Echelle Spectra in EPRV Era

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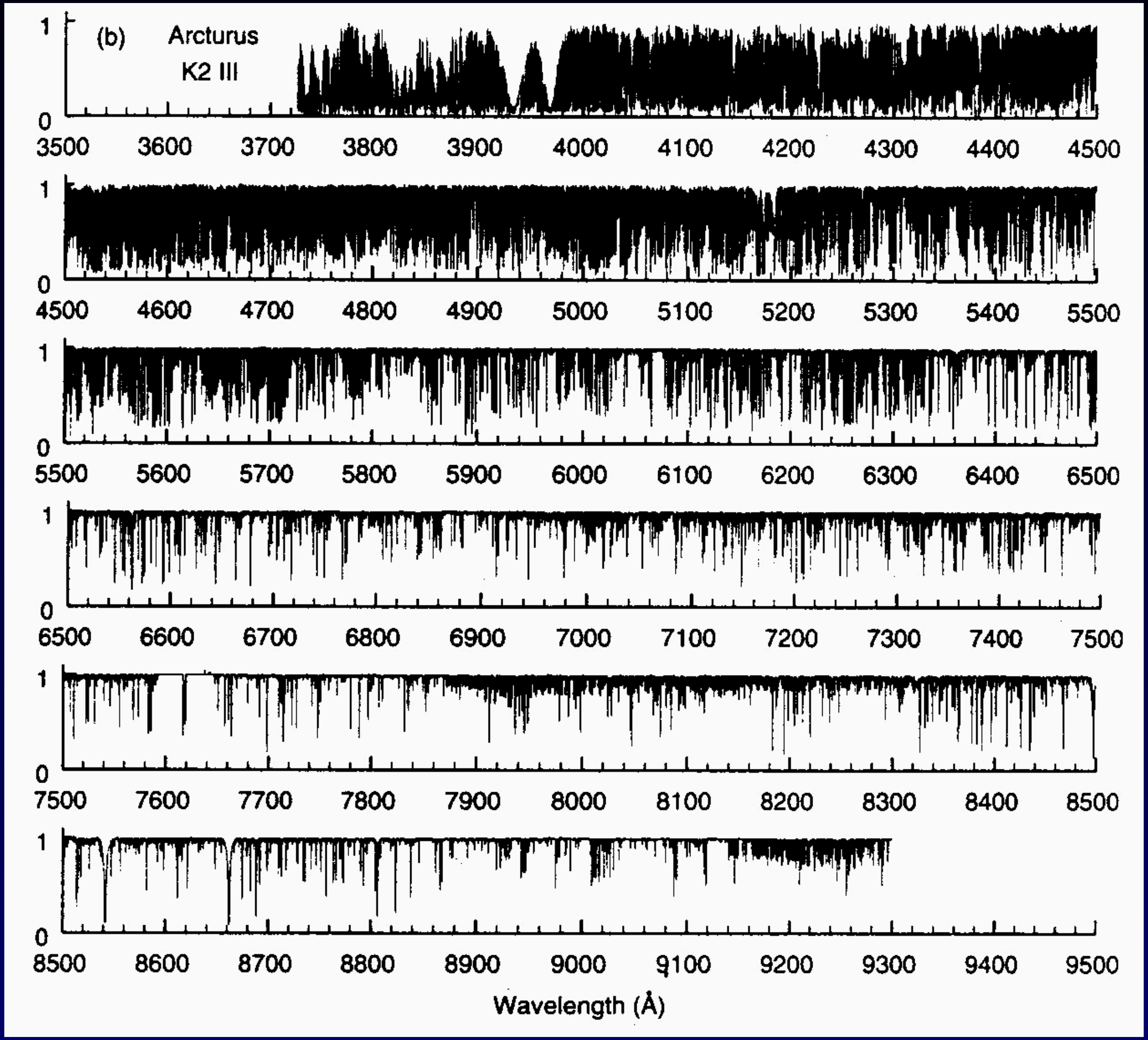
Credits

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.

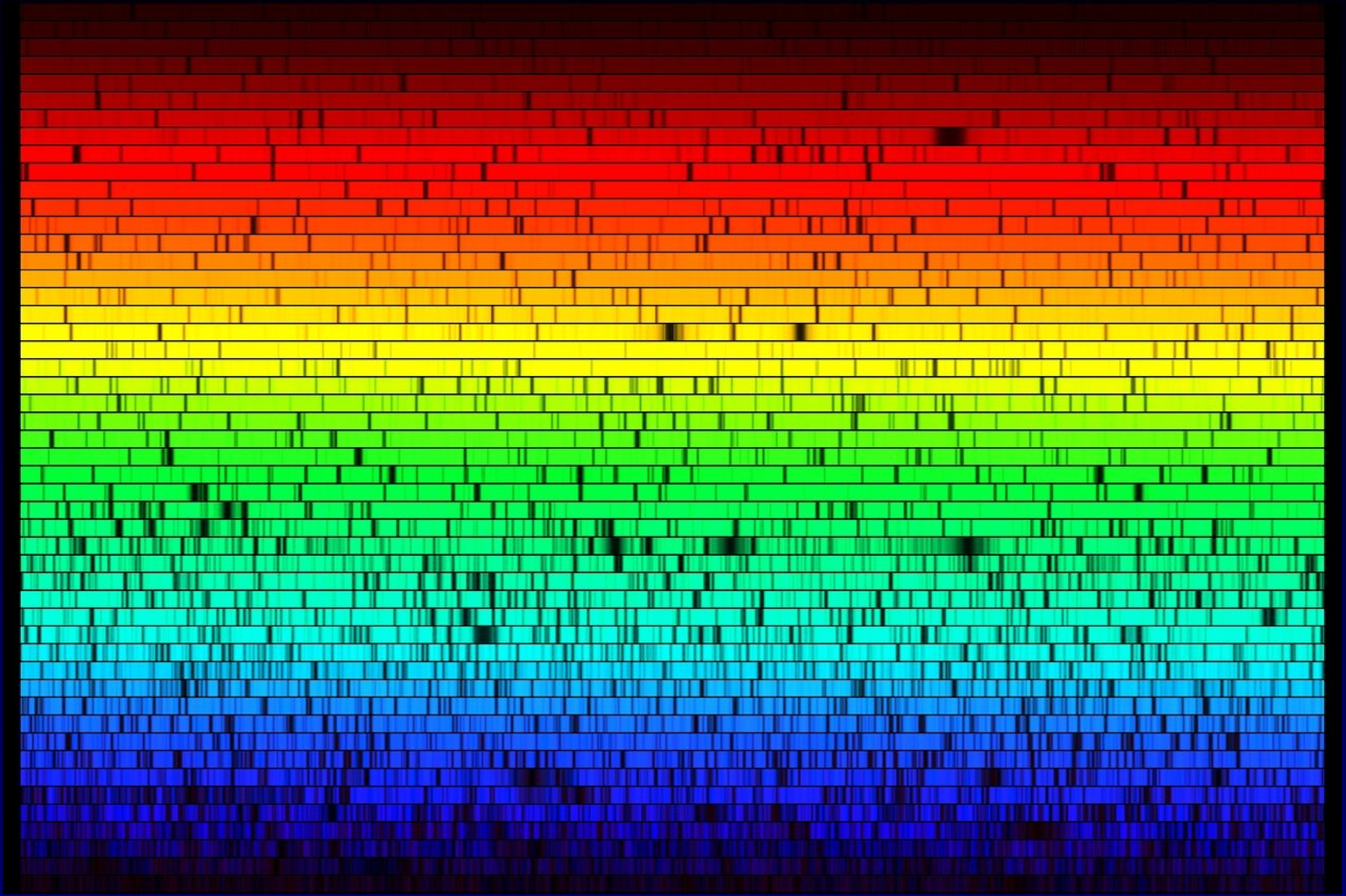
Echelle Spectra

Atlas of Arcturus – 1D Normalized



Arcturus: Hinkle et al. 2000

Spectrum of Arcturus (pixel-order)



KPNO NOIRLab

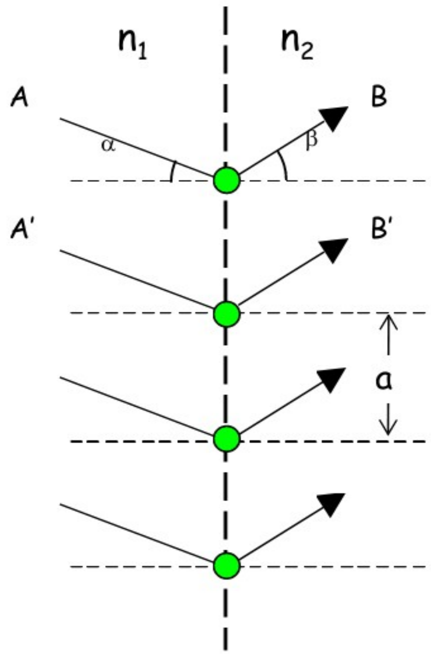
Grating Equation

- Interference condition:

⇒ *path difference between AB and A'B'*

- Grating equation:

$$m\rho\lambda = n_1 \sin\alpha + n_2 \sin\beta \quad \text{where} \quad \rho = \frac{1}{a}$$



Note the *m* is the spectrum (interference) order

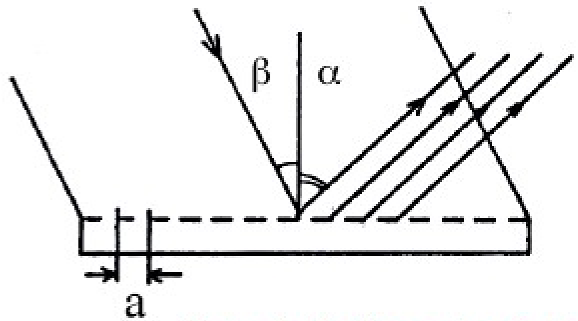
High order – high dispersion R ~ m*N (no of rules in beam)

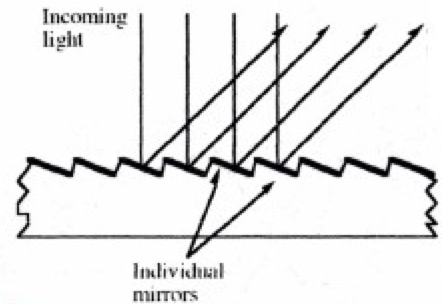
Èchelle – stairway in French - coarse grooves (big steps)
HARPS 31.6/mm

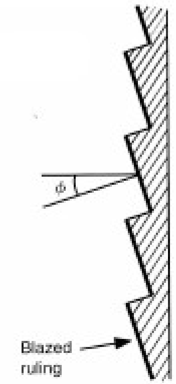
Echellette – normal grating in 1^{st} , 2^{nd} order …. e.g. 833 /mm

Blazed Grating Intensity

Solution: Blazed Grating

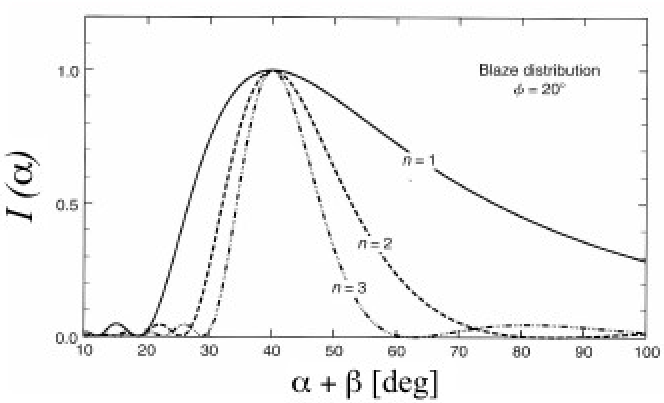


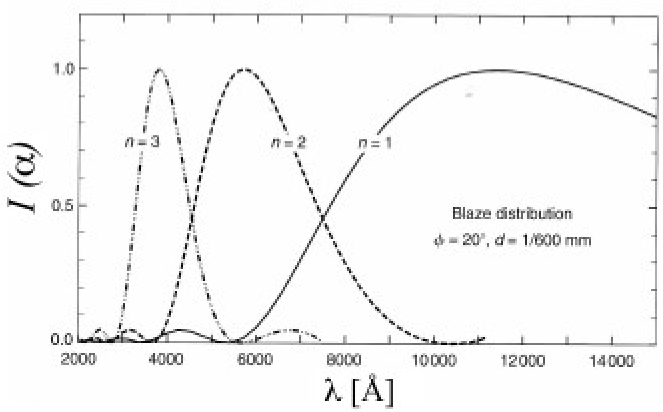




Single-slit diffraction envelope for blazed grating

$$I(\beta) = \left[\frac{\sin\{(\pi b/\lambda)\left[\sin(\alpha+\phi)+\sin(\beta+\phi)\right]\}}{(\pi b/\lambda)\left[\sin(\alpha+\phi)+\sin(\beta+\phi)\right]} \right]^2$$



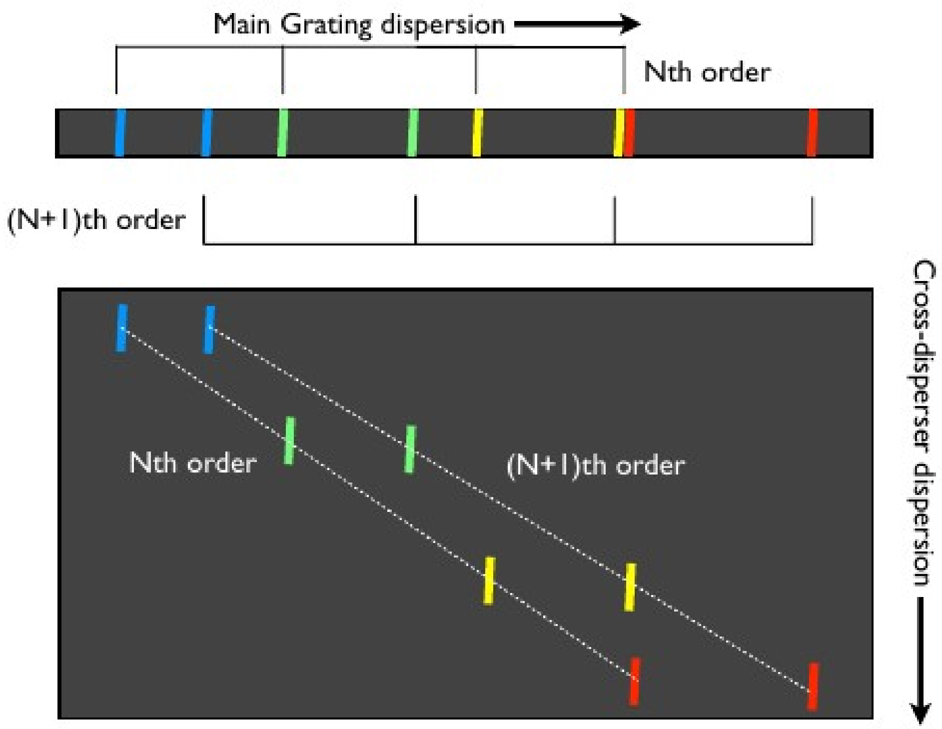


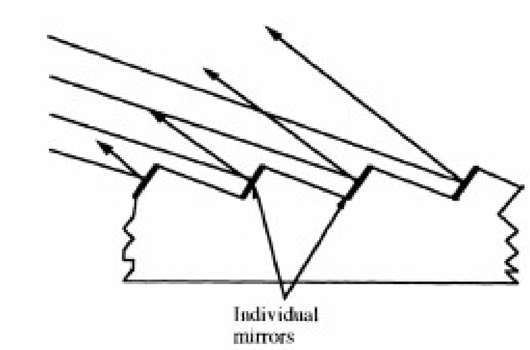
Sbordone 2020, ESO La Silla school, lecture Basics of Spectroscopy.

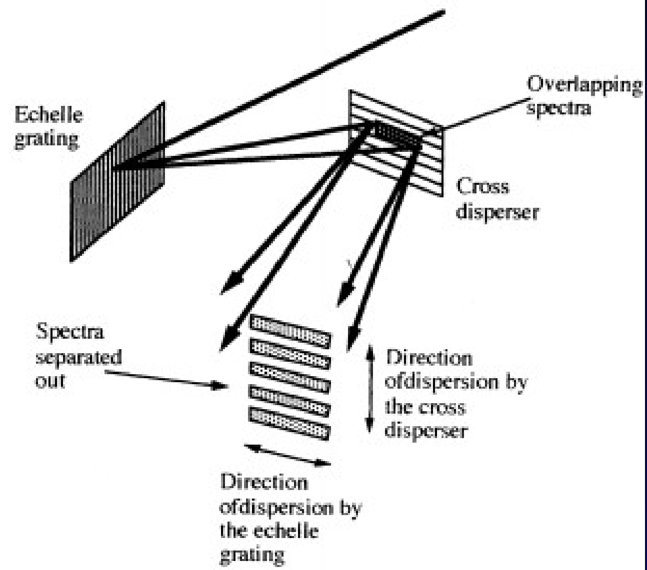
Need for Cross-Dispersion

The èchelle cross-dispersed spectrograph

- No shadowing, very high orders (100+), high dispersion
- Order overlap avoided by cross-dispersion





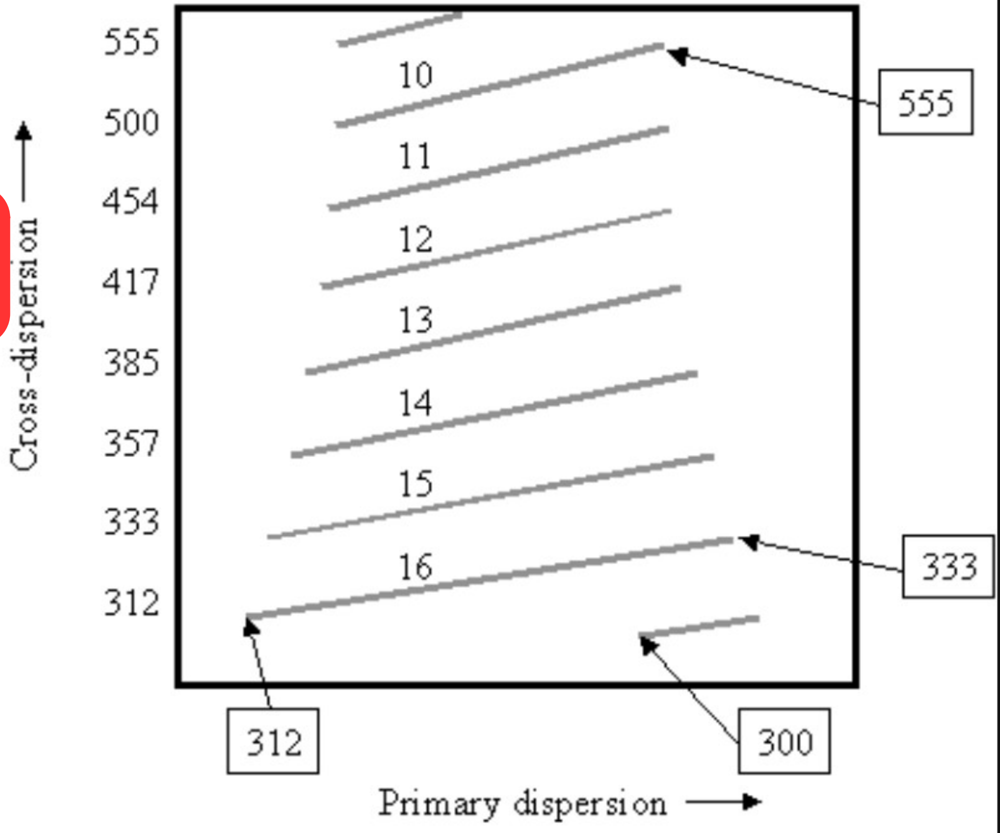


Sbordone 2020, ESO La Silla school, lecture Basics of Spectroscopy.

