High Accuracy Ground-based near-Earth-asteroid Astrometry using Synthetic Tracking

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Outline

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- Data Processing
- Results
- Summary and Future works

Introduction

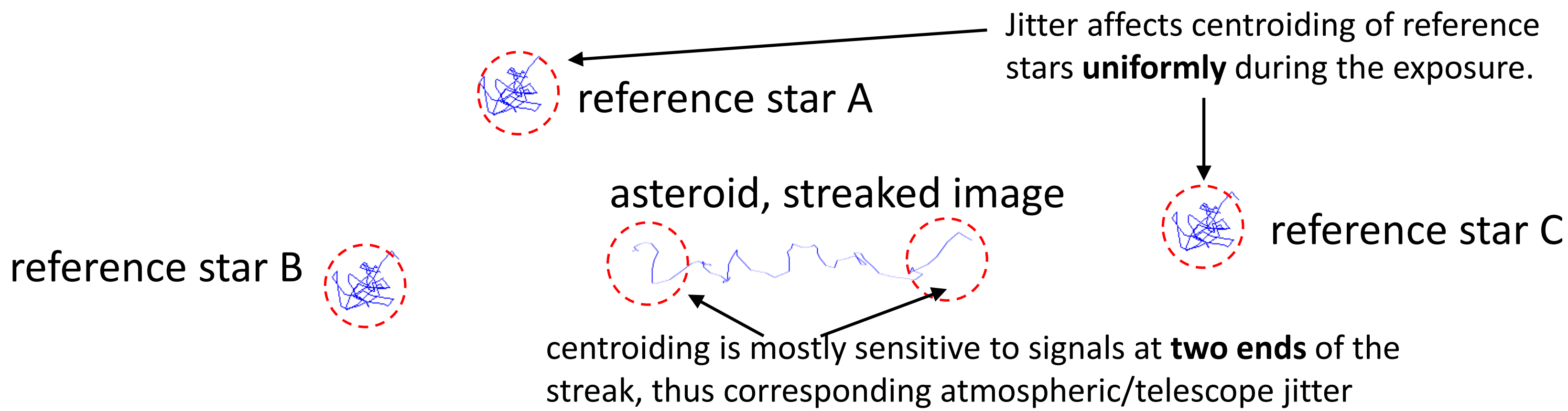
- Why Near-Earth-Asteroid (NEA) astrometry?
  - Produce **more accurate NEA orbit**
    - reducing chance of losing the track of detected asteroids
    - better predicting the probability of impacting Earth
  - Use asteroids as **proxy of future spacecraft** carrying optical communication lasers to demonstrate accuracy of measuring spacecraft position in the plane-of-sky for **optical navigation**. (JPL's Interplanetary Network Directory (9x) is funding this study.)
- Two main ideas of the approach:
  - ESA's Gaia mission will provide sub-mas astrometry for a billion of stars. **Very narrow angle astrometry** using **Gaia's catalog** enables to achieve mas-level astrometry with reasonable integration time by making atmospheric effect common between reference and target.
  - **Synthetic tracking** enables to achieve astrometry for moving objects such as NEAs with accuracy comparable to stellar astrometry

What is synthetic tracking ?

