Non-streaking moving objects from iPTF

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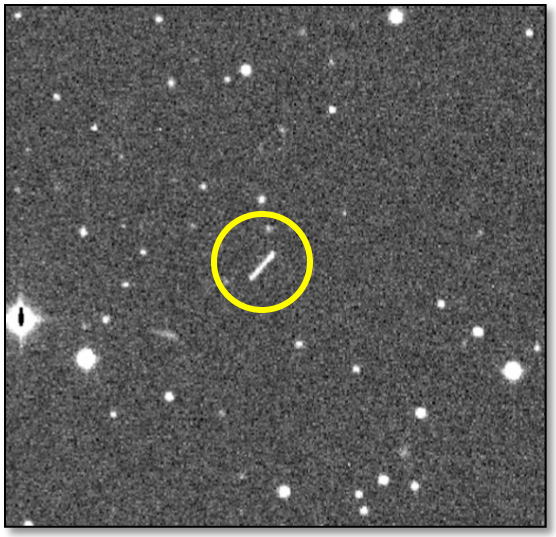
Goals

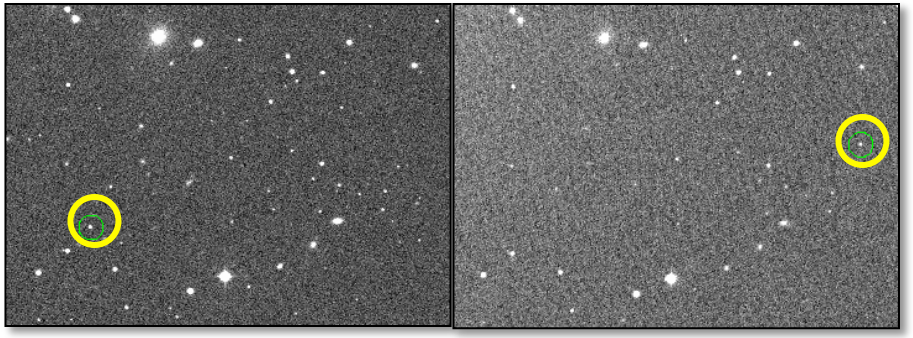
- To complement search for streaked objects in iPTF exposures (fast movers), implemented software to search for non-streaking objects: those that move with apparent velocities of

  <~ 3 arcsec / min or <~ 1.5 FWHM / 60 sec exposure

- New software is referred to as PTFMOPS: PTF Moving Object Pipeline System
- Currently in tuning and refinement phase. Hope to run in real-time operations pipeline soon



~ 16 arcsec/min

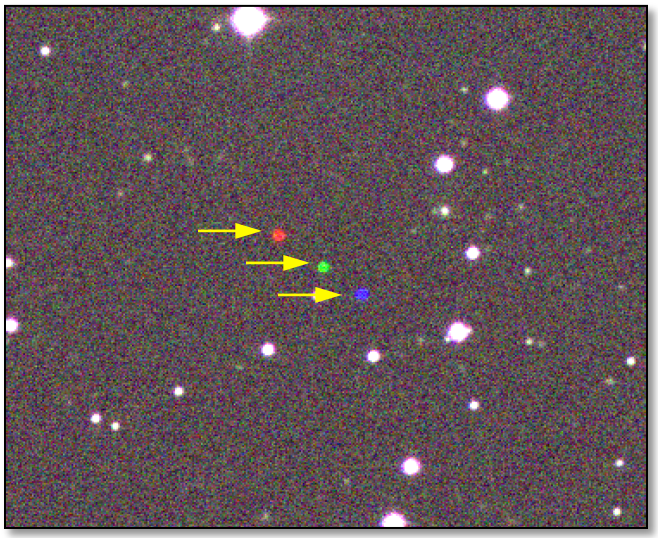


~ 1.3 arcsec/min

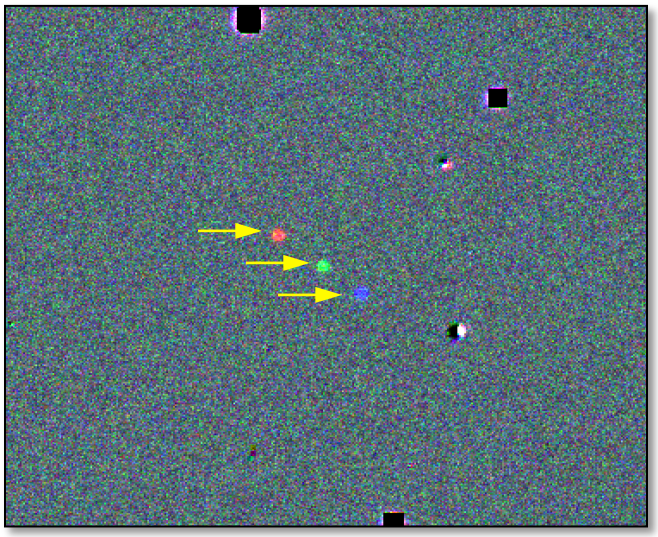
Inputs are Difference-Image PSF-extractions from PTFIDE

