# Gaia Parallax Distances

## What Can Go Wrong, and How to Fix it

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# Basic Parallax

- Measure an angle
- Calculate a distance
- ???
- Profit

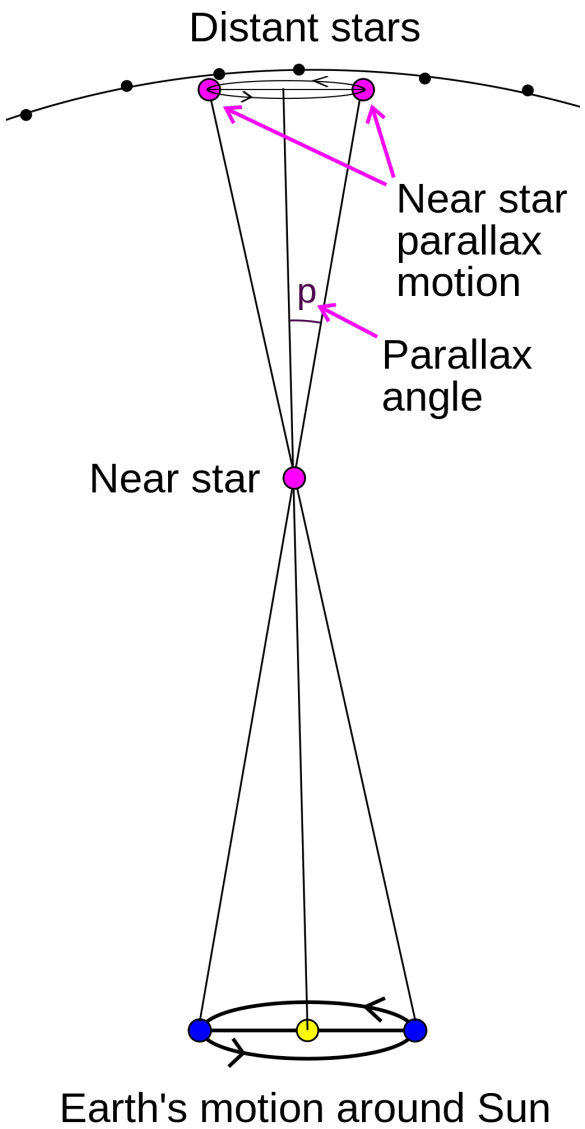


Figure: You have (almost certainly) seen this picture on wikipedia

# Scanning Law

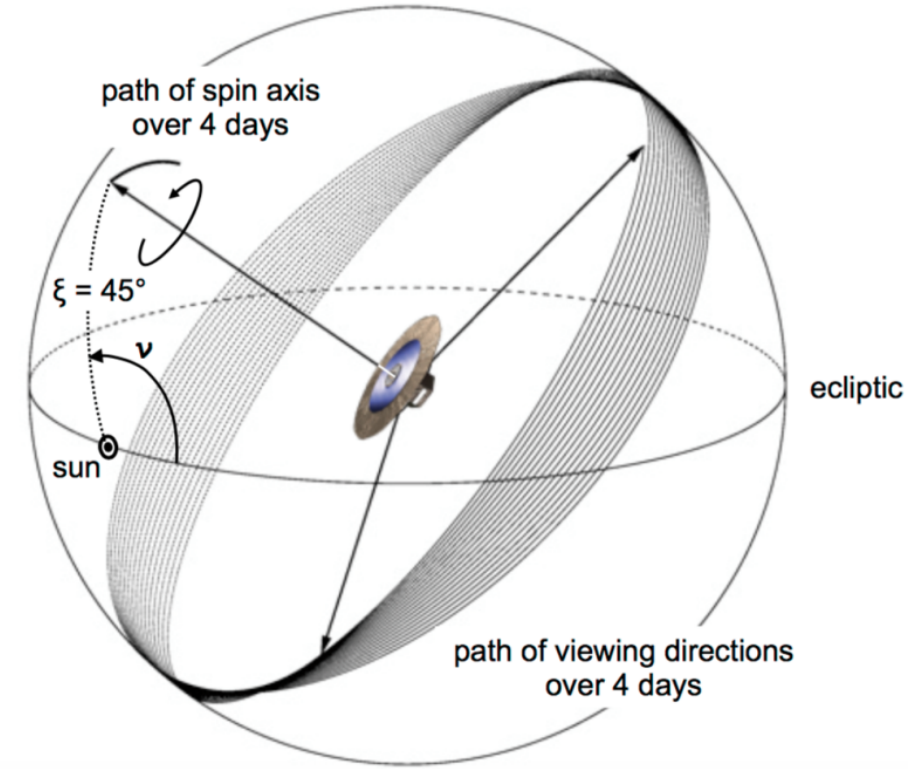


Figure: Gaia Scan illustration[1]

