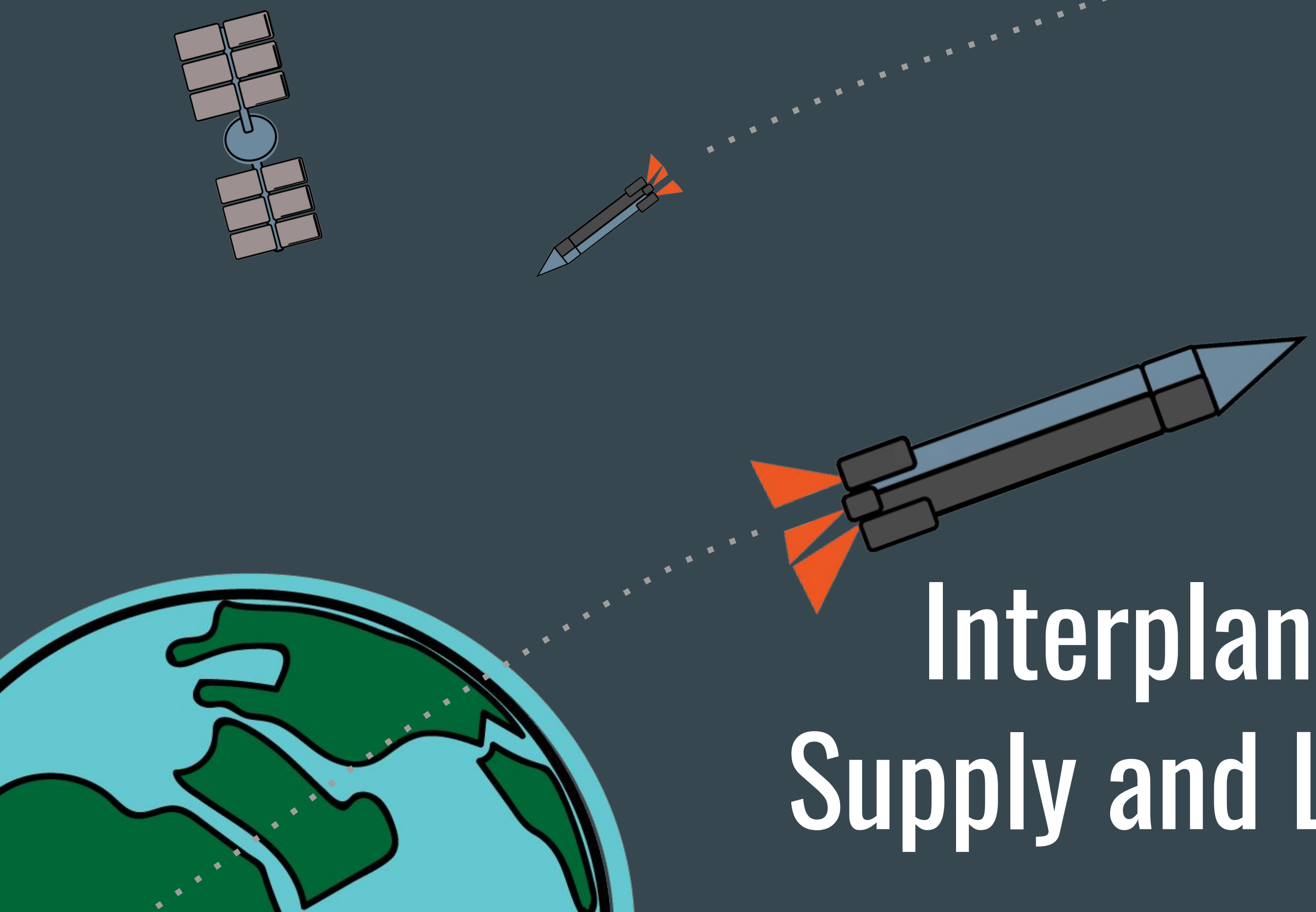


Interplanetary Supply and Logistics

1.1 Why Space?

- Economic Purposes
  - To build space stations and colonize local planets
    - This provides new living space for people and whatever parts of the earth's ecosystem we bring with us.
  - To utilize new technologies for harvesting naturally occurring resources in the sterile environment of space such as minerals and precious metals in asteroids
  - To develop new interplanetary infrastructure such as fuel depots and communication stations.
  - Interplanetary transport for civilians.

