

# Galactic Streams: Challenges From Subaru-HST Joint Survey Processing

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*Joint Survey Processing Splinter Session*

# JOINT SURVEY PROCESSING (JSP)

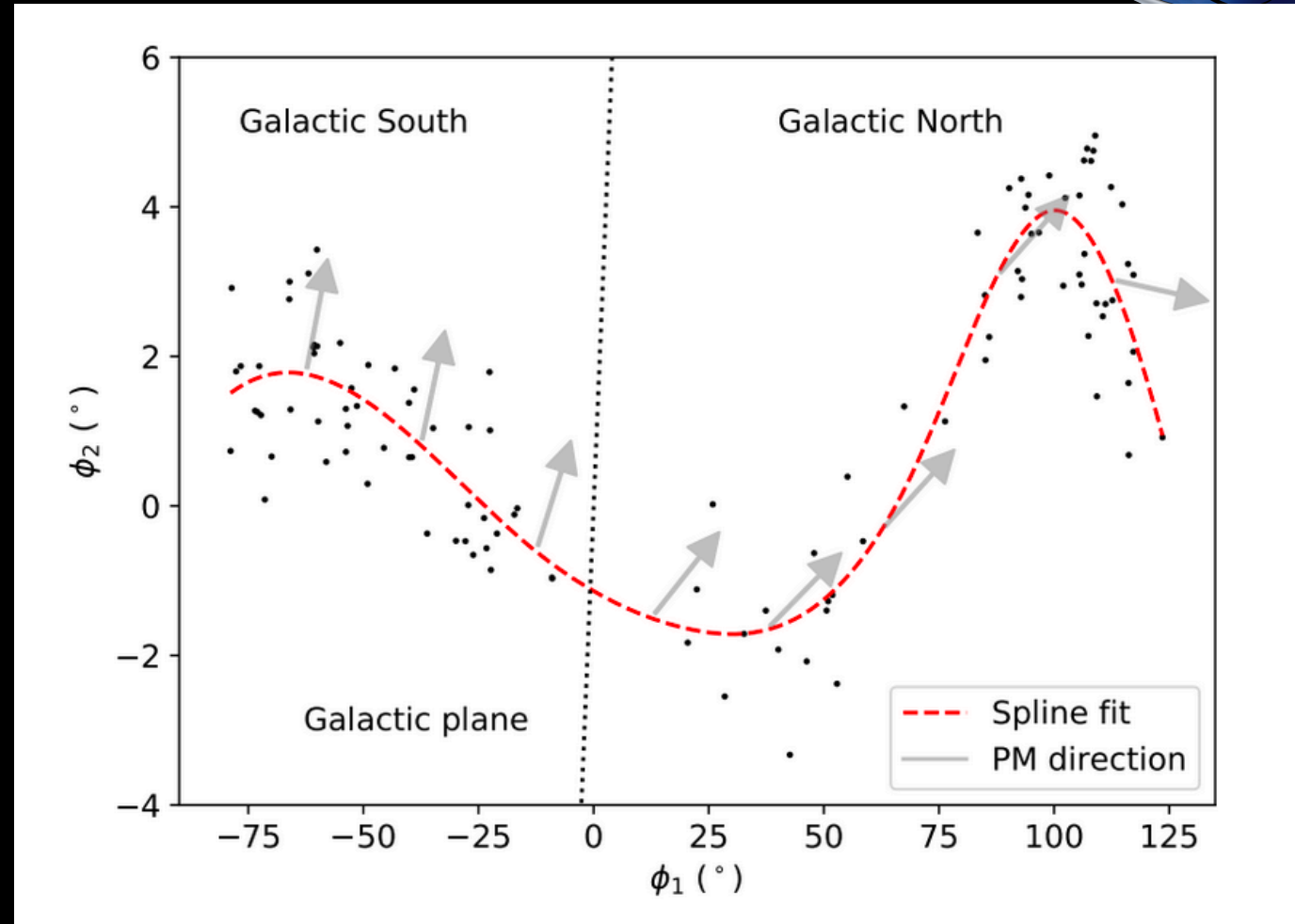


- Joint Survey Processing of *Euclid*, *Rubin*, and *Roman* data at the pixel level has the objectives of: Producing multiwavelength images and catalogs of precise agreement in the sky areas of overlap, and providing a science platform where these images and catalogs can be processed and analyzed by the community.
- Observations with these facilities of Gaia-measured and fainter stars will allow multi-epoch cross-identifications. These observations will then yield improved proper motions and photometry, allowing for deconfusion of sources in the Galaxy and in external galaxies.

# AN EXAMPLE OF PROPER MOTIONS AND GALACTIC STRUCTURE



- Orphan Stream exhibits proper motions along the stream in its northern part, and  $\perp$  to the stream in its southern part.
- These “sideways” motions are  $\sim 0.5$  mas/yr.
- May be related to the flyby of the LMC, if it has a mass 10% that of the Milky Way.



Erkal et al. (2019)

