

"The Gaia distances"

Jan Rybizki (MPIA - CU8)
Gaia Data Workshop
Heidelberg 06/19/18

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Estimating distances from parallaxes IV: Distances to 1.33 bn Stars in Gaia DR2

**Bailer-Jones, C. A. L.; Rybizki, J.;
Fouesneau, M.; Mantelet, G.; Andrae, R.**

Within context

- Paper 1: Bailer-Jones (2015):
didactic article exploring priors and biases

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- Paper 4: Bailer-Jones+ (2018): GDR2 geometric distance catalog

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TGAS geometric distance catalog
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- Also check:
 - Luri+ (2018) - Using Gaia parallaxes (lots of examples and online tutorials)
 - Lindegren+ (2018) - The astrometric solution

Inferring distance from parallaxes

- Could use more data to get better distance estimates e.g. see:
 - Sanders & Das (2018):
Astrometry + Photometry + Spectroscopy

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Inferring distance from parallaxes

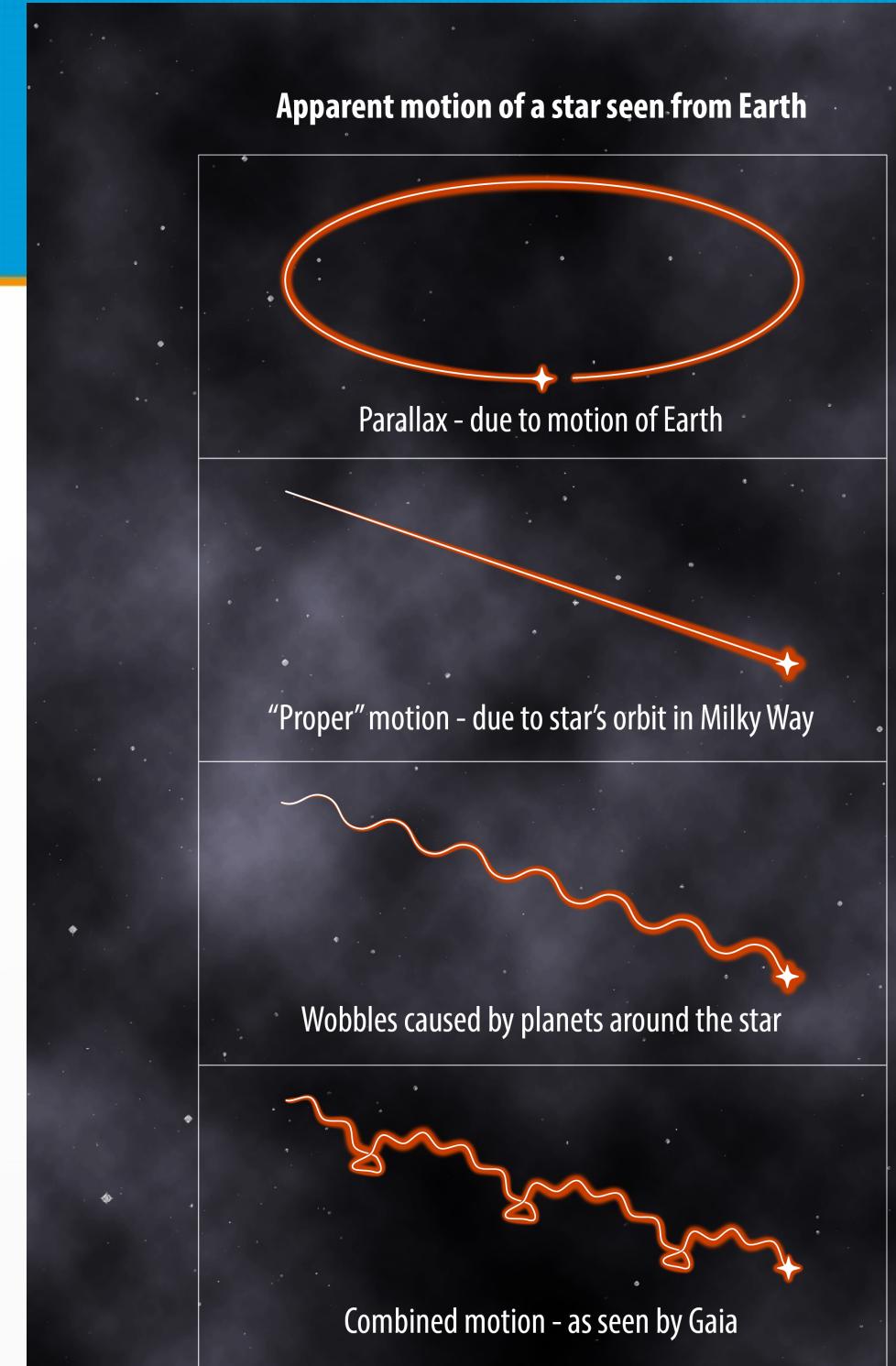
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Astrometry + Photometry + Spectroscopy
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Distances for RVS sample from parallaxes + Grvs prior
- We wanted a pure geometric distance inference for all GDR2 stars with 5 parameter solution

Gaia vision

- Motion of the star on the sky as seen from L2

Gaia vision

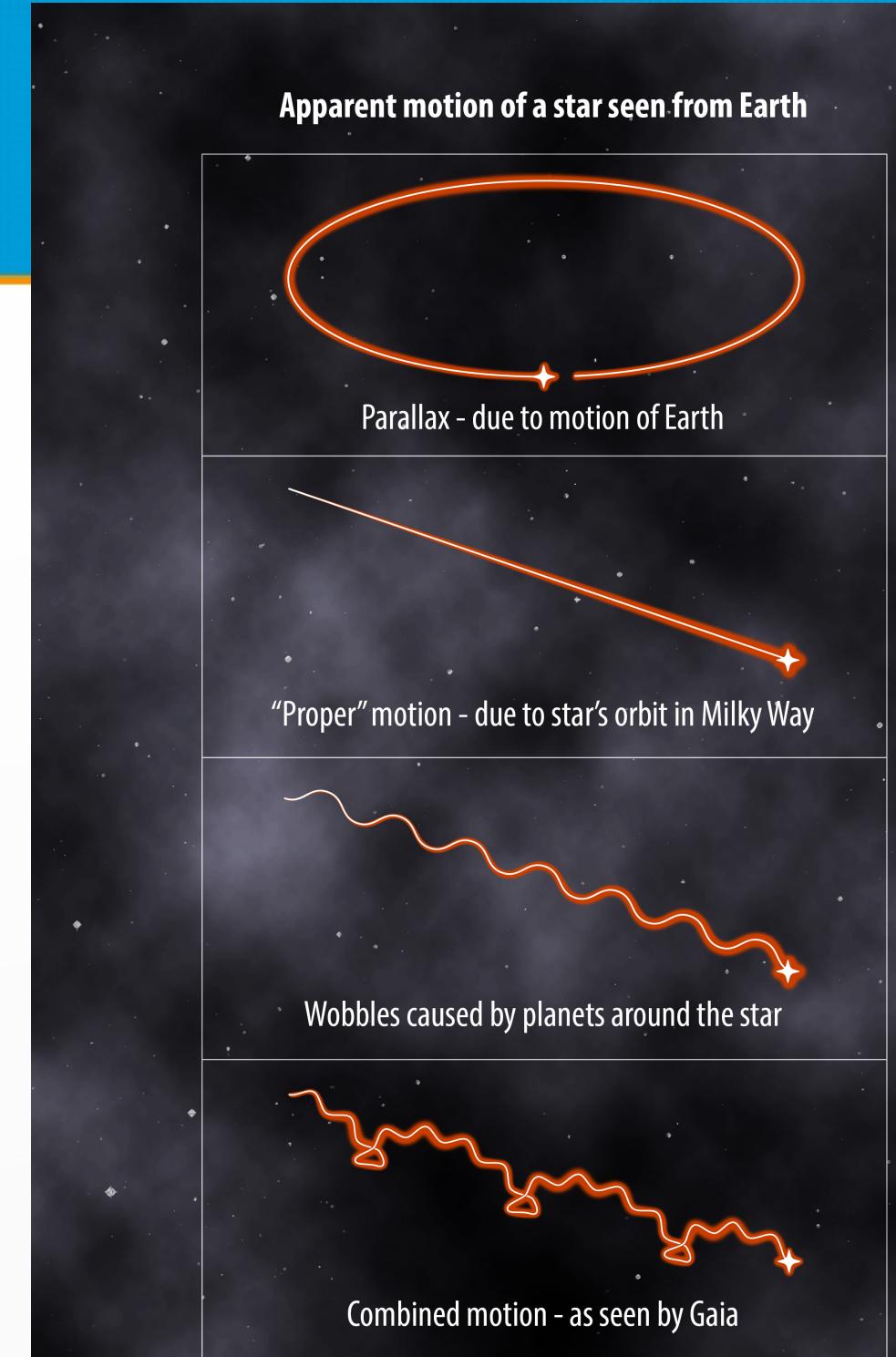
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Credit: ESA

Gaia vision

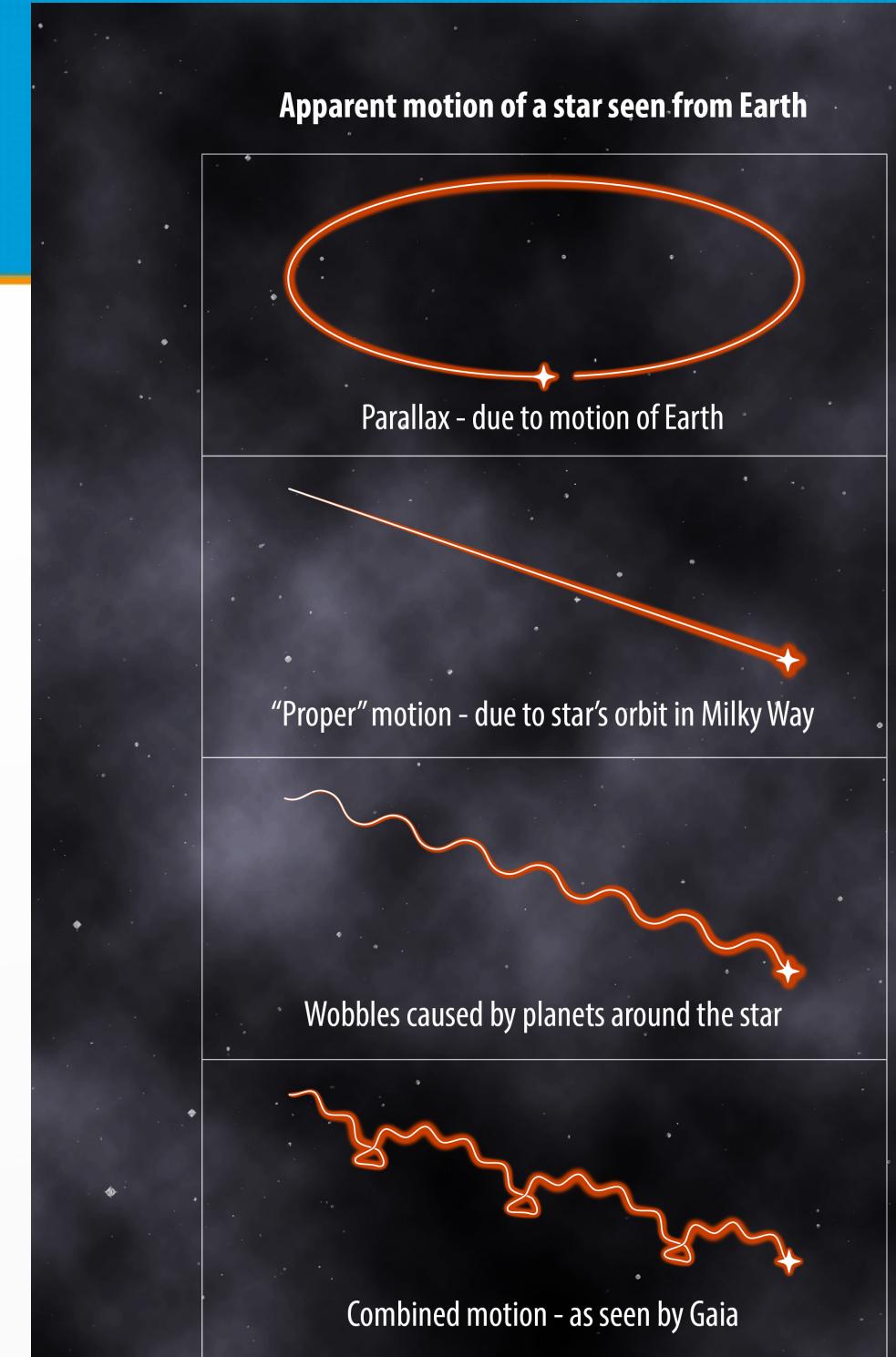
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- parsec (pc) → arcsec (as)
 - 30 arcmin ~ Moon / Sun
 - 1 arcmin ~ eye's resolution
 - 1 as ~ 1 cent in 4km
 - 20 μ as ~ Gaia uncertainty



Credit: ESA

Gaia vision

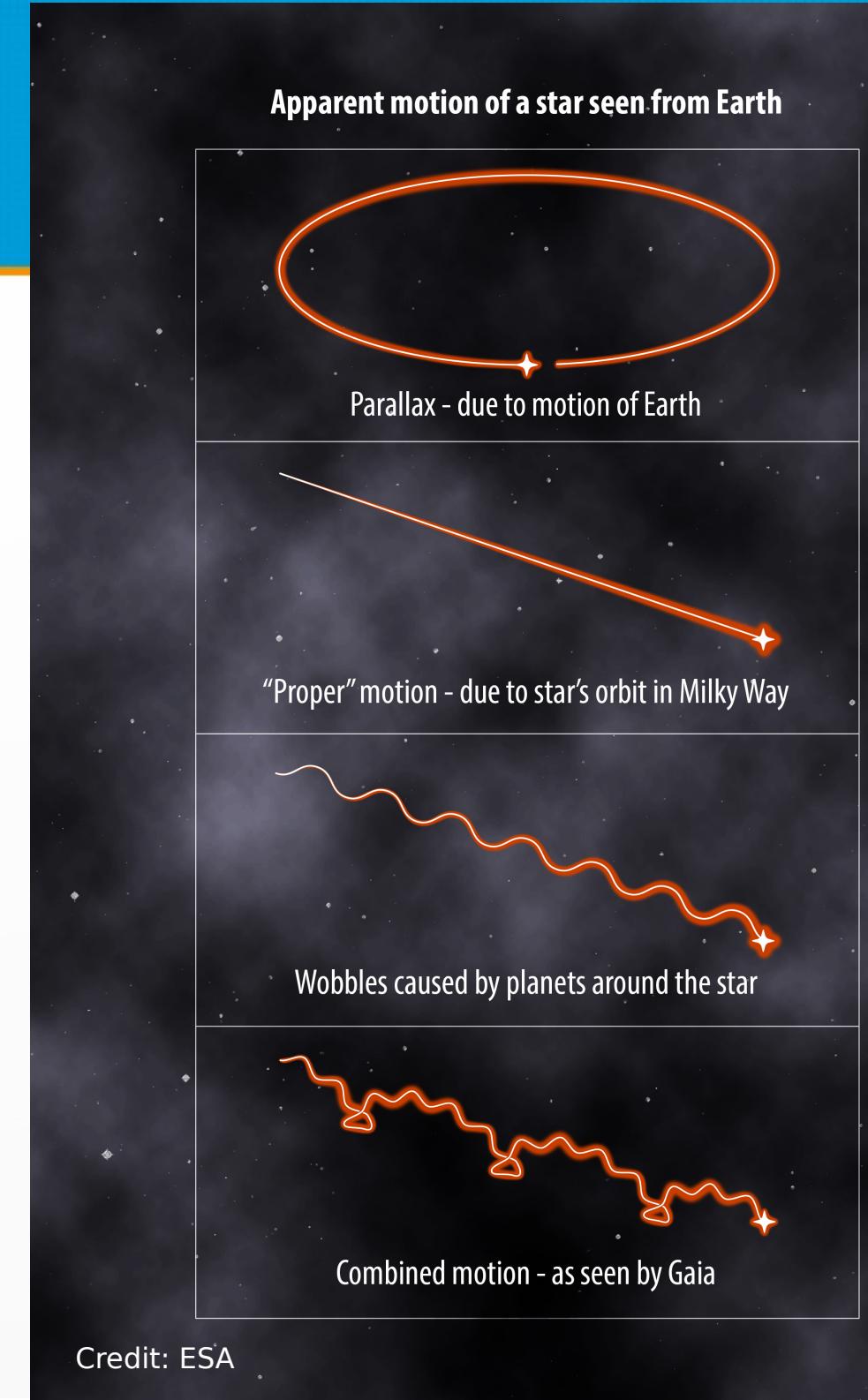
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10.3 as/yr



