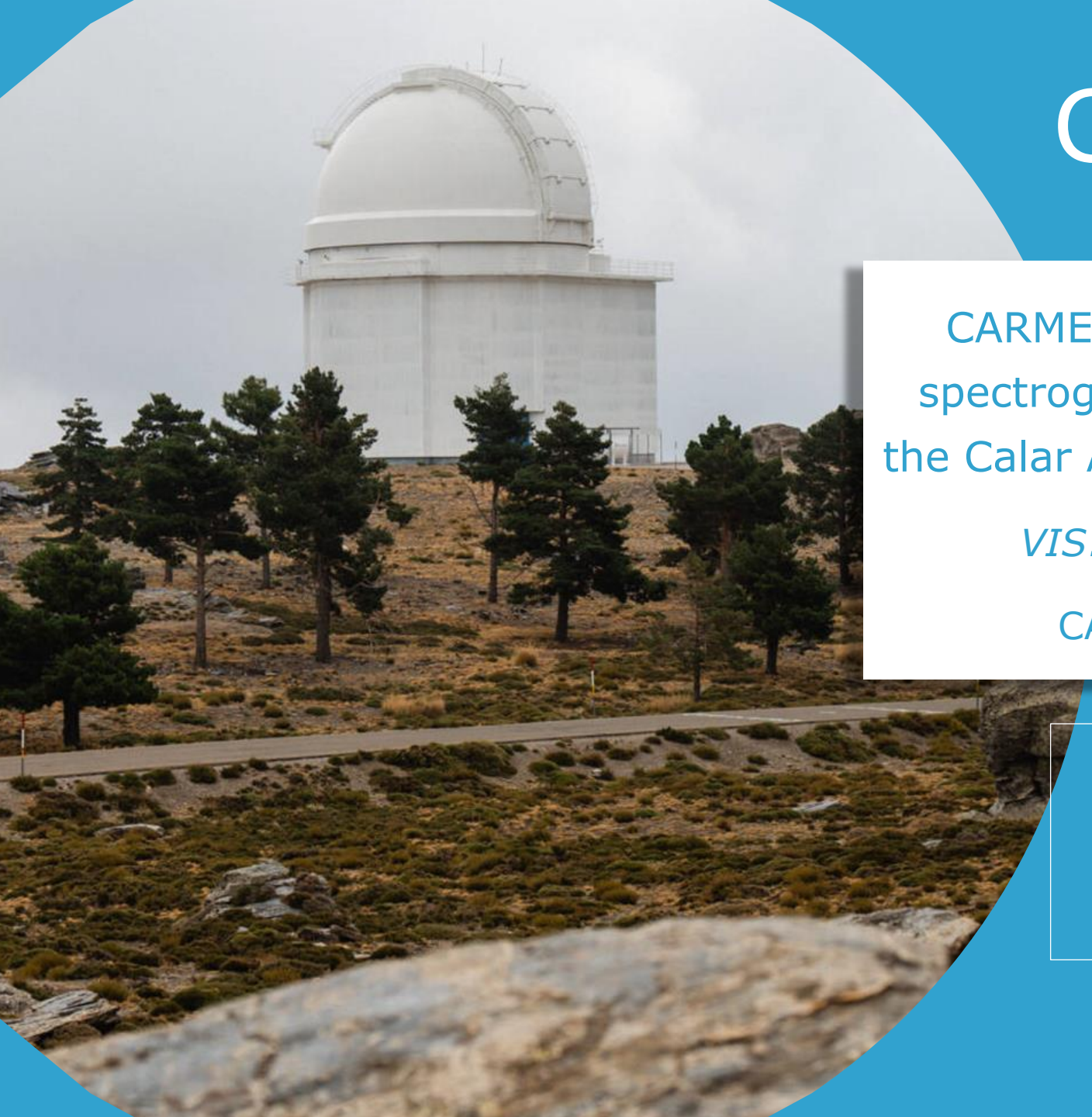
Present and future of high-resolution spectroscopy of exoplanets around ultracool dwarfs

Roberto Varas (*He/Him*), PhD researcher

30 Years of Substellar Science

BD30 – La Gomera
1-5 September 2025



CARMENES

CARMENES is a dual-channel high-resolution spectrograph installed at the 3.5m telescope at the Calar Alto Observatory (CAHA, Almería, Spain)

VIS: 520-960 nm and NIR: 960-1710 nm

CARMENES started observing in 2016

CARMENES has re-analysed 17 known planets and has discovered and confirmed 59 new planets, a dozen of which are potentially habitable

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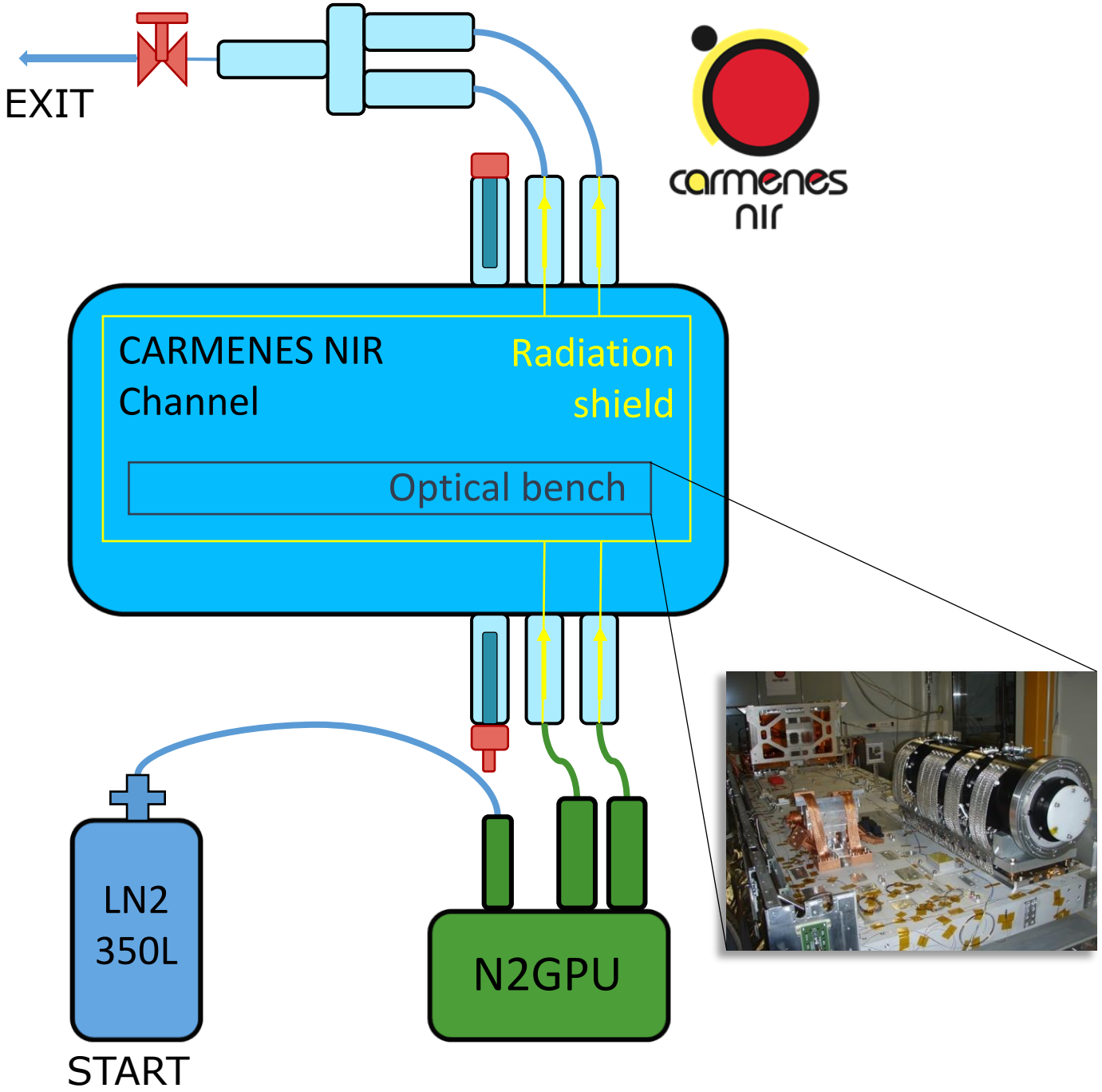
CARMENES NIR cooling system

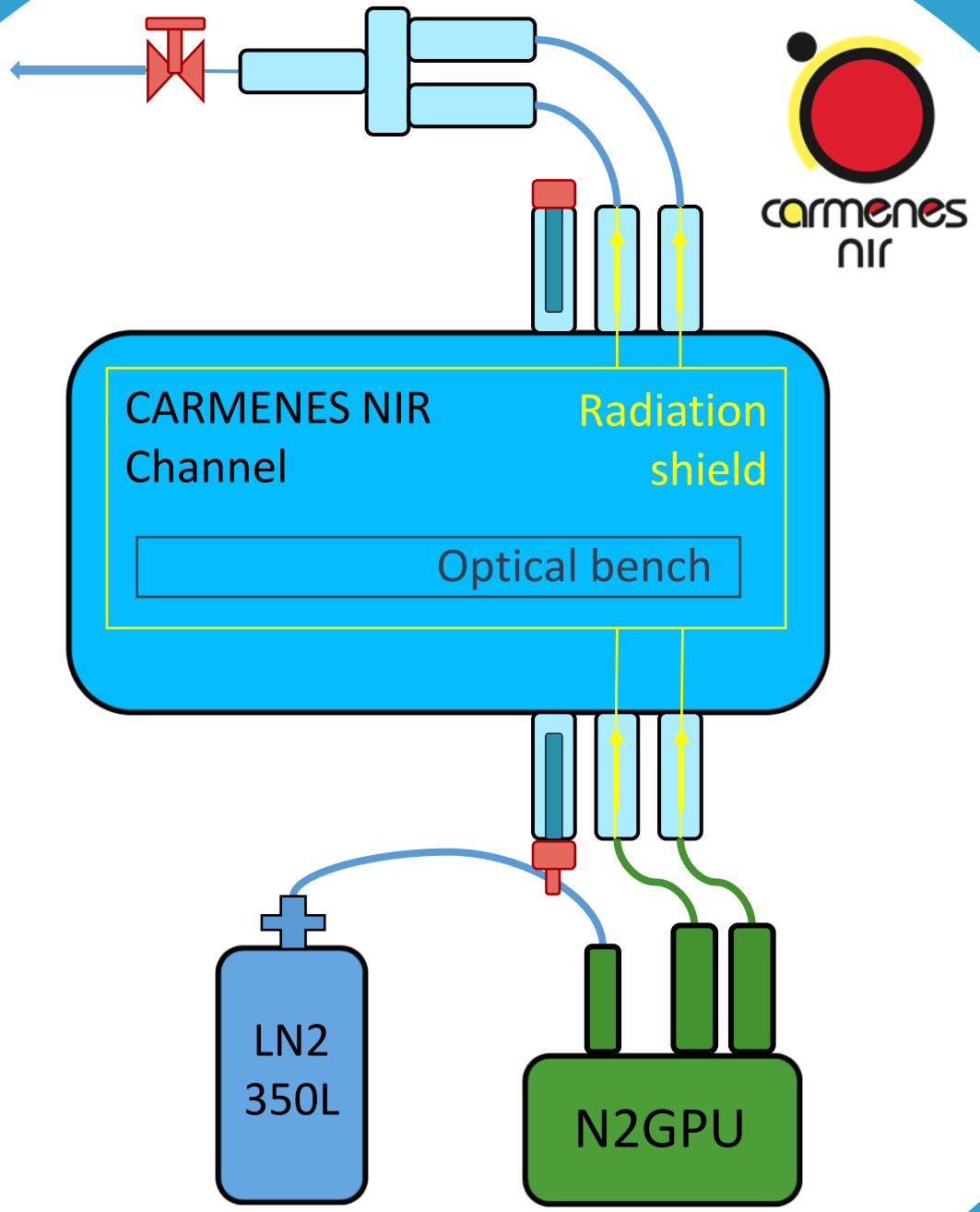


Liquid nitrogen is evaporated in the gas preparation unit (N2GPU) and cools down the radiation shield

The spectrograph is passively cooled down by the radiation shield

The cooling system was designed to work with a discontinuous mode Flow: the gas either pass or not the system

CARMENES-PLUS



Varas et al. (2025)

CARMENES-PLUS started in 2020 with the aim to improve CARMENES performance

CARMENES NIR interventions started in February 2021 and finished in June 2022

Four main upgrades were proposed:

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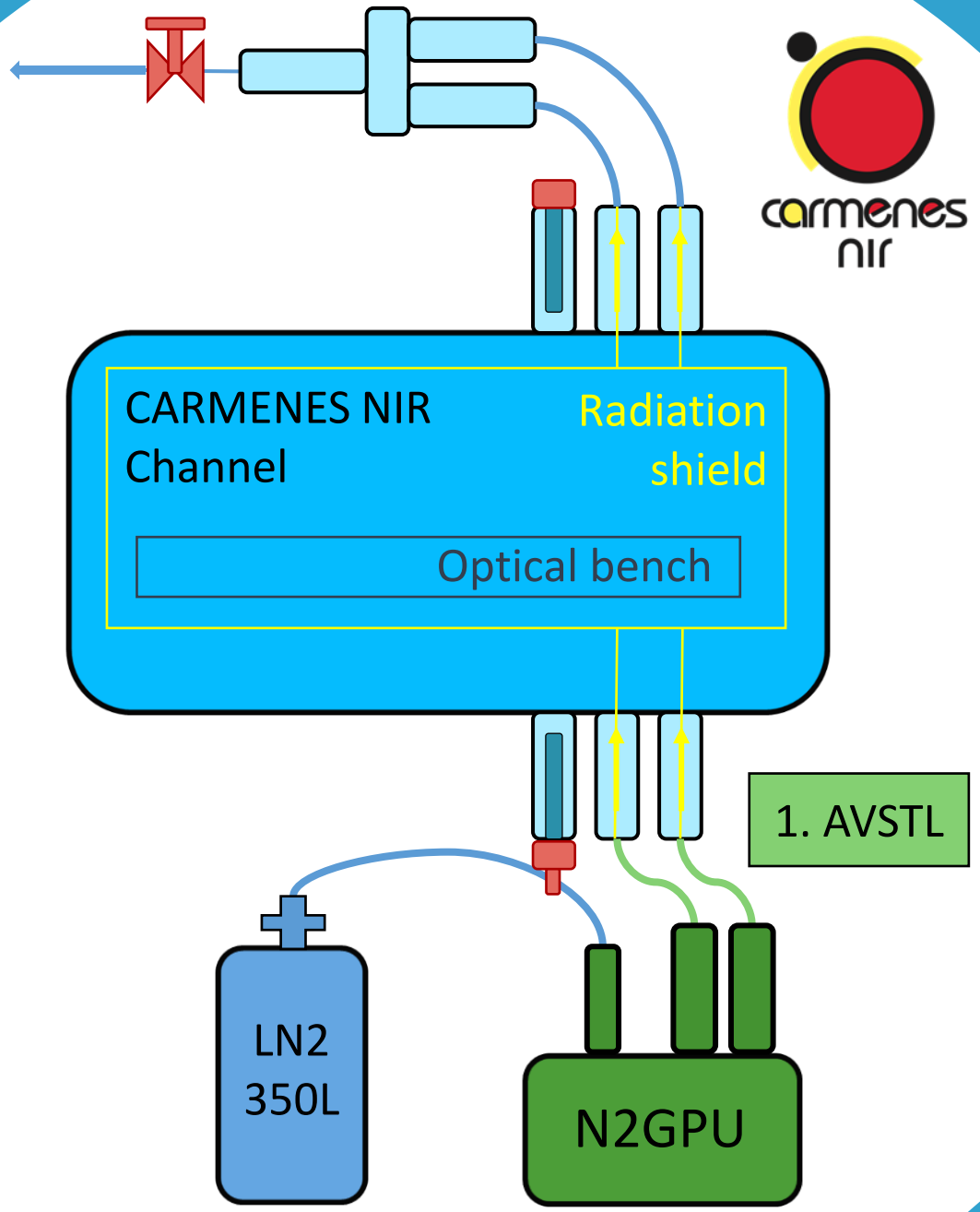
CARMENES-PLUS



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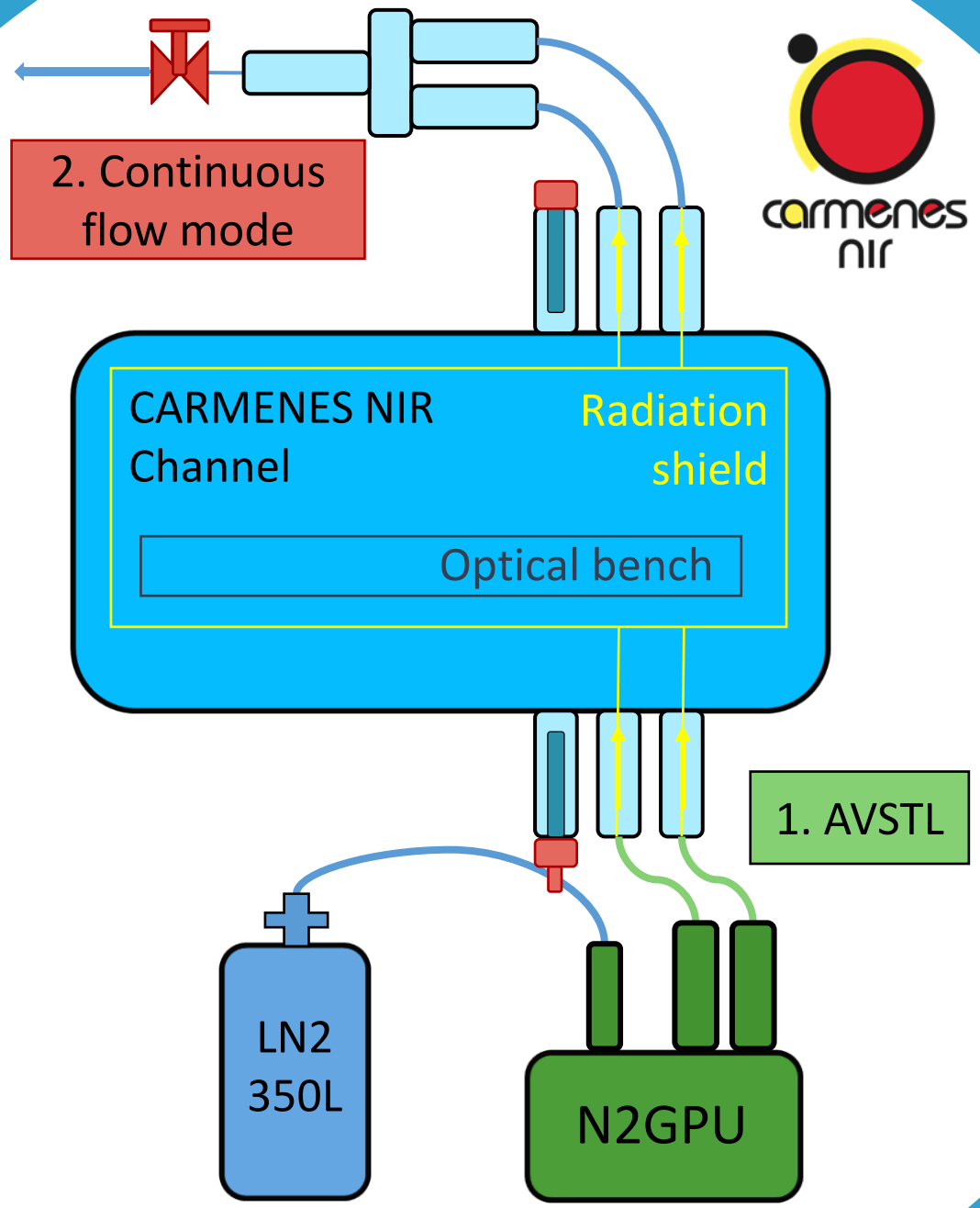

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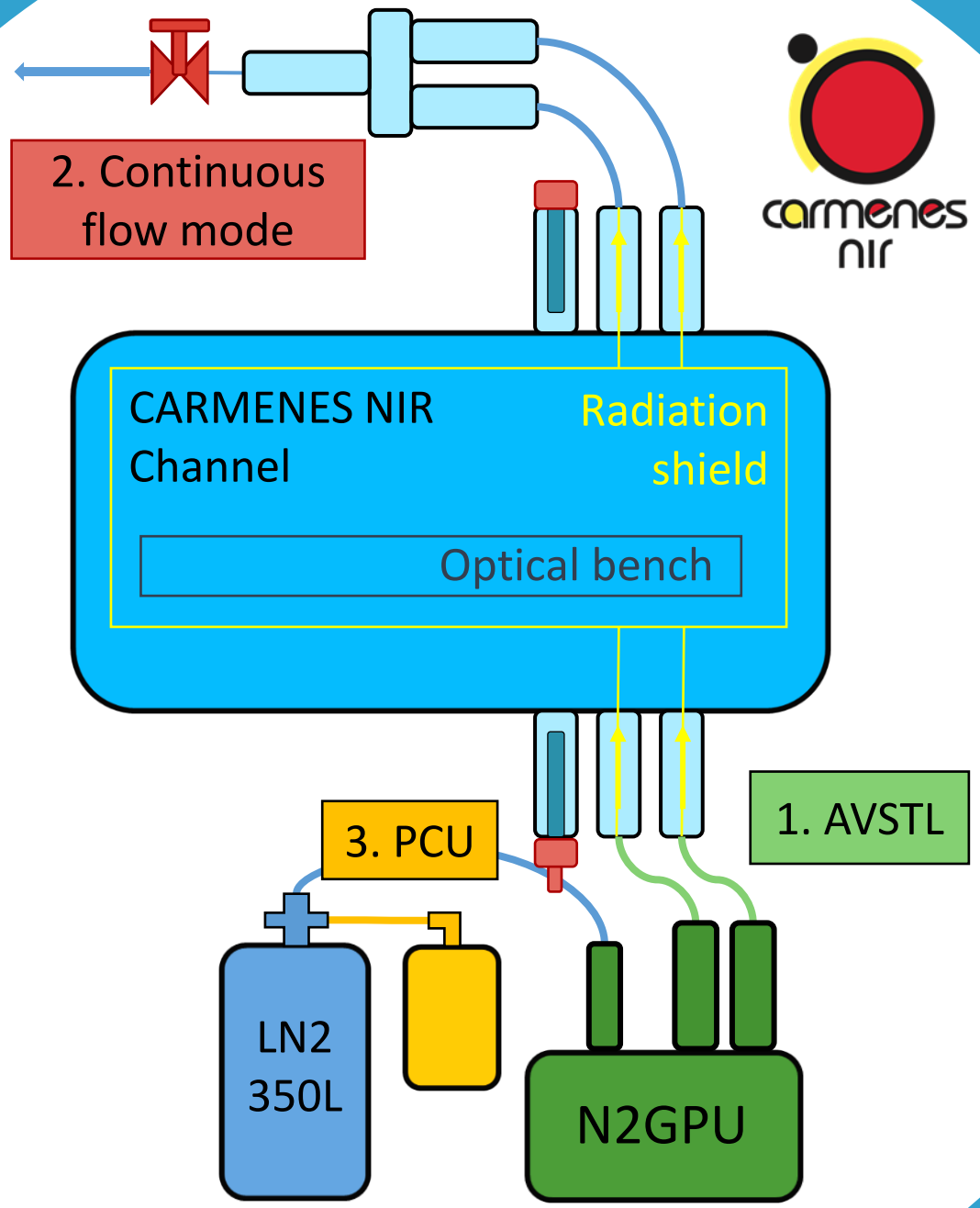
CARMENES-PLUS



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3. Pressure control unit

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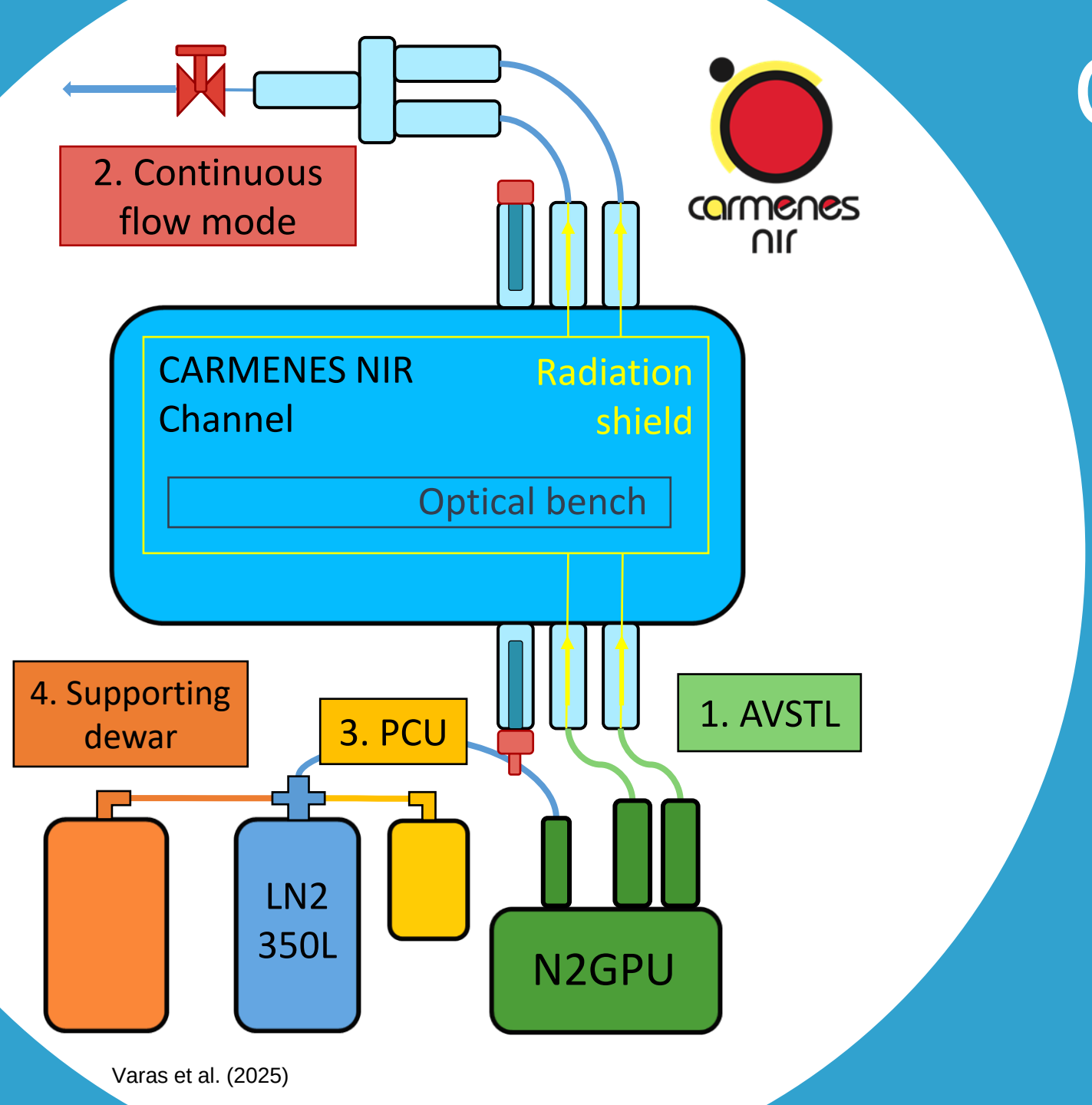
CARMENES-PLUS



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2. Continuous Flow mode
3. Pressure control unit
4. Supporting dewar

Varas et al. (2025)

