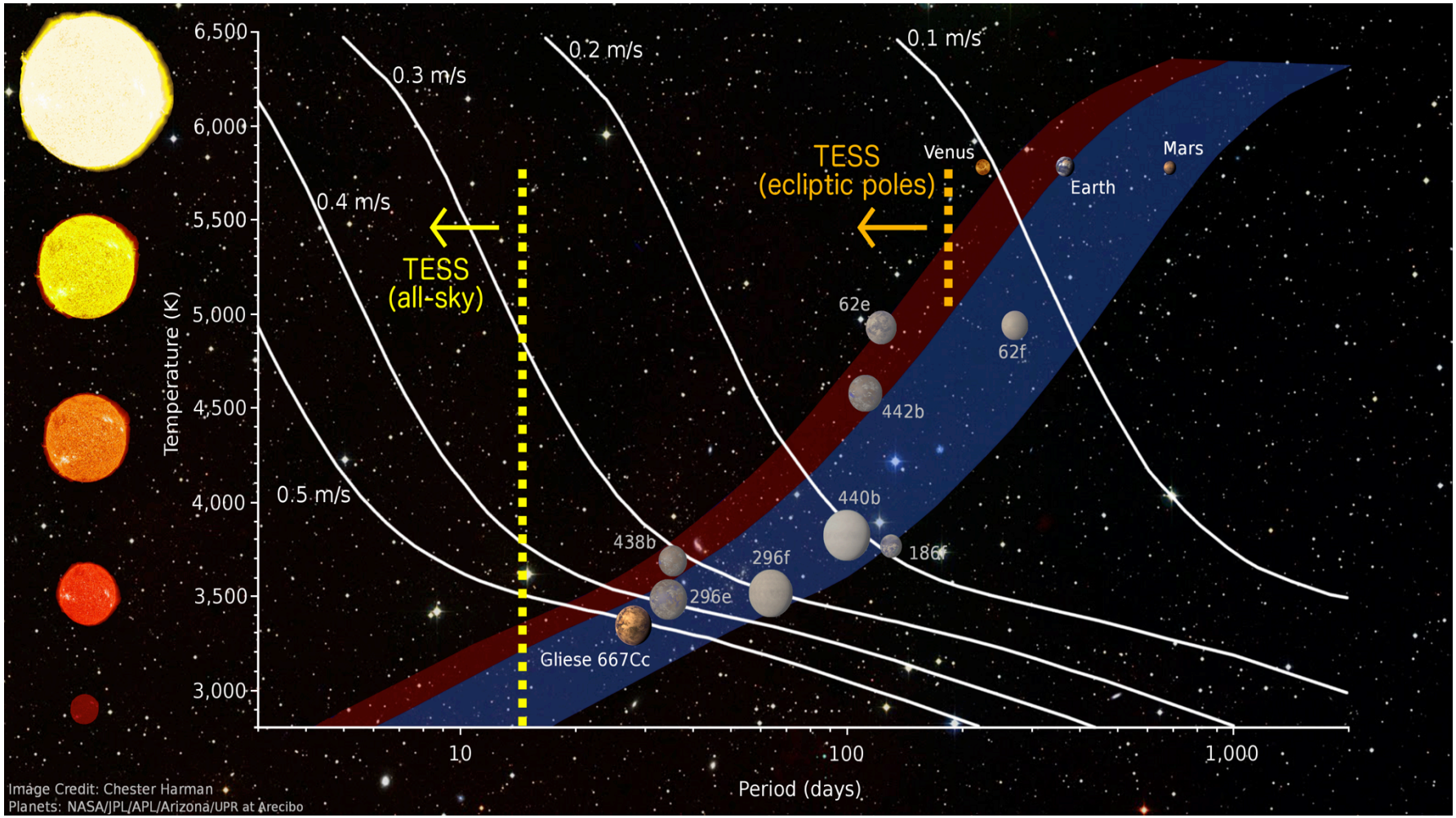
Observational Needs for Radial Velocity Surveys

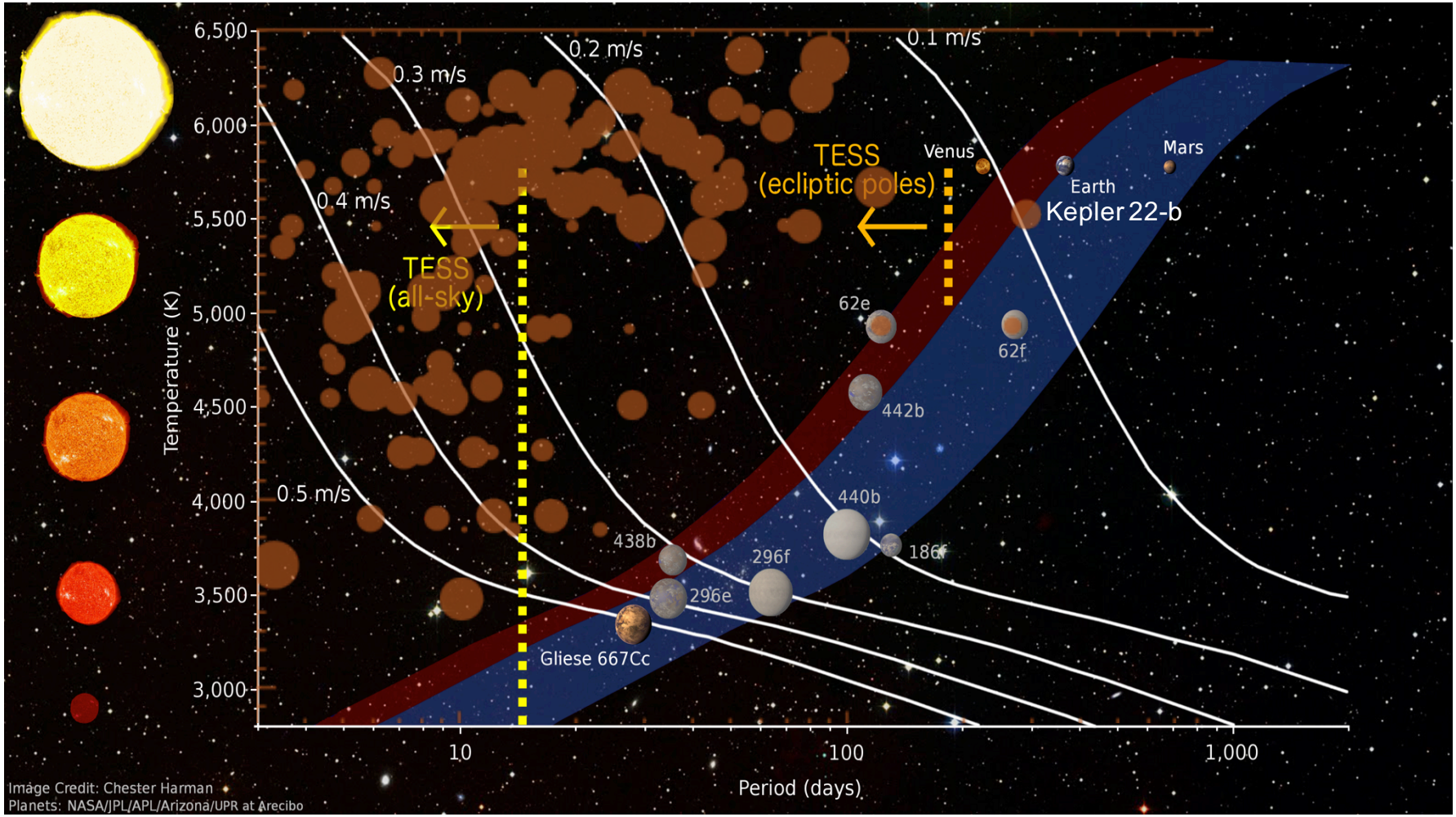
RV×K2.com

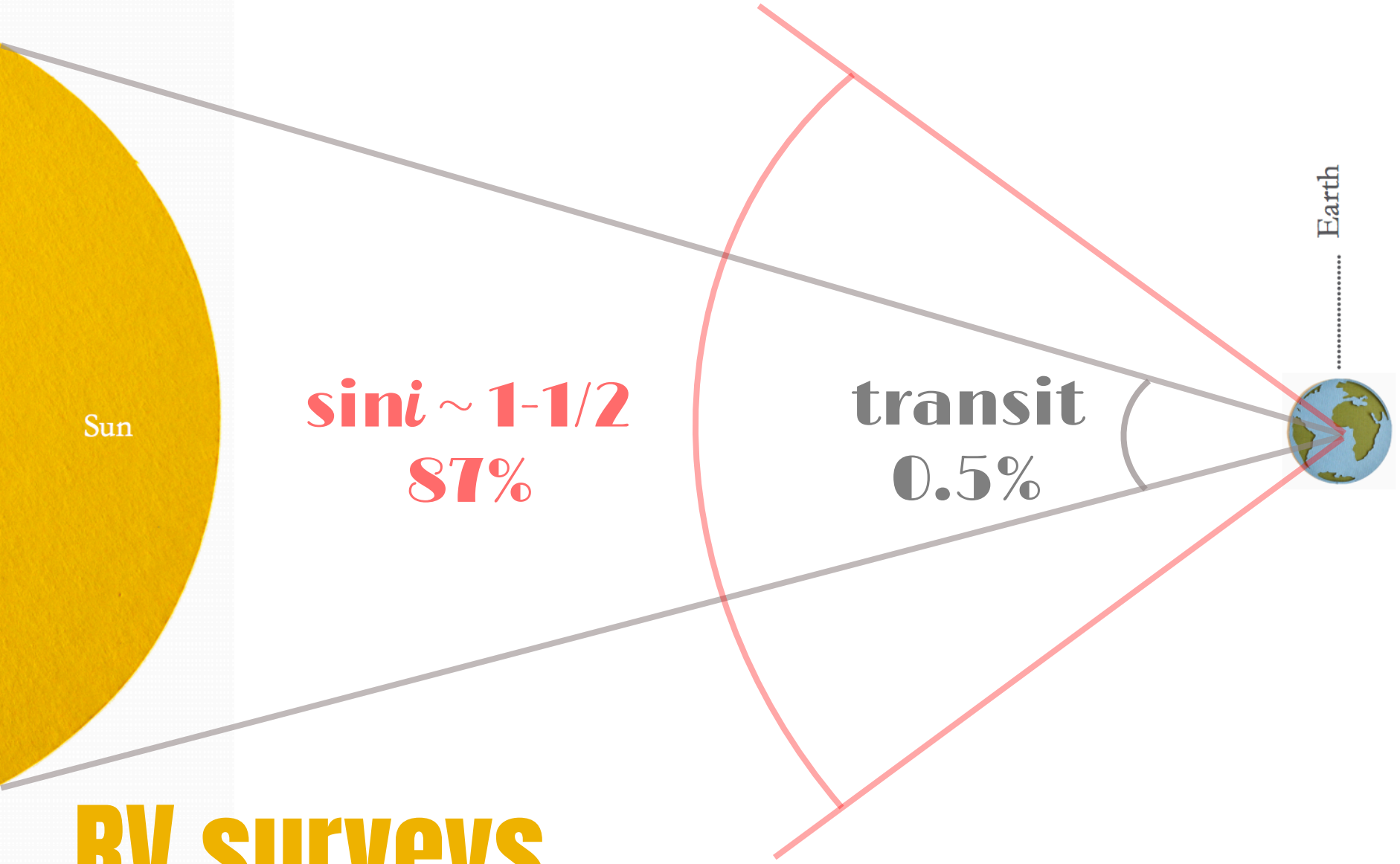
Sharon Xuesong Wang
Carnegie Fellow @ DTM

Measuring masses for transiting planets.



No RV detections for transiting HZ planets yet.





