The cynosure of space exploration

Announcements about a forthcoming opera by Jennifer Walshe (*inter alia* Fellow of Worcester College and Professor of Composition in the University of Oxford) set on Mars has attracted much interest, as reflecting renewed excitement in exploring other planets, manifested not only by the well-publicized current flurry of activities spearheaded by the so-called “tech billionaires” such as Elon Musk, but also by strong interest among students, as evinced for example by the new master’s study programme launched last autumn by the ETH Zürich.[1] Such developments have brought space exploration back into the same prominence that it enjoyed in the decades immediately following World War II. That was indeed a time of pioneering excitement, epitomized by the scientific and literary work of Arthur C. Clarke, sometime chairman of the British Interplanetary Society (BIS, founded in 1933).[2] My father, a fellow of the BIS, and fired by the same euphoria of interplanetary and, as he often emphasized , interstellar exploration as an even more inspiring goal, had settled in Buckinghamshire to work at the Rocket Propulsion Establishment (RPE) at Westcott, newly established by the British government under conditions of great secrecy (it was not even marked on maps). For much of this time we lived in a purpose-built townlet—essentially a little colony of German and British scientists and engineers—the atmosphere of which was presumably similar to those of Soviet cities devoted to science and technology like Arzamas-16—albeit on a very small scale. The Germans had been brought over after the end of World War II to boost British efforts in developing space rockets, much as others had been brought to the USA and USSR. Some of the books in our library particularly attracted my attention—most memorably one containing photographs of paintings by Chesley Bonestell, both of the relatively familiar planets and moons in the solar system as well as of what are now called exoplanets [1]. Most of the book contained text by Willy Ley (one of the first members of the VfR), very engagingly written and well accessible to a science-minded schoolboy (far more so than the highly technical works like Sutton’s *Rocket Propulsion Elements* or Stemmer’s *Raketenantriebe* [2,3]. I read Ley’s text very thoroughly and found the interspersed reproductions of Bonestell’s paintings highly inspirational. Such books, conversations at home and the frequent interactions with our English and German neighbours imbued me with the “life scientific” as a matter of course. The launching site for the rockets was at Woomera in South Australia; some of our neighbours had done turns of duty there, which added a further exotic touch to our environment.

RPE was highly successful, developing the first stage of the three-(later four-)stage rocket of the European Launcher Development Organization (ELDO). This project was unfortunately repeatedly let down by failures of the following stages, developed by the other European partner countries.[3] Black Arrow, an all-UK project, successfully launched a satellite (Prospero) from Woomera in 1971, just after the project (and the entire independent UK space effort) had unfortunately been cancelled on economic grounds—the government of Edward Heath having concluded that it was cheaper to launch UK satellites using US rockets. ELDO morphed into the European Space Agency (ESA), which went on to develop the successful Ariane launcher with France as the leading partner (hence the launch site became Kourou in French Guiana). Unsurprisingly, the cancellation of Black Arrow caused profound disappointment at RPE. The old pioneering excitement was irrevocably lost, and while research continued for military applications, this exclusive focus brought ethical considerations into play and many of the staff could not wholeheartedly approve of this change of direction. Morale was further eroded by frequent administrative reorganizations—the establishment successively came under the Ministry of Supply, the Ministry of Technology, the Ministry of Defence &c., and repainting signs and

1 “Kaum ein anderer Lehrgang der ETH Zürich hat so viel Aufmerksamkeit erregt” (GLOBE 4/2024, p. 26).

2 A society with similar aims (Общество изучения межпланетных сообщений) had already been founded in 1924 in the USSR, reflecting the veneration accorded to science in both the official and the popular minds. The Verein für Raumschiffahrt (VfR) was founded in Germany, probably then the leader in rocketry, in 1927. In the USA, the American Interplanetary Society was founded in 1930.

