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EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

# AMI Commissioning Analysis

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# Analysis Scripts Overview

0. AMI science readiness criterion
1. Observables comparable with analytical values and noisy simulations
2. Calibrator observables internally consistent
3. Calibrator observables comparable with expected point source values, noisy simulations
4. Data quality (DC levels, bad pixels) consistent, as expected
5. Measured positions of NRM sub-apertures are as expected
6. Comparison of the actual PSF location with commanded pixel location indicates successful TA
7. Dithers and sub-dithers match the commanded values.
8. Charge migration existence/characterization
9. PSF characterization
10. Kernel phase analysis

# Organization

## Driver script:

- Output organization: runs with different pipeline settings, observable extraction settings, bad pixel fixing routines, can be easily organized
- Step toggling: turn all pre-analysis and analysis steps on and off from one location

## Observation dictionary:

- Allows filename-independent analysis scripts, easy selection of exposures based on observation configuration
- Prerequisite data validation with APT file

## Command line interface:

- As well as being callable from other pipeline scripts, each step can also be called from the command line with various arguments

# Pre-analysis

- Data validation
  - verify_1093_xml.py
  - check_niriss_headers.py
  - data_quicklook.py
- JWST calibration pipeline (Detector1, Image2)
  - run_ami_pipeline.py
- Kernel phase extraction (xara calwebb_kpi3)
  - run_kernel_stage3.py
- Bad pixel correction
  - run_bp_fix.py
- Observable extraction & calibration (ImPlaneIA or AMICAL)
  - run_implaneia_1.py
  - run_implaneia_2.py
  - run_amical.py

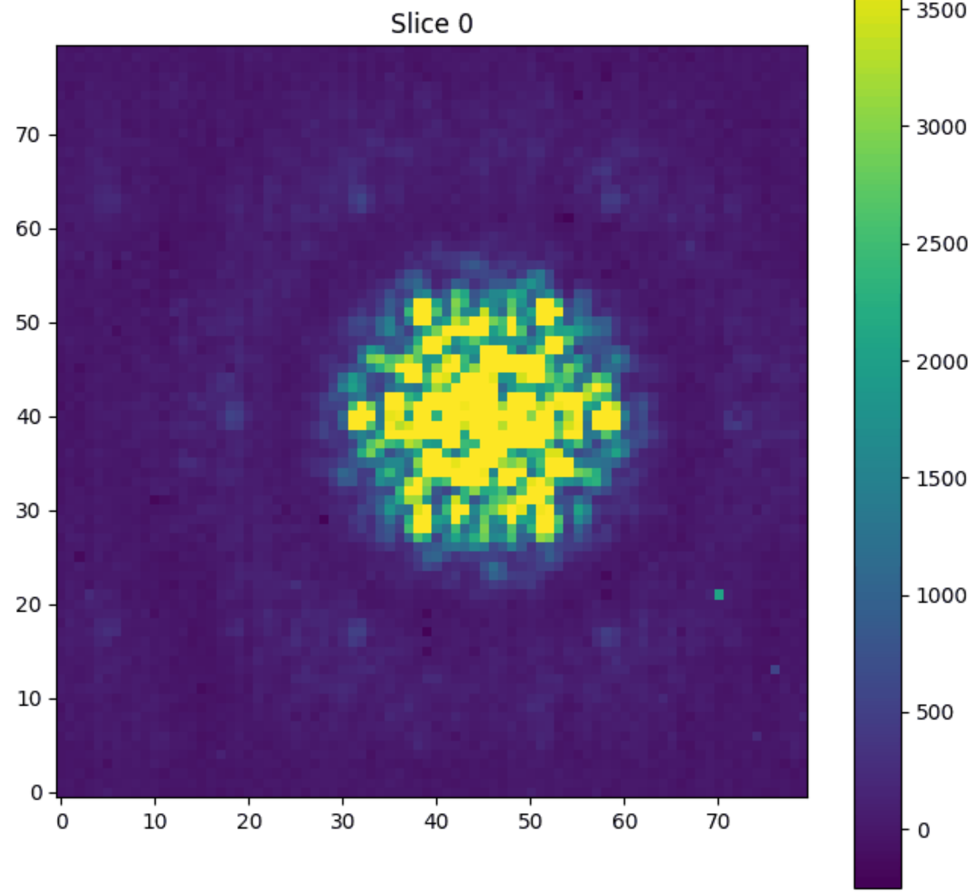
```
obs012_NRM_F380M_2_160_pri1_sub0: jw01093012001_03104_00001_nis
obs012_NRM_F430M_4_82_pri1_sub0: jw01093012001_03103_00001_nis
obs012_NRM_F480M_13_29_pri1_sub0: jw01093012001_03105_00001_nis
obs012_NRM_F480M_5_69_pri1_sub0: jw01093012001_03102_00001_nis
obs012ta_NRM_F480M_7_1_pri1_sub0: jw01093012001_02101_00001_nis
obs012ta_NRM_F480M_7_1_pri2_sub0: jw01093012001_02101_00002_nis
obs012ta_NRM_F480M_7_1_pri3_sub0: jw01093012001_02101_00003_nis
obs012ta_NRM_F480M_7_1_pri4_sub0: jw01093012001_02101_00004_nis
obs013_NRM_F380M_2_160_pri1_sub0: jw01093013001_03104_00001_nis
obs013_NRM_F430M_4_82_pri1_sub0: jw01093013001_03103_00001_nis
obs013_NRM_F480M_13_29_pri1_sub0: jw01093013001_03105_00001_nis
obs013_NRM_F480M_5_69_pri1_sub0: jw01093013001_03102_00001_nis
obs013ta_NRM_F480M_7_1_pri1_sub0: jw01093013001_02101_00001_nis
obs013ta_NRM_F480M_7_1_pri2_sub0: jw01093013001_02101_00002_nis
obs013ta_NRM_F480M_7_1_pri3_sub0: jw01093013001_02101_00003_nis
obs013ta_NRM_F480M_7_1_pri4_sub0: jw01093013001_02101_00004_nis
obs014_NRM_F480M_5_69_pri1_sub1: jw01093014001_03102_00001_nis
obs014_NRM_F480M_5_69_pri1_sub2: jw01093014001_03102_00002_nis
obs014_NRM_F480M_5_69_pri1_sub3: jw01093014001_03102_00003_nis
obs014_NRM_F480M_5_69_pri1_sub4: jw01093014001_03102_00004_nis
obs014_NRM_F480M_5_69_pri1_sub5: jw01093014001_03102_00005_nis
obs014ta_NRM_F480M_7_1_pri1_sub0: jw01093014001_02101_00001_nis
obs014ta_NRM_F480M_7_1_pri2_sub0: jw01093014001_02101_00002_nis
obs014ta_NRM_F480M_7_1_pri3_sub0: jw01093014001_02101_00003_nis
obs014ta_NRM_F480M_7_1_pri4_sub0: jw01093014001_02101_00004_nis
obs015_NRM_F380M_4_118_pri1_sub0: jw01093015001_03104_00001_nis
obs015_NRM_F430M_9_78_pri1_sub0: jw01093015001_03103_00001_nis
obs015_NRM_F480M_12_61_pri1_sub0: jw01093015001_03102_00001_nis
obs015ta_NRM_F480M_11_1_pri1_sub0: jw01093015001_02101_00001_nis
obs015ta_NRM_F480M_11_1_pri2_sub0: jw01093015001_02101_00002_nis
obs015ta_NRM_F480M_11_1_pri3_sub0: jw01093015001_02101_00003_nis
obs015ta_NRM_F480M_11_1_pri4_sub0: jw01093015001_02101_00004_nis
```

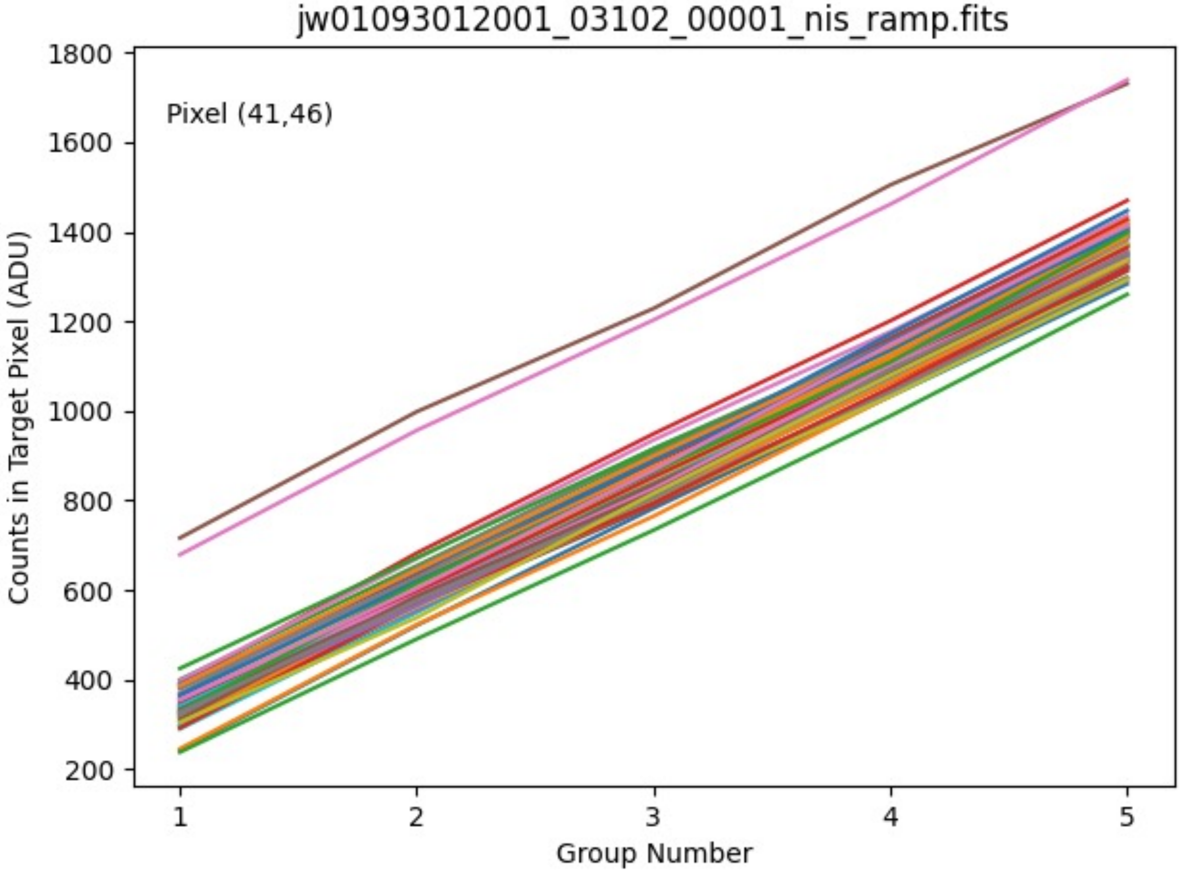
prog1093.yml

Dictionary format:

obsnum_pupil_filter_ngroups_nints_primarydither_subdither : filename root

# Pre-analysis



# Quicklook notebooks

quicklook2_wbadpx.ipynb:

- Calibrate AB Dor and two reference stars at one detector position, one filter, and extract observables with ImPlaneIA.

quicklook2_wbadpx.ipynb:

- Examine observables, fit with binary model using CANDID

Quick way to get first results and familiarize yourself with software

# Analysis 0: AMI Science Readiness

**Summary:** Run CANDID or Fouriever for MCMC modeling of binary parameters; check for 5$\sigma$ agreement between predicted and measured binary parameters. Use Fouriever to do a multi-wavelength fit to all calibrated OIFITS files.

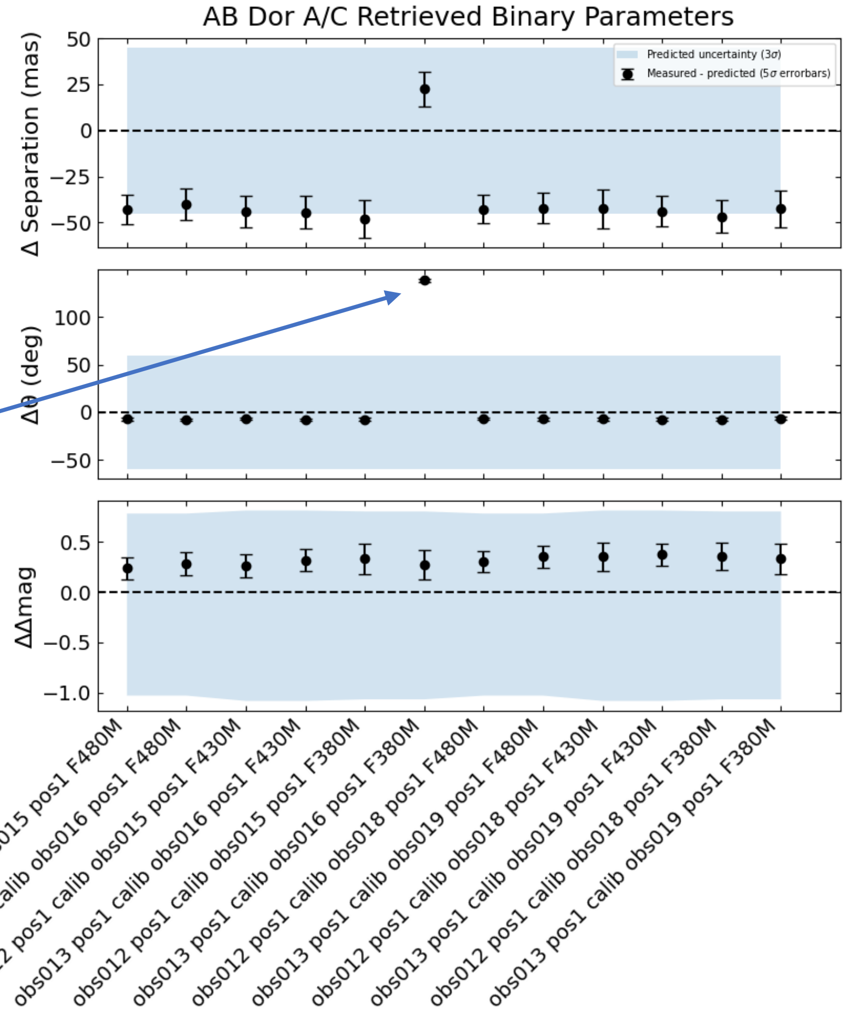
**Input:** Calibrated OIFITS files (AB Dor at two primary dither positions in filters F480M, F430M, F380M, calibrated by either HD 37093 or HD 36805)

**Output:**

- **analysis0_fit.pkl:** Pickled dictionary of all CANDID fit results
- **analysis0_fit_results.dat**: Human-readable table of binary parameters from each observation - analysis0_fit_truefalse.dat: True/False table of whether retrieved binary parameters are within the confidence interval of the expected binary params
- **[oifits_name]_detection_map_candid.pdf**: Detection map showing the most probable position of the companion
- **[oifits_name]_fit_candid.pdf**: Plotted observables with the best-fit model observables
- **[oifits_name]_lim_detection_candid.pdf**: Detection limit map (injection method)
- **all_abdor_smear_cov_chi2map.pdf**: Chi-squared map of companion location from Fouriever multiple-filter binary fit
- **all_abdor_smear_cov_mcmc_chains.pdf**: Fouriever MCMC walks for each modeled binary parameter
- **all_abdor_smear_cov_mcmc_corner.pdf**: Fouriever corner plot of MCMC best-fit binary parameters
- **all_abdor_smear_cov_t3_bin**: Fouriever plot of data vs model closure phases
- **all_abdor_smear_cov_sub_[*].pdf**: Results of secondary Fouriever fit to data after best-fit companion subtracted

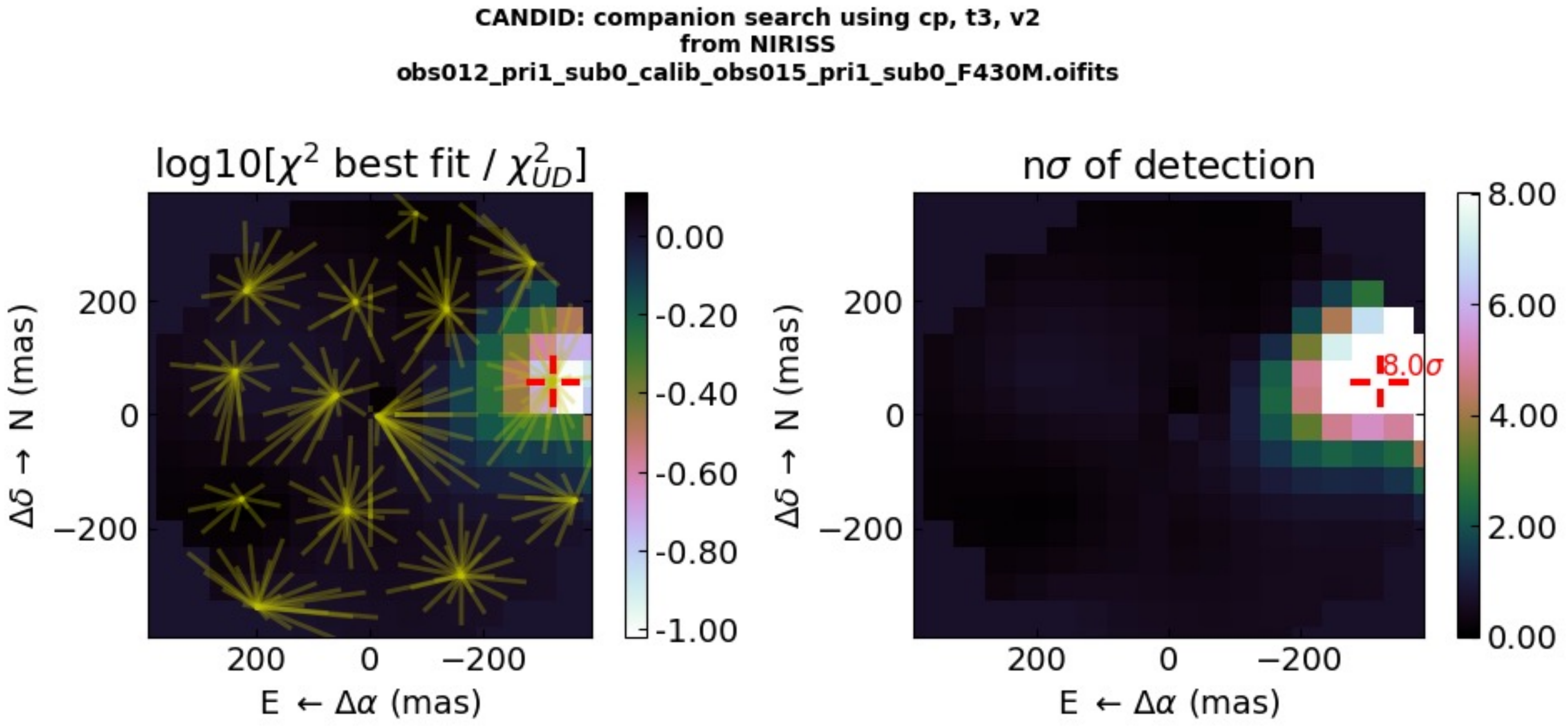
# Analysis 0: AMI Science Readiness

| Calibrated OIFITs | Separation | Position Angle | Mag Diff |
|---|---|---|---|
| obs012_pri1_sub0_calib_obs015_pri1_sub0_F480M.oifits | True | True | True |
| obs013_pri1_sub0_calib_obs016_pri1_sub0_F480M.oifits | True | True | True |
| obs012_pri1_sub0_calib_obs015_pri1_sub0_F430M.oifits | True | True | True |
| obs013_pri1_sub0_calib_obs016_pri1_sub0_F430M.oifits | True | True | True |
| obs012_pri1_sub0_calib_obs015_pri1_sub0_F380M.oifits | True | True | True |
| obs013_pri1_sub0_calib_obs016_pri1_sub0_F380M.oifits | True | False | True |
| obs012_pri1_sub0_calib_obs018_pri1_sub0_F480M.oifits | True | True | True |
| obs013_pri1_sub0_calib_obs019_pri1_sub0_F480M.oifits | True | True | True |
| obs012_pri1_sub0_calib_obs018_pri1_sub0_F430M.oifits | True | True | True |
| obs013_pri1_sub0_calib_obs019_pri1_sub0_F430M.oifits | True | True | True |
| obs012_pri1_sub0_calib_obs018_pri1_sub0_F380M.oifits | True | True | True |
| obs013_pri1_sub0_calib_obs019_pri1_sub0_F380M.oifits | True | True | True |

