DEPARTMENT OF AEROSPACE ENGINEERING

Comet Divers

~Exploring Our Past While Defending Our Future~

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Project Description

- The INSECT mission uses four spacecraft—Cricket, Hornet, Honeybee, and Butterfly—to intercept an Oort Cloud comet and fulfill objectives from the 2023 Planetary Science and Astrobiology Decadal Survey. Operating from an L2 orbit, the fleet characterizes comet features, samples dust and plasma, and studies solar interactions. Hornet impacts the surface to expose subsurface material, while the others conduct flybys and imaging. The mission advances early solar system science and planetary defense through autonomous, integrated deep-space operations.

Why it Matters

- A comet impact is believed to have caused the mass extinction that ended the age of the dinosaurs. By studying Oort Cloud comets up close, our mission helps us better understand these distant threats—improving our ability to detect, predict, and defend against future impacts that could endanger life on Earth.

Science Objectives

1. The mission shall characterize the comet's size, shape, rotation, and morphology.
2. The mission shall determine the surface composition of the nucleus and the composition of the coma, including its volatile inventory.
3. The mission shall characterize the dust environment and the evolution of dust and gas within the coma.
4. The mission shall measure the magnetic and plasma environment around the comet and its interaction with the Sun.
5. The mission shall include an impactor to generate an observable crater, relay telemetry to one of the other spacecrafts, and flyby spacecraft(s) to observe crater formation, ejecta distribution, and material composition of the dispersed interior.
6. Multiple spacecraft shall image different perspectives of the comet nucleus to form a 3D model.

