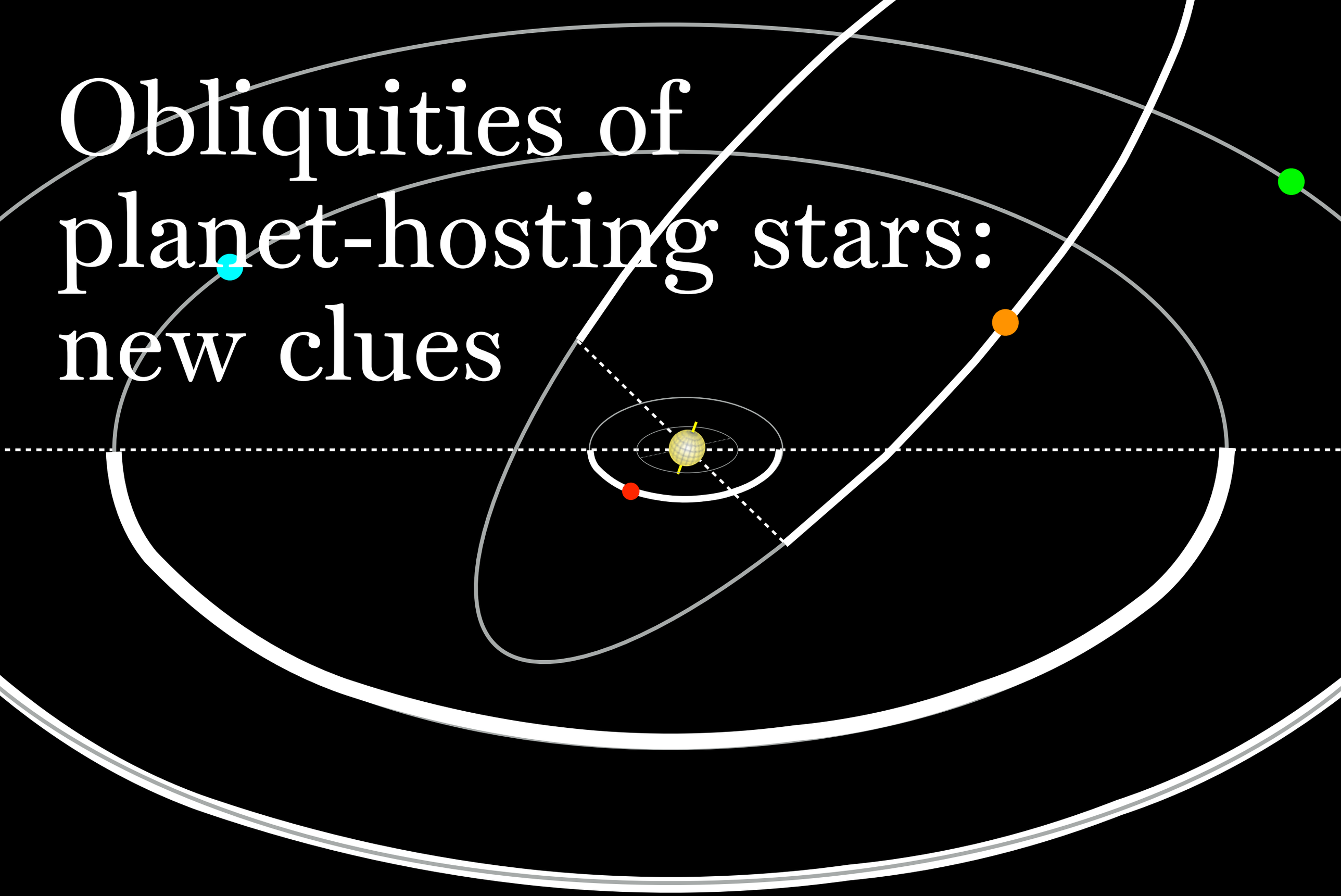
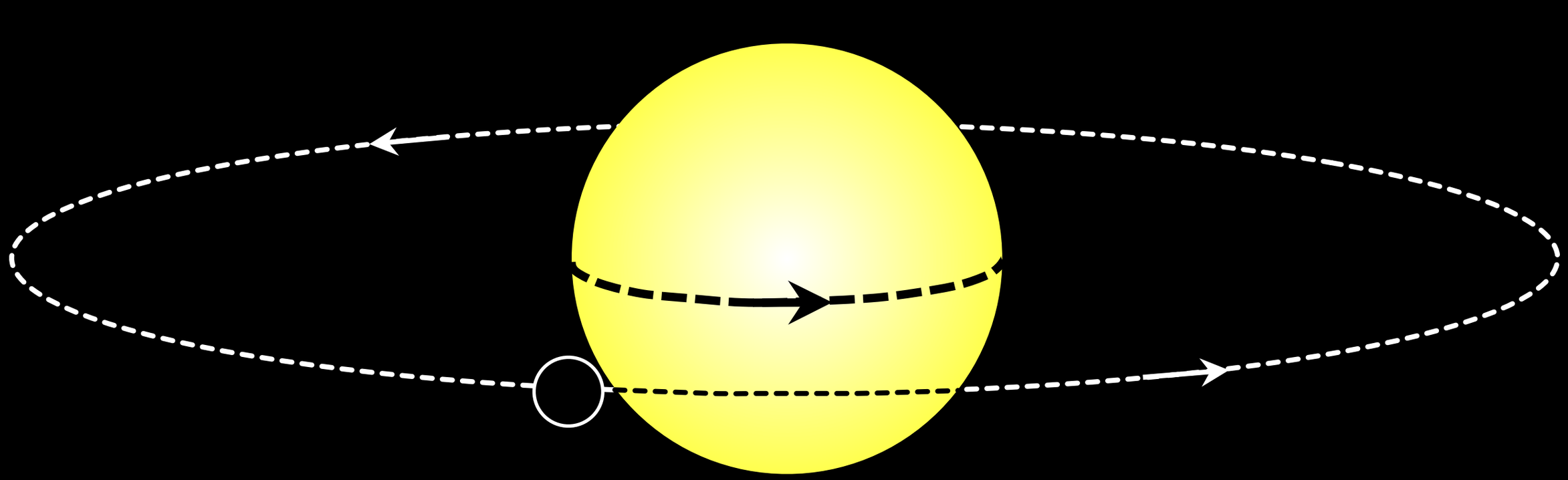
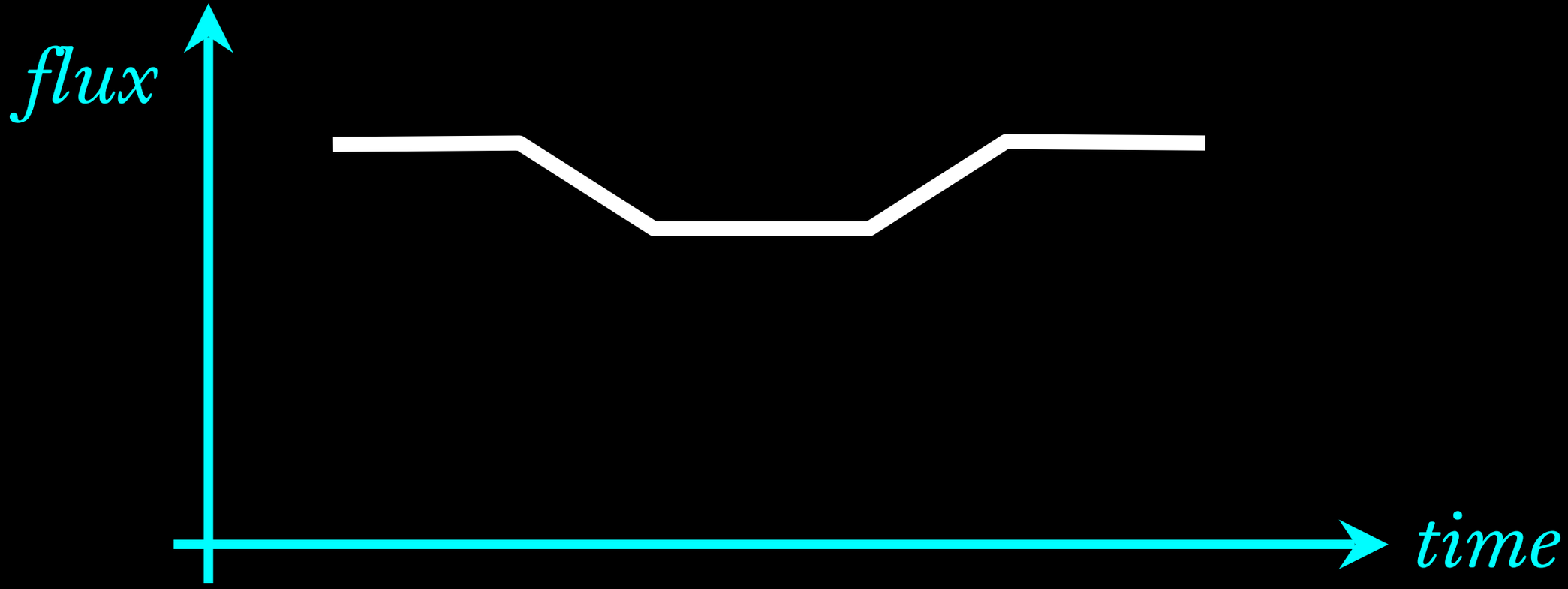
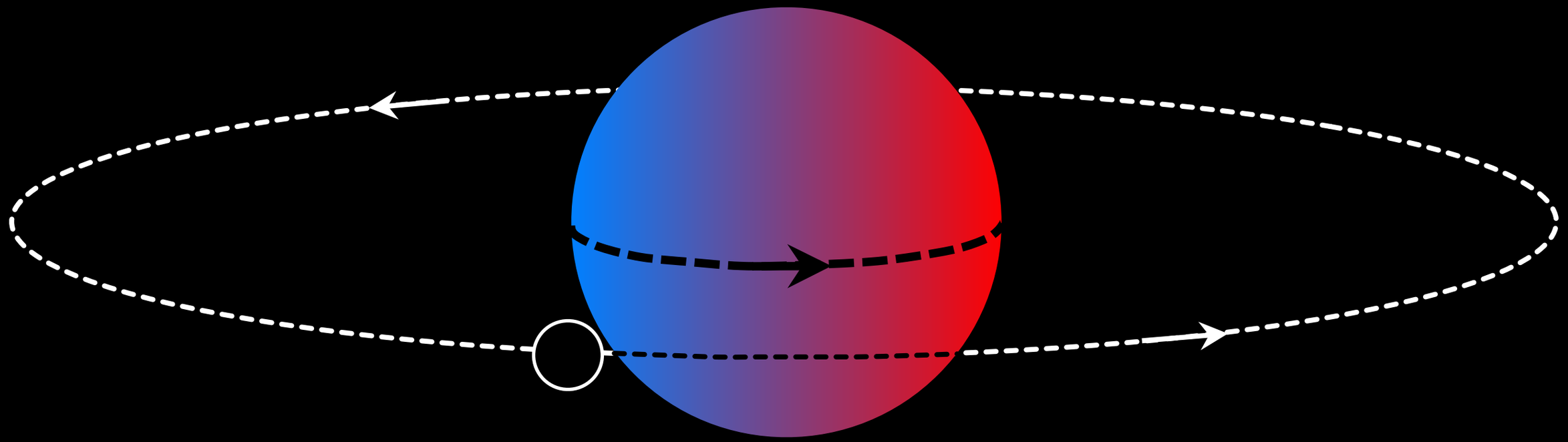
Obliquities of planet-hosting stars: new clues

