Vera C. Rubin Observatory
Systems Engineering

Determining the Accuracy and Precision of Astrometric Positions and Covariances from the LSST Science Pipelines and the Vera C. Rubin Observatory Using LSST's Data Preview 1 and 2

Draft

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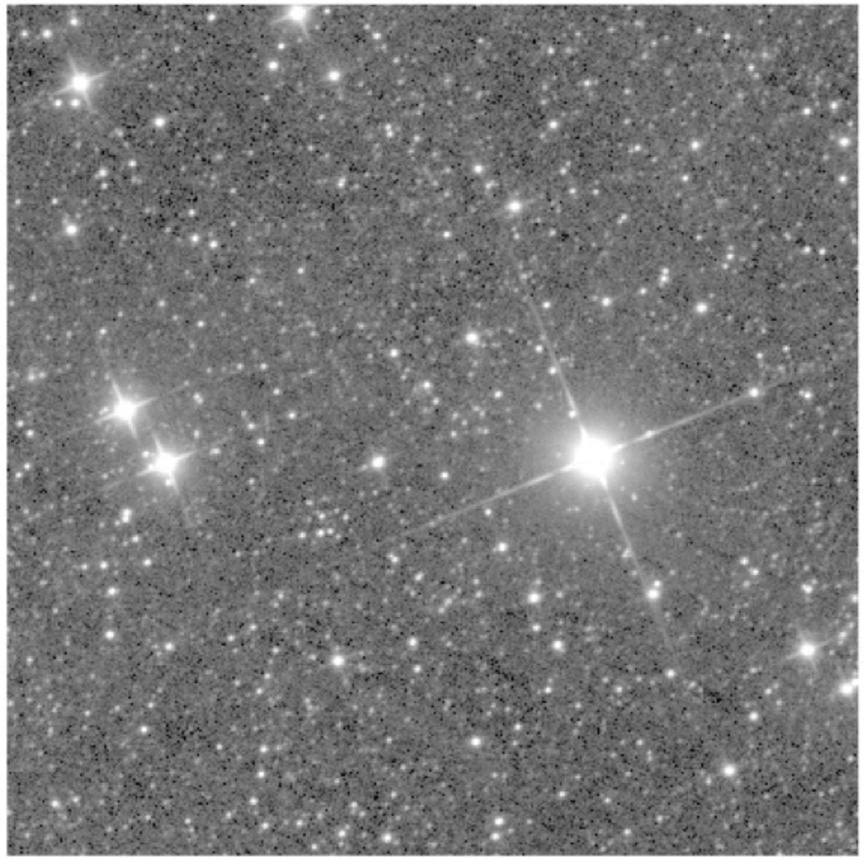
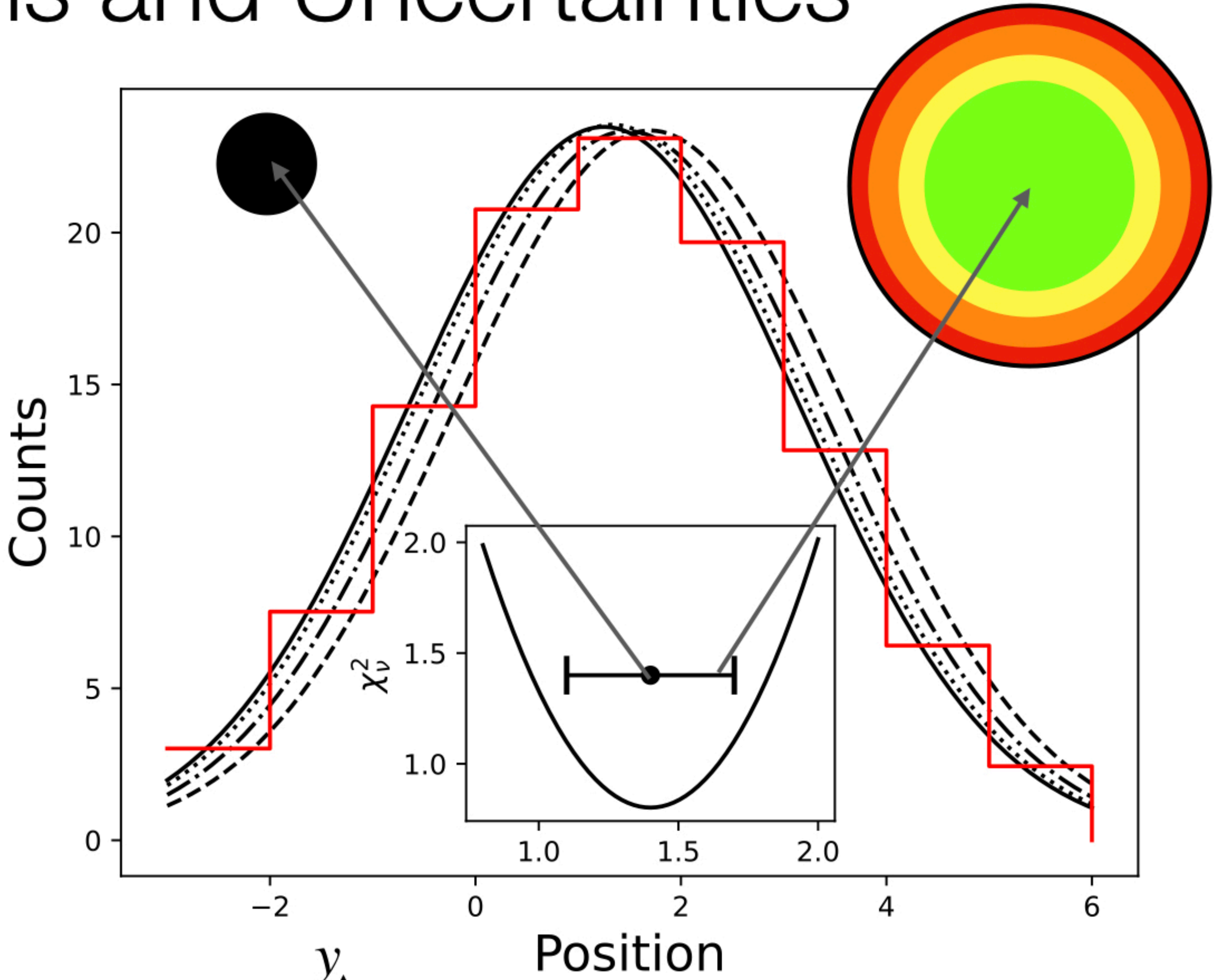
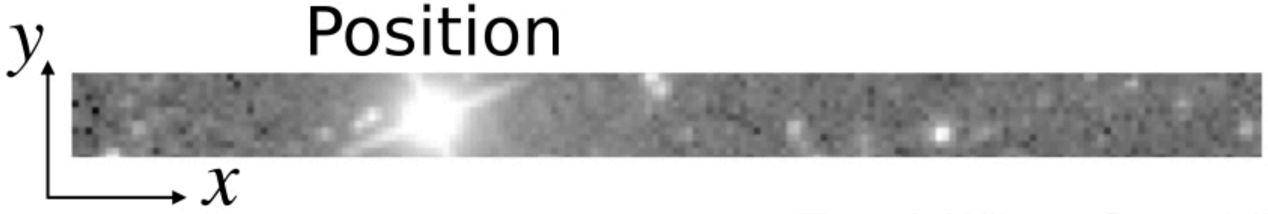
LSST:UK Consortium
Science and Technology Facilities Council
University of Exeter

Astrometry: Positions and Uncertainties



WISE - Wright et al. (2010)





