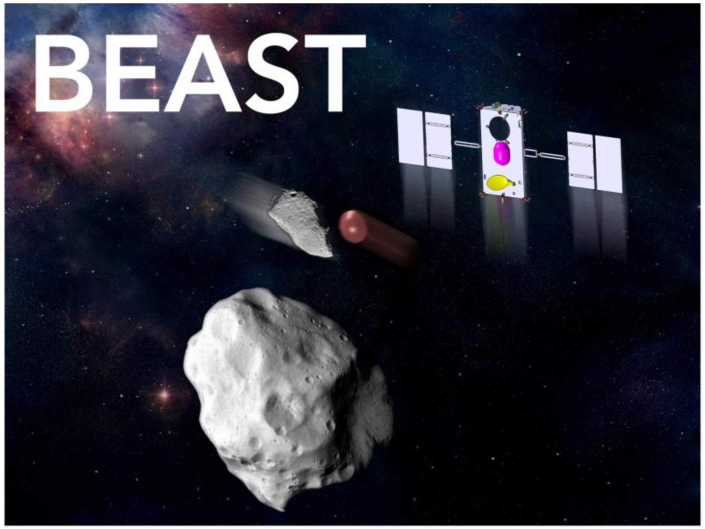
2013 IAA PLANETARY DEFENSE CONFERENCE

# BEAST

# BINARY ASTEROID ORBIT MODIFICATION






INNOVATING SOLUTIONS

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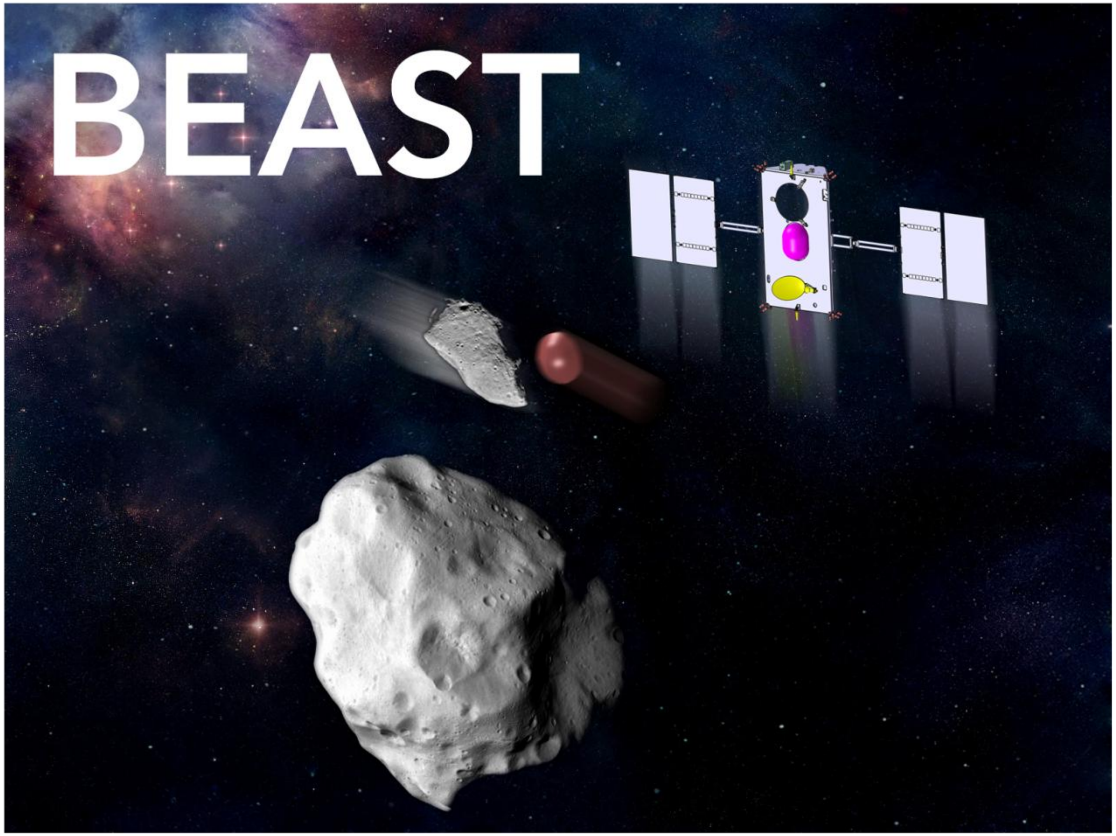

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# MISSION CONCEPT

# OBJECTIVES

ESA study description

- Modify and measure the orbital period of small secondary body of binary asteroid
- Overall mission cost below **150 M€**
- Reference scenario
  - Mass secondary 250 Ton (D > 5 m)
  - $\Delta$V 0.8 mm/s
  - Duration < 3 years

BEAST mission

- Demonstrate feasibility to perform impact and measure deflection
- Provide envelope of missions

 

# BEAST MISSION

Re-use commercial platform (cost-driven)

- Keep low cost of space segment
- Minimize risk of technology development

Reference mission architecture (preliminary trades)

- Single, chemically propelled SC
- Direct launch into escape trajectory
- Operational procedures based on ROSETTA experience
- Modified commercial platform carrying as payload
  - Impactor (“dead mass”) + release mechanism
  - Additional sensors for near-asteroid operations

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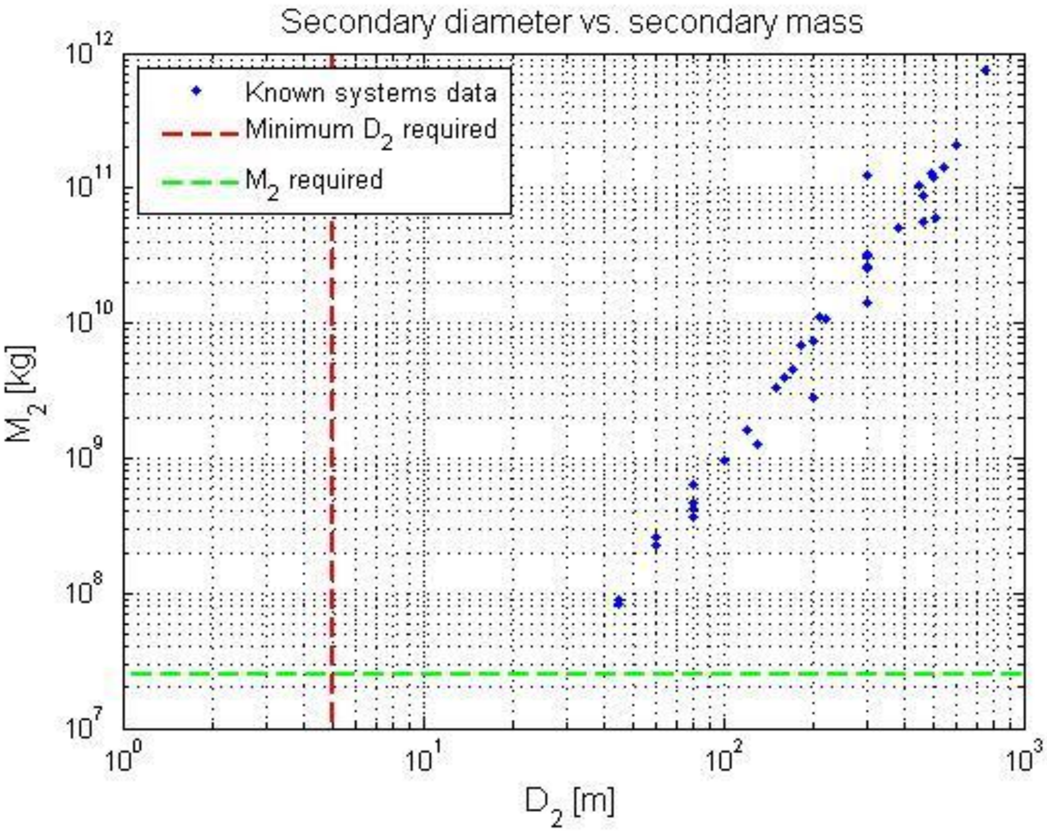
# ASTEROID SELECTION & IMPACT ANALYSES

