Reconstruction of the NuSTAR PSF using single-laser metrology

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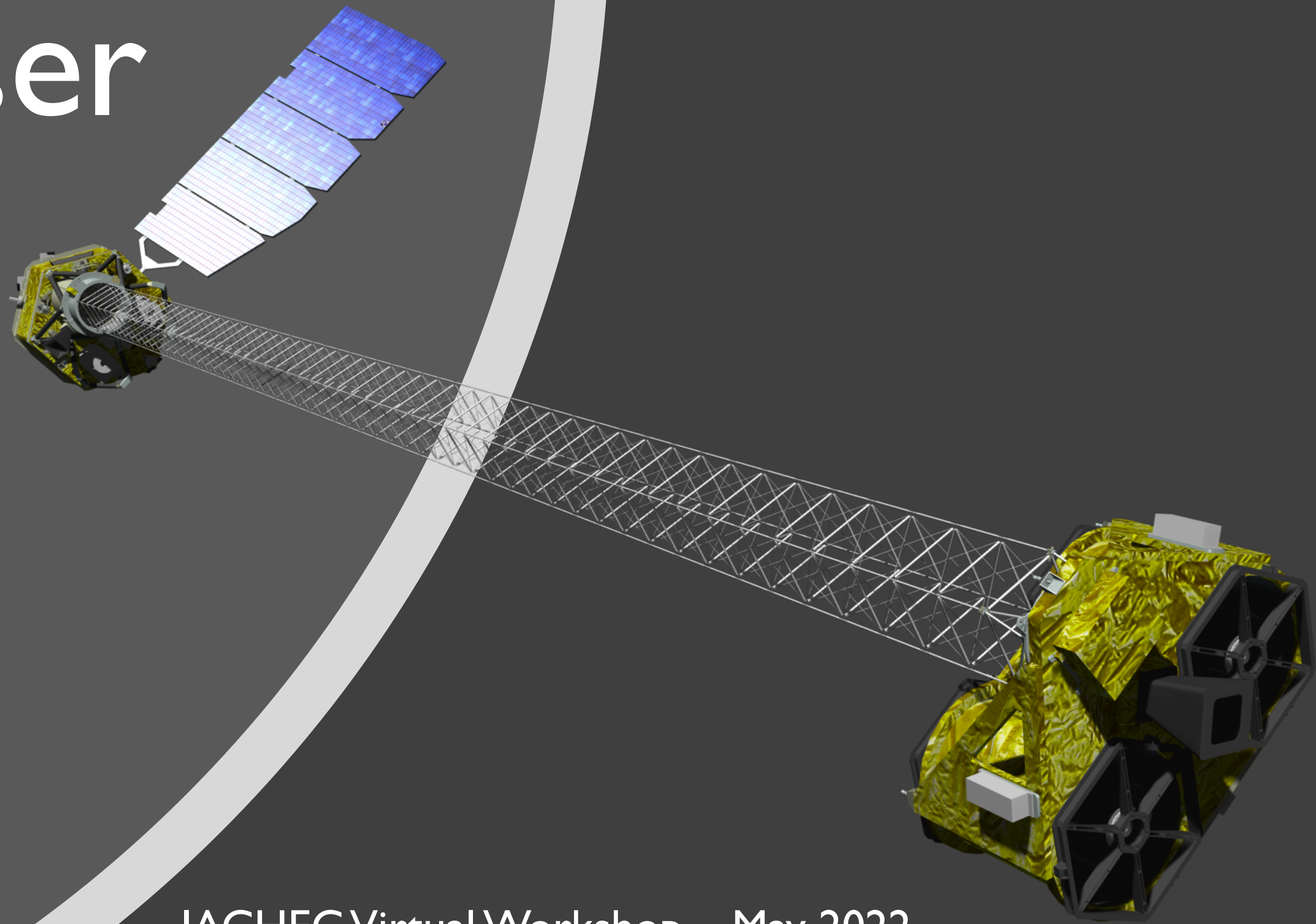
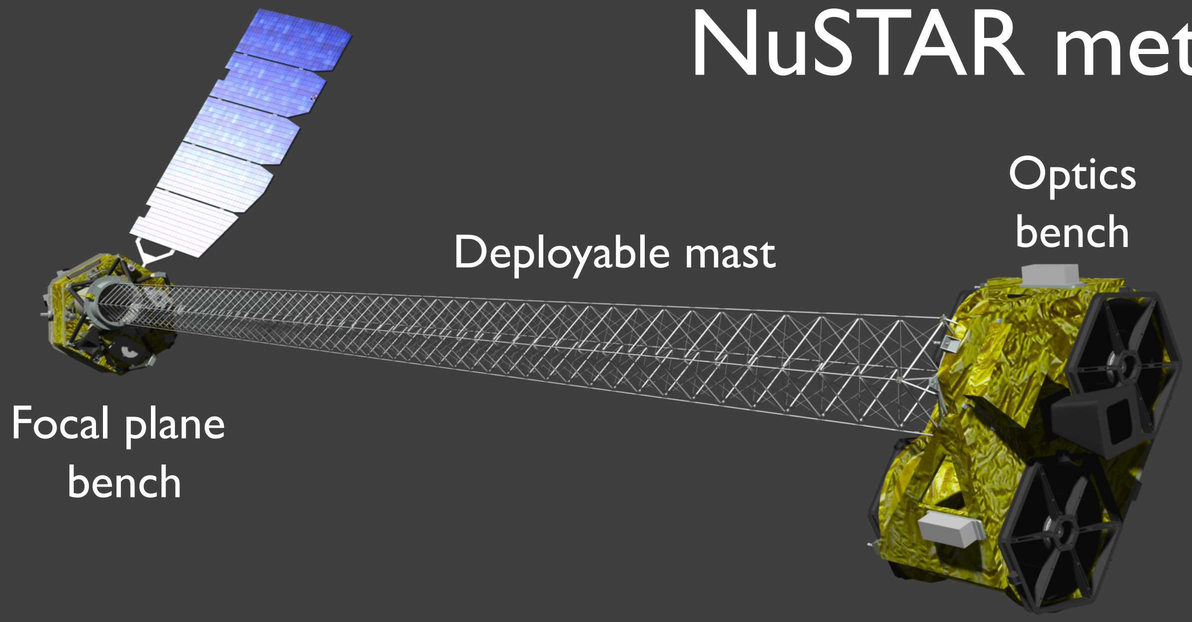


IACHEC Virtual Workshop – May 2022

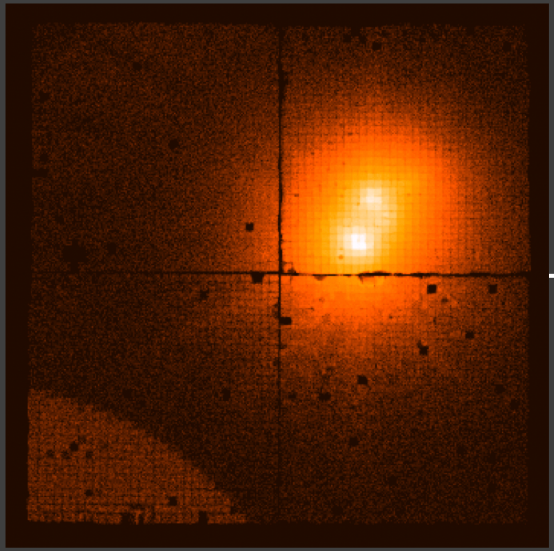
NuSTAR metrology system

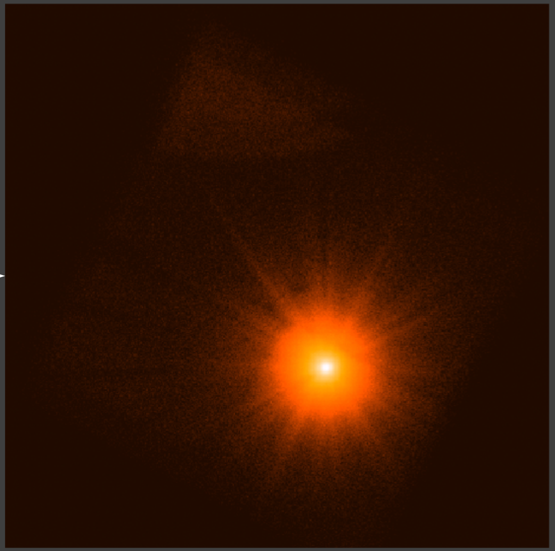


NuSTAR is a hard (3–79 keV) X-ray focusing telescope, requiring a long focal length.