# EXAMPLE PROPER MOTION STAR IN COSMOS FIELD HUBBLE ACS & SUBARU HYPER-SUPRIME CAM (HSC)

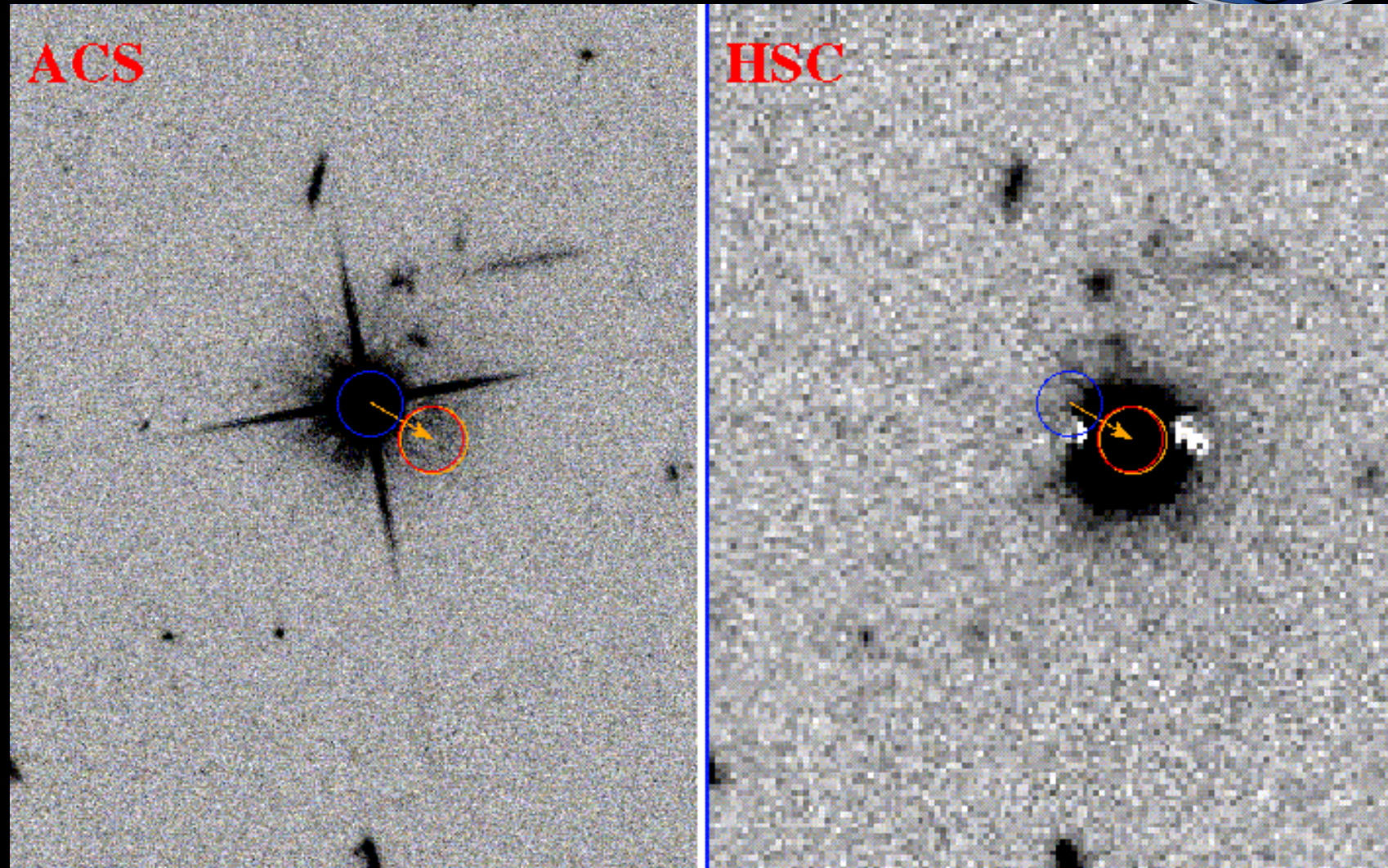


- Proper motion measured by Gaia ( $\sim 200$  mas/yr).

Position at the ACS epoch (2004.58).

Position at the HSC epoch (2015.06).

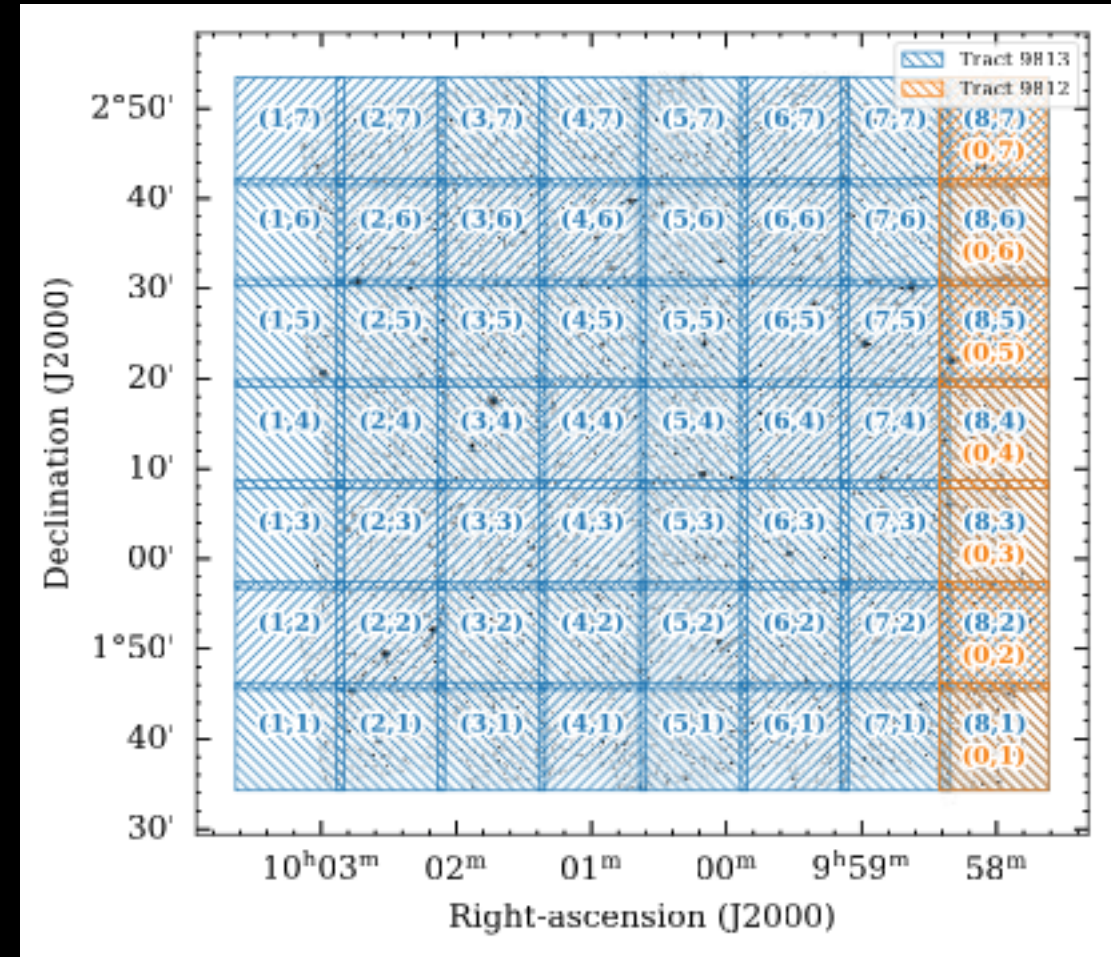
With JSP we reproduced Gaia star proper motions (down to 20.8 mag), opening the door for estimates for fainter stars.



