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Implementing an Accurate and Precise Catalogue Cross-Match Service, Including Flux Information and the Effects of Blended Objects

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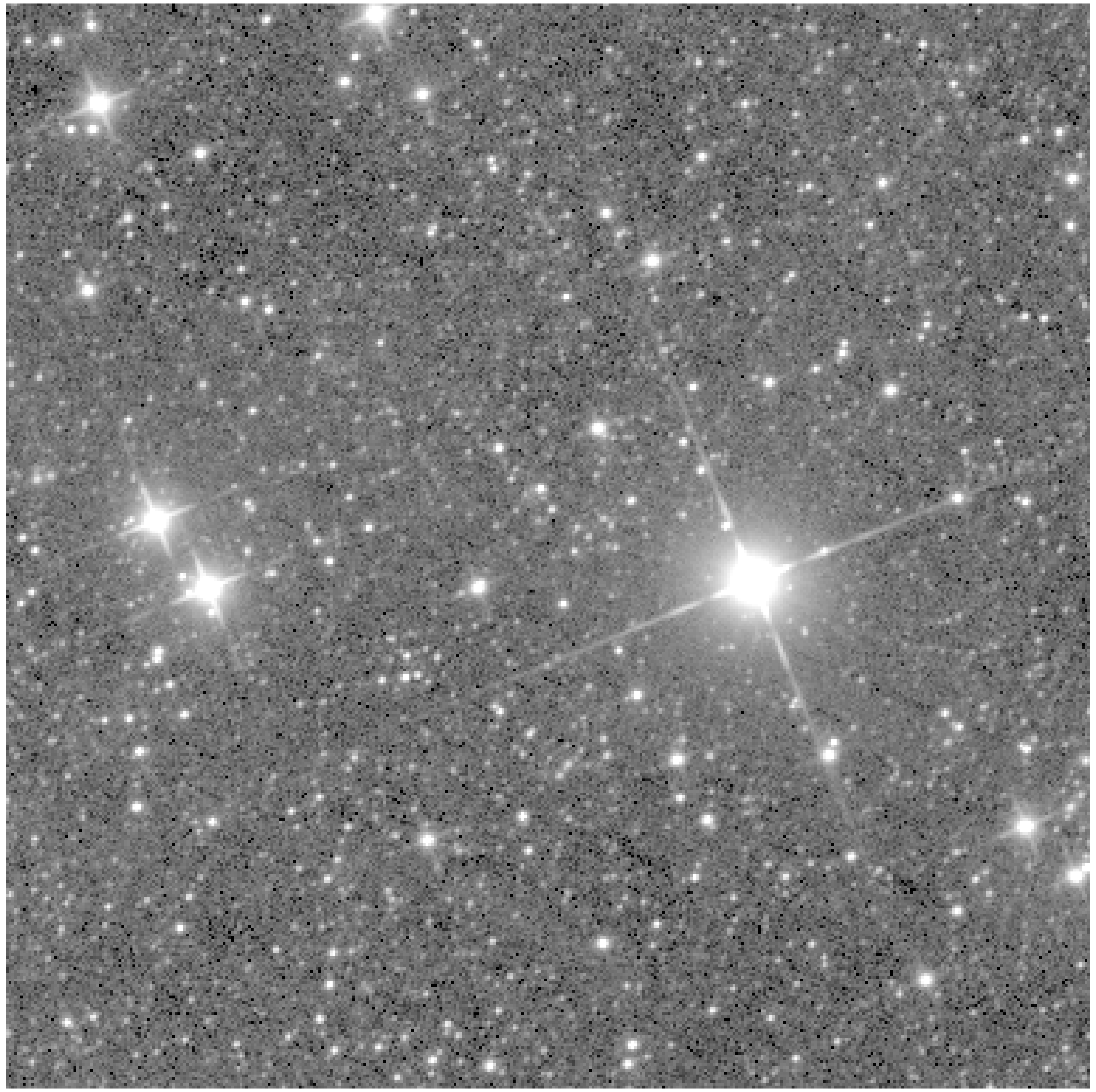
UNIVERSITY OF EXETER
LSST:UK Consortium
VERA C. RUBIN OBSERVATORY

Photometric Observations



WISE - Wright et al. (2010)

WISE W1

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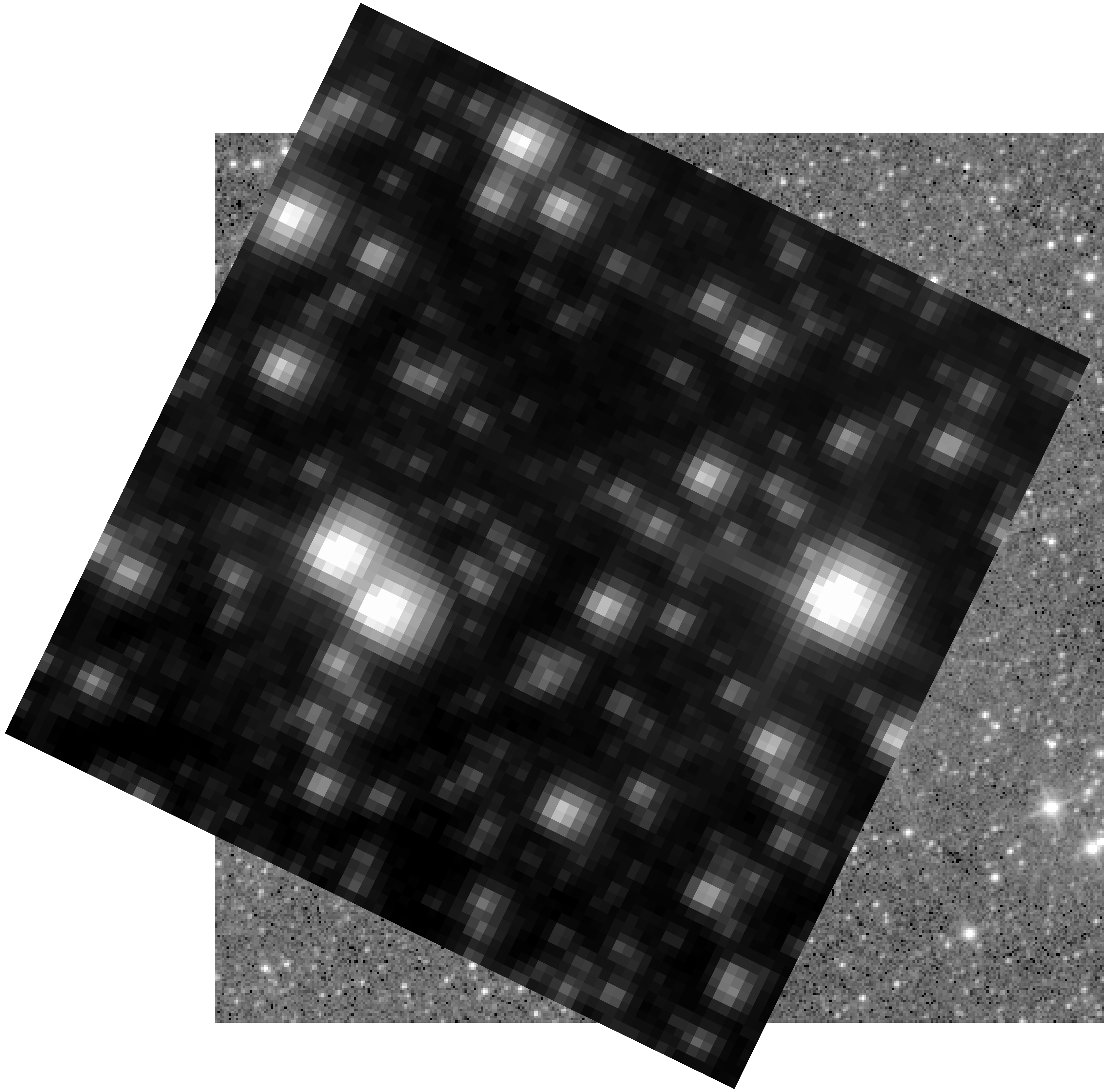
Photometric Observations



WISE - Wright et al. (2010)
TESS - Ricker et al. (2015)

TESS T

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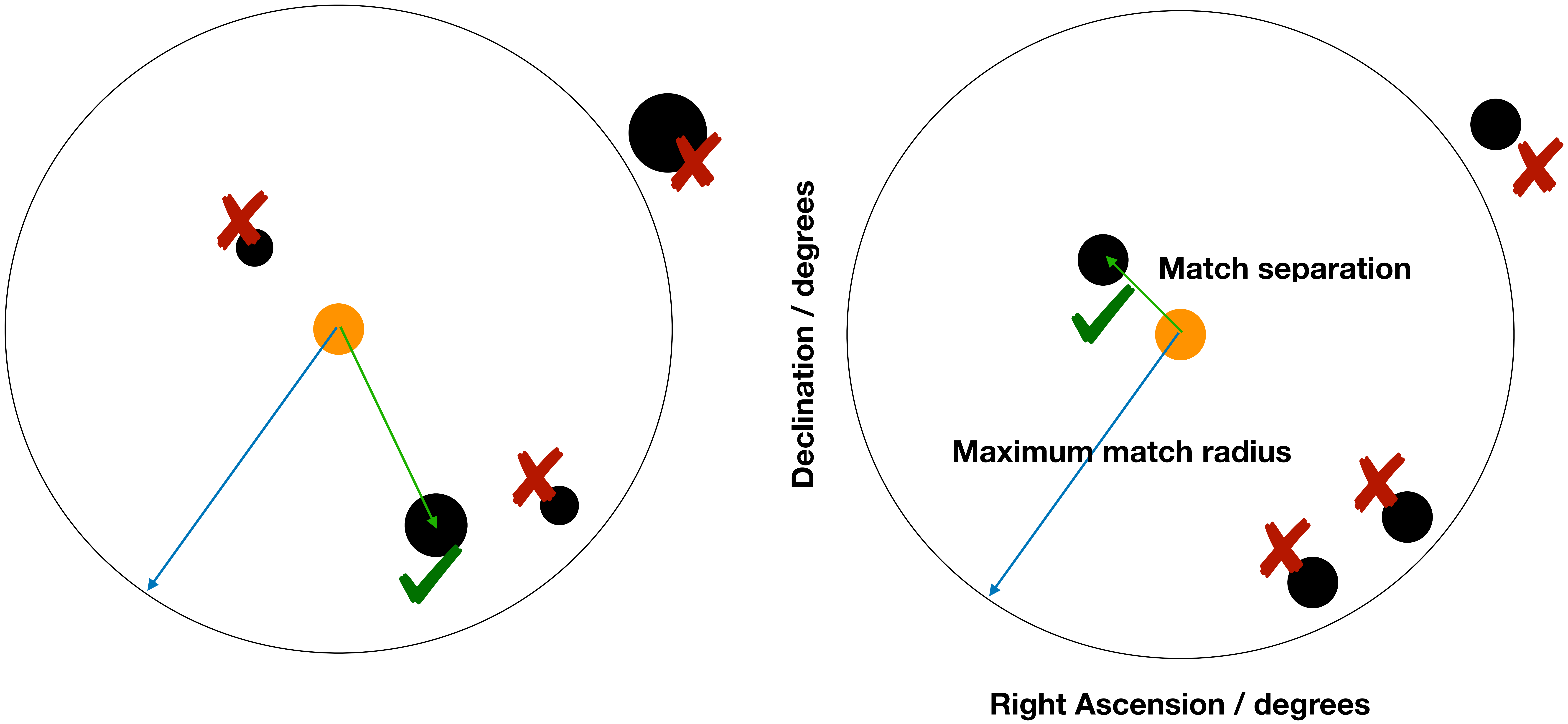
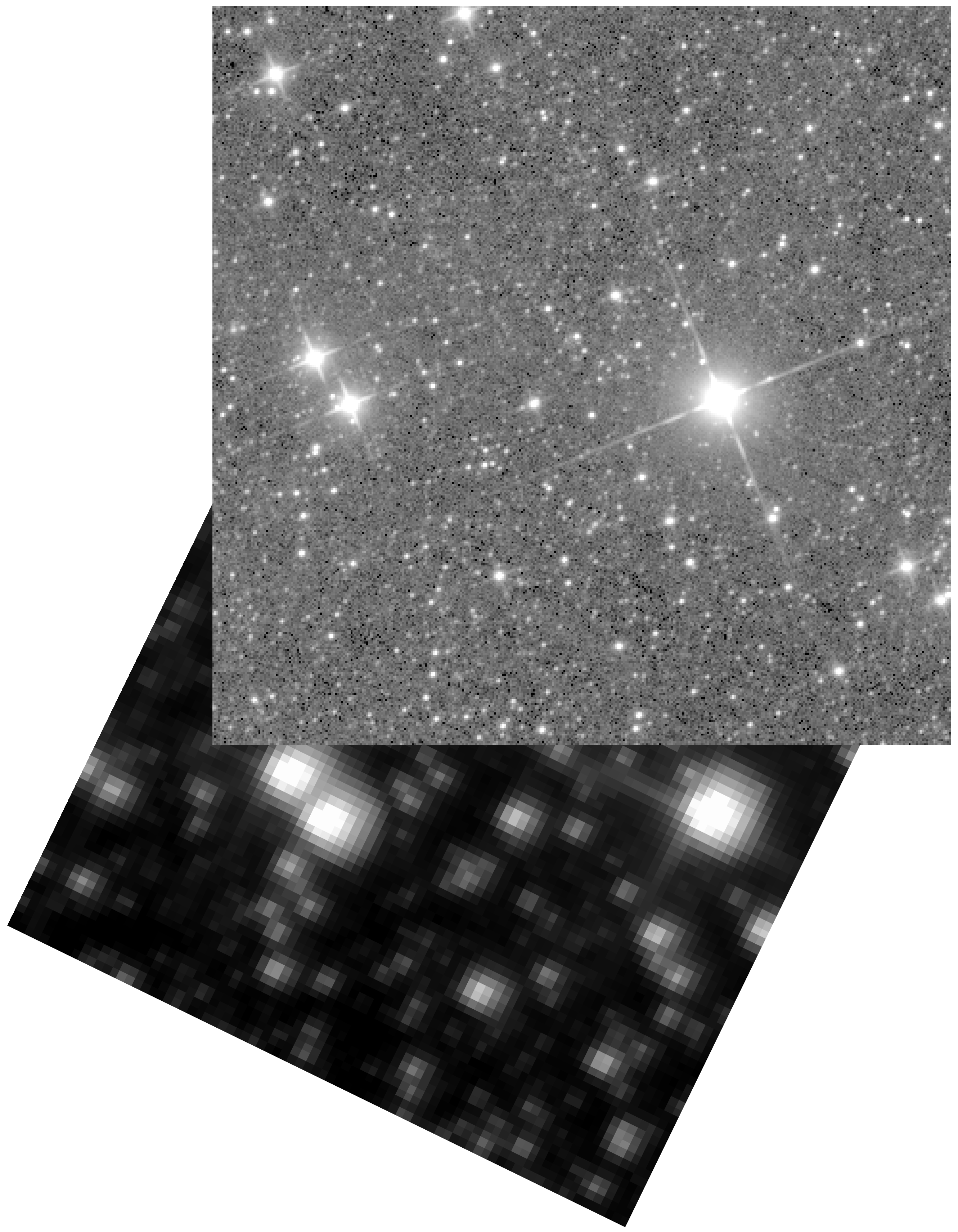
“Traditional”/“Simple” Cross-Matching