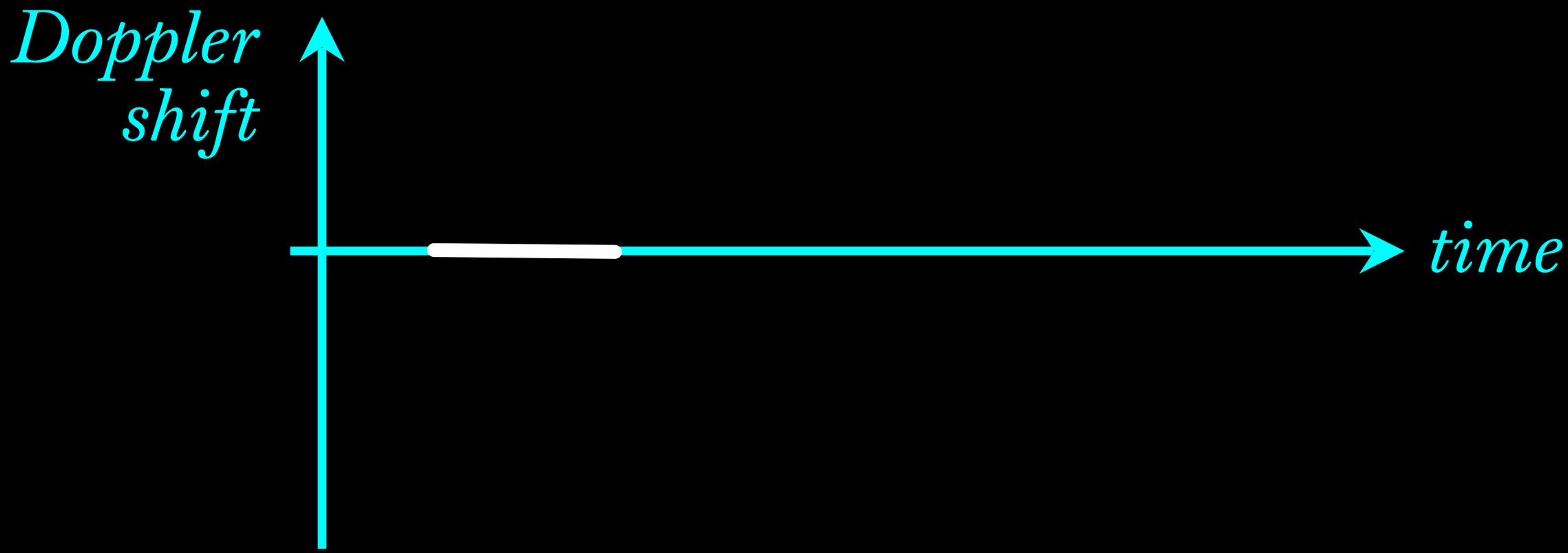


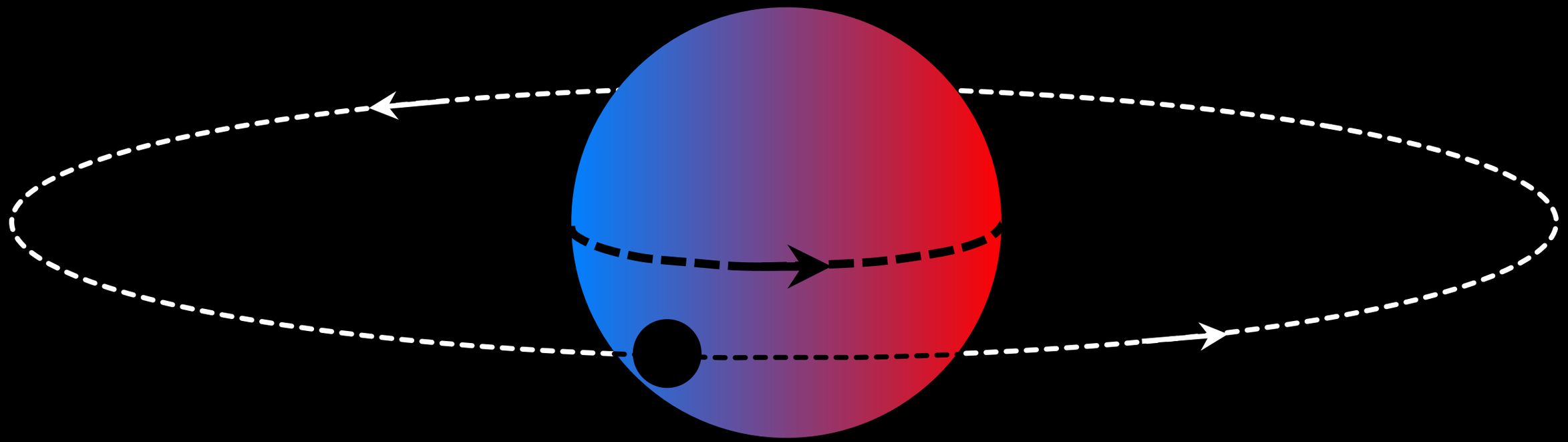
Josh Winn PRINCETON UNIVERSITY

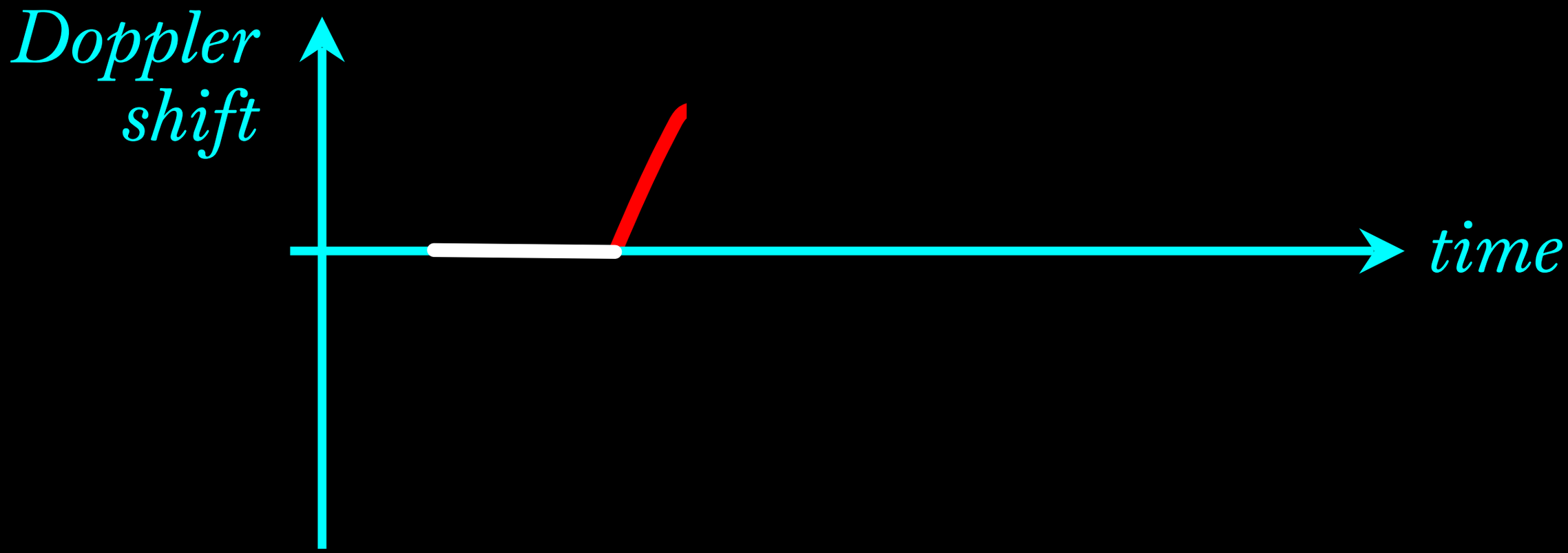


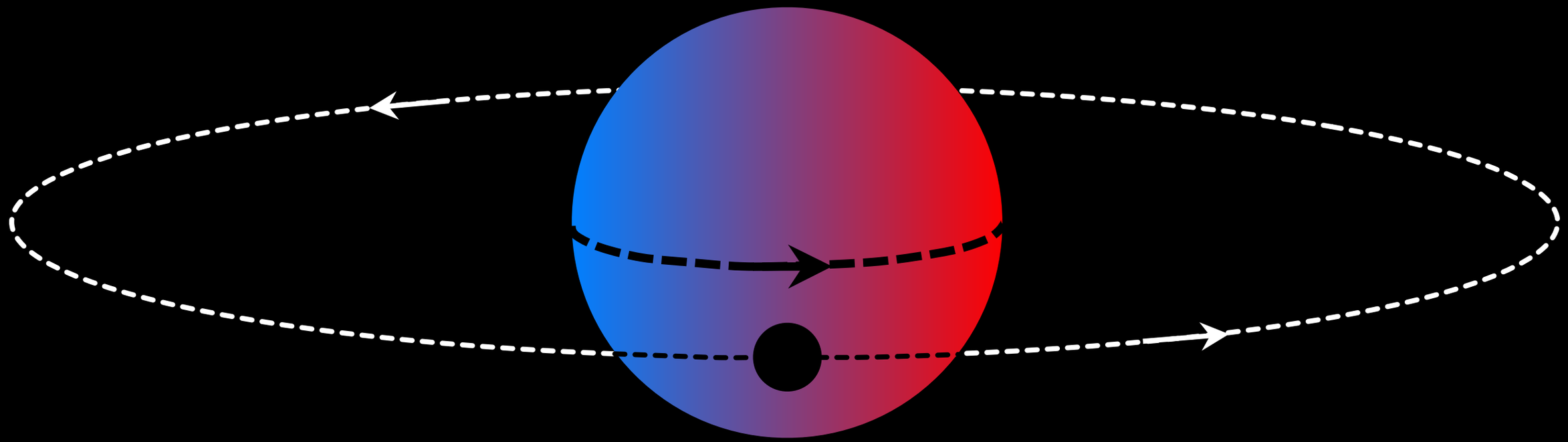

flux
time

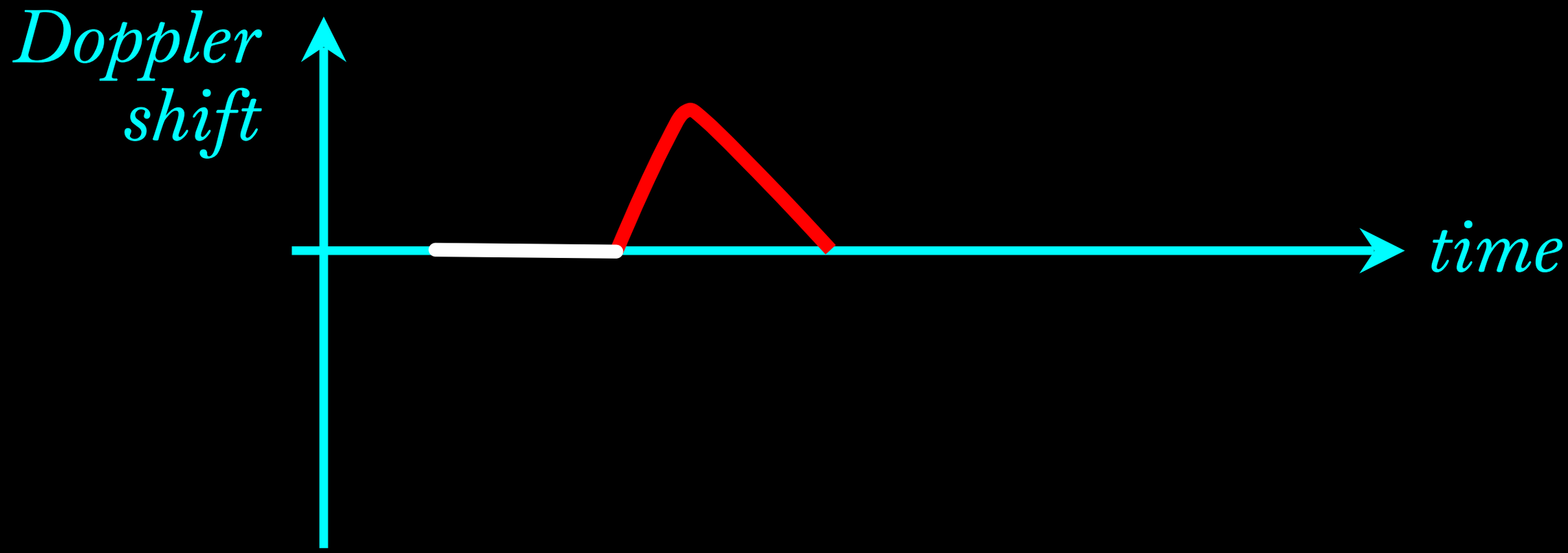


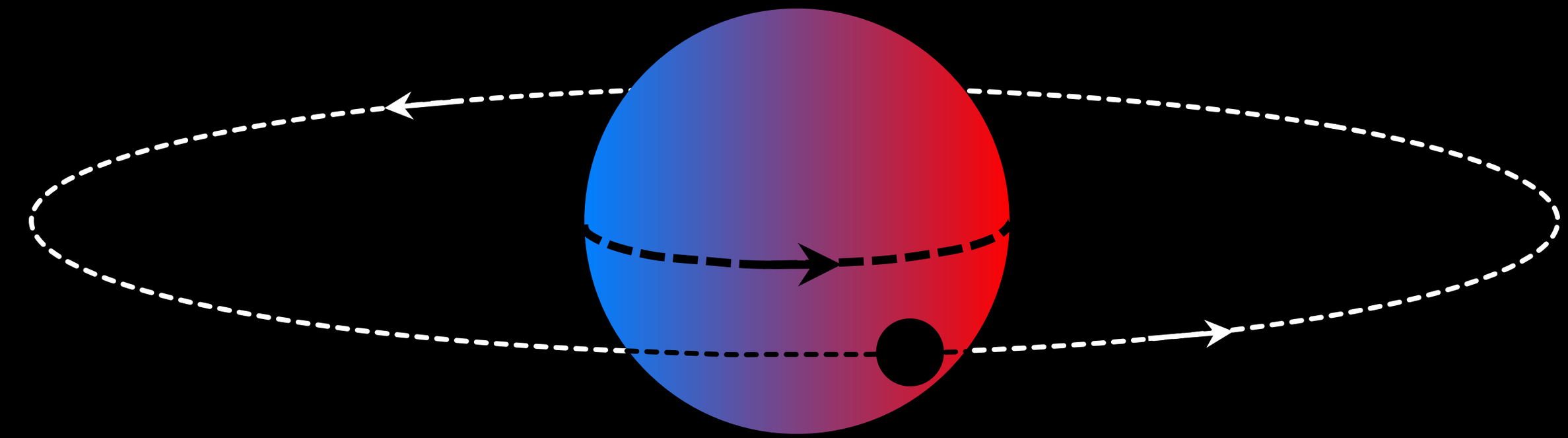

Doppler shift
time

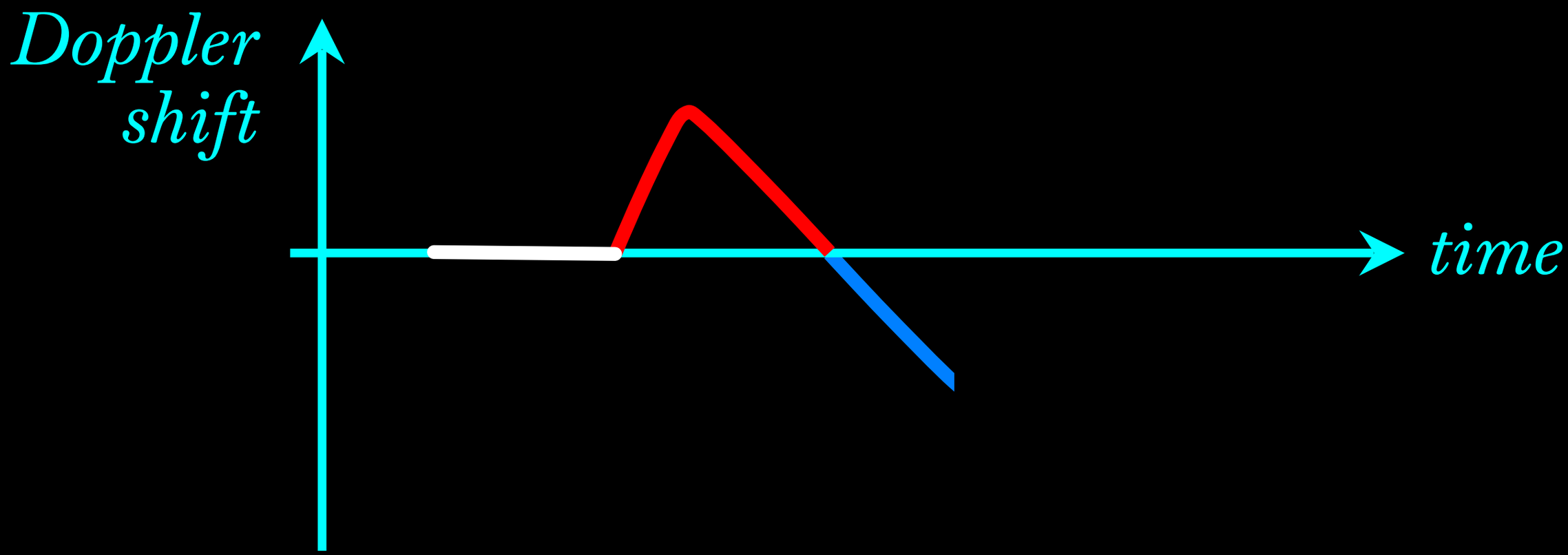


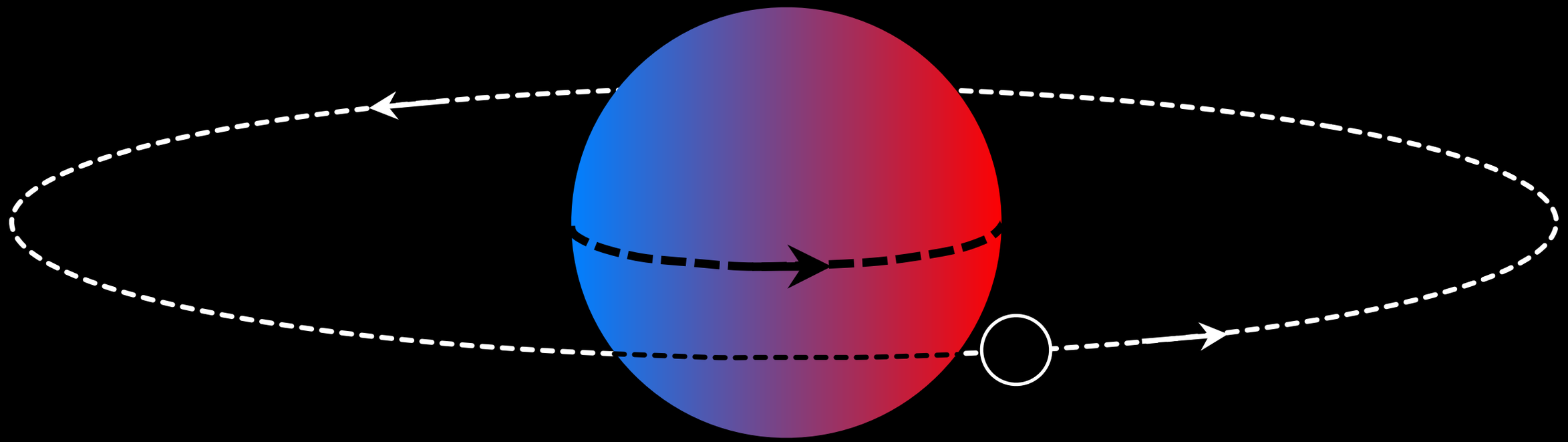

Doppler shift
time

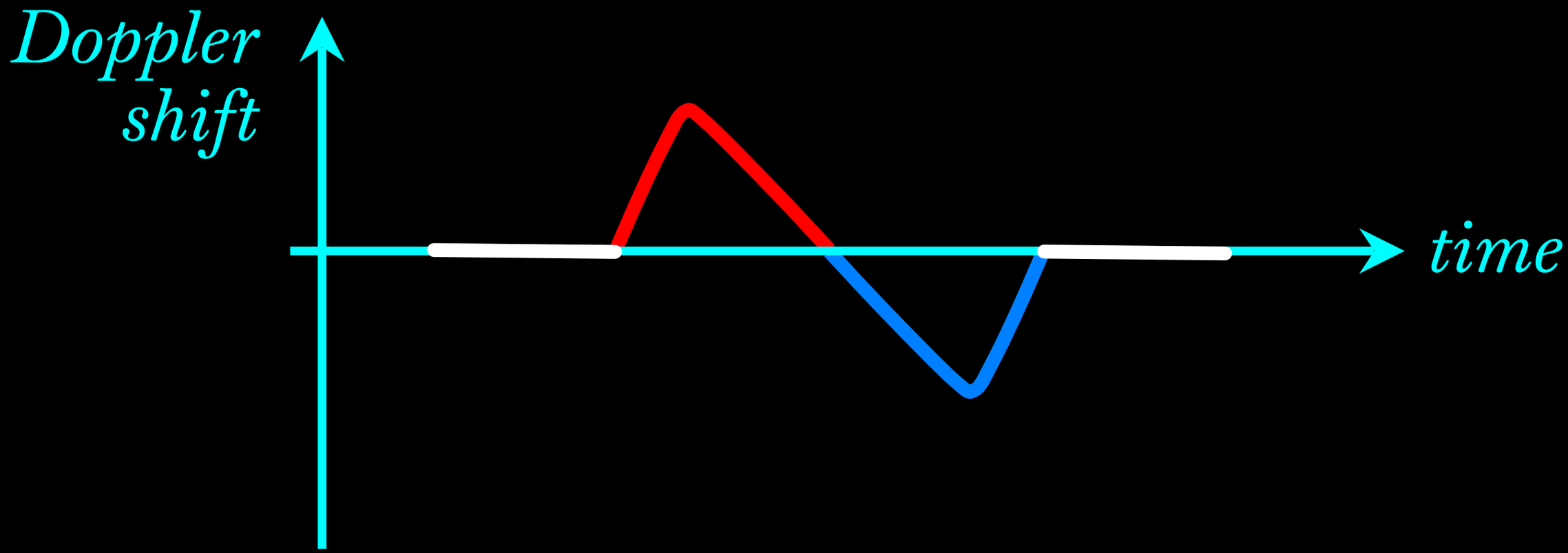



Doppler shift
time

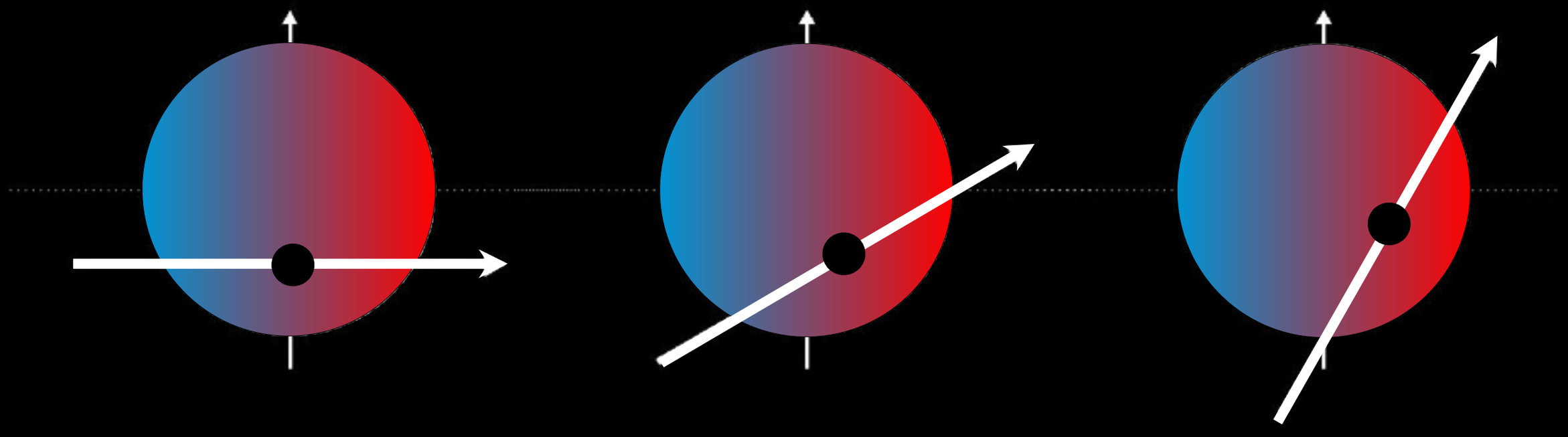


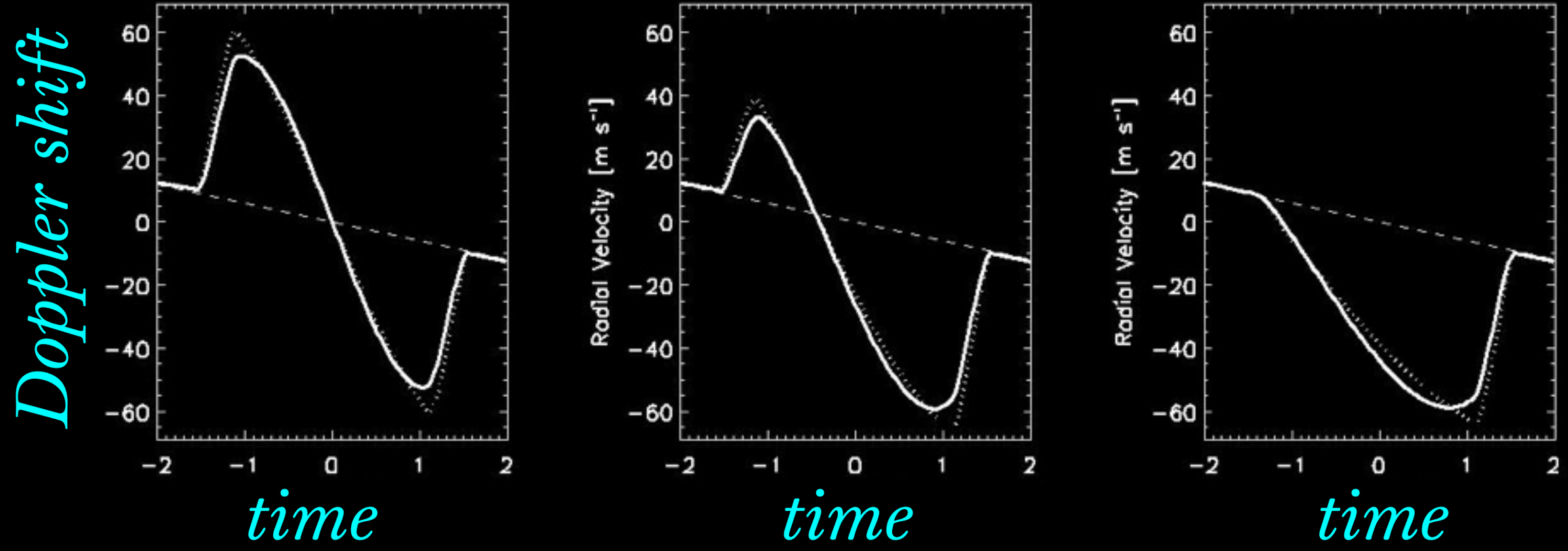

Doppler shift
time



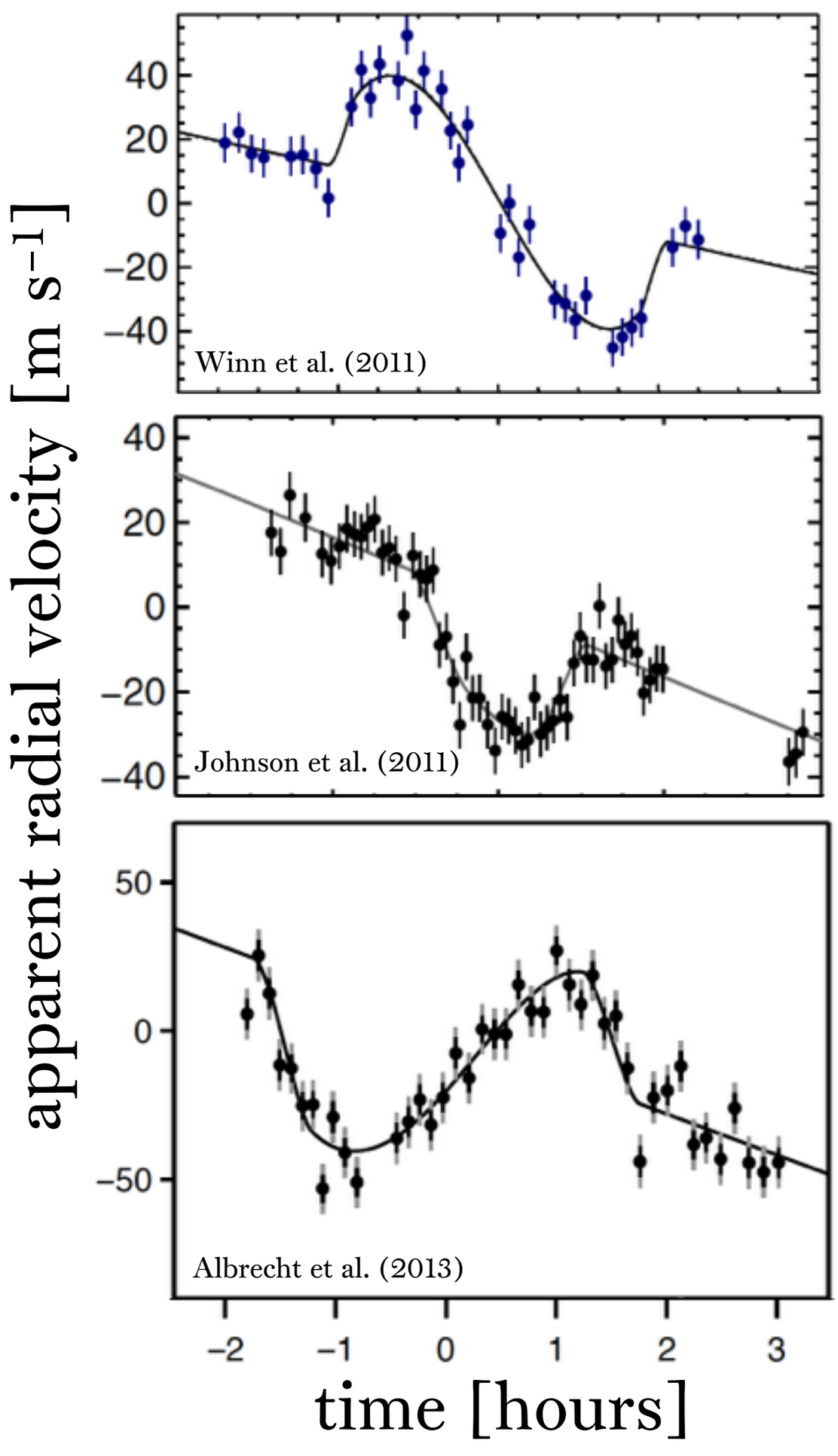

Doppler shift
time

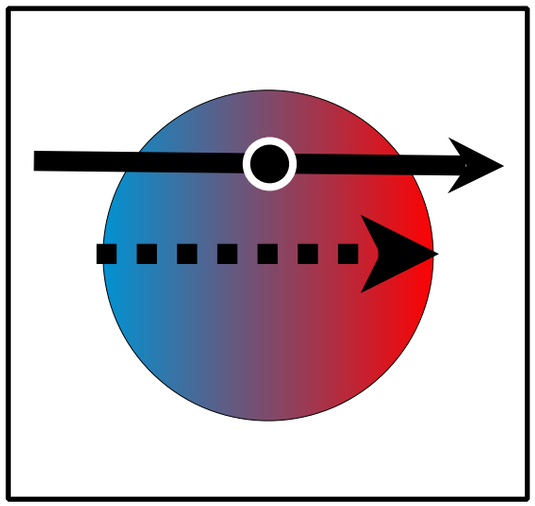
Rossiter-McLaughlin effect



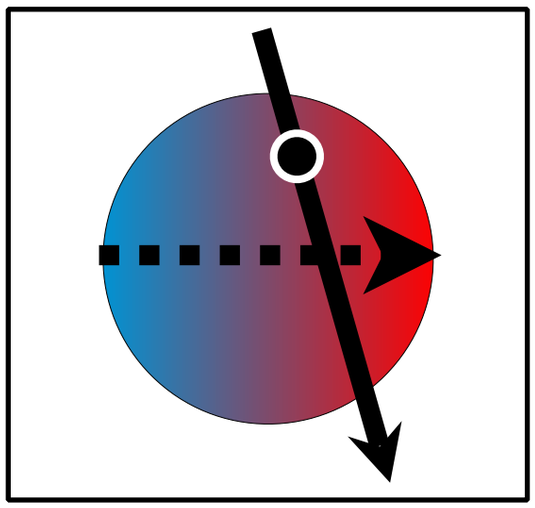


Holt (1893), Schlesinger (1909)