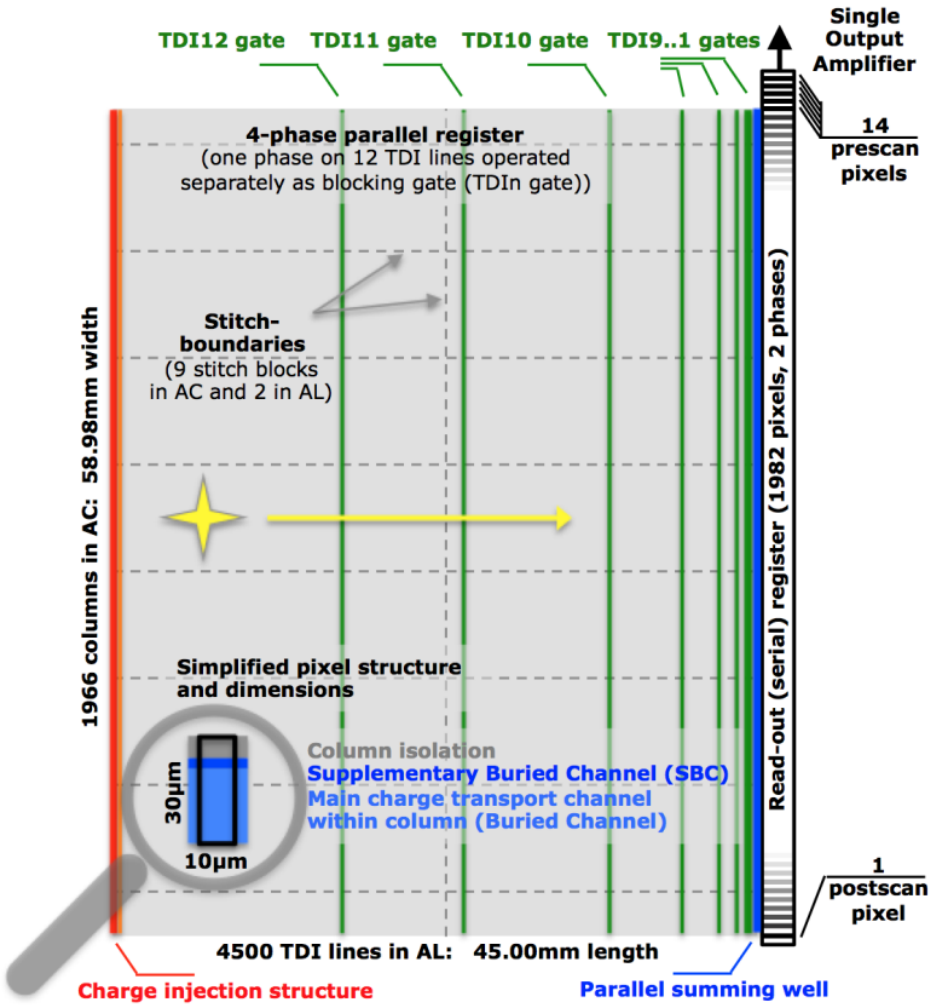


Figure: Gaia CCD schematic[1]

