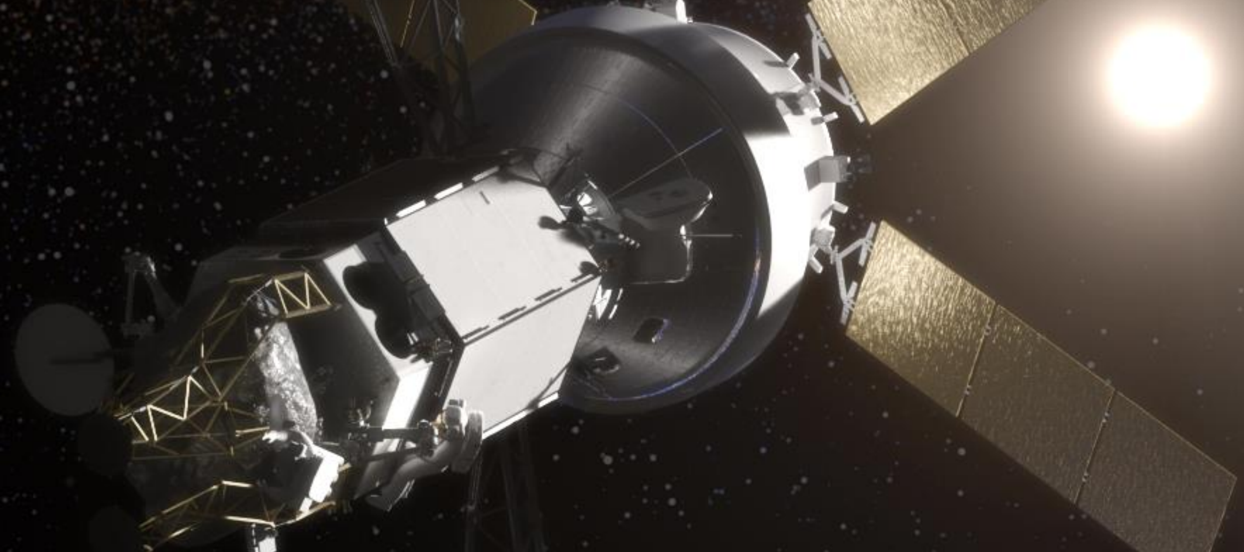
National Aeronautics and Space Administration

Asteroid Redirect Mission (ARM) Planetary Defense Demonstration Overview



Space Mission Planning Advisory Group (SMPAG)

7th Meeting – October 14, 2016

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ARM Mission Investigator

SMPAG Statement on Asteroid Orbit Deflection Demos

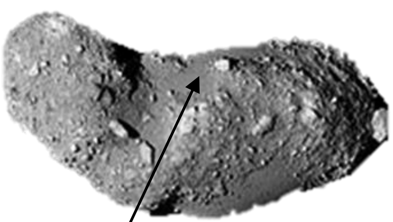
- **Statement on Asteroid Orbit Deflection Demonstrations from international Space Mission Planning Advisory Group's 6th meeting, February 2016:**

  "Given the degree of international interest in asteroid research and awareness of the impact hazard, **advantage should be taken of opportunities to investigate asteroid deflection physics, techniques and effects as a part of science and technology demonstration missions.** While general science and technology efforts are vital, the Space Mission Planning Advisory Group (SMPAG) has identified the need to gain sufficient confidence in the viability of any proposed technique to deflect an asteroid from an impact trajectory. **Therefore the performance of the deflection technique to be utilized must have been actively demonstrated in a realistic planetary defence scenario to increase the current level of confidence.**

  The SMPAG encourages actual demonstration of the kinetic impactor technique with a space mission, as it appears at this point in time to be the most technologically mature method of asteroid deflection. **SMPAG also supports the investigation of the gravity tractor technique for demonstration as a part of any space mission using ion or other low-thrust propulsion technology planned to visit an asteroid.** SMPAG also encourages the investigation and technology maturation of other potential deflection and impact mitigation techniques to determine their viability, particularly in combination with other missions."

