

RV measurements and PLATOSpec

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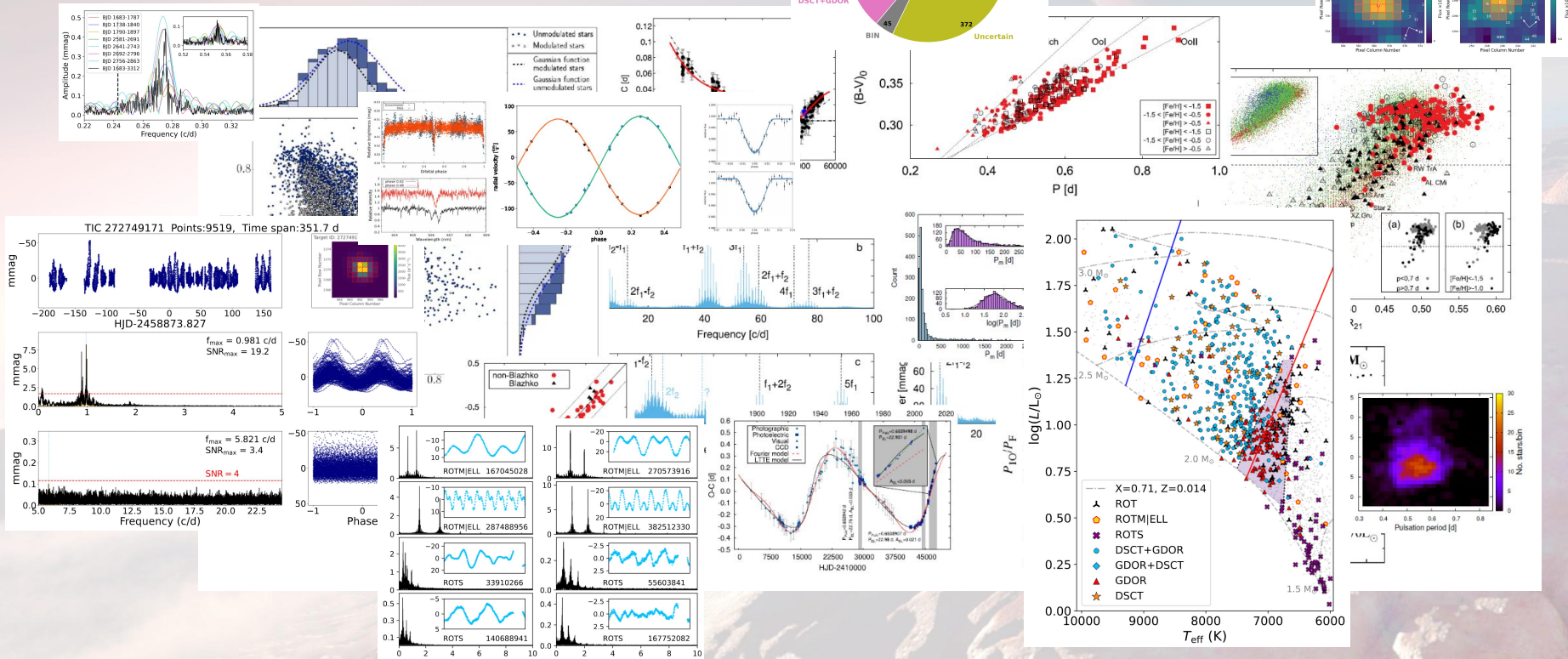
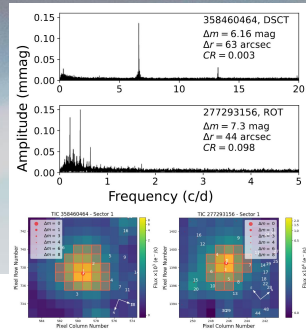


**Astronomical
Institute**
of the Czech Academy
of Sciences

Marek Skarka (*1982)

Stellar variability among intermediate-mas stars,
variability classification, RR Lyrae stars,
exoplanets, stellar systems, ...

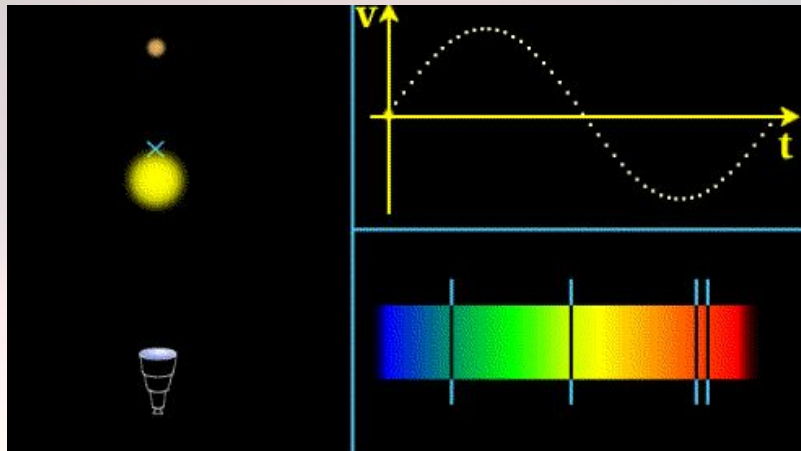
Member of scientific teams:
PLATO (PCOT, SCT)
QUVIK
ULTRASAT



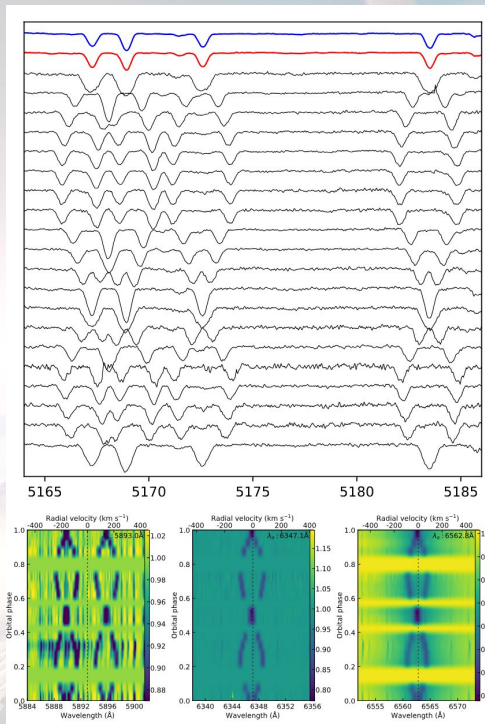


Doppler shift

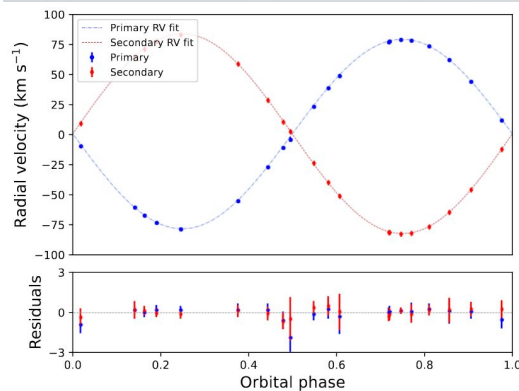
Change of frequency due to common movement of the object and observer



$$\frac{v}{c} = \frac{\lambda_{\text{obs}} - \lambda}{\lambda} = \frac{\Delta\lambda}{\lambda}$$



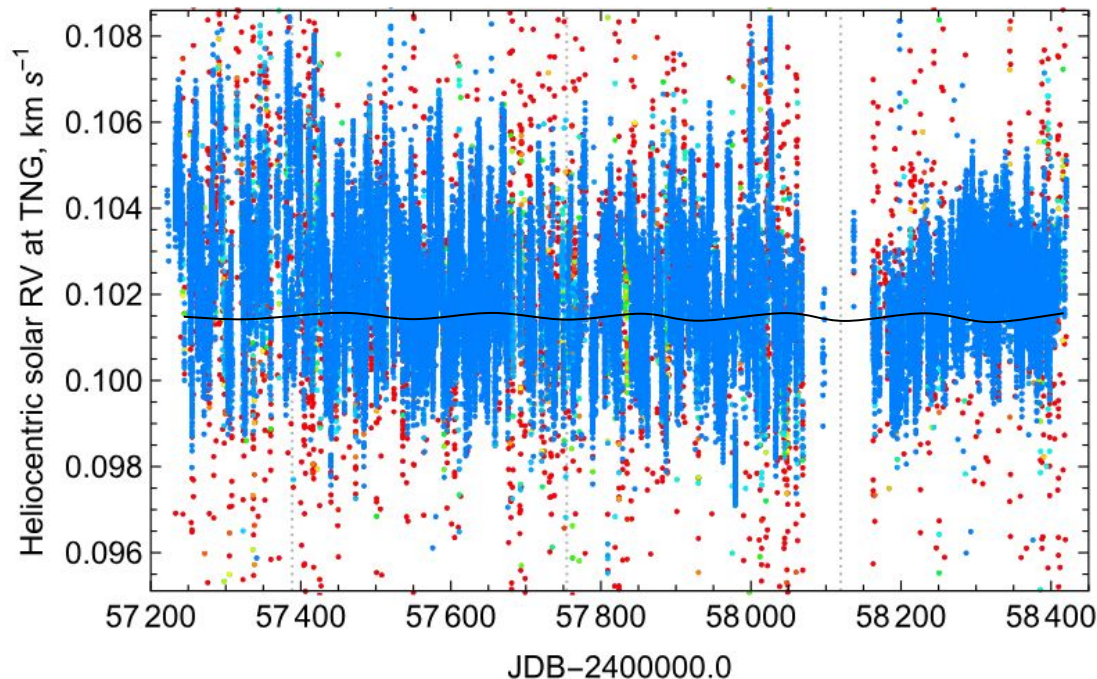
Skarka+, 2025A&A...698A..48S



Line shifts are very small. For exoplanets, $\Delta\lambda < \sim 0.002$ nm in optical range
Special considerations and techniques are required

Radial velocities

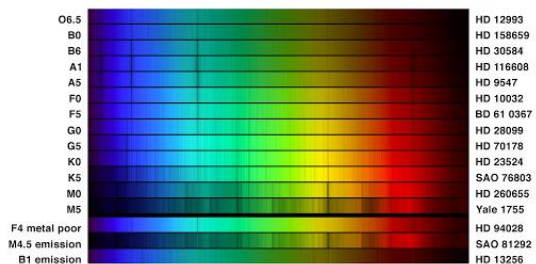
$$RV = RV_{\text{stellar}} + RV_{\text{orbital}} + RV_{\text{instrumental}}$$



RV_{stellar} - stellar variability
(rotation, activity,
pulsations) + systemic
velocity

RV_{orbital} - reflection motion
due to a companion

$RV_{\text{instrumental}}$ - stability of the
instrument & telescope,
weather conditions,
movement of the observer,
data quality, data reduction
& analysis, Earth
atmosphere



Radial velocities

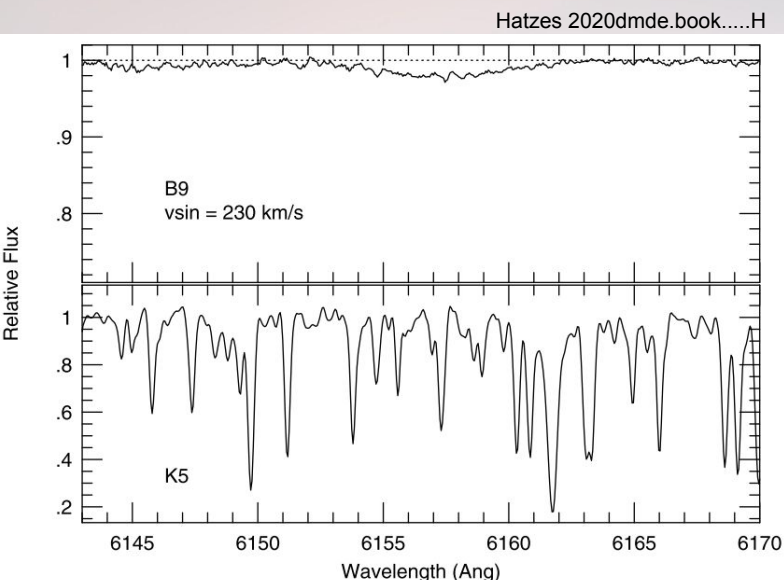
$$\sigma \text{ [m/s]} \propto$$

$$f(V)(0.16e^{1.79(T/5000)})$$

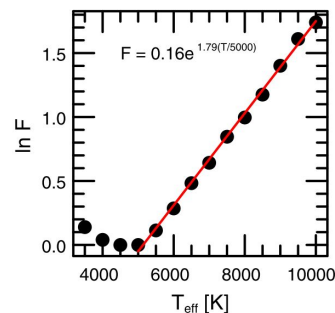
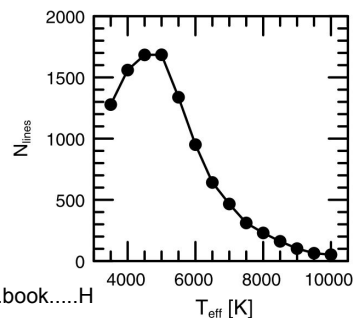
Stellar characteristics (cannot be changed) impact the precision of the RV measurements

RVs of fast rotators can be estimated only with precision of about a few km/s

RV uncertainty will be about 2.8x larger for a star with $T=8000$ K than for a star with $T=5000$ K



- Lines are blended in cool stars creating large absorption regions
- Continuum is badly defined



Hatzes 2020dmde.book.....H

Radial velocities

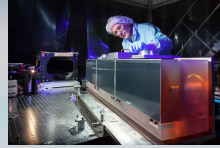
$$\sigma \text{ [m/s]} \propto \Delta\lambda^{-1/2}(S/N)^{-1}R^{-1.2}f$$

Instrumental characteristics (can be designed)

