APIES: Exploring the Asteroid Belt with Satellite Swarms

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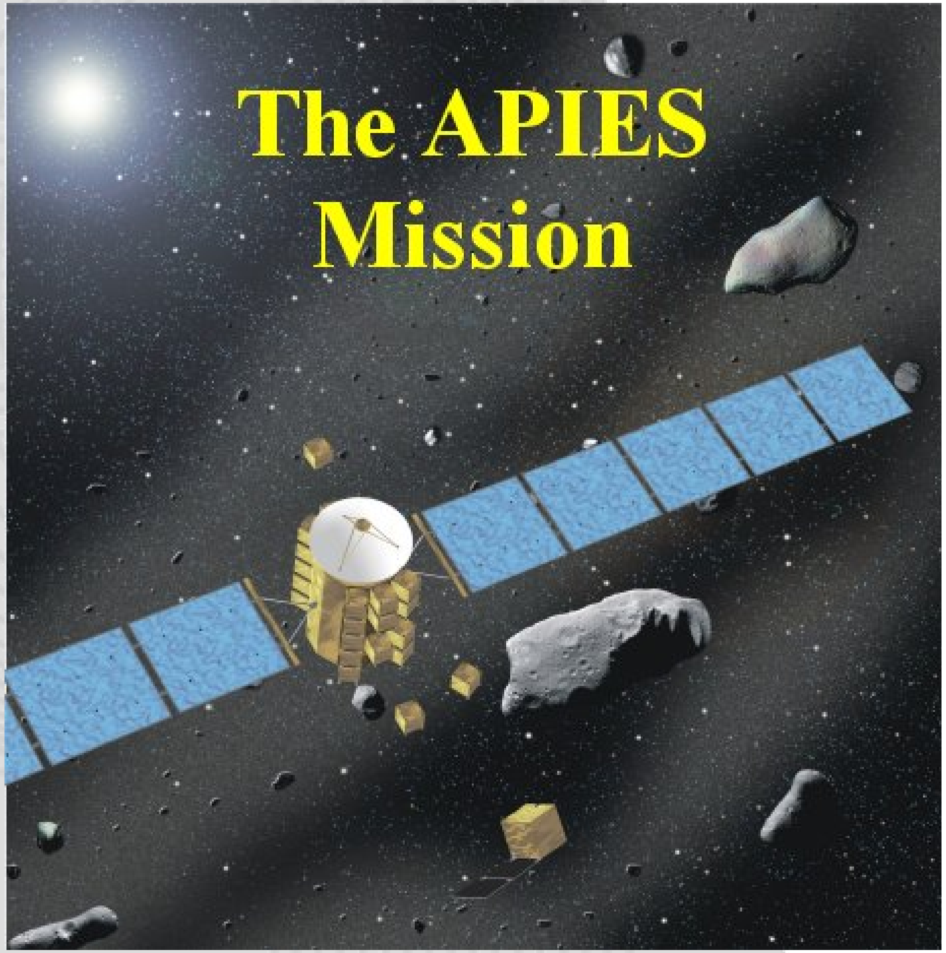
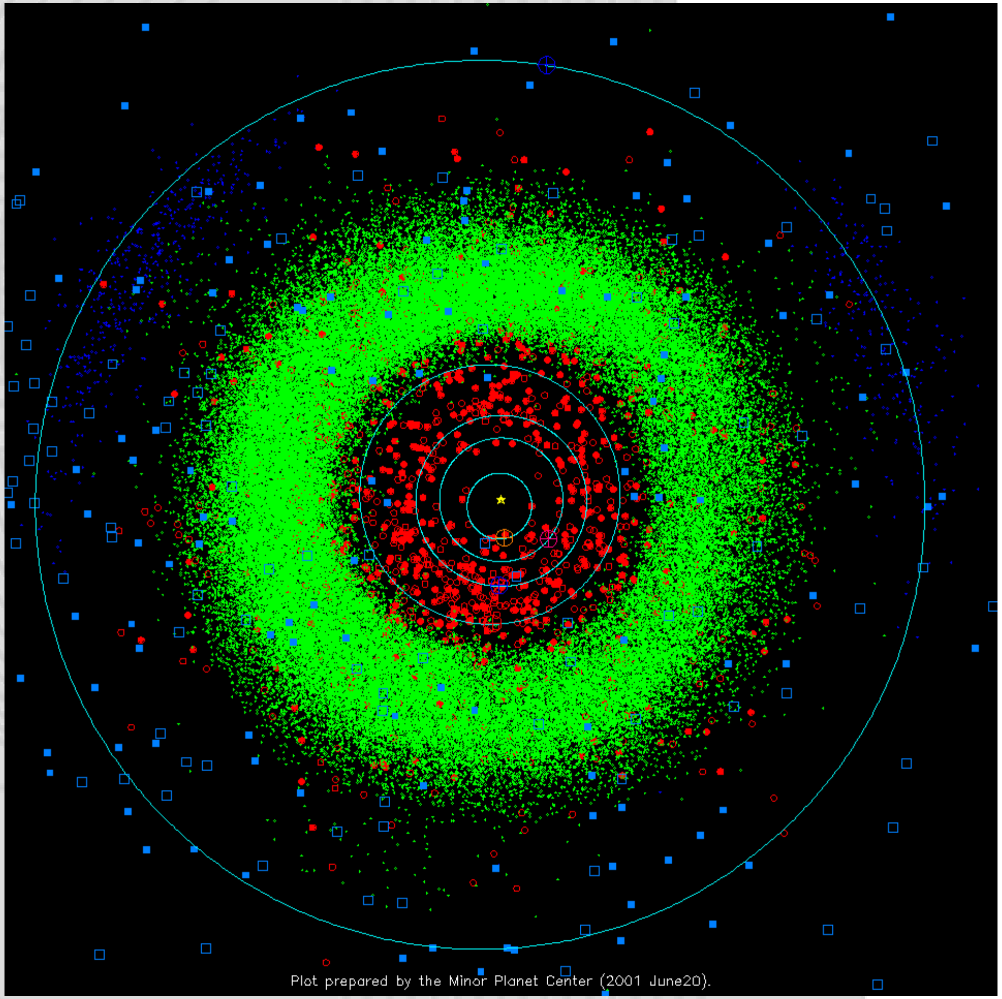
What is APIES?

- APIES: Asteroid Population Investigation & Exploration Swarm
- Concept:
  - Flotilla of 19 microspacecraft performing multiple flybys of asteroids (BEE = BElt Explorer)
  - Conventional carrier spacecraft also acting as communication centre for the swarm (HIVE = Hub & Interplanetary VEhicle)
  - Aim to visit at least 100 asteroids during 6 years of operation (one every 2-3 weeks!)