Current Candidate Target Asteroids

ITOKAWA



Muses C –
Hayabusa landing

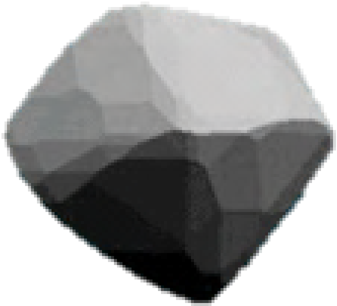
BENNU

Radar –
OSIRIS-REx target

2008 EV5

Radar – boulders and extremely pronounced bulge at equator suggests movement of loose material

1999 JU3



Expected valid target - Hayabusa 2 target

Asteroids not to scale

Comparison of current candidate target asteroids

	Itokawa	Bennu	2008 EV_5	1999 JU_3
Size	535 x 294 x 209 m	492 x 508 x 546 m	420 x 410 x 390 m	870 m diameter
V_∞	5.68 km/s	6.36 km/s	4.41 km/s	5.08 km/s
Aphelion	1.70 AU	1.36 AU	1.04 AU	1.42 AU
Spin Period	12.13 hr	4.297 hr	3.725 hr	7.627 hr
Type	S	B (C-grp volatile rich)	C (volatile rich)	C (volatile rich)
Precursor	Hayabusa (2005)	OSIRIS-REx (launched 9/8/2016, 8/2018 arrival)	None currently planned (boulders implied from 2008 radar imaging)	Hayabusa 2 (launched 12/4/2014, 7/2018 arrival)

NASA continues to look for additional targets in accessible orbits.

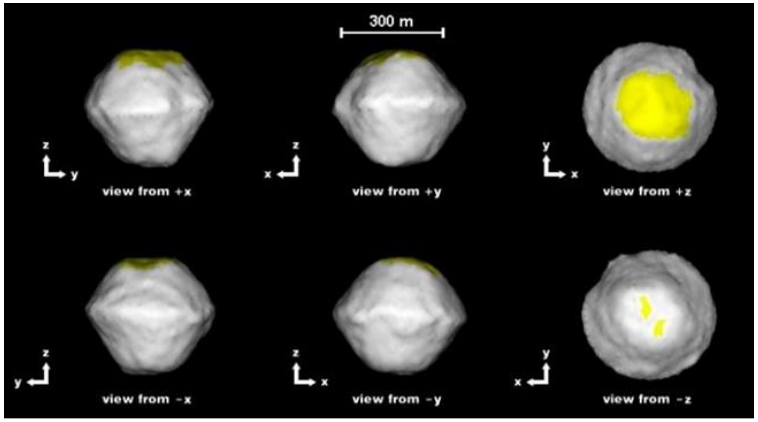
Reference ARRM Target

Science and Resource Interest in Reference Target 2008 EV_5

The planetary science small body community has significant interest in 2008 EV_5 specifically for solar system evolution science and resource utilization.

– This asteroid appears to have a composition analogous to primitive carbonaceous meteorites. Therefore materials from this asteroid may be rich in volatiles like water and organics such as amino acids and other prebiotic molecules necessary for forming the building blocks of life.

- Possibly contains significant water content (up to ~20 wt. %).
- Carbonaceous meteorites are relatively rare in the meteoritic collections and are of key interest to astrobiology.



