

# Resolving Tensions Around a Rare Multi-Planet System (HR 8799): An Investigation of Planet Masses and the Search for a Hidden 5th Planet



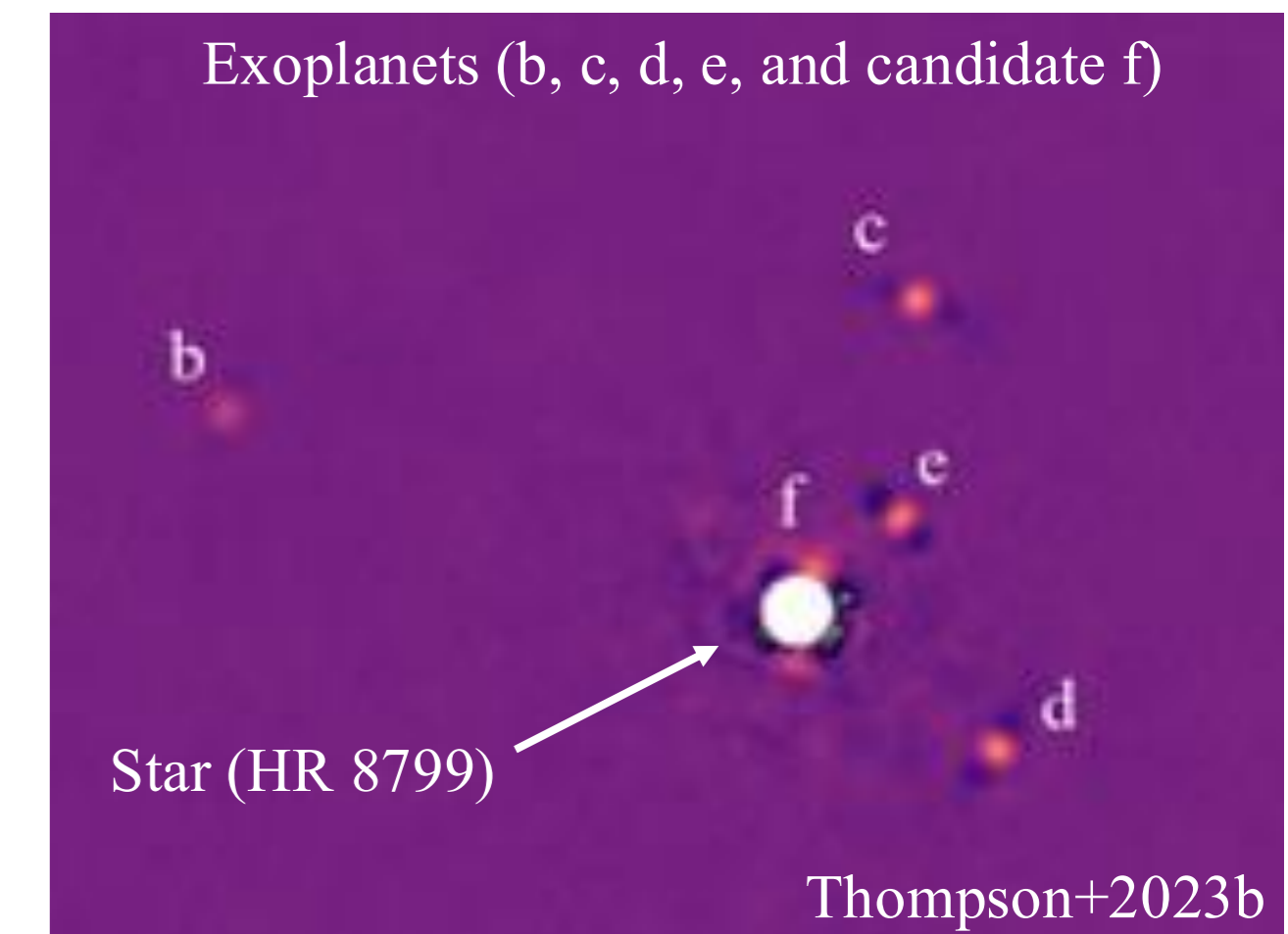
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**IN PROGRESS**