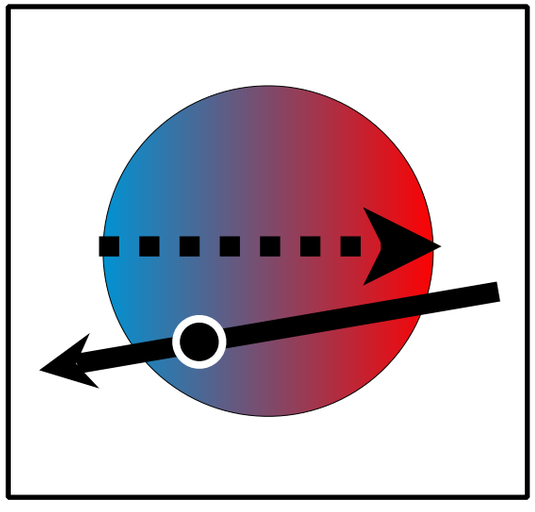




Well-aligned

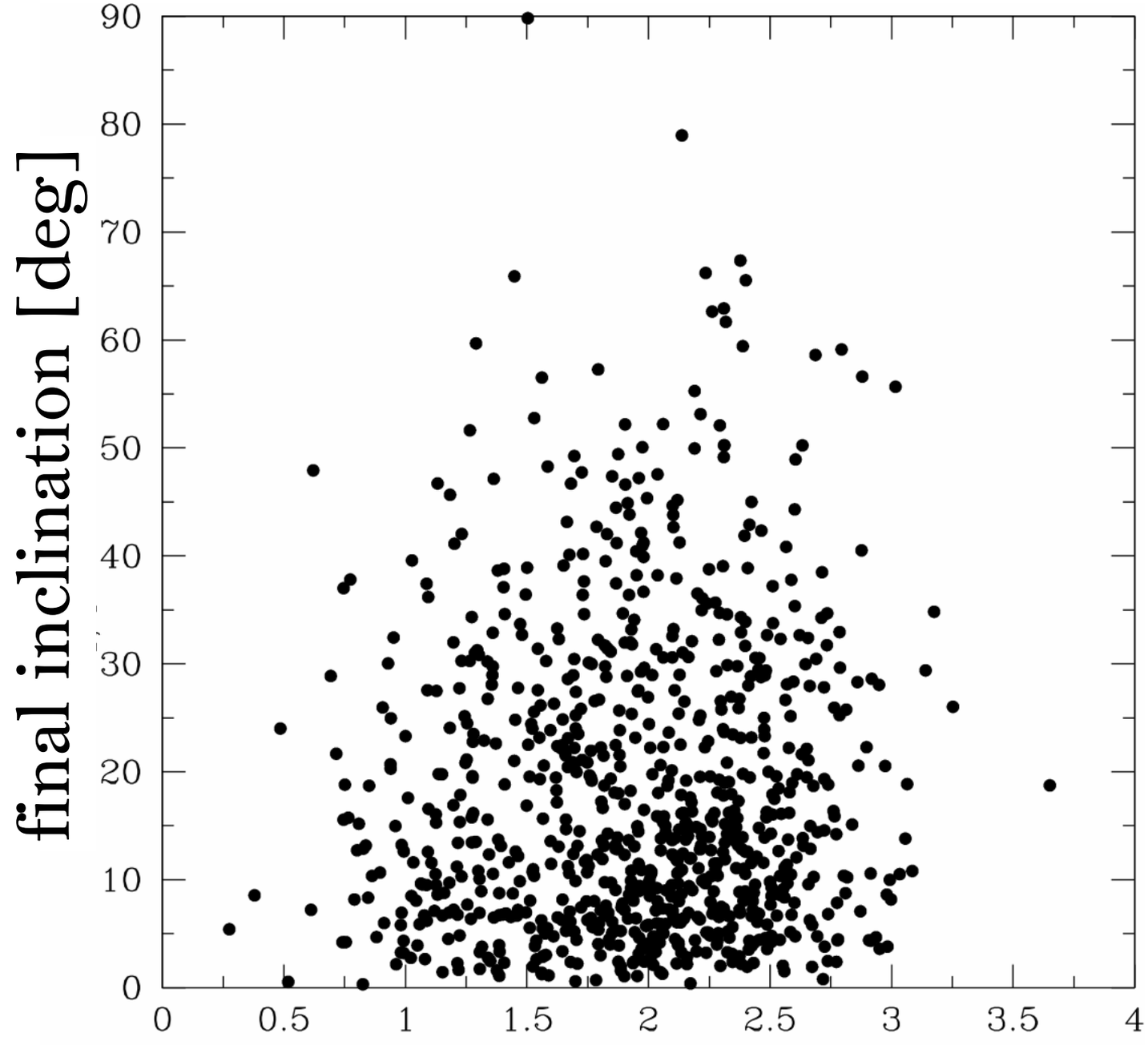


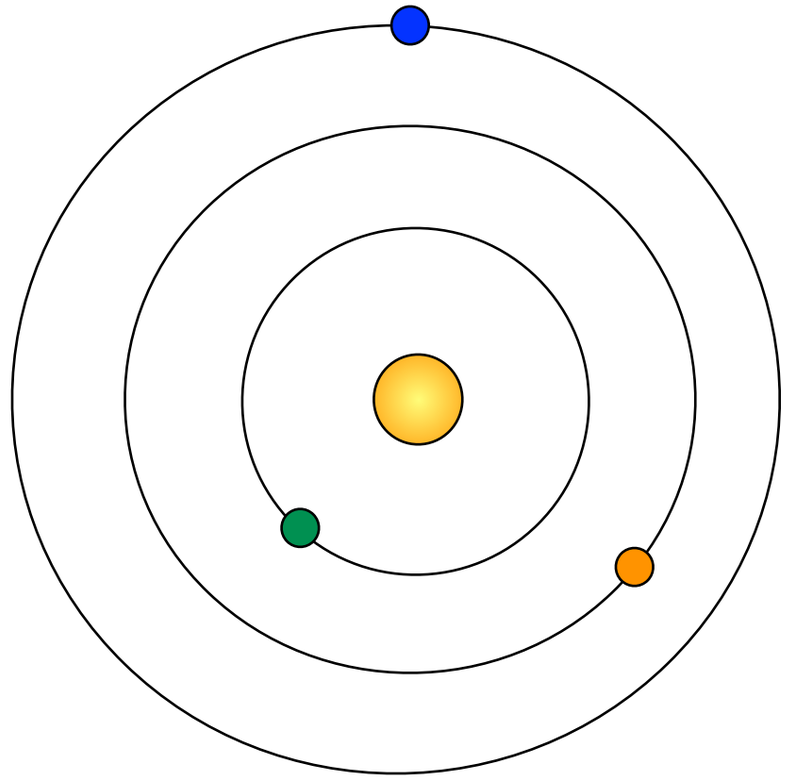
Misaligned



Retrograde

Tilt the orbit:
planet-planet scattering

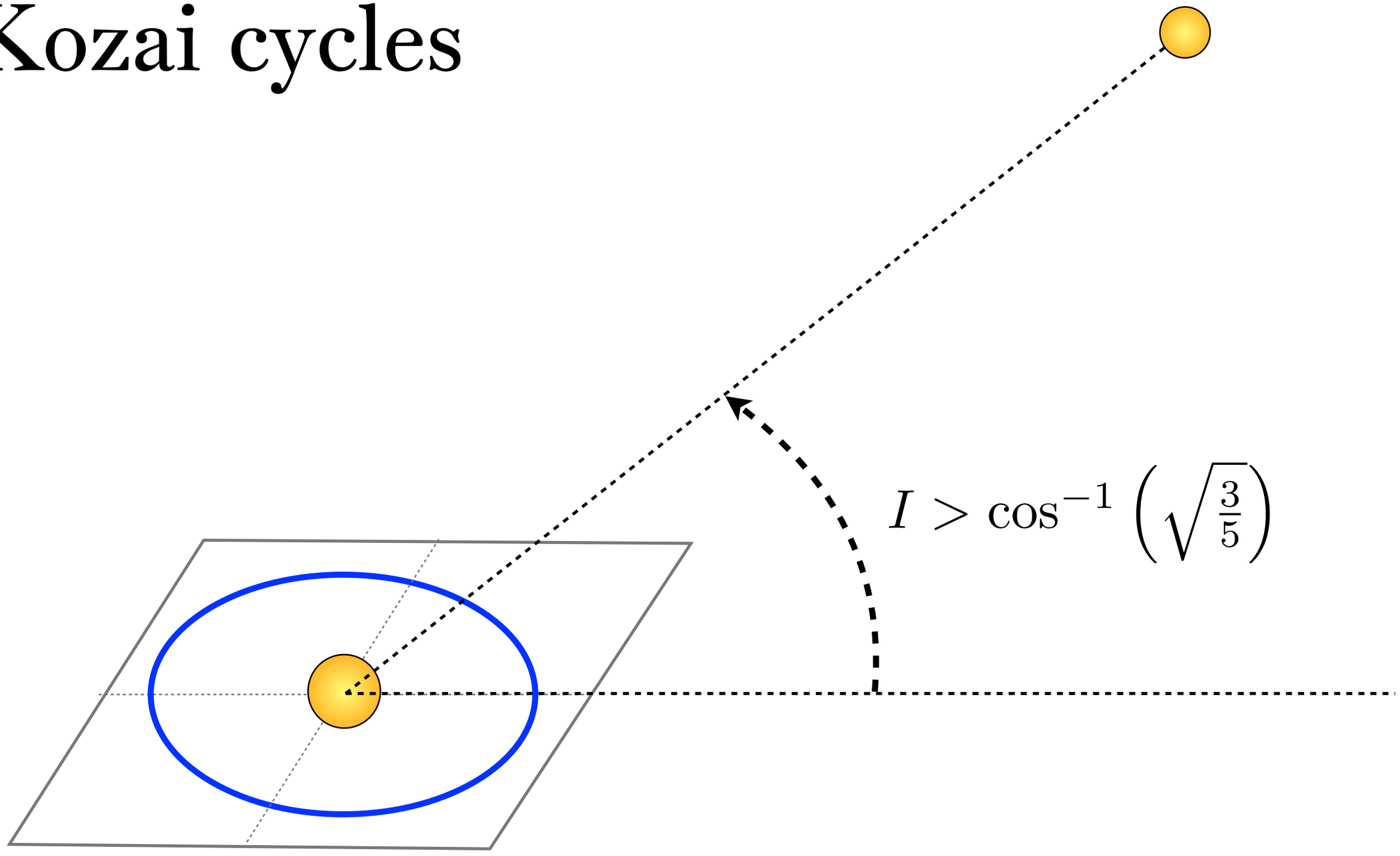




Chatterjee et al. (2008)

Tilt the orbit:

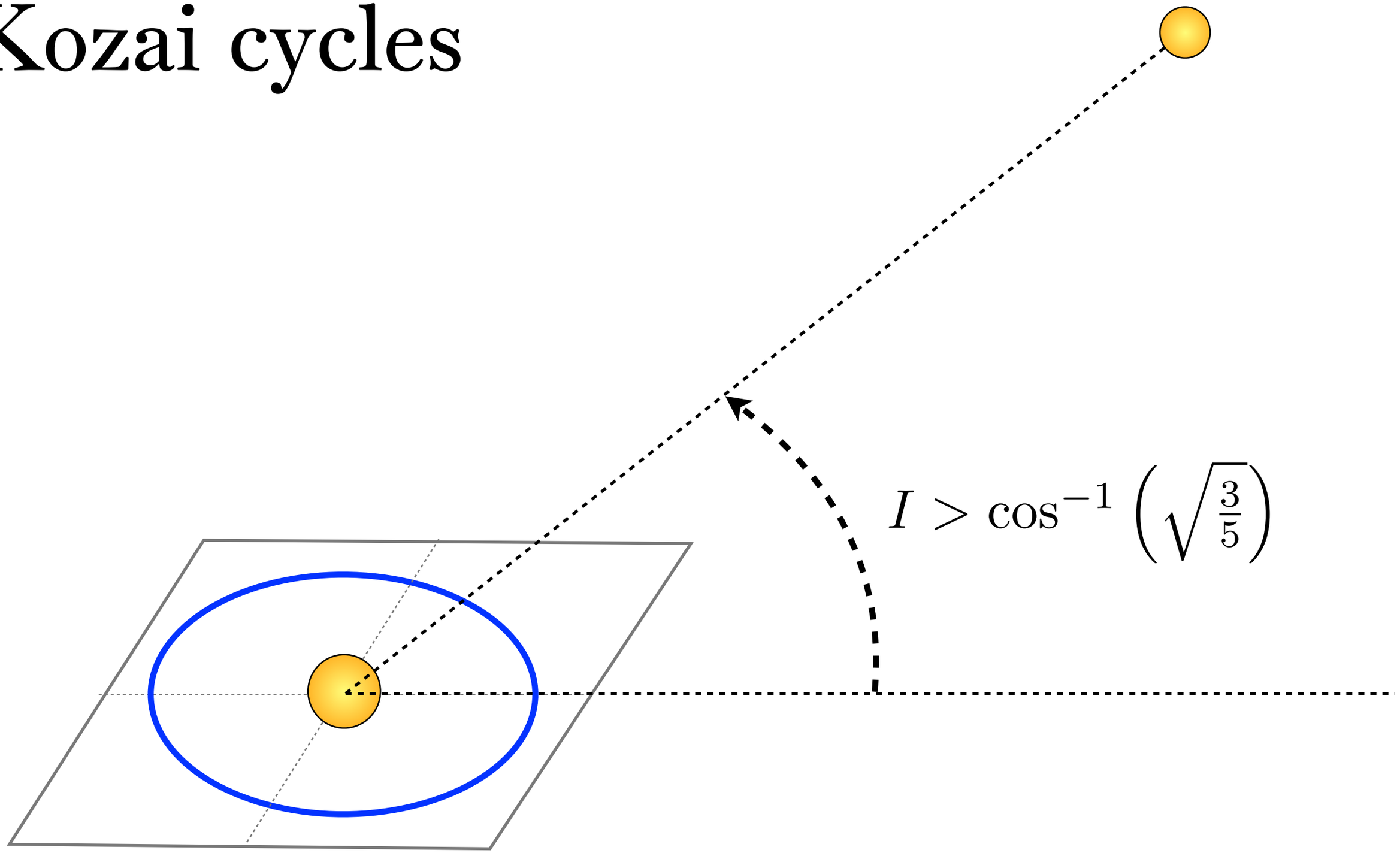
Kozai cycles



Fabrycky & Tremaine (2007)

Tilt the orbit:

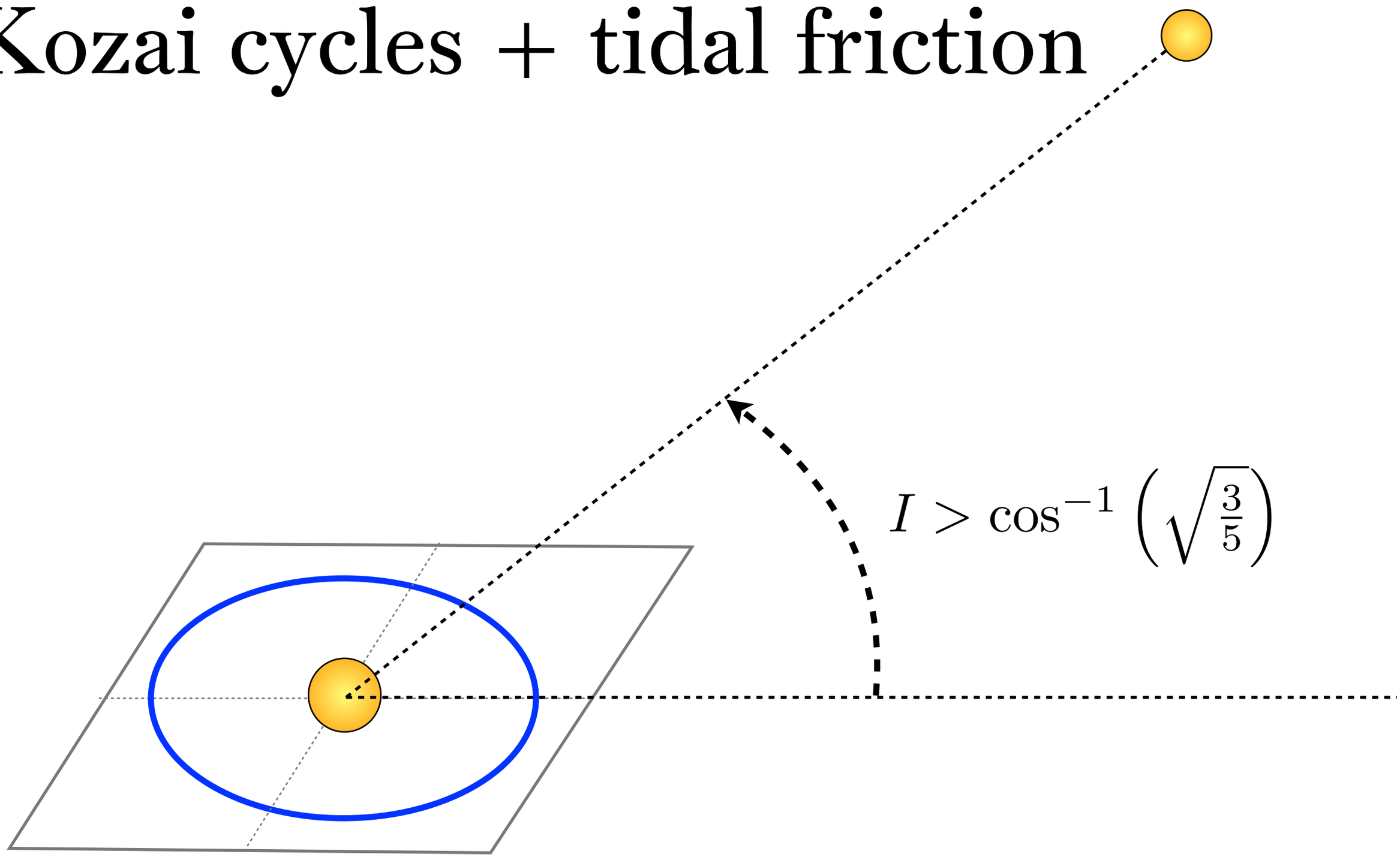
Kozai cycles



Fabrycky & Tremaine (2007)

