Wide Binaries in Gaia

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IAU Symposium 330:
Astrometry and Astrophysics in the Gaia Sky
Nice, France

Julio Chanamé (PUC)
Marcel Agüeros (Columbia)

Sirius A/B System

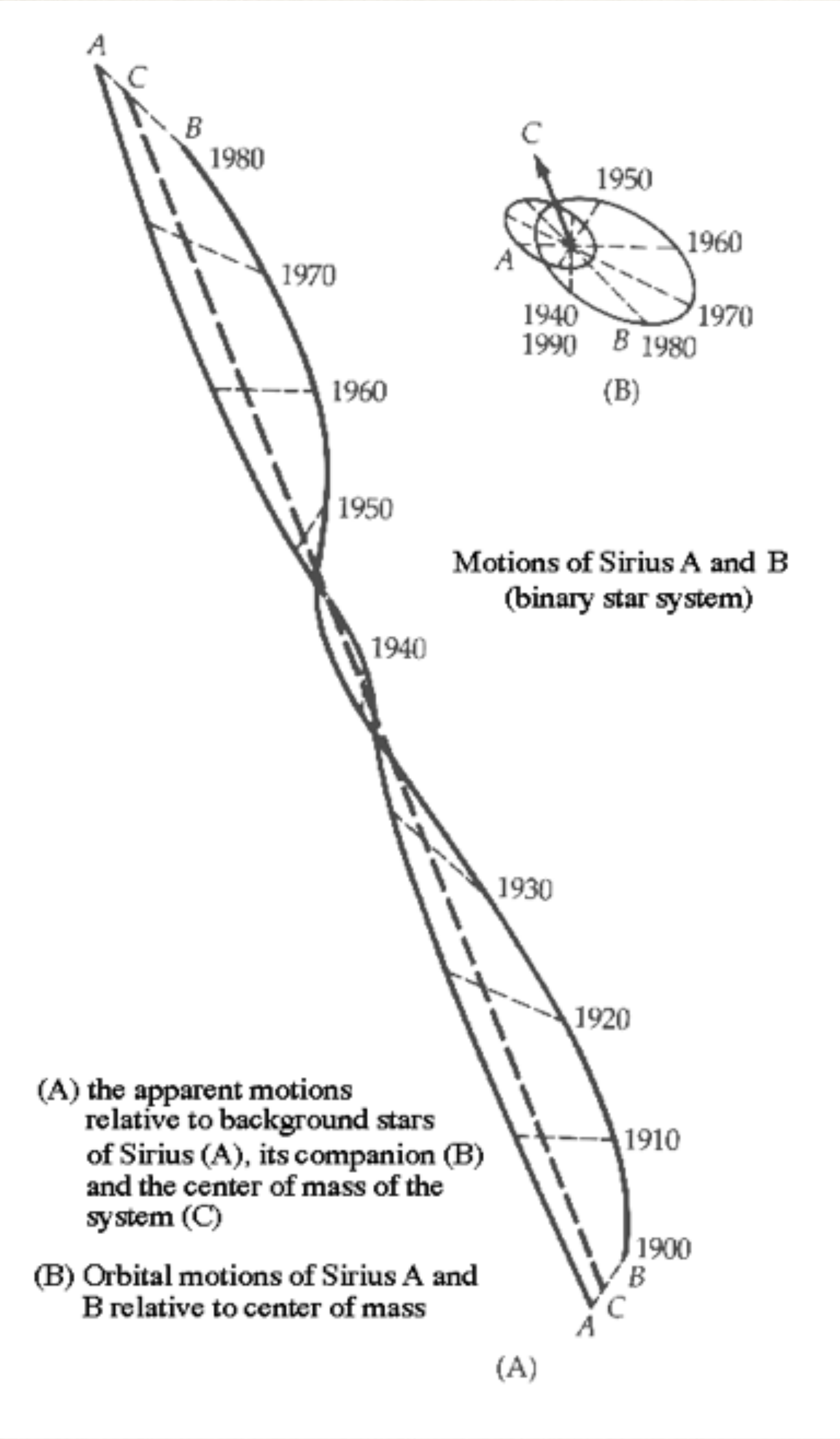
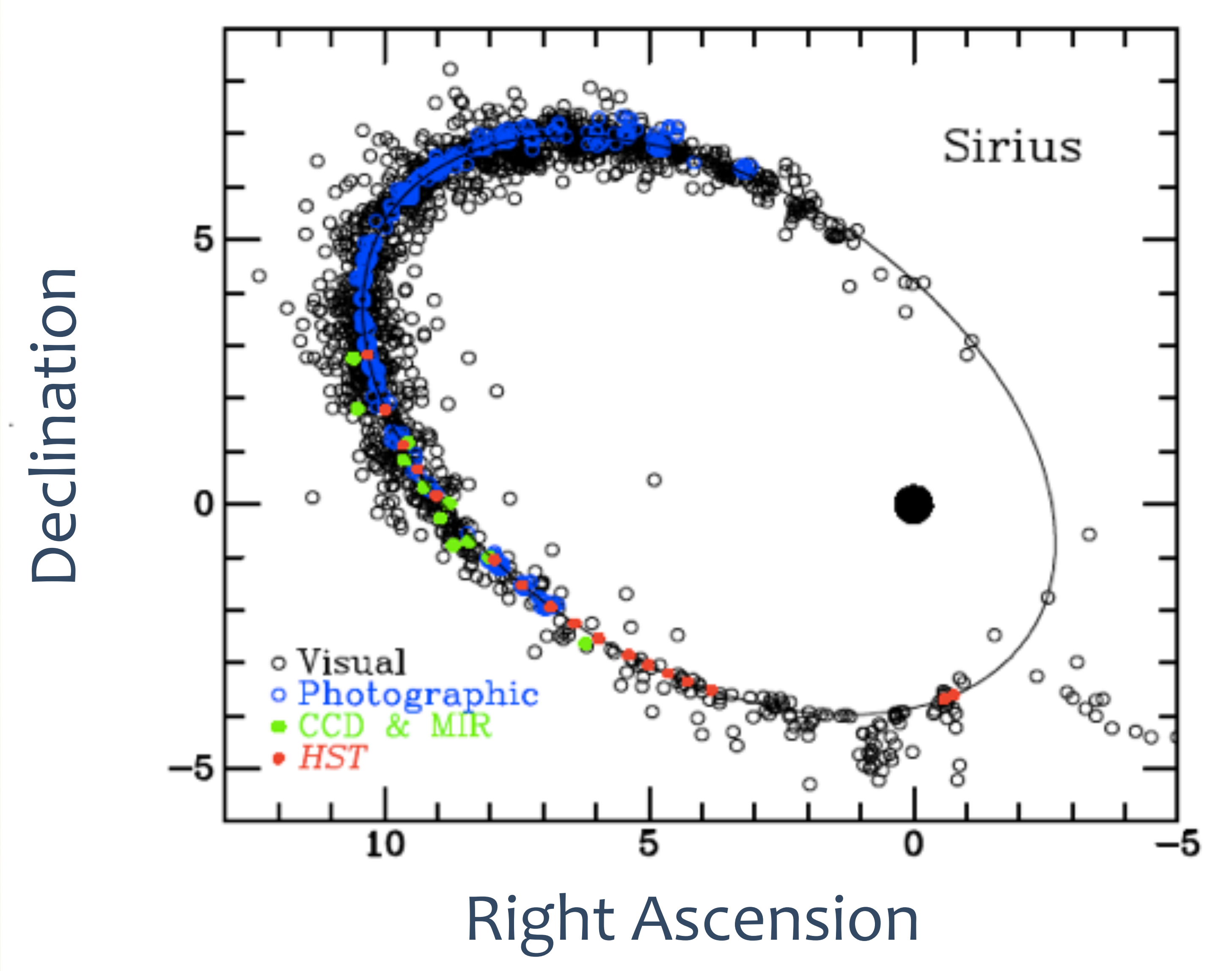
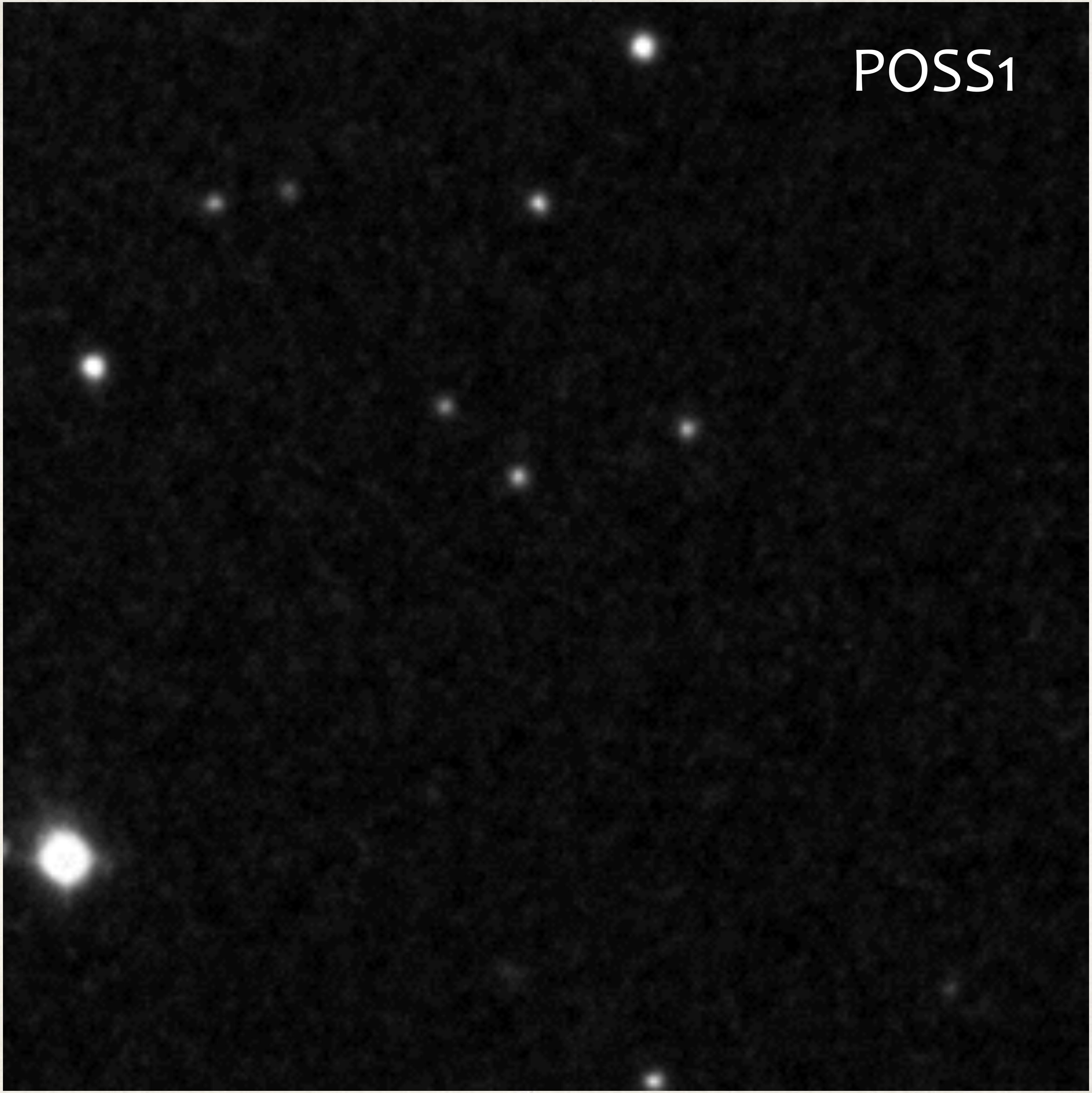
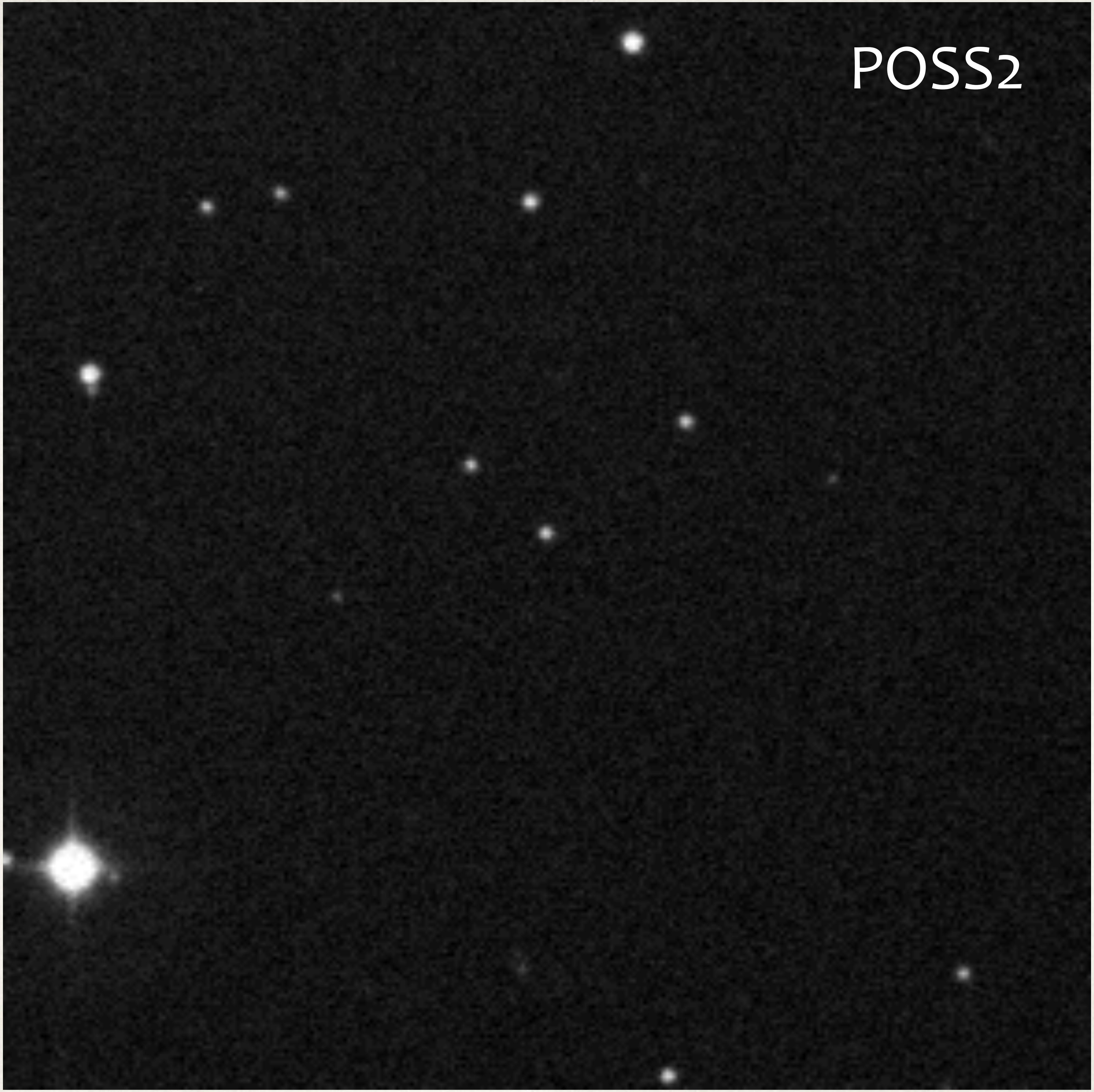


Image Credit: Michael Rulison



Bond et al. (2017)

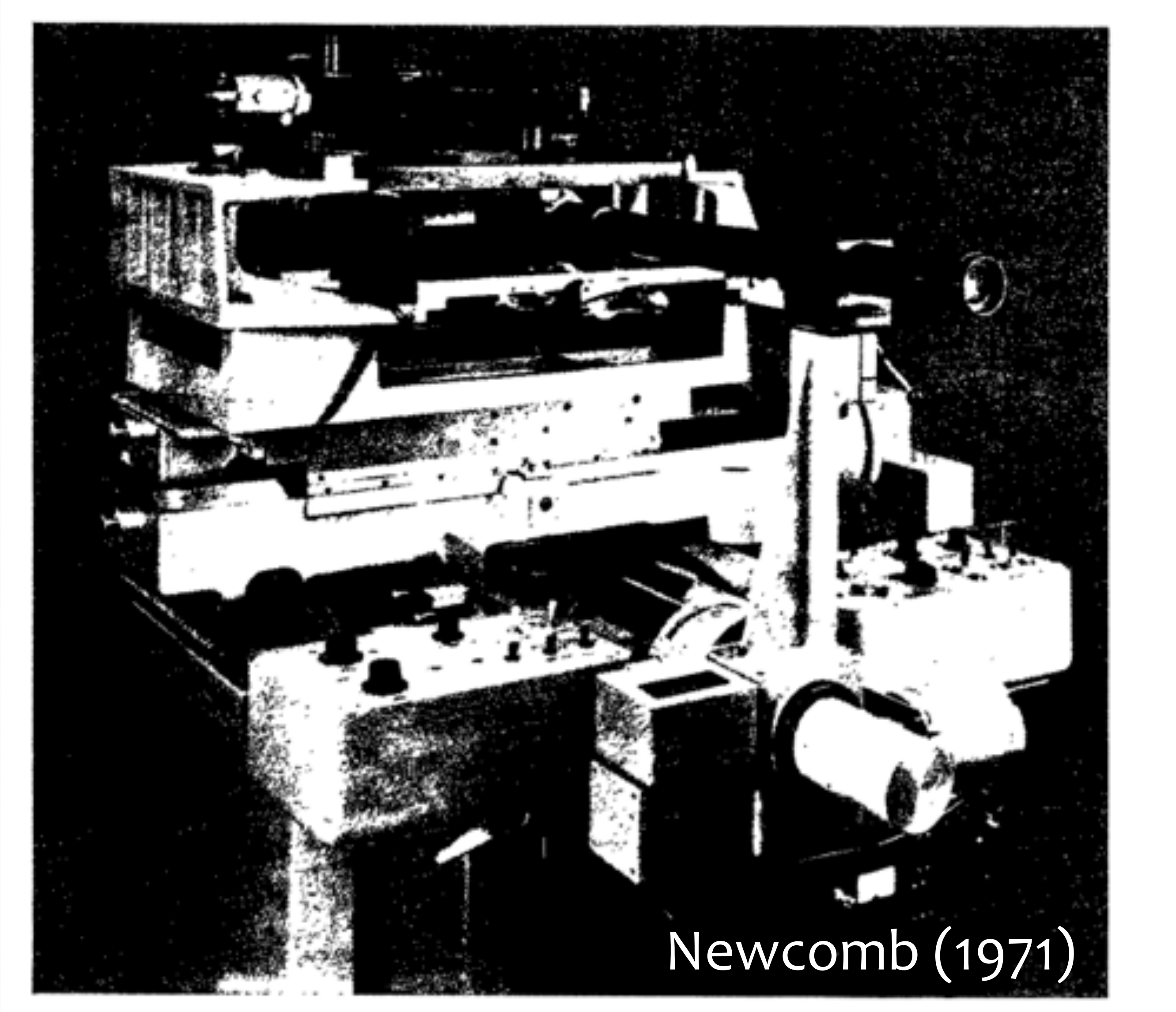

POSS1


POSS2

Proper Motions from Photometric Plates

Willem Luyten

Laser Scanning Microdensitometer



IAU Colloquia 5:
Coordination of Observing
Techniques of Visual Double Stars
Nice, France September 1969

