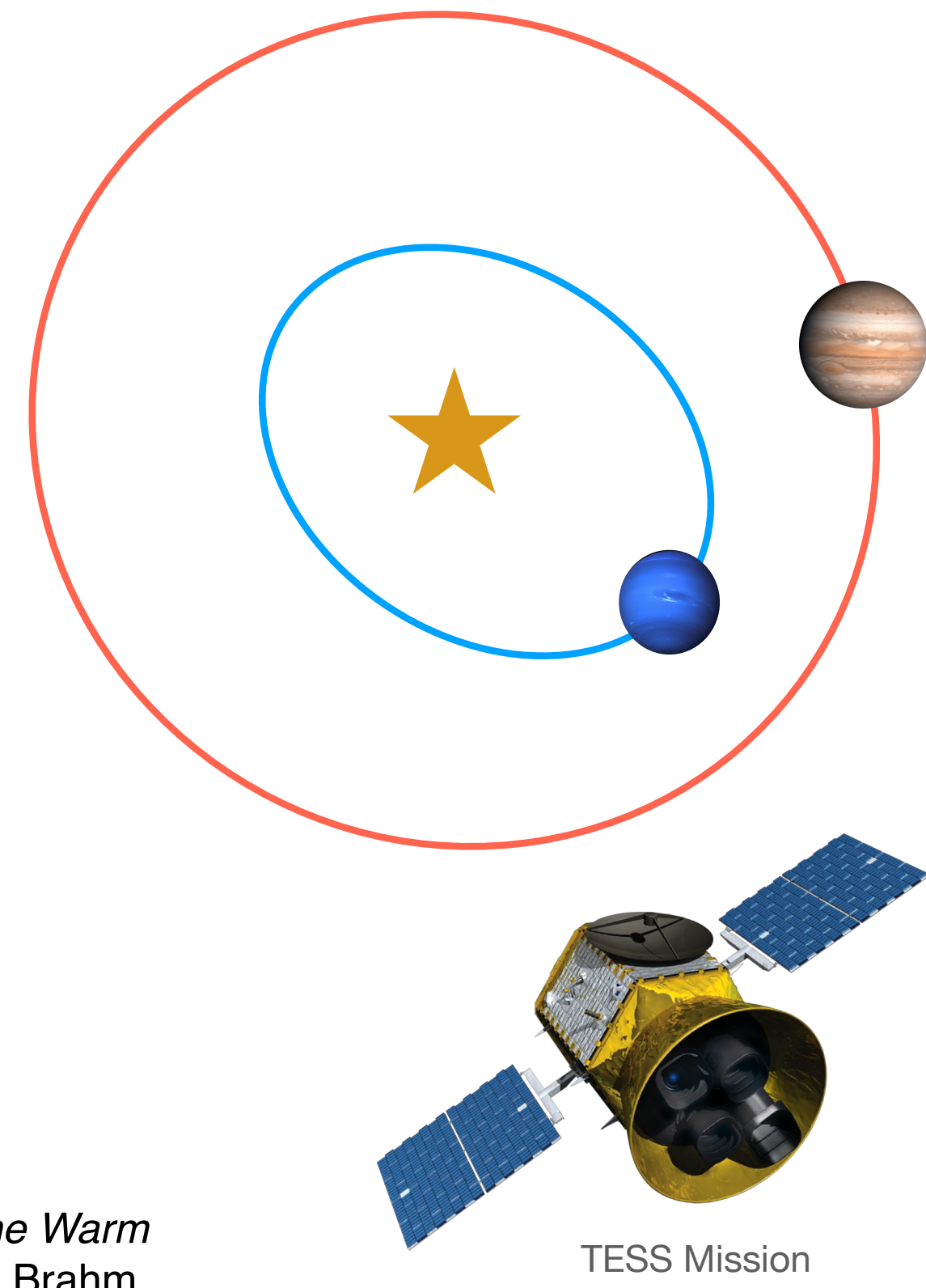


Precise Characterization of a 2:1 Resonant Pair

The **Warm Jupiter TOI-216c** and **Eccentric Warm Neptune TOI-216b**

Rebekah Dawson (Penn State) and collaborators

Precise Transit and Radial-velocity Characterization of a Resonant Pair: The Warm Jupiter TOI-216c and Eccentric Warm Neptune TOI-216b, Dawson, Huang, Brahm, Collins, et al. 2021, AJ, 159, 223
TOI-216b and TOI-216 c: Two Warm, Large Exoplanets in or Slightly Wide of the 2:1 Orbital Resonance, Dawson, Huang, Lissauer, Collins, Sha, et al. 2019, AJ, 158, 65



TESS and ground-based follow up teams

TOI-216b and TOI-216c: Two Warm, Large Exoplanets in or Slightly Wide of the 2:1 Orbital Resonance

