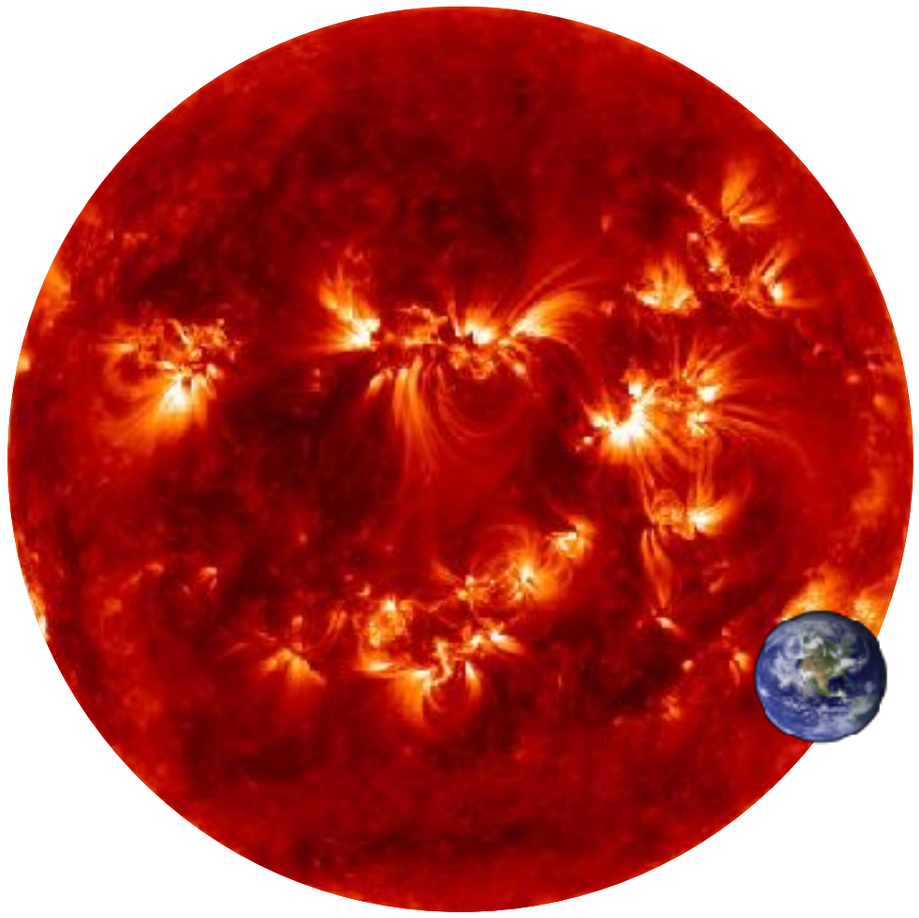
Reconciling the planetary interpretation of the radial velocity super-Earth K2-18c

Ryan Cloutier

EPRV IV
March 18th 2019



CPS

Astronomy & Astrophysics
UNIVERSITY OF TORONTO

INSTITUT DE RECHERCHE SUR LES EXOPLANÈTES
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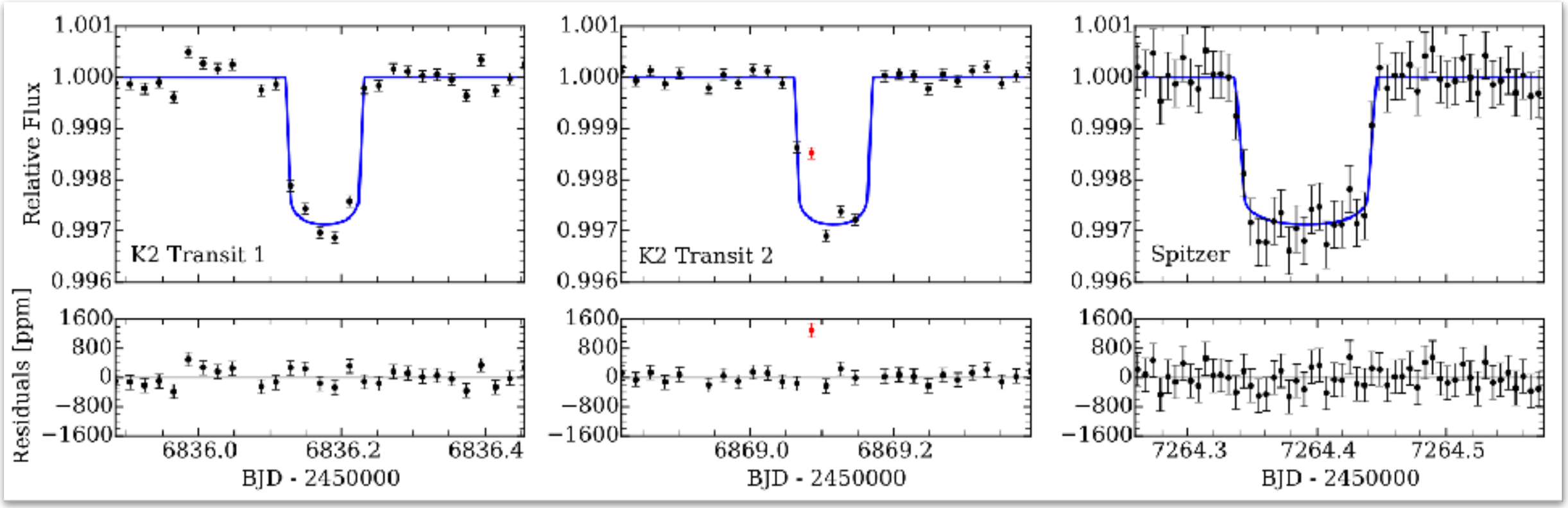
Université de Montréal

K2-18: a mid-M dwarf with a temperate transiting sub-Neptune

K2-18	**K2-18b**
JHK_s = 9.76, 9.14, 8.90	r_p = 2.7 $R_\oplus$
$M_\star$ = 0.50 $M_\odot$	P = 33 days
$R_\star$ = 0.47 $R_\odot$	T_{eq} = 265 K (w/ Earth-like albedo)



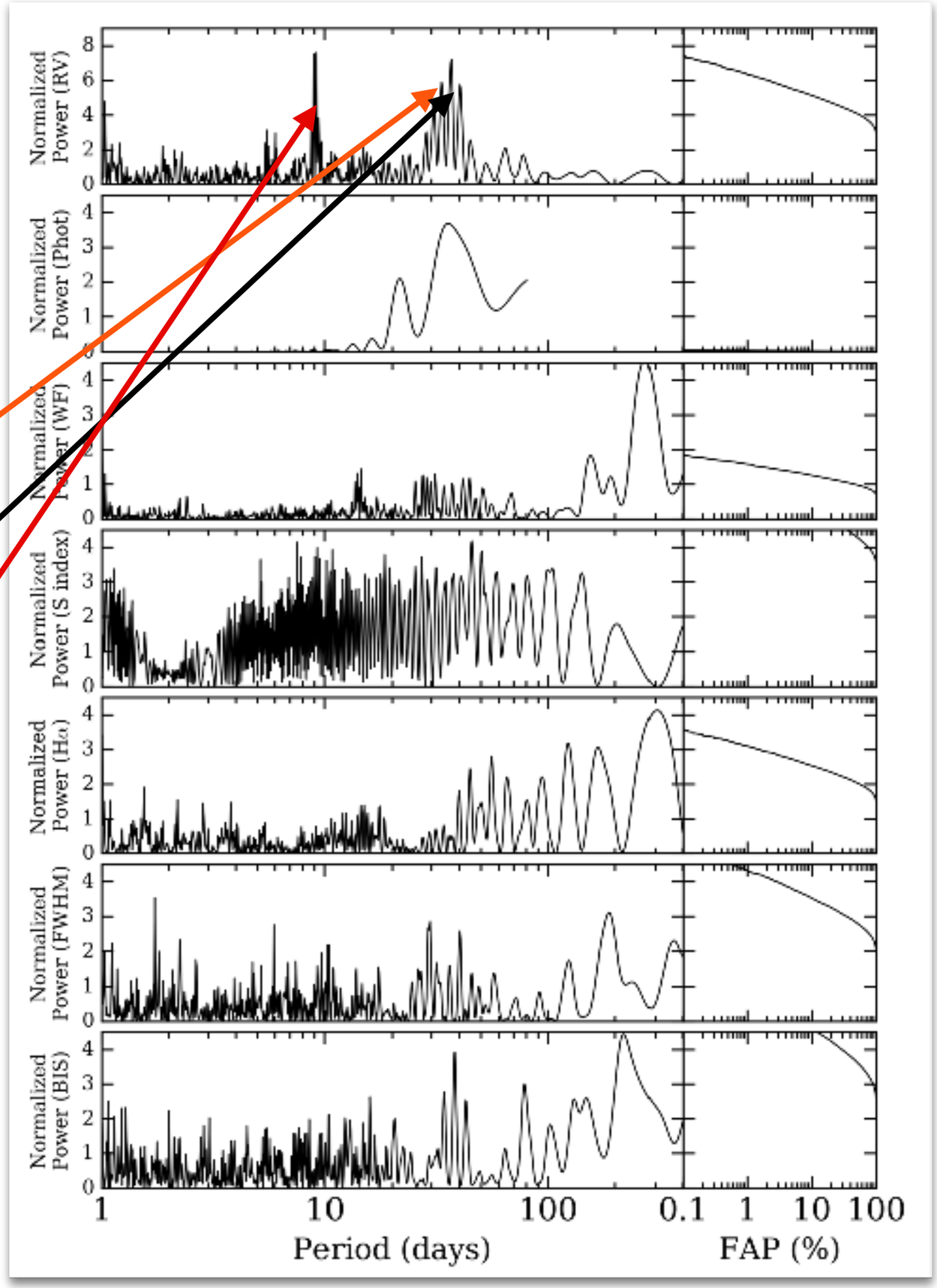
Benneke et al. (arXiv:1610.07249)

