UNIVERSITY OF EXETER

Catalogue Matching at LSST Depths

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But Tom Wilson did most of the preliminary work.

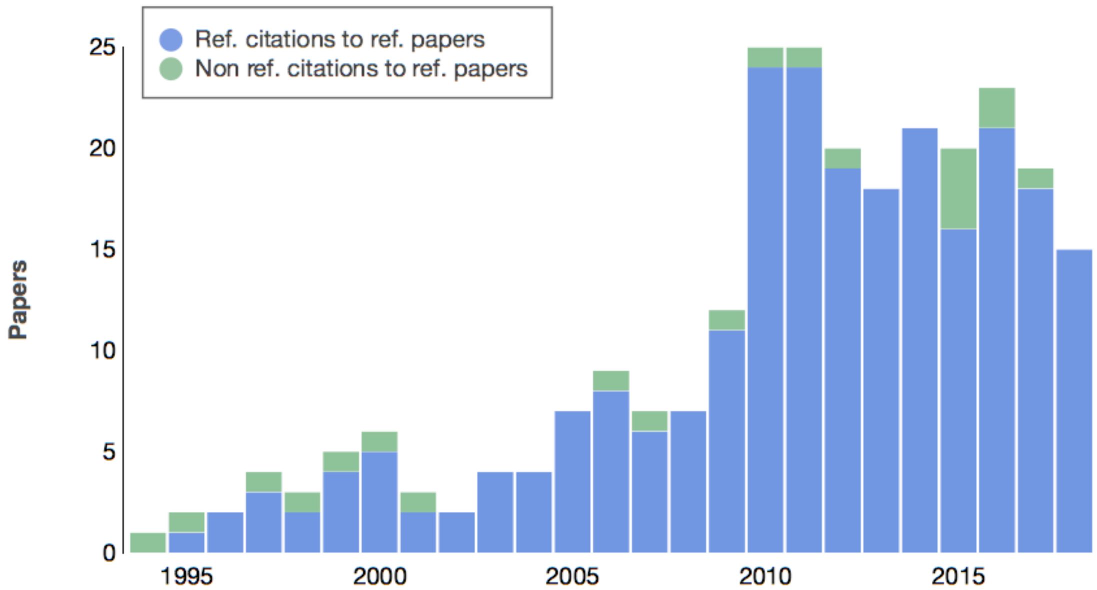
With help from Sarah Casewell, Aleks Scholz, Vicky Scowcroft.

What am I going to say?

- LSST is so crowded (at all galactic latitudes) that
  - "error circle” matching will give high false positive rates
  - faint stars will affect the astrometric positions.
- But
  - Bayesian matching will remove most false positives
  - we can parameterize the “astrometric tug”.
- We aim to provide these via a Phase B package.
- Already provided a Gaia DR2 vs WISE match (Wilson & Naylor MNRAS 2018b).

The papers

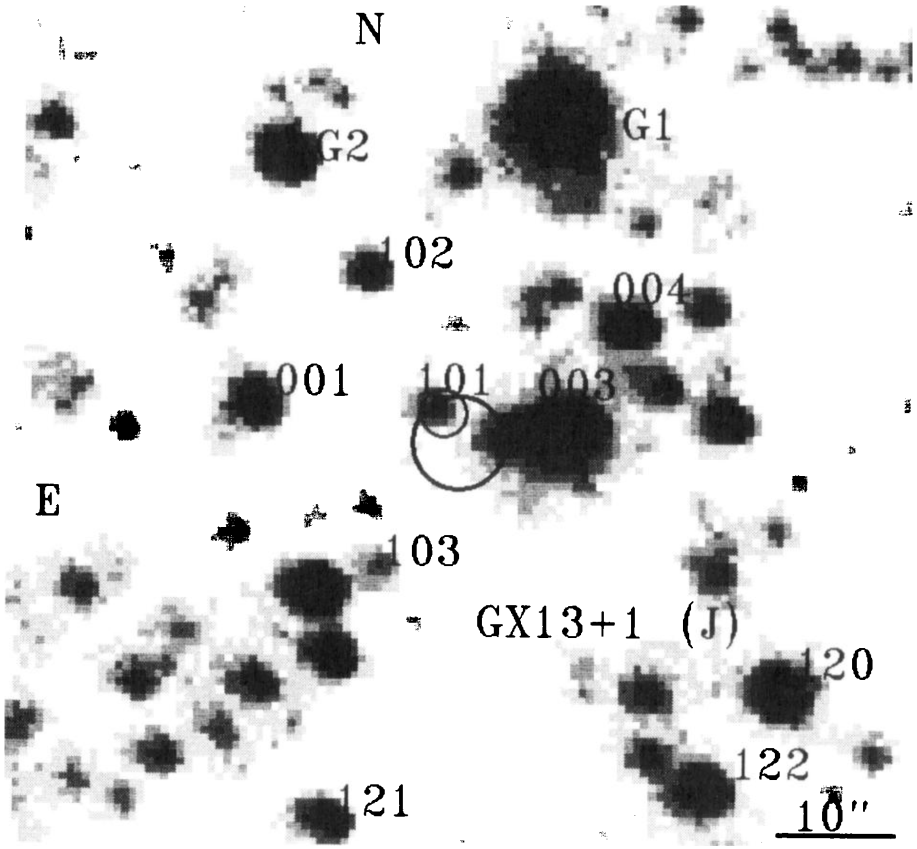
- Sutherland & Saunders (MNRAS, 1992).
- Naylor, Broos & Feigelson (ApJS, 2013).
- Wilson & Naylor (MNRAS, 2017)
- Wilson & Naylor (MNRAS, 2018a,b)



Why is this important?

