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

Sarah M. Hörst[1], M. P. J. Benfield[2], F. J. Calef III[3], D. O. Cersosimo[4], R. I. Citron[5], R. Effinger[6], K. E. Gibson[7], D. J. Gombosi[8], J. A. Hesch[9], D. Ionita[10], E. A. Jensen[11], C. C. Jolley[12], E. L. Ryan[9], D. Takir[13], M. W. Turner[2]

[1]University of Arizona, horst@lpl.arizona.edu, [2]University of Alabama at Huntsville, [3]University of Alaska Fairbanks, [4]University of Missouri, [5]University of Colorado, [6]Massachusetts Institute of Technology, [7]Washington University St, Louis [8]Syracuse University, [9]University of Minnesota, [10]Georgia Institute of Technology, [11]ACS Consulting, [12]Montana State University, [13]University of Tennessee

TRACER (TRojan And CEntaur Reconnaissance) Mission Overview

TRACER would be the first spacecraft to visit a Trojan and a Centaur. The mission's scientific objectives are to determine if Trojans and Centaurs formed in their present positions, test dynamical models for the evolution of the solar system, and place Trojans and Centaurs in context with other small outer solar system bodies.

TRACER would leave Earth on an Atlas V 541 around March 12, 2019. The spacecraft utilizes a Solar Electric Propulsion (SEP) system. The trajectory includes the flybys of the Trojan Antenor on November 28, 2023 and the Centaur 2001 BL41 on February 7, 2027. Each flyby includes high resolution imaging, visible and infrared spectral mapping, and chemical and physical characterization. The spacecraft would also perform dust flux measurements in the Trojan asteroid region and a photopolarimetric survey of the Trojan asteroid region.

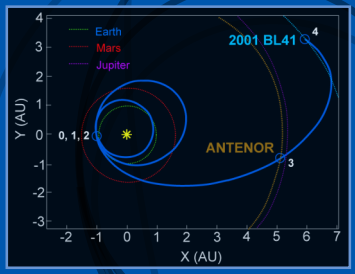
This is a New Frontiers class mission with a total PI-managed mission cost of $650M (FY2009$). The use of a medium range launch vehicle increases this cap to $690M. This pre-Phase A design has a cost of $716M, including JPL's standard 30% reserve, which is $26M over the cap.

The following mission design was developed during the 2009 JPL Planetary Science Summer School by a group of graduate students and recent PhDs in a variety of science and engineering fields working in conjunction with Team X at JPL.

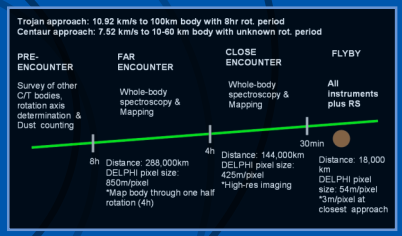
This design is a response to the 2009 New Frontiers Announcement of Opportunity.

Mission Timeline

Launch March 12, 2019
Antenor Flyby November 28, 2023
2001BL41 Flyby February 7, 2027



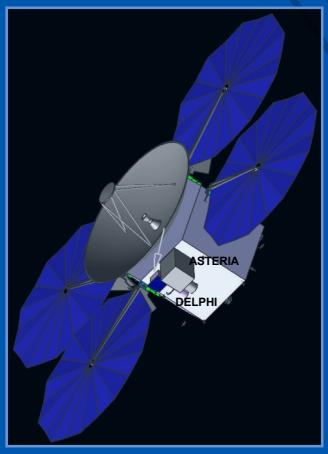
Mission Trajectory and Encounter Strategy



Science Objectives and Instrumentation

- Determine the formation region of the Trojans and Centaurs
- Determine the physical properties (size, mass, density) of a Trojan and a Centaur
- Measure dust fluxes in the outer solar system
- Determine the chemical composition of Trojan and Centaur volatiles, ices and organics
- Map the color, albedo and surface morphology of a Trojan and Centaur at high resolution

Instrument	Description	Heritage	Mass / Power
ASTERIA	**Visible and near infrared spectrometer** • images at 3 mrad/pixel, two 640 x 480 HgCdTe detectors • Spectral resolution of 5 nm from 0.4-2.5 µm and 10 nm from 2.5-5 µm	Europa Orbiter	28 kg 25 W
DELPHI	**Narrow angle camera** • CCD Camera: 2048 by 2048 pixels, 10 µm/pixel • Nominal Field of view (FOV): 6 mrad, IFOV: 3 µrad • Exposure time: minimum of 10 milliseconds • Schmidt-Cassegrain Telescope: aperture 0.3 m, focal length 3.33 m • Filters: 430, 550, 700, 860, 960, and 1010 nm + 4-position angle polarizers	Hayabusa AMICA New Horizons LORRI	25 kg 10 W avg 2 W sleep
GAEA	**Ion and neutral mass spectrometer** • 1-100 amu range, M/ΔM≥100 • Minimum source density: ~10^4 mol/cm^3 • Capable of detecting: H_2, CO, CO_2, NH_3, H_2O, ^{14,13}N, HD, ^{36}Ar, and chained/aromatic hydrocarbons	Cassini INMS	10 kg 23 W avg 13 W sleep
ILIAD	**Dust counter** • 0.1 m^2 collector • Capable of measuring particles 10^{-12} to 10^{-9} kg • Up to 10^4 impacts per second	New Horizons VBSDC	1.6 kg 5 W