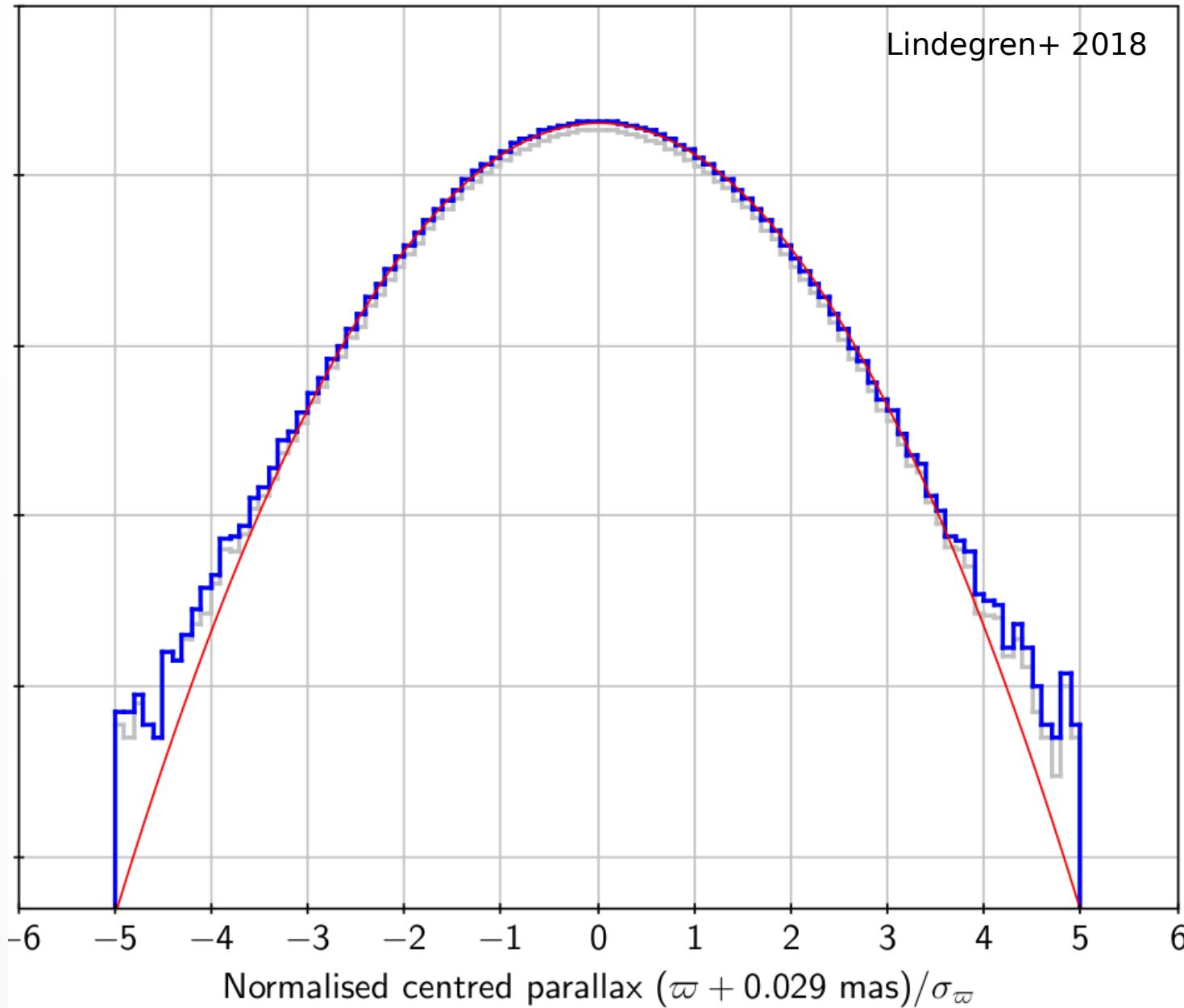
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- Bernard's Star has pm 10.3 as/yr
- Parallax uncertainty dependent on G and N_obs