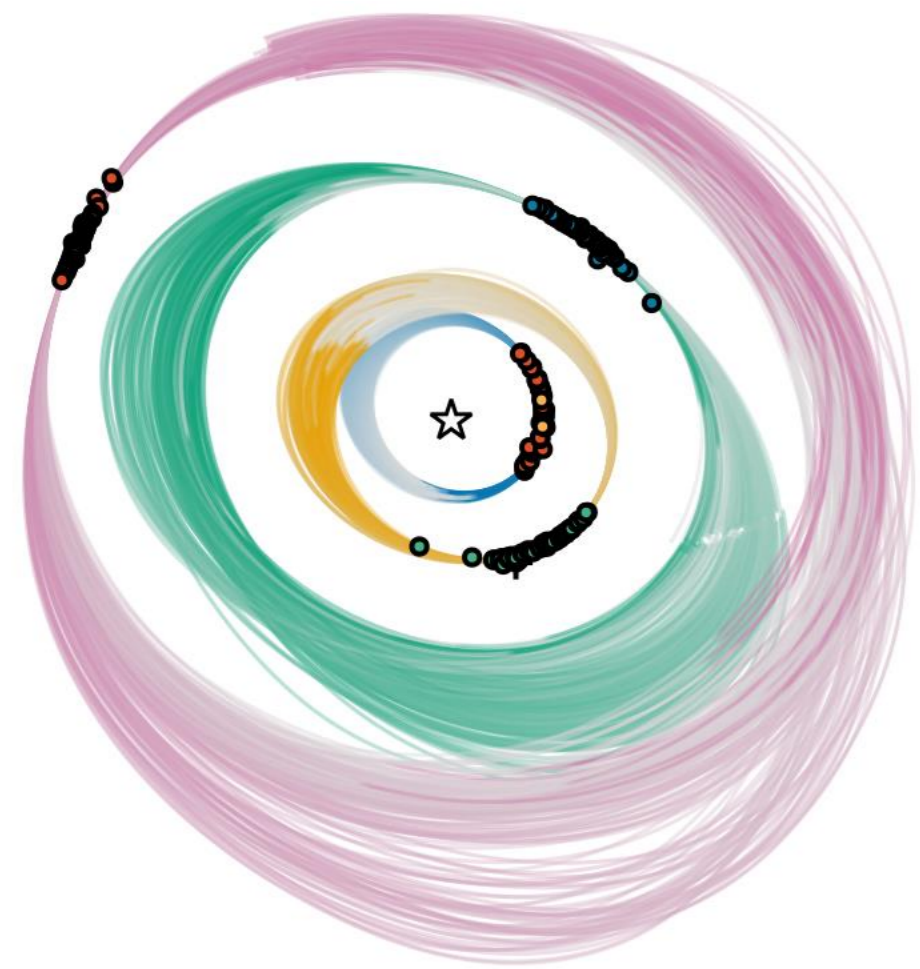
## Introduction & Motivation

HR 8799 has **4 confirmed Jupiter-mass exoplanets** in orbits ranging from 15-80 au from their host star. At these orbital distances, however, planetary systems tend to be unstable living for only  $\sim 100,000$  yrs.<sup>1</sup> Yet, follow-up campaigns indicate that HR 8799 has been stable for around 30 Myr.<sup>2</sup> The stability of this system, however, is highly sensitive to the masses of the inner planets. Recent estimates of these masses by Brandt+2021 add tension to this apparently stable system, as they found **inner planet (c, d, e) masses too high to allow for stability**. If we posit that the true masses of the planets must be lower than the values reported by Brandt+2021, the most plausible explanation is that there is an additional, previously undetected planet in the system throwing off these measurements.



