Vera C. Rubin Observatory
Systems Engineering

Determining the Accuracy and Precision of Astrometric Positions and Covariances from the LSST Science Pipelines Using Rubin's Operations Rehearsal 3 Data

University of Exeter

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SITCOMTN-159

https://sitcomtn-159.lsst.io/

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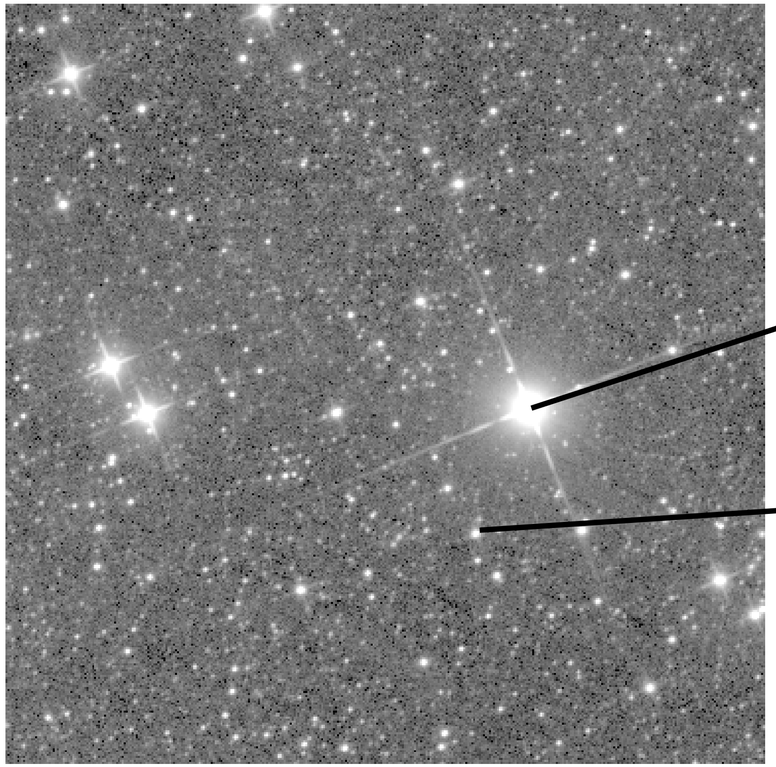
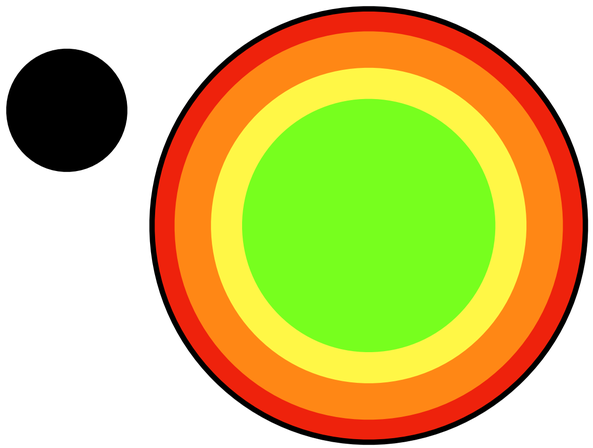
What's In A Photometric Catalogue?

(Ironically, it's half astrometry!)



WISE - Wright et al. (2010)

Source ID	Position (deg)	Uncertainty (arcsecond)	Brightness (mag)	Uncertainty (mag)
1	218.4763	0.073	14.94	0.04
2	218.3951	0.217	20.32	0.15



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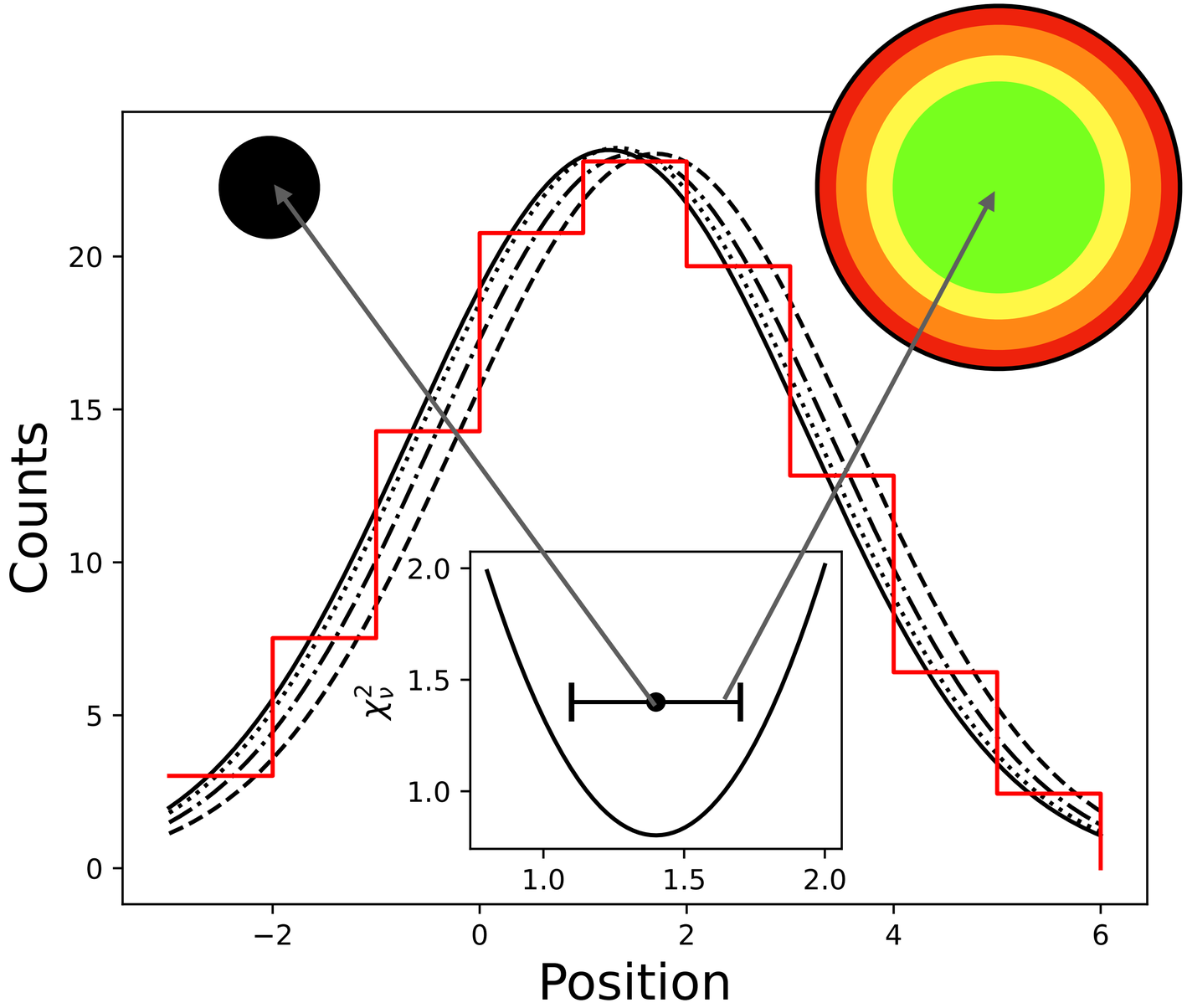
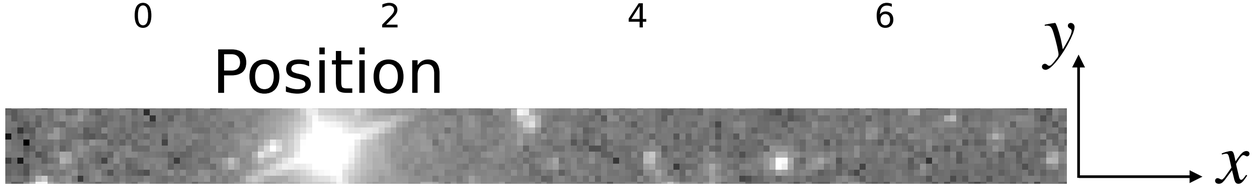
Centroid Positions and Uncertainties



