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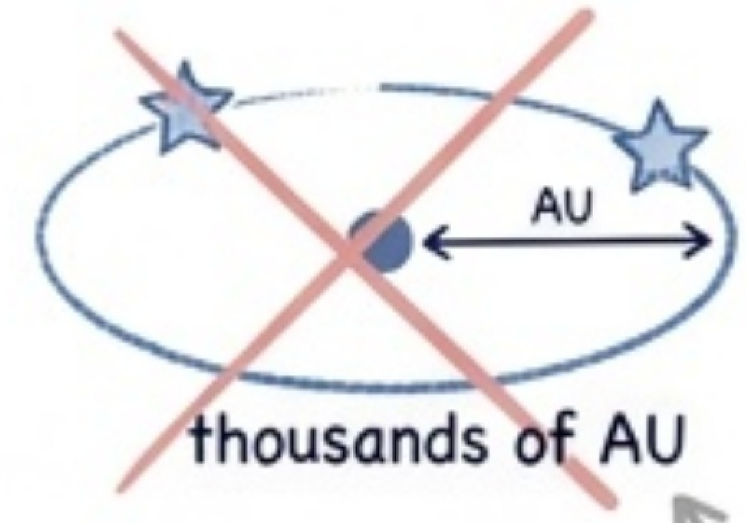
CRITICAL POINT:
How you MODEL the
3D orbit matters!



This paper shows the reported anomaly (from Chae et al. 2026) might just be orbital parameter miscalculation.

Gravitational Anomaly Measurement in Wide Binaries is Sensitive to Orbital Modeling

Serat M. Saad[1] and Yuan-Sen Ting[1,2,3]

[1]Department of Astronomy, The Ohio State University, Columbus, OH 43310, USA
[2]Center for Cosmology and AstroParticle Physics (CCAPP), The Ohio State University, Columbus, OH 43…
[3]Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

ABSTRACT

Recent work by Chae et al. (2026) reported a gravitational anomaly … gravity boost factor of $\gamma = G_{\rm eff}/G_{\rm N} \approx 1.60^{+0.17}_{-0.14}$ at low accelerations, consistent with predictions from Modified Newtonian Dynamics (MOND). We reanalyze the same dataset using a hierarchical Bayesian model that infers a global γ across all systems while fitting three-dimensional orbital elements. Our model yields $\gamma = 1.12^{+0.17}_{-0.22}$, consistent with Newtonian gravity ($\gamma = 1$) at the $\sim 0.4\sigma$ level. To identify the source of the discrepancy, we perform a test using an approach similar to Chae et al. (2026), replacing the semi-major axis with a geometric de-projection of the observed projected separation. This test yields $\gamma = 1.56^{+0.27}_{-0.18}$, closely matching the result of Chae et al. (2026). This suggests that the inferred value of γ is sensitive to how the three-dimensional orbital separation is modeled, and including an independent semi-major axis parameter can account for velocity excesses that would otherwise be attributed to non-Newtonian gravity.

THE CHALLENGE OF MOND

Chae et al.: $\gamma \sim 1.6$
Our reanalysis: $\gamma \sim 1.12$

Keywords: gravitation — methods: statistical — techniques: radial velocities — binari… stars: kinematics and dynamics

THIS IS THE MOND ACCELERATION SCALE – where things are meant to get weird

$a_0 = 1.2 \times 10^{-10}\ \mathrm{ms^{-2}}$

1. INTRODUCTION

Testing gravity in the low-acceleration regime is an ongoing challenge in astrophysics. On galactic scales, the observational predictions deviate from Newtonian predictions based on visible matter alone (Zwicky 1977; Rubin & Ford 1970; Sofue & Rubin 2001). The standard ΛCDM cosmological model accounts for these … viating by i… 2002; E… between … and the o… oration et al. 2020a,b… approach, Modified Newtonian Dynamics (MOND), was proposed by Mordehai Milgrom in 1983 (Milgrom 1983). MOND suggests that gravity is modified below an acceleration scale $a_0 \approx 1.2 \times 10^{-10}\ \mathrm{m\,s^{-2}}$ (Milgrom 1983). MOND has been successful in reproducing galaxy rotation curves and scaling relations (Sanders & McGaugh 2002; Famaey & McGaugh 2012; McGaugh 2016; Lelli et al. 2016), but faces challenges on cluster and cosmological scales (Sanders 2003; Angus 2008). Distinguishing between these two frameworks requires tests in environments where their predictions differ and the systematic uncertainties can be controlled.

We show that including an extra orbital parameter (semi-major axis) effectively ERASES the apparent anomaly! Newton stays!

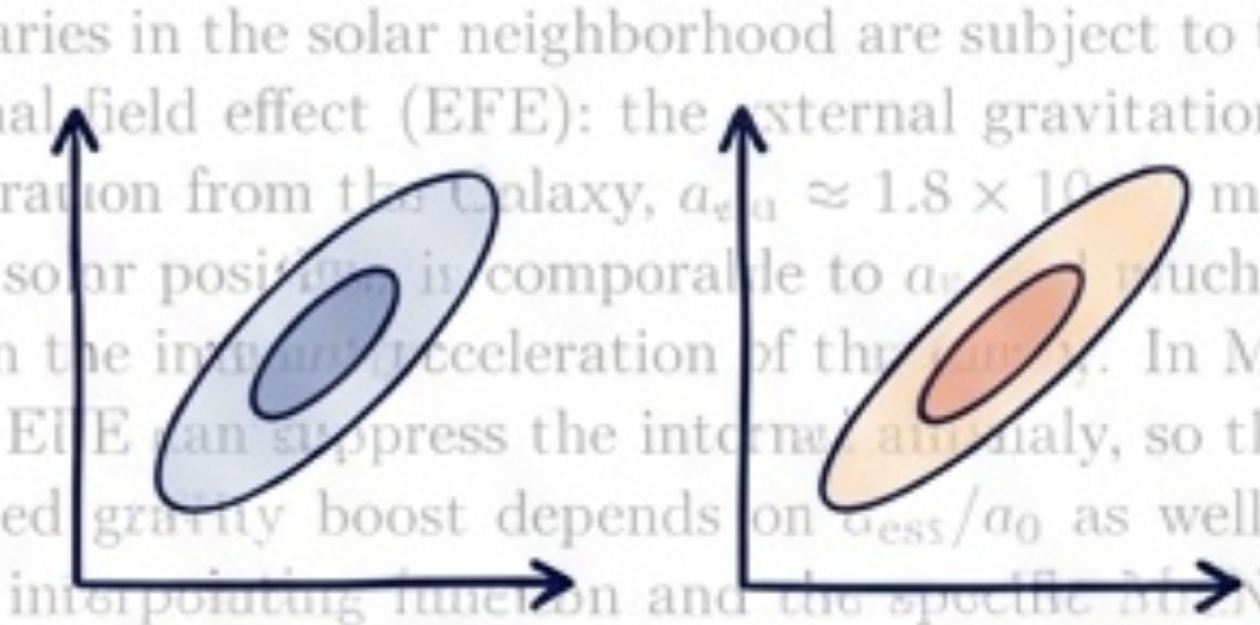
NEWTONIAN REIGN - standard gravity usually works… until it doesn't.

