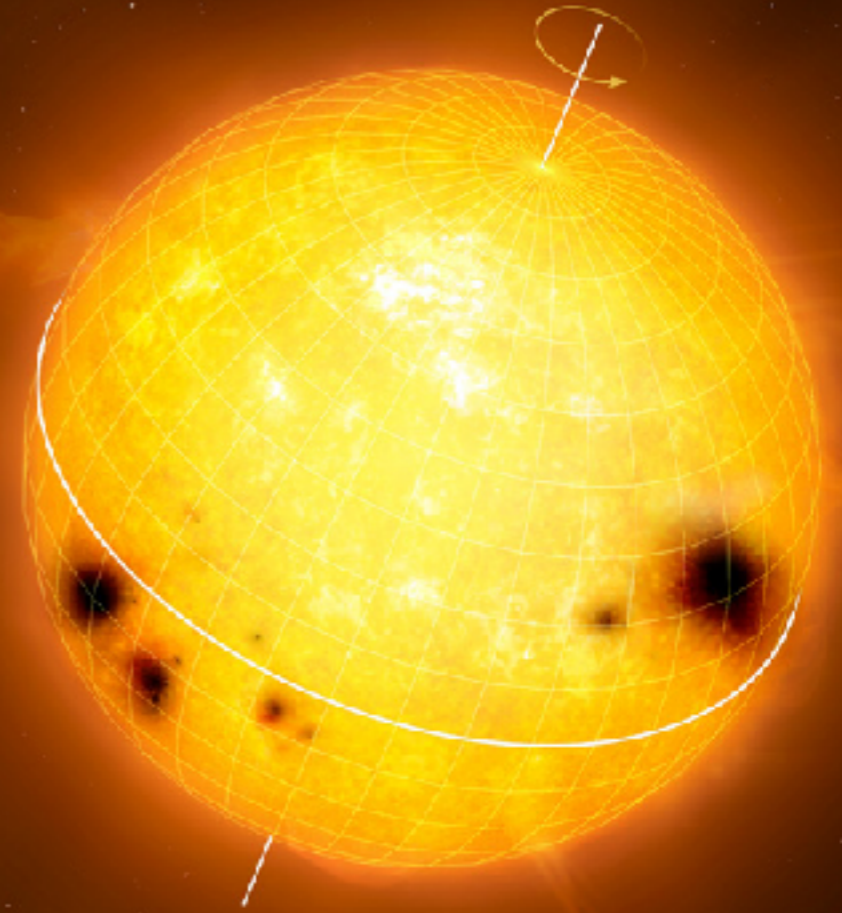
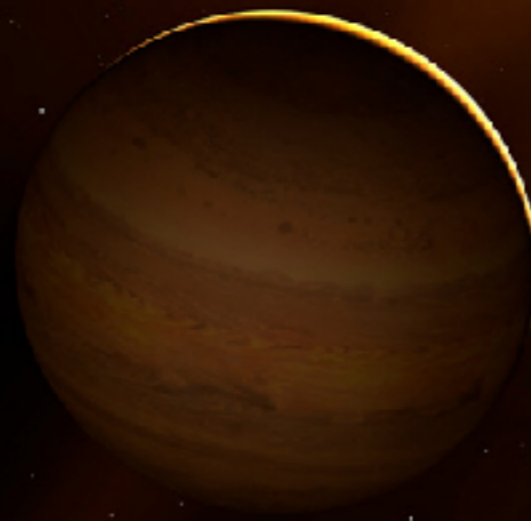


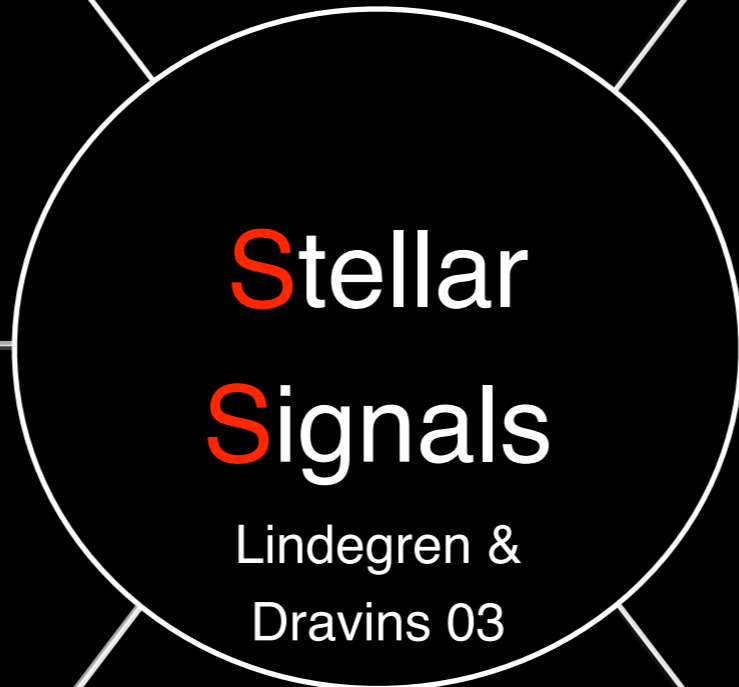
Line by line radial velocities to mitigate stellar activity



Xavier Dumusque
Branco-Weiss fellow



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DE GENÈVE



~ 1 h

Flares

<1 m/s (only active M)

Saar 09, Reiners 09

15 min - 2 d

Granulation

a few m/s (Dumusque+ 11)

Del-Moro+ 04, Del-Moro 04
Cegla+ 12, Cegla+ 14

< 15 min

Oscillations

a few m/s (Dumusque+ 11)

Kjeldsen+ 95, Bouchy & Carrier 01,
Butler+ 04, Bedding & Kjeldsen 07

Stellar Signals

Lindgren &
Dravins 03

Active regions

a few m/s (Meunier+ 10)

Saar & Donahue 97, Queloz+ 01
Hatzes 02, Meunier+ 10,
Boisse+ 11, Dumusque+ 11,
Lanza+ 11, Aigrain+12,
Boisse+ 12, Dumusque+ 14
Meunier+ 17

10 - 50 d

Magnetic Cycles

1-20 m/s (Lovis+ 11)

Makarov 10, Dumusque+ 11
Dumusque+ 12, Meunier+ 13

Gravitational Redshift

< 10 cm/s (Cegla+12)

10 d - 10 yrs

~ 10 yrs

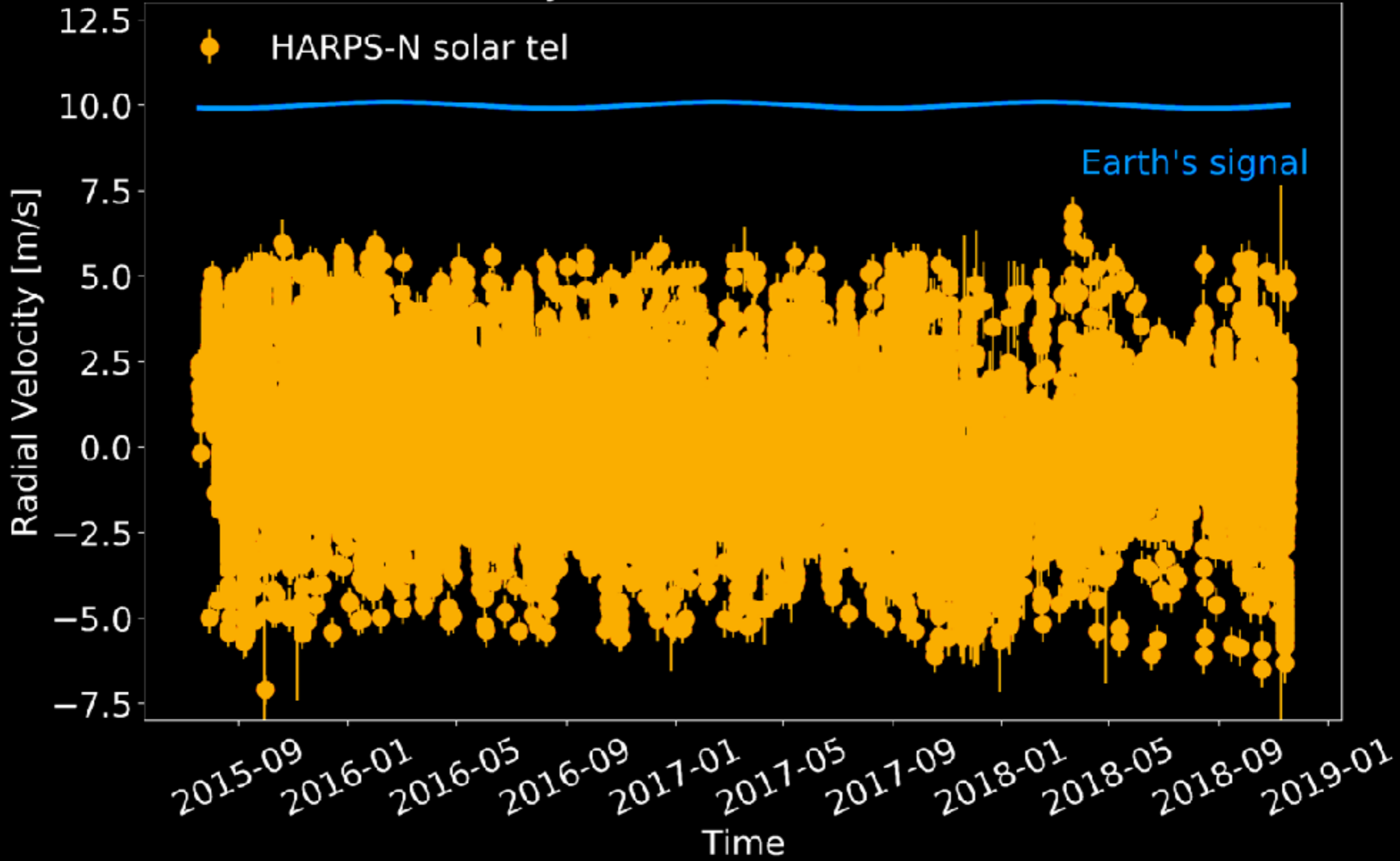
HARPS-N

PIs: D. Phillips, X. Dumusque



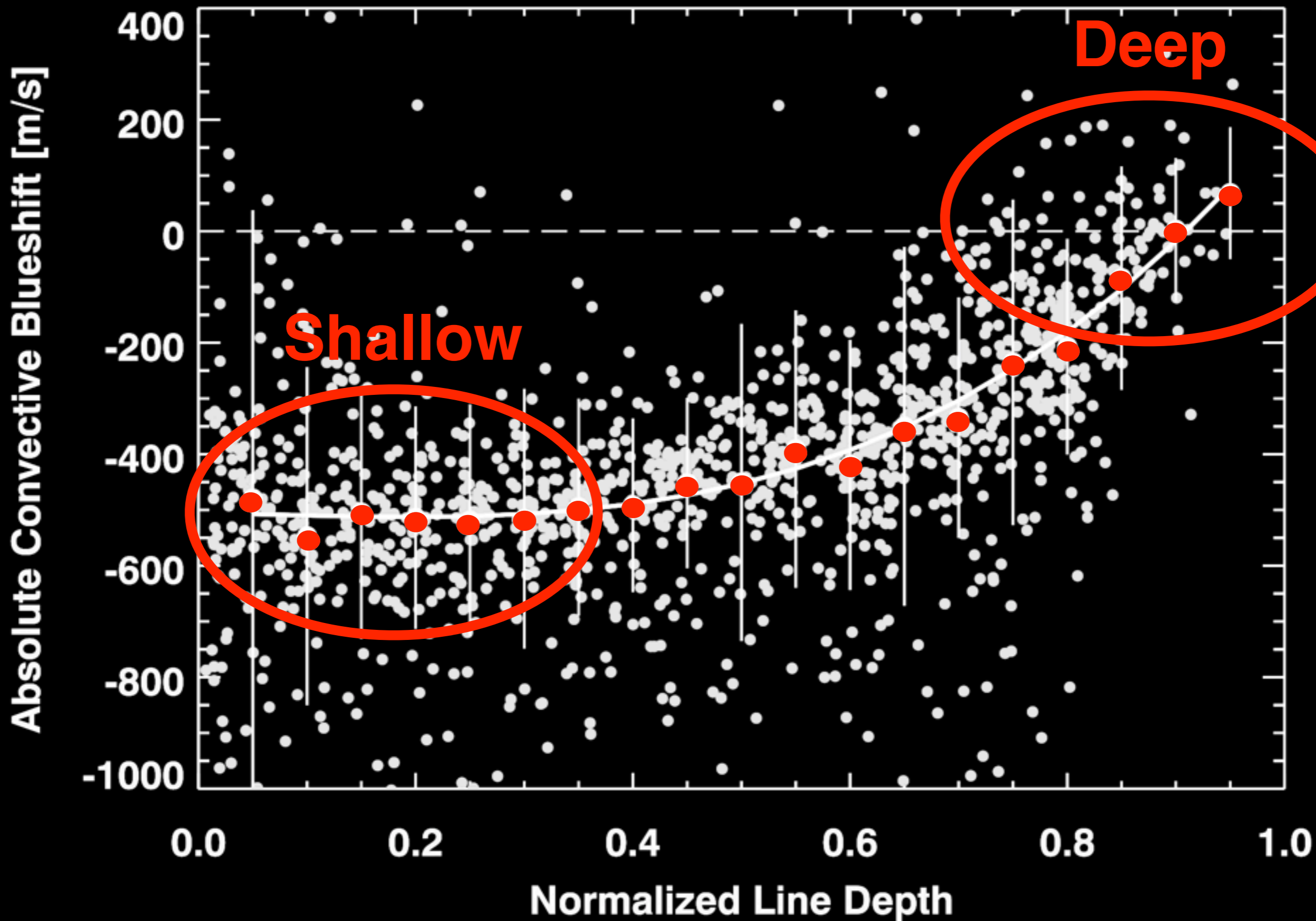
Credits: A. Glenday

Radial Velocity of the Sun as a function of time

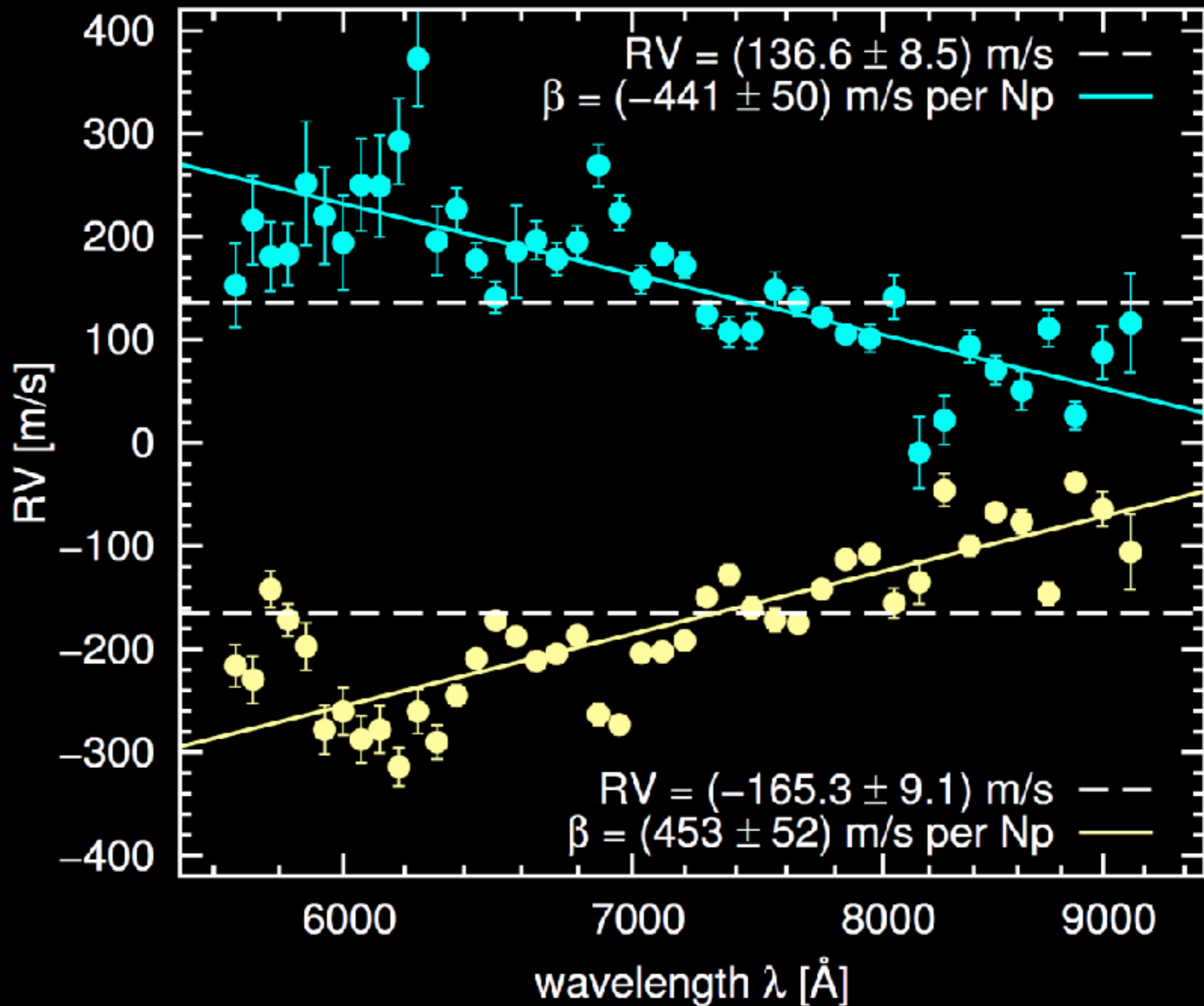


The **RV effect** induced by **stellar activity** of solar-type stars is driven by the **inhibition of convection** in active regions

Convective blueshift



The **RV effect** induced by **stellar activity** of solar-type stars is also driven by contrast of **active regions**

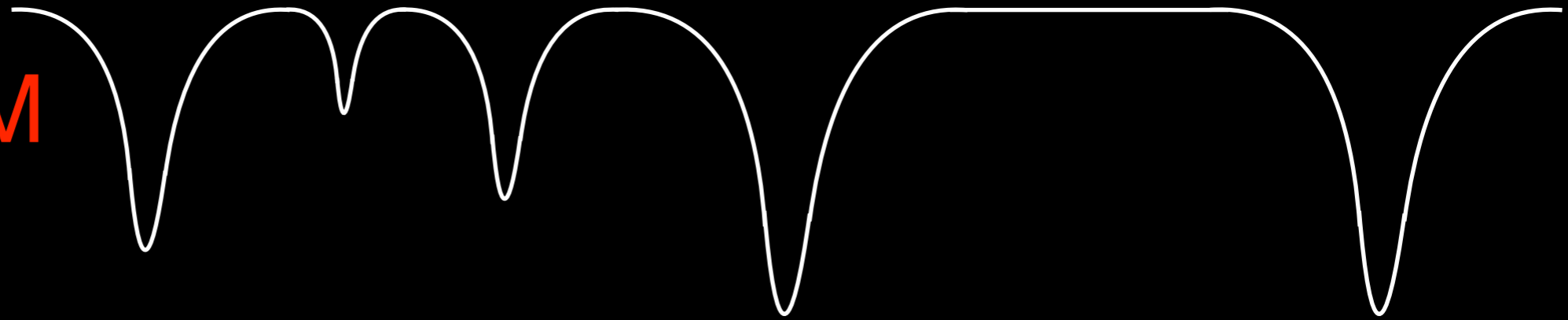


Each stellar **spectral line**
should be affected **differently**
by **stellar activity**

How do we derive precise RV measurements?

