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LOW-COST MISSION ARCHITECTURES TO SMALL BODIES

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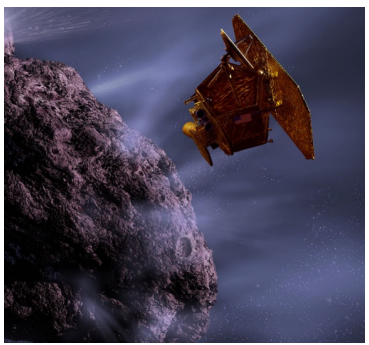
Low-cost approach to NEO missions for small body science and planetary defense make use of existing and planned space vehicles

Past small-body missions have been re-purposed to achieve new objectives

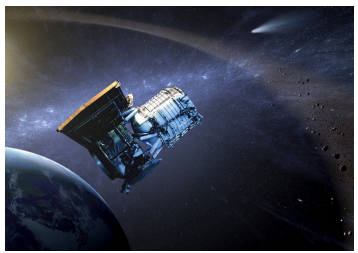
DI -> EPOXI



Credit: NASA/JPL/UMD/Pat Rawlings

2005 -> 2010 -> 2013

WISE -> NEOWISE



Credit: NASA

2009 -> 2013 -> present

Kepler -> K2

Credit: NASA

2009 -> 2014 -> 2018

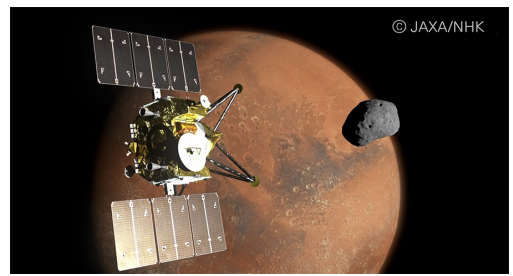
Current and Future Missions will have Propellent. Could reach NEOs!

O-Rex -> APEX

Credit: NASA

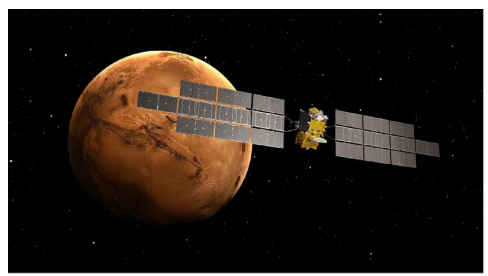
2016 -> 2023 -> present

MMX



2024 est. -> 2029 est. -> ??