Wide-binary stars, separated by thousands of AU, provide one such environment where gravity can be tested. At these separations, the … tional acceleration of the binary can … the MOND acceleration scale a_0. MO… therefore predicts deviation from Newtonian gravity in these systems. Testing MOND with wide binaries requires careful consideration of several theoretical ingredients. In MOND, the transition from Newtonian to … …rned by an … …th $\mu \to$ … tonian regime) and $\mu \to x$ for $x \ll 1$ … regime). The exact form of μ is not … fied by the theory, and different chai… predicted gravity enhancements at intermediate accelerations (Famaey & McGaugh 2012). Furthermore, wide binaries in the solar neighborhood are subject to the external field effect (EFE): the external gravitational acceleration from the Galaxy, $a_{\rm ext} \approx 1.8 \times 10^{…}\ \mathrm{m\,s^{-2}}$ at the solar position, is comparable to a_0 and much larger than the internal acceleration of the binary. In MOND, the EFE can suppress the internal anomaly, so the predicted gravity boost depends on $a_{\rm ext}/a_0$ as well as on the interpolating function and the specific MOND formulation (… 2018; Chae … 22).

A unique (and annoying!) feature of MOND that we must consider.

Banik & Zhao 2018
Chae et al. – 2022

These previous works argue FOR modified gravity in wide binaries. We are arguing AGAINST it.



WHAT IS THIS "GRAVITY BOOST"? → $\gamma = G_{eff}/G_N$

... boost factor $\gamma = G_{eff}/G_N$, de- ... can be measured independently of these theoretical choices. The inference of γ is a kinematic measurement that assumes only Keplerian orbits; it does not assume any particular value of a_0, ... specific interpolating function, or any MOND framework. Previous wide-binary studies using ... data have taken this approach, reporting $\gamma = 1.43 \pm 0.06$ (Chae 2023), $\gamma = 1.49 \pm 0.2$ (Chae 2024), $\gamma = 1.5 \pm 0.2$ (Hernandez et al. 2024), and most recently $\gamma = 1.6 \pm 0.2$ (Chae et al. 2026), which can be compared to AQUAL predictions of $\gamma \approx 1.4$ for wide binaries in the EFE-dominated regime of the solar neighborhood (Banik & Zhao 2018; Chae et al. 2022). In contrast, Banik et al. (2024) reported preference for Newtonian gravity ($\gamma = 1$). ... that the result may be ... methodology or the data used for ...

The same datasets have yielded DIFFERENT conclusions...

Chae 2023
Chae 2024
Hernandez et al. 2024
Chae et al. (2024)
Chae et al. (2026

...some finding standard Newton (~ 1), others finding an anomaly (~ 1.6)!

Recent work has introduced high-precision radial velocities (RVs) to enable three-dimensional analysis of ... orbits. Saglia et al. (2025) obtained RVs ... binaries and found results broadly consistent ... gravity. Chae (2025b) reanalyzed ... reported a tentative gravitational ... $/G_N \approx$ ... with low internal acceleration ... (2026) assembled a sample of ... high-precision 3D velocities and ... claiming a > 3σ detection of deviation from Newtonian gravity. The methodology used by Chae et al. (2026) and Chae (2025b) ... for each binary ... used to derive a ... $\sqrt{7}$ along ... per-system ... derive a co... aspects of the ... amount of projected s... independent semi-major axis parameter, may influence the inferred γ.

This hints that the *results* are very sensitive to how you do the statistical math!

In our previous work (Mahmud Saad & Ting 2025, hereafter S&T25), we developed a hierarchical Bayesian framework for testing MOND with wide-binary kinematics and applied that to the wide binaries from the C3PO survey (Yong et al. 2023). That model fit three-dimensional orbital elements for all systems while inferring a global MOND acceleration scale a_0. The framework included the MOND interpolating function and an analytic treatment of the EFE, and tested two interpolating functions ($b = 1$ and $b = 2$). The C3PO systems were found to reside in the MOND transition regime, and the analysis yielded tension with the canonical a_0 value at $\sim 3\sigma$ ($b = 1$) and $\sim 2\sigma$ ($b = 2$). Although, because the C3PO test was performed in the transition regime, the results were sensitive to the choice of interpolating function and the EFE treatment.

In this paper, we adapt the framework of S&T25 to infer the gravity boost factor γ for 36 wide binaries from Chae et al. (2026). In Section 2, we describe the dataset from Chae et al. (2026). In Section 3, we present our hierarchical Bayesian model. In Section 4, we report the results of our two model variants, discuss the interpretation of these results, and place our findings in the context of previous wide-binary gravity tests.

2. DATA

We use the sample of 36 wide-binary systems assembled by Chae et al. (2026). This sample was constructed through selection criteria designed to identify gravitationally bound pairs with 3D kinematics: multi-epoch RV verification, speckle interferometry to exclude unresolved tertiary companions, Hipparcos-Gaia proper motion consistency checks, and Gaia RUWE < 1.4.