K2-18b RV characterization w/ 75 **HARPS** RVs

P_b ~ 33 days

P_{rot} ~ 39 days

$P_{??}$ ~ 9 days



HARPS RVs

K2 photometry

HARPS WF

HARPS S-index

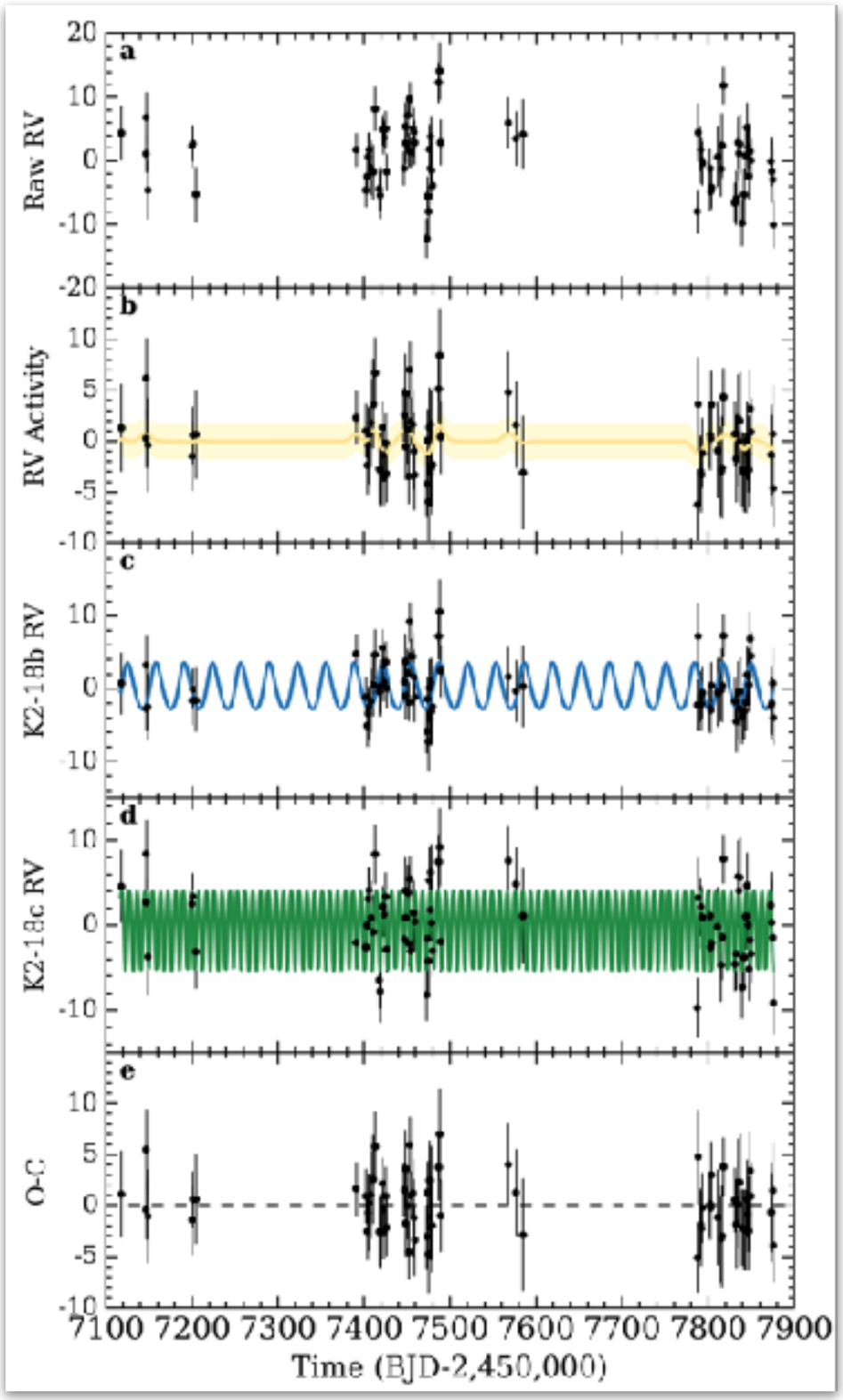
HARPS Hα

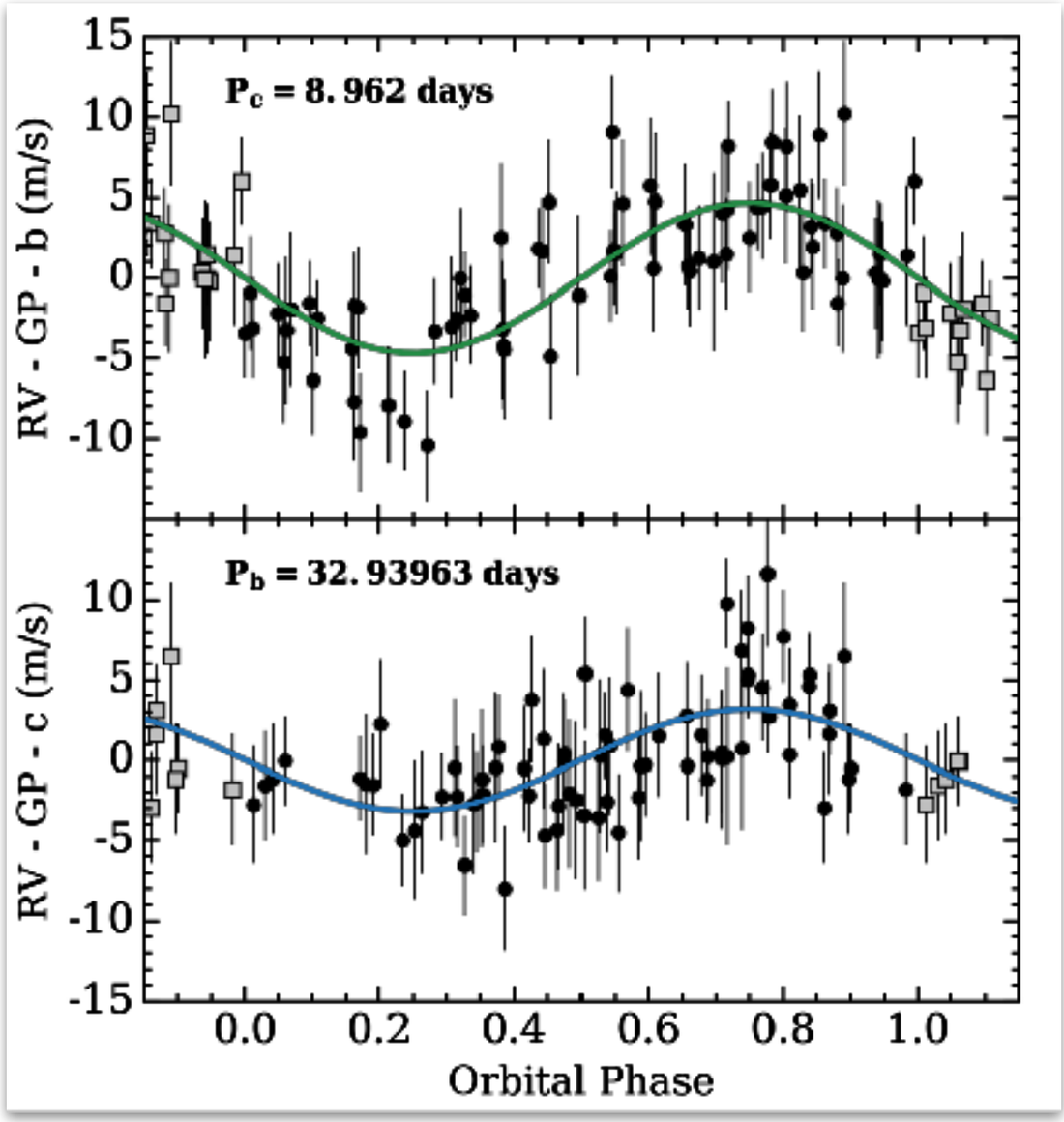
HARPS FWHM

HARPS BIS

Cloutier et al. (arXiv:1707.04292)

K2-18 **HARPS** RV modelling: GP activity + 2 planets





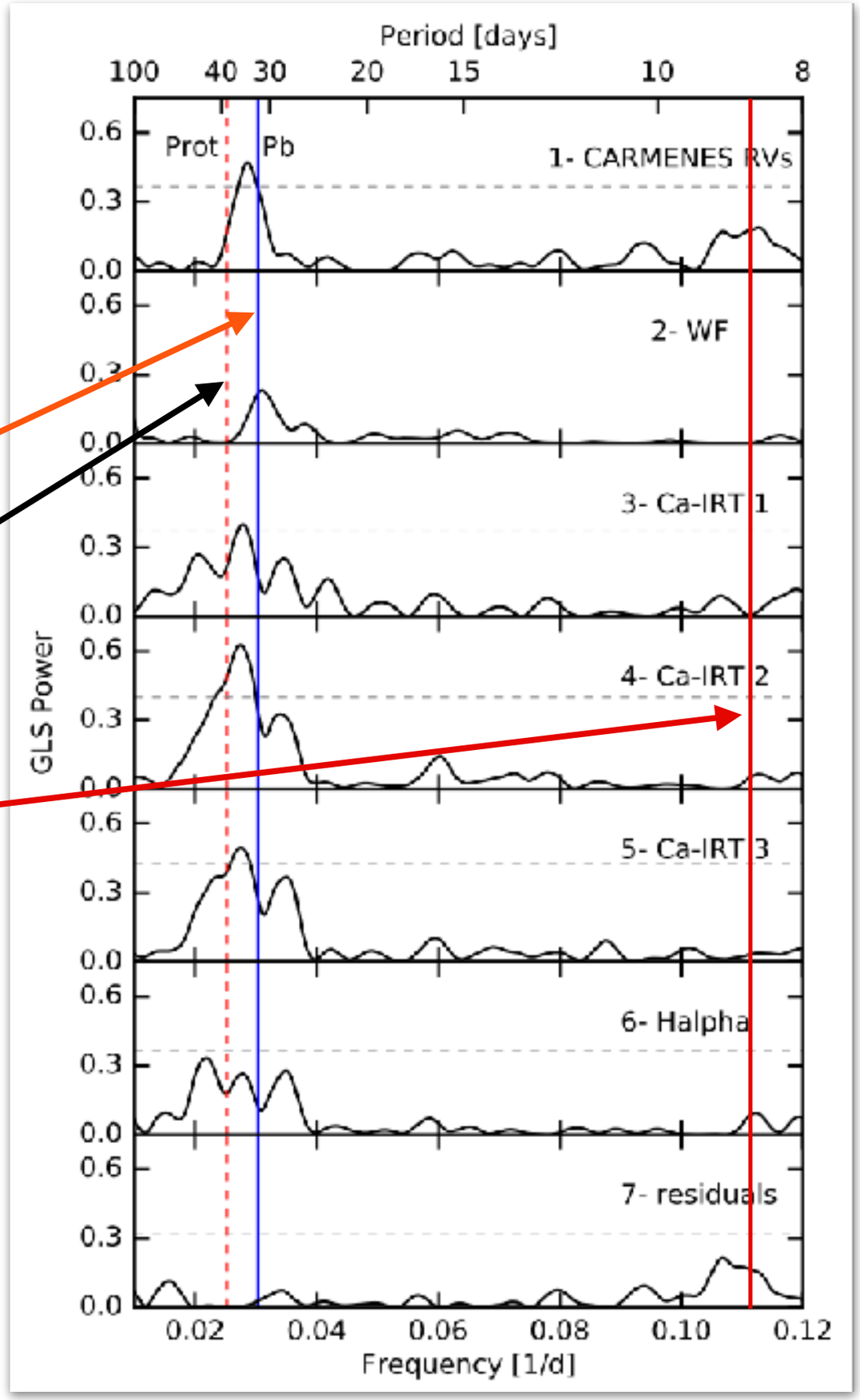
Cloutier et al. (arXiv:1707.04292)

K2-18b RV characterization w/ 58 **CARMENES** RVs

P_b ~ 33 days

P_{rot} ~ 39 days

$P_{??}$ ~ 9 days



CARMENES RVs

CARMENES WF

CARMENES Ca-IRT 1

CARMENES Ca-IRT 2

CARMENES Ca-IRT 3

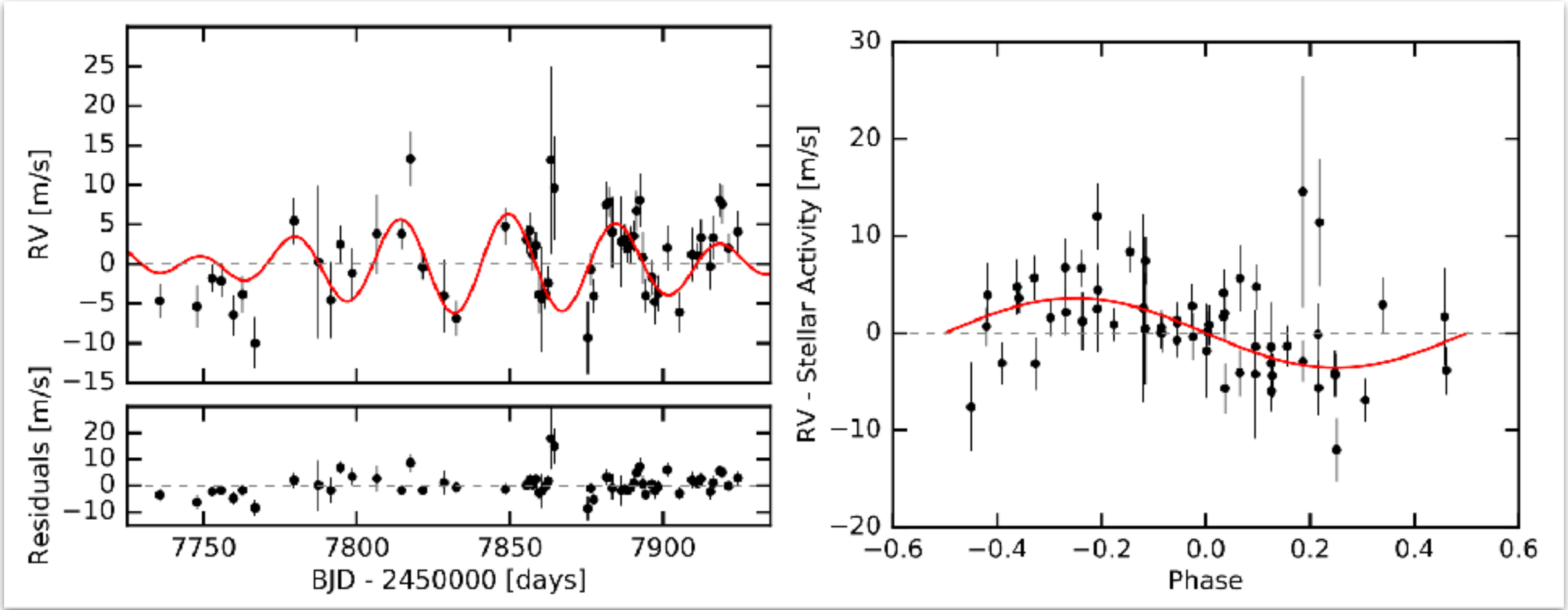
CARMENES Hα

residuals = RVs - activity - K2-18b

Sarkis et al. (arXiv:1805.00830)