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Probabilistic Cross-Matching

The Likelihood Ratio

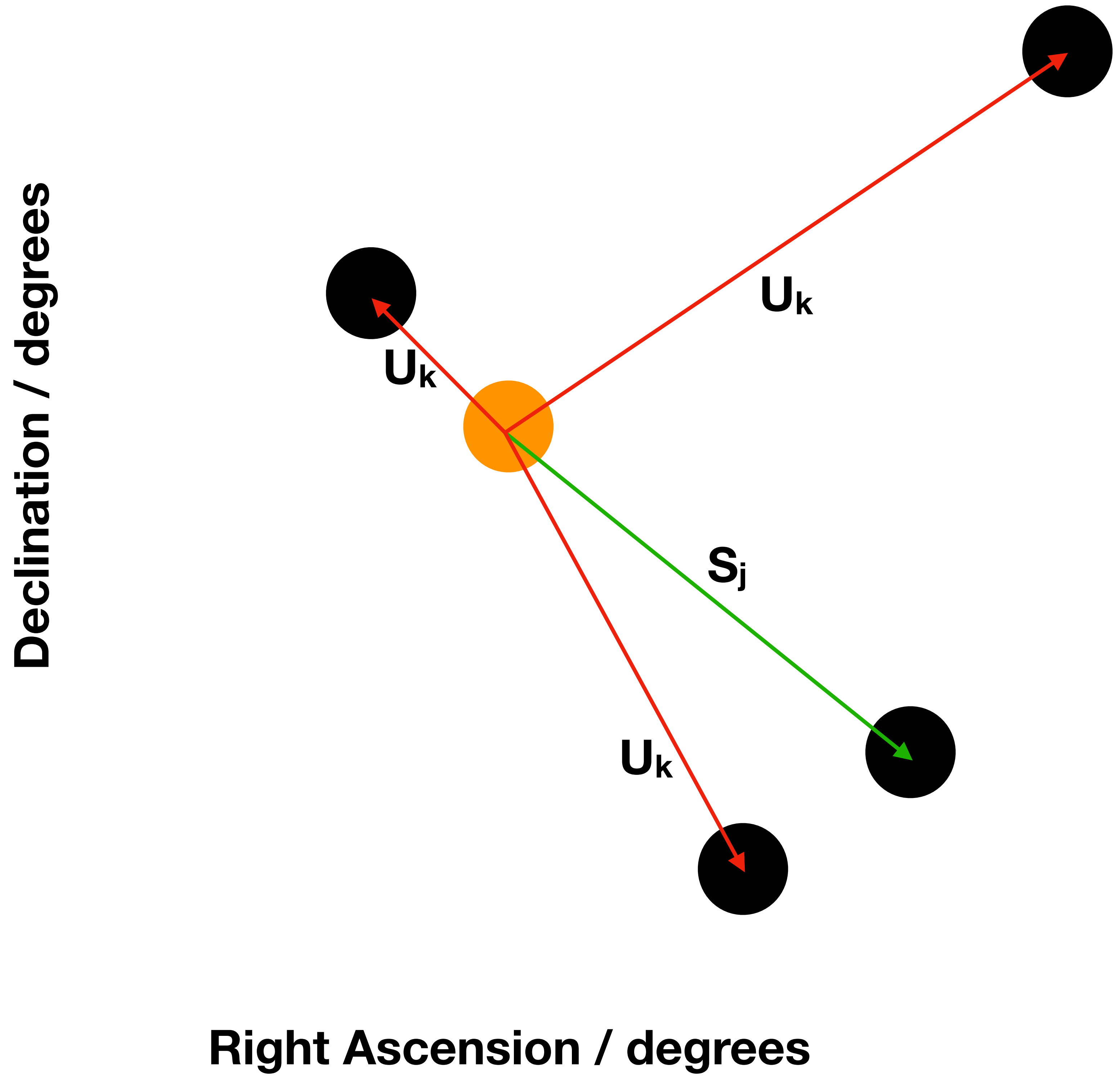
$$dp_{\mathrm{id}} = Qr\exp\left(\frac{-r^2}{2}\right)dr.$$

$$dp_{\mathrm{uo}} = 2\lambda r\,dr$$

$$LR(r) = \frac{dp_{\mathrm{id}}}{dp_{\mathrm{uo}}} = \frac{Q\exp(-r^2/2)}{2\lambda}$$

Wolstencroft et al. (1986)

The "Reliability" — Sutherland & Saunders (1992)



$$R_j = \frac{L_j}{\sum_i L_i + (1-Q)}$$

$$L = \frac{q(m,c)\,f(x,y)}{n(m,c)}$$

$$P(i) = \frac{\frac{Xc(m_i)\,g(\Delta x_i, \Delta y_i)}{Nf(m_i)}}{1 - X + \sum_j \frac{Xc(m_j)\,g(\Delta x_j, \Delta y_j)}{Nf(m_j)}}$$

Naylor, Broos, & Feigelson (2013)

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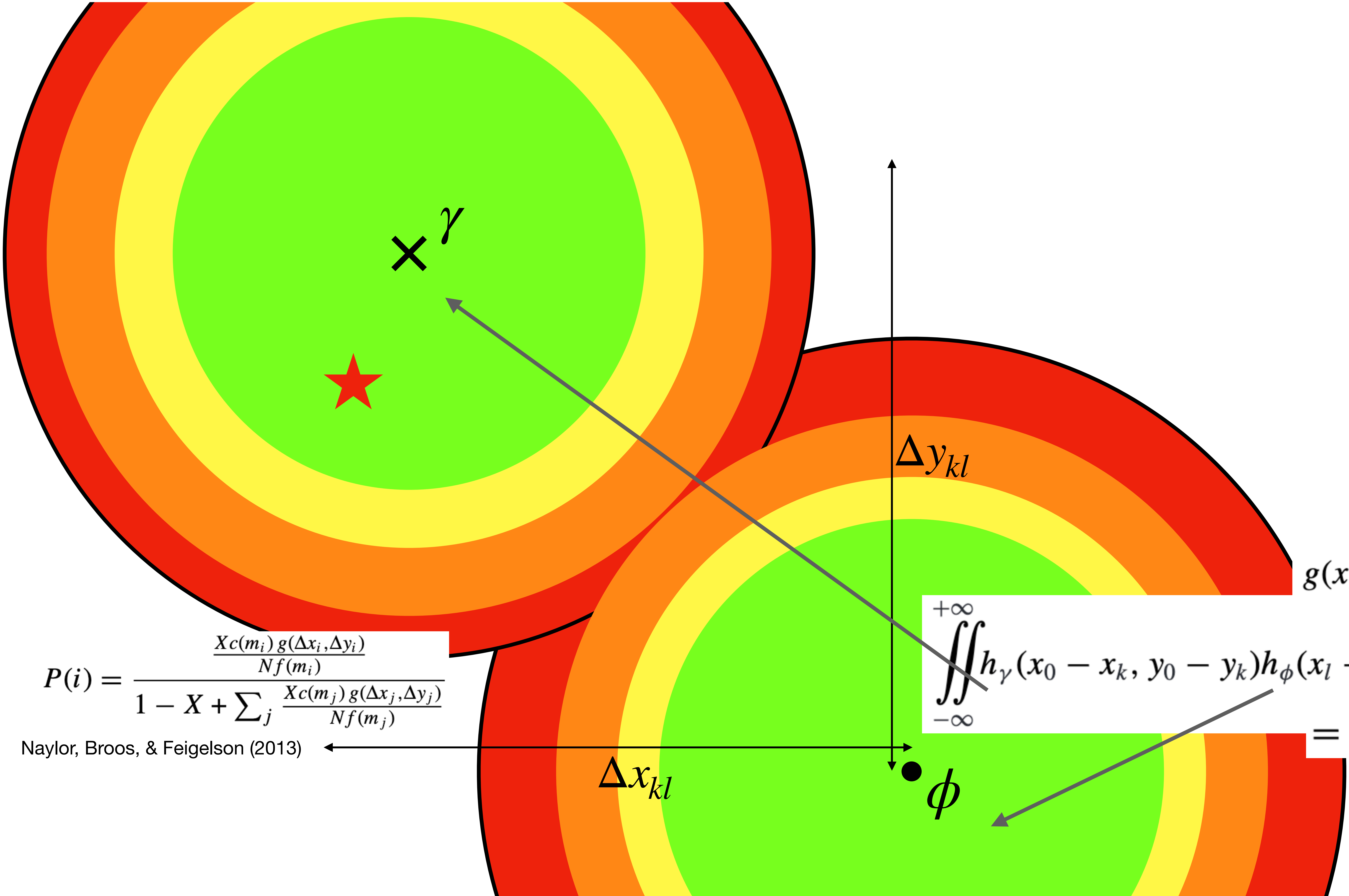
Match Separation Probability



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Naylor, Broos, & Feigelson (2013)

$$g(x_k, y_k, x_l, y_l) = \iint_{-\infty}^{+\infty} h_\gamma(x_0 - x_k, y_0 - y_k) h_\phi(x_l - x_0, y_l - y_0) p(x_0, y_0)\, \mathrm{d}x_0\, \mathrm{d}y_0$$

$$= N_\mathrm{c} \times (h_\gamma * h_\phi)(\Delta x_{kl}, \Delta y_{kl})$$

Wilson & Naylor (2018a)