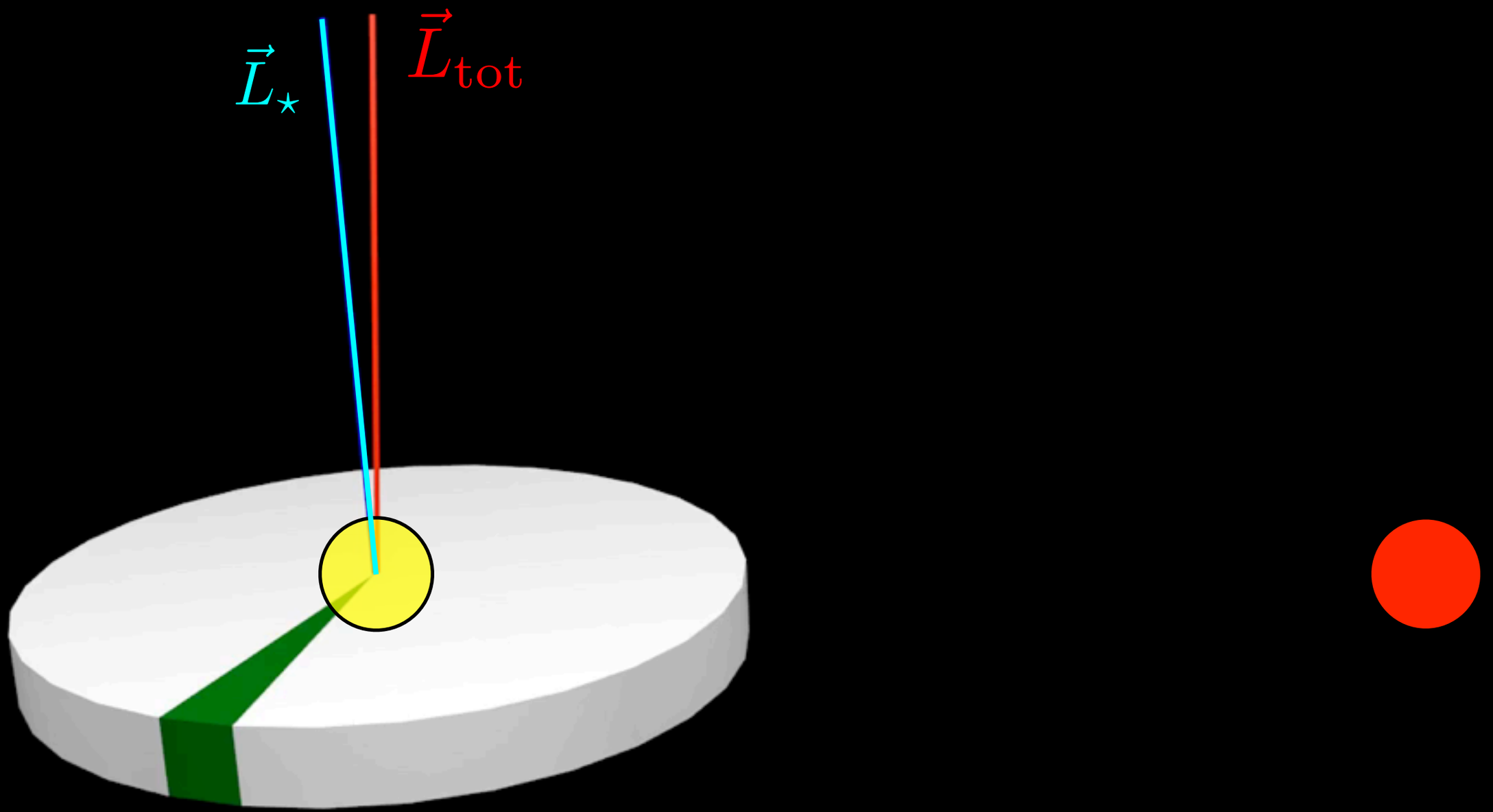
Tilt the orbit:

Kozai cycles + tidal friction

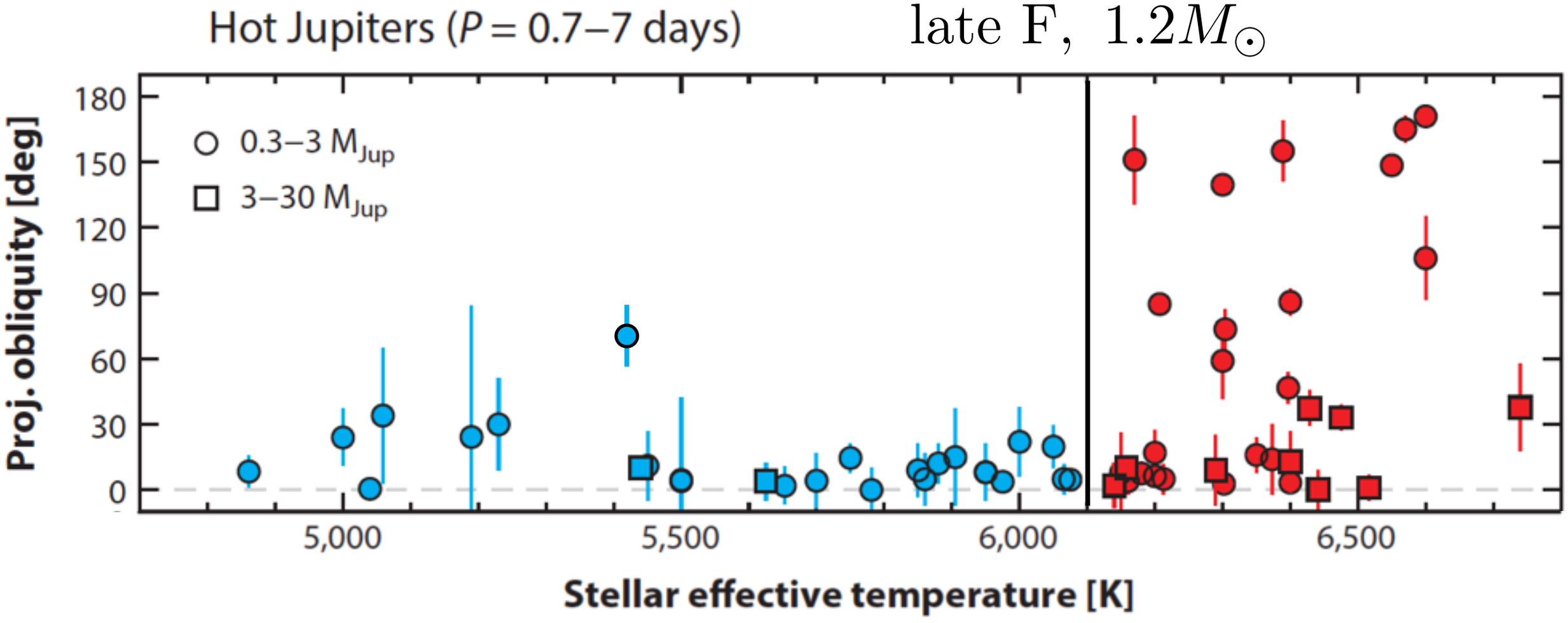


Fabrycky & Tremaine (2007)

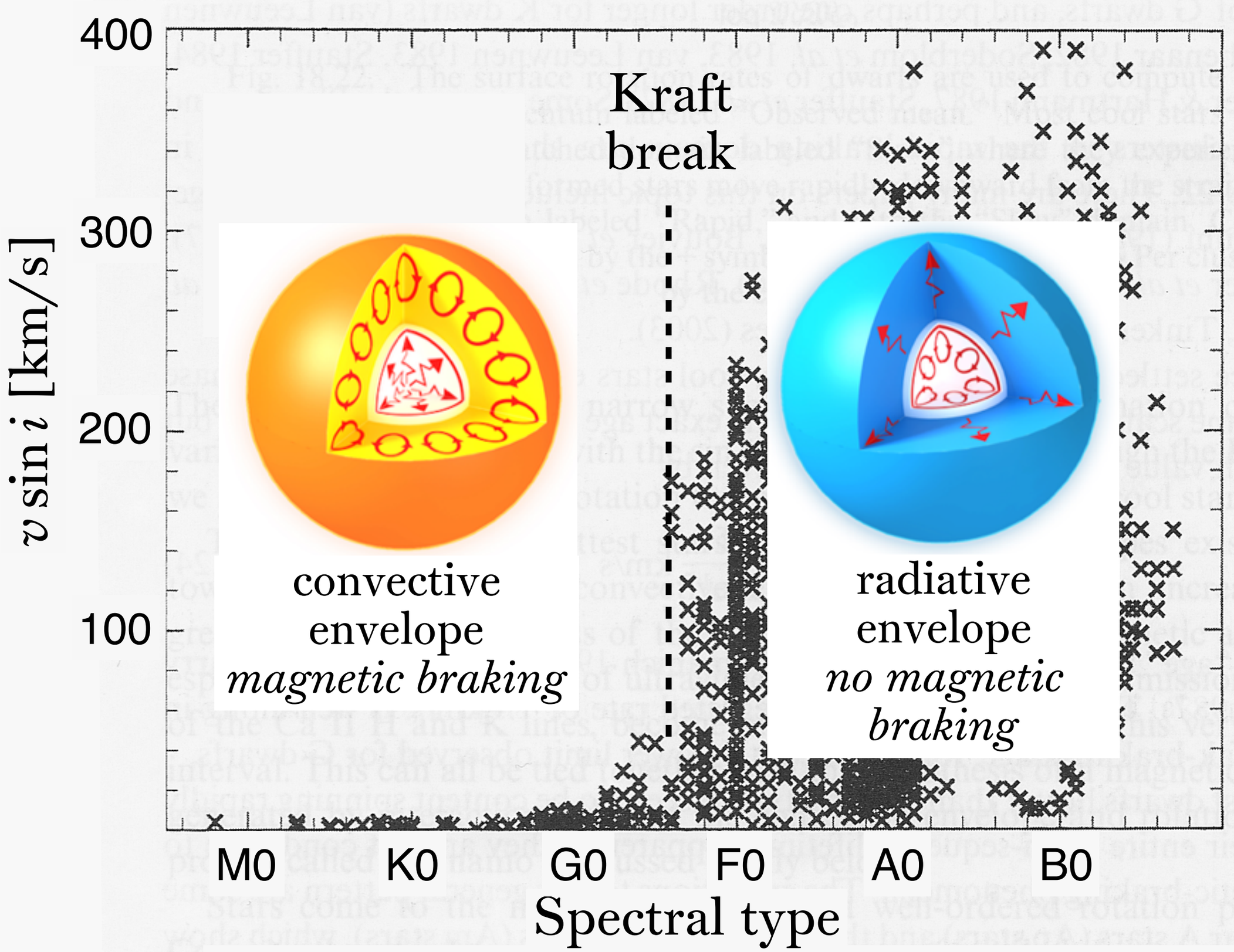
Tilt the disk:
stellar flyby, or distant companion



Hot stars with hot Jupiters have high obliquities

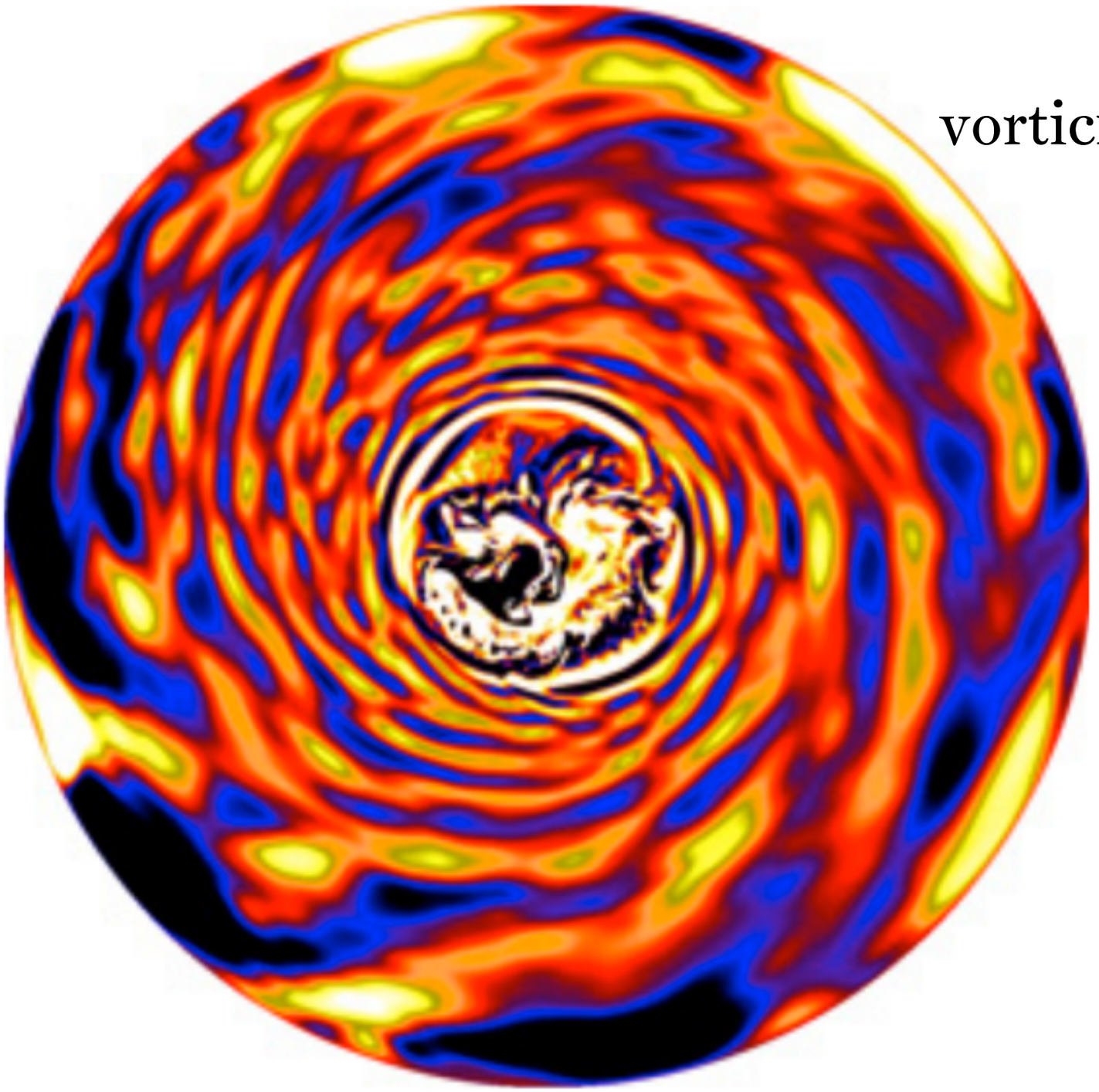


Winn et al. (2010), Albrecht et al. (2012), Dawson (2014)



Schatzman (1959), Gray (2004)

Internal gravity waves



vorticity

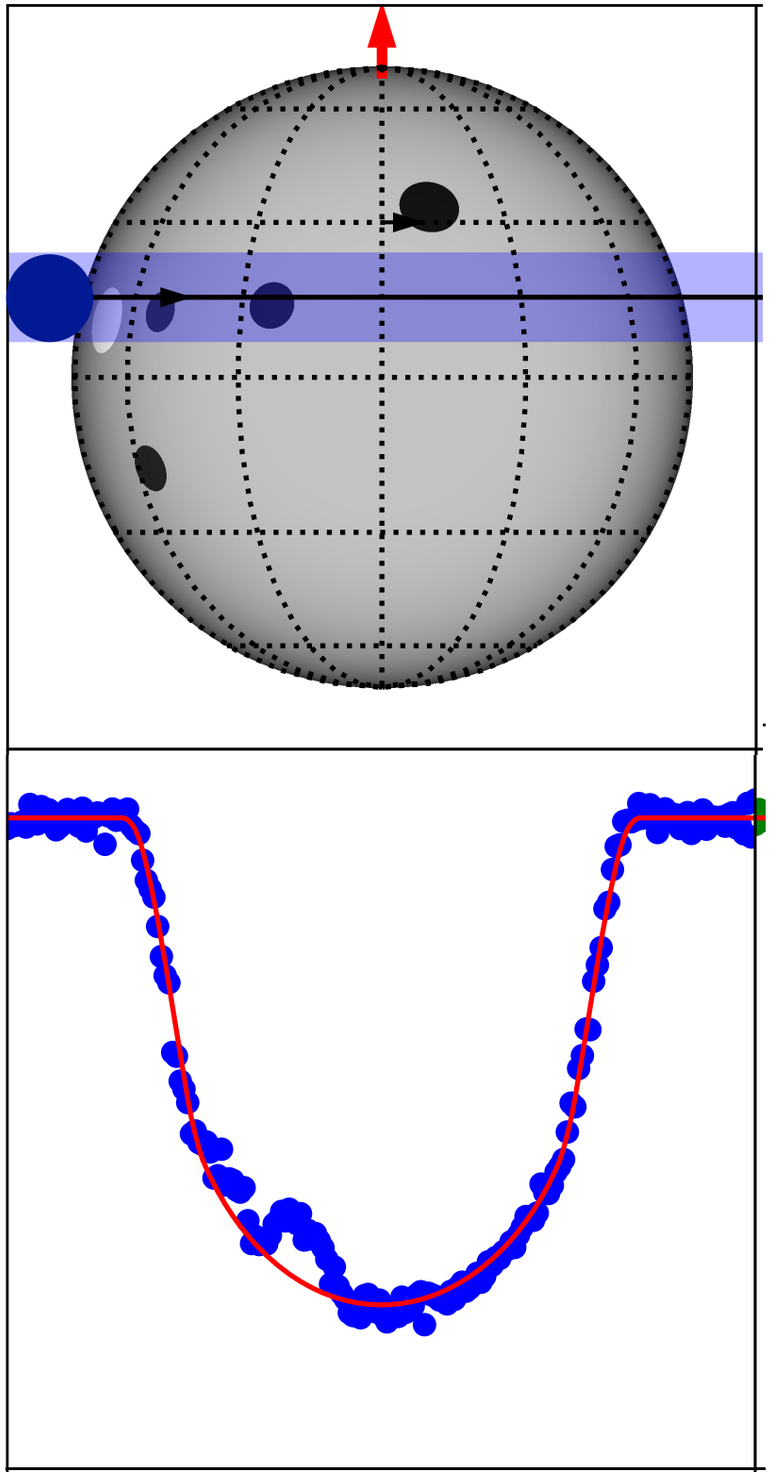
stellar equatorial plane

prediction:
hot stars are misaligned in general

(not only hot Jupiters)

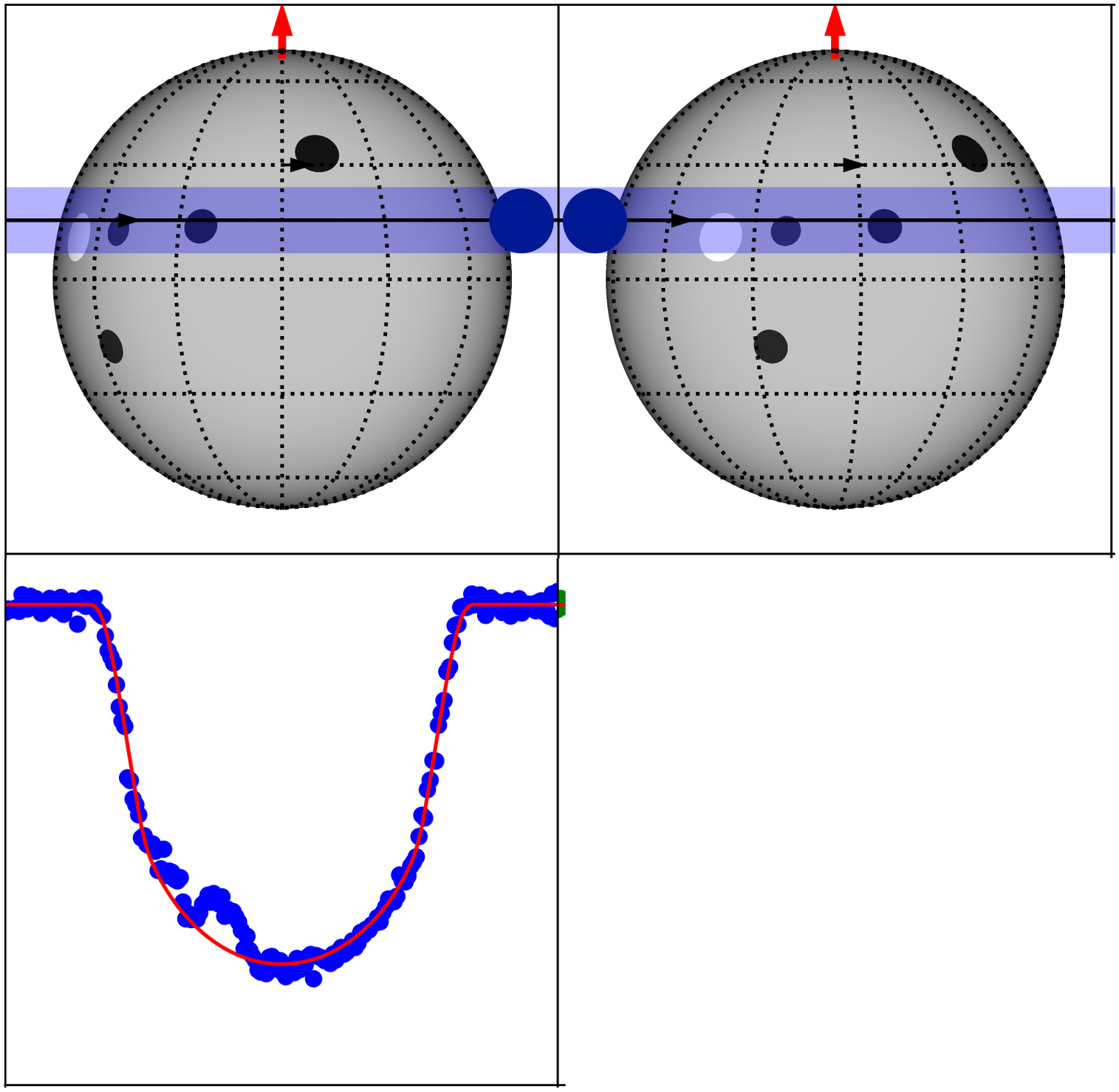
Rogers et al. (2013)

