ASTEROIDS, NOT MARS, ARE THE KEY TO HUMANITY'S SURVIVAL

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ABSTRACT

Colonizing Mars is a feasible idea, but the wrong idea. Building spacecraft out of asteroids provides a much cheaper and easier alternative to ensuring humanity's survival. We show that we can get thousands of tons of usable nickel-iron to Earth's orbit within a decade and that our limiting factor to moving all humans into space is our launch rate from Earth's surface. This is the fastest, cheapest, and easiest way to ensure humanity's survival.

1. IDEA

We need to reevaluate our focus on colonizing planets, especially Mars. We have shown that humans can live above a planet's surface, so why settle for another planet's surface? The current goal of colonizing Mars is unnecessarily restricting and clouds our judgement to better non-planet alternatives for colonization.

I propose that we move off of the surface of planets and move into outer space permanently, using asteroids as the primary construction material.

Plan:

1. Use "mining drones" to mine asteroids and send the metal to Earth's orbit.
2. Create spacecraft with this metal.
3. Establish a self-sufficient society with these spacecraft.
4. Move all of humanity off of the Earth's surface.

2. PROS AND CONS OF COLONIZING MARS COMPARED TO MANUFACTURING ASTEROIDS INTO SPACECRAFT

There are many pros and cons to colonizing Mars compared to manufacturing asteroids into spacecraft. The bold items below are the important reasons.

<u>**Pros**</u>

1. **It is currently easier to create fuel and propellant from the Martian atmosphere.**
2. Easier to "plant a flag" on the only surface.
3. More research conducted on Mars than asteroids.
4. More total mass on Mars than all of the asteroids in our solar system combined.

<u>**Cons**</u>

1. **Most humans will still remain on Earth**
2. **Only 1 backup in case of disaster on Earth**
3. **More expensive**

   We can use asteroid mining to fund the entire process by sending asteroid samples down to Earth.

   Space tourism can't be achieved by colonizing Mars.
4. **No potential for luxury**
5. **Harder to make usable materials**

   The surface of Mars is covered in iron oxide, which is difficult to convert into usable iron.
6. **Lack of motivation**

   Besides exploration and ensuring humanity's survival, there is no reason to settle on Mars. Terraforming would be an incredible undertaking.
7. **Slower**
8. **Humans have never been to Mars**

   There is an inherent risk of the unknown.
9. **Acceleration due to gravity is 38% that of Earth's**

   Untested whether or not humans can survive for extended conditions in this environment.
10. **Static dust**
11. **Dust storms**
12. **Nights**

    This means larger solar panels will be needed for the same energy at the same distance from the Sun.
13. **Harder to scale**

    Does not easily lead to humanity being interstellar.

14. **Tougher on rockets**

    Landing and launching from Mars causes additional stress.

    Months of travel through outer space causes additional stress.

15. **Further distance from Earth**
16. **Further distance from the Sun**
17. **More meteors pulled into the gravity well**
18. **Less livable surface area**
19. **Life might exist on Mars and more people would disturb it**
20. Marsquakes
21. Unchangeable orbit
22. Days are not exactly 24 hours

The cons far outweigh the pros. The only considerable pro for colonizing Mars is the feasibility of creating fuel from the Martian atmosphere whereas we will need to develop new mining equipment to create solar sails from asteroids.

The cons are significant and are completely avoided using metal mined from asteroids as spacecraft.

3. METAL PURIFICATION DESIGNS

We can create spacecraft out of silica, iron, nickel, and practically any metal found in the main belt.

M-Type asteroid compositions vary and are not as well studied as Mars. 16 Psyche is an m-type asteroid and is mainly composed of iron, nickel, pyroxene, and carbonaceous chondrite [1]. Hereinafter, I will assume that all other m-type asteroids have the same composition, which is a necessary extrapolation for simplicity. We are given the option to use the asteroid as-is, purify the nickel-iron, purify the pyroxene, or purify the carbonaceous chondrite. We will purify the nickel-iron because it is the most abundant material in m-type asteroids. It is also strong, malleable, and reflective when manufactured correctly.