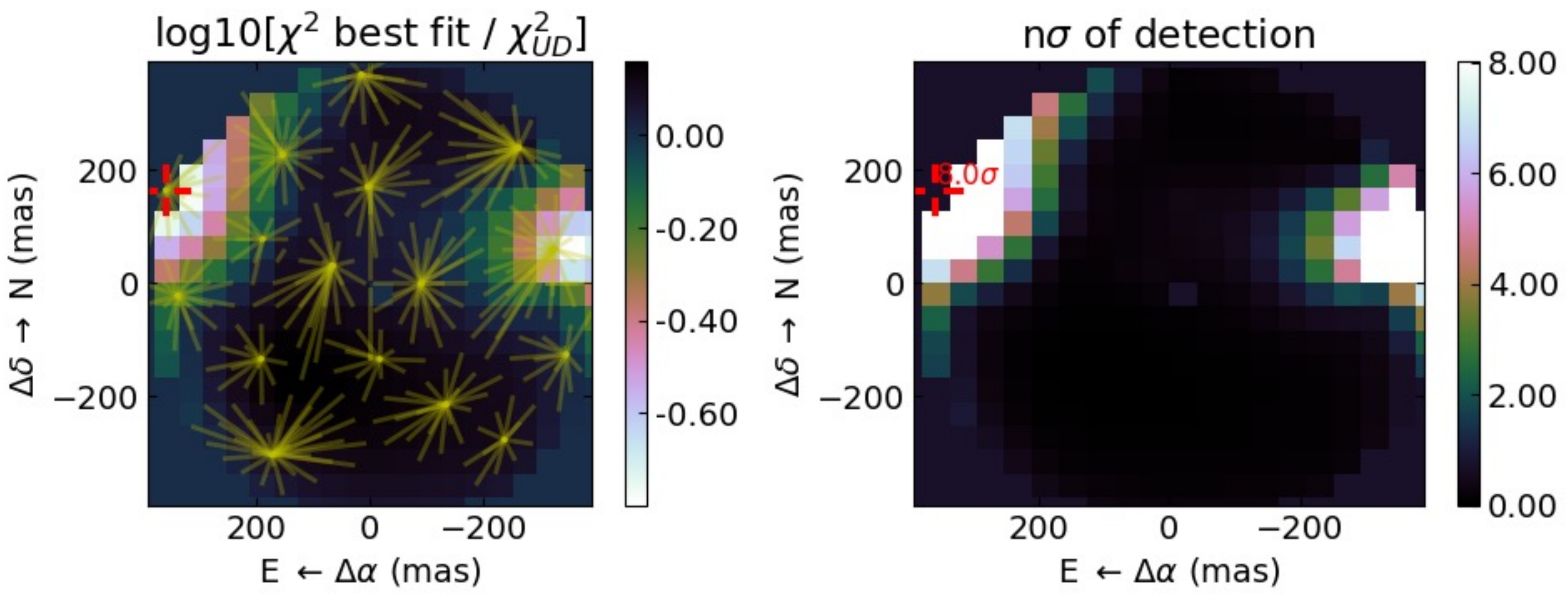



| Calibrated OIFITS | Sep/mas | PA/deg | DM/mag | chi^2 | nsigma |
|---|---|---|---|---|---|
| obs012_pri1_sub0_calib_obs015_pri1_sub0_F480M.oifits | 328.179 +/- 7.90 | 279.908 +/- 1.30 | 4.440 +/- 0.11 | 0.06 | 8.03 |
| obs013_pri1_sub0_calib_obs016_pri1_sub0_F480M.oifits | 330.894 +/- 8.61 | 279.405 +/- 1.35 | 4.485 +/- 0.11 | 0.07 | 8.03 |
| obs012_pri1_sub0_calib_obs015_pri1_sub0_F430M.oifits | 326.811 +/- 8.51 | 280.100 +/- 1.42 | 4.415 +/- 0.12 | 0.09 | 8.03 |
| obs013_pri1_sub0_calib_obs016_pri1_sub0_F430M.oifits | 326.536 +/- 8.78 | 279.367 +/- 1.44 | 4.474 +/- 0.11 | 0.09 | 8.03 |
| obs012_pri1_sub0_calib_obs015_pri1_sub0_F380M.oifits | 322.812 +/- 10.15 | 279.600 +/- 1.78 | 4.415 +/- 0.15 | 0.09 | 8.03 |
| obs013_pri1_sub0_calib_obs016_pri1_sub0_F380M.oifits | 393.508 +/- 9.49 | 425.517 +/- 1.39 | 4.353 +/- 0.15 | 0.09 | 8.03 |
| obs012_pri1_sub0_calib_obs018_pri1_sub0_F480M.oifits | 328.198 +/- 7.78 | 280.238 +/- 1.28 | 4.507 +/- 0.11 | 0.06 | 8.03 |
| obs013_pri1_sub0_calib_obs019_pri1_sub0_F480M.oifits | 328.870 +/- 8.45 | 279.935 +/- 1.36 | 4.554 +/- 0.11 | 0.06 | 8.03 |
| obs012_pri1_sub0_calib_obs018_pri1_sub0_F430M.oifits | 328.412 +/- 10.59 | 280.015 +/- 1.73 | 4.512 +/- 0.14 | 0.12 | 8.03 |
| obs013_pri1_sub0_calib_obs019_pri1_sub0_F430M.oifits | 327.088 +/- 8.21 | 279.662 +/- 1.32 | 4.529 +/- 0.11 | 0.07 | 8.03 |
| obs012_pri1_sub0_calib_obs018_pri1_sub0_F380M.oifits | 324.216 +/- 8.93 | 279.656 +/- 1.57 | 4.438 +/- 0.14 | 0.07 | 8.03 |
| obs013_pri1_sub0_calib_obs019_pri1_sub0_F380M.oifits | 328.393 +/- 9.95 | 280.448 +/- 1.73 | 4.417 +/- 0.15 | 0.09 | 8.03 |

# Analysis 0: AMI Science Readiness

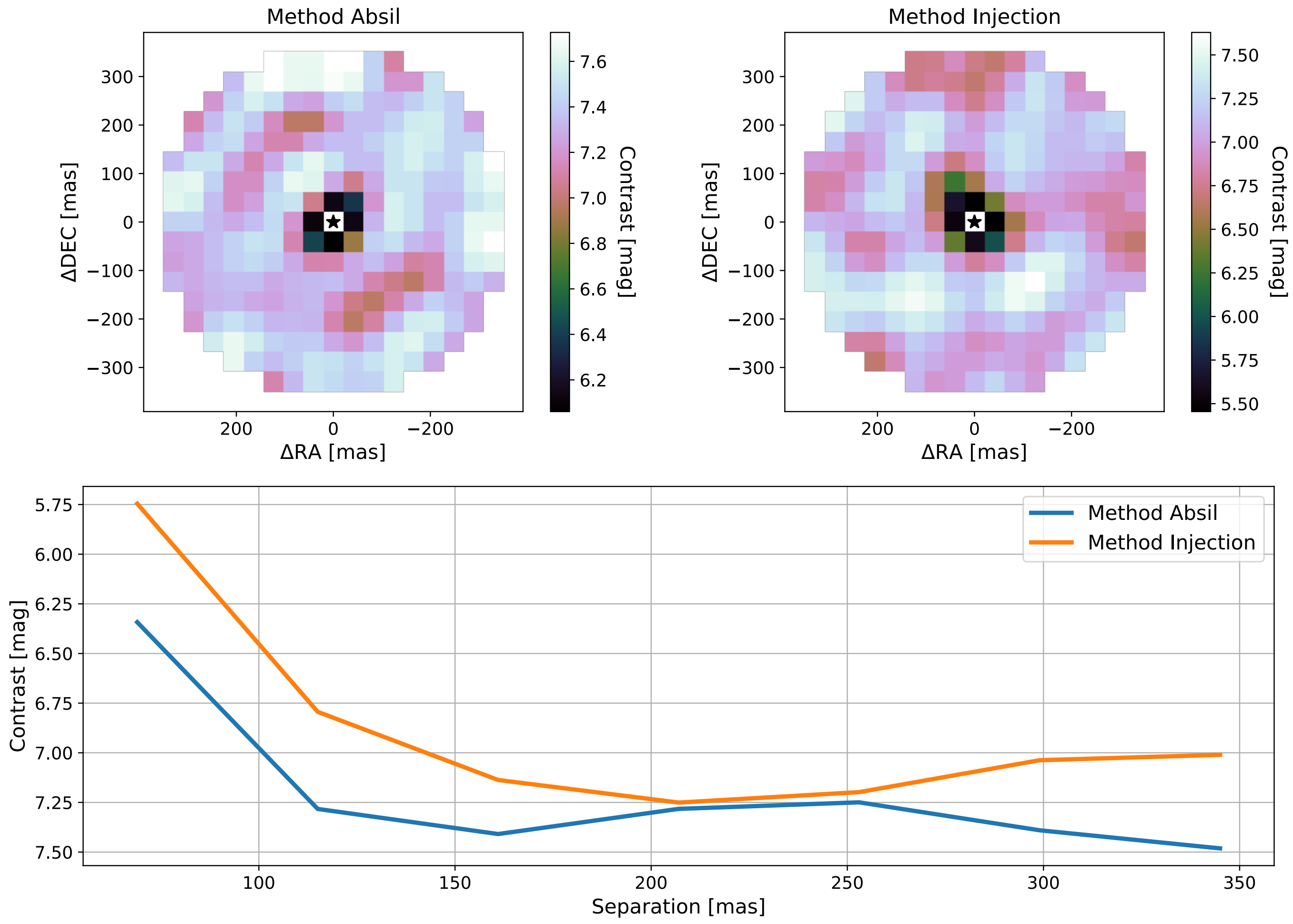


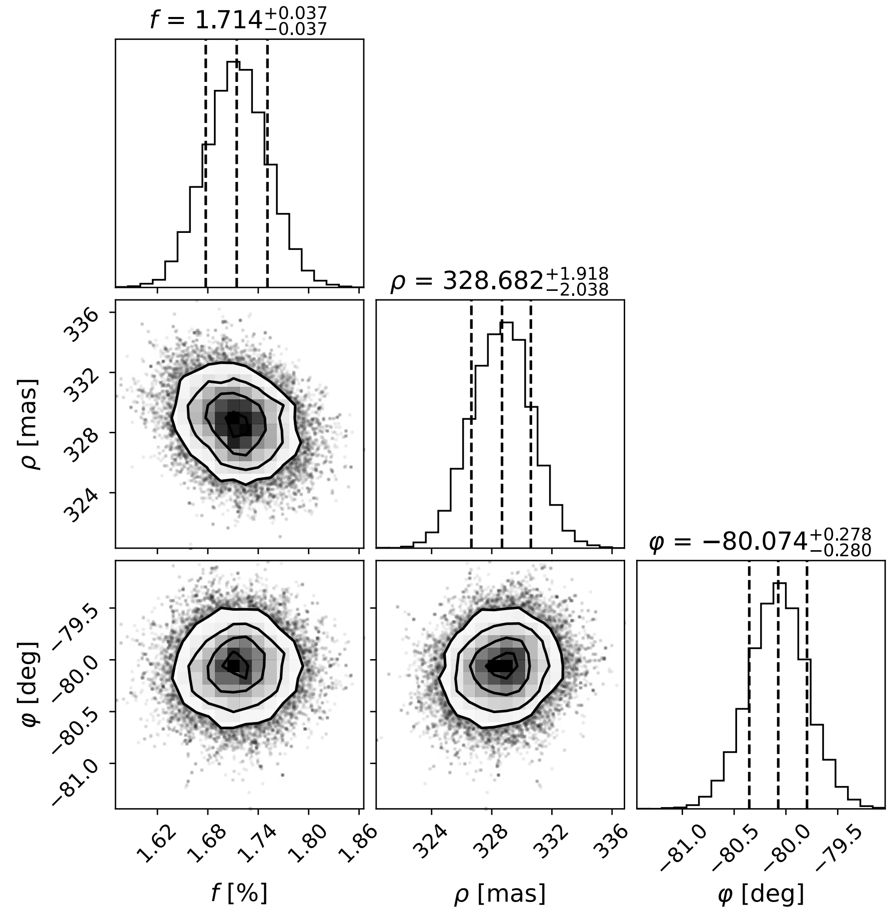
CANDID: companion search using cp, t3, v2
from NIRISS
obs013_pri1_sub0_calib_obs016_pri1_sub0_F380M.oifits



# Analysis 0: AMI Science Readiness

Detection limits (3-$\sigma$)




https://github.com/kammerje/fouriever

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# Analysis 1: Compare raw observables with simulations, calculations

**Summary:** Split each uncal file into 10 chunks of ints, process through pipeline, extract observables. Compare CPs, SqVs from each chunk to equivalent from simulations, analytical formulae. Check stdev of each CP across each of 10 chunks of ints <1e-1 rad, SqV stdev < 1e-1 for both target and calibrator files. Check that pupil phases (pistons) have a standard deviation < 50 nm.

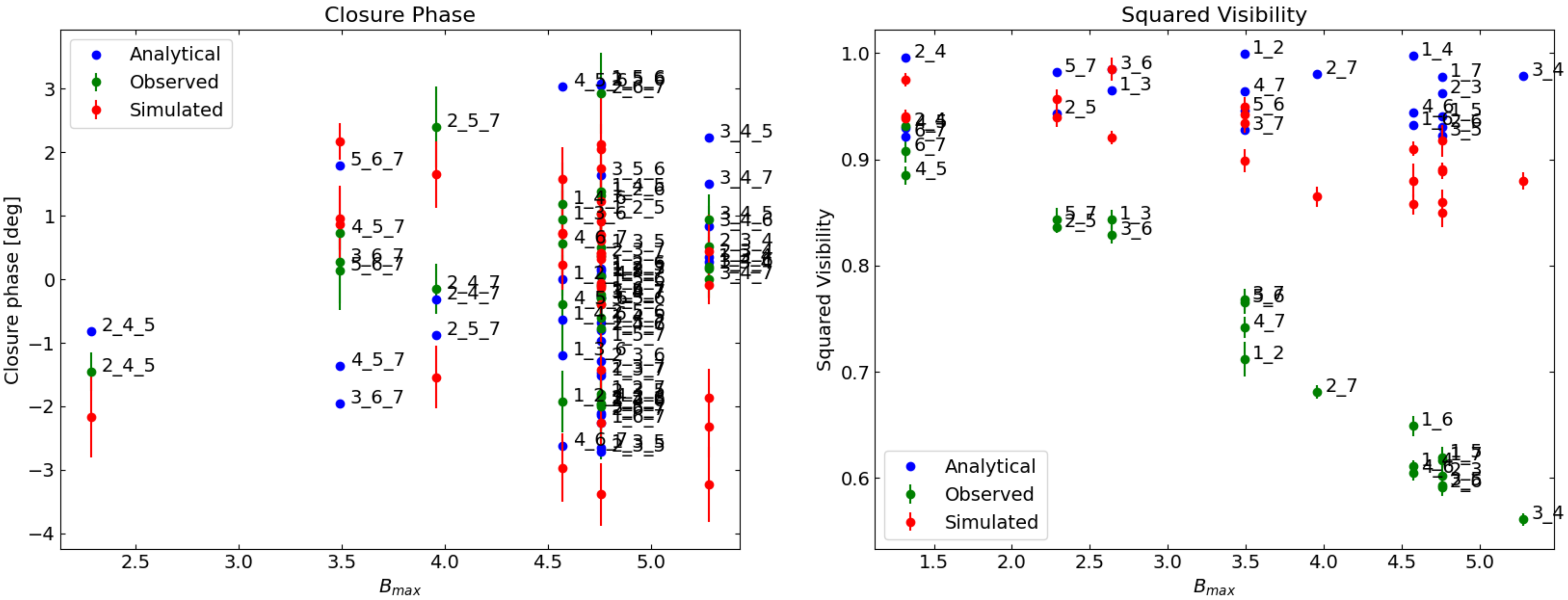
**Inputs:** Uncal files for AB Dor and HD 37093, 2 dither positions, F480M only

**Outputs:**

- jw01093...Nints_chunkM_[suffix]: For each of 4 input files, 10 "faked" uncal, trapsfilled, rate/rateints, cal/calints, and oifits files. Original filename has Nints_chunkM appended, where N is the number of integrations in the file, M is the order in which they were taken from the original exposure (out of 10 chunks)
- [obs_key]_chunkM_observables_plot.png: Closure phases and squared visibilities from analytically calculated, noisy simulated, and in-flight (uncalibrated) exposures of AB Dor.
- [obs_key]_CPs.dat: Table of closure phase standard deviations from all 10 chunks produced from each exposure
- [obs_key]_SqVs.dat: Table of squared visibility standard deviations from all 10 chunks produced from each exposure
- [obs_key]_pistons_plot.png: Plot of the 7 pistons (pupil phases) from ImPlaneIA solution in degrees and nm OPD over the 10 chunks of integrations
- piston_stdevs.png: Plot of the piston standard deviations for each of the four exposures examined

# Analysis 1: Compare raw observables with simulations, calculations

obs012_NRM_F480M_5_69_pri1_sub0_chunk1



# Analysis 1: Compare raw observables with simulations, calculations

| Hole Indices | Baseline [m] | CP STD #1 | CP STD #2 | CP STD #3 | CP STD #4 | CP STD #5 | CP STD #6 | CP STD #7 | CP STD #8 | CP STD #9 | CP STD #10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1_2_3 | 4.759 | 0.8667 | 0.7395 | 0.7568 | 0.3735 | 0.4911 | 0.5321 | 0.5891 | 0.6646 | 0.9142 | 0.5427 |
| 1_2_4 | 4.573 | 0.4855 | 0.5710 | 0.4542 | 0.7261 | 0.7382 | 0.9260 | 0.5633 | 0.5687 | 0.5176 | 0.3474 |
| 1_2_5 | 4.759 | 0.7244 | 0.4535 | 0.8282 | 0.4234 | 0.7206 | 0.7582 | 0.4375 | 0.7048 | 0.7951 | 0.6686 |
| 1_2_6 | 4.759 | 0.8826 | 0.6156 | 0.3718 | 0.4881 | 0.8544 | 0.6927 | 0.8603 | 0.6472 | 0.3516 | 0.4724 |
| 1_2_7 | 4.759 | 0.5751 | 0.6317 | 0.6616 | 0.6794 | 0.6767 | 0.6155 | 0.6893 | 1.0759 | 0.6019 | 0.2399 |
| 1_3_4 | 5.280 | 0.2081 | 0.7608 | 0.5226 | 0.6401 | 0.5391 | 0.5747 | 0.8547 | 0.5995 | 0.6165 | 0.4365 |
| 1_3_5 | 4.759 | 0.5778 | 0.3148 | 0.8194 | 0.5104 | 0.6233 | 0.2392 | 0.5610 | 0.8653 | 0.4946 | 0.5804 |
| 1_3_6 | 4.573 | 0.7184 | 0.5724 | 0.3528 | 0.2390 | 0.4133 | 0.2690 | 0.2844 | 0.7127 | 0.4338 | 0.3504 |
| 1_3_7 | 4.759 | 0.6167 | 0.3014 | 0.3900 | 0.4058 | 0.7057 | 0.2332 | 0.4348 | 0.8613 | 0.5074 | 0.4699 |
| 1_4_5 | 4.759 | 0.2985 | 0.7537 | 0.8731 | 0.7012 | 0.4123 | 0.7640 | 0.6784 | 0.5617 | 0.7980 | 0.6454 |
| 1_4_6 | 4.573 | 0.6567 | 0.7737 | 0.9223 | 0.7791 | 0.3507 | 0.8041 | 0.8628 | 0.5718 | 0.6675 | 0.5190 |
| 1_4_7 | 4.759 | 0.5070 | 0.9144 | 0.6007 | 0.8668 | 0.7448 | 0.5021 | 0.9445 | 0.5494 | 0.7164 | 0.7154 |
| 1_5_6 | 4.759 | 0.4541 | 0.5247 | 0.7932 | 0.5650 | 0.6031 | 0.6624 | 0.5250 | 0.6756 | 0.5732 | 0.2979 |
| 1_5_7 | 4.759 | 0.7420 | 0.5690 | 0.6771 | 0.7657 | 0.9801 | 0.5122 | 0.5166 | 0.7982 | 0.1948 | 0.7170 |
| 1_6_7 | 4.759 | 0.6957 | 0.2804 | 0.3172 | 0.5877 | 0.8071 | 0.2642 | 0.5597 | 0.4924 | 0.6624 | 0.2504 |
| 2_3_4 | 5.280 | 0.6328 | 0.4530 | 0.6497 | 0.4804 | 0.4260 | 0.4429 | 0.4919 | 0.4408 | 0.8710 | 0.4525 |
| 2_3_5 | 4.759 | 0.6507 | 0.6458 | 0.9456 | 0.6798 | 0.6765 | 0.6847 | 0.6205 | 0.7950 | 0.5097 | 0.9959 |
| 2_3_6 | 4.759 | 0.4587 | 0.7594 | 0.7460 | 0.5704 | 0.4960 | 0.4905 | 0.5269 | 0.8573 | 0.8126 | 0.5178 |
| 2_3_7 | 4.759 | 0.7640 | 0.4983 | 0.5315 | 0.3616 | 0.3453 | 0.3581 | 0.3206 | 0.8454 | 0.8965 | 0.5791 |
| 2_4_5 | 2.286 | 0.3046 | 0.1912 | 0.6608 | 0.4605 | 0.6442 | 0.3259 | 0.3187 | 0.7579 | 0.6915 | 0.4336 |
| 2_4_6 | 4.759 | 0.7847 | 0.8734 | 0.7926 | 0.9810 | 0.8645 | 0.7745 | 0.4494 | 1.0203 | 0.5694 | 0.6454 |
| 2_4_7 | 3.960 | 0.3885 | 0.3485 | 0.5372 | 0.4997 | 0.4759 | 0.7393 | 0.5054 | 0.1827 | 0.3586 | 0.6082 |
| 2_5_6 | 4.759 | 0.7294 | 0.4449 | 0.7437 | 0.7996 | 0.4406 | 0.6973 | 0.6889 | 0.3635 | 0.4770 | 0.5942 |
| 2_5_7 | 3.960 | 0.6324 | 0.0996 | 0.3086 | 0.3585 | 0.3883 | 0.5685 | 0.4264 | 0.6197 | 0.4403 | 0.4637 |
| 2_6_7 | 4.759 | 0.6351 | 0.4212 | 0.6447 | 0.8219 | 0.6652 | 0.4975 | 0.4298 | 0.5098 | 0.2356 | 0.4599 |
| 3_4_5 | 5.280 | 0.3916 | 0.5355 | 0.3981 | 0.7752 | 0.7677 | 0.2974 | 0.8463 | 0.7915 | 0.5470 | 0.3025 |
| 3_4_6 | 5.280 | 0.4763 | 0.9502 | 0.6019 | 0.5620 | 0.6241 | 0.6362 | 0.8768 | 0.7557 | 0.6993 | 0.7376 |
| 3_4_7 | 5.280 | 0.3140 | 0.5833 | 0.2409 | 0.5291 | 0.4551 | 0.7865 | 0.3618 | 0.7797 | 0.7509 | 0.6341 |
| 3_5_6 | 4.759 | 0.5913 | 0.4554 | 0.4618 | 0.5430 | 0.8076 | 0.7357 | 0.6993 | 0.4388 | 0.6459 | 0.5141 |
| 3_5_7 | 4.759 | 0.6992 | 0.4573 | 0.5333 | 0.5516 | 0.7431 | 0.4147 | 0.5179 | 0.4632 | 0.6833 | 0.8880 |
| 3_6_7 | 3.492 | 0.7472 | 0.5468 | 0.3904 | 0.3789 | 0.3839 | 0.0883 | 0.7152 | 0.6450 | 0.4531 | 0.4710 |
| 4_5_6 | 4.573 | 0.7744 | 0.7343 | 0.6241 | 0.7487 | 0.4958 | 0.7911 | 0.7105 | 0.9276 | 0.5980 | 0.7030 |
| 4_5_7 | 3.492 | 0.2853 | 0.4829 | 0.6223 | 0.5928 | 0.7628 | 0.4000 | 0.5036 | 0.4984 | 0.5210 | 0.8056 |
| 4_6_7 | 4.573 | 0.8265 | 0.7168 | 0.4915 | 0.5968 | 0.5972 | 0.9777 | 0.7789 | 0.7921 | 0.5877 | 0.7497 |
| 5_6_7 | 3.492 | 0.5099 | 0.2534 | 0.7359 | 0.4559 | 0.6321 | 0.7322 | 0.5788 | 0.3403 | 0.5152 | 0.6233 |

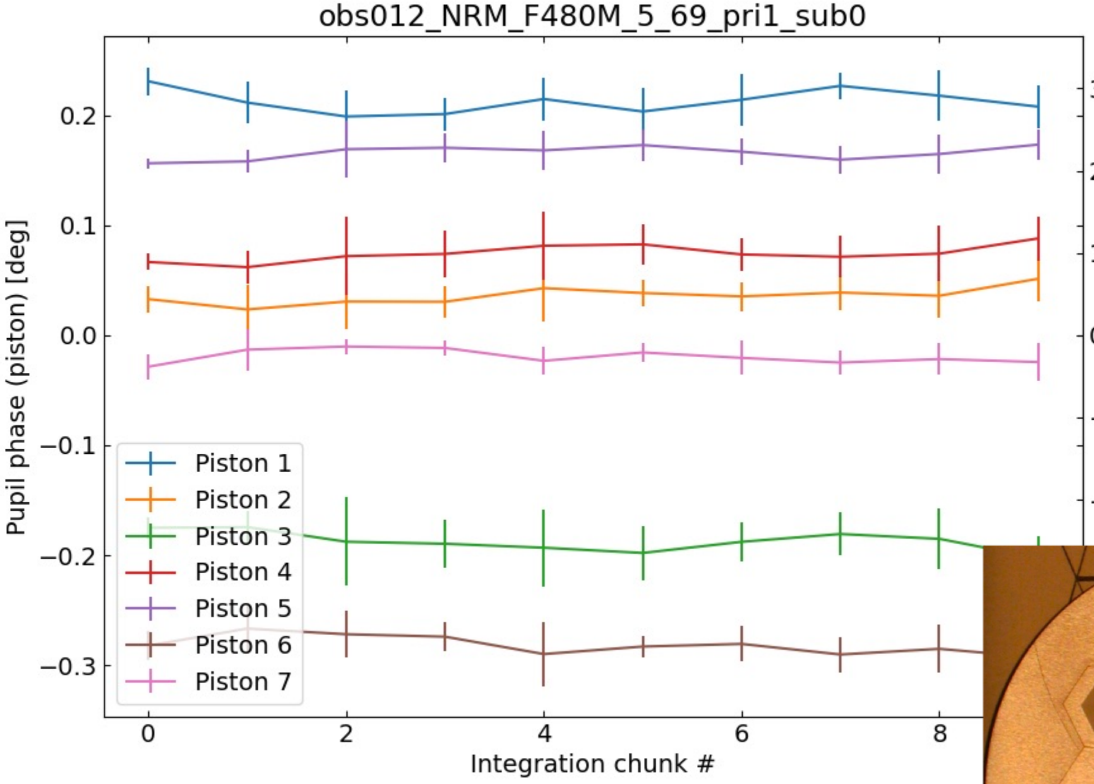
CP stdevs < 0.1 rad (5.7 deg)?