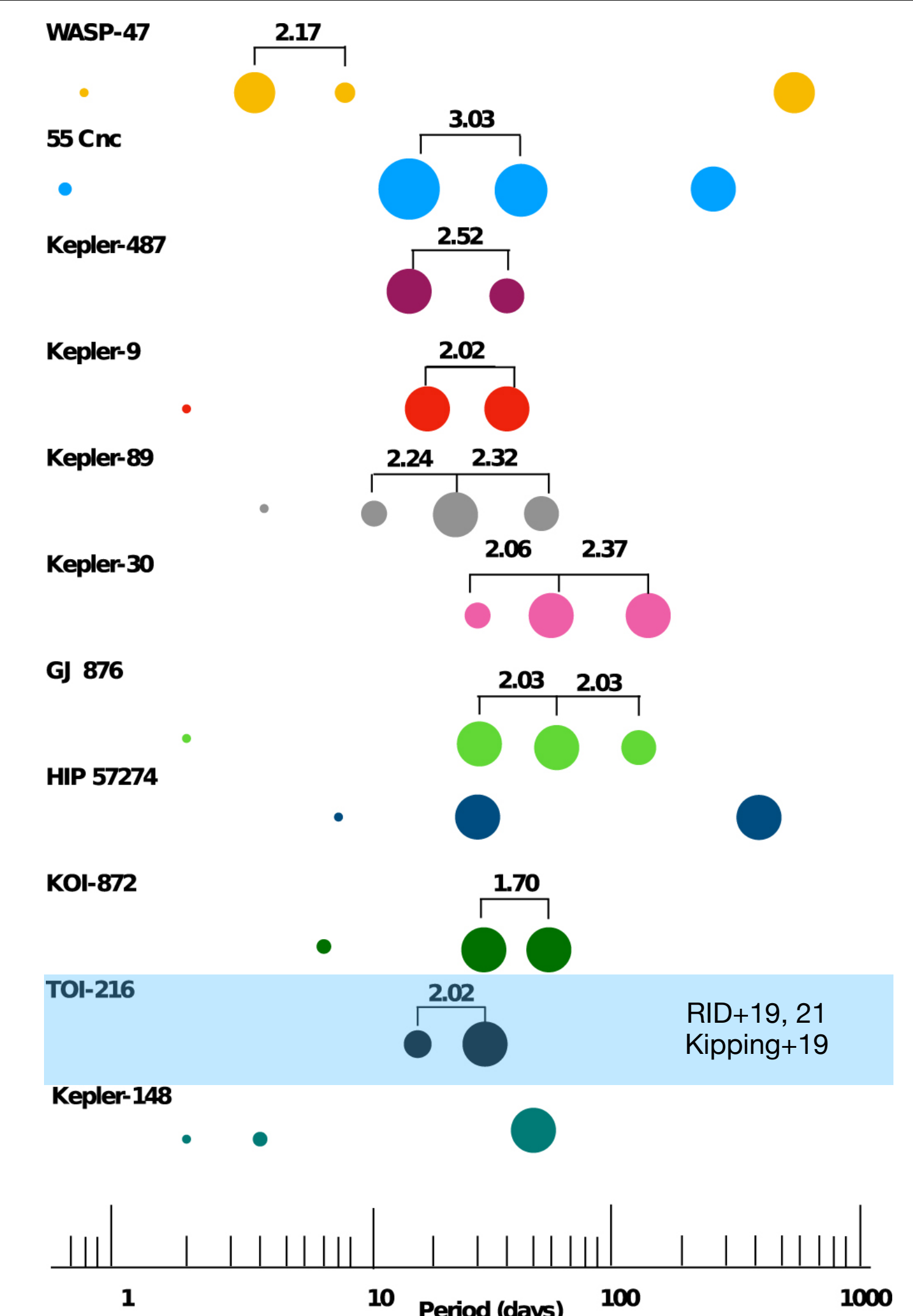
Rebekah I. Dawson¹, Chelsea X. Huang^{2,22}, Jack J. Lissauer³, Karen A. Collins⁴, Lizhou Sha², James Armstrong⁵, Dennis M. Conti⁶, Kevin I. Collins⁷, Phil Evans⁸, Tianjun Gan⁹, Keith Horne¹⁰, Michael Ireland¹¹, Felipe Murgas^{12,13}, Gordon Myers¹⁴, Howard M. Relles³, Ramotholo Sefako¹⁵, Avi Shporer², Chris Stockdale¹⁶, Maruša Žerjal¹, George Zhou⁴, G. Ricker², R. Vanderspek², David W. Latham⁴, S. Seager^{2,17,18}, J. Winn¹⁹, Jon M. Jenkins², L. G. Bouma¹⁹, Douglas A. Caldwell^{3,20}, Tansu Daylan^{2,23}, John P. Doty²¹, Scott Dynes², Gilbert A. Esquerdo⁴, Mark Rose³, Jeffrey C. Smith^{3,20}, and Liang Yu²