# Astrometric Solutions

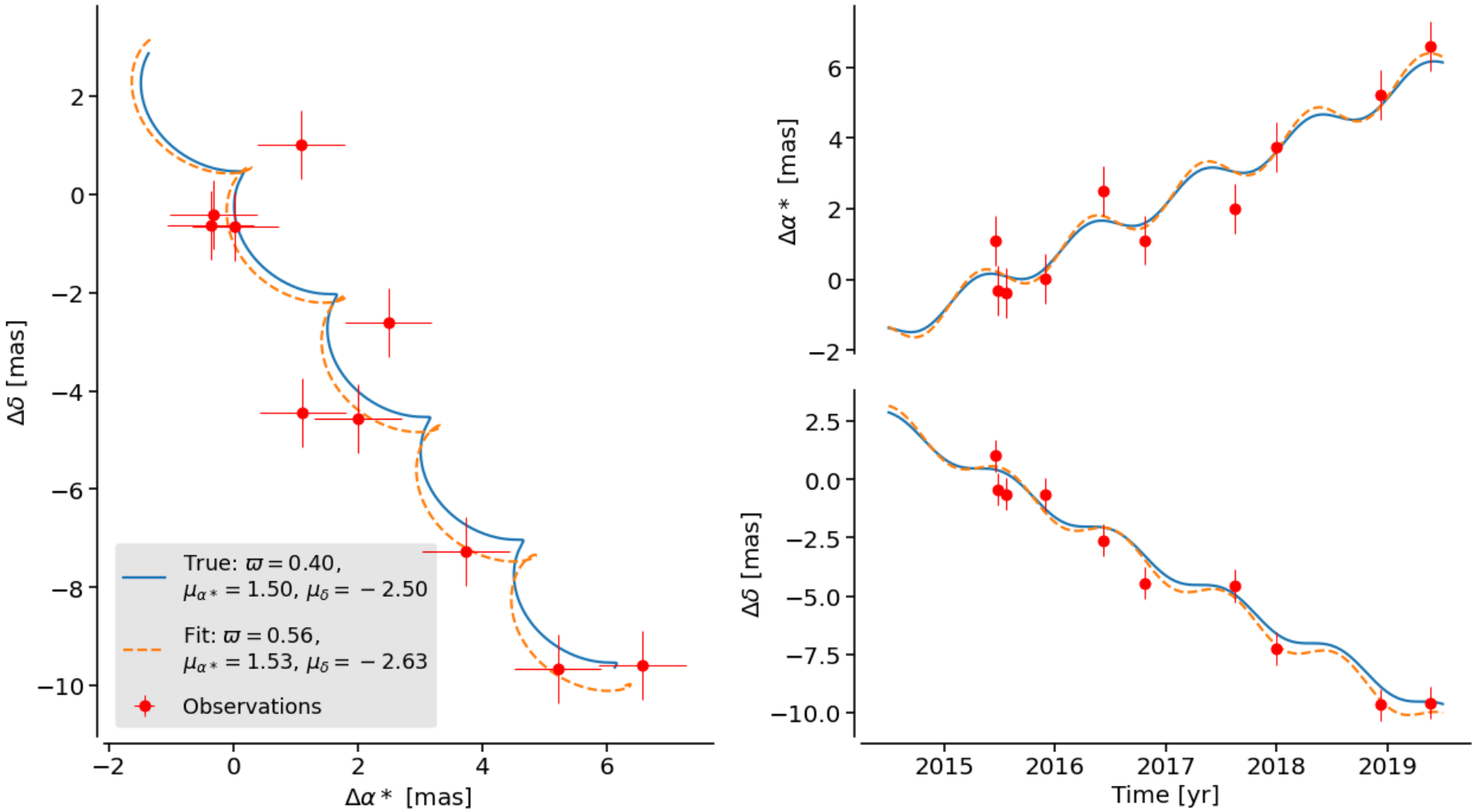


Figure: Figure generated from code in[2]

What could possibly go wrong?

# What could possibly go wrong?

## Wrong assumptions

- Source Identification
- Source motion is linear
- Curve has a good fit

## Causes

- Dim sources
- Bright sources
- Fast sources
- Slow sources
- Crowded fields
- Multiple star sources
- Variable sources
- Gravitational lensing
- Dark Companions

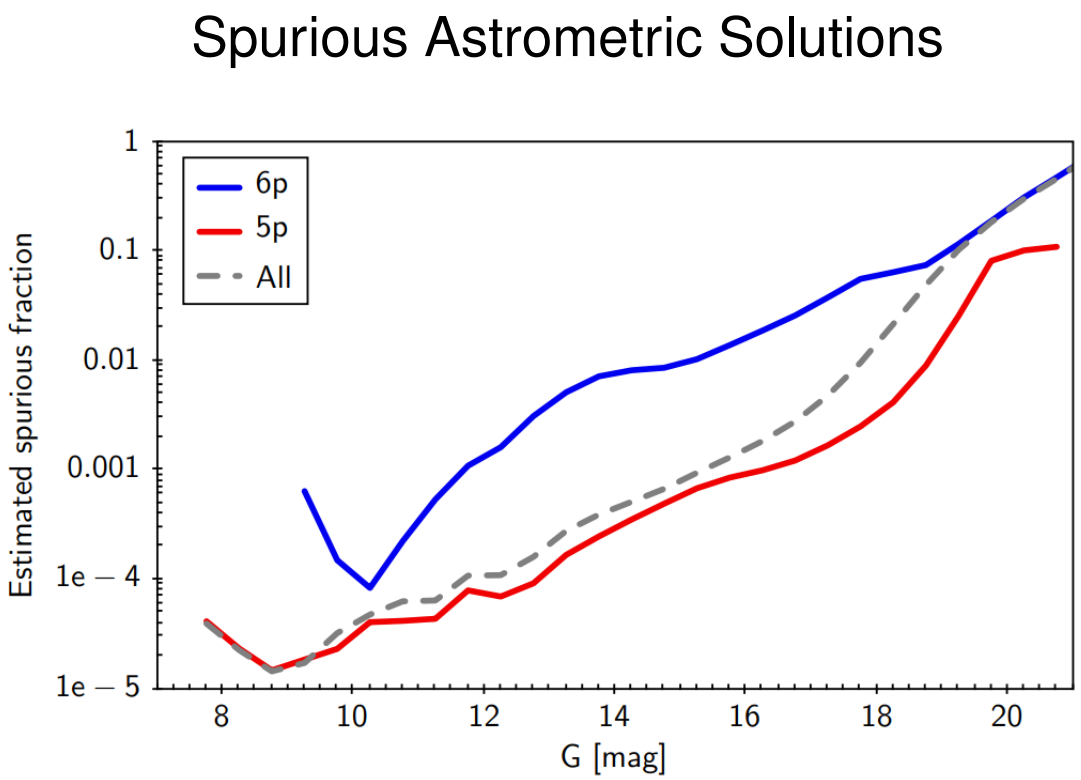


Figure: Fraction of Spurious Astrometric solutions [3]

