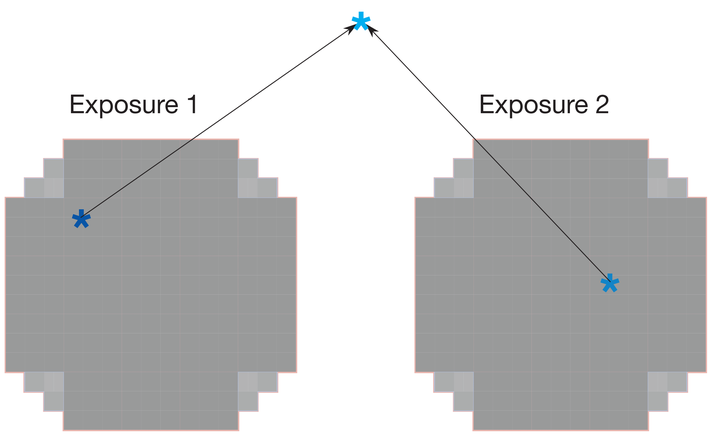
Jointcal: Optimized Astrometry & Photometry for Thousands of Exposures with Large Mosaic Cameras

Large Synoptic Survey Telescope

Introduction and Algorithm

- Jointcal is a new software package developed for the LSST Science Pipelines to optimize the astrometric and photometric calibrations of a set of mosaic camera images of an area of sky.
- Jointcal can operate on cameras supported by the LSST software, including Canada-France-Hawaii Telescope (CFHT) Megacam, Dark Energy Camera (DECam), Subaru Hyper SuprimeCam (HSC), and simulated LSST images from phosim and imsim.
- The jointcal algorithm matches both between exposures and to external reference catalogs; this allows many more sources to be fit when the images are significantly deeper than those of the reference catalogs (for example, LSST's 30-second r-band exposure depth will be 24.7 compared with r < 20 for Gaia's final survey depth).

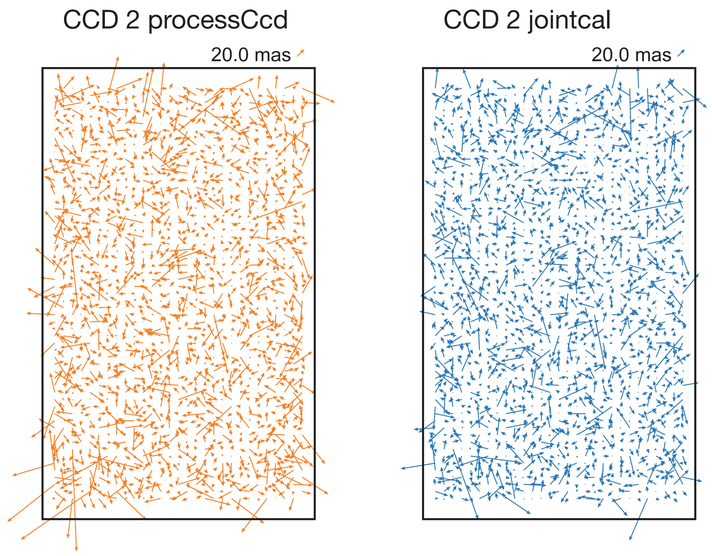


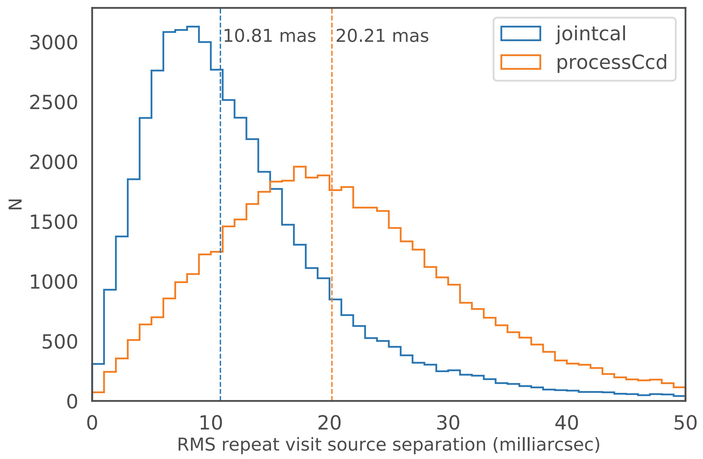
$$\chi^2 = \sum_{\gamma,i} [M_\gamma(S_{\gamma,i}) - F_i]^T W_{\gamma,i} [M_\gamma(S_{\gamma,i}) - F_i] \quad \text{(meas. terms)}$$
$$+ \sum_j [F_j - R_j]^T W_j [F_j - R_j] \quad \text{(ref. terms)}$$

- Jointcal minimizes the χ^2 equation shown above, jointly fitting the sensor-to-sky model and the "true"-to-reference catalog value.
- The 45 exposures in this example include >500,000 stars + >3500 model parameters.
- Jointcal uses the sparseness of the Hessian matrix (2nd derivatives of the model parameters) of χ^2 to rapidly solve the large linear system.
- Running jointcal on 45 visits of HSC takes about 5 hours (single core).
- Plan to parallelize reading data and outlier rejection.