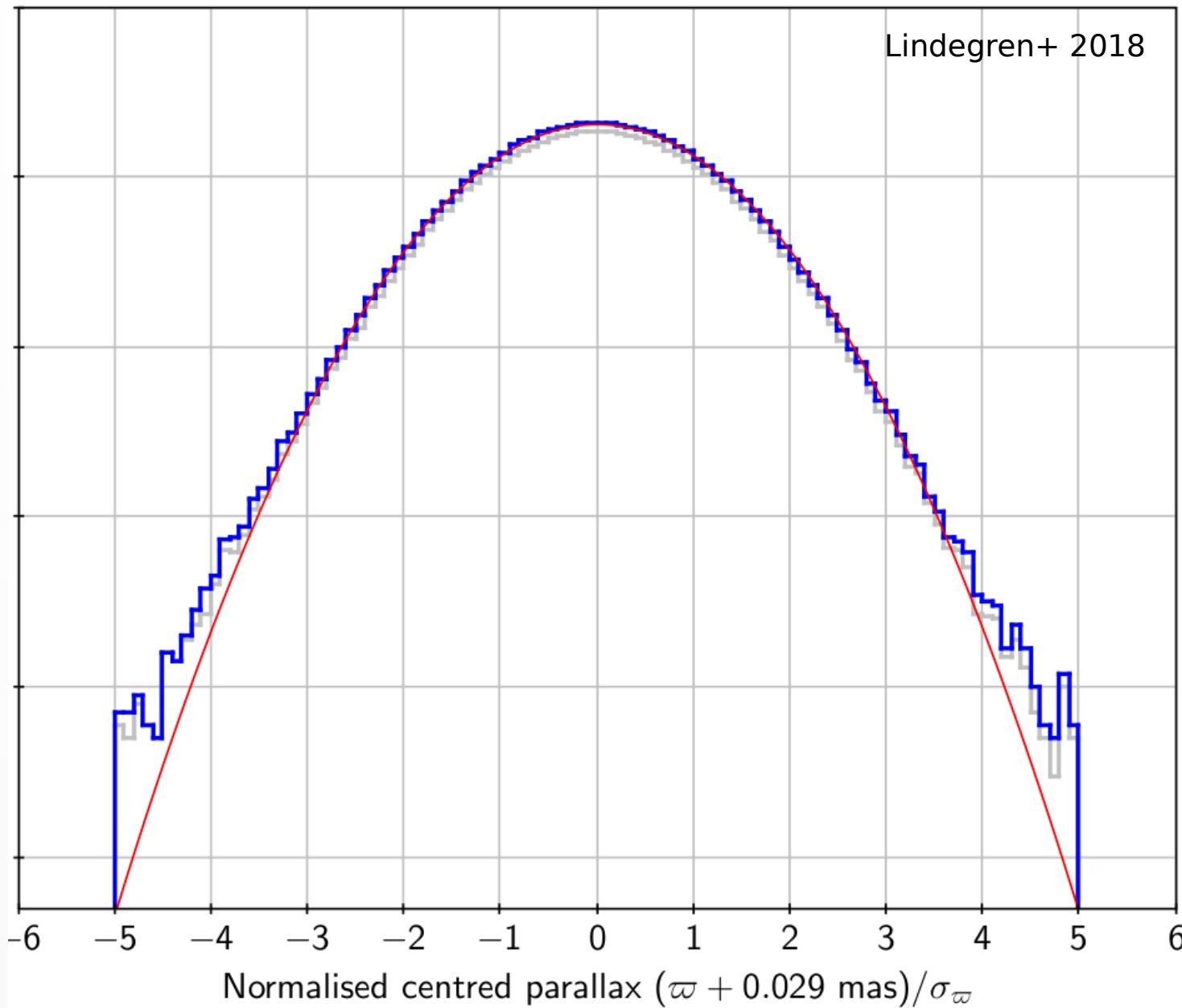


Parallax measurement



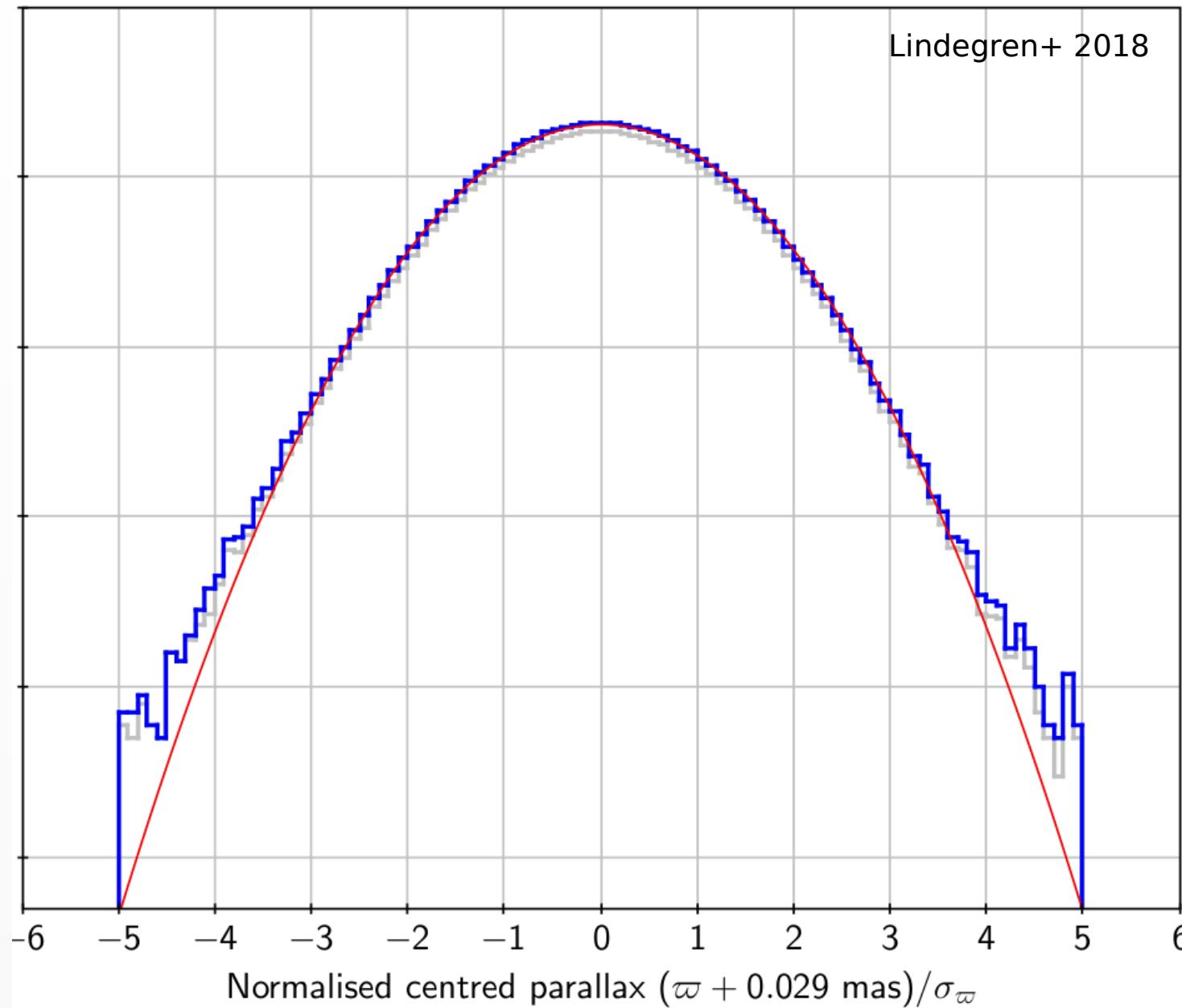
Parallax measurement

- Is Gaussian



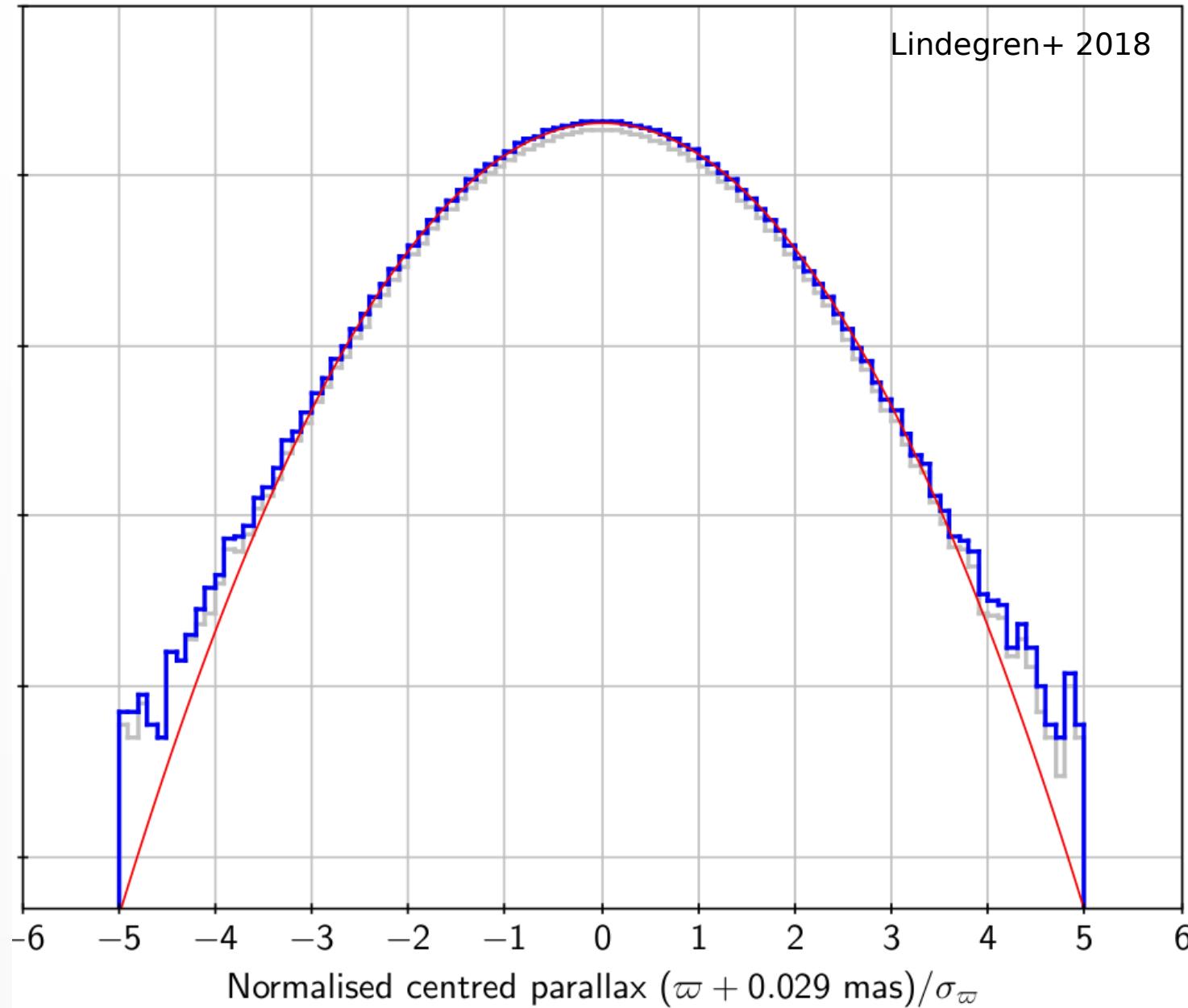
Parallax measurement

- Is Gaussian
- Zero-point offset



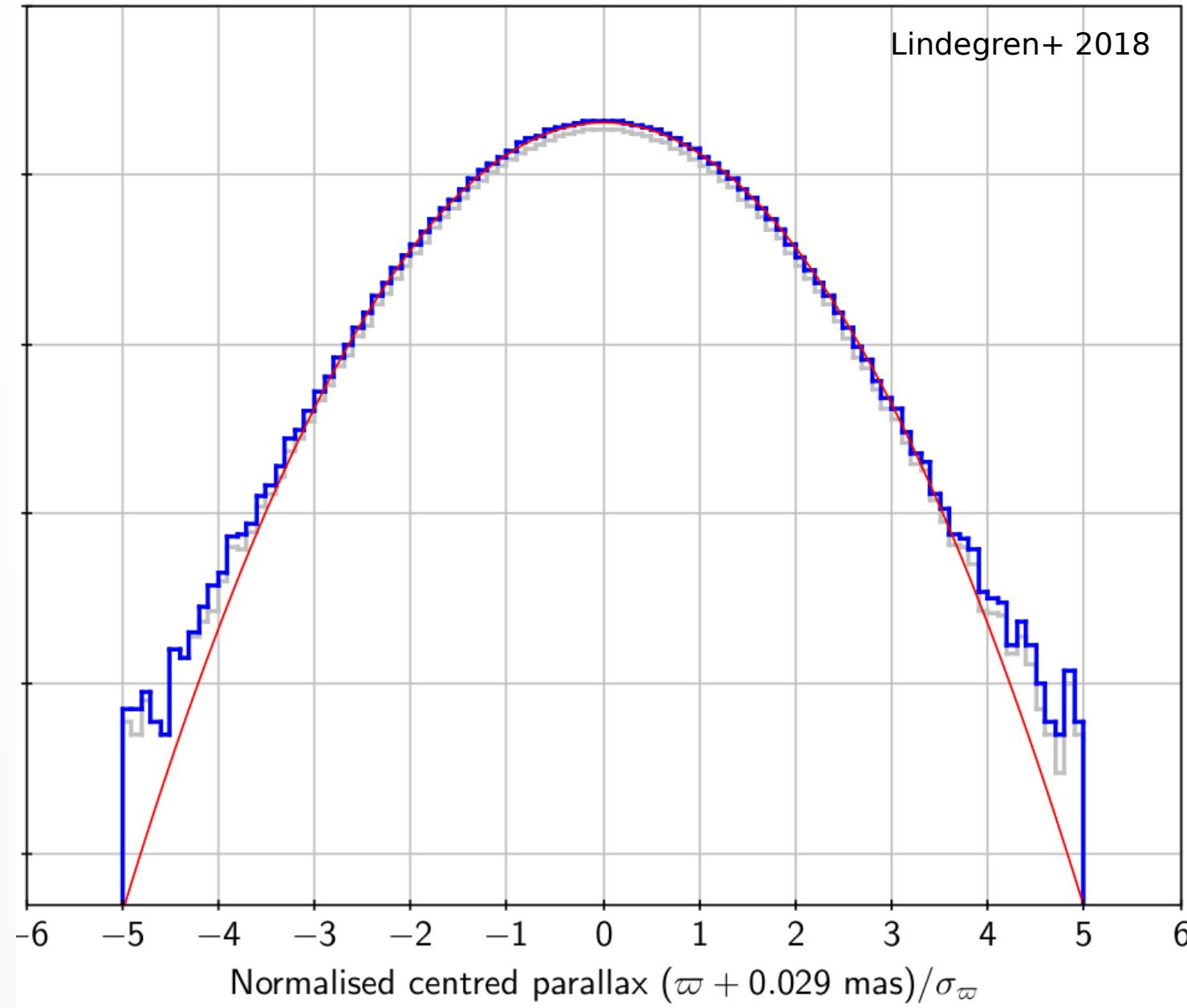
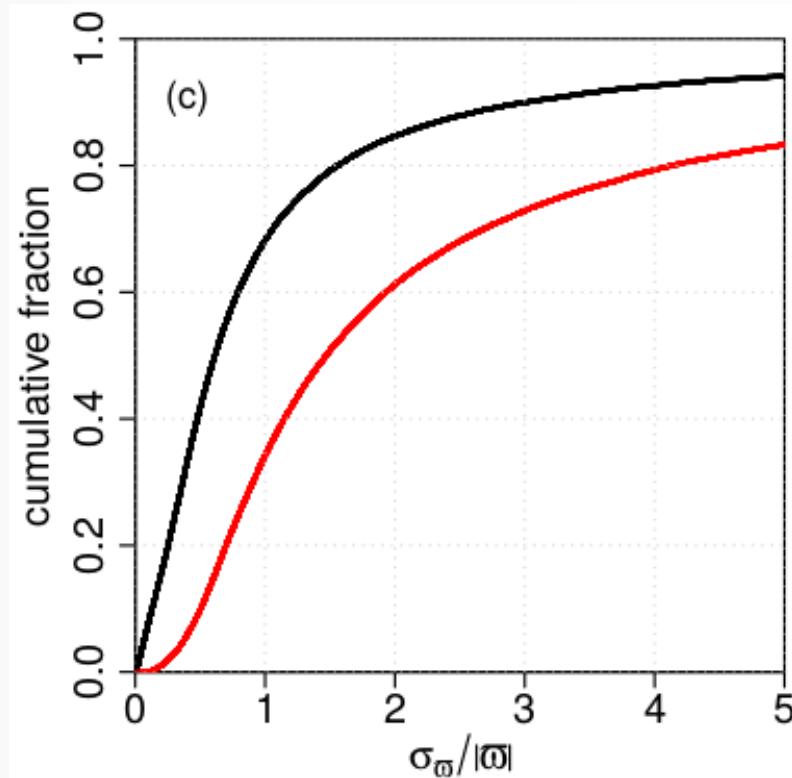
Parallax measurement

- Is Gaussian
- Zero-point offset
- Distant stars have higher σ_ϖ / ϖ



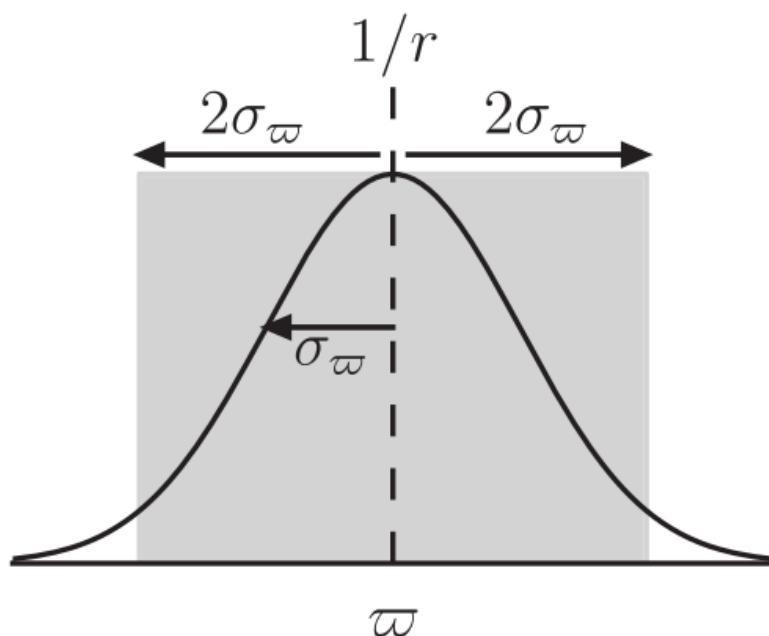
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Likelihood function

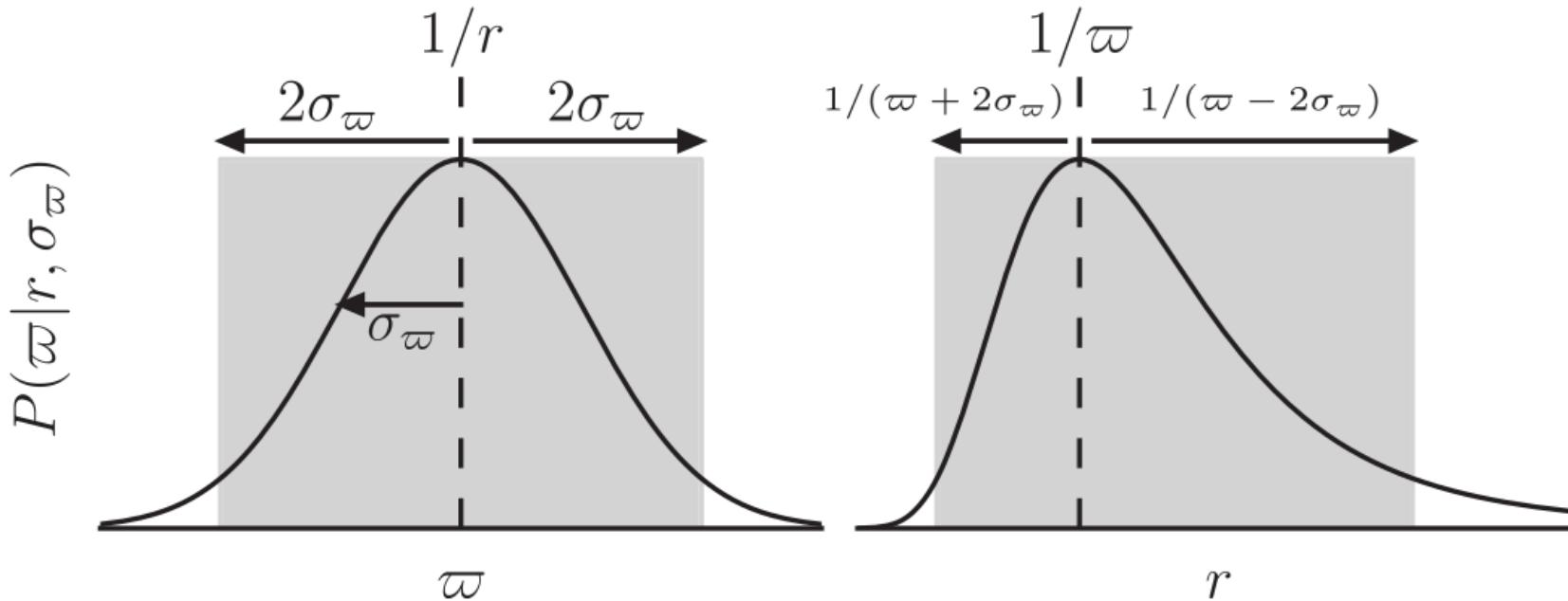
$$P(\varpi | r, \sigma_\varpi) = \frac{1}{\sqrt{2\pi} \sigma_\varpi} \exp \left[-\frac{1}{2\sigma_\varpi^2} \left(\varpi - \frac{1}{r} \right)^2 \right], \quad \sigma_\varpi \geq 0$$



Likelihood function

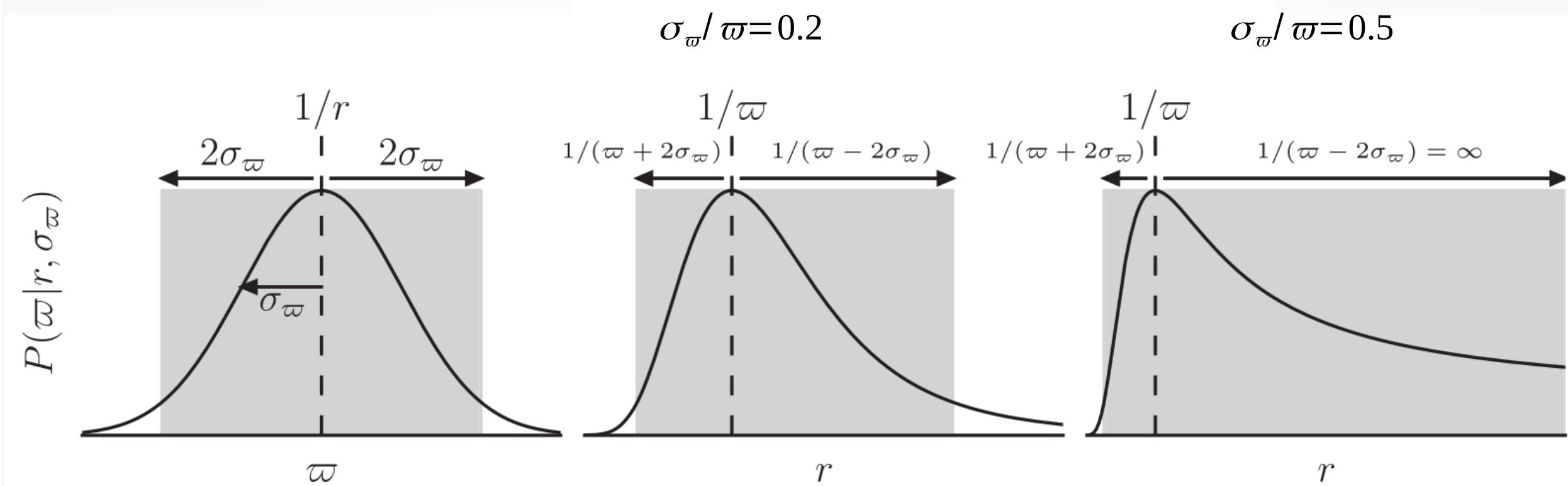
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$$\sigma_\varpi / \varpi = 0.2$$



Likelihood function

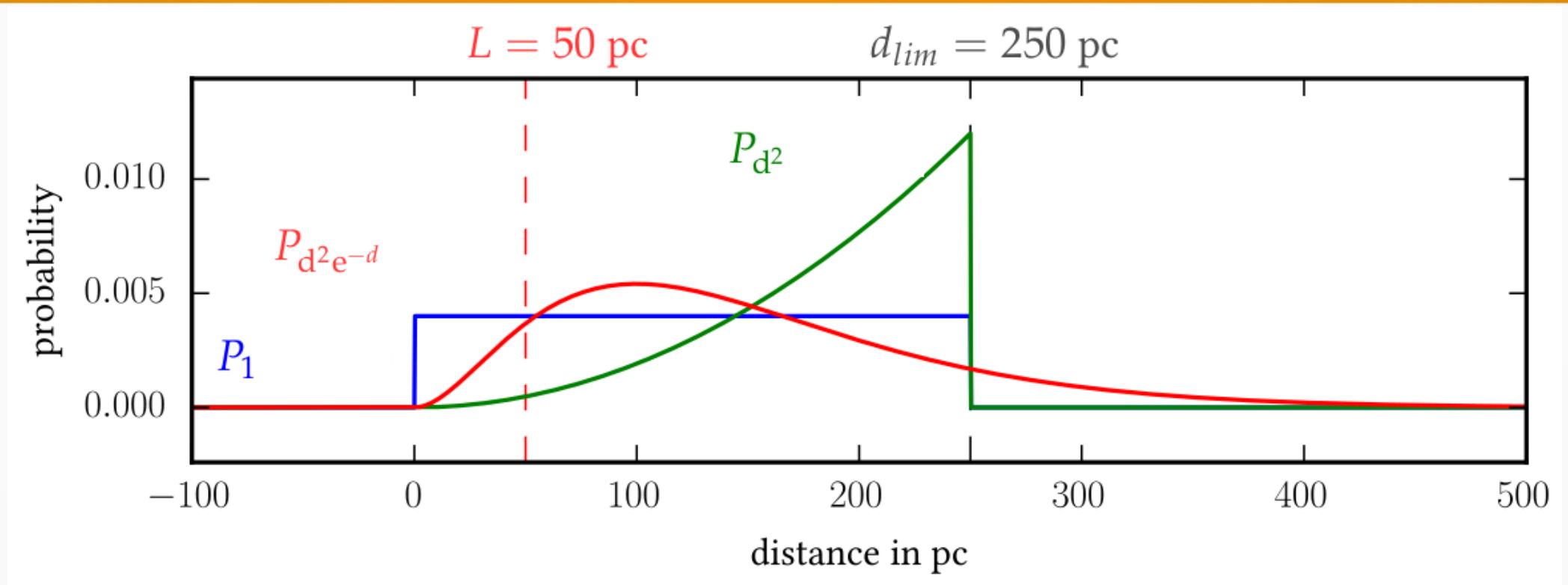
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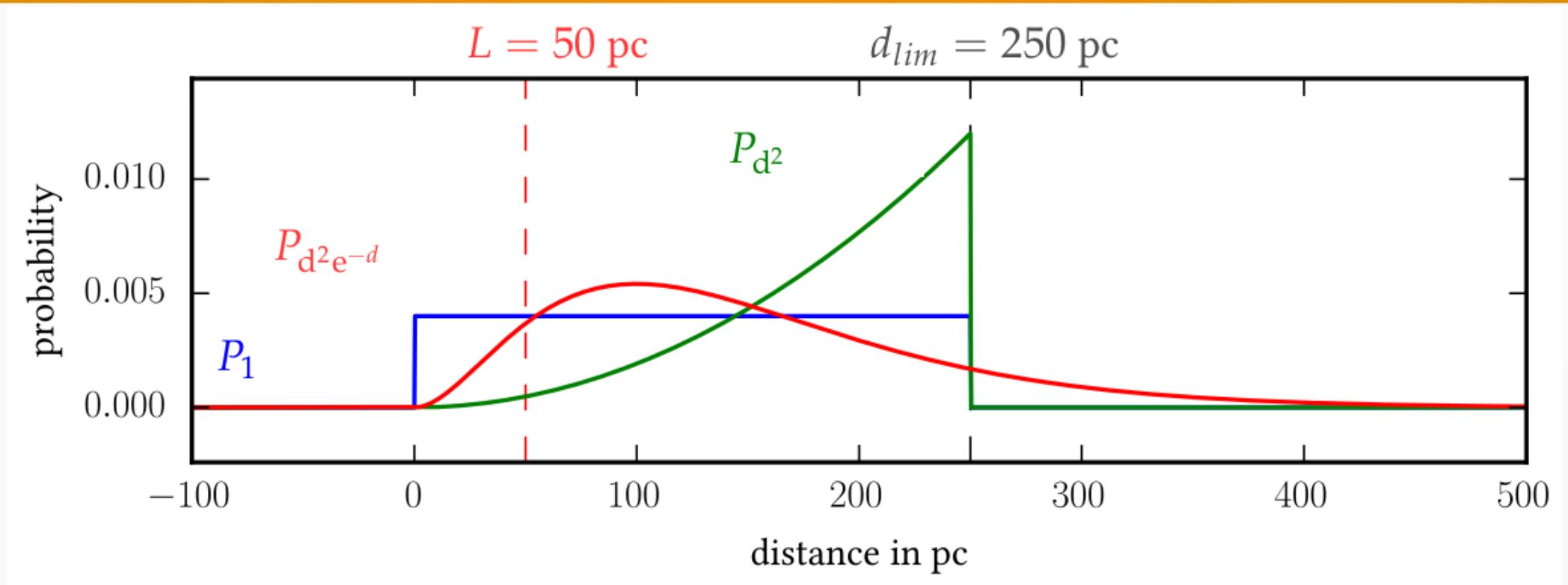
Prior



