Accuracy of Gaia Reference Fields for Exoplanet Astrometry

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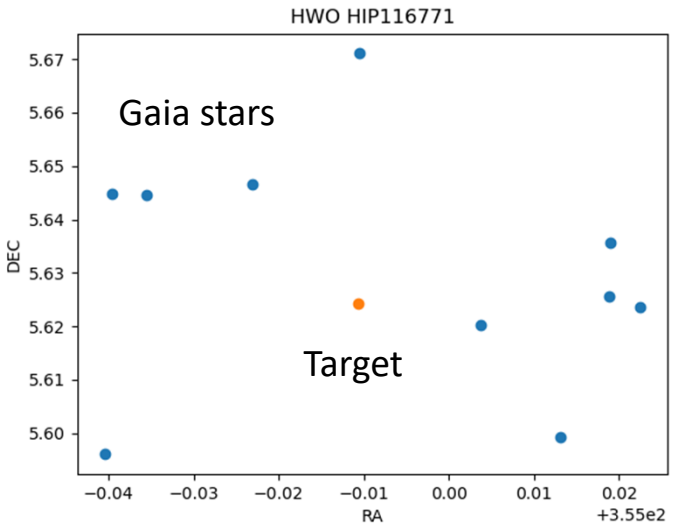
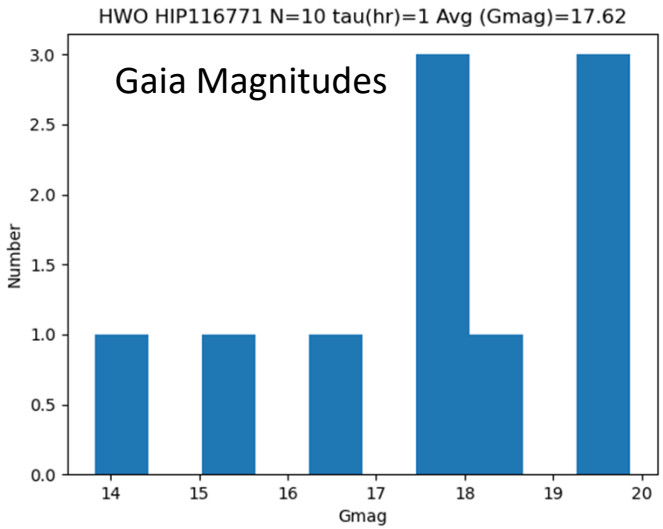
Analysis model

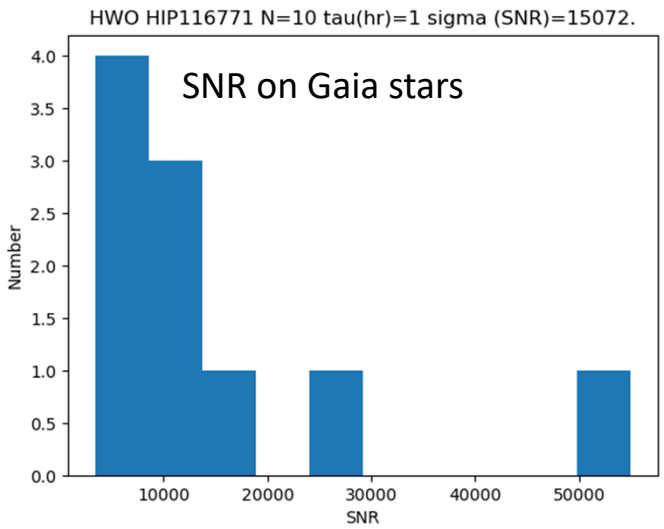
- Mamajek & Stapelfeldt tabulate 164 most favorable HWO targets (Mamajek, & Stapelfeldt 2024, arXiv:2402.12414)
- Use Gaia to establish reference frames surrounding HWO targets
  - Search for Gaia stars around each to assess ability to generate local reference frame with 1) HWO and 2) Theia
  - Must have parallax & proper motion, ruwe<1.1, Rmag<19
- Consider only photon noise, number of stars