# COSMOS ULTRA-DEEP FIELDS: SUBARU HSC, HUBBLE ACS, AND GAIA STAR PROPER MOTIONS



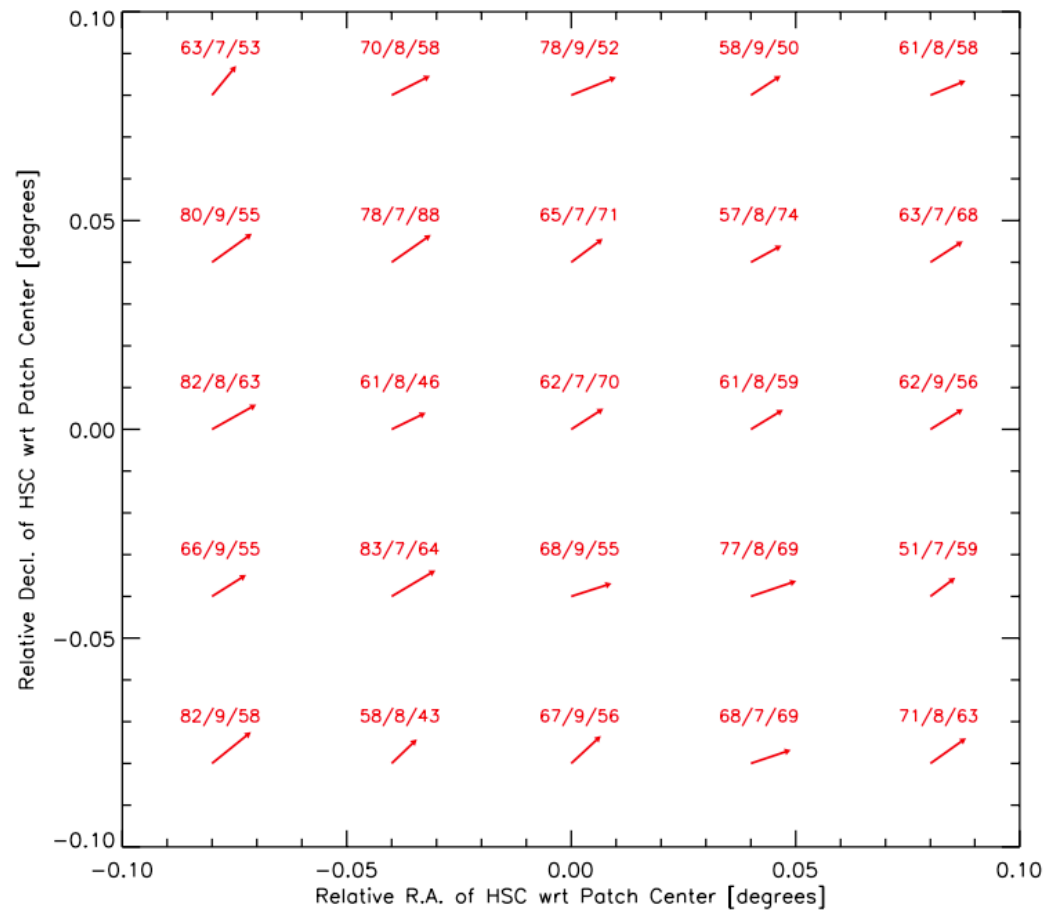
- COSMOS Hubble ACS astrometry jointly processed with Subaru HSC.
- Gaia stars (single, non-variable) matched to stars in 63 coadded-exposures in the HSC i-filter and ACS F814W-filter. Typically ~30-50 matches per exposure.
- There is reasonable agreement in Gaia stars' proper-moved positions and ACS and HSC sources.
- However, depth of Gaia is ~21 mag, vs. ~27.5 mag for HSC i-filter in the COSMOS fields.



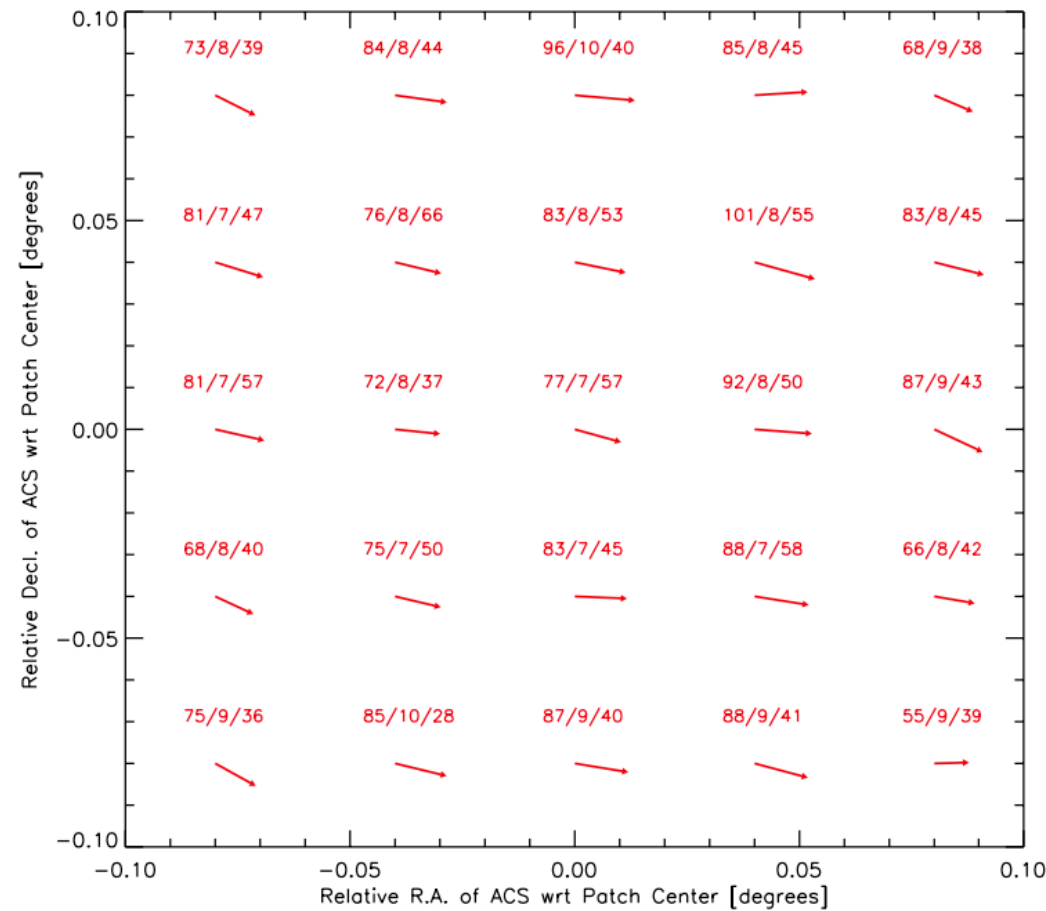
# HSC & ACS ASTROMETRIC CORRECTION wrt GAIA



Astrometric Offsets of HSC sources wrt Gaia DR2  
Gaia G-mag > 18.5. Coadds observed also with ACS.  
Gaia DR2 matched sources with  $\pi > 0$ , Knn method.



