

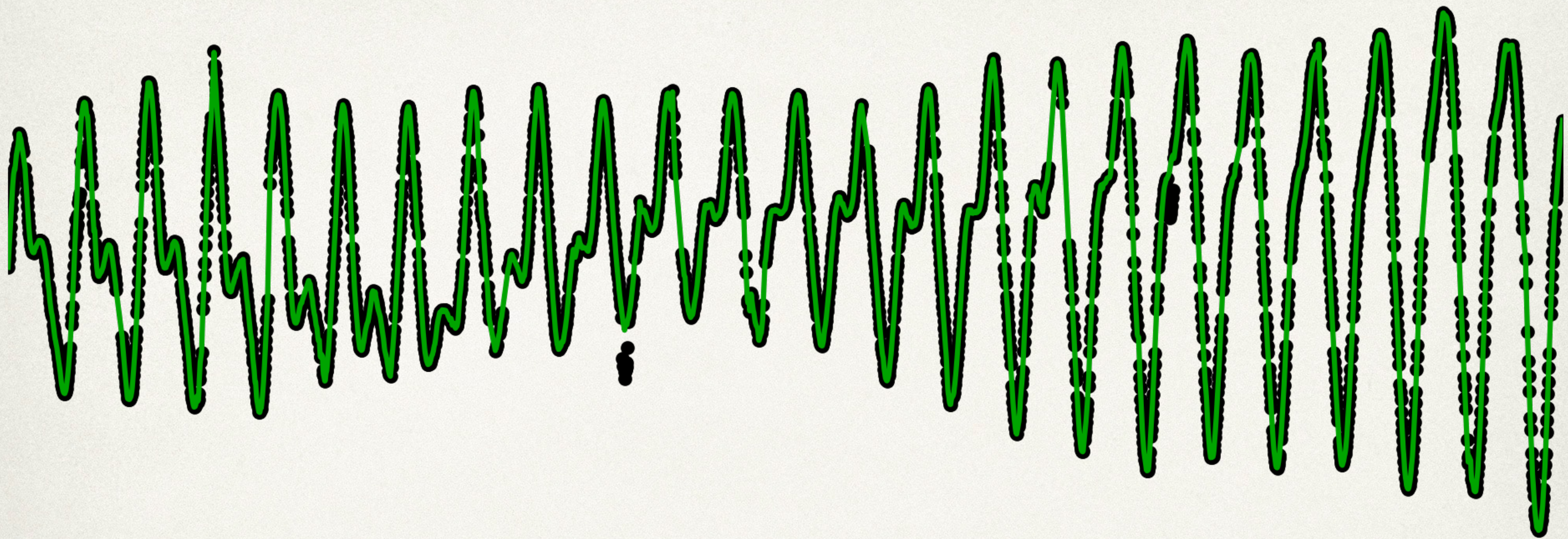
# *Spitzer* follow-up of the young (transiting Jupiter-sized) planet V1298 Tau b

John Livingston, U. Tokyo

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*Subaru 20th Anniversary Meeting, Hawaii, USA, August 27, 2019*

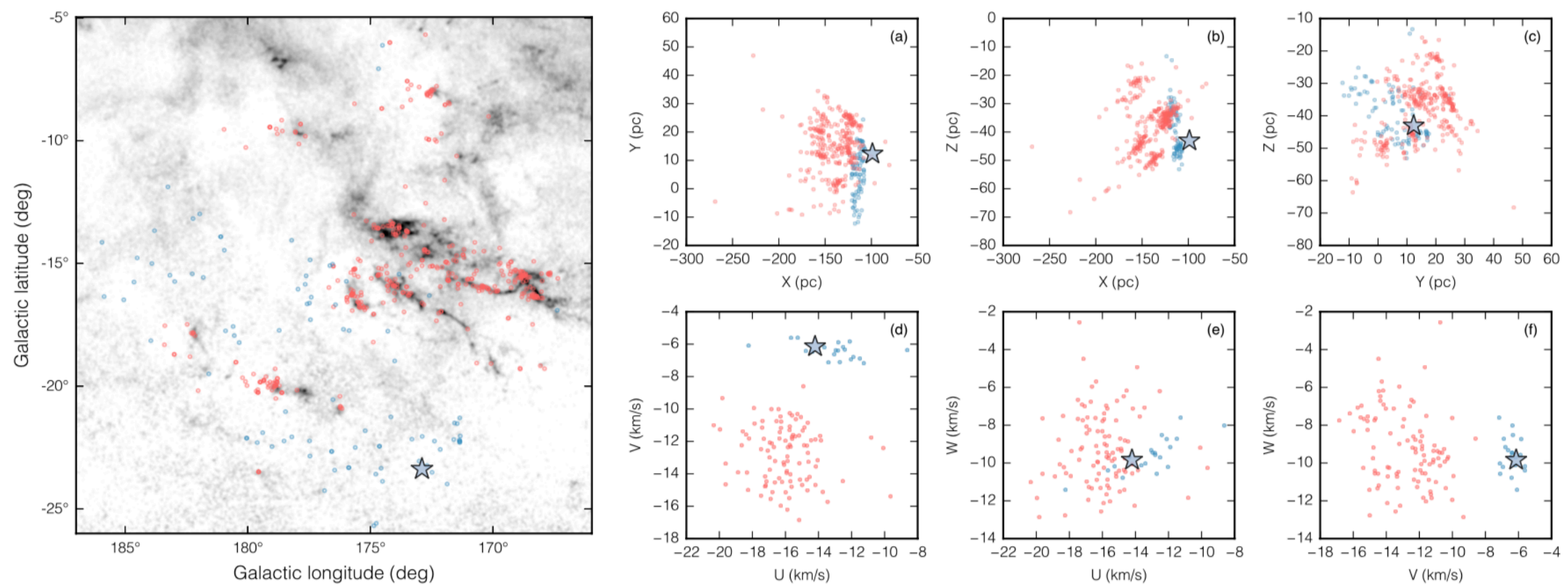




$23 \pm 4$  Myr K0–K1.5 star

$2.865 \pm 0.012$  day rotation period





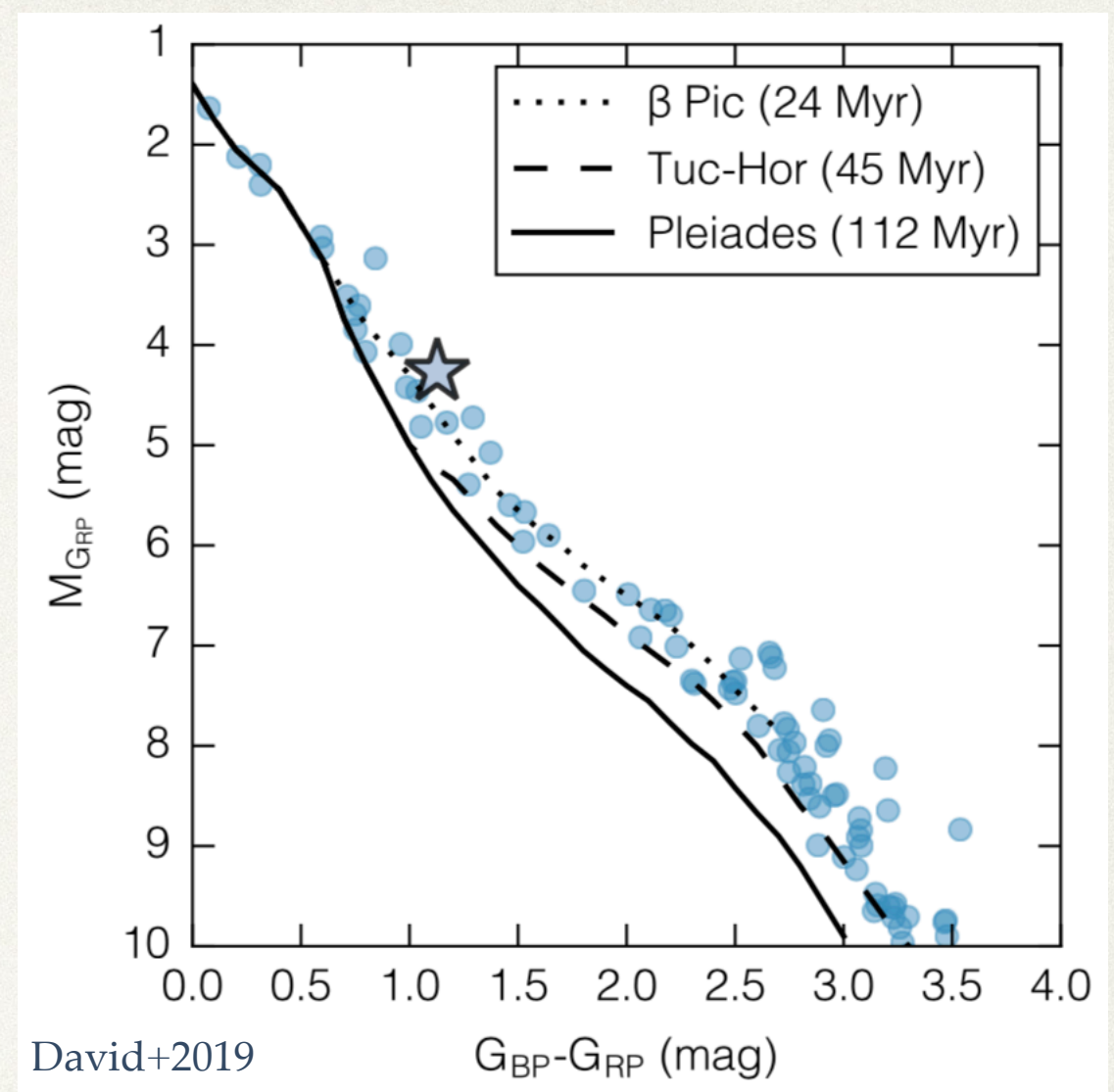
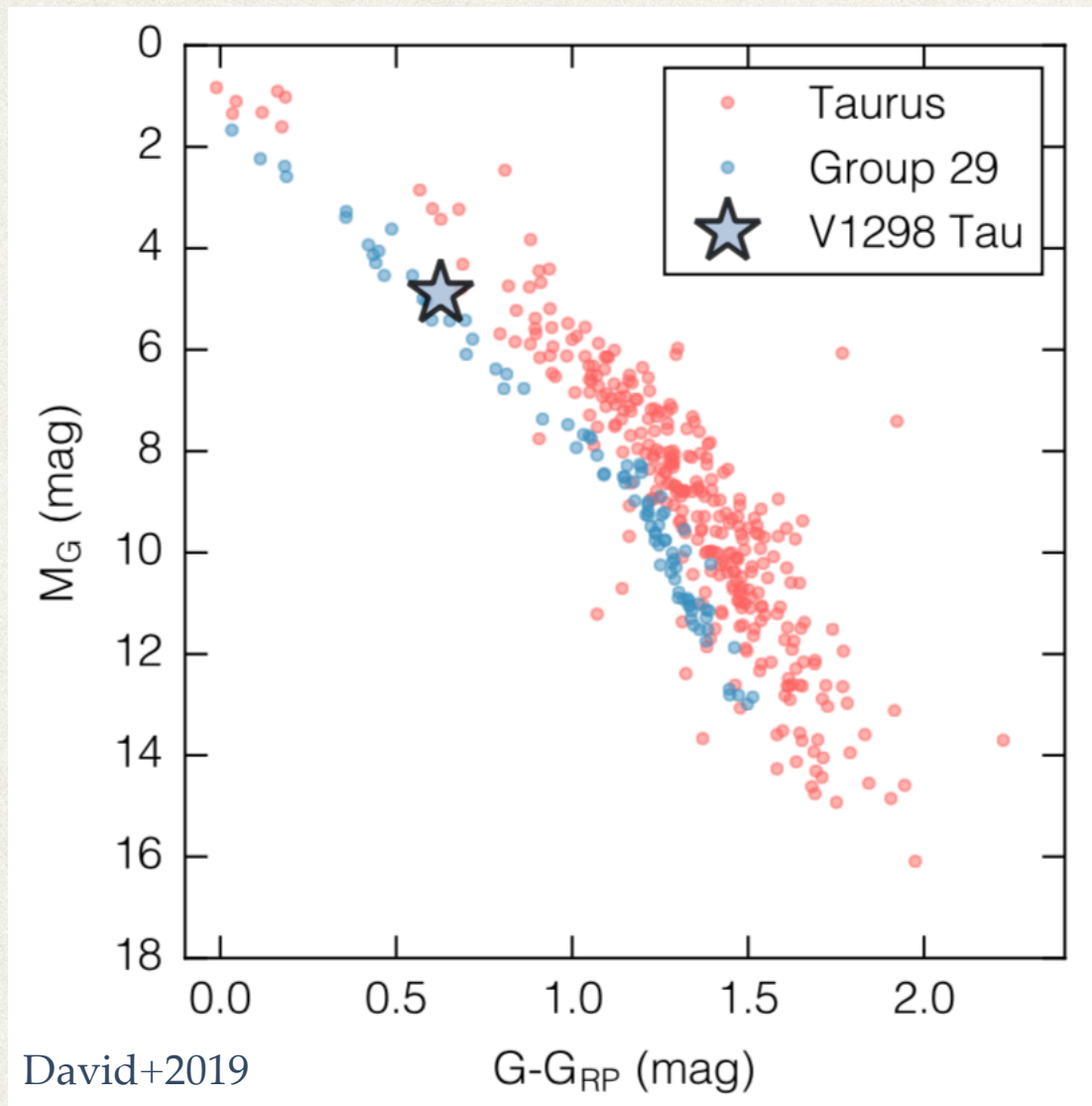
David+2019