RV surveys

find & characterize the **nearest**

HZ planets, especially Earth analogs

Observational Needs for RV Surveys

Lots and lots of spectra

…and photometry

…and images

Observational Needs for RV Surveys

Target Selection	**Stellar Multiplicity**	Imaging
	Stellar Jitter+Activity Level	Photometry Spectroscopy
Survey Design	**Stellar Jitter+Activity Characteristics**	Photometry Spectroscopy
Data Interpretation	**Stellar Jitter+Activity Characteristics**	Photometry Astrometry Spectroscopy
	Stellar Parameters	

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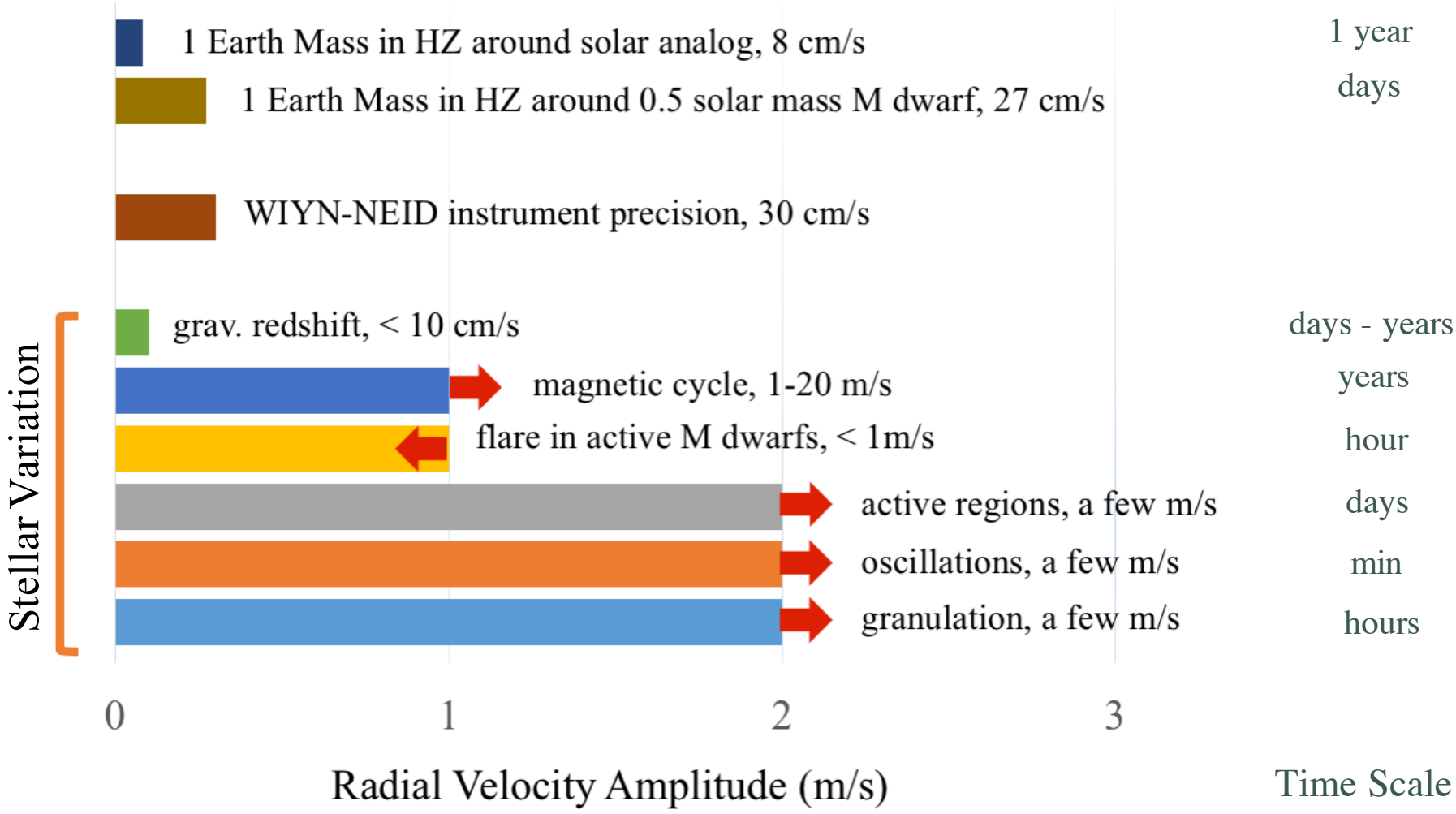
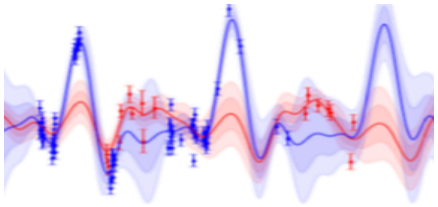
Stellar variation holds the tallest tent pole in RV error budget.



e.g., Lindegren & Dravins [18]; based on slide by Xavier Dumusque

Stellar Variation

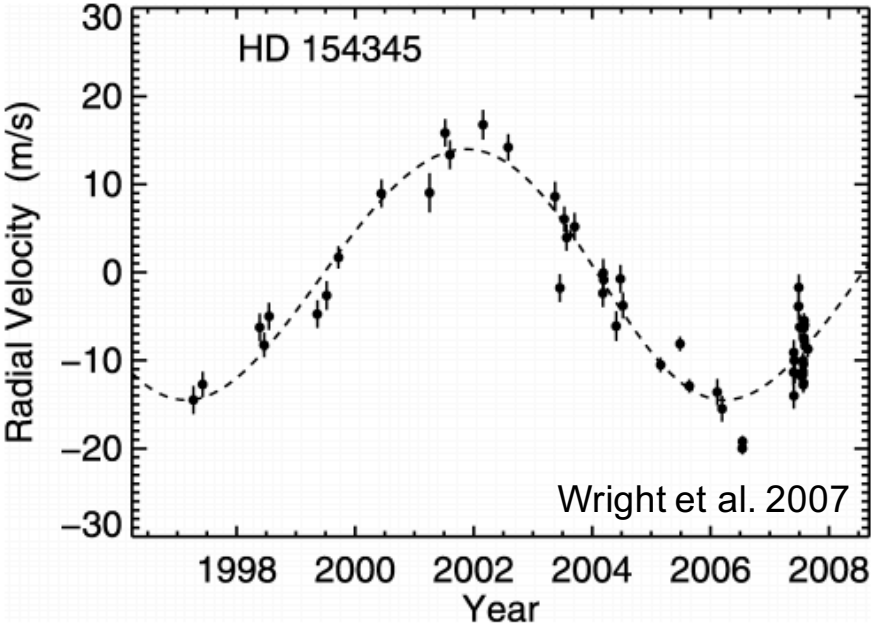


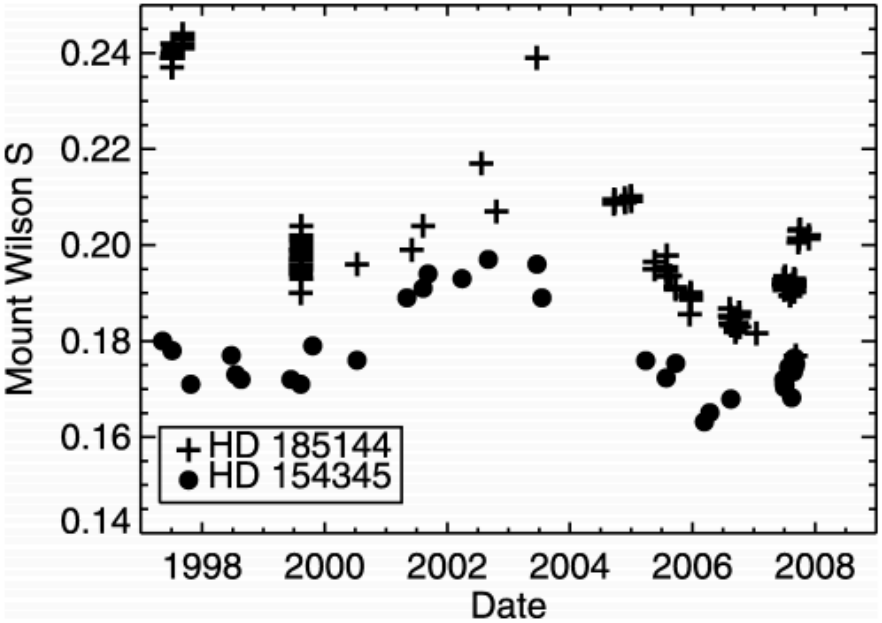
Overall Amplitude → Temporal Behavior

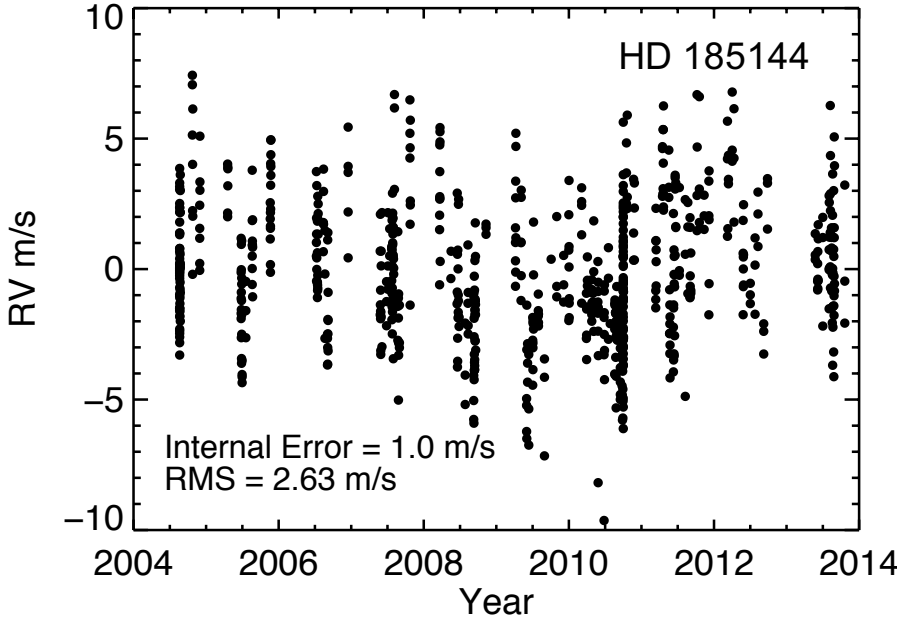
photometric variation
spectroscopic indicators
(single epoch)

e.g. Ca H&K, flicker (log g)

photometric variation
spectroscopic indicator variation



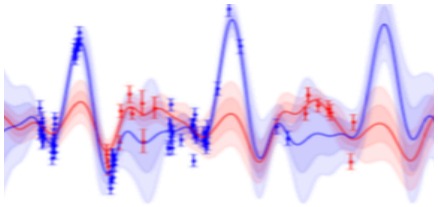




the extreme example: HD 154345

Wright 2016 arXiv:1603.08384

Stellar Variation



Overall Amplitude → Temporal Behavior

photometric variation
spectroscopic indicators
(single epoch)

e.g. Ca H&K, flicker (log g)

photometric variation
spectroscopic indicator variation

Goal

A grasp on the temporal behavior of stellar variations:
what they look like, and how to deal with them.

Stellar Activity

Activity-induced RV signals arise from the rotational modulation and intrinsic evolution of magnetized regions, and are thus naturally correlated in time, often quasi-periodic, and non-stationary.

