

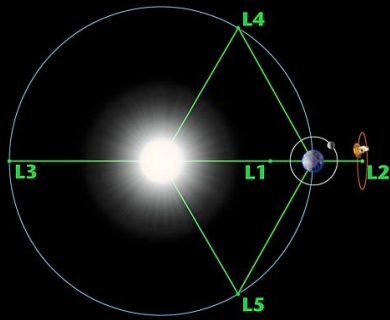
Technical Value of the Asteroid Retrieval Mission (ARM) Key Questions



Doug Cooke
Cooke Concepts and Solutions
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Opportunities for Human Explorers



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



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



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	✓

High Impact

The meteor that exploded in the atmosphere over Chelyabinsk on Friday was the largest reported since the 1908 impact in Tunguska, Russia.

SOME NOTABLE EVENTS

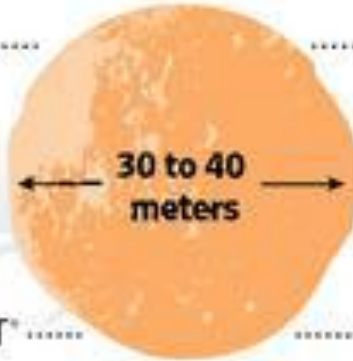
Chelyabinsk, Russia
Feb. 15, 2013

Tunguska, Russia
June 20, 1908

Chicxulub, Yucatán Peninsula, Mexico
65 million years ago

ESTIMATED DIAMETER

15 meters



10 kilometers

ESTIMATED ENERGY FROM IMPACT*

Less than 1 megaton of TNT

15 megatons

100,000,000 megatons

IMPACT FREQUENCY OF THIS SIZE

Once every 100 years

Once every 200 to 1,000 years

Once every 50 million to 100 million years

Moscow

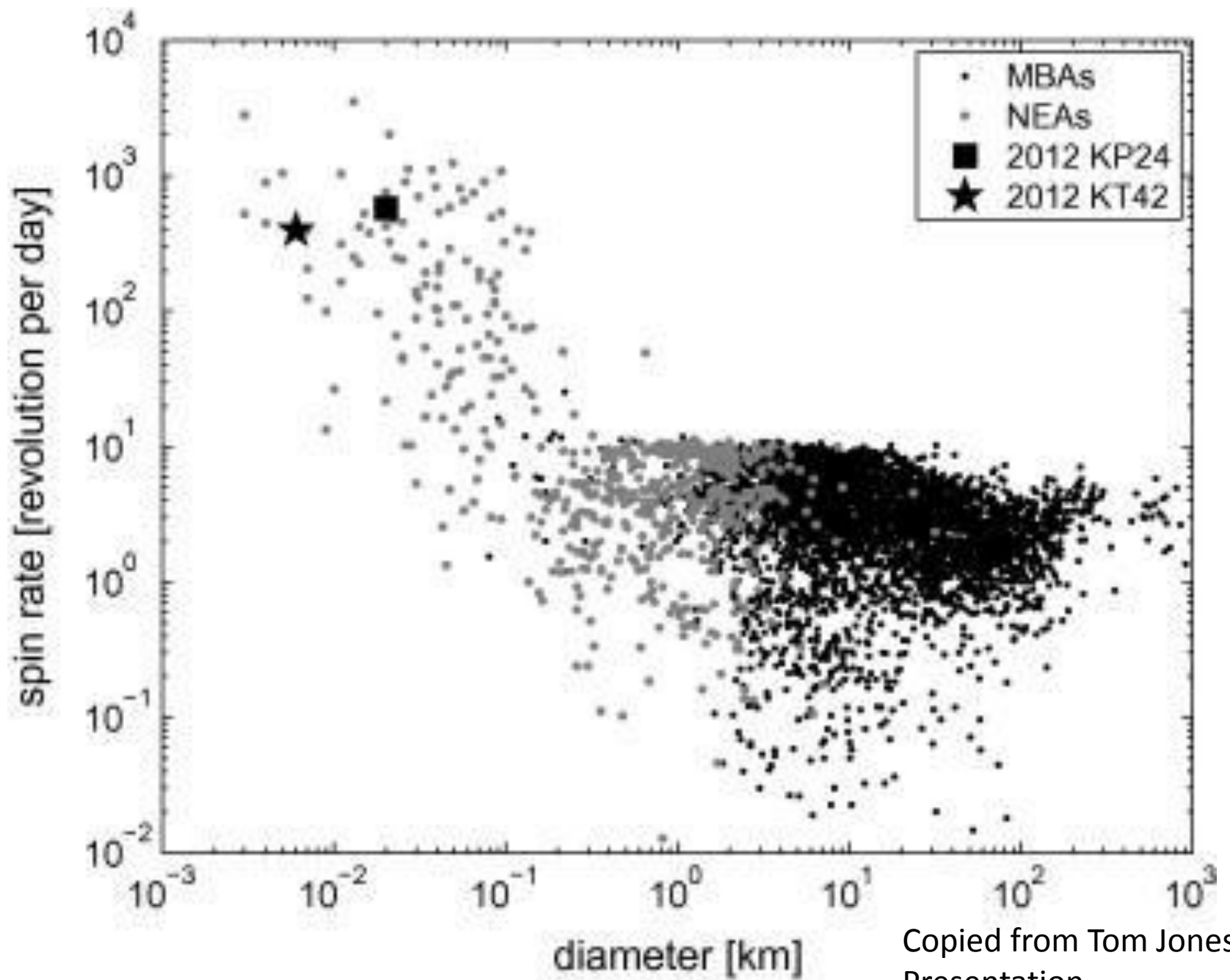
Chelyabinsk

RUSSIA

*Atomic bomb dropped on Hiroshima, Japan, was equivalent to 0.02 megaton of TNT

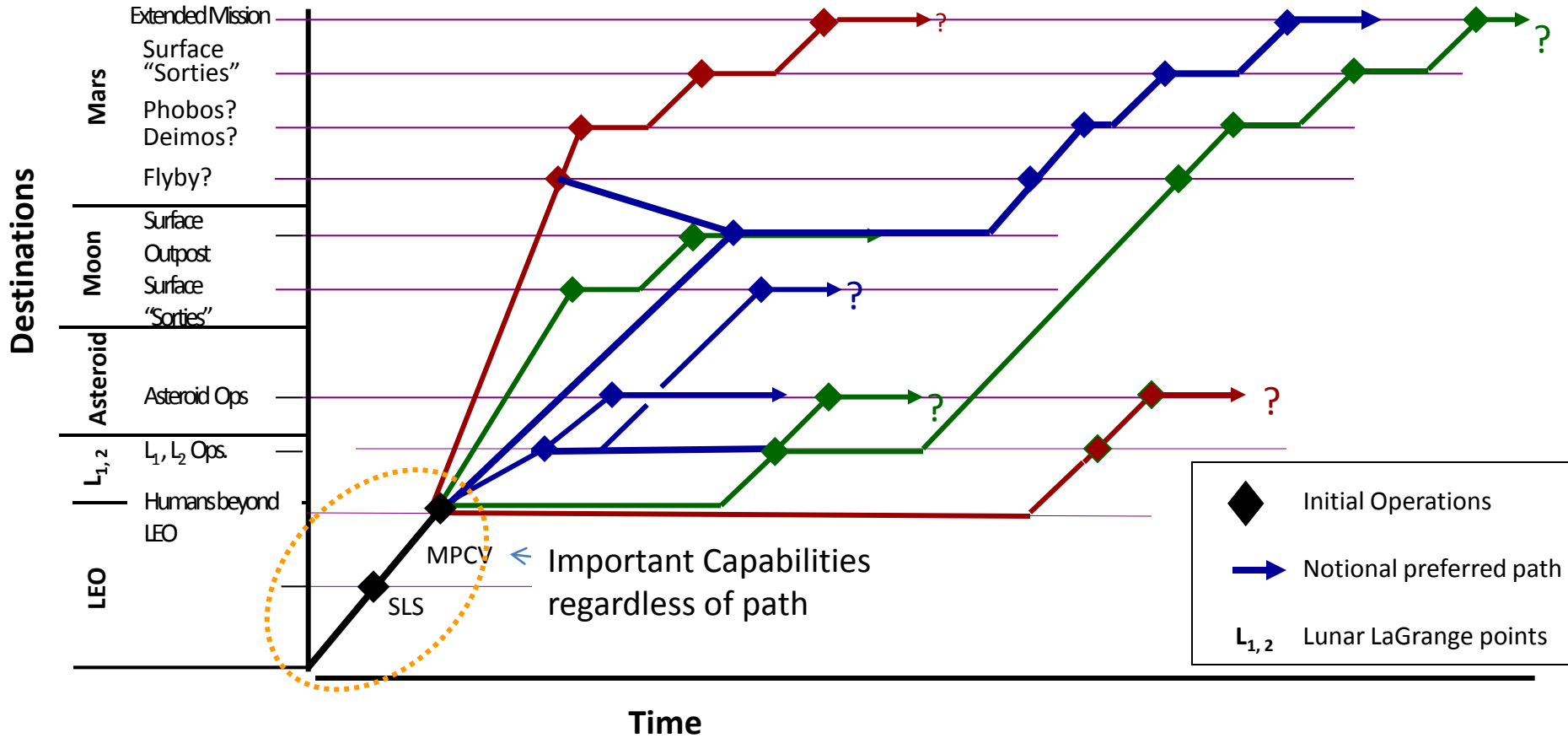
Sources: NASA; Stephen Nelson, Tulane University; Scientific American; Trinity Atomic website

