A Low-Cost NEO Micro Hunter-Seeker Mission Concept

A $100M micro-mission to discover and visit multiple near-Earth objects

Joseph E. Riedel, Colleen Marrese-Reading, & Young H. Lee
Jet Propulsion Laboratory, California Institute of Technology,
 joseph.e.riedel@jpl.nasa.gov

With critical contributions from
David Eisenman, Dan Grebow,
Tim McElrath and Juergen Mueller

Low Cost Planetary Missions – 10 Conference, June 19 2013
Copyright 2013, all rights reserved

The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech
NEO Hunter-Seeker

NEO Hunter/Seeker is a Proposed Ride-Along Mission for the un-crewed 2017 SLS/Orion First flight.

A 50 kg micro spacecraft, called “µEx$^2$”, would be carried with the Orion.

µEx$^2$ would use a new and revolutionary form of micro-electric propulsion, called Micro-Electro-fluidic-spray Propulsion, “MEP”.

After inspecting the Orion, µEx$^2$ would use MEP to travel to a NEO and rendezvous, thrusting over 5 km/s over 3 years. Once there, it will gather important data.
(1) Hunter-Seeker would travel on a 0.1AU ‘inside Earth’ orbit to hunt for NEOs.

(2) Trajectory has 15 year synodic period, leading Earth at a relative 2 km/s.

(3) \(\mu\text{Ex}^2\) wide-FOV, wide-aperture Camera is sensitive to detection of 7 m asteroids at <0.1 AU.

(4) \(\mu\text{Ex}^2\) carries 15 km/s delta-v, sufficient for rendezvous with 5-6 newly discovered objects and make remote observations.

(5) Optional contact science may include material strength, morphology, microstructure, stability and spectroscopy.

(6) As a final operation, \(\mu\text{Ex}^2\) may leave a long-lived navigation beacon on an Earth-threatening asteroid to provide a permanent means of assessing Earth-impact threat.
Hunter-Seeker Spacecraft

**Micro Exo Explorer (µEx²) Notional Design**

- Uses Micro-Electro-fluidic-spray Propulsion (MEP) - (Isp of 7,000+ s), Indium propellant – *Solid state propulsion: an entirely solid-state spacecraft*
- Carries 5 kg of Indium; 5 mN thrust, 10 km/s propulsion ability
- Automated (self-navigating/controlling)

- **Contact probe**
- **~60 cm**
- **X-band Medium Gain Antenna**
- **MEP propulsion module**
- **Wide-angle/Wide-aperture NEO Search Camera (w/o sunshade)**
- **Automated onboard optical navigation (AutoNav) camera (Narrow Angle Camera)**

- ~50 kg, 220 W power generation (@ 1 AU) at any thrust attitude
Critical Questions about the Near-Earth Asteroid Population

- What is the population of human-accessible asteroids? (e.g., orbits with 6-month round trip achievable mission, with under 2km/s delta-v)
- What is the population of small (e.g., under 10 m) NEO’s that are redirection/retrieval candidates?
  - Earth-based observations are unlikely to find out
    - Observing from Earth to detect 3-5 years in advance of launch an object that has a 20-30 year synodic period is nearly impossible (e.g. 27th apparent magnitude)
  - Venus-like-orbit searching missions will likely not be sensitive enough to see 30 m rocks (let alone 10 m) from 0.5 AU

✓ Hunter-Seeker may be a highly affordable and effective means of discovering these objects

Some Potential Target Mission Options

<table>
<thead>
<tr>
<th>Target</th>
<th>Apophis</th>
<th>2008 EV5</th>
<th>2000 SG344</th>
<th>&quot;FASTEST&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Launch from GEO</strong></td>
<td>Start Date</td>
<td>12/17/15 0:00</td>
<td>9/26/15 0:00</td>
<td>4/12/15 0:00</td>
</tr>
<tr>
<td><strong>Lunar Flyby</strong></td>
<td>Date</td>
<td>7/13/17 19:08</td>
<td>4/23/17 1:02</td>
<td>10/22/16 18:06</td>
</tr>
<tr>
<td></td>
<td>TOF to Date (day)</td>
<td>574.80</td>
<td>575.04</td>
<td>559.75</td>
</tr>
<tr>
<td></td>
<td>Lunar Passage (km)</td>
<td>19705.74</td>
<td>21475.89</td>
<td>18864.66</td>
</tr>
<tr>
<td></td>
<td>Mass to Date (kg)</td>
<td>48.73</td>
<td>48.73</td>
<td>48.77</td>
</tr>
<tr>
<td>(Begin Interplanetary)</td>
<td>TOF to Date (day)</td>
<td>597.92</td>
<td>597.77</td>
<td>590.40</td>
</tr>
<tr>
<td></td>
<td>Mass to Date (kg)</td>
<td>48.68</td>
<td>48.68</td>
<td>48.70</td>
</tr>
<tr>
<td><strong>Rendezvous</strong></td>
<td>Date</td>
<td>6/26/21 5:56</td>
<td>2/26/22 15:18</td>
<td>3/20/20 1:45</td>
</tr>
<tr>
<td></td>
<td>TOF to Date (yr)</td>
<td>5.49</td>
<td>6.42</td>
<td>4.94</td>
</tr>
<tr>
<td></td>
<td>Mass to Date (kg)</td>
<td>45.58</td>
<td>44.83</td>
<td>46.02</td>
</tr>
</tbody>
</table>
Minimum Time Trajectory to Apophis