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



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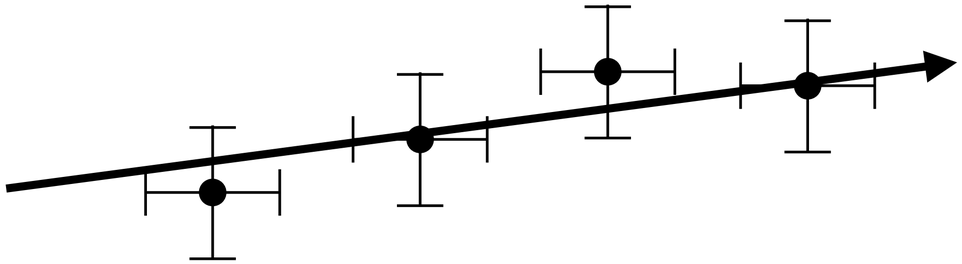
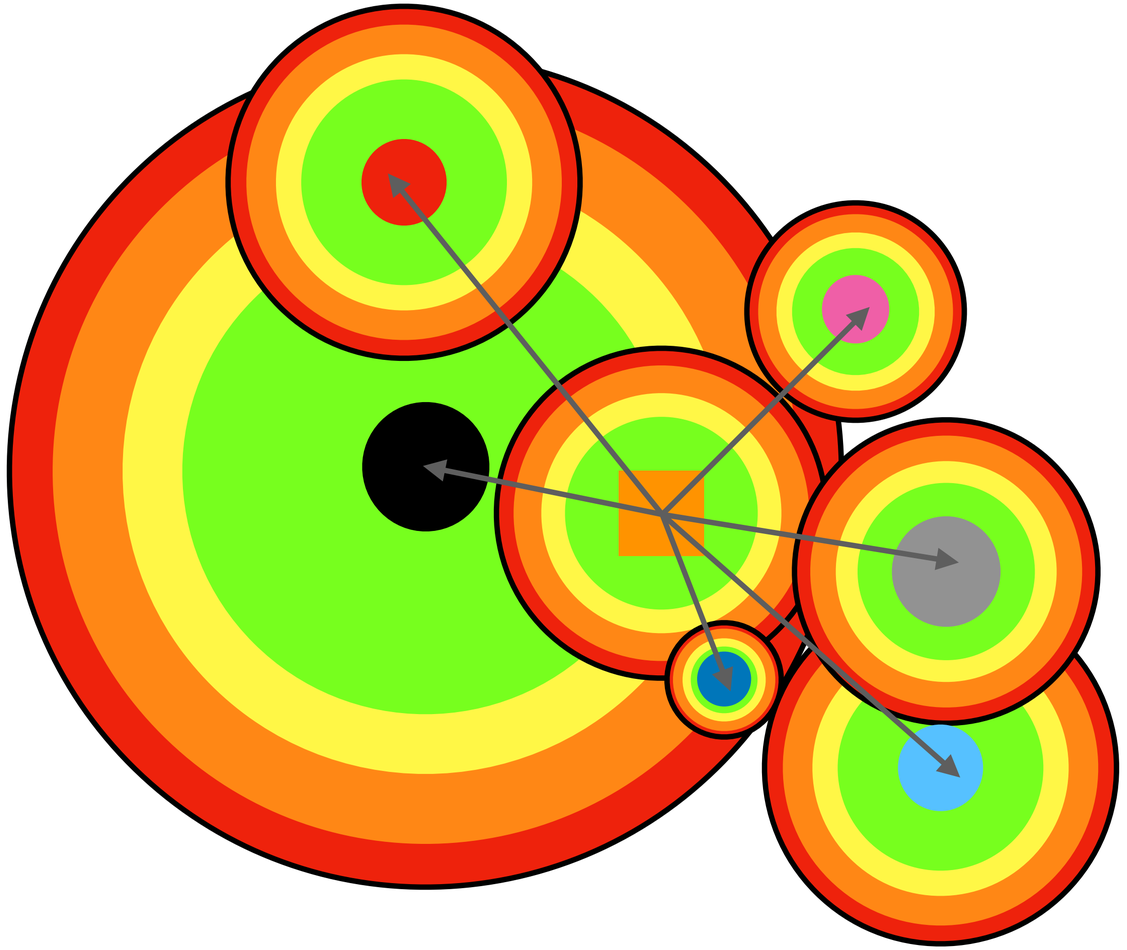
Centroid Positions and Uncertainties

Second-order information such as proper motion and parallax



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



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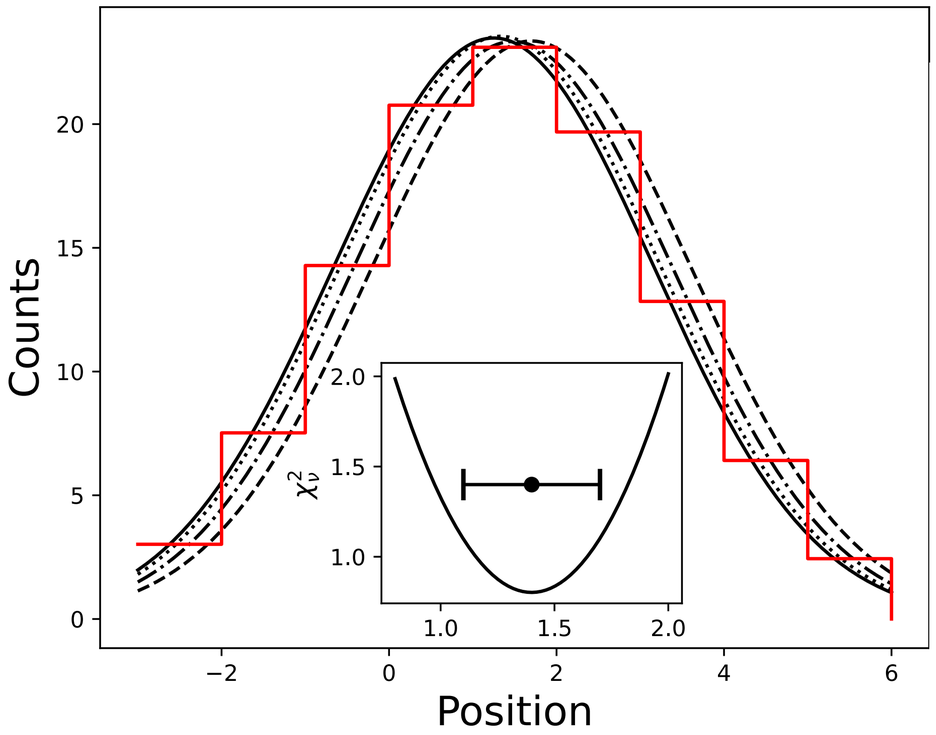
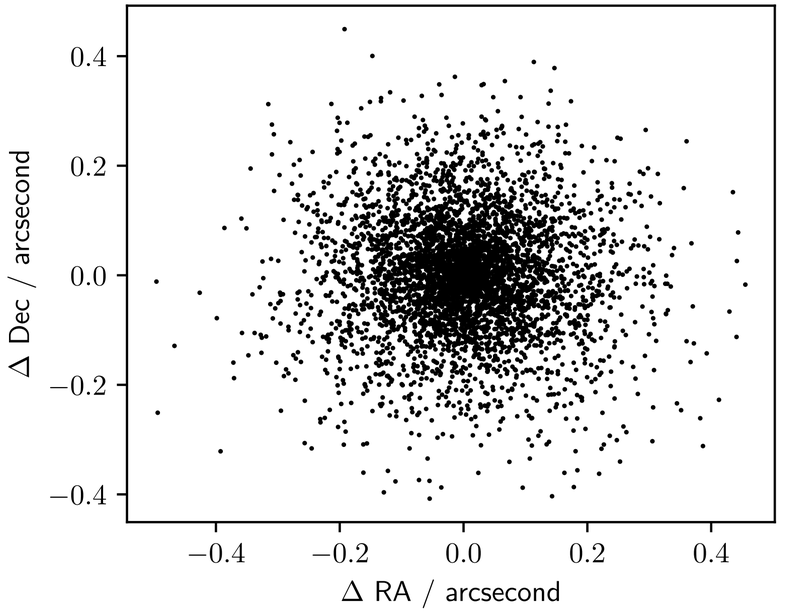
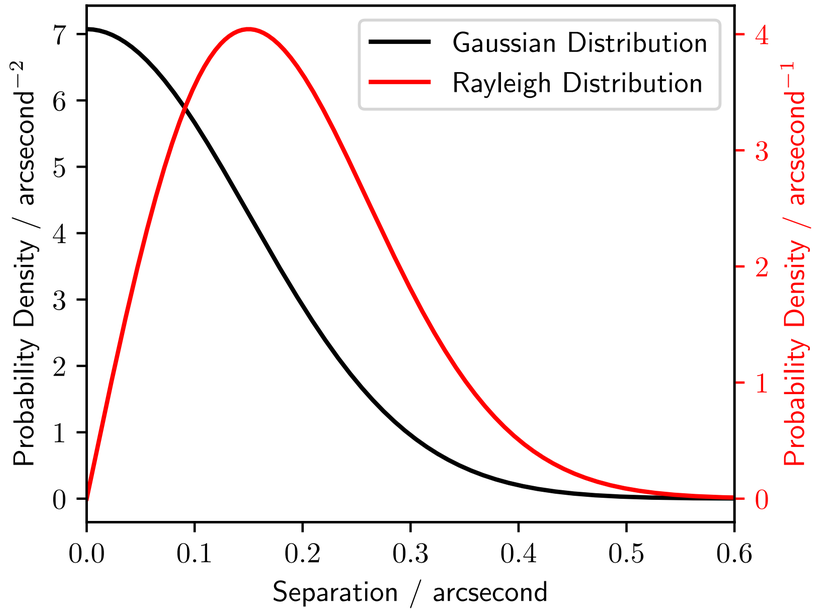
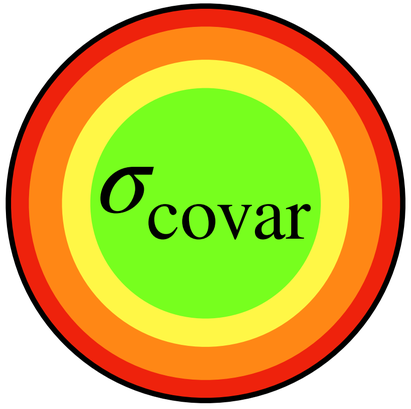
Verifying Pipeline Positions and Precisions

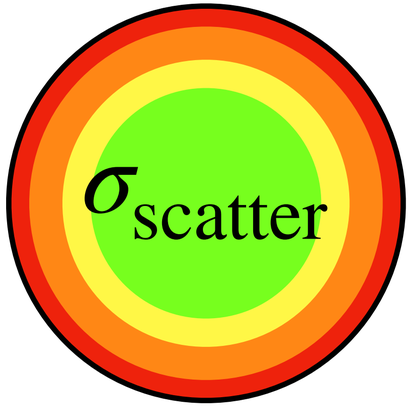


$$g(x, y, \sigma) = (2\pi\sigma^2)^{-1}\exp\left(-\frac{1}{2}\frac{x^2+y^2}{\sigma^2}\right) \longrightarrow g(r, \sigma) = \frac{r}{\sigma^2}\exp\left(-\frac{1}{2}\frac{r^2}{\sigma^2}\right)$$