Precise Transit and Radial-velocity Characterization of a Resonant Pair: The Warm Jupiter TOI-216c and Eccentric Warm Neptune TOI-216b

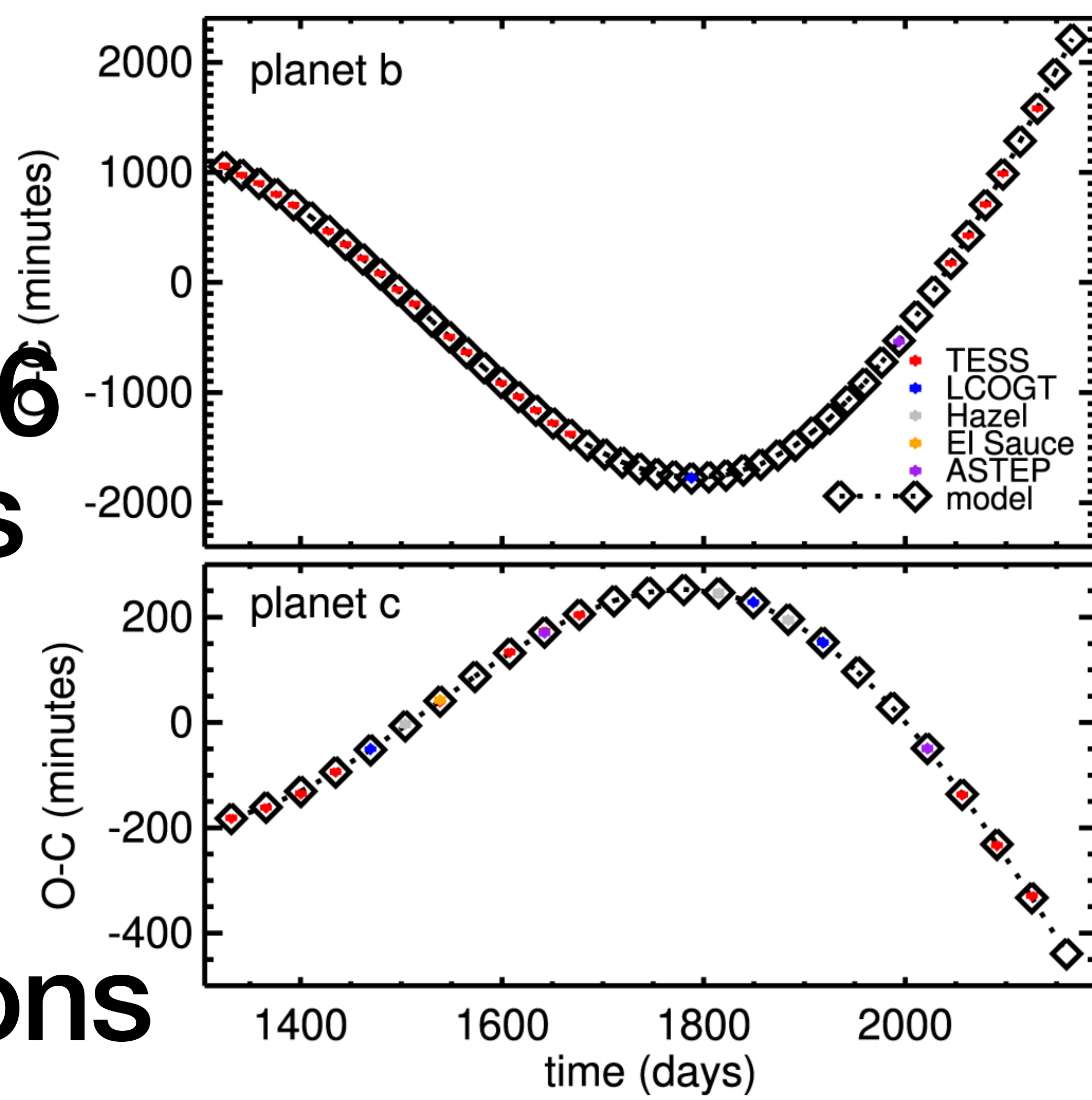
Rebekah I. Dawson¹, Chelsea X. Huang^{2,36}, Rafael Brahm^{3,4}, Karen A. Collins⁵, Melissa J. Hobson^{4,6}, Andrés Jordán^{3,4}, Jiayin Dong^{1,7}, Judith Korth⁸, Trifon Trifonov⁹, Lyu Abe¹⁰, Abdelkrim Agabi¹⁰, Ivan Bruni¹¹, R. Paul Butler¹², Mauro Barbieri¹³, Kevin I. Collins¹⁴, Dennis M. Conti¹⁵, Jeffrey D. Crane¹⁶, Nicolas Crouzet¹⁷, Georgina Dransfield¹⁸, Phil Evans¹⁹, Néstor Espinoza²⁰, Tianjun Gan²¹, Tristan Guillot¹⁰, Thomas Henning⁹, Jack J. Lissauer²², Eric L. N. Jensen²³, Wencelas Marie Sainte²⁴, Djamel Mékarnia¹⁰, Gordon Myers²⁵, Sangeetha Nandakumar¹³, Howard M. Relles⁵, Paula Sarkis⁹, Pascal Torres^{4,6}, Stephen Shectman¹⁶, François-Xavier Schmid¹⁰, Avi Shporer², Chris Stockdale²⁶, Johanna Teske^{16,37}, Amaury H. M. J. Triaud¹⁸, Sharon Xuesong Wang¹⁶, Carl Ziegler²⁷, G. Ricker², R. Vanderspek², David W. Latham⁴, S. Seager^{2,28,29}, J. Winn³⁰, Jon M. Jenkins²², L. G. Bouma³⁰, Jennifer A. Burt³¹, David Charbonneau³, Alan M. Levine², Scott McDermott³, Brian McLean³³, Mark E. Rose²², Andrew Vanderburg^{34,38}, and Bill Wohler^{22,35}

Warm Jupiters commonly have companions in or near resonance but resonant behavior is usually uncertain

