Constellation of MicroSats to Search for Near Earth Asteroids

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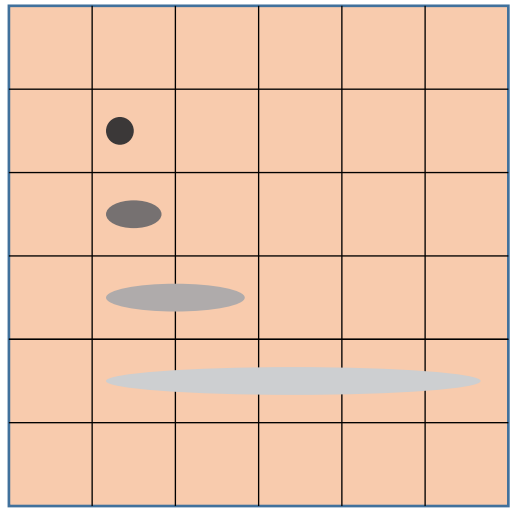
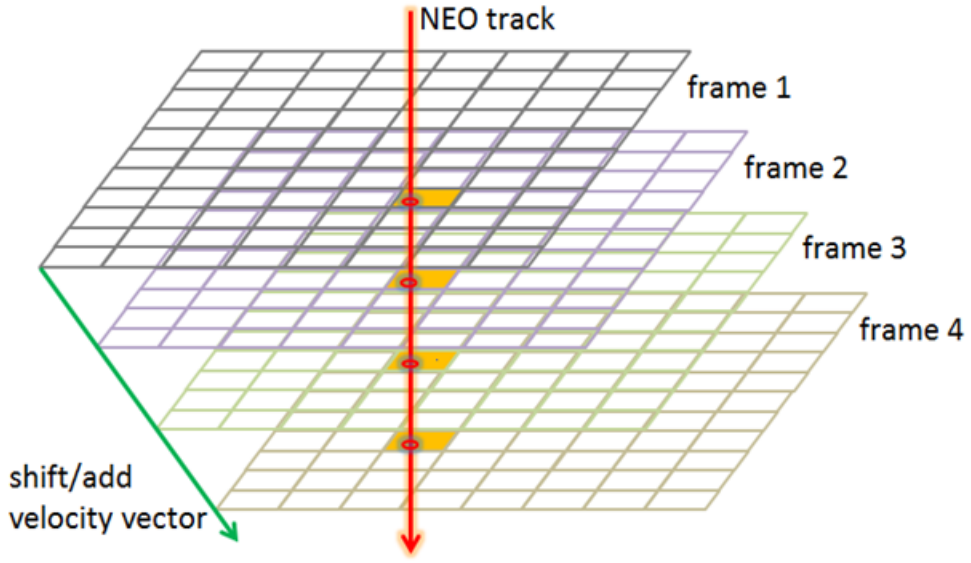
Outline

- What is synthetic tracking, what are its advantages
- Simulation of a constellation 8 of microsats. In searching for NEO compared to Next generation NEO search facilities.
- The saturation effect. Why a constellation of microsats with 20~30 cm telescopes can dramatically outperform the next generation of planned NEO search facilities.
- Summary

Detection of Moving Objects

- When an object is moving across a focal plane the photons are deposited across a streak of pixels.
- The maximum SNR occurs for an integration time where the motion ~= PSF diameter.
  - Longer exposure times do no increase the peak flux, just the sky background noise.
- Synthetic tracking overcomes this by taking multiple short exposures and “stacking” them with a shift/add algorithm.
  - For this advantage to be realized, two technologies need to exist, that have become available in the last several years.