Aigrain, Pont & Zucker, 2012

Ways to Mitigate Stellar Activity

- Correlate RVs with spectral activity indicators and remove

e.g. Saar et al 1998, Queloz et al. 2001

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- Photometry informed spot modeling, FF', GP, or a combination

e.g. Haywood et al. 2014

Improve
Ways to Mitigate Stellar Activity

- Correlate RVs with spectral activity indicators and remove

e.g. Saar et al 1998, Queloz et al. 2001

Find better spectral indicators (e.g. Robertson et al. 2016);
Use better techniques (e.g. Rajpaul et al. 2015a).

- "Model out" rotation period and harmonics

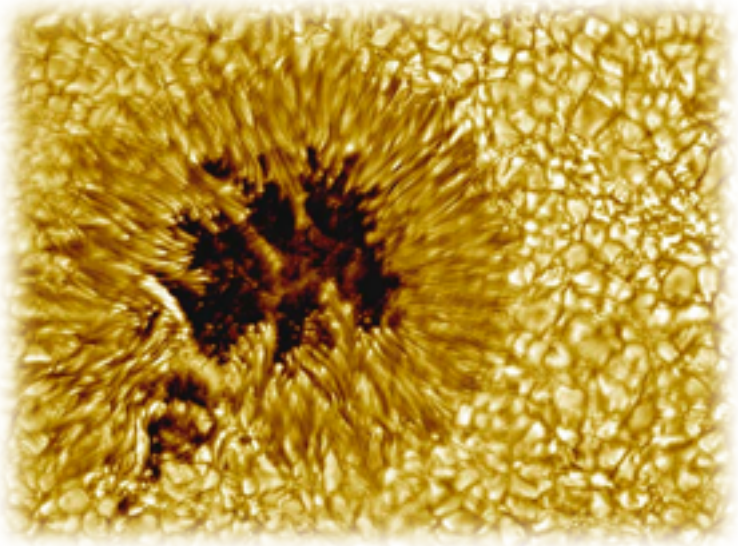
e.g. Boisse et al. 2011

Use better techniques (e.g. Gregory 2016 as in Dumusque et al. 2017).

- Photometry informed spot modeling, FF', GP, or a combination

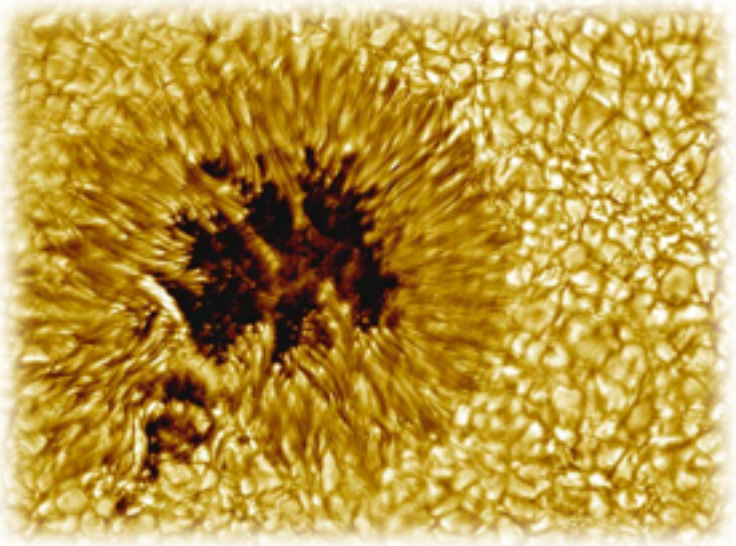
e.g. Haywood et al. 2014

Can we get rid of photometry and make more efficient use of the data?