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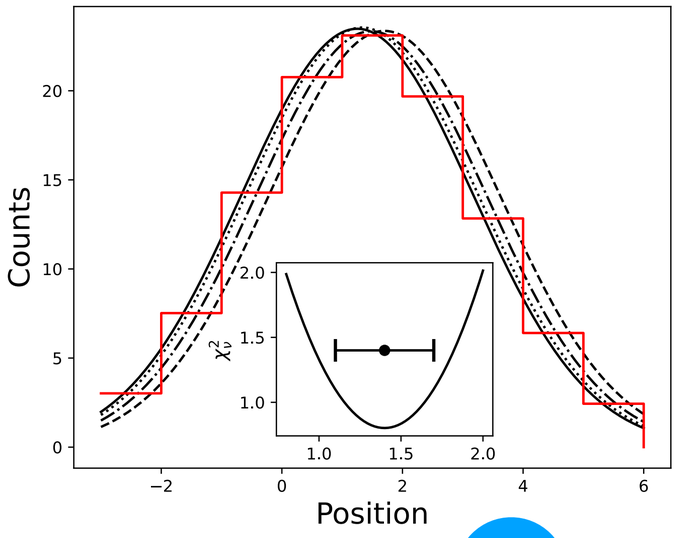
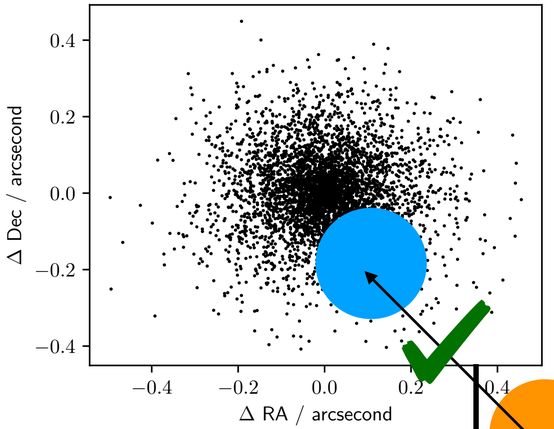
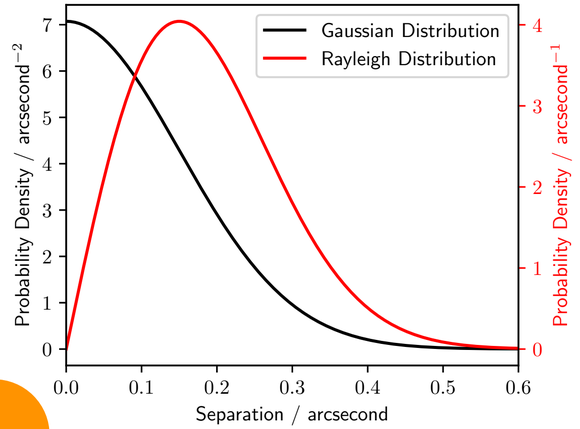
Verifying Pipeline Positions and Precisions



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





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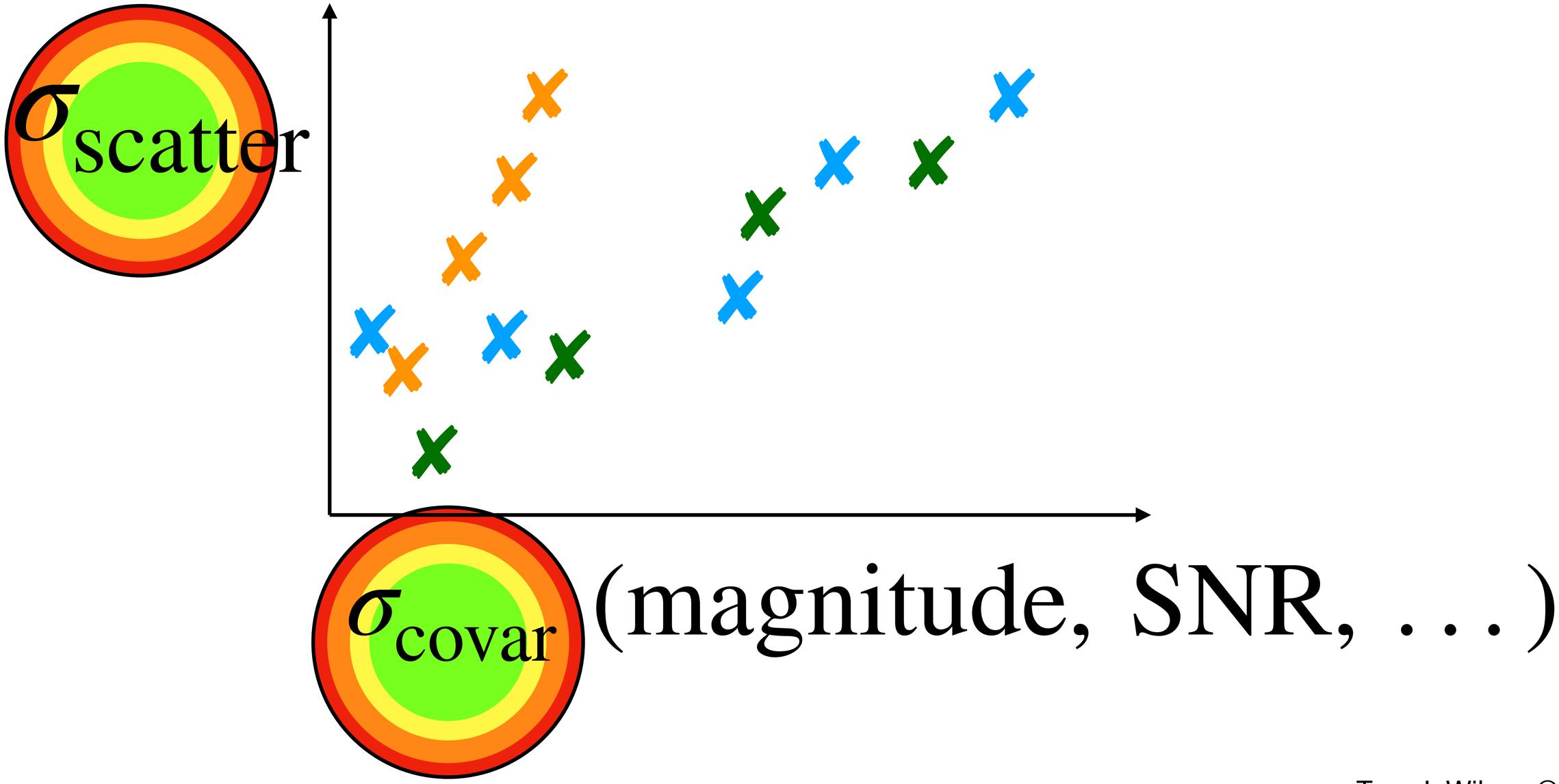
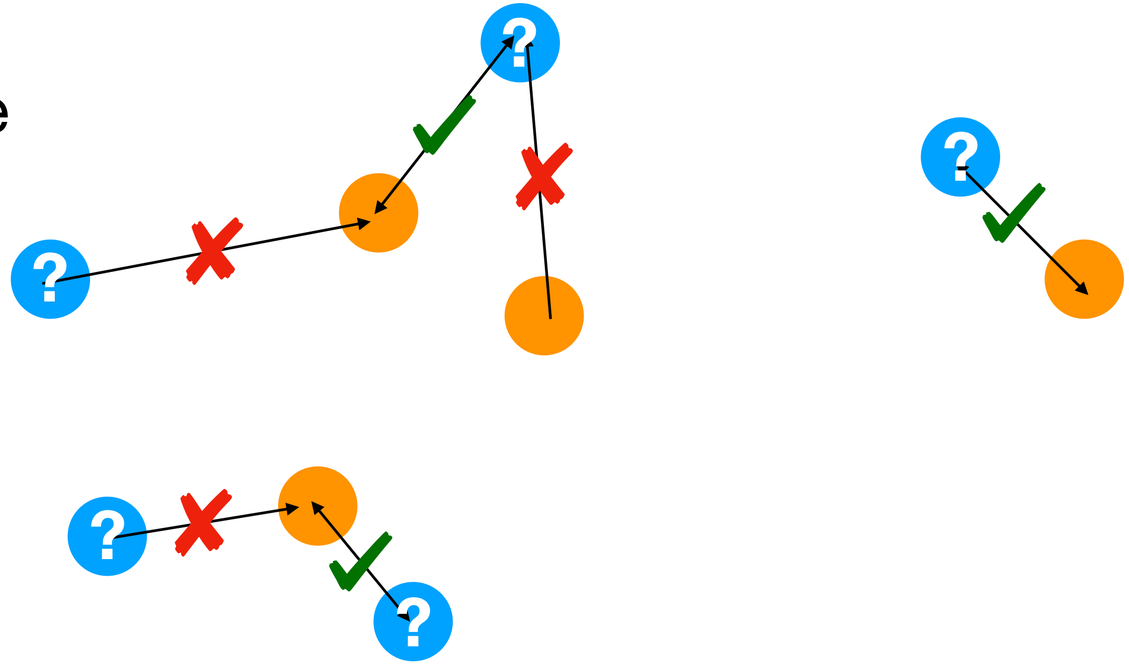
Verifying Pipeline Precisions

