Update on IPAC segment (LMODE) of LSST Simulation study

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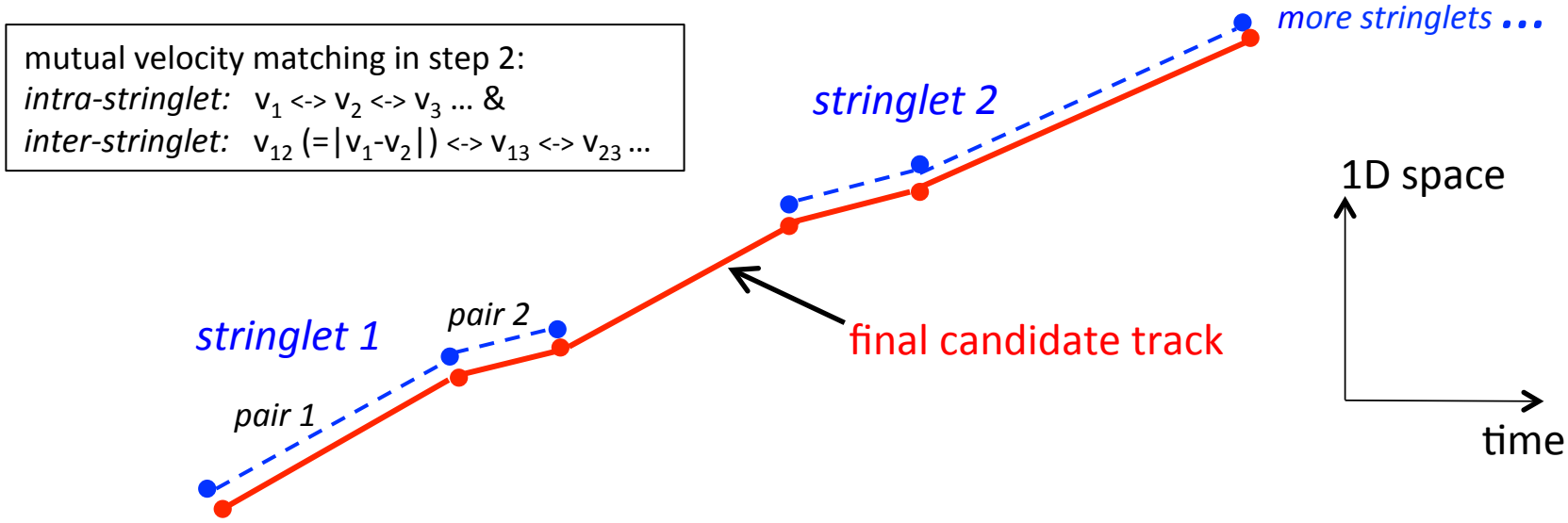
Update on IPAC study using LMODE software

- LMODE = LSST Moving Object Discovery Engine, originally developed for the Palomar Transient Factory; uses a different algorithm for building moving-object tracks.
  - software was updated to handle input detection lists from LSST simulations
  - optimized to be faster and more memory efficient than original version by adapting to LSST observing cadence
- This report gives an update on progress and testing, and on near-term plans
- LMODE was tested on subsets of a simulated LSST detection list spanning 12 days
  - based on LSST's "enigma1189" survey simulation: uses the original baseline cadence
  - this will be replaced by other simulation runs as cadence design evolves
  - data used so far include only asteroid populations comprising of both NEAs and MBAs; astrometric and photometric noise is included
  - No other transients and no artifacts are present in this version of the simulation

Overview of baseline LMODE algorithm

1. **Construct atomic building blocks:** connect adjacent pairs of detections in any band by matching velocities within given tolerances relative to a common center detection to form a *triple*. This becomes a "*stringlet*", presumably marking a single moving object. Two constraints on the observation timespans are imposed:
   (i) <= 9 hrs for *any* one of the pairs (i.e. same night); **(ii)** the other pair spans <= 3 days.
2. **Merge the *stringlets*** from (1) in relative-velocity space to construct object tracks. Both *intra-* and *inter-stringlet* velocity matching is used.
3. **Use simple QA metrics** to filter the tracks from (2) to weed out unreliable cases.



