



Astronomical Institute
of the Czech Academy of Sciences

Time Series in Exoplanet Research



Petr Škoda

Astronomical Institute of the Czech Academy of Sciences, Ondřejov

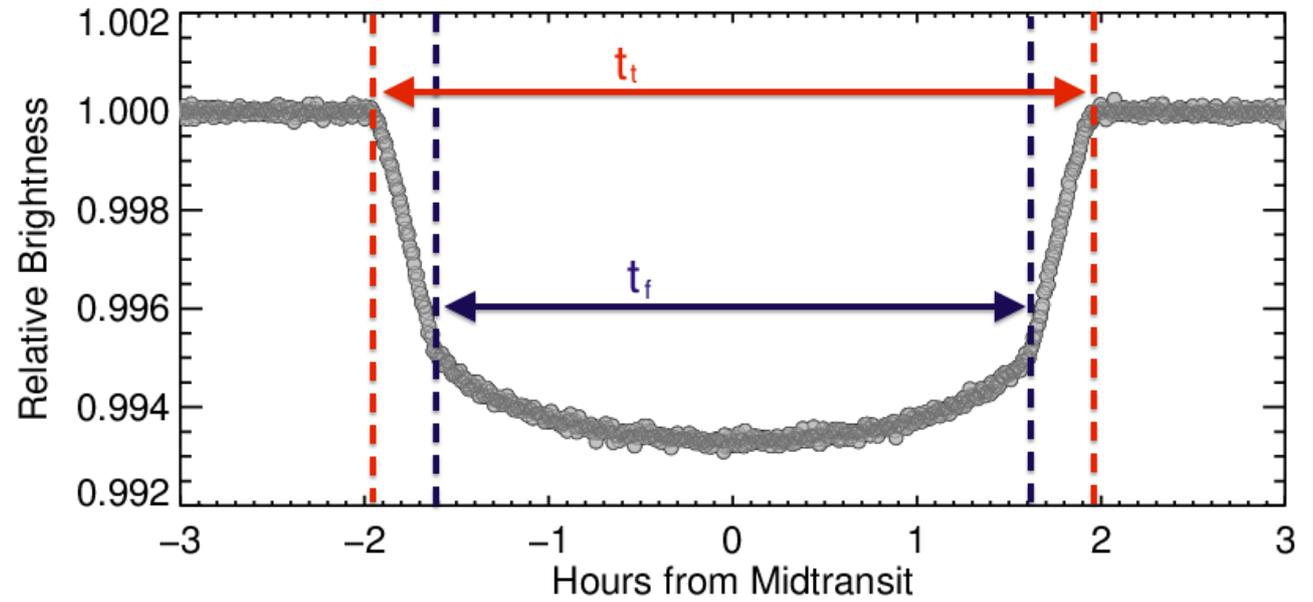
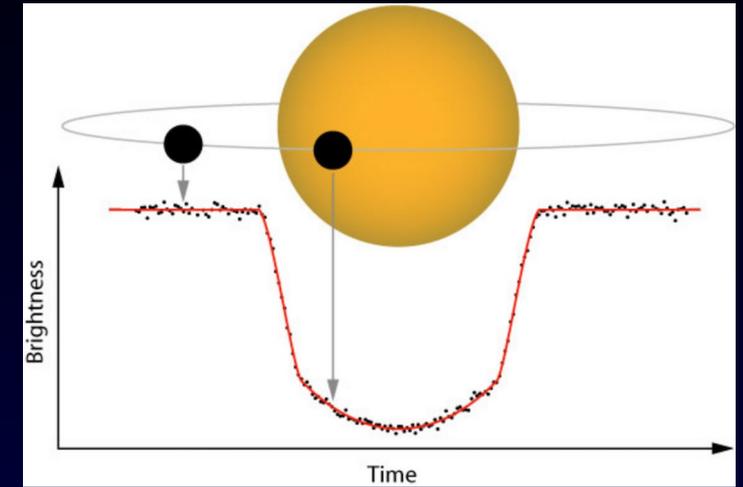
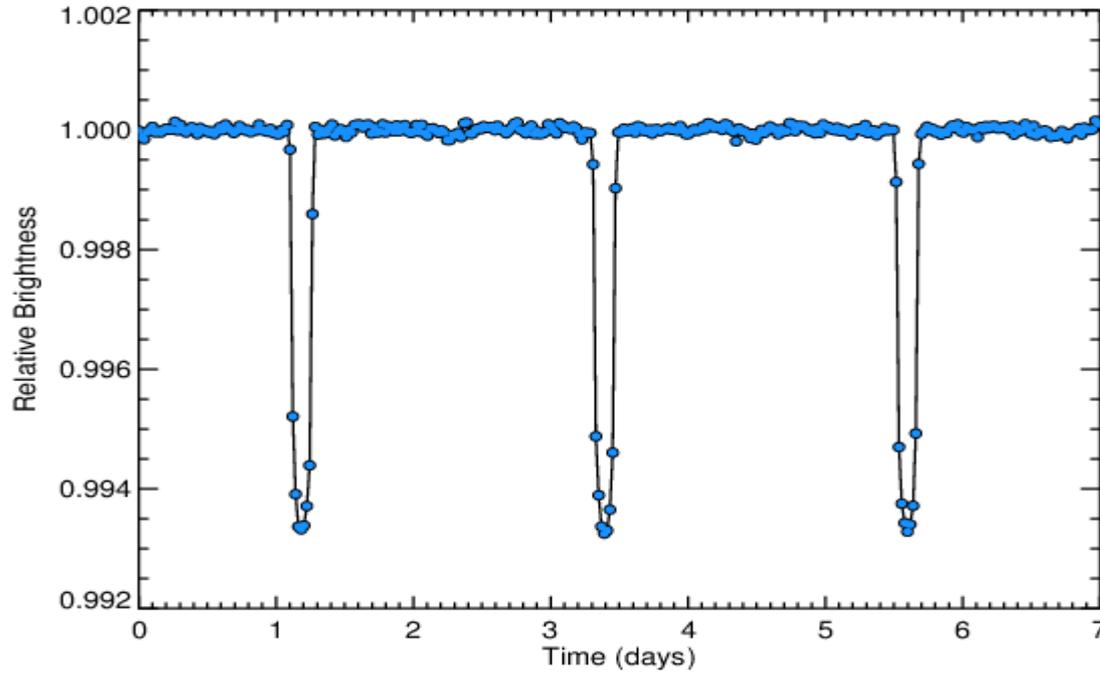
IVOA Interoperability Meeting
Time Domain Interest Group Session
Goerlitz, Germany
November 14th 2025

Credits

The presentation is based on many different sources – mainly the on-line published slides from IVOA meetings, EPRV group slides and docs, ADASS meetings, tutorials, manuals or pictures found on Internet.

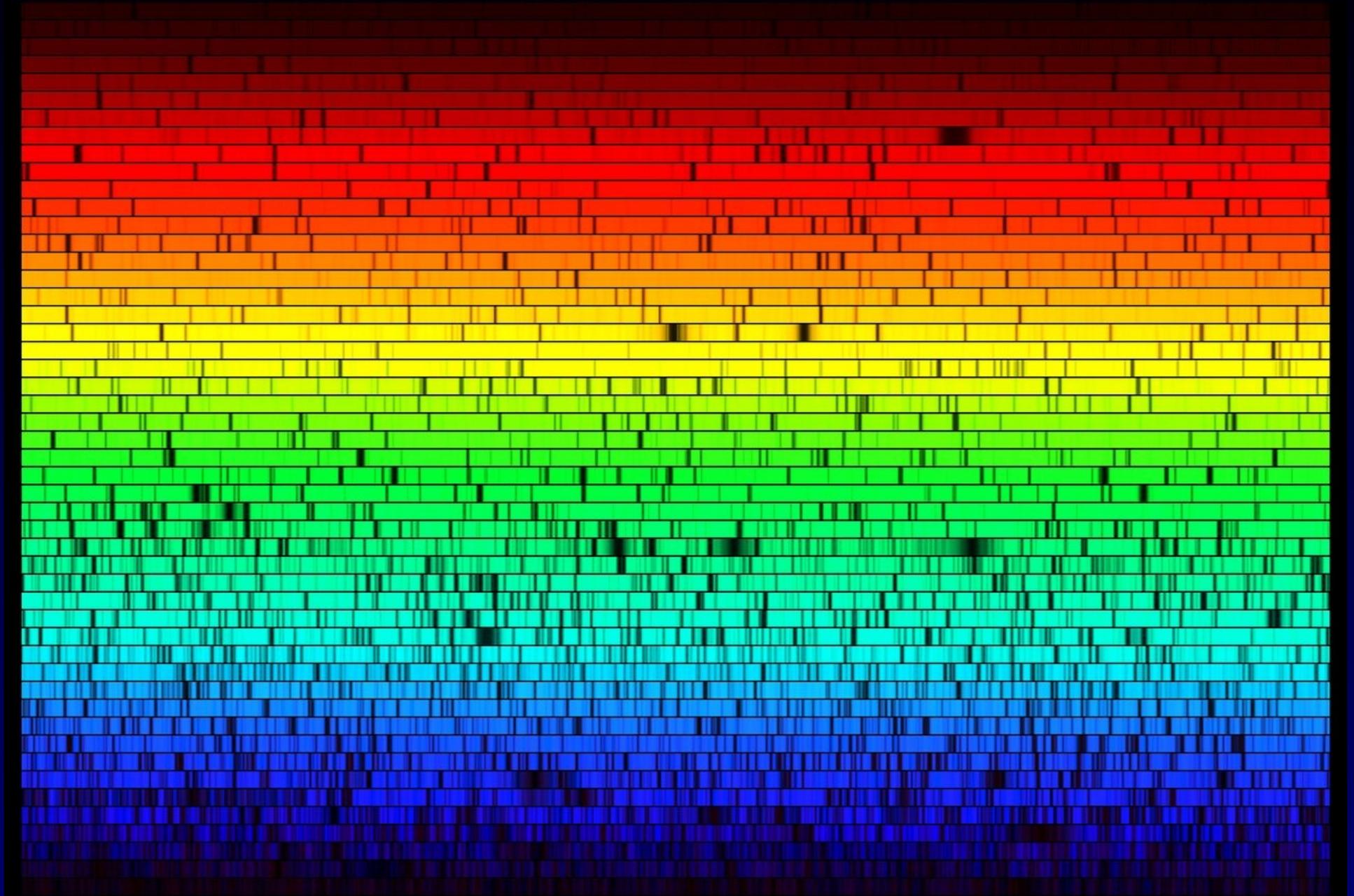
Light Curve

Light Curve HAT-P-7b



Echelle Spectra

Spectrum of Arcturus (pixel-order)