Mission Architecture

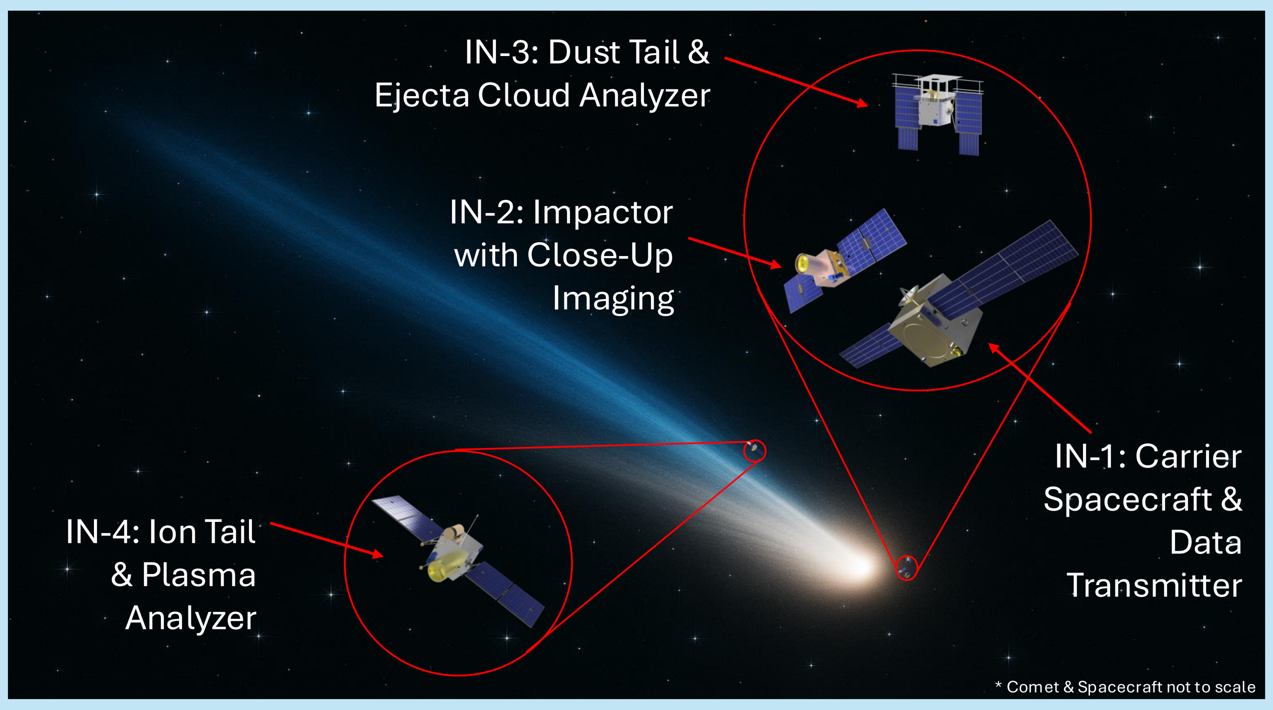

Fig 1. Illustration of the Mission

Launch Vehicle: Falcon Heavy

Mission Sequence: Pre-Flyby

*L = time of launch
*I = time of intercept

Launch (L-30d)
- Launch from KSC, FL into parking orbit
- Perform insertion burn into L2 orbit

Loiter at L2 (I-Ld)
- Await notice from ground station of a comet of interest

Discovery & Approach (I-336d)
- Initiate systems & approach intercept pt.
- TOF ~306d

Initial Separation (I-30d)
- Spacecraft separates, while staying in close formation

Primary Separation (I-5d)
- IN-1,3, & 4 perform separation burns
- IN-2 stays on impact path

Mission Flyby (I-24hr to I-0)
- Begin guidance systems & data communications
- Enact INSECT maneuvers & data collection

Mission Sequence: Flyby and Interception

Terminal Guidance (I-24hr)
- Start navigation & imaging
- Begin data communication with IN-1

Maneuvers (I-12 to I-6hr)
- All spacecraft enact two corrections at I-12 & I-6 hrs

IN-2 Correction (I < 20m)
- IN-2 enacts course corrections at I-20, I-5, & I-3 min to ensure impact

Begin Data Collection (I < 3m)
- IN-1,3,4 begin data collection & imaging
- IN-2 begins rapid imaging
- Send data to IN-1

Impact (I-0)
- IN-2 impacts the comet, sending its last message to IN-1
- IN-2 destroyed

End Data Collection (I > 0)
- IN-1, 3, & 4 finish collecting data
- IN-3,4 transfer data to IN-1 then to GS

Intercept Trajectories

Case	Required ΔV	Flyby Velocity	Sun Phase Angle	Earth-S/C Distance
Best	0.39 km/s	51.9 km/s	100°	0.69 AU
Average	2.57 km/s	53.8 km/s	103°	1.39 AU
Worst	4.16 km/s	55.6 km/s	106°	0.38 AU

Table 1. Possible Intercept Trajectories based on Historical Comet Analysis

- Lowest ΔV trajectory occurs at Ecliptic plane crossing, 20.7d after perihelion and 1.14 AU from Sun
- Required ΔV depends on relative phasing of Earth and comet
- 60% prop mass fraction (305s Isp, 2.72 km/s dV) can reach 53.3% of orbits