Orders Define Geometry

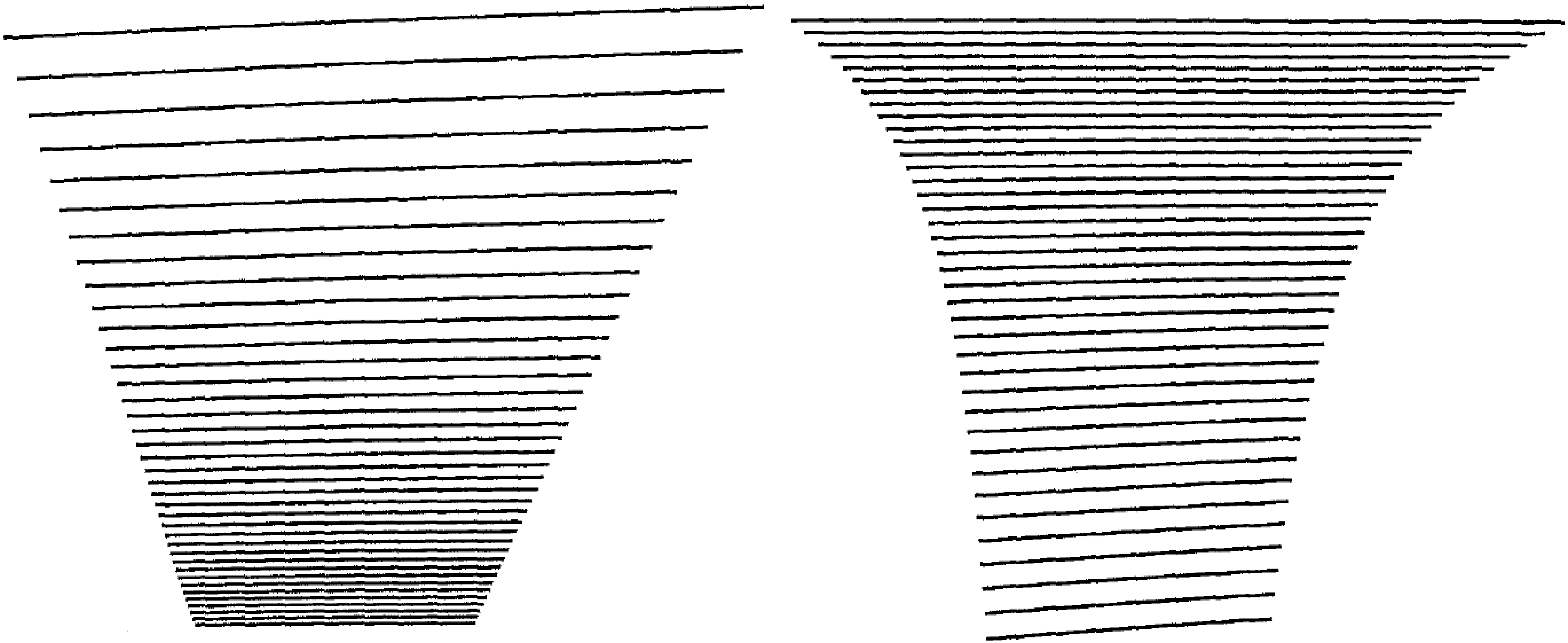
Multiple orders

- Many orders to cover desired $\lambda\lambda$:
  Free spectral range
  $\Delta\lambda = \lambda/m$
- Orders lie on top of each other:
  $\lambda(m) = \lambda(n) \times (n/m)$
- Solution:
  - use narrow passband filter to isolate one order at a time
  - cross-disperse to fill detector with many orders at once



Cross dispersion may use prisms or low dispersion grating

Cross-Disperser Type


(a) Grating cross dispersion

(b) Prism cross dispersion

Barnes 2005 Design study of HERCULES at NZ

Definition of Orders

Appendix A ESPRESSO Spectral Format

Table 7 and Table 8 describe the spectral format recorded by each of the detectors, as provided by the ESPRESSO ETC. For each order number, from left to right, the wavelength of the central column, the free spectral range (FSR) size, the minimum and maximum wavelengths, the order starting and ending wavelengths and size, and the template spectra (TS) range, are given.

When comparing the ETC output with DRS products, be aware that the order numbering is different:

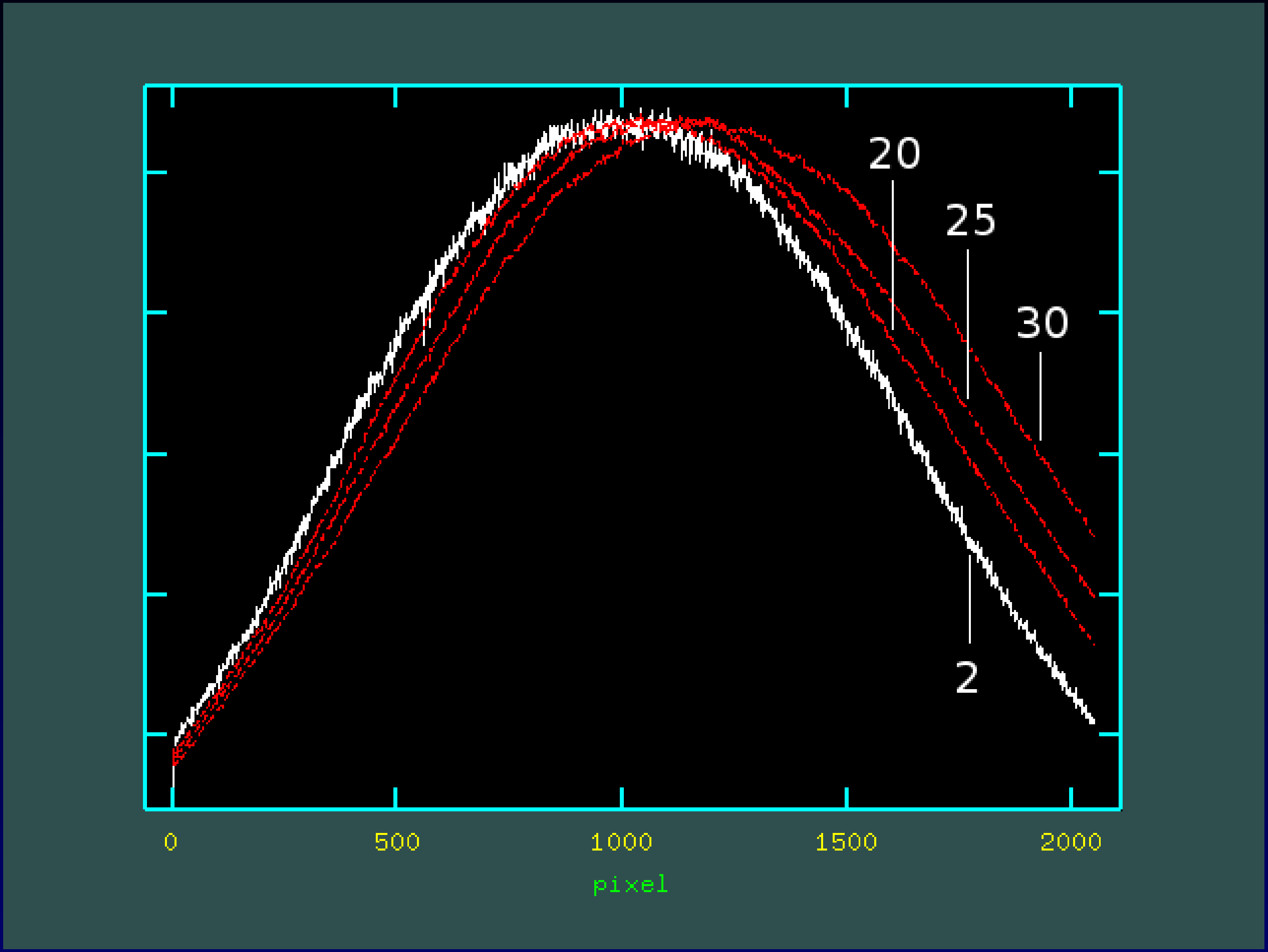
- *interference orders vs numbered orders on the detector*: while ETC numbers the orders using the physical interference orders m, the DRS products have their orders numbered from 1, starting from the bluest one;
- *single orders versus double orders in singleHR and singleUHR*: while the ETC considers interference orders, the DRS products contain the two individual orders imaged on the detector for each of the interference order (see Sect. 3.3 for details). As such, the S/N reported by the ETC corresponds to the quadratic sum of the two orders in the DRS products.

ESPRESSO User manual 2020

Repeating Comp Structures

OES – Miroslav Šlechta

OES Blaze shift



Šlechta

Overlapping Orders

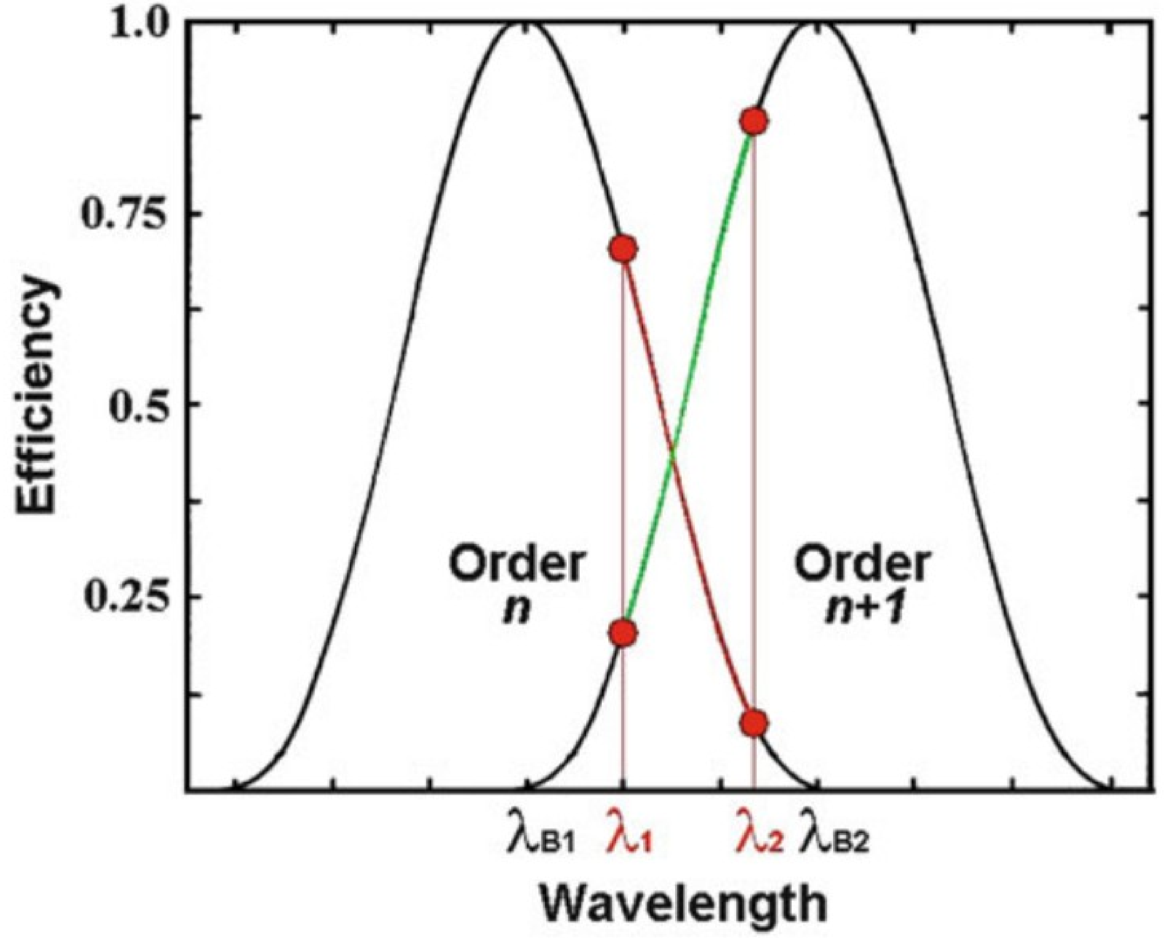
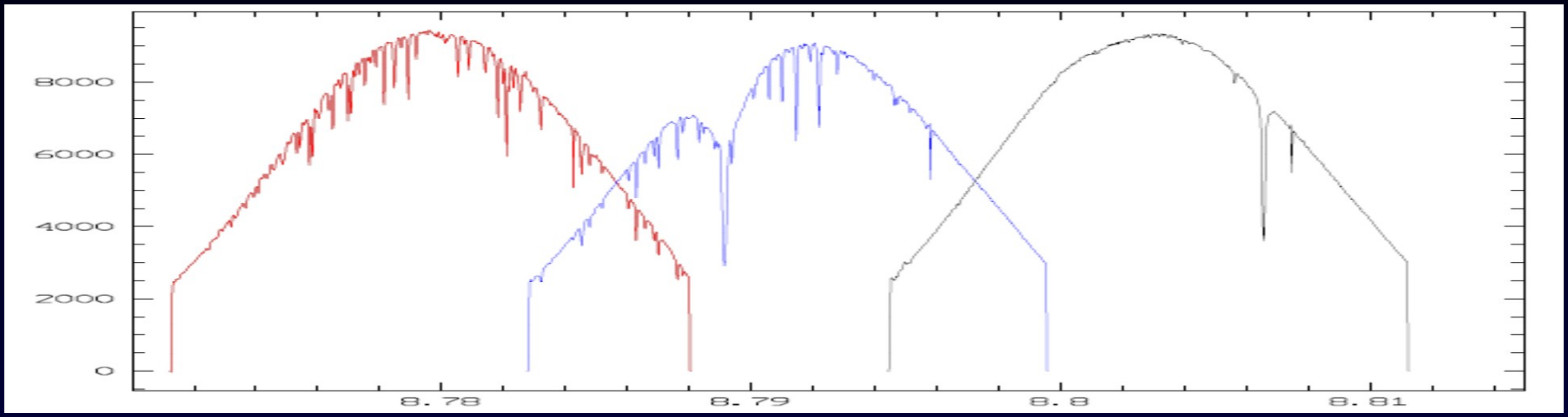
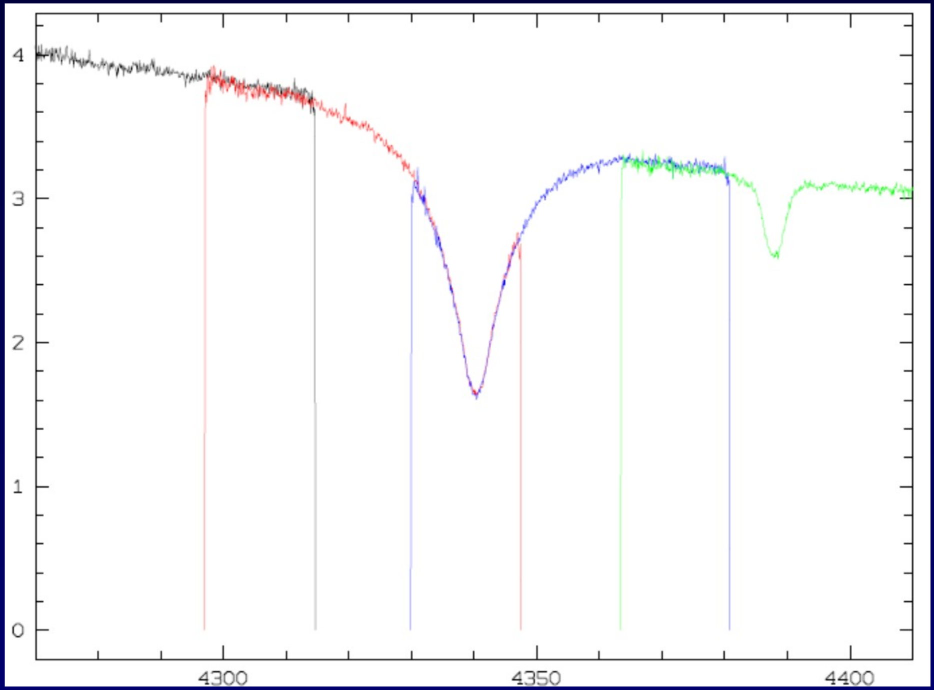