K2-18 CARMENES RV model:

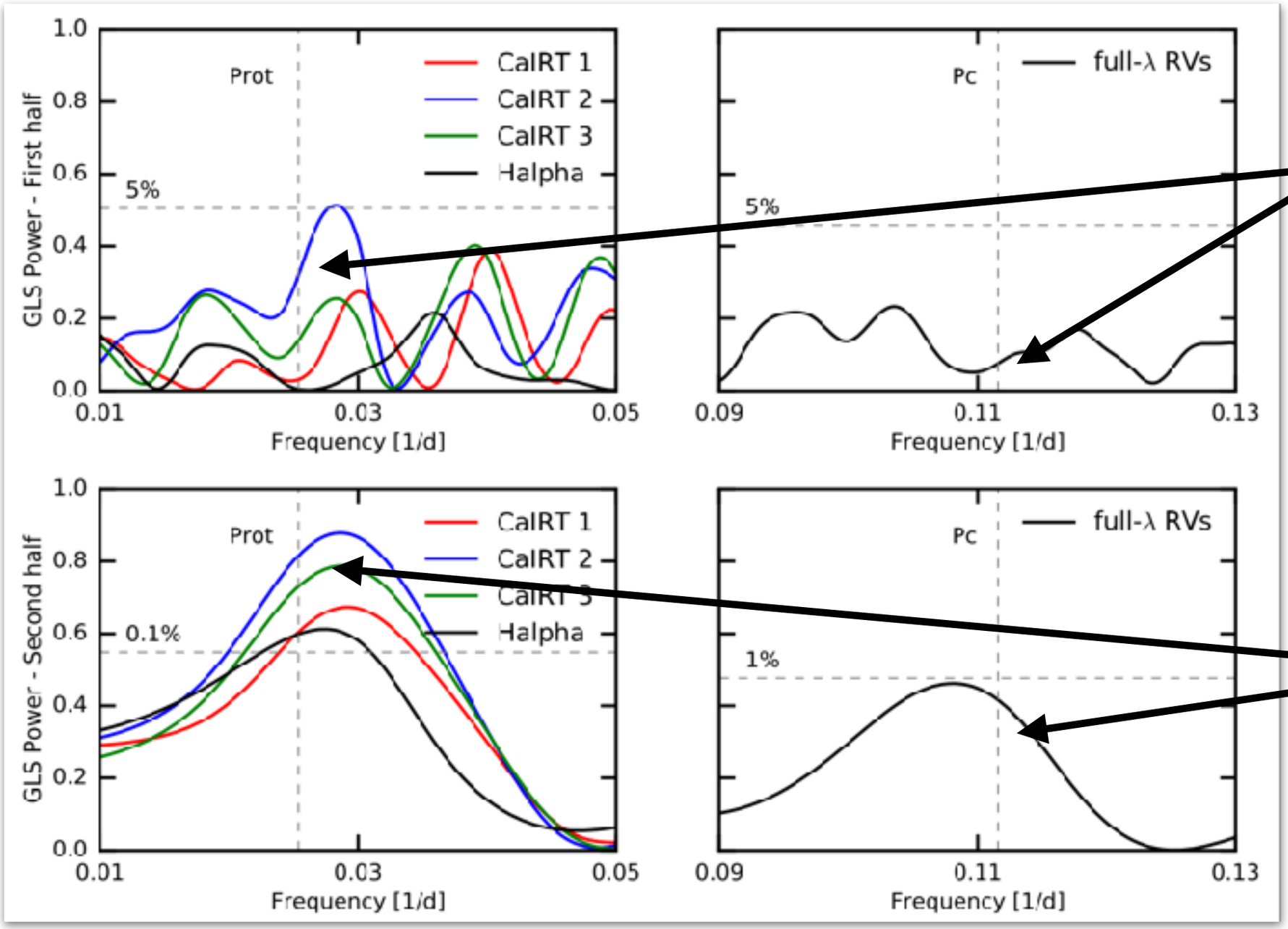
sinusoidal activity + 1 planet



Sarkis et al. (arXiv:1805.00830)

K2-18 CARMENES RVs:

temporal variations in the 9 day signal



weak activity and weak RV signal at 9 days

increased activity and stronger RV signal at 9 days

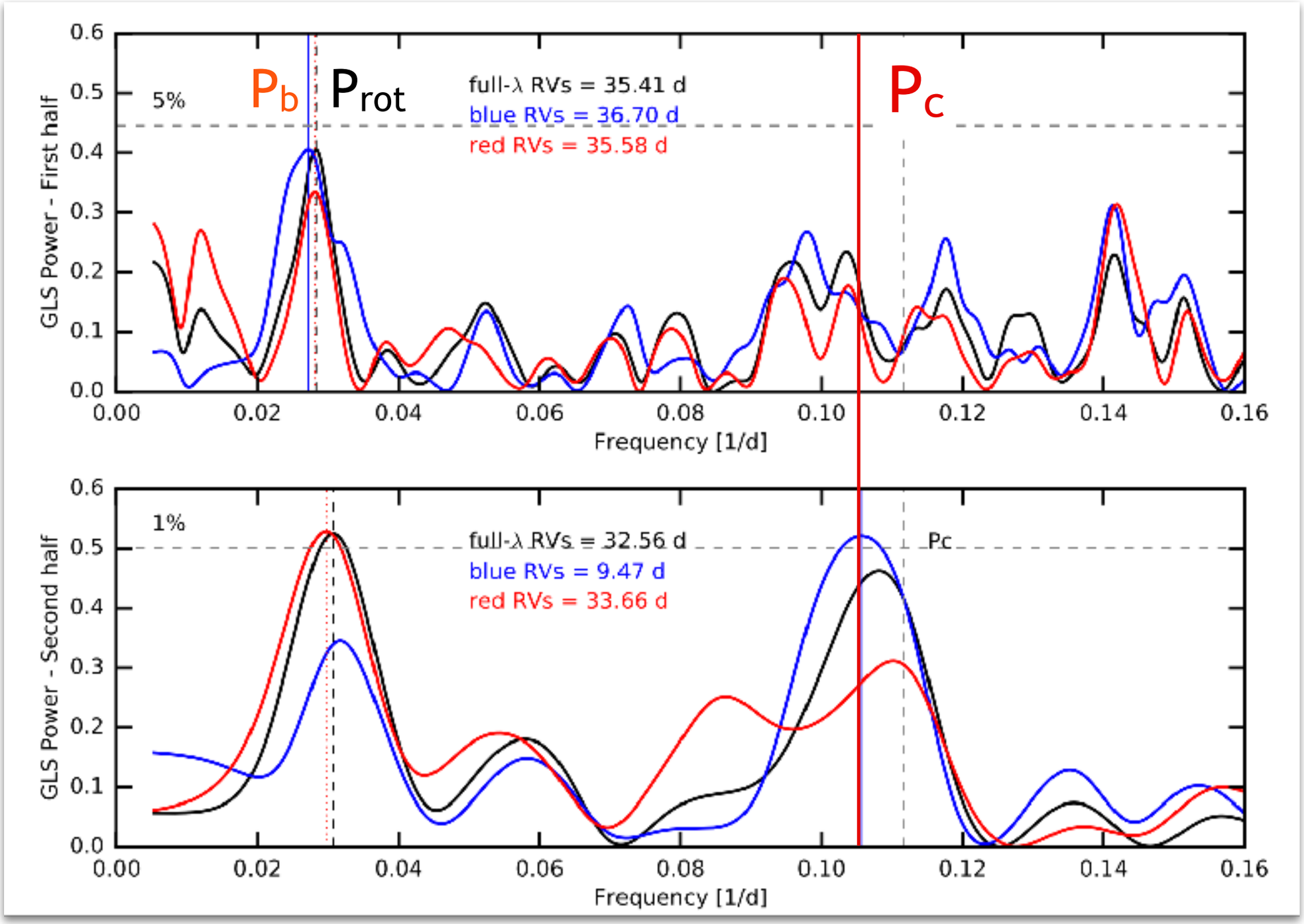
Sarkis et al. (arXiv:1805.00830)

K2-18 CARMENES RVs:

chromatic variations in the 9 day signal

blue orders:
561-689 nm

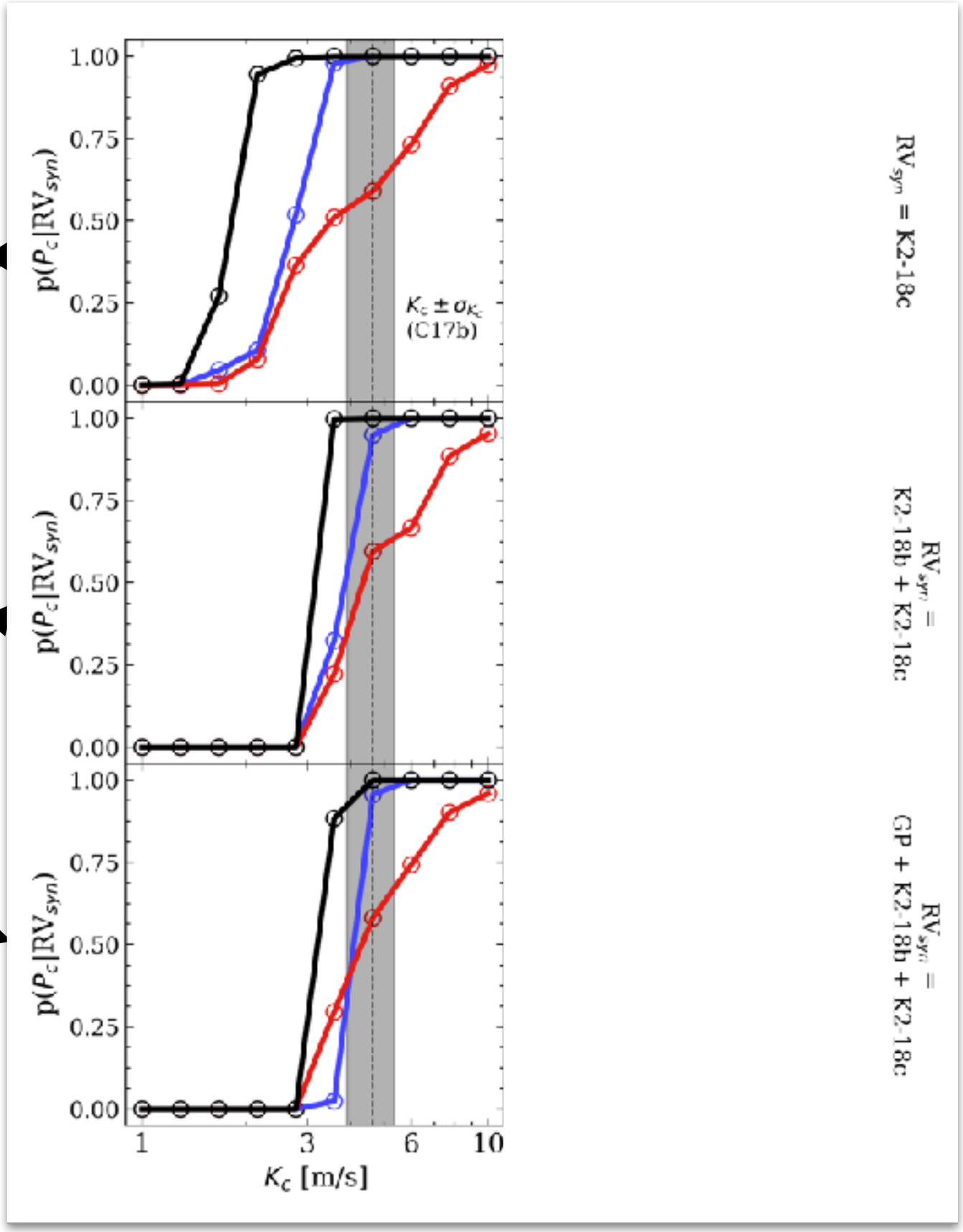
red orders:
697-905 nm



Sarkis et al. (arXiv:1805.00830)

