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DEFINING THE FUTURE

# Small Body Mission Concepts

Presentation to the Small Bodies Assessment Group

January 13th, 2009

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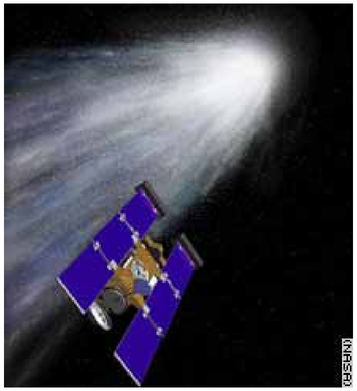
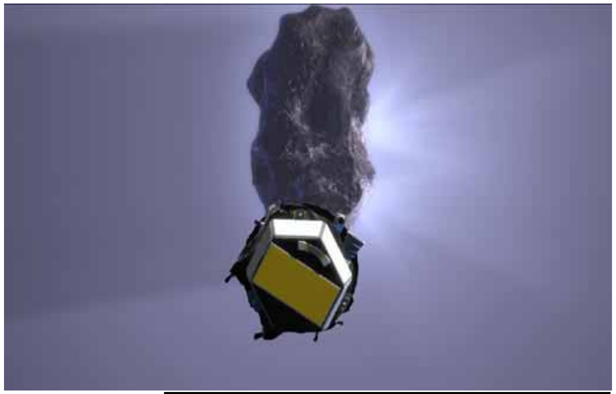
# SBAG Presentation Outline

- **EELV Secondary Payload Concepts**
  - LCROSS System Description
  - Candidate secondary payload missions to 4015 Wilson-Harrington
  - LCROSS Derivative Capabilities
    - Power
    - Propulsion
    - Communications
- **Primary Spacecraft Concepts**
  - Trajectories to 4015 Wilson-Harrington
  - Elst-Pizarro





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# Secondary Payload Concepts

# Secondary Payload Definition

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- Independent missions built into the launch vehicle adapter for a primary payload
  - Current primary payloads often defined by the Delta II lower launch mass
- Utilize excess capacity in EELV
  - Some primary missions can add strap-on solid motors for increased throw weight capability
  - Some primary missions are flying with upper stages not fully fueled
- Drastically reduced launch costs
- Must 'not impact' primary mission
  - Time of launch, trajectory etc restrictions
- Can be impacted by requirements of primary mission
  - Launch dates
  - Trajectory available – though the destination can be different from the primary payload
  - Launch slips or other issues
- Current Example: LCROSS

# Why a Secondary Payload?

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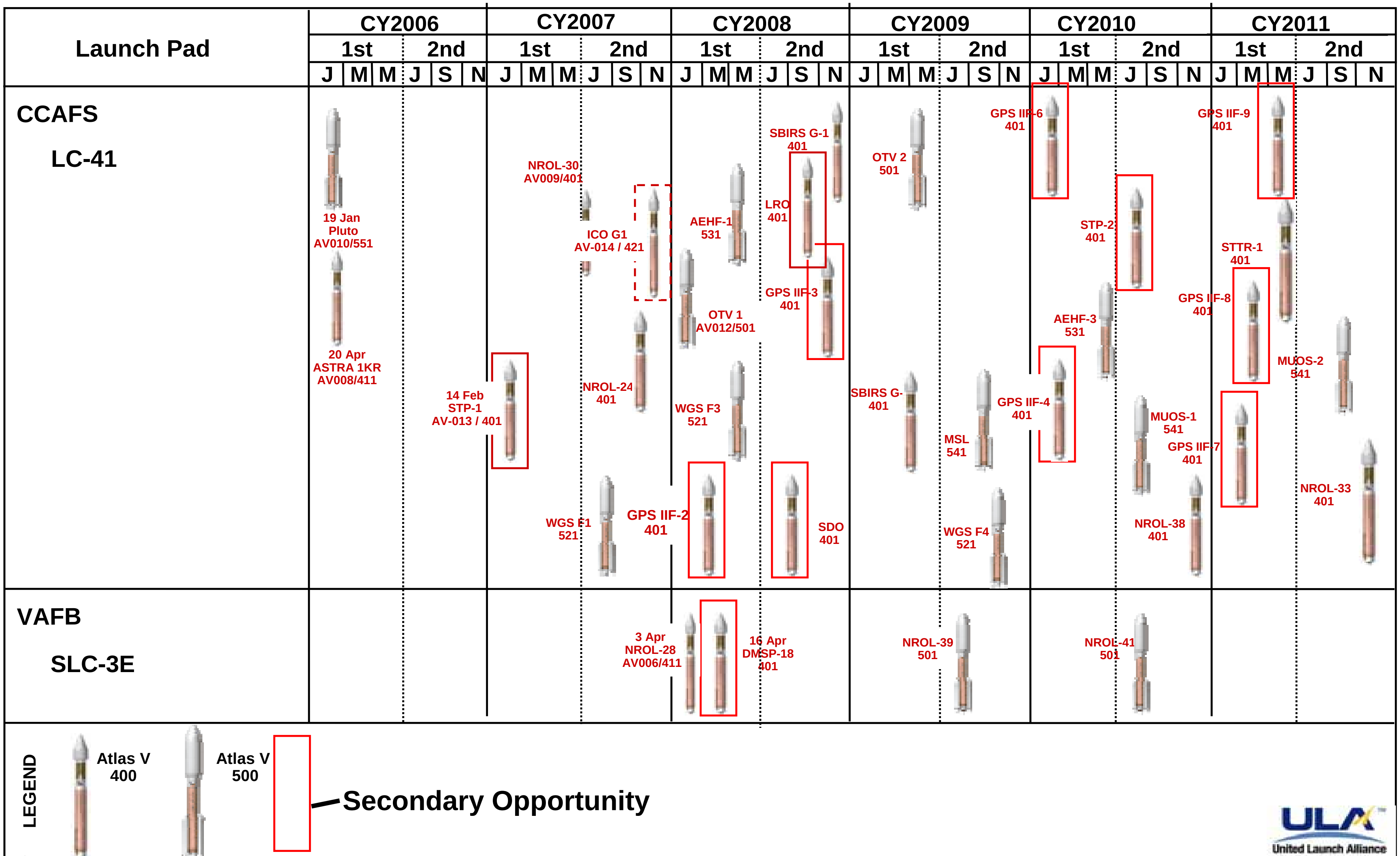
- Lower launch costs (much lower), with large throw masses
  - If the option is allowed by the AO
- With existing technology, it is possible to get to a small body with reasonable payload, propulsion, power, and comm to do first rank science
- Overall quality of the spacecraft/mission would be no different from a regular Discovery or other mission
- The only difference is a lower launch cost, for which the trade is a particular configuration and perhaps the need for higher onboard delta-V

# Atlas V Secondary Manifest Capability



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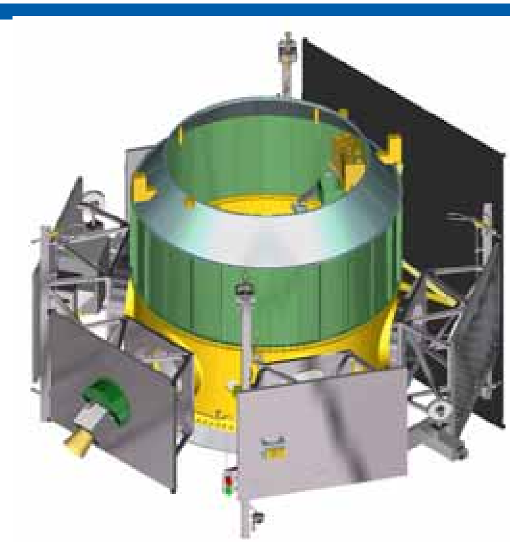
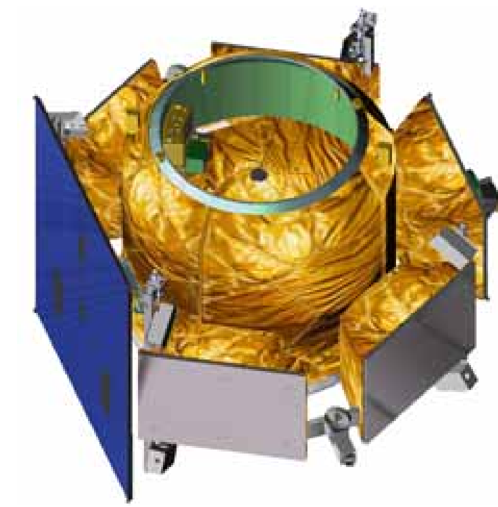
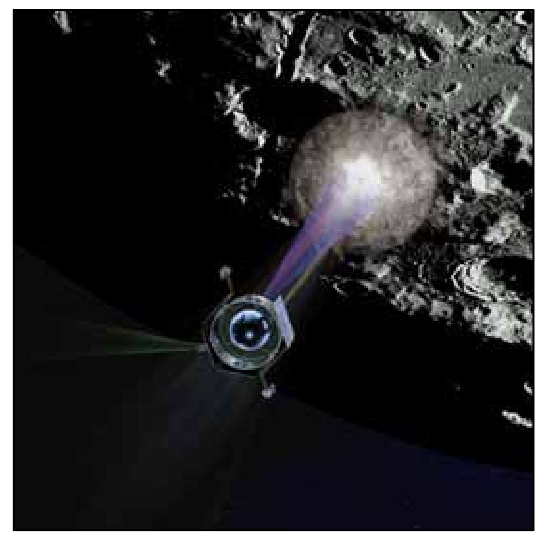
# LCROSS Spacecraft

# LCROSS Mission

- LCROSS – low-cost quick turn-around system
  - Search for $H_2O$ in dark craters
  - Quick 'low cost' mission development cycle
  - Low-Cost secondary launch
  - ESPA-Ring structure
  - LRO derived avionics
  - Robust propulsion capability

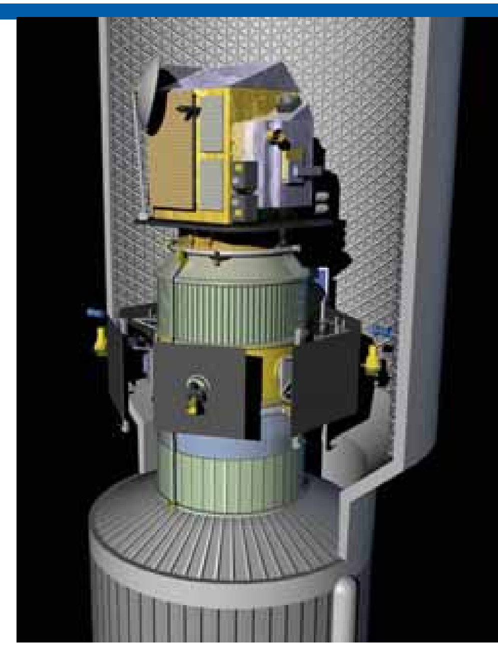






# LCROSS Mission Design

- **Class-D Mission, Cost = $80M;**
- **26-month Program: from authorization to proceed (ATP) to spacecraft delivery**
- **Mass: total = 895 kg**
  - **Spacecraft (dry) = 610 kg**
- **Power:**
  - **Solar Array = GaAs**
  - **Batteries = Li-ion**
- **LRO based avionics**
  - **C&DH, Power, Sensors, Transponder**
- **Thruster based pointing control:**
- **Communications: S-band**



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# Candidate Secondary Payload Missions to 4015 Wilson-Harrington

