Spectroscopy

A search for runaway stars!

Matti Dorsch — Ondřejov 2023

How to identify runaway stars?

The easy way: find **fast young** stars

B-type main sequence stars have short lifetimes

3 $M_\odot$	$\rightarrow$	500 Myr
15 $M_\odot$	$\rightarrow$	20 Myr
Halo	$\rightarrow$	$>$ 6000 Myr!

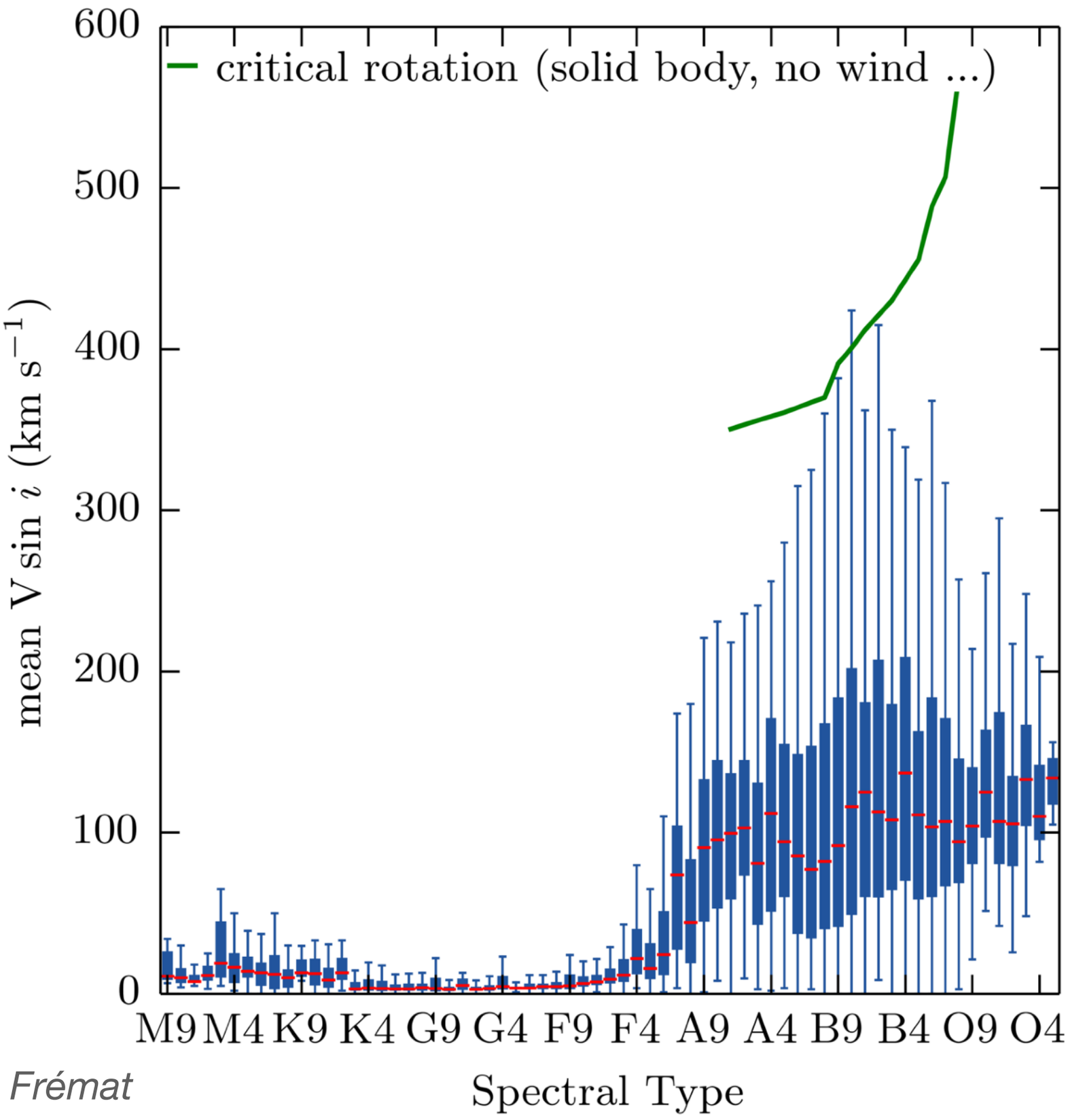
How to identify young runaway stars?

- **Fast** stars:
  - High radial velocity, high tangential velocity

    → Galactic orbit calculation
- **Young** stars, *not* **BHB** stars!
  1. Spectral type O/B/A
  2. Fast (projected) rotation
  3. Stellar parameters: radius, luminosity, mass

Identifying young MS stars: rotation

Rotational broadening — $v_{\mathrm{rot}} \sin i$



Conservation of angular momentum

+

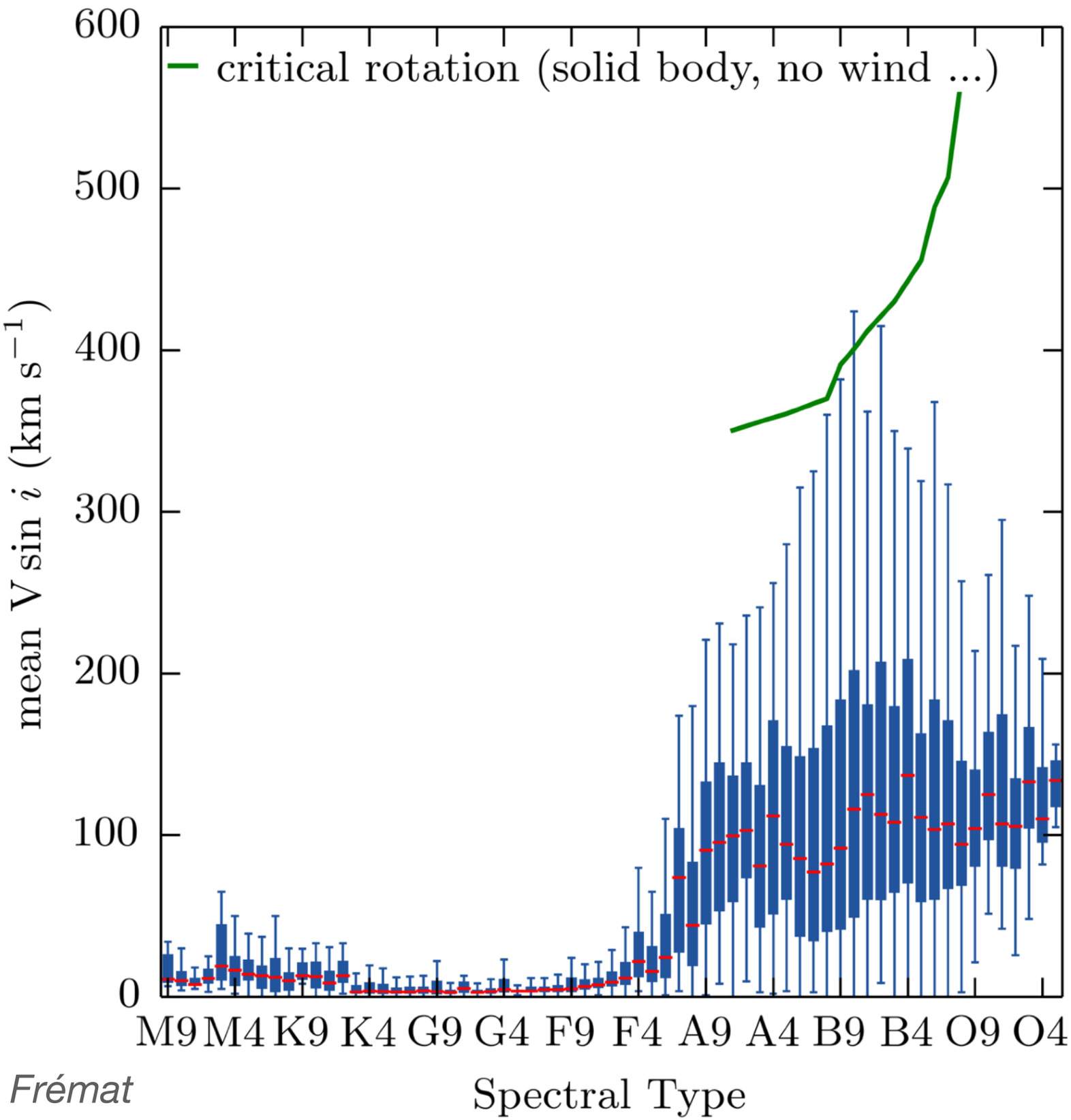
Contraction

↓

Fast rotation

Y. Frémat

Rotational broadening — $v_{\mathrm{rot}} \sin i$



Time

+

Magnetic field + mass loss (stellar wind, …)

↓

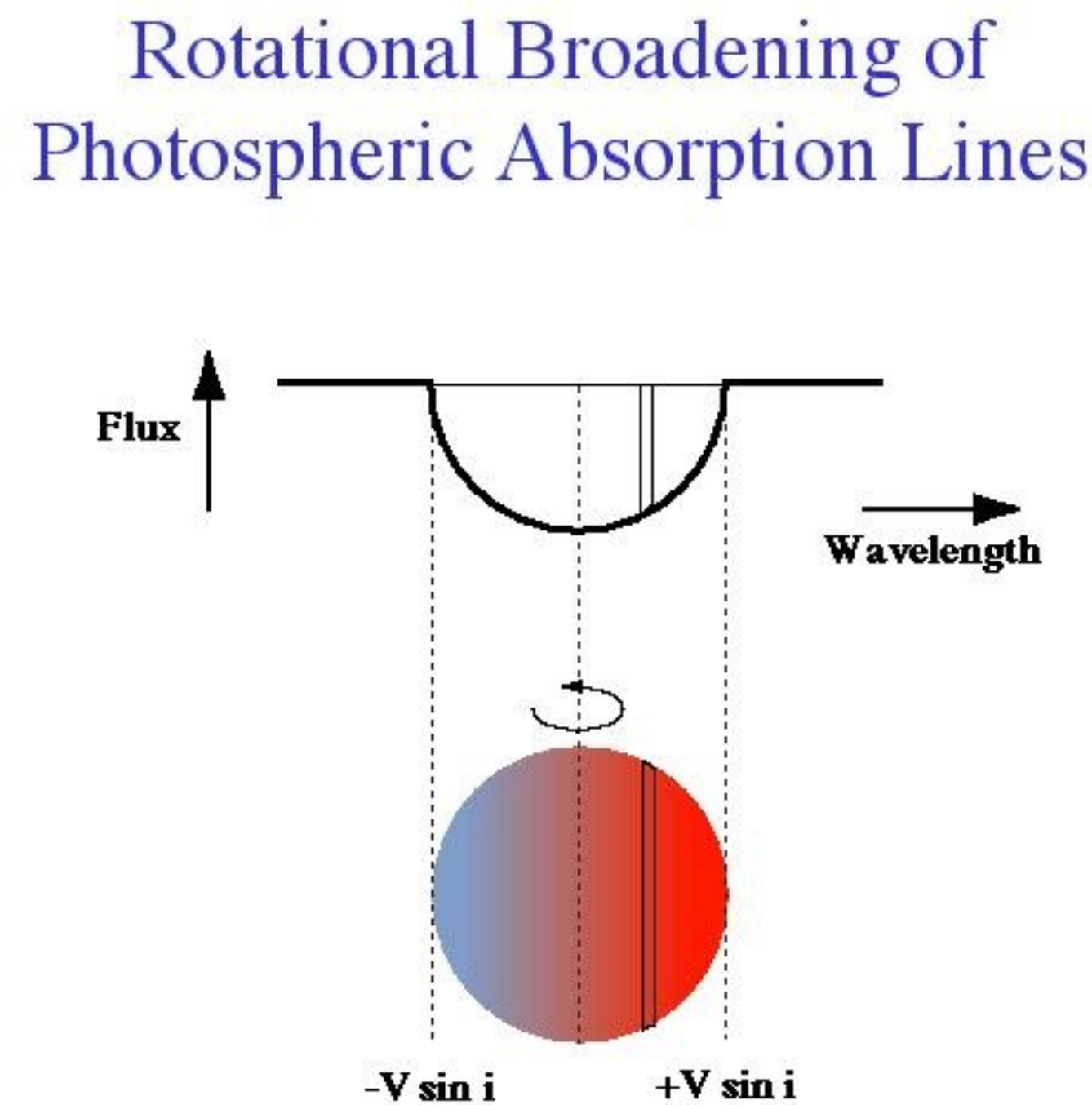
Slower rotation (spin down)

Y. Frémat

BHB stars are old → a lot of time to spin down

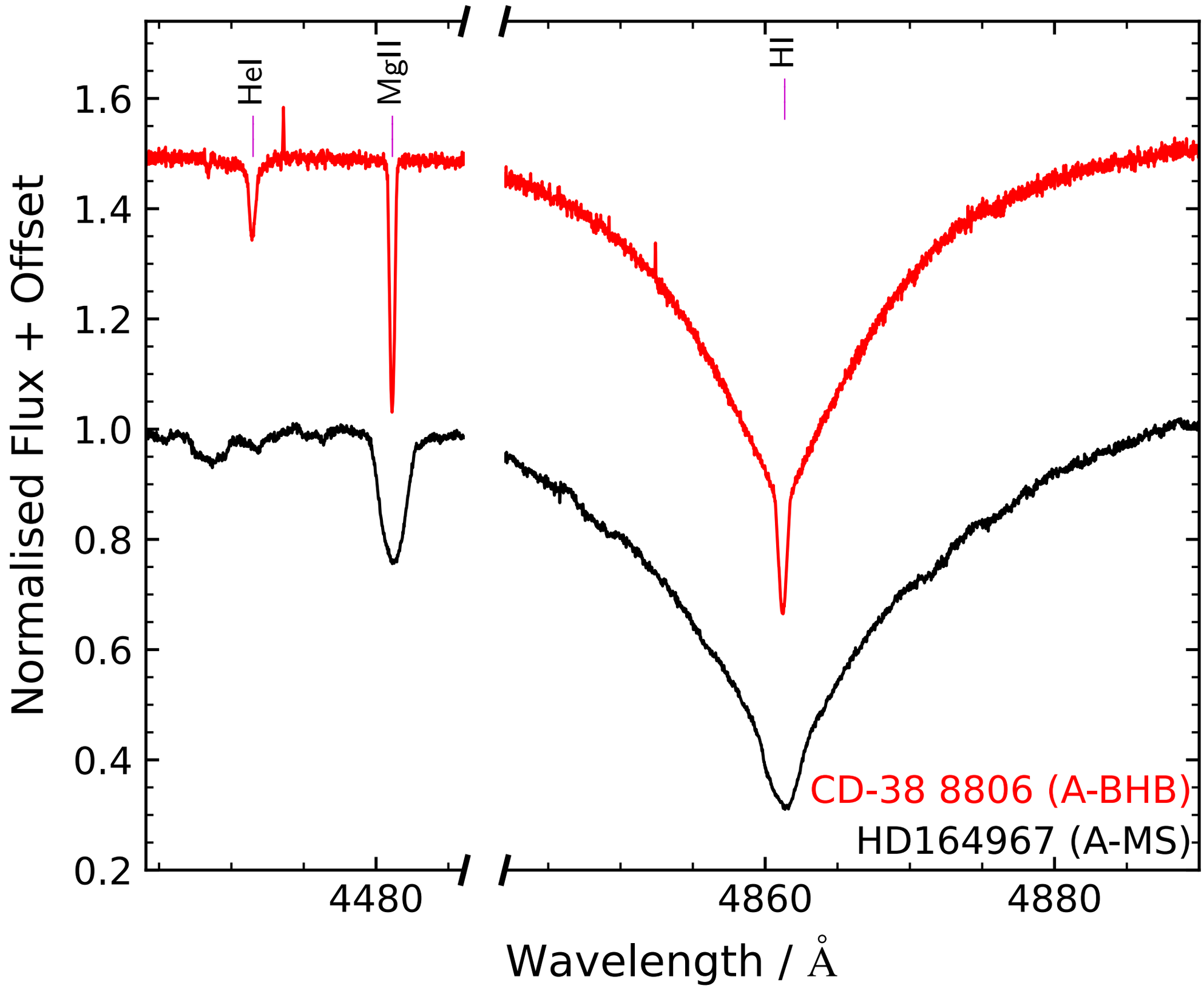
How do we measure rotation?

Rotational broadening — $v_{\mathrm{rot}} \sin i$



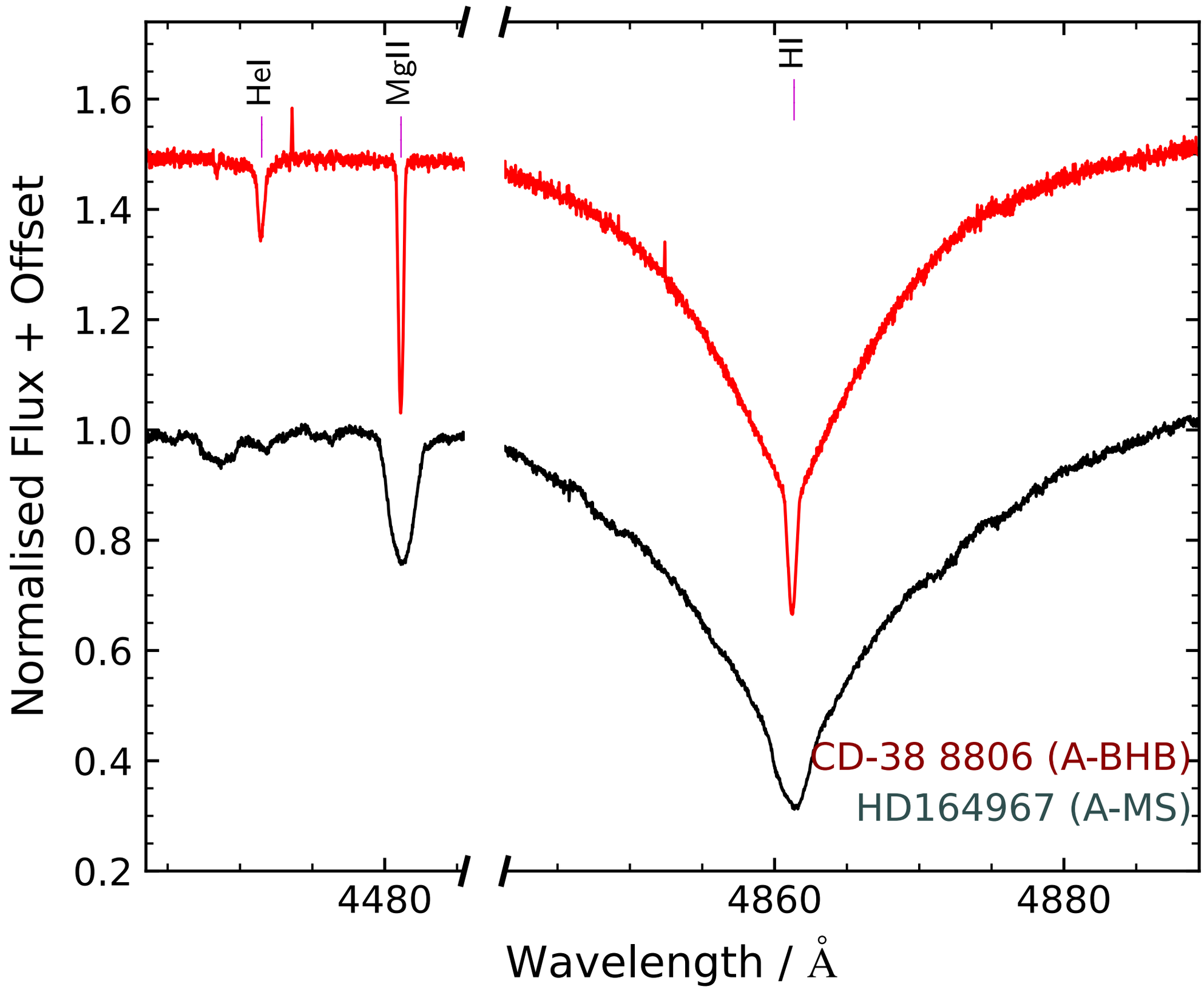
by Stan Owocki

Radial velocity — $v_{\rm rot} \sin i$

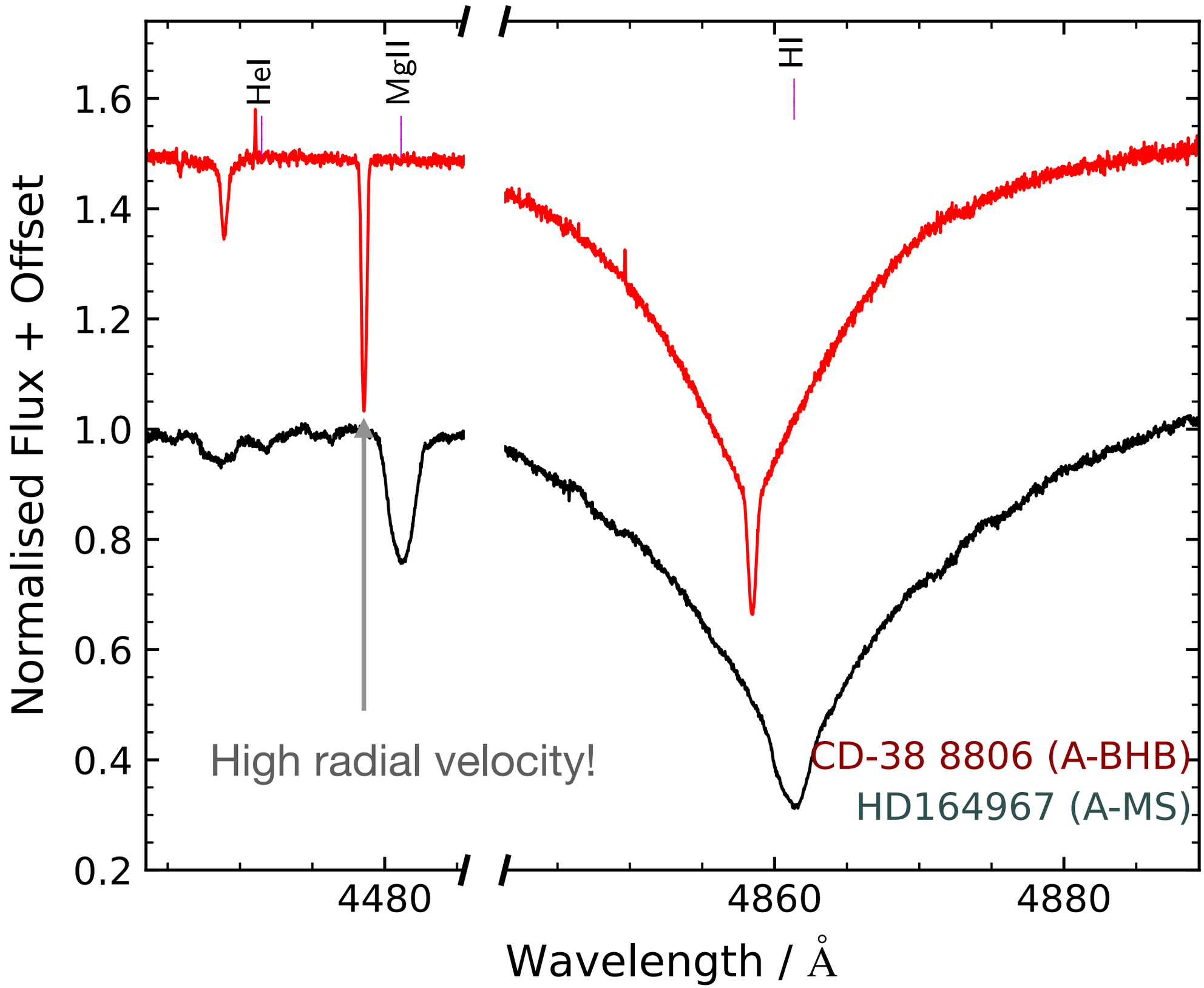


I. Radial velocity

Radial velocity — v_{rad}

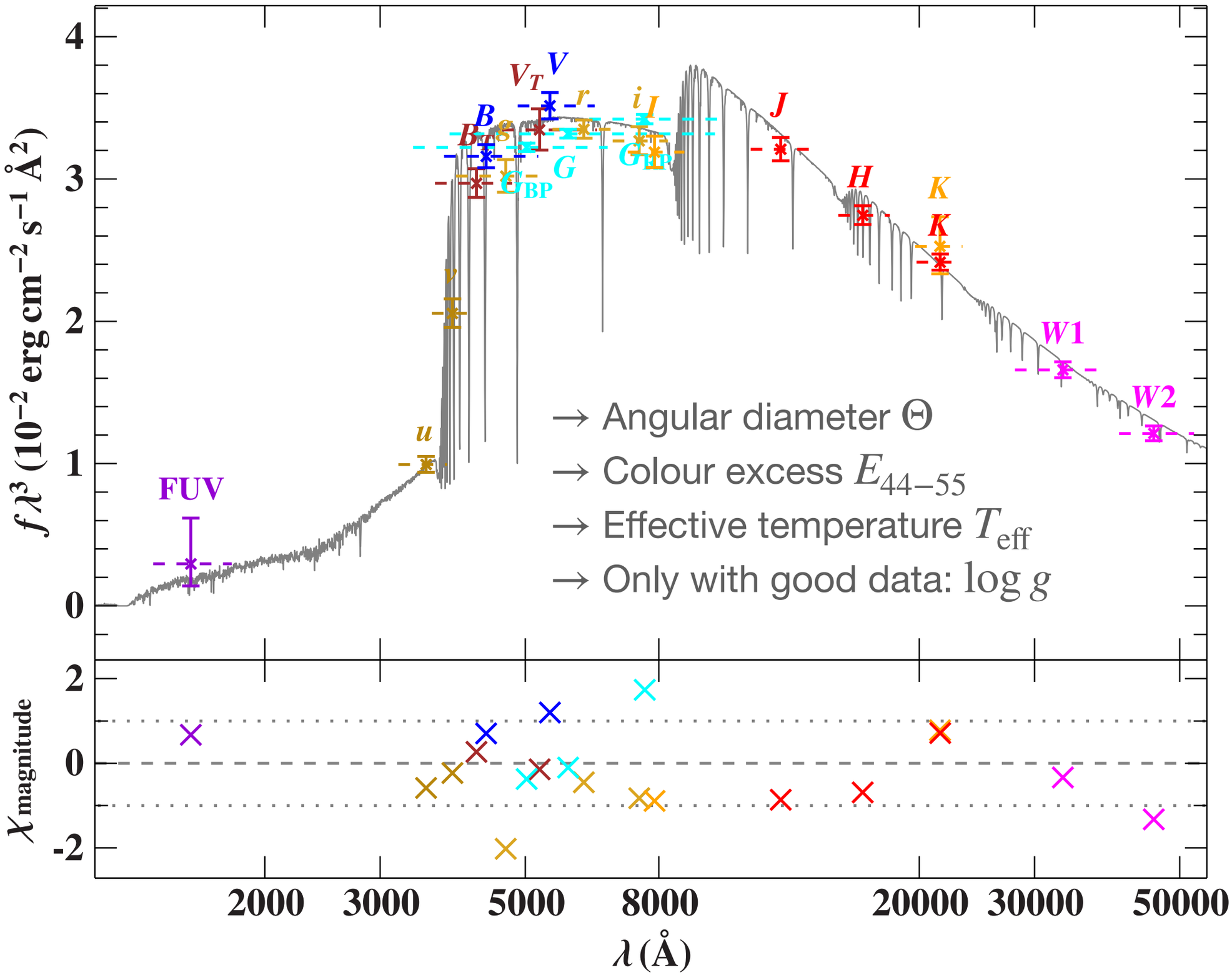


Radial velocity — v_{rad}



II. Spectral energy distribution — *R*, *L*, *M*

Spectral energy distribution (SED)



Radius, mass, and luminosity

©ESA

Radius R, mass M, and luminosity L from

- Spectroscopy
  $\rightarrow$ surface gravity $g = GM/R^2$, T_{eff}
- SED fit using spec. atm. parameters
  $\rightarrow$ angular diameter Θ
- Parallax measurements by *Gaia* EDR3 $\rightarrow$ distance $d = 1/\varpi$

Then, with the gravitational constant G:

$$R = \frac{\Theta}{2\varpi} \qquad M = \mathrm{R}^2 \cdot \frac{g}{G} \qquad L = 4\pi\sigma \mathrm{R}^2 {T_{\mathrm{eff}}}^4$$

Object: CD-38 8806	68% confidence interval
Color excess $E(B-V)$ from SFD (1998)	0.0745 ± 0.0016 mag
Color excess $E(B-V)$ from S&F (2011)	0.0641 ± 0.0014 mag
Color excess $E(B-V)$ from Stilism (Capitanio+ 2017)	0.043 ± 0.020 mag
Distance from Stilism and $E(44-55)$	510^{+280}_{-330} pc
Color excess $E(44-55)$	$0.040^{+0.017}_{-0.021}$ mag
Extinction parameter $R(55)$ (fixed)	3.02
Angular diameter $\log(\Theta\,(\mathrm{rad}))$	$-9.943^{+0.010}_{-0.009}$
Parallax ϖ (*Gaia*, RUWE = 1.19)	1.52 ± 0.05 mas
Distance d (*Gaia*)	658^{+22}_{-21} pc
Effective temperature T_{eff}	10600^{+400}_{-500} K
Surface gravity $\log(g\,(\mathrm{cm\,s^{-2}}))$	4.0 ± 0.4
Microturbulence ξ (fixed)	$0\,\mathrm{km\,s^{-1}}$
Metallicity z (fixed)	0 dex
Helium abundance $\log(n(\mathrm{He}))$ (fixed)	-1.05
Radius $R = \Theta/(2\varpi)$ (mode)	$1.66 \pm 0.07\,R_\odot$
(median)	$1.67 \pm 0.07\,R_\odot$
Mass $M = gR^2/G$ (mode)	$0.5^{+1.1}_{-0.4}\,M_\odot$
(median)	$1.0^{+1.2}_{-0.6}\,M_\odot$
Luminosity $L/L_\odot = (R/R_\odot)^2(T_{\mathrm{eff}}/T_{\mathrm{eff},\odot})^4$ (mode)	32 ± 6
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Gravitational redshift $v_{\mathrm{grav}} = GM/(Rc)$	$0.18^{+0.39}_{-0.12}\,\mathrm{km\,s^{-1}}$
Generic excess noise δ_{excess}	0.010 mag
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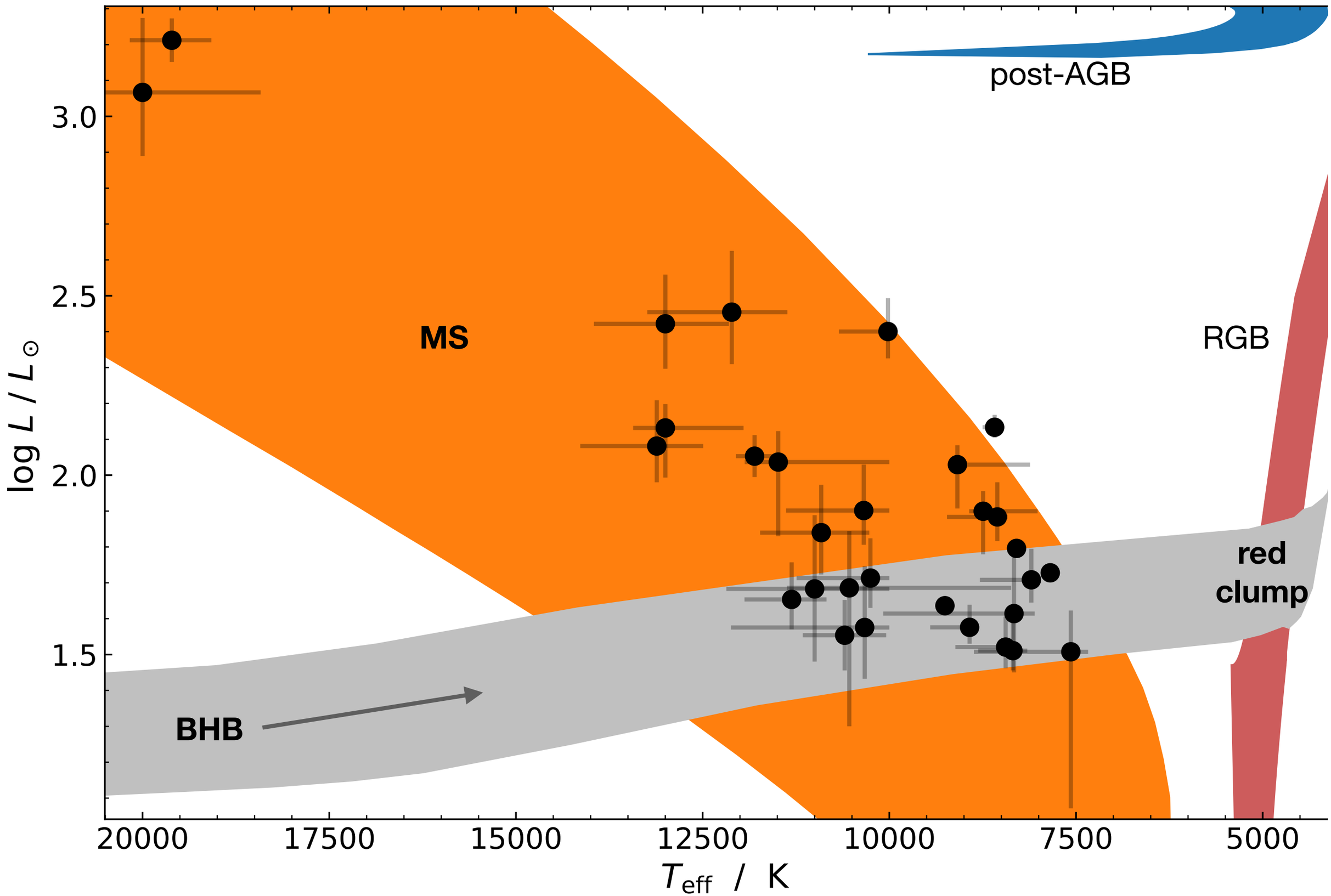


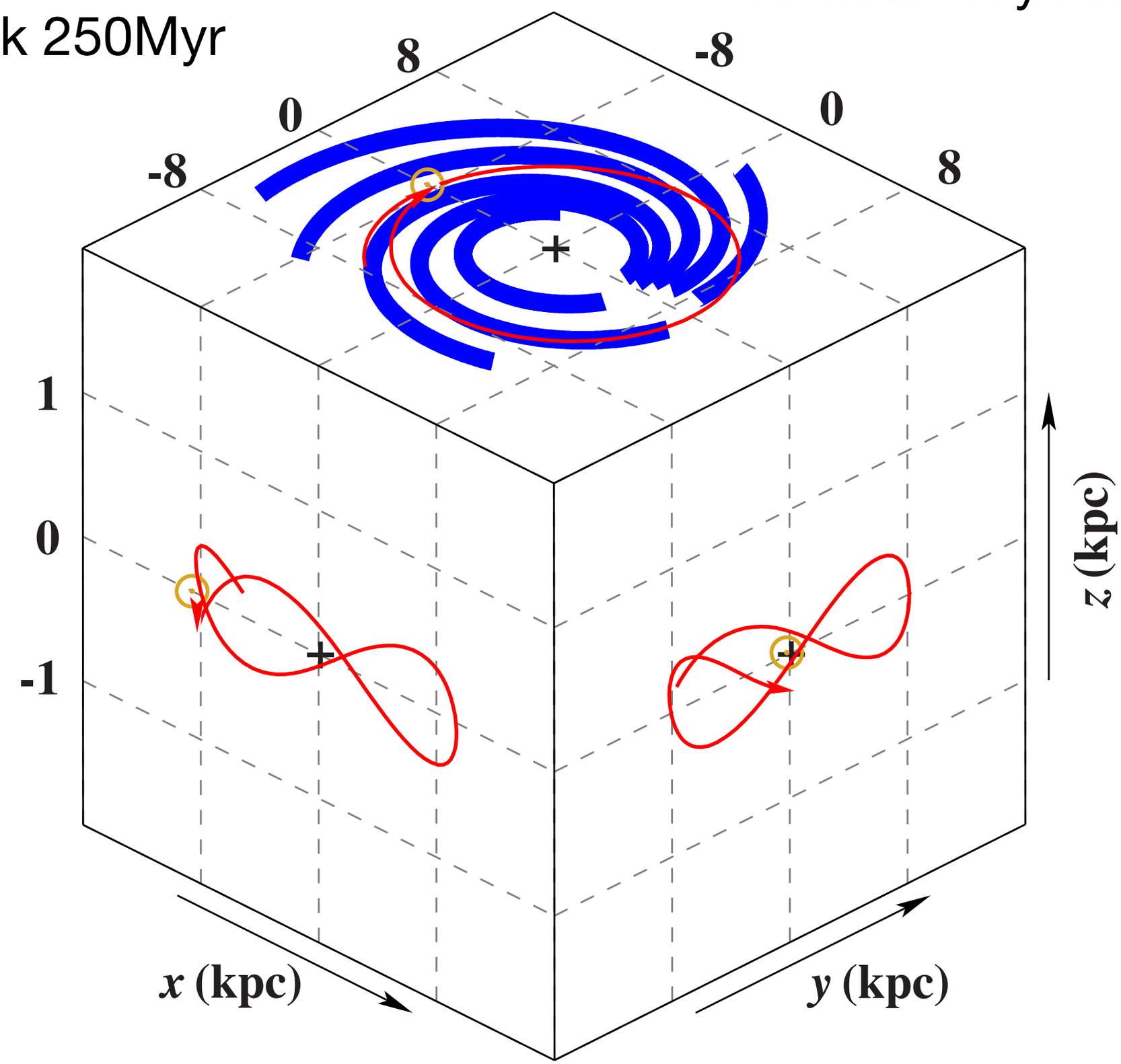
HB: Dorman et al. (1993) MS+RGB: BaSTI (Hidalgo et al. 2018) post-AGB: Miller-Bertolami et al. (2016)

III. Galactic kinematics

Galactic orbits

„Normal“ thin disk orbit:
not much beyond z = 0.3kpc

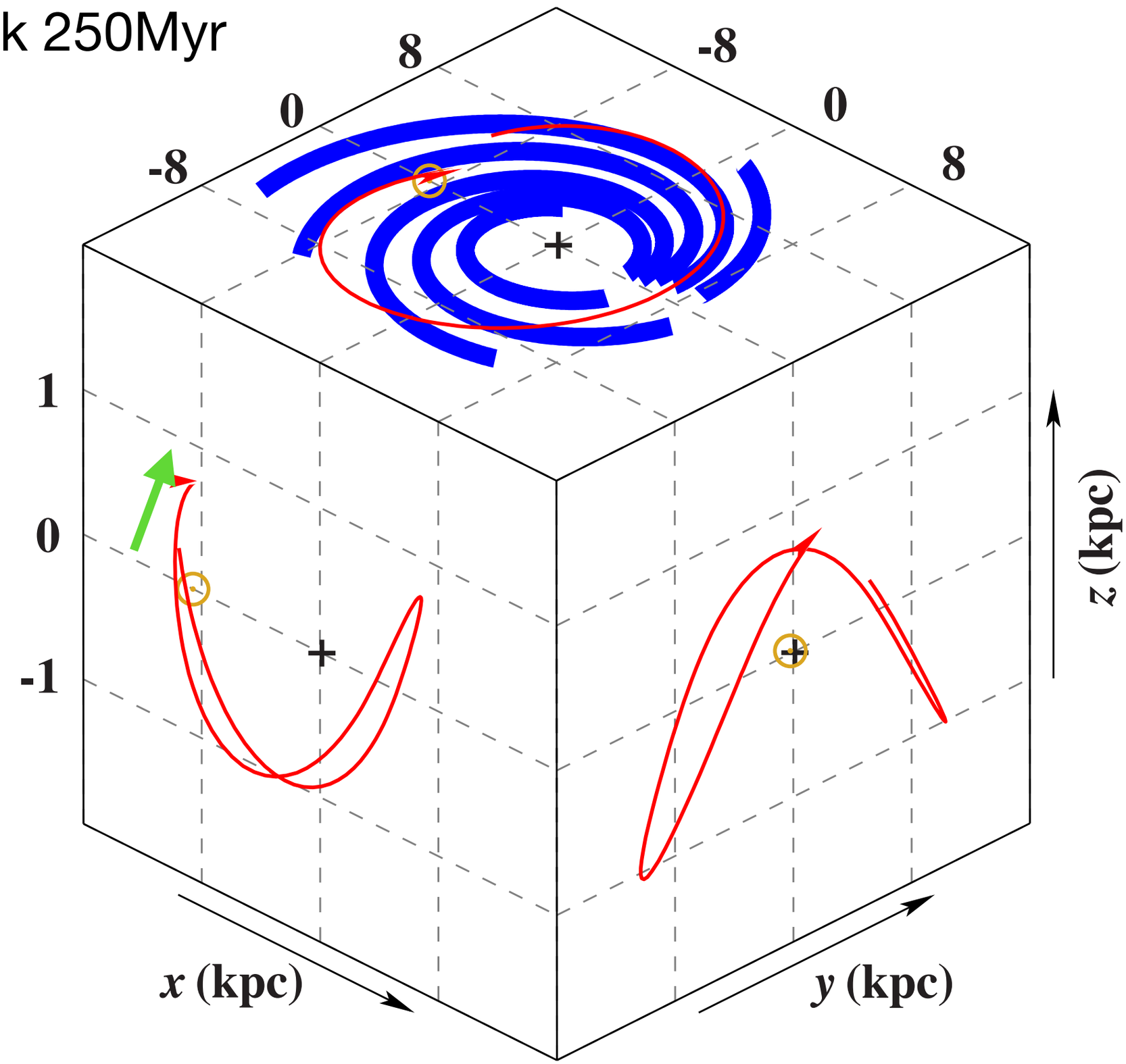
traced back 250Myr



Galactic orbits

traced back 250Myr

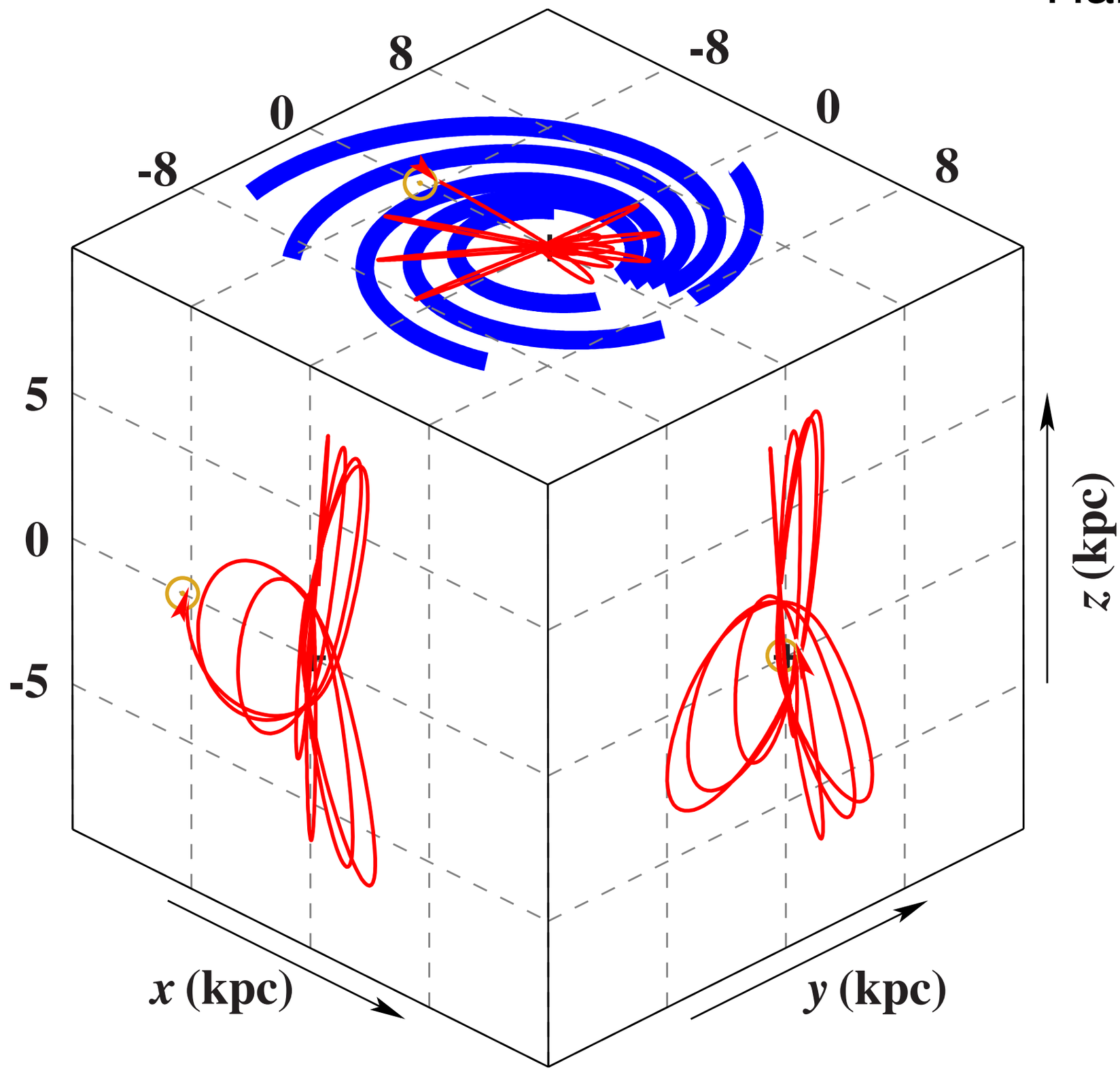
Escape from the disk!



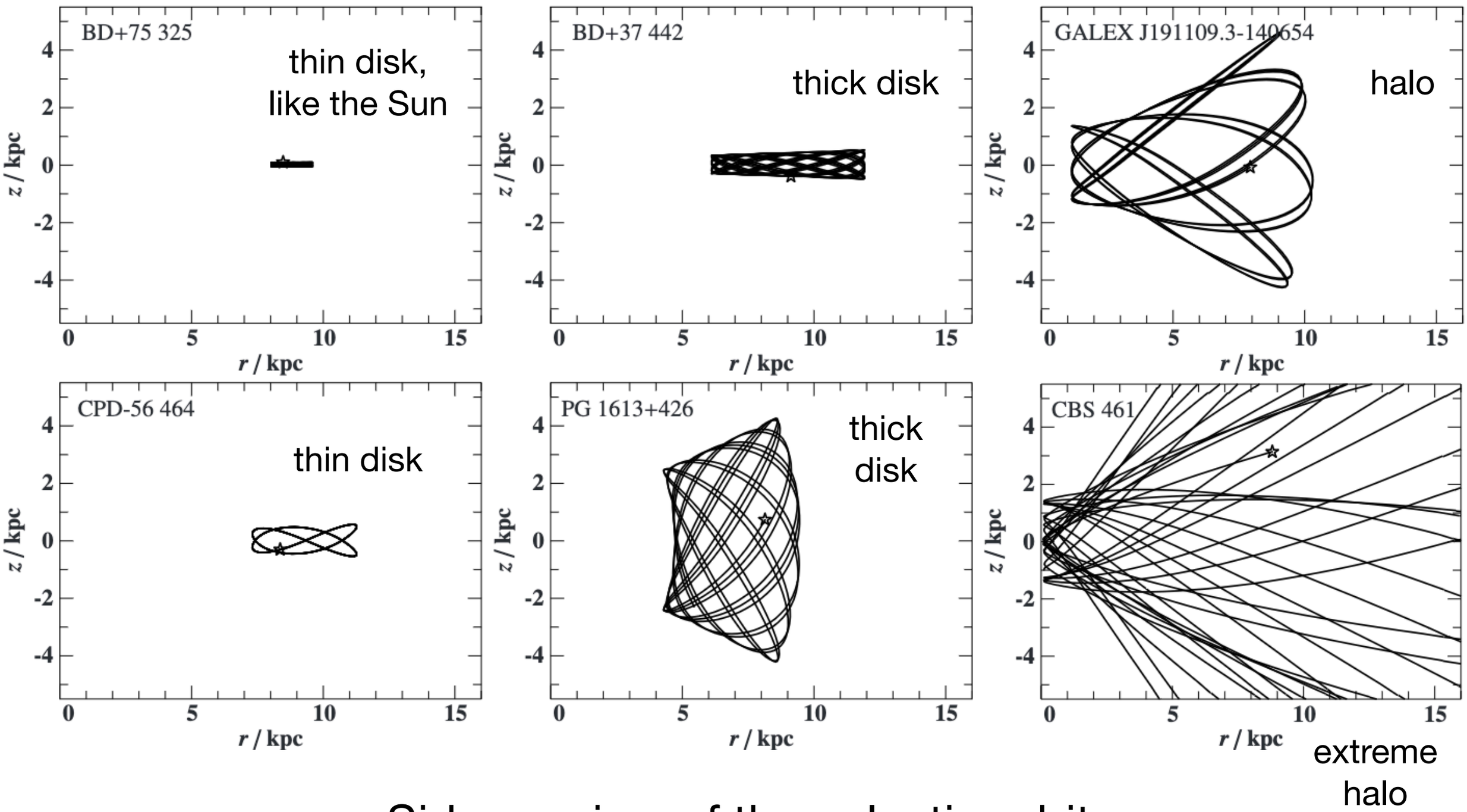
Galactic orbits

Halo orbit!

Note the difference in scale



Galactic orbits

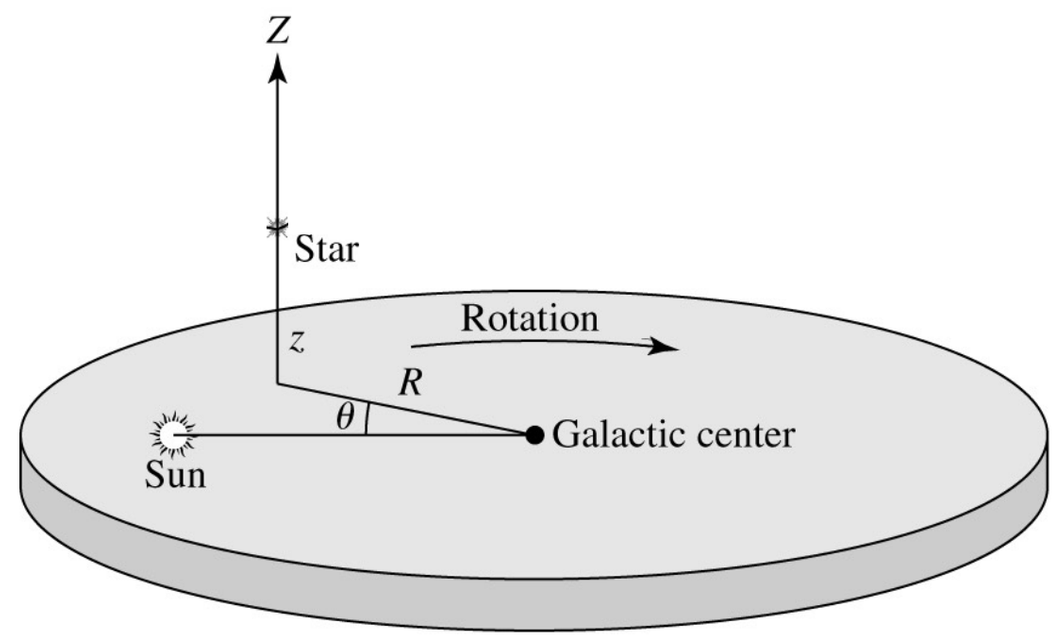


Side-on view of the galactic orbit
with abs(r)

Relevant parameters for runaway stars

- Current space velocities in galactocentric coordinates:
  - Radial velocity *U (v_r)*
  - Circular velocity *V (v_phi)*
  - Vertical velocity *W (v_z)*

→ Toomre diagram: V vs $\sqrt{U^2 + W^2}$



by Chris Mihos, Case Western Reserve University

- x, y (or R, phi) of last disk crossing
- Time of flight: time since the last disk crossing (z = 0)
  - Should be consistent with the stellar age
- Ejection velocity at the time of the last disk crossing
  - Tells us about the possible ejection mechanisms

Just suggestions on this slide!

Practical part

Get the necessary tools here:

`https://www.astro.physik.uni-potsdam.de/~mdorsch/`

Set up the line list for the „SPAS“ tool:

```
cp linelist_spas ~/.spas
```

The SED fitting script

SEDs — automatic fits

```
isis photometry_auto.sl 6114877567905306496
```

Gaia DR3 ID
or Simbad name

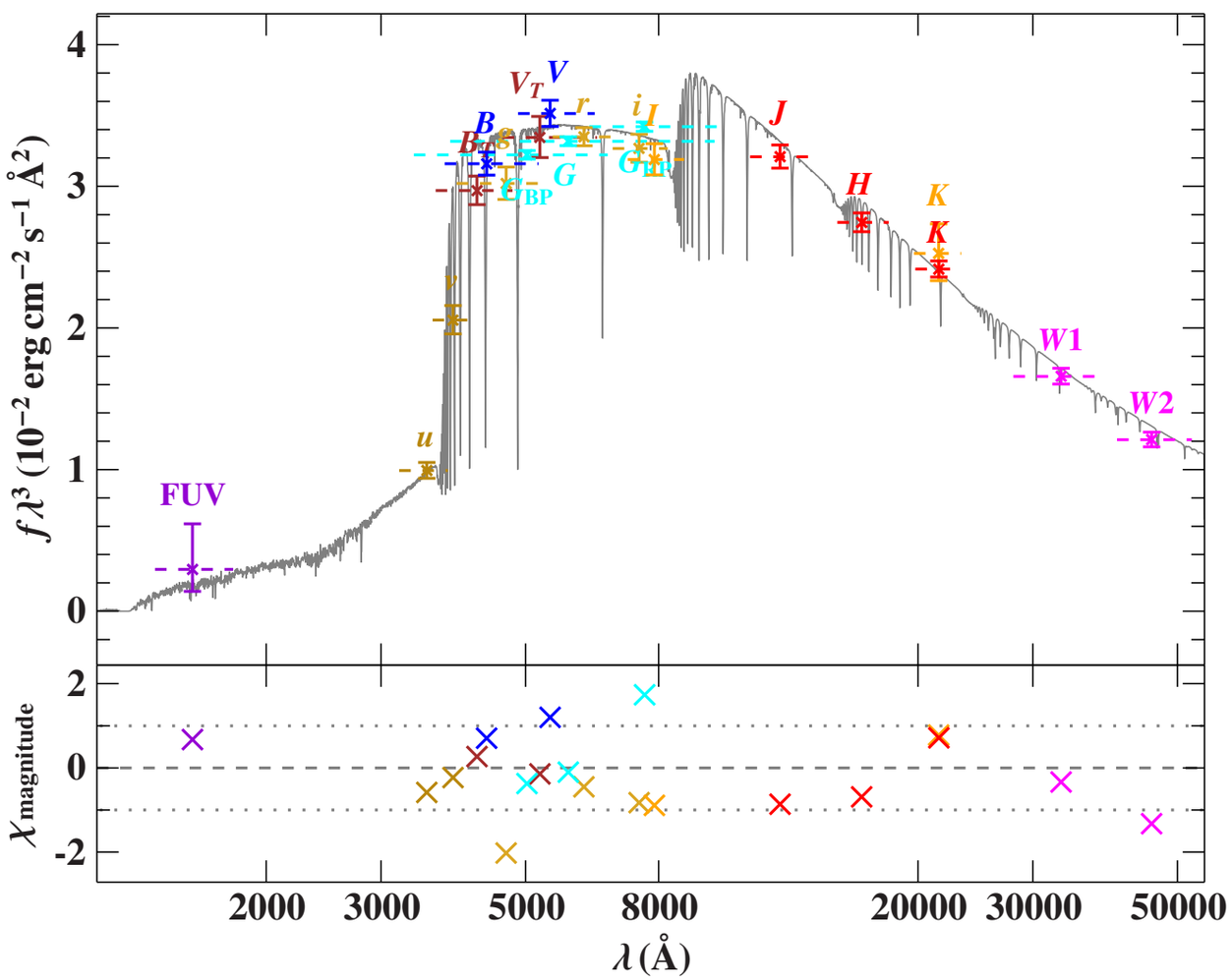
This works for any star, independent of spectroscopy.

Limited only by model grids:

- MS grid: $2300 \leq T_{\rm eff} \leq 15000\ {\rm K}, \quad 2.0 \leq \log g \leq 5.2$
- BHB grid: $9000 \leq T_{\rm eff} \leq 20000\ {\rm K}, \quad 3.8 \leq \log g \leq 7.0$
- Steven3/4: up to $T_{\rm eff} = 40000\ {\rm K}$

SEDs

```
isis photometry_auto.sl 6114877567905306496
```



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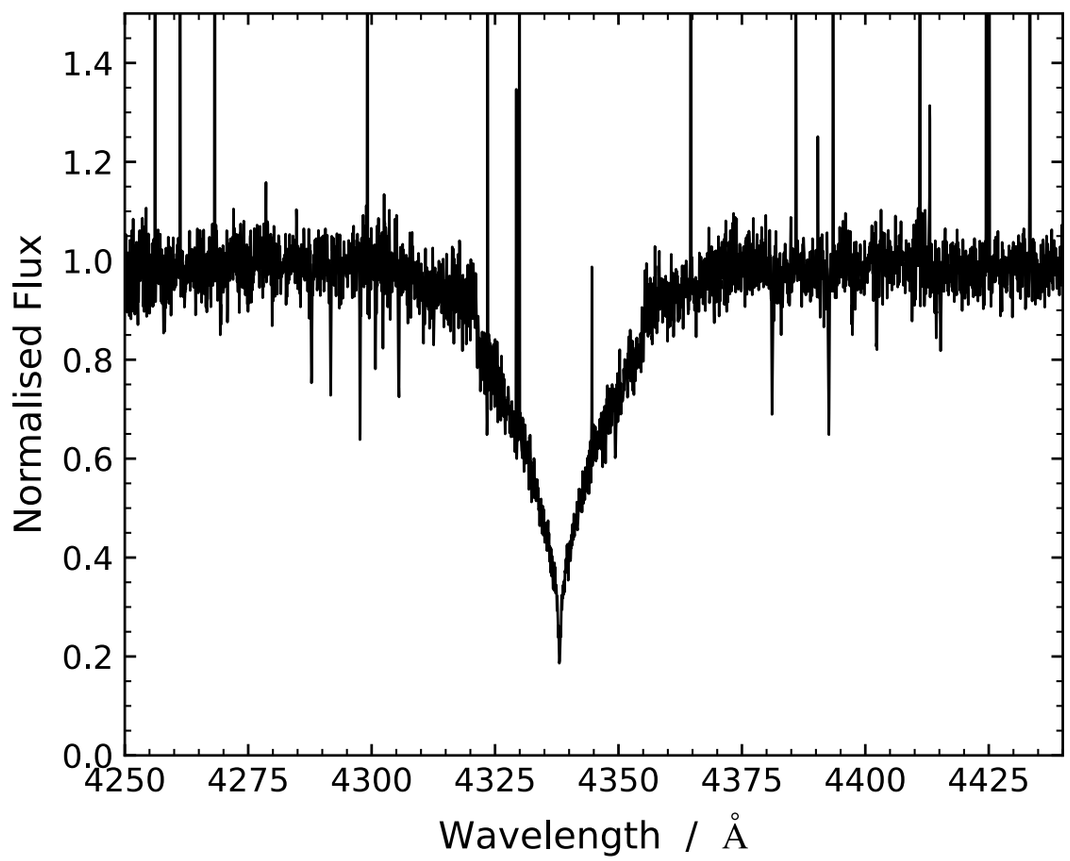
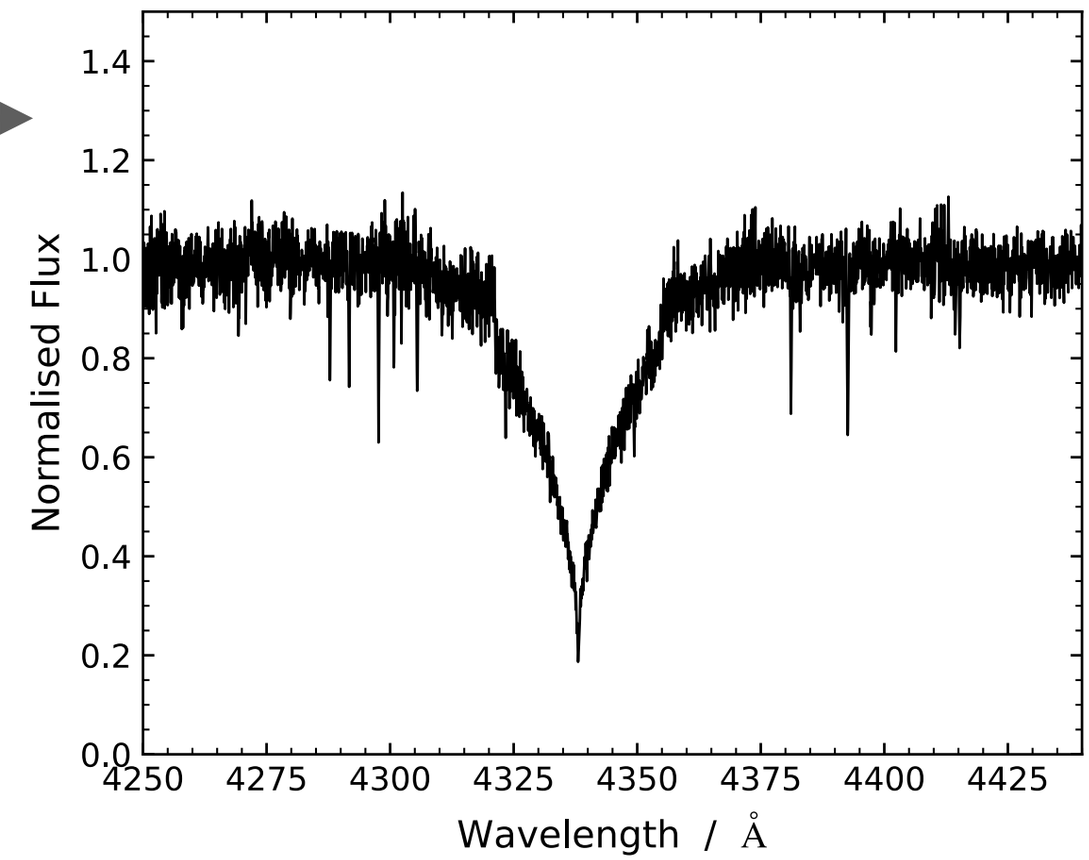
Radial velocity

SPAS — RV fitting





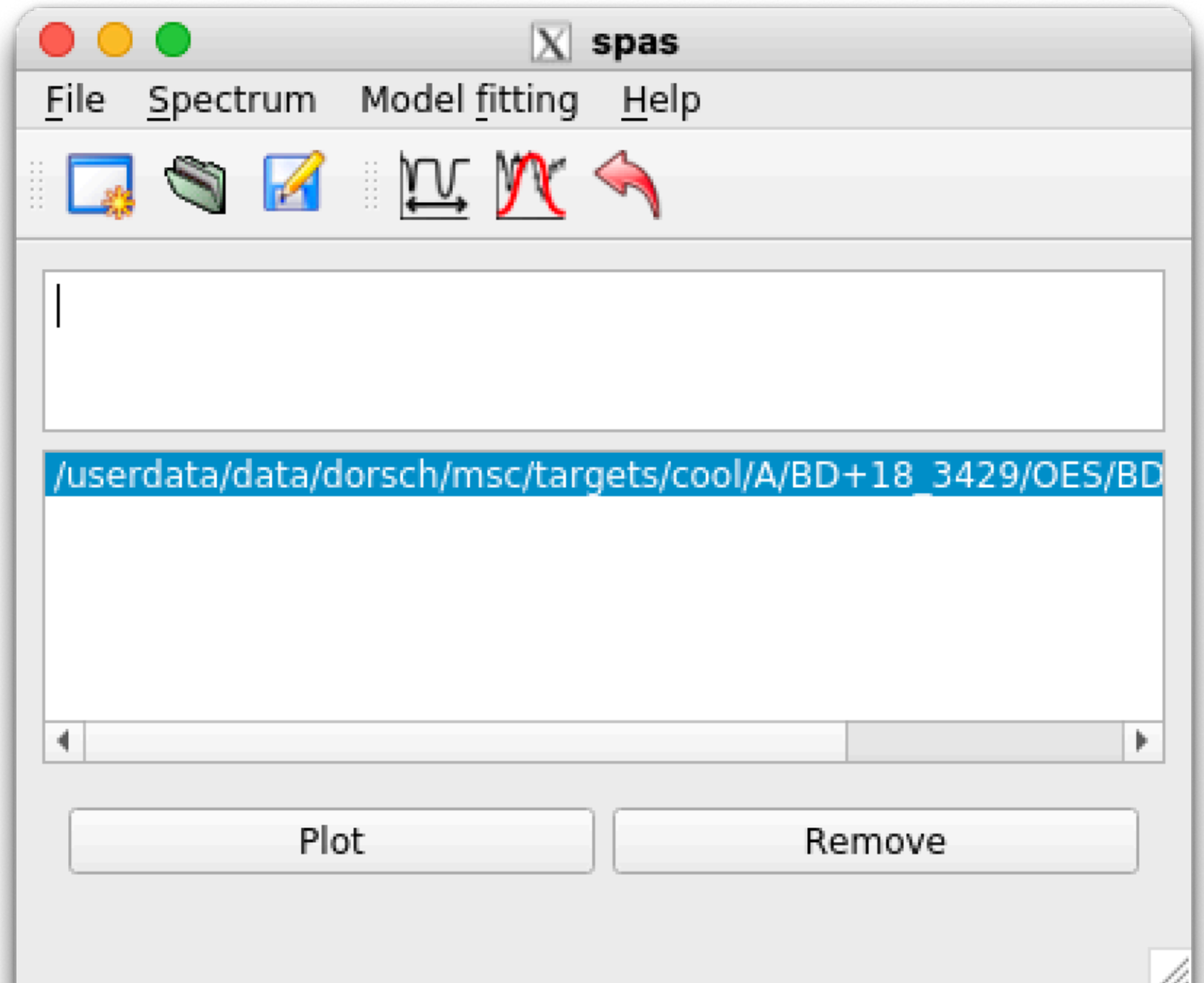
Convert „.fit“ extracted spectra to „.ascii“ tables. Searches for „.fit“ files in local dir:

```
mkdir spectroscopy; cd spectroscopy
cp /path/to/reduced_spectrum.fit .
isis convert_to_ascii.sl
```

This also removes cosmics and adds a column with estimated uncertainties.

SPAS — RV fitting

```
cp linelist_spas ~/.spas
~/bin/spas /path/to/reduced_spectrum.ascii
```



SPAS — RV fitting

```
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~/spas reduced_spectrum.ascii
```
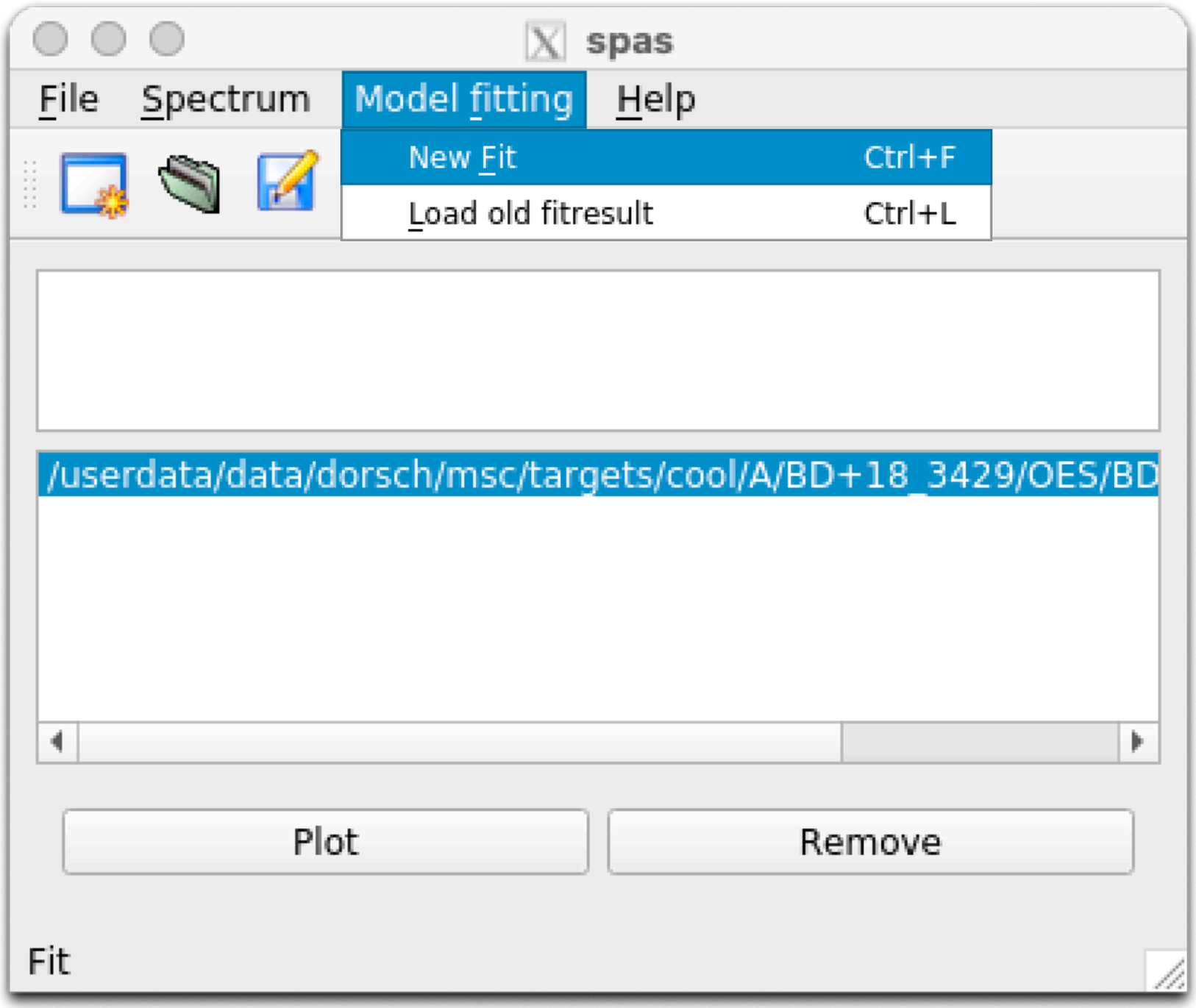
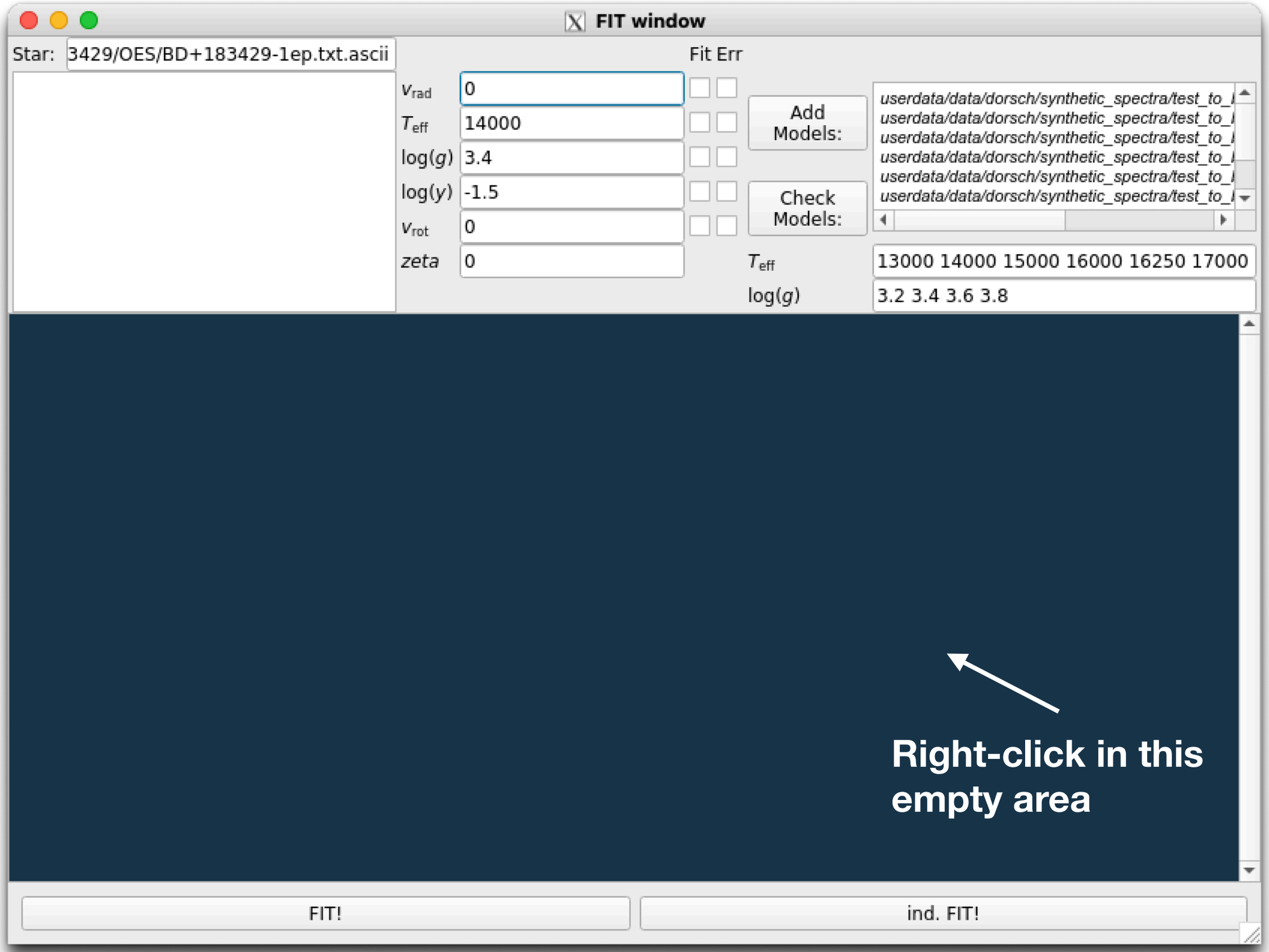
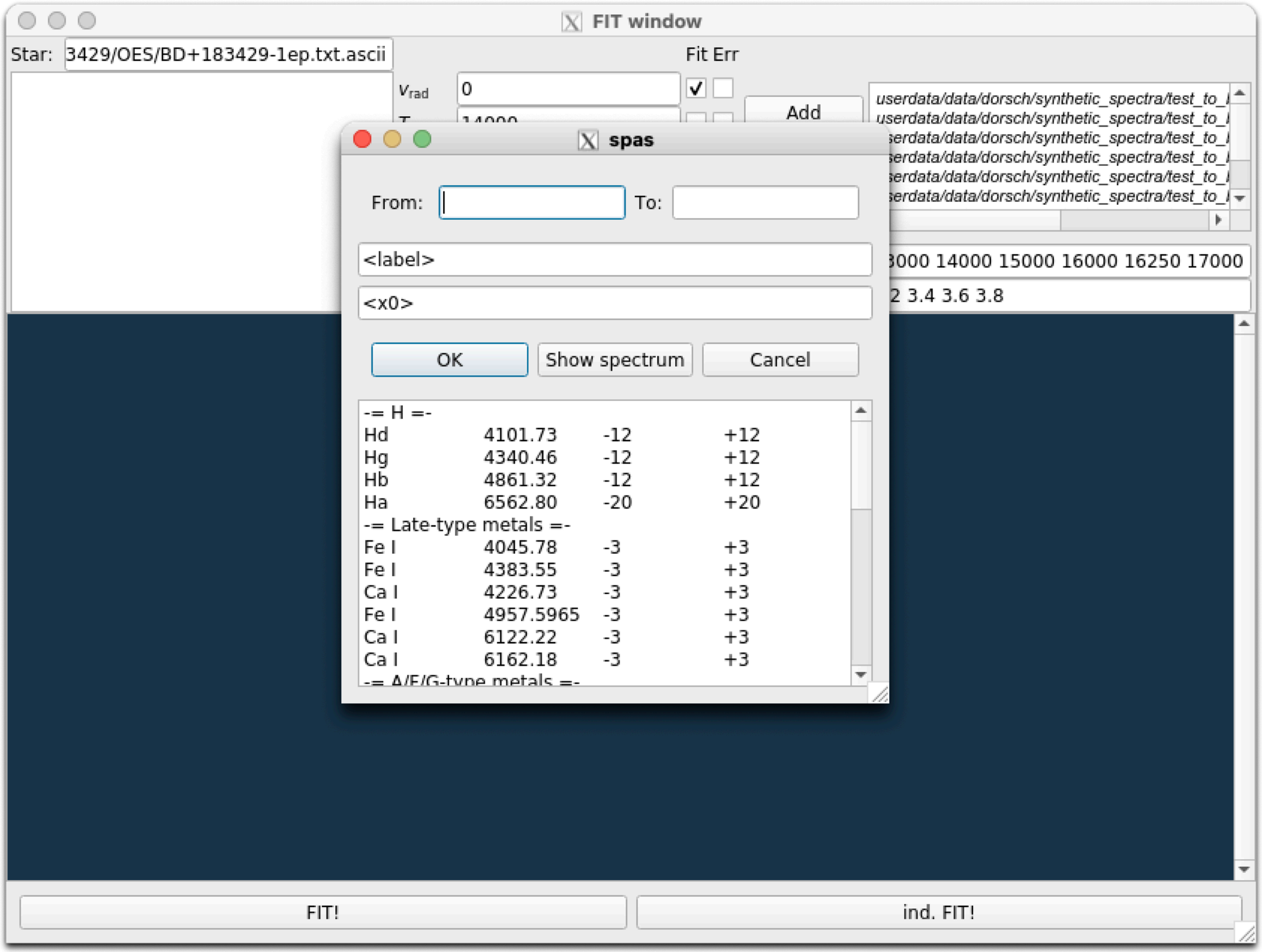



SPAS — RV fitting

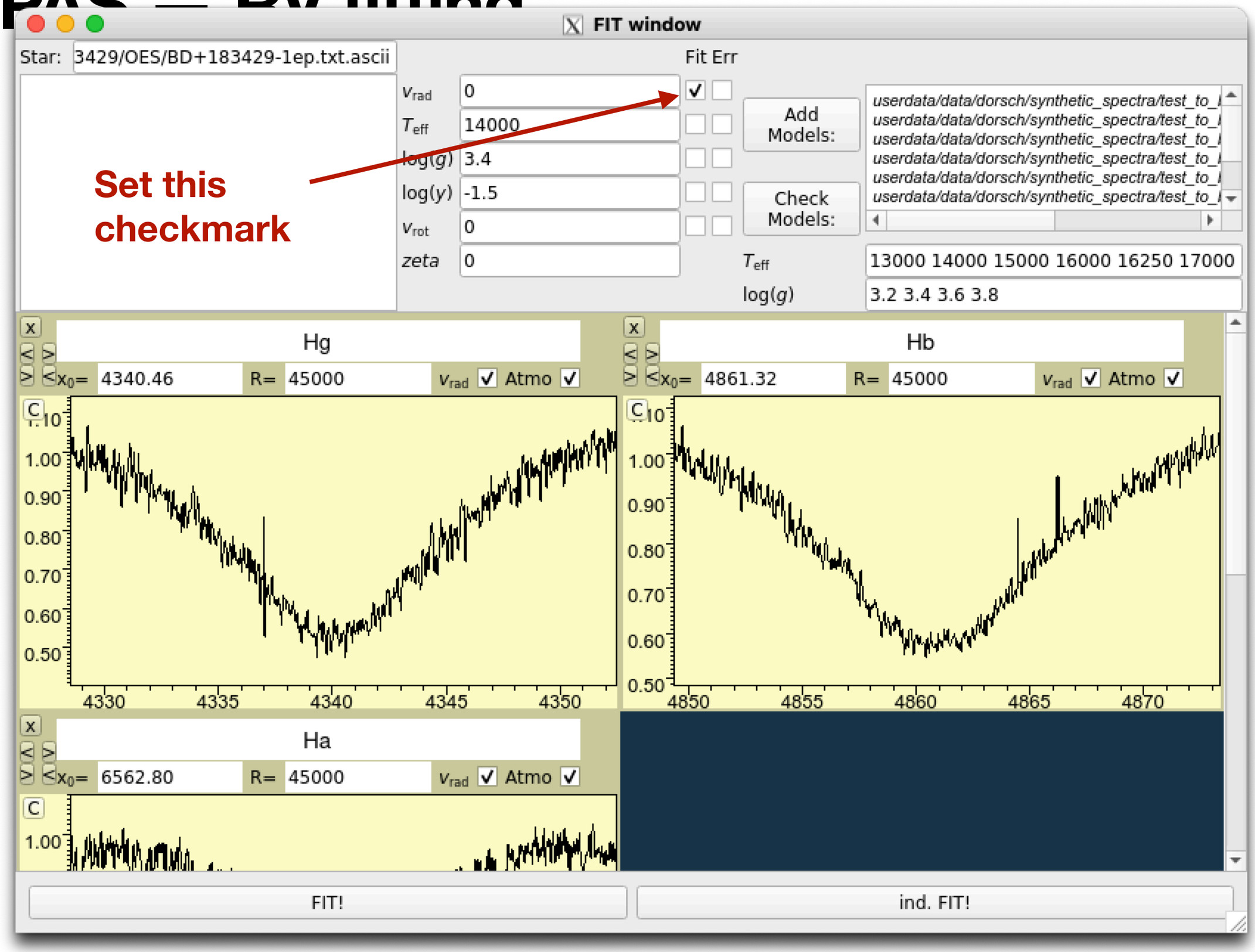


SPAS — RV fitting



SPAS — RV fitting

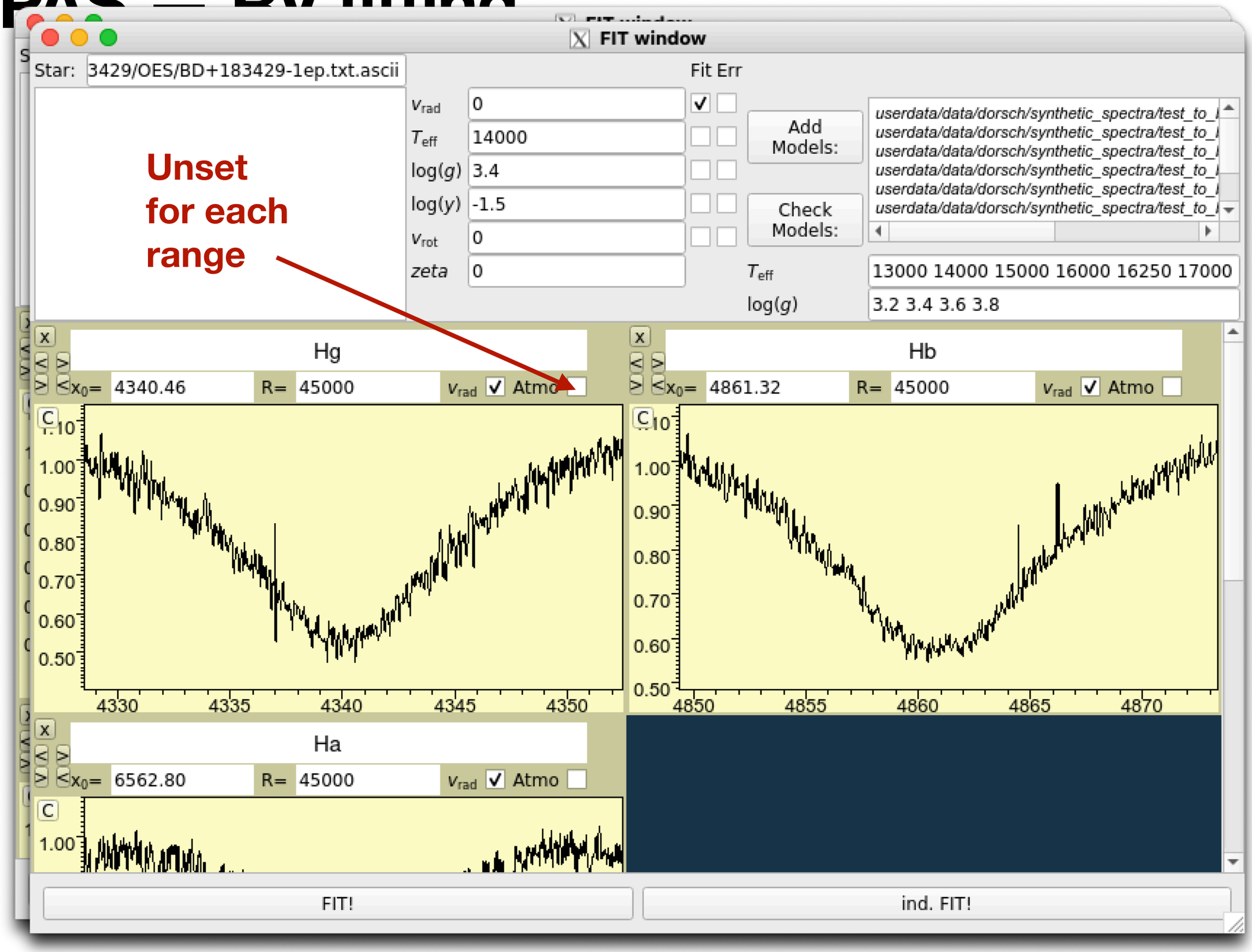
Without model grid



Set this checkmark

SPAS — RV fitting

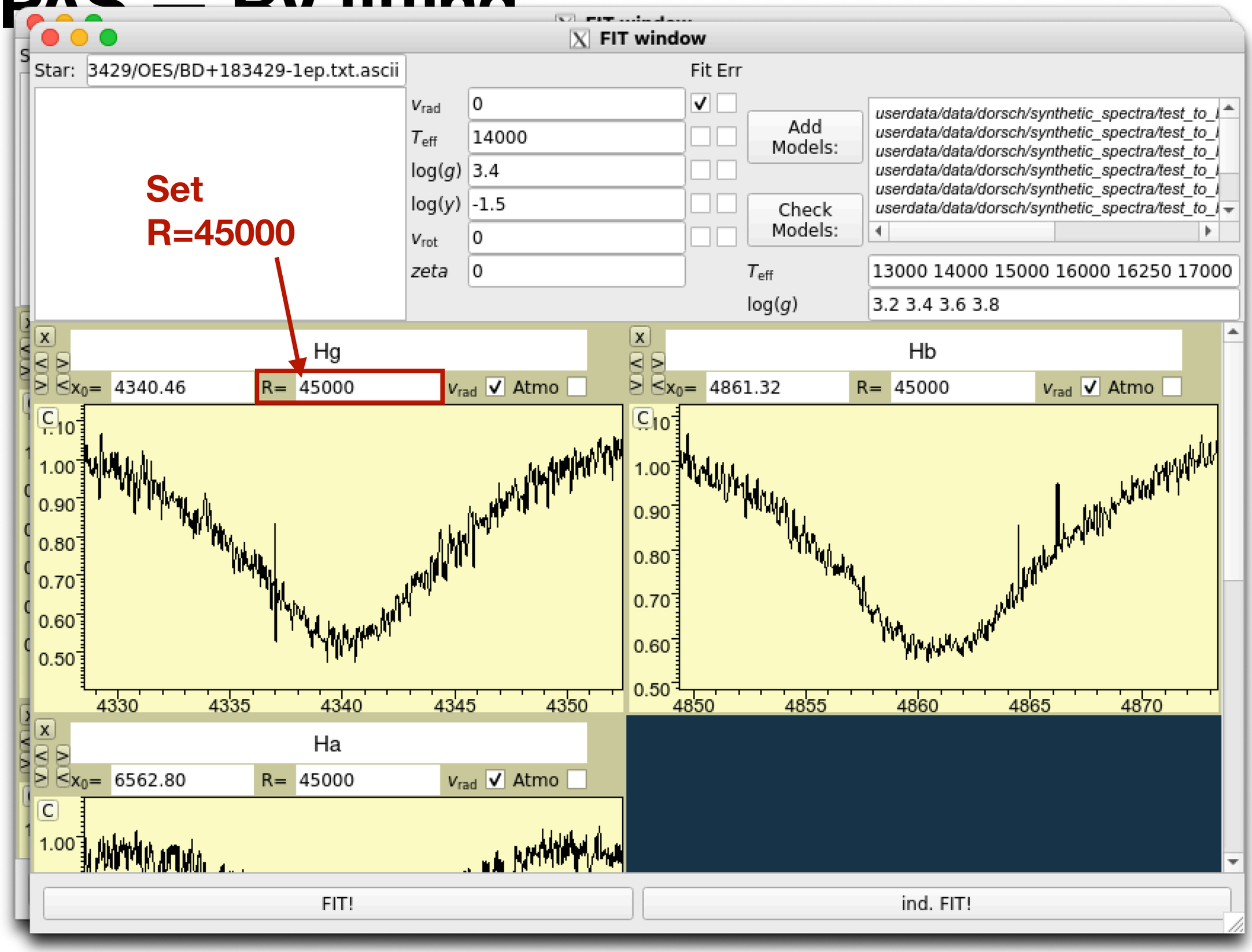
Without model grid



Unset for each range

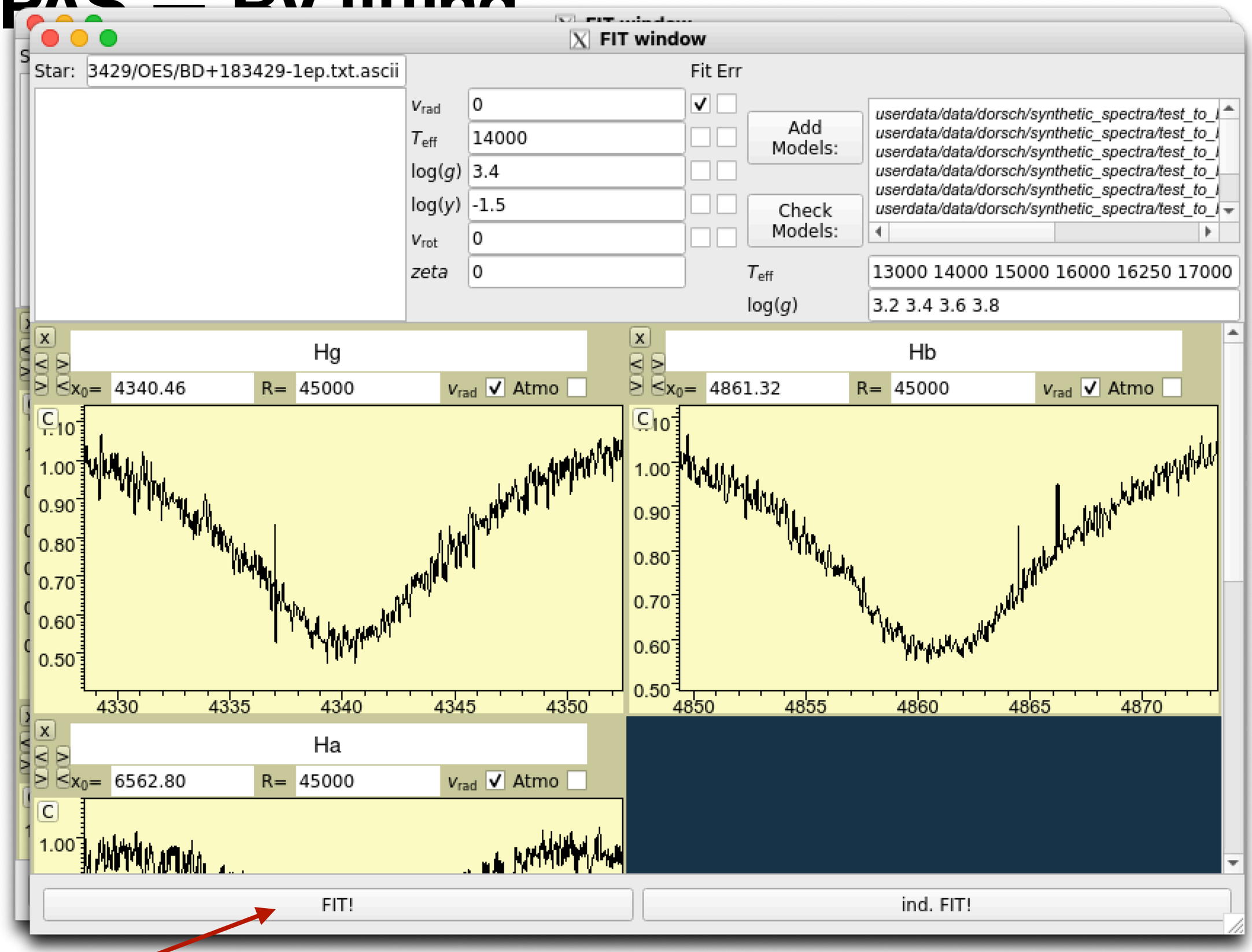
SPAS — RV fitting

Without model grid



SPAS – RV fitting

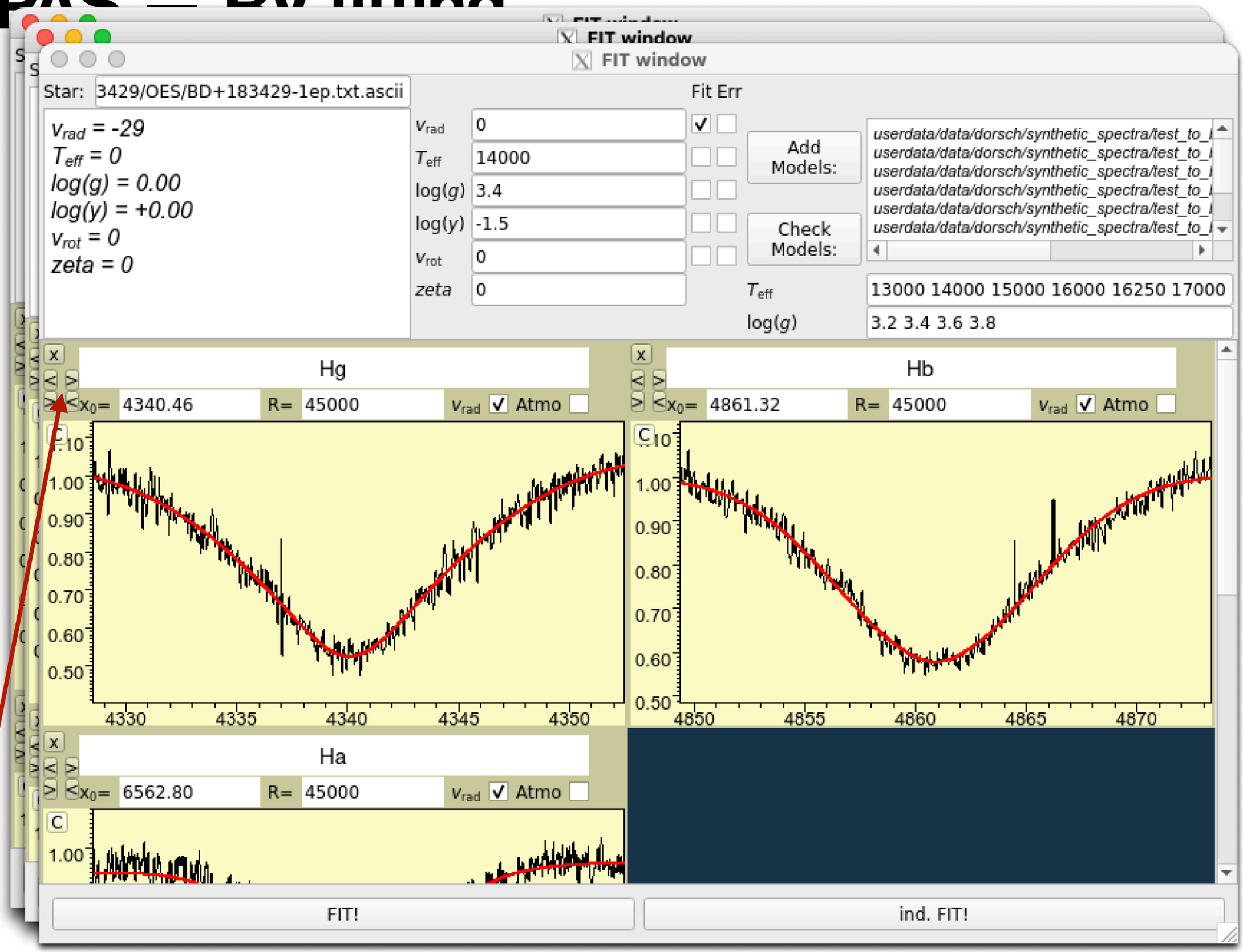
Without model grid



Then press „FIT!“

SPAS — RV fitting

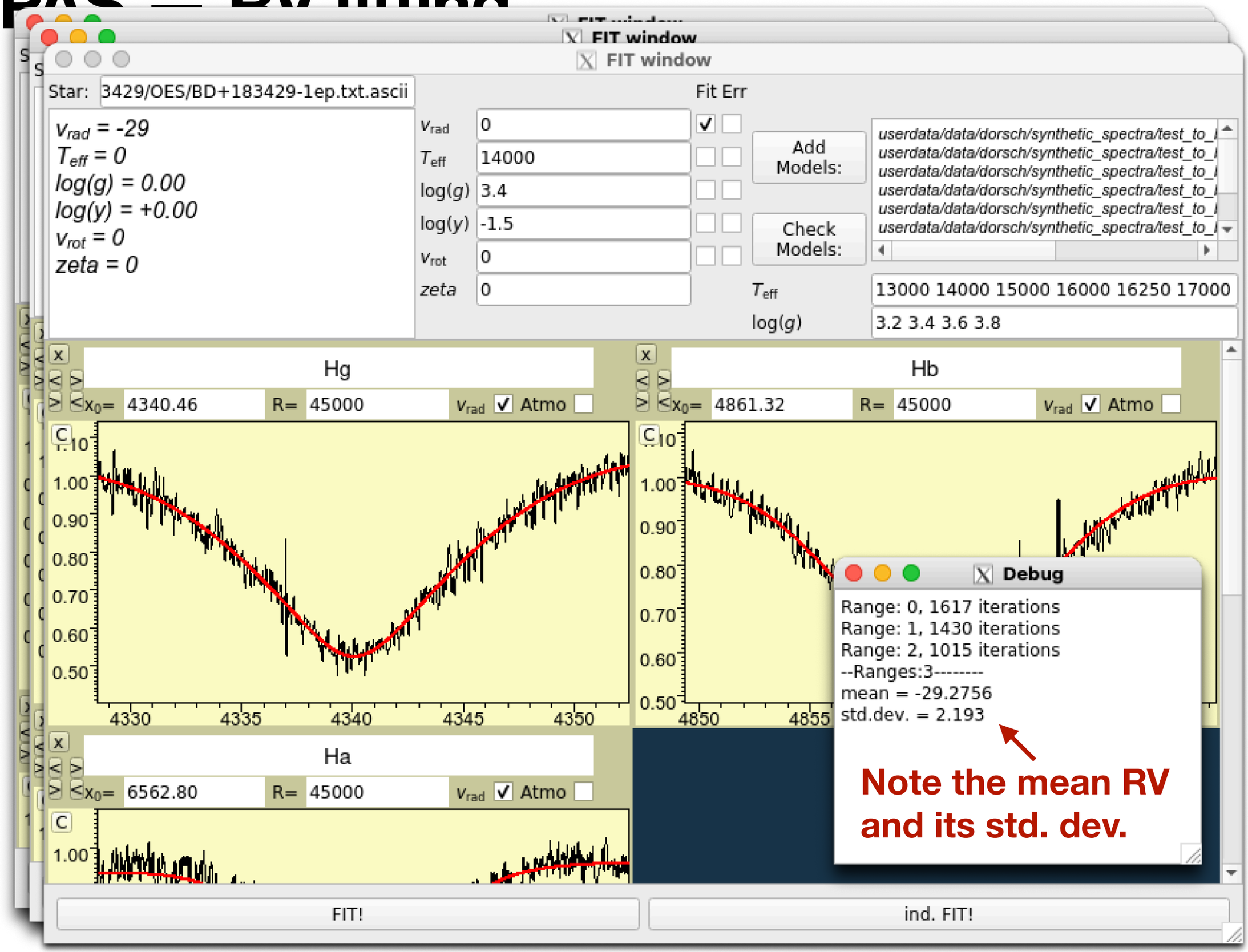
Without model grid



Use these buttons to change the range until the fit works. Center the correct line.

SPAS — RV fitting

Without model grid



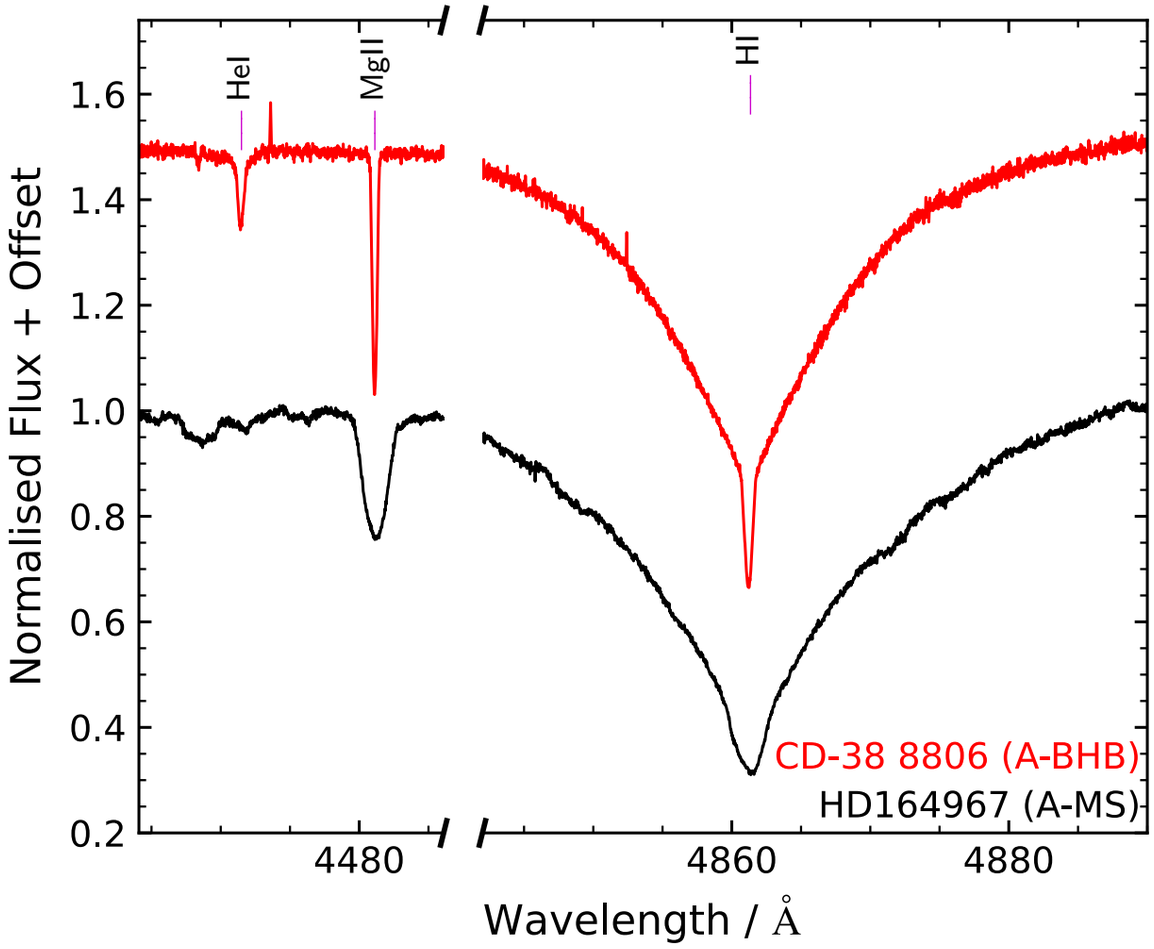
Note the mean RV and its std. dev.

Rotation

Projected rotational velocity

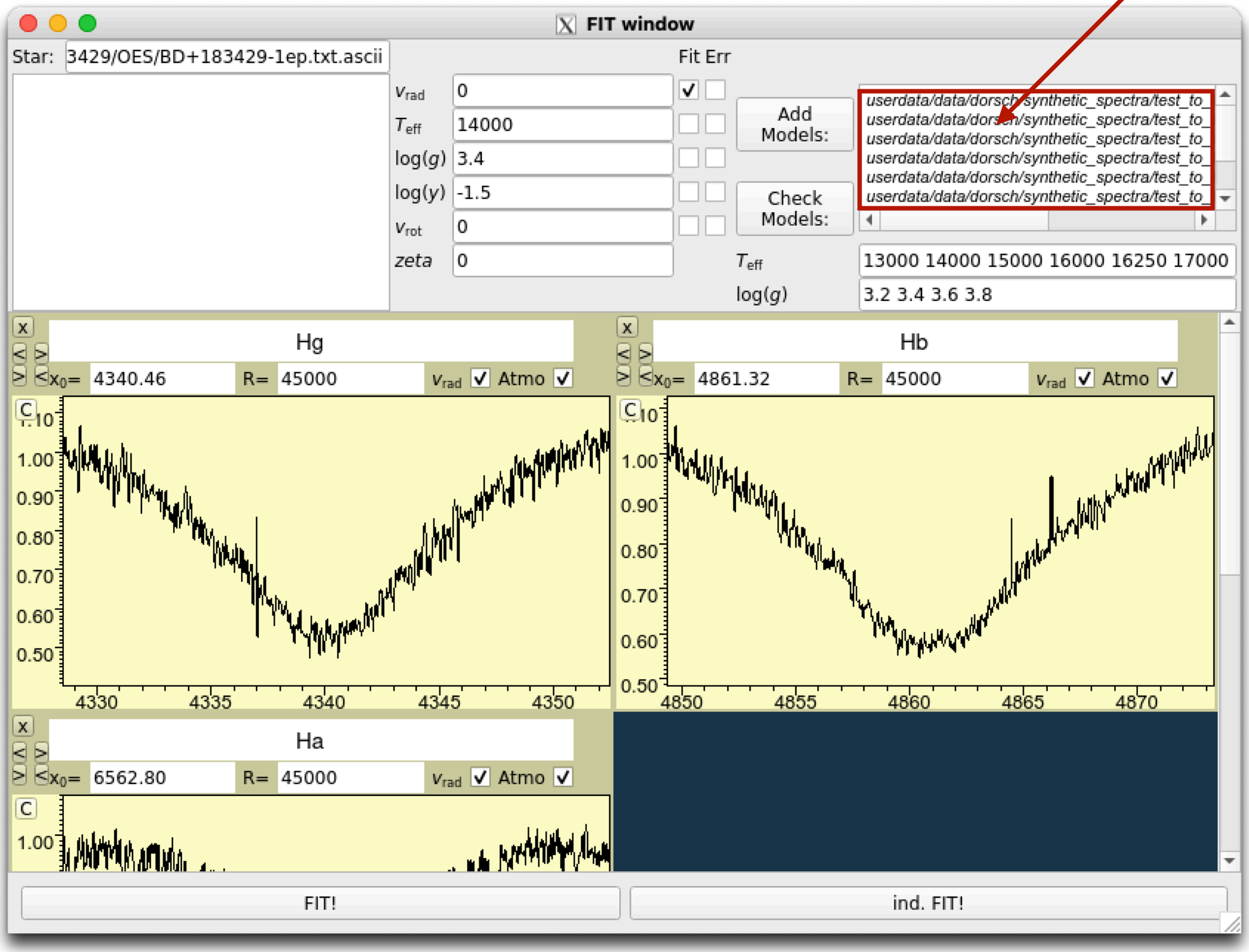
Plotting spectra

- Show some evidence of (projected) rotation or lack thereof
- You can use:
  - IRAF
  - SPAS
  - Python
  - gnuplot
  - whatever you like



SPAS — RV fitting with grids

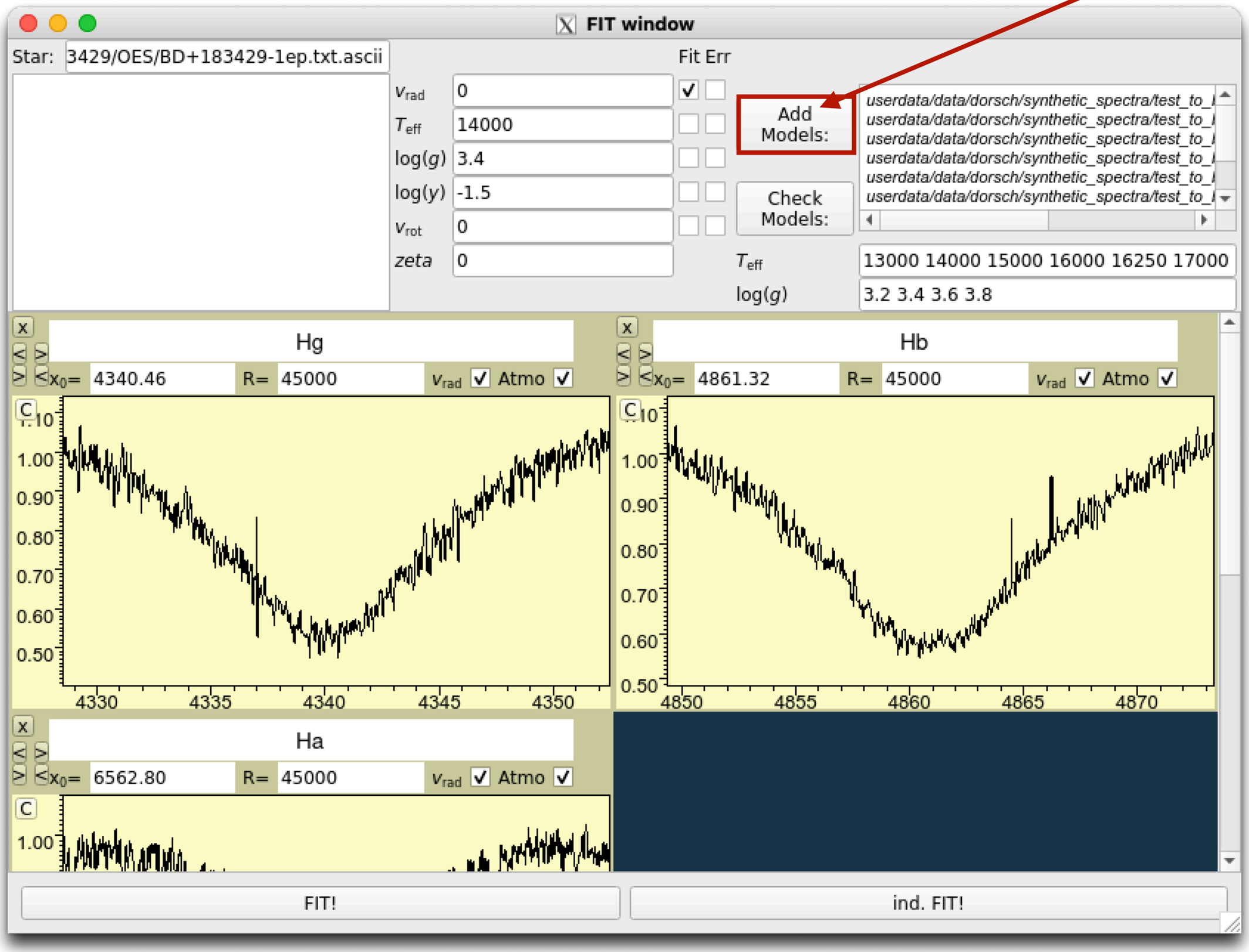
Remove this text



With model grid

SPAS — RV fitting with grids

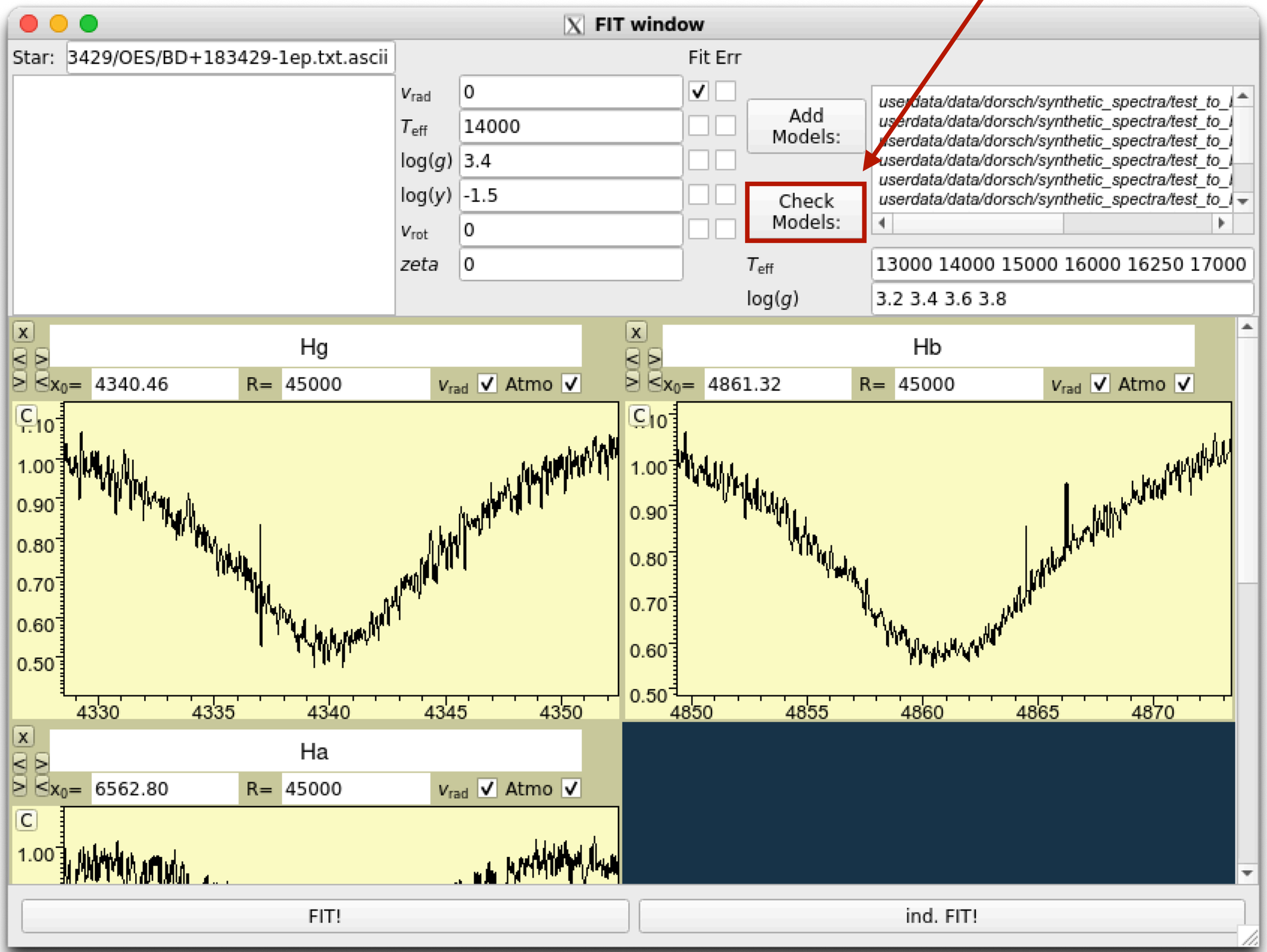
Add .bin files



With model grid

SPAS — RV fitting with grids

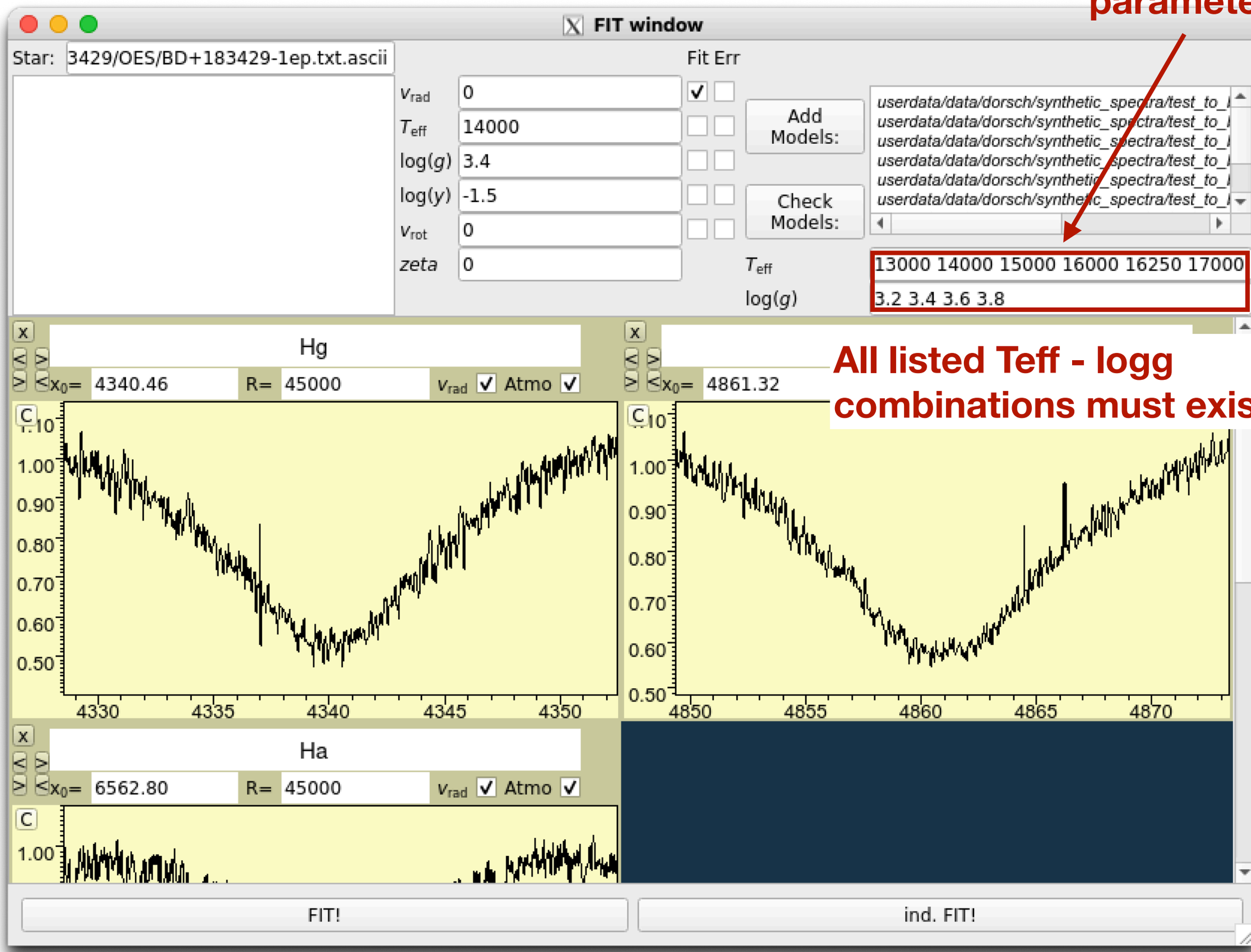
Check models to see coverage



With model grid

SPAS — RV fitting with grids

Set available parameters

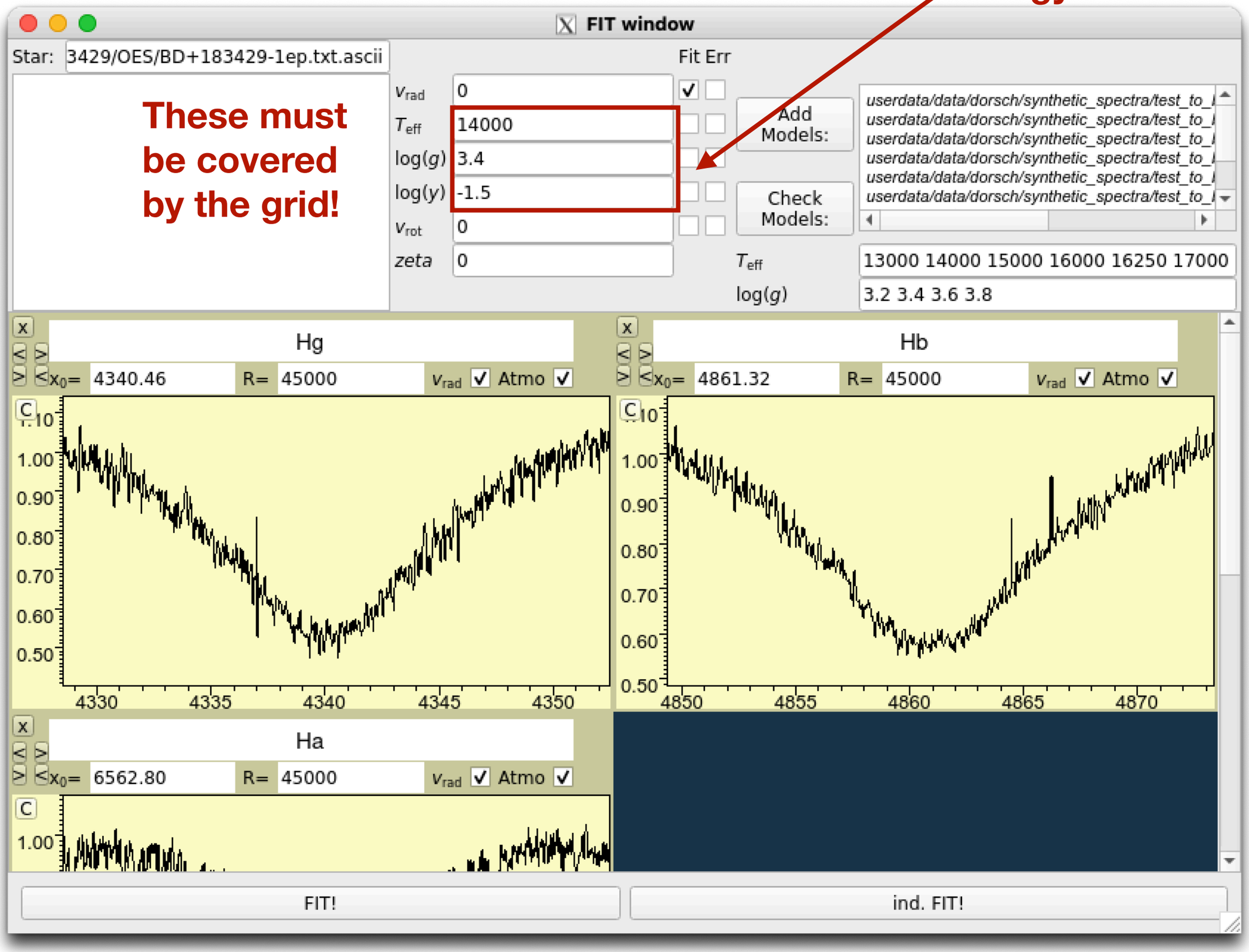


All listed Teff - logg combinations must exist!

With model grid

SPAS — RV fitting with grids

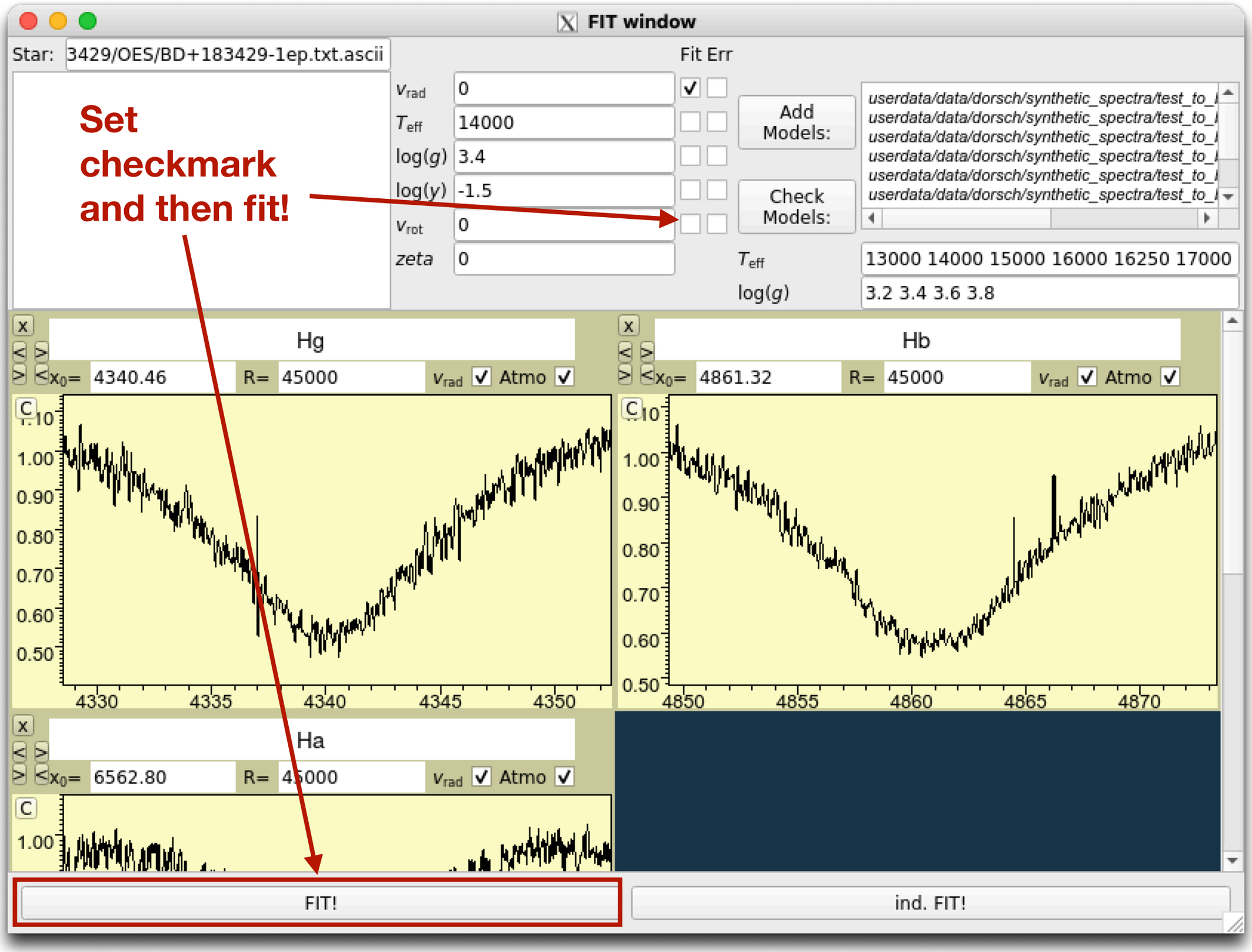
Set Teff, logg from SED; logy ~-1



These must be covered by the grid!

