The Effects of Near-Resonant Companions on Planetary Spin States

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The Small Star Advantage

- Favorable Geometry for Transits
- Ubiquitous
- Long-lived
- Many Earth-sized planets already found

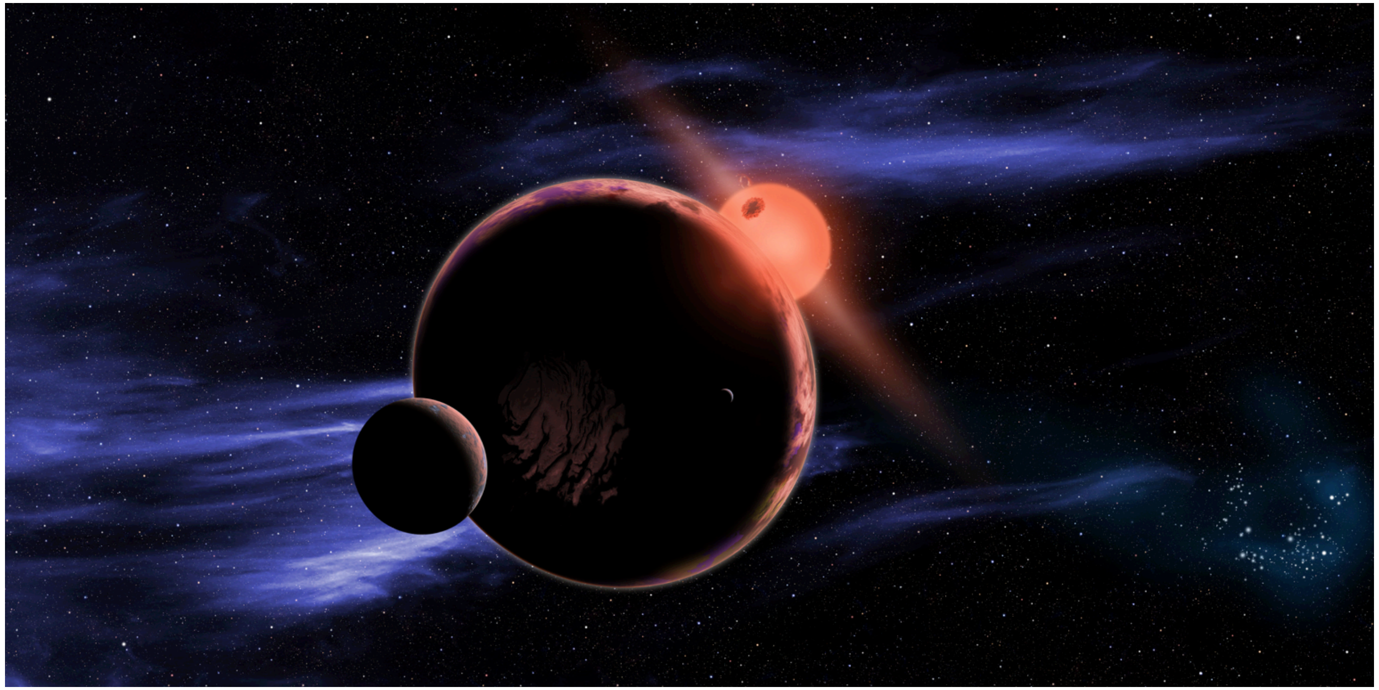


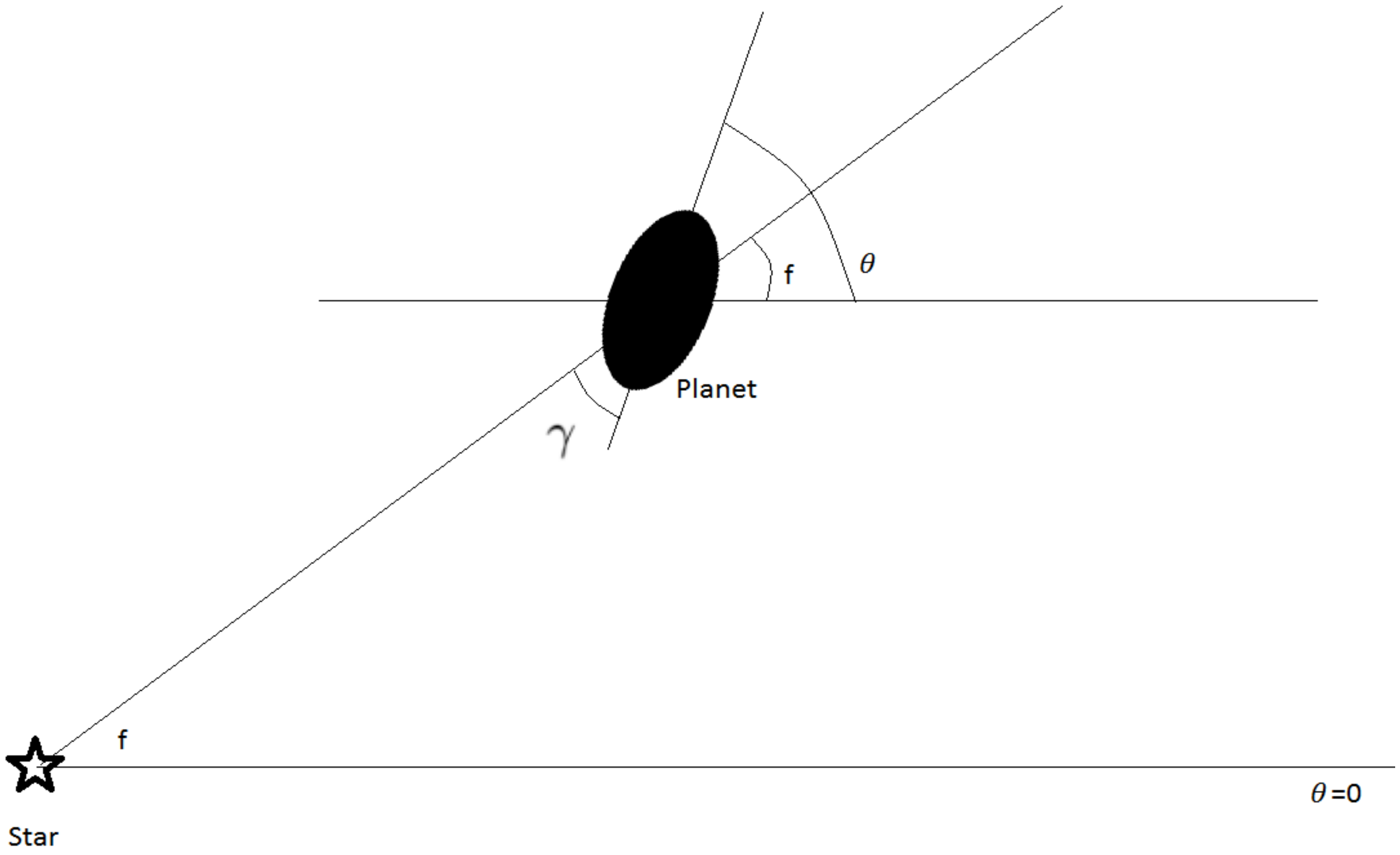
Image Credit: D. Aguilar/Harvard CFA

The Small Star Disadvantage

- Long pre-main sequence phase, up to ~Gyr
- High XUV flux and potential for water loss
  - (Belmont et al. 2017 find that planets in HZ of ultra-cool dwarfs may retain enough water.
- TIDAL LOCKING!
  - Synchronous rotation leads to perpetual day and night sides.
  - Some possible solutions:
    - 3:2 states (like Mercury)
    - Atmospheric Tides (Leconte et al. 2015)

Standard "Pendulum" Spin Model

$\gamma + \frac{1}{2} \omega_S^2 \sin(2\gamma) = 0$



Let’s Throw in Another Planet! (In a mean-motion resonance)

