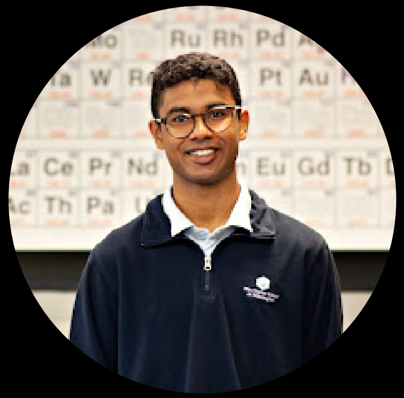
AstroTech

Asteroid Mining of the Future

The New York Academy of Sciences

Meet the Team



Srijay Chenna, Team Lead

Delaware
The United States of America

Mehedi Utsob*, Computer Scientist

Rajshahi
The People's Republic of Bangladesh

Akshay Shankar, Physicist

Gujurat
The Republic of India

Vibhuti Bafna, Chemist

Delhi
The Republic of India

Jana Yehia, Researcher

Giza
The Arab Republic of Egypt

Kinza Khan, Environmentalist

Punjab
The Islamic Republic of Pakistan

*Unfortunately due to extenuating circumstances regarding Bangladeshi politics, Mehedi Utsob was unable to contribute to the final stages of the project.

Background

Background: Minerals of Technology Crisis

Energy
Minerals are increasingly important for new, sustainable, clean sources of energy.[1]

Environment
The use of unsustainable mining practices means negative environmental impacts in prolific mining regions.[2]

Economy
Current mines in developing regions sustain local economies through child labor.[3]

Background: Asteroid Mining's Flaws

Asteroid mining can be used to address the minerals of technology crisis by looking to the vast minerals in space as a replacement of those on Earth. However, there are critical considerations that have not yet been considered. Most essentially there are the following:[4]

Finding
asteroids of optimal composition that hold enough potential to justify the pursuit of mining them.

Exploiting
asteroids, after finding them is a necessary step to make efficient again considering the price-benefit of exploitation.

Background: Our Skyhook/Data Solution

Finding with Data

By collecting data on location and asteroid composition and analyzing it using a computer program, we can determine the asteroids optimal for mining through our skyhook methedology. Data will be collected by the following methods.

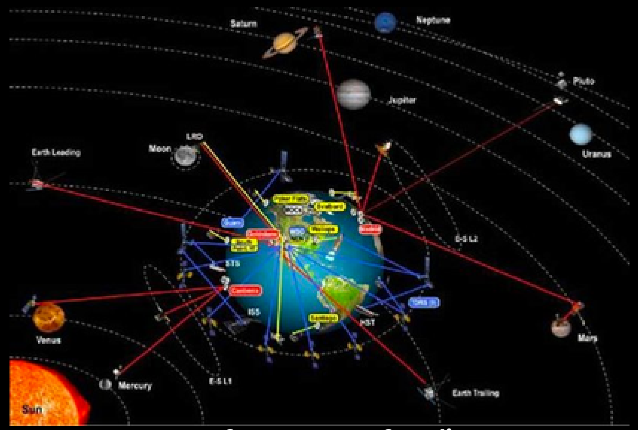


Image from news.softpedia.com

a)

NASA's planetary data system holds an integrated data base for location data on interplanetary bodies including asteroids.

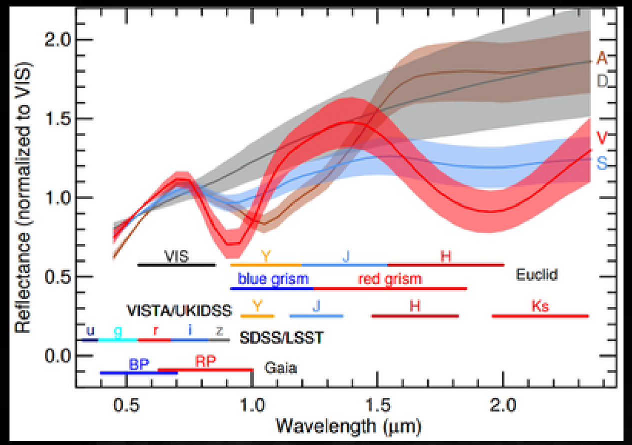


Image from researchgate.net

b)

Real-time spectral reflectance can help determine the mineral composition of asteroids. An example of spectral reflectance for asteroid analysis is shown to the left.

Exploiting with Skyhooks

The utility of skyhook technolgy for asteroid mining increasing the efficacy of this practice if used in the described manner.

