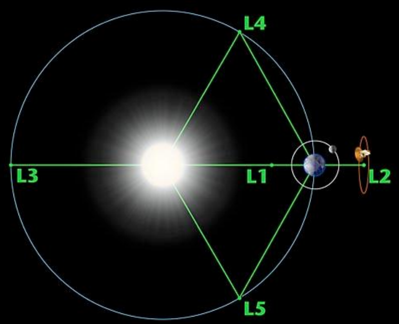
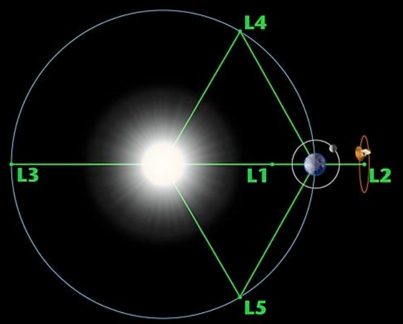


Technical Value of the Asteroid Retrieval Mission (ARM) Key Questions

Doug Cooke
Cooke Concepts and Solutions
July 9, 2013

Opportunities for Human Explorers



Mars and its Moons:
- A premier destination for discovery: Is there life beyond Earth? How did Mars evolve?
- True possibility for extended, even permanent, stays
- Significant opportunities for international collaboration
- Technological driver for space systems

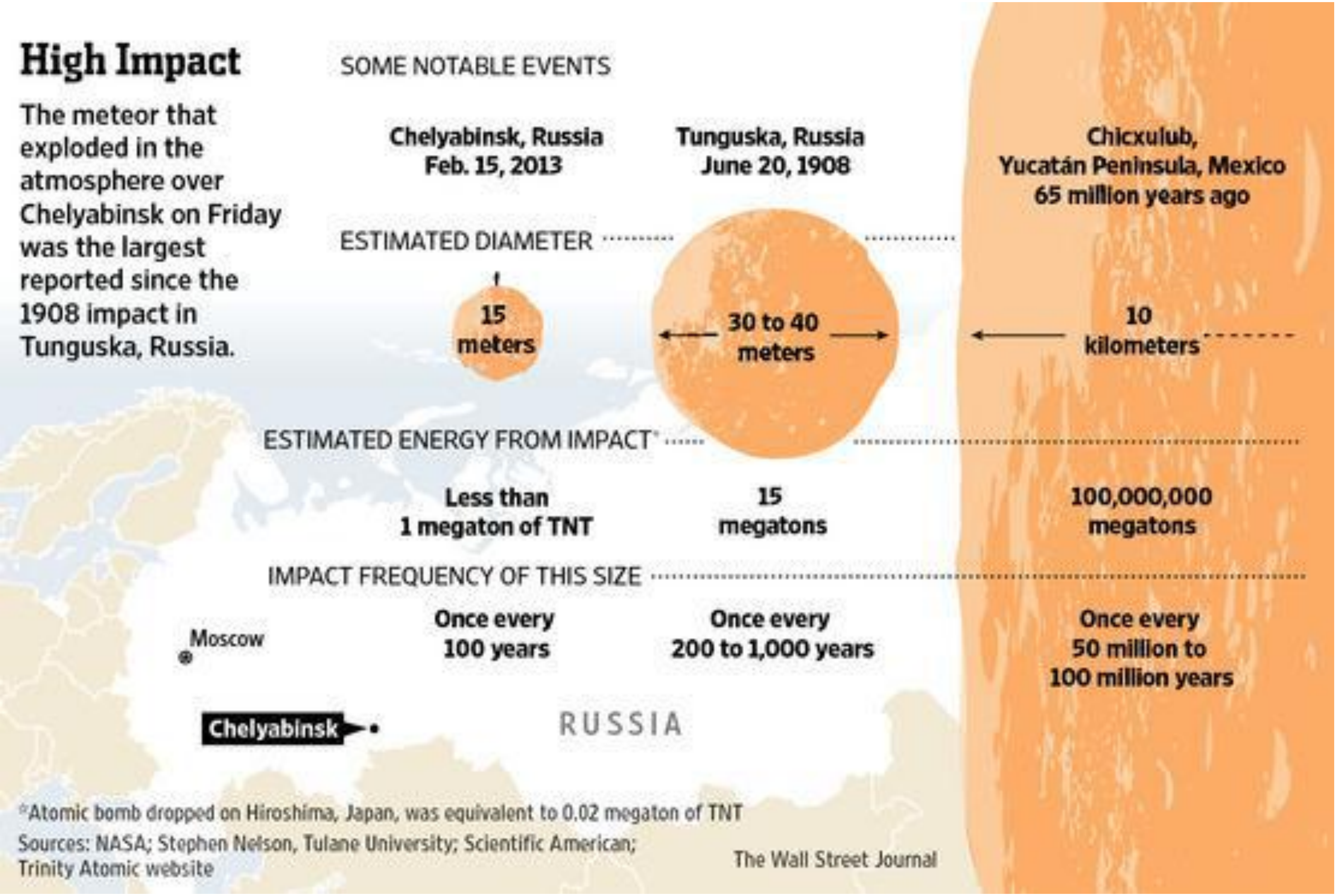
HEO/GEO/Lagrange Points:
- Microgravity destinations beyond LEO
- Opportunities for construction, fueling and repair of complex in-space systems
- Excellent locations for advanced space telescopes and Earth observers