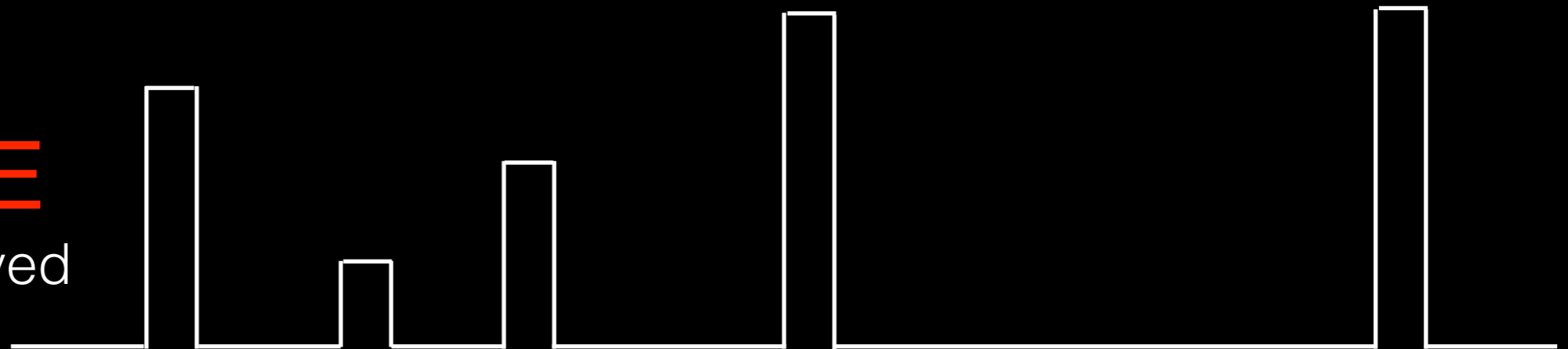
SPECTRUM

visible spectrum



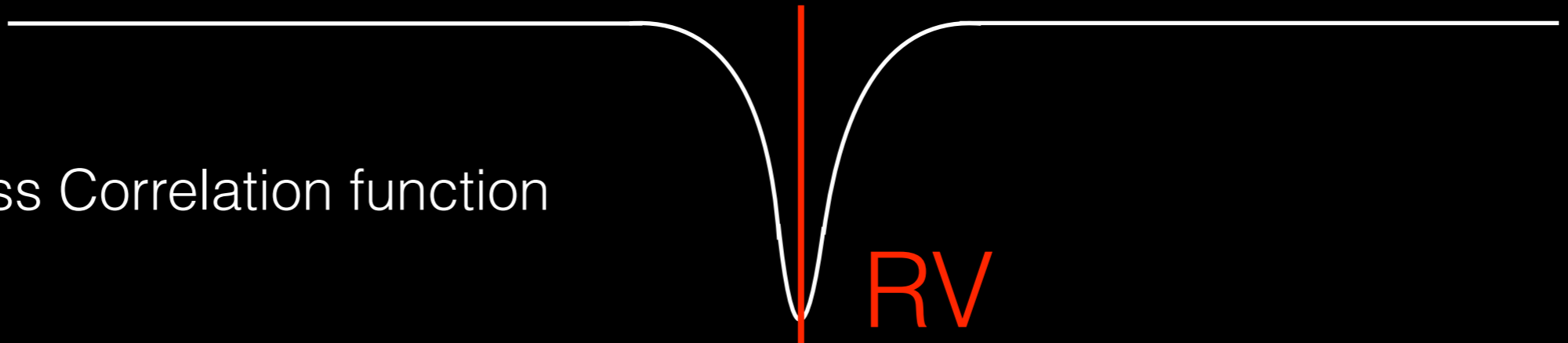
TEMPLATE

synthetic or observed



=

CCF Cross Correlation function



How do we derive **precise RV** measurements?

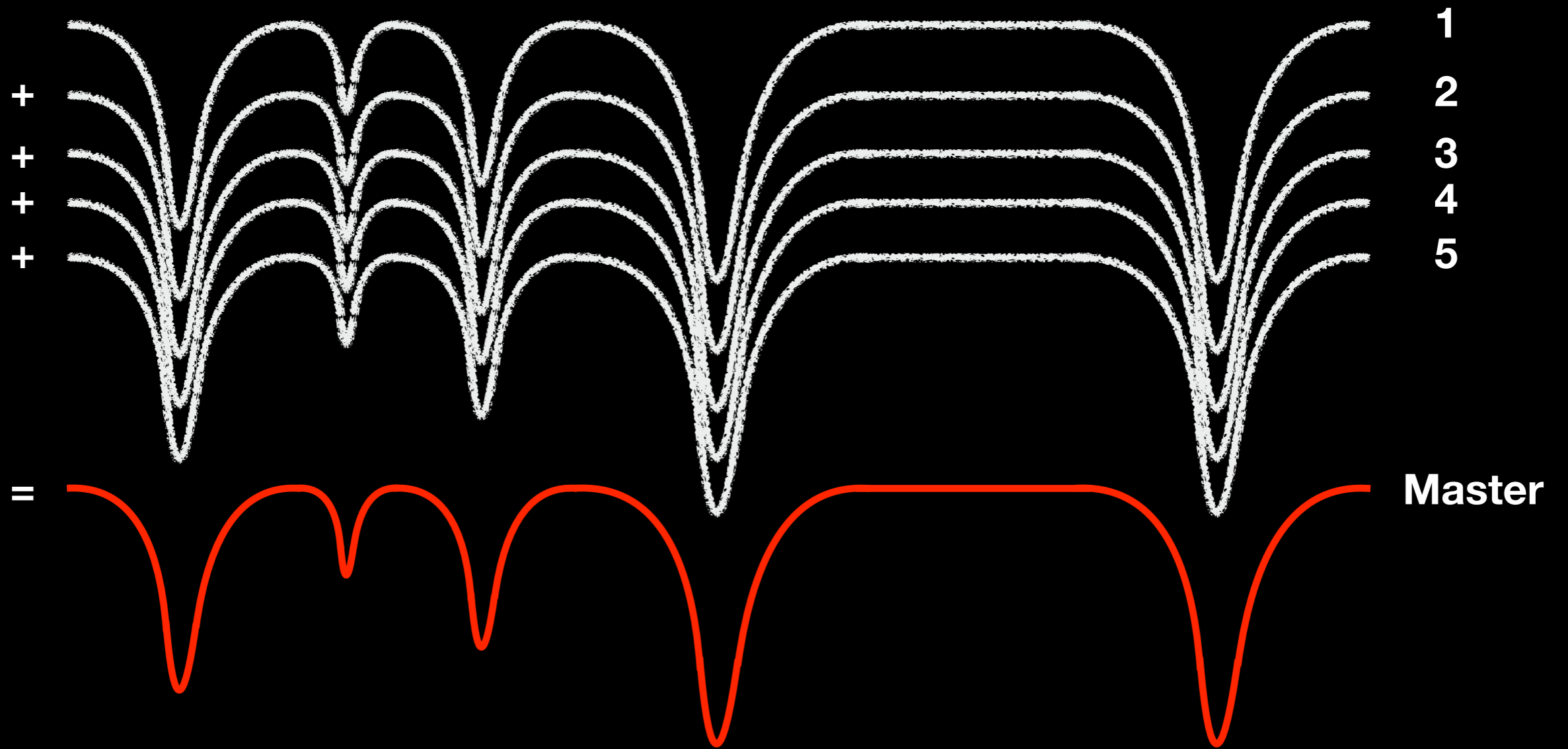
CCF technique

Averaging the RV of all the lines at once

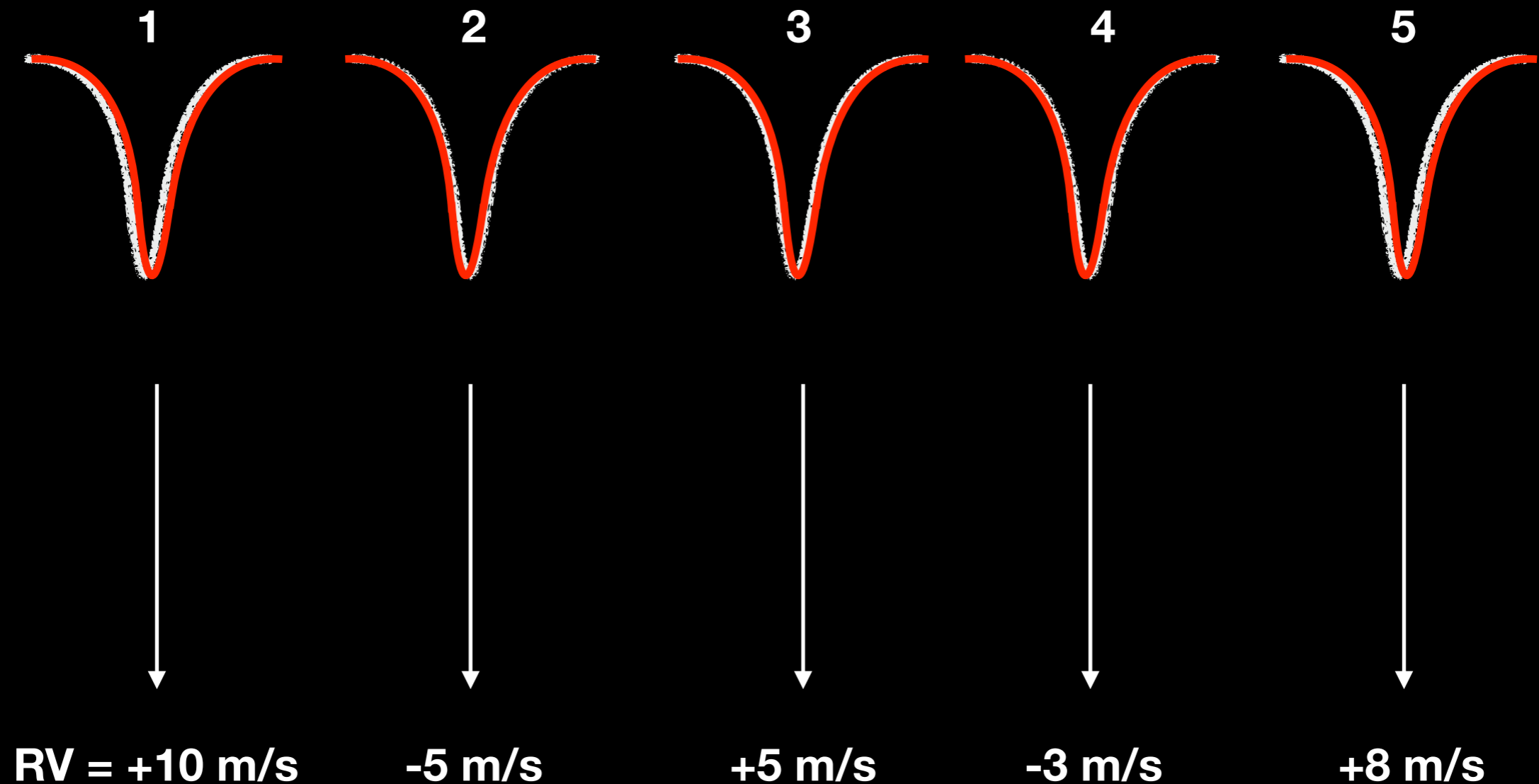
New technique

Measuring the radial velocity of each line

Building a high SNR master spectrum

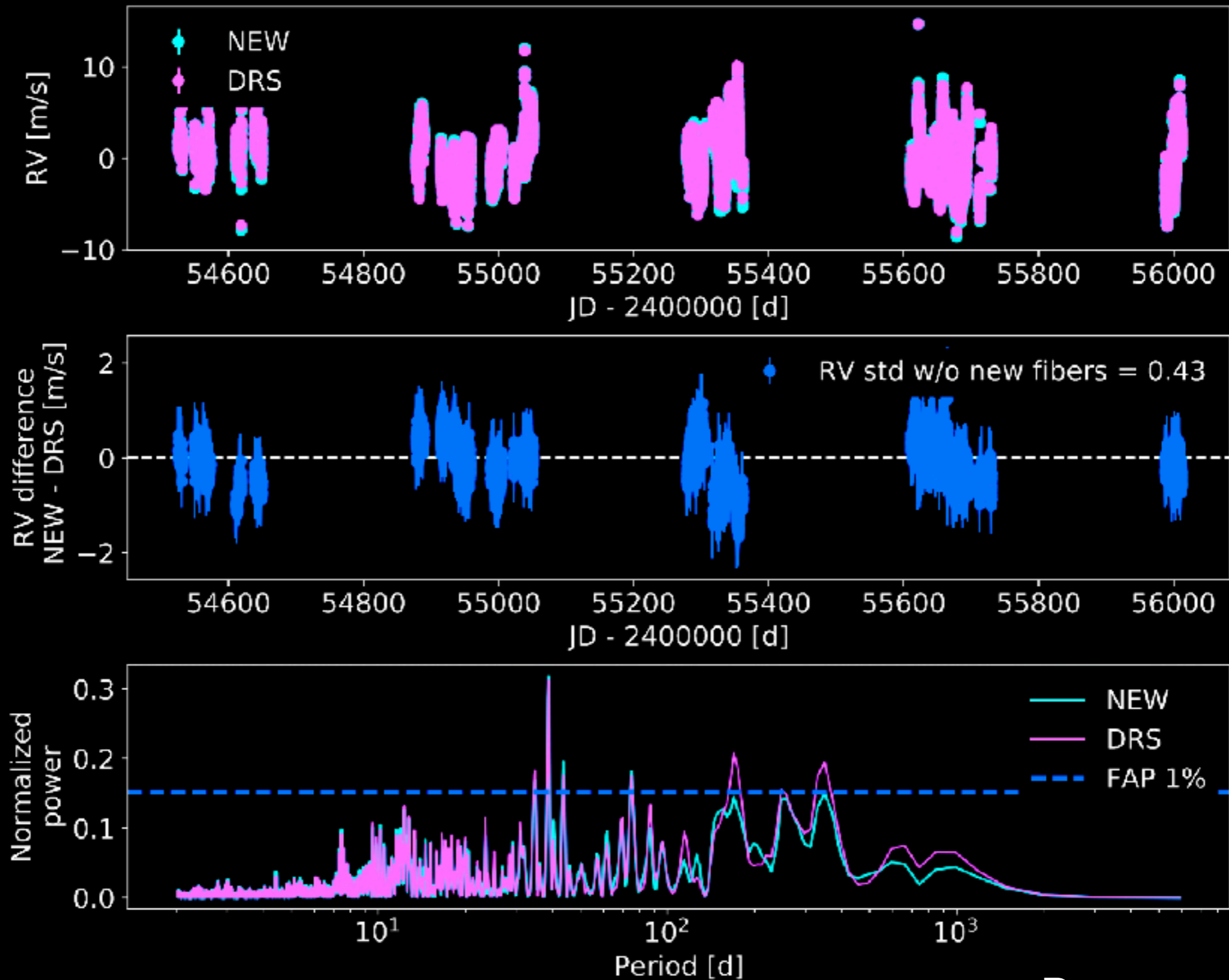


Measuring the RV on each spectral line

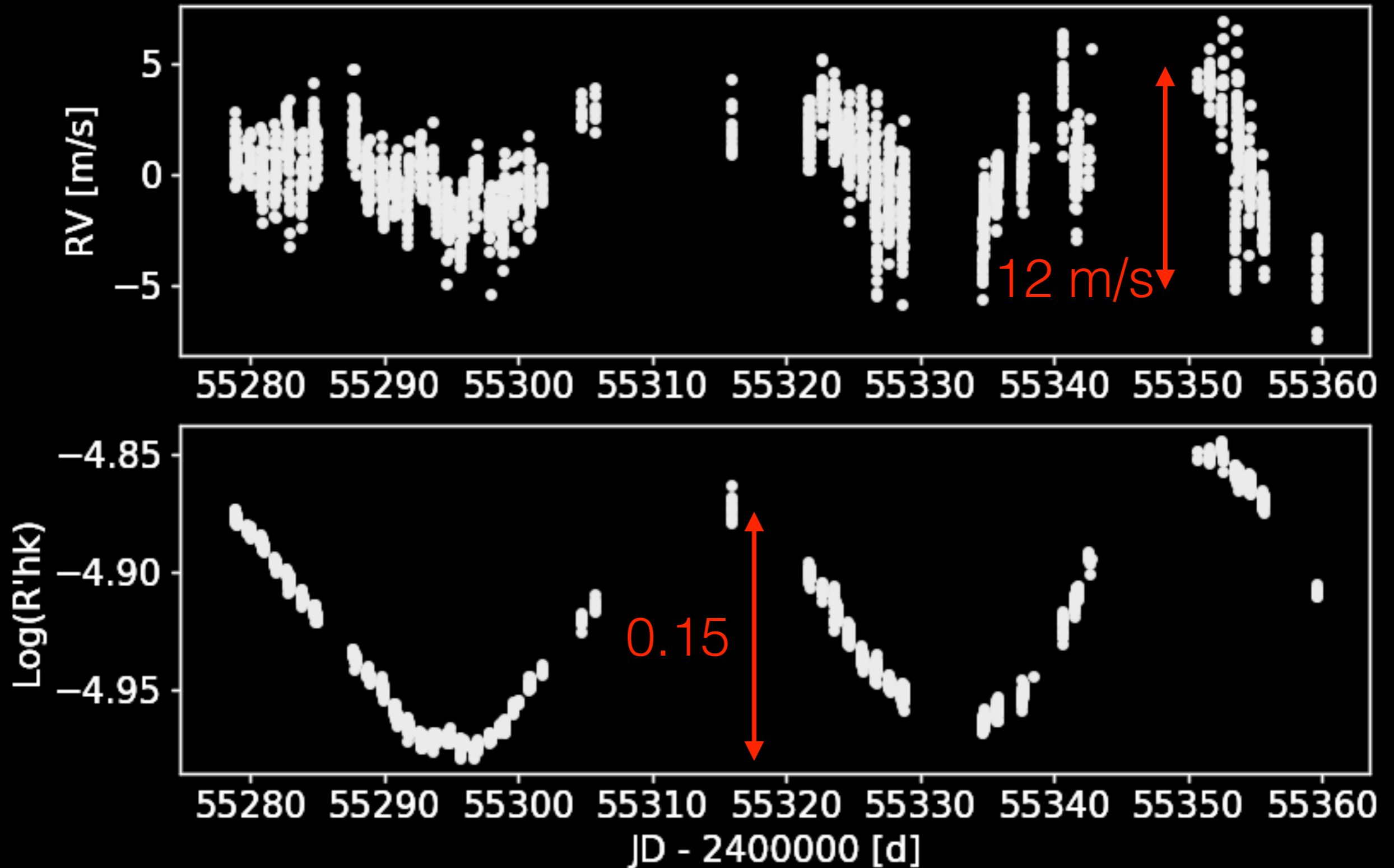


We do this for all spectral lines

Alpha Cen B (RV by combining the RV of all the lines)