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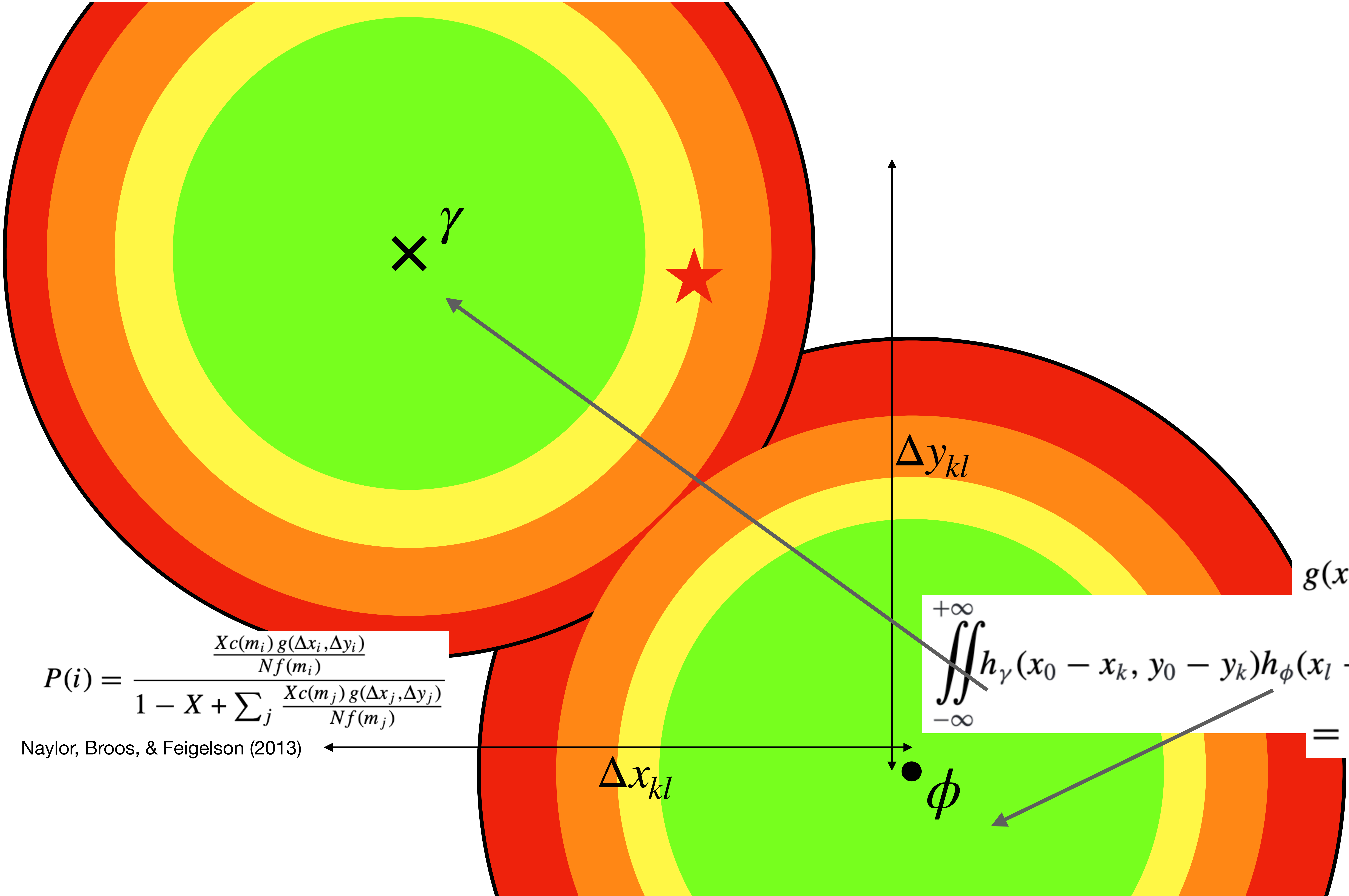
Match Separation Probability



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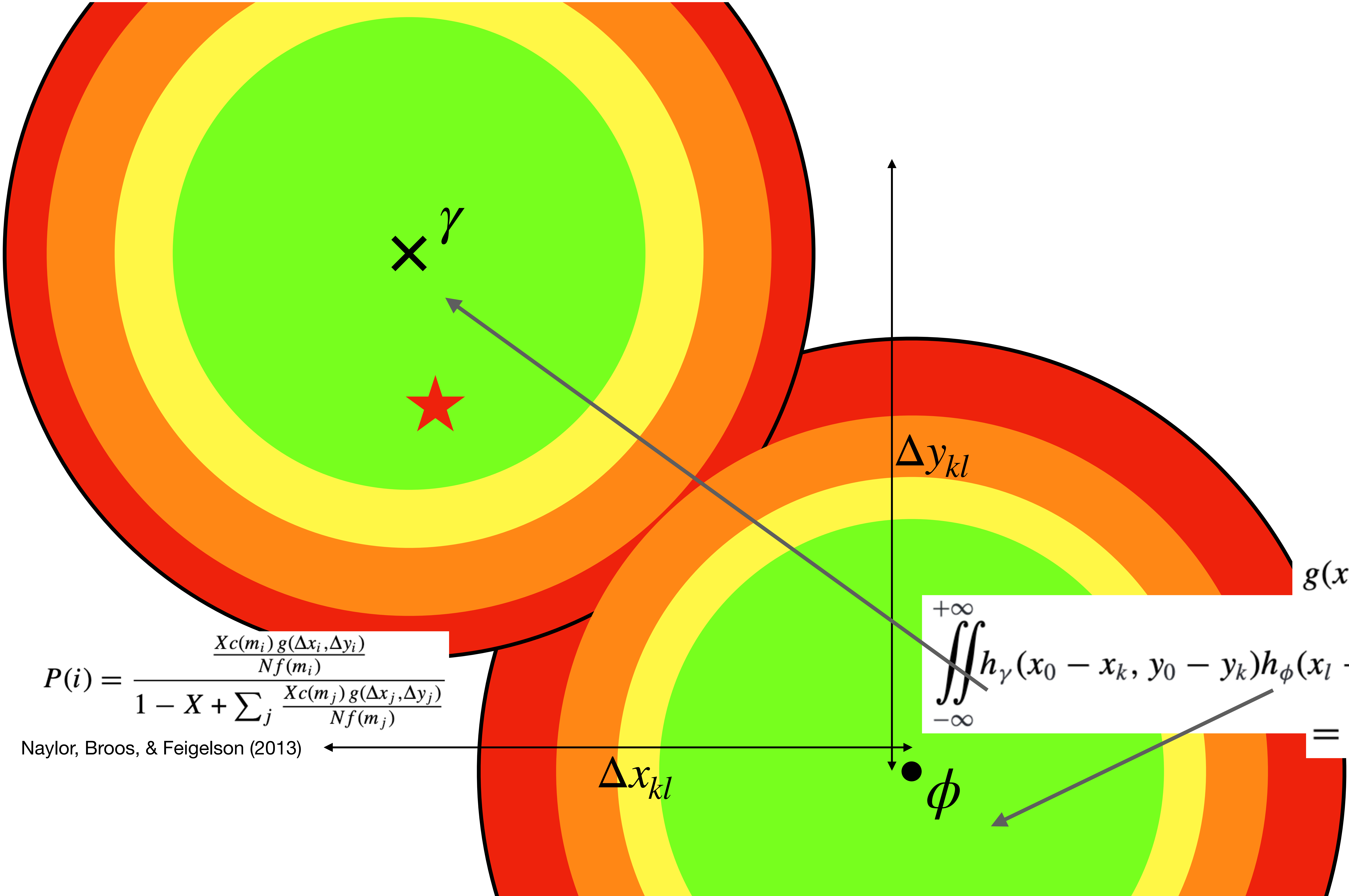

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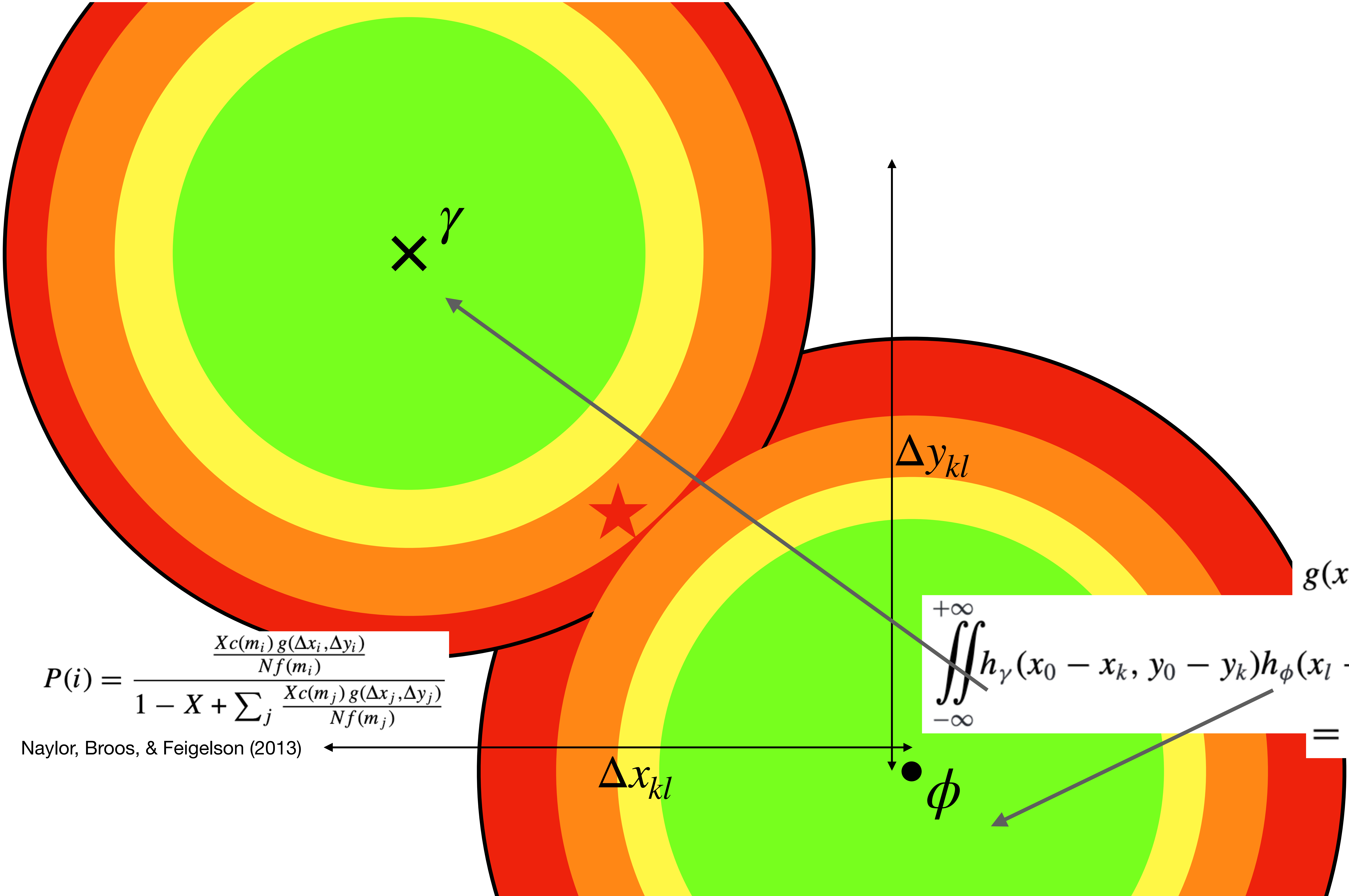