Technology Requirements for Synthetic Tracking

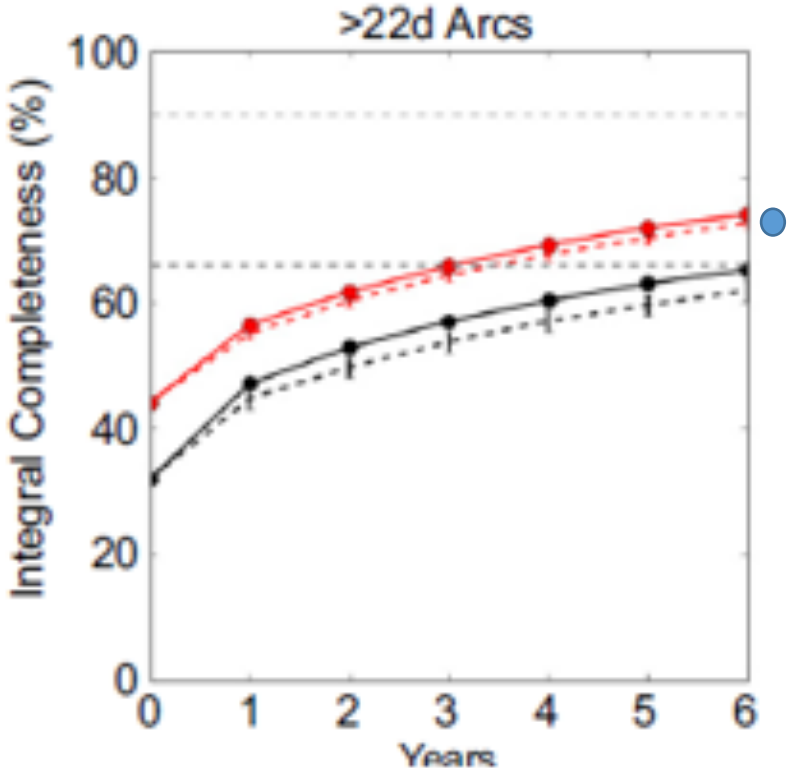
- The first is low noise, high frame rate focal planes
  - The read noise must be below the photon noise of the zodi-sky background.
    - The current generation of sCMOS detectors with ~1.5e read noise satisfies this requirement. 16Mpix devices are now available and 36Mpix and even >120Mpix devices will soon be available.
- When using shift/add algorithm, we don't know what velocity the object is moving until it's detected. As a result we have to "try" many velocities, as many as allowed by the target set we're trying to detect. Typically for NEOs we try ~10,000 velocities.
- This is computationally expensive and requires teraflop class processing. The data volume is large (we're taking video not single images) and in many instances its inconvenient to transport the data from the mountain to a super computer.
  - Modern GPUs and FPGAs are now available that can provide TFLOP processing at very low cost.