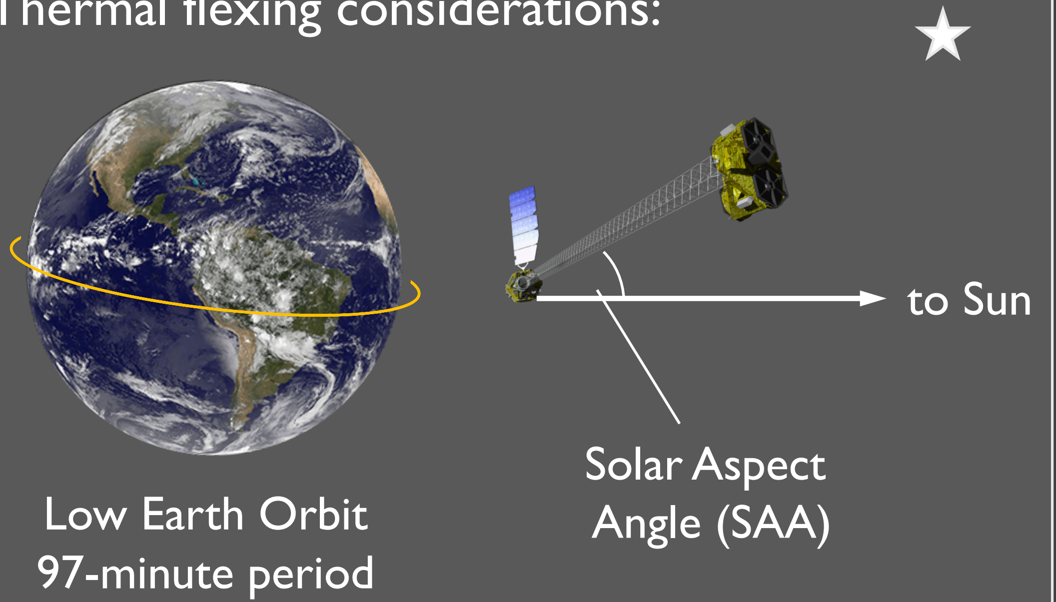
This is achieved with two benches separated by a 10-m rigid carbon fiber mast.

Slight motion due to thermal flexing needs to be accounted for to reconstruct a non-blurred image.

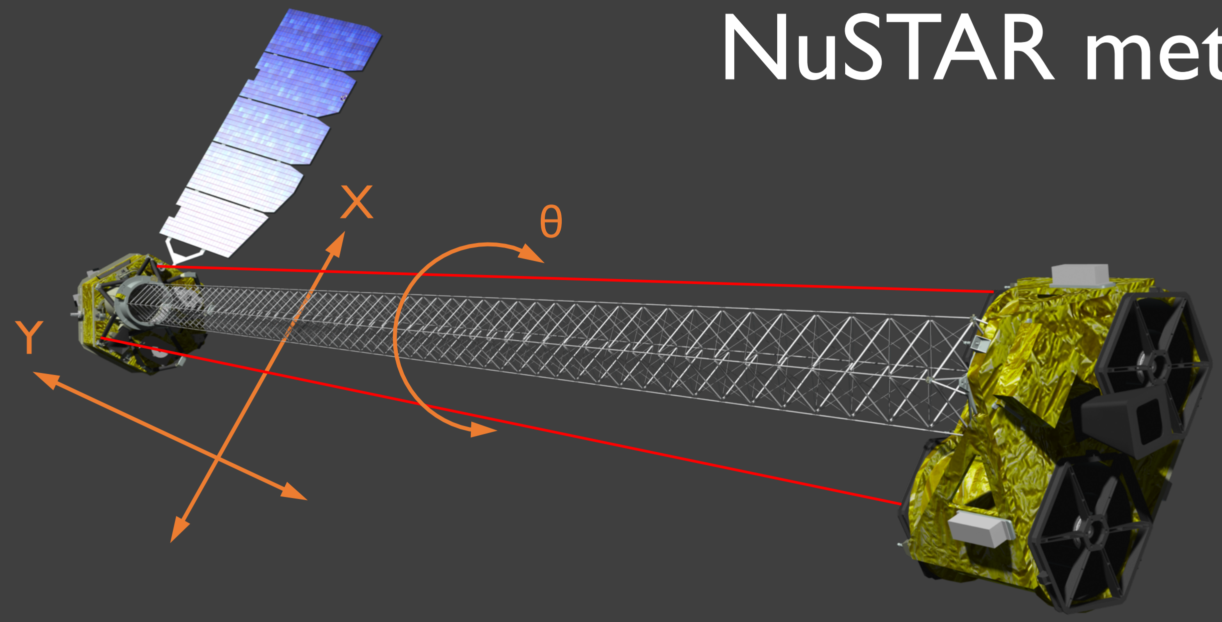

Detector image


Sky image

Thermal flexing considerations:



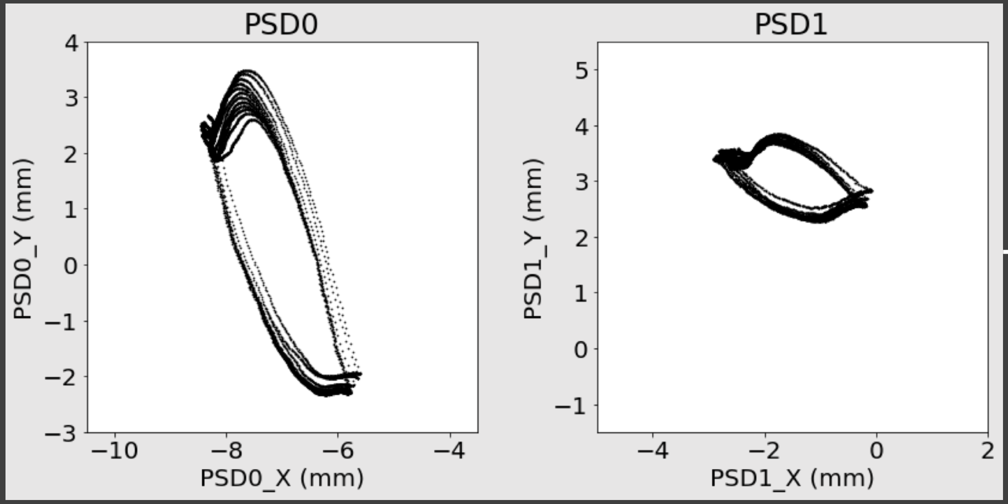
NuSTAR metrology system



The NuSTAR metrology system is made up of two lasers on the optics bench shining on two position sensitive detectors (PSDs) on the focal plane bench.

