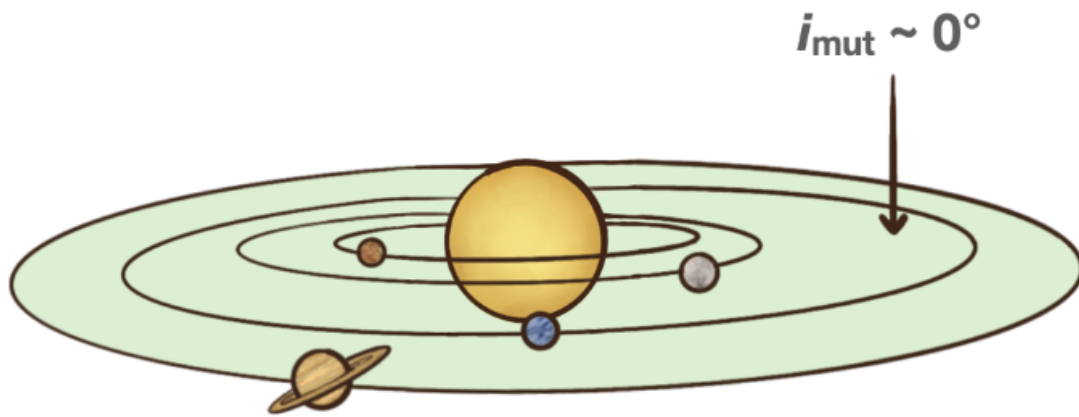


Spin-Orbit Measurements of the resonant chain HD 110067

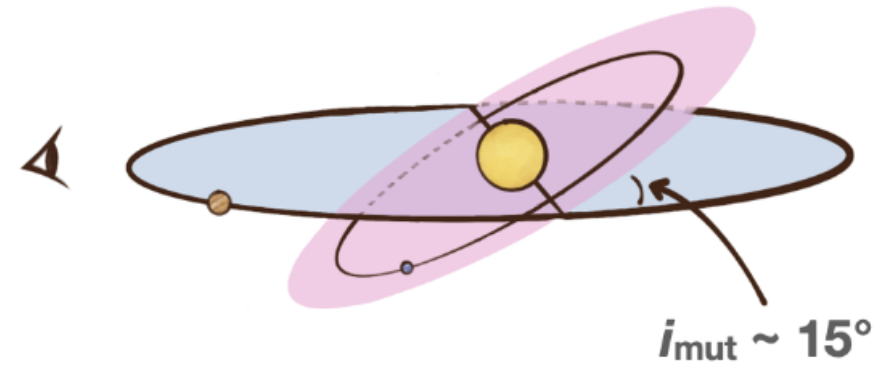
Jiří Žák

Astronomical institute of Czech Academy of Sciences

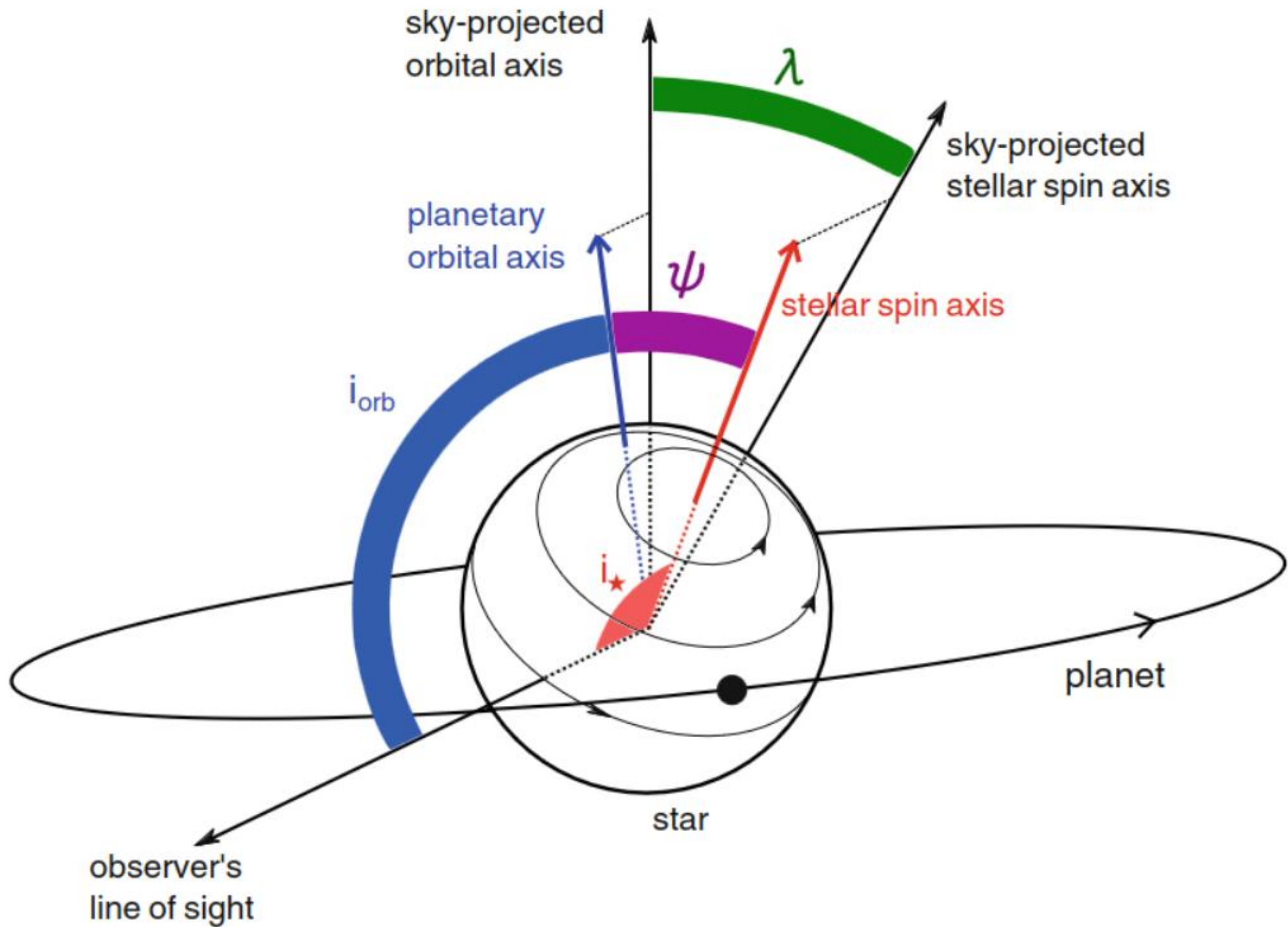




**Low Mutual Inclination:
“Solar System-Like”**



**High Mutual Inclination:
KOI-134**



Rossiter-McLaughlin effect

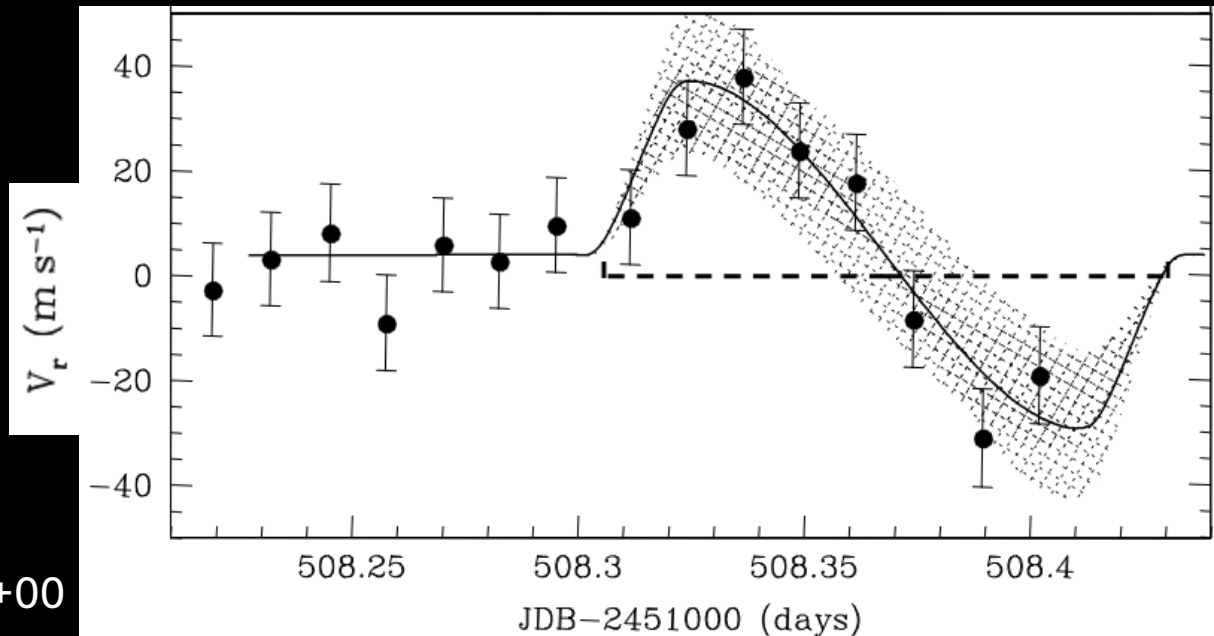
- Spectroscopy phenomenon during transit

