

## INTERSTELLAR COLONIZATION: WILL IT BE POSSIBLE? AND WHEN?

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### SPACE TECHNOLOGY & INDUSTRY

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### ABSTRACT

Slow interstellar travel (at speeds well below the speed of light) is the only form of interstellar travel we are sure we will be able to pursue in a not too far future. Other alternatives, up to FTL voyages, are still speculative and, while hoping that they will be possible, for now we should concentrate on what we are sure we can do. In two recent papers the author discussed the technological advances required to launch an interstellar human colonization mission to the nearest stars known to have planets (perhaps easily terraformable ones), mostly concentrating on propulsion. The result was that a slow-boat type generation ship, travelling at about 1% of the speed of light requires a thruster able to work at an ejection velocity of more than  $2 \times 10^7$  m/s. With a thruster operating in variable exhaust velocity (VEV) conditions, it is possible to build a 'slow boat, travelling at about 1% of the speed of light with a payload plus structure mass ratio of about 50%, which is an interesting result owing to the large payload required, including not only the people, their life support system and consumables, but also the landing vehicles and the habitat on the destination planet, or the devices to build it from locally available materials. Such an ejection velocity requires an advanced nuclear fusion thruster (which needs just the application of well known physics) or an antimatter drive (which requires much greater development efforts). Apart from realizing innovative thrusters, and solving other technical problems, various other aspects must be solved before attempting getting out of our solar system, such as, to name a few,

- Ethical aspects, which are determinant in choosing the mission architecture,
- Minimum crew size,
- Role of hibernation, even partial hibernation, in such a mission, and
- Possibility of building the spacecraft in space.

### PAPER

#### 1 Will interstellar travel be ever possible?

We are just on the verge of becoming a multi-planetary civilization, returning to the Moon, this time to start its exploration and hopefully its colonization. The exploration and then the colonization of Mars are in the agenda of some space agencies, but above all of a few private companies like Space X. With these developments humankind can hope to develop beyond its present limitations. Predictable advances of our technology, in particular the development of fusion nuclear propulsion, regenerative life support systems, in-space manufacturing, radiation screening, etc. will allow us to start settling any interesting place of our solar system.

Looking beyond this predictable future, we can ask whether such a multiplanetary civilization will be forever limited to our solar system, mainly by the huge distances which separate the stars in this zone of our galaxy. The closest star to us is Alpha Centauri, a triple star located at 4.334 ly from us; the star closest to the latter is Luhman 16, a double star at 3.58 ly from Alpha Centauri. If we consider a sphere with a radius of 20 ly centred in the Sun, it includes 96 stars, mostly dwarf stars, and the average distance between each of them and its closest star is 4.24 ly, so that the situation of our Sun having a closest star at a little more than 4 ly can be considered as typical in our galactic neighbourhood.

However, not all stars are equally important for us. If we consider only the stars having a planetary system, the distance increases, and if we take into account only those having terrestrial type planets is even greater. However, trying to compute average distances is useless, since the search of extrasolar planets is far from being completed and new planets are continuously discovered. An important recent discovery is that of 4 planets orbiting the Barnard Star [1]. An interesting planet has also been discovered orbiting our closest star, Proxima Centauri, the component closest to us of Alpha Centauri.

## 2 Our galactic neighbourhood

The 96 star systems closest to us have a total of 58 planets (plus some unconfirmed ones) out of which 39 are rocky planets. But to know that a planet exists is just a first step and instruments are being devised to assess whether an exoplanet has an atmosphere, by which gases it is made, and finally to image its surface. All this is essential to understand whether a planet can sustain life and which one can be eventually colonized or, later, even terraformed. Since the stars closer to the Sun are mostly red dwarfs, the first point is whether life may develop on a planet orbiting such a star and whether these planets may be colonized.

Each star has a habitable zone, often called Goldilock zone, a zone not too far to be too cold, or too close to be too hot, so that water can remain in liquid form at least in some zones of the planet for most of the time. Stars, however, are not the only source of heat a planet could have: a planet, close to a star, or a satellite orbiting close to a planet, can be subjected to tidal heating and host liquid water even if is outside the Goldilock zone. On the opposite side, the habitable zone is quite close to a dwarf star, and a planet lying in it may be locked by tidal effects in synchronous rotation: one of the hemispheres of the planet is freezing while the other is hot, and life may be possible just in a narrow strip between them.

The period (in days) of 29 small planets orbiting 9 red dwarf stars, not too far from Earth, are reported in Fig. 2, together with their distance from our planet. All of them have a year that lasts less than 25 days.

Each planet is thus a case on its own, and detailed observations are required to assess its conditions. Another interesting case may be that of a satellite orbiting a gas giant: if the giant planet is in the Goldilock zone, the satellite might be habitable, even if tidally locked to the planet. Some gas giants orbiting close enough to the star to be in that zone have been discovered. The cases are many, because also trojans of gas giants may exist in the habitable zone of a star and other interesting situations may be anticipated. But these are just theoretical ideas, since none of these situations has been observed: it is already difficult to discover extrasolar planets, to state whether they have satellites or trojans is completely beyond the possibilities of today's astronomy.