# Bad Curve Fit

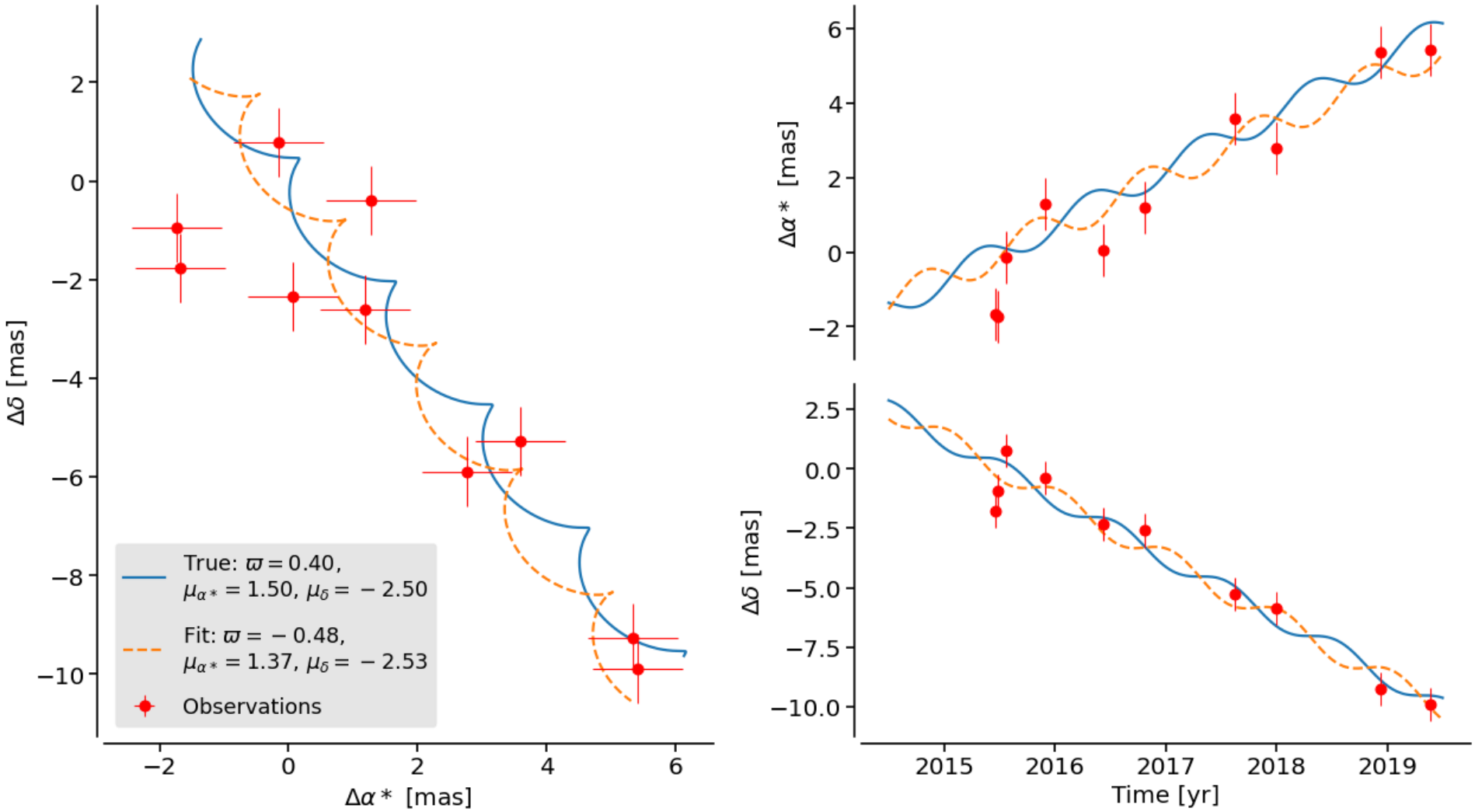


Figure: Figure generated from code in [2]