- Advantage of difference-imaging: stationary sources are rejected/suppressed!
  - huge plus in confused / high-source density regions
- Traditionally, moving objects found using full extraction catalogs after stationary object filtering using cross-matching
  - E.g., WISE, CRTS, Pan-STARRS …
  - Stationary object filtering is expensive and places a strain on processing
- PSF-extractions ensure sources are ~ point-like
  - small streaking allowed to bridge gap with faster moving objects

RGB composite of 3 science exposures at different epochs

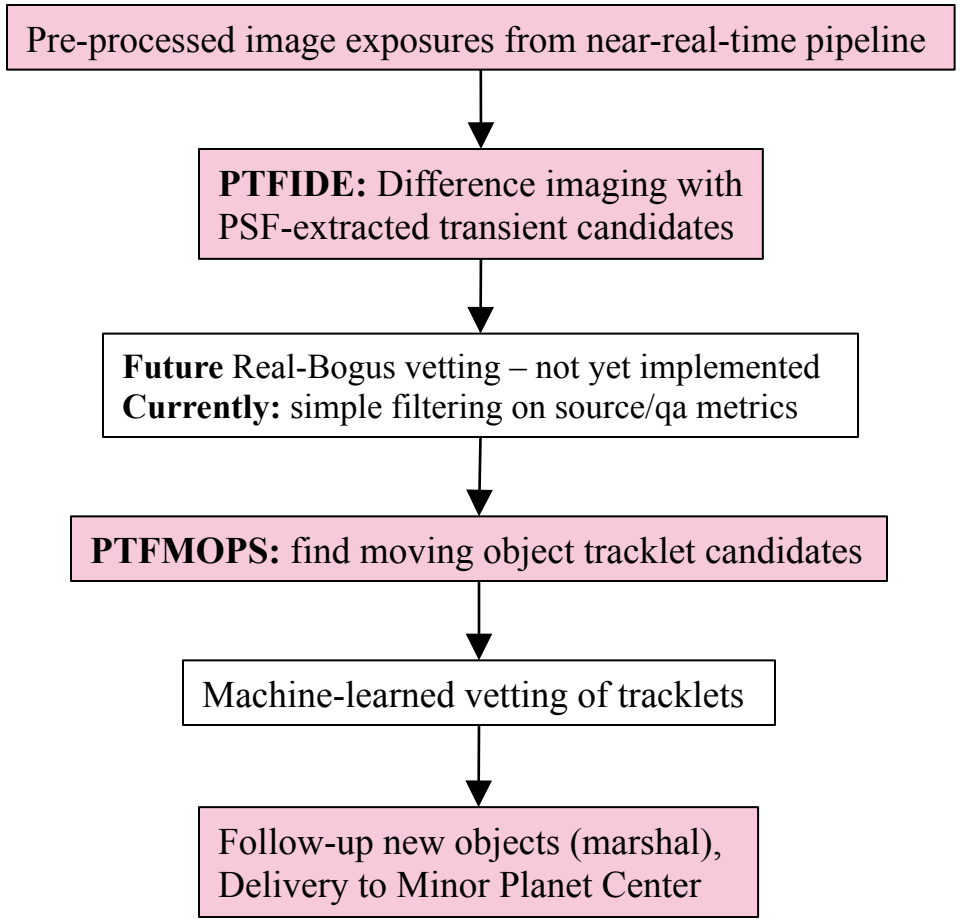


RGB composite of corresponding difference images



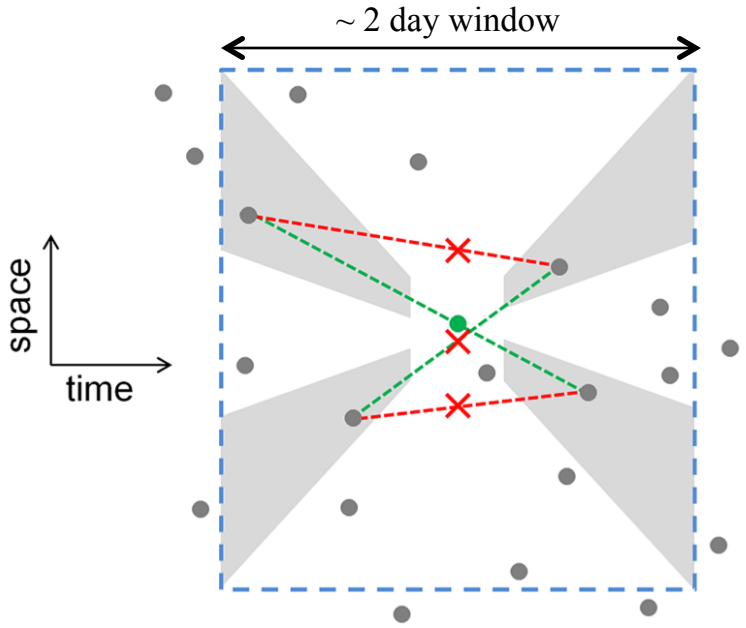
Provisional Processing Flow