An exoplanet may be defined as:

1. too hostile to be of interest for colonization,

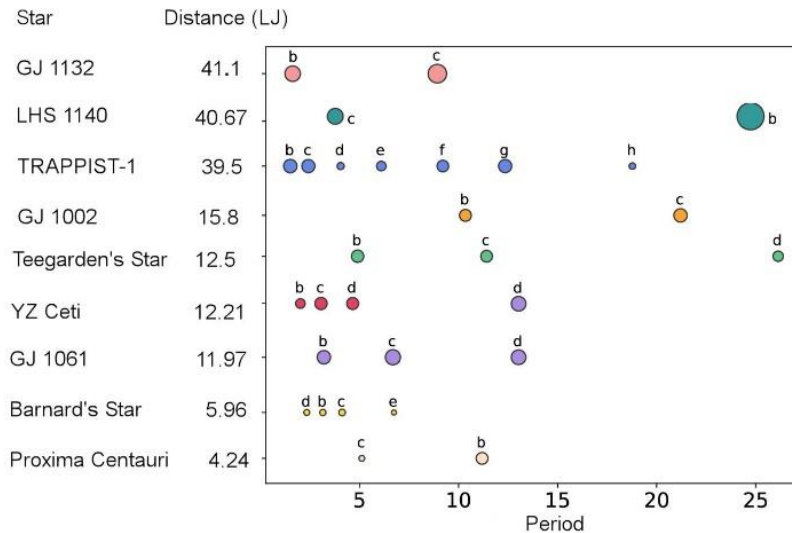


Fig. 2. Small terrestrial planets orbiting some red dwarfs not too far from Earth. The size of the symbols is proportional to the planet's mass.

2. hostile, but colonizable in protected habitats,
3. bio-compatible,
4. habitable,
5. inhabited by lower life-forms,
6. inhabited by higher life-forms,
7. inhabited by intelligent life-forms.

Obviously, these definitions are referred to life as we know it, because if we hypothesize that completely different types of life may exist, even planets which are too hostile for us might host higher or even intelligent forms of life.

Planets of type 1 may be like Venus, which is hostile because of a combination of very high temperature and very high atmospheric pressure, absence of a magnetic field, chemically aggressive atmosphere and very slow rotation. Other conditions may have similar effects in making colonization and terraforming very difficult, impossible at our technological level.

Planets of type 2 may be like Mars (low temperature, too thin atmosphere, no magnetic field), the Moon (similar to Mars, but no atmosphere, too slow rotation and large temperature variations), or Mercury, similar to the Moon, but too hot. However, today's technologies, perhaps with some improvements, will allow human beings not only to survive, but also to live, work and feel at home. Some of these planets may be terraformed without great difficulties, while others may require greater efforts and to develop specific technologies not available at present.

A bio-compatible planet (type 3) is a planet with an atmosphere where human beings can live, perhaps using a breathing apparatus, since the atmosphere cannot be breathed as it is. An example might be Mars as it was before losing its atmosphere, when liquid water existed on its surface. A planet of this type might be terraformed in an easy way.

We can define a habitable planet (type 4) as a planet on whose surface we could live without particular protective devices. The partial pressure of oxygen in its atmosphere must be high enough to allow us to breathe and no poisonous gas must be present at dangerous levels; there must be something which keeps the radiation level low enough and the temperature should be neither too high or too low.

Finally, planets may be inhabited by some forms of life at different levels (type 5, 6 and 7). In this case the problems are mostly at the ethical level, and become more severe with increasing complexity of the existing life (from 5 to 7). At present, we know very little about the possibility of extraterrestrial life, and it is possible to hear statements going from the impossibility of the existence of life outside Earth, to others assessing that life develops everywhere the conditions allow it.

Since habitable planets need to have an atmosphere containing enough oxygen to breathe, it is a common opinion that only planets inhabited by at least very simple form of life of terrestrial type can be habitable. Since

oxygen is very reactive, the presence of oxygen requires the presence of something producing it continuously and the only mechanism we know is the presence of life, to the point that oxygen in a planetary atmosphere is considered a biomarker for life. Earth was not habitable by oxygen breathing organisms like us, before microorganisms changed the composition of its atmosphere.

Astronomers devised an index, the Earth Similarity Index (ESI) to assess how much is a planet similar to Earth [2]. It goes from 0 (no similarity) to 1 (very similar). (Mars has a ESI of 0.64).

The main characteristics of the closest exoplanets which lie in the habitable zone of some nearby stars are reported in Tab. 1. Since the table is limited to 20 ly from the Sun, some very interesting planetary systems, are not reported. In the table the distance of the star from the Sun, the mass of the planet, its radius (in multiples of the mass and of the radius of Earth), the surface temperature in °C, the orbital period in days, the Earth similarity index and whether the rotation of the planet is synchronous are reported. Many of these data are uncertain and some are unknown.

