Real Time Improvement of Orbits of Space Debris by Fusing SLR and Astrometric Data Acquired by a Night-Tracking Camera

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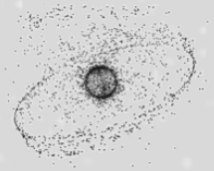

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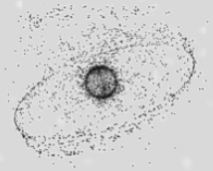


Motivation

- Improvement of SLR observations
  - Satellite acquisition time
  - Number of observation per NPT
  - Pass Observation rate
  - Successful satellite acquisition (by visual inspection)

- Improved orbit determination through fusion of range and angular data (especially for short observation arc)
- Attitude studies based on light curve and laser light curve and range variation analysis
- Retrieving angular measurements for fast moving objects with small field of view (no reference stars for astrometry)
- Synchronous acquisition of measurements for attitude and orbit determination

The Night-Tracking Camera

- **ZIMLAT Telescope**
  - 1-m Aperture Ritchey-Crétien
  - Coudé focus for Laser
  - Nasmyth Focus for tracking and CCD cameras
- **Neo 5.5 sCMOS Camera**
  - 5.5 megapixel sensor, 6.5 µm pixels
  - 22 mm diagonal field of view
  - Rolling and Global Shutter
  - Rapid frame rates
    - 30 fps over extended kinetic series
    - Burst to memory at 100 fps full frame
- **Integration of the new camera into the SLR system**
- **Development of observation and tracking software**
- **Development of a quasi-real time analysis pipe**

Credits: Oxford Instruments 2018

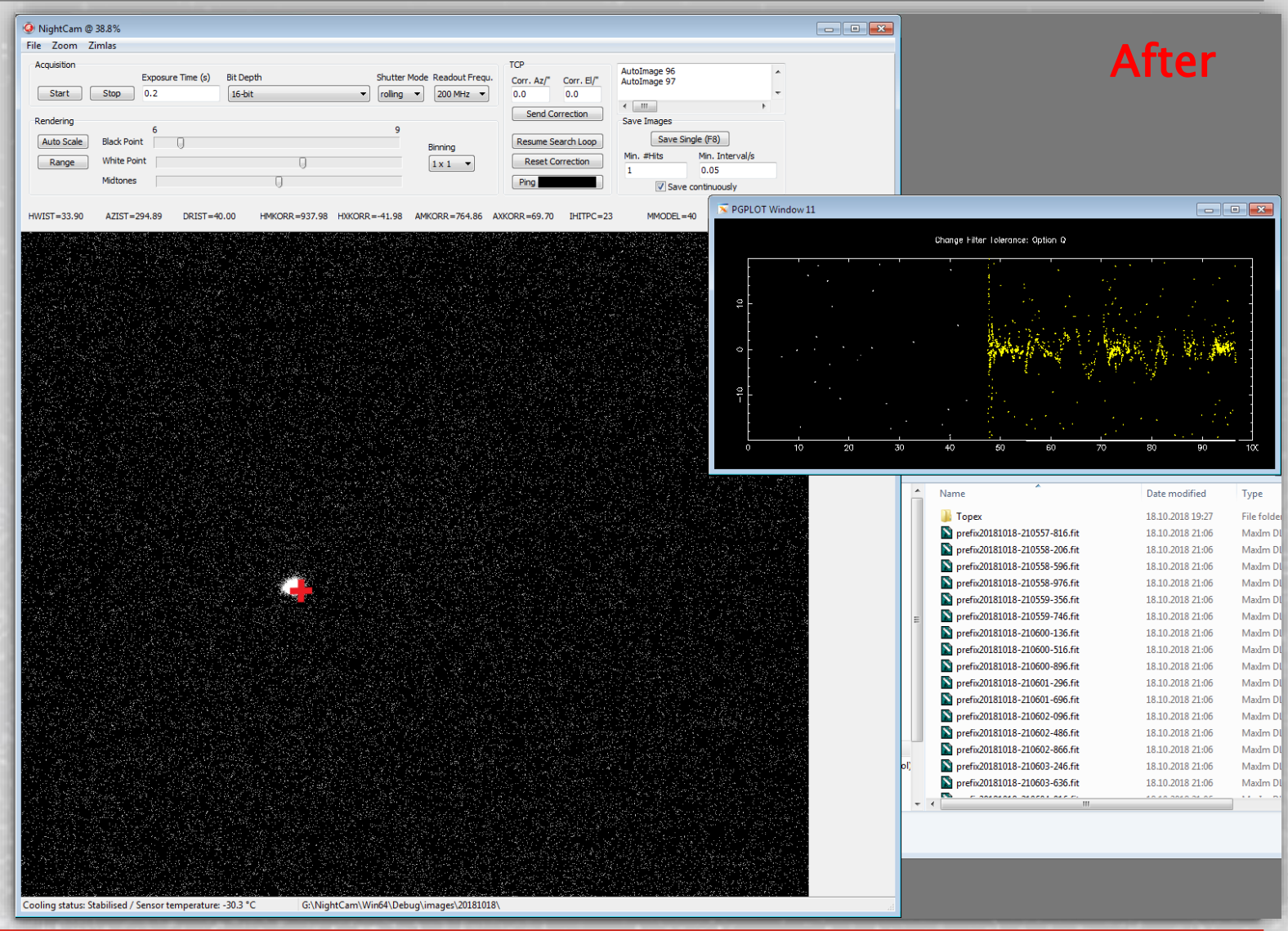
The NightCam at Work

NightCam Capabilities

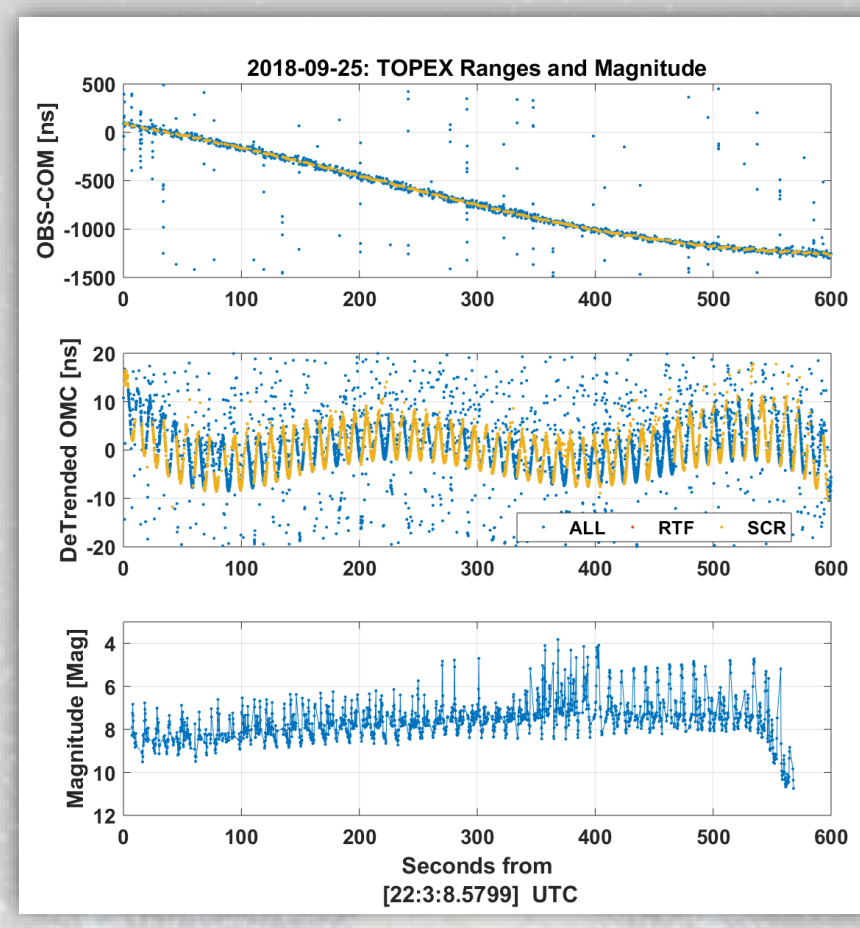
- Set up camera parameters
- Target Acquisition
  - Target Position w.r.t. Laser Position
  - Azimuth/Elevation ephemeris correction handling
  - Storing of Images with telescope data (pointing directions and measurement epoch)
- Synchronous observations acquisition
  - Azimuth/Elevation
  - Range
  - Light curve