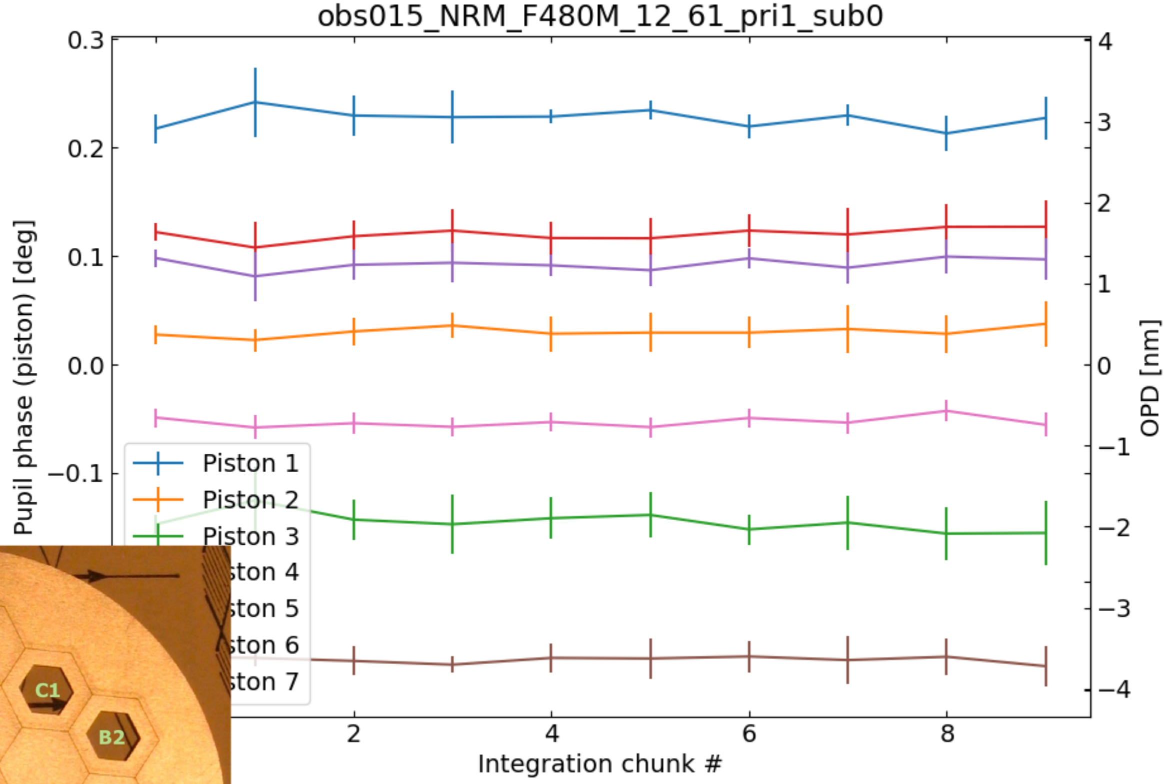
# Analysis 1: Compare raw observables with simulations, calculations

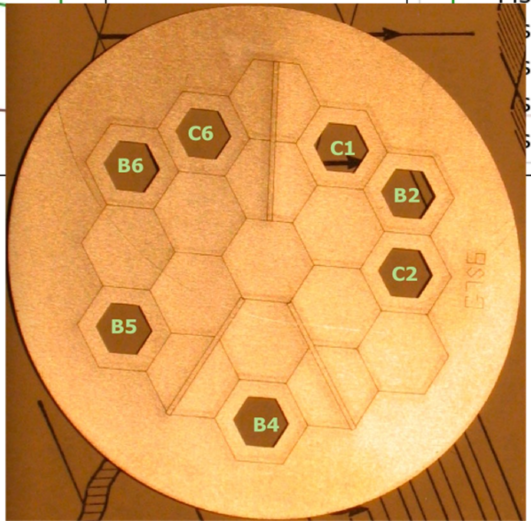
| Hole Indices | Baseline [m] | Sq Vis STD #1 | Sq Vis STD #2 | Sq Vis STD #3 | Sq Vis STD #4 | Sq Vis STD #5 | Sq Vis STD #6 | Sq Vis STD #7 | Sq Vis STD #8 | Sq Vis STD #9 | Sq Vis STD #10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1_2 | 3.492 | 0.0160 | 0.0053 | 0.0055 | 0.0070 | 0.0109 | 0.0084 | 0.0130 | 0.0127 | 0.0065 | 0.0101 |
| 1_3 | 2.640 | 0.0094 | 0.0081 | 0.0162 | 0.0158 | 0.0076 | 0.0066 | 0.0091 | 0.0075 | 0.0074 | 0.0116 |
| 1_4 | 4.573 | 0.0054 | 0.0105 | 0.0042 | 0.0063 | 0.0046 | 0.0079 | 0.0068 | 0.0143 | 0.0101 | 0.0112 |
| 1_5 | 4.759 | 0.0097 | 0.0104 | 0.0083 | 0.0089 | 0.0069 | 0.0095 | 0.0113 | 0.0076 | 0.0134 | 0.0063 |
| 1_6 | 4.573 | 0.0094 | 0.0085 | 0.0110 | 0.0166 | 0.0056 | 0.0090 | 0.0114 | 0.0117 | 0.0102 | 0.0112 |
| 1_7 | 4.759 | 0.0060 | 0.0041 | 0.0057 | 0.0030 | 0.0067 | 0.0101 | 0.0132 | 0.0071 | 0.0043 | 0.0119 |
| 2_3 | 4.759 | 0.0084 | 0.0118 | 0.0088 | 0.0121 | 0.0071 | 0.0068 | 0.0072 | 0.0085 | 0.0110 | 0.0094 |
| 2_4 | 1.320 | 0.0069 | 0.0174 | 0.0086 | 0.0128 | 0.0076 | 0.0096 | 0.0111 | 0.0063 | 0.0099 | 0.0108 |
| 2_5 | 2.286 | 0.0052 | 0.0155 | 0.0032 | 0.0098 | 0.0112 | 0.0040 | 0.0116 | 0.0111 | 0.0133 | 0.0138 |
| 2_6 | 4.759 | 0.0079 | 0.0128 | 0.0102 | 0.0115 | 0.0108 | 0.0137 | 0.0051 | 0.0036 | 0.0093 | 0.0109 |
| 2_7 | 3.960 | 0.0065 | 0.0149 | 0.0047 | 0.0078 | 0.0064 | 0.0073 | 0.0094 | 0.0071 | 0.0126 | 0.0069 |
| 3_4 | 5.280 | 0.0057 | 0.0088 | 0.0076 | 0.0156 | 0.0096 | 0.0128 | 0.0090 | 0.0107 | 0.0089 | 0.0093 |
| 3_5 | 4.759 | 0.0078 | 0.0086 | 0.0076 | 0.0073 | 0.0050 | 0.0087 | 0.0146 | 0.0084 | 0.0062 | 0.0099 |
| 3_6 | 2.640 | 0.0087 | 0.0104 | 0.0089 | 0.0061 | 0.0077 | 0.0066 | 0.0069 | 0.0075 | 0.0117 | 0.0097 |
| 3_7 | 3.492 | 0.0097 | 0.0140 | 0.0078 | 0.0119 | 0.0075 | 0.0070 | 0.0093 | 0.0111 | 0.0075 | 0.0086 |
| 4_5 | 1.320 | 0.0089 | 0.0107 | 0.0161 | 0.0113 | 0.0105 | 0.0073 | 0.0156 | 0.0116 | 0.0073 | 0.0105 |
| 4_6 | 4.573 | 0.0077 | 0.0144 | 0.0149 | 0.0141 | 0.0119 | 0.0077 | 0.0141 | 0.0121 | 0.0104 | 0.0149 |
| 4_7 | 3.492 | 0.0101 | 0.0169 | 0.0091 | 0.0135 | 0.0068 | 0.0153 | 0.0062 | 0.0062 | 0.0090 | 0.0112 |
| 5_6 | 3.492 | 0.0107 | 0.0077 | 0.0091 | 0.0044 | 0.0094 | 0.0139 | 0.0072 | 0.0144 | 0.0133 | 0.0105 |
| 5_7 | 2.286 | 0.0116 | 0.0043 | 0.0119 | 0.0151 | 0.0090 | 0.0102 | 0.0065 | 0.0092 | 0.0107 | 0.0138 |
| 6_7 | 1.320 | 0.0113 | 0.0153 | 0.0125 | 0.0066 | 0.0090 | 0.0108 | 0.0071 | 0.0084 | 0.0118 | 0.0087 |

Sq Vis stdevs < 0.1?

# Analysis 1: Compare raw observables with simulations, calculations




Piston stdevs < 50 nm OPD?

# Analysis 2: Calibrator observables internally consistent

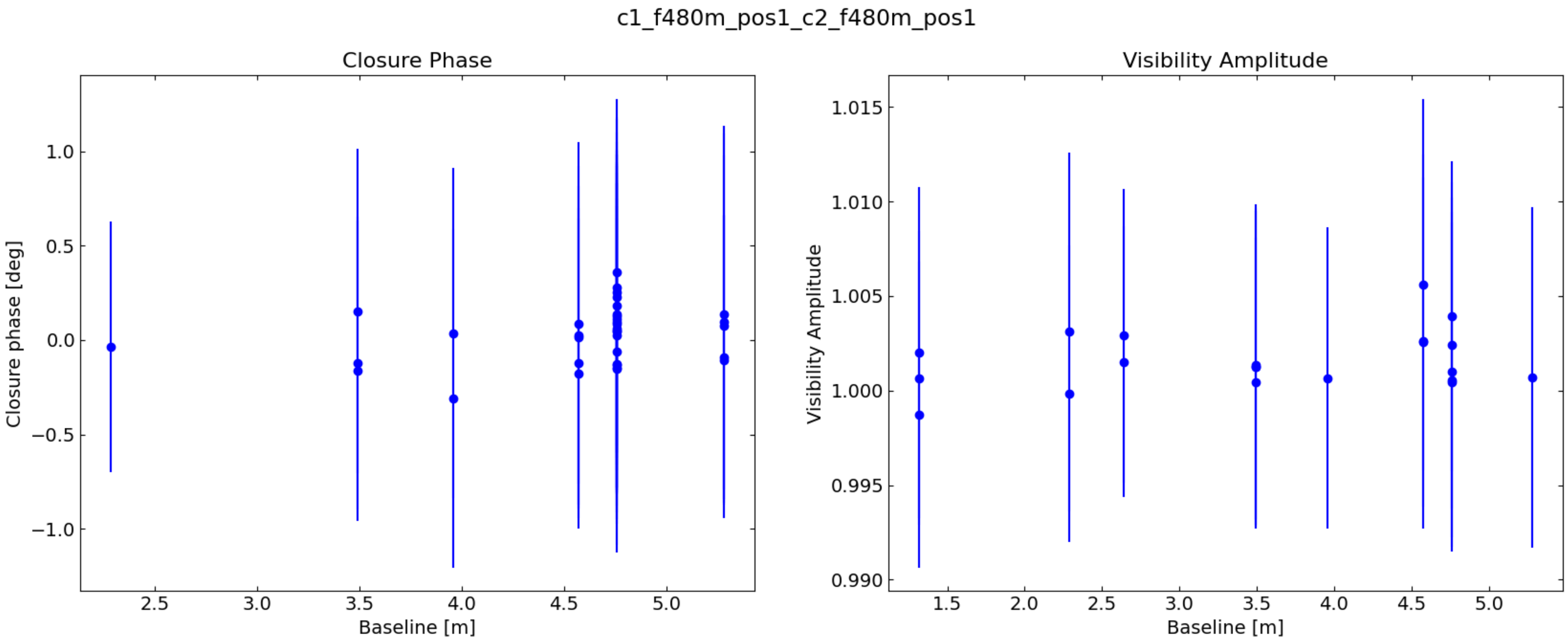
Summary: "Calibrate" each HD37093 exposure by the corresponding HD36805 exposure, and vice versa. Calibrators' closure phases must differ from each other by less than ~3e-3 radians (standard deviations of CPs of one calibrator "calibrated" by the other), fringe amplitude standard deviations < 3e-2. Run CANDID on calibrated-by-calibrator pairs to produce detection limit plots.

Input: Multi-integration OIFITS files of two calibrators HD 37093 and 36805 at 2 dither positions, 3 filters

Output:

- [calibrator_str]_ca_diff.dat: Table of closure amplitude differences, sorted by baseline length
- [calibrator_str]_cp_diff.dat: Table of closure phase differences, sorted by max baseline length
- [calibrator_str]_visamp_ratio.dat: Table of visibility amplitude ratios, sorted by max baseline length
- [calibrator_str]_cp_va_plot.png: Plot of "calibrated" closure phases and visibility amplitudes vs baseline length
- [oifits_name]_lim_detection_candid.png: CANDID detection limit plot.
- [oifits_name]_detection_map_candid.pdf: Detection map showing the attempted binary fit
- [oifits_name]_fit_candid.pdf: Plotted observables with the attempted binary model observables

# Analysis 2: Calibrator observables internally consistent




CPs close to 0, vis amps close to 1?

# Analysis 2: Calibrator observables internally consistent

| Hole Indices | Baseline [m] | Closure phase Cal1-Cal2 |
|---|---|---|
| 2_4_5 | 2.286 | -0.035 +/- 6.64e-01 |
| 4_5_7 | 3.492 | -0.120 +/- 7.77e-01 |
| 5_6_7 | 3.492 | 0.154 +/- 8.58e-01 |
| 3_6_7 | 3.492 | -0.162 +/- 7.96e-01 |
| 2_4_7 | 3.960 | -0.309 +/- 8.96e-01 |
| 2_5_7 | 3.960 | 0.038 +/- 8.73e-01 |
| 1_2_4 | 4.573 | -0.122 +/- 8.24e-01 |
| 1_3_6 | 4.573 | 0.027 +/- 7.89e-01 |
| 1_4_6 | 4.573 | 0.088 +/- 9.62e-01 |
| 4_5_6 | 4.573 | -0.179 +/- 8.23e-01 |
| 4_6_7 | 4.573 | 0.015 +/- 9.10e-01 |
| 1_2_7 | 4.759 | 0.084 +/- 9.02e-01 |
| 1_2_5 | 4.759 | 0.024 +/- 8.23e-01 |
| 1_3_7 | 4.759 | -0.062 +/- 8.15e-01 |
| 1_4_5 | 4.759 | -0.131 +/- 8.41e-01 |
| 1_4_7 | 4.759 | 0.097 +/- 8.87e-01 |
| 1_5_6 | 4.759 | 0.181 +/- 9.94e-01 |
| 1_5_7 | 4.759 | 0.111 +/- 8.94e-01 |
| 1_6_7 | 4.759 | 0.059 +/- 8.65e-01 |
| 1_3_5 | 4.759 | 0.052 +/- 8.34e-01 |
| 3_5_6 | 4.759 | 0.362 +/- 9.19e-01 |
| 3_5_7 | 4.759 | 0.279 +/- 9.02e-01 |
| 1_2_3 | 4.759 | 0.135 +/- 7.97e-01 |
| 2_3_5 | 4.759 | 0.253 +/- 8.46e-01 |
| 2_3_7 | 4.759 | -0.126 +/- 9.58e-01 |
| 2_4_6 | 4.759 | -0.148 +/- 9.80e-01 |
| 1_2_6 | 4.759 | 0.048 +/- 9.62e-01 |
| 2_3_6 | 4.759 | 0.226 +/- 8.25e-01 |
| 2_5_6 | 4.759 | 0.128 +/- 8.17e-01 |
| 2_6_7 | 4.759 | -0.153 +/- 7.96e-01 |
| 1_3_4 | 5.280 | -0.089 +/- 7.54e-01 |
| 2_3_4 | 5.280 | 0.139 +/- 9.99e-01 |
| 3_4_5 | 5.280 | -0.109 +/- 7.66e-01 |
| 3_4_6 | 5.280 | 0.076 +/- 1.02e+00 |
| 3_4_7 | 5.280 | 0.094 +/- 8.84e-01 |

"calibrated" CPs stdevs < 3e-3 rad (0.17 deg),
amplitude stdevs < 3e-2 ?

| Hole Indices | Baseline [m] | Visbility amplitude Cal1/Cal2 |
|---|---|---|
| 2_4 | 1.320 | 0.999 +/- 8.08e-03 |
| 4_5 | 1.320 | 1.002 +/- 8.76e-03 |
| 6_7 | 1.320 | 1.001 +/- 7.75e-03 |
| 5_7 | 2.286 | 1.003 +/- 9.48e-03 |
| 2_5 | 2.286 | 1.000 +/- 7.85e-03 |
| 3_6 | 2.640 | 1.002 +/- 7.16e-03 |
| 1_3 | 2.640 | 1.003 +/- 7.76e-03 |
| 4_7 | 3.492 | 1.001 +/- 8.15e-03 |
| 5_6 | 3.492 | 1.000 +/- 7.64e-03 |
| 1_2 | 3.492 | 1.001 +/- 8.57e-03 |
| 3_7 | 3.492 | 1.001 +/- 8.36e-03 |
| 2_7 | 3.960 | 1.001 +/- 7.98e-03 |
| 1_4 | 4.573 | 1.003 +/- 9.90e-03 |
| 1_6 | 4.573 | 1.003 +/- 8.71e-03 |
| 4_6 | 4.573 | 1.006 +/- 9.84e-03 |
| 1_7 | 4.759 | 1.002 +/- 8.63e-03 |
| 1_5 | 4.759 | 1.001 +/- 9.23e-03 |
| 3_5 | 4.759 | 1.000 +/- 8.99e-03 |
| 2_3 | 4.759 | 1.004 +/- 8.21e-03 |
| 2_6 | 4.759 | 1.001 +/- 8.34e-03 |
| 3_4 | 5.280 | 1.001 +/- 9.00e-03 |

## Analysis 3: Calibrator observables close to expected values, simulations

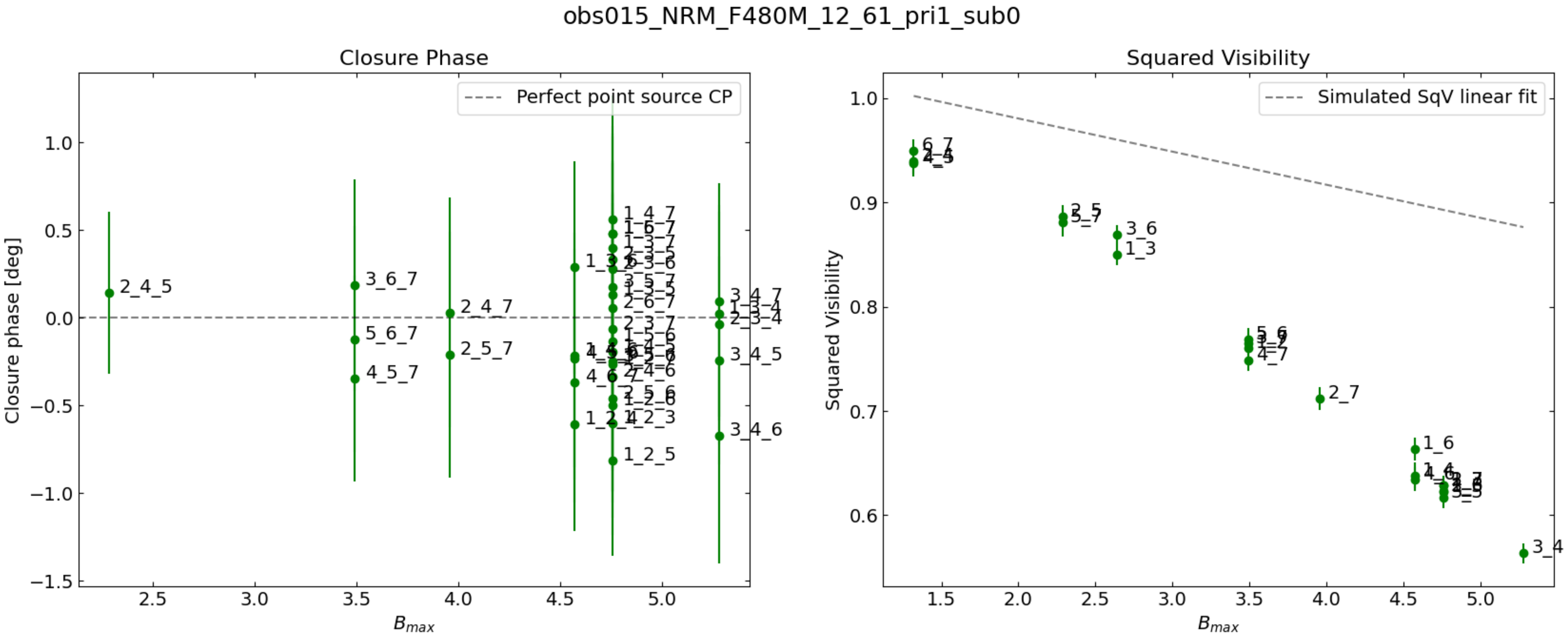
Summary: Check if 0 is within 3 sigma confidence interval for closure phases; check if linear-fit squared visibilities within 3 sigma for squared visibilities. For each exposure generate plots of observables and save tables of observables sorted by baseline length.