From the table, the most promising planet is Teegarden's Star b which has an ESI of 0.95, is slightly bigger than Earth and has a good average temperature, but is at 12.4 ly from us. Also, Proxima Centauri b is not bad, with an ESI of 0.87, similar size and somewhat colder, but much closer to us. Almost all the planets in the table have a very short revolution period (a few days), which is unavoidable for planets orbiting a dwarf star – the only exceptions are those of Tau Ceti, a yellow star just a little smaller than the Sun.

*Table 1: The main characteristics of the closest exoplanets which lie in the habitable zone of stars at less than 20 ly from the Sun. YZ Ceti b is the only planet possessing a magnetic field (for what we know).*

Planet	Dist (ly)	Mass	Rad	Temp (°C)	Per (days)	ESI	Rotation
Proxima Centauri b	4.224	1.07	1.03	-12	11.2	0.87	S
Barnard's Star b	5.963	0.3	0.67	165	3.15	?	S?
Ross 128 b	11.007	1.40	1.11	43	9.87	0.86	?
Tau Ceti f	11.912	6.67	?	-40?	642	0.63	?
Tau Ceti e	11.912	4.29	?	70?	168	0.46	NS
LTT 1702 c	11.984	1.74	1.18	-37	13.0	0.86	?
LTT 1702 d	11.984	1.64	1.16	-27	6.69	0.86	?
YZ Ceti b	12.122	0.70	?	?	2.0	?	?
Lutyten's Star b	12.348	1.51	1.06	18	18.6	0.85	?
Teegarden's Star b	12.407	1.16	1.05	20	4.91	0.95	S
Teegarden's Star c	12.407	1.05	1.02	-52	11.4	0.66	?
LHS 2 b	15.806	1.08	1.03	-13	10.3	0.86	?
LHS 2 c	15.806	1.36	1.10	-68	21.2	0.58	?
Wolf 1061	14.050	3.41	1.66	33	17.9	0.80	S
HD 204961 c	16.201	4.40	1.93	-58	17.5	0.81	S?
HD 42581 A c	18.906	8.58	2.87	-46	121	0.56	?

### 3 The biggest problem: going there

The distances are so large that to reach even the closest star in a reasonable time is a major problem. It is so not mainly because of the 'universal speed limit' stated by relativity which prevents us to travel at speeds higher than the speed of light, but because of the huge quantities of energy required to reach high speeds even below those at which relativistic effects are present. For instance, to reach 1% of the speed of light (3,000 km/s), with an efficiency equal to 1, a specific energy of 4.5 TW/kg is required, neglecting the energy required to brake once destination is reached, like when performing just a very high-speed flyby.

Moreover, the spacecraft must also exit the gravitational well of the starting planet and of the solar system before accelerating to the interstellar cruise speed. This can be done in a single burn, two or three separate burns or using a low, continuous thrust engine. The first strategy is the most efficient one, in terms of propellant required, followed by the others, in this order.

The  $\Delta V$  required to reach the interstellar cruise velocity  $V_{\infty}$ , starting from a 300 km Earth orbit, is reported in in Fig. 3. In the figure a linear scale was used for relatively low speeds, like those typical of interstellar

precursor missions, and logarithmic scales for higher speeds, up to 10% of the speed of light (larger speeds are not considered since no relativistic effects have been taken into account). Note that:

- if the cruise speed  $V_\infty$  tends to 0, what dominates is exiting the solar system. The single burn strategy is the most convenient, since the burn is performed as low as possible in the gravitational field of Earth.
- For speeds higher than 20 km/s the single burn strategy is again the best. The  $\Delta V$  is lower than  $V_\infty$ .
- For very high speeds, above 0.01% the speed of light, the kinetic energy corresponding to the cruise velocity is much higher than the potential energy of the gravitational fields of the Sun and Earth, to the point that the latter becomes negligible and  $\Delta V \sim V_\infty$ . Also, the differences between the strategies practically vanish. Some results for a few values of  $V_\infty$  are reported in Tab. 2.

*Tab. 2: Values of  $\Delta V$  to exit the solar system with 4 different values of  $V_\infty$ , using the 3 strategies described above (3b: 3 burns, 2b: 2 burns, 1b: single burn).*

$V_\infty$ (km/s)	0	100 (0.033 % c)	3,000 (1 % c)	30,000 (10 % c)
$\Delta V$ (3b) (km/s)	15.535	115.53	3,015.5	30,016
$\Delta V$ (2b) (km/s)	15.535	81.95	2,973.7	29,973
$\Delta V$ (1b) (km/s)	8.743	71.75	2,962.8	29,963

In this computation the direction of the exit velocity  $V_\infty$  has not been considered. In the three burns case, the result obtained doesn't depend on it, since when the third burn is applied the velocity of the spacecraft is very low (theoretically 0). In the other cases, if the exit velocity lies outside the plane of the ecliptics, the  $\Delta V$  increases.