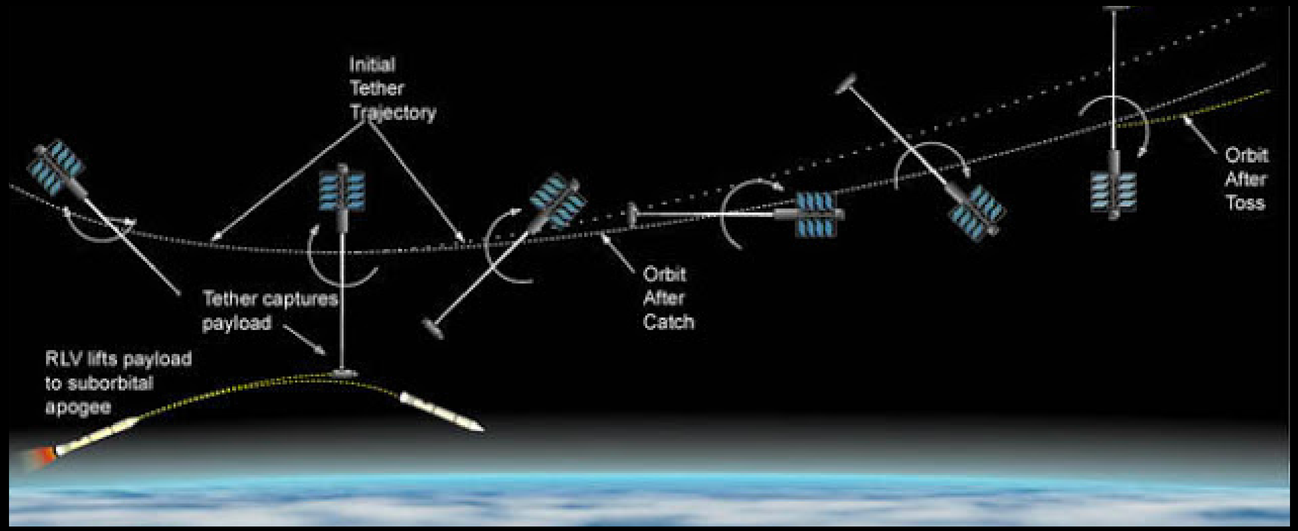
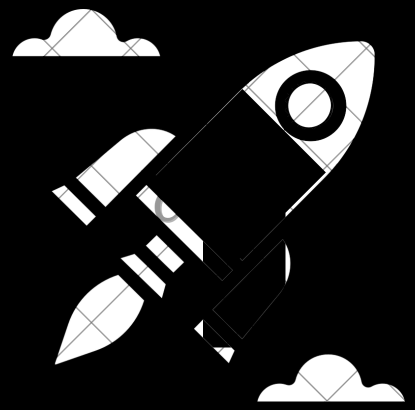


Image from spacehabitats.co.uk

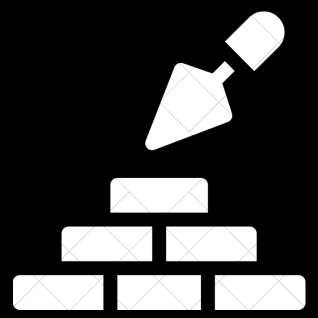
By using extra-terrestrial tethers different objects in space can be manipulated and redirected for purpose. As detailed in following slides, the use of spacehook tethers can be used for manipulation of asteroids and mining tools for efficient mining that disregards the inefficient use of liquid fuel in transporting mining tools and pursuing mining methods.