ERO for MSR

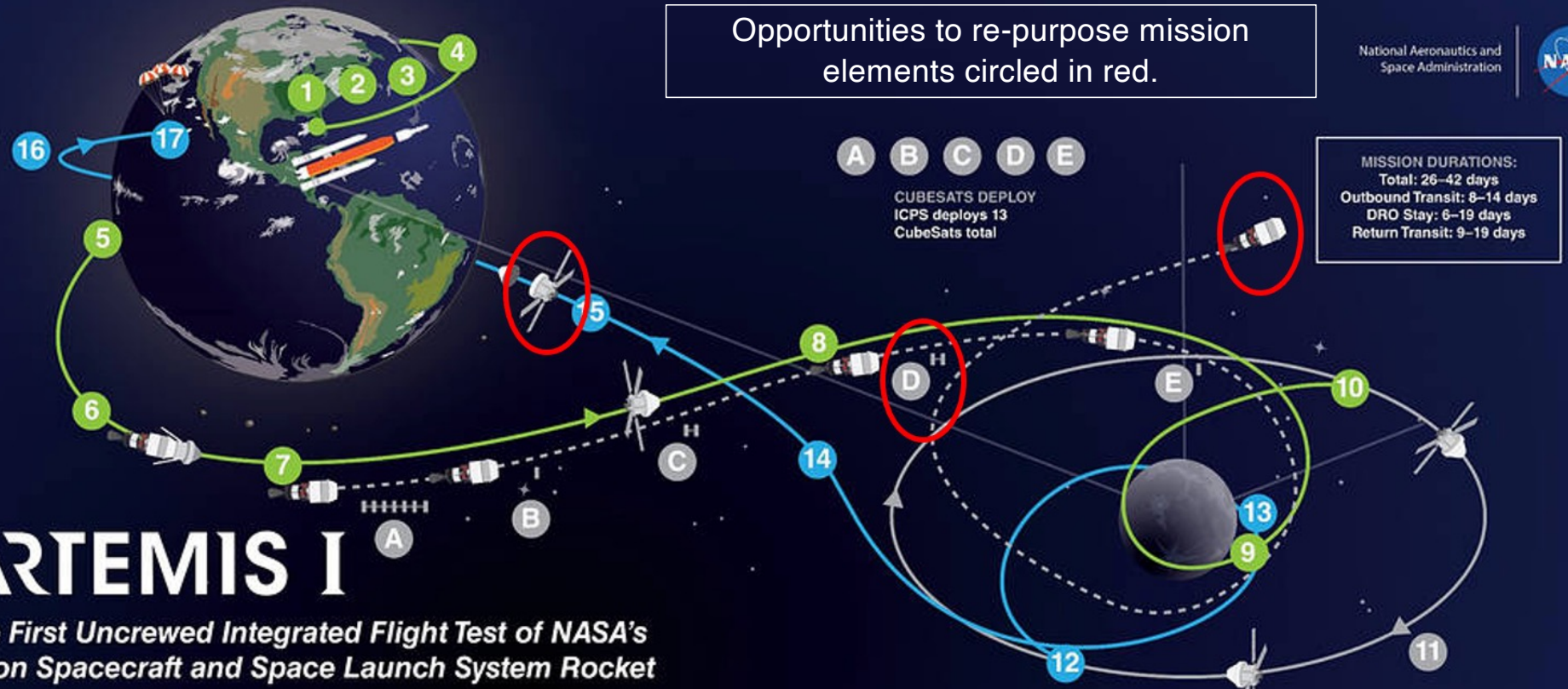


Credit: Airbus

2026 est. -> 2031 est. -> ??

Opportunities to re-purpose mission elements circled in red.

National Aeronautics and Space Administration



ARTEMIS I

The First Uncrewed Integrated Flight Test of NASA's Orion Spacecraft and Space Launch System Rocket

1. **LAUNCH**
   SLS and Orion lift off from pad 39B at Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
   With separation.
4. **PERIGEE RAISE MANEUVER**
5. **EARTH ORBIT**
   Systems check with solar panel adjustments.
6. **TRANS LUNAR INJECTION (TLI) BURN**
   Maneuver lasts for approximately 20 minutes.
7. **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION AND DISPOSAL**
   The ICPS has committed Orion to TLI.
8. **OUTBOUND TRAJECTORY CORRECTION (OTC) BURNS**
   As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).
9. **OUTBOUND POWERED FLYBY (OPF)**
   60 nmi from the Moon; targets DRO insertion.
10. **LUNAR ORBIT INSERTION**
    Enter Distant Retrograde Orbit.
11. **DISTANT RETROGRADE ORBIT**
    Perform half or one and a half revolutions in the orbit period 38,000 nmi from the surface of the Moon.
12. **DRO DEPARTURE**
    Leave DRO and start return to Earth.
13. **RETURN POWERED FLYBY (RPF)**
    RPF burn prep and return coast to Earth initiated.
14. **RETURN TRANSIT**
    Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere.
15. **CREW MODULE SEPARATION FROM SERVICE MODULE**
16. **ENTRY INTERFACE (EI)**
    Enter Earth's atmosphere.
17. **SPLASHDOWN**
    Pacific Ocean landing within view of the U.S. Navy recovery ship.

Numerous NEOs Are Reachable by ESM After Prime Mission

Analysis Assumptions

- **Artemis II Planned Launch Date**: May 2024
- **Orion/ESM Return**: 10 days after launch
- **Return Window**: May-Sep 2024 (to account for delayed launches)
- **ESM DV Capability after Prime Mission:**
  0.98 km/s (300 kg Scientific P/L)
- **ESM Earth return C_3 ~ 0**
- **Targets**: a pool of ~7,000 NEO's
- **ToF after Prime mission** < 3.5 yr

	Target	Launch	ToF (yr)	DV for Rendezvous (km/s)	DV for Flyby (km/s)	Arrival Vinf (km/s)
1	2014 MF18	7/2024	0.83	**0.753**	**0.315**	0.438
2	2014 MF18	7/2024	1.64	**0.579**	**0.353**	0.227
3	2002 NV16	9/2024	0.59	**0.796**	**0.535**	0.261
4	2011 AM24	7/2024	0.59	X	**1.025**	0.919
5	Itokawa	6/2024	1.24	X	**0.817**	0.973
6	Itokawa	5/2024	2.77	X	**0.896**	0.577
7	2001 CQ36	5/2024	2.71	X	**0.471**	0.819
8	2011 CG2	7/2024	2.07	X	**0.411**	0.832
9	2007 YJ	5/2024	1.8	X	**0.621**	1.945
10	2007 YJ	6/2024	1.8	X	**0.382**	2.470
11	2008 EV5	6/2024	0.5	X	**0.812**	1.305
12	2008 EV5	6/2024	0.5	X	**0.289**	4.036
13	2001 WC47	5/2024	1.4	X	**0.748**	2.103
14	2001 WC47	5/2024	1.0	X	**0.240**	2.103
15	2006 QQ23	9/2024	0.6	X	**0.575**	2.768