3 ELDO was formally created in 1964. The first launch of stage 1, based on the earlier Blue Streak rocket, which had been cancelled in 1960, failed but the second in the same year and the third in the following were successful. Thereafter there were seven launches (one or two a year) of the complete rocket, named Europa-1; stage 1 functioned successfully in all of them. The first two had dummy stages 2 and 3 and payload; the real stage 2, “Coralie” built by France, failed on the next two (with dummy stage 3 and payload) but was thereafter successful. Stage 3, “Astris” built by Germany, failed in the two subsequent launches and the payload (a satellite built by Italy) was therefore lost. The entire rocket worked successfully for the last launch in 1970, but the satellite failed to go into orbit. Thereafter the project was cancelled. All these launches were from Woomera but realization that it was unsuitable for putting satellites into geostationary orbit led to the decision to move the launching site to Kourou, from which a successor, named Europa-2 (with an added stage 4) was successfully launched in 1971, but the guidance system failed and the satellite was lost.

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reprinting letterheads seemed to take up more effort, and accorded a higher priority, then pursuing any actual research.[4]

Not surprisingly the centre of gravity shifted to the USA and the USSR. The success of the former was epitomized above all by the Apollo moon landings (the first, Apollo 11, in 1969;[5] the last, Apollo 17, in 1972). These achievements were rivalled by those of the USSR, which had not only launched the first artificial satellite (Sputnik 1, in 1957), but also landed the first moon rover (Lunokhod, which in many ways was more effective than a human explorer for the lunar environment) in 1970. The most remarkable achievements of the USSR in space were connected with Venus. The planet had already been reached in 1961 by Venera 1 (followed by the USA's Mariner 2 flyby in 1962), and in 1970 Venera 7 made the first soft landing on another planet. The first US landing was by Pioneer Venus 2 in 1978. The final Venera missions were 13 and 14 in 1981 [4]. The USSR also led the way to Mars, accomplishing the first soft landing in 1971 (Mars 3) but contact was lost a few minutes after touchdown. The Mars 5 orbiter (1973) successfully sent back images of the planet's surface. The USA had accomplished the first Martian flyby in 1964 with Mariner 4 and achieved landing in 1975 (Viking 1) and, effectively, the first rover on another planet (Sojourner) in 1996 (the USSR's Mars rover PrOP-M had been launched in 1971 on both the Mars 2 and Mars 3 missions, but the first crashed upon landing and the ultimate fate of the other remains unknown.

Travel to the outer solar system was thrust into the public eye by the film "2001: A Space Odyssey" produced by Stanley Kubrick and released in 1968, which also saw publication of an eponymous science-fiction novel cowritten by Kubrick and Arthur C. Clarke (who ultimately became the official author of the book, which describes a manned mission to Saturn's moon Japetus). Serious exploration of the outer solar system had begun with the US NASA missions Voyager 1 and Voyager 2, launched in 1977 and now in interstellar space, and still functioning and sending back signals from well outside the solar system. The remarkable Galileo mission of NASA was launched in 1986; it encompassed explorations of two asteroids and several of Jupiter's moons as well as Jupiter itself, in the atmosphere of which it was finally deliberately destroyed in 2005. Juno was launched in 2011 and reached Jupiter in 2016. It is still in orbit and sending back data, also from Jupiter's closest large (Galilean) moon, Io. The even more remarkable Huyghens–Cassini mission, a joint effort of NASA (Cassini) and ESA (Huyghens) ranks as the most inspirational success of ESA to date. Cassini explored Saturn and released the Huyghens probe to land on Titan, sending back data for a couple of hours. It was the first landing on an extraterrestrial satellite, and the farthest landing of any hitherto accomplished. More missions are on the way: ESA's Jupiter Icy Moons Explorer (Juice) launched in 2023 is expected to arrive at Jupiter's largest moon, Ganymede, in 2034, and NASA's Europa Clipper, launched in 2024, is expected to arrive at Europa in 2030.

Although in the popular mind manned space travel enjoys a higher prestige than sending robots to explore other planets, when I visited the USSR in 1989, 1990 and 1991 the spirit of glasnost was well established and the health consequences of human space travel were being vigorously and openly discussed. Early cosmonauts such as Yuri Gagarin had, it was now revealed, suffered from a range of health problems upon their return to Earth, but this information had previously been withheld from the public (as it had been in the USA). Given the primordial influence of gravity on the evolution of life on Earth [5], it should occasion no surprise that a sudden transition to zero gravity creates problems if prolonged (the gravity of the moon is about one sixth of that of Earth; that is, comparable to what one experiences when immersed in water).