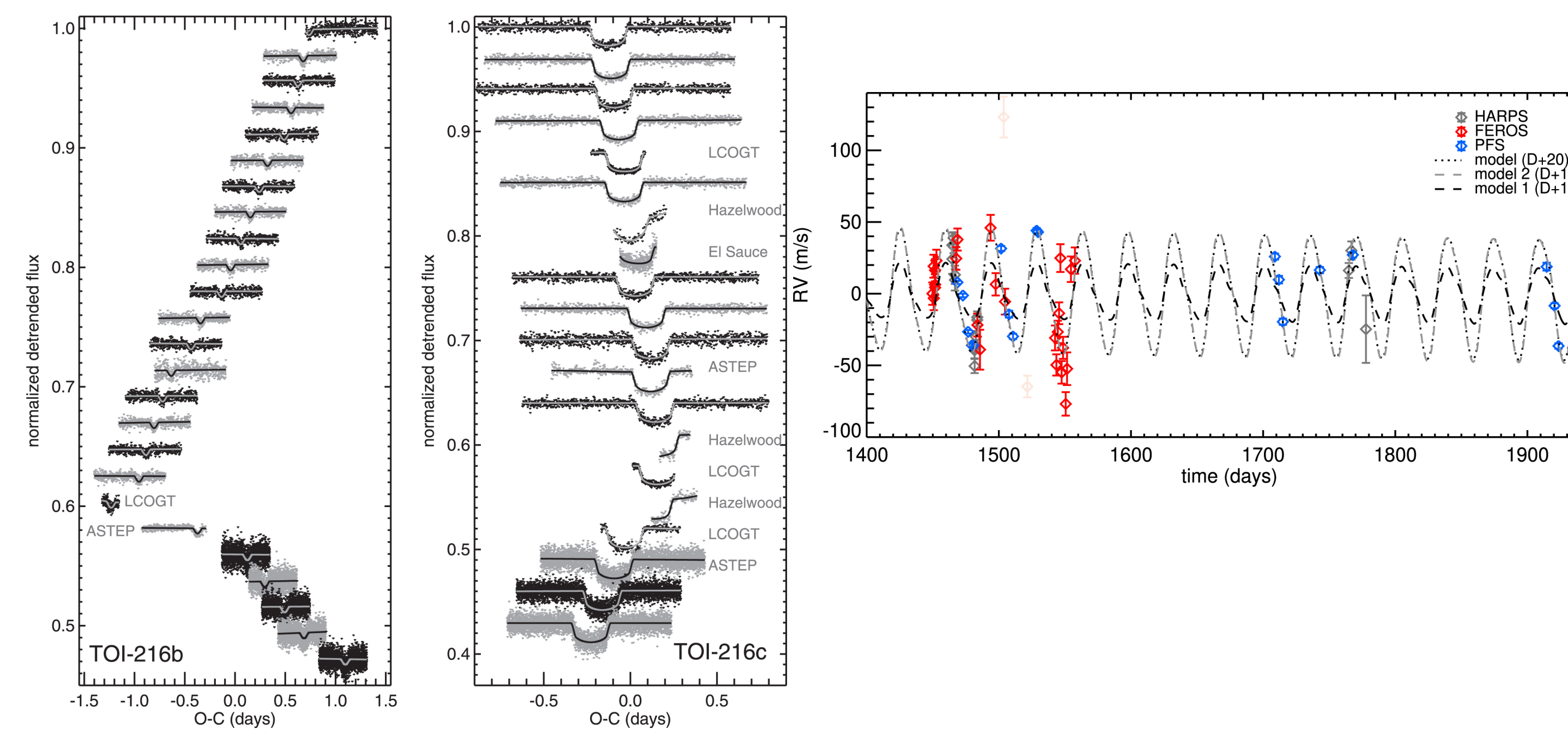
Even resonant warm Jupiters' origins are debated (disk migration, Lee & Peale 2002; in situ formation, Dong & RID 2016, Morrison, RID, & MacDonald 2020)