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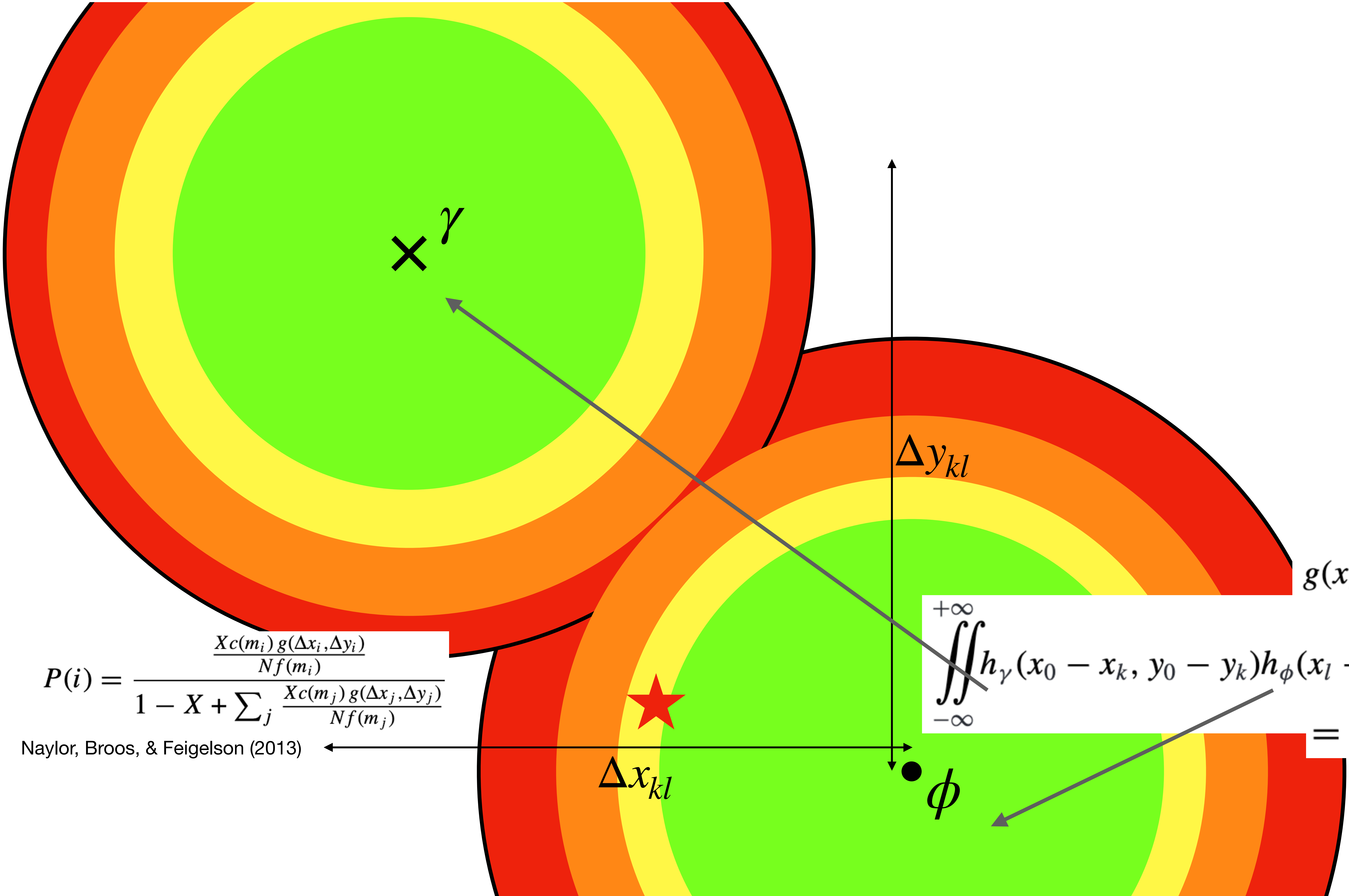

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Wilson & Naylor (2018a)

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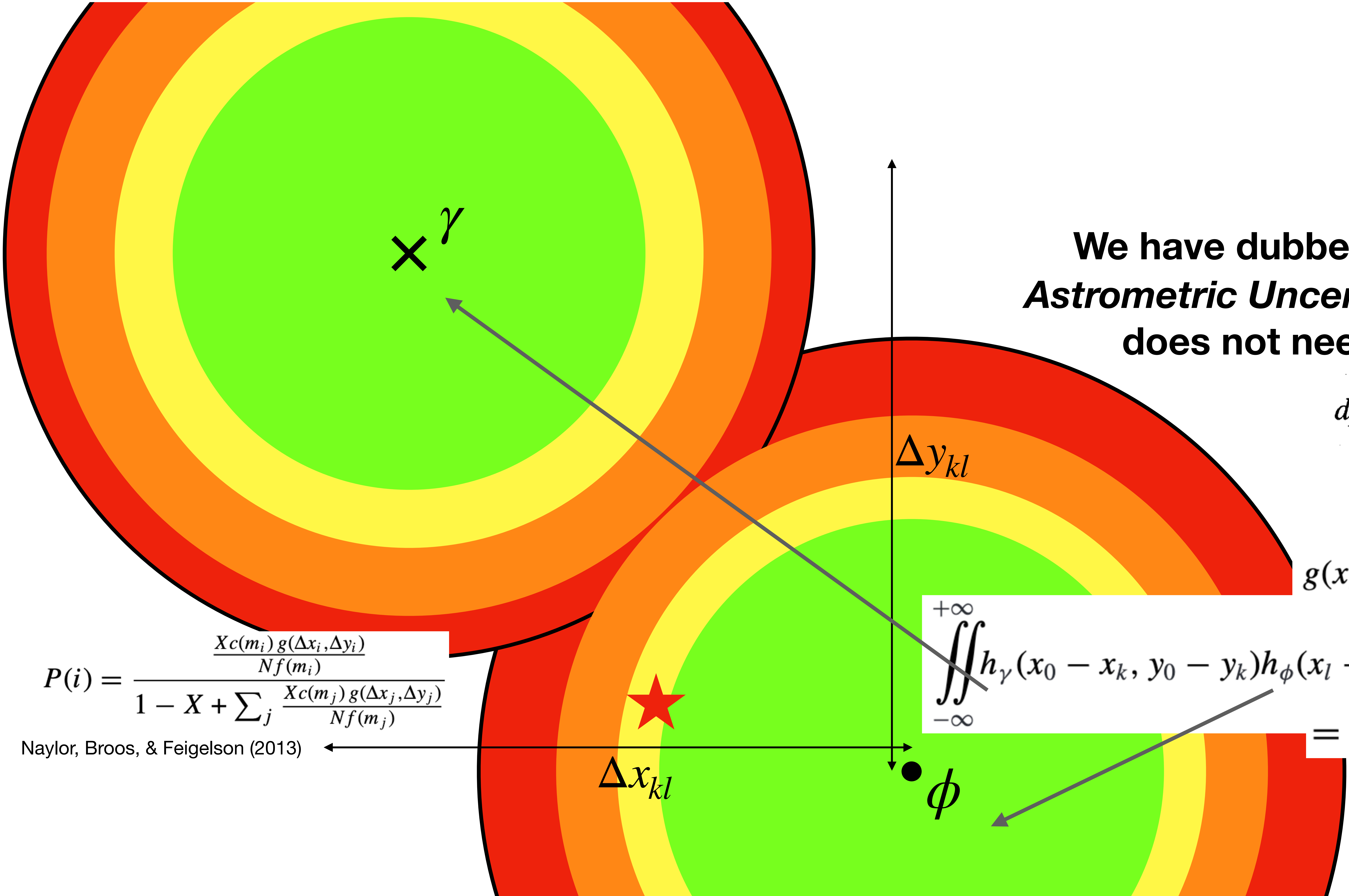

We have dubbed this function h the *Astrometric Uncertainty Function*, which does not need to be Gaussian

$$dp_{\mathrm{id}} = Qr \exp\left(\frac{-r^2}{2}\right) dr.$$

Wolstencroft et al. (1986)

$$g(x_k, y_k, x_l, y_l) = \iint_{-\infty}^{+\infty} h_\gamma(x_0 - x_k, y_0 - y_k) h_\phi(x_l - x_0, y_l - y_0) p(x_0, y_0)\,\mathrm{d}x_0\,\mathrm{d}y_0 = N_\mathrm{c} \times (h_\gamma * h_\phi)(\Delta x_{kl}, \Delta y_{kl})$$

Wilson & Naylor (2018a)

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Naylor, Broos, & Feigelson (2013)

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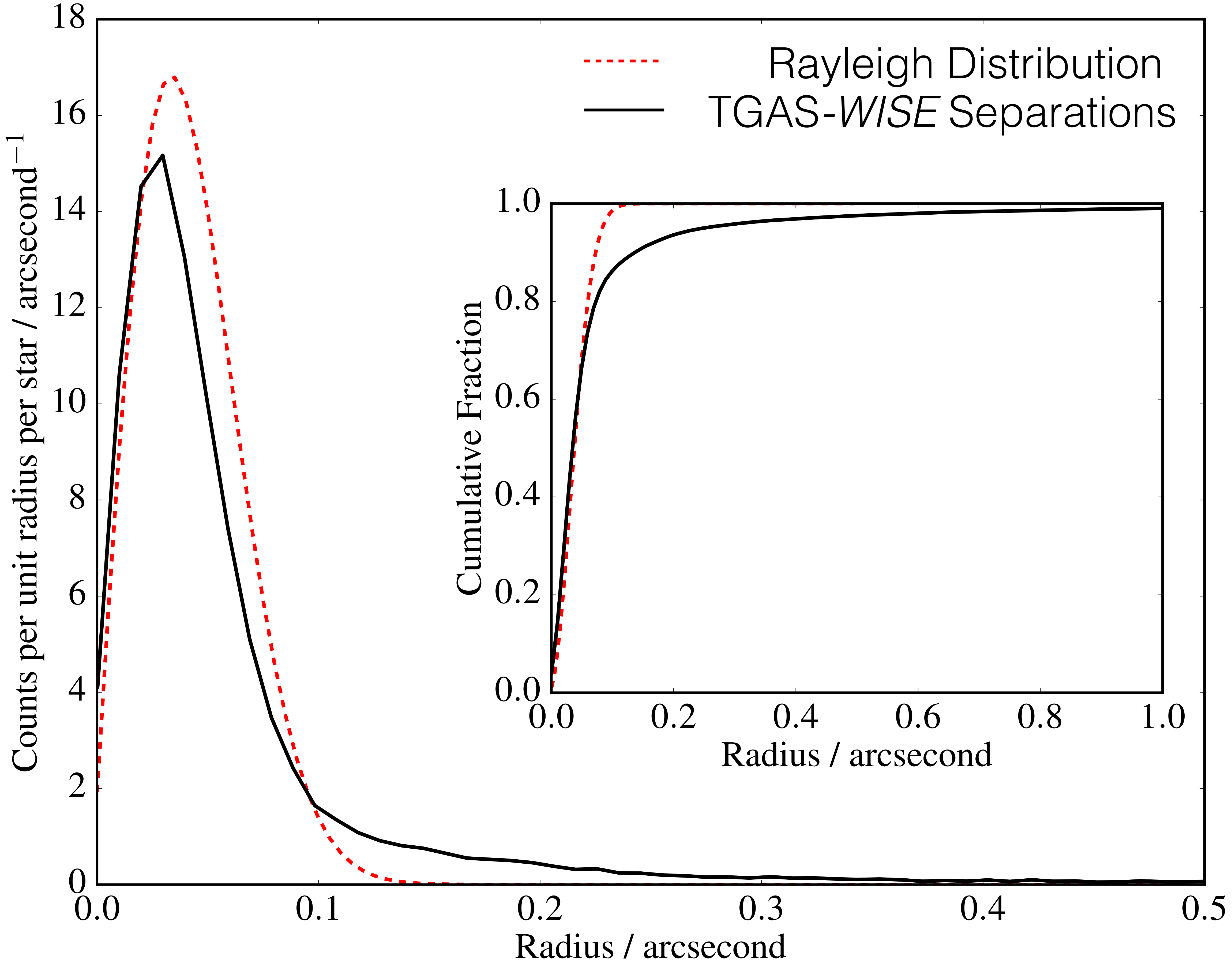
Match Separation Distributions

What does a flexible, non-Gaussian Astrometric Uncertainty Function allow us to do?