Wide Binary Science

Galactic Structure

Wide binaries are fragile, sensitive to structure

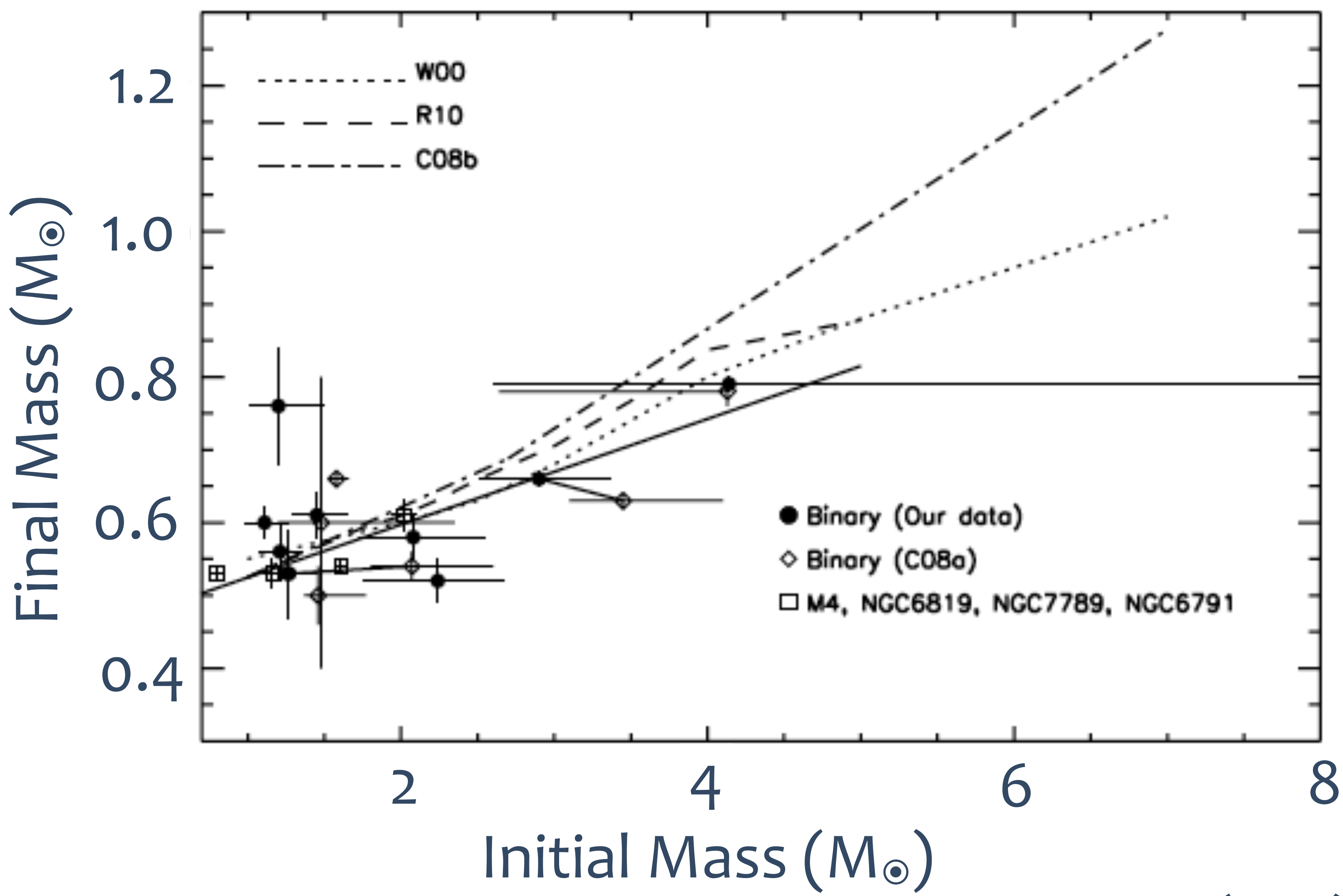
Stellar Dynamics

Triple system dynamics

Stellar Astrophysics

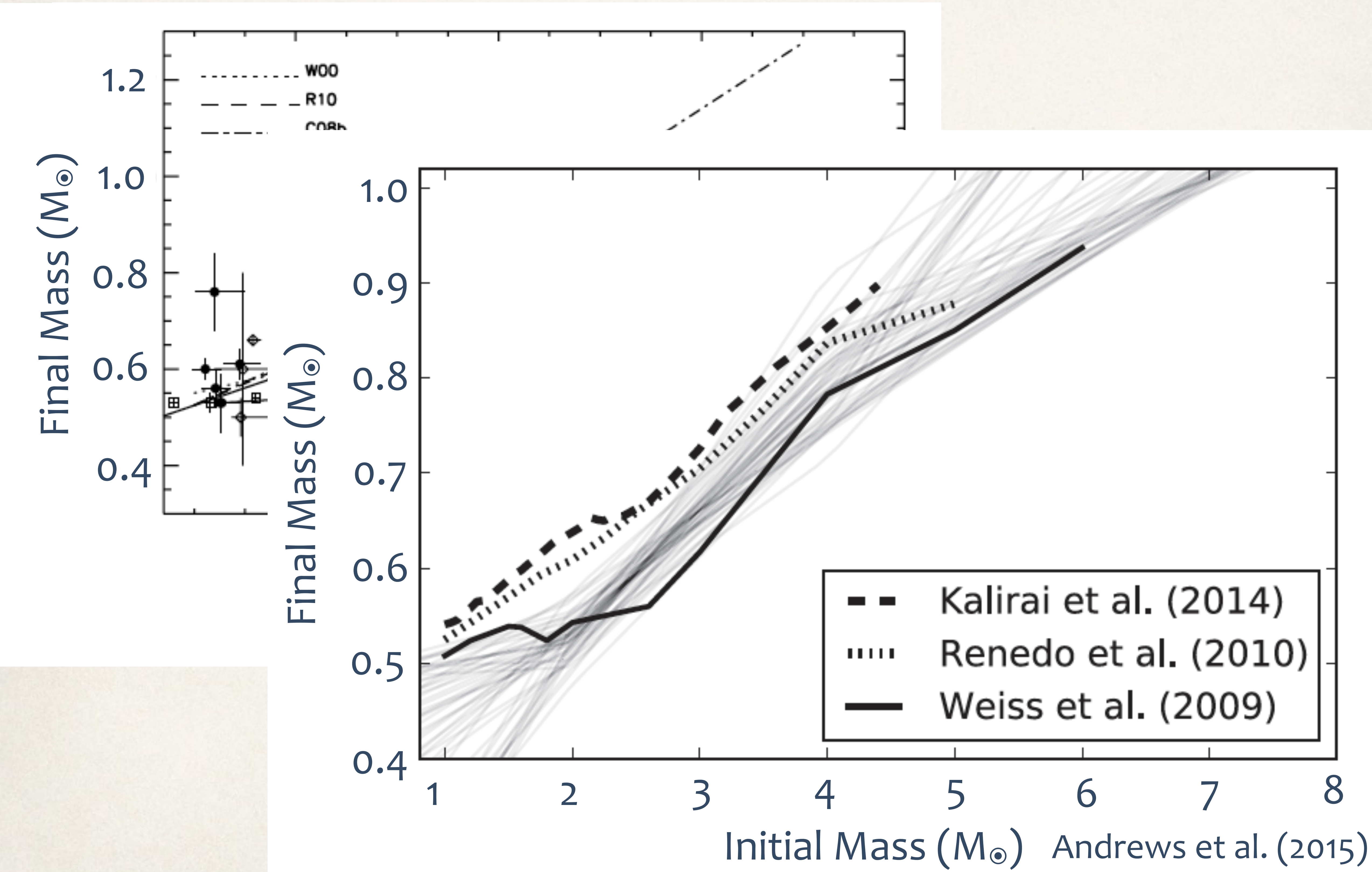
Components are co-eval, independent, same metallicity

Initial-Final Mass Relation



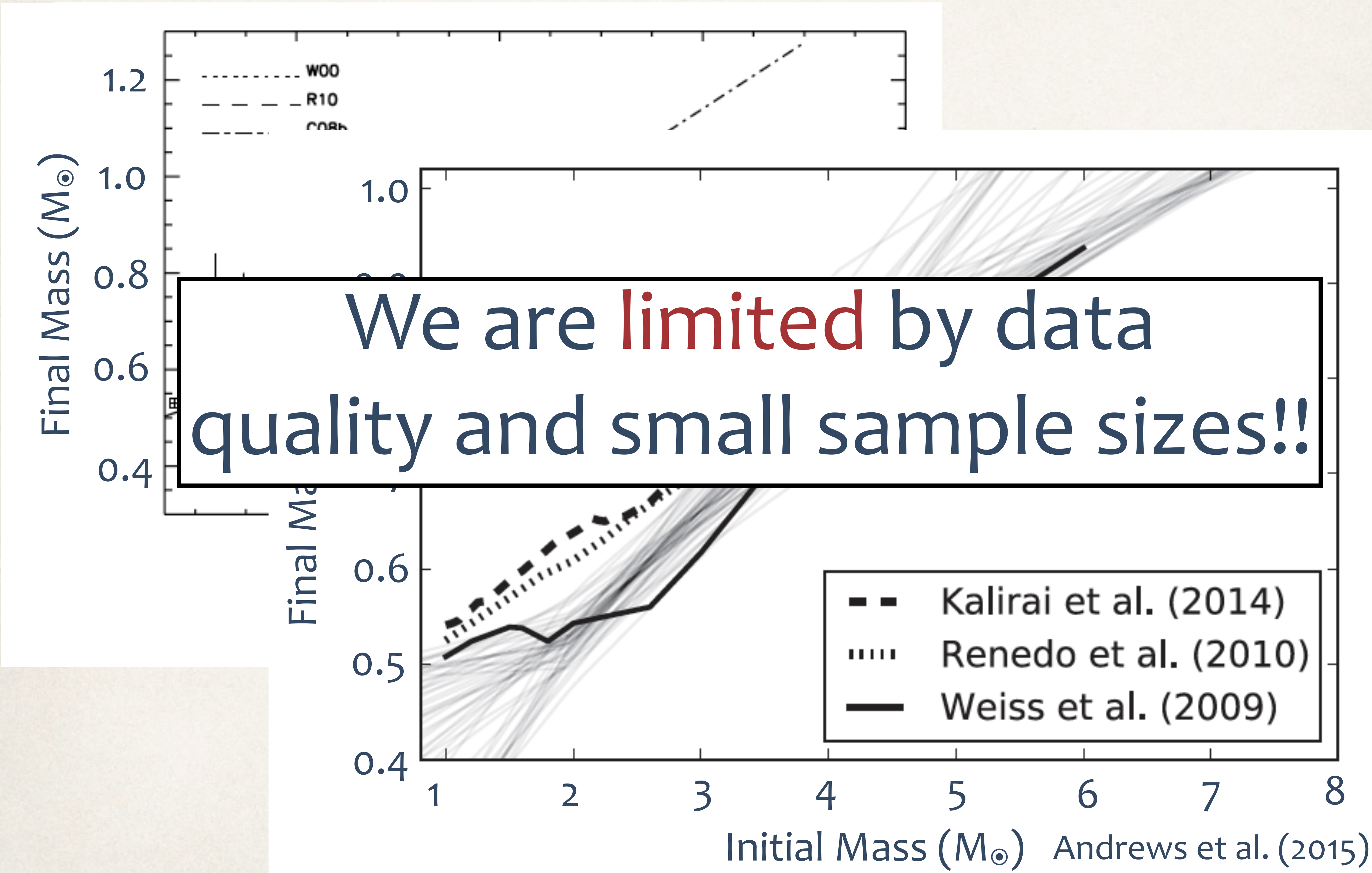
Zhao et al. (2012)

Initial-Final Mass Relation



Andrews et al. (2015)

Initial-Final Mass Relation

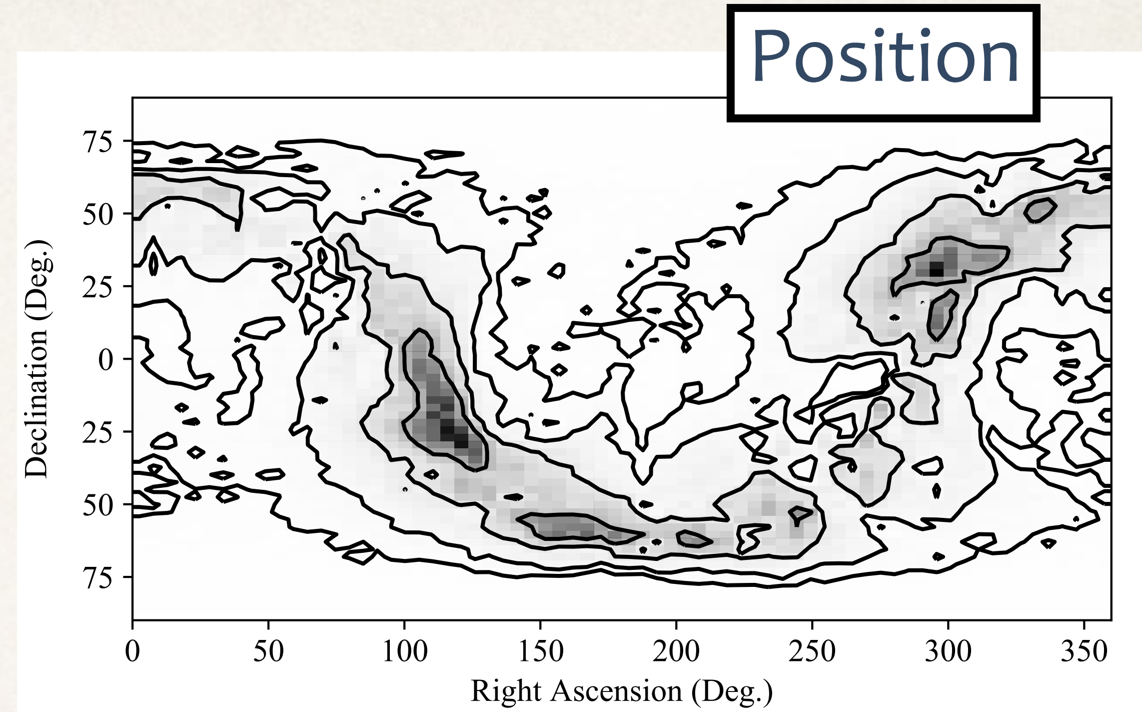


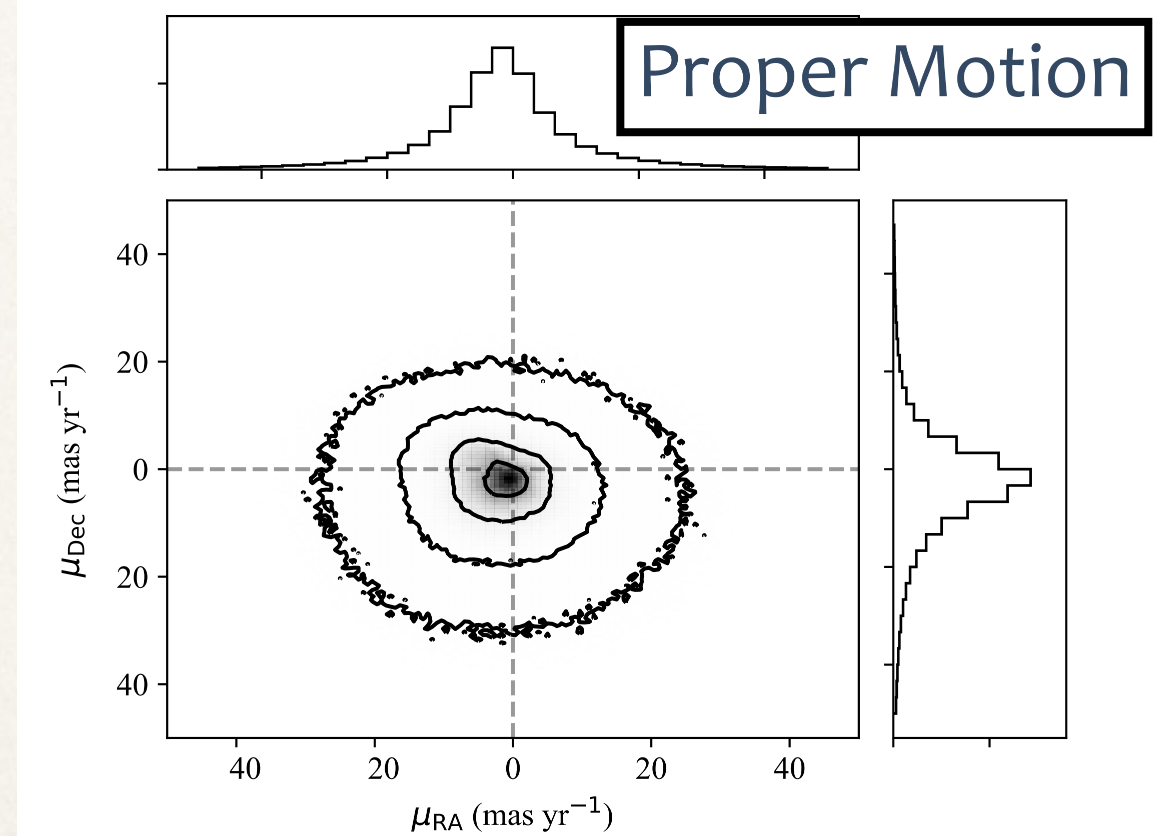
We are limited by data quality and small sample sizes!!

Wide Binaries using TGAS

TGAS Characteristics:
- 2 million stars
- Minimum separation ~ 2”
- Bias at separations <10”
- g mag < 12

Our Goal: Match on 5 Dimensions of Phase Space
- Position
- Proper motion
- Parallax
- Correlated uncertainties
- No radial velocities (yet)





Andrews et al.
ArXiv: 1704.07829

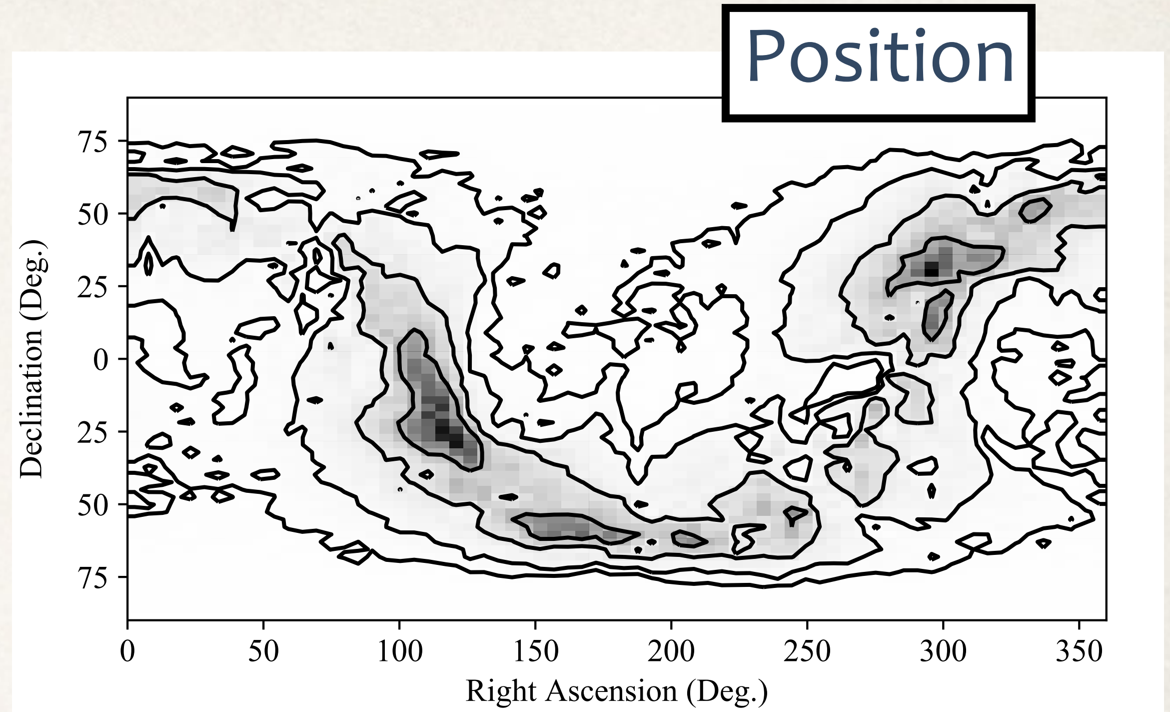
Method - Bayesian Priors

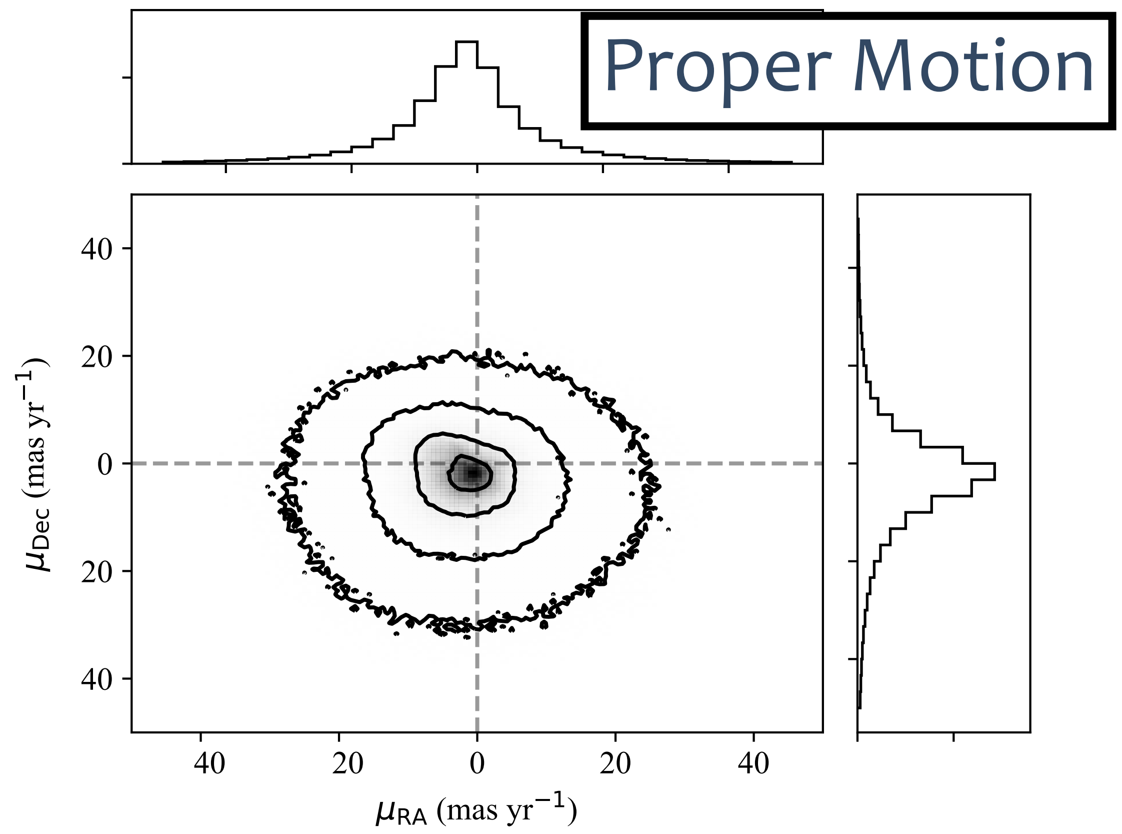
Random alignment prior $\propto \rho(\hat{x})^2$