1.2 Why Space?

- Humanistic Purposes - Betterment of humankind
  - It’s not about stealing the earth’s resources and leaving it behind
  - It challenges humankind to achieve more
  - It forces us to become more environmentally aware

1.3 Why Space?

- Scientific Purposes
  - To develop liveable habitats in unfamiliar conditions
    - Medical development
    - Space Station Conditions
    - Artificial Ecosystems
  - To explore space
  - To develop new interplanetary technologies

But We Need Infrastructure

- Liveable Infrastructure
  - Basic needs
    - Food, Water, Oxygen, etc.
  - Interplanetary Communications
  - Transport depots for civilians and supplies
  - Research to enable the growth and sustainment of plant and animal ecosystems

- Medical Technology to Meet New Conditions
  - High radiation exposure and low gravity will create never before seen medical concerns

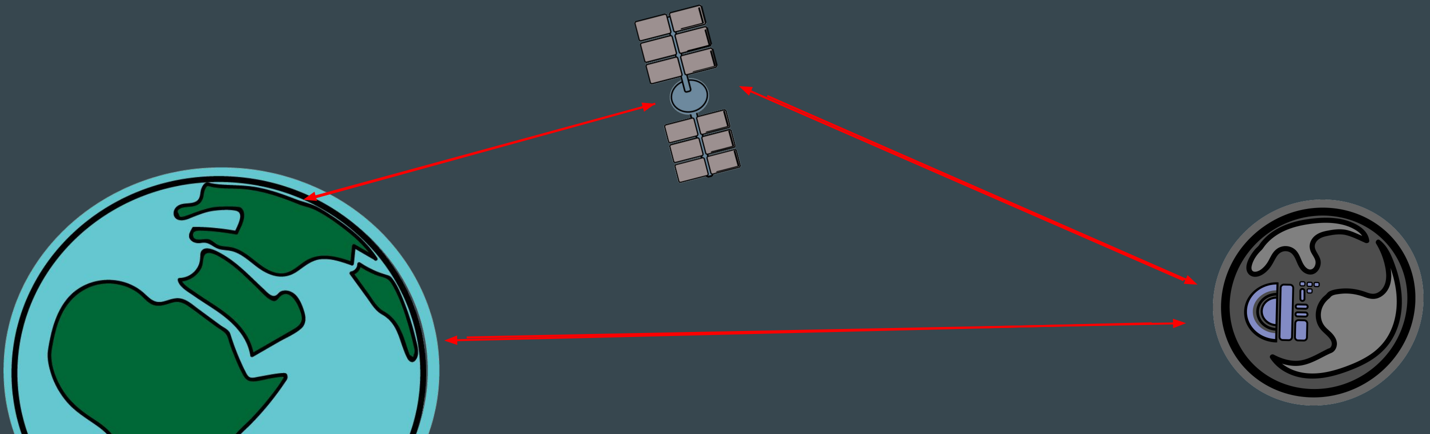
Our presentations focus are the developments that will get us there.

- Interplanetary Communications
- Supply Chain
- Reusable Rockets
- Satellites and Space Probes
- Asteroid Mining/ Harvesting
- Space Stations
- Habitats
- 3D Printing
- Putting it all together

Interplanetary Communications

Aside from atmospheric conditions on earth and interference from solar storms, direct communication between earth, the moon and any stations set in between would be relatively simple using a high powered laser or traditional RF.

When expanding beyond the earth-moon system, obstacles like the sun get in the way.



