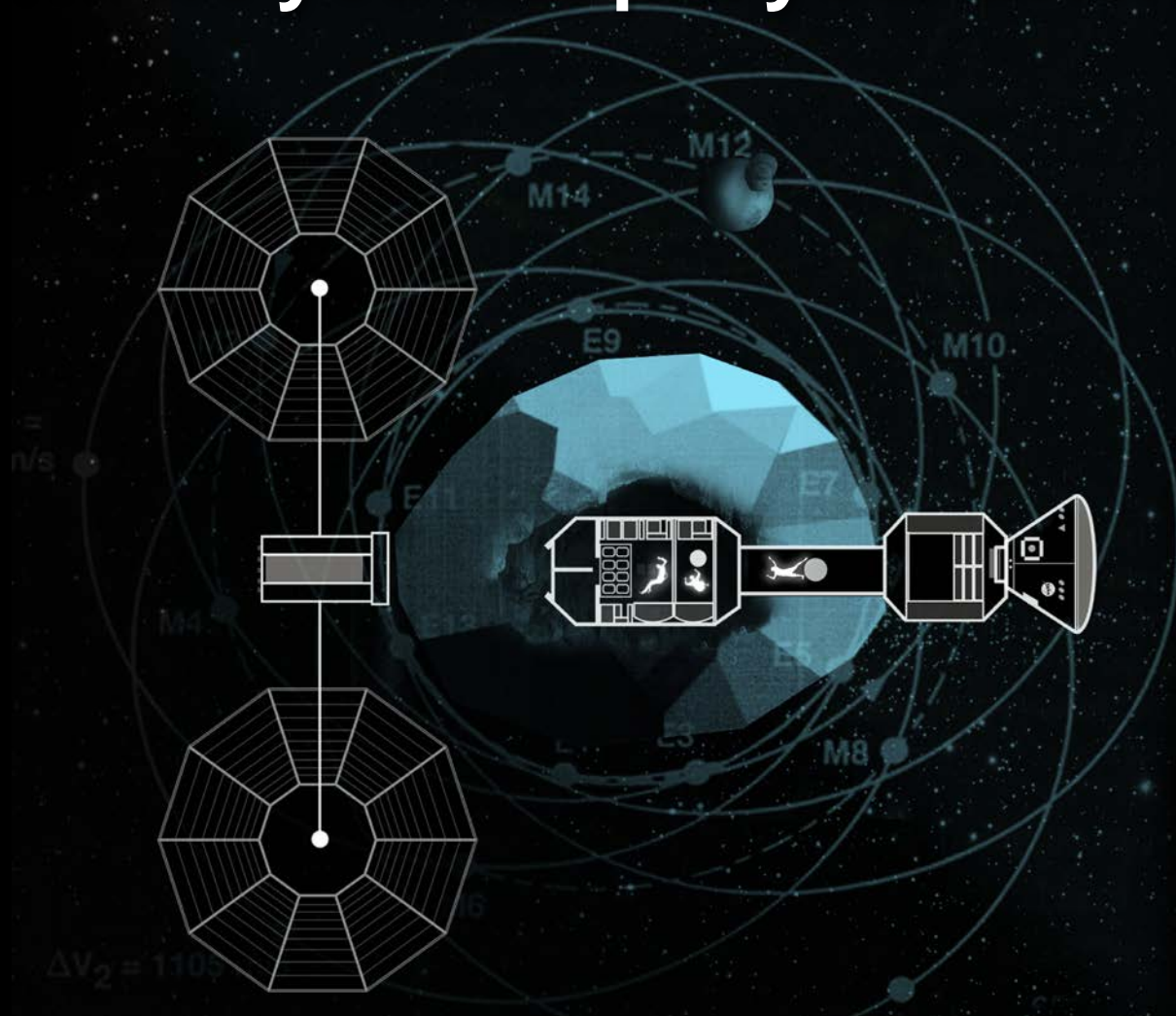


# Where you can put your asteroid

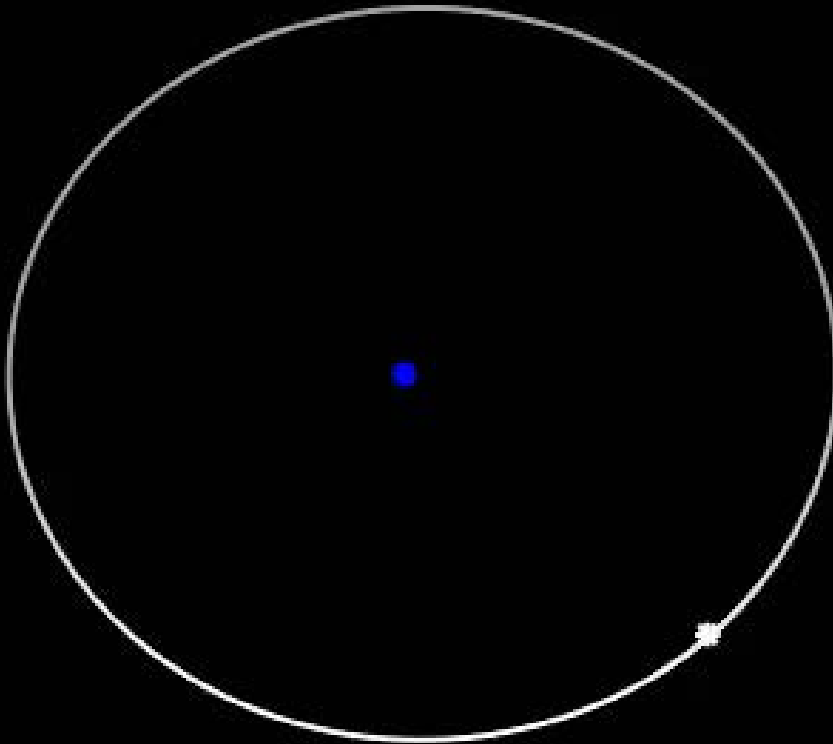


Nathan Strange, Damon Landau, and ARRM team  
NASA/JPL-CalTech

# Distant Retrograde Orbits



Inertial Frame



Earth-Moon Rotating Frame



Works for Earth, Moon, Mars, Phobos, Deimos etc... very stable orbits

# Other Lunar Storage Orbit Options

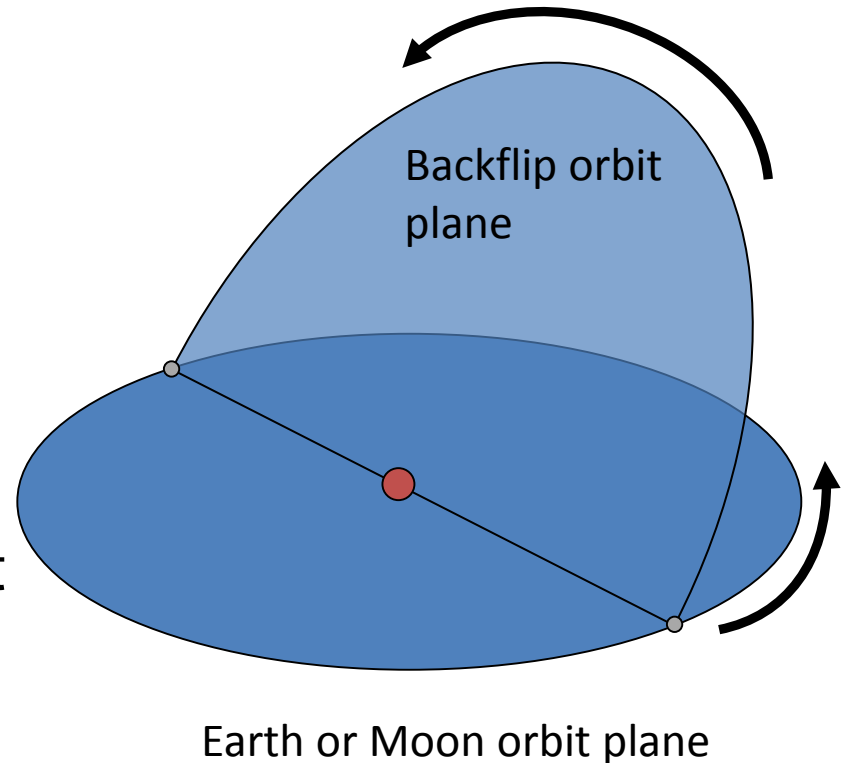


- Lagrange Points
  - Earth-Moon L1/L2
    - Unstable; this instability enables many interesting low-energy transfers but vehicles require active station keeping to stay in vicinity of L1/L2
  - Earth-Moon L4/L5
    - Some orbits in this region is may be stable, but are difficult for MPCV to reach
- Lunar Weakly Captured Orbits
  - These are the transition from high lunar orbits to Lagrange point orbits
  - They are a new and less well understood class of orbits that could be long term stable and could be easier for the MPCV to reach than DROs
  - More study is needed to determine if these are good options
- Intermittent Capture
  - Weakly captured Earth orbit, escapes and is then recaptured a year later
- Earth Orbit with Lunar Gravity Assists
  - Many options with Earth-Moon gravity assist tours