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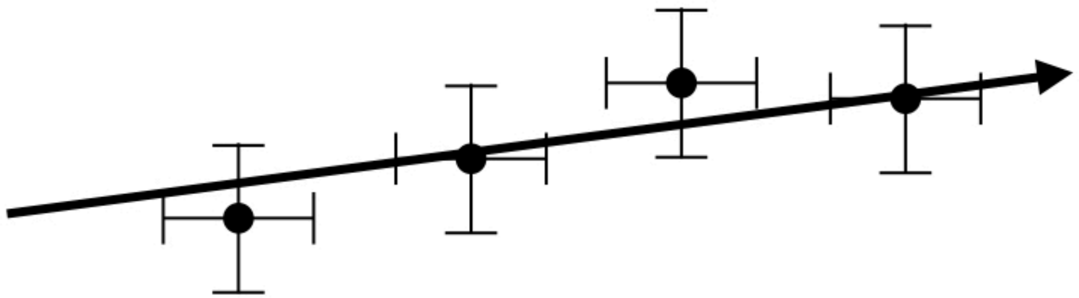
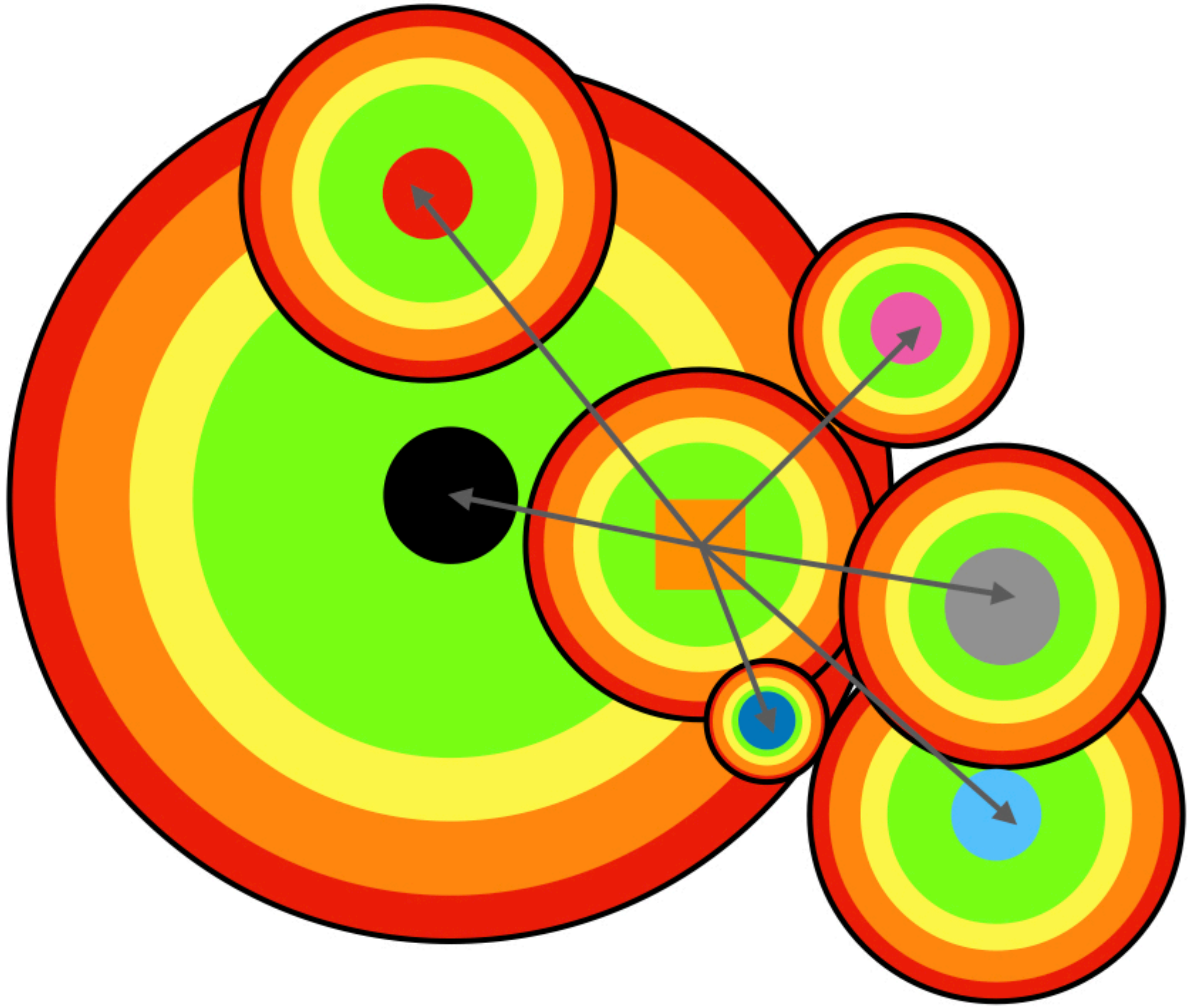
Centroid Positions and Uncertainties

Second-order information such as proper motion and parallax



Derived information like counterparts between datasets (LSST-to-*Gaia*, VISTA, SDSS, …)



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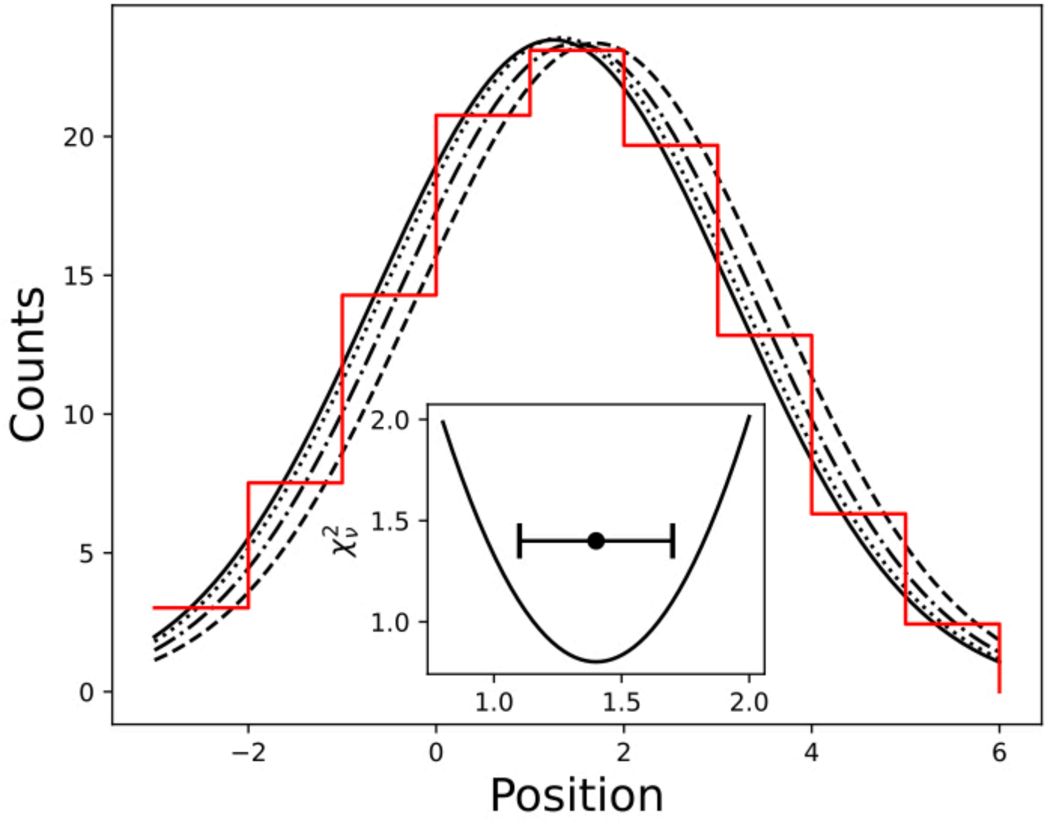
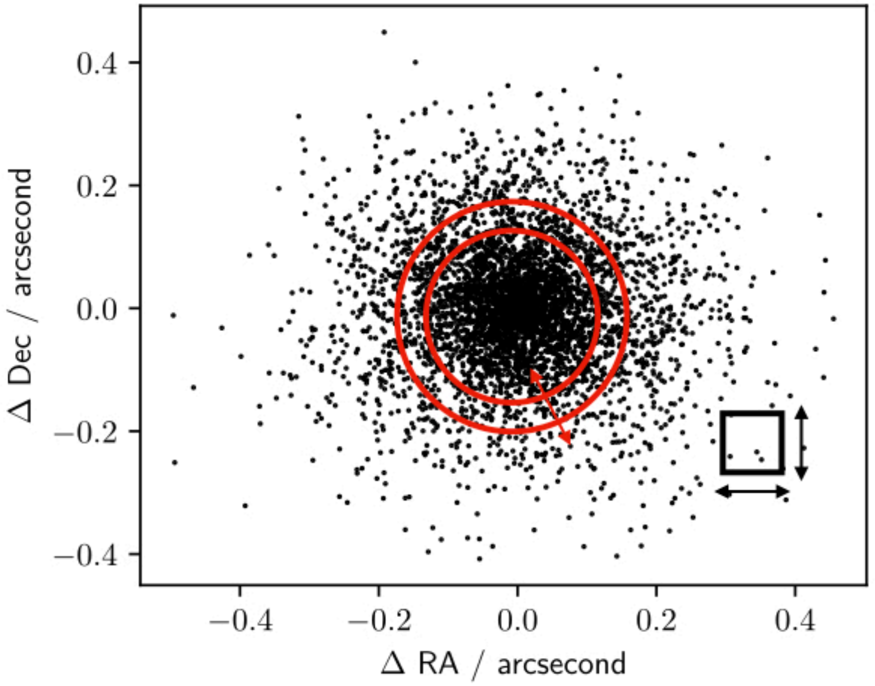
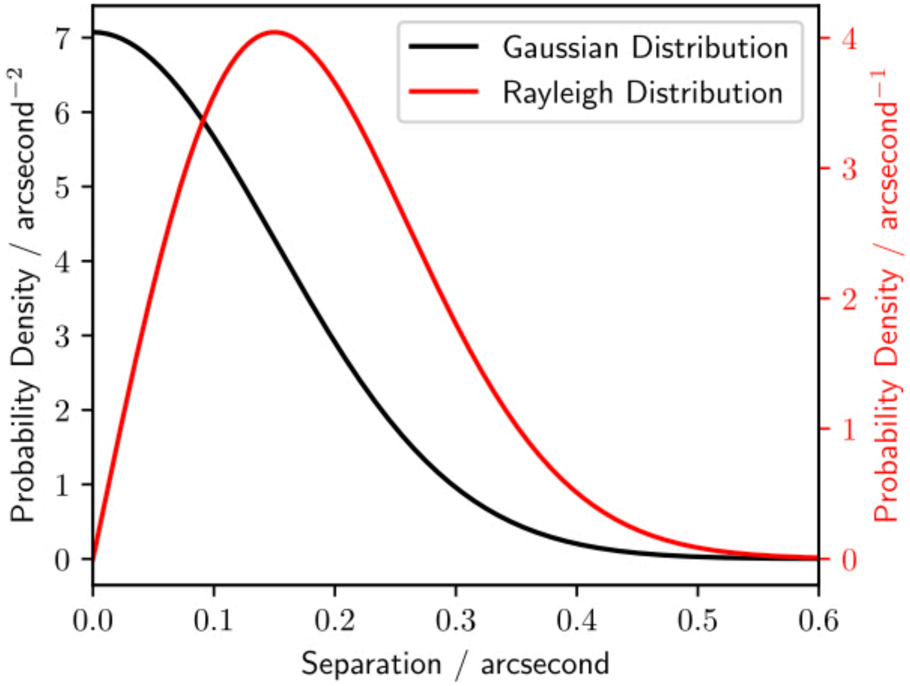
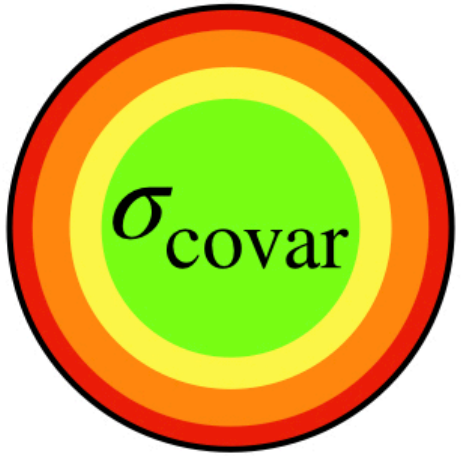
Verifying Pipeline Positions and Precisions