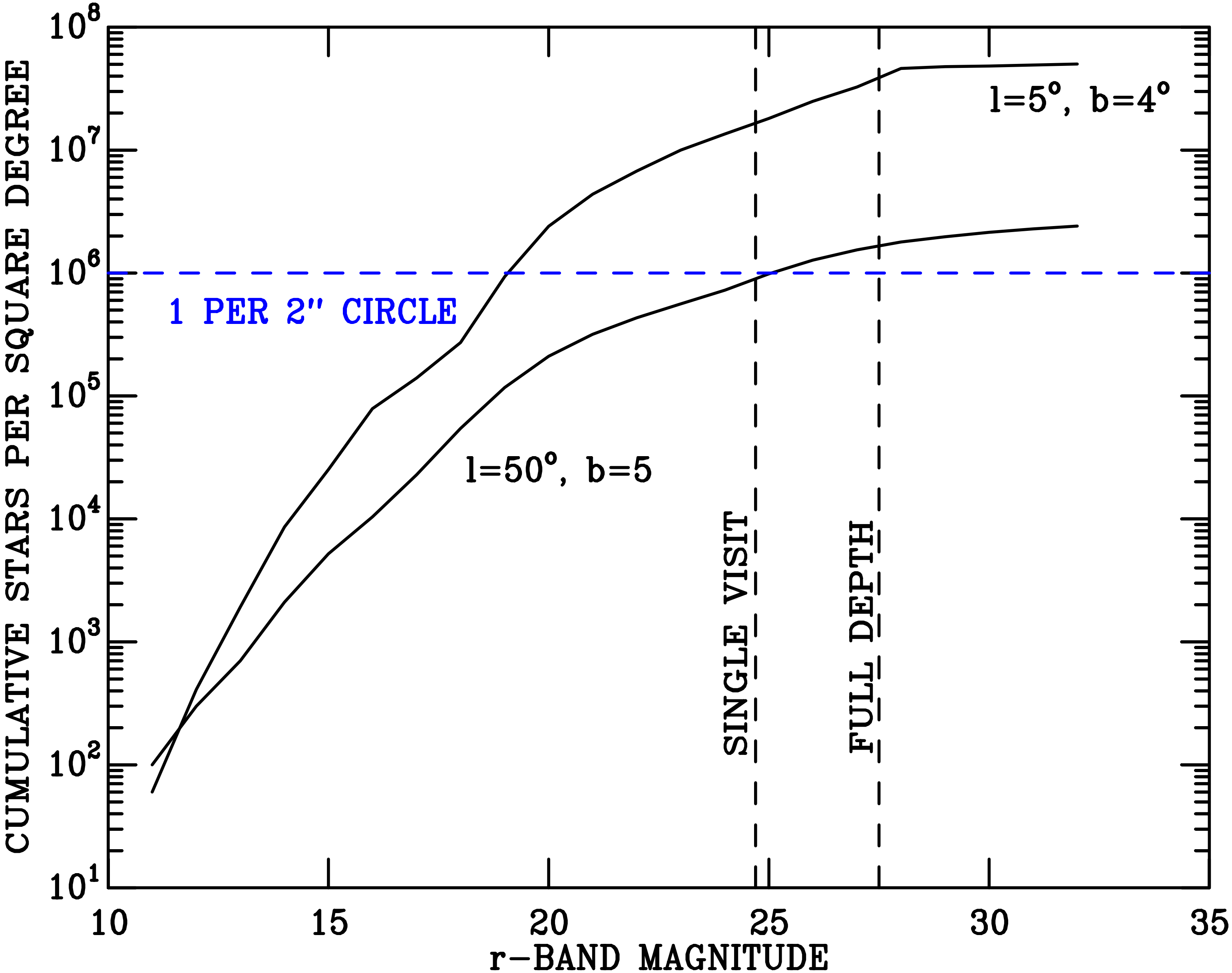
- Many science cases call for drawing in information from other wavelengths.
- E.g. a UK strength is using legacy IR catalogues, and EUCLID.

