

DIVING INTO THE PLANETARY SYSTEM OF PROXIMA WITH NIRPS

A. Suárez Mascareño
NIRPS Consortium



Universidad
de La Laguna

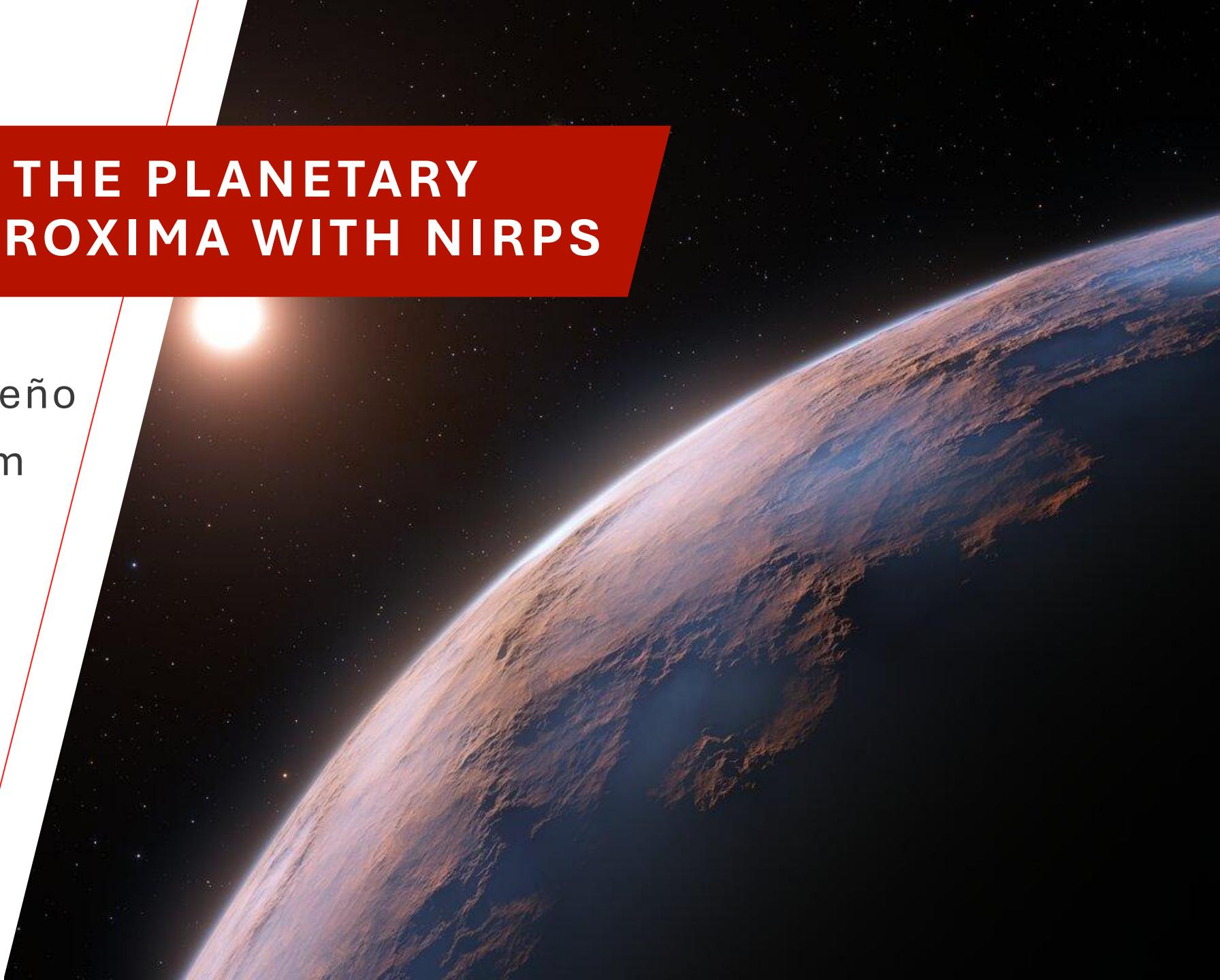


GOBIERNO
DE ESPAÑA

MINISTERIO
DE CIENCIA, INNOVACIÓN
Y UNIVERSIDADES



EXCELENCIA
SEVERO
OCHOA
CONSEJERO DE INVESTIGACIONES



NIRPS Consortium

Univ. Geneva (Switzerland), Univ. Montreal (Canada), IAC (Spain), Univ. Porto (Portugal)
Univ. Grenoble (France), Univ. Rio Grande do Norte (Brazil)



NIRPS

NIR spectrograph

3.6m ESO telescope

- La Silla Observatory

YJH-band coverage

R~75 000 – 90 000

AO-assisted

Designed for 1 m/s

- Thermally/pressure stabilized
- Precise wavelength calibration



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PROXIMA

Sp. Type: M5.5V

Eff. Temperature: 2900 K

Mass: $0.12 M_{\text{Sun}}$

Radius: $0.15 R_{\text{Sun}}$

Age: 4.9 Gyr

Visual magnitude: 11.1

Rotation ~83 days

Cycle ~7 years*

*Not really

Proxima Star

Light Years

4 Light Years

2 Light Years

Oort Cloud

Sun

Alpha Centauri A&B
Proxima Centauri

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1 confirmed planet
2 candidate planets

Proxima b (confirmed)
P. orb 11.19 d – Habitable zone
Mass $1.1 M_{\oplus}$
Krv 1.25 m/s – Benchmark for NIRPS

Proxima c (candidate, challenged)
P. orb 1900 d
Mass $5.2 M_{\oplus}$
Krv 1.2 m/s

