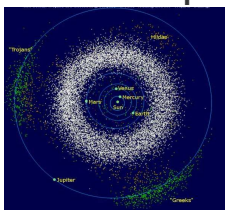
MARCHING TOWARDS TROY: EXPLORATION OF THE JUPITER TROJAN ASTEROIDS

PURDUE UNIVERSITY

S. J. Saikia[1], A. Das[1], F. Laipert[1], C. Dapkus[1], J. Kendall[2], T. Bowling[2], J. Steckloff[2], S. Holbert[1], K. Graves[2], T. Antony[1], R. Bobick[2], Y. Huang[2], J. Stuart[1], D. A. Minton[2], J. M. Longuski[1],

[1]School of Aeronautics and Astronautics, [2]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, Indiana 47907-2045, [1]sarag@purdue.edu.sarag@purdue.edu

What are Jupiter Trojans? Why should we explore them?



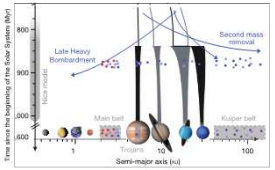
+ More than half a million objects larger than 1 km in diameter, called the Jupiter Trojans Asteroids
+ Librate about Jupiter's L4 and L5 Lagrange points
+ Potential source of insights into long standing questions on the origin and early history of the Solar System.

+ Very low albedos and great distance from the Sun have made ground-based observations very difficult
+ Two distinct subpopulations that are distinguishable in visible (redder) and near-infrared spectra (less red)
+ Spectral groupings not conclusively linked to physical characteristics or other observed parameters (e.g. albedo)

Formation Theories
1. Formation alongside Jupiter?
2. Interlopers from other parts of the solar system like the Kuiper Belt? – Nice Model - Chaotic Capture *(Morbidelli et al. 2005)* - Jupiter-Jump Capture *(Nesvorny et al. 2013)*

One of highest priority New Frontiers Class missions in the 2013 Planetary Science Decadal Survey

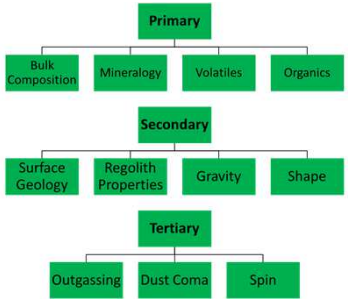
What we know about Trojans?



DeMeo and Carry (2014)

What We "Think" We Know	
Orbital Characteristics	a = Approx. 5 AU e < 0.3 i < 40°
Size	< 1km... >100km
Approx. Mean Collisional Velocity	5 km/s
Approx. Combined Mass	5.97×10^{20} kg
Systems	Binary/Non-Binary

Prioritization of Science Objectives



Prioritized according to the 2013 Planetary Science Decadal Survey

	Bulk Composition	Surface Composition	Surface Features	Regolith Properties	Gravity/ Shape	Outgassing	Dust Coma
Gamma/Neutron Ray Spectrometer							
Visible-Near IR Hyperspectral Imager							
Wide/Narrow Angle Camera							
Thermal Radiometer							
Laser Altimeter							
Ultraviolet Spectrometer							

Five instruments to achieve the science objectives

(a) surface mineralogical and elemental composition,
(b) interior structure,
(c) physical state of surface regolith: evidence and consequences of external modification processes

A New Frontiers Mission Concept: Science Drives Mission Design

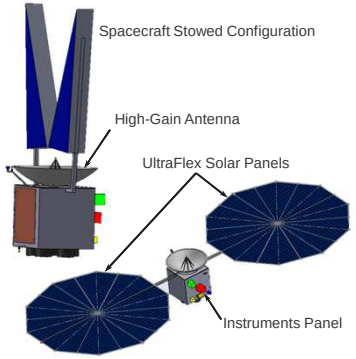
Mission that conducts science on two asteroid of different spectra

REDDER	LESS RED
Achilles	Diomedes
Hektor	Agapenor
Agamemnon	Deipylos
Neoptolemus	Kalchas
Teucer	Eurybates
Automedon	Amphilochos
Meriones	XO79

Mission Requirements

1. Rendezvous with two asteroids of different spectra
2. At least 6 months primary science mission at each target
3. Fulfill the science objectives highlighted in the 2013 Planetary Science Decadal Survey
4. Within cost constraints of New Frontiers mission class ($800 M in FY2015 $)
5. Use only solar power (no ASRG allowed)