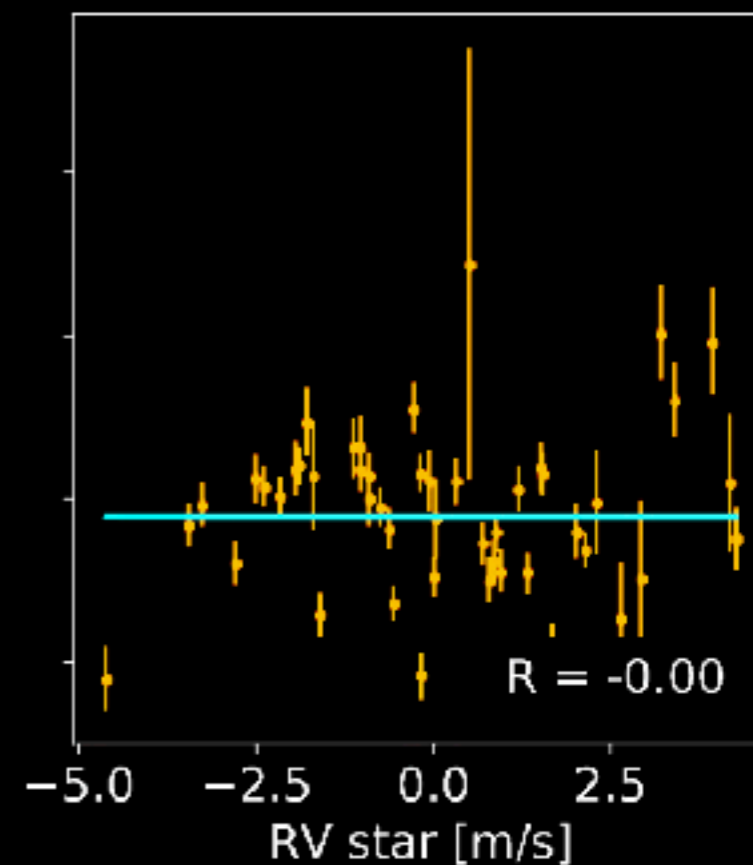
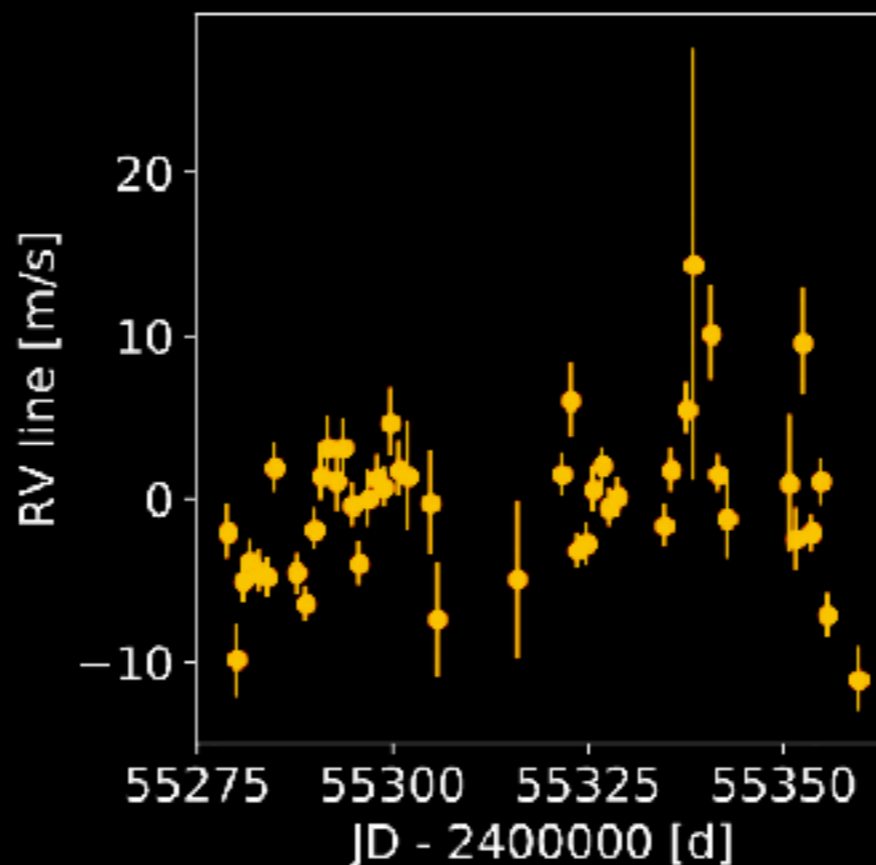


Activity of Alpha Cen B (2010 data)

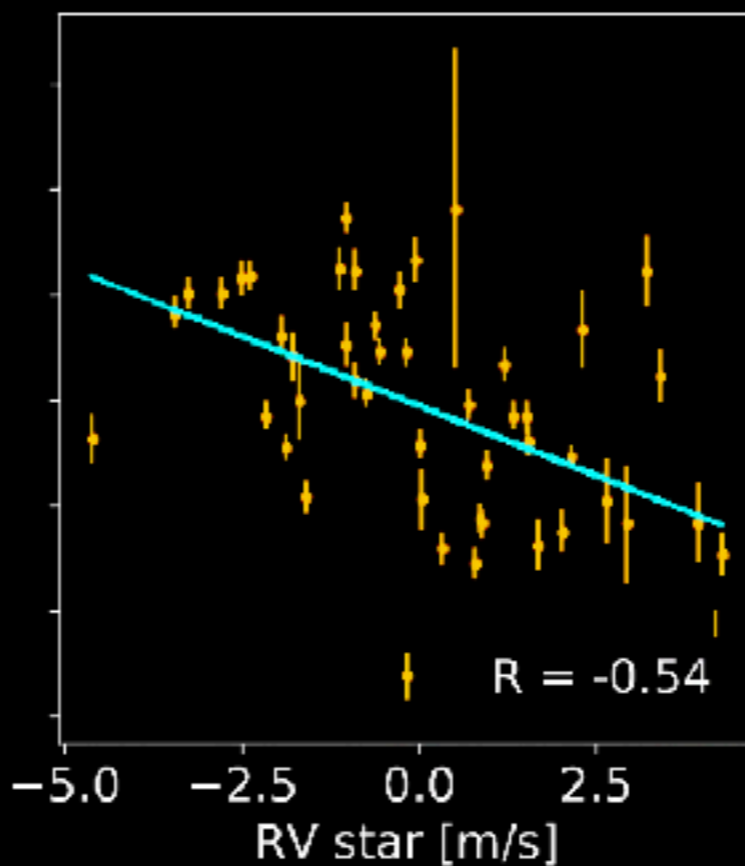
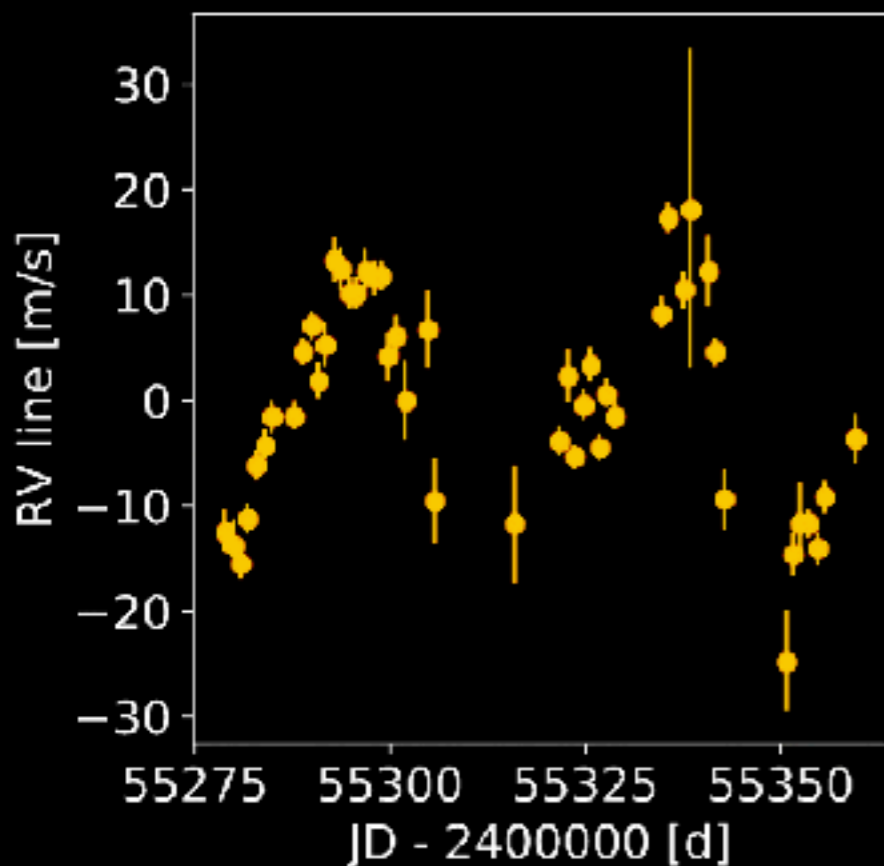


RV of a few lines

freq = 4337.05, pixel=1630 ($\langle \text{svrad} \rangle = 8.9 \text{ m/s}$)

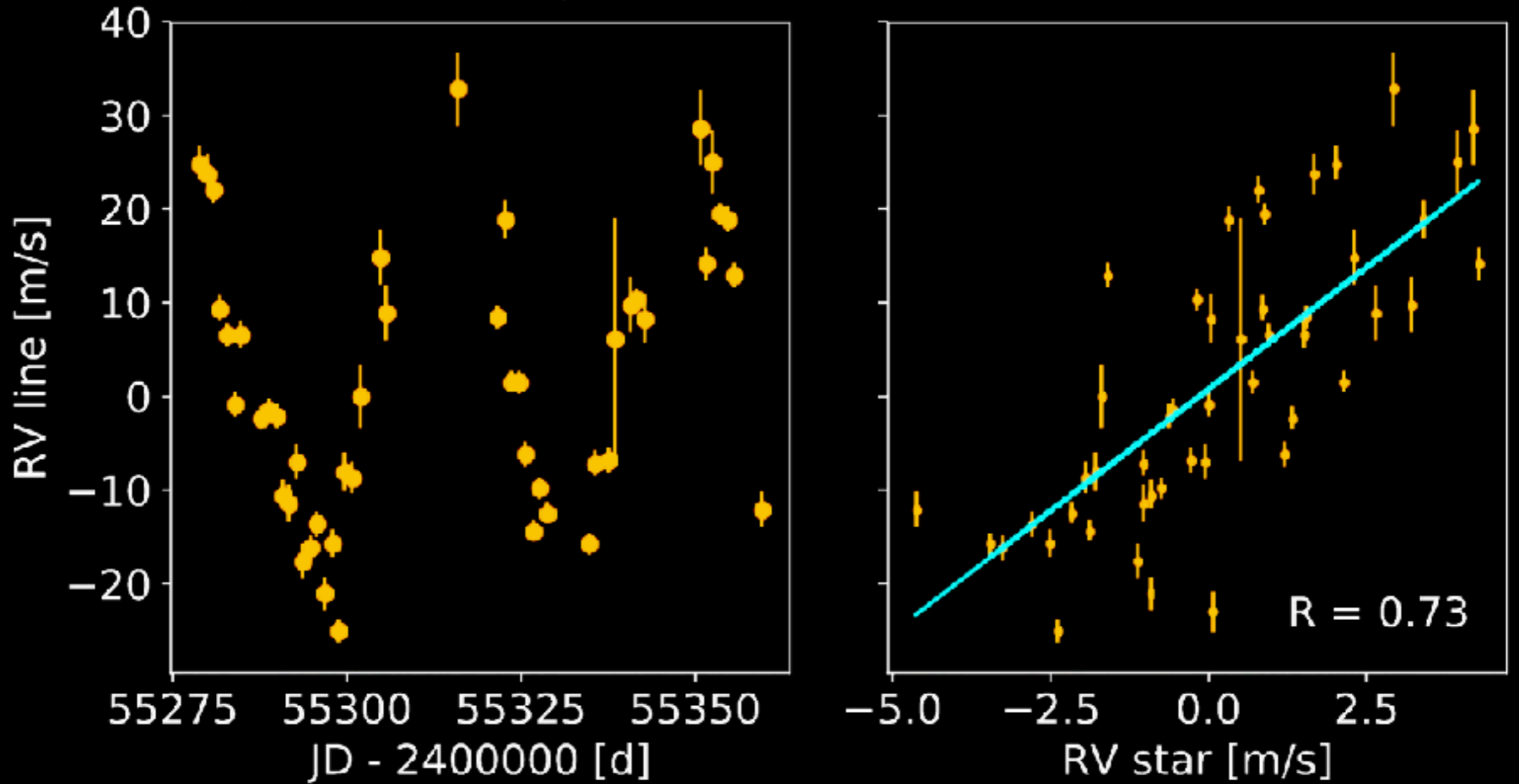


freq = 4173.93, pixel=2870 ($\langle \text{svrad} \rangle = 10.0 \text{ m/s}$)

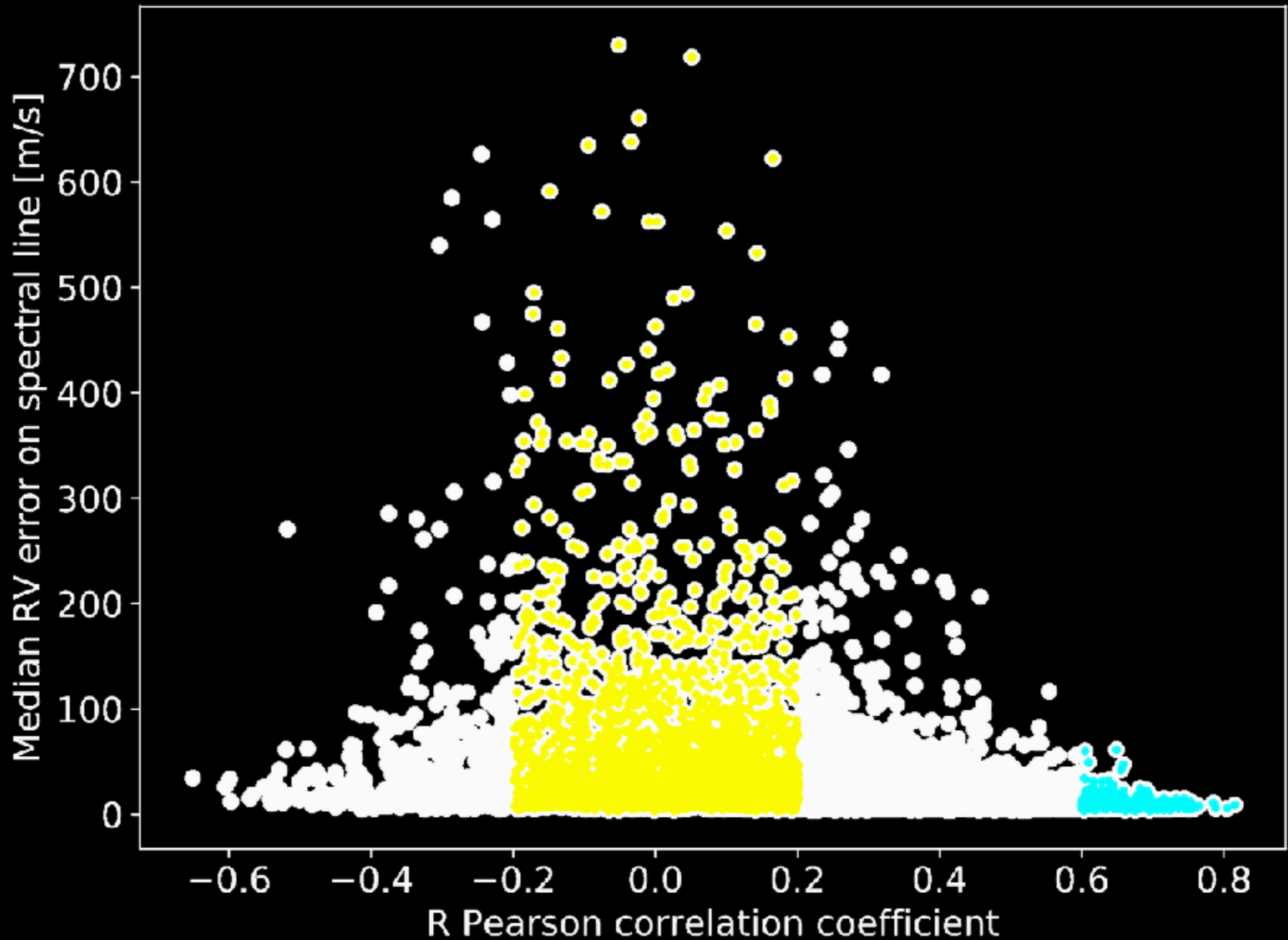


RV of a few lines

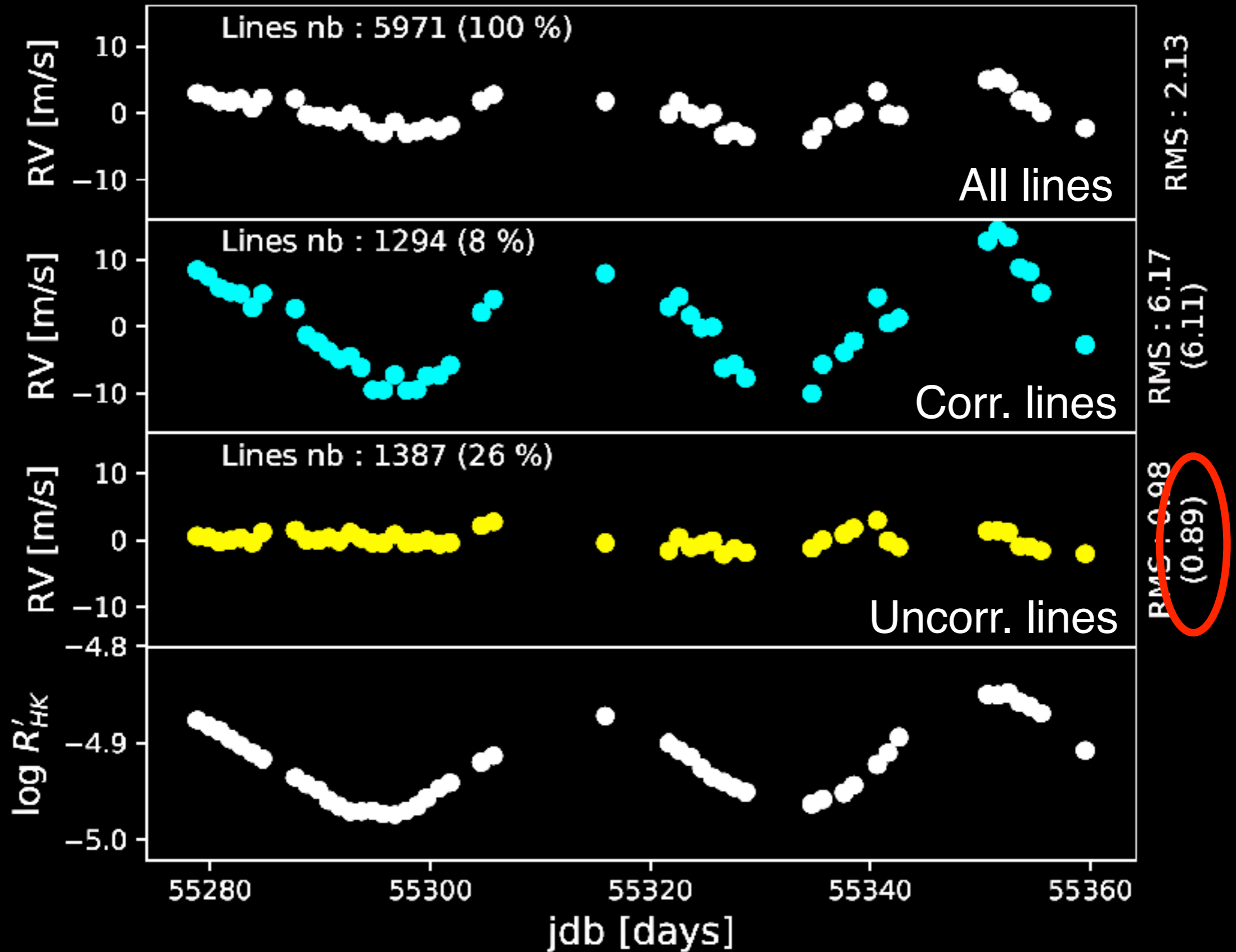
freq = 5602.91, pixel=1192 ($\langle \text{svrad} \rangle = 8.7 \text{ m/s}$)