# Group 29

Taurus-Auriga vicinity

*Luhman et al. 2018, Oh et al. 2017*



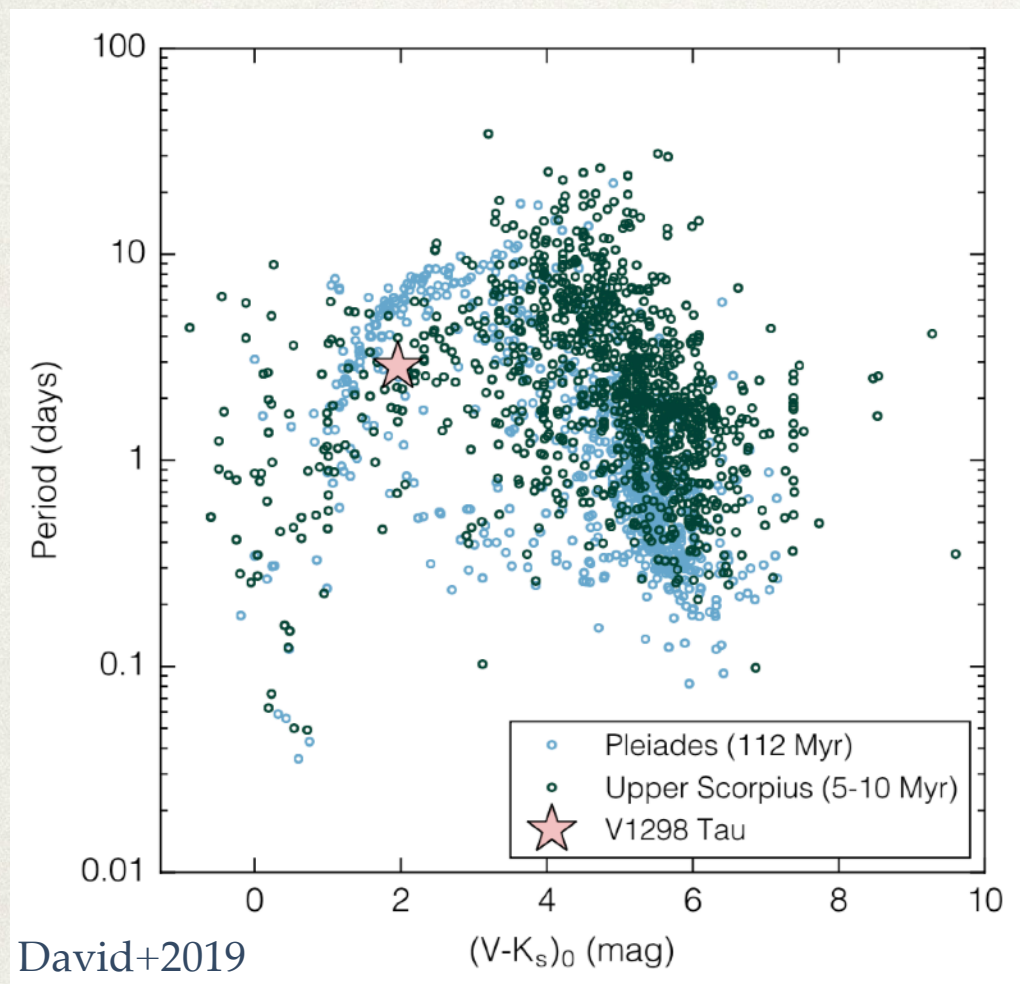


# Group 29

Taurus-Auriga vicinity

*Luhman et al. 2018, Oh et al. 2017*

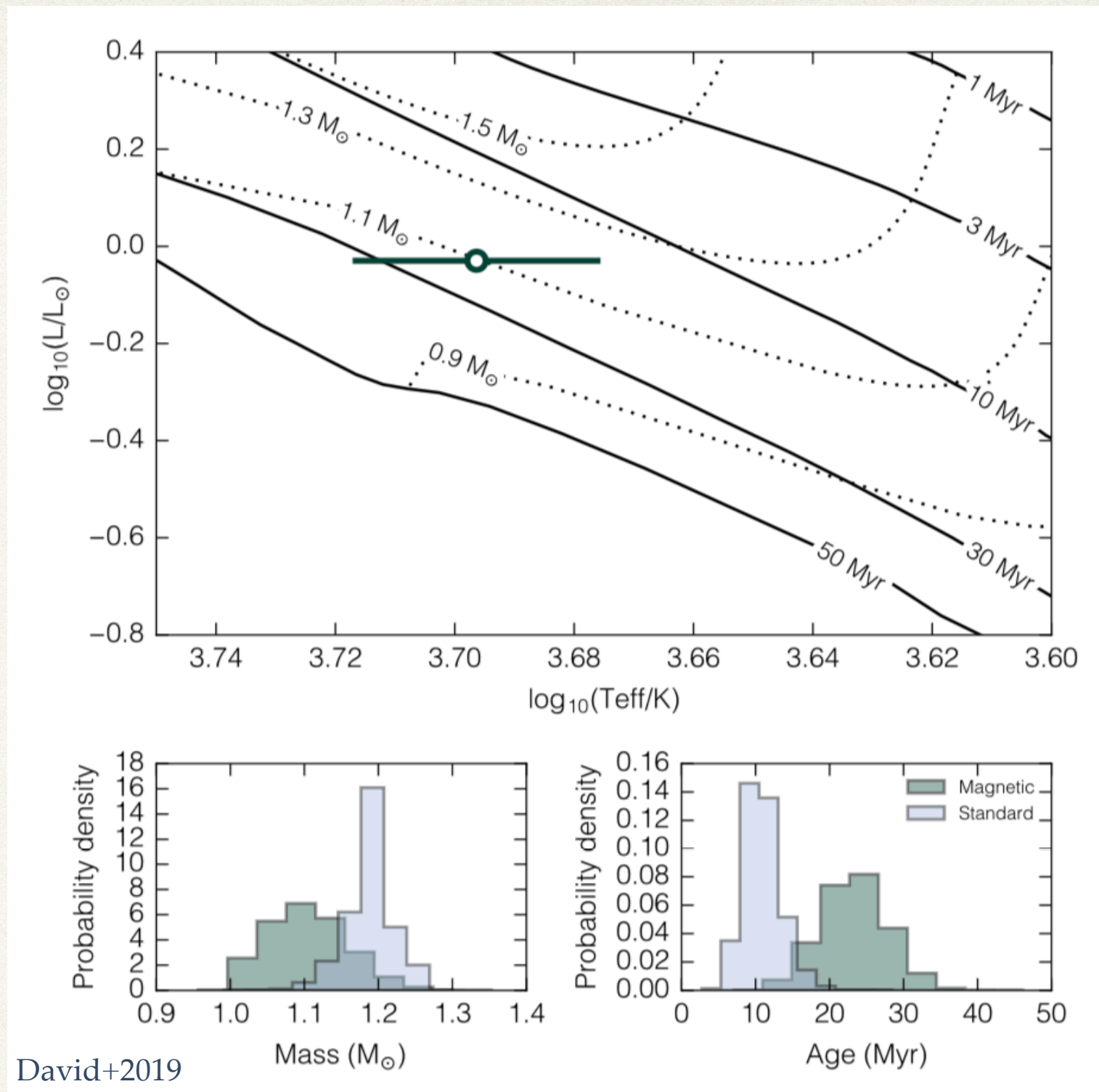




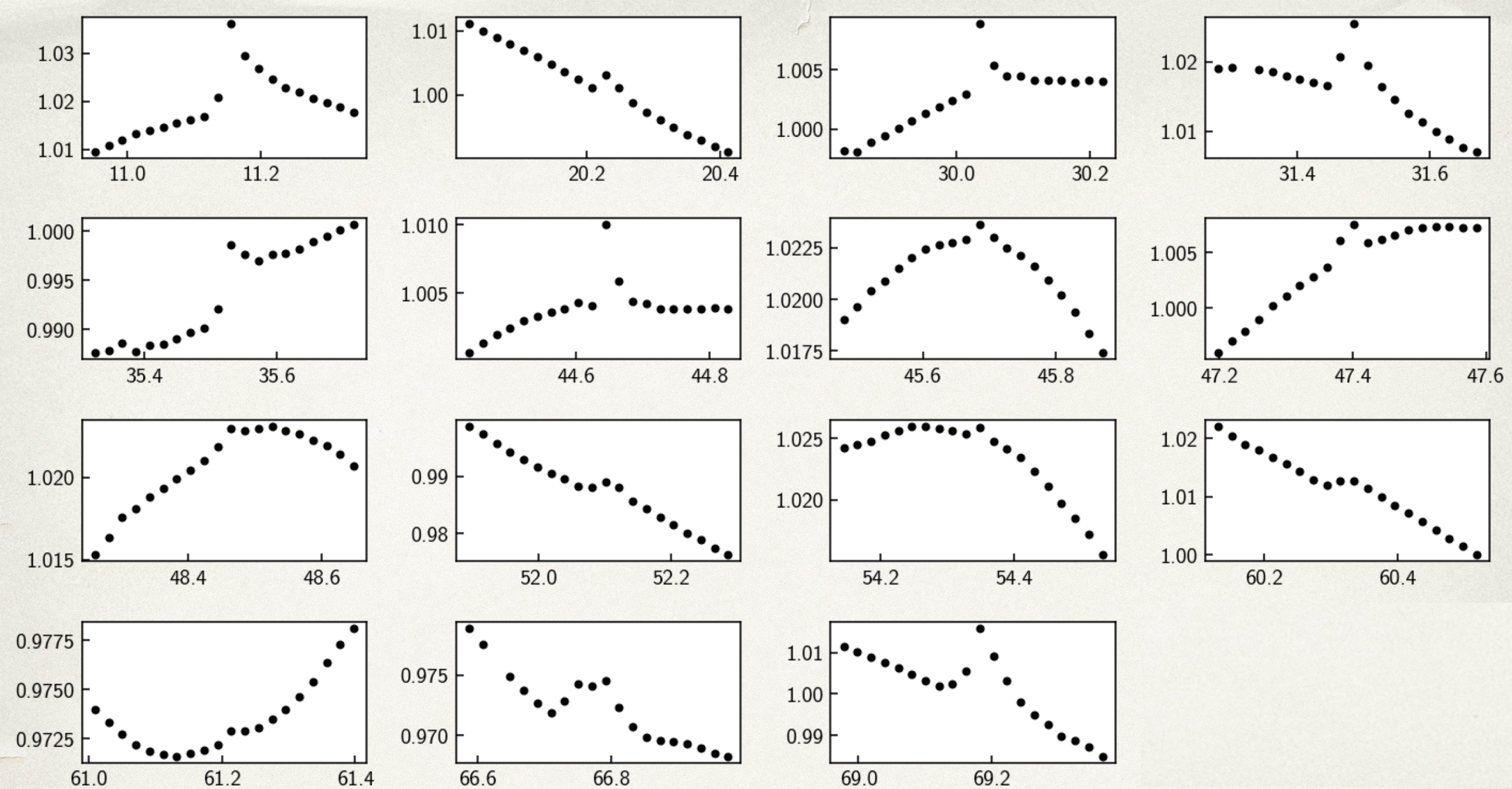
# V1298 Tau

Group 29

David et al. 2019a





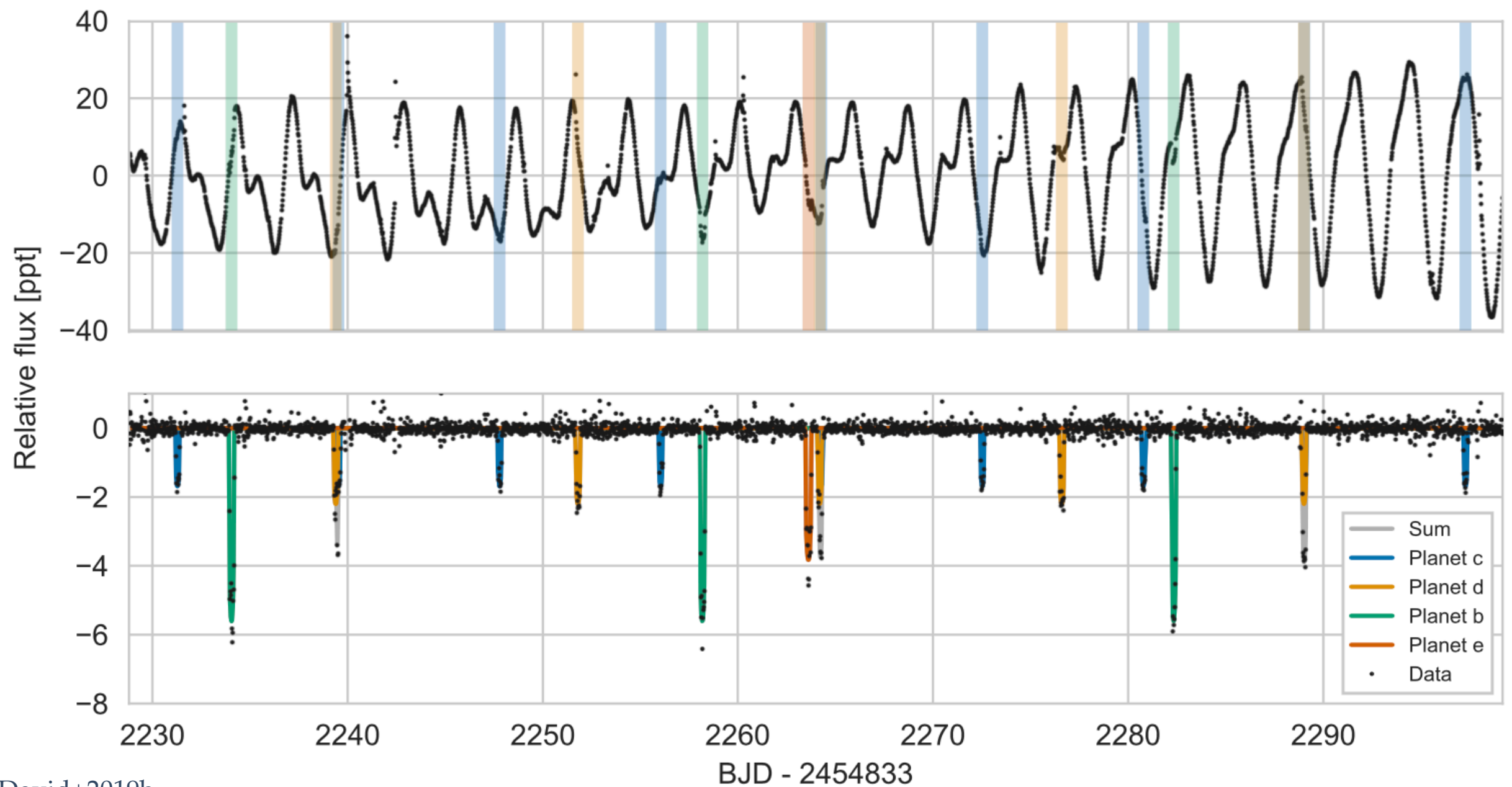


# Stellar flares(?)

Found by manual inspection

*Should be masked or explicitly modeled*