Earth's Moon:
- Witness to the birth of the Earth and inner planets
- Has critical resources to sustain humans
- Significant opportunities for commercial and international collaboration

Near Earth Asteroids:
- Compelling science questions: How did the Solar System form? Where did Earth's water and organics come from?
- Planetary defense: Understanding and mitigating the threat of impact

Technology Needs for Multiple Destinations

	Moon	Lagrange Points	NEOs	Mars
Advanced In-Space Propulsion: Enabling low-cost and rapid transport of cargo and crew beyond LEO.	✔	✔	✔	✔
Autonomous Systems & Avionics: Extending human exploration capability by reducing workload and dependence on support from Earth.	✔	✔	✔x	✔
Cryogenic Propellant Storage & Transfer: Enabling the in-space infrastructure to store and transfer propellants.	✔	✔	✔ x	✔
Entry, Descent, & Landing Technology: Landing large payloads safely and precisely on extra-terrestrial surfaces and returning to Earth.	✔			✔
EVA Technology: Enabling humans to conduct “hands-on” surface exploration and in-space operations outside habitats and vehicles.	✔	✔	✔x	✔
High-Efficiency Space Power Systems: Providing abundant and low-cost power where it is needed.	✔	✔	✔?	✔
Human-Robotic Systems: Amplifying human productivity and reducing mission risk by partnering humans and robots.	✔	✔	✔?	✔
In-Situ Resource Utilization: Enabling sustainable human exploration by using local resources.	✔		✔ ?	✔
Life Support & Habitation Systems: Enabling humans to live for long periods in deep-space environments.	✔	✔	✔x	✔
Lightweight Spacecraft Materials & Structures: Enabling lightweight systems to reduce mission costs.	✔	✔	✔x	✔