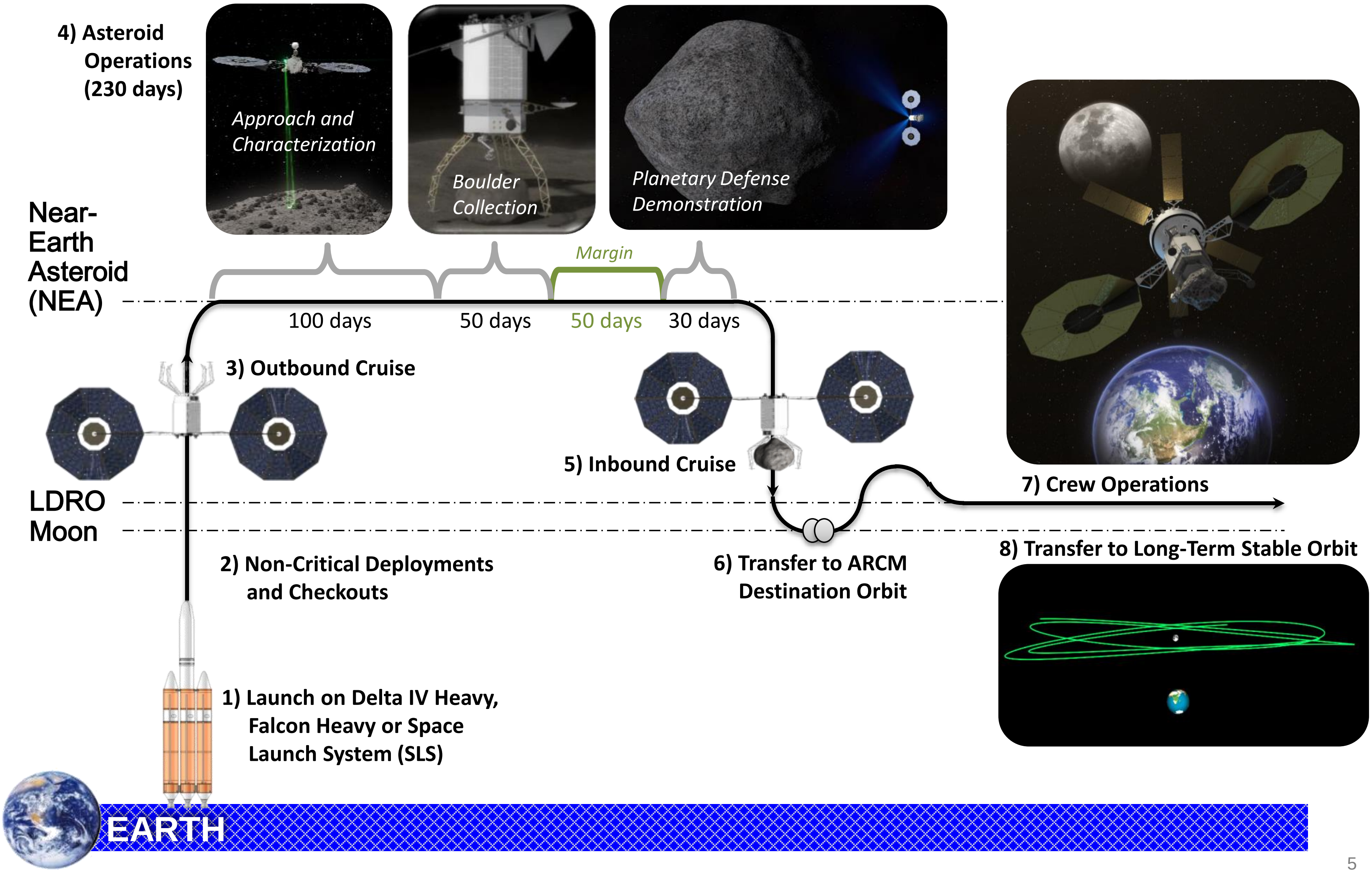
2008 EV_5 shape model from radar observations.

– Returned carbonaceous material can provide important information about how the early Solar System formed and insight on how life may have begun on Earth.

– 2008 EV5 has been a prime target for previously proposed sample return missions due to its assessed high science value.