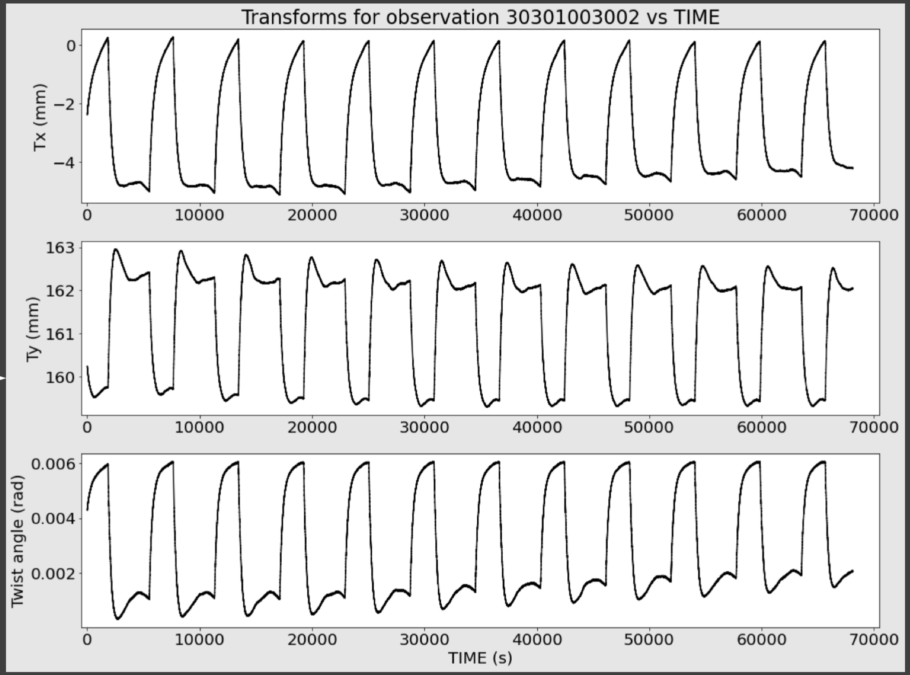
Two lasers are required to measure three degrees of freedom: X, Y, and θ. What if one is lost?

Laser tracks:

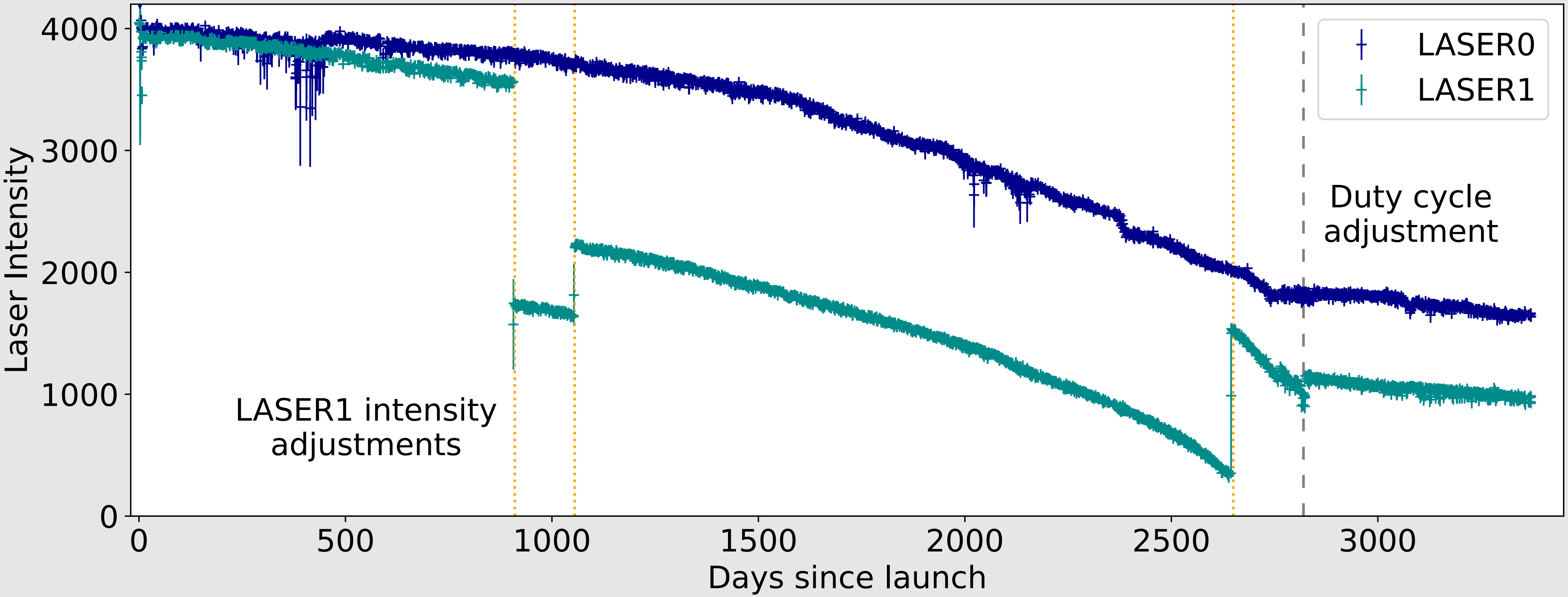


numetrology

calculates mast solution



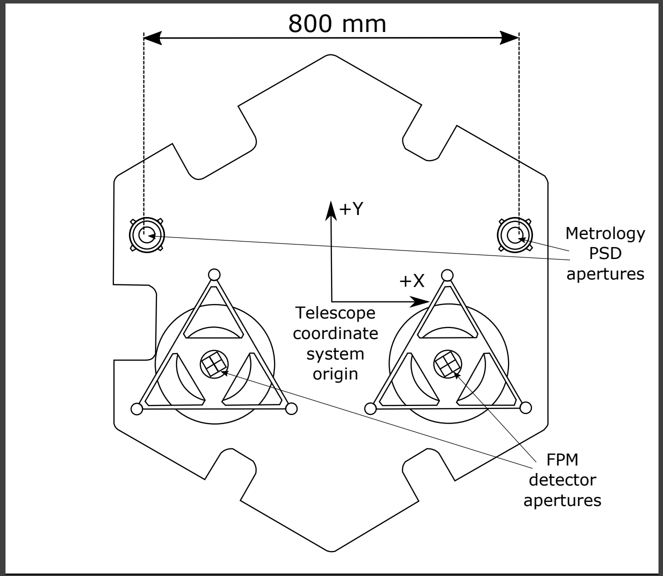
NuSTAR metrology system



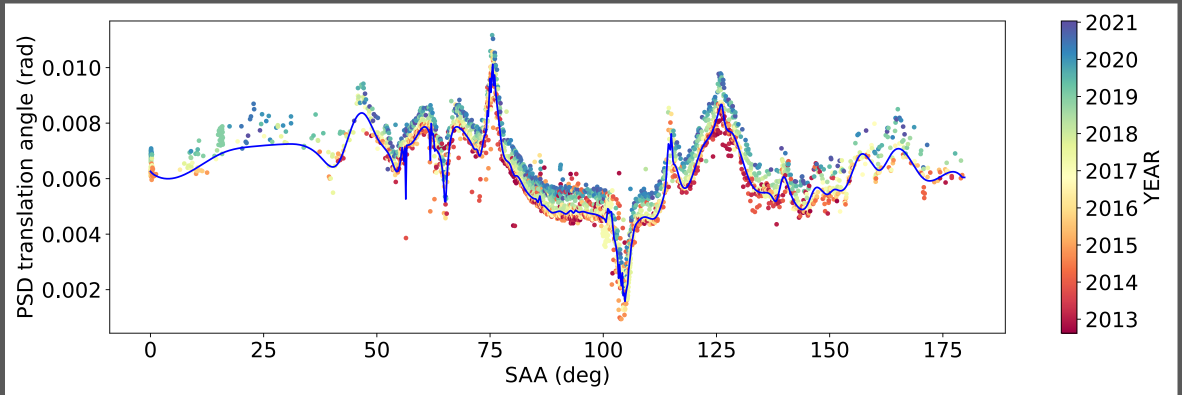
Step 1: translate PSD track

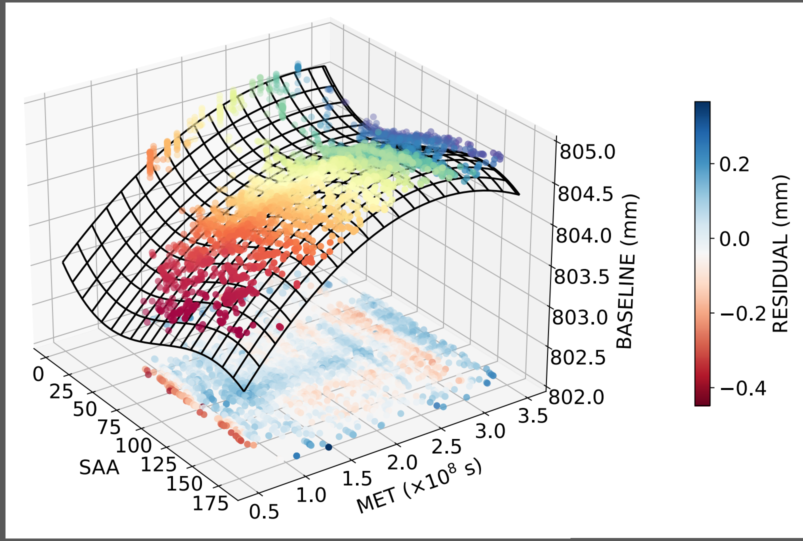
The NuSTAR pipeline needs two PSD tracks to function, so as a first step, we translate the measured PSD0 track to the expected position of the PSD1 track.

