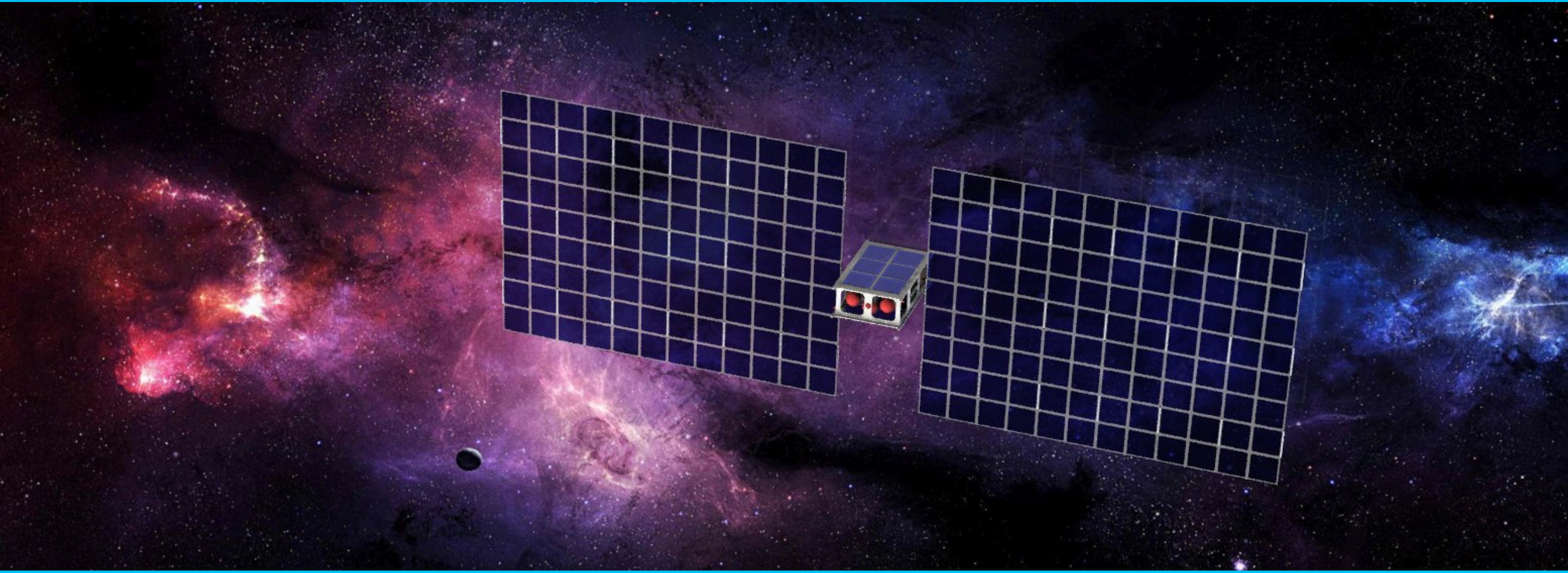
Using CubeSats to survey asteroids as part of an asteroid mining mission



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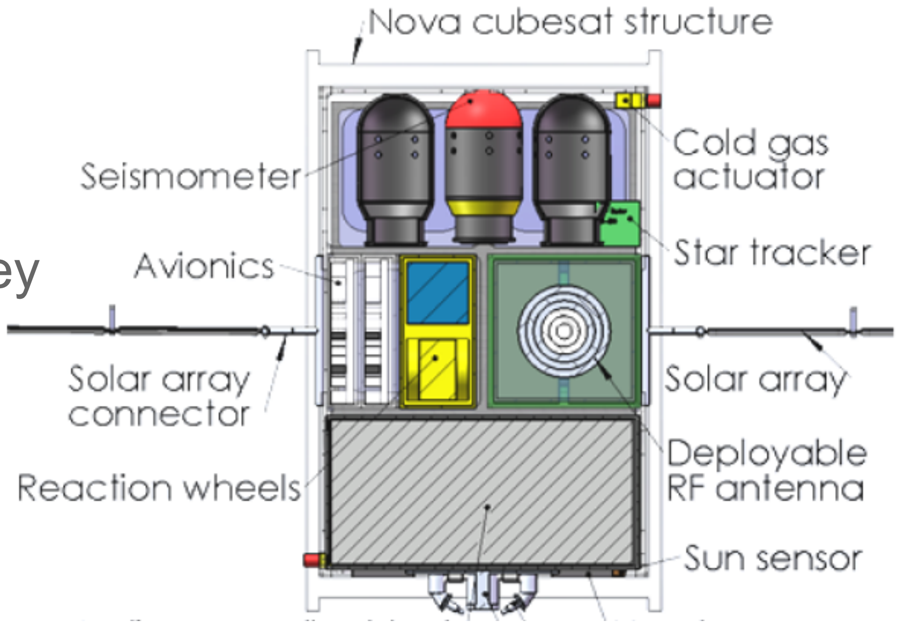
Introduction