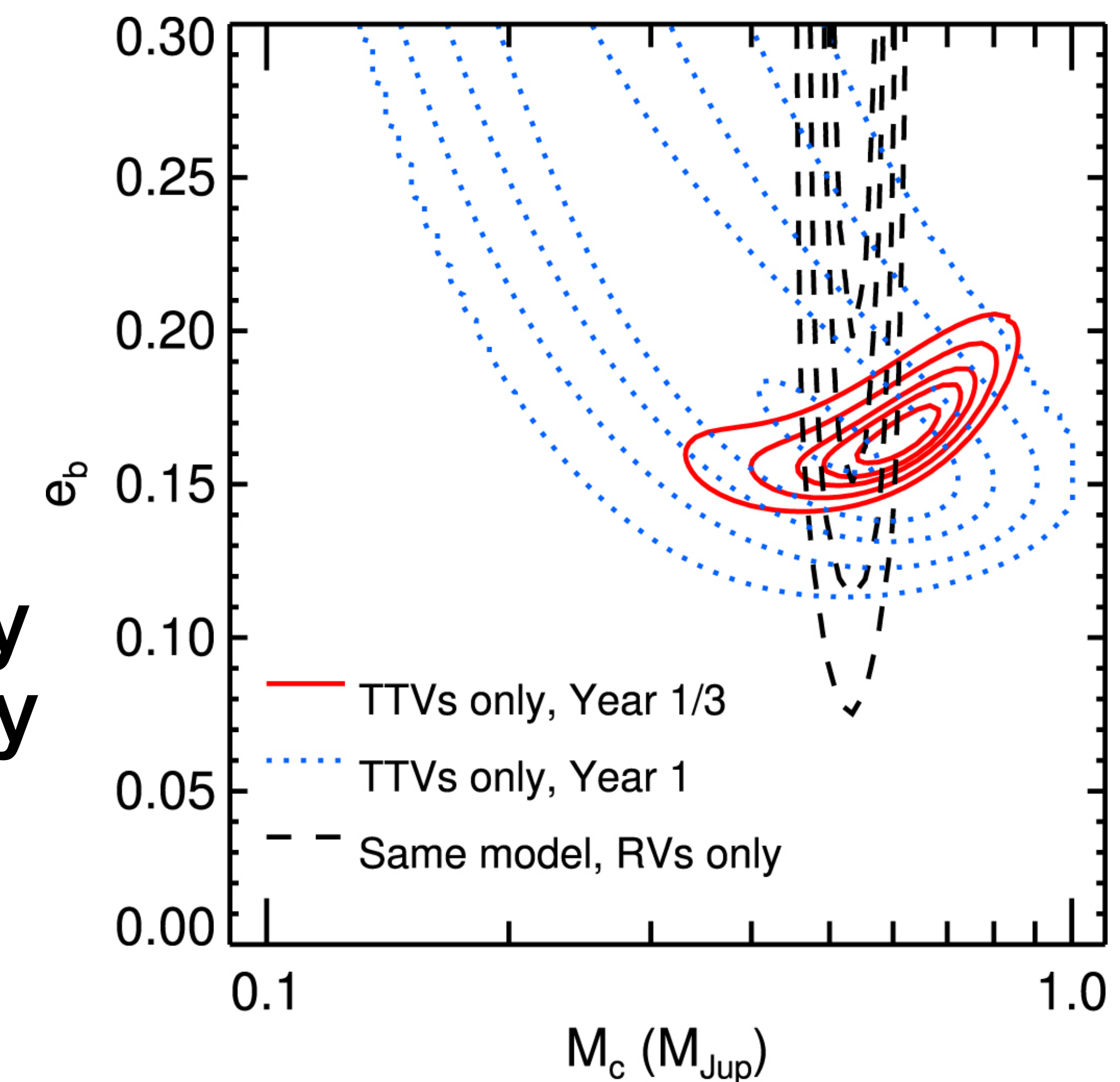
TOI-216 planets exhibit transit timing variations