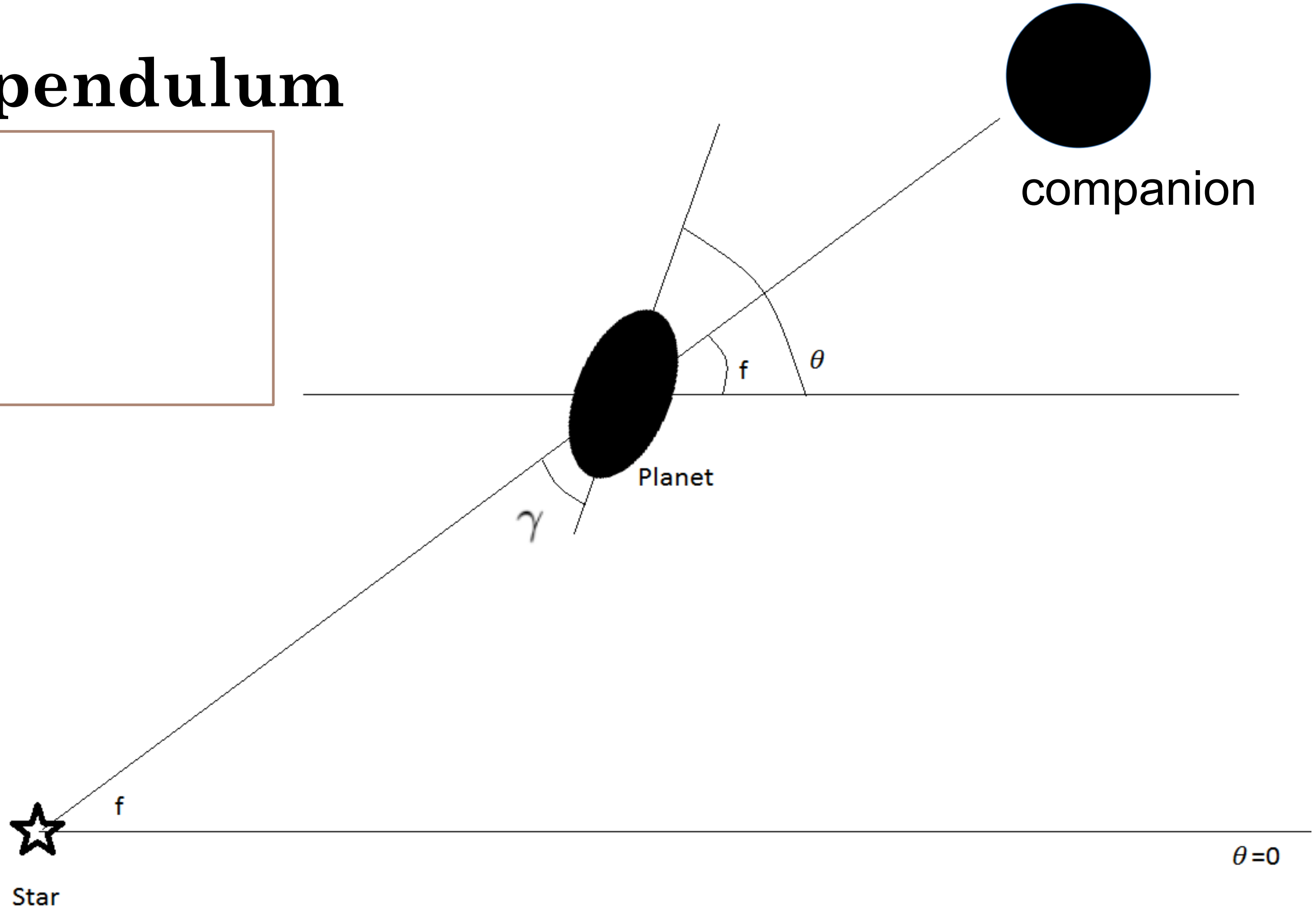
Becomes a **driven pendulum**

$$\gamma + \frac{1}{2}\omega_S^2 \sin(2\gamma) + n = 0$$

$$n = -\frac{1}{j}\omega_M^2 \sin\phi$$

$$\phi = -\omega_M^2 \sin\phi$$

$$\phi = (j+1)n' + jn - \omega$$



Plus Tidal Damping…

$$\tau = \frac{15}{2} \gamma \frac{M}{m} \left(\frac{R}{a}\right)^{6} MR^{2} \sigma$$

$$\gamma + \frac{1}{2} \omega_{S}^{2} \sin(2\gamma) + n - \tau = 0$$

- Classical Picture (planet and star only): undriven pendulum + dissipation → tidal locking.
- Our model: Driven pendulum + dissipation → ??