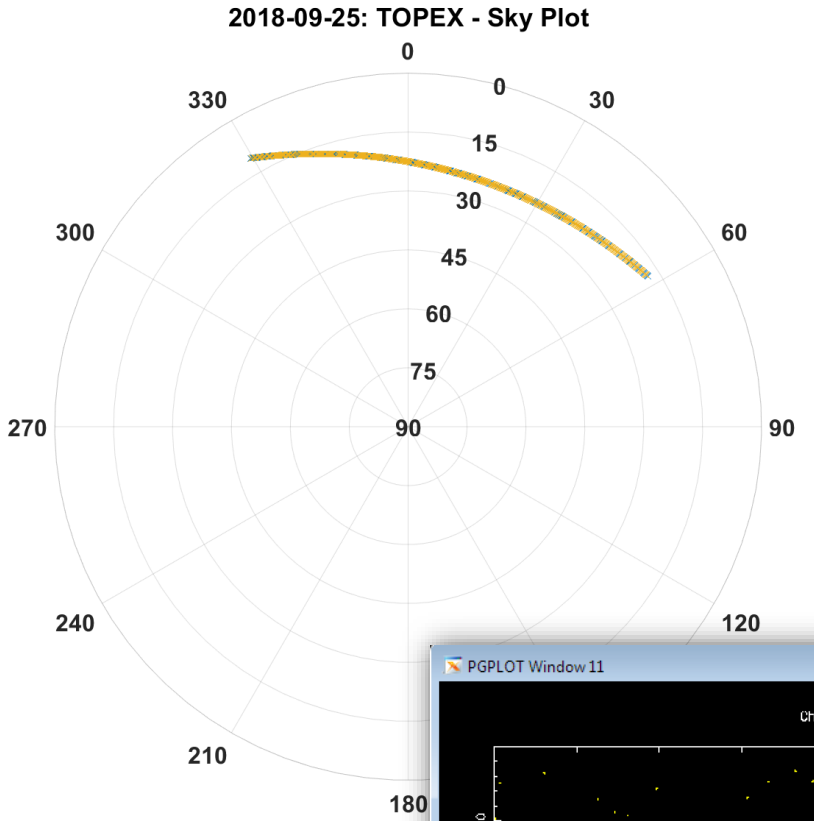
Target: TOPEX **Date:** 2018/10/19

Initial Ephemeris offset: ~68 arcsec



NightCam Output

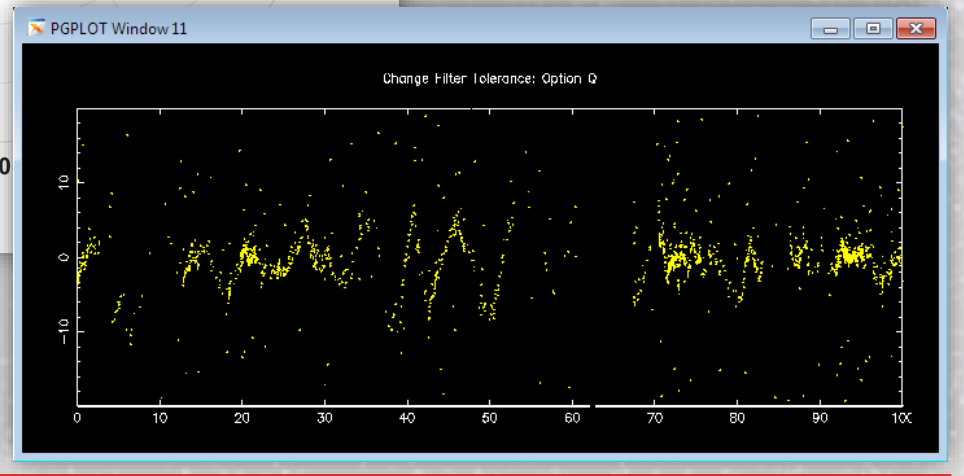




Date: 2018/09/25
From: 22:03 UTC
To: 22:13 UTC

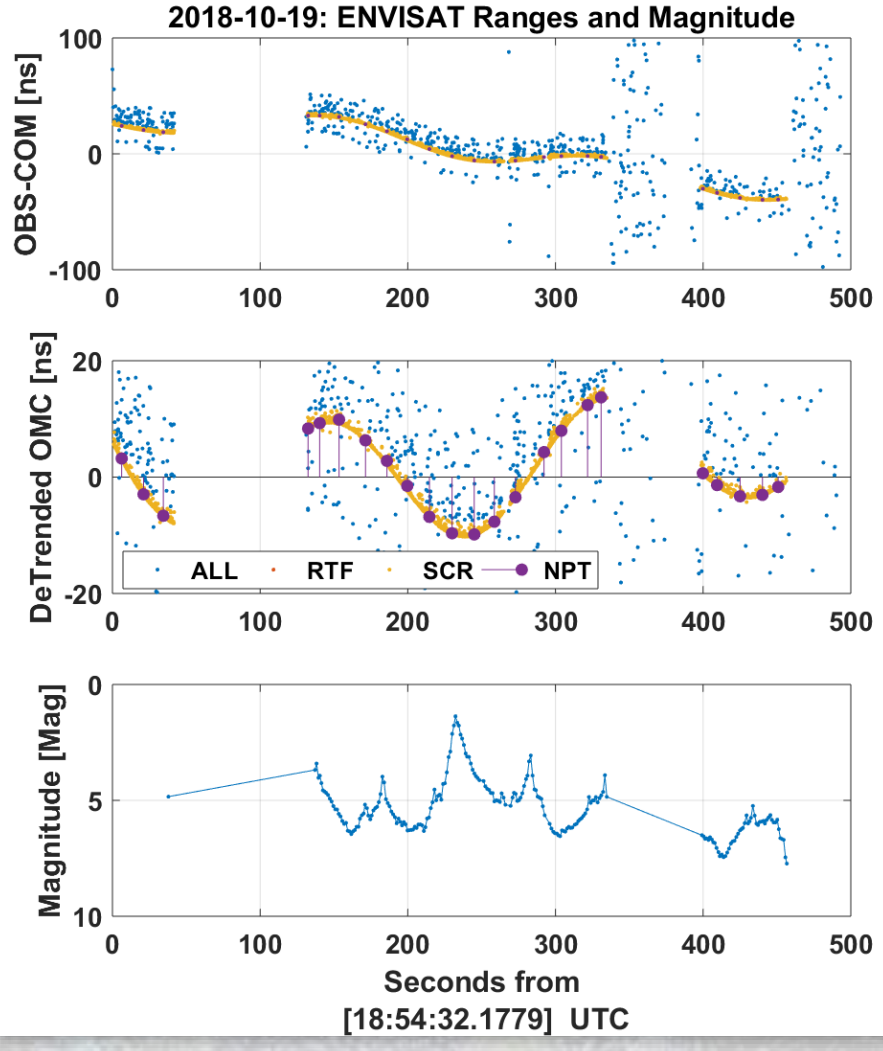
Target: TOPEX

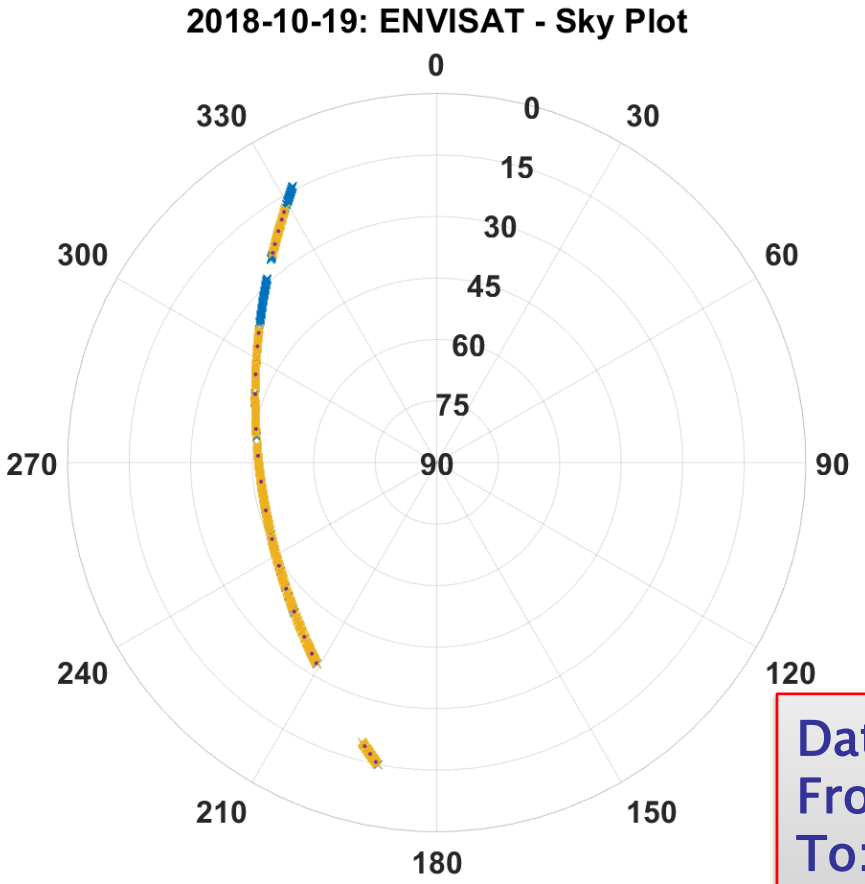
Exp. Time: 0.1s



*OBS-COM Difference from expected (given by ephemeris) and measured time of flight of the laser pulse.