Solution: Skyhook

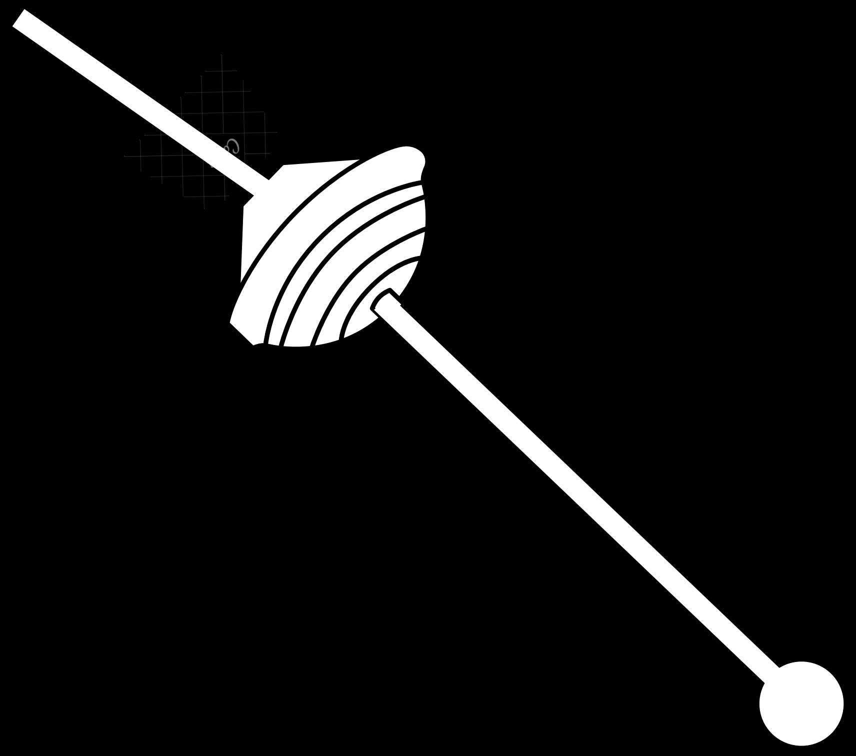
Skyhook: Benefits



Space travel as of now is like carrying a jetpack almost 10 times your size, fighting against the laws of physics as it pulls you back down to the surface. To deliver a payload almost 90% of the weight simply goes into the fuel, and this process when scaled does not remain the same ratios, in fact the percent weight of fuel just increases.



But just like any form of traveling, we must tackle this problem just as we have from the beginnings of invention. Too much energy to go hunting for food? Grow crops domestically for abundant food. Too much time to walk on foot across mountains and valleys to the next village? Create roads and bridges for horseback, and develop automobiles for faster travel. The main similarity in the solutions we come up with is in setting the foundation for cheaper, convenient, and more efficient routes to our objective.



Skyhooks drive down costs and make traveling through space more efficient. The skyhook is a tethering system that stores momentum through its revolutions around the earth. This tether provides a massive boost in energy to spaceships that tether to it. As the skyhook continues to fling spaceship, it will begin to loose momentum. This is solved by a counterweight with a propulsion system that boosts its rotation back to its origin, keeping the system functional. It can also exploit the laws of physics by performing the opposite reaction and grappling spaceships downwards, building momentum.

Skyhook: Function

1 - Skyhook Tether

- The Skyhook Tether is a large, strong cable which is deployed in space, extending from a capture device to a counterweight or anchor point, such as a satellite or space station.
- The tip of the skyhook would reach speeds of mach 10 which means it endures great amounts of tension and would be prone to collapse if not made of a strong material that has high tensile strength and is also lightweight and flexible. A material which can withstand the following:
  - Gravitational influence of celestial bodies
  - Solar radiation pressure and heat
  - Possible micro collisions over a period of time
  - Stress of the body
  - Possible collisions with payloads
- Thus, the best material for the above conditions is something similar to Zylon.