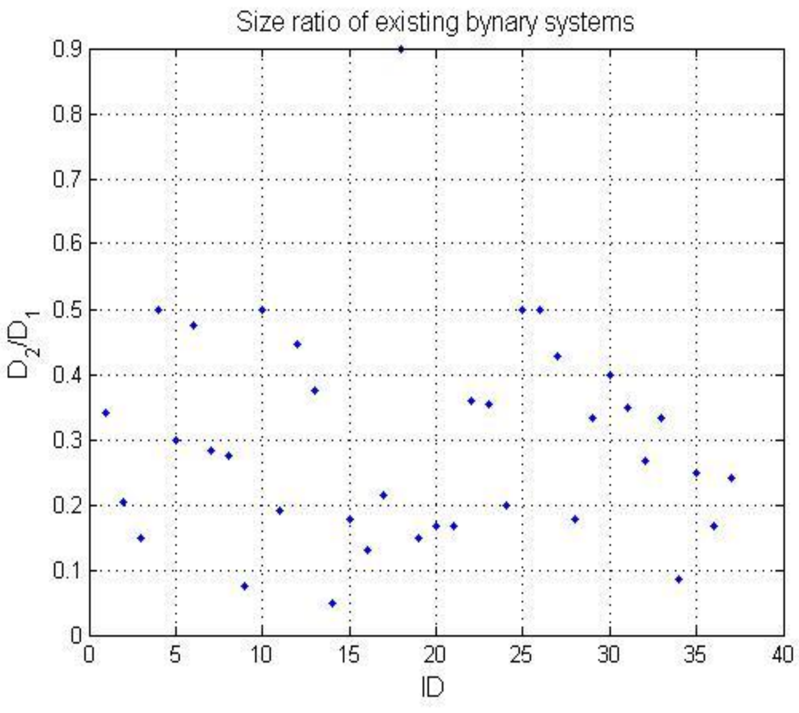
# BINARY ASTEROID ASSESSMENT

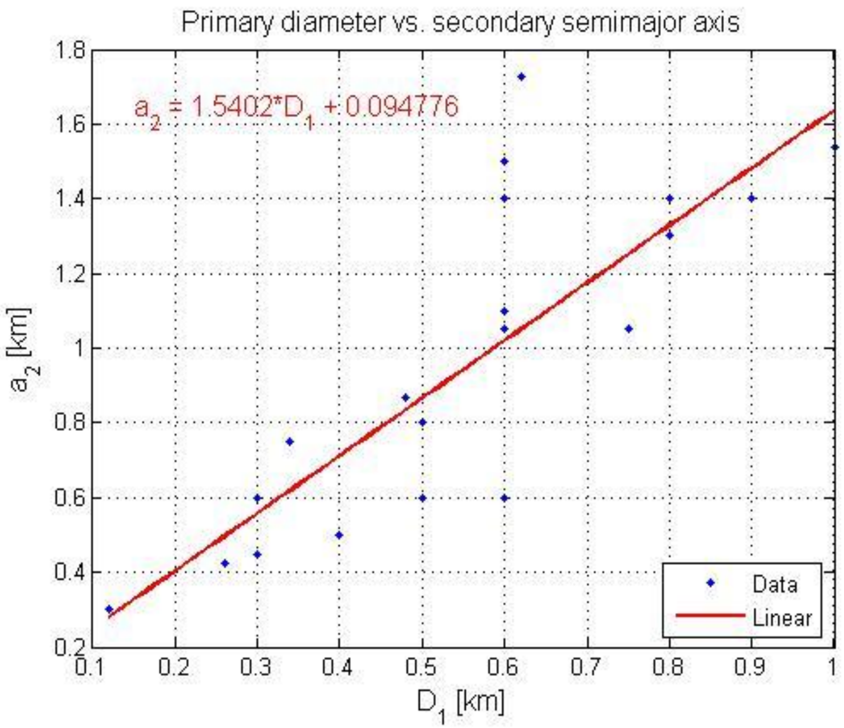
- Provide list of potential targets for mission analysis
- Starting point known binary asteroids
  - Larger mass and diameter than reference requirements
  - 'Deflectable' secondary (impactor momentum)



# POTENTIAL BINARY ASTEROIDS (1/2)

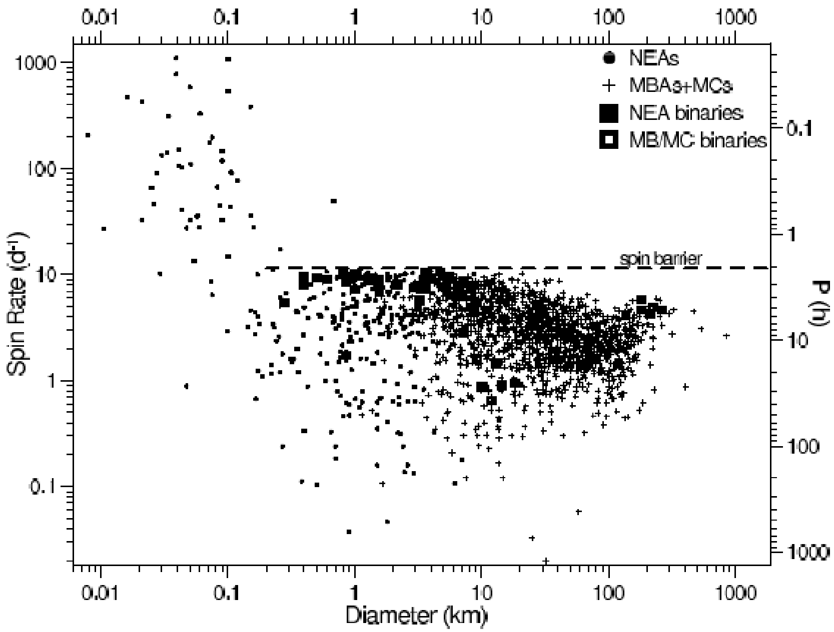
- Analysis of single asteroids that could host a secondary
  - Focus on small bodies
- Estimate envelope of binary system properties
  - Masses and diameters of primary and secondary
  - Orbit of secondary around primary



# POTENTIAL BINARY ASTEROIDS (2/2)

- Small asteroids with some likelihood to have suffered rotational disruption
  - Estimate angular momentum of binary asteroids (within envelope)
  - Estimate primary asteroid rotational angular momentum
  - Identify current single asteroids matching angular momentum
- Three groups of asteroids considered for mission design




| Heliocentric parameters | 2009 UD |
|---|---|
| $D_2[m]$ | 5.000 |
| $D_1[m]$ | 16.799 |
| $M_2[kg]$ | 2.500E+05 |
| $M_1[kg]$ | 8.460E+06 |
| $a_2[m]$ | 120.650 |

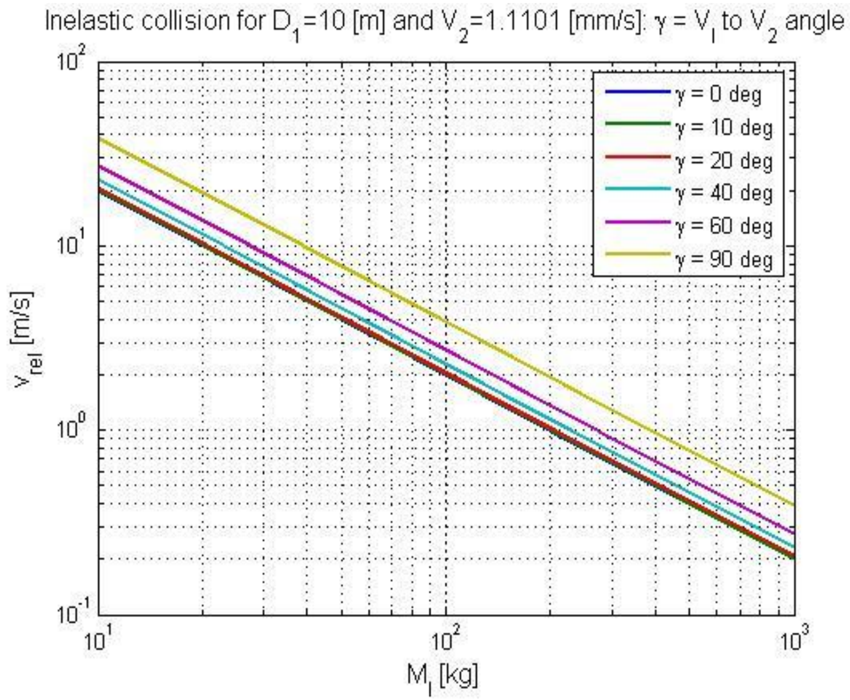
| Heliocentric parameters | 54509 YORP 2000 |
|---|---|
| $D_2[m]$ | 20.000 |
| $D_1[m]$ | 67.195 |
| $M_2[kg]$ | 2.500E+05 |
| $M_1[kg]$ | 8.460E+06 |
| $a_2[m]$ | 198.272 |