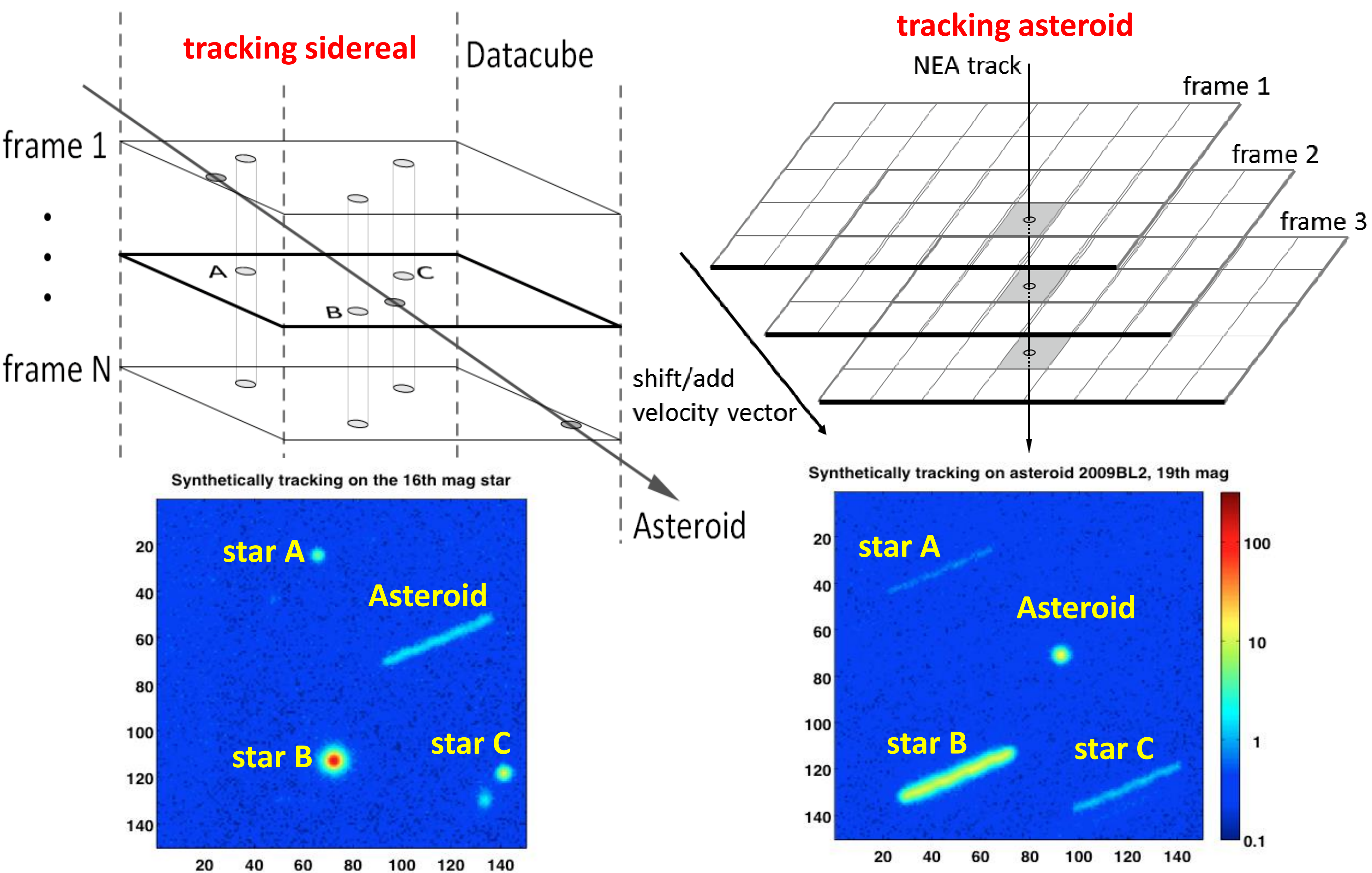
- Replace a relatively long exposure frame (typically by CCDs) with **multiple short-exposure frames** (enabled by sCMOS or EMCCDs) so that the image of moving object does not streak in individual frames.
  – Requiring camera to have significant **low read noise**, so that we are **limited by background noise** instead of read noise.
- Integrate frames in post-processing
  – Allowing us to s**ynthesize images tracking at any desired velocities** in post-processing. This technique is especially powerful for searching for an unknown signal. GPUs are very effective in speeding up the integrations for tracking on a large set of velocities .

Why synthetic tracking?