# Parallax SNR

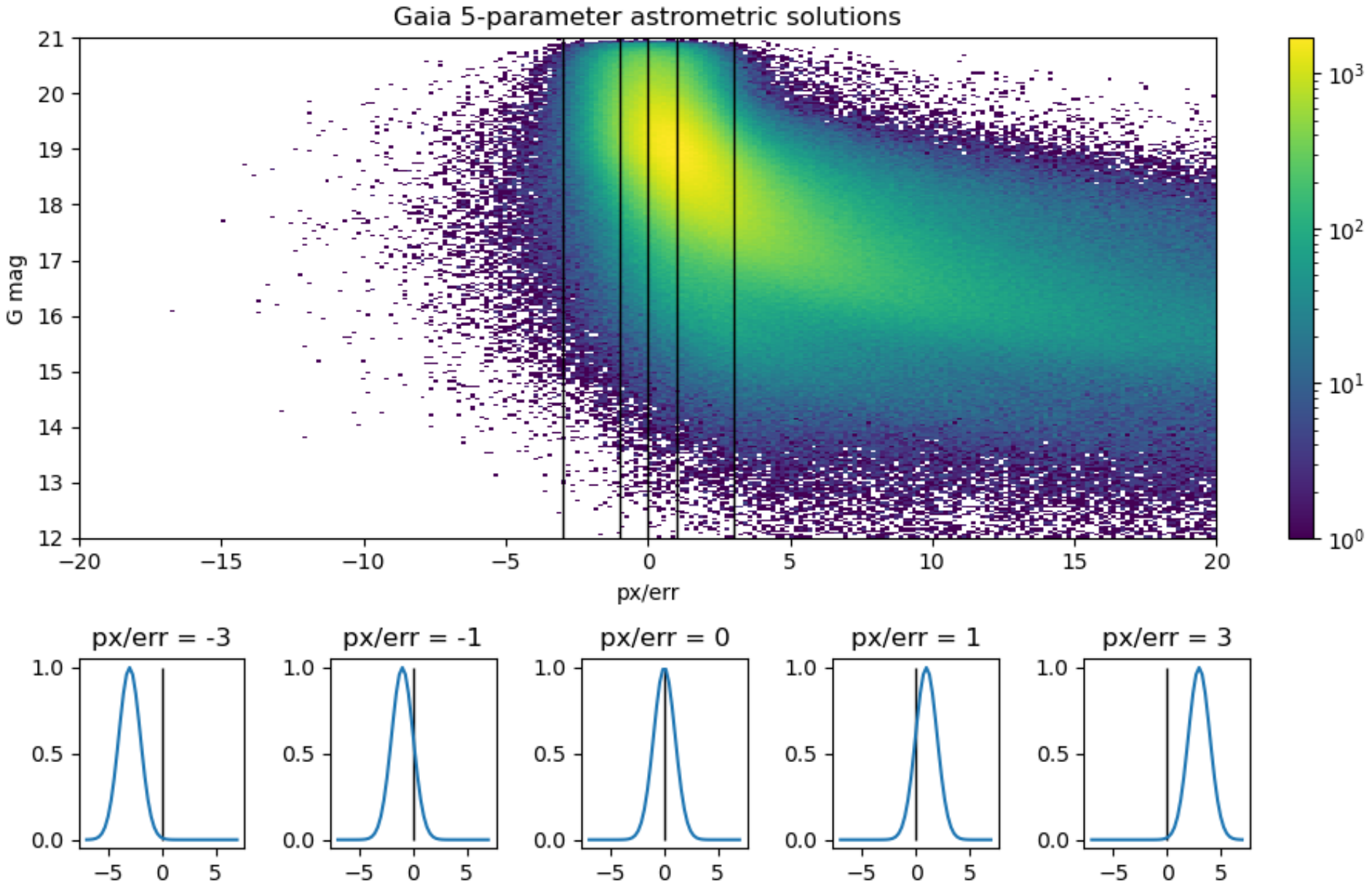


Figure: Data from [4][1]

# Bailer-Jones and Bayesian Inference

Geometric: $P^*(r|\omega, \sigma_\omega, p) = P(r|p)P(\omega|r, \sigma_\omega)$

Photogeometric: $P^*(r|\omega, \sigma_\omega, p, G, c) = P(Q_G|c, p)P(r|p)P(\omega|r, \sigma_\omega)$

- Likelihood: $P(\omega|r, \sigma_\omega)$ Probability you measure this parallax given a distance and error bars
- Distance Prior: $P(r|p)$ Probability of distance given sky location from, Galaxy model fit to Gaia DR3 Simulated Galaxy[5]
- Photometric prior $P(Q_G(r)|c, p)$ Probability you measure $Q_G = G - 5log_10(r) + 5$ given the color and sky location[5]
- To use: `...JOIN external.gaiaedr3_distance as d USING (source_id)...`
- Parallax-only method with limited assumptions (unlike GSP-Phot)