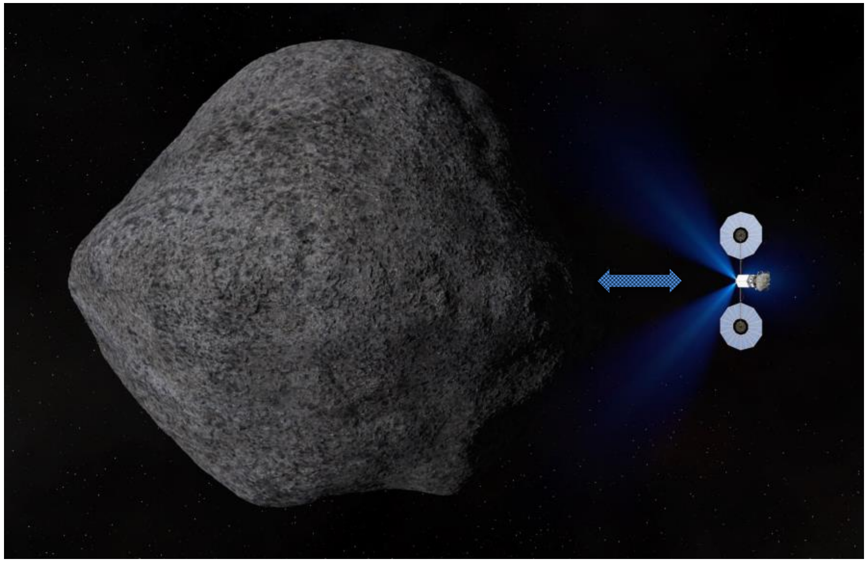
Detailed analyses of 2008 EV_5's orbit evolution indicates it probably did not experience temperatures high enough to deplete organic and hydrated compounds below the top ~5 cm of any surfaces on the asteroid.

ARM Robotic Segment Overview

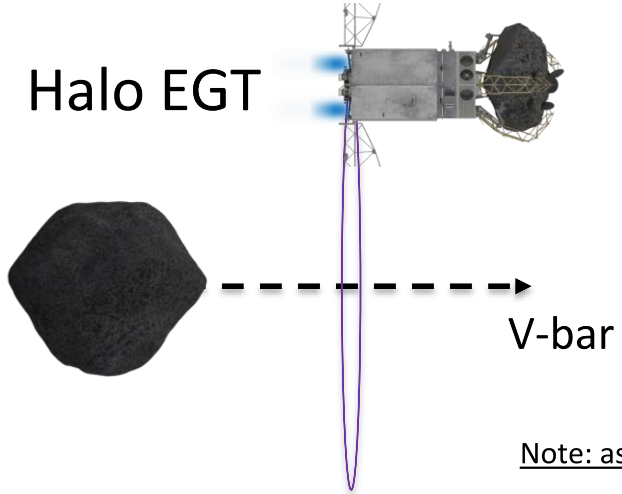


Planetary Defense Demonstration

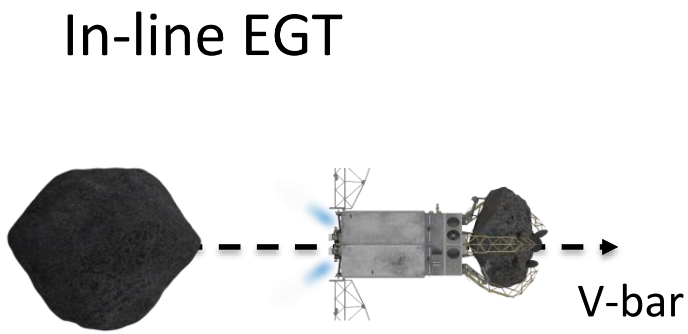
- **Enhanced Gravity Tractor (EGT)**
  - Uses the mass of the collected boulder to augment the mass of the spacecraft and increase the gravitational attraction
- **Small, but measurable deflection will be imparted on hazardous size asteroid**
  - 30 days for EGT operations allocated in timeline.
  - Collected boulder mass is limited by requirement to return the boulder to lunar vicinity. Current return capability from 2008 EV5 is ~20 t.
  - 2008 EV_5 deflection can be verified using ground-based radar (opportunities available in 2023, 2024, and 2025)
  - Other targets may require the Asteroid Redirect Vehicle (ARV) to loiter near the asteroid for deflection verification via differential ranging to the ARV.
- **Actual EGT planetary defense mission could utilize more power/propellant and collect much more mass, increasing the effectiveness of this technique.**



Halo vs. In-line EGT Demonstration for ARRM Baseline



vs.