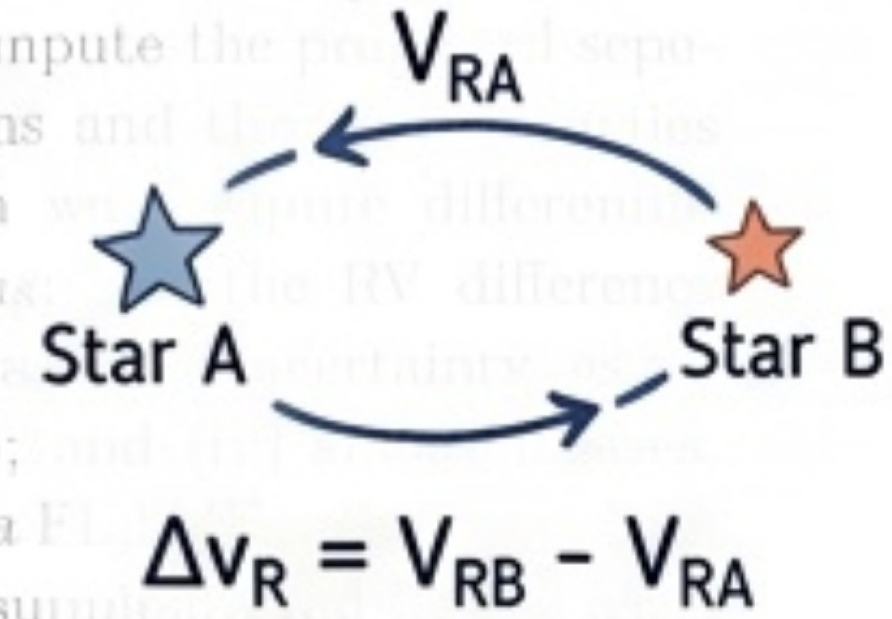
The RVs come from multiple instruments: the ... Obser... Spu... spectr... Radial ve... ...ph on the ... 3.6m telescope (Saglia et al. 2025), and the Apache Point Observatory Galactic Evolution Experiment (APOGEE) from Sloan Digital Sky Survey (SDSS) Data Release 17 (DR17) (Abdurro'uf et al. 2022). The RV precisions vary across instruments, with HARPS providing the highest precision (~1–5 m s^{-1}) and LCO/NRES providing precisions of ~30–300 m s^{-1}.

Gaia DR3
NRES
MAROON-X
HARPS
APOGEE
SDSS

We're using HIGH-PRECISION radial velocities (RVs) from a bunch of powerful ground-based telescopes.

For each system, we use the following observational quantities: (i) the positions of both components from ... we compute the projected separ... ...tions and ... ...ich ... differen... $\Delta\mu$; ... The RV differenc... ...ported by Chae et al. (2026); and ... For stellar masses, we use Gaia FLAME ... available (Sacco et al. 2014), supplemented ... estimates from Chae (2023) for systems lacking FLAME values. Unlike our previous analysis in S&T25, which used differential RVs measured from the same spectrograph in a single epoch, the RVs in the Chae et al. (2026) sample are absolute RVs measured independently for each ... epochs. ... RV... from

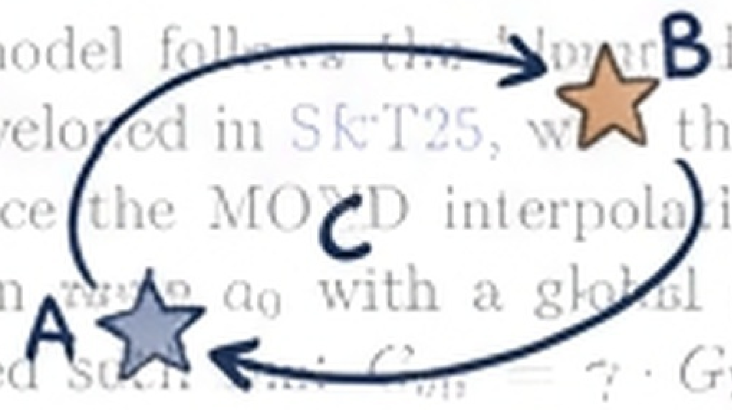
By looking at how differential nove RVs.
By looking at how much faster one star moves relative to its partner...



Now we're ready to put their analysis to the test with our improved modeling framework!

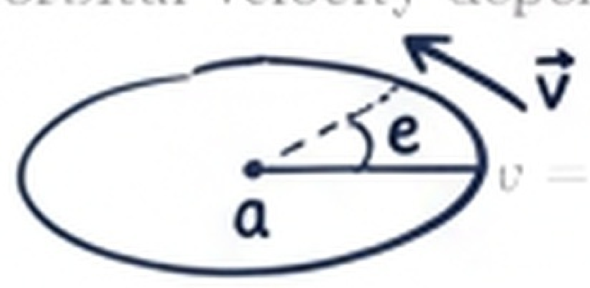
Our improved framework models each each pair as a two-body Keplerian system.

3. METHODS



Our model follows the hierarchical Bayesian framework developed in S&T25, with the key difference that we replace the MOND interpolating function and acceleration with a global gravity boost factor γ, defined such that $G_{\rm eff} = \gamma \cdot G_{\rm N}$. Newtonian gravity corresponds to $\gamma = 1$, while MOND predictions for wide binaries in the solar neighborhood give $\gamma \approx 1.4$–1.6 (Banik & Zhao 2018; Chae et al. 2022, 2020). The quantity $\Gamma = \log_{10}\sqrt{\gamma}$ used by Chae et al. (2026) is related by $\gamma = 10^{2\Gamma}$, with $\Gamma = 0$ correspondi...

We model each wide binary as a ... system with six orbital elements: semi-major axis a, eccentricity e, inclination i, longitude of ascending node Ω, argument of periastron ω, and mean anomaly M. The orbital velocity depends on γ through



Equation 1

$$v = \sqrt{\frac{\gamma\, G_{\rm N}\, M_{\rm tot}}{r} \cdot F} \quad (1)$$

where r is the instantaneous separation, $F = (1 + e^2 + ...$

Speed depends on parameters (a, e, ...) and the gravity boost γ. This is crucial for calculating Δv_r and compar- comaring with data.

... ($r_\perp$, Δv_r, $\Delta\mu$) ... inate transformation described in S&T25.

3.1. *Hierarchical Bayesian model*

Rather than fitting γ independently for each system and then combining the results as in Chae et al. (2026), we fit a global γ shared across all 36 systems. The graphical model is shown in Figure 1.