There are many asteroids in the main belt. Some of these have a significant amount of acceleration due to gravity and others do not. If we want to mine the large asteroids, we have the advantage of being able to separate the materials by melting point more easily, but there are significant drawbacks: we have to orbit the asteroid with the parabolic reflector at the same period the asteroid rotates, land on the asteroid, and launch from the asteroid.

If we mine asteroids without a significant acceleration due to gravity, "0g" hereinafter, we have to separate based on boiling point or induce centripetal acceleration to separate by melting points.

Given the complications of landing on an asteroid with a significant acceleration due to gravity, we will focus on 0g asteroids.

Looking at Appendix subsection 11.7 we can see that we can boil off the nonmetals in a low pressure chamber and be left with primarily nickel-iron, "metal" hereinafter. The nonmetals will completely boil off once we reach temperatures of around 2600°C at 1 bar.

This purification design of boiling off the nonmetals in 0g may not be best. Another solution would be to separate the metals and nonmetals by melting point with centripetal acceleration. For the rest of this paper, assume that the boiling design will be used as it may have fewer moving parts.

4. MINING AND PURIFICATION PROCESS

M-Type Asteroids are metal-rich, so they will be the focus of our metal mining.

Process:

1. Use mining equipment to get a sample of the asteroid (see Appendix subsection 11.6).

2. Heat the sample to boil off the nonmetals in a boiling chamber.

    Use the light absorber/parabolic reflector to heat the chamber and sample.

    Maintain a small pressure by venting the gases.

    Continue heating until approximately 2600°C.

    The boiling chamber compartments have a few requirements:

    (a) Made from a material with a high melting point, high thermal conductivity, and minimal chemical interaction with iron, nickel, pyroxene, and carbonaceous chondrite. There are a few suitable materials, such as hafnium diboride [2], titanium diboride [3], zirconium diboride [4], titanium carbide [5], or silicon carbide [6].

    (b) Capable of pressurizing 1 bar.

    (c) Each compartment holds a solid/liquid sample of asteroid.

    (d) Have direct contact with the sample, so we do not need rely on radiation to heat the sample.

At the end of this two step process, we are left with liquid nickel-iron.

5. MANUFACTURING PROCESS

After the mining and purification process, we are left with liquid nickel and iron to be crafted. For the early part of the operation all of the metal will be put into manufacturing reflective panels for our parabolic reflector. After the manufactured parabolic reflector suits our energy needs, we will manufacture solar sails and spacecraft.

To create the **parabolic reflector**, we:

1. Create wire by pushing the metal through a hole, similar to injection molding.
2. Create foil strips by flattening this wire.
3. Align these foil strips into panels using wire frames and an assembling robot following a wire.

Our process to create **solar sails** is the same as the parabolic reflector, but shaped differently.

To create our **spacecraft**, we can take advantage of cold welding. If we don't flatten the wire into foil, we can use the assembling robot to lay the wire in the shape of spacecraft. The wire will weld together upon contact.

6. SENDING THE METAL BACK TO EARTH

At this point, we have plenty of metal in the forms of foil and spaceship shells. Given the physics of solar sails, we can't use the sun's lights to send a solar sail directly back to Earth. However, we can create a 2 part solar sail system. The first part is a solar sail as we've talked about before. The second part is a parabolic reflector designed to reflect the light towards the solar sail. This design provides solar pressure opposite the sun's solar pressure, thus making it possible to transport our metal anywhere in the solar system, including back to Earth. Another key feature of this design is its scalability. With the assumption that we have 1+ km^2 of metal foil, we can create a solar pressure many times the typical solar pressure between 1 AU and 2.7 AU from the sun. We are essentially creating a super powerful laser to propel our solar sail back to Earth.

7. MINING DRONE DESIGN

Manufacturing drone components:

1. Computers
2. Communications equipment
3. Solar panels
4. Solar sail / parabolic reflector
5. Sample collector
6. Light absorber and boiler
7. Structural components
8. Manufacturing setup

Assume that a rocket and a high impulse thruster will be able to put 100 tons into GEO.

Computers and communications equipment are standard and weigh 260 kg since each Starlink satellite weighs 260 kg and this is not much more complicated [7].

Solar panels are required to power the computers, communications equipment, sample collector, and manufacturing setup. Assume they weigh approximately 500 kg.