Density in position and proper motion phase space

Binary prior $\propto f_{\text{bin}} \, \rho(\hat{x})$

Binary fraction





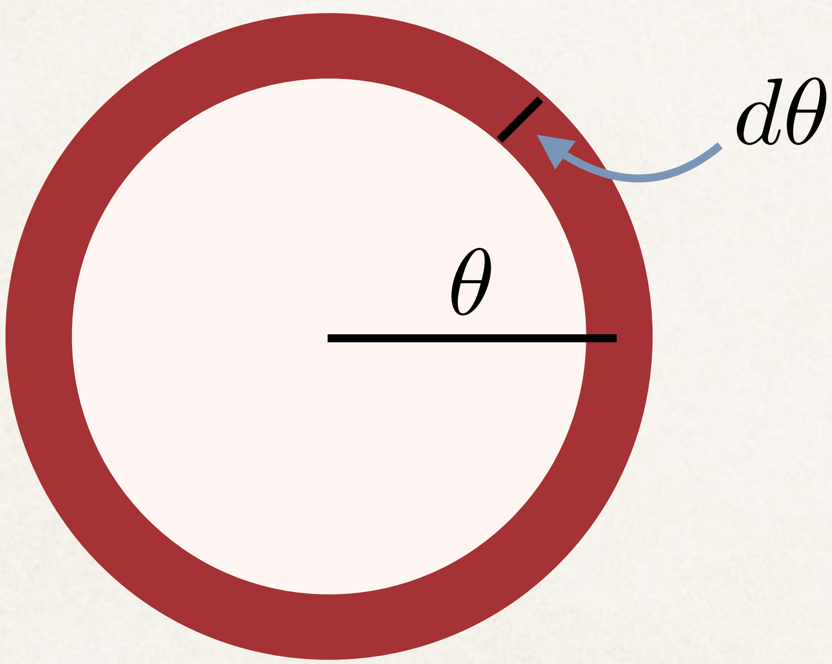
Andrews et al.
ArXiv: 1704.07829

Method - Random Alignment Likelihood

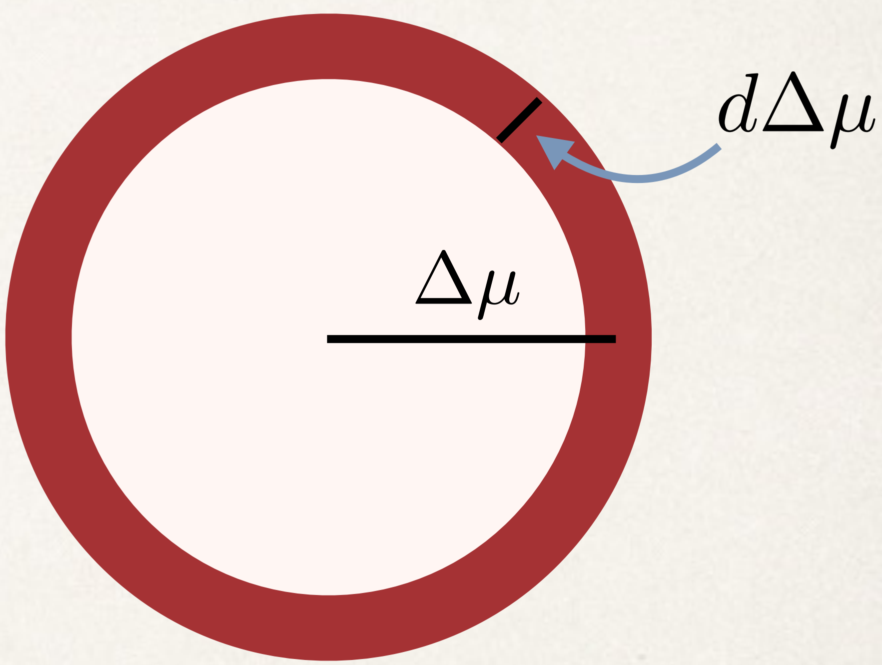
Probability = density x area

The area of an infinitesimally thin annulus is 2πrdr

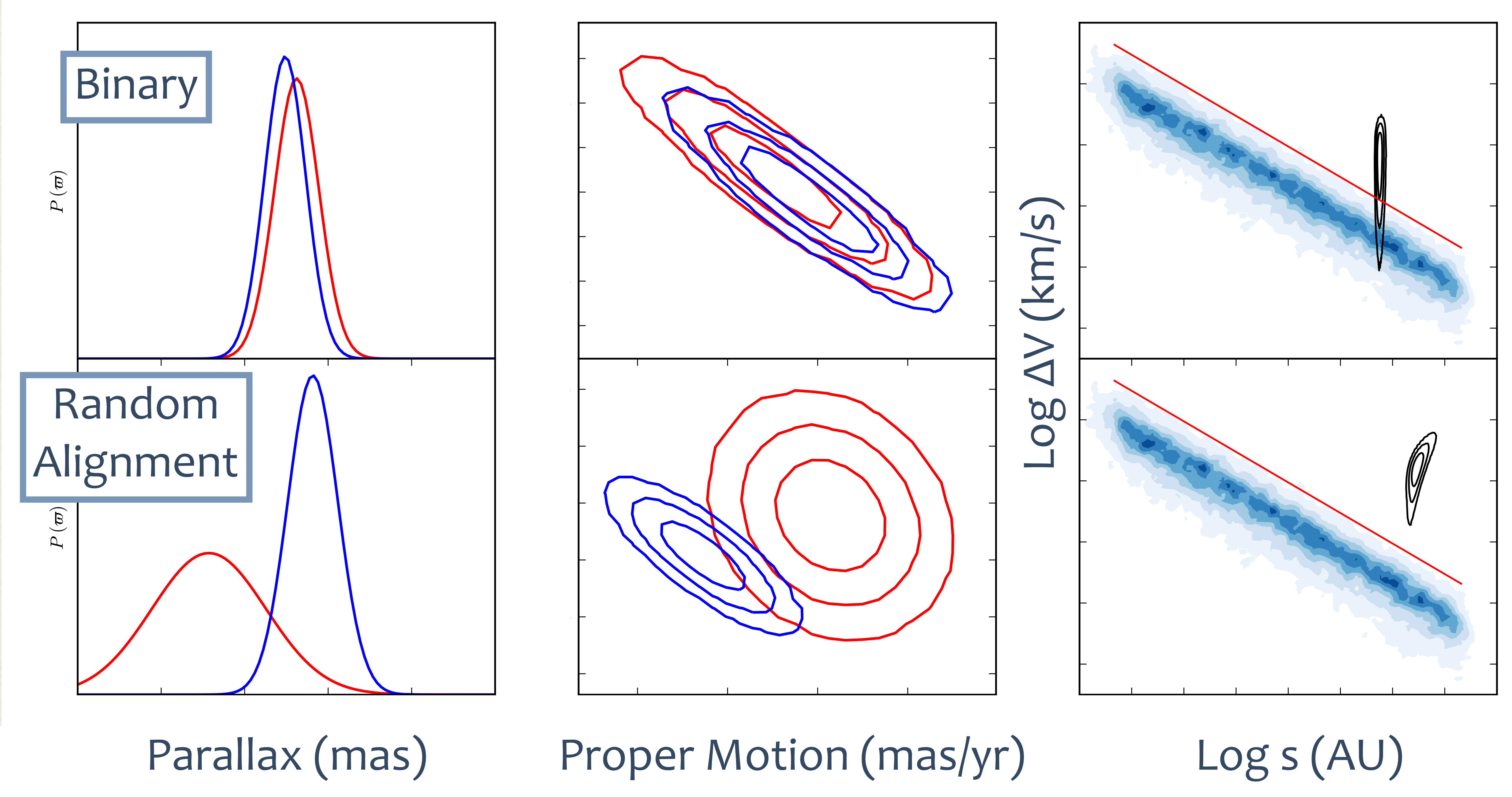
Position



Proper Motion



Method - Binary Likelihood



A Catalog of Only Random Alignments

Shift the catalog by:

- +1° in declination
- +3 mas/yr in right ascension
- +3 mas/yr in declination

Example from
Lepine & Bongiorno (2007)

A Catalog of Only Random Alignments

Shift the catalog by:

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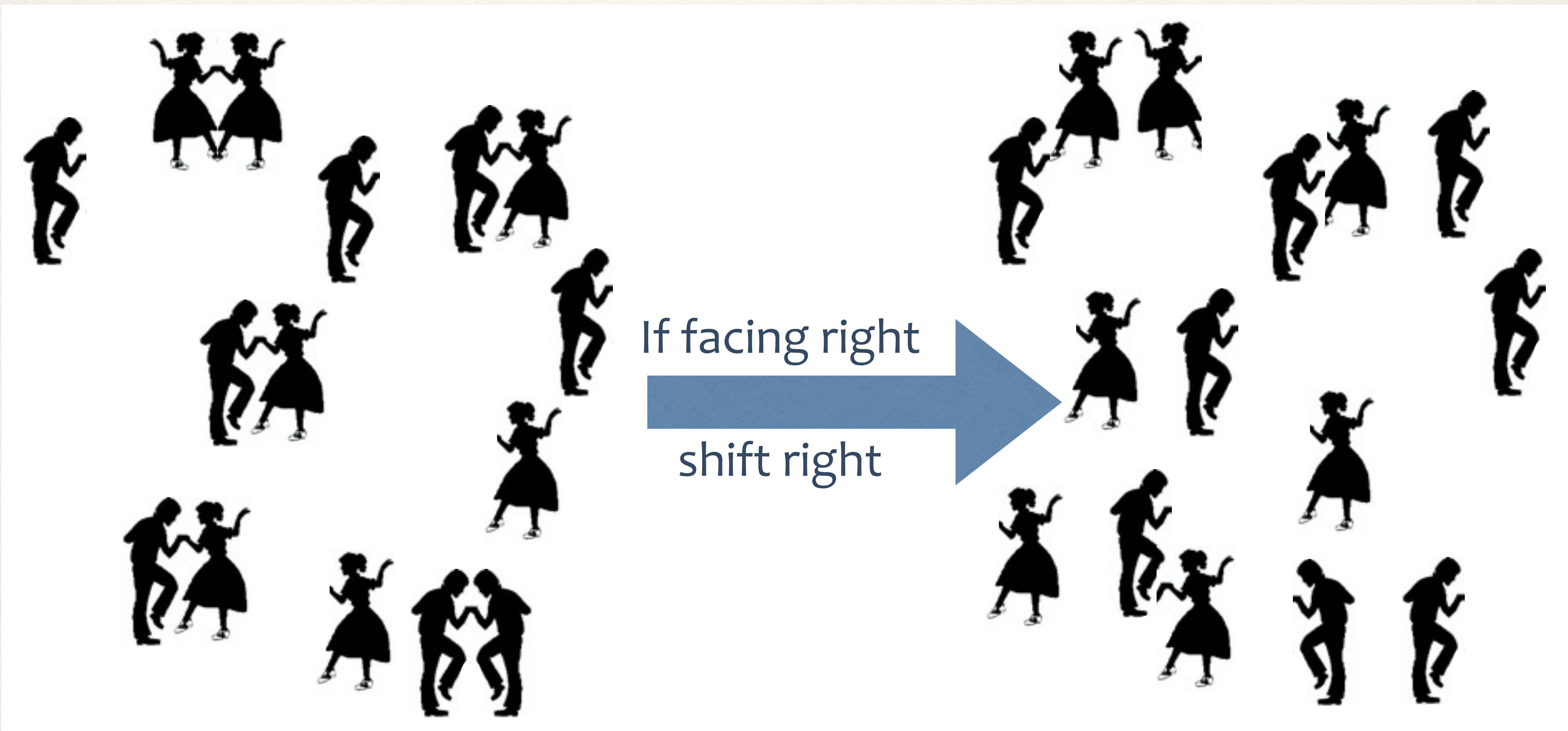
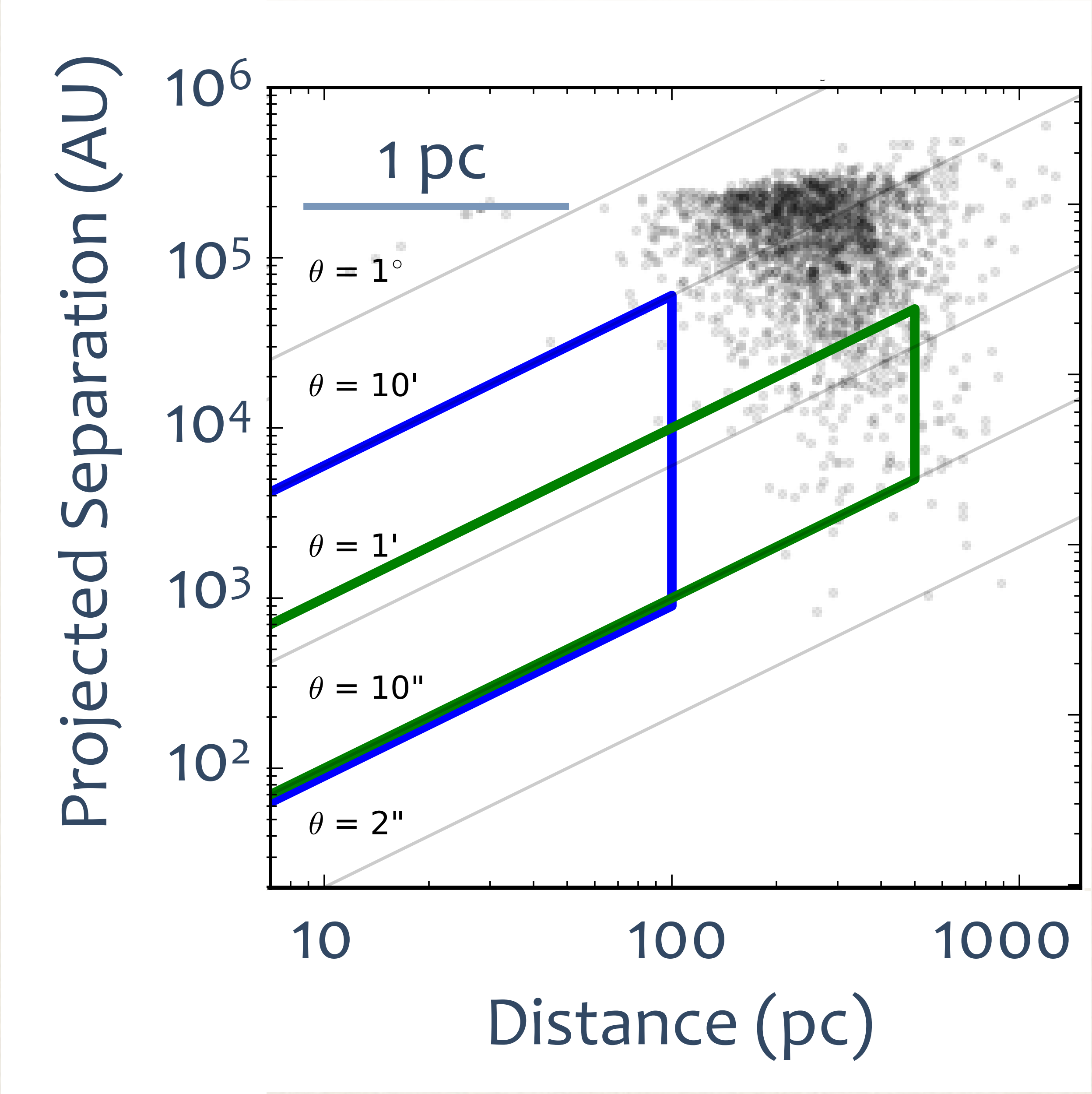


Example from
Lepine & Bongiorno (2007)