The Asteroid Main Belt: Still Unexplored

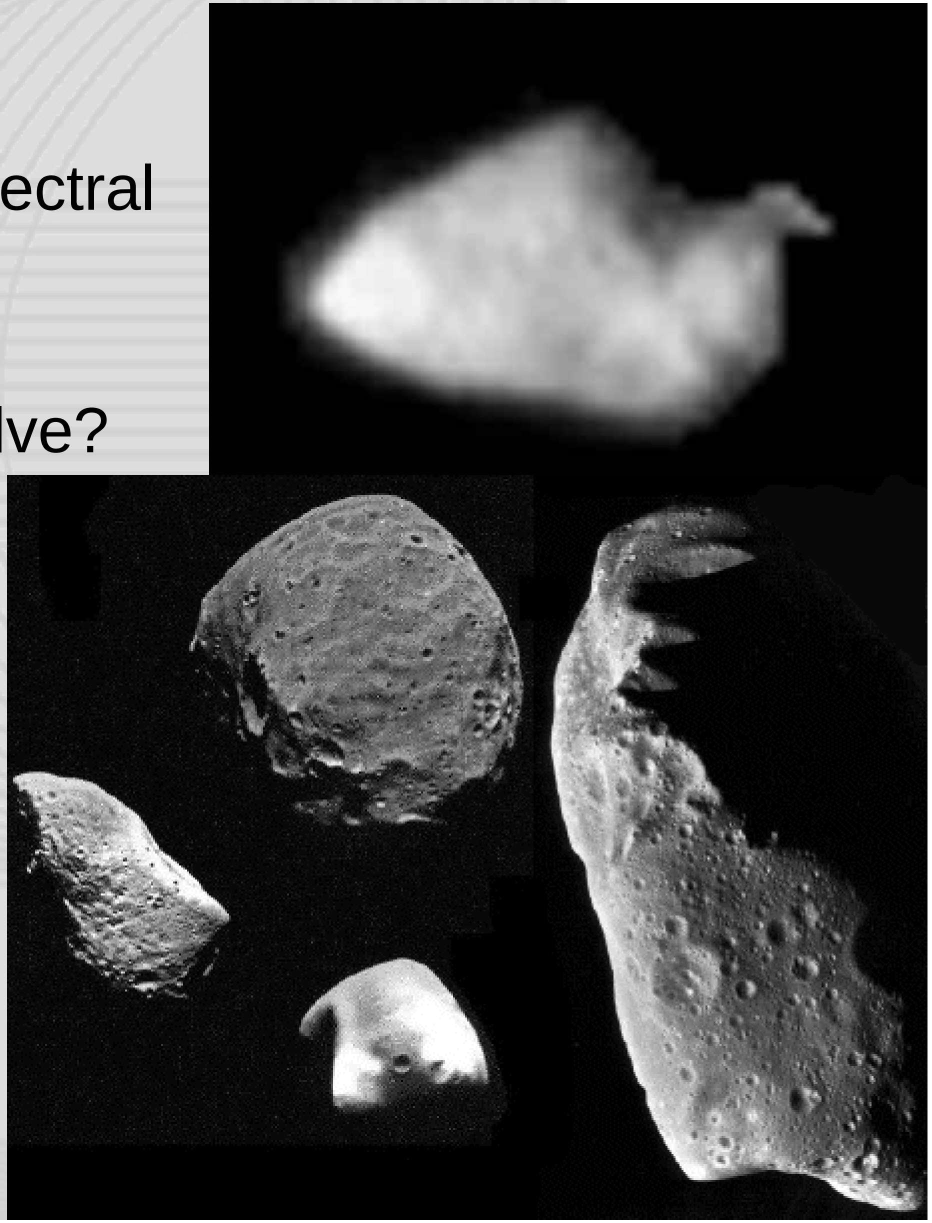
- The asteroid main-belt (MB) is one of the least known parts of the solar system
- >65,000 catalogued MB asteroids and millions of smaller ones, but only 2-3 have been studied in detail by a spacecraft
- MB asteroids can give us invaluable information on the origin & evolution of the Solar System



The asteroid main belt (green)

APIES: the Key Questions

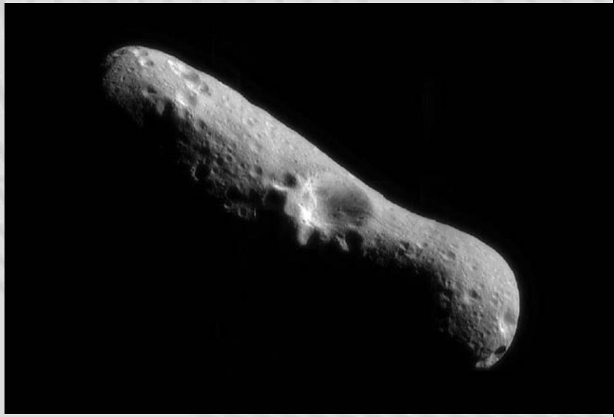
- What are asteroids made of?
- How is composition linked to spectral properties?
- What is their internal structure?
- How do asteroids form and evolve?
- What is their link to planets and comets in the Solar System?
- What is their link to meteorites?
- What can asteroids tell us about planet formation and evolution of life on Earth?



