Using Disk Morphology to Constrain the Orbit of HD106906b

Anna Fehr, A. Meredith Hughes
Department of Astronomy, Van Vleck Observatory
Wesleyan University, Middletown, CT 06459

HD 106906: Host to Debris Disk & Planet

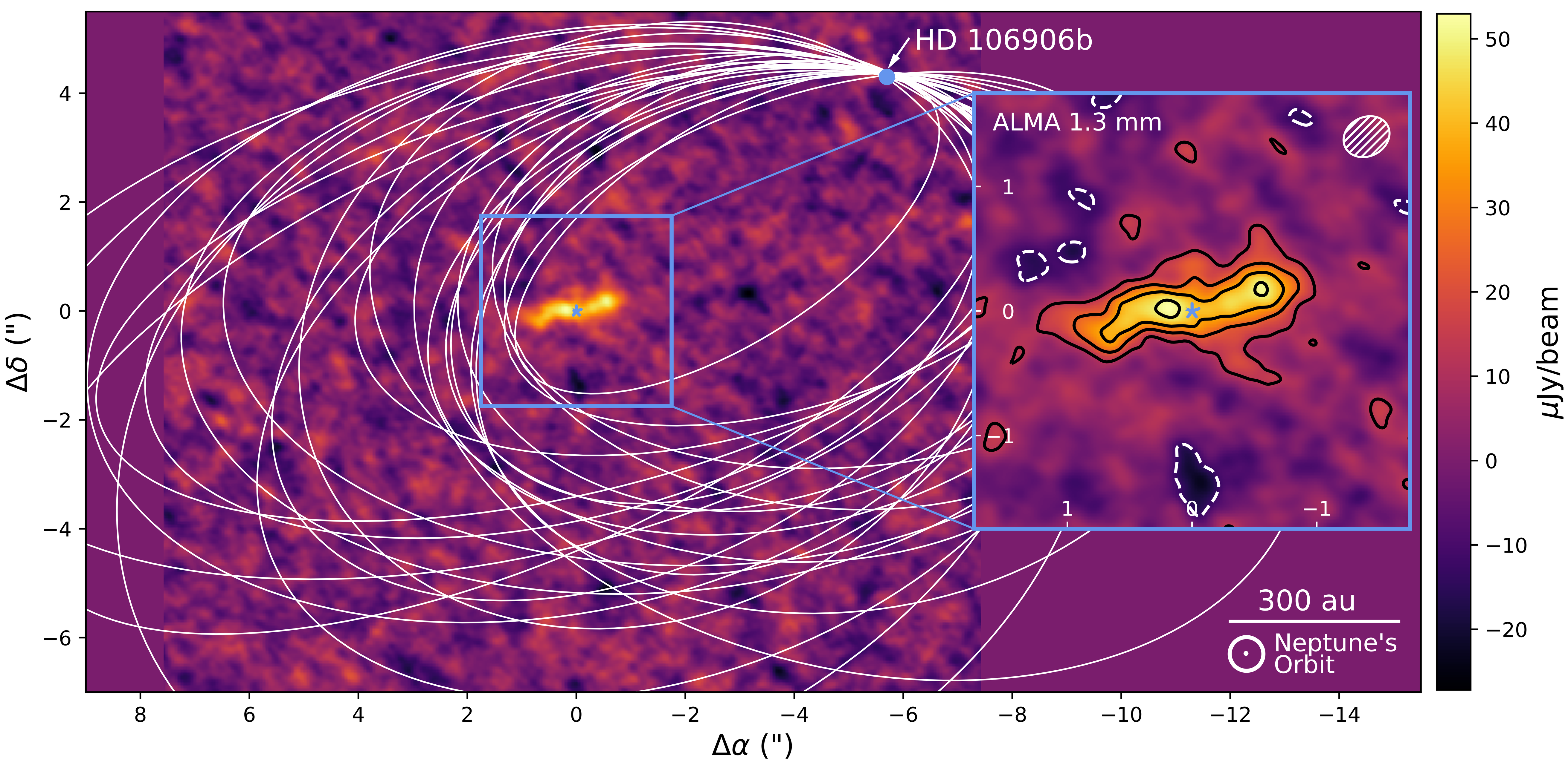

Figure 1 ALMA 1.3 mm continuum image of the HD 106906 system. The location of the central binary is marked by the star symbol and the HST observation of the planet is marked by a dot. 25 orbits sampled from the posterior distribution of orbital elements in Nguyen et al. 2020 are overplotted. The white ellipse represents beam size and orientation. The contour levels are [-2, 2, 4, 6, 8] x σ, where σ is the rms noise in the image (6.2 μJy/beam).