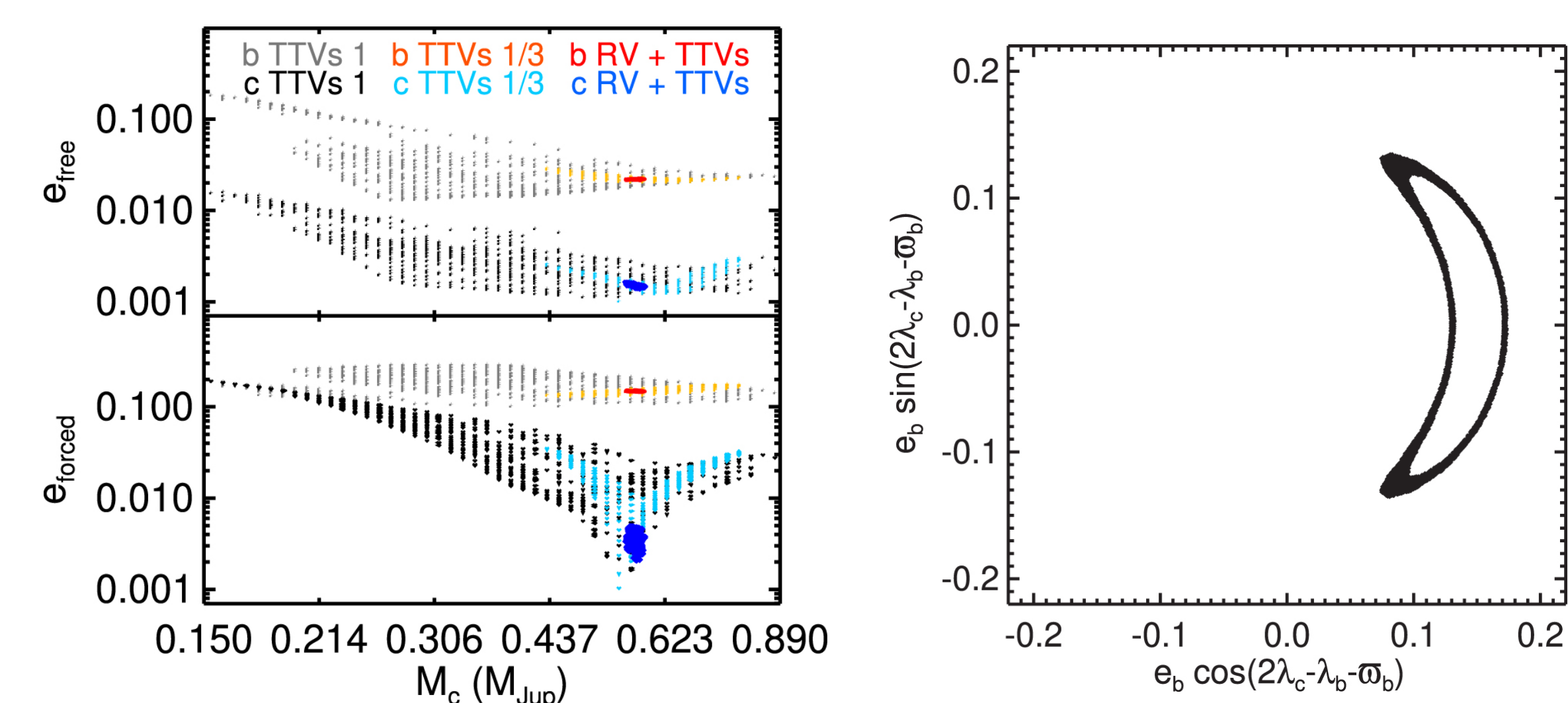
Radial velocity observations and an extended TTV baseline