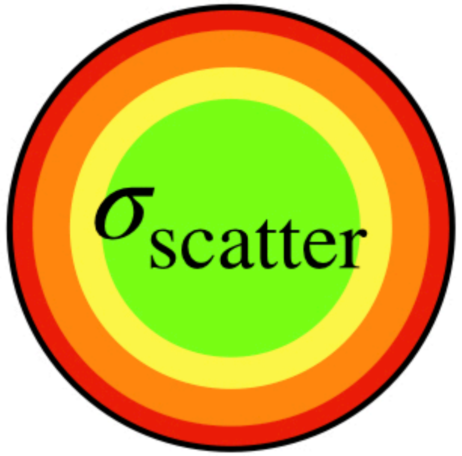
$$g(x, y, \sigma) = (2\pi\sigma^2)^{-1}\exp\left(-\frac{1}{2}\frac{x^2+y^2}{\sigma^2}\right) \longrightarrow g(r, \sigma) = \frac{r}{\sigma^2}\exp\left(-\frac{1}{2}\frac{r^2}{\sigma^2}\right)$$











*** you have to account for all other sources of object displacement, like proper motion and model misspecification due to unresolved hidden contaminant sources, to compare *centroid* position to covariance, but I don't have time to get into that!**

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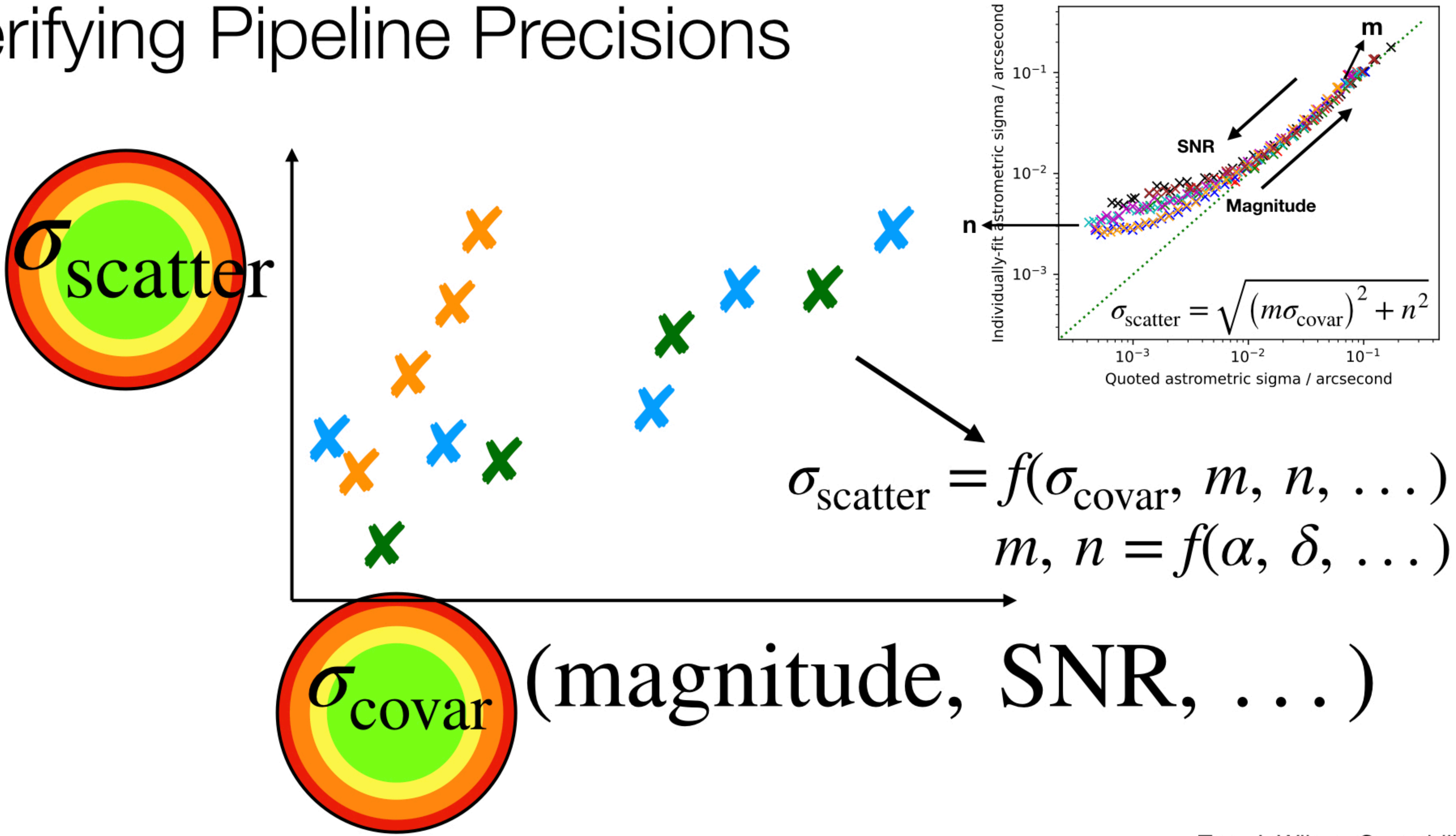
Verifying Pipeline Precisions



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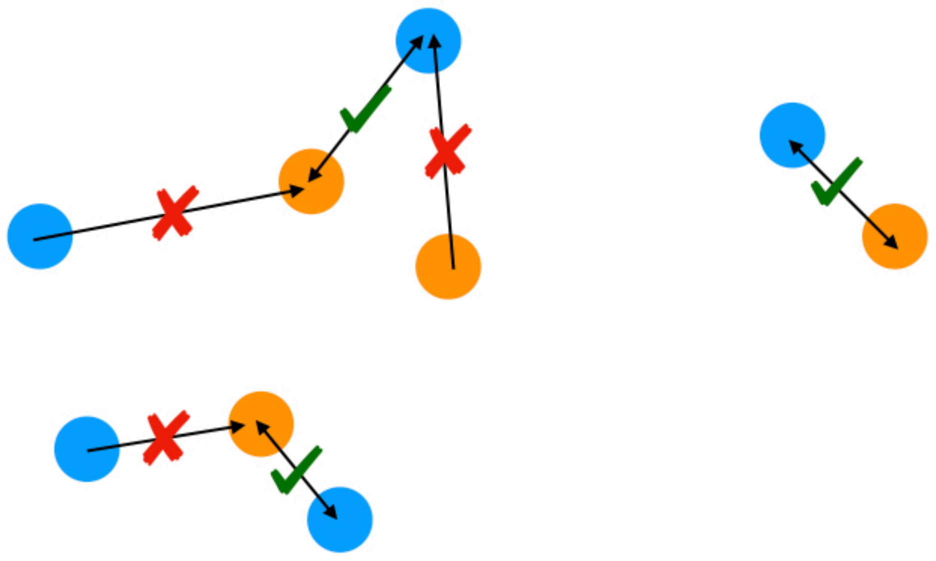
Investigating the LSST Data Previews

- Normally we can't say what the *real* deviation from "truth" is.
- Higher-astrometric-precision datasets, like *Gaia*, are the best you can do with actual data.
- But *Gaia* is bright by LSST standards, so we also use the *Hubble* Source Catalog to probe below 20th magnitude.



	***Gaia* (exquisite astrometry, very bright)**	***Hubble* (low coverage, matches LSST depth)**
Object Table (Deep, lower N)	🧐	😍
Source Table (Shallower, repeat observations)	😊	😄

Gaia Collaboration et al. (2021, A&A, 649, A1); Whitmore et al. (2016, AJ, 151, 134)