Asteroids are a unique source of information about the early Solar System

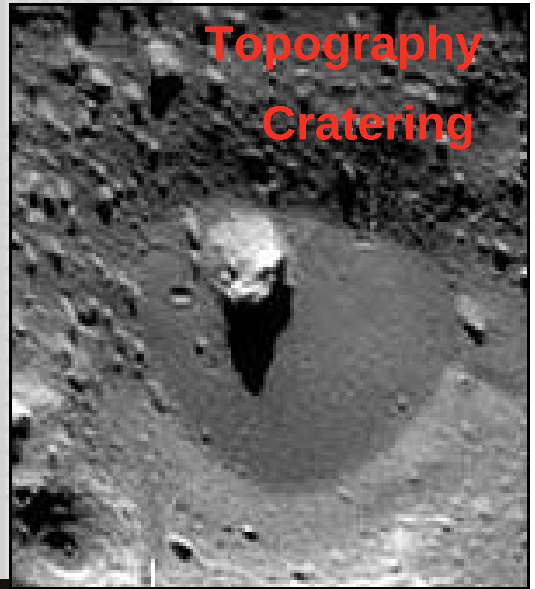
APIES Science Goals

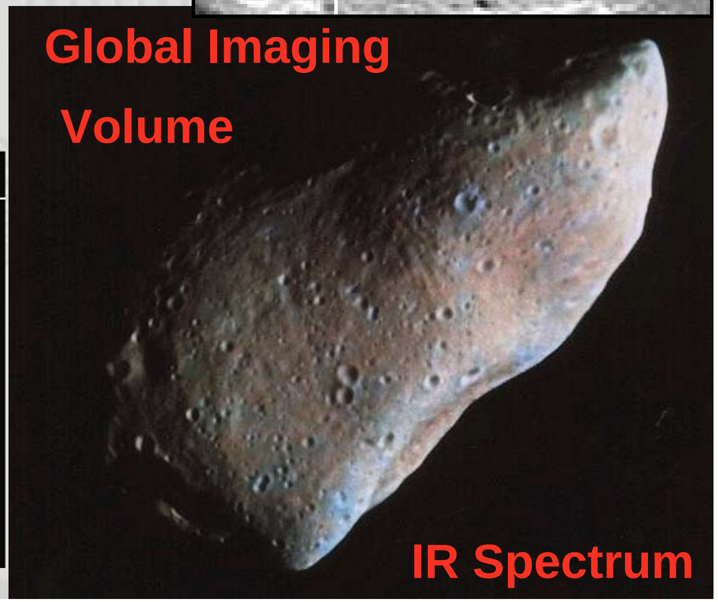
- Characterize asteroid population:
  – Measure mass & density
  – Surface physical properties (Vis & IR)
- Analyse a statistically significant sample:
  – Several samples from major spectral classes
  – Include a few rare spectral types
  – ~100 objects in total



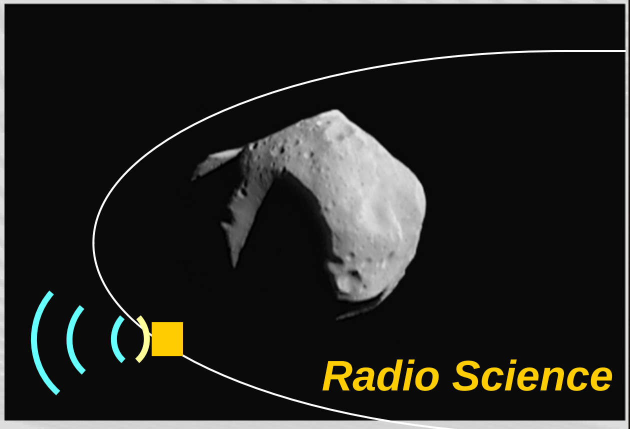
APIES Payload

- Simple payload focussed on key objectives:
  - – Imager for surface properties & volume
  - – IR spectrometer for mineralogy
  - – Radio science for mass & density
- Payload performance:
  - – 100 m/pix (global imaging) + 10 m/pix close-up
  - – 1.0-2.0 µm IR spectrum, 6 nm resolution
  - – 20% density measurement accuracy



