A JPL Planetary Science Summer School Trojan and Centaur Reconnaissance Mission: Science

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Science Motivation:

A number of surveys of extrasolar planets in our galaxy have revealed many Jupiter size and larger planets in close orbit with their parent star. Current models of planet formation indicate that these planets could not have formed in situ and must have migrated and friction with an outer debris disk is often suggested as a potential mechanism (Marcy and Butler 1998). A similar model for the migration of the gas giants in our own solar system, the *Nice Model* (Tsiganis et al. 2005; Morbidelli et al. 2005; Gomes et al. 2005), can explain the current orbits of the gas giants, and provides a mechanism for the period of Late Heavy Bombardment.

The *Nice Model* generates observable predictions for the current state of the solar system; this includes the delivery of carbon rich small bodies from what we now know as the Kuiper Belt into the outer main belt and Trojan asteroid populations (Levison et al. 2009). To test this prediction, the composition of Centaurs, which we know dynamically must come from the Kuiper Belt, can be compared to the compositions of the Trojan asteroids to determine if members of their population share a common origin. We have identified 5 key science questions that could be investigated with a Trojan and Centaur flyby mission.

Key Science Question 1: Where in the solar system did Trojan and Centaur asteroids originate?

Based on albedos and colors, the Trojans and the Centaurs seem very similar (Fernandez et al. 2003; Bauer et al. 2003), yet are very different dynamically.
Did they form in the same region and do they have common compositions or are they from two different source regions in the solar system?

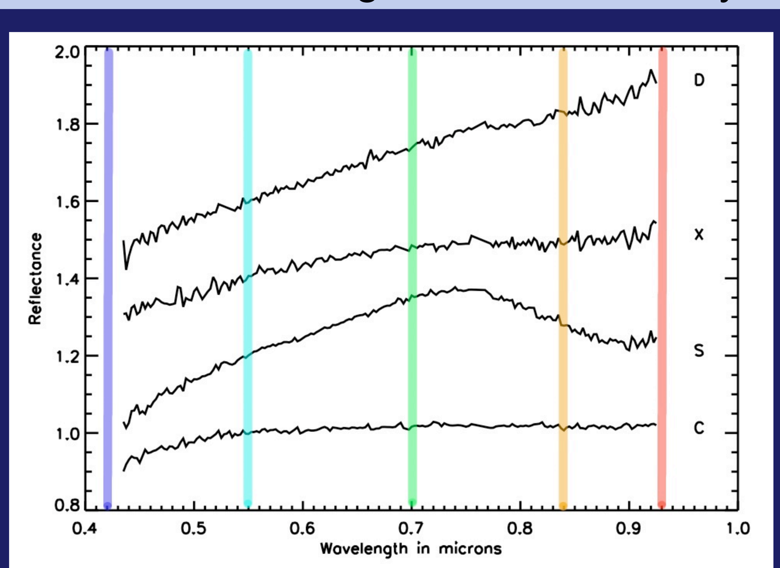


Figure 1a and b: Reflectance spectra of asteroids from Bus and Binzel (2002) showing the X,S and C classes of the main belt and then the D taxonomic class typical of Trojan asteroids and the colored bars indicating the central wavelengths of 5 of our proposed optical filters. The D type spectra is similar to the spectra in 1b.

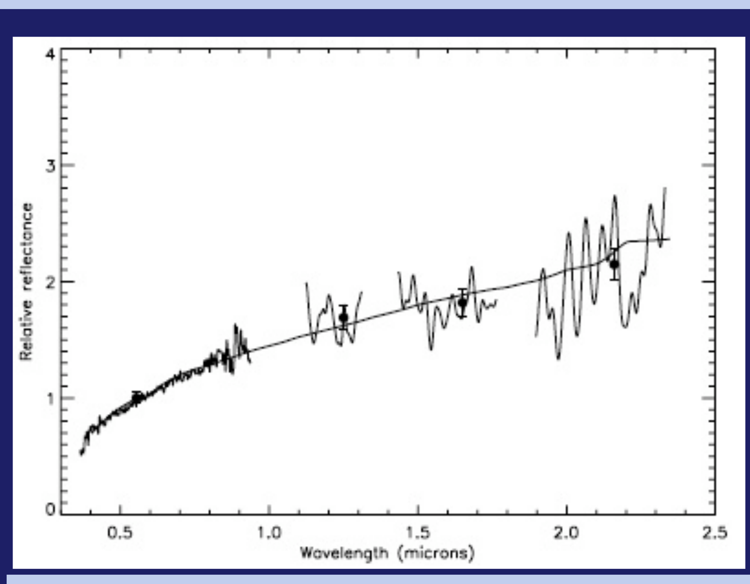


Figure 1b: Reflectance spectra of Centaur 2001 BL41 from Doressoundiram et al. (2003) which is fit by a mixture of suggested model for the composition of 17% Triton tholin, 10% ice tholin, and 73% amorphous carbon.