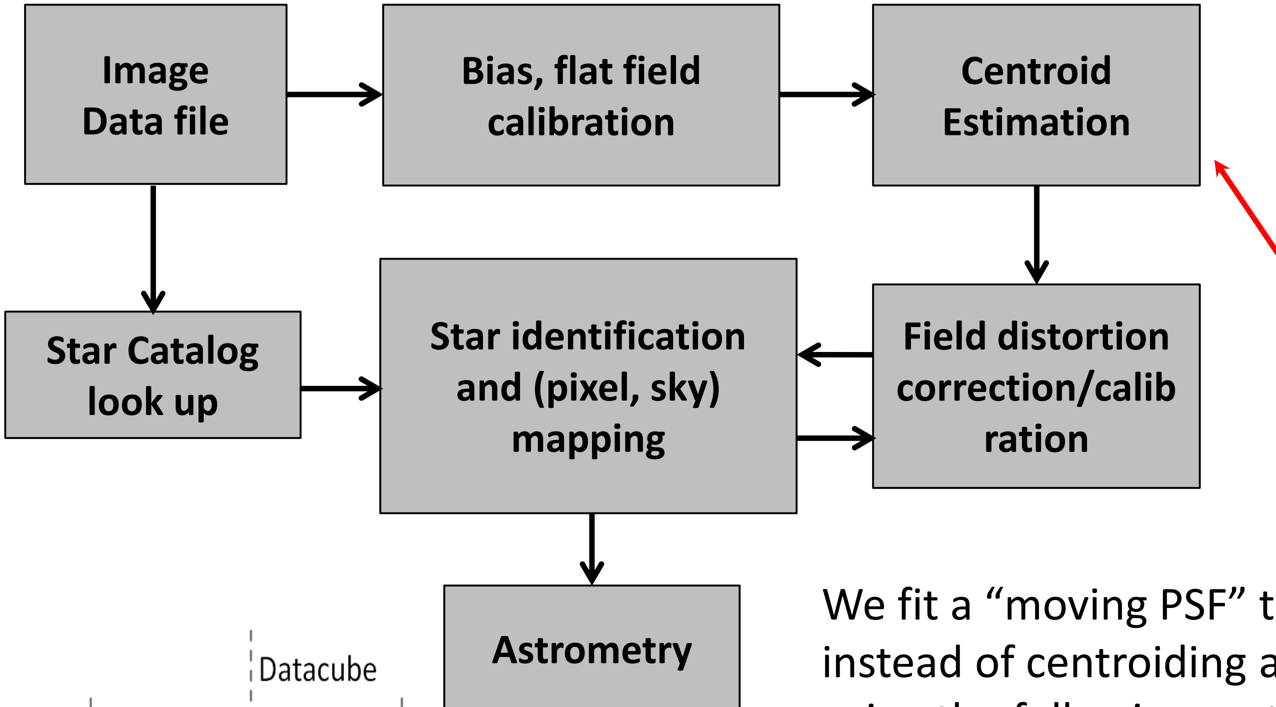
- It **avoids streaked images**
  - **Improve signal-to-noise r**atio (SNR) both for detection and astrometry.
  - Use **compact PSF** for more accurate astrometry (seeing/optical limited, no streak)
  - Making **atmospheric/telescope pointing jitter effects common** between moving object and reference stars.