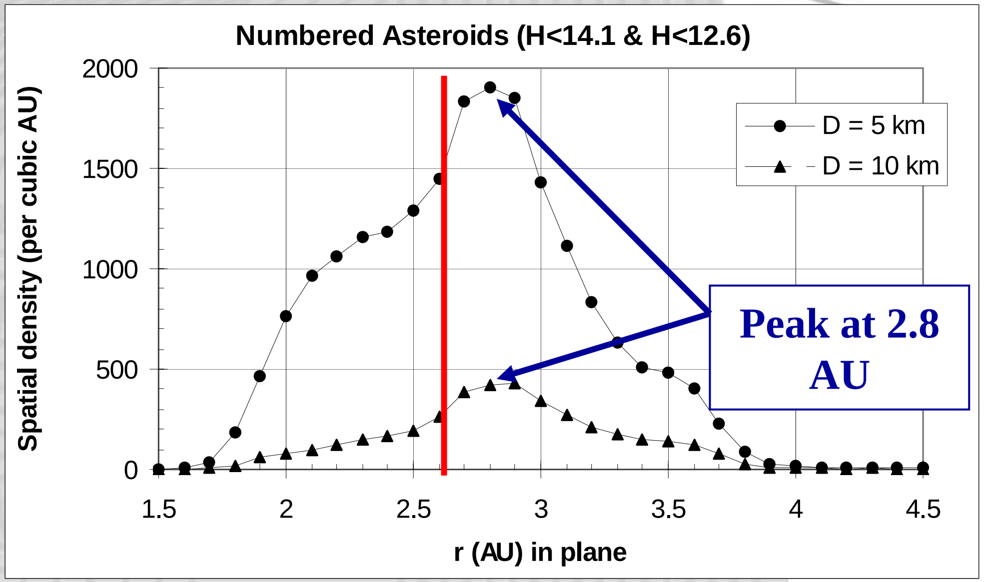


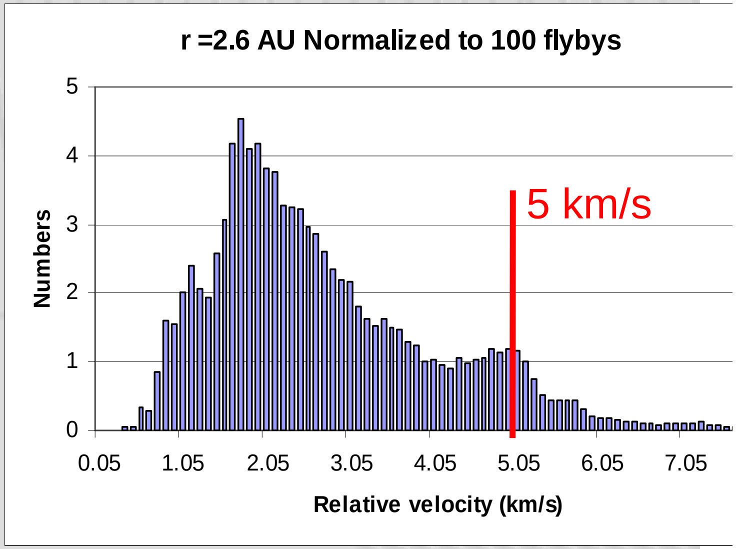
Total payload mass: 2.5 kg

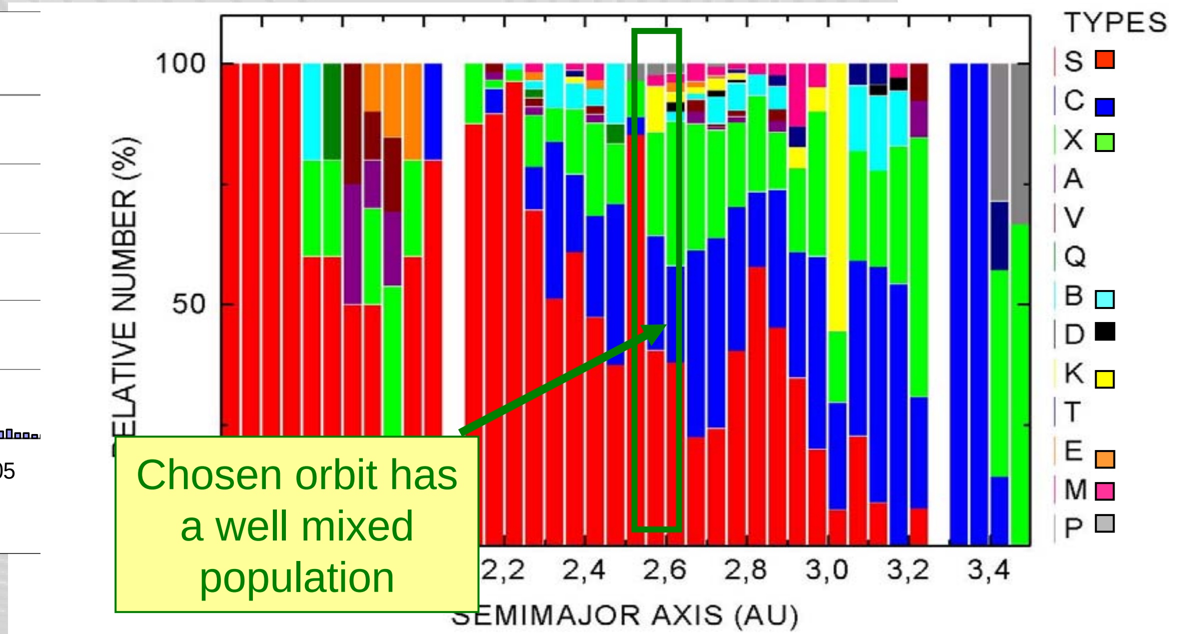


Orbit Selection

- Orbit at 2.6 AU chosen for its mixed population, high spatial density of asteroids and relative accessibility
- Flyby velocity limited to 5.0 km/s (>90% objects)