Conventional Catalogue Cross Matching

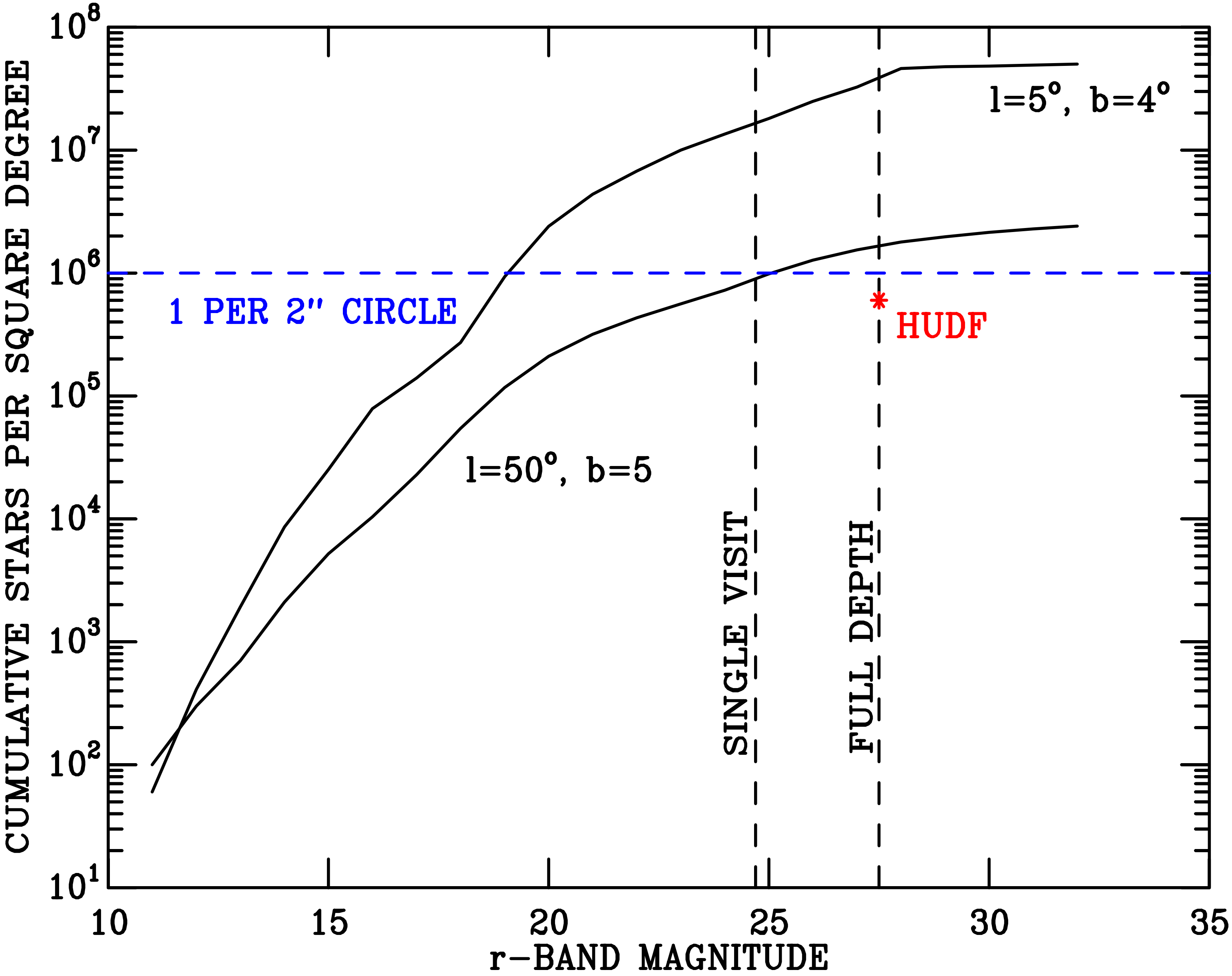


- Draw 99% confidence circle.
- Pick closest star.
- Find false positive rate with randomly placed circles.

Naylor, Charles & Longmore (1991)



CUMULATIVE STARS PER SQUARE DEGREE
r−BAND MAGNITUDE
1 PER 2″ CIRCLE
l=5°, b=4°
l=50°, b=5
SINGLE VISIT
FULL DEPTH
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10
15
20
25
30
35



CUMULATIVE STARS PER SQUARE DEGREE
r−BAND MAGNITUDE
1 PER 2″ CIRCLE
HUDF
l=5°, b=4°
l=50°, b=5
SINGLE VISIT
FULL DEPTH
10
15
20
25
30
35
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8

Problems of Conventional Cross Match

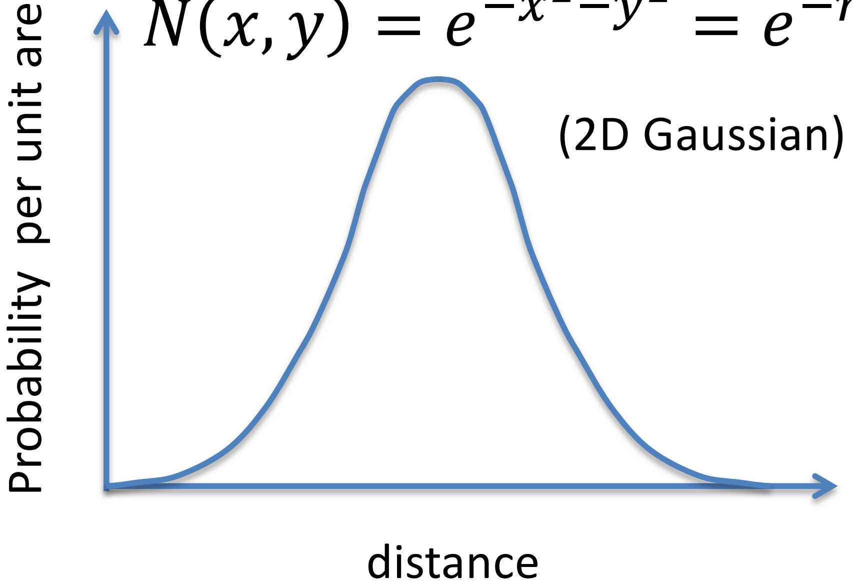
- No preference for close matches
- (Indeed error circles typically far too large.)
- What about close faint stars?
- Intuition…
  - closer stars are more likely to be the counterpart
  - fainter stars are more likely to be field stars.

The Problem

- Have to understand astrometric uncertainties.
- 2D Gaussian, Quetelet (1796 – 1874), cited by John Herschel.

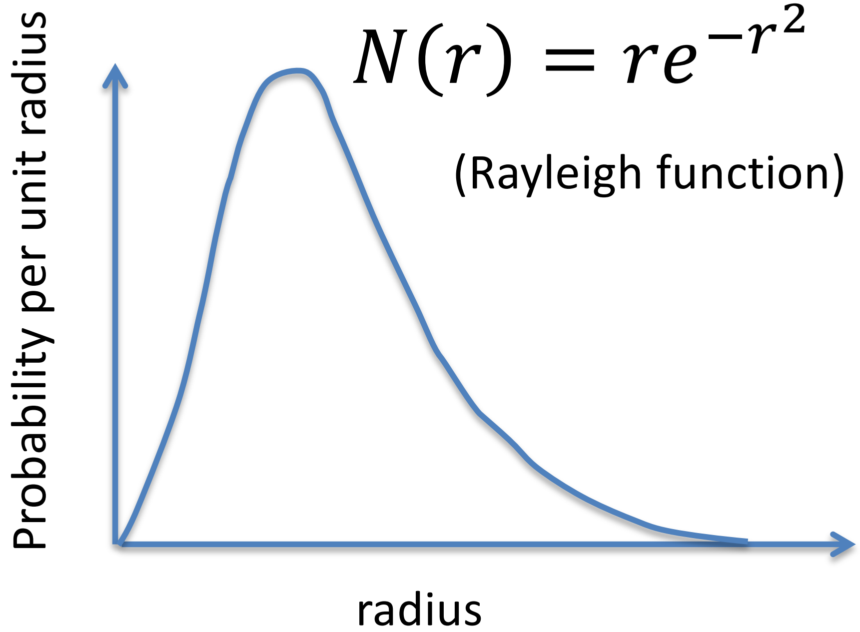
$$N(x,y) = e^{-x^2-y^2} = e^{-r^2}$$

(2D Gaussian)