TRAPPIST-1

- 0.08 M_sun
- We look at planet d, and examine effects of nearest outer companion (planet e, in a 3:2 mean-motion resonance).
- Make assumptions in initial conditions.
- Make assumptions, or deductions, in sphericity of the planet, eccentricity, mass of perturber (planet e).

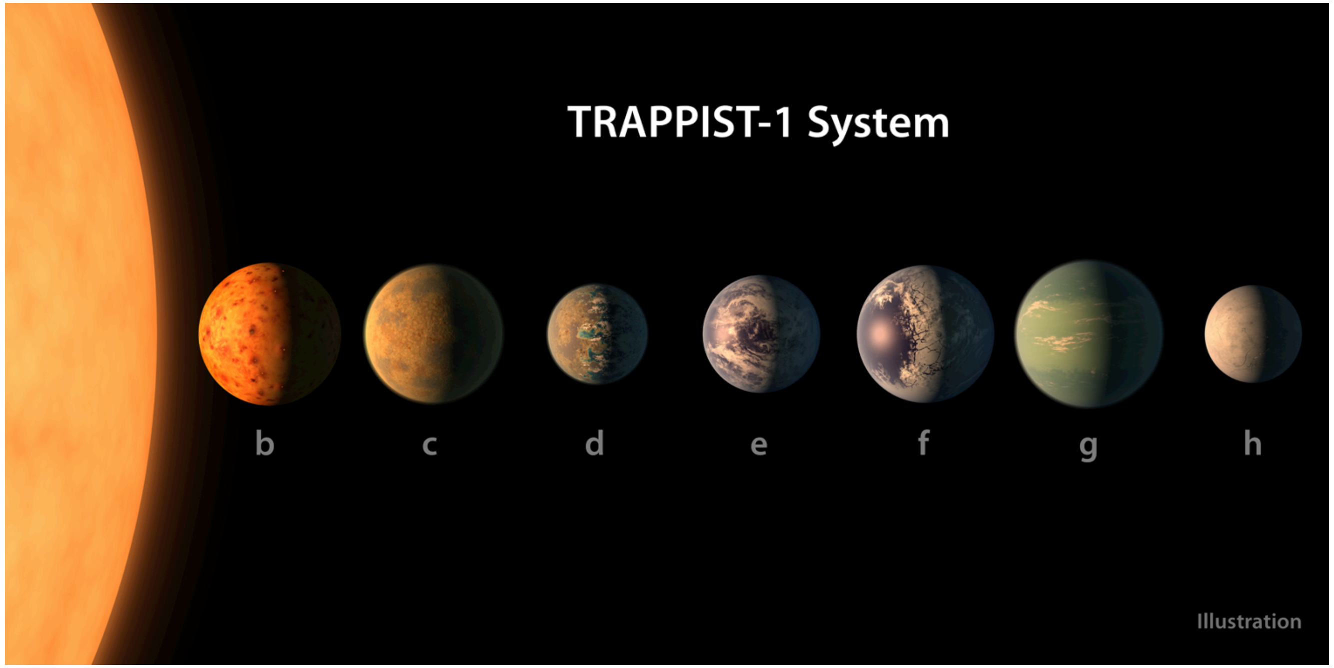
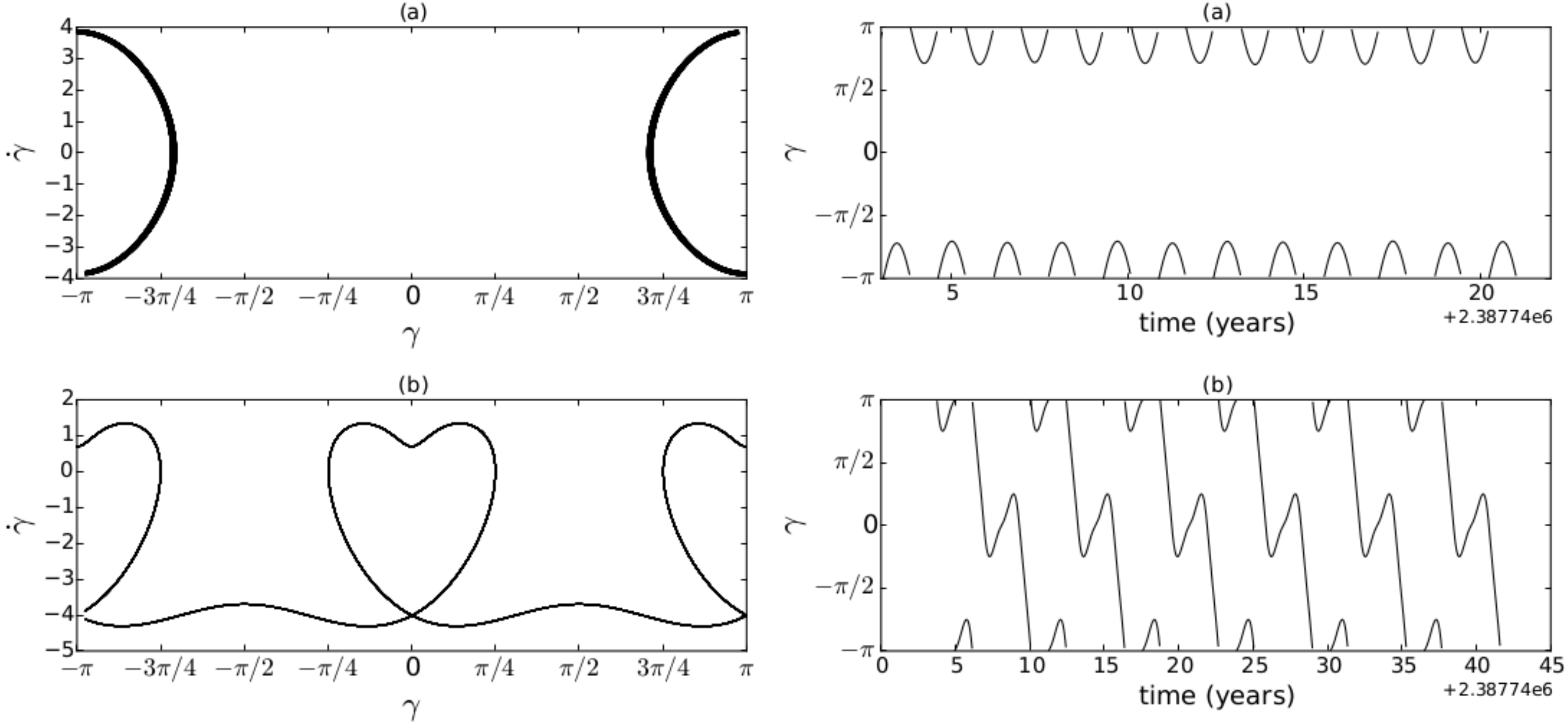


