On Using Doubly Imaged Quasars for Time-Delay Cosmography

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Previous TDC Analyses

Doubles

1) SDSS 1206+4332:
   H_0 = 68.8 km/s/Mpc at ~7.8% precision (Birrer et al. 2019)
2) HE 1104-1805:
   $H_0 = 64.2 \times \lambda_{int}$ kms/s/Mpc at ~8.4% precision (Paic et al. 2025)

Quads

1) B1608+656
2) RXJ1131−1231
3) HE 0435−1223
4) WFI2033−4723
5) PG 1115+080
6) WGD 2038 4008

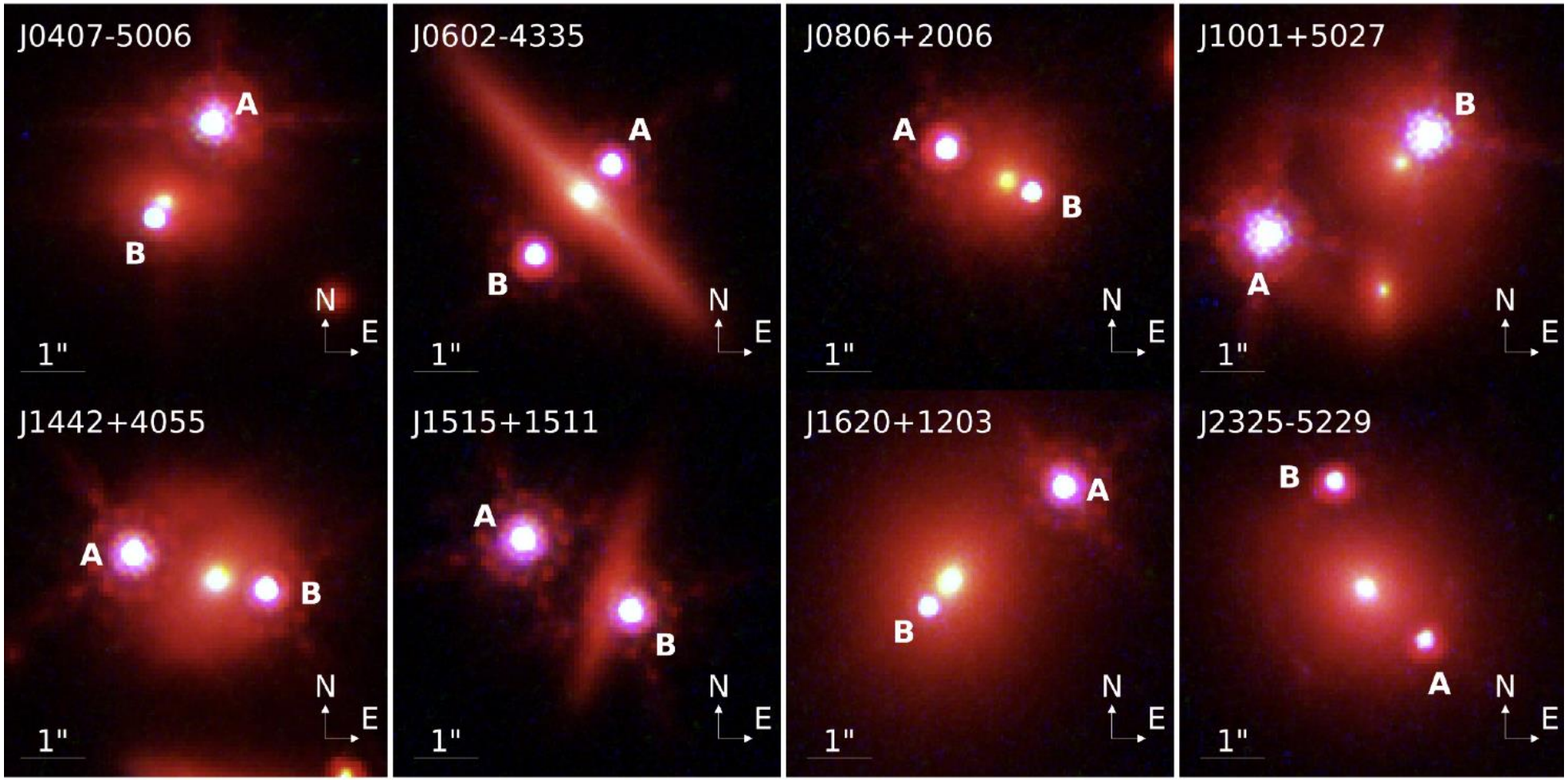
Alongside SDSS 1206+4332,

H_0 = 71.6 km/s/Mpc at 4.6% precision (TDCOSMO Collaboration 2025)