Rossiter-McLaughlin effect

- Spectroscopy phenomenon during transit
- Binaries and exoplanets since 2000
- RV anomaly with an amplitude:

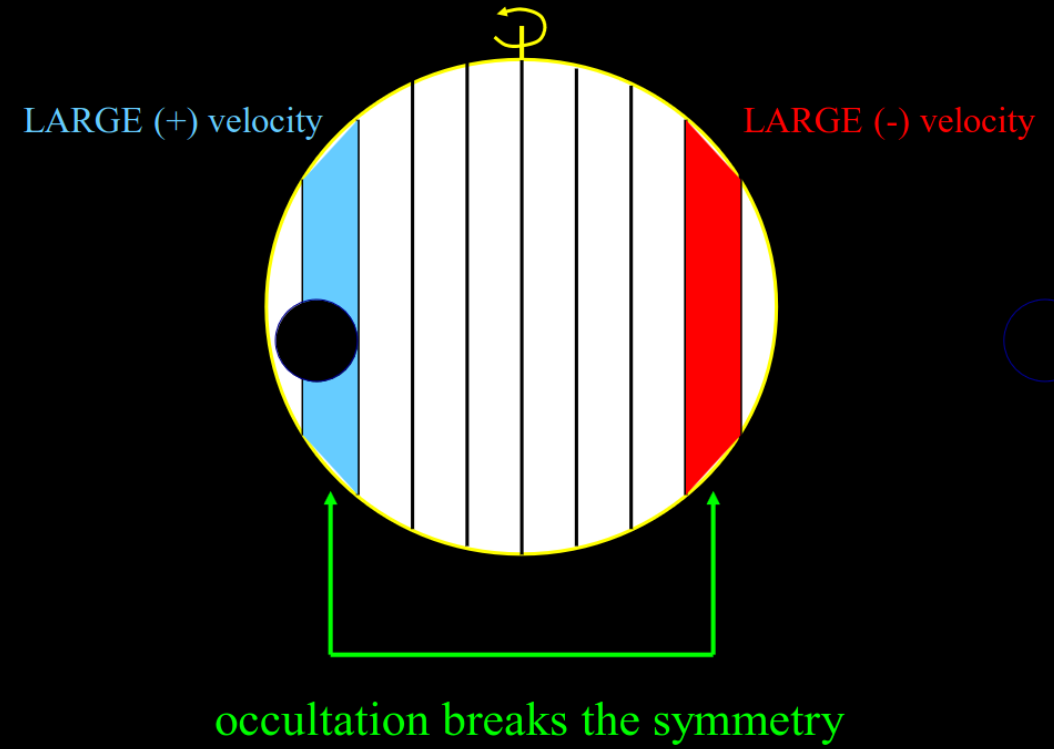
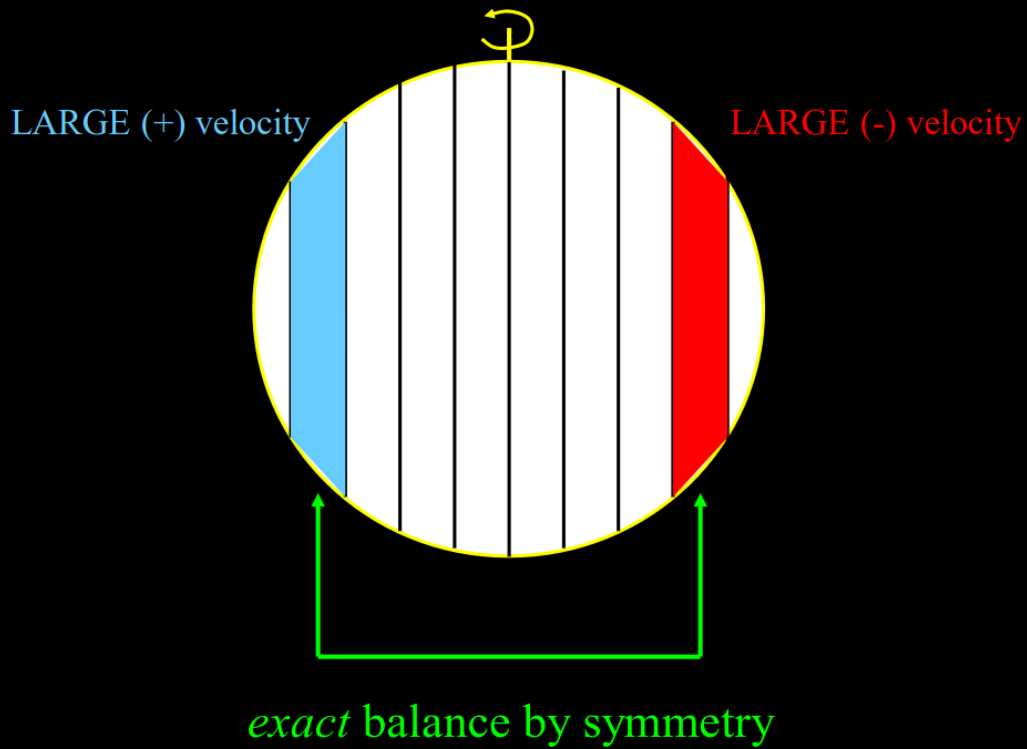
$$K_{\text{RM}} \propto v \sin(i) \left(\frac{R_p}{R_\star} \right)^2 \sqrt{1 - b^2}$$