Spacecraft Design

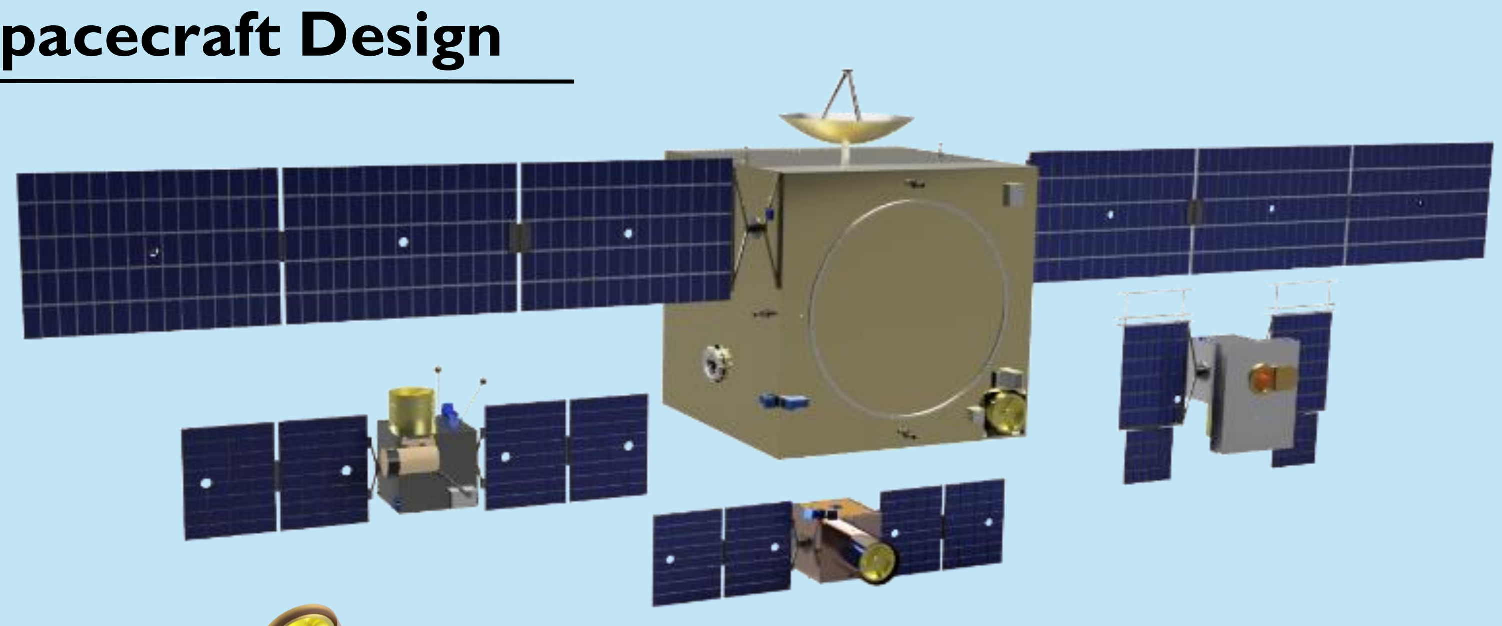

Fig 3. CAD Rendering of Entire Fleet

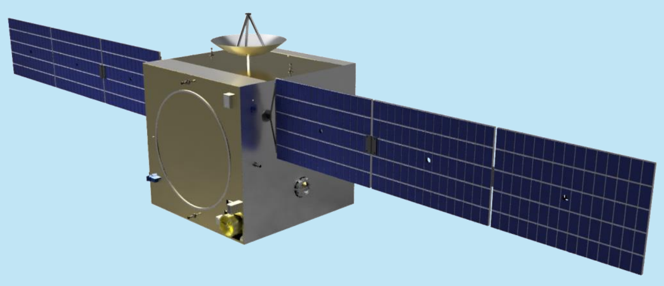

Fig 4. IN-1 CAD

INSECT-1: Cricket

- Main carrier spacecraft
- Relays communication between entire fleet
- Transmits data to Earth
- Mass: 2294 kg
- Cost: 302 $M2025

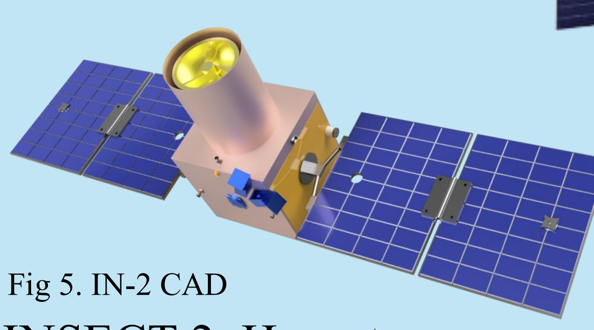

Fig 5. IN-2 CAD

INSECT-2: Hornet

- Impactor
- Generates crater and ejecta
- Returns close-up images of comet surface until destruction
- Mass: 98 kg
- Cost: 93 $M2025