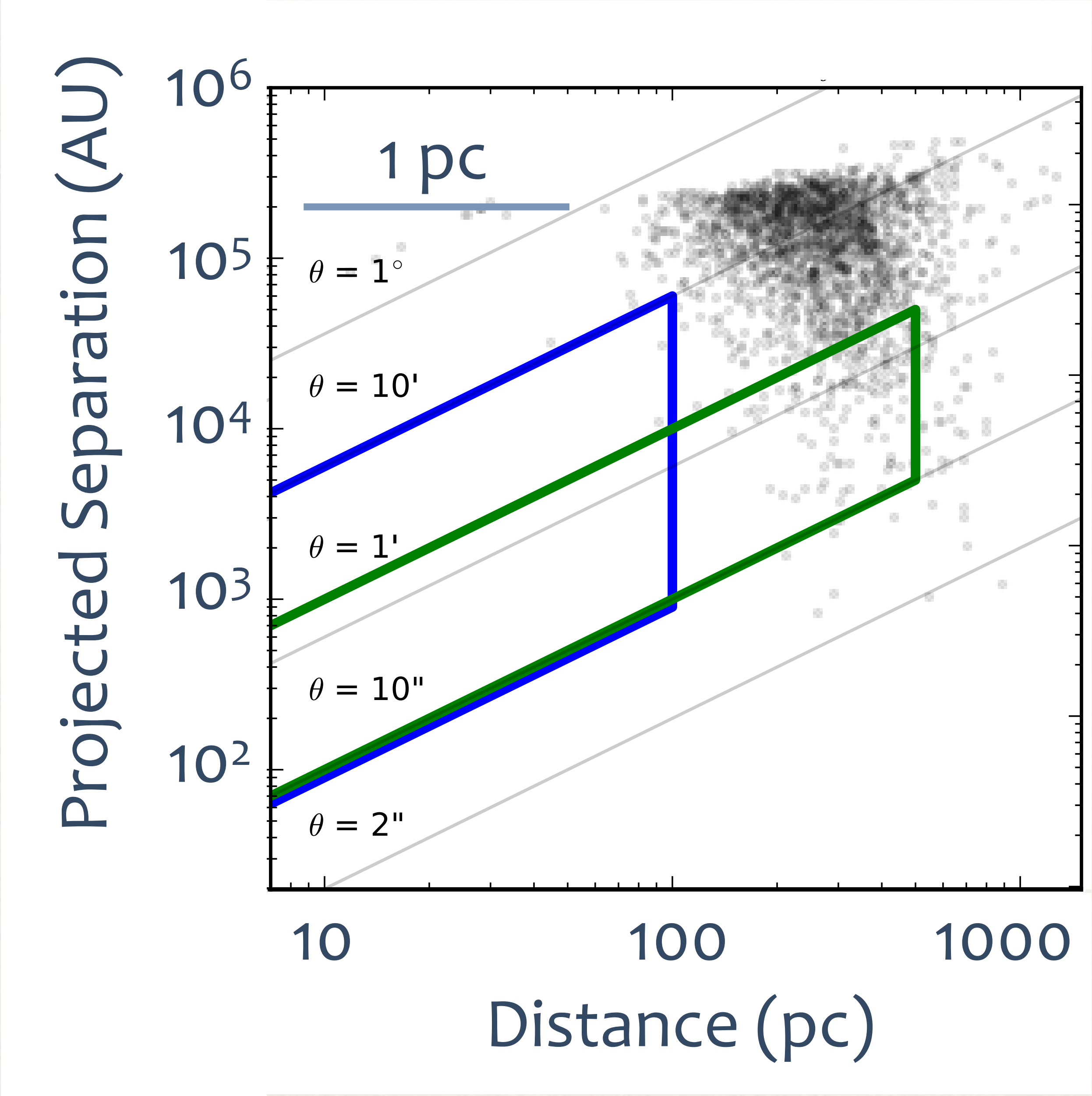
Results

Only Random Alignments

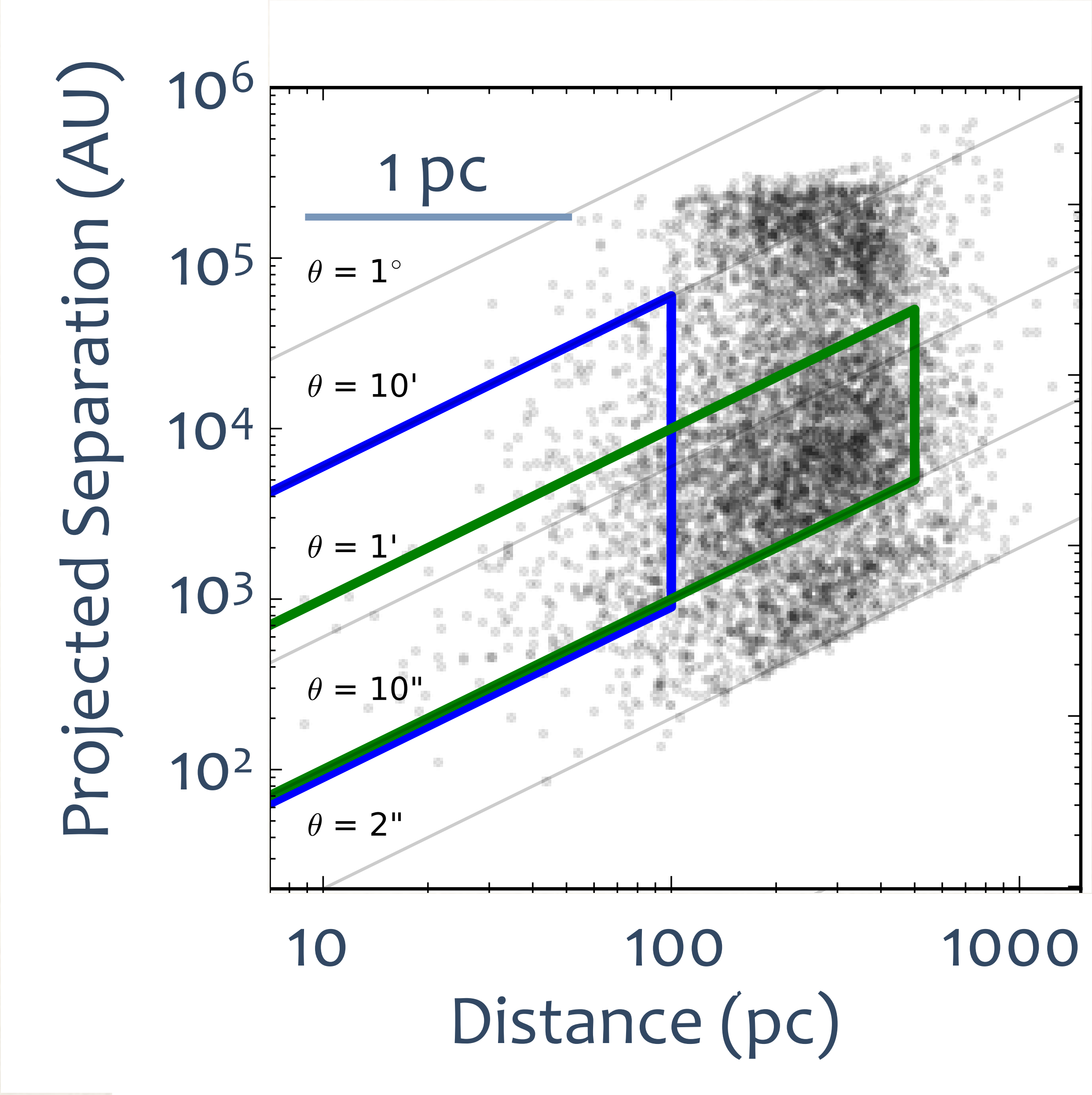


Results

Only Random Alignments



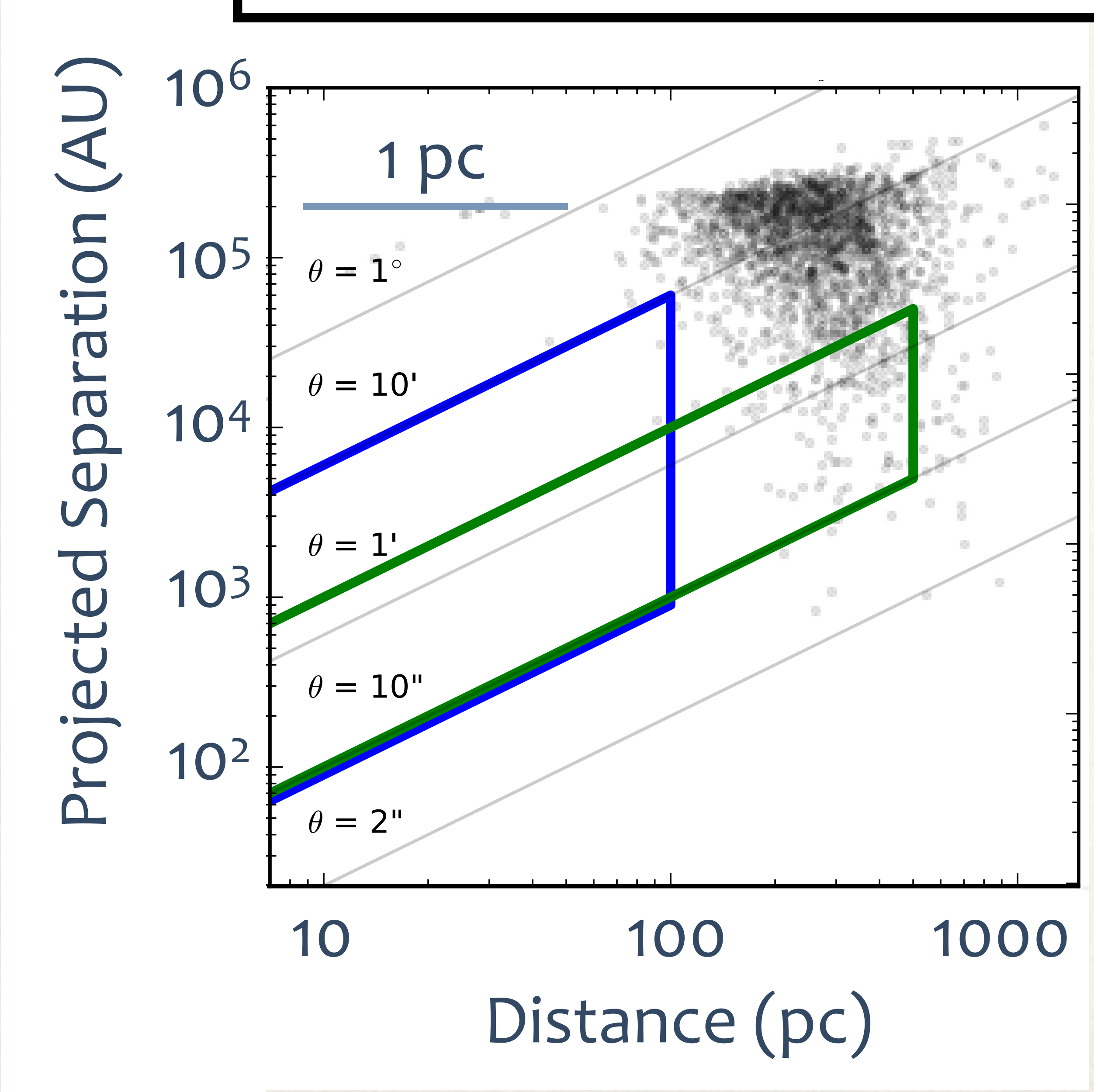
Catalog of TGAS Wide Binaries

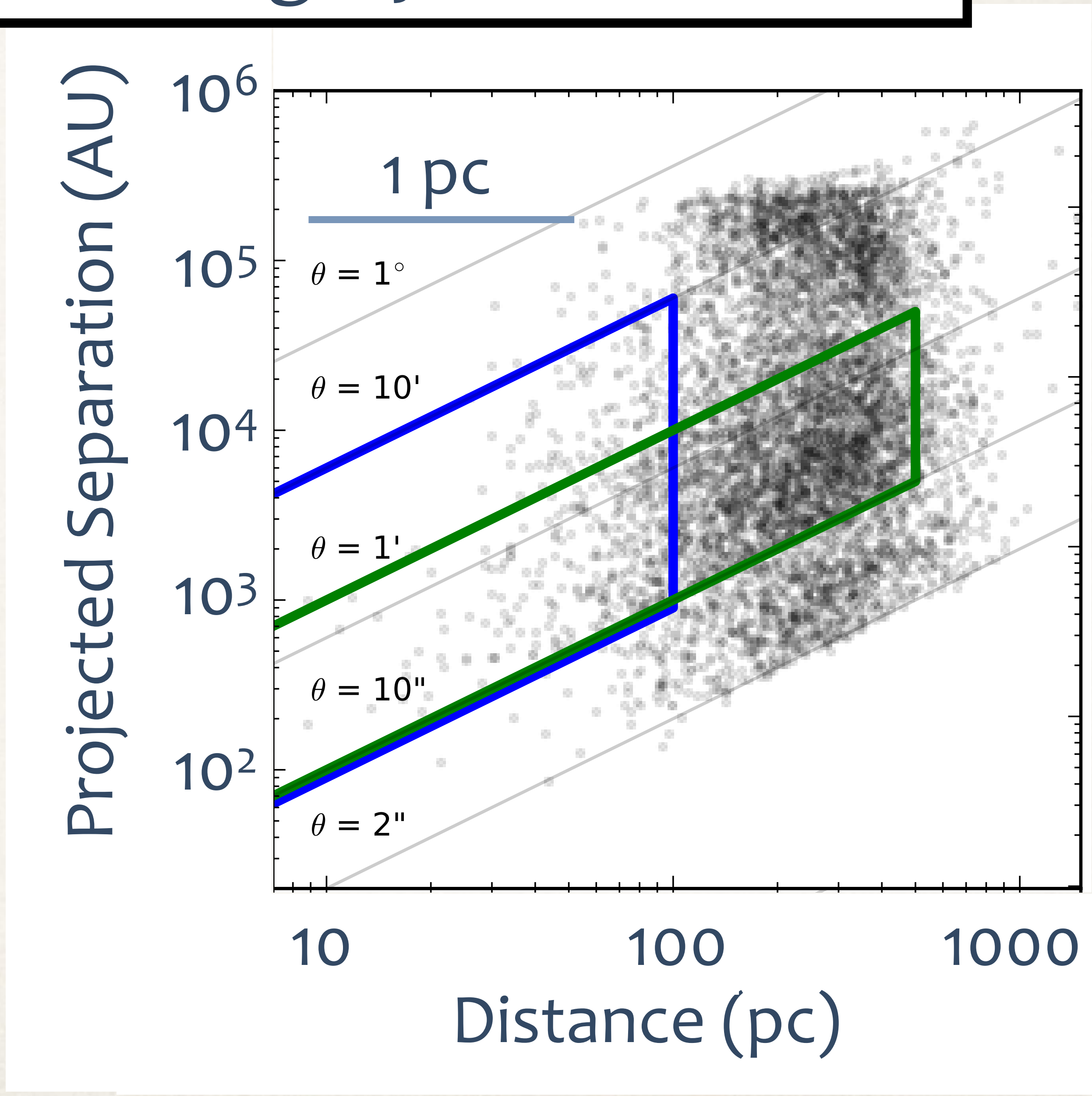


Results

6196 Wide Binaries

For pairs with projected separations <4x10⁴ AU, contamination is roughly 5%

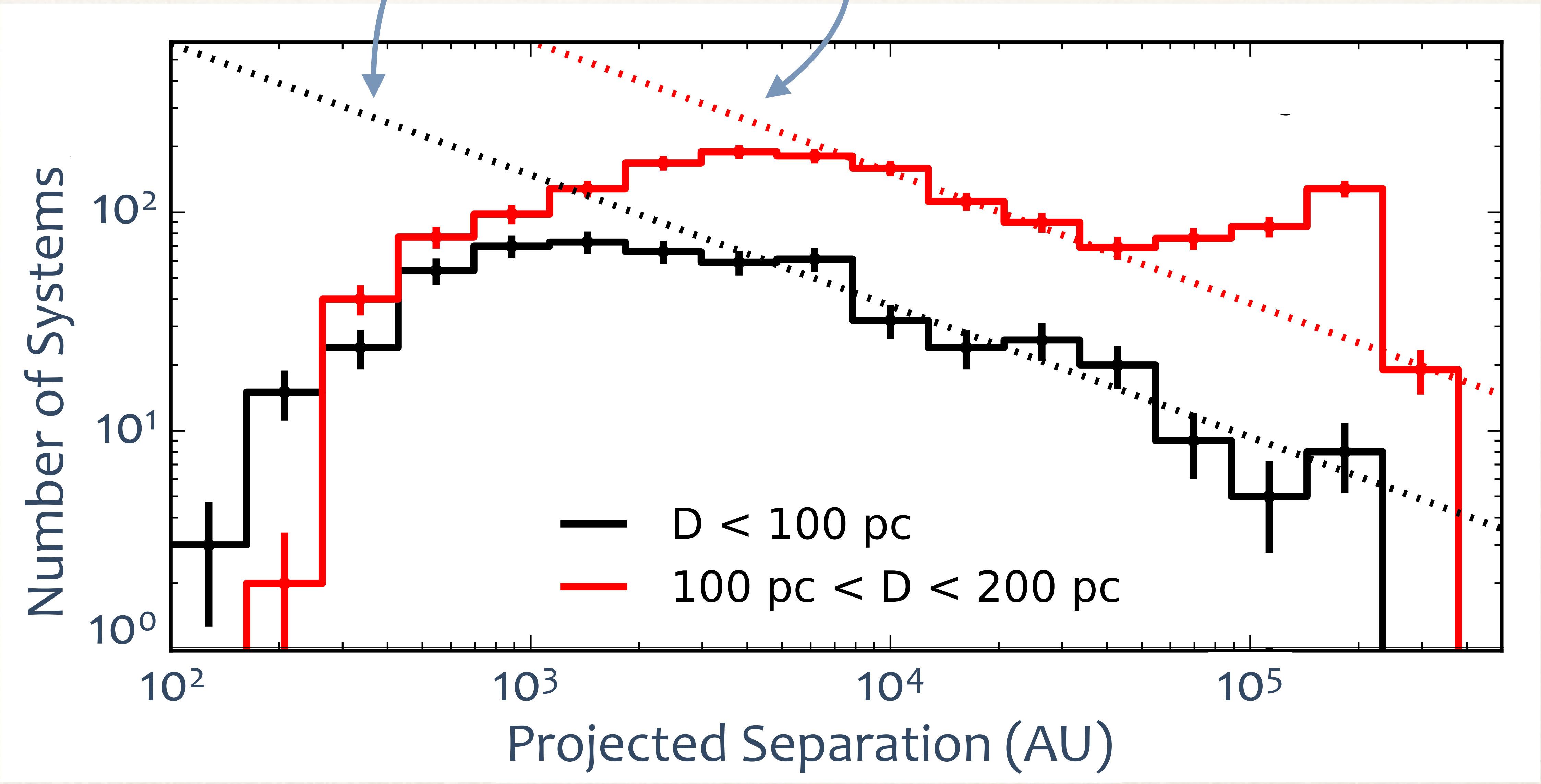




Orbital Separation Distribution

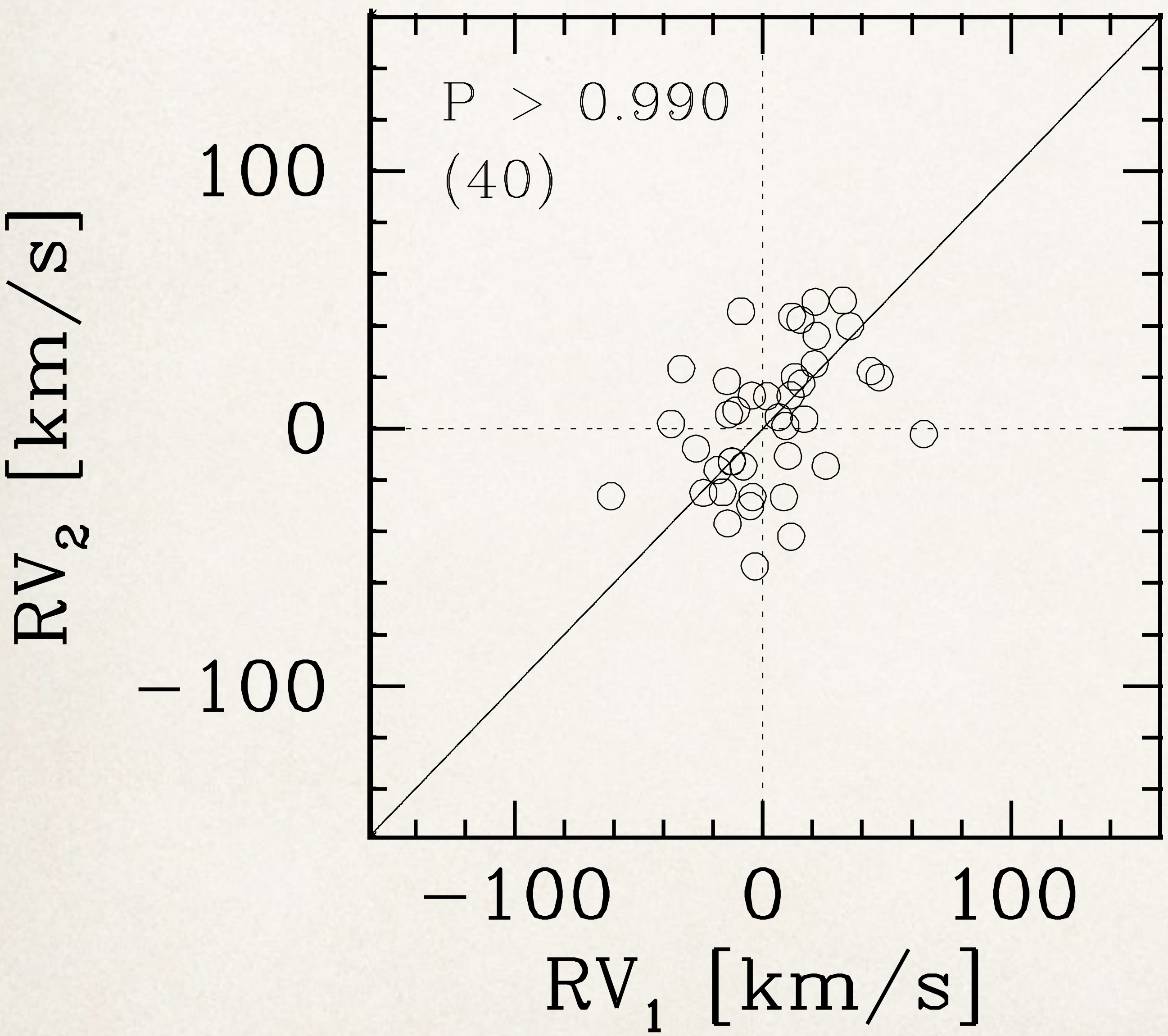
Power law:

$P(a) \sim a^{-1.6}$

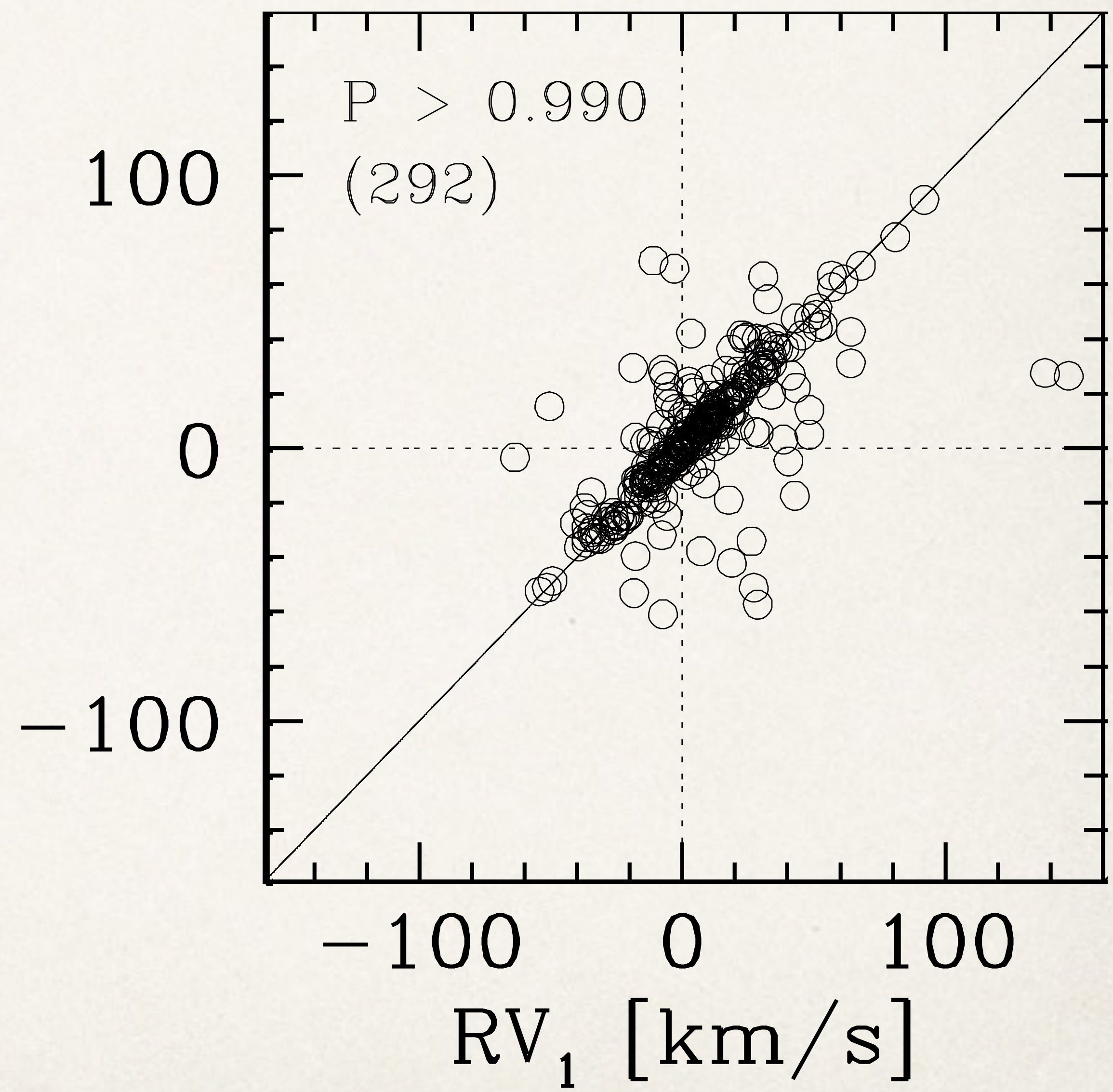


RAVE Radial Velocity Test

Only Random Alignments



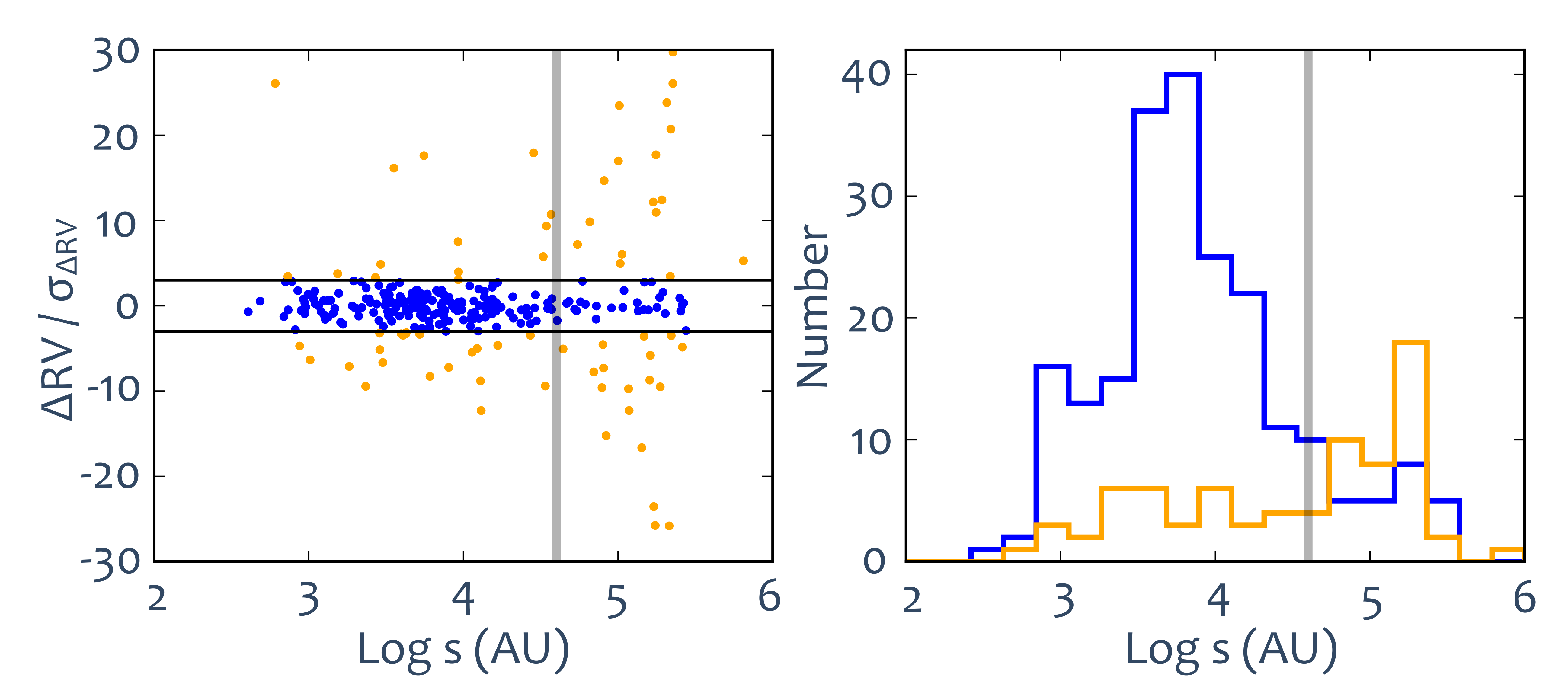
Catalog of TGAS Wide Binaries



Triple Systems

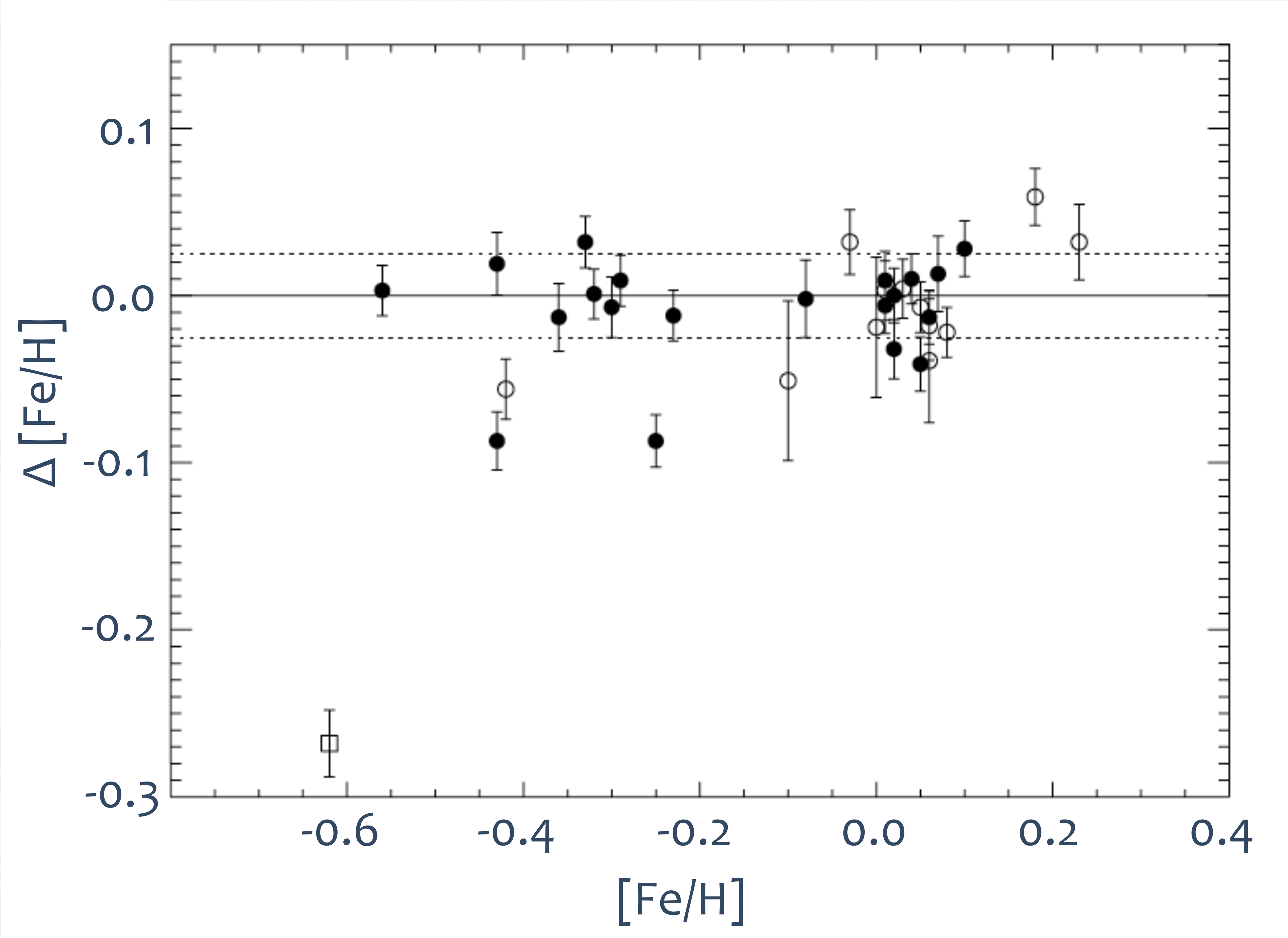
"more than 25% of [common proper motion] components are spectroscopic or astrometric binaries themselves."

Makarov et al. (2008)



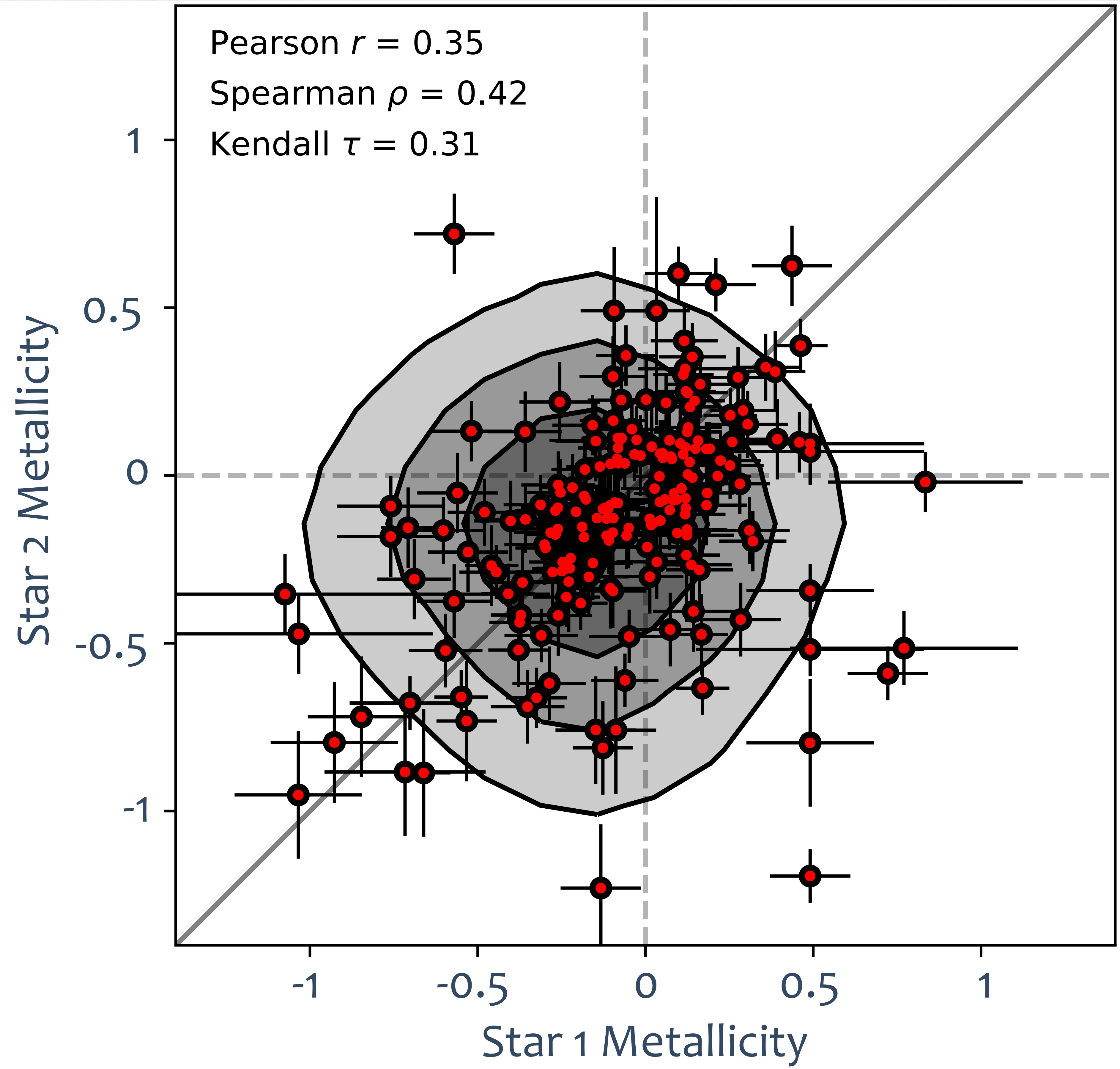
Chanamé et al. (in prep)

Wide Binary Metallicity Comparison



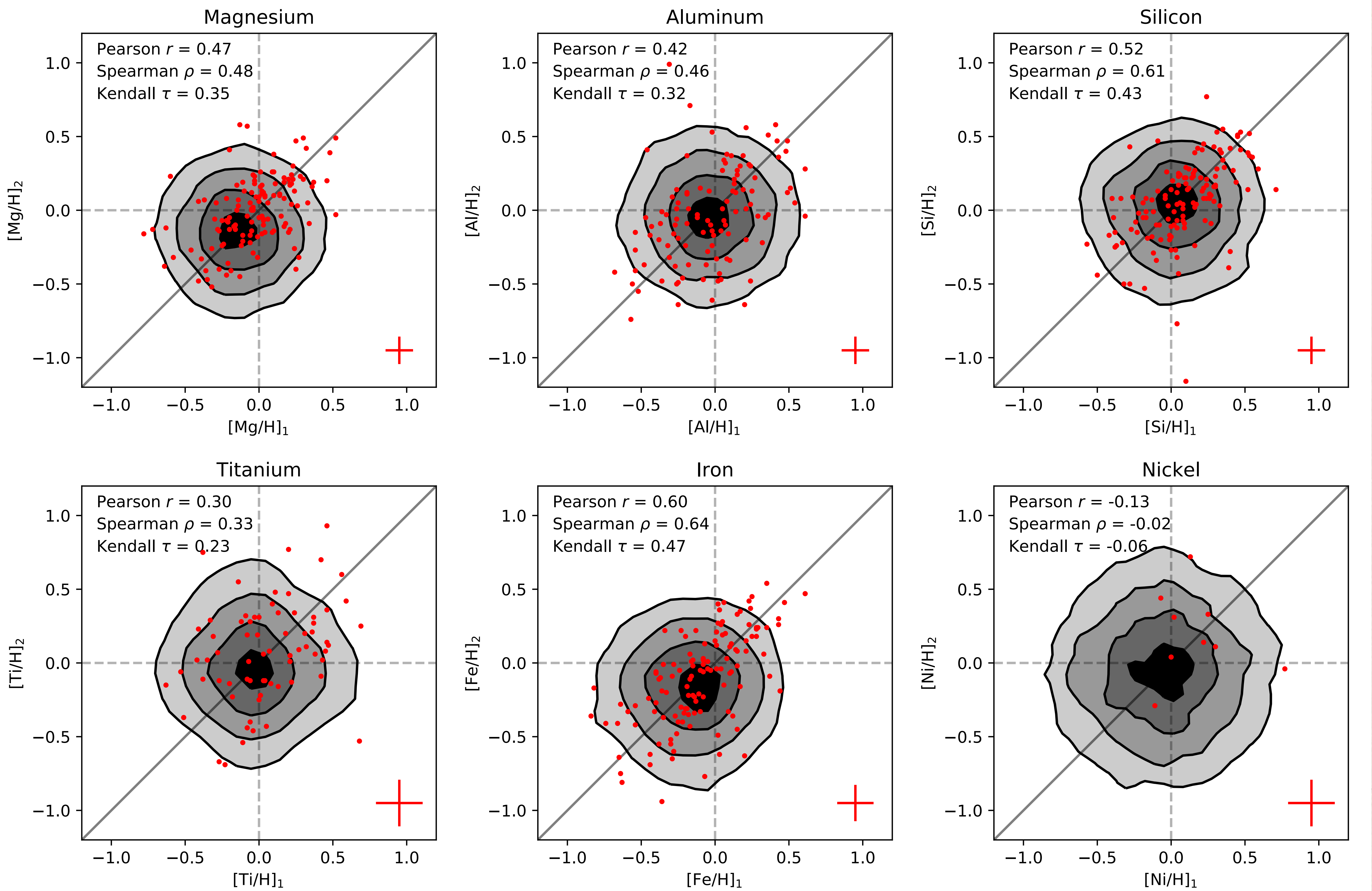
Decidera et al. (2006)

RAVE Metallicity Comparison



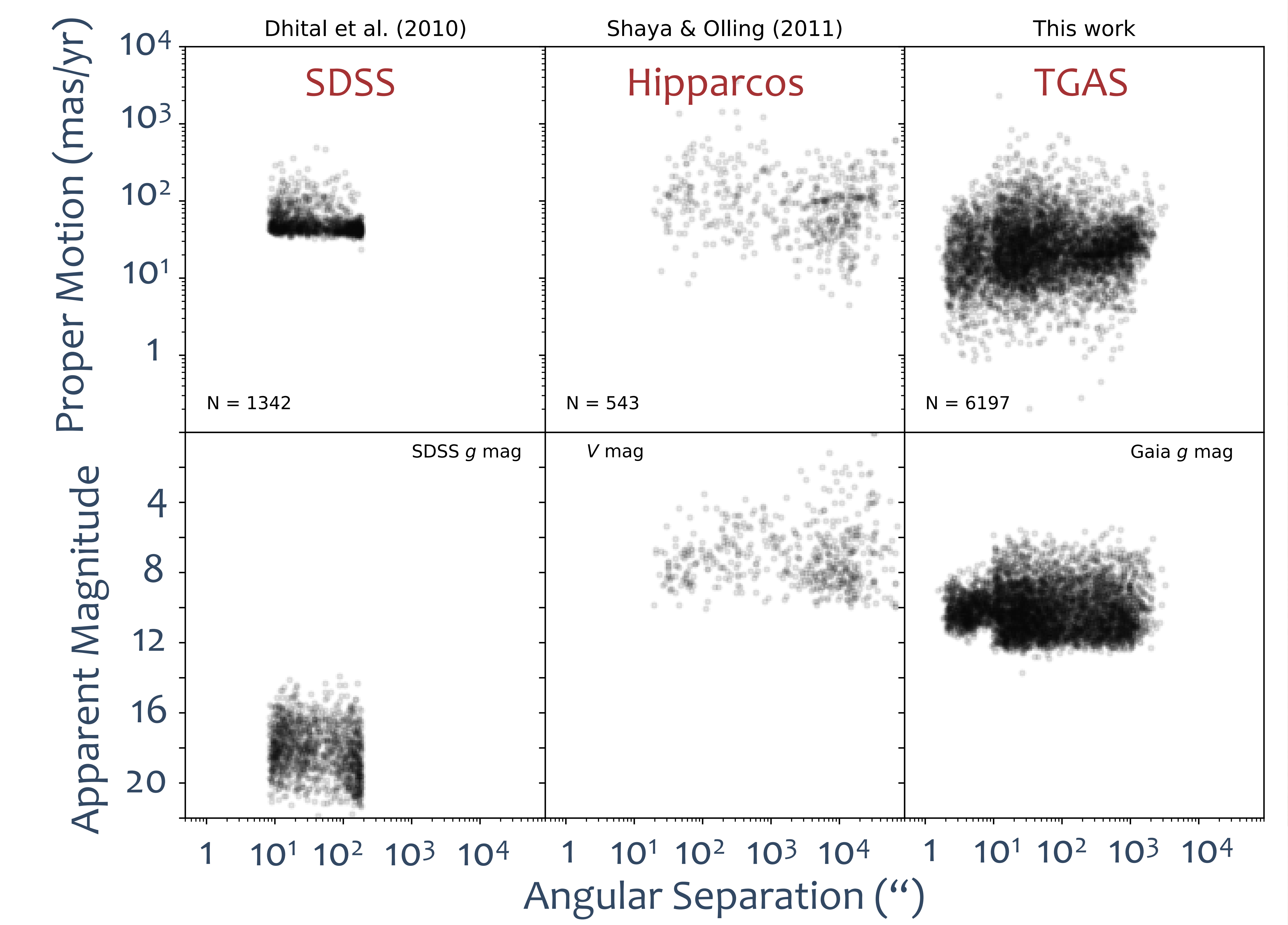
Andrews et al. (in prep)

RAVE Chemical Abundances

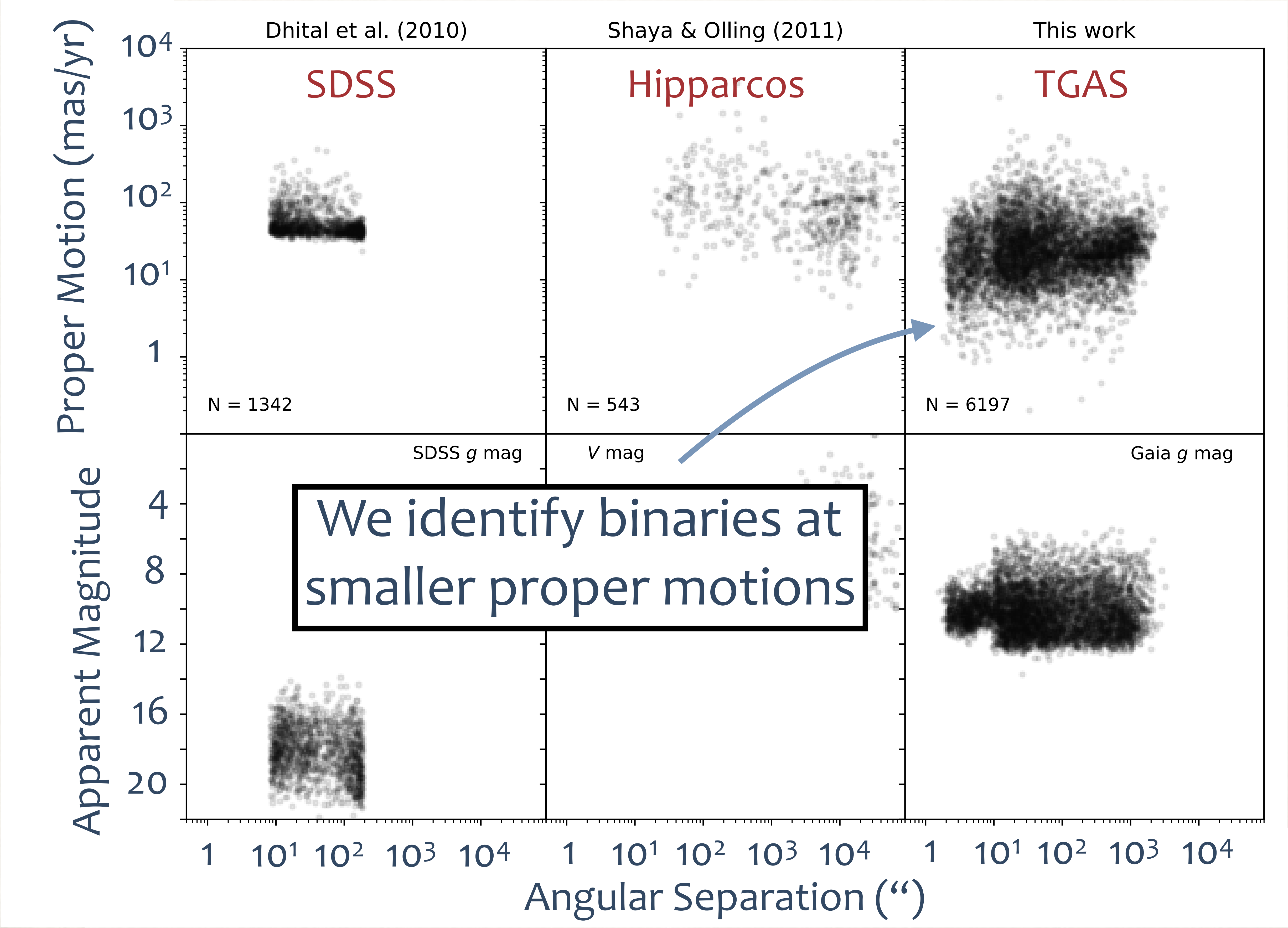


Andrews et al. (in prep)