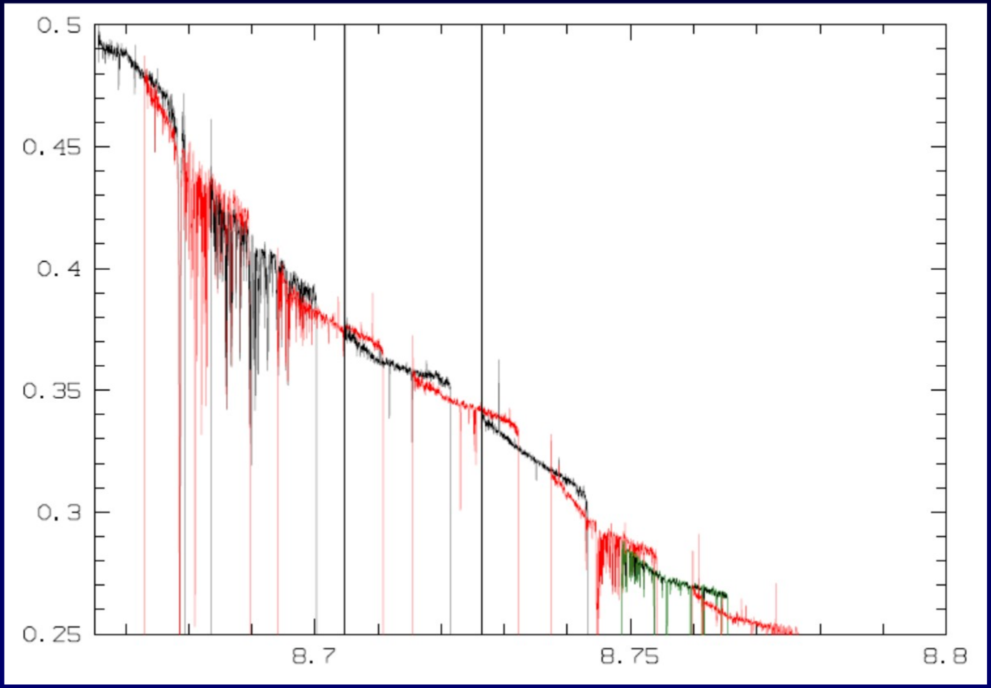
Fig. 5.15 Sketch of the efficiencies in two adjacent orders. Identical wavelength intervals in the orders are indicated in *red* and *green*. Both wavelengths λ_1 and λ_2 are imaged in the two orders n and $n+1$. The two blaze peaks of the orders are positioned at λ_{B_1} and λ_{B_2}

Eversberg, Vollmann. Spectroscopic Instrumentation 2015

Echelle Spectra Problems in Hot Stars







ESO X-Shooter

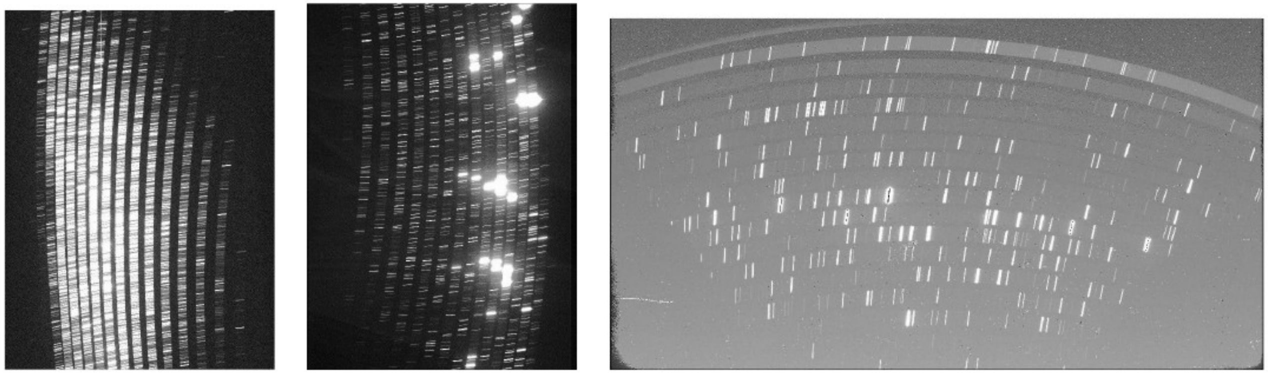
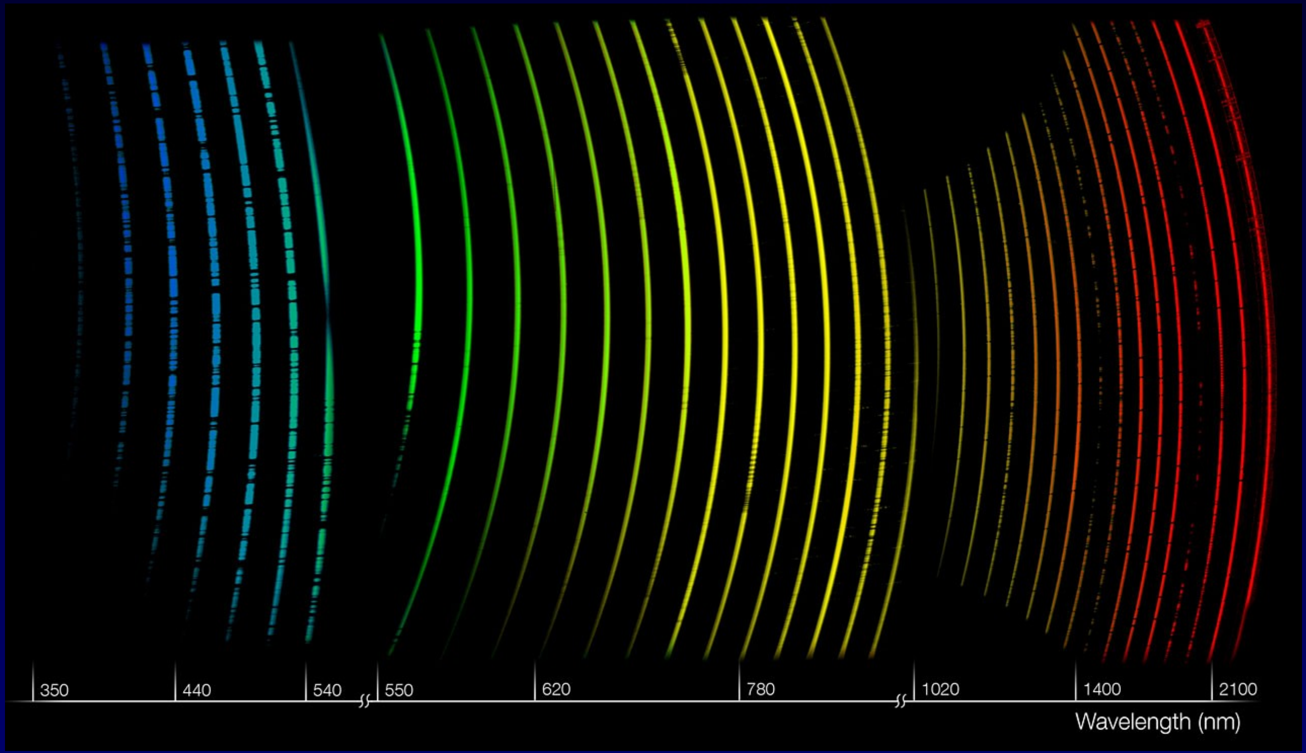
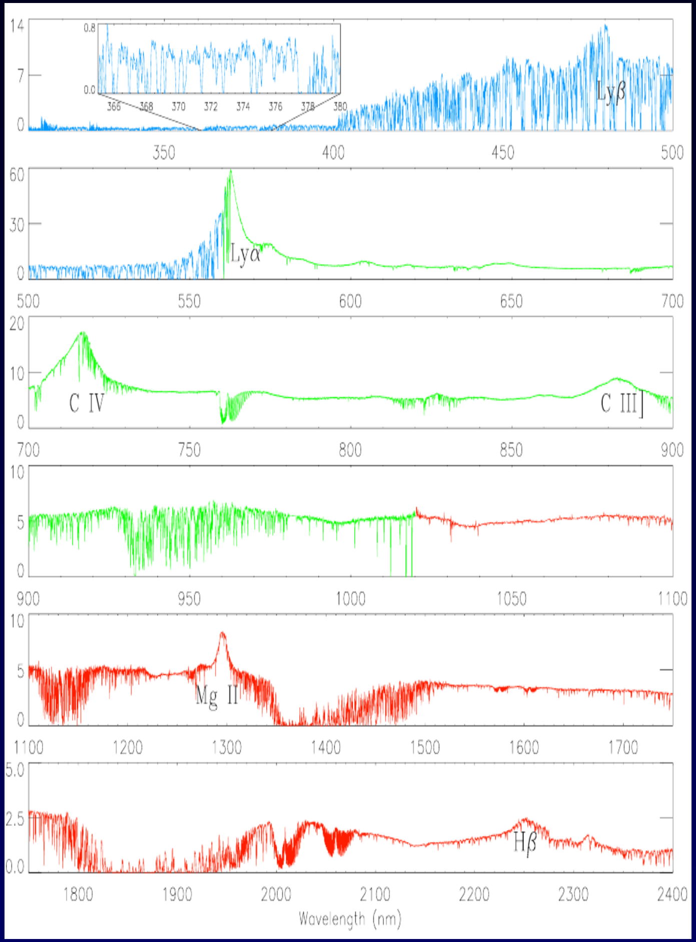


Figure 1. This image displays left to right the XSH UVB, VIS and NIR spectral formats with different image scales.



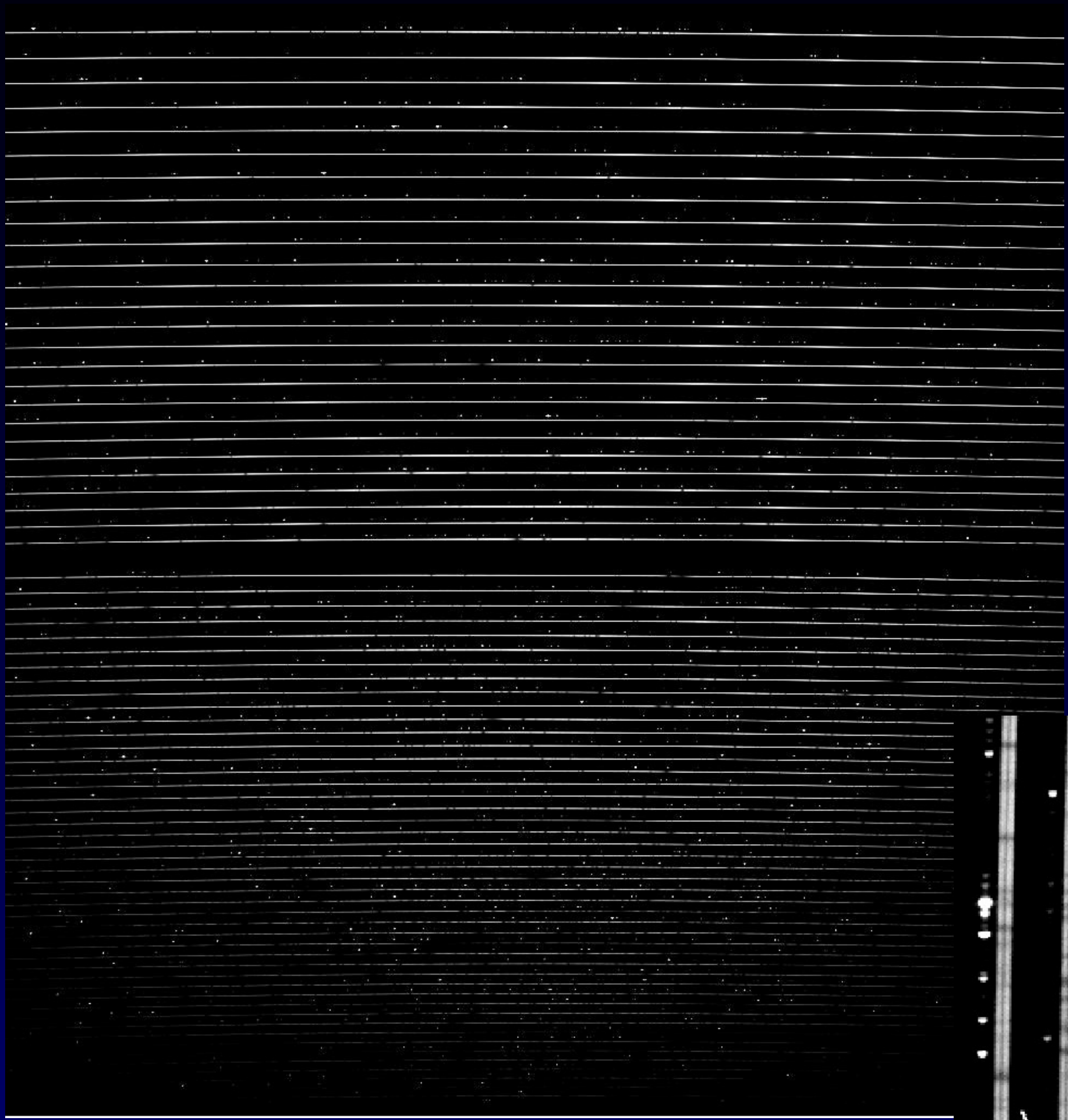
Modigliani et al. 2010

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

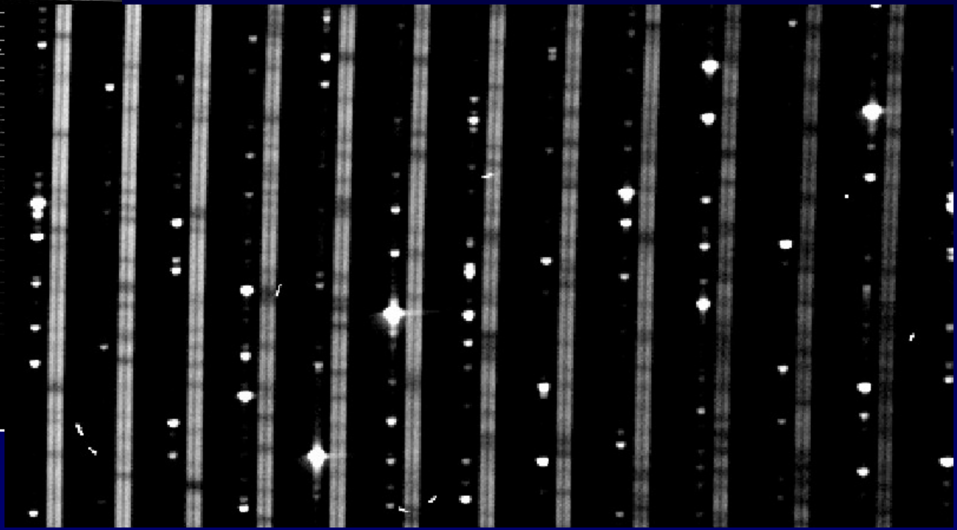
3780-6910 A

R~115000

dRV~3m/s

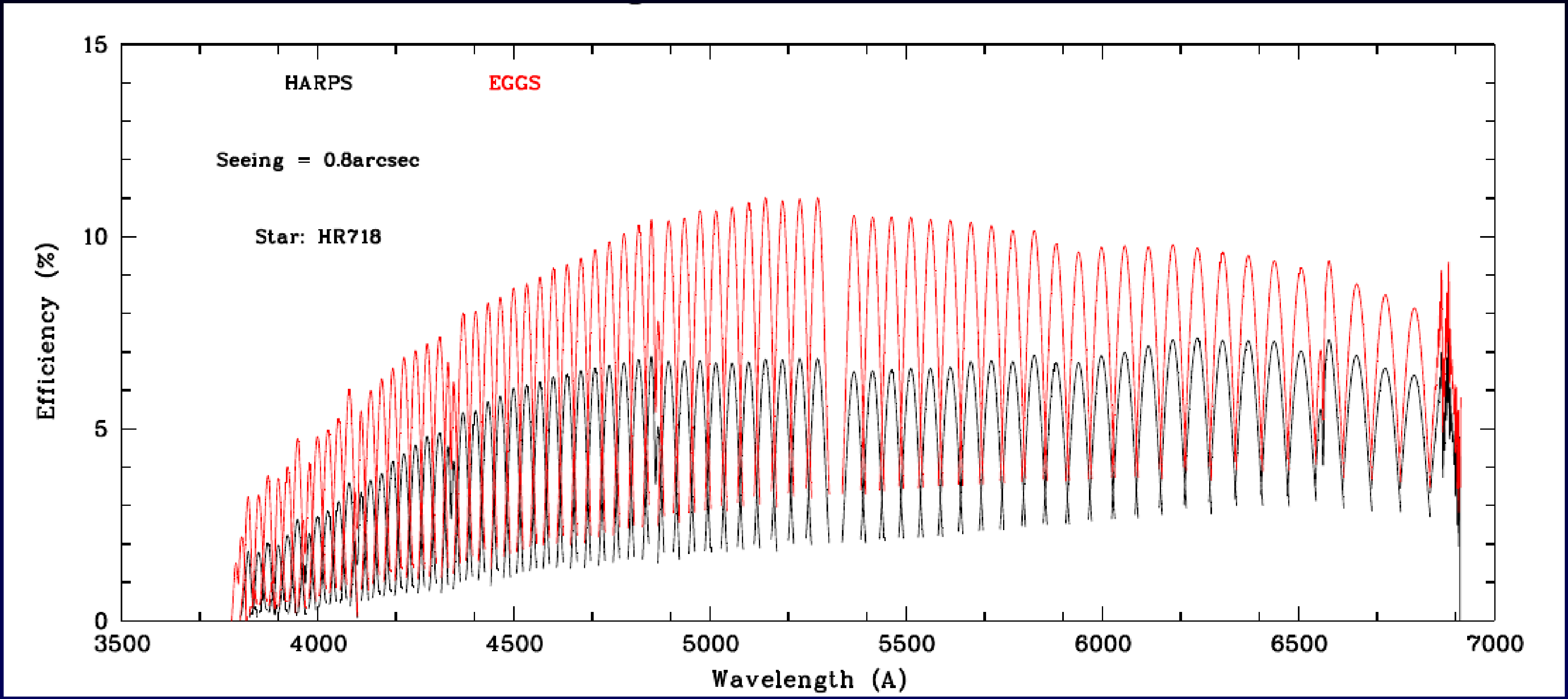
Simultaneus ThAr/Laser comb/Fabry Perot

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



PlatoSpec simcal ThAr

HARPS-S


HARPS
EGGS
Seeing = 0.8arcsec
Star: HR718
15
10
5
0
Efficiency (%)
3500
4000
4500
5000
5500
6000
6500
7000
Wavelength (A)

(Simple) Spectra in VO

Simple Spectra Access Protocol
Spectral Data Model

Simple Spectral Access Protocol V1.04

International
Virtual
Observatory
Alliance

Simple Spectral Access Protocol

Version 1.04
IVOA Recommendation Feb 01, 2008

This version:
http://www.ivoa.net/Documents/REC/DAL/SSA-20080201.html
Latest version:
http://www.ivoa.net/Documents/latest/SSA.html
Previous version(s):
Version 1.03, December 2007
Version 1.02, September 2007
Version 1.01, June 2007
Version 1.00, May 2007
Version 0.97, November 2006
Version 0.96, September 2006
Version 0.95 May 2006
Version 0.91 October 2005
Version 0.90 May 2005
Editors:
D.Tody, M. Dolensky
Authors:
D.Tody, M. Dolensky, J. McDowell, F. Bonnarel, T.Budavari, I.Busko, A. Micol, P.Osuna, J.Salgado, P.Skoda, R.Thompson, F.Valdes, and the data access layer working group.