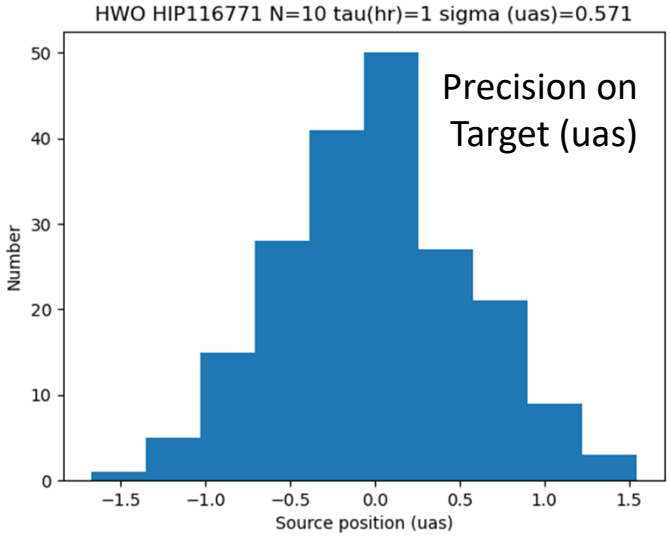
Individual Target Analysis

- Run Monte Carlo on each HWO target star
  - Select Gaia stars around HWO target position in 2040 (HWO FOV=3', Theia FOV=30')
  - Propagate uncertainty in coordinates from DT=2040-2016
    - RA_{2040} =RA_{2016} + DT*RandomVariate(ura0,sigma_ura) + RandomVariate(0,sigma_plx)
    - DEC_{2040} =DEC_{2016} +DT+ RandomVariate(udec0,sigma_udec) + RandomVariate(0,sigma_plx)
  - Calculate pixel coordinates, Pixels, wrt to HWO target including a rotation, eg θ=25 deg
    - dra, ddec = HWO.spherical_offsets_to(GaiaStars)
    - r = R.from_rotvec([0,0, θ])
    - Pixels =r.apply([dra, ddec])
  - Add centroid uncertainty to each Gaia star
    - Sigma_centroid=PSF/2/SNR
    - Where PSF=FWHM~0.8*1.2 l/D at 0.55 μm for D=0.8 m(Theia) or D= 6 m (HWO)
    - SNR=sqrt(electrons) for Vmag, dlam=0.2 μm, effic=0.5.
    - Tau=1 hr for HWO, 10hr for Theia
  - Use stellar coordinates and pixel values with centroid error to establish WCS
    - w = fit_wcs_from_points(xy=pixels, world_coords = GaiaStars, projection='TAN')
  - Evaluate pixel location of host star using WCS to determine uncertainty in each trial
    - HWOpix=w.wcs_world2pix(raHWO, decHWO)
- Repeat N times