break the mass-eccentricity degeneracy

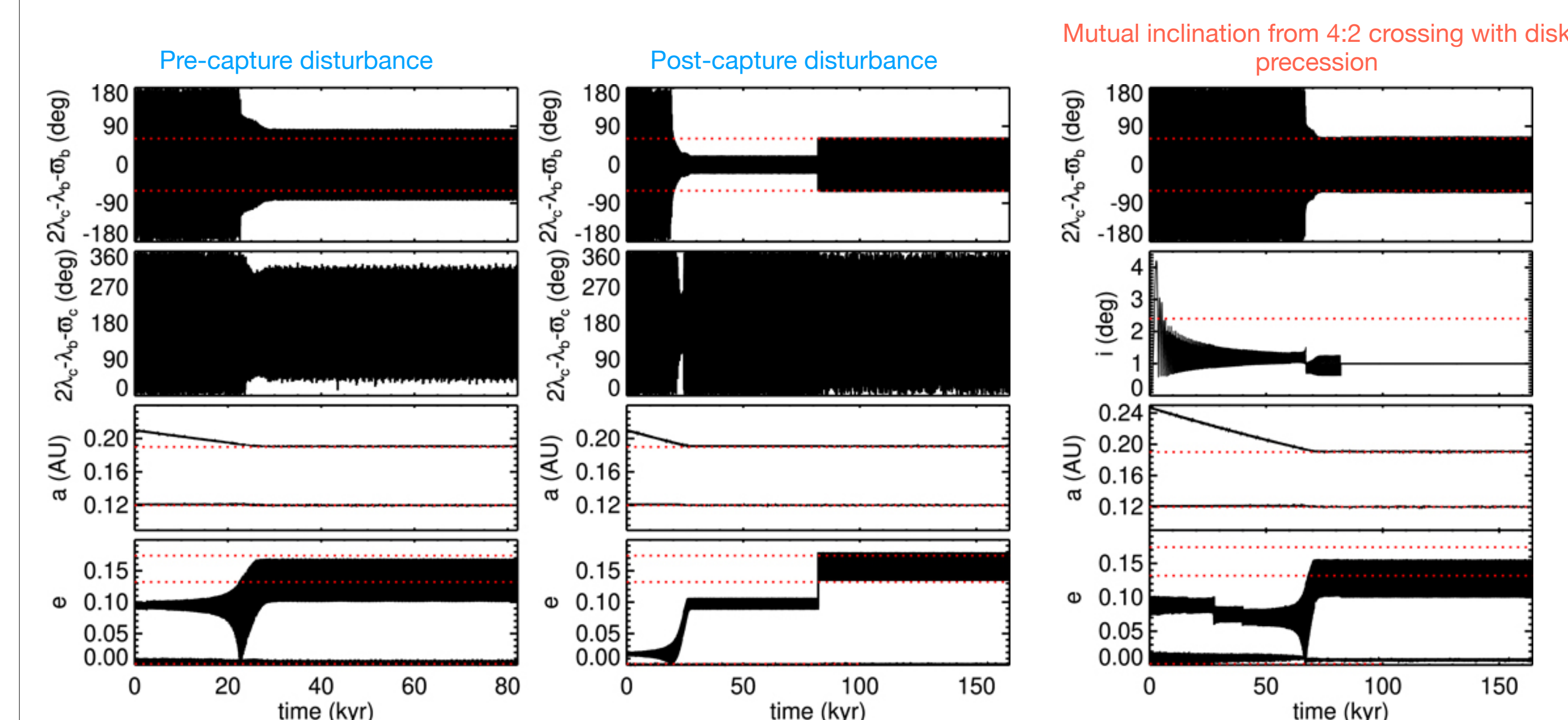


Small but significant libration amplitude, free eccentricity, and mutual inclination



Libration amplitude $60^\circ \pm 2^\circ$
 Free eccentricity (b) $0.0222 +0.0005/-0.0003$
 Mutual inclination $1.2 - 3.9^\circ$ (95% confidence interval)

Example origins scenarios: disturbance from additional planet(s) and/or disk



Summary and Future Work

- The TOI-216 pair librates in the 2:1 resonance with a small but significant libration amplitude, free eccentricity, and mutual inclination, likely generated by a disturbance beyond simple smooth disk migration.
- Origins scenarios must match the now tightly-constrained dynamical parameters
- Future transit observations may confirm transit duration variations (hints in the current dataset). Additional RV observations could ideally place constraints on the presence of other planets, but stellar activity is a challenge. JWST should be able to constrain the C/O ratio for the outer planet.