# How well does this work?

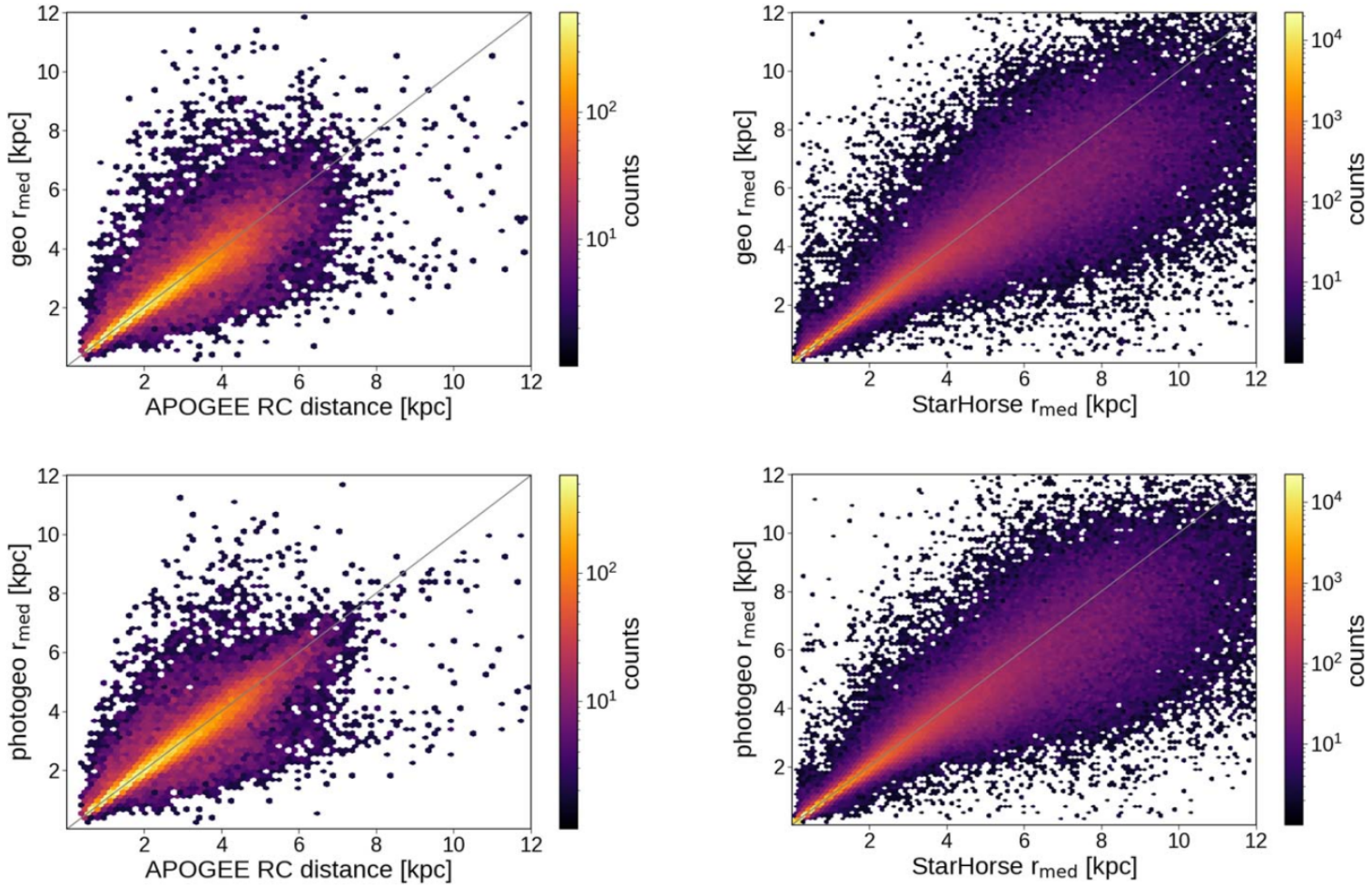


Figure: Comparison of Bailer Jones distances to other methods [5]

- Around 6 kpc you start to see difference in prior coming out
- Hard to test a distance measure

# DR4 makes it better?

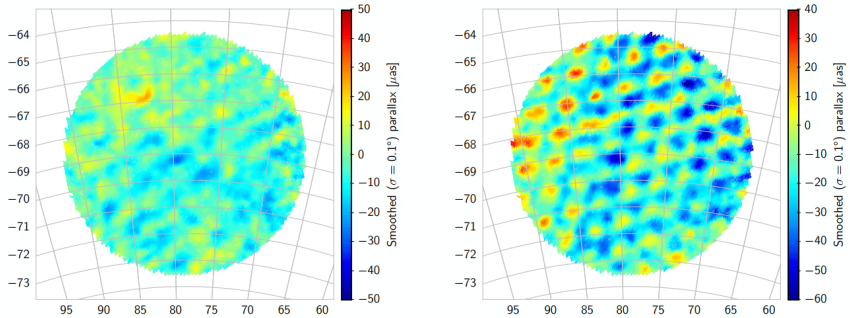

**Fig. 14.** Smoothed maps of parallaxes in the LMC area, visualising small-scale systematics (the 'checkered pattern') in *Gaia* EDR3 and DR2. *Left:* Smoothed parallaxes in EDR3 for sources in the magnitude range $G = 16$–$18$ (median $G = 17.4$), kinematically selected as probable members of the system (see Appendix B in Lindegren et al. 2020 for details). *Right:* Smoothed parallaxes in DR2 for the same sample of sources. Both maps were smoothed using a Gaussian kernel with standard deviation 0.1°. While the sample includes about 730 000 sources within 5° radius of the adopted centre, only smoothed points within a radius of 4.5° are shown to avoid unwanted edge effects. Comparison between the two diagrams is facilitated by the use of the same colour scale, only shifted by 10 $\mu$as to compensate for the mean difference in parallax between DR2 and EDR3.

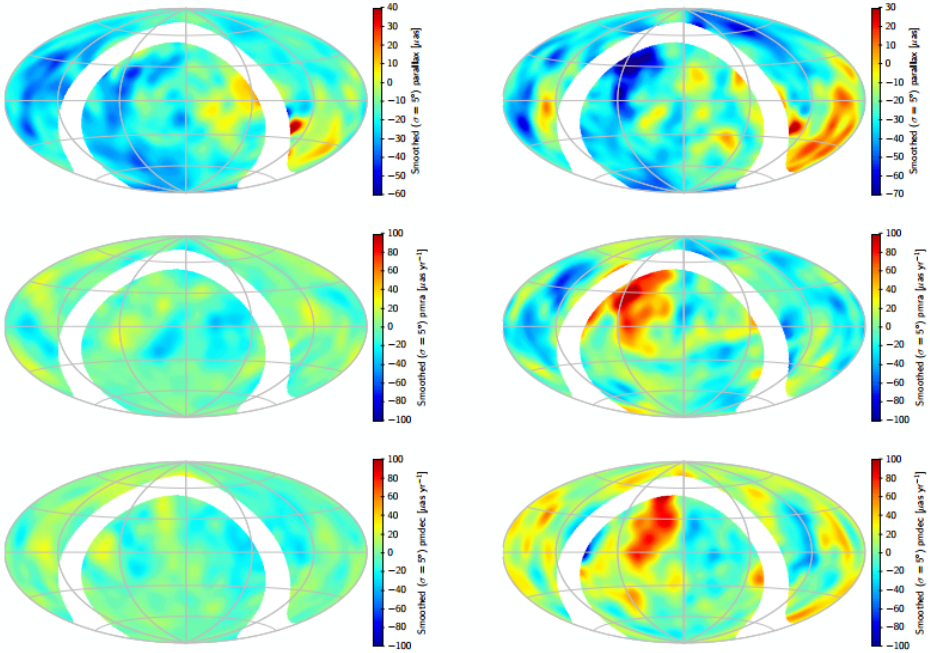

Figure: Comparison of DR2 and EDR3 from [6]