In focal bench coordinates, we need to apply a translation vector with baseline (distance) and angle from the X-axis. To estimate these values, we plotted archival values of baseline and angle against SAA and time.

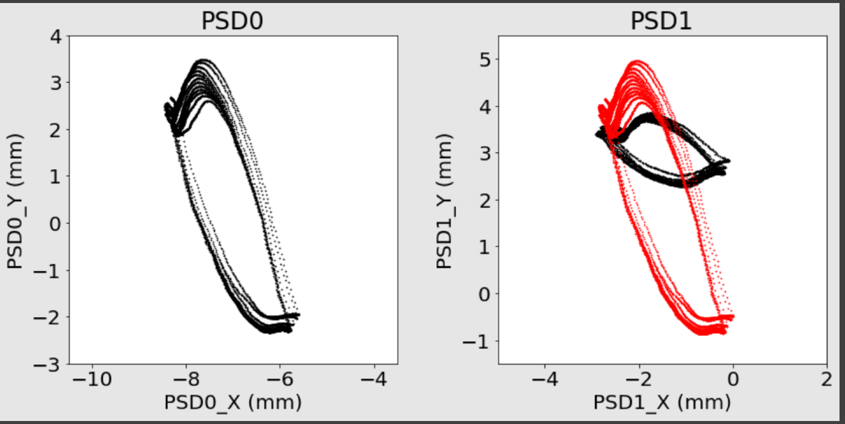


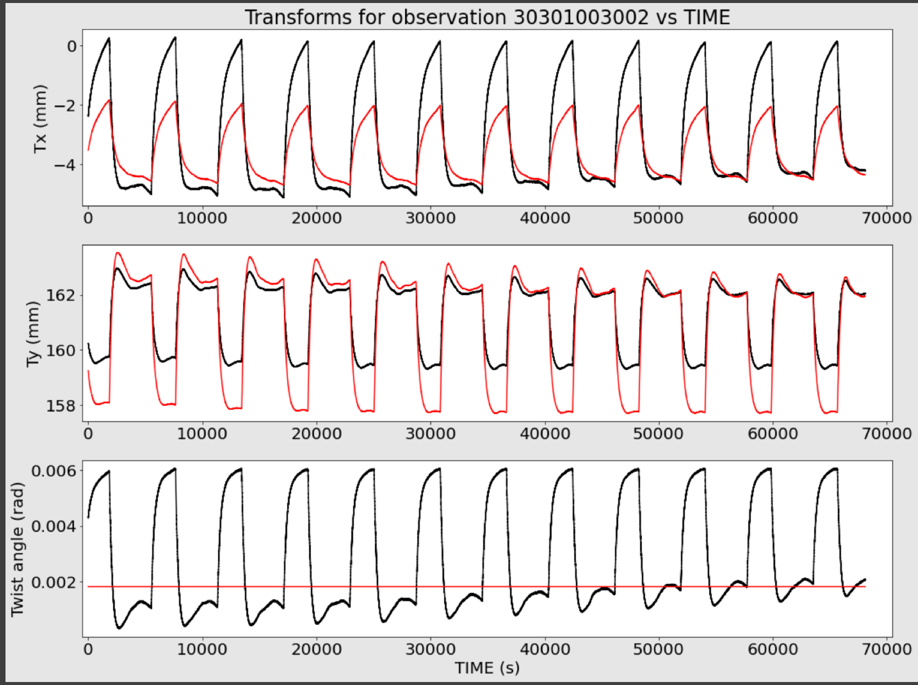
Estimating translation parameters:



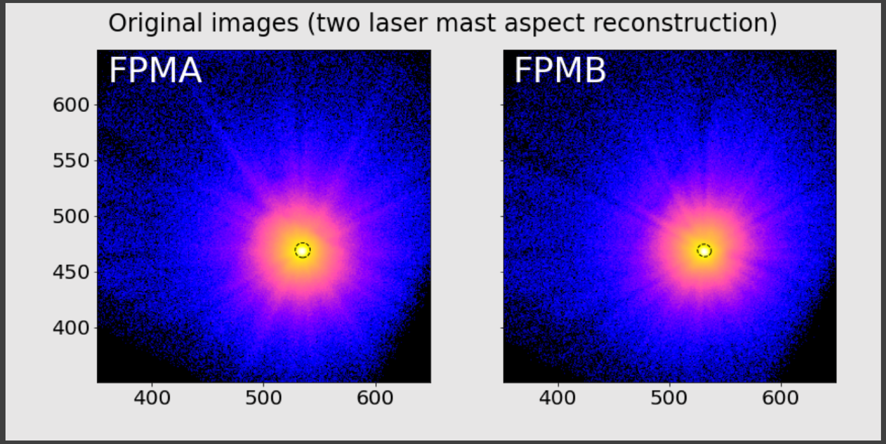


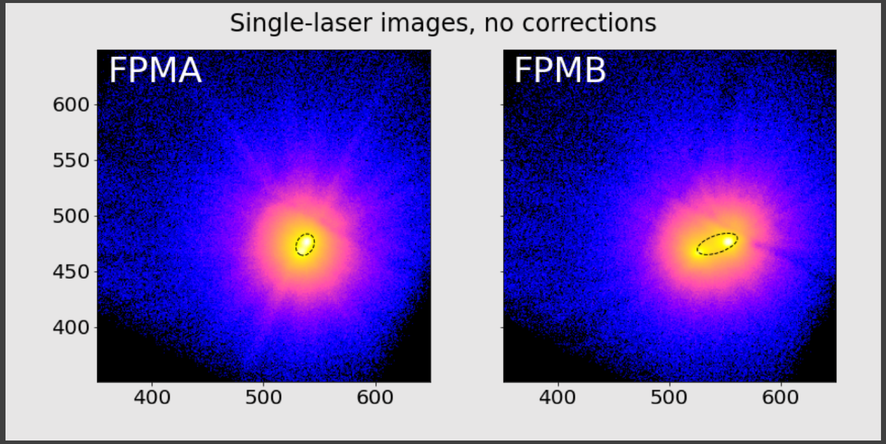
Step 1: translate PSD track





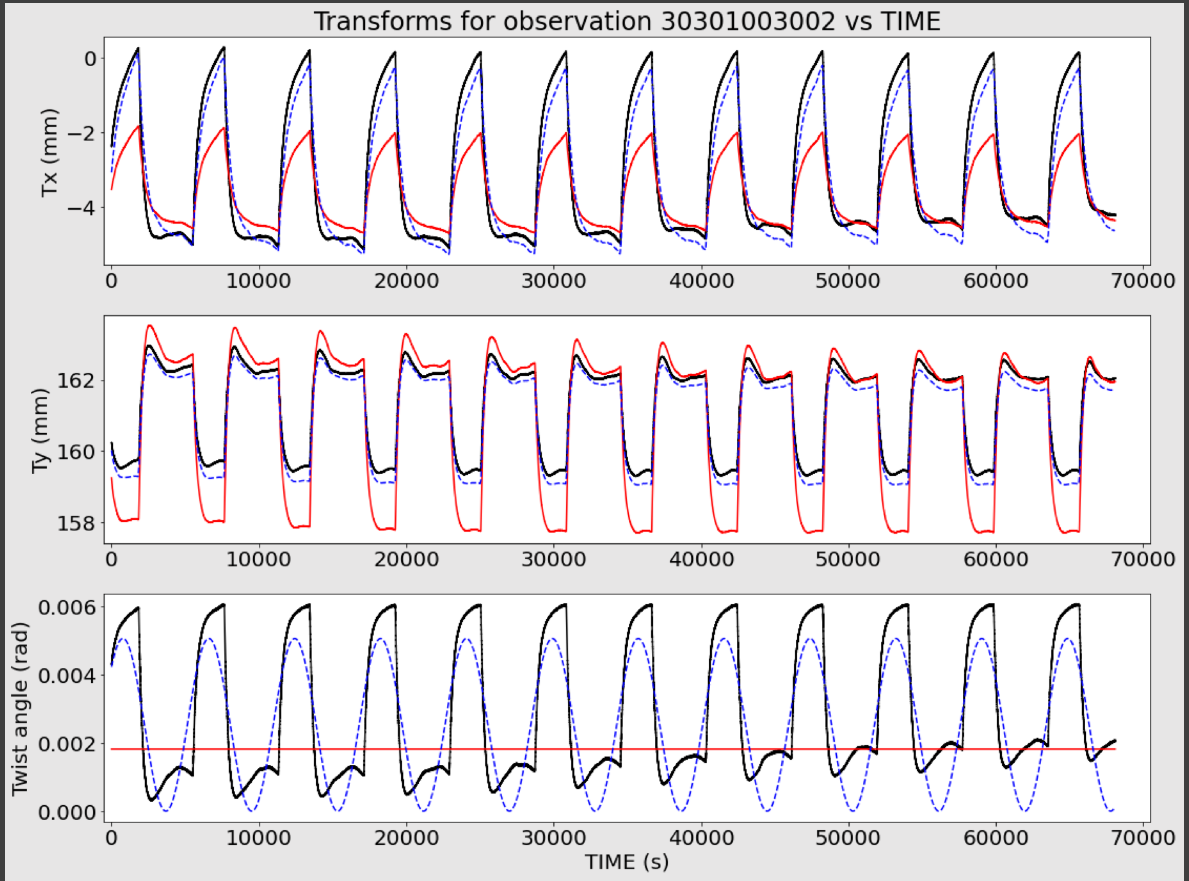
When we do this, while some features of the two-laser solution are replicated, twist angle information is lost and the resulting PSF is highly distorted.

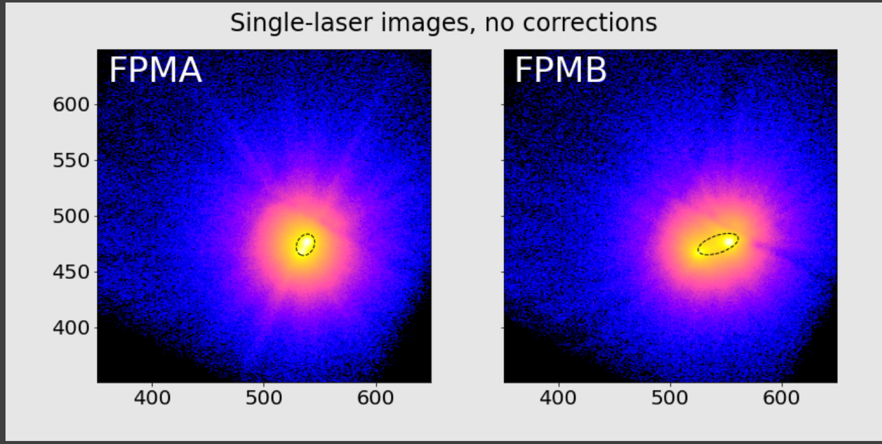


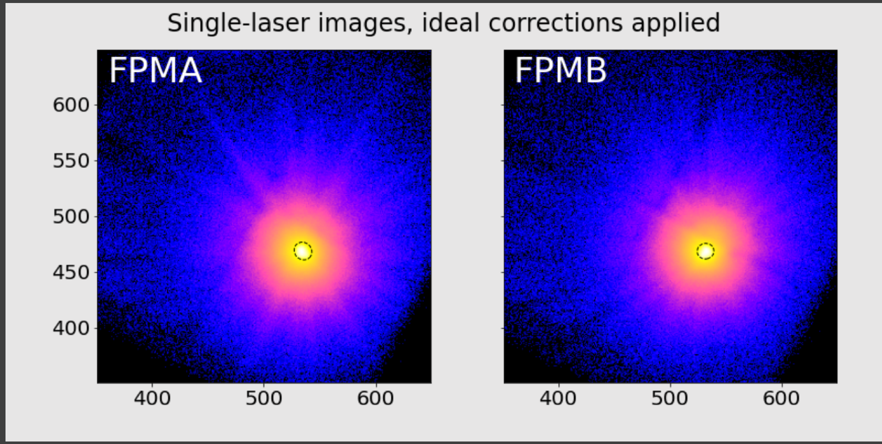


Step 2: apply corrections

We take an 'ideally corrected' mast file to have transform variation amplitudes equal to the original amplitudes, and θ approximated by a sine curve with the orbital period.