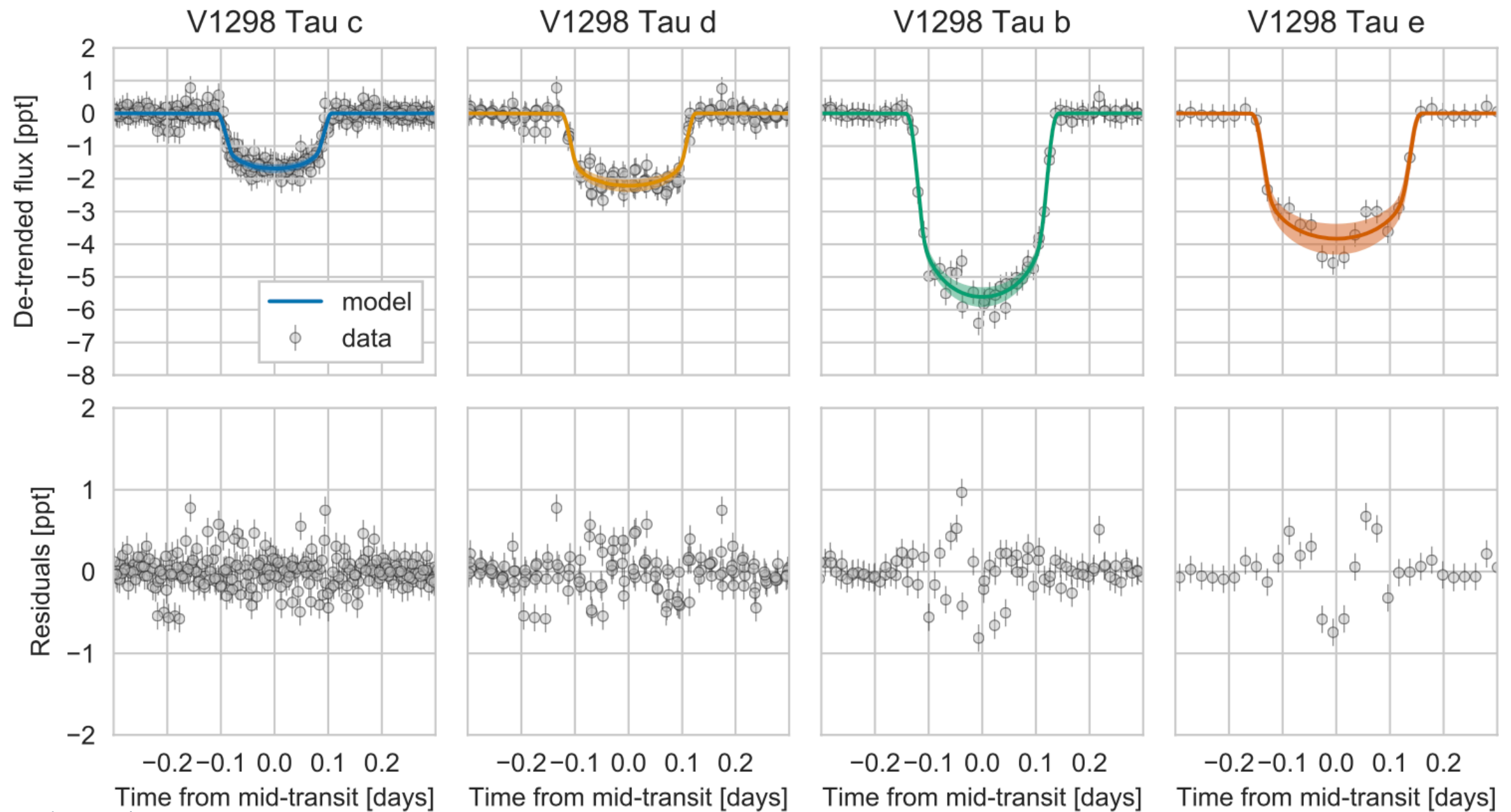
David+2019b

# Four young planets

8.2, 12.4, 24.1, and 42-120 day orbital periods

David et al. 2019b





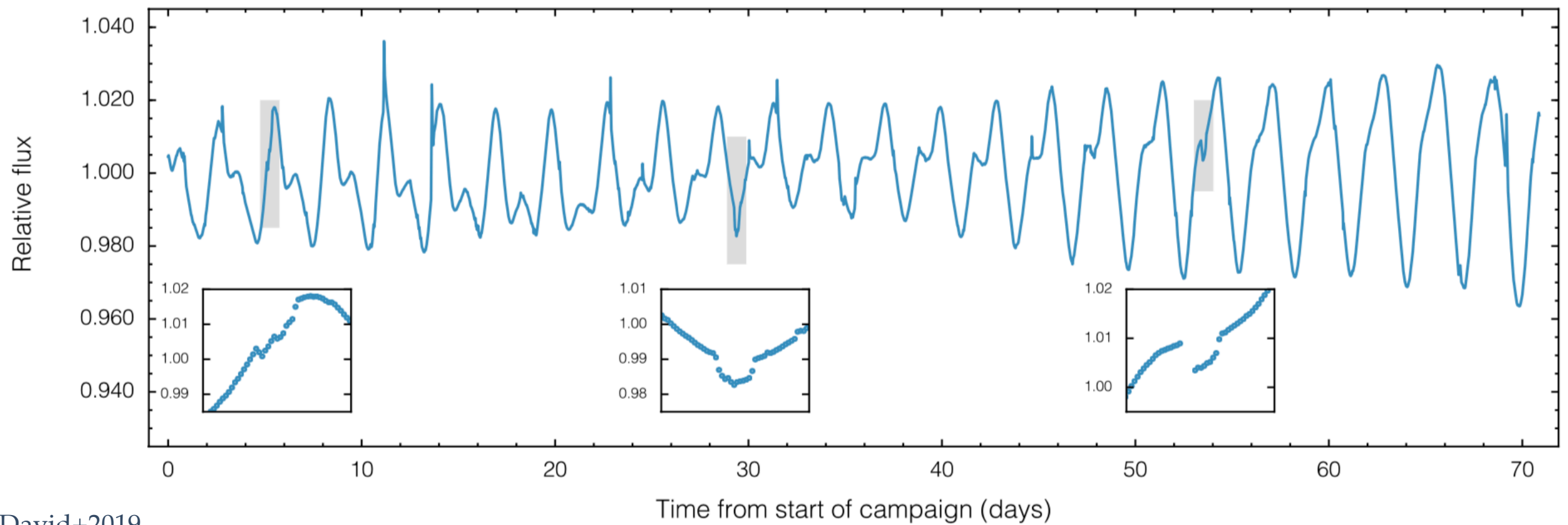
David+2019b

# Four young planets

8.2, 12.4, 24.1, and 42-120 day orbital periods

David et al. 2019b



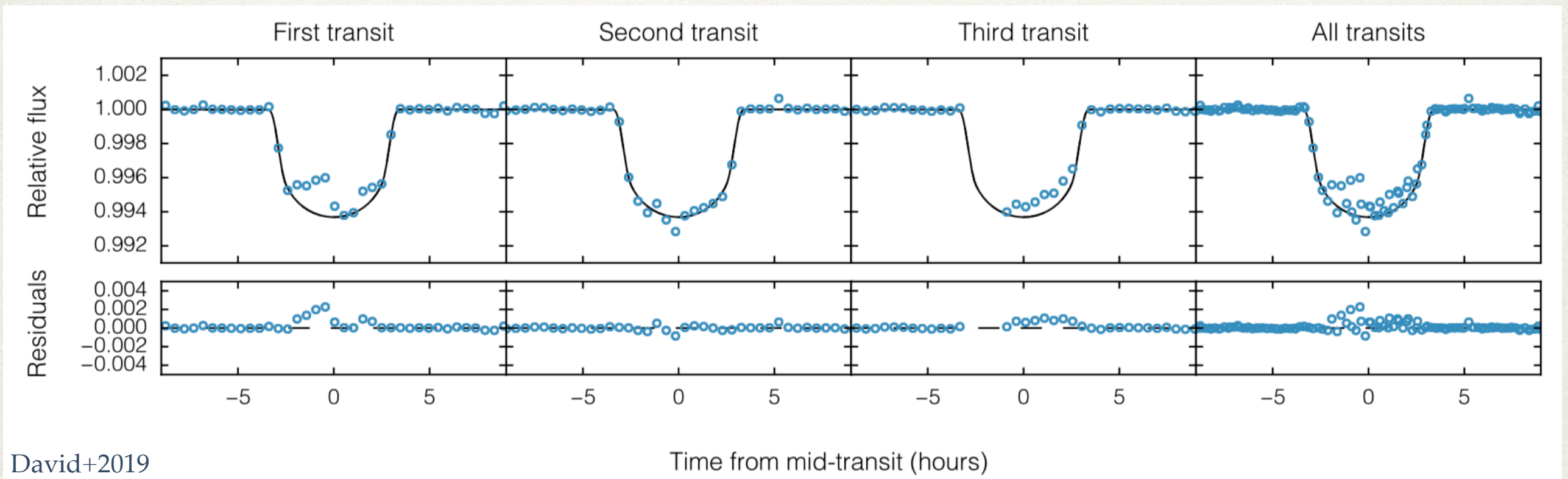


David+2019

$$R_p = 0.9 \pm 0.05 R_{\text{Jup}}$$

24.1 day orbital period

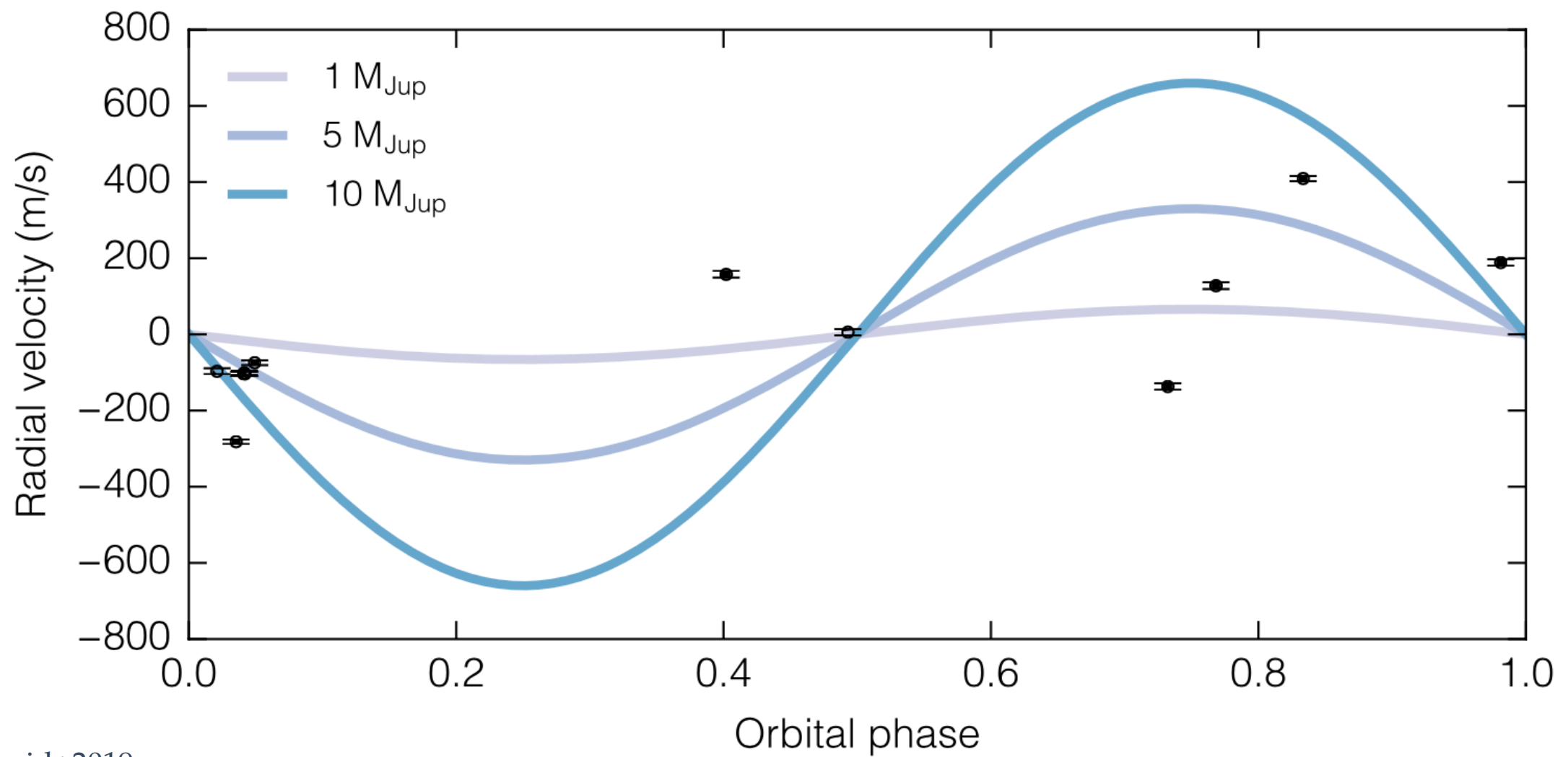