The GO-17199 Dataset (PI: Lemon)

Data Bands:

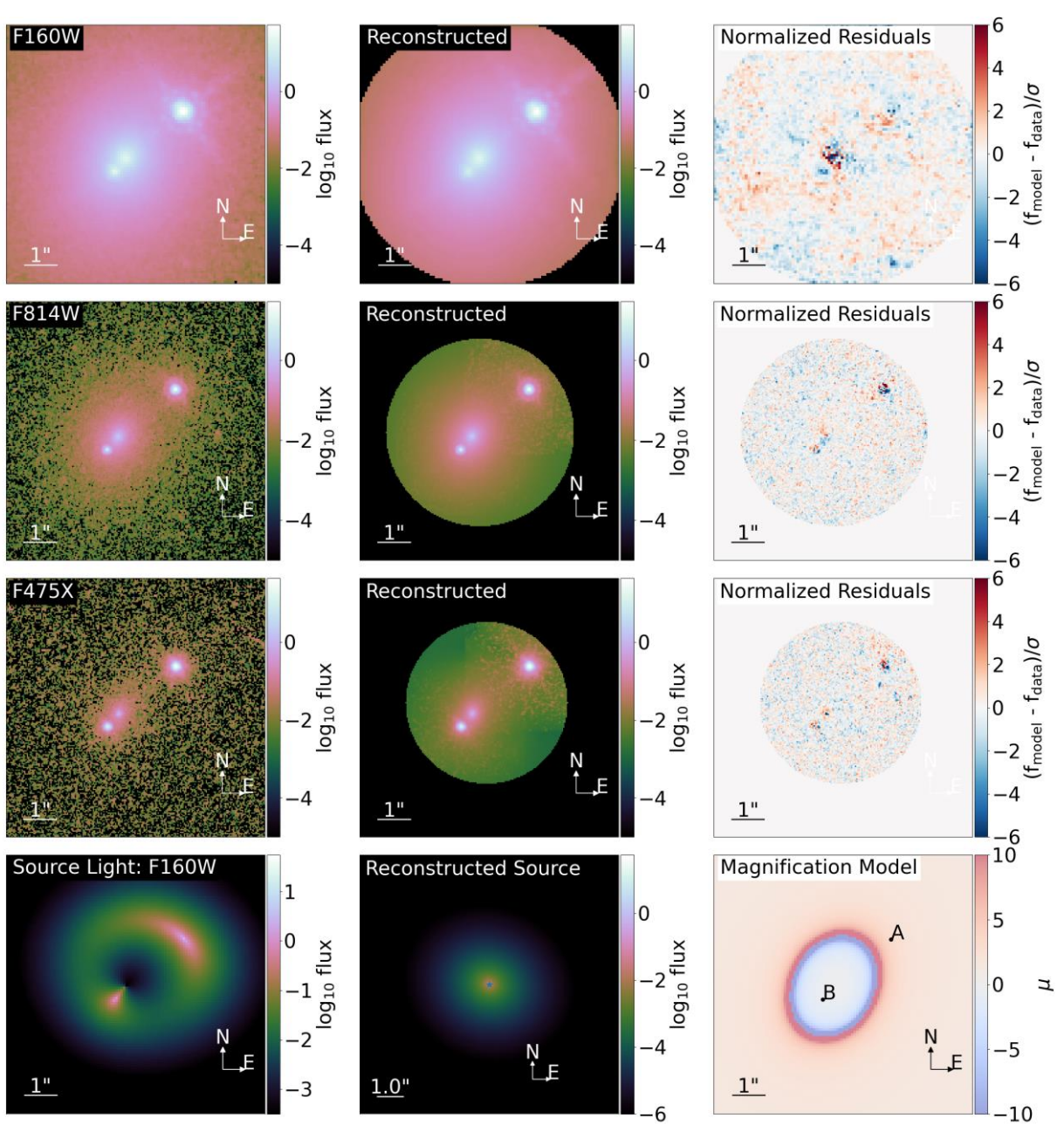
IR – F160W
UVIS – F814W
UVIS – F475X



Brady et al. (2026)