# MOMENTUM TRANSFER & MOID

## Momentum transfer analysis

- Definition of envelope for asteroid selection and mission design
- Conservative analyses for impactor mass
  - Perfect inelastic collision (blunt-shaped impactor)
  - No momentum enhancement due to ejecta
- Small 'misalignment' aimed for orbital period change



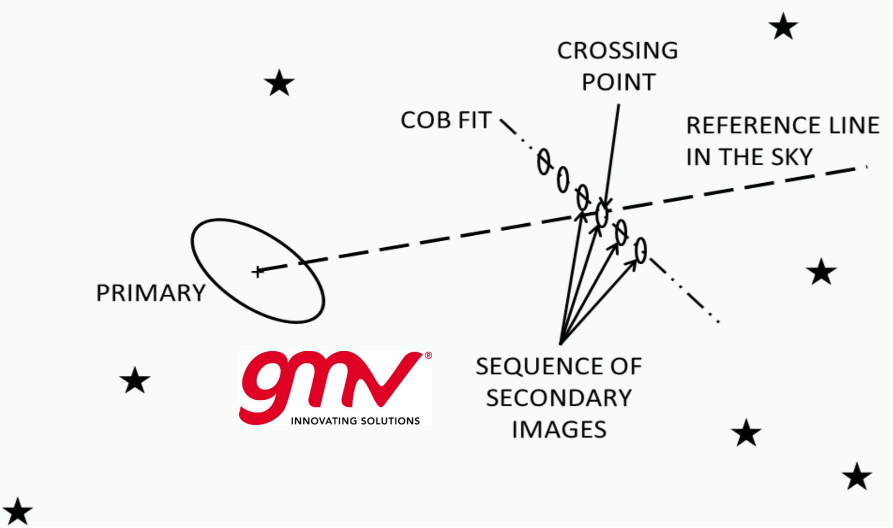

## MOID variation

- Worst case scenario
- Reference candidates show very small MOID variation
  - **~0.1 m** (worst case)

# IMPACT $\Delta$V ESTIMATION (2/2)

- Analysis of feasible techniques to estimate effect of impact
  - Determination of orbital period change due to impact
  - Ground based estimation using **camera only** measurements
- Observation of secondary asteroid transits
  - Several revolutions to improve accuracy (care of perturbations)
- Delta-V to secondary might be estimated with RMS < 3%
  - Large primaries (secondary period < 1 day)
  - For small primaries the delta-V should be smaller to avoid escape




| | | |
|---|---|---|
| **Period change** | 2.14 h | 0.65 h |
| **Relative change of the period** | 11 % | 4.6 % |
| **RMS of the measured period** | 111 s | 60 s |
| **RMS of the relative error of the period change** | 1.44 % | 2.56 % |

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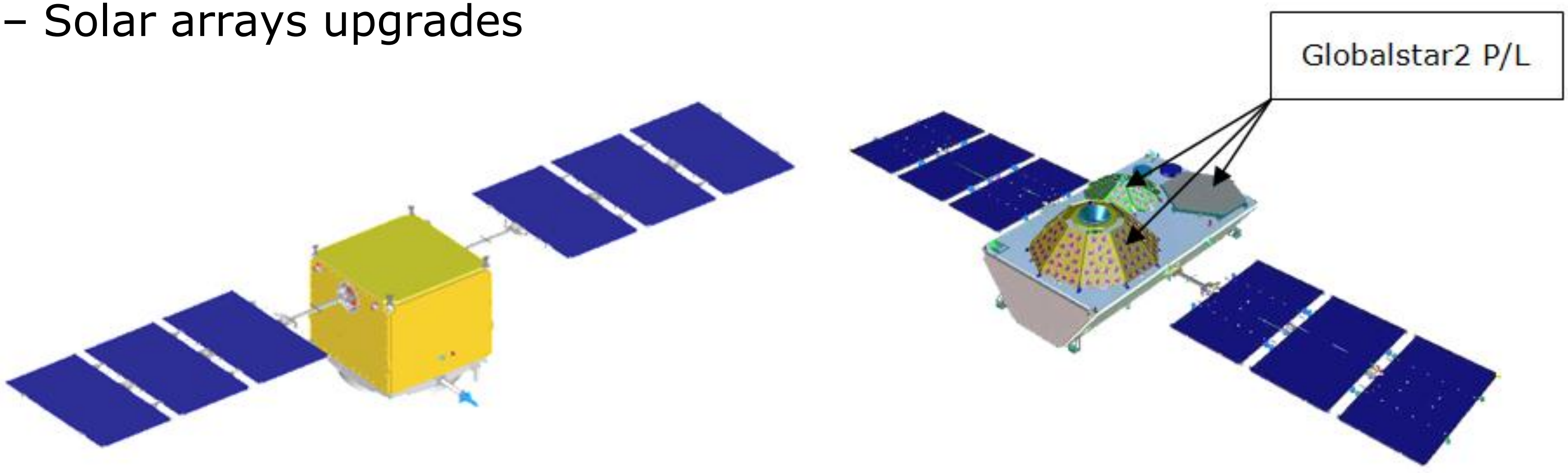
# SPACE SEGMENT

# MAJOR TRADE-OFFS

- Cost-driven system trades
- Commercial platform re-use (Iridium or Proteus Mark-II)
  - Direct escape launch (Soyuz Fregat 2-1b)
  - Mono-propellant propulsion system
  - Impactor and GNC equipment included as payload
- Major remaining system trades
  - Propellant tank upgrades
  - Solar arrays upgrades



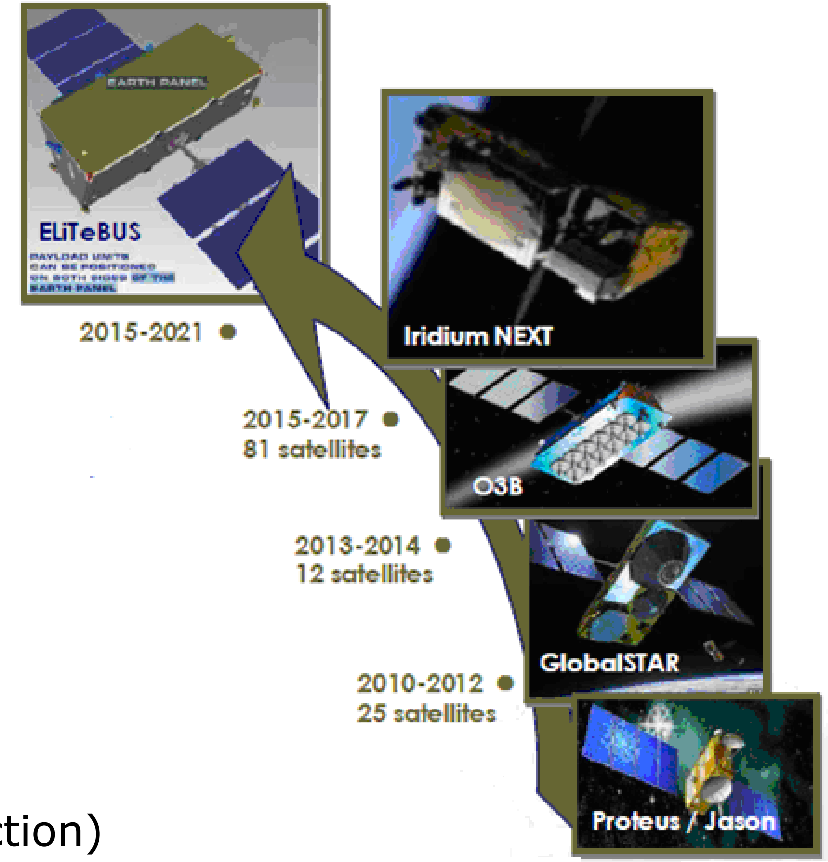

Proteus Mark 2 platform (without any P/L)