$$R_p = 0.9 \pm 0.05 R_{\text{Jup}}$$

24.1 day orbital period



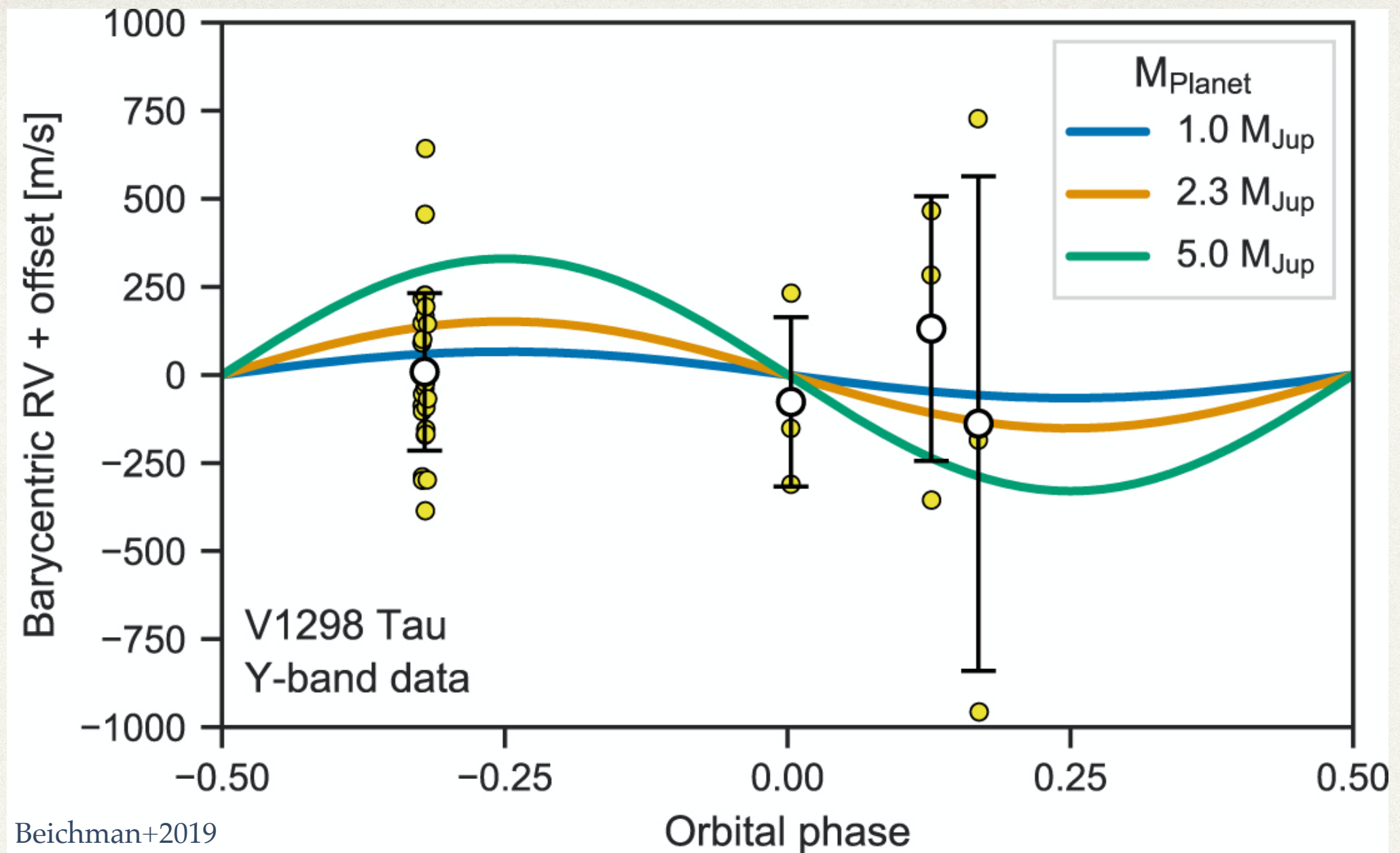


David+2019a

$$M_{\text{P}} < 8.3 M_{\text{Jup}}$$

Keck/HIRES

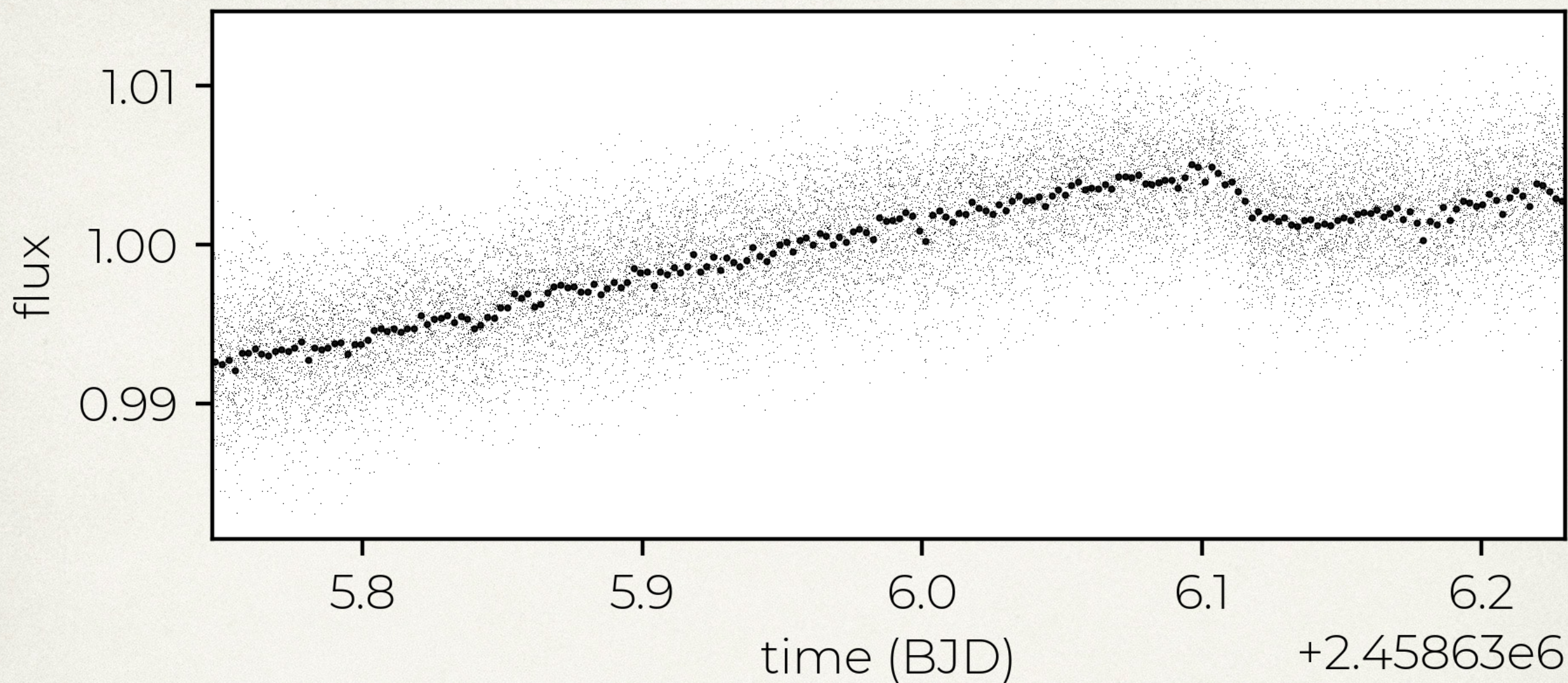




$$M_P < 2.2 M_{\text{Jup}}$$

Subaru/IRD





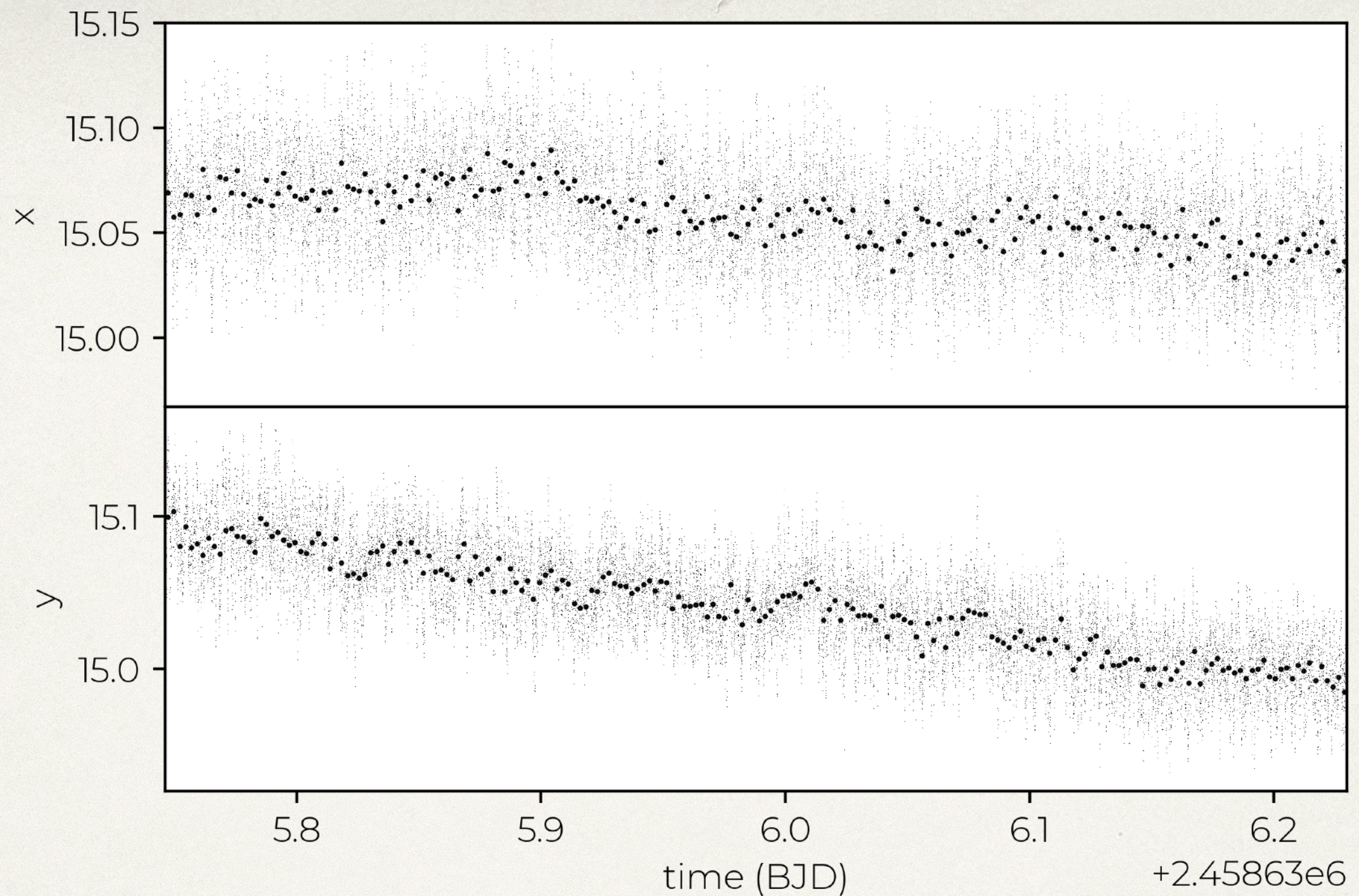
# *Spitzer* follow-up

IRAC2 (4.5  $\mu\text{m}$ ), Program ID 14227 (P.I. Mamajek)

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*Livingston et al. (in preparation)*