Uniform Lenstronomy Fitting

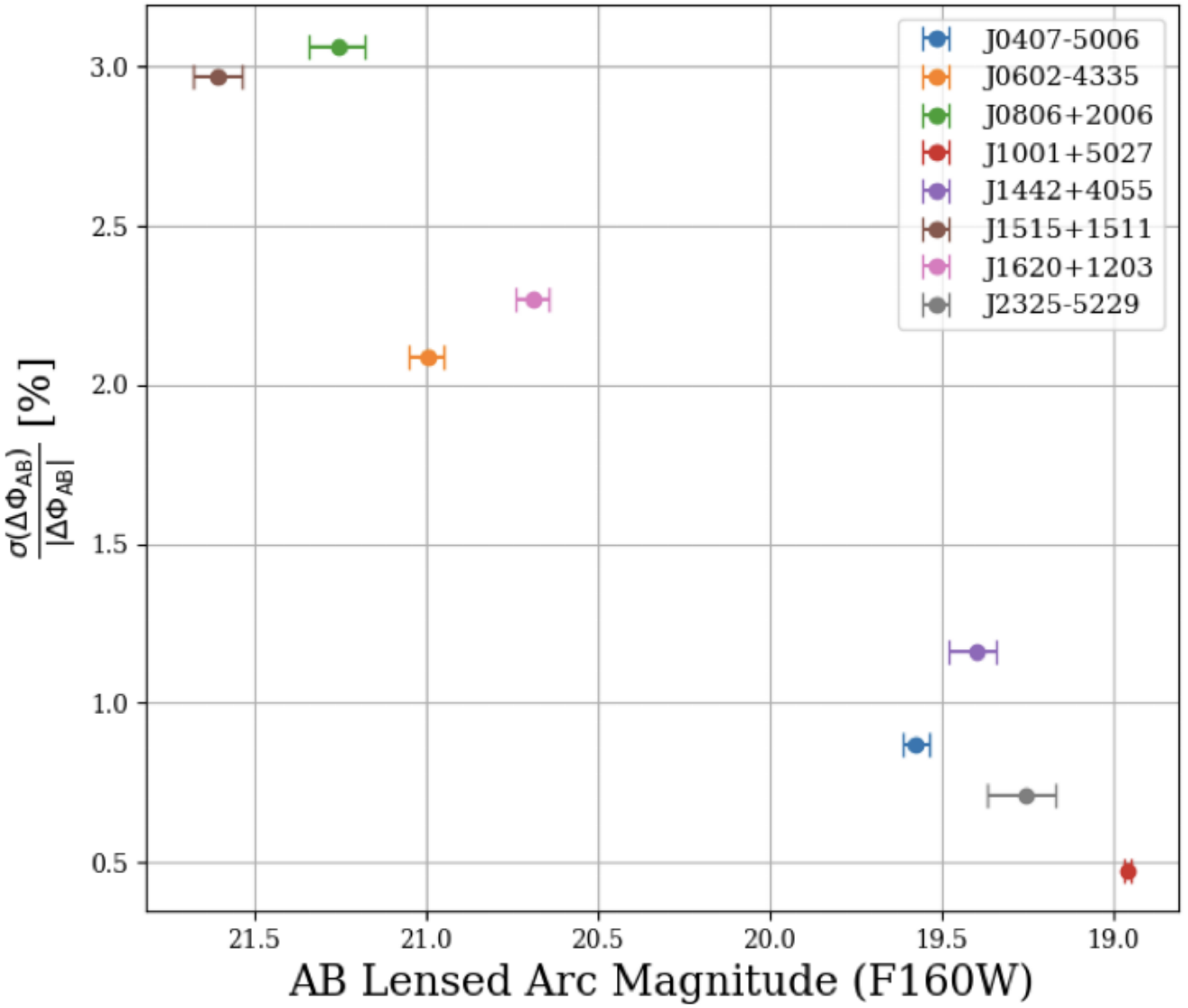
1. Lens Mass: SIE + External Shear
2. Lens Light: Elliptical Sersic
3. Source Light: Elliptical Sersic
4. QSO Images: point sources via PSF