Red-shaded boxes: implemented (in test/tuning phase)



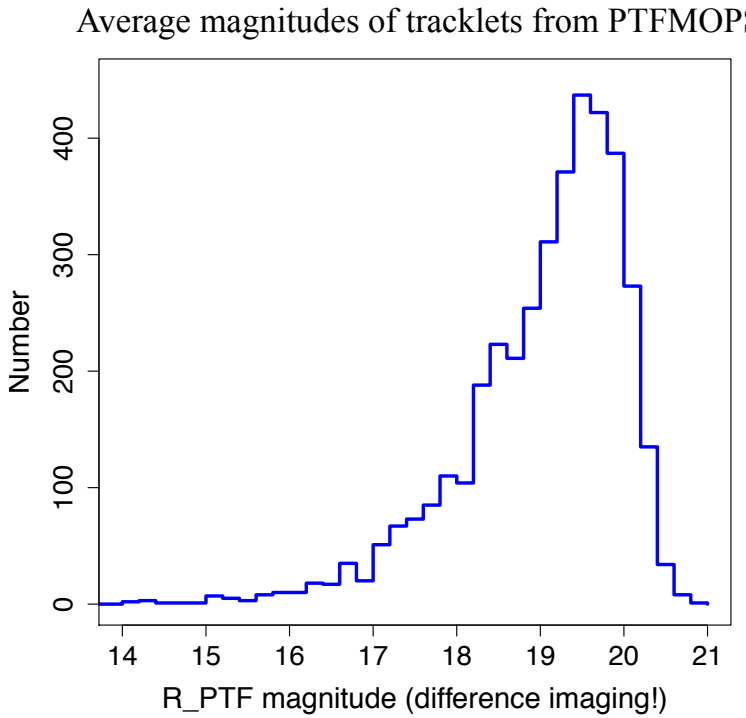
Tracklet Finding Algorithm

- Interesting computer science problem that makes using of tree-search algorithms
- Overall idea borrowed from Adam Waszczak's "home-brew" MOPS software, then enhanced
  - Waszczak et al., 2013, MNRAS, 433, 3115
- Implemented from scratch to take advantage of multi-threaded vector/matrix coding methods optimized for our multi-core architectures
- A two step process:
  1. Find tracklet pairs (object triples) within min/max velocity cone by matching velocities and fluxes (loosely)
  2. Bin velocity vectors and merge all tracklet pairs belonging to same object. Devil is in the details!