Iridium Platform (with Globalstar2 P/L)

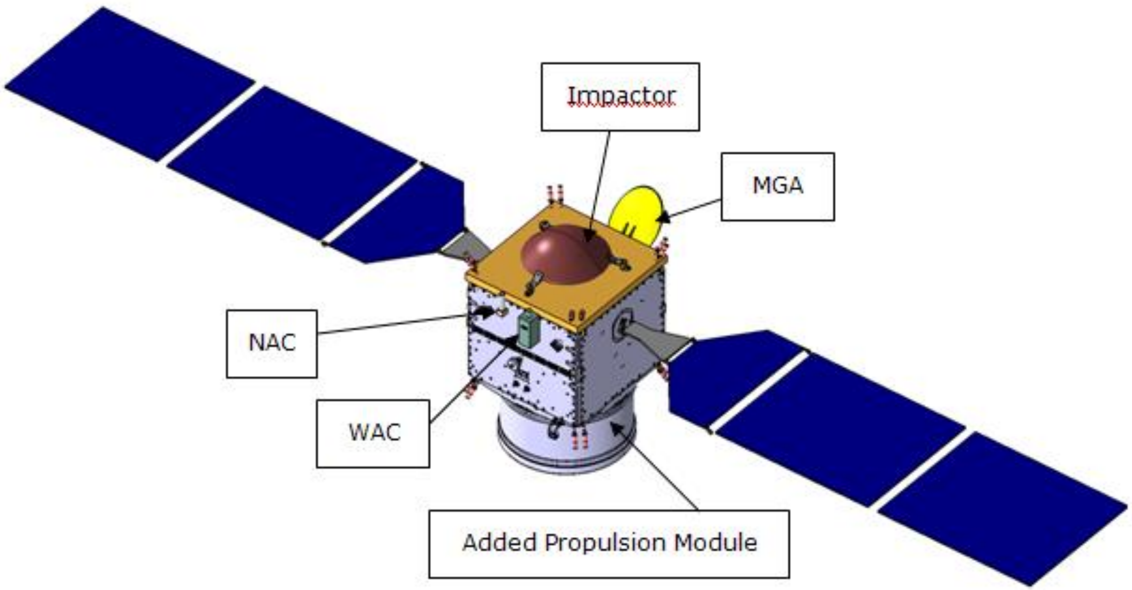
# CONSIDERED PLATFORMS

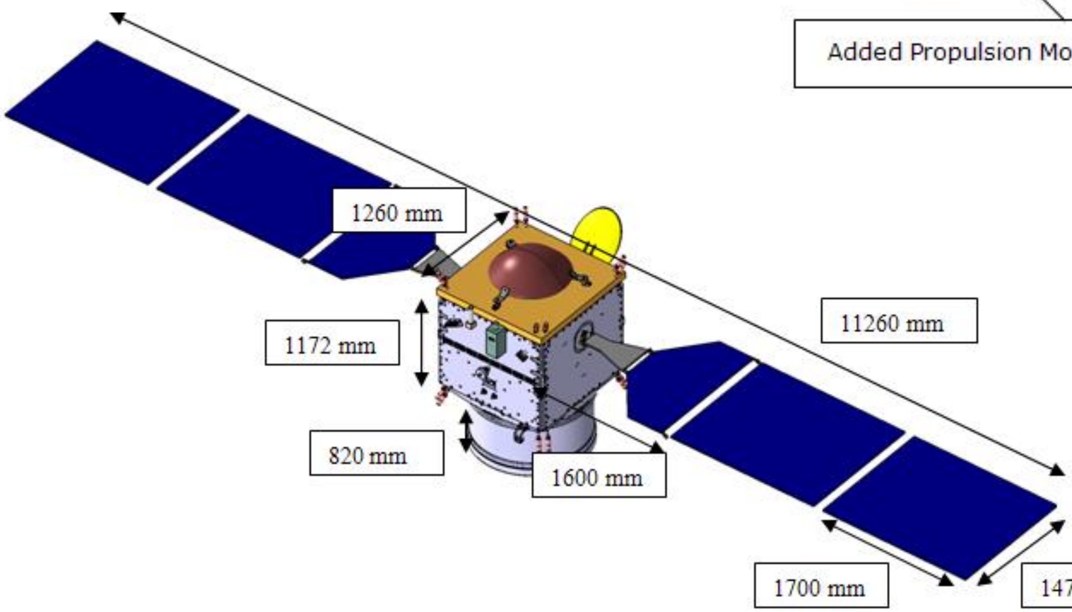
- Proteus Mark 2
  - **Case P1**
    - 400 kg hydrazine
    - 10 m² solar array
- Iridium NEXT platform cases
  - **Case I1**
    - 300 kg hydrazine
    - 10 m² solar array
  - **Case I2**
    - 160 kg hydrazine (no tank upgrade)
    - 10 m² solar array
  - **Case I3**
    - 160 kg hydrazine (no tank upgrade)
    - 5 m² solar array (solar array area reduction)