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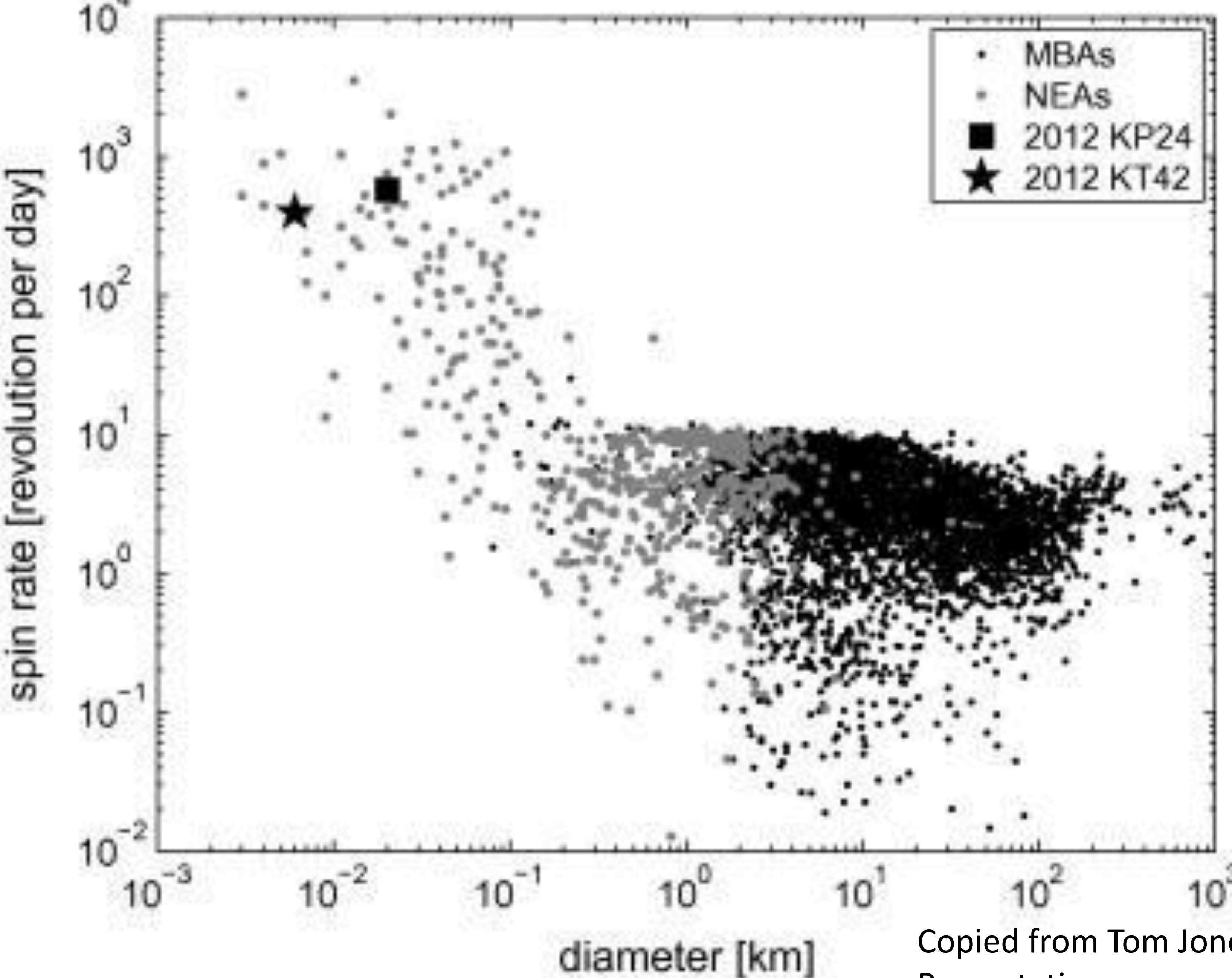

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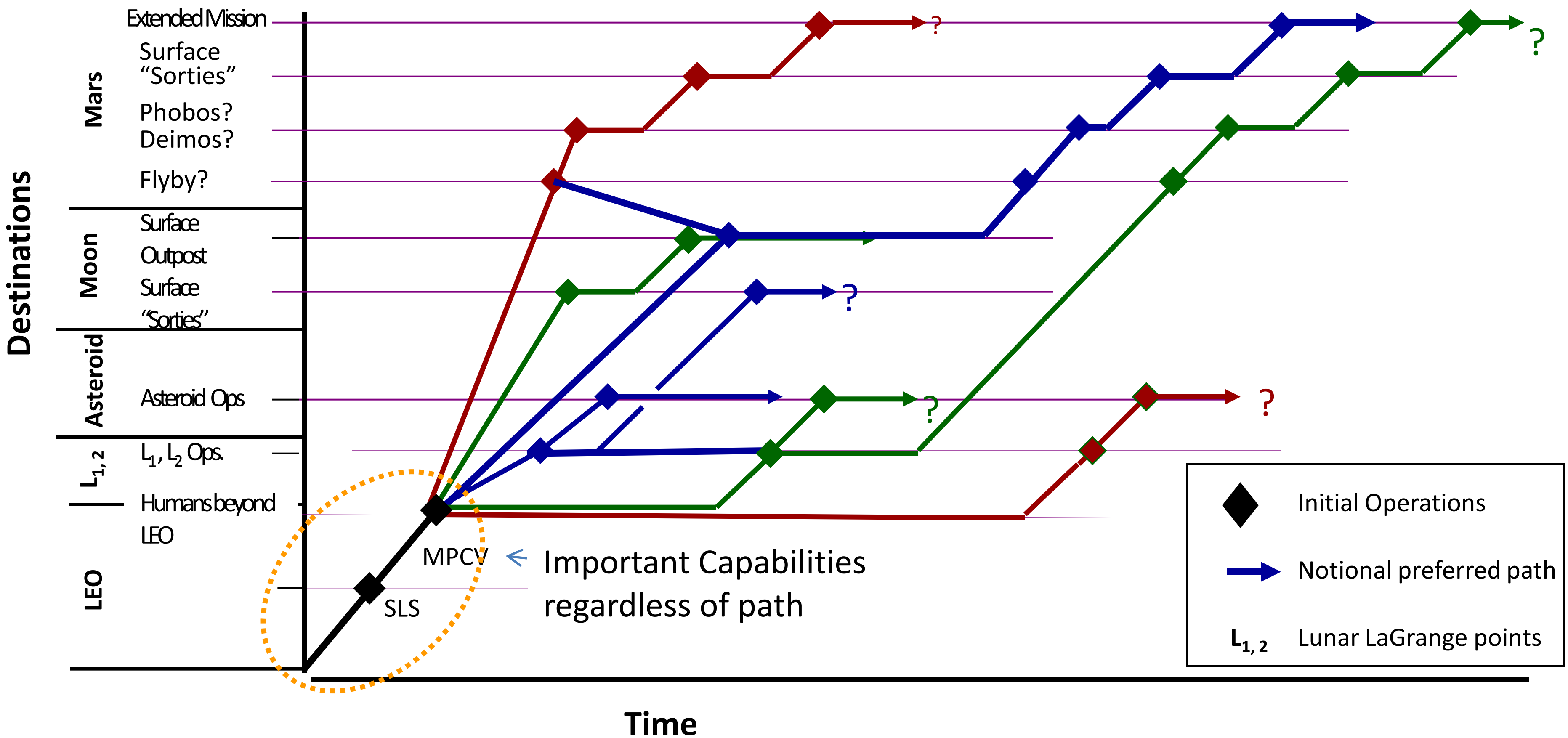
Possible Strategy for Architecture Pathways