Proxima d (candidate)
P. orb 5.12 d
Mass $0.26 M_{\oplus}$
Krv 0.39 m/s

NIRPS GTO DATA

NIRPS

149 epochs

RMS RV 1.69 m/s

sigRV 55 cm/s

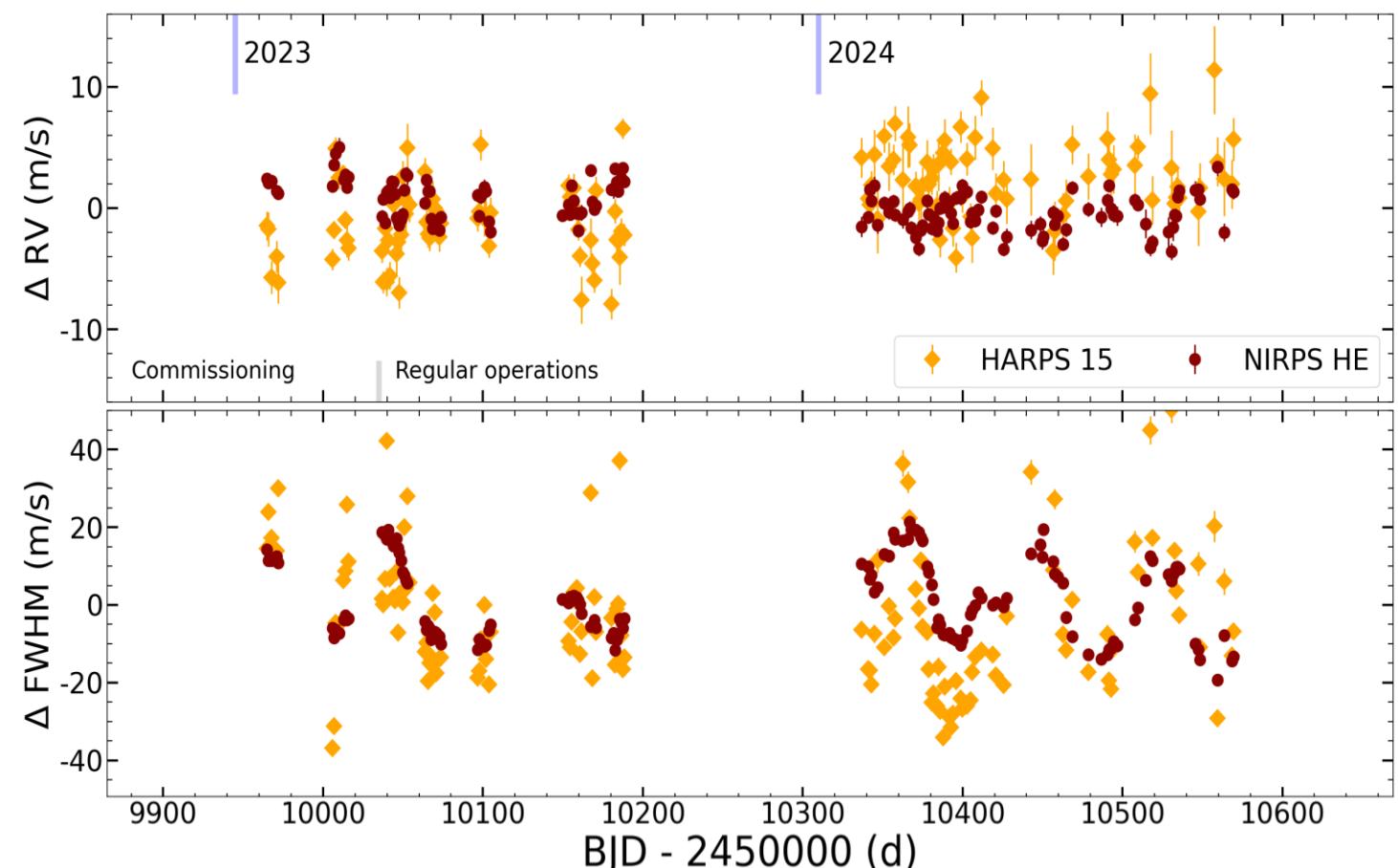
HARPS

135 epochs

RMS RV 3.5 m/s

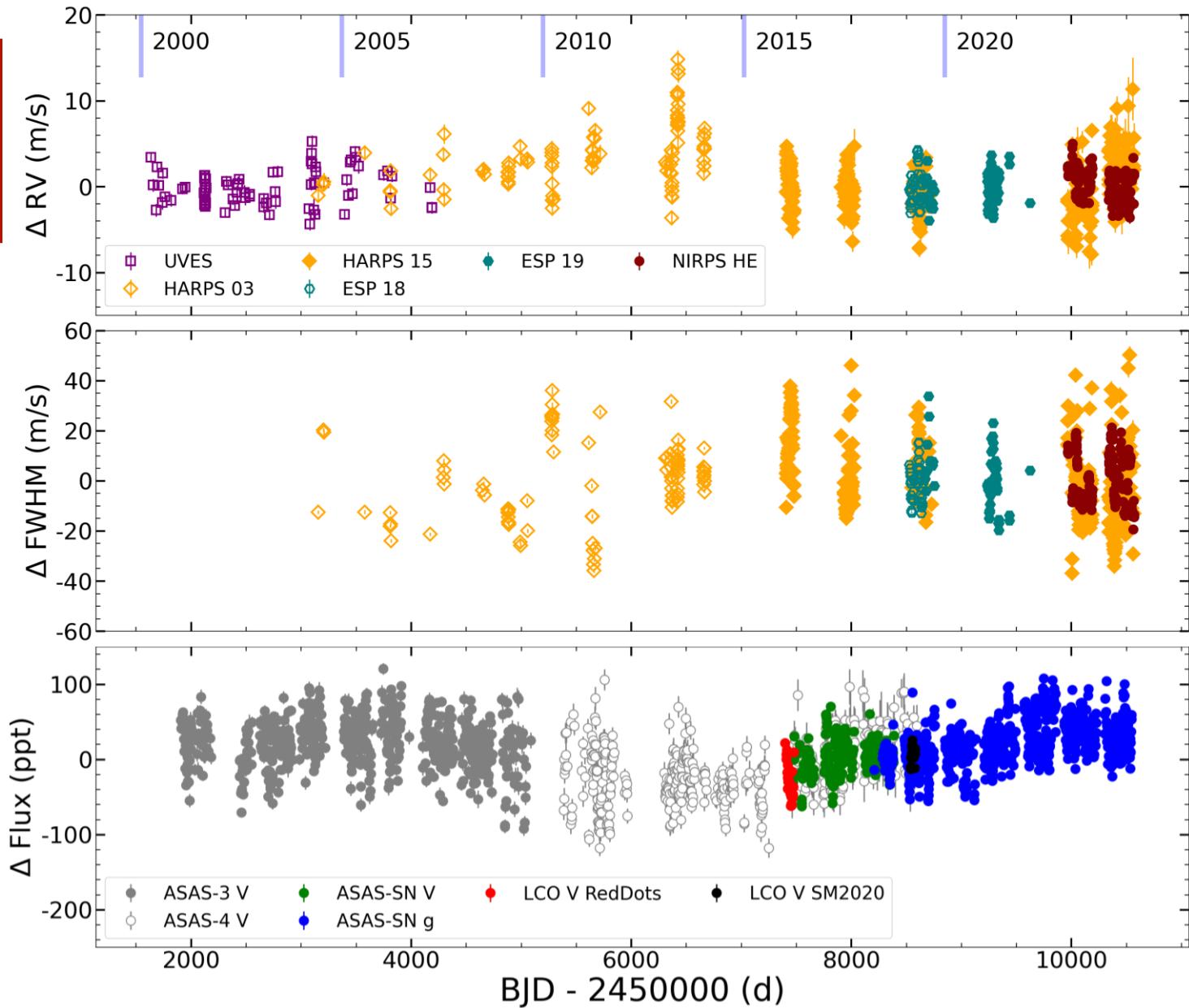
sigRV 1.4 m/s

Baseline 600 days



ALL DATA

- **NIRPS** – 149 epochs
RMS RV 1.69 m/s
- **HARPS** – 393 epochs
RMS RV 3.2 m/s
- **ESPRESSO** – 116 epochs
RMS RV 1.98 m/s
- **UVES** – 77 epochs
RMS RV 2.0 m/s
- **Photometry** – 2200 epochs
- Baseline 24 years

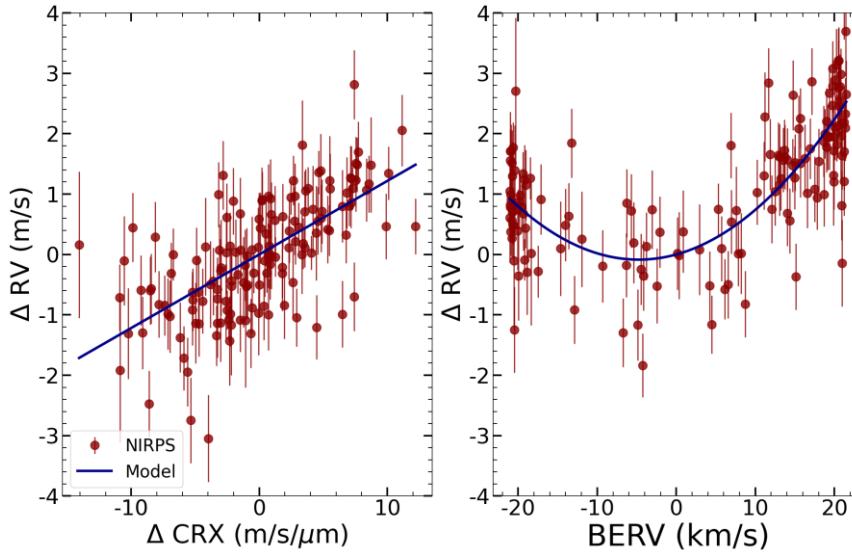


MODEL DEFINITION

The “null” model includes:

- Cycle component
- Multi-dimensional GP (S+LEAF), using phot. And FWHM
- Trend against CRX
- Polynomial against BERV

$$\begin{aligned}\Delta Flux &= V0 + Cycle + Rot , \\ \Delta FWHM_{NIR} &= V0 + Cycle + Rot , \\ \Delta FWHM_{VIS} &= V0 + Cycle + Rot , \\ \Delta RV_{NIR} &= V0 + f_{CRX} + f_{BERV} + Cycle + Rot + Planets , \\ \Delta RV_{VIS} &= V0 + f_{CRX} + f_{BERV} + Cycle + Rot + Planets \\ k(\tau, P_{rot}, L) &= k_{SHO\ 1}(\tau, \sigma_1, P_1, Q_1) + k_{SHO\ 2}(\tau, \sigma_2, P_2, Q_2) \\ &\quad + (\sigma^2(t) + \sigma_j^2) \cdot \delta_\tau\end{aligned}$$



NIRPS-ONLY

Very significant detection of Proxima b

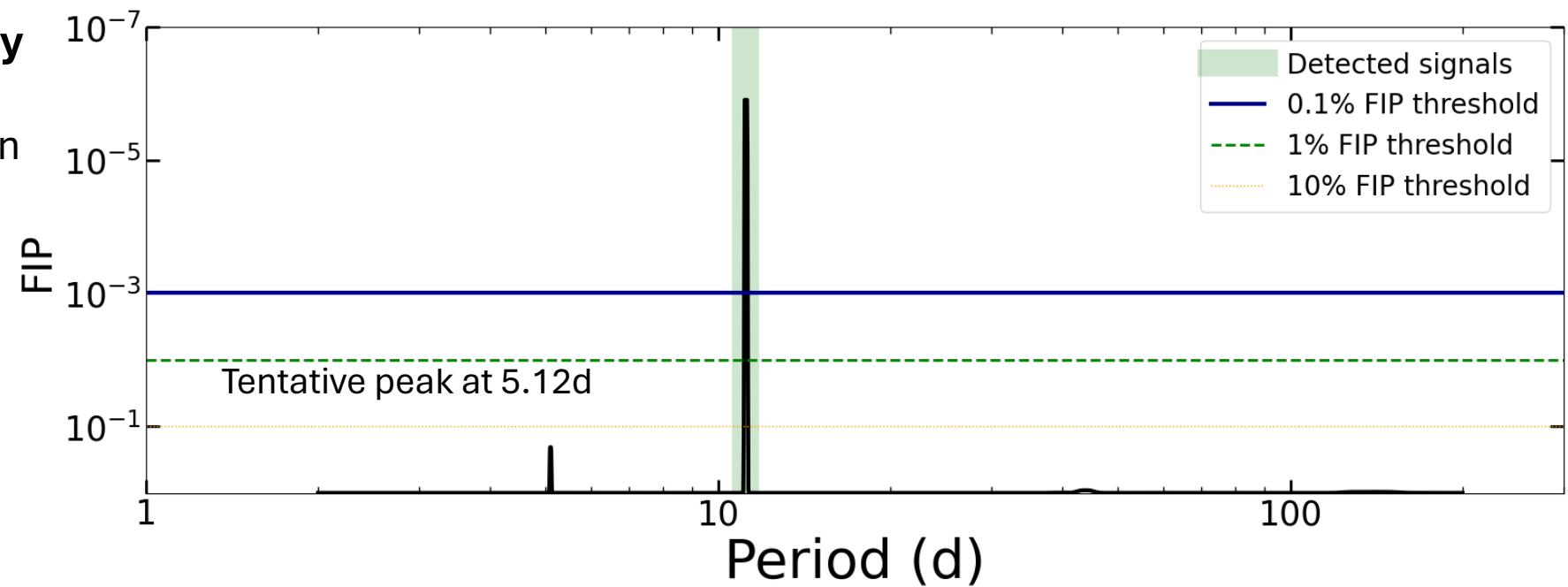
False inclusion probability

Based on the fraction of samples of the posterior within each frequency bin.