Queloz+00

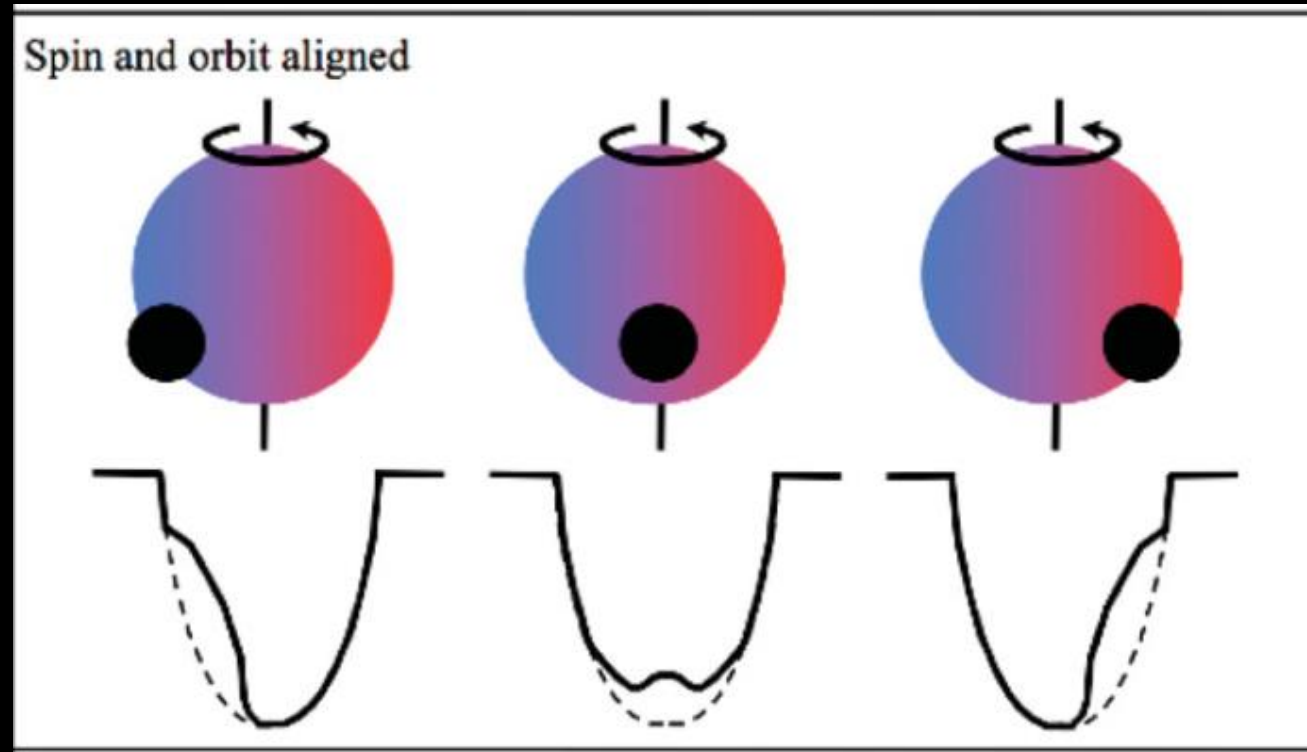


Rossiter-McLaughlin effect

W. Welsch



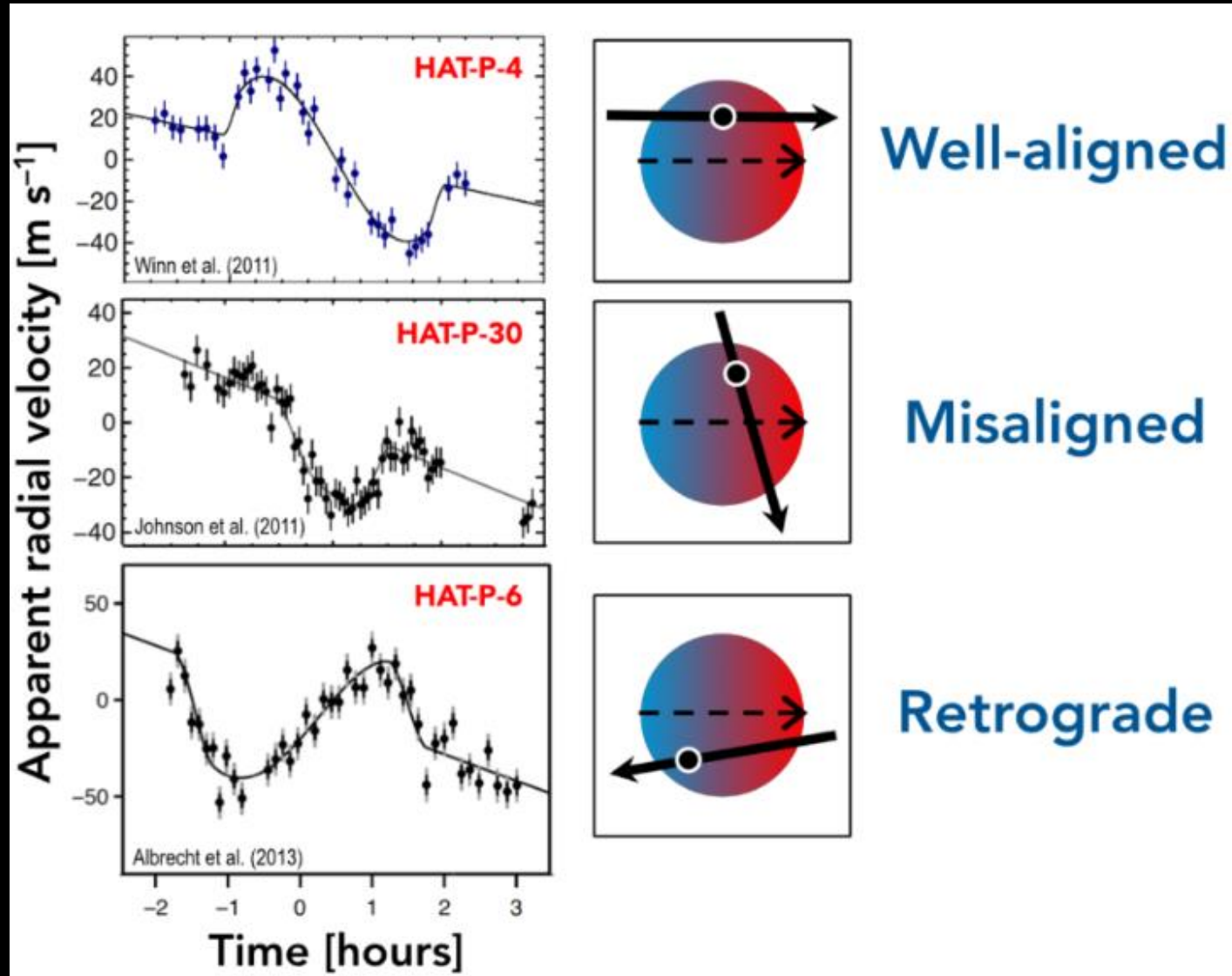
Rossiter-McLaughlin effect



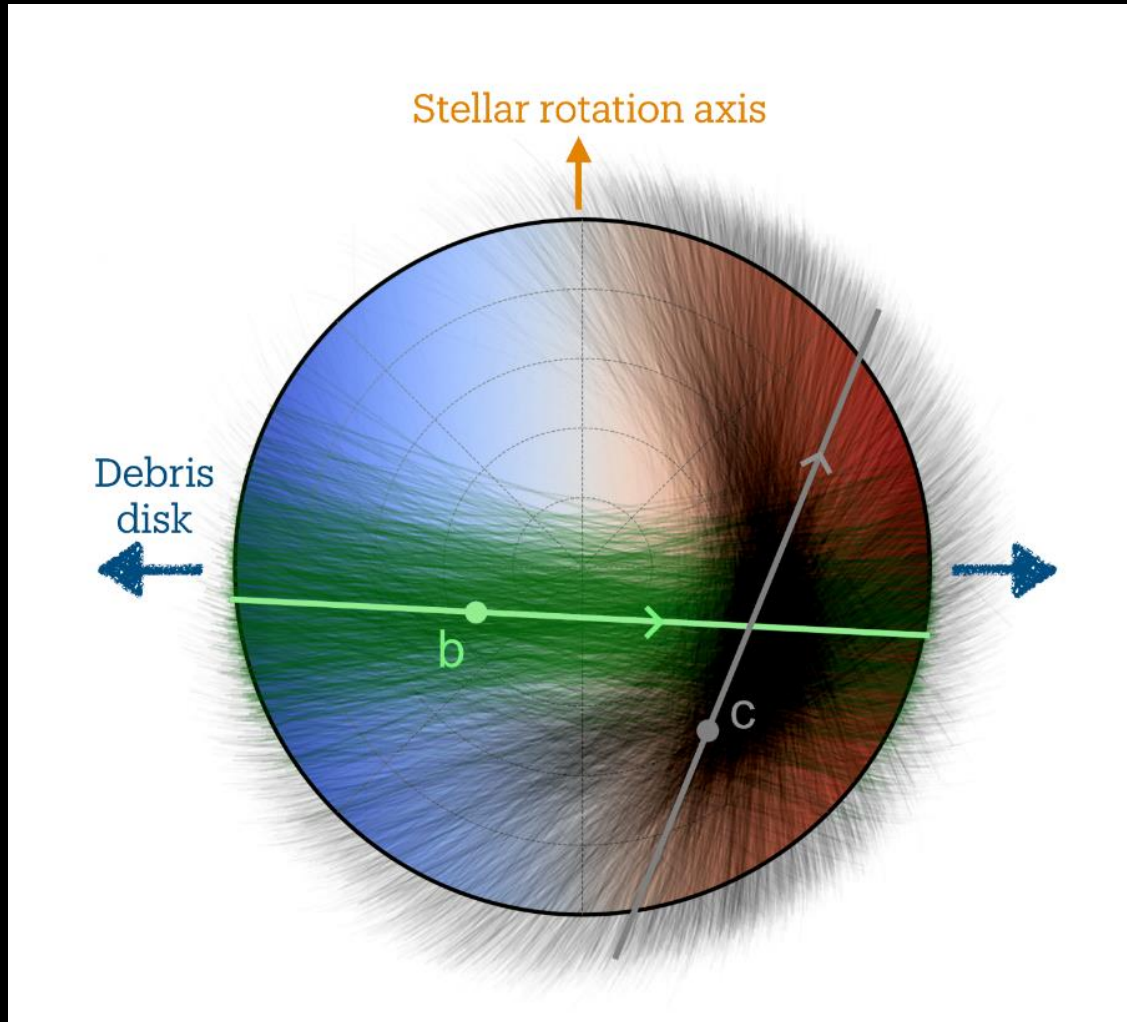
Winn (2010)