Prior

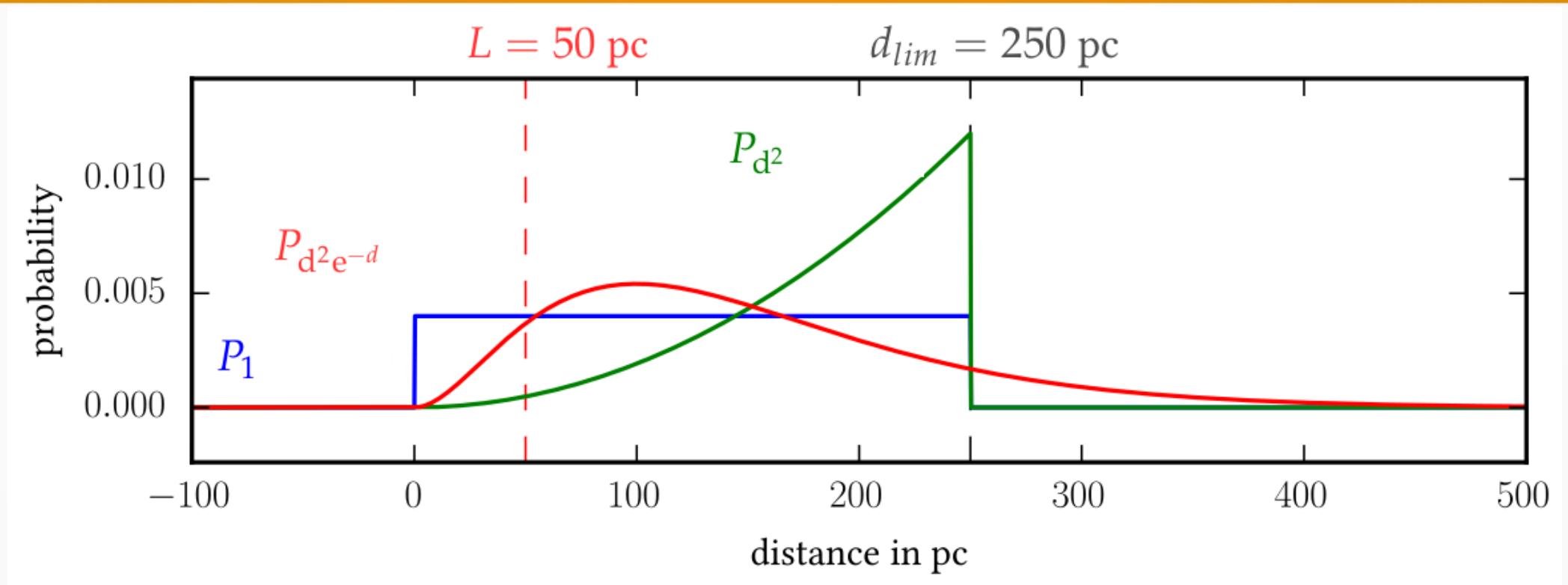


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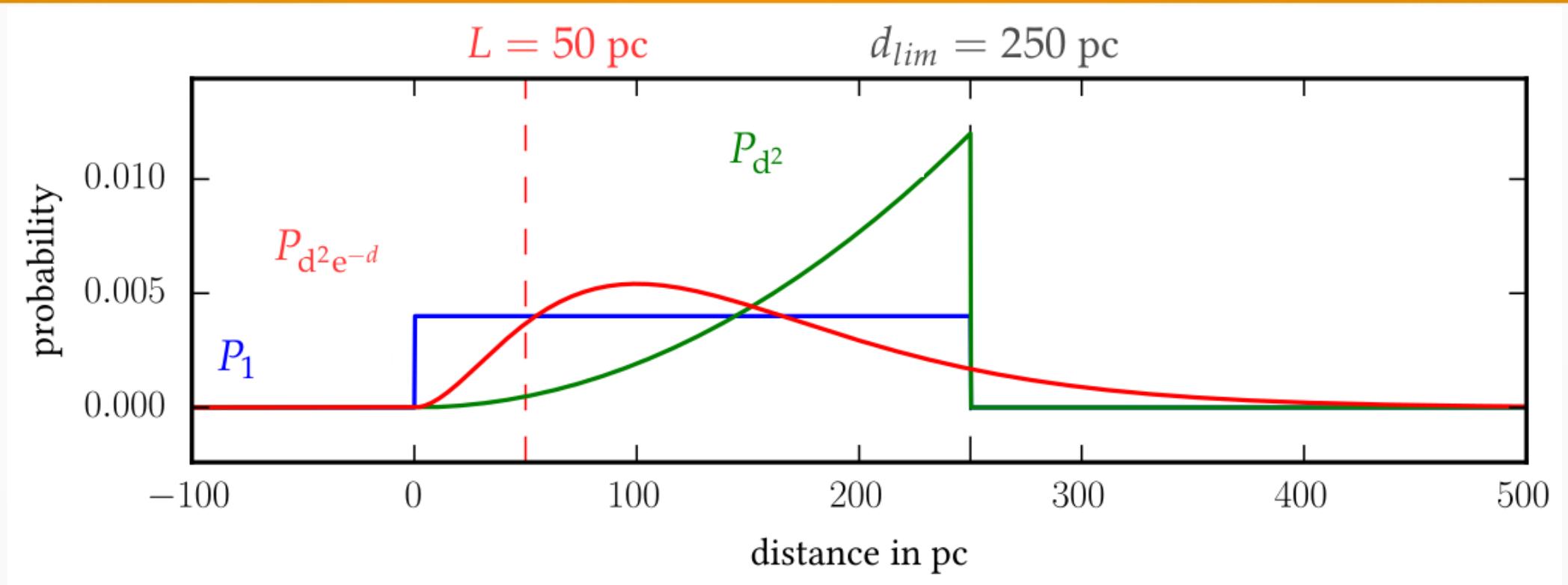
- Exponentially decreasing volume density prior

Prior

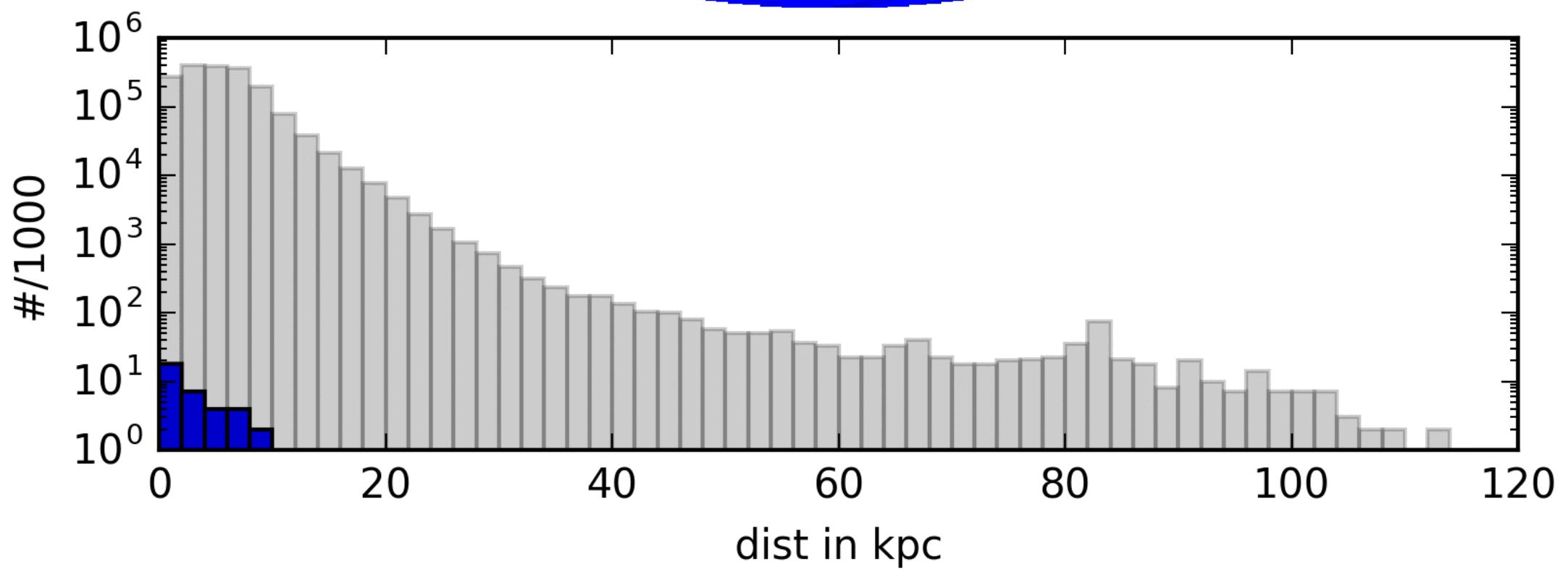
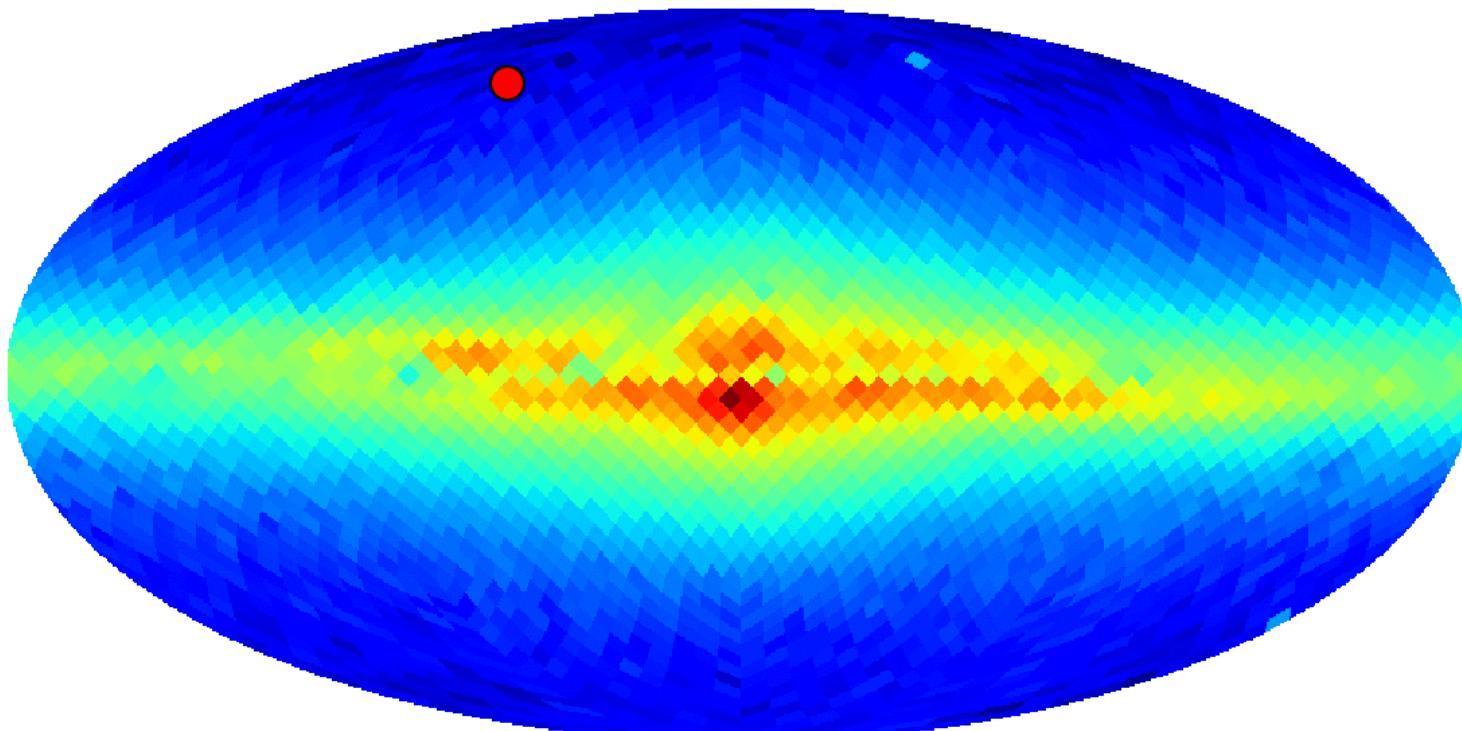


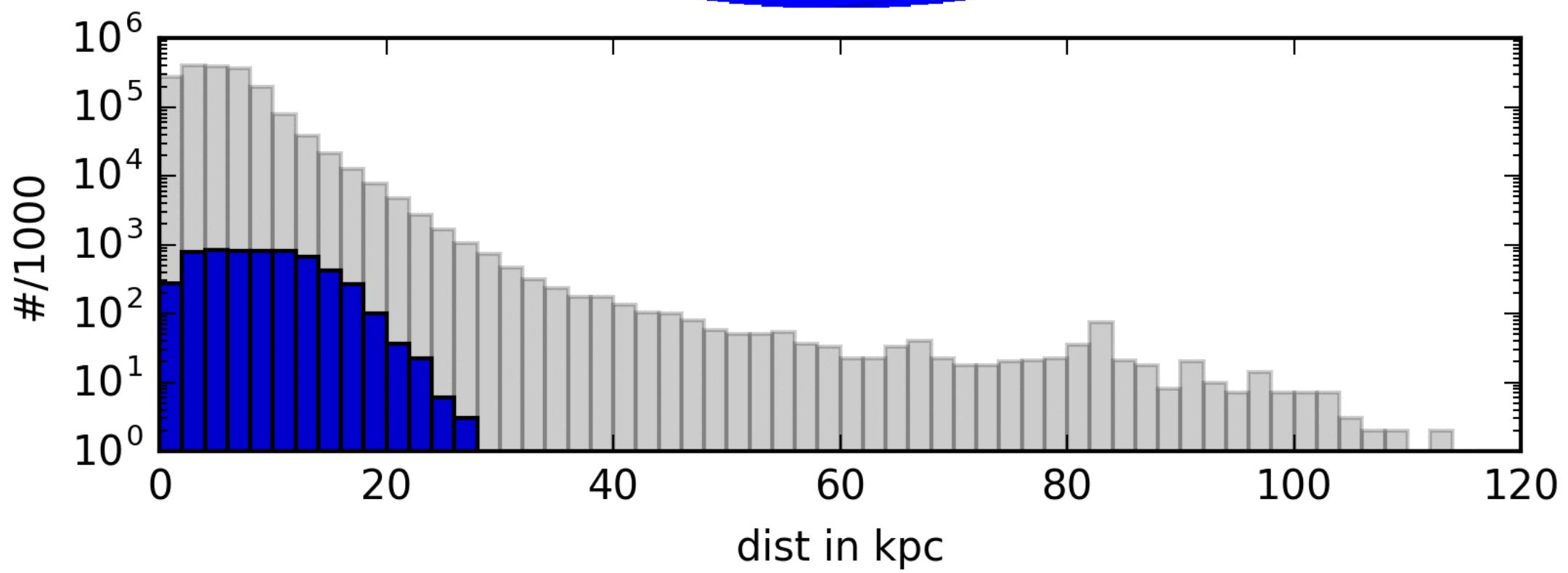
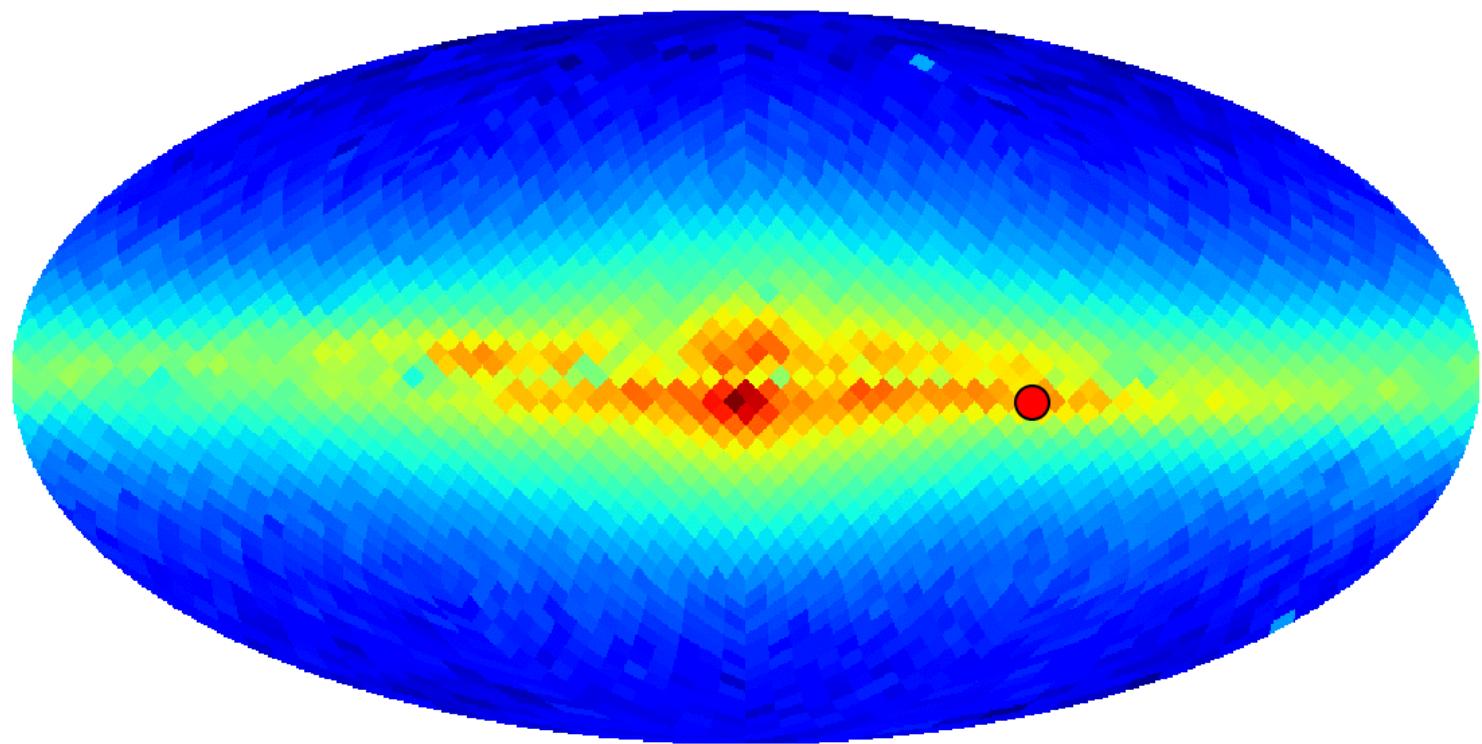
- Exponentially decreasing volume density prior
- As a function of Galactic longitude and latitude