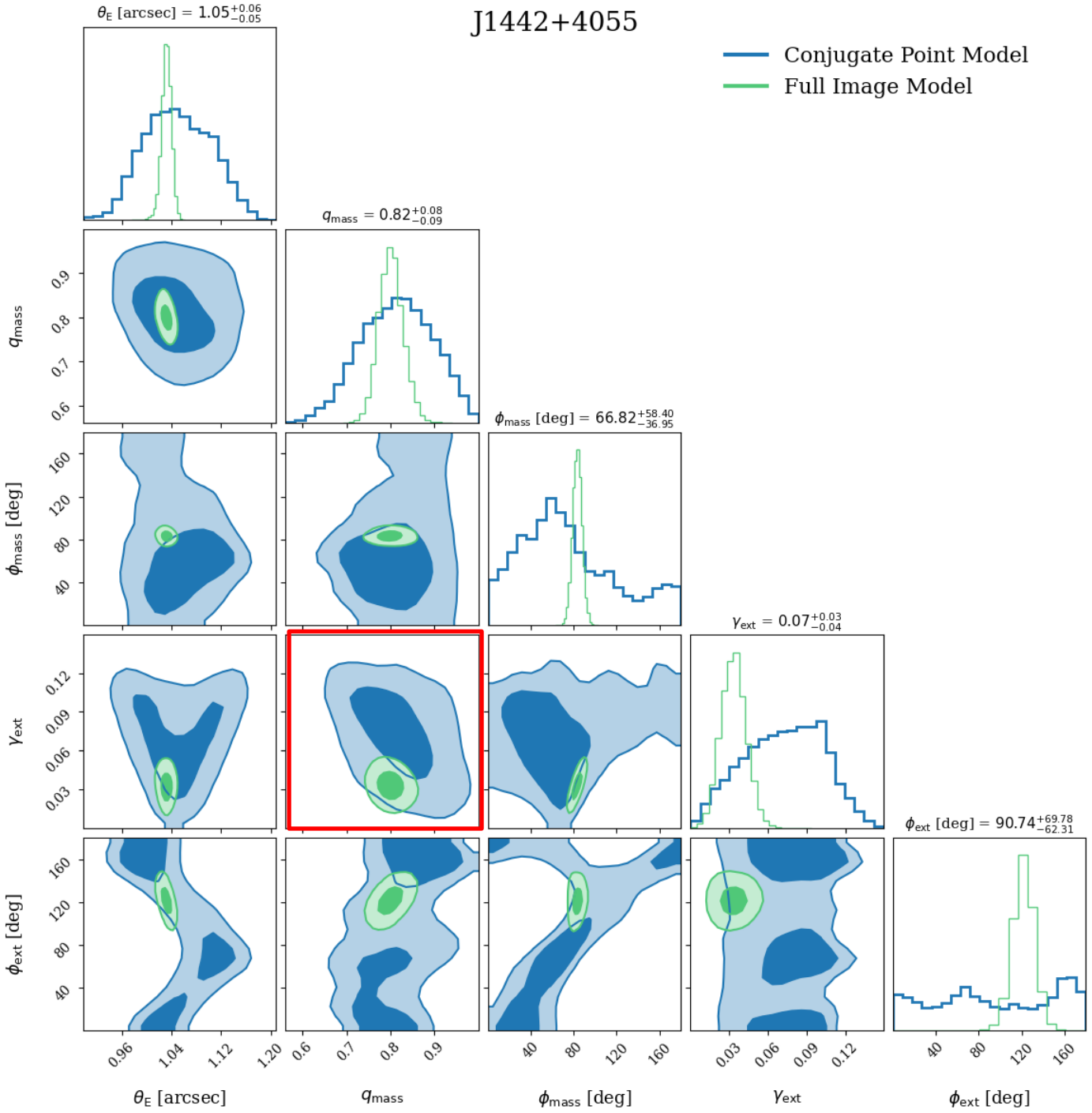
Brady et al. (2026)

Validation & Arc-Precision Relation

1) Modeled Einstein radii agree with previous literature at an average of 1.5σ
2) R.M.S. image separations agree with Gaia DR2 measurements on average within 3.6 mas
3) Using empirical data, the Fermat potential precision is shown to be directly proportional to the lensed arc magnitude
($r = 0.97$, $p = 5 \times 10^{-4}$)



Brady et al. (2026)