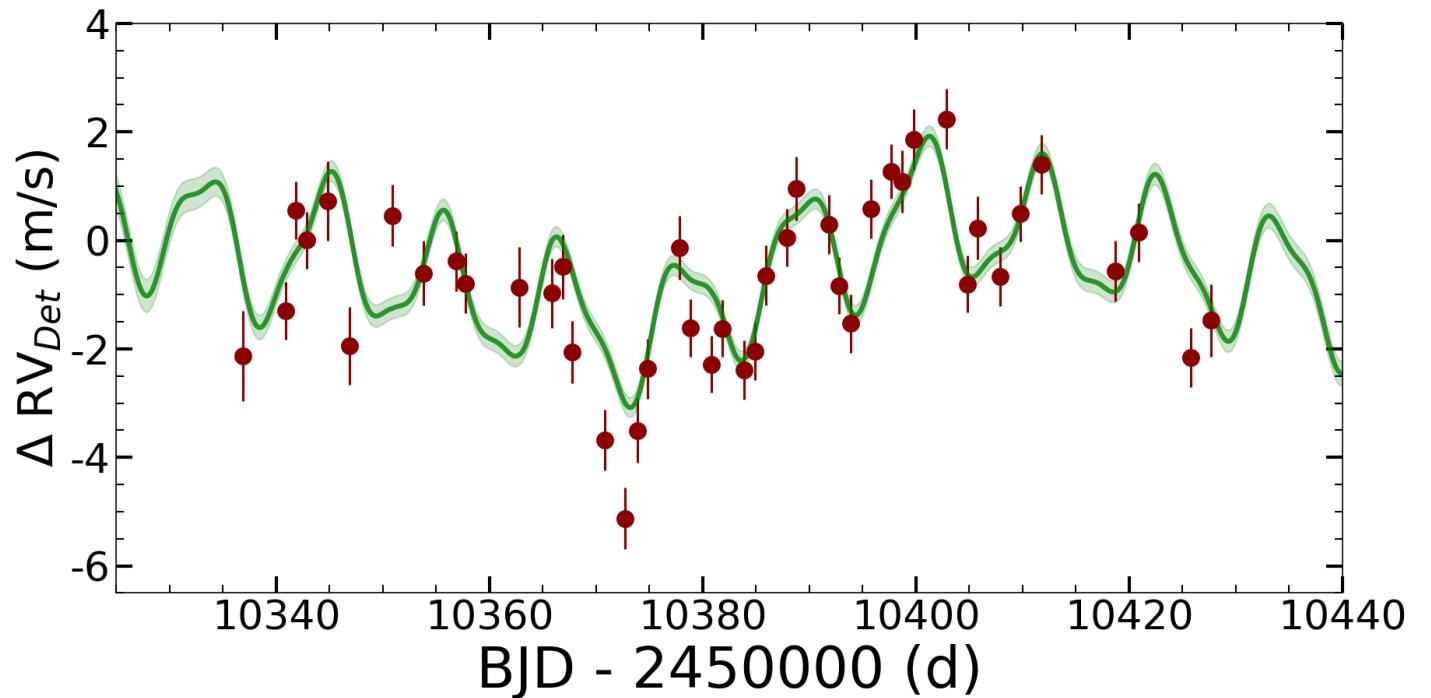
Optimistic threshold 50%

Conservative threshold 1%

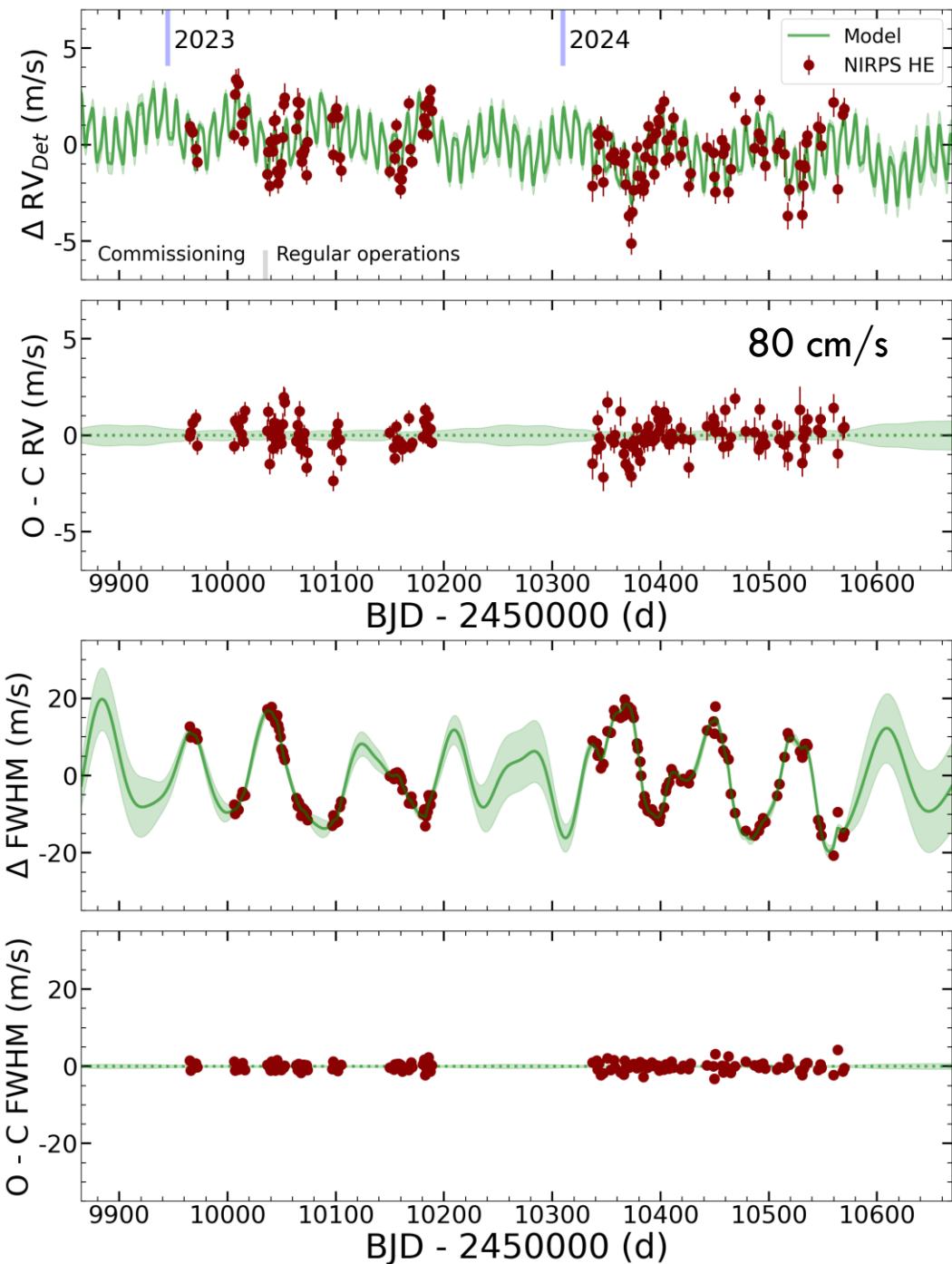
(see Hara. N. C. et al. 2022)

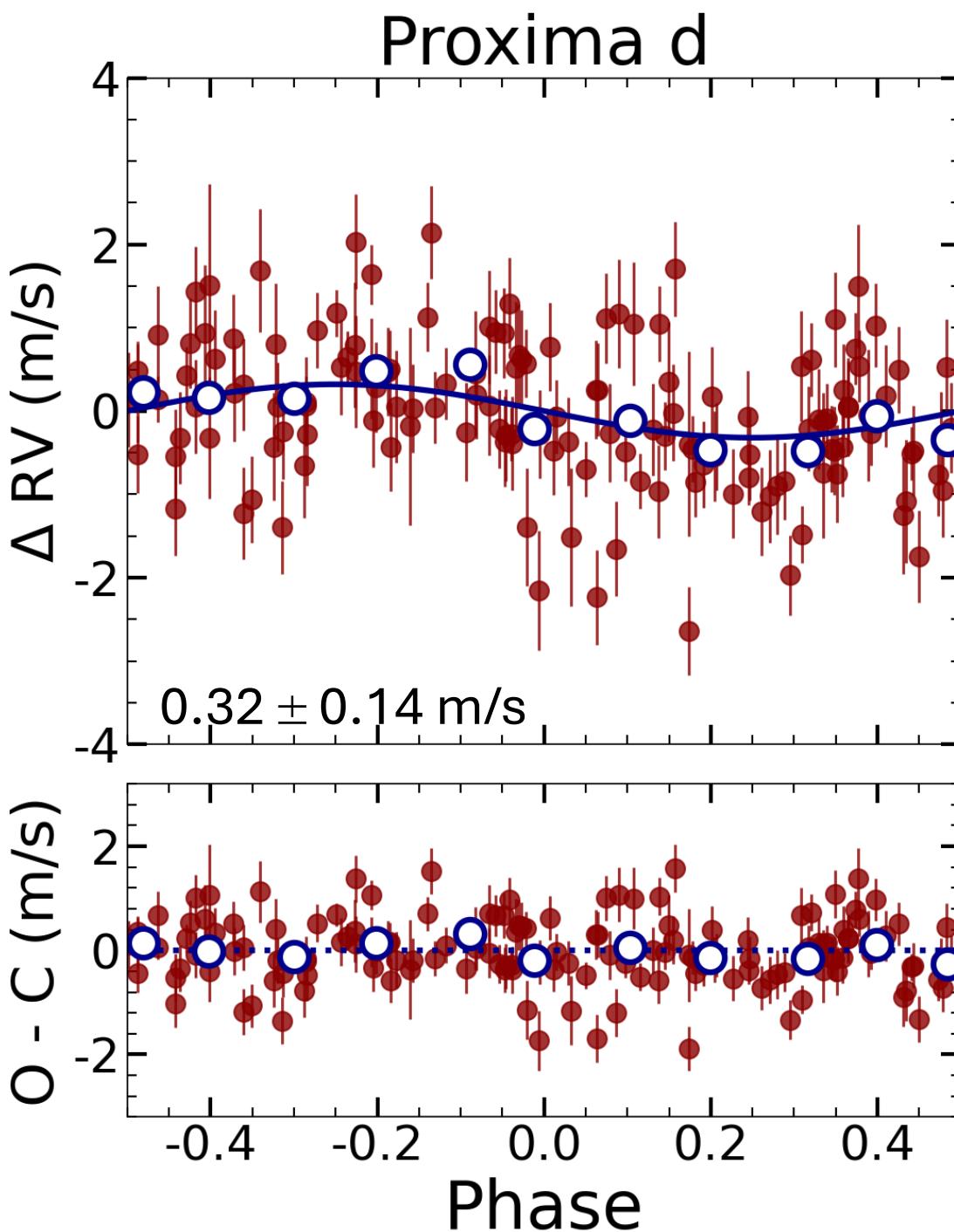
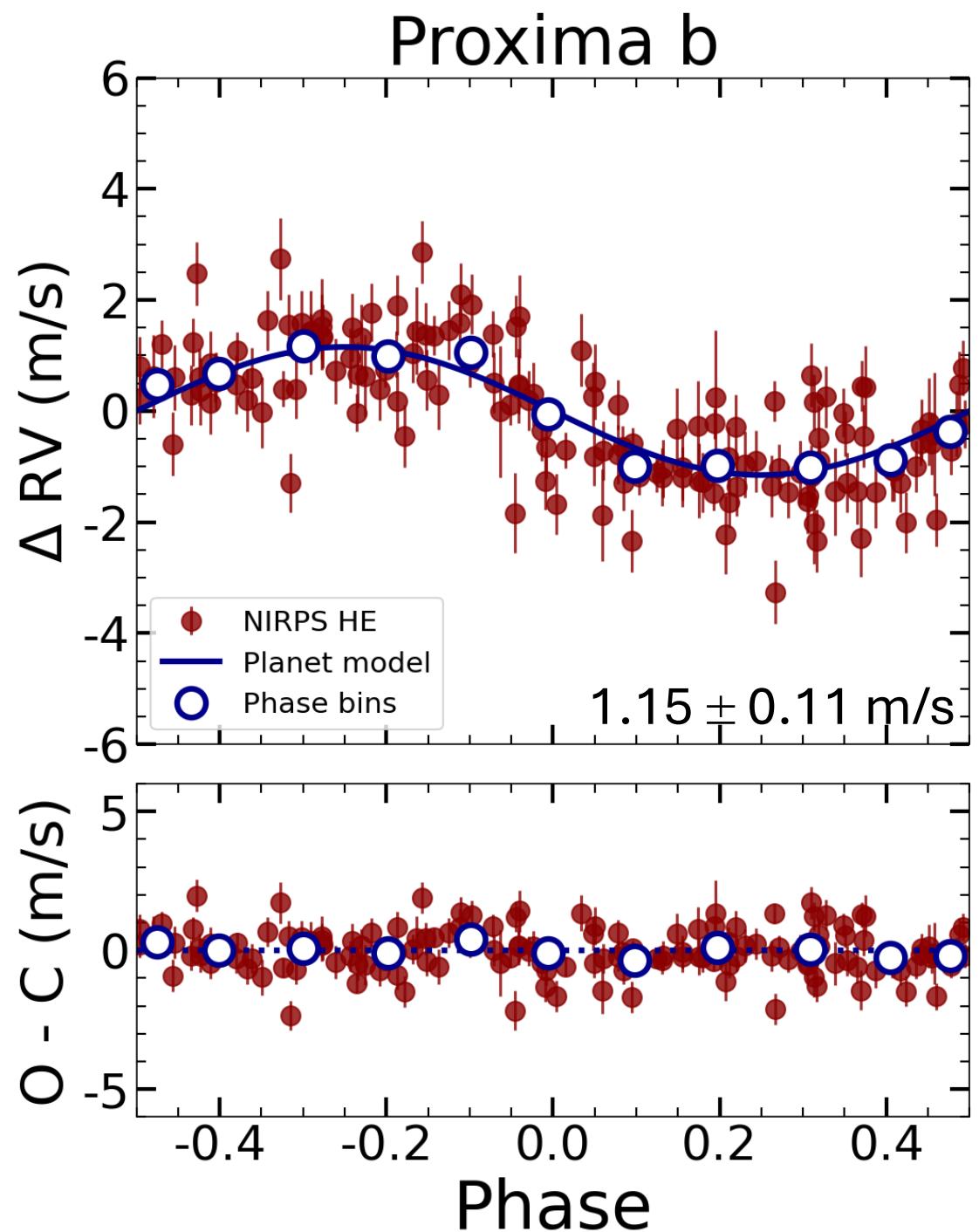


NIRPS-ONLY



*RV data has been detrended from CRX and BERV





NIRPS + HARPS (GTO)