- The study focussed on mining water from NEAs in the region of 0.8-1.3AU.
- Minimum of 14 asteroids for P_{rich} in water.
- Two CubeSats designed to survey each asteroid.
  - One equipped with Laser communications and IR spectrometer.
  - Other equipped with deployable high gain antenna and penetrators.



Top Level System Requirements

	Required	Achieved	
		Tyche	Autolycus
Development Cost	< $50 million	$30 million	
Mission Duration	< 450 days		
Wet Mass	<20 kg	17.04kg	19.41kg
Communication Data Rate	> 3kbps	10kbps	5kbps
Communication Range	> 0.5AU	0.5AU	0.5AU

- Data required:
  - Spin, Size, Landing sites
  - Chemical composition
  - Stratigraphic record

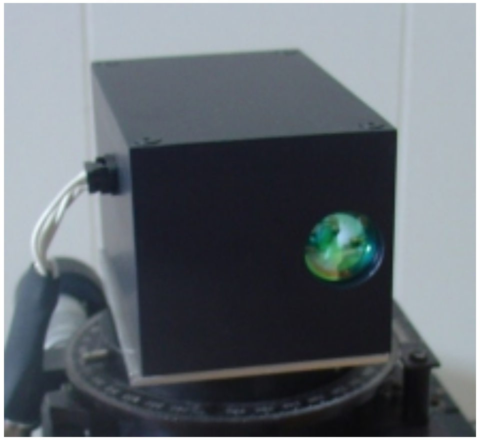
Payload

Cranfield UNIVERSITY

- IR Camera x2
  - OWL SW1.7CL 640
    - Used already in Aerospace Applications
    - 5W, 282g each

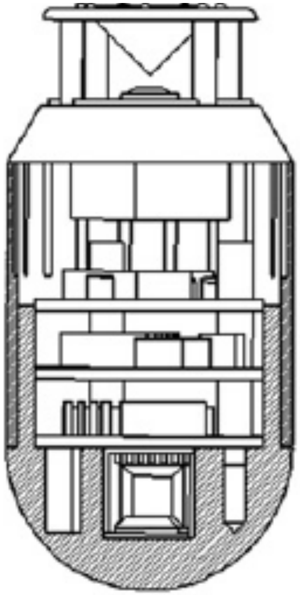
- IR Spectrometer
  - Thoth Argus 1000SK Spectrometer
    - Space Ready
    - 0.5W, 232g

- Seismic Penetrators x3
  - Unrivalled asteroid detail
  - Not yet prototyped
    - 2.3W, 1.2kg each



Seismic Penetrators

- 10cm long and 5cm in diameter
  - Blunt nose to minimise impact depth, varies from 0.2m to 11.67m
  - Varies due to asteroid composition and impact velocity