Discrepancy in the 9 day signal strength due to *sampling*

- injected signals:
  - 9 day keplerian
  - 9 & 33 day keplerians
  - 9 & 33 day keplerians plus samples from the GP activity prior



Cloutier et al. (arXiv:1810.04731)

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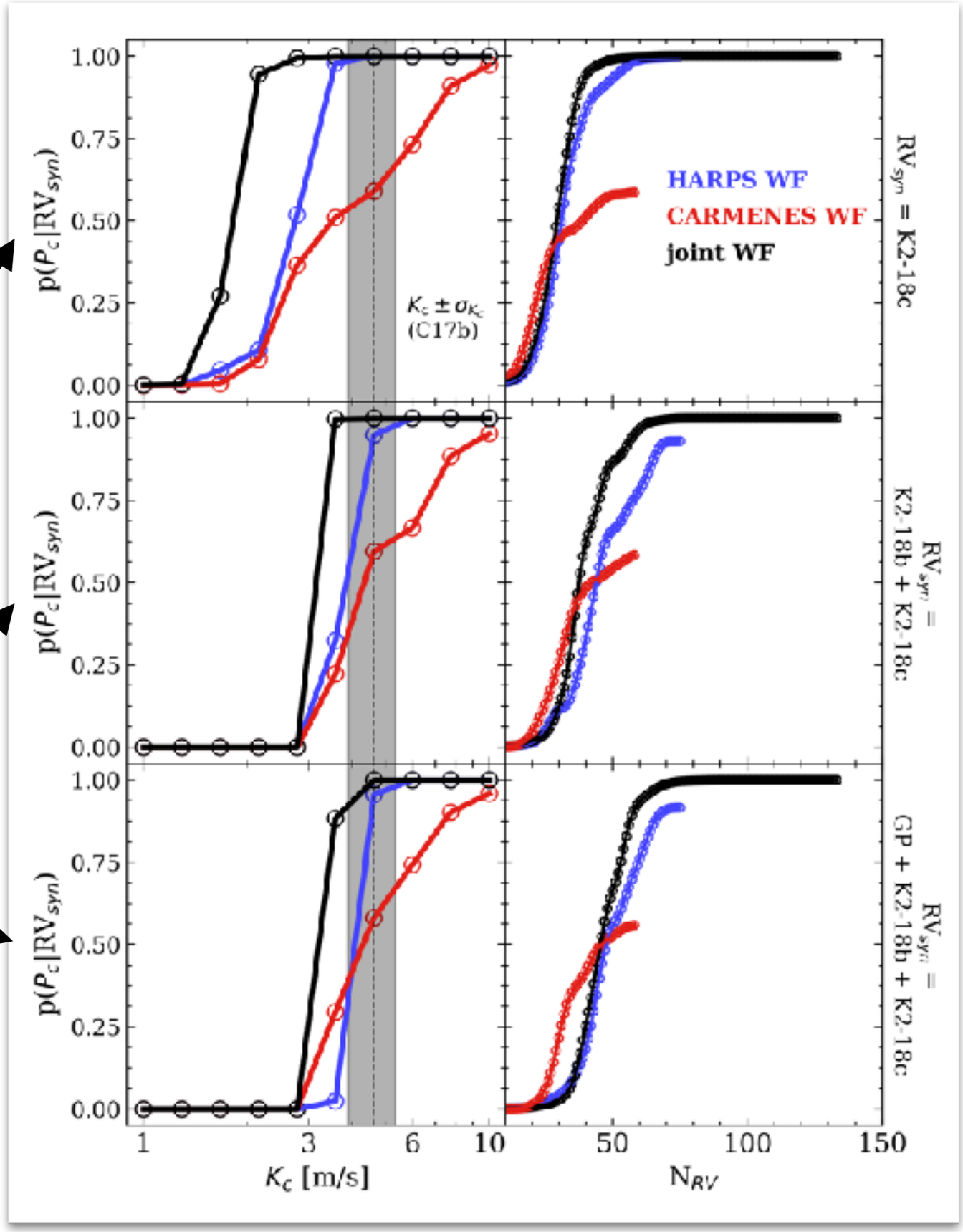
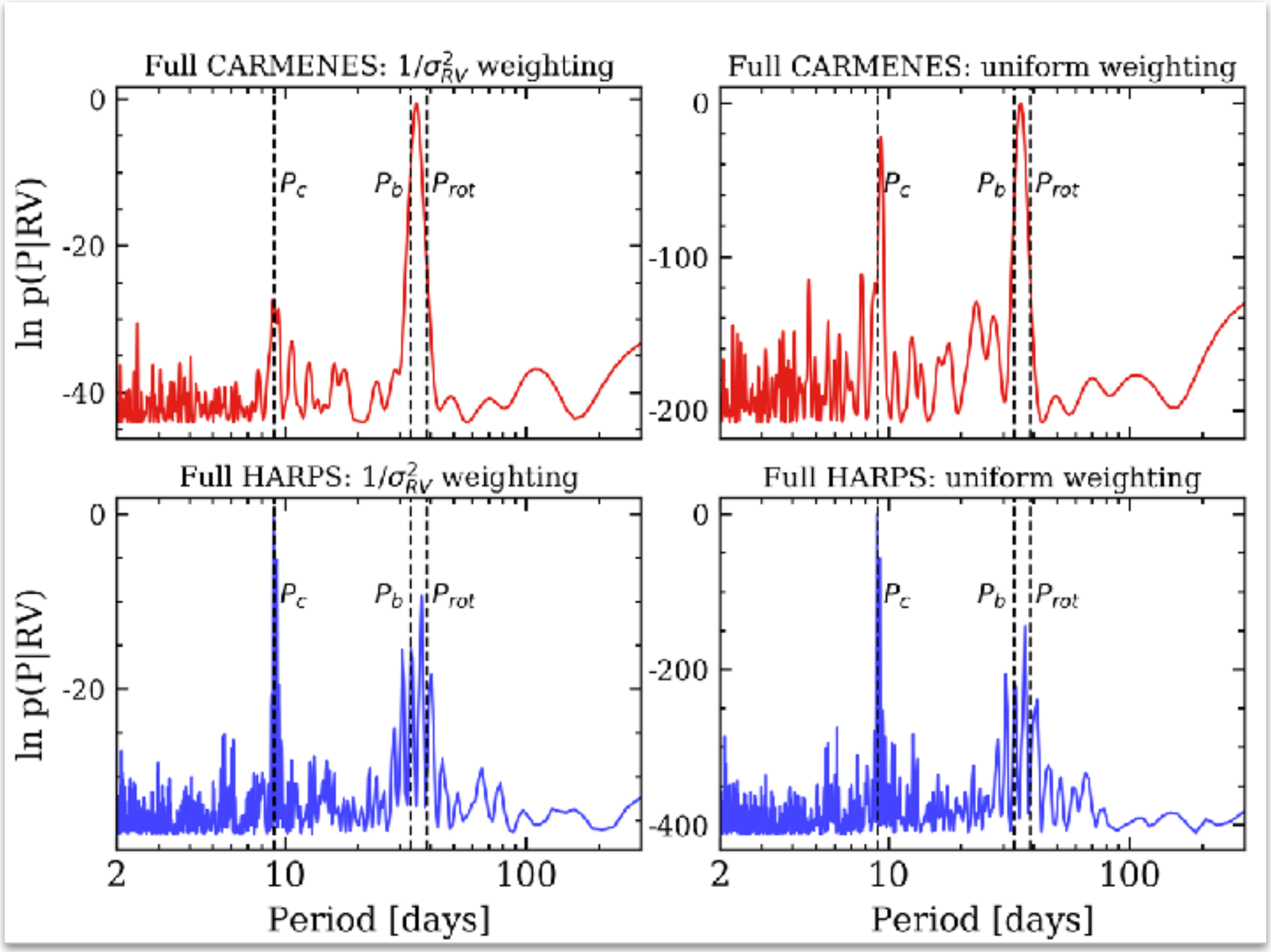


Cloutier et al. (arXiv:1810.04731)

Discrepancy in the 9 day signal strength due to *weighting*

CARMENES

HARPS



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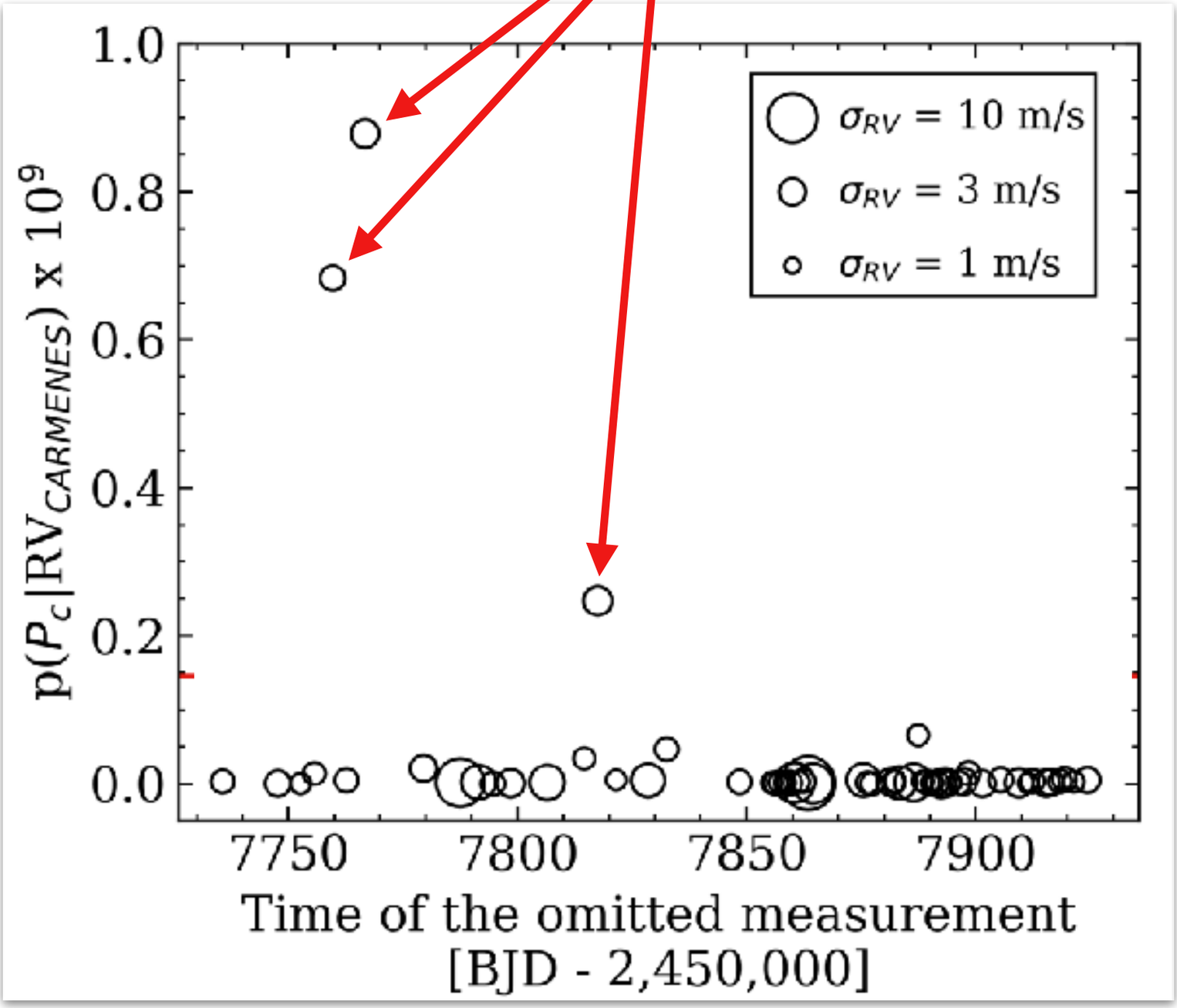
Discrepancy in the 9 day signal strength due to *anomalous RVs*