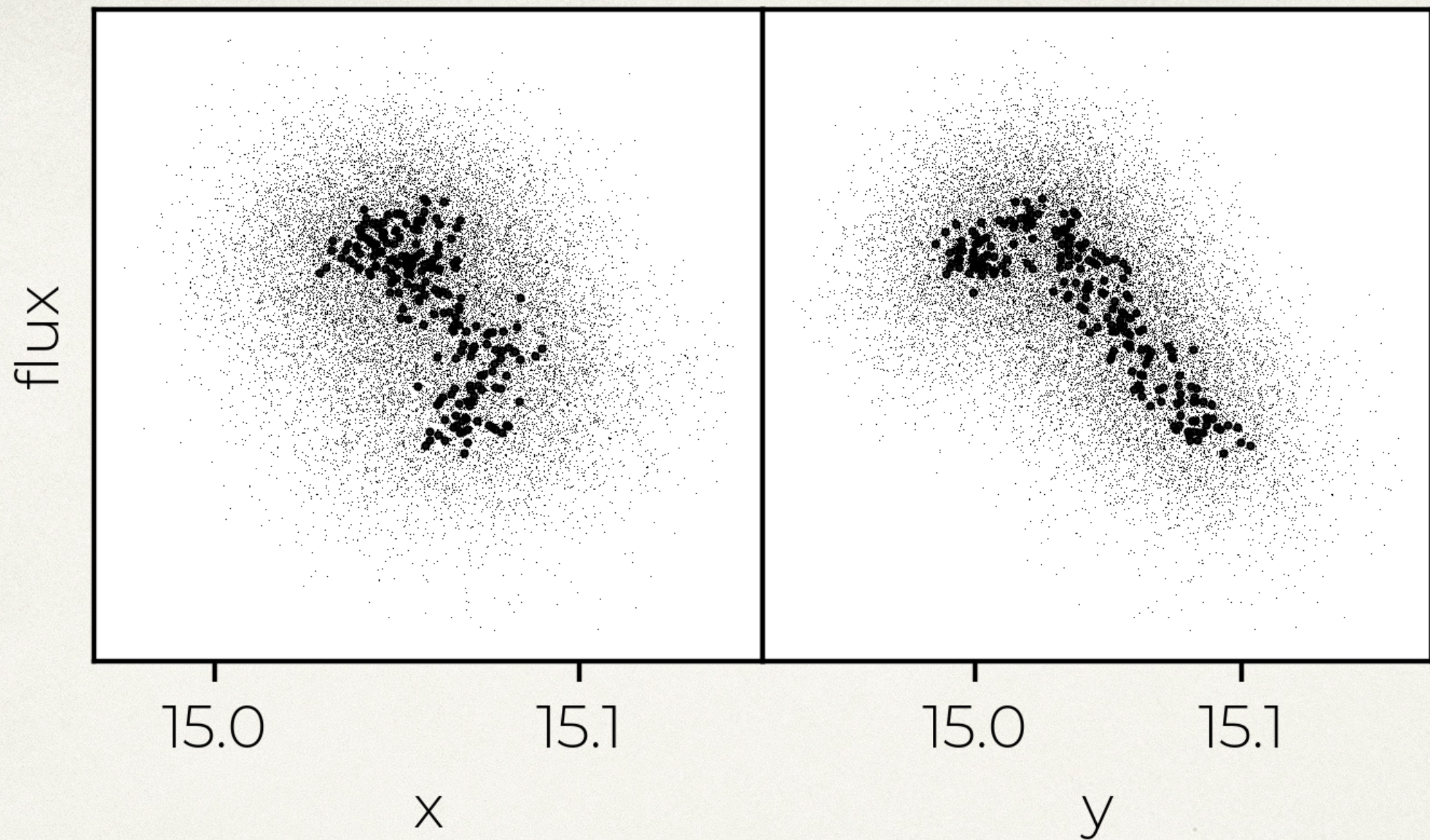
# *Spitzer* systematics

Induced by pointing jitter + intra-pixel gain variations

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*Slow drift + 40-minute battery heater cycle + ???*





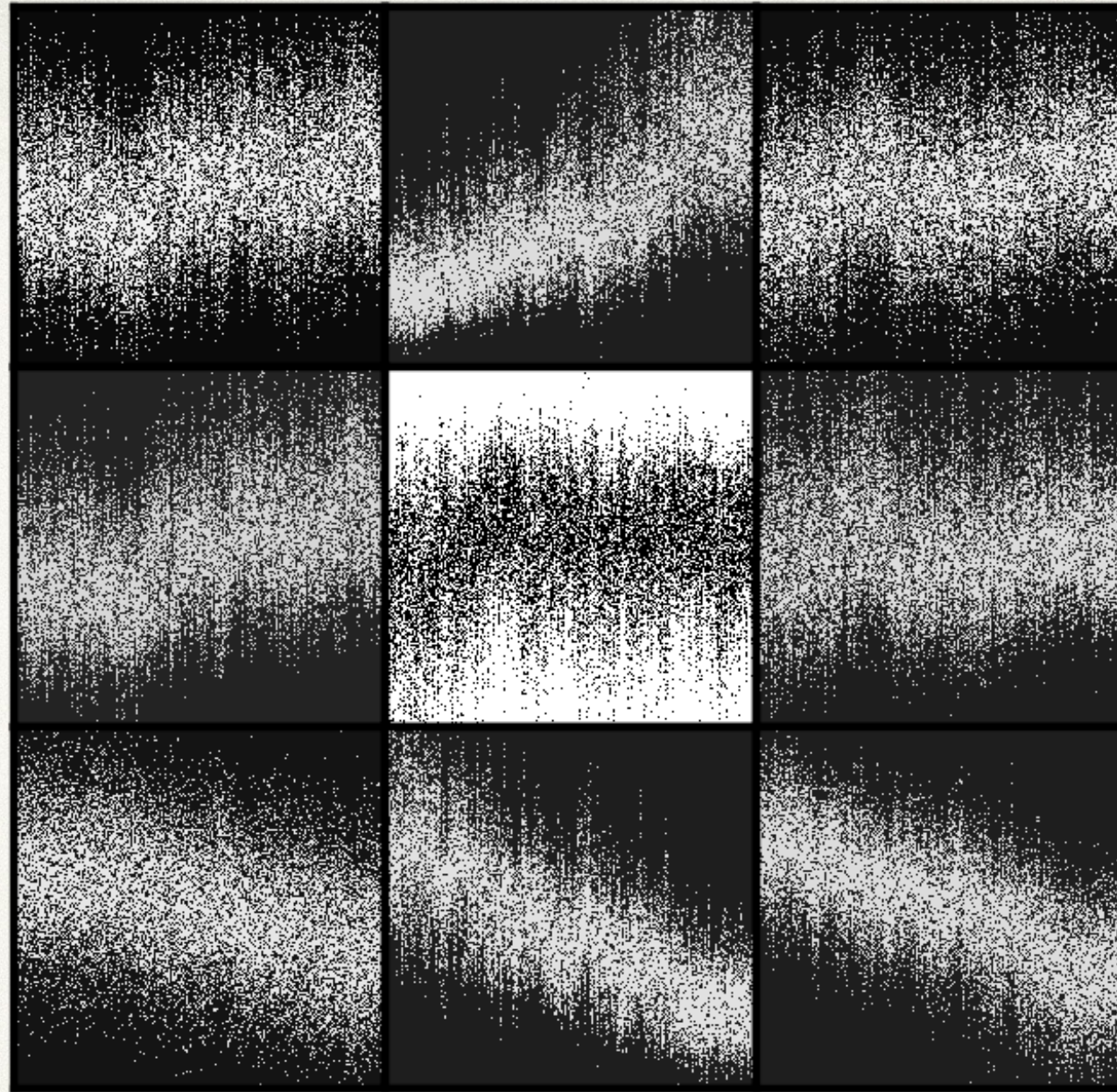
# *Spitzer* systematics

Induced by pointing jitter + intra-pixel gain variations

---

*Slow drift + 40-minute battery heater cycle + ???*





# Normalized pixel light curves

Form a basis set for PLD

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*Livingston et al. (in preparation)*



Transit model

PLD coefficients

Gaussian noise

$$\Delta S^t = M_{\text{tr}}(\boldsymbol{\theta}, t) + \frac{\sum_{i=1}^9 c_i P_i^t}{\sum_{i=1}^9 P_i^t} + \alpha t + \varepsilon(\sigma)$$

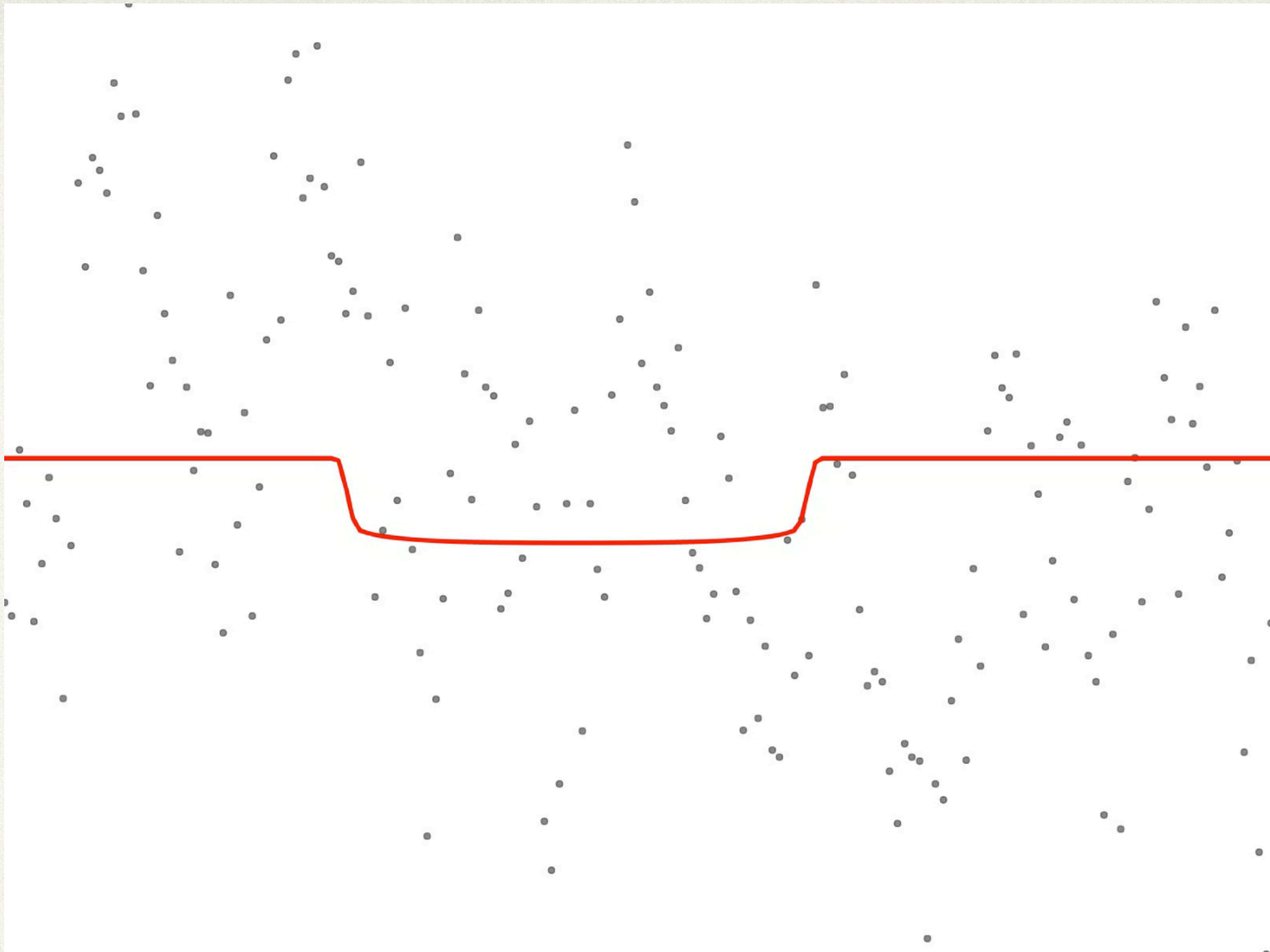
Total signal

Linear trend

# Systematics model

Pixel-level decorrelation systematics model (PLD; Deming et al. 2015)