Spot crossings



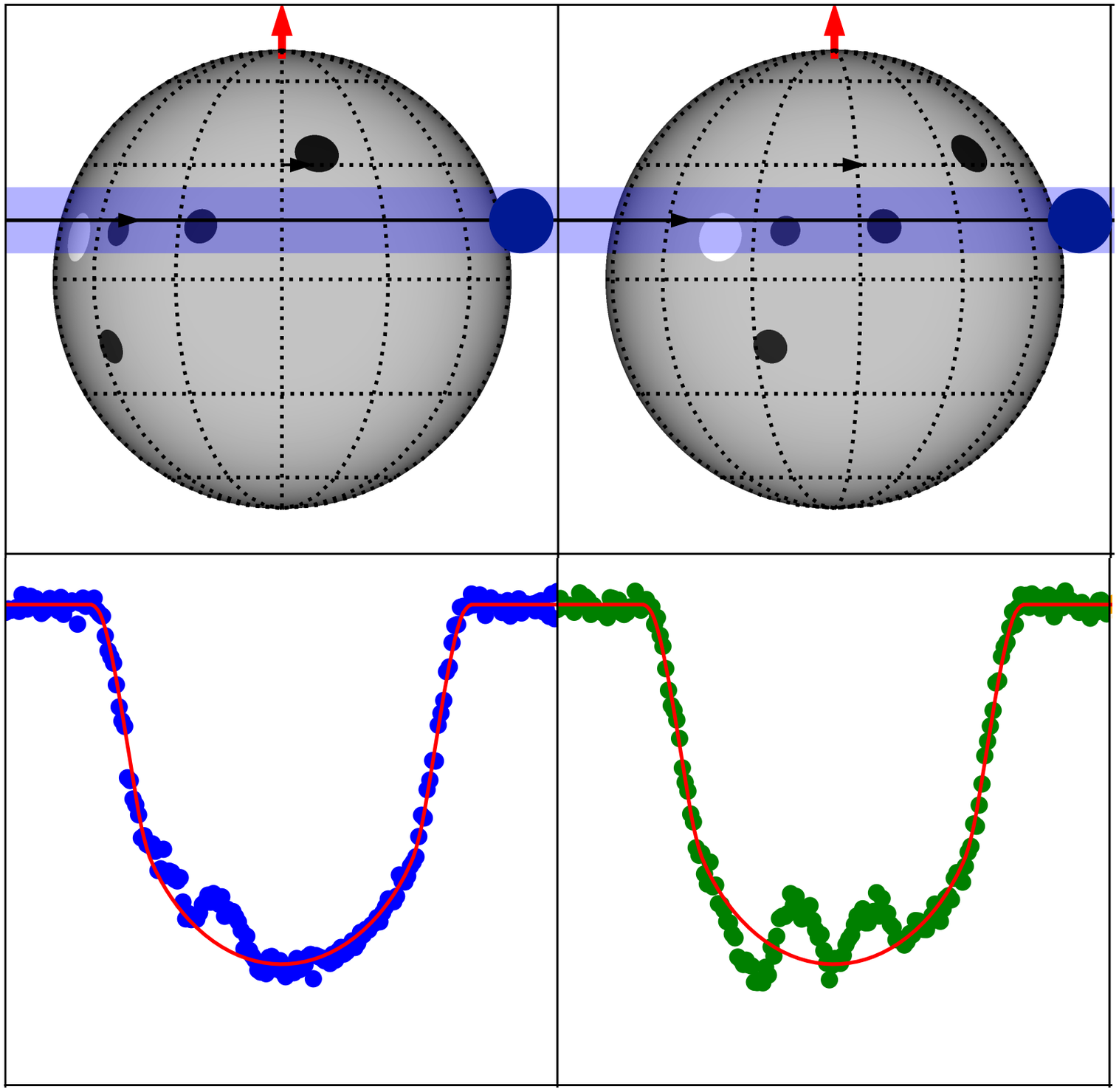
Dai et al., in prep.

Spot crossings



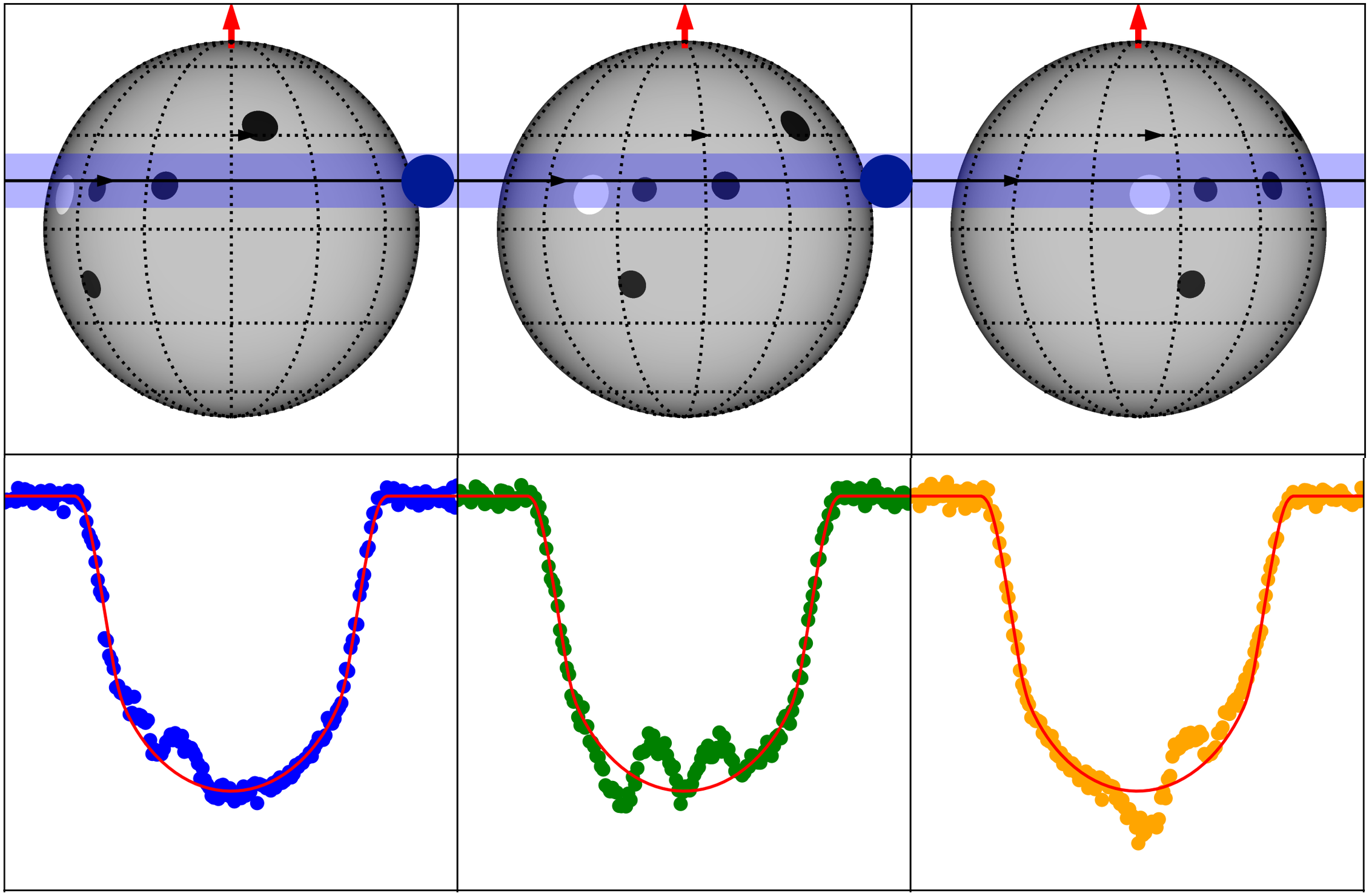
Dai et al., in prep.

Spot crossings



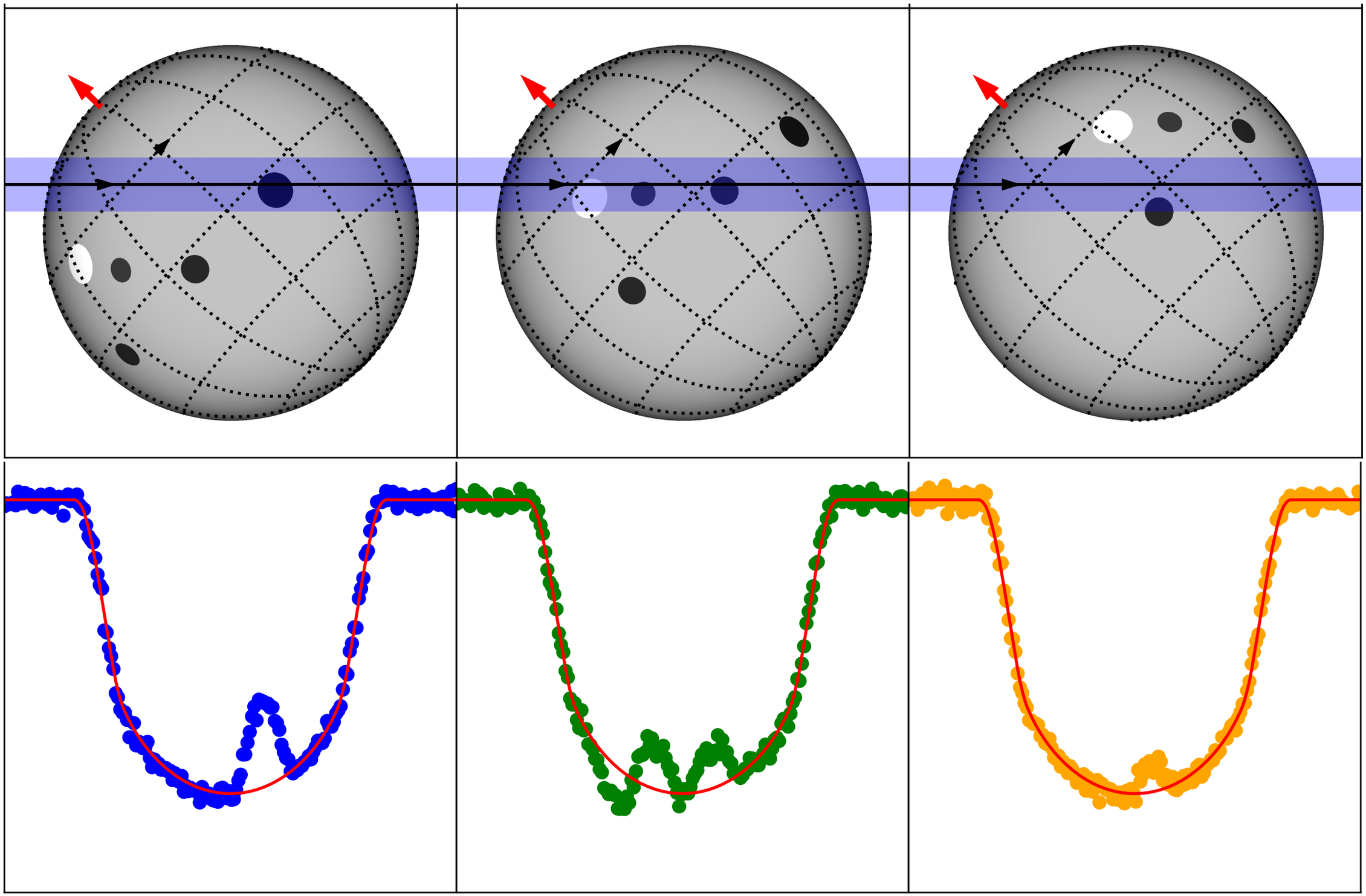
Dai et al., in prep.

Spot crossings



Dai et al., in prep.

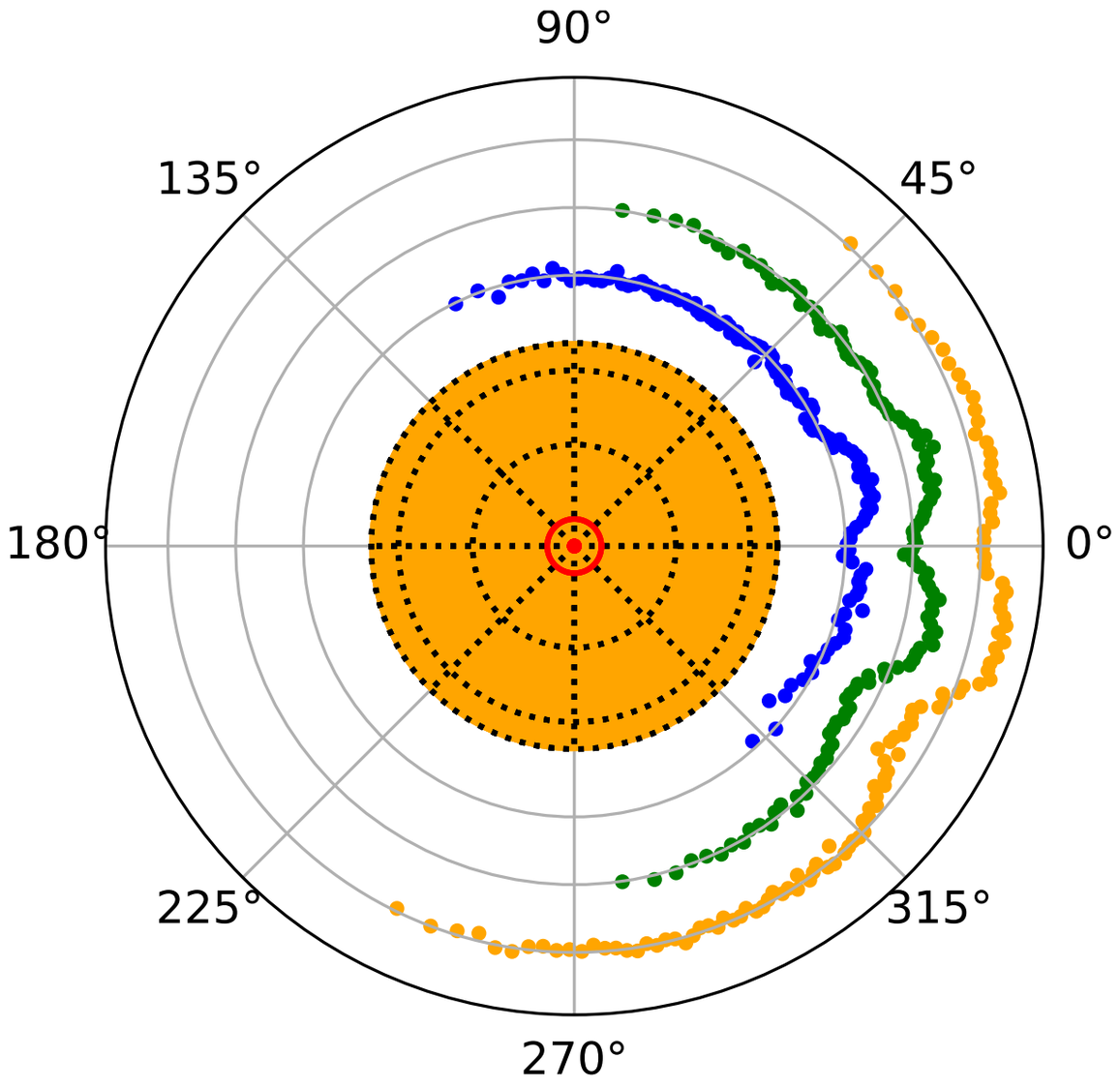
Spot crossings



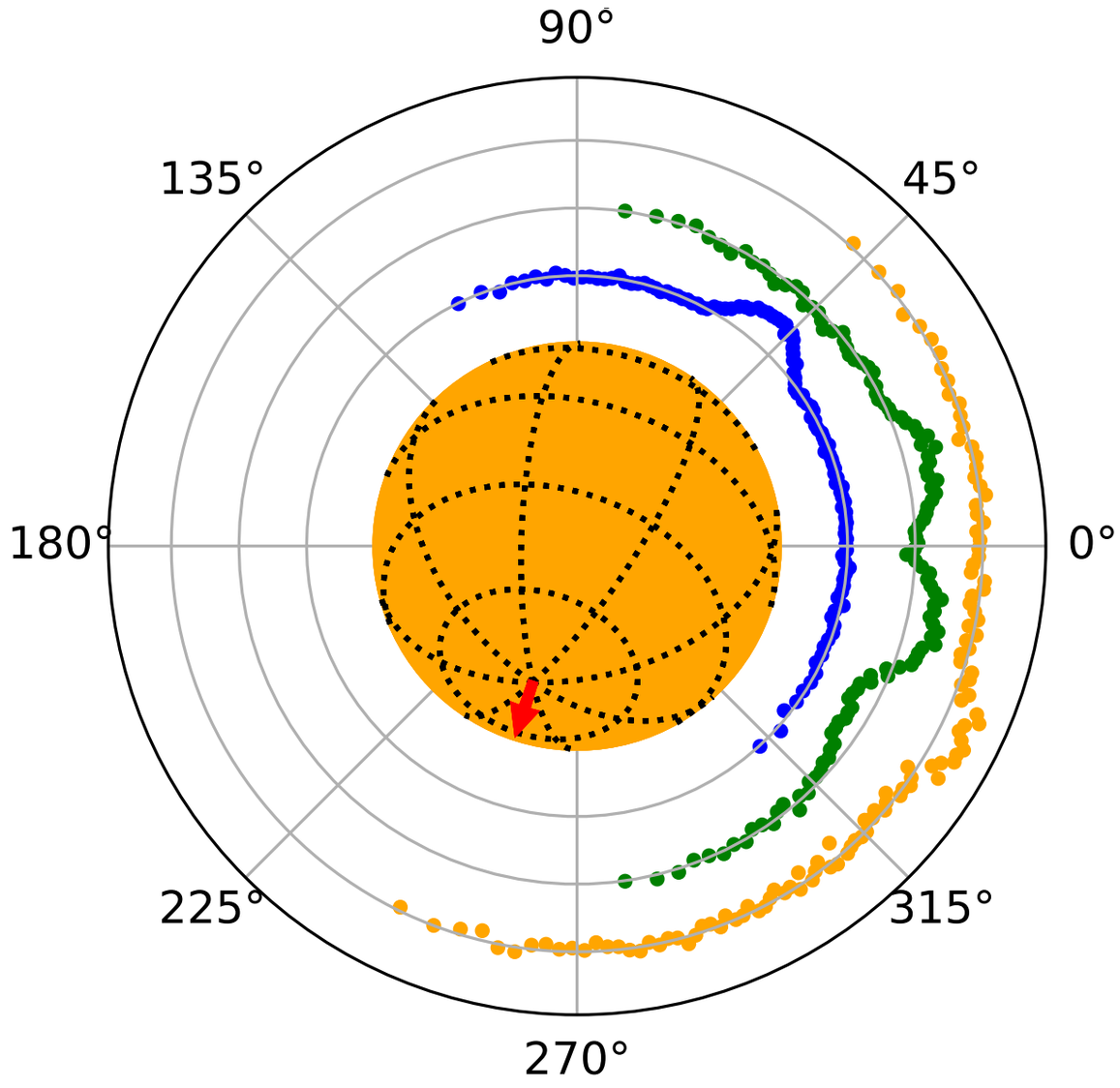
Dai et al., in prep.