# Secondary payload mission concept to 4015 Wilson-Harrington

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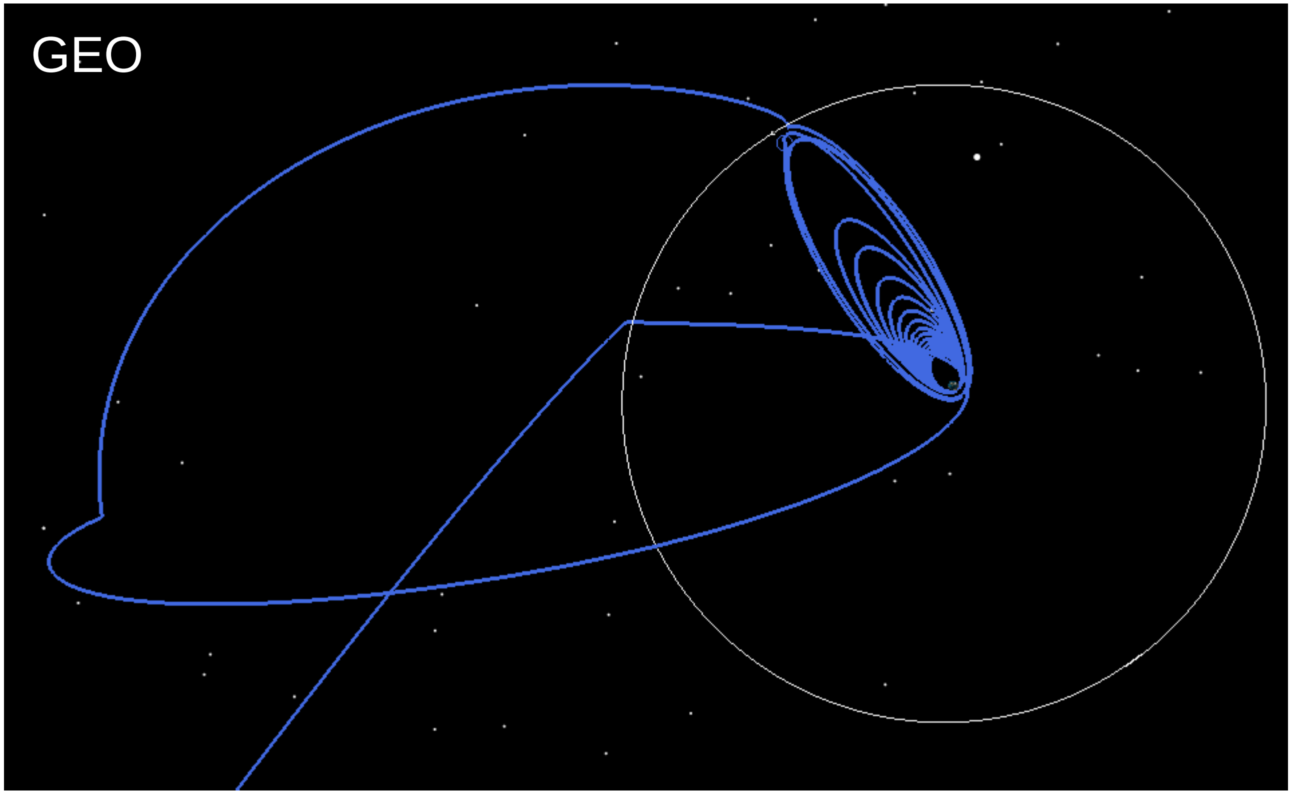
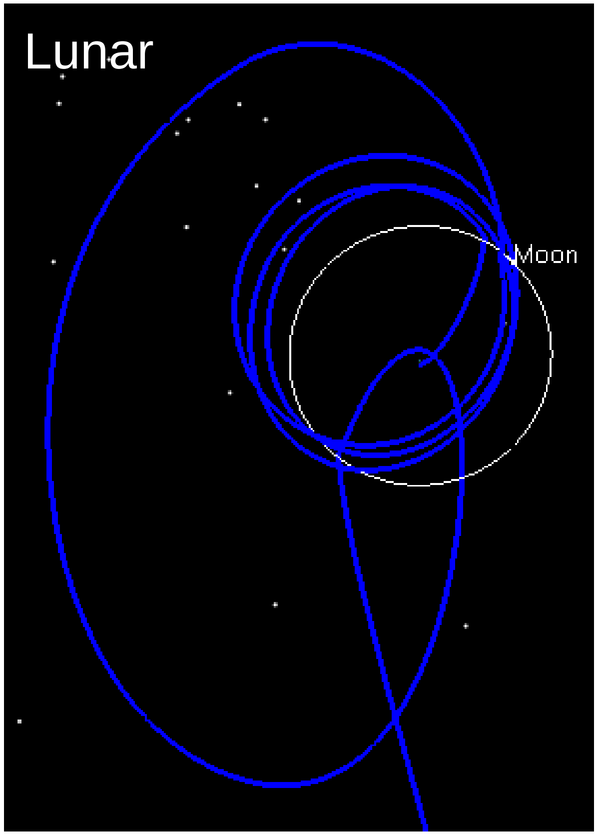
- Based on the LCROSS architecture
  - Assumed improved thrusters ($I_{sp}$ of 315)
- Looked at primary launches to:
  - Geostationary transfer orbit (launch with a commercial or military payload)
  - Trans-lunar trajectory (launch with a NASA payload)
- Two trajectory segments
  - GTO/TLI to Escape
  - Interplanetary
- Segments patched together
  - Segments boundaries do not match
  - $\Delta V$ may be higher due to mismatch
  - Additional lunar gravity assists may be necessary to match the required escape asymptotic right ascension

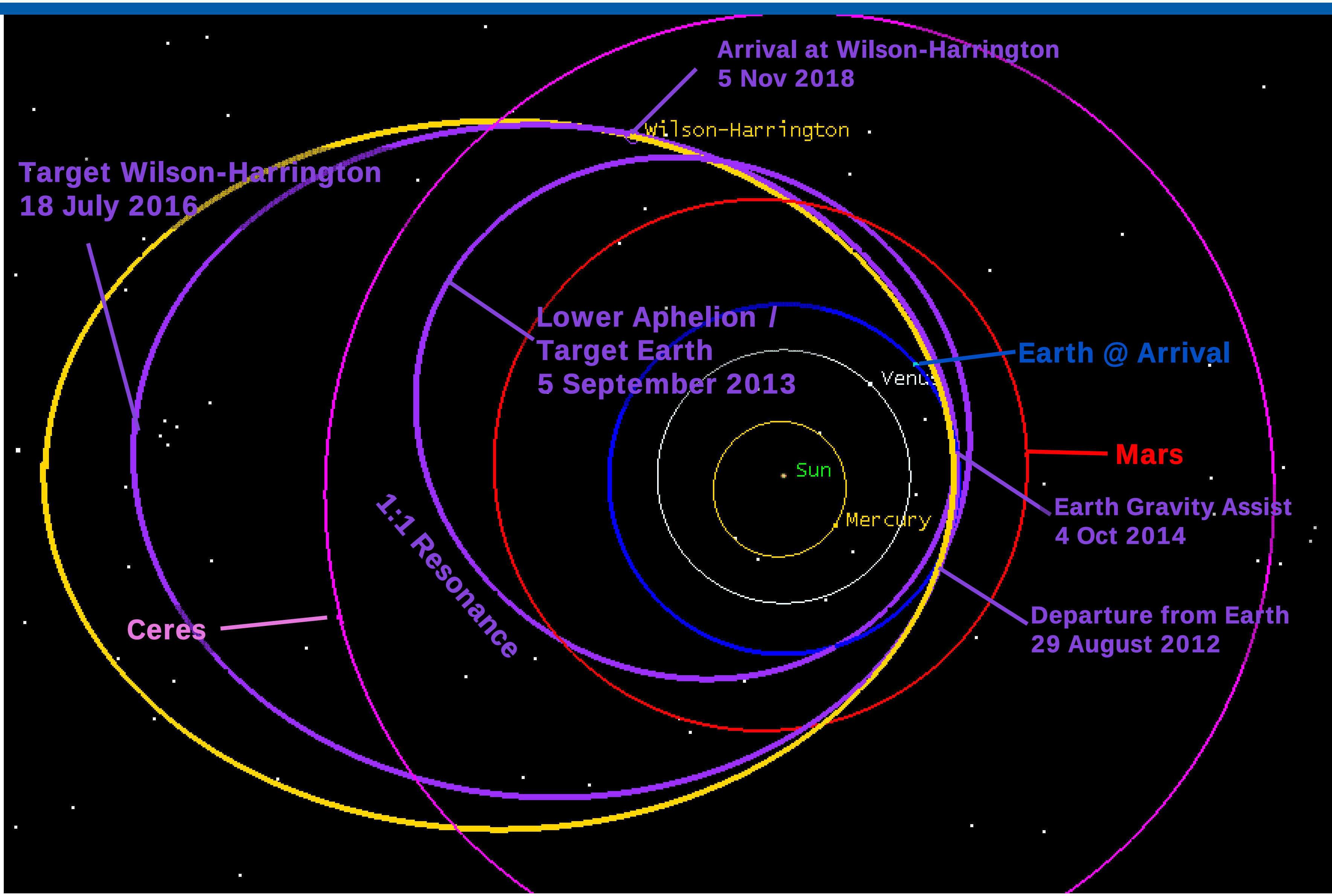
# Candidate Primary Mission Types and Secondary Asteroid Trajectories

- GEO - Uses onboard propulsion to escape via lunar gravity assist
- Lunar - Uses lunar gravity assist to escape via lunar gravity assist
- L1/L2 - Uses onboard propulsion and gravity assist to escape
- Planetary - Uses onboard propulsion to make slight changes to trajectory to reach nearby asteroids



# Secondary Mission: GTO to Wilson-Harrington in 6.6 years (Interplanetary Segment)



# Secondary payload mission concept to 4015 Wilson-Harrington

| Type of Launch | Delta-V (km/sec) | Wet Mass (kg) | Dry Mass (kg) | Cruise Duration (yr) |
|---|---|---|---|---|
| GTO | 4.0 | 3365 | 778 | 6.6 |
| Trans-Lunar | 3.6 | 2788 | 778 | 6.4 |

Necessary changes to the LCROSS architecture

- Propulsion
  - Equivalent of ~ 4 TDRS tanks
  - Pressurant tank and pressure regulator
    - May be traded for blow down system
  - Biprop, higher thrust engine
- Comm
  - Larger antenna/higher power might be needed due to larger distance (up to ~5 AU)
- Power
  - Additional solar panels due to larger aphelion (up to 4.2 AU)
- Structure
  - Adequate for loads. May need additional mounting surface for tanks
  - May affect CG of launch stack
  - Might be large enough to affect primary payload
- Thermal
  - Thermal environment different from LCROSS
- Longer lifetime
  - Higher redundancy

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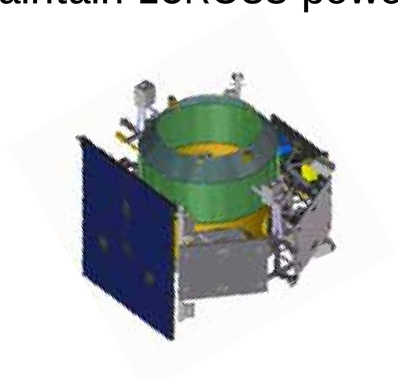
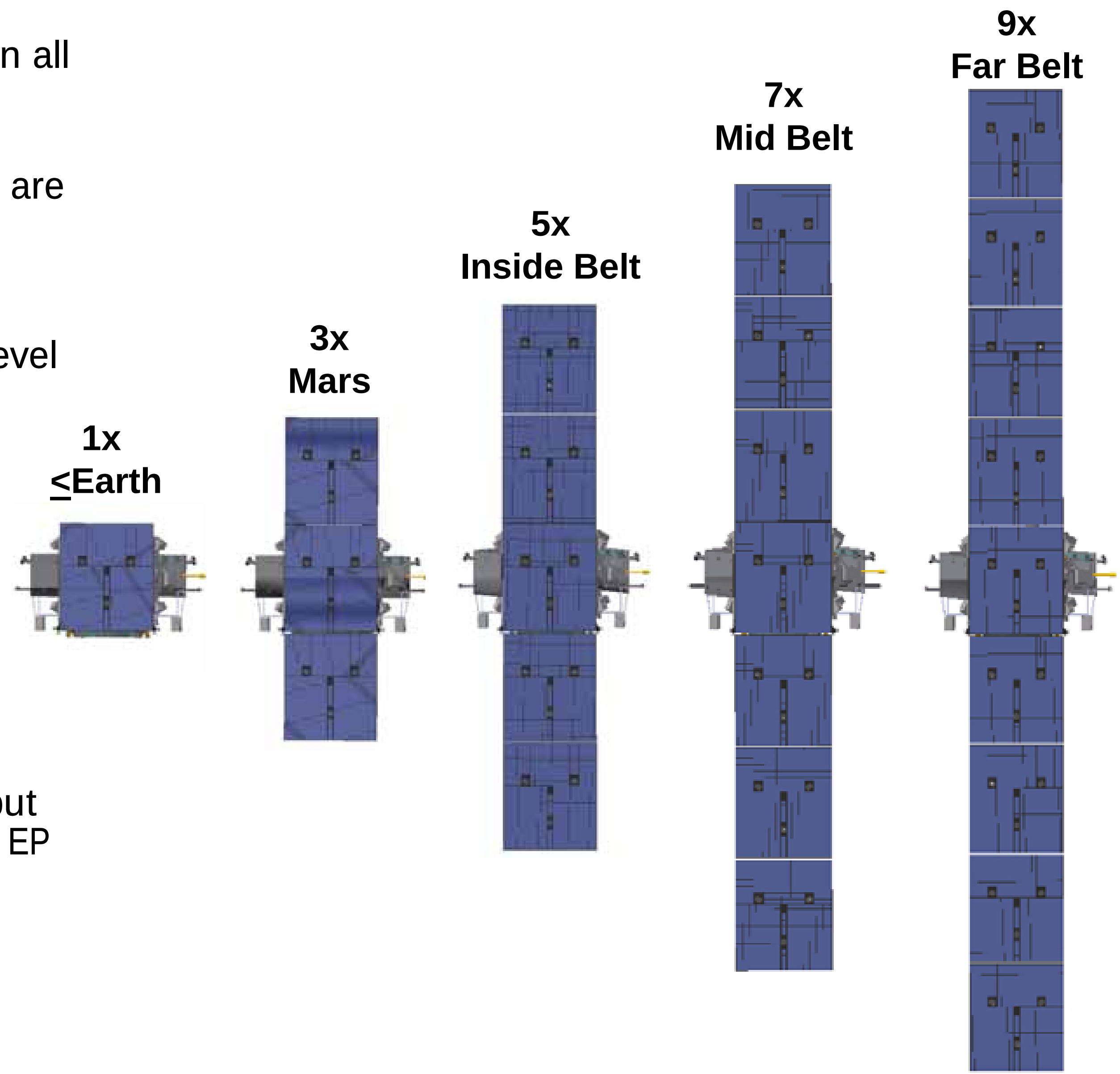
# LCROSS Derivative Power Capability