Input: Raw calibrator oifits files (2 targets, 2 dithers, 3 filters)

Output:

- [obs_key]_cps.dat: Table of closure phases sorted by max baseline length, including True/False column to check if within 3 sigma of 0.
- [obs_key]_sqvis.dat: Table of squared visibilities sorted by baseline length, including True/False column to check if within 3 sigma of 0.
- [obs_key]_observables_plot.png: Plot of closure phases and squared visibilities vs baseline length

# Analysis 3: Calibrator observables close to expected values, simulations



# Analysis 3: Calibrator observables close to expected values, simulations

CPs within 3 sigma of 0? SqVs within 3 sigma of simulations?

| Hole Indices | Baseline [m] | Closure phase | 0 within 3 sigma? |
|---|---|---|---|
| 2_4_5 | 2.286 | 0.143 +/- 0.46 | True |
| 4_5_7 | 3.492 | -0.346 +/- 0.59 | True |
| 5_6_7 | 3.492 | -0.121 +/- 0.64 | True |
| 3_6_7 | 3.492 | 0.187 +/- 0.60 | True |
| 2_4_7 | 3.960 | 0.031 +/- 0.66 | True |
| 2_5_7 | 3.960 | -0.210 +/- 0.70 | True |
| 1_2_4 | 4.573 | -0.607 +/- 0.61 | True |
| 1_3_6 | 4.573 | 0.287 +/- 0.61 | True |
| 1_4_6 | 4.573 | -0.218 +/- 0.70 | True |
| 4_5_6 | 4.573 | -0.231 +/- 0.62 | True |
| 4_6_7 | 4.573 | -0.370 +/- 0.68 | True |
| 1_2_7 | 4.759 | -0.267 +/- 0.72 | True |
| 1_2_5 | 4.759 | -0.811 +/- 0.55 | True |
| 1_3_7 | 4.759 | 0.396 +/- 0.64 | True |
| 1_4_5 | 4.759 | -0.192 +/- 0.64 | True |
| 1_4_7 | 4.759 | 0.562 +/- 0.70 | True |
| 1_5_6 | 4.759 | -0.134 +/- 0.74 | True |
| 1_5_7 | 4.759 | 0.477 +/- 0.57 | True |
| 1_6_7 | 4.759 | 0.481 +/- 0.61 | True |
| 1_3_5 | 4.759 | 0.131 +/- 0.59 | True |
| 3_5_6 | 4.759 | -0.250 +/- 0.61 | True |
| 3_5_7 | 4.759 | 0.177 +/- 0.72 | True |
| 1_2_3 | 4.759 | -0.603 +/- 0.54 | True |
| 2_3_5 | 4.759 | 0.336 +/- 0.56 | True |
| 2_3_7 | 4.759 | -0.063 +/- 0.77 | True |
| 2_4_6 | 4.759 | -0.333 +/- 0.66 | True |
| 1_2_6 | 4.759 | -0.500 +/- 0.74 | True |
| 2_3_6 | 4.759 | 0.279 +/- 0.60 | True |
| 2_5_6 | 4.759 | -0.458 +/- 0.59 | True |
| 2_6_7 | 4.759 | 0.055 +/- 0.60 | True |
| 1_3_4 | 5.280 | 0.021 +/- 0.59 | True |
| 2_3_4 | 5.280 | -0.038 +/- 0.68 | True |
| 3_4_5 | 5.280 | -0.244 +/- 0.59 | True |
| 3_4_6 | 5.280 | -0.671 +/- 0.73 | True |
| 3_4_7 | 5.280 | 0.093 +/- 0.68 | True |

| Hole Indices | Baseline [m] | Squared visibility | Within 3 sigma of simulations? |
|---|---|---|---|
| 2_4 | 1.320 | 0.941 +/- 0.01 | False |
| 4_5 | 1.320 | 0.931 +/- 0.01 | False |
| 6_7 | 1.320 | 0.930 +/- 0.01 | False |
| 5_7 | 2.286 | 0.856 +/- 0.01 | False |
| 2_5 | 2.286 | 0.868 +/- 0.01 | False |
| 3_6 | 2.640 | 0.815 +/- 0.01 | False |
| 1_3 | 2.640 | 0.797 +/- 0.01 | False |
| 4_7 | 3.492 | 0.693 +/- 0.01 | False |
| 5_6 | 3.492 | 0.701 +/- 0.01 | False |
| 1_2 | 3.492 | 0.691 +/- 0.01 | False |
| 3_7 | 3.492 | 0.697 +/- 0.01 | False |
| 2_7 | 3.960 | 0.644 +/- 0.01 | False |
| 1_4 | 4.573 | 0.556 +/- 0.01 | False |
| 1_6 | 4.573 | 0.574 +/- 0.01 | False |
| 4_6 | 4.573 | 0.550 +/- 0.01 | False |
| 1_5 | 4.759 | 0.543 +/- 0.01 | False |
| 1_7 | 4.759 | 0.544 +/- 0.01 | False |
| 3_5 | 4.759 | 0.529 +/- 0.01 | False |
| 2_3 | 4.759 | 0.529 +/- 0.01 | False |
| 2_6 | 4.759 | 0.536 +/- 0.01 | False |
| 3_4 | 5.280 | 0.472 +/- 0.01 | False |

# Analysis 4: data quality check

Summary: Summarize bad pixel types and quantities in each exposure. Save median-difference GIFs of each exposure. Compare DC levels measured by ImPlaneIA (uniform background) to noisy MIRAGE simulations DC levels, and compare pipeline-calibrated data uniform background measured in a corner of the subarray to those from simulations.

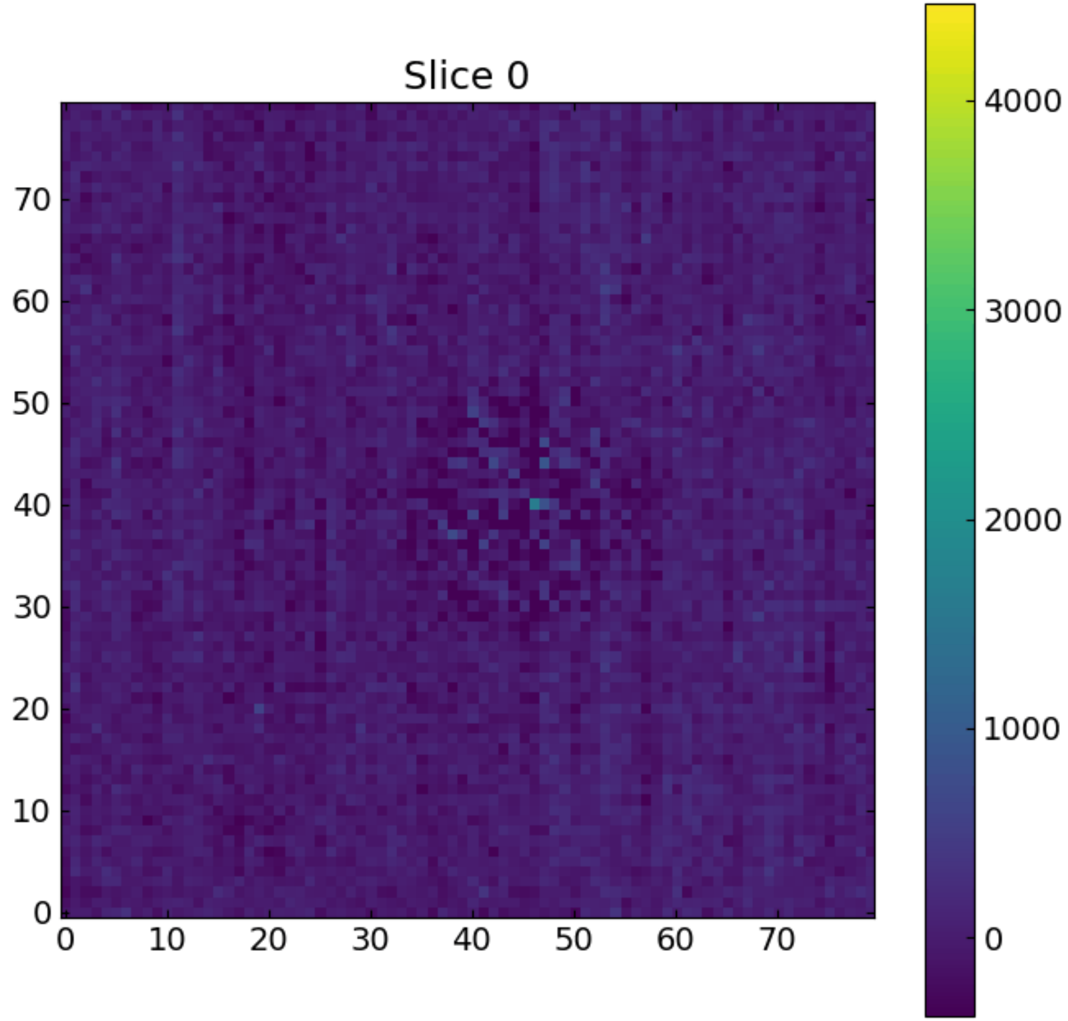
Input: All pipeline-calibrated (calints) files and oifits files

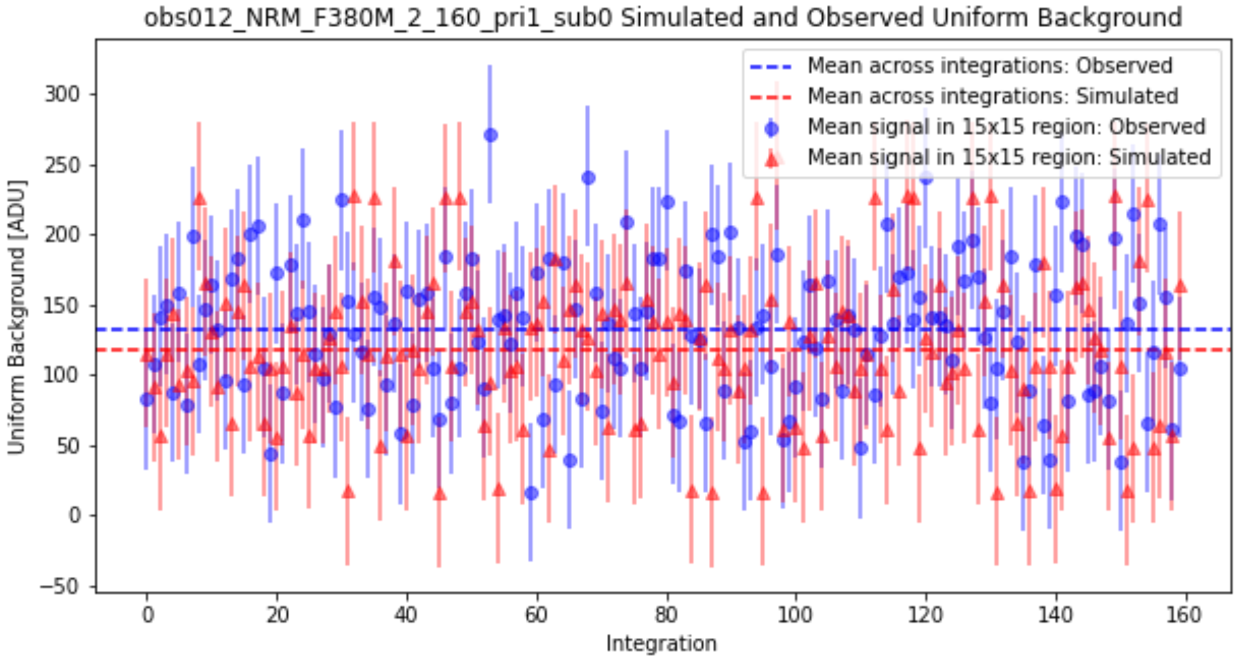
Output:

- [obs_key]_bptypes.txt: Text summary of pipeline-flagged bad pixels in each exposure
- [obs_key]_DQ_dnu.gif: GIF of pixels flagged DO_NOT_USE in each integration of an exposure
- [obs_key]_median_diff.gif: GIF of difference from the median of a "chunk" of ints for each integration of an exposure
- [obs_key]_sim_vs_obs_bkgd.png: Plot of uniform background measured from cutout of each exposure, observed vs. simulated
- DCplot.png: Mean DC level from ImPlaneIA in each exposure from observed vs simulated data.

# Analysis 4: data quality check

```
Observation: obs001_NRM_F380M_2_94_pri1_sub0
AVERAGE FLAGGED PIXELS PER SLICE:
        DO_NOT_USE: 439 px
        NO_LIN_CORR: 325 px
        NO_SAT_CHECK: 325 px
        UNRELIABLE_FLAT: 406 px
        REFERENCE_PIXEL: 319 px
        BAD_REF_PIXEL: 0 px
        UNRELIABLE_SLOPE: 32 px
        TELEGRAPH: 28 px
        HOT: 5 px
        RC: 5 px
        UNRELIABLE_BIAS: 1 px
        UNRELIABLE_DARK: 9 px
        WARM: 8 px
        DEAD: 5 px
        NO_FLAT_FIELD: 4 px
        14288 pixels flagged DO_NOT_USE
        2.38 percent of all pixels flagged
```



Thomas Vandal

# Analysis 5: NRM sub-aperture positions

Summary: Check that the measured FT splodge positions are consistent with AMICAL's predicted values for a given filter's central wavelength. Measure the u and v offsets for each splodge, parametrize the overall differences with a 2d model for affine transformations (2x2 matrix, dx and dy)

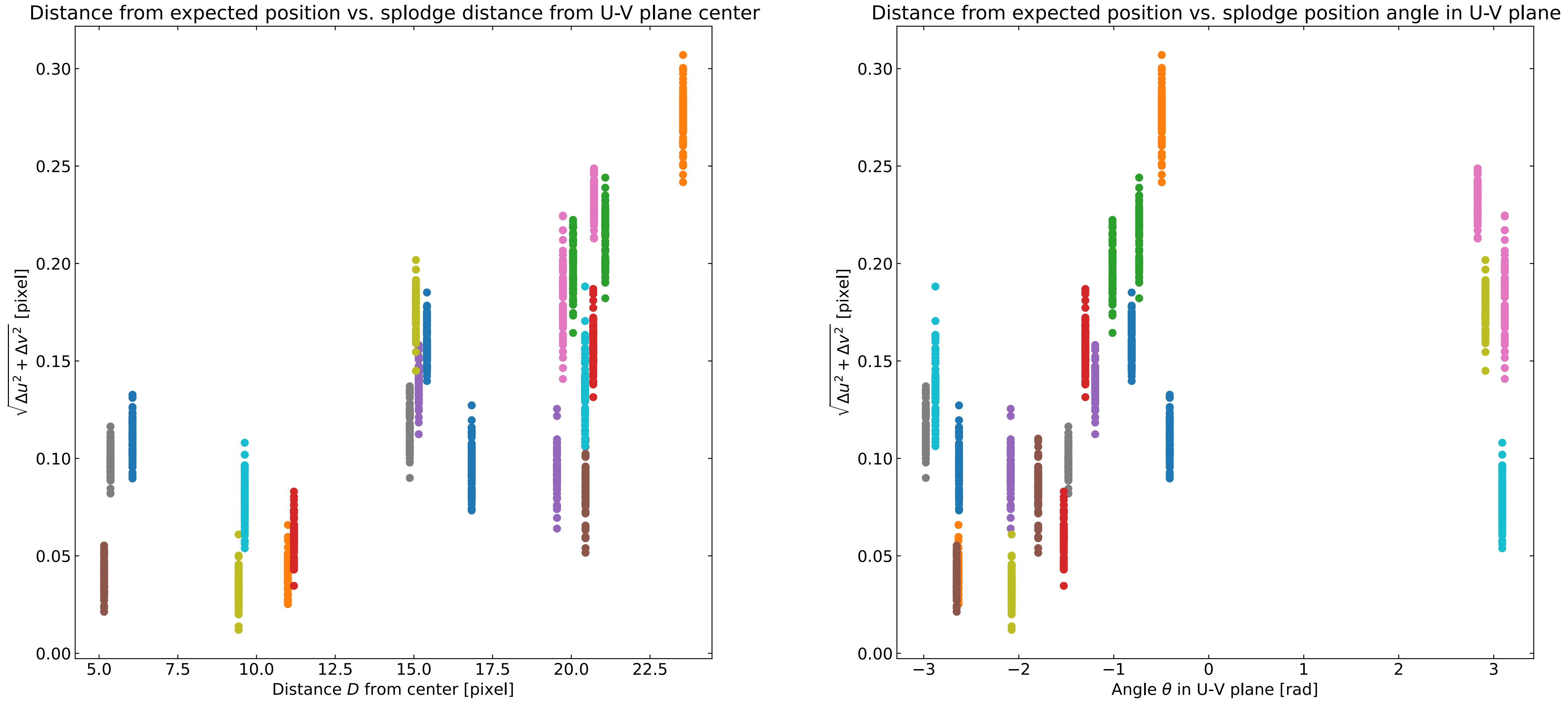
Input: All AMI calints files

Output:

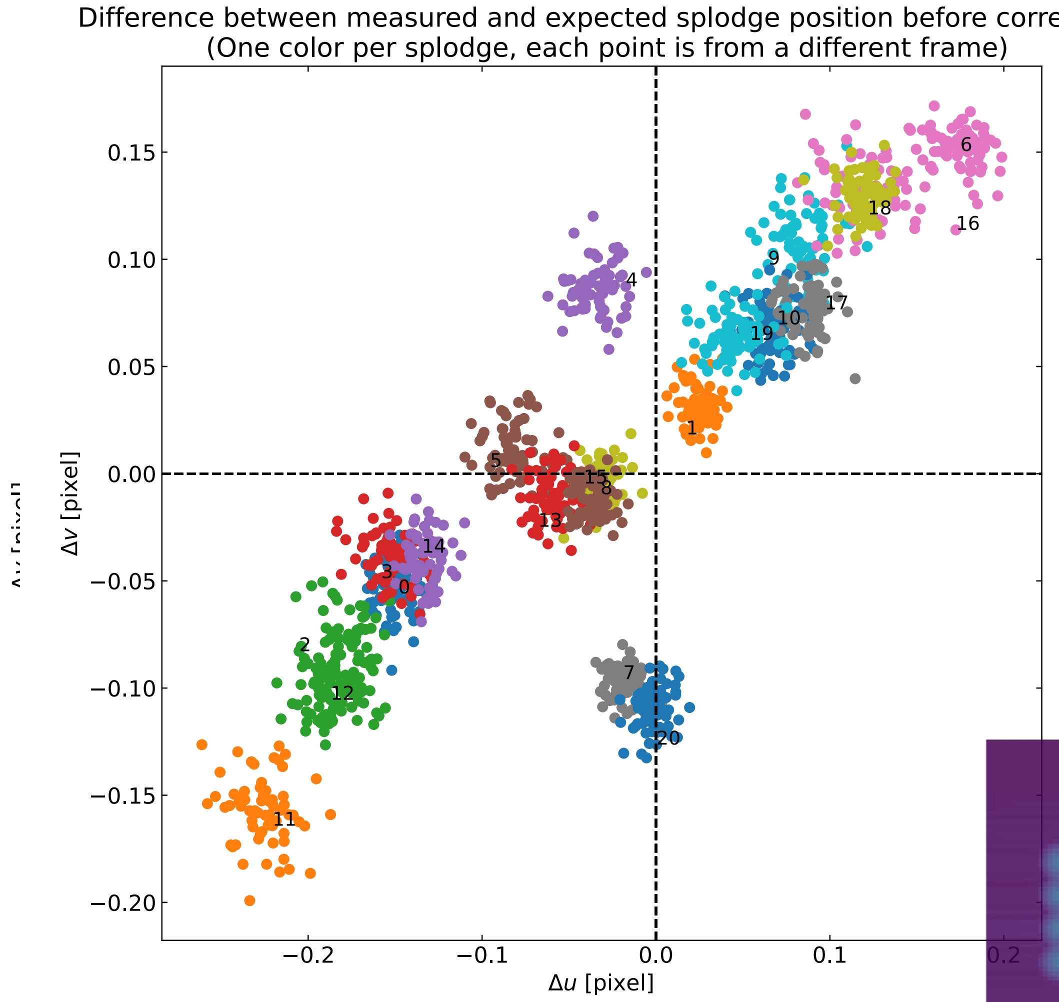
- off_vs_dist_[calints].pdf: plots of measured subaperture offset vs distance
- off_vs_angle_[calints].pdf: plots of measured subaperture offset vs. angle
- uv_diff_[calints].pdf: plots of measured-expected subaperture position in uv plane
- uv_diff_recon_[calints].pdf: plots of measured-expected subaperture position in uv plane, after measured affine transform applied
- uv_output.csv: U-V pixel coordinates (measured and model), U-V pixel coordinates after best-fit affine transform correction, and U-V differences between expected and fitted positions. This can be loaded with pandas to have a 3-level hierarchical index dataframe (per file, frame, and baseline)
- params.csv: Parameters of the affine 2D model. Can be loaded with pandas in a 2-level hierarchical index (per file and per frame).

