hundred galaxies, such as the Council of Giants, a ring of twelve galaxies, which surrounds our Local Group. The Sculptor Galaxy, a bright starburst galaxy, is found 11 million ly from Earth.

Clearly, there is a vast amount of research data from space exploration on the topics of impacts, symmetries, habitable zone, chemical compositions, atmosphere, climate and geology. They need to be evaluated by a theory of decision based on strategies of reflection on empirical research and cooperation. Modern technological applications, inventions and innovations are being tested for the implementation of the objective to find habitable worlds. Space science and technology, therefore, are focusing on efficiency, computability, polyvalence, feedback control etc. This effort needs, however, to be assisted by a re-evaluation of conceptual, physical and mathematical frameworks, with the adoption of new definitions and new units of measurement.

An example of the requirement for conceptual re-evaluation is the increasing significance of astrobiology, as it is exemplified by the quest for water, life and habitable planets. Hereby philosophy of physics meets the philosophy of biology, since the concept of life could be revised by space exploration, while ethical problems on the value of space medicine, health and information arise, as well.

An instance of the demand for reflection on mathematical terminology is the task for an efficient motion of spacecraft to the interstellar medium, to Proxima Centauri b and other exoplanets. Such a task should require the adoption of new units of measurement, for instance, of the magnitude of 6.000 km/s (30 times faster than the Parker Solar Probe), being thus better comparable to the speed of light (since 6.000 km/s equal to 1/50 or 2% of the speed of light).

Moreover, a crucial challenge to reflection is the role of magnetosphere, magnetic fields and dynamos for the development and the motion of the planets of our solar system and exoplanets. A successful procedure to explaining the contribution of the magnetic field to planetary dynamics may help us answer serious scientific questions and probably may contribute to the discovery of a new unified physical theory of everything.

It is remarkable that the scientific definition of a star is a “collection of hydrogen (with traces of other elements) that is so large that is has collapsed under its own weight, causing hydrogen fusion in the core and making the whole object glow.”[2] According to spectrometry data, hydrogen and helium comprise more than 98% of observed galaxies and stars.

The Dyson Sphere[3] is a relevant research concept that was proposed in the framework of the Search for Extraterrestrial Intelligence and Technology (artefact SETI as complementary to communication SETI). A realistic application of the Dyson Sphere should be feasible through the development of a unified super-smart grid connecting Earth with extraterrestrial places.

Evidently, interstellar journey requires immense amounts of energy. An interstellar journey to Alpha-Centauri that would last 15 years should reach a 64% of the speed of light and specific impulse of $1.97 * 10^7$ s. Pioneer 10, Pioneer 11, Voyager 1 and Voyager 2 and several other space missions were powered by radioisotope thermoelectric generators (RTG). Future interstellar missions have been also proposed to be propelled by chemical propulsion, electrodynamic tether, ion thrusters, solar sails or sailcraft, combination of nuclear reactor and ion engine, combination of rocket and laser propulsion, nuclear electric propulsion, laser beam lightsail, plasma,

[2] HarvardX: SPU30x: Super-Earths and Life, Glossary.
[3] Dyson, F.J. (1960). “Search for Artificial Stellar Sources of Infrared Radiation.”

full fusion (magnetic, inertial, electrostatic-inertial, magnetic-inertial), magneto-plasma-dynamic thrusters and magneto-shell shields, swarms of laser sail probes for the advancement of communication, matter and antimatter annihilation (probably with positronium utilisation), photonic propulsion, impulsive propulsion etc (Bruno & Matloff, 2013; Czysz et al. 2018; Long, 2015).

The energy produced by plutonium fission is 82 TJ/kg, while Uranium-235 has a specific energy of 144 TJ/kg and tritium reaches 576 TJ/kg, while undergoing deuterium-tritium fusion reaction. The energy per unit mass available from ^{235}U fission is approximately 10^7 times larger than in combustion. Nuclear energy, therefore, can afford not only speeds at least ten times faster, but also at nearly constant acceleration, as Czysz et al. (2018) point out.