- HD 106906 is a **short-period binary** that hosts a **wide-separation planet** and **debris disk**
- Dust-dominated debris disks are **common** and associated with **planet formation**
- Although **lower mass than planets**, disks are generally **easier to detect** due to **large surface area**
- However, **only a few systems** contain a **disk and directly imaged planet**
- Large planets play a role in the **dynamical history** of disks through **gravitational interactions**
- The origin of **wide separation planets is poorly understood**, but HD 106906b likely **formed closer to the host star**

Disk Features

Stellar offset	$\delta_x = 19 \pm 6$ au $\delta_y = -6 \pm 6$ au	Indicates **moderate** eccentricity (e = 0.5±0.2)
$\frac{\text{apo}}{\text{peri}}$ flux	1.0 ± 0.2	Indicates **low** eccentricity (e = 0±0.2)
Scale height	0.0520 ± 0.0005 (Crotts et al. 2021)	Indicates a **vertically thin** disk

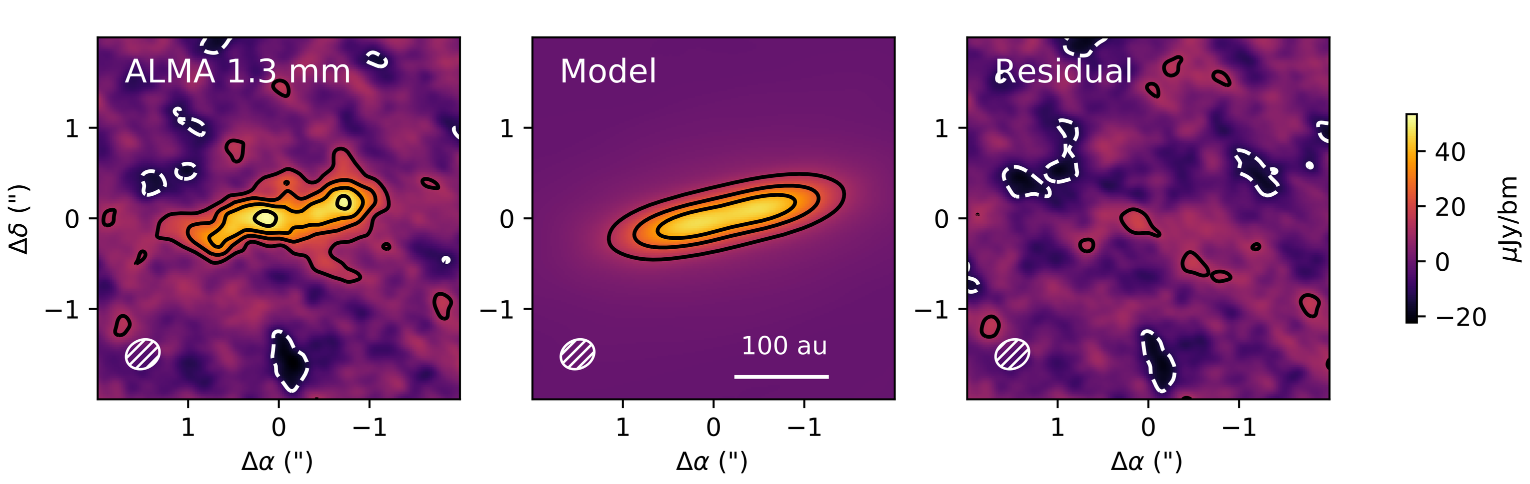

Figure 2 *Left:* 1.3 mm ALMA disk image. *Center:* Simulated ALMA observation of best fit similarity solution model. *Right:* Residual (data-model) image. The contour levels in all panels are as in figure 1.