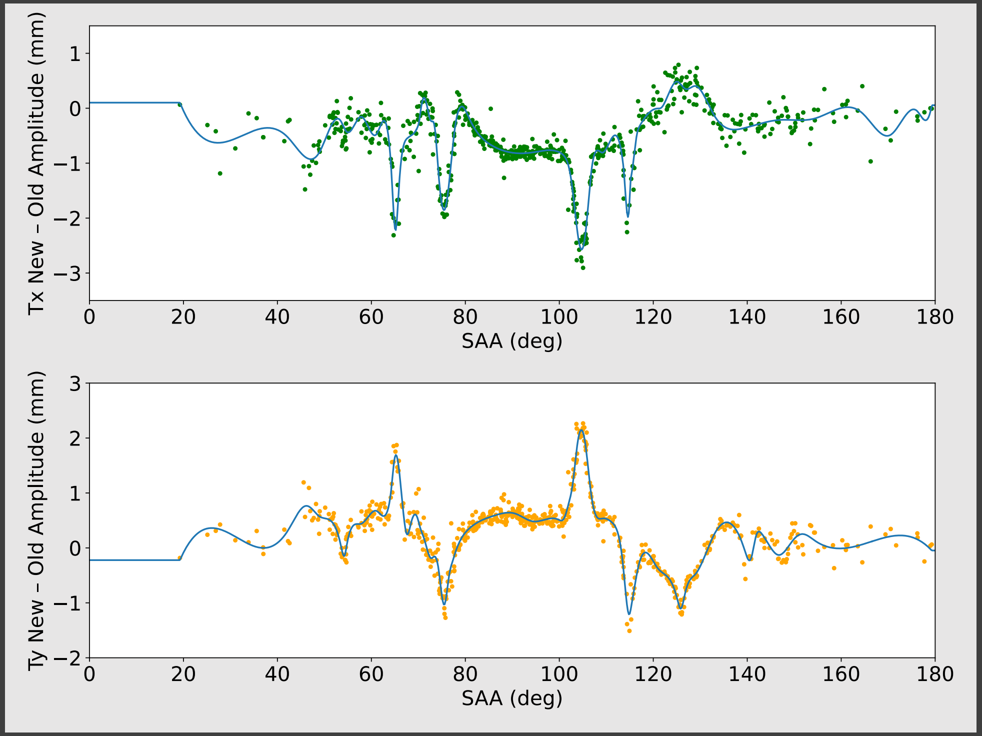


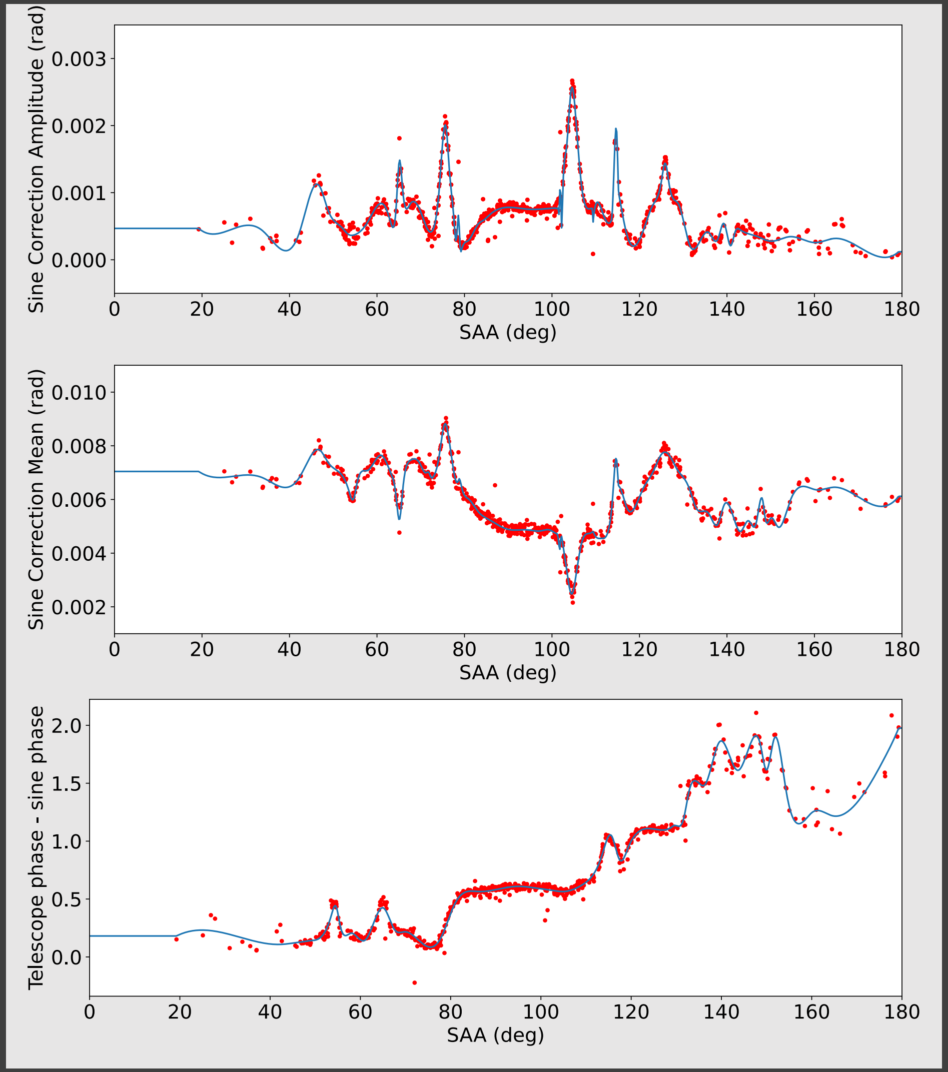
Step 2: apply corrections

Correction parameters:

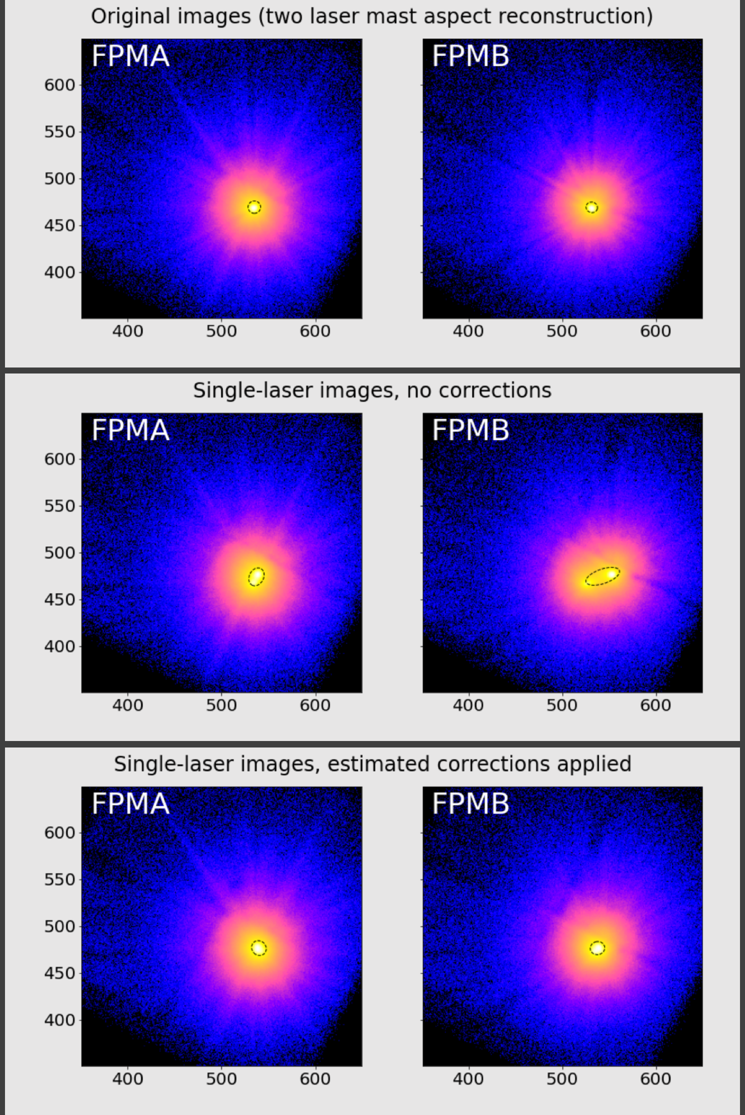
- X and Y transform amplitude increase/decrease
- Twist sine curve mean, amplitude, and phase

Calculated for all archival observations of bright sources, plotted against SAA and fitted with a spline to predict values for future observations.