Moreover, nuclear fusion of Hydrogen and its isotopes releases energy 3 or 4 times larger, per unit mass, than ^{235}U fission, as Bruno and Matloff (2013) suggest. Nuclear fusion occurs when the repelling forces between protons are overwhelmed by high density and extremely high kinetic energy (temperature), through gravitational compression and radiation pressure of very hot plasma. An advantage of nuclear fusion is the relative abundance of its fuel, namely, hydrogen, deuterium and lithium.

Further important facts about energy resources refer to the electric fields created by the uneven distribution of electrons in polar molecules, such as water. Water vapour, methane, ammonia and hydrogen gas exist on other planets in our own solar system, as well as in interstellar clouds. According to measurements of the Sun's composition[3] and chemical thermodynamics, the most abundant species in the initial material of the solar system and probably of the molecular cloud core collectively pertain to the category "HCON", namely, hydrogen (H_2), carbon monoxide (CO), water (H_2O), nitrogen (N_2), together with similar ones, and the noble gas helium (He). However, HCON and noble gasses comprise a lower part of Earth's mass.[4] This is a first asymmetry of chemical composition, as Earth's mass comprises iron (35%), silicon (15%), magnesium (13%), nickel (2,4%). Carbon corresponds, however, only to 0,025% of the mass of Earth's crust, whereas the percentage of oxygen in the mantle and the core of Earth is nothing more than a conjecture.

Oxygen is generally considered as a sign of life and biosignature of habitable exoplanets. While Oxygen corresponds now to 1% of the mass of the universe, Hydrogen comprises 73-74% of the visible universe and Helium 25%. The Sun also is mainly composed by Hydrogen (~73%) and Helium (~25%), whereas the rest elements are mostly Oxygen, Carbon, Neon and Iron. This is a second asymmetry, because of the higher abundance of Oxygen in human body (65%) and in the Earth

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[4] According to Wikipedia, around 90% of the mass of the Earth is composed of the iron–nickel alloy (95% iron) in the core (30%), and the silicon dioxides (c. 33%) and magnesium oxide (c. 27%) in the mantle and crust. Lower contributions are from iron oxide (5%), aluminium oxide (3%) and calcium oxide (2%), besides numerous trace elements (iron and oxygen c. 32% each, magnesium and silicon c. 15% each, calcium, aluminium and nickel c. 1.5% each). Carbon accounts for 0.03%, water for 0.02%, and the atmosphere for about one part per million.

(48,8%), since it is playing a dominant role as a biosignature gas. A spontaneous remark refers to the increased abundance of Oxygen in developed life compared with H and He, while our solar system contains considerable amounts of water.

Another related question is “where did other elements -apart from H, He and Li- like carbon, nitrogen and oxygen come from?” Some researchers point out to the 13.7 Gyr of the alleged age of the universe, after the so called “Big Bang”. Temperature is the pivotal factor, for instance, in the plausible fusion and fission processes of Fe and in the role of supernovae for the nucleosynthesis of elements after Fe.

Regarding the parameters of the Drake Equation, nowadays we have adequate information for the average rate of star formation in our galaxy, the fraction of those stars that have planets and the average number of planets that can potentially support life per star with planets. However, we don’t know yet the fraction that actually develop life at some point, the fraction of planets with life that actually go on to develop intelligent life (civilization), the fraction of civilisations that develop a technology that releases detectable signs of their existence into space and the length of time for which such civilisations release detectable signals into space.

Moreover, the research of the findings and the potentials of space exploration in regions distant from the Earth may help us to start solving riddles about thermophiles, extremophiles, birth of life, outcast stars, rogue planets and intelligent aliens, while advancing innovations in energy production and spacecraft motion such as gravitational boost, parabolic and hyperbolic orbits, ion thrusters, etc.

Finally, the engineering advancement is one of the most demanding aspects of interstellar flight, as the proposal of warp drive showed. Since fusion or antimatter propulsion cannot alone achieve the required tremendous increment in Delta-V and specific impulse (namely 300 times faster than the ones being currently built), ultra-light and ultra-strong nano-materials production, appropriate innovations in machine architecture, interstellar ramjets, high-level improvements of motors and turbines, and sufficient leaps in propulsion design shall also stand as significant hallmarks of future interstellar travel.

Resources

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