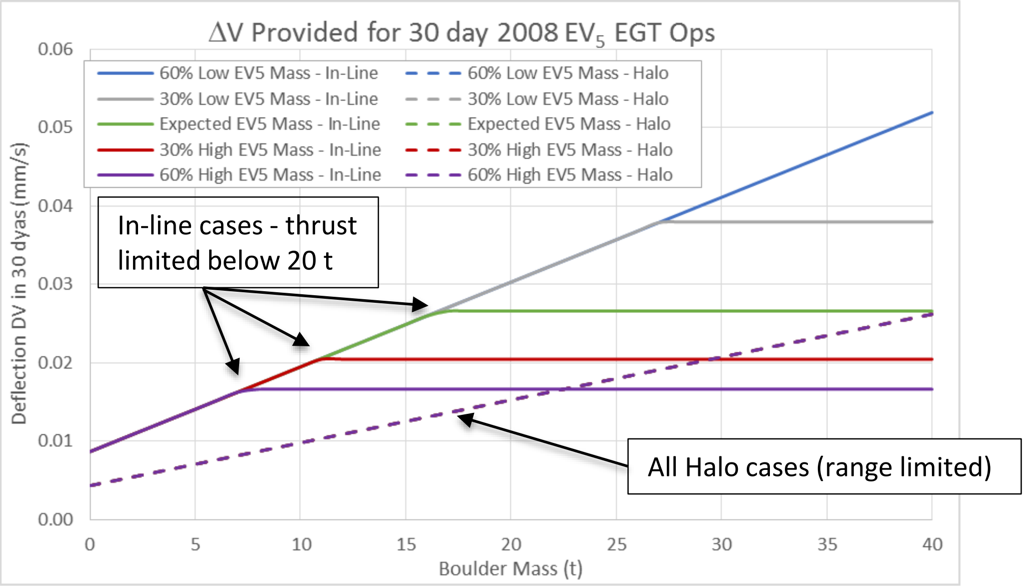
<u>Note: asteroid and spacecraft/boulder are not to scale.</u>

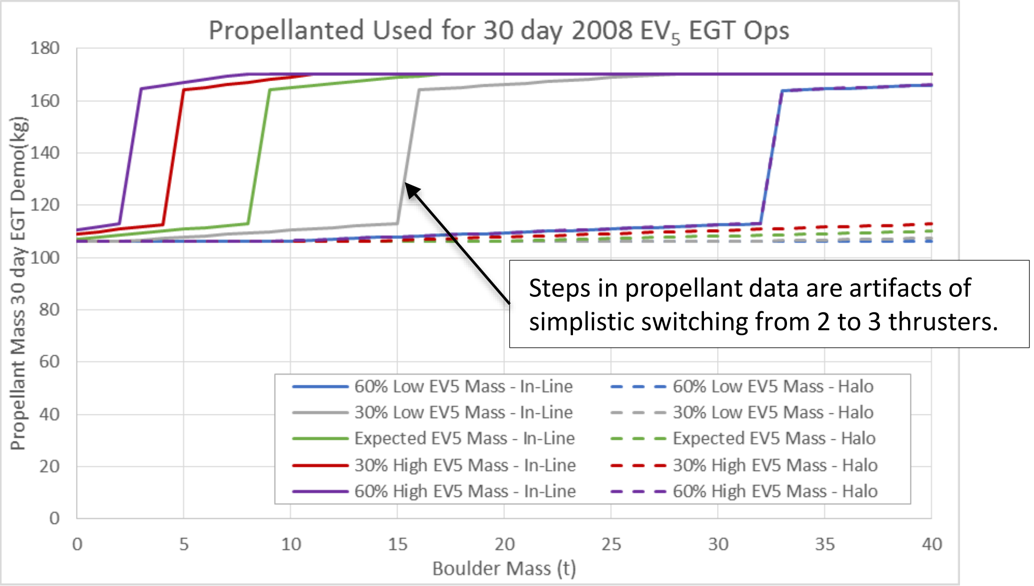
- **<u>Strengths</u>**
  - Time efficacy and mass efficiency better for high boulder masses
  - Higher thrust efficiency – nominally, no SEP engine gimballing required (except for low boulder/asteroid mass)
- **<u>Weaknesses</u>**
  - Lower time efficacy and mass efficiency at low boulder masses
  - Full ARRM 2008 EV_5 trade space coverage (asteroid & boulder masses) requires lower SEP thrust level certification
  - GN&C is more complex