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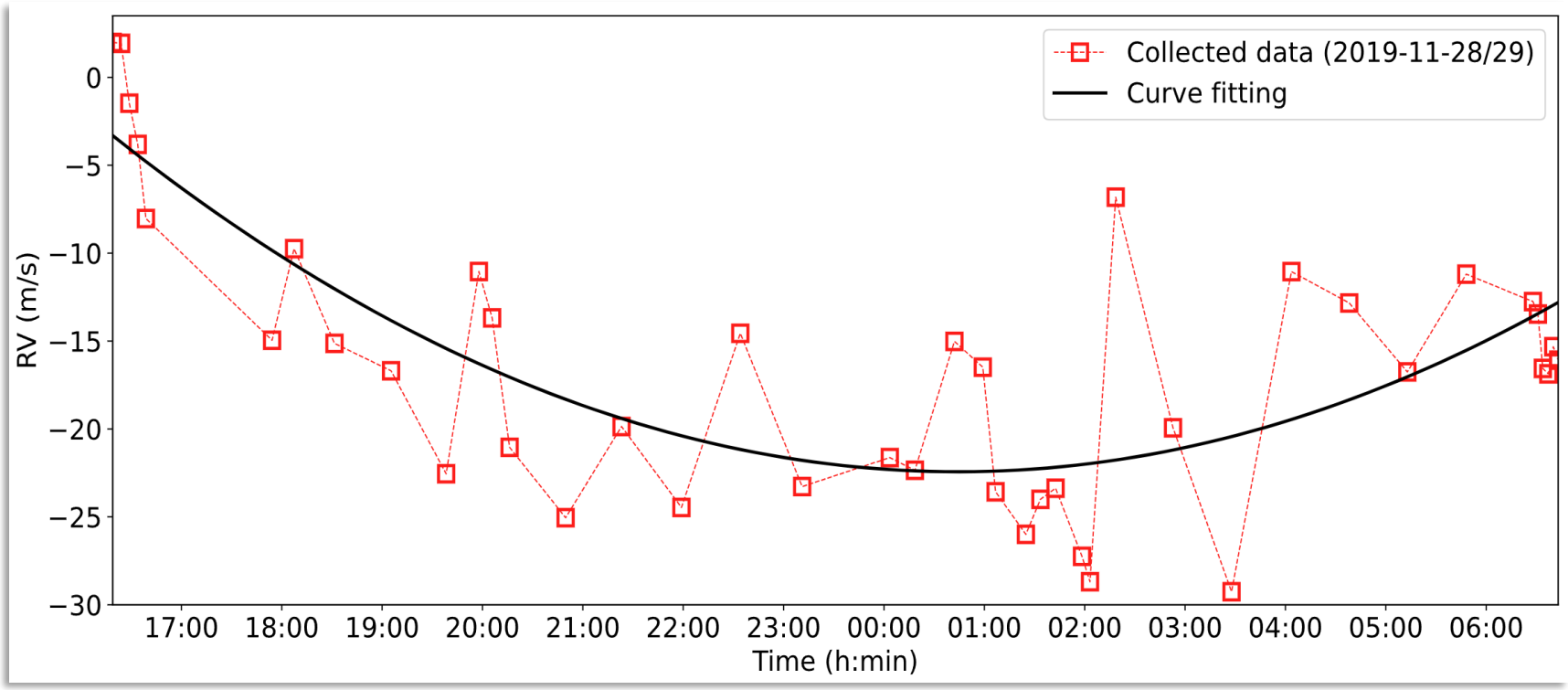
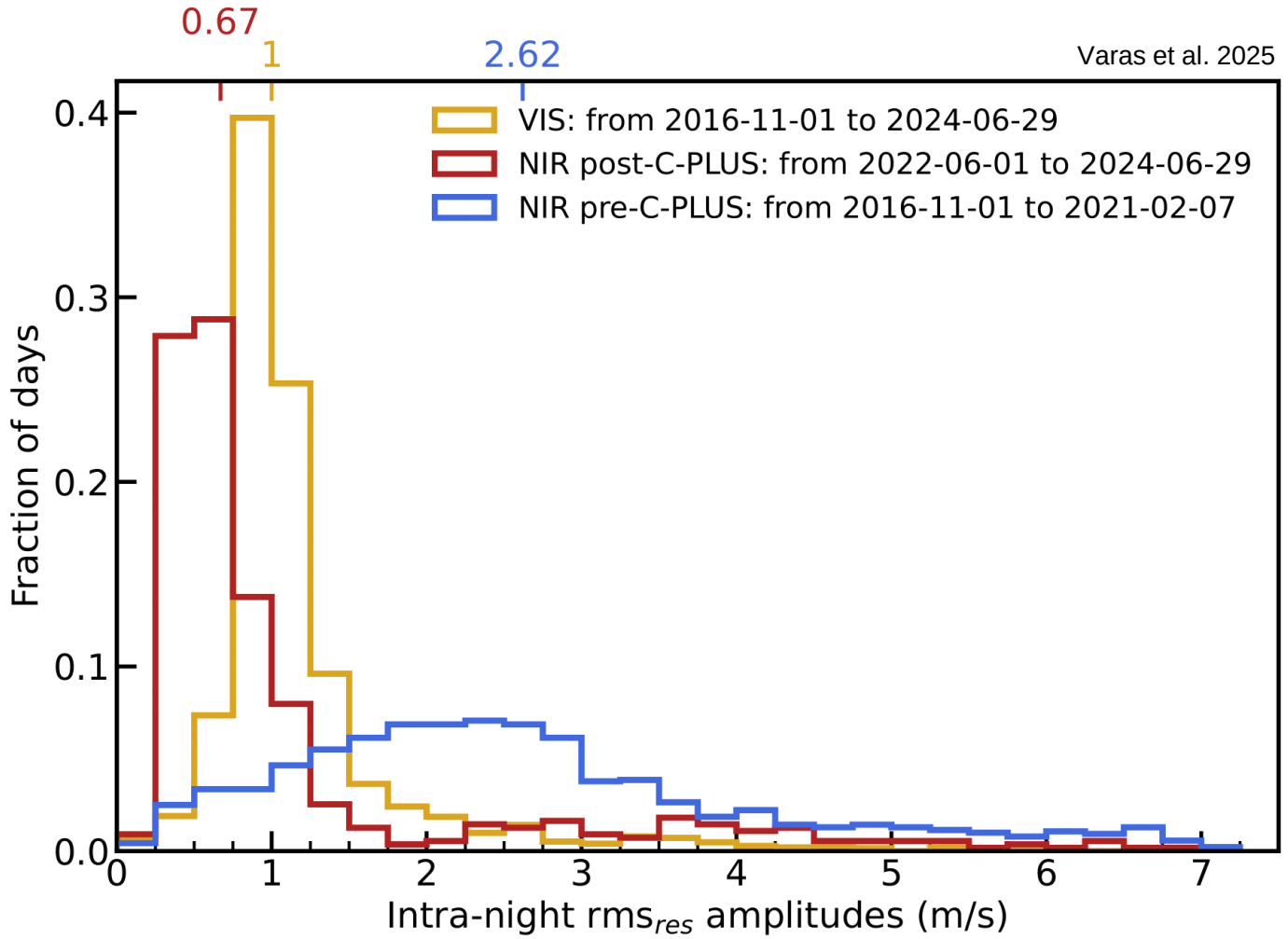
Fabry-Pérot calibration measurements



We use RV from calibration of the FP to evaluate the stability of the spectrographs

For each night we compute the rms of the residuals after applying a quadratic fit

Intrinsic RV precision



We compute the histogram of this rms of the residuals for every CARMENES night with calibrations

We define the intrinsic RV precision of the spectrographs as the median value of the histogram

The intrinsic RV precision of CARMENES NIR has decreased in 2 m/s, and is better than the VIS channel, both below 1 m/s

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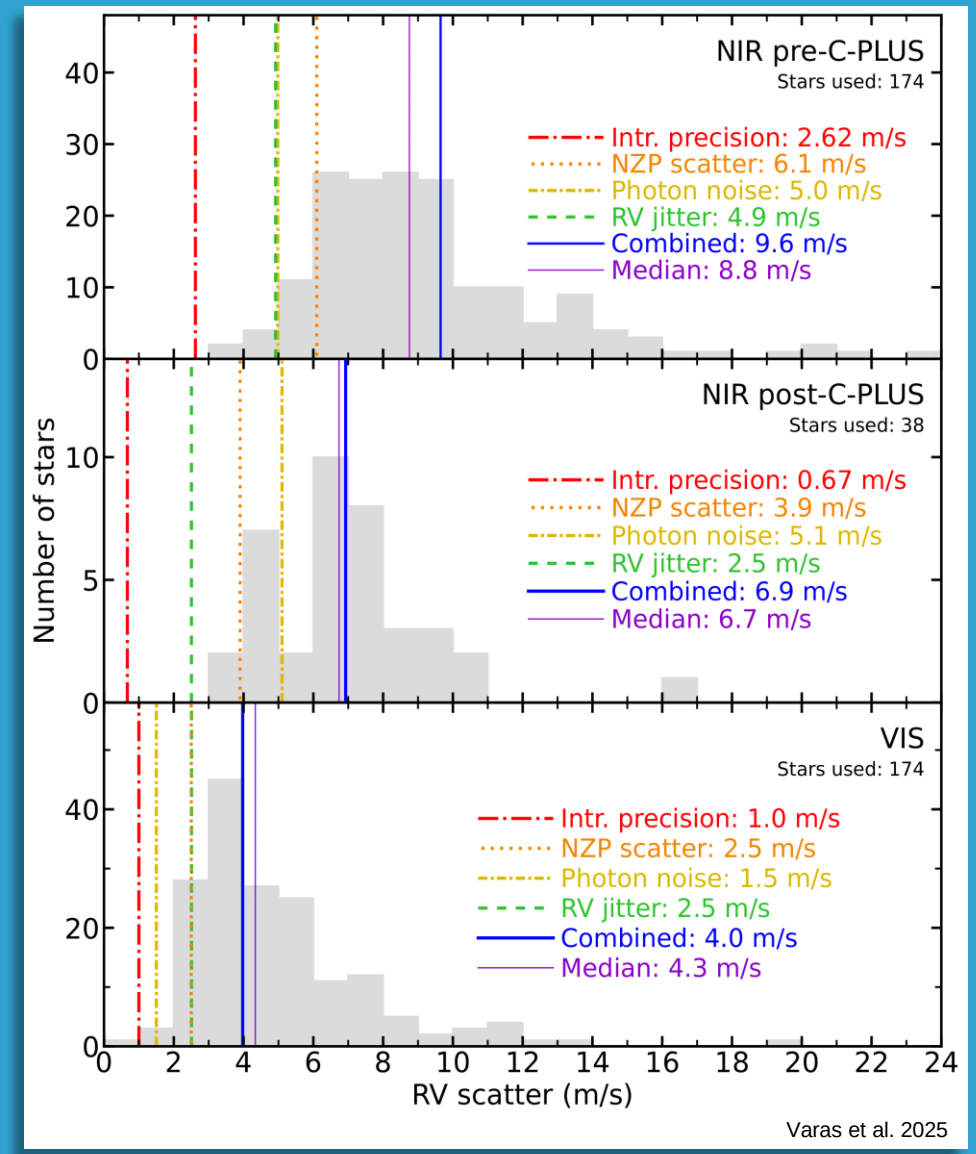
CARMENES M dwarfs RV scatter

The intrinsic RV precision and NZP scatter has decrease due to the CARMENES-PLUS upgrades

The photon noise limit is significantly higher in the NIR tan in the VIS, affecting to the overall RV scatter

Most CARMENES stars are early to mid M dwarfs, the difference between NIR and VIS precision might be different for the latest spectral types

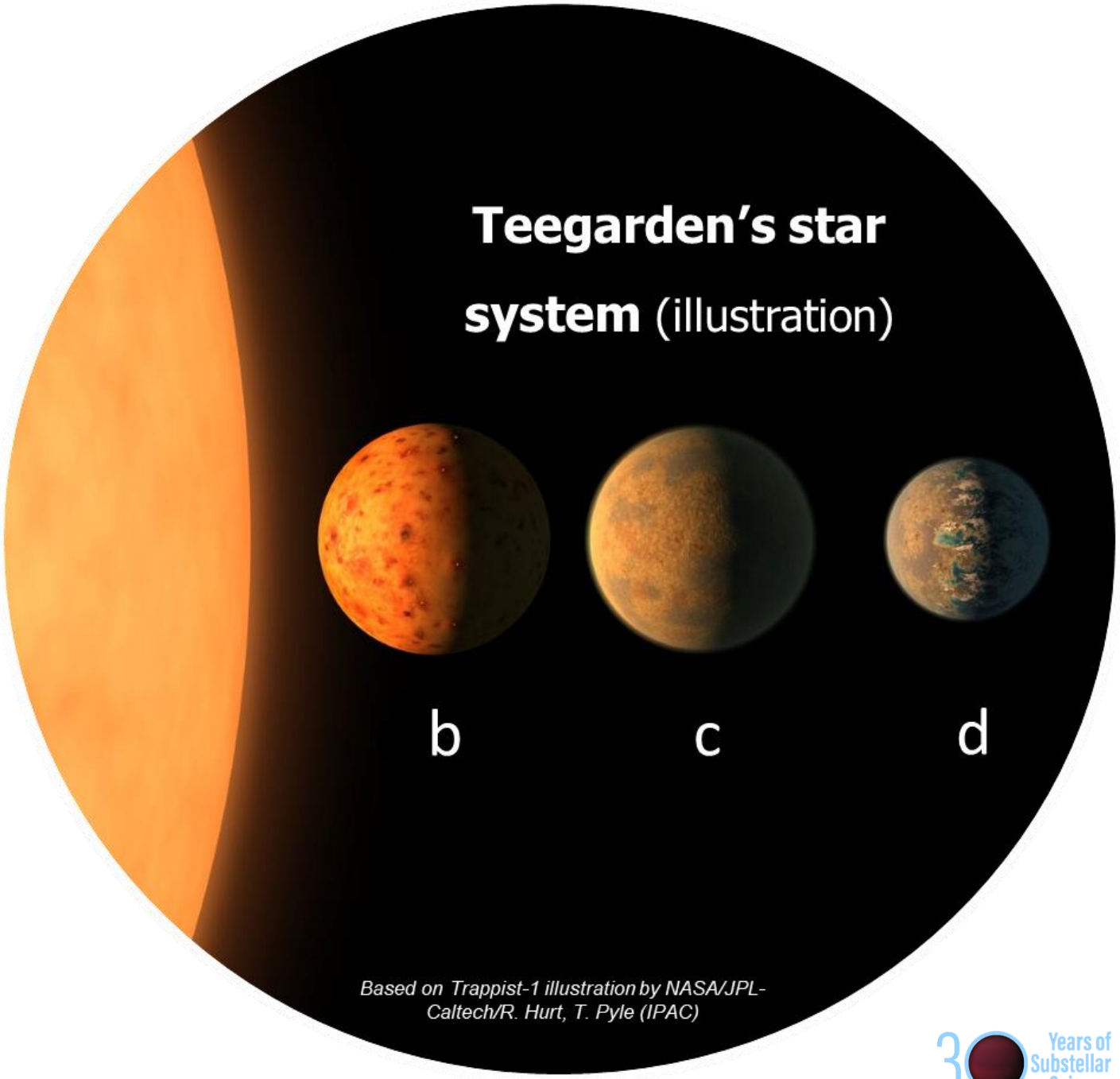


Ultracool dwarfs

UCDs are M6.0 and later stars and sub-stellar objects (BDs)