Correlation of all lines



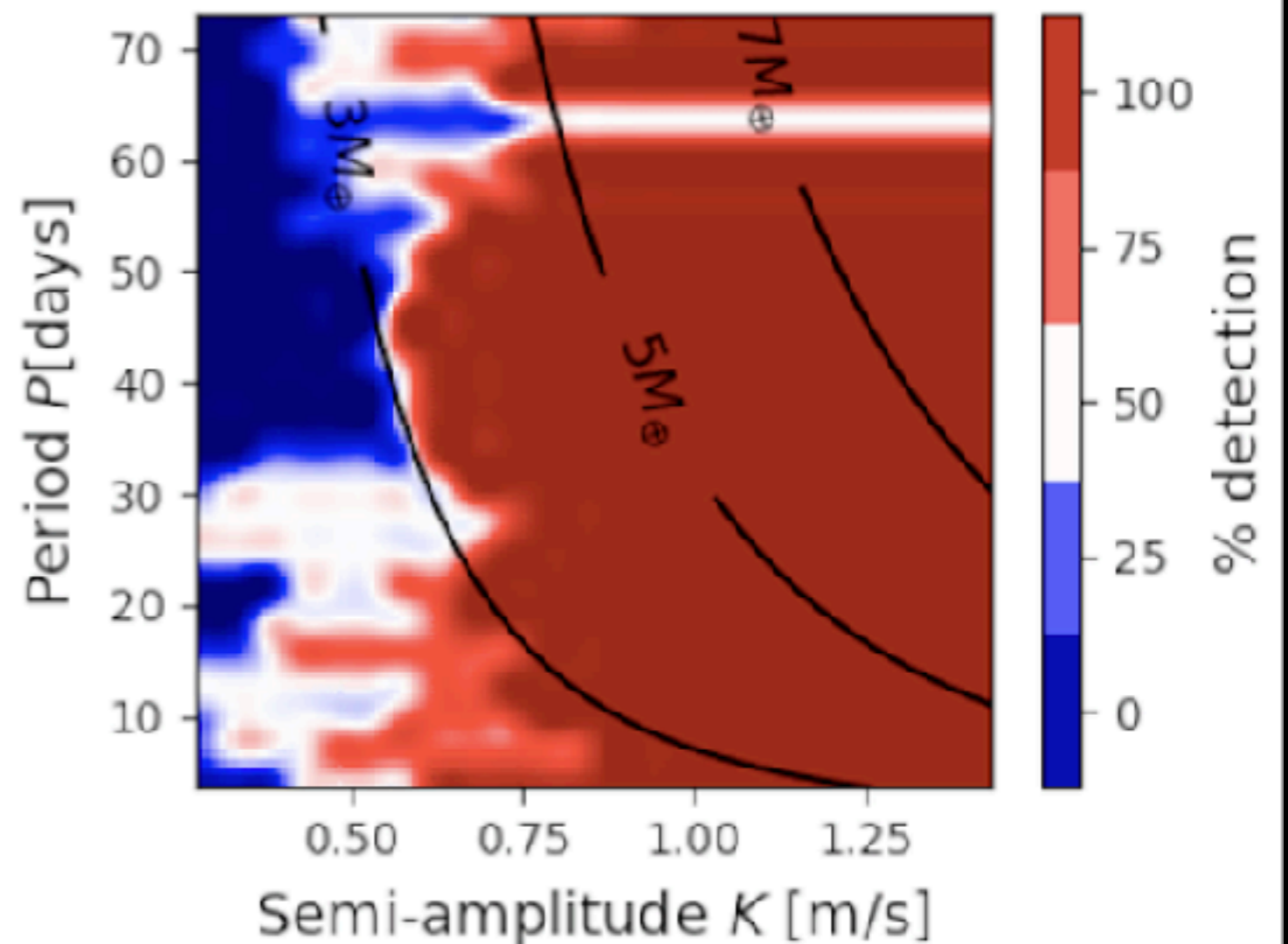
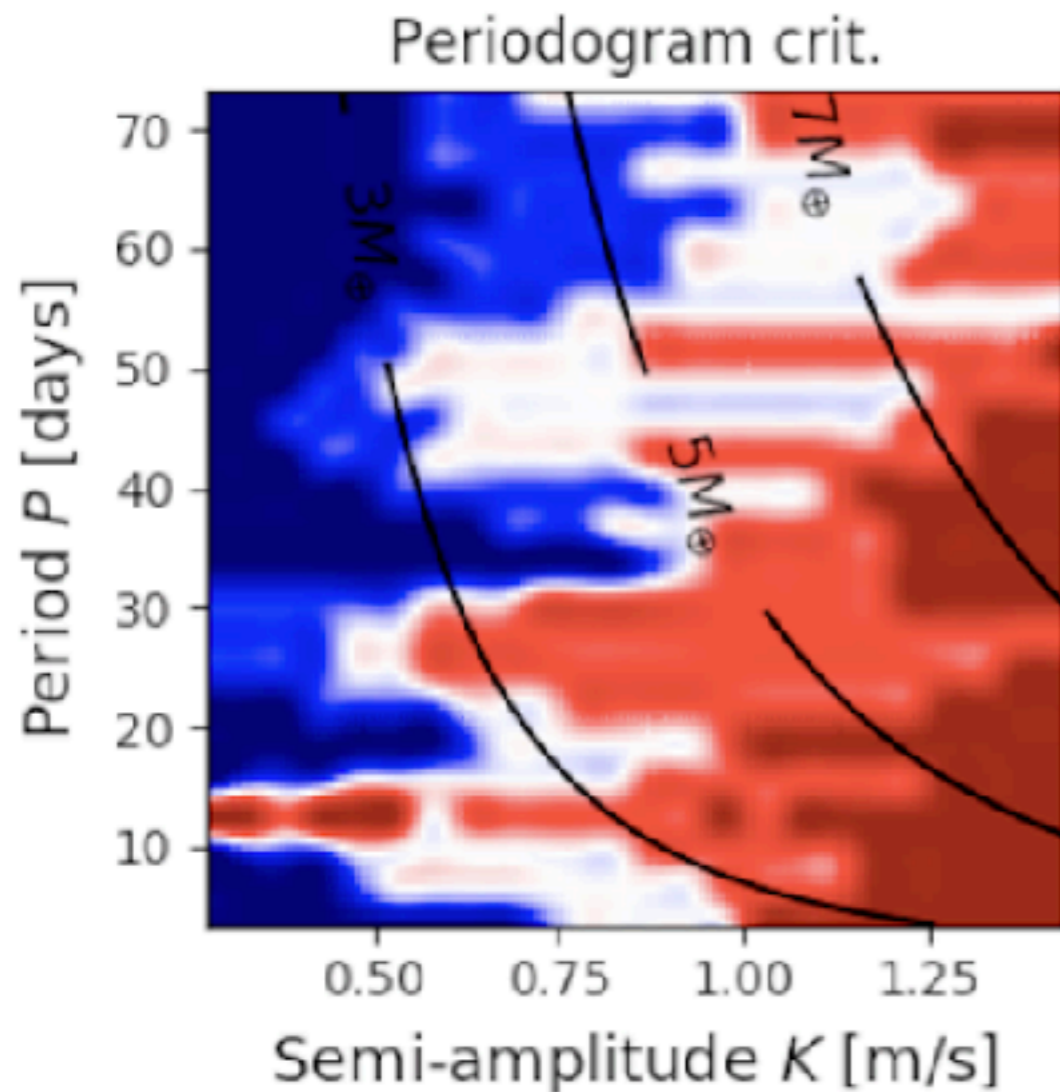
Mitigating stellar activity



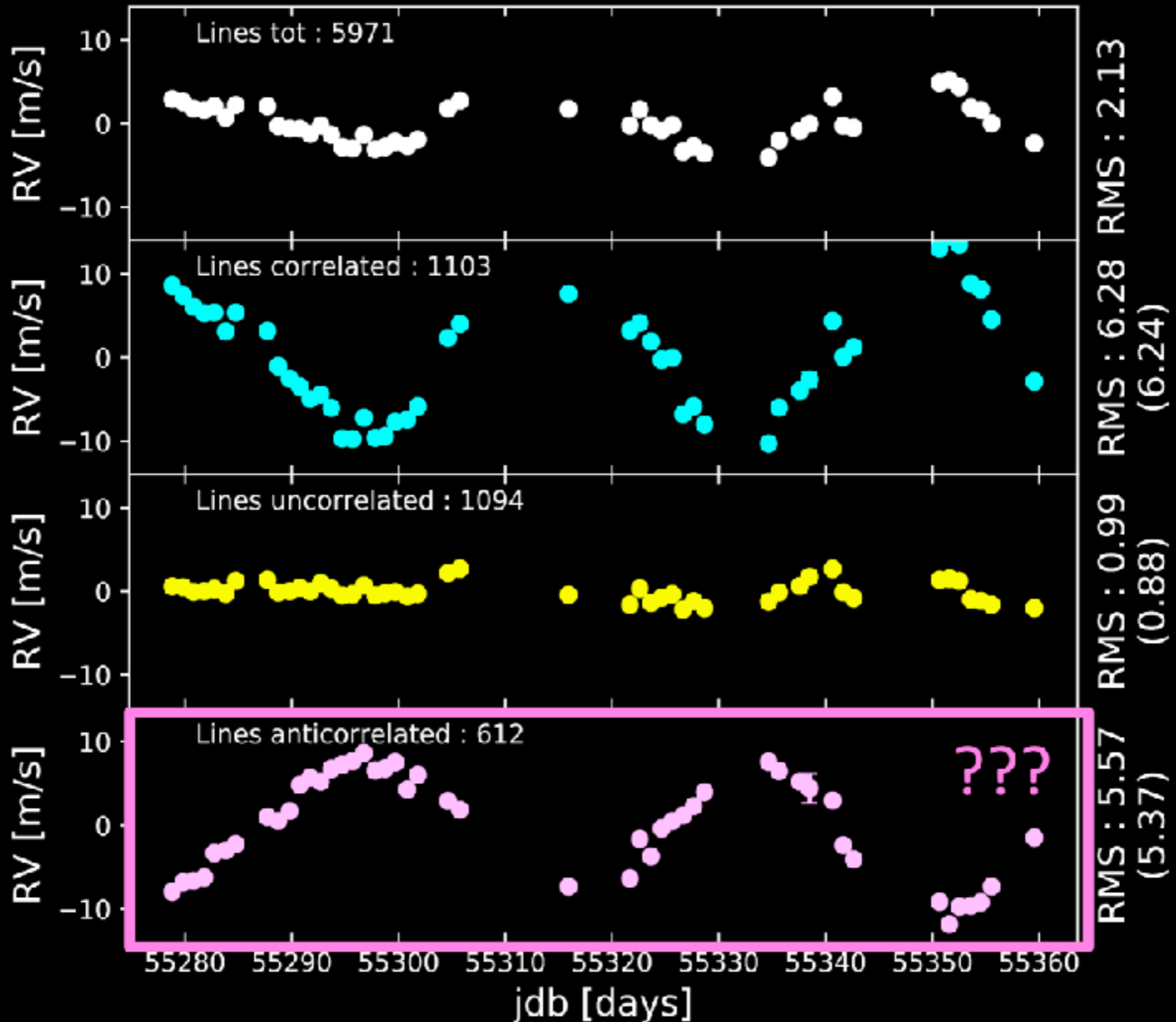
Planetary Detection limits

RV using all the lines

RV using best line selection



Weird behavior of some spectral lines



Michael Cretignier

Mitigating Stellar Activity In Radial Velocities

M. Cretignier¹, N. Dumusque¹, F. Pepe¹, C. Lovis¹, C. Baran¹ and the HARPS-N Solar Telescope Team

¹ Observatoire de Genève, Université de Genève, Switzerland

ABSTRACT

Stellar activity (SA) may be seen to add a noisy component to the measurements of the radial velocity (RV) of a star. This is due to the fact that the photosphere of stars is not perfectly spherical, but rather exhibits a non-axisymmetric shape. This is due to the fact that the photosphere is not perfectly spherical, but rather exhibits a non-axisymmetric shape. This is due to the fact that the photosphere is not perfectly spherical, but rather exhibits a non-axisymmetric shape.

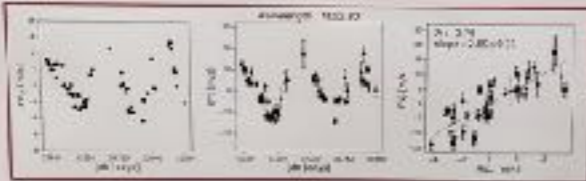
From the physics of stellar atmospheres, it is expected that spots rotate differently with a daily speed. We have investigated the detailed structure of spots induced by a non-axisymmetric photosphere. We have used the HARPS-N radial velocities (RVs) of the star HD 187510 to study the impact of SA on the RVs. The HARPS-N data show a clear periodic variation in the RVs, which is not explained by the presence of a planet. This variation is likely due to the presence of spots on the star's surface. We have used the HARPS-N data to study the impact of SA on the RVs. The HARPS-N data show a clear periodic variation in the RVs, which is not explained by the presence of a planet. This variation is likely due to the presence of spots on the star's surface.

An empirical measure of the strength of stellar activity was derived using the RVs of a sample of 100 stars. This measure is based on the RVs of the stars and is independent of the RVs of the stars. We have used this measure to study the impact of SA on the RVs. The HARPS-N data show a clear periodic variation in the RVs, which is not explained by the presence of a planet. This variation is likely due to the presence of spots on the star's surface.

By modeling the photosphere of the HARPS-N stars as a non-axisymmetric shape, we have derived a model for the RVs. This model is based on the RVs of the stars and is independent of the RVs of the stars. We have used this model to study the impact of SA on the RVs. The HARPS-N data show a clear periodic variation in the RVs, which is not explained by the presence of a planet. This variation is likely due to the presence of spots on the star's surface.

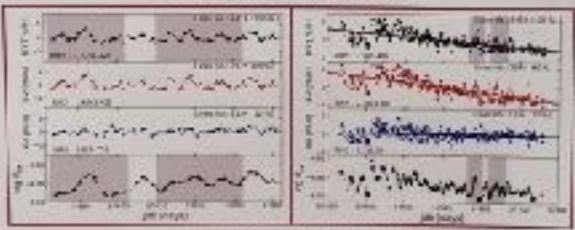
INDIVIDUAL STARACTIVITY

Figure 1. Left: Radial velocity (RV) of the star HD 187510. The RV is shown as a function of time. The RV shows a clear periodic variation. Right: The RV residuals (RV - fit) are shown as a function of time. The residuals show a clear periodic variation.



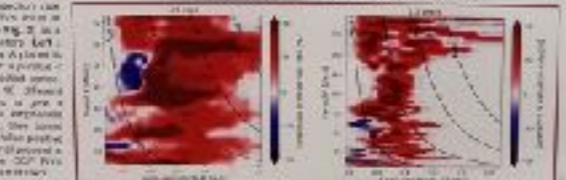
MODELS FOR THE ACTIVITY

Figure 2. Top row: The RV residuals (RV - fit) are shown as a function of time. The residuals show a clear periodic variation. Middle row: The RV residuals (RV - fit) are shown as a function of time. The residuals show a clear periodic variation. Bottom row: The RV residuals (RV - fit) are shown as a function of time. The residuals show a clear periodic variation.



SHAPING OF SPOTS AND LITERATURE VALUES

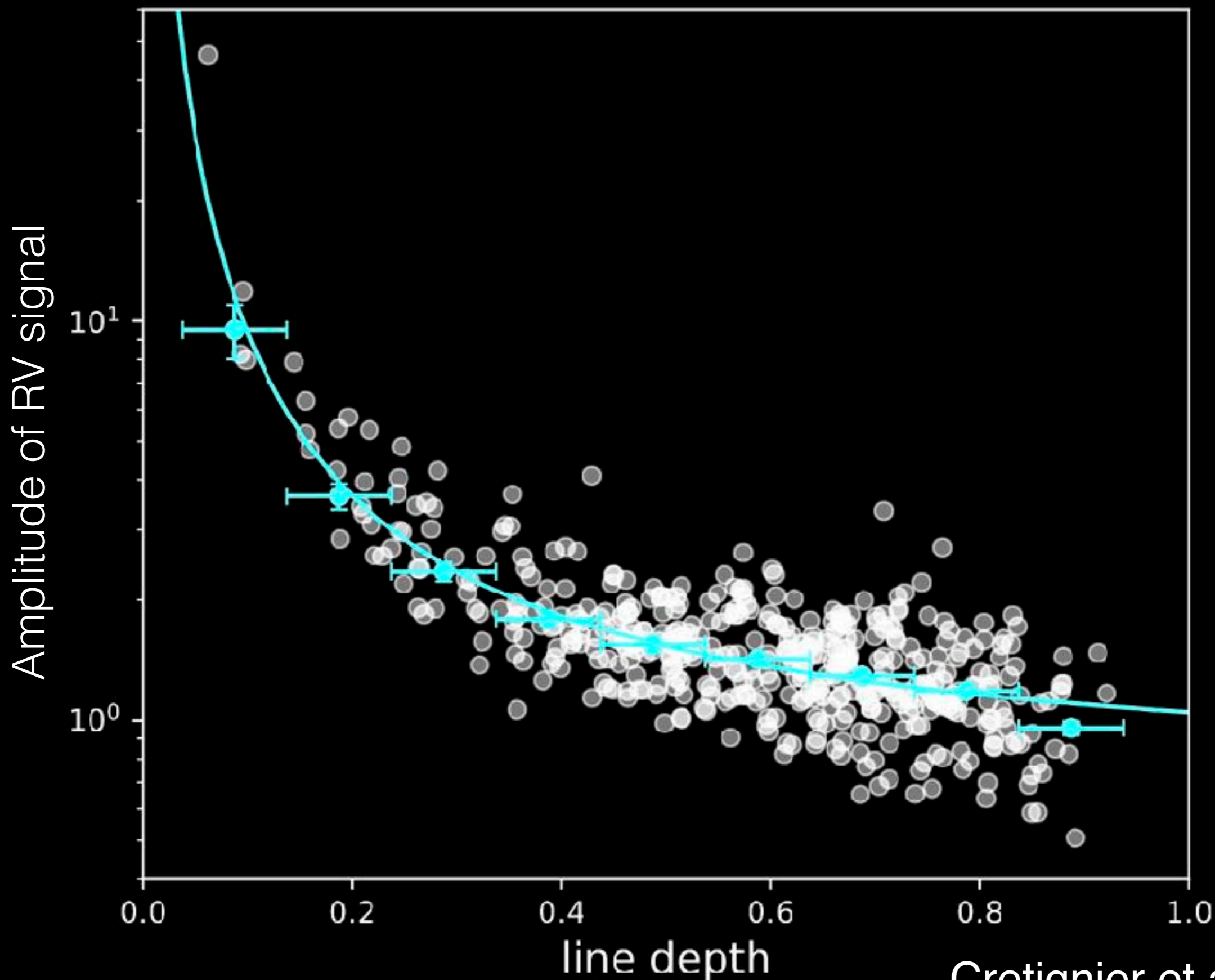
Figure 3. Left: The shape of the spots is shown as a function of time. The spots show a clear periodic variation. Right: The shape of the spots is shown as a function of time. The spots show a clear periodic variation.