Although Venus is almost the same size (and has almost the same mass) as Earth, being only half our distance from the sun should make it much hotter. On the other hand the planet is, tantalisingly, entirely covered by thick cloud (now known to be made from sulfuric acid), giving it the very high albedo (around 0.7, compared with Earth's 0.3 and Mars's 0.2) that makes it so prominent in the early night sky. Hence much of the incoming solar radiation is reflected, from which it was inferred that the rocky surface of the planet might be quite cool and dim. The various missions have, however, established that the surface is very hot (around 460 °C) and the atmosphere (mostly CO_2) has a pressure of around 9 MPa (compared with Earth's 0.1 MPa), from which it has been inferred that the planet has undergone a runaway "greenhouse effect". The clouds do indeed block most of the incoming sunlight, and the surface irradiance is only about one tenth of that on Earth.

4 RPE was initially founded as the Guided Project Establishment in 1946 by the Ministry of Supply. It was renamed RPE in 1959. In 1973 it was merged with the Explosives Research and Development Establishment (ERDE) at Waltham Abbey in Essex and in 1977 the combined institute was renamed the Propellant, Explosives and Rocket Motor Establishment (PERME), until it was incorporated into the Royal Ordnance Factories in 1984, prior to their acquisition British Aerospace in 1987. See also ref. 3a.

5 At the time we were on holiday in France and I still remember the breathless excitement of the hotel guests gathered around a television set to watch those first extraterrestrial steps of mankind.

Hence there has been far more interest in Mars, whose gravity is about one third of Earth's, as a planet on which human beings might live, even though it is twice our distance from the sun, and which might even have life of its own—as epitomized by Bonestell's paintings of the planet. More recently, the wealth of information from the various unmanned missions, as well as the ever-improving observations from Earth and orbiting telescopes, have established that its atmosphere, also mostly CO_2, has a pressure of only about 6 hPa and its mean surface temperature is –60 °C, although it can climb up to +35 °C. So far no extant life has been discovered, although whether there is evidence of past life, now extinct, is still a matter of ongoing research. Given these attributes, Mars does not appear to be particularly attractive for a human colony.

Venus might therefore be a better choice for terraforming [6]. Consideration should, however, also be given to Titan and Ganymede, both larger than our moon. Titan, with its nitrogen (about 95 %) and methane (about 5%) atmosphere [7] having a pressure of 1500 hPa, has a methane cycle resembling Earth's hydrocycle—methane oceans (the surface temperature is about –180 °C) evaporating to form clouds and then rain—albeit that Saturn, being about ten times further from the sun than Earth, only enjoys 1% of our solar irradiance, but this is still thousands of times brighter than even the brightest moonlight. Ganymede, slightly bigger than Titan (both are bigger than Mercury) is already known to have an atmosphere containing oxygen, albeit with a pressure of only about 1 μPa, and enormous underground water reserves. Doubtless we shall know more after the arrival of Juice. Currently, however, the interest in these objects is not so much the feasibility of terraforming them but rather the possibility of life having arisen on them.

The relative importance of the planets in our solar system has recently been overshadowed by the discovery of evidence for exoplanets [8], initially using terrestrial telescopes. Since then, evidence for thousands has been accumulated, and it seems to be more common for a star to have one or more planets than not. Given, therefore, that our galaxy alone contains of the order of 10^{11} stars, and that there may be more than 10^{12} galaxies in the universe, clearly planets are likely to be abundant. Admittedly many of these exoplanets are far larger than Earth and orbit their star far closer than we do, but their apparent preponderance is at least partly due to the greater difficulty of evidencing smaller, earthlike, exoplanets.