photometric variation

RV variation

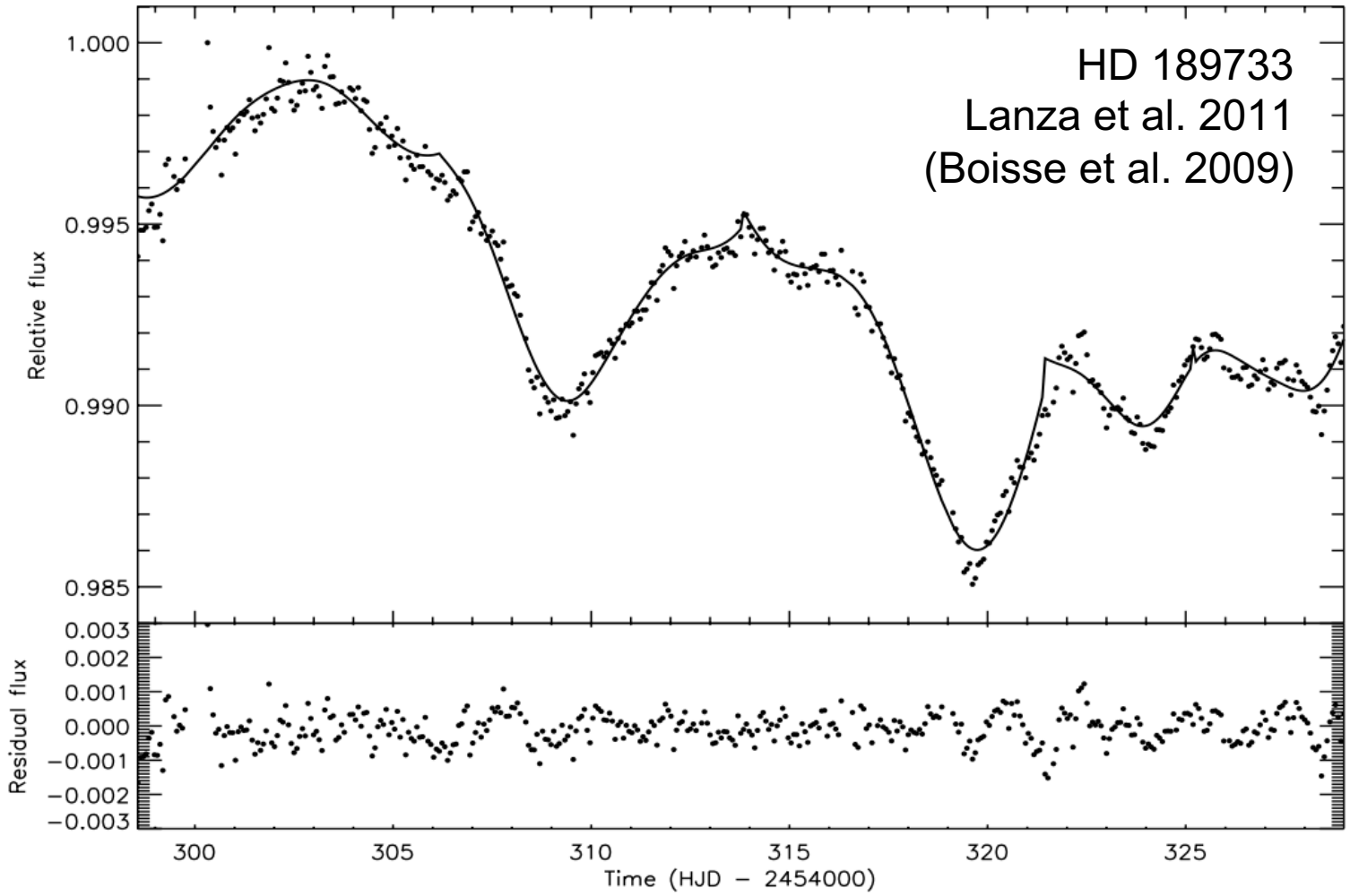


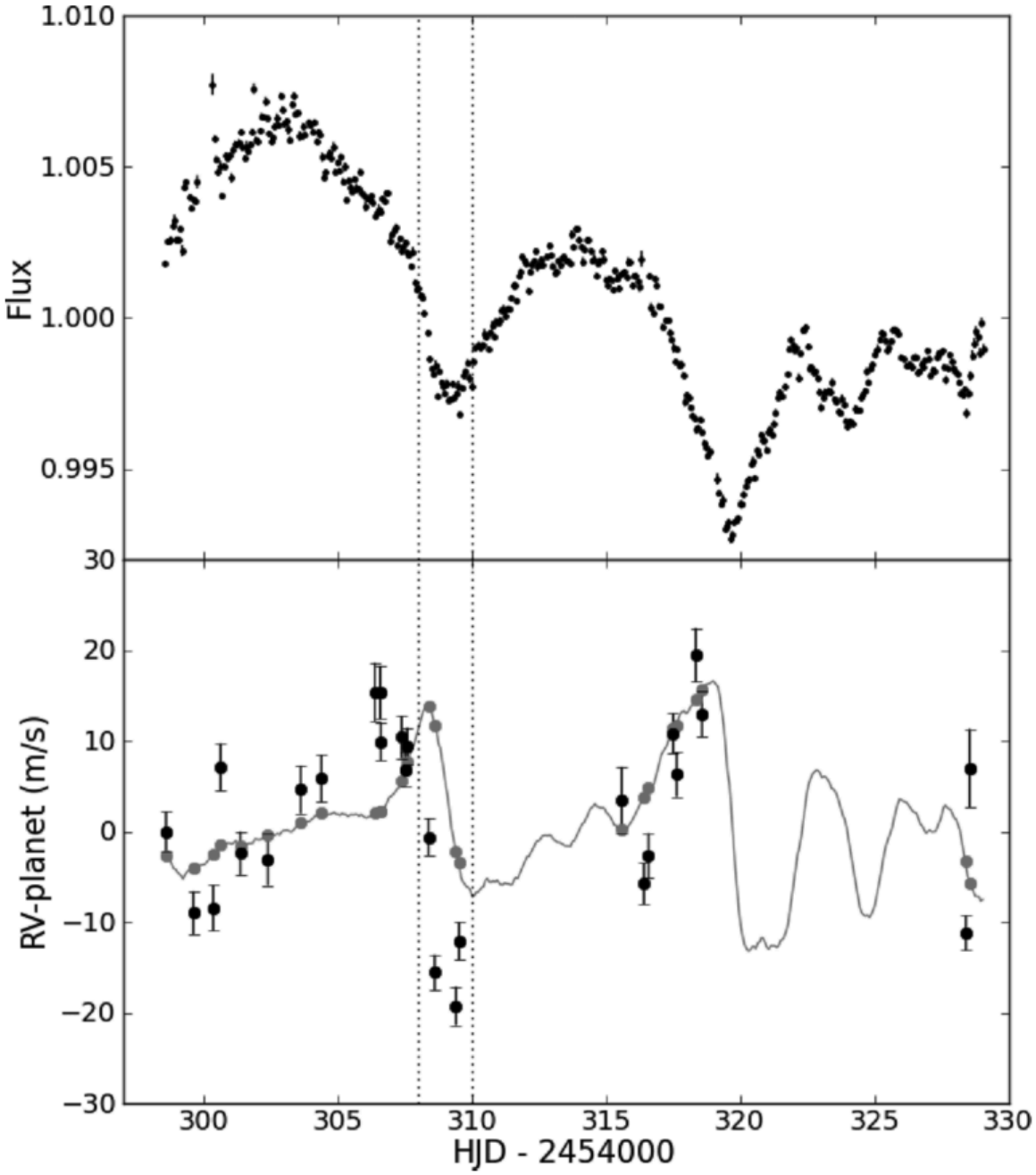
photometric variation

RV variation

- ✓ time scale
- ✓ amplitude

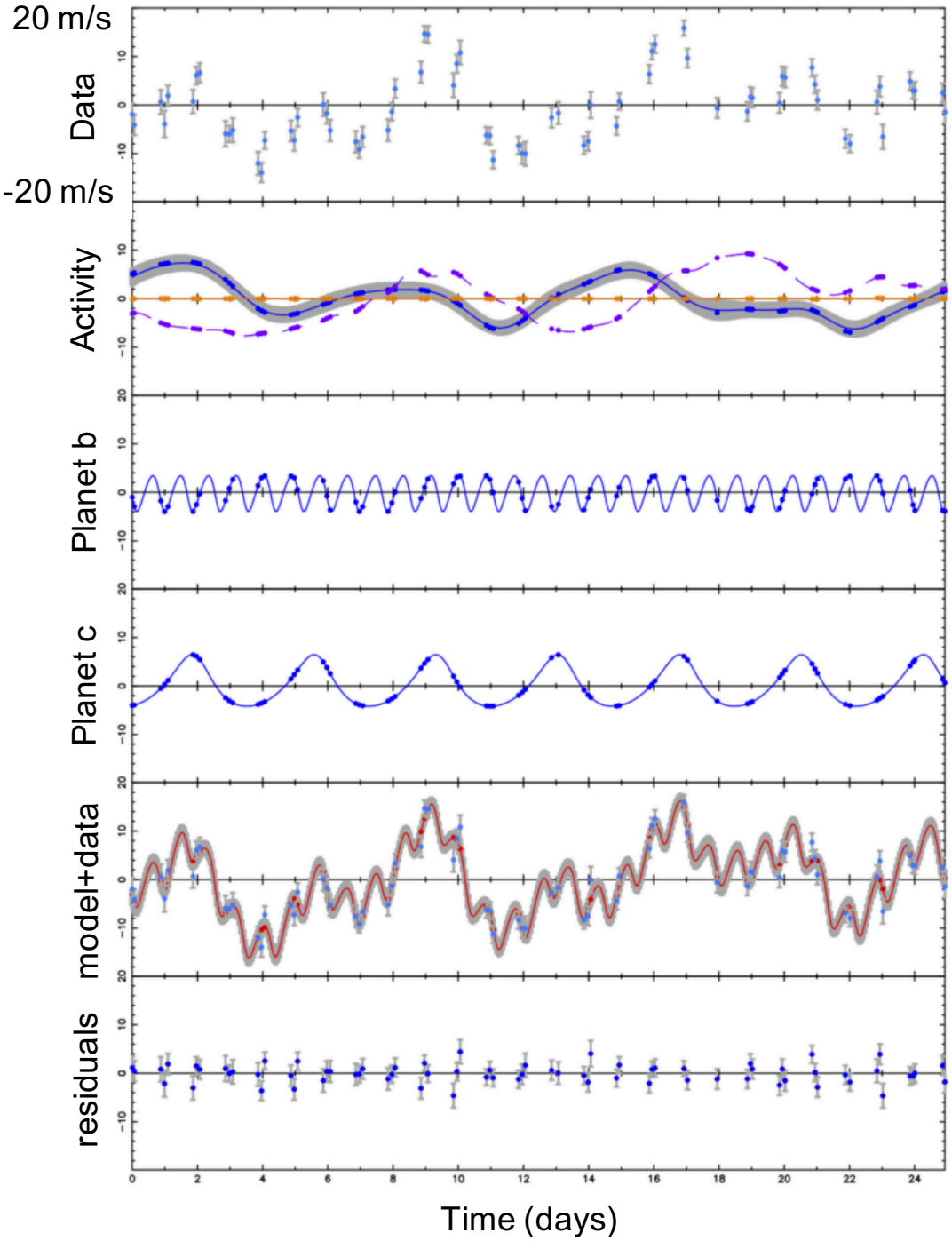
Simultaneous MOST photometry + spot modeling





FF' method

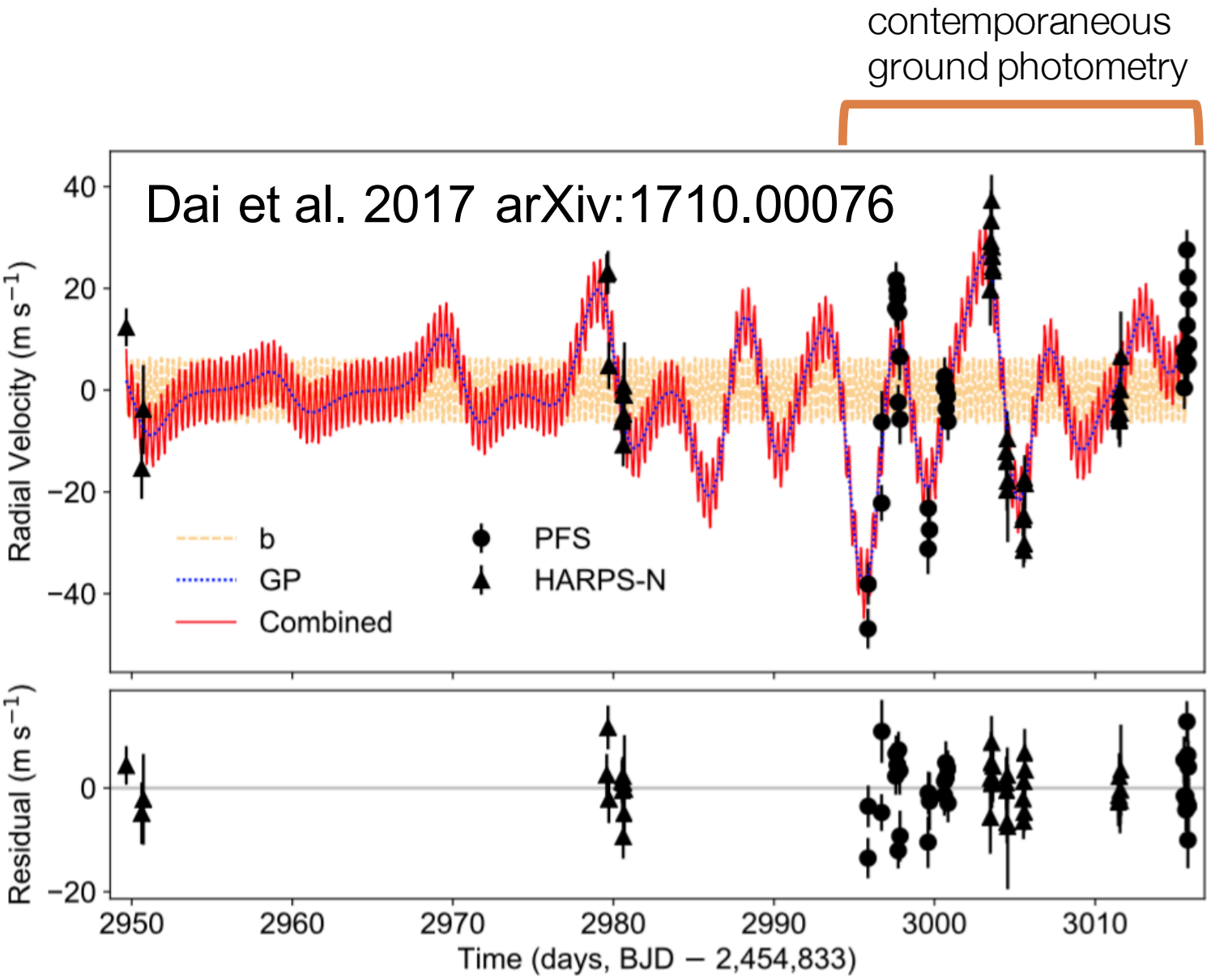
HD 189733
Aigrain, Pont & Zucker 2012



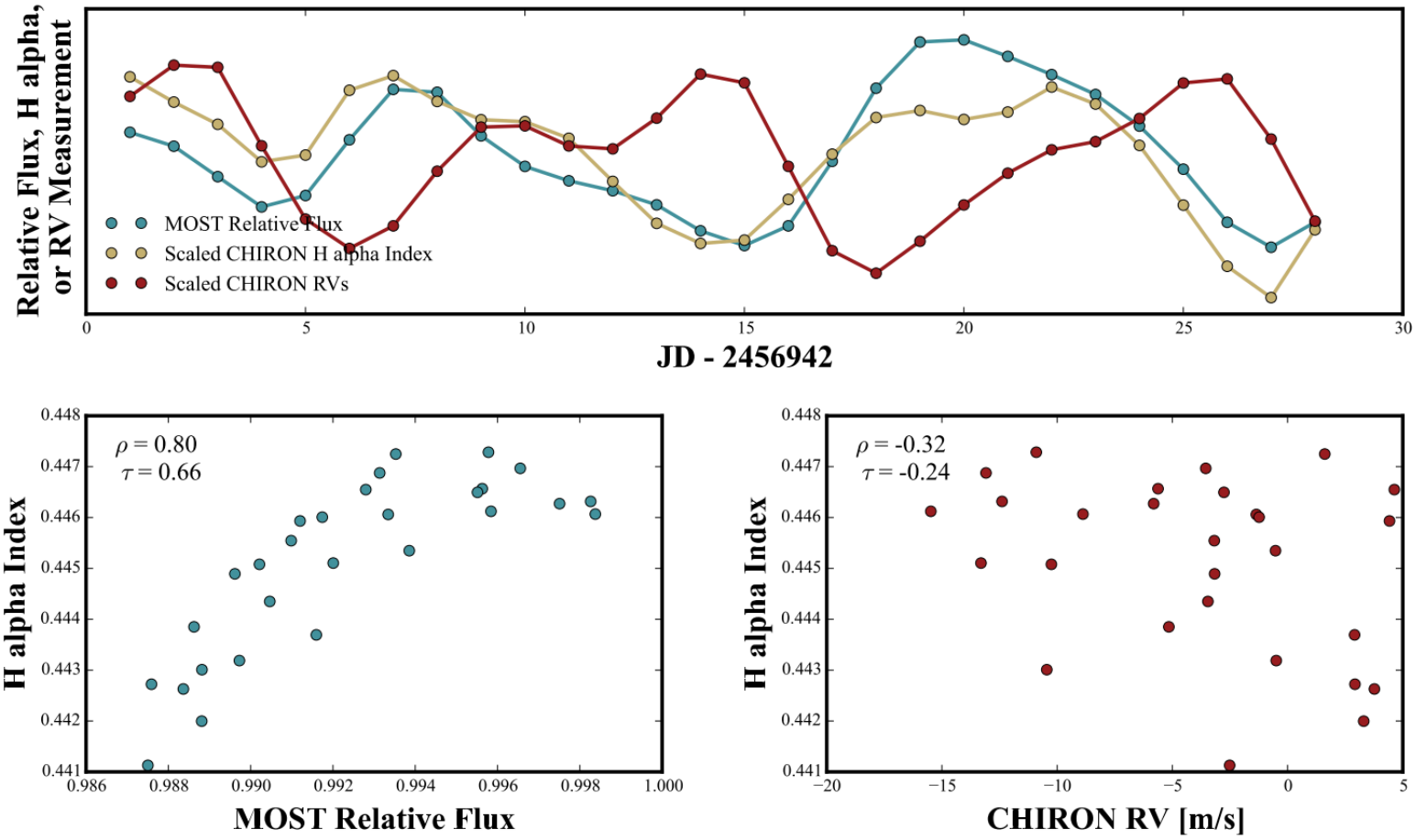
CoRoT photometry informs Gaussian Process