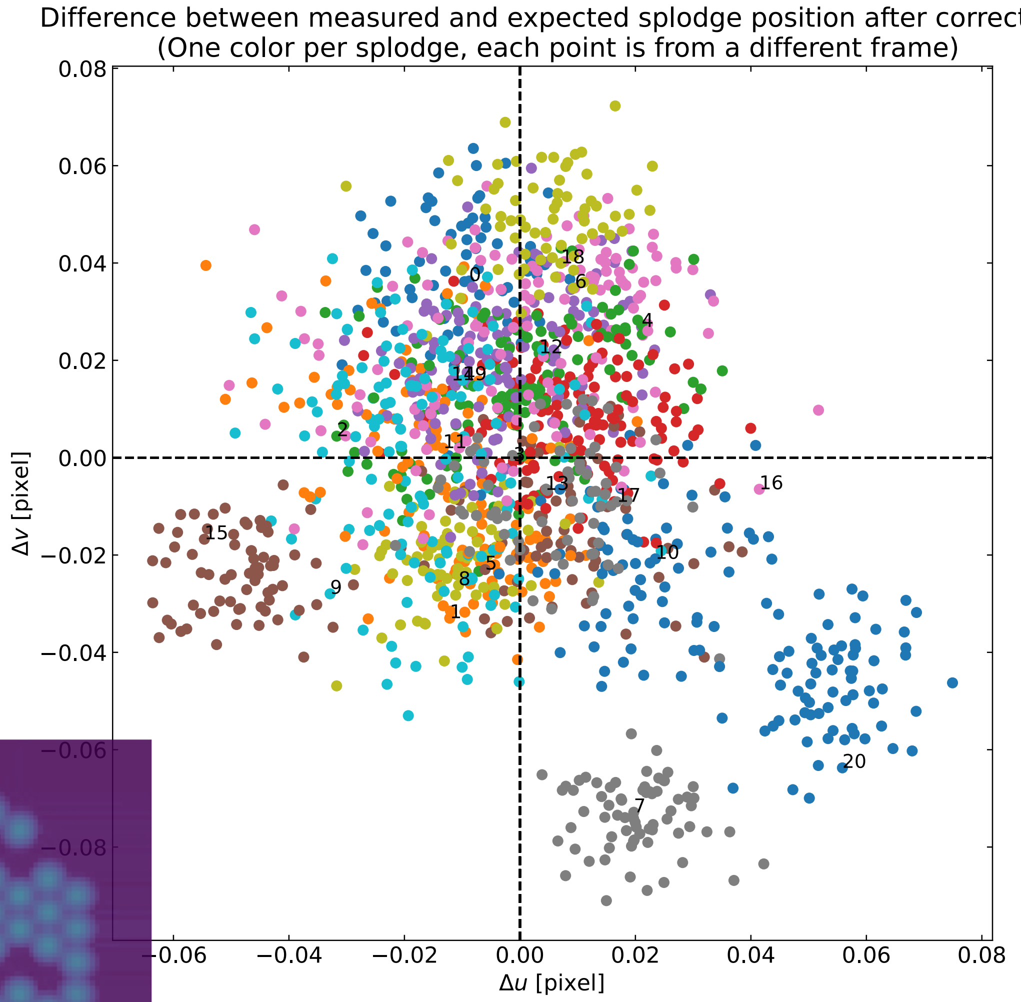
Thomas Vandal

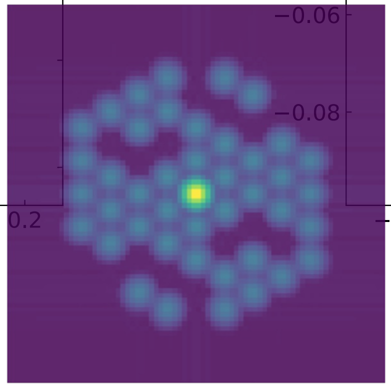
# Analysis 5: NRM sub-aperture positions



# Analysis 5: NRM sub-aperture positions



One color per splodge, each point
is a different integration

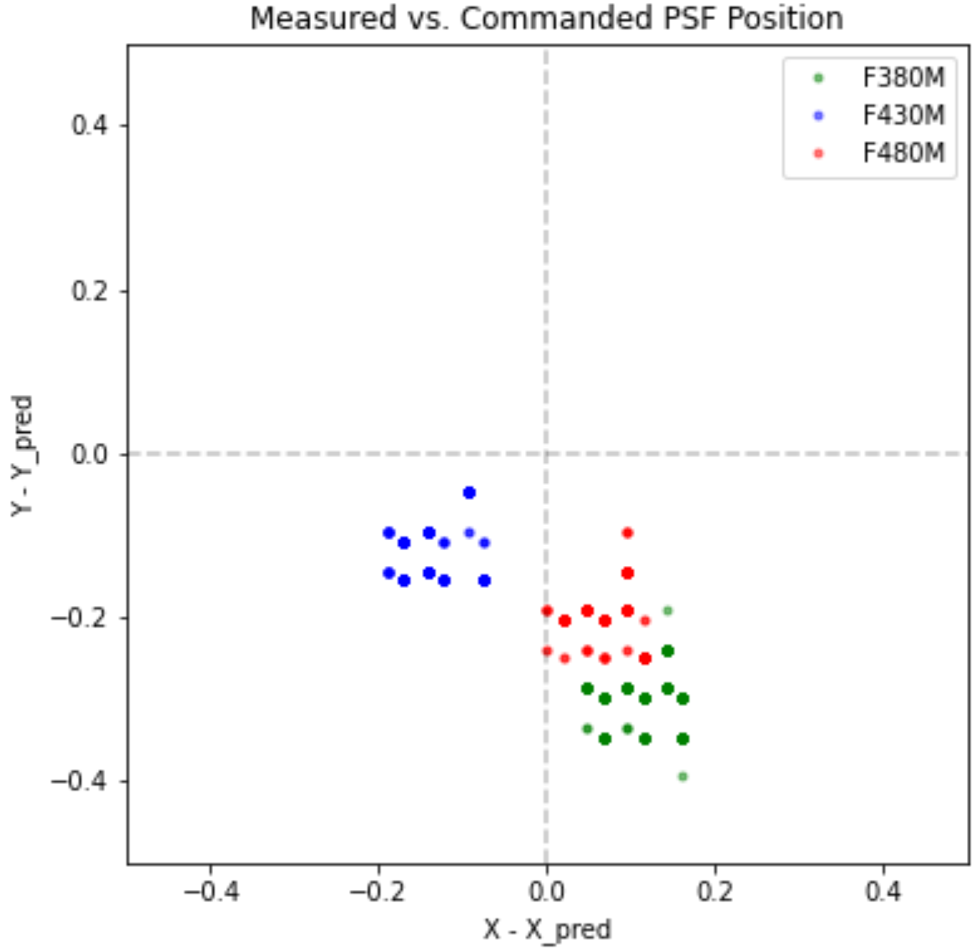
# Analysis 6: PSF primary dither location check

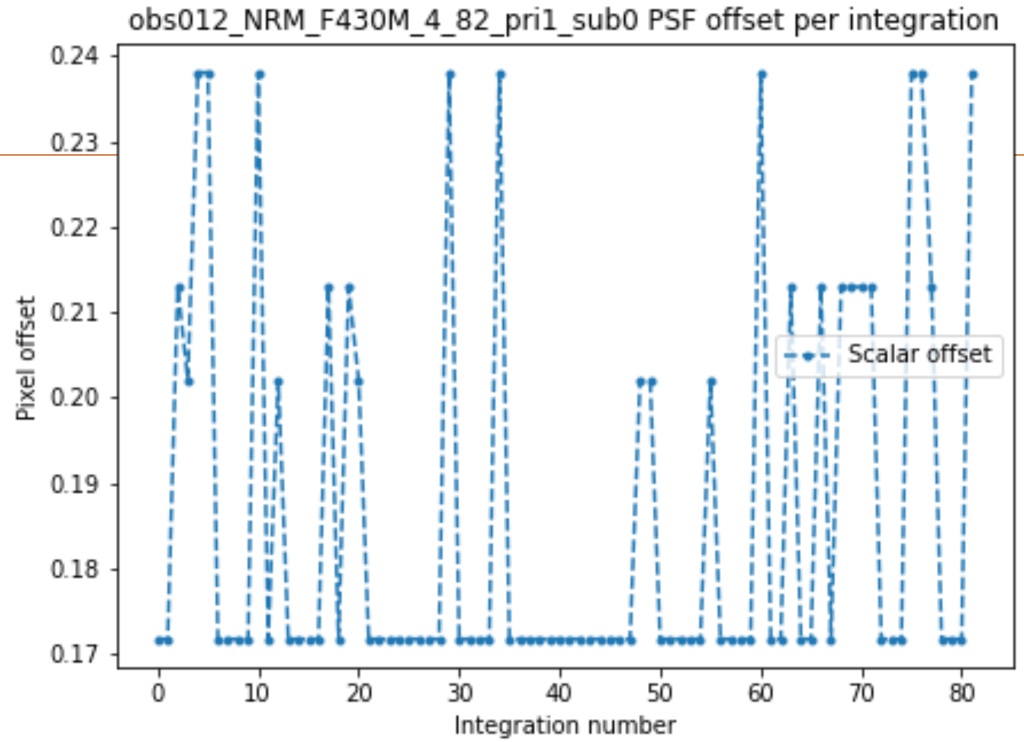
Summary: For each primary dithered NRM observation, use the Anderson & King method to locate the PSF sub-pixel location and calculate offset from the commanded position.

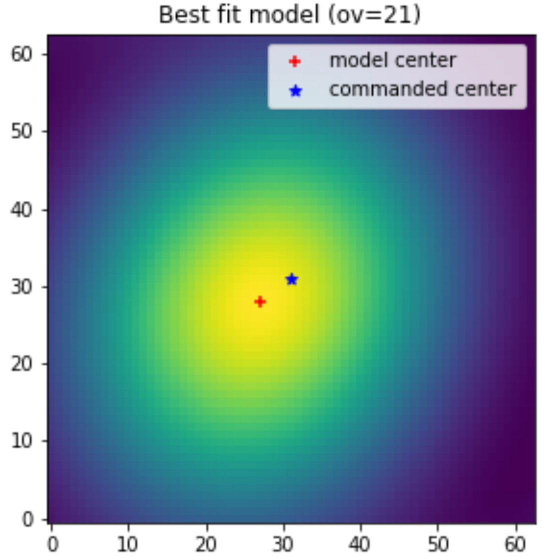
Input: Calints files of primary dithers (calibrator stars)

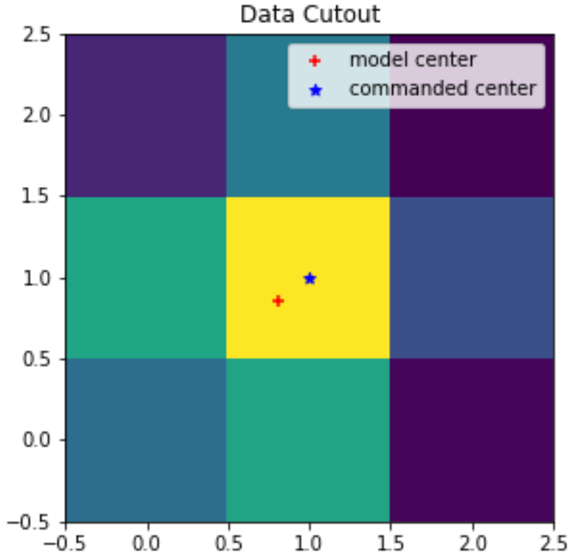
Output:

- [obs_key]_offset_per_int.png: scalar offset from commanded position for each integration of an exposure
- [obs_key_xy_offset.png: Scatter plot of measured offsets in X and Y from commanded position. Offsets are "quantized" by 1/oversampling step used
- all_offsets.png: All X and Y offsets from all exposures displayed in plot


Measured vs. Commanded PSF Position
F380M
F430M
F480M
Y - Y_pred
X - X_pred


obs012_NRM_F430M_4_82_pri1_sub0 PSF offset per integration
Pixel offset
Scalar offset
Integration number


Best fit model (ov=21)
model center
commanded center


Data Cutout
model center
commanded center

# Analysis 7: Sub-dither location check

Neil Cook,
Étienne Artigau

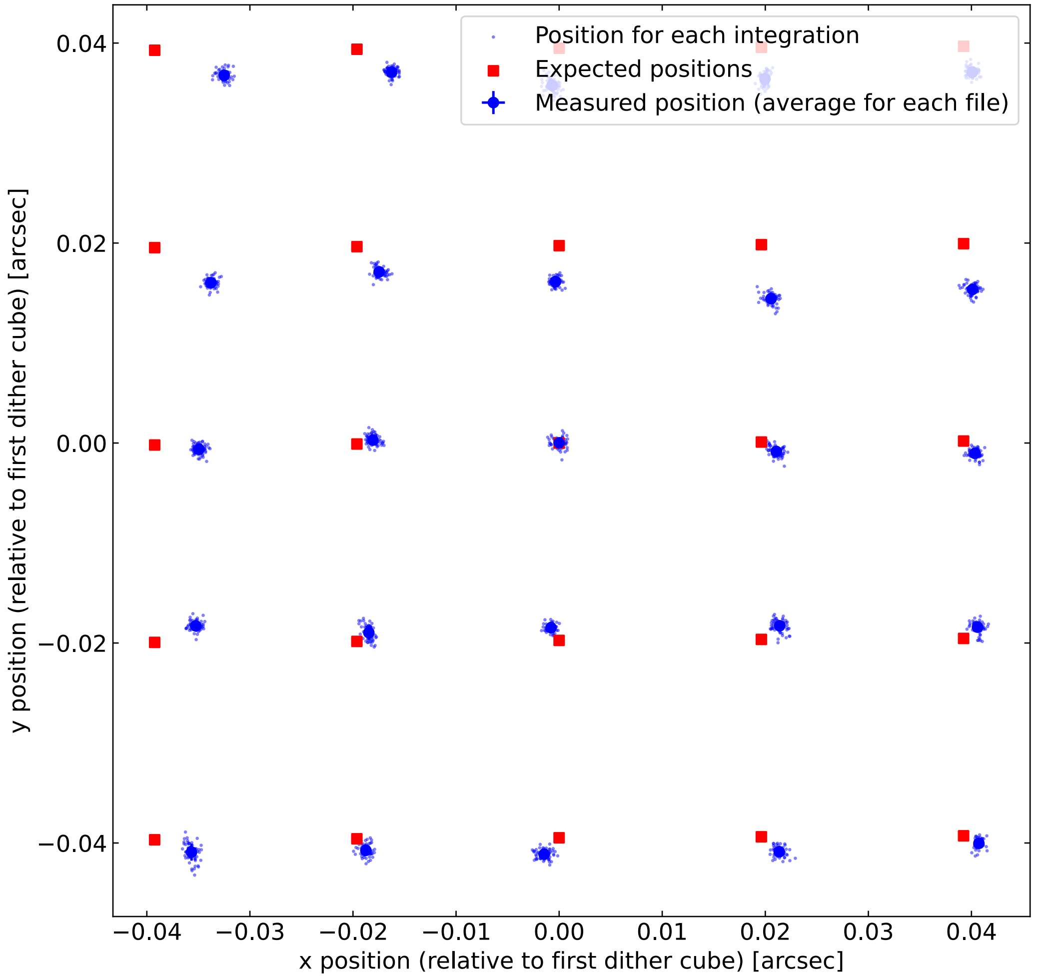
Summary: Fits for the sub-pixel centroid position of each frame and averages over frame to get a plot of how the dithers differ from their expected position. Uncorrected bad pixels are masked when performing the fit.

Input: Two 5-pt, one 25-pt set of subpixel dither pattern calints files

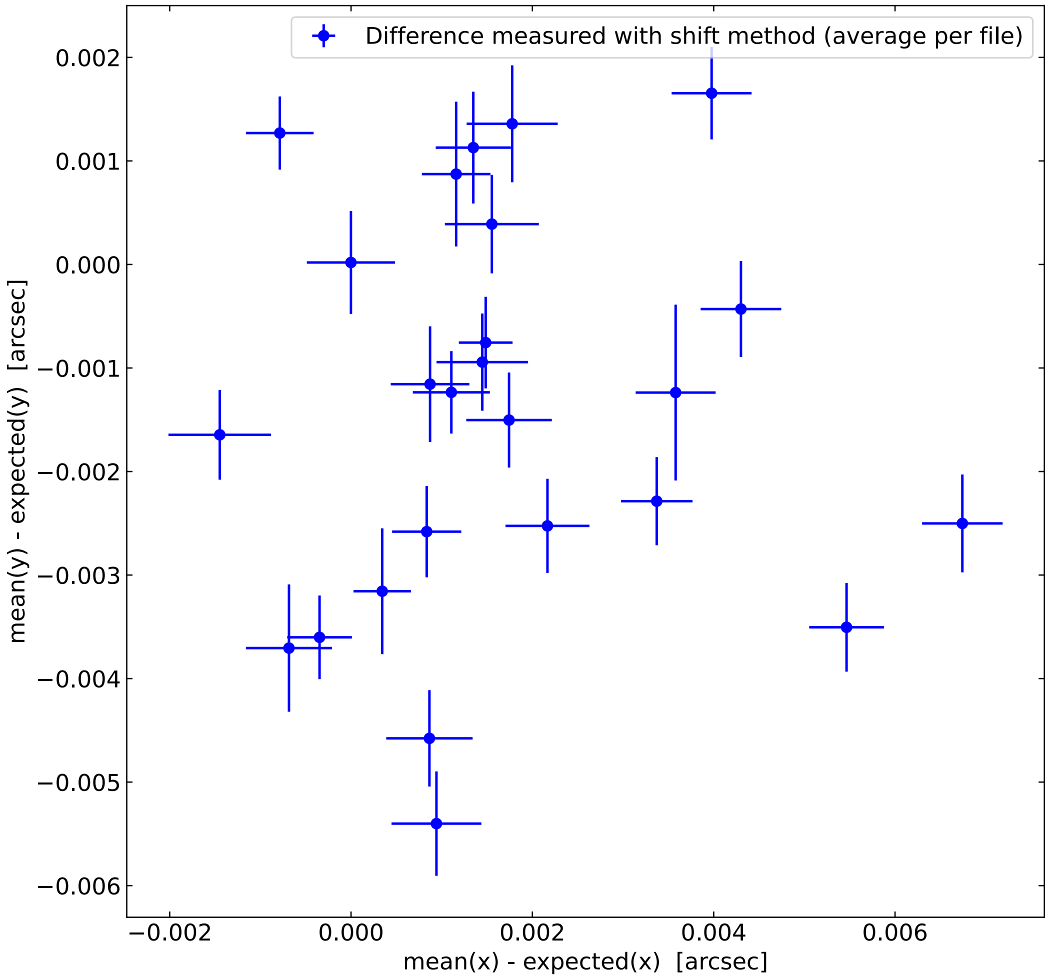
Output:

- analysis7_diffs.pdf: scatter plot x vs y absolute for all integrations (along with averaged and expected position)
- analysis7_positions: Difference between expected and measured (average) dither positions
- "stats" files: measured_dither_position.csv and measured_dither_position.fits
- report.txt: summary of all results, agreement between measured and expected positions

## X and Y centroid position for each integration and averaged per exposure (Fourier shift method)




## Difference between measured and expected position for each dither



# Analysis 8: charge migration existence

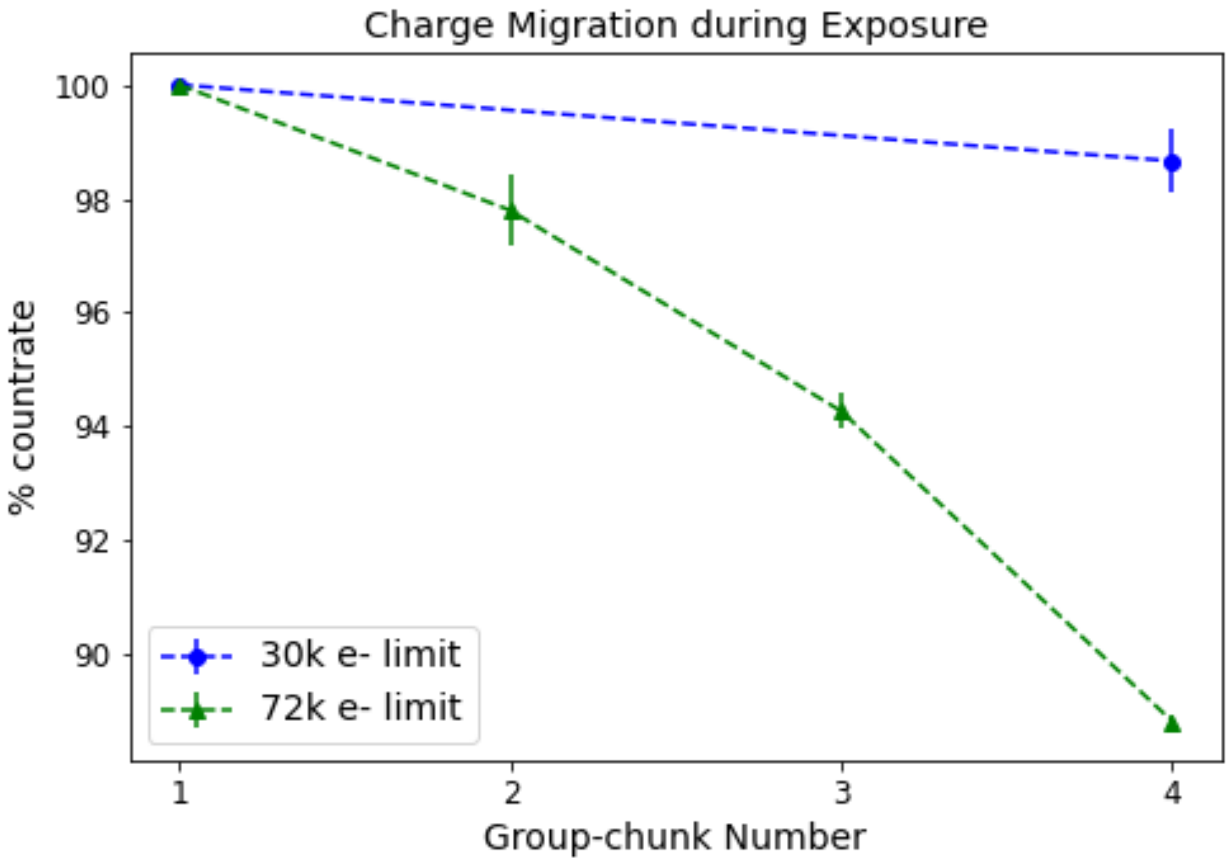
Summary: Divide each integration of 30k e- limit data into 2 chunks of groups to produce "fake" uncal files containing the first and second halves of ramps. Run through JWST pipeline to produce 2d cal files. Plot change in count rate in brightest pixel vs surrounding ring of 8 pixels. Repeat with 72k e- limit data and 4 chunks of groups.

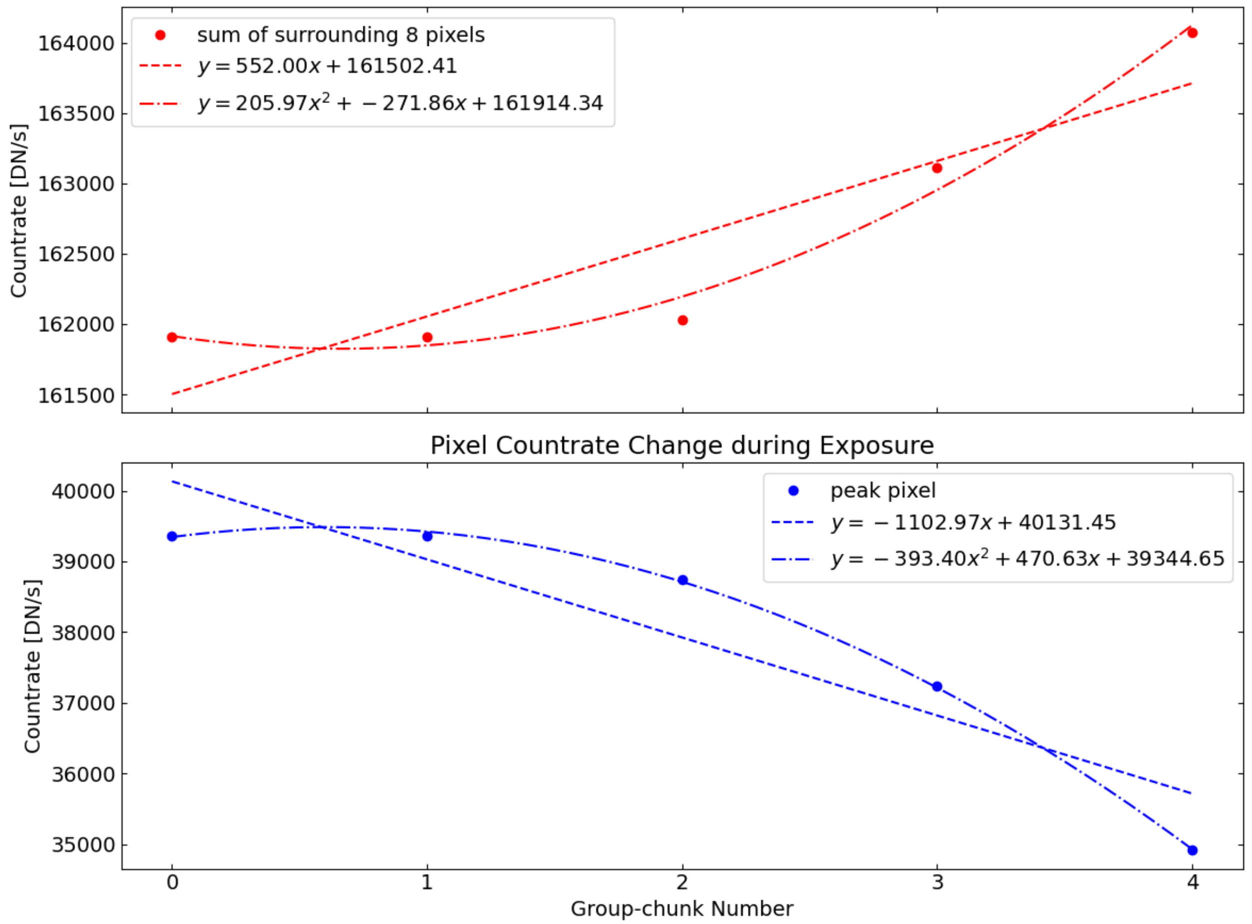
Input: AB Dor uncal files with signal limits of 30k e- and 72k e- (2 dither positions, F480M)

Output:

- [original_fn]_Xgroups_chunkY_Z_[suffix].fits: FITS files with suffixes rate, rateints, trapsfilled, cal, calints. Xgroups is the number of groups in the new "faked" files, chunkY_Z indicates the chunk number out of the total number of chunks of groups.
- [N]_counts_[M]_chunks_countrate_diff.png: Plot of percent difference in count rate between group-chunks. N is the signal limit for the observations (either 30k or 72k here), M is the number of chunks of groups the original exposure was divided into.
- [N]_counts_[M]_chunks_countrate_groups.png: Plot of sum of counts in peak pixel and in surrounding ring for each chunk. Each are plotted with both a linear and quadratic least-squares fit.