There is of course great interest in ascertaining whether life exists on these exoplanets. There is some merit in the consideration that the advantages of carbon, with its tetrahedral valence and the immense variety of structures which that makes possible, coupled with water, with a similar tetrahedral valence (through its hydrogen bonding capabilities to its congeners), as a reaction medium, are so overwhelming that life like ours must be the dominant form. Hence, a very basic criterion for the possible existence of life on a planet is the existence of liquid water, a quite stringent criterion and one relatively easy to establish from the measured mass and orbit and the luminosity of the star. Fewer than 1% of exoplanets fulfil this criterion.[6]

Whether life has to evolve *de novo* on each planet independently, or whether it can also be distributed—panspermia [10]—is an open question, as is the question whether it can emerge *de novo* more rapidly than it apparently did on Earth (several hundred million years after its formation, but during the first two or three hundred million years the planet was merely cooling down sufficiently to meet the liquid water criterion). A striking feature of earthlike life is its ability to transform the atmosphere from carbon dioxide-rich to oxygen-rich.[7] Given that atmospheric compositions can be detected spectroscopically [11], evidence for extant life is discoverable remotely. Presumably if life once existed and then became extinct, an ever-present possibility [12], the atmosphere would slowly revert to its primordial state, although this might take rather a long time.

Tempering the excitement of exoplanet discovery is the realization of the immense distances separating us from other stars. Our nearest, Proxima Centauri, is about 4.24 light-years away—4×10^{12} km. It would take Voyager 1, now travelling at almost 20 km/s, more than 6000 years to reach it if it were going in the right direction. NASA's Parker Space Probe has travelled ten times faster, but it would still take 600 years. Anyway, Proxima Centauri's exoplanet does not seem to be habitable—it orbits far too close to its star, albeit that it is only a red dwarf. Sirius looks more promising, but it is about twice as distant and has no known exoplanet.

Without some dramatic new discovery, therefore, anything beyond the solar system is, practically, inaccessible, tantalisingly so if one were to find evidence of life beyond it. And once life had been detected—which could simply be based on very primitive organisms—the next challenge would be to detect evidence of civilization—advanced, intelligent organisms comparable to ourselves. But what we are really looking for is intelligence with agency. If life is defined, ostensively, as something with the essential features of

[6] The water is not necessarily present on the surface: Ganymede, Europa and Callisto may have large subsurface oceans, but this has been established by missions to those moons and is hard to evince from observations from Earth or Earth orbit. See also ref. 9.

[7] Ganymede's tenuous oxygen atmosphere is more likely to have been formed from the photolysis of water directly by ultraviolet light.

what we see around us, the most essential and characteristic feature is the ability to adapt [13], which encompasses "intelligence with agency", and this does not *per se* depend on our particular carbon and water-based chemistry, hence would not necessarily leave an atmospheric signature and might not need to be based on a planet at all.

All this raises the question of whether settling human beings on Mars is relevant to advancing humanity's goals, compared with, say, greatly increasing efforts to explore the outer solar system using unmanned probes, or neighbouring solar systems using telescopes. The answer must be that surely it is relevant, in both a general and a specific sense. The general sense is that it will force us to acquire ever more experience and achieve mastery of more and more advanced technologies. Compare the faltering efforts and frustrating failures of early projects such as ELDO, 50 years ago, with the magnificent achievements of, say, Huyghens–Cassini. The specific sense is that a Mars settlement, which will presumably encompass a prior lunar settlement, will facilitate not only long-range observations of our galaxy and beyond, but also the exploitation of planetary resources and terraforming Venus and possibly Mars as well. The material and technological needs of these programmes are immense, but if exponential economic growth continues we should get there eventually [14]. Kardashev estimated about 3,000 years to achieve a Type II civilization [15], possibly with the help of a Dyson sphere [16,17], which is a far greater challenge than the apparatus needed for terraforming Venus, for which Birch has estimated a few hundred years are needed [6]. Given these timescales, interplanetary interstellar voyages in immense spaceships carrying tens of thousands of people lasting hundreds of years, i.e. many generations, are entirely commensurate and conditions on board are likely to be more comfortable than those prevailing in a lunar or Martian colony.