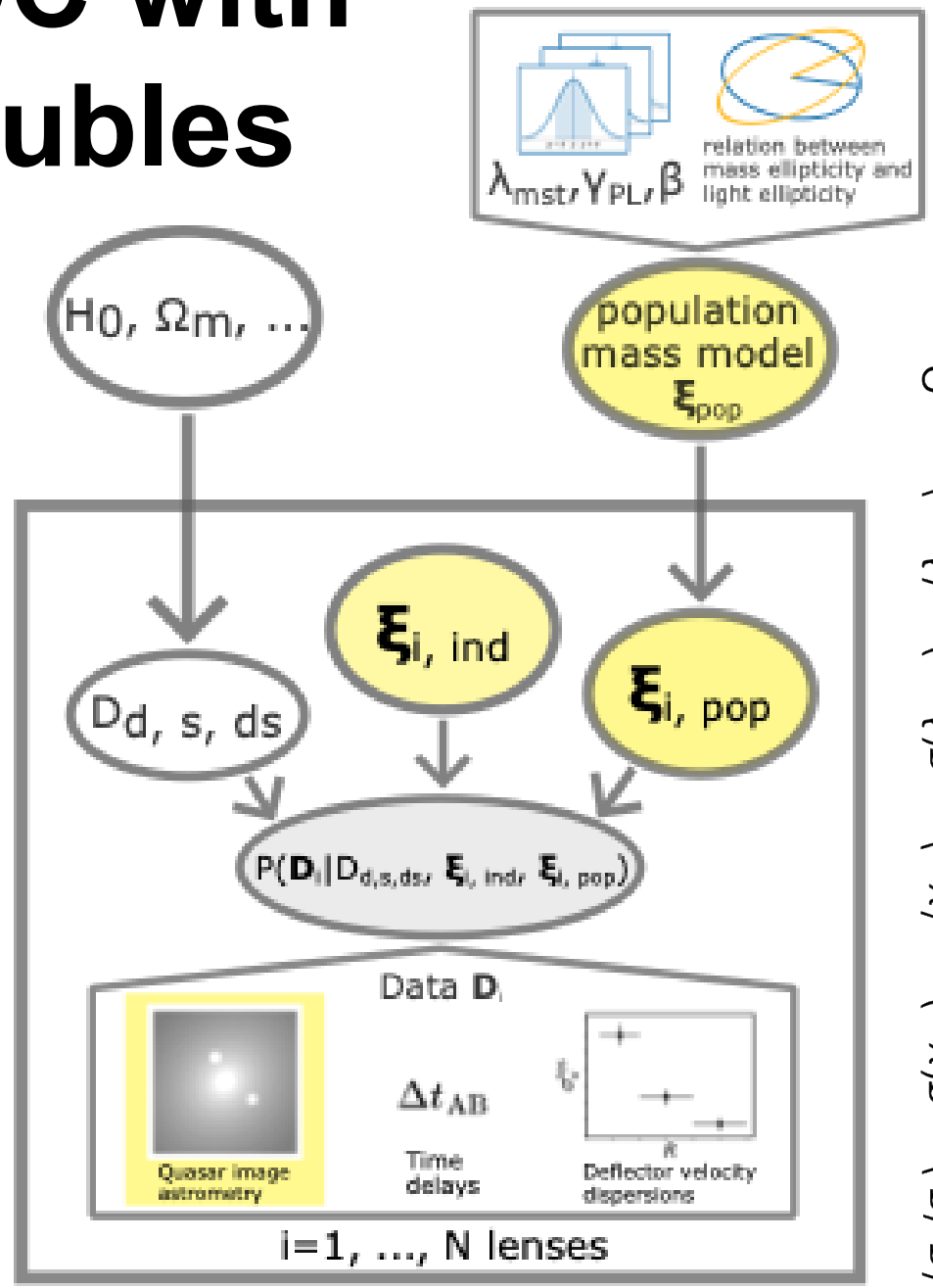


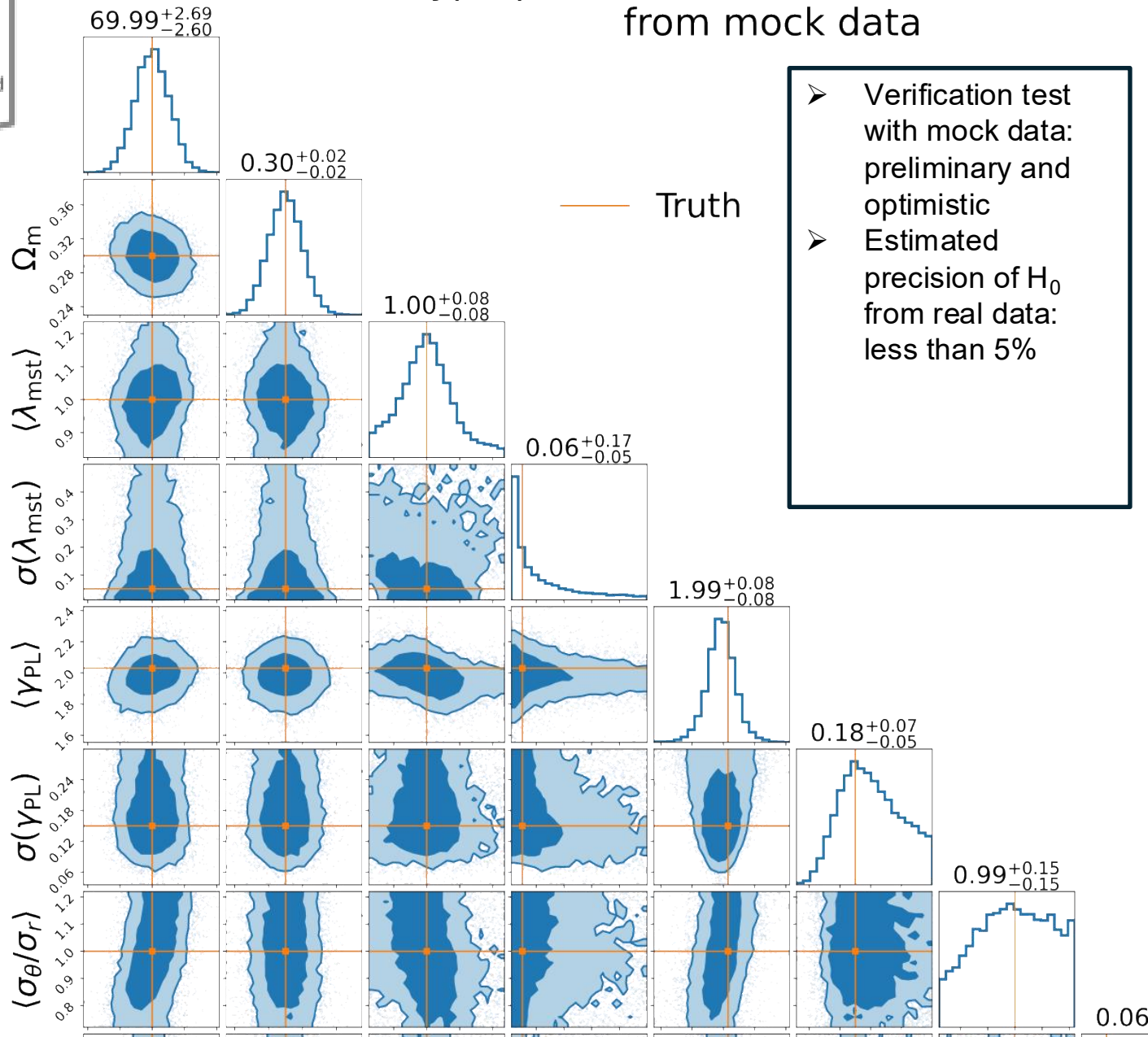
Conjugate Point Analysis

1) We re-modeled all eight systems using *only* the QSO best-fit image positions and lens mass centroids
2) Across the sample, the conjugate point θ_E has an average offset of -0.41%