Gravitational Interaction with HD 106906b

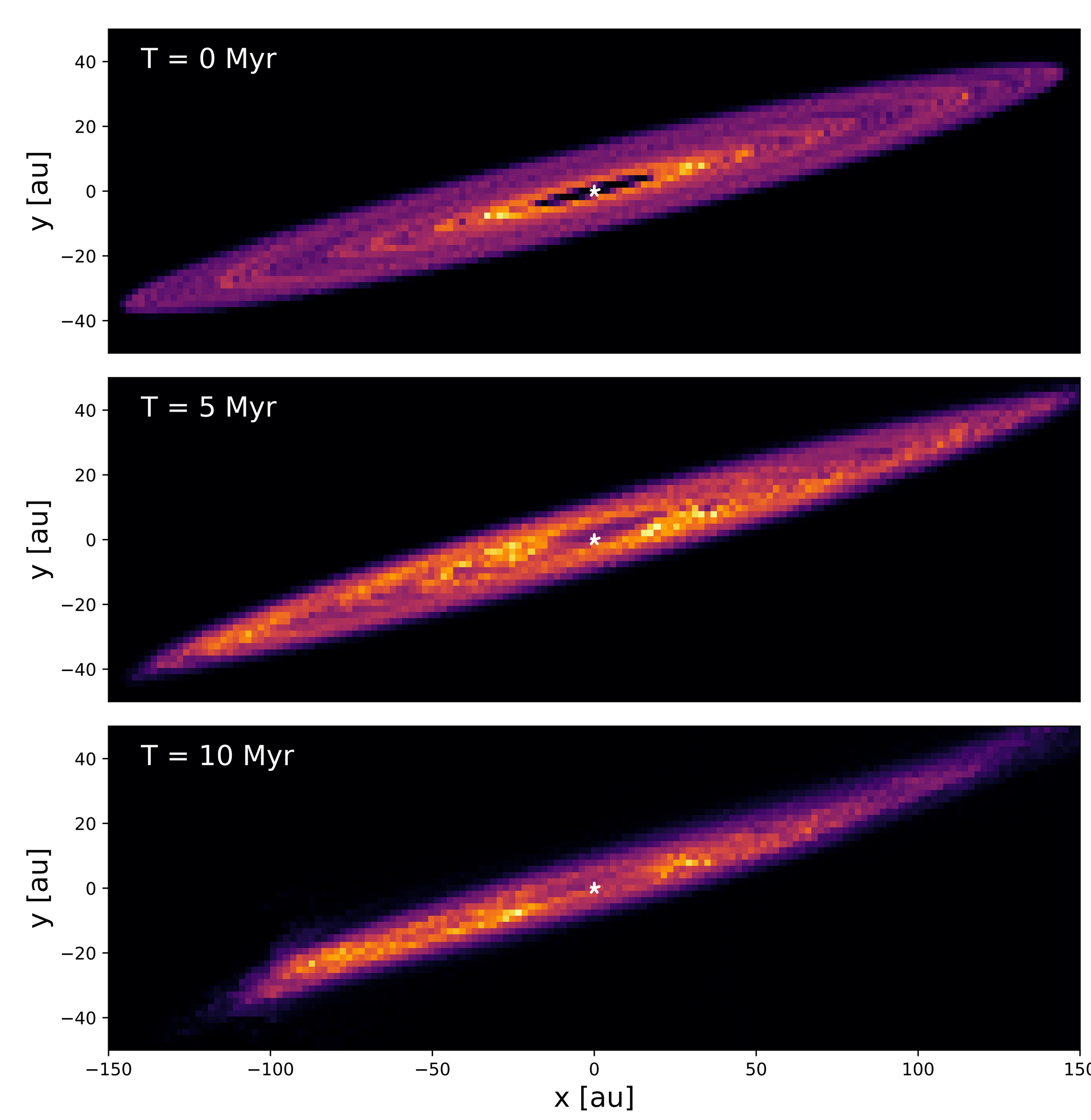

Figure 3 Example distribution of simulated disk particles in sky plane after 0, 5, and 10 Myr of integration using *N*-body code REBOUND (Rein & Lieu 2012, Rein et al. 2019). The star symbol shows the location of the system's center of mass.

- Even a distant planet can affect the shape of a disk through **gravitational interactions**
- Hence, the **observed morphology of disks** can be used to constrain the path of a **planet's orbit**
- For example, a planet on a **highly eccentric** orbit **inclined** relative to the disk midplane might **induce eccentricity** and **inclination in disk particles**

Comparing Dynamical Simulations to Data

- We used an ***N*-body code**, REBOUND (Rein & Lieu 2012, Rein et al. 2019) to model the interaction between HD 106906b and disk test particles for a range of orbital parameters, drawn from **astrometric measurements of the planet**
- As predicted by dynamical theory, high **mutual inclination planets** induced **vertical thickness** in the disk, while **high eccentricity planets** induced **eccentricity in disk particles**
- Although a **possible stellar offset in the ALMA data** as well as **optical wavelength observations** of the disk suggest **eccentricity**, brightness symmetry at mm wavelengths suggests a circular disk
- In addition, a **planetary orbit** within the parameters space supported by astrometric observations **able to induce eccentricity would also result in a puffy disk**
- Hence, ALMA observations suggest that **the disk eccentricity is low** and **not induced by the planet**
- This suggests a **low eccentricity, large semi-major axis** orbit for HD 106906b