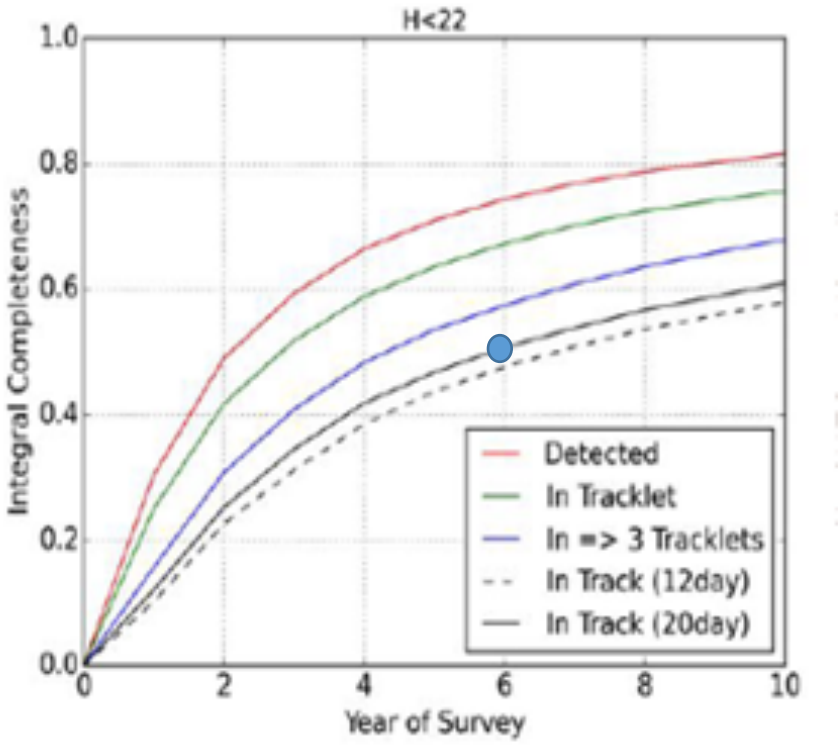
Advantages

- Medium and large telescopes searching for NEOs use 30~45 sec CCD exposures. Similar sensitivity can be had with much smaller telescopes and multiple exposures and total integration times much longer than 30sec.
  - The longer integration time means less sky coverage (sqdeg/hr) but can be compensated by using multiple small telescopes.
  - The economic advantage can be very substantial. For ground based NEO searches a Cluster of (~6)) 28cm telescopes (< 10K/each) can equal a ~2m class telescope with > 1 Gpix focal plane.
- In space the economic advantage is even larger.
- For NEOs much smaller than 140m, on average they are much closer to the Earth by the time they become detectable, and a 30 sec exposure is too long, giving synthetic tracking an even greater advantage.

Major near future facilities

- Two potential near future facilities are LSST and NEOCam. Both are extremely capable observatories, that significantly exceed existing ground based facilities





Results of simulations of NEOcam and LSST
The cataloging of 90% of NEOs would take > 15 yrs

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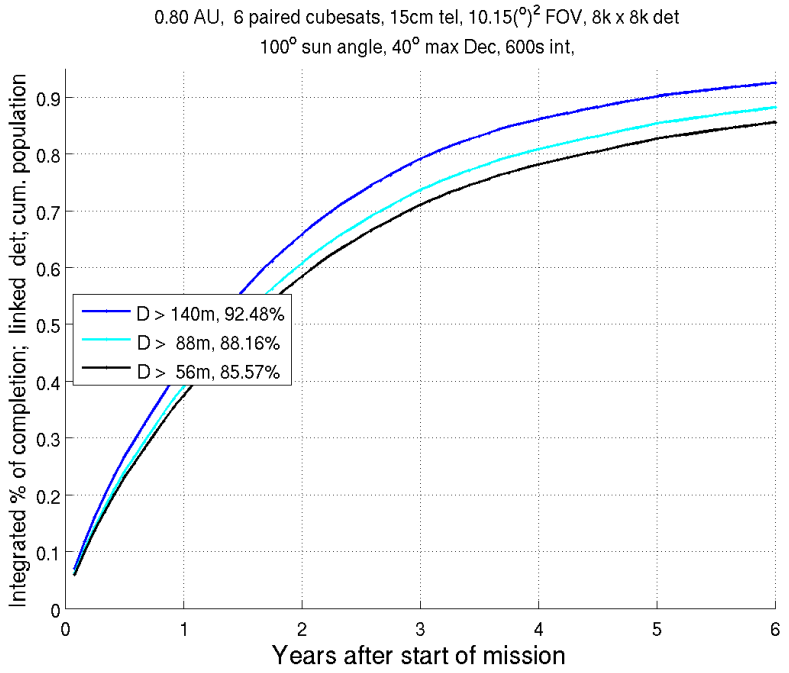
Chesley et. Al. 2017