3) Conjugate point models display evidence of the mass-ellipticity-shear degeneracy (Keeton et al. 1997)

Brady et al. (2026)

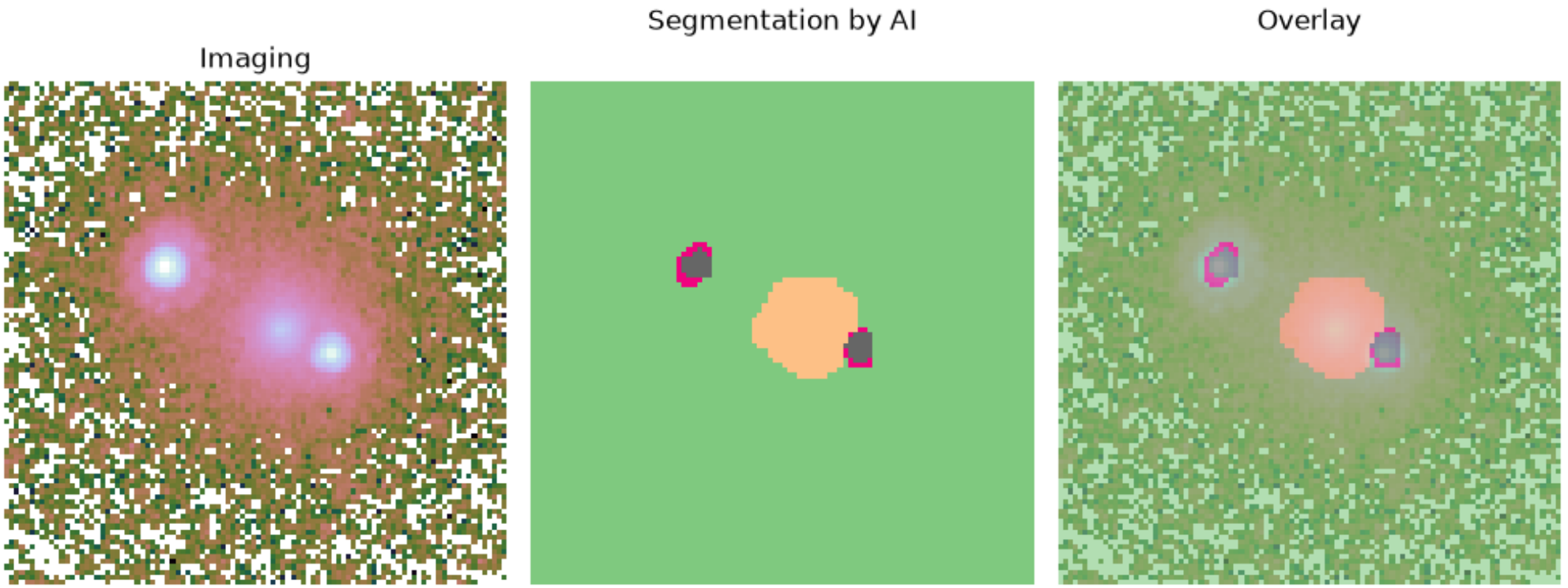
TDC with doubles





- Verification test with mock data: preliminary and optimistic
- Estimated precision of H_0 from real data: less than 5%