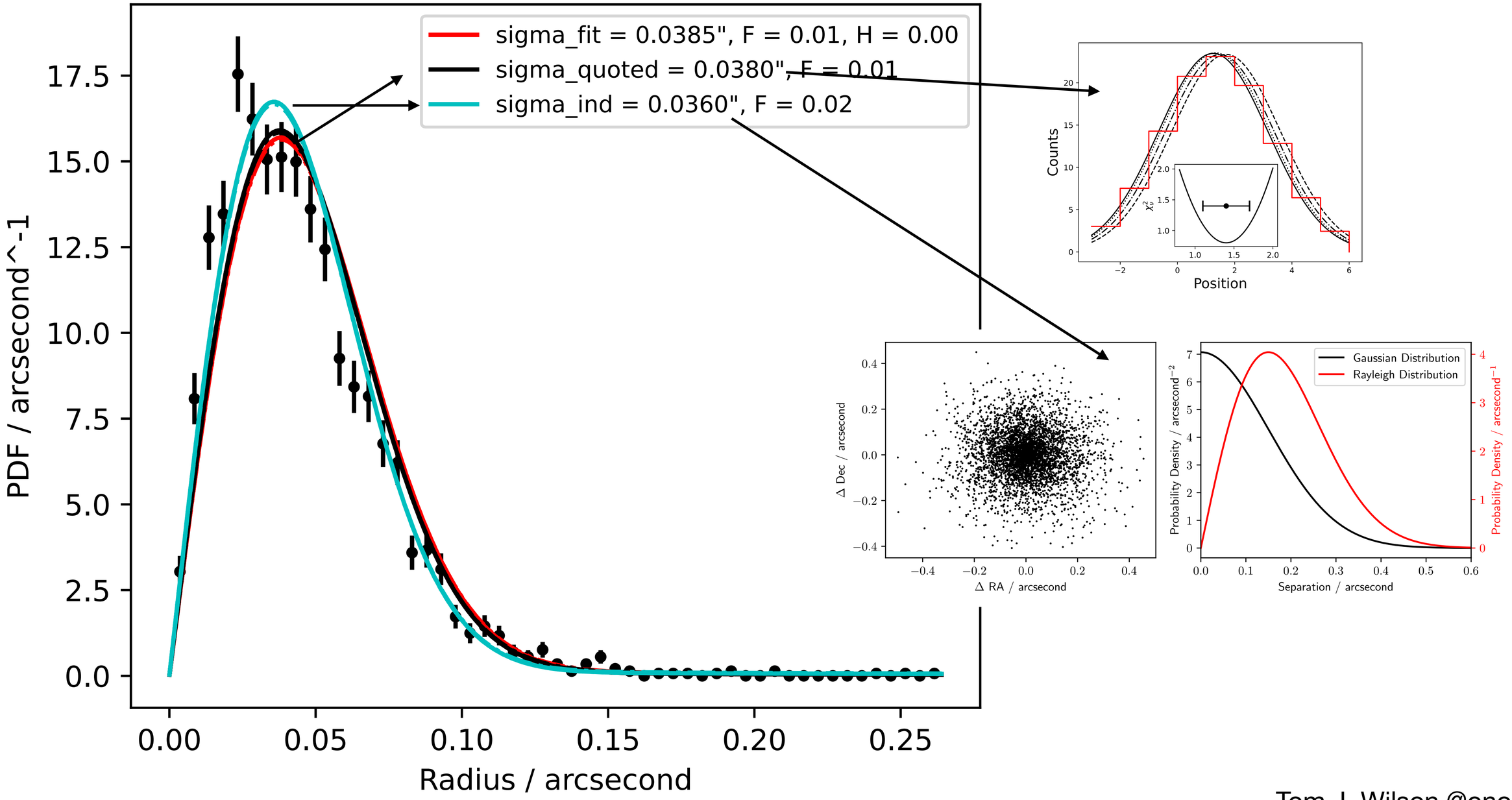


“Deviation from True Position”

- Normally we can’t say what the *real* deviation from “truth” is.
- Higher-astrometric-precision datasets, like *Gaia*, are usually the best you can do.
- But OR3 actually does give a truth table since it’s a simulation — very handy!
- Operations Rehearsal 3 was a simulated run of a few nights’ of the LSST for readiness purposes.



Source table, “250 2” pointing, i=22.75



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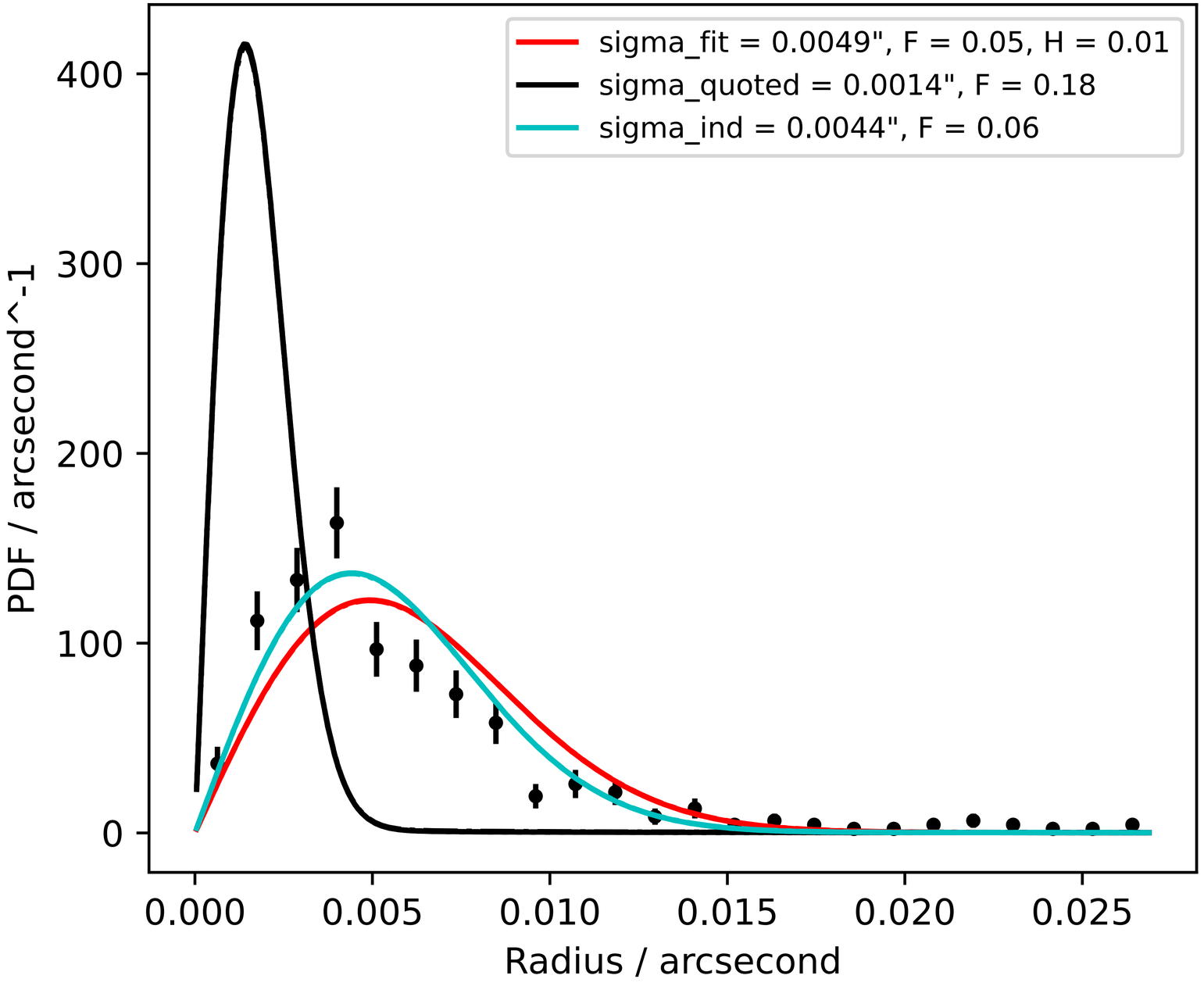
Source table, “250 2” pointing, *i*=18.5



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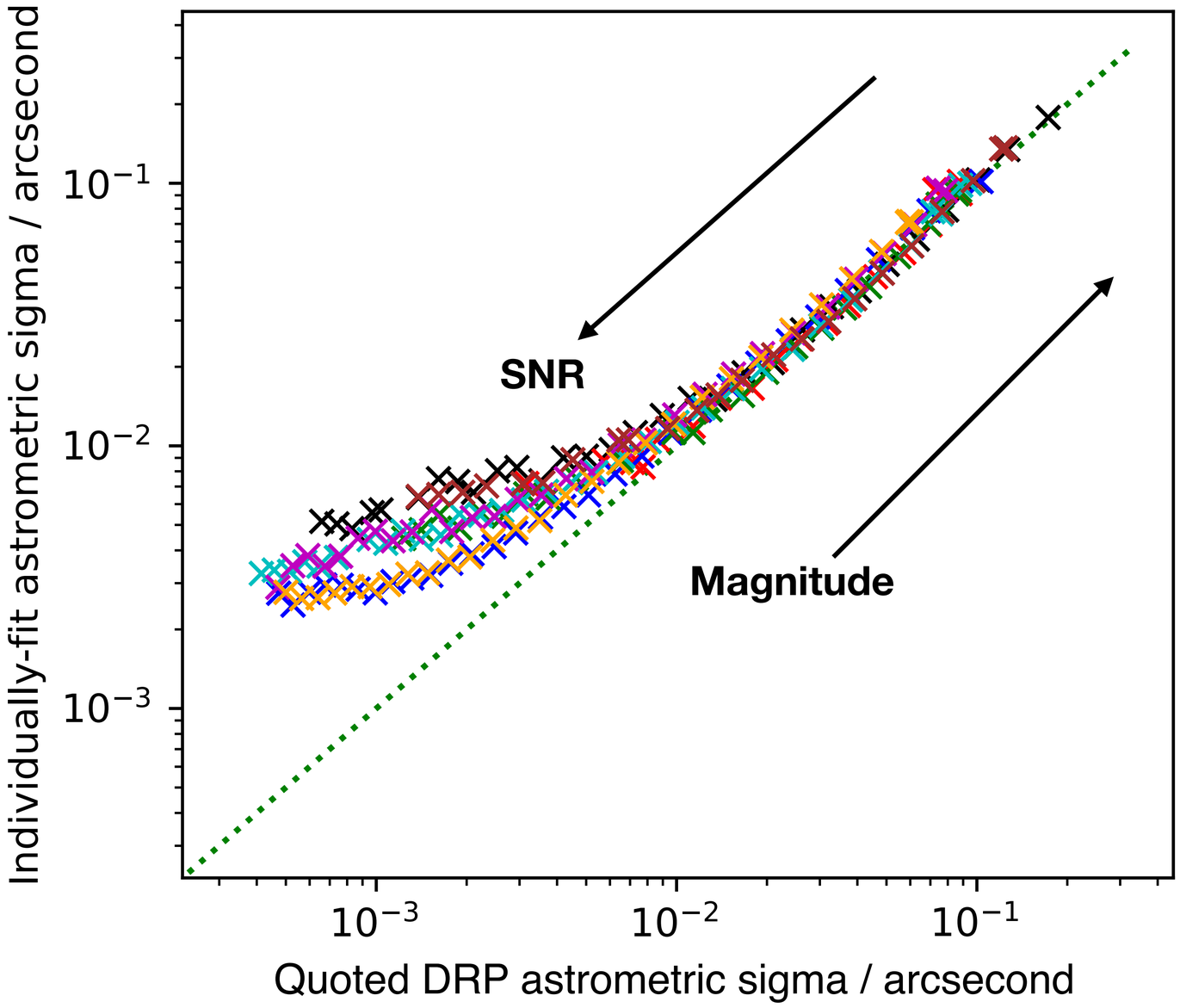
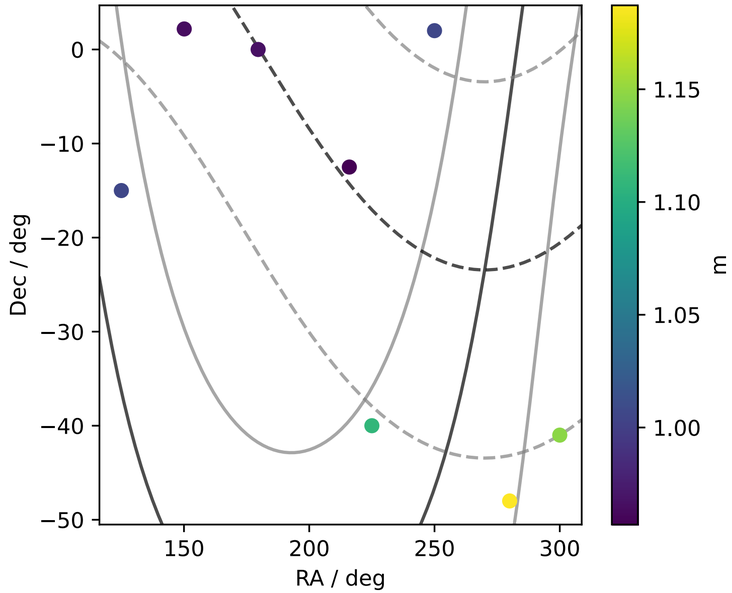
Source table, all pointings