2 - Space Station

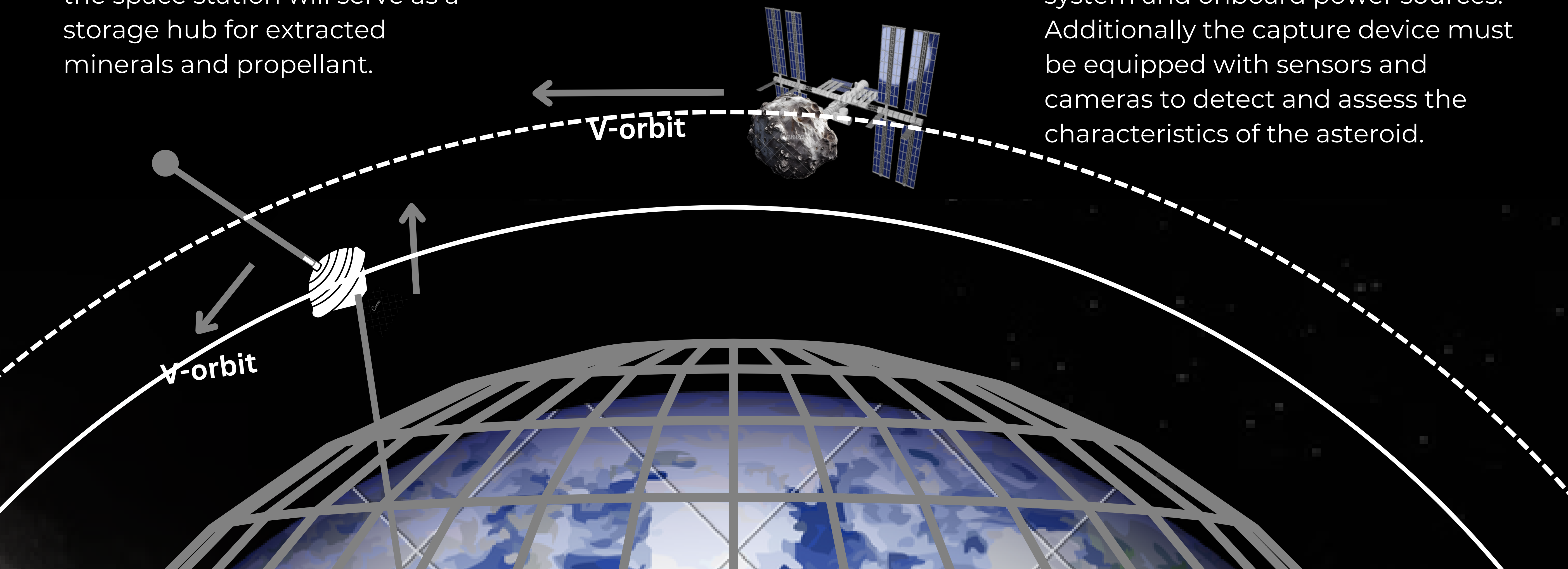
- The tether's anchor point and counterweight are provided by the Skyhook space station. It is situated in a stable platform, or geosynchronous orbit around the Earth.
- Solar panels are used on the station to power communication systems, mission control, and power generation. In addition, the space station will serve as a storage hub for extracted minerals and propellant.

3 - Tether Deployment Mechanism:

- The space station is equipped with a motorized mechanism that allows for the controlled extension of the tether ensuring it reaches its length.

4 - Asteroid Capture Spacecraft:

- A specialized spacecraft has been specifically designed to capture and stabilize the asteroid, which will be connected to the end of the tether.
- This spacecraft incorporates propulsion systems, robotic arms equipped with capturing mechanisms, solar panels for power generation scientific instruments, for studying the asteroid a magnetic field deployment system and onboard power sources. Additionally the capture device must be equipped with sensors and cameras to detect and assess the characteristics of the asteroid.



Skyhook: Using Skyhook for Asteroid Capture

1 - Asteroid Selection and Mission Planning:

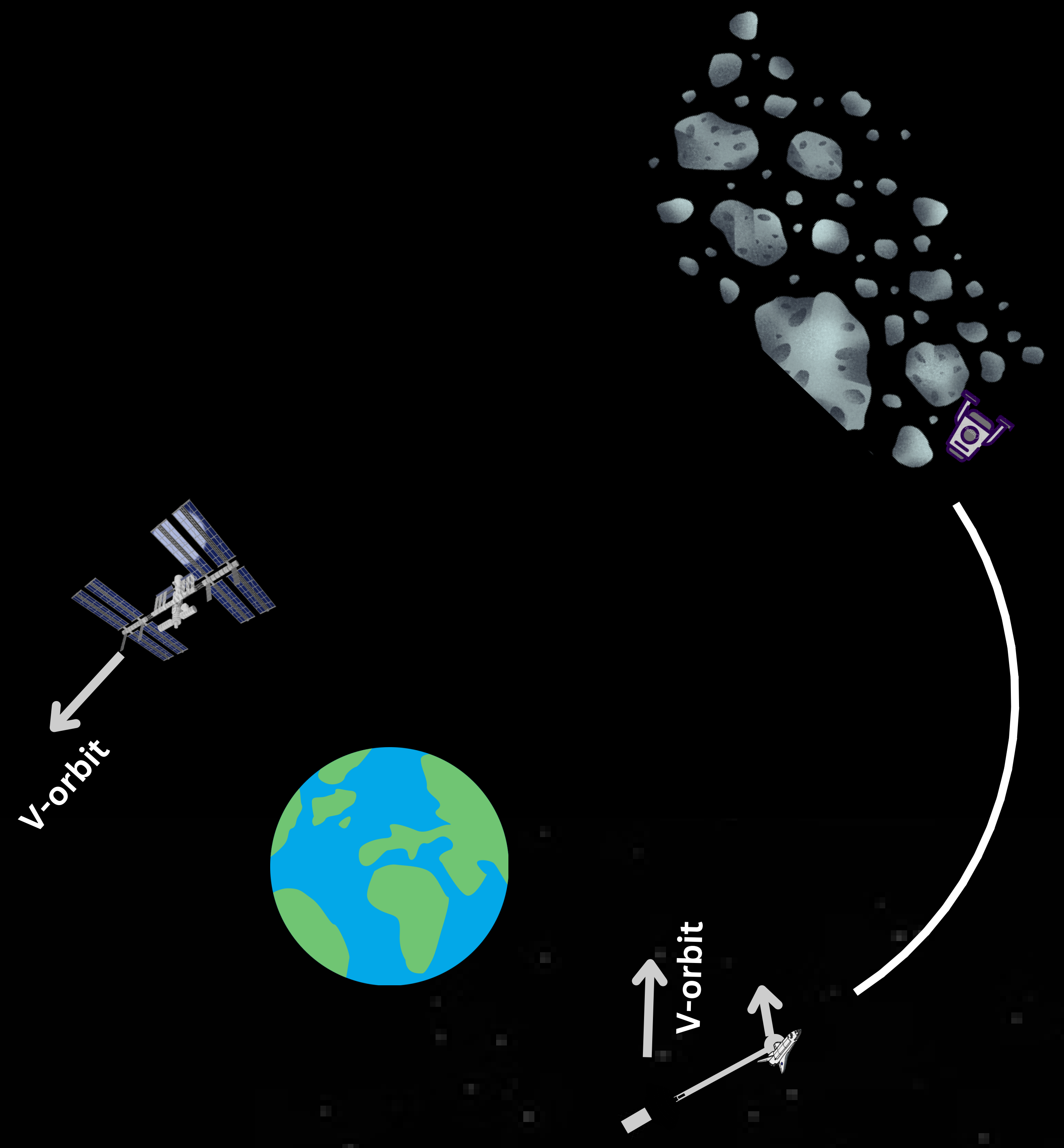
- The process of asteroid prospecting and exploration facilitates in the identification of potential asteroids for capture.
- The size, composition, spin rate, and distance of the asteroid from Earth are taken into account when planning a mission

2 - Launch and Rendezvous:

- The tether-attached capture spacecraft is propelled toward the target asteroid at a high speed during launch.
- The target asteroid and the tether engage in dynamic interaction. The tether absorbs and exchanges momentum when the asteroid and the capture device move at high speeds in relation to one another.
- The momentum transfer allows the capture device to gradually match the speed and trajectory of the asteroid.

3 - Capture and Anchoring:

- As the spacecraft gets closer to the asteroid. mechanical, robotic arms reach out and securely hold onto the surface of the asteroid
- Anchoring probes may be used to ensure a stable connection if the surface is irregular.
- The spacecraft deploys a secondary tether with a docking mechanism that connects to the main Skyhook tether.
- Once the asteroid is caught we can employ the skyhook system to adjust its orbit. By adjusting the tension and length of the cable this system has the ability to influence both the trajectory and orbital characteristics of the captured object.



Skyhook: Using Skyhook for Asteroid Capture (Cont.)

4 - Slowing down the spin-rate of the asteroid:

- AstroTech suggests employing Hypersonic Skyhook Tether technology to reduce asteroid spin rates.
  i. Tether Dynamics:
    - The supersonic skyhook tether refers to an robust cable that stretches from the capturing device or spacecraft to a counterweight, such, as a satellite or space station.
    - This tether encounters tension and its dynamic behavior follows the principles of mechanics and celestial dynamics.

  ii. Counteracting Angular Momentum:
    - Angular momentum, which is a vector quantity aligned with the axis of rotation plays a role in countering the rotation of an asteroid. Adjustments to the tethers tension can be made in such a way that opposes this momentum.
    - The objective here is to transfer momentum from the rotating asteroid to the tether effectively decelerating its spin.

  iii. Strategic Tether Adjustments:
    - Manipulating the tension in the tether involves controlling forces acting upon it. The length of the tether can be altered, as strategically increasing or decreasing its tension.
    - These adjustments are made in response to the asteroids rotation inducing torque that impacts its momentum.

  iv. Torque and Angular Momentum Transfer;
    - Torque (τ) acts as the counterpart of force and is determined by multiplying force with the lever arms length ($\tau = r \times F$).
    - By adjusting tension in the tether torque is applied to exert an influence, on the asteroid. The torque mentioned has an impact, on the asteroid’s angular momentum.

  v. Conservation of Angular Momentum:
    - According to the conservation of angular momentum, the total angular momentum of an isolated system remains constant unless acted upon by external torques.
    - Gradual adjustments to the tether's tension transfer angular momentum from the rotating asteroid to the tether, leading to a reduction in the asteroid's spin.