Wilson & Naylor (2017)
WISE - Wright et al. (2010)

TGAS - Michalik, Lindegren, & Hobbs (2015)
Gaia - Gaia Collaboration, Brown A. G. A., et al. (2016)

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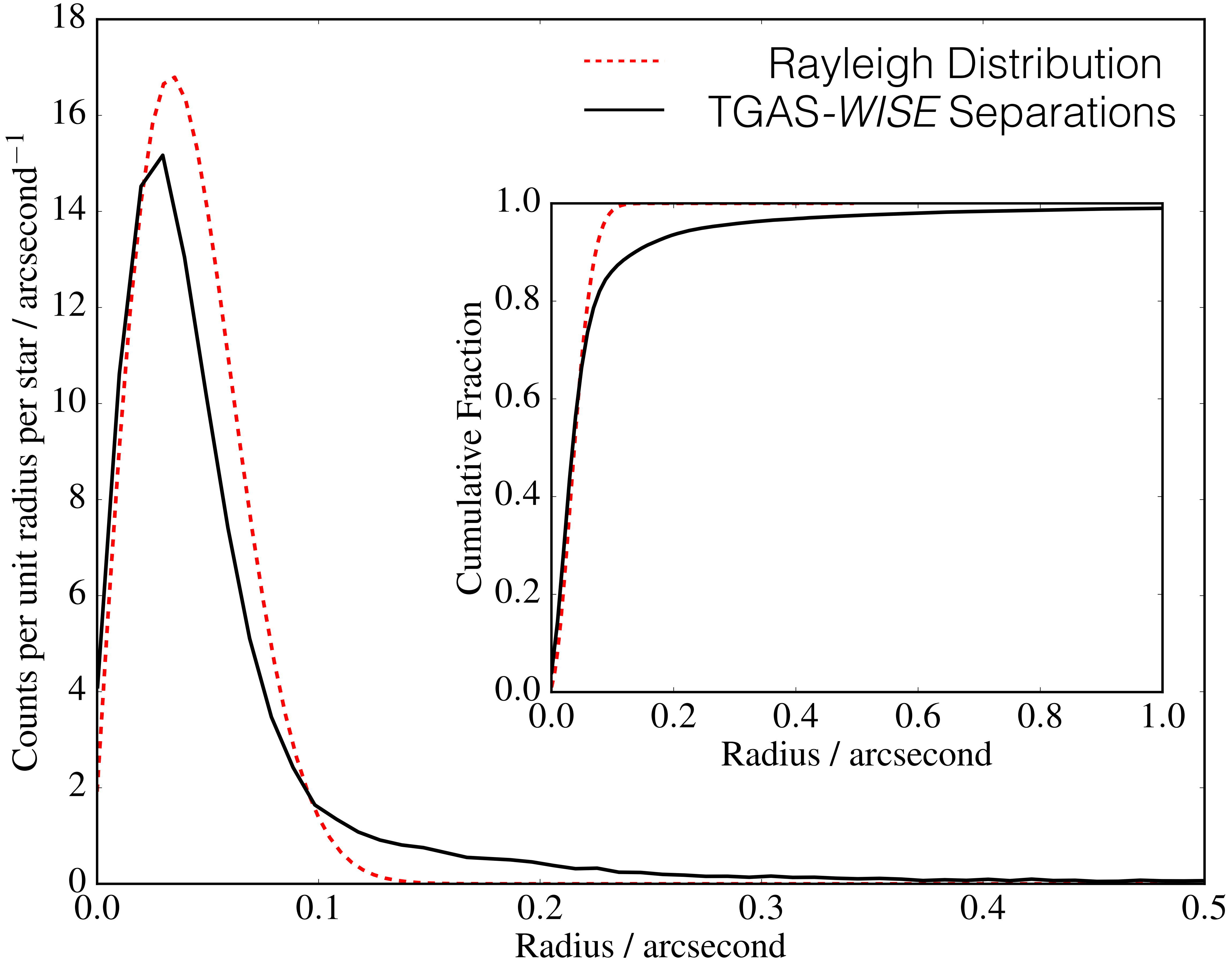
Match Separation Distributions

Reasons for large separations:
1) proper motions (e.g. AllWISE Supplement 6.4, Cutri et al. 2012) — no, TGAS provided for all sources
2) false matches — no, 0.1% chance of random match within 0.5 arcseconds
3) What else could it be? What component of the Astrometric Uncertainty Function are we missing?



Wilson & Naylor (2017)
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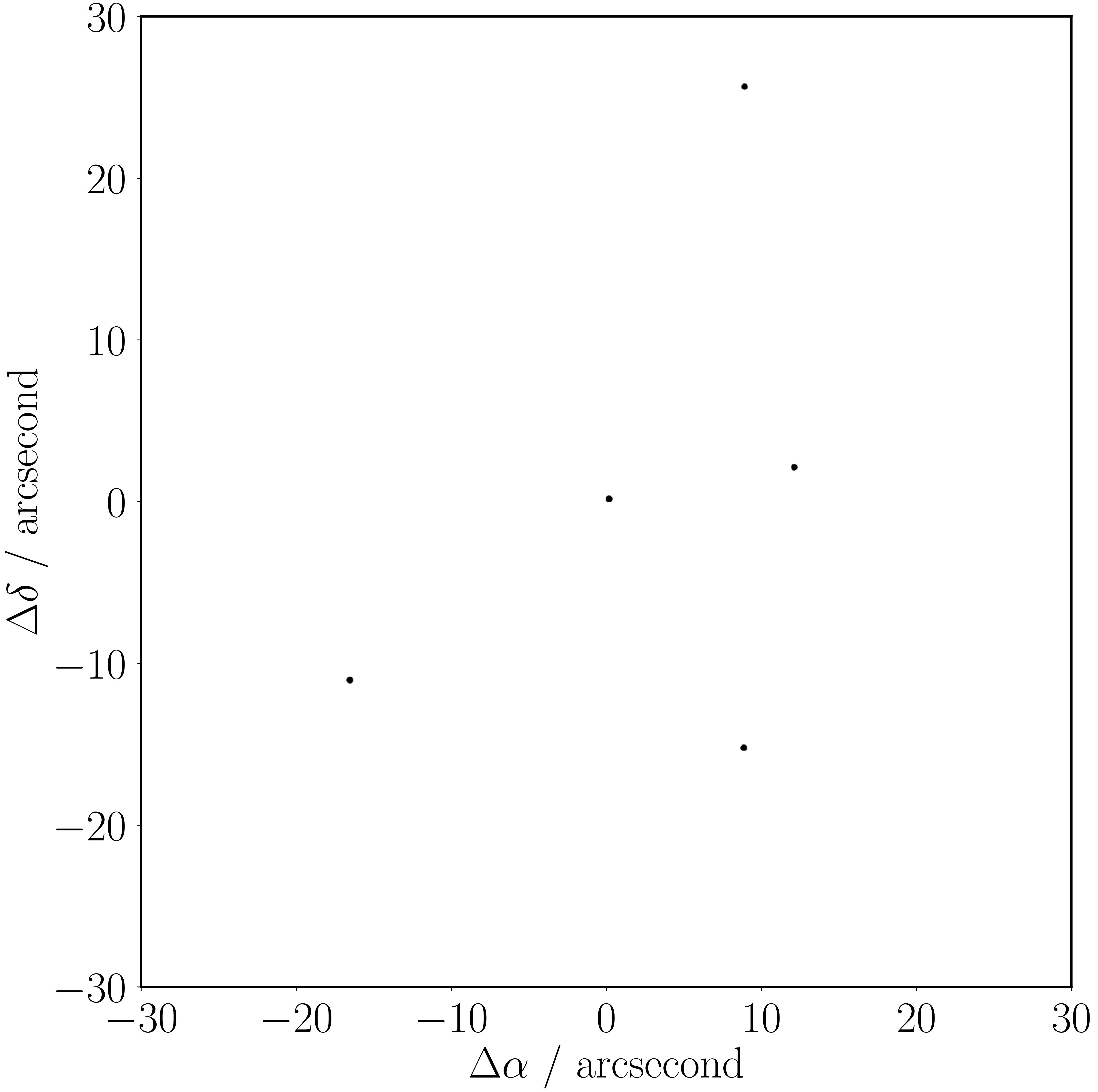
The AUF: Crowding



Wilson & Naylor (2017)

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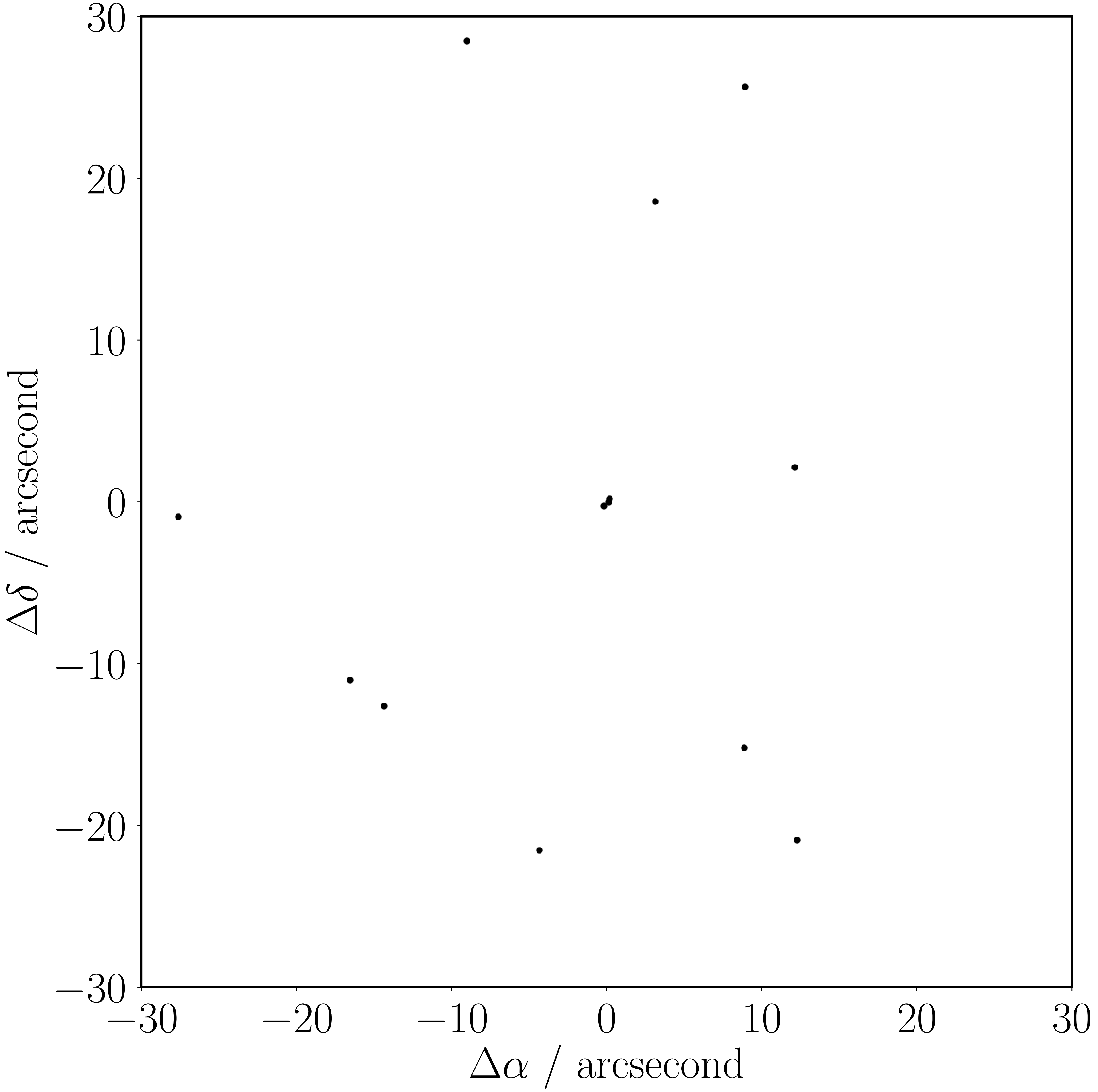
The AUF: Crowding



Wilson & Naylor (2017)