The Wall Street Journal



Copied from Tom Jones
Presentation

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

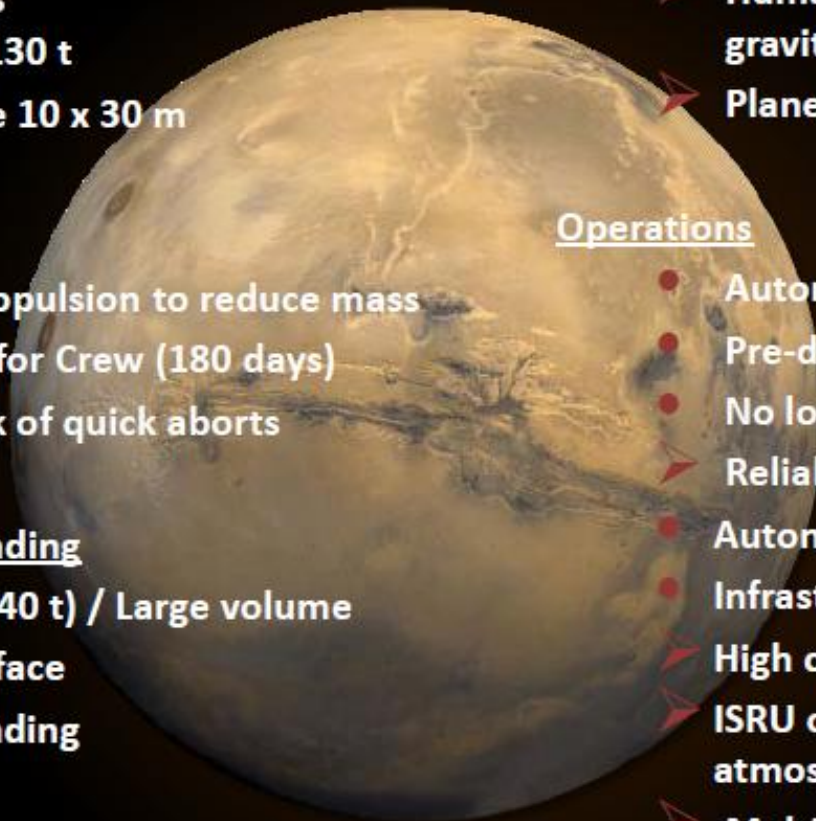
- Large mass (40 t) / Large volume
- Abort to surface
- Precision landing

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
 - → Despin time ~33 minutes, 300 kg propellant