SHEPHERD* - A Concept for Gentle Asteroid Retrieval with a Gas-Filled Enclosure

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*Secure Handling through Encapsulation of a Planetesimal Heading for Earth-Moon Retrograde Delivery
SHEPHERD: A Concept for Gentle Asteroid Retrieval with a Gas-Filled Enclosure

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ABSTRACT
Sealing a small asteroid within an enclosure enables innovative approaches to the Asteroid Redirect Mission concept that pave the way for future in situ asteroid resource utilization. A sealed enclosure would make it possible to use an introduced atmosphere of xenon gas to detumble and despin the asteroid, and then to push the asteroid by using a steady xenon gas flow inside this enclosure to transfer the force of the spacecraft's exterior solar electric propulsion engine to the asteroid. The gas will affect the cohesion forces of the asteroid, but the differential pressures exerted on the asteroid and surface regolith will be much less than the expected combined cohesion forces of weakly

However, the most interesting materials for retrieval and study are primitive and fragile, especially those too frail to be represented in our meteorite collections. Loose agglomerations of rocks and regolith may be common materials in space. Understanding the internal strength of small asteroids may be the single most important parameter affecting planetary defense operations and future mining or volatiles resource utilization operations. Candidate asteroid 2011 MD is thought to be a rubble pile.3-4

Ideally, ARM would deliver the fragile primitive condition as it was found in space, and missions will visit an asteroid, not a bag of free-floating weakly consolidated asteroid. Many of the same challenges as when visiting an asteroid in heliocentric orbits in a longer mission to ARM mission would step into a stepping stone of visiting asteroids in solar orbit, and

Here, we propose a modification to current concepts that makes them capable of capturing a target that has uncertainty in its mass, shape, and spin rate, and that may be a rubble pile. The concept is based on creating a sealed enclosure around the asteroid, which is also key to enabling future asteroid mining operations.
Introduction: Asteroid 2008 TC3

2008 October 7

20h advanced warning
1.2kT; ø4m
Spin/precession period: 99.0/97.0 sec.
Muawia Shaddad

33 km
ARM option “A”

ARM targets:
- Small ~7-m diameter asteroid
- Ideally an interesting one (primitive)
ARM option “A”

Engineering challenges:
- Tumbling asteroid can tear fabric during capture
- Asteroid disintegrates, no longer a proving ground
Strength in atmospheric entry

Ram pressure – characteristic strength: compressive, tensile or shear

<100–1000 kPa typical for first breakup
- Mass: 22-70,000 kg
- Speed: 12 –23 km/s
- Densities: 1.64-3.59 g/cm³
- Porosity: 0-40 %
- Asteroids

Very Gentle Touch = ~ 1 kPa

O. Popova
Rubble pile asteroid

- Gravity & Rotation: Surface gravity of 180-m sized asteroid = 0.00001 G (micro G); fast rotating 360-m 1999 KW4: <0.0000001 (100 nG)
- In microgravity: van der Waals forces between small grains become significant, fine grains keep larger boulders in a “van der Waals concrete”
- Surface regolith is like cohesive powder on Earth (> 25 Pa)
Even tumbling 2008 TC3
Could have been a rubble pile
Asteroid mining

Problems: Low gravity!
- Asteroids may fall apart
- Debris goes everywhere
Asteroid mining

Problems: Low gravity!
- Asteroids may fall apart
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NEEDS AN ENCLOSURE
SHEPHERD: capture & handling

Turbulent dissipation of angular momentum: 7–70h
Feasibility

- Up to 10 metric ton Xe as fuel
  - Use 2 metric ton in 20-m enclosure, 0.1 atm (10 kPa) pressure
- Internal energy of gas: $6 \times 10^7$ J
  - Spin kinetic energy of 100-1000 metric ton asteroid: $1 \times 10^3$ J; Tumble kinetic energy ~$1 \times 10^3$ J
  - Gas is not heated significantly if turbulent dissipation
  - Turbulent dissipation to 1% of gas in enclosure, drag power is 0.5 J/s > about 7h needed for dissipation
- Apply force to enclosure to gently dissipate angular momentum
  - Gas may start co-rotating, dissipate to enclosure: dissipate with external engine
  - Increases time for angular momentum dissipation (order of magnitude longer?)
Gentle ARM option “A”

Engineering challenges met:
- No or little spin left, no tearing of fabric
- Asteroid may still disintegrate, but more gentle and controlled
15-m $\varnothing$, 0.1 atm balloon (ULD1)
SHEPHERD: soft structure vs rigid

Outer and inner envelopes separated by air beams supporting ductwork and blisters with lighting, cameras
Watch SHEPHERD Asteroid Capture and Handling at:
https://vimeo.com/121835462
Key issue: how to seal enclosure

Use sticky NuSil CV-8151 silicone layer for sealing fabric?
SHEPHERD: capture

2 ton Xe

100-1000 ton tumbling
SHEPHERD: alternative to sealing

2 ton Xe

100-1000 ton tumbling
Other issues: power generation, thermal management
SHEPHERD: re-direct
Driving Phase: gas flow and recycling

(LENGTH) 20m

(HEIGHT) 1.80m

(WIDTH) 20m
Feasibility

- 1.5 N of force applied to enclosure by SEM
  - To transfer 1.36 N to asteroid requires flow velocity of about 2 m/s if directed to 1 m² area (4-know wind, light breeze)
  - Stable in sense that undersupply of force will drift asteroid closer to gas outlet, oversupply will drift asteroid away
  - Requires pumping about 2 m³/s of Xe gas for duration of cruise phase

- Gas loss during cruise phase
  - Operational pressure much lower than 0.1 atm.
  - Micrometeoroid impacts can cause leaks (in 5-y mission, largest meteoroid to hit would be about 0.2 cm Ø)

- Other forces
  - Solar radiation pressure on enclosure much less than supplied force
  - Force due to gas leaks, can be compensated by gas thrusts into enclosure
Key issue: autonomous control
LIDAR for proxops
Blister: thruster, return vent, lighting, camera
Bring asteroid in-tact to Earth
Future in-space operations for asteroid mining: CO gas mineral extraction, electroforming (Mond process)
Volatile capture, condensation, separation
Liquid phase biosphere harvesting consumables
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