# Analysis 8: charge migration existence



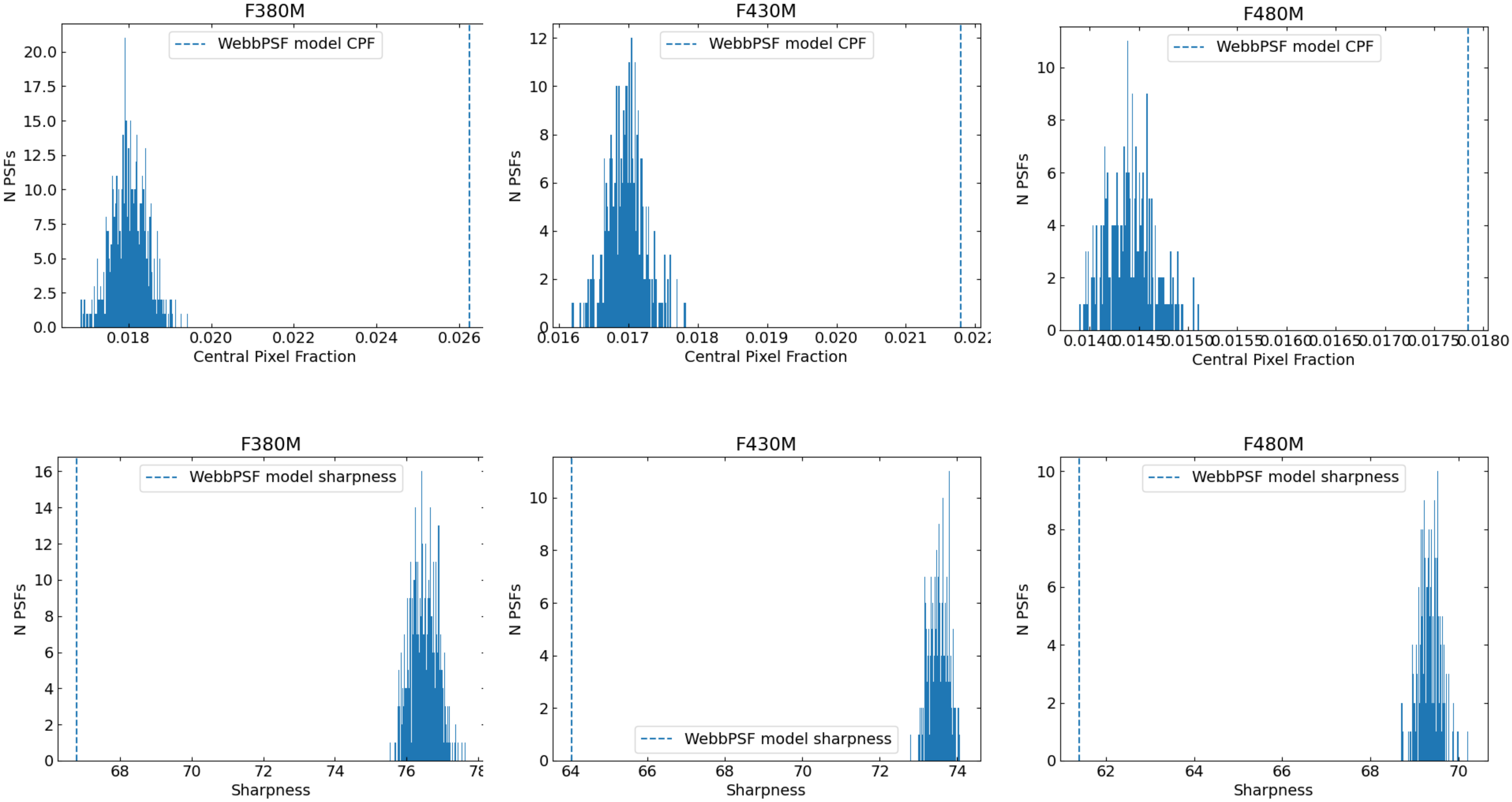
# Analysis 9: PSF characterization

Summary: Calculate the sharpness, where sharpness is the squared sum of the intensities divided by the sum of the squared intensities, and central pixel fraction of each point source observation by filter. Each integration is treated as a separate psf. Calculate the same quantities for WebbPSF models and compare distributions of sharpness and CPF to model values.

Input: All calibrator star calints files

Output:

- [obs_key]_CPF_cutouts.png: Postage stamp cutouts used to calculate central pixel fraction (one stamp per integration)
- [obs_key]_sharpness_cutouts.png: Postage stamp cutouts used to calculate sharpness (one stamp per integration)
- CPF_hist_[filter].png: Histogram of central pixel fraction measurements for each filter, with WebbPSF value indicated
- sharpness_hist_[filter].png: Histogram of sharpness measurements for each filter, with WebbPSF value indicated

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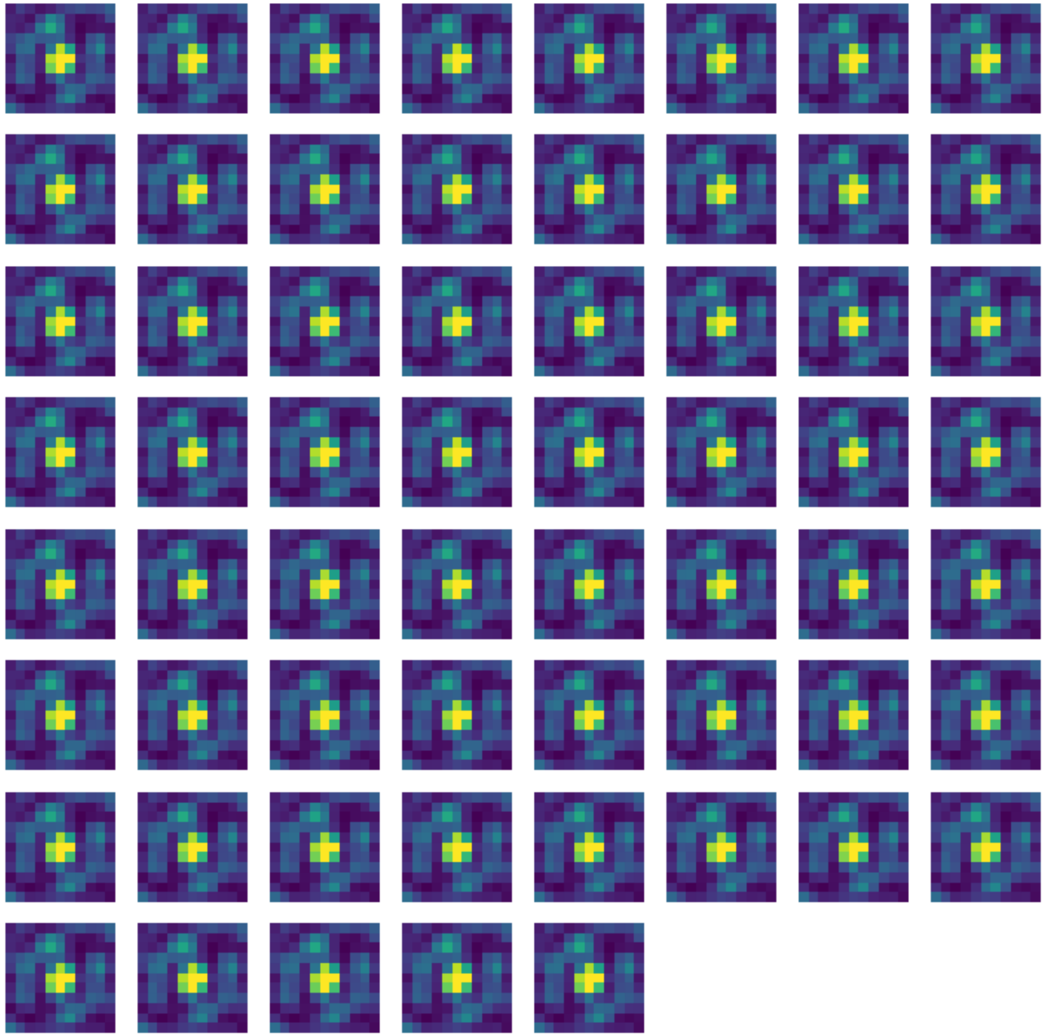
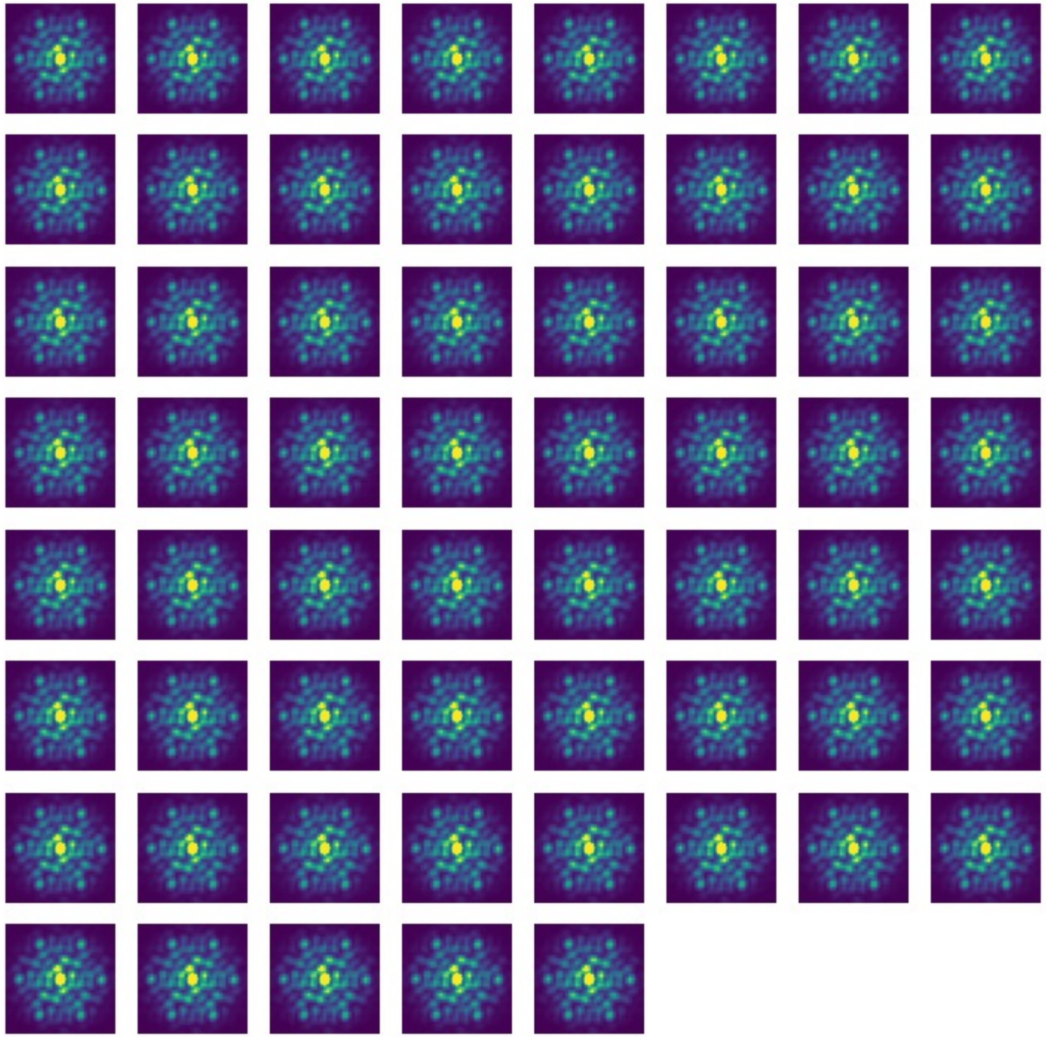
obs016_NRM_F480M_12_61_pri1_sub0



obs016_NRM_F480M_12_61_pri1_sub0



Thomas Vandal

# Analysis 10: Kernel phase analysis

Summary: Inspect the raw kernel phase outputs from the 4 point sources observed with CLEARP, calibrate the kernel phases, evaluate detection limits, and evaluate pupil model quality.

Input: Raw kernel phase "kpfits" files

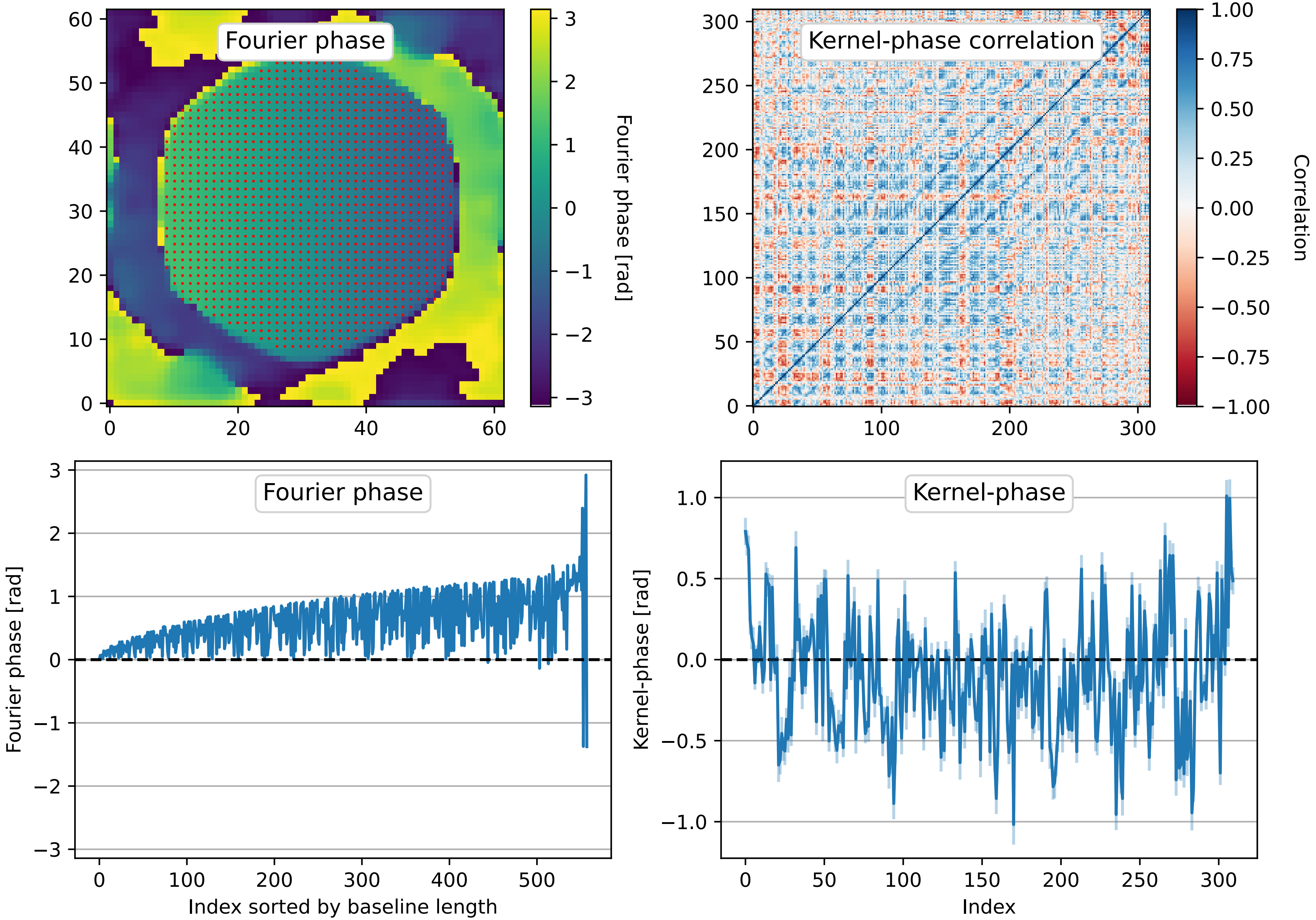
Output:

- calibrated kernel phases
- PDF plots of the following for each raw file:
  - Kernel phase vs index for all files (to show kernel phase scatter)
  - Fourier amplitude vs baseline redundancy (to evaluate pupil models)
  - Raw kernel detection limit curve for each object
  - Calibrated kernel phase detection limits for each object (using the other 3 targets as calibrators)

# Analysis 10



## Extract kerphase step



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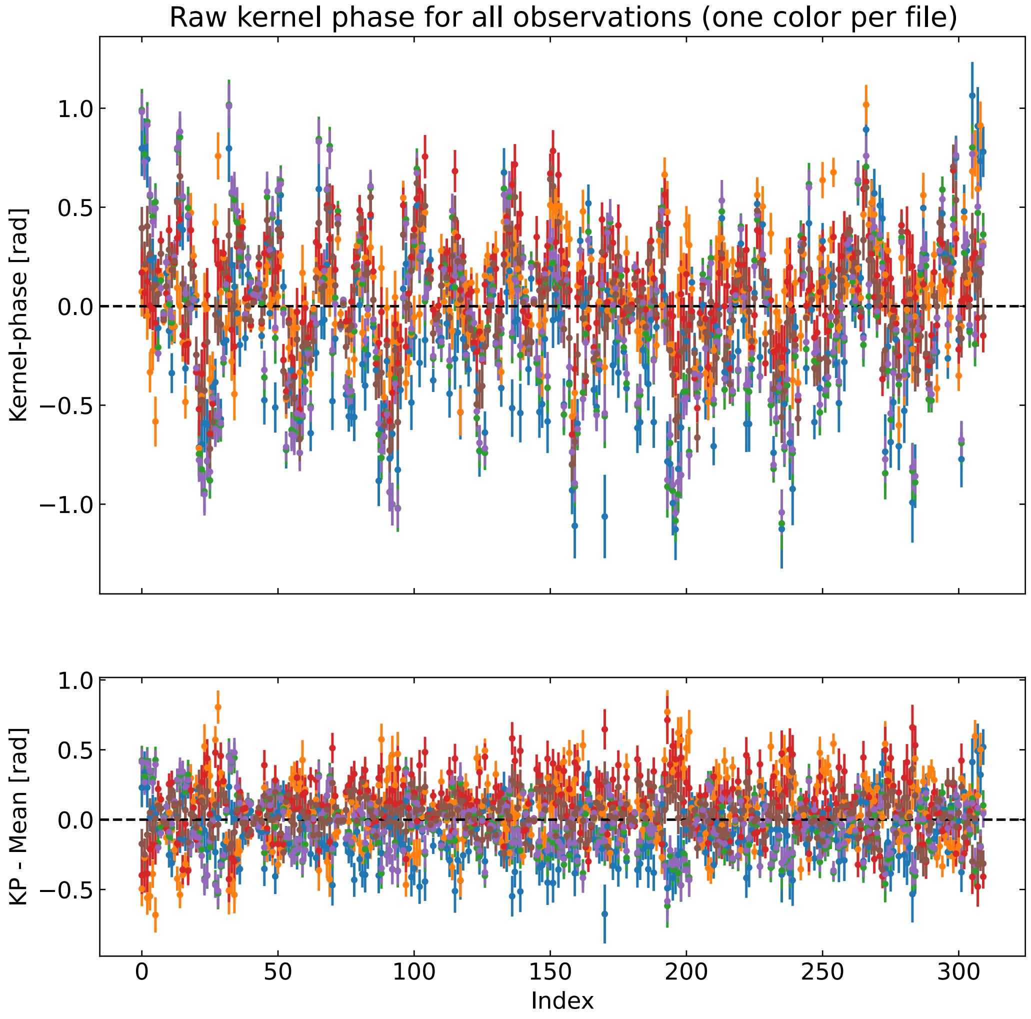
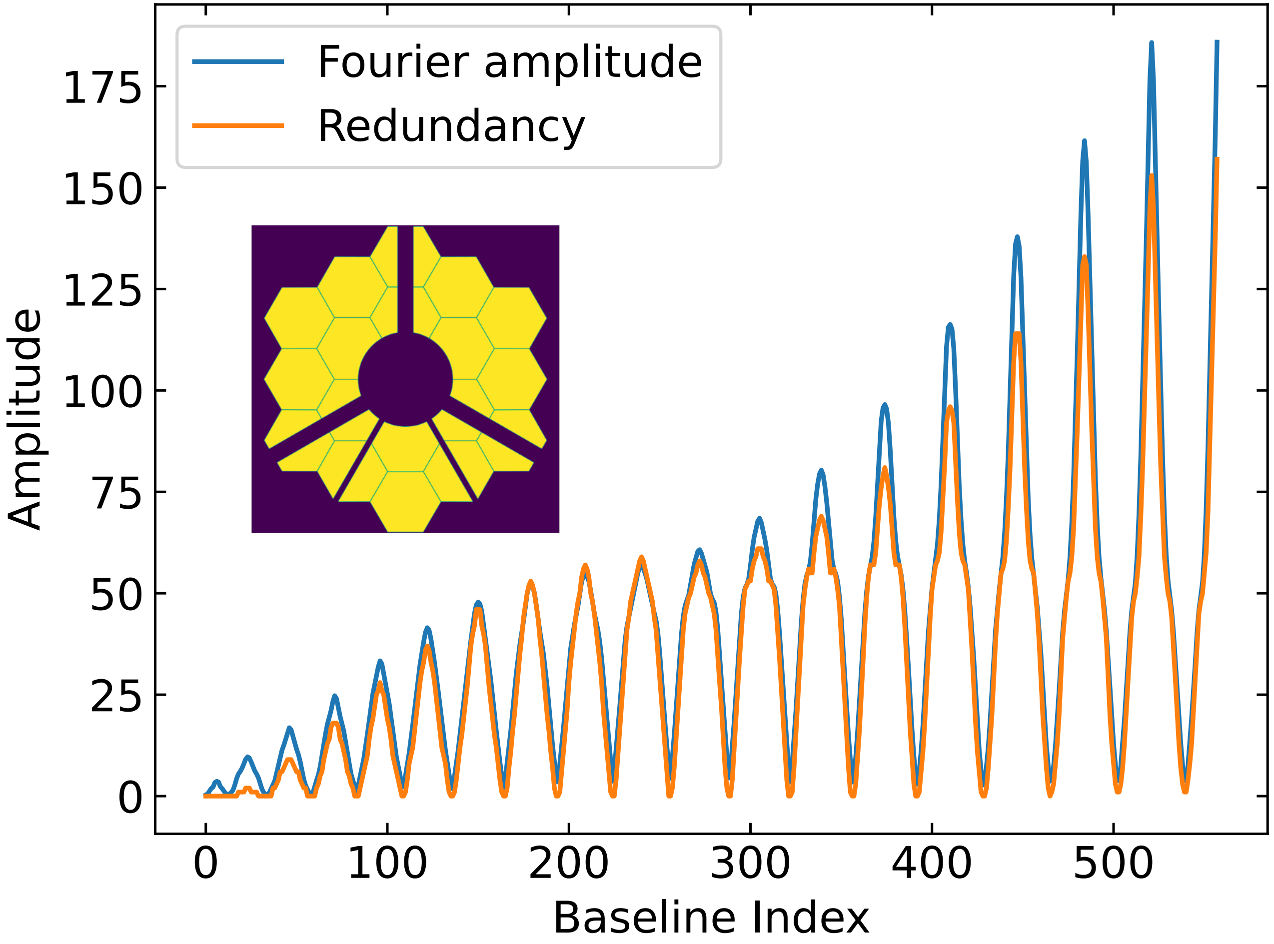
# Analysis 10: Kernel phase analysis