To reach a speed equal to 1% c a  $\Delta V$  of 3,000 km/s is needed (at 1% c the  $\Delta V$  to escape the solar system is negligible with respect to that to accelerate to speed), and, considering that the spacecraft must then brake in the destination system, the total  $\Delta V$  is 6,000 km/s.

Considering that a space ark must carry a large payload, the ejection velocity of the thruster must be of the order of the  $\Delta V$ , or preferably higher, an ejection velocity between  $6 \times 10^6$  and  $2 \times 10^7$  m/s is required. An ejection velocity of  $2 \times 10^7$  m/s (a specific impulse of 2 million seconds) may be reached using an advanced nuclear fusion thruster (which requires just the application of well-known physics) or an antimatter drive (which requires much greater development efforts). Fusion propulsion is at present studied by space agencies, universities and private companies and a private company, namely Pulsar Fusion [3] claimed to be not far from building a fusion thruster of the DDFD (Dual Direct Fusion Drive) type, designated as *Sunbird*. The declared maximum ejection velocity would be 223 km/s, which is still two orders of magnitude lower than the mentioned value for interstellar journeys, but is at any rate almost two orders of magnitude higher than present values. They plan to test it in orbit in 2027. Once a fusion thruster is built, a first step toward the stars is achieved mainly because its ejection velocity may be greatly improved (not for interplanetary use, for which the mentioned value is already greater than the optimal one) and because humankind will be on its way to start a spacefaring civilization, which is required to undertake interstellar travel [4].

With a thruster operating in variable exhaust velocity (VEV) conditions, it is possible to have a mass breakdown of about  $m_p/m_i = 0.273$ ,  $m_{ps}/m_i = 0.210$ ,  $m_{ta}/m_i = 0.016$  and  $(m_u+m_s)/m_i = 0.501$ . About half of the initial mass is made of the structures (not including tanks and propulsion system) plus payload which is an interesting result owing to the large payload required, which not only includes the people and their life support system and the consumables, but also the landing vehicles and the habitat on the destination planet, or the devices to build it from locally available materials.

Other interesting results of [5, 6] can be mentioned here:

- Ethical aspects are determinant in choosing the mission architecture
- A total number of 1000 people, perhaps together with a sperm bank, can be sufficient to provide the genetic variety to produce a healthy population.
- To increase the chance of success, 2 or 3 smaller space arks can be used, possibly planning periodic rendezvous in interstellar space, to swap a part of population among the ships

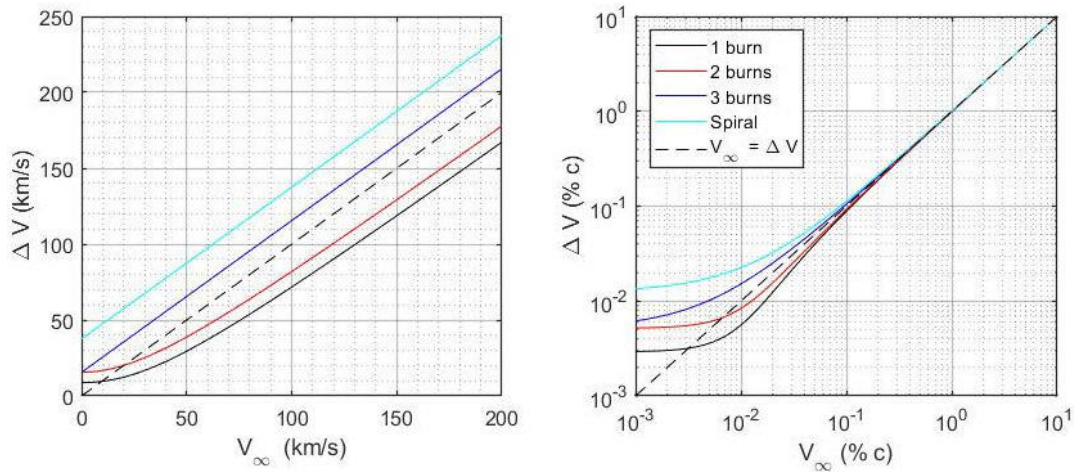


Fig. 3.  $\Delta V$  to escape the gravitational wells of Earth and the Sun as a function of the interstellar cruise speed  $V_{\infty}$ . Starting orbit at an altitude of 300 km from Earth surface.

The mission architecture here studied, i.e. a 'slow boat'<sup>1</sup> space ark travelling at about 1% c, means that the duration of the journey to the nearest star will be of about 400 years, a time several times longer than human lifespan. Assuming that a generation equals to 25 years, those arriving at destination will be the 7<sup>th</sup> to 9<sup>th</sup> generations descendants of those who left the Earth.

#### 4. Generation ships Vs. hibernation

Apart from possibilities at the same time strongly questionable from the ethical viewpoint and unlikely to be technically feasible, like sending frozen embryos or human minds emulated on computers, there are two possibilities which seem to be possible in the medium term: generation ships and hibernation. Generation ships, or space arks, seem to be the most feasible one, in particular by a civilization which has become a multiplanetary civilization, in which many people live permanently out of Earth and in particular in space stations. The greatest difficulties seem to be the realization of adequate radiation screening, regenerative life support systems, simulated gravity, high reliability systems of all type which can work for centuries with little maintenance, long range communication systems. All of them are practically the same technologies which are required for living in space in general, only much more sophisticated.