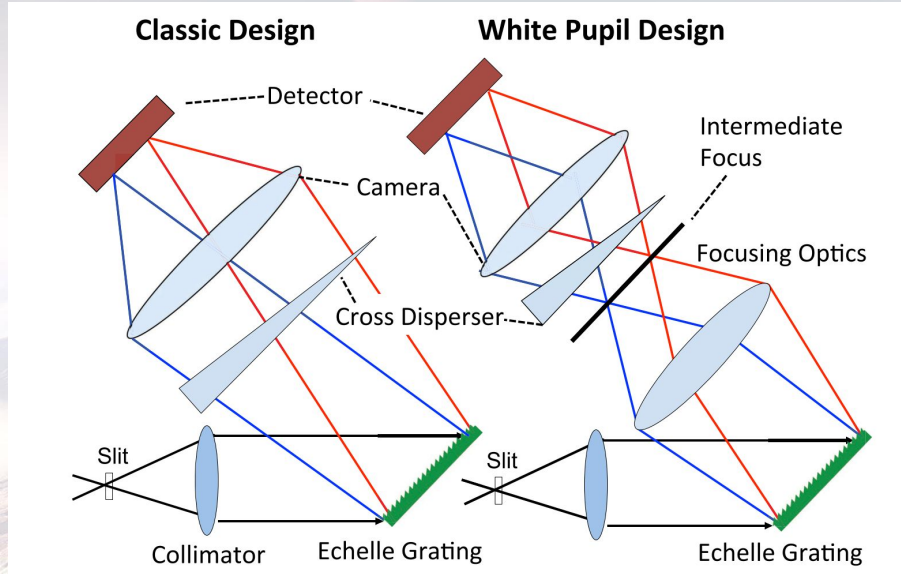
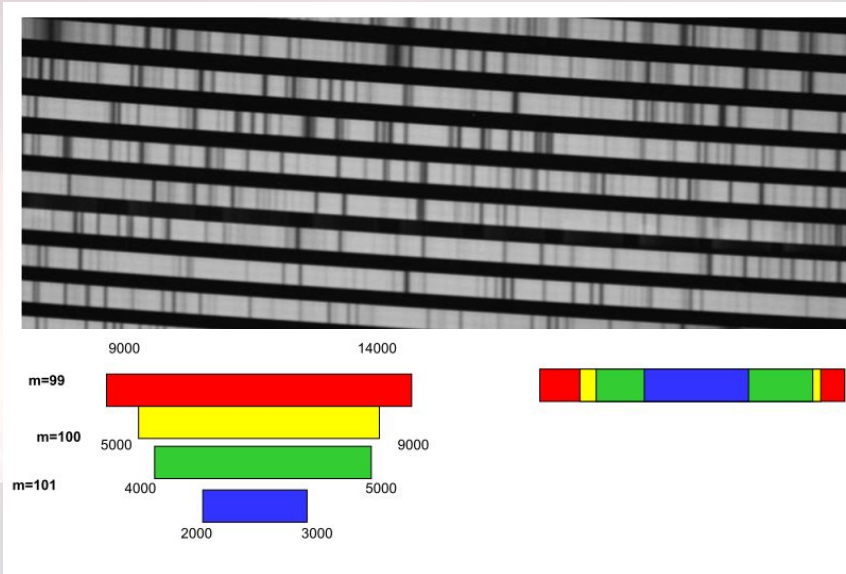
- Spectral range (instrument characteristics)
- Resolving power (instrument characteristics)
- Quality of the data (efficiency of the instrument and optical system, pointing, observing strategy, observing conditions, data reduction, data calibration, analysis)

Radial velocities - spectrographs

$$\sigma \text{ [m/s]} \propto \Delta\lambda^{-1/2} (S/N)^{-1} R^{-1.2} f$$



- Wide spectral range and high resolving power → ECHELLE SPECTROGRAPHS



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$$R = \frac{\lambda}{\delta\lambda} = \frac{N \cdot m}{\cos \beta}$$

High orders, blazed gratings
White pupil design preferred

$$R = \frac{\lambda}{\delta\lambda} = \frac{2 \tan \Theta_B}{d_{\text{obj}}} \frac{f_{\text{tel}}}{w_{\text{slit}}} \frac{d_{\text{col}}^2}{D_{\text{tel}}}$$

Radial velocities - spectrographs

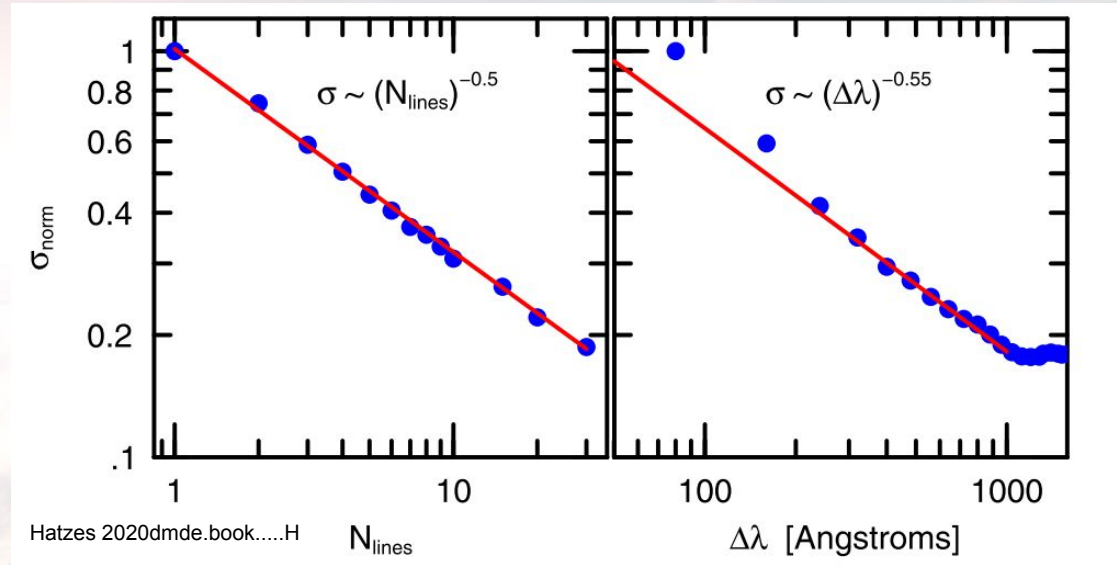
$$\sigma \text{ [m/s]} \propto \Delta\lambda^{-1/2} (S/N)^{-1} R^{-1.2} f$$

- Wide spectral range and high resolving power $\longrightarrow$ ECHELLE SPECTROGRAPHS

$$\sigma_{N_{\text{lines}}} = \sigma_{1\text{line}} / \sqrt{N_{\text{lines}}}$$

- Single line precision $\sim$ km/s
- Different lines originate in different layers

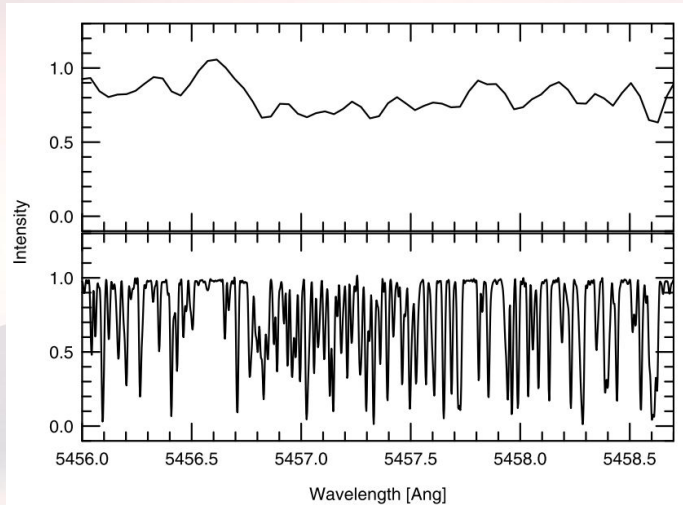
$\longrightarrow$ The more lines, the better
 $\longrightarrow$ The larger spectral range, the better



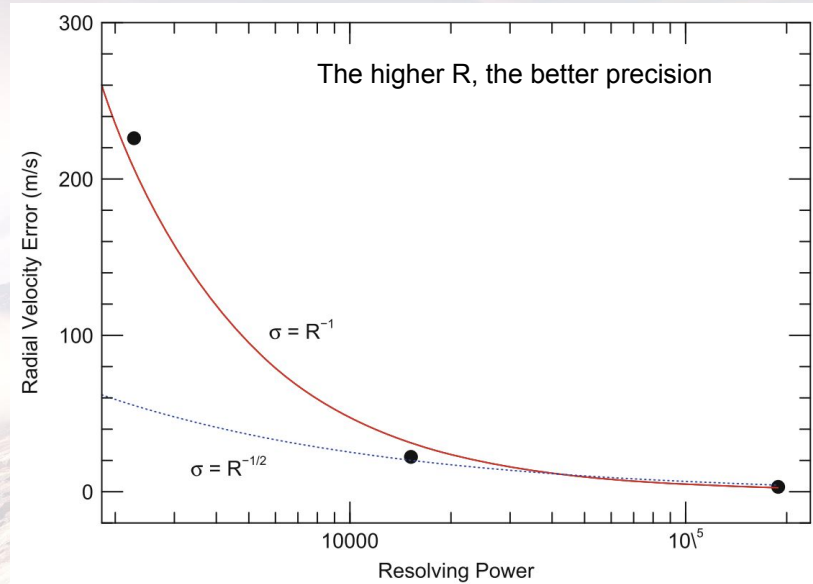
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Radial velocities - spectrographs

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- Wide spectral range and high resolving power → ECHELLE SPECTROGRAPHS

	HARPS@3.6 m	ESPRESSO@8.2 m	ANDES@39 m
Spectral range	380-690 nm	380-790 nm	400-1800 nm
Resolving power	115000	70000, 140000, 190000	100000
Precision	1 m/s	0.1 m/s	0.02 m/s

Radial velocities - spectrographs

$$\sigma \text{ [m/s]} \propto \Delta\lambda^{-1/2} (S/N)^{-1} R^{-1.2} f$$

- Wide spectral range and high resolving power → ECHELLE SPECTROGRAPHS

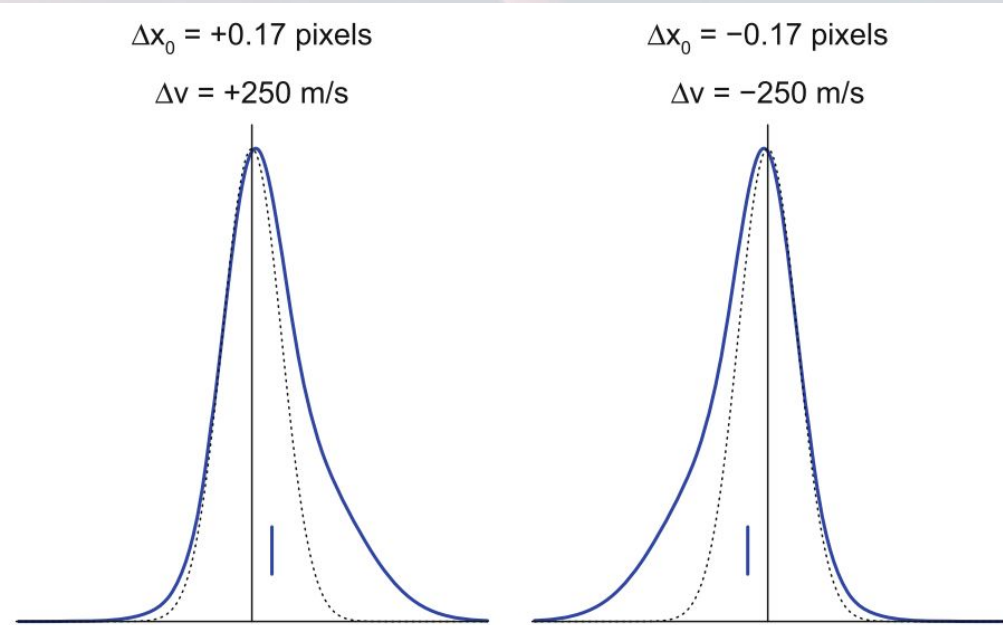
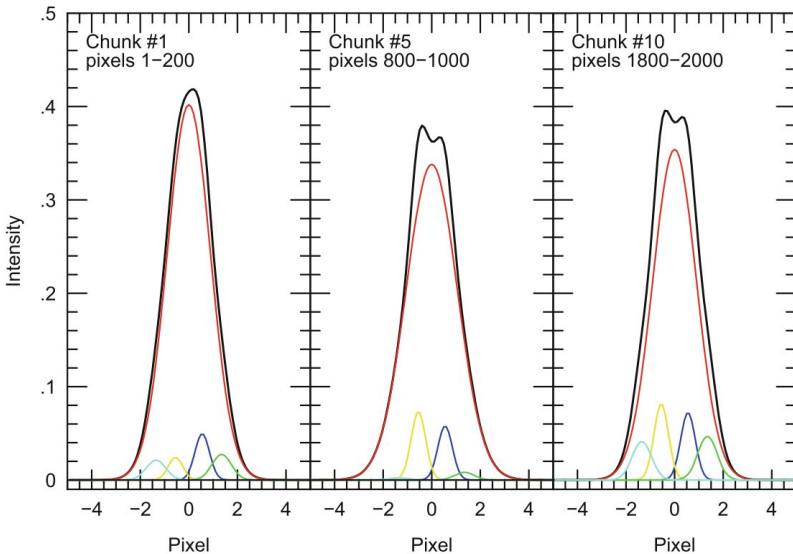
	Coralie@1.2 m	FEROS@2.2 m	FIDEOS@1.0 m	PLATOSpec@1.5 m	OES@2.0 m
Spectral range	390-680 nm	350-920 nm	420-800 nm	380-680 nm	380-9100 nm
Resolving power	60000	48000	43000	70000	50000
Precision	7 m/s	25 m/s	5-8 m/s	3-5 m/s	~10 ¹ (I2); ~10 ² m/s