Image Credit: NASA/JPL-Caltech

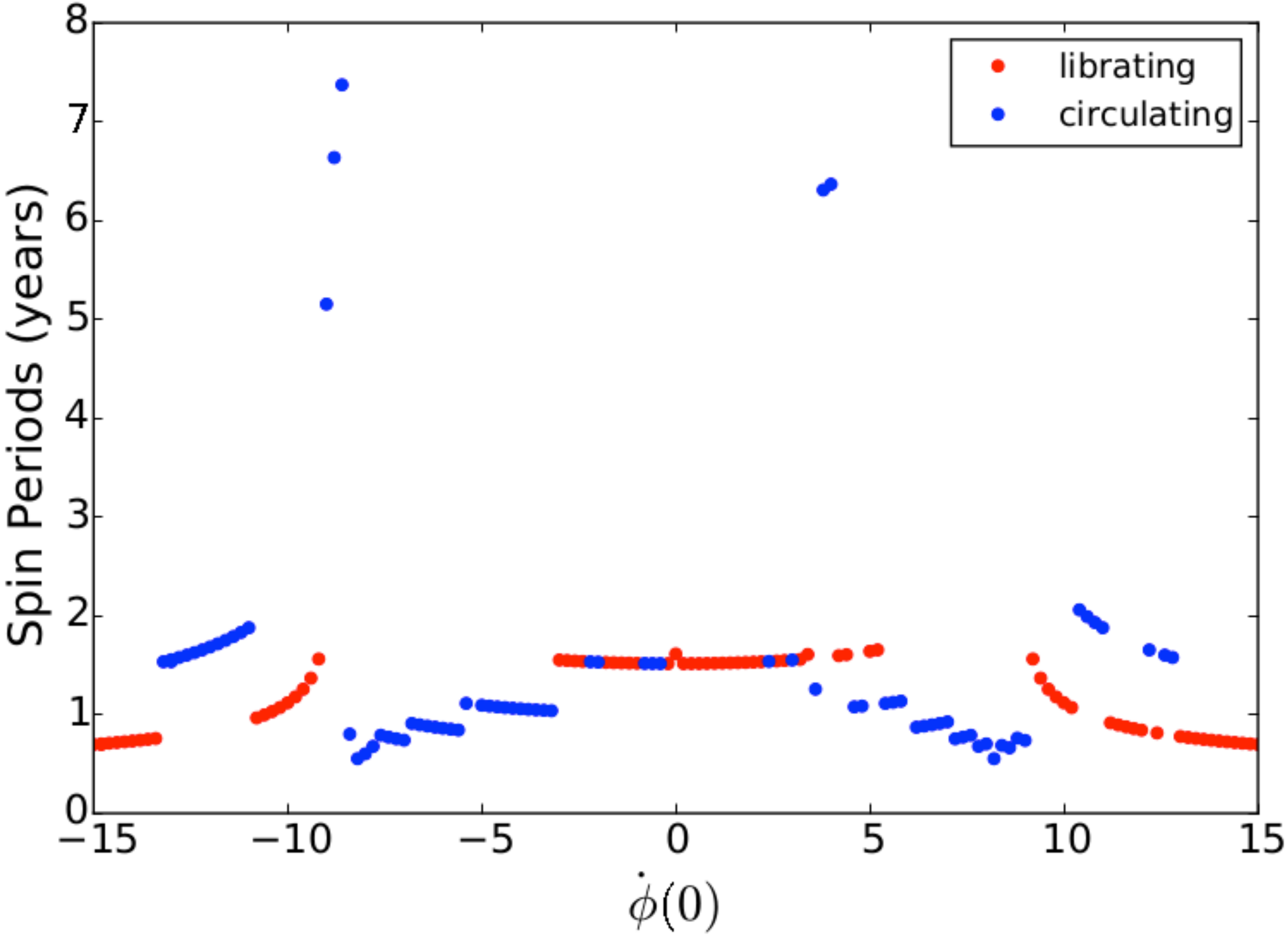
TRAPPIST-1d: Slight Difference in initial conditions



$\phi(0)=3.0$

$\phi(0)=3.4$

Both sims: $\gamma(0)=5.0/yr$, $\gamma(0)=0$, $\phi(0)=0$



(Proximity to resonance)

Summary

- Presence of a companion near a mean-motion resonance can have significant effects on spin states.
- In our model, we find otherwise tidally locked planets receiving full stellar coverage on the order of years or decades.
- Others have higher-amplitude libration.
- Chaotic spins at early times could make ultimate limit cycles very unpredictable.
- Could be applicable to observed systems such as TRAPPIST-1