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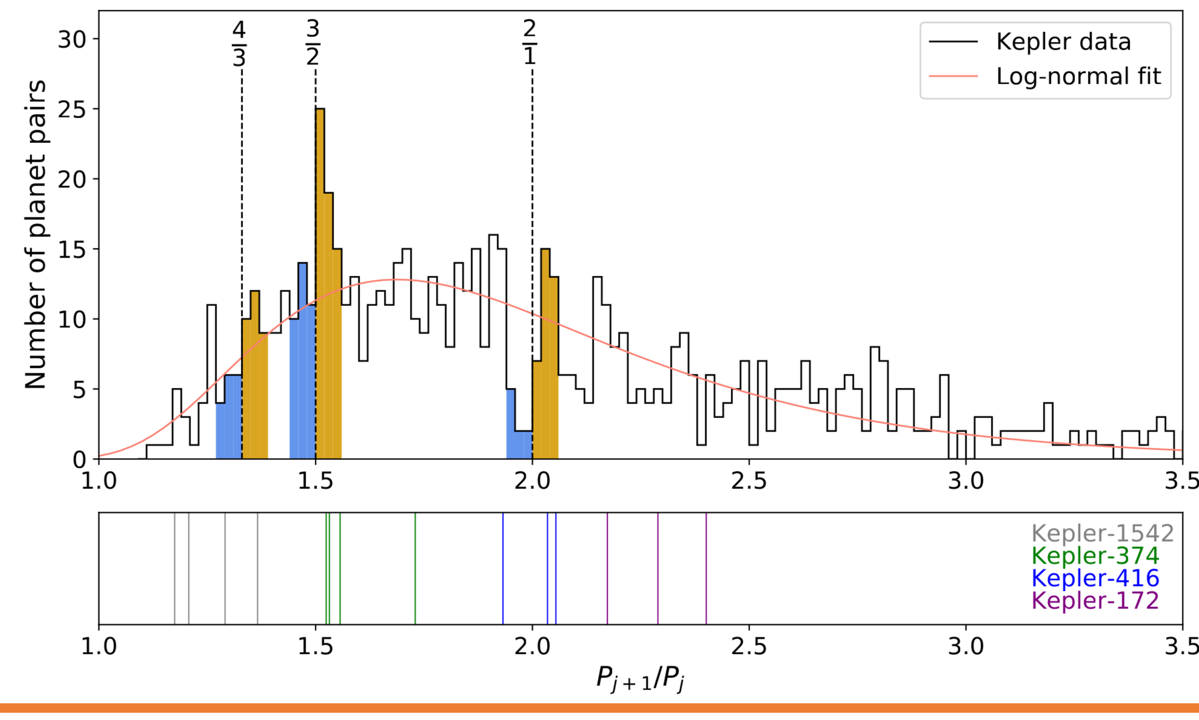
Caltech

Dynamics and Origins of the Near-Resonant Kepler Planets

Max Goldberg & Konstantin Batygin (*Caltech*)

A subset of Kepler planets lie near **mean motion resonance (MMR)**

- Why do planets lie preferentially slightly outside of resonance?
- Why are resonant planets so rare?
- Do resonant and non-resonant planets have the same formation pathway?



From Weiss et al. (2022)

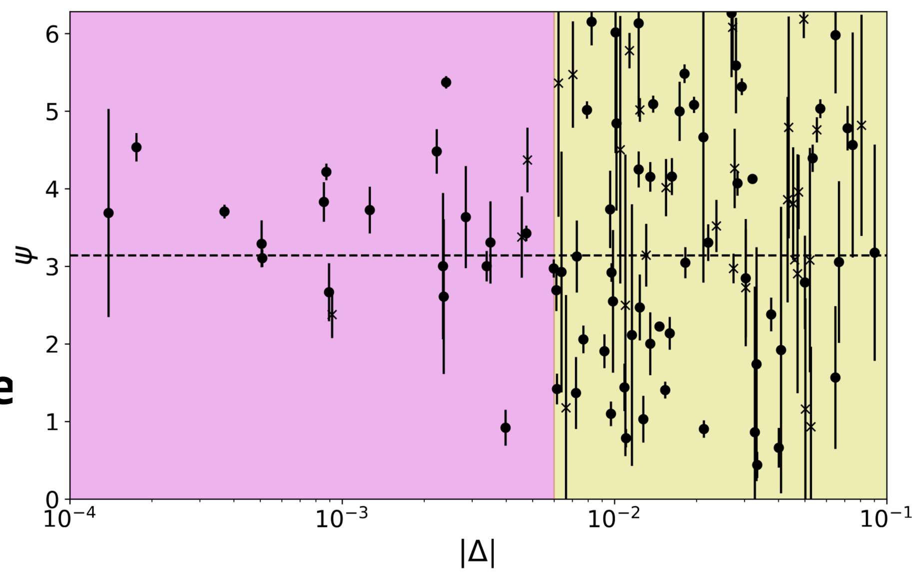
The orbits of near-resonant planets can be probed in detail with **transit timing variations (TTVs)**