International
Virtual
Observatory
Alliance

IVOA Spectral Data Model
Version 1.03
IVOA Recommendation 2007-10-29

This version (Recommendation Rev 1)
http://www.ivoa.net/Documents/REC/DM/SpectrumDM-20071029.pdf
Latest version:
http://www.ivoa.net/Documents/latest/SpectrumDM.html
Previous versions:
http://www.ivoa.net/Documents/PR/DM/SpectrumDM-20070913.html

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SSAP Parameters

4.1.1 Mandatory Query Parameters

The following parameters **must** be implemented by a compliant service:

Parameter	*Sample value*	*Physical unit*	*Datatype*
POS	52,-27.8	degrees; defaults to ICRS	string
SIZE	0.05	degrees	double
BAND	2.7E-7/0.13	meters	string
TIME	1998-05-21/1999	ISO 8601 UTC	string
FORMAT	votable	-	string

4.1.2 Recommended and Optional Query Parameters

Parameter	Sample value	Unit	Req	Datatype
APERTURE	0.00028 (=1")	degrees	OPT	double
SPECRP	2000	λ/dλ	REC	double
SPATRES	0.05	degrees	REC	double
TIMERES	31536000 (=1yr)	seconds	OPT	double
SNR	5.0	dimensionless	OPT	double
REDSHIFT	1.3/3.0	dimensionless	OPT	string
VARAMPL	0.77	dimensionless	OPT	string
TARGETNAME	mars		OPT	string
TARGETCLASS	star		OPT	string
FLUXCALIB	relative		OPT	string
WAVECALIB	absolute		OPT	string
PUBDID	ADS/col#R5983		REC	string
CREATORDID	ivo://auth/col#R1234		REC	string
COLLECTION	SDSS-DR5		REC	string
TOP	20	dimensionless	REC	int
MAXREC	5000		REC	string
MTIME	2005-01-01/2006-01-01	ISO 8601	REC	string
COMPRESS	true		REC	boolean
RUNID			REC	string

The spatial, spectral, and time resolution of the data may all be used as query constraints

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)

Spectra - query output and previews

CCD700 Spectra Web Interface

Help

Service info

Related

CCD700 SSAP

Metadata

Identifier

ivo://asu.cas.cz/ccd700/q/

Description

CCD700 public web interfa

Keywords

Optical spectroscopy

Creator

[Logo]

Created

2014-05-09T10:57:00

Data updated

2016-06-14

Reference URL

Service info

Try ADQL to query our data.

Please report errors and problems to the site operators. Thanks.

Privacy | Disclaimer

Log in

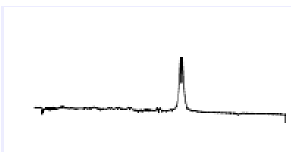
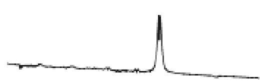
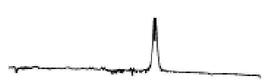
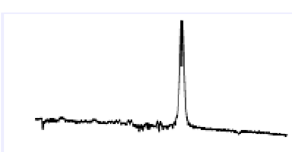
Parameters

- Object standard name: ['psiper']

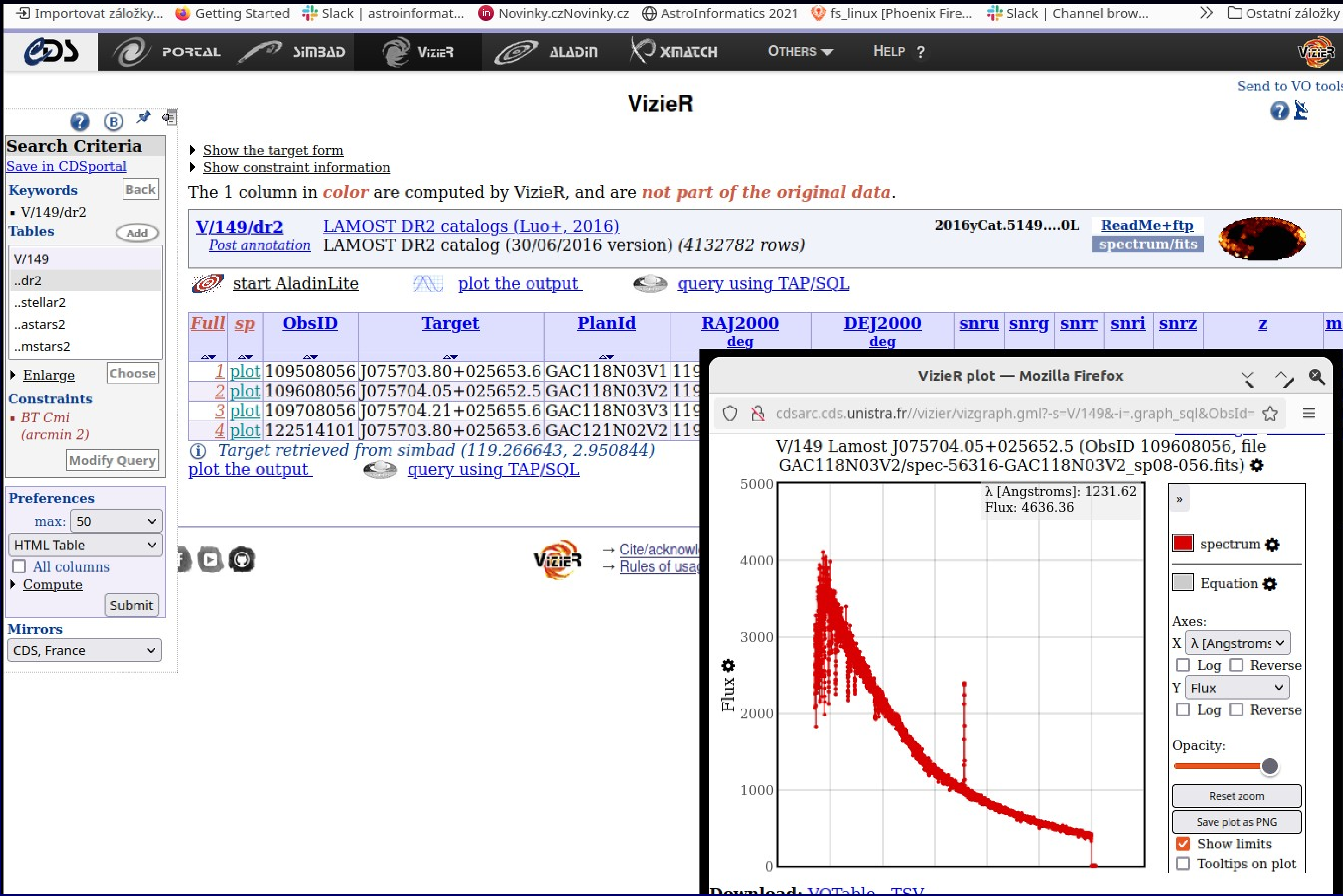
Result

Matched: 44

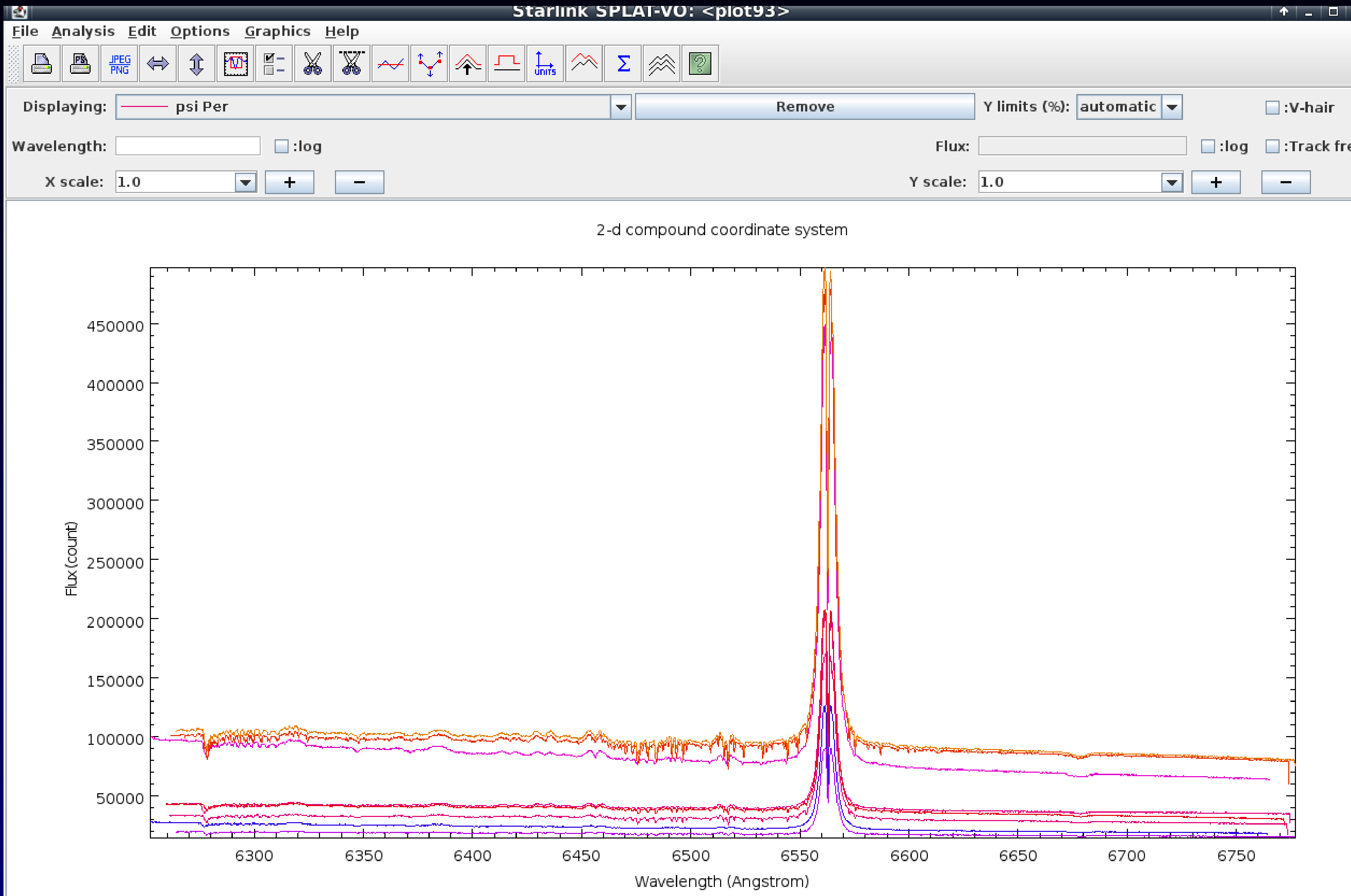
Send via SAMP | Quick Plot

Product key	Object	Raj2000	Dej2000	Band start [Angstrom]	Band end [Angstrom]	Date Obs.	Observer	Exp. Time [s]	MHJD
tg180048.fit	psi Per	03:36:29.380	+48:11:33.40	6261.00	6773.40	2010-07-19T01:43:36Z		150.0	55396.0696765
 oc220022.fit	psi Per	3:37:01.1	48:12:17.1	6262.34	6774.66	2005-03-22T21:16:04Z	Kubat, Sarounova	899.564	53451.8889388
 ul070006.fit	Psi Per	03:36:29.380	+48:11:33.40	6252.67	6764.96	2011-12-07T20:21:43Z	Kraus, Kotkova	800.0	55902.8579726
va300019.fit	psi Per	03:36:29.380	+48:11:33.40	6252.09	6764.42	2012-01-30T17:13:10Z		130.0	55956.7202446
mi180074.fit	psi Per	3:37:03.2	48:10:44.2	6259.63	6772.03	2003-09-19T02:34:39Z		60.0	52901.1096669
ng290040.fit	Psi Per	3:36:46.8	48:11:39.4	6261.83	6774.26	2004-07-30T00:40:28Z	Kubat, Kalas	600.0	53216.0292701
 nh100015.fit	psi Per	3:36:42.4	48:13:02.0	6264.34	6776.77	2004-08-11T01:02:47Z	Stefl + Rezna	218.373	53228.0435205
 nh310030.fit	Psi Per	3:36:46.3	48:13:02.4	6264.01	6776.40	2004-09-01T00:22:31Z	Libich, Sarounova	60.0	53249.016454

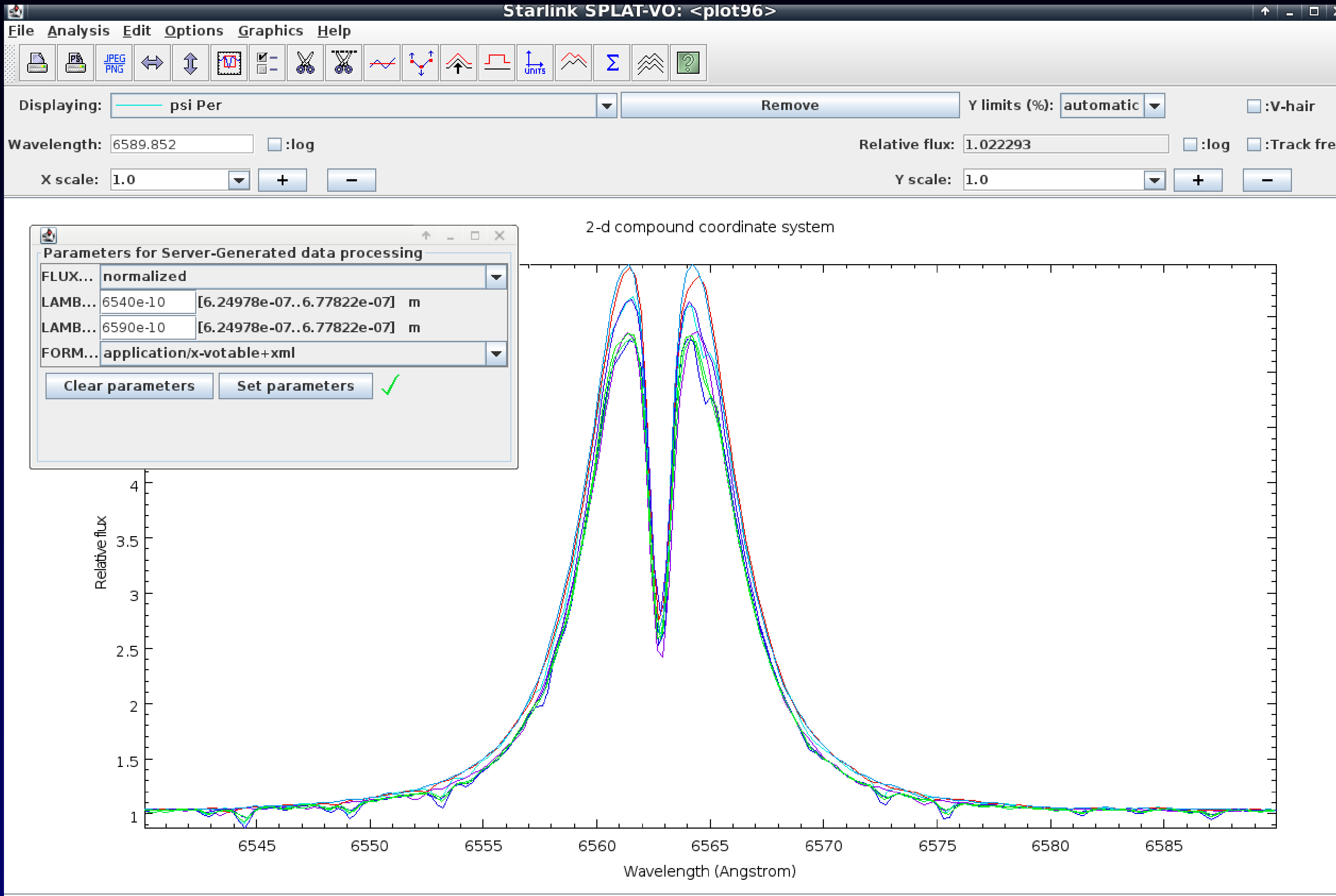
Spectra in Vizier (VO)