Synthetic tracking enables to track at multiple velocities in post-processing



Data processing

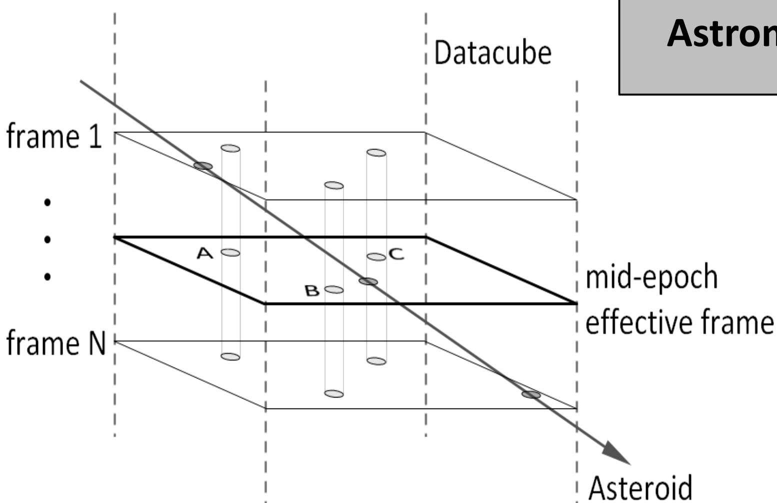


The only difference from a typical NEA data processing is centroiding.

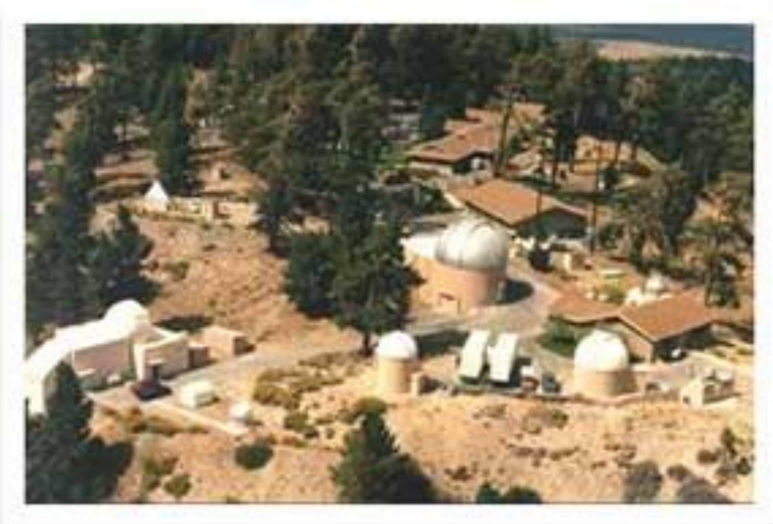
We fit a "moving PSF" to a data cube, instead of centroiding a 2-d image using the following cost function:

$$\underset{\{X_C,Y_C,V_X,V_Y\}}{Arg\min} \sum_{x,y,t} \left| I(X,Y,t) - \alpha P(X - V_X t - X_C, Y - V_Y t - Y_C) - I_{bg} \right|^2$$

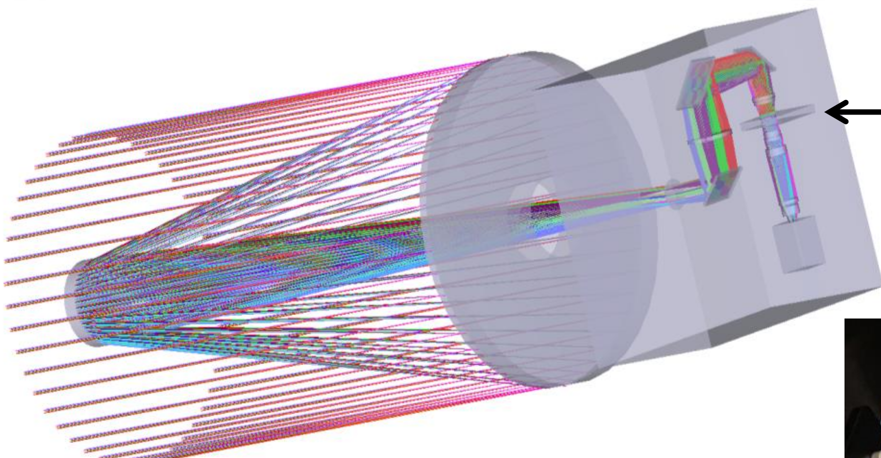
to obtain an estimate of the centroid (X_C, Y_C) and moving velocity (V_X, V_Y).