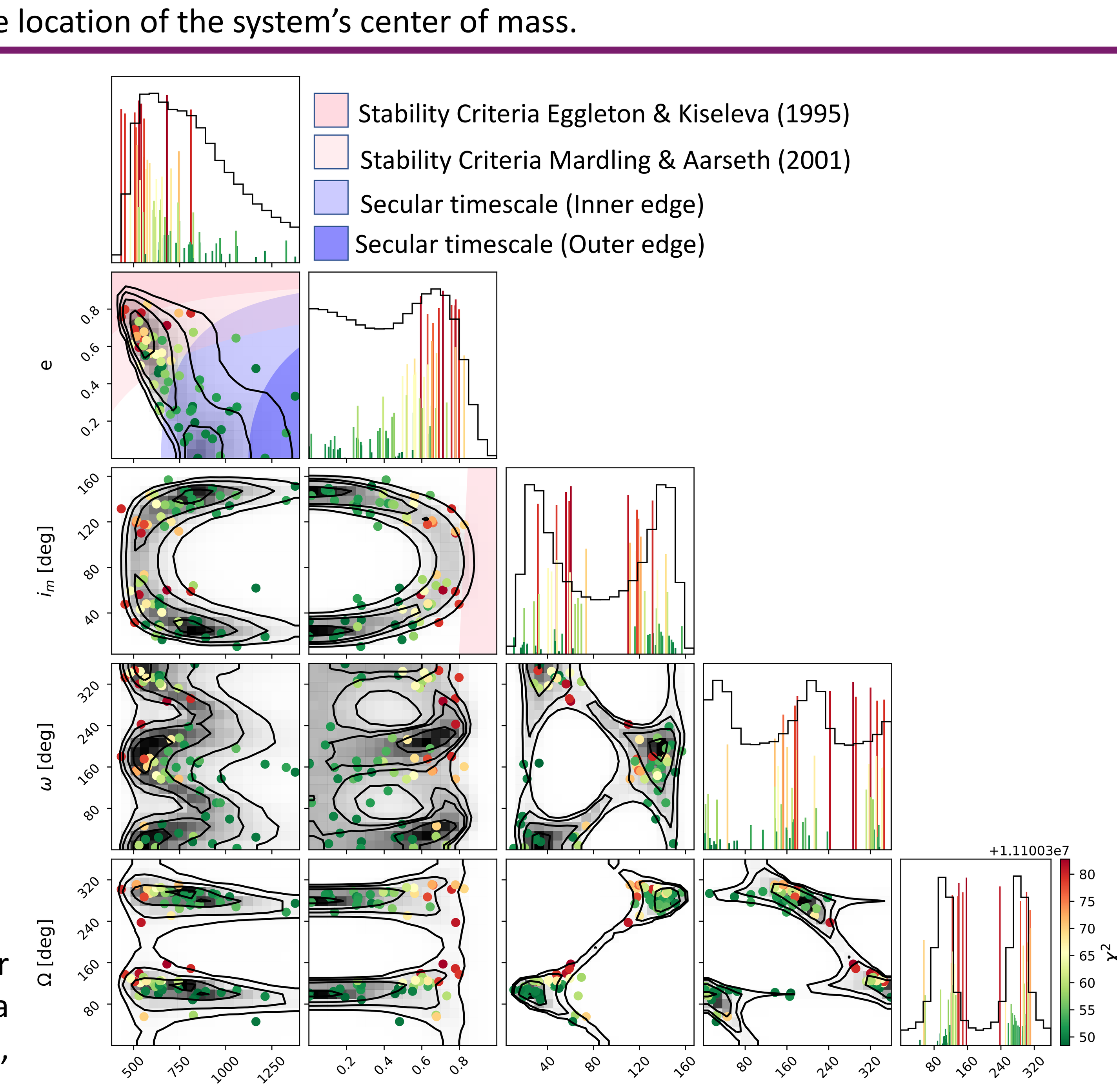

Figure 4 Corner plot of orbital parameters for HD 106906b. The background histogram shows the posterior distribution from a fit to the astrometric observations (Nguyen et al. 2021). Each scatter point represents a simulated disk, with the color corresponding to the goodness of fit. Colored shading shows theoretical criteria, with the red sections showing instable conditions and the blue sections representing an unperturbed disk.

Acknowledgments I would like to thank Prof. Rebekah Dawson for insightful discussion about dynamical simulations and theory and Prof. Meredith Hughes for her mentorship in this work. Funding for this work comes from the Wesleyan CIS Summer 2021 Research in the Sciences program.

References
Crotts, et al., 2021, ApJ
Nguyen, De Rosa & Kalas, 2021, AJ
Nesvold, Naoz, Fitzgerald, 2017, ApJ
Hanno, Tamayo & Brown, 2019, MNRAS
DeRosa & Kalas, 2019, AJ
Eggleton & Kiseleva, 1995, ApJ
Mardling & Aarseth, 2001, MNRAS
Murray & Dermott, 2000