Communication Relays

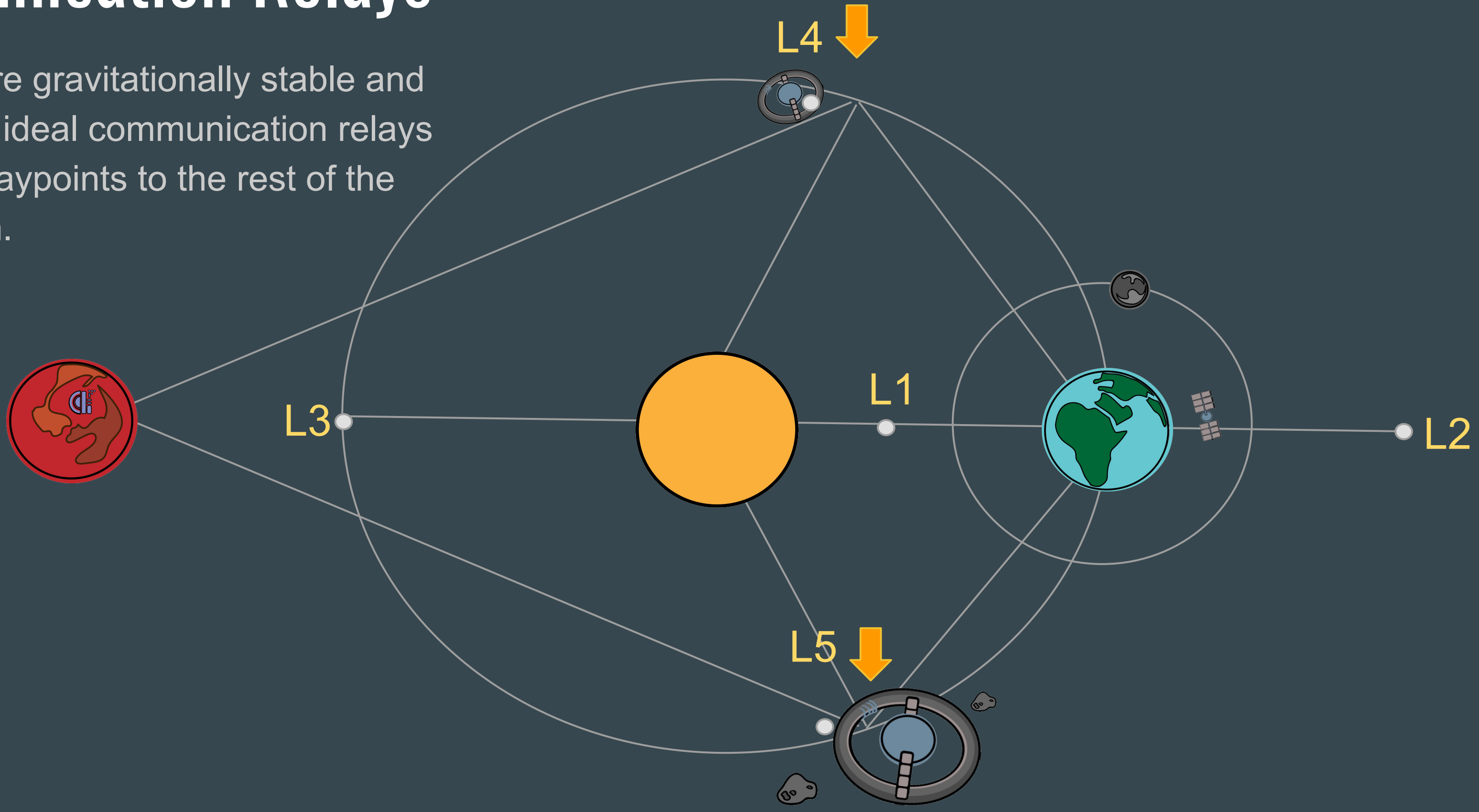
Between the earth and moon, communication is relatively simple, just point the sender at the receiver. But sometimes Mars is on the other side of the sun (called "opposition.") What then?

Interplanetary Communications

Lagrange points. Five points (L1-L5) located in space where the gravity of two large masses meet. These spaces can allow a small object to orbit between the two masses. L1, L2, and L3 are unstable, but...

Communication Relays

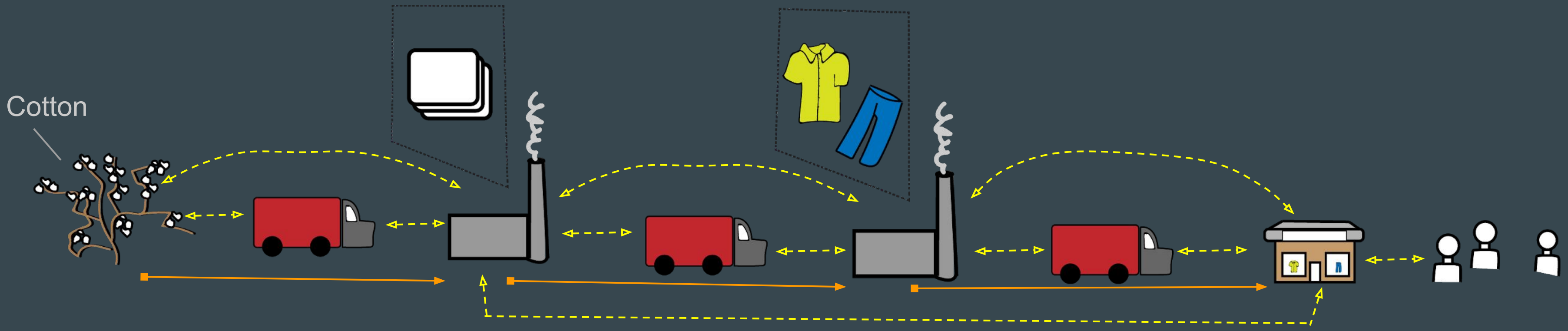
L4 and L5 are gravitationally stable and would make ideal communication relays as well as waypoints to the rest of the solar system.



What is Supply Chain?