# Derivative Solar Array Configurations

- LCROSS solar array used in all configurations
- LCROSS Cell: EMCORE InGap/GaAs/Ge 26% cells are upgraded to 29% cells by screening
- Primary objective is to maintain LCROSS power level






- When not at maximum distance from the Sun additional solar array output can be used by the 1.8kw EP thruster

# Scaling of LCROSS Panels Required By Distance from Sun Trade Space

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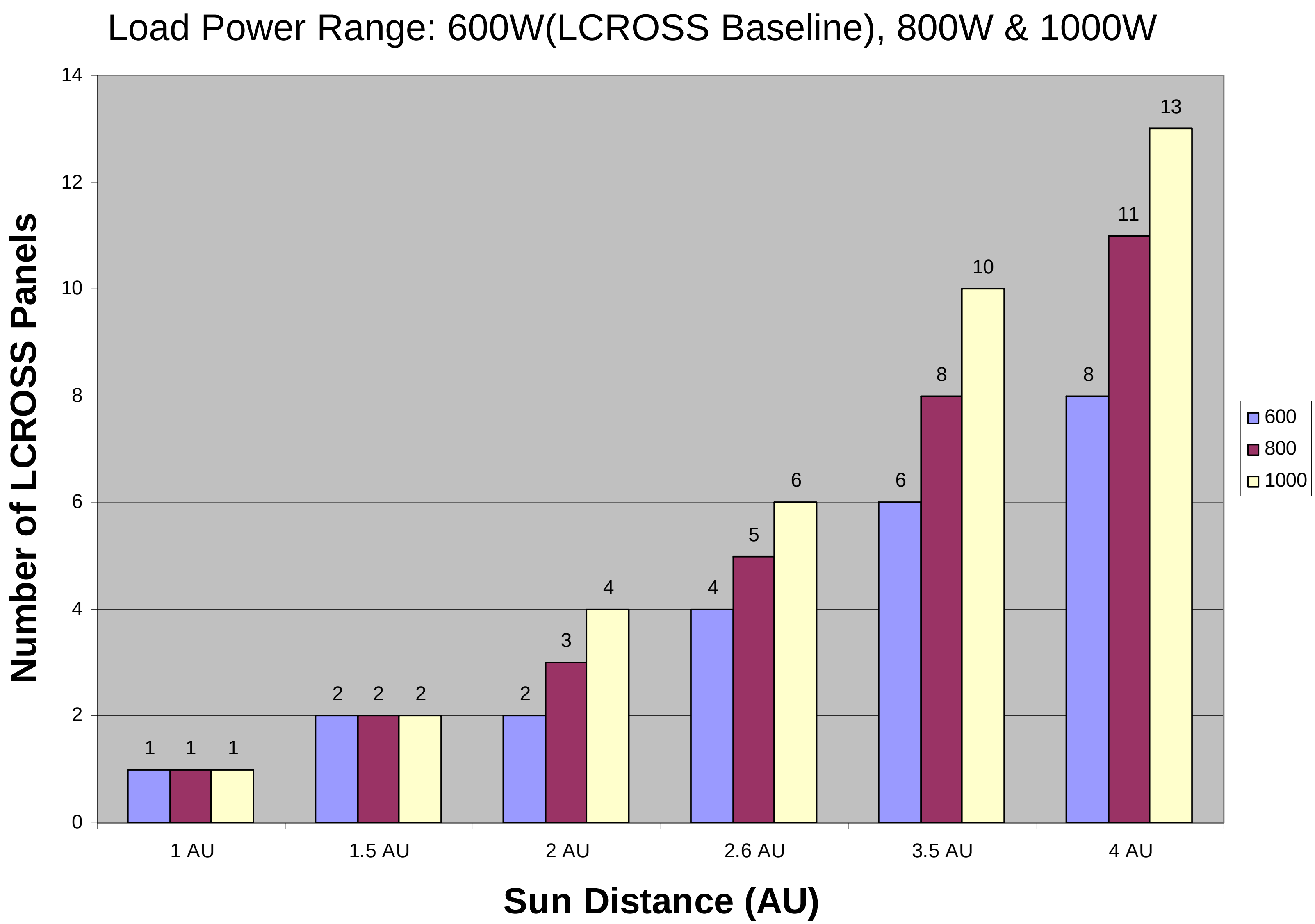

# ASRG Option Planned for Discovery

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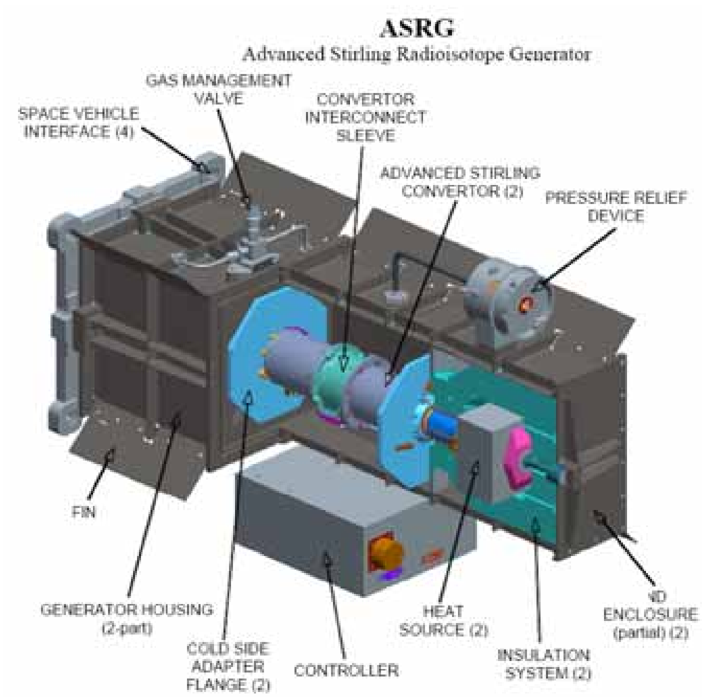


| **Parameter** | **ASRG – 650 C** |
|---|---|
| Technology | Stirling Convertor (650°C) |
| Power per Unit (BOL), [We] | 143 |
| Power Degradation Rate, [%/yr] | ~ 0.8 (power decays roughly with fuel decay) |
| Mass per Unit, [kg] | ~ 20.2* |
| Dimensions [mm] | Length: 762 mm ; Width: 394 mm ; Height: 457 mm |
| Radiation Tolerance (RDF=1) | 126 krad** |
| Additional Shielding, [kg] | Mission Specific, required only for controller if left attached to generator housing in a high-radiation environment** |
| Number of GPHS Modules per Unit | 2 |
| Thermal Power (BOL), [Wt] | 500 |
| Unit Specific Power (BOL), [We/kg] | 7.0 |
| Conversion Efficiency | ~ 28 % |
| Redundancy*  Sunpower Advanced Stirling Convertor (2 per Generator) | Single-fault tolerant, with N+1 redundant controller cards and the capability for the engines to operate independently of one another in the event of single engine failure. Initial reliability estimate ranges from 0.937 to 0.991 at 17 yrs, depending on conservatism of assumptions. (Further redundancy at the generator level should be left to mission analysts.)*** |
| Operating Environment | Vacuum and Atmosphere |
| Lifetime requirement, [years] | 14 + 3 (storage) |
| Current Technology Readiness Level (TRL) | 5**** |

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# LCROSS Derivative Propulsion Capability

# Propulsion Schematic, Integration Diagram

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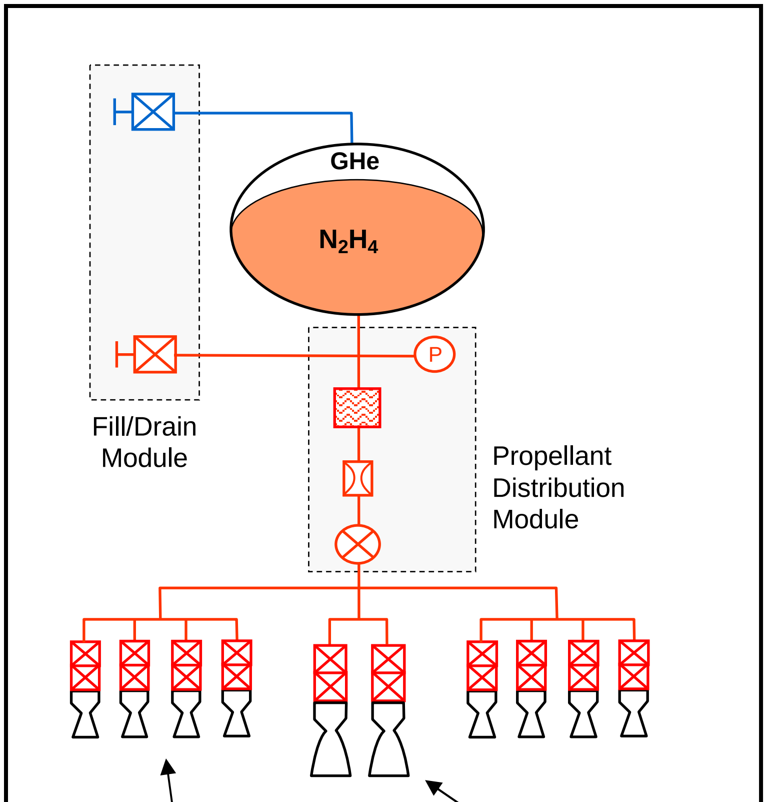
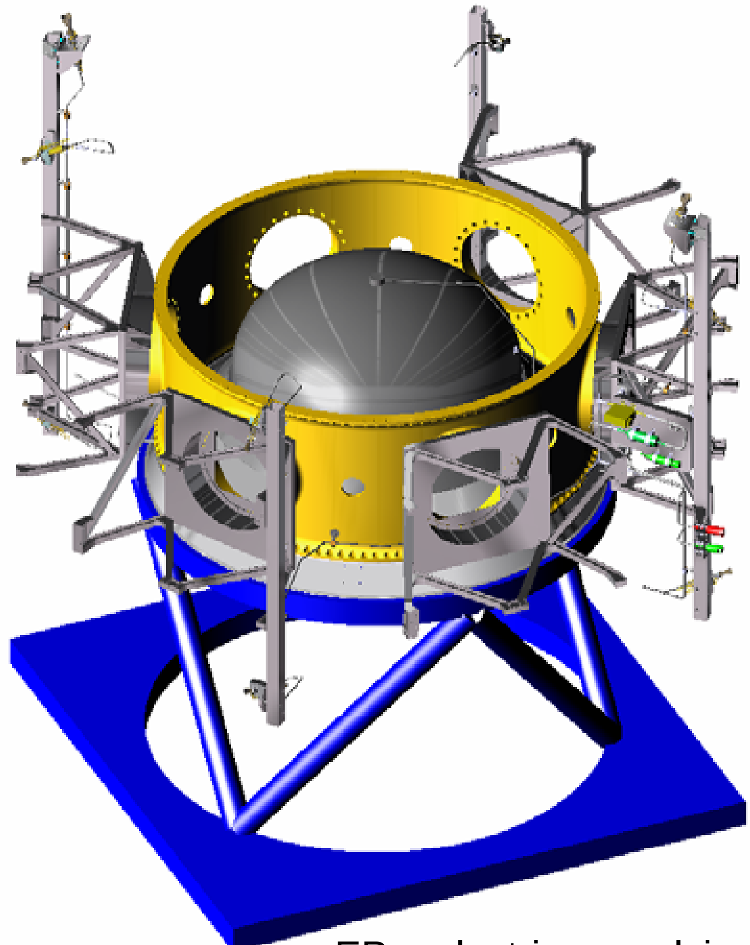