Key Science Question 2: Have these bodies migrated?

If the compositions of Trojans indicate that they formed in the outer solar system and have compositions similar to the Centaurs, it would be good evidence that these bodies were trapped into stable orbits due to some interaction between the Kuiper Belt and the gas giants. The compositions of Trojans offer a critical test of the Nice model (Levison et al. 2009) which may have important implications for the dynamical evolution of the Kuiper Belt and the solar system as a whole.

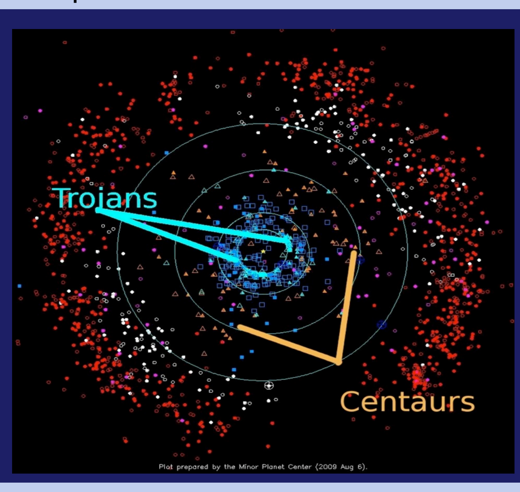


Figure 2: View of the outer solar system with Trojans marked in cyan and the Centaurs marked in orange. The proposed source region for both Trojans and Centaurs from the *Nice Model* is the Kuiper Belt, marked in red.

Key Science Question 3: What evolutionary processes have modified these bodies?

Have these bodies undergone regular collisions? Are the two distinct color groups detected within the Trojan population (Emery et al. 2008) the result of composition or are they a tracer of the age of the bodies? How much dust is produced due to collisions? Is there any evidence of thermal alteration such as outgassing?

Key Science Question 4: Do these bodies show evidence for organic material?

The albedos of Trojans and Centaurs are similar to Jupiter family comets, thus we expect that Trojans and Centaurs should have organic rich compositions.

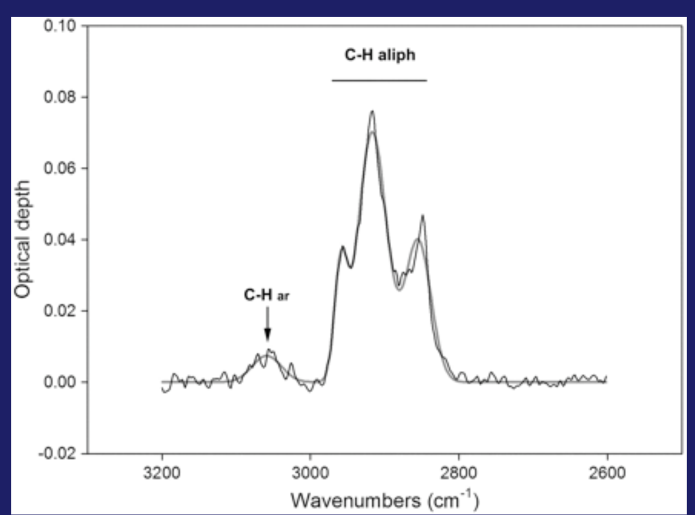


Figure 3: Detection of aromatic and aliphatic C-H stretch features from comet dust collected by the Stardust mission (Keller et al. 2006)

Key Science Question 5: What are the physical properties of these bodies?

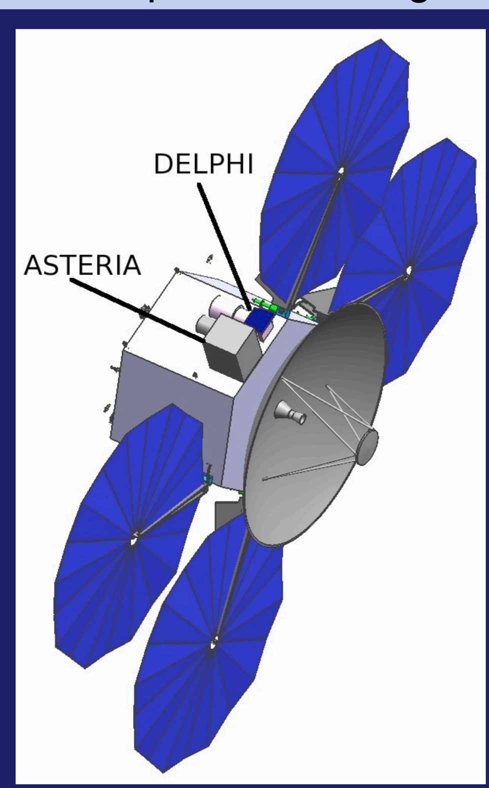
Are these bodies rubble piles or monoliths? Do they have companions? Are they differentiated?