ESO X-Shooter

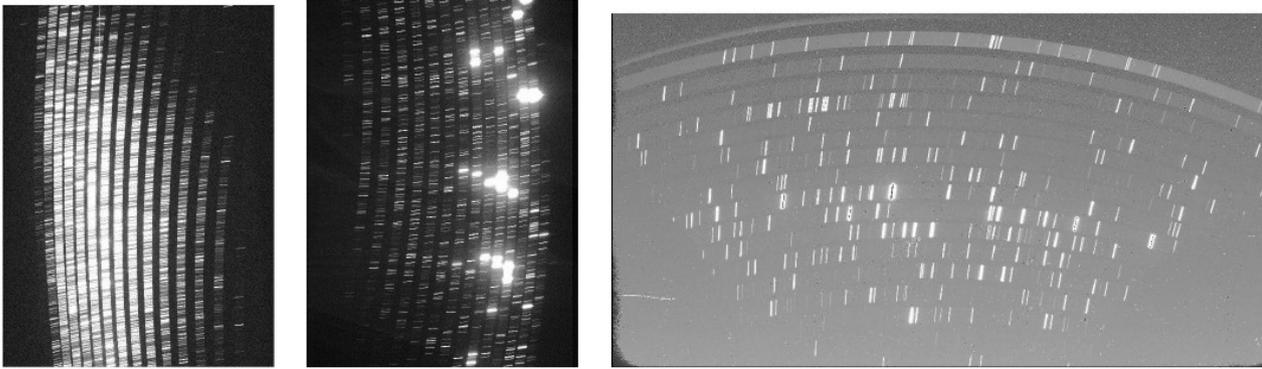
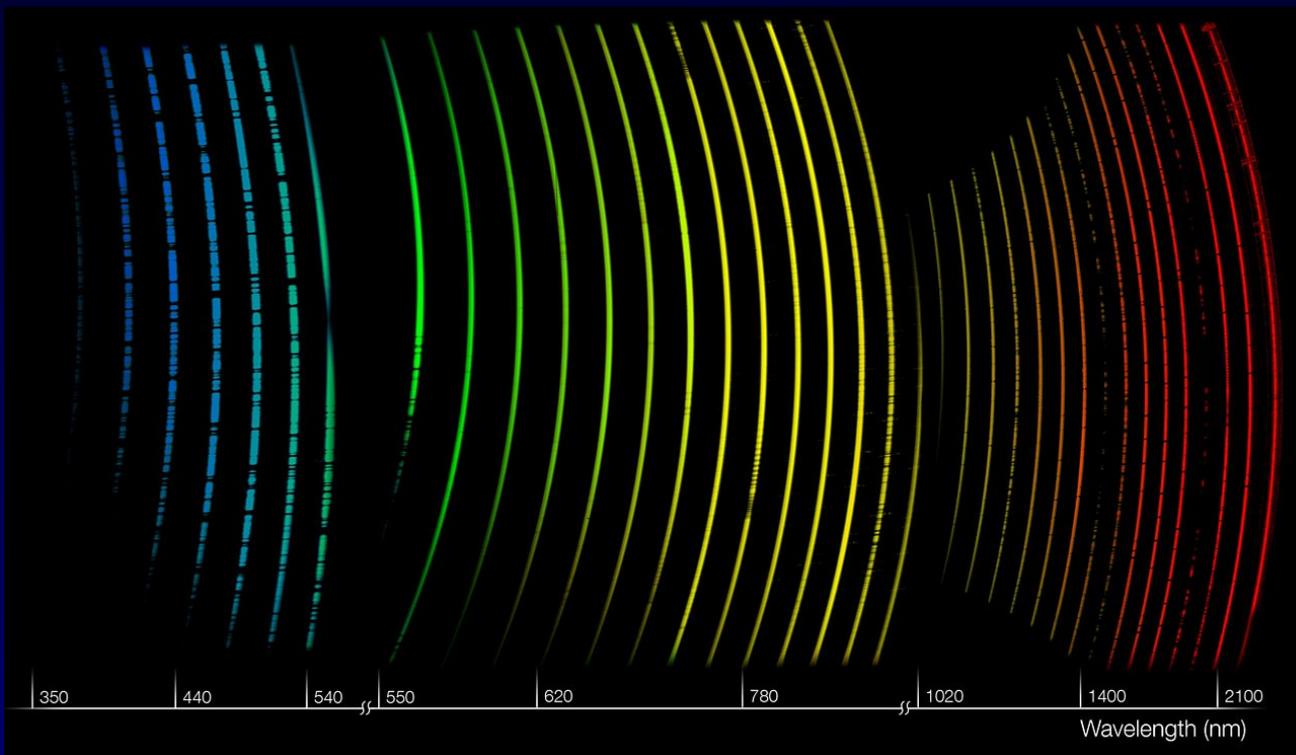
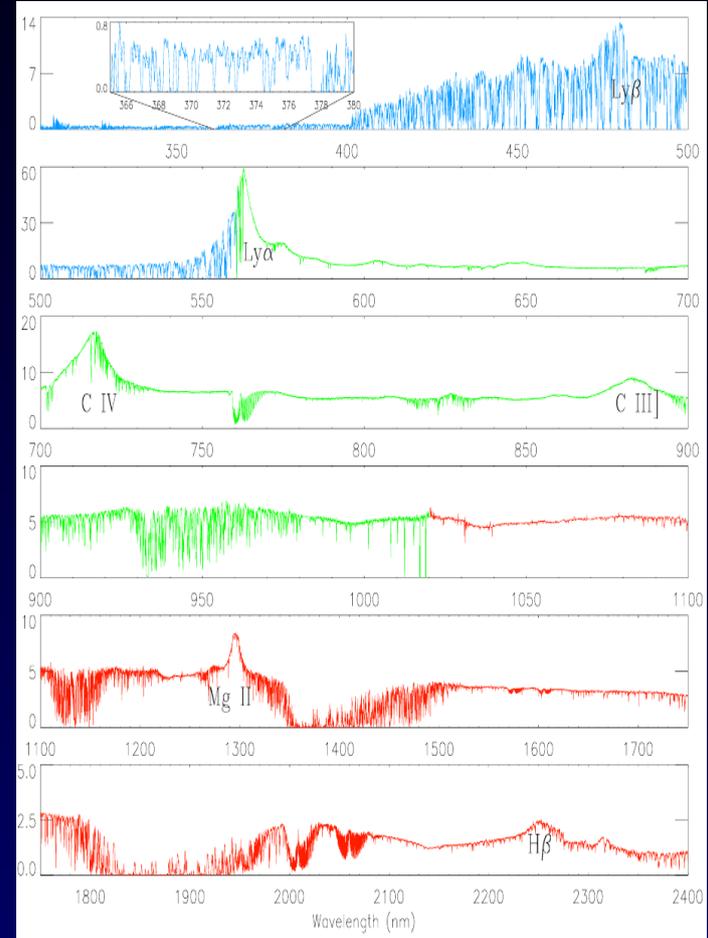


Figure 1. This image displays left to right the XSH UVB, VIS and NIR spectral formats with different image scales.



Modigliani et al. 2010

2936-24807 A,
R ~9100,17400,11300
0.5arcsec slit



High-z QSO
Vernet et al. 2011

HARPS-S



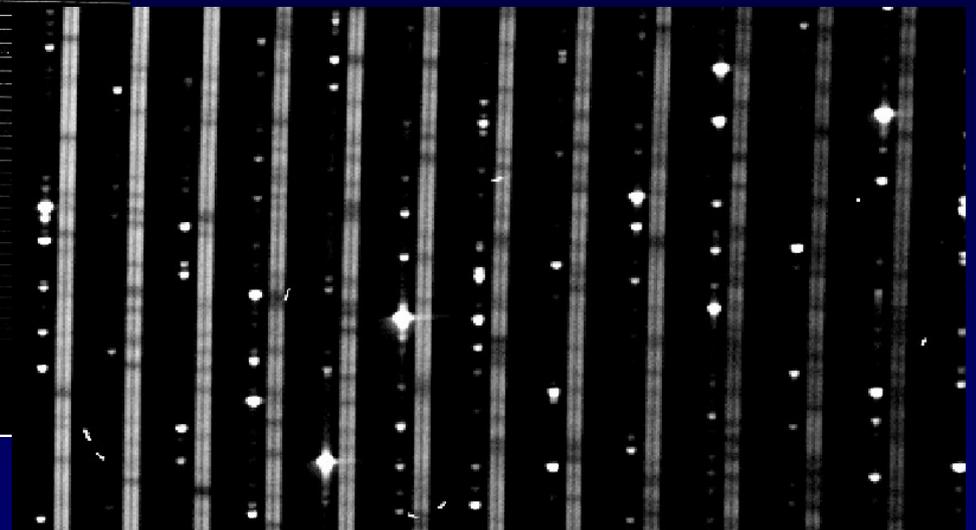
71 orders (89-161) – 115 not

3780-6910 Å

$R \sim 115000$

$dRV \sim 3\text{m/s}$

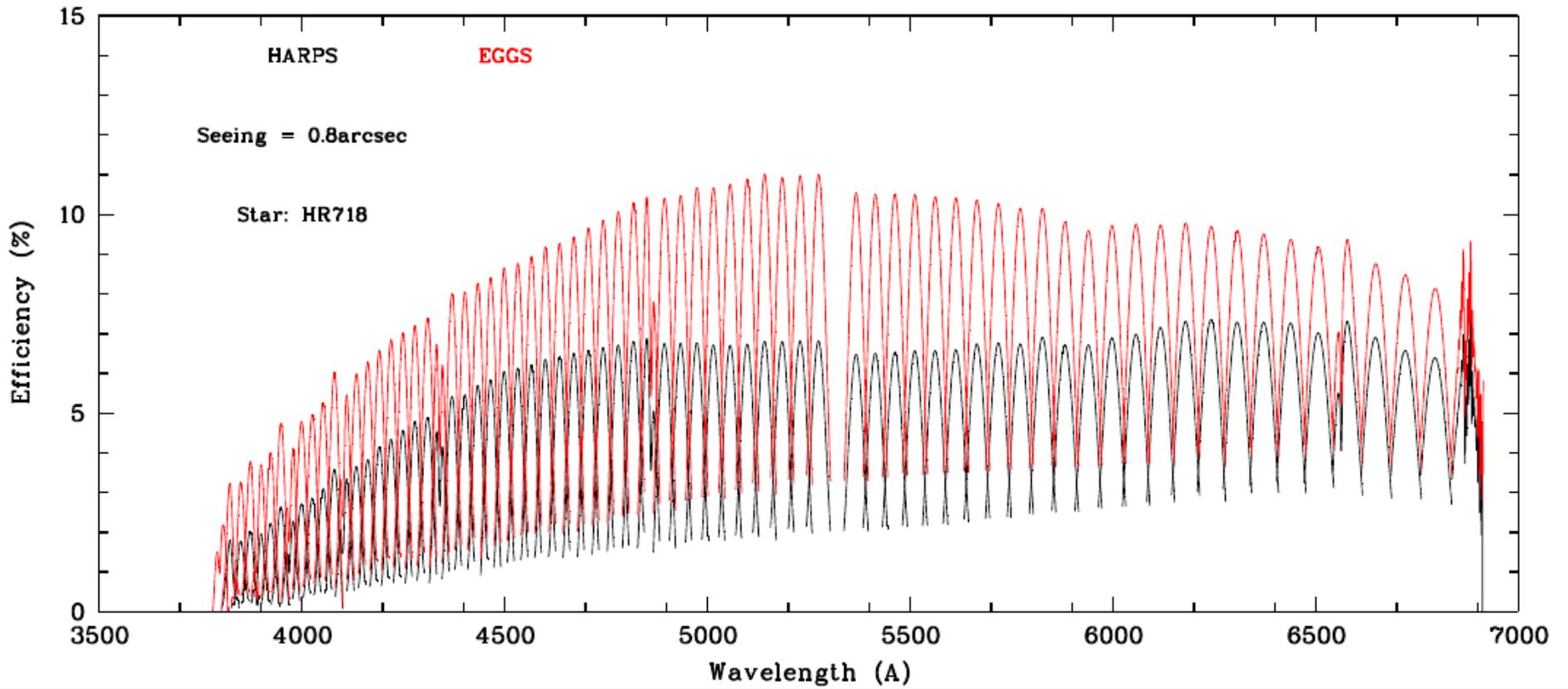
Simultaneous ThAr/Laser
comb/Fabry Perot



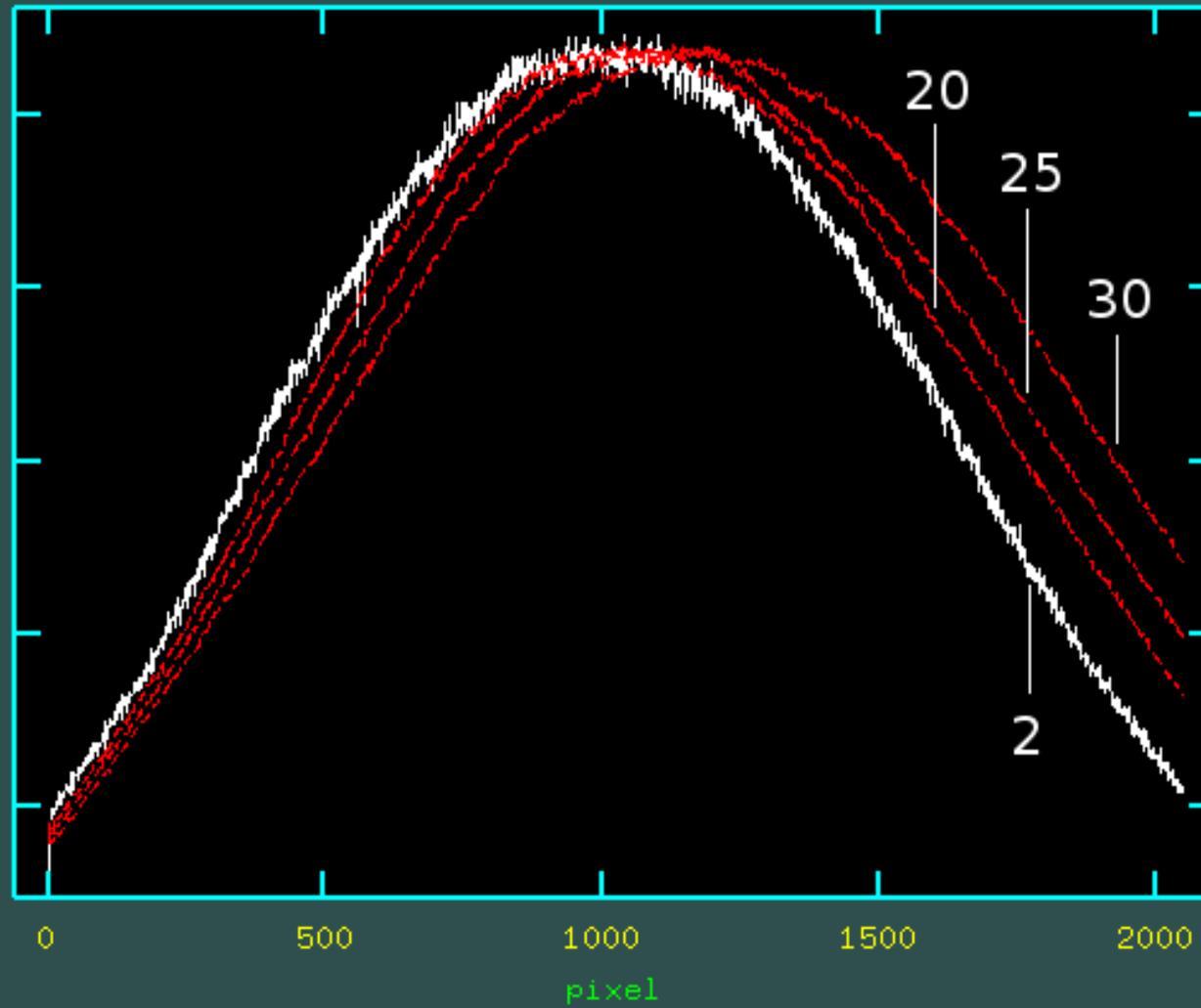
<https://cdn.eso.org/images/large/eso0308c.jpg>