# Backflip Orbits

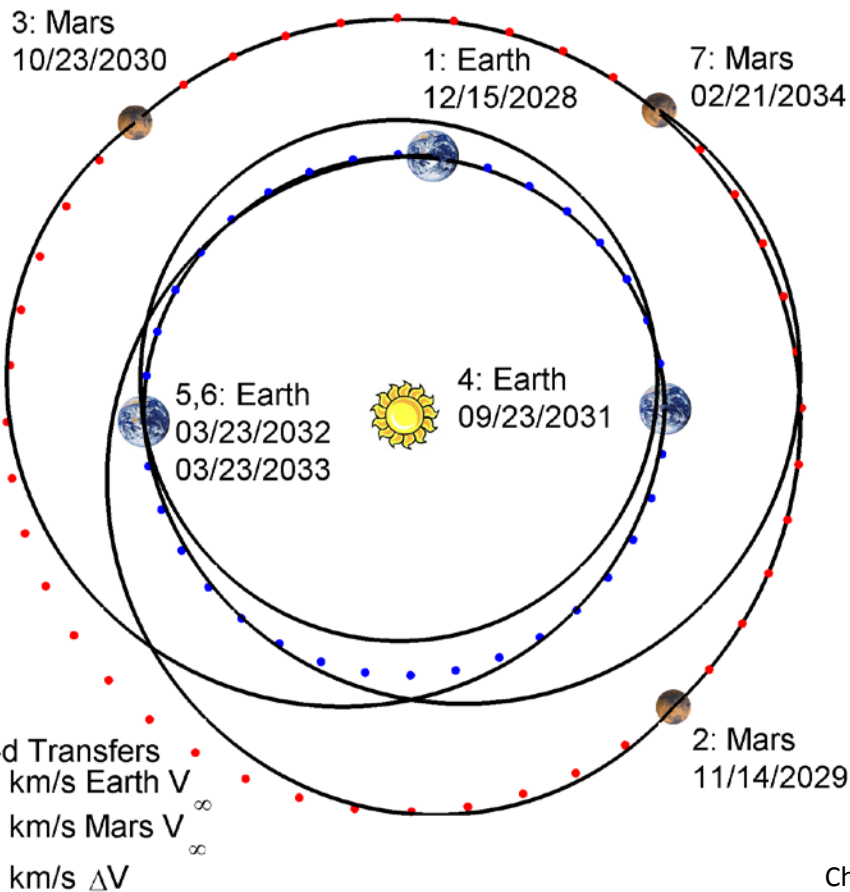


- A backflip orbit is two flybys half a rev apart
- Could be done with the Moon, Earth or Mars.
- Lunar backflips are nice because they could be used to “catch and release” asteroids
- Earth backflips are nice orbits in which to construct things out of asteroids before sending them on to places like Earth-Mars cyclers