Supply Chain is a system which takes raw materials to be processed and manufactured. The resulting goods or services are then delivered to consumers. There are two main components of supply chain:

- Physical distribution
- Information sharing



Supply Chain: Business Model

The business supply chain model applies these three main goals

- Improve customer services
- Reduce operating costs
- Improve financial position

Supply Chain: Military Model

All supplies need to be brought along in military operations. This will also be true when we first move into space. Ordering and receiving goods as needed will be impossible.

- Large stocks of critical supplies with redundancies for all vital systems will be needed
    - As a result, this supply chain model will be expensive, but will provide relief for situations where critical machinery and other systems may fail.

Supply Chain: NASA Model

NASA is focused on new missions, but has had to operate continuously on a fairly low budget with shifting directives from the US government. As a result, NASA operations and logistics are focused on getting maximum results with limited funding or other resources.

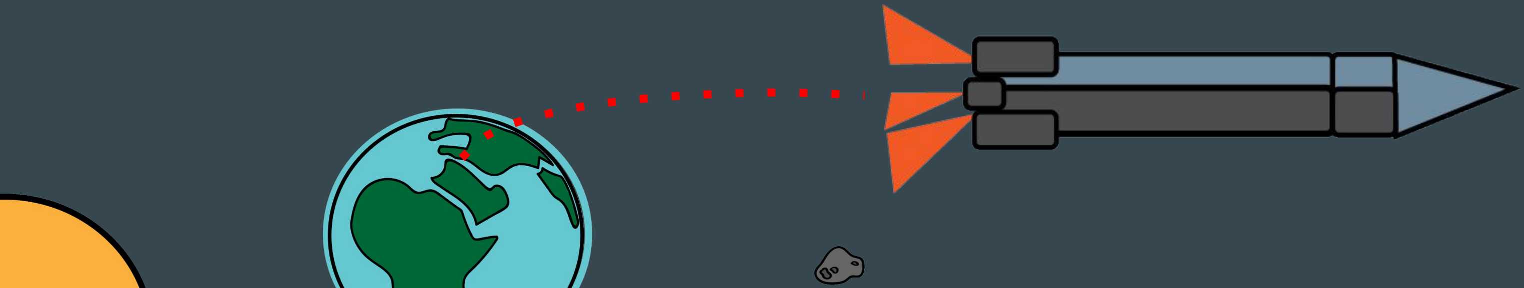
- NASA's model for reducing costs and maximizing results will be necessary for us during initial exploratory and research missions using probes and other autonomous systems to investigate yet unexplored environments.

A New Model

In the long term, we will see aspects of each of these models combined into a new model. The most effective model will combine scientific principles accounted for by NASA with the cost-efficiency focus of business and the redundancies of military systems for the preservation of human life.

Reusable Rockets

- Prior to the Space X program, most rockets were lost or destroyed after launch, never to be reused again.
  - Space X is the only company to refurbish a rocket that has already been launched previously.
- By designing rockets that can be reused, costs of launches will be significantly reduced thus reducing the price of space travel as a whole.
  - This is done by attempting to land rockets on landing pads after sending them into orbit.



Reusable Rockets

Reusable Rockets

- Companies have created several working models of reusable rockets such as Blue Origin's New Shepard, United Launch Alliance's Vulcan, and Space X's Falcon 9.

- All major advancements in interplanetary logistics are dependant on the development of this technology in order to make space travel more accessible for personal and commercial use.

Q&A: What is the resource cost in order to do such travels, for both manned and unmanned travels?

This is a fairly complicated problem because of Tsiolkovsky's Rocket Equation:

ΔV = m/s; V_e = exhaust velocity;

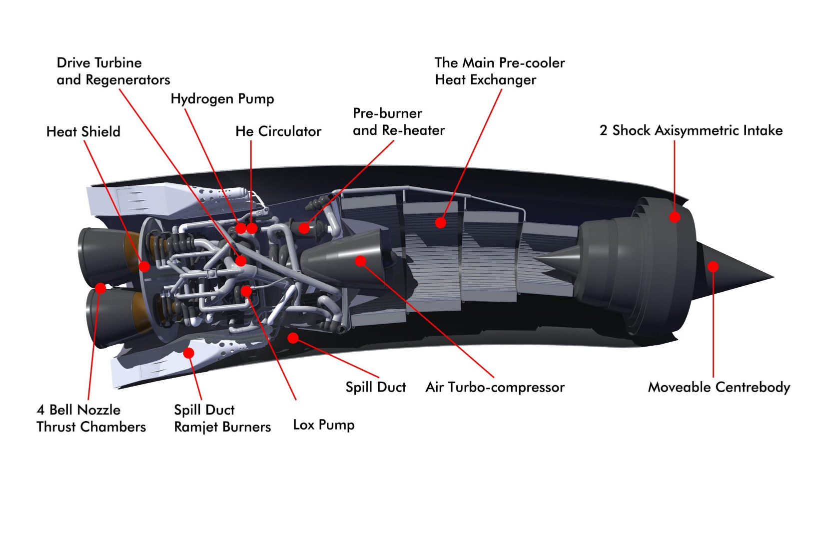
$$\Delta V = V_e \ln \frac{M_e + M_p}{M_e}$$