PlatoSpec simul ThAr

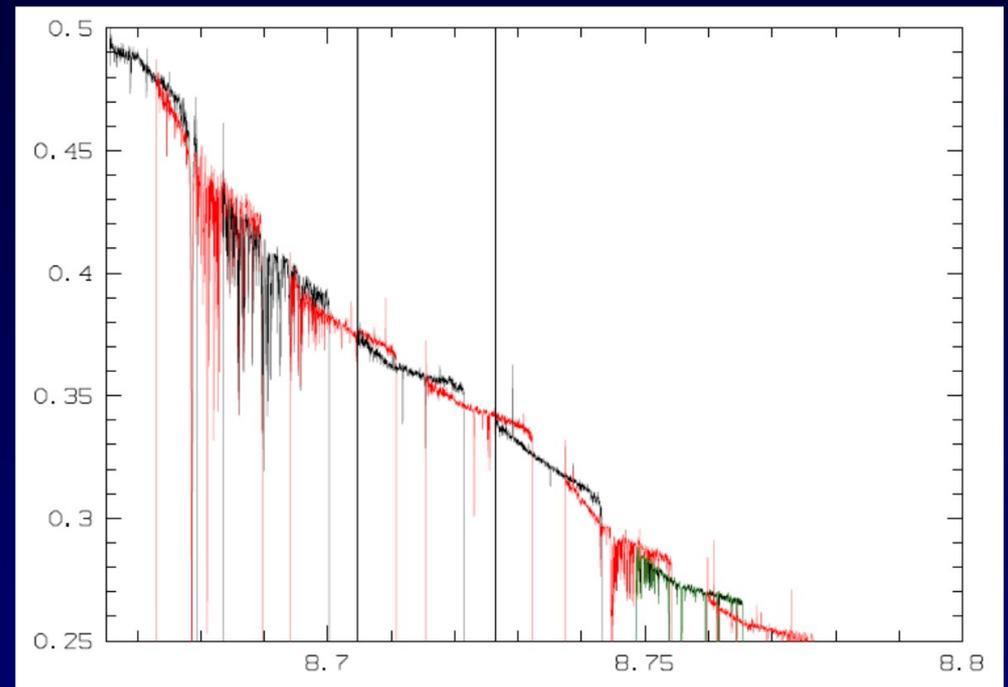
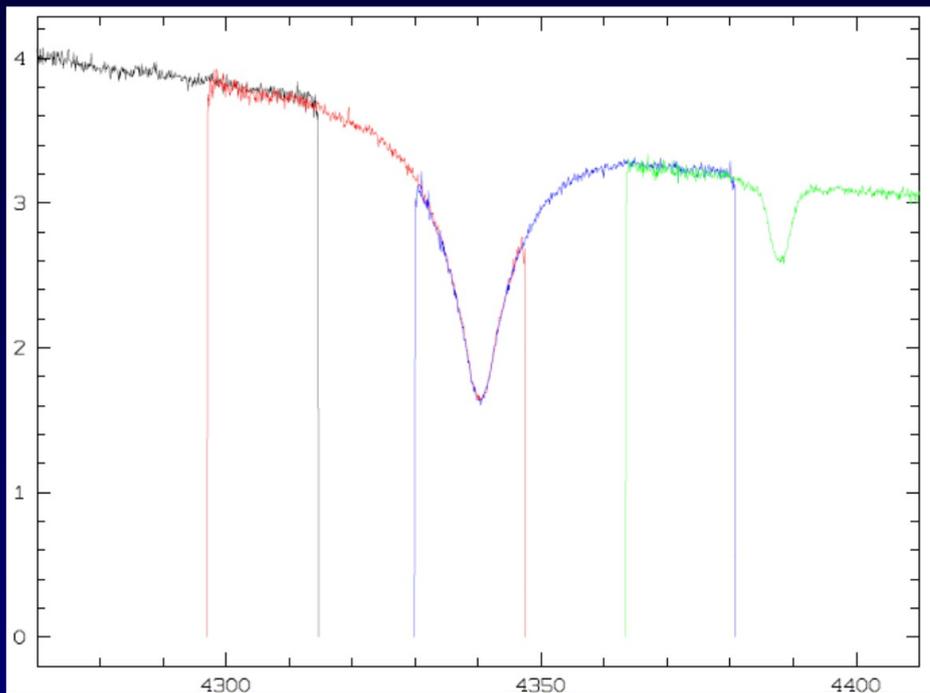
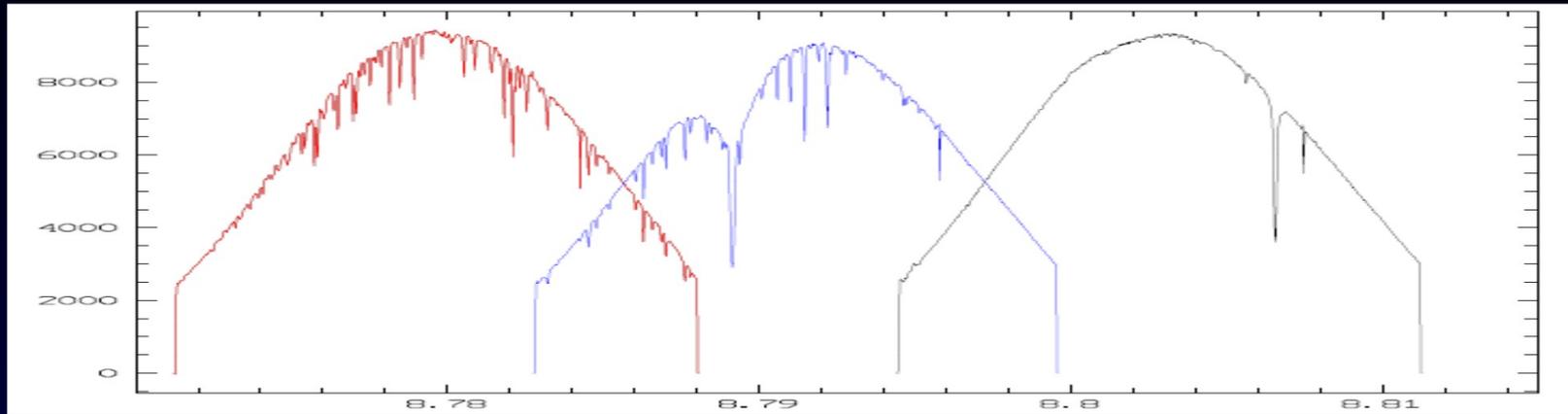
HARPS-S



OES Blaze shift



Echelle Spectra Problems in Hot Stars



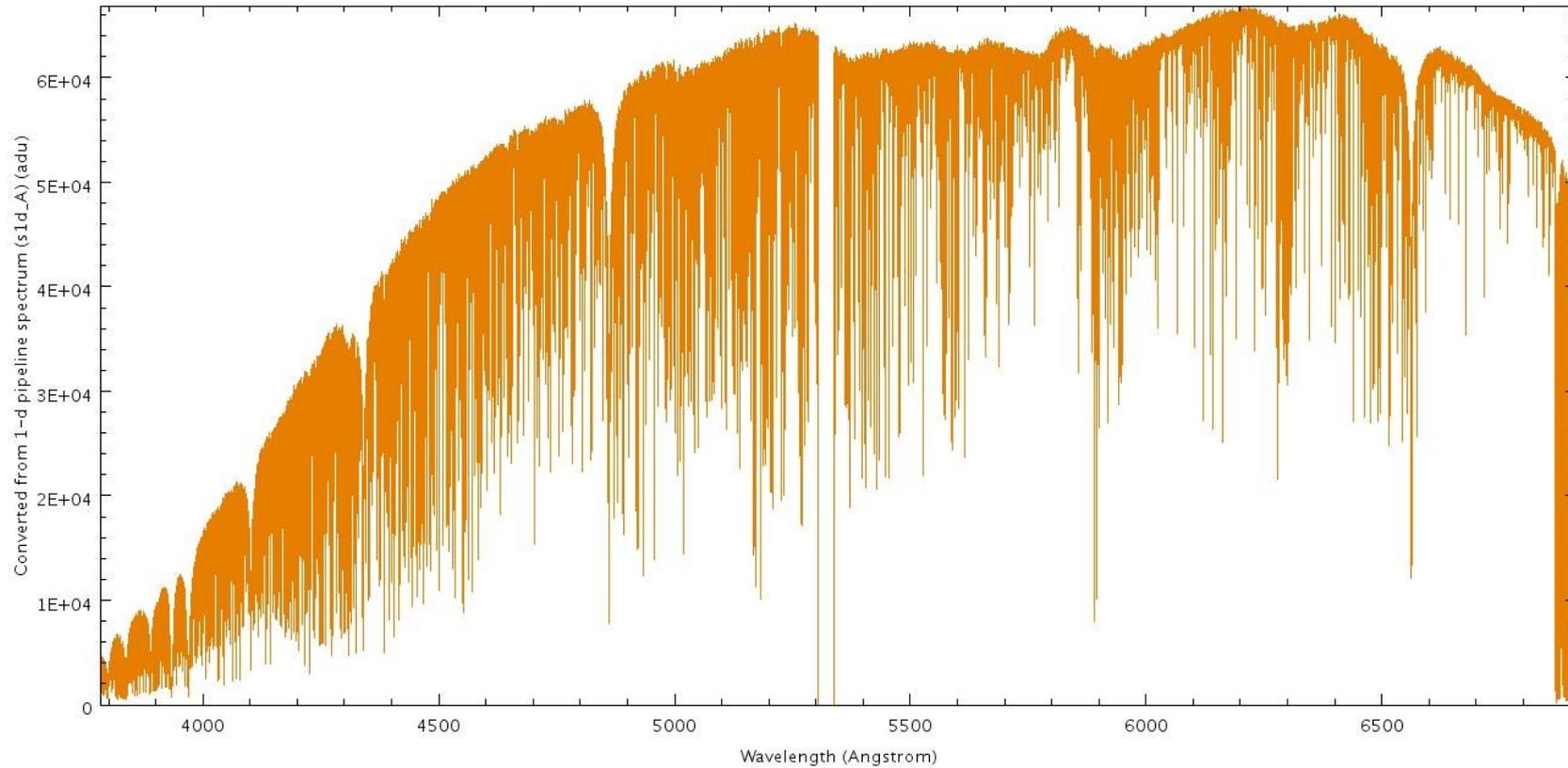
(Simple) Spectra in VO

VO Tools

- SPLAT-VO (GAVO – Ondrejov)
- CASSIS (OMP)
- IPAC Firefly (IRSAViewer)
 - All NASA data, LSST (Rubin)
 - Spectra in echelle – started
 - <https://github.com/Caltech-IPAC/firefly>
- Not Supported:
 - SpecView (HST)
 - VOSpec (ESA)