Very significant detection of Proxima b

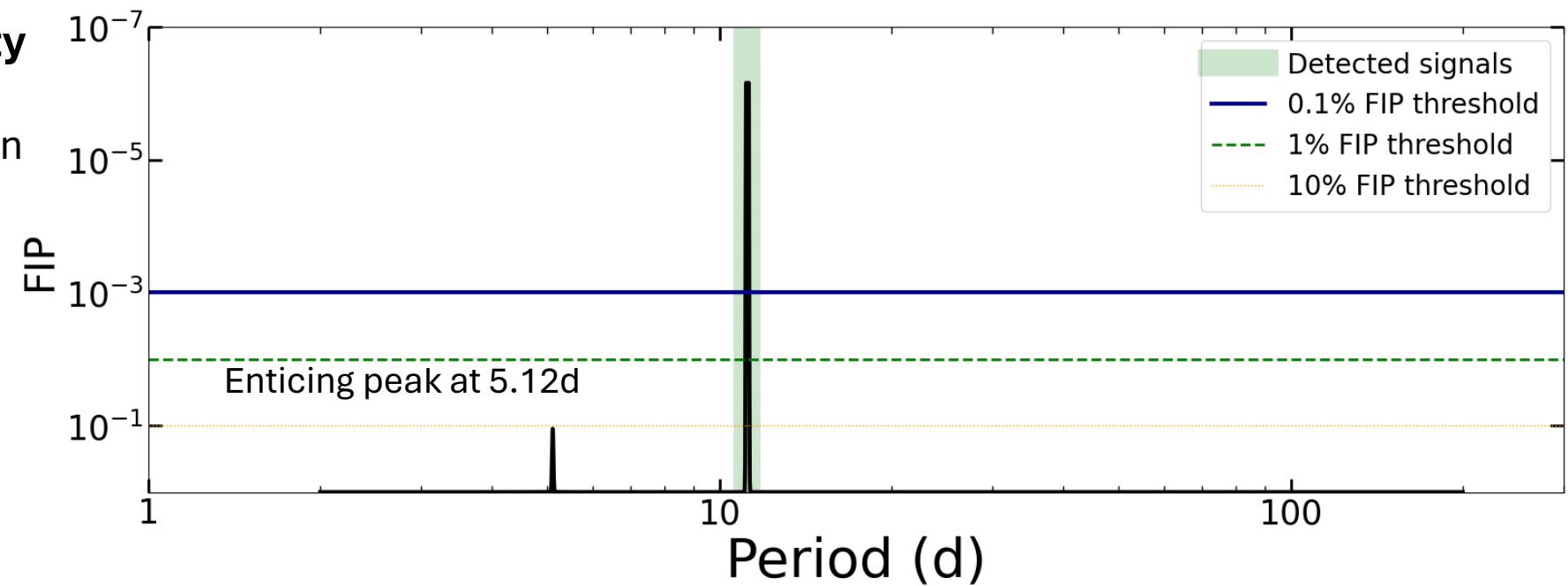
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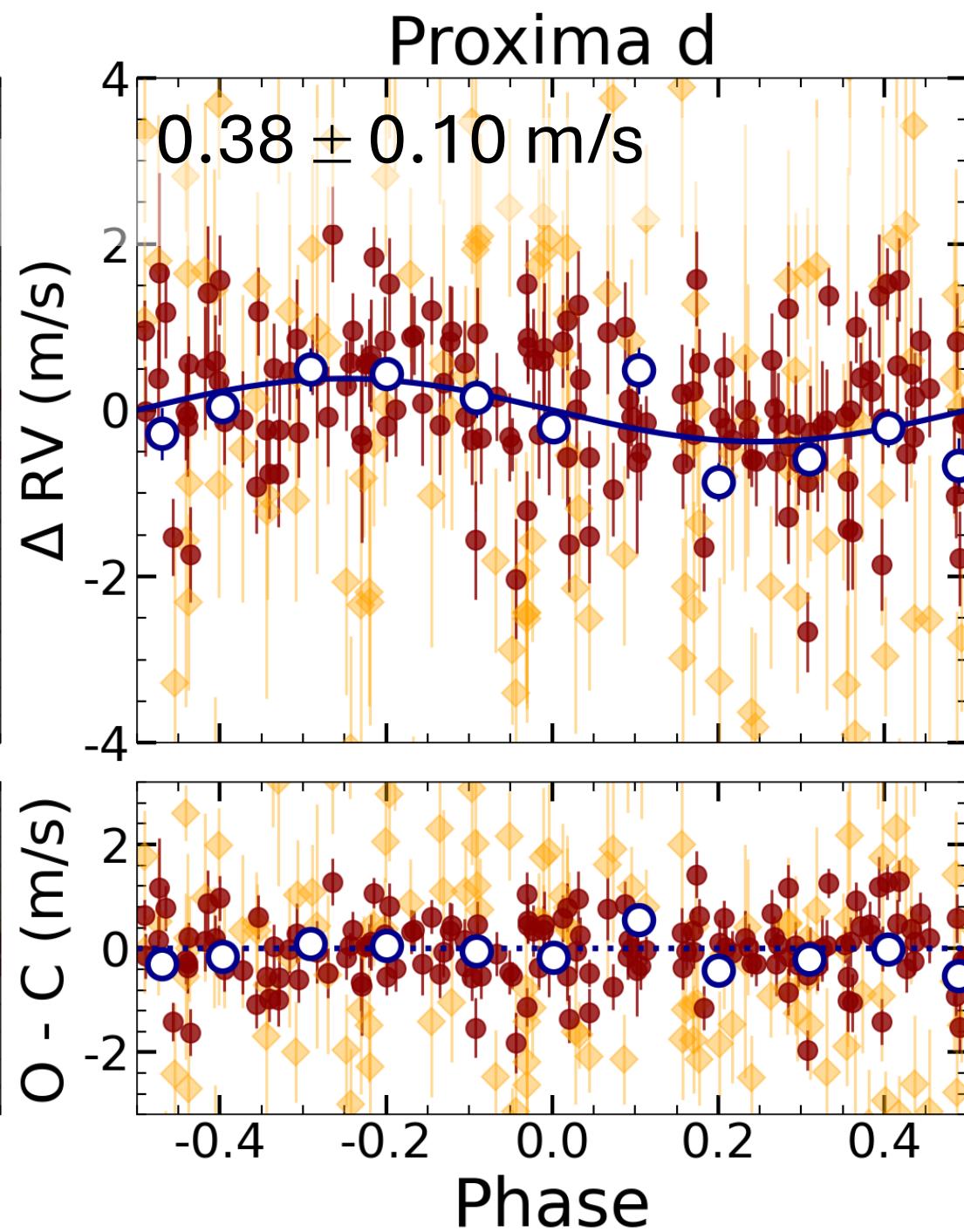
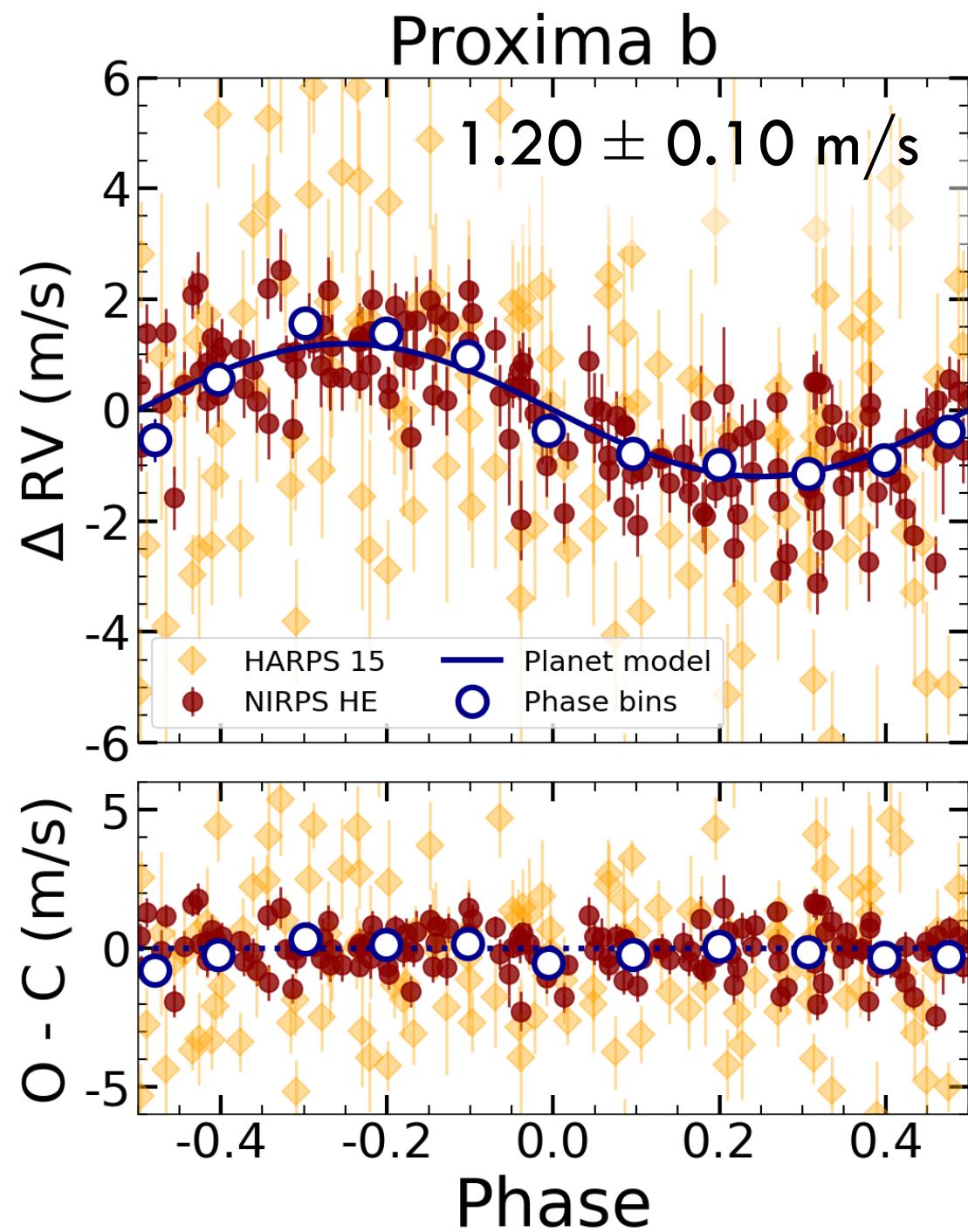
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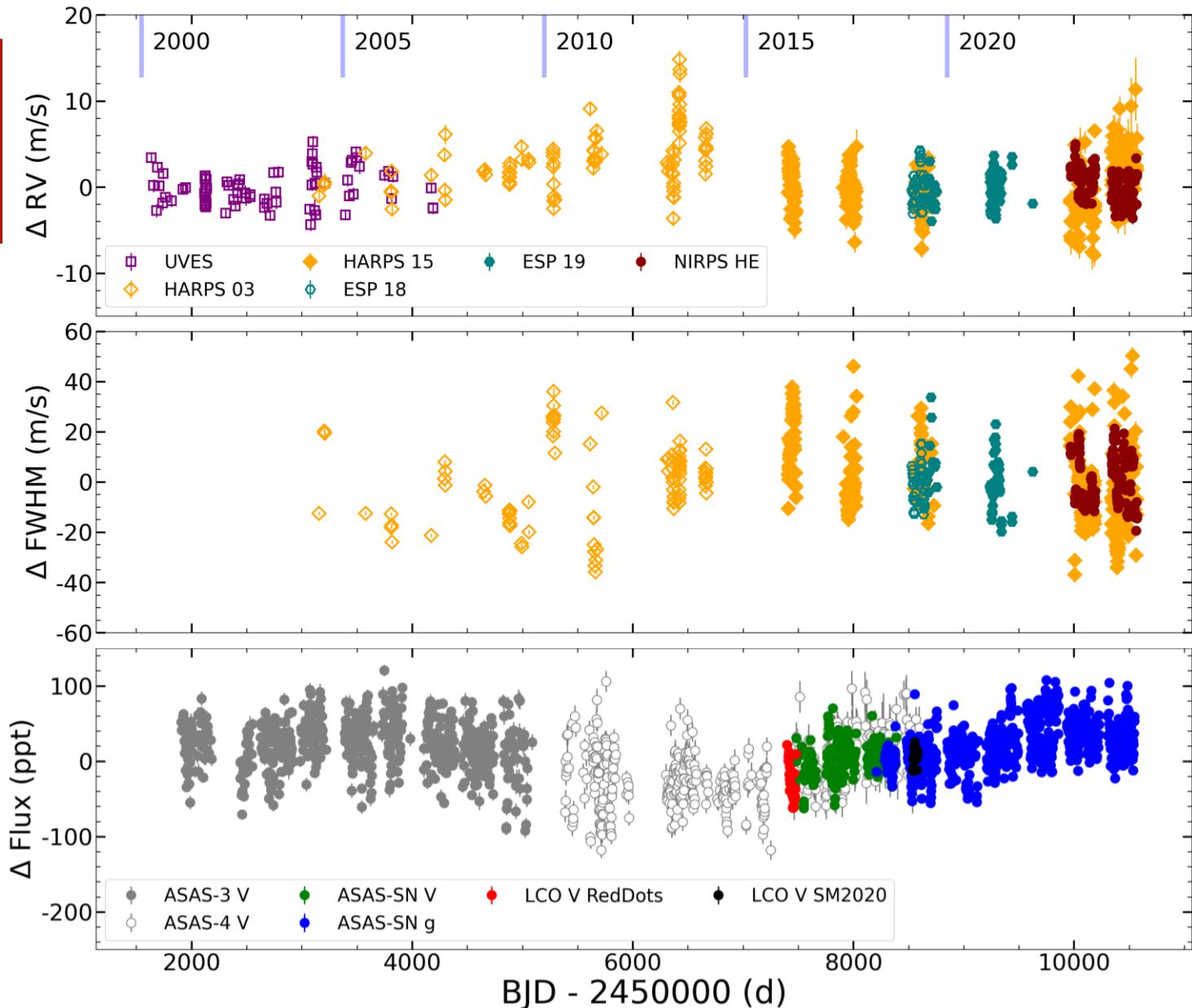
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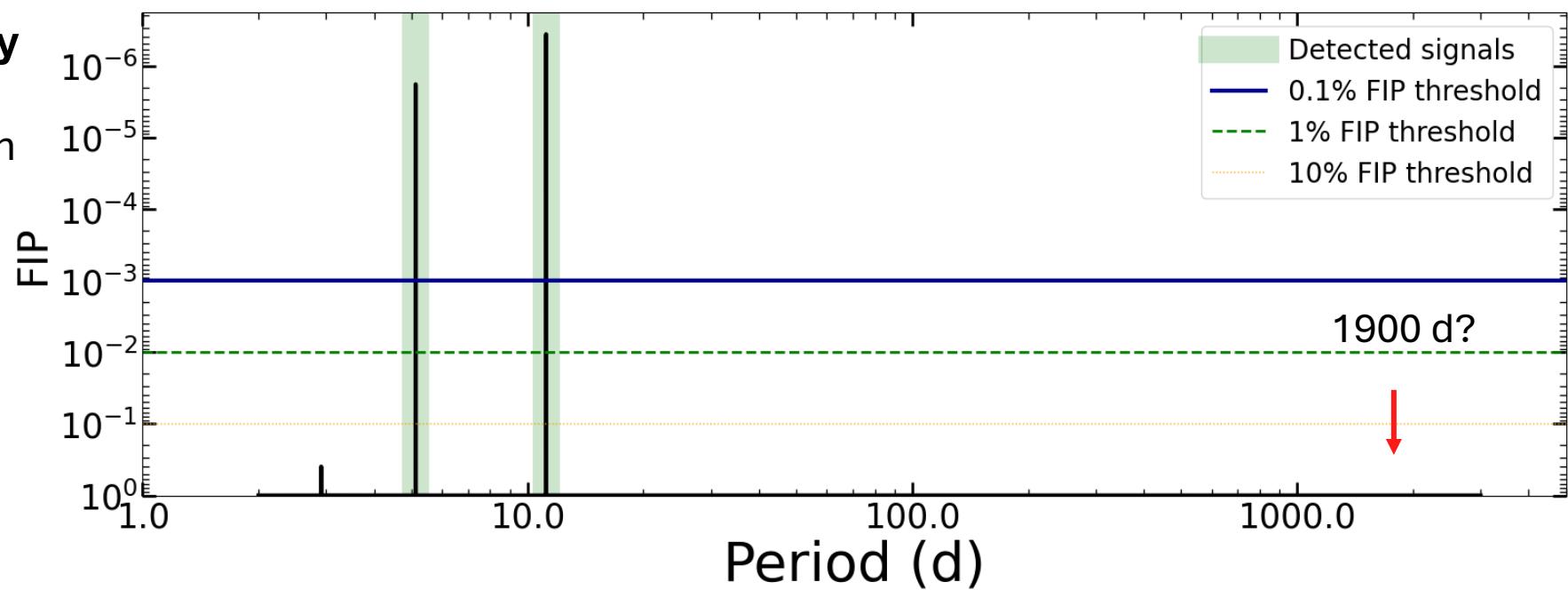
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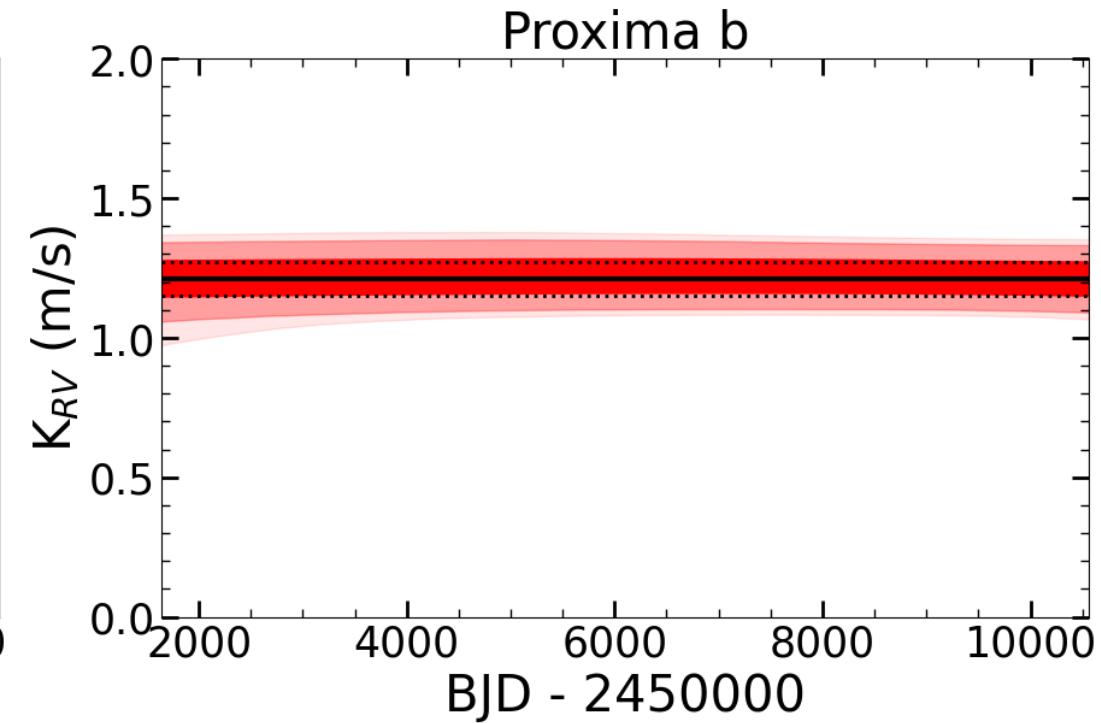
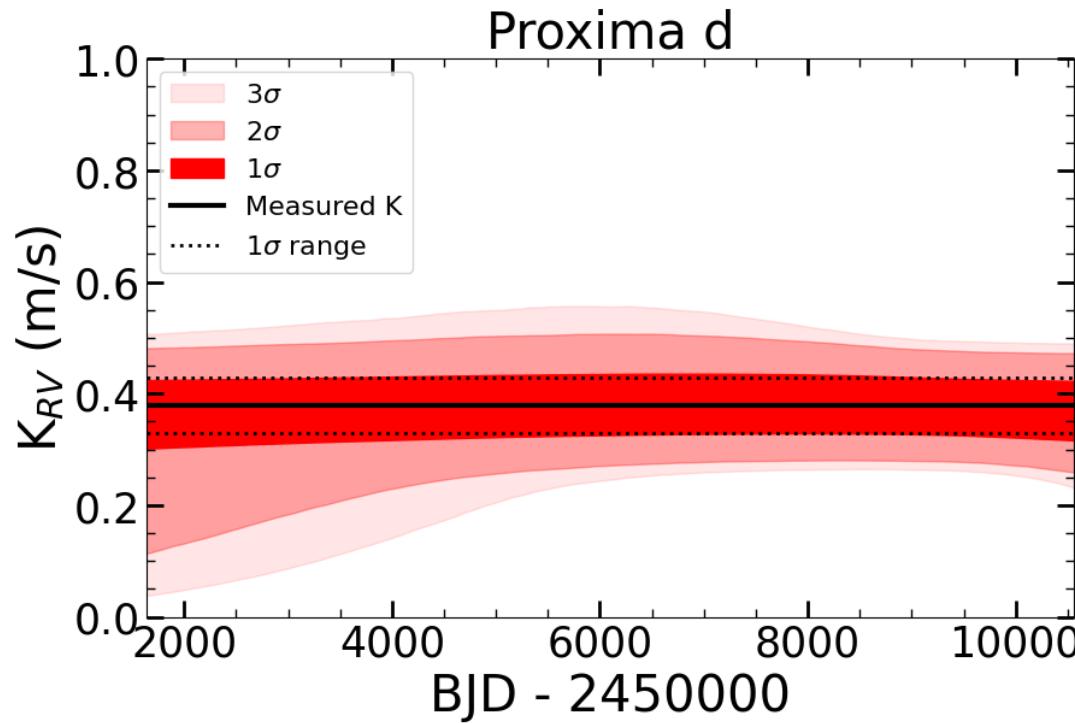
Very significant detection of Proxima b and d



SIGNAL STABILITY

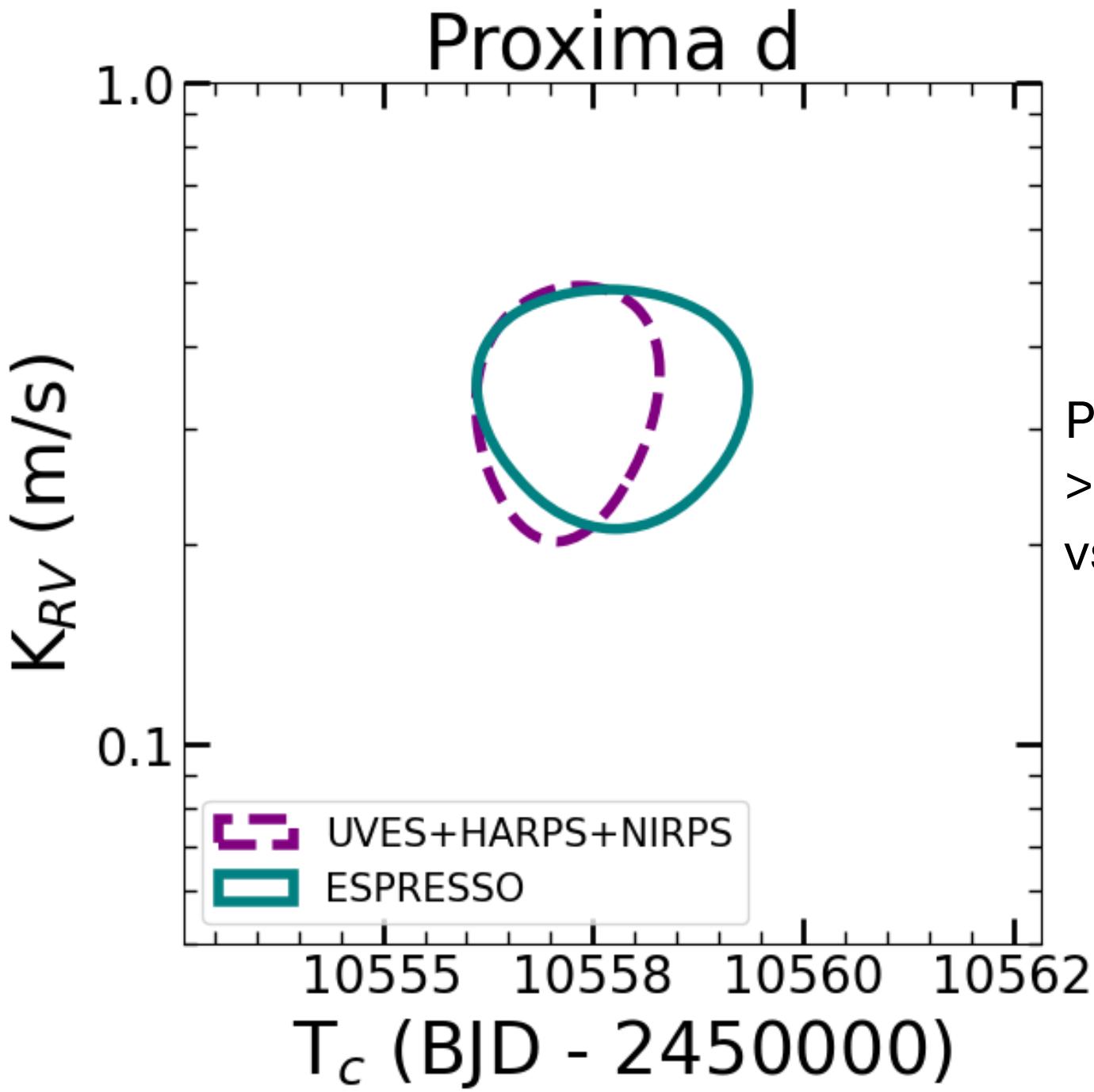
Apodized signals (Hara, N. C. et al. 2022)

$$y(t) = -K \cdot \sin(2\pi \cdot (t - t_0)/P_{pl}) \cdot G(\mu, \sigma)$$



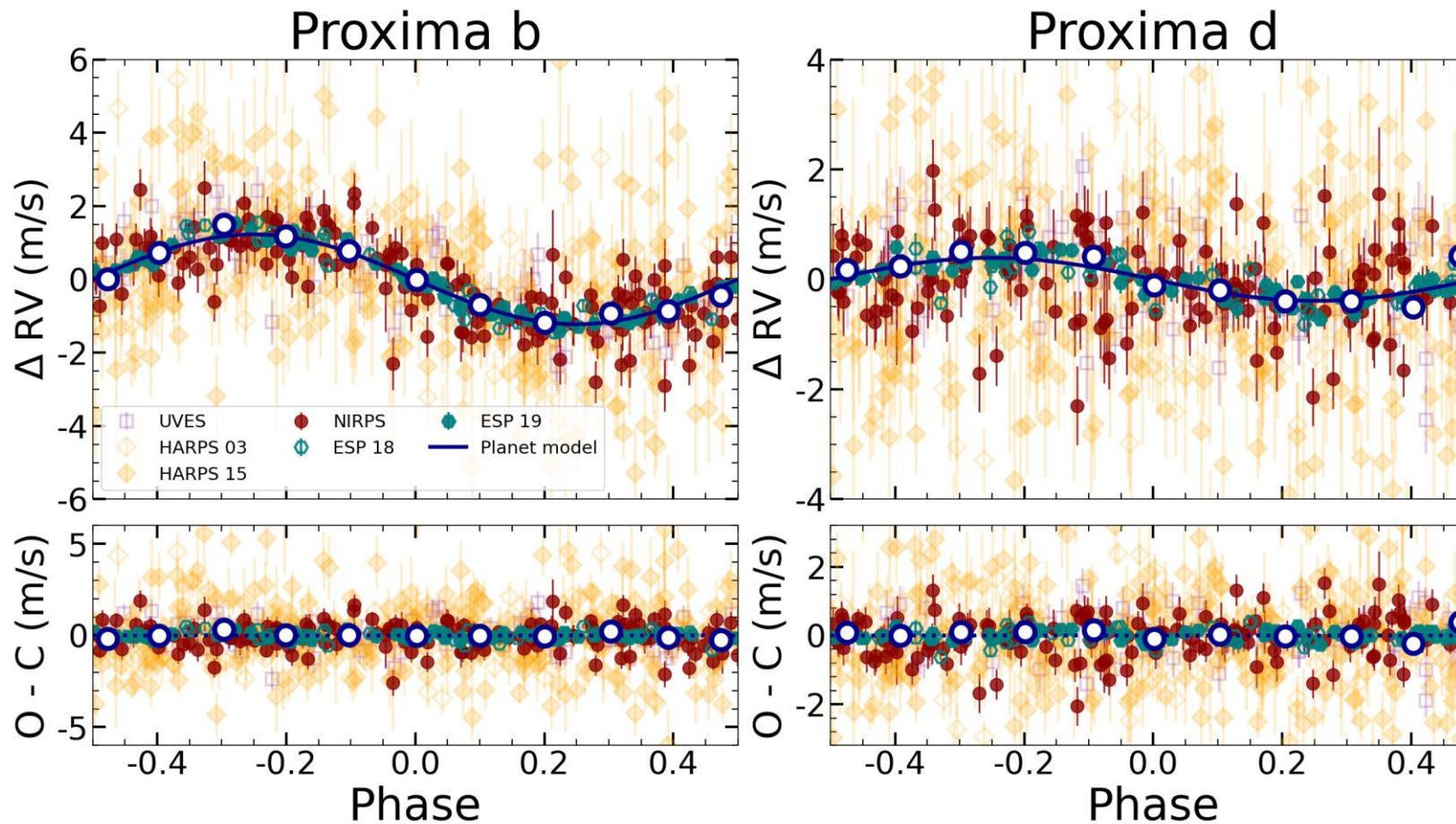
Signals of Proxima b and d are stable over time

SIGNAL STABILITY



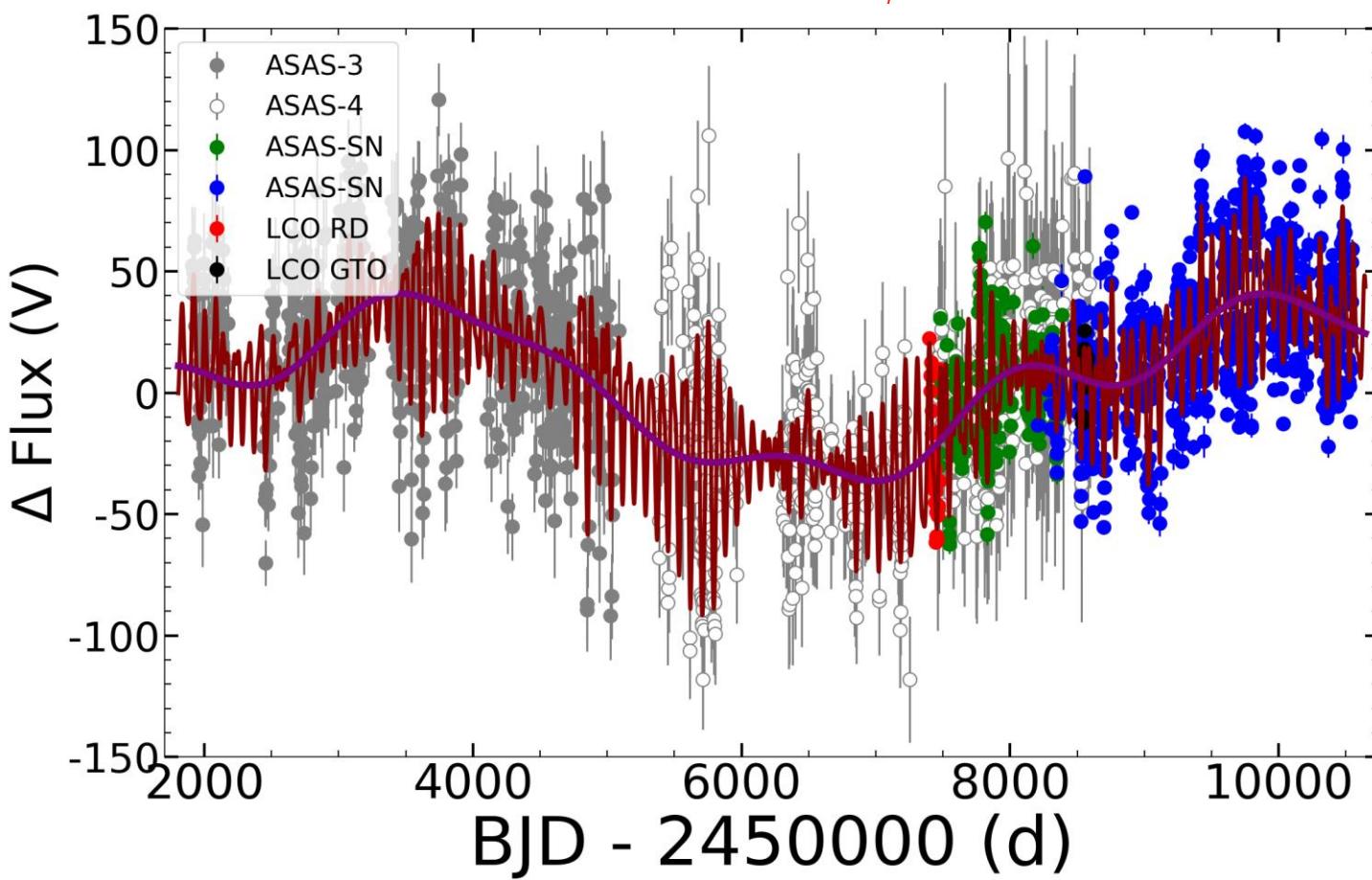
Parameters of Proxima d:
-> Consistent ESPRESSO
vs non-ESPRESSO

ADOPTED MODEL



Parameter	Value
Proxima d	
$T_0 - 2450000$ [d]	10557.55 ± 0.16
P_{orb} [d]	5.12338 ± 0.00035
$m_p \sin i$ [M_\oplus]	0.260 ± 0.038
a [au]	0.02881 ± 0.00017
e	0 (fixed)
Incident flux [S_\oplus]	1.92 ± 0.71
$T_{\text{eq A=0.3}}$ [K]	282 ± 23
K [$\text{cm}\cdot\text{s}^{-1}$]	39.2 ± 5.7
Proxima b	
$T_0 - 2450000$ [d]	10548.59 ± 0.12
P_{orb} [d]	11.18465 ± 0.00053
$m_p \sin i$ [M_\oplus]	1.055 ± 0.055
a [au]	0.04848 ± 0.00029
e	0 (fixed)
Incident flux [S_\oplus]	0.68 ± 0.25
$T_{\text{eq A=0.3}}$ [K]	218 ± 18
K [$\text{cm}\cdot\text{s}^{-1}$]	122.6 ± 6.2

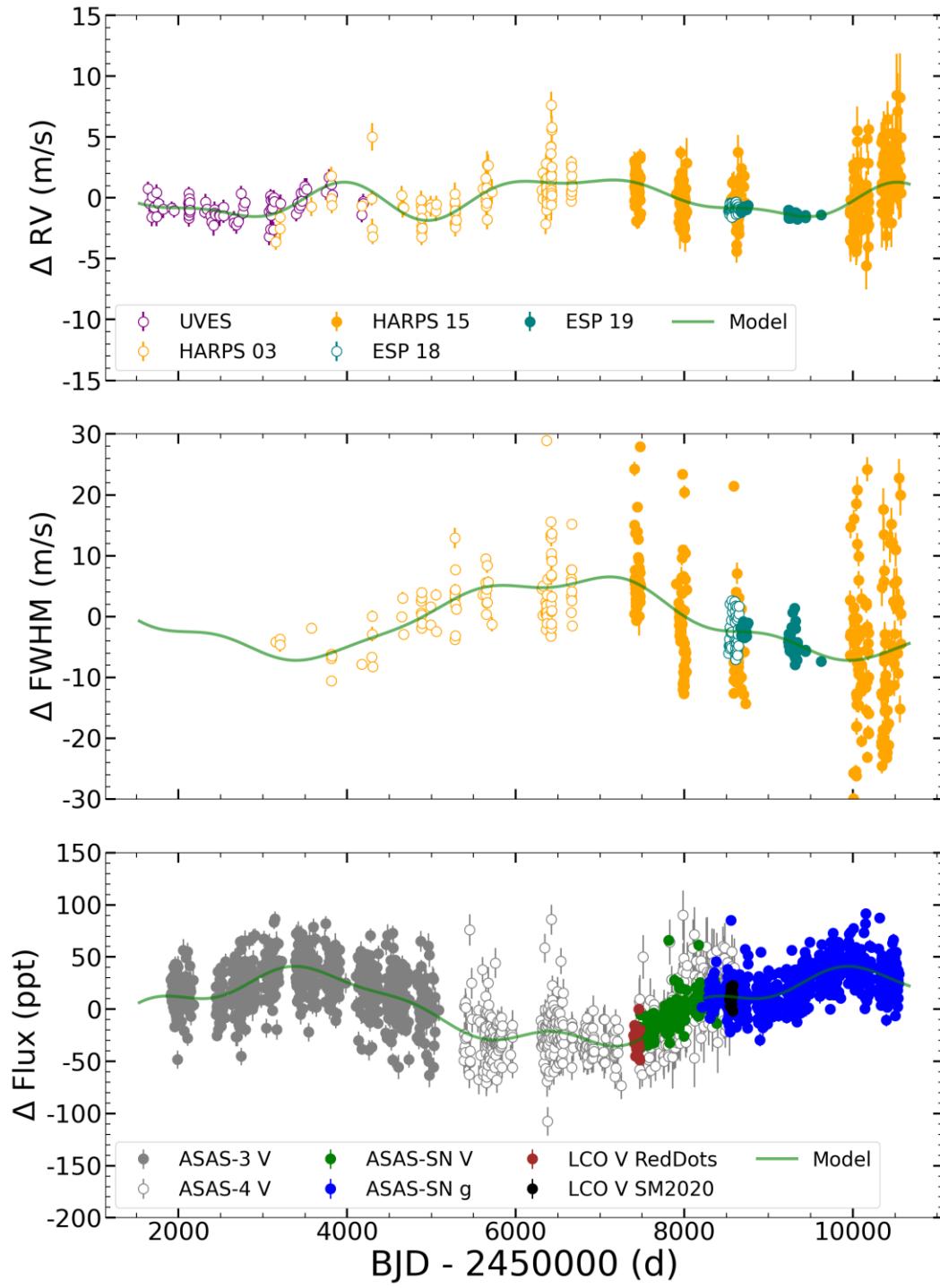
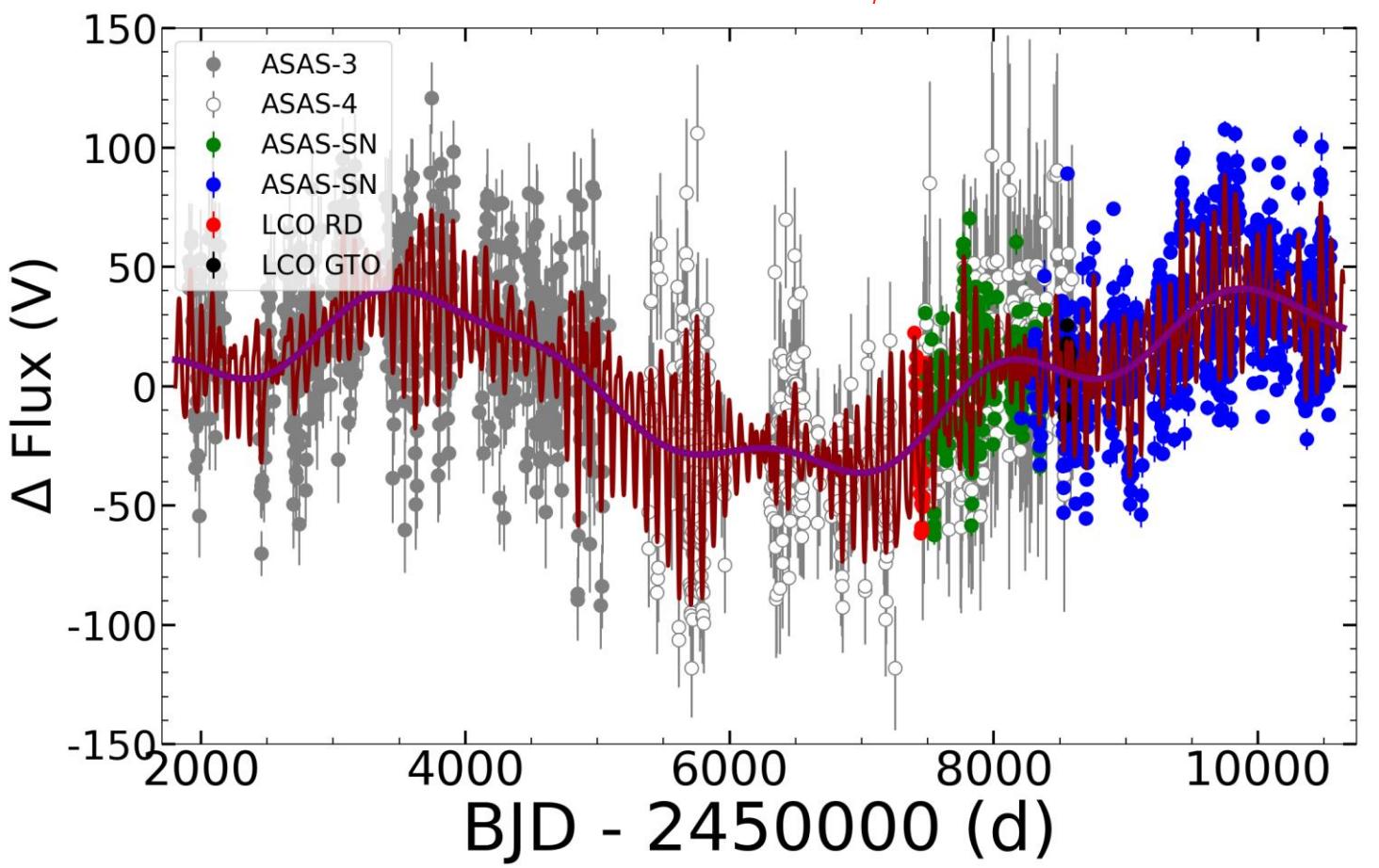
WHAT ABOUT PROXIMA?



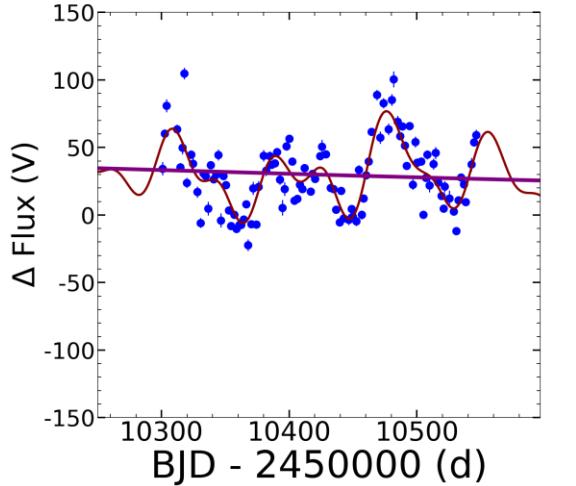
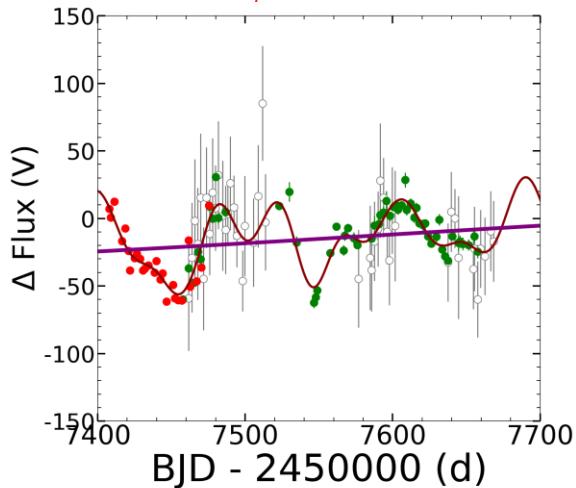
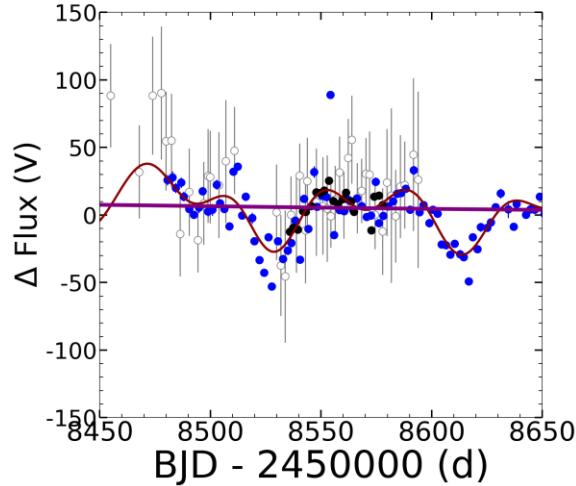
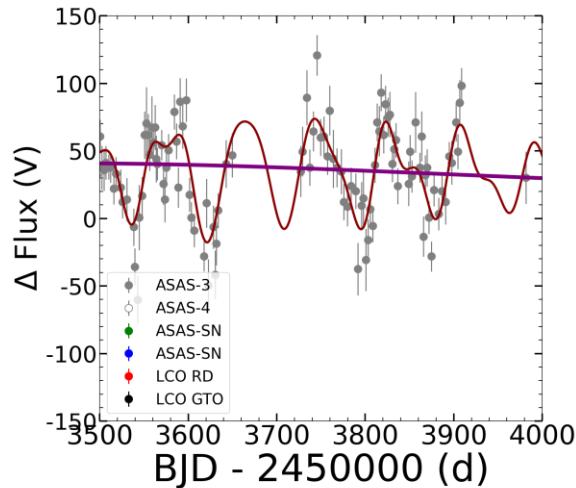
Cycle length \sim 17.7 years

Much longer than previously thought!

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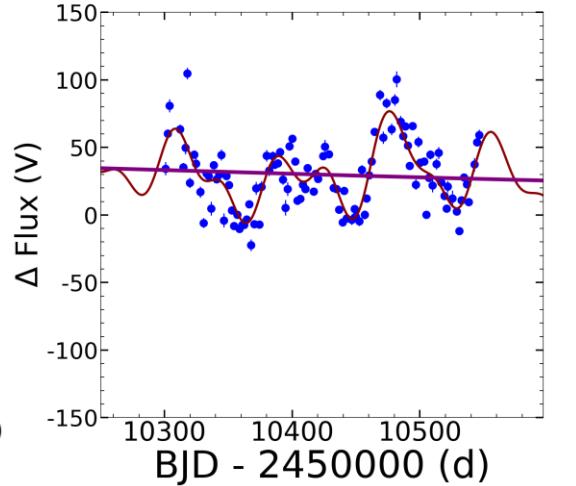
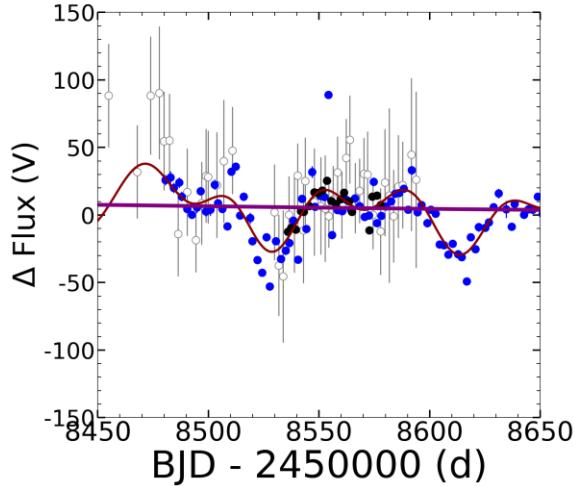
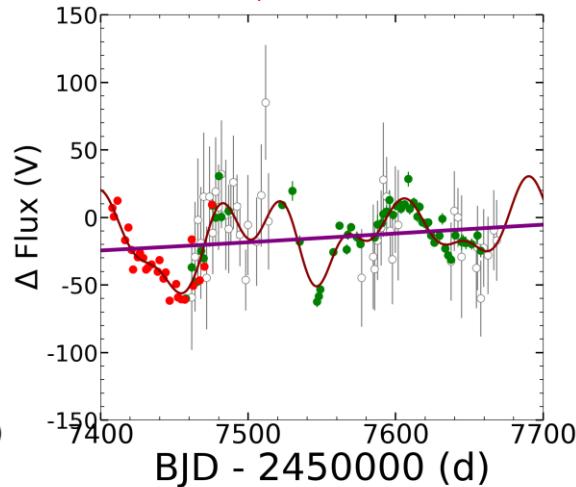
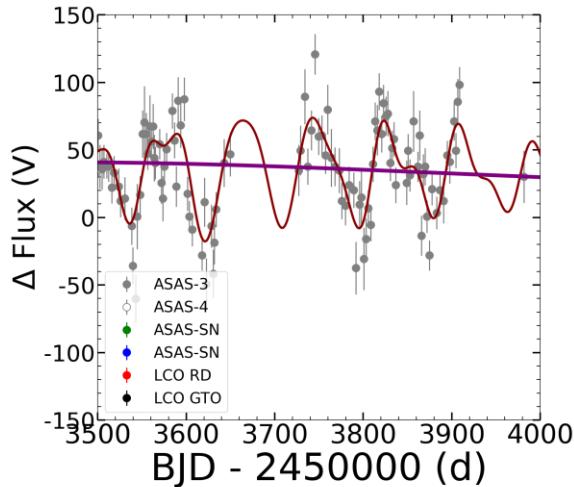
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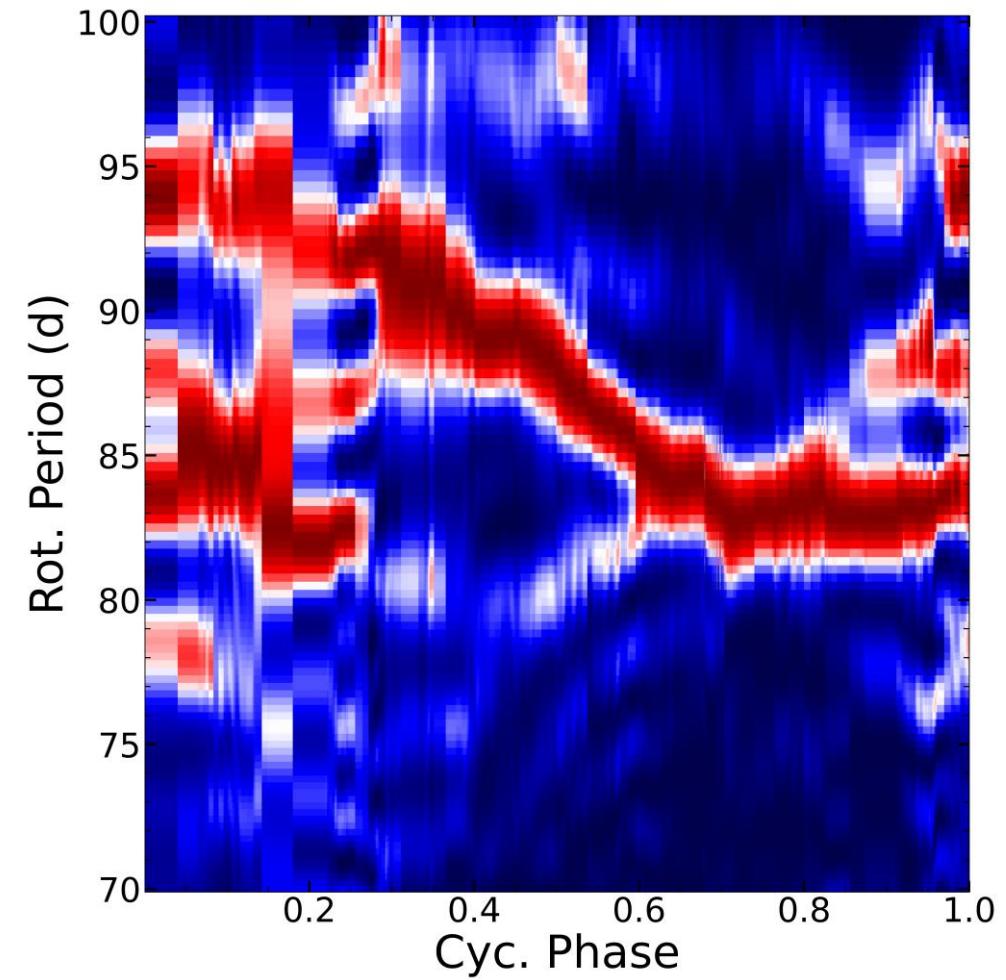
Rotation signal evolves over the years

*Discussed by Wargelin et al, 2017

WHAT ABOUT PROXIMA?



Sun-like differential rotation?





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Diving into the planetary system of Proxima with NIRPS* **

Breaking the meter per second barrier in the infrared

Alejandro Suárez Mascareño^{1,2,*}, Étienne Artigau^{3,4}, Lucile Mignon^{5,6}, Xavier Delfosse⁶, Neil J. Cook³, François Bouchy⁵, René Doyon^{3,4}, Jonay I. González Hernández^{1,2}, Thomas Vandal³, Izan de Castro Leão⁷, Atanas K. Stefanov^{1,2}, João Faria^{5,8}, Charles Cadieux³, Pierrot Lamontagne³, Frédérique Baron^{3,4}, Susana C. C. Barros^{8,9}, Björn Benneke³, Xavier Bonfils⁶, Marta Bryan¹⁰, Bruno L. Canto Martins⁷, Ryan Cloutier¹¹, Nicolas B. Cowan^{12,13}, Daniel Brito de Freitas¹⁴, Jose Renan De Medeiros⁷, Elisa Delgado-Mena^{15,8}, Pedro Figueira^{5,8}, Xavier Dumusque⁵, David Ehrenreich^{5,16}, David Lafrenière³, Christophe Lovis⁵, Lison Malo^{3,4}, Claudio Melo¹⁷, Christoph Mordasini¹⁸, Francesco Pepe⁵, Rafael Rebolo^{1,2,19}, Jason Rowe²⁰, Nuno C. Santos^{8,9}, Damien Ségransan⁵, Stéphane Udry⁵, Diana Valencia¹⁰, Gregg Wade²¹, Manuel Abreu^{22,23}, José L. A. Aguiar¹, Khaled Al Moulla⁵, Guillaume Allain²⁴, Romain Allart³, Tomy Arial⁴, Hugues Auger²⁴, Luc Bégin³, Nicolas Blind⁵, David Bohlander²⁵, Isabelle Boisse²⁶, Anne Boucher³, Vincent Bourrier⁵, Sébastien Bovay⁵, Christopher Broeg^{18,27}, Denis Brousseau²⁴, Alexandre Cabral^{22,23}, Andres Carmona⁶, Yann Carteret⁵, Zalpa Challita^{3,26}, Bruno Chazelas⁵, João Coelho^{22,23}, Marion Cointepas^{5,6}, Uriel Conod⁵, Eduardo Cristo^{8,9}, Ana Rita Costa Silva^{8,9,5}, Antoine Darveau-Bernier³, Laurie Dauplaise³, Jean-Baptiste Delisle⁵, Roseane de Lima Gomes^{3,7}, Thierry Forveille⁶, Yolanda G. C. Frensch^{5,28}, Félix Gracia Témich¹, Dasaev O. Fontinele⁷, Jonathan Gagné^{29,3}, Frédéric Genest³, Ludovic Genolet⁵, João Gomes da Silva⁸, Nolan Grieves⁵, Olivier Hernandez²⁹, Melissa J. Hobson⁵, H. Jens Hoeijmakers^{30,5}, Norbert Hubin¹⁷, Farbod Jahandar³, Ray Jayawardhana³¹, Hans-Ulrich Käuf¹⁷, Dan Kerley²⁵, Johann Kolb¹⁷, Vigneshwaran Krishnamurthy¹², Benjamin Kung⁵, Alexandre L'Heureux³, Pierre Larue⁶, Henry Leath⁵, Olivia Lim³, Gaspare Lo Curto²⁸, Allan M. Martins^{7,5}, Jaymie Matthews³², Jean-Sébastien Mayer⁴, Yuri S. Messias^{3,7}, Stan Metchev³³, Leslie Moranta^{3,29}, Dany Mounzer⁵, Nicola Nari^{34,1,2}, Louise D. Nielsen^{5,17,35}, Ares Osborn¹¹, Mathieu Oueller⁴, Jon Otegi⁵, Léna Parc⁵, Luca Pasquini¹⁷, Vera M. Passegger^{1,2,36,37}, Stefan Pelletier^{5,3}, Céline Peroux¹⁷, Caroline Piaulet-Ghorayeb^{3,38}, Mykhaylo Plotnykov¹⁰, Emanuela Pompei²⁸, Anne-Sophie Poulin-Girard²⁴, José Luis Rasilla¹, Vladimir Reshetov²⁵, Jonathan Saint-Antoine^{3,4}, Mirsad Sarajlic¹⁸, Ivo Saviane²⁸, Robin Schnell⁵, Alex Segovia⁵, Julia Seide^{28,39,5}, Armin Silber²⁸, Peter Sinclair²⁸, Michael Sordet⁵, Danuta Sosnowska⁵, Aviadaan Srivastava^{3,5}, Márcio A. Teixeira⁷, Simon Thibault²⁴, Philippe Vallée^{3,4}, Valentina Vaultato⁵, Joost P. Wardenier³, Bachar Welbe^{22,23}, Drew Weissman¹¹, Ivan Wevers²⁵, François Wildi⁵, Vincent Yariv⁶, Gérard Zins¹⁷

Article under review in Astronomy & Astrophysics

- Demonstration of NIRPS performance
- Detection of Proxima b with NIRPS
- Full confirmation of Proxima d
- Characterization of Proxima's magnetic cycle
- Characterization of Proxima's differential rotation



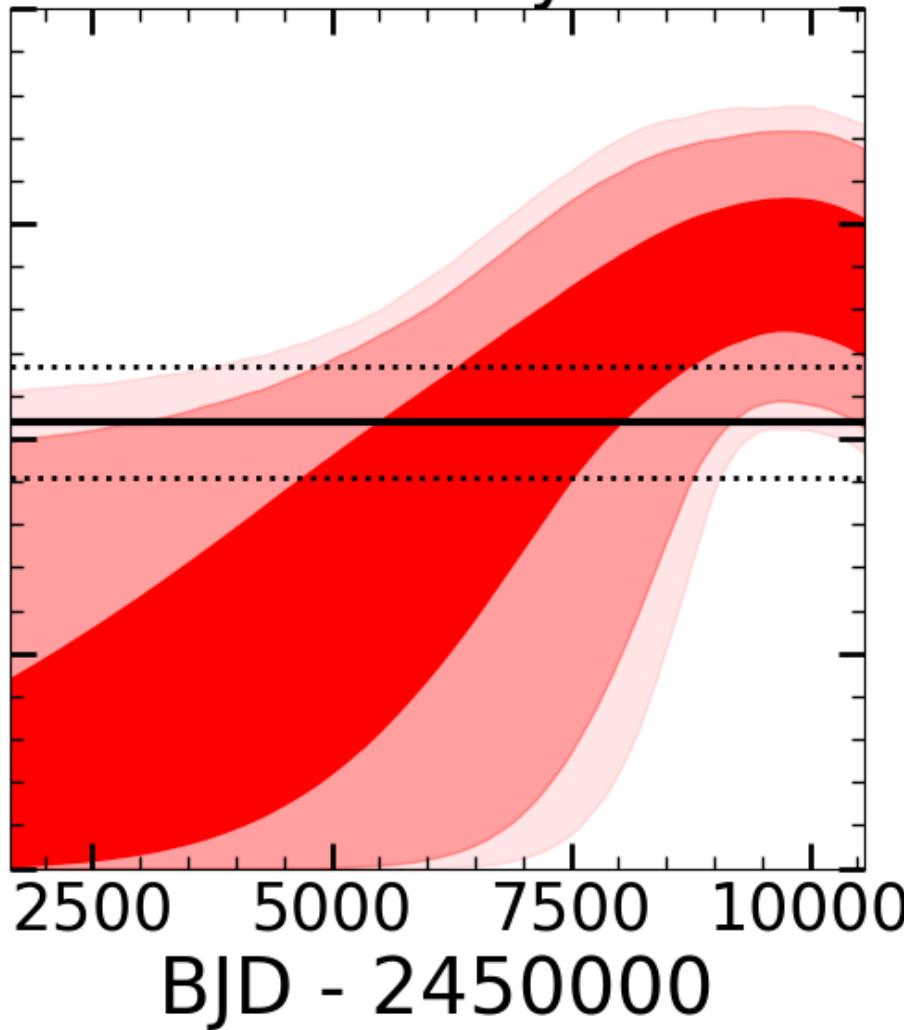
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A BIT ABOUT PROXIMA

FWHM \sim -Flux