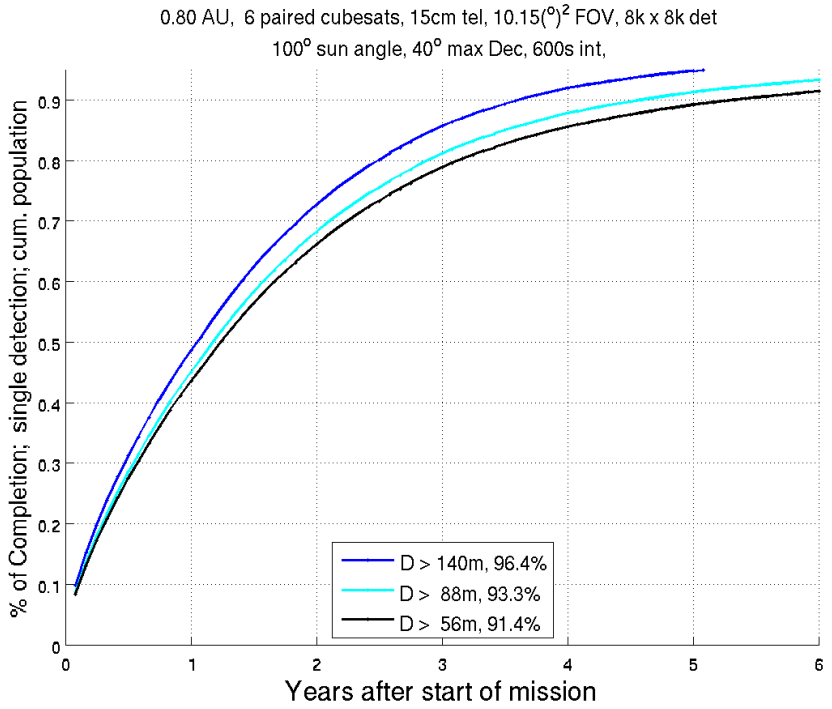
Definition of Terms

- Detect a NEO. The object is detected during a search. It's position (and perhaps velocity) and apparent brightness is recorded at 1 point in time.
  - Detecting a NEO just once, does not allow one to predict where it'll be in the future. Just one detection means it's found and then subsequently lost.
- Detailed orbit. NEOs are detected when they come near the Earth. If the same NEO is observed multiple times, over a period of years, its orbit is very precisely known, to a point we can precisely predict where it'll be in the future.
- Cataloged observation. If a NEO is observed multiple times over a short arc, a "crude" orbit can be established. Some orbital parameters will degrade with time, but others will not. The concept behind the term "cataloged" observation is that two cataloged observations decades apart can be unambiguously linked.
- Cataloged observations have lasting scientific value, while single observations do not.

Constellation of Cubesats



Detect one or more tracklets



Detect 20 day track (cataloged/linked)

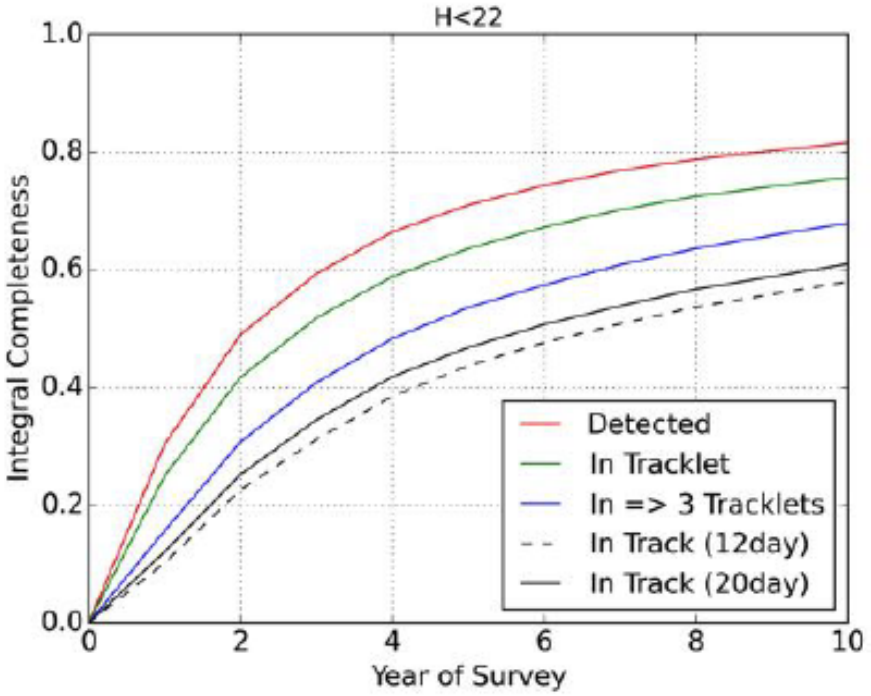
- Constellation of 12 cubesats (20cm telescopes)
- 20 day tracks of 70% of 140m NEOs in 1 yr, 70% in 2yrs and 90% in 3.8yrs