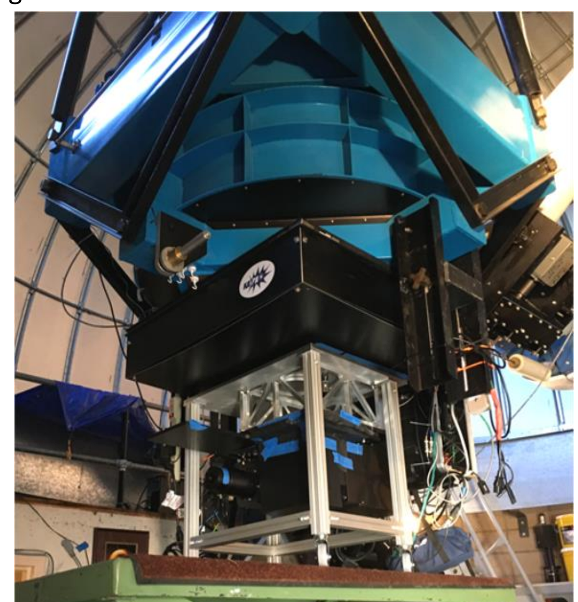
Our Instrument on the Pomona College's 1 m telescope at the Table Mountain Facility (TMF)



https://tmf.jpl.nasa.gov

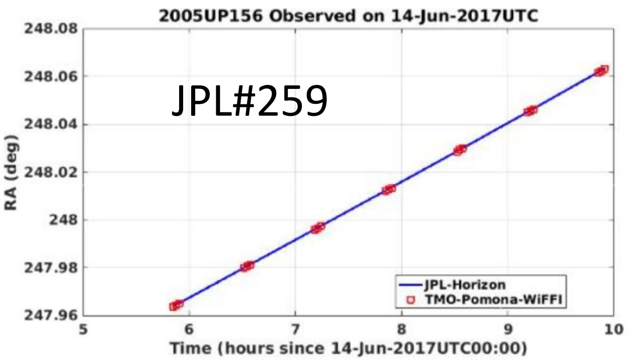


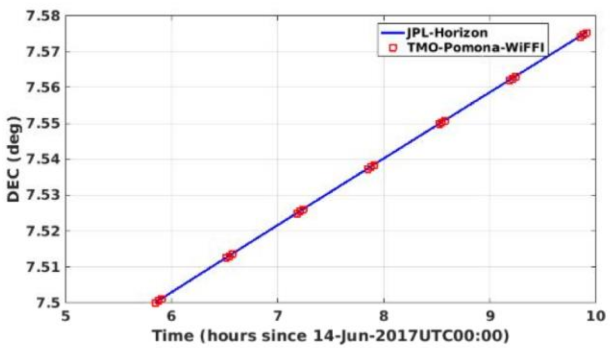
filter wheel

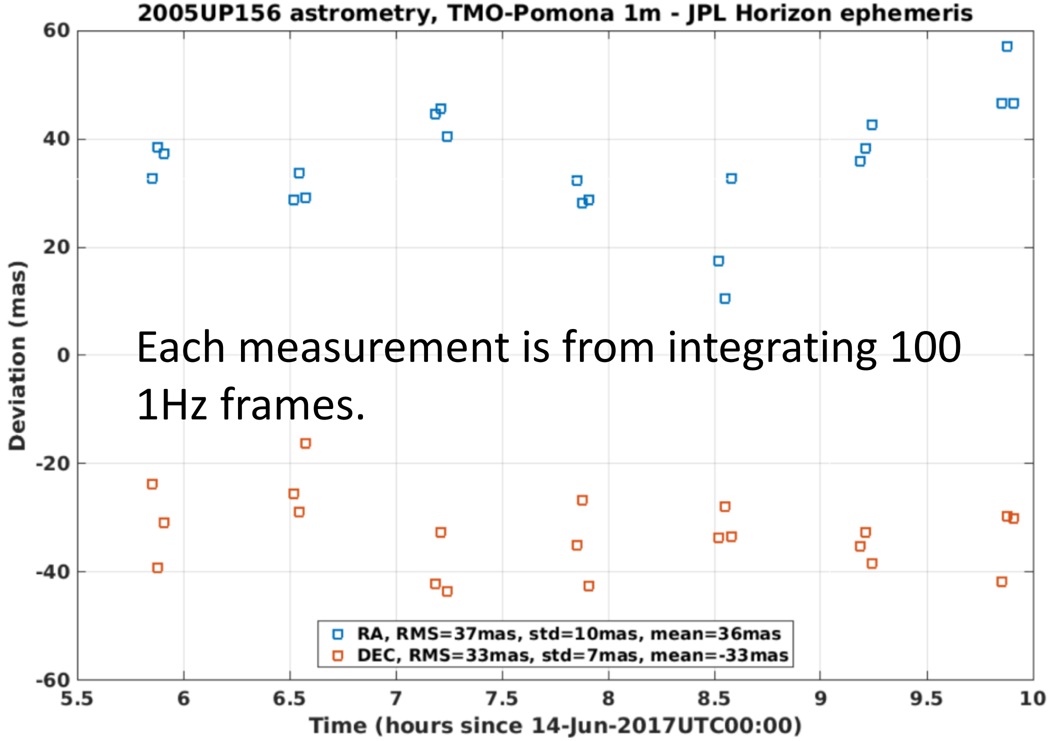


Andor Zyla 5.5 Detector