‘Unlimited’ observing time

Radial velocities - spectrographs

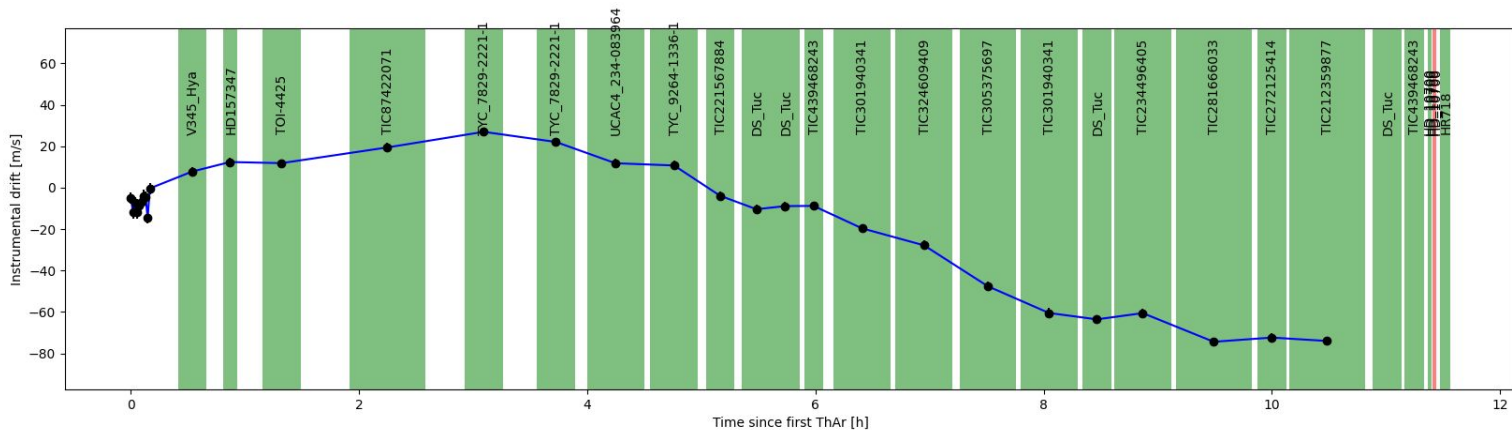
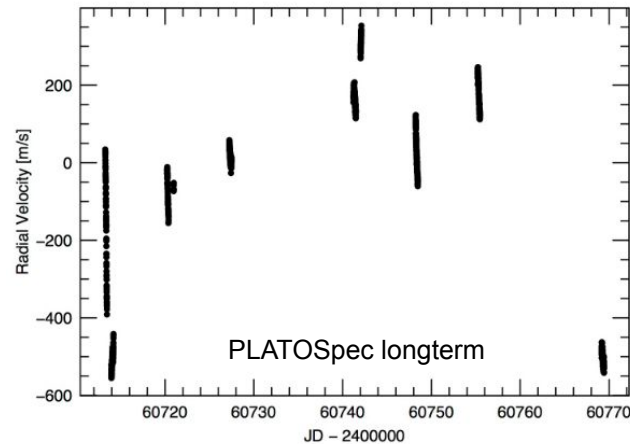
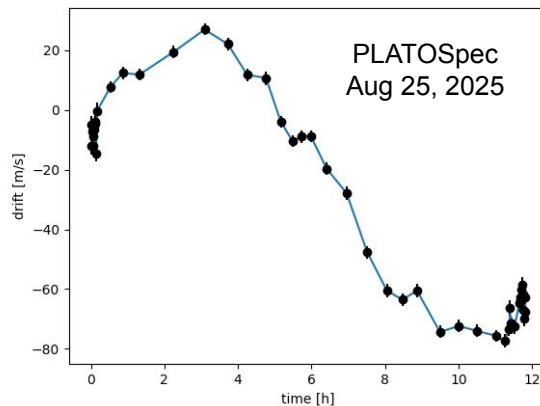
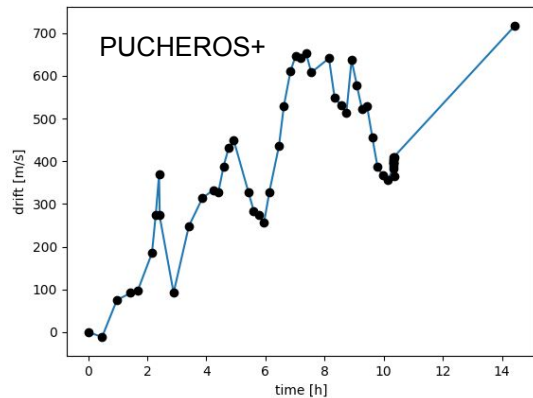
$$\sigma \text{ [m/s]} \propto \Delta\lambda^{-1/2} (S/N)^{-1} R^{-1.2} f$$

- Instrumental profile - stability matters

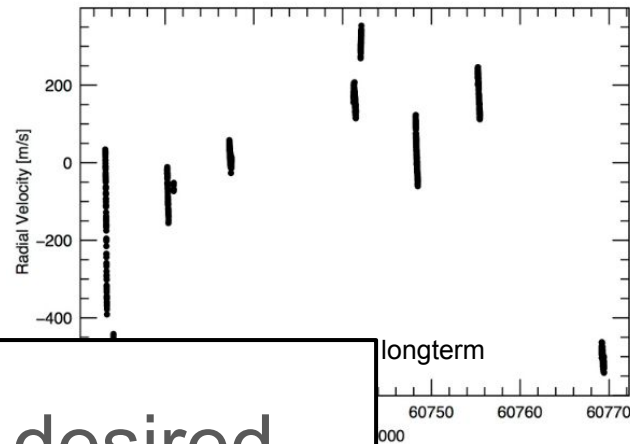
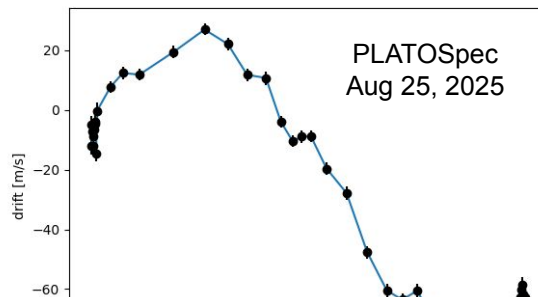
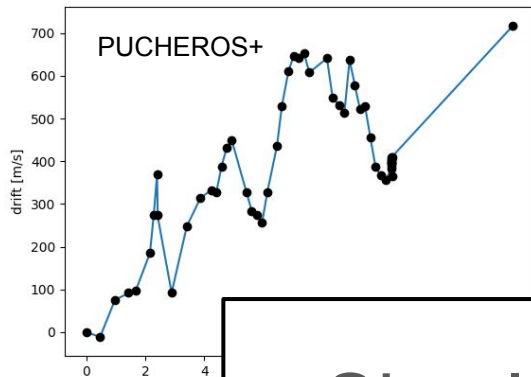


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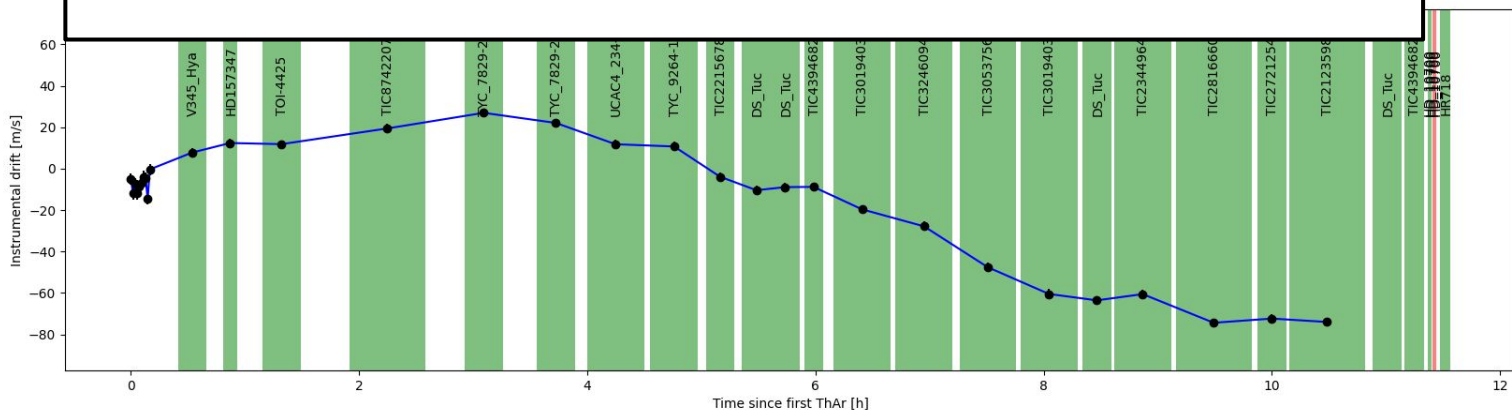
Radial velocities - spectrographs



Radial velocities - spectrographs



Simultaneous calibration desired

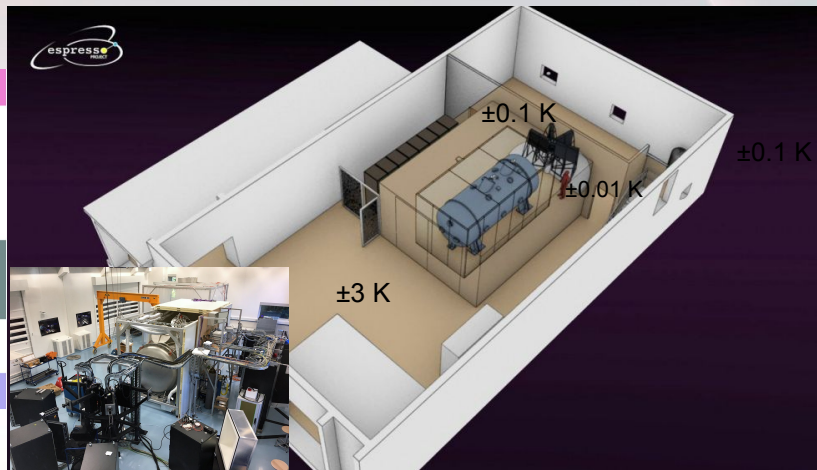
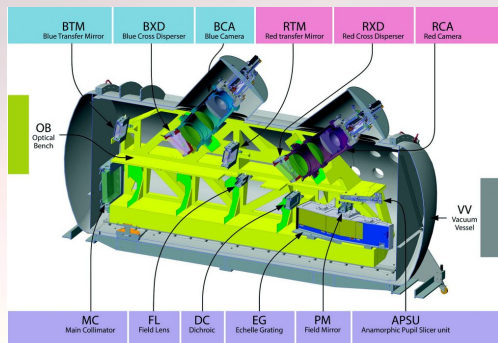


Radial velocities - spectrographs

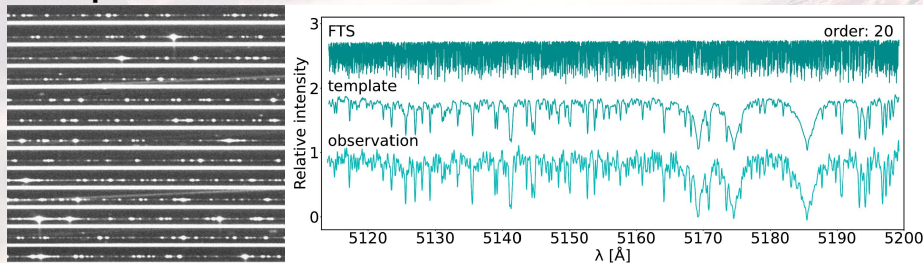
- Stability and calibrations are crucial ($\Delta p \sim 100$ Pa $\rightarrow \Delta RV \sim 80$ m/s)

ESPRESSO@VLT: $\delta T \sim 1$ mK, $\Delta p \sim 0.1$ Pa; ~ 0.1 m/s

HARPS@3.6mLaSilla: $\delta T \sim 10$ mK, $\Delta p \sim 1$ Pa; ~ 1 m/s



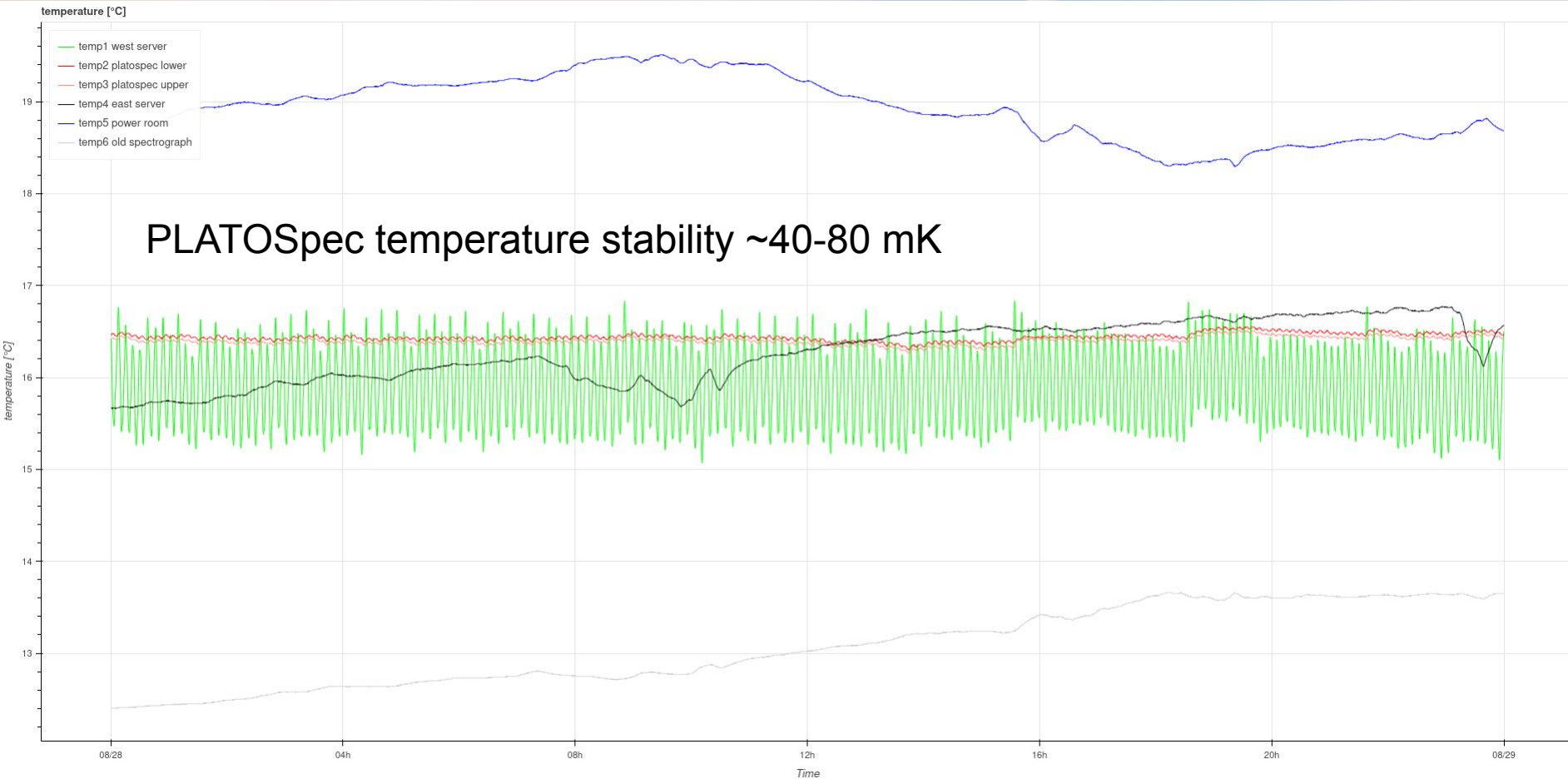
PLATOSpec has simultaneous ThAr and I2 calibrations



Fabry-Perot and laser combs



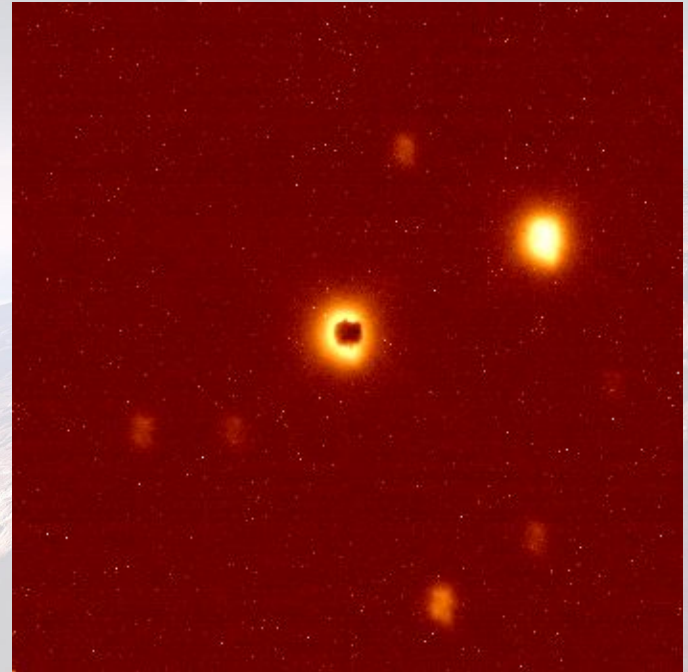
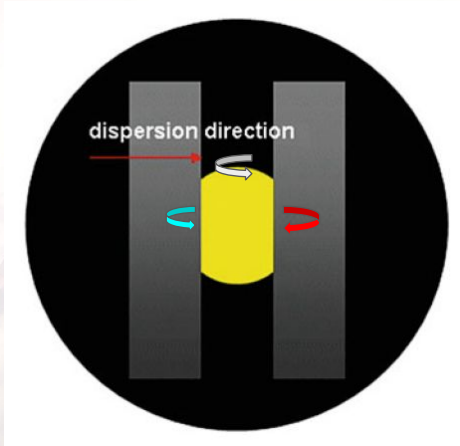
Radial velocities - spectrographs