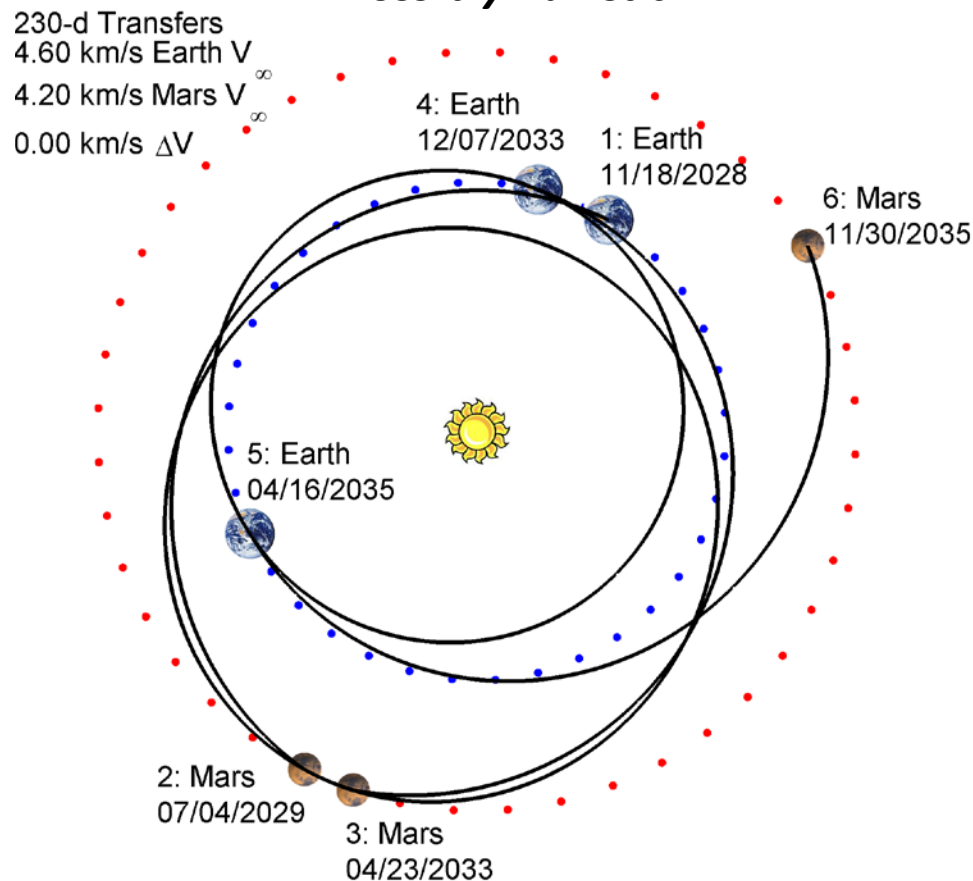


# Example Mars Cyclers

## Two-Synodic-Period Cyclers



## Three-Synodic-Period Cyclers *Possibly Ballistic*

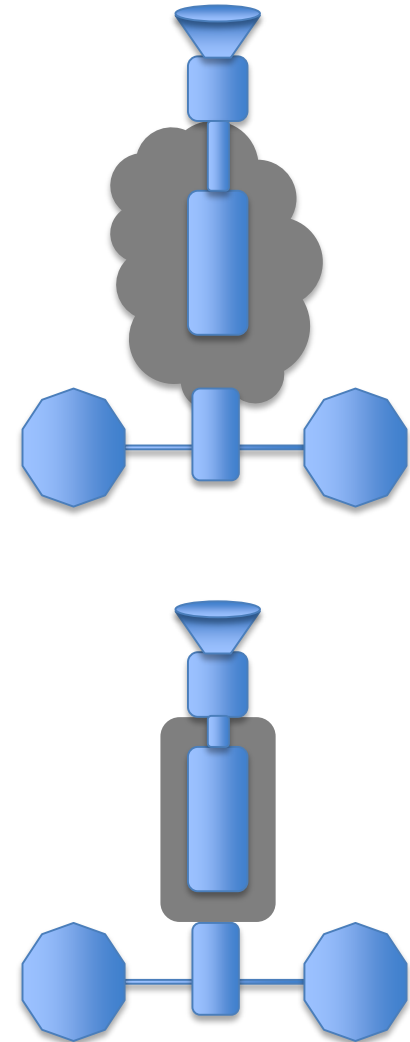


Chen, et al., "Powered Earth-Mars Cyclers with Three Synodic-Period Repeat Time," *Journal of Spacecraft and Rockets*, Sept.-Oct. 2005, pp. 921-927.

# Two Ways to Turn Asteroids into Cyclers



- “Natural” approach redirects an asteroid directly onto a cycler. Cycler vehicle constructed from asteroid in interplanetary space.
  - This is the most efficient way to get a lot of asteroid mass
- “Artificial” approach redirects asteroids to the Earth-Moon system where they are used to construct cycler spacecraft that are then boosted onto cycler.
  - Allows construction and testing of spacecraft in Lunar orbit “dry dock”