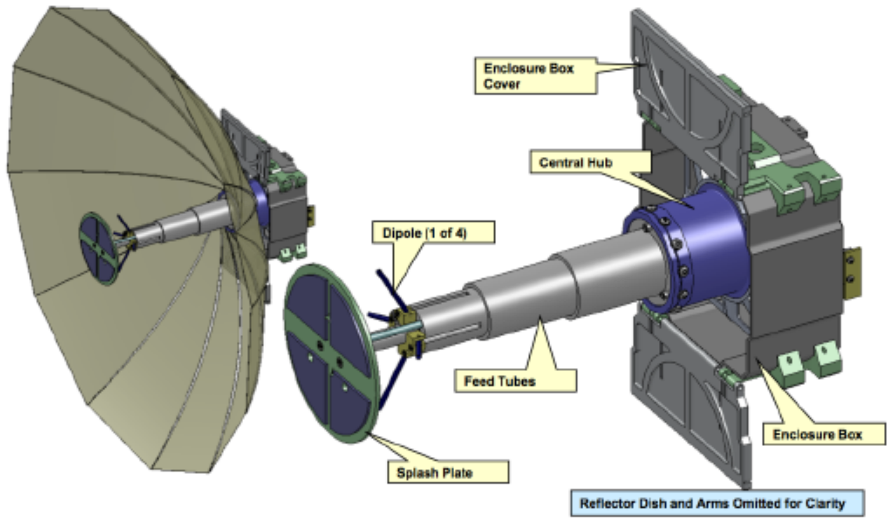


- Multi stage solid motor used for greater impact velocity
  - Isp 187s, V_{impact} from 20m/s to 40m/s
- 3 Axis Accelerometer and Thermistors/Thermocouples
  - Used in conjunction with two further impacts to determine stratigraphic asteroid makeup and temperature variation
- Microstrip Antenna
  - Used for comms with iCubeSat

Communications

- Two types of communications system used
- Laser Communications
  - ADCS to minimise Transmitter Divergence Angle, 0.207 mRad
  - High Data Rate, 100Kbps
  - 24W

- Conventional Expandable Antenna
  - High reliance on ADCS
  - Smaller power req, 21W
  - Lower Data Rate, 50Kbps



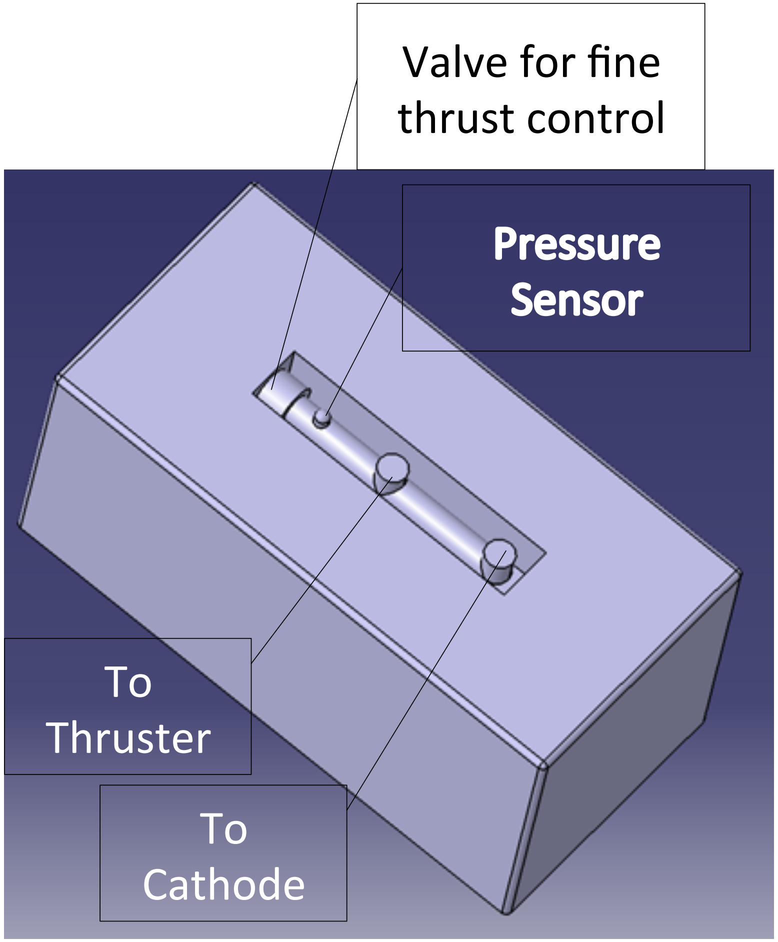
- Isotropic Antenna

Propulsion

- To save cost CubeSats use on-board propulsion to reach asteroids.
- Busek BHT-200 Hall effect thruster.
- Produces 17mN thrust at 300W.
- $I_{sp} = 1390s$.
- Used on FalconSat-5 launched November 2010.