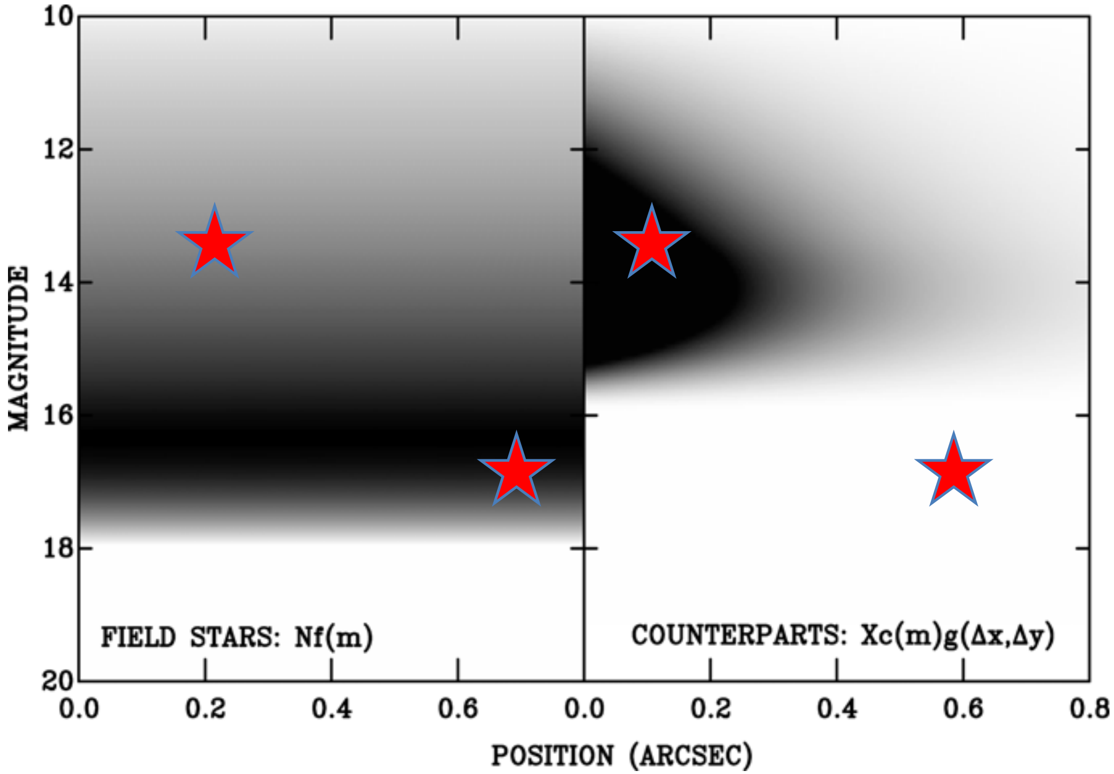


$$N(r) = re^{-r^2}$$

(Rayleigh function)



How the Bayesian Match Works



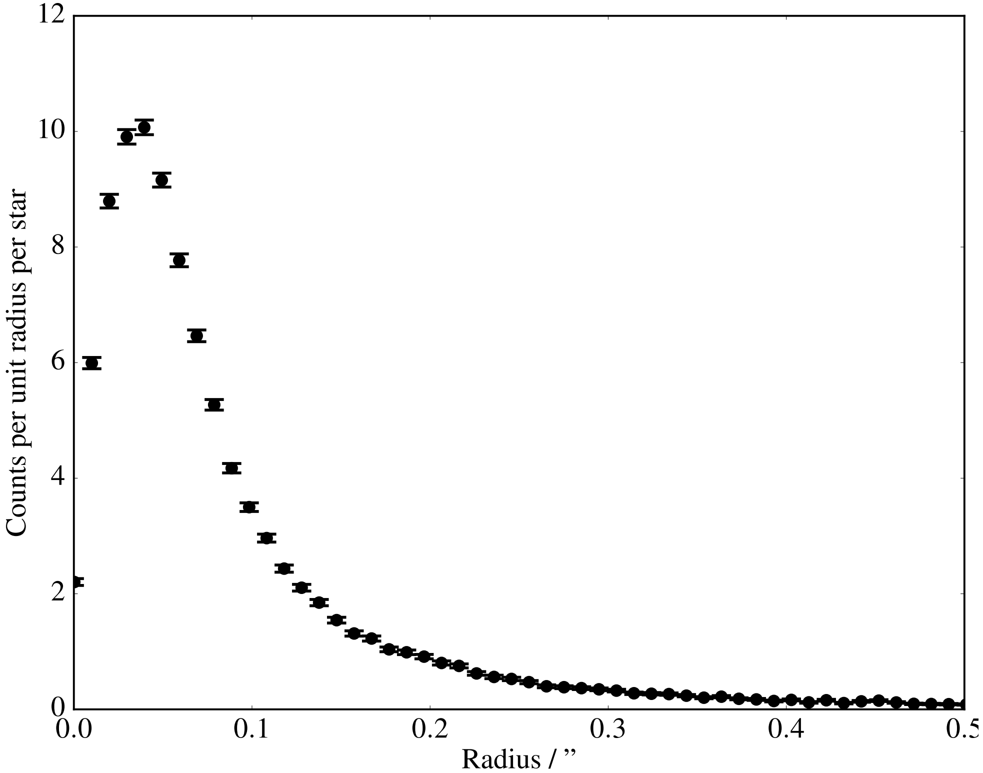
$$P(H_a|D) = \frac{\frac{Xg(\Delta x,\Delta y)}{N_\gamma}\,\frac{c(m_a)}{f_\gamma(m_a)}}{1 - X + \sum_\alpha \frac{Xg(\Delta x,\Delta y)}{N_\gamma}\,\frac{c(m_\alpha)}{f_\gamma(m_\alpha)}}$$

