The CASTAway mission

CubeSat possibilities in the asteroid belt

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The mineralogy of the asteroid belt

How do we link meteorites to individual asteroids, and therefore mineralogy to broad distributions, and finally use this to understand solar system formation & evolution?
Planet formation and asteroids

- Small bodies are left over from planet forming process
- They preserve, to some degree, the composition of the location in the disc where they formed
- We now see a mix of types, possibly due to stirring of the disc during planet migration

DeMeo & Carry 2014, Nature
Asteroid spectroscopy

• Approx 4500 asteroids with spectra so far (7\times10^5 known)
  – Mostly visible only
  – Few hundred NIR < 2.5 \mu m
  – Few 10s NIR \sim 3 \mu m
• Important features in NIR, especially \sim 3 \mu m
• Earth’s atmosphere & faintness of small asteroids limits progress
• Big surveys coming:
  – Gaia, \sim 3\times10^5 vis spectra
  – LSST, \sim 5\times10^6 vis photometry
• Big telescopes coming:
  – E-ELT, JWST: NIR spectra of \sim km ones, but only of a few
Questions in 2030s

• How do compositions vary across asteroid size; within the same taxonomic classes, families or pairs; with apparent surface age; and across different geomorphology on resolved surfaces?

• How do surface compositions relate to meteorite types (mineralogical classification)?

• How do mega-surveys correlate with composition determined over the 0.3-5 μm range?

• What is the evidence for different degrees of heating in different regions of the early Solar System?

• Is our understanding of surface ages correct? What is the typical size distribution of craters and of small impactors?

• How do surfaces vary with size, shape and spin rate; with the presence or absence of satellites; across different dynamical environments?
The CASTAway mission

• Three key measurements in one simple spacecraft
  – 0.3-5 μm survey of >10,000 asteroids of all sizes, types
  – Spatially resolved imaging & spectroscopy in close flybys of >10 asteroids of a variety of types
  – Discovery of very small asteroids (1-10m diameter)

• Spacecraft is a small space telescope (50cm) that loops through the asteroid belt
  – Main telescope with NIR spectrograph + vis. imager
  – Thermal IR camera for flybys
  – Small asteroid discovery with star-tracker type cameras

• Proposed for ESA M5 opportunity, launch ~2029
CASTAway instruments

• Spectrograph:
  – 1 degree long slit
  – 0.6-5 μm, single detector (JWST NIRspec Teledyne type)
  – Stare mode in survey, pushbroom mode in flyby
  – V=15 limit (S/N~100 in 20min)

• Imager:
  – 1 deg FOV, 2″/pix = 10m @1000 km
  – 0.3-1 μm CCD
  – ugriz filters for survey
  – OH+UV cont for water search
  – Narrowband for flybys

• Thermal camera
  – 6-20 μm imager
  – Broadband for thermal properties + narrowband for mineralogy
  – Stand-alone instrument

• Asteroid detection cameras
  – Based on μASC star tracker cameras
  – 4x1.5 deg FOV, V=16 limit
  – Co-aligned with main telescope
    • Enables target-of-opportunity spectroscopy of ~1-10m size asteroids
  – Mature tech (tested on Juno)
CASTAway trajectory

- 7 year mission
- Gravity assist at Mars to raise perihelion distance, spend more time in asteroid belt
- 10 flybys in nominal trajectory
- One of many possible solutions
  - Search performed with limited database of 10,000 asteroids
- Optimisation to get a variety of types, sizes, spin-rates, dynamic groups, etc.
- With post-LSST catalogue, 10-20 flybys
CASTAway + CubeSats

• Proposal also lists ‘optional extras’ to consider in phase A:
  – Laser range finder to improve orbits for small asteroid discoveries
  – Polarimetry elements in camera for surface properties
  – Deployable probes based on CubeSats

• CubeSat option envisaged a competition to study a few options, similar to ESA AIM-COPINS
AIM COPINS

- AIM mission proposed to visit near-Earth asteroid Didymos as part of ESA/NASA asteroid deflection experiment
- Technology demonstration one of goals
- CubeSat Opportunity Payloads (COPINS) study of options for 2x 3U deployable probes
- Five proposals studied with ESA funding
- AIM not approved at ESA ministerial meeting 😞

- AGEX
  - Seismometers; structure and impact effects
- ASPECT
  - Visible/NIR spectrometer
- DustCube
  - Nephelometers (dust concentration in ejecta plume)
- CUBATA
  - Cameras, gravity field
- PALS
  - Magnetometer, volatile composition analyser, camera, vis spectrometer – detailed study of ejecta plume
CASTAway + CubeSats

• CASTAway designed to launch with Soyuz, but expect to use Ariane 6.2 in late 2020s
• Expected to have ~50% better performance
• Should have significant spare mass margin, which will become clearer as A6.2 performance better understood
• CubeSat launcher with N cubes can be imagined
• CubeSats relay data via CASTAway
  – Opportunity to use CubeSats in deep space
  – Probably each one relatively short-lived
CubeSat opportunities

• Release shortly before asteroid flybys
  – Much closer approach to asteroid without risking main spacecraft
  – Higher resolution views
  – Gravity field
  – Exosphere?
  – Magnetic fields?
  – (Sub-)surface science (landing/impacting)
  – Impact experiments?