NightCam Output





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To: 19:03 UTC

Target: ENVISAT

Exp. Time: 0.1s

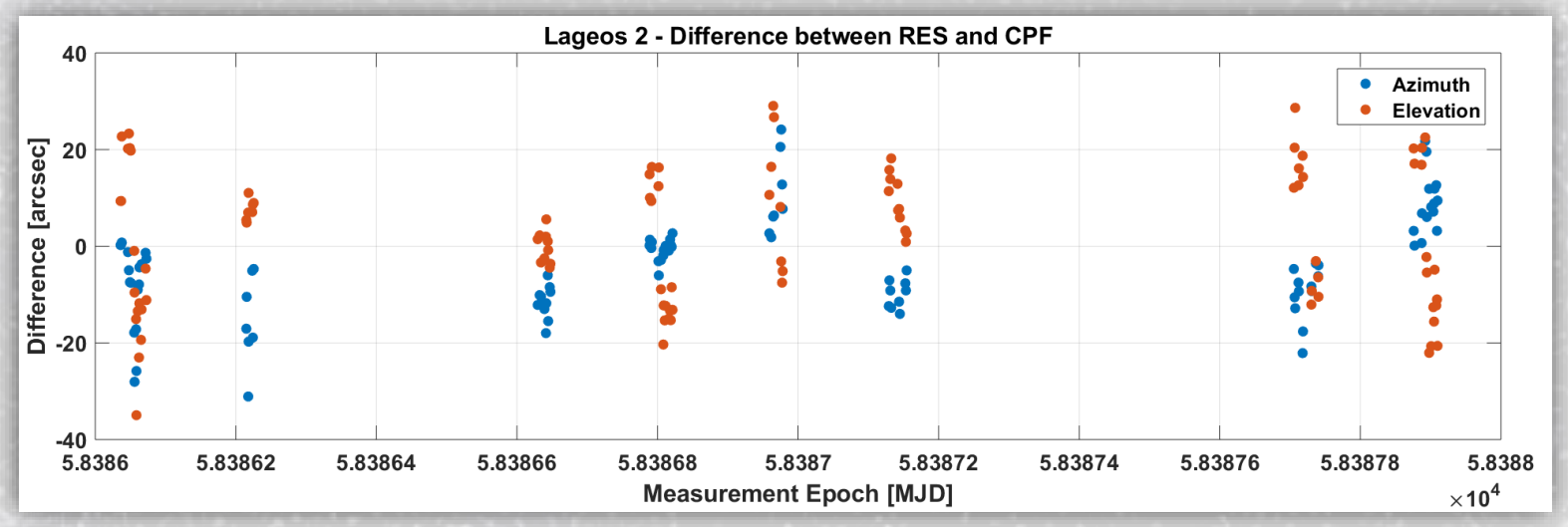
*OBS-COM Difference from expected (given by ephemeris) and measured time of flight of the laser pulse.

What can we do with these data?

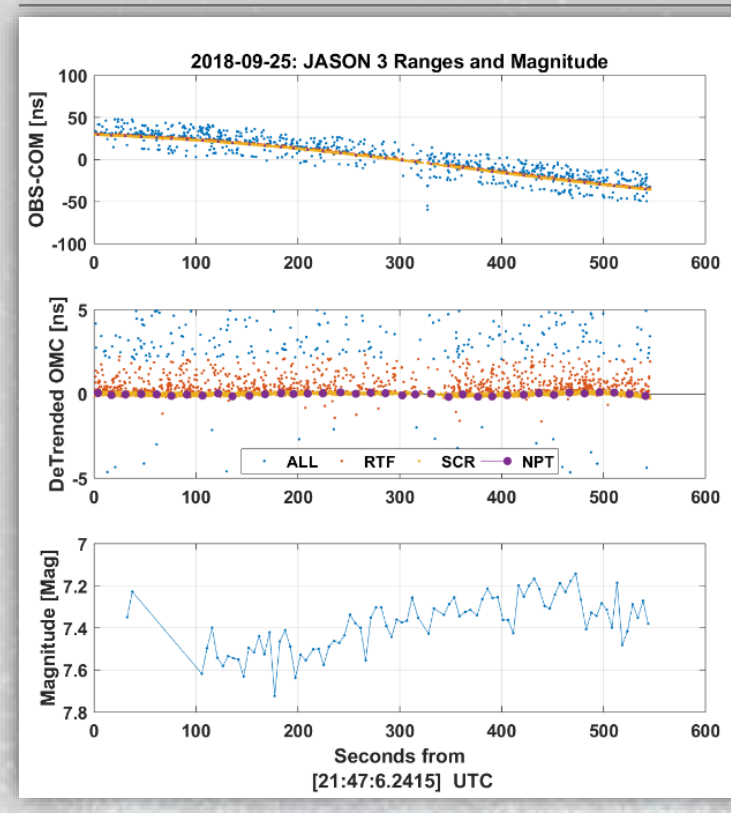
- Light curve analysis → Attitude determination
  - Spin axis direction
  - Rotation period
- Ranges
  - Orbit Determination/Improvement (especially for short observation arc)
  - Attitude Determination
- Azimuth, Elevation → Orbit Determination/Improvement
  - Need to be validated
  - Error Estimation

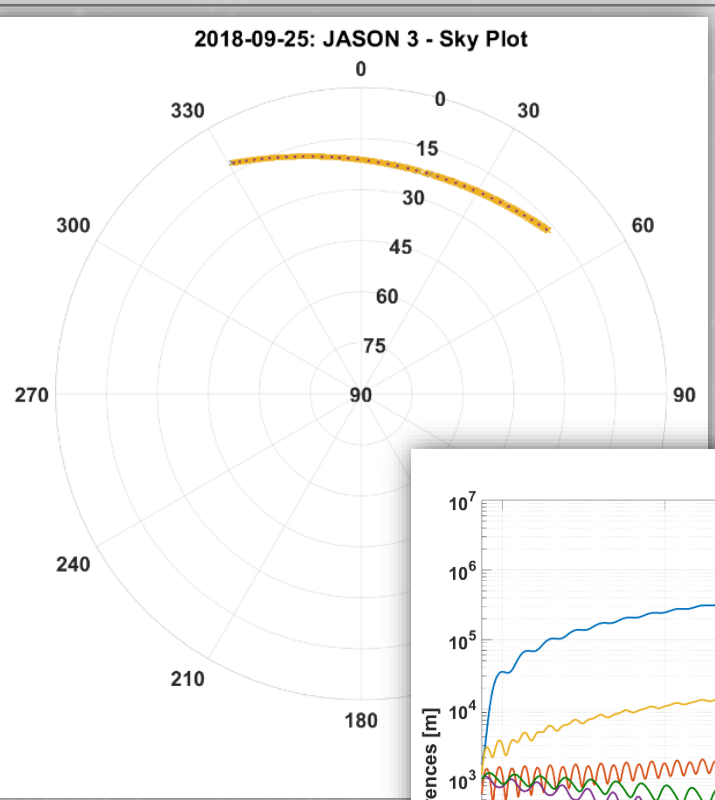
  ⇒ Ephemeris Comparison

⇒ YES, we can improve it!!!