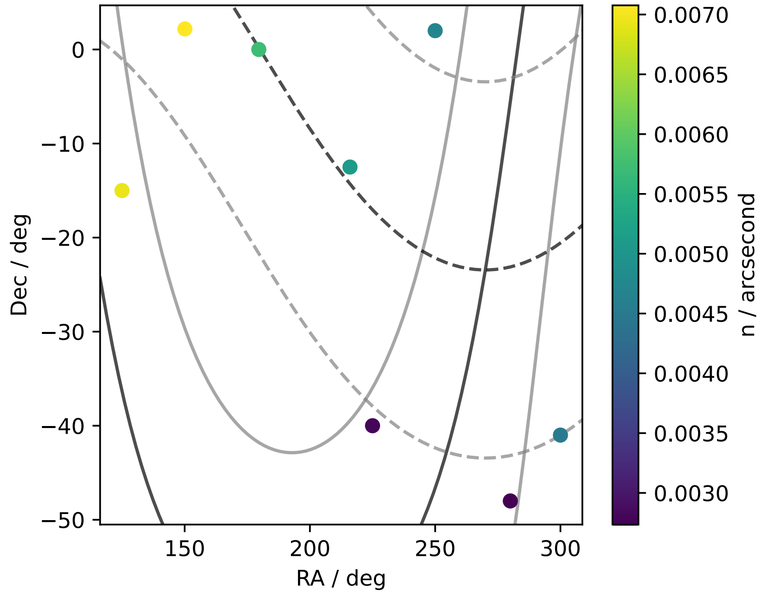


Source table, all pointings

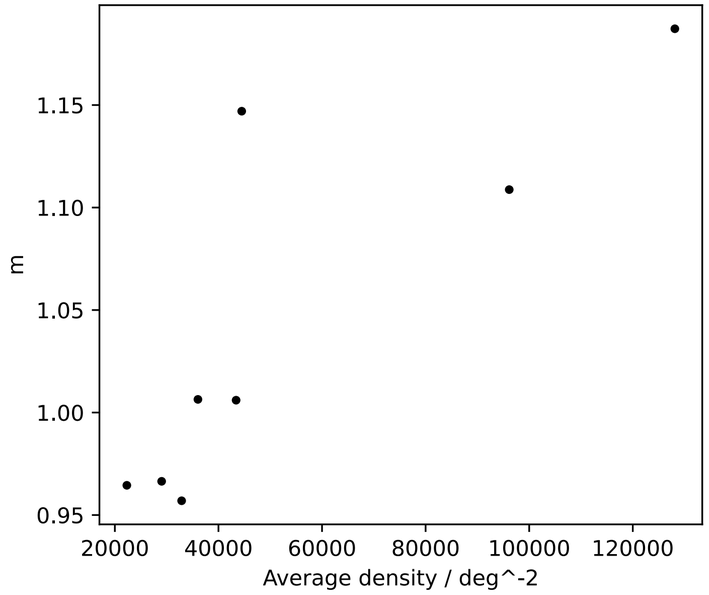
m

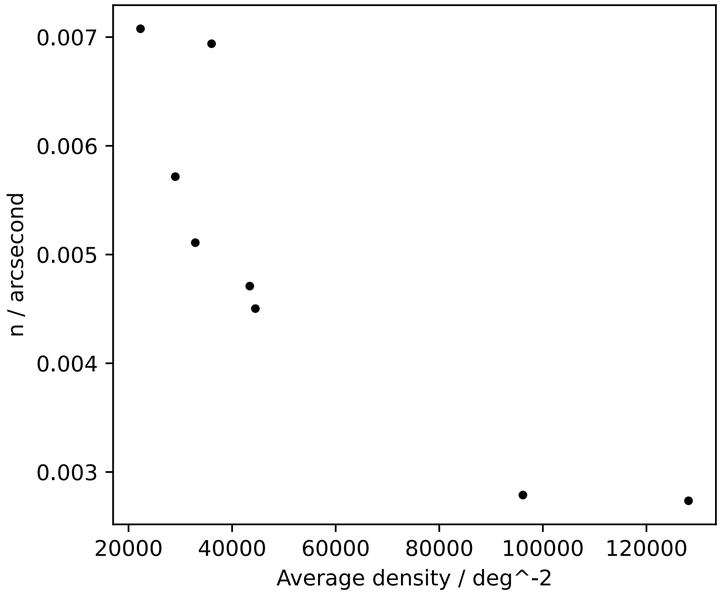


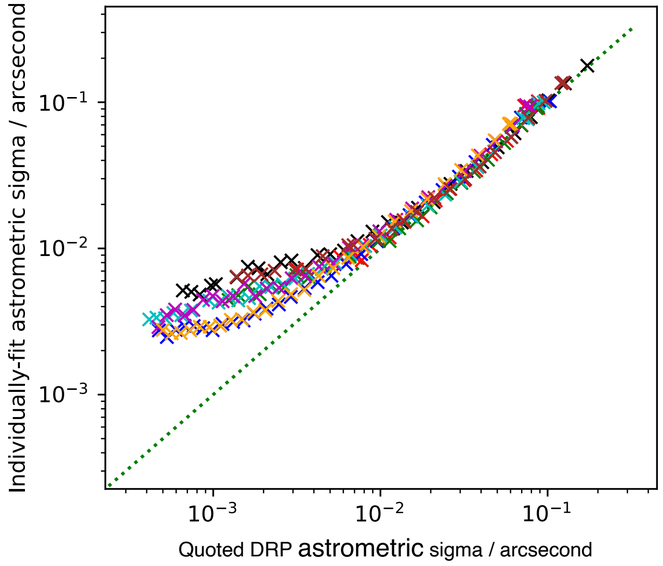
n



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







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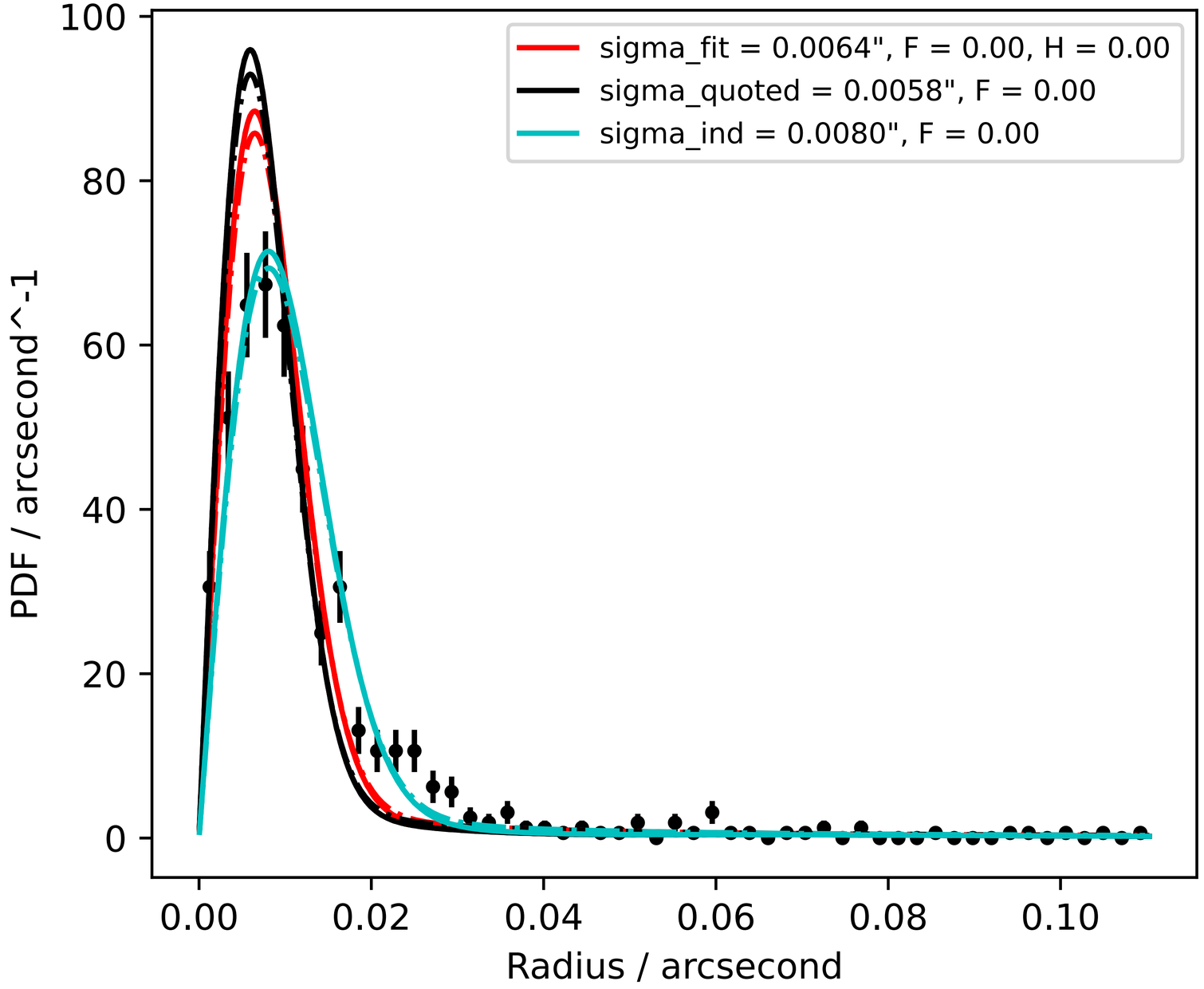
Object table, tract 3384, *i*=22.5