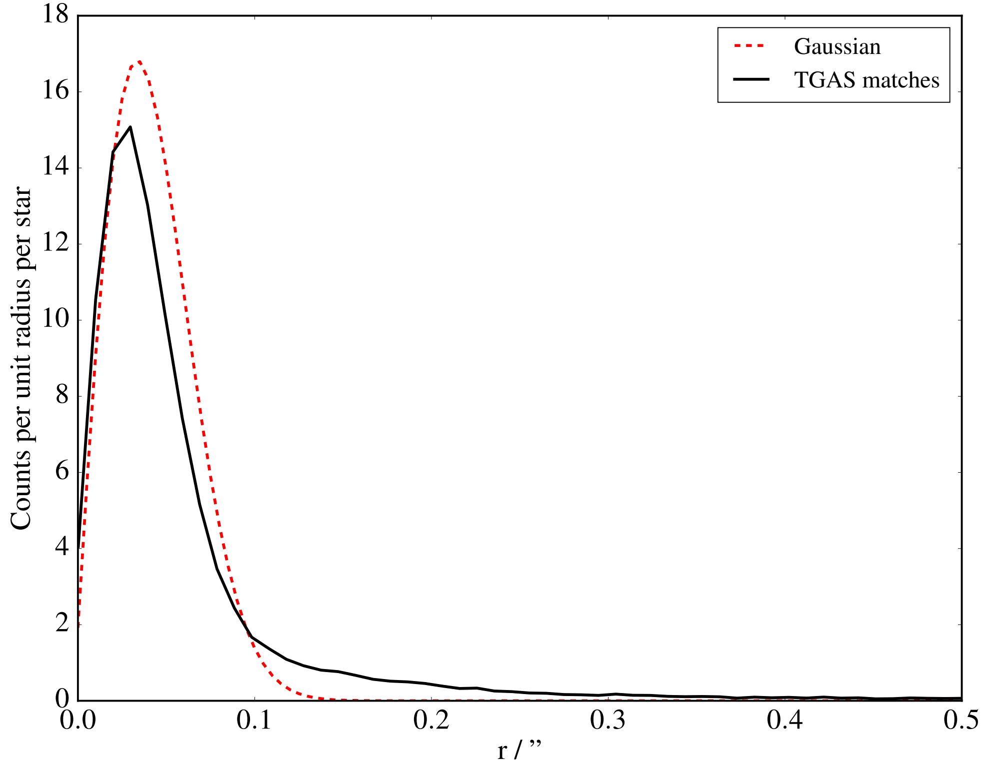
$$P(H_0|D) = \frac{1 - X}{1 - X + \sum_\alpha \frac{Xg(\Delta x,\Delta y)}{N_\gamma}\,\frac{c(m_\alpha)}{f_\gamma(m_\alpha)}}$$

The Plan

1. Use Bayesian matching – decreases area searched by factors of >100.

WISE data in Galactic Plane



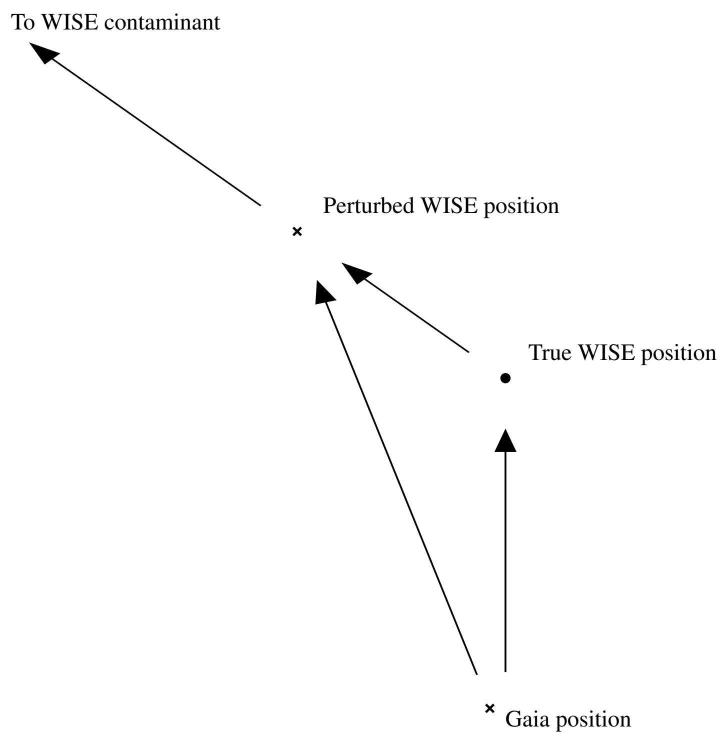


- Why Wise? Comparable to single visit LSST.
- Gaia DR1 vs WISE.
- Long, non-Gaussian tail.