Orbit Determination Result: JASON 3





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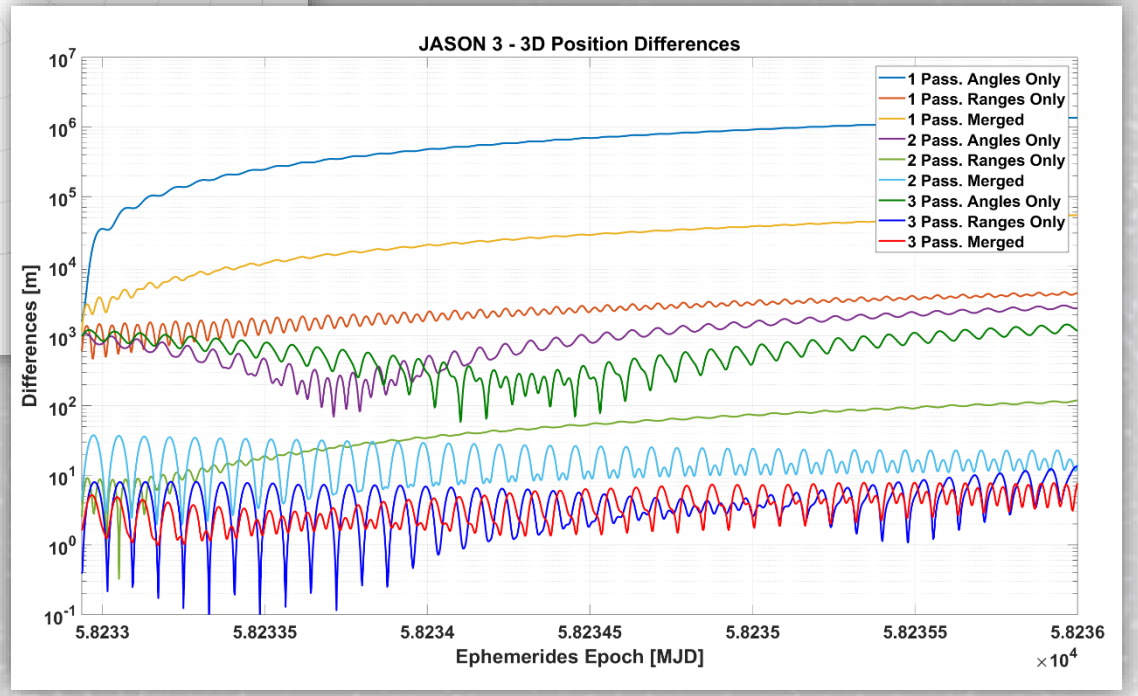
Target: JASON 3

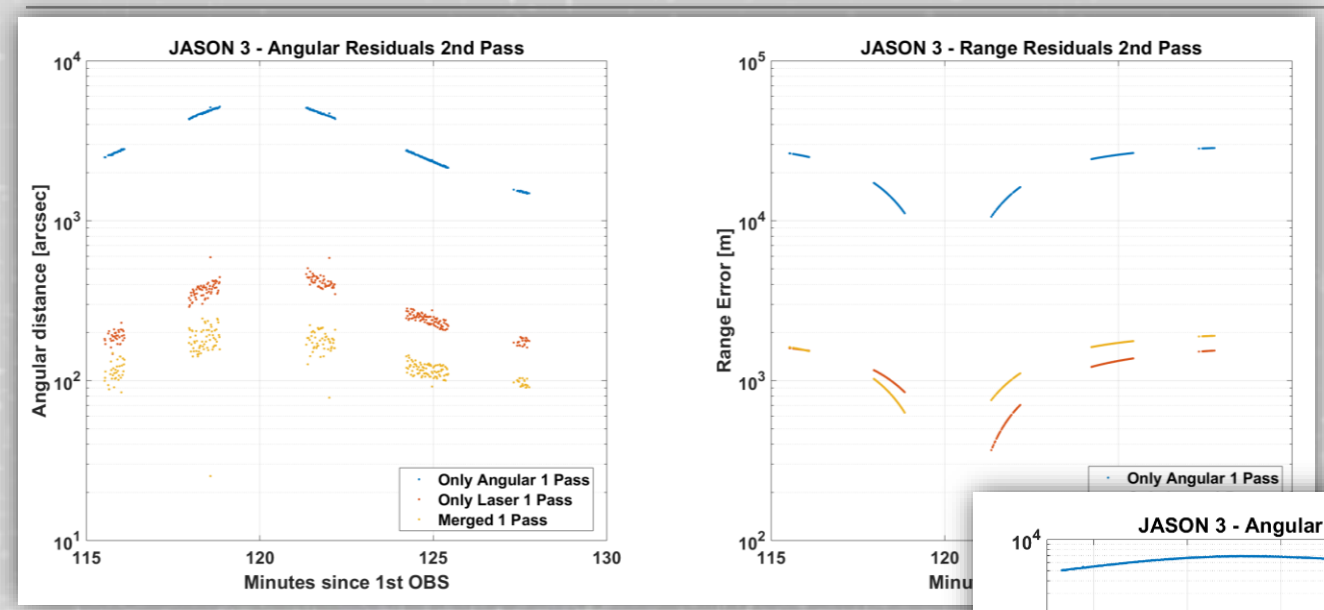
Exp. Time: 0.1s



Orbit determination performed with only angular, only ranges, and merged measurements.

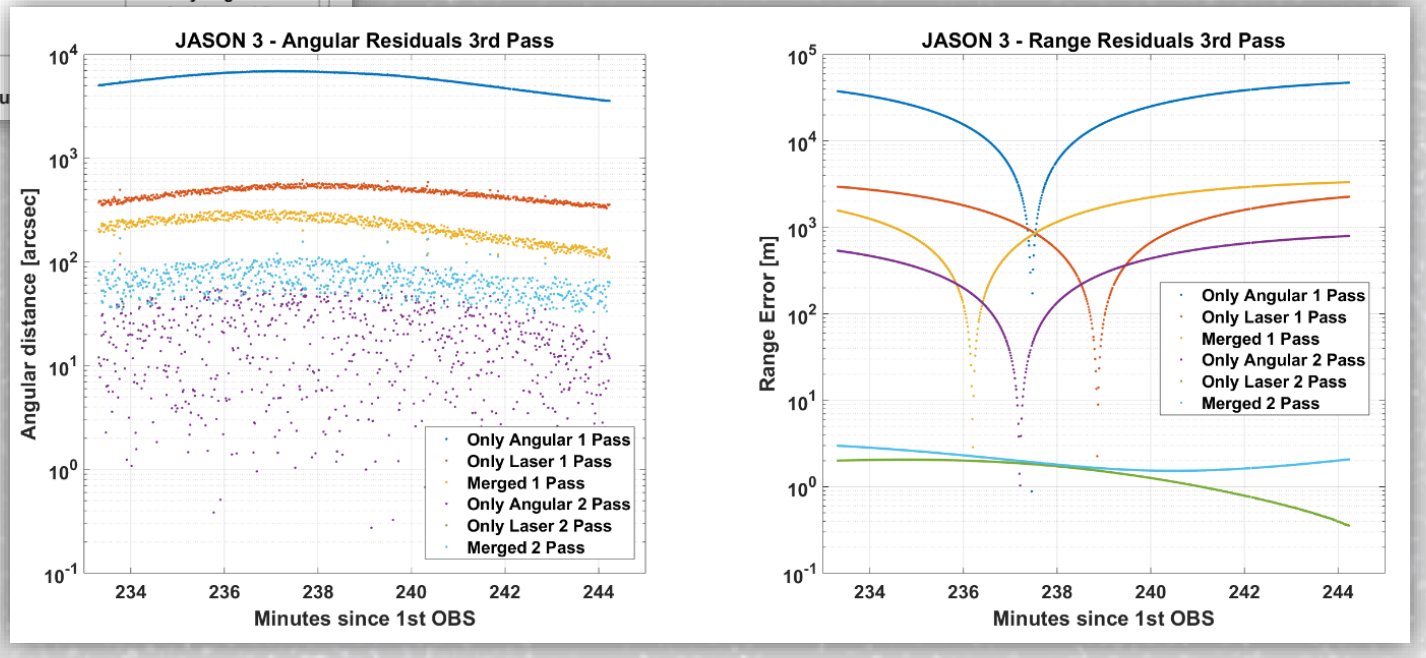
Comparison w.r.t. CPF Ephemeris.