Catalog Comparison



Catalog Comparison



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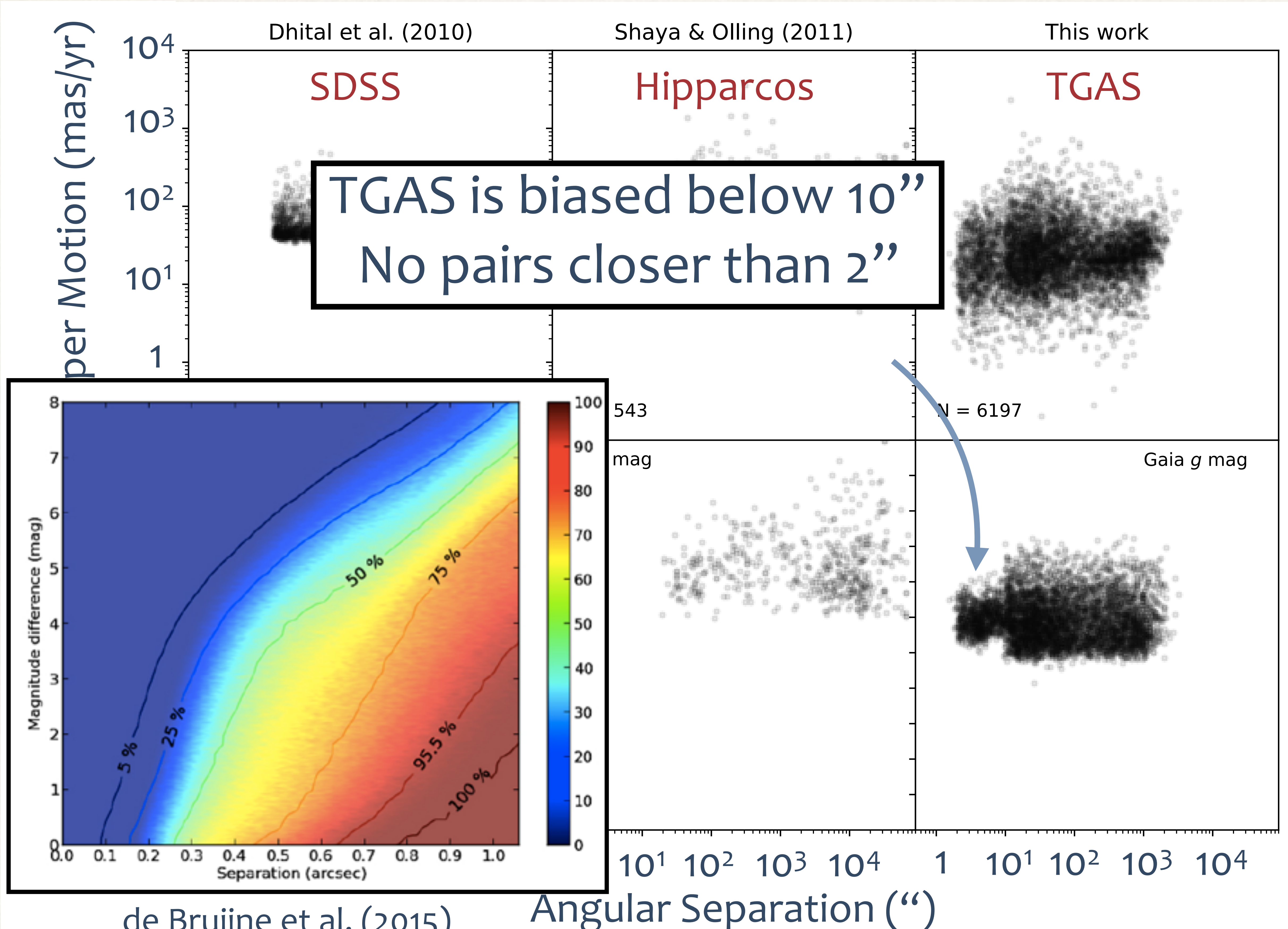
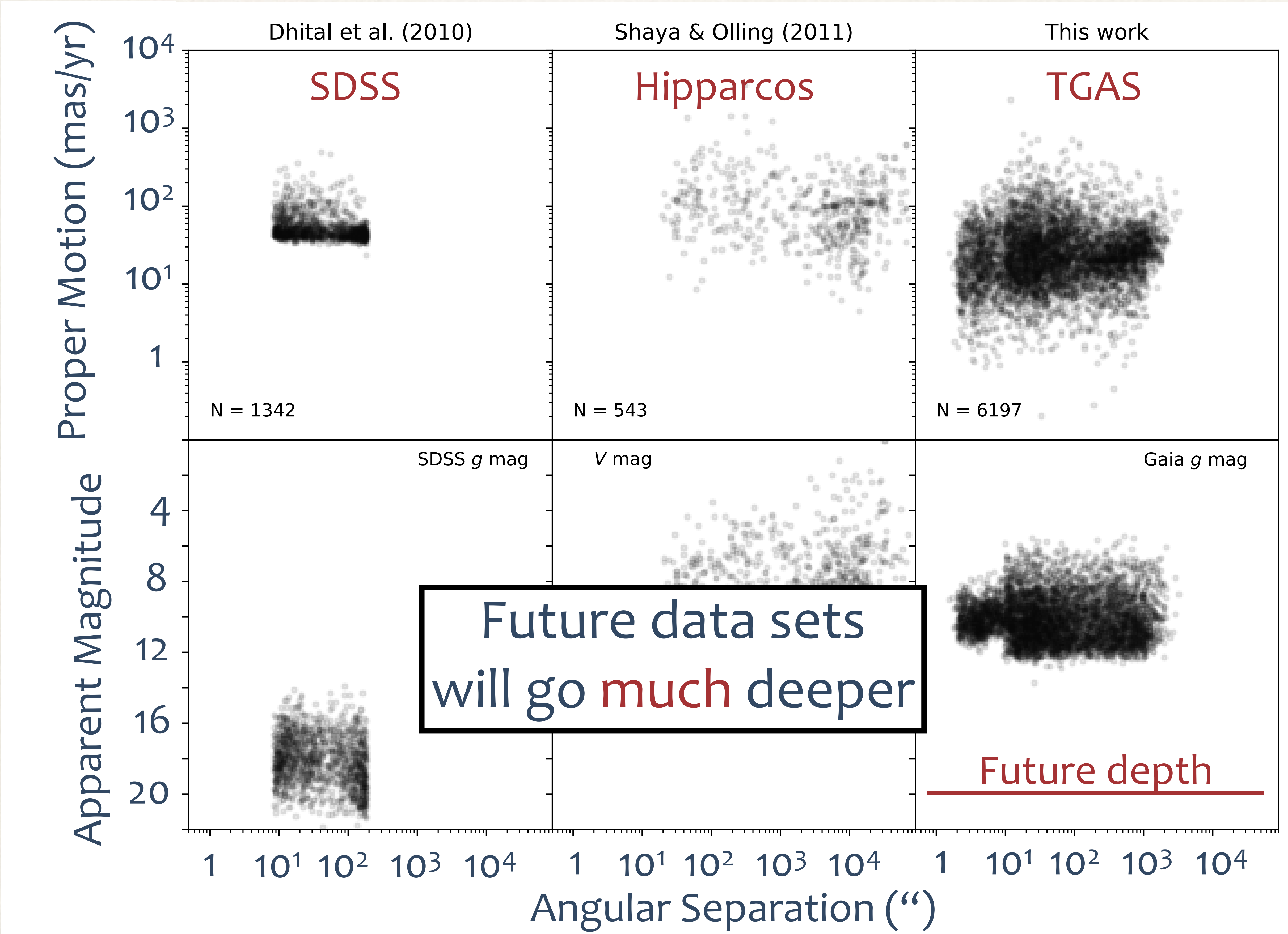


de Bruijne et al. (2015)

Catalog Comparison



Conclusions

- We have found over 4000 wide binaries with separations $<4 \times 10^4$ AU and contamination < 5%.

- There is lots of potential science:
  - stellar triples
  - stellar abundances
  - galactic structure

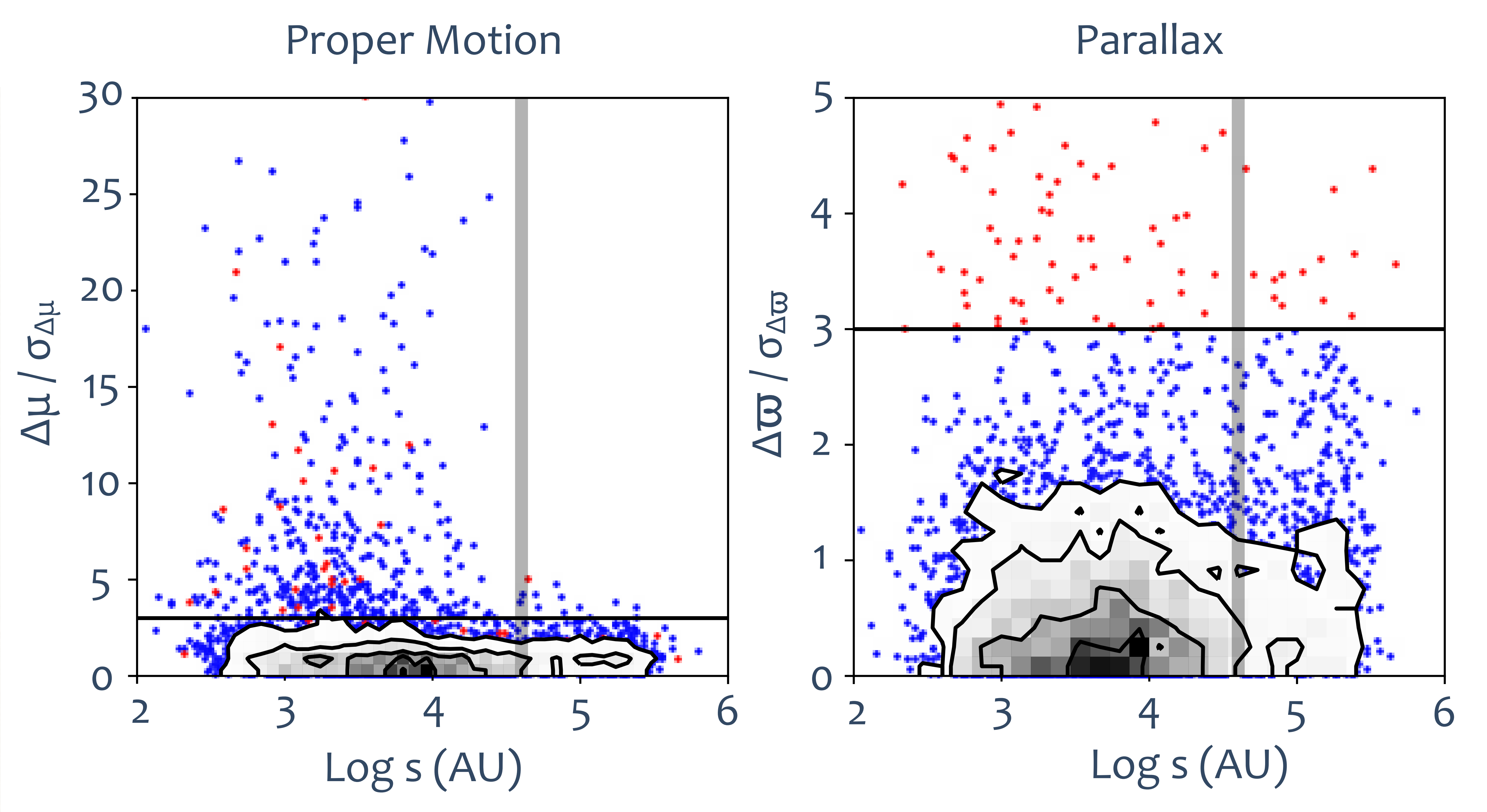
- We will likely find 2 orders of magnitude more wide binaries in future Gaia catalogs

- N^2 scaling makes this problem very challenging in DR2

See details on the ArXiv: 1704.07829

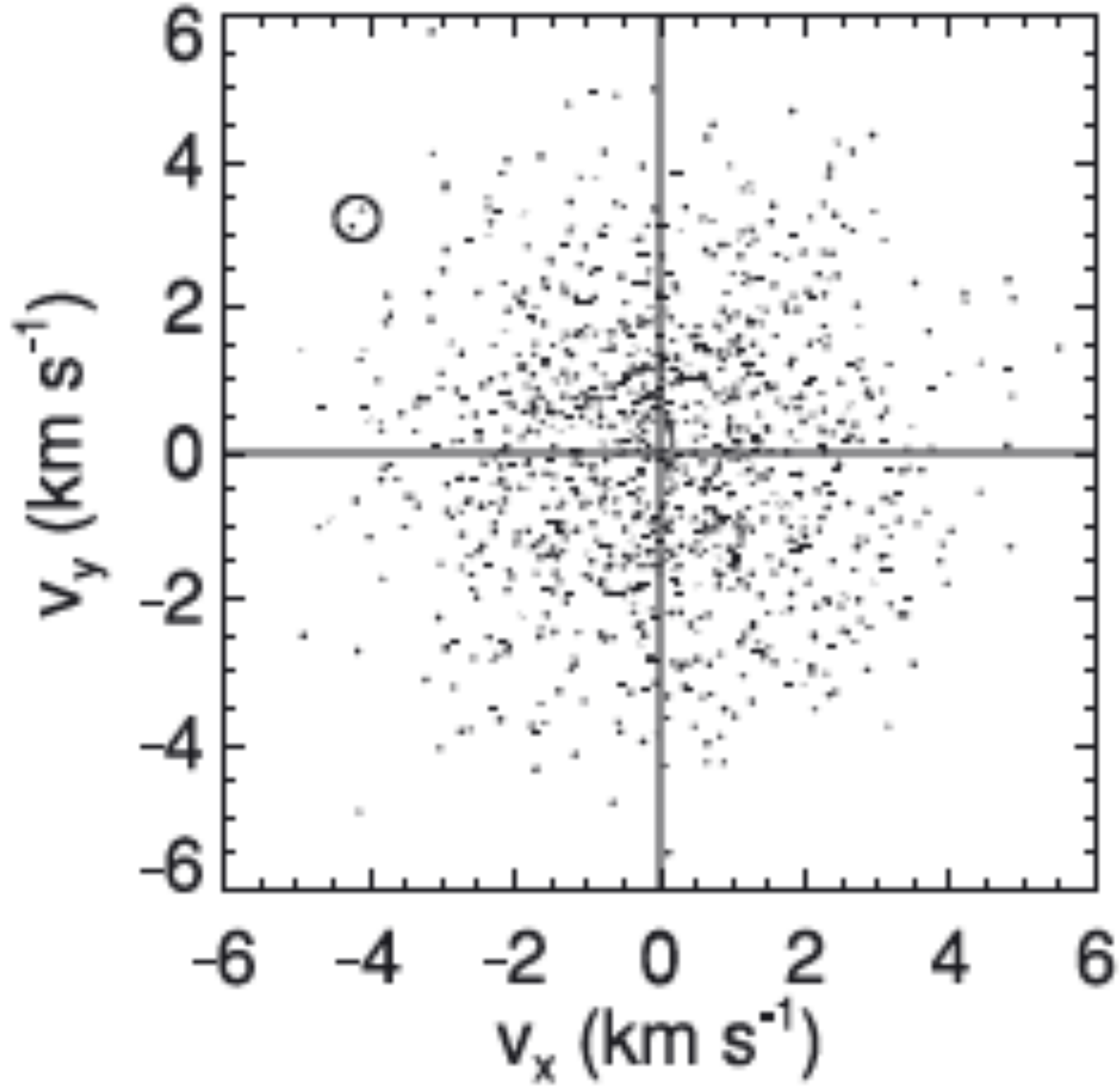
Extra Slides

Detecting Orbital Velocities



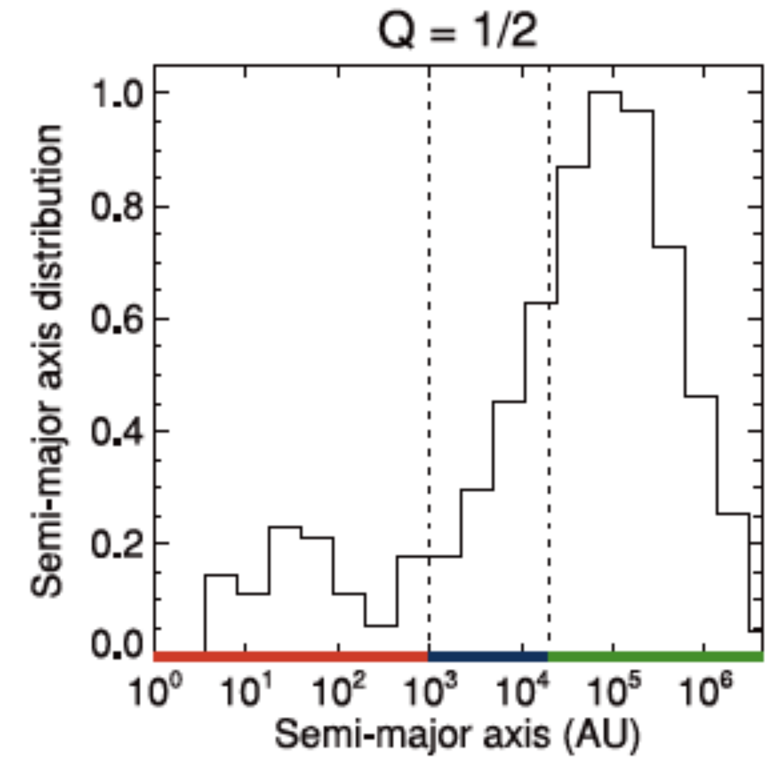
Cluster Dissolution

Simulate open cluster dispersal

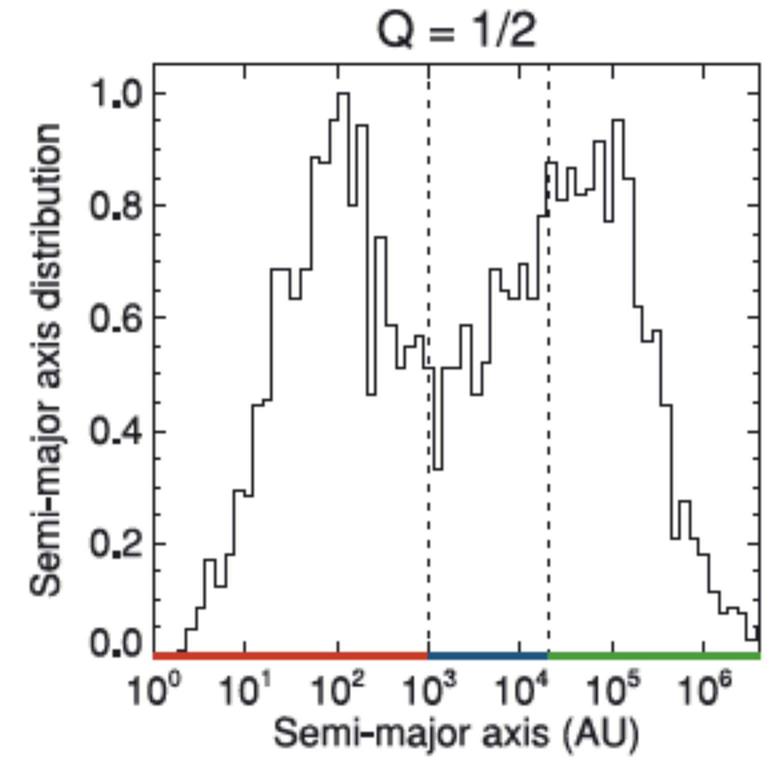


Kouwenhoven et al. (2010)