CoRoT-7
Haywood et al. 2014

An ultra short period sub-Neptune discovered by K2

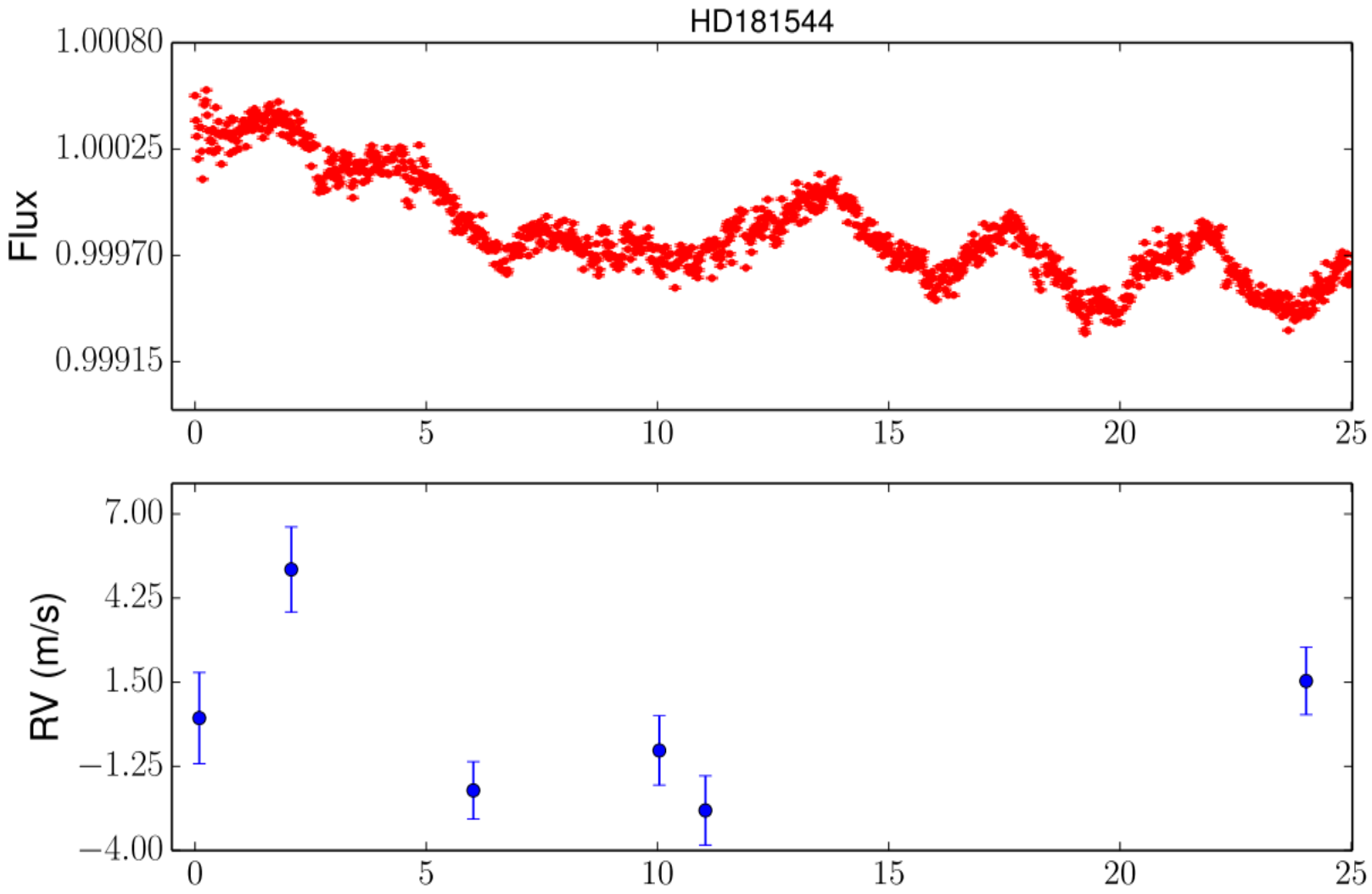


Simultaneous photometry can help identify spectroscopic indicators.



Epsilon Eridani
Giguere et al. 2016

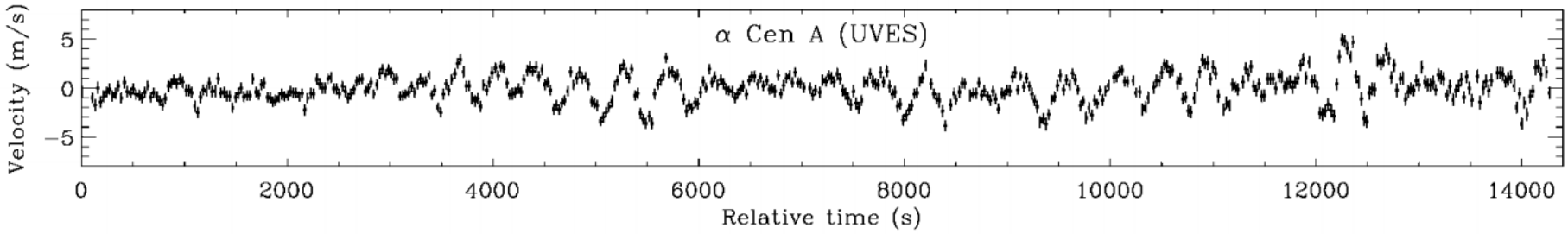
Simultaneous HARPS RVs with K2 Campaign 7 & 8



Oshagh et al. 2017

But what about stellar jitter?

Stellar oscillation is a significant source of jitter.



Butler et al. 2004

Averaging strategy: Dumusque et al. 2011

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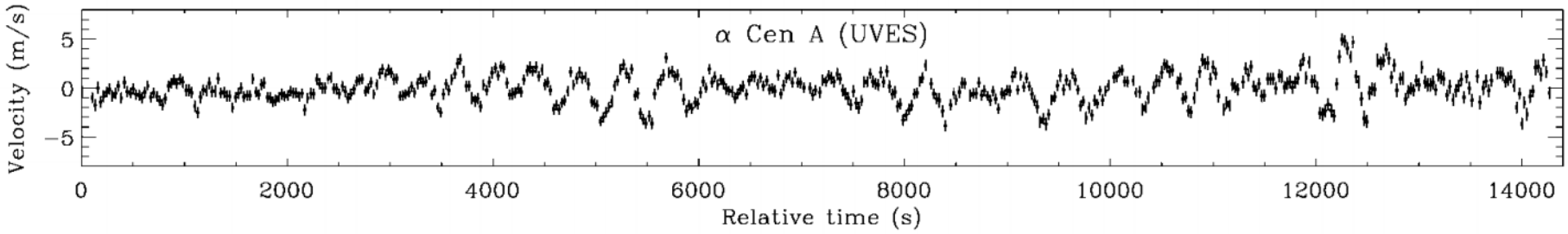

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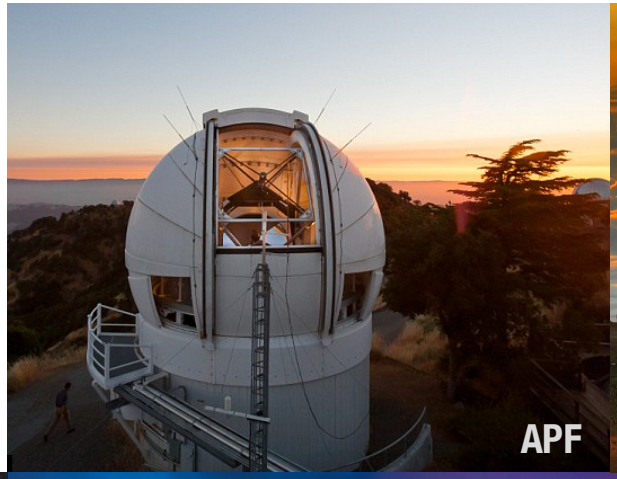
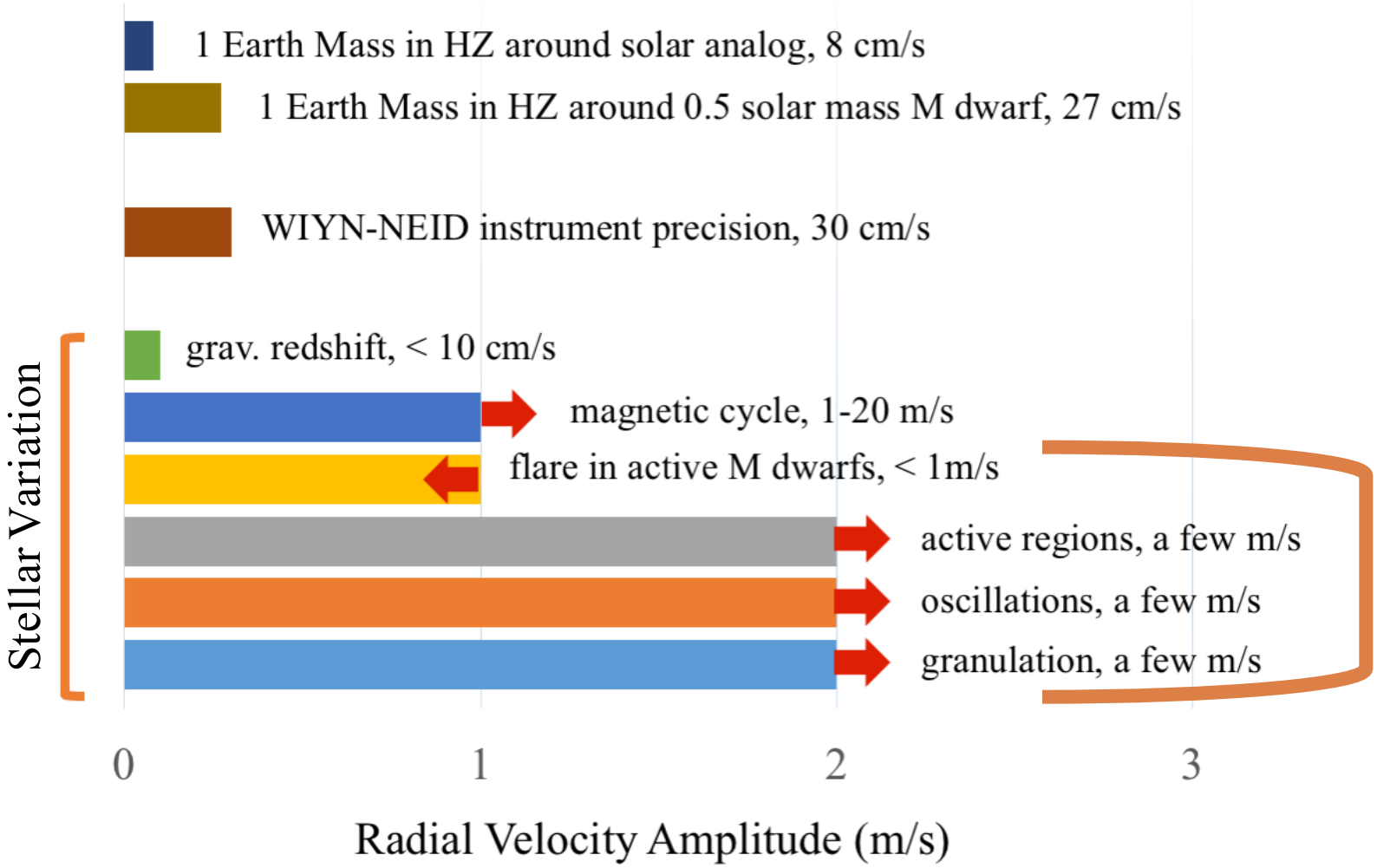
But what about granulation?



study **stellar jitter & activity**
with **simultaneous**
precise RV and Kepler/K2 light curve

RV × K2

RV × K2



e.g., Lindegren & Dravins [18]; based on slide by Xavier Dumusque

C16: Dec 7, 2017 – Feb 25, 2018

K2 1-min Cadence

HD 76445	7.6	G5 IV
HIP 44072	9.3	M0 V
HD 76780	7.6	G5 V
HD 75784	7.9	K3 IV
HD 73534	8.2	G5 IV

K2 30-min Cadence

HIP 43418	9.3	K0 V
HIP 42783	10.1	K7 V

RV × K2

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simultaneous
RV+photometry
asteroseismology

RV × K2

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simultaneous
RV+photometry
asteroseismology

granulation signal

$A_{vel} \propto L$

Kjeldson & Bedding 2011

RV × K2

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Solar Analog

- **asteroseismology**
- **(super)-granulation?**

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RV × K2

C16: Dec 7, 2017 – Feb 25, 2018

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M and K dwarf activity on short time scales and over 80 days