HARPS-S in SPLAT

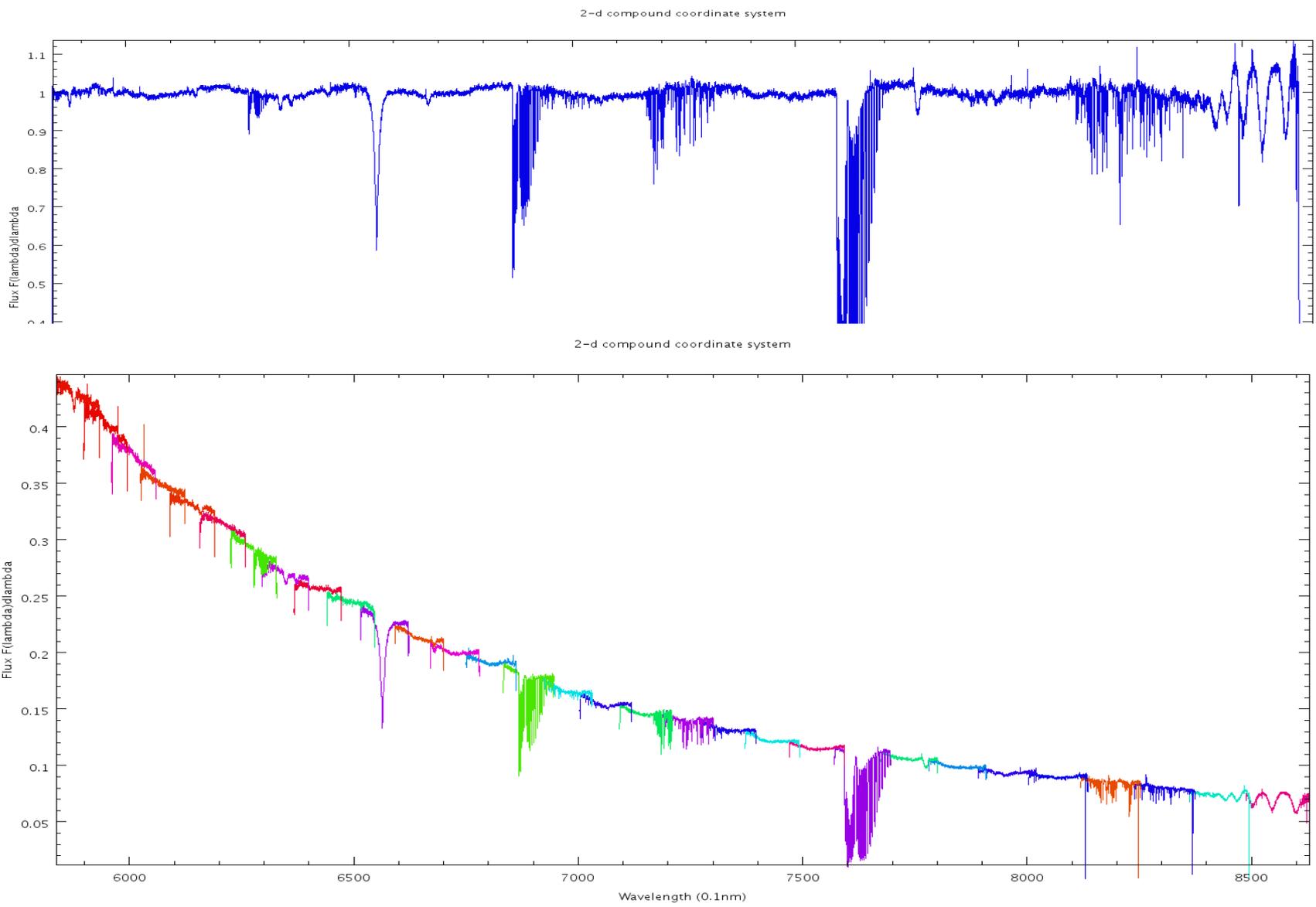
2-d compound coordinate system



313138 points

Procyon

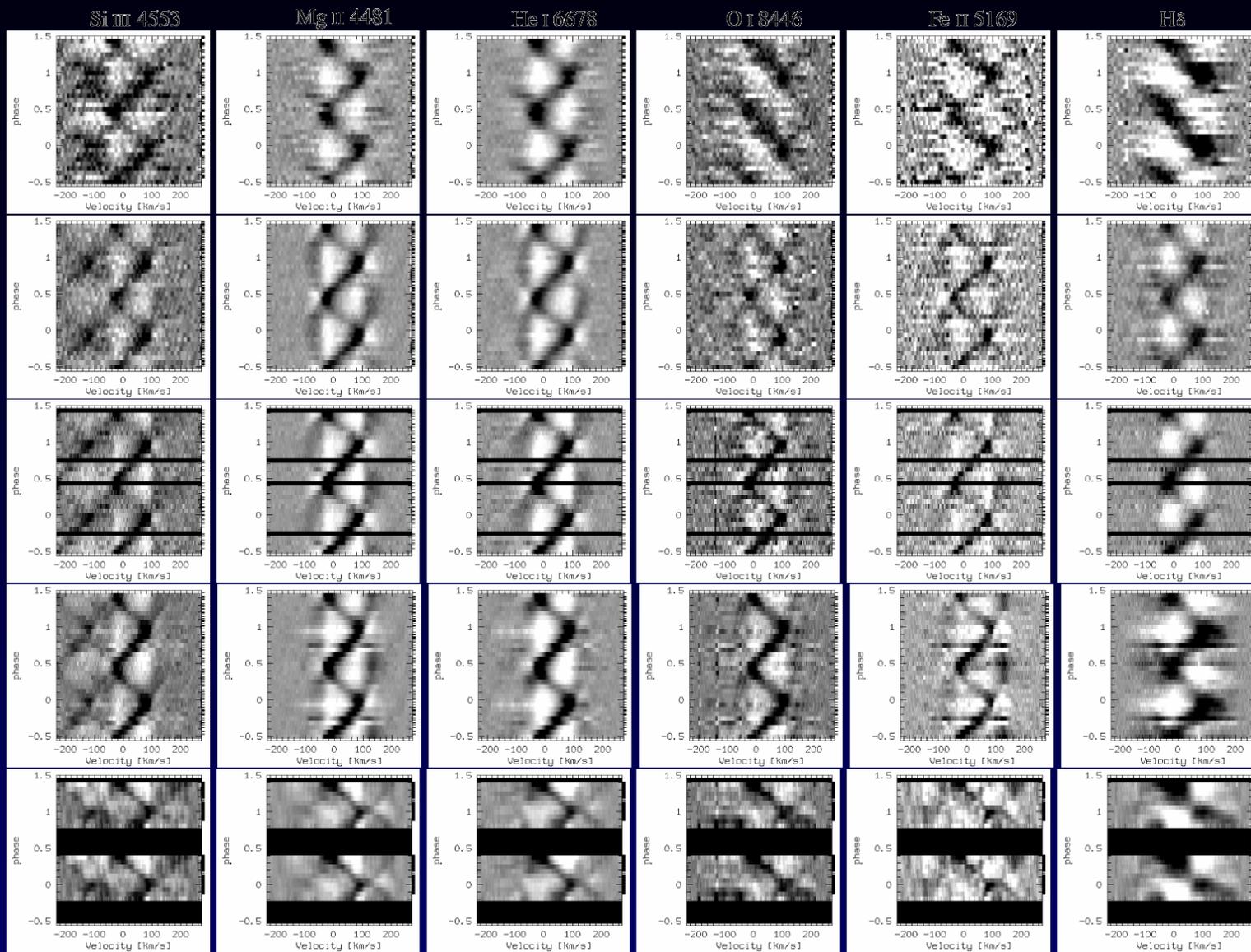
DaCHS Testbed Split-Order SSAP



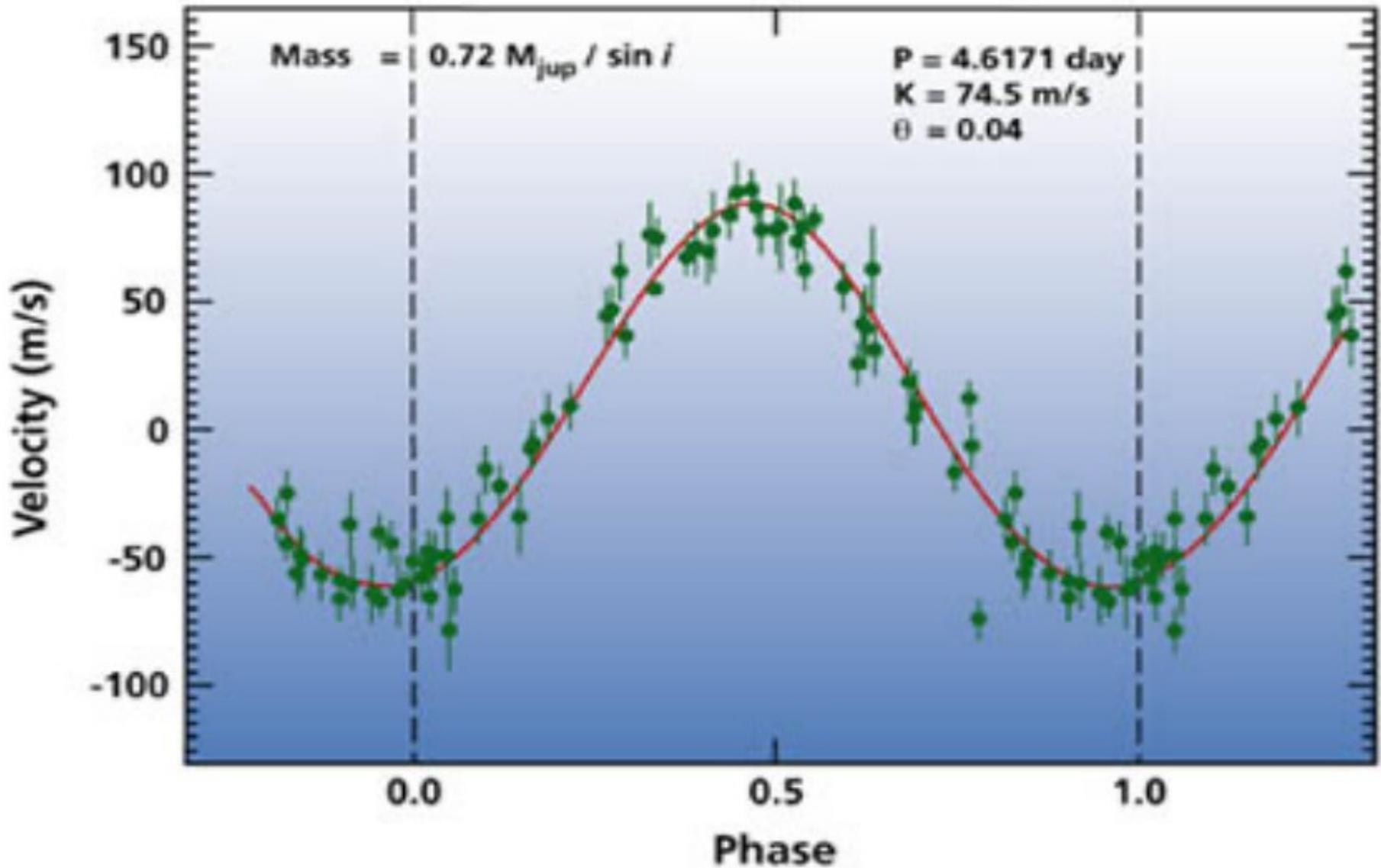
nu Pup HEROS red

Products derived from spectra

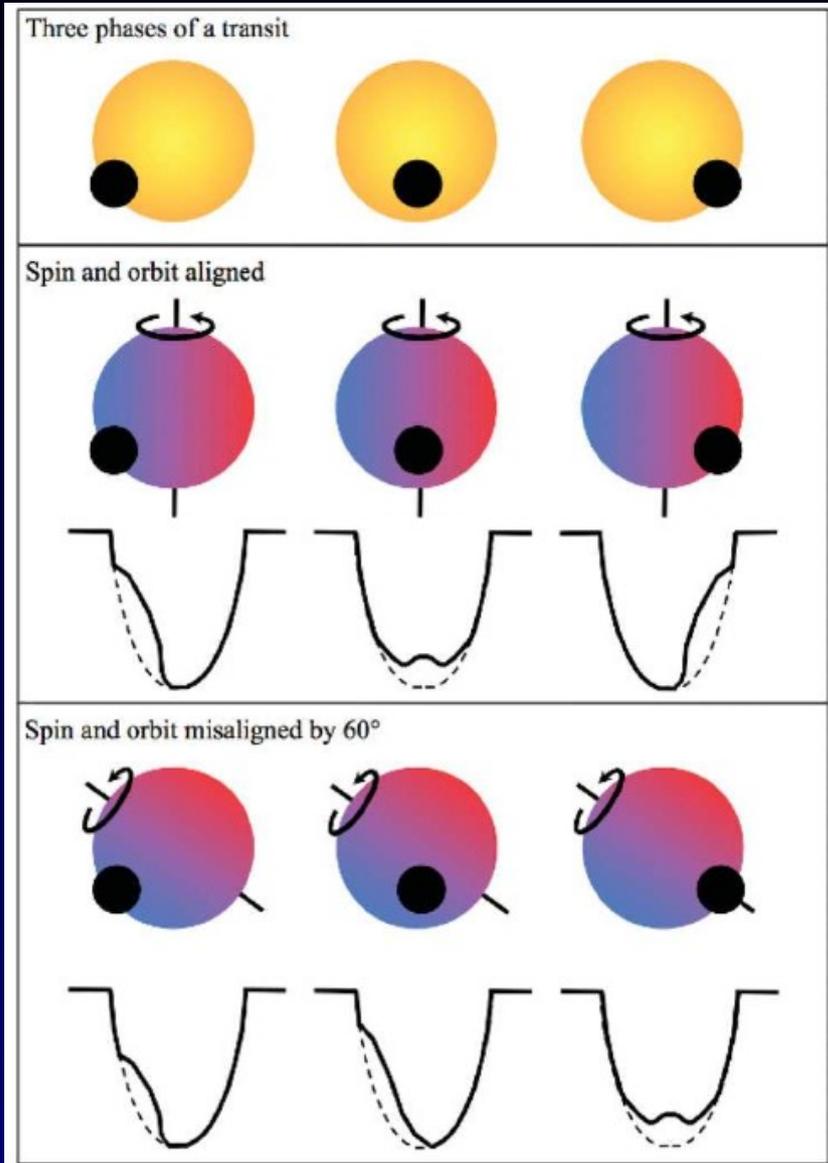
Dynamic Spectra



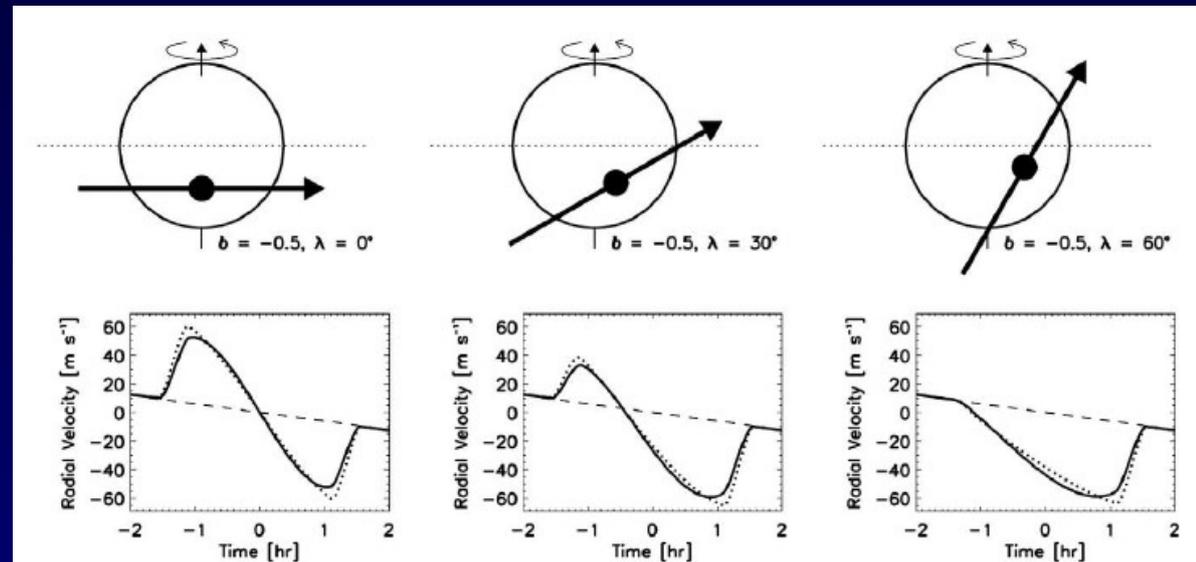
Radial Velocity Curve



Rossiter-McLaughlin effect

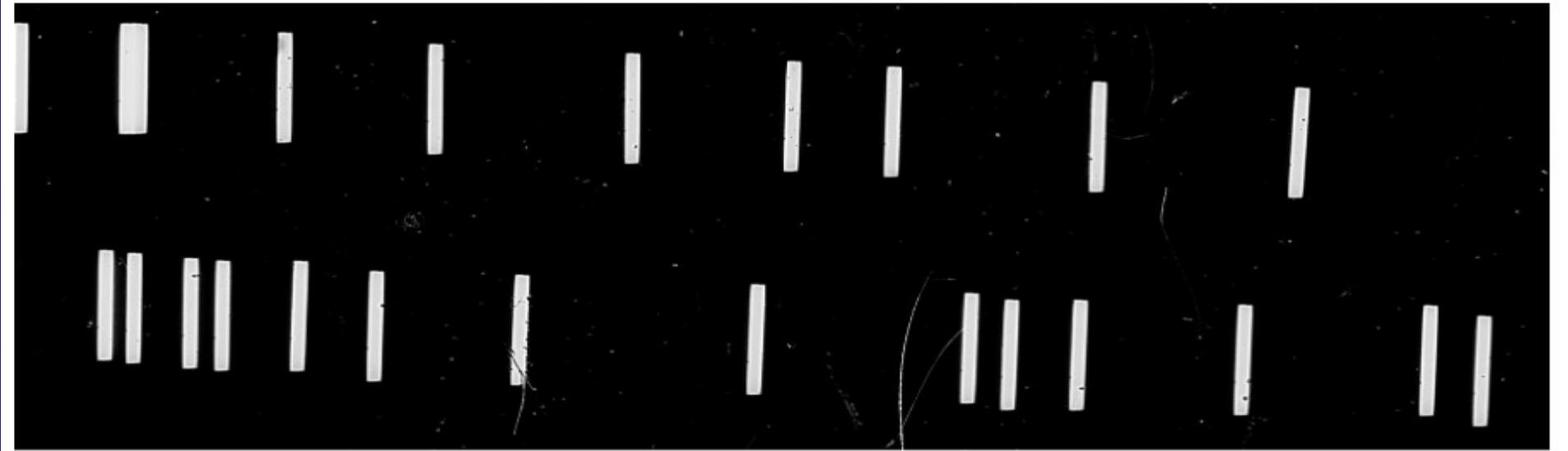
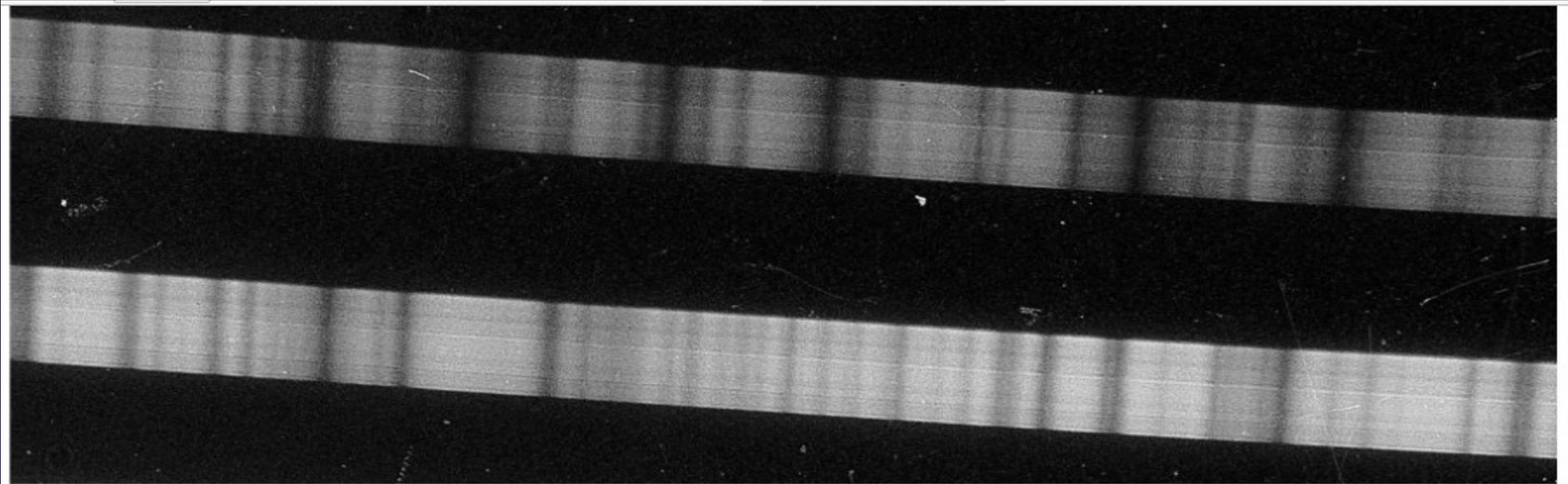