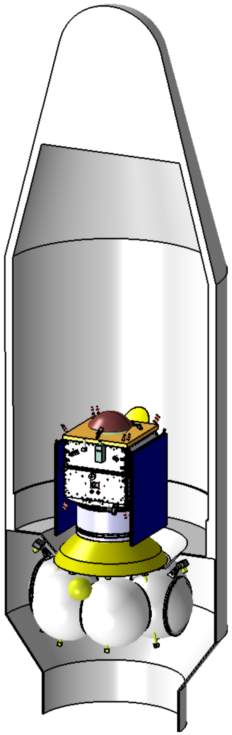


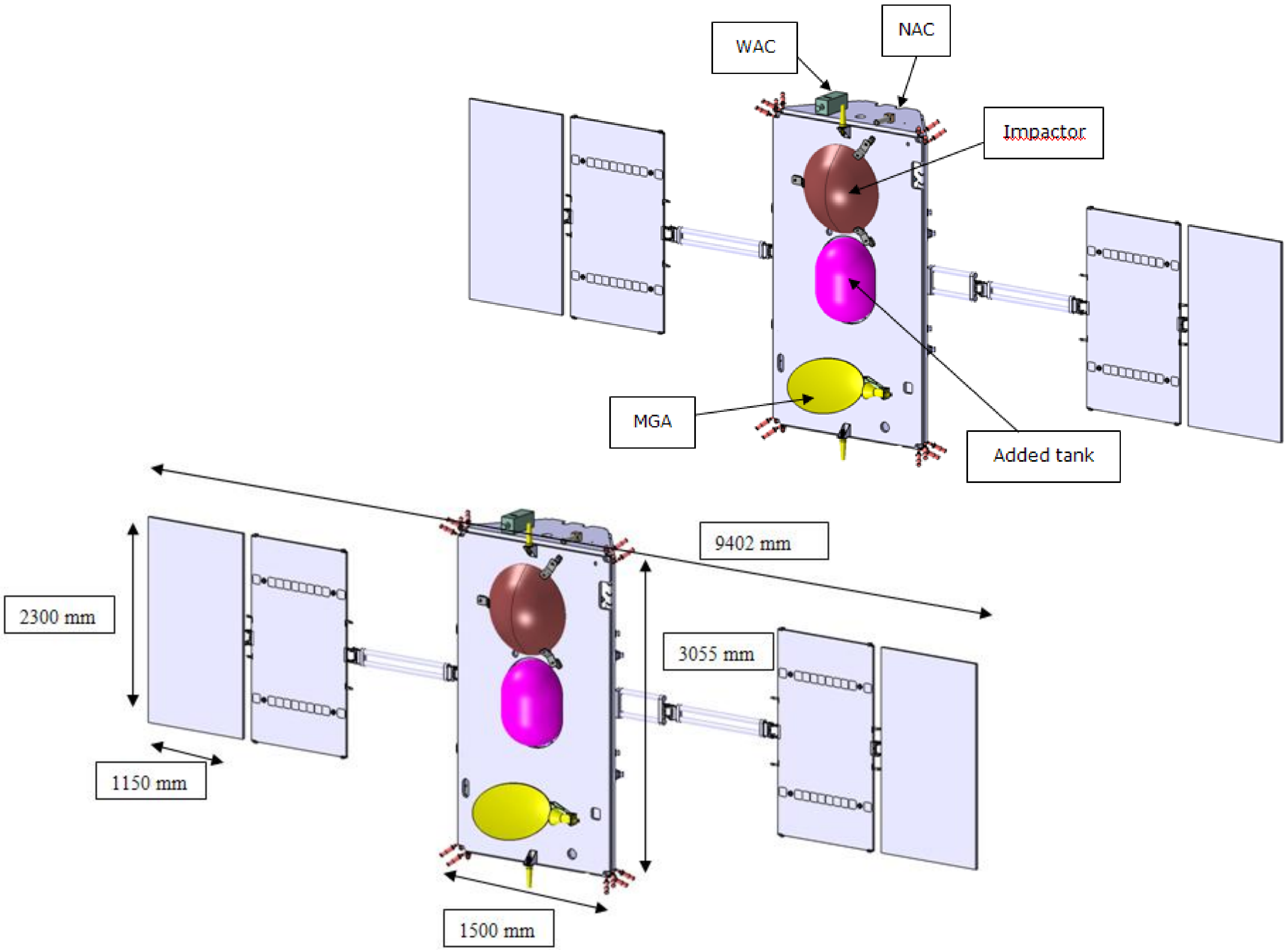
# PROTEUS MARK 2 OVERVIEW

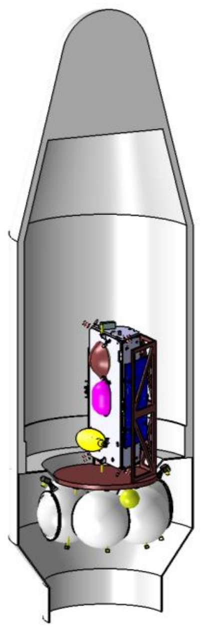


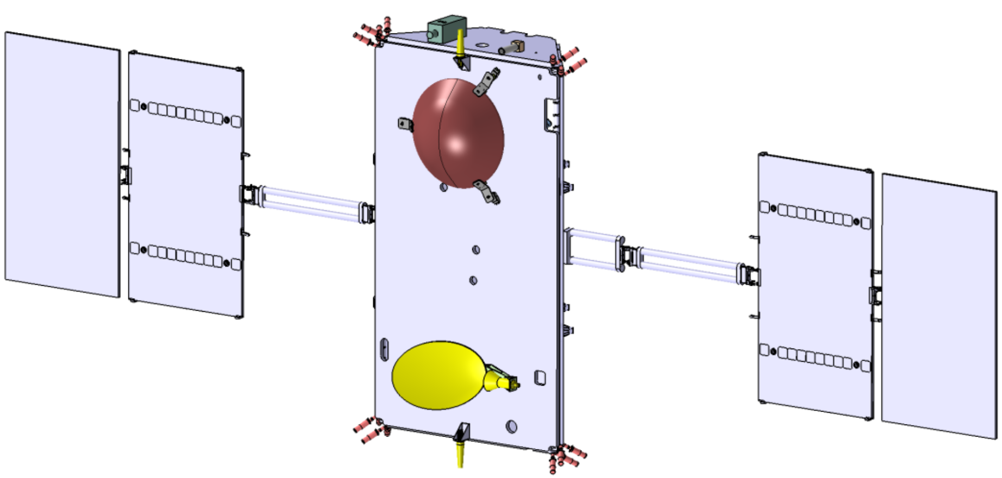
# IRIDIUM NEXT I1 OVERVIEW



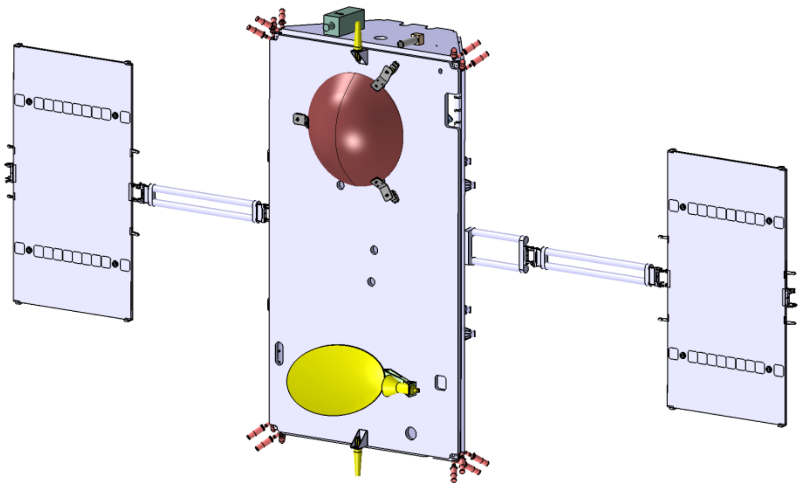



# IRIDIUM NEXT I2 & I3 OVERVIEW

**Iridium NEXT case I2**



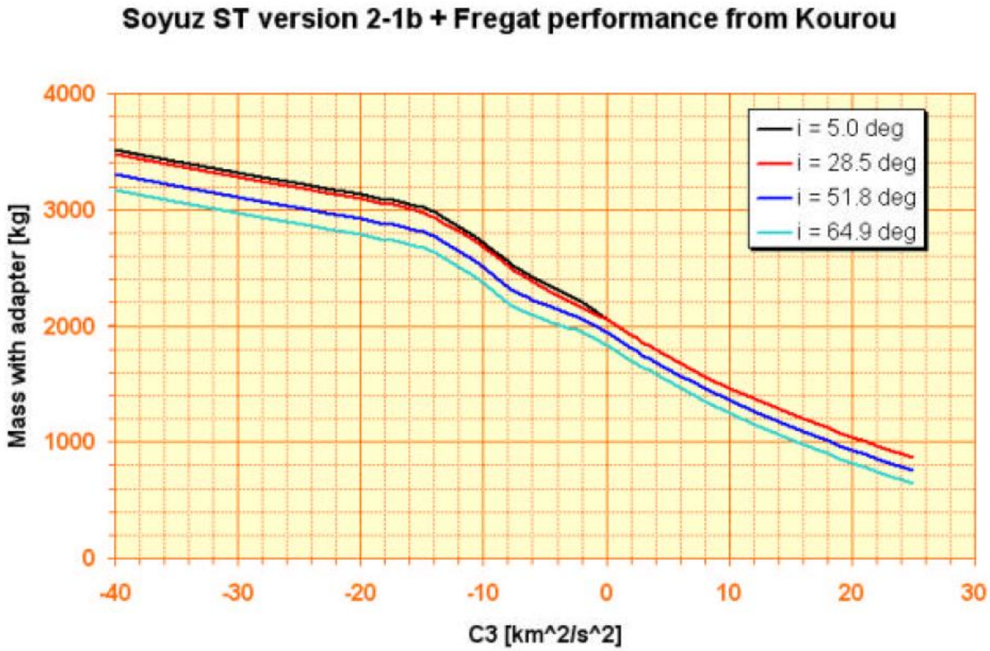
**Iridium NEXT case I3**



# MISSION ANALYSIS

- Exhaustive search of trajectories
  - Three groups of asteroids
  - Direct transfer and $\Delta$V-EGA
  - Mono-prop & bi-prop
  - Four platforms
- Constraints
  - Launcher capability
  - Duration
  - Propellant mass
  - Max. distance to Sun
- Navigation analyses
  - Radiometric measurements only (no $\Delta$DOR)

| Platform | P1 | I1 | I2 | I3 |
|---|---|---|---|---|
| Dry Mass [kg] | 719.9 | 646.8 | 620.4 | 598.3 |
| Propellant Mass [kg] | 400 | 300 | 160 | 160 |
| Adaptor Mass [kg] | 110 | 140 | 140 | 140 |
| Launch Mass [kg] | 1229.9 | 1086.8 | 920.4 | 898.3 |