RV × K2

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K2 30-min Cadence

HIP 43418	9.3	K0 V
HIP 42783	10.1	K7 V

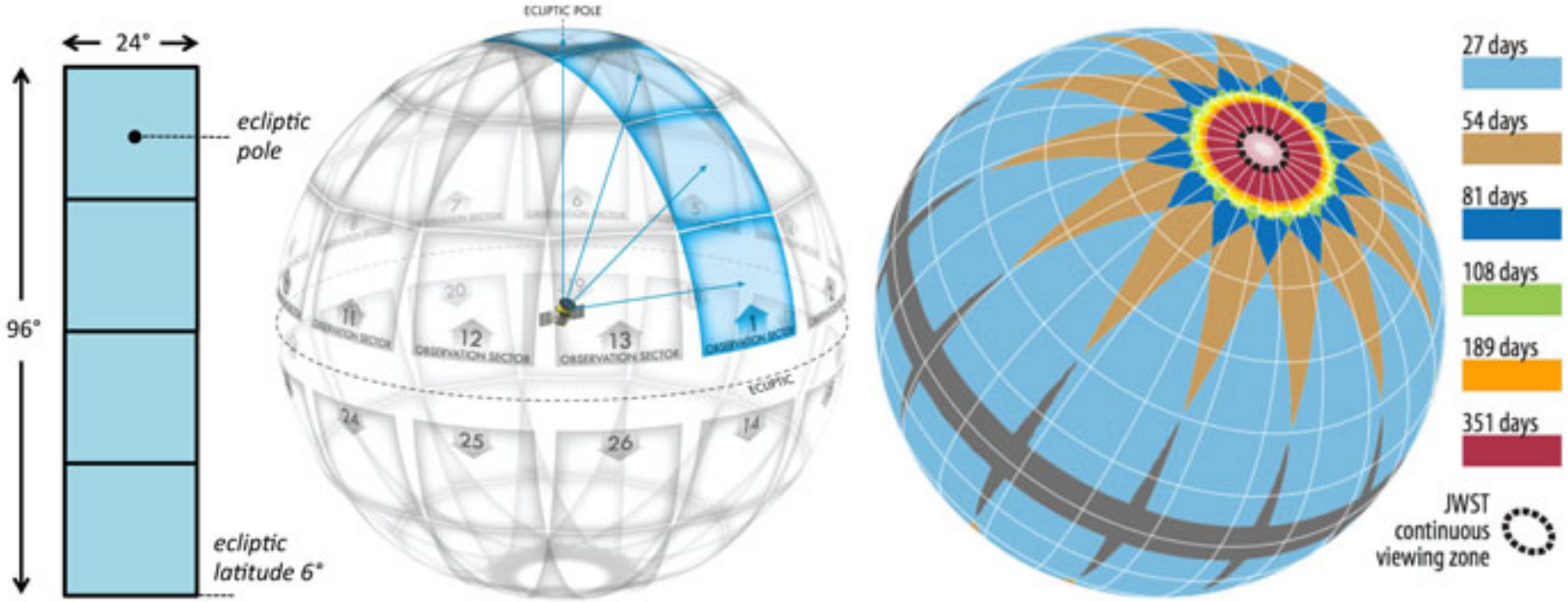
Keck/HIRES
minute - hours

APF + IRTF/iSHELL
M/K dwarfs
~nightly in Dec. – Jan.

SONG, MINERVA, PARAS
~nightly on others

RV × K2

A Trial Run for simultaneous RVs in the TESS era



Thank you & let's Collaborate!

RV×K2.com

Team Members: Jason Wright, John Johnson, Fabienne Bastien, Heather Cegla, Jacob Luhn, Jennifer Burt, Elisabeth Newton, Jason Eastman, Johanna Teske, Peter Plavchan, Andrew Vanderburg, Courtney Dressing, Paul Robertson, Abhijit Chakraborty, Frank Grundahl, Brad Holden, Howard Isaacson, Andrew Howard, and Paul Butler

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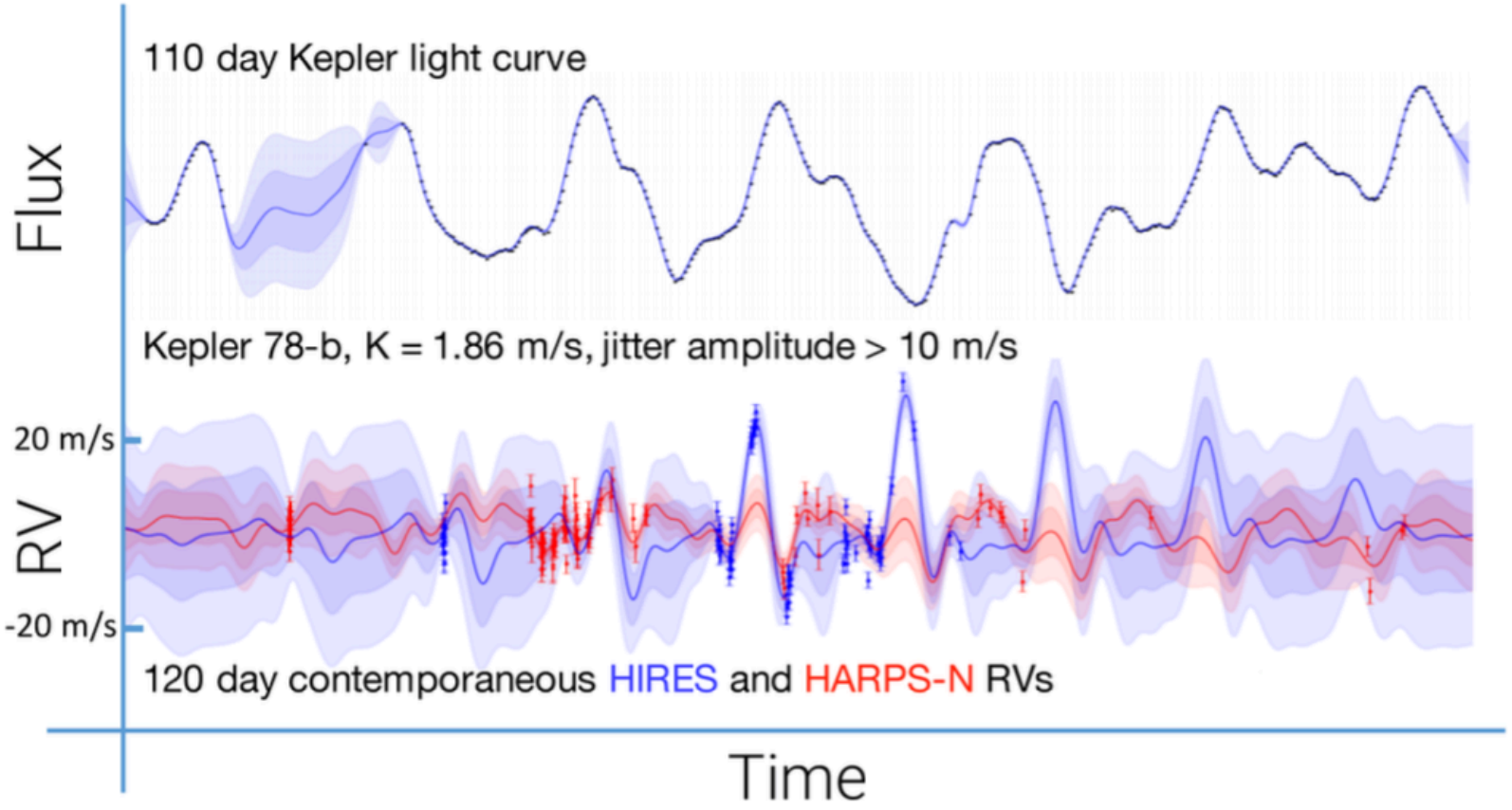
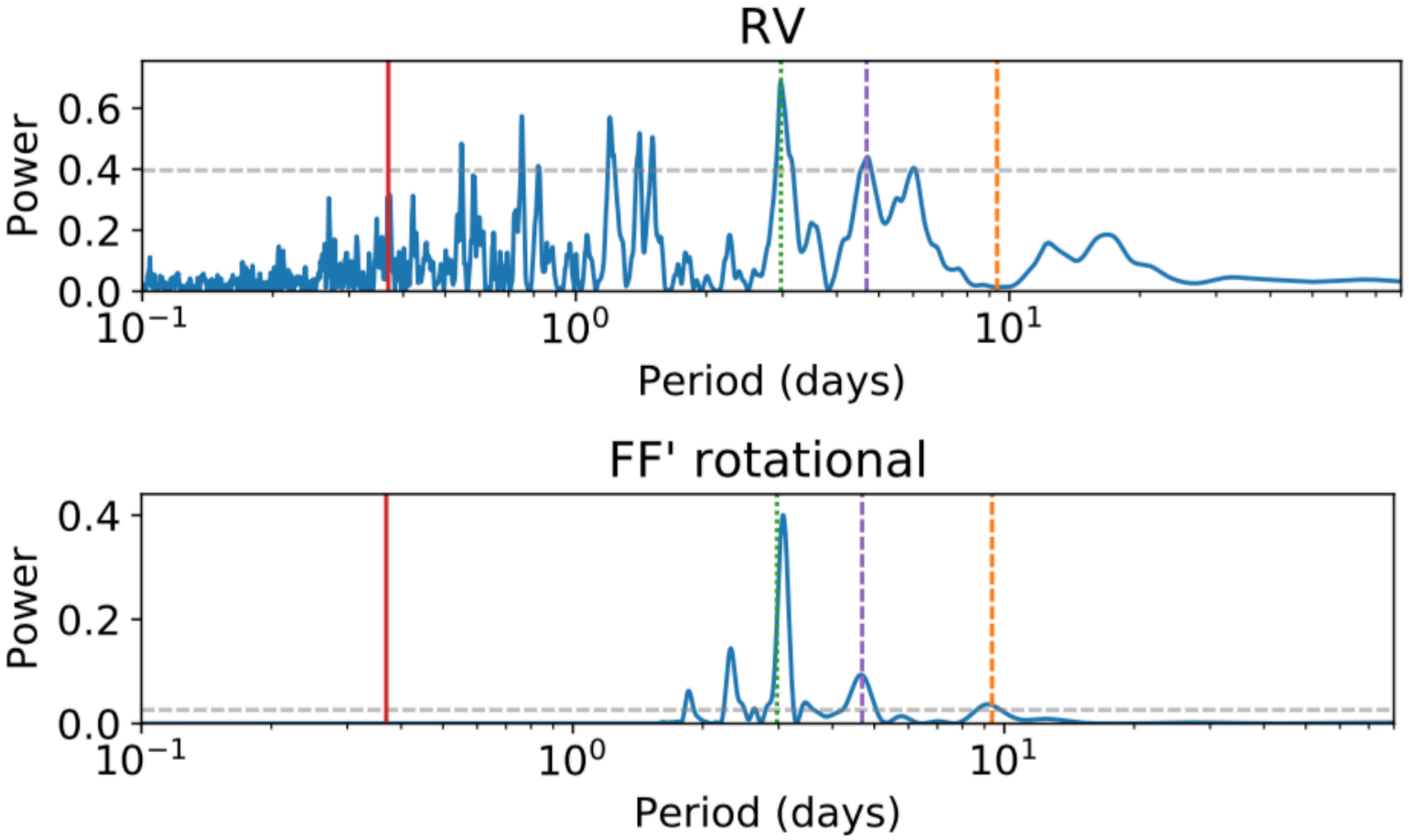
RV × K2

Use photometry to inform GP fit to RVs.