The joint posterior is:

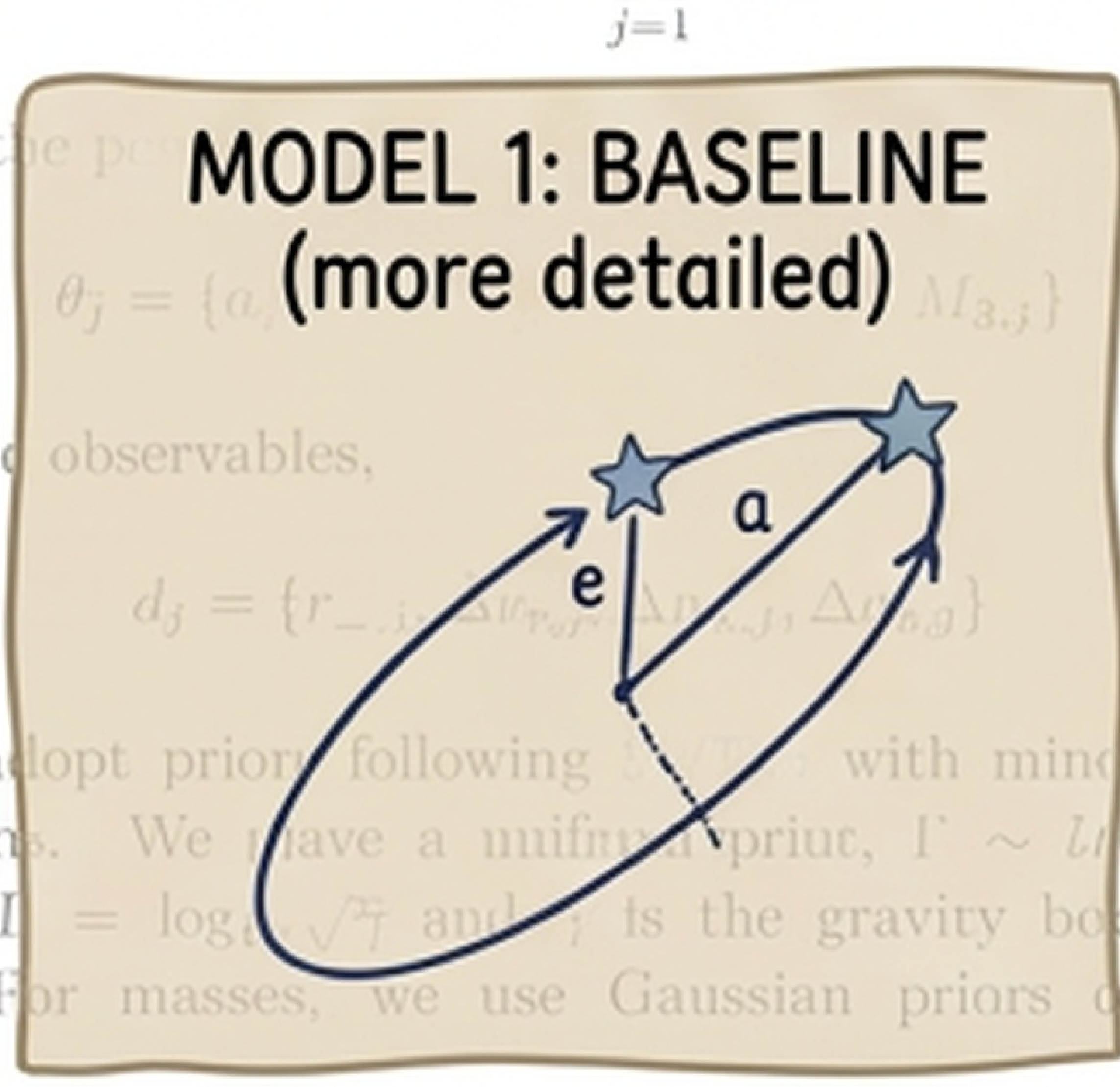
$$p(\gamma, \{\theta_j\}|\{d_j\}) \propto p(\gamma) \prod_{j=1}^{N} p(d_j|\gamma, \theta_j)\, p(\theta_j) \quad (2)$$

where the p...

$$\theta_j = \{a, ... M_{3,j}\}$$

and, the observables,

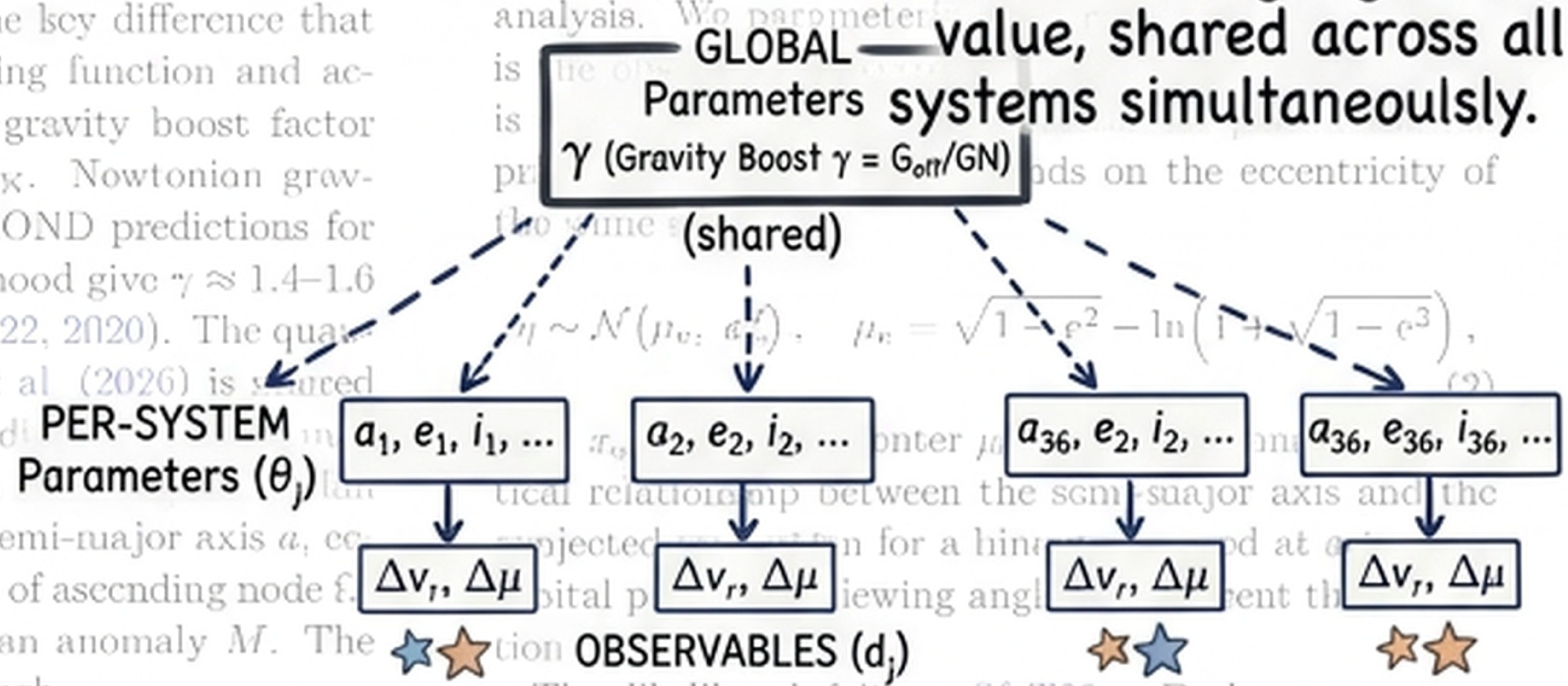
$$d_j = \{r_{\perp,j}, \Delta v_{r,j}, \Delta\mu_{x,j}, \Delta\mu_{y,j}\}$$