TRACER Spacecraft

Attitude Control System

- 3-axis stabilized, fine-pointing using reaction wheels with monoprop thrusters for coarse pointing and momentum dumping
- Stellar and inertial attitude determination using precision star trackers and gyros
- Full onboard redundancy
- System Design Drivers:
  - Wheel torque: flyby maneuver (0.55°/sec)
  - Wheel momentum: slewing (90° in 5min)
  - Pointing Knowledge: Delphi (15 arcsec)
  - Pointing Control: Delphi (120 arcsec)
  - Pointing Stability: Delphi (6 arcsec/sec)

Telecom and Ground Systems

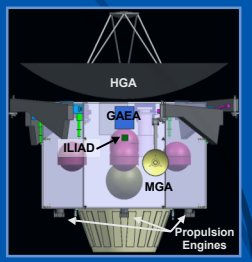
- X-band, SSPA – 5W RF, 15W DC
- Antennas:
  - HGA: fixed (ACS pointing), 75 kg, pointing accuracy = 0.04°
  - MGA: gimbaled (encounter Doppler tracking and emergency communication)
  - 2x LGA antennas (launch)
- Redundant design, NEAR-Shoemaker heritage
- Links:
  - Carrier-only link for Doppler tracking
  - Data volume: 18 Gb at Trojan, 11 Gb at Centaur includes over head. Additional data during pre-encounter, cruise phase (minor)
- DSN 34 m Beam WaveGuide (BWG) subnet
  - Trojan downlink @ 6 kbps, 8-hr pass/day for 105 days
  - Centaur downlink @ 3 kbps, 8-hr pass/day for 125 days

Thermal

- The shortwave detector on ASTERIA is passively cooled to 160 K and the longwave detector is cooled to 80 K by a radiator
- The spacecraft and Sun are excluded from the field of view
- The SEP tanks are kept at 25 °C
- The PPU for the SEP tanks requires a thermal radiator

Spacecraft Overview

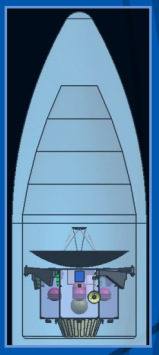
- Atlas V 541 launch vehicle
- Dual cold redundant
- No radioisotopes
- Hexagonal bus
- Communication
  - 4 m HGA
  - 0.75 m MGA
- Solar Power
  - 4 ultra-flex arrays
- Propulsion
  - Solar Electric (Xenon)
  - Chemical (Hydrazine)
- 4 Instruments
  - ASTERIA
  - GAEA
  - DELPHI
  - ILIAD
  - radio science



Spacecraft Subsystems

Design Assumptions

- GAEA and ILIAD mounted in direction of travel
- ASTERIA and DELPHI co-pointed
- 600 µrad control, 30 µrad/sec stability



Power

- 4 MultiFlex solar panels
  - Triple junction solar cells, cell packing factor = 0.89, 58.8 m^2 surface area
- 5 30W-hr Li-Ion batteries
  - 4 primary, 1 redundant
- Power output:
  - 19.8 kW at 1 AU
  - 540 W at end of mission

Propulsion

- Main Engine: Solar Electric Propulsion
  - 4 BPT- 4000 developed by Aerojet
  - Propellant: 1807 kg of Xe in 5 tanks
  - Nominal operational power 4.5 kW/engine
- RCS Chemical Monopropellant
  - 16 Aerojet MR-103M (1N each)
  - Isp between 221 and 206 seconds
  - Propellant: 41 kg of Hydrazine

Command and Data Handling/Software

- Flight Computer:133Mhz PowerPC FSW:MSAP based, NPR compatible
- Data storage: 96GB in-chassis NVRAM card (heritage: WISE mission)
- High-speed LVDS interface: Telecom, DELPHI, and ILIAD
- Low-speed 1553 bus interface: ACS, ASTERIA, and GAEA

Cost

Cost Summary (FY2009 $M)	CBE	Res.	PBE
Development Cost	$428.4 M	30%	$556.4 M
Phase A	$12.3 M	30%	$15.9 M
Phase B	$43.7 M	30%	$56.9 M
Phase C/D	$372.4 M	30%	$483.6 M
Operations Cost	$142.0 M	12%	$159.6 M
Project Cost (w/o LV)	$570.4 M	26%	$716.0 M

The New Frontiers cost cap is $650M (FY2009 $) excluding the launch vehicle. The use of a medium range launch vehicle (e.g. Atlas V 541) increases the cap $40M, to a total PI-managed mission cost of $690M. This pre-Phase A design has a total PI-managed mission cost of $716M ($26M above cap).

Acknowledgements

JPL Informal Education Office, Charles Budney, Anita Sohus, Amber Norton, JPL Team X, Abby Allwood, Valeria Cottini