Spot crossings

transform time ⟶ stellar longitude (in the rotating frame)



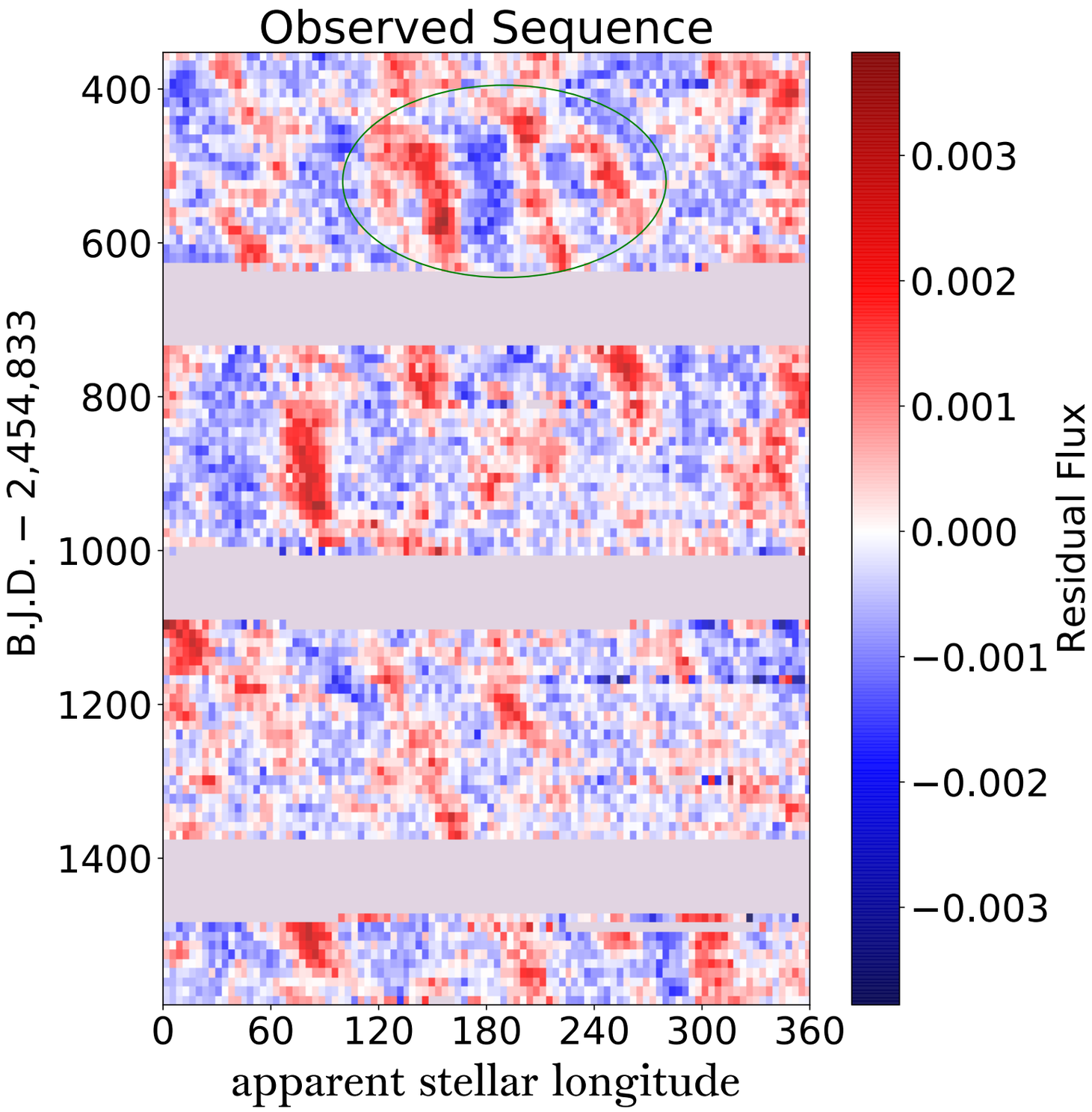
strong correlations between flux anomalies in consecutive transits



no correlation

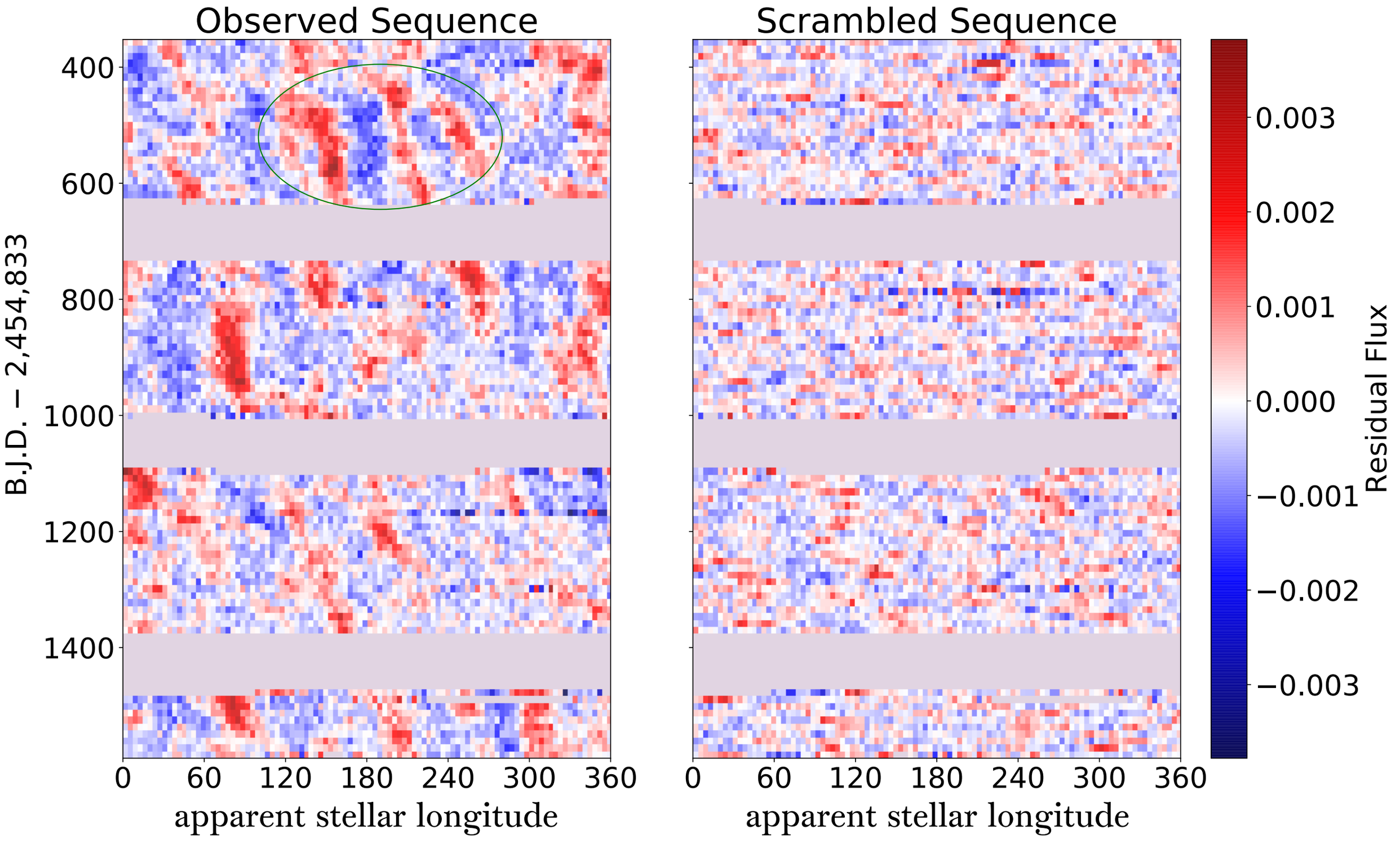
Dai et al., in prep.

Spot crossings

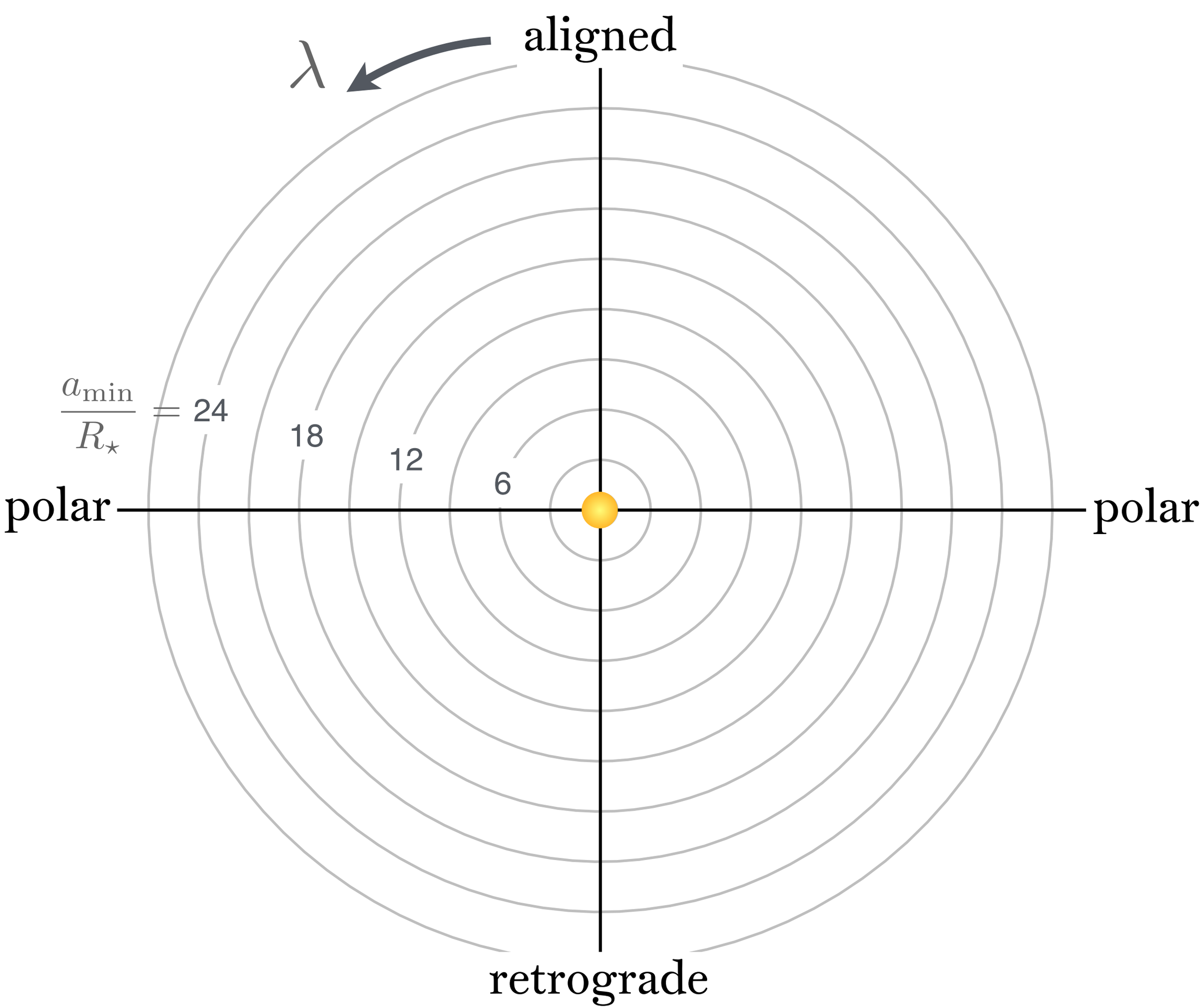


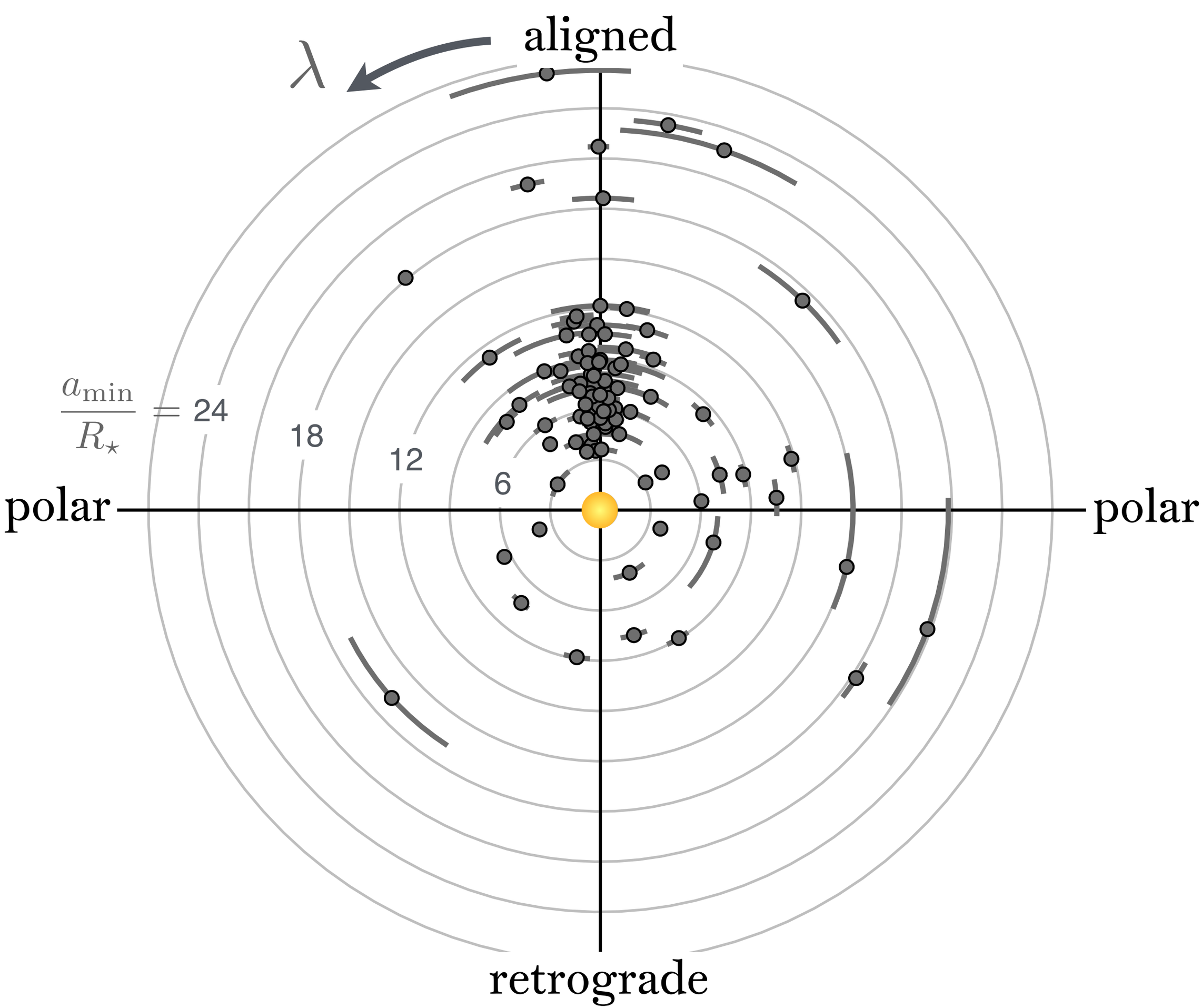
Dai et al., in prep.

Spot crossings



Dai et al., in prep.