# Natural Asteroid Cyclers



- Although several asteroids naturally have multiple Earth and Mars encounters, none are naturally on cycler orbits because these orbits are unstable
- However, any asteroid that crosses the Earth's orbit with a C3 of  $9 \text{ km}^2/\text{s}^2$  or more could be redirected onto a Cycler *eventually* with several Earth flybys (i.e. a gravity-assist tour)
  - Lower C3's may be possible as well using extra SEP thrusting
- Asteroids with return dates and C3s that line up with Earth cycler encounters are the best candidates for establishing the cycler in just a few years (i.e with a just a couple flybys)
- Asteroids on Earth-Mars cyclers could be impact risks if control is lost (this needs further study)
- Most asteroids have very uncertain mass and shape and may need characterization by a robotic precursor before redirection

# Example: 2013 UX2 onto S1L1 Cyclor

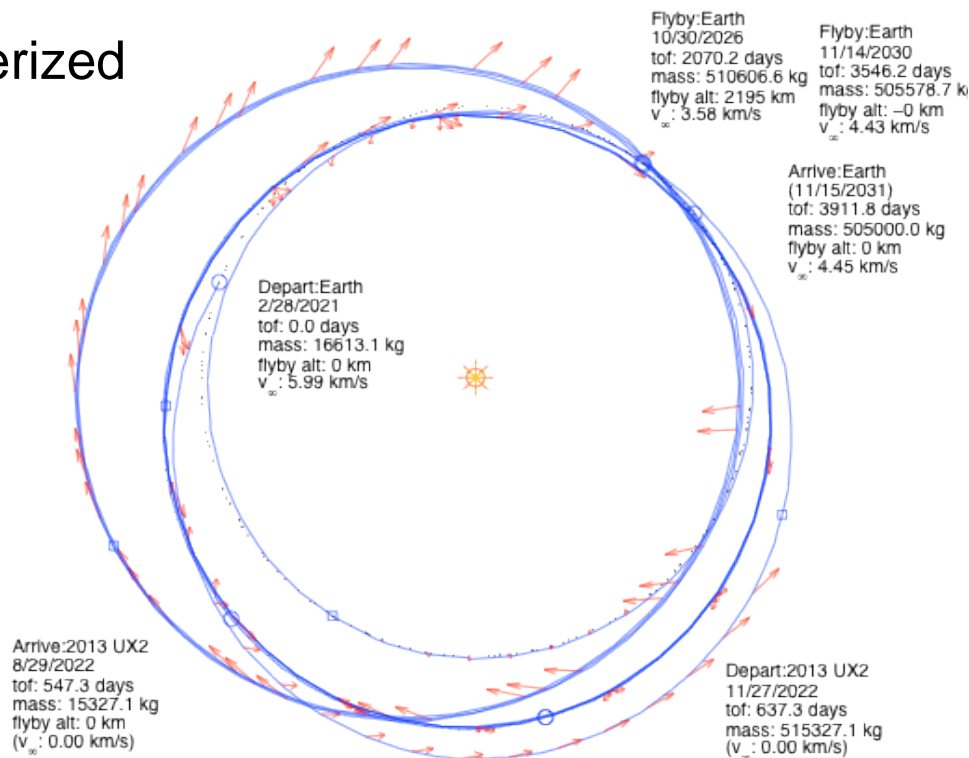


## 2013 UX2

- Discovered Oct 2013, not characterized
- Natural Return Oct 2026
- Abs. Magnitude: 29.2
- 3-14 m; 29-2600 t

Power	Xe Prop	Max Asteroid Mass
40 kW	10 t	300 t
50 kW	12 t	500 t
100 kW	12 t	800 t
200 kW	12 t	950 t

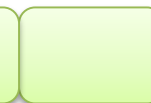
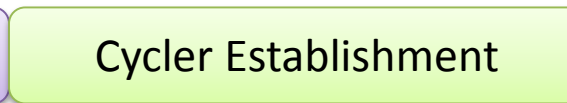
*all cases assume SLS launch*