- Allows for determination of the projected angle between the stellar spin axis and the orbital plane

Types of orbits

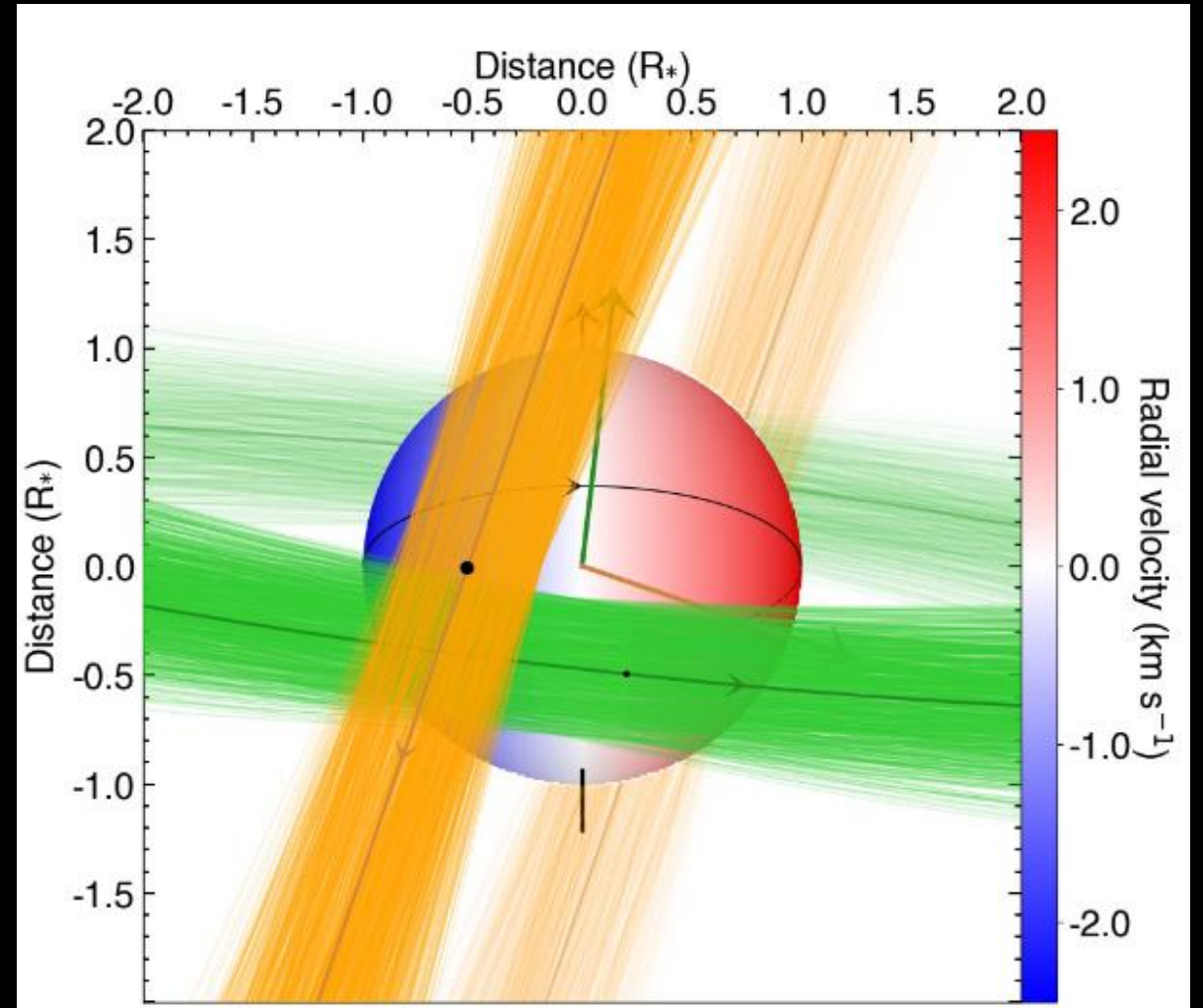


AU Mic



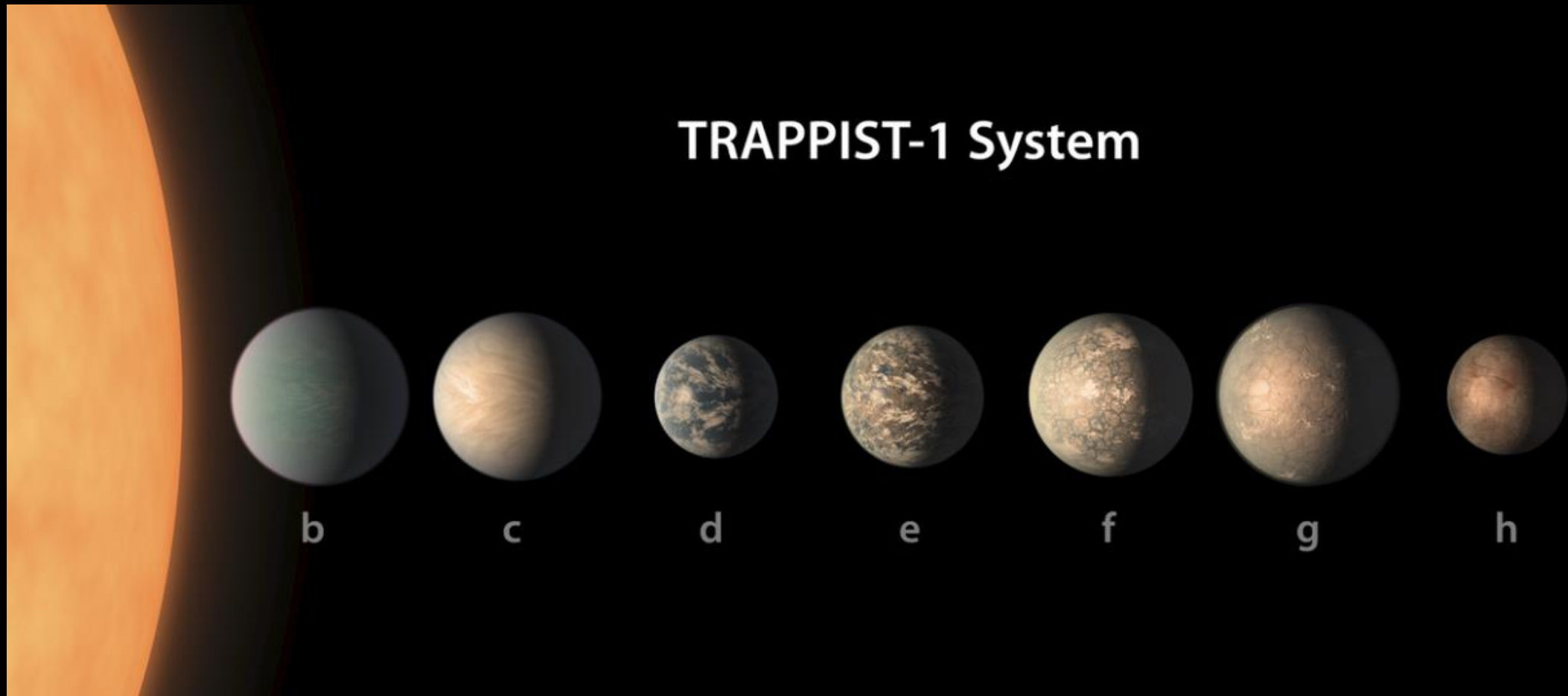
Yu+25

HD 3167



Bourrier+21

Resonant chain systems



Resonant chain systems

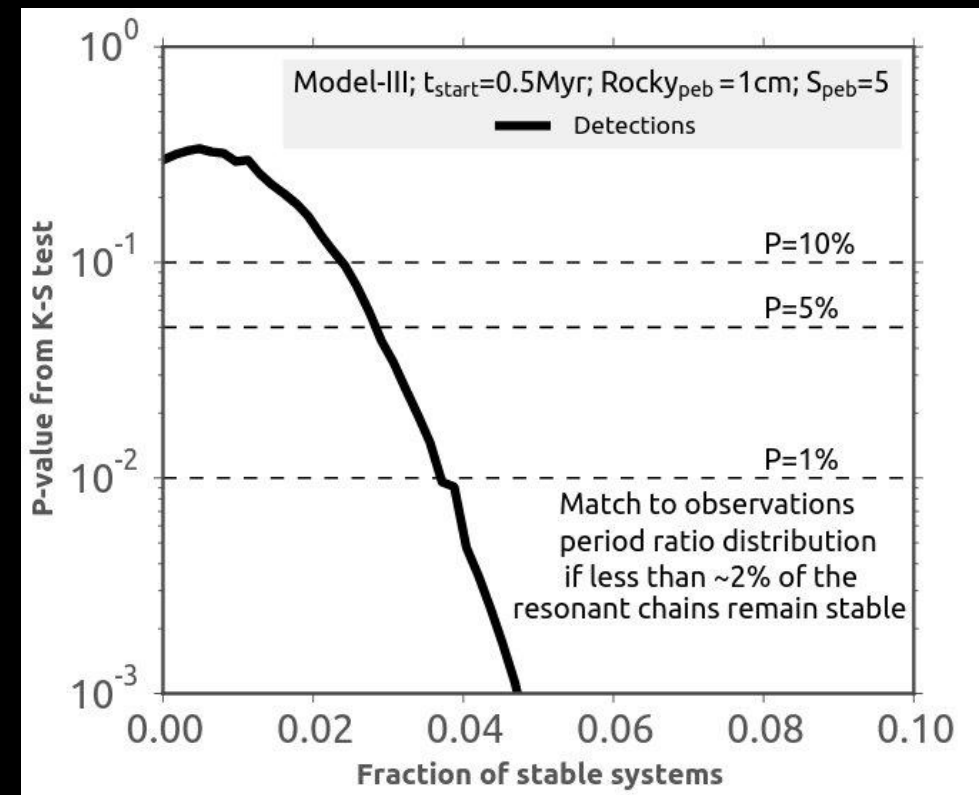
- Multiple planets are locked into a series of orbital resonances

Resonant chain systems

- Multiple planets are locked into a series of orbital resonances
- Quiescent formation is expected

Resonant chain systems

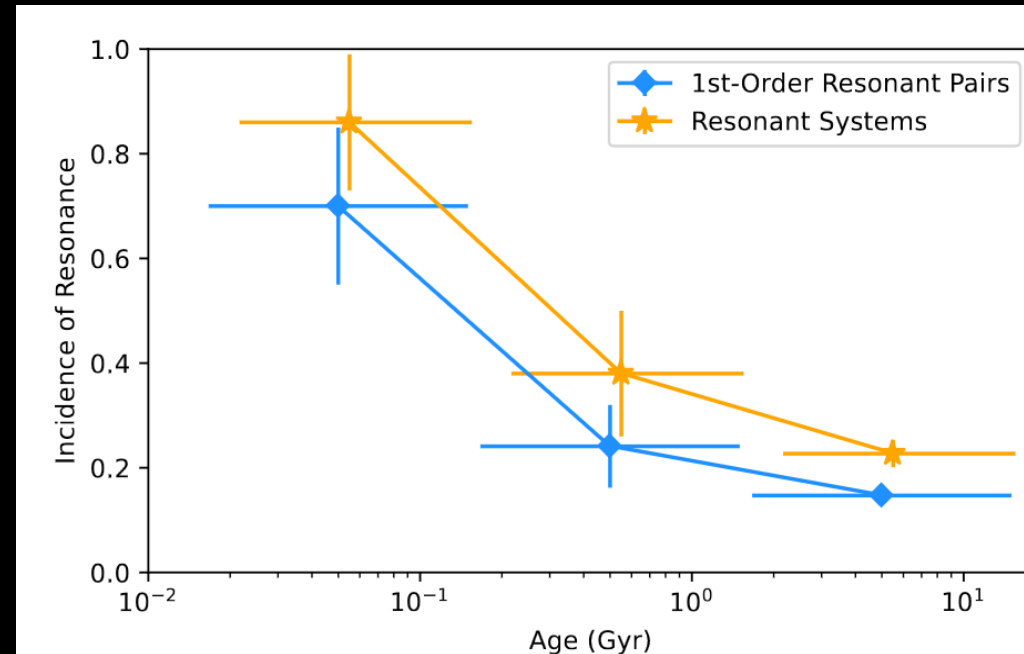
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- Why we don't observe more of them?
~5% of observed systems are resonant



Resonant chain systems

- Multiple planets are locked into a series of orbital resonances