Distance from resonance

$\Delta = \frac{P_2}{P_1}\frac{k-1}{k} - 1$

Generalized resonant angle

$\psi = k\lambda_2 - (k-1)\lambda_1 - \hat{\varpi}$



Among Kepler planets,
when $|\Delta| < 0.6\%, \psi$ librates
when $|\Delta| > 0.6\%, \psi$ circulates

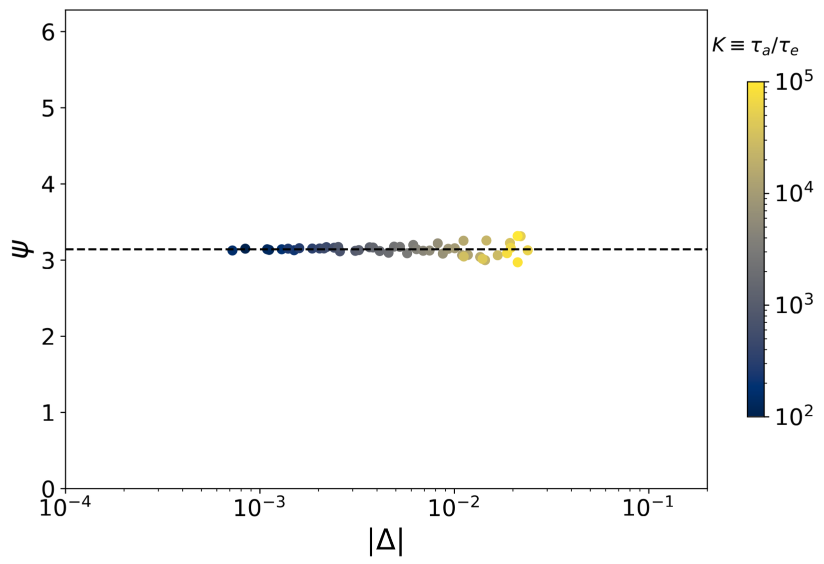
This is a non-equilibrium state

What can we learn about the **origin** of these planets?

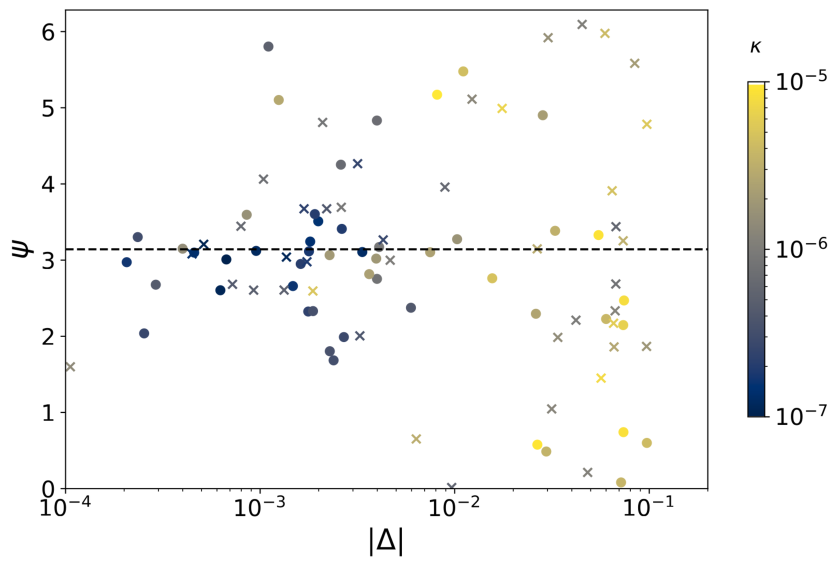
MMRs form during the protoplanetary disk phase and are highly sensitive to disk conditions

We tested 4 hypotheses proposed to explain the presence of planets wide of MMR:

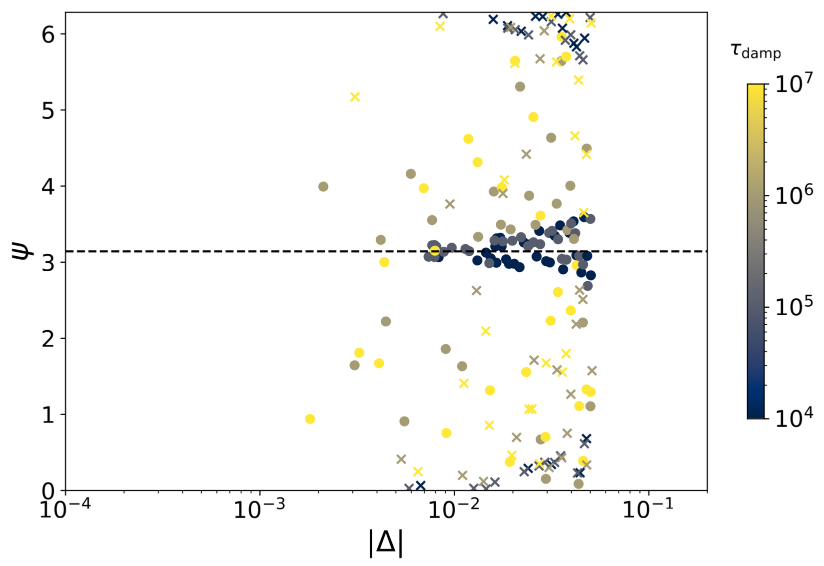
Laminar disk



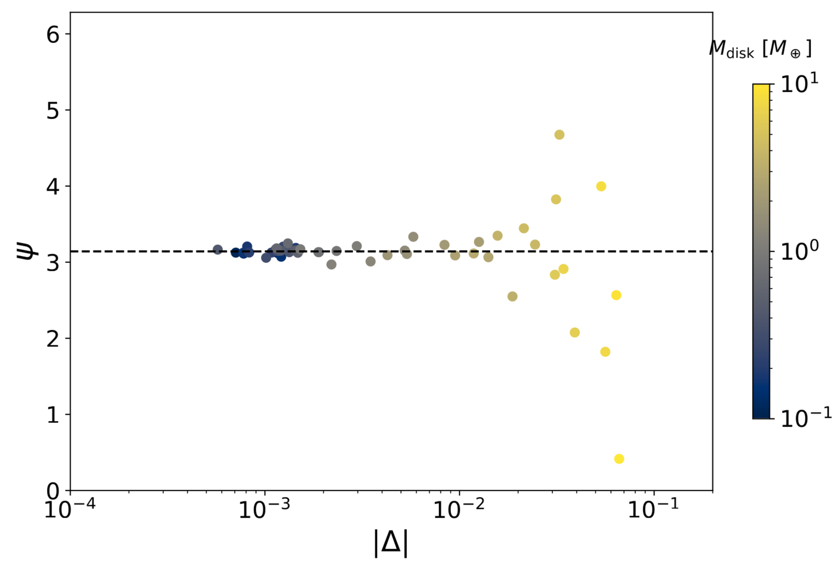
Turbulent disk



Tidal damping



Planetesimal damping

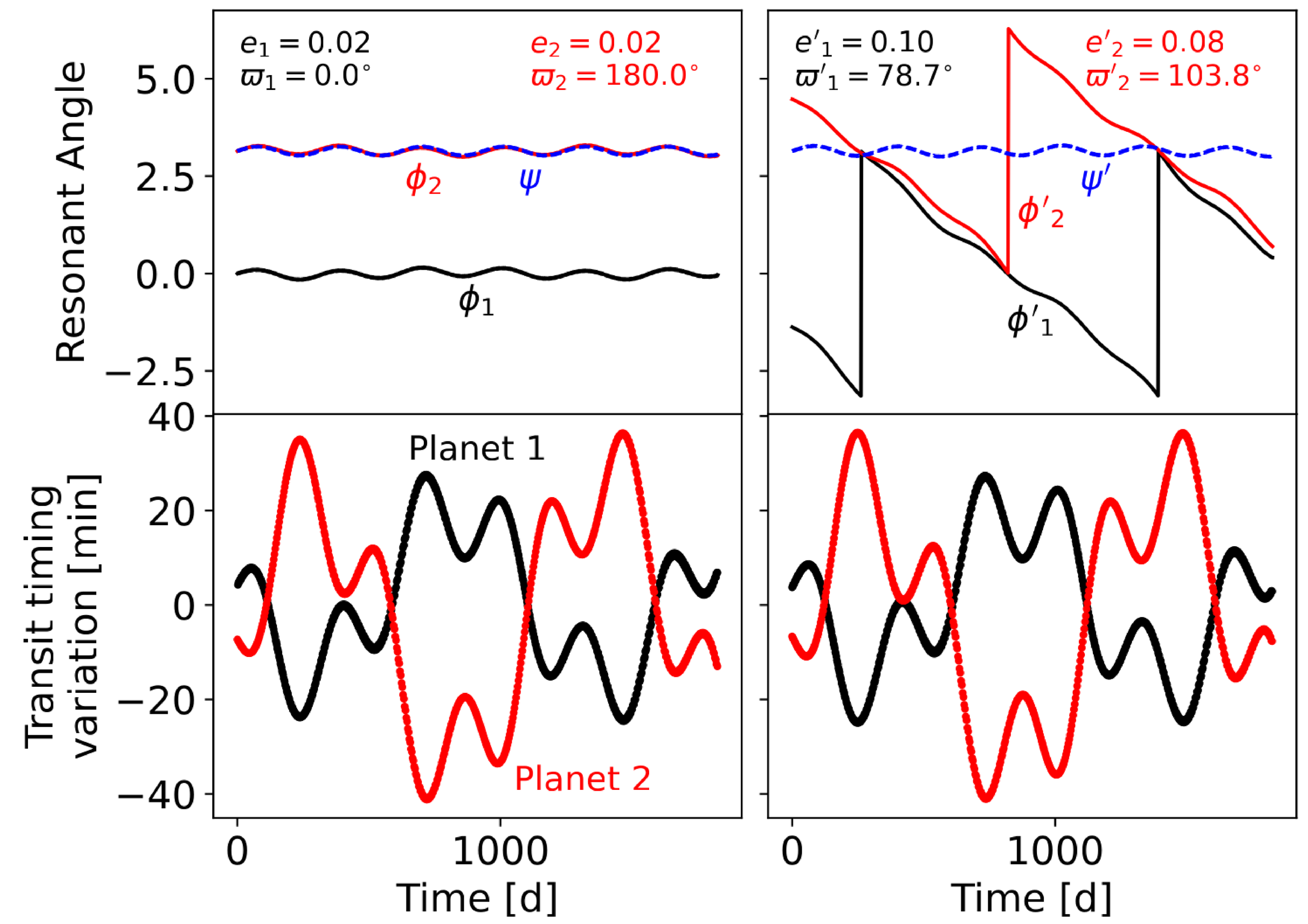


Paper is published!

Goldberg, M. and Batygin, K. (2023). Dynamics and Origins of the Near-resonant Kepler Planets. The Astrophysical Journal, 948:12.

Aside:

Determining resonance from TTV data is tricky due to degeneracies! Make sure to use the generalized resonant angle ψ instead of standard resonant angles ϕ_1, ϕ_2 (see paper for details).



Conclusions:

Some dynamical excitation is required to reproduce the near-resonant Kepler systems. Stochastic forces from turbulent eddies in the inner disk is a compelling solution to this problem.

References:

Choksi, N., & Chiang, E. 2023, Monthly Notices of the Royal Astronomical Society, 522, 1914, doi: 10.1093/mnras/stad835
Delisle, J.-B., & Laskar, J. 2014, Astronomy and Astrophysics, 570, L7, doi: 10.1051/0004-6361/201424227
Flock, M., Fromang, S., Turner, N. J., & Benisty, M. 2017, The Astrophysical Journal, 835, 230, doi: 10.3847/1538-4357/835/2/230
Ghosh, T., & Chatterjee, S. 2023, The Astrophysical Journal, 943, 8, doi: 10.3847/1538-4357-aca58e
Hadden, S., & Lithwick, Y. 2014, The Astrophysical Journal, 787, 80, doi: 10.1088/0004-637X/787/1/80
—. 2017, The Astronomical Journal, 154, 5, doi: 10.3847/1538-3881/aa71ef
Jontof-Hutter, D., Wolfgang, A., Ford, E. B., et al. 2021, The Astronomical Journal, 161, 246, doi: 10.3847/1538-3881/abd93f
Lithwick, Y., & Wu, Y. 2012, The Astrophysical Journal Letters, 756, L11, doi: 10.1088/2041-8205/756/1/L11
Rein, H. 2012, Monthly Notices of the Royal Astronomical Society, 427, L21, doi: 10.1111/j.1745-3933.2012.01337.x
Weiss, L. M., Millholland, S. C., Petigura, E. A., et al. 2022, Architectures of Compact Multi-planet Systems: Diversity and Uniformity