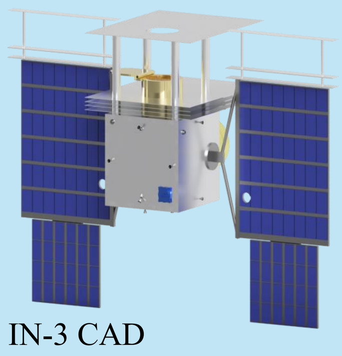

Fig 6. IN-3 CAD

INSECT-3: Honeybee

- Science observer
- Examines comet's dust tail
- Monitors the ejecta cloud generated by Hornet
- Mass: 148 kg
- Cost: 137 $M2025

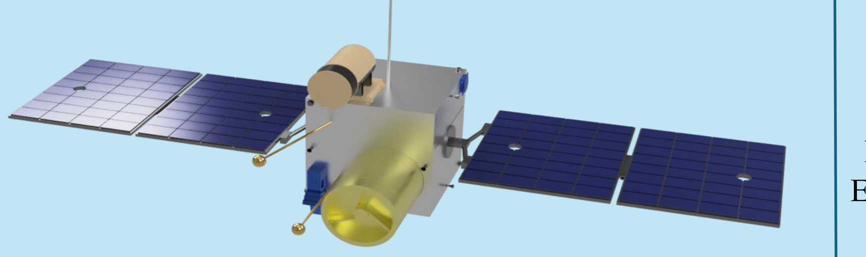

Fig 7. IN-4 CAD

INSECT-4: Butterfly

- Environmental observer
- Examines plasma environment
- Monitors the comet's ion tail
- Mass: 83 kg
- Cost: 108 $M2025

Overall cost: 640 $M2025 || Overall mass: 2623 kg

Science Instruments

Fig 8. Primitive Object Volative Explorer (PrOVE) Comet Camera (ComCAM)

Infrared (IR) Spectrometer

- Onboard IN-1 for analyzing comet emittance in the 2.7-4.7 µm wavelength range

Fig 9. ROSETTA UV Imaging Spectrograph (ALICE)

Ultraviolet (UV) Imager

- Onboard IN-1 for analyzing comet emittance in the Lyman-alpha (1215.67 Å) and Lyman-beta (1025.72 Å) bands

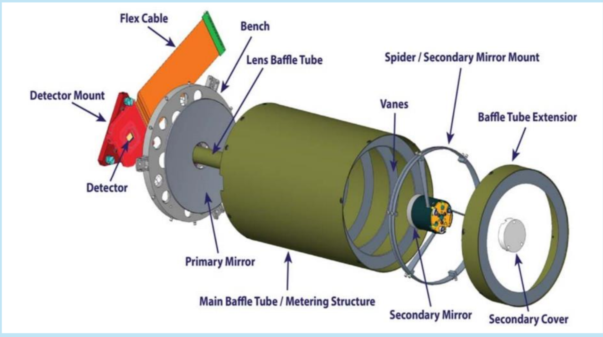

Fig 10. Didymos Reconnaissance and Asteroid Camera for Optical Navigation (DRACO)

Navigation and Imaging Camera

- Onboard all INSECTS for high resolution (2.5 µrad) imaging

Fig 11. Cassini Cosmic Dust Analyzer

Spectrometer + Dust Detector

- Onboard IN-1 to examine the dust in the ejecta plume and coma tail to characterize the material of the comet

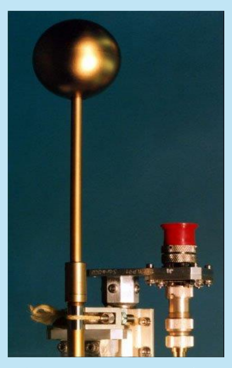

Fig 12. Rosetta Plasma Consortium (RPC) Langmuir Probe (LAP)