We adopt priors following S&T25 with minor modifications. We have a uniform prior, $\Gamma \sim \mathcal{U}(-1, 1)$, where $\Gamma = \log_{10}\sqrt{\gamma}$ and γ is the gravity boost factor. For masses, we use Gaussian priors centered on the *Gaia* FLAME or Chae (2023) estimates. For angular elements, we assign isotropic priors ($\cos i \sim \mathcal{U}(-1, 1)$; $\omega, \Omega, \phi \sim \mathcal{U}(0, 2\pi)$), and for eccentricity, we use seperation-dependent thermal distribution of Hwang et al. (2022) as described in S&T25.

The prior on the semi-... analysis. We parameterize ... is ... is ... pr... ends on the eccentricity of the same s...

We fit a single global γ value, shared across all systems simultaneously.



$$\eta \sim \mathcal{N}(\mu_\eta, \sigma_\eta^2), \quad \mu_\eta = \sqrt{1 - e^2} - \ln\left(1 + \sqrt{1 - e^2}\right), \quad (3)$$

... σ_η ... enter μ ... tical relationship between the semi-major axis and the projected separation for a binary observed at ... orbital p... viewing angl... ent th... tion ...

The likelihood follows S&T25. Each system contributes three terms:

$$r_{\perp,\rm obs} \sim \mathcal{N}(r_{\perp,\rm model}, \sigma_r^2) \quad (4)$$

$$\Delta v_{r,\rm obs} \sim t_5\left(\Delta v_{r,\rm model}, \sigma^2_{\Delta v_r} + \sigma^2_{\rm jitter}\right) \quad (5)$$

$$\Delta\mu_{\rm obs} \sim \mathcal{N}(\Delta\mu_{\rm model}, \sigma_\mu^2 + \sigma^2_{\rm pm,jit}) \quad (6)$$

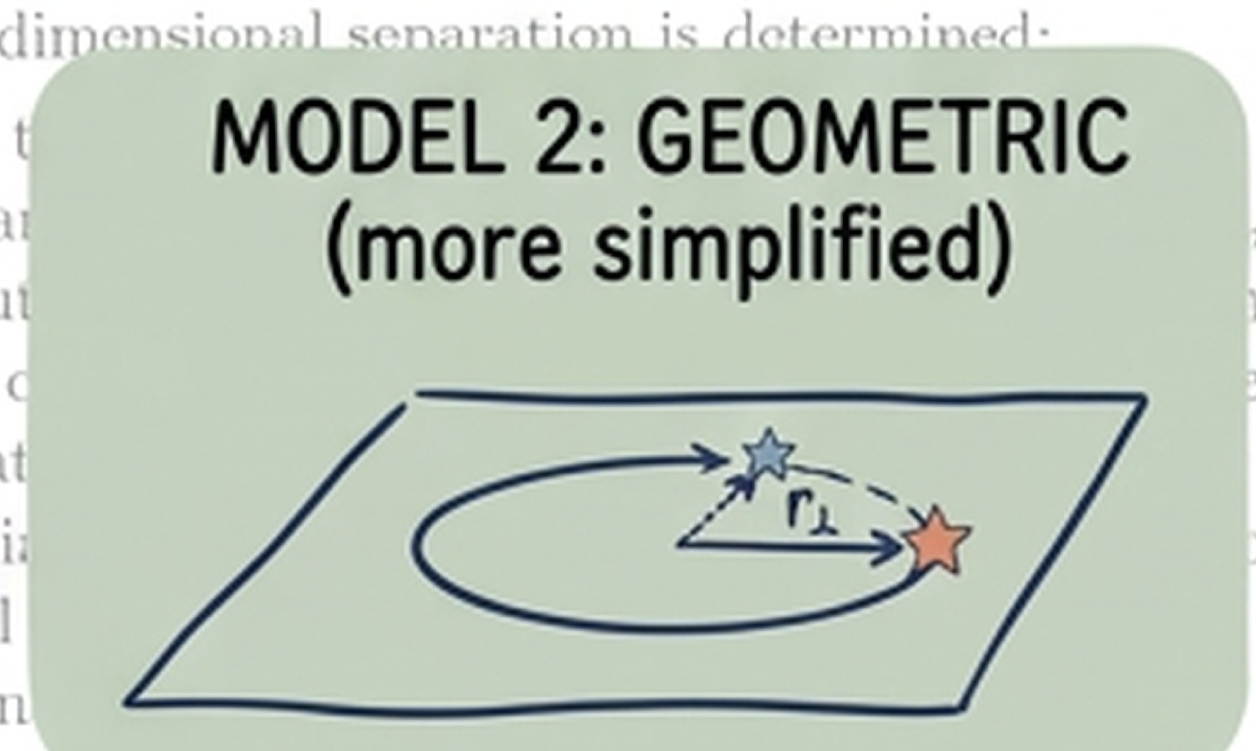
where t_5 denotes a Student-t distribution with five de... for th... outlie... al nuisan... perform... MC) wit... ...an et al. 2014), implemented in PyMC ... following the ... approach ... ting st... ability of 0.98.

We also add 'jitter' to model additional, unknown sources of noise or uncertainty.

3.2. *Using two different models*

We consider two model variants that differ in how the three-dimensional separation is determined:

For t... is a free par... is comput... Kepler's ... ected separat... with Gaussi... or an orbital ... separation...



We also consider a geometric-de-projection model. In this vers... we replace the semi-major axis parameter with ... projected ...

We're comparing two ways to relate the observed 2D data to the underlying 3D orbits.