5 - Transfer to Earth's Orbit:

- Once the asteroid's motion is stabilized and de-spun, the tethered connection allows for controlled manipulation.
- The asteroid is then transferred into a stable Earth orbit, which may involve further adjustments in its trajectory.

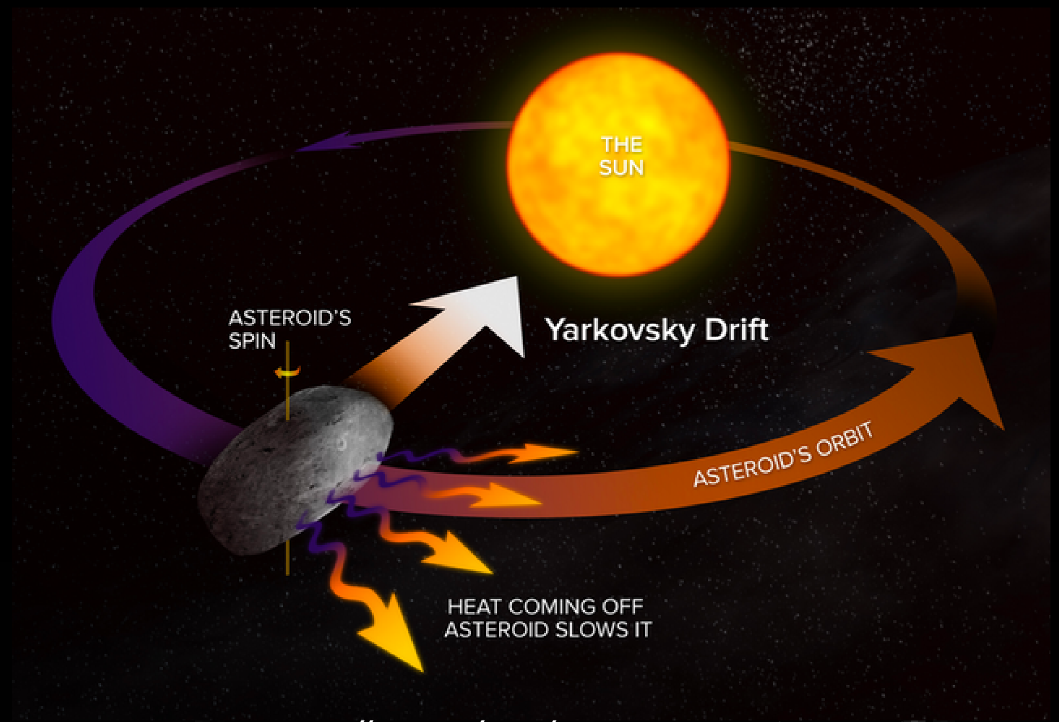


Image from http://phys.org/news/2013-02-close-passing-asteroid.html

Figure 1 - Visualized considerations for reductions in asteroid spin-rate before mining or transport.

Possible Testing and Validation Procedures

Due to the highly theoretical nature of this concept, it is important acknowledge the difficulty in testing or even implementing such technology. The good news is that it is possible to simulate the application of this technology but unfortunately this takes a very high level understanding of fundamental mathematics.

At its core, the simulation would rely on physics and dynamics models encompassing a wide spectrum of physical principles, including celestial mechanics, thermodynamics, and material properties. These fundamental models provide the basis for understanding how objects interact, move, and respond to external forces and internal forces present within the system. An orbital dynamics simulation would serve as the heart of the simulation, accurately predicting the orbital behaviours of both the skyhook and the space station. This component accounts for gravitational forces experienced through every element in the system, celestial mechanics and principles, and the impact of Earth's oblate shape, allowing the system to simulate orbits and positions.