Orbit Determination Result: JASON 3

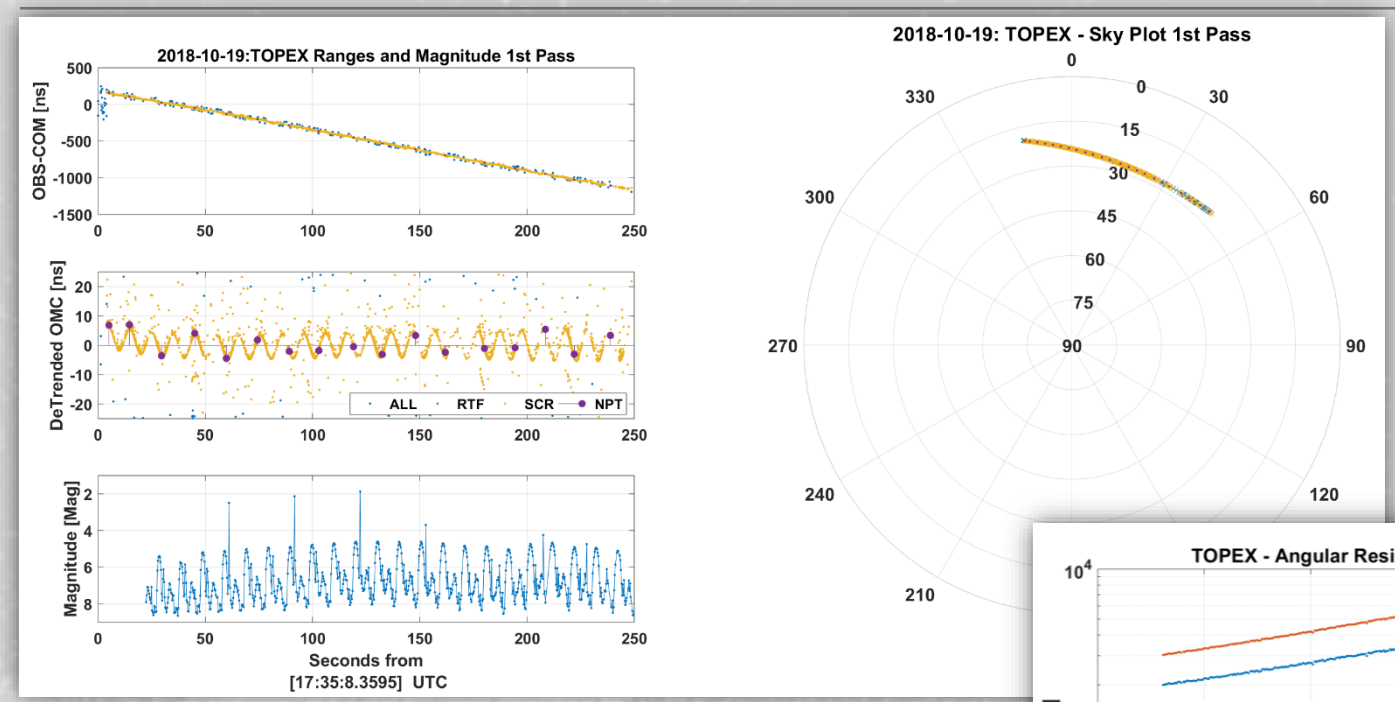


Orbit determination performed with only angular, only ranges, and merged measurements.

Comparison w.r.t. 2nd and 3rd Satellite pass.

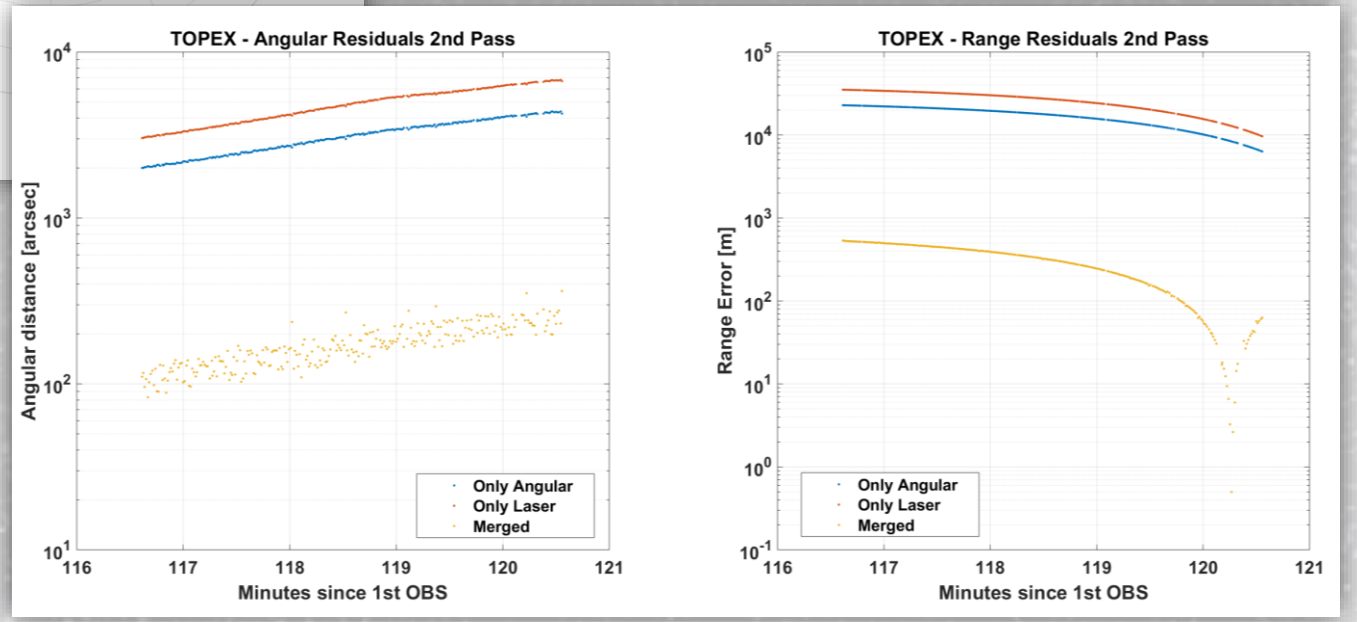


Orbit Determination Result: TOPEX



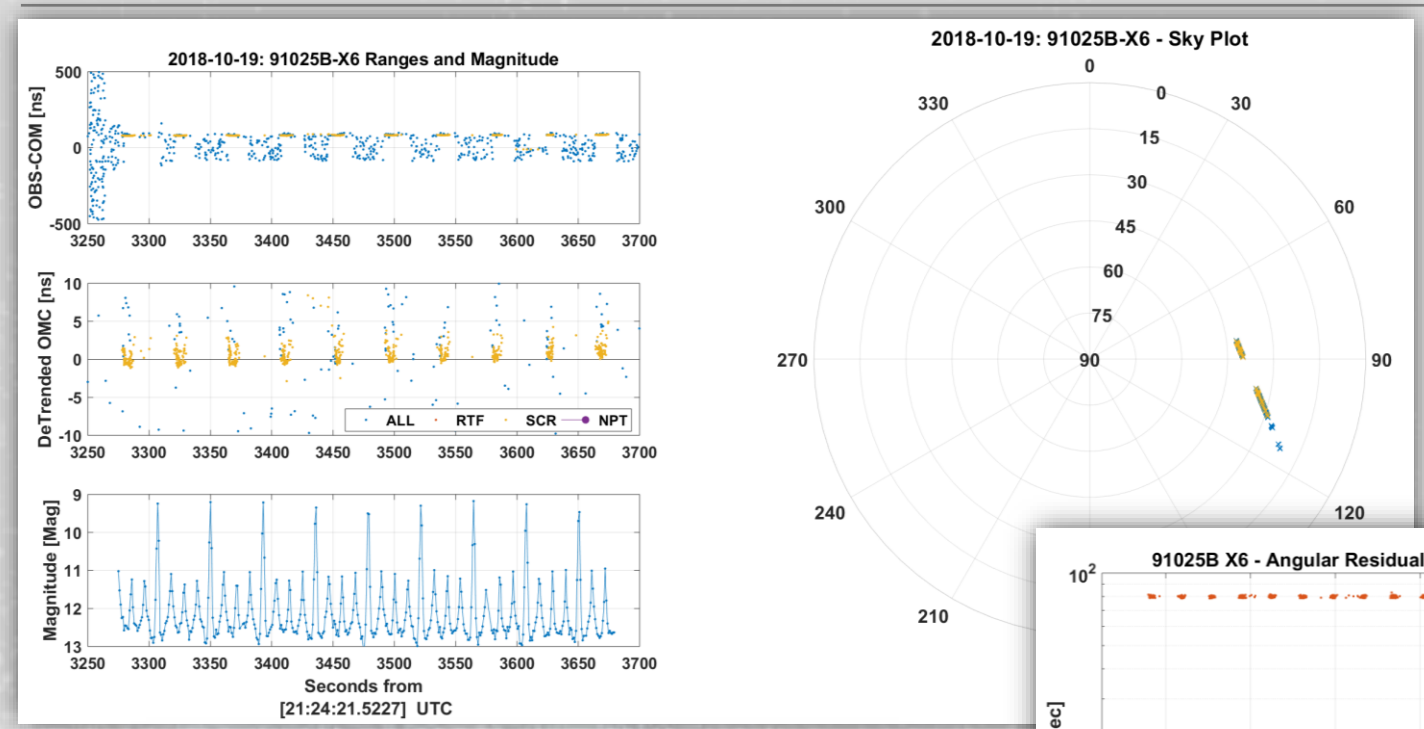
Orbit determination performed with only angular, only ranges, and merged measurements.

Comparison w.r.t. 2nd Satellite pass.