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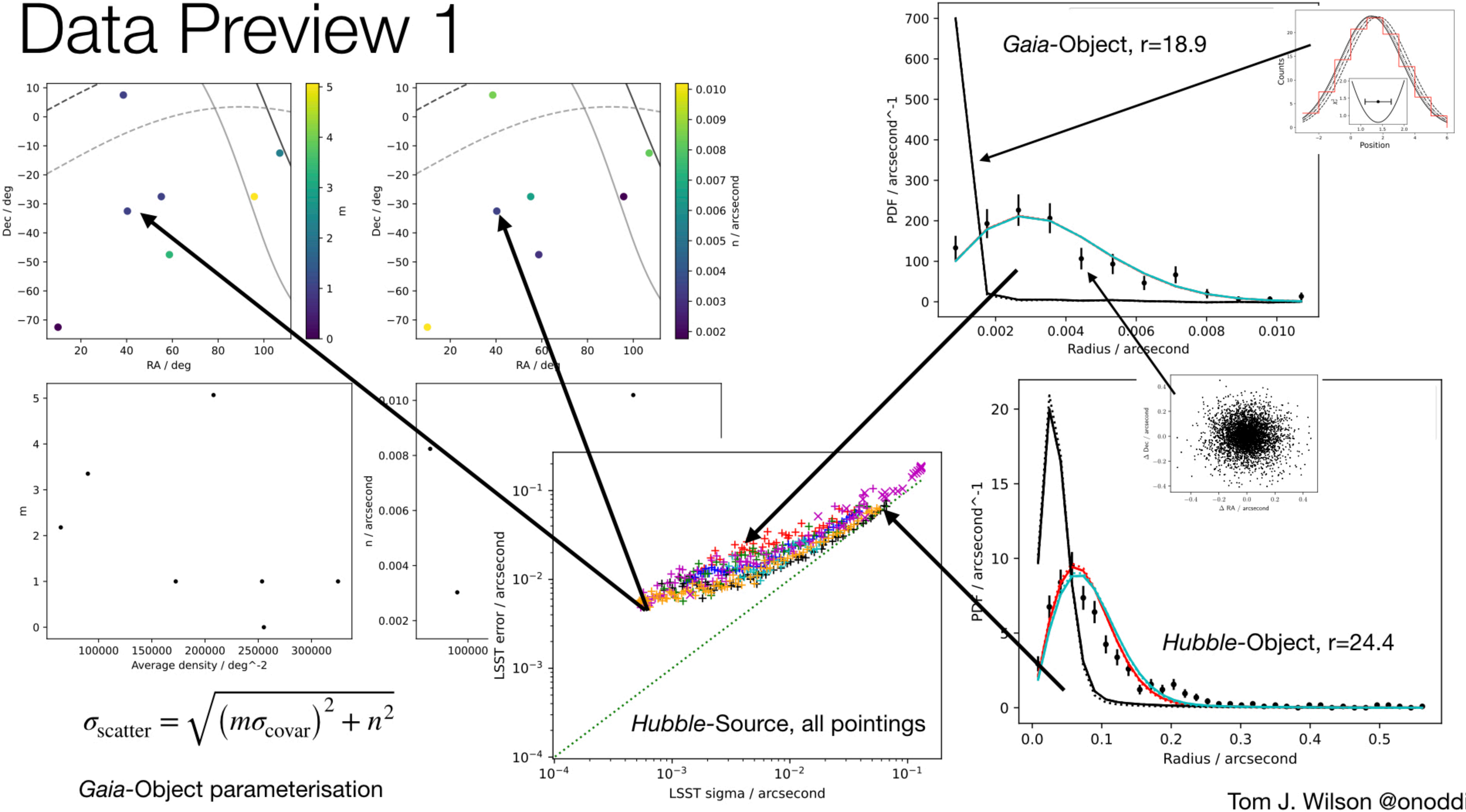
Data Preview 1



$$\sigma_{\text{scatter}} = \sqrt{\left(m\sigma_{\text{covar}}\right)^2 + n^2}$$

Gaia-Object parameterisation

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Data Preview 1

$$\sigma_{\mathrm{scatter}} = \sqrt{\left(m\sigma_{\mathrm{covar}}\right)^2 + \ldots}$$

Gaia-Object parameterisation

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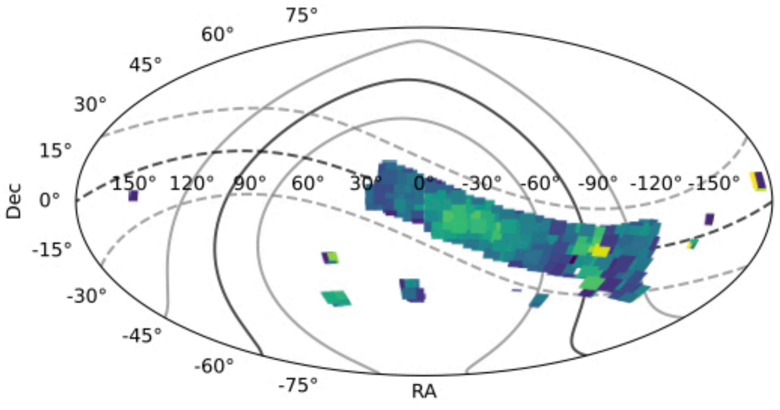
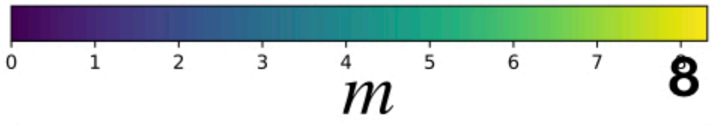
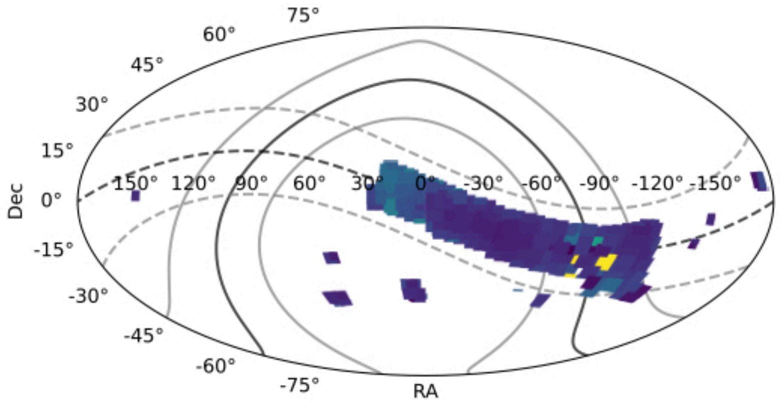
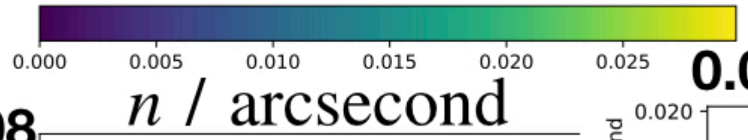
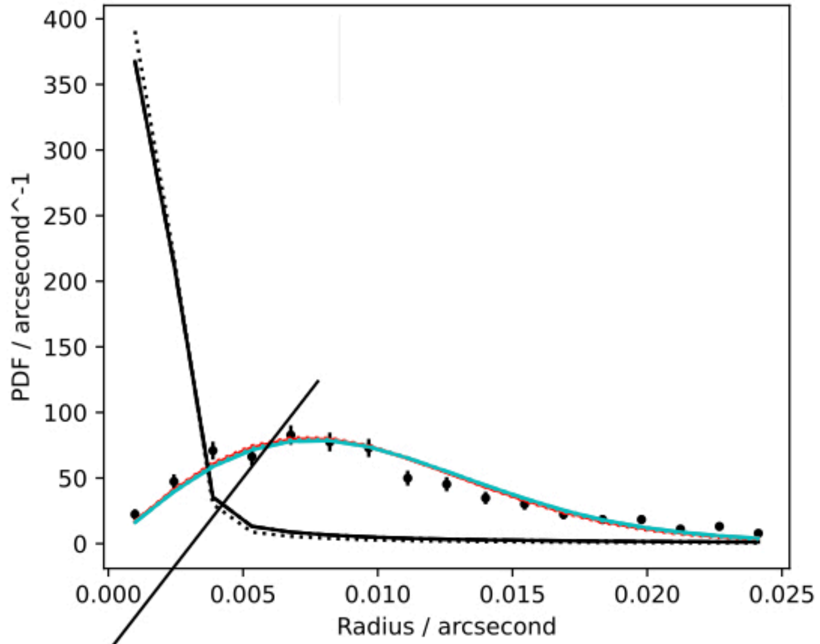
Data Preview **2**: Object-*Gaia*