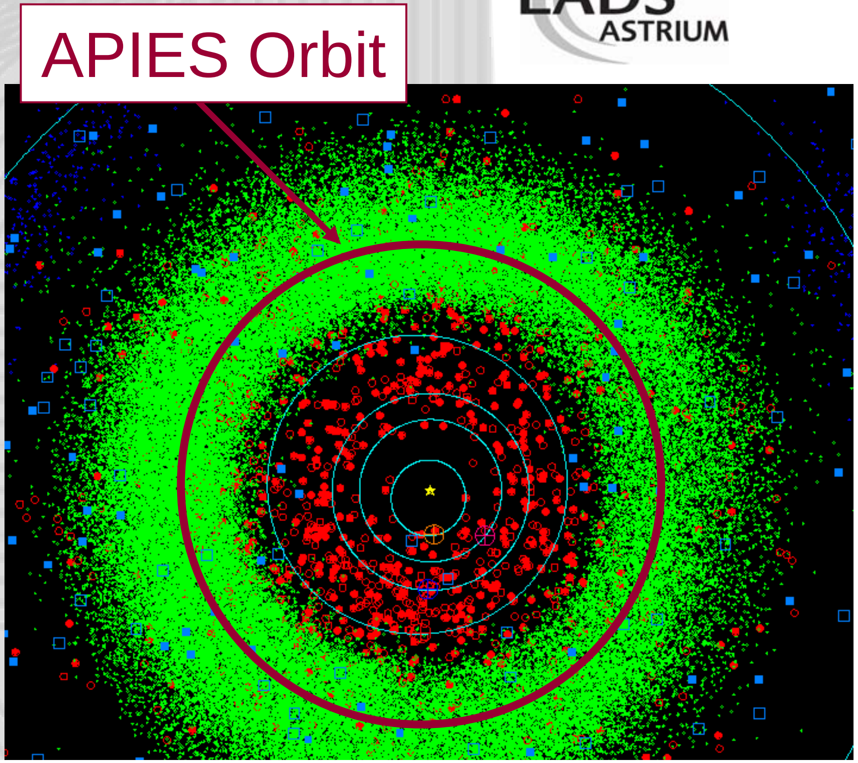


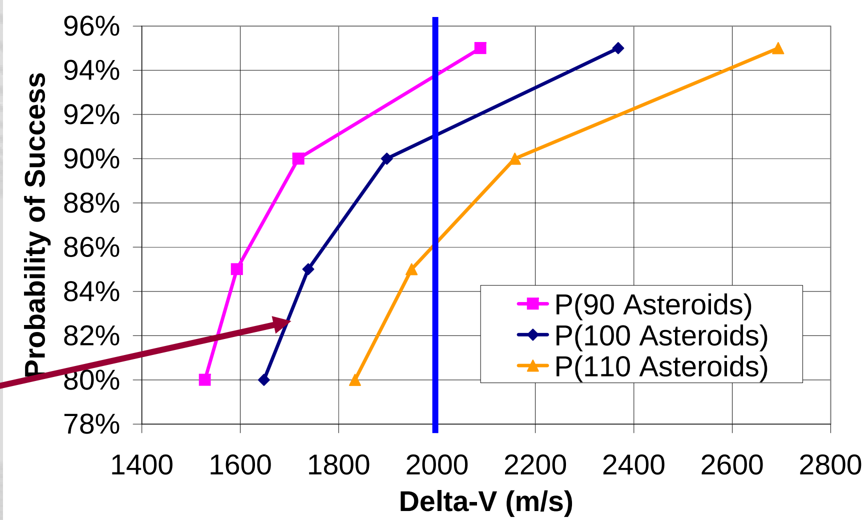




Orbit & Mission Design

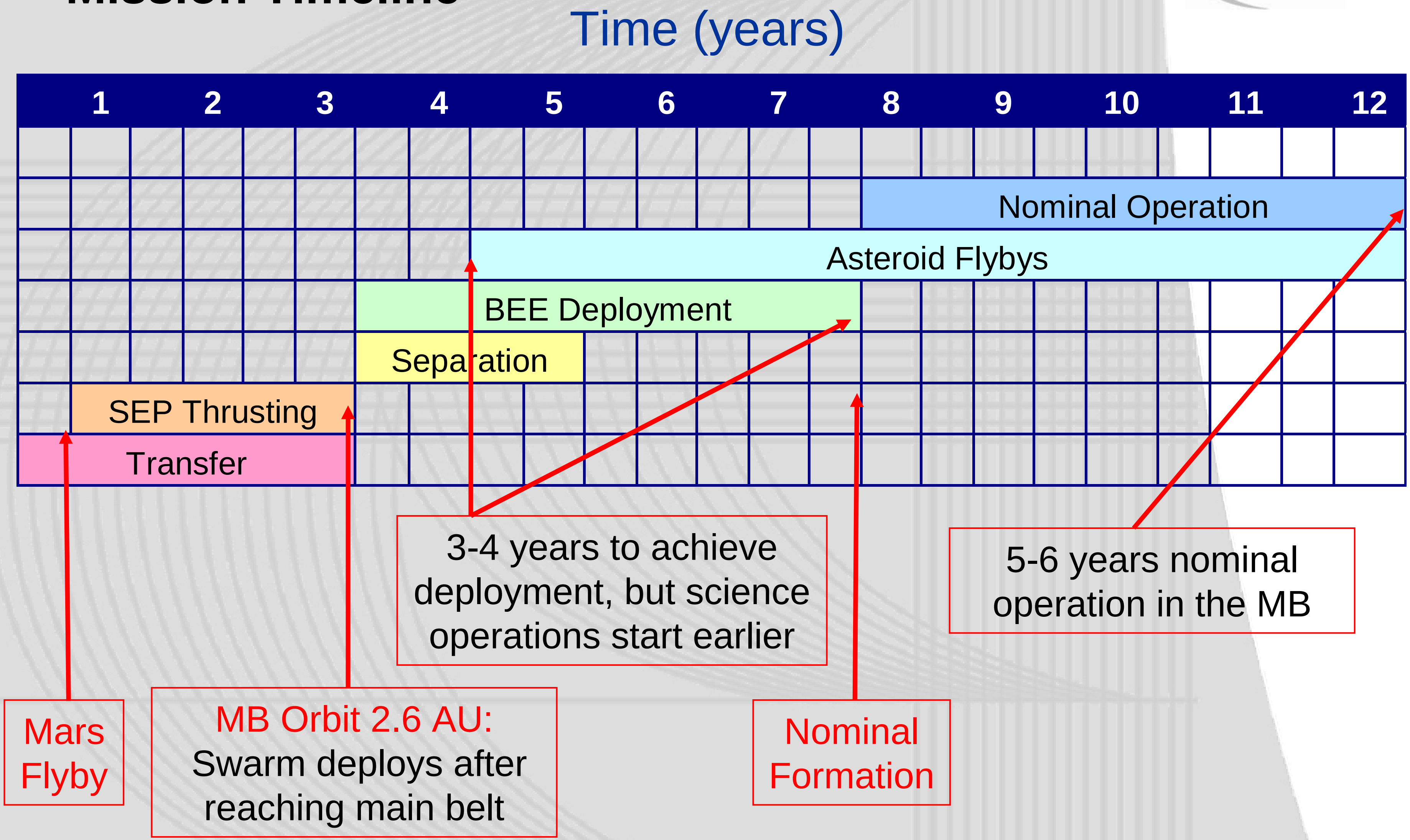
- Mission Constraints:
  - Soyuz-Fregat single launch
  - 12 Years mission duration
  - ⇒ 1400 kg launch mass with Mars gravity assist, 850 kg total for Swarm with SEP on HIVE S/C
  - ⇒ ~3 years to reach orbit + ~3 years for deployment needed
- Propulsion capability on each BEE S/C calculated against probability of 100 intercepts:
  - Statistical analysis over 6 years
  - 2 km/s for >90% confidence





Mission Timeline

12 Years Total
Mission Duration



Swarm Formation Design

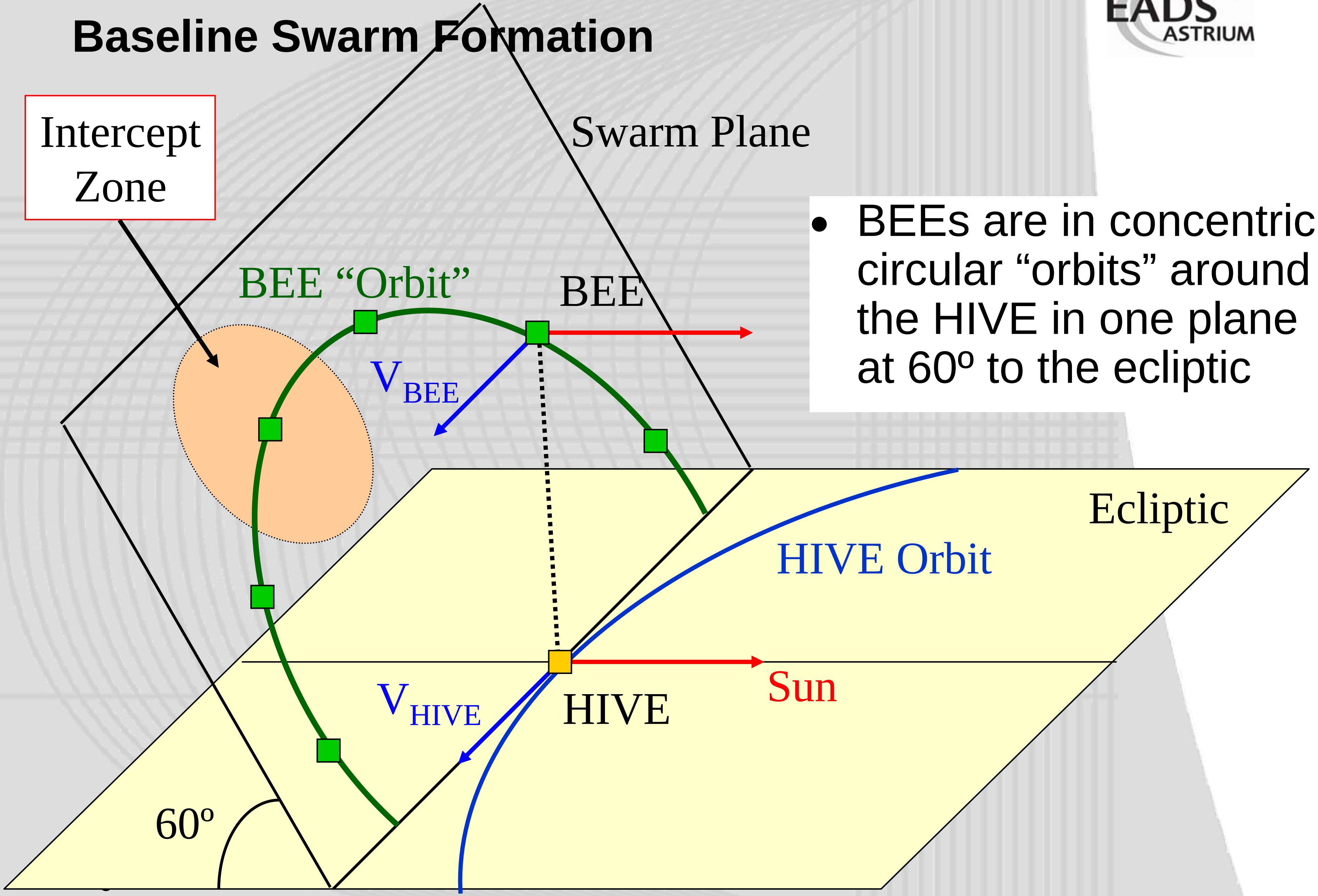
Key Drivers:

- Large cross-section to asteroid flux $\Rightarrow$ formation plane close to normal to flux direction
- Low deployment ΔV, low station-keeping ΔV
- Compact formation to ease communications

APIES Solution:

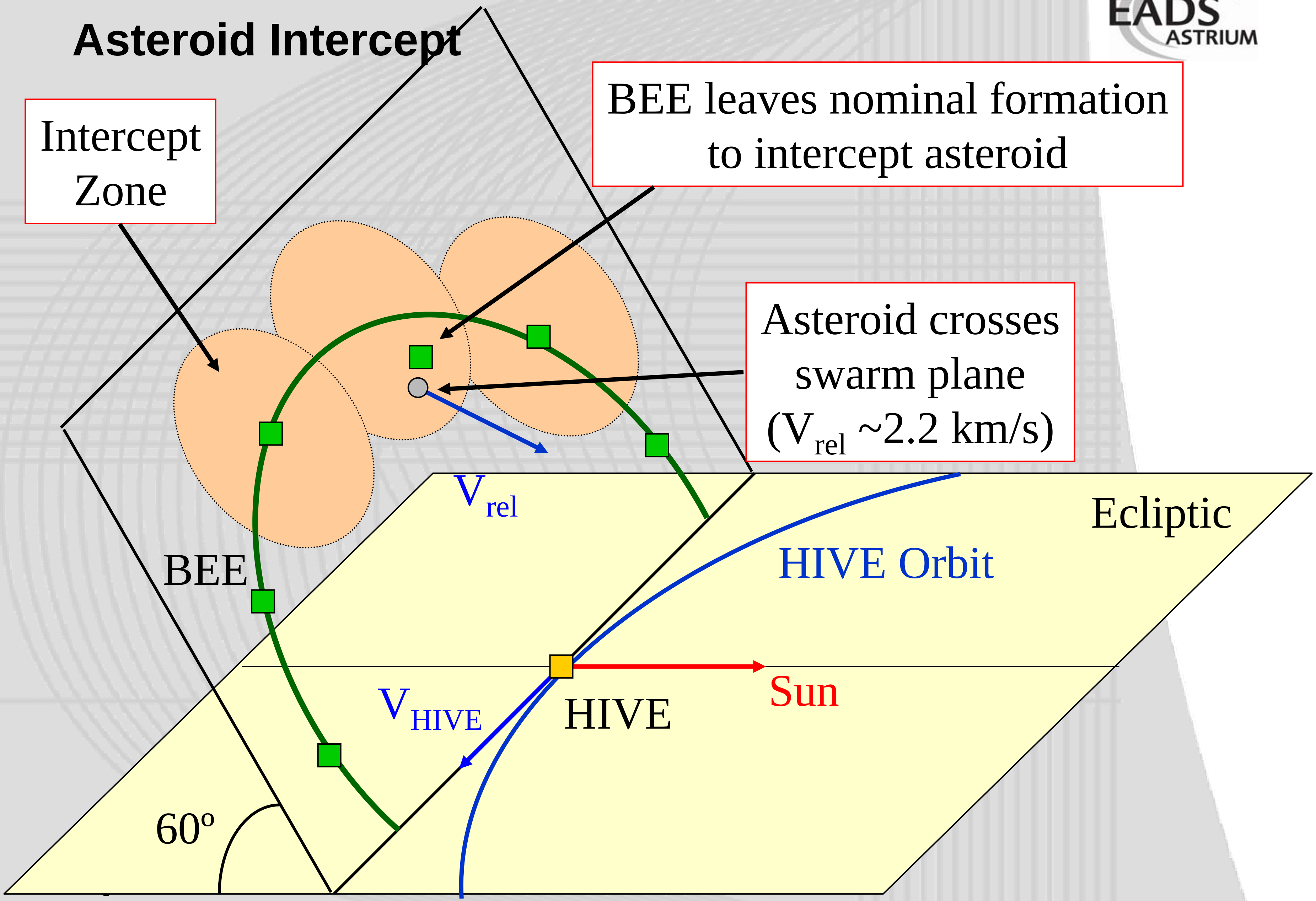
- Swarm nominal formation in a single plane at 60º to the ecliptic and containing HIVE velocity vector
- BEEs distributed in concentric circular rings around the HIVE, each at the centre of a circular “intercept zone”, where asteroid flybys occur
- BEE leave nominal formation to achieve intercepts