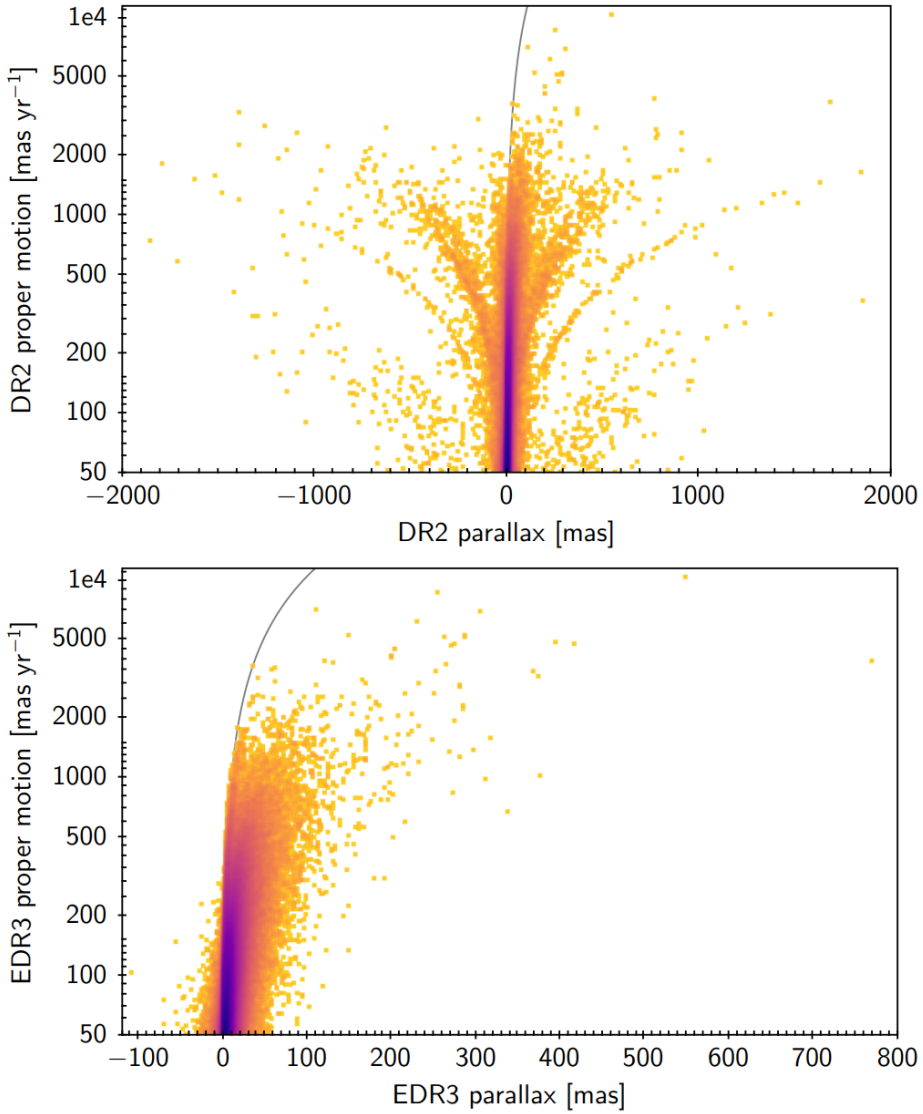


**Fig. 10.** Proper motion versus parallax for large proper motions. *Top*: in *Gaia* DR2. *Bottom*: in *Gaia* EDR3. The grey line shows the locus of tangential velocity 500 km s$^{-1}$.

# Microlensing

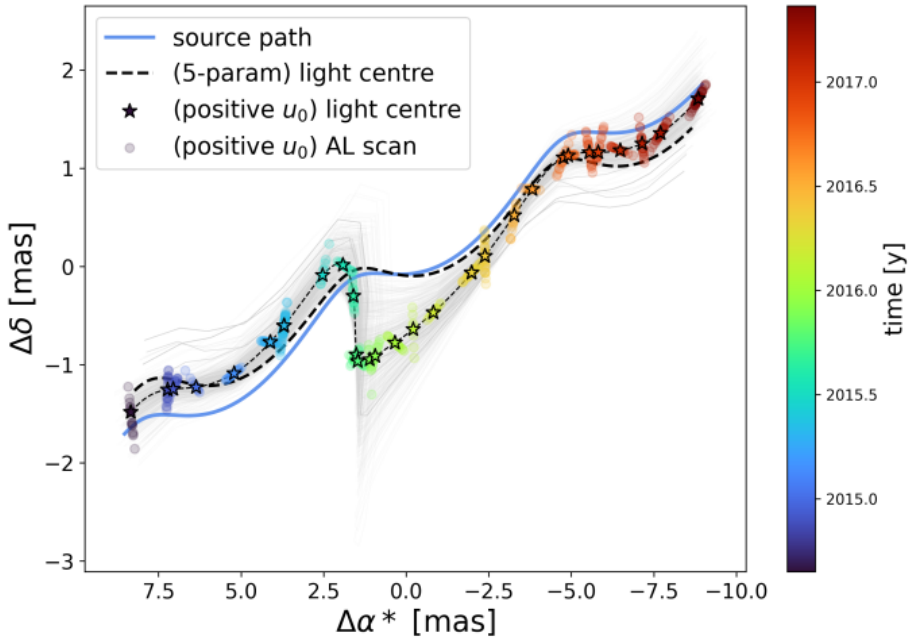


Figure: Figure from [7]