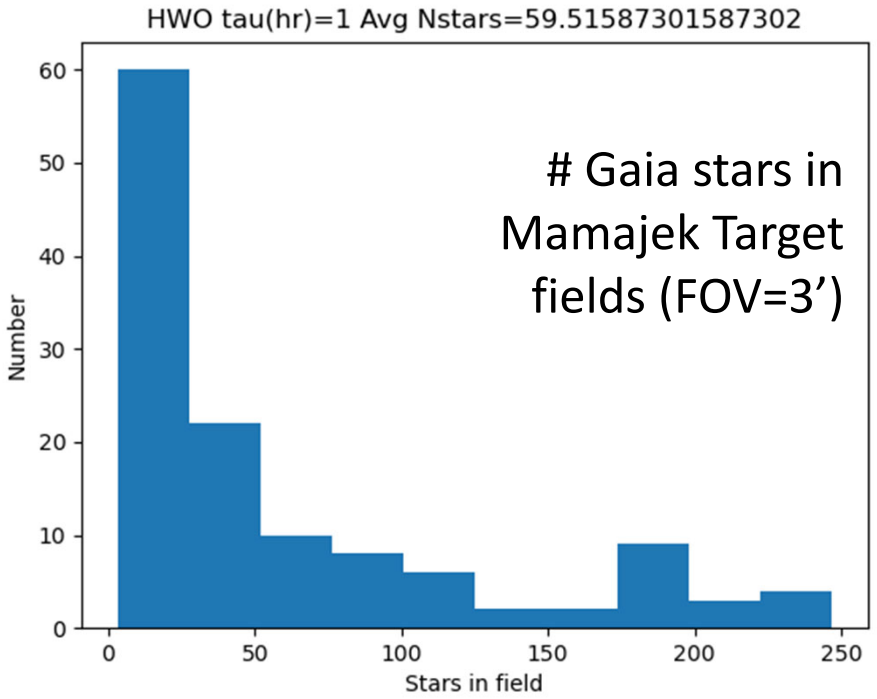




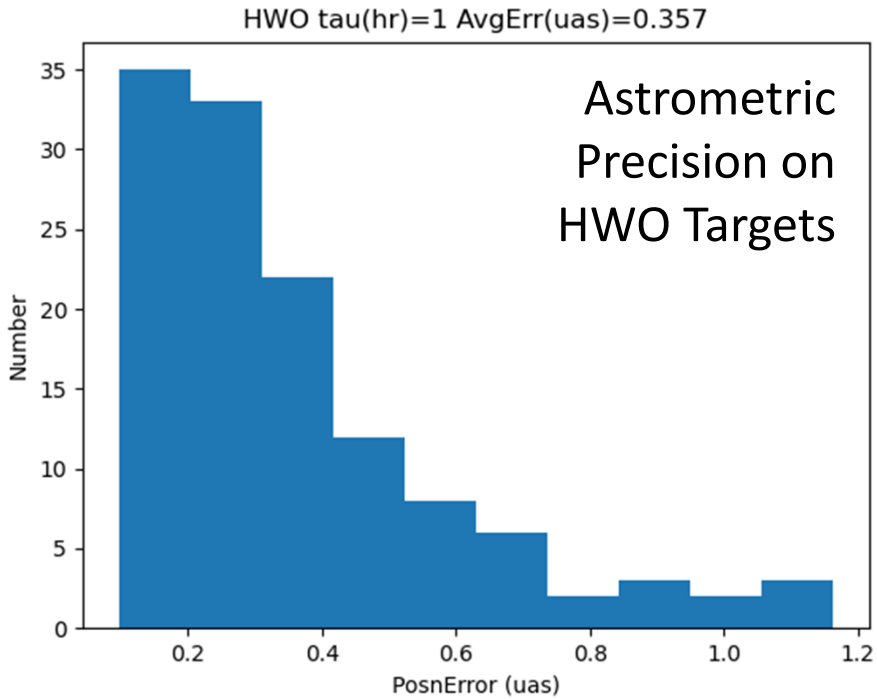


Illustrative Target With HWO

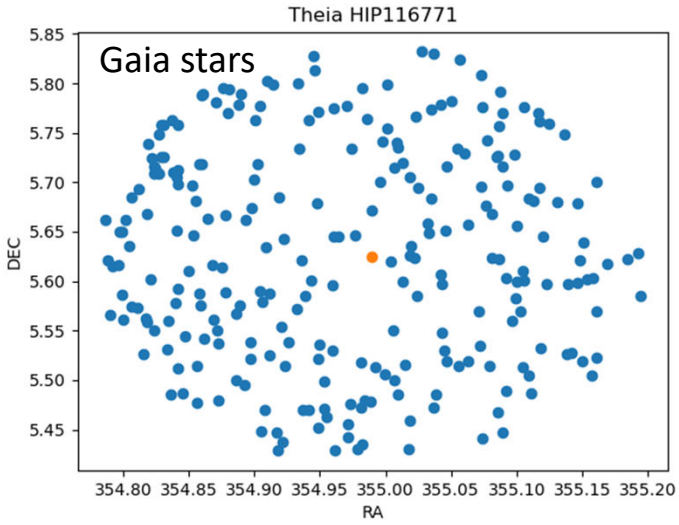