## Relative Astrometry Orbit Analysis

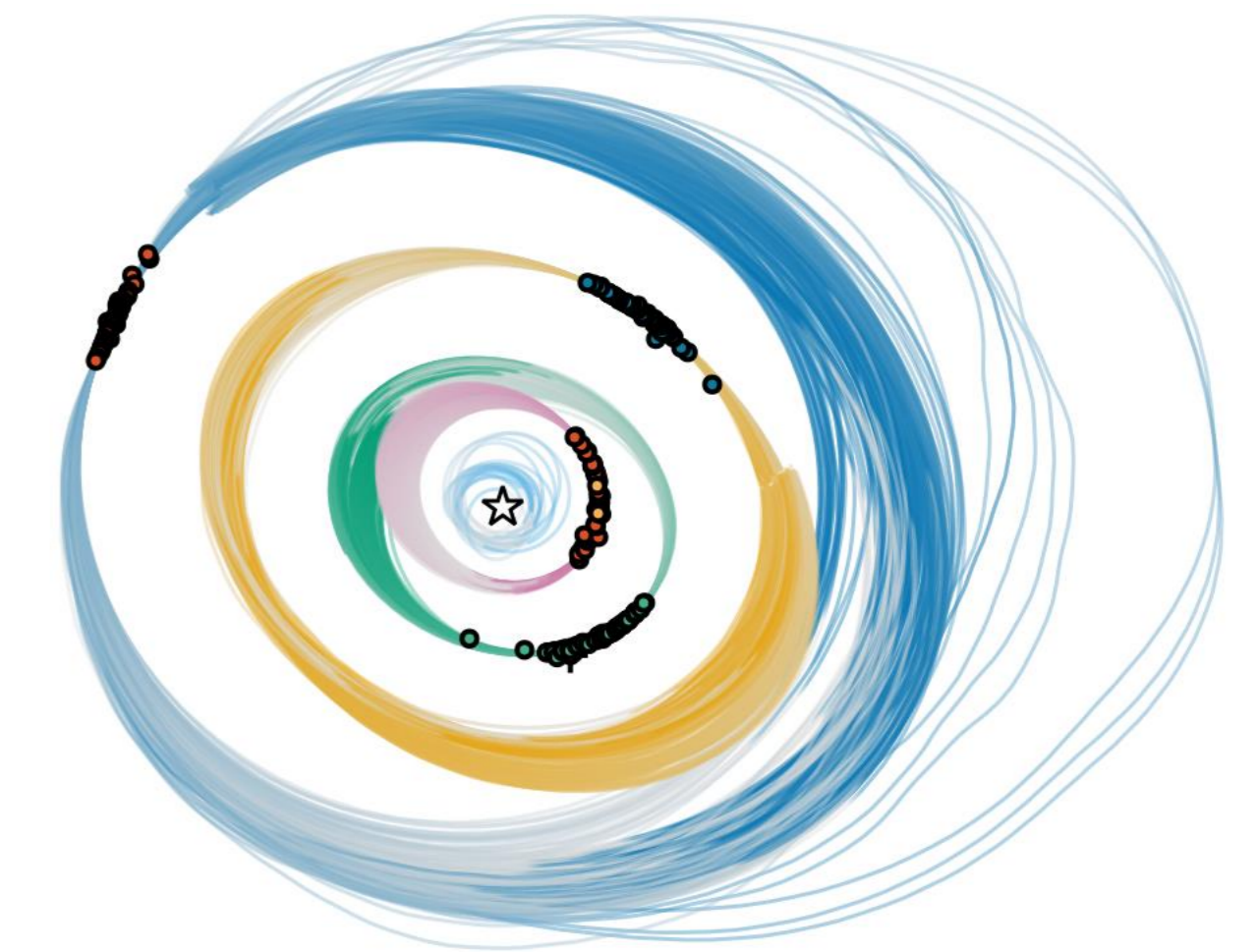
### 4-Planet Model



Using a Julia-based orbit modelling code called **Octofitter**<sup>5</sup>, we model the possible orbits for a 4-planet and a 5-planet system independently using relative astrometry data. This allows us to:

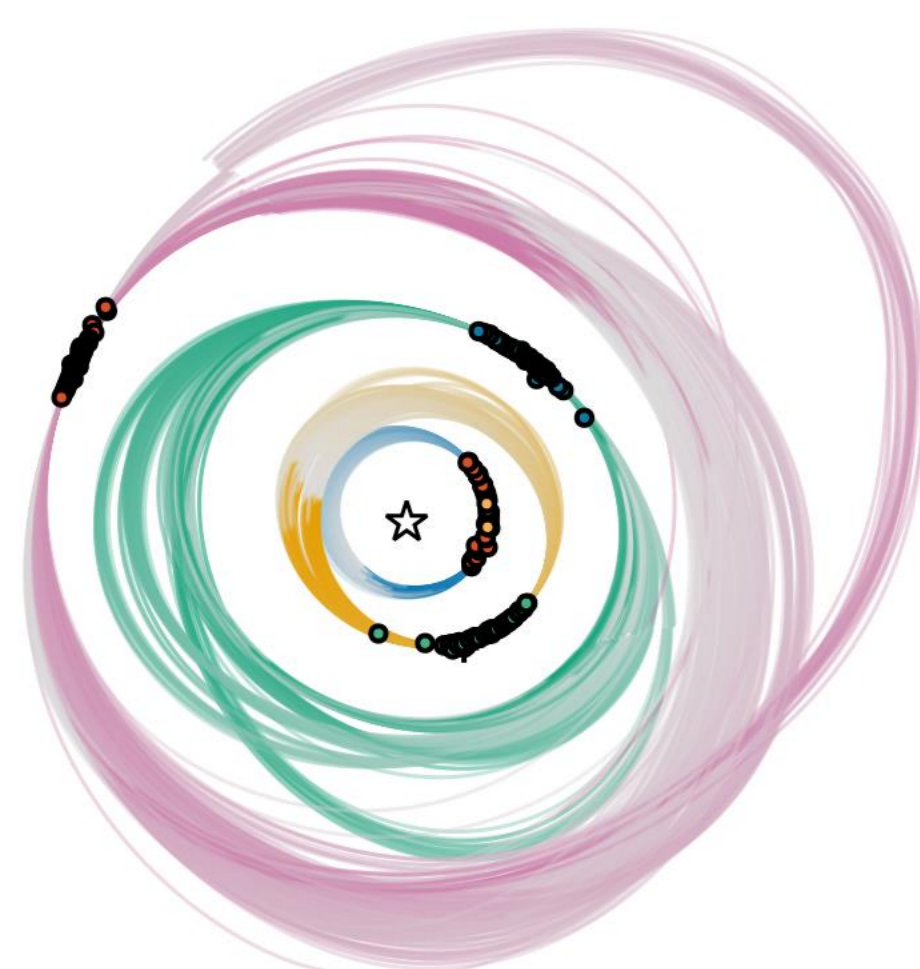
1. **Predict the mass and orbital parameters** for each planet independently according to each system.
2. Perform a **direct comparison between the two models** using the statistical evidence for each case produced naturally when using the Pigeons MCMC.<sup>6</sup>