Delta V is a measure of how much additional energy is needed to get somewhere.
Some solutions:
Carbon nanotube airframes (reduce mass)

- 200 times stronger, 5 times more elastic than steel.
- NASA is experimenting with it.
- So is the Portland State Aerospace Society (PSAS).

Jet/Rocket Hybrid

- Jet/Rocket Hybrids are another form of reusable space travel.
- Engines such as Reaction Engine's SABRE are designed to create vehicles with single-stage-to-orbit capabilities–meaning they can travel from Earth to space without the use of disposable boosters and with horizontal take off.

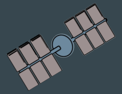


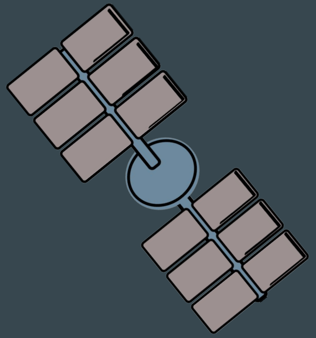
Satellites + space probes

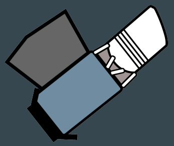
We need more than just ground infrastructure to make living in space possible. Autonomous networks of satellites and space probes will be crucial. Autonomous networks of satellites, space probes, landers and rovers will be crucial to begin creating a space-infrastructure.

Their uses:

- Prospecting and mining asteroids.
- Communication relays.
- Constructing starting bases for humans to inhabit and expand.
- Solar system mapping, other astronomical research.







Asteroid Harvesting: Right Now

Governmental space agencies and a few start up businesses are investigating the prospects of harvesting asteroids for rare metals, water, and other resources. Initial exploratory missions are occurring or are planned to occur in the next couple of years.

The economic impact will be profound. Instead of being an expense, going to space will be a profitable venture.

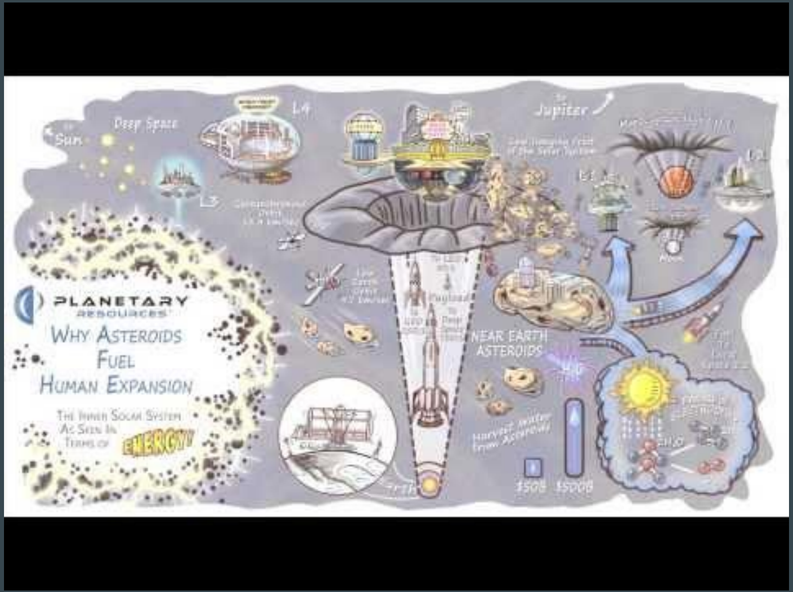
Asteroid Mining

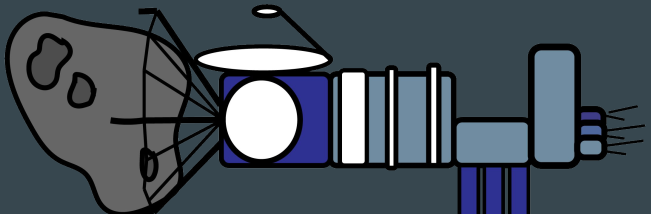
As well as governmental space agencies such as NASA, there are two businesses with valid credentials with plans to mine asteroids:

How will they do it?