Langmuir Probe

- Onboard IN-4 for analyzing the plasma density in the comet tail

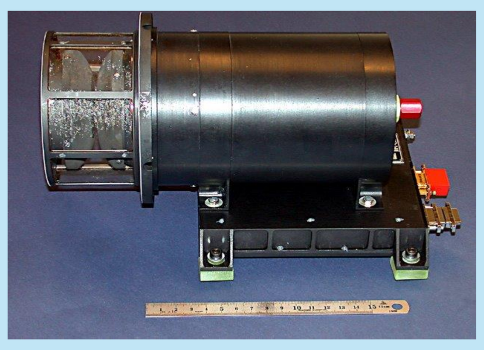

Fig 13. Rosetta Plasma Consortium (RPC) Ion Composition Analyzer

Ion Analyzer

- Onboard IN-4 for analyzing the distribution of ions in the tail of the comet

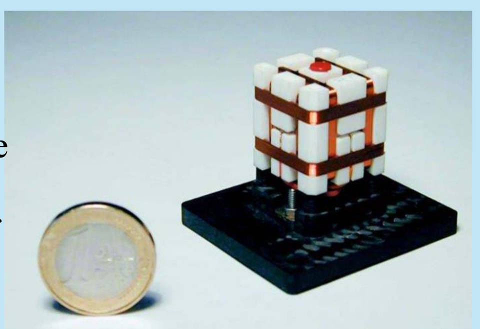

Fig 14. Rosetta Plasma Consortium (RPC) Fluxgate Magnetometer (MAG)

Fluxgate Magnetometer

- Onboard IN-4 for analyzing the magnetic environment of the comet tail

Power

Solar Panels

- Deployable Solar Arrays with IMM SolarCells
- Efficiency: **32%**
- Specific Power: **122.1 W/kg** at 1.2 AU
- Power: **2.309 kW** at 1.2 AU

Batteries

- Lithium Ion (Li-Ion) rechargeable batteries
- **90 min lifetime**, **0.8** depth of discharge(DoD)[3]
  - Specific Energy: **178 W-hr/kg**
  - Battery Storage: **3052 W-hrs**
  - Battery Mass: **17.15 kg**