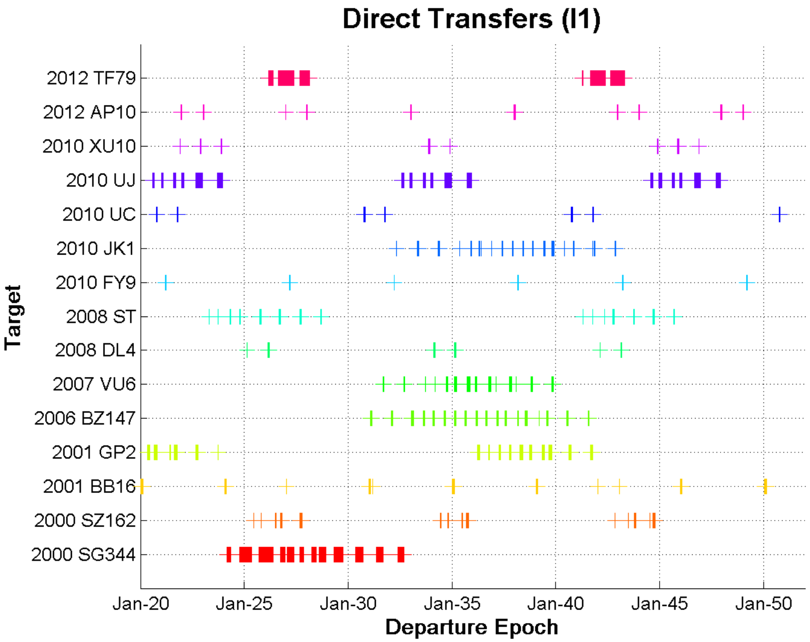

 

# MISSION ANALYSIS SUMMARY

- Different asteroids reachable by Proteus and Iridium I1
  - Iridium I2 and I3 much less capable (low delta-V)
- Bi-propellant would increase the reachable targets
- Different targets reached with ΔV-EGA trajectories
  - Few years of duration increase (1:1, 4:3, 3:2)
  - Different effect on different platforms

## Direct Mono-prop

| Platform | P1 | I1 | I2 | I3 | All | Total Asts |
|---|---|---|---|---|---|---|
| Group I | 0 | 0 | 0 | 0 | 0 | 27 |
| Group II | 6 | 7 | 3 | 1 | 8 | 13 |
| Group III | 82 | 83 | 53 | 34 | 96 | 131 |
| Total | 88 | 90 | 56 | 35 | 104 | 171 |



# ADDITIONAL PAYLOAD CAPABILITY

- GNC cameras (WAC + NAC) considered in the power budget
- 257 W for payload are available during proximity operations
- Most asteroids show mass margin for additional payload (science experiments or technology demonstrations)

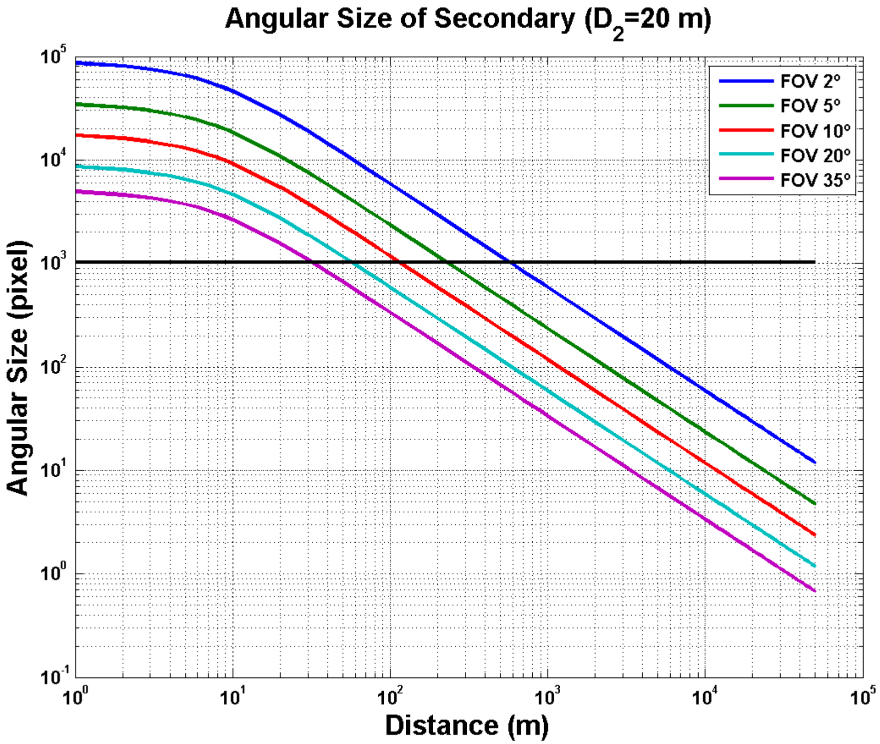
| NEA | (P1) Extra Mass [kg] | (I1) Extra Mass [kg] | (I2) Extra Mass [kg] | (I3) Extra Mass [kg] |
|---|---|---|---|---|
| 2000 SG344 | 801.2 | 846.0 | 872.4 | 894.5 |
| 2000 SZ162 | 362.4 | 404.7 | 369.7 | 391.8 |
| 2001 BB16 | 344.9 | 390.8 | 417.2 | 439.3 |
| 2001 GP2 | 622.0 | 666.4 | 692.8 | 714.9 |
| 2006 BZ147 | 474.8 | 521.4 | 547.8 | 502.8 |
| 2007 VU6 | 490.0 | 486.1 | 137.9 | 160.0 |
| 2008 DL4 | 472.2 | 519.5 | 467.0 | 489.1 |
| 2008 ST | 460.2 | 506.5 | 532.9 | 555.0 |
| 2010 FY9 | 171.3 | 207.4 | 107.0 | 129.1 |
| 2010 JK1 | 208.8 | 206.6 | 193.1 | 130.2 |
| 2010 UC | 373.0 | 420.9 | 242.2 | 264.3 |
| 2010 UJ | 602.6 | 649.9 | 661.6 | 683.7 |
| 2010 XU10 | 460.9 | 507.2 | 533.6 | 555.7 |
| 2012 AP10 | 298.6 | 345.2 | 371.6 | 393.7 |
| 2012 TF79 | 636.5 | 603.7 | 57.9 | 80.0 |