Now, we can gather all equations, and apply formulas for the gravitational forces derived in the previous section. The equation of motion of the center of mass (41) takes the form

$$\ddot{\mathbf{R}}_C = \mathbf{g}_C^0 + \frac{1}{M}\sum_{k=2}^{\infty} \mathbf{g}_C^k I_0^k + \frac{\mathbf{\Phi}_0}{M}, \tag{75}$$

the equation of the quasi-rigid rotation (59) can be rewritten as

$$\ddot{\boldsymbol{\tau}}_1 + \Omega_0^2\, u_1 \boldsymbol{\tau}_1 = \mathbf{g}_C^1 + \frac{1}{J_C}\sum_{k=2}^{\infty} \mathbf{g}_C^k I_1^k + \frac{\mathbf{\Phi}_1}{J_C}, \tag{76}$$

and the equations of tether oscillation (37), $n = 2, 3, \ldots$, can be reduced to

$$\ddot{\mathbf{q}}_n + \beta_n^2 \Omega_0^2 \left[k_E\, \mathbf{e}_1 q_{en} + \nu_n\, \mathbf{e}_1 \dot{q}_{en} + u_1 (\mathbf{q}_n - \mathbf{e}_1 q_{en})\right] = \frac{\mu_E}{R_C^3}\left[3\mathbf{e}_R(\mathbf{e}_R, \mathbf{q}_n) - \mathbf{q}_n\right] + \frac{1}{||U_n||}\sum_{k=2}^{\infty} \mathbf{g}_C^k I_n^k + \frac{\mathbf{\Phi}_n}{||U_n||}. \tag{77}$$

After deriving and defining forces and variables you could use these series of equations for simulation as described by the NASA Dynamics Simulation Model for Space Tethers

Solution: Data Analysis*

**Unfortunately due to the loss of our lead programmer due to extenuating circumstances, all cited code is Chat-GPT 4 Generated*

Data Analysis: Competitive Evaluation of Location

By prioritizing the convenience of asteroids' location in relativity to earth we can establish scores for later competitive evaluation of asteroid compoisition.

```python
class Asteroid:
    def __init__(self, name, distance, size, velocity):
        self.name = name
        self.distance = distance
        self.size = size
        self.velocity = velocity

    def score(self):
        # Assuming the maximum distance an asteroid can be is 1000 (arbitrary units)
        # The score is inversely proportional to the distance and velocity, and
directly proportional to the size
        return (1000 - self.distance) + self.size - self.velocity

# Example usage:
asteroid1 = Asteroid("Asteroid1", 500, 50, 20)
print(f"The score for {asteroid1.name} is {asteroid1.score()}")

asteroid2 = Asteroid("Asteroid2", 300, 70, 10)
print(f"The score for {asteroid2.name} is {asteroid2.score()}")
```

This code generates a score for an asteroid with position information that prioritizes slower moving, larger, and close-to-earth asteroids.

Data Analysis: Competitive Evaluation of Composition

After prioritizing location for mining convenience, we can evaluate composition secondarily in the top three percent of location scores of asteroids in the data set. Taking real-time spectral reflectance data we can input it into the following code.

```python
def score_asteroid(composition):
    # Define a scoring system for each mineral
    scores = {
        'Iron': 5,
        'Nickel': 4,
        'Cobalt': 3,
        'Water': 10,
        'Helium-3': 20,
        'Gold': 30,
        'Platinum': 40,
        'Palladium': 50,
        'Rhodium': 60,
        'Ruthenium': 70,
        'Iridium': 80,
        'Osmium': 90
    }

    # Calculate the total score for the asteroid
    total_score = 0
    for mineral, percentage in composition.items():
        if mineral in scores:
            total_score += scores[mineral] * percentage
```

```python
    return total_score

# Example usage:
asteroid_composition = {
    'Iron': 20,
    'Nickel': 15,
    'Water': 10,
    'Helium-3': 5,
    'Gold': 2,
    'Platinum': 1
}

print(score_asteroid(asteroid_composition))
```

From this, the highest scores can be listed in order to generate a list of asteroids that can be prioritized to consider for mining via the afore-detailed skyhook technology.

Other Considerations

Environmental Benefits of Solution

1 - Diminished Impact on Land

- Comparing Conventional Terrestrial Mining: Conventional mining on Earth entails considerable disturbance of the surface, deforestation, and habitat degradation. Soil erosion, water pollution, and biodiversity loss can result from extensive excavations and resource extraction.
- Analysis: By operating in space, asteroid mining helps to preserve Earth's ecosystems by avoiding these negative effects on land. Asteroids provide an attractive alternative to Earth because of the decrease in environmental damage on Earth.

2 - Renewable Energy Prospects

- Comparing Traditional Mining with Renewable Energy: Conventional mining operations frequently use non-renewable energy sources, which raises greenhouse gas emissions. In terrestrial mining, fossil fuels are frequently utilized for energy needs, machinery, and transportation.
- Analysis: Asteroid mining's potential utilization of space-based solar power and other renewable sources aligns with sustainable practices. The reduced reliance on fossil fuels contributes to a lower carbon footprint, addressing climate change concerns associated with traditional mining.