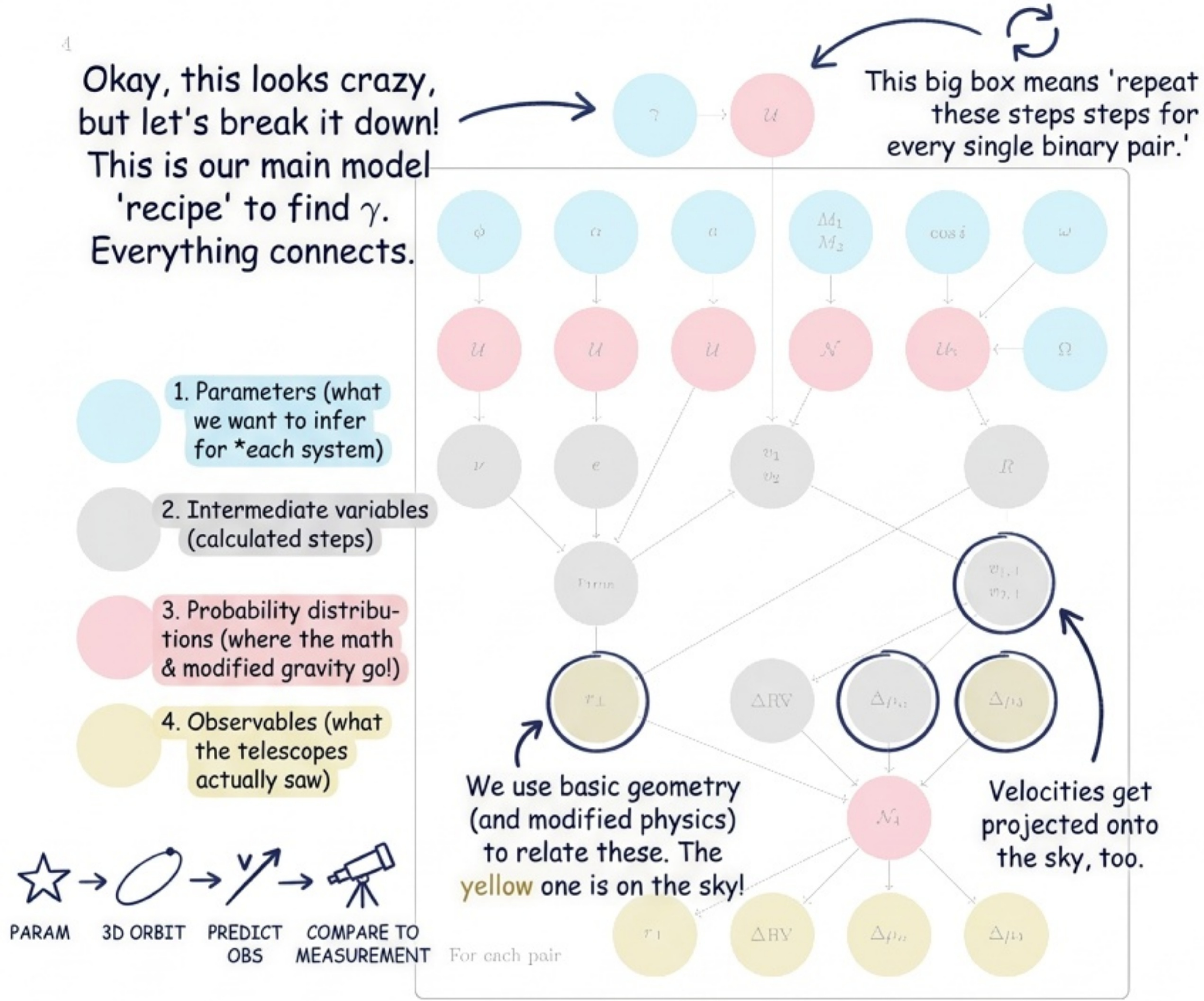


Figure 1. Graphical representation of the hierarchical Bayesian model for inferring the gravity boost factor γ. The global paznmetor γ (blue) is shared across all binary systems. The plate notation indicates that the enclosed structure is replicated for each of the $N = 36$ systems. For each system, we infer six orbital elements (a, α, ϕ, i, ω, Ω) and masses (M_1, M_2). These determine intonnodiate quantities (gray): true anomaly ν, true separation $r_{\rm true}$, rotation matrix R, and component velocities v_1, v_2. The model predicts four observables (yellow): projected separation r_-, RV difference Δv_r, and differential proper motions $\Delta\mu_\alpha$, $\Delta\mu_\delta$. Red nodes denote probability distributions.

separation, following the approach of Chae et al. (2026). The true separation is derived as,

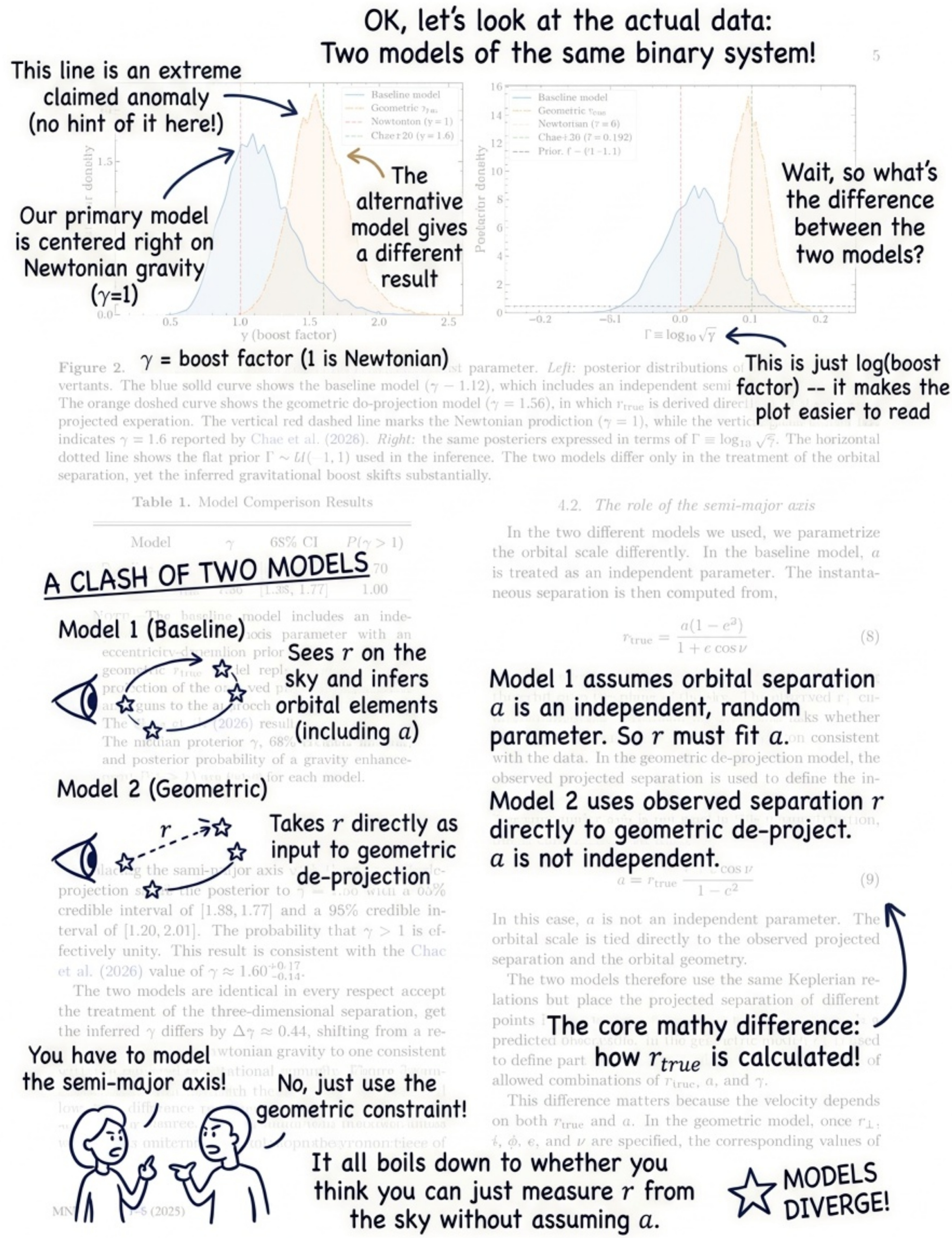
$$r_{\rm true} = \frac{r_\perp}{\sqrt{\cos^2\phi + \cos^2 i \sin^2\phi}} \tag{7}$$