Programmatic and Engineering Questions

- Will a reasonable Near Earth Asteroid target be found for this mission?
  - Will a target be found that is not spinning/tumbling? Will we know?
  - Is the size/likely composition relevant for science, ISRU, planetary protection?
- What will mission cost? Estimates- $1.0B (NASA) to $2.6 (Keck)
  - Complexity of capture vehicle-
    - Spinning/tumbling NEA problem (tumbling- likely unworkable)
      - Accelerations/loads/ impact loads for spacecraft design-
      - De-spinning/fuel allocation
      - Solar array & antenna retraction during spinning de-spinning /batteries?
    - CG control during powered flight,
      - Fixing the NEA captured position,
      - Thrusting through CG/stability of NEA position,
- Where does the funding come from? –
  - No new money.
  - Budgets already tight.

Programmatic and Engineering Questions

- Relevance to future Human Exploration?
  - Use of SLS/Orion
  - Advanced in-space propulsion- Solar electric- Scale?
  - Orbital mechanics/Prox-ops– Demonstrated with robotic NEA missions
  - The capture spacecraft relevance is minimal if any, other than propulsion (my view)
- Relevance to planetary protection? NASA "Grand Challenge"
  - The 7 meter size is not a major threat
  - Capture spacecraft is not likely to be relevant for deflection of a large asteroid
- Relevance to Commercial Asteroid Mining?
- Are missions to other destinations more relevant to long term human space exploration?

Back up

Human Exploration of Mars Capability Needs

Launch

- Multiple launches
- Short spacing
- Large mass: 130 t
- Large Volume 10 x 30 m

Space Transportation

- Advanced propulsion to reduce mass
- Fast Transits for Crew (180 days)
- Limited / lack of quick aborts

Entry Descent and Landing

- Large mass (40 t) / Large volume
- Abort to surface
- Precision landing

Crew Surface Health and Support

- Crew acclimation post landing
- Human Support (radiation, hypo-gravity, dust, behavior)
- Planetary protection

Operations

- Automated, rendezvous and docking
- Pre-deploy cargo
- No logistics
- Reliability, maintenance and repair
- Autonomous operations post landing
- Infrastructure emplacement (power)
- High continuous power (40 kWe)
- ISRU oxygen production - atmosphere
- Multiple EVAs, long-range roves, routine exploration

Capture

- Solar arrays folded to facilitate matching spin
- Radar used for precision approach
- SC matches surface velocity
- DARPA algorithms for non-cooperative orbit capture
- Asteroid positioned inside capture "bag"
- Bag is tightened around asteroid creating one object controlled by SC SEP thrusters
- Ring between SC and bag allows imparting force on asteroid
- Residual velocity and spin are small
- Assume 1100 T, 1 RPM , 6x12 m
  - **200 Nt thrusters**
  - **→ Desptin time ~33 minutes, 300 kg propellant**