Solution Pitfalls/Mitigation Strategies

Pitfalls:

1 - Space Debris & Collisions

- Space debris may accumulate as a result of frequent space journeys for mining operations, increasing the threat of collisions and endangering space ecosystems.
- Space debris may also prove dangerous for future space travel

2 - Extraterrestrial Ecosystem Disturbance

- The potential disturbance of asteroids' microorganisms or organic compounds has raised concerns regarding unknown ecological impact as well as unintended consequences on extraterrestrial ecosystems.

Mitigation Strategies:

Space Debris Management:

- Debris removal and collision avoidance systems are among some of the effective ways to manage space debris.
  - Vacuum Extraction Systems:
    - Combine vacuum systems with mining tools to trap and hold dust and debris produced during work.
  - Enclosed Processing Units:
    - Make sure that mining equipment has enclosed processing units that do not release dust in the atmosphere.
  - Dust Collection Hoods:
    - Fixing dust collection hoods on mining tools will capture particles at their source.
  - Dust Recycling:
    - Implement systems to recycle collected dust for use in propulsion or other spacecraft functions, reducing waste.

Body of Regulation: International Collaboration

1- The Committee on the Peaceful Uses of Outer Space (COPUOS) of the United Nations

- Due to its representation of a wide variety of countries, COPUOS is best suited for the development and execution of international legislation. As such, it can be a venue for dialogue and drafting policies.

2 - The International Telecommunication Union (ITU)

- The ITU facilitates the allocation of frequencies for communication related to activities in asteroid mining with the aim of guaranteeing uninterrupted operations.

3 - The International Asteroid Warning Network (IAWN)

- IAWN as a global tracking network for forecasting asteroid hazards can support responsible mining practices and provide an indication about potential collision risks within the context of legislation.

4 - Office for Outer Space Affairs (UNOOSA), United Nations:

- UNOOSA, as the UN entity responsible for promoting international cooperation in the peaceful use and exploration of outer space, can actively participate in shaping and implementing the regulatory framework.

To sum up, ethical and sustainable exploitation of asteroids needs a well-defined regulatory framework that has the support from around the world. Therefore, in order to ensure this guideline does not conflict with national interests, company goals or environmental conservation concerns in outer space; worldwide efforts must be coordinated by key countries so that they achieve these objectives together.

Monetary Considerations

When we reached out to experts in astrophysics a common concern was budgetary considerations.

Gautham Ganesan, Astrodynamics Engineer

"...there are several factors at play here such as...budget..."

Gautham Ganesan, Astrodynamics Engineer

"Total cost of project should be analysed as well."

We determined that the best way to consider the budget is by cost-benefit. Asteroids which can hold up to 700 quintillion USD in materials,[5] are economically viable to both fund further asteroid mining endeavors as well as pay reparations to developing economies damaged by extraterrestrial mineral mining and increase the accessibility of technology.

Bibliography

[1] Ali, S. H. (2023). The US should get serious about mining critical minerals for clean energy. Retrieved from https://www.nature.com/articles/d41586-023-00790-y#:~:text=We%20are%20living%20in%20a%20time%20of%20a,lithium%2C%20copper%2C%20nickel%2C%20cobalt%2C%20manganese%20and%20rare-earth%20elements.

[2] The Problem With Unsustainable Mining Practices - Eco Friendly Home Making. (2023). Retrieved from https://ecofriendlyhomemaking.com/the-problem-with-unsustainable-mining-practices/#:~:text=Unsustainable%20mining%20practices%20are%20those%20that%20do%20not,water%20pollution%2C%20air%20contamination%2C%20and%20other%20ecological%20damage.

[3] Dcomm. (2005). Retrieved from https://www.ilo.org/global/publications/world-of-work-magazine/articles/WCMS_081364/lang--en/index.htm#:~:text=More%20than%2030%20per%20cent%20of%20the%20mining,of%20all%20family%20members%2C%20including%20children%20and%20adolescents.

[4] Kian Raafat, J A Burnett, Thomas Chapman, Charles S Cockell, The physics of mining in space, Astronomy & Geophysics, Volume 54, Issue 5, October 2013, Pages 5.10–5.12,

[5] Yarlagadda, S. (2022). Economics of the Stars: The Future of Asteroid Mining and the Global Economy. Retrieved from Harvard International Review

Special Thank You to

The New York Academy of Sciences

For providing us with this platform to collaborate, learn, and contribute.

Thank you for taking the time to review our work!