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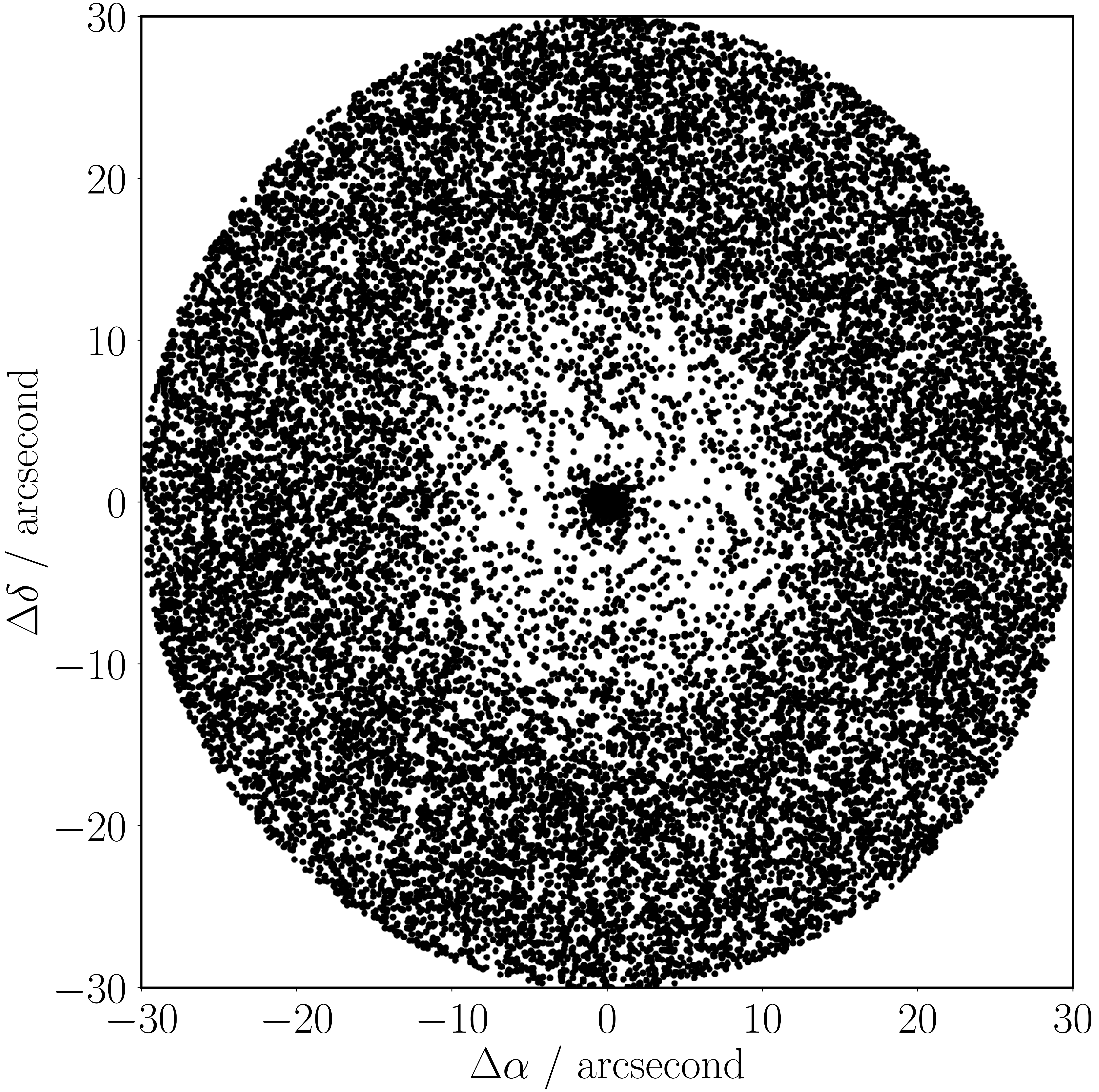
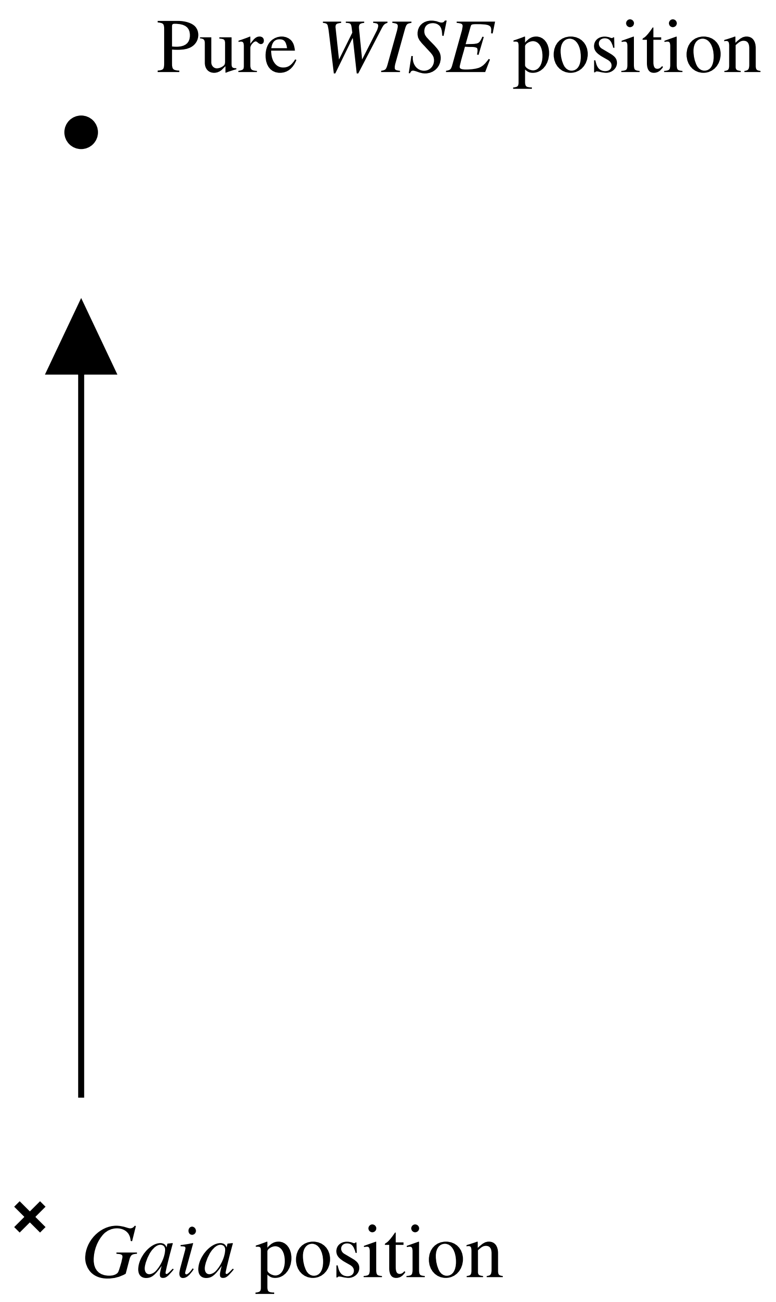
The AUF: Crowding



Wilson & Naylor (2017)

The AUF: Perturbation



Wilson & Naylor (2017)
Wilson & Naylor (2018b)
WISE - Wright et al. (2010)
Gaia DR2 - Gaia Collaboration, Brown A. G. A., et al. (2018)

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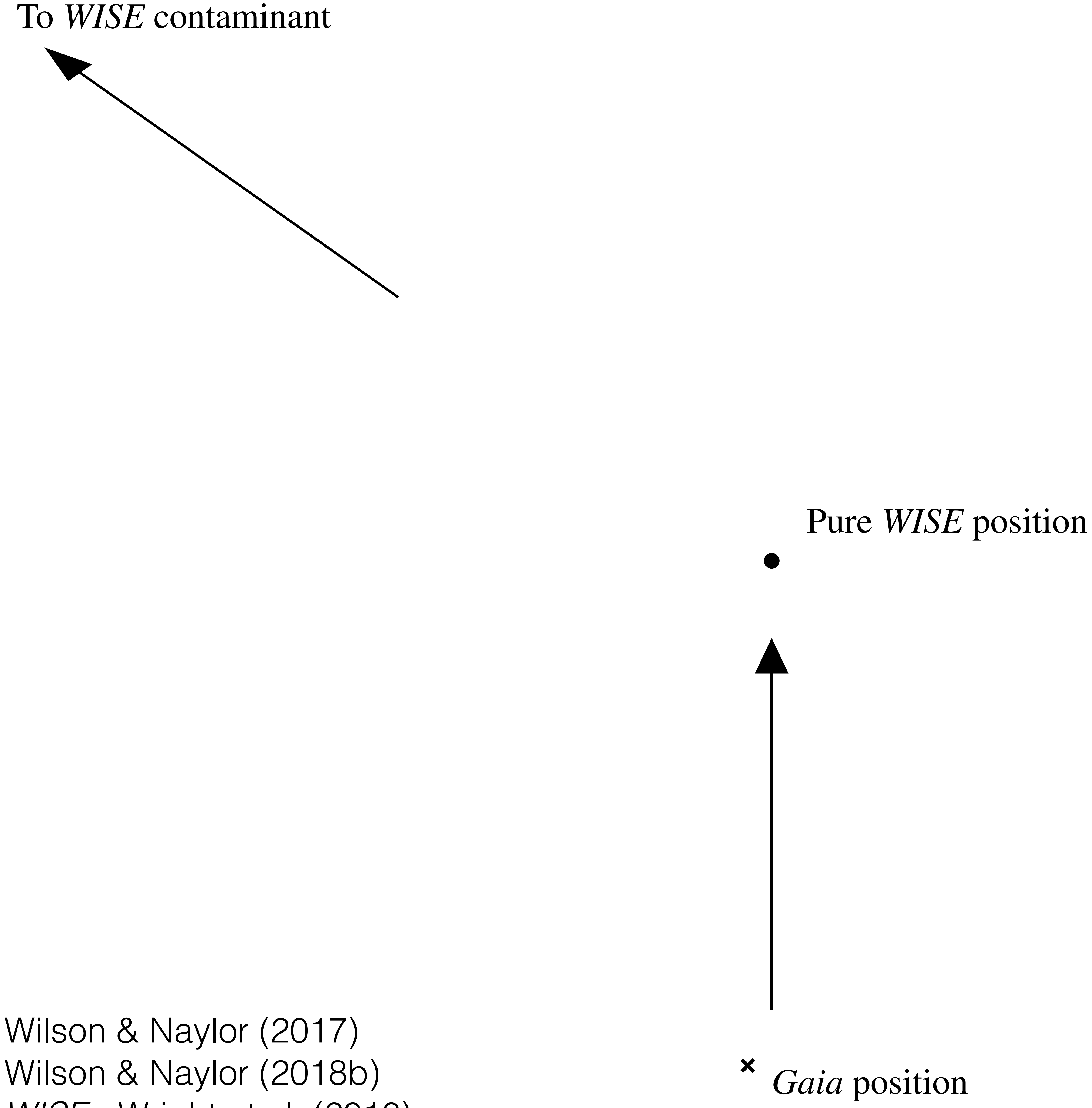

Wilson & Naylor (2017)
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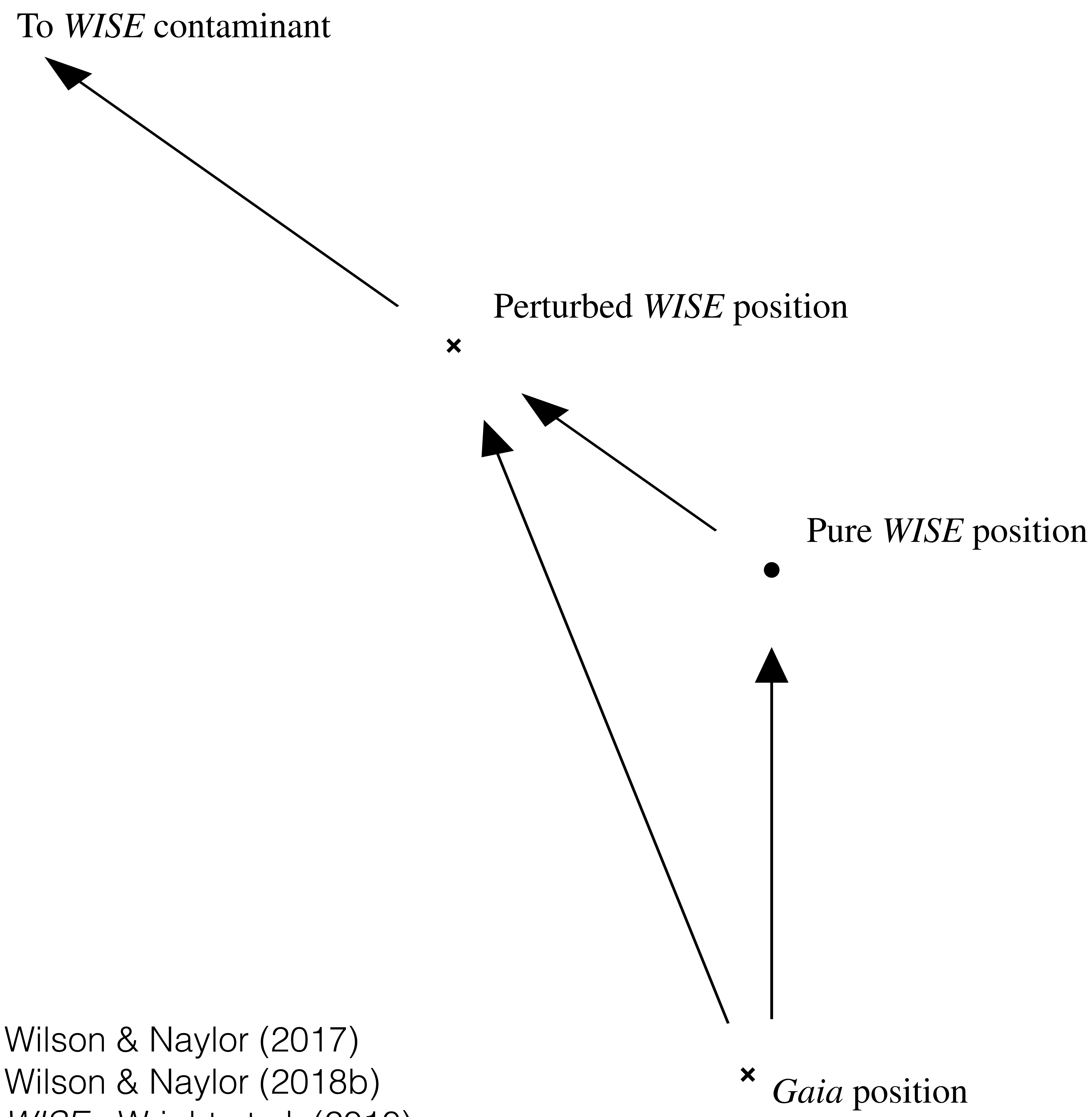