Launch 2021  
Arrival 2022

Natural Return 2026

Earth Flyby 2030



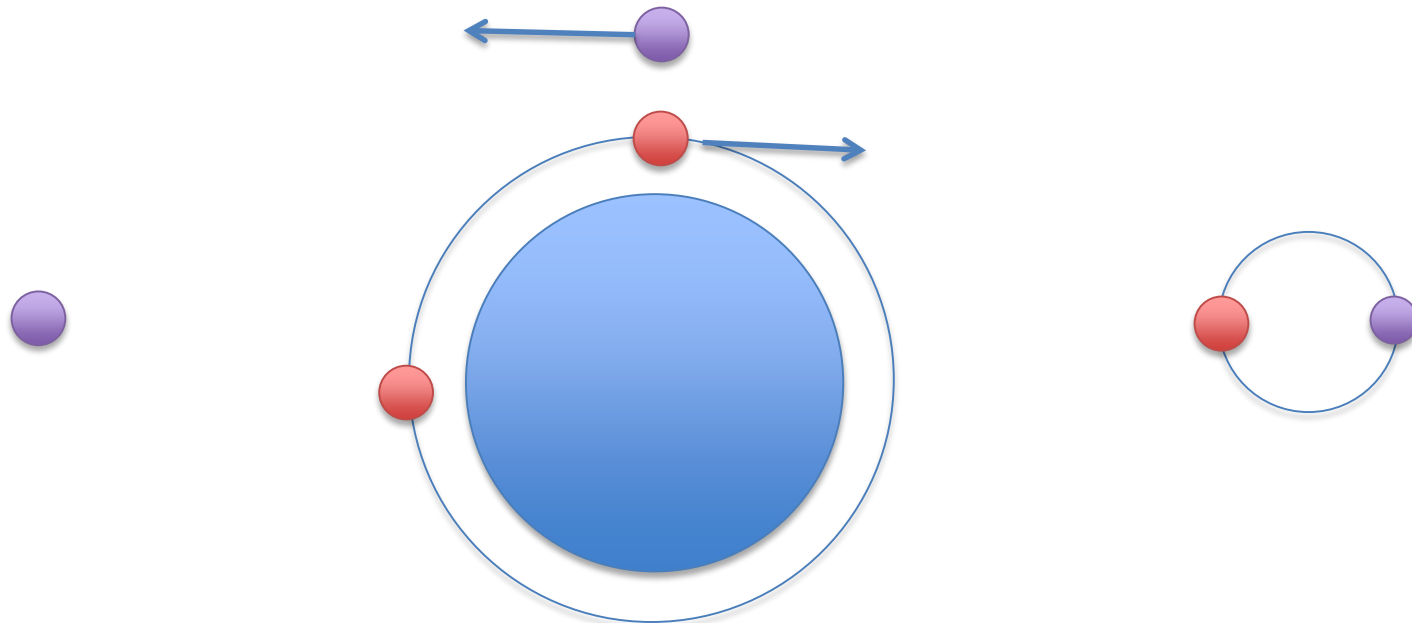
Cyclor 2031



# Binary Asteroid Capture/Escape



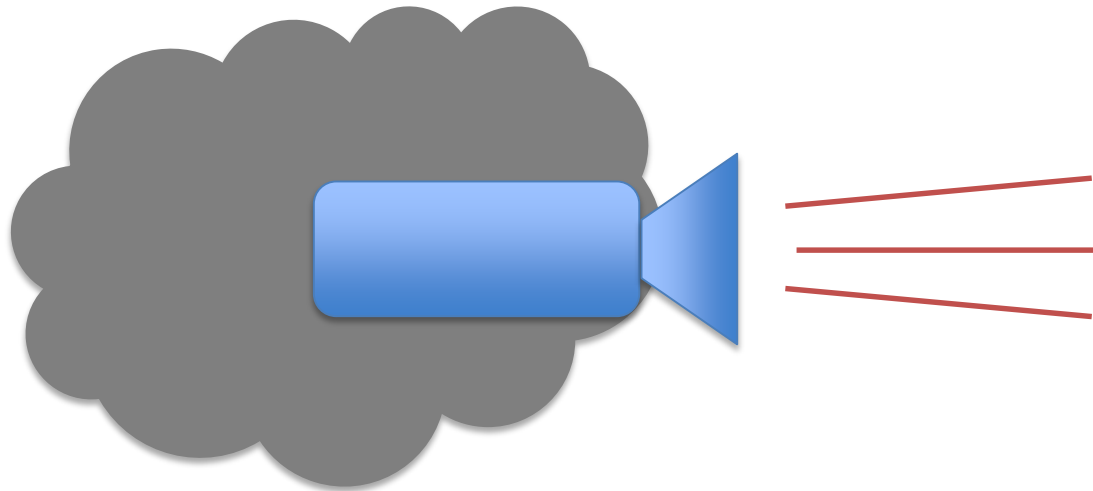
- A binary asteroid pair passing close to a planet could be used to capture one asteroid and eject the other
  - One way to capture an asteroid at Mars or Venus
  - Could also be used to eject an asteroid from the Solar System at high speed