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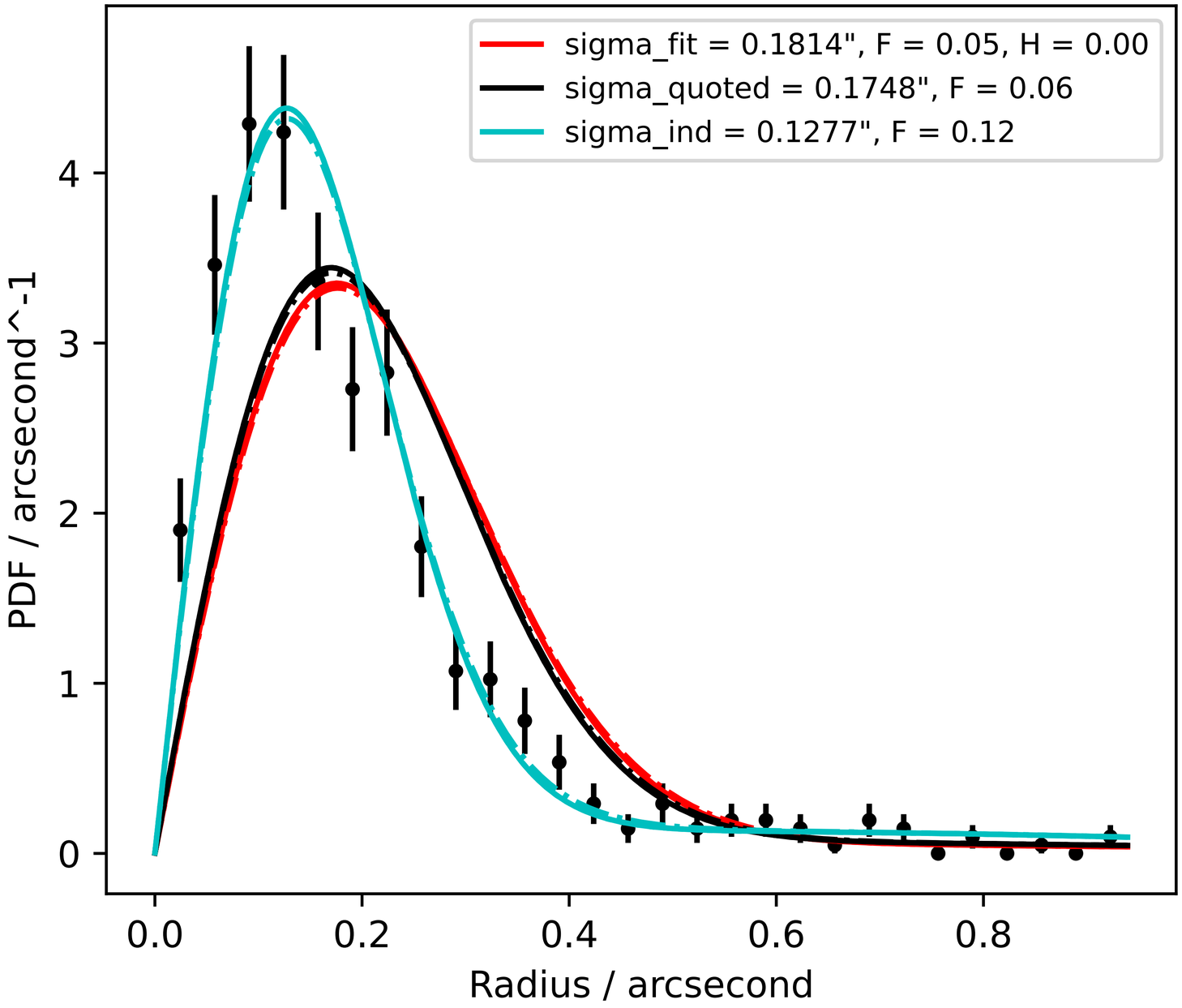
Object table, tract 3384, *i*=25.75



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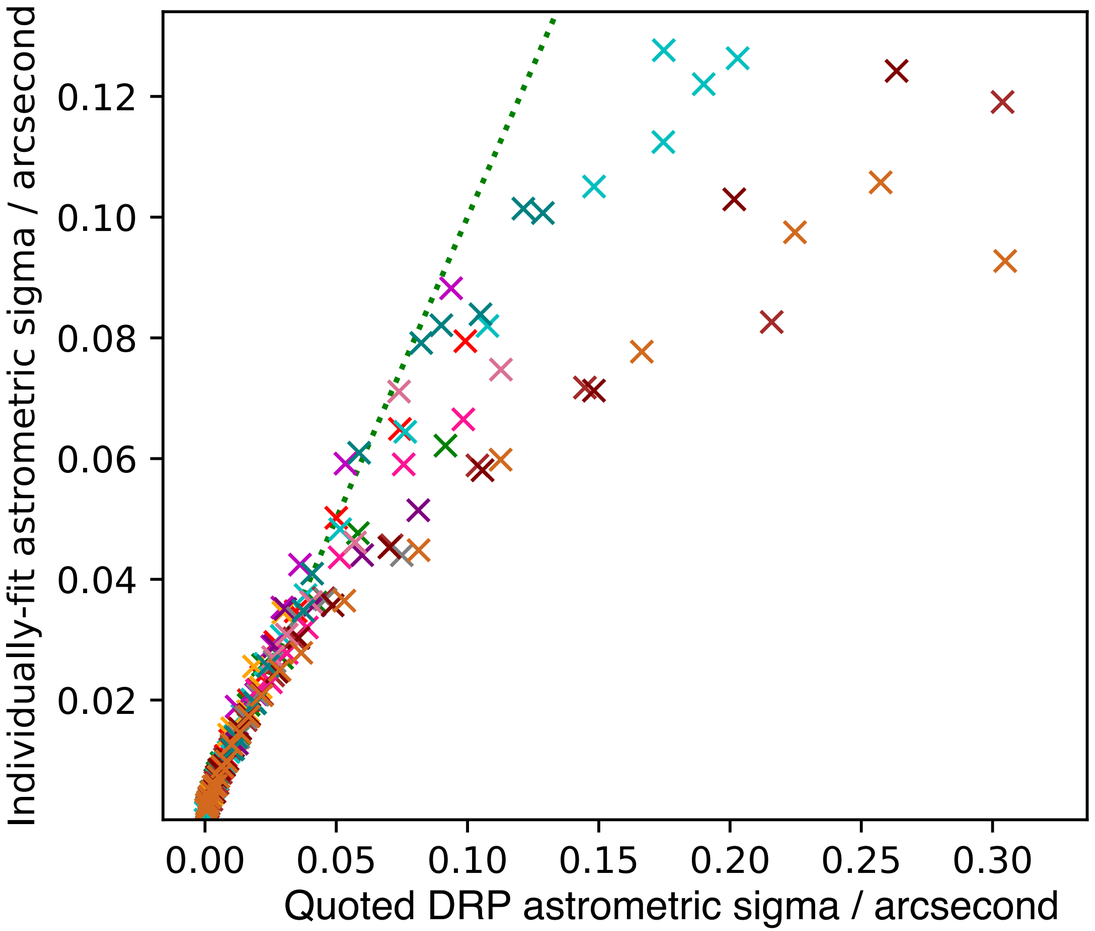
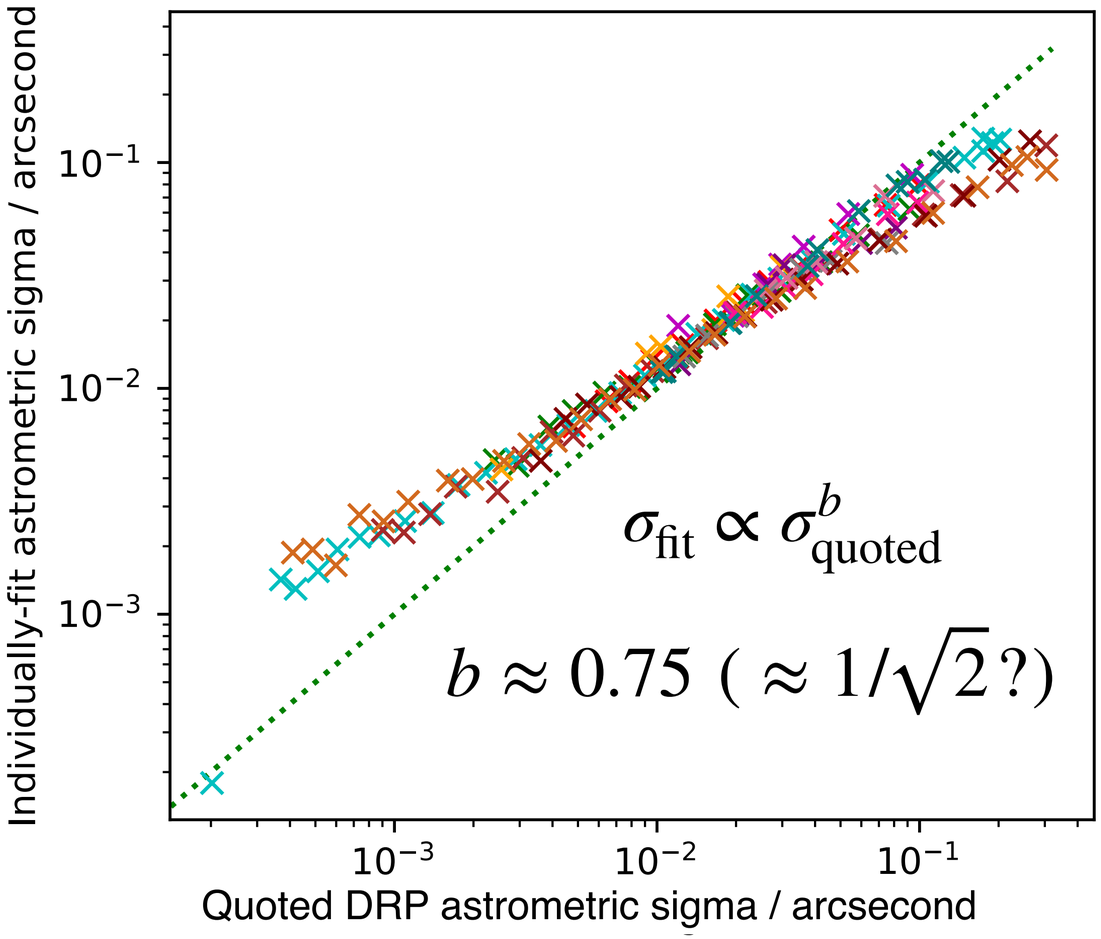
Object table, all *valid* tracts