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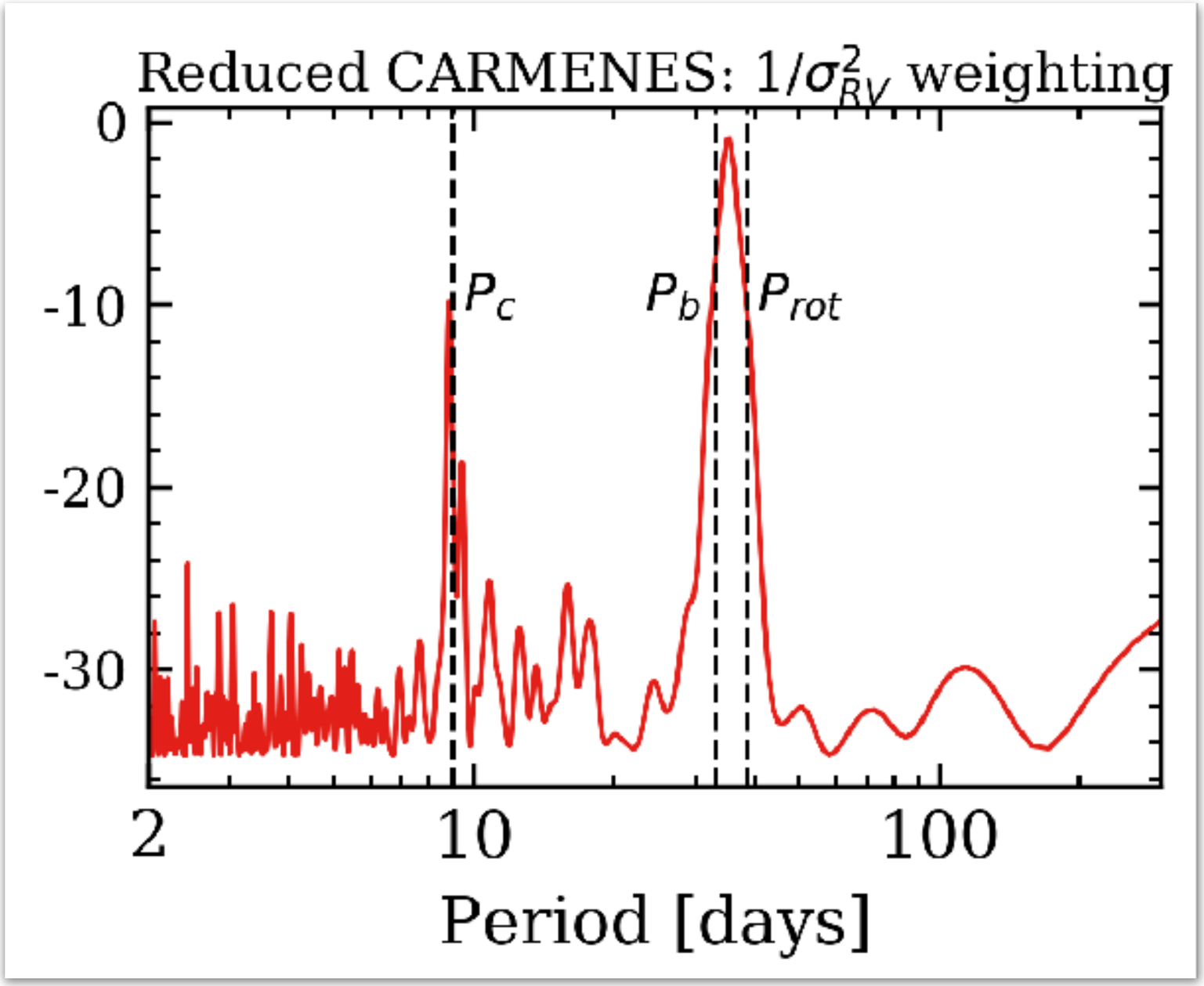
Discrepancy in the 9 day signal strength due to *anomalous RVs*

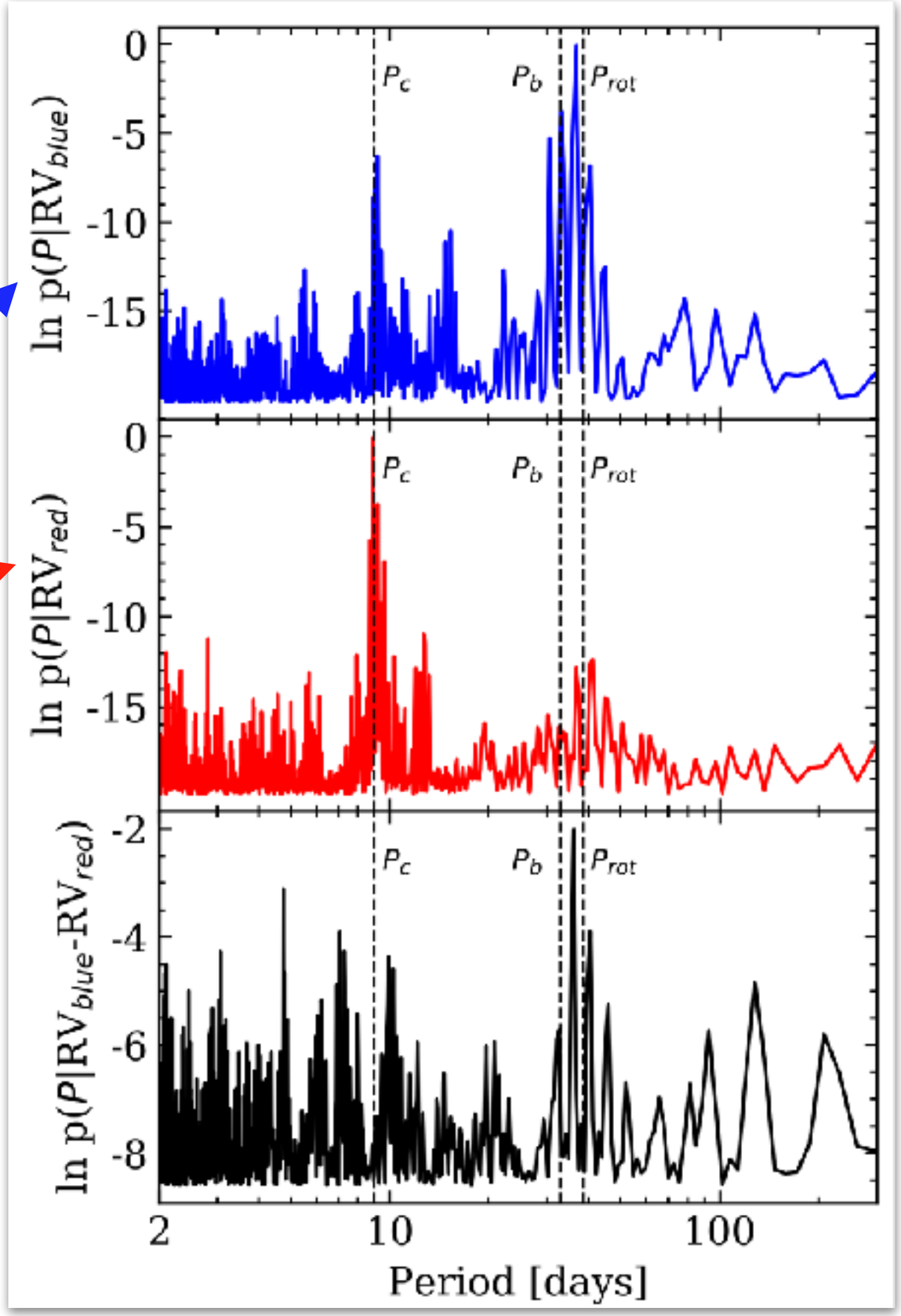


Cloutier et al. (arXiv:1810.04731)

K2-18 **HARPS** RVs:
chromatic variations

blue orders: 498-594 nm

red orders: 618-688 nm



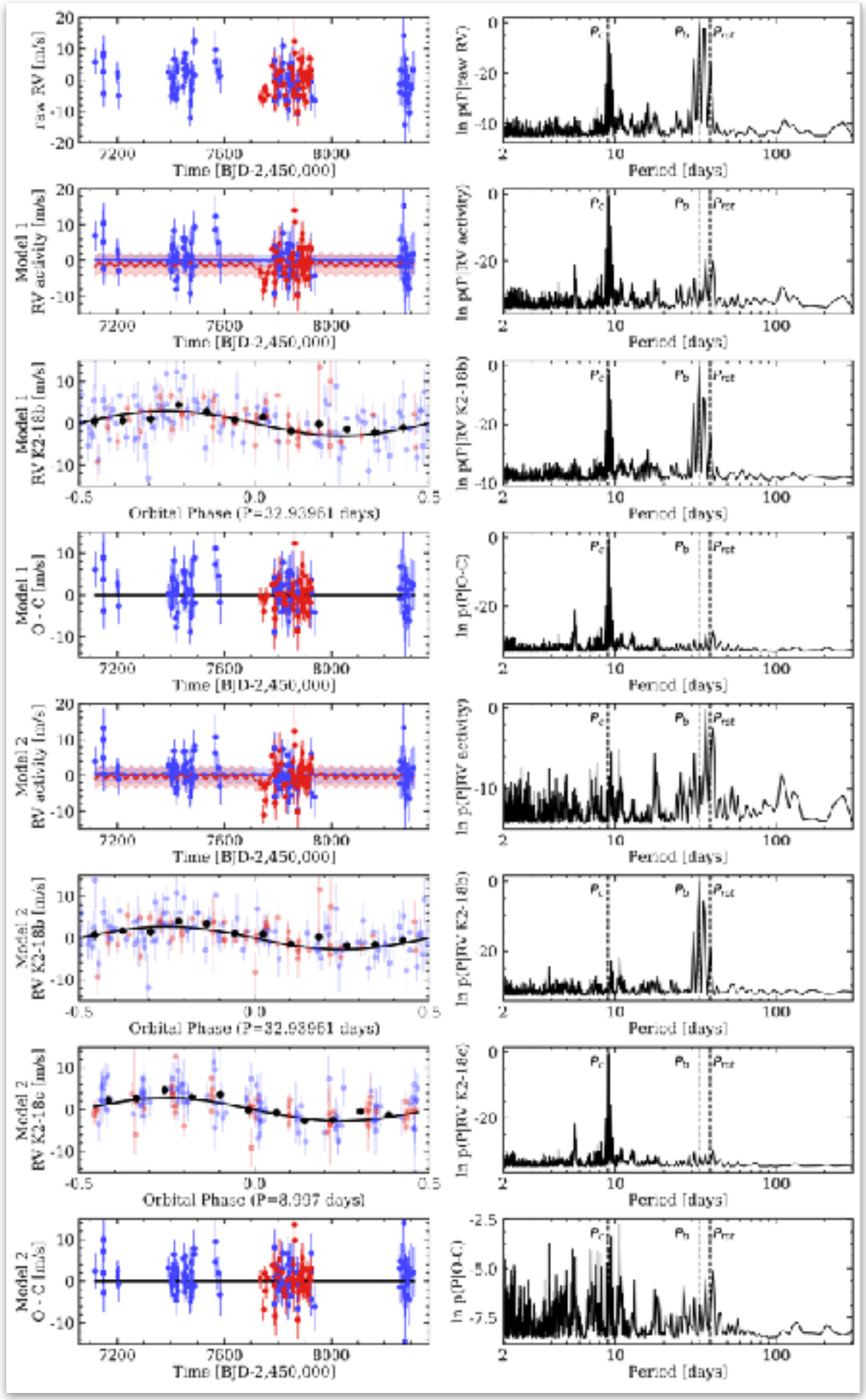
Cloutier et al. (arXiv:1810.04731)