The possibility of human hibernation has not yet been confirmed and remains on a theoretical level, and to be used in interstellar journeys the crew must be hibernated for very long times, much longer than human lifespan, and this is even more questionable. Moreover, a starship carrying hibernated humans must work in a completely autonomous way, which requires large advances in artificial intelligence, we are not sure will be feasible.

A possibility is a sort of hybrid between a generation ship and a hibernation ship: If hibernation like that useful for interplanetary travel will be achieved, part of the humans on board can be hibernated in turns for periods of months or years – which is likely much easier than hibernating them for a few centuries – so that a smaller and less automatic ark can be used. For instance, if the maximum safe hibernation time is 10 years, and the 'guard' time is 5 years, both the habitable volume of the habitat and the number of generations needed to reach the destination may be reduced to one third. Since this routine may continue after reaching destination, also when the starship has been transformed into a orbiting space station, the space will be sufficient. Then as people starts to leave the station and goes to live permanently on the planet, the hibernation time can be reduced.

<sup>1</sup> Slow boat space ark is a term usually referred to a starship travelling at a speed between 0.1% and 10 % of the speed of light carrying up to 1000 people.

The time people must spend on the space ark depends on the destination planet: if it is directly habitable, the colonists can disembark a short time after waking up, and so the starship can be much smaller. A different concept may even be explored: by reducing the mass of the habitat, a larger quantity of propellant can be carried on board, and a higher speed can be reached, decreasing the travel time. But if the planet cannot be directly colonized, and many infrastructures need to be built, the starship can be transformed into an orbiting space station where most of the people can live in the meantime, and so its size cannot be much reduced.

## 4 A space ark for Proxima centauri

Assume that by year 2190:

- The colonization of the solar system has started and humankind is on its way to becoming a true multiplanetary civilization, able to build fusion propelled spaceships on the Moon or some asteroid<sup>1</sup>
- Nuclear fusion has been harnessed both to produce energy and to propel spacecraft. However, no breakthrough in energy technology like the harnessing zero-point energy, development of antimatter or propellantless propulsion or revolutionary concepts like Einstein-Rosen bridge or warp drive has been achieved.
- Long term experience on nuclear fusion propulsion has been obtained, so that the reliability of this technology is high enough to commit to it the lives of the crew for the long times required for a space ark to reach its destination. Assume also that these fusion thrusters can operate at an ejection velocity of  $2 \times 10^7$  m/s with a mass-power ratio of the propulsion system equal to  $\alpha = 2 \times 10^{-5}$  kg/W.
- Living in space or in small habitats on hostile planets has become a customary condition for many people and most of the ethical problems related to the life in a space ark have thus been solved.
- Telescopic observations performed using a coronagraph-type space telescope and then some nanoprobes of the Starshot type gave the certainty that Proxima Centauri b is a planet worth further investigation. At least one probe travelling at 10% of the speed of light has reached orbit around Proxima Centauri b and is broadcasting data about the planet giving the certainty that humans can live on its surface in a habitat of known characteristics and, possibly, that the planet can be terraformed in a reasonable time.
- Possibly, but not absolutely required, human hibernation for times much shorter than the duration of the interstellar journey has become a standard practice in medicine and likely in space travel. In this way periods in hibernation can be used to reduce radiation damage and to reduce the number of people who, at any time, require food, water and other consumables.

Under these assumptions, in 2190 the interstellar adventure can start.

In the literature [7-10] it was shown that to have a genetic variety sufficient to avoid inbreeding, a variety of specialization to maintain cultural inheritance and to have good possibility of surviving in case of accidents, a population of 1000 people is sufficient with no need of resorting to ethically questionable practices like having a crew of only women and carrying on board a sperm bank.

To reduce the risk of a complete failure in case of an accident to one of the arks, instead of sending a single starship, assume to split the crew on 3 ships carrying about 330 people each with periodic rendezvous to exchange people among them to maintain the whole colony as a single population

Following the simplified procedure shown in [5], based on the designs of several space colonies [8], the habitat of each ark should have a mass of 235,000 t and a surface of 120.000 m<sup>2</sup>.

Assuming that to produce the required artificial gravity, the habitat can have the shape of a number of interconnected elliptical tori. A schematic cross section of the ring is shown in Fig. 4. To provide a gravity of 1 g on the lower floor, which is at a radius of 93 m from the rotation axis, the habitat must rotate at 0.32 rad/s (3.1 rpm). The gravitational acceleration at the second floor is slightly smaller, 0.95 g, while in the 'underground' floor, dedicated to the services and to the garden/greenhouse, it is 1.03 g. If the recent results (obtained on mice, stating that at 0.7 g there is no damage and at Mars gravity (0.38 g) they are very limited, the rotational velocity can be reduced. To obtain a simulated gravity of 0.7 g, the angular velocity is 2.6 rpm. Since most of the exoplanets are smaller than Earth, (but this is not the case for Proxima Centauri b, which has a mass of

about 1.07 Earth masses) the rotation of the habitat may be slowed during the journey, so that to train the colonists to the gravity of their new home.