Spectra in SPLAT-VO direct access

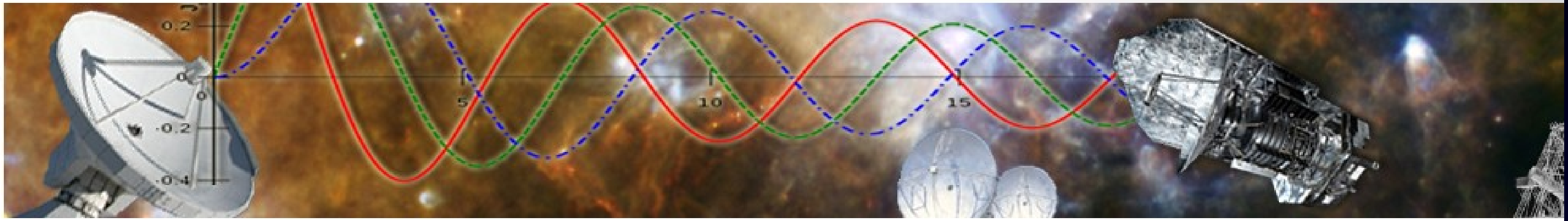


Spectra in SPLAT-VO - DataLink



CASSIS

CASSIS
A free interactive spectrum analyser



CASSIS
- Presentation
- Download & Installation
- CASSIS Online
- Documentation & Data

- What's new?
- FAQ
- Caveats and tricks
- Cassis in Hipe
- Bugs report

- Publications and Talks
- Credits
- Authors
- Catalogs
- License
- Links
- Help Online

The current version of CASSIS is 6.3, released October 10, 2022

- Project Scientists
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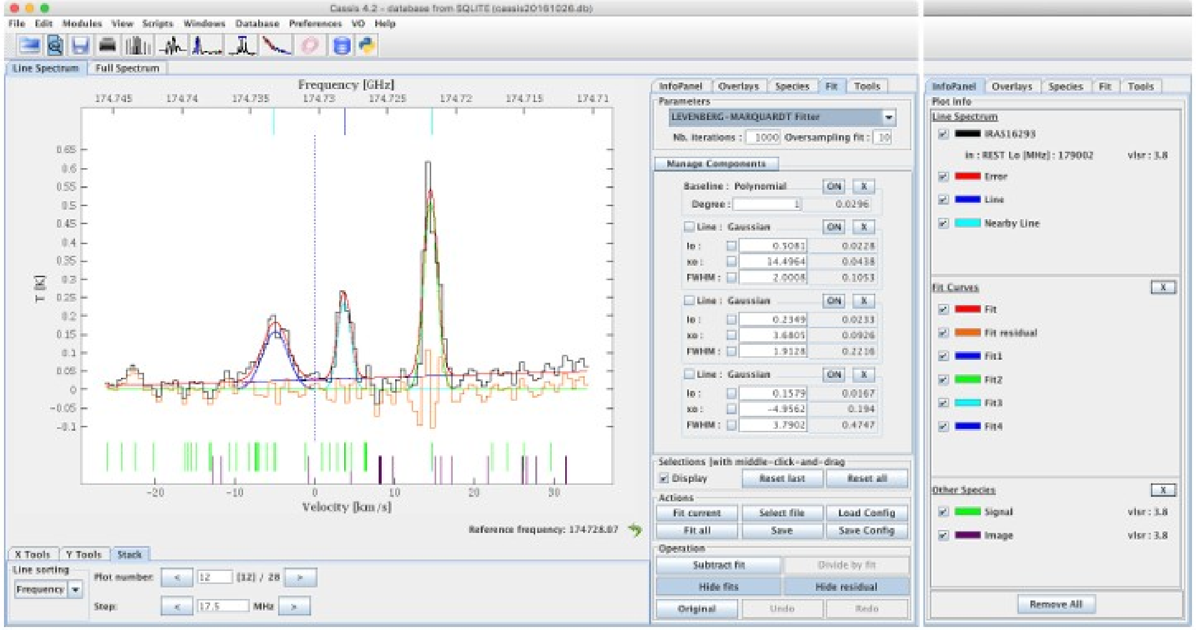
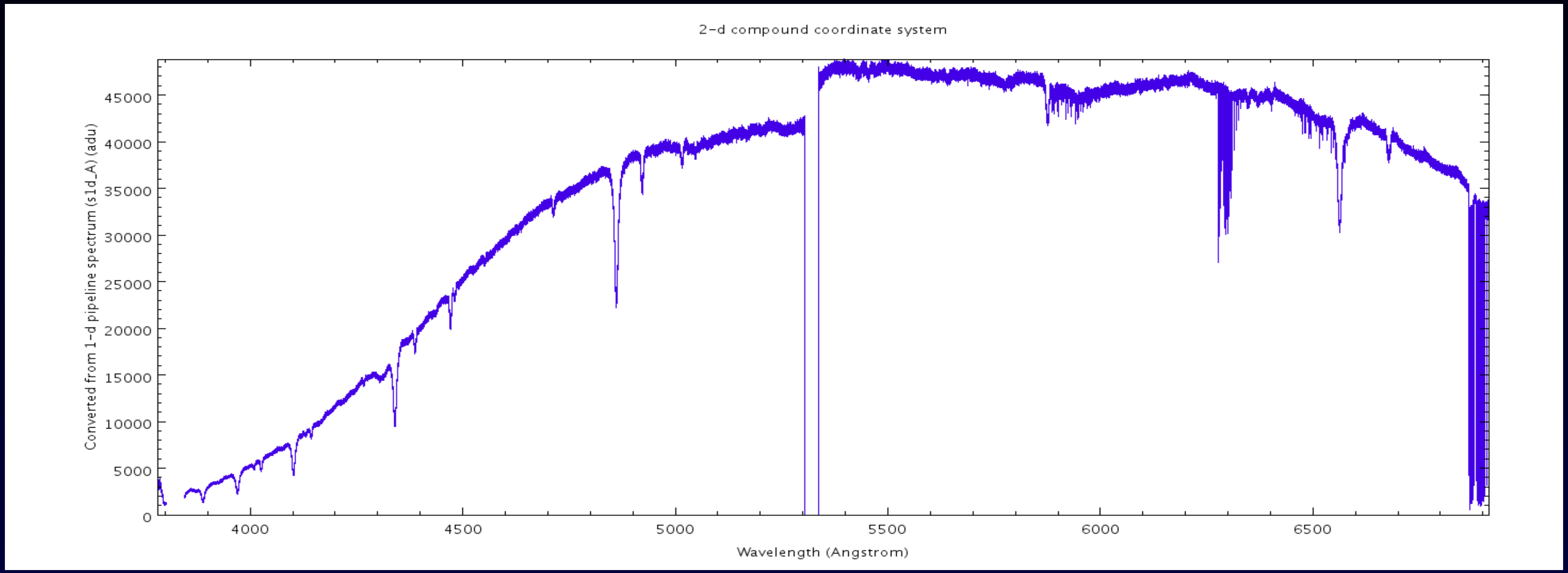
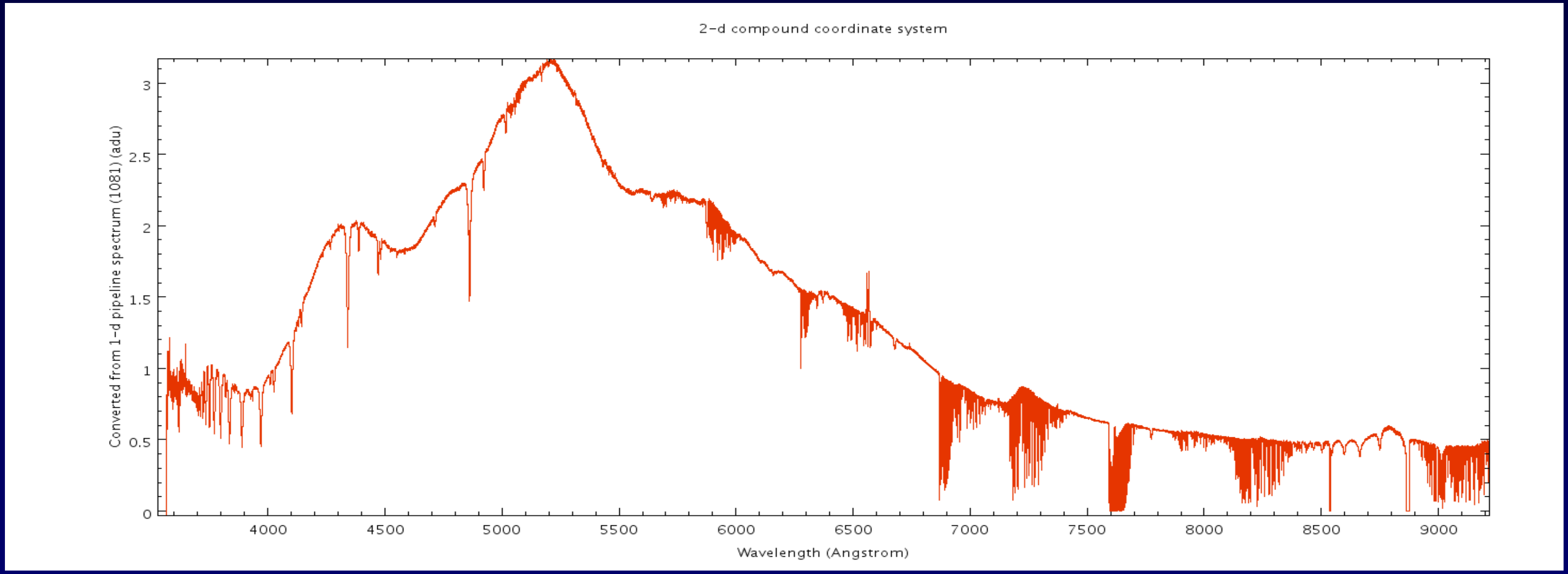
  - Emmanuel Caux (PI): Emmanuel.Caux{at}irap.omp.eu
  - Audrey Coutens: Audrey.Coutens{at}irap.omp.eu
  - Charlotte Vastel: Charlotte.Vastel{at}irap.omp.eu
- Project Manager
  - Jean-Michel Glorian : Jean-Michel.Glorian{at}irap.omp.eu
- Developer
  - Mickaël Boiziot : Mickael.Boiziot{at}irap.omp.eu



1D Merges in SPLAT-VO

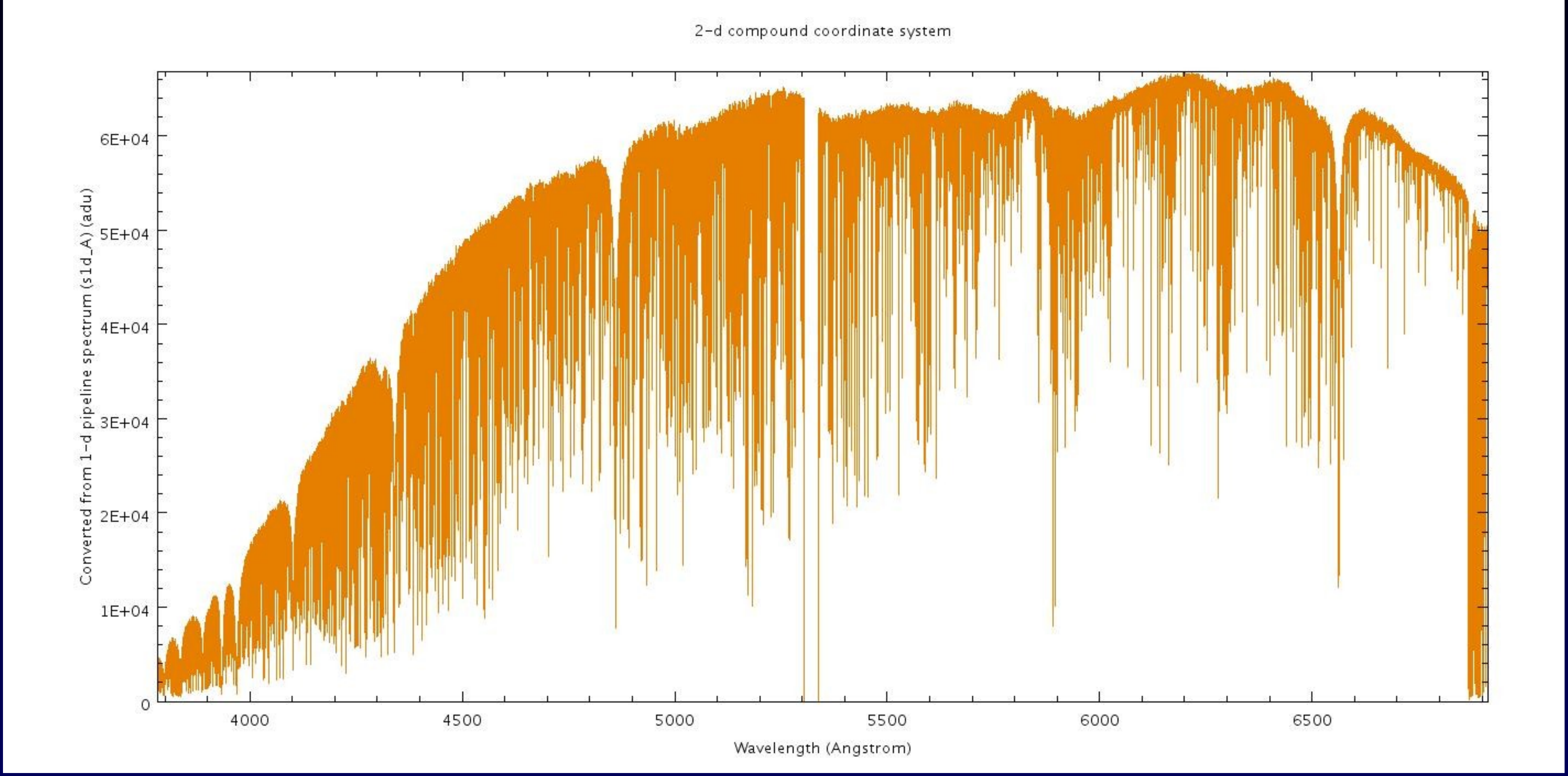


HARPS
unblazed



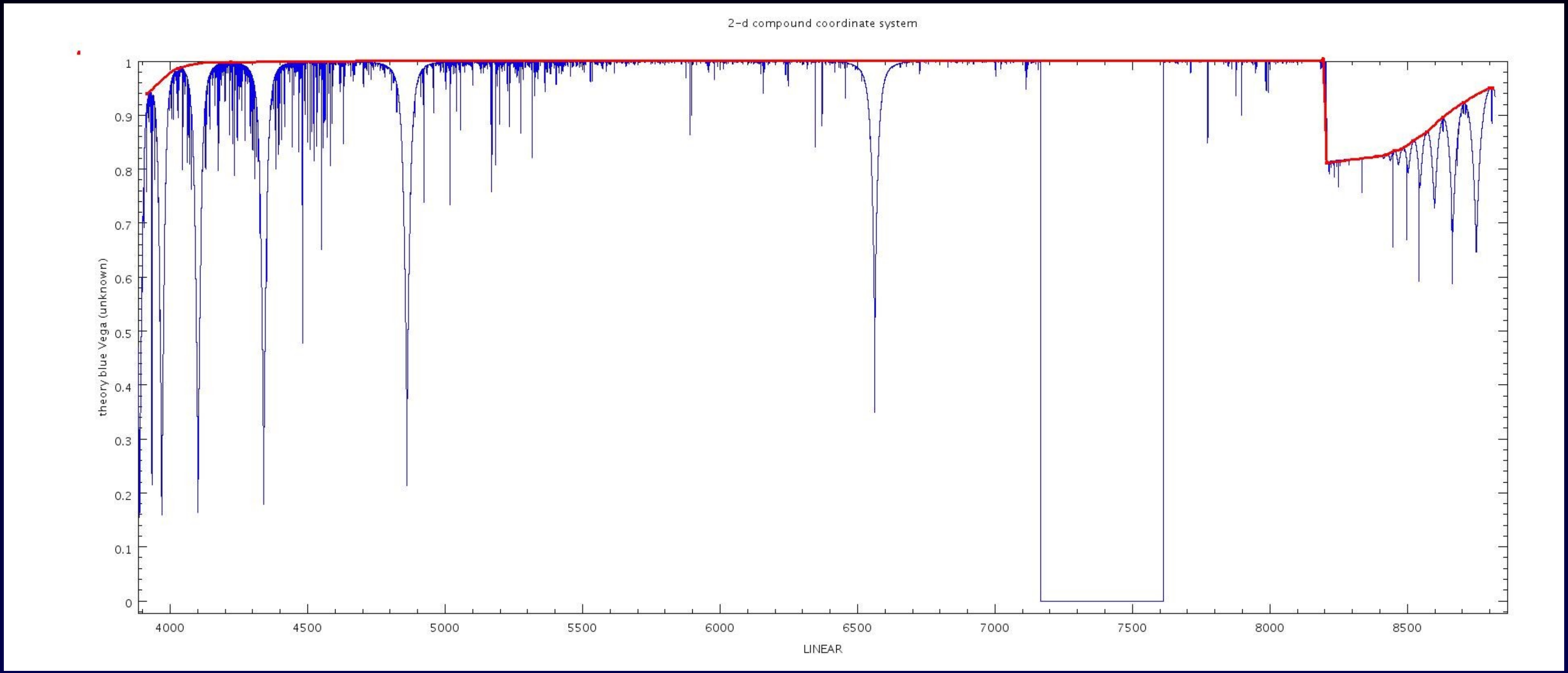
FEROS
pseudonormalized

HARPS-S in SPLAT



313138 points Procyon

Continuum Normalisation



Theoretical spectrum of Vega

The continuum is NOT ALWAYS at 1.0 !