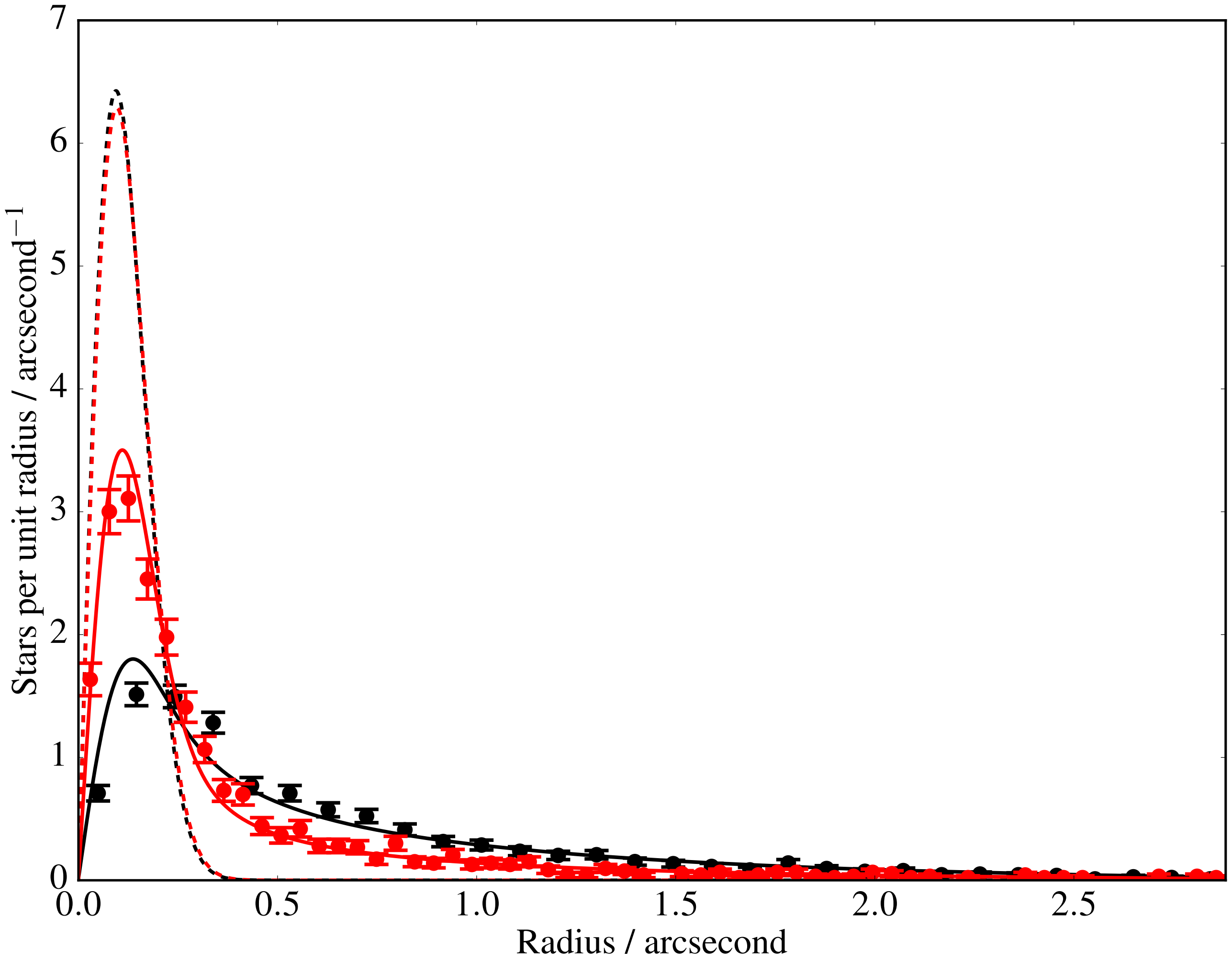
Hypothesis - stars Hiding in the PSF- the astrometric tug

- WISE PSF is 6” (in shorter bands).
- Star 4” away, 20x (3 mags) fainter.
- Gives 0.2” disturbance.