The available area on the two floors is 129,000 m<sup>2</sup>, plus another 68,000 m<sup>2</sup> in the ‘underground’ floor. The total available volume is about 603,000 m<sup>3</sup>.

The detailed design of the habitat must take into account a number of considerations:

- Radiation protection, which is essential for the health and the genetic stability of the inhabitants. To reduce the external surface/volume ratio, the cross section of the rim should be elliptical or made by a number of ellipses.
- Interstellar space is full of debris, mostly in the form of dust. Assuming that the dust is stationary, it impacts at a relative velocity of 1 % of the speed of light, i.e., at 3,000 km/s. The actual speed should be larger, but not much, and the relative velocity is close to be aligned with the direction of motion. The front of the ring must thus be provided with a shield, possibly with a triangular cross section, which is likely to be quite heavy.
- In the first part of the journey the starship accelerates and the thrusters are located at the rear, while in the last part they must be located in the front to decelerate. The simplest solution is to have the shields on both the front and the rear, and to simply rotate the ship at mid-way. This however compels to have double shields for both the tanks and the habitat, while it is possible to rotate the ship while detaching the shields from the front and locating them at the rear. It depends mostly on the nature or the debris which are found in the interstellar space, something which now is little known and needs to be investigated before launching

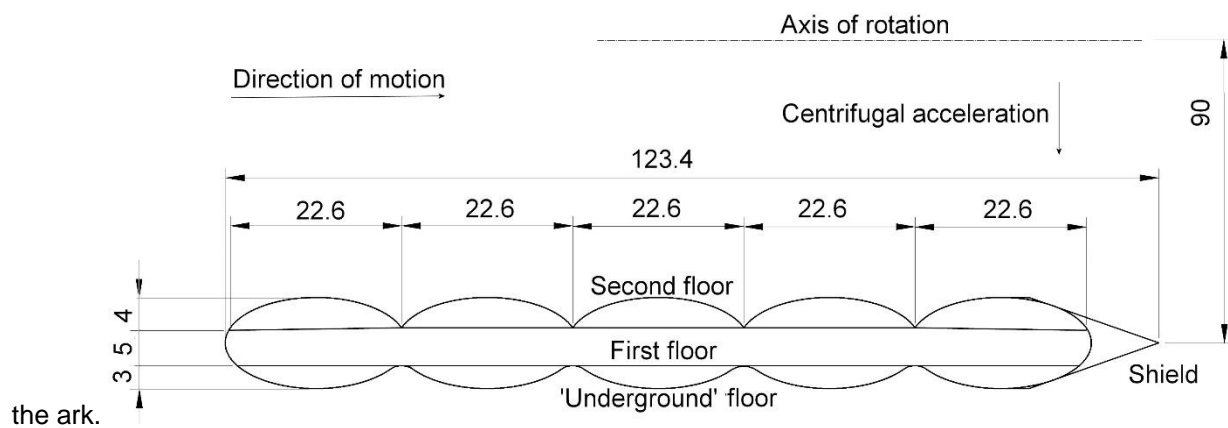


Fig. 3. Cross section of the ring habitat. Dimensions in m.

The rim of the habitat is subjected to two load conditions: the centrifugal acceleration and the internal pressure which both produce tensile stresses, which can be alleviated by using cables located. The stresses due to the propulsion thrust are much smaller and in a preliminary evaluation can be neglected.

- between the floor of the ‘underground’ level and the ceiling of the second level, and inside the floor of both levels for what the internal pressure is concerned,
- between the inner side of the ring and the tanks located at the rotation axis of the starship like the spokes of bike wheels to counteract the centrifugal acceleration. The tension of the latter can be actively controlled to compensate for the variations of the rotation rate of the spacecraft.

The distance to Proxima Centauri is 4.364 ly, i.e.,  $4.1288 \times 10^{13}$  km. Propulsion is used to exit the solar system, to reach the cruise speed of slightly more than 1% the speed of light and to slow down from that speed at arrival. The tangential and radial velocities due to the proper motion of Proxima Centauri are about –16 and –22 km/s and thus their resultant is 27 km/s. If compared with the spacecraft speed of 3,000 km/s, it is negligible in a first evaluation of the propulsion requirements.

A fairly high tankage ratio can be assumed:  $k_{ta} = 0.1$ . This is due to the fact that boil-off must be completely avoided (the fuel must be stored for centuries) and interstellar space contains much debris.