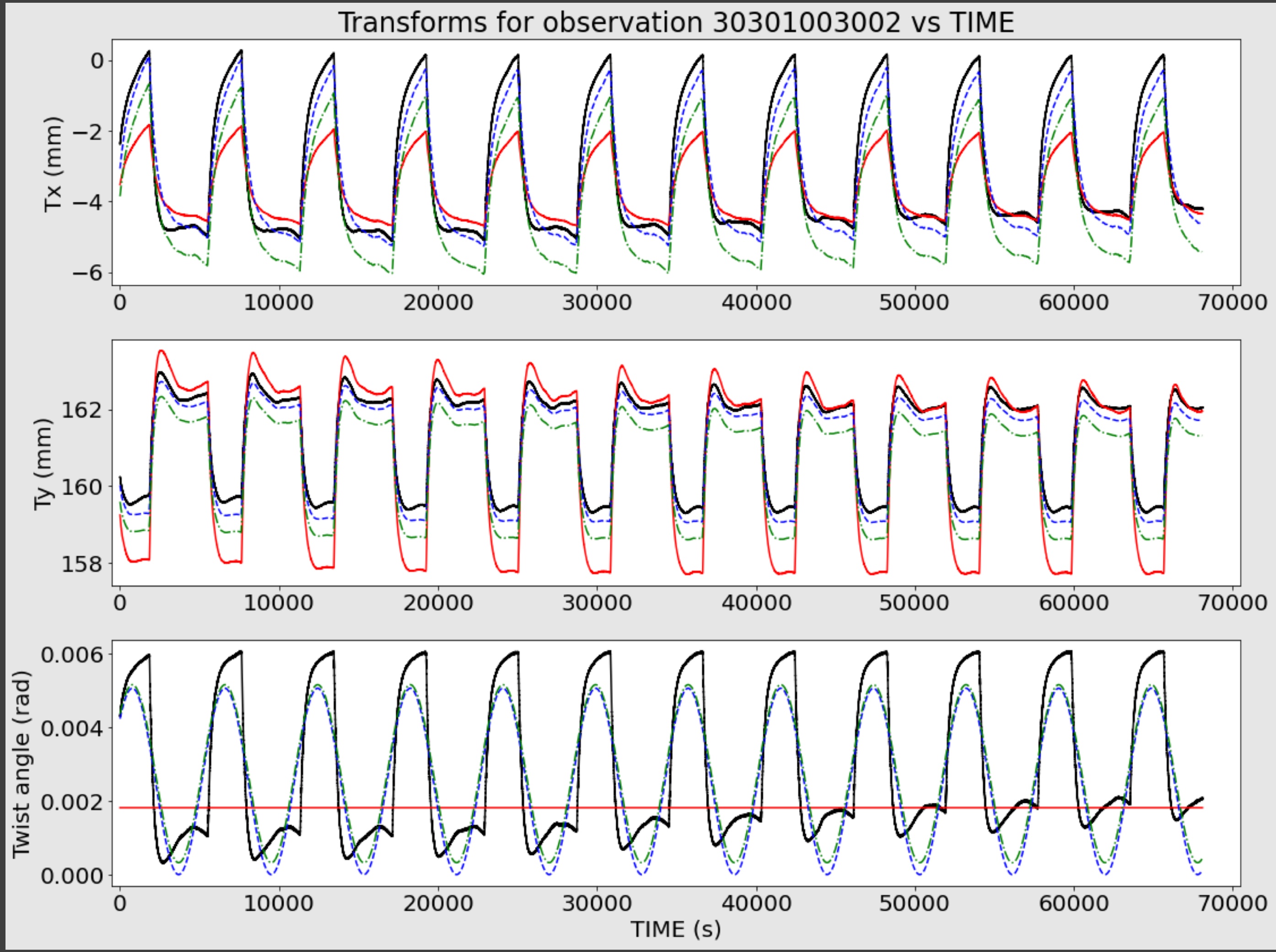




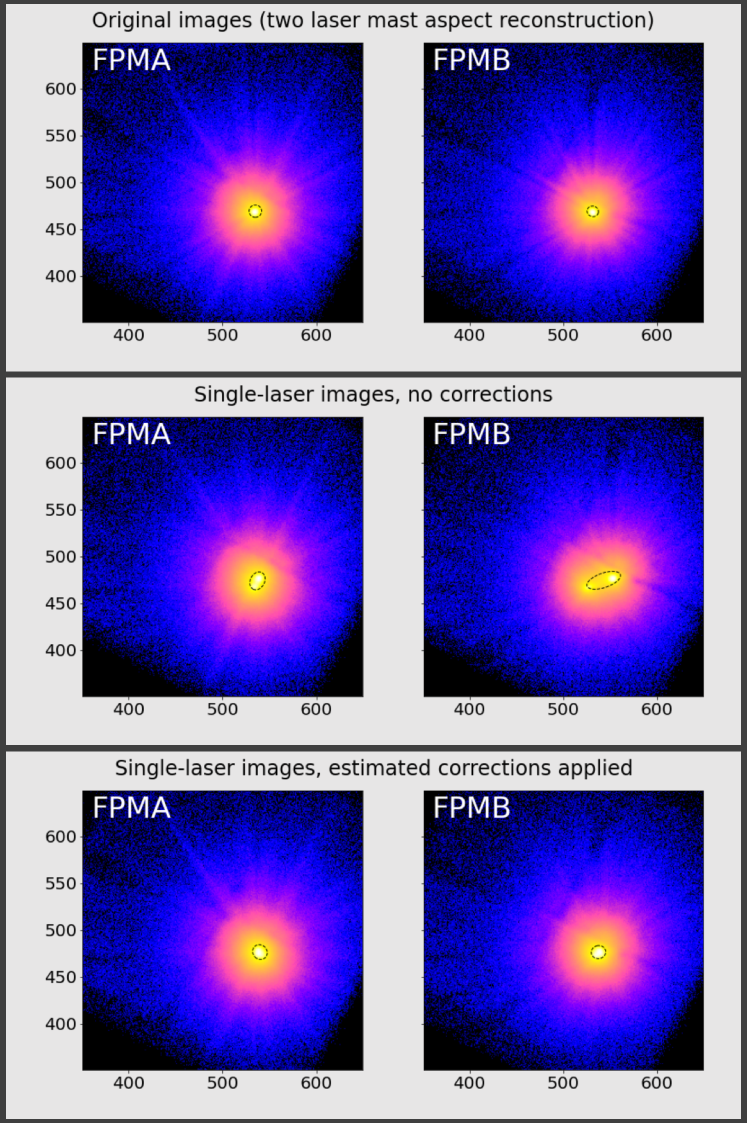
Step 2: apply corrections



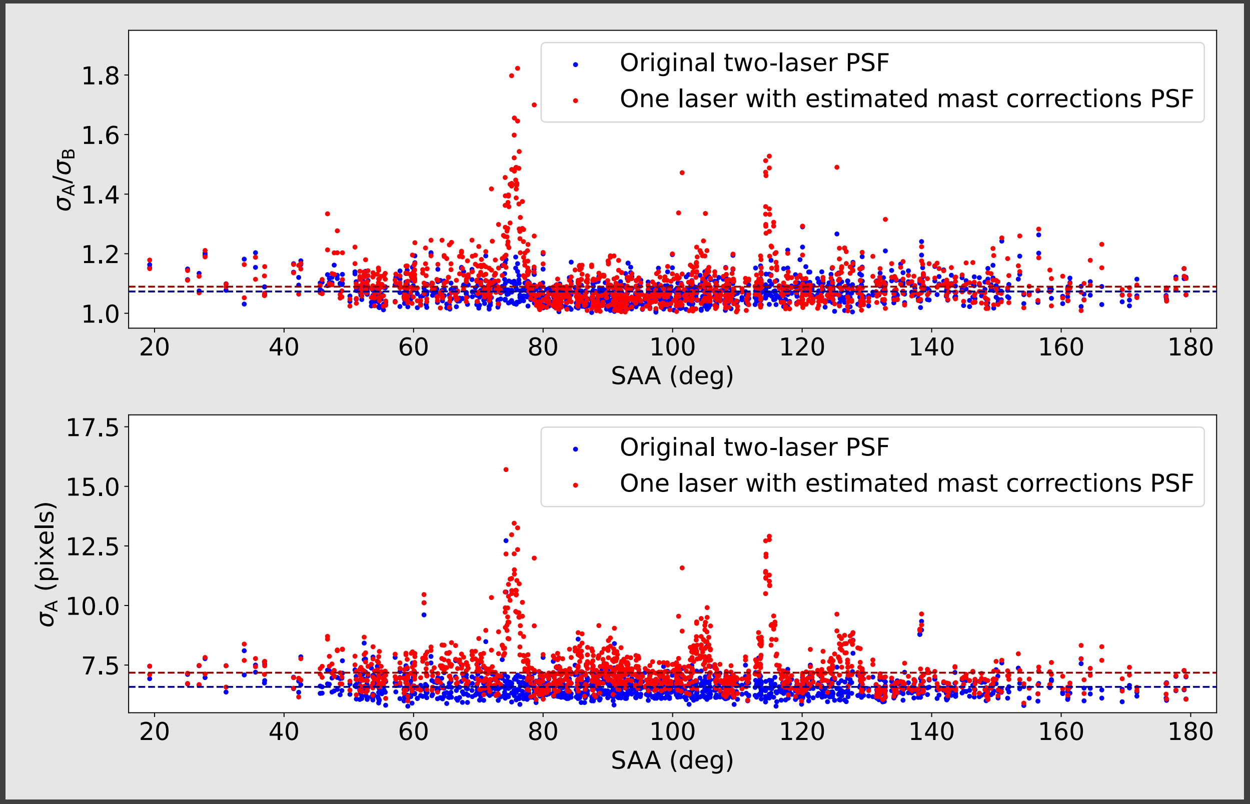
Estimated transforms in green:



Results: PSF fitting

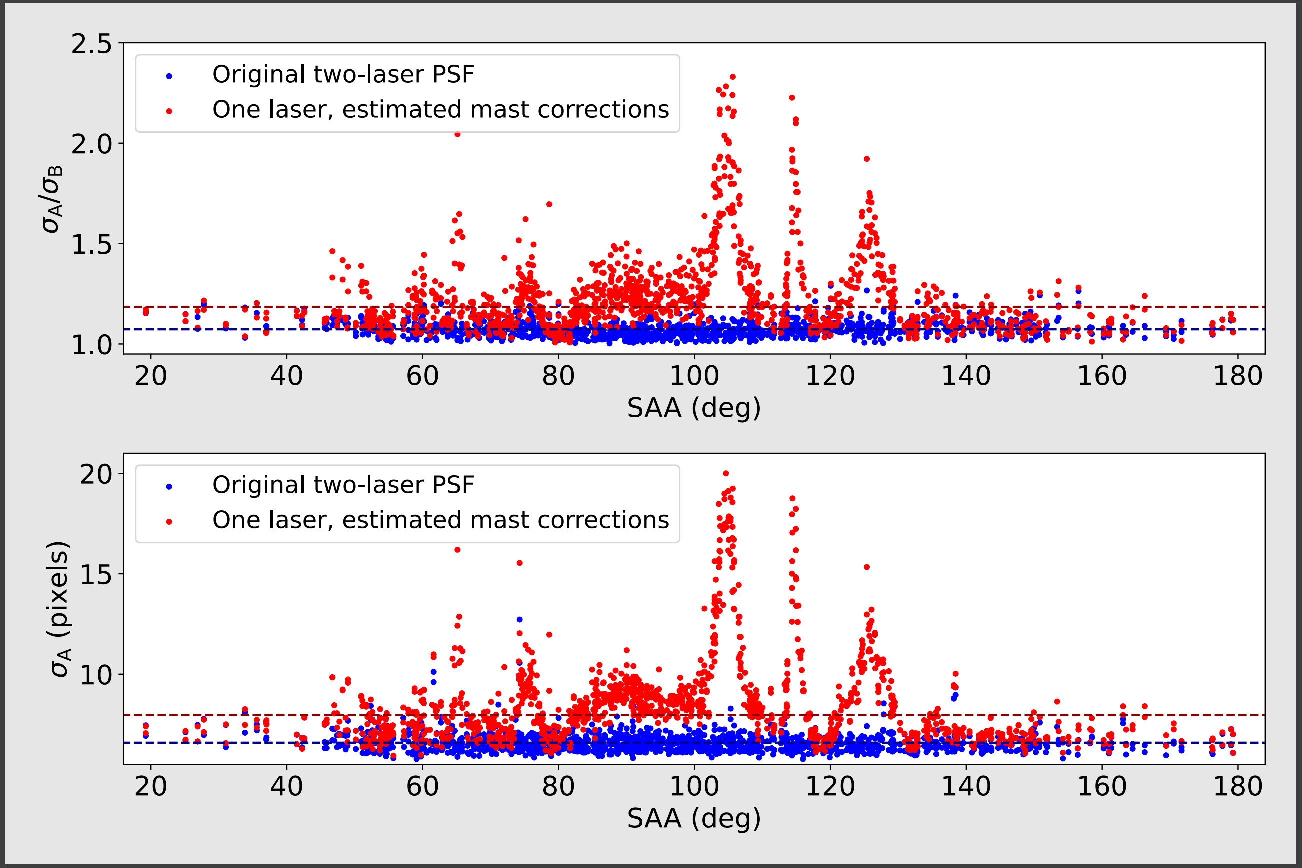


To test performance, PSFs generated using these single-laser mast files corrected with parameters estimated from the SAA relations were fitted with a 2D Gaussian function to evaluate PSF broadening and distortion. Performance generally good except for two narrow ranges of SAA.



Results: Reversing the lasers

Until now, we assumed LASER1 failed and LASER0 is operational, because LASER1 was declining in intensity faster and is assumed to be the likelier of the two to fail. Performing same process for the opposite scenario yields slightly worse results, with higher distortion and more bad SAA ranges.



Implications & Next Steps

- In the case of the loss of a metrology laser, we are confident that we can approximate mast aspect reconstruction using the working laser, the mission elapsed time, the SAA of the observation, and knowledge of the telescope phase.
- Now we are generating single-laser PSD and mast files for each observation to track how well this solution works into the future and working on the infrastructure required to make a quick transition to this method if necessary.
- Observation scheduling with a single metrology laser would be impacted due to narrow SAA ranges in which single-laser aspect reconstruction is poor. Additionally, this method is not calibrated for Solar observations i.e., SAA = 0.
- For more details see Earnshaw et al. 2022, JATIS, 8 (1), 014009

Thank you!

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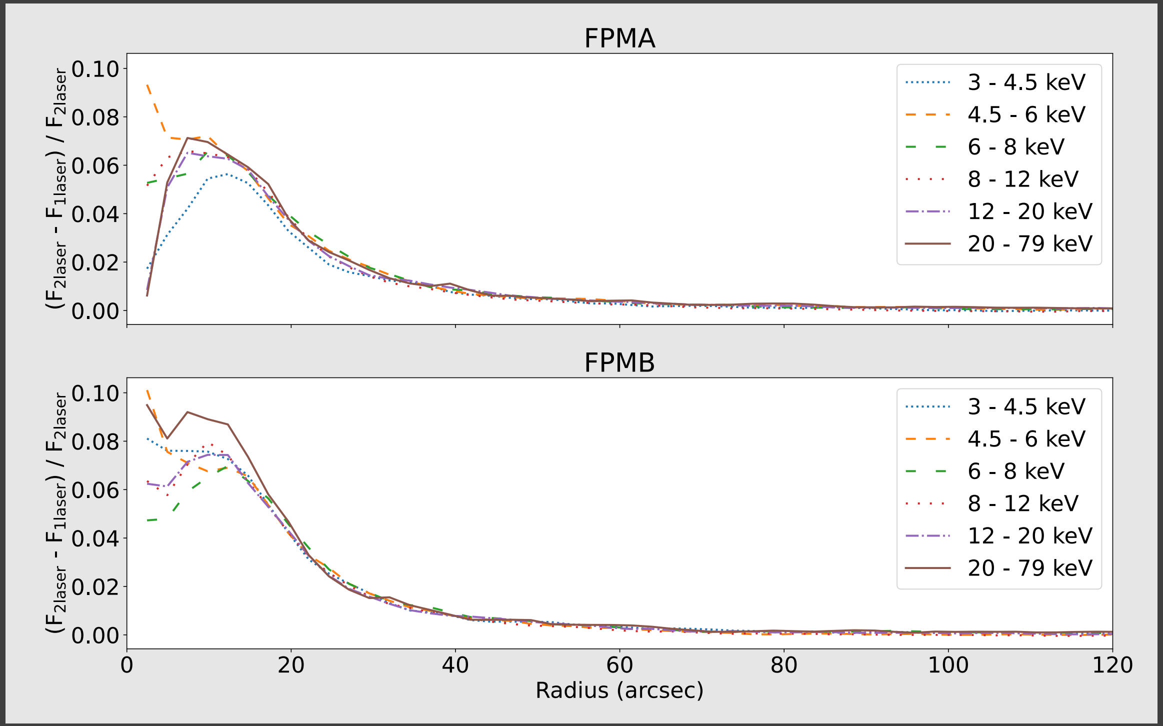
Results: Her X-1

Five observations of bright, well-studied X-ray binary Her X-1 were studied to investigate in further detail the PSF broadening resulting from single-laser mast aspect reconstruction.

Plotting the Enclosed Energy Fraction, and the fractional difference between the two-laser and one-laser scenarios, shows that the difference in EEF becomes negligible at ~50 arcsec (typical source extraction regions are equal to or larger than this; size of the NuSTAR PSF is ~1 arcmin)



Why the bad SAA ranges?

At SAA~74 and SAA~114, the mast motion occurs in a complex pattern that makes the two laser tracks different enough in shape that a good approximation cannot be made to either the Y or the X transform from using the existing laser track.