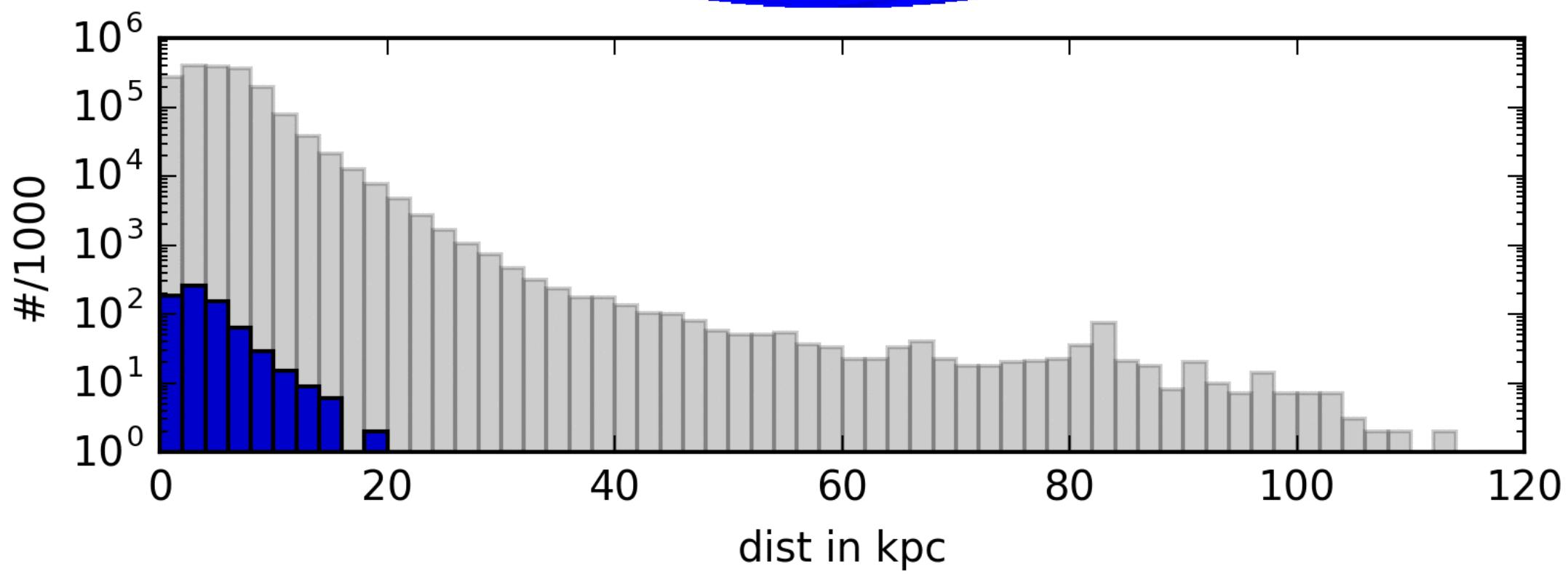
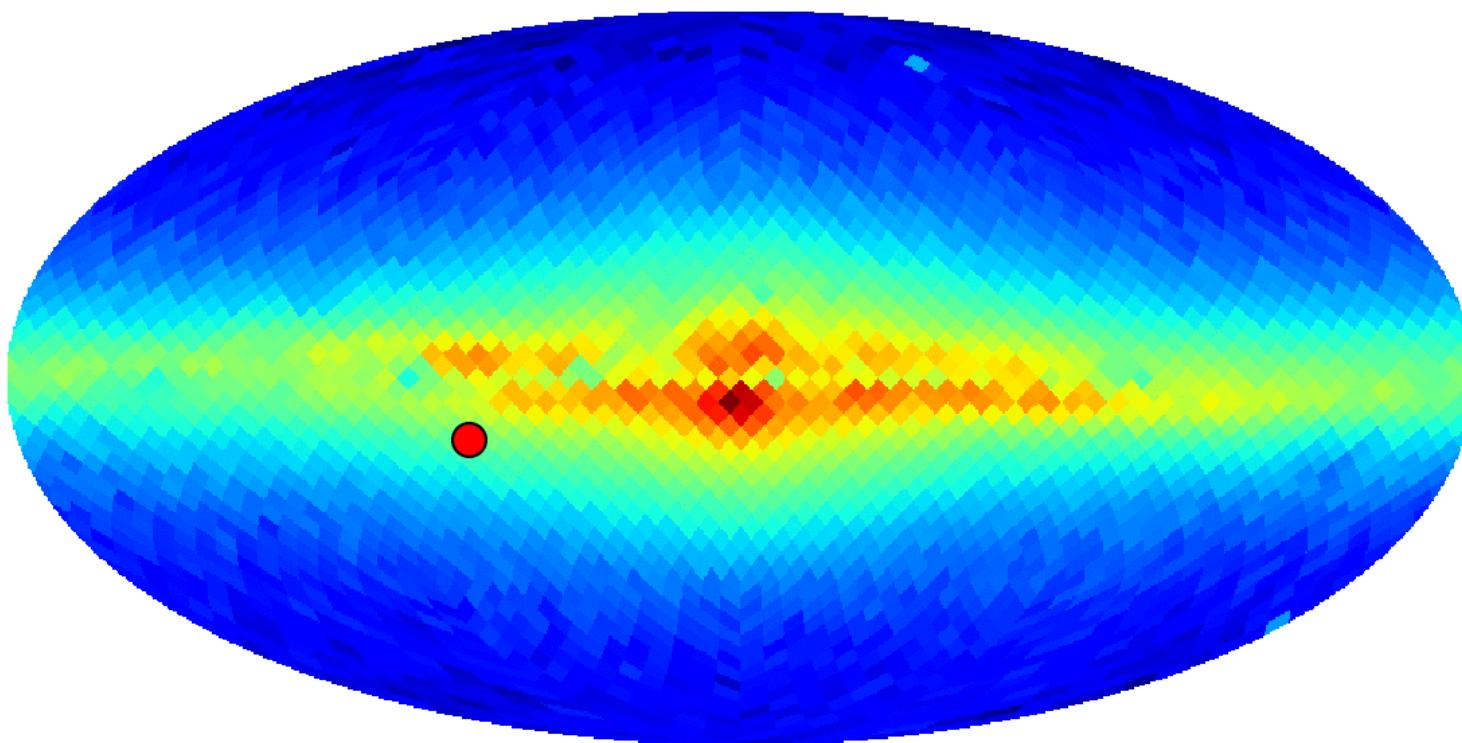
Prior



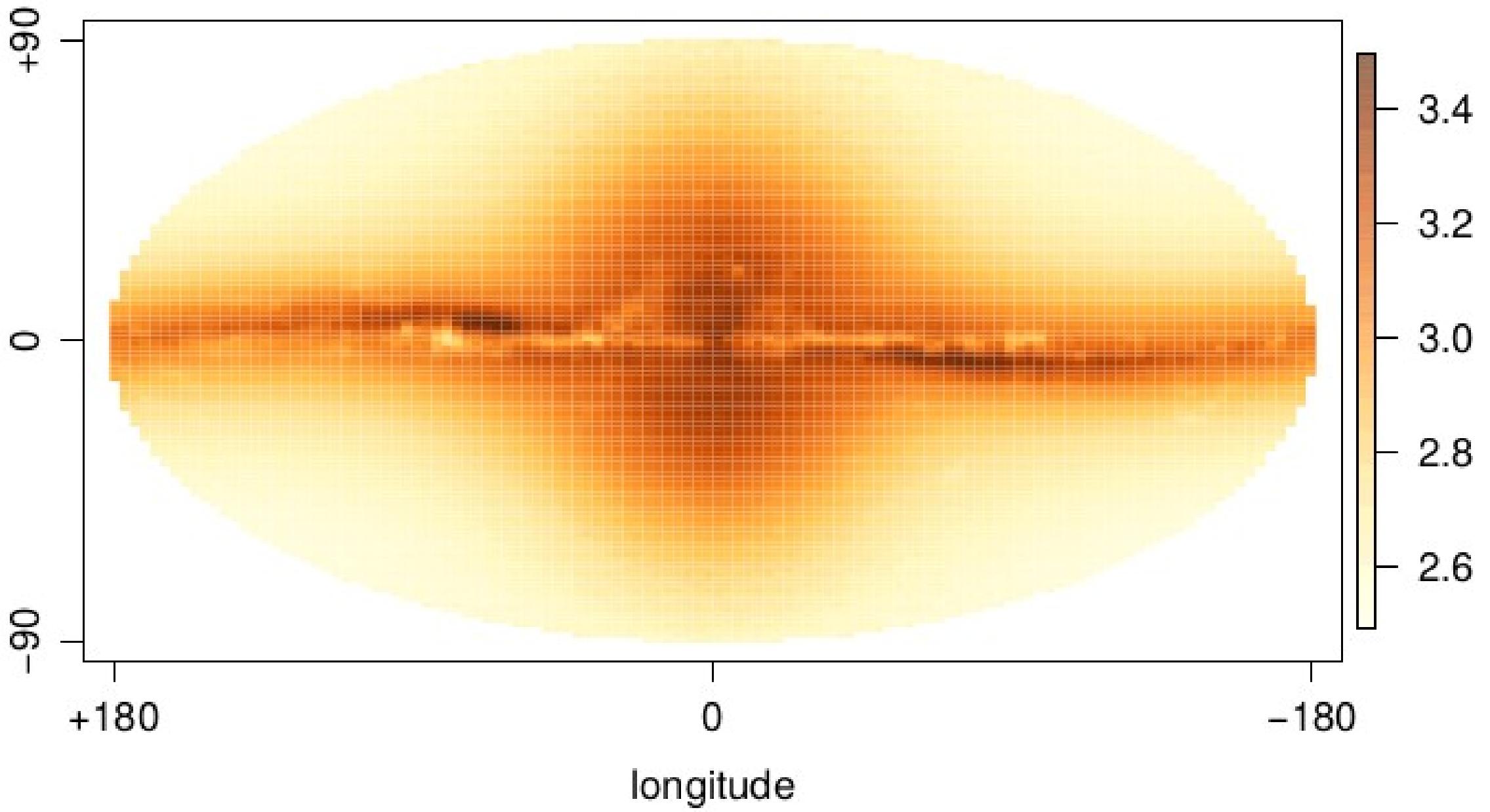
- Exponentially decreasing volume density prior
- As a function of Galactic longitude and latitude
- GDR2mock as spin-off (Rybicki+ 2018)



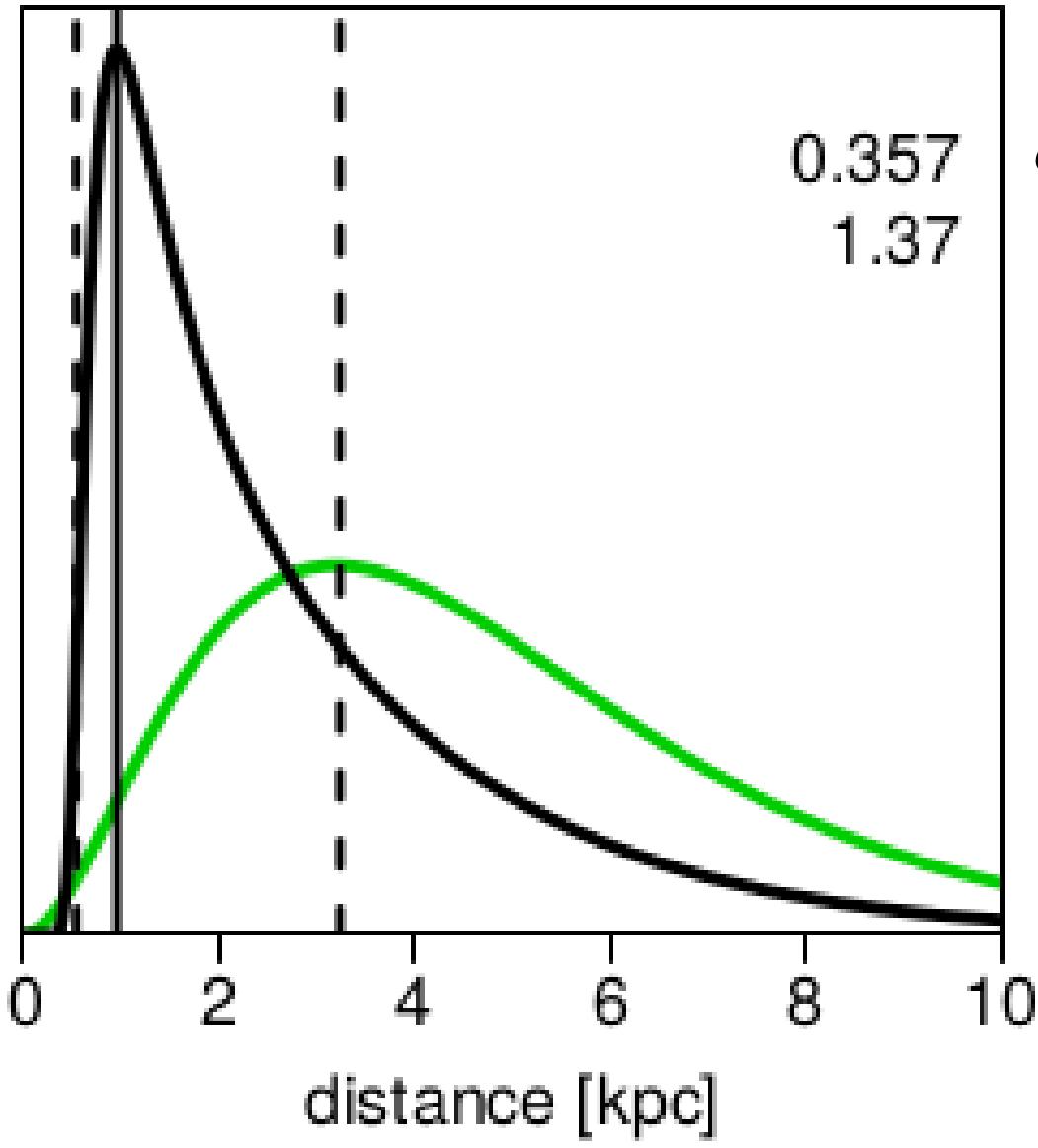




Prior Lengthscale(l, b)