Hence, renewed enthusiasm for space travel is to be welcomed, provided it keeps these lofty ambitions in mind and is not merely a bubble of meretricious chrematism. Above all, there needs to be proper recognition of the timescales and commitment required. One knotty problem, scarcely discussed hitherto in the context of ambitious space exploration, is the need for a far greater degree of global coöperation than that to which we are currently accustomed. It is knotty because one way of achieving such coöperation is through global government, but this in turn implies a degree of control that will surely be inimical to the unfettered creativity required to solve the many problems that will be encountered during the realization of intensive space exploration. Possibly we need to revisit Kropotkin's concept of anarchism as a viable model [18], essentially of a self-organizing society. Kropotkin very convincingly demonstrated the essential rôle of coöperation in successful human societies, as well as in animal communities [19]; his ideas need to be reëxamined for their adaptation to our present circumstances—a globalized society that has undergone at least two revolutions since he wrote, scientific and compunications [20].

My final thought for the present on this topic concerns the logic of cancelling projects like Black Arrow on the grounds that the desired results can be obtained more cheaply by purchasing the technology from elsewhere. That is, of course, apparently in line with Adam Smith's theory of absolute advantage [21]. But when Smith formulated this theory, world trade was dominated by primary goods; the Industrial Revolution was getting under way in Great Britain, which became practically the only country exporting manufactured goods (its share of global trade in such goods exceeded 90%).[8] Given the cumulative advantage of focusing on technology, leading to the exponential growth with which we are nowadays familiar (e.g., Moore's law), it was plainly of extreme advantage to Great Britain to promote the notion of absolute advantage.

Nevertheless, as we know some countries eventually acquired their own capabilities in technology—think of the G7 and China—and Great Britain is no longer the world's leading exporter. But whereas the absolute advantages associated with a primary commodity are, essentially, geographical in nature, in principle advanced technologies can be developed anywhere—temperate climates doubtless offer some general advantages compared to the tropics—hence to hold a position of absolute advantage is as much a matter of resolve as anything else, presupposing an adequate supply of sufficiently talented engineers and scientists. It is very likely that during the learning phase of acquiring a new technology other countries can supply it more cheaply but, as Stalin repeatedly emphasized during the development of the atomic bomb in the USSR, cost was irrelevant—the essential thing was to acquire the bomb as rapidly as possible in order to achieve strategic parity with the USA [23].

Because of the exponential nature of technological growth, it is extraordinarily difficult to regain a leading position once one has abandoned the effort to remain at the forefront. Presumably this explains the huge disparity between the aggregate sizes of US and European high-

[8] Smith was probably unaware of previously significantly higher manufacturing activity and export in India and China, but which were undergoing deindustrialization (for different reasons) at the time Smith was writing [22].

technology companies. Only in pharmaceuticals does Europe remain at the forefront.[9] But how, in may be asked, can a small country compete with giants? It would appear that the USA, with a population five times that of the UK (which in turn has a population ten times that of Switzerland), has a permanent advantage because of the absolute size of its economy. The immense cost of developing an atomic bomb was only affordable in the USSR by imposing a great degree of general privation, to an extent probably only possible in a command economy. Still, it is noteworthy that Europe's largest pharmaceutical companies are in small countries—Denmark and Switzerland. This achievement is probably enabled not only by a relentless focus on research, development and innovation by the companies themselves, but also by a stable, minimally interventionist government (*pace* Kropotkin) and an excellent educational system. The UK also enjoys the latter (Europe's leading universities are all in the UK, followed by Switzerland), and AstraZeneca, Europe's third largest pharmaceutical company, is UK-based.

Switzerland never had a space programme, and the UK's was run on a shoestring—indeed its achievement was admirable considering the very limited financial resources made available to it (cf. the tradition of the Cavendish Laboratory, Cambridge of carrying out experiments as cheaply as possible). Both Switzerland and the UK now have a lively start-up scene in the space sector, which offers some hope that these, and other, countries will have the ability to meaningfully participate in future developments requiring global coöperation. Typical of this new impetus is the Starshot Breakthrough Initiative, which aims to send microprobes propelled at c/5 by laser-driven lightsails to the Alpha Centauri system [24].

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[9] https://www.visualcapitalist.com/cp/worlds-50-largest-pharmaceutical-companies/