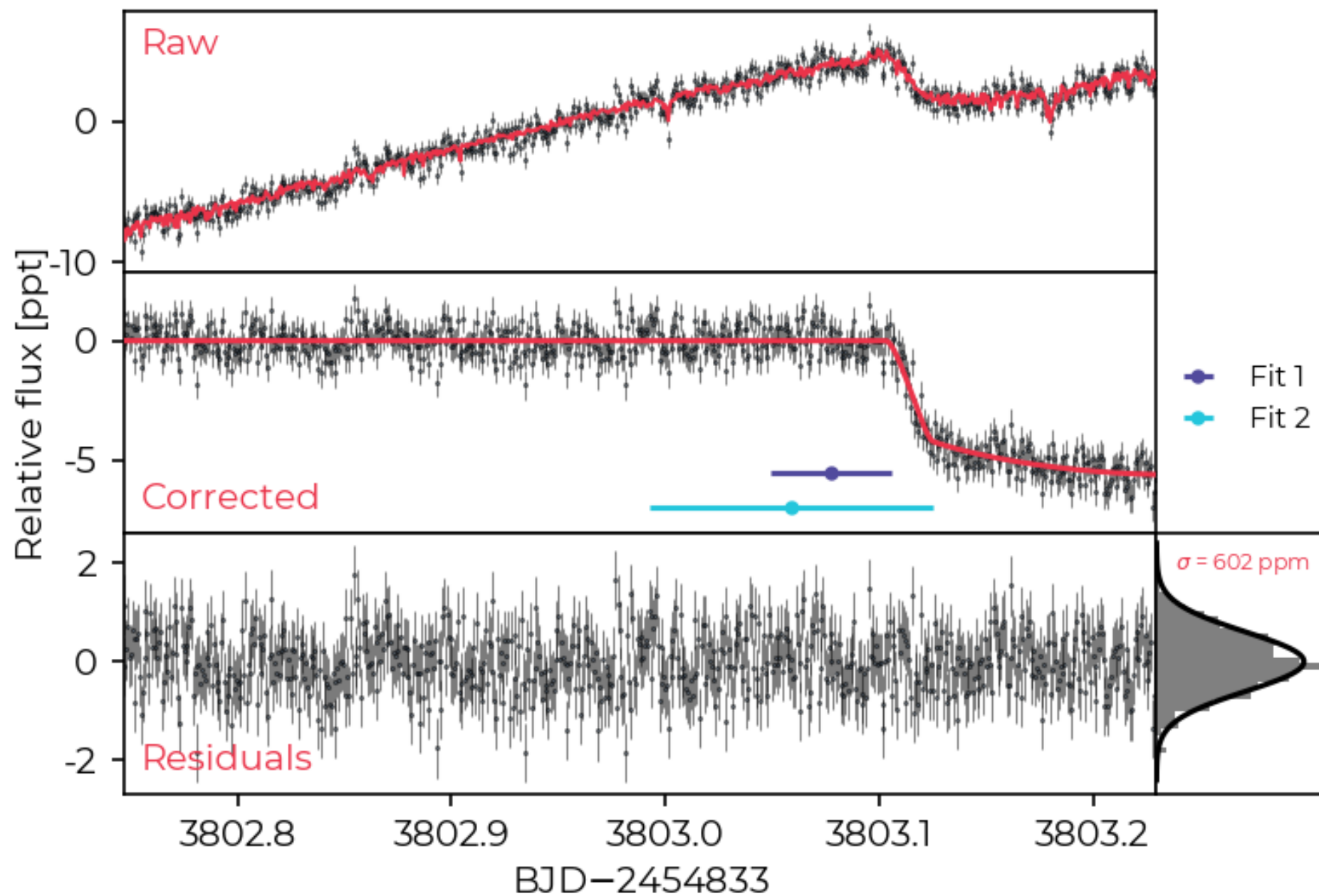
# PLD demo

Transit and systematics parameters fit simultaneously

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*(different dataset)*



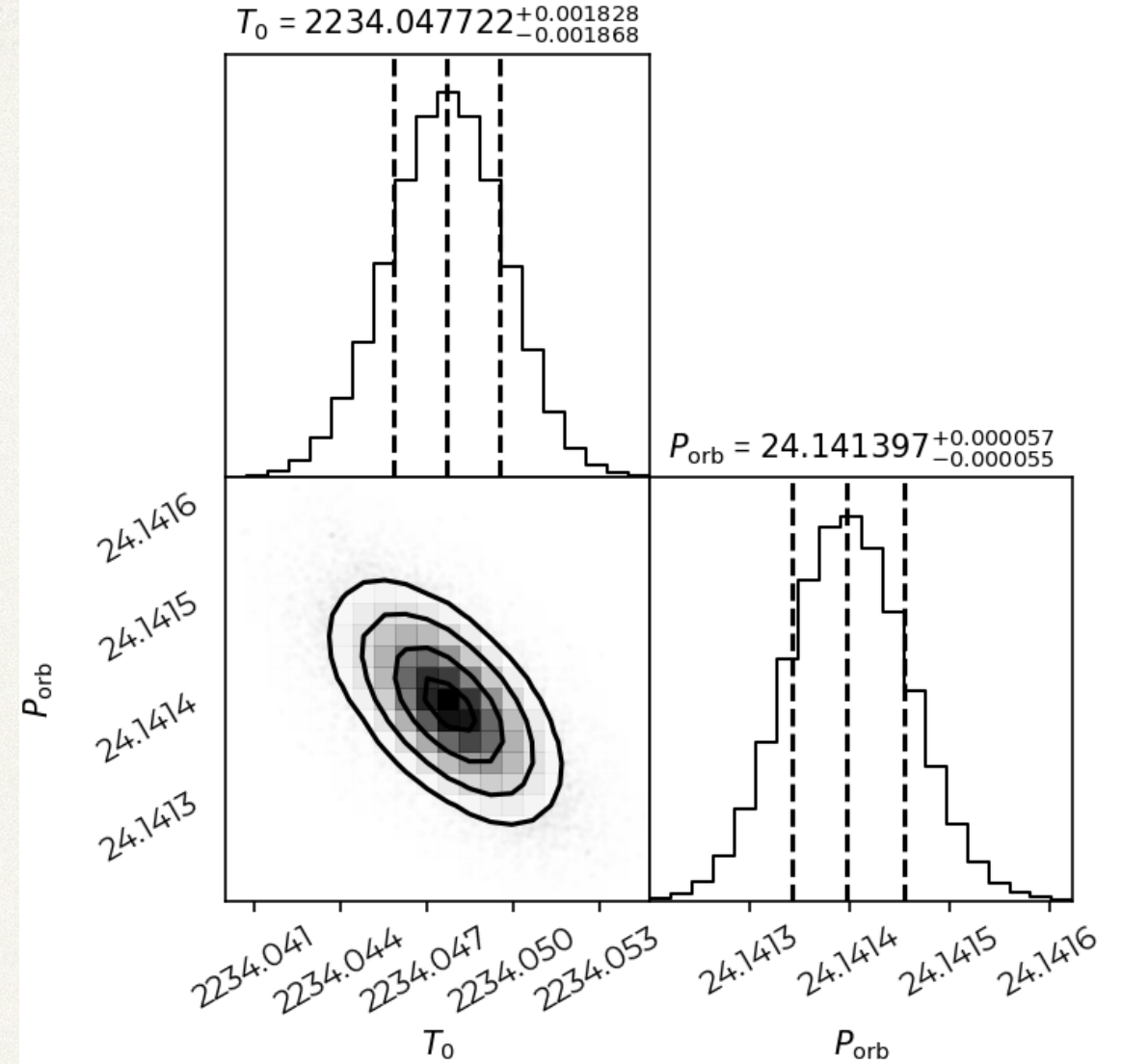
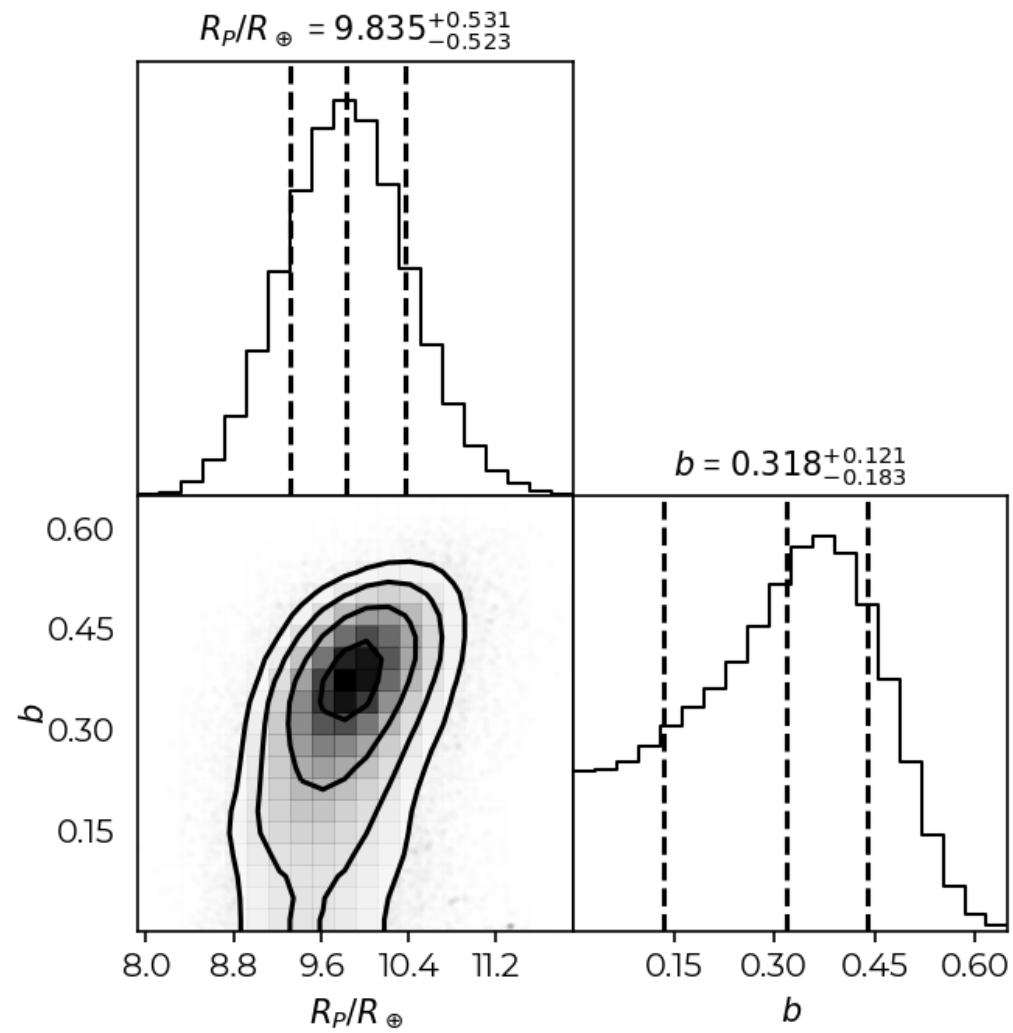


# *Spitzer* fit

(Fit jointly with *K2* data, Fits 1 & 2 from David+2019)

*Livingston et al. (in preparation)*



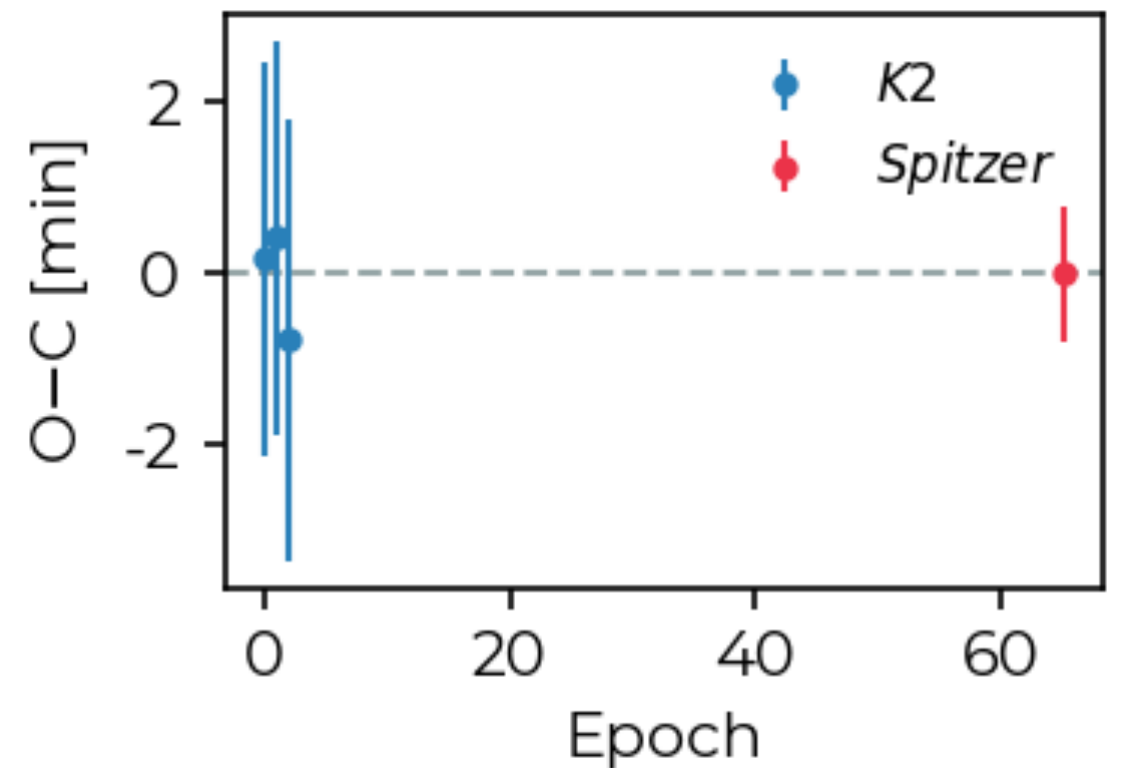
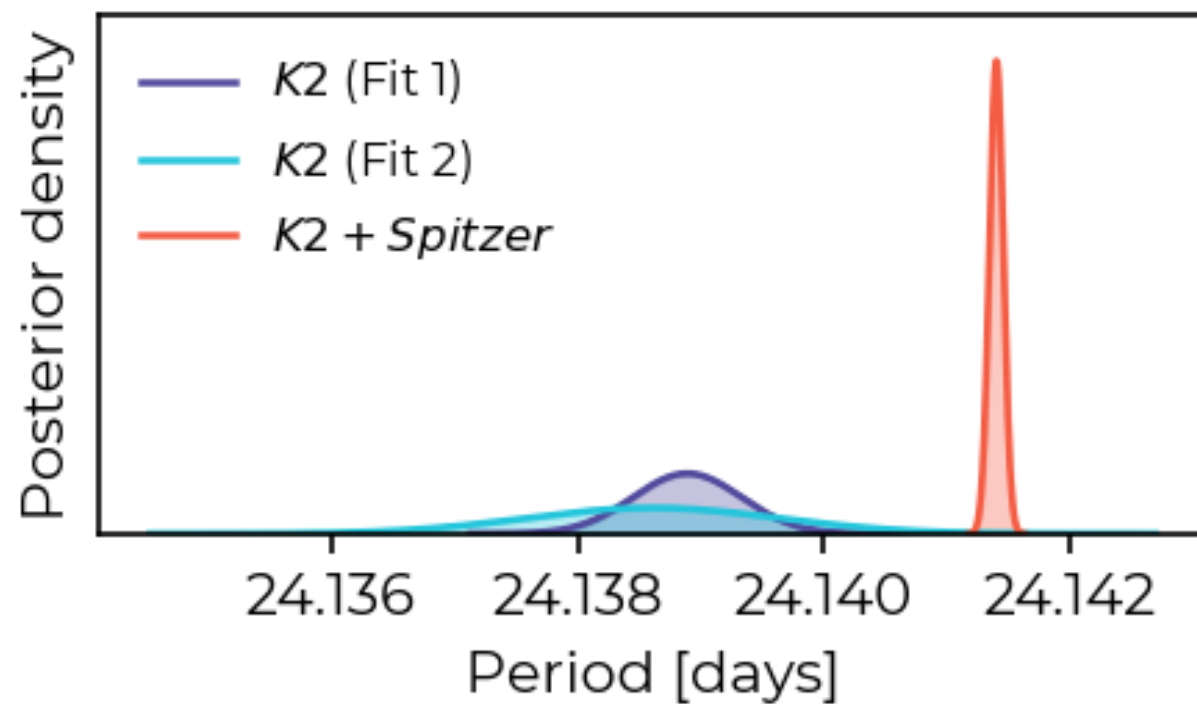