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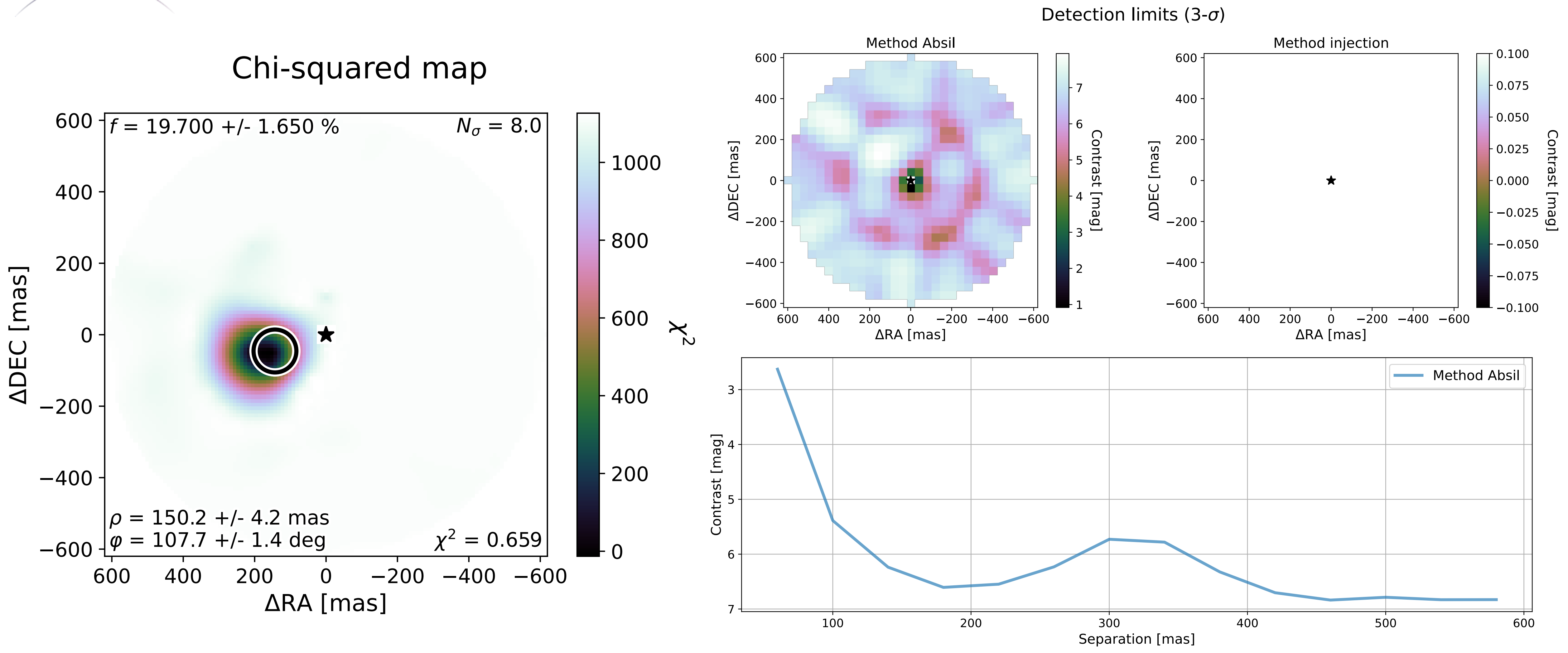
# Analysis 10: Kernel phase analysis

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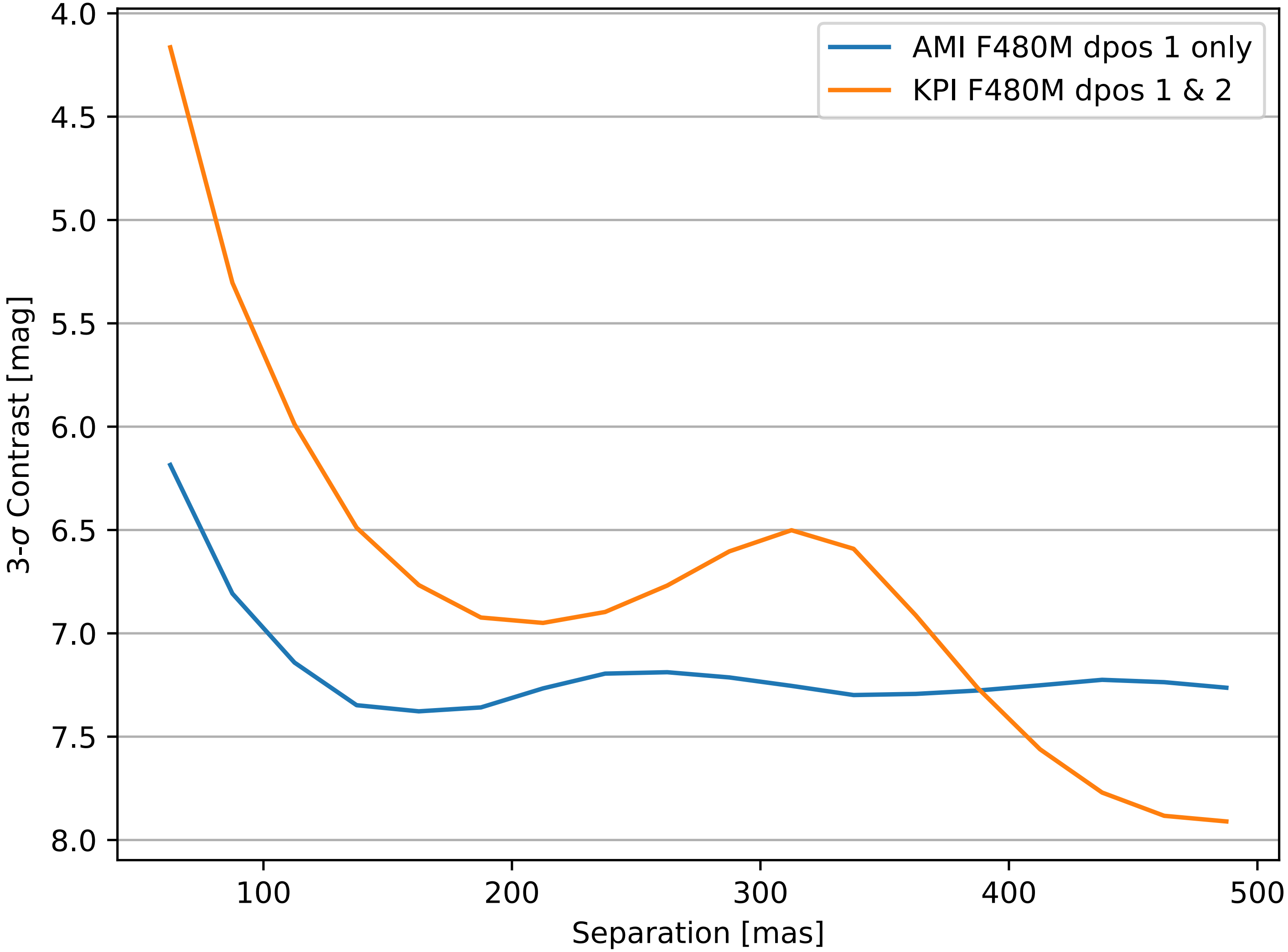
# AMI vs KPI

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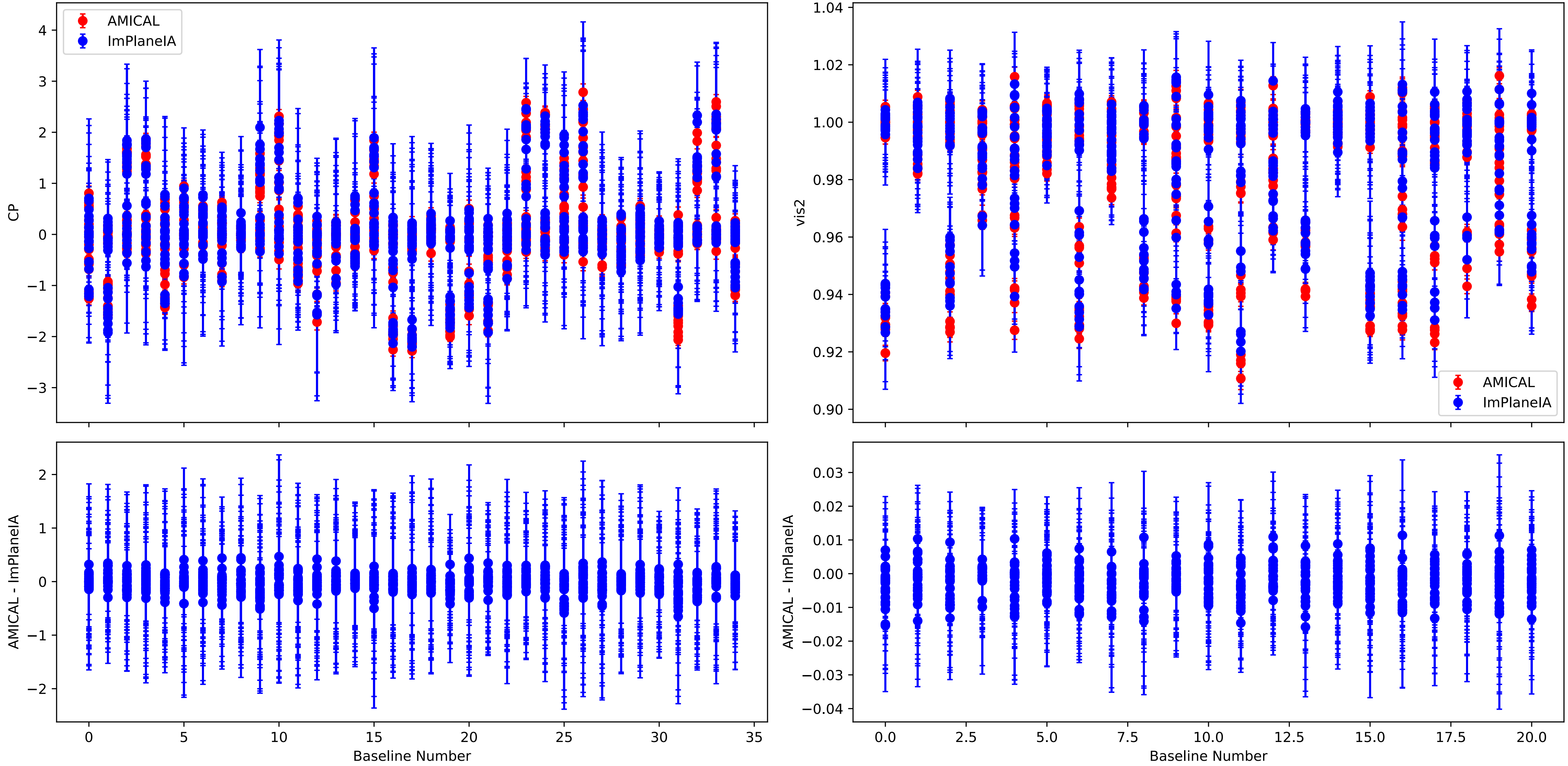
# Pipeline comparison

## ImPlaneIA vs. AMICAL observables:

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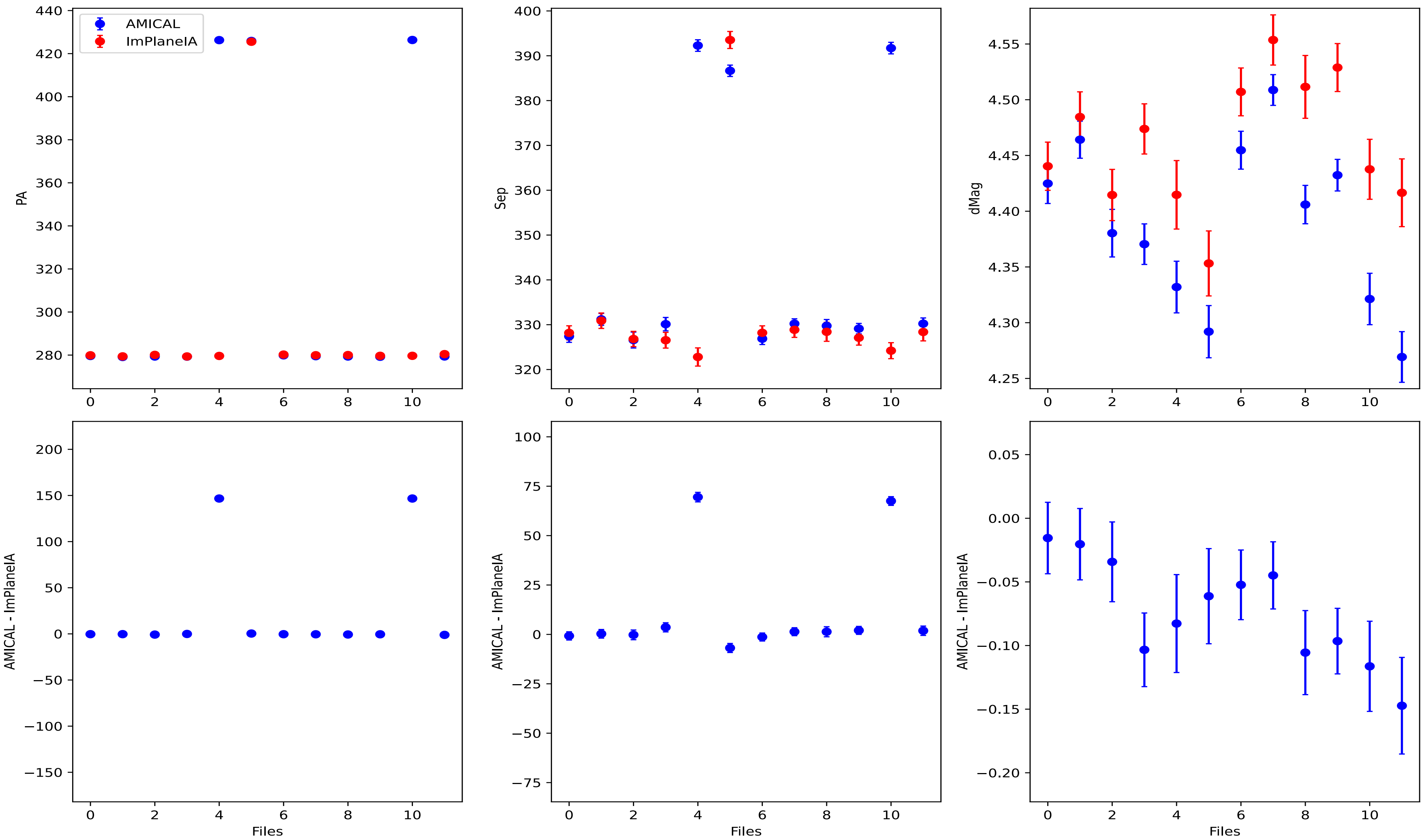
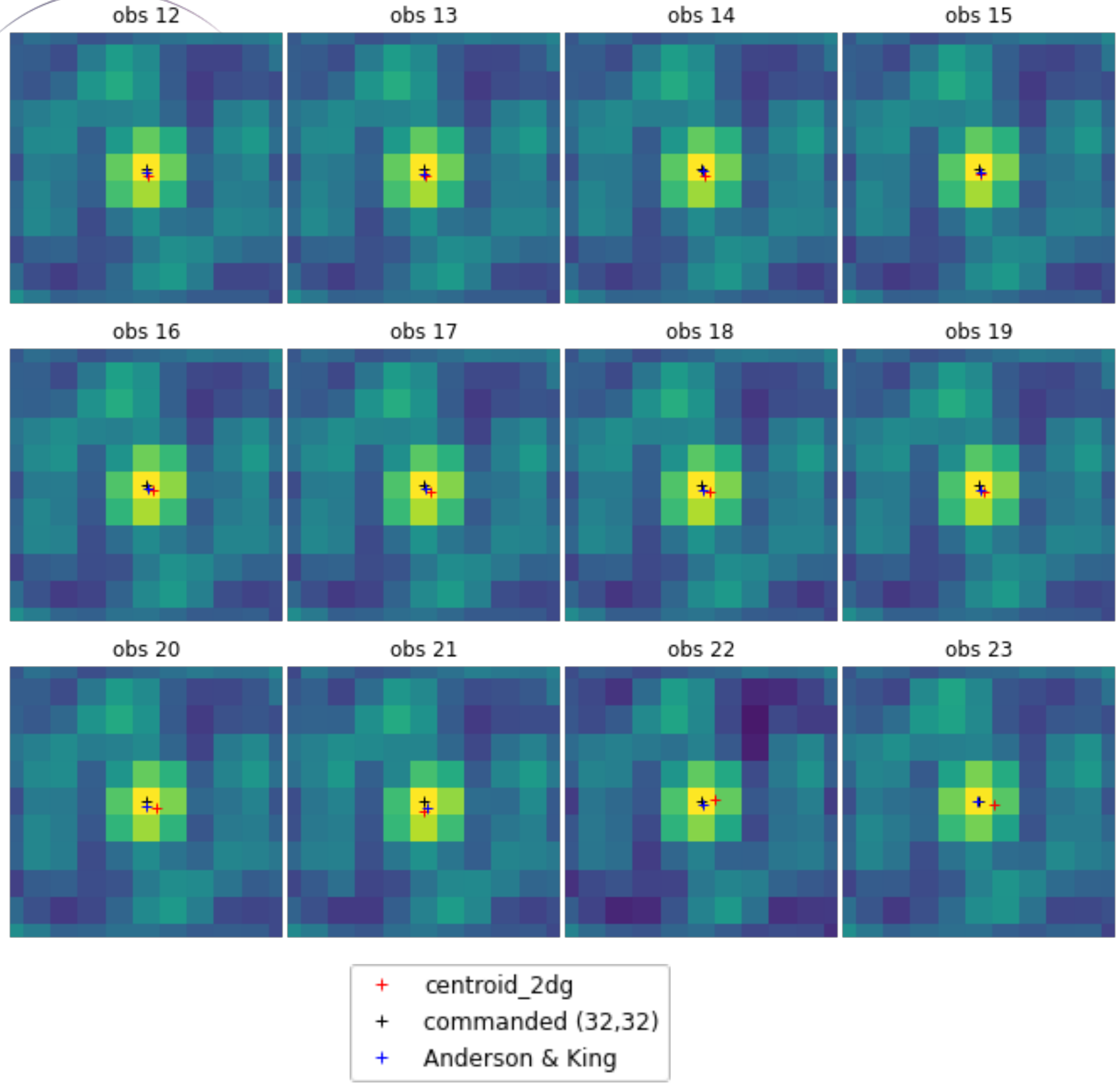
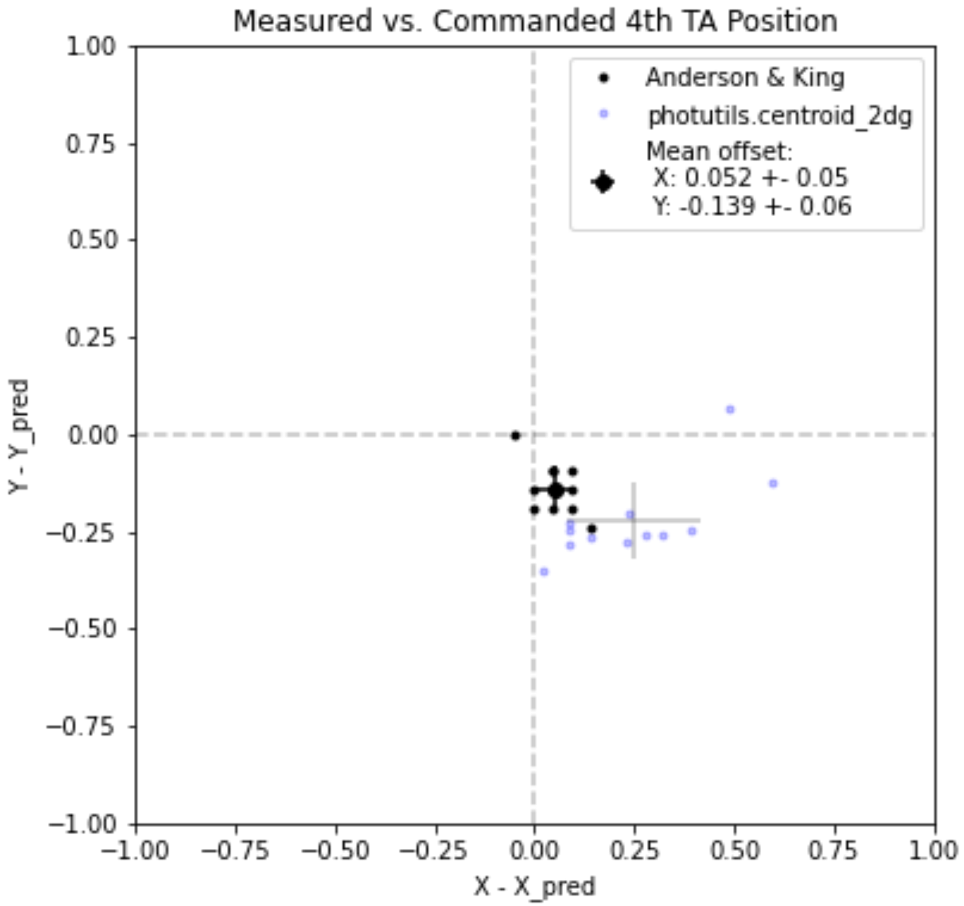
# Pipeline comparison