2005UP156, observed on 2017-06-14







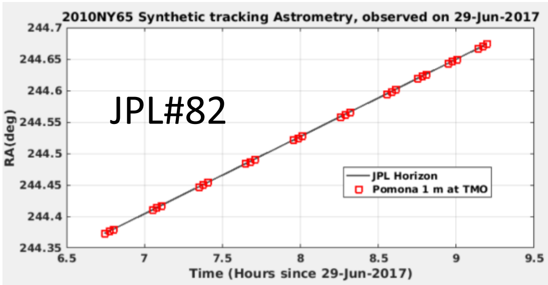
2005UP156, 1km size asteroid, 6/14/2017, it was at ~ 0.16AU from the earth with apparent magnitude ~ 14.7, moving at ~0.025 as/second

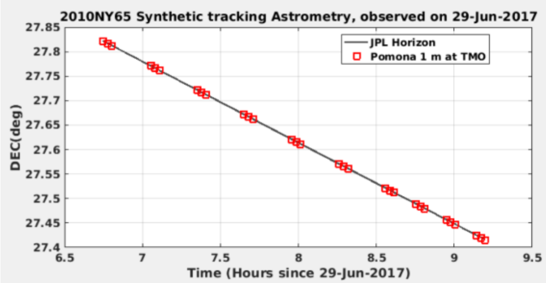
Residuals from comparing with JPL Horizon #259, 3-sigma of (RA, DEC) = (115, 175) mas,

