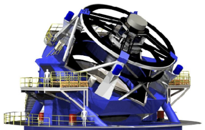

Asteroids!

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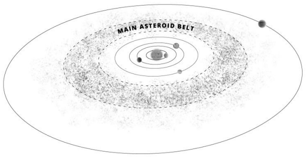
Motivation

Be smarter than the dinosaurs! Instead of getting surprised by a killer asteroid, lets detect it with enough time to take action.



Background

- Asteroid paths are specified by 6 Orbital Elements.
- Most asteroids live in the Asteroid Belt, so have similar orbital elements.
- Currently asteroids are discovered by taking sets of observations very closely spaced in time, so that individual asteroids can be matched up.
- The Large Synoptic Survey Telescope (LSST) will begin surveying the entire sky in 2021, and is tasked with detecting 90% of all potentially hazardous asteroids (among many other science goals).
- The main complicating factor is *noise* in images - for LSST we expect a ratio of false positives to real asteroids to be > 100.

Goal

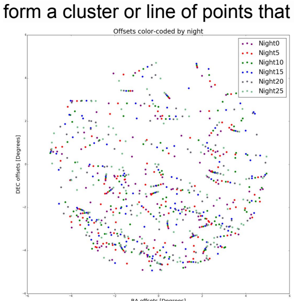
Design an algorithm for asteroid detection that does away with the requirement of repeat observations closely-spaced in time.

Then future telescopes like LSST will have freedom to spend more time pursuing diverse scientific questions about our Universe.

Methods

Phasing Observations

Instead of actual asteroid positions, observe positions *relative* to a reference asteroid. Then an asteroid with orbital parameters that are similar to the reference asteroid will form a cluster or line of points that map its relative position.

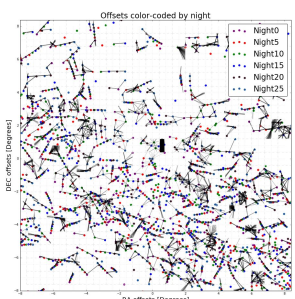


In the absence of noise, your eye easily picks out these phased nightly sequences of asteroids.

Hough Transform

Algorithm for feature extraction from images. In the simplest implementation, the idea is that a line y = mx + b maps to a point (m,b), and conversely each point (x,y) can be mapped to a line in slope-intercept space. A voting procedure results in the most popular lines being those that pass through many points.

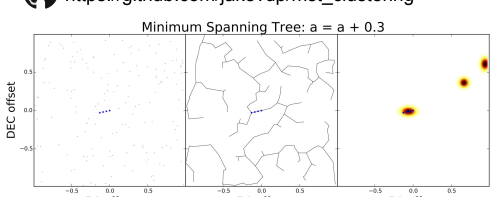
Hough Transform within gridded sections of the sky (no noise).



Minimum Spanning Tree

Machine learning clustering algorithm, with a tunable cutoff distance between clusters:

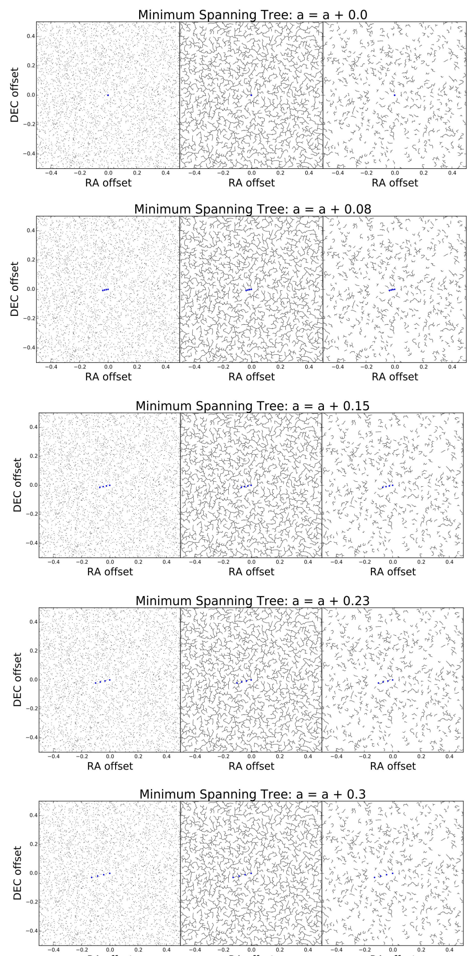
https://github.com/jakevdp/mst_clustering



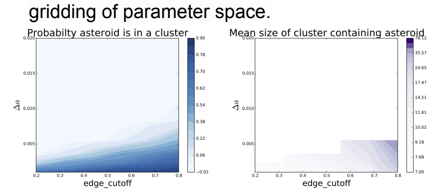
- Example with a single asteroid is shown here (in blue), observed on 4 nights, with a background of random noise.
- A minimal-length graph is constructed to connect all points.
- This graph is then trimmed to include only the edges shorter than some threshold distance (the "edge cutoff").
- The final panel reveals 3 clusters for this choice of cutoff.

Results

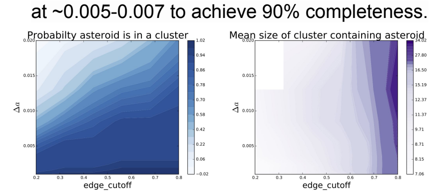
Minimum Spanning Tree applied in a realistic noisy background: Below we vary one of the orbital parameters, relative to the reference asteroid. In this example we "lose" the asteroid once its semi-major axis (distance from the sun) is offset from the reference asteroid by 0.15 astronomical units.



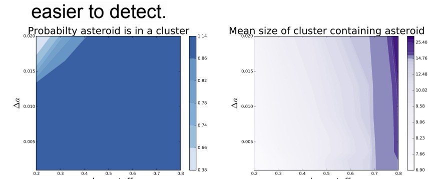
Asteroids at Earth's radius (a=1) are hard to detect (they move fast), and will require a fine gridding of parameter space.

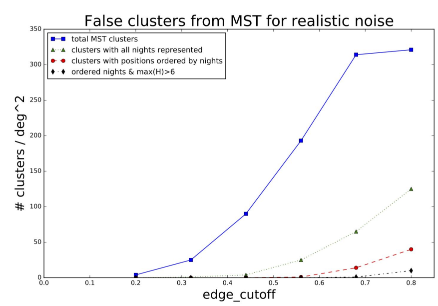


Main Belt Asteroids (a=3) will require a search through semi-major axis space gridded at ~0.005-0.007 to achieve 90% completeness.



Distant Asteroids (a=5 and beyond) are much easier to detect.





Minimize False Detections: a cluster representing a *real* asteroid will...

1. contain a point from every night of observation,
2. ordered sequentially by night, and
3. lie close to a straight line (Hough Transform).

Future Work

- Design an optimal grid through all 6 dimensions of orbital parameter space.
- Demonstrate asteroid detection at ≥ 90% completeness.
- Ensure algorithm can scale to LSST data rate of about 20 TB/night.

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