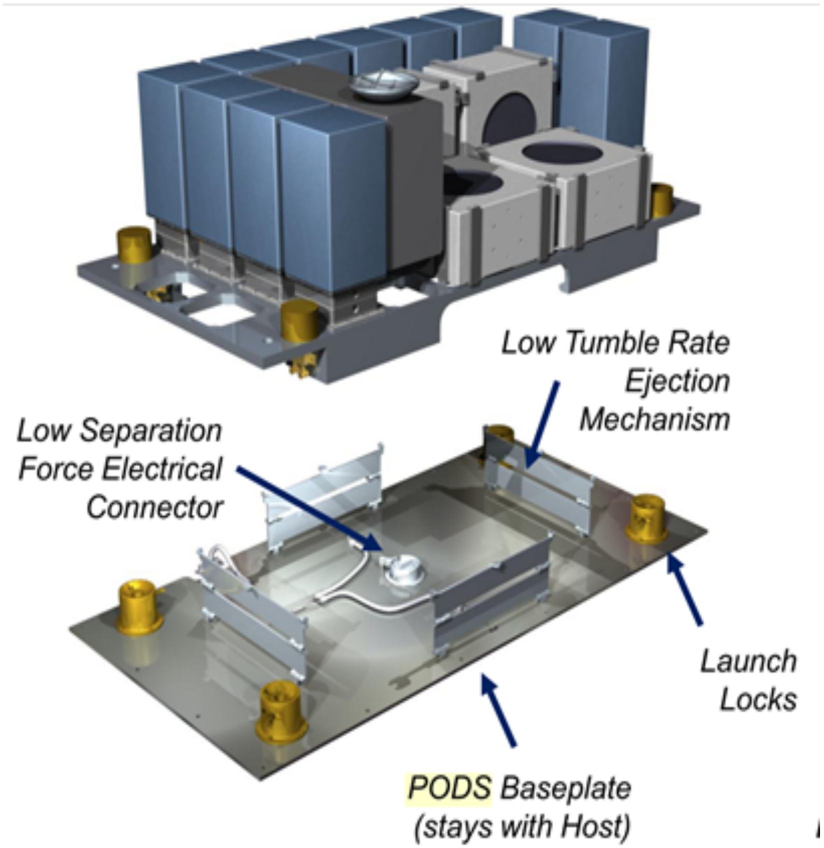
Propulsion

- Significant volume constraints in CubeSat.
- Iodine used as a propellant instead of Xenon.
- Storage density 3 times that of Xenon.
- Significantly lower cost.
- Lower pressure storage reduces tank mass.
- Stored as a solid which must be heated to a gas for use.
- Heating storage tank acts as coarse throttle control.