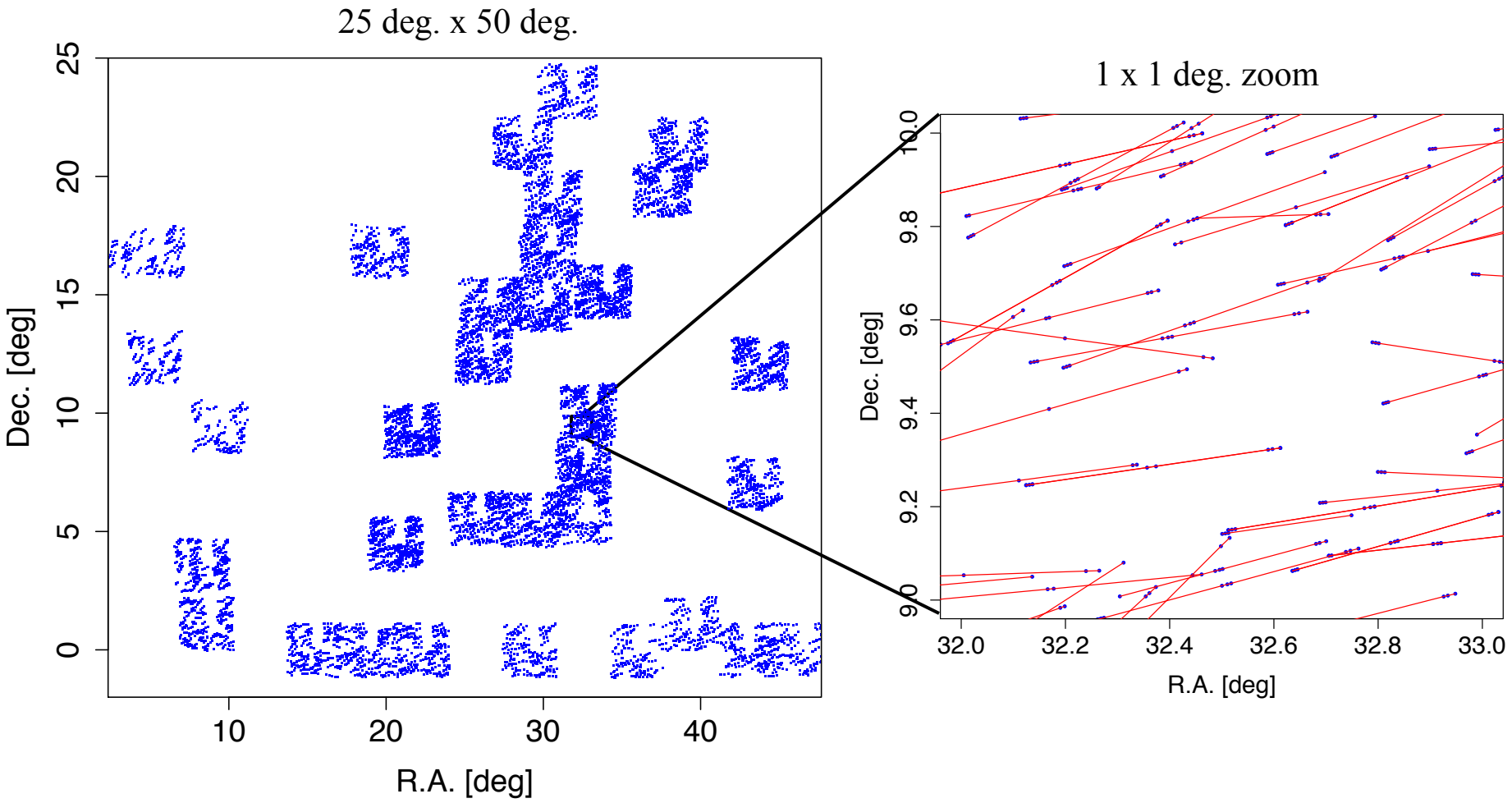


Performance

- Explored recovery fraction (completeness) and reliability of tracklets found using the new PTFMOPS run on diff-image transient extractions over a 3 night run in Nov 2013 in a 1500 sq.deg. region
- To ensure some reliability of raw extractions, filtering was applied using source metrics:
  - ~ point-like; S/N > 5; away from frame edges; > 2 arcsec from stationary sources; no bad pixels
  - recall that no Real-Bogus infrastructure yet exists
- Truth set is from the predicted occurrences of asteroids in all iPTF frames down to V ~ 23 (Adam)