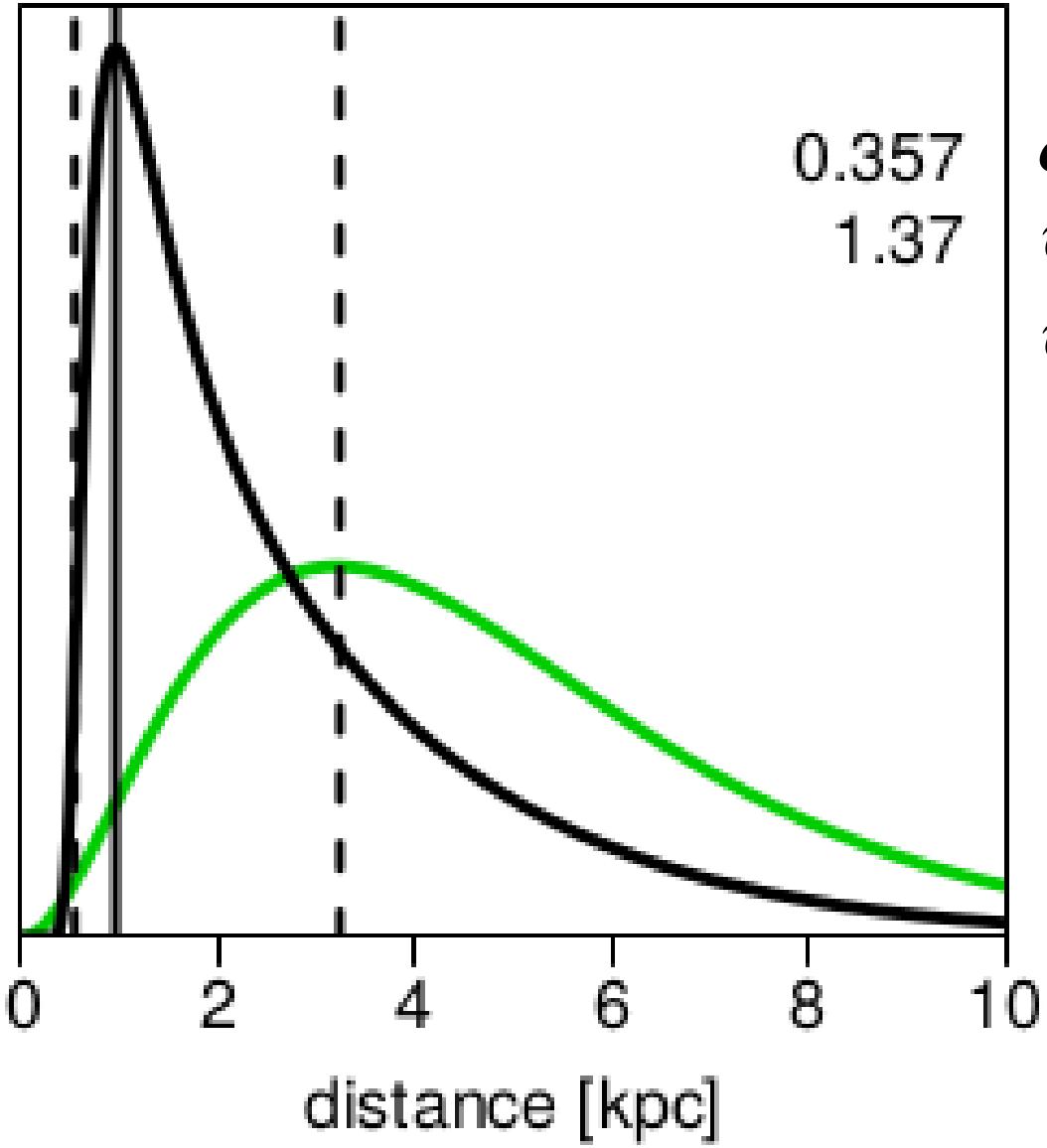


Posterior Highest Density Interval



$$\begin{aligned}\sigma_\varpi / \varpi \\ \varpi [\text{mas}] \\ \varpi^{-1} = 0.73 \text{ kpc}\end{aligned}$$

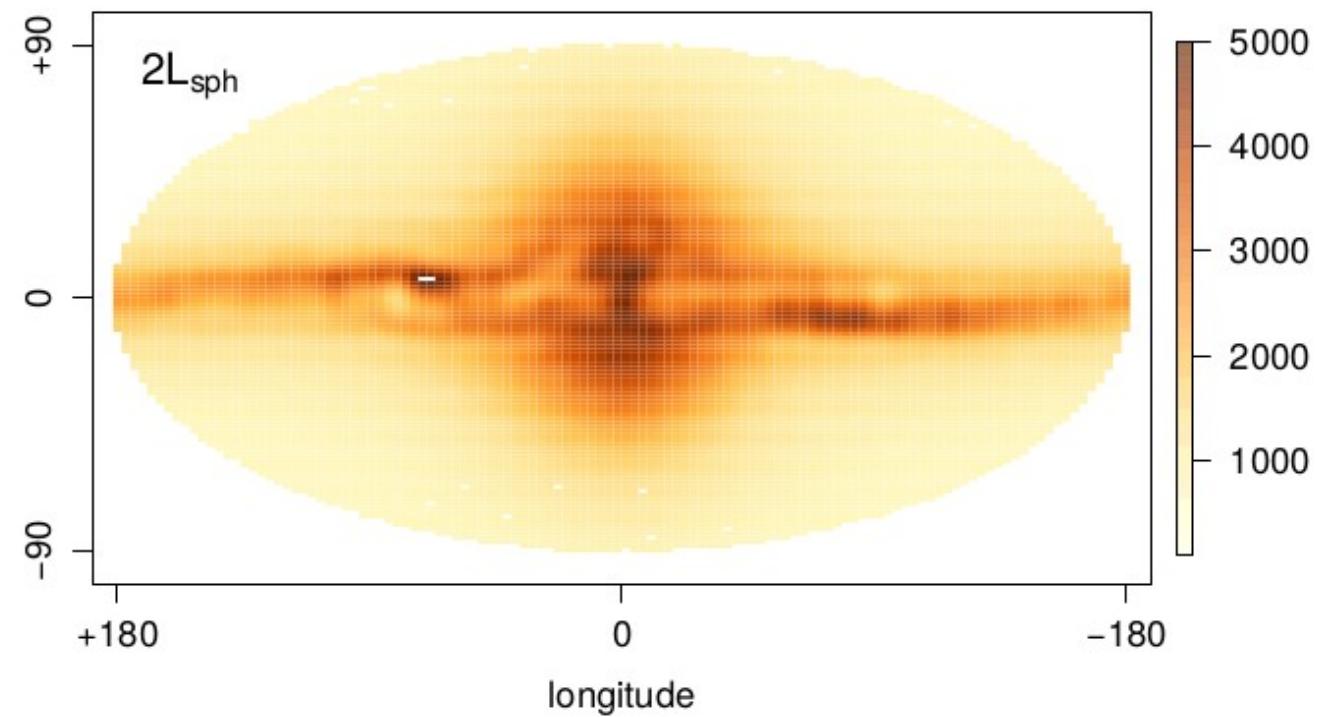
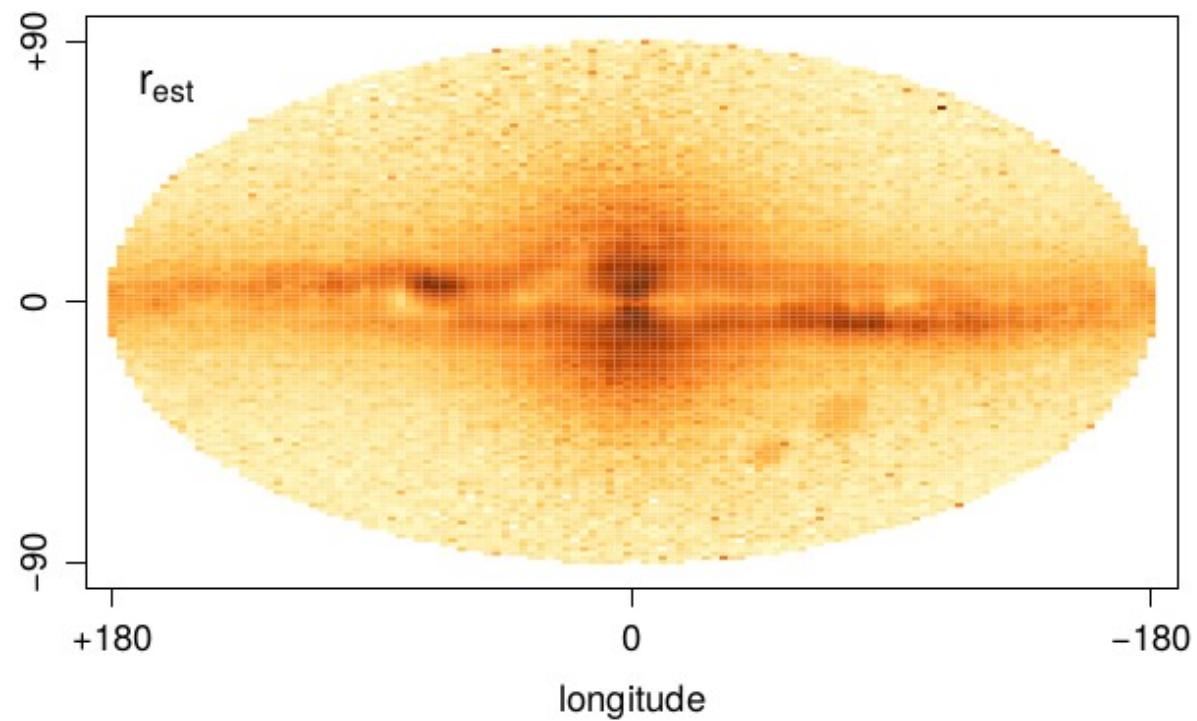
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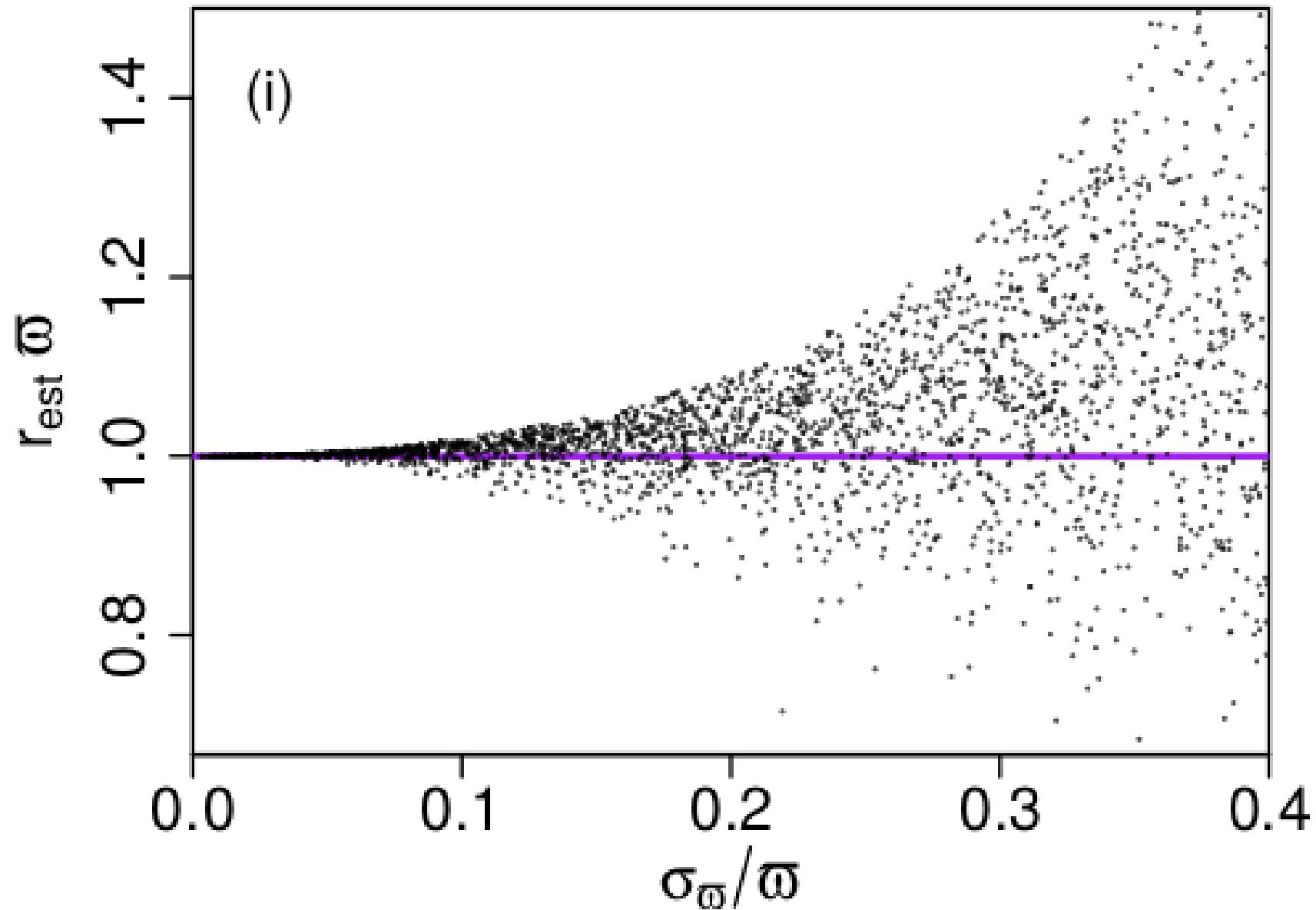
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Catalog entries:
Source ID, r_est, r_lo, r_hi, r_len,
result_flag [mode, mean], modality_flag

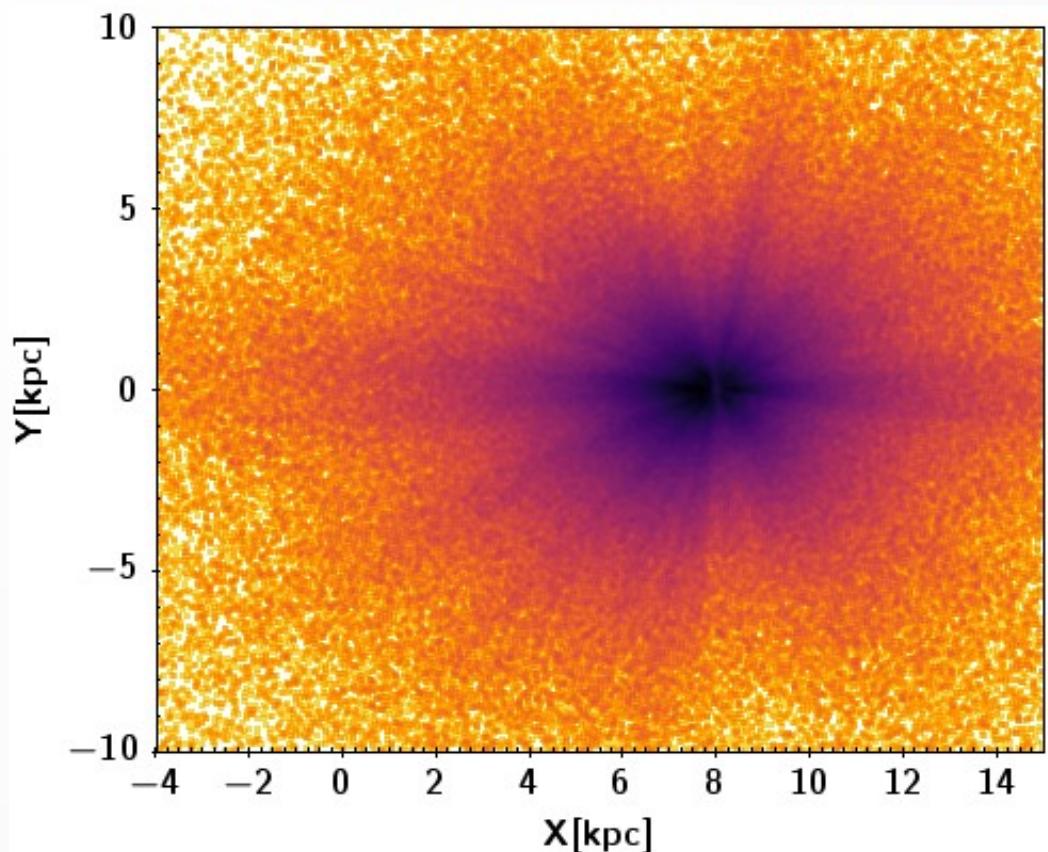
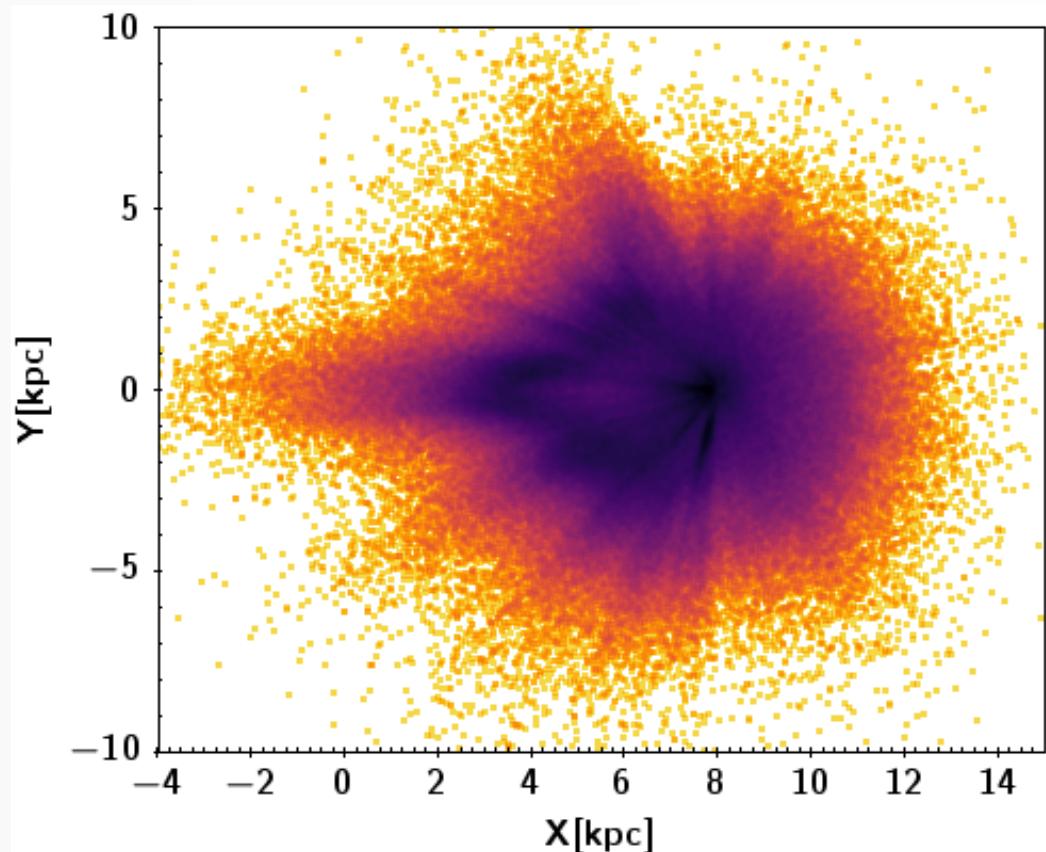
Prior vs. Posterior