8 x 4N ACS thrusters

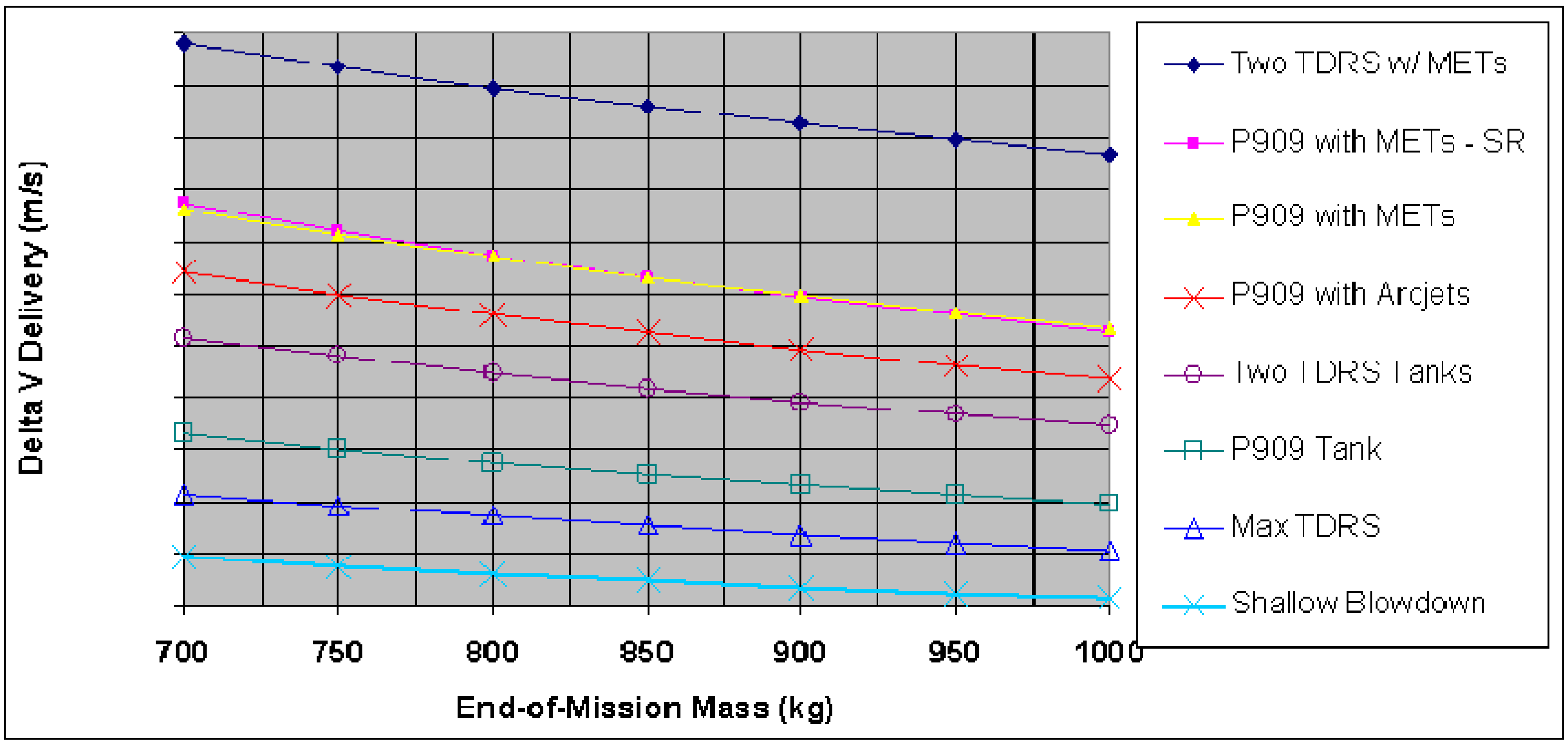
2 x 4N for shallow blowdown system Freeflyer; 2 x 20N for Impactor; with addition of 2 monopropellant Arcjets or METs for EP missions (Hydrazine not Xenon)



EP = electric propulsion
MET = microwave electrothermal thruster

# Delta V Capability vs End-of-Mission Mass

- End-of-mission mass = 613 kg (LCROSS predict) + Prop ME + EPS ME + Com ME + DMS ME + Thermal ME + Structure ME + Payload + Dry Mass Margin
- EP options assume first 67% of delta V delivery via EP except for sample return (SR) at 33% EP, then 33% chem, then 33% EP




ME = mission enhancements needed to achieve particular mission

# TacSat-2: 200 W Heterodyne Electric Thruster (HET) Propulsion System

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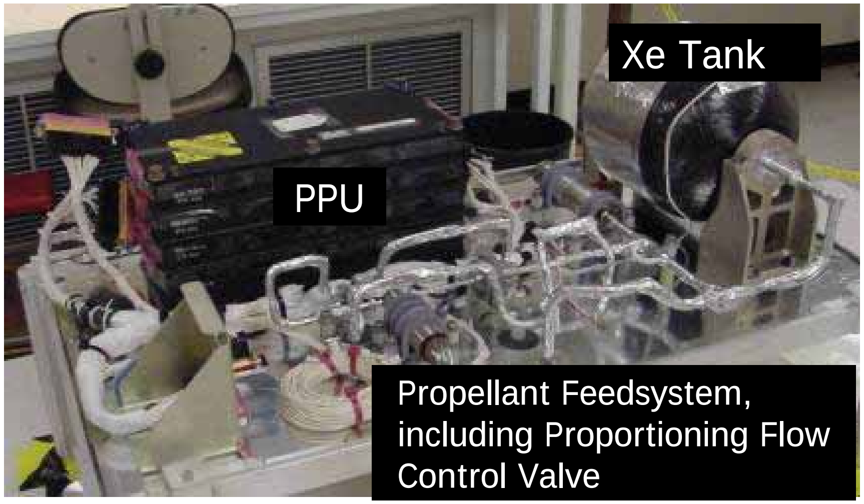
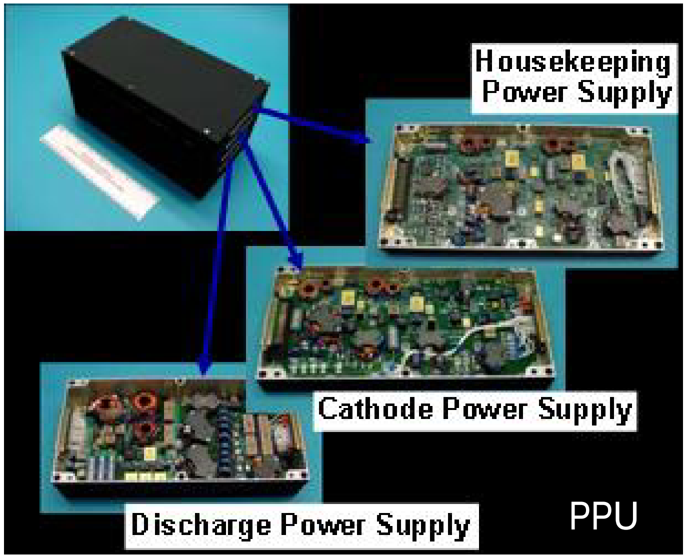
- 200 Watt HET system and sensor suite
  - Flight hardware delivered May 05 for spacecraft I&T
  - 1600 + hours of life test prior to launcg with no HET performance change
  - Minotaur 1 launch from Wallops Island
  - First flight of USA build Hall Effects thruster
- NGST was responsible for:
  - Propulsion system engineering, integration & test
  - Power Processing Unit (PPU) development (including Digital Control Interface Unit)


**200 W Xenon HET**



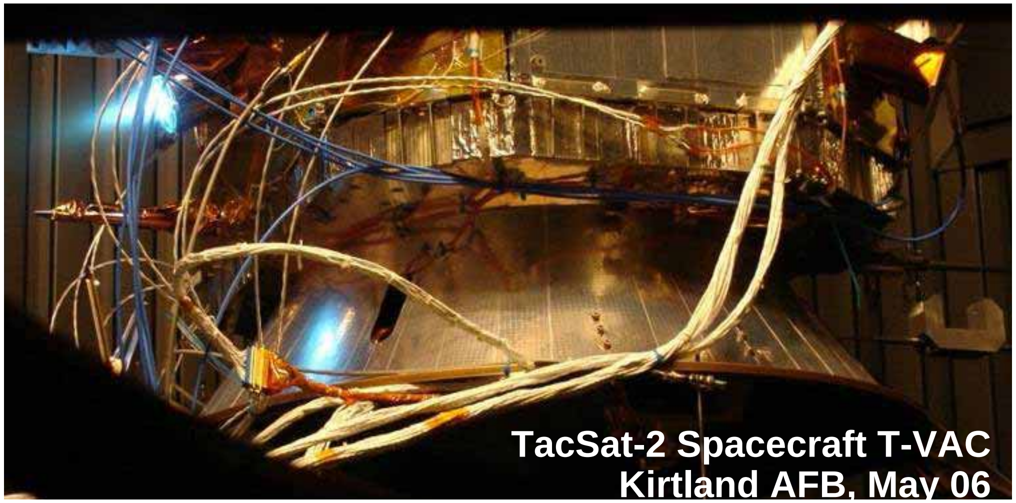

***Innovation: low power (SOA ~2kW), pulsing (SOA steady state) HET for SmallSats and Formation Flying Operation***

# TacSat-2: 200W HET Propulsion System


Technical Requirements

- Delta-V: 200 m/s minimum for 200 kg spacecraft
- Six month operational lifetime, with a 12 month goal (surpassed)
- Minimum Impulse Bit of 22 mN-s, with a goal of 5 mN-s
- Mass not to exceed 14 kg
  - HET, PPU, tank, propellant feedsystem, and ~ 1 kg of Xenon