• Release in survey mode
  – Stereo views (nearby asteroid discovery)
CubeSat challenges

• Fast fly-bys
  – Around 10 km/s relative velocity to asteroid
  – CA ~ 1000 km
  – Fly-by lasts ~hours
  – Asteroids 1-100 km diameter
  – Release of CubeSats days/weeks in advance? (tbc)

• Large distance from Earth (and Sun)
  – Comms only via CASTAway
  – Radiation environment

(1 – 100 km)

(~10 km/s)

(~2-3 AU)

(~1000 km)
CubeSat concepts

• Close approach
  – Aimed to just miss asteroid (<10 km)
  – Camera
    • close up views
    • Better than 10m/pix
  – Radio tracking / accelerometers
    • mass, gravity field
• Magnetometer?
  • Primordial magnetic field?
CubeSat concepts

- Impact
  - Penetrator science?
    - Material properties
    - Composition
    - Difficult! (10 >> 0.3 km/s)
  - Two cubes?
    - First is impactor, second watches / relays, transmits data, before also hitting / just missing
    - Cameras
    - Any other instruments?
    - Close up views, impact experiment (cratering, plume sampling...)

(not to scale)
CubeSat concepts

- **Survey mode**
  - Deep space operation
  - Stereo view with main spacecraft
    - Star-tracker type cameras
    - Parallax measurement for nearby small asteroids discovered
    - Better orbits, sizes, size distribution
    - Longer lived CubeSat

1 - 10 m

0.5°

~20,000 km

~200 km
CASTAway mission

• Simple spacecraft that investigates asteroid belt at all size ranges
  – Double number of visited asteroids in one mission
  – First large NIR spectroscopic survey
    • Real composition map and tie to meteorites
  – Discover and characterise very small asteroids
• Feasible for ESA M-class, or similar
  – Plenty of targets, with more choice available post LSST
  – Works with Soyuz-like performance of launcher, even better if A62 more capable (as expected)
  – High TRL spacecraft & payload components
  – Fits in cost cap with generous margins
• Can act as mother-ship for CubeSats
  – Significant mass margin probably available
  – Fast flybys – challenge is to find good experiments for short-lived CubeSat probes
  
  ESA didn’t select CASTAway for M5
  Concept will be back...

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Or.... Castalia

- Also proposed for M5, still in competition
- Rendezvous mission to a Main Belt Comet / active asteroid
- Remote sensing + in situ sampling payload (Rosetta-like)
- No lander in baseline, but simple/low mass lander would be a nice option to add
- Single target (133P), but in orbit
  - Low relative velocity (~0)
  - 6-12 months operation in orbit
  - 5-20 km altitude
BACKUP SLIDES
Survey performance

Flyby targets

Survey targets

Discovery targets

~few thousand asteroids in 1, 10, 100m bins

For Soyuz launch. If Arianne 62 performance OK, can get deeper into belt
Survey targets across mission
Active asteroids / MBCs

- Mass losing bodies in asteroid belt
- Cometary activity -> ice?
# Castalia payload

Four packages, simple operations. One science team!

<table>
<thead>
<tr>
<th>Package</th>
<th>Instrument (Name, Purpose)</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
<th>TRL</th>
<th>Pointing</th>
<th>Heritage</th>
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<tbody>
<tr>
<td>Surface remote sensing</td>
<td>MBCCAM Vis/NIR Imager</td>
<td>20</td>
<td>17-30</td>
<td>&gt;5</td>
<td>Nadir, limb, dust</td>
<td>DAWN FC, Rosetta OSIRIS WAC</td>
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<td></td>
<td>TMC Thermal IR Imager</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>Nadir, limb</td>
<td>UKTechDemoSat,</td>
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<td>Interior</td>
<td>SOURCE Deep Radar</td>
<td>20.2</td>
<td>150</td>
<td>≥6</td>
<td>Nadir</td>
<td>MRO Sharad, MEx MARSIS, Rosetta CONSERT</td>
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<td>SSR Shallow Radar</td>
<td>1.7</td>
<td>16</td>
<td>&gt;5.6</td>
<td>Nadir</td>
<td>ExoMars WISDOM, Rosetta CONSERT, AIM</td>
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<td>Radio Science</td>
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<td>n/a</td>
<td>9</td>
<td>n/a</td>
<td>Rosetta RSI</td>
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<tr>
<td>Material and composition</td>
<td>CAMS (+COUCH) Mass Spectrometer</td>
<td>6.44 (1.5)</td>
<td>14.03 (20)</td>
<td>CAMS: 7, CADS: 9, (COUCH: 6-9)</td>
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<td>Rosetta ROSINA, (Philae Ptolemy)</td>
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<td></td>
<td>GIADA Dust detector</td>
<td>7.8</td>
<td>22</td>
<td>9</td>
<td>Nadir</td>
<td>Rosetta GIADA</td>
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<td>COSIMA Dust composition</td>
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<td>Rosetta COSIMA</td>
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<td>DIDIMA Combined dust inst.</td>
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<td>27</td>
<td>5 - 6</td>
<td>Nadir</td>
<td>Rosetta GIADA and COSIMA</td>
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<td>Plasma environment</td>
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<td>Sensor: 9 Electronics: 5</td>
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<td>CINEMA</td>
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<tr>
<td></td>
<td>ChAPS Plasma Package</td>
<td>0.65</td>
<td>1</td>
<td>5-6</td>
<td>Various</td>
<td>TechDemoSat, Solar Orbiter</td>
</tr>
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</table>
Castalia Mission

Mission phases – 6-12 months at MBC

• 100km quasi-orbit:
  Long drifts near the comet, with orbit corrections to change direction

• 20km orbit
  – Survey & “parking” orbit
  – Terminator orbit is stable

• 5km hover
  – 3.5h control cycle, incl. 1.5h science mode with no contamination
  – Fully autonomous, with redundant failure detection and collision avoidance maneuver