# Spitzer fit

(Fit jointly with K2 data)

Livingston et al. (in preparation)

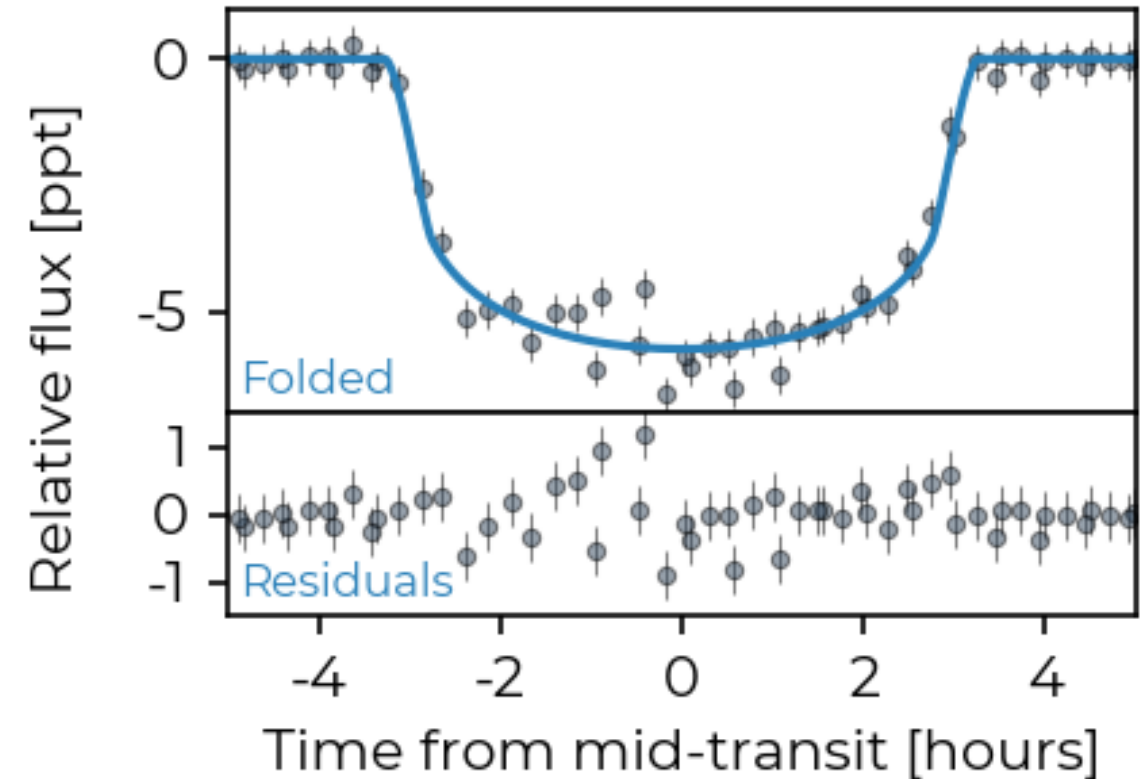
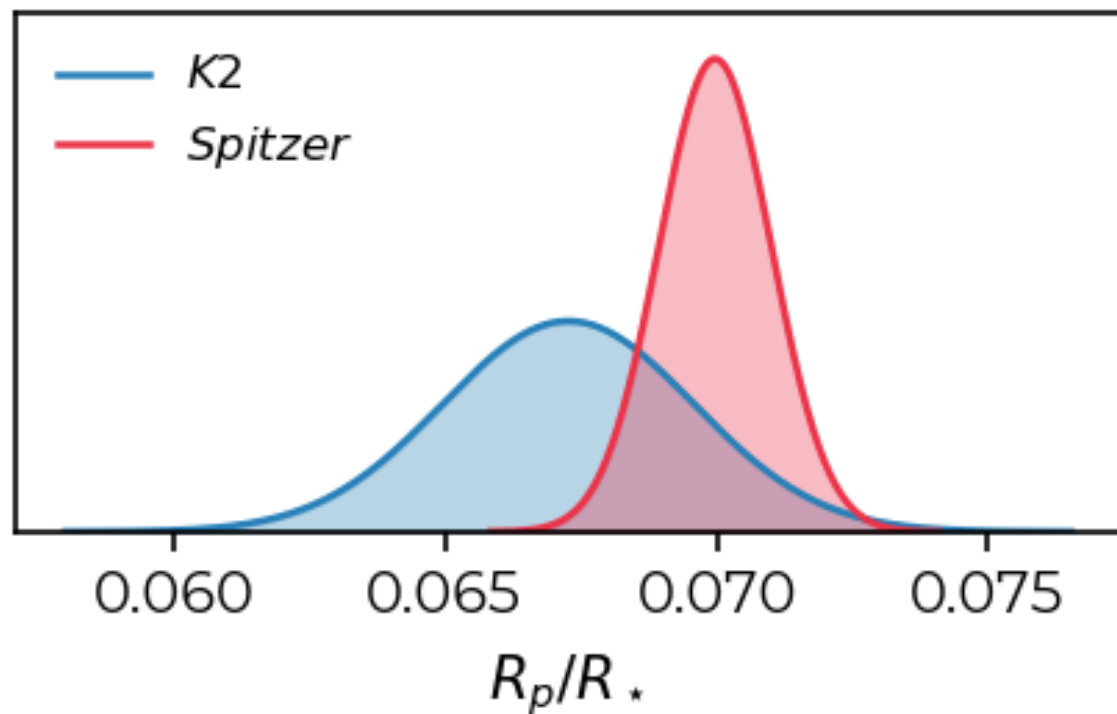




# Ephemeris constraints

(Fit jointly with *K2* data, Fits 1 & 2 from David+2019a)



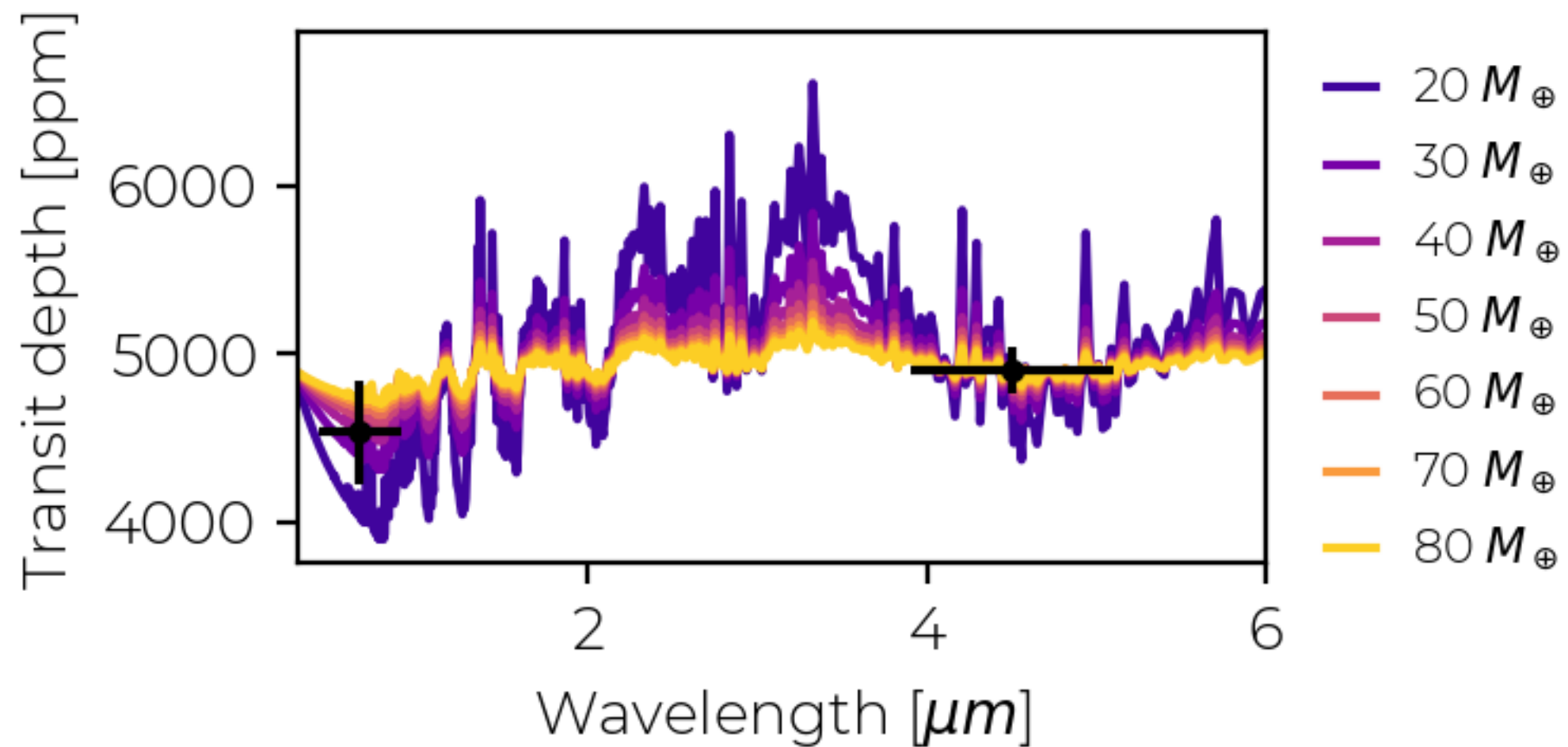


# Planet radius constraints

(Fit jointly with K2 data, Fits 1 & 2 from David+2019)

*Livingston et al. (in preparation)*





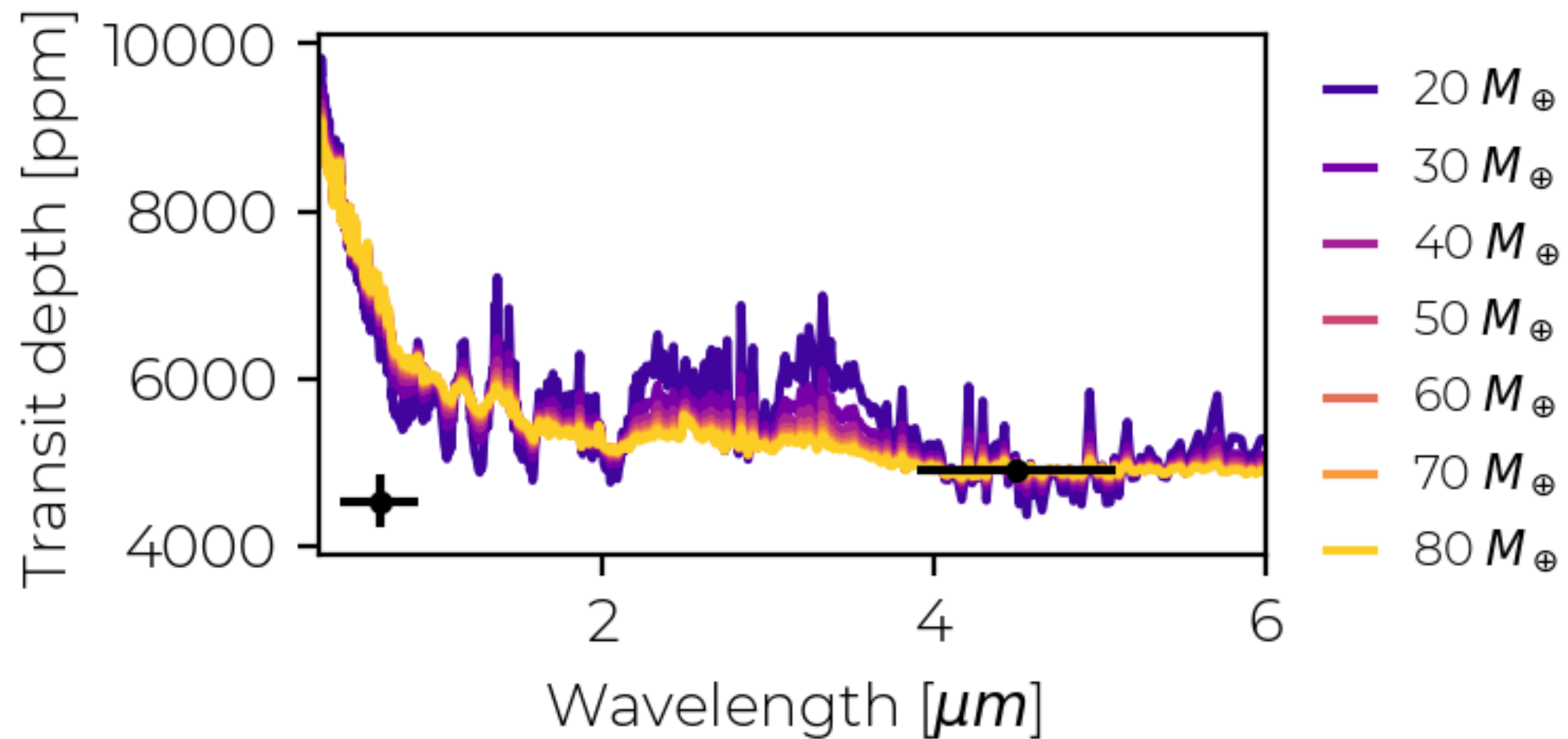
# Expected atmospheric signal

Assuming solar metallicity and clear H atmosphere

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*Livingston et al. (in preparation)*