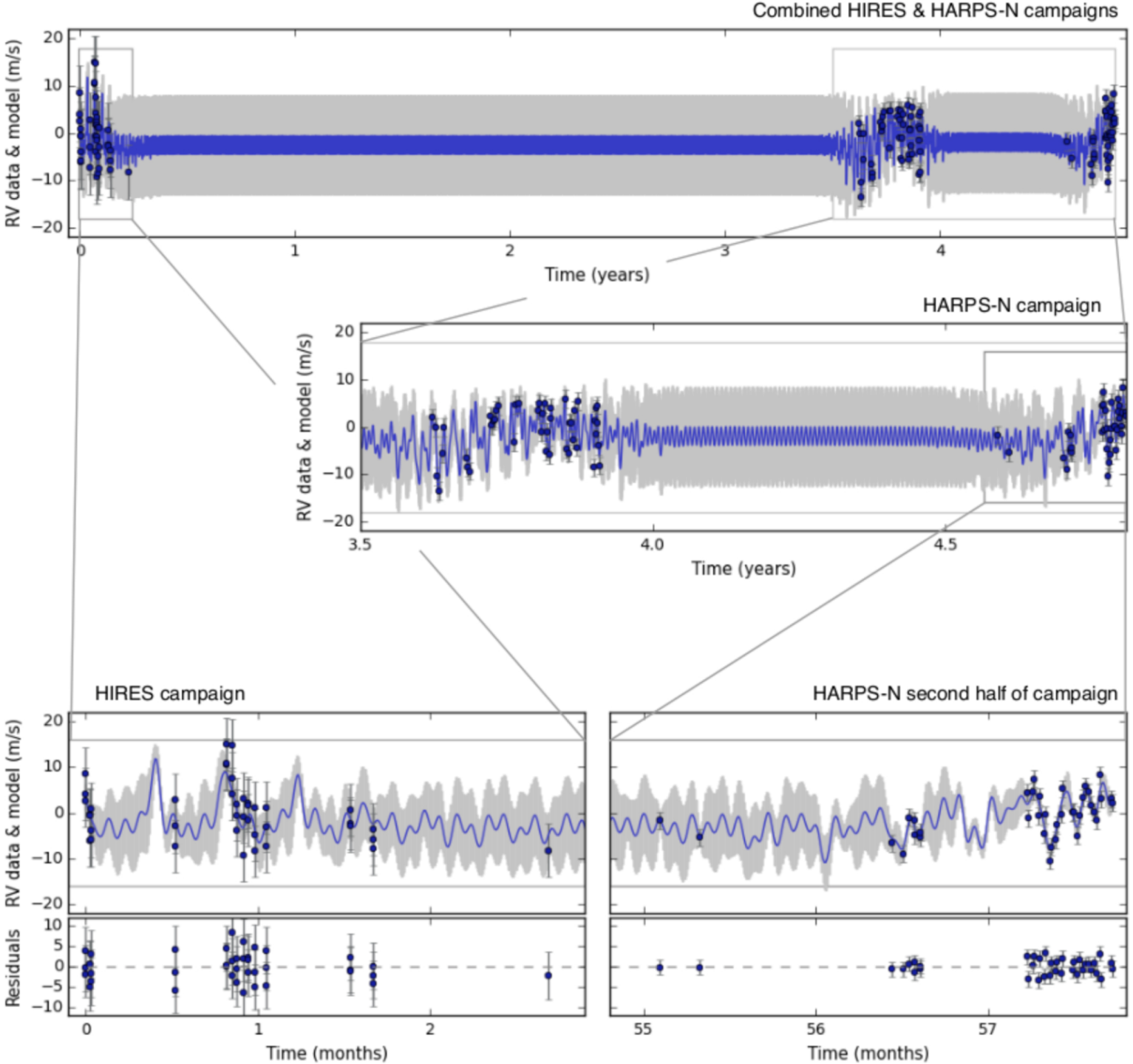


Grunblatt et al. 2015

The most prominent RV signal is a rotation harmonic, which did not show up in any spectroscopic indicators.



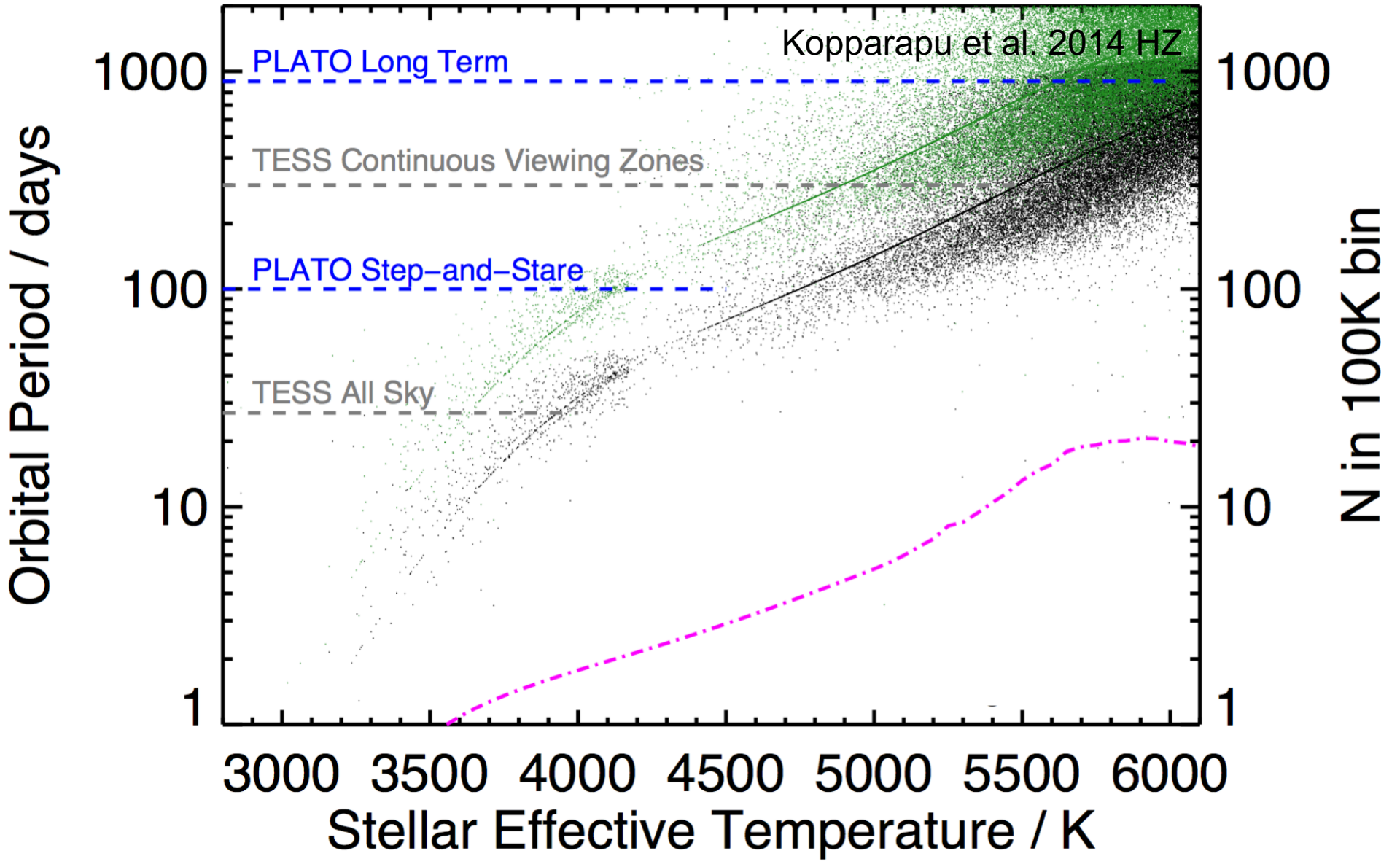
Dai et al. 2017 arXiv:1710.00076



Kepler 21-b

López-Morales et al. 2016

Find the Nearest HZ Planets.



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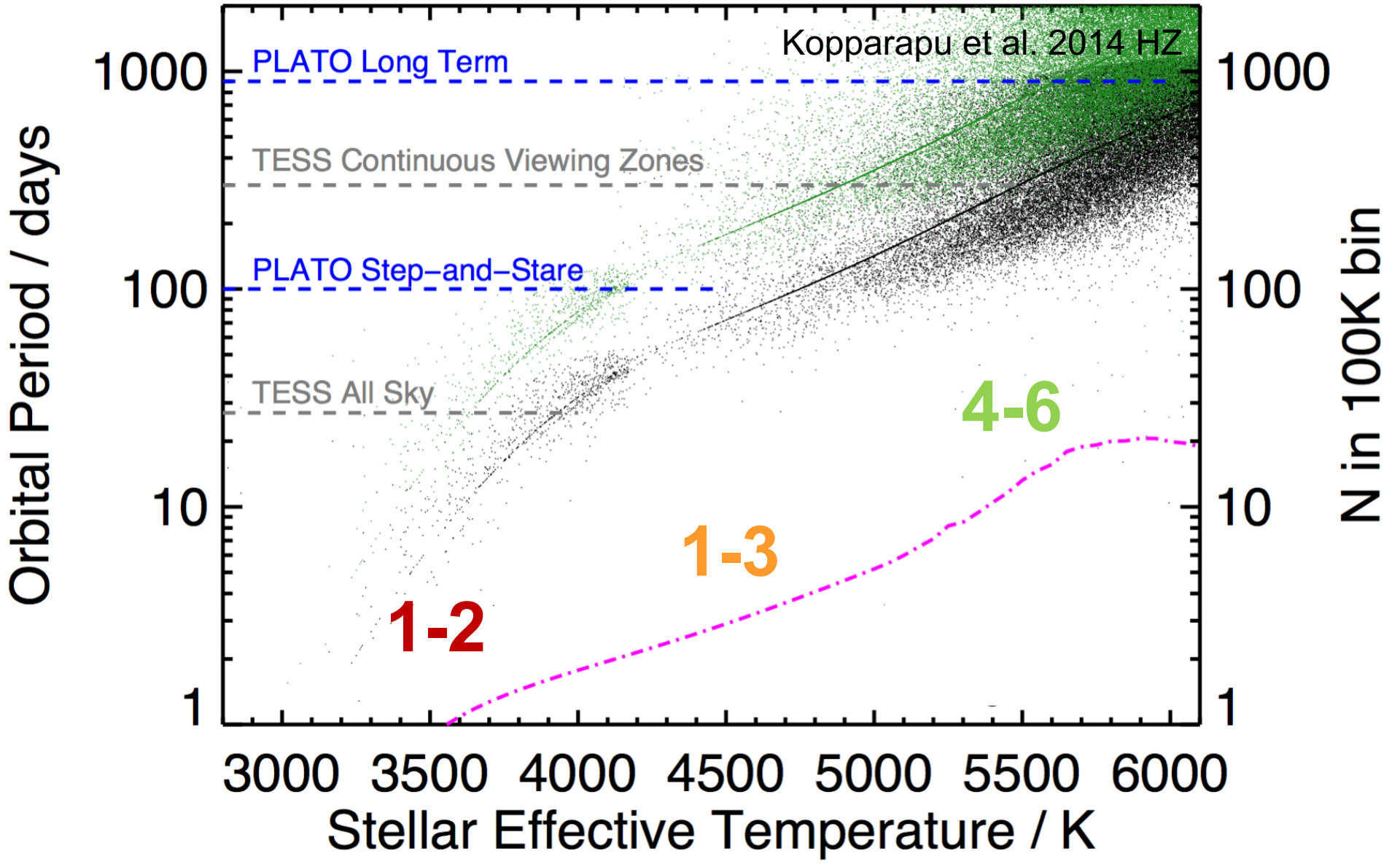