The usually host small-rocky exoplanets and have a close Habitable Zone. On top of that, they have a relatively big planet-to-star radii ratio, which makes things easier for transits and atmosphere characterization

UCDs are indeed very cool objects for understanding exoplanets, planet formation (rocky planets, Jupiter-like planets, …) and are specially interesting in the search for life



UCDs problematics

Only four planetary systems have been detected: SPECULOOS-2 and 3, Trappist-1, and Teegarden's star

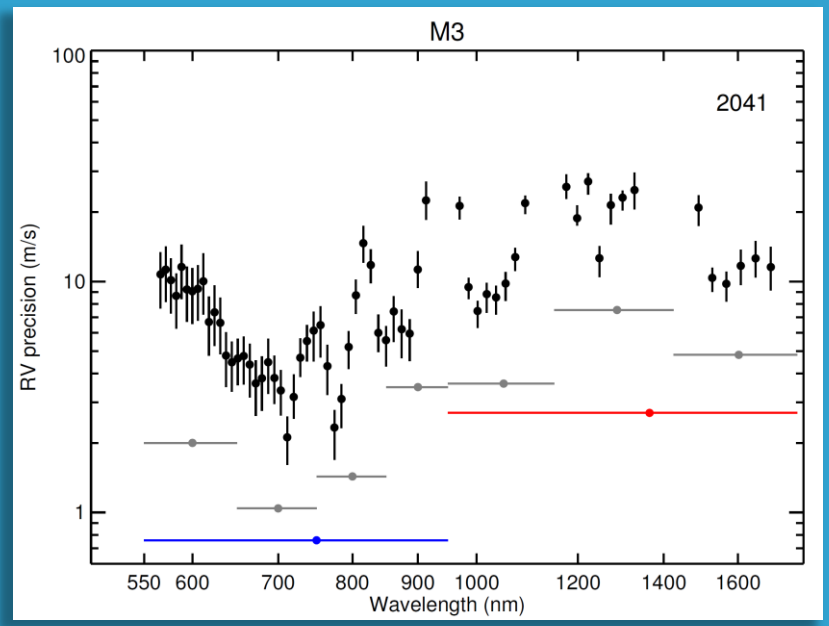
Faint stars: low signal to noise ratio

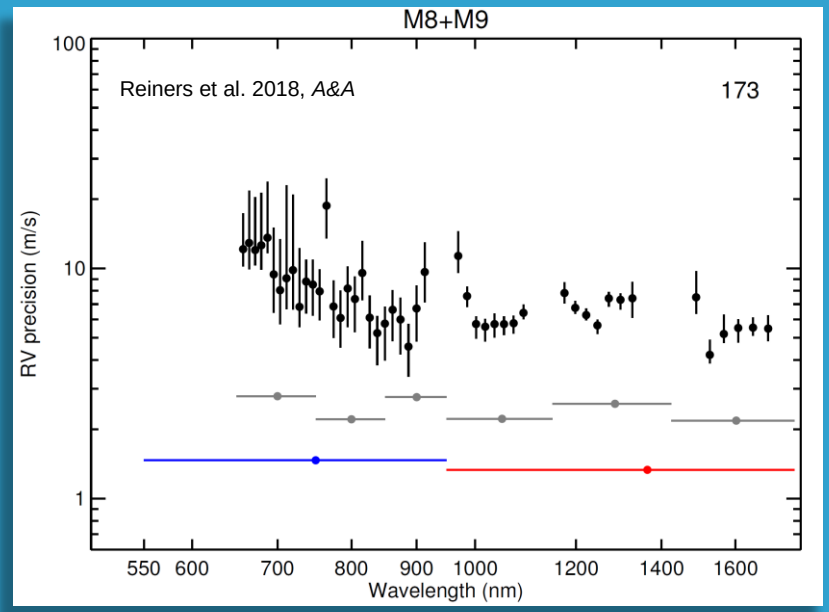
The flux peaks in **NIR**

Less spectral information in the NIR than in the VIS

Small planets, inducing small RV

Active and "fast" rotating stars





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CARMENES UCDs

Star's name	karmn	Spectral type	J (mag)	$v \sin i_\star$ (km/s)	Observations (VIS/NIR)	S/N (VIS/NIR)
LP 411-006	J02465+164	M6.0 V	10.971	2.11	18/18	22.0/35.6
LP 299-036	J03142+286	M6.0 V	10.993	2.34	13/10	16.2/25.9
LP 560-035	J14321+081	M6.0 V	10.108	8.09	58/58	32.5/55.4
Wolf 359	J10564+070	M6.0 V	7.085	3.41	78/63	73.8/187.1
LP 783-002	J07403-174	M6.0 V	10.155	1.03	53/54	26.9/50.8
GJ 1111	J08298+267	M6.5 V	8.235	10.67	35/29	76.1/177.8
LP 731-058	J10482-113	M6.5 V	8.857	2.36	79/72	51.1/122.7
LP 368-128	J09003+218	M6.5 V	9.436	14.65	25/20	41.1/96.6
vB 8	J16555-083	M7.0 V	9.776	6.17	128/110	25.3/61.2
NLTT 20861	J09033+056	M7.0 V	10.766	7.71	31/27	22.5/40.0
Teegarden's star	J02530+168	M7.0 V	8.394	1.23	298/274	69.6/149.0
LP 044-162	J17572+707	M7.5 V	11.452	36.83	2/2	15.6/30.2
LSR J0539+4038	J05394+406	M8.0 V	11.109	5.69	21/29	15.5/41.5
V1298 Aql	J19169+051S	M8.0 V	9.908	5.48	51/44	22.4/70.0
LSPM J1925+0938	J19255+096	M8.0 V	11.214	62.84	100/97	9.0/32.1
TRAPPIST-1	J23064-050	M8.0 V	11.354	3.63	163/130	3.9/13.2
LSR J0419+4233	J04198+425	M8.5 V	11.094	8.36	35/42	10.4/36.2
LSR J1835+3259	J18356+329	M8.5 V	10.27	55.88	60/65	13.6/48.5
LP 666-009	J08536-034	M9.0 V	11.212	9.3	45/43	6.2/29.0
LSPM J2049+3336	SPECULOOS-3[1]	-	-	-	-	-

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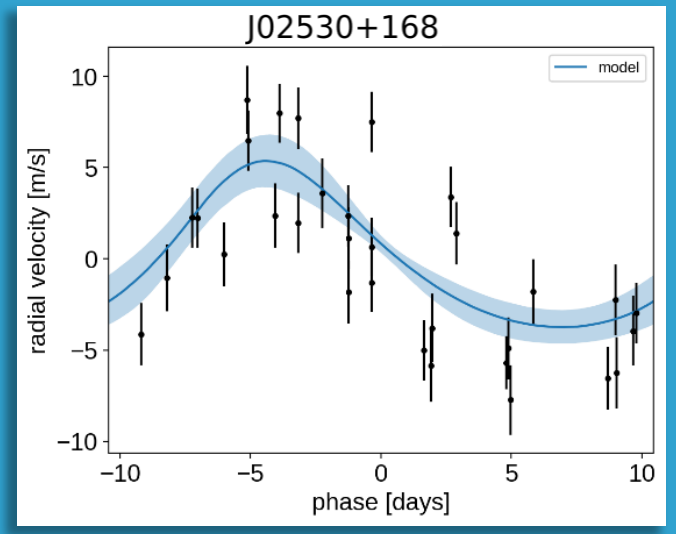
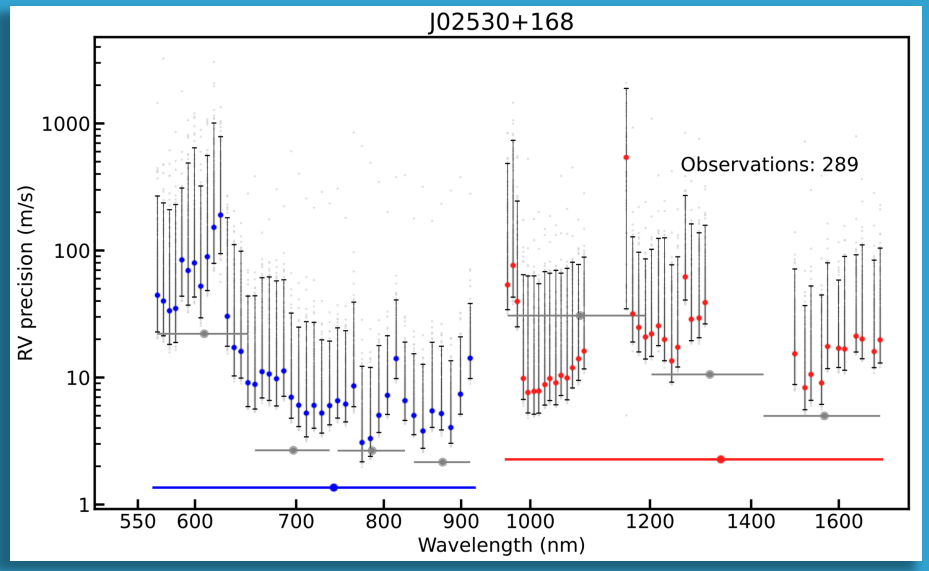
Spectral orders optimization



RV timeseries

RV precision



Spectral order	RV precision (m/s)
1	56.23
2	43.11
0	38.87
21	23.46
30	12.95

Remove worst spectral order

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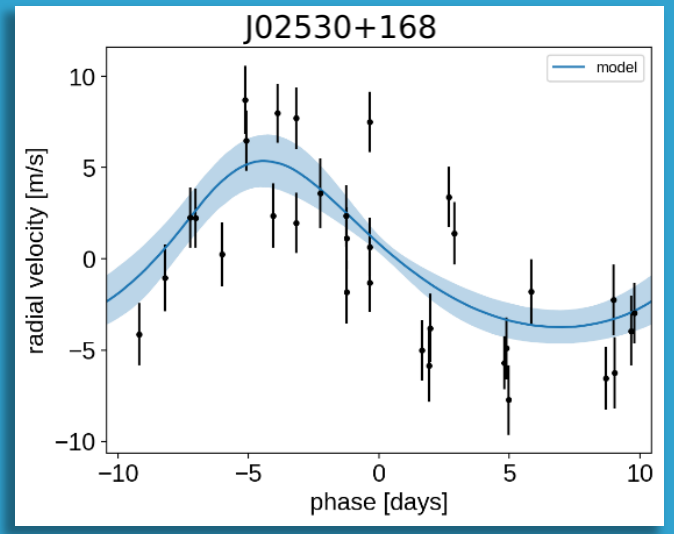
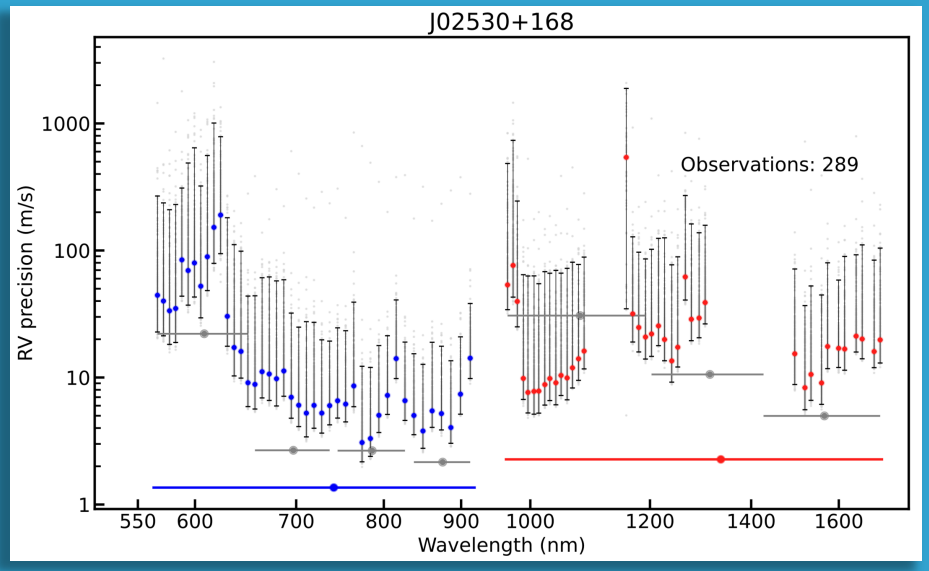
Spectral orders optimization