Asteroid Mining - Impacts

- In-situ resource utilization = using local available/grown resources
- Heavy mining and manufacturing can be done in a sterile, already uninhabitable environment.
- Rare, useful metals will flood the market (rare-earth, platinum class metals)
- Water is also plentiful in space!





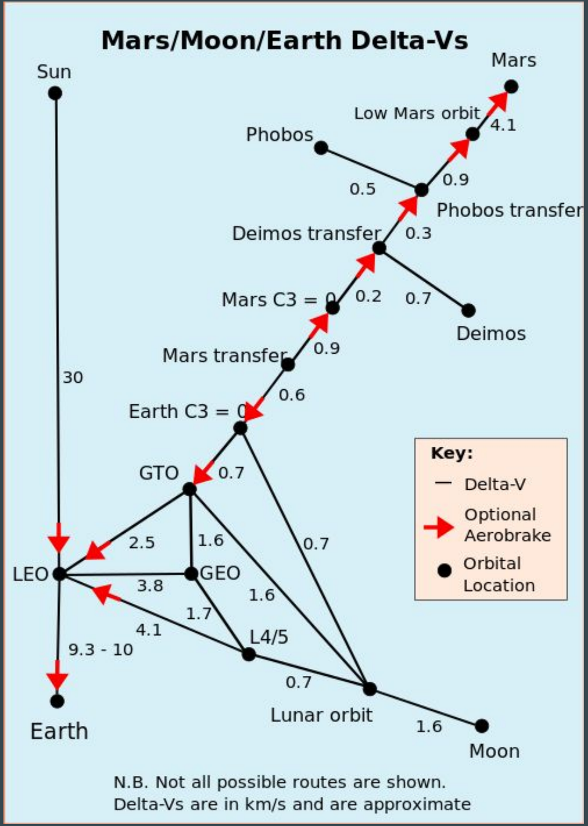
Q&A: How much ∆V is required to intercept the nearest asteroids? Are there estimates on ∆V required for retrieval of an entire asteroid?

There are!

∆V to the moon: **1.6 km/s**

∆V to a NEA (within 0.3 AU): **0.3 km/s**

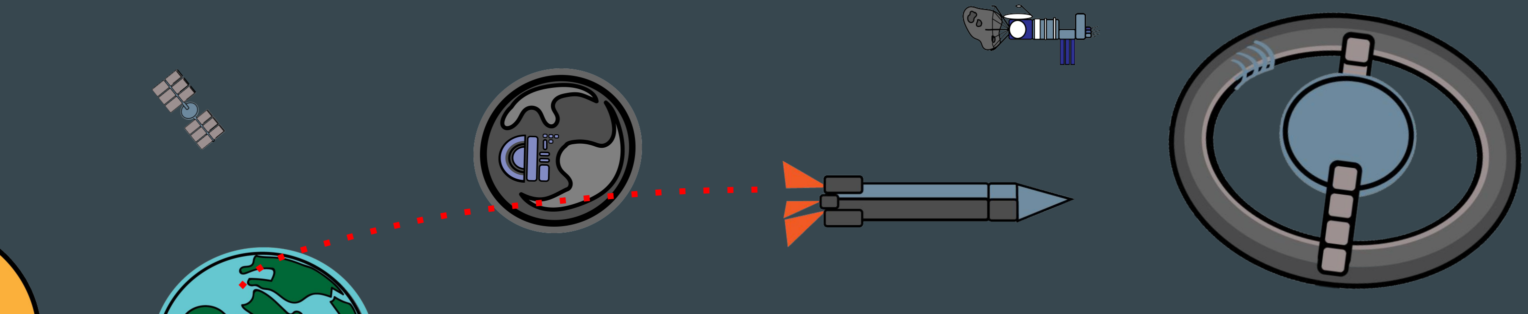
∆V (minimum) to move an 8m asteroid to earth orbit: **60 m/s.**



Space Stations

Space stations will be multifunctional outposts for our interplanetary supply chain.