aligned
λ
$\frac{a_{\rm min}}{R_\star} = 24$
18
12
6
polar
polar
retrograde


aligned
λ
$\frac{a_{\min}}{R_\star} = 24$
18
12
6
polar
polar
retrograde

aligned

λ

$\frac{a_{\min}}{R_\star} = 24$

18

12

6

polar

polar

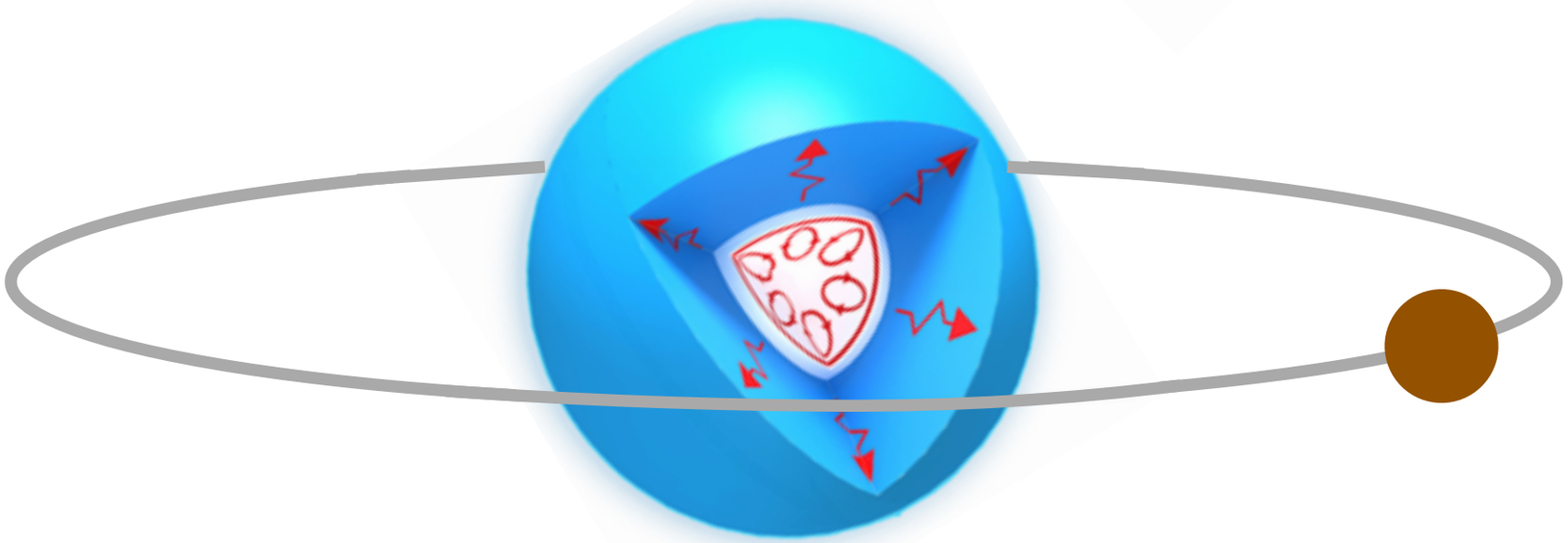
retrograde

$T_{\rm eff} > 6100\,{\rm K}$

$T_{\rm eff} < 6100\,{\rm K}$

tidal realignment

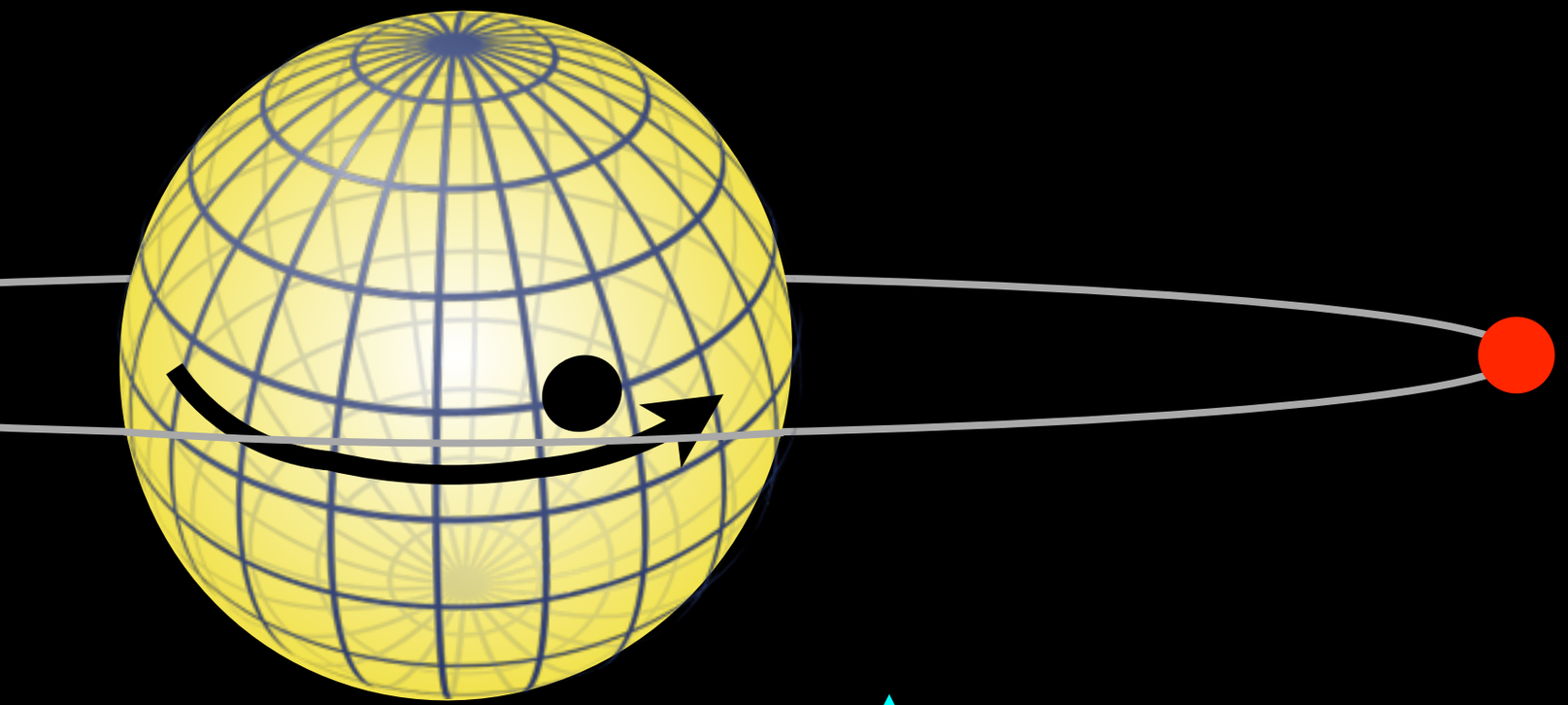
tidal forces too weak

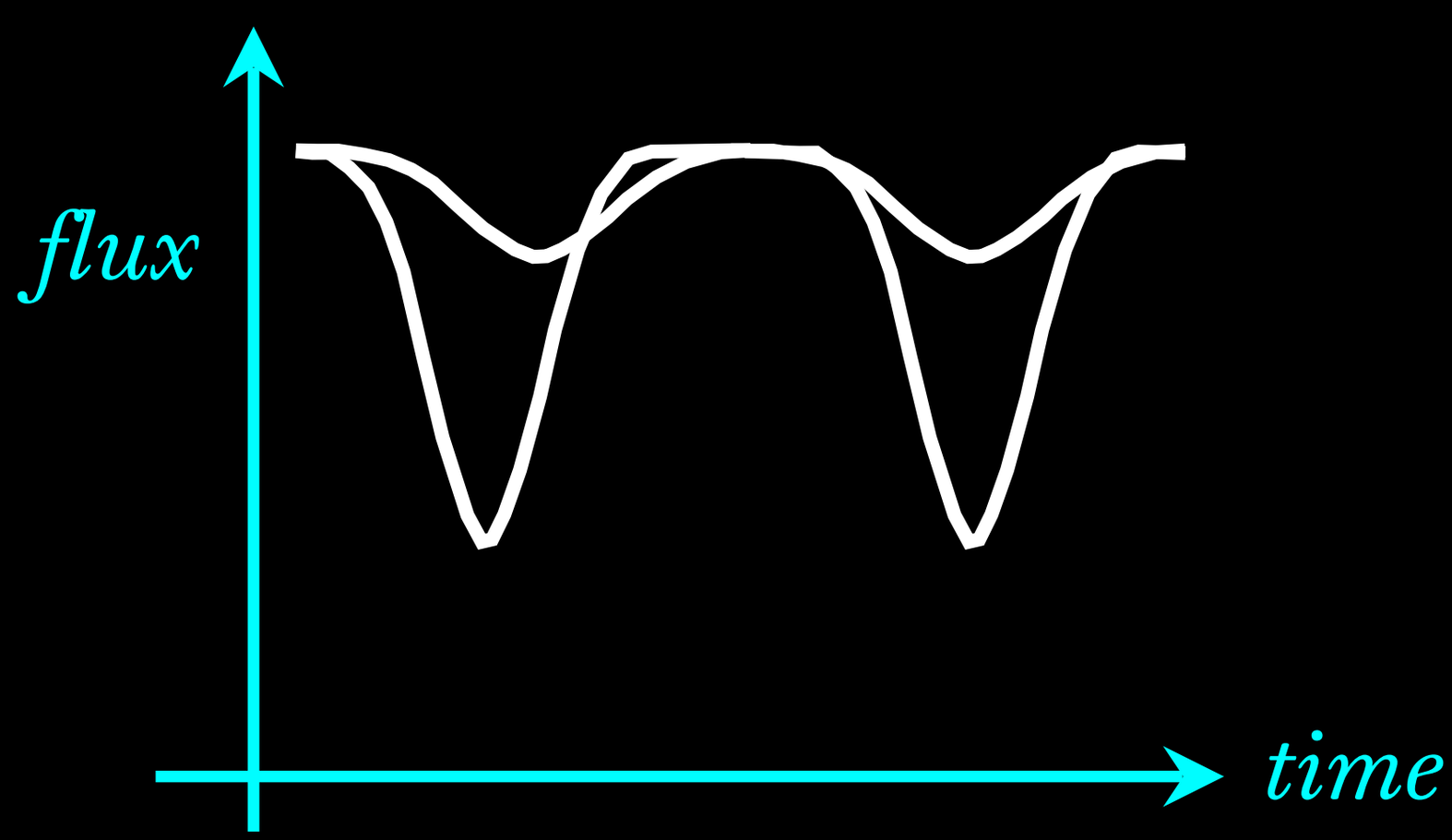


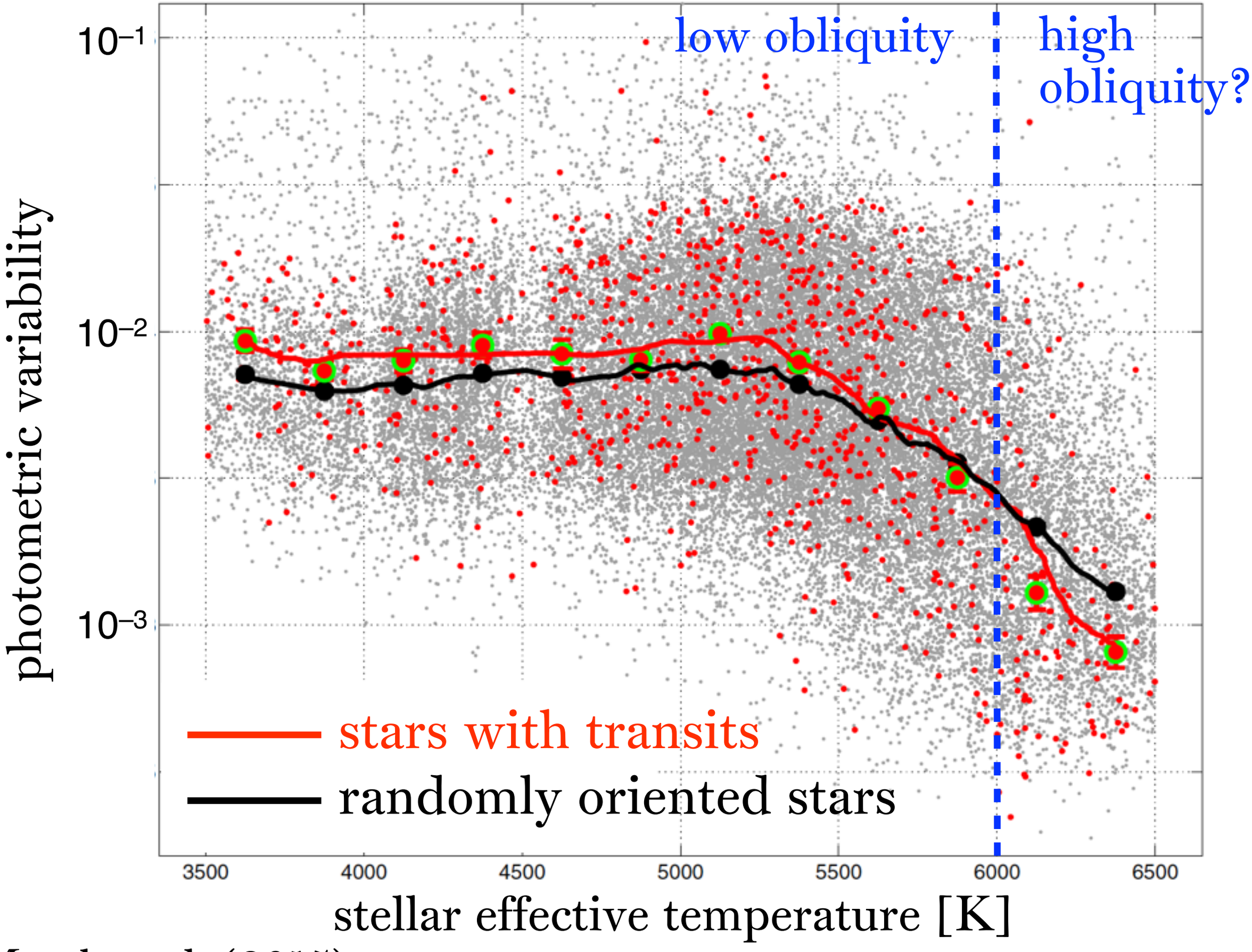
tidal dissipation
too slow

rotation too fast
(Dawson 2014)

starspot variability

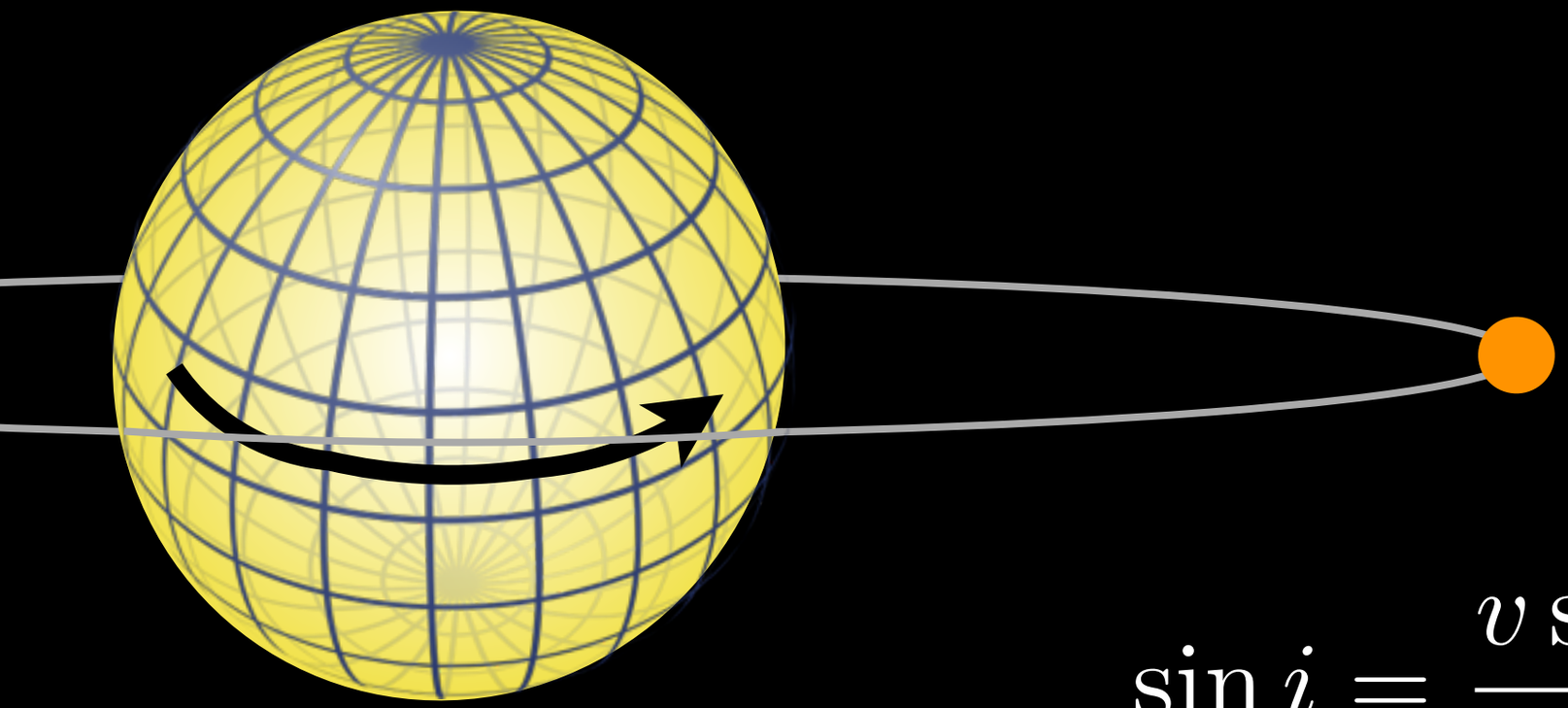




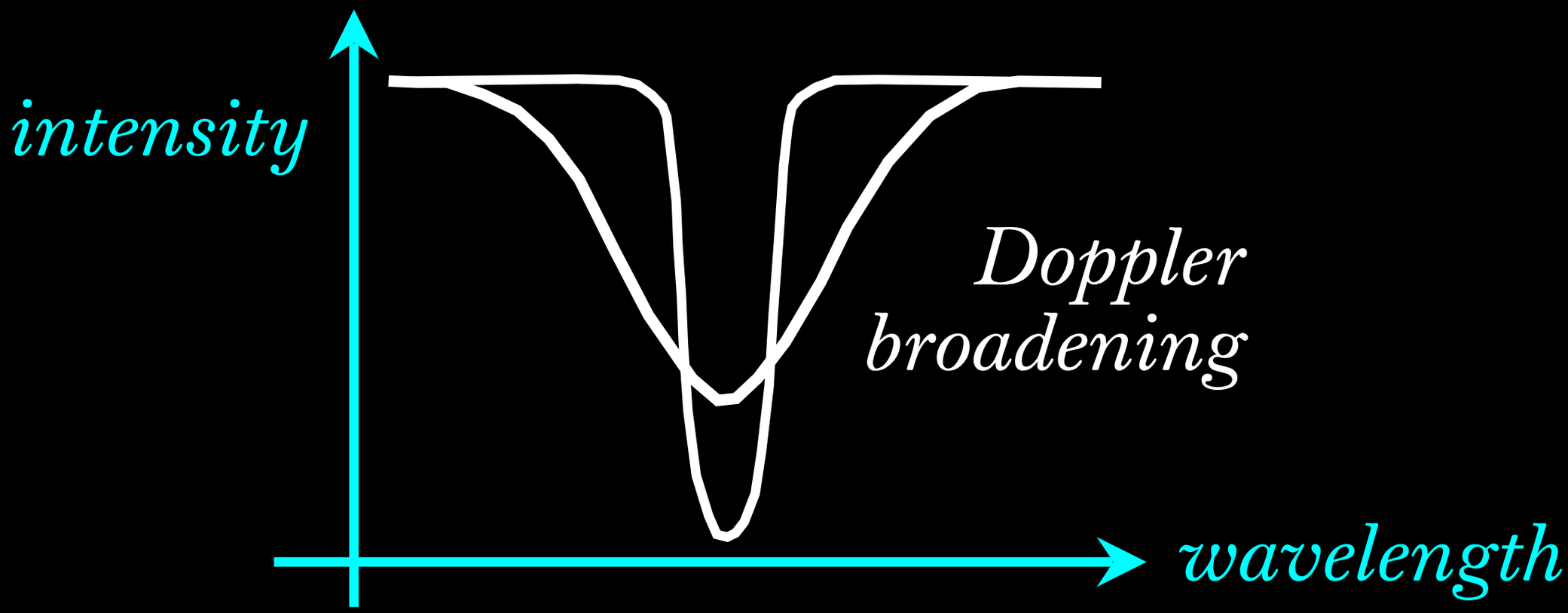


Mazeh et al. (2015)