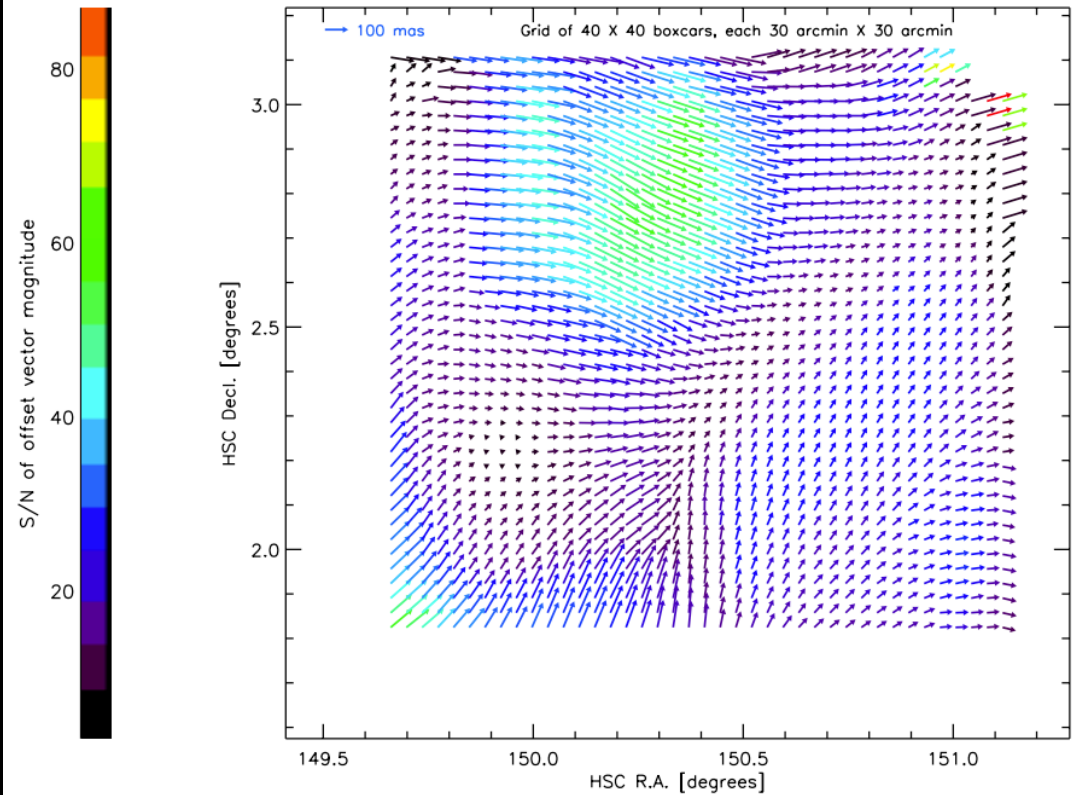
Astrometric Offsets of ACS sources wrt Gaia DR2  
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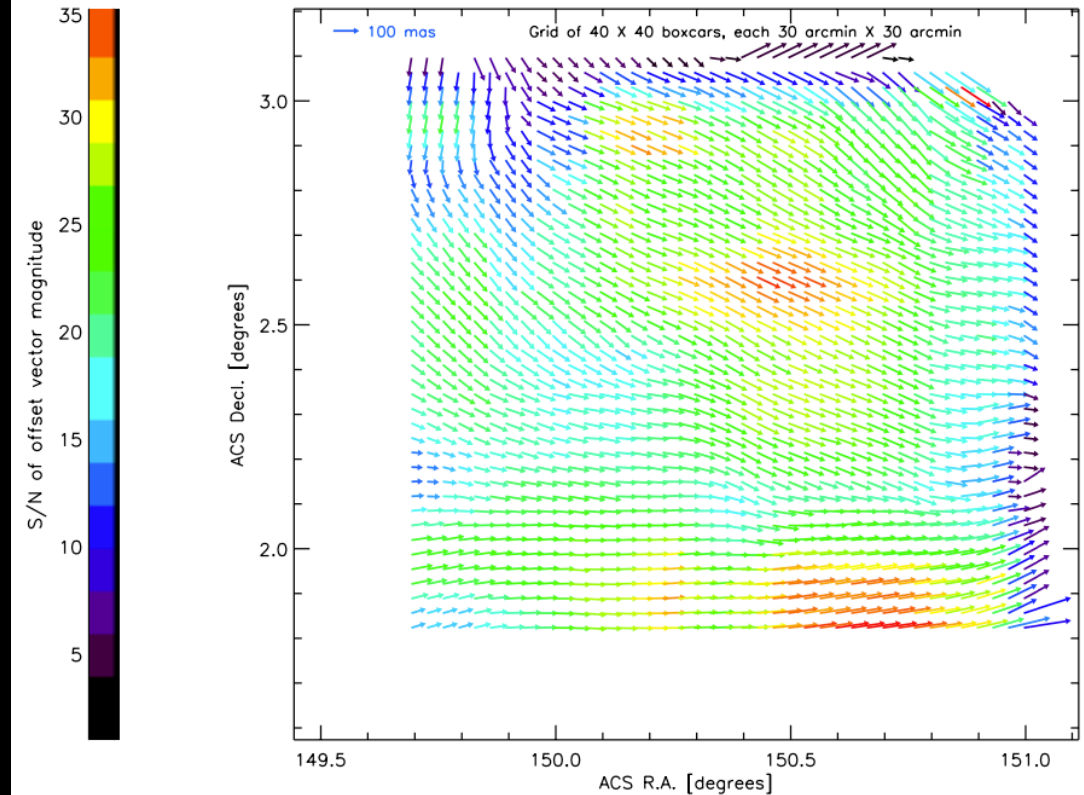
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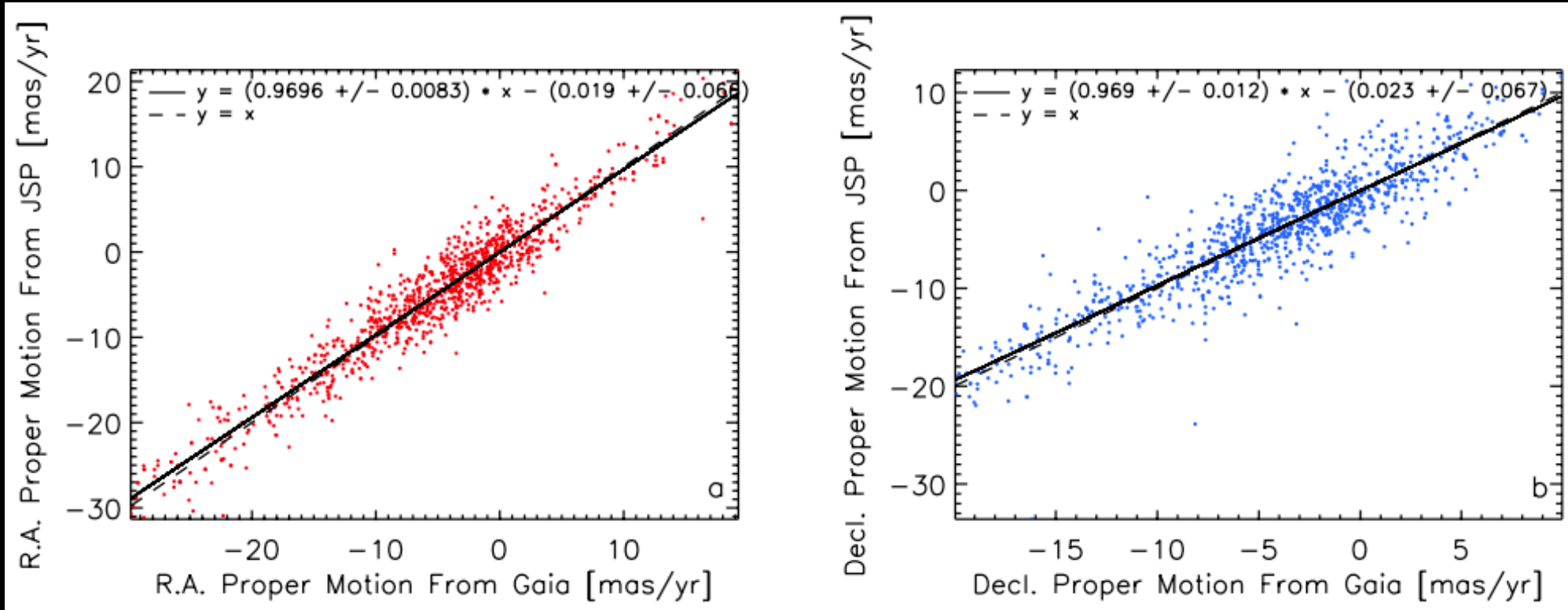


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- Median  $\Delta(\text{HSC} - \text{Gaia})$  (left) or  $\Delta(\text{ACS} - \text{Gaia})$  (right), 14-nearest neighbors method, smoothed with 30' X 30' boxcars.
- Color-coding indicates S/N of magnitude of  $\Delta$  vectors.
- Minimum spatial scale over which variations in  $\Delta$  vectors occur is  $\sim 2'$ .

