Project Status
MISSION GOALS

• 90% of NEOs with D>140m
• Build a more complete catalog of PHAs
• For those discovered, provide multi-decade warning for PHAs
• Add to catalog for smaller objects
  • Better determination of size-frequency distribution
  • Identify potentially interesting mission targets
BASELINE MISSION CONCEPT

• Infrared 0.5m space telescope
  • Passive cooling on telescope structure
  • Active cooling on detector
  • Expendables: thruster fuel for desaturating gyros

• Orbit interior to Earth
  • $a=0.66$ AU, $i=0.27^\circ$, $e=0.091$
  • Gravity assist from Venus to lower aphelion
  • Short synodic period between Sentinel and PHOs
BASELINE MISSION CONCEPT

- 1.9° x 5.2° field-of-view imager
  - 2.15 arcsec/pixel scale = 1.6*FWHM
  - 5 – 10 micron sensitivity
  - Six 30-s exposures for cosmic ray strike removal
  - Filling factor is 96.3% (1.1mm gaps between detectors)
- Field of regard covers the sky > 80° from the Sun
  - 28 days to cover the field of regard four times
  - [0,1,48,49] hour timing on field samples
- Low data rate to DSN
  - Full images not usually transmitted
  - Region of interest around transients returned to ground

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ANALYSIS OF SYSTEM PERFORMANCE

- Orbit quality
- Sensitivity
- Completion rate
  - Differential
  - Cumulative
- System design trades
- Main-belt asteroid impact on survey
- Limiting factors
ORBIT QUALITY

• Initial detection and first orbit estimate comes from 4 measurements spanning 49 hours
  • Linkable tracklet
• First recovery provides a 28-day arc (or better)
  • Goal for object to be considered discovered
• Second recovery provides a 56-day arc (or better)
  • Orbit good enough for recovery with reasonable effort for at least 100 years
Object not observable if solar elongation is ≤ 80°

Observations are in groups of 4 (observing cycle)

Sampling rate between observing cycles set by time needed to cover the field-of-regard (FOR)

SNR ≥ 5, sources are all transients
## TEST OBJECT LIST

<table>
<thead>
<tr>
<th></th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
</tr>
</thead>
<tbody>
<tr>
<td>α</td>
<td>1.1</td>
<td>1.13</td>
<td>2.13</td>
</tr>
<tr>
<td>e</td>
<td>0.05</td>
<td>0.15</td>
<td>0.55</td>
</tr>
<tr>
<td>i</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Ω</td>
<td>127.2</td>
<td>127.2</td>
<td>127.2</td>
</tr>
<tr>
<td>ω</td>
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</tr>
<tr>
<td>M</td>
<td>285</td>
<td>285</td>
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</table>

#1 – orbit close to Earth’s orbit
#2 – intermediate orbit
#3 – high eccentricity orbit
OBJECT #1
MISSION COVERAGE

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OBJECT #2
MISSION COVERAGE

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OBJECT #3
MISSION COVERAGE

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OBJECT #1, 1H ARC (2 OBS)

![Graphs showing orbital parameters vs. semi-major axis](image-url)
OBJECT #1, 2D ARC (4 OBS)
OBJECT #1, 28D ARC (8 OBS)

\[ e \]
\[ \theta \]
\[ O \]
\[ M \]

\[ a \text{ [AU]} \]

\[ a \text{ [AU]} \]

\[ a \text{ [AU]} \]

\[ a \text{ [AU]} \]
OBJECT #1, 56D ARC (12 OBS)
OBJECT #1, 53D ARC

- 24d predict  Positional error $\sigma_\alpha = 1.1''$  $\sigma_\delta = 2.3''$
- 0.5y predict  Positional error $\sigma_\alpha = 16''$  $\sigma_\delta = 1''$
- 10y predict  Positional error $\sigma_\alpha = 18''$  $\sigma_\delta = 2.3''$