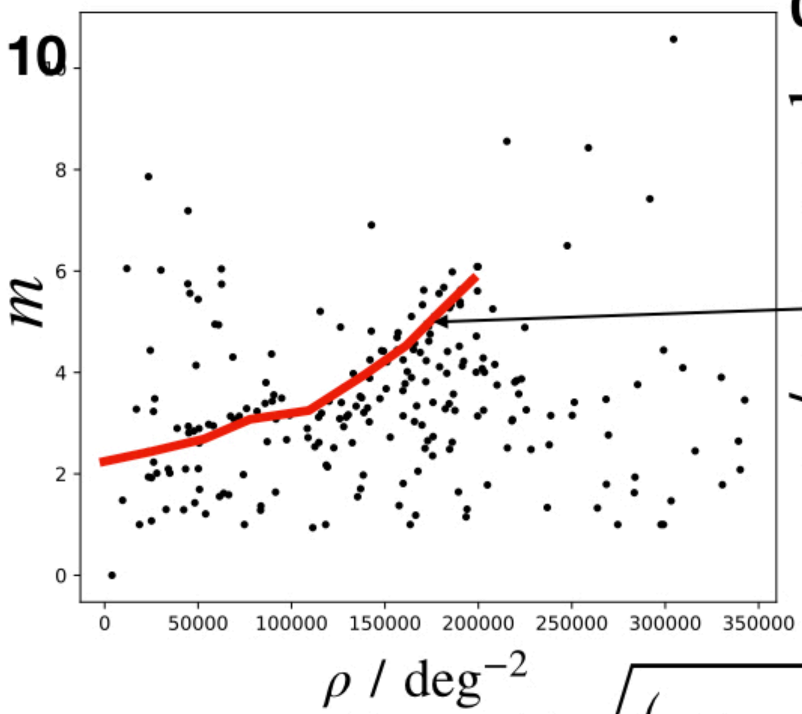


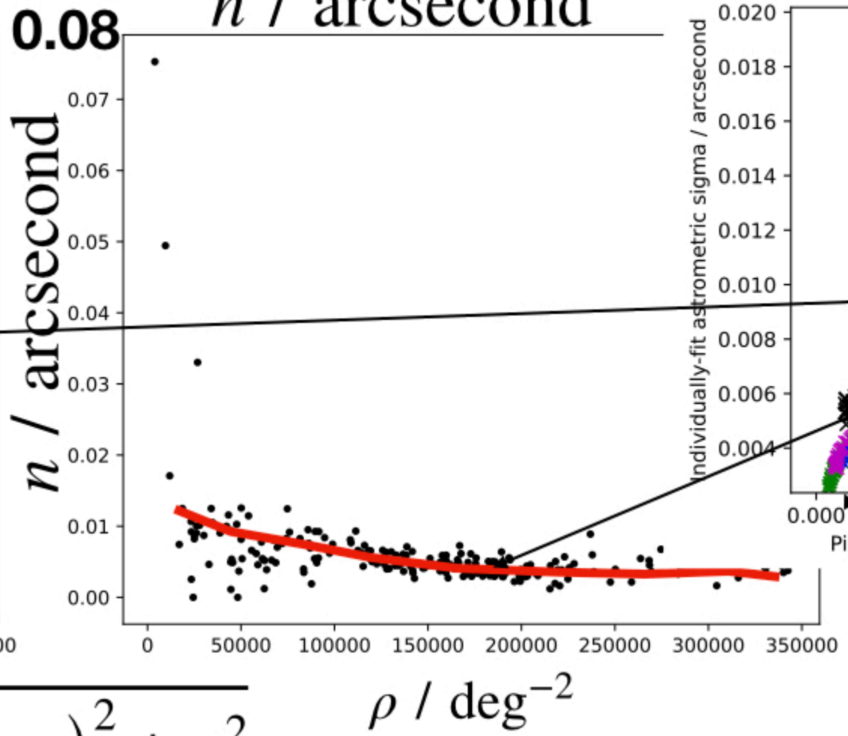


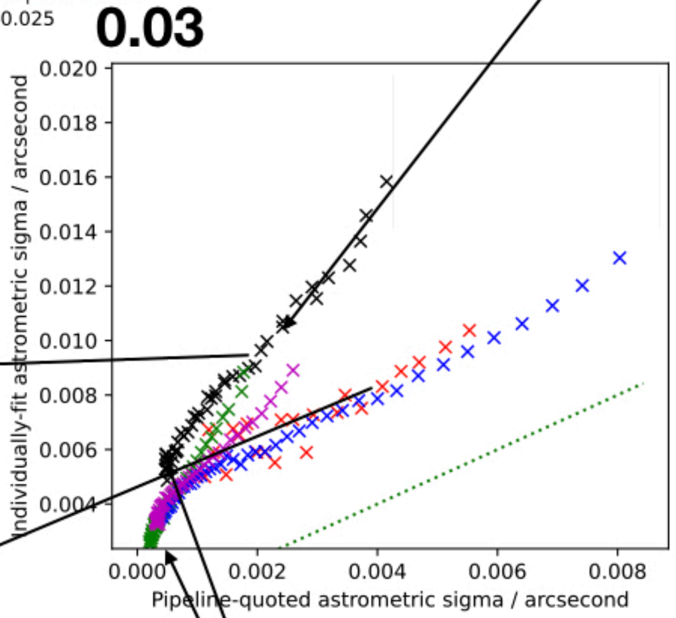


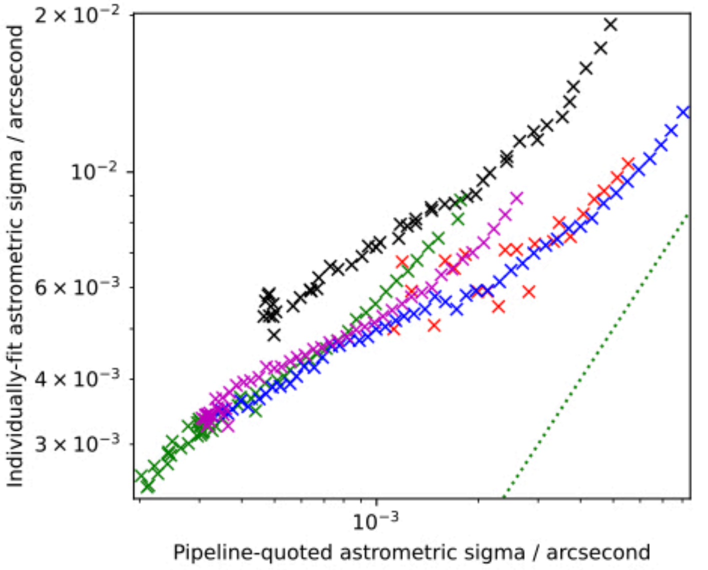












$$\sigma_{\text{scatter}} = \sqrt{\left(m\sigma_{\text{covar}}\right)^2 + n^2}$$

* fits drawn with the “draw with pen” keynote tool, no maths used

* ***Gaia* limited to five- and six-parameter solutions to keep its astrometry contribution to well below 1 mas**

*** saturation**

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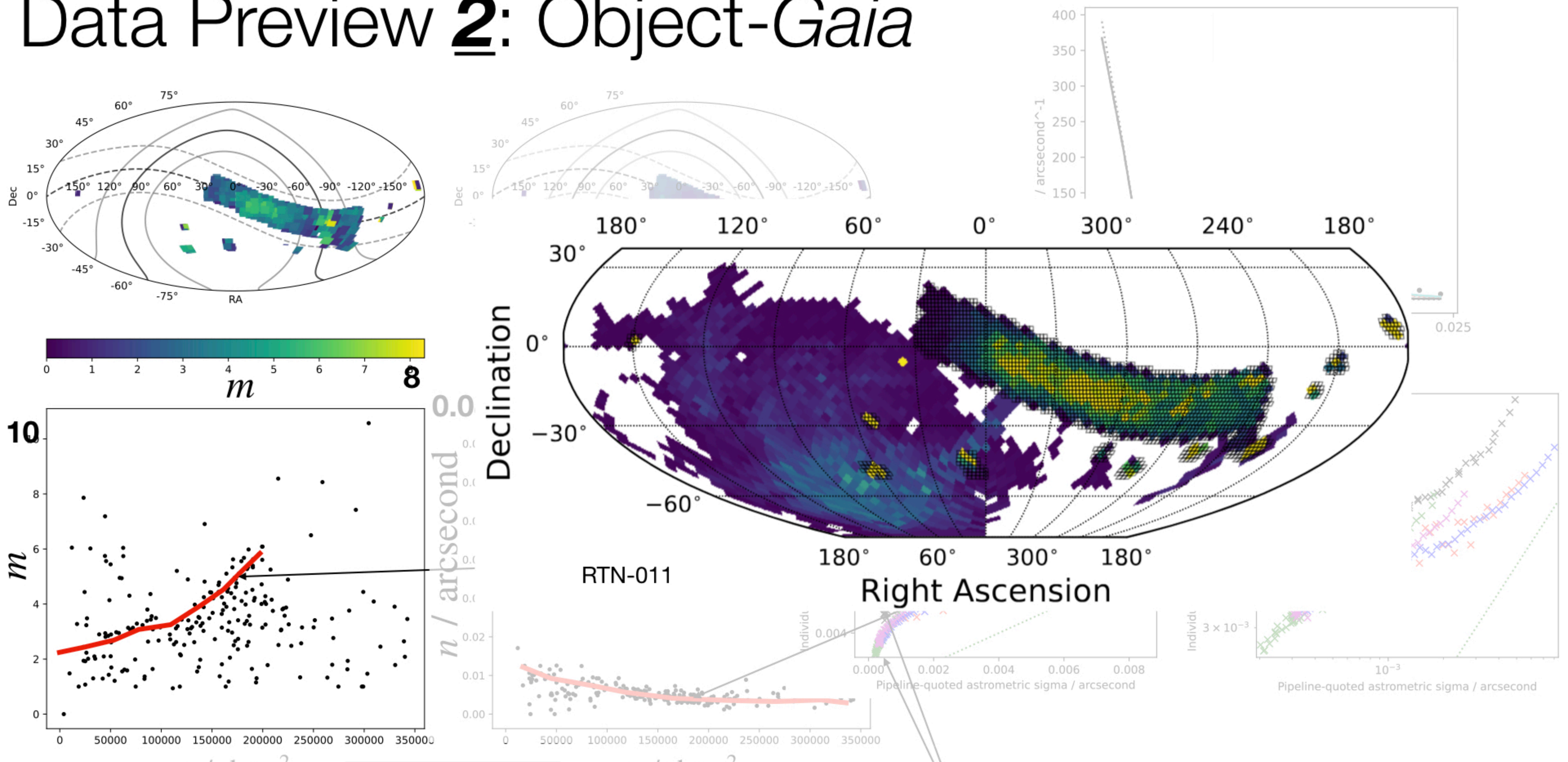
Data Preview **2**: Object-*Gaia*



$$\sigma_{\rm scatter} = \sqrt{\left(m\sigma_{\rm covar}\right)^2 + n^2}$$

* fits drawn with the “draw with pen” keynote tool, no maths used

* *Gaia* limited to five- and six-parameter solutions to keep its astrometry contribution to well below 1 mas