# COMPARISON OF JSP AND GAIA PROPER MOTIONS



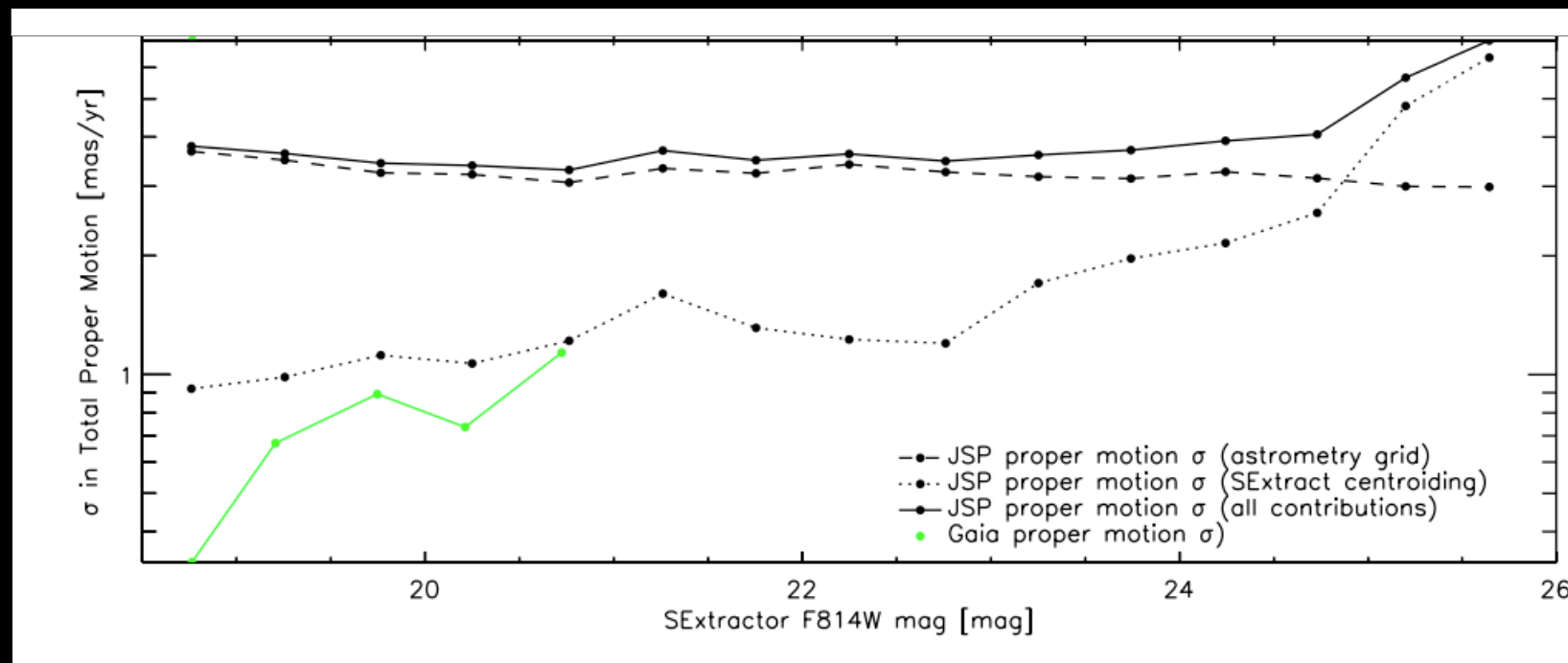
- Based on 1,135 Gaia DR2 stars with reliable ACS and HSC astrometry:
- Very good comparison of proper motions from JSP and Gaia DR2
- Through Monte Carlo simulations estimate that error in JPS proper motions is  $\sim 2$  mas/yr



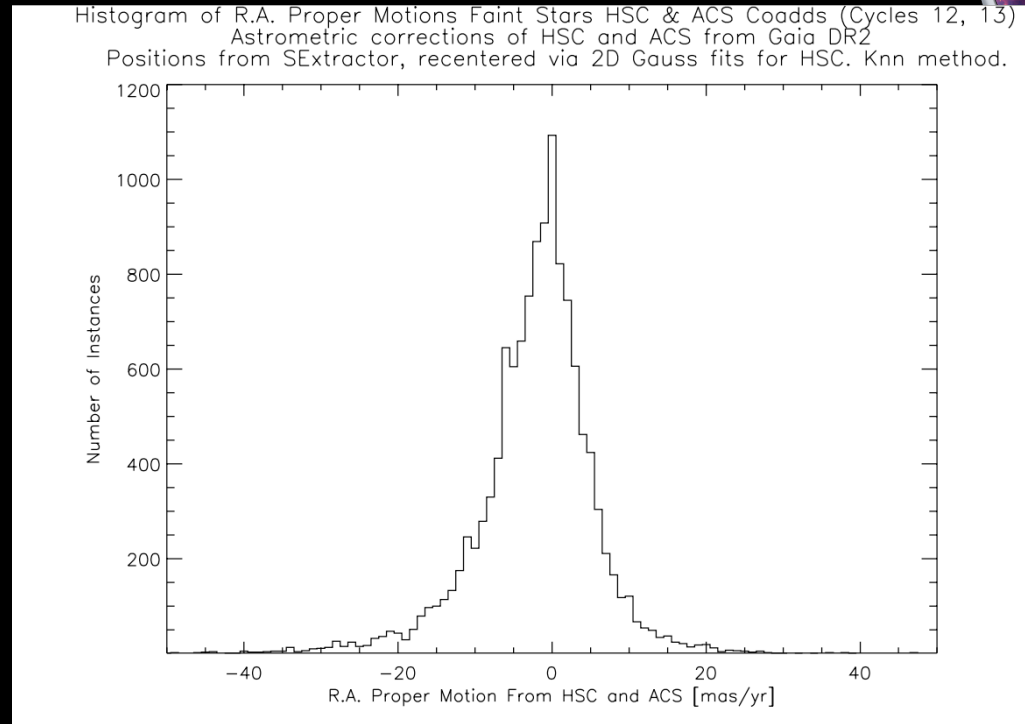
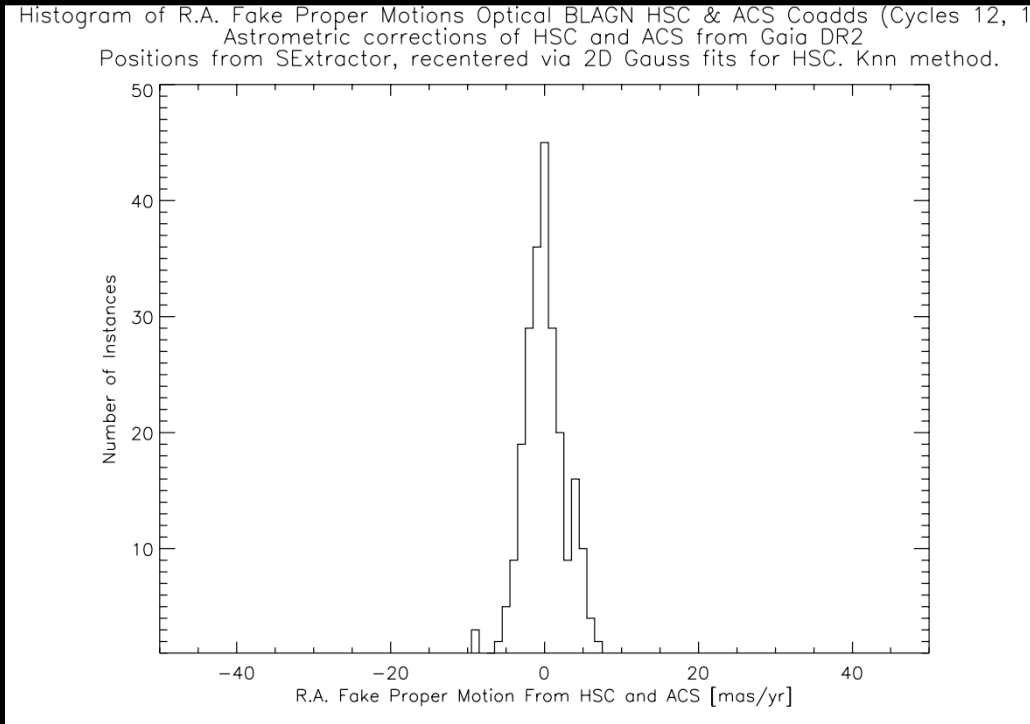
# DETAILED UNCERTAINTIES OF JSP PROPER MOTIONS