Date:	2018/10/19
1st Pass From:	17:35 UTC To: 17:40 UTC
2nd Pass From:	19:31 UTC To: 19:35 UTC
Target:	TOPEX
Exp. Time:	0.1s

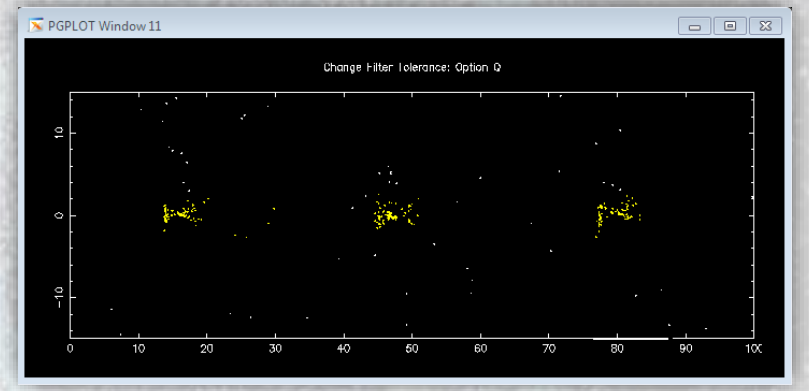
Orbit Determination Result: GLONASS

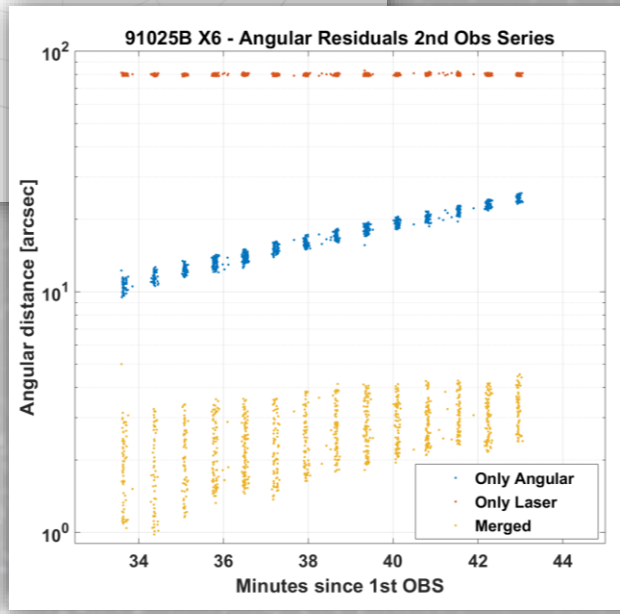


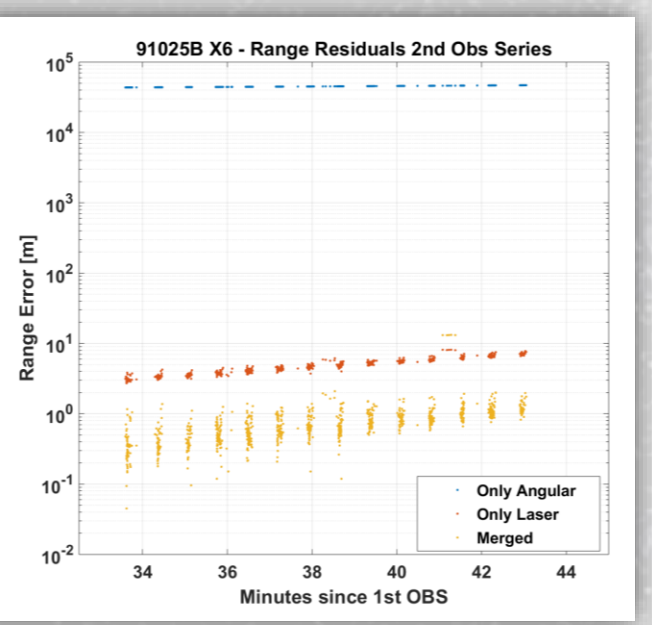
Orbit determination performed with only angular, only ranges, and merged measurements.

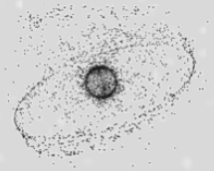
Comparison w.r.t. 2nd obs. series. of Satellite

Date:	2018/10/19
1st Obs. Series From:	21:47 UTC To: 21:59 UTC
2nd Obs. Series From:	22:18 UTC To: 22:25 UTC
Target:	GLONASS 91025B
Exp. Time:	0.7s









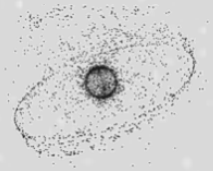
Conclusions

Summary

- Integration of the new camera into the SLR system
- Development of observation and tracking software
- Real time orbit improvement via ephemeris correction
- Quasi real time orbit improvement using short arc data fusion
- Simultaneous observation for orbit and attittude determination of space debris
- Validation of estimated orbit via real measurements

Interesting outcomes

- LEO Orbit determination without astrometric data reduction
- Possibility of SLR tracking of LEO and MEO defunct satellites
- Generation of ephemeris which allow target reobservation in the next pass

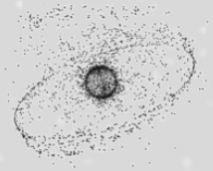


Outlook

Next Steps

- Improvements of Azimuth, Elevation accuracy
  - Laser Pointing Model
- Correction improvements from Azimuth, Elevation to Along-, Cross-Track
- Automatization
  - Object recognition
  - Ephemeris Correction
  - Analysis pipeline
    - Orbit determination/improvement
    - Ephemeris Generation
- Active Real time tracking of object with poorly known or unknown orbit (Stare and Chase)
- Day time application?!


Thank you for your attention!



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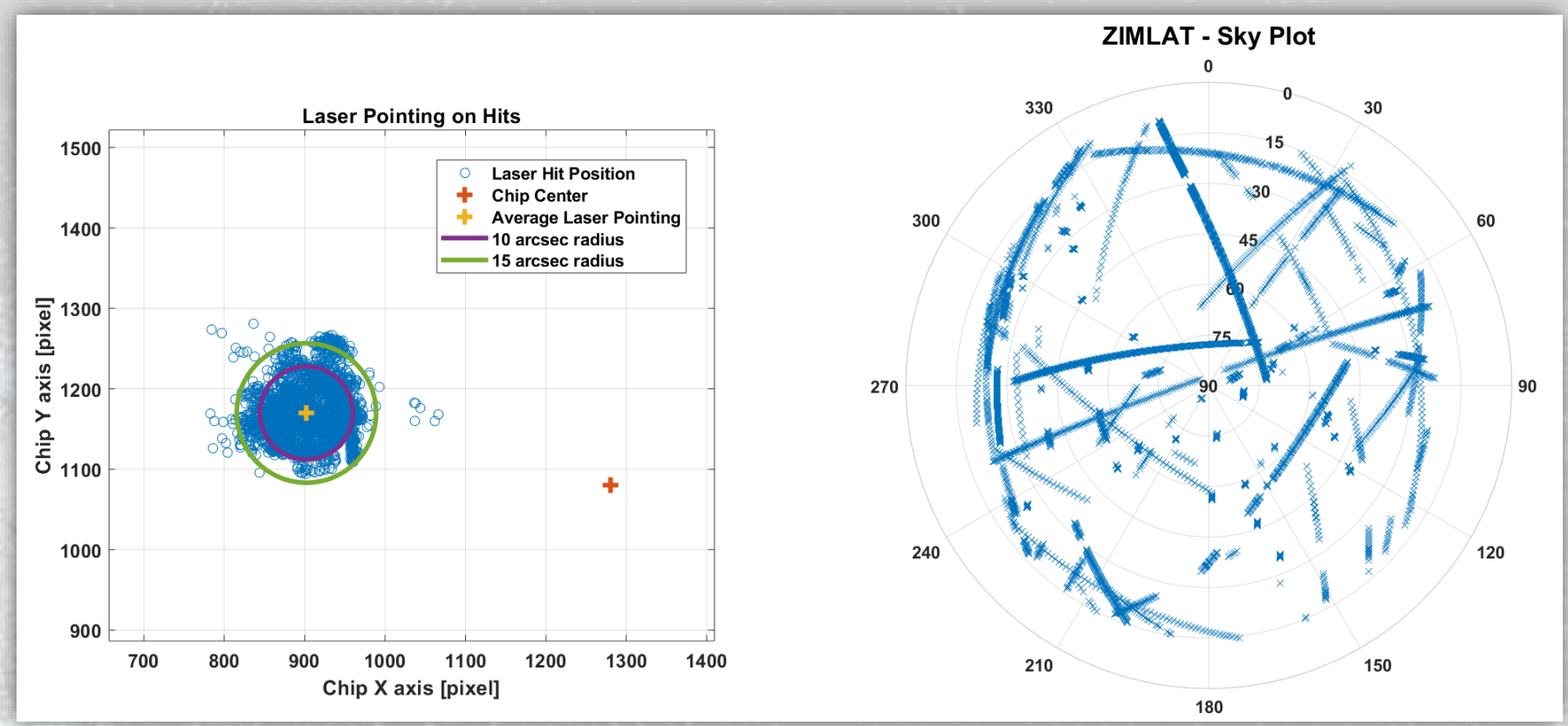
Derivation of Pointing Model