K2-18 HARPS+CARMENES RV modelling:

GP activity + planets

*nearly all datasets considered favour a 2-planet model

Cloutier et al. (arXiv:1810.04731)



Final thoughts:

- the notion that **individual measurements can have such large effects on periodicities is concerning**

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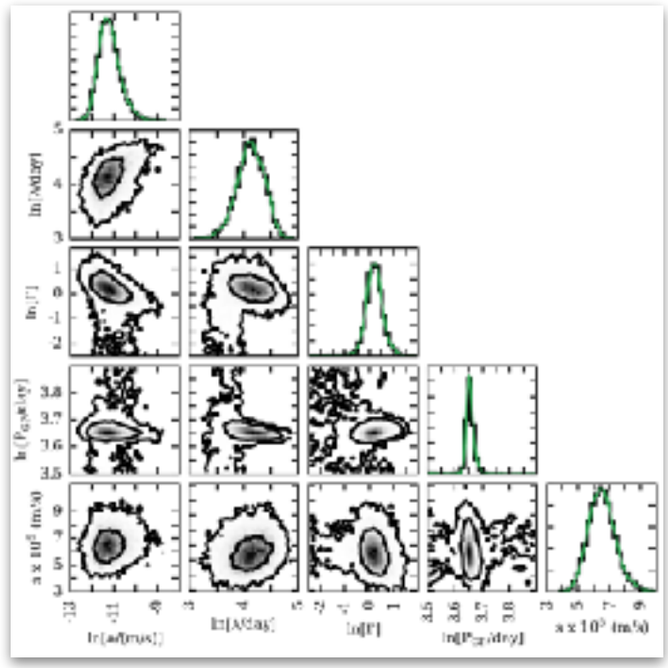
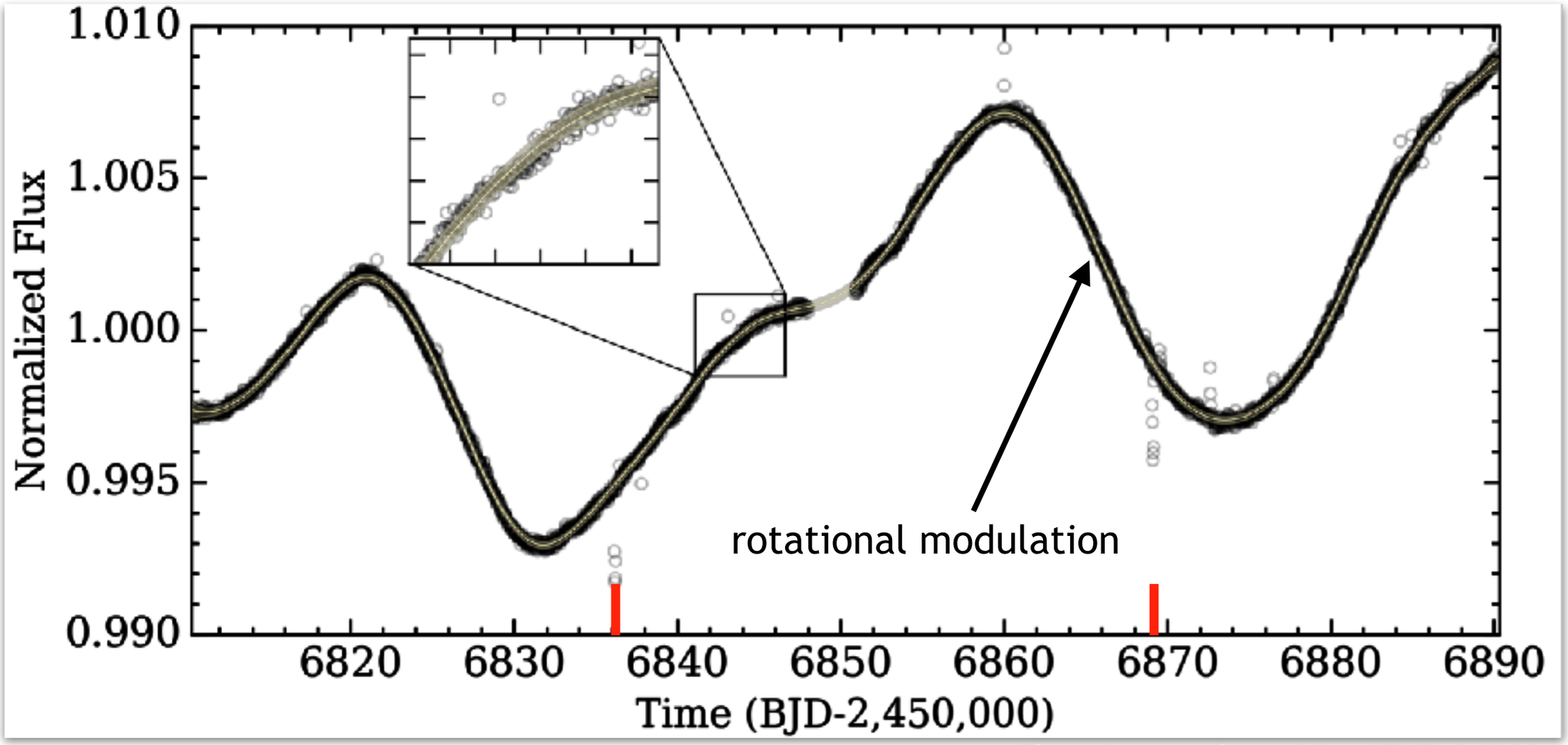
- the notion that **individual measurements can have such large effects on periodicities is concerning**
- this is a prime example of a case in which **distinguishing between planets and activity is not completely unambiguous**
- **the nature of the 9 day signal seems to favour the planetary interpretation** but some checks of the nature of the three anomalous CARMENES RVs is desirable:
  - e.g. check if other stars observed by CARMENES on that night are similarly anomalous
  - e.g. check the stability of the telluric correction (or other nightly quality flags) on those nights
  - other ideas?

Illustration by Alex Boersma www.alexboersma.com

Stellar activity & model training using photometry

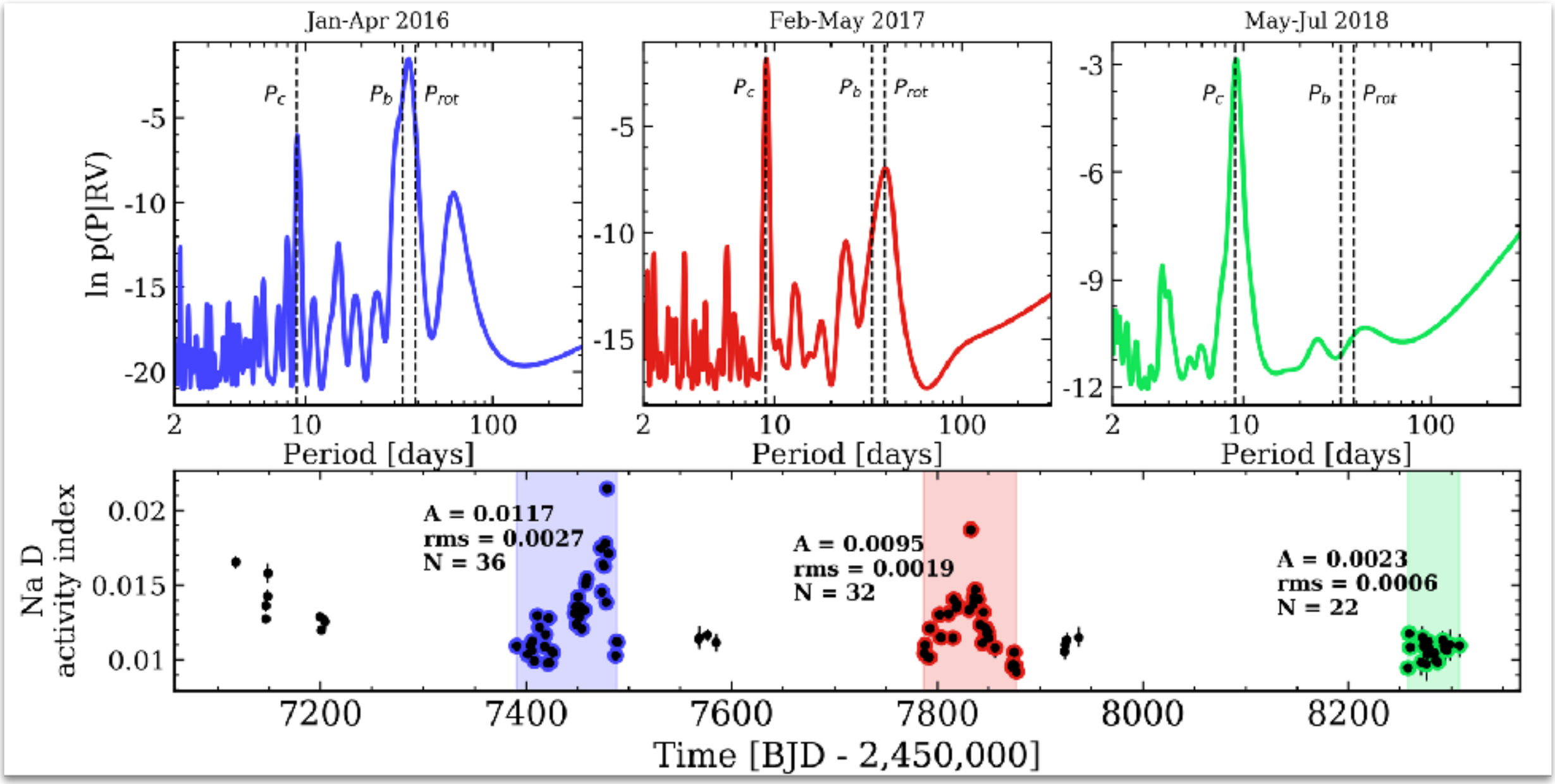
covariance
amplitude
exponential timescale
coherence
periodic timescale
jitter





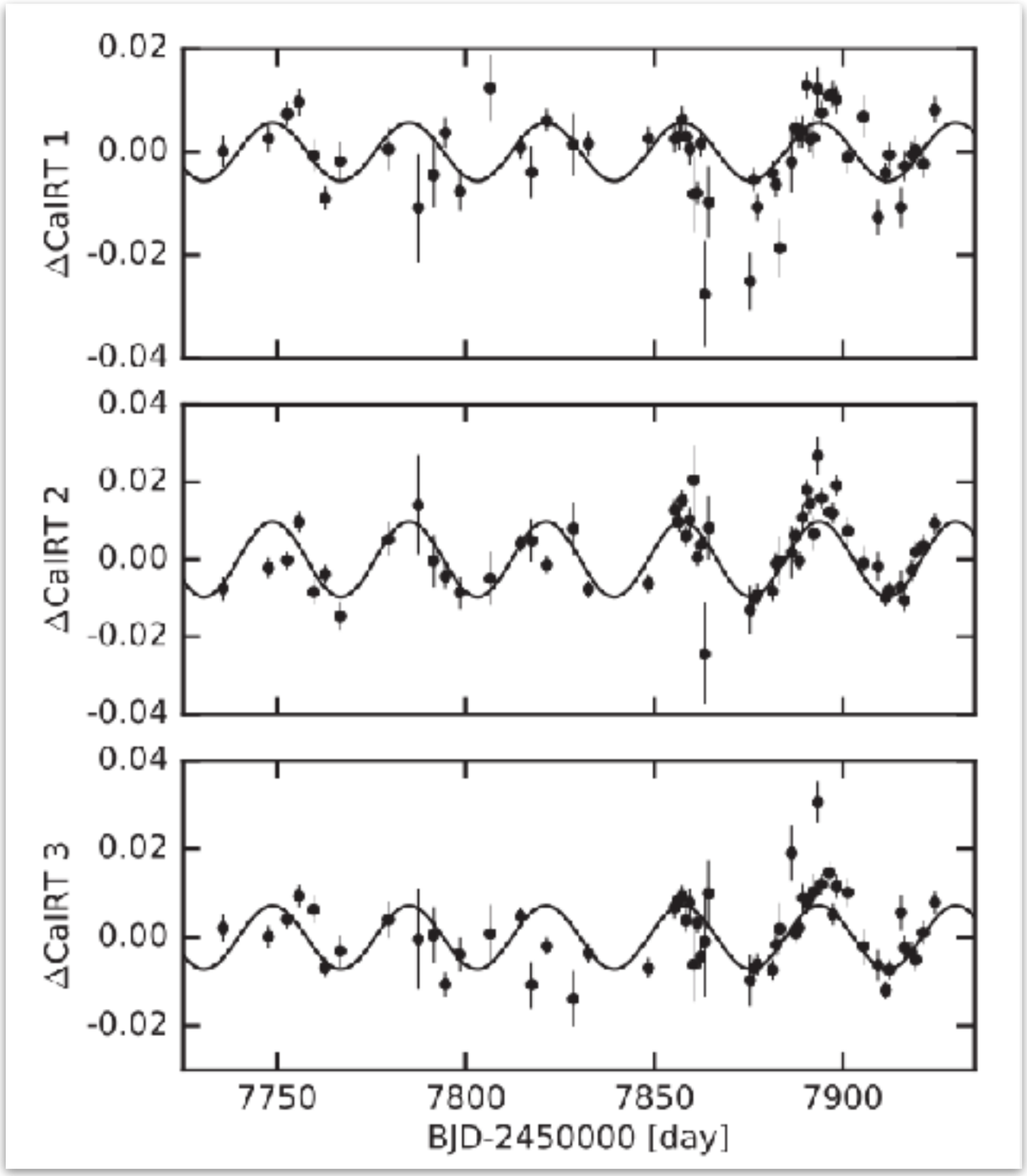
Cloutier et al. (arXiv:1707.04292)