RV timeseries

Smallest avg error
4.09 m/s --> 3.56 m/s

RV precision



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Remove worst spectral order

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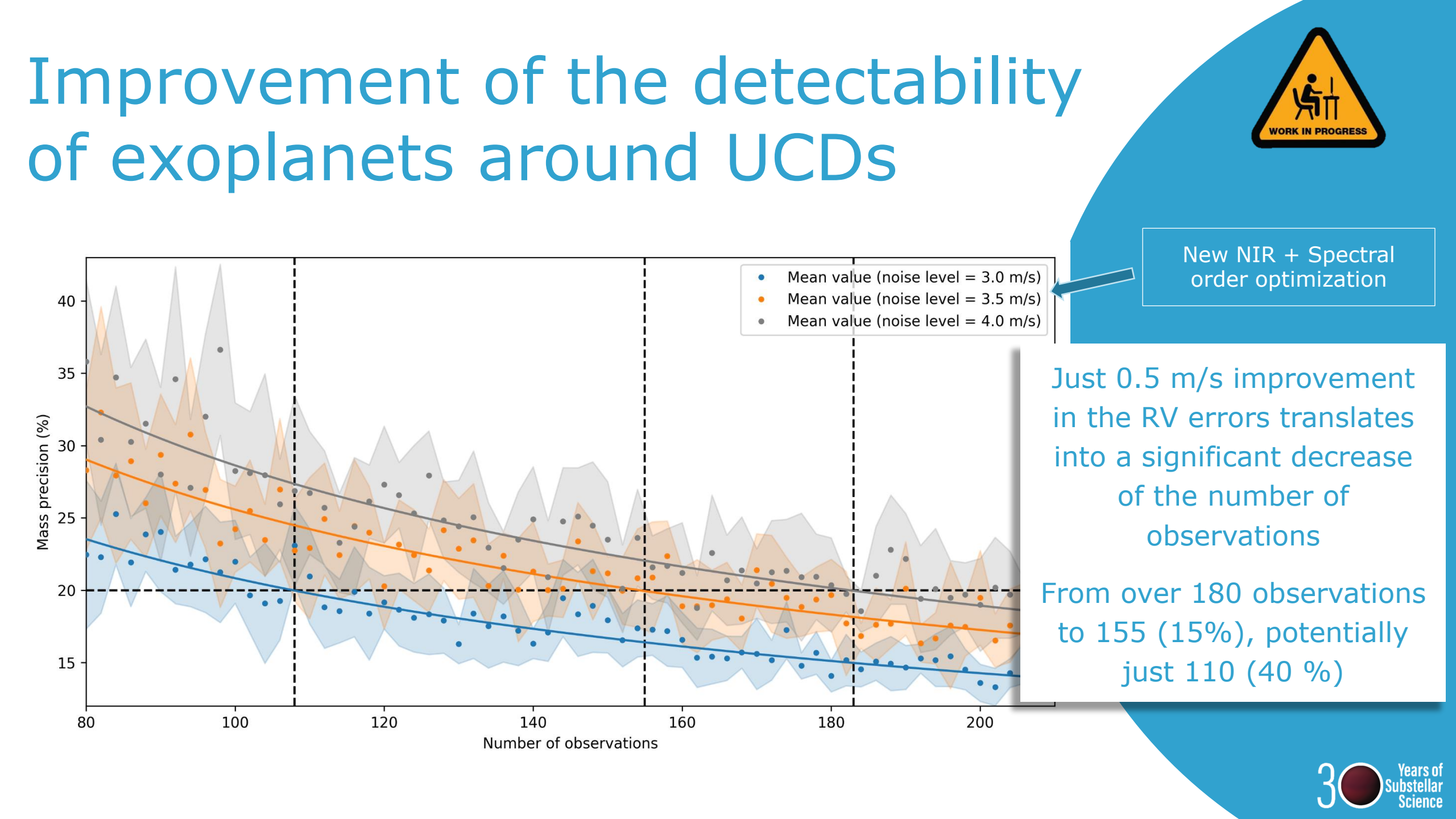
Improvement of the detectability of exoplanets around UCDs



New NIR + Spectral order optimization

Just 0.5 m/s improvement in the RV errors translates into a significant decrease of the number of observations

From over 180 observations to 155 (15%), potentially just 110 (40 %)

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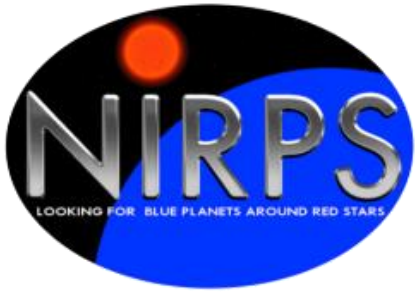
Present and future infrastructures for UCD studies



SPECULOOS

We have many present and future infrastructures for doing spectroscopic and photometric studies of UCDs

Collaborative and multi-infrastructure campaigns would be critical for UCD studies

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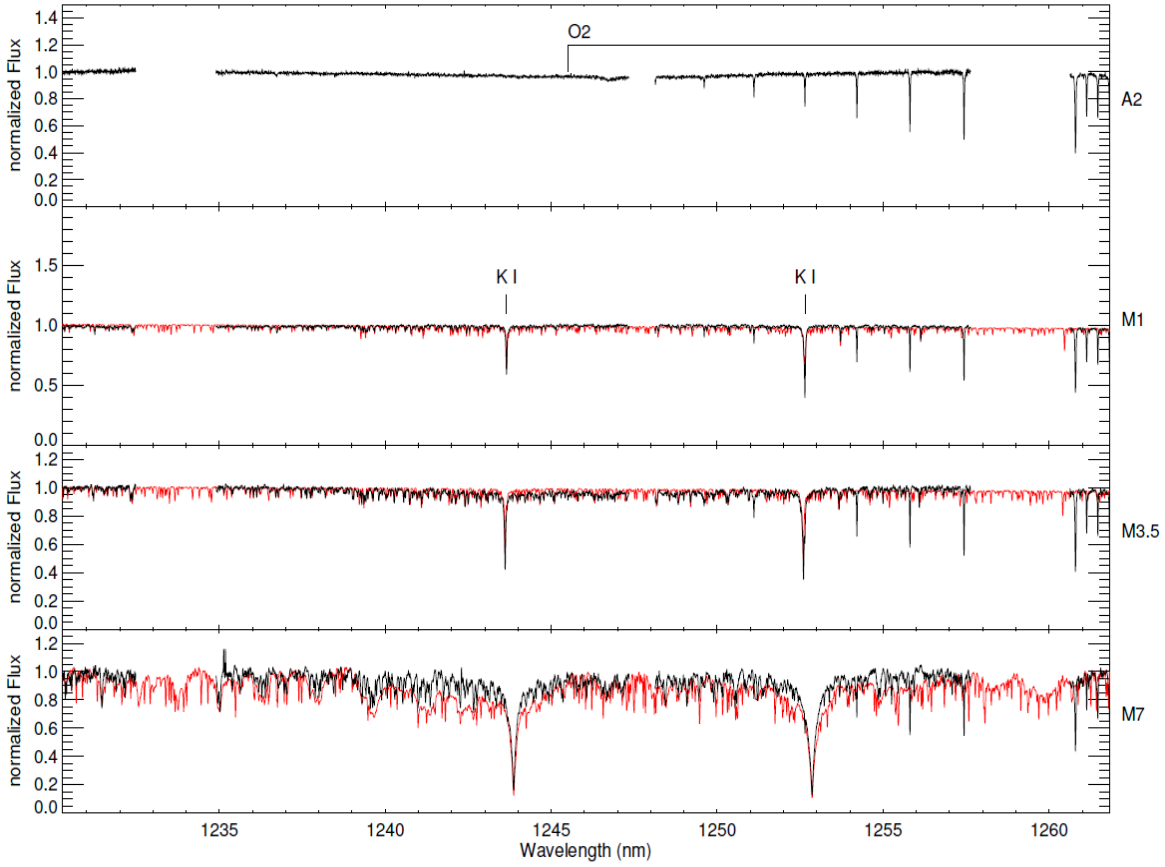
What can we do with available spectra



CARMENES and other surveys have thousands of high-resolution spectra of late M-dwarfs

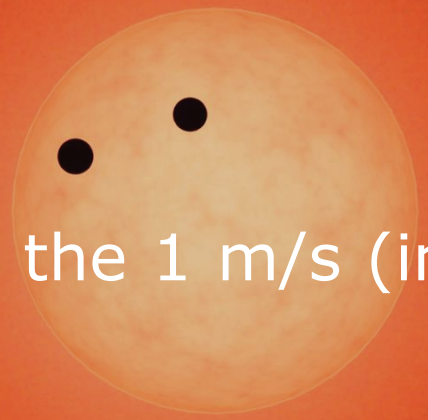
What can we do with these spectra?

Build a reference and homogeneous catalogue?

Look for more targets, not for RV but spectral analysis?

Observation strategy specific for NIR?