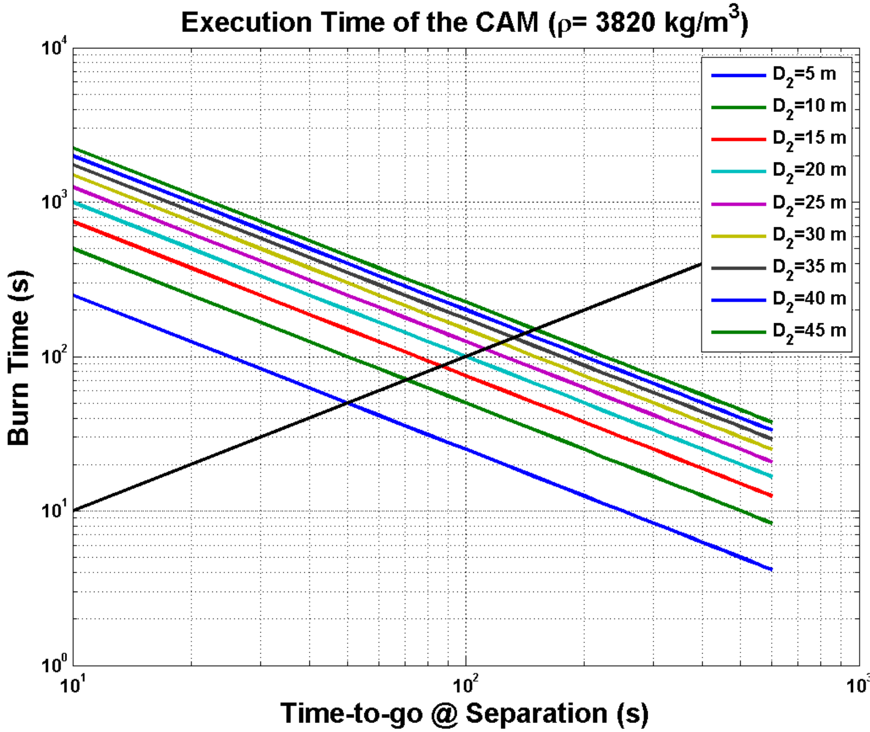
# GNC ASSESSMENT

- Nominal equipment from commercial platform
  - 4 reaction wheels (8 Nms, 75 mNm)
  - 2 IMU
  - 3 star trackers plus 2 electronic boxes (Sodern Hydra model)
  - 2 coarse sun sensors
- Propulsion: 8 (+8 redundant) 20 N mono-prop
- Additional equipment
  - 1 (+1 redundant) Wide Angle Camera
  - 1 (+1 redundant) Narrow Angle Camera
  - 1 FPGA for IP with HW/SW algorithms implementation
- Spare room for additional sensors (radar altimeter)
- GNC for impact phase is most critical
  - Fully autonomous (on board estimation of time-to-impact)
  - Divert manoeuvres (predictive impulsive) to cancel impact radius
  - Centre-of-brightness estimation from image processing

# IMPACT PHASE ASSESSMENT

- FOV driven by secondary size & distance at last manoeuvre
- No detectability problems for faintest secondary ($D_2$ = 5 m)
- Resolvable binary system with WAC and close orbit (100 m)
- CAM limits minimum time-to-go for impactor release

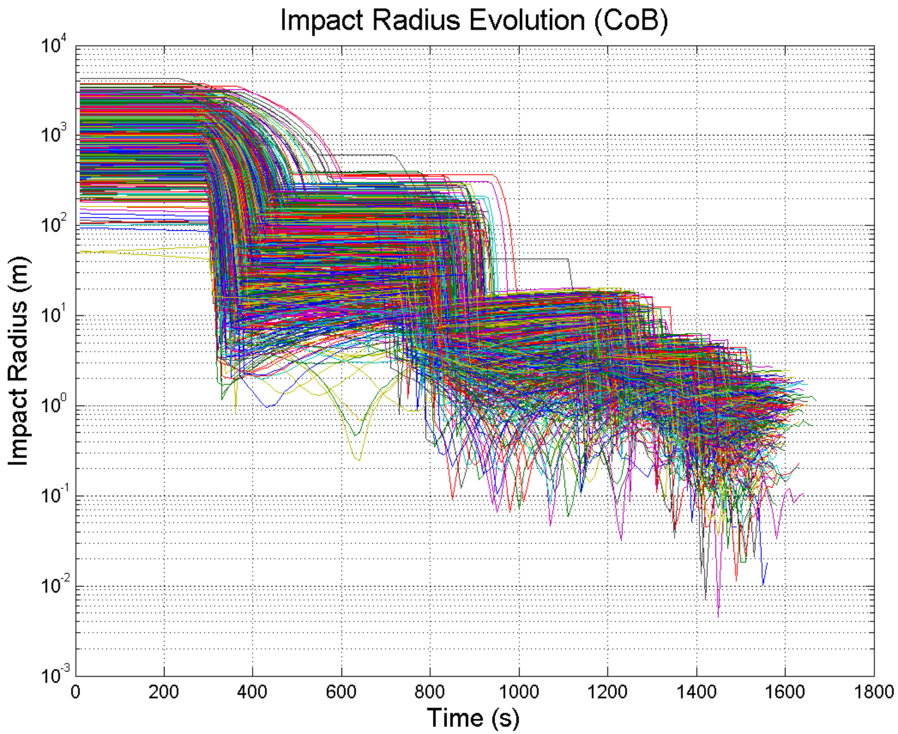


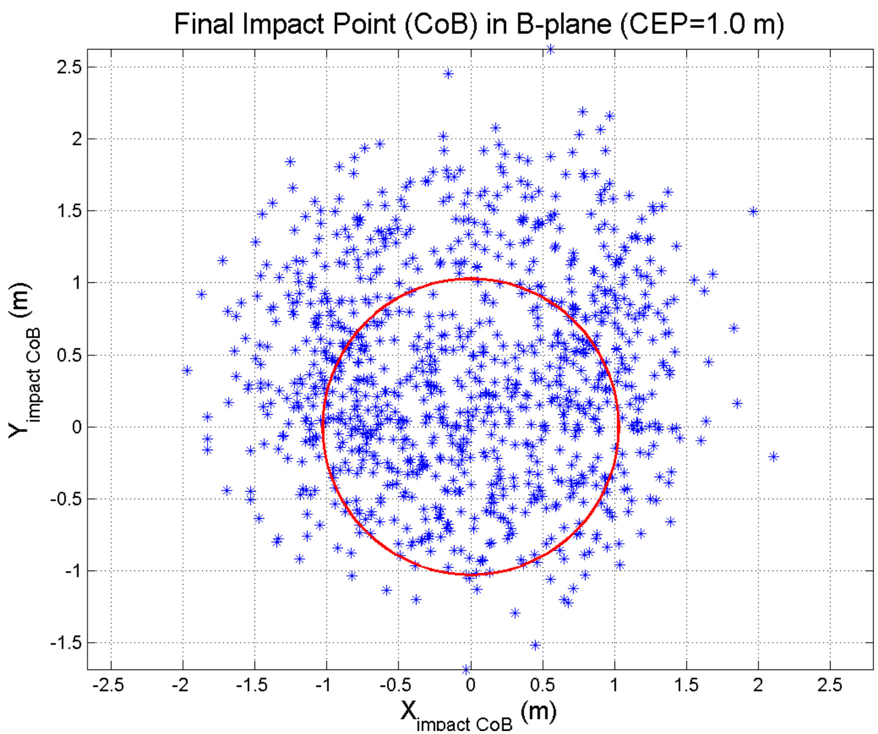



# IMPACT PERFORMANCES

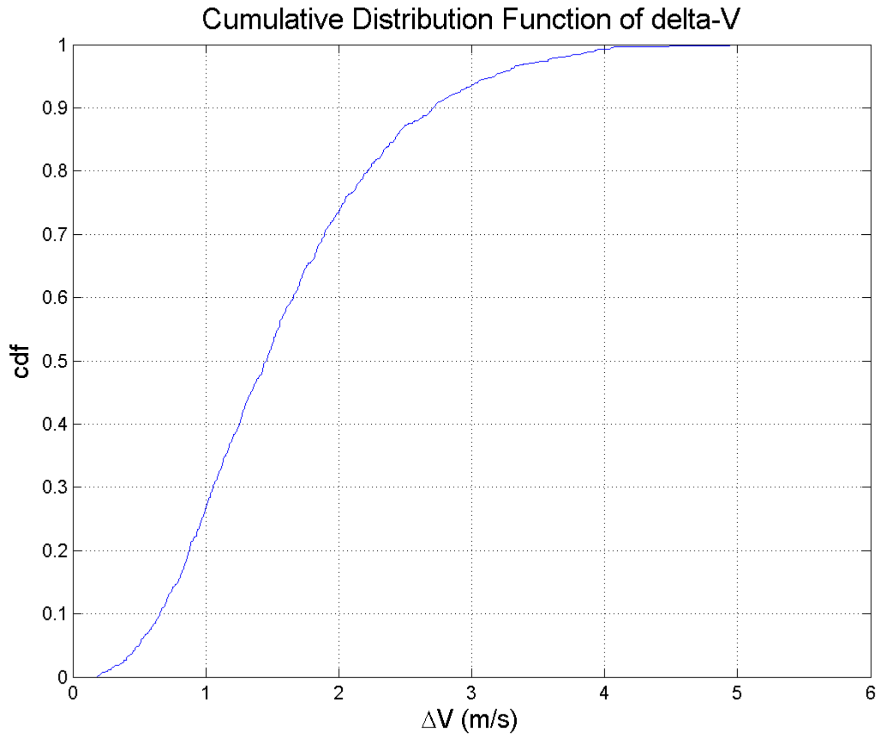
- Closed loop simulation of impact phase
  - Start at safe haven with large initial dispersion (1 km)
  - Relative velocity 20 m/s (tangential impact sought)
  - Target 5 m diameter
  - Critical parameter is the time-to-go at separation