where ϕ is the orbital position angle and i is the inclination. This couples the three-dimensional orbital scale directly to the observed $r_\perp$ and does not allow for an independent determination of a. All other aspects of the model remain identical to the baseline.

4. RESULTS & IMPLICATIONS

4.1. *Results*

The results of both model variants are summarized in Table 1 and Figure 2. For the baseline model, our hierarchical Bayesian analysis yields $\gamma = 1.12$ with a 68% credible interval of [0.90, 1.38] and a 95% credible interval of [0.74, 1.72]. The Newtonian value $\gamma = 1$ is well within the 68% credible interval. The probability that



OK, let's look at the actual data:
Two models of the same binary system!
This line is an extreme claimed anomaly (no hint of it here!)
Our primary model is centered right on Newtonian gravity (γ=1)
The alternative model gives a different result
Wait, so what's the difference between the two models?
γ = boost factor (1 is Newtonian)
This is just log(boost factor) -- it makes the plot easier to read
A CLASH OF TWO MODELS
Model 1 (Baseline)
Sees r on the sky and infers orbital elements (including a)
Model 2 (Geometric)
r
Takes r directly as input to geometric de-projection
Model 1 assumes orbital separation a is an independent, random parameter. So r must fit a.
Model 2 uses observed separation r directly to geometric de-project. a is not independent.
The core mathy difference: how r_true is calculated!
You have to model the semi-major axis!
No, just use the geometric constraint!
It all boils down to whether you think you can just measure r from the sky without assuming a.
MODELS DIVERGE!

Figure 3: This flow chart is a detailed roadmap of where our two models diverge and how that affects the final boost factor calculation.

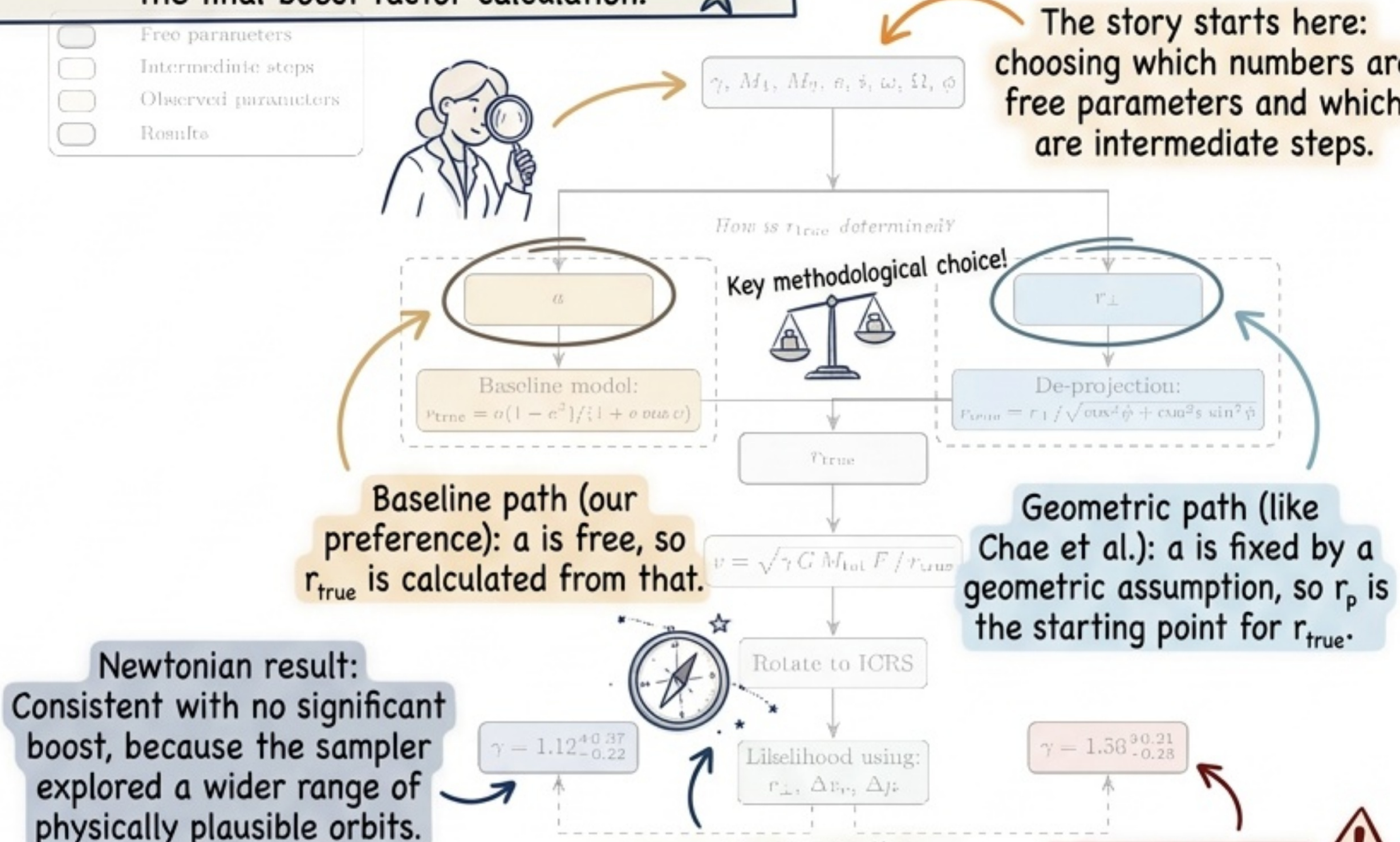


Figure 3. Diagram showing how the two model va... r_{true}, while sharing all other components. At the bra... and computes r_{true} from Kepler's equation, yielding ... r_{true} directly from the observed projected separation ... the anomaly reported by Chae et al. (2026). All othe... observables are identical between the two models.