Recent updates to LMODE algorithm

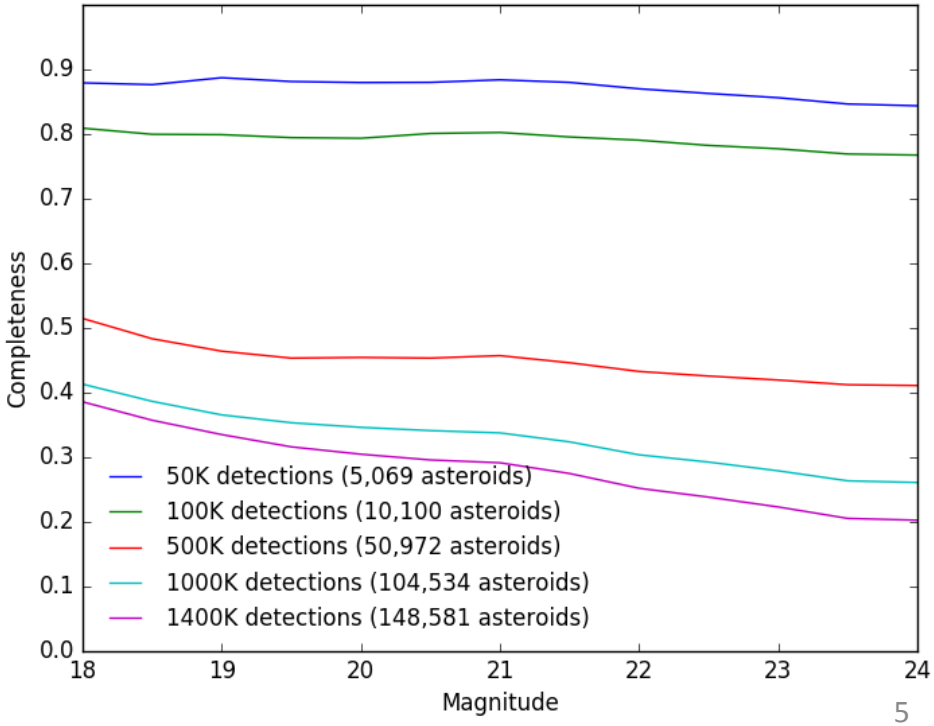
- Initial results of testing showed that the LMODE detection efficiency (aka completeness) was sensitive to the spatial density of input sources used
  - ➢ Contamination from multiple asteroids was an issue in the baseline algorithm
- To mitigate confusion in the stringlet and final track construction steps, we implemented an iterative approach on top of the baseline method.
- This consists of progressively "thinning out" the input detection list by removing all detections associated with *reliable* tracks identified at each iteration. Following each iteration, remaining detections would then be less affected by confusion, enabling more reliable and efficient track recovery.
- The approach involves slowly increasing velocity-match thresholds to first detect the most linear (reliable) tracks to more non-linear/challenging tracks.
- Our goal is to identify and remove as much of the contaminating MBA population as possible so that NEOs can be revealed.
- A track is considered reliable if it consists of >= 6 linked detections *from the same object*, regardless of the distribution of detection time tags over 12 days.