- Quiescent formation is expected
- Why we don't observe more of them?
~5% of observed systems are resonant
- Age dependency (Dai+24)

Dai+24



Resonant systems

- What breaks the resonances?

Resonant systems

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- Overstable librations? Post-disc secular changes? Primordial misalignment? Something else?

Resonant systems

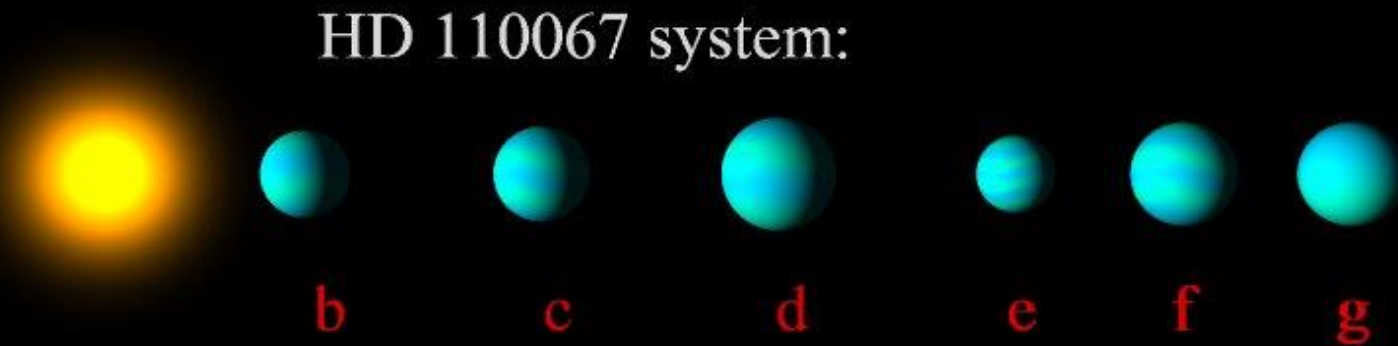
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- Only 2 resonant chain systems have R-Me measurement

Resonant systems

- What breaks the resonances?
- Overstable librations? Post-disc secular changes? Primordial misalignment? Something else?
- Only 2 resonant chain systems have R-Me measurement
- Small R-Me amplitude, lack of resonant systems, TTVs