K2-18 HARPS RVs:
temporal variations



Cloutier et al. (arXiv:1810.04731)

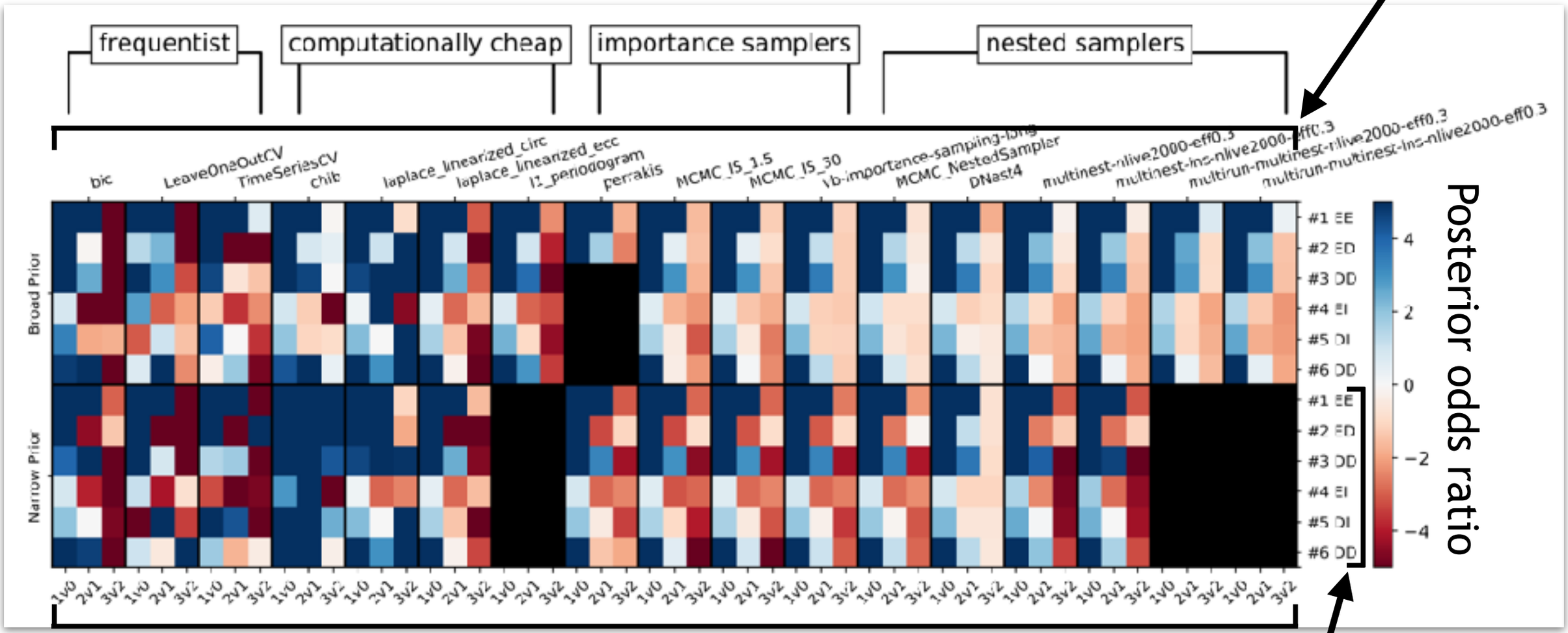
K2-18 CARMENES activity model

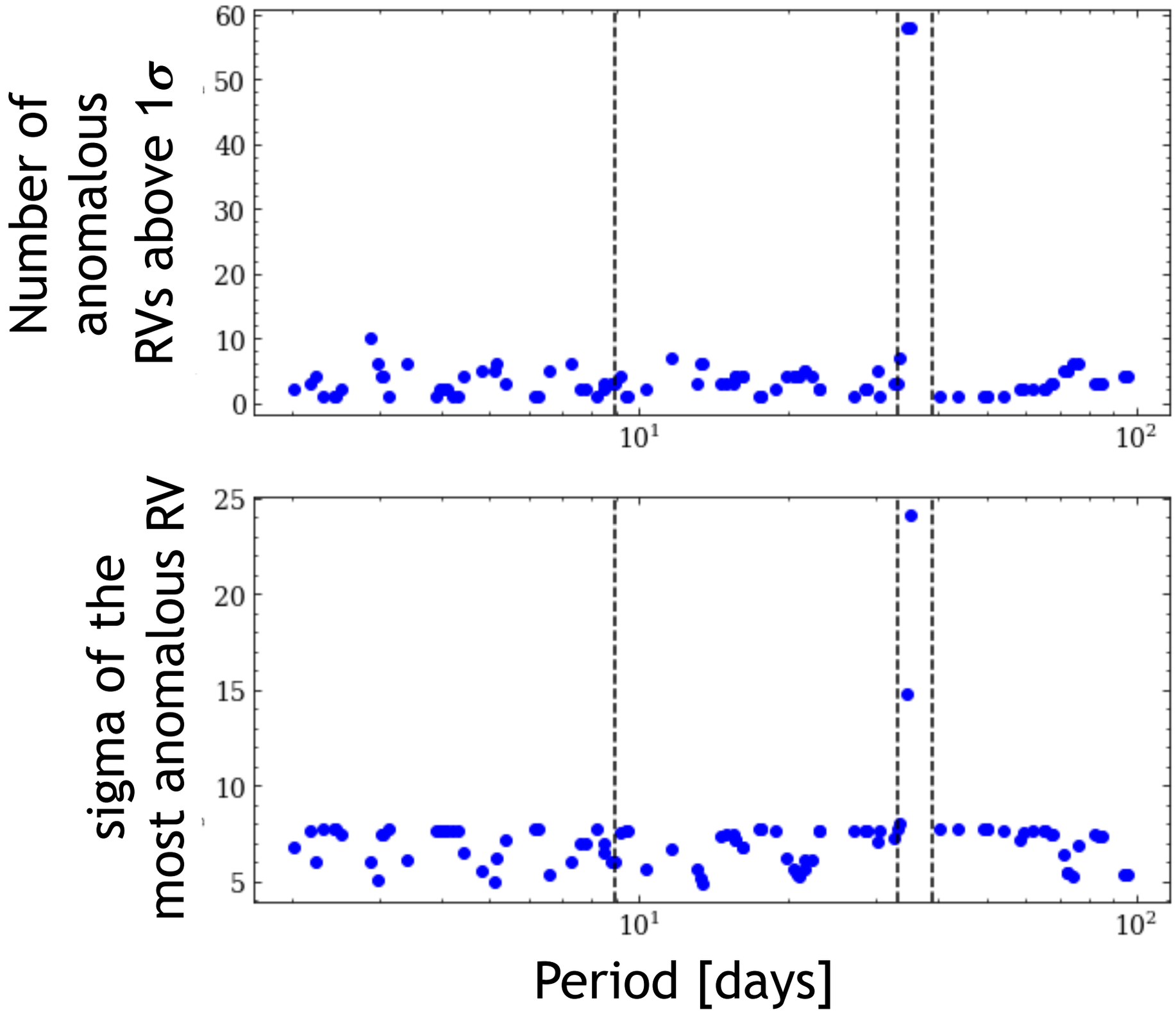


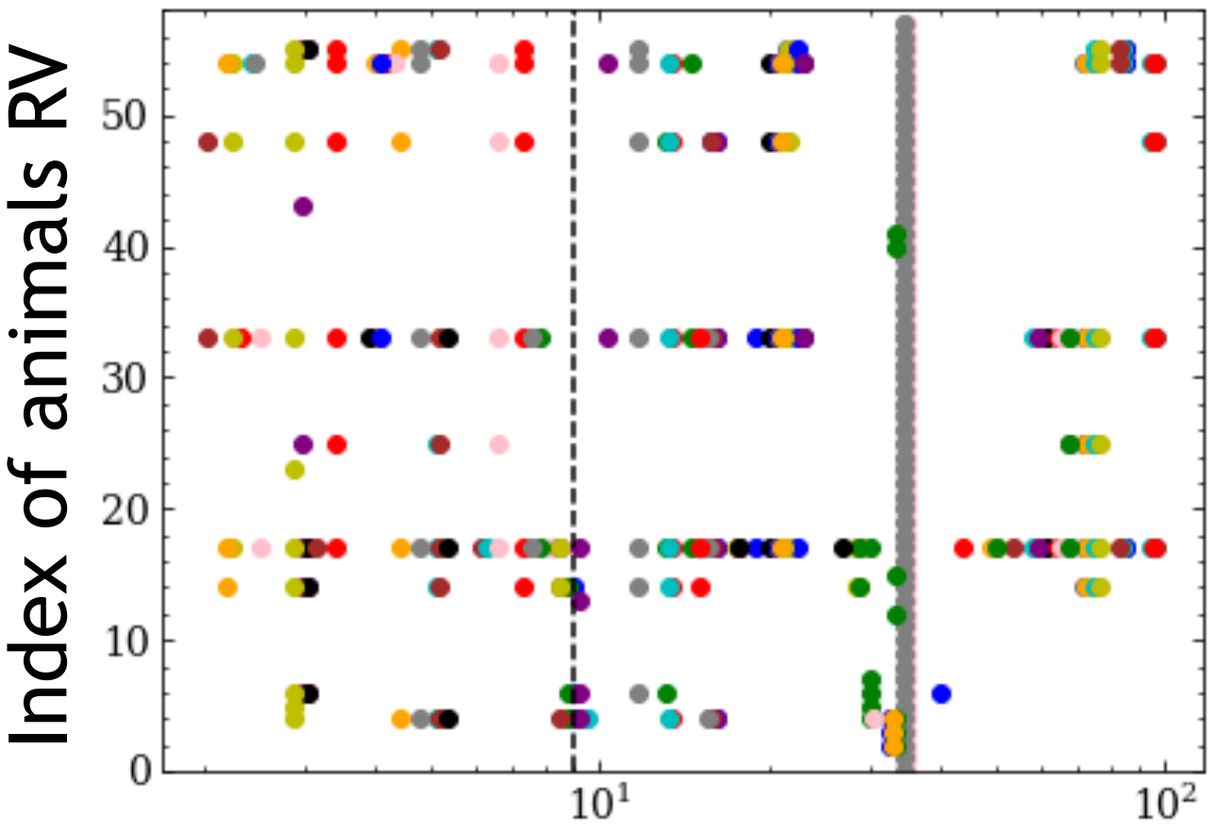
Sarkis et al. (arXiv:1805.00830)