Model 1



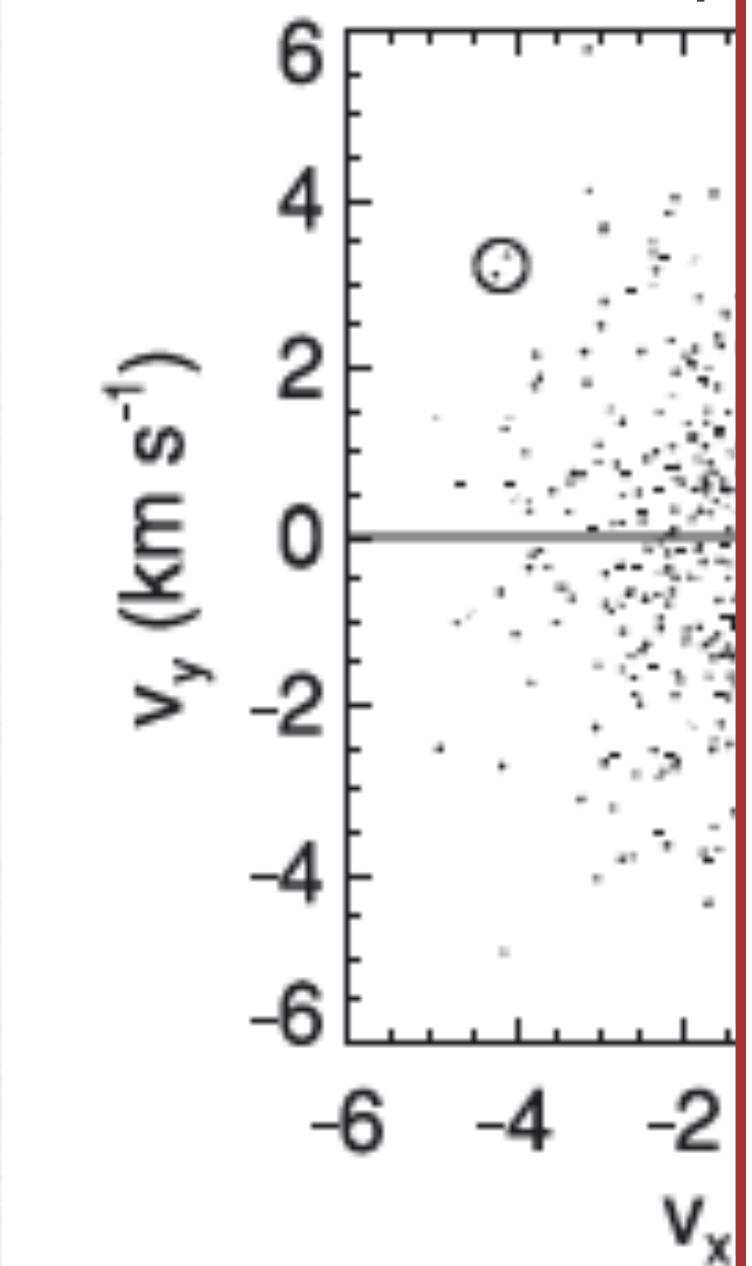
Model 2

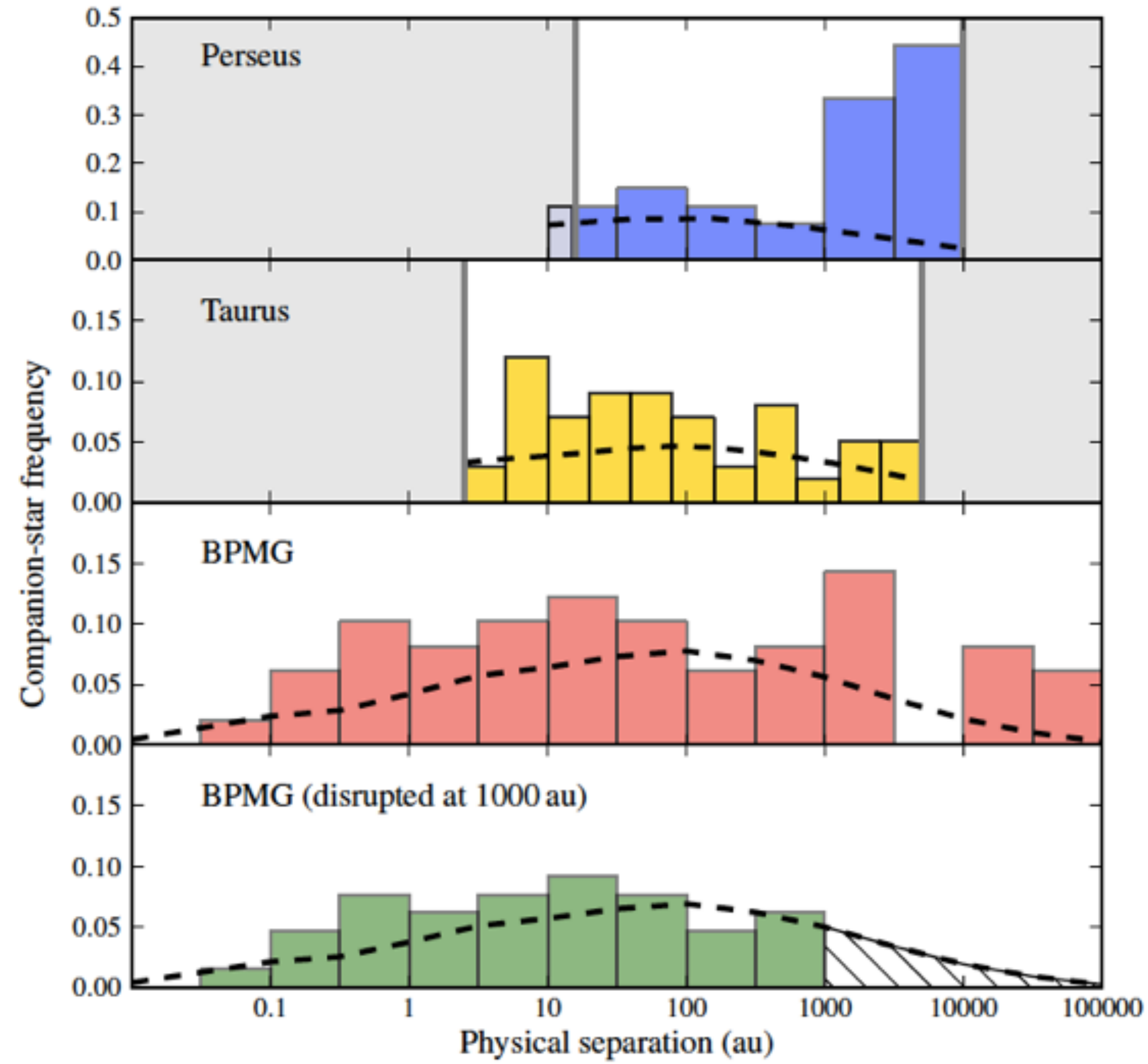


Cluster Dissolution

Model 1

Simulate op





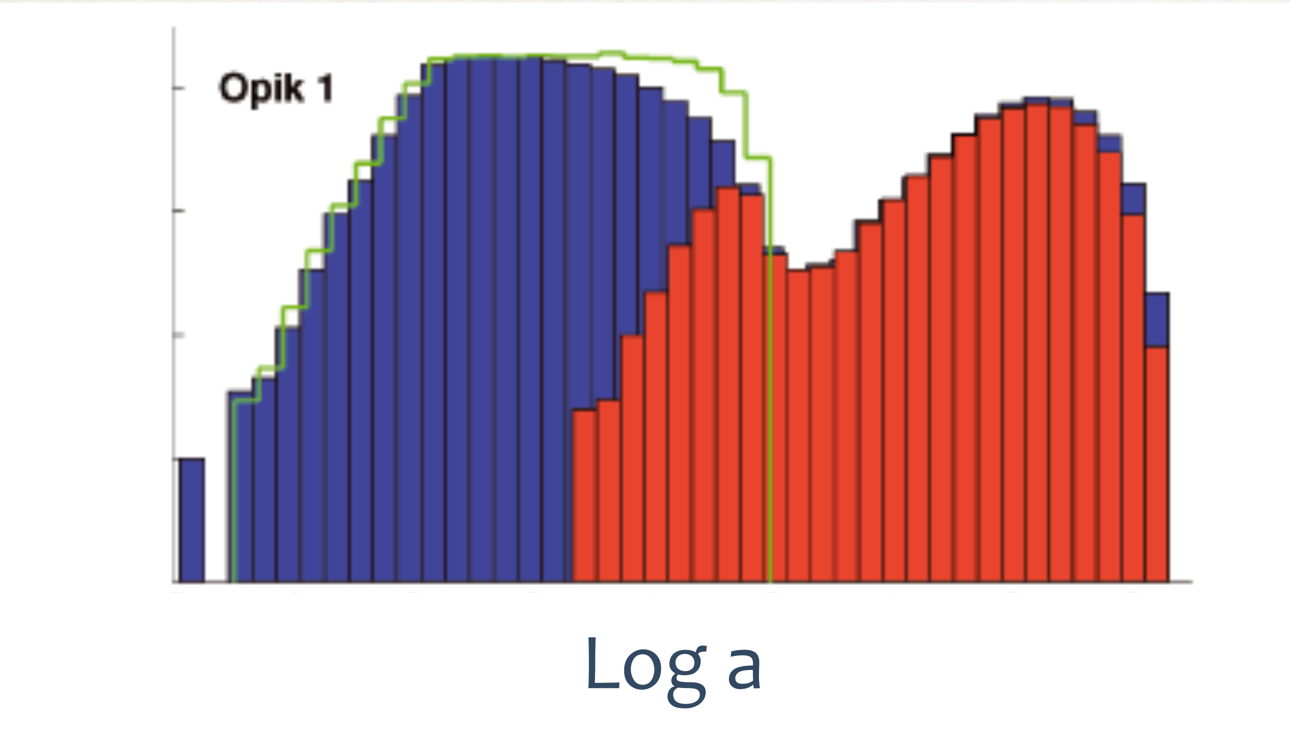
Elliott & Bayo (2016)

See also Alonso-Floriano et al. (2015)

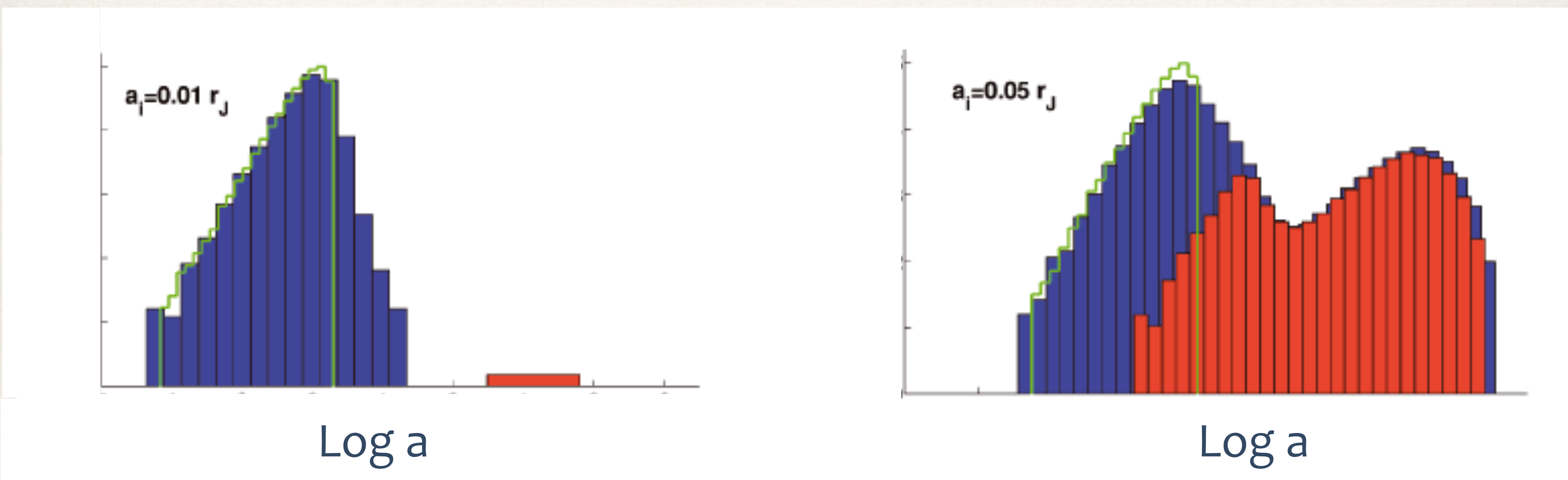
Semi-major axis (AU)

Kouwenhoven et al. (2

The Galactic Potential



Binaries become unbound due to passing stars and the Galactic tide

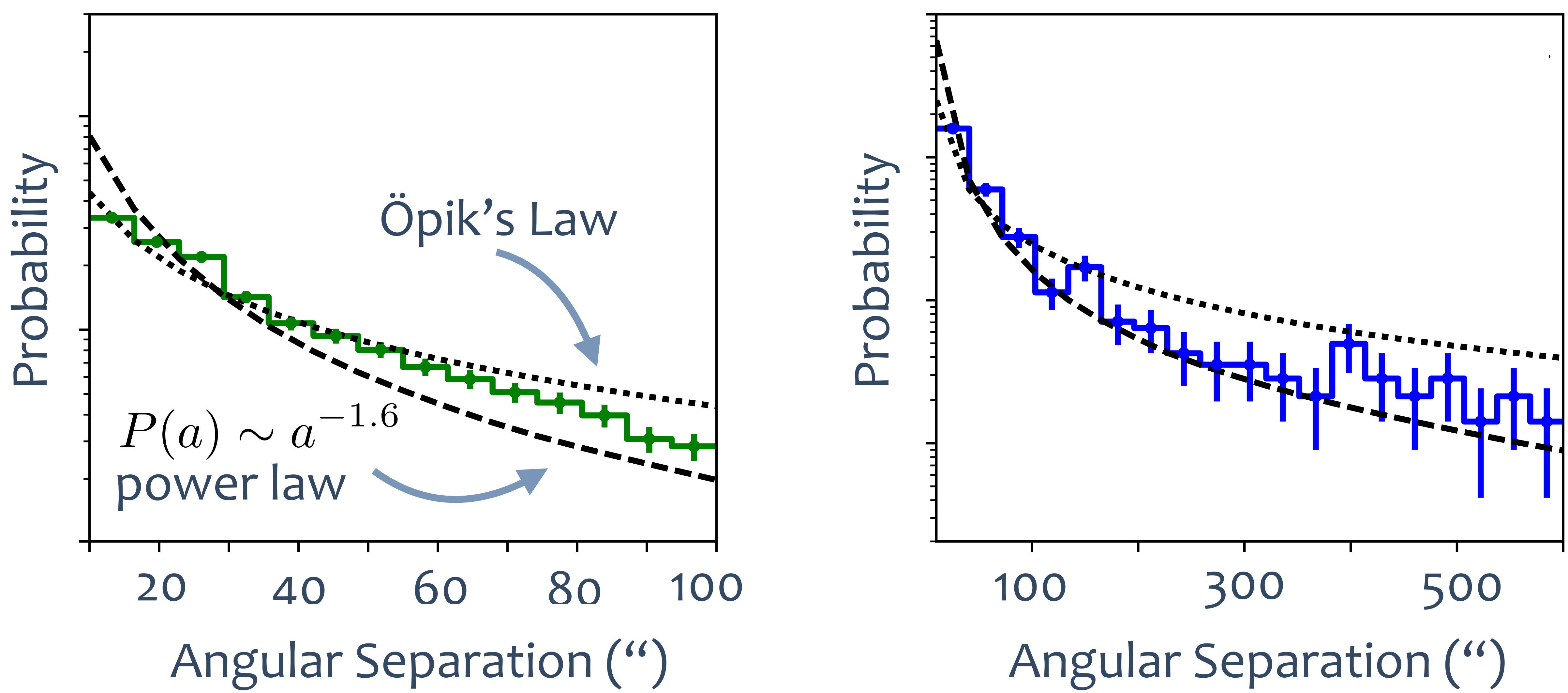


Jiang & Tremaine (2010)

Orbital Separation Distribution

Region 1
"Small"
Separations

Region 2
"Large"
Separations

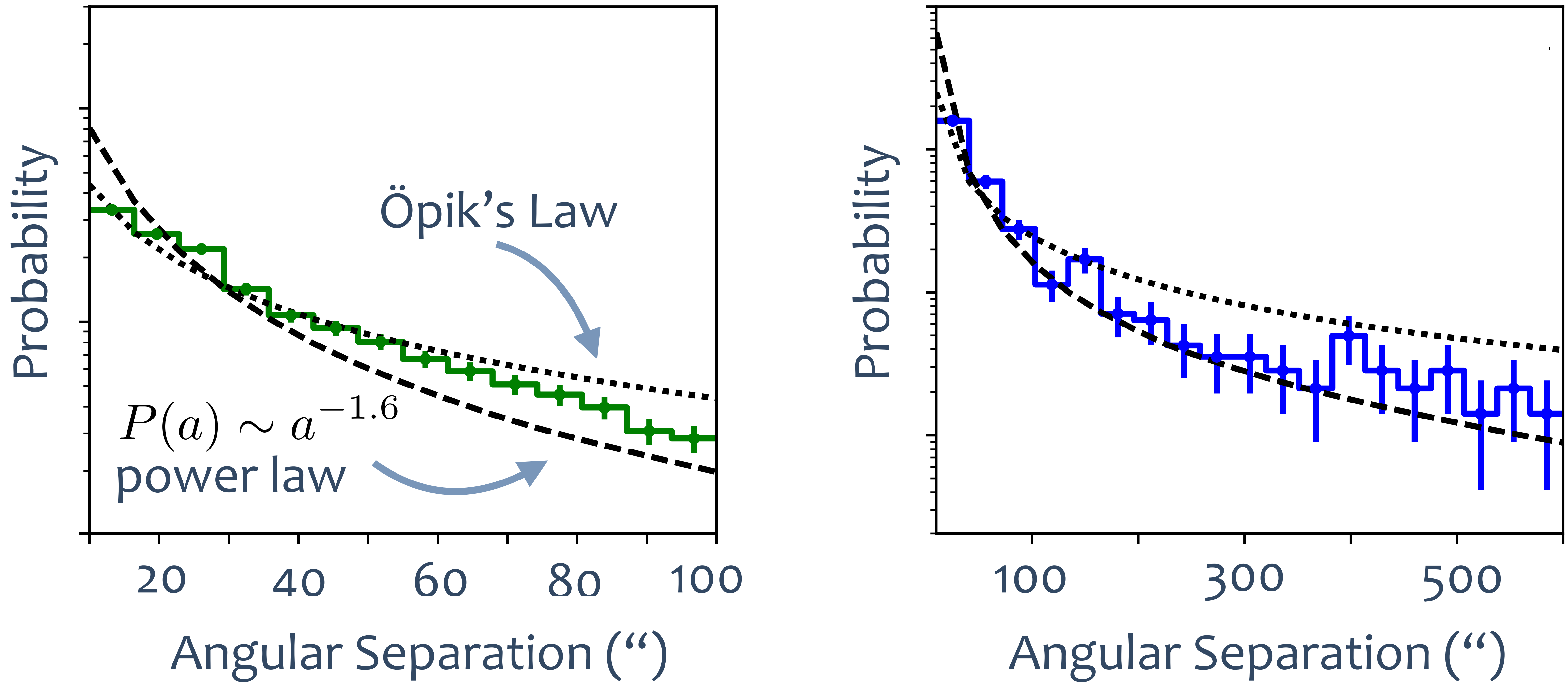


Orbital Separation Distribution

Region 1
"Small"
Separations

Region 2
"Large"
Separations

Öpik's Law only consistent at small separations



Wide Binary Science

Galactic Structure

Weinberg et al. (1985) - Binary stars dissipate over time

Bahcall & Tremaine (1985) - MACHOs cannot be larger than 2 Msun

Yoo et al. (2004) - MACHOs cannot be form dark matter in the Milky Way

Penarrubia et al. (2016) - Constrain dark matter in nearby ultrafaint galaxies

Stellar Dynamics

Kouwenhoven et al. (2010) - Formed from dissolution of stellar clusters

Reipurth & Mikkola (2012) - Formed from dynamical unfolding of stellar triples

Andrews et al. (2016) - Constrain Lidov-Kozai mechanism

Tokovinin (2017) - Formed from bound, nearby star-forming cores

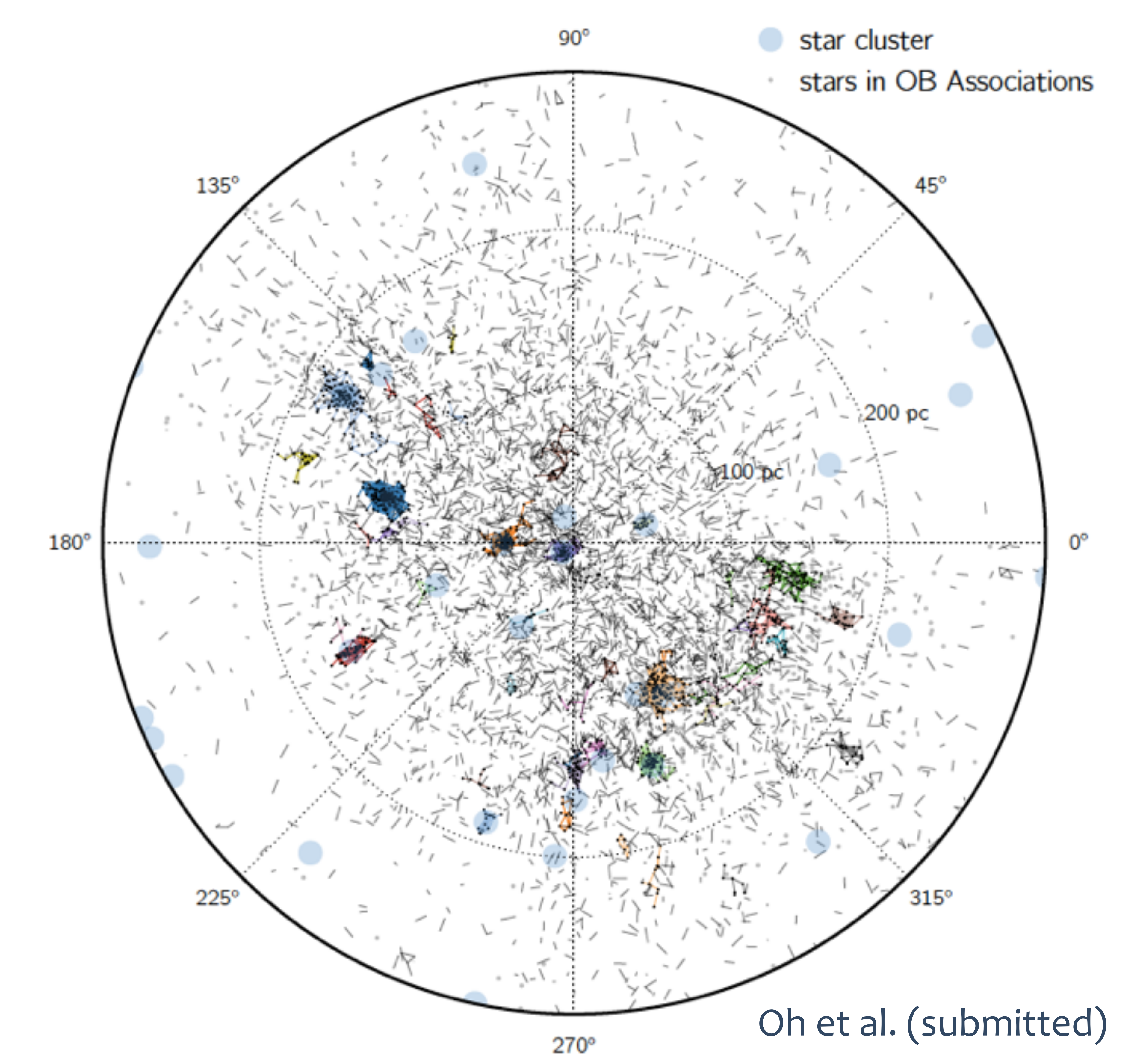
Stellar Astrophysics

Bonfils et al. (2005) - Calibrate M-dwarf metallicities

Garcés et al. (2011) - Calibrate stellar chromospheric ages

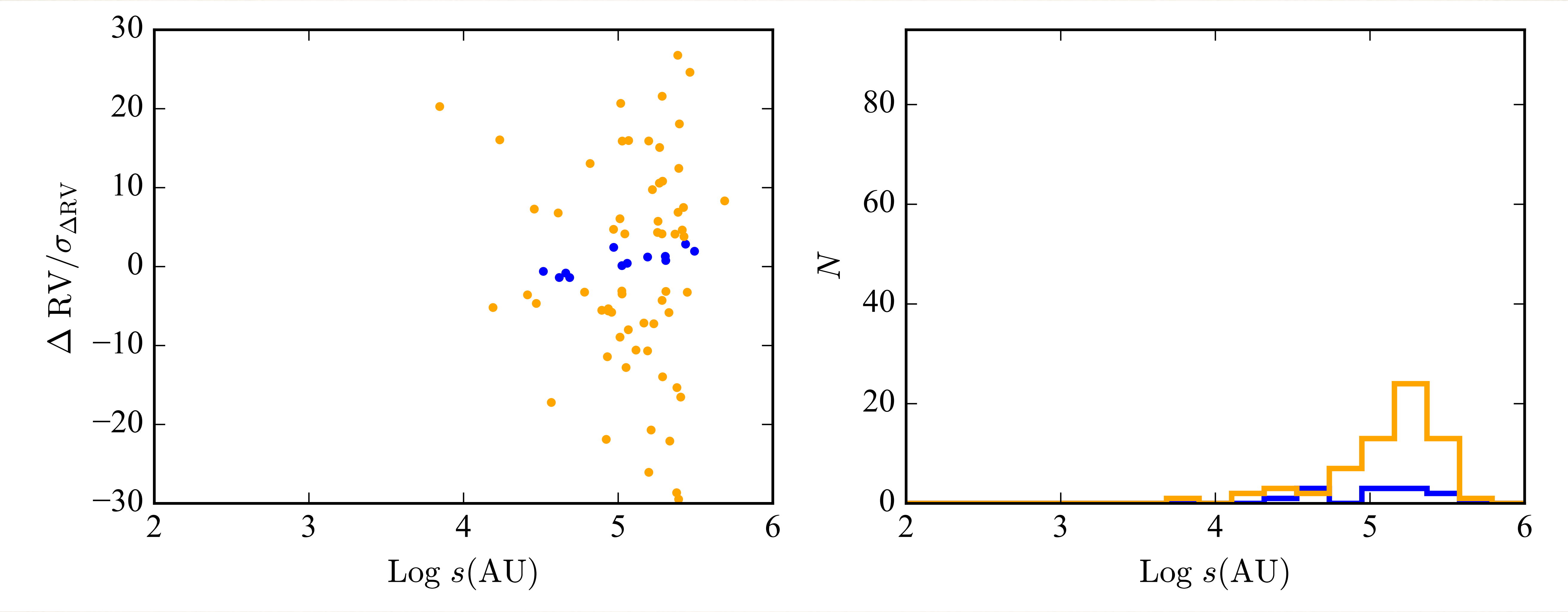
Andrews et al. (2015) - Constrain the Initial-Final mass relation