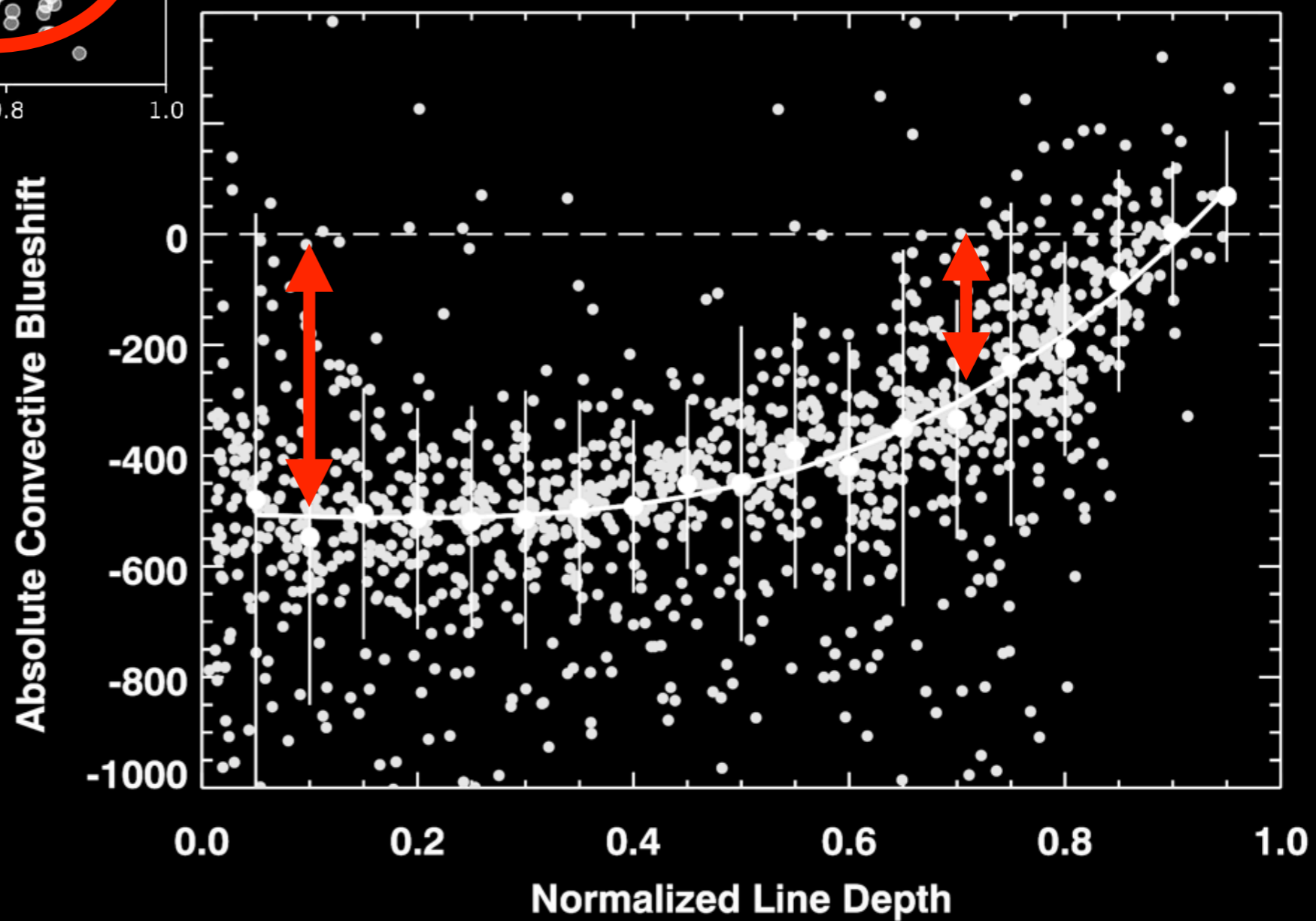
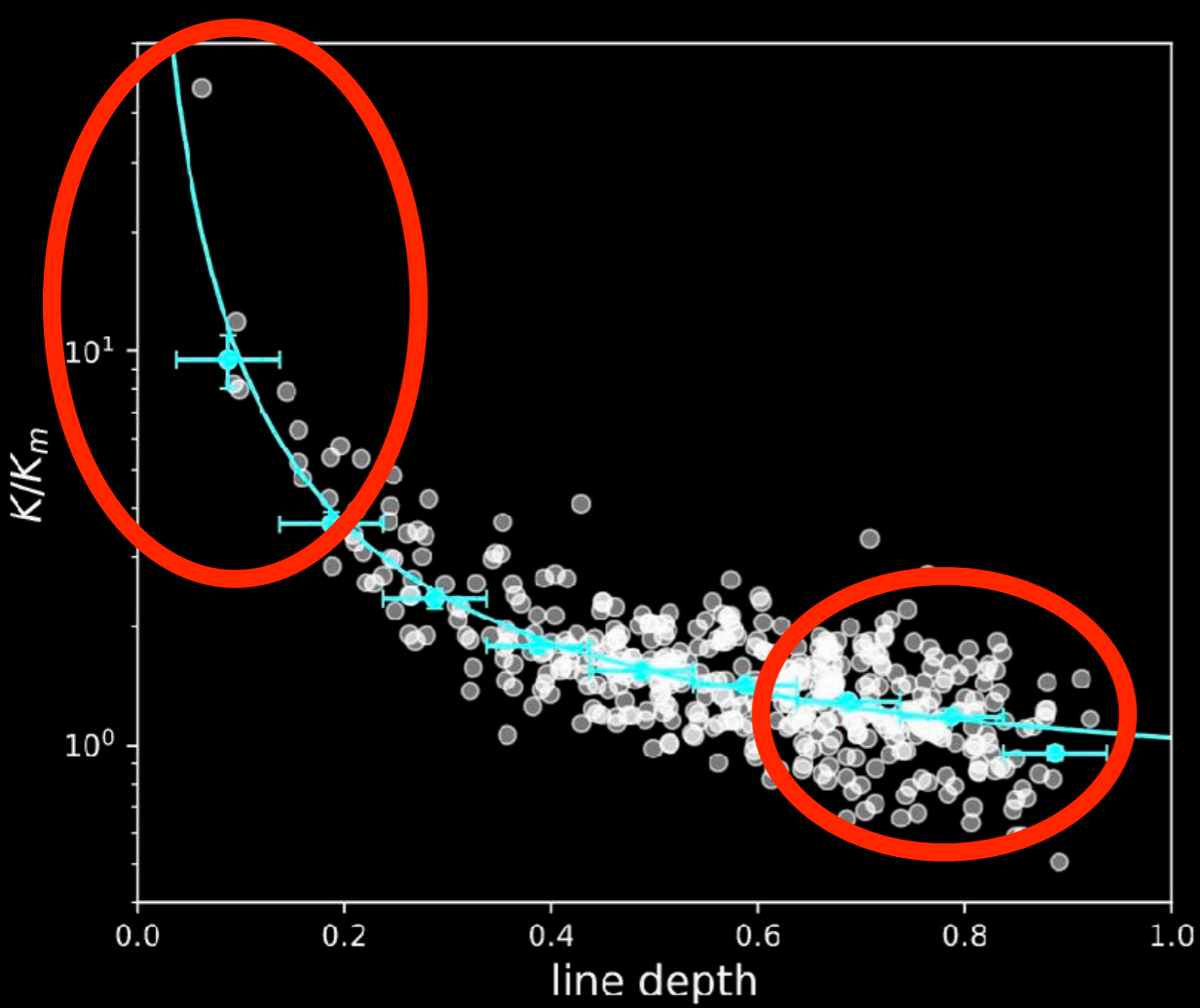


REFERENCES

[1] Cretignier, M., Dumusque, N., Pepe, F., Lovis, C., Baran, C., et al. (2018). Mitigating stellar activity in radial velocities. *Astronomy & Astrophysics*, 613, A10.

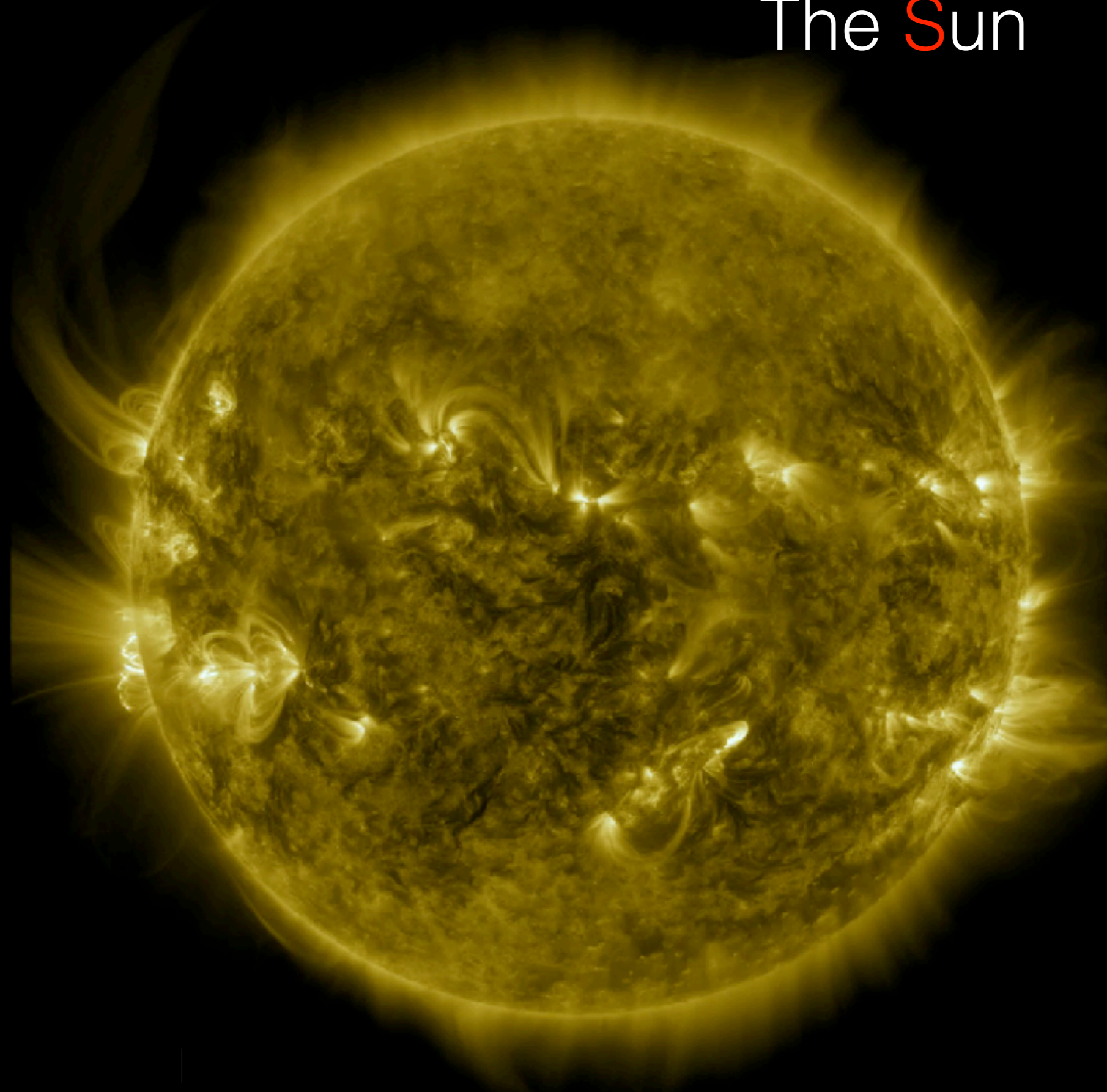
Amplitude of **RV** signal du to **a**ctivity vs depth





