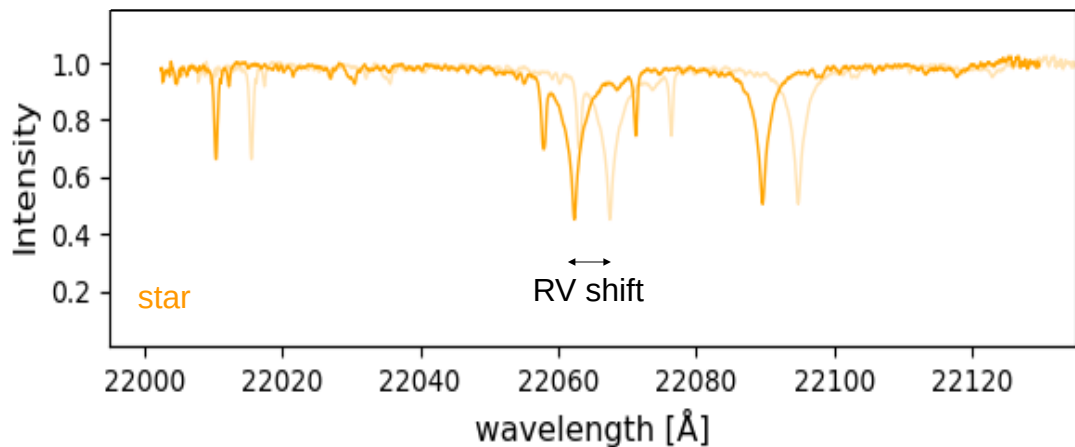




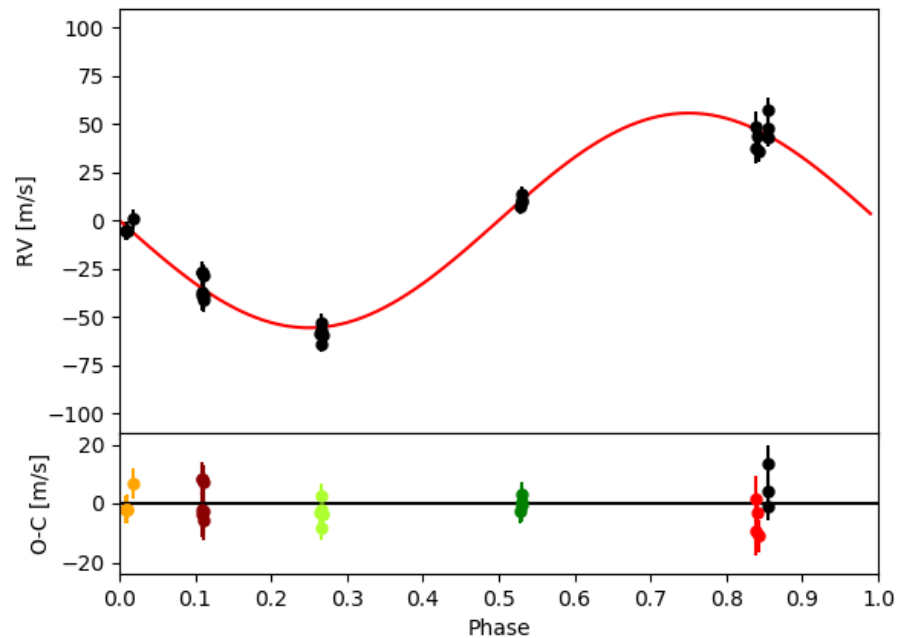
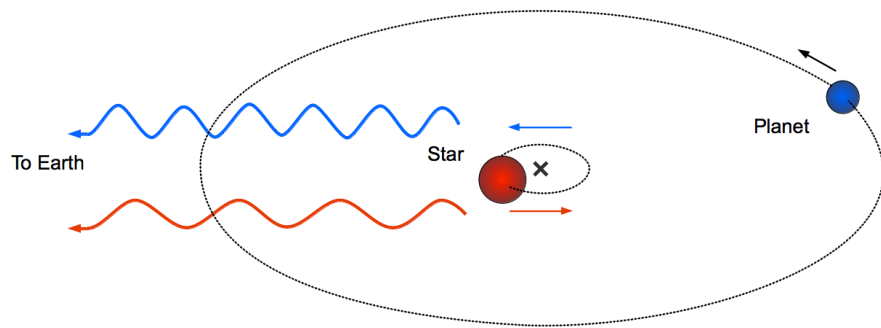
RV estimation with viper - Theory + Tutorial -

Jana Köhler (TLS Tautenburg)

Ondrejov, 2025-09-09



- Stellar light get Doppler shifted due to planet star interaction
- RVs are measured via wavelength shifts of stellar absorption lines



The way to high precision RVs

RV estimation at the beginning

- mainly done via cross-correlation
- no correction for instrument instabilities
 - no high precision RV estimation possible

Later: Tellurics (Earth's atmosphere) for calibration

- Telluric lines have fixed wavelength
 - accuracy up to 10 m/s
 - used for wavesolution
- Problem: Tellurics change strongly with time and are hard to model

Using Cell for calibration

- same idea as with Tellurics
- but using a stable Cell with known lines

Butler et al., 1996

- model instrument parameters (IP, Blaze, wavesolution) to estimate RV
- uses Cell lines for calculation of wavesolution
 - allows high RV precision

Basic concept of Butler et al.

Observation (with Cell)
- stellar through Cell

Stellar template (without Cell)
- “reference” spectra

FTS – Cell Spectra

Input

$$I_m = k [T_{cell}(\lambda) I_{stellar}(\lambda + \delta\lambda)] * IP$$

Output
(optimized
parameters)

Normalization
→ Blaze function

RV shift

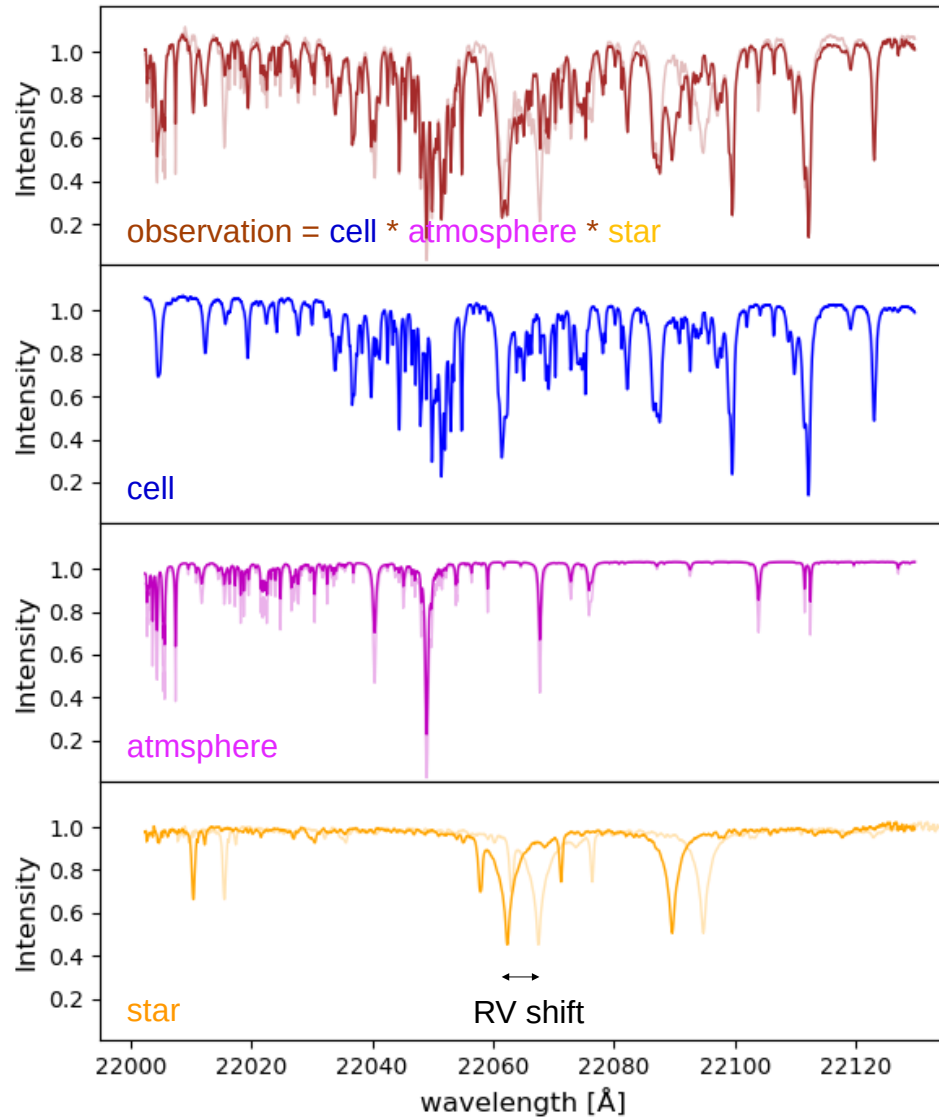
Instrument Profile

wavelength

- estimated via wavelength solution
(wavelength vs pixel)
→ Cell Spectra is used as reference

least-square fit is used to
estimate all parameters
simultaneously

The way to high precision RVs



$$I_m = k [T_{cell}(\lambda) T_{atm}(\lambda + \delta\lambda_{atm}) I_{stellar}(\lambda + \delta\lambda_{star})] * IP$$

$$RV = \text{radial velocity} = \frac{\delta\lambda}{\lambda} c$$

RV in example = 70,000 m/s

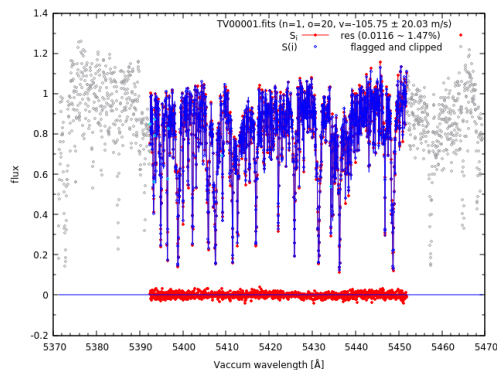
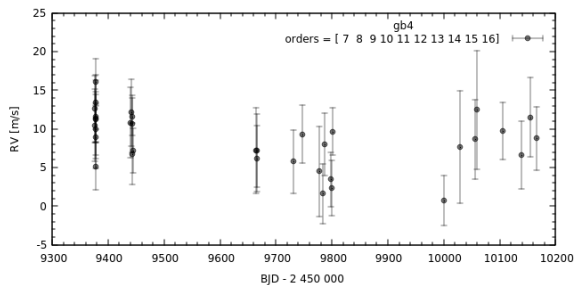
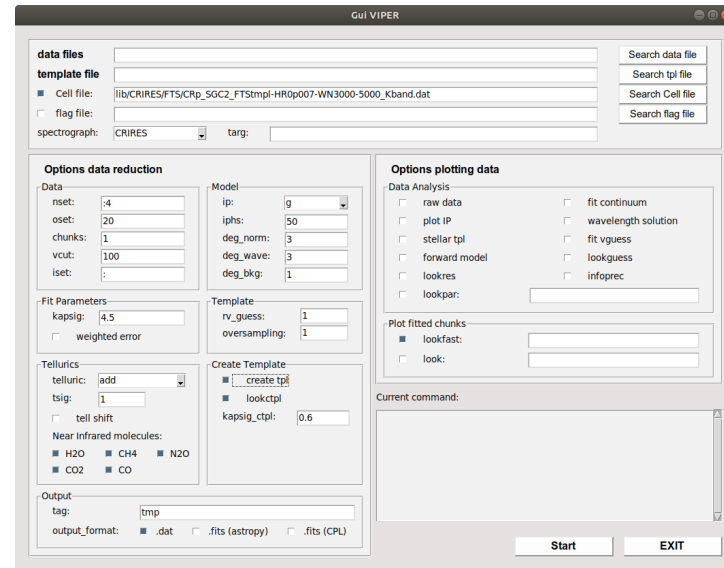
RV we want ~ 10-20 m/s

We need a software that can model our observations to estimated the RVs

- Started by Mathias Zechmeister and Sireesha Chamarthi
- Allows to obtain high precision **Radial Velocity measurements** for different instruments
- Is available via github
 - https://mzechmeister.github.io/viper_RV_pipeline
 - <https://github.com/mzechmeister/viper>
 - Paper: <https://arxiv.org/abs/2505.08315>
 - If you publish results with viper, please acknowledge it by citing its bibcode from <https://ui.adsabs.harvard.edu/abs/2021ascl.soft08006Z>.

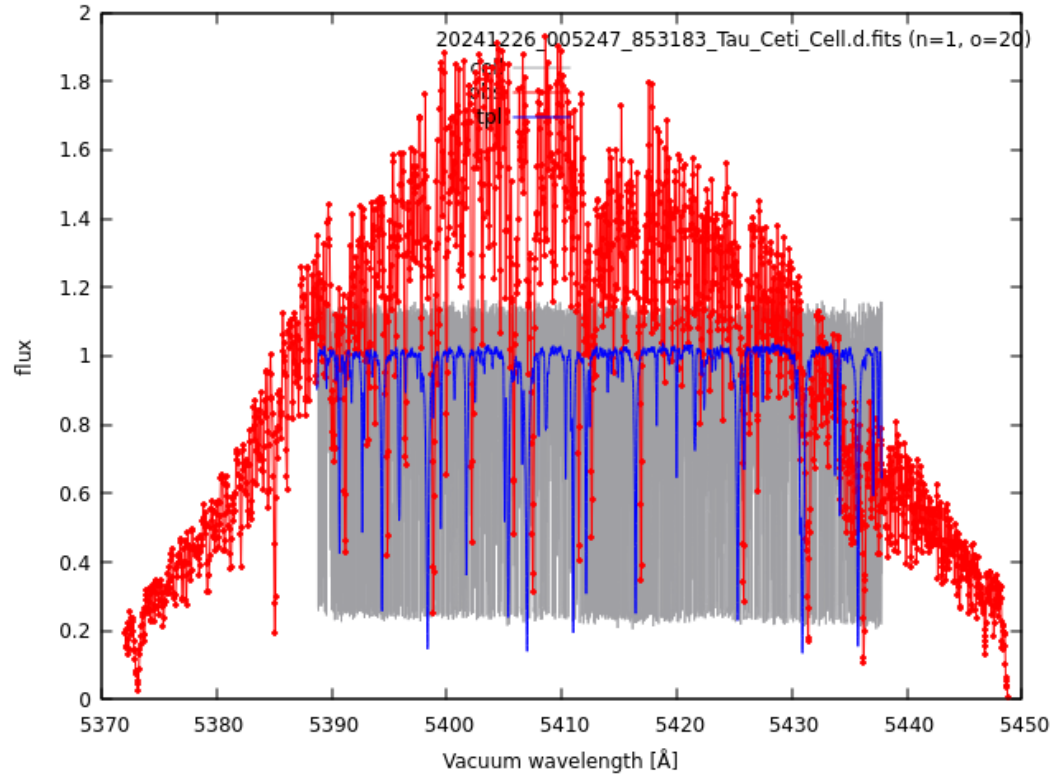
Current instruments:

- CRIRES+
- TLS Spectrograph
- UVES
- KECK
- Ondrejov OES
- CES
- **PLATOSpec**

The screenshot shows the 'Gui VIPER' window with the following sections:

- data files**: Fields for 'template file' (lib/CRIRES/FTS/CRP_SGC2_FTStmpl-HR0p007-WN3000-5000_Kband.dat), 'flag file', and 'spectrograph' (CRIRES).
- Options data reduction**: Includes 'Data' (nset: 4, oset: 20, chunks: 1, vcut: 100, iset: 1), 'Fit Parameters' (kapsig: 4.5, weighted error), 'Tellurics' (telluric: add, tsig: 1, tell shift), 'Near Infrared molecules' (H2O, CH4, N2O, CO2, CO), and 'Output' (tag: tmp, output_format: .dat, .fits (astropy), .fits (CPL)).
- Options plotting data**: Includes 'Data Analysis' (raw data, plot IP, stellar tpl, forward model, lookres, lookpar), 'Model' (ip: 9, iphs: 50, deg_norm: 3, deg_wave: 3, deg_bkg: 1), 'Template' (rv_guess: 1, oversampling: 1), and 'Plot fitted chunks' (lookfast, look).
- Current command**: A text area for entering commands.
- Buttons**: 'Start' and 'EXIT' buttons at the bottom right.



$$I_m = k [T_{cell}(\lambda) I_{stellar}(\lambda + \delta\lambda)] * IP$$

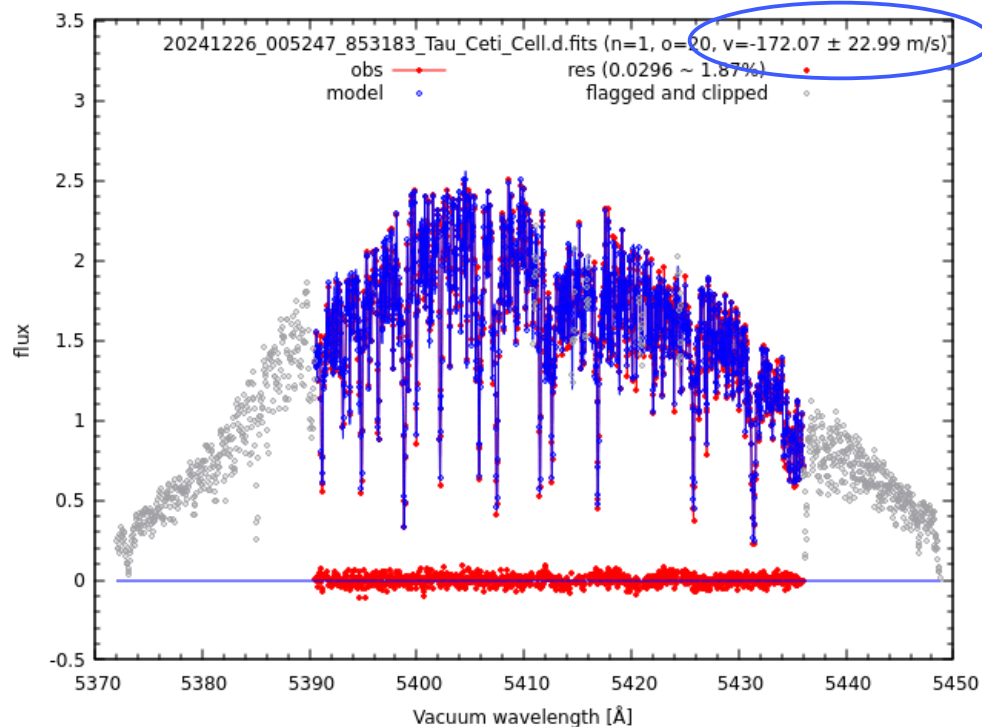
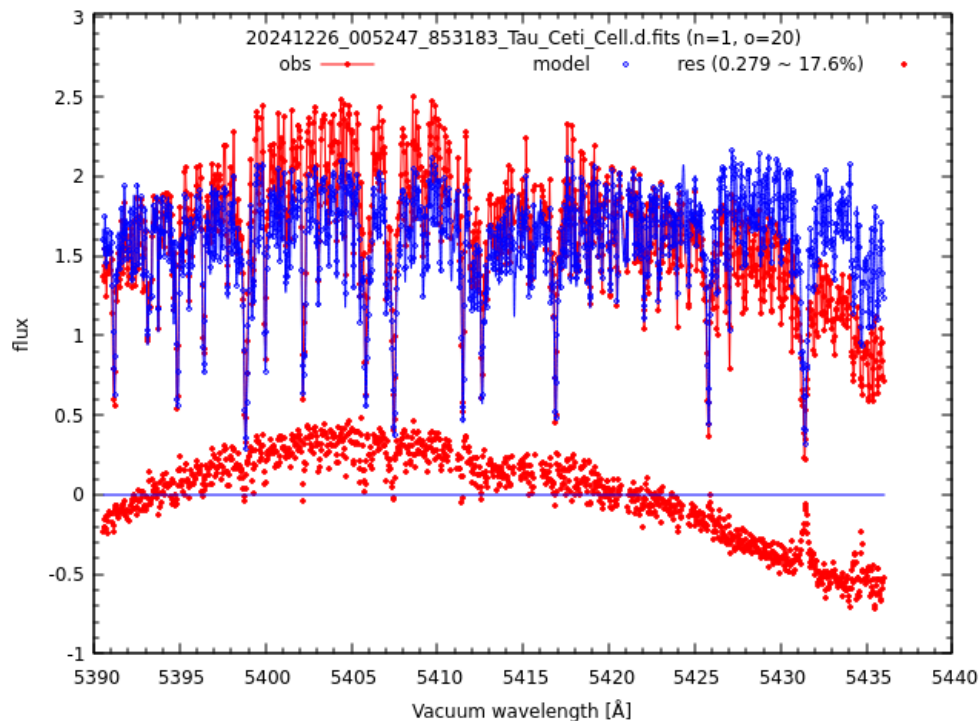
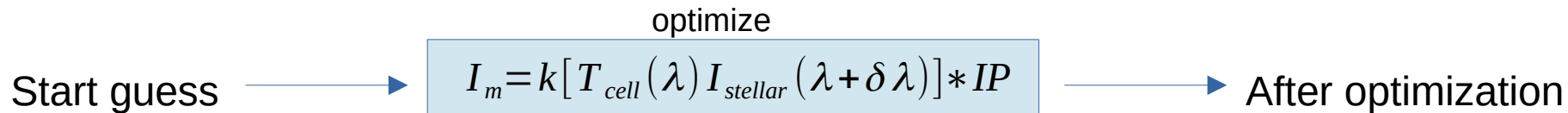
Input to viper:

Observation with cell

Tpl – observation without cell

Cell – Fourier Transformed Spectrum (FTS)

Modelling the data



$$I_m = k [T_{cell}(\lambda) I_{stellar}(\lambda + \delta\lambda)] * IP$$

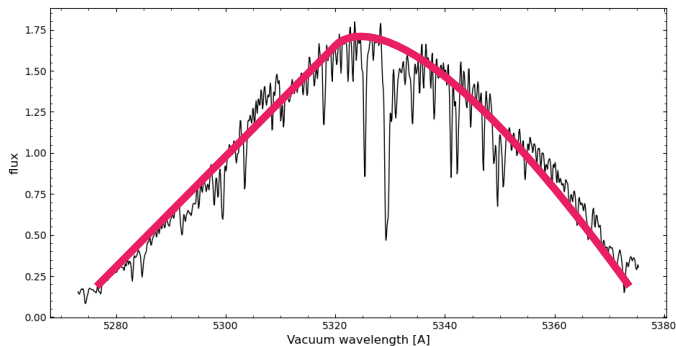
wavelength solution (deg_wave)

$$\lambda = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 \cdot x^3$$

x: detector pixel

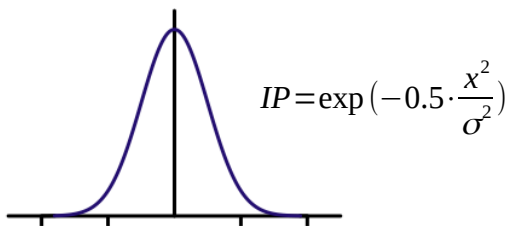
Blaze (deg_norm)

$$k = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3$$

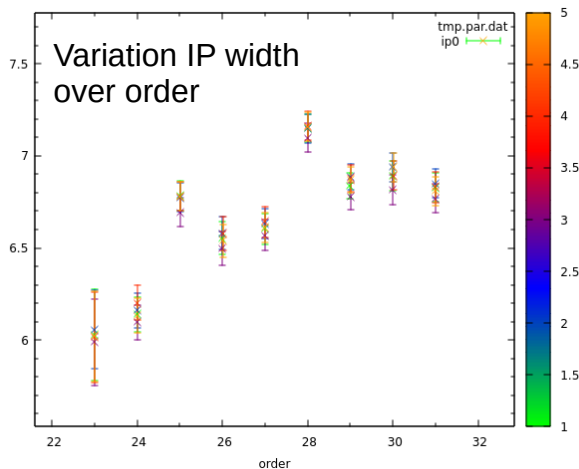
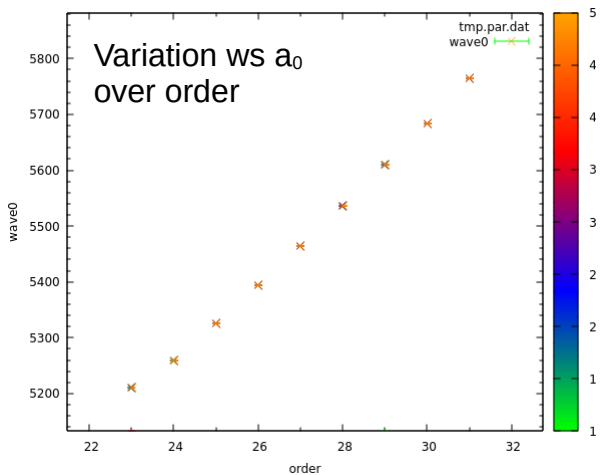
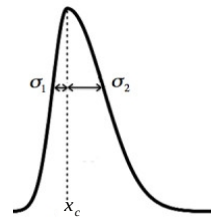


Instrument profil (IP)

Gaussian



BiGaussian

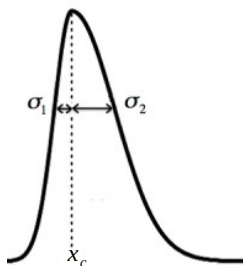


Example: IP modeling 51 Peg (TLS)

IP = BiGaussian (bg)

$$IP = \begin{cases} \exp\left(-0.5 \frac{(x-x_c)^2}{\sigma_1^2}\right) & \text{for } x+x_c < 0 \\ \exp\left(-0.5 \frac{(x-x_c)^2}{\sigma_2^2}\right) & \text{for } x+x_c > 0 \end{cases}$$

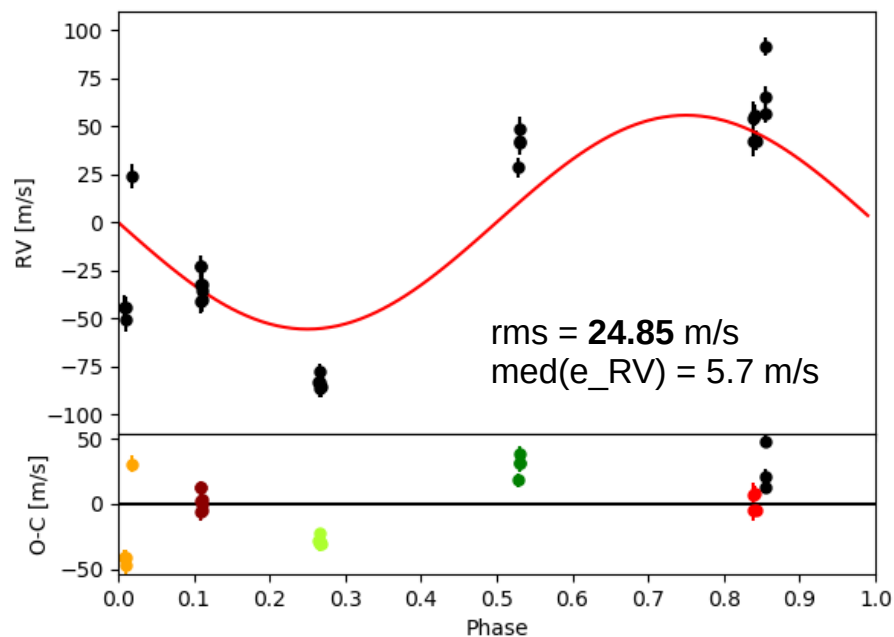
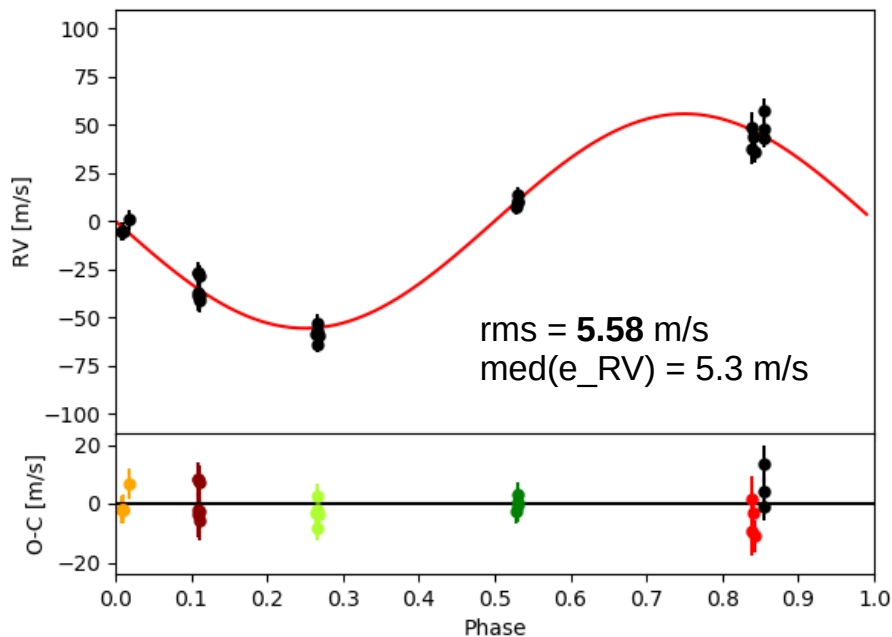
$$x_c = \sqrt{\frac{2}{\pi}} \cdot \frac{\sigma_1^2 + \sigma_2^2}{\sigma_1 + \sigma_2}$$



$$I_m = k [T_{cell}(\lambda) I_{stellar}(\lambda + \delta \lambda)] * IP$$

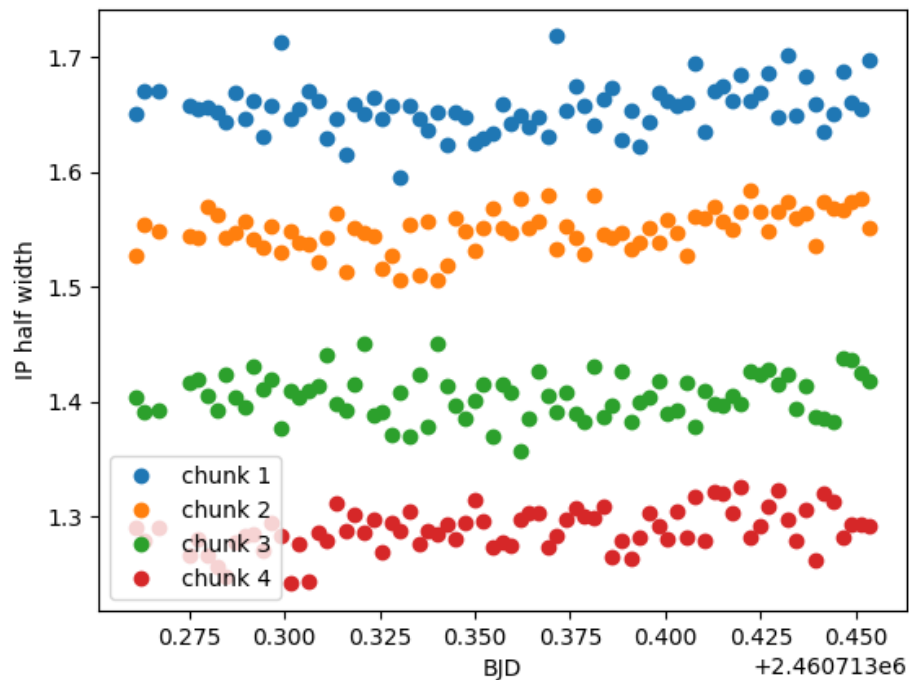
IP = Gaussian (g)

$$IP = \exp\left(-0.5 \cdot \frac{x^2}{\sigma^2}\right)$$

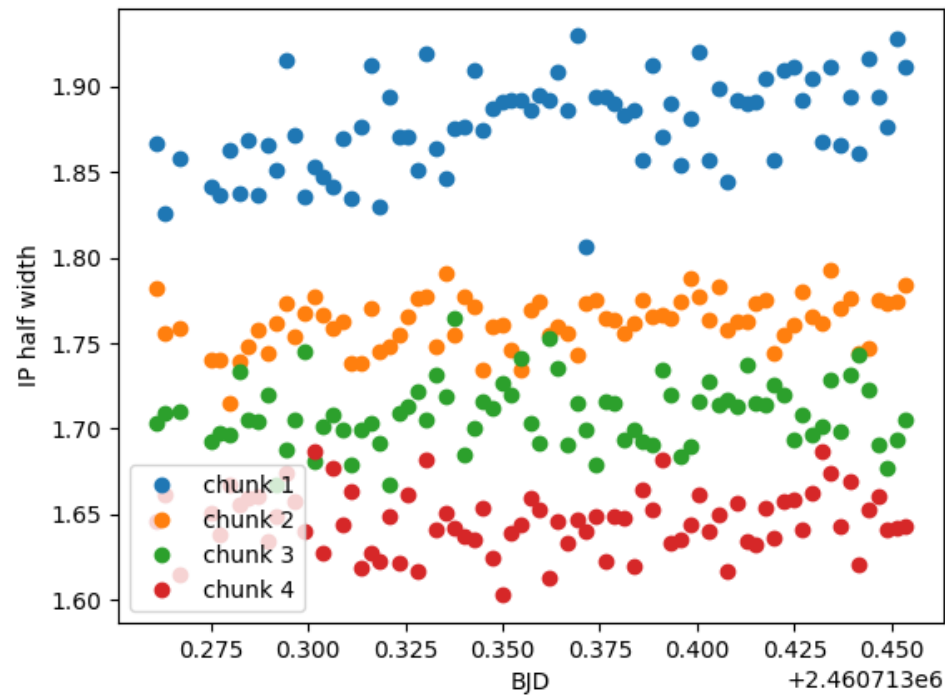


Order 18 – 4 chunks – BiGaussian IP

Left side IP



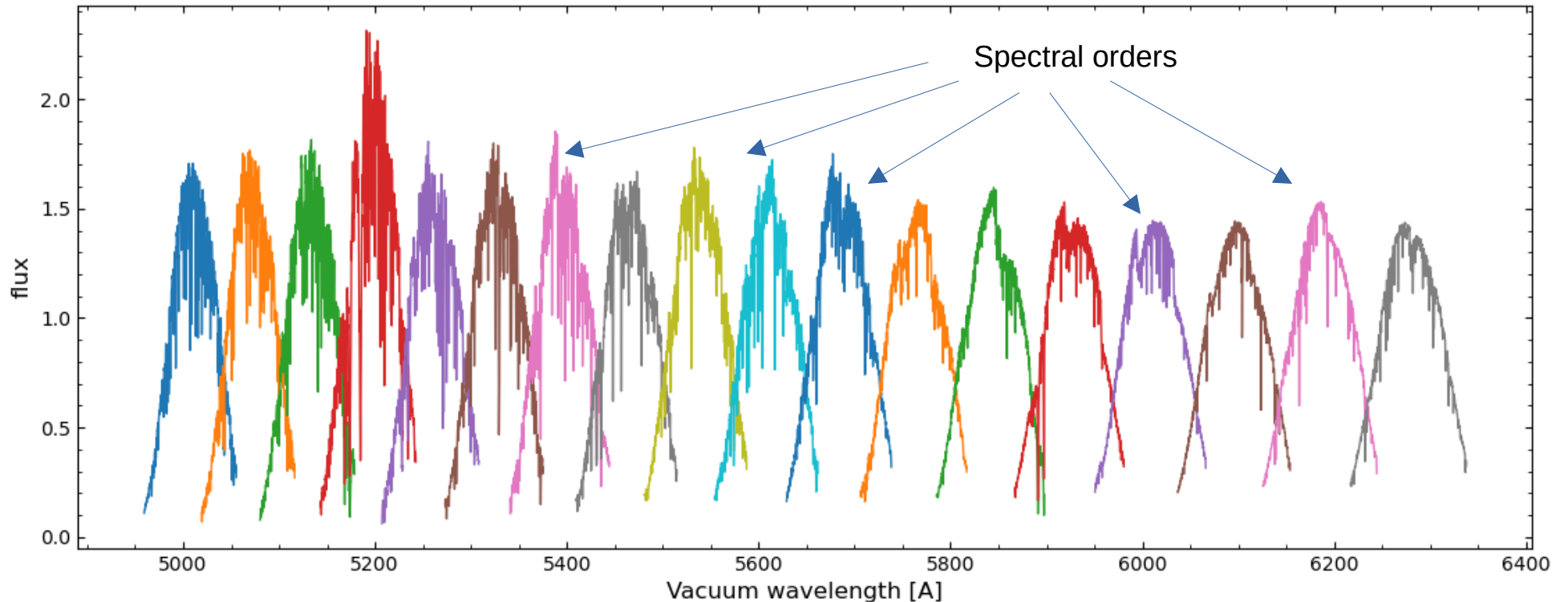
Right side IP



Estimating the RVs

Instrument parameters vary for each spectral order

- RV estimation will be done for each spectral order separately
- afterwards combined by weighted mean



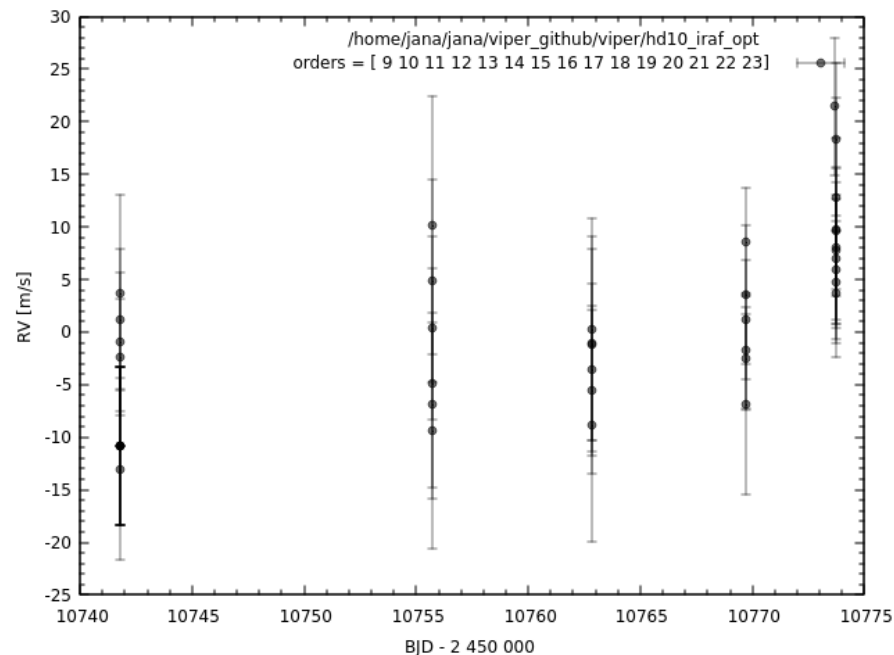
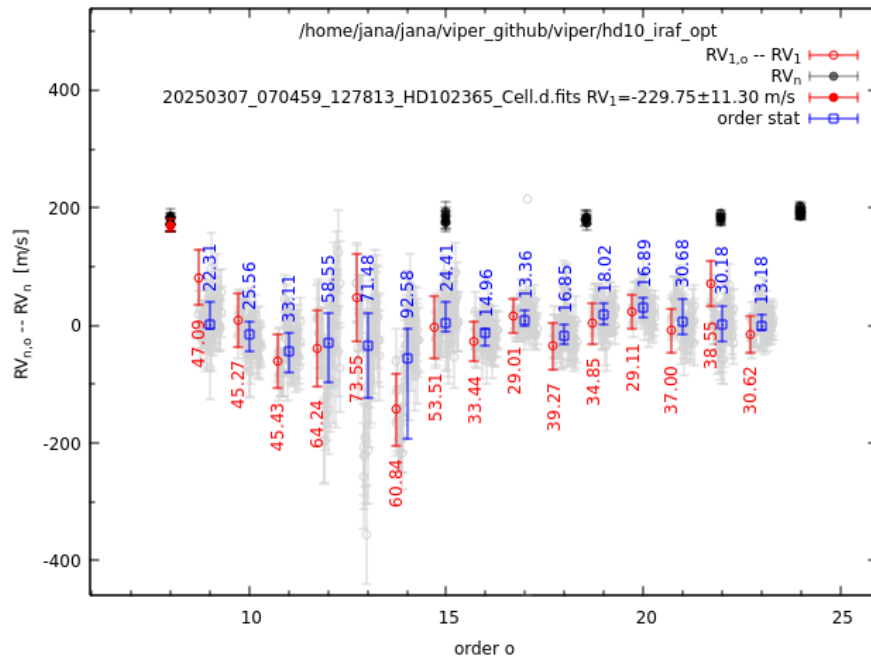
Final RVs – combination of all orders

$$RV = \frac{\sum \epsilon_o^{-2} \cdot RV_o}{\sum \epsilon_o^{-2}}$$

RVs per order



combined RVs



Starting viper

Gul VIPER

data files

template file

☒ **Cell file:**

☐ **flag file:**

spectrograph: **targ:**

Options data reduction

Data
 nset:
 oset:
 chunks:
 vcut:
 iset:
Model Setup
 ip:
 iphs:
 deg_norm:
 deg_wave:
 deg_bkg:

Fit Settings
 kapsig:
 wgt:

Template
 rv_guess:
 oversampling:

Tellurics
 telluric:

Create Template
☐ create tpl

Output
 tag:
 output_format: ☒ .dat ☐ .fits (astropy) ☐ .fits (CPL)

Options plotting data

Data Analysis
☐ raw data ☐ fit continuum
☐ plot IP ☐ wavelength solution
☐ stellar tpl ☐ fit vguess
☐ forward model ☐ lookguess
☐ lookres ☐ infoprec
☐ lookpar:

Plot fitted chunks
☒ lookfast:
☐ look:

Current command:

```
python3 viper.py '/home/jana/jana/VIPER/data/Pucheros/Science/HD10700/*_Cell.e.fits' /home/jana/jana/VIPER/data/Pucheros/Science/HD10700/HD10700_2024-07-29T09_53.e.fits -inst PUCHEROS -nset :40 -oset 23:32 -chunks 1 -vcut 300 -iset : -ip g -iphs 300 -deg_norm 3 -deg_wave 3 -deg_bkg 1 -rv_guess 1 -demo 0 -t arg HD10700 -tag tmp -kapsig 150 -oversampling 1 -lookpar -fts /home/jana/jana/viper_github/viper_240816/lib/TLS/FTS/TLS_I2_FTS.fits -wgt None -telluric mask -output_format dat
```

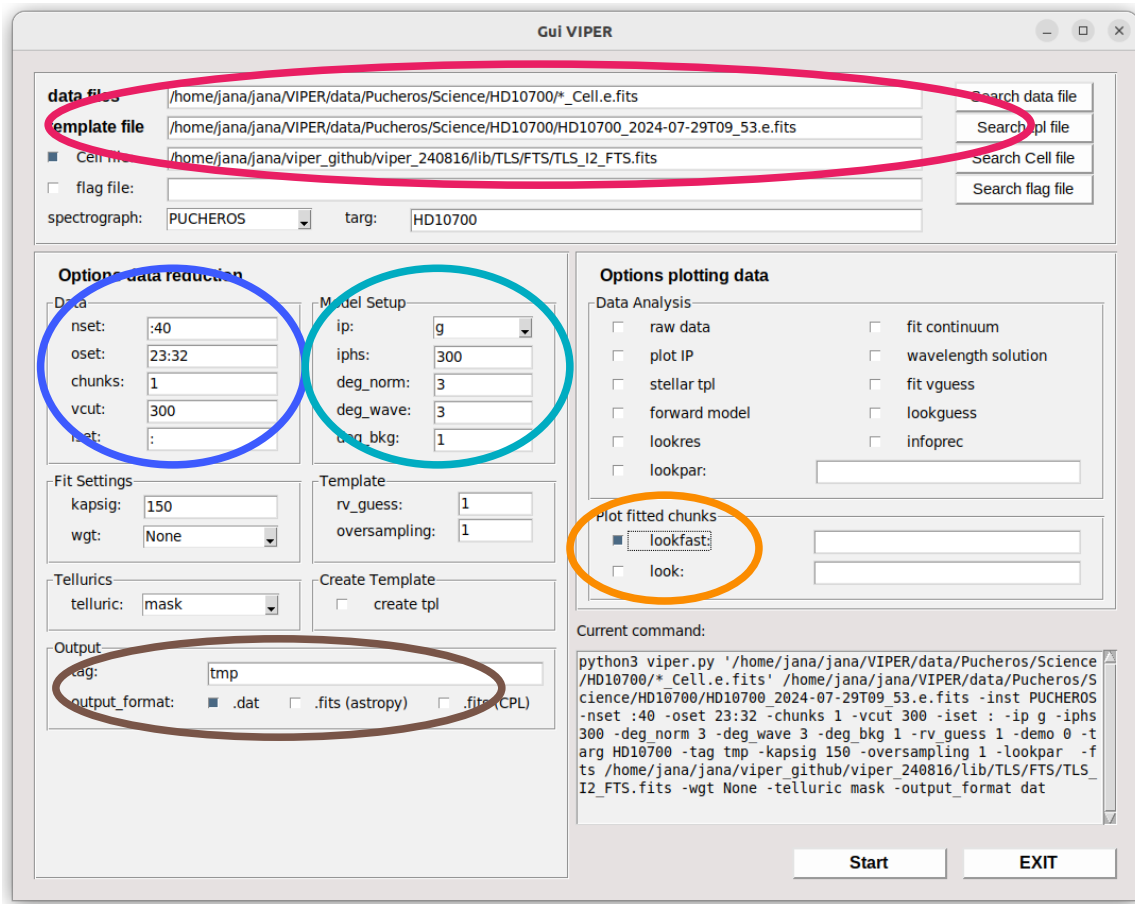
> GUI_viper config_viper.ini PlatoSpec

or

> python3 GUI_viper.py
config_viper.ini PlatoSpec

sudo apt-get install gnuplot
gnuplot-x11 gnuplot-doc

Starting viper



The screenshot shows the GUI VIPER interface with the following fields highlighted:

- Input data (pink circle):** data files, template file, and Cell file.
- Options data reduction (blue circle):** nset, oset, chunks, vcut, and ipset.
- Options plotting data (orange circle):** lookfast and look.
- Output name and format (brown circle):** tag and output_format.

The interface also includes sections for Model Setup, Fit Settings, Template, Tellurics, and a Current command window.

Input data

- observation with cell
- stellar template (without cell)
- instrument/ cell file

Observation and order selection

Parameter settings

- IP model and width
- degree wavelength solution
- degree blaze

Plotting options

- no plotting
- fast plotting (without pause)
- pause each plot

Output name and format

- default: tmp
- will be overwritten each time!

Gui VPR

RV plots Parameters Residuals

Plot RVs

Input

rvo file 1:

rvo file 2:

oset rvo 1

■ 23 ■ 24 ■ 25 ■ 26 ■ 27

■ 28 ■ 29 ■ 30 ■ 31

oset rvo 2

center RV values

☐ cen RVs to zero median

☐ ocen rvo 1

☐ ocen rvo 2

Plotting Options

sort by:

offset rvo:

Other

average:

output:

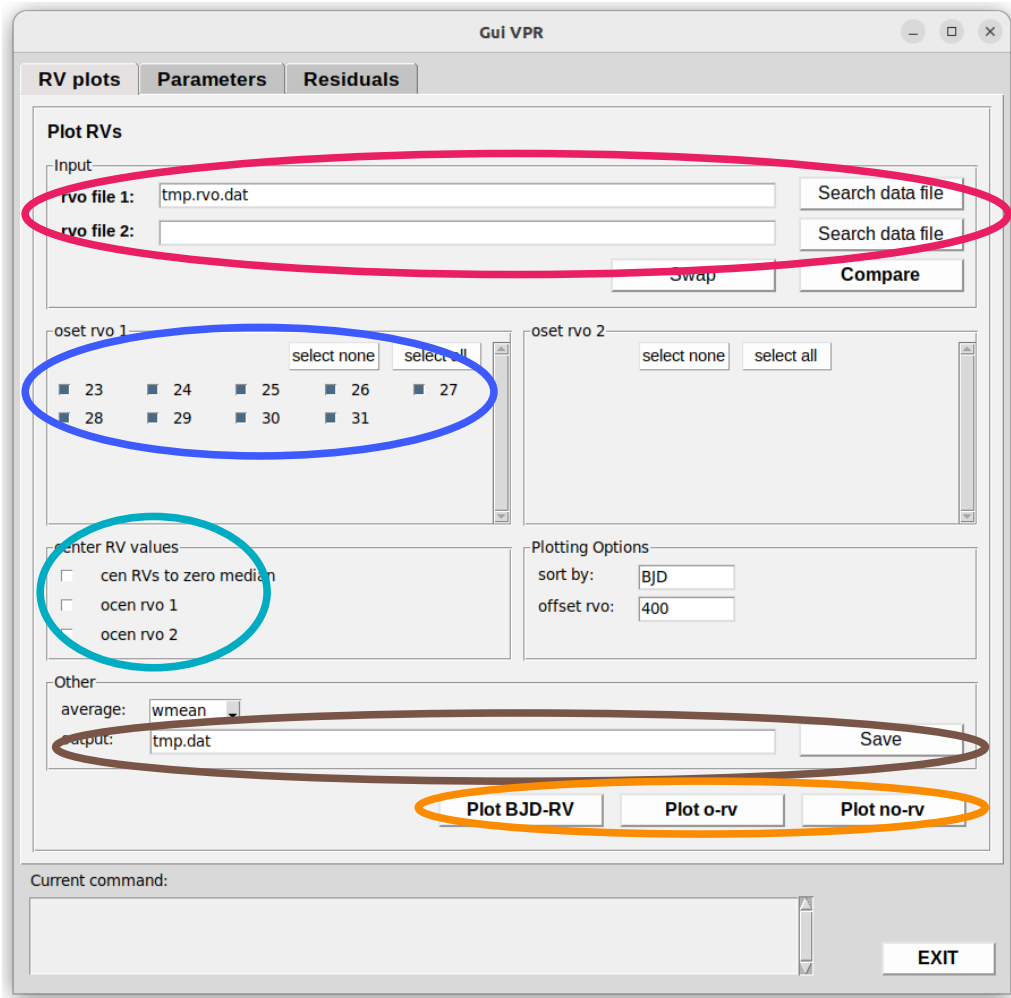
Current command:

> GUI_vpr

or

> python3 GUI_vpr.py

Post-processing of the RV data



Gui VPR

RV plots Parameters Residuals

Plot RVs

Input

rvo file 1: tmp.rvo.dat Search data file

rvo file 2: Search data file

Swap Compare

oset rvo 1 select none select all

23 24 25 26 27

28 29 30 31

oset rvo 2 select none select all

center RV values

☐ cen RVs to zero median

☐ ocn rvo 1

☐ ocn rvo 2

Plotting Options

sort by: BJD

offset rvo: 400

Other

average: wmean

output: tmp.dat Save

Plot BJD-RV Plot o-rv Plot no-rv

Current command:

EXIT

Input data

- #.rvo.dat file
- RVs for all orders and observations

Order selection

Parameter settings

- center combined Rvs
- subtract order offset

Plotting options

- combined RVs vs time
- RVs of single orders

Output name and format

- write out final RVs
- will be overwritten each time!

Exercises

1. Start viper

```
> GUI_viper config_viper.ini PlatoSpec
```

2. Load in data

3. Run with default settings

4. Use vpr for order selection ect.

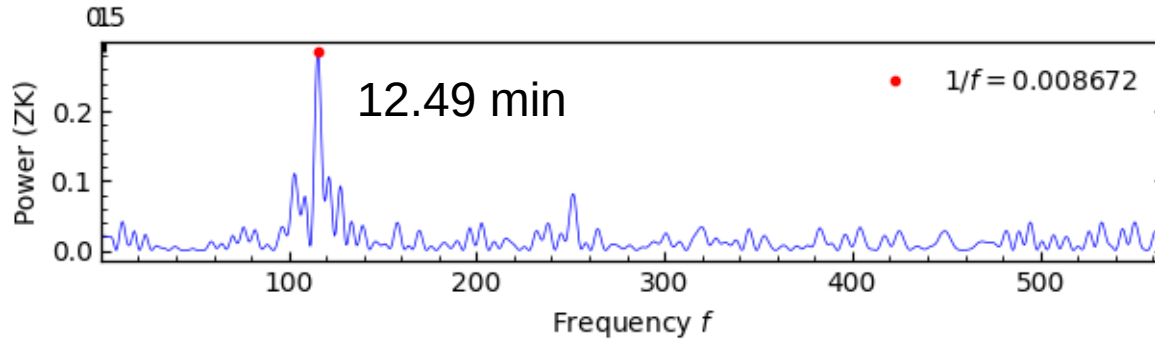
```
> GUI_vpr
```

5. Change IP from Gaussian (b) to BiGaussian (bg)

6. Use larger number of chunks (for example 2, 3, 4)

7. Compare results. What do you see?

Period



The discovery of 12.5-minute oscillations in the cool magnetic Ap star, γ Equ

D. W. Kurtz *Department of Astronomy, University of Cape Town, South Africa*

Received 1981 December 9

Discovery of magnetic field variations with the 12.1-minute pulsation period of the roAp star γ Equulei

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