- Gaia DR2 catalog  $\rho$  shown in green color.  $< 1$  mas/yr.
- JSP  $\rho$  from centroiding shown as dotted lines. Increase with decreasing brightness.
- JSP  $\rho$  from astrometric grid correction (difference between Gaia DR2 and compact galaxies grids) shown as dashed lines.



# CROSS-CHECK R.A. PROPER MOTIONS AFTER GAIA DR2 GRID CORR.

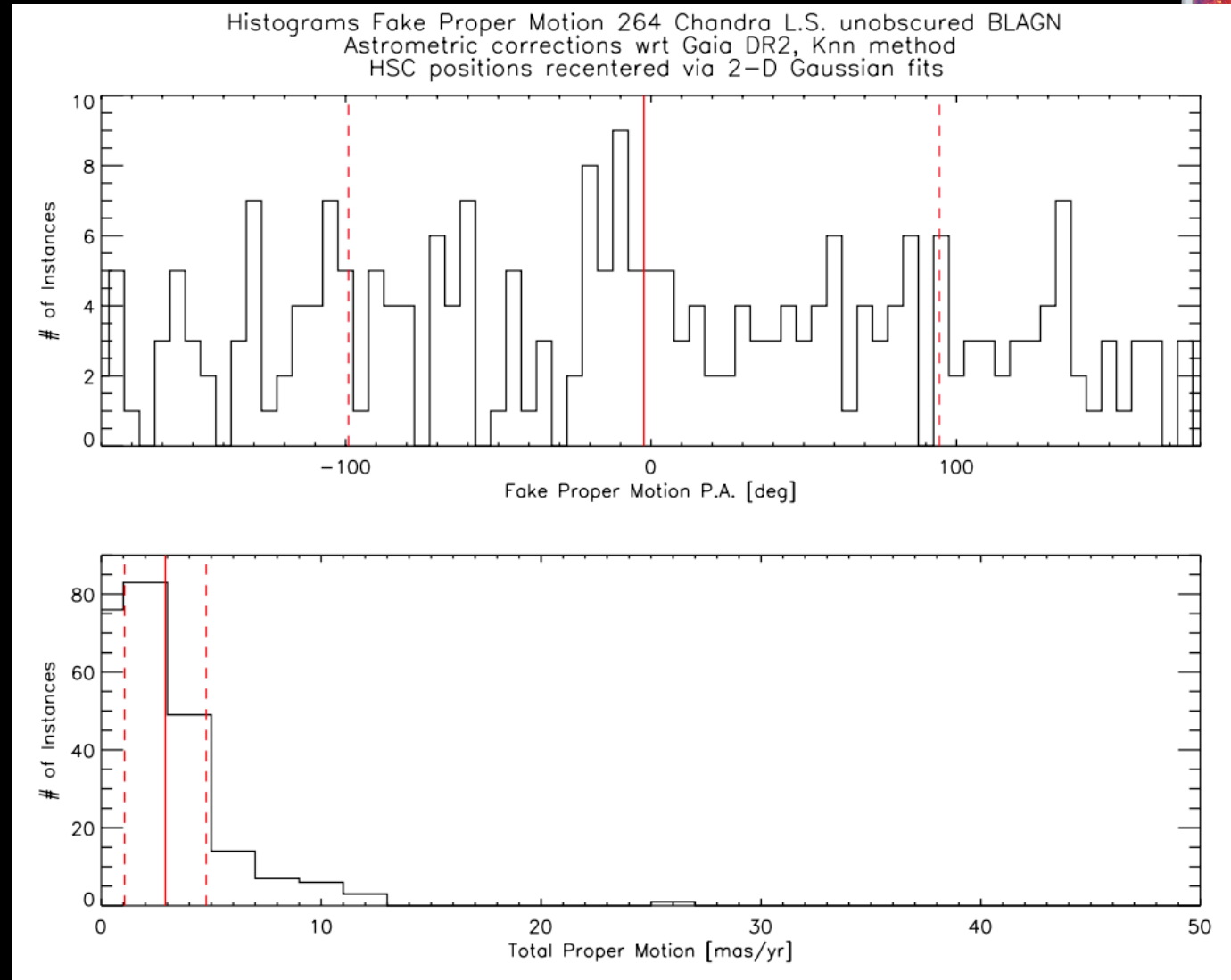


- **LEFT PANEL:** From ACS, HSC positions of 296 optically-selected unobscured BLAGN from the Chandra Legacy Survey (Civano et al. 2016, Marchesi et al. 2016), corrected to the grid of Gaia DR2. Compute “fake motions” (expected to be zero) between the ACS and HSC epochs of these BLAGN. FWHM of the symmetric distribution,  $\sim 3\text{-}4$  mas/yr is comparable to  $\rho$  in proper motions.
- The **RIGHT PANEL** is actual proper motions of 11,500 stars in COSMOS. Distribution is asymmetric and FWHM  $\sim 12$  mas/yr.