The Sun

Star



NASA/SDO

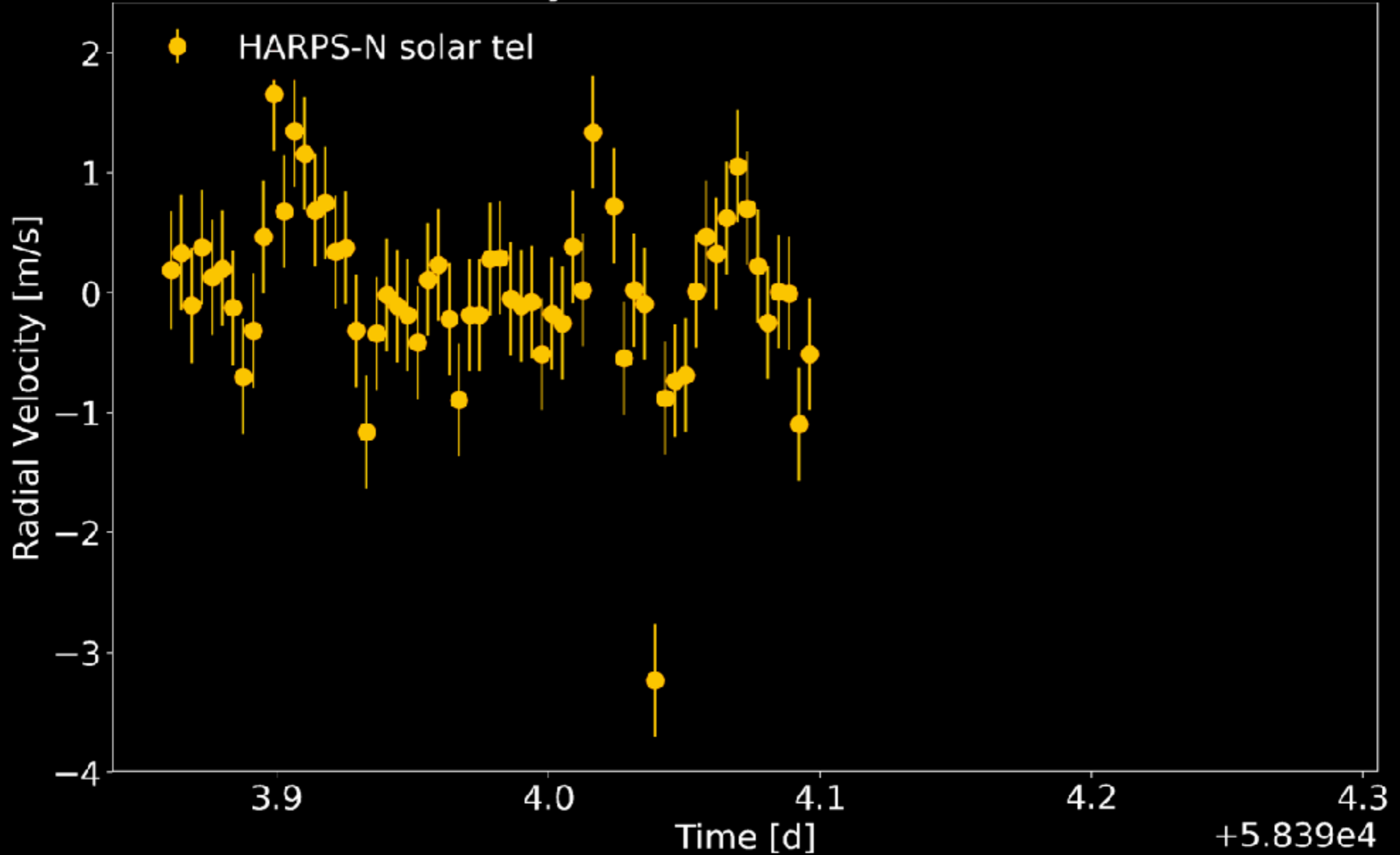
HARPS-N

PIs: D. Phillips, X. Dumusque

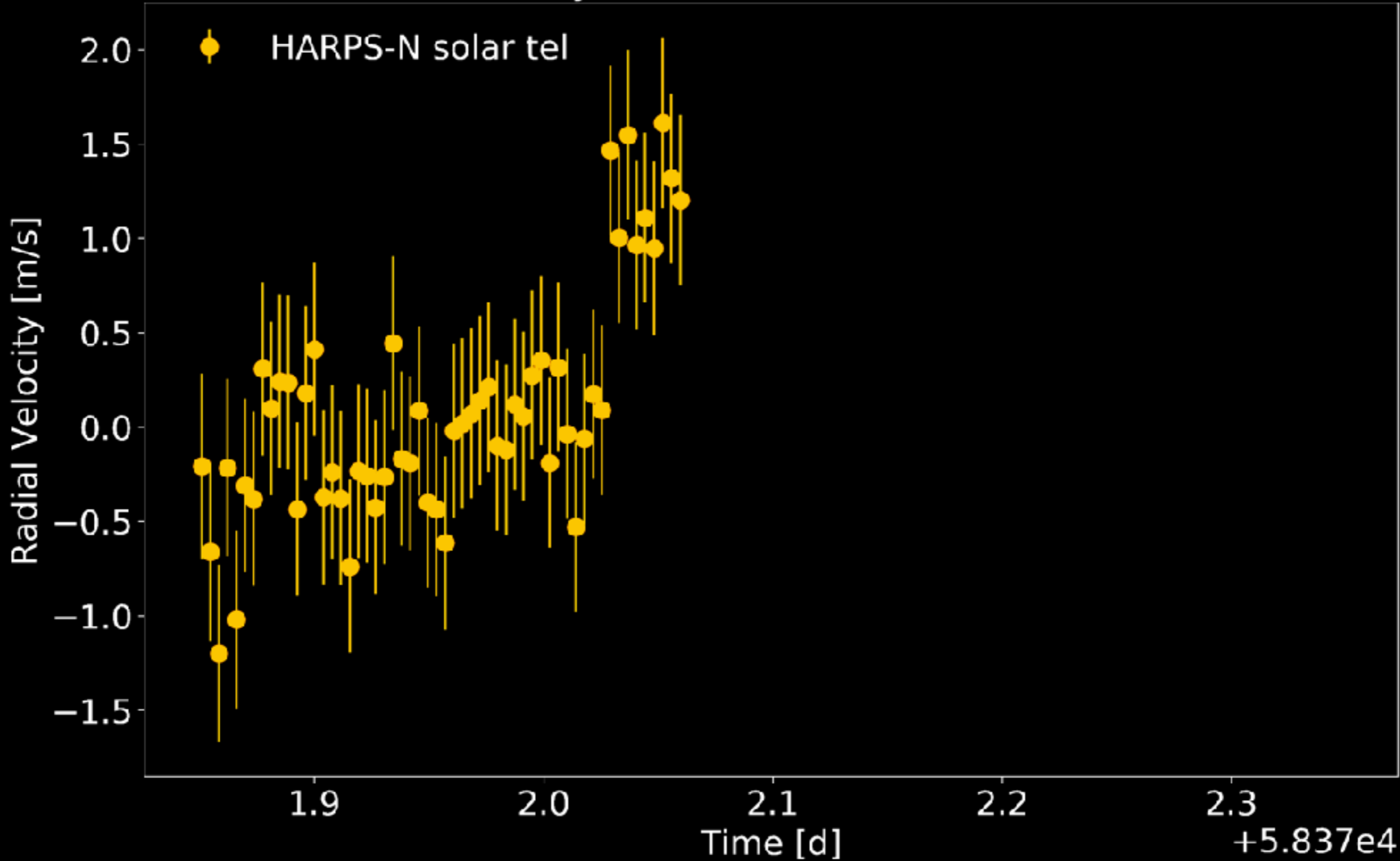


Credits: A. Glenday

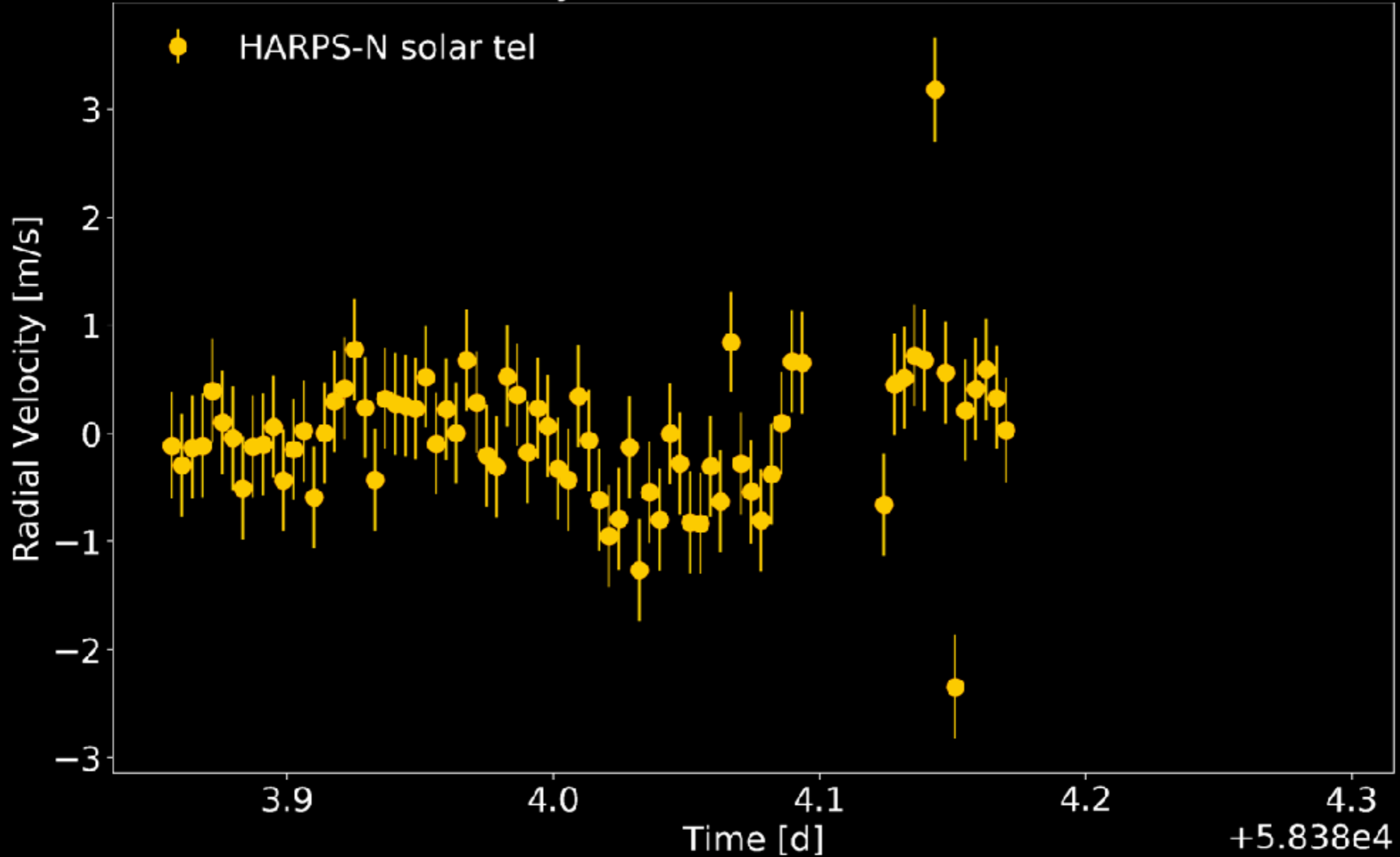
Radial Velocity of the Sun as a function of time

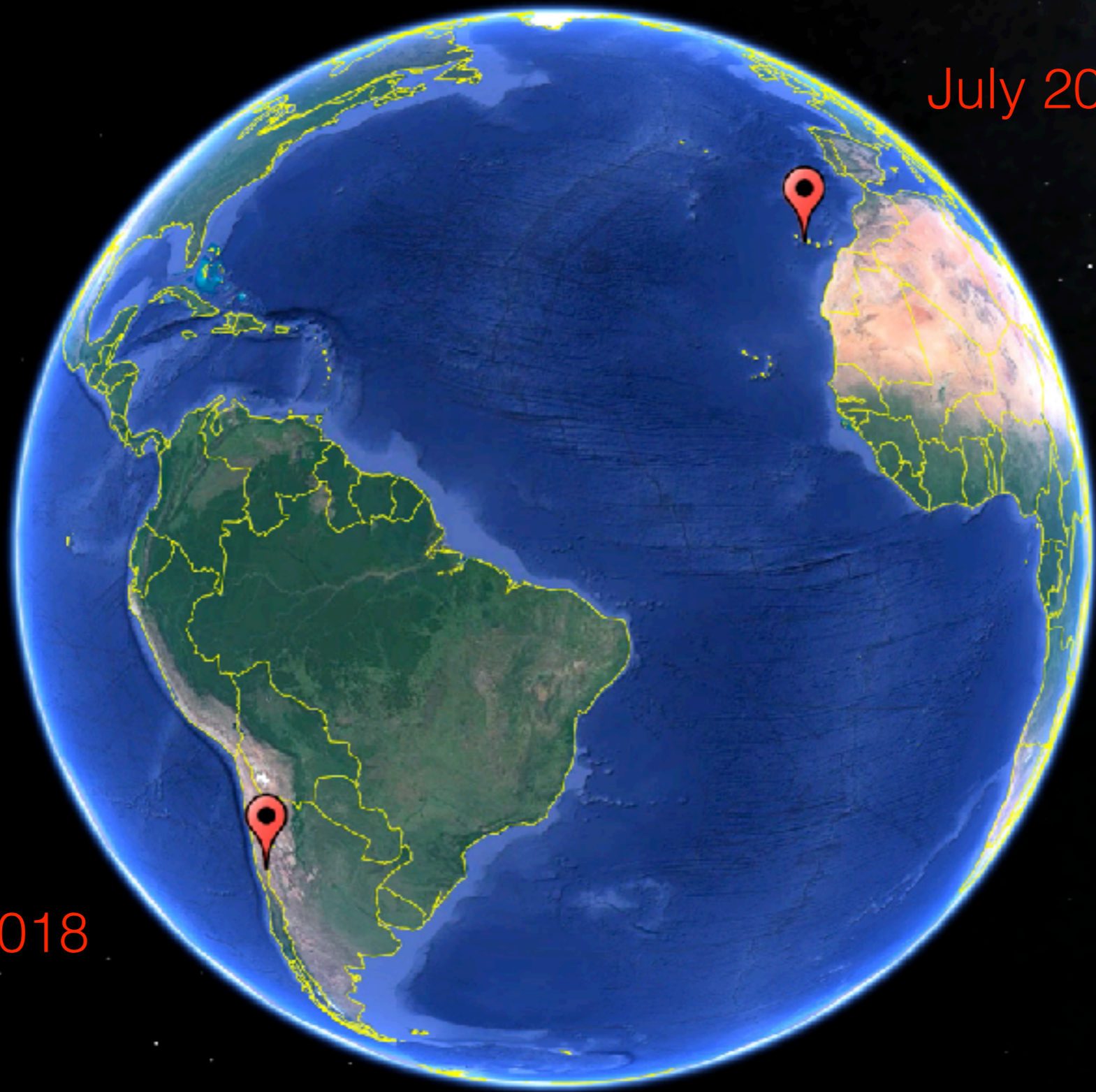


Radial Velocity of the Sun as a function of time



Radial Velocity of the Sun as a function of time





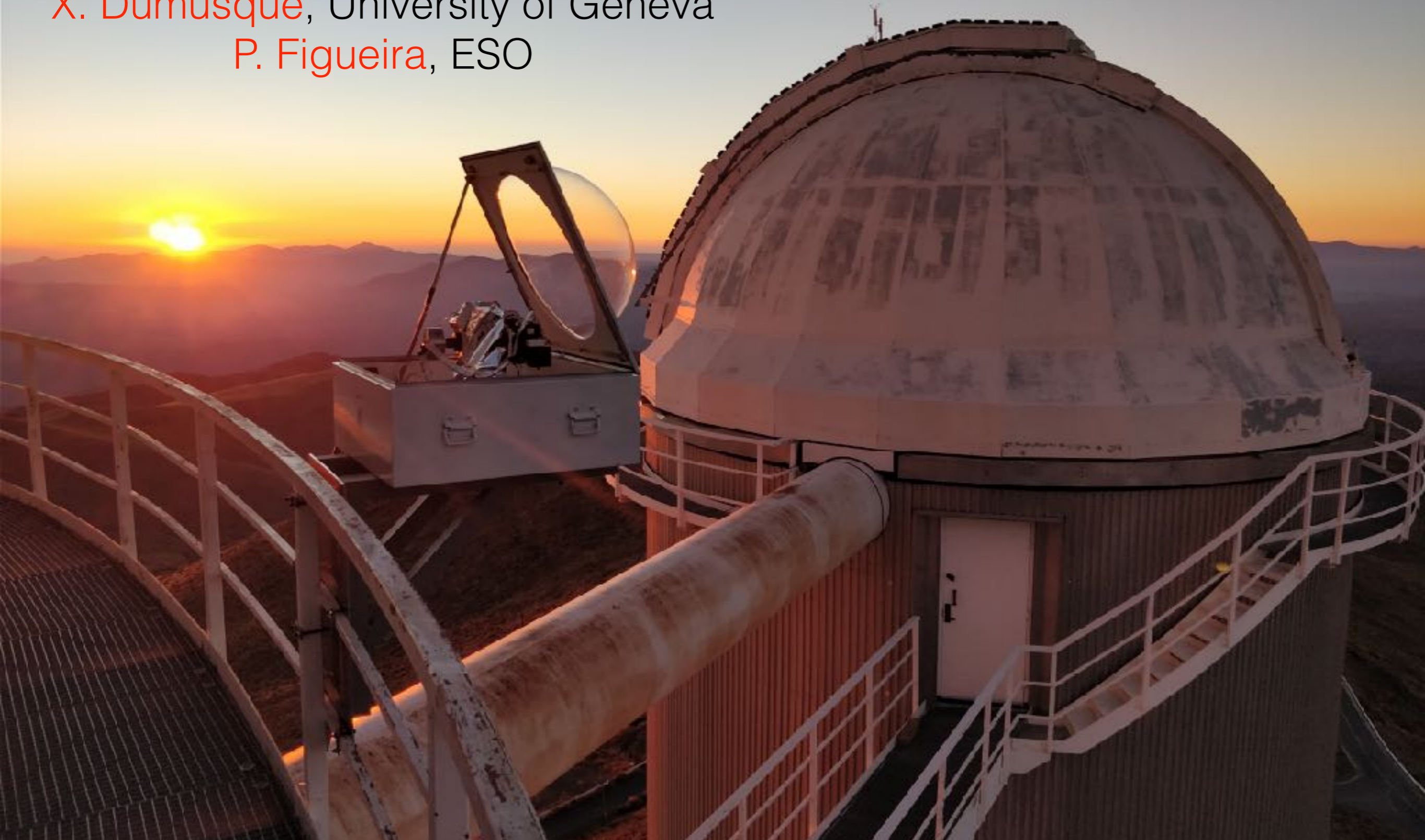
July 2015

April 2018

HELIOS

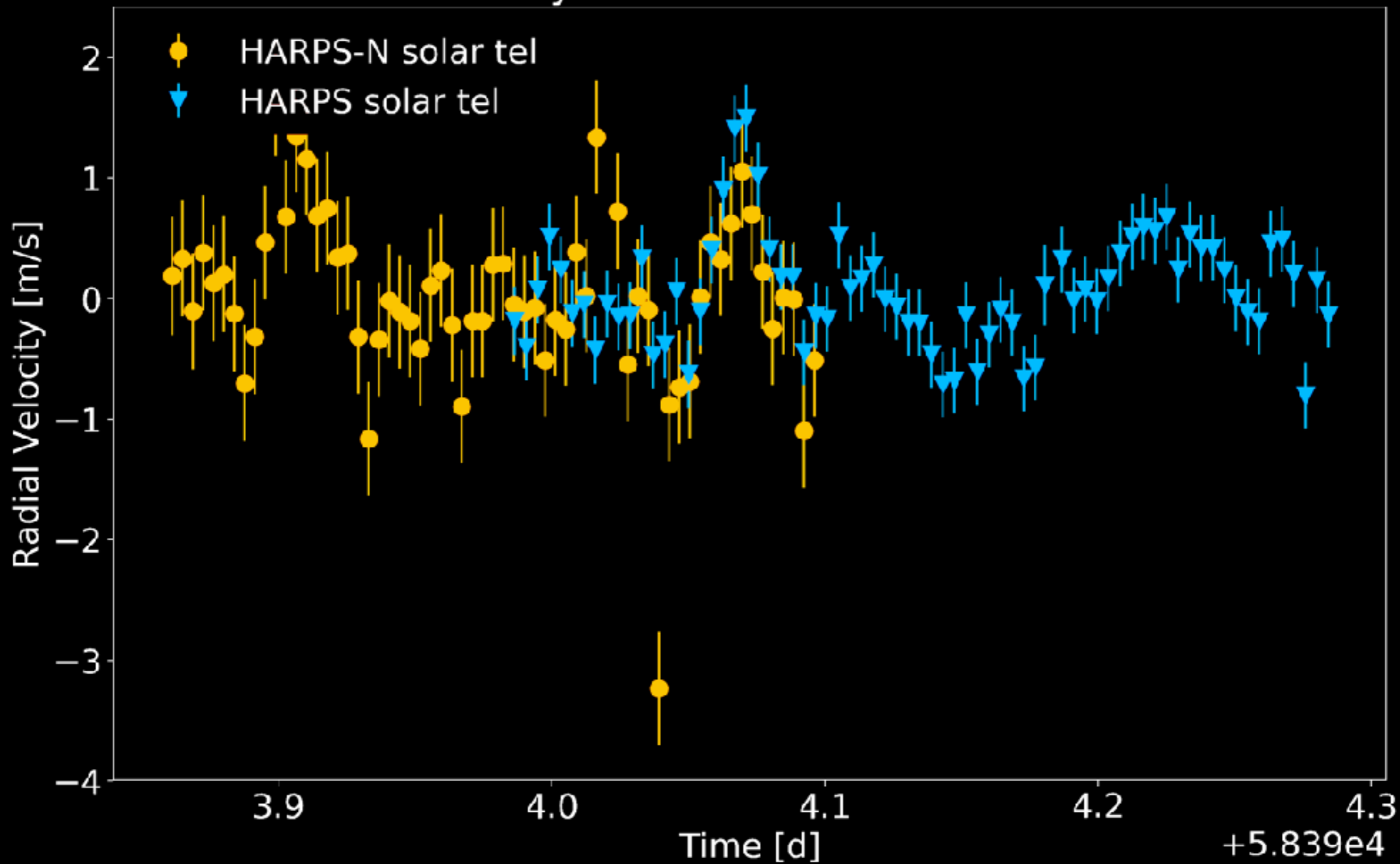
X. Dumusque, University of Geneva

P. Figueira, ESO

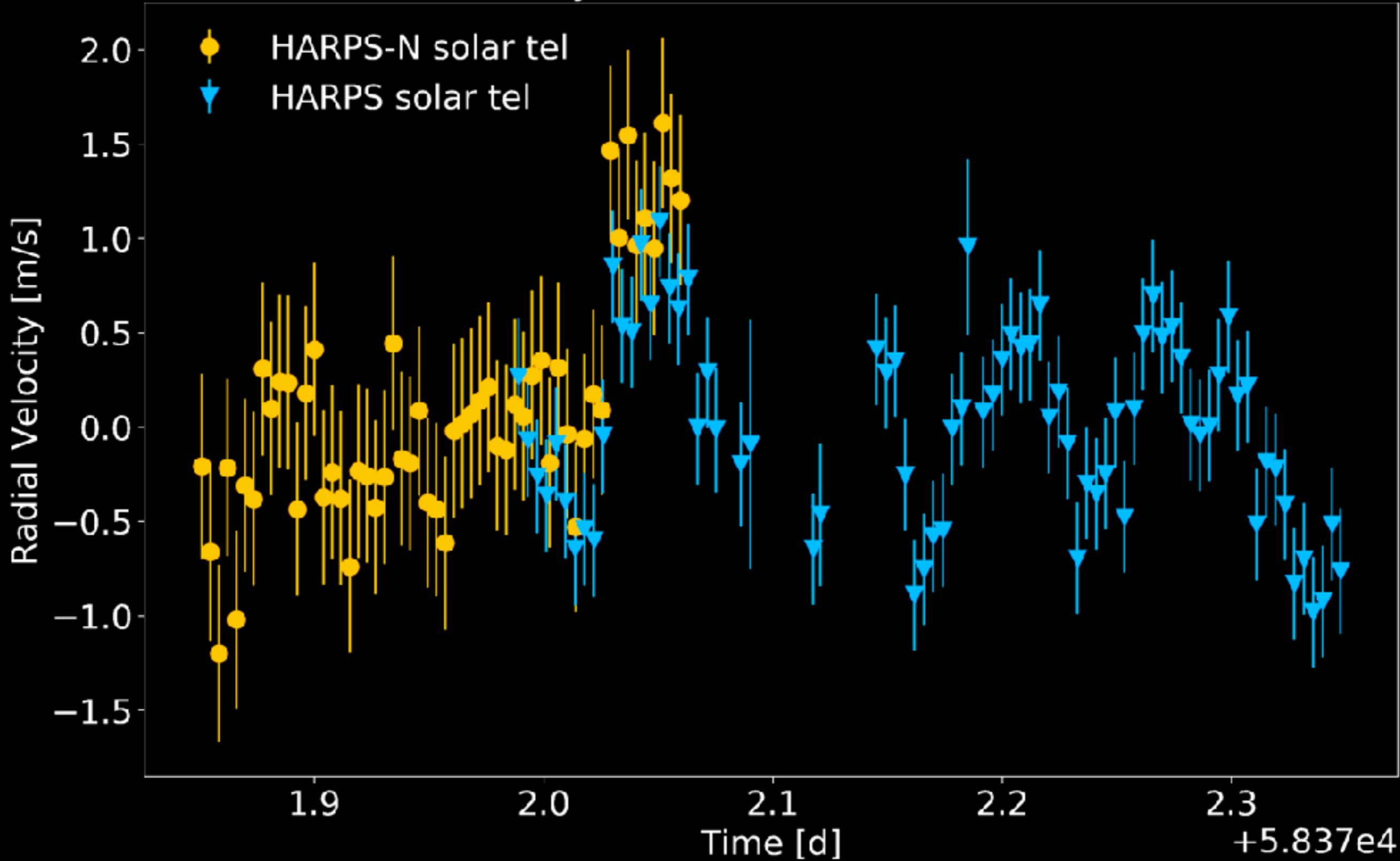


François Wildi, Gaspare LoCurto, Thibault Pirson, Thibault Wildi, Francesco Pepe, David Phillips, Stephane Udry, Christophe Lovis, Nuno Santos