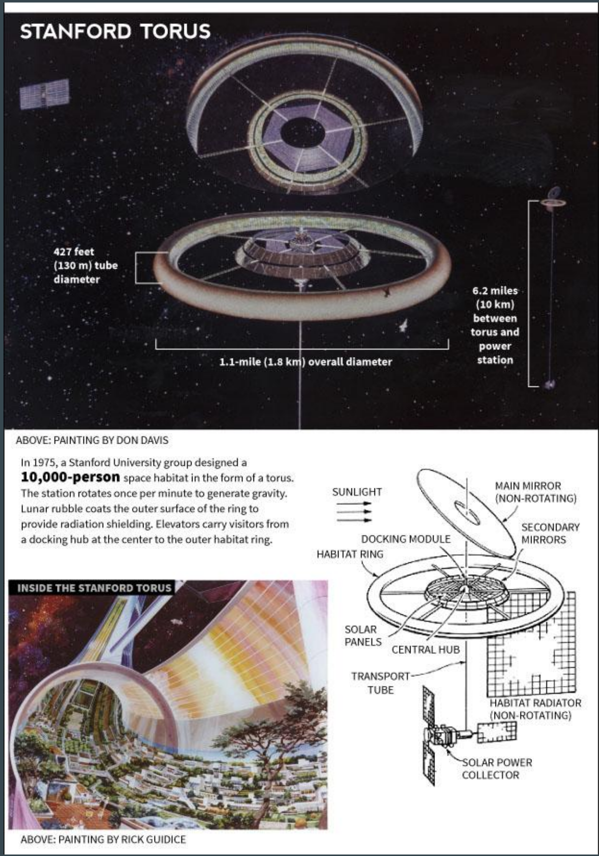
- They will ping communication/information between planets and other stations.
  - Some will be located in Lagrange points
- People will work and live there
- They could act as waypoints for goods and people moving between locations



Habitats

Human habitats in space and on planets will serve multiple purposes

- They will keep their inhabitants safe and comfortable
- Will allow their inhabitants to keep the supply chain moving materials, information and people
- There will be variations in use
  - Temporary: meant to move people between locations
    - Space crafts on route
  - Permanent
    - On planet locations
    - Space colonies



Credits: Karl Tate

Habitats

Right Now

- Nasa in establishing public-private partnerships
- Aug 2016 NASA selected six companies to develop full size ground prototypes and concepts for deep space habitats

- Create opportunities to:
  - Increasing private company involvement
  - Advance deep space habitation development
  - Stimulate commercial activities in low-Earth orbit
    - Move beyond Low Earth Orbit, into the space between earth and the moon and to Mars
    - Reduce the cost of future ventures

NASA's Habitat Focus

Bigelow Expandable Activity Module (BEAM) May 2016 Bigelow Aerospace

Habitats

Right Now

Programs exist to simulate and test living away from Earth:

NASA funded HI-SEAS (Hawaii Space Exploration Analog and Simulation), tests a Mars-like habitat on the Big Island of Hawaii

Aug 2015- Aug 2016: They tested how a six person team would handle a confined environment together

- Habitat had a “habitable volume of 13,000 cubic feet”
- Space included sleeping quarters, kitchen, laboratory, bathroom, simulated air lock, and dirty work area
- All communications were on 20 minute delay with no real-time communication
- Couldn’t leave without space suit
- Received supplies every two and four months respectively

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Growing Food in Space

Growing plants would have multiple benefits for humans living and working in space.

- They supply nutrients
- In large quantities they can scrub carbon dioxide from habitat
- Could be psychologically beneficial
  - Provide piece of home
  - Changes and grows in structured environment
- Might provide some protection for humans against radiation

Growing Food in Space: Right Now

- Nasa has already grown multiple harvests on ISS
- NASA testing long-term Lunar/Mars greenhouse methods to support deep space pioneers

To grow plants on Mars/moon we would use:

- Red, blue, green, white LED lights
- Underground location- protect plants from radiation
- Lunar/Martian water source
- Nutrient salts -added to water
- Water system that oxygenates, flows continuously, re-incorporates water into storage

Credits: University of Arizona

University of Arizona's Controlled Environment Agriculture Center (in partnership with NASA)

3D Printing

3D printing is likely the way humans will build structures on the moon and Mars.

- It can be done remotely
- Printing allows for highly functional building designs
  - Rounded to resist wind
  - Thicker on the north side
- It can be done cheaply
  - It uses local ingredients
- It can be done quickly

3D Printing

MIT researchers built a 3D printer capable of printing a 12 foot high, 50 foot diameter dome in 14 hours.

Printer is a vehicle on a track, carrying an industrial robotic arm with a smaller precision-motion robotic arm on end.) Researchers describe the design as “highly controllable.”