CONCLUSIONS

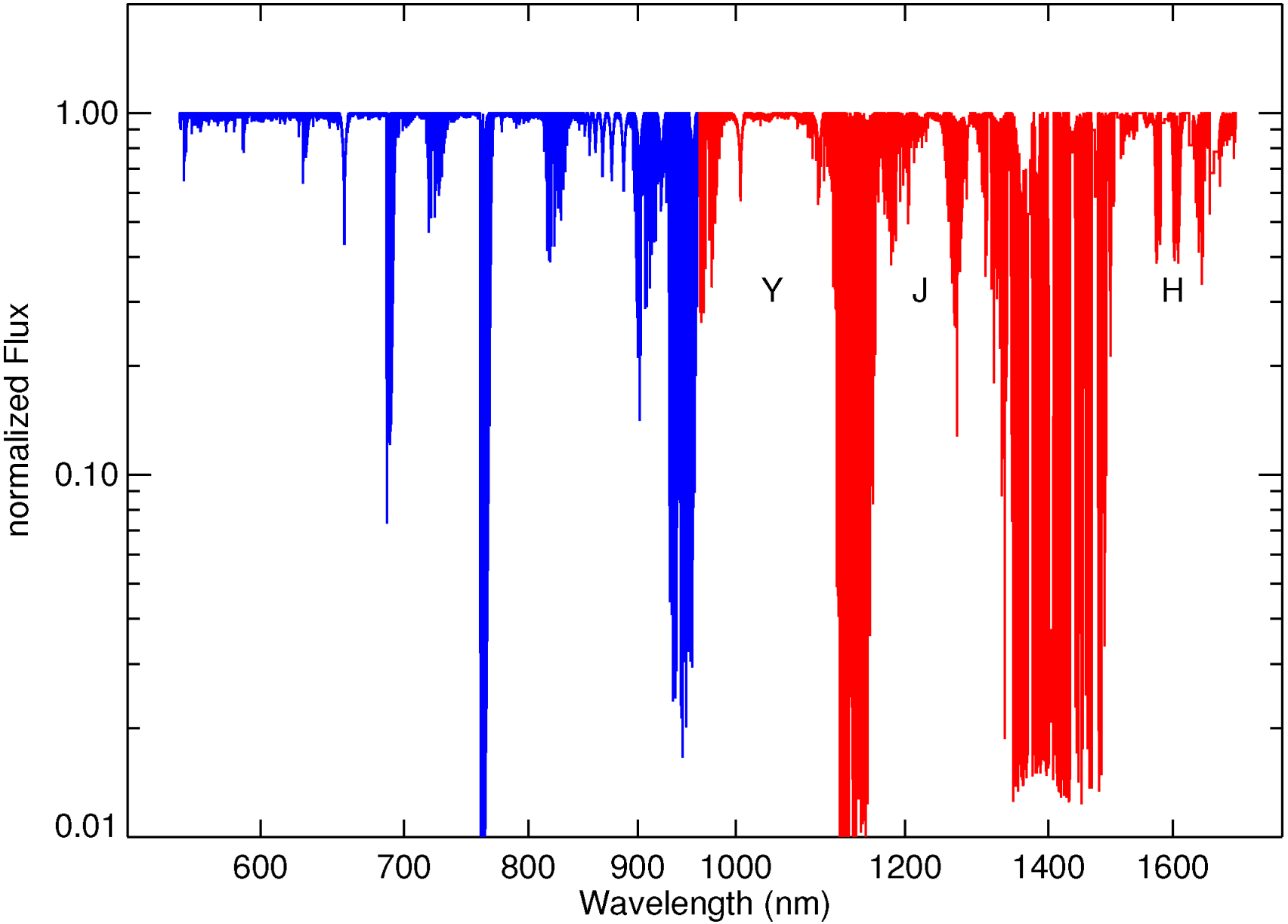


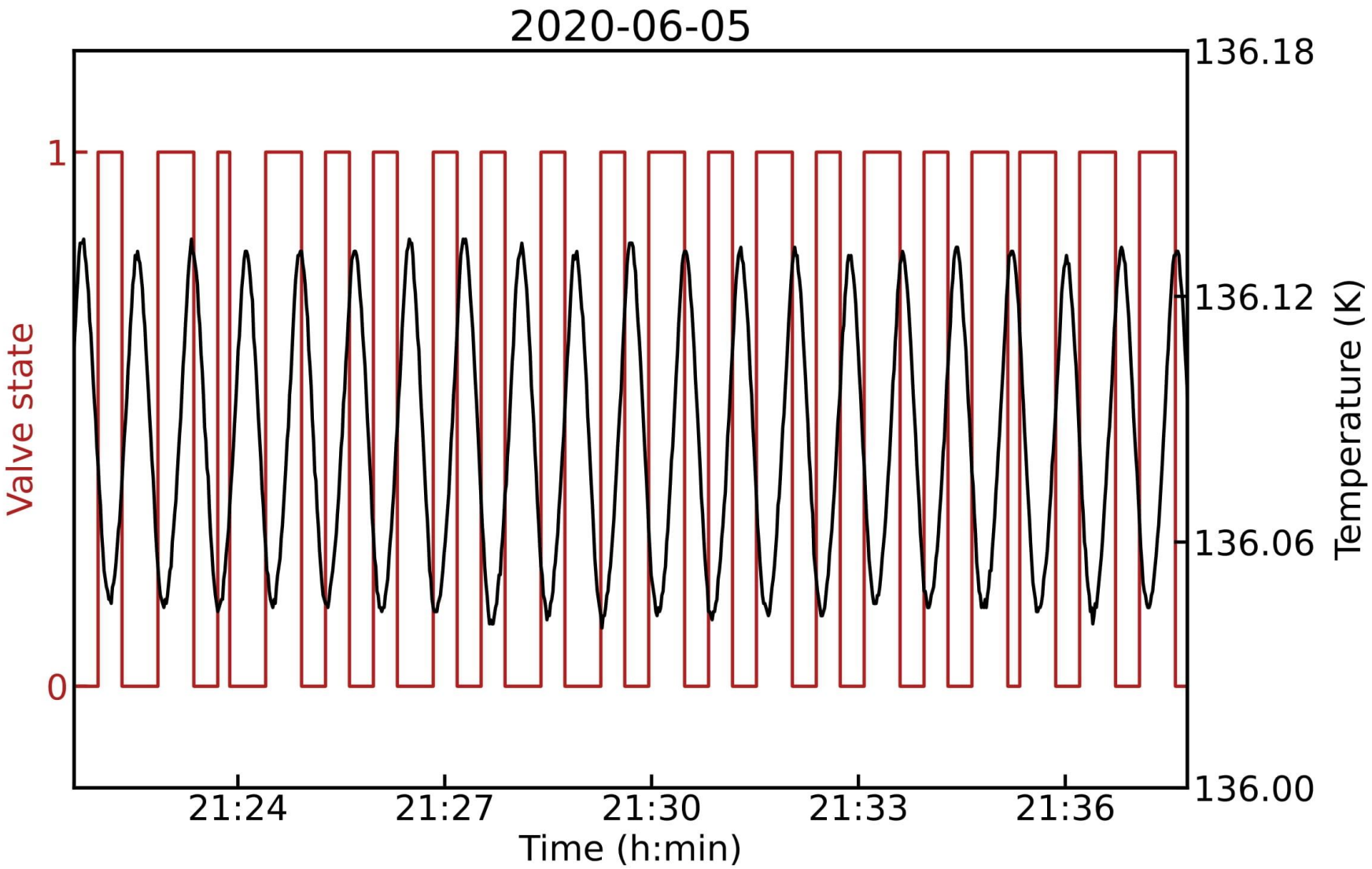
- CARMENES NIR channel is now performing under the 1 m/s (intrinsic precision)
- A spectral order analysis reduces the RV errors in more than a 10 %
- All this improvements translates into a significant decrease of the number of observations needed
- A multi-observatory approach will be critical for UCD studies
- Looking in detail to UCDs spectra of CARMENES (and others)

THANK YOU FOR ATTENDING

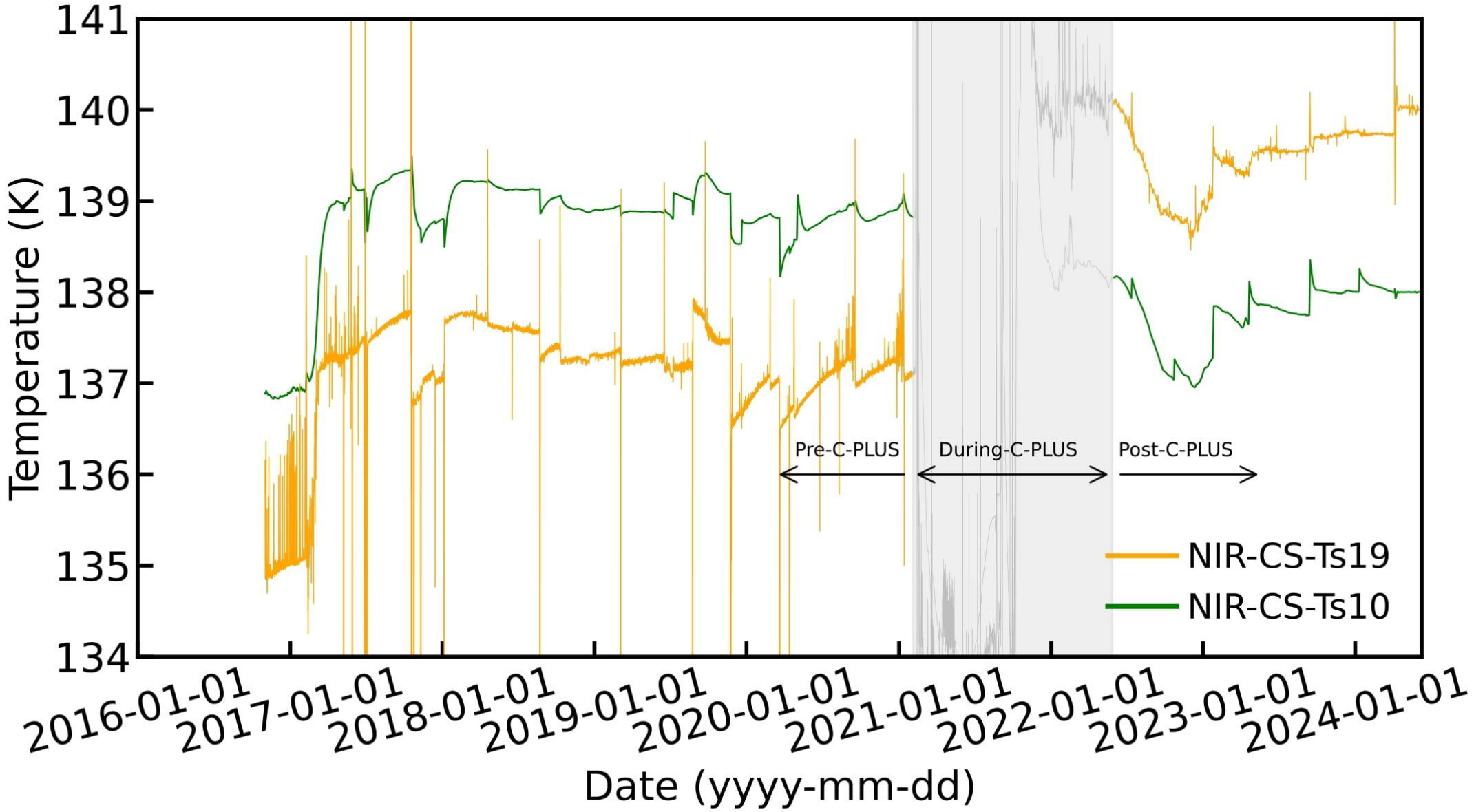
QUESTIONS or SUGGESTIONS?

Author Roberto Varas acknowledges financial support from the Severo Ochoa grant CEX2021-001131-S funded by MICIU/AEI/ 10.13039/501100011033 and AST22 00001 8 of the Junta de Andalucía and the Ministerio de Ciencia, Innovación y Universidades funded by the NextGenerationEU and the Plan de Recuperación, Transformaci´on y Resiliencia

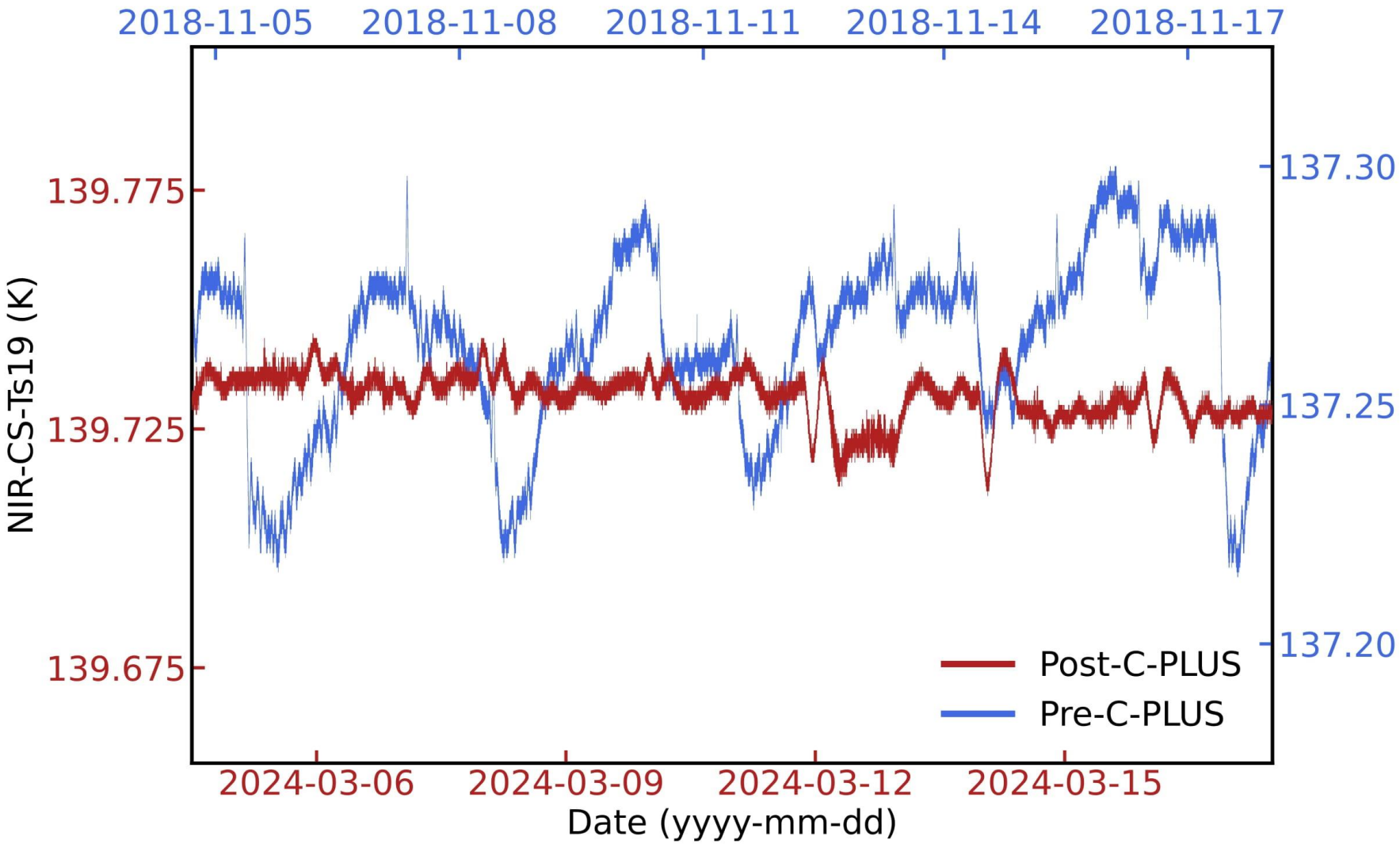




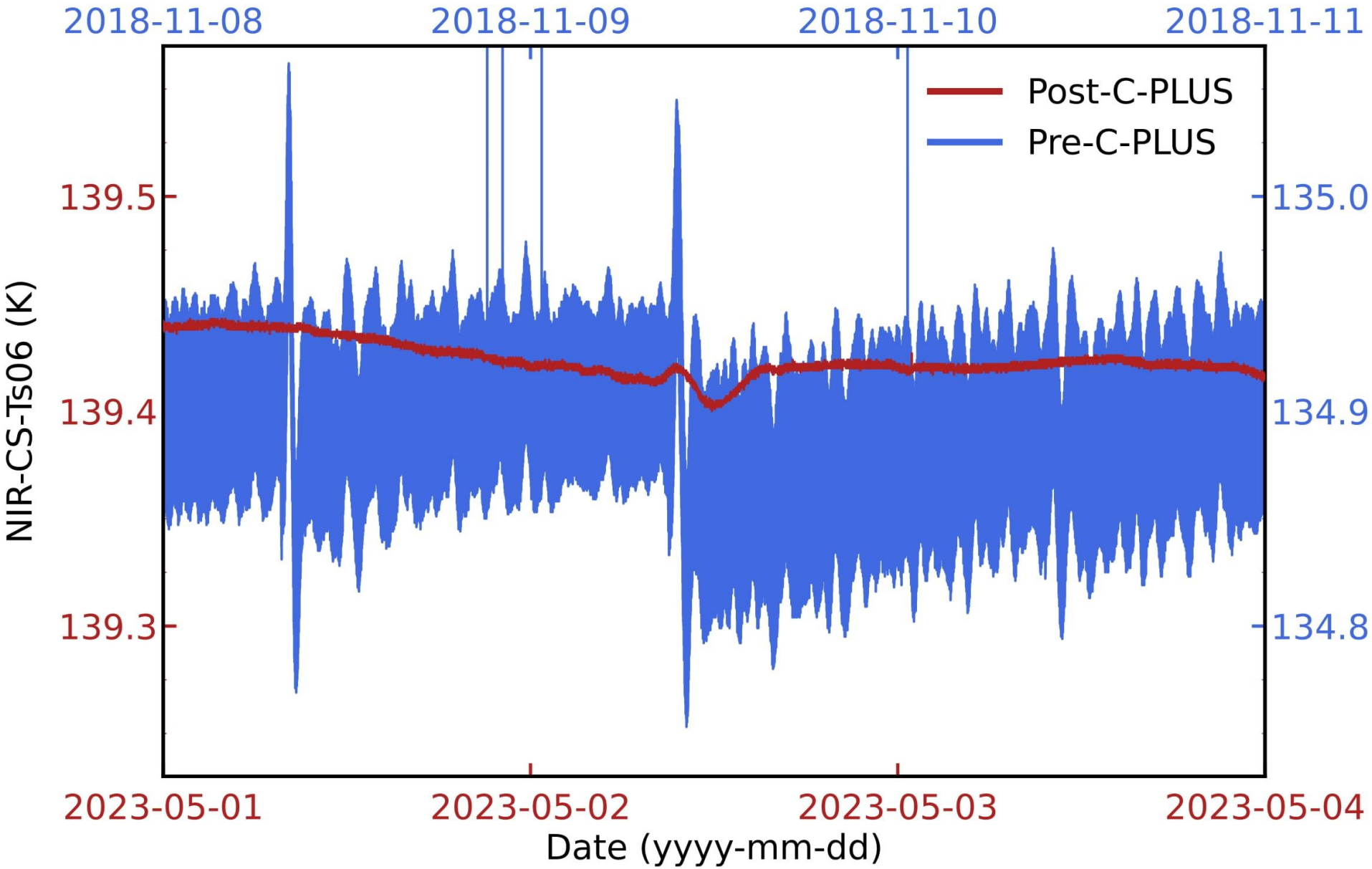
Temperature during On-Off



Temperature history



Temperature at the Radiation Shield



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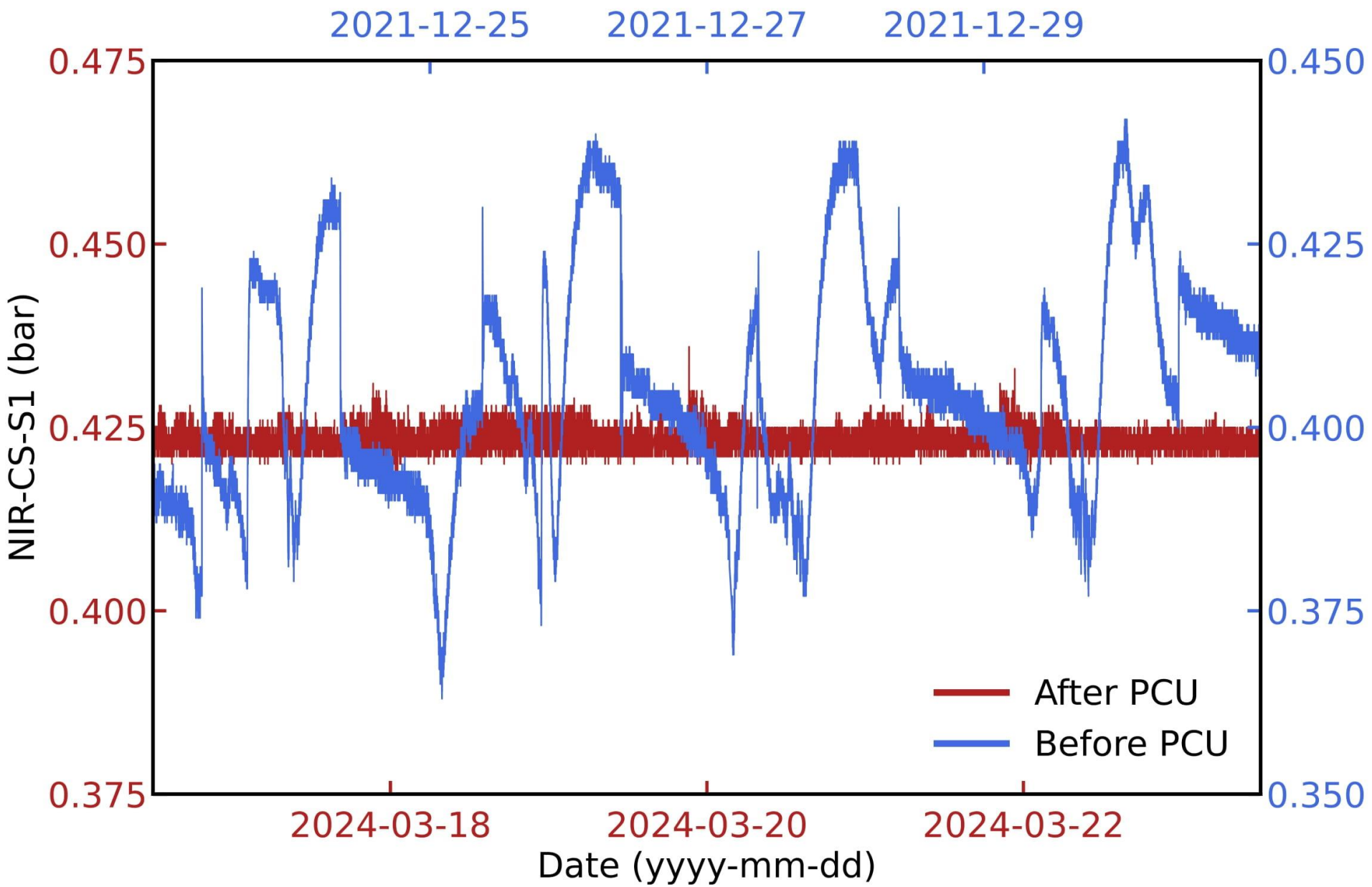
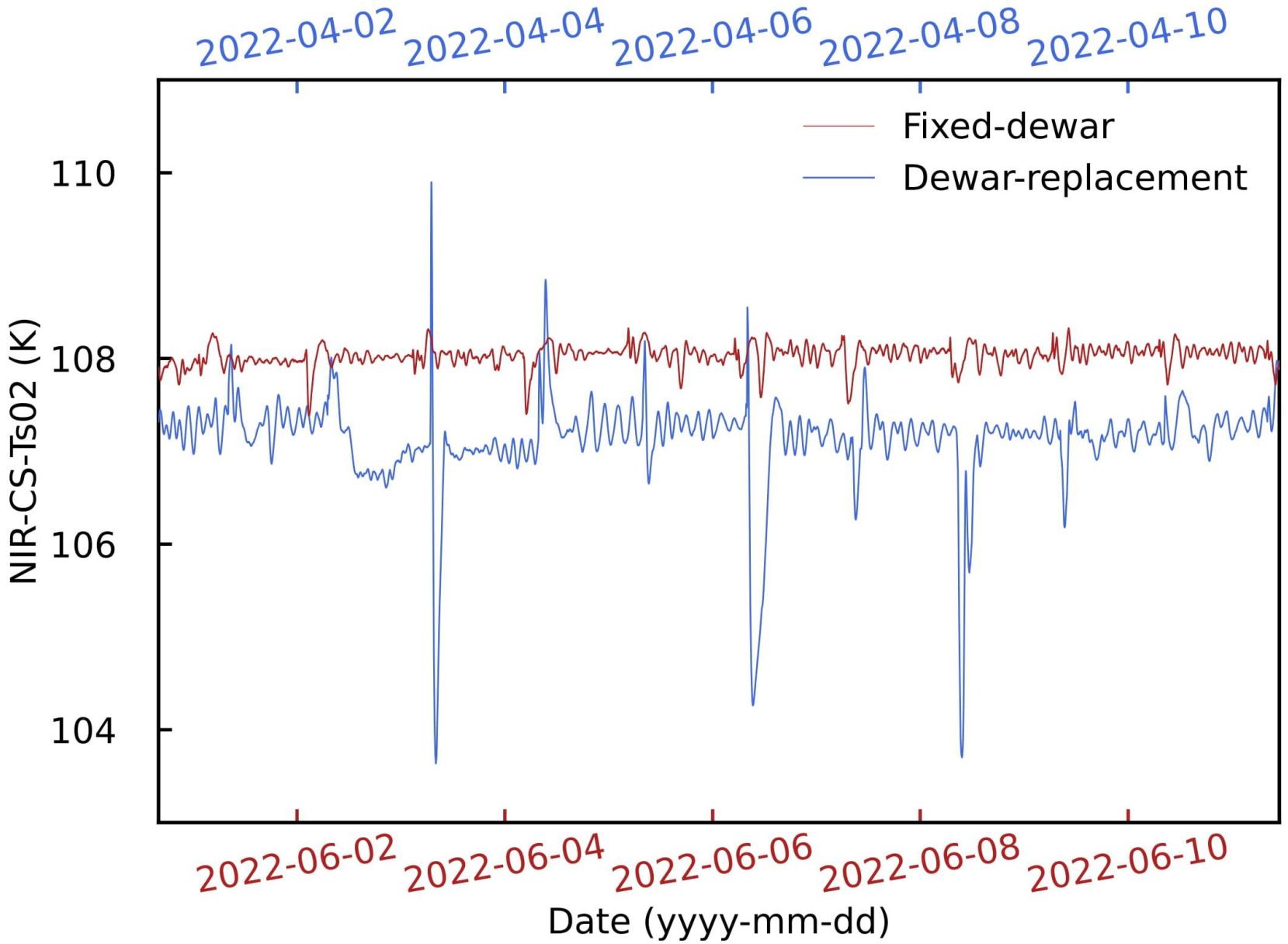
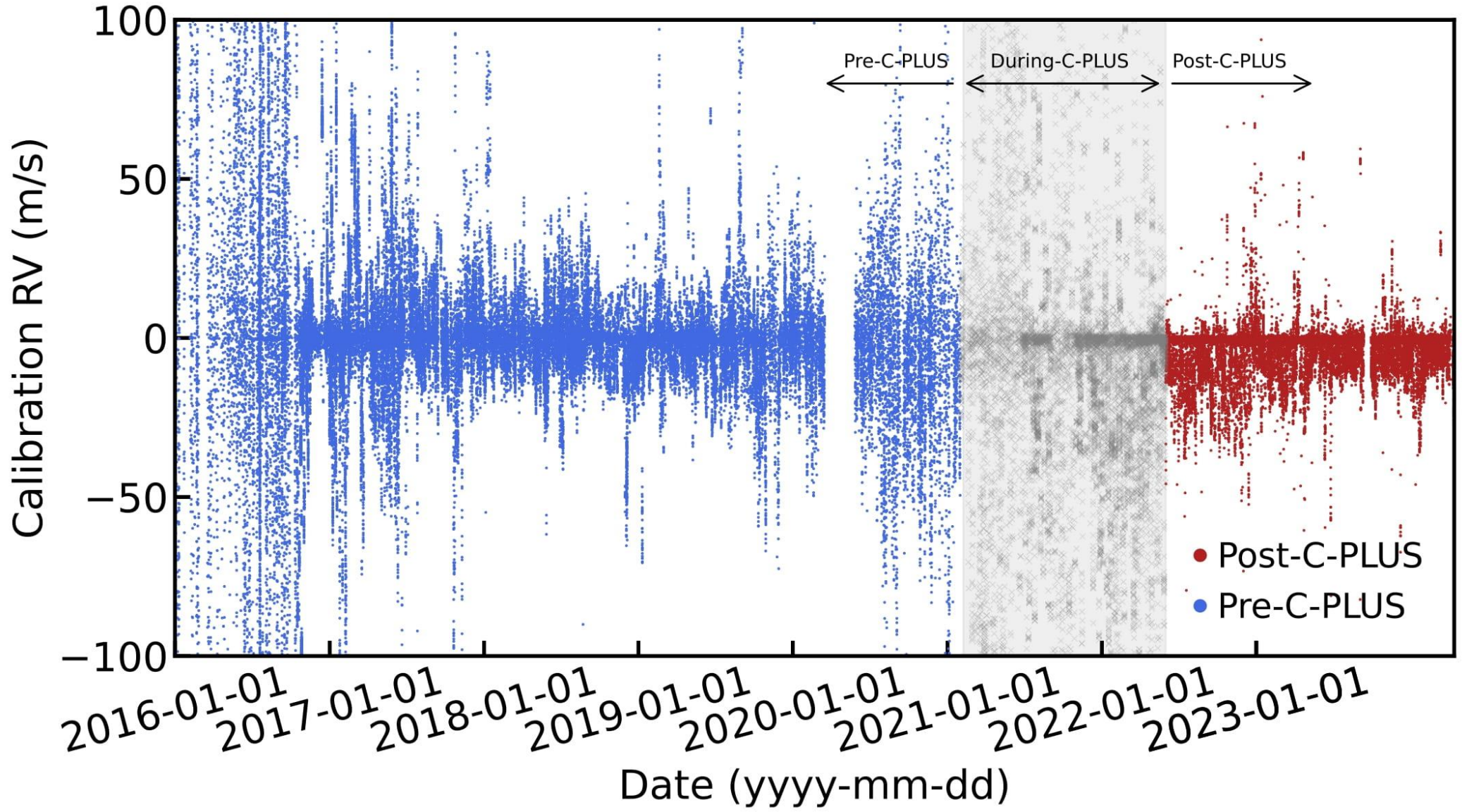


Pressure difference with PCU



Temperature with dewar configurations



Nightly RV drifts history

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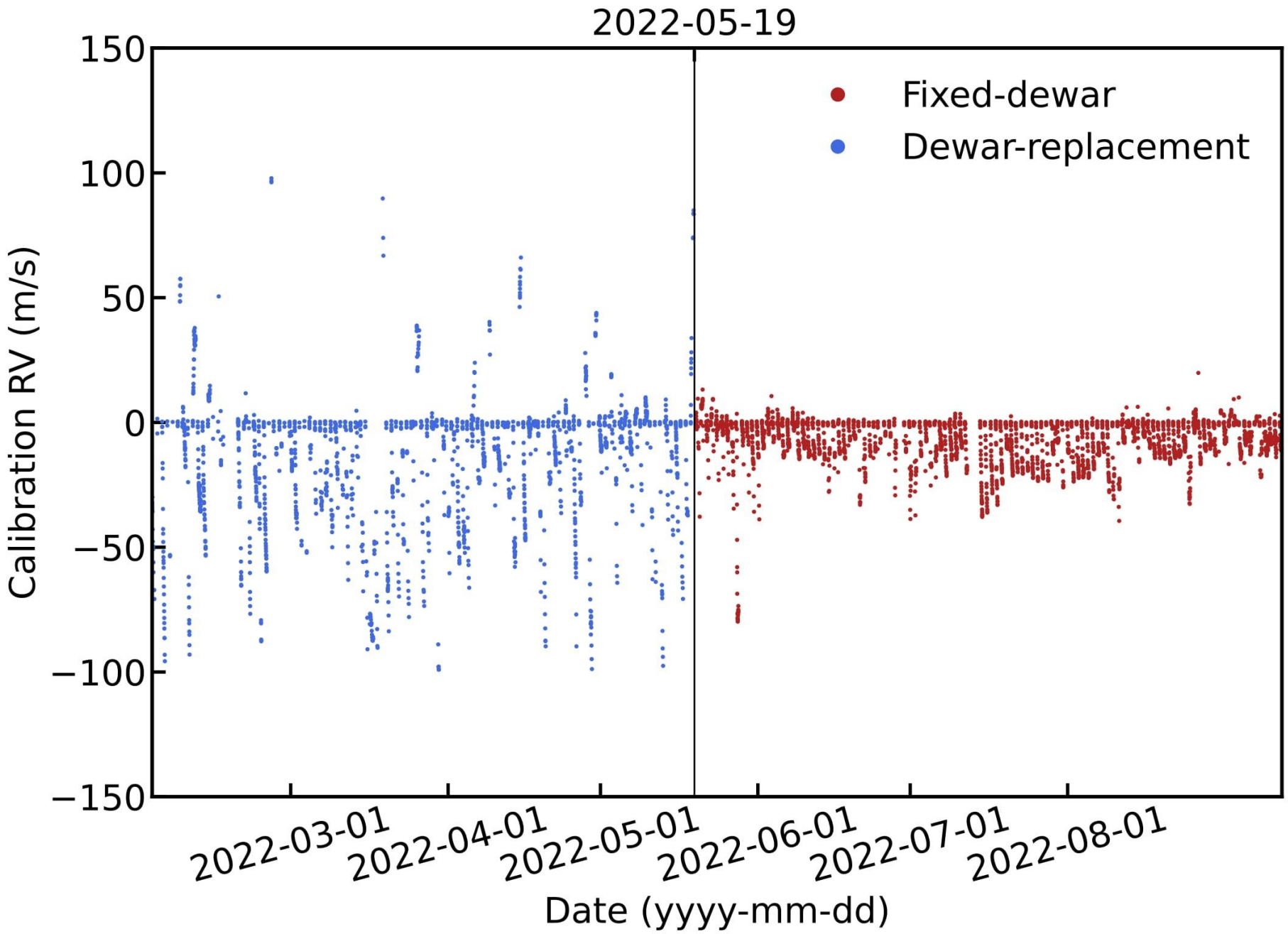
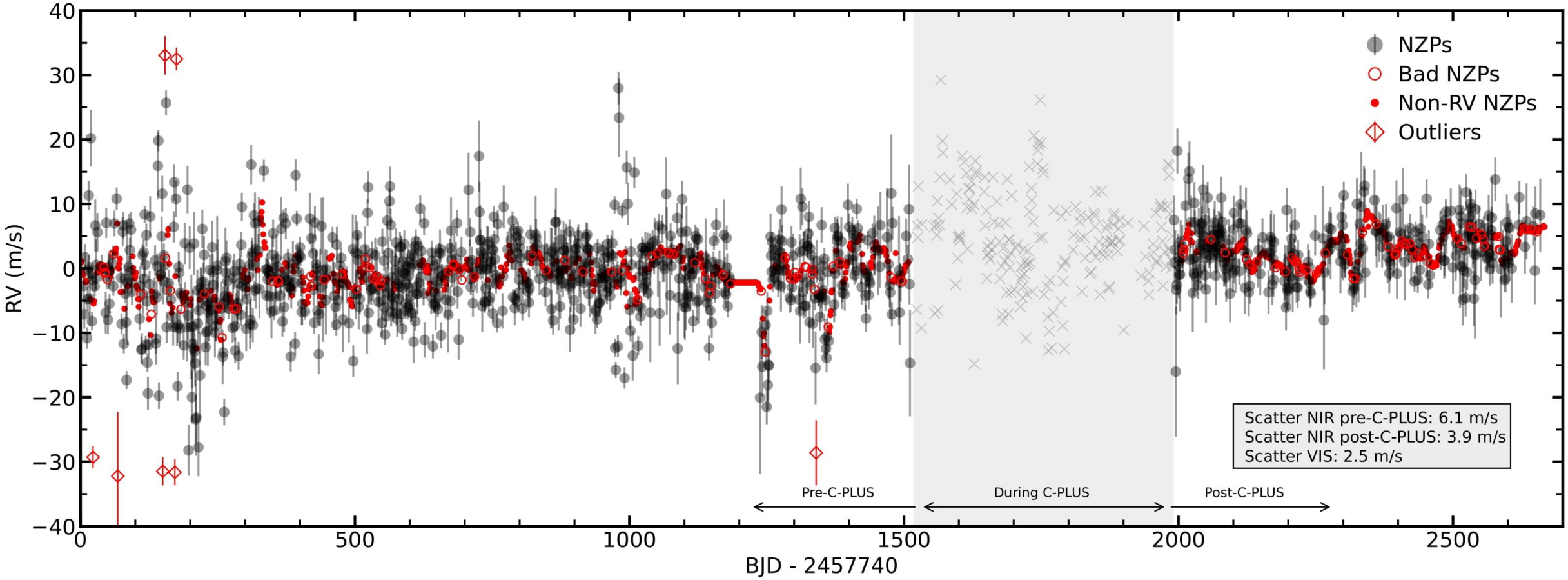
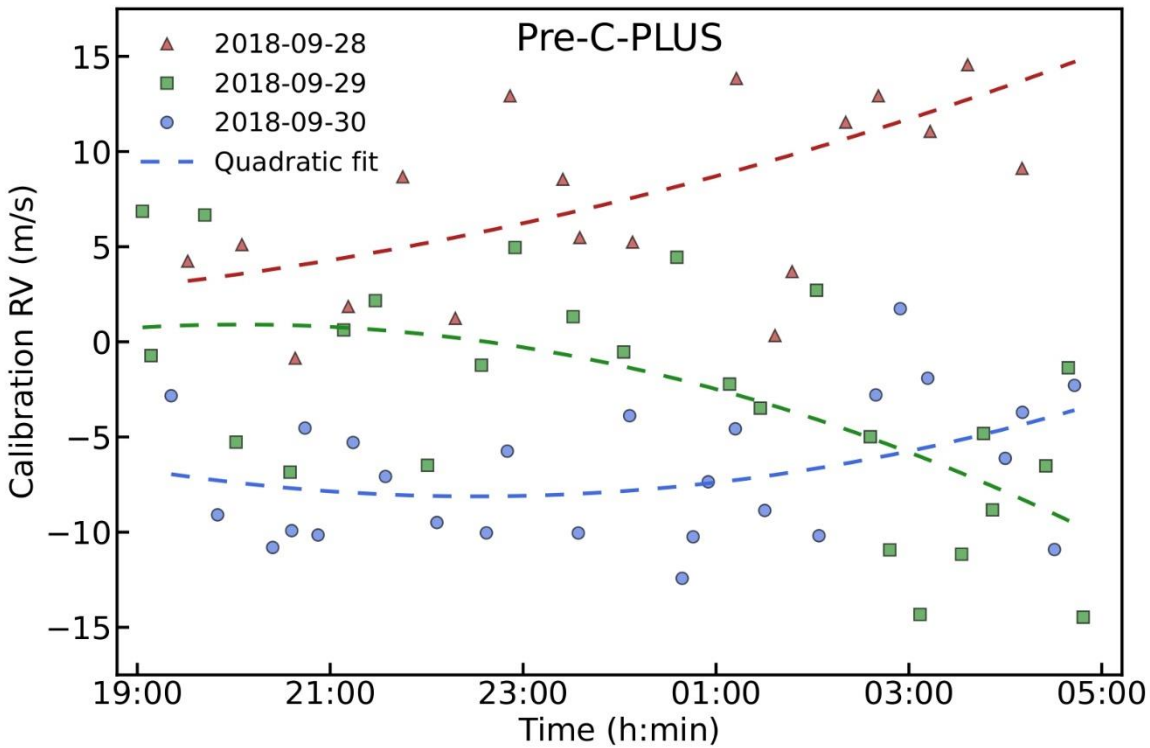
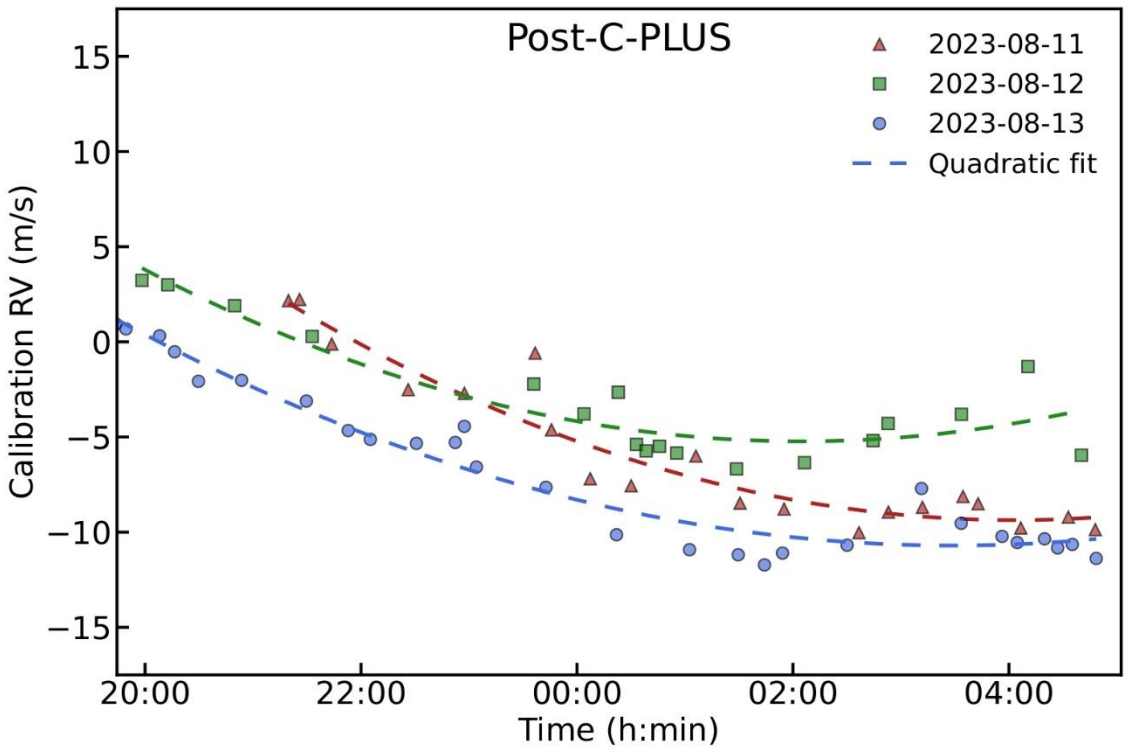


Nightly RV drifts with dewar configurations



NZPs drift





Typical nights for FP calibrations

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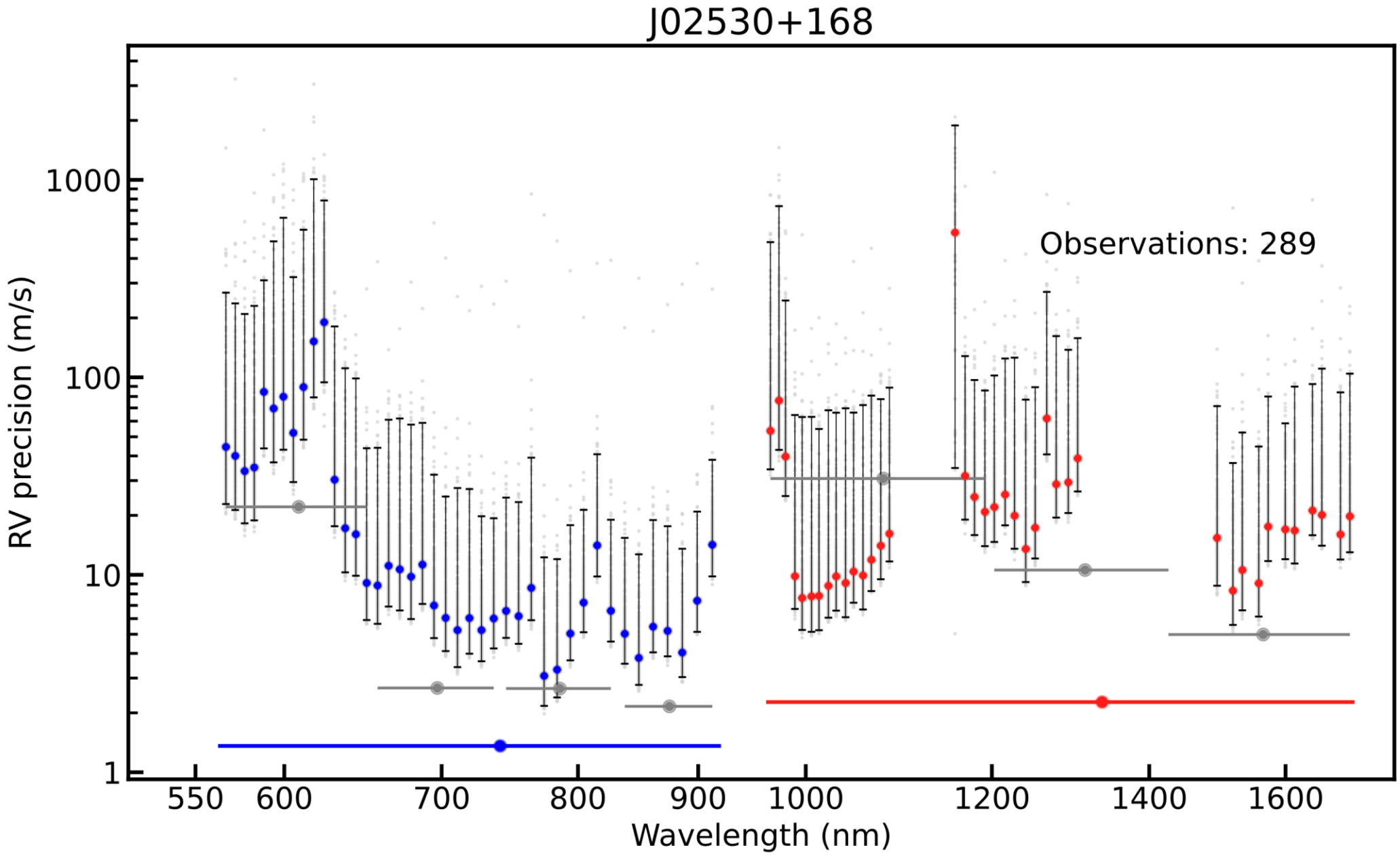

RV precision per order for Teegarden's star