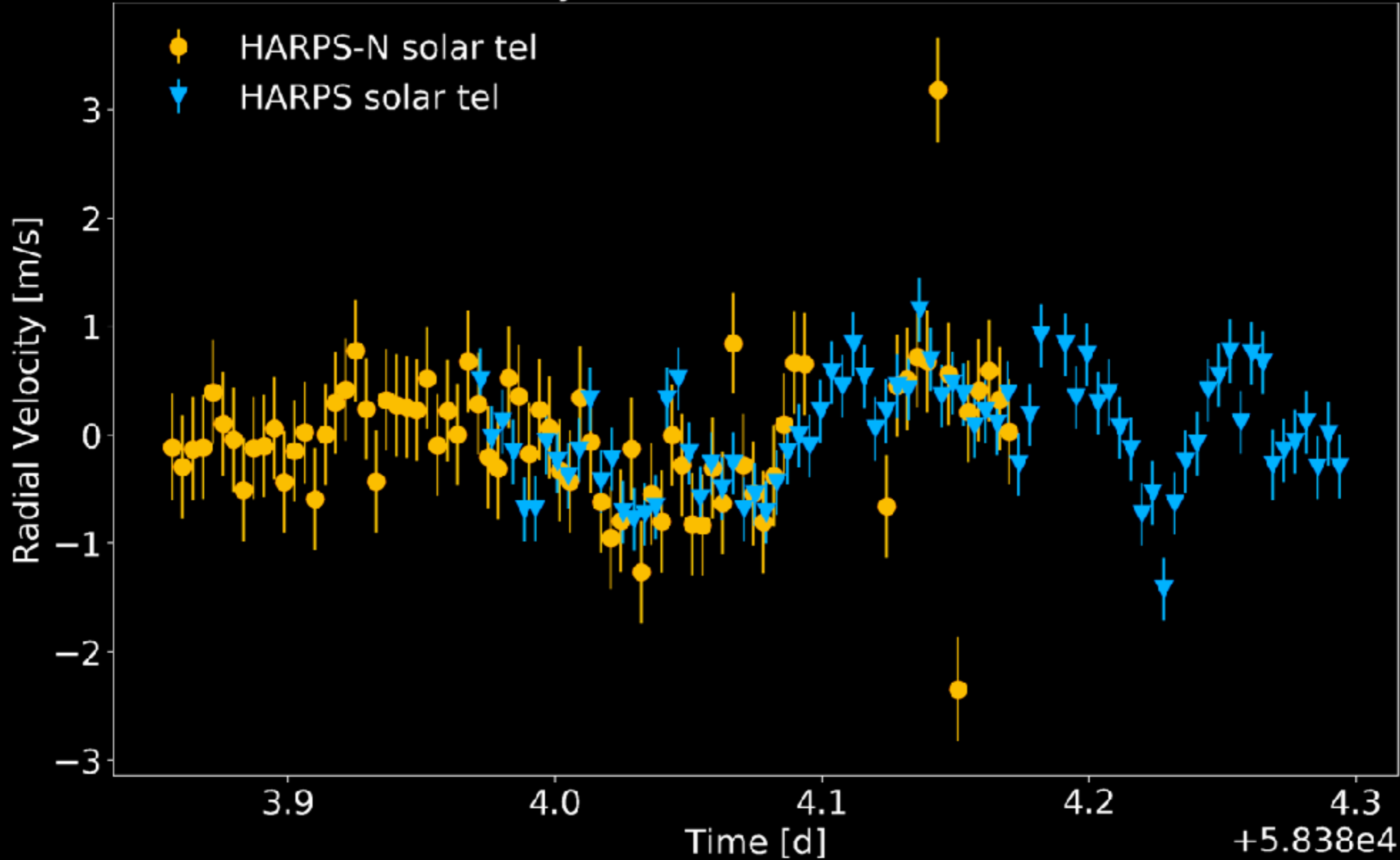
Radial Velocity of the Sun as a function of time



Radial Velocity of the Sun as a function of time

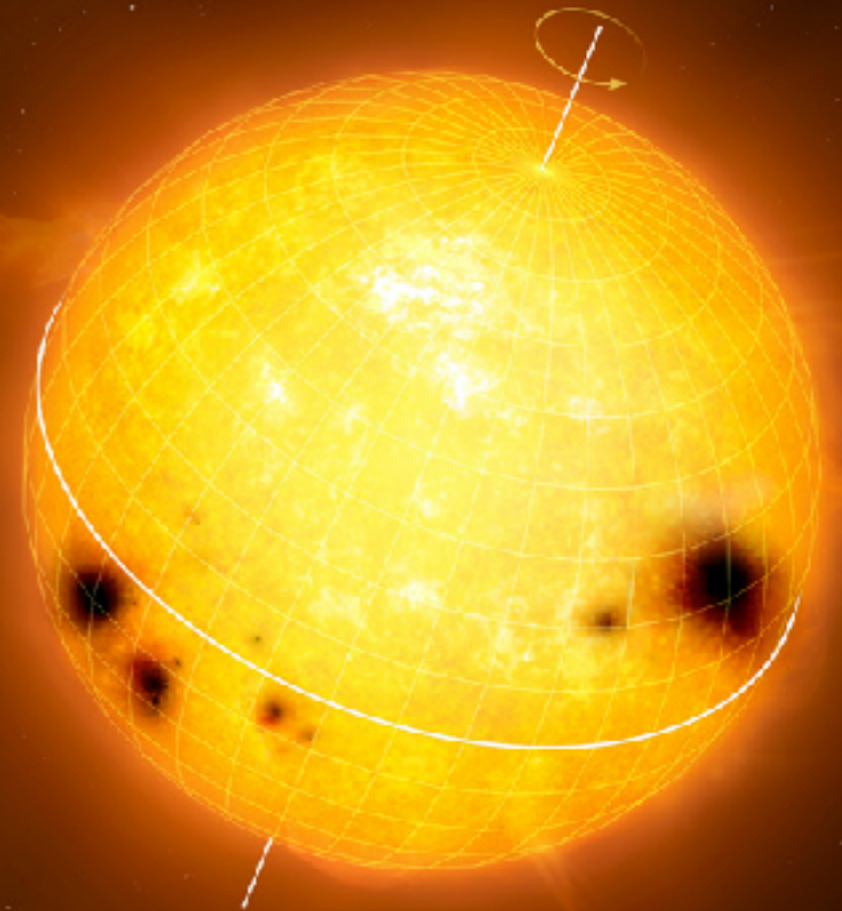
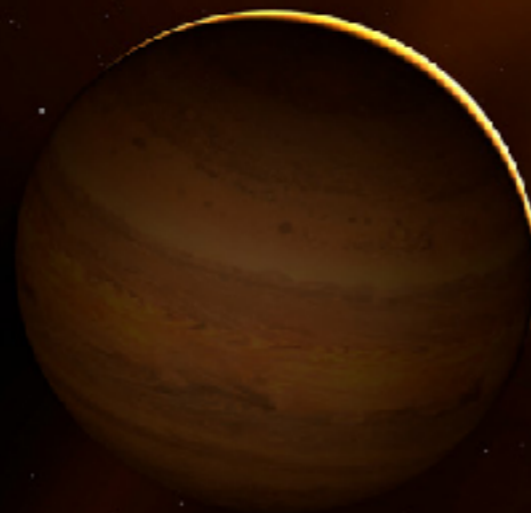


Radial Velocity of the Sun as a function of time



Line by line radial velocities
-> promising way to solve
for stellar activity

Excellent data
-> solar feeds for
EPRV instruments

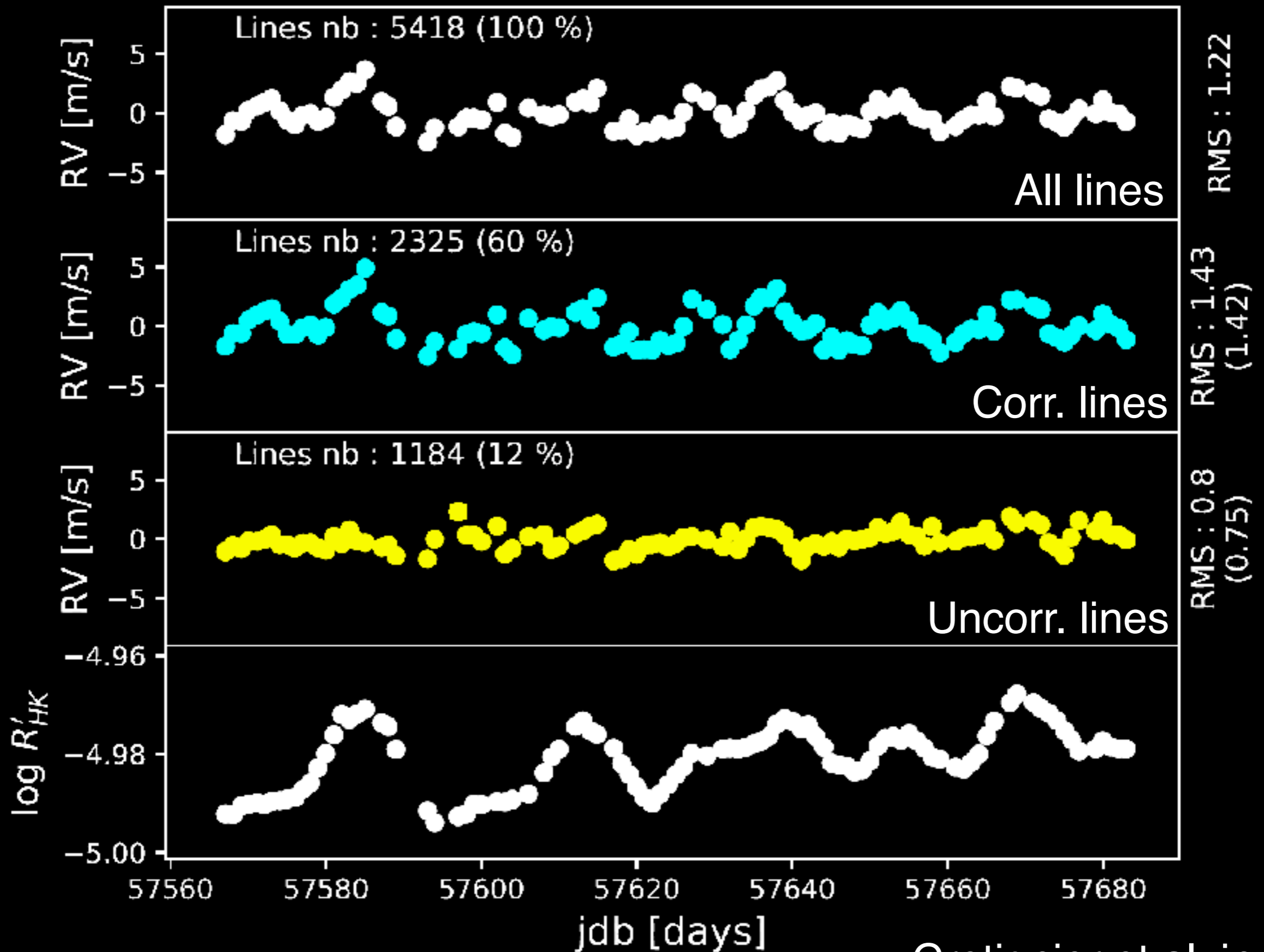


Xavier Dumusque
Branco-Weiss fellow

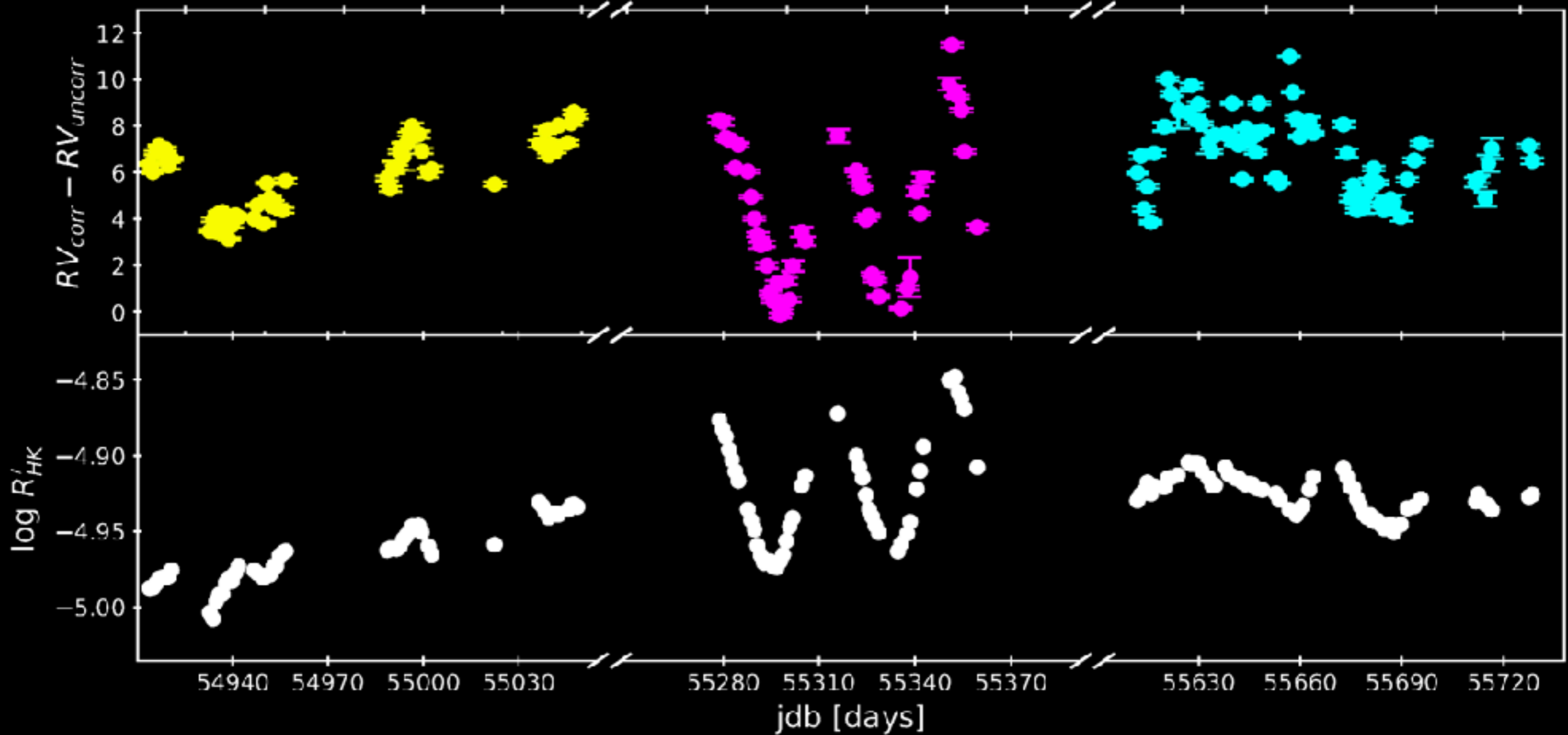


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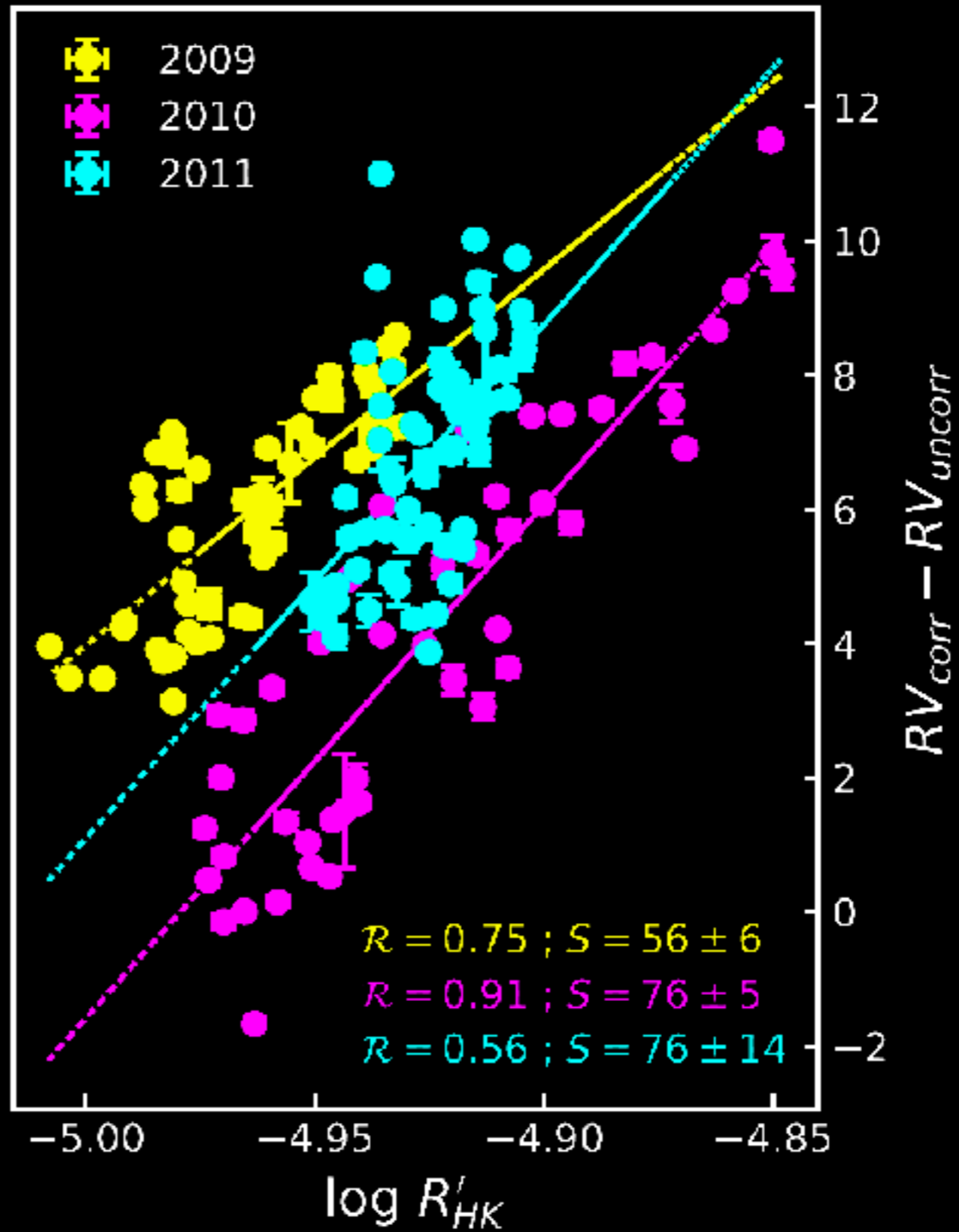
The Sun