A simple **sample collector** design would be a drill with a core sample head attached to an arm. More designs are discussed in Appendix subsection 11.6. This should weigh less than 2 tons.

Assume the **structural component** weighs 5 tons.

The **manufacturing setup** should be incredibly simple. The wire is created using pressure to push out a stream of molten metal, similar to injection molding. The foil is manufactured by flattening this wire. The assembly robot applies slight pressure between two metal surfaces and welds them together via cold welding. This whole setup should require less than 2 tons of mass, including the backups in case of failure.

At this point, we are left with optimizing the light absorber and boiler vs. the solar sail / parabolic reflector. We only need enough of a solar sail / parabolic reflector to get to an appropriate asteroid in a reasonable time. Assuming we want to get to an asteroid within 5 years, we need a **solar sail** of mass 27.66 tons (refer to Appendix subsection 11.1 for the calculations). Now we have (100 - 0.26 - 0.5 - 2 - 5 - 27.66 = 64.58) tons to allocate for the light absorber and boiling chamber.

Appendix subsection 11.2 shows that we have 64580 **boiling chambers**, each with an averaged mass of 1kg. This means we have a total volume of $64580 * 0.1^2 * \pi * 0.5m$ = 1014m^3 and a surface area of $64580{*}2\pi{*}0.1{*}0.5$ = 20288 m^2. The total purification rate is now based upon the heat transfer rate between the asteroid sample and the boiling chamber walls. This part of the entire process is the most complicated and has a higher throughput the more surface area.

8. SPACE CITIES

Let's assume that people will live in cities with 1 million people with 9.81 m/s^2 of centripetal acceleration. The easiest way to have centripetal acceleration on a spacecraft would be to rotate two spheres attached by a cable. For 1 million people, each sphere will hold 500k people. Appendix subsection 11.3 shows that this would require 5.84E6 tons of iron, or a comparable weight in nickel-iron. Housing all 8 billion humans would require 4.672E10 tons of iron.

Assuming the metal purification process is limited only by the energy output, we can estimate how long it will take both to house the first million humans and to house all humans. Appendix subsection 11.5 shows that if this is the case, then we can purify enough metal to house the first million humans in less than 3.5 hours and we can house all humans in less than 6.5 hours. Obviously energy output will not be the limiting factor in this mining and purification process. So what are the limiting factors?

Possible limiting factors:

1. Boiling chamber: Limited by the heat transfer between the container and the samples.
2. Sample collector: Limited by the mass collection rate.
3. Manufacturing: Limited by any of the processes:
   (a) Cooling
   (b) Pressing into wire
   (c) Flattening
   (d) Assembling the wire and foil, which is limited by the ”coordination” of the robot or the travel speed on the wire.

Given the complicated nature of the boiling chamber, it is safe to assume that it will be the limiting factor.

If each sample chamber purifies its sample in 1 hour, we get 812 m^3 of metal per hour. This is approximately 7200 tons of metal per hour. Converting this into foil we get 150 km^2 per hour, assuming nickel-iron foil weighs 0.0484 kg/m^2 (see Appendix subsection 11.5).

We want to ensure that humans don’t just survive, but are happy. 16 Psyche, estimated to contain about 1% of the mass in the asteroid belt has an estimated mass of 2.41E16 tons. With 80% of the asteroid’s mass as metal, we get 1.93E16 tons of metal in 1% of the asteroid belt [8]. (Note: we are using 16 Psyche because it is well studied.) Using just the metal from 16 Psyche and the assumption that 5.85 tons of metal can provide 136m^3 of suitable living space, we can provide every human with 5.6E7m^3. That translates to every human having 412k studio apartments, using them however they please. This is more than enough space for every human to live luxuriously.

9. HOW CAN THIS HELP THE EARTH?

Asteroid mining currently has a few benefits for the Earth, namely ending climate change, ending nickel and iron mining on Earth, and reducing the number of humans on Earth.