The Future of TDC with Doubles

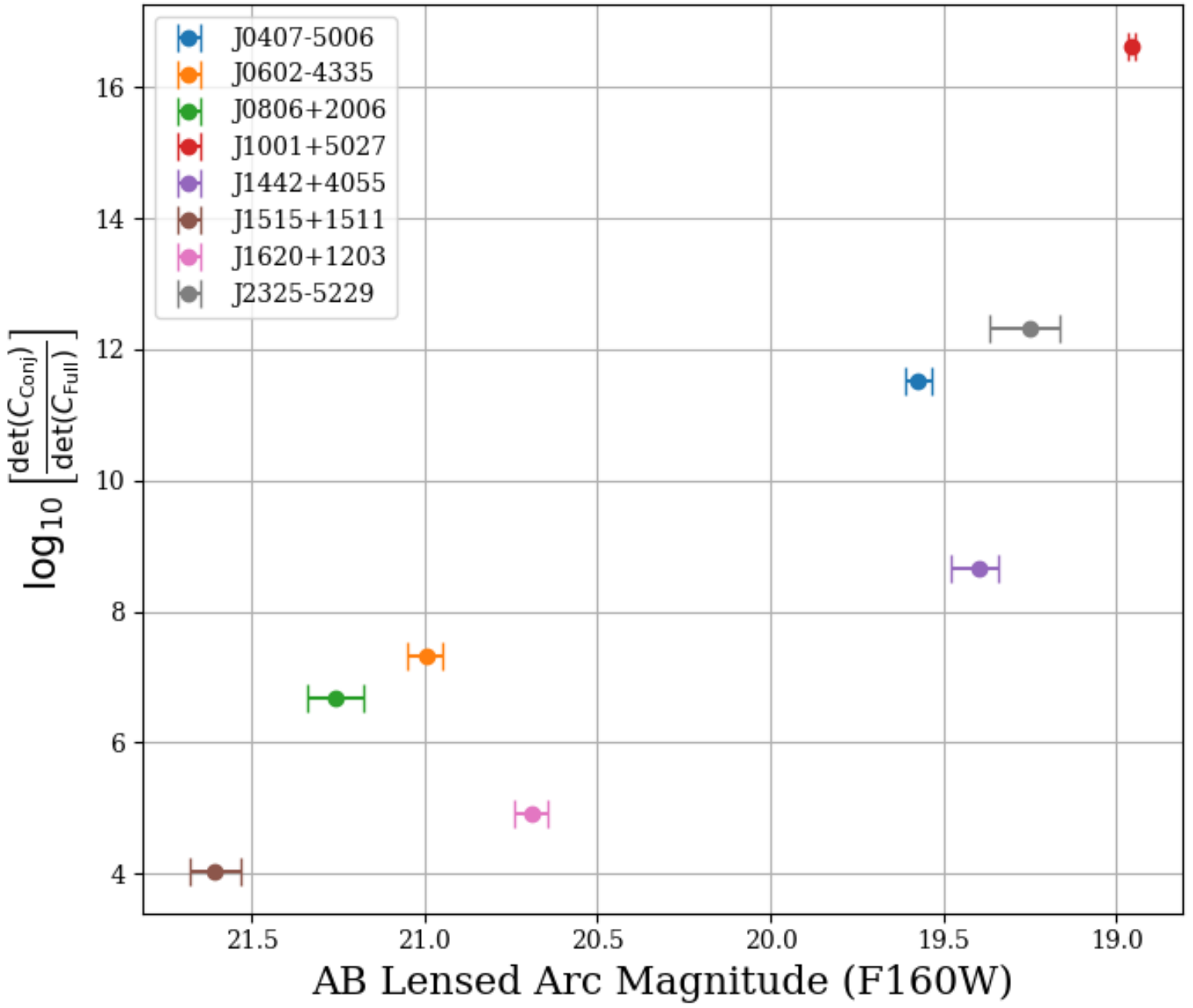


1) As large-scale surveys become operational, the incorporation of doubles into TDC analyses is **necessary**
2) Our mock hierarchical framework demonstrates that six doubles can have a precision of 5% on H_0
3) Implementation of modeling routine into *dolphin* (Shajib et al. 2025), going from full science mosaic → PSF → AI setup → preliminary model in as little as 6 function calls