Baseline Swarm Formation

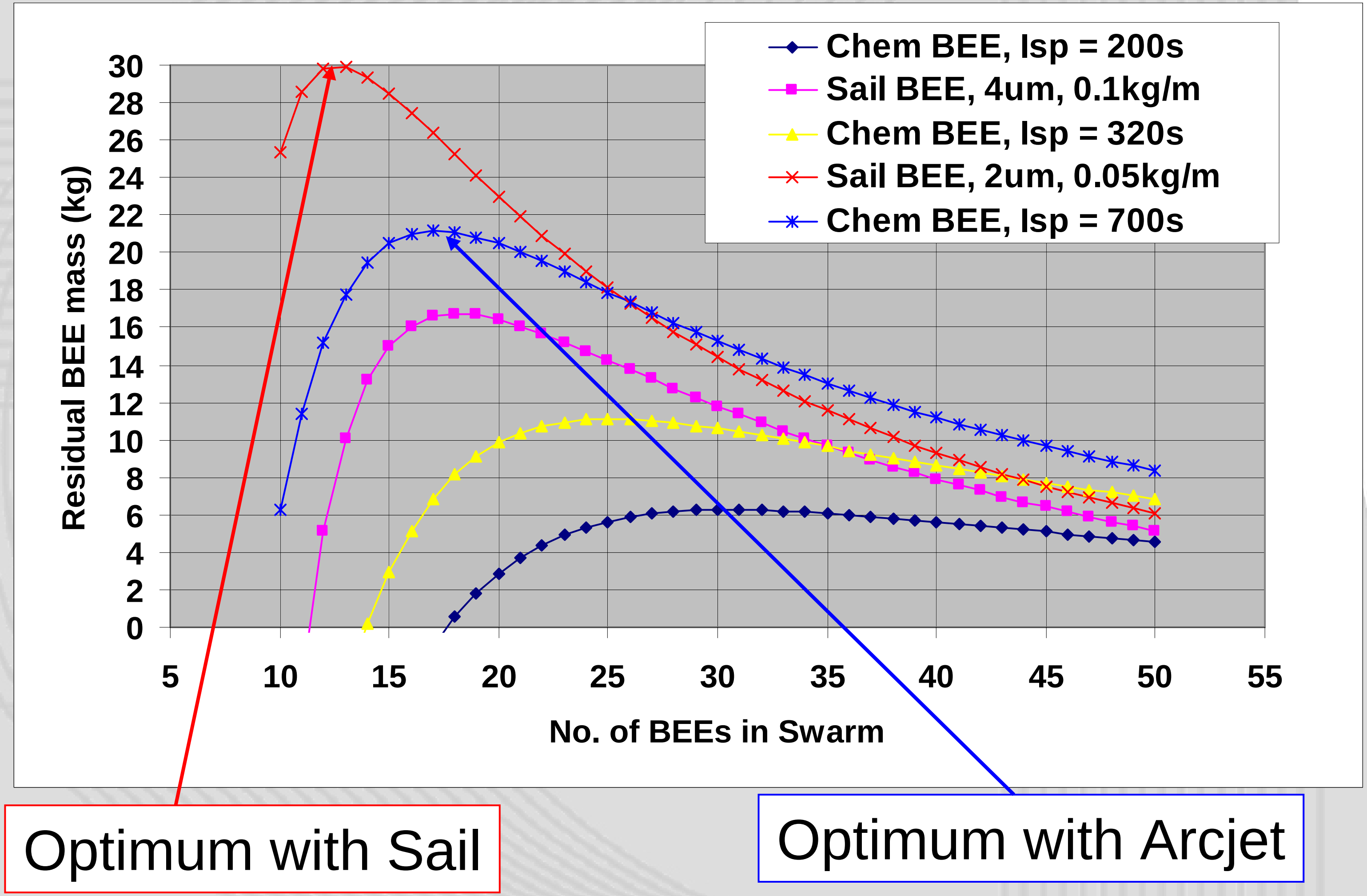


- BEEs are in concentric circular "orbits" around the HIVE in one plane at 60º to the ecliptic

Asteroid Intercept

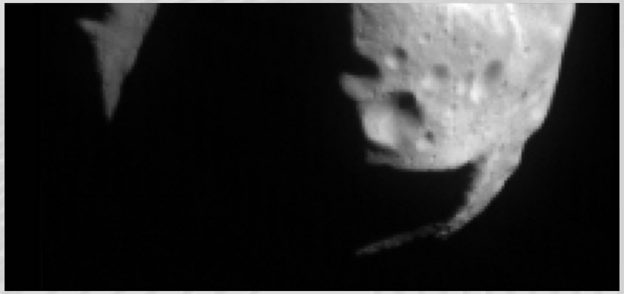


System Optimization:
BEE Propulsion Technology & Swarm Size

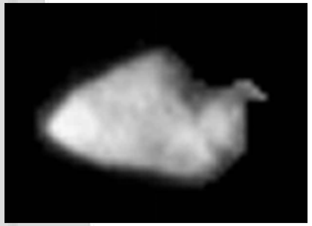


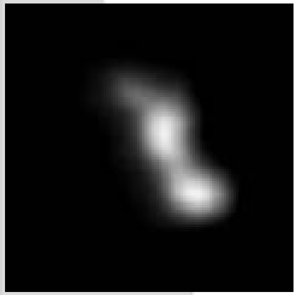
Arcjet selected because of manoeuvrability

Design Solutions:
Asteroid Flybys



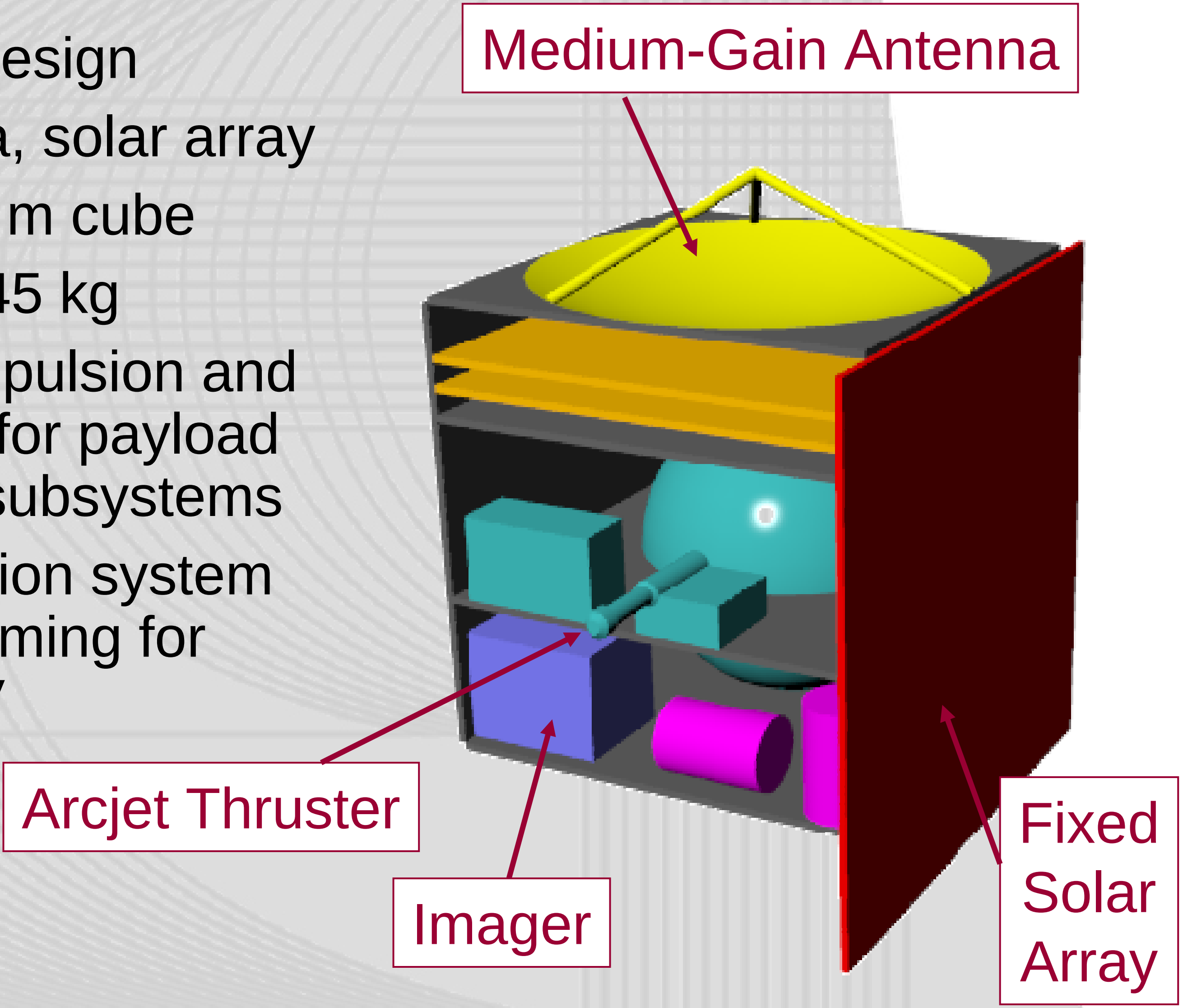
- Large swarm (19 BEEs) + Frequent flybys demand innovative solutions
- For each flyby:
  - Autonomous visual navigation to target on BEE using science payload (imaging camera)
  - Radio tracking of BEE from HIVE before & after flyby
  - Closed-loop tracking of asteroid during closest approach using BEE AOCS (steering microsat to point the imager)
  - Autonomous flyby operations on BEE (no intervention from the ground is possible)
  - Store of flyby data on the BEE and download to HIVE after completion of flyby operations for relaying back to Earth