Clustered Pairs

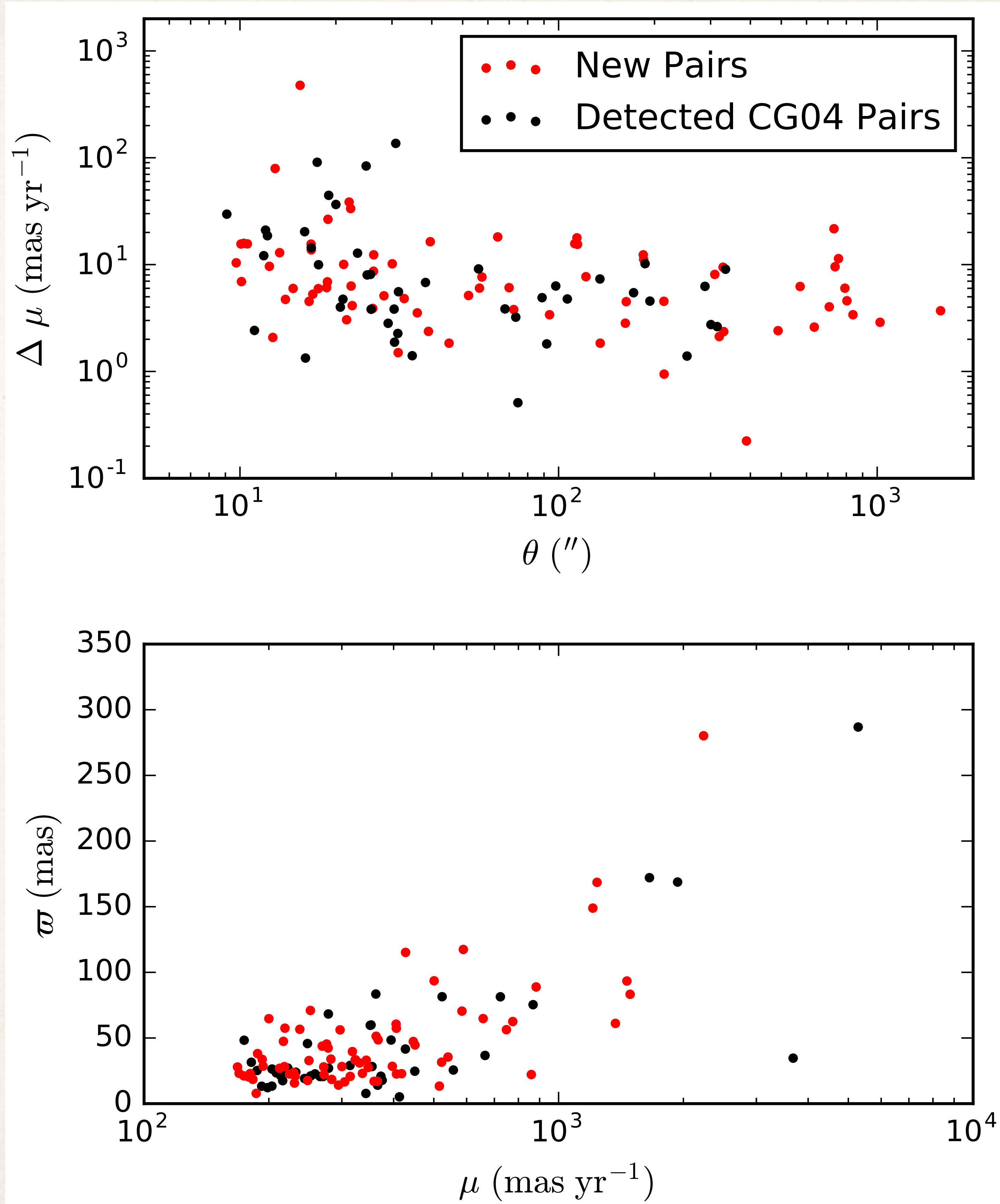


Oh et al. (submitted)

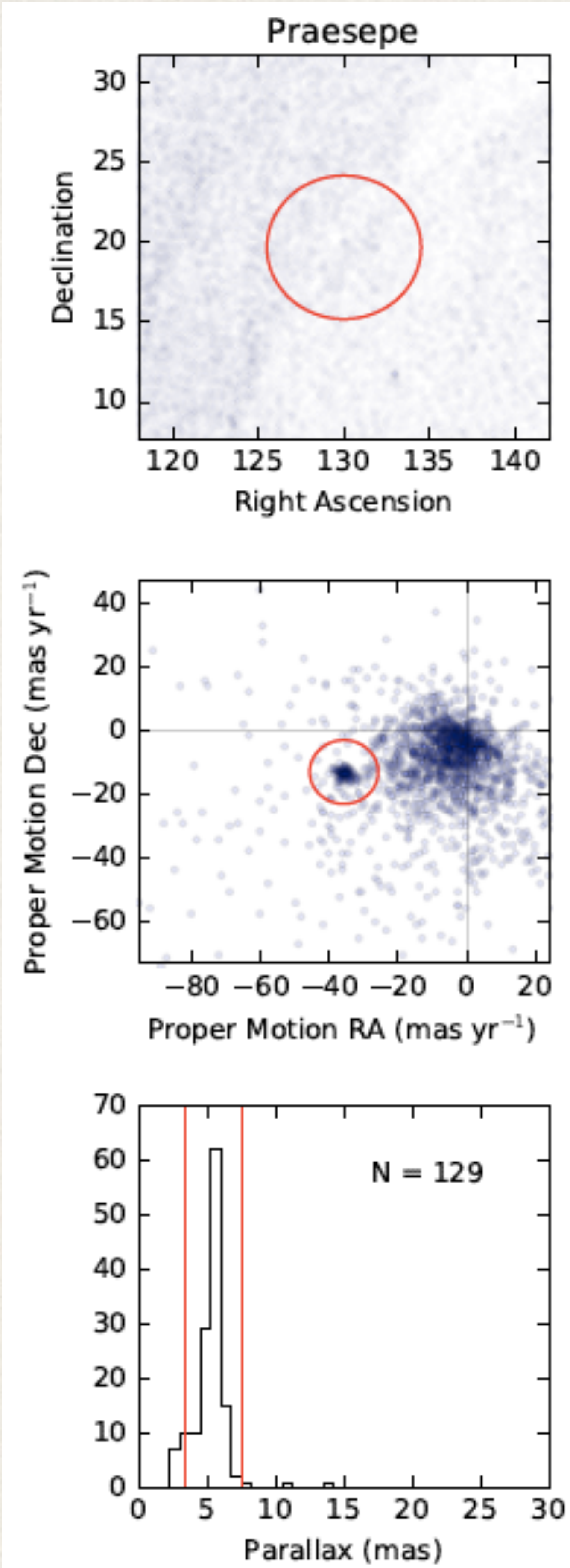
Random Alignments - Radial Velocities



Method Test - rNLTT

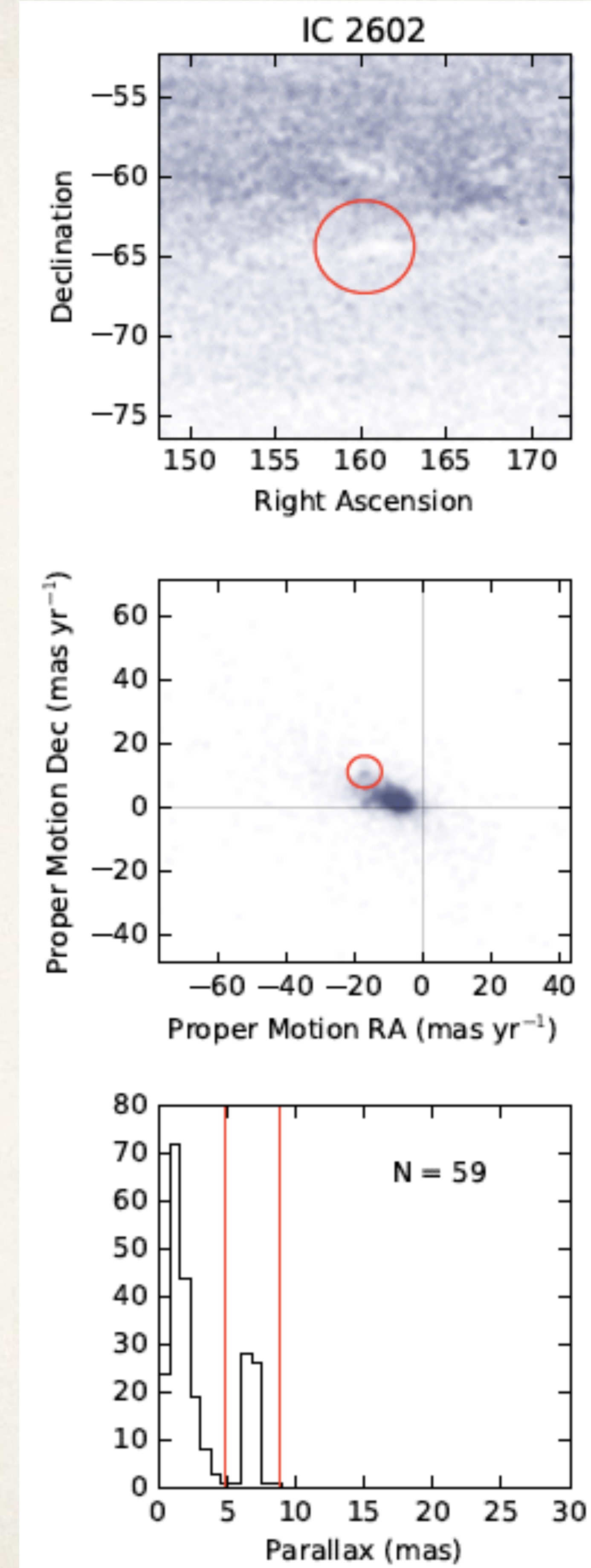


Open Clusters

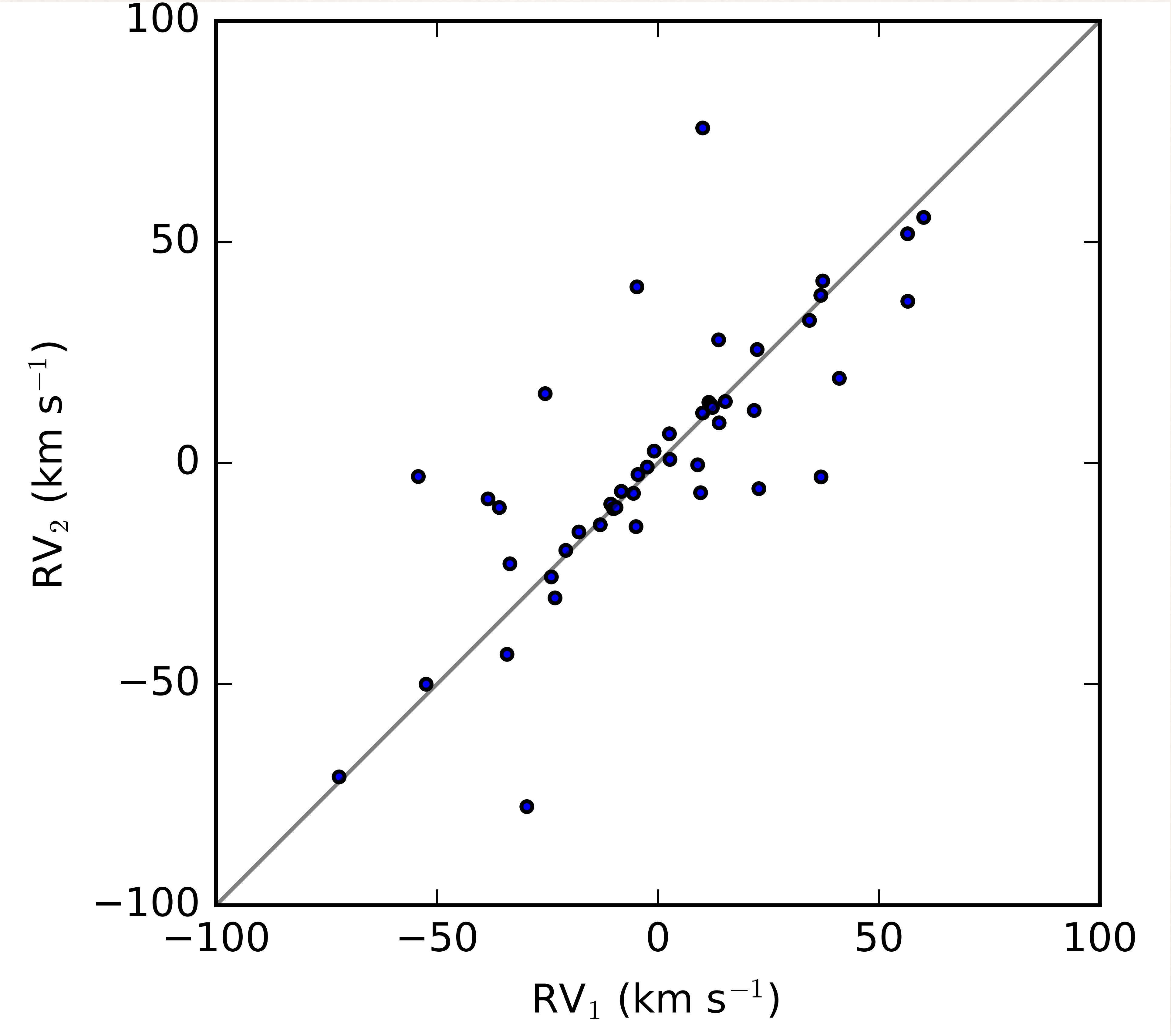


We remove 12 open clusters:

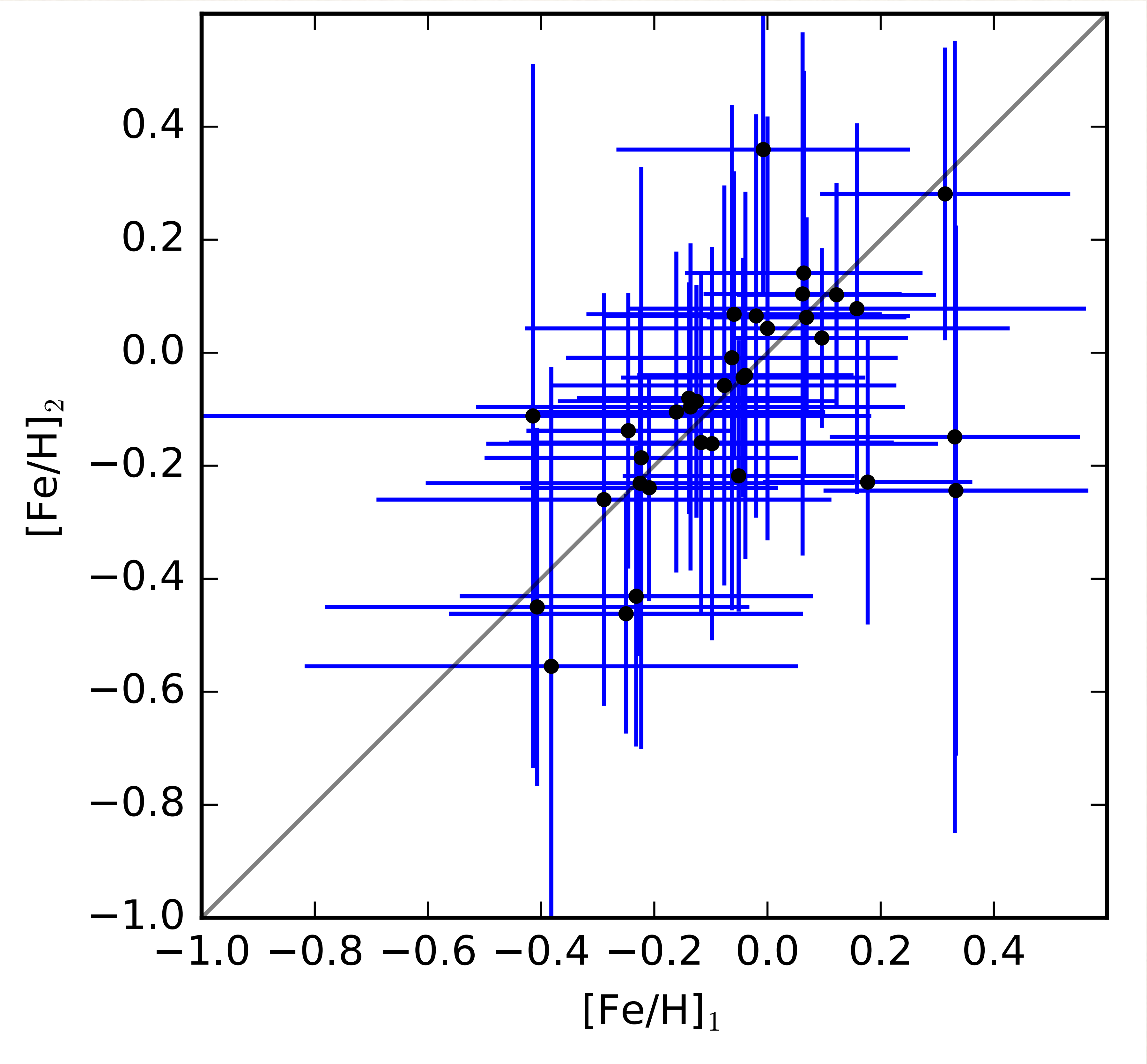
- Pleiades
- Coma Ber
- Hyades
- Praesepe
- α Per
- IC 2391
- IC 2602
- Blanco I
- NGC 2451
- NGC 6475
- NGC 7092
- NGC 2516



Cross-Matching with LAMOST - Radial Velocities



Cross-Matching with LAMOST - Metallicities



Gaia for Planets

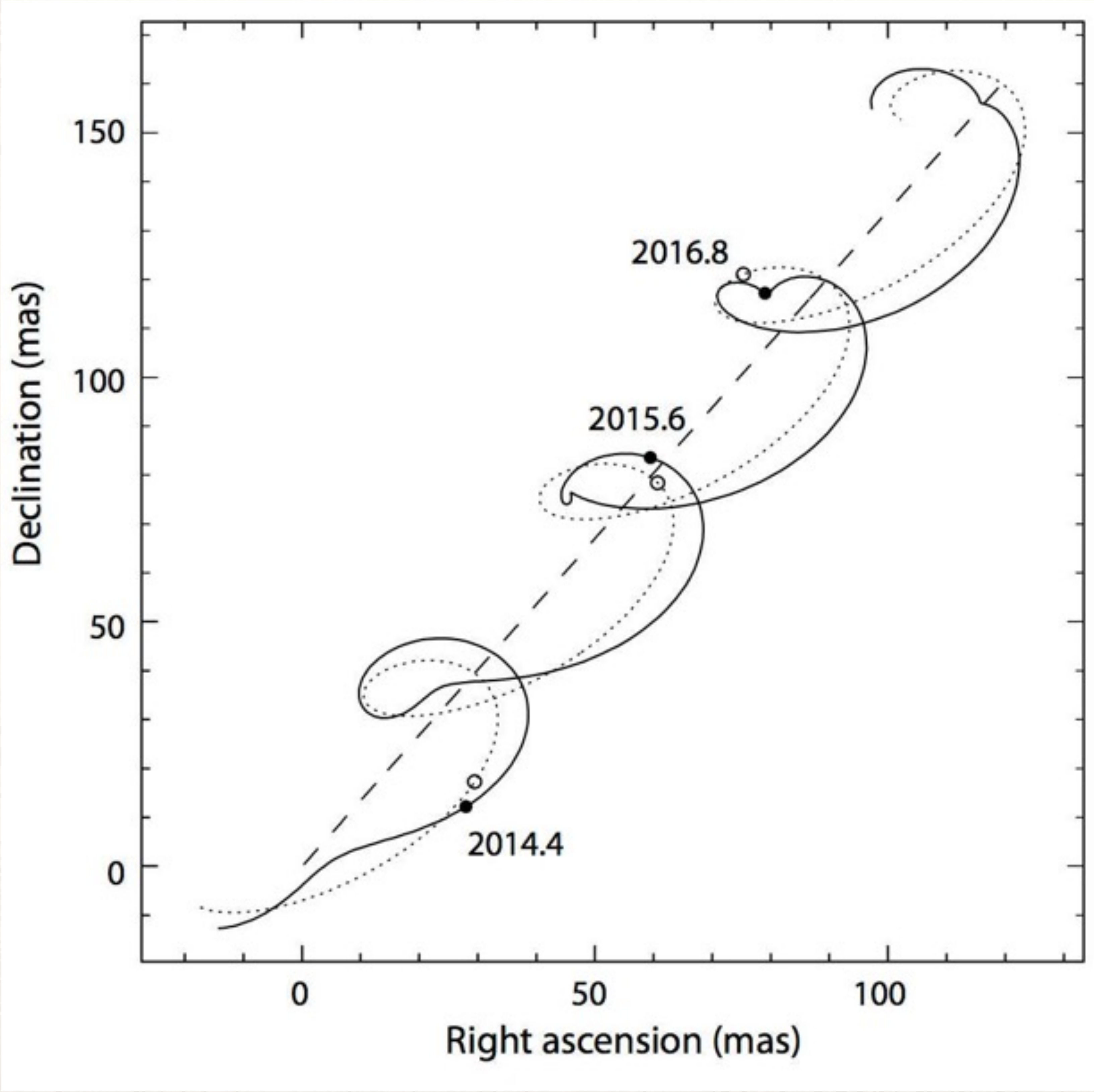


Image Credit: ESA Gaia

Detecting Orbital Velocities - Prediction