* saturation

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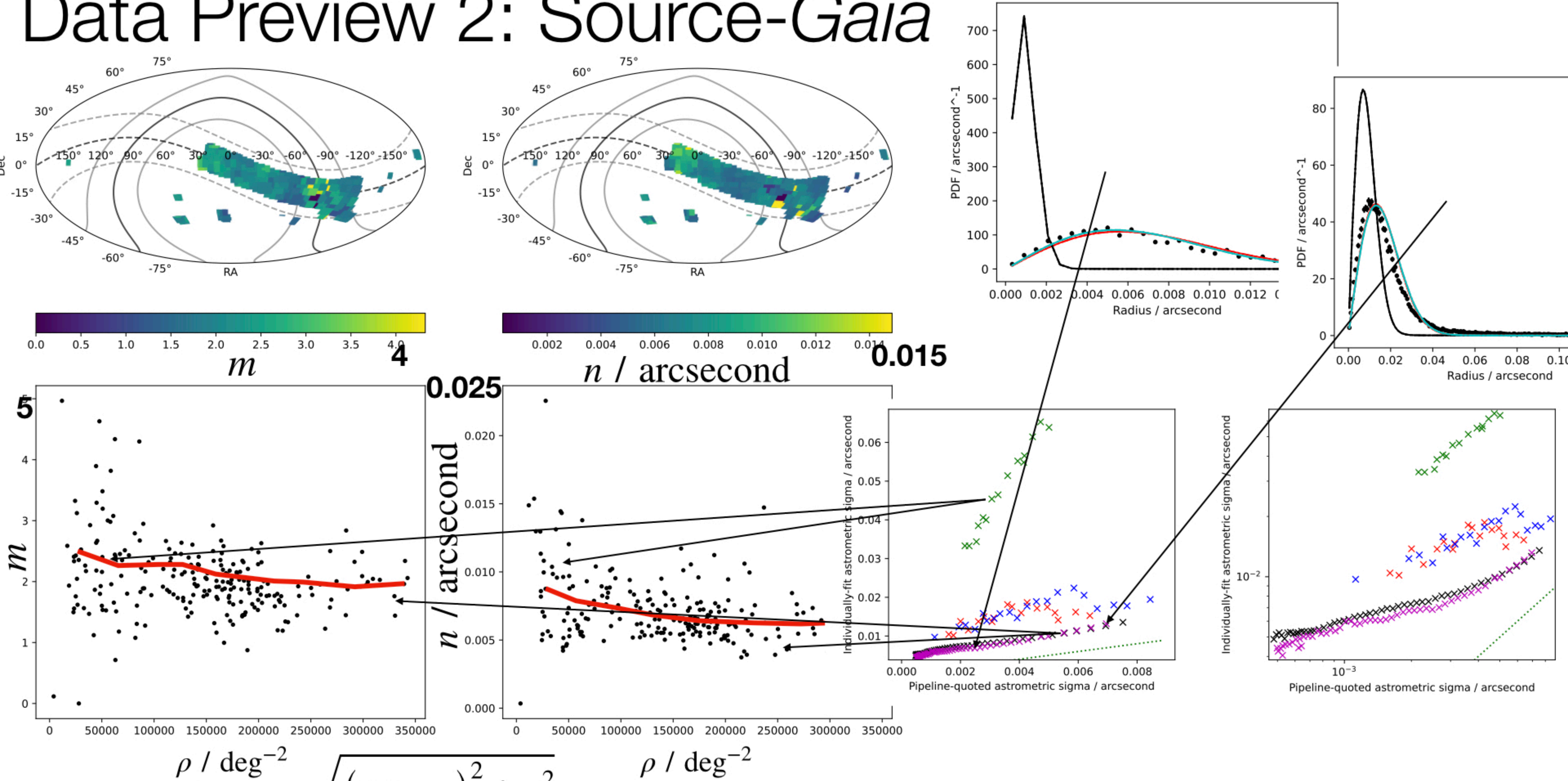
Data Preview 2: Source-*Gaia*



$$\sigma_{\mathrm{scatter}} = \sqrt{\left(m\sigma_{\mathrm{covar}}\right)^2 + n^2}$$

* fits drawn with the “draw with pen” keynote tool, no maths used

* *Gaia* limited to five- and six-parameter solutions to keep its astrometry contribution to well below 1 mas

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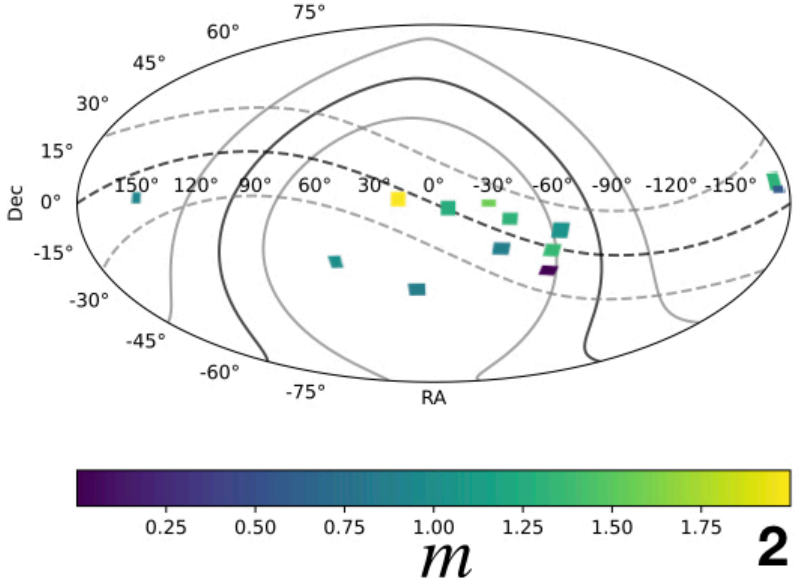
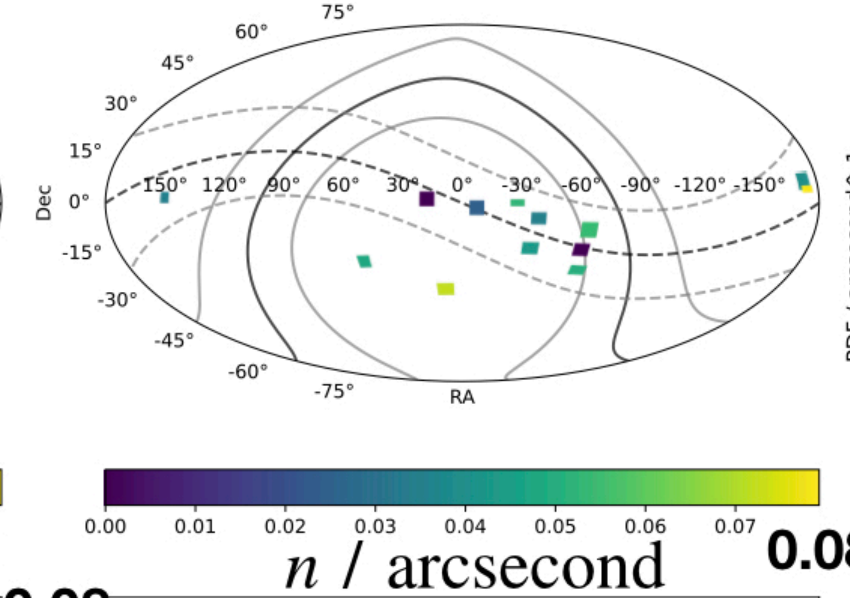
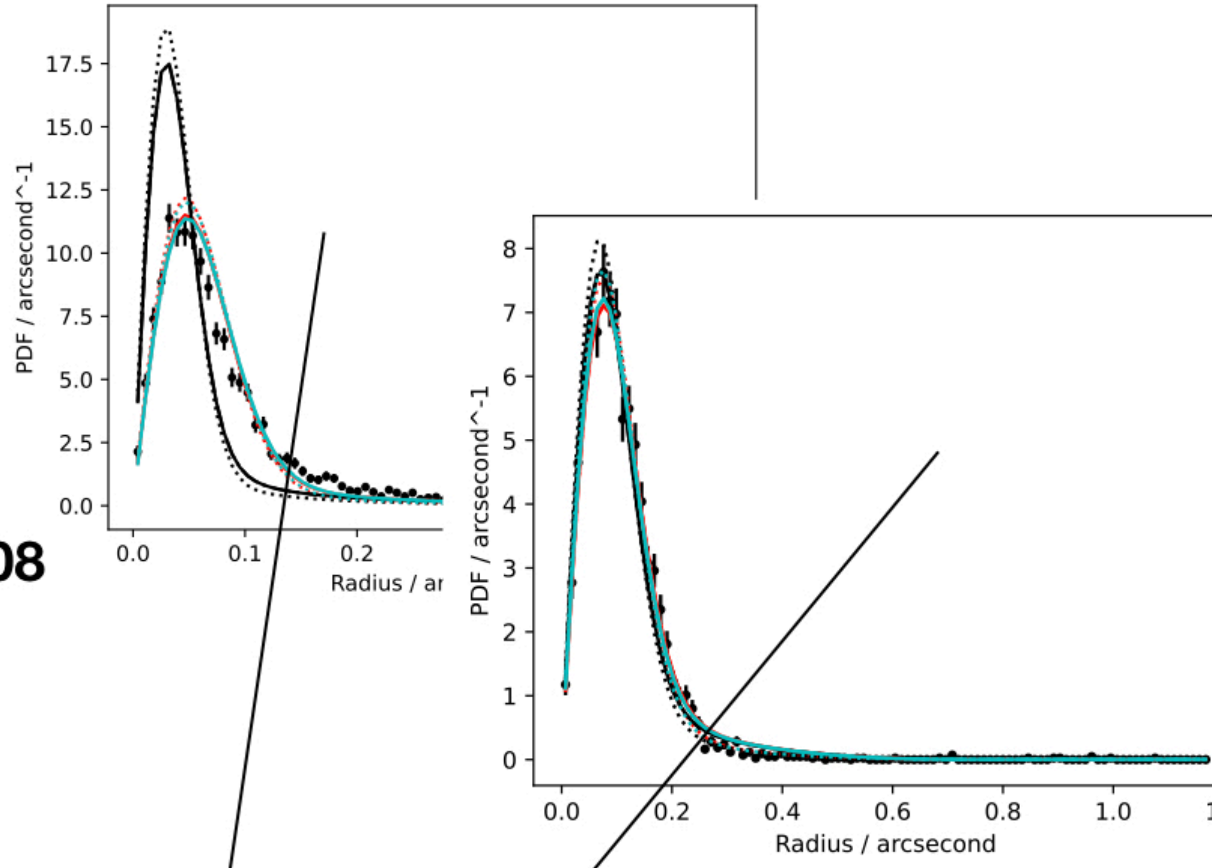
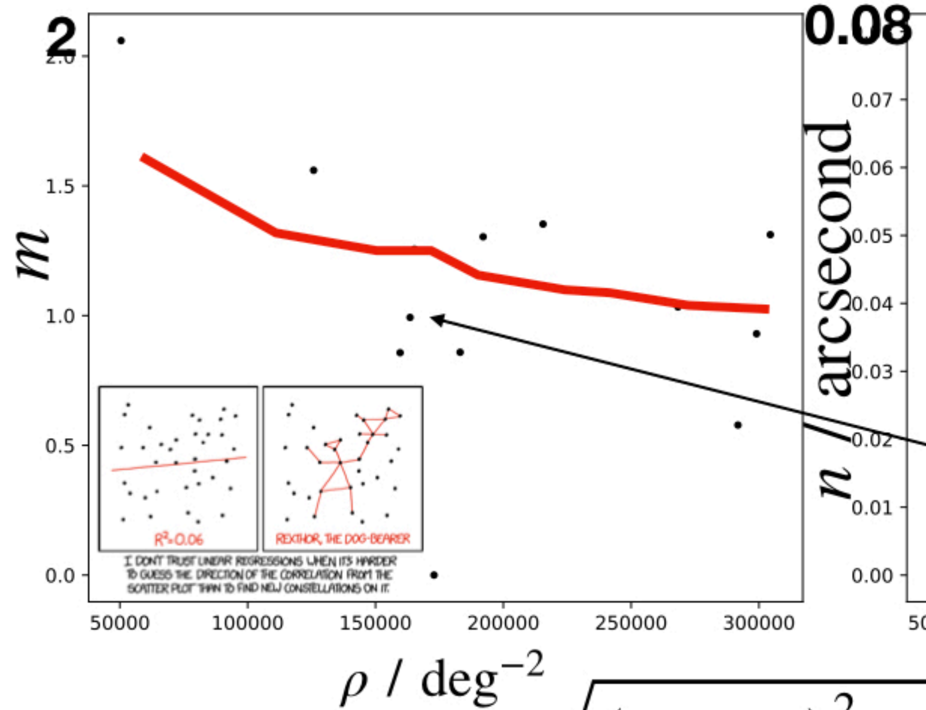
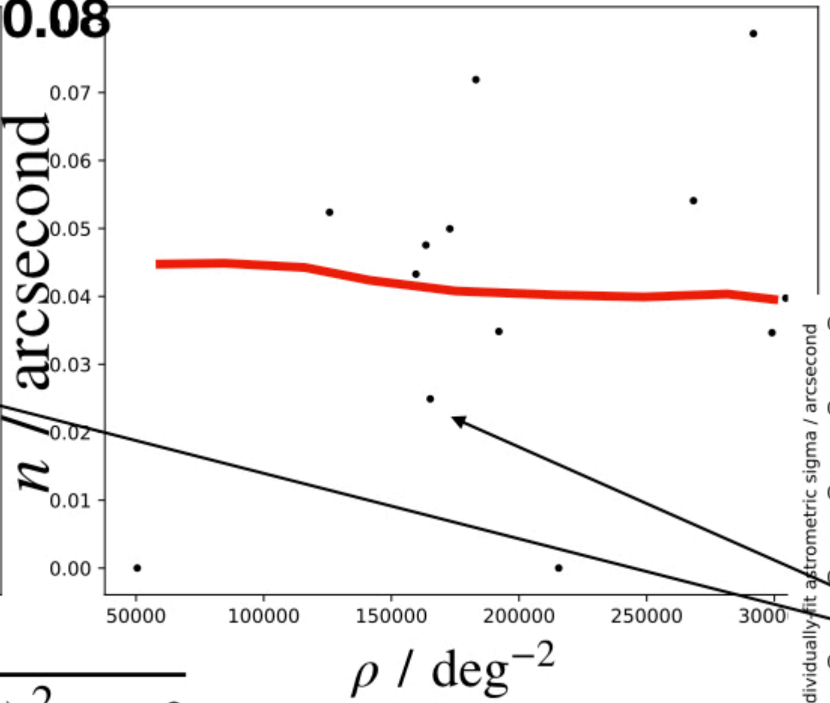
Data Preview 2: Object-*Hubble*