Interplanetary Mission, Leg 1:
3.85 yr, 3.1 kg propellant

Initial s/c wet mass = 50 kg,
thrust = 2 mN,
constant Isp = 8,000 s

Arrive: Apophis
6/26/2021
tof: 1408.6 days
mass: 45.6 kg
flyby alt: 0 km
(v\_\infty: 0.00 km/s)

Depart: Earth
8/17/2017
tof: 0.0 days
(mass: 48.7 kg)
flyby alt: 0 km
(v\_\infty: 0.00 km/s)
Science Capability Overview

- **Imaging**: Size, topography, surface structure, age, and evolution
  - MRO Optical Nav Camera (ONC)
- **Multi-spectral analysis**: mineralogy and genesis
  - Mini-Moon Mineralogy Mapper (Maxi M$^3$ Flew on Chandrayaan-1)
- **Radiometrics**: mass, moments, and some internal structure
- **Surface contact**: regolith structural cohesion, micro structure (with close-up imaging), and surface stability
  - Surface contact (either direct or with blowing gas) is an option for the final asteroid visit (to reduce dust contamination and deposition issues)

Mini-M$^3$ (~3 kg)
MRO OpNav Cam (~2.5 kg)
MEP Thruster technology is under development for precision pointing, slewing, and orbit transfer of very small to very large deployable spacecraft with a highly distributed architecture capability.

MEP is highly scalable with a low mass, simple and compact architecture
- Scalable microfabricated components
- Highly integrated capillary force driven feed system
- 6 parts total in head, feed system and reservoir
- No valves or pressurized reservoir
- High density solid indium propellant, 7 g/cm^3
- Micronewtons to millinewtons of thrust, per element – elements can be arrayed in any-size propulsion system
- 100 micronewton thruster mass < 10 grams
3D Array of MEP thrusters, arranged to allow removal of 3 dimensions of torque via bank-wise off-pulsing via Indium propellant heater cycling

Individual MEP solid-state thruster chips, for propulsion and limited attitude control

Butane micro-thruster clusters for proximity operations and rapid attitude changes

Full thruster array provides up to 5 mN thrust, which provides up to 3 km/s / year. Total power consumption of MEP, under 100 W (for 2 mN)
Other Launch Opportunities

Space, and mass-margin for up to four $\mu$Ex$^2$ spacecraft in every LSS GEO launch

Shared rides to GEO for economical and flexible launch opportunities
μEx² Mass Overview
For NEO Hunter-Seeker Mission

Structure, Power, Antennas: 6.9 kg
Science and Navigation Payloads: 6.0 kg
Avionics 4.4 kg
MEP (main and ACS) 4.4 kg
Butane propulsion system 5.4 kg
Miscellaneous 1.0 kg
Butane Propellant 5.0 kg
Indium Propellant 8.0 kg
Total (Maximum Expected Value) 41.1 kg
Mass Contingency/Reserve 8.9 kg

Total Allocated Wet/Loaded Mass 50.0 kg
**Mission Cost**

- Grass-roots ROM estimate of mission cost: $99M (sans launch cost, FY’12 $’s)
- JPL Innovation Foundry Parametric Mission Cost Model (PMCM): $97M (sans launch cost, and FY’12 $s)
- It contains 5 year mission operation cost

**Spacecraft Cost**

- DoD/Aerospace Small Sat Model cost vs. mass curve for 50 kg => $9.6M (circa 1994)
- NASA cost vs. mass curve for 50 kg => $22.9M (circa 1998)
- Cost of XSS-11 (AFRL autonomous rendezvous experimental mission) (100 kg) 2002 bus: $13M
- ROM from spacecraft builders: $10-20M
- Georgia Tech Spacecraft Design Class: two teams developed designs for a similar s/c, with cost estimates under $10M using current technology

*The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.*
NEO Hunter-Seeker Mission

Conclusions

• Micro Electo-spray Propulsion (MEP), a new JPL technology, enables a new class of deep space micro missions for very low cost (much lower than ‘Discovery-Class’) with scalable green, micro-propulsion

• Using other advanced COTS technologies, such as high-capability processors and other avionics components will lead to streamlined and lower cost mission operations, featuring many automated capabilities

• A 5 year micro mission to search for and visit several near-earth asteroids can be mounted for under $100M (FY’12 $s), and is being considered as a shared payload on the unmanned 2017 SLS-Orion lunar test-mission

• This mission concept reveals the power of combining MEP and autonomous navigation technologies