HD 110067

- System of 6 planets in resonant chain in a triple system



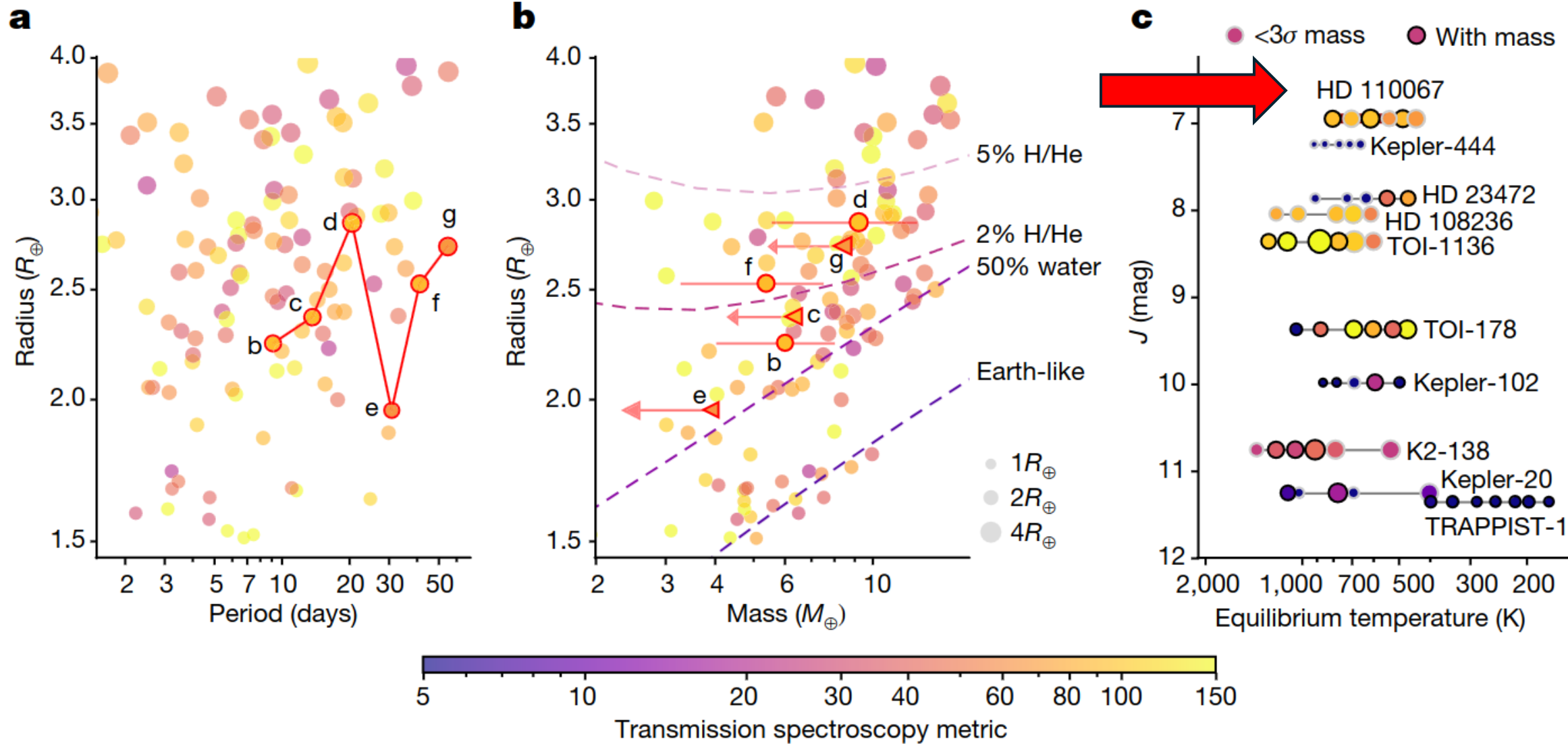
Mericanto

HD 110067

- System of 6 planets in resonant chain in a triple system
- Brightest multi-planetary transiting system (>4)

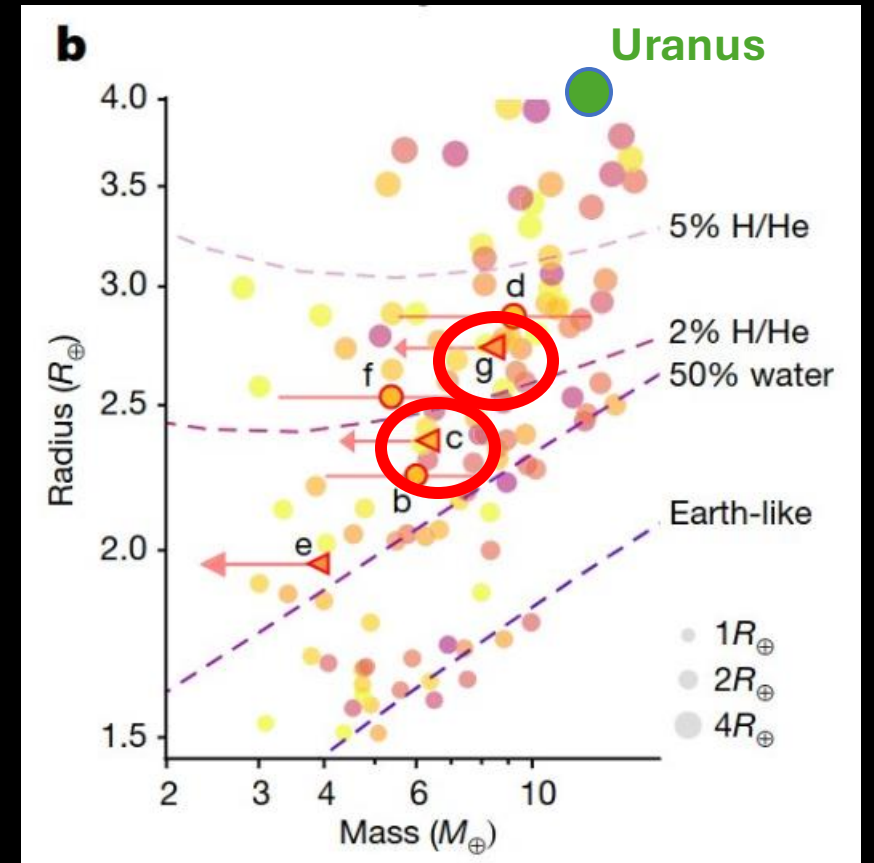
HD 110067

- System of 6 planets in resonant chain in a triple system
- Brightest multi-planetary transiting system (>4)
- Most planets with significant atmospheric mass fraction