# FAKE MOTIONS OF OPTICAL BLAGN



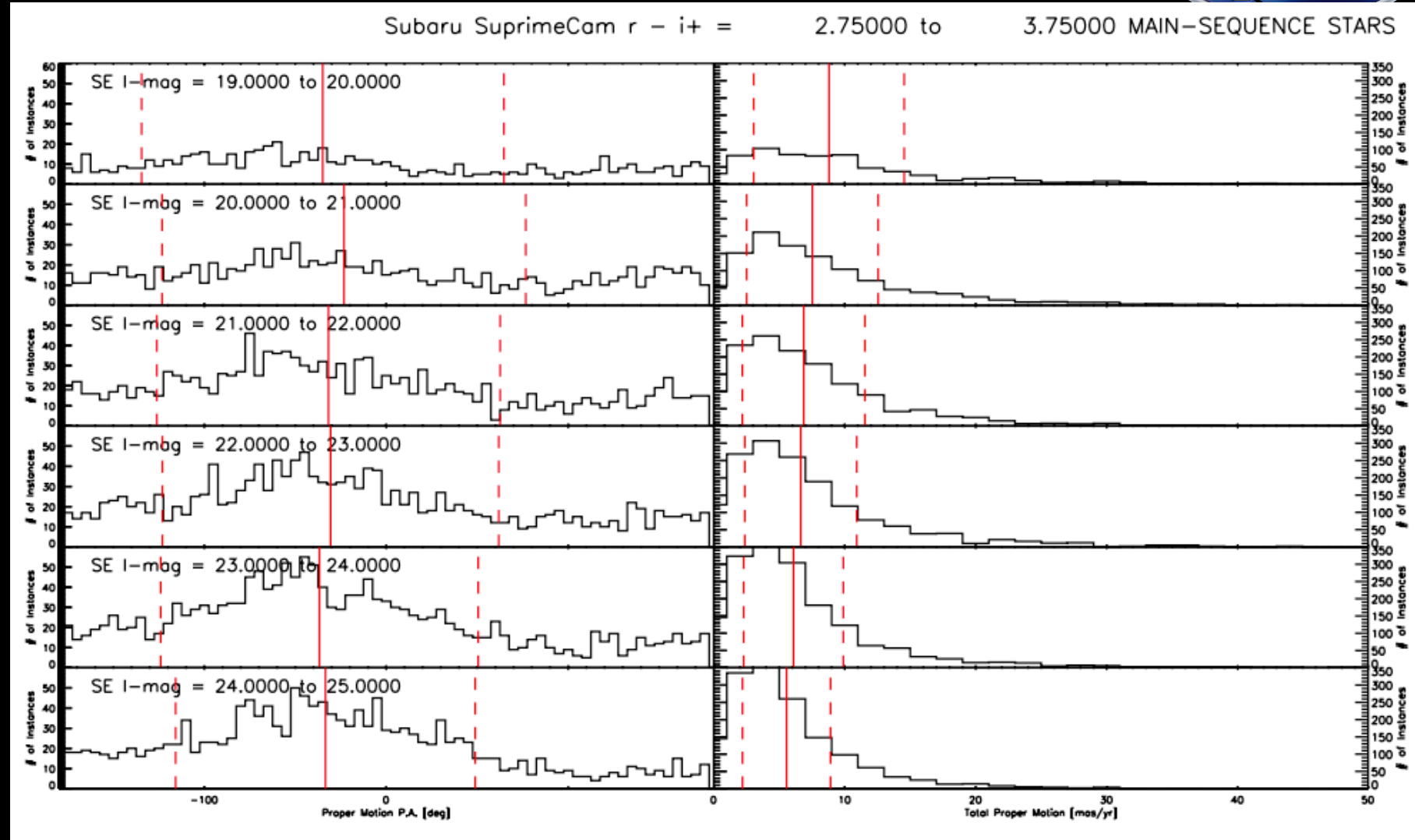
- 296 BLAGN do not any show preferential “motions”
- Mean direction is consistent with random orientations
- Mean “motion” is 3 mas/yr, consistent with 1  $\rho$  of JSP proper motions.



# PROPER MOTIONS OF LATE M DWARFS



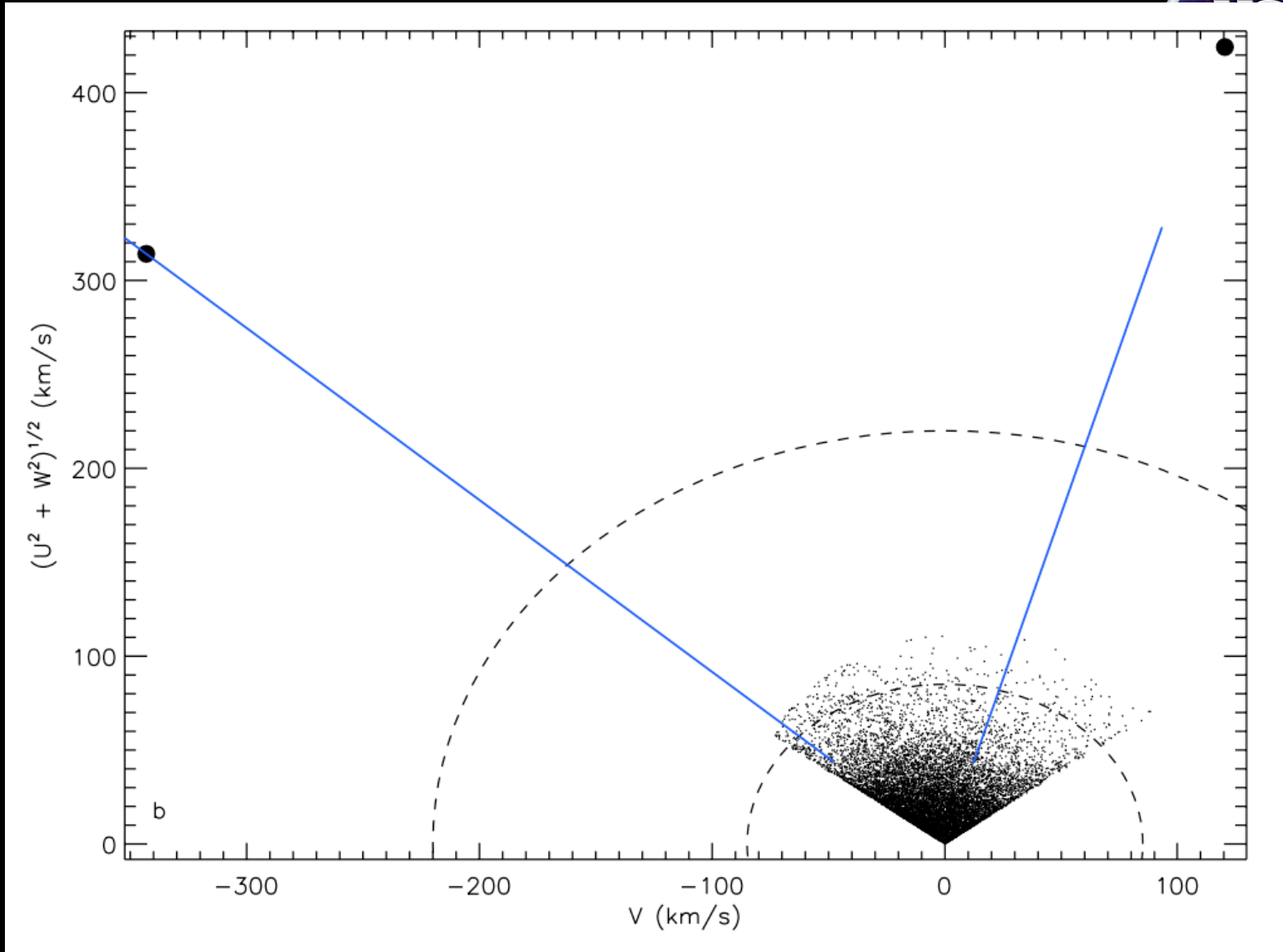
- 7,970 late M dwarfs at  $\sim 1$  Kpc (400 pc – 1.1 Kpc) show preferential proper motions
- Mean direction is towards  $-30^\circ$  relative to East (ESE)
- Mean proper motion ranges from 5 to 9 mas/yr