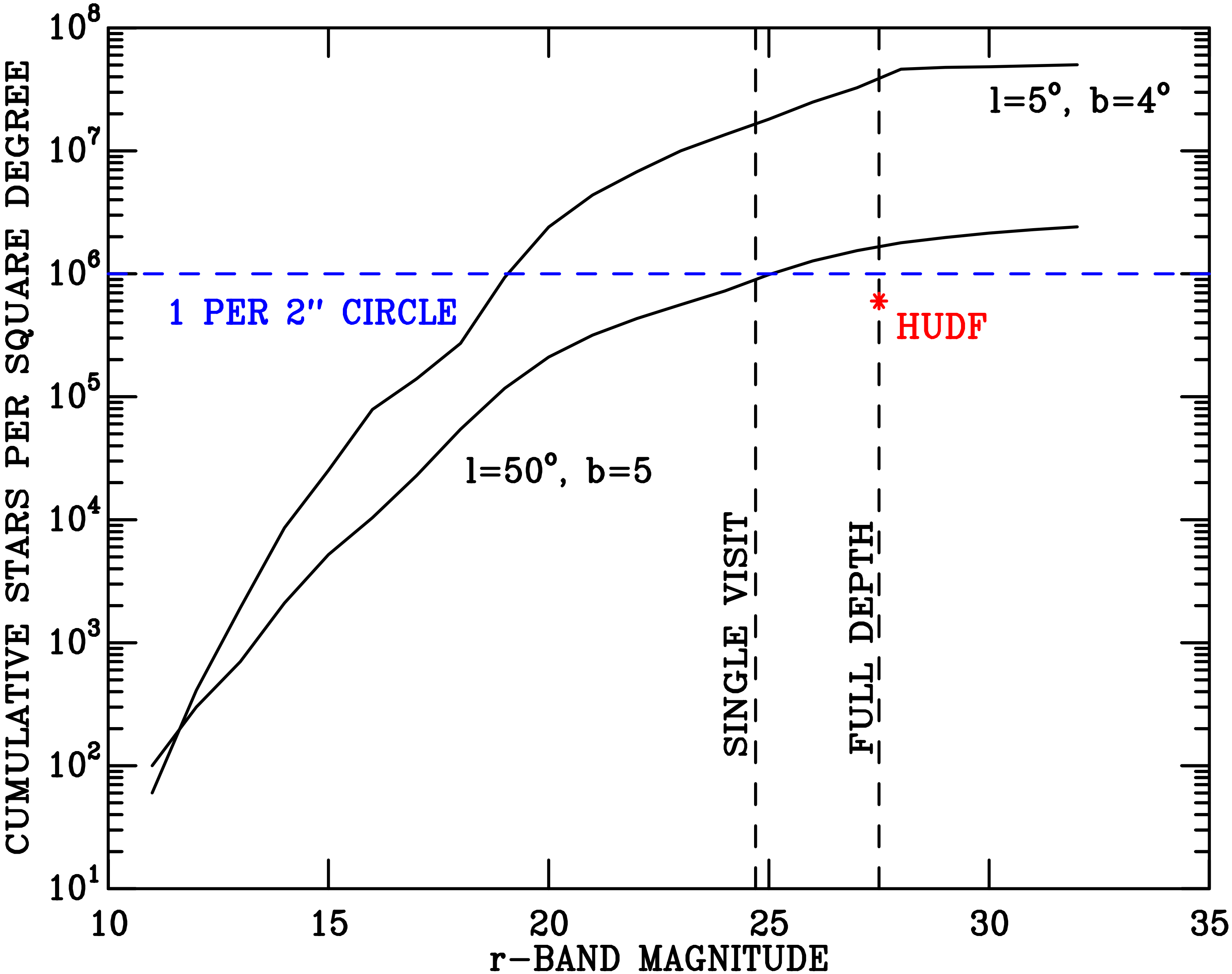
Picture Credit: Damen



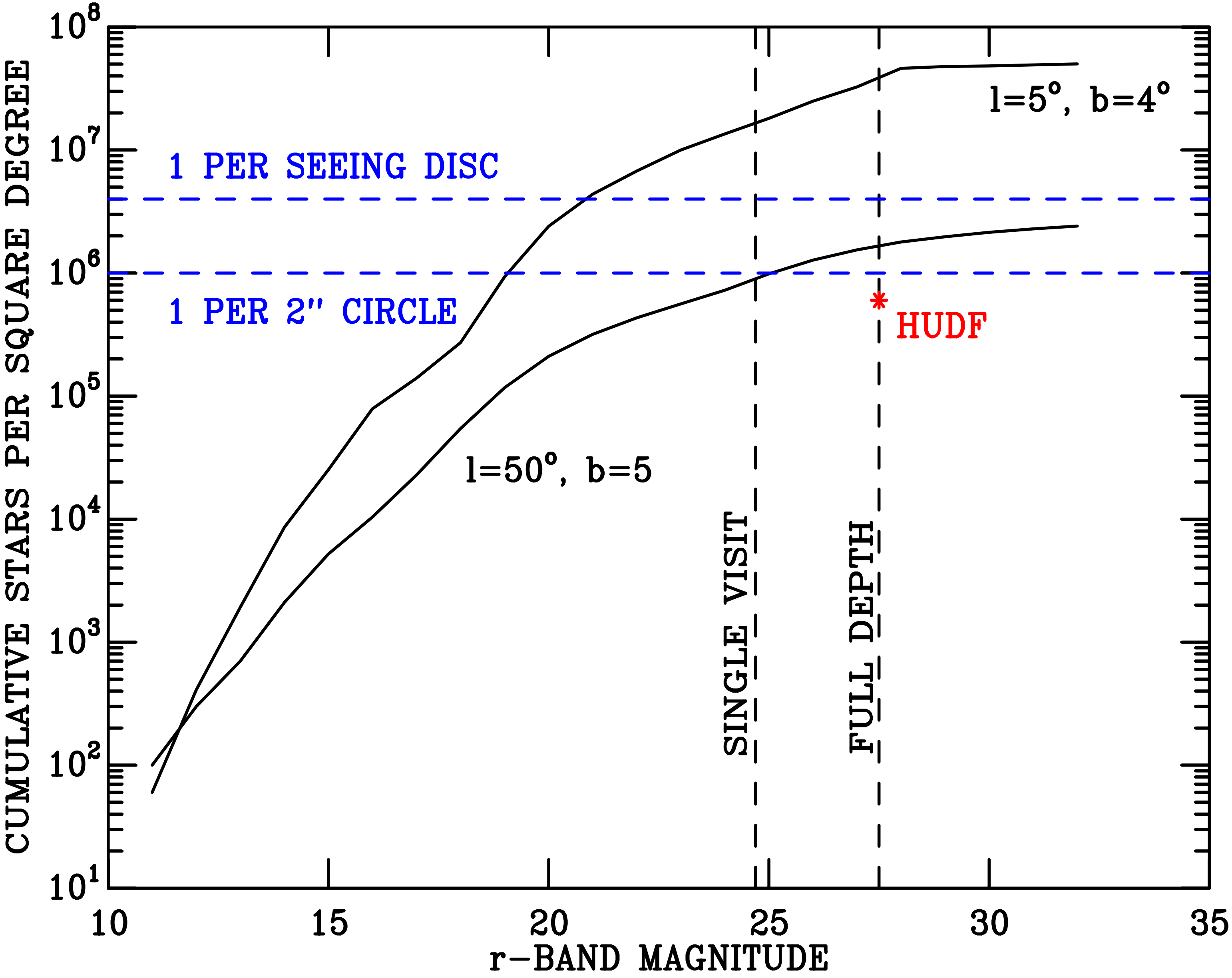
Simulation



- Assume no deblending.
- Nicely puts in non-Gaussian tail, which increases as stars get fainter.