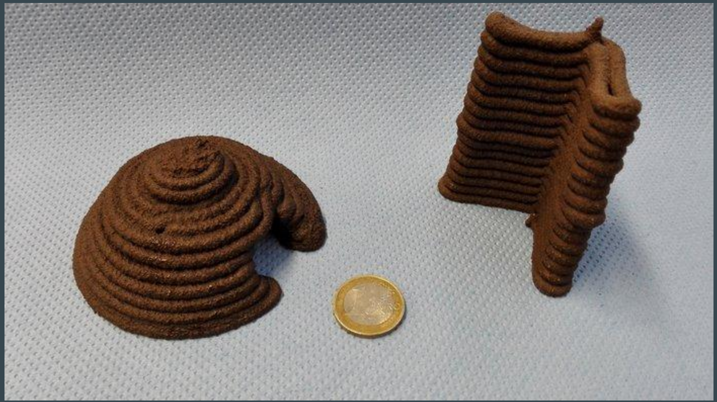
- Can build object of any size
- Can direct construction nozzles for pouring concrete or spraying insulation
- Can use digital fabrication end effectors: milling head
- Nozzles could be adjusted to “vary the density of material being poured” or mix different materials as it builds
- Self-sufficient
  - Can collect local materials, prepares surface
  - Can adjust to environment using sensors: temp, light and other parameters
  - Can use solar panels

3D Printing

3D Printing

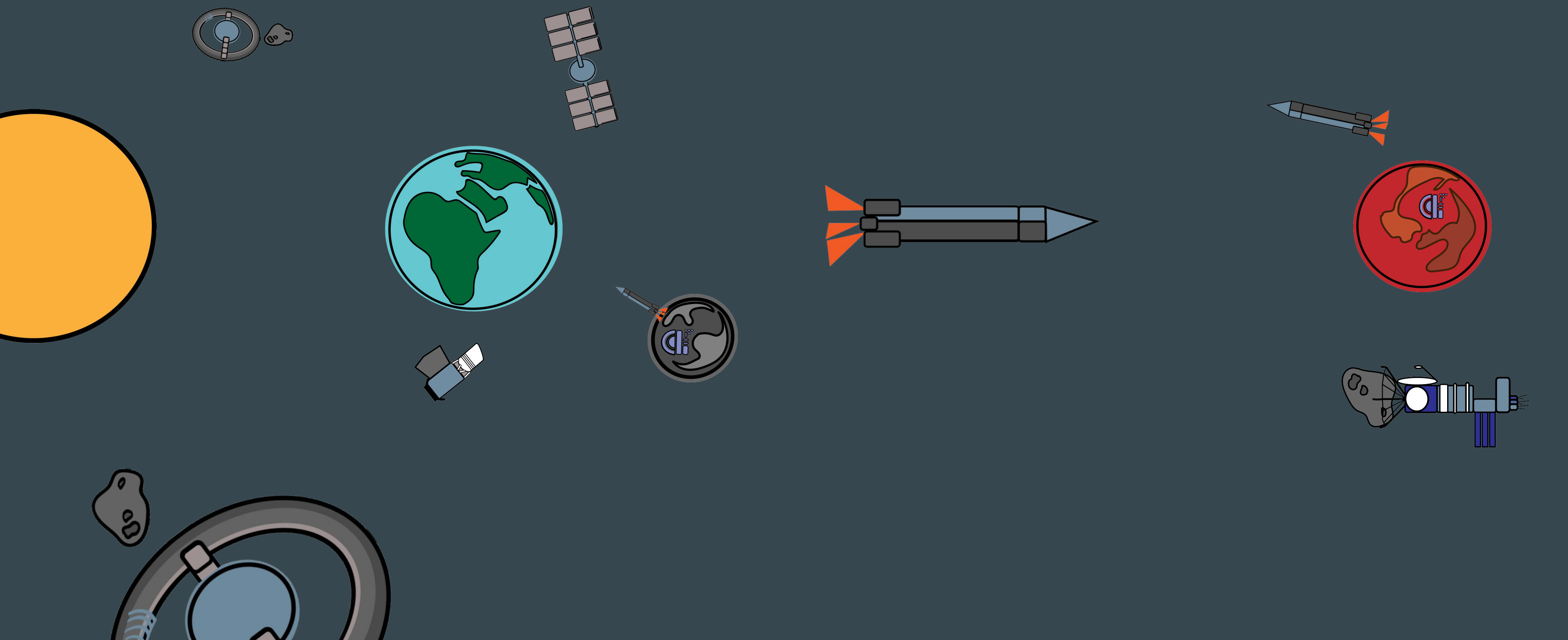
The University of Applied Sciences in Wiener Neustadt, Austria in partnership with the European Space Agency (ESA)

- Mixed simulated Mars dust (JSC-Mars-1A) with binder of phosphoric acid.
- 3D printed miniature structures, similar to those that could be built on Mars



Source: Fotec

Questions/Comments



Resources:

15 - https://youtu.be/Zk2Vaeg7F_c
https://www.nasa.gov/feature/nanotechnology-flight-test-material-impact-on-the-future

18 - http://www.space.com/15391-asteroid-mining-space-planetary-resources-infographic.html

19 - https://youtu.be/VLouRKHknOU

21 - https://forum.nasaspaceflight.com/index.php?topic=36319.0