- **<u>Strengths</u>**
  - Full ARRM 2008 EV_5 trade space coverage (asteroid & boulder masses) achieved
  - Adjusting engine gimbal angle is easier than SEP thrust
  - Time efficacy and mass efficiency can be roughly twice as good as halo for low boulder masses
- **<u>Weaknesses</u>**
  - High maximum gimbal angle leads to low boulder mass cases that have severe cosine losses (low thrust efficiency)
  - Lower mass efficiency for high boulder masses

Efficacy/Efficiency	Definition
Time efficacy (ΔV/time)	Determines the stay time to reach a detectable deflection
Thrust efficiency	How much applied thrust is projected along the desired inertial direction
Mass efficiency (ΔV/propellant)	Determines how much propellant is needed to reach a detectable deflection

Halo vs. In-line for ARRM Baseline – ΔV & Propellant



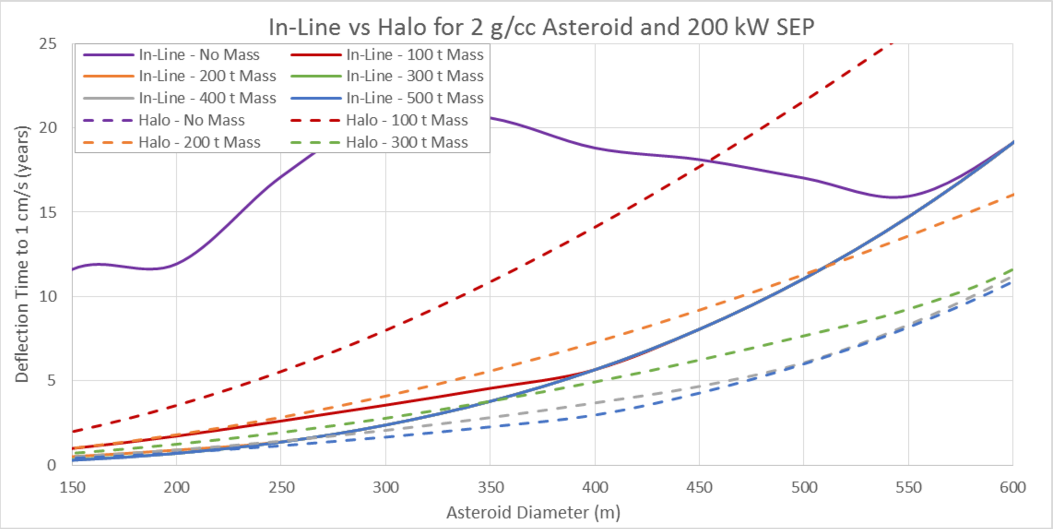


- **For 20 t ARRM mass return requirement, the in-line option will always provide more ΔV than halo option for 2008 EV_5.**
- **Preliminary ARRM EGT demo minimum ΔV for verification is estimated at ~0.01 mm/s, which requires a 10 t boulder for the halo option.**
- **Depending on 2008 EV_5 mass and boulder mass, the in-line option could use up to ~50 kg more xenon over the 30 day demonstration.**
  - Less variance in xenon usage for the halo option.
  - Propellant usage for EGT demo is small portion of total xenon load (~1% of 5.3 t) assuming I_{sp} of 2,600 s.
  - Further analysis is needed to understand use of three thrusters in a “tri-pod” configuration for the in-line option.