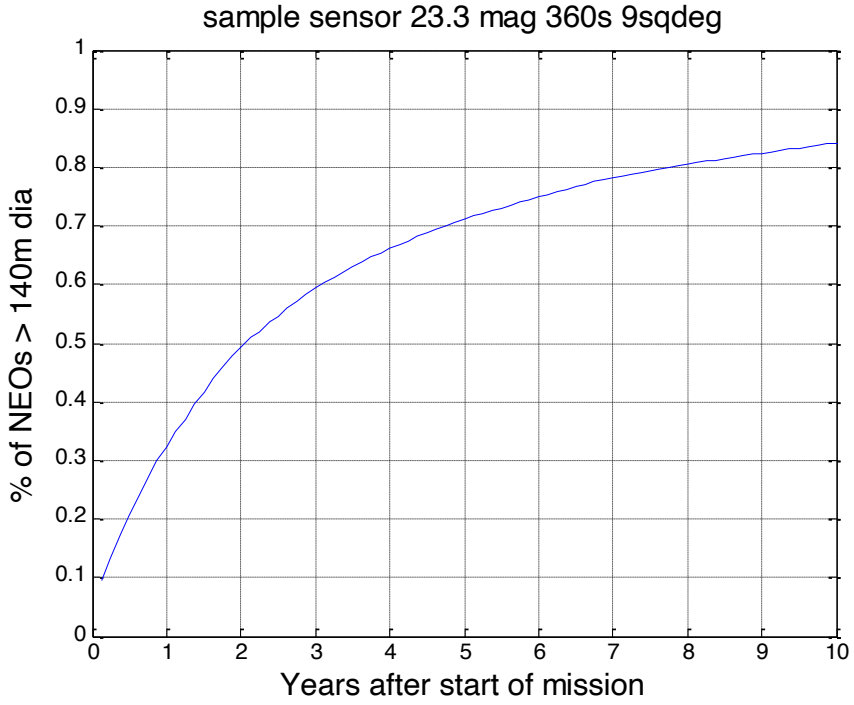
Why is a Constellation so Much Faster? (Saturation)

- There's a common theme in "Every" simulation, that is the discovery rate is highest at the beginning of the survey. The amount of time going from 0% to 10% is much (order of magnitude?) shorter than going from 90% to 100%.
- Vast majority of NEOs have very eccentric orbits. That bring them into the inner solar system once every few years. If the Earth is on the other side of the Sun at that time, it won't be detected. And it's many years before it comes into the inner solar system again.
- A constellation of telescopes will detect a NEO the 1st time it comes into the inner solar system (< 1.2AU from the Sun).
- Increasing the capability of an observatory on Earth (or Earth orbit) will not help detect the NEOs on the other side of the Sun. We call this the saturation effect, when increasing capability does not significantly shorten the time to detect 90% of 140m NEOs.

Simulations of Saturation (baseline facility)

- We constructed a medium sized space telescope whose discovery performance was roughly the same as LSST. (show below) This space telescope had a limiting magnitude of 23mag and 9sqdeg FOV. But it operated 24/7 rather than just at night, and had no sensitivity to the Moon or weather.