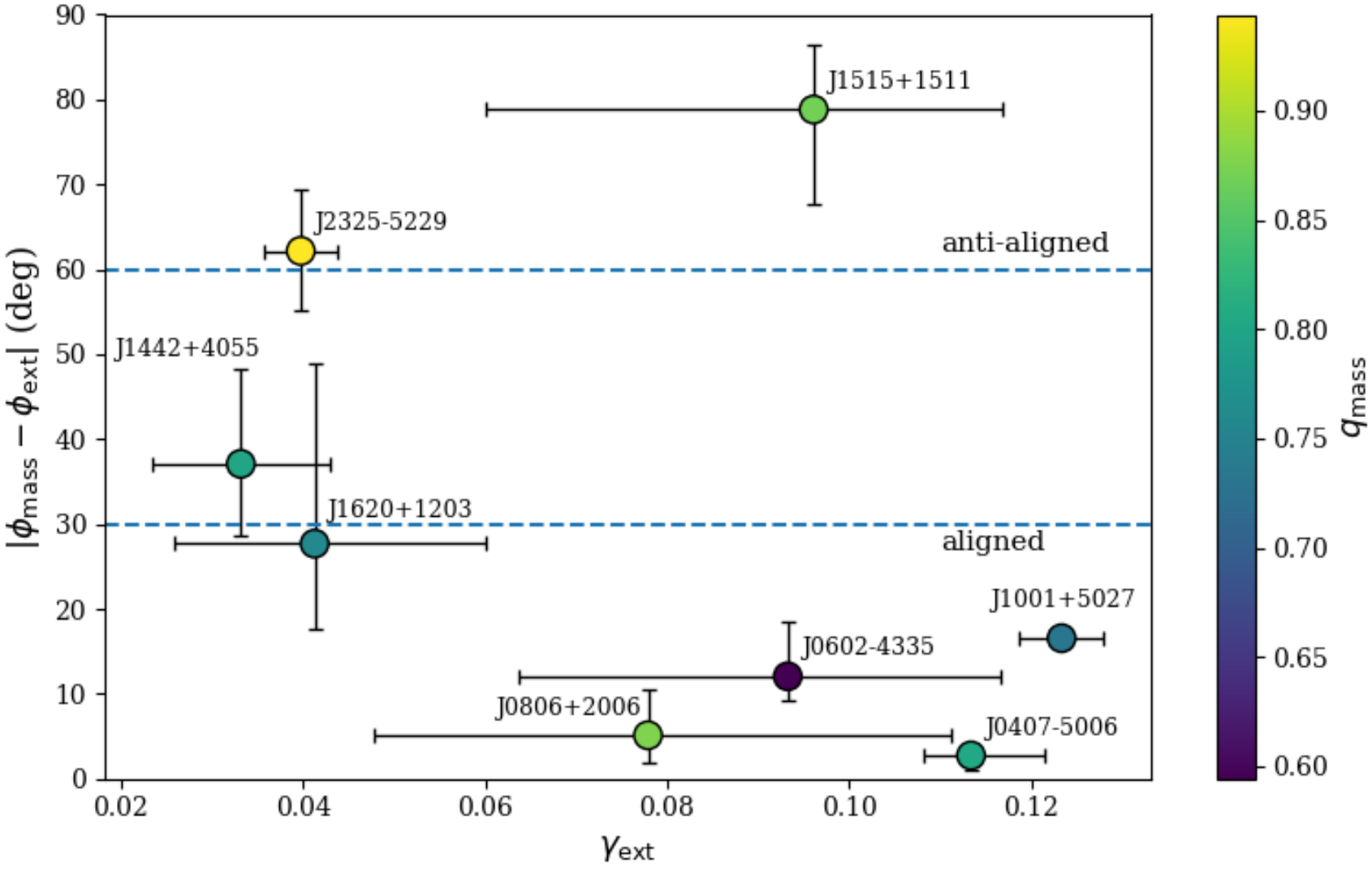
Appendix

Mass Parameter Hypervolume

1) Conjugate point mass hypervolume greater by an average factor of 10^9 times
2) Observed arc-hypervolume correlation ($r = -0.87$ and $p = 0.005$) suggests that improved constraints progenate primarily from the information content of the extended arc surface brightness



Brady et al. (2026)



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Too Simple?

1) External shear shows evidence of compensating for residual mass model complexity rather than tracing a physical perturbation
2) Future precision analyses should utilize sophisticated mass models (i.e. Elliptical Power-Law) and focus on systems with high SNR arcs to reduce lens modeling degeneracies