HWO Results for Mamajek Sample

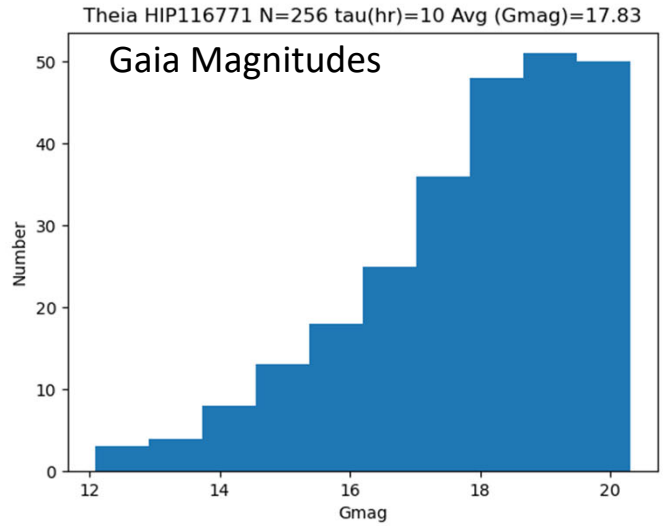


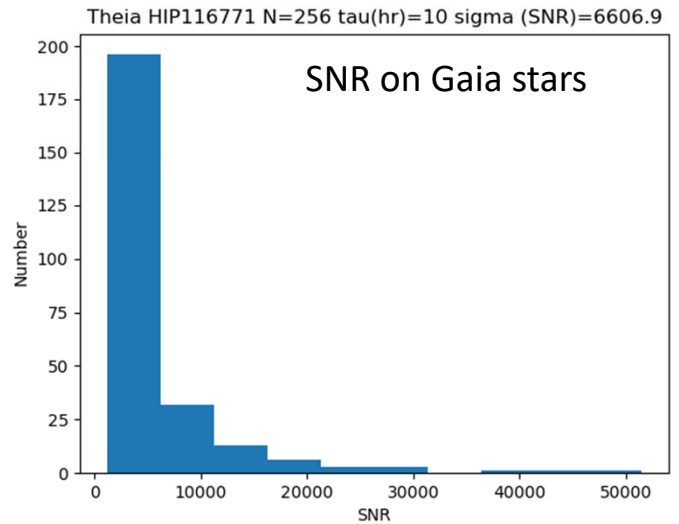
Gaia stars in Mamajek Target fields (FOV=3')