To apply corrections to satellite ephemeris, we needed to determine:

- The Azimuth Elevation direction in the camera system
  - Number of reflections
  - Camera oritentation
  - Derotator position
- The pointing of the laser on the camera
  - Telescope pointing direction
  - Derotator position

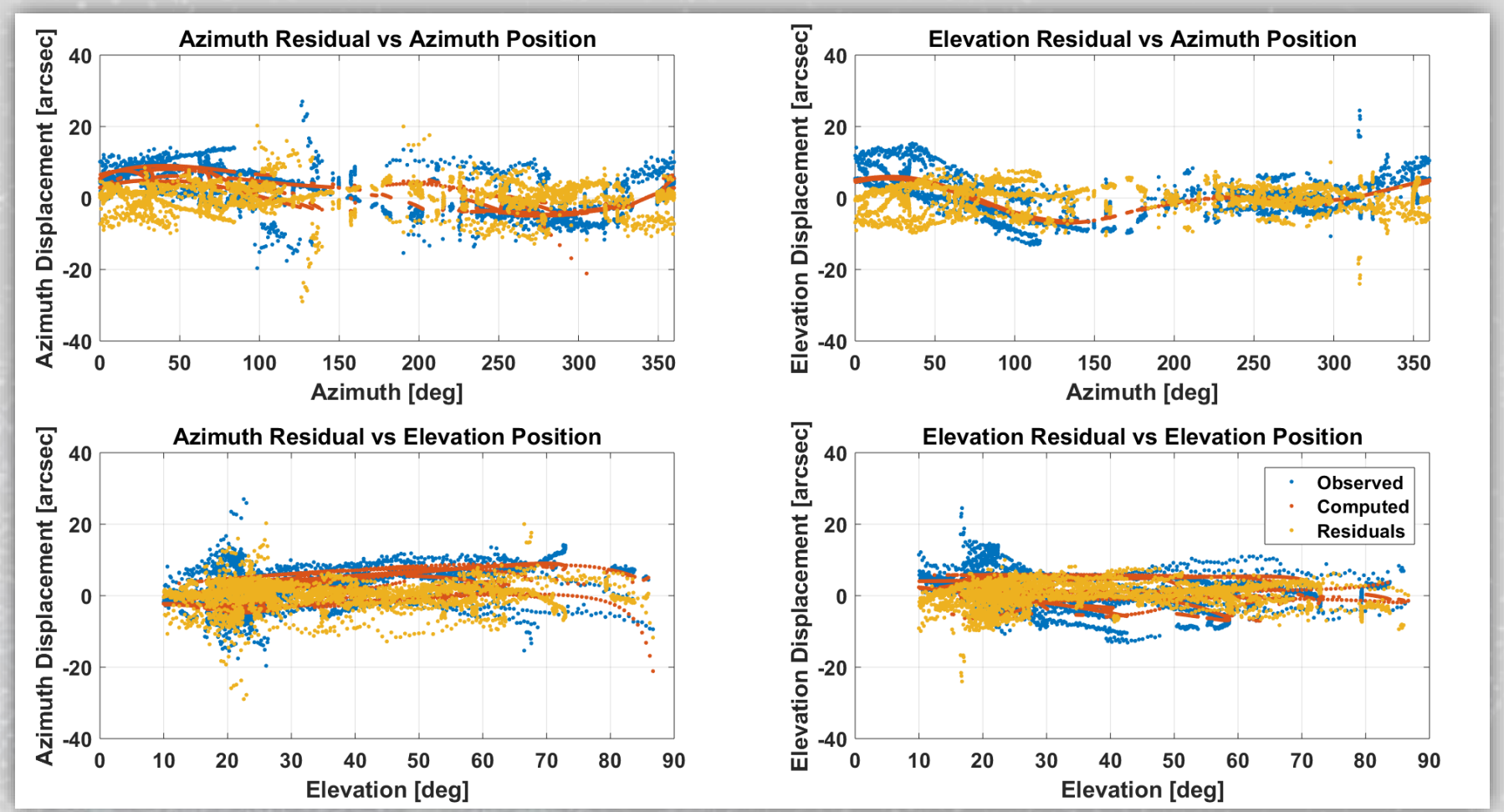
Star fields for camera orientation

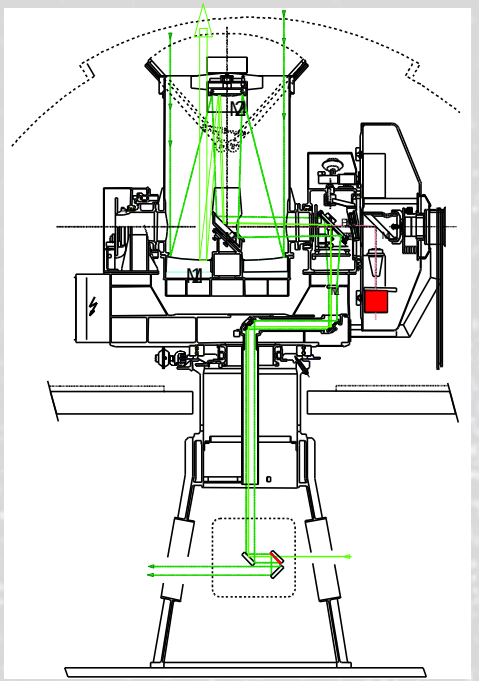
Derived from images when laser hits the target