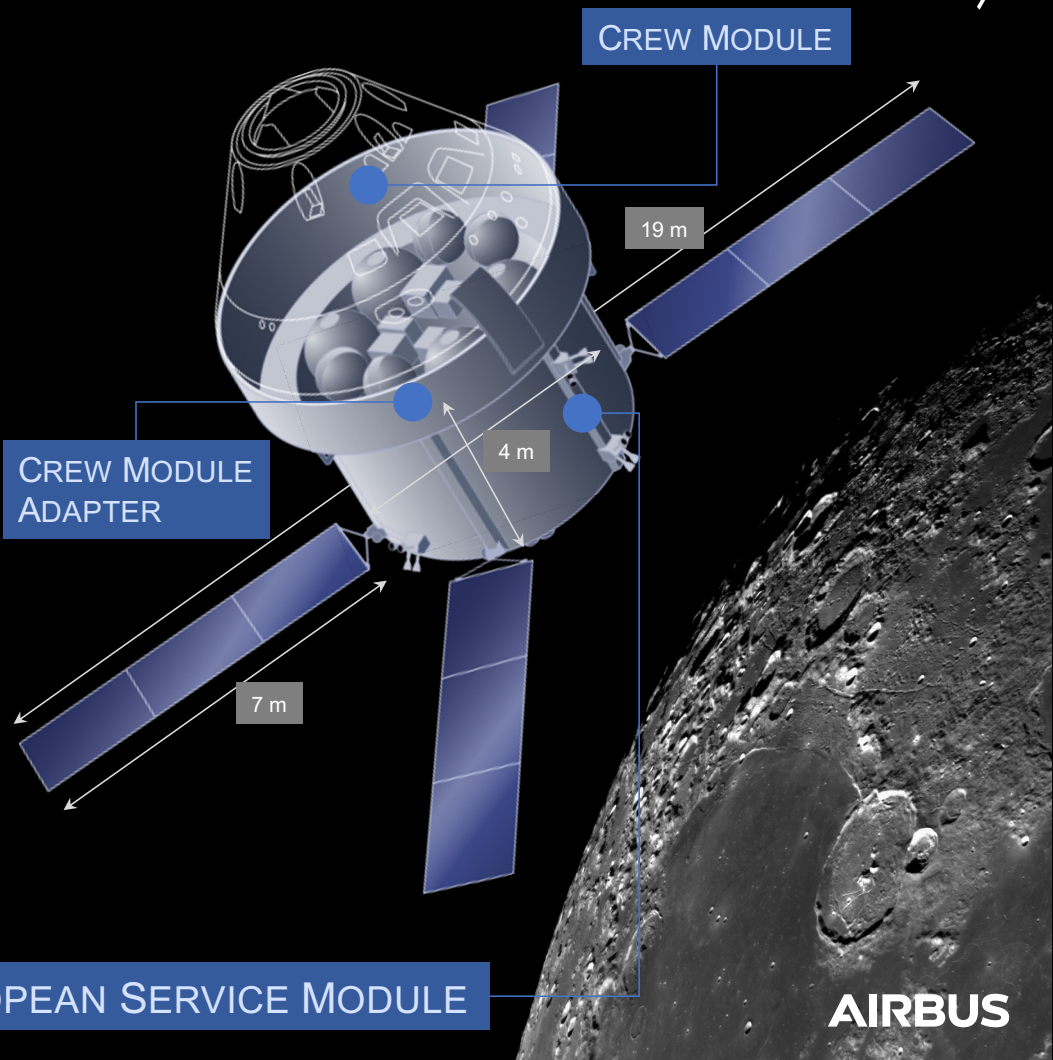
Orion ESM

ORION spacecraft for NASA's Artemis Mission to the Moon, designed to transport astronauts further into Space than ever before

ARTEMIS-I: Successful mission in Nov/Dec 2022
ARTEMIS-II: Launch scheduled for Nov 2024
ARTEMIS-III to VI: ESMs in Production
ARTEMIS-VII to IX: ESM funding confirmed at ESA Council Ministerial 2022