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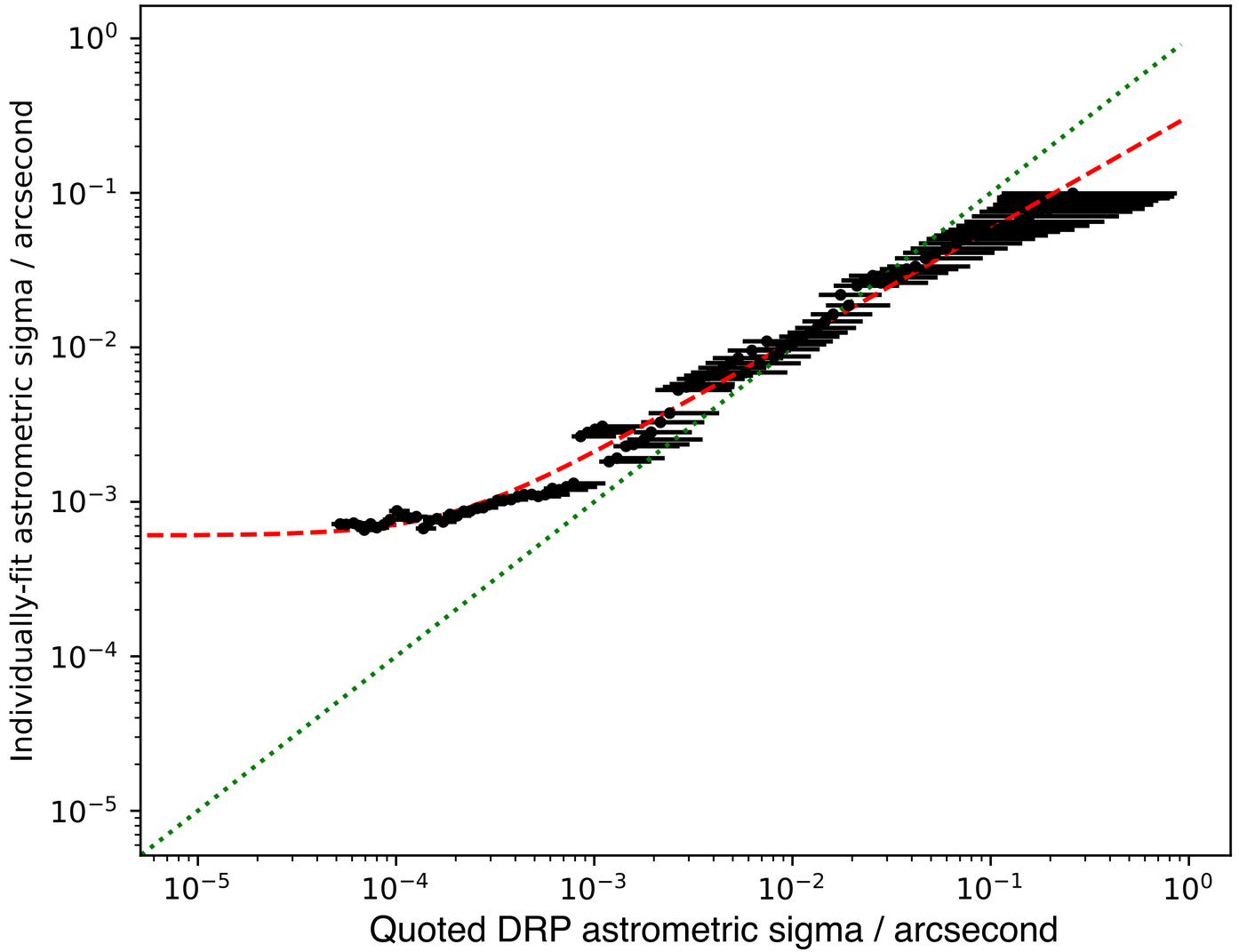
Object table, all *valid* tracts merged together



$$\sigma_{\text{fit}} = \sqrt{\left(m\sigma_{\text{quoted}}^{b}\right)^{2} + n^{2}} \longrightarrow b \approx 0.7\ (\approx 1/\sqrt{2}\,?),\ n \approx 0.6\,\text{mas}$$

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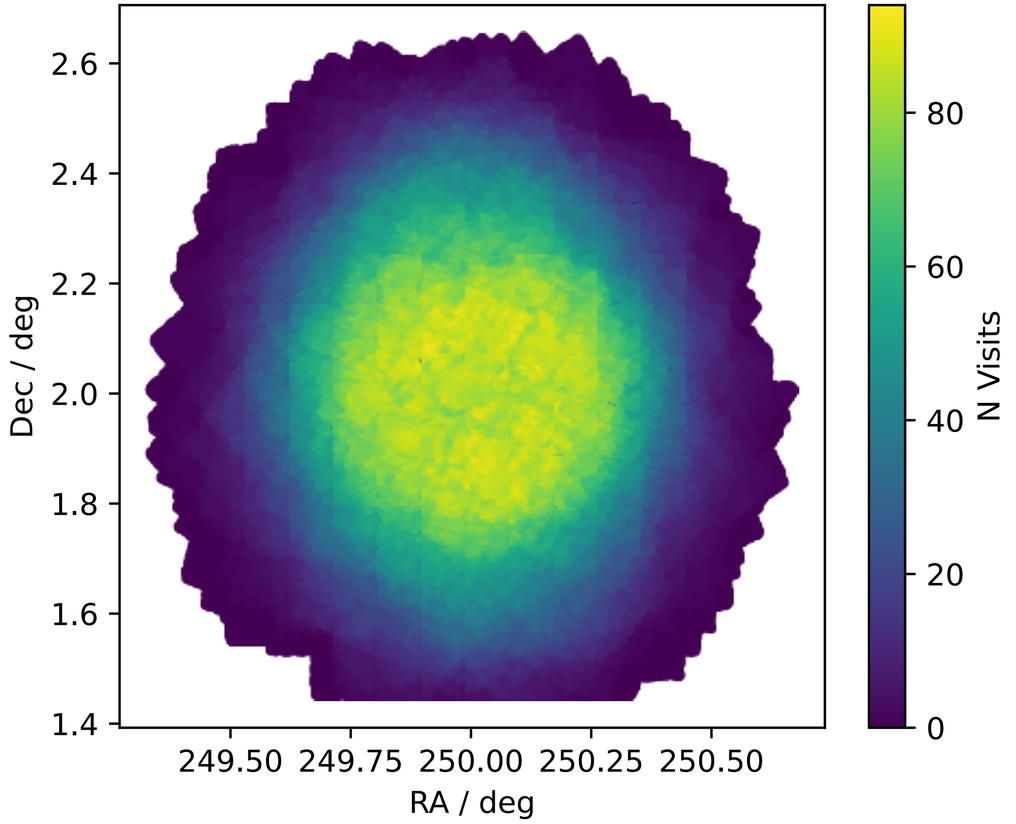
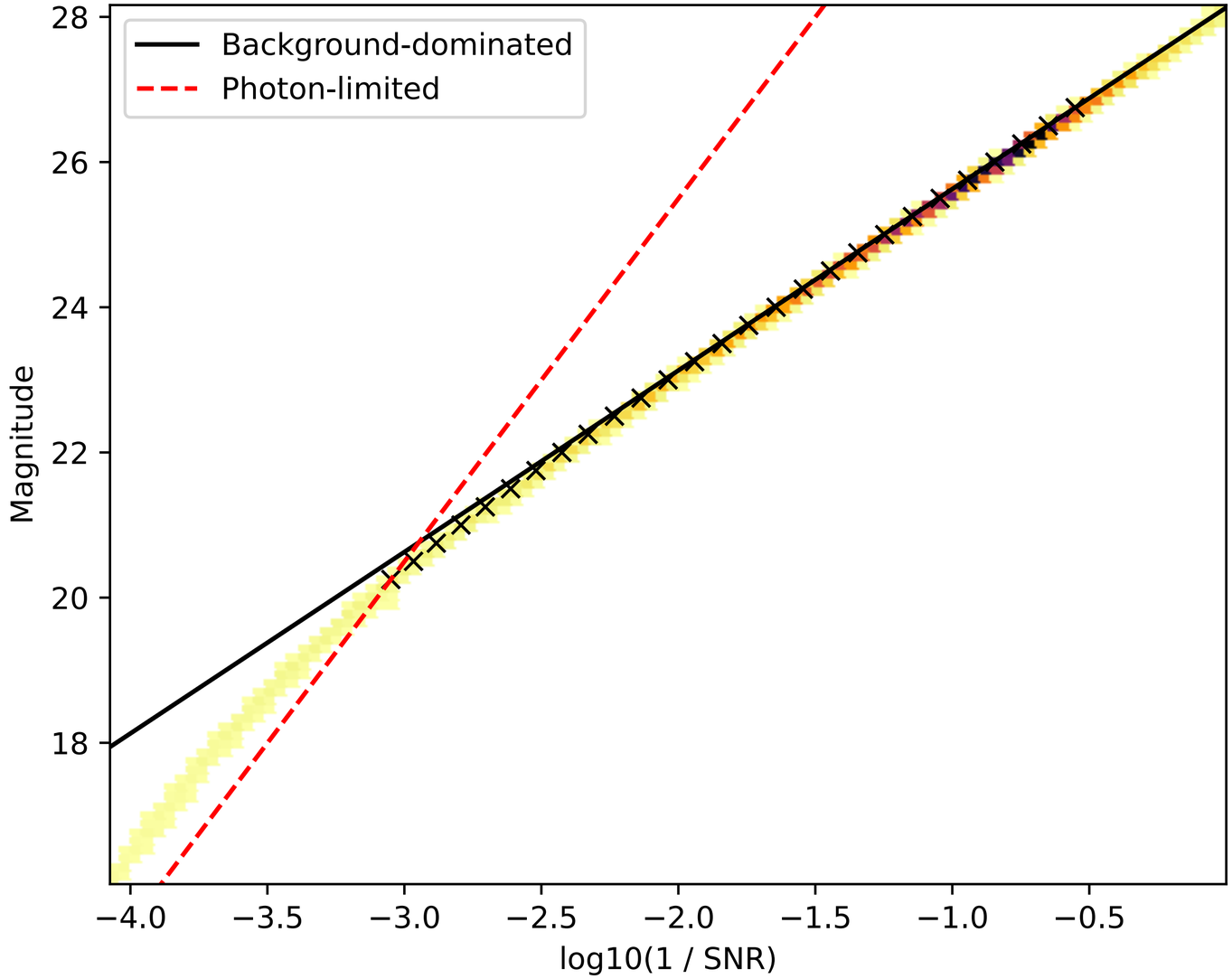
Scatter-Covariance Power Law?