Initial results from baseline LMODE: recovery efficiency vs. density (all objects)

- The input list of simulated detections was subsetted by object name (retaining the 12 day span) to explore dependence on detection density (equivalent to number in list). The last (magenta) curve uses the full input list.
- Apparent magnitudes are for any of the filters: *g, r, i, z, y*; any band detection admitted
- This plot is for all Solar System object populations simulated (NEOs + MBAs)

- number of detections & corresponding number of asteroids are in parentheses
  - Average: ~10 detections/asteroid
- Completeness approaches 90% for low-confusion cases
- Completeness drops as density of detections increases
- Reliability (accuracy) levels of >~ 98% were achieved for all cases

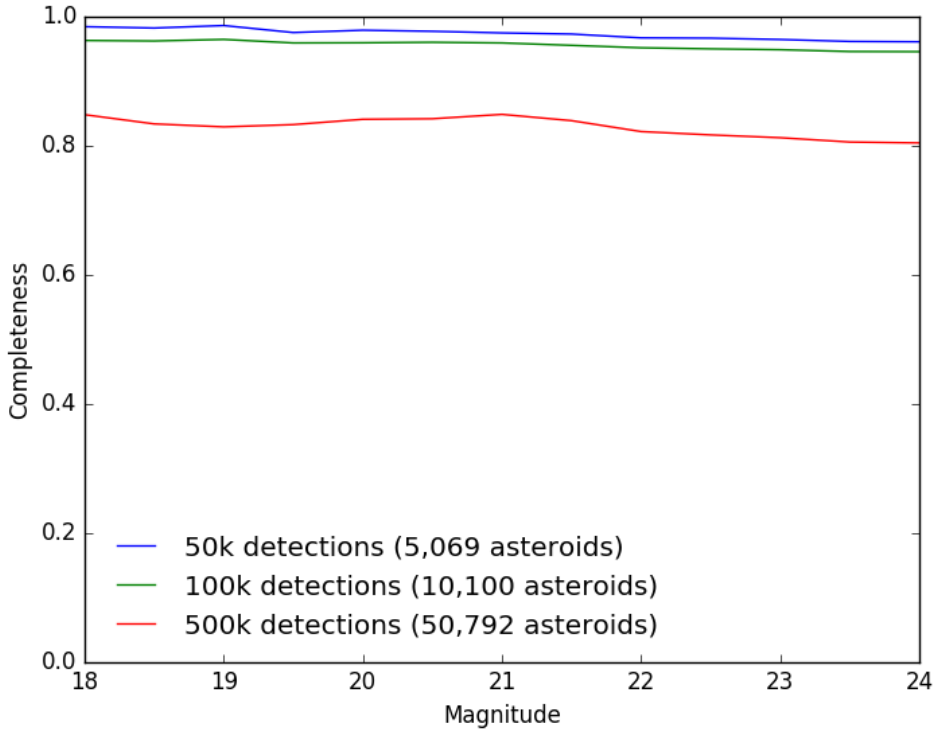
C = # unique tracks len ≥6 (LMODE) / # sim. list input
R = # unique tracks len ≥6 (LMODE) / # total LMODE



Updated LMODE: recovery efficiency vs. density (all objects)

- Below are some preliminary results using the new updated LMODE software (i.e., using iterative thinning of the input detection list to improve efficiency).
- This is for all Solar System object populations simulated (NEOs + MBAs)
- Processing for the 1000k and 1400k input cases is in progress.

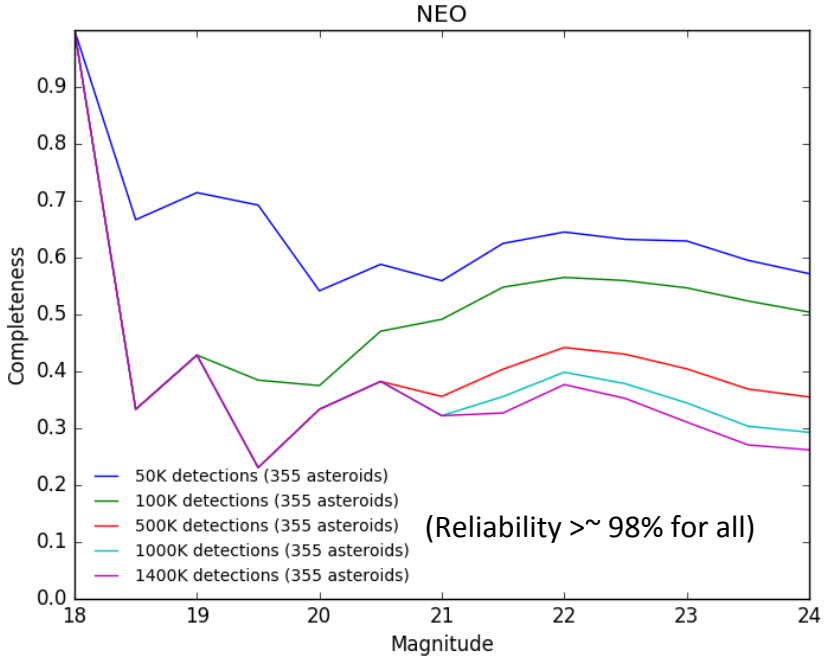
- Efficiency (completeness) is significantly improved (>80%), but reliability is diminished.
- As yet, no simple metrics have been identified to remove unreliable tracks (with < 6 same-object detections) without impacting efficiency.
- Orbit fitting will be added to assess tracks and recover reliability.