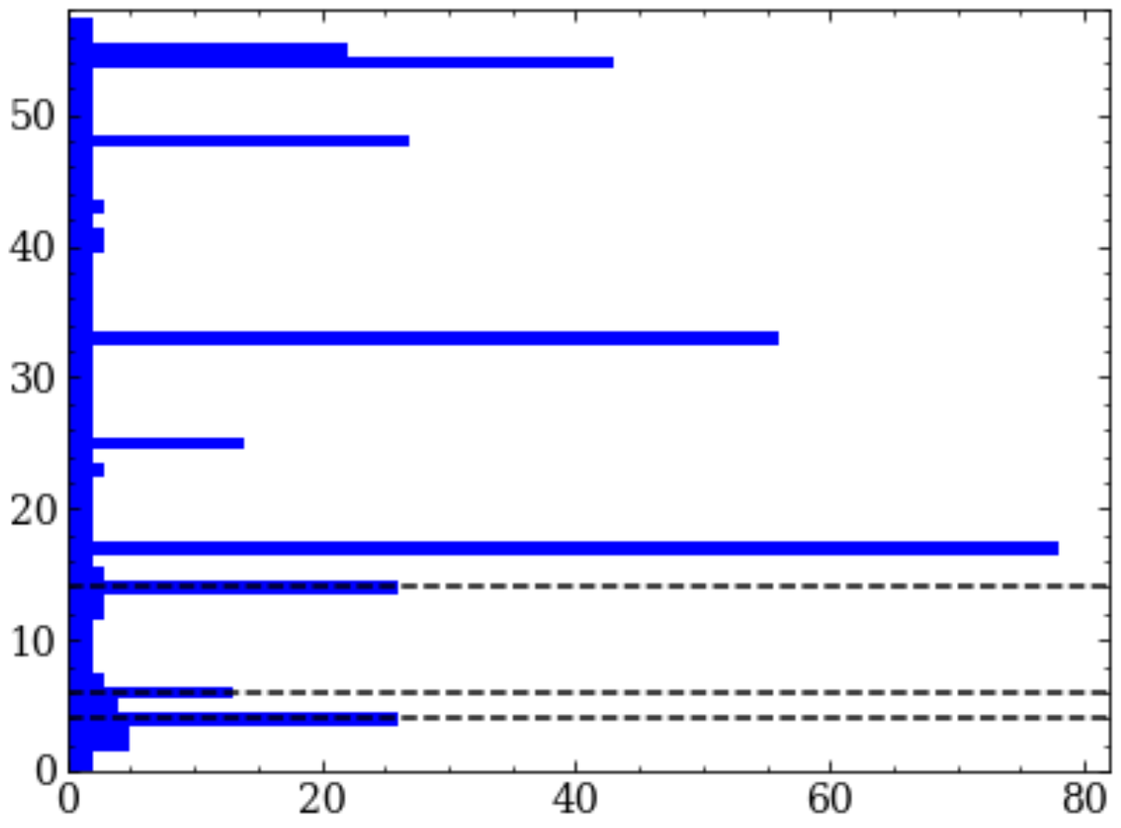
Diversion: planet model comparison methods

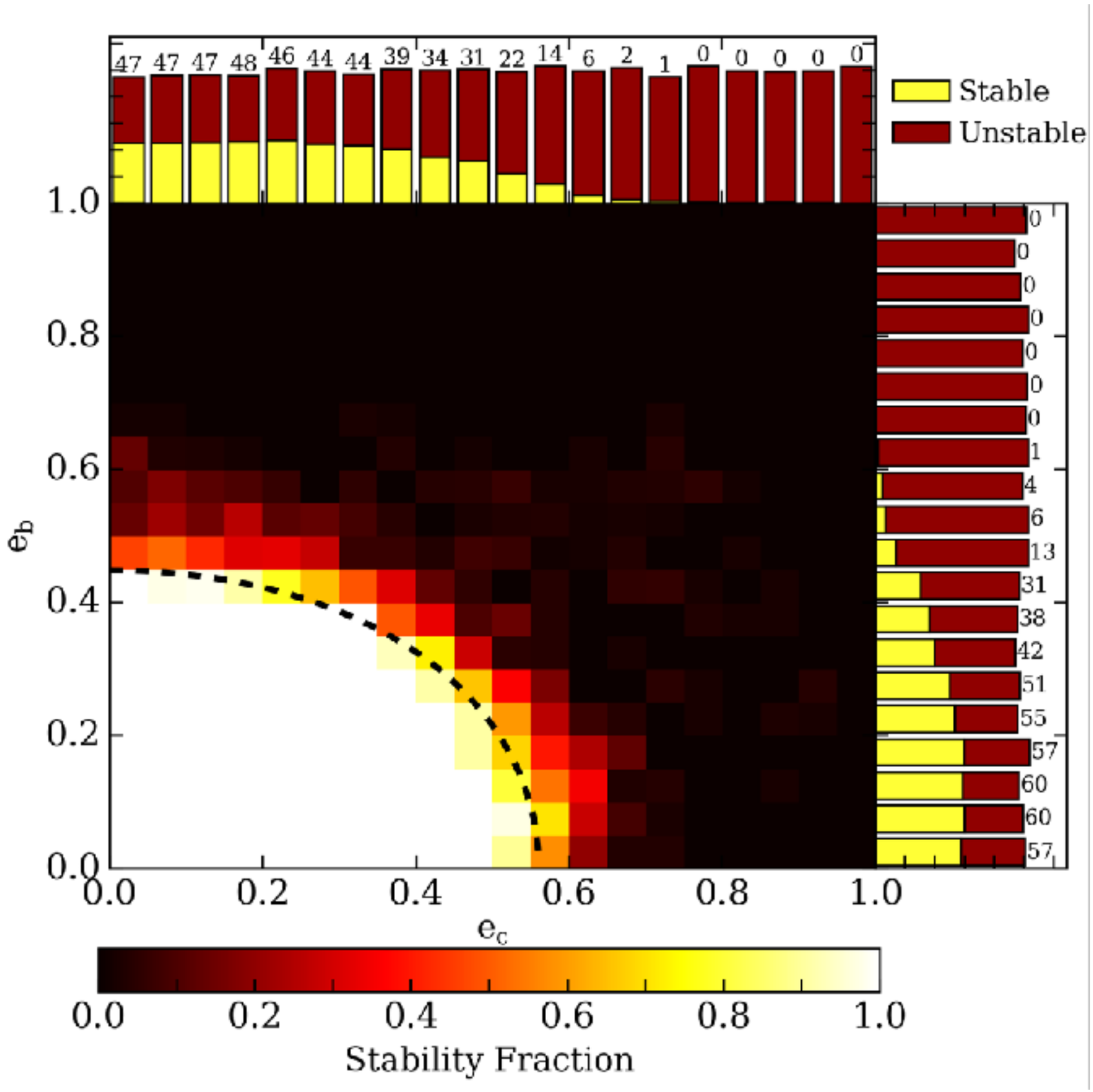
Nelson et al. (arXiv:1806.04683)

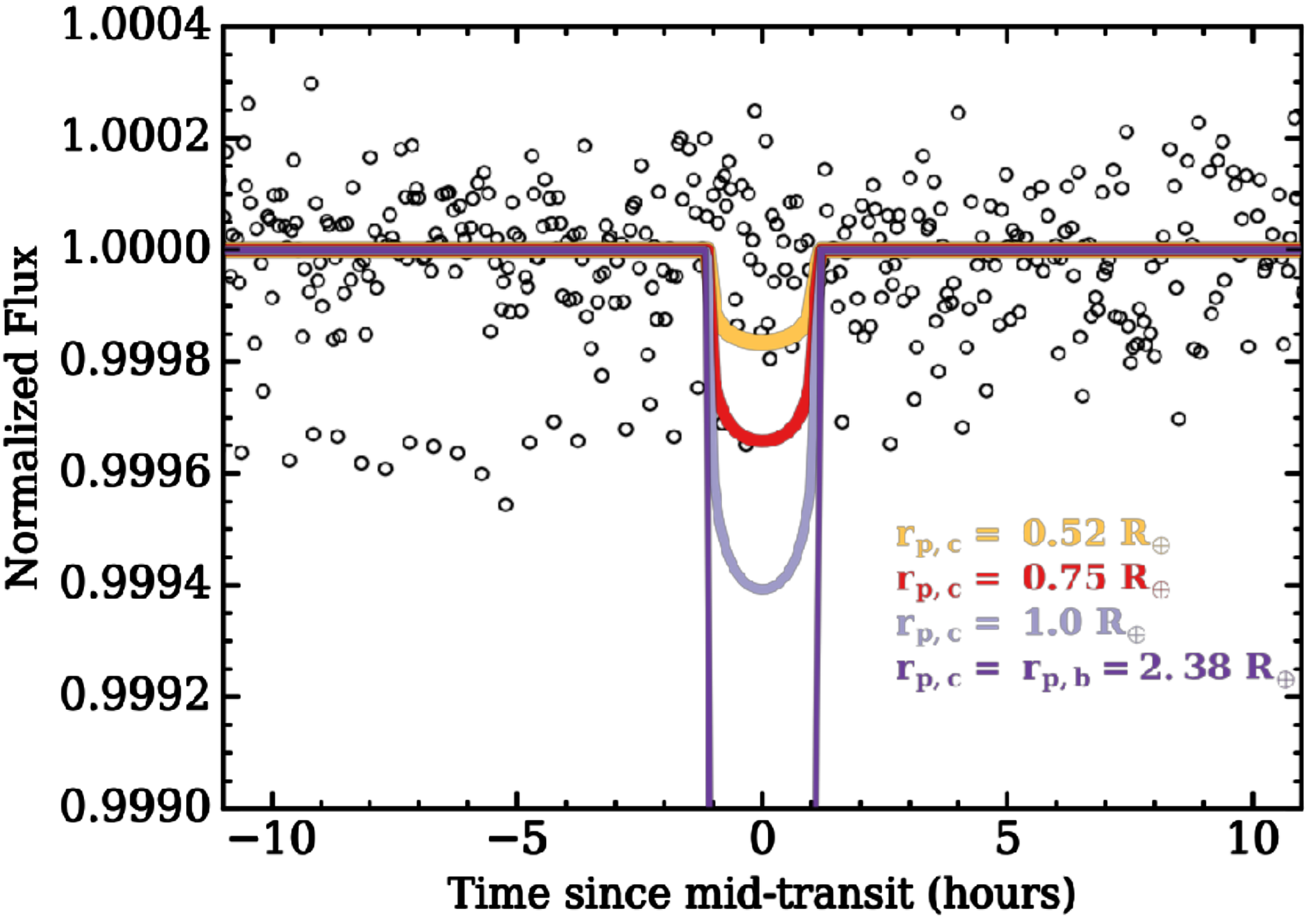



Number of anomalous RVs above 1σ
60
50
40
30
20
10
0
10^1
10^2
sigma of the most anomalous RV
25
20
15
10
5
10^1
10^2
Period [days]


Index of animals RV
0
10
20
30
40
50
10^1
10^2
Period [days]


0
10
20
30
40
50
0
20
40
60
80
Number of times this RV was anomalous


47 47 47 48 46 44 44 39 34 31 22 14 6 2 1 0 0 0 0 0
Stable
Unstable
0 0 0 0 0 0 1 4 6 13 31 38 42 51 55 57 60 60 57
1.0
0.8
0.6
0.4
0.2
0.0
e_b
0.0 0.2 0.4 0.6 0.8 1.0
e_c
0.0 0.2 0.4 0.6 0.8 1.0
Stability Fraction


1.0004
1.0002
1.0000
0.9998
0.9996
0.9994
0.9992
0.9990
Normalized Flux
−10
−5
0
5
10
Time since mid-transit (hours)
$r_{p,c} = 0.52\ R_\oplus$
$r_{p,c} = 0.75\ R_\oplus$
$r_{p,c} = 1.0\ R_\oplus$
$r_{p,c} = r_{p,b} = 2.38\ R_\oplus$