ImPlaneIA vs. AMICAL binary fit results:

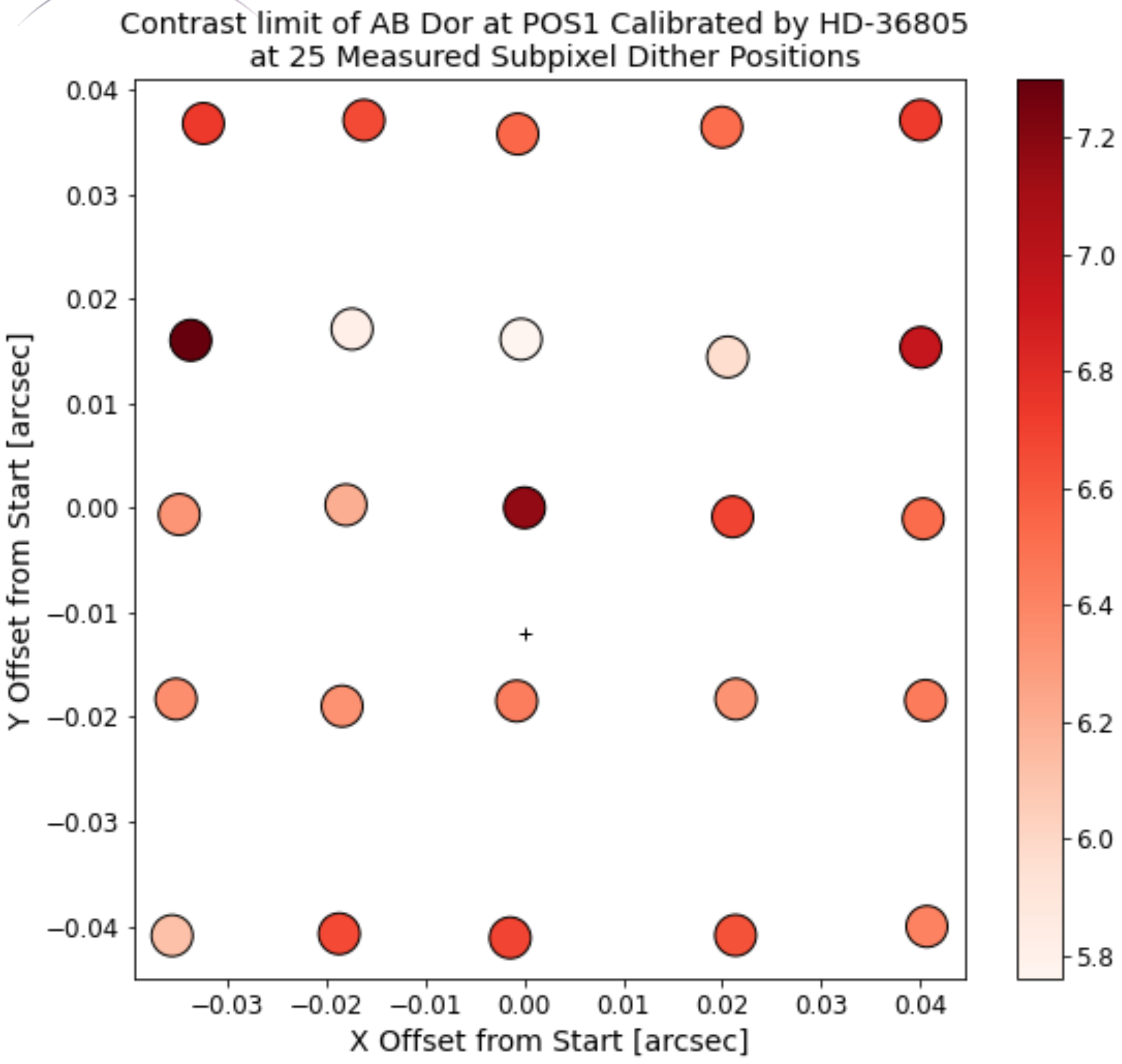


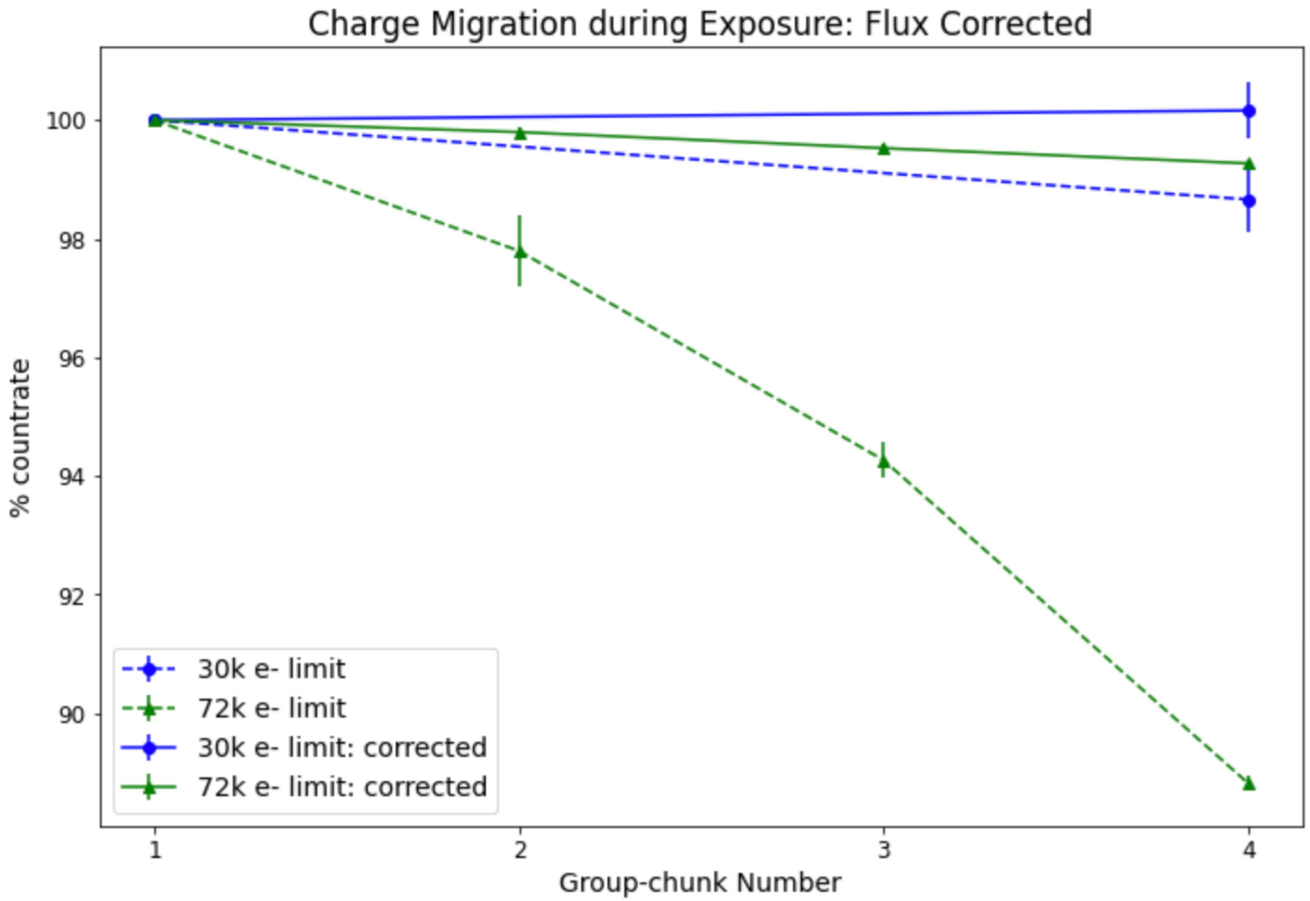
# TA accuracy

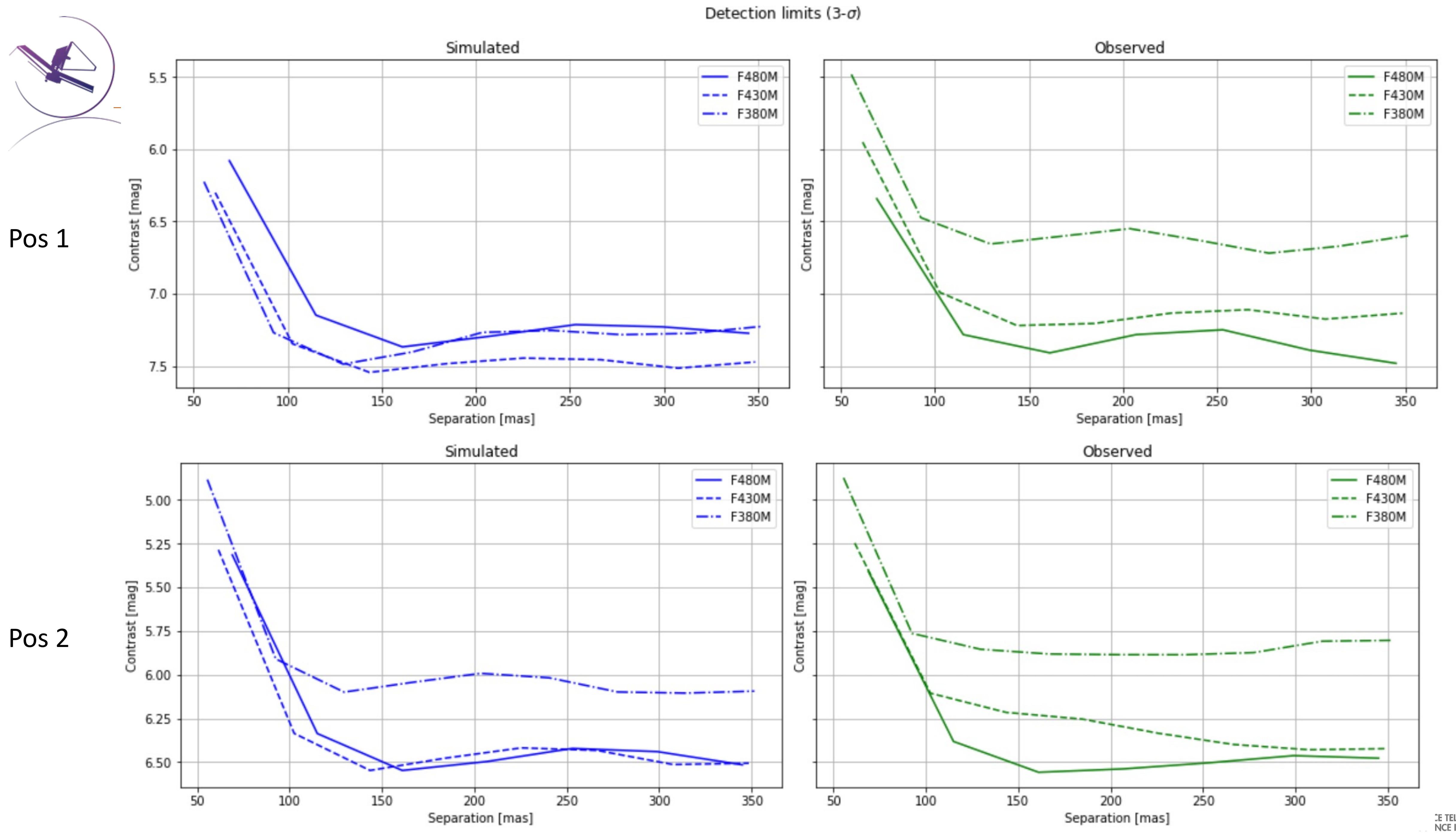

obs 12
obs 13
obs 14
obs 15
obs 16
obs 17
obs 18
obs 19
obs 20
obs 21
obs 22
obs 23
centroid_2dg
commanded (32,32)
Anderson & King


Measured vs. Commanded 4th TA Position
Anderson & King
photutils.centroid_2dg
Mean offset:
X: 0.052 +- 0.05
Y: -0.139 +- 0.06
Y - Y_pred
X - X_pred
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00

# Further analysis



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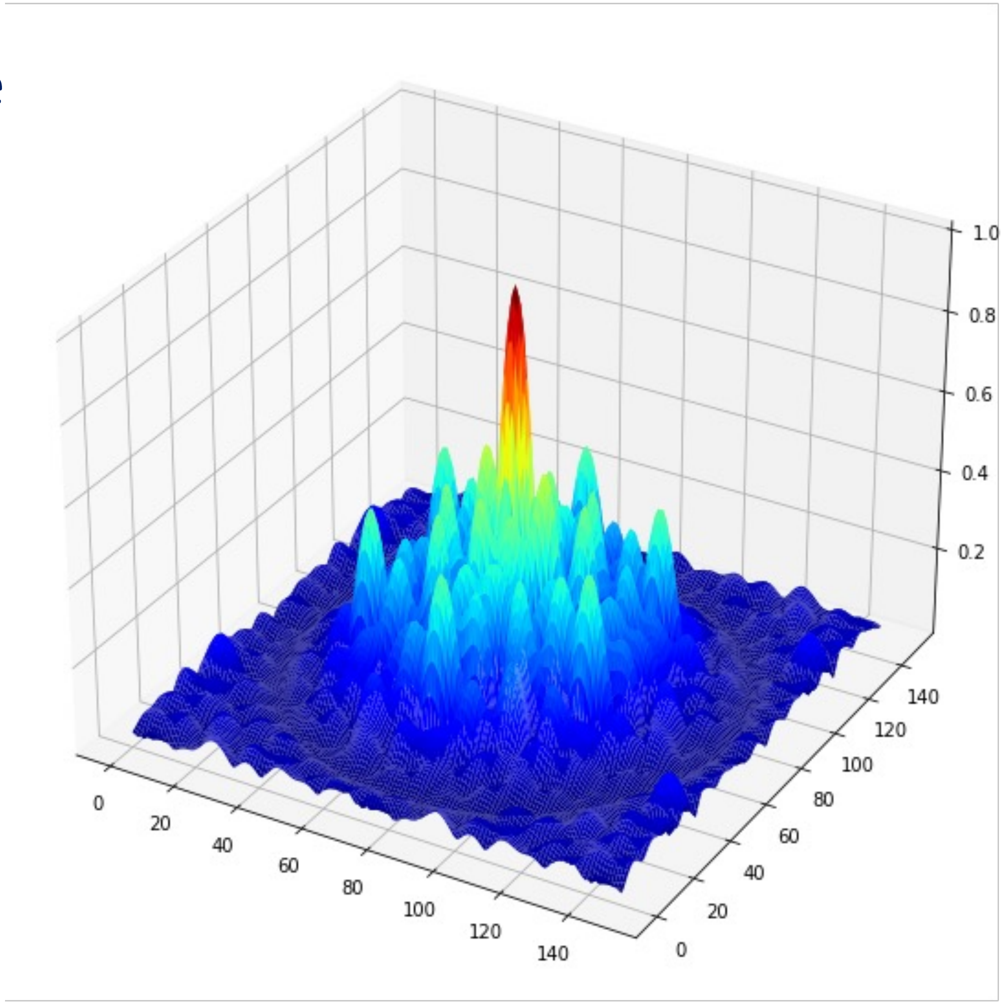
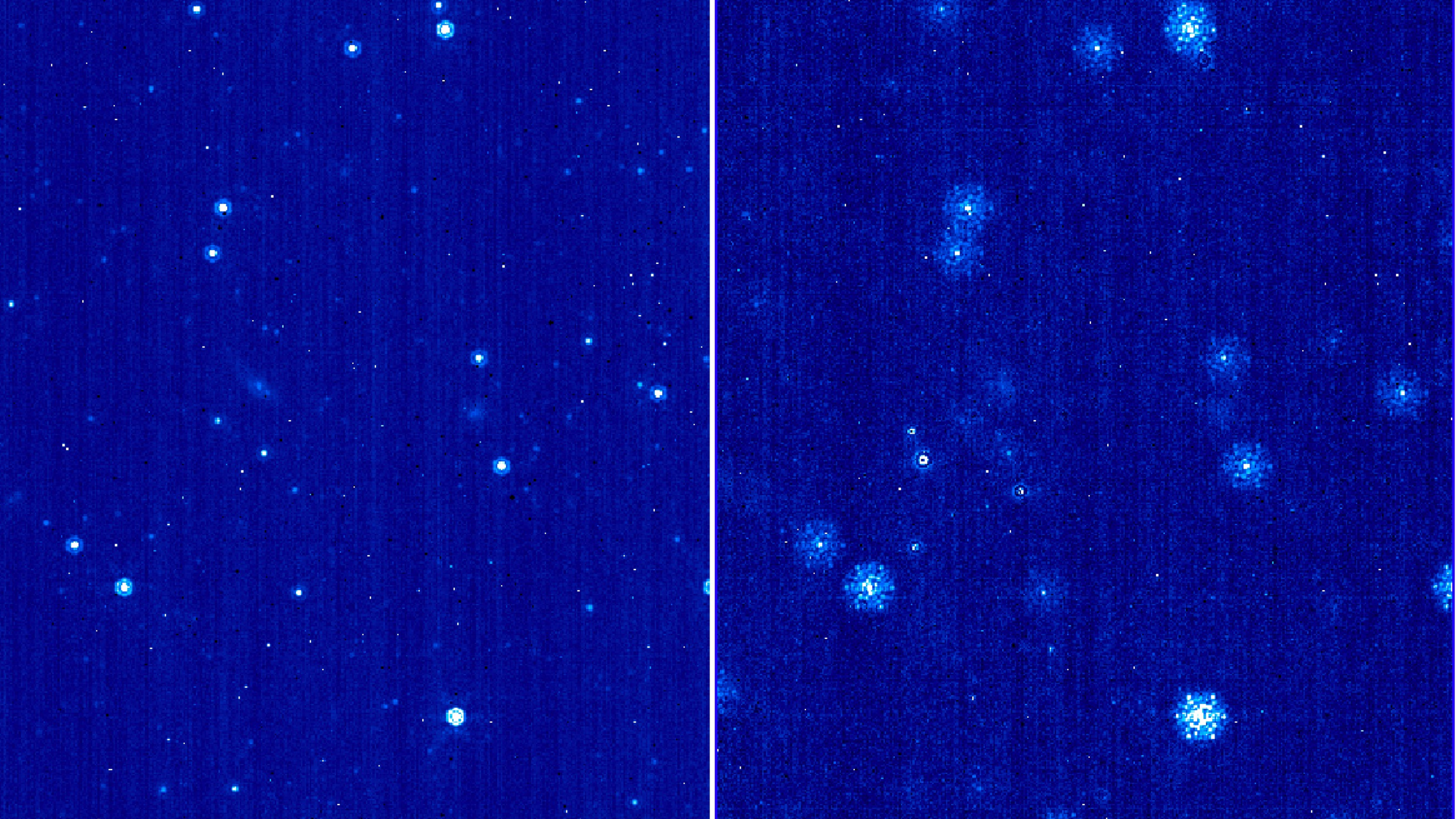
# What’s next?

We’ve barely scratched the surface of what can be done with these data!

- Two data sets separated by a couple weeks (epoch 1 not ideal in terms of target placement). Extra detector positions!
- Other AMI commissioning data: full frame AMI (NIS-010, NIS-020)
- Further pipeline comparisons: SAMpip, other observable extraction codes?
- Improved calibration – how can we push detection limits?
- More useful data visualizations





# Helpful links:

Box link for data:

- https://stsci.app.box.com/folder/167501282178?s=aa398j2grz5if65dbw3baeihx8lgqt5l

Github repositories:

- Commissioning scripts: https://github.com/anand0xff/niriss-commissioning
- ImPlaneIA: https://github.com/anand0xff/ImPlaneIA
- AMICAL: https://github.com/SydneyAstrophotonicInstrumentationLab/AMICAL
- JWST Pipeline: https://github.com/spacetelescope/jwst

# OIFITS files

Averaged OIFITS files & multi-integration OIFITS files saved from ImPlaneIA

```
1  fits.info(indir+'Saveoif/jw01093012001_03102_00001_nis.oifits')
```

```
Filename: /ifs/jwst/wit/niriss/rcooper/nis_019/comout2/pipeline_calibrated_bpcorr/Saveoif/jw01093012001_03102_00001_n
is.oifits
No.    Name         Ver    Type        Cards   Dimensions   Format
  0  PRIMARY          1 PrimaryHDU      18   ()
  1  OI_WAVELENGTH      1 BinTableHDU      17   1R x 2C   [1E, 1E]
  2  OI_TARGET        1 BinTableHDU      56   1R x 17C   [1I, 16A, 1D, 1D, 1E, 1D, 1D, 1D, 8A, 8A, 1D, 1D, 1D, 1D, 1E, 1
E, 16A]
  3  OI_ARRAY         1 BinTableHDU      37   7R x 8C   [16A, 16A, 1I, 1E, 3D, 1D, 6A, 2D]
  4  OI_VIS           1 BinTableHDU      44   21R x 12C   [1I, 1D, 1D, 1D, 1D, 1D, 1D, 1D, 1D, 1D, 2I, 1L]
  5  OI_VIS2          1 BinTableHDU      38   21R x 10C   [1I, 1D, 1D, 1D, 1D, 1D, 1D, 1D, 2I, 1L]
  6  OI_T3            1 BinTableHDU      50   35R x 14C   [1I, 1D, 1D, 1D, 1D, 1D, 1D, 1D, 1D, 1D, 1D, 1D, 3I, 1L]
```

```
1  fits.info(indir+'Saveoif/multi_jw01093012001_03102_00001_nis.oifits')
```

```
Filename: /ifs/jwst/wit/niriss/rcooper/nis_019/comout2/pipeline_calibrated_bpcorr/Saveoif/multi_jw01093012001_03102_0
0001_nis.oifits
No.    Name         Ver    Type        Cards   Dimensions   Format
  0  PRIMARY          1 PrimaryHDU      18   ()
  1  OI_WAVELENGTH      1 BinTableHDU      17   1R x 2C   [1E, 1E]
  2  OI_TARGET        1 BinTableHDU      56   1R x 17C   [1I, 16A, 1D, 1D, 1E, 1D, 1D, 1D, 8A, 8A, 1D, 1D, 1D, 1D, 1E, 1
E, 16A]
  3  OI_ARRAY         1 BinTableHDU      37   7R x 8C   [16A, 16A, 1I, 1E, 3D, 1D, 6A, 2D]
  4  OI_VIS           1 BinTableHDU      44   21R x 12C   [1I, 1D, 1D, 1D, 69D, 69D, 69D, 69D, 1D, 1D, 2I, 1L]
  5  OI_VIS2          1 BinTableHDU      38   21R x 10C   [1I, 1D, 1D, 1D, 69D, 69D, 1D, 1D, 2I, 1L]
  6  OI_T3            1 BinTableHDU      50   35R x 14C   [1I, 1D, 1D, 1D, 69D, 69D, 69D, 69D, 1D, 1D, 1D, 1D, 3I, 1L]
```