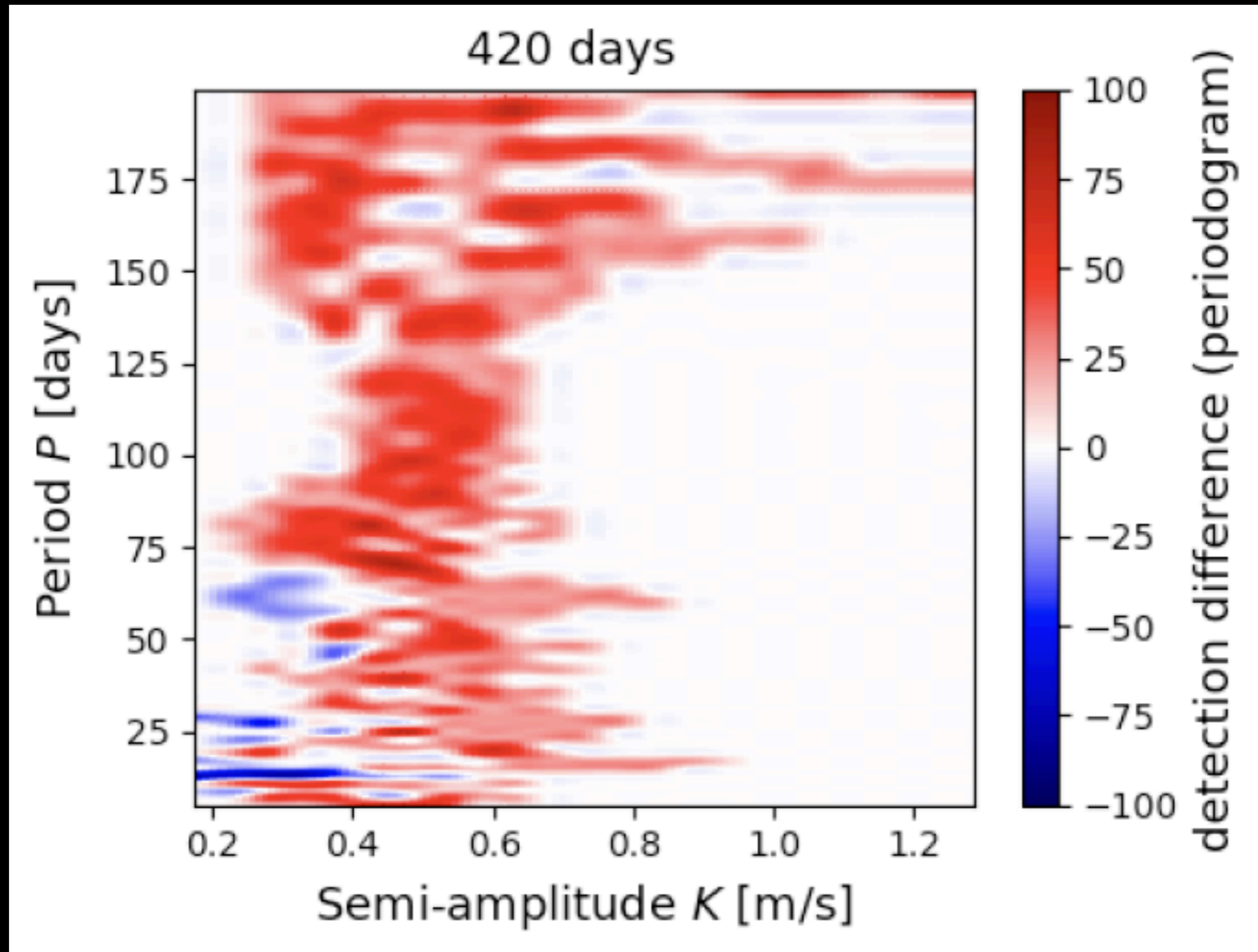
New Activity Indicator



New Activity Indicator

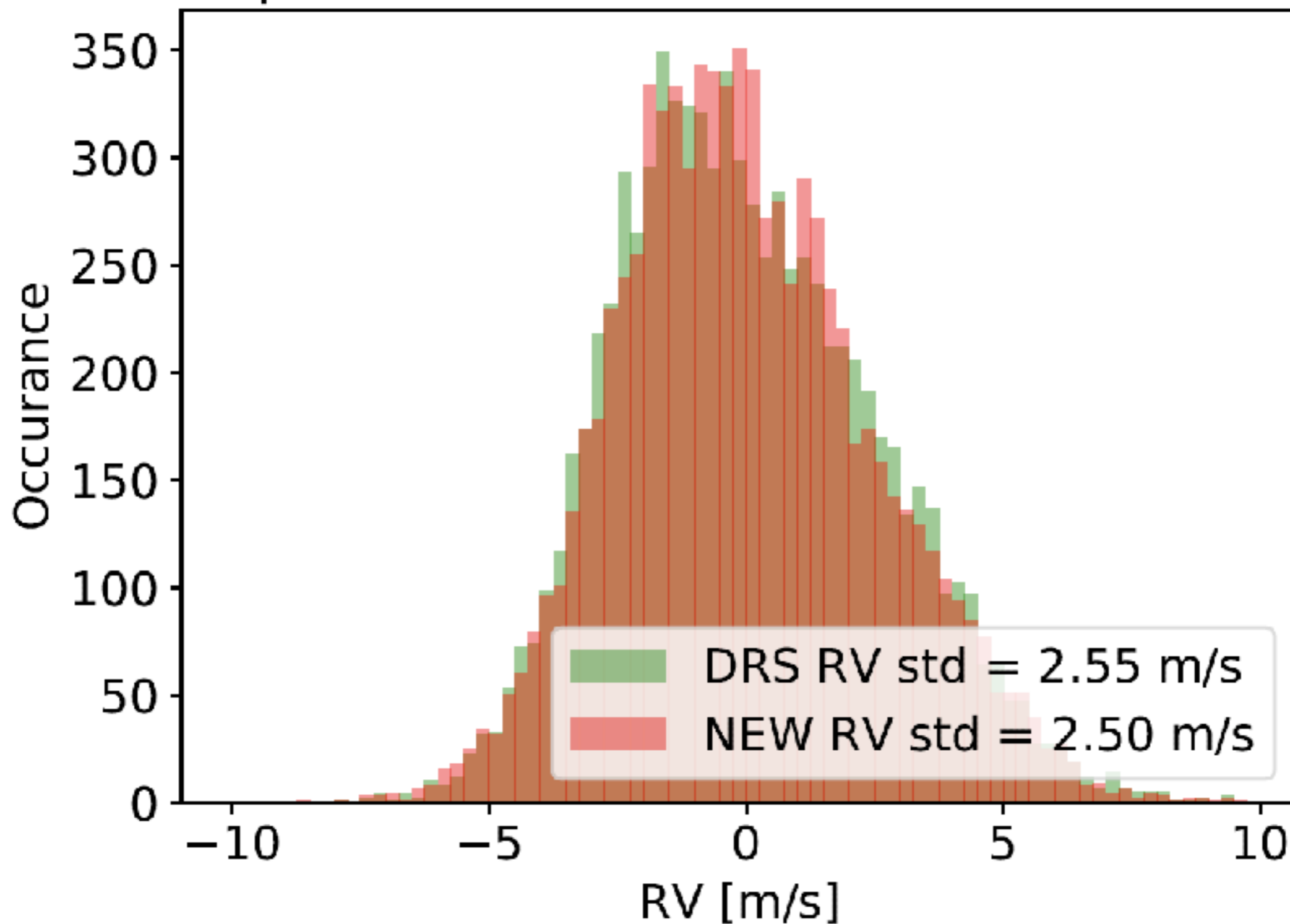


Difference in detection limits for the Sun

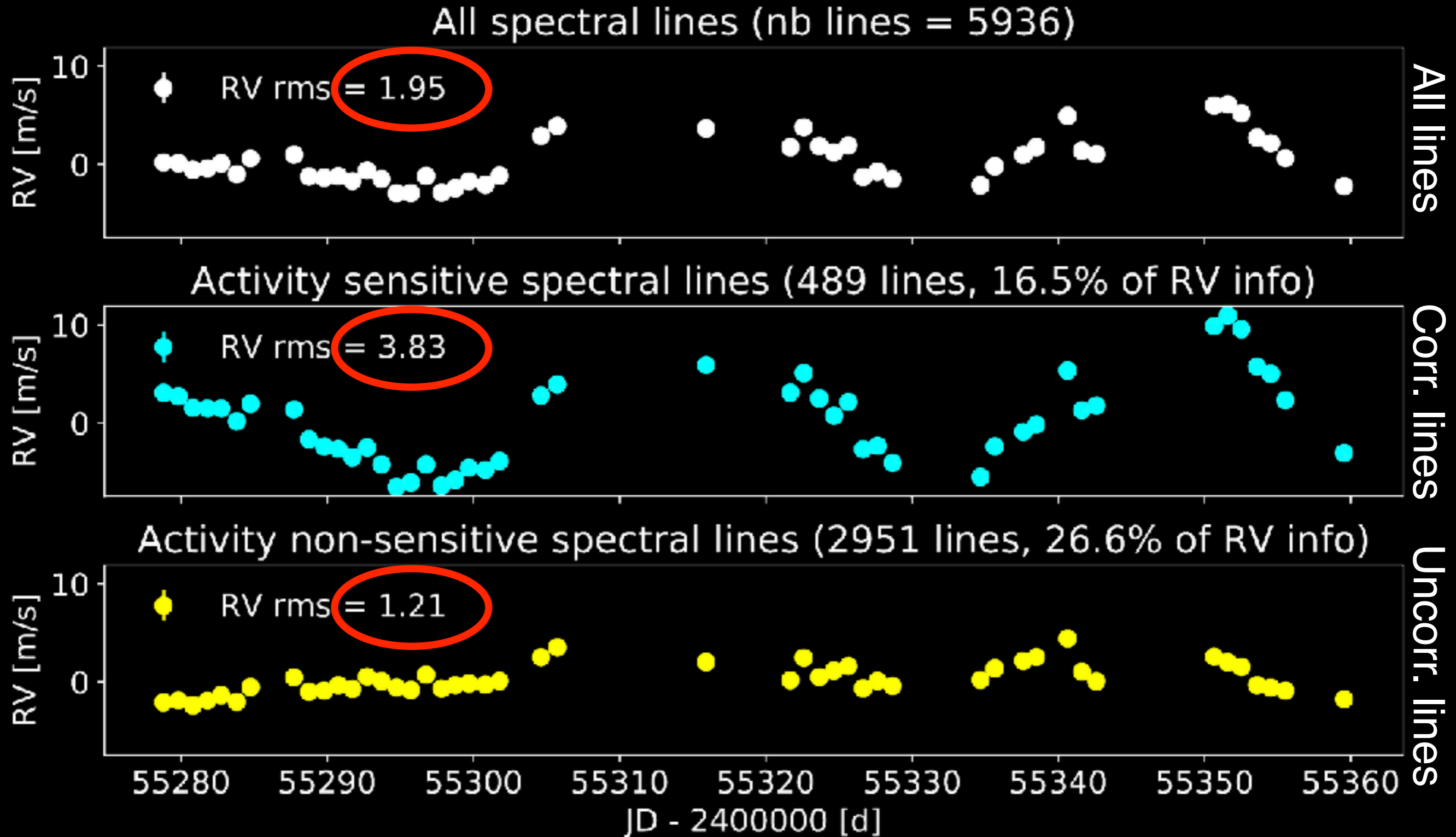


Alpha Cen B

Comparison between the RVs of HD128621

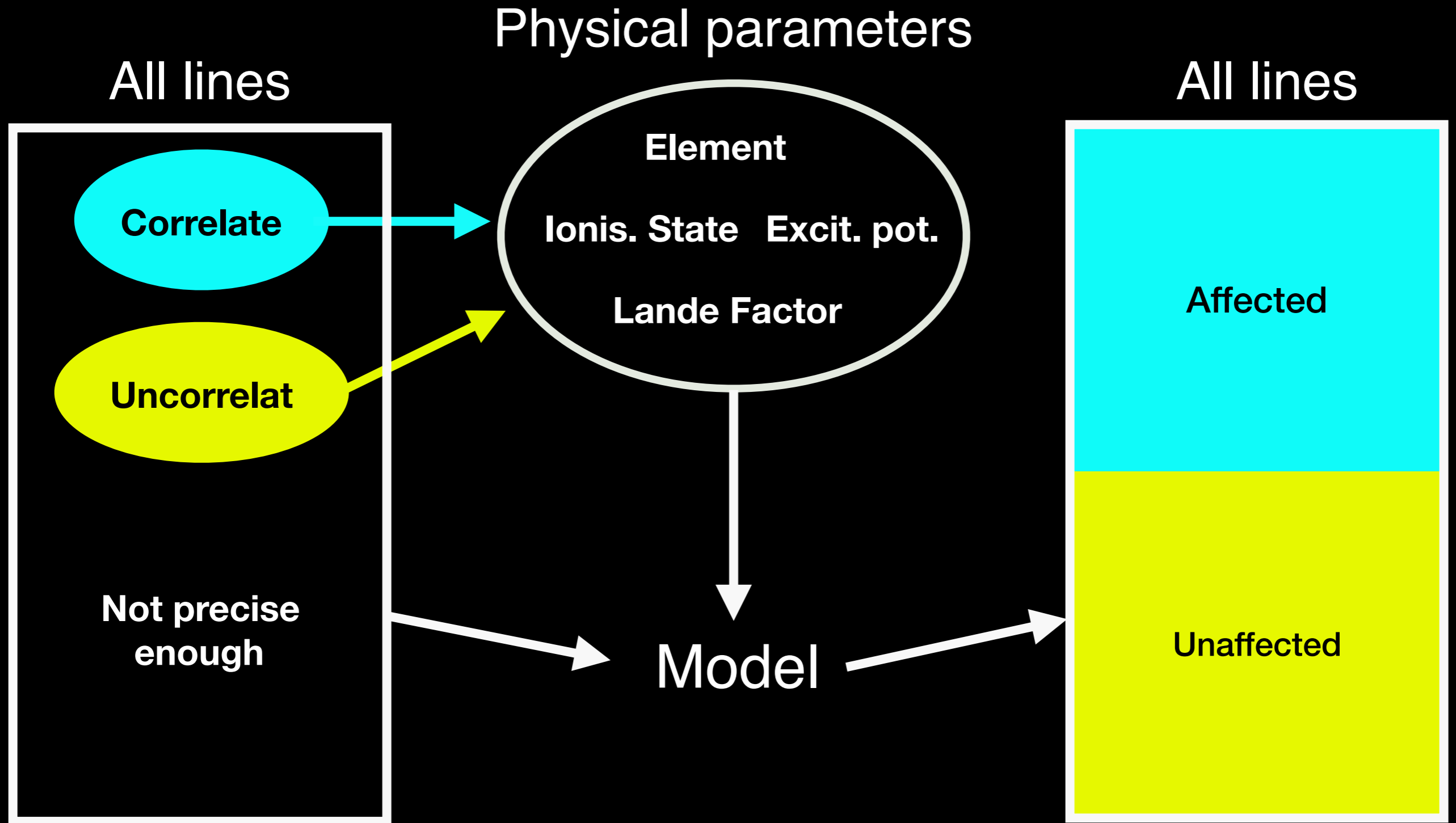


Mitigating stellar activity



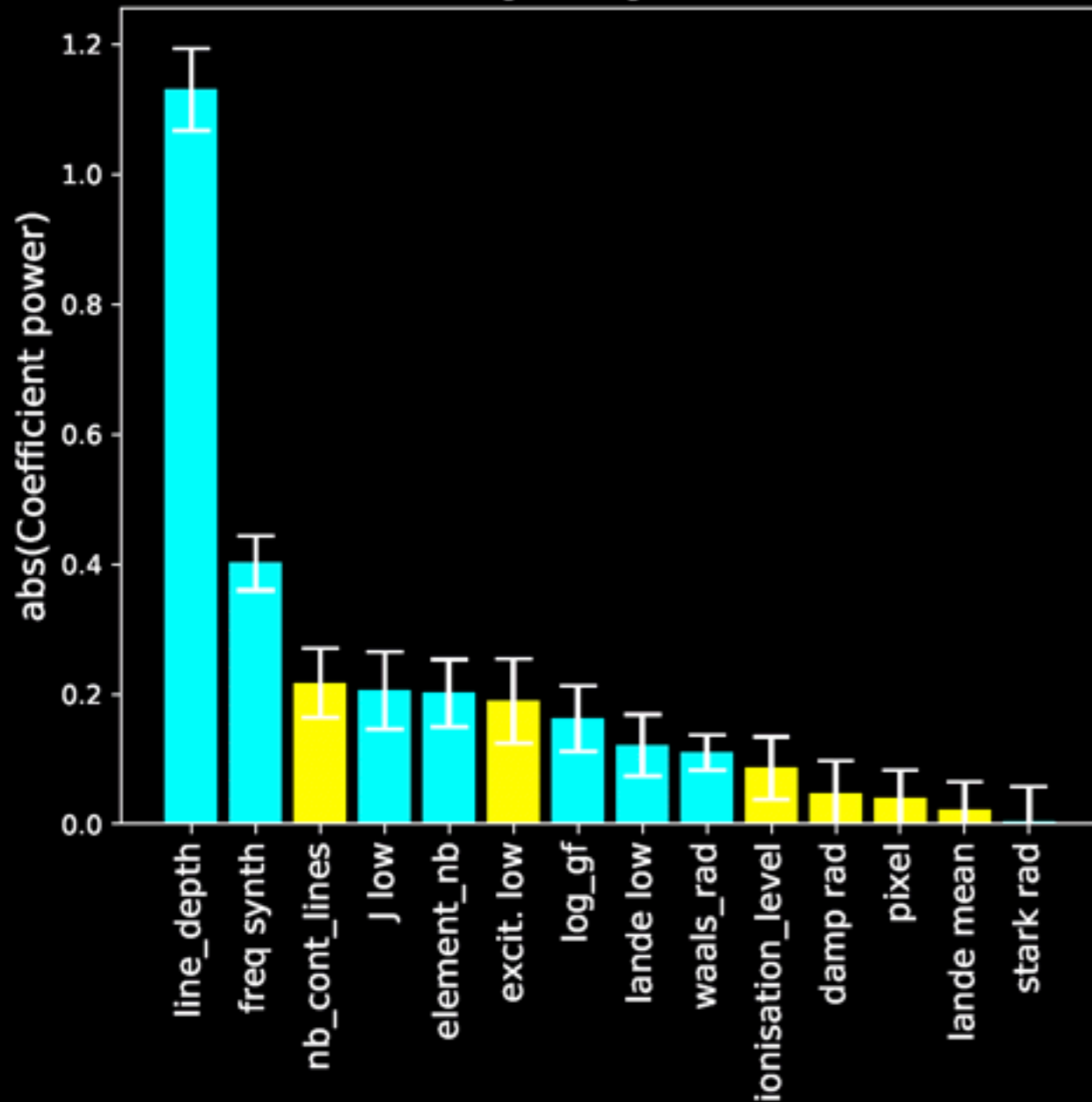
We need **precise** enough spectral **lines**

Machine Learning



Dependance on physical line parameters

Logistic regression



XGB classification