9.1. End Climate Change with a Space Mirror

One of the potential solutions to ending climate change is a space mirror, which lies between the Earth and the sun and reflects sunlight before it gets into Earth’s atmosphere. This reduces the amount of energy entering the Earth’s atmosphere and thus reduces the ultimate temperature on the surface of the Earth. This has been theorized but never put into practice because of the cost of putting the reflective materials into Earth’s orbit. By mining asteroids we have more than enough metal to create an effective space mirror. Lowell Wood calculated that a 1.6E6 km^2 space mirror orbiting at Lagrange point L1 would restore climate stability [9]. With our throughput of 7200 tons of metal per hour, or 149km^2 of foil per hour, it would take 450 days to restore climate stability.

The solar mirror is essentially a solar sail, so placing it in Lagrange point L1 would immediately push it towards Earth. Placing it closer to the Sun and balancing the force of the thrust from the solar sail and the force of gravity by adjusting the weight-to-thrust ratio could allow the sail to remain in place indefinitely. A potential design for this would be to have a foldable or rotatable solar mirror.

9.2. End Nickel and Iron Mining on Earth

Nickel and iron mining cause ecological disruption. By transporting our metal down to the Earth’s surface, we reduce the need for mining these metals on Earth. This saves ecosystems from being destroyed.

9.3. Reduce the Number of Humans on Earth

Humans are inherently ecosystem disrupting. By moving humans off of the planet we will reduce the impact they have on the planet. The biggest planet destroyers are the richest humans, who will be the first to inhabit interplanetary space. Ultimately, with most humans off of the planet, nature will slowly heal.

10. CONCLUSION

We have shown that we need to switch our focus from Mars to asteroids. Building spacecraft out of asteroids is the fastest and cheapest way to move all of humanity to space. The current requirements are unnecessarily restricted and switching to creating spaceships from asteroids is better. Please reconsider colonizing Mars.

11. APPENDIX

11.1. Solar Sail Mass

Assume:

1. Solar pressure: 5N per 6.4E5 m^2 at 1 AU [10]
2. Aluminum foil thickness of 6 micrometers
3. Aluminum reflects 95% of light
4. Average Δv for the entire duration
5. Δv of 9.96 km/s from LEO to the asteroid [11]

$$a = 9960m/s/5years = 6.31E-5m/s^2$$

$$F = ma = 100000kg * 6.31E-5 = 6.31N$$

$$6.31N * 6.4E5m^2/5N = 8.08E5m^2$$

Aluminum foil mass for 1m^2 area:

$$6E-6m^3 * 2710kg/m^3 = 0.01626kg$$

8.08E5 m^2 * 16.2 kg / 1000 m^2 * 1/0.95 = 13.83 tons of aluminum foil if at 1 AU the entire time. If the solar sail is at 2.7 AU the entire time, it will take 36.45 years to get to an asteroid. Neither of these distance assumptions are true, so assume this mass of solar sail gets to the asteroid in 20 years. Let's double the size of the solar sail to 27.66 tons to get to the asteroid in 10 years. This timing assumption is complicated and ignores the $\frac{1}{r^2}$ relationship of radiation and it also avoids the orbital mechanics. Further analysis should study this section much more. For now, we will continue with the 27.66 ton solar sail assumption.

11.2. Boiling Chamber Mass

Assumptions:

1. Maximum pressure will be 1 bar
2. The core sample sizes will be 10cm diameter cylinders 0.5m long.
3. Material tensile strength = 45 bar. This is the tensile strength of silica [12].

Thin-walled assumption

$$\sigma = \frac{Pr}{t} \tag{1}$$

Solving for thickness of tungsten required for each sample chamber:

$$t = \frac{Pr}{\sigma} = 2.22E-3m \tag{2}$$

The thickness will not depend on the pressure in the chamber. The thickness will depend on the mechanical durability of the chosen material. Let's assume the material weighs 1kg total weight per boiling chamber. This is including the light absorber and the support equipment for the boiling chamber averaged out.

11.3. Million Person City

Assumptions:

1. 500k people per sphere
2. 1 ATM of pressure
3. The outside walls are 0.5m thick, made from pure iron.
4. Everyone has 100 kg of possessions.
5. Each person's net wall mass is 50 kg.
6. The average person weighs 62 kg.
7. Everyone is suspended using iron wires.
8. Each person gets 136m^3, which is about the size of a studio apartment in the United States (600 ft^2) [13].
9. Iron has a tensile strength of 540 MPa [14].
10. Assume 8 billion total humans.