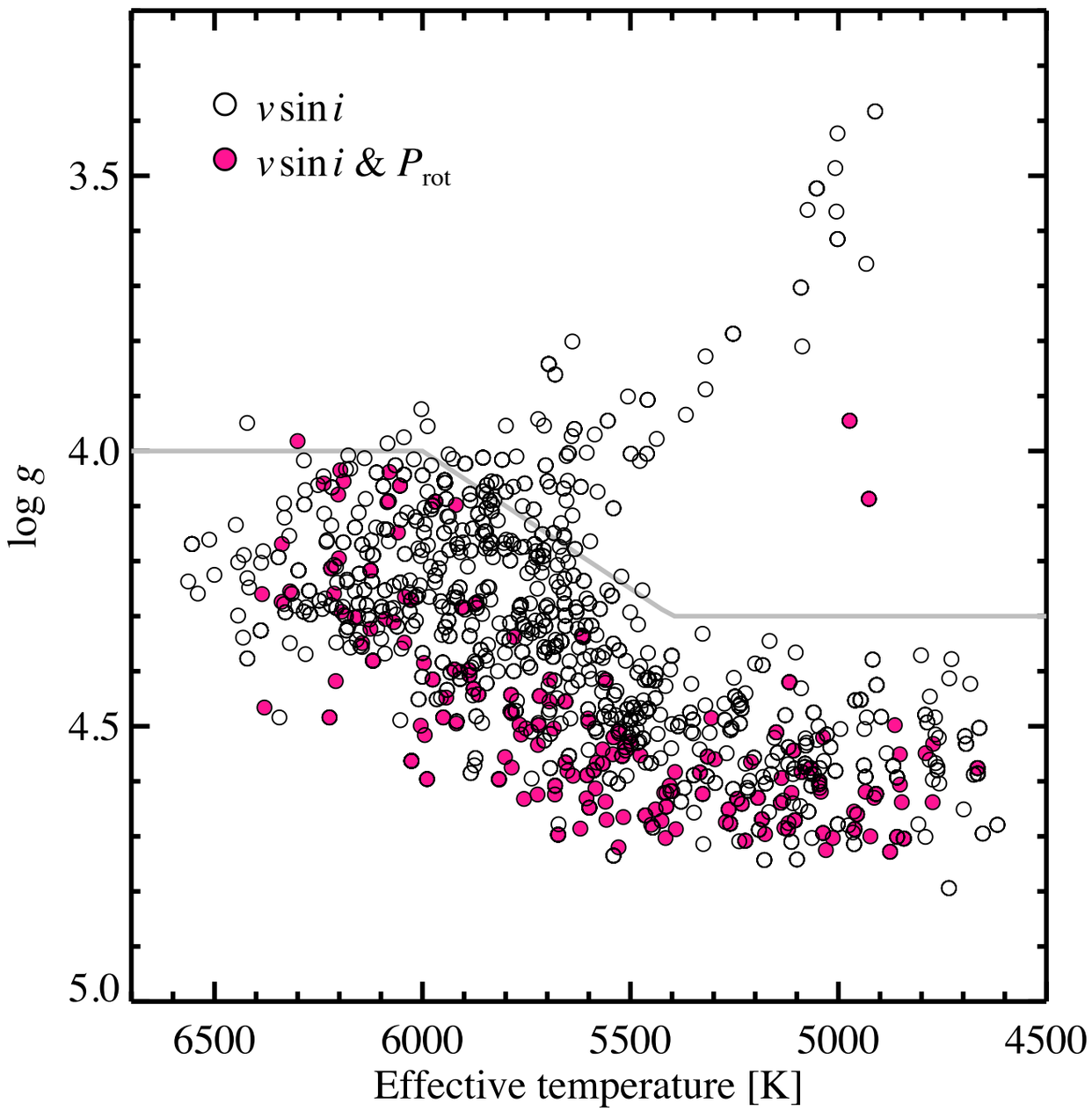
$v \sin i$ method

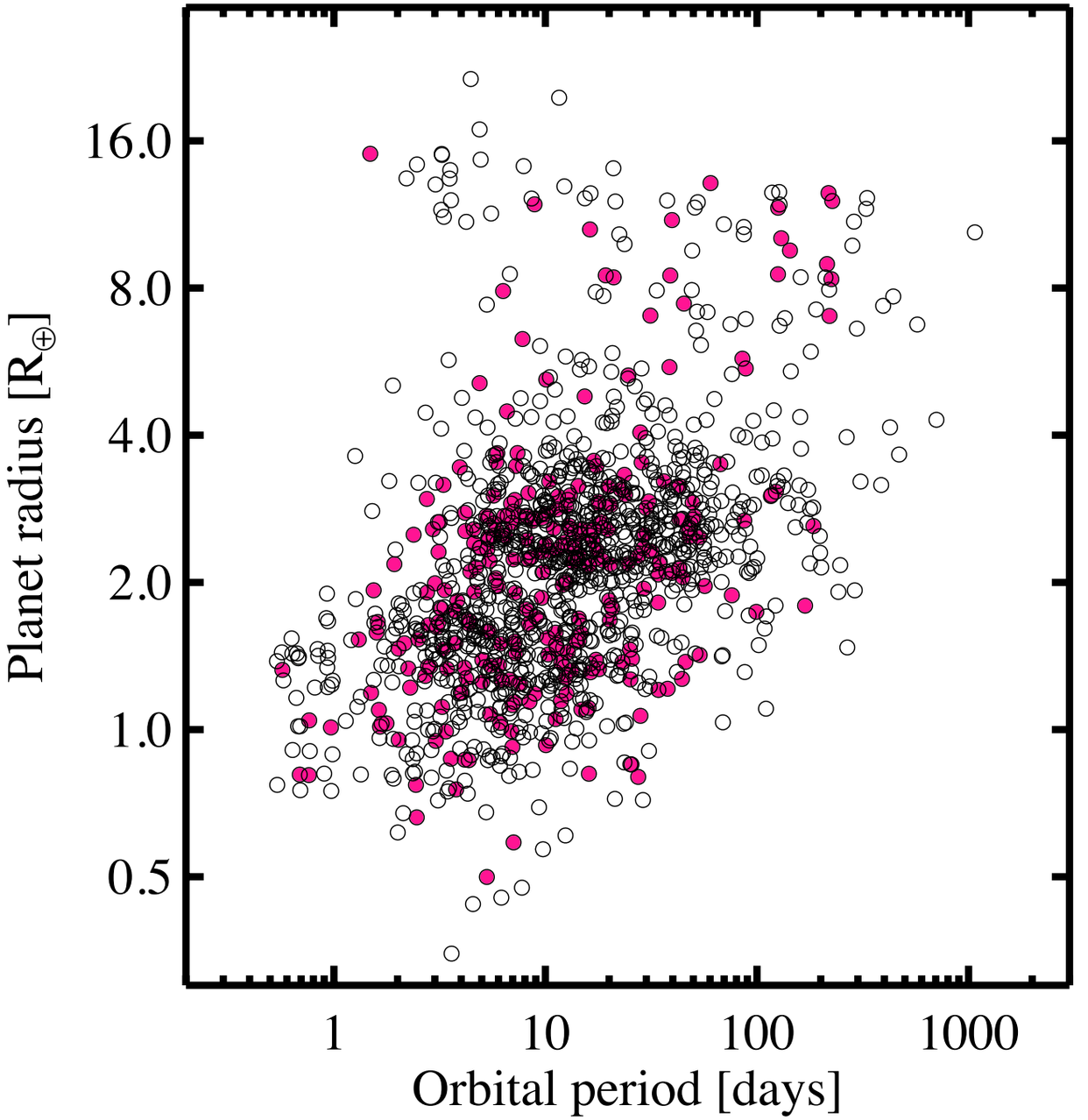


$$\sin i = \frac{v \sin i}{v} = \frac{v \sin i}{2\pi R_\star / P_{\rm rot}}$$

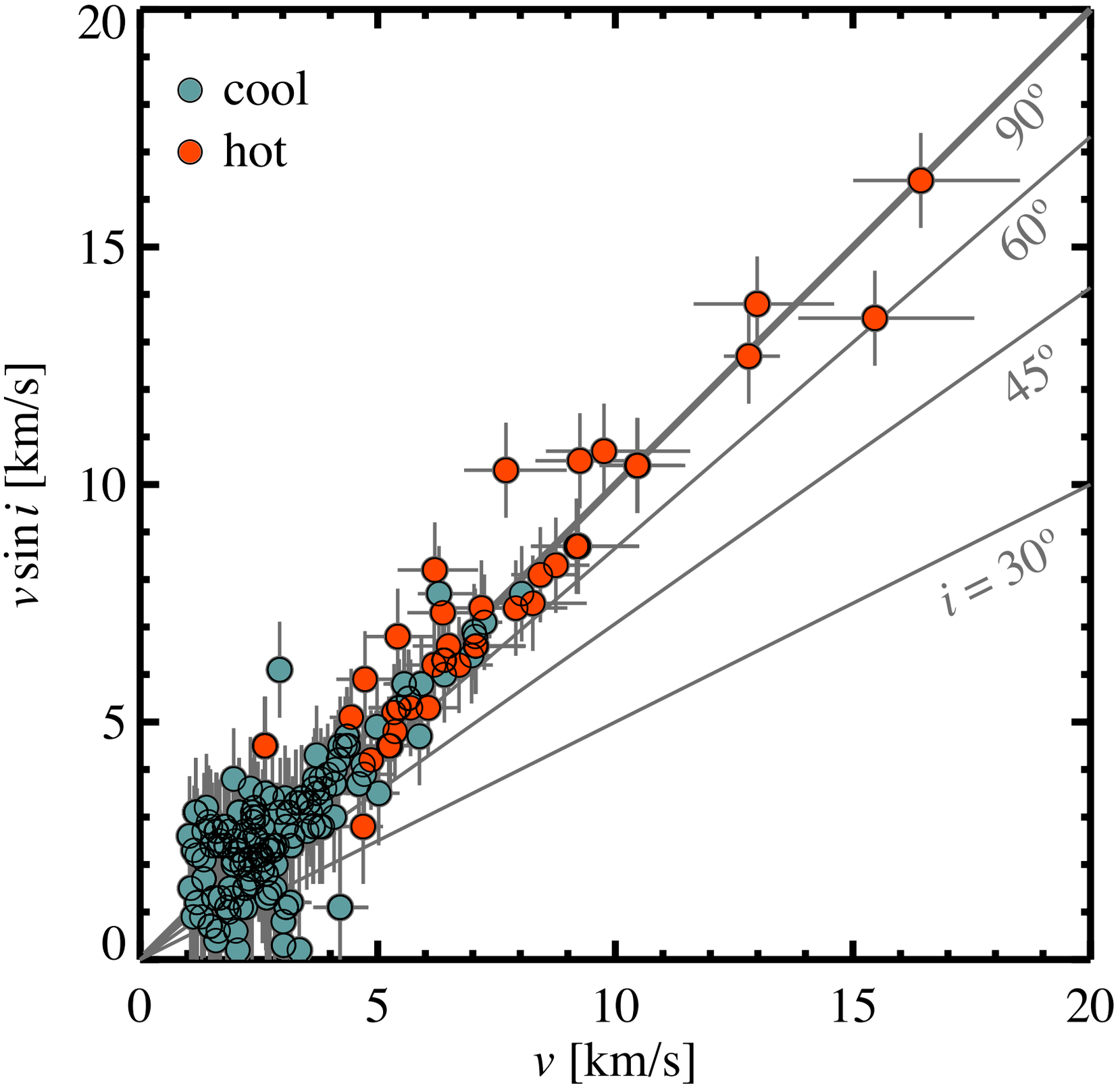


California *Kepler* Survey



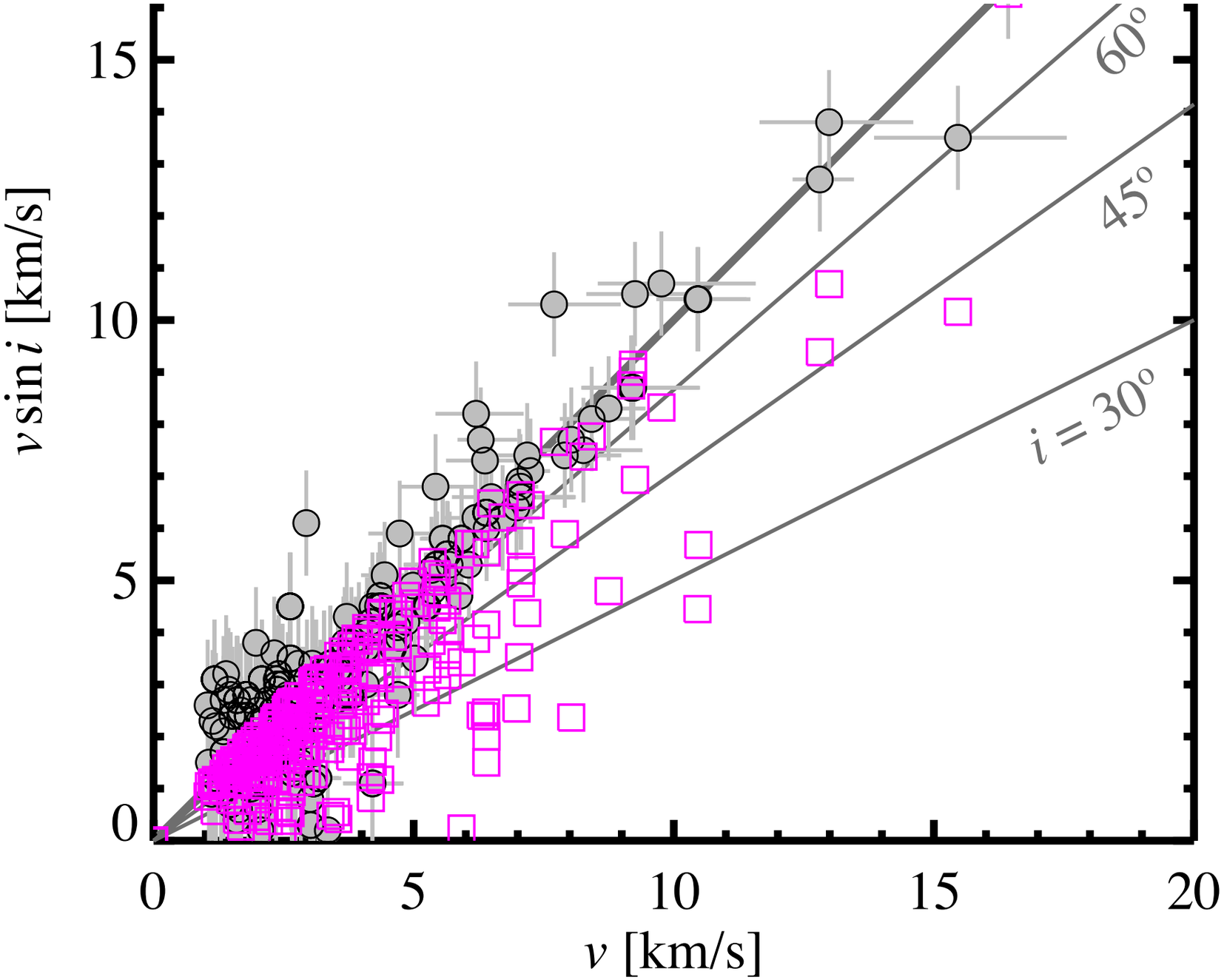


Petigura et al. (2017), Johnson et al. (2017)



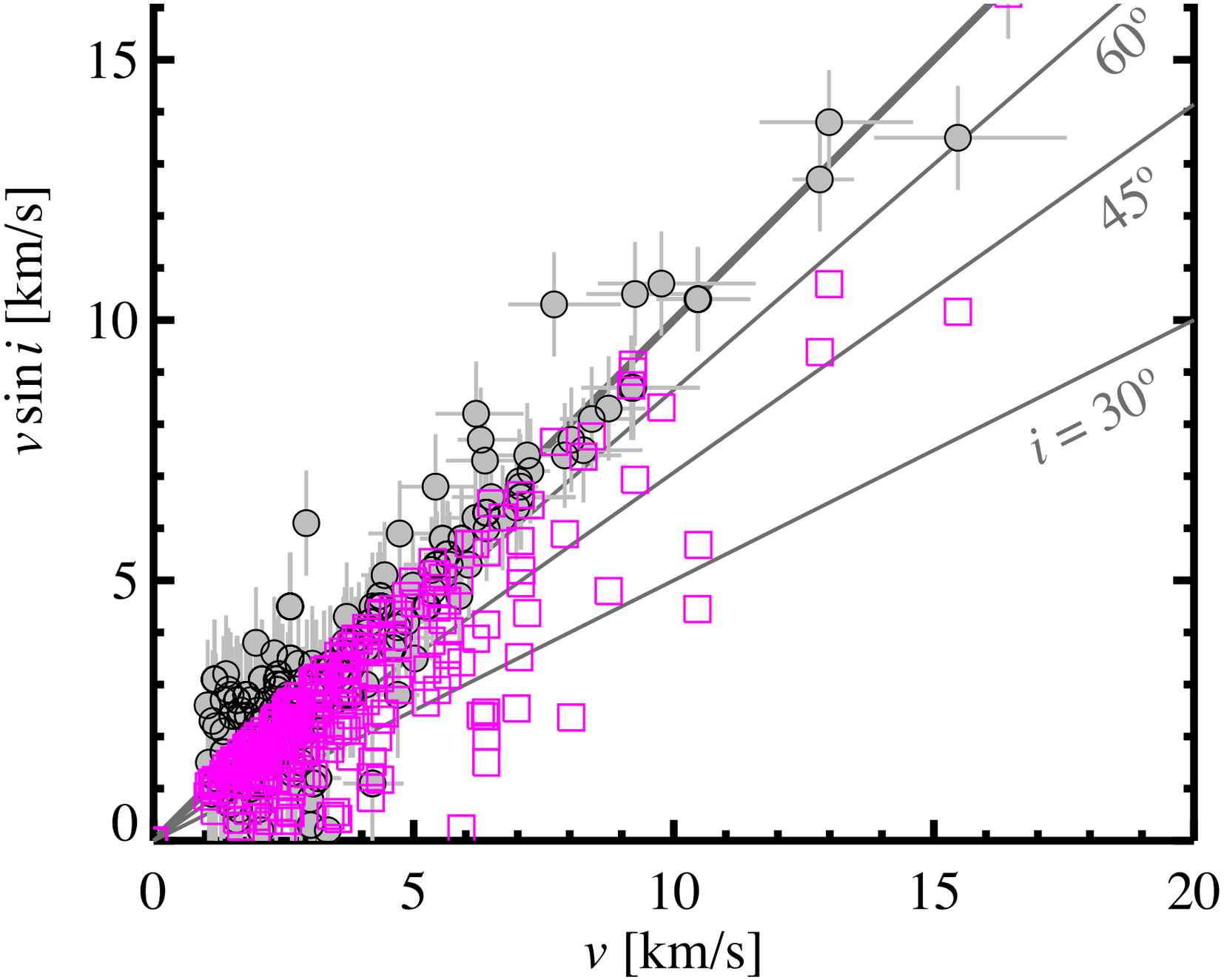
Winn et al. (2017)

Hot stars with hot Jupiters have high obliquities



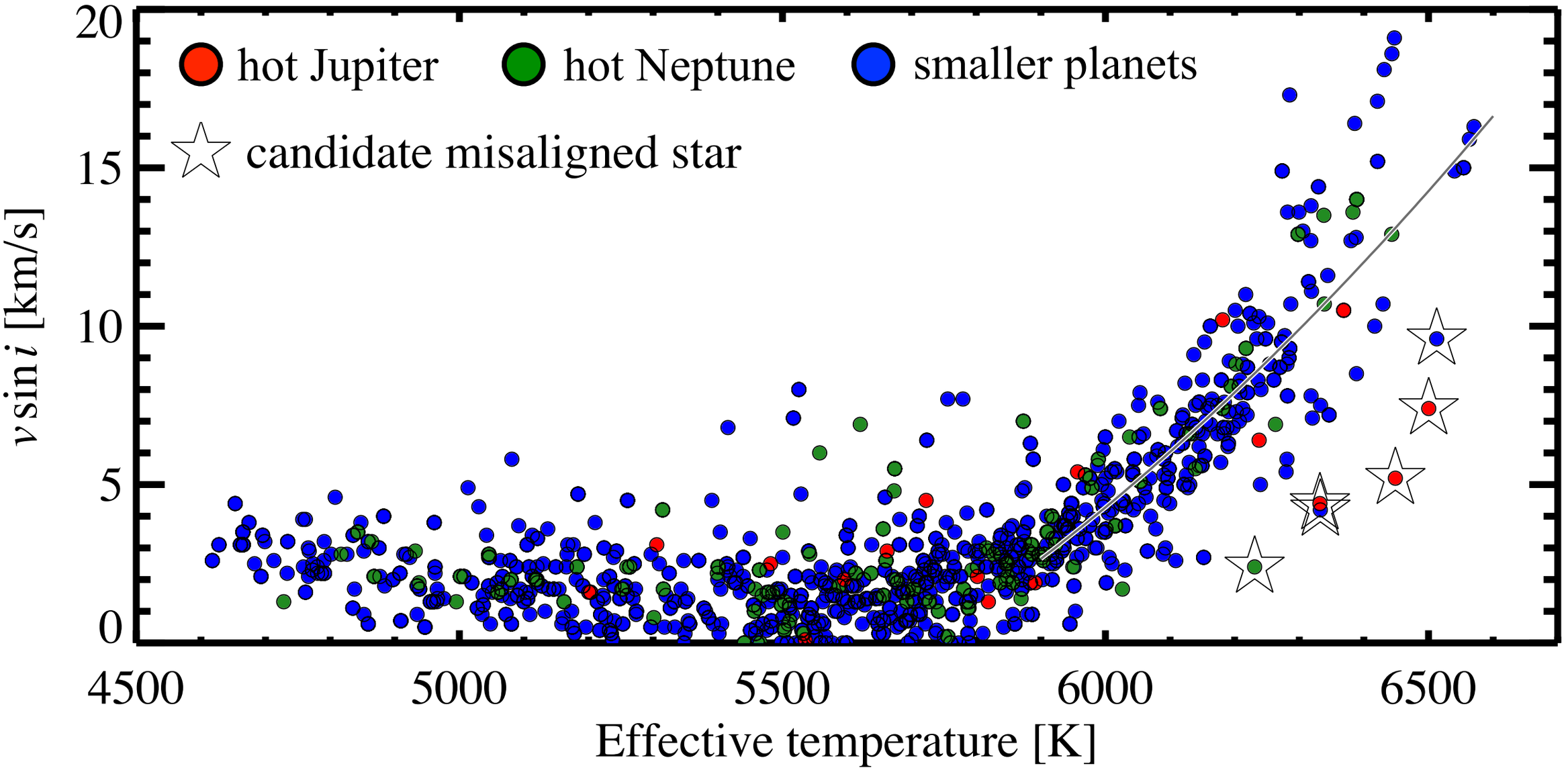
Winn et al. (2017)

Hot stars *without* hot Jupiters have *low* obliquities



Winn et al. (2017)

Hot stars *without* hot Jupiters have *low* obliquities

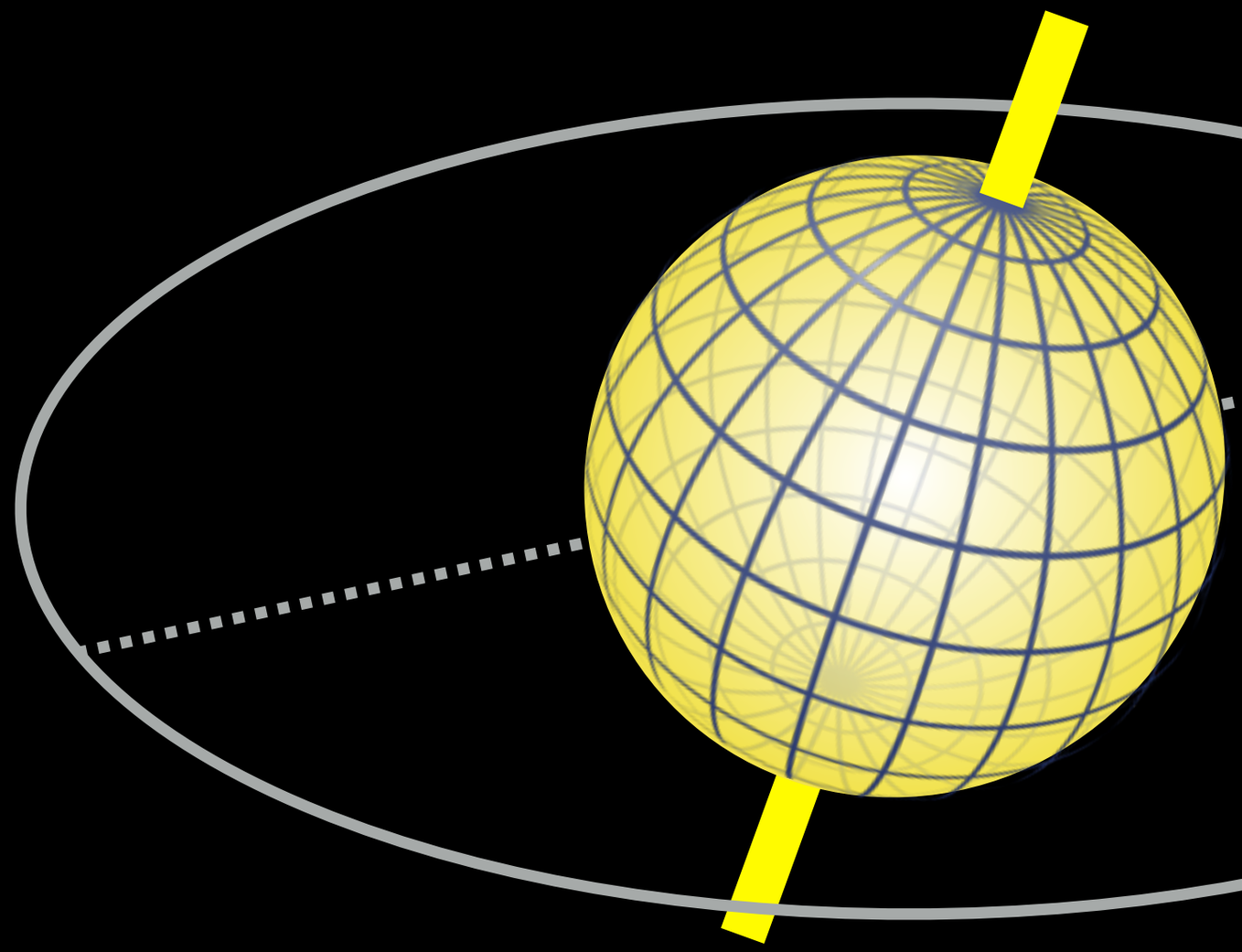


Winn et al. (2017)

Risk factors for high obliquity

- hot star with hot Jupiter
- cool star with warm Jupiter
- name is Kepler-56

(see next talk)



Theories

misalignment mechanism

tilt the *star*: internal gravity waves, spin-orbit resonance

tilt the *disk*: chaotic accretion,
★ stellar flybys or companions, magnetic interactions

★ tilt the *planet*: Kozai cycles, p-p scattering, …

realignment mechanism

star-planet tides

star-disk interactions