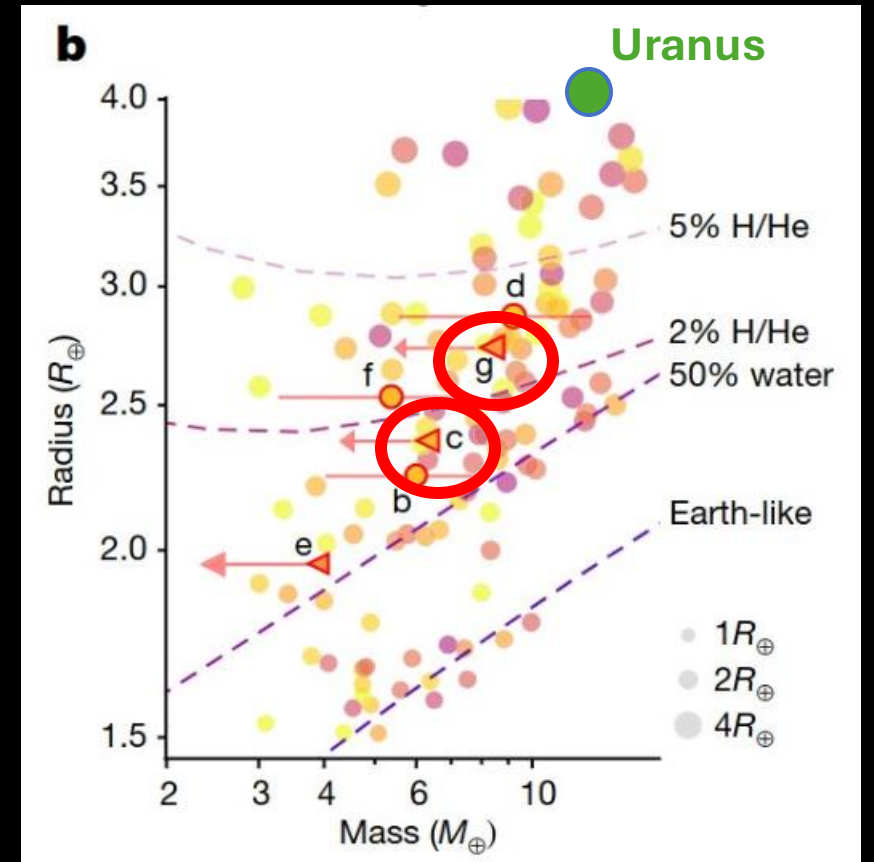
HD 110067

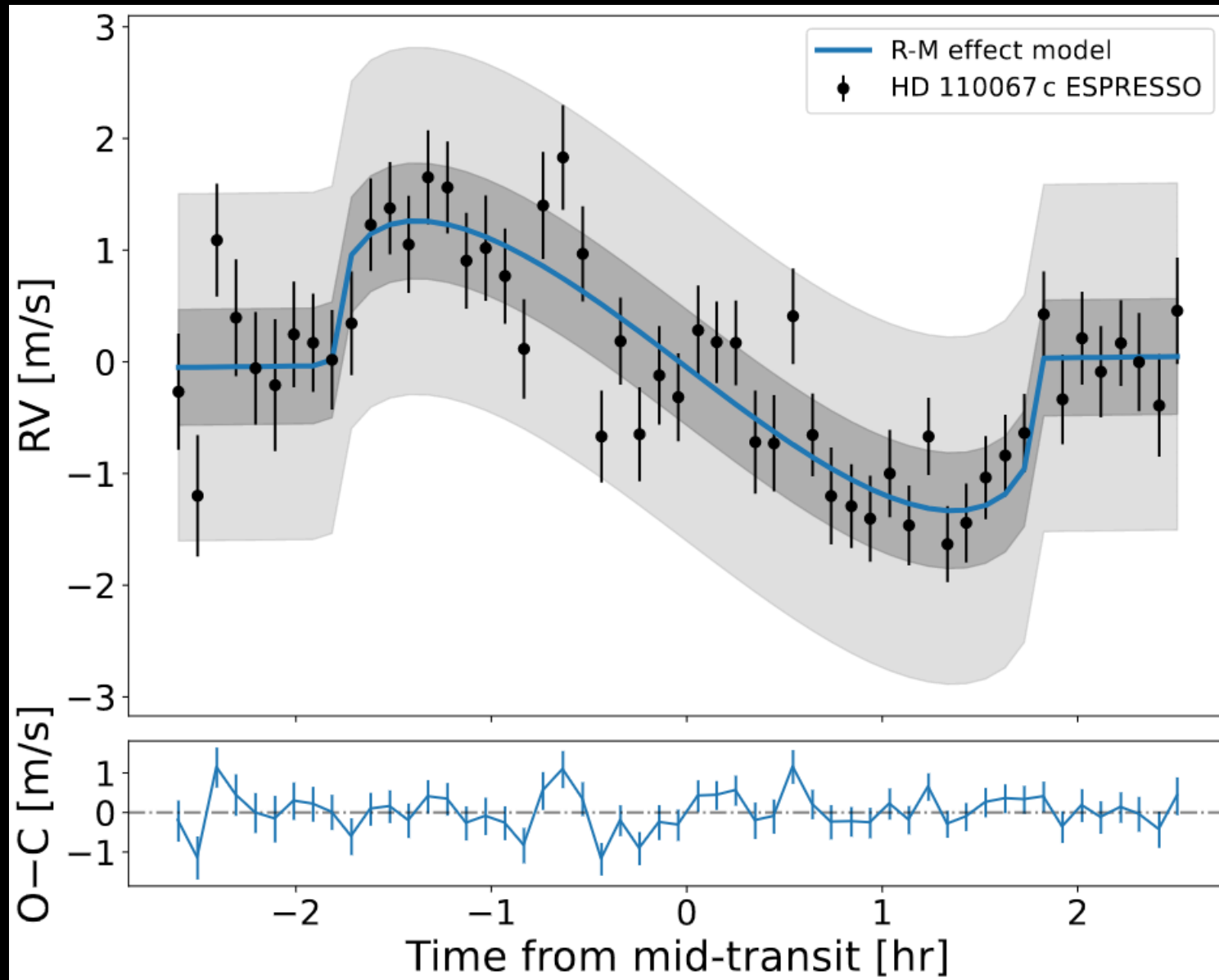
- Planet c and g (2nd closest and last)
- Sub-Neptunes with 13 and 55 day period



HD 110067

- Planet c and g (2nd closest and last)
- Sub-Neptunes with 13 and 55 day period
- What is their spin-orbit alignment?
- Only ~ 1.5 m/s amplitudes
- \Rightarrow ESPRESSO, MAROON-X





HD 110067

- Well-aligned orbits

HD 110067

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- Confirms quiescent history
- Supports the idea of formation through convergent disc migration

HD 110067

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- Confirms quiescent history
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- Third resonant chain with measured R-Me, first multi-planet