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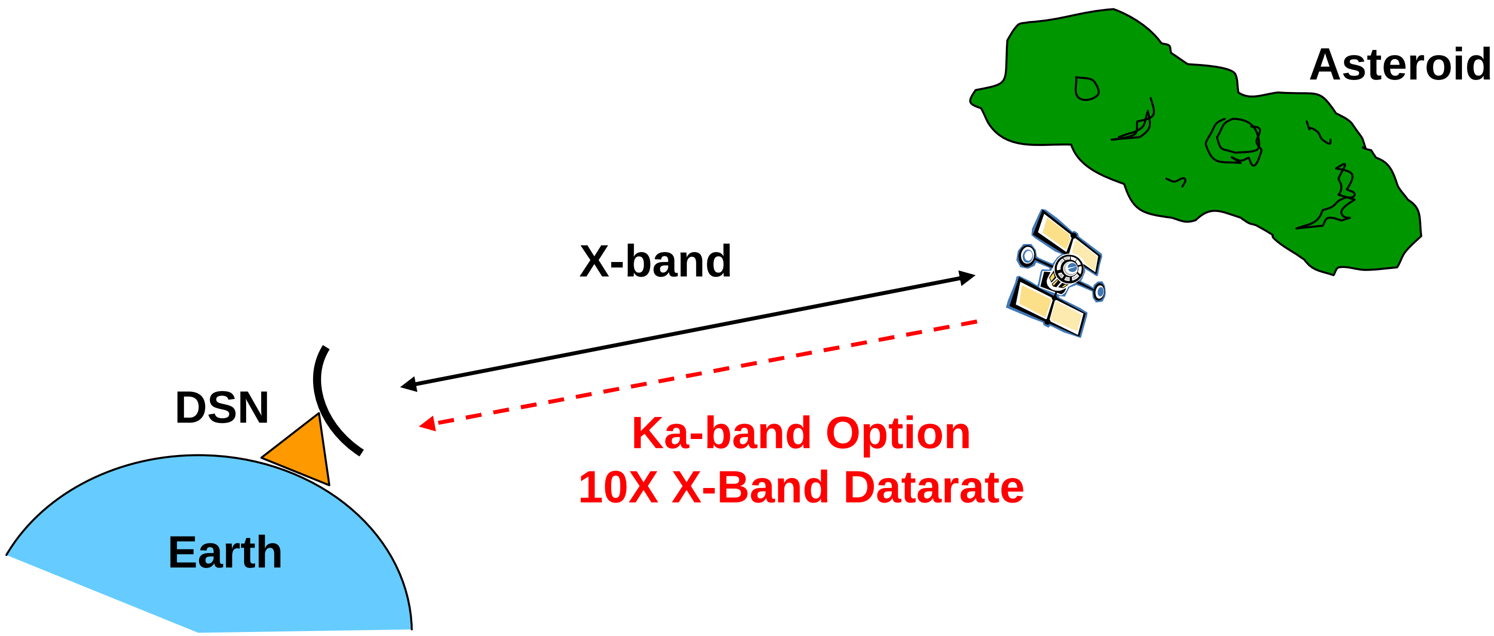
# LCROSS Derivative Communication Capability

# Comm Ground Rules & Assumptions

- Change LCROSS S-band baseline to X-band
  - Maintain Single-String Design
  - An additional Ka-band optional downlink to increase data rates would add weight, power, and cost
- Earth-to-Spacecraft distances:  0.5 – 4.5 AU (Deep Space)
- Baseline DSN 34m Stations for routine Communications; 70m Stations for critical events (flybys, impacts, emergencies, etc.)



# Downlink Data Rate Summary

| | Earth Range | | | |
|---|---|---|---|---|
| Comm Configuration | 0.5 AU | 1.0 AU | 2.0 AU | 4.0 AU |
| X-Band 10 Watt, 0.6 m dish w/1.5 deg pointing | 10/25 kbps | 2.5/6.2 kbps | 625/1562 bps | 160/400 bps |
| X-Band 25 Watt, 0.6 m dish w/1.5 deg pointing | 40/100kbps | 10/25 kbps | 2.5/6.2 kbps | 625/1562 bps |
| X-Band 100 Watt, 1 m dish w/1 deg pointing | 100/400 kbps | 25/100 kbps | 6.25/25 kbps | 1.6/6.2 kbps |
| X-Band 100 Watt 1.7 m dish w/0.5 deg pointing | 1/4 Mbps | .25/1 Mbps | 62.5/250 kbps | 16/62.5 kbps |

**Data rates are given for 34m / 70m DSN Stations**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Primary Mission Capability

# Primary mission concepts: 4015 Wilson-Harrington

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- Looked at two launch vehicles
  - Atlas V 401 (potentially better for Discovery-class missions)
  - Atlas V 551 (for New Frontiers-class missions)
- Two different launch scenarios
  - C3 of 69 $km^2/sec^2$: shorter duration, but smaller mass
  - C3 of 28 $km^2/sec^2$: longer duration, larger mass
- Orbiter/Lander mission trajectories are the same as sample return except for the burn back to Earth

| Mission Type | Launch C3 (km2/s2) | Atlas V | Duration (year) | $\Delta$V (m/s) | Wet Mass (kg) | Dry Mass (kg) |
|---|---|---|---|---|---|---|
| Orbiter/Lander | 69.1 | 401 | 4.09 | 1714 | 545 | 297 |
| Orbiter/Lander | 69.1 | 551 | 4.09 | 1714 | 1630 | 889 |
| Sample Return | 69.1 | 551 | 8.06 | 2356 | 1630 | 707 |
| Orbiter/Lander | 28.0 | 401 | 6.19 | 1772 | 1940 | 1039 |
| Orbiter/Lander | 28.0 | 551 | 6.19 | 1772 | 3820 | 2045 |
| Sample Return | 28.0 | 401 | 10.16 | 2414 | 1940 | 825 |
| Sample Return | 28.0 | 551 | 10.16 | 2414 | 3820 | 1625 |

Note: DAWN = 745 kg dry

# 4.1 Years to Wilson-Harrington ($C3 = 69\ km^2/s^2$)

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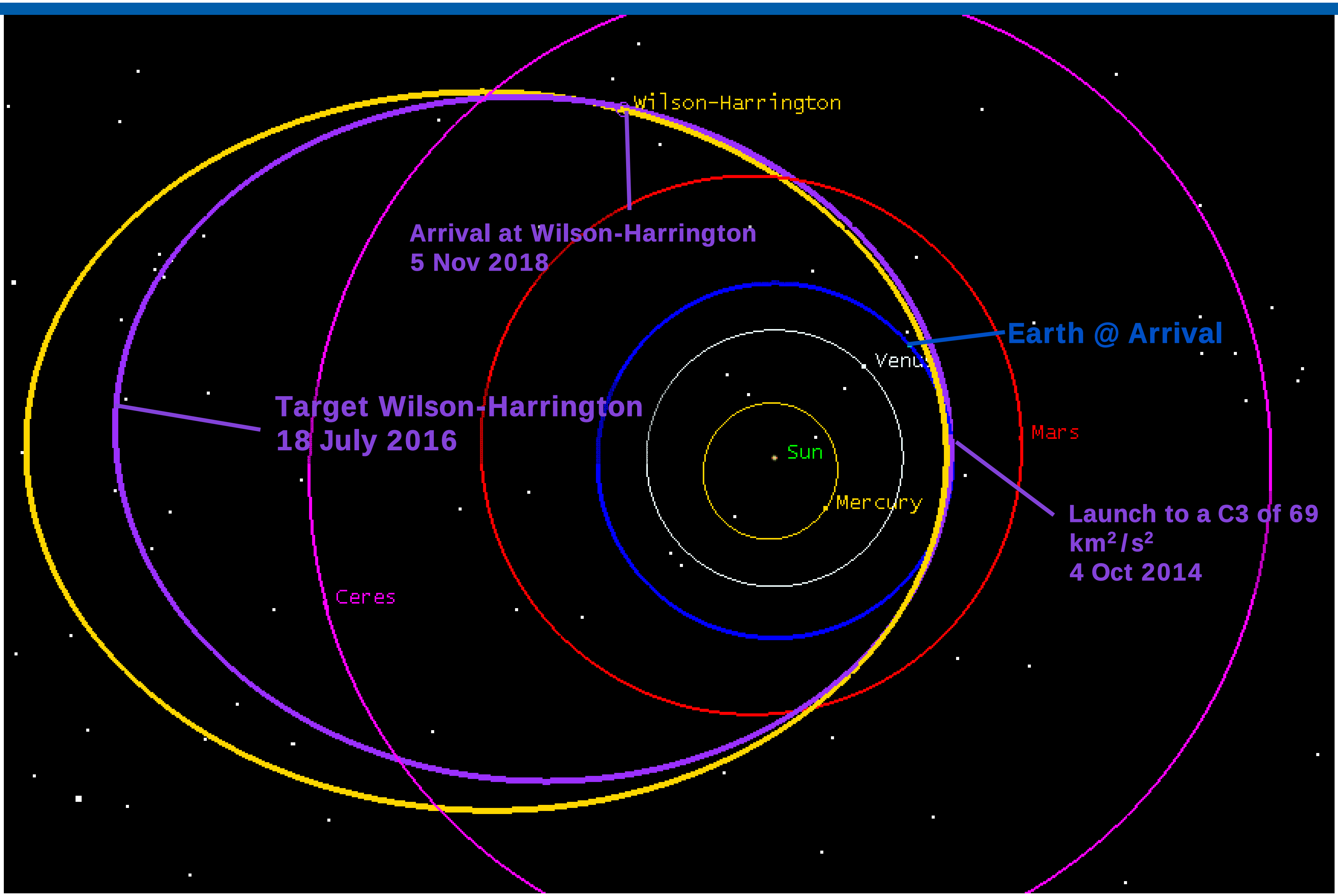

# 10.2 Year Sample Return (C3 = 28 km$^2$/s$^2$)

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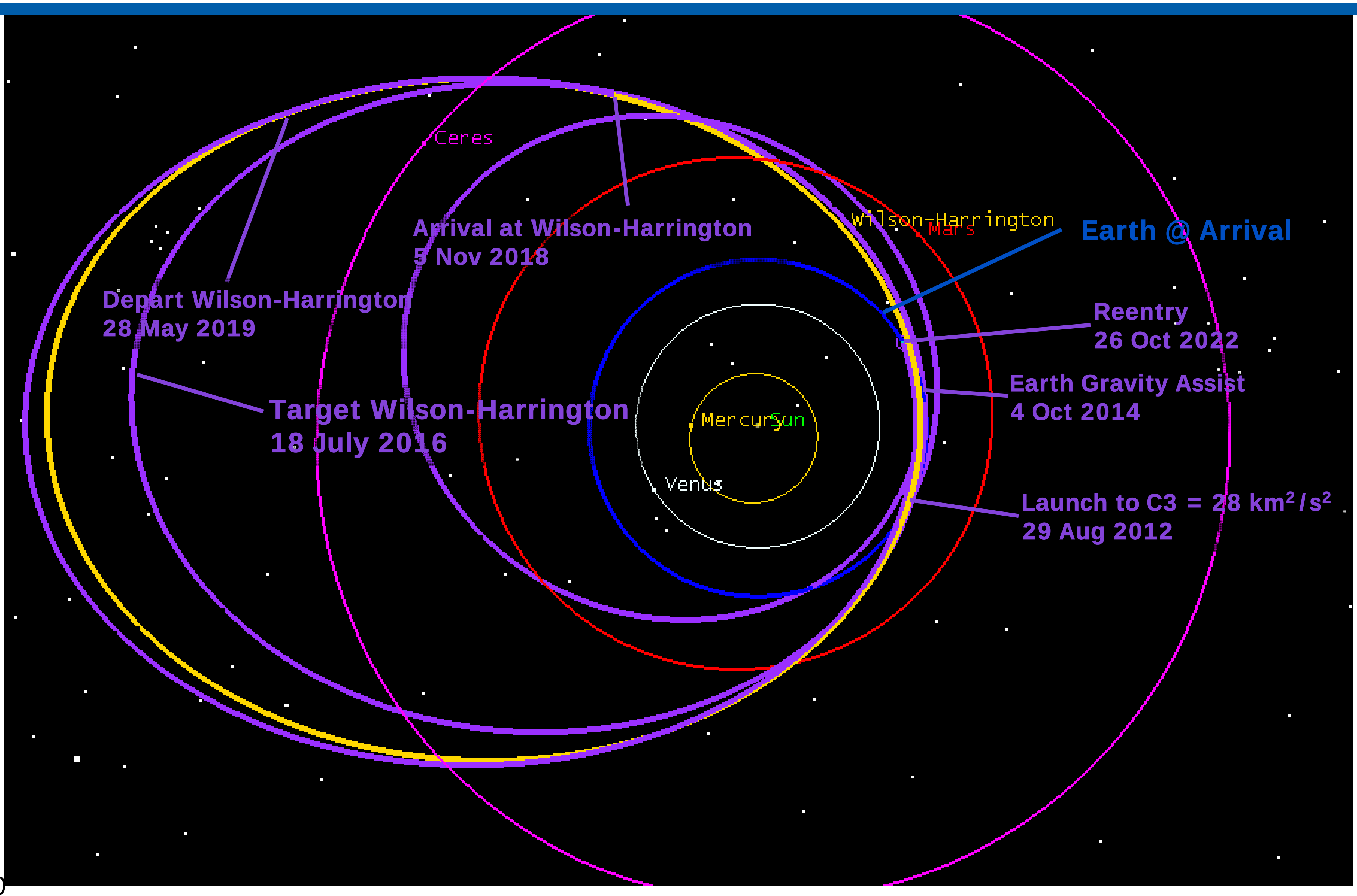