If 1D Order Merging is Applied

- Resampling to common lambda grid (flux)
  Introduces always pixel correlations !!!
- Loosing lambda precision (1/3 pixels missing)
- Resampling to log lambda better (RV)
- High noise at the edges (must cut off)
- Unblazing by 1D flat or 2D flat – not ideal
- Undulating structures
- If corrected – wobbles on continuum
- Science precision is preferred (vs. visual)

Why Not Use 1D Order-Merged Spectra

ESO	ESPRESSO Pipeline User Manual	Doc:	ESO-331895
		Issue:	Issue 3.0.0
		Date:	Date 2023-01-31
		Page:	67 of 73

Error propagation for S2D spectra is relatively straightforward since there is no resampling step in the process. Extracted pixels remain independent of each other.

S1D Spectra

The resampling process that is necessary to generate S1D spectra from S2D spectra inevitably introduces correlations between adjacent rebinned pixels in the S1D spectra. To calculate the errors on the S1D spectra one propagates errors in the usual way to the S1D

We note however that the existence of correlations makes the use of the S1D spectrum non-trivial for science purposes

In general, the use of the S2D spectrum is recommended whenever possible to avoid correlations between adjacent data points, which are unavoidable as soon as some resampling is performed.

The most important novelty of the code is the fact that non-rebinned reduced data are propagated throughout the analysis process alongside the standard rebinned spectrum obtained from coaddition. Tests on simulated absorption lines show that the results of line fitting performed on an ensemble of rebinned spectra do not follow a chi-squared distribution (Cupani et al., in prep). In fact, errors in the rebinned spectra are correlated across pixels and the degrees of freedom are ill-defined due to degeneration among the line parameters. The problem is avoided when using non-rebinned spectra; this is the only safe condition in which a chi-squared best-fitting test can be applied, and it will be first made available for quasar spectral analysis by the ESPRESSO DAS.

Cupani et al. 2016

Echelle Spectra Formats

- MANY
- Each order is one spectrum (BeSS)   - not seen easily
- Each order SEPARATED – different WCS + overlaps
- Tables CSV (Opera), FITS Binary tables
- 6-10 FITS extensions (CERES package)

IRAF *.ec files

Figure 4: Echelle Spectrum with Legendre Polynomial Function

```
WAT0_001= 'system=multispec'
WAT1_001= 'wtype=multispec label=Wavelength units=Angstroms'
WAT2_001= 'wtype=multispec spec1 = "1 113 2 4955.442888635351 0.05...
WAT2_002= '83 256 0. 23.22 31.27 1. 0. 2 4 1. 256. 4963.0163112090...
WAT2_003= '976664 -0.3191636898579552 -0.8169352858733255" spec2 =...
WAT2_004= '9.081188912082 0.06387049476832223 256 0. 46.09 58.44 1...
WAT2_005= '56. 5007.401409453303 8.555959076467951 -0.176732458267...
WAT2_006= '09935064388" spec3 = "3 111 2 5043.505764869474 0.07097...
WAT2_007= '256 0. 69.28 77.89 1. 0. 2 4 1. 256. 5052.586239197408 ...
WAT2_008= '271 -0.03173489817897474 -7.190562320405975E-4"
WCSDIM  =                    2
CTYPE1  = 'MULTISPE'
LTM1_1  =                   1.
CD1_1   =                   1.
CTYPE2  = 'MULTISPE'
LTM2_2  =                   1.
CD2_2   =                   1.
```

5.6 Pixel Array Dispersion Function

The parameters for the pixel array dispersion function consists of just the number of coordinates ncoords. Following this are the wavelengths at integer physical pixel coordinates starting with 1.

To evaluate a wavelength at some physical coordinate, not necessarily an integer, a linear interpolation is used between the nearest integer physical coordinates and the desired physical coordinate

Valdes 1988 , part of IRAF help, docs, specwcs.ps.Z
summary in ADASS 1993

IRAF splot

splot -- plot and analyze spectra

USAGE

splot images [line [band]]

PARAMETERS

images

List of images (spectra) to plot. If the image is 2D or 3D the line and band parameters are used. Successive images are plotted following each 'q' cursor command.

line, band

The image line/aperture and band to plot in two or three dimensional images. For multiaperture spectra the aperture specified by the line parameter is first sought and if not found the specified image line is selected. For other two dimensional images, such as long slit spectra, the line parameter specifies a line or column. Note that if the line and band parameters are specified on the command line it will not be possible to change them interactively.

IRAF splot

(

In multiaperture spectra go to the spectrum in the preceding image line. If there is only one line go to the spectrum in the preceding band.

)

In multiaperture spectra go to the spectrum in the following image line. If there is only one line go to the spectrum in the following band.

#

Get a different line in multiaperture spectra or two dimensional images. The aperture/line/column is queried.

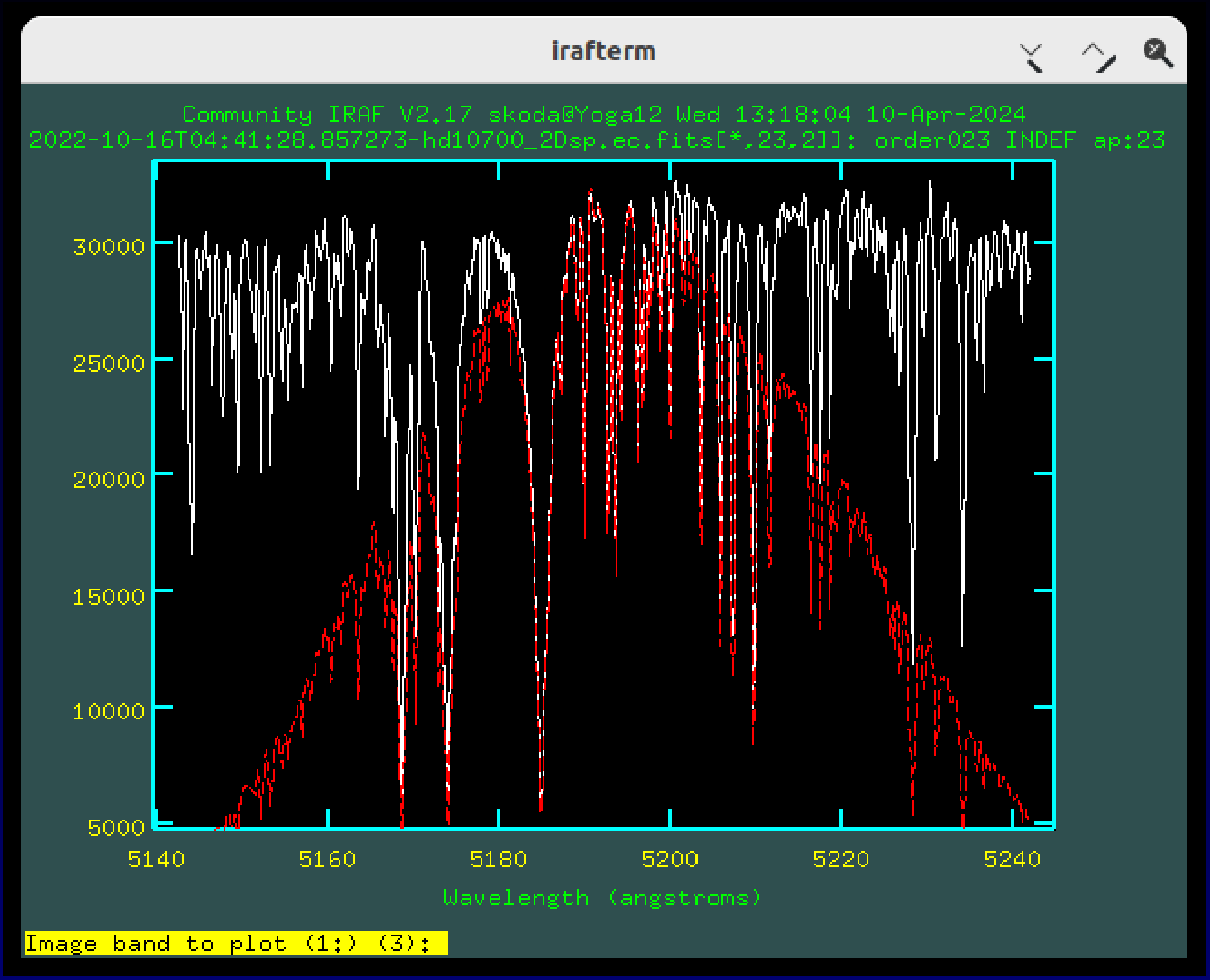
%

Get a different band in a three dimensional image.

$

Switch between physical pixel coordinates and world (dispersion) coordinates.

PUCHEROS+ in IRAF



Pucheros/PlatoSpec Pipeline
CERES+ : Upgrade of CERES 2017

Publications of the Astronomical Society of the Pacific, 129:034002 (18pp), 2017 March
https://doi.org/10.1088/1538-3873/aa5455

CrossMark

CERES: A Set of Automated Routines for Echelle Spectra

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Abstract

We present the Collection of Elemental Routines for Echelle Spectra (CERES). These routines were developed for the construction of automated pipelines for the reduction, extraction, and analysis of spectra acquired with different instruments, allowing the obtention of homogeneous and standardized results. This modular code includes tools for handling the different steps of the processing: CCD image reductions; identification and tracing of the echelle orders; optimal and rectangular extraction; computation of the wavelength solution; estimation of radial velocities; and rough and fast estimation of the atmospheric parameters. Currently, CERES has been used to develop automated pipelines for 13 different spectrographs, namely CORALIE, FEROS, HARPS, ESPaDOnS, FIES, PUCHEROS, FIDEOS, CAFE, DuPont/Echelle, *Magellan*/Mike, Keck/HIRES, *Magellan*/PFS, and APO/ARCES, but the routines can be easily used to deal with data coming from other spectrographs. We show the high precision in radial velocity that CERES achieves for some of these instruments, and we briefly summarize some results that have already been obtained using the CERES pipelines.

CERES output

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rabrahm Update README.md · 72a95b2 · 9 months ago · 196 Commits

About

A set of pipelines and routines for echelle spectrographs

direction. The ten entries in the first dimension correspond to:

```
0-  Wavelength
1-  Extracted Flux
2-  Measurement of the error in the extracted flux [1./sqrt(Var)]
3-  Blaze corrected Flux
4-  Measurement of the error in the blaze corrected flux
5-  Continuum normalized flux
6-  Measurement of the error in the continuum normalized flux
7-  Estimated continuum
8-  Signal-to-noise ratio
9-  Continumm normalized flux multiplied by the derivative of the wavelengtl
10- Corresponding error of the 9th entrance
```

Not in CERES+

CERES+ 2D Format

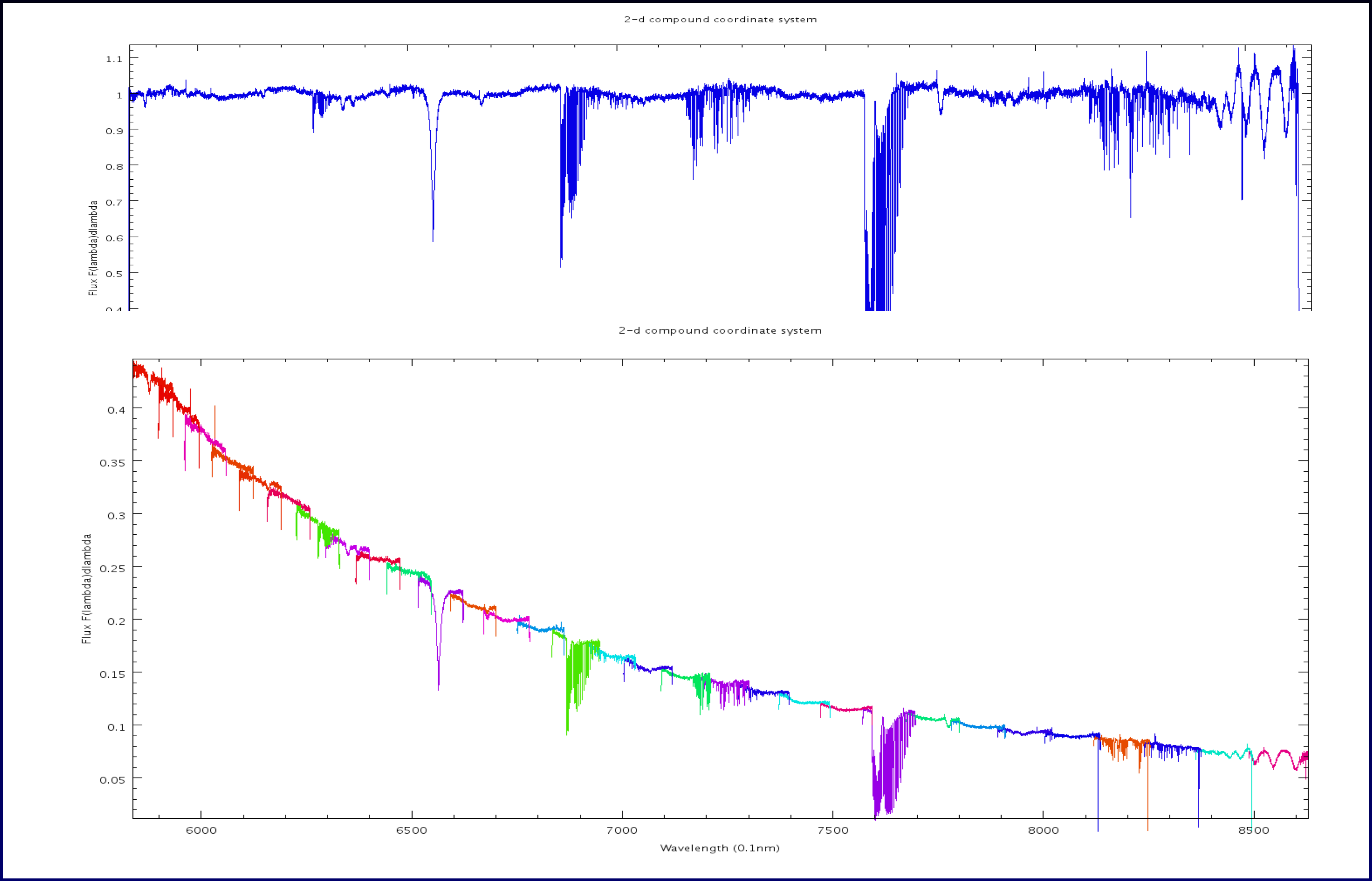
```
hdu.info()
```

```
Filename: 2024-03-05T03:05:48.137129-zet_Pup_2Dsp.fits
No.    Name      Ver    Type      Cards   Dimensions   Format
  0  PRIMARY       1 PrimaryHDU     125   (1024, 45)   float64
  1  FLUX          1 ImageHDU         8   (1024, 45)   float64
  2  FLUX_E        1 ImageHDU         8   (1024, 45)   float64
  3  DFLUX         1 ImageHDU         8   (1024, 45)   float64
  4  DFLUX_E       1 ImageHDU         8   (1024, 45)   float64
  5  NFLUX         1 ImageHDU         8   (1024, 45)   float64
  6  NFLUX_E       1 ImageHDU         8   (1024, 45)   float64
```

Those extensions contain

0. *wavelength* in PRIMARY
1. *raw extracted flux* in FLUX
2. *Error of the flux* in FLUX_E = $\frac{1}{\sqrt{(variance(FLUX))}}$
3. *Deblazed flux (extracted stellar flux divided by extracted flat)* in DFLUX
4. *Error of the deblazed flux* in DFLUX_E
5. *Normalized flux (deblazed flux fitted by small order polynomial to get contiuum normalization* in NFLUX
6. *Error of the normalized flux* in NFLUX_E

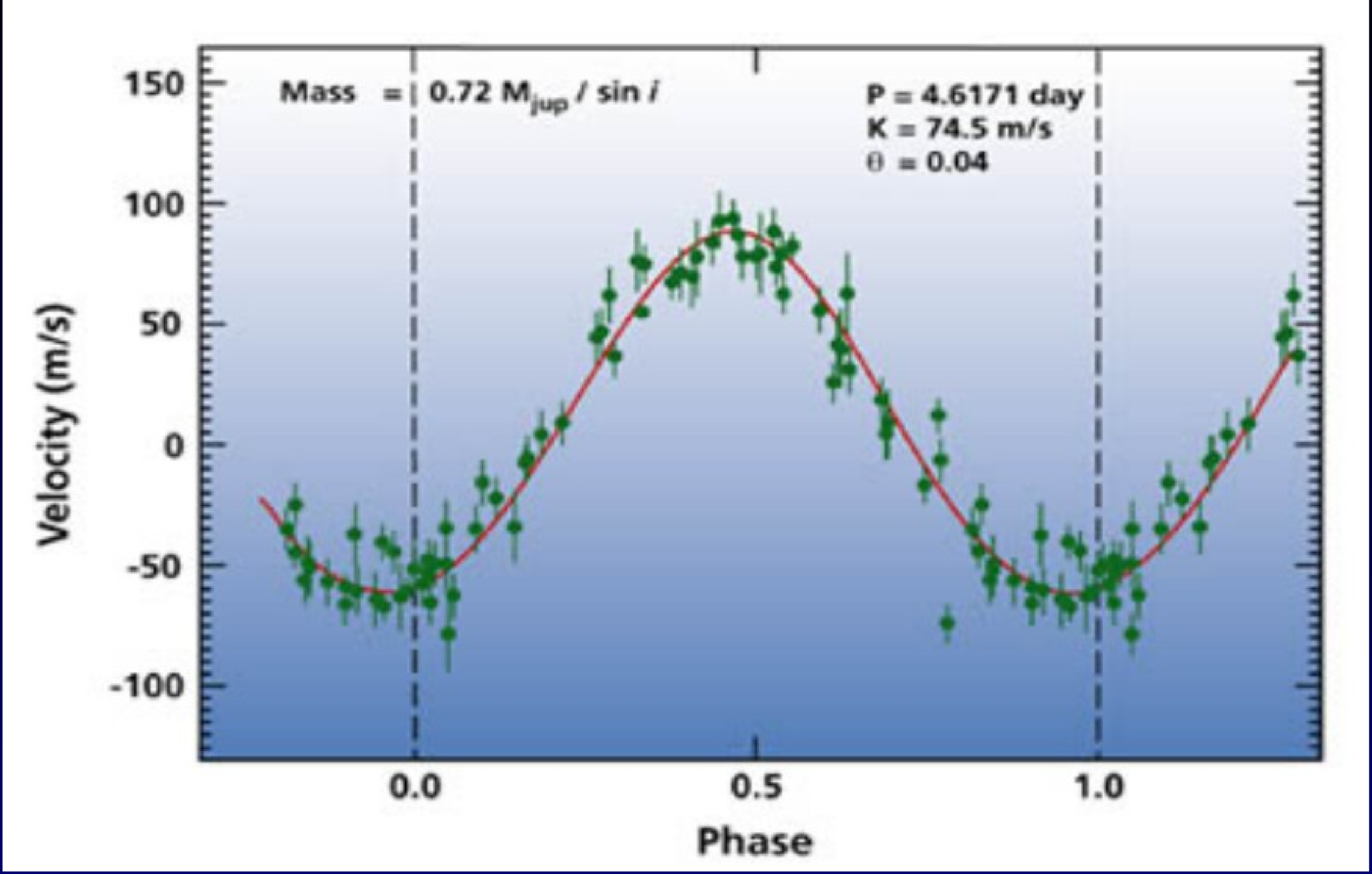
DaCHS Testbed Split-Order SSAP



nu Pup HEROS red

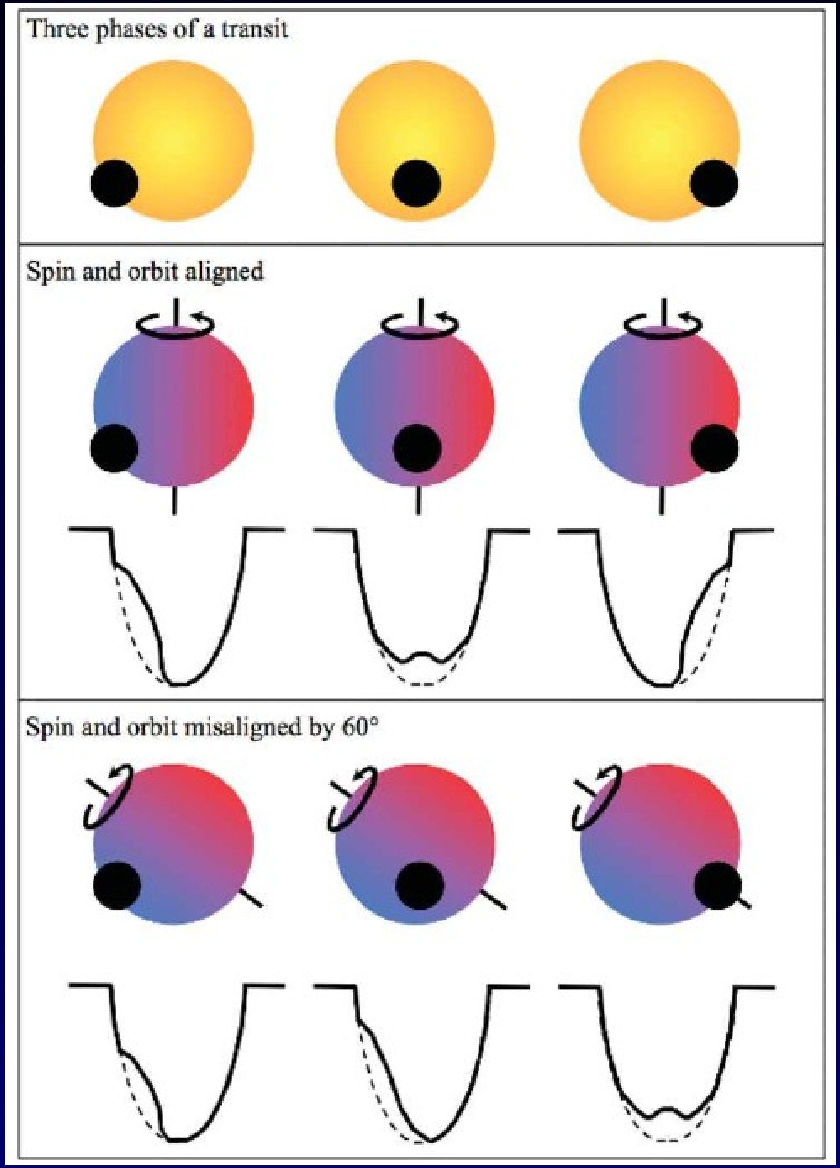
Products derived from spectra

Radial Velocity Curve



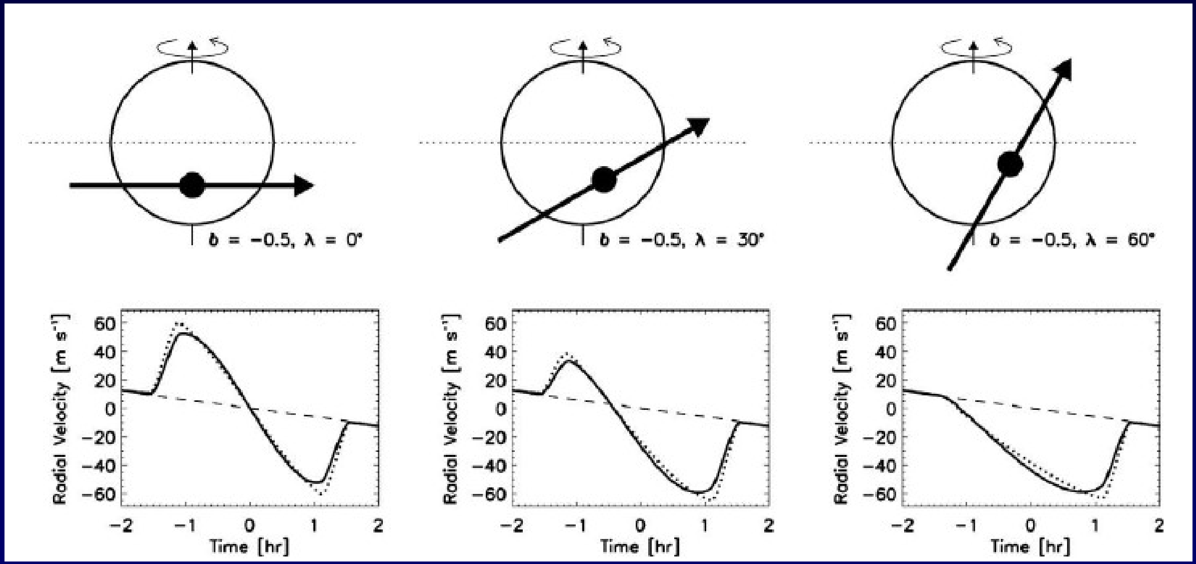
51 Peg b, Mayer and Queloz 1995

Rossiter-McLaughlin effect



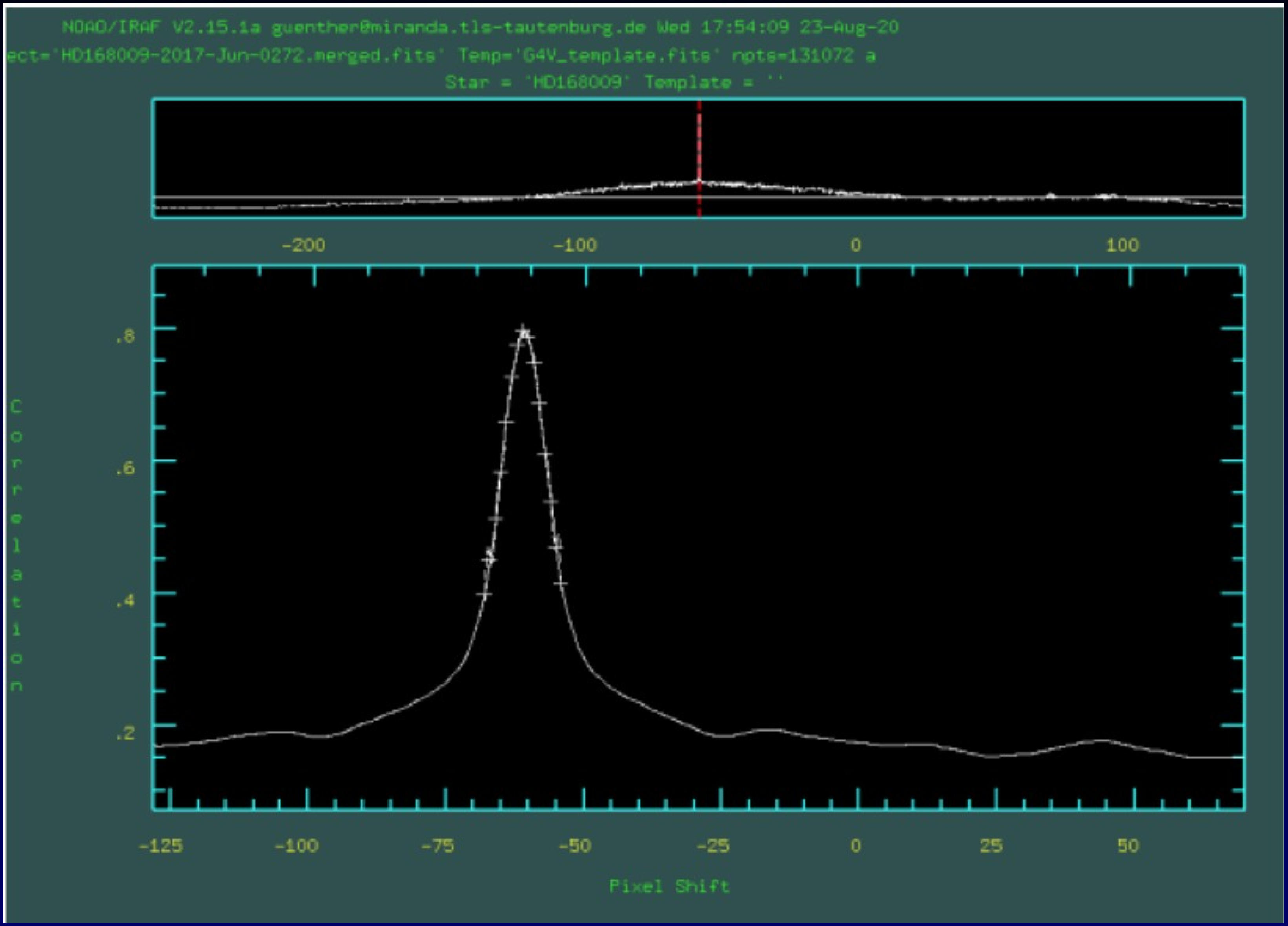
RV Curve – time series of RV

Only for direct occultation



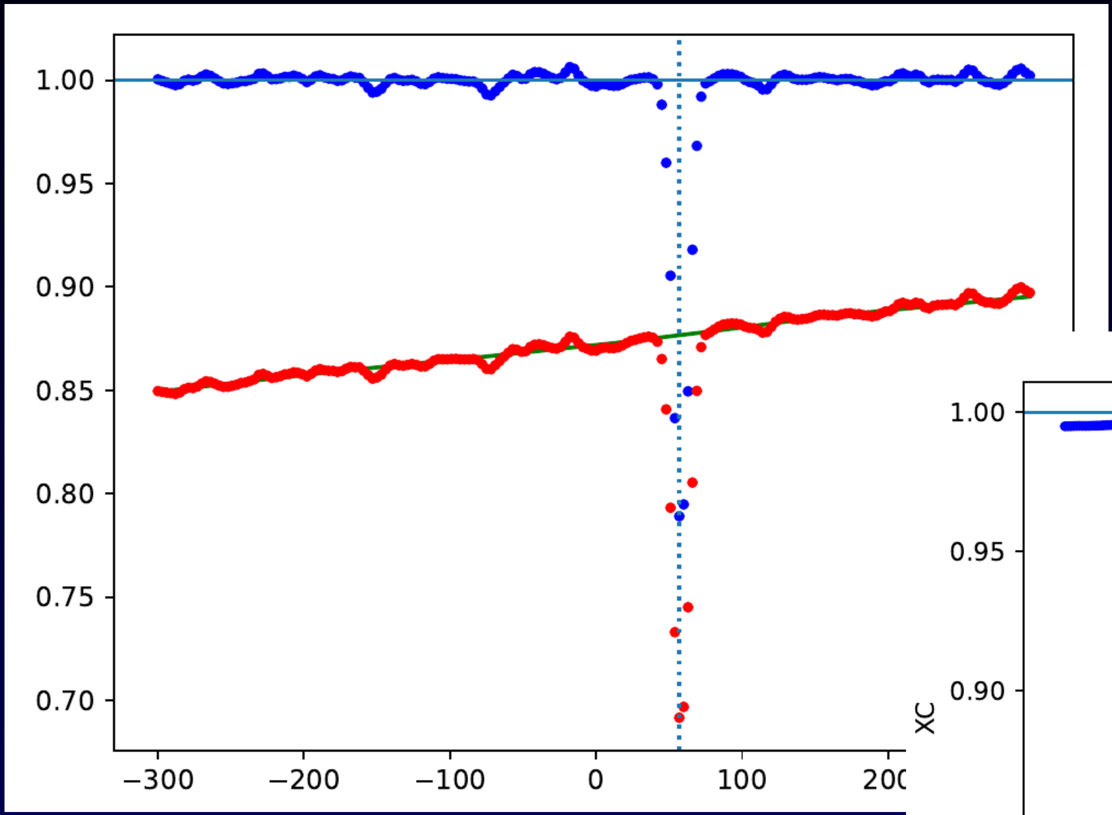
Winn 2010

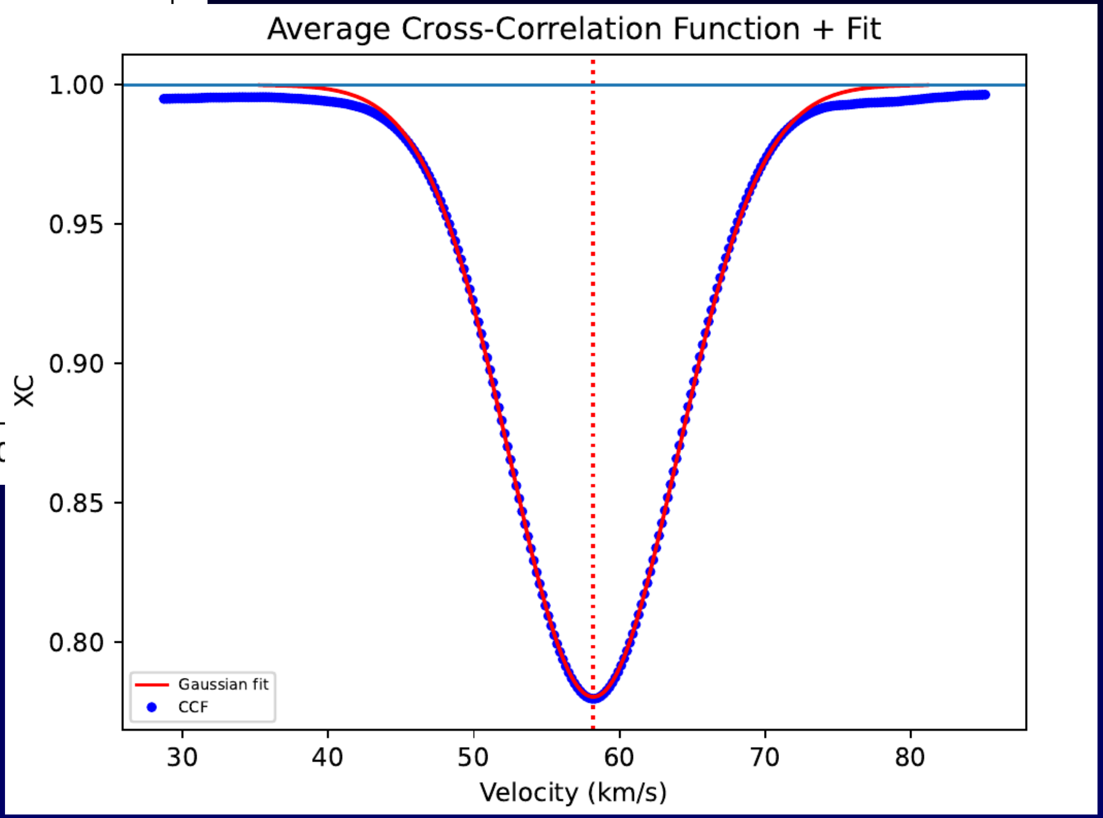
Cross Correlation Function



IRAF fxcor task

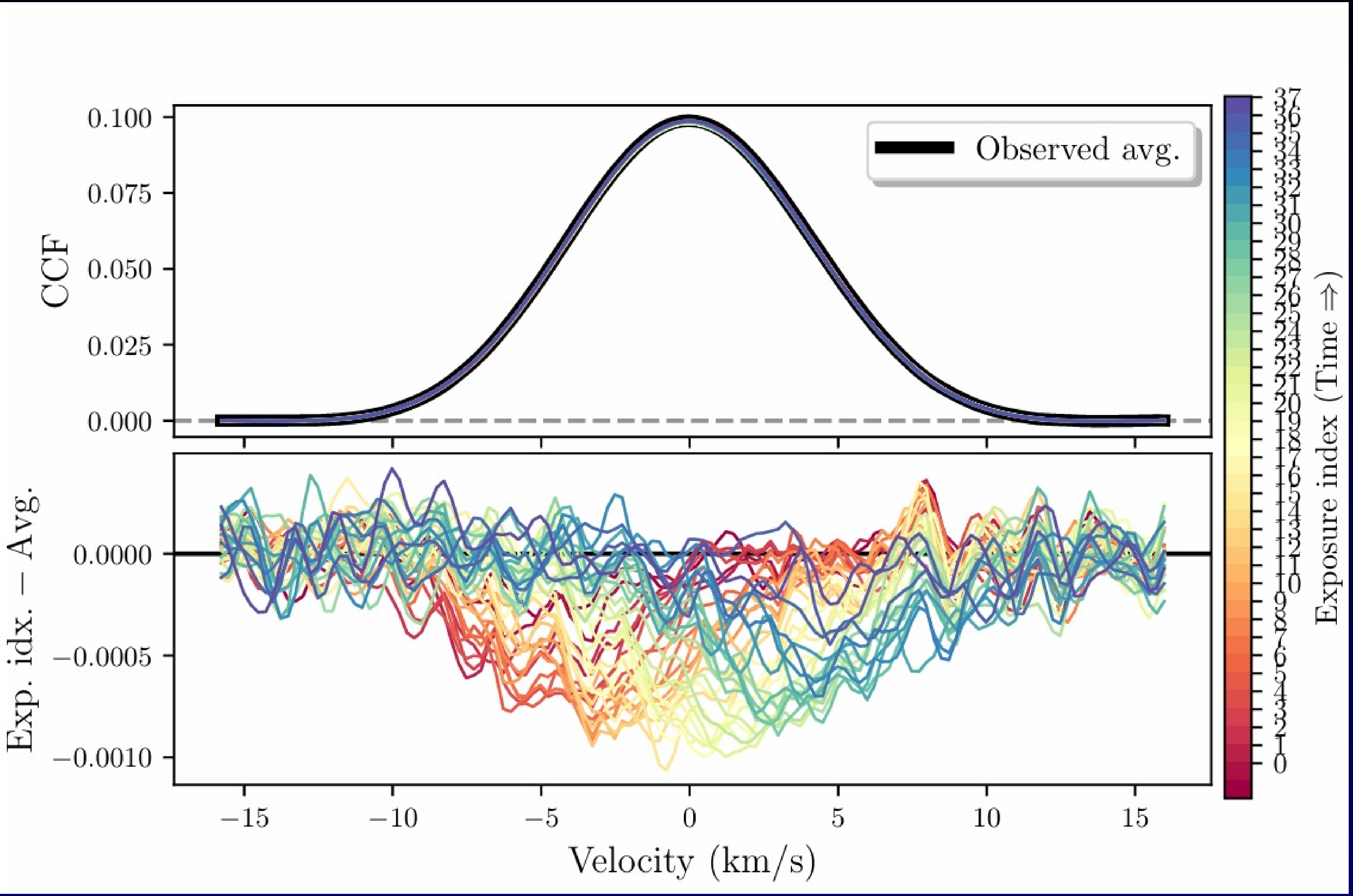
Cross Correlation Function - CCF



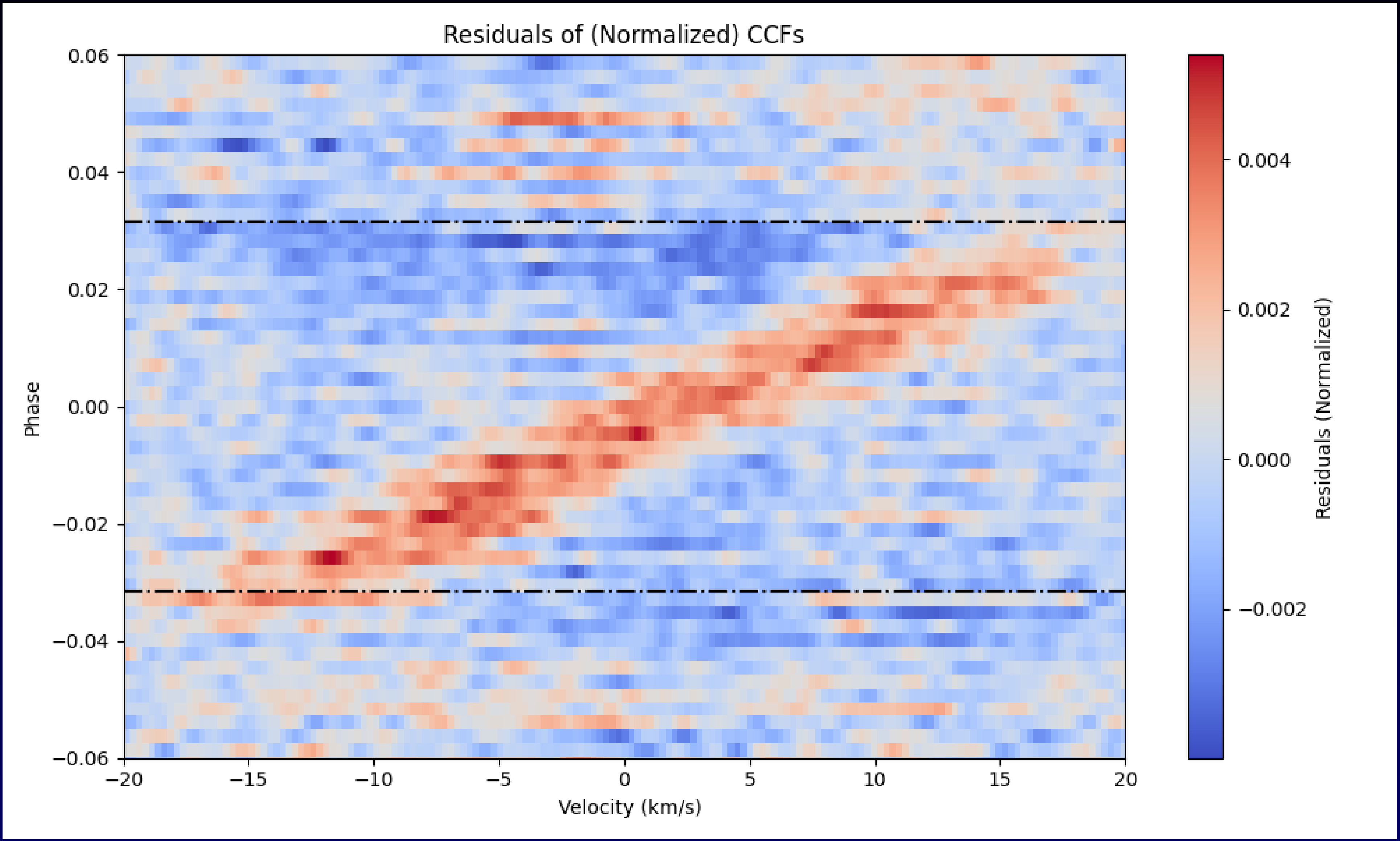


Example of PlatoSpec data reduced by CERES+

Residual CCF

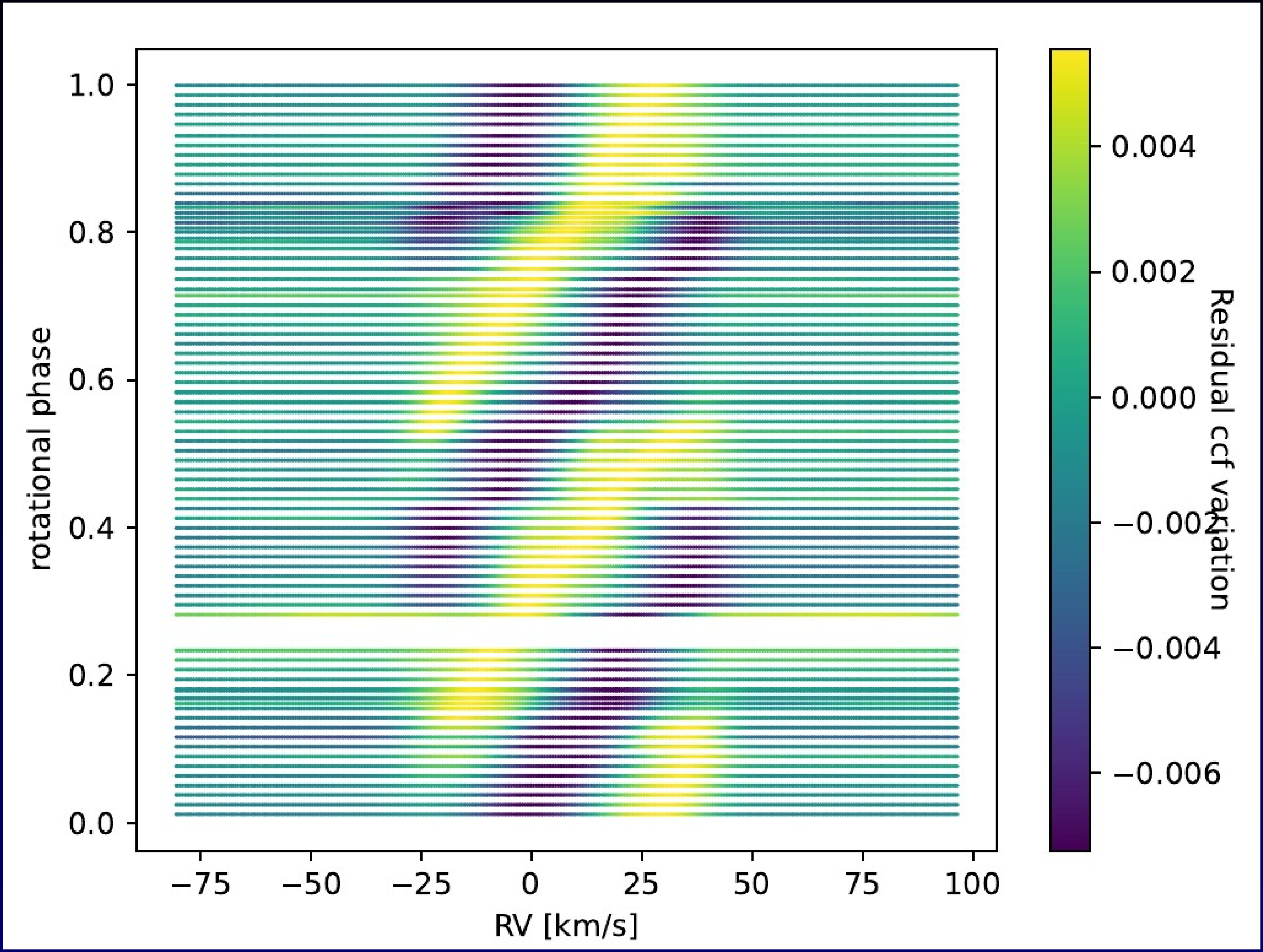


Doppler Shadow



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

Dynamic spectra – CCF



Lipták 2025, private comm.

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	DataType	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_DESCRIPT	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_COR
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_
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 ….)

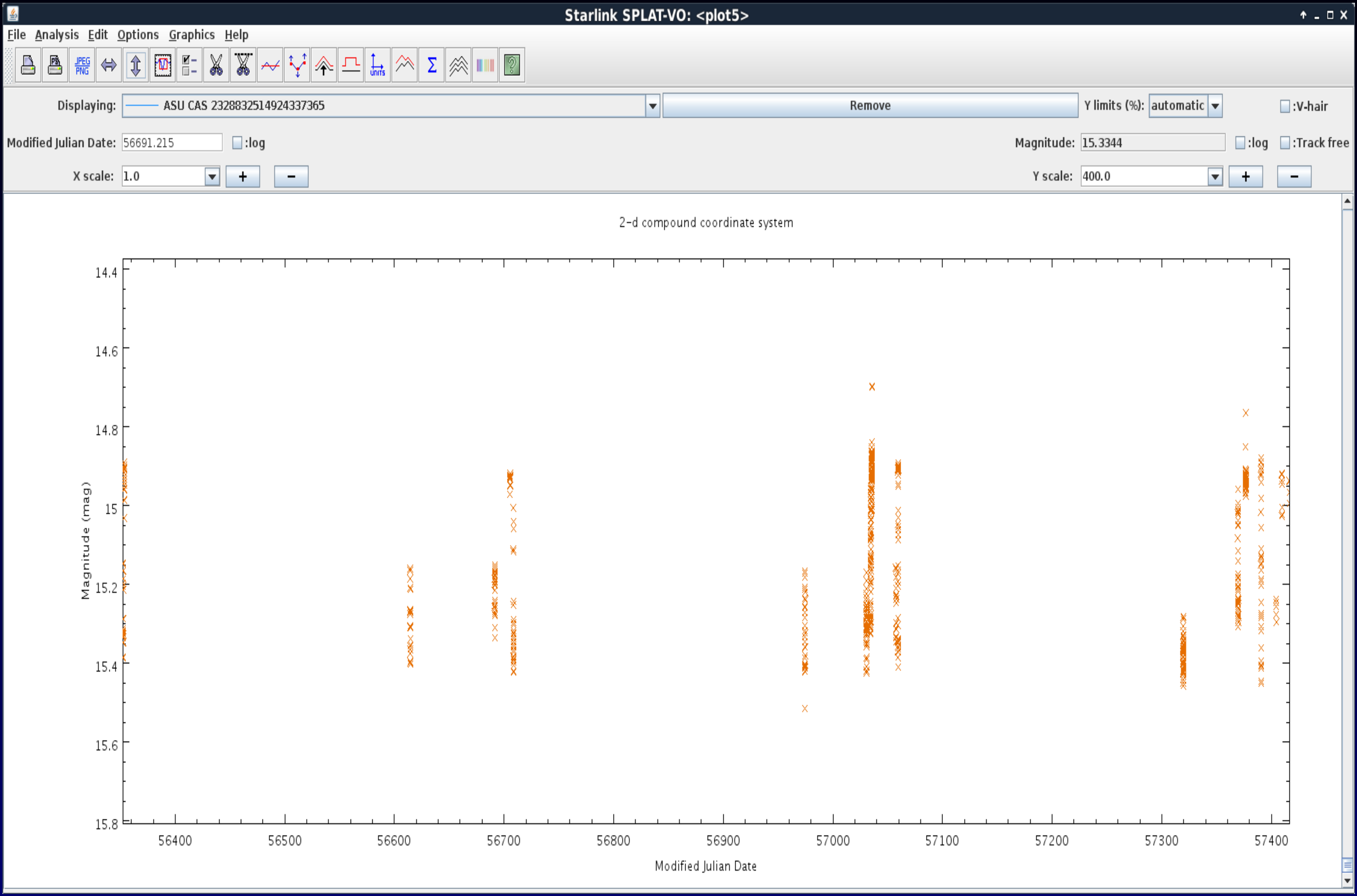
It is the most important output of pipeline

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

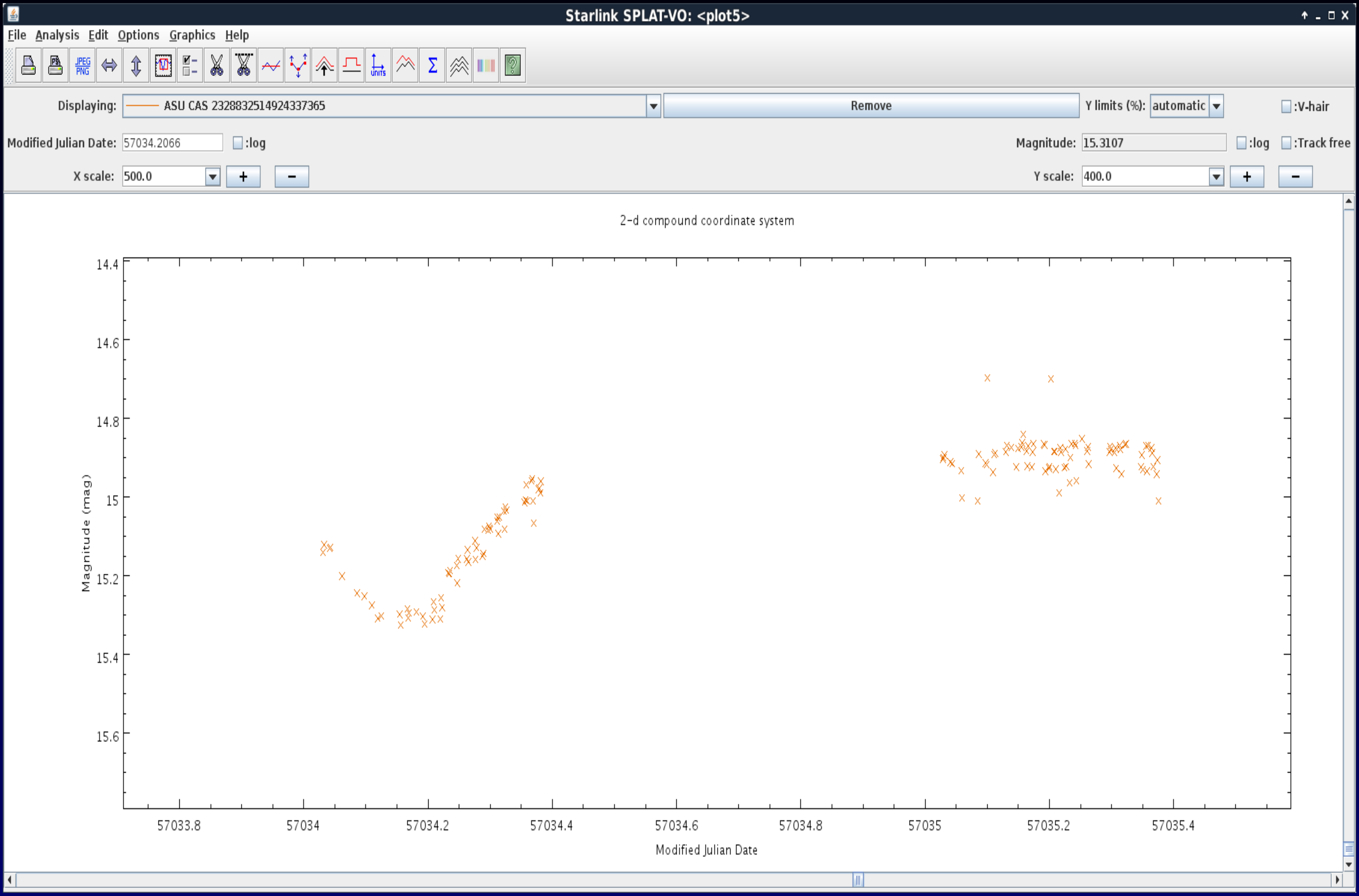
VO can do it on the fly (select all observation, apply SODA extract , create time series)

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

Light Curve in SPLAT-VO



Light Curve in SPLAT-VO (zoom)



Thank you