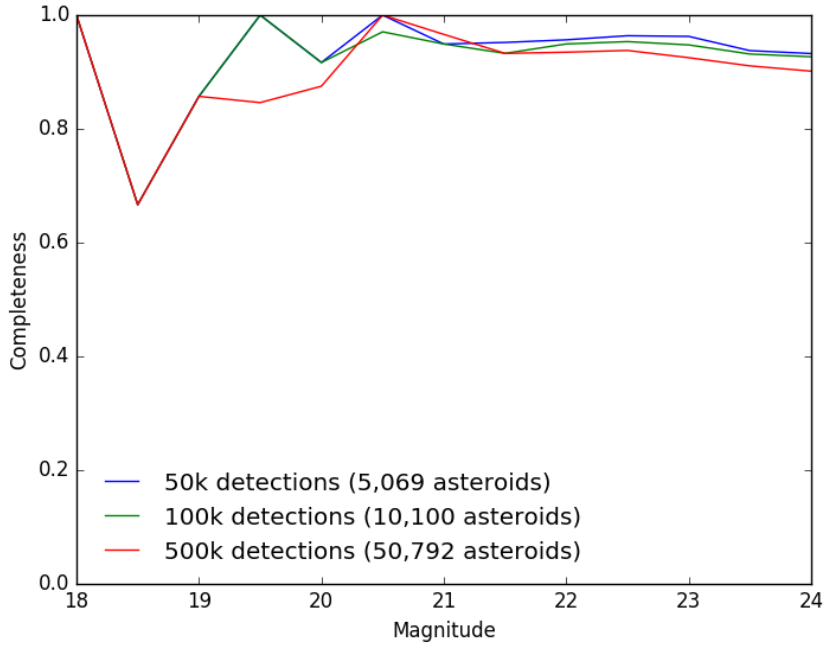
recovery efficiency vs density (NEOs only)

- Similar to previous plot using *only* NEOs in the input simulation subset; same 12day span
- Efficiency increased to >~ 90% using new LMODE software. Larger input runs in progress.
- Reliability however is reduced. Orbit fitting will be added to recover reliability.
- Variance is greater due to small number statistics in the input simulation subset.

Initial baseline LMODE result



Updated LMODE software result



Work in Progress

- Test updated LMODE software on larger input simulation files, i.e., that use full simulation density, including artifacts and other astrophysical sources/transients.
- Use latest simulation inputs that follow updated LSST observing/cadence strategies; in consultation with JPL and UW groups.
- Implement orbit determination to validate final object track lists and improve reliability. Currently, simplistic quality assurance criteria are used.

Questions for JPL:

- More recent simulation files? Need to be consistent.
- How to assess completeness relative to true underlying NEO/MBA population? How are length < 6 tracks handled?
- Related to previous: how to quantify limitations of LSST on recovering underlying populations as a function of physical properties … de-biasing?
- State of the art orbit-fitting code? Portability?
- Efficiency / runtime / resources required by JPL software?