# Candidate Missions to Elst-Pizarro

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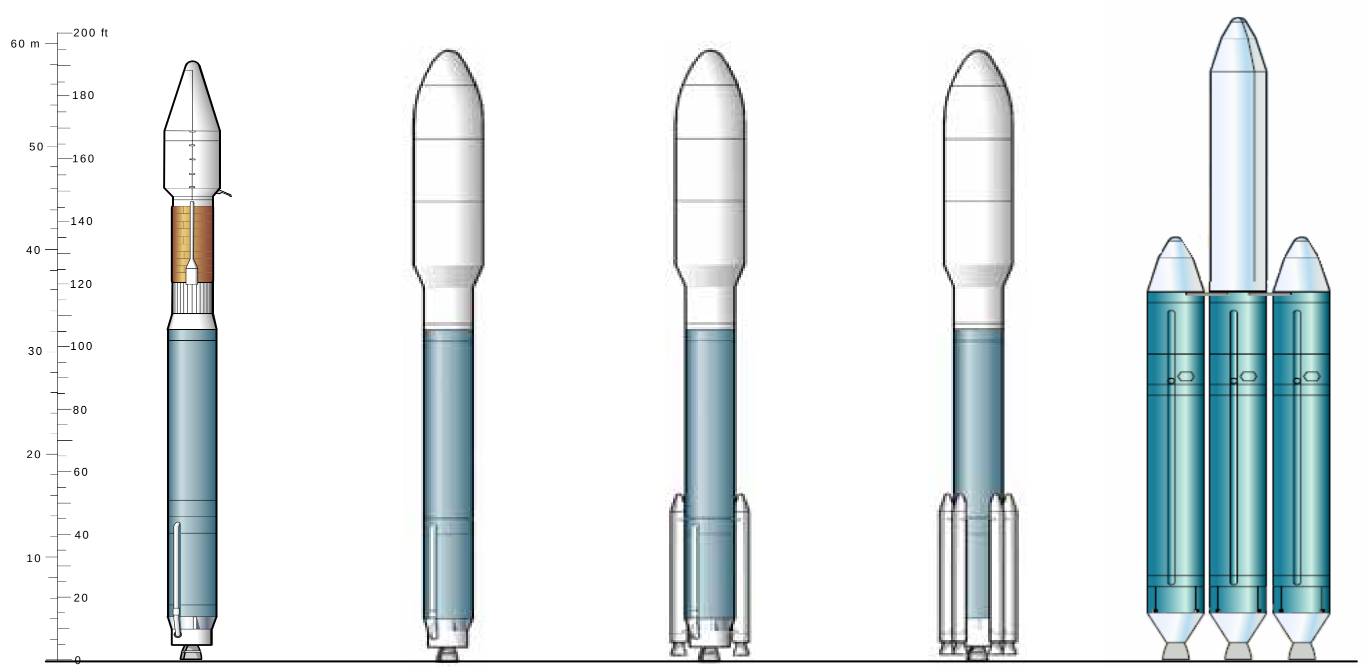
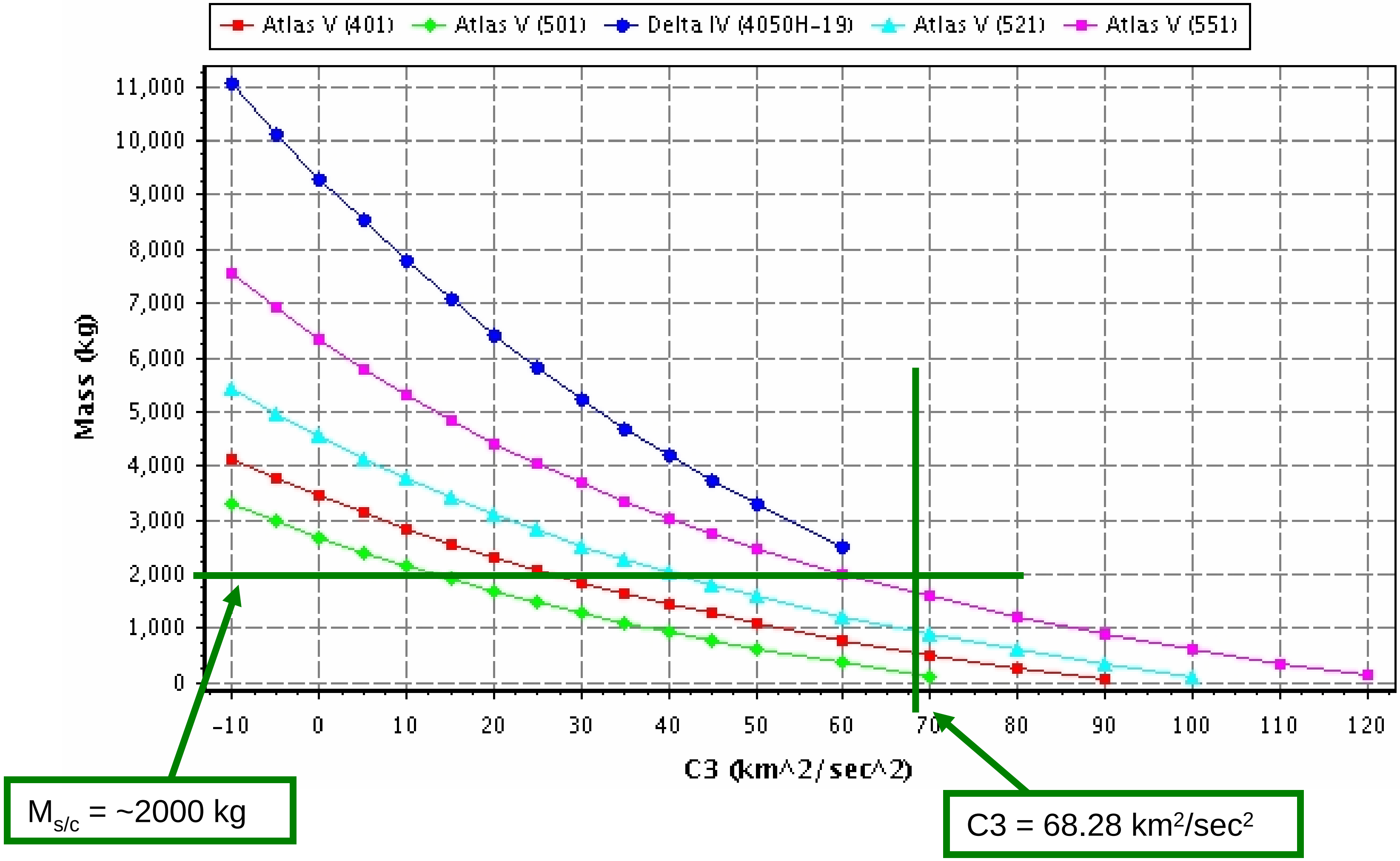
- High $C_3 > 60\ km^2/sec^2$



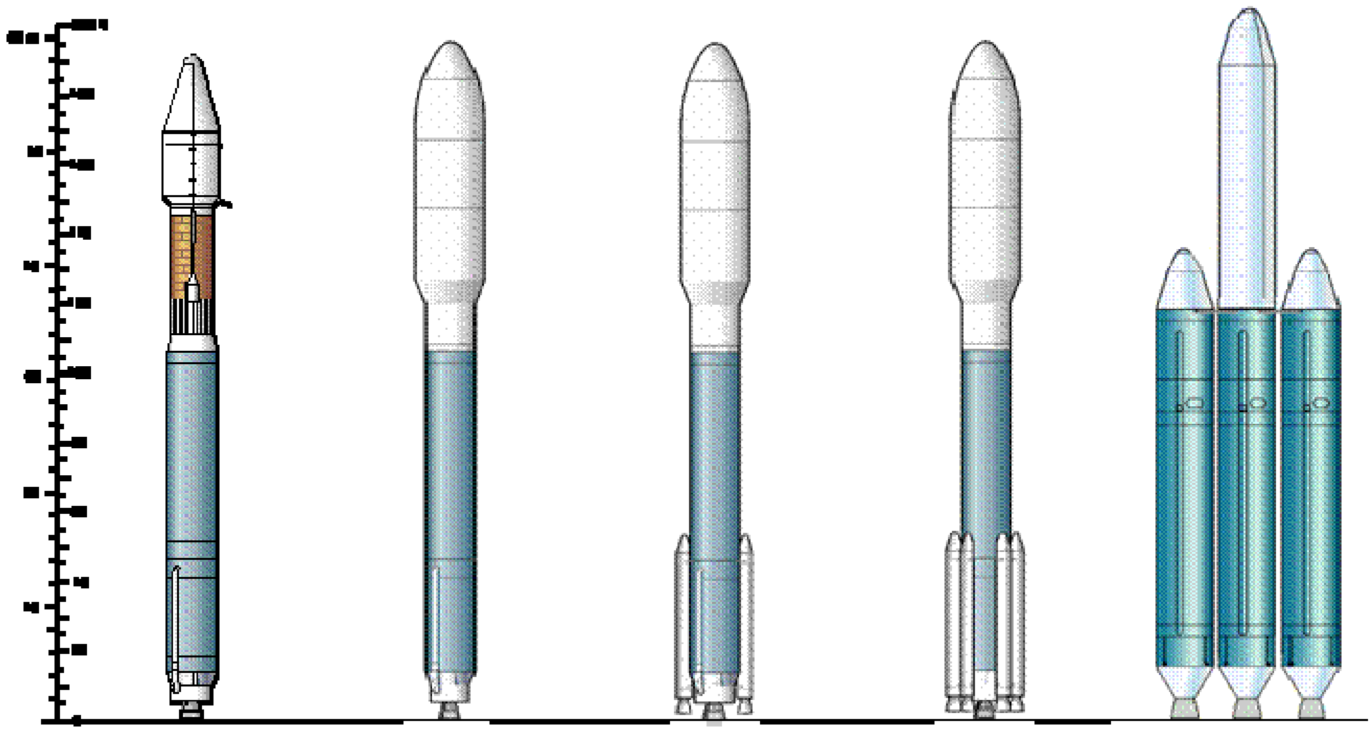

| | Atlas 401 | Atlas 501 | Atlas 521 | Atlas 551 | Delta IV Heavy |
|---|---|---|---|---|---|
| Throw weight (kg) | 550 | 250 | 980 | 1650 | ~2000 |
| Fairing Diameter (m) | 3.75 | 4.572 | 4.572 | 4.572 | 4.572 |
| Faring Length (m) | 9.397 | 10.184 | 10.184 | 10.184 | 10.971 |

