BEAST
BINARY ASTEROID
ORBIT MODIFICATION
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2013 PDC
MISSION CONCEPT

[Logos of ESA, Thales Alenia Space, Politecnico Milano, and GMV]
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)
  - ΔV 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
**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

![Graph showing asteroid parameters]

<table>
<thead>
<tr>
<th>Heliocentric parameters</th>
<th>2009 UD</th>
<th>Heliocentric parameters</th>
<th>54509 YORP 2000</th>
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<tr>
<td>( D_2 ) [m]</td>
<td>5.000</td>
<td>( D_2 ) [m]</td>
<td>20.000</td>
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<td>( D_1 ) [m]</td>
<td>16.799</td>
<td>( D_1 ) [m]</td>
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<td>( M_2 ) [kg]</td>
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<td>( M_2 ) [kg]</td>
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<td>( M_1 ) [kg]</td>
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<tr>
<td>( a_2 ) [m]</td>
<td>120.650</td>
<td>( a_2 ) [m]</td>
<td>198.272</td>
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</table>
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

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<th>GMV</th>
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<tr>
<td>Period change</td>
<td>2.14 h</td>
<td>0.65 h</td>
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<tr>
<td>Relative change of the period</td>
<td>11 %</td>
<td>4.6 %</td>
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<tr>
<td>RMS of the measured period</td>
<td>111 s</td>
<td>60 s</td>
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<tr>
<td>RMS of the relative error of the period change</td>
<td>1.44 %</td>
<td>2.56 %</td>
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</table>
2013 PDC

SPACE SEGMENT

[Logos of ESA, Thales Alenia Space, Politecnico di Milano, and GMV]
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
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)
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)

<table>
<thead>
<tr>
<th>Platform</th>
<th>P1</th>
<th>I1</th>
<th>I2</th>
<th>I3</th>
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<tr>
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<td>719.9</td>
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<tr>
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<td>300</td>
<td>160</td>
<td>160</td>
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<tr>
<td>Adaptor Mass [kg]</td>
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<td>140</td>
<td>140</td>
<td>140</td>
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<tr>
<td>Launch Mass [kg]</td>
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<td>1086.8</td>
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</table>
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**

<table>
<thead>
<tr>
<th>Platform</th>
<th>P1</th>
<th>I1</th>
<th>I2</th>
<th>I3</th>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>7</td>
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<td>1</td>
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<td>Total</td>
<td>88</td>
<td>90</td>
<td>56</td>
<td>35</td>
<td>104</td>
<td>171</td>
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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)

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<td>507.2</td>
<td>533.6</td>
<td>555.7</td>
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<tr>
<td>2012 AP10</td>
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<td>345.2</td>
<td>371.6</td>
<td>393.7</td>
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<td>2012 TF79</td>
<td>636.5</td>
<td>603.7</td>
<td>57.9</td>
<td>80.0</td>
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</table>
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
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.
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

<table>
<thead>
<tr>
<th>Segment</th>
<th>Launcher</th>
<th>Ground</th>
<th>Space</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Proteus Mk2 P1</td>
</tr>
<tr>
<td>Nominal Cost (M€)</td>
<td>47.0</td>
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<tr>
<td>Margin</td>
<td>10%</td>
<td>25%</td>
<td>20%</td>
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<tr>
<td>Cost (M€)</td>
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<td>Percentage of total cost</td>
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<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>159.2</td>
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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
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

<table>
<thead>
<tr>
<th>Option</th>
<th>Proteus P1</th>
<th>Iridium I1</th>
<th>Iridium I2</th>
<th>Iridium I3</th>
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</thead>
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<tr>
<td>Propellant mass [kg]</td>
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<tr>
<td>Solar array area [m²]</td>
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<tr>
<td>Wet mass [kg]</td>
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<td>Launch mass [kg]</td>
<td>1229.9</td>
<td>1086.8</td>
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<td>898.3</td>
</tr>
<tr>
<td>Number of targets (Direct, Mono-Prop)</td>
<td>88</td>
<td>90</td>
<td>56</td>
<td>35</td>
</tr>
<tr>
<td>Number of targets (Direct, Bi-Prop)</td>
<td>115</td>
<td>112</td>
<td>85</td>
<td>46</td>
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<tr>
<td>Number of targets (ΔV-EGA, Mono-Prop)</td>
<td>100</td>
<td>87</td>
<td>39</td>
<td>20</td>
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<tr>
<td>Number of targets (ΔV-EGA, Bi-Prop)</td>
<td>128</td>
<td>113</td>
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<td>Cost (M€)</td>
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Thank you

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