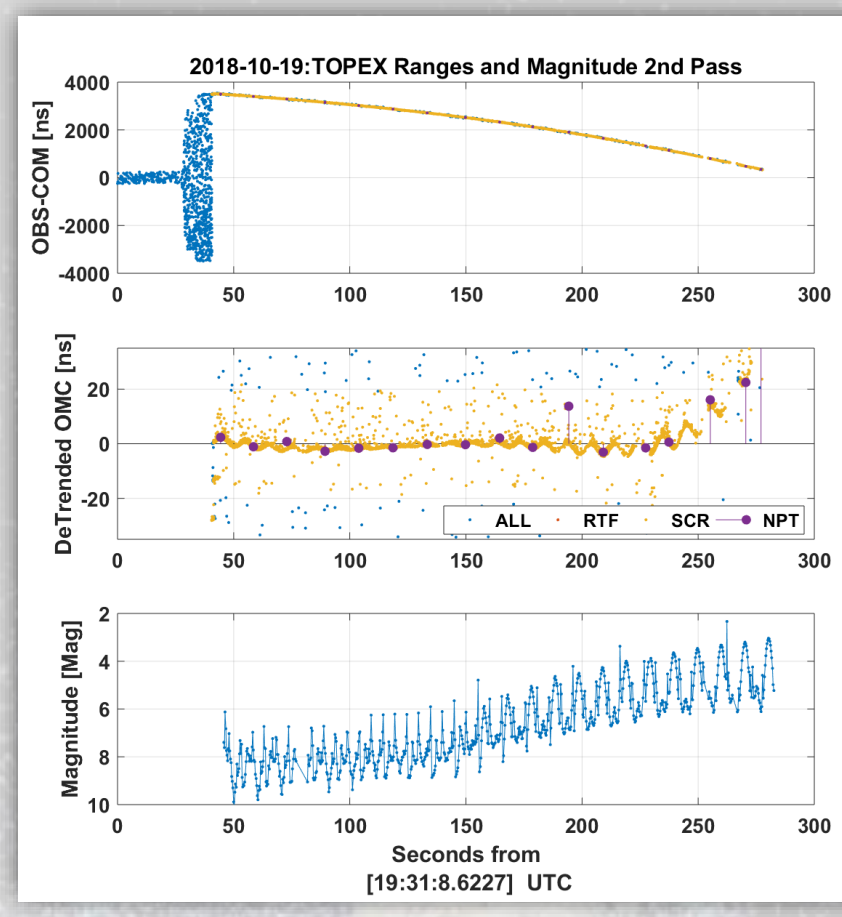
Improvement of the Pointing Model

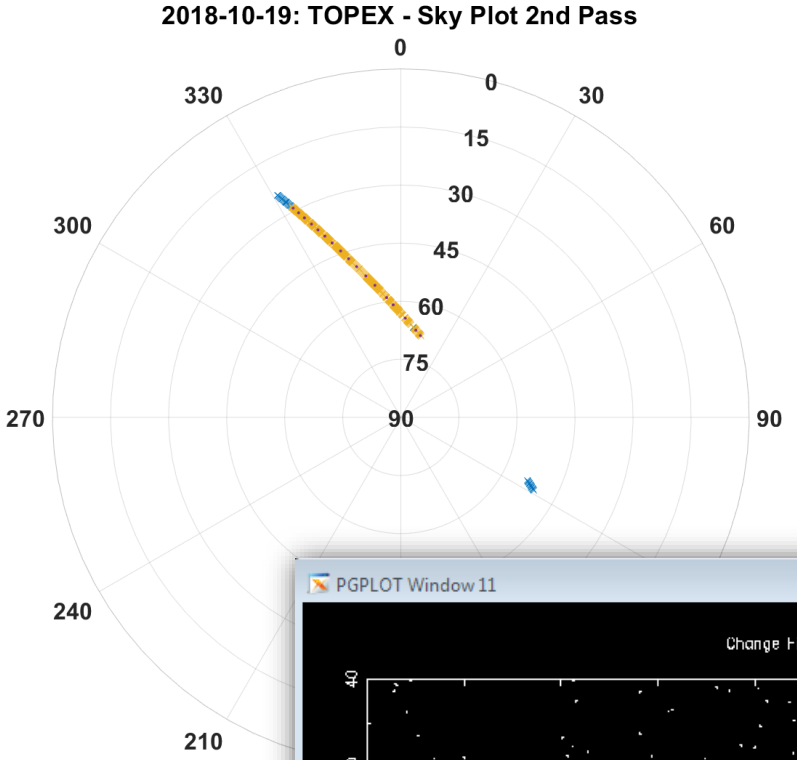
- Temporary Solution → Average Laser coordinates on chip
- Optimal Solution → Modelling of the wobble due to telescope pointing direction → To be implemented





TOPEX: 2019/10/19 2nd Pass





Date: 2018/10/19

1st Pass

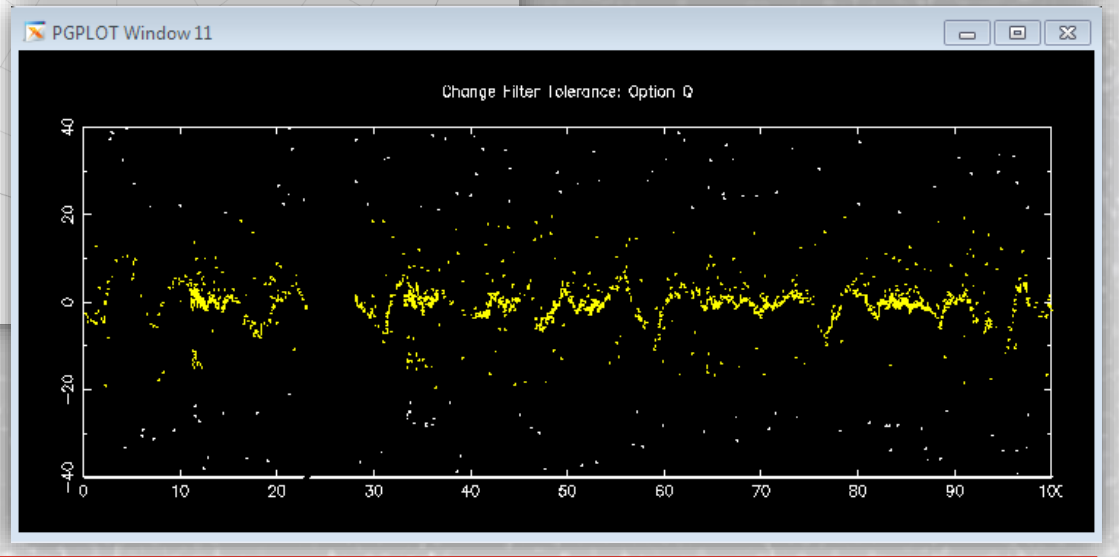
From:17:35 UTC To: 17:40 UTC

2nd Pass

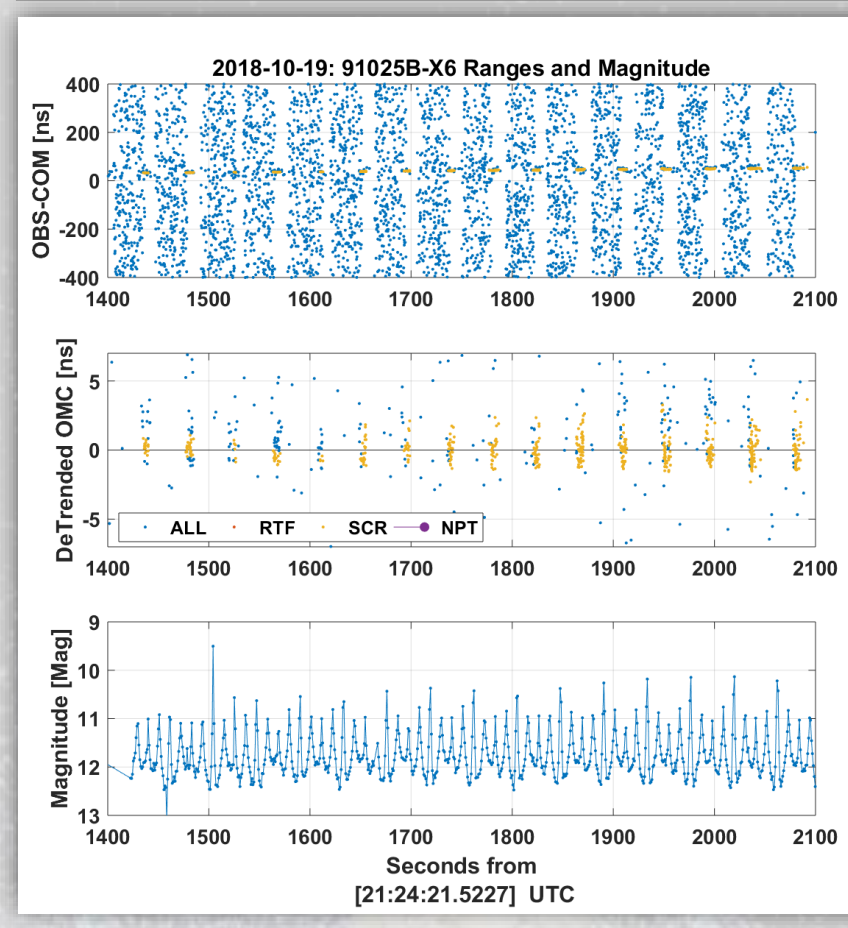
From:19:31 UTC To: 19:35 UTC

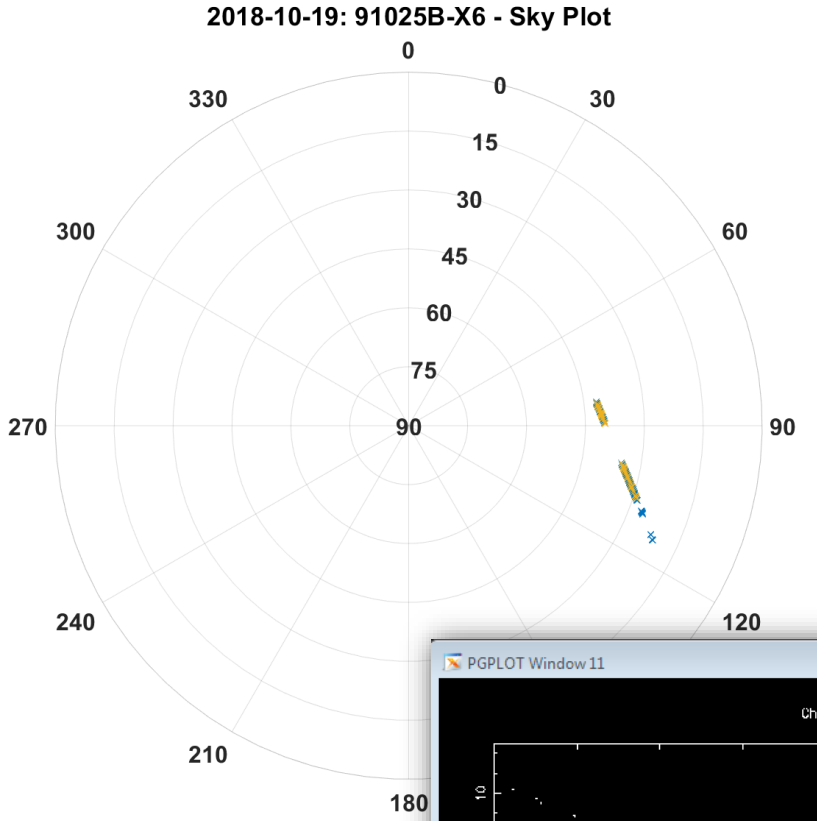
Target: TOPEX

Exp. Time: 0.1s



91025B-X6: 2019/10/19 1st part of Obs.





Date: 2018/10/19
1st Obs. Series
From: 21:47 UTC To: 21:59 UTC
2nd Obs. Series
From: 22:18 UTC To: 22:25 UTC

Target: GLONASS 91025B (X6 Internal)

Exp. Time: 0.7s