# Elst-Pizarro: C3 = 68.28 $km^2/sec^2$



# Mars Flyby

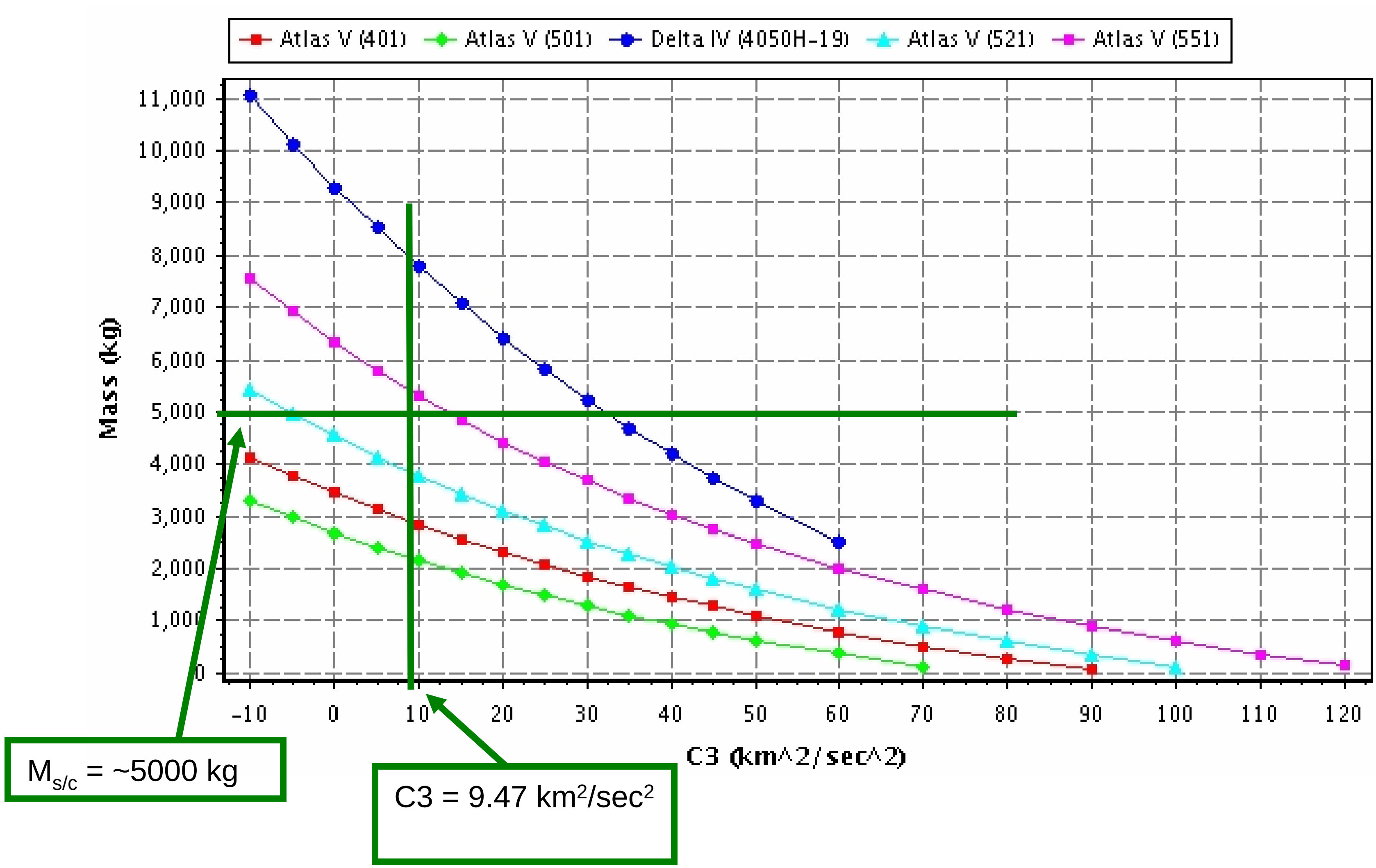
- Low $C_3 < 10\ km^2/sec^2$
- Requires Atlas 401 with 30% margin



| | Atlas 401 | Atlas 501 | Atlas 521 | Atlas 551 | Delta IV Heavy |
|---|---|---|---|---|---|
| Throw weight (kg) | 2900 | 2250 | 3800 | 5450 | 7950 |
| Fairing Diameter (m) | 3.75 | 4.572 | 4.572 | 4.572 | 4.572 |
| Faring Length (m) | 9.397 | 10.184 | 10.184 | 10.184 | 10.971 |

# Elst-Pizarro: C3 = 9.47 $km^2/sec^2$

(Mars fly by w/ 2nd stage solid motor)



# Chemical Thrust Can Relieve Power Pressures of 280W Limit of ASRG

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| | Characteristic of Option | Chemical Propulsive Option | Electric Propulsive Option |
|---|---|---|---|
| Descriptive | **Total ΔV (m/s)** | **2045** | **1543** |
| | **TCMs** | **60** | **60** |
| | **MOI + gravity loss** | **898** | **898** |
| | **Orbit adjust** | **180 periapsis raising**<br>**667 apoapsis lowering** | **50 walk-in/-out (estimated)**<br>**300 periapsis raising (from previous chart)** |
| | **Maintenance, Reserves, etc.** | **240** | **240** |
| | **S/C Dry Mass (kg)** | **1339** | **1339 (estimate as the same)** |
| | **Propellant Load (kg)** | **1385 (294s effective average $I_{sp}$)** | **949 (294s effective average $I_{sp}$)** |
| | **Propulsion System** | **Bi-prop, full-diameter tanks** | **Bi-prop, full-diameter tanks** |
| | **Launch Mass (kg)** | **2721** | **2288** |
| | **Launch Vehicle** | **Atlas V 411** | **Atlas V 401 – minimal cost savings over 411** |
| | **Spacecraft design** | • **Propulsion system sized by MOI** | • **Propulsion system still sized by MOI**<br>• **Thermal, aero-interaction NRE** |
| Evaluative | **Performance / Operations / Schedule** | • 1.5 months **from MOI to operational orbit**<br>• **Can support MSL EDL from an interim orbit, and rapidly support MSL surface ops**<br>• Option to get to operational orbit in ~10 days, prior to MSL EDL | • **Up to** 6 months **from MOI to operational orbit**<br>• **May pause aerobraking operations to support MSL EDL, but adds ΔV and time penalty** |
| | **Cost** | • More expensive LV<br>• Lower cost spacecraft | • Cheaper LV<br>• Higher cost spacecraft |
| | **Risk** | • Low: raise periapsis to 4450 km within 15 days of MOI, low-risk propulsion sys. | • Med-High: up to 6 months with periapsis ≤ 250 km, significant atmospheric interaction |

# Conclusions

Secondary Payloads

- Secondary payloads might be a viable way to design a low-cost Discovery class mission
  - A variety of targets are accessible to secondary payloads
  - Much lower launch costs
  - The first version already exists (LCROSS)
- Adaptation of the LCROSS architecture to future missions is relatively straightforward

Primary Payloads

- We have looked a number of potentially intriguing options
  - 1000 kg of dry mass delivered to 4015 Wilson-Harrington with an Atlas V 401
  - Sample return with an Atlas V 401?
- For missions to the outer asteroid belt, chemical propulsion might allow for ASRG power

These are only examples of locations we could go. Where would SBAG like to go?

# Backup Slides

# 6.2 Years to Wilson-Harrington ($C3 = 28\ km^2/s^2$)

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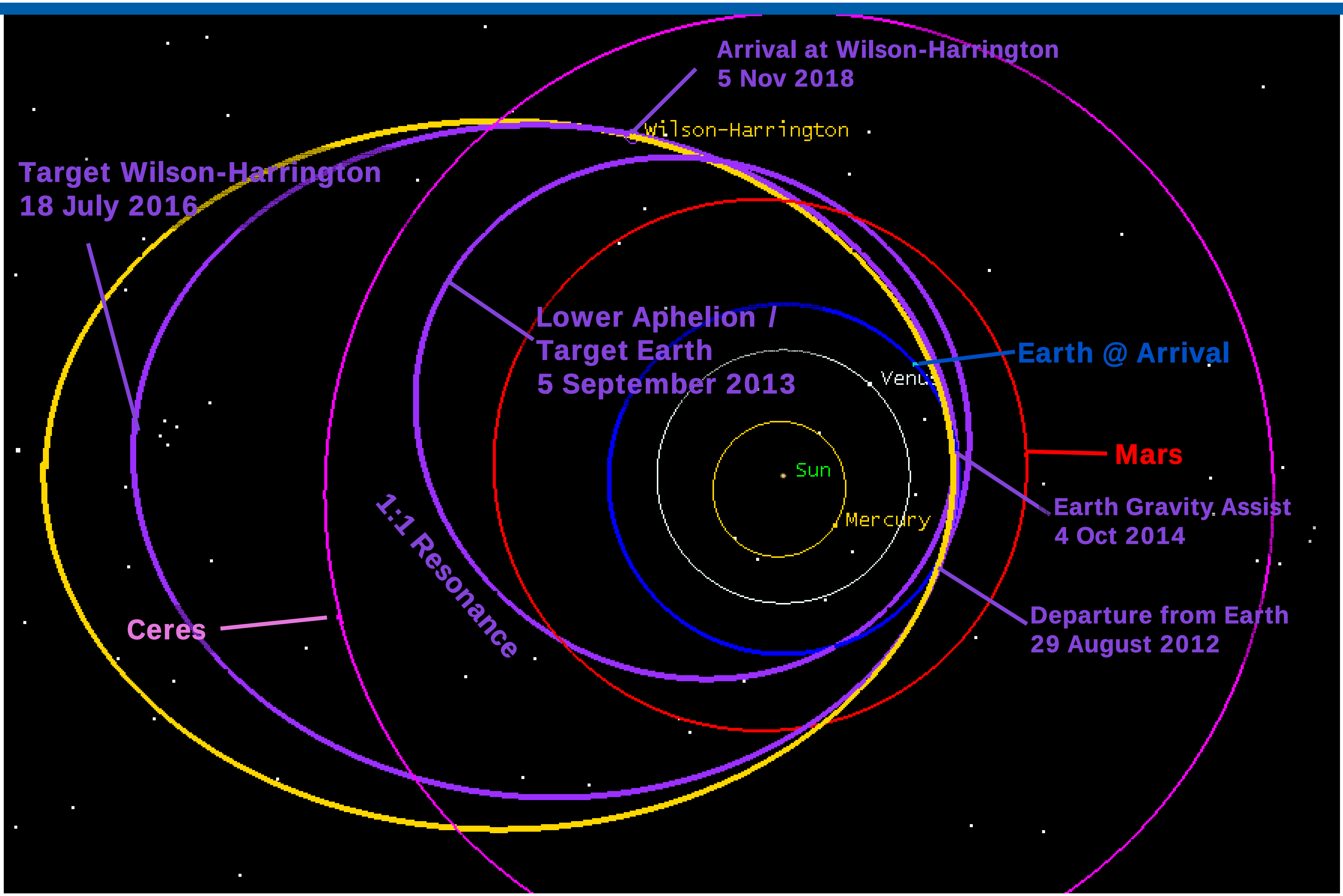

# 8.1 Year Sample Return (C3 = 69 km$^2$/s$^2$)

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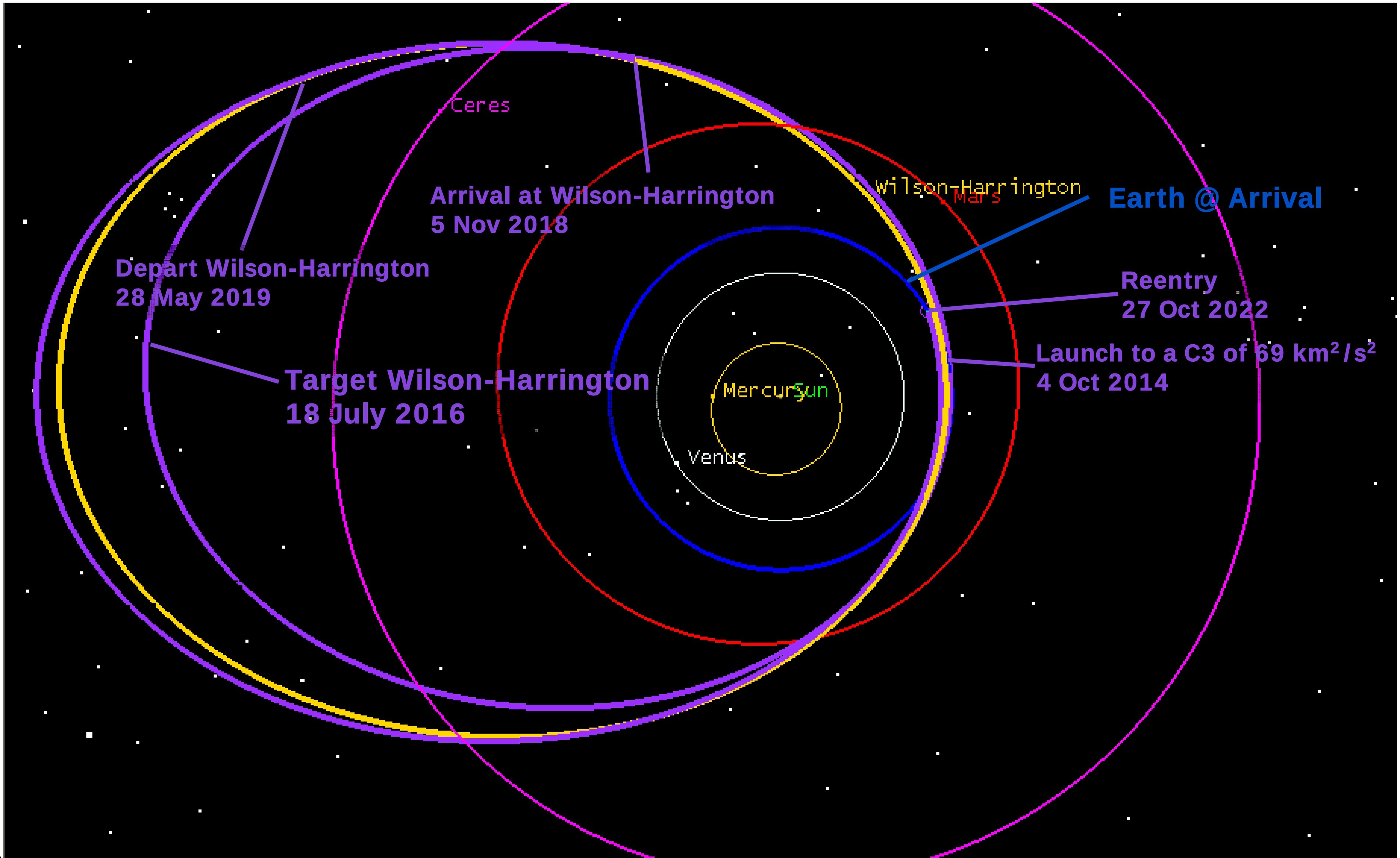
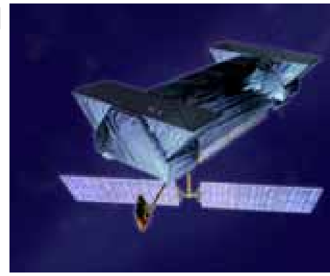