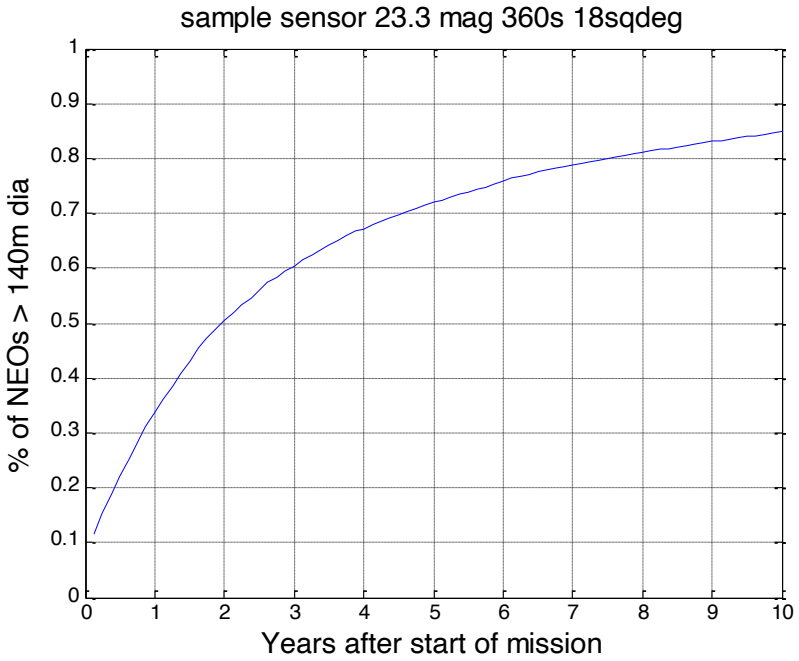


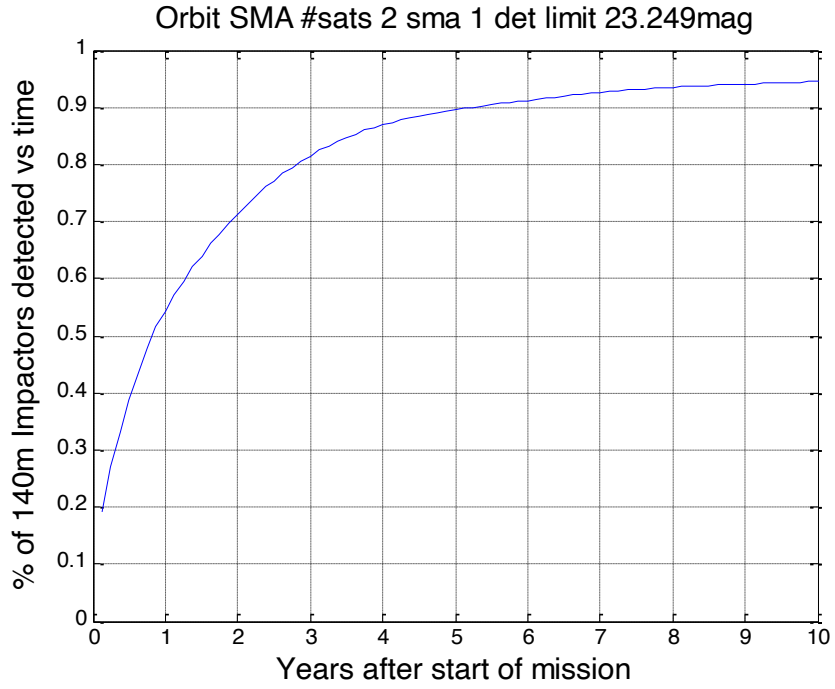


Doubling sky coverage

- Doubling Sky Coverage (eg build a 2nd telescope next to the 1st one.
- After 10yrs the # of unique NEOs detected increased from 83% to 85%
  - Time to detect 80% decreased from 8.0 to 7.6 yrs
  - ½ the sky coverage decreased it from 83 to 81%.
- An observatory this capable is working far into saturation.
- Place a 2nd telescope on the other side of the Sun
  - 95% complete after 10 yrs
  - < 4 years to detect 80%

Saturation Effect		
	% 10yr	Yrs @ 80%
Single large telescope	83%	8.0
Two in Earth orbit	85%	7.6
1/2 in Earth orbit	81%	9.0
1.3X dia 0.26mag	86%	6.5
Two in solar orbit	95%	3.0





Summary

- Synthetic tracking enables the use of small telescopes to have sensitivity comparable to much large telescopes. (significantly lowering the cost)
- The lower cost lead one to think about a constellation of small telescopes.

- Because of saturation, even large telescopes (equal to 8m ground based telescopes) can **NOT** catalog 90% of 140m NEO is < 10yrs. A single large facility is working far into the saturated regime. Building two large facilities only provides a marginal improvement in # of unique NEOs cataloged.
- A constellation of small telescope can catalog 90% of 140m NEOs in < 5 years. While each telescope is far less capable, they avoid saturation by being distributed across the solar system.

Acknowledgements

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