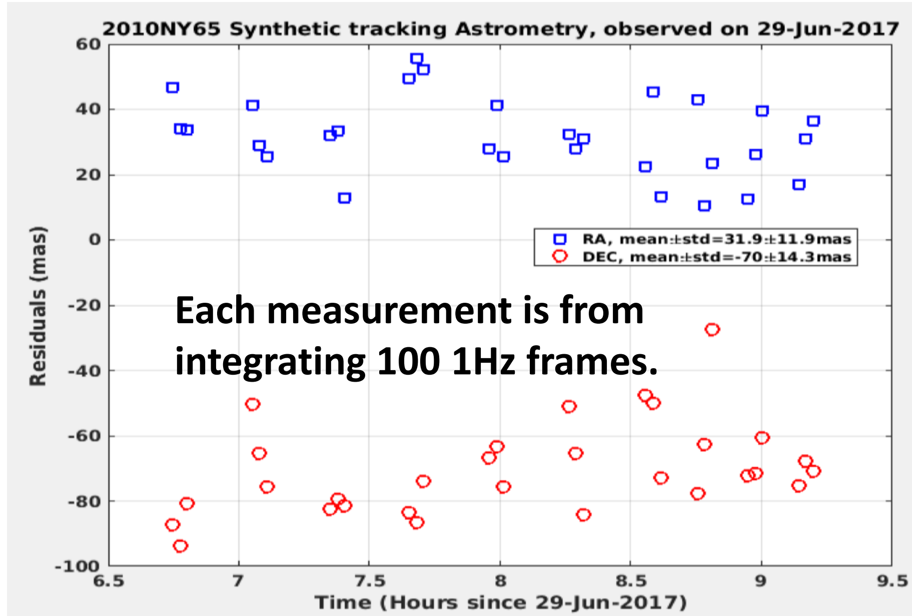
RA: mean = 36 mas, std = 10 mas,

DEC: mean = -33mas, std = 7 mas,

2010NY65, observed on 2017-06-29





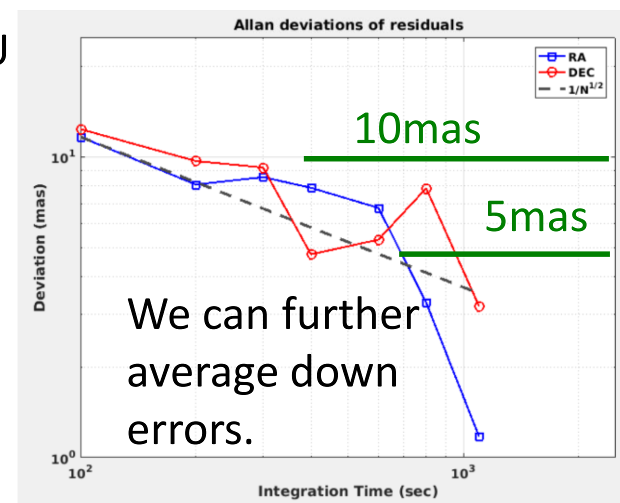


2010NY65, 200m size asteroid, 6/29/2017, it was at ~ 0.042AU from the earth with apparent magnitude ~ 16.8, moving at ~ 0.2 as/s

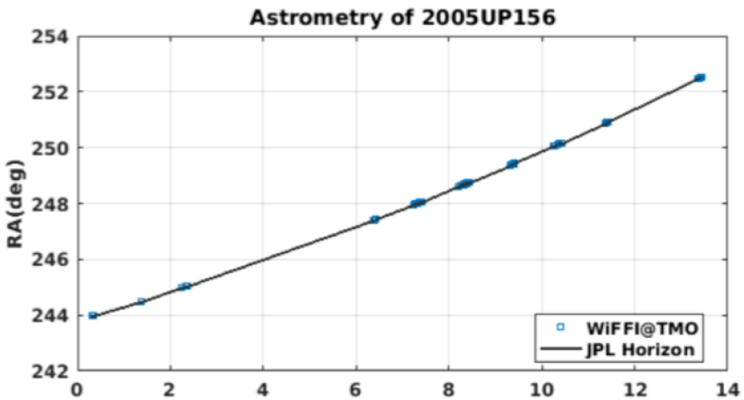
Residuals from comparing with JPL Horizon #82, 3-sigma of (RA, DEC) = (190, 140) mas,