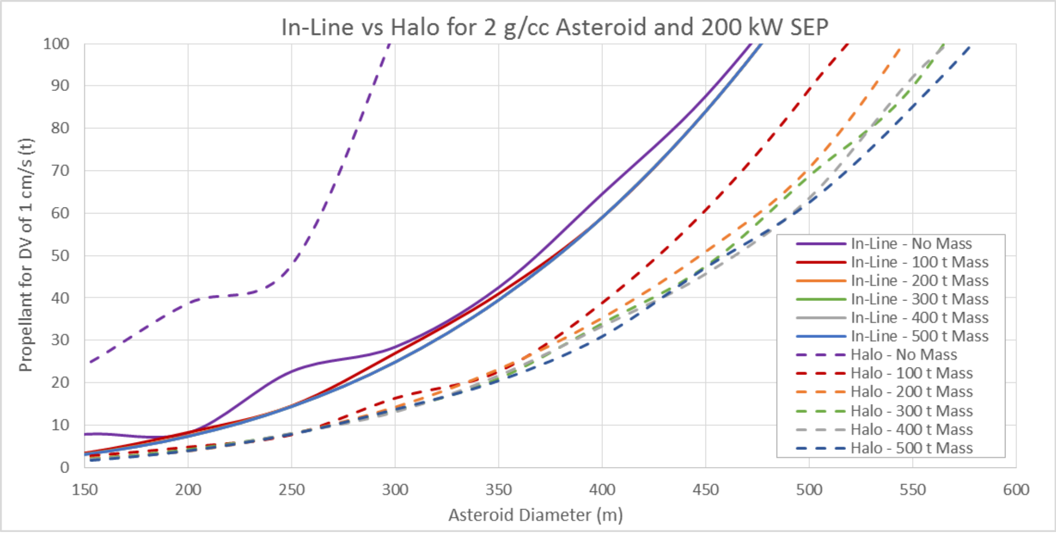
Halo vs. In-line for ARRM Baseline Decision

- **For the ARRM baseline mass ranges (boulder and asteroid), the in-line EGT was determined to be preferable to the halo option.**
  - Robust to nearly all mass scenarios, while the halo orbit is infeasible for lower asteroid and boulder mass combinations.
  - Significantly simplifies GN&C architecture.
  - Provides greater asteroid accelerations resulting in higher applied ΔV.
  - Could require somewhat higher propellant usage, but this is not a significant issue for 30-day demonstration.
- **Decision was made to update the ARRM operations concept to utilize in-line EGT with large gimbal range-of-motion using the baseline SEP thruster.**

EGT Extensibility Example – 200 kW SEP and I_{sp} of 2,600 s Time & Propellant



Note: "Halo - No Mass" case exceeds 25 year deflection time for asteroids > 150 m and is not visible