# Our MTO Design Incorporates Approaches and Technologies From NGST Programs

**EOS Aqua & Aura**
- High-capacity electrical power system
- Multi-unit cost savings

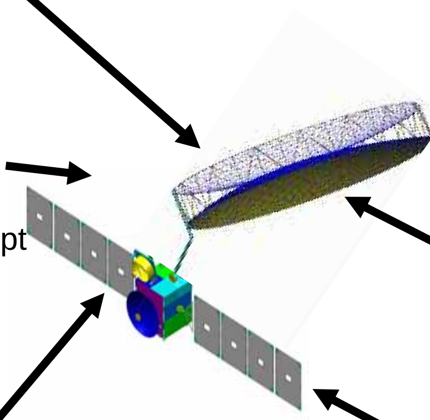
**TDRSS 1-7**
- Fixed trunk-line communications and pointing operations concept

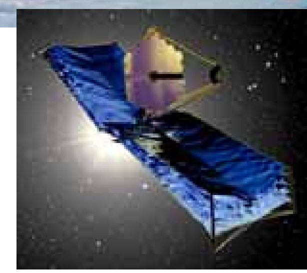
**GeoLITE**
- Mass-efficient structure
- Precision thermal control
- Breakaway panel payload accommodation
- Large delta-V bi-prop propulsion
- Proven optical comm accommodation
- Electromagnetic Compatibility accommodation



**SIM**

**NPOESS**





**JWST**

- High-rate data management
- Fault management

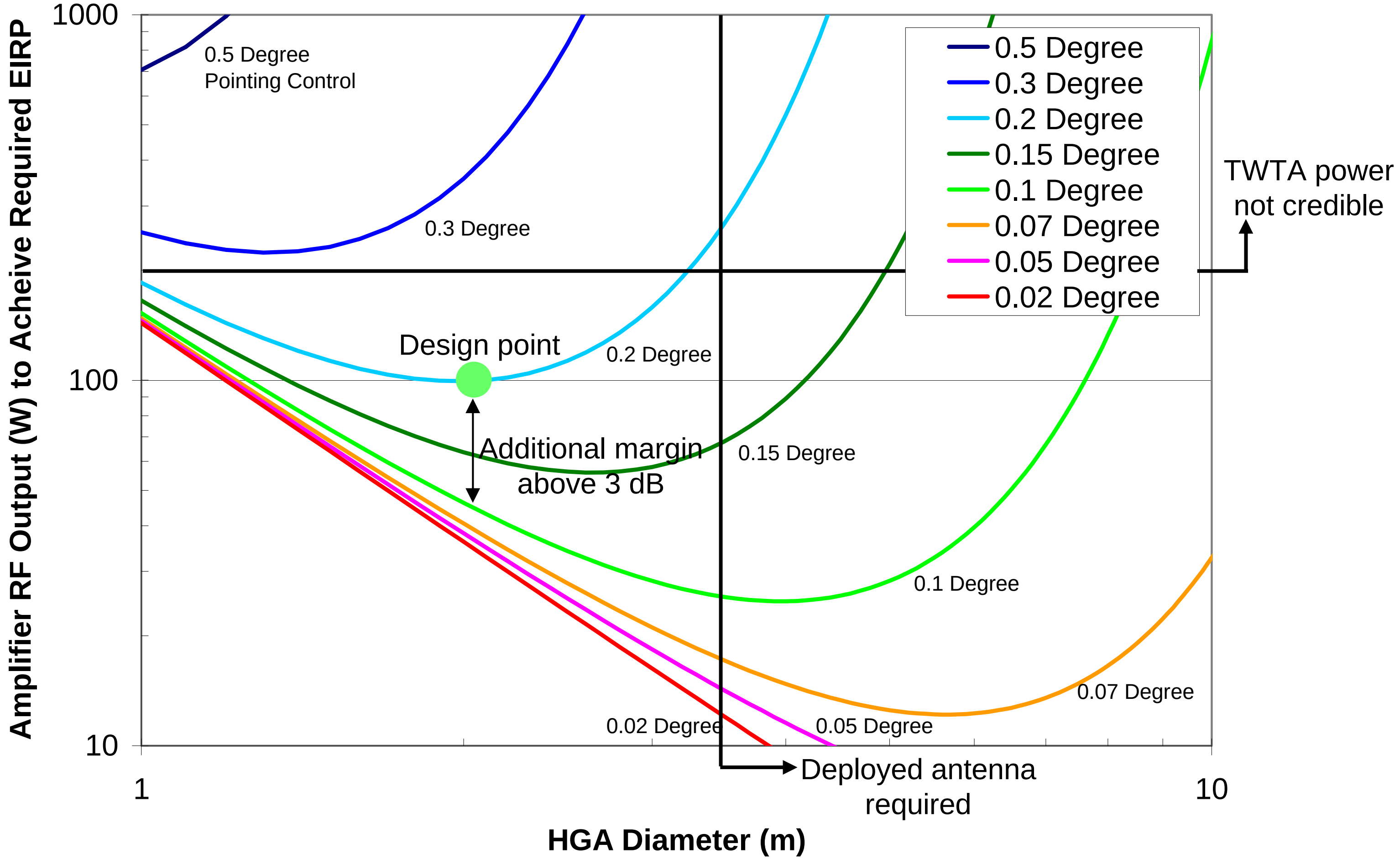
**Other**
- Ka-band rates of 20 Mbps from Jupiter
- telecom

**Chandra**
- High-thrust propulsion

Existing product

Development product

# Ka-band Power/Aperture & Antenna Trade

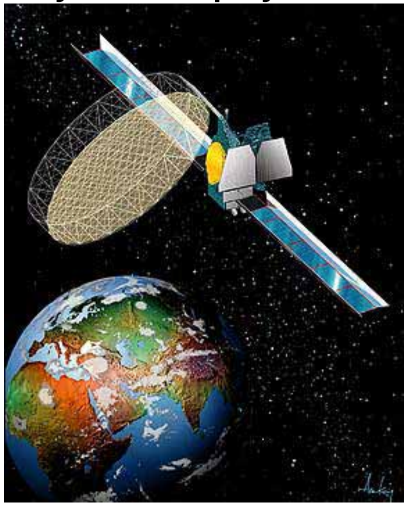


# NGST Has Long History of Space-Based Communications Systems Development

**TDRSS 1-7 Prime Contractor**

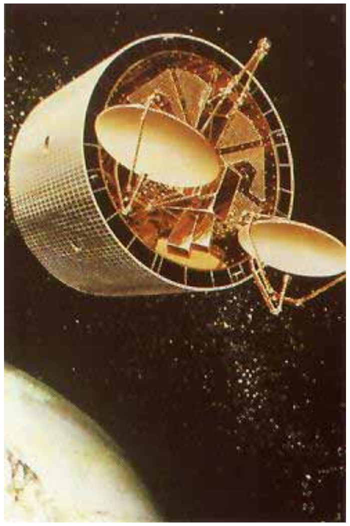
**Milstar Medium and Low Data Rate Payloads**

**Thuraya 12m Deployable HGA**



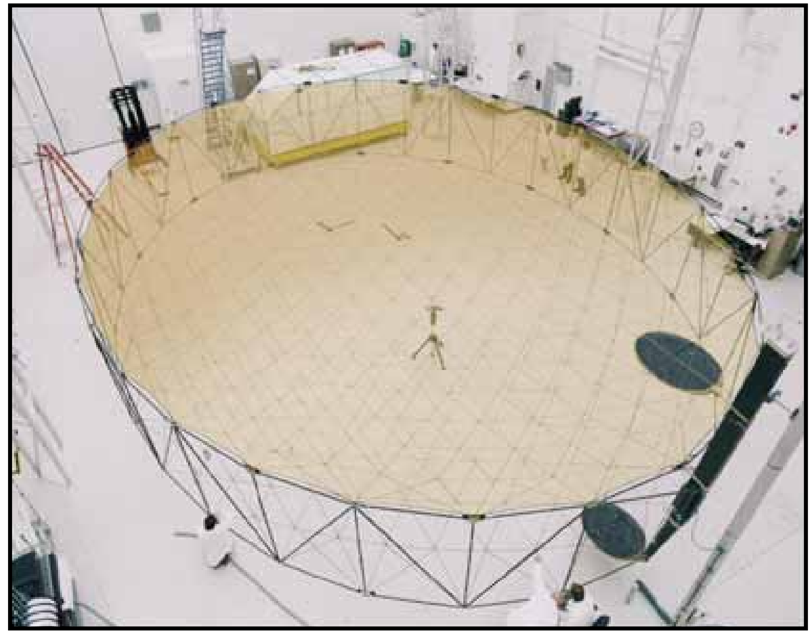
**FLTSATCOM Prime Contractor**

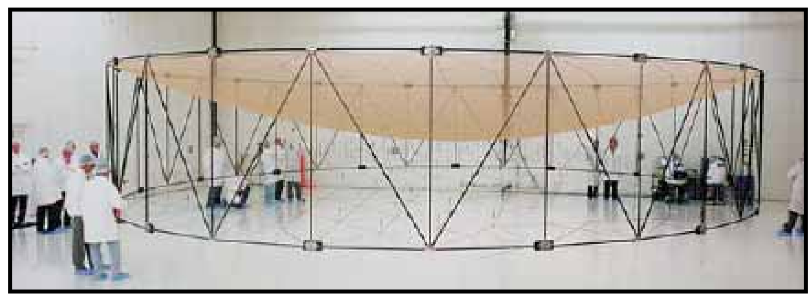
**DSCS-2 Prime Contractor**



# NG AstroMesh Reflector – TRL-9

NORTHROP GRUMMAN





**SPECIFICATIONS**

| Performance | 6-Meter | 12-Meter |
|---|---|---|
| Mass (Reflector only) | 32.0 lb (14.5 kg) | 125.7 lb (57.0 kg) |
| **Stowed Dimensions** | | |
| Diameter | 2.0 x 2.2 ft (0.60 x 0.66 m) | 3.0 x 3.7 ft (0.91 x 1.14 m) |
| Length | 5.05 ft (1.54 m) | 12.50 ft (3.81 m) |
| **Deployed Configuration** | | |
| Aperture | 18.05 ft (5.50 m) | 40.19 ft (12.25 m) |
| Center Offset | 12.3 ft (3.75 m) | 27.2 ft (8.30 m) |
| F/d | 0.64 | 0.45 |
| First Mode (Fixed Boom) | 2.00 Hz | 0.80 Hz |
| **Surface Accuracy** | | |
| **Total (RSS)** | 0.026 inch (0.62 mm) | 0.055 inch (1.40 mm) |
| Faceting (Geometric) (RMS) | 0.013 inch (0.33 mm) | 0.043 inch (1.10 mm) |
| Manufacturing (RMS) | 0.015 inch (0.38 mm) | 0.020 inch (0.50 mm) |
| Thermal (RMS) | 0.010 inch (0.25 mm) | 0.020 inch (0.05 mm) |

NORTHROP GRUMMAN

DEFINING THE FUTURE