Orion ESM

- Propulsion (1 x 26.7 kN main engine, 8 x 490 N auxiliary engines)
- Attitude Control (24 x 220 N RCS thrusters, 8 sun sensors)
- Power Generation, Conditioning and Distribution (11.2 kW)
- Thermal Control (heaters, cooling loop, radiators)
- Payload Support (up to ~380 kg with power and data interface)
- Consumables (~8600 kg of propellant, 90 kg of oxygen, 30 kg of nitrogen, 240 litres of water)



Adaptations for ESM Asteroid Mission

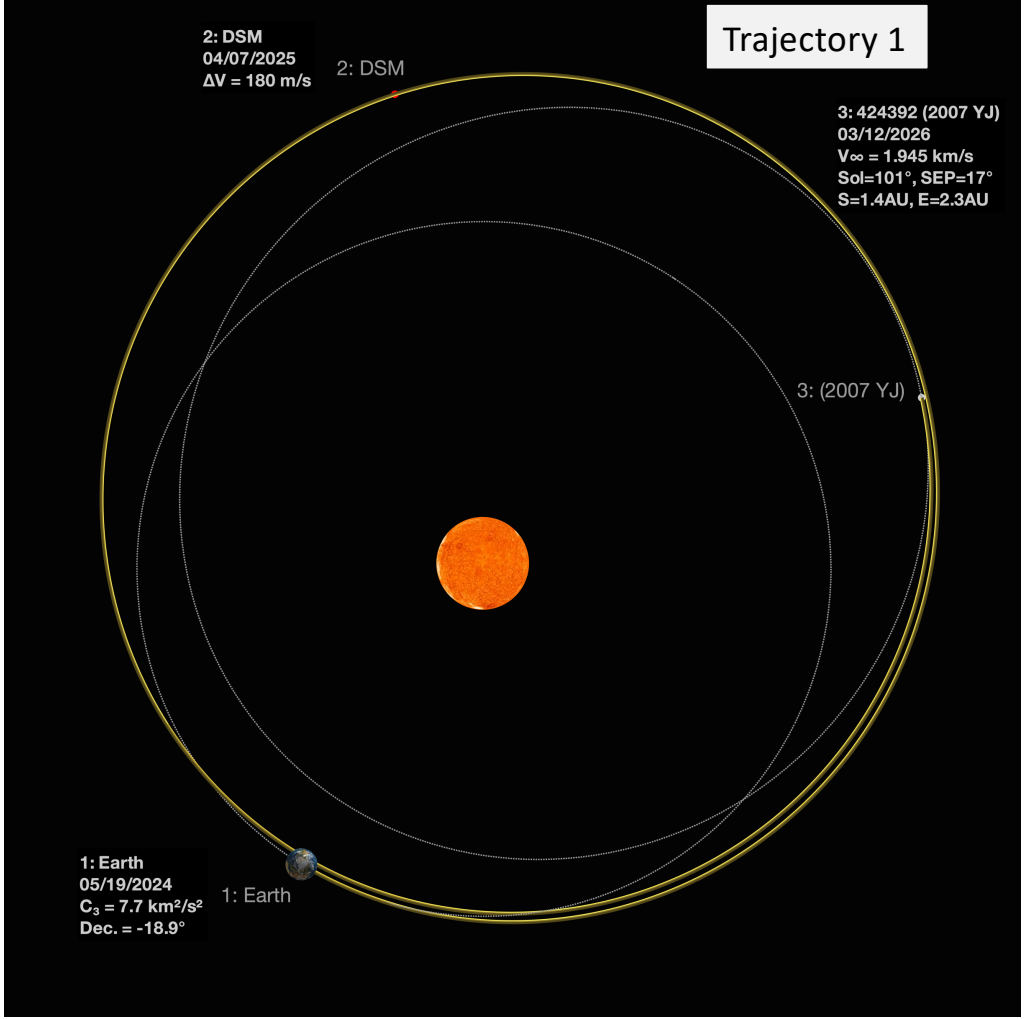
- Several spacecraft functions are relying on the Crew Module
- Additional hardware has to be added in the unpressurised cargo area:
  - Extension of existing S-band communication hardware, including Doppler ranging capability
  - Additional On-Board Computer
  - Battery
  - Additional GNC sensors (star trackers, Inertial Measurement Unit)
  - Scientific Payloads
- Flight Software has to be updated for the new flight configuration
- Assessment needed if duration between Crew Module separation and first re-entry interface needs to be adapted