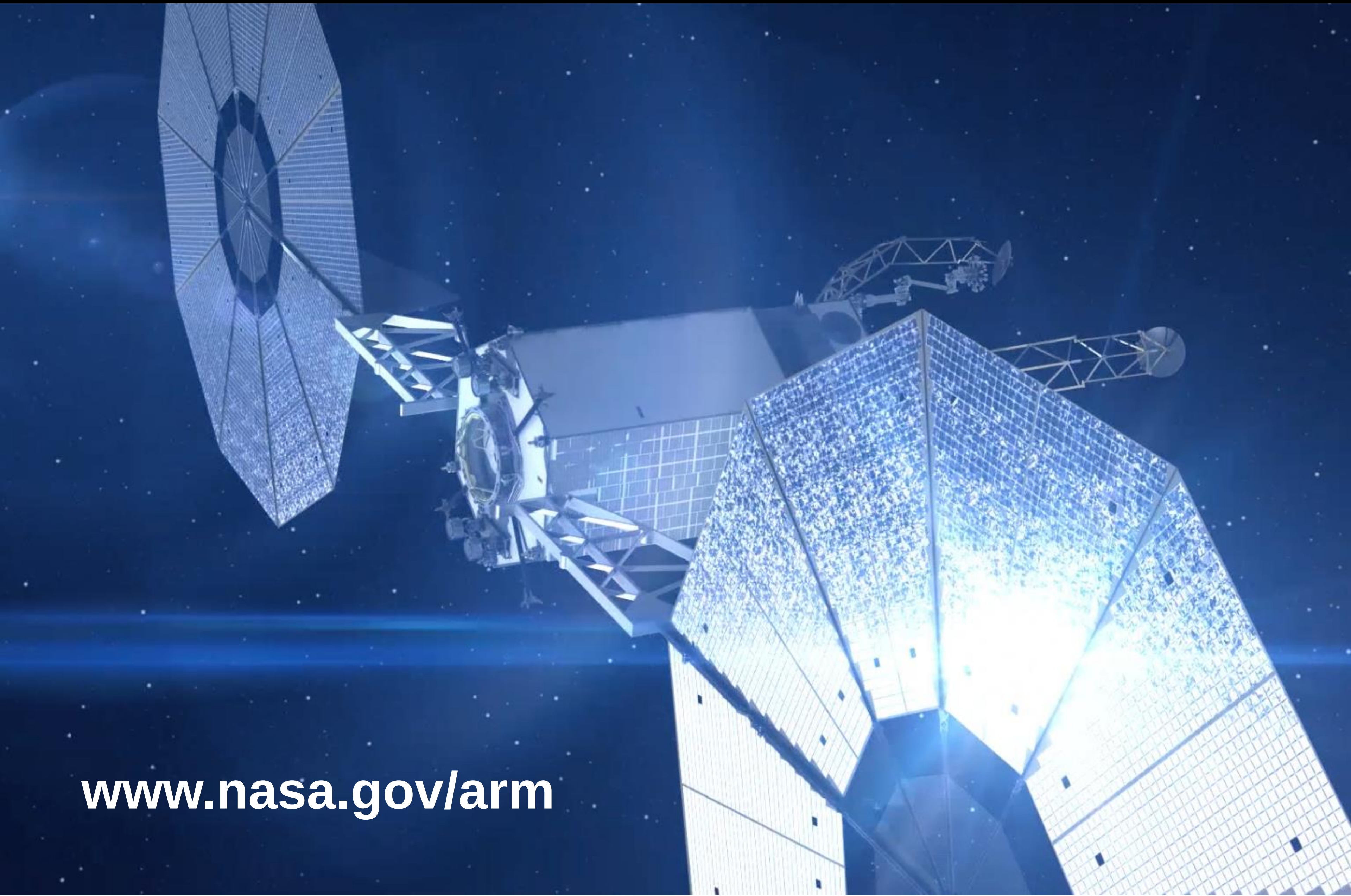


- **For collected masses less than ~200 t, in-line option requires less time for all asteroids less than ~500 m.**
- **For collected masses over ~40 t, halo option requires less propellant for all applicable asteroid sizes.**
- **Deflection time scales linearly with ΔV required.**
- **Changing asteroid densities would adjust applicable asteroid sizes.**

EGT Extensibility Observations

- **EGT is applicable for planetary defense depending on ΔV required and warning time, but is limited by reasonable propellant masses and vehicle lifetimes, along with impactor spin state and mass availability for collection.**
- **Assuming a single spacecraft with fixed I_{sp} of 2,600 s, 30 t maximum propellant load, 15 year maximum tractoring time, and asteroid bulk density of 2 g/cm^3:**
  - In-line option limit at ~325 m asteroids with 80+ t collected mass.
  - Halo option limit at ~400 m diameter with 500+ t collected mass.
  - Propellant is main limiting factor and therefore increasing SEP power does not increase applicable range.
  - With less than ~80 t collected mass, the halo option is either not applicable due to propellant usage or is less efficient than the in-line option.
- **Options for larger asteroids and decreasing deflection times are possible.**
  - Additional SEP power along with increased thrust and propellant.
  - Halo allows for multiple spacecraft to perform EGT at the same time multiplying the force applied (may be possible with in-line, but less efficient with operational issues likely).

Thank you for your attention - questions?



www.nasa.gov/arm