The Mission is named "DUSK" as a tribute to the DAWN Mission

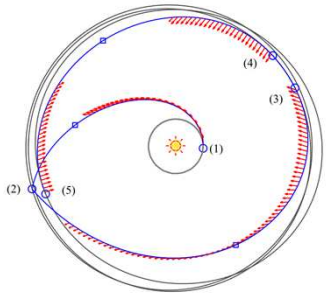


DUSK Spacecraft Details

DUSK is a 3-axis stabilized spacecraft	
S/C Bus	2x2x2 m
Thrusters	5 HiVHAc (Hall) Thrusters 0.3 – 3.9 kW, Xe Fuel = 2030 kg
Power	Solar (UltraFlex) 40kW
Dry Mass CBE/MEV	888 kg/ 1004 kg
Dry Mass Reserves	301 kg (30% of MEV)
Propellant CBE	1934 kg Xenon
Power	1.32 kW (at Trojan Distance)

INTERPLANETARY TRAJECTORY AND MISSION OPERATIONS

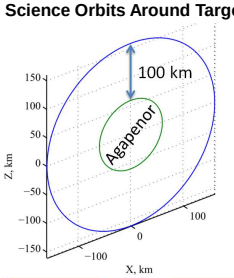
No orbit insertion maneuvers required at both Agapenor and Hektor

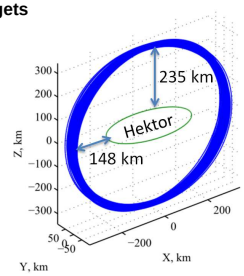


1. Atlas V 551used for launch
2. Launch date 9/18/2026 with an initial mass of 3439 kg
3. Jupiter gravity assists for maximum inclination change, 1/2029
4. Rendezvous with Agapenor in 10/2033, with a 7.05 year TOF
5. Approaches Agapenor at 0 km/s
6. 6-month primary science mission at Agapenor
7. Rendezvous with Hektor in 9/2038 followed by 6-month primary science mission (12 year TOF)
8. Prior to both Agapenor and Hektor arrival, opportunistic flybys of other asteroids possible

Science Operations, Risk, and Cost of the Mission

Science Orbits Around Targets

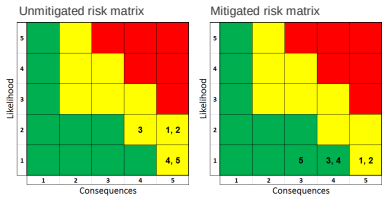




	Agapenor	Hektor
Model	Point-mass model	Triaxial ellipsoid (370x195x195 km)
Period, hr	~24	14.6
Velocity, m/s	10-20	40

+ Shapes of the targets are not properly known
+ Agapenor is modeled as a point mass and Hektor as a triaxial ellipsoid
+ Because of the shapes science orbits around the targets will need regular station-keeping
+ A 235 X 148 km orbit around Hektor is stable for around 30 days: ΔV needed to maintain orbit
+ The moon of Hektor is not considered while designing science orbits
+ Science orbits station-keeping and science operations drive attitude control propellant
+ Extra propellant is carried to account for uncertainties in the long-term propagation of science orbits
+ Velocities of spacecraft around Agapenor (~20 m/s) and Hektor (~40 m/s) helps in instruments operations

Risk Assessments via NASA's Priority Score System



#	Component/Mechanism Names	Risk Description	Type
1	HiVHAC Hall Thruster	If it fails, the system would not be able to control its movement direction.	Technical
2	Hydrazine Thrusters	If it fails, the system would not be able to control its movement direction.	Technical
3	Reaction Wheels	Medium. The system would not be able to make fine adjustments.	Technical
4	UltraFlex solar wings	Very low	Technical
5	Wing deployment mechanism	Very low	Technical

+ Risks can be mitigated via appropriate actions

COST

- The cost of the mission is $752 Million in FY2015 $ (cost cap of $800 M)
- Analogy-based, quasi-parametric, and grassroots models
- Reserves: 50% for Phases A–D, and 25% for Phases E and F

MISSION SUMMARY

- 13-year New Frontiers mission to two Trojan asteroids
- Time to commencing first science Ops: 7 years
- Rendezvous Agapenor and Hektor
- Opportunistic flybys of other asteroids
- 6x Instruments to answer science goals
- $752 Million (New Frontiers) - $48M to spare!

This early mission concept study was carried out as an academic exercise at Purdue University. We thank Dr. Ralph Lorenz from the Johns Hopkins University Applied Physics Laboratory; Dr. Charles Budney and Dr. Karl Mitchell of the NASA Jet Propulsion Laboratory for reviewing the concept.