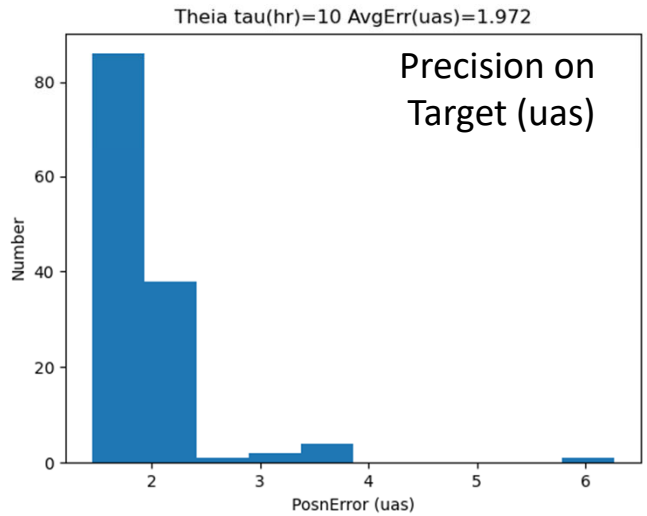


Astrometric Precision on HWO Targets



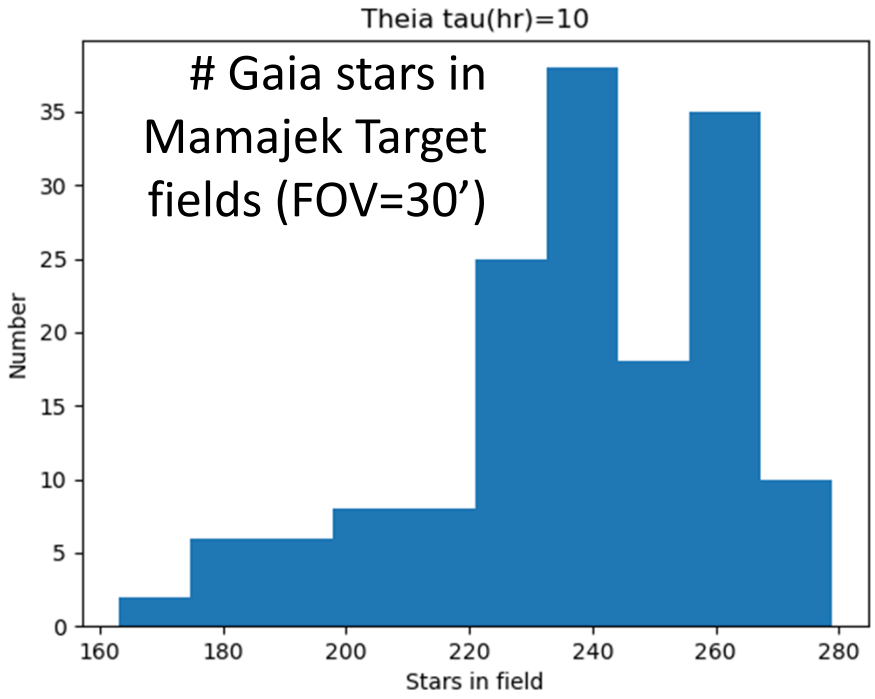


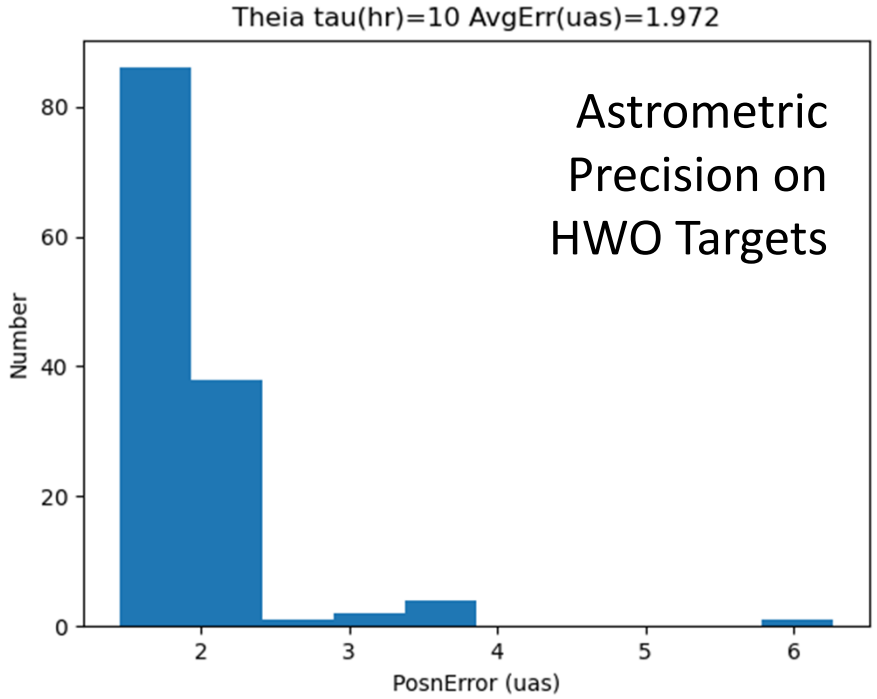




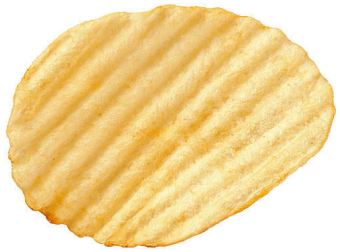
Illustrative Target With Theia

Theia Results for Mamajek Sample





Initial Results and Concerns



Telescope and focal plane at picometer scale

- Results
  - HWO achieves 0.35 μas reference frame precision in 1 hr
  - Theia achieves 2.0 μas reference frame precision in 10 hr
- Remaining Concerns
  - 0.03 μas noise floor for 10s detection of HZ Earth at 10 pc (0.3 μas) will require excellent repeatability and stability of ~3 years.
  - Challenge of mapping focal plane and detector plane distortion models to < 1 μas with available Gaia ref stars , especially for small HWO FOV
  - Chromatic effects between target and reference stars (broad filters)
  - Detector dynamic range of target Gmag~5 vs ref stars Gmag~18 mag
  - Observing time needed for N=50-100 observations for single planet, more for multiple systems
  - Etc…