# ISRU Rockets



- Water  $\rightarrow$  LH<sub>2</sub> + LOX
- Magnesium
- Dusty Gas (Heat from Solar, Nuclear, or Chemical Reaction)
- Oxygen Hall
- Dusty Hall
- Dusty Arcjets
- Ablation

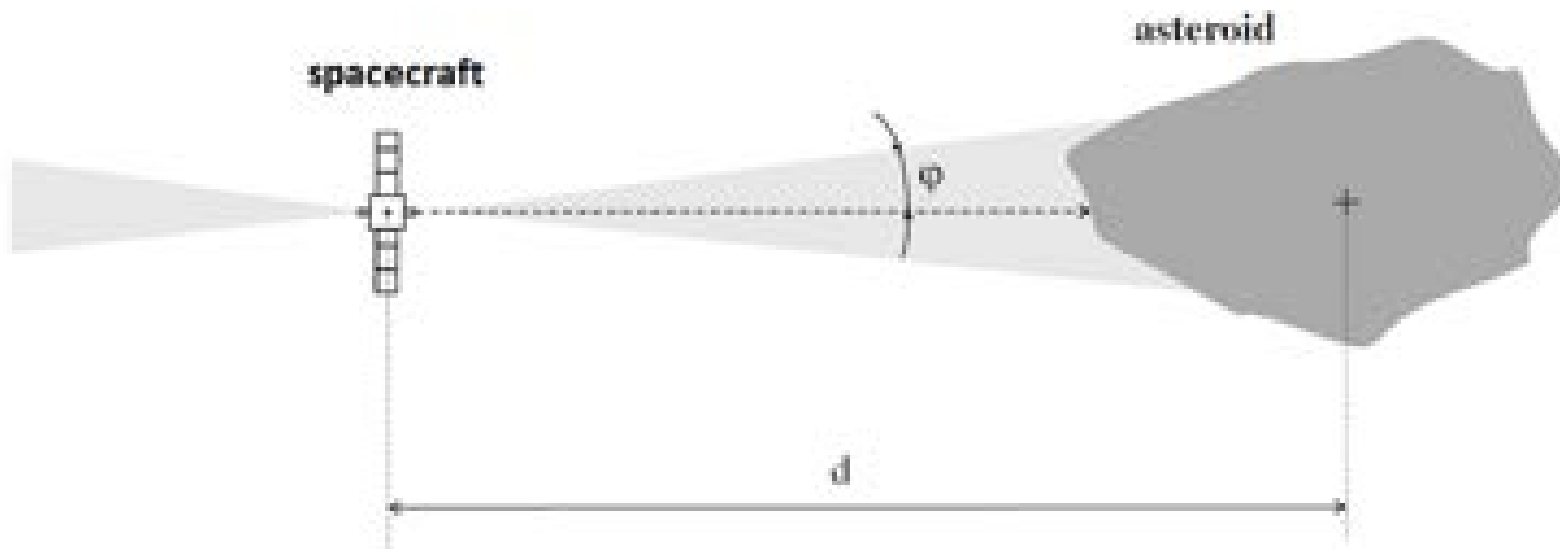


# “No Touch” Redirection



“No Touch” deflection technologies allow redirection of large objects without anchoring and de-spinning

- Laser Ablation
- Ion Beam Deflection
- Stand-off Ionization & Acceleration (?)



# Possible Destinations



## Moon



- Lunar DRO
- Earth-Moon Lagrange Points
- Lunar Backflip

## Earth



- LEO / ISS
- High Elliptical Orbit
- Earth-Sun Lagrange Points
- Earth DRO
- Earth Backflip



## Jupiter

- Ganymede-Europa Cyclers
- Redirect a comet
- Steal an irregular moon

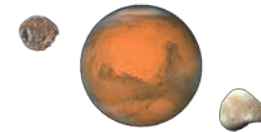


## Ceres?

## Main Belt?

## Mars

- Earth-Mars Cyclers
- Binary Capture
- Aerocapture
- Phobos/Deimos (Impact?)



## Interplanetary

- “Stepping Stones”
- Lower synodic period

## KBO?

## Interstellar?



## Venus

- Binary Capture
- Aerocapture
- Impact