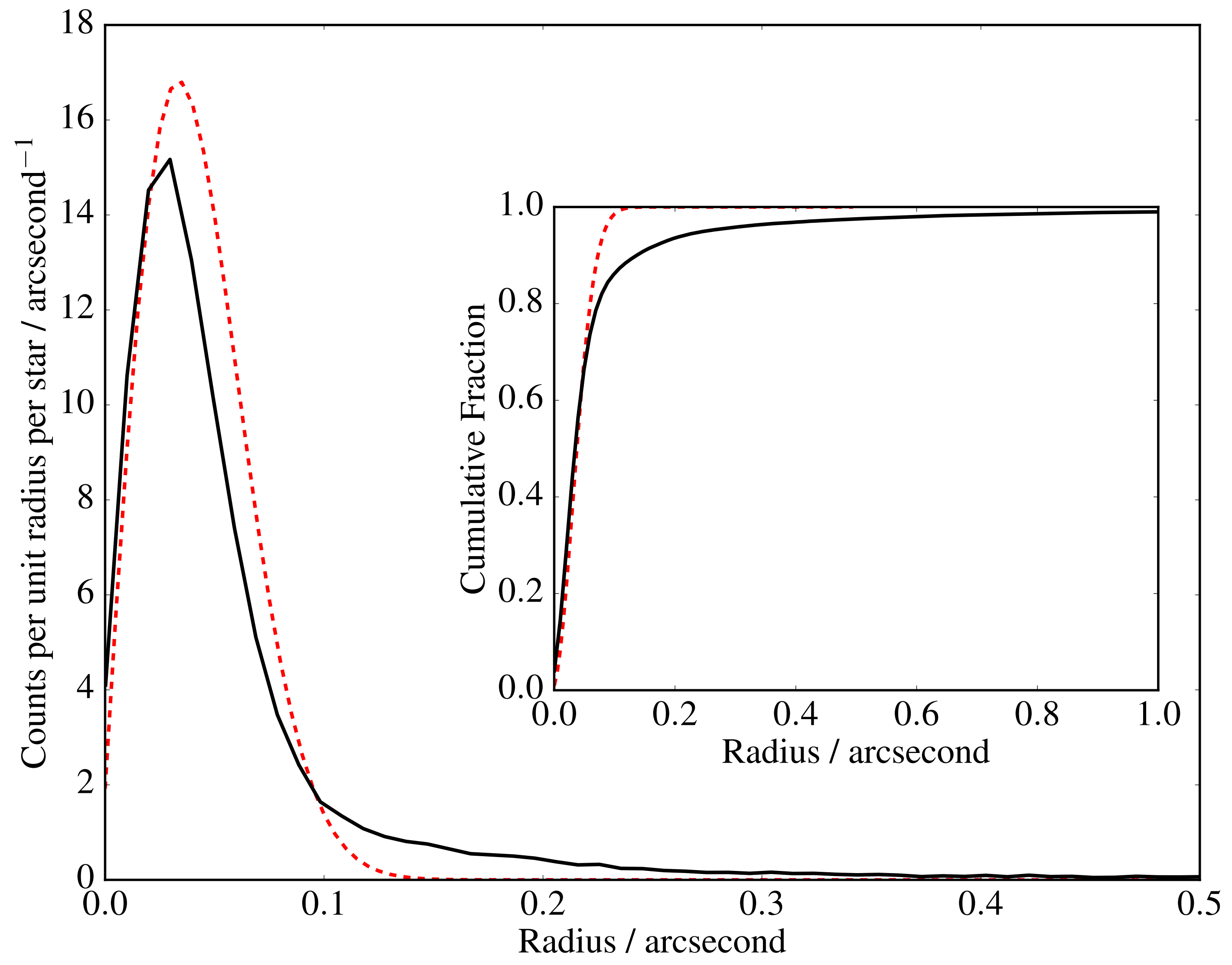

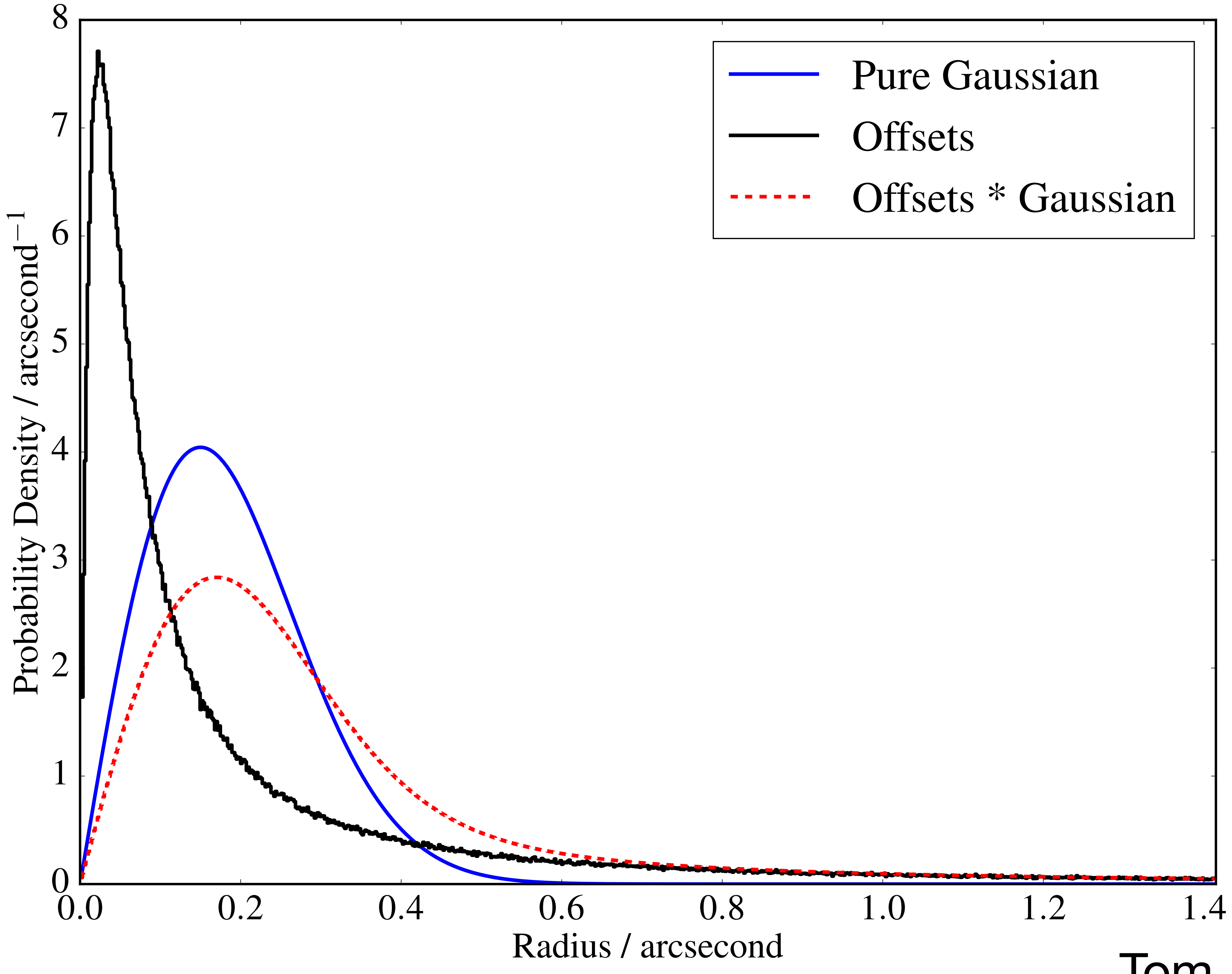

Wilson & Naylor (2017)
Wilson & Naylor (2018b)
WISE - Wright et al. (2010)
Gaia DR2 - Gaia Collaboration, Brown A. G. A., et al. (2018)

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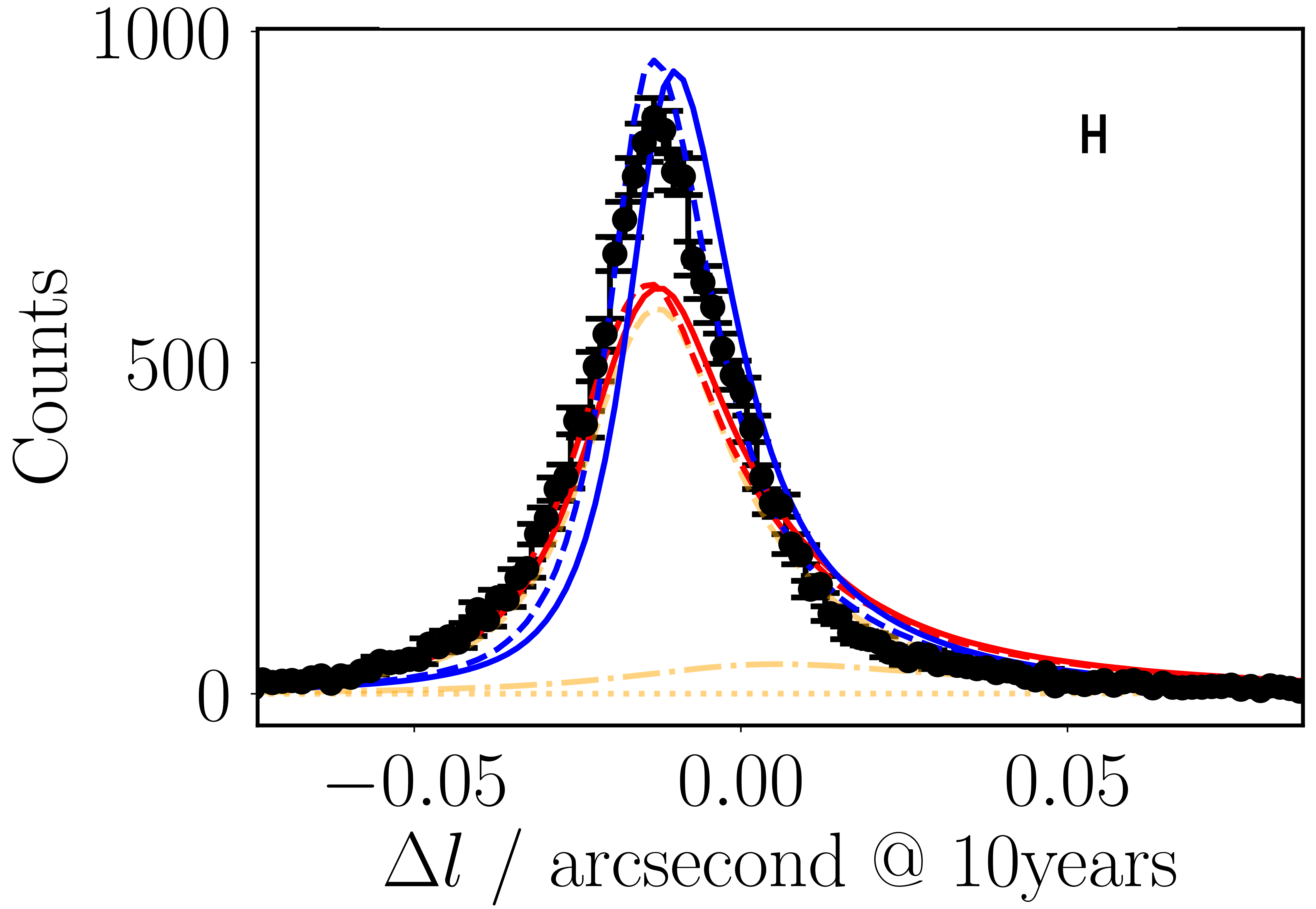
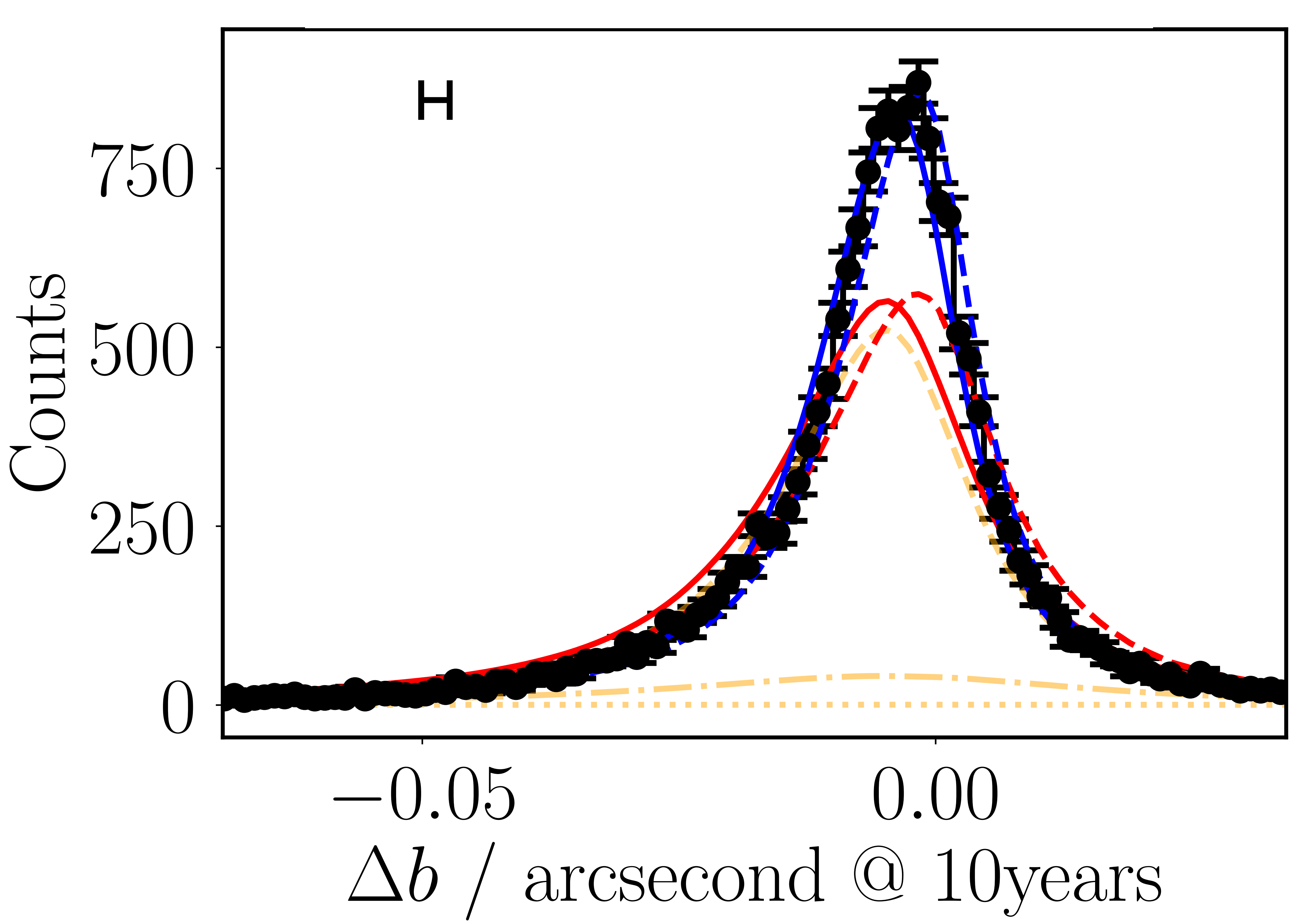
Including Unknown Proper Motions