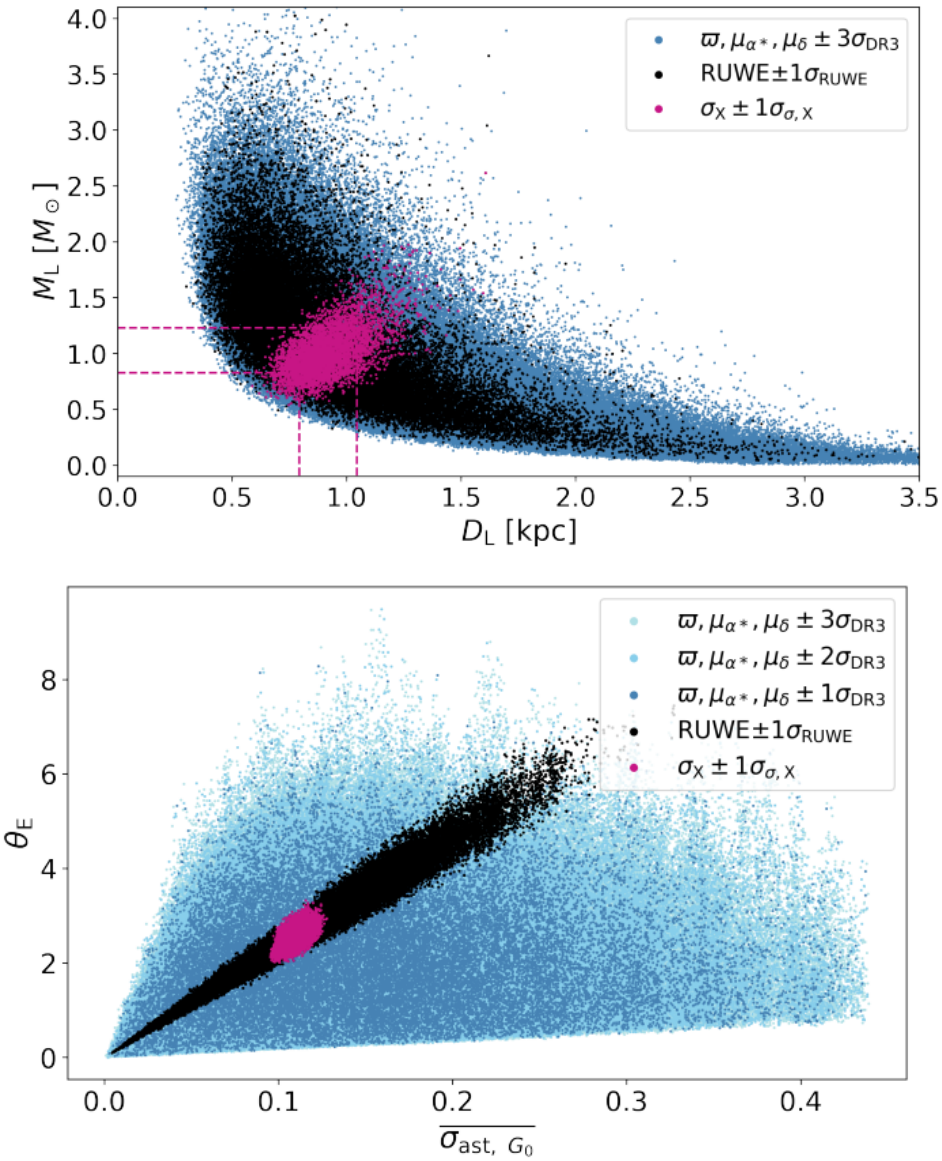


Figure: Figure from [7]

# References


1. Collaboration, G. “The Gaia Mission”. (Sept. 14, 2016).
2. Luri, X. *et al.* “Gaia Data Release 2: Using Gaia Parallaxes”. *Astronomy & Astrophysics* **616,** A9. arXiv: 1804.09376 [astro-ph] (Aug. 2018).
3. Fabricius, C. *et al.* “Gaia Early Data Release 3 - Catalogue Validation”. *Astronomy & Astrophysics* **649,** A5 (May 1, 2021).
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5. Bailer-Jones, C. A. L., Rybizki, J., Fouesneau, M., Demleitner, M. & Andrae, R. “Estimating Distances from Parallaxes. V. Geometric and Photogeometric Distances to 1.47 Billion Stars in Gaia Early Data Release 3”. *The Astronomical Journal* **161,** 147 (Feb. 2021).
6. Lindegren, L. *et al.* “Gaia Early Data Release 3: The Astrometric Solution”. *Astronomy & Astrophysics* **649,** A2. arXiv: 2012.03380 [astro-ph] (May 2021).
7. Jabłońska, M. *et al.* “Is There a Nearby Microlensing Stellar Remnant Hiding in Gaia DR3 Astrometry?” *Astronomy & Astrophysics* **666,** L16. arXiv: 2206.11342 [astro-ph] (Oct. 2022).