r_est vs. 1/parallax



r_est vs. 1/parallax



Do's with the catalog

- Provides probable distance range for stars
 - Does a set of stars have consistent distances?

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Do's with the catalog

- Provides probable distance range for stars
 - Does a set of stars have consistent distances?
- Select a set of stars on which other inferences are then performed
- A baseline against which to compare other distances
- 3D space distribution of a set of stars
 - Distances are inferred independently but prior is correlated on small scales (and parallaxes may as well)

Don'ts with the catalog

- Infer cluster distance from a set of probable cluster members using our distances

Don'ts with the catalog

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 - Set up a model for the cluster in which its distance is a free parameter and solve for this using the original parallaxes (accomodating for their spatial correlation)

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Don'ts with the catalog

- Infer cluster distance from a set of probable cluster members using our distances
 - Set up a model for the cluster in which its distance is a free parameter and solve for this using the original parallaxes (accomodating for their spatial correlation)
- Use our distances as intermediate step in a calculation (e.g. abs mag or transverse velocity)
 - Infer those quantities directly

Advertisement

- Python package GDR2 completeness:
github.com/jan-rybizki/gdr2_completeness

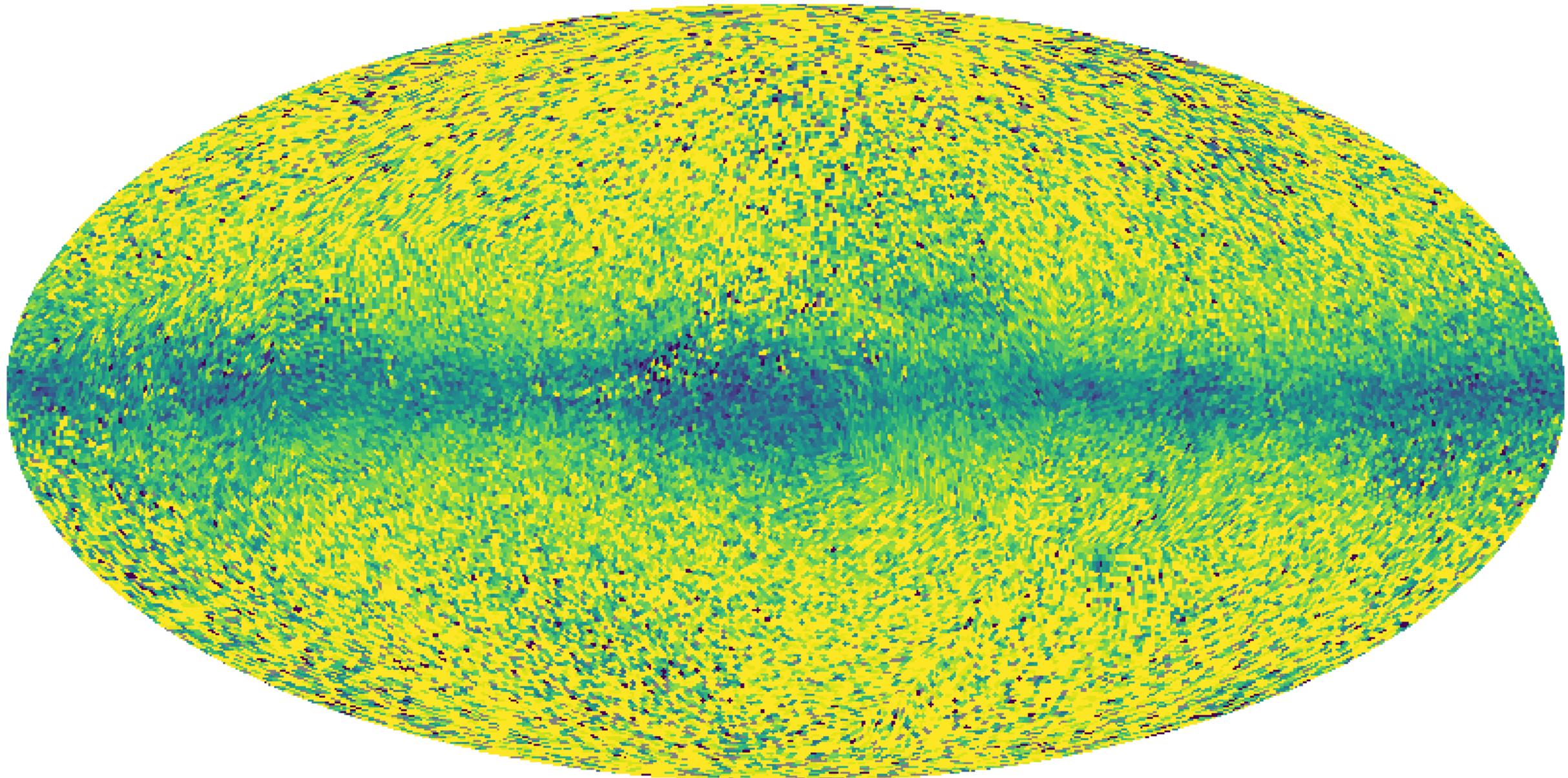
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github.com/jan-rybizki/gdr2_completeness
- 1) Automatically chunking TAP queries into healpix bins
 - 2) Calculate the GDR2 completeness in bins of healpix and magnitude for arbitrary selection

Total completeness RVS sample with $\varpi/\sigma_\varpi > 5$ [10.0 < G < 10.5]



Summary

- Distance estimates + confidence intervals for 1.33 bn stars

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- Frame your prior assumptions

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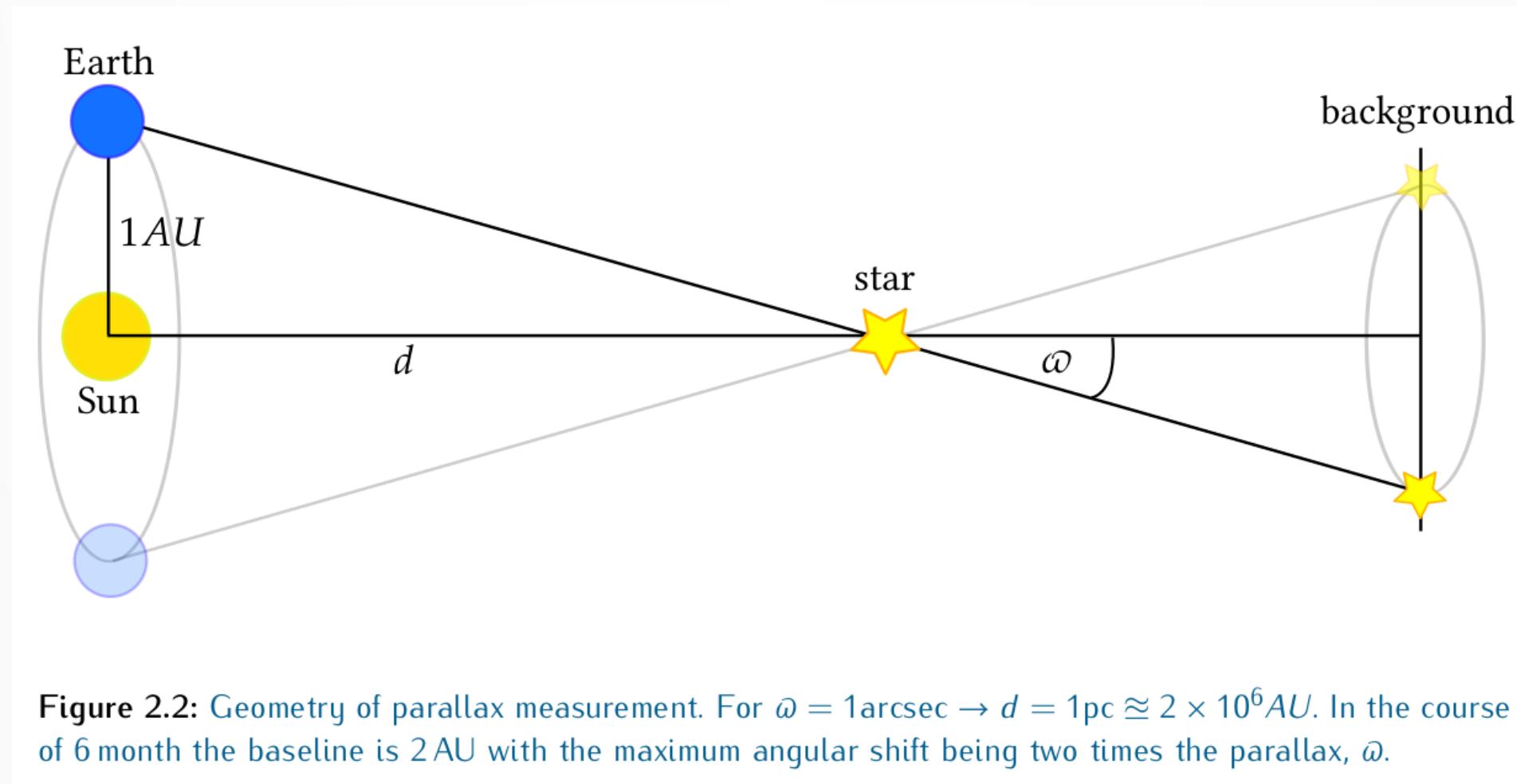
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- Gaia's precision is incredible

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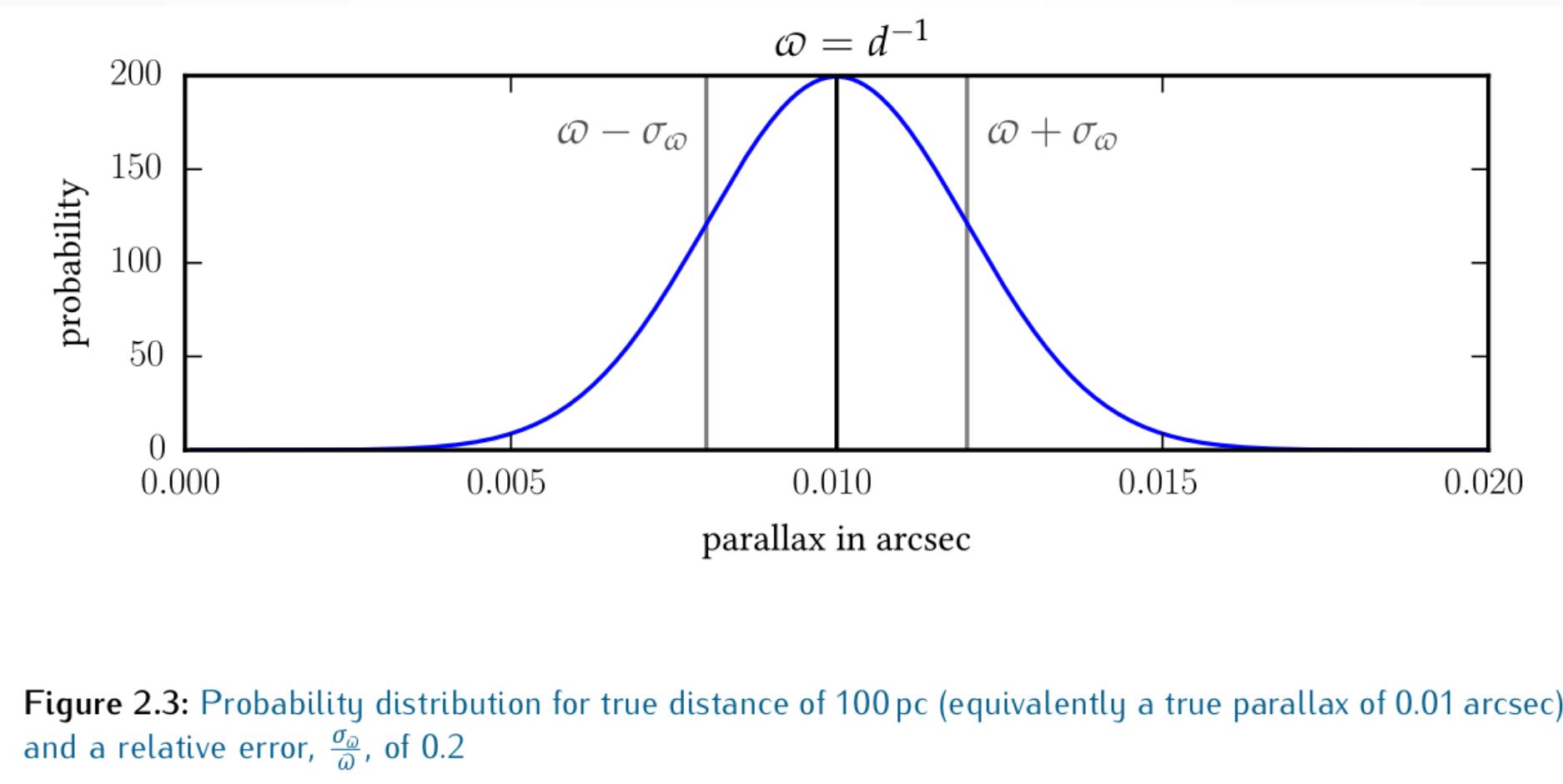
- Distance estimates + confidence intervals for 1.33 bn stars
- Frame your prior assumptions
- Gaia's precision is incredible
- GDR2 is a huge amount of information