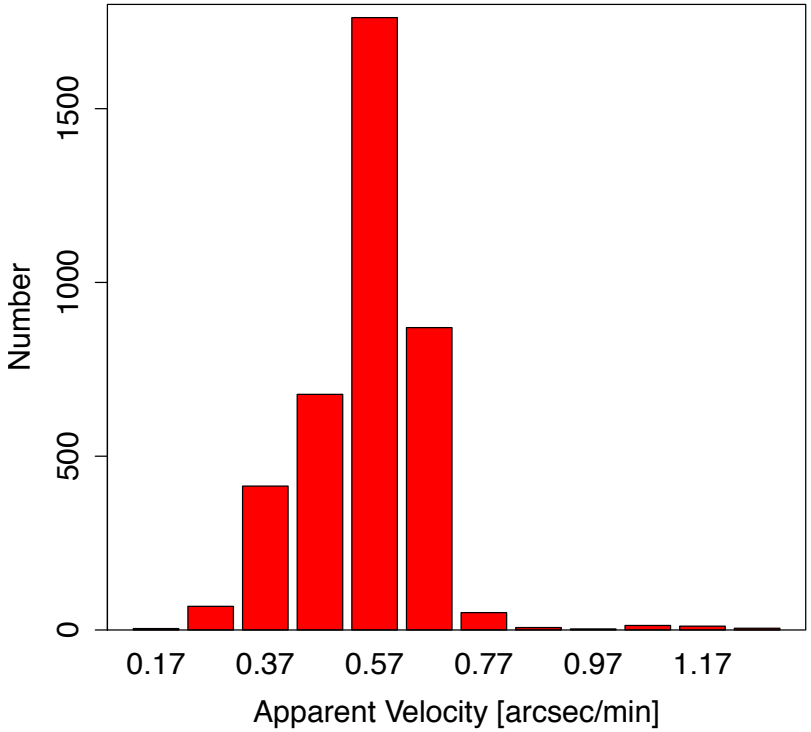


Sky snapshot of tracklets discovered by PTFMOPS

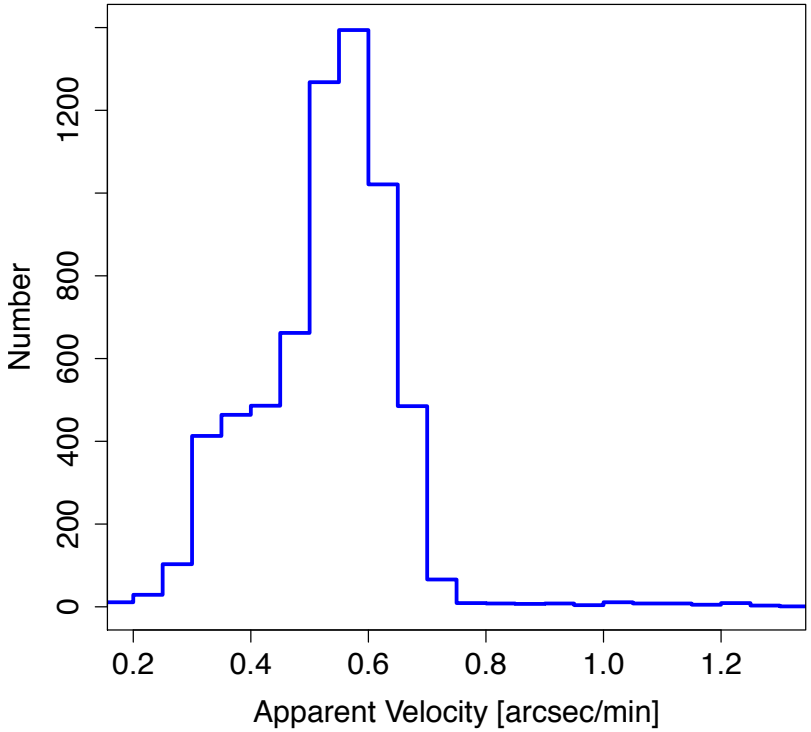


Velocity Distributions

Candidate tracklets from PTFMOPS



Tracklets from truth set (predicted)



Velocities are characteristic of Main Belt Asteroids

Completeness & Reliability

- In total, 3437 candidate tracklets with ≥ 4 detections/tracklet were found by the new PTFMOPS to R_{PTF} ~ 20, S/N > 5, in a 1500 sq.deg. region.
- The truth set contained 3813 tracklets to an equivalent R_{PTF} ~ 20 (or V ~ 20.2) in same region
- **Note:** given complex pre-filtering of input transient candidates, selection function is complicated
- Metrics below are based on cumulative numbers and pertain to length ≥ 4 tracklets

R mag limit	Completeness %	Reliability %	# Recovered (matched to truth)
16	74.13	100	43
17	82.66	100	143
18	88.46	100	529
19	93.09	100	1509
20	88.09	97.73	3359

- For comparison, Adam's "home-brew" MOPS can recover ~80-90% of known asteroids in iPTF

Conclusions

- The new PTFMOPS software is very capable of finding large numbers of reliable asteroid tracklets based solely on transients extracted from difference imaging
- More testing/tuning needed to optimize completeness and reliability according to different cadences and observing timespans
- Need real-bogus vetting of both input transient candidates and output tracklet candidates