### 5-Planet Model



## + Astrometric Motion Orbit Analysis

### 4-Planet Model

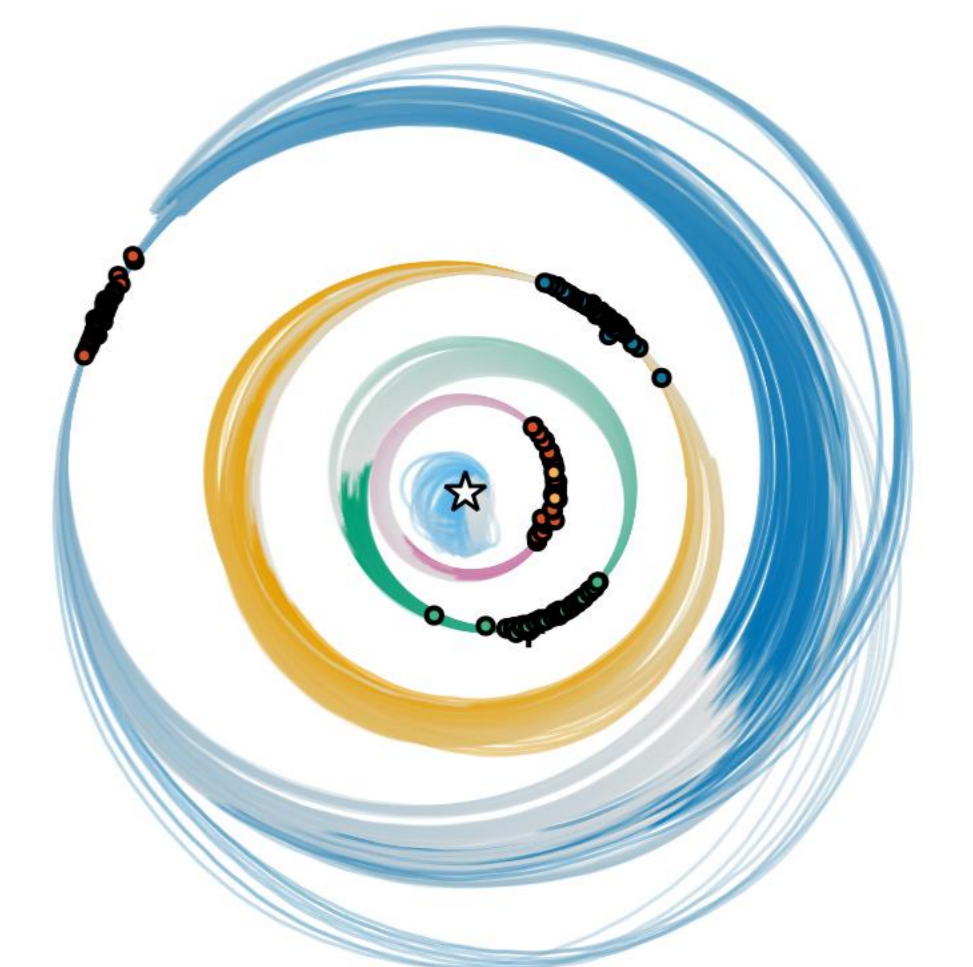


Building on the models above, we are adding the **astrometric motion** from Gaia and Hipparcos to each model. This addition considers the motion of HR 8799 as well as the observed positions of the planets.

**Note: The outputted models are under progress and will be updated as our results converge.**

Following this, we can calculate the ratio between the evidence for the two models producing the Bayes Factor, where a **larger factor indicates stronger support for one model over the other**. This will be performed for both analyses.

### 5-Planet Model



## Results & Future Work

	Eccentricity	Semi-Major axis	Mass ( $M_{jup}$ )
Planet b	$0.11^{+0.03}_{-0.04}$	$73.9^{+2.2}_{-1.1}$	$21^{+28}_{-15}$
	$0.10^{+0.04}_{-0.06}$	$66^{+3}_{-4}$	$36^{+31}_{-27}$
Planet c	$0.07^{+0.04}_{-0.06}$	$48^{+3}_{-4}$	$41^{+19}_{-22}$
	$0.032^{+0.018}_{-0.022}$	$40.6^{+1.0}_{-1.9}$	$71^{+21}_{-23}$
Planet d	$0.12^{+0.10}_{-0.04}$	$25.6^{+0.8}_{-1.8}$	$32^{+8}_{-9}$
	$0.19^{+0.04}_{-0.03}$	$24.7^{+0.5}_{-0.8}$	$22^{+13}_{-14}$
Planet e	$0.108^{+0.025}_{-0.027}$	$15.8^{+0.6}_{-0.5}$	$3^{+4}_{-2}$
	$0.066^{+0.018}_{-0.015}$	$15.4^{+0.4}_{-0.3}$	$7^{+9}_{-5}$
Planet f	-	-	-
	$0.95^{+0.02}_{-0.12}$	$5.54^{+0.22}_{-0.09}$	$34^{+4}_{-9}$

Our **preliminary** results from our astrometric motion models show a **higher** probability for a 5-planet system but current results indicate further data will likely be required to get conclusive mass estimates.

We will continue running our models to finalize our mass and orbit predictions with the available data. If the results indicate a higher probability for a 5-planet system, we will **apply for imaging time** on VLT-GRAVITY, GPI2 or SCExAO, with a goal of directly imaging the 5<sup>th</sup> inner planet around HR 8799.

Example	4-Planet Model Parameter Estimate
	5-Planet Model Parameter Estimate

## References

- <sup>1</sup>Goździewski K., Migaszewski C., 2014, MNRAS, 440, 3140
- <sup>2</sup>GRAVITY Collaboration et al., 2019, A&A, 623, L11
- <sup>3</sup>Brandt G. M., Brandt T. D., Dupuy T. J., Michalik D., Marleau G.-D., 2021, ApJ, 915, L16
- <sup>4</sup>Thompson W., et al., 2023b, AJ, 166, 164
- <sup>5</sup>Thompson W., et al., 2023a, AJ, 165, 29
- <sup>6</sup>Surjanovic N., Biron-Lattes M., Tiede P., Syed S., Campbell T., Bouchard-Côté A., 2023, arXiv e-prints, p. arXiv:2308.09769



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