Thanks for your attention

Backup slides - Geometry



Parallax measurement

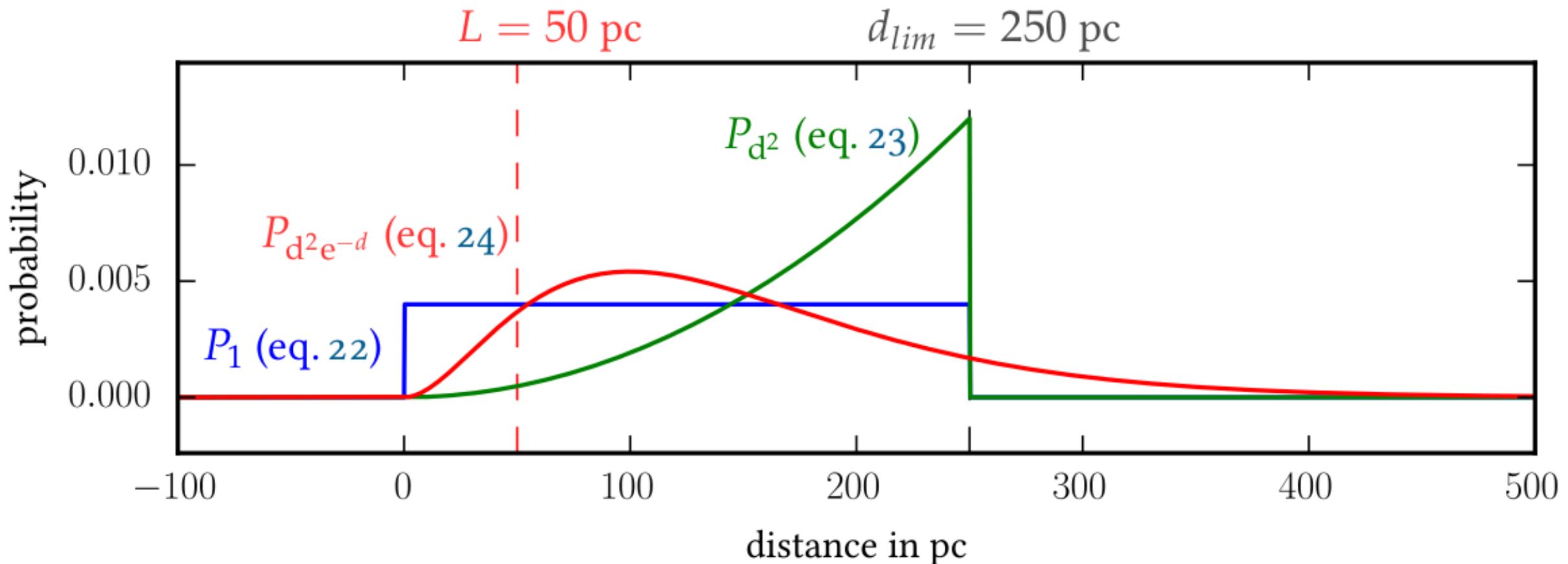


Normalized Priors

$$P_1(d) = \begin{cases} \frac{1}{d_{\lim}} & \text{if } 0 < d < d_{\lim} \\ 0 & \text{if } d \leq 0 \vee d \geq d_{\lim} \end{cases}$$

$$P_{d^2}(d) = \begin{cases} \frac{3}{d_{\lim}^3} d^2 & \text{if } 0 < d < d_{\lim} \\ 0 & \text{if } d \leq 0 \vee d \geq d_{\lim} \end{cases}$$

$$P_{d^2 e^{-d}}(d) = \begin{cases} \frac{1}{2L^3} d^2 e^{-\frac{d}{L}} & \text{if } d > 0 \\ 0 & \text{if } d \leq 0. \end{cases}$$



Negative parallaxes

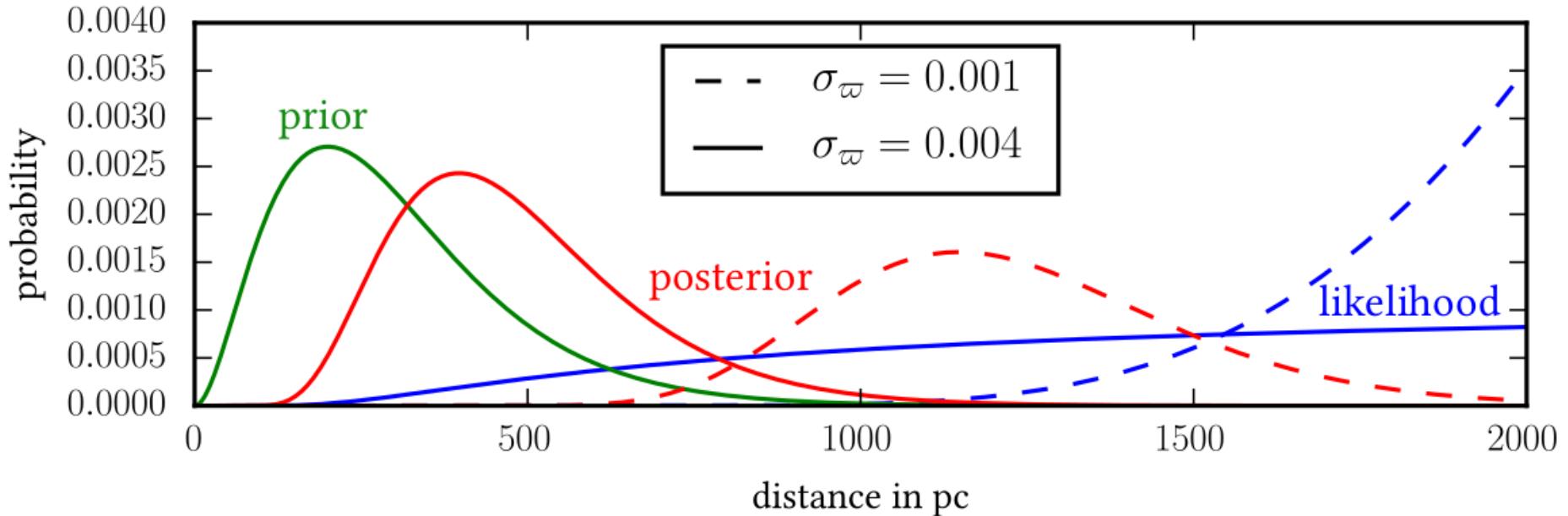
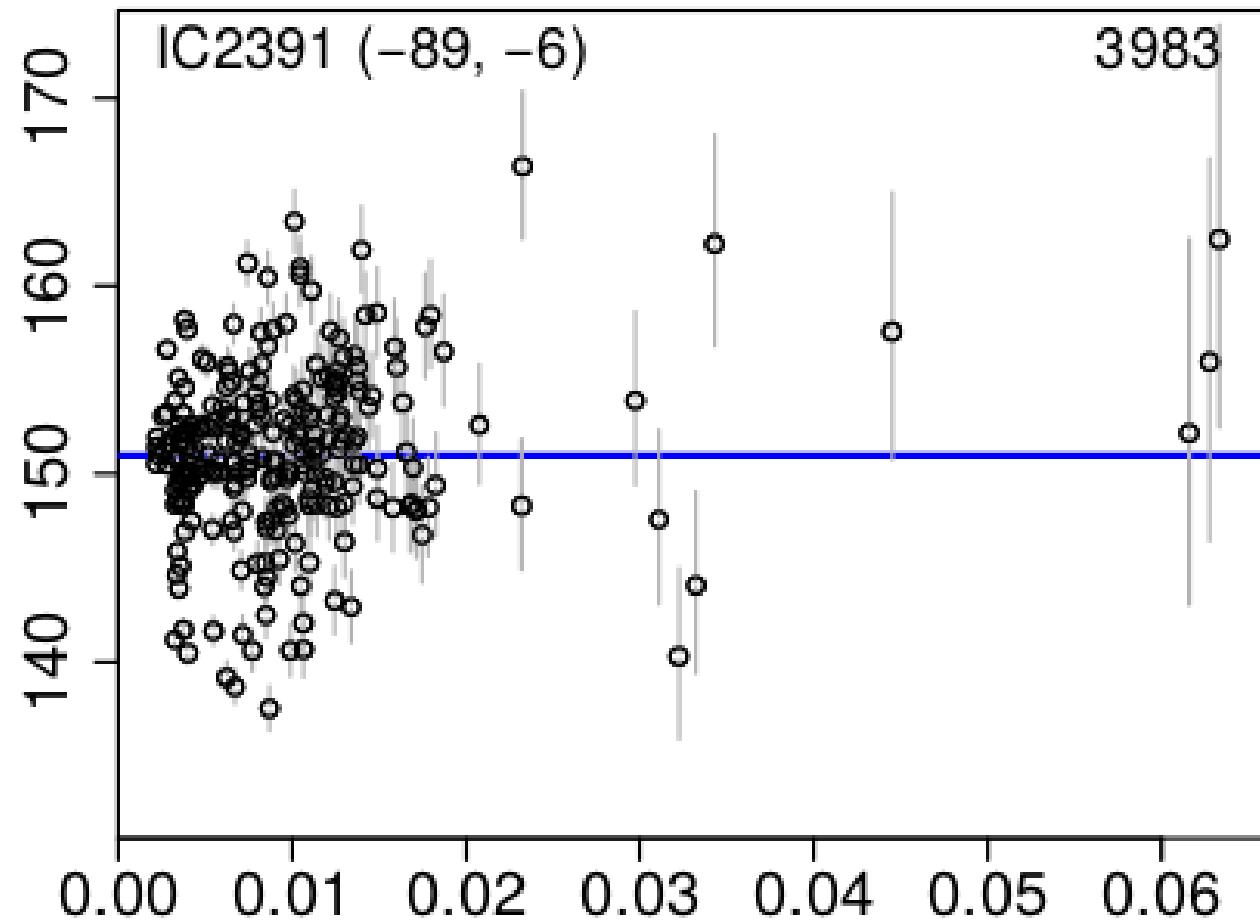


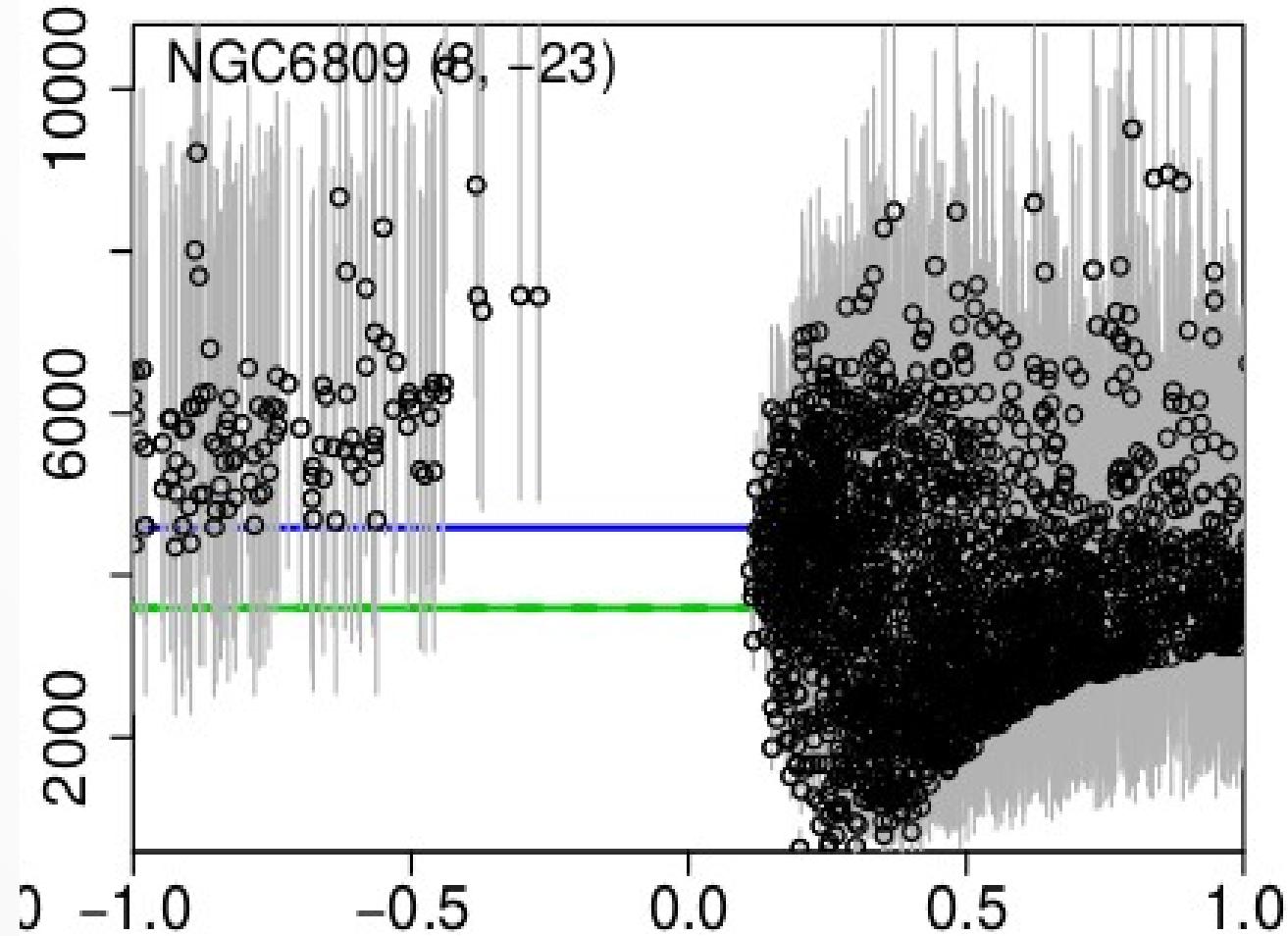
Figure 2.7: Likelihood in blue and posterior in red for negative parallax, $\omega = -0.01$, and different relative parallax errors, $\frac{\sigma_\omega}{\omega} = 10\%$ in dashed lines and 40% in solid lines. The prior in green stays unaffected. What is visible of the likelihoods as functions of distance is arbitrarily normalised to unity.

$$P(\omega|d, \sigma_\omega) = \frac{1}{\sqrt{2\pi\sigma_\omega^2}} \exp\left(-\frac{(\omega - \frac{1}{d})^2}{2\sigma_\omega^2}\right)$$

Cluster validation

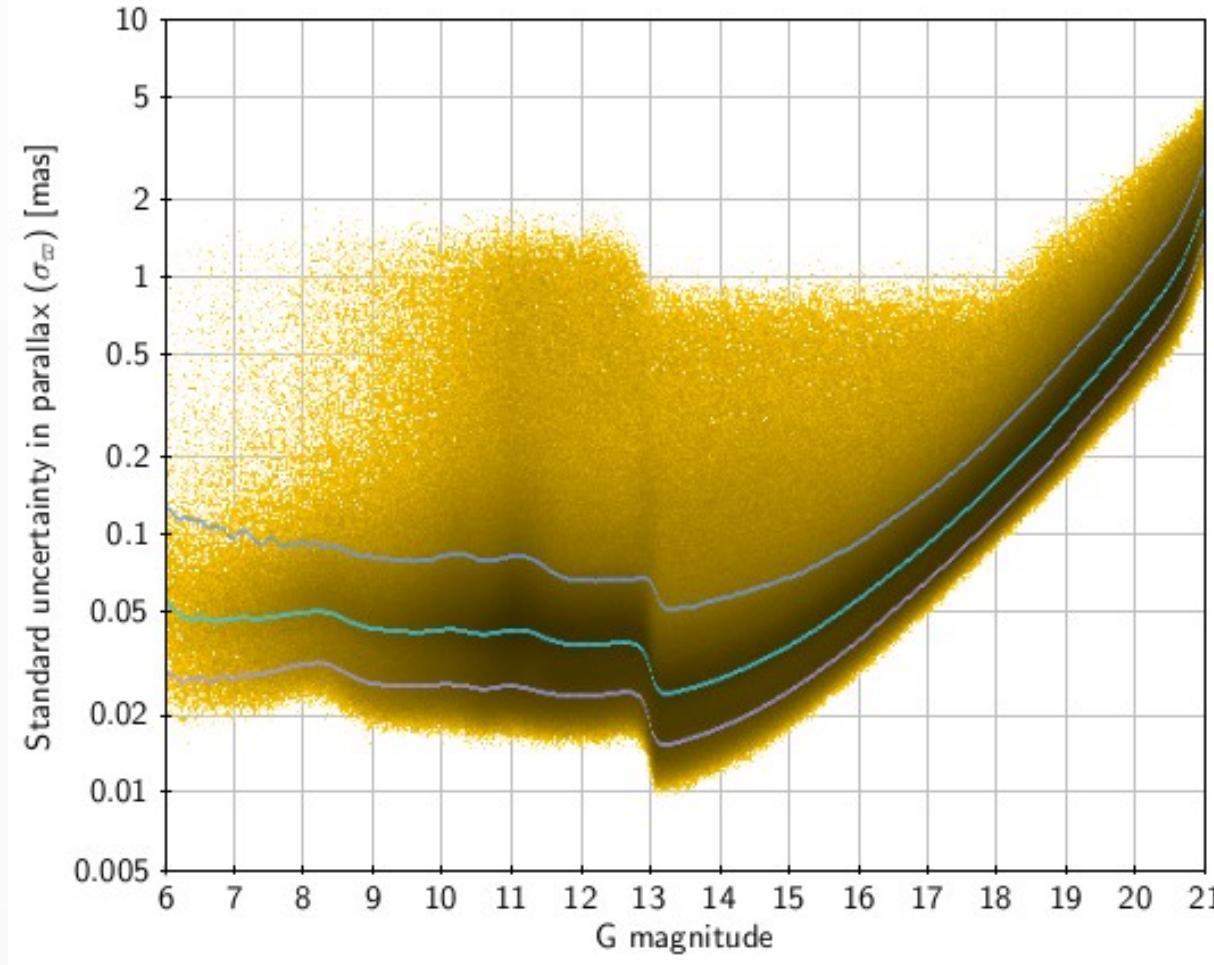


Cluster validation



Parallax uncertainty

Lindgren+ 2018



Bimodal HDI