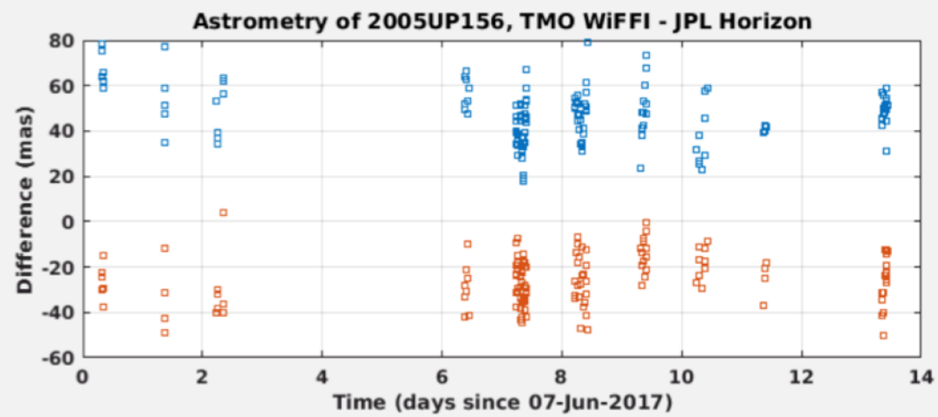
RA: mean = 32 mas, std = 12 mas,

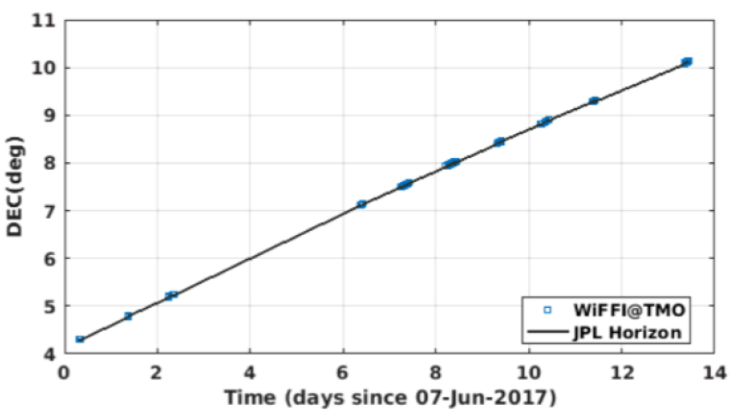
DEC: mean = -70mas, std = 14 mas,

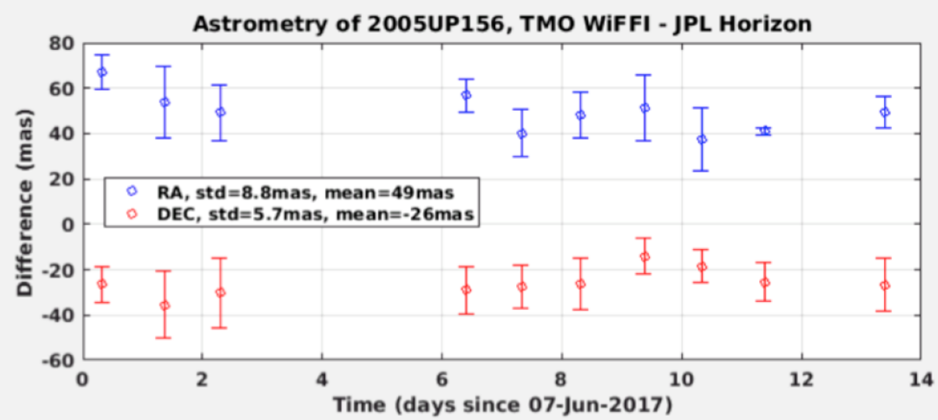


2005UP156, observed over two weeks









Observations using the Pomona College 1m at the Table Mountain Facility

- Since June of 2017, we have submitted more than 400 NEA observation data to the Minor Planet Center.
- Vast majority of the observations have accuracy better than 50 mas.
- Bright asteroid observations have accuracy ~10-20 mas, which is the level of systematic errors, mainly due to chromatic distortion from refractive elements in the optics.
- Synthetic tracking allows us to achieve similar accuracy for fast moving NEAs compared with slowly moving ones.

Summary and future works

- Summary
  - We were able to achieve 10-20 mas level astrometry for bright NEAs using Synthetic Tracking.
  - The accuracy is insensitive to how fast the NEA moves.
- Future works
  - Putting detector directly at Cassegrain focus to eliminate refractive elements, and thus minimize chromatic distortion effect.
  - Use the Gaia Data Release 2 Catalog (DR2)