Assuming a travel time of 400 years, the mass break down of each space ark is reported in Tab. 3. The times of the three phases of the journeys are: acceleration  $t_1 = 101$  years, coasting  $t_2 = 217$  years and deceleration  $t_3 = 82$  years)

## 6. Conclusions

A space ark is a huge machine, but its mass is comparable with that of the largest oceangoing vessels as shown in Fig. 9. In the figure, the outline of a space ark is compared with that of an aircraft carrier (the Gerard Ford), a cruise ship (The Legend of the Seas) and of the largest supertanker ever built (the Seawise Giant), considered as the biggest manufact ever built by humankind.

Tab. 3: Mass breakdown of a space ark

Habitat	235,000t	Propellant reserve	18,900 t
Structures	23,500 t	Tanks	21,000 t
Propellant for acceleration	106,200 t	Propulsion system	66,700 t
Propellant for deceleration	84,500 t	<b>TOTAL</b>	<b>555,800 t</b>

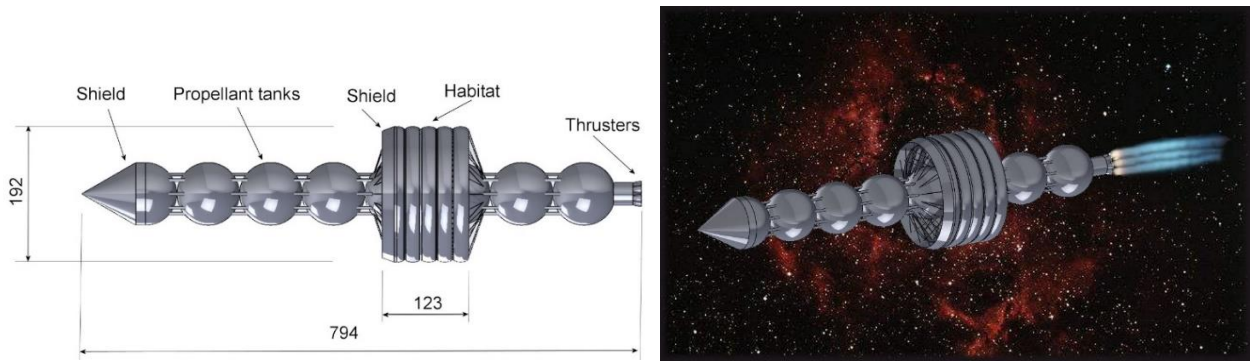


Fig. 7: Sketch and artist's impression of the space ark.

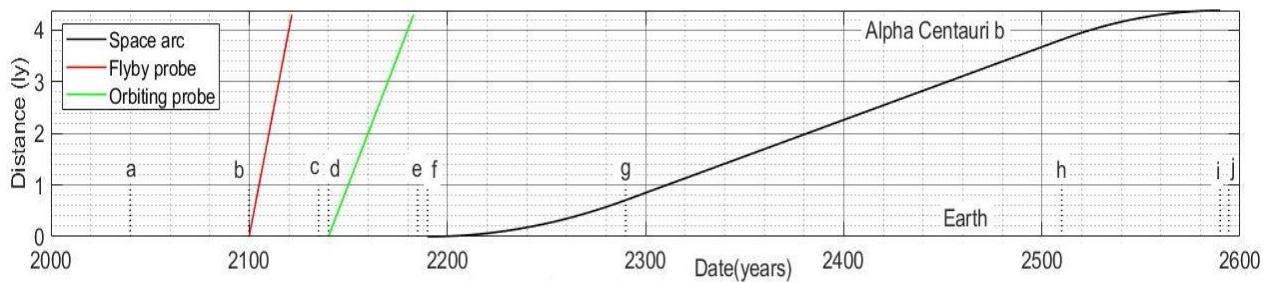


Fig. 8. Time-distance plot of the space ark and of the probes.,

- |   |  |
|---|--|
| a) Starting of detailed telescopic observations | f) Starting of the space ark                               |
| b) Starting of a fast flyby probe,              | g) End of the acceleration phase                           |
| c) Data from the probe received                 | h) Starting of the deceleration phase                      |
| d) Starting of the orbiting probe               | i) Arrival of the space ark                                |
| e) Data from the orbit probe start arriving,    | j) The news of the arrival of the ark ship arrive on Earth |

Our present economy allows to build some giant oceangoing vessels of this size plus many other slightly smaller ones for military purposes (and in this case the construction is paid for by states) or for commercial purposes, in which case they are built and operated by private companies.

From the above points it could seem that the main problems to be solved are those related to propulsion. This is only partially true, since we need to develop a number of different technologies spanning from regenerative life support system, to food production, from protection from radiation and from interstellar dust and larger debris, to reliability and maintainability of all the required complex machinery for a period of centuries. Not to speak about the ethical, psychological, medical and biological aspects which must be studied in detail.