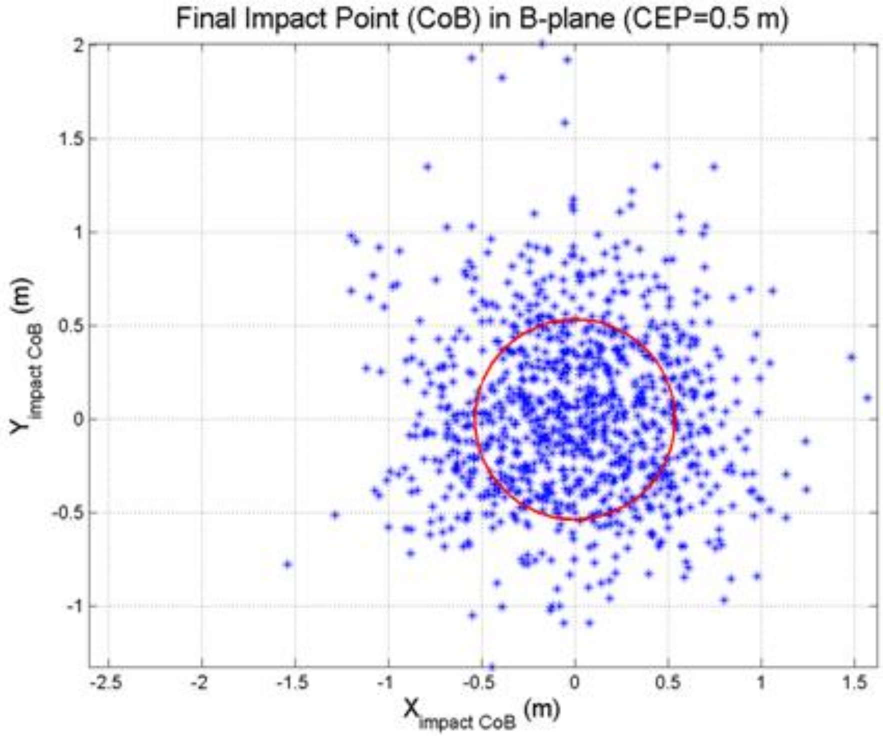


# IMPACT PERFORMANCES

- Simulations show max time of separation is 60 s
- Major sources of error
  - Manoeuvre execution errors (thrusters misalignment, MIB and noise)
  - Navigation errors from IP and poor observability at small miss dist.



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# CONCLUSIONS

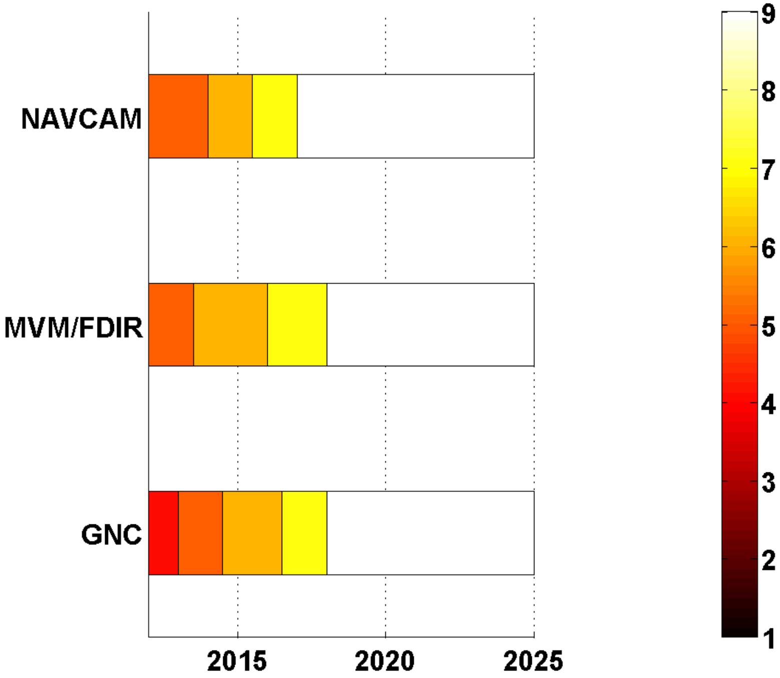
# PRELIMINARY COST ASSESSMENT

- Assessment of ground segment
  - Development of new systems (SIM, MPS, FDS)
  - Recurrent costs with conservative autonomy assumptions
- Cost of space segment
  - Platform upgraded for interplanetary mission
  - Impactor + release mechanism + on-board SW + cameras

| Segment | Launcher | Ground | Space | | | |
|---|---|---|---|---|---|---|
| | | | Proteus Mk2 P1 | Iridium I1 | Iridium I2 | Iridium I3 |
| Nominal Cost (M€) | 47.0 | | | | | |
| Margin | 10% | 25% | 20% | 20% | 20% | 20% |
| Cost (M€) | 51.7 | | | | | |
| Percentage of total cost | | | | | | |
| TOTAL | | | 159.2 | 136.9 | 135.4 | 130.8 |

# TECHNOLOGY ROADMAP

- Relatively high reuse of technologies and platform reduces development time and cost
- Assuming Phase B KO in Q1 of 2015, launch could be
  - 2019 for Option 1 (P1, I1)
  - 2018 for Option 2 (I2, I3)
- TRL 7 for critical technologies could be achieved in 2018
  - More analysis on integration into overall platform AIT/AIV program
- Additional optimizations for defined target could be performed



# SUMMARY

- Feasibility of reused commercial platform for binary impact
- Impactor and GNC system included as payload
- Platforms cover different missions (targets, cost) for flexibility
- Room (power, mass, *cost*) for additional P/L and/or experiments

| Option | Proteus P1 | Iridium I1 | Iridium I2 | Iridium I3 |
|---|---|---|---|---|
| **Propellant mass [kg]** | 400 | 300 | 160 | 160 |
| **Solar array area [m2]** | 10 | 10 | 10 | 5 |
| **Additional payload mass [kg] (2008ST)** | 444.7 | 491.9 | 387.9 | 410.0 |
| **Dry mass [kg ]** | 719.9 | 646.8 | 620.4 | 598.3 |
| **Wet mass [kg]** | 1119.9 | 946.8 | 780.4 | 758.3 |
| **Launch mass [kg]** | 1229.9 | 1086.8 | 920.4 | 898.3 |
| **Number of targets (Direct, Mono-Prop)** | 88 | 90 | 56 | 35 |
| **Number of targets (Direct, Bi-Prop)** | 115 | 112 | 85 | 46 |
| **Number of targets (ΔV-EGA, Mono-Prop)** | 100 | 87 | 39 | 20 |
| **Number of targets (ΔV-EGA, Bi-Prop)** | 128 | 113 | 71 | 40 |
| **Cost (M€)** | **159.2** | **136.9** | **135.4** | **130.8** |

# Thank you

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