r_{true} and a are fixed. In the baseline model, the sampler can explore a wider range of orbital scales while still requiring the predicted $r_\perp$ to agree with the data. The same observed system can therefore be assigned different posterior support in the two parameterizations.

In our analysis, this leads to different inferences for γ. When a is treated as an independent parameter ... obtain $\gamma = 1.12^{+0.37}_{-0.22}$, which is consistent with Ne... nian gravity. When the orbital scale is set by geom... de-projection of the observed projected separation ... obtain $\gamma = 1.56^{+0.21}_{-0.18}$, consistent with Chae et al. (20... This comparison shows that for the present dataset, the inferred value of γ is sensitive to how the orbital scale is introduced into the model.

4.3. *Additional methodological differences*

Beyond the semi-major axis treatment, several other differences exist between our approach and that of Chae et al. (2026) that may contribute at a smaller level.

Firstly, we use NUTS/HMC in PyHC, which explores high-dimensional correlated posteriors efficiently, while Chae et al. (2026) uses emcee with 200 walkers. For a six-parameter per-system model, emcee is adequate, ...ence is unlikely to drive the discrepancy

Wait, could it just be the sampling algorithm? Chae et al. used emcee, while we used NUTS.

...hierarchical model where γ is a ...ntly across all sy... ...for each ... ...-system ... (2011) ... ...ll their ... a ... framework thi... through the joint likelihood, ... (2026) approach the consolidation ... system posterior widths. This difference is ... to be the primary driver of the discrepancy.

The paper says it is *unlikely* to be the primary cause, but it is another difference to be aware of.

Thirdly, the treatment of the projected separation may also play a role. In our baseline model, $r_\perp$ enters as an observable with Gaussian uncertainty, so that

Conclusion of Section 4: The difference in boost factors is *primarily* driven by the assumption about orbital scales, not the sampling method or other secondary factors.

any error ... is ... on γ. In the Chae et al. (2026) model, $r_\perp$ is treated as a fixed quantity. Since $v^2 \propto \gamma/r$, an underestimated separation could contribute to an overestimated γ. To test whether this treatment matters in practice, we run an additional variant of the geometric de-projection model in which $r_\perp$ is treated as exact and the $r_\perp$ likelihood term is removed. This yields $\gamma = 1.59^{+0.23}_{-0.20}$, nearly identical to the geometric model with $r_\perp$ likelihood included ... $=$ ... r ... son fit ...

4.4. *Relation to previous work*

Our result is consistent with our previous analysis (Mahmud Saasl & Ting 2025), where we applied a similar hierarchical Bayesian framework to the C3PO wide-binary sample and found the canonical MOND value of $a_0 = 1.2 \times 10^{-10}\ \mathrm{m\,s^{-2}}$ to be excluded at $\sim 3\sigma$ and $\sim 2\sigma$ for two different interpolating functions. The present analysis is more informative because it uses the same data as Chae et al. (2026), who reported a gravitational anomaly in these 36 systems. Is also differs from our ... in that her ... oice of ...

... consis ... Pittordis ... the statistics of Gaia ... clude that Newtonian gravity is preferred. We note that ... provided ... of the HARPS ... 2026) ... n Keplerian orbits provide ad... systems. Their analysis di... parameter; rather, it dom... kinematics are consistent w... fact that Chae et al. (2026) h... lapping data underscores that the infer... de-pends on the modeling framework, consistent with the sensitivity to orbital parameterization that we identify in this work.

Wait, so did any other papers find a boost factor?

5. CONCLUSIONS

We reanalyzed the 36 wide binaries from Chae et al. (2026) using a hierarchical Bayesian model that fits a global gravity boost factor γ while modeling three-dimensional Keplerian orbits for each system. In our baseline model, where the semi-major axis is treated as an independent parameter, we find $\gamma = 1.12^{+0.27}_{-0.23}$, which is consistent with Newtonian gravity. This differs from the result of Chae et al. (2026), who reported $\gamma \approx 1.60^{+0.17}_{-0.14}$ for the same systems.

To understand this difference, we repeated the analysis with a second model that follows the geometric de-projection approach used by Chae et al. (2026), where the three-dimensional separation is derived directly from the observed projected separation and no independent semi-major axis is included. This model gives $\gamma = 1.56^{+0.31}_{-0.18}$, in close agreement with Chae et al. (2026). This comparison indicates that the inferred value of γ depends strongly on how the orbital scale is introduced into the inference.

Our result suggests that the current evidence for a gravitational anomaly in this 36-system sample is not robust to reasonable changes in orbital modeling. For this dataset, the conclusion about whether γ is consistent with Newtonian gravity depends on the assumed relation between projected separation, true separation, and semi-major axis. More generally, this indicates that wide-binary gravity tests require careful treatment of orbital scale and model assumptions before drawing conclusions about non-Newtonian gravity.

ACKNOWLEDGMENTS

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This work has made use of data from the European Space Agency (ESA) miesion *Gaia* (https://www.cosmos.esa.int/gaia), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC) ...

MAIN TAKEAWAY:
The current data for a gravitational gravittional anomaly in this 36-system sample is not robust.

DATA & CODE AVAILABILITY

Th... pol...

TL;DR: The supposed evidence for modified gravity in wide binaries seems to be an artifact of modelling, not new physics.

Okay, we're done with the math! Now we can see the full 'cast of characters' who made this work possible.

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Wow, so many names! It really is a massive collaborative effort to push science forward.

Shout out to all the global collaborators! SCIENCE HAS NO BORDERS.

A paper isn't just about one set of results, it's also about summarizing the *journey* of how we got here.

Ah, Fritz Zwicky... and here he is. He's a legend! Known for finding clues to dark matter way before anyone else. His name pops up in everything!

I wonder if I can use some of these studies in my own work?