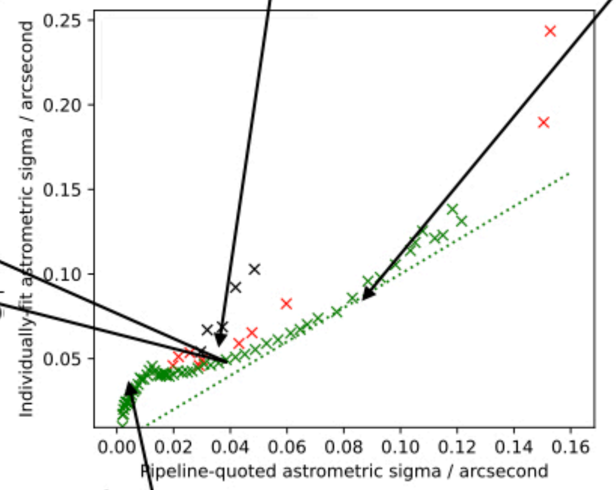


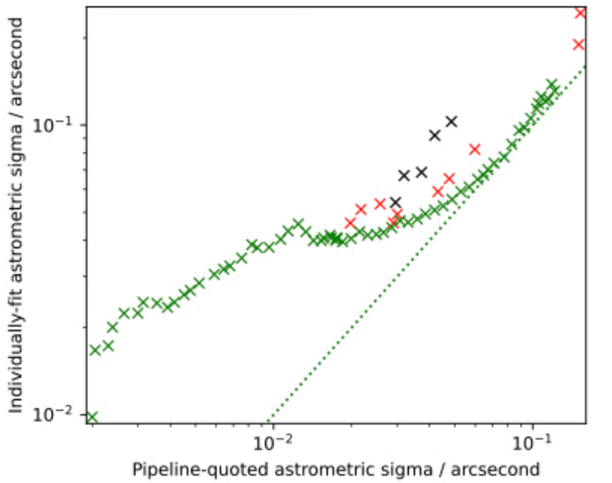












$$\sigma_{\text{scatter}} = \sqrt{\left(m\sigma_{\text{covar}}\right)^2 + n^2}$$

xkcd 1725

*** fits drawn with the "draw with pen" keynote tool, no maths used**

*** *Hubble* astrometry isn't as good as *Gaia*'s, but we have removed the estimated ~15 mas HSC contribution from these results**

*** saturation?**

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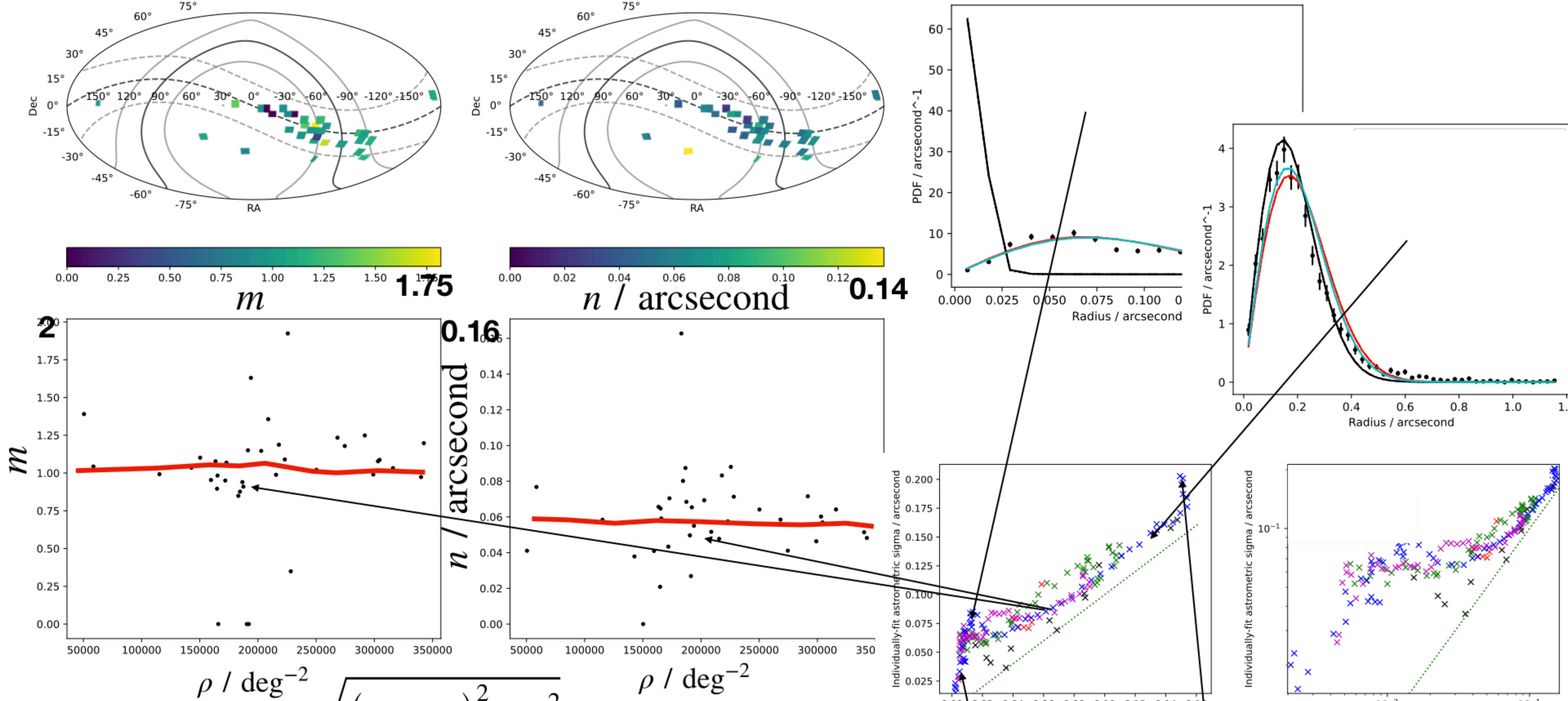
Data Preview 2: Source-*Hubble*



$$\sigma_{\mathrm{scatter}} = \sqrt{\left(m\sigma_{\mathrm{covar}}\right)^2 + n^2}$$