# HIGH VELOCITY STARS



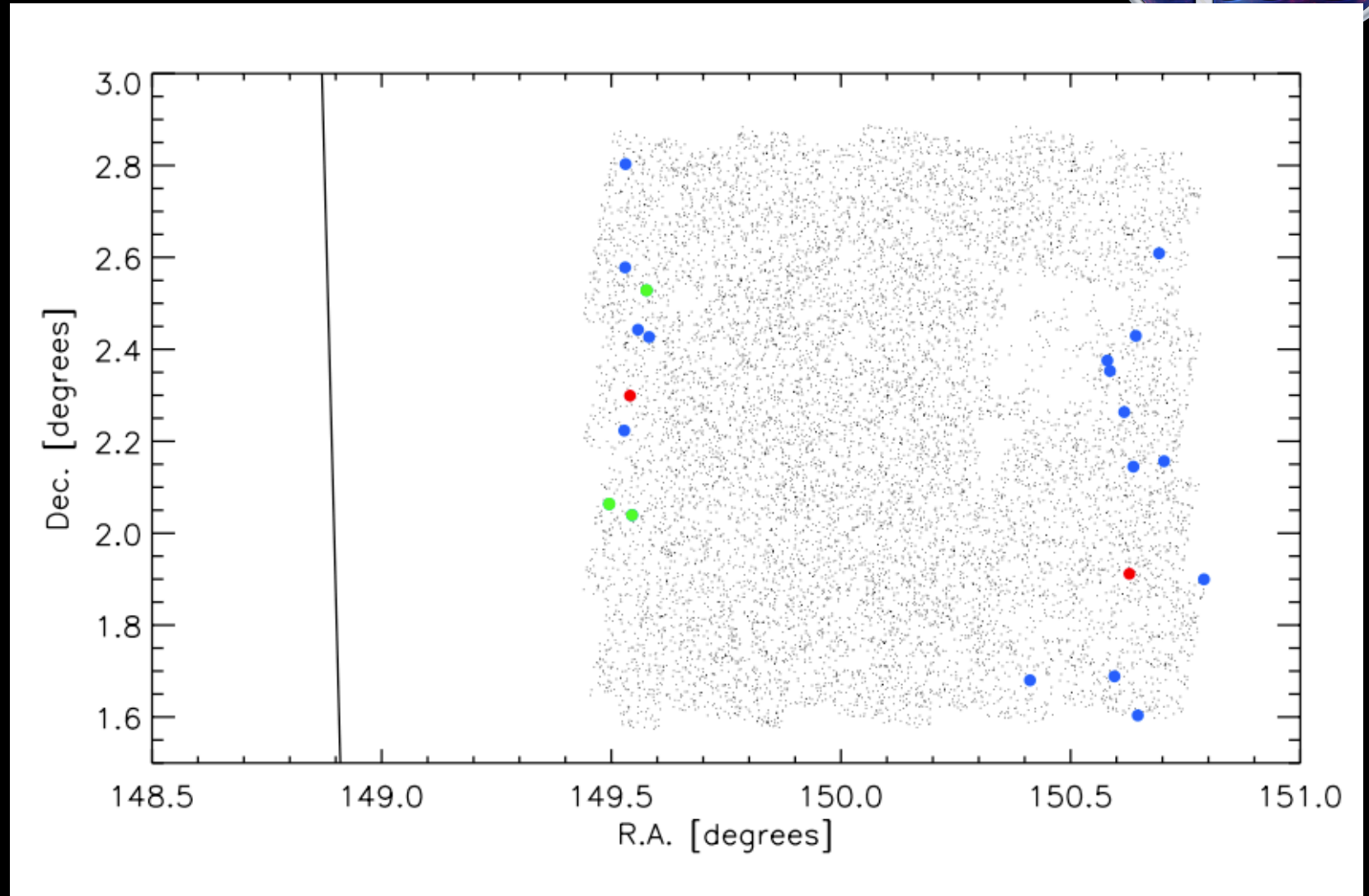
- Toomre diagram of 10,818 stars with AB mag 19-25 (F814W ACS)
- Loci of 220 km/s and 85 km/s delimit halo, thick, and thin disks
- Two giant stars detected that may be members of the Sagittarius stream
- *Large circles:*  $[Fe/H]_{\odot}$
- *Blue lines:* range of velocities for metal-poor giants



# SANGARIUS STREAM



- 10,818 stars with AB mag 19-25 (F814W ACS) and well-defined JSP proper motions
- Near-vertical line is the center of the Sangarius stream (Grillmair 2016)
- *Red circles*: Two giant stars of high velocities from Toomre diagram
- *Blue and green circles*: Giant stars of poor metallicity, at 20 kpc, from color-mag diag
- Might have detected edge of Sangarius stream (stars in l.h.s.) and a splinter from it (stars in r.h.s.)



# CONCLUSIONS



- As a precursor to joint processing of *Euclid*, *Rubin*, and *Roman*, we are analyzing the proper motions and photometry of stars in the COSMOS field, as imaged by the HST ACS and Subaru HSC cameras (over an ~11 year baseline).
- Joint processing of allowed measurements of proper motions of 11,500 stars as faint as 25 mag, vastly augmenting Gaia proper motions of 3,900 stars as faint as 20.8 mag. Coupled with multiwavelength observations, empirical parallaxes, spectral types, and luminosities were estimated for the faint stars.
- We detected bulk motions in the thick and thin disks of the Galaxy.
- We identified 21 candidate members of the 20-kpc distant Sangarius stream.
- These measurements illustrate the studies of galactic structure that will be possible with *Euclid*, *Rubin*, and *Roman*. They will yield absolute luminosities from optical to infrared photometry, and improved derived stellar radii, Galactic structure studies, and measurements of the mass distribution in external galaxies.