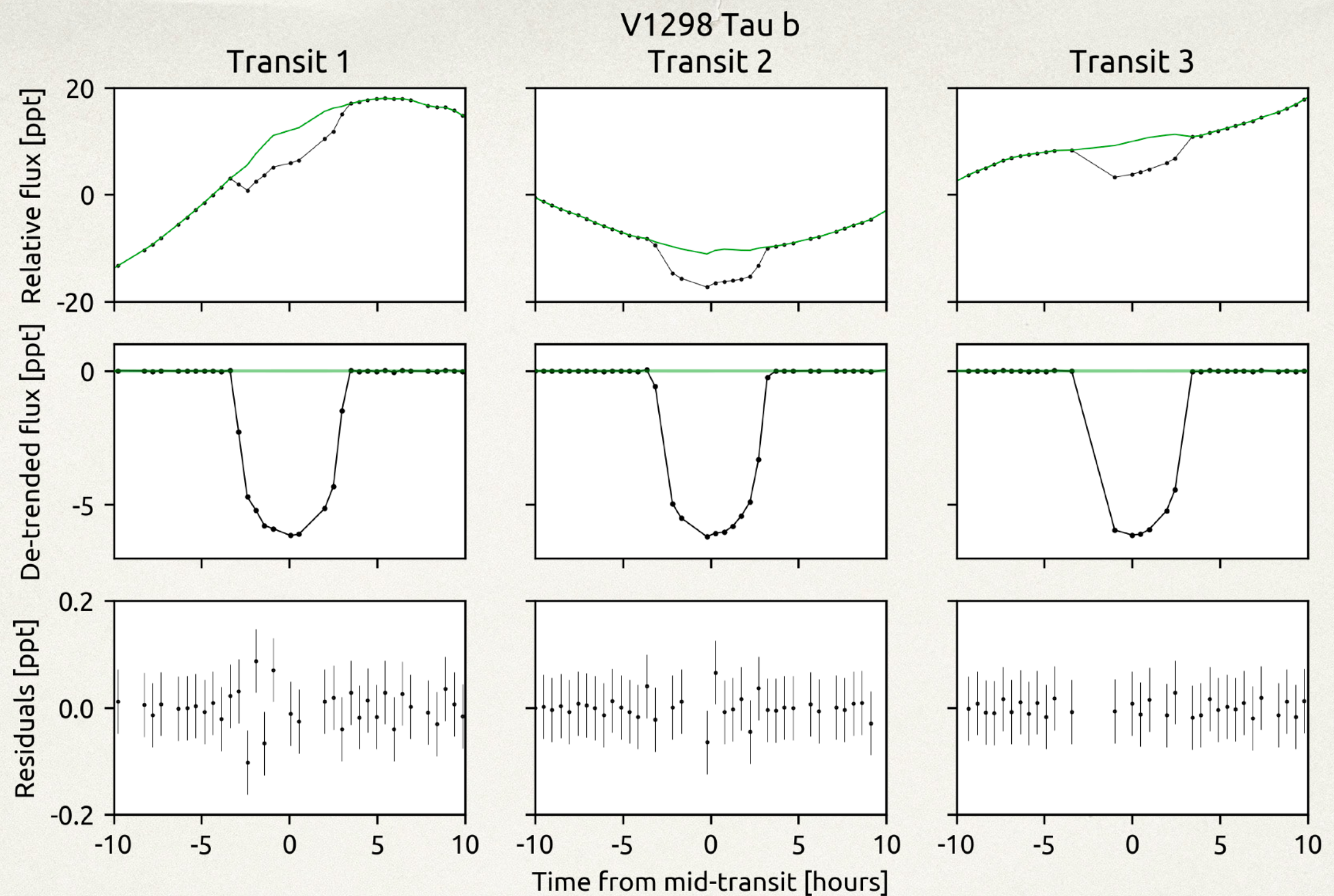




# Expected atmospheric signal

Assuming spot coverage fraction = 50% and spot temperature contrast ratio = 0.8



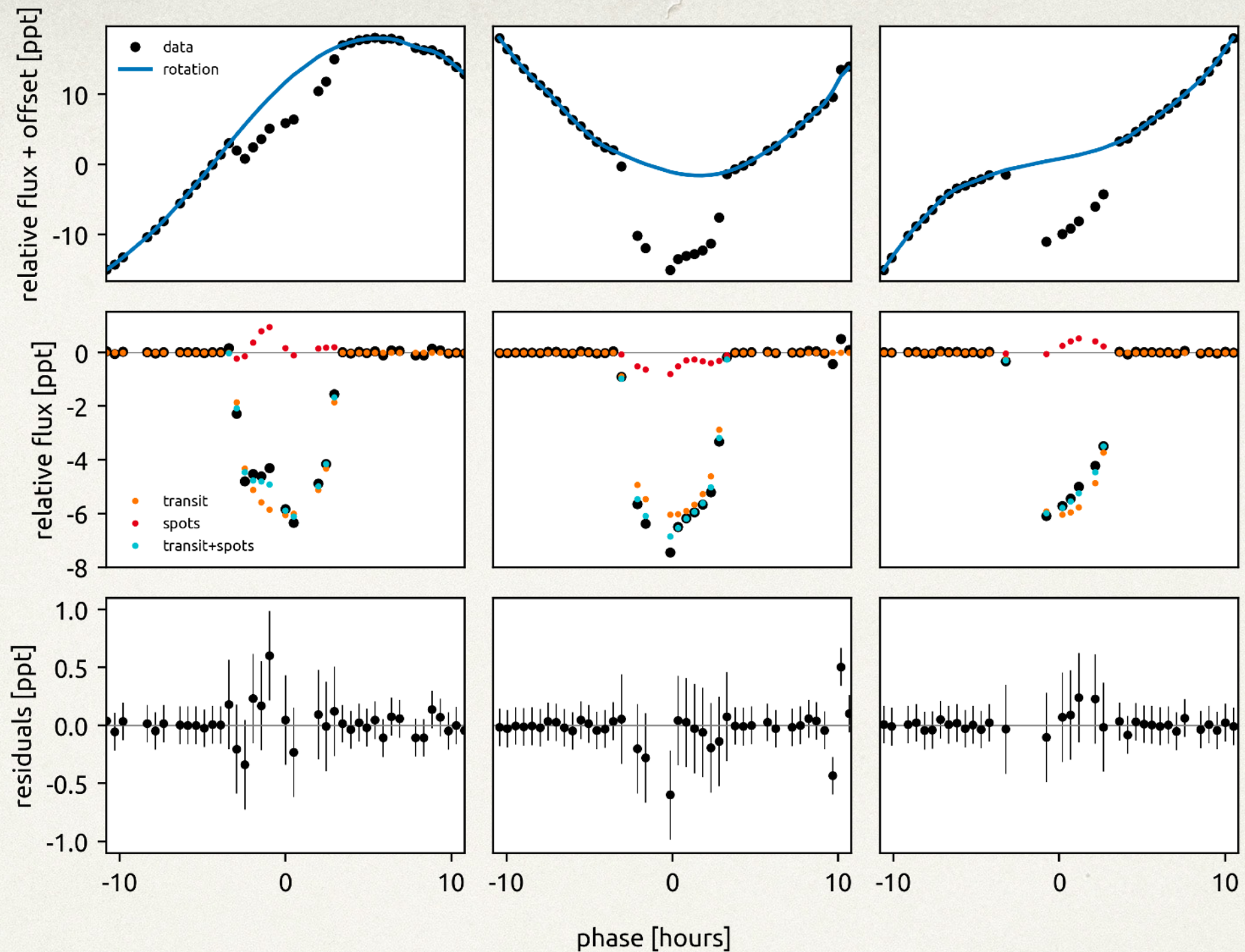


# *K2* transits

Gaussian Process (GP) model for stellar variability and spot-crossing events

*Livingston et al. (in preparation)*



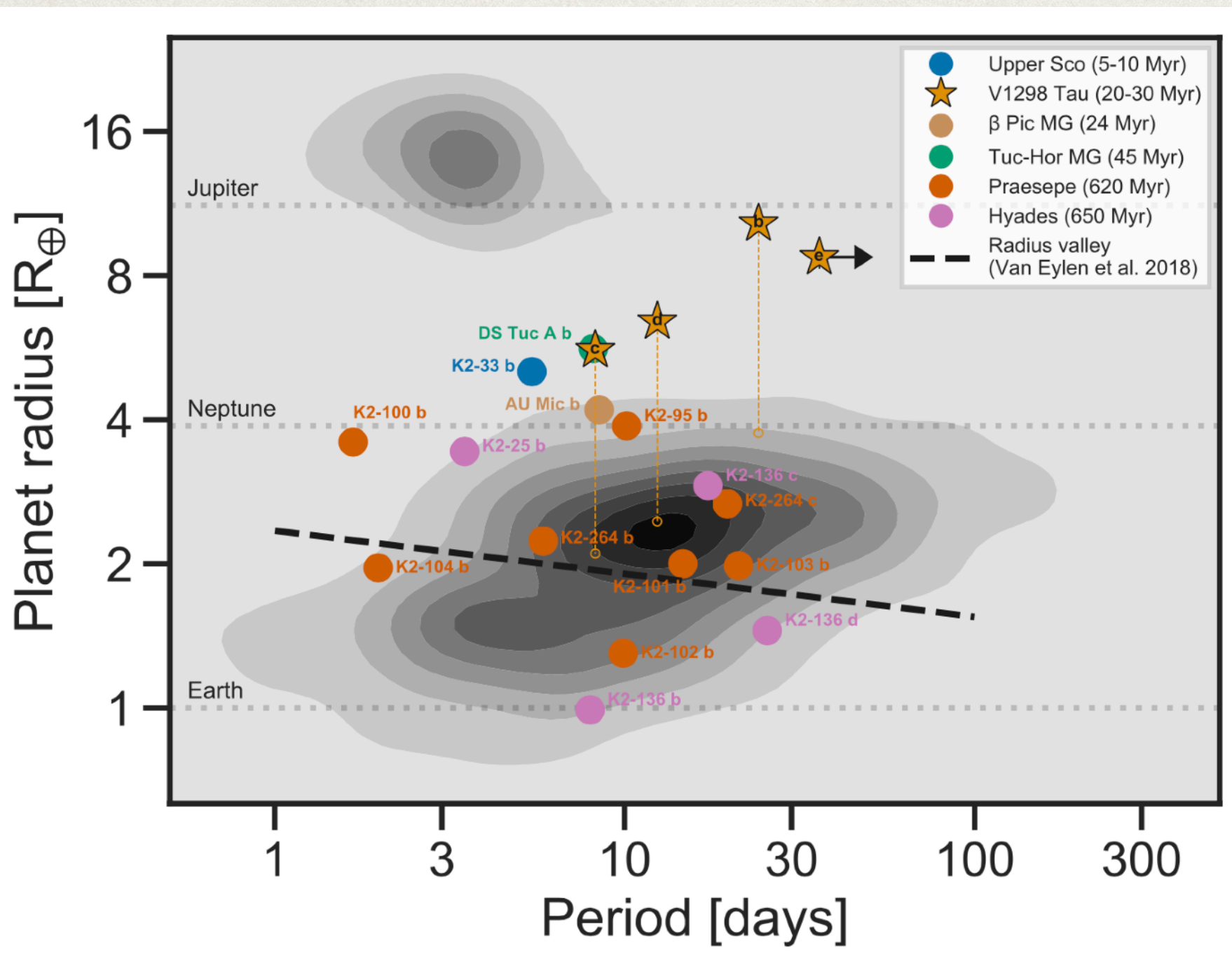


# Separate the kernels

Rotation kernel sees only out-of-transit data, Matern-3/2 kernel sees only in-transit kernel

*Livingston et al. (in preparation)*





# Young planets have much to teach us!

Transiting planets are a window into photo-evaporation