BEE Spacecraft Summary

- Simple BEE design
- Fixed antenna, solar array
- BEE size: 0.6 m cube
- BEE mass: ~45 kg
- ~20 kg for propulsion and 25 kg remain for payload and all other subsystems
- Arcjet propulsion system as best performing for ~2000 m/s ΔV



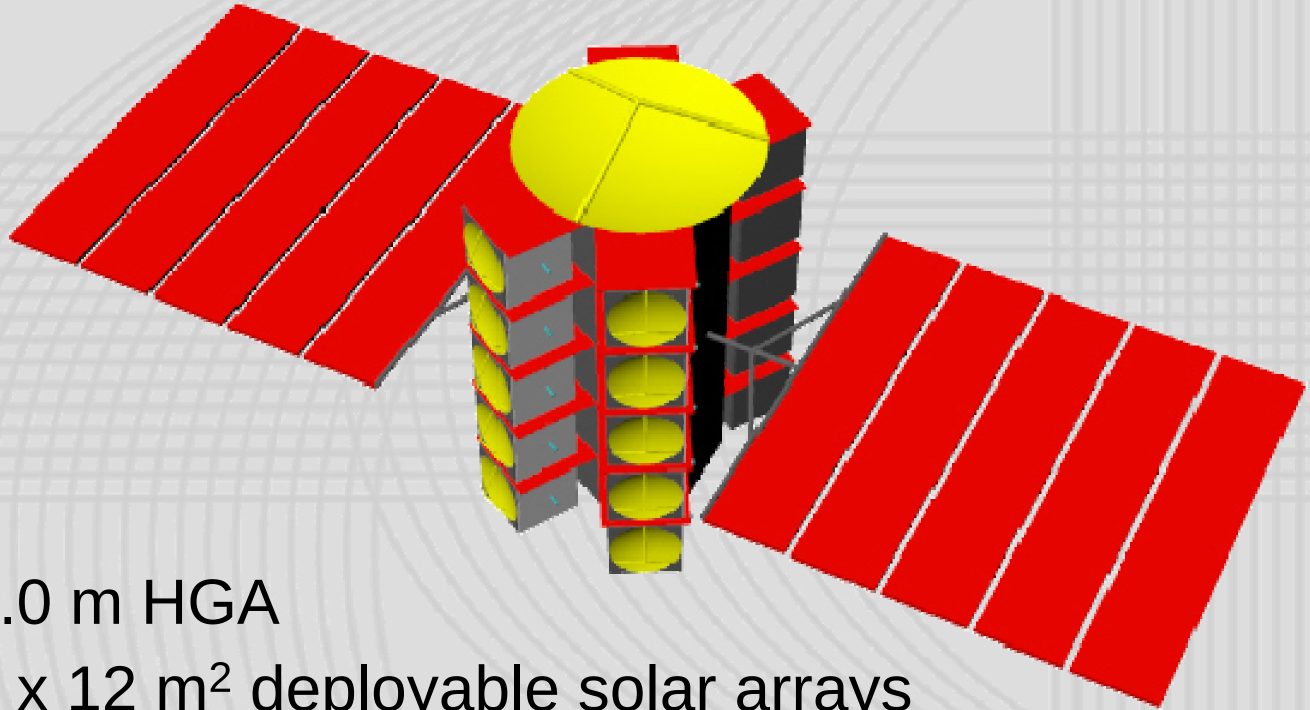
BEE Mass Budget Summary

- BEE wet mass:
  43.4 kg with margin
  38.0 kg w/o margin
- Allowable mass:
  44.7 kg, assuming 19-BEE swarm and 850 kg swarm mass
- ⇒ 6.7 kg margin available (17.6%)
- 11 kg propellant, corresponding to 2000 m/s ΔV on each BEE

BEE Mass Budget Summary	Arcjet BEE	
Payload	2.50	kg
Structure	3.30	kg
Propulsion	7.30	kg
Thermal	0.32	kg
Harness	0.50	kg
Power	4.07	kg
Communications	5.28	kg
AOCS + Electronics	6.28	kg
System Mass Margin	2.96	kg
Total s/c Dry Mass	**32.51**	**kg**
Propellants	10.88	kg
Total Mass @ Launch	**43.39**	**kg**

A low thrust (15mN), low power (100W) Arcjet system is the critical technology to develop to achieve this mass

HIVE Spacecraft Summary



- 2.0 m HGA
- 2 x 12 m^2 deployable solar arrays
- Hexagonal monocoque structure: ~3.5 m long
- BEEs accommodated on 4 out of 6 sides
- Total HIVE mass: 550 kg

APIES Cost Approach

Ambitious mission at low cost:

- Target cost-effective launcher (Soyuz-Fregat)
- Simple science payload (only what is essential)
- Dual use of science payload (imager/star tracker, radio science/communications)
- Highly autonomous operation (navigation, control & science measurements)
- Advanced technology when delivering key mass savings (propulsion, communications)
- Minimize communications with Earth (high data downlink rate through HIVE)
- Swarm mission: zero redundancy on each spacecraft + mass production

Conclusions

- APIES represents a novel approach to mission design and mission architecture, enabling new science and exploration beyond the means of conventional spacecraft designs
- Science goal is an integral part of mission optimization, affecting swarm, spacecraft and technology solutions
- The resulting mission has proven to be feasible with a realistic level of technology development
- APIES could study over 100 asteroids >5km in 6 years (one every 3 weeks) + probably image many more smaller objects!
- Similar concepts can be applied to other missions (e.g. Jupiter system exploration)

The APIES Team

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