$$h_{\mathrm{tot}} = h_{\mathrm{pure}} * h_{\mathrm{perturb}} * h_{\mathrm{pm}}$$





Wilson & Naylor (2018b)
Gaia DR2 - Gaia Collaboration, Brown A. G. A., et al. (2018)

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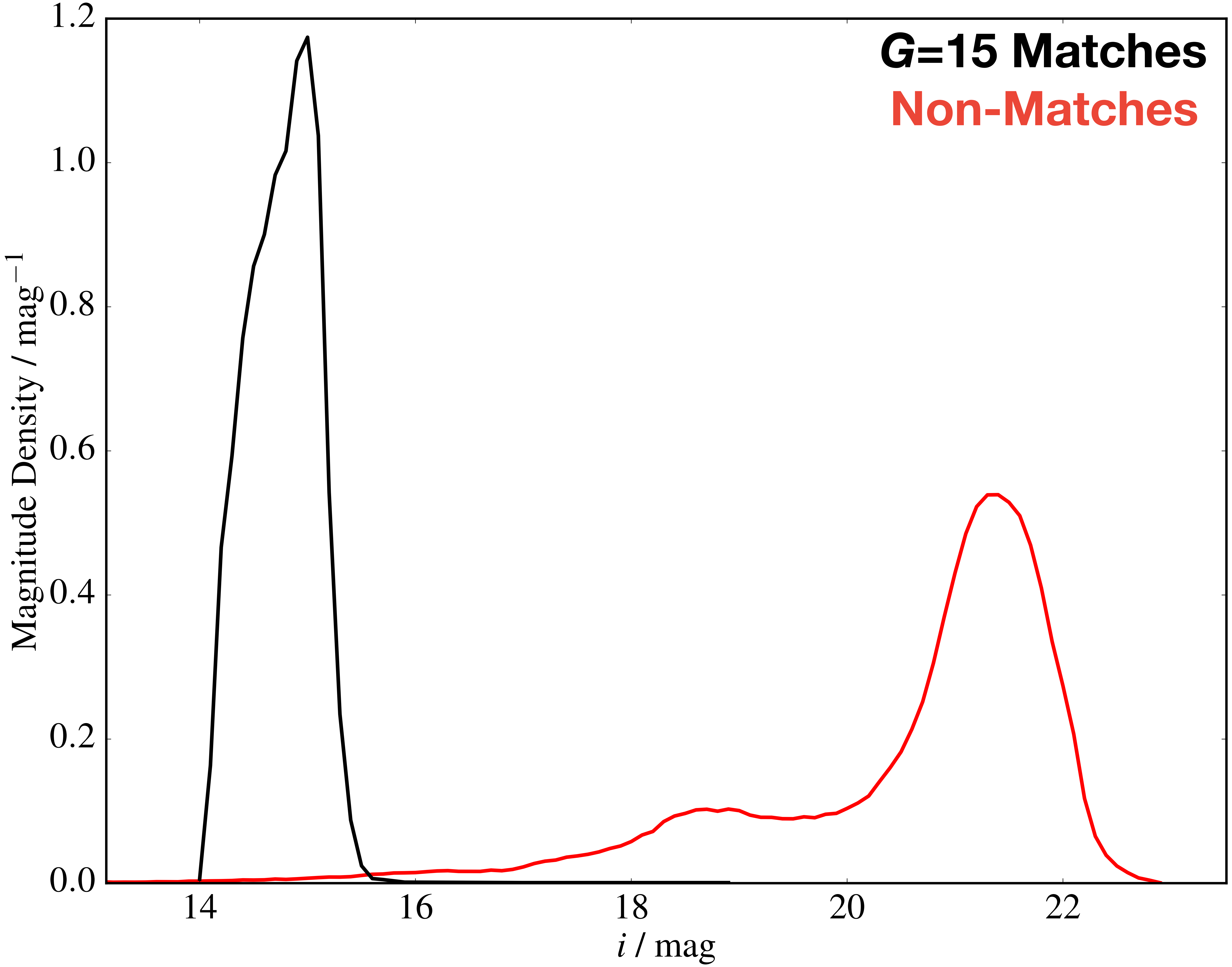
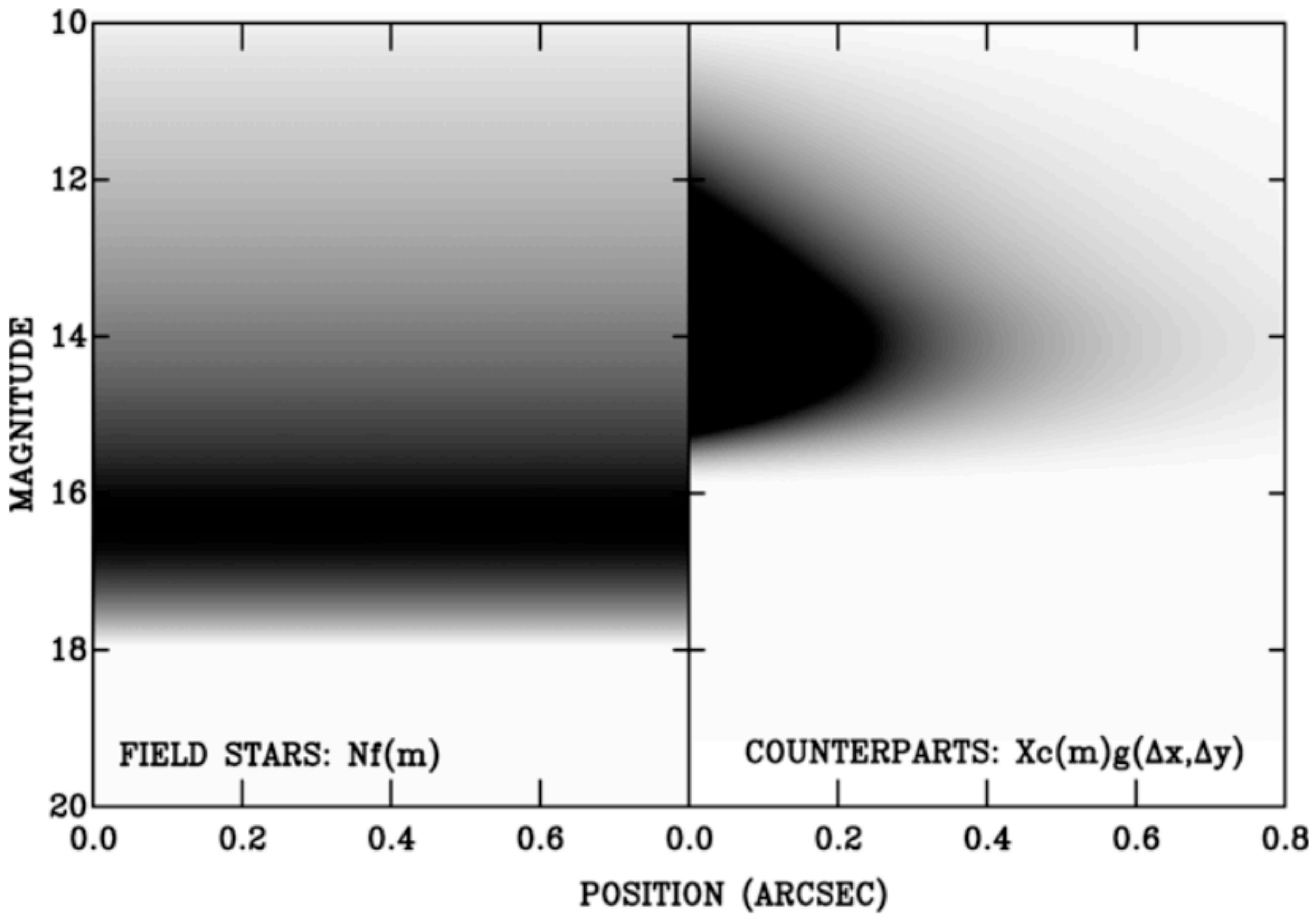
Including Magnitude Information



$$L = \frac{q(m,c)\,f(x,y)}{n(m,c)}$$

Sutherland & Saunders (1992)



Naylor, Broos, & Feigelson (2013)

Wilson & Naylor (2018a)
IPHAS - Barentsen et al. (2014)
Gaia DR2 - Gaia Collaboration, Brown A. G. A., et al. (2018)

Conclusions

- **LSST will suffer significantly from blending of sources, and many false matches, in its crowded fields**
- **Robust modelling of perturbations allows for their effects to be included in the cross-match process**
- **Inclusion of photometry allows us to reject false matches from randomly nearby sources during matching**
- **Can include unknown proper motions easily in Astrometric Uncertainty Function**
- **Modelling of statistical flux contamination allows for the recovery of "true" fluxes**

- **Upcoming LSST:UK cross-match service macauff — let me know your thoughts/needs/hopes/dreams**
    - **Provide tables of cross-matches between LSST and <your favourite catalogue here!>**

Wilson & Naylor, 2017, MNRAS, 468, 2517
Wilson & Naylor, 2018a, MNRAS, 473, 5570
Wilson & Naylor, 2018b, MNRAS, 481, 2148