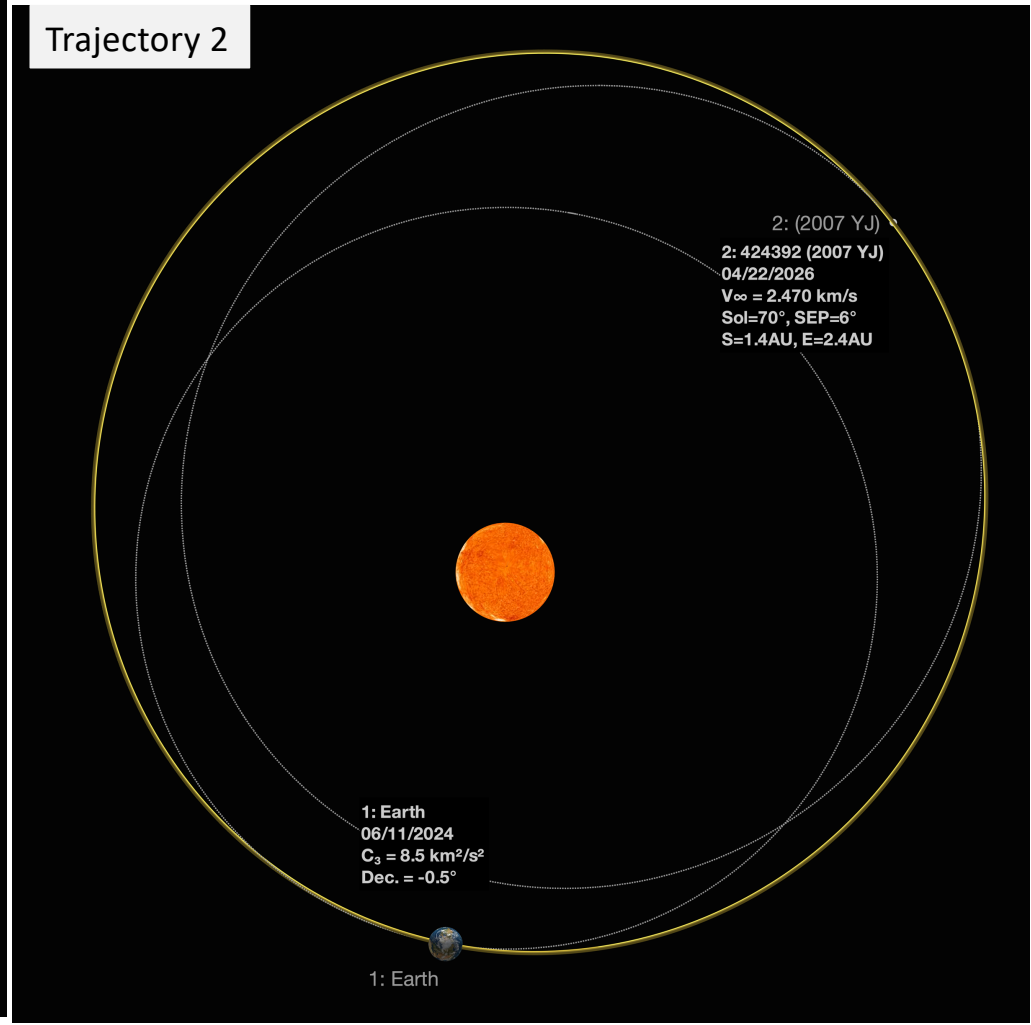
Conclusions

- History of successful reuse of in-space asset
- Numerous current/future missions offer opportunities to reach NEOs
- Preliminary analyses show ESM for Artemis 2 could reach numerous asteroids

Re-purpose existing mission elements,
partner with international space agencies
for a comprehensive, affordable program
to achieve planetary defense and small body science objectives

Backup


Trajectory 1
2: DSM
04/07/2025
ΔV = 180 m/s
2: DSM
3: 424392 (2007 YJ)
03/12/2026
V∞ = 1.945 km/s
Sol=101°, SEP=17°
S=1.4AU, E=2.3AU
3: (2007 YJ)
1: Earth
05/19/2024
C3 = 7.7 km²/s²
Dec. = -18.9°
1: Earth


Trajectory 2
2: (2007 YJ)
2: 424392 (2007 YJ)
04/22/2026
V∞ = 2.470 km/s
Sol=70°, SEP=6°
S=1.4AU, E=2.4AU
1: Earth
06/11/2024
C3 = 8.5 km²/s²
Dec. = -0.5°
1: Earth