Calculations:

- Total volume required per sphere: 68E6 m^3
- Radius of the sphere = 253m

$$SA_{sphere} = 4\pi r^2 = 8E5m^2 \tag{3}$$

- Everyone has an average suspension cable length of r = 253m.
- Cable area required per person = F / P = 212*9.81/540000 = 0.00385 m^2.
- This translates to $0.00385m^2*253m*500000$ = 4.87E5 kg of iron
- The walls require $8E5m^2 * 0.5 * 7300$ = 2.92E9 kg of iron
- In total, this design requires 5.84E6 tons of iron.
- This translates to 5.84 tons per person.
- Housing all humans requires 4.672E10 tons of iron.

11.4. Energy Required to Purify Metals

Assumptions:

1. The asteroid's temperature is approximately -73 C [15]
2. The composition by mass of the average m-type asteroid is [1]:

   82.5% metal Assume 80% iron, 20% nickel

   7% low-iron pyroxene

   10.5% carbonaceous chondrite

3. Solid iron specific heat = 0.450 J/g°C [16]

4. Iron's latent heat of fusion = 11.7 kJ/mol [17]

5. Liquid iron specific heat = 0.820 J/g°C [18]

6. Solid nickel specific heat = 0.444 J/g°C [19]

7. Nickel latent heat of fusion = 17.47 kJ/mol [20]

8. Liquid nickel specific heat = 0.73 J/g°C [21]

9. It is hard to find data on pyroxene and chondrite, so assume they have the same properties as silica.

10. Solid silica specific heat = 0.71 J/g°C [22]

11. Could not find silica's specific heat as liquid or gas. Assume the same as when a solid.

12. Silica latent heat of fusion = 50.55 kJ/mol [22]

13. Silica latent heat of vaporization = 384.22 kJ/mol [22]

14. Heating from -73°C to 2600°C

For 1 kg sample of an m-type asteroid:

Iron (0.66 kg):
Q = m($c_{solid}\Delta T + \Delta H_{fus} + c_{liquid}\Delta T$)

= 800g*(0.450 * (1611°C) + 11700 J/mol * 1 mol / 55.845g + 0.820*(2600°C-1538°C))
= 1.2E6 J

Nickel (0.165 kg):
Q = m($c_{solid}\Delta T + \Delta H_{fus} + c_{liquid}\Delta T$)
$= 165g(0.444 * 1528$°C + 17470 J/mol * 1 mol / 58.693 g + 0.73*(2600°C-1455°C))
= 2.98E5 J

Silica (0.175 kg):
Q = m($c_{solid}\Delta T + \Delta H_{fus} + c_{liquid}\Delta T) + \Delta H_{vap} + c_{gas}\Delta T)$
$= 175g(0.71 * 1788$°C + 50550 J/mol * 1 mol / 60 g + 0.71*(2230°C-1788°C) + 384220 J/mol * 1 mol / 60 g + 0.71*(2600°C-2230°C))
= 1.59E6 J

Total energy to bring an asteroid sample to 2600°C = 3.09E6 J/kg

11.5. Exponential Metal Purification

Assuming the metal purification process is limited only by the energy output, we can estimate how long it will take both to house the first million humans and to house all humans.

Assumptions:

1. Metal purification requires 3.09E6 J/kg.
2. Main belt asteroids get 187 watts of sunlight per m^2 (2.7 AU from the sun)
3. Our metal reflects 95% of light
4. Our metal is 6 micrometers thick
5. Iron has a density of 7850 kg/m^3 [23]
6. Nickel has a density of 8908 kg/m^3 [23]

Foil calculations:

- 1 m^2 is a volume of 6E-6 m^3
- which is a mass of (0.8*7850+0.2*8908)*6E-6 = 0.0484 kg
- Which translates to 20.66 m^2/kg nickel-iron.

To avoid the calculus required for precise rough estimations, we can assume the metal production is a 2^n function where n is the number of iterations of the process of using the foil to make more foil.

20.66 m^2 of sunlight at 2.7 AU from the sun translates to 3863 watts.

3.09E6 J / 3863 watts = 800 s

It takes 800s to create enough energy to double in size.