Radial velocities - observations

$$\sigma \text{ [m/s]} \propto \Delta\lambda^{-1/2} (S/N)^{-1} R^{-1}$$

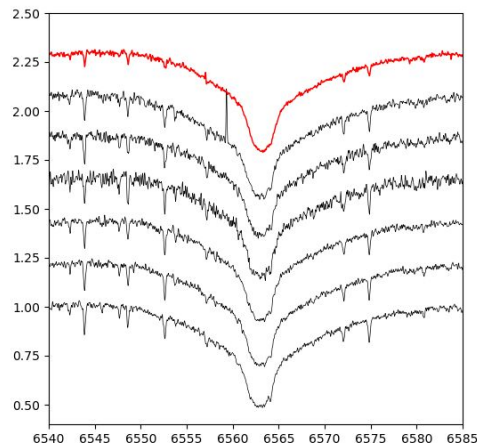
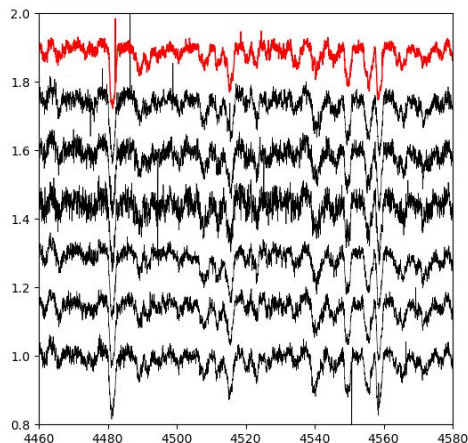
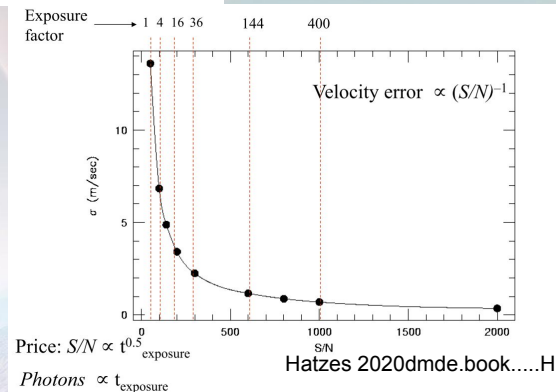
- Pointing



Radial velocities - observations

$$\sigma \text{ [m/s]} \propto \Delta\lambda^{-1/2} (S/N)^{-1} R^{-1}$$

- Pointing
- Exposure time
- Air mass
- Observing condition (stability, clouds, seeing)



1.1.2025; 1200 s; alt 63°; hum 53 %; snr~120

8.11.2023; 1200 s; alt 82°; hum 89 %; snr~90

8.11.2023; 600 s; alt 82°; hum 89 %; snr~70

8.11.2023; 300 s; alt 82°; hum 89 %; snr~50

8.11.2023; 1200 s; alt 80°; hum 89 %; snr~100

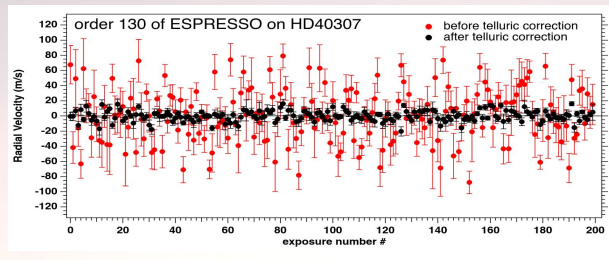
8.11.2023; 1200 s; alt 77°; hum 89 %; snr~110

8.11.2023; 1200 s; alt 74°; hum 89 %; snr~110

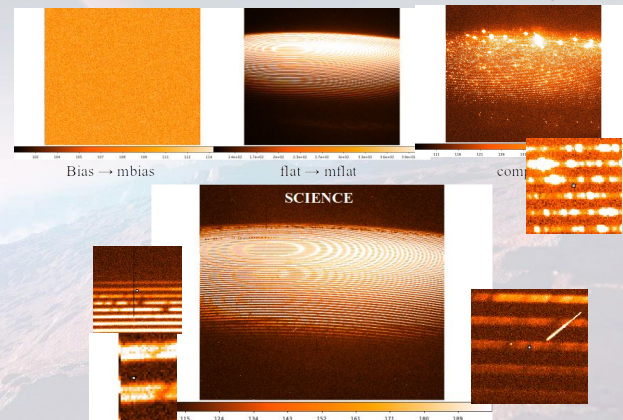
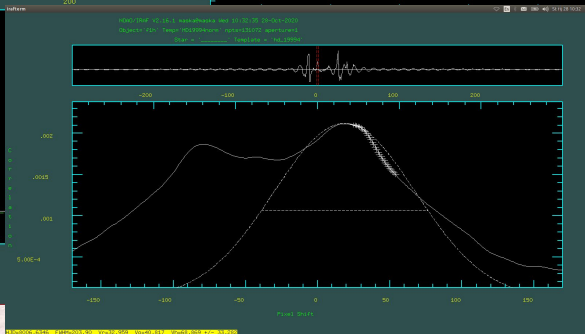
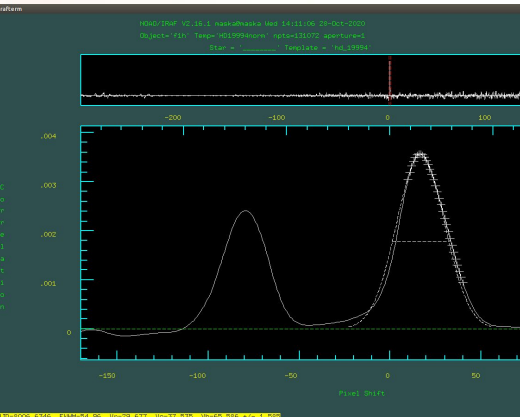
Radial velocities - data handling

- Data reduction (bias, flats, cossmics removal)
- Extraction of apertures
- Wavelength calibration
- Radial velocity determination (method, parameters, template selection, tellurics, corrections)

Ivanova+, 2023A&A...673A..56I



This figure displays two spectroscopic plots. The top plot shows a spectrum with a sharp peak at approximately 0 m/s, labeled 'before telluric correction'. The bottom plot shows the same spectrum after telluric correction, with the peak shifted to approximately 10 m/s, labeled 'after telluric correction'. The x-axis for both plots is 'Wavelength (nm)' and the y-axis is 'Flux'.

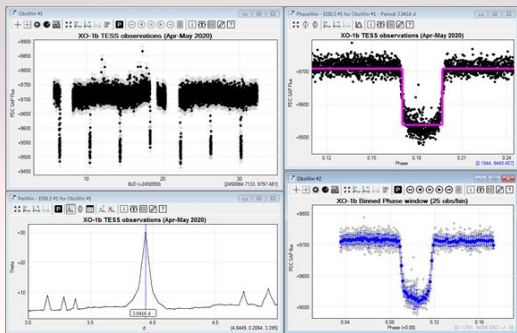


Courtesy A. Silva

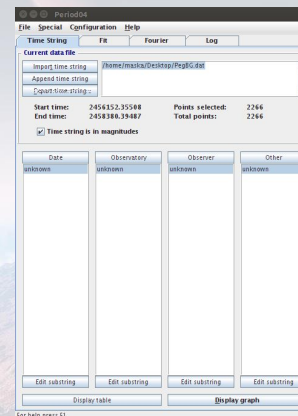
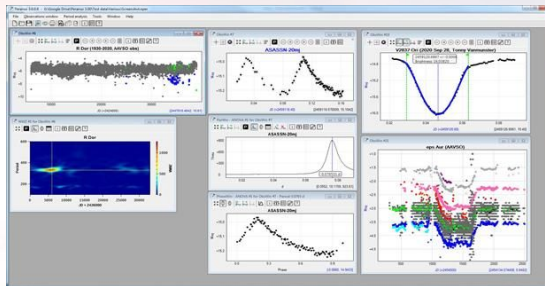


Light/radial velocity curve and periods

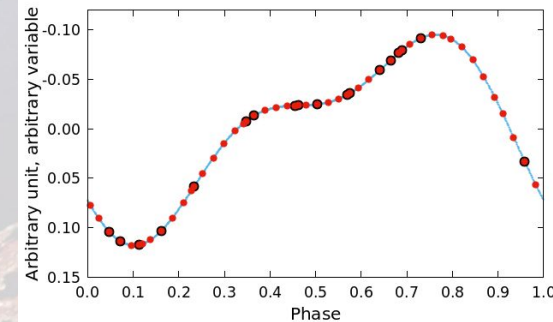
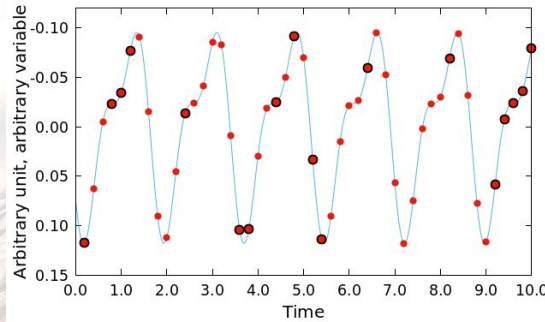
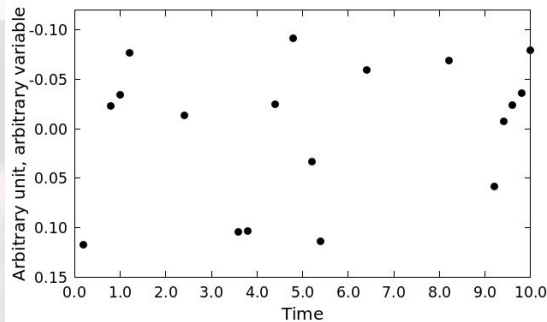
- Time series -> periods
 - Fourier methods (DFT, NUFFT, Lomb-Scargle, Bloomfield, Deeming, Cleanest, wavelet, etc.)
 - Minimalization methods (PDM, Jurkevich, Schwaryenberg-Czerny, Lafler-Kinman, box-car, etc.)



$$\phi = \frac{t - M_0}{P} - \text{INT} \left(\frac{t - M_0}{P} \right)$$

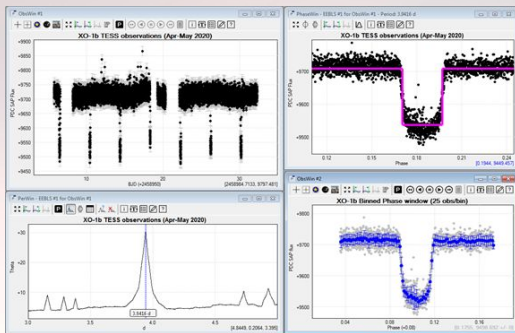


Peranso,
Period04,
python libraries

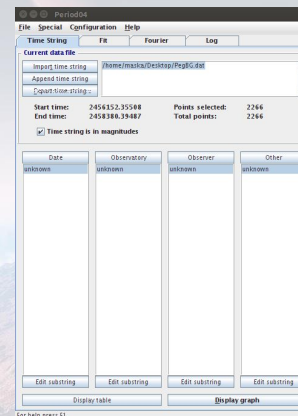
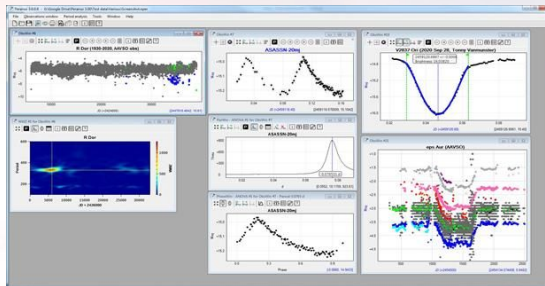


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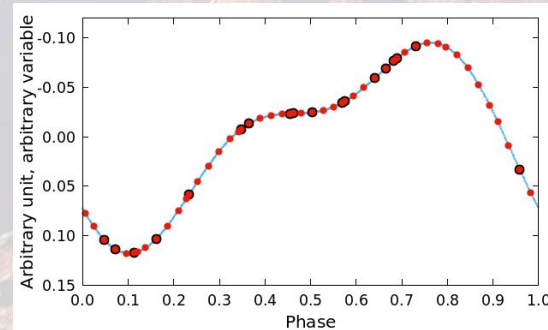
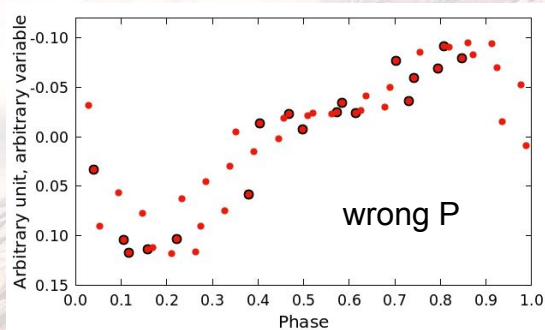
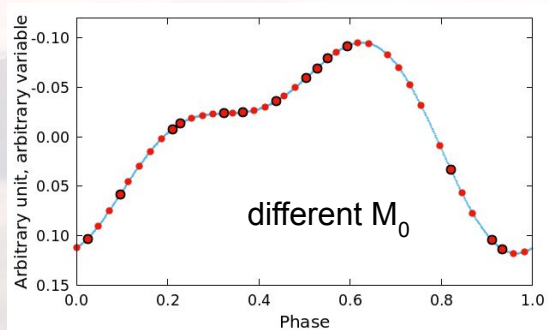
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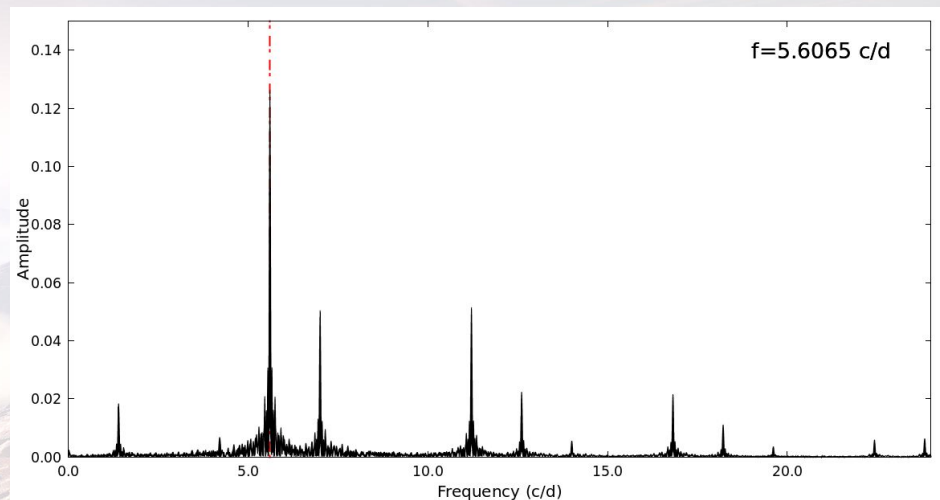
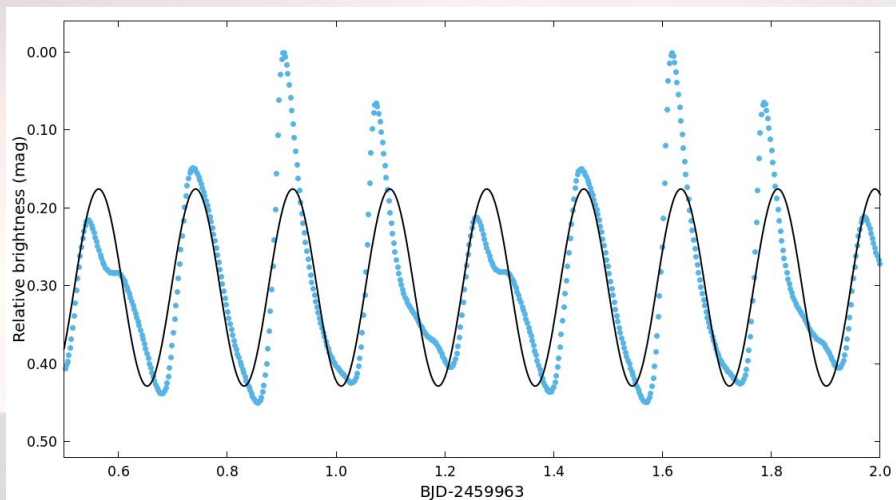