- Uncertainties, magnitude, and relative local source density all fixed in analysis, so “best-fit” uncertainties should be for like-for-like objects.
- False positives accounted for in the fitting process.
- Source table analysis works well, verifies predictions of Ivezić et al. (2019).
- Visit numbers in the coadd images fixed to roughly ±10% to avoid SNR-magnitude relation correlation issues.



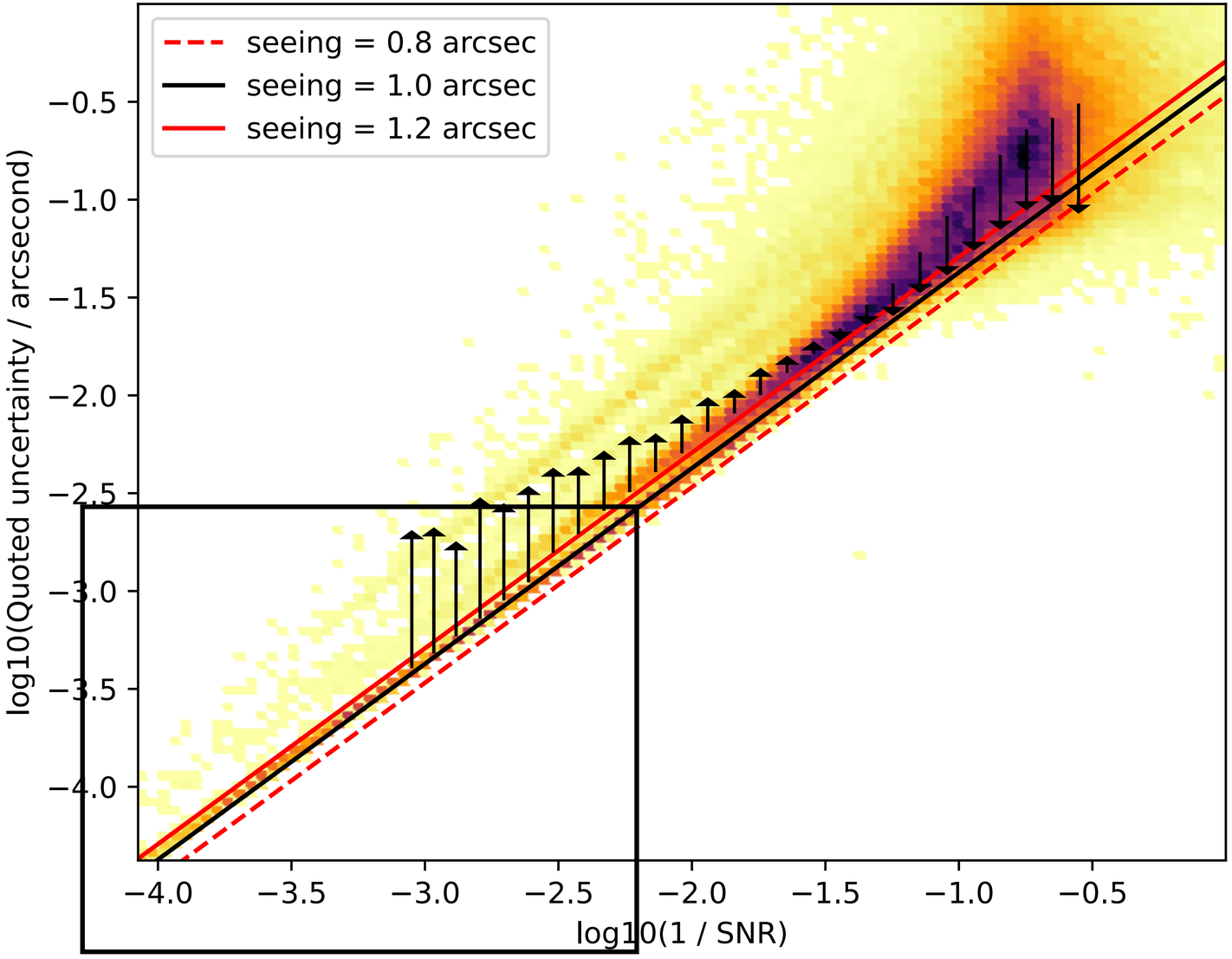
Scatter-Covariance Power Law?

- Photometry is good, SNR-magnitude relationships are clean and monotonic (with visit count corrected for).



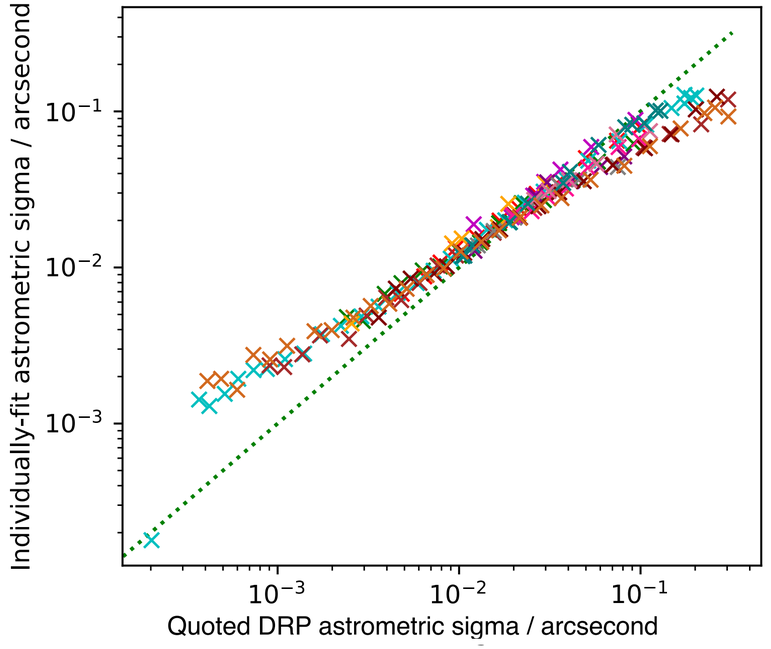
Scatter-Covariance Power Law?

- Bright source statistical uncertainties look good, based on their SNR and the “necessary” seeing to explain the relationship (King 1983), but these are aperture photometry magnitudes which may hide higher-order problems with e.g. variance propagation.



Conclusions

- Single-visit image pipeline reductions produce astrometric maximum-likelihood positions and corresponding covariances that are in agreement.
- Requires a ~3-7mas systematic uncertainty to model position scatter of bright objects, in line with expectations (but it is a simulation of expectations…!).



- **Coadd-image pipeline analysis harder to explain, producing what looks like a power-law relationship between pipeline-derived astrometric precisions and ensemble, scatter-based uncertainties.**
- Preliminary evidence for reaching sub-mas systematic precisions, but this needs larger sky areas to reach sufficient number statistics to confirm.

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