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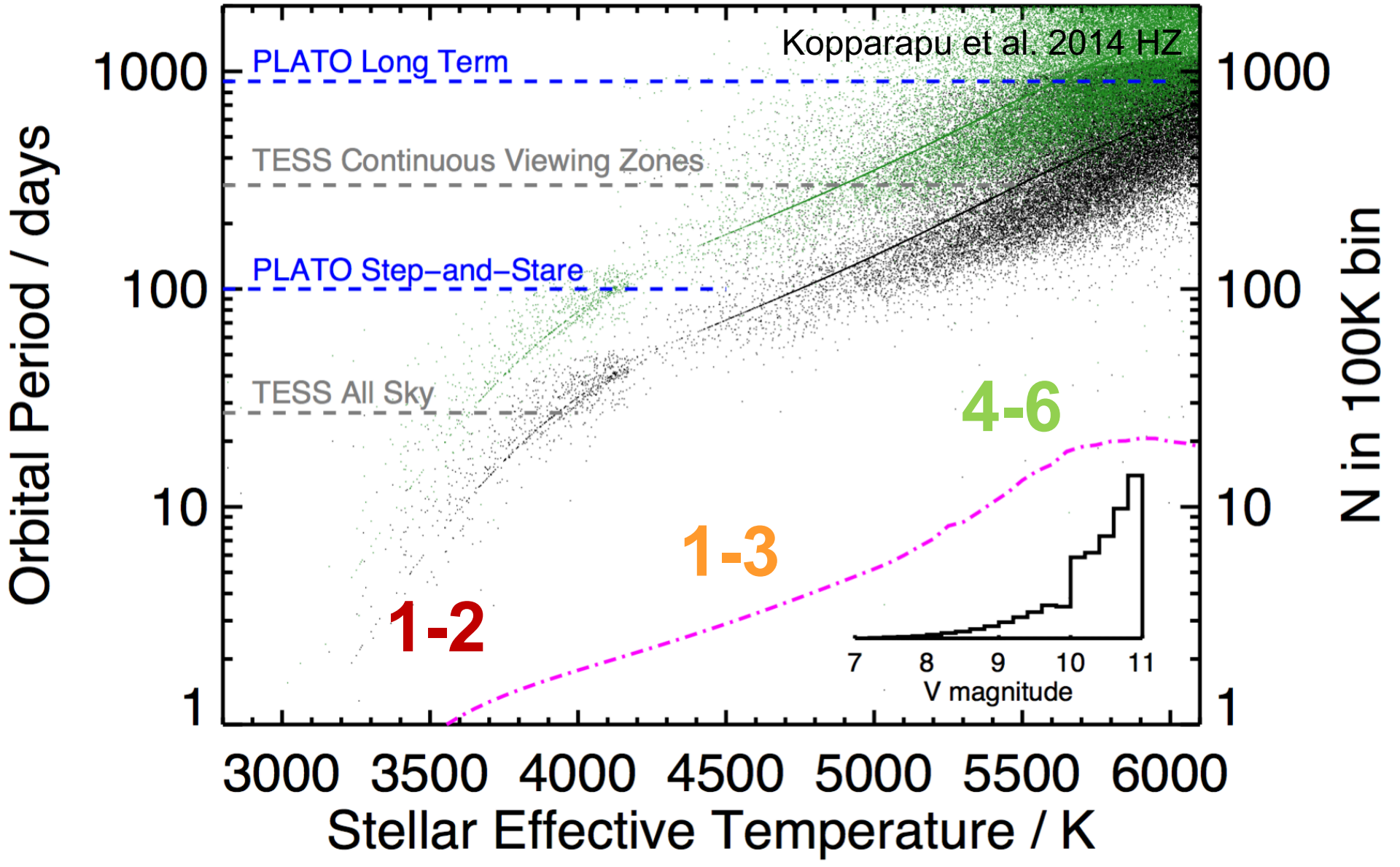
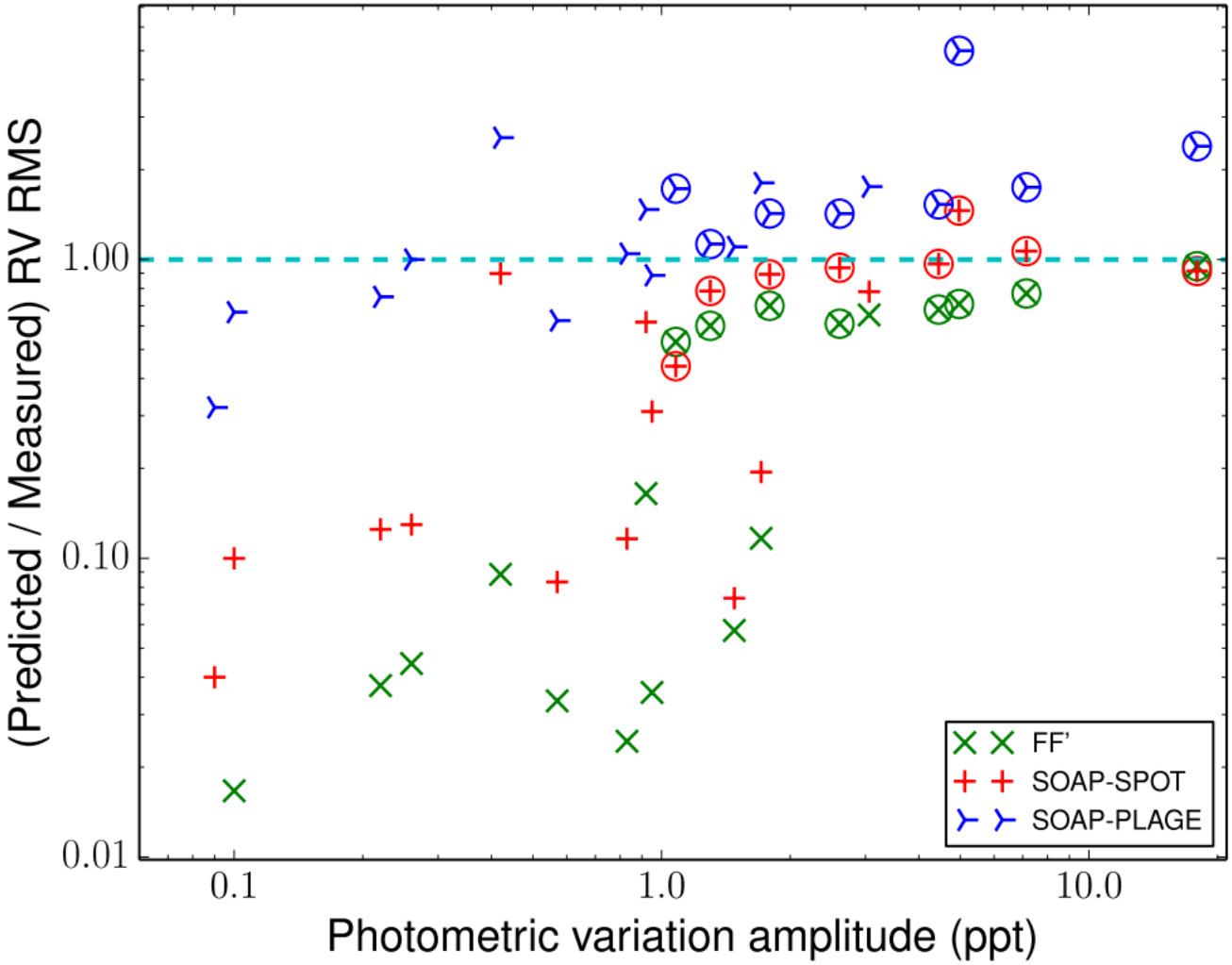
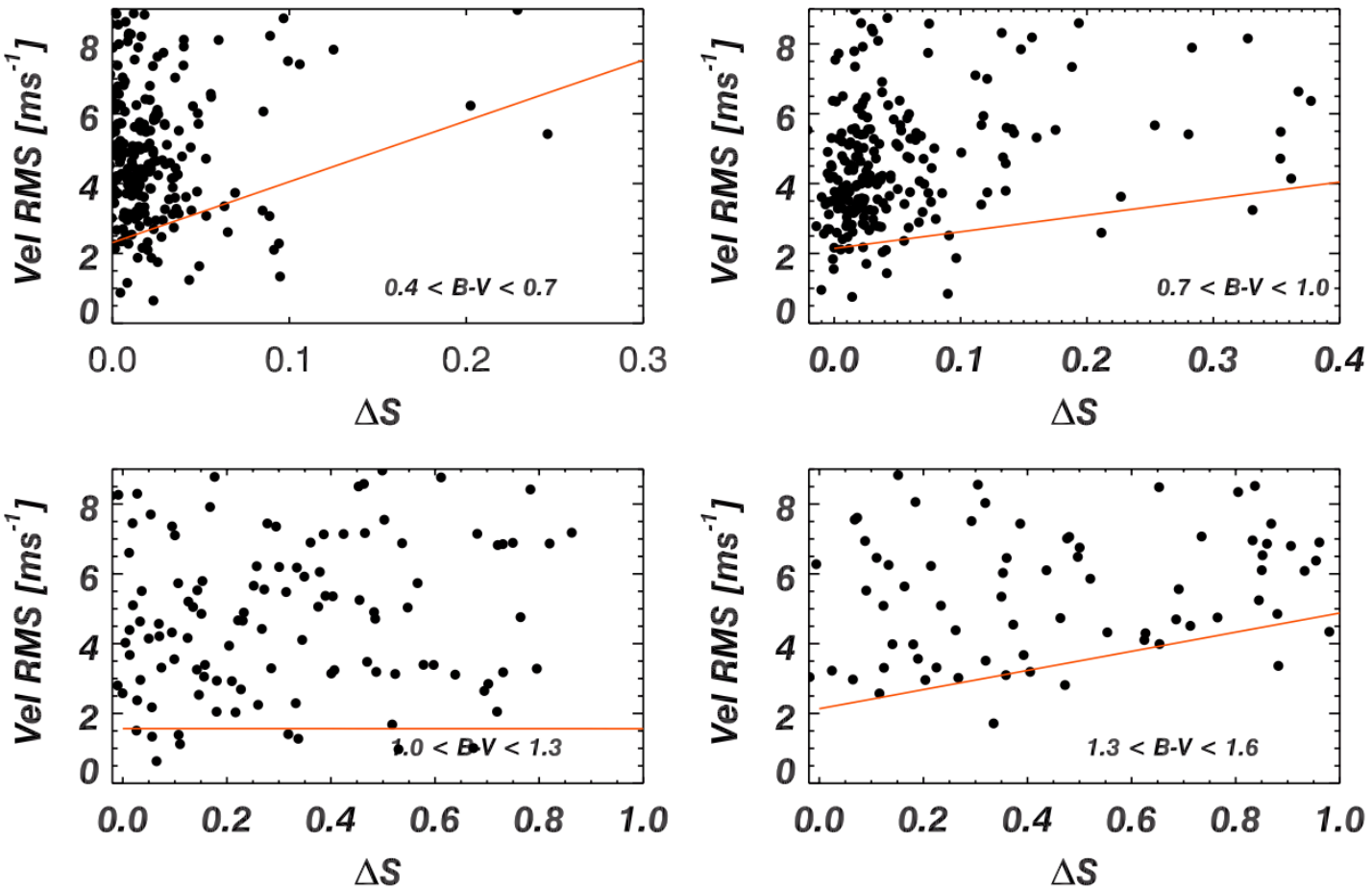


Simultaneous HARPS RVs with K2 Campaign 7 & 8



Oshagh et al. 2017

Ca H&K measurements have limited power in predicting stellar activity level.



Isaacson & Fischer 2010
also: Wright et al. 2004, Lovis 2011