* fits drawn with the “draw with pen” keynote tool, no maths used

* ***Hubble*** **astrometry isn’t as good as** ***Gaia*****’s, but we have removed the estimated ~15 mas HSC contribution from these results**

*** saturation?**

*** LSST completeness!**

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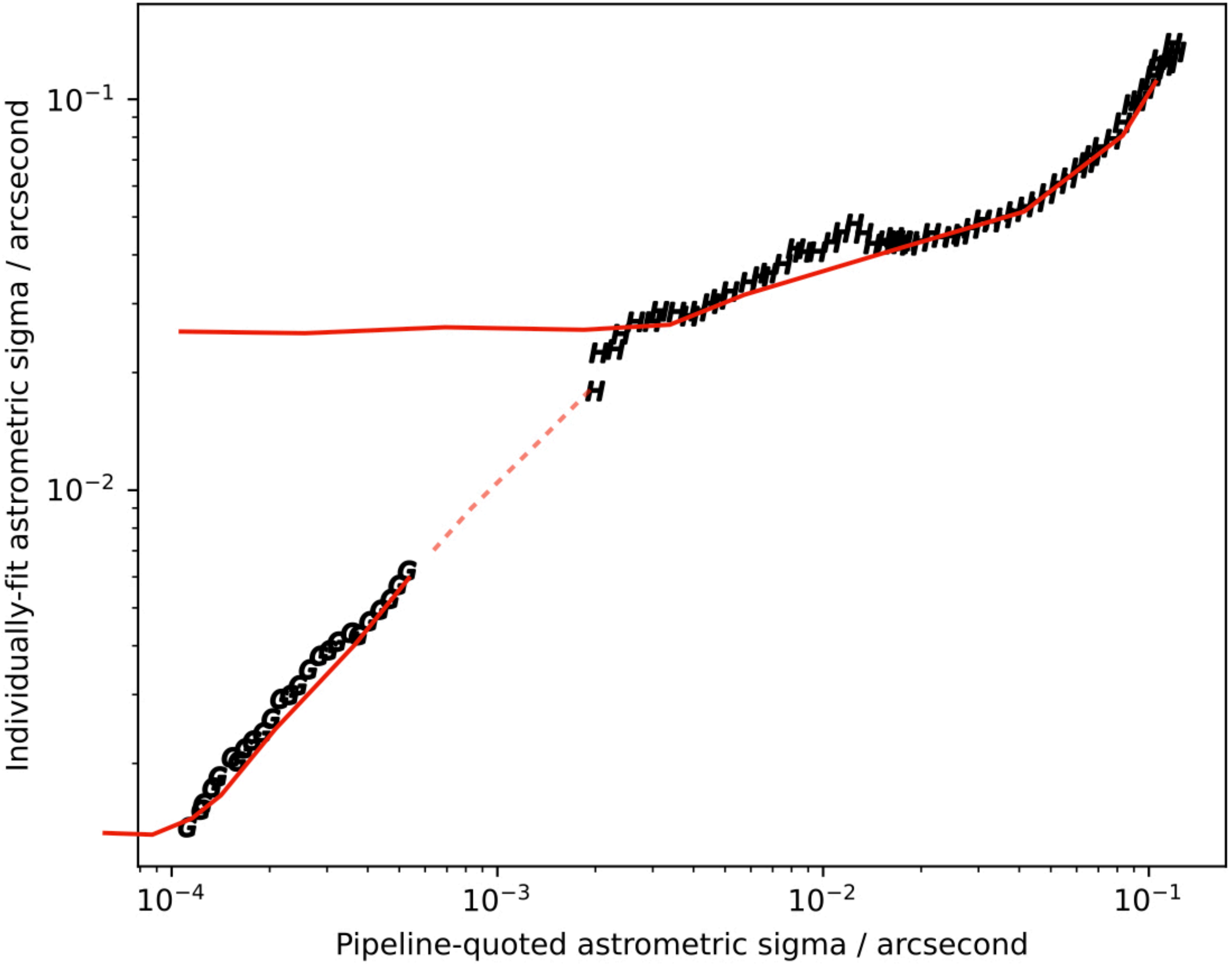
Data Preview 2: *Hubble* Systematic Precision *n*



* fits drawn with the “draw with pen” keynote tool, no maths used

* ***Hubble*** **astrometry isn't as good as *Gaia*'s, but we have removed the estimated ~15 mas HSC contribution from these results**

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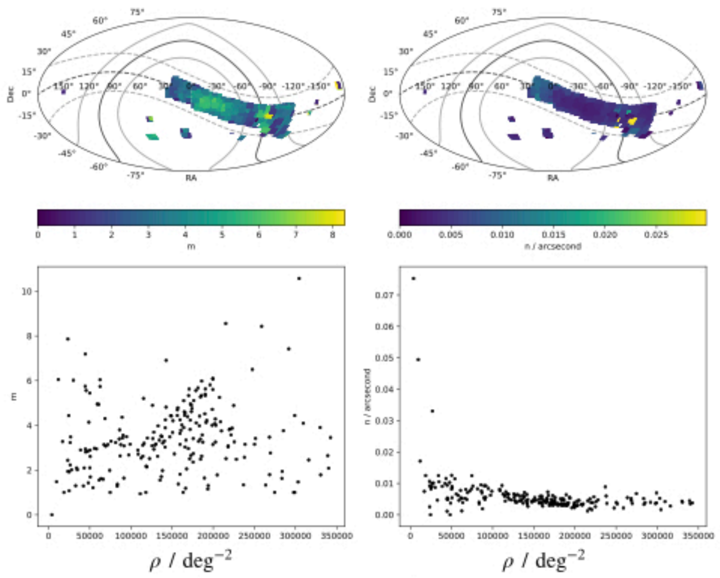
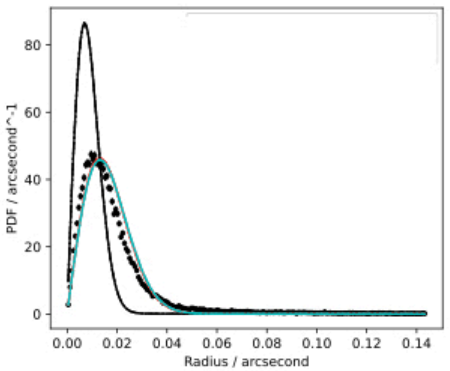
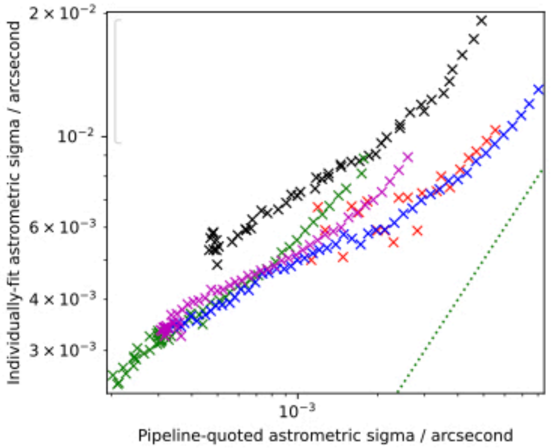
Conclusions



$$\sigma_{\mathrm{scatter}} = \sqrt{\left(m\sigma_{\mathrm{covar}}\right)^2 + n^2}$$

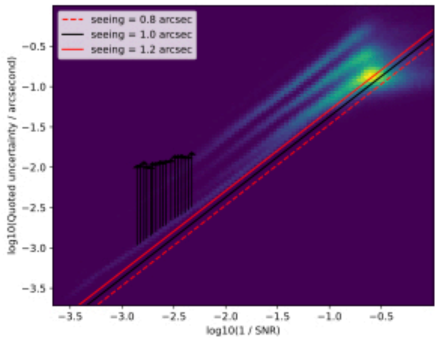


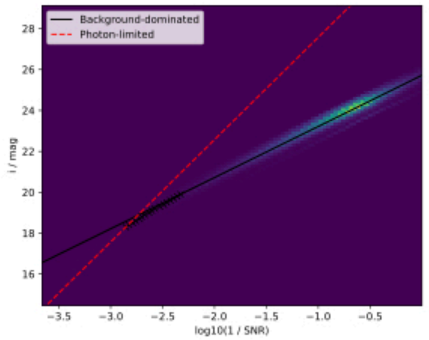


	Gaia **(exquisite astrometry, very bright)**	***Hubble*** **(low coverage, matches LSST depth)**
Object Table (Deep, lower N)	m ~ 2-6, n ~ 5-10 mas?	m ~ 1 maybe, n unconstrained (~50 mas, but probably not)
Source Table (Shallower, repeat observations)	m ~ 2, n ~ 5-10 mas?	m ~ 1, n unconstrained (~50 mas, but probably not)

Three open questions:
why the bright-end systematic floor ~0.005-0.01" (AM1?) &
why the bright-but-not-that-bright slope? (Is it turbulence?)
Is the covariance low or the position-scatter too high?

(Statistical astrometric precisions agree with theory, e.g. King 1983; SNR-magnitude relations are tight and monotonic)





Coming soon to Wilson & Naylor, SITCOMTN-180 (https://sitcomtn-180.lsst.io/)

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