- Three linked observing cycles achieves a very good orbit for long-term future followup observations.
- This example is for consecutive observing cycles. Furture predictions are more accurate if these cycles are not consecutive.
## BASELINE CADENCE SUMMARY

<table>
<thead>
<tr>
<th>Nobs</th>
<th>Ncycles</th>
<th>Arc-length</th>
<th>Predict-arc</th>
<th>$\sigma_\alpha$</th>
<th>$\sigma_\delta$</th>
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<tbody>
<tr>
<td>2</td>
<td>½</td>
<td>1 hour</td>
<td>2 days</td>
<td>229&quot;</td>
<td>251&quot;</td>
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<tr>
<td>4</td>
<td>1</td>
<td>2 days</td>
<td>26 days</td>
<td>2.4°</td>
<td>3.2°</td>
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<tr>
<td>8</td>
<td>2</td>
<td>28 days</td>
<td>28 days</td>
<td>30&quot;</td>
<td>69&quot;</td>
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<tr>
<td>12</td>
<td>3</td>
<td>56 days</td>
<td>28 days</td>
<td>2&quot;</td>
<td>3.7&quot;</td>
</tr>
<tr>
<td>12</td>
<td>3</td>
<td>56 days</td>
<td>10 years</td>
<td>37&quot;</td>
<td>12&quot;</td>
</tr>
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SENSITIVITY

- Thermal emission from object
  - Rapid rotator
  - Average aspect
- Detector read-noise ignored
- Background flux from zodiacal light
  - Dominant noise source
- Rate of motion
  - Objects moving slower than 0.03°/day are not recognized as “moving” and never transmitted to the ground
  - No sensitivity loss for rates between 0.03°/day and 0.57°/day
  - Sensitivity degrades linearly with rates faster than 0.57°/day
COMPLETION RATE

- Size distribution from Harris (2010)
- Orbit distribution from Bottke et al. (2002)
- Monte Carlo simulation with single size for differential completion rate
  - 20,000 random orbits from distribution
- Integrate differential results to get cumulative completion rate
- Simulation tool based on orbital calculations by OpenOrb
D=1 KM COMPLETION

2+ final completeness = 99.51%

Completeness vs. Time during survey (years)

1+ cycles
2+ cycles
3+ cycles
1 cycle
D=140M COMPLETION

2+ final completeness = 64.93%

Completeness vs. Time during survey (years)
For the baseline case, there are 31,000 objects found with D>140m and 270,000 objects with D>30m.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>D&gt;140m</th>
<th>D&gt;30m</th>
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</thead>
<tbody>
<tr>
<td>Baseline/NEO</td>
<td>74%</td>
<td>7%</td>
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<tr>
<td>Baseline/PHA</td>
<td>77%</td>
<td>9%</td>
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INVESTIGATIONS USING SURVEY TOOL

- Modifications to field-of-regard
- Fill factor optimizations
- Implication of triples/quads/sextuples
- Detection location vs. \( \cos(\text{ecliptic latitude}) \)
- Importance of the Zodiacal background model
- Observation visit timing vs. changes in approach
- Alternative spacecraft orbits
- Variations with NEO distribution models
- Orbit distribution of detected objects vs. size
- Main-belt asteroid influence on survey
SOME CONCLUSIONS

- Two linked cycles will put an object into the found category
- Three linked cycles (or more) will result in a very good orbit estimate
- Ecliptic longitude coverage is not usually complete
- Orbit periods close to an (integer) $\times$ (Sentinel orbit period) will have some blind spots
- While these last two issues are real, they will likely not be an issue with regard to mission success
SOME CONCLUSIONS

• Baseline mission design is a very effective survey tool
  • Zodiacal background is the dominant noise source
  • Time scale for completion set by range of orbit eccentricities in target population

• Main-belt asteroids will generate a large number of detections
  • Largest consequence is in data load but there are credible mitigation options

• Most of the objects detected will be smaller than the survey “goal” size (D=140m) and will provide excellent constraints on the size distribution down to 30m.