CUMULATIVE STARS PER SQUARE DEGREE
r−BAND MAGNITUDE
1 PER 2″ CIRCLE
HUDF
l=5°, b=4°
l=50°, b=5
SINGLE VISIT
FULL DEPTH



CUMULATIVE STARS PER SQUARE DEGREE
r−BAND MAGNITUDE
1 PER SEEING DISC
1 PER 2'' CIRCLE
l=5°, b=4°
l=50°, b=5
HUDF
SINGLE VISIT
FULL DEPTH
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10
15
20
25
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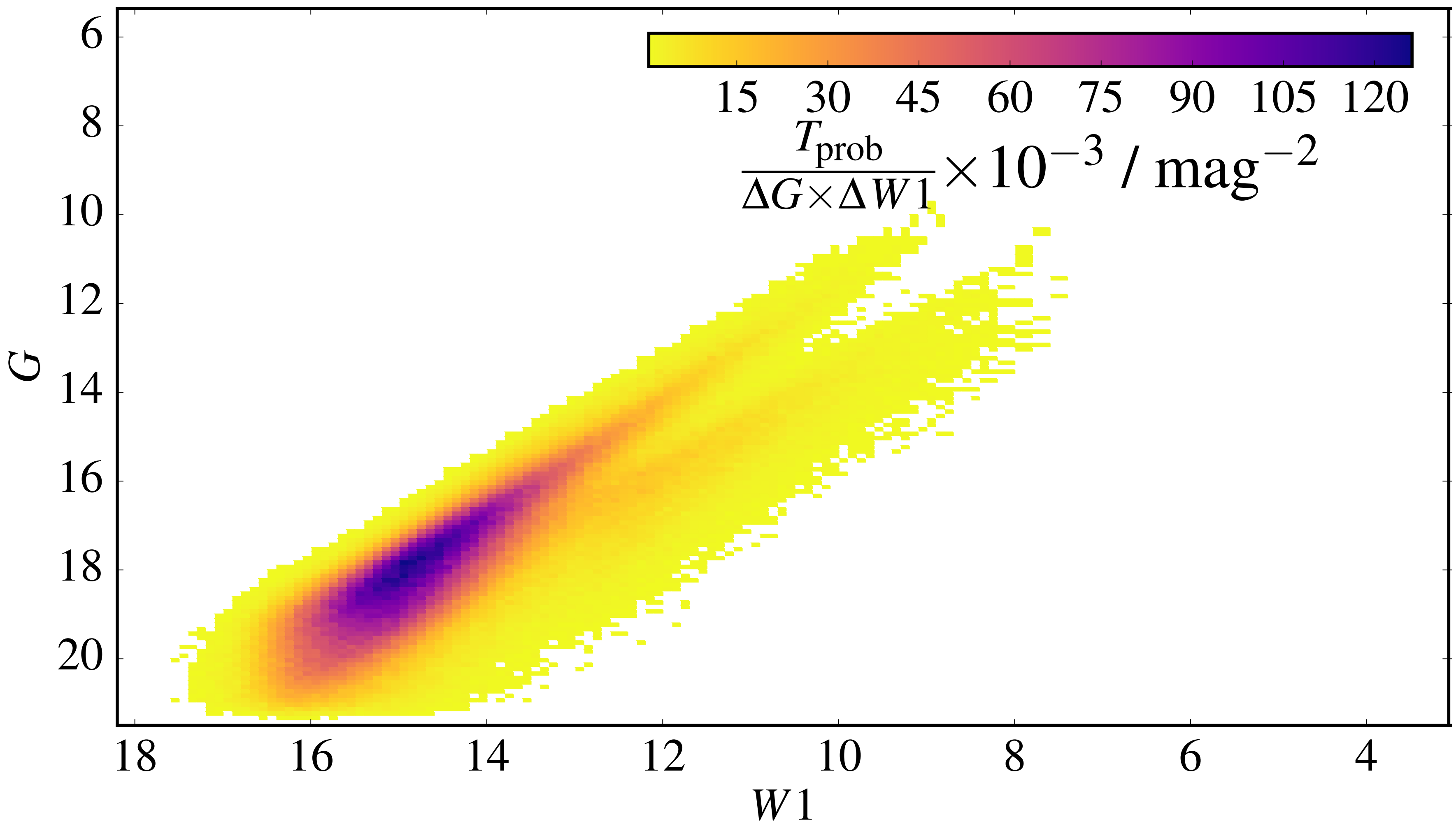
35

The Plan

1. Use Bayesian matching – decreases area searched by factors of >100.
2. Allow for ”astrometric tug”.

Model also useful for moving objects.



15 30 45 60 75 90 105 120
$\frac{T_{\rm prob}}{\Delta G \times \Delta W1} \times 10^{-3}$ / mag^{-2}
6
8
10
12
14
16
18
20
G
18 16 14 12 10 8 6 4
W1

The Plan

1. Use Bayesian matching – decreases area searched by factors of >100.
2. Allow for ”astrometric tug”.

   Model also useful for moving objects.
3. Add in photometric information – improves Bayes factors by an order of magnitude.

Column Name	FITS Name	Description
Match Probability	MATCH_P	Probability of match
η	ETA	Photometric logarithmic likelihood ratio
ξ	XI	Astrometric logarithmic likelihood ratio
1% Contamination Probability	CONT_P1	Probability of source having contaminant of at least 1% relative flux given its separation from its corresponding Gaia detection.
10% Contamination Probability	CONT_P10	Ditto at 10%.
Average Contamination	AVG_CONT	Mean contaminating relative flux for local field

Conclusions

- LSST positions will be affected by contamination from fainter stars.
- In galactic plane this is estimated to be as bad as WISE, i.e. dominant
  - (though the numbers are very uncertain).
- Bad news.
  - It will affect ability to identify faint progenitors.
  - It will affect proper motions, and be really bad if we use different spatial resolution surveys to get baseline.
- Good news.
  - We can cure this, either as a matching tool, or catalogues of matches.
  - Data fusion will then provide best magnitudes.