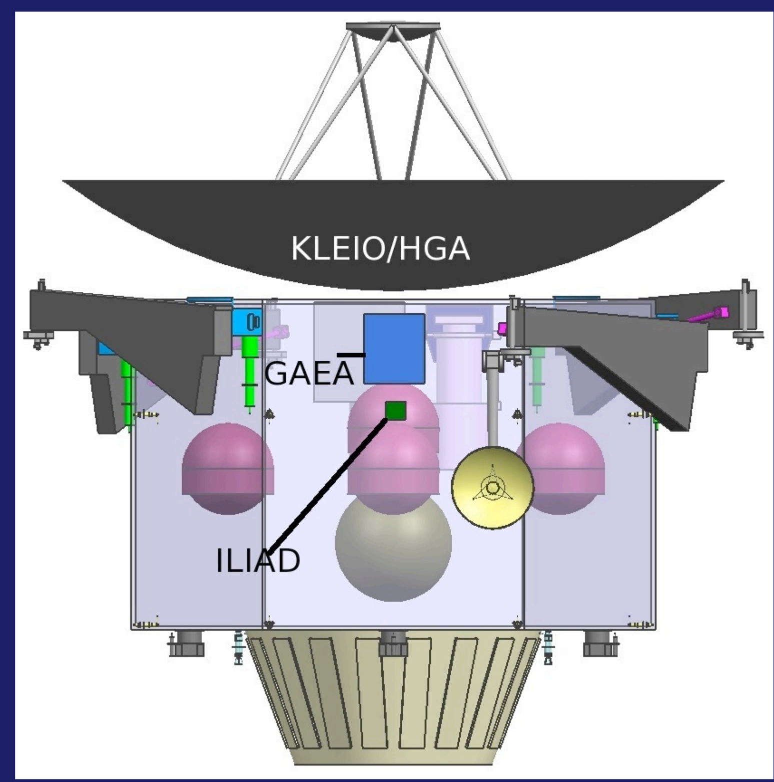
Figure 4a and b:
4a (left) image of the rubble pile asteroid Itokawa as seen by Hayabusa

4b (right) image of the monolith Phobos as seen by HiRise

Proposed instruments:

DELPHI: optical imager with 6 color filters and one polarization filter
ASTERIA: Optical and IR spectrograph covering 0.4 to 5 microns
ILIAD: Dust counter
GAEA: Neutral and Ion Mass Spectrometer with 1 to 100 AMU range
KLEIO: Radio experiment using the DSN and the High Gain Antenna





Science Traceability Matrix:

Science Question	Measurement	DELPHI	ASTERIA	ILIAD	GAEA	KLEIO
Where in the solar system did these bodies form?	Measure silicate absorption bands of hydrated silicates, olivine and pyroxene, and plagioclase		X			
	Measure the presence of carbons, and determine the ratio of amorphous vs crystallines from the slope and optical constants		X			
	Determine the presence of ices and relative abundances		X		X	
	Measure isotope ratios of D/H and ratios of CH4, H2O, He, 36Ar				X	
Have these bodies migrated?	Presence of ices and relative abundances		X		X	
	Degree of activity	X				
	Determine if volatiles are present via outgassing products		X		X	
What evolutionary processes have taken place?	Count impact craters for collisional history and obtain colors of materials in ejecta blankets for relative dating	X				
	Determine the amount of dust in the Trojan population due to collisions			X		
	Determine if thermal evolution has modified Centaurs using the abundance of crystalline and amorphous ice phases		X			
	Determine if thermal evolution is currently taking place by measuring the size and distribution of a potential coma	X	X	X		
What are the physical characteristics of these bodies?	Measure the mass					X
	Measure the 3D size and shape	X				
	Determine the presence of a satellite via imaging	X				
	Determine the spin axis of the bodies with imaging on approach	X				
Do these targets have organic material?	Measure absorption due to 3.3 micron C-H stretching in aromatics		X			
	Measure absorption due to 3.4 micron C-H stretching in aliphatics		X			
	Measure molecular weights of the dust				X	

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References: Marcy and Butler, 1998, ARA&A, 36, 57; Tsiganis et al., 2005, Nature, 435, 459 ; Morbidelli et al., 2005, Nature, 435, 462 ; Gomes et al. 2005, Nature, 435, 466; Levison et al., 2009, Nature, 460, 364; Fernandez et al., 2003, AJ, 126, 1563; Bauer et al., 2003, Icarus, 166,195; Bus and Binzel, 2002, Icarus, 158, 146; Doressoundiram et al., 2003, AJ, 125, 2721; Emery et al., 2009, LPI, 40, 1442