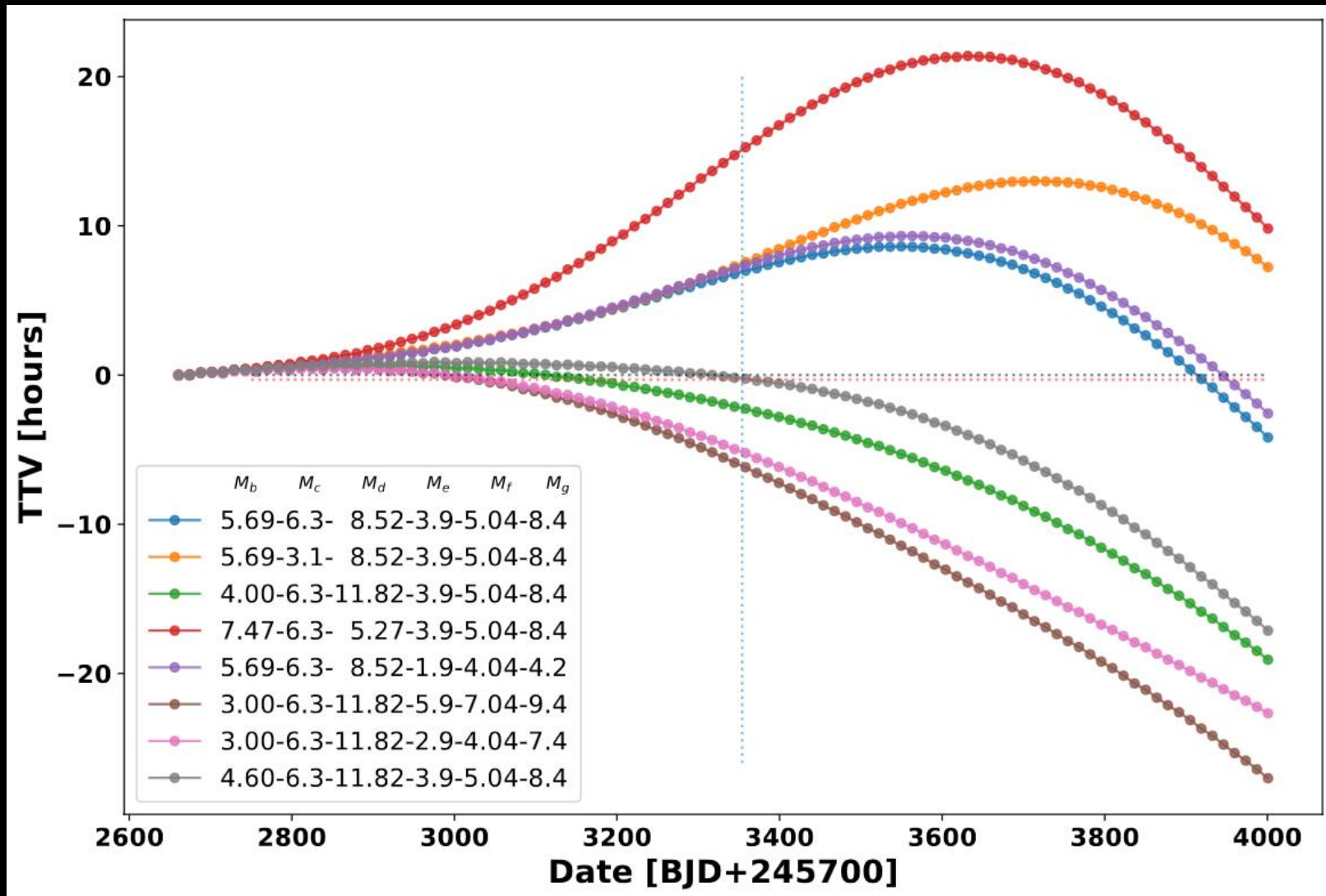
TTVs from spectroscopy

- Transit of planet c too shallow for ground-based photometry

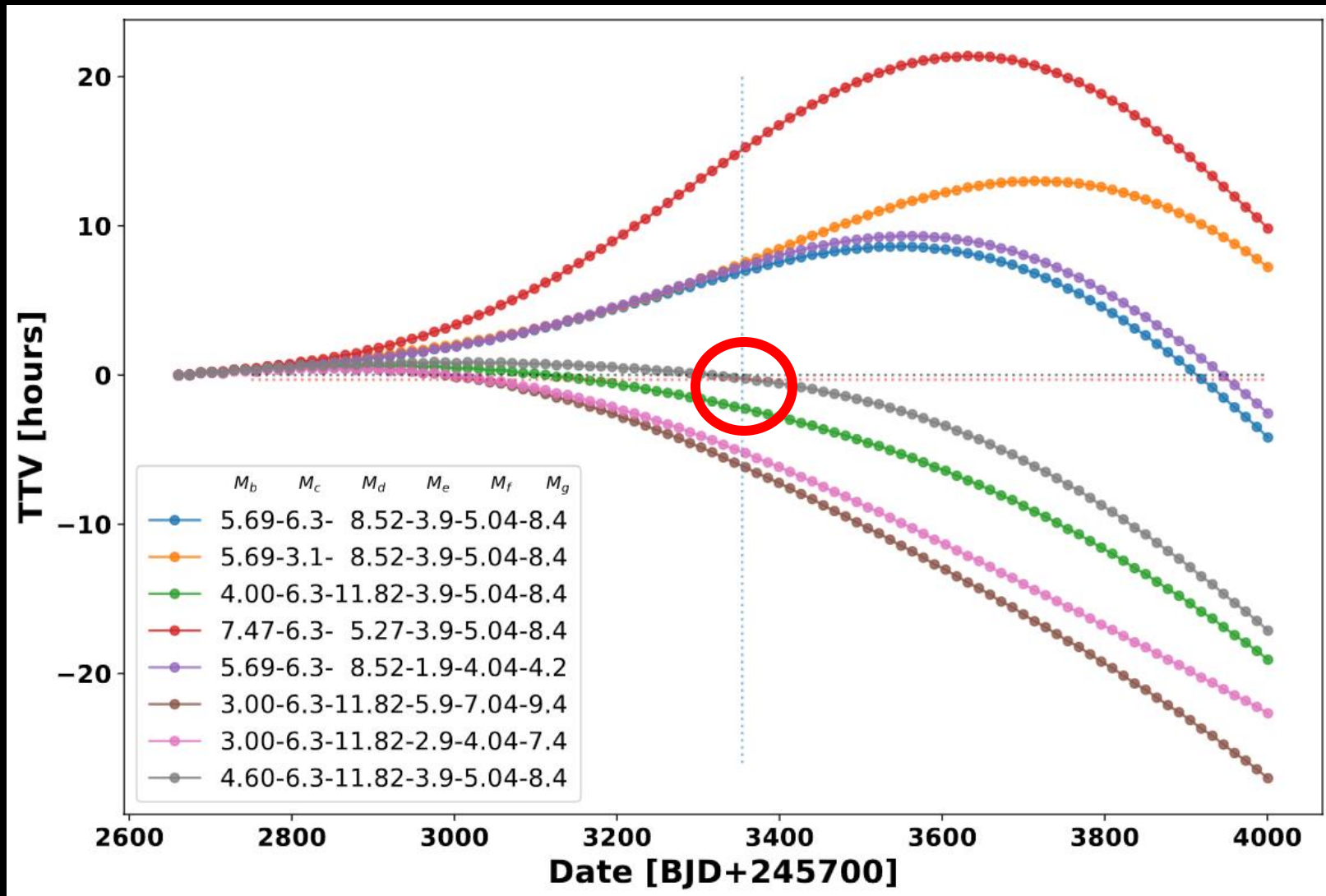
TTVs from spectroscopy

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Surprisingly small TTVs



Surprisingly small TTVs



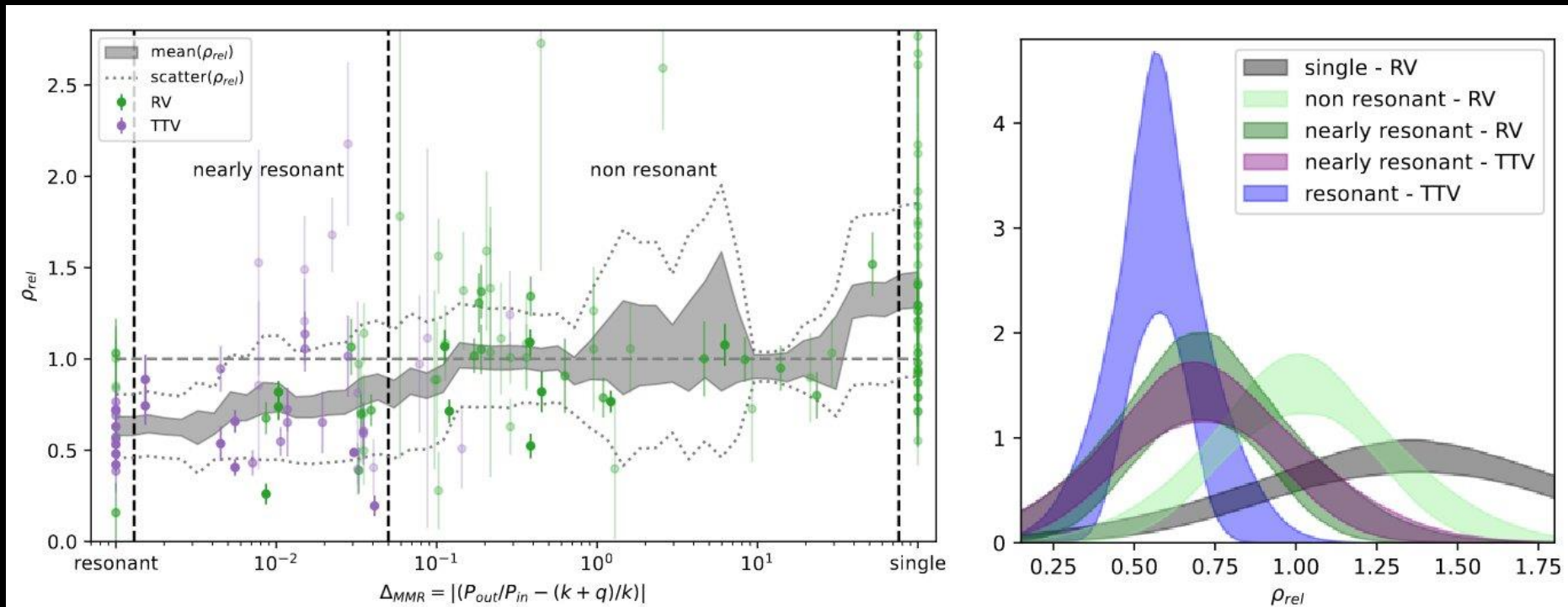
TTVs from spectroscopy

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- Do resonant systems have different internal structure?

(Mills & Mazeh, 2017; Adibekyan+, 2024; Leleu+, 2024)

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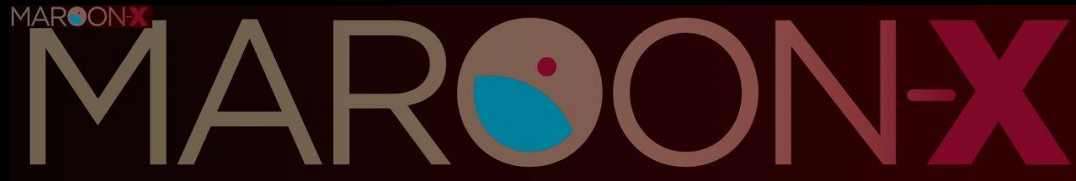


Future prospects

Future prospects

- Small R-Me amplitude

Several ESPRESSO-like instruments operational



Future prospects

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- Lack of resonant systems

TESS, PLATO, Nancy Roman will deliver several more



ESA

Future prospects

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Several ESPRESSO-like instruments operational

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TESS, PLATO, Nancy Roman will deliver several more

- TTVs
- CHEOPS+PLATO+ground-based

ESA



Future prospects

- 3 resonant chains & 2 near-resonant with R-Me characterized

Future prospects

- 3 resonant chains & 2 near-resonant with R-Me characterized
- ~ 10 systems with *PLATO* delivering more

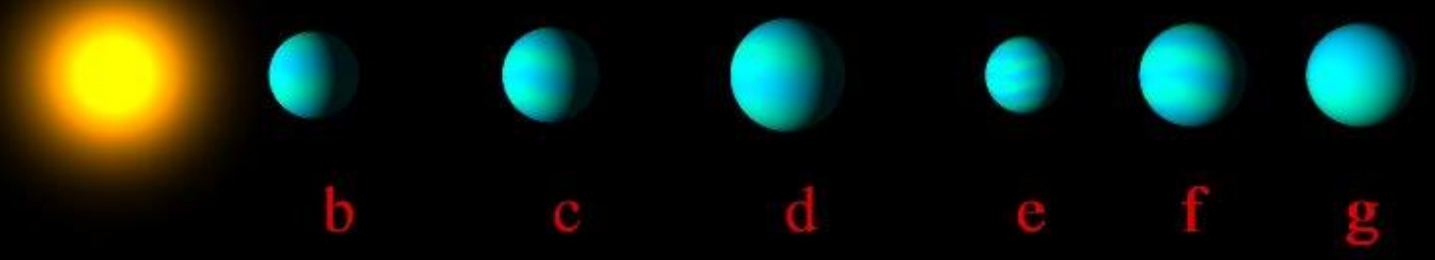
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Future prospects

- 3 resonant chains & 2 near-resonant with R-Me characterized
 - ~ 10 systems with *PLATO* delivering more
 - Compare spin-orbit distribution for resonant vs non-resonant
 - Composition and thermal structure with JWST and Ariel
- Use resonant systems as anchors of disc migrating planets
- "What are the mechanisms shaping the resonant systems?"*

HD 110067 system:



Questions?