Communication

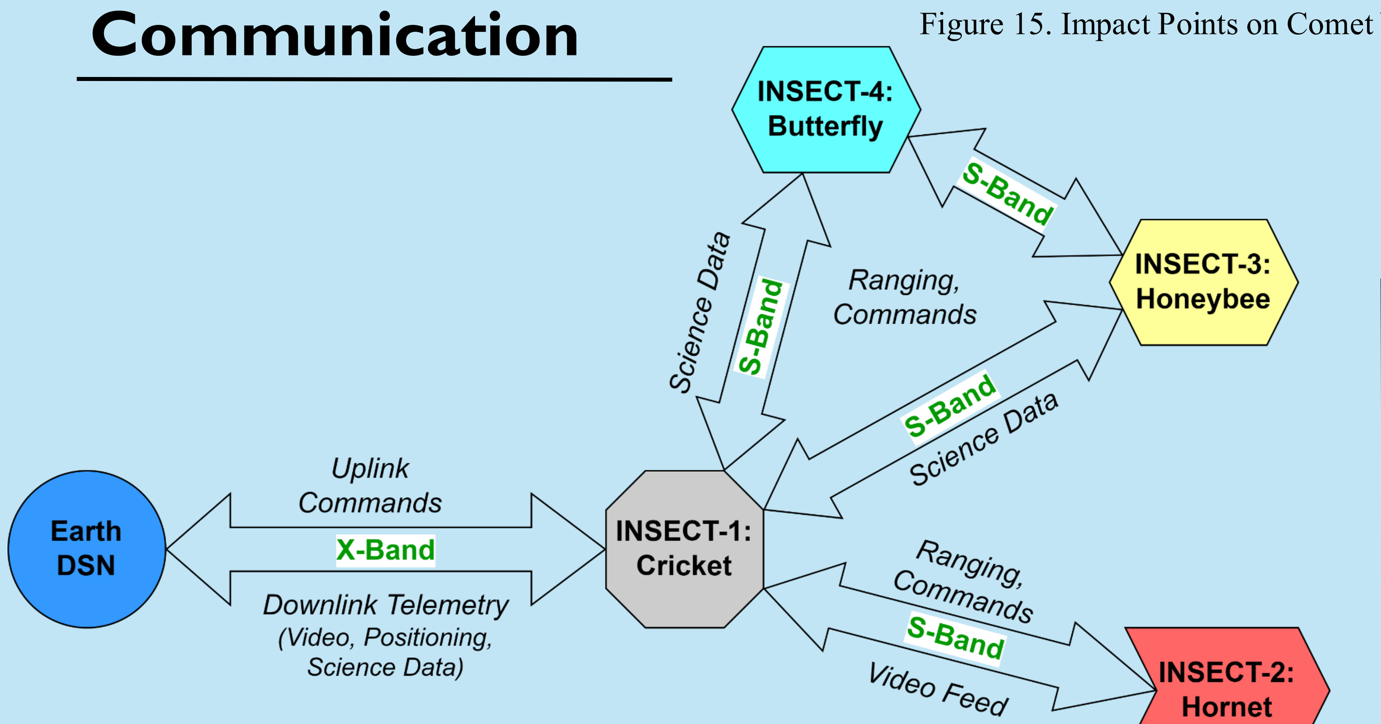

Figure 16. Communications Flow Chart

Monte Carlo Simulation

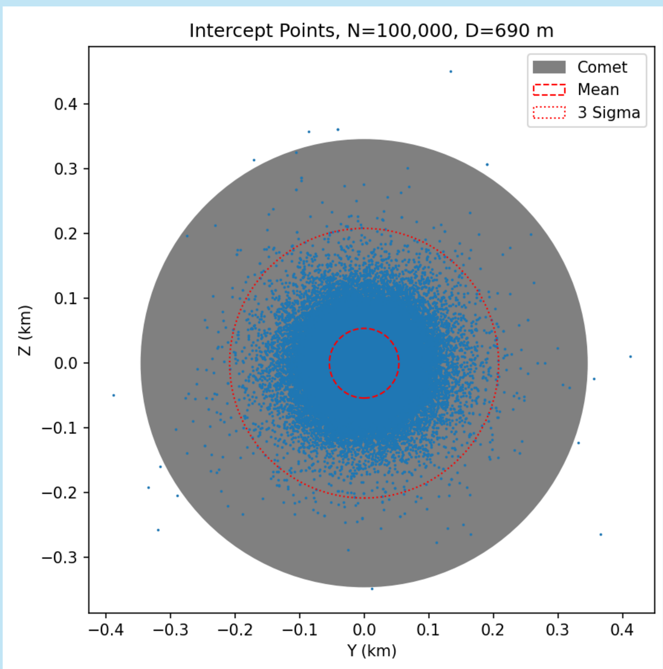

Figure 15. Impact Points on Comet Nucleus

Monte Carlo Simulation of Terminal Guidance for Comet Impact

- Start: **1 day before impact**, **65 km/s** flyby velocity (worst case).
- Target: **≥690 m** comet diameter.
- Detection: **DRACO**, **1.5 days** out (110° phase, 1.2 AU, 0.03 albedo).
- Initial Error: **100 km**, **2 m/s** relative state uncertainty.
- Guidance: Add optical nav errors before each maneuver; apply maneuvers with scale/bias errors.
- Separation: Start at **350 km** for parallax; minimize while retaining navigation quality.

References

- https://elvperf.ksc.nasa.gov/Pages/Vehicles.aspx (Fig 2)
- https://ntrs.nasa.gov/api/citations/20190001696/downloads/20190001696.pdf (Fig 8)
- https://arxiv.org/pdf/astro-ph/0603585 (Fig 9)
- https://iopscience.iop.org/article/10.3847/PSJ/ad823a (Fig 10)
- https://sbn.psi.edu/pds/resource/cdaDataHB-5-4-17.pdf (Fig 11)
  https://nssdc.gsfc.nasa.gov/nmc/experiment/display.action?id=2004-006A-12 (Fig 12)
- https://www2.irf.se/press/rosetta_ica.html (Fig 13)
- https://pds-smallbodies.astro.umd.edu/holdings/ro-ss-rpcmag-3-prl-calibrated-v9.0/document/rpcmag_instrument.pdf (Fig 14)