RV Curve – time series of RV
Only for direct occultation



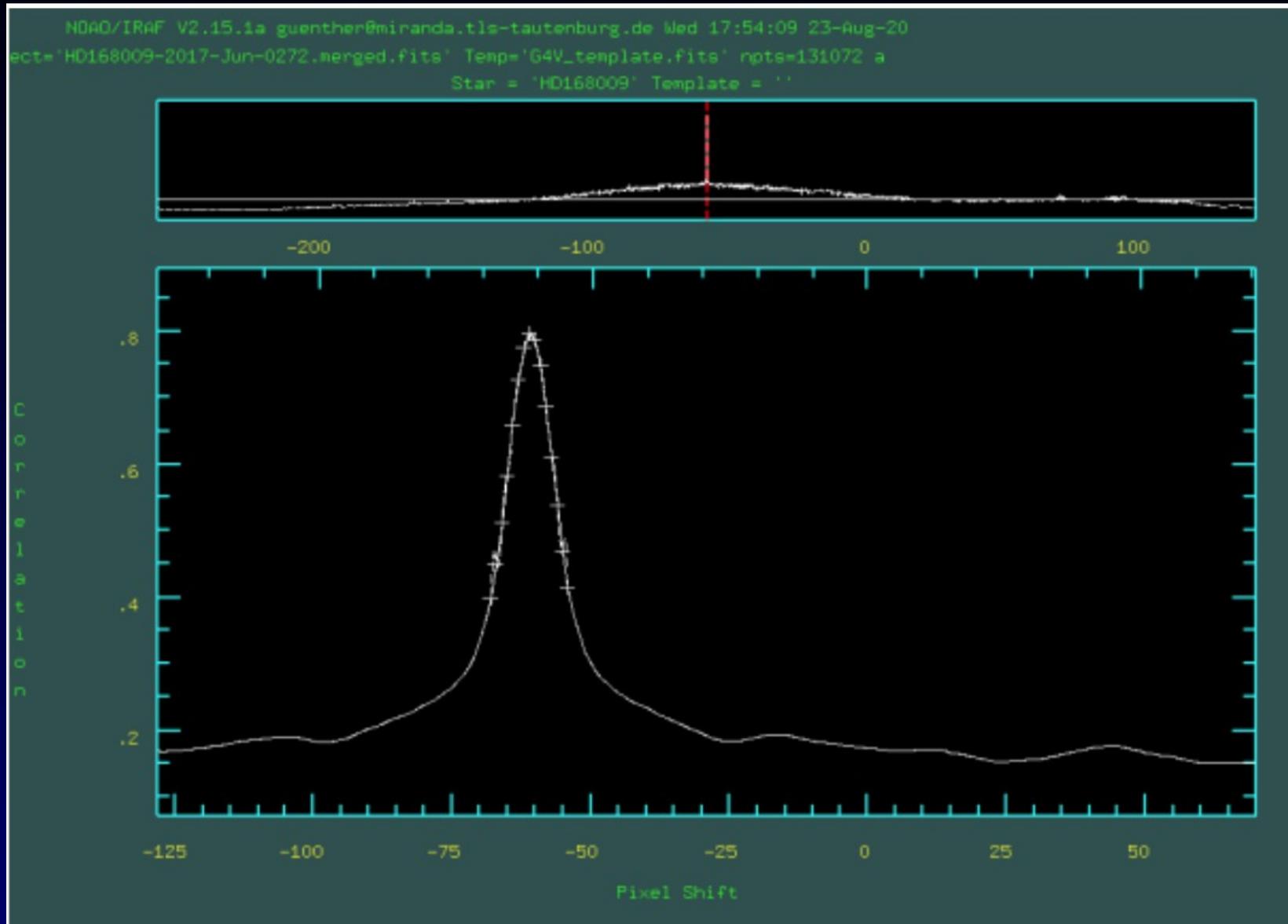
Cross Correlation

Analogue Technique



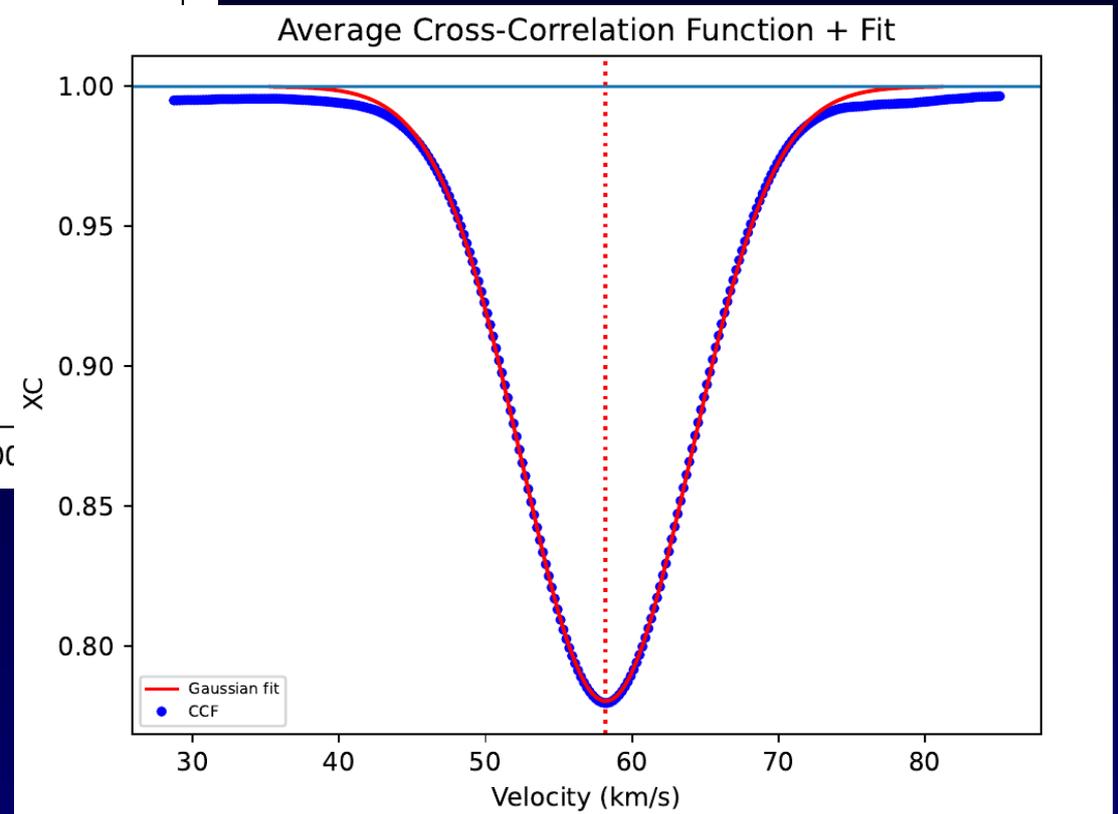
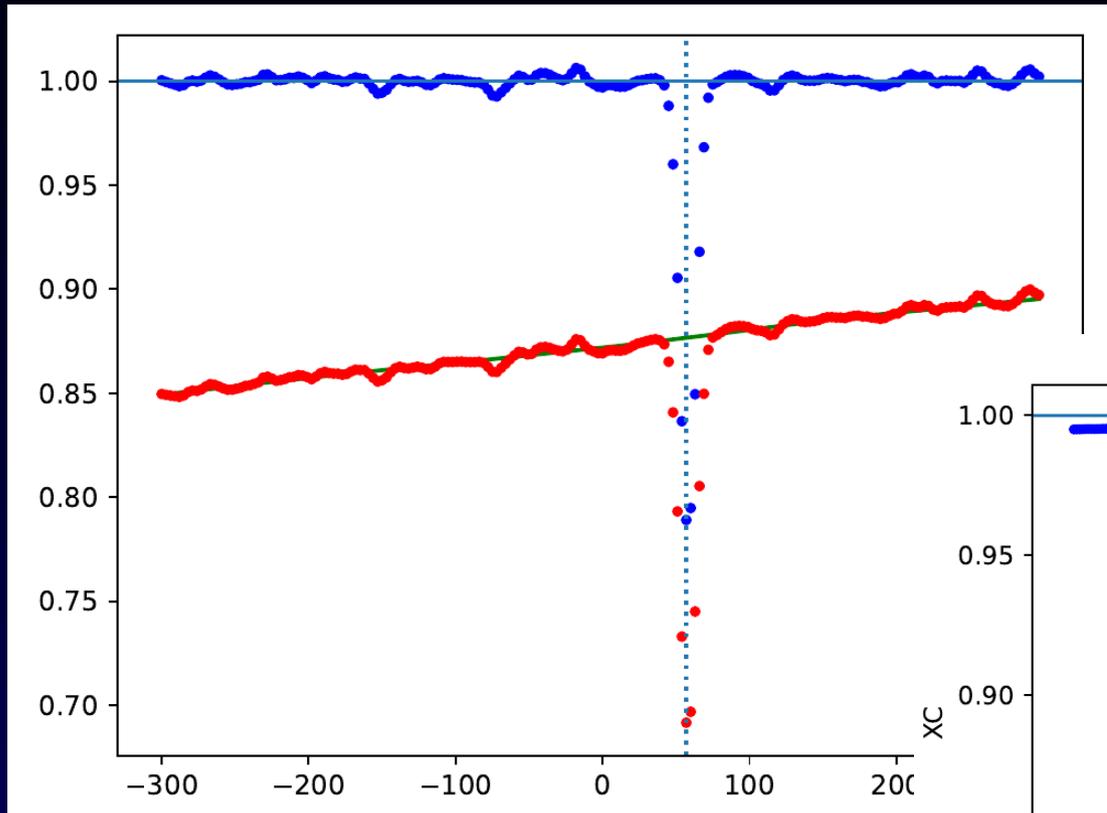
First principle Griffin 1967, DAO 122, CORAVEL ESO D154 1981

Cross Correlation Function

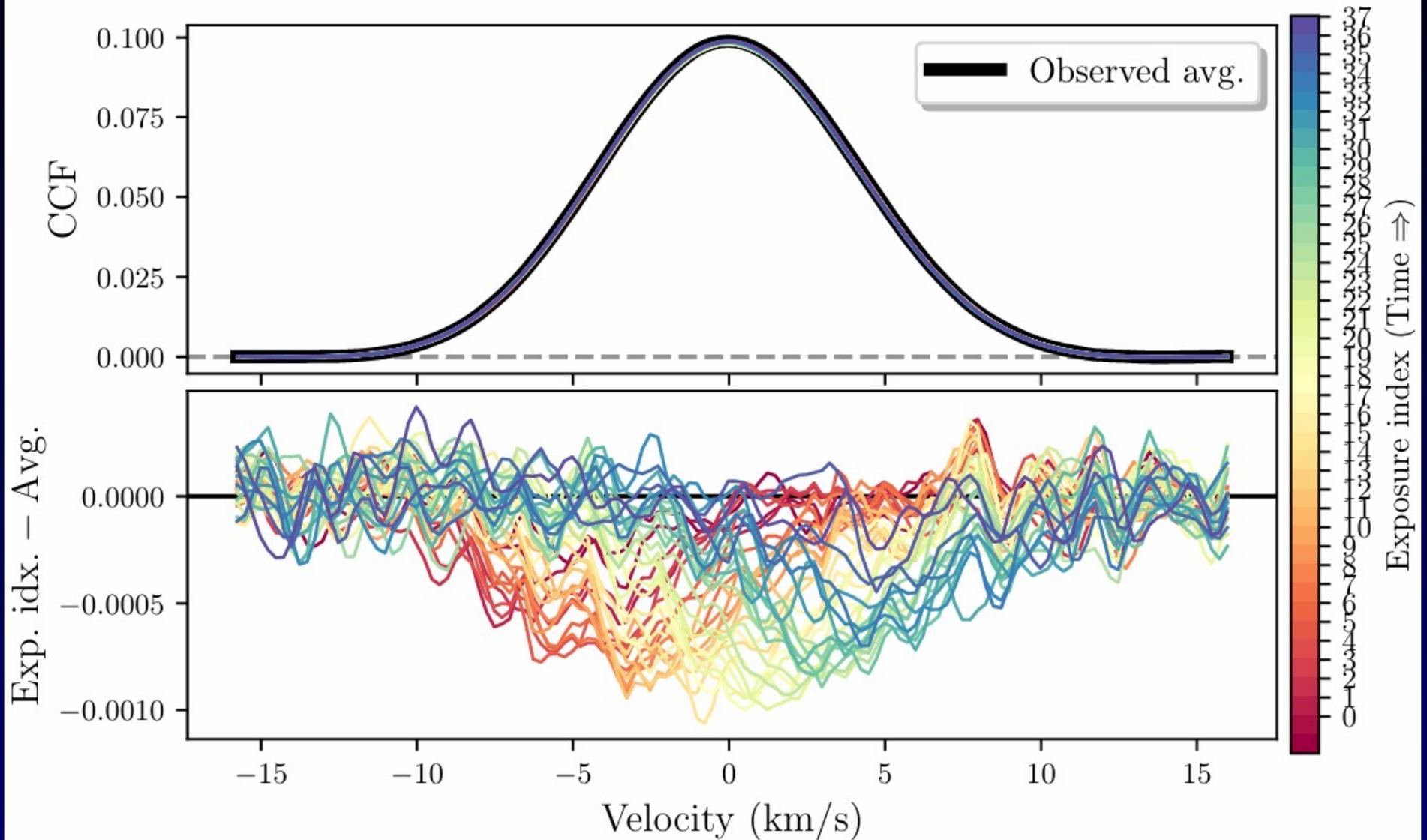


IRAF fxcor task

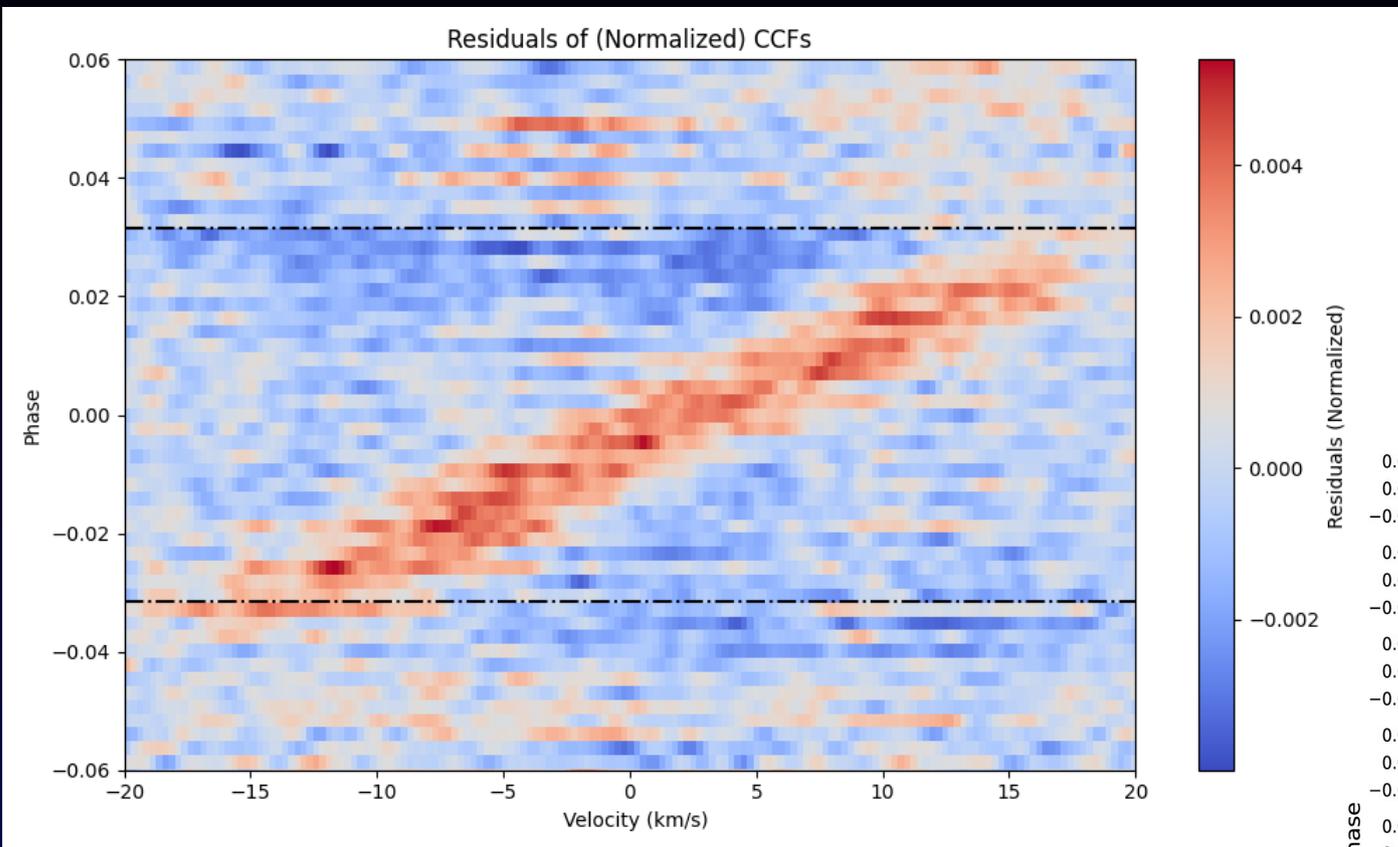
Cross Correlation Function - CCF



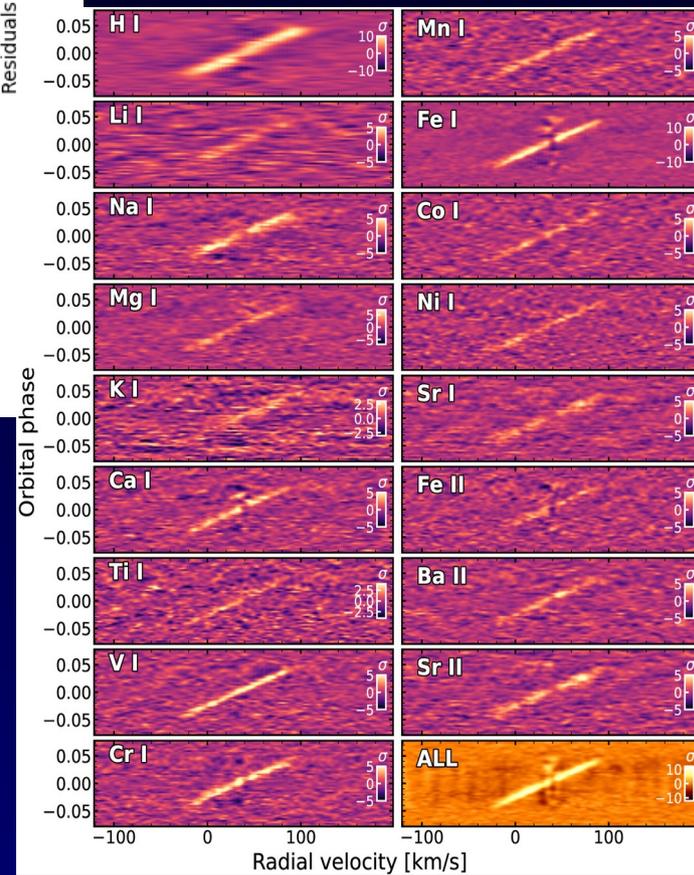
Residual CCF



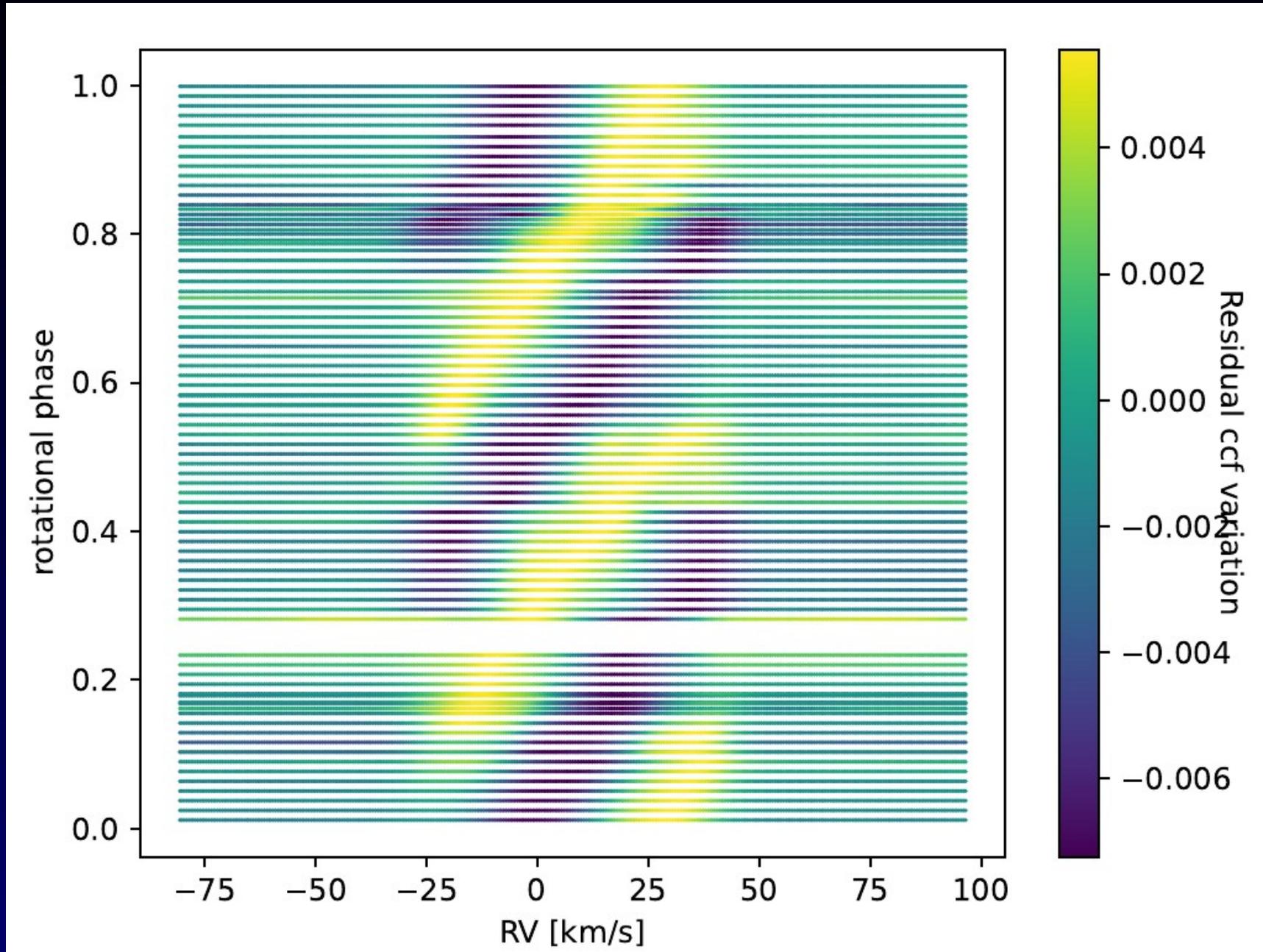
Doppler Shadow



HARPS-N archival CCF of HAT-P-41A. Balkoová 2025



Dynamic spectra – CCF



EPRV Standard

- About 15 spectrographs (~ 5 passively following)
e.g. CARMENES)
- Translators from native format
- Started 2024
- NASA JPL driven (EPRV project - WG)
- Bruce Berriman at IVOA 2025 June (after my advice to contact IVOA)

<https://github.com/EPRV-RCN/RVData>

<https://eprv-data-standard.readthedocs.io/en/latest>

EPRV L2 – Order by Order Unblazed

HDU	Name	Data Type	MinBetDepth	Multiplicity	Required	Description
0	PRIMARY	PrimaryHDU		False	True	EPRV Standard FITS HEADER (no data)
1	INSTRUMENT_HEADER	ImageHDU		False	True	Inherited instrument header (no data)
2	RECEIPT	BinTableHDU		False	True	Table of operations that have been performed on this file
3	DRP_CONFIG	BinTableHDU		False	True	Pipeline details (settings etc) to go from native data to L2
4	EXT_DESCRIPTOR	BinTableHDU		False	True	Table describing contents of each extension
5	ORDER_TABLE	BinTableHDU		TRUE	TRUE	Table capturing the wavelength extent of each order
6	TRACE1_FLUX	ImageHDU		True	True	Flux in trace 1
7	TRACE1_WAVE	ImageHDU	64	True	True	wavelength solution for trace 1
8	TRACE1_VAR	ImageHDU		True	True	variance for trace 1
9	TRACE1_BLAZE	ImageHDU		True	True	blaze for trace 1
10	BARYCORR_KMS	ImageHDU		False	True	barycentric correction in km/s
11	BARYCORR_Z	ImageHDU		False	True	barycentric correction in redshift
12	BJD_TDB	ImageHDU	64	False	True	Photon weighted midpoint
13	DRIFT	ImageHDU		False	False	Drift measurement map in delta lambda
14	TRACE1_QUALITY	ImageHDU	UINT8	True	False	Quality of each pixel in trace 1
15	EXPMETER	BinTableHDU		False	False	Table of exposure meter counts timeseries over the exposure
16	TELEMETRY	BinTableHDU		False	False	Table of telemetry collected during the exposure
17	TRACE1_TELLURIC	ImageHDU		True	False	Telluric model for trace 1
18	TRACE1_SKYMODEL	ImageHDU		True	False	Sky model for trace 1
19	ANCILLARY_SPECTRUM	ImageHDU		True	False	Extension(s) that store ancillary spectra
20	IMAGE	ImageHDU		True	False	Extension(s) that store useful support images
21	CUSTOM1_TRACE1_FLUX	ImageHDU		True	False	Additionally corrected flux in trace 1
22	CUSTOM1_TRACE1_WAVE	ImageHDU		True	False	Additionally corrected wavelength solution for trace 1
23	CUSTOM1_TRACE1_VAR	ImageHDU		True	False	Additionally corrected variance for the flux in trace 1

EPRV L3 – Merged orders normalized

This is what we already know – SSAP, “distorted data low precision”

HDU	Name	DataType	Multiplicity	Required	Description
0	PRIMARY	PrimaryHDU	False	True	EPRV Standard FITS HEADER (no data)
1	INSTRUMENT_HEADER	ImageHDU	False	True	Inherited instrument header (no data)
2	RECEIPT	BinTableHDU	False	True	Table of operations that have been performed on this file
3	DRP_CONFIG	BinTableHDU	False	True	Pipeline details (settings etc) to go from native data to L2
4	ORDER_TABLE	BinTableHDU	TRUE	TRUE	Table capturing the wavelength extent of each order
5	STITCHED_CORR_TRACE1_FLUX	ImageHDU	True	True	Order stitched blaze-corrected flux in trace 1
6	STITCHED_CORR_TRACE1_WAVE	ImageHDU	True	True	Order stitched BC- and drift-corrected wavelength solution for trace 1
7	STITCHED_CORR_TRACE1_VAR	ImageHDU	True	True	Order stitched variance for the flux in STITCHED_CORR_TRACE1_FLUX
8	COMBINED_STITCHED_CORR_FLUX	ImageHDU	True	True	Order stitched and blaze-corrected flux co-added across all traces
9	COMBINED_STITCHED_CORR_WAVE	ImageHDU	True	True	Order stitched BC- and drift-corrected wavelength solution
10	COMBINED_STITCHED_CORR_VAR	ImageHDU	True	True	Order stitched variance for the combined flux in COMBINED_STITCHED_CORR_FLUX
11	STITCHED_CUSTOMCORR1_TRACE1_FLUX	ImageHDU	True	False	Additional corrections made to STITCHED_CORR_TRACE1_FLUX
12	STITCHED_CUSTOMCORR1_TRACE1_WAVE	ImageHDU	True	False	Wavelength solution corresponding to STITCHED_CUSTOMCORR1_TRACE1_FLUX
13	STITCHED_CUSTOMCORR1_TRACE1_VAR	ImageHDU	True	False	Variance corresponding to STITCHED_CUSTOMCORR1_TRACE1_FLUX
14	COMBINED_STITCHED_CUSTOMCORR1_FLUX	ImageHDU	True	False	Additional corrections made to COMBINED_STITCHED_CORR_FLUX
15	COMBINED_STITCHED_CUSTOMCORR1_WAVE	ImageHDU	True	False	Wavelength solution corresponding to COMBINED_STITCHED_CORR_WAVE
16	COMBINED_STITCHED_CUSTOMCORR1_VAR	ImageHDU	True	False	Variance corresponding to COMBINED_STITCHED_CORR_VAR

EPRV L4 – Derived core exo science

Radial Velocity and Cross Correlation Function (various masks)

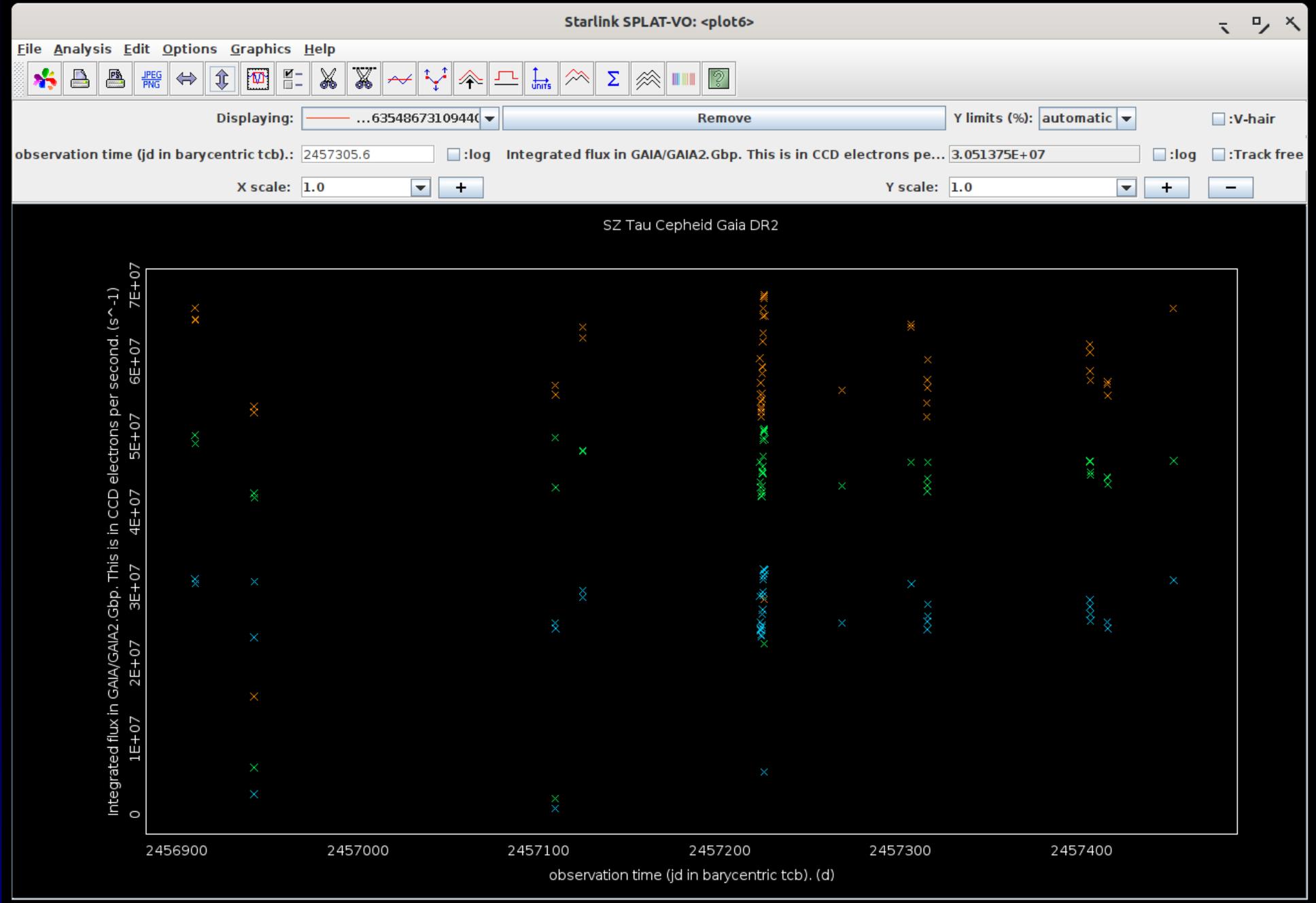
It is the most important output of pipeline

But exoscientists need Time Series (RV curves , Doppler shadows)

VO can do it on the fly (select all observation, apply SODA extract , create time series)

HDU	Name	DataType	Multiplicity	Required	Description
0	PRIMARY	PrimaryHDU	FALSE	TRUE	EPRV Standard FITS HEADER (no data)
1	INSTRUMENT_HEADER	ImageHDU	FALSE	TRUE	Inherited instrument header (no data)
2	RECEIPT	BinTableHDU	FALSE	TRUE	Table of operations that have been performed on this file
3	DRP_CONFIG	BinTableHDU	FALSE	TRUE	Pipeline details (settings etc) to go from native data to L2
4	RV1...N	BinTableHDU	TRUE	TRUE	Derived Radial Velocity Measurement
5	CCF1...N	ImageHDU	TRUE	FALSE	Array with same dimensionality of RV1...N, that contains the CCF that produced each RV1...N
6	DIAGNOSTICS1...J	BinTableHDU	TRUE	FALSE	Activity indicators, CCF metrics, etc
7	CUSTOM_CCF1...N	ImageHDU	TRUE	FALSE	Additional CCFs from (e.g.) different masks
8	CUSTOM_RV1...N	BinTableHDU	TRUE	FALSE	Derived Radial Velocity Measurement from CUSTOM_CCF1...N

Gaia DR2 Light Curves



Gaia DR2 Light Curves - Zoom

Starlink SPLAT-VO: <plot6>

File Analysis Edit Options Graphics Help



Displaying: ...63548673109440

Remove

Y limits (%): automatic

observation time (jd in barycentric tcb): 2457221.89

:log

Integrated flux in GAIA/GAIA2.G. This is in CCD electrons per ...

6.035605E+07

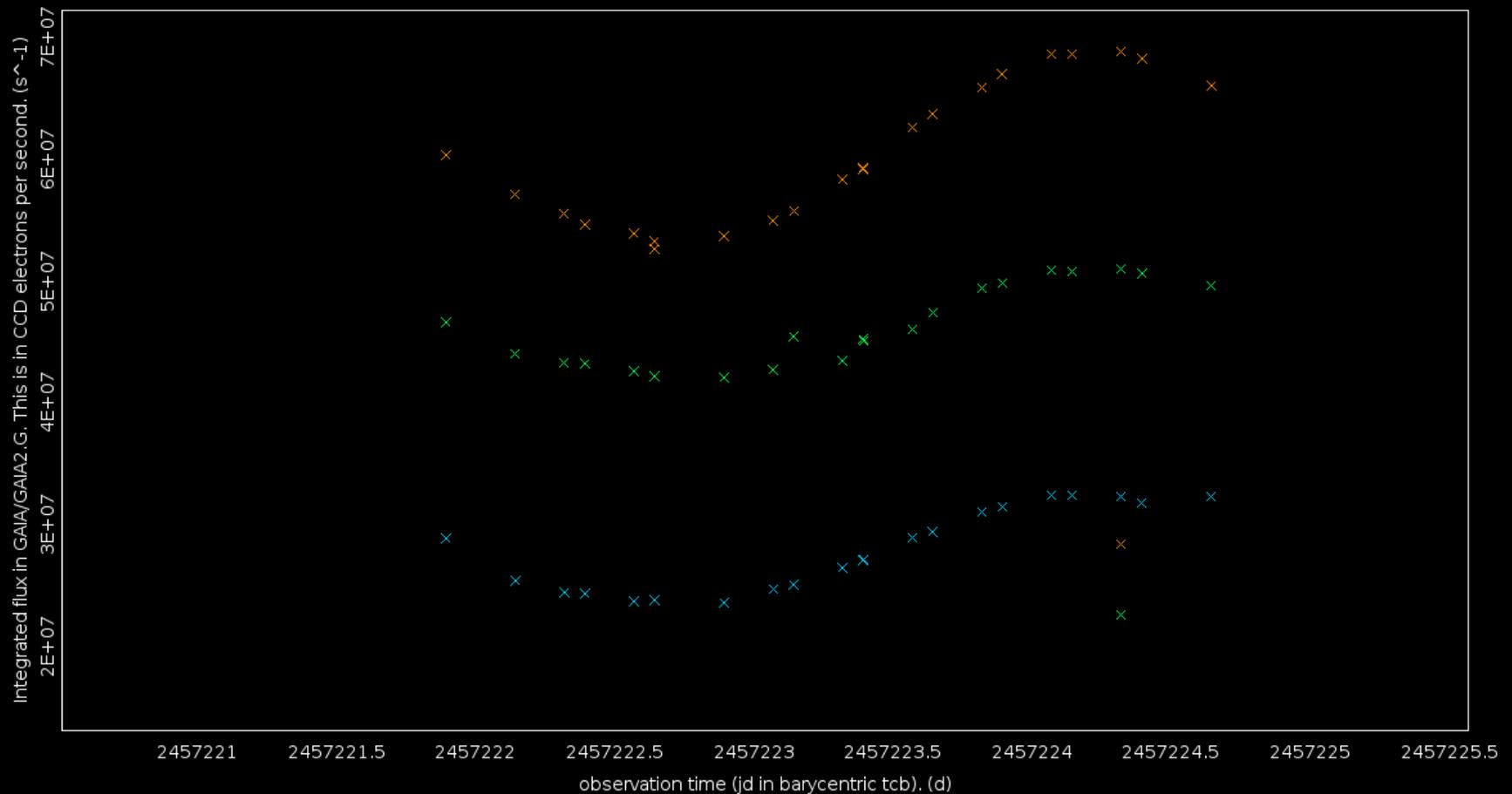
:log

:Track

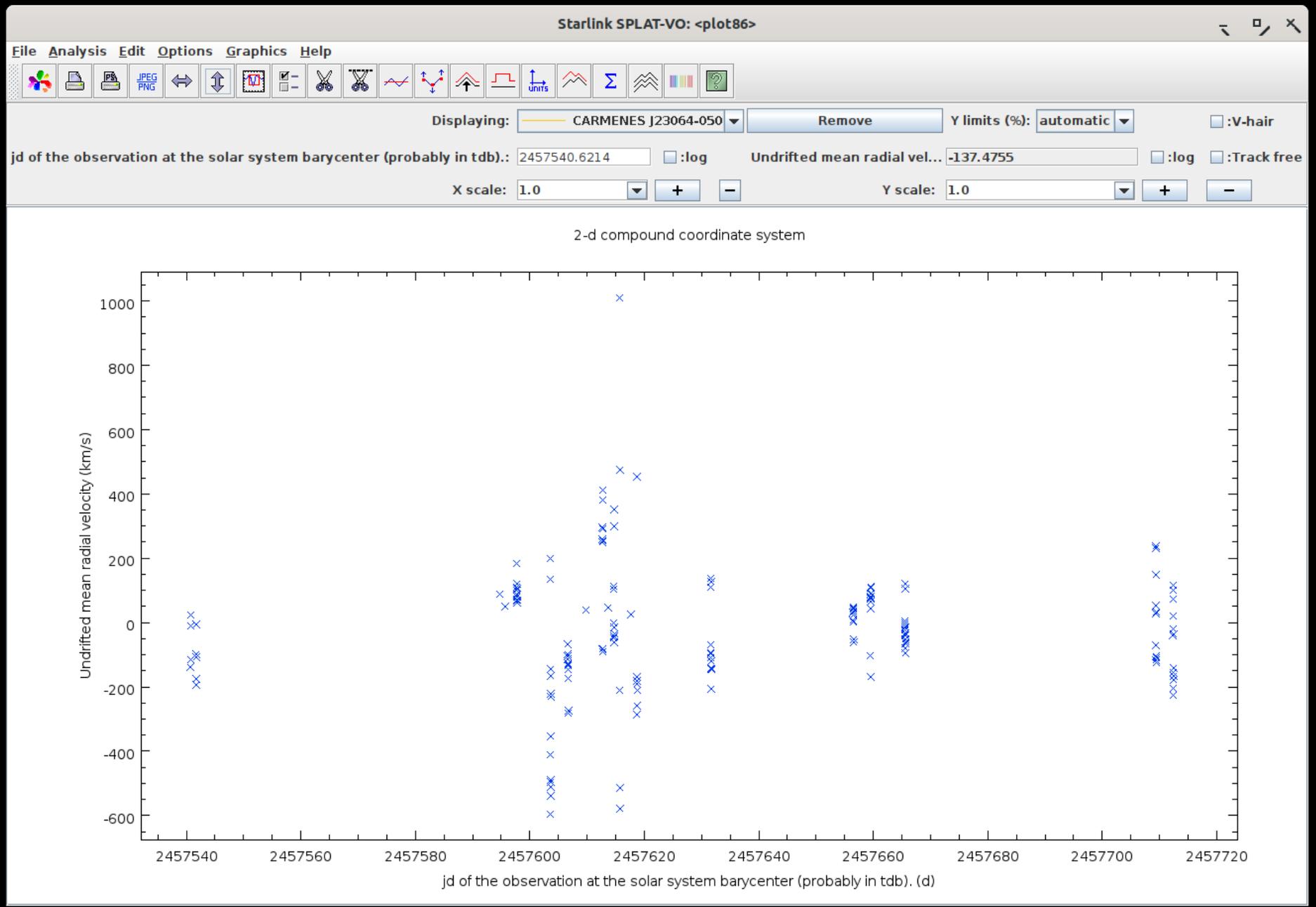
X scale: 78.762794

Y scale: 1.1626029

SZ Tau Cepheid Gaia DR2



Trappist-1 RV Curve – Carmenes



AST Library – SSAP “flux”

```
Nov 12, 2025 9:21:20 PM uk.ac.starlink.splat.ast.ASTJ makeSpectral
INFO: Data units unknown: km/s (AST: Error at line 420 in file AstObject.c.
astGetSystem(FluxFrame): The current units (km/s) cannot be used with any of the supported flux systems.
```

```
Nov 12, 2025 9:48:08 PM uk.ac.starlink.splat.ast.ASTJ makeSpectral
INFO: Data units unknown: s^-1 (AST: Error at line 420 in file AstObject.c.
astGetSystem(FluxFrame): The current units (s^-1) cannot be used with any of the supported flux systems.
```

4.2.5.4 General Dataset Metadata

General dataset metadata describes the overall dataset.

<i>UTYPE</i>	<i>Description</i>	<i>Req</i>	<i>Default</i>
Dataset.DataModel	Datamodel name and version	MAN	Spectrum-1.0
Dataset.Type	Type of dataset	OPT	Spectrum
Dataset.Length	Number of points in spectrum	MAN	
Dataset.Deleted	Set to deletion time, if dataset is deleted	OPT	
Dataset.TimeSI	SI factor and dimensions	OPT	
Dataset.SpectralSI	SI factor and dimensions	OPT	
Dataset.FluxSI	SI factor and dimensions	OPT	
Dataset.SpectralAxis	SpectralAxis column name (native data)	OPT	
Dataset.FluxAxis	FluxAxis column name (native data)	OPT	

SSAP

4.2.5.9 Dataset Characterization Axis Metadata

The Characterization axis metadata specifies the type of physical quantity on each physical measurement axis as well as the observable.

<i>UTYPE</i>	<i>Description</i>	<i>Req</i>	<i>Default</i>
Char.FluxAxis.Ucd	ucd for flux	REC	
Char.SpectralAxis.Ucd	ucd for spectral coord	REC	

Thank you