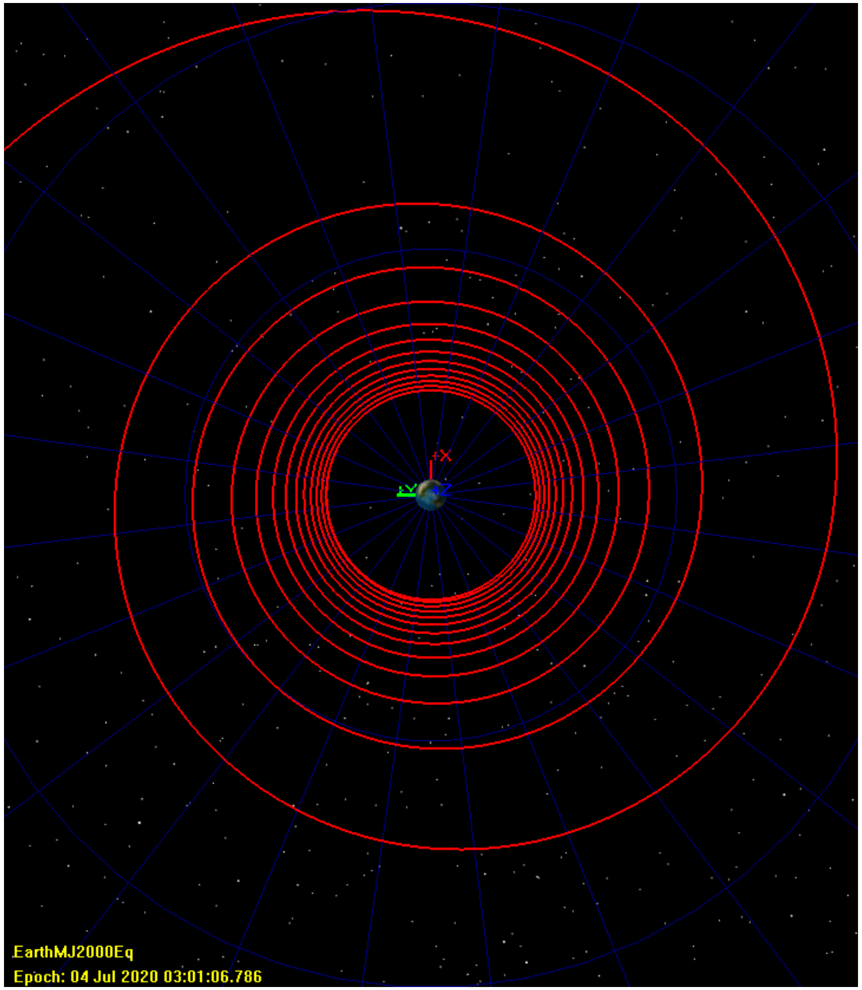
Launch

- CubeSat Launched into GEO
- Piggyback launch on telecommunications satellite using SSL 'PODS'
- 6-8 telecommunications satellite launches/year with SSL ~20/year in total.



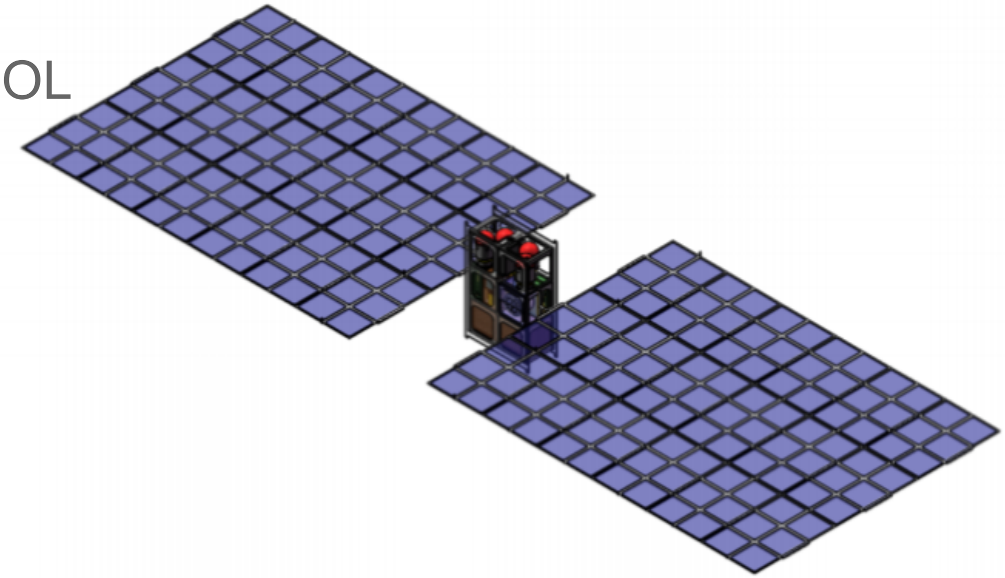
Trajectories

- Low thrust trajectory
- Analytical method used at this stage for Earth escape
- MatLab script used to prove ability to reach from Earth escape to the required range of asteroids.