Peranso,
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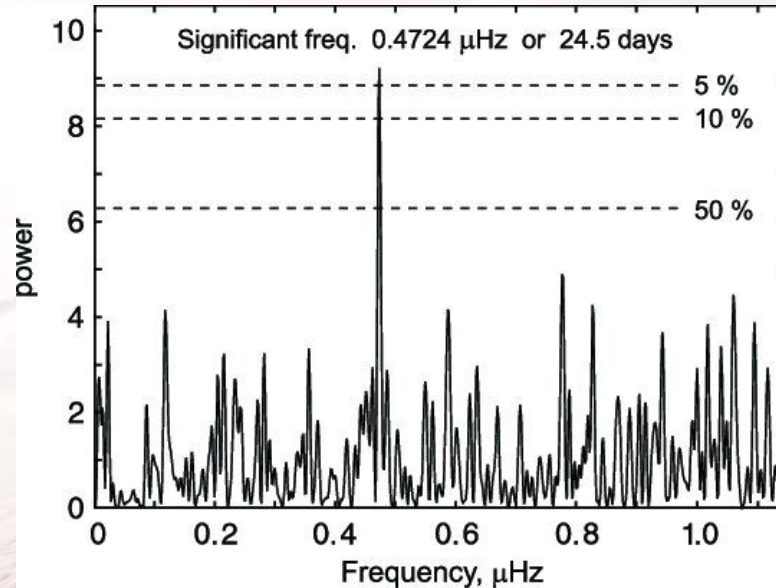
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Periodogram

- Significance of the periods (peaks)
- False alarm probability $FAP \sim Ne^{-z}$ - z is the amplitude in Lomb-Scargle periodogram, N is the number of observations, "Likelihood that the peak is generated by a random noise"
- SNR for FT - significant when $SNR > 4$ (Breger 1993),

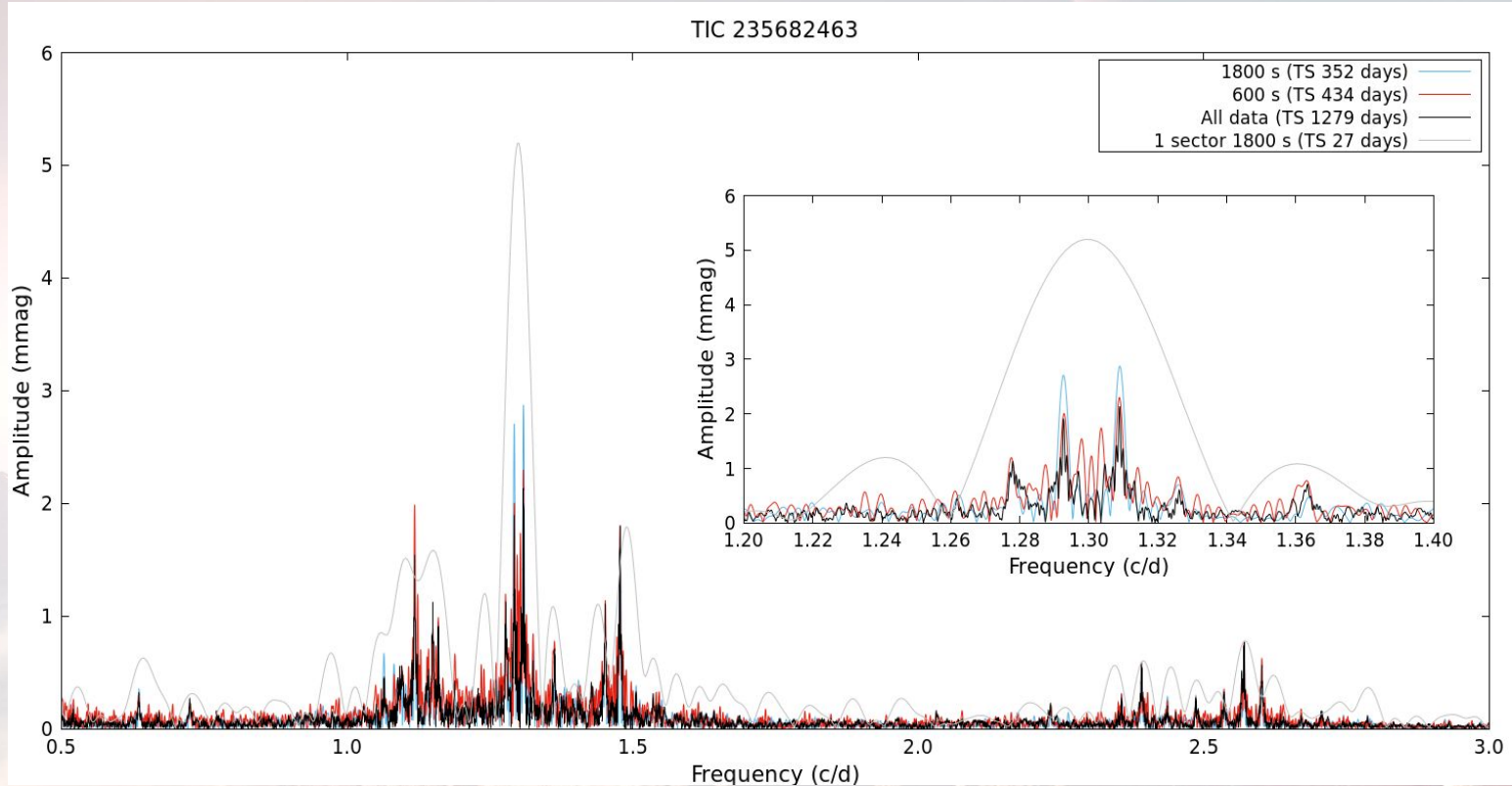
$$\log(FAP) \sim -2.5 + 2.62 \cdot SNR - 0.69 \cdot SNR^2 \text{ (Kushnig 1997)}$$



Periodogram

- Times span of the data defines the frequency resolution

$$\Delta\nu = \frac{2}{TS}$$

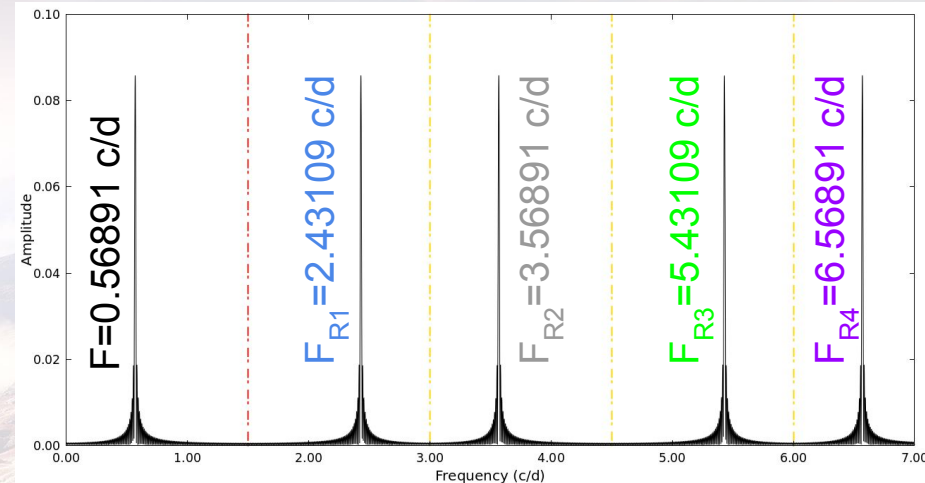
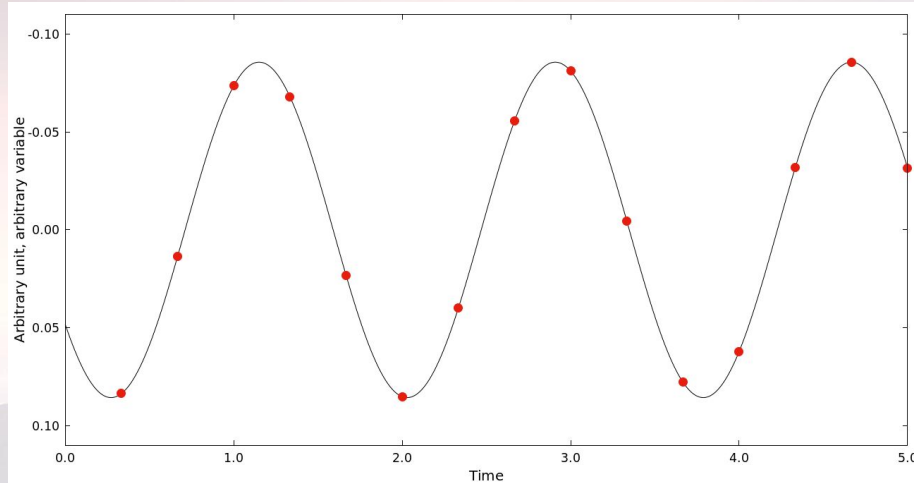


Periodogram

- Sampling frequency defines the highest detectable frequency
- Damped when the sampling is not strict

$$\nu_{max} = \frac{f_{\text{Samp}}}{2} = \frac{1}{2\Delta t}$$

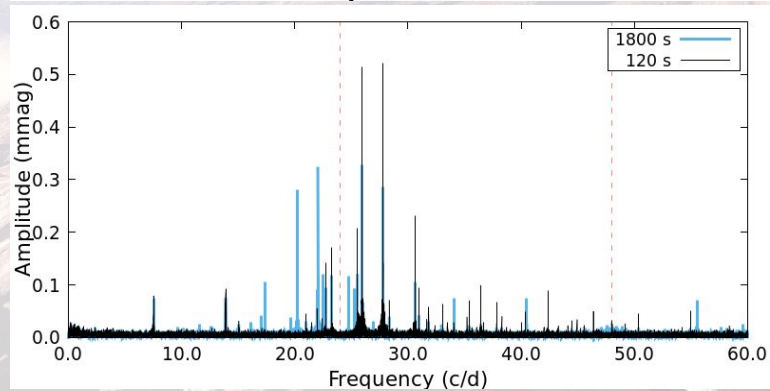
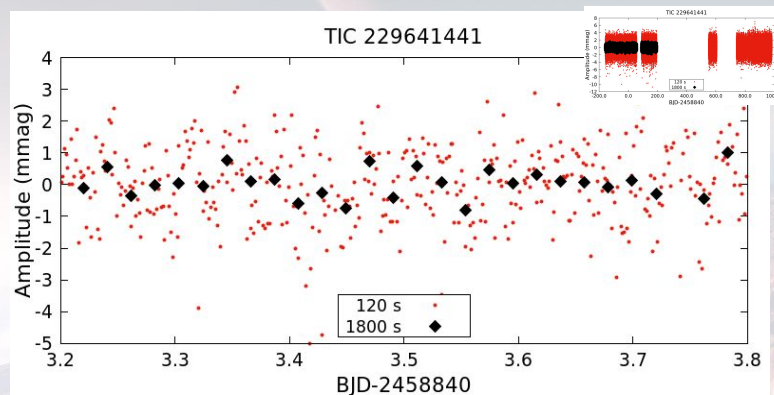
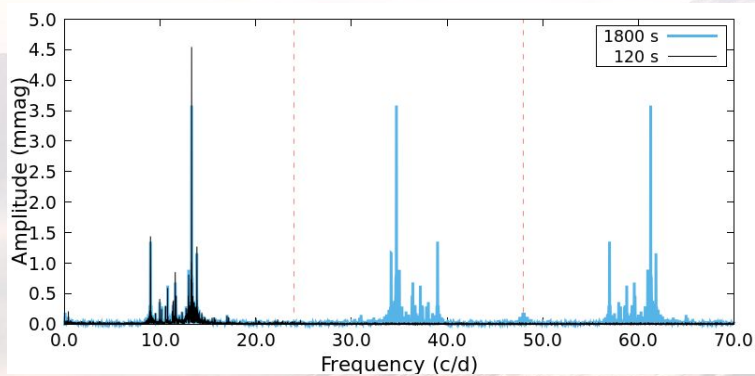
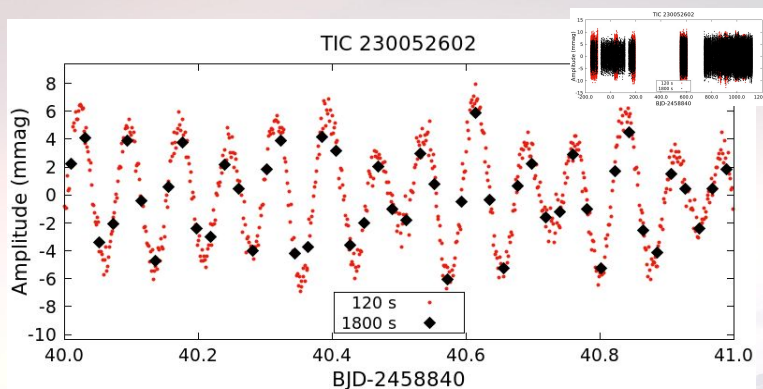
Nyquist reflections