Astrometric Calibration

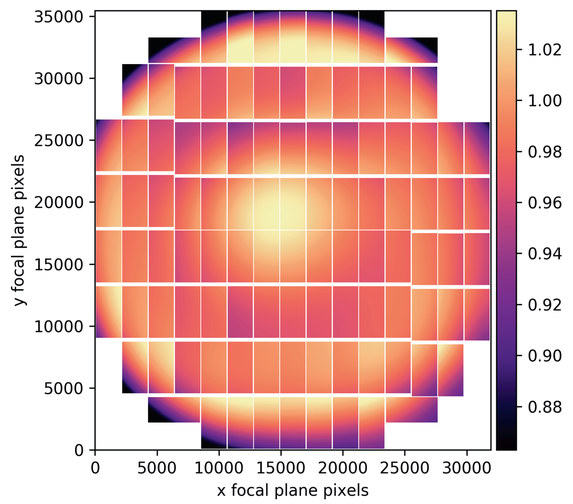
- Here we demonstrate jointcal's astrometric and photometric calibration performance on HSC data (101 CCDs), with 45 exposures of one field (XMM-WIDE HSC-I band).
- We fit a 7th order polynomial per exposure over the whole focal plane, and an affine transform (x/y rotation, translation, and scale) for each sensor (fixed for all observations).
- Residuals are markedly reduced on the edges of CCDs. More sources and a polynomial that continues beyond the edge help the model to not diverge compared with fitting CCDs individually.



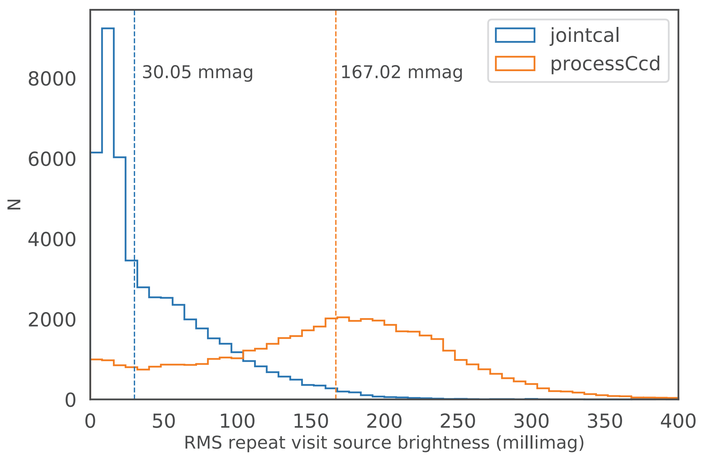


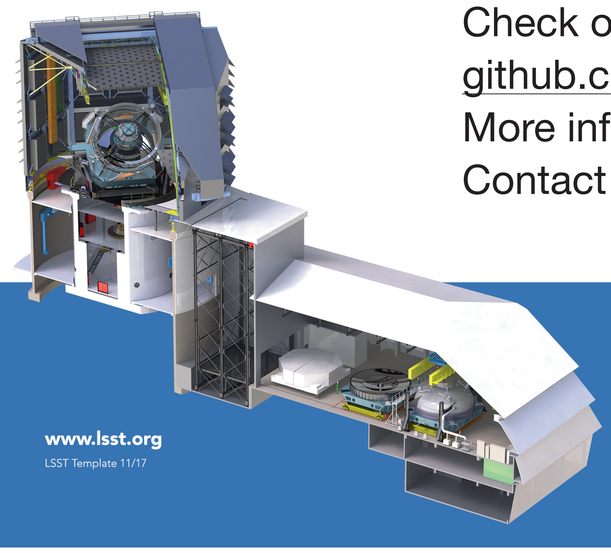
Photometric Calibration

- Here is jointcal's photometric calibration of one HSC exposure (one scale factor per CCD, times a 7th order chebyshev polynomial per visit), with the single frame algorithm (*processCcd*) divided out.
- The largest changes are at the edges of the focal plane, where HSC is significantly vignetted.
- The middle of the focal plane has improvements at the >2% level.



- Both panels below show the RMS of the residuals on bright stars that are measured on multiple exposures.
- The dashed lines are the median RMS; jointcal performs markedly better in both astrometry and photometry.





Check out jointcal on GitHub:
github.com/lsst/jointcal
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