We are starting with 16.2E5 m^2 of parabolic reflector area, which would be 78 tons if our nickel-iron foil was the equivalent area.

$$m_i * 2^n = m_f \tag{4}$$

$$n = log_2 \frac{m_f}{m_i} \tag{5}$$

Number of iterations required to house 1 million humans:

$$n = log_2 \frac{m_f}{m_i} = log_2 \frac{5.84E9kg}{78E3kg} = 16.2 iterations \tag{6}$$

This means that it takes 3.6 hours to get enough metal to house 1 million humans.

Number of iterations required to house all million humans:

$$n = log_2 \frac{m_f}{m_i} = log_2 \frac{9.35E13kg}{8.6E3kg} = 30.16 iterations \tag{7}$$

This means that it takes 6.7 hours to get enough metal to house all humans if we are only limited by the power output of our parabolic reflector.

11.6. Example Sample Collection Designs

Our sample collection system has two main requirements: low power and durable. With just these constraints, two easy designs come to mind: electromagnetic jackhammering or drilling the asteroid. If we use nickel-iron for the hammer and drill bit respectively, we can continuously replace the only part that will see any significant wear. This results in a total collection system with almost no mechanical wear.

11.7. M-Type Asteroid Regolith Physical Properties

Assuming that all m-type asteroids are identical to 16 Psyche, m-type asteroids are composed of 82.5% metal, 7% low-Fe pyroxene, and 10.5% carbonaceous chondrite [1].

Pyroxenes are a group of minerals of the form XYZ_2O_6 where X and Y can be a couple of a few different metals, and Z can be Si or Al [24]. Pyroxenes are classified as silicates. Since there is a lack of readily available knowledge on these different minerals, we are going to assume that their properties are similar to silica for the missing information, particularly the boiling point.

Carbonaceous chondrites are largely composed of olivine and pyroxene and commonly contain metallic iron and nickel. They were initially classified as iron meteorites with silicate inclusions due to their high iron content. However, chondrites are so diverse in their mineralogical characteristics that its difficult to provide a broad generalization of their typical composition [25].

Overall, we are left with the conclusion that m-type asteroids have a high metallic nickel and iron content with pyroxene, olivine, and other silicate inclusions. With this information, we can determine the best methods of purifying the metal of these asteroids. Looking at table 1 we can see that the melting points of the silica and the metals are similar but the boiling points are not. This means it is relatively easy to boil off the silicate impurities and be left with the metals. Looking at the phase diagram of iron in Figure 1, we can see that we need to keep a pressure of at least 1 bar in order to not boil off the iron.

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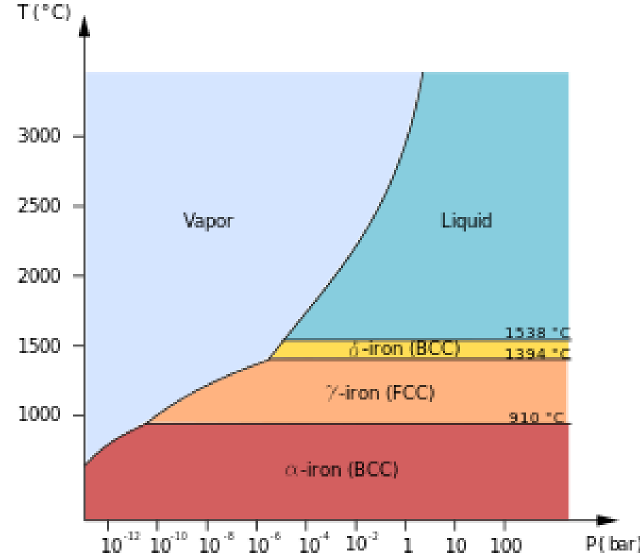

Fig. 1: Low-pressure pure iron phase diagram [26]

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Material	Melting Point (°C)	Boiling Point at 1 ATM (°C)
Iron	1538	2862
Nickel	1455	2730
Silica	1710	2230
Pyroxene	1000 [27]	Could not find data. Assume similar to silica [24].
Olivine	1890 [28]	Could not find data. Assume similar to pyroxene.

Table 1: Boiling and Melting Points of Common M-Type Asteroid Materials

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