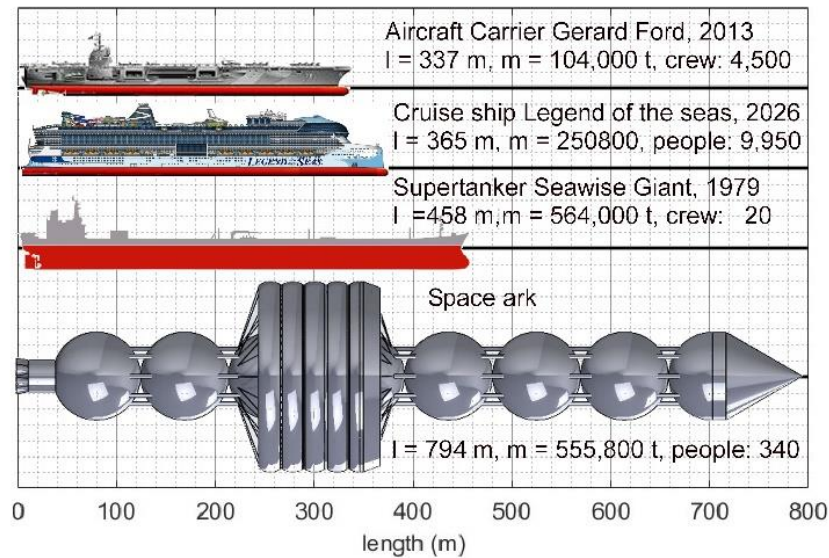


Fig. 2. The outline of a space ark, compared with that of an aircraft carrier (the *Gerard Ford*), a cruise ship (The *Legend of the Seas*) and of the largest supertanker ever built (the *Seawise Giant*), which is the heaviest of them all.

For instance, the first problem posed by generation ships deals with the need to spend the whole life on a spacecraft in space, The first generation has taken this decision freely, and they have all rights to do so, but the following generations are compelled to do so without having chosen it. A similar problem holds also for hibernation ships, because the offspring of the travellers are compelled to live in a small colony on an alien planet, and certainly will have a harder and more dangerous life than the descendants of the rest of humankind.

Other problems are linked with the lack of freedom which will characterize a space ark – and also a colony on an extrasolar planet. The limitations to the mobility and also the need for a strict command hierarchical structure are obvious. More important might be the strict birth control to which all on board must be subjected. The number of offspring will be strictly controlled since the population must be kept constant to exploit in the best way the on-board resources.

The distance separating the stars of our galaxy, at least in the zone where the Sun is, are so large that interstellar travel requires speeds which are well beyond our present capabilities, even in case of the slowest generation ships.

The first problem we must solve is thus improving the performance of propulsion devices to the point that no existing systems or those predicted for a close future are sufficient.

1. To Reach  $\alpha$  Centauri in about 400 years, travelling at an average speed slightly larger than 1% of the speed of light, the thruster must be able to reach an exhaust velocity of at least 20,000 km/s (better 50,000 km/s) and have a mass/power ratio less than  $2 \times 10^{-5}$  kg/W = 0.02 kg/kW. These values are even beyond the nuclear fusion thrusters which are being now designed (like Direct Fusion Drives, DFD [11]) but can become possible using more advanced fusion rockets.
2. With a thruster of this type, a space ark, carrying 330 people, having an initial mass of about 556,000 t, may be designed. It is a huge machine, but is lighter than the largest sea-going tankers presently in service.
3. The colonization mission can be performed by two or three such ark ships travelling at close distance one from the other: the presence of at least two starship will decrease the risks of loss of mission (which in this case likely involves also loss of crew) in case of malfunctioning or accident involving a ship. Building a certain number of smaller ships is also convenient from the cost viewpoint.
4. Smaller ark-ships are more maneuverable and can perform in an easier way their tasks once the destination planetary system is reached. They can visit various asteroids to acquire needed materials and finally, when

the orbit of the destination planet is reached, the habitats can be assembled to create a large space station where people can live while starting the colonization operations.

5. The mass and the size of the starship makes it very difficult and costly to launch in space the starship built on Earth, even in the case the Earth is provided with a space elevator by the time the mission is implemented. It will be expedient to build the vehicle's components on the Moon or on an asteroid. If the shipyard is on the moon, the parts so built can be launched in space and assembled outside its gravitational well, while if it is built on an asteroid all operations can be made on its surface.
6. An arkship of the same type can be used also for the colonization of a planet orbiting a slightly more distant star. For instance, in 1000 years it can reach ε Eridani, and there are 20 stars reachable in about 1200 years, many having planets and some terrestrial planets. If more than one colonization mission is planned, a small scale production of space arks can be undertaken.
7. If a space drive will ever be built, a slow boat seems to be its ideal application.
8. Up to now only the possibility of building the propulsion system for the ark ship has been investigated. However, other aspects like the regenerative life support system, food production, protection from radiation and from interstellar dust and larger debris, and above all reliability and maintainability of all these complex machinery for a period of centuries must be studied in detail.

Finally, a reason not to build a space ark of this type needs to be mentioned. Quite conservative assumptions about the propulsion system have been made, so that advances in this field can be predicted for the years following the launch date of this starship. In this case a much faster starship might be built later, a starship which will overtake this mission in interstellar space. The best scenario (but the worst from this point of view) is the possibility of developing faster than light (FTL) propulsion before the completion of this mission.

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