Power

- To reduce battery mass thruster will not be operated in eclipse.
- Eclipse avoided by launching into GEO.
- GaAs triple junction cells with BOL efficiency of 30% used.
- Total Solar array area of $2m^2$
- Small Li-ion batteries used to allow payload to operate in asteroid eclipse.



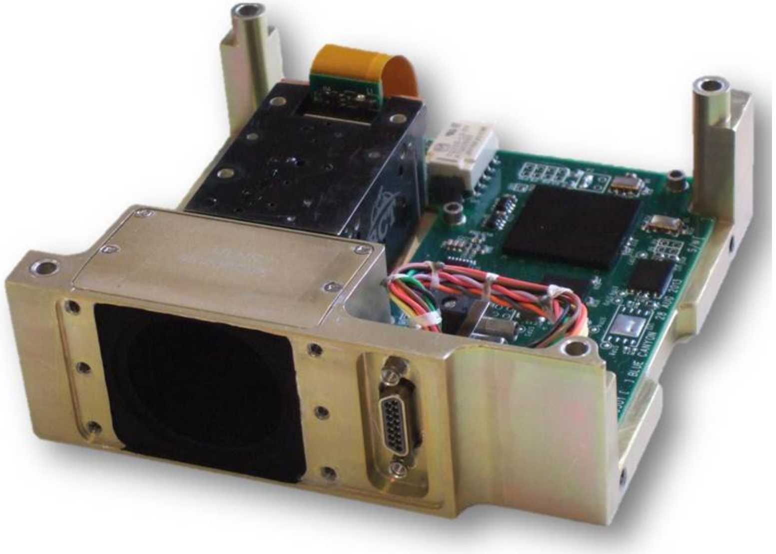
AOCS

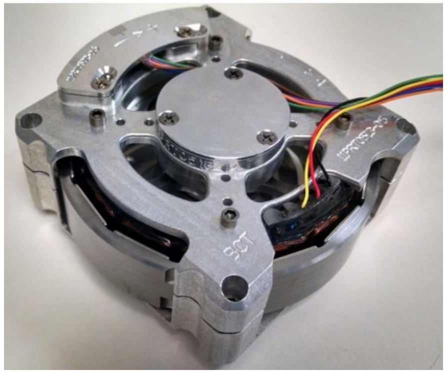
- High pointing accuracy for communications.
- Low jitter for clear images.
- Large solar arrays mean large moments of inertia.
- Large solar arrays will also be difficult to damp

$$\boldsymbol{I} = \begin{bmatrix} 0.05 & 0.00 & 0.00 \\ 0.00 & 2.85 & 0.00 \\ 0.00 & 0.00 & 2.91 \end{bmatrix} kgm^2$$

AOCS – Sensing & Actuation

- 2 2-axis sun sensors
- Star tracker on sun shadow face used for fine 3-axis attitude determination. (Accuracy of 6 arcseconds).
- Inertial measurement unit used to measure rates.
- Using BCT RWp100 Reaction wheels.
  - Low Jitter design
  - Larger than normally used on CubeSats
- Thruster System used for reaction Using a butane cold gas system in development by JPL.
- Further investigation on use of solar radiation pressure





Cost

- Where possible COTS parts have been used.
- Unavoidable for hall effect thruster.

	Orbiter	Penetrator
Payload	$194,035.85	$155,000.00
Structures	$8,452.50	$8,452.50
Thermal	$100.00	$100.00
Power	$398,376.52	$395,888.23
TT&C	$5,000.00	$5,000.00
Comms	$10,000.00	$5,000.00
OBDH	$15,000.00	$15,000.00
AOCS	$54,500.00	$54,500.00
Propulsion	$90,000.00	$90,000.00
Propulsion Fuel	$2,562.03	$2,562.03
Contingency	$38,901.35	$36,575.14
TOTAL	$816,928.25	$768,077.90

Conclusion & Further Work

- Top level design of two CubeSats for asteroid survey missions completed.
- Risks:
  - Radiation
  - Power requirement
  - Operating environment
- Further work:
  - AOCS design.
  - Generating sufficient power to start up HET.