Periodogram

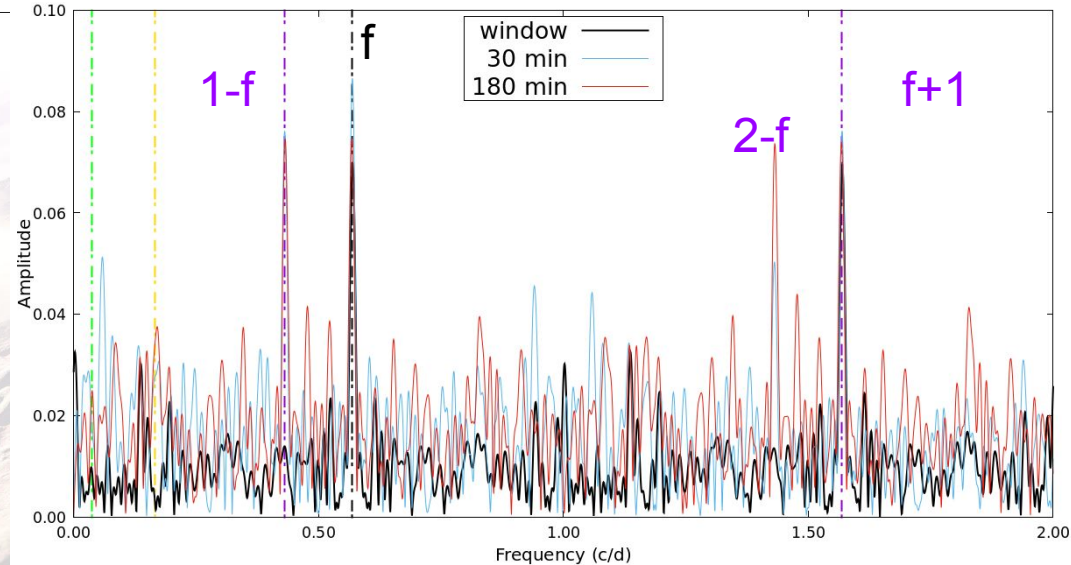
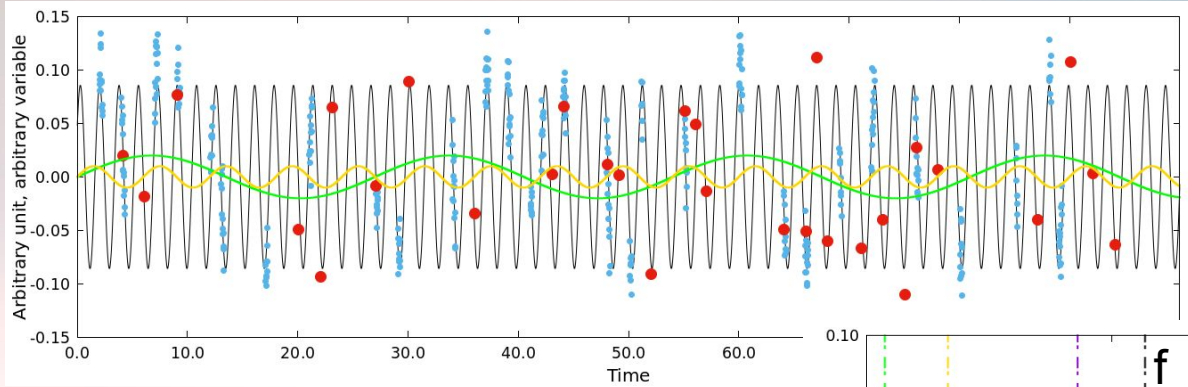
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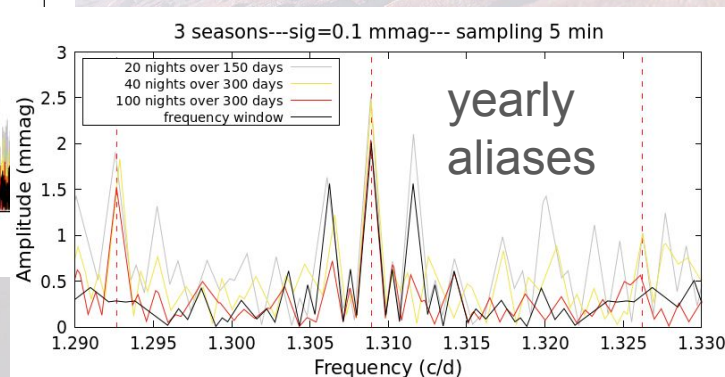
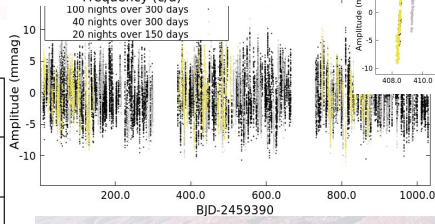
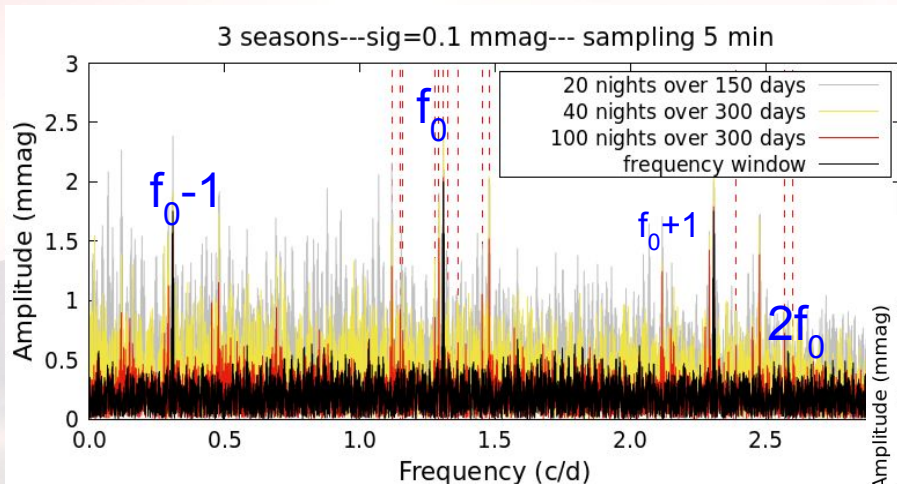
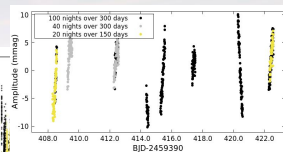
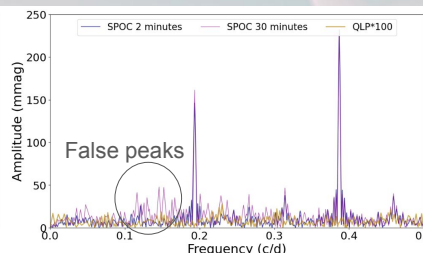
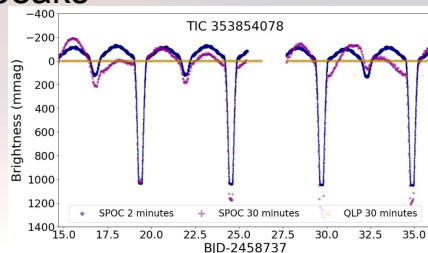
Periodogram

- Gaps in observations produce aliases - frequency window



Periodogram

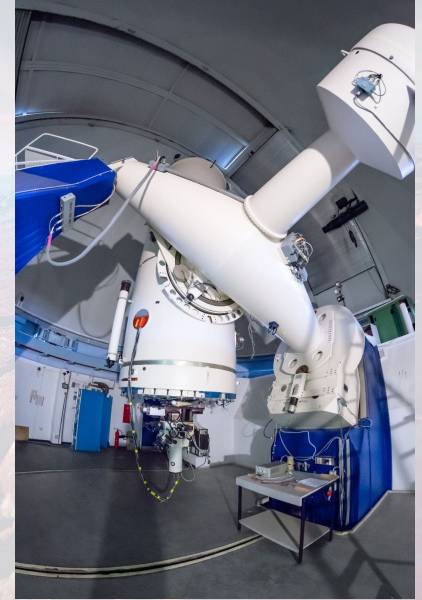
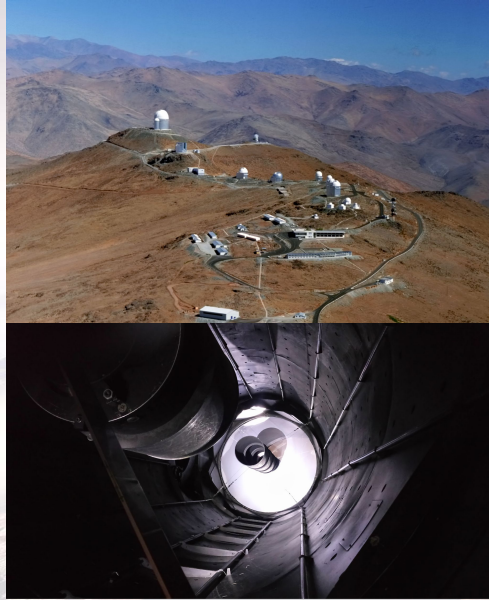
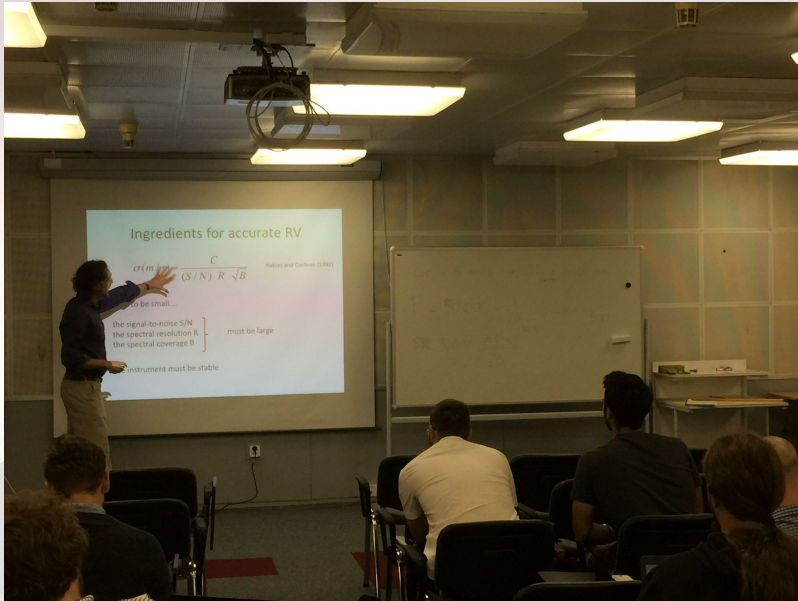
- Gaps in observations produce aliases - frequency window
- Trends produce false peaks



Daily aliases

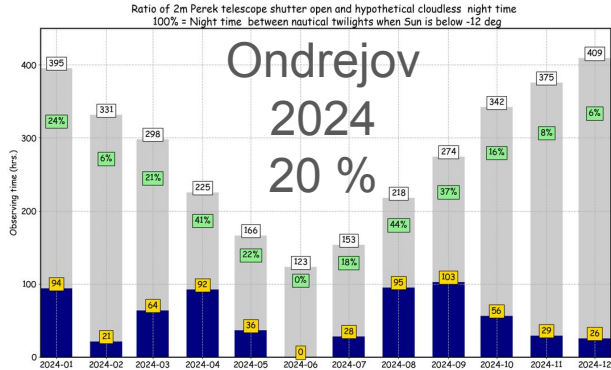
PLATOSpec project

- High-resolution, stable spectrograph as a support for the PLATO (and other) mission(s)
- La Silla, Chile, telescope E152 (E2)



PLATOSpec project

- High-resolution, stable spectrograph as a support for the PLATO (and other) mission(s)
- La Silla, Chile, telescope E152 (E2)



PLATOSpec: 82 %
(since its installation)

<https://stel.asu.cas.cz/plato/>



PLATOSpec project

- High-resolution, stable spectrograph as a support for the PLATO (and other) mission(s)
- La Silla, Chile, telescope E152 (E2)



Document: Referees proposed by the Consortium of La Silla 1.52-m project for ground based support of PLATO mission
Document number: 3
Document version and date: V1 on 13 September 2017

Remark: The Consortium is represented by Petr Kabath (ASU), Artie Hatzes (TLS-Thüringer Landessternwarte Tautenburg), Eike Guenther (TLS), Leonardo Vanzini (Universidad Católica de Chile)

Dear Council members,

hereby, we propose referees who we believe are competent experts referee report about La Silla 1.52-m project.

On behalf of the consortium,

Sincerely,

Petr Kabath

Petr Kabath

PLATOSpec document No. 1	PLATOSpec Science Case Study
Title: _____	
Version: 6.0 12.01.2018	

Title: Ground based support of PLATO space mission

Purpose of the document: Scientific justification of PLATO mission spectroscopic ground based follow-up facility at 1.52-m ESO telescope

Expertise	Email
exoplanets, stars, space missions	frid@
brown dwarfs	rrk@
stars, exoplanets, CHEOPS	wib@
stars, GIANO team, Instrumentation	lva@
Instrumentation	olva@
Instrumentation, CARMENES	lw@

suggested by colleagues from interest.



PLATOSpec stellar astrophysics in the era of PLATO



Prepared by : P. Kabath (AI Ondrejov, CZ)
 Edited by : A. Hatzes, E. Guenther (TLS), L. Vanzini (UCatolica)
 Version : 6.0 (12.01.2018)

Approved by: P. Kabath 12.01.2018
 Released by: P. Kabath 12.01.2018

CONSORTIUM of PLATOSpec

Major participant



Astronomical Institute
of the Czech Academy of Sciences

Team members

Dr. Petr Kabáth - ASU Ondřejov
Dr. Marek Skarka - ASU Ondřejov



Thüringer Landessternwarte Tautenburg

Team members

Prof. Artie Hatzes - Tautenburg
Dr. Elke Guenther - Tautenburg



Universidad Católica de Chile

Team members

Prof. Leo Vanzí - UC Chile

Minor participant



Masaryk University
Faculty of Sciences

Team members

Dr. Jan Janík - MU Brno



Universidad Adolfo Ibáñez

Team members

Rafael Brahm (assistant professor UAI FIC)
Marcelo Tala (postdoc UAI FIC)
Andrés Gajardo (PhD student in data science UAI FIC)



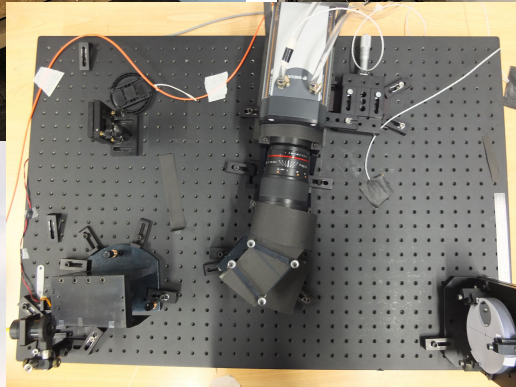
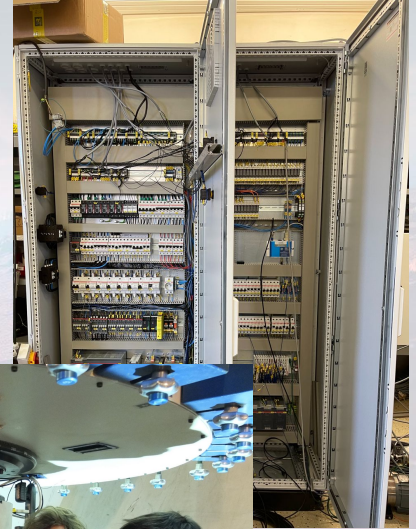
Institute of Plasma Physics
of the Czech Academy of Sciences

Team members

Dr. Pavel Pintr

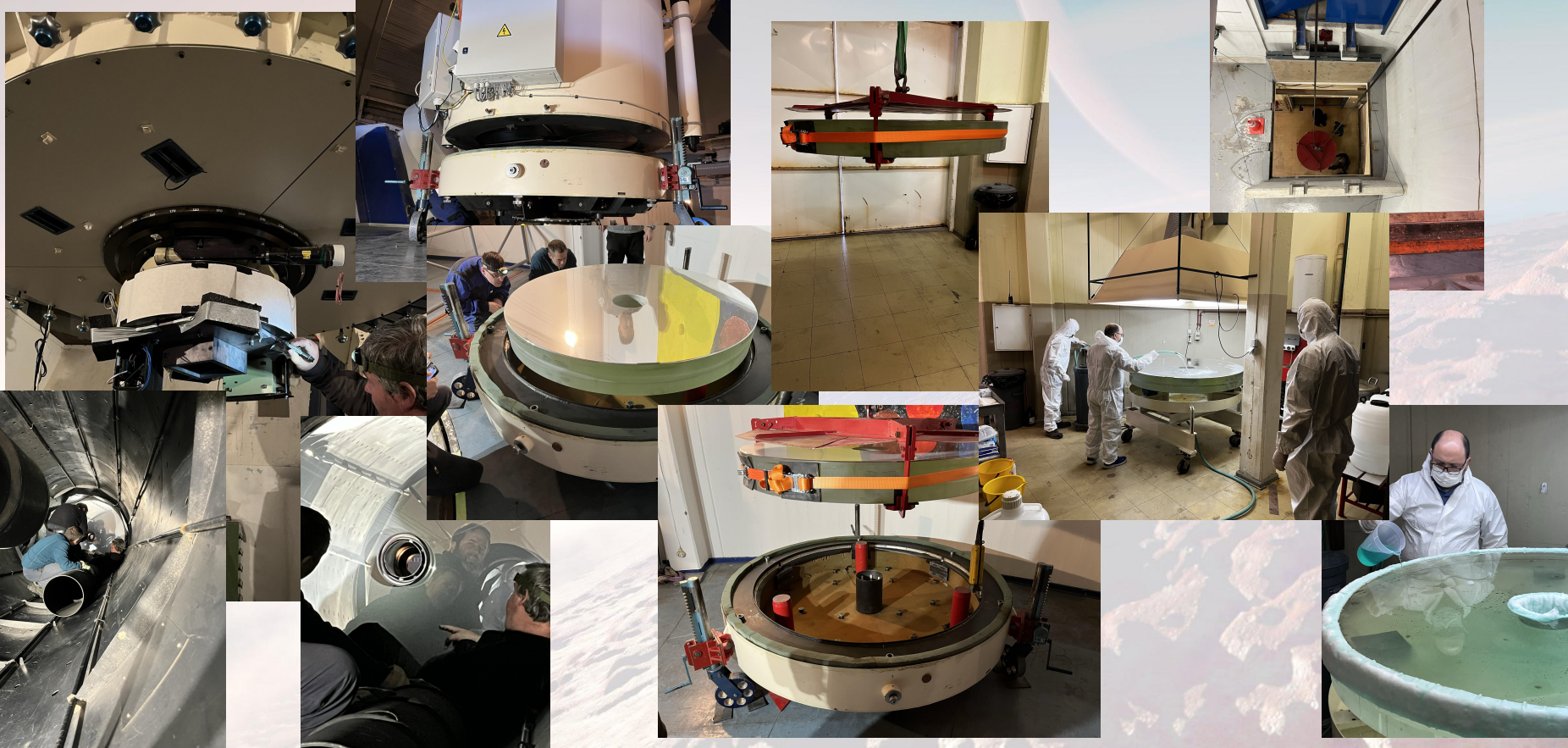
PLATOSpec project

- 2021-2022 - Telescope refurbishment (Projectsoft), PUCHEROS+



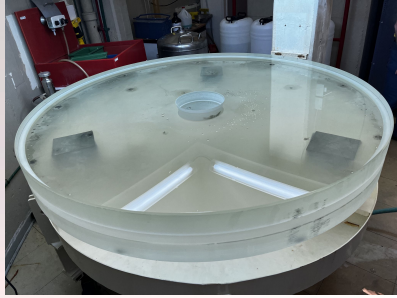
PLATOSpec project

- 2023 - recoating of the mirror, observations with PUCHEROS



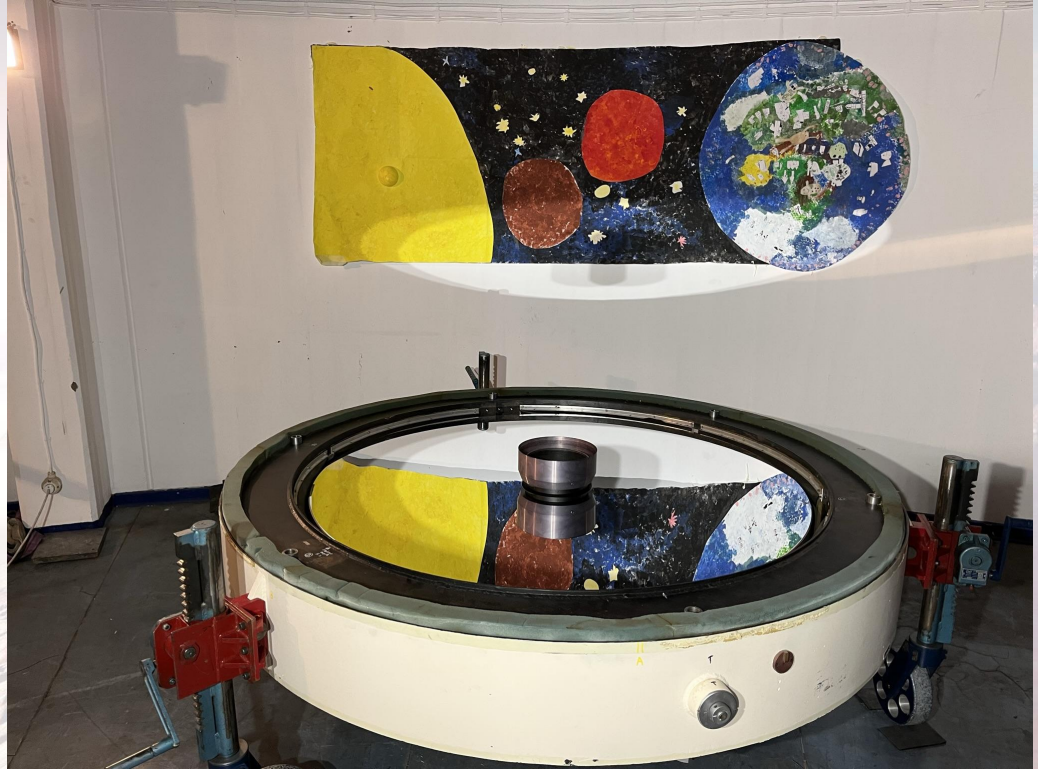
PLATOSpec project

- 2023 - recoating of the mirror, observations with PUCHEROS



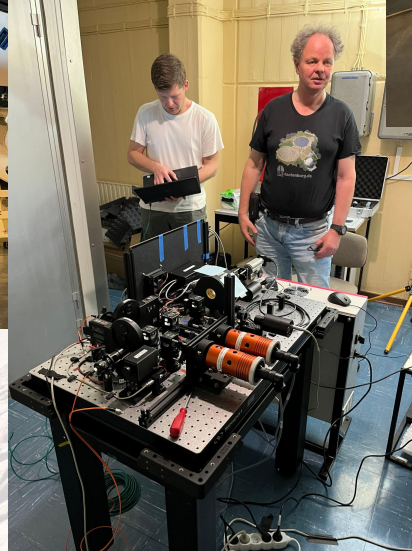
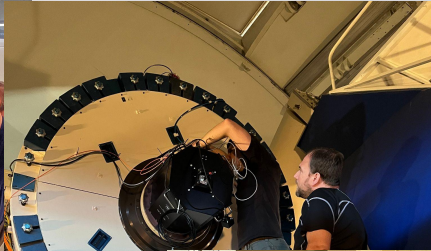
PLATOSpec project

- 2023 - recoating of the mirror, observations with PUCHEROS



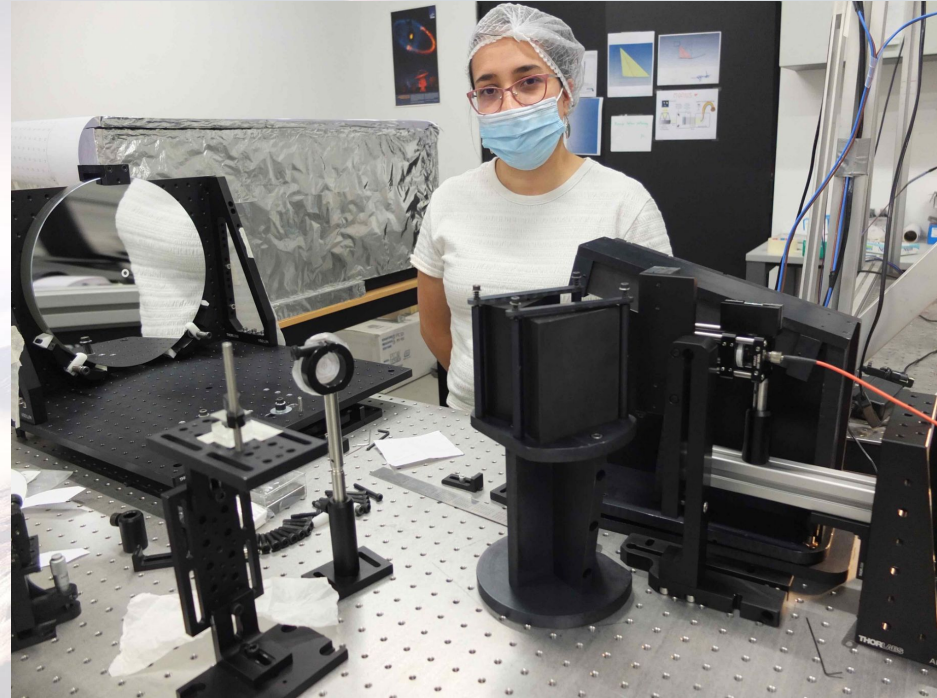
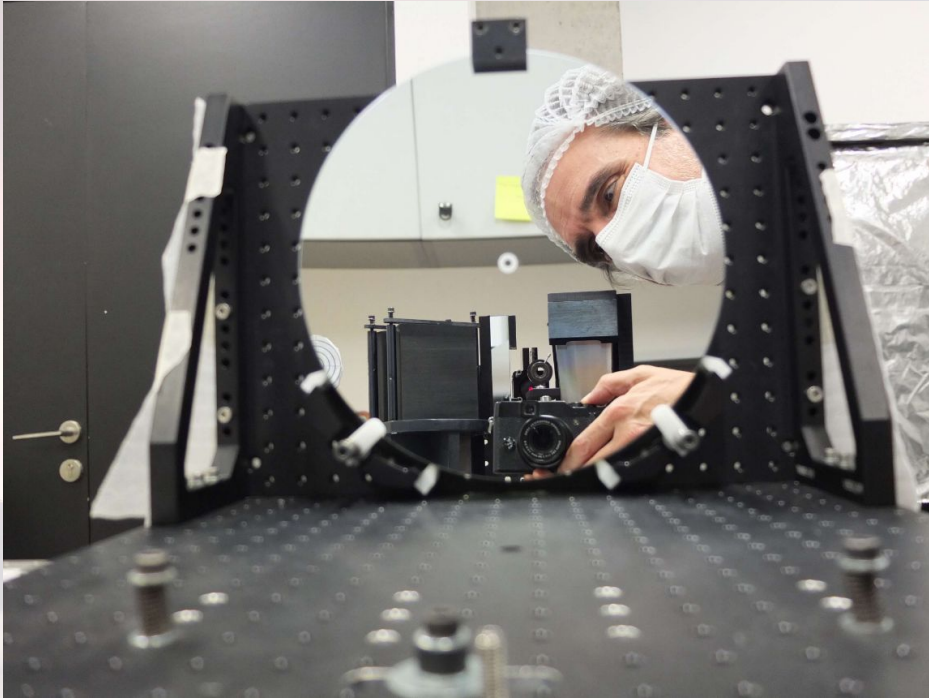
PLATOSpec project

- 2024 - FE, CU, optical fibers, balancing of the telescope, installation of PLATOSpec



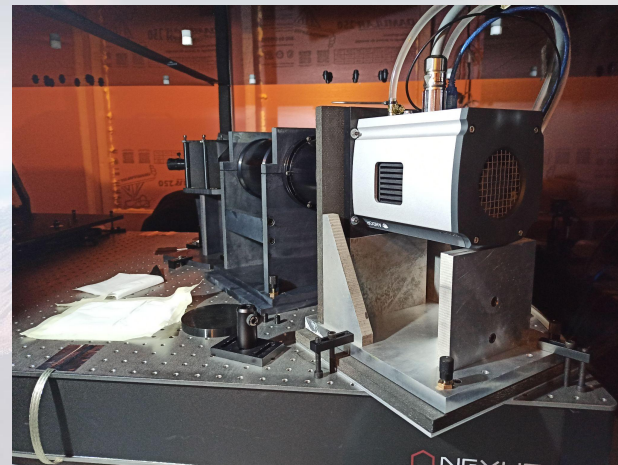
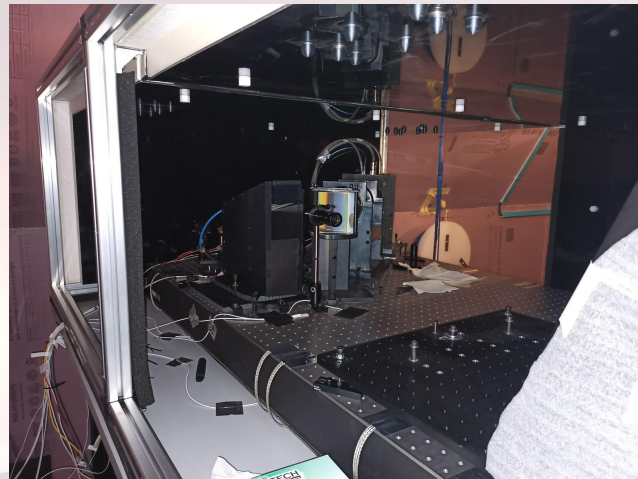
PLATOSpec project

- 2024 - FE, CU, optical fibers, balancing of the telescope, installation of PLATOSpec



PLATOSpec project

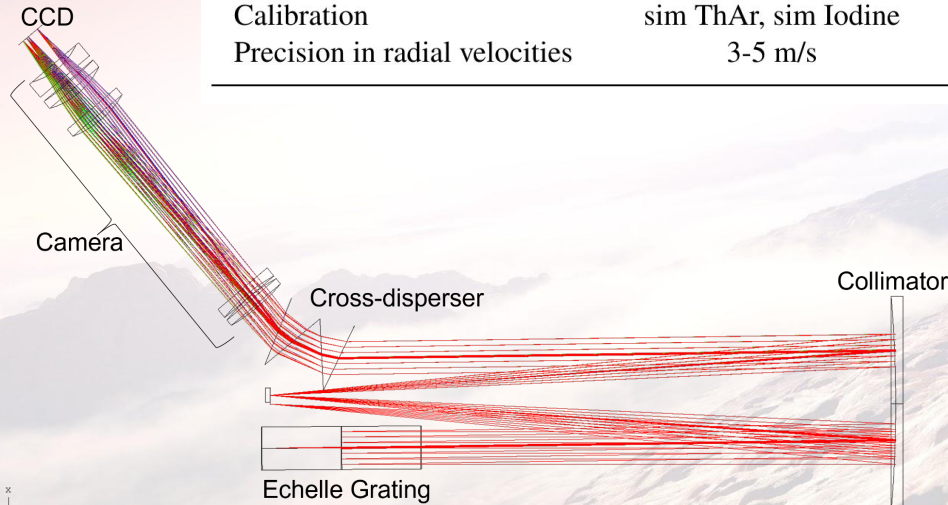
- 2024 - FE, CU, optical fibers, balancing of the telescope, installation of PLATOSpec



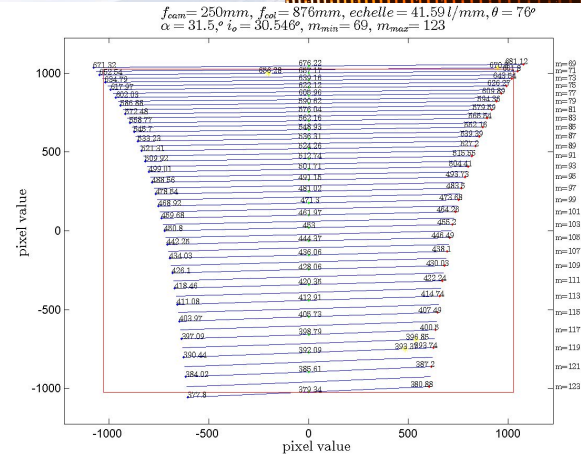
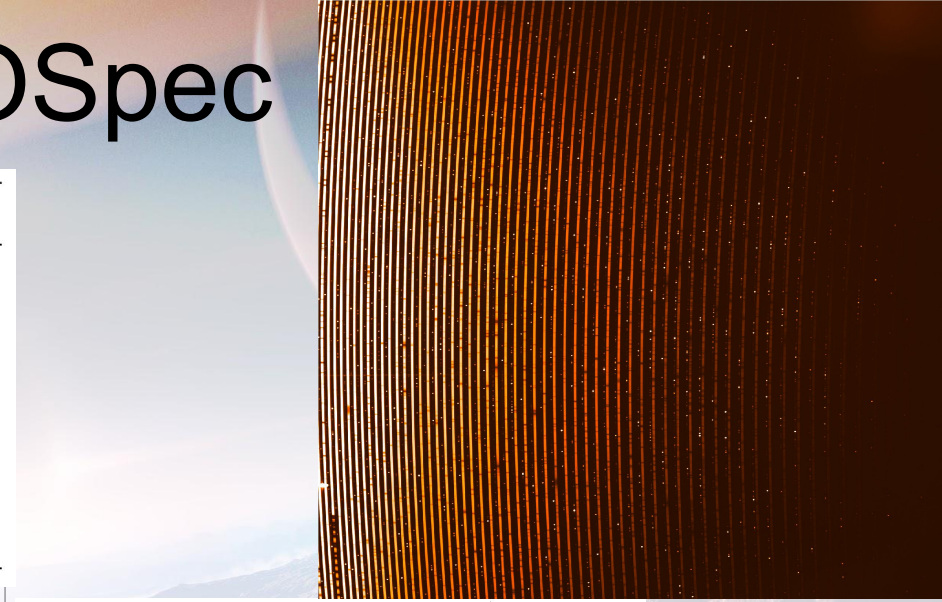
November 25, 2024
- first light and regular
observations

PLATOSpec

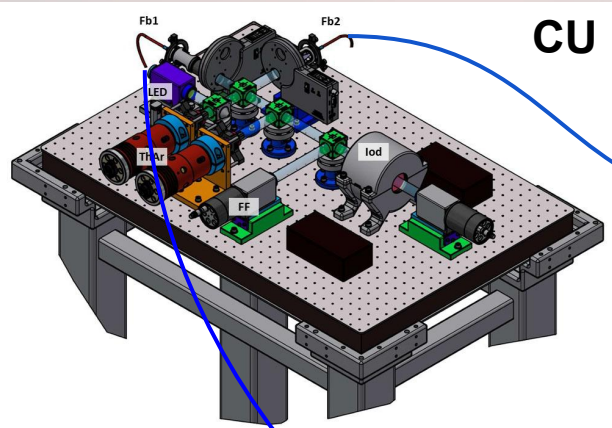
Parameter	Value
Spectrograph feeding	fiber, image slicer
Spectrograph type	echelle, white pupil
Detector	Andor Ikon GLx (2k×2k)
Wavelength range	380-700 (nm)
Resolving power	70,000
Number of orders	55
Calibration	sim ThAr, sim Iodine
Precision in radial velocities	3-5 m/s



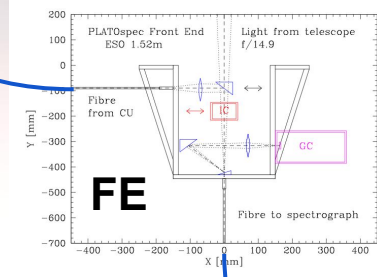
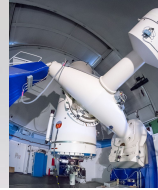
3D Layout



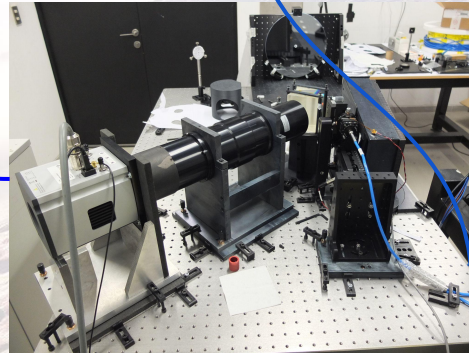
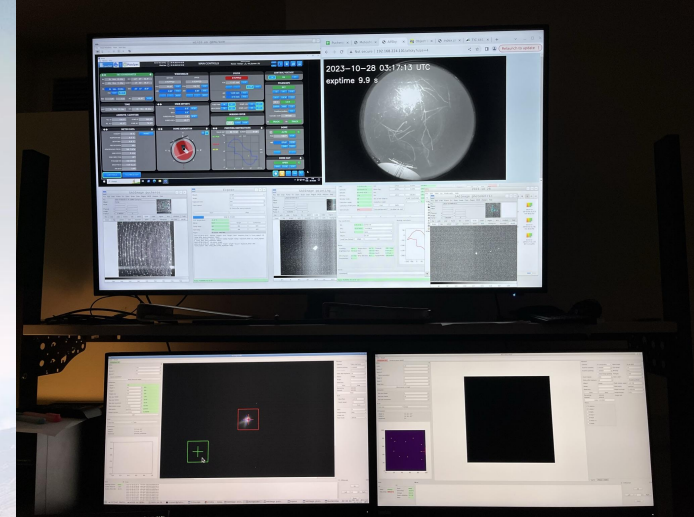
PLATOSpec - operations



CU



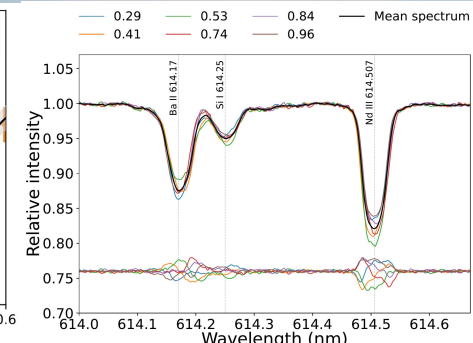
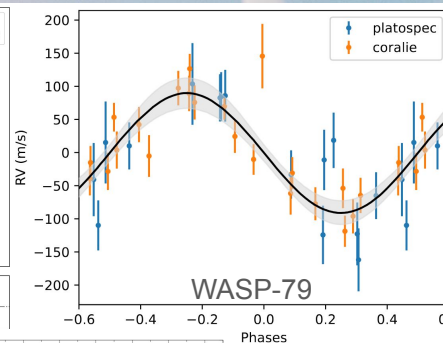
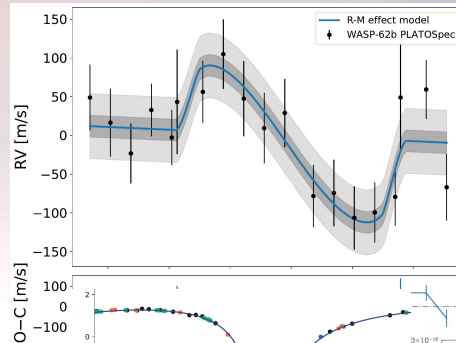
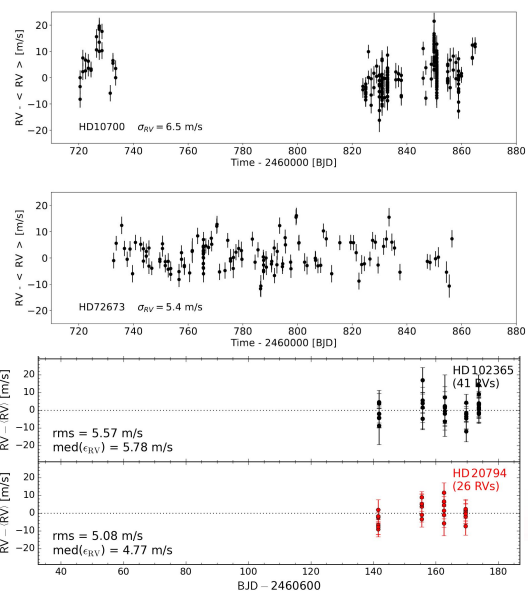
FE



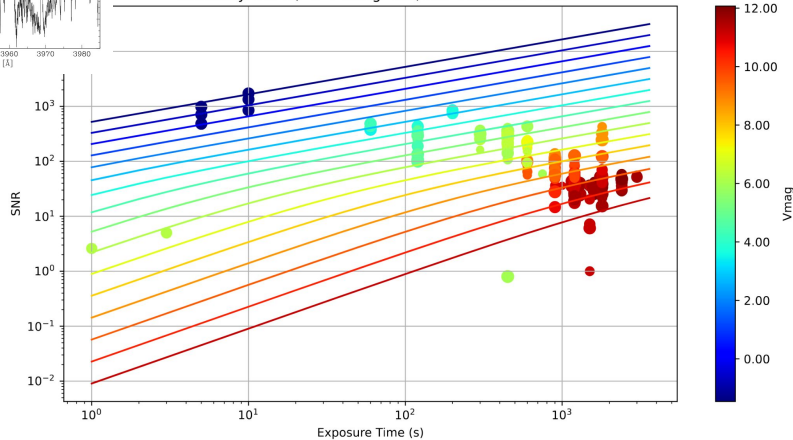
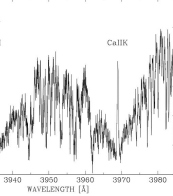
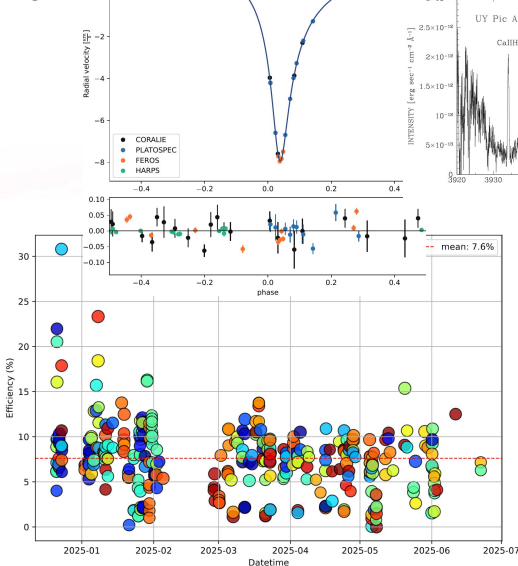
Spectrograph

	SLEW	Target	RA	DEC	Mag	ExpTime	Number	Notes	Start	End	Priority	Altitude	Azimuth	Position
16		HD170	2:28:09	6:27:36	4.3	300	1	aim. ThAr	08:13	08:18	0.5	52-52	11-9	see
19		HD170	2:28:09	6:27:36	4.3	300	1	IC (PE) aim. ThAr	08:16	08:23	0.6	52-52	9-7	see
20		TIC2128754	5:02:20	-40:01:04	10.0	1200	1	aim. ThAr	08:30	08:36	1.2	49-49	118-119	see
21		HD 27463	4:16:26	-46:56:54	6.4	900	1	aim. ThAr	08:30	08:36	1.1	55-56	160-163	see
22		TIC5037412	6:12:49	-17:34:39	11.0	1200	1	aim. ThAr	08:33	08:33	1.3	49-49	90-93	see
23		DS Tau	22:30:29	-89:11:44	8.2	900	2	longer exp., guiding exp. 6.00s, hovers 3000; aim. ThAr	09:00	09:10	2.0	39-39	20-26	see
24		HP 23311	00:00:49	-4:45:13	8.2	900	2	HP 23311	09:10	09:20	8.1	81-84	21-24	see

PLATOSpec - performance



SNR vs Exposure Time v/s Seeing (0.4 to 0.7)
328 observations between 2024-12-20 to 2025-07-03,
efficiency: 7.6 %, $-1 < V_{mag} < 13$, $1.0 < \text{airmass} < 1.1$



Kabáth et al.,
submitted to MNRAS

PLATOSpec - future

- Study of systematics
- Tip-tilt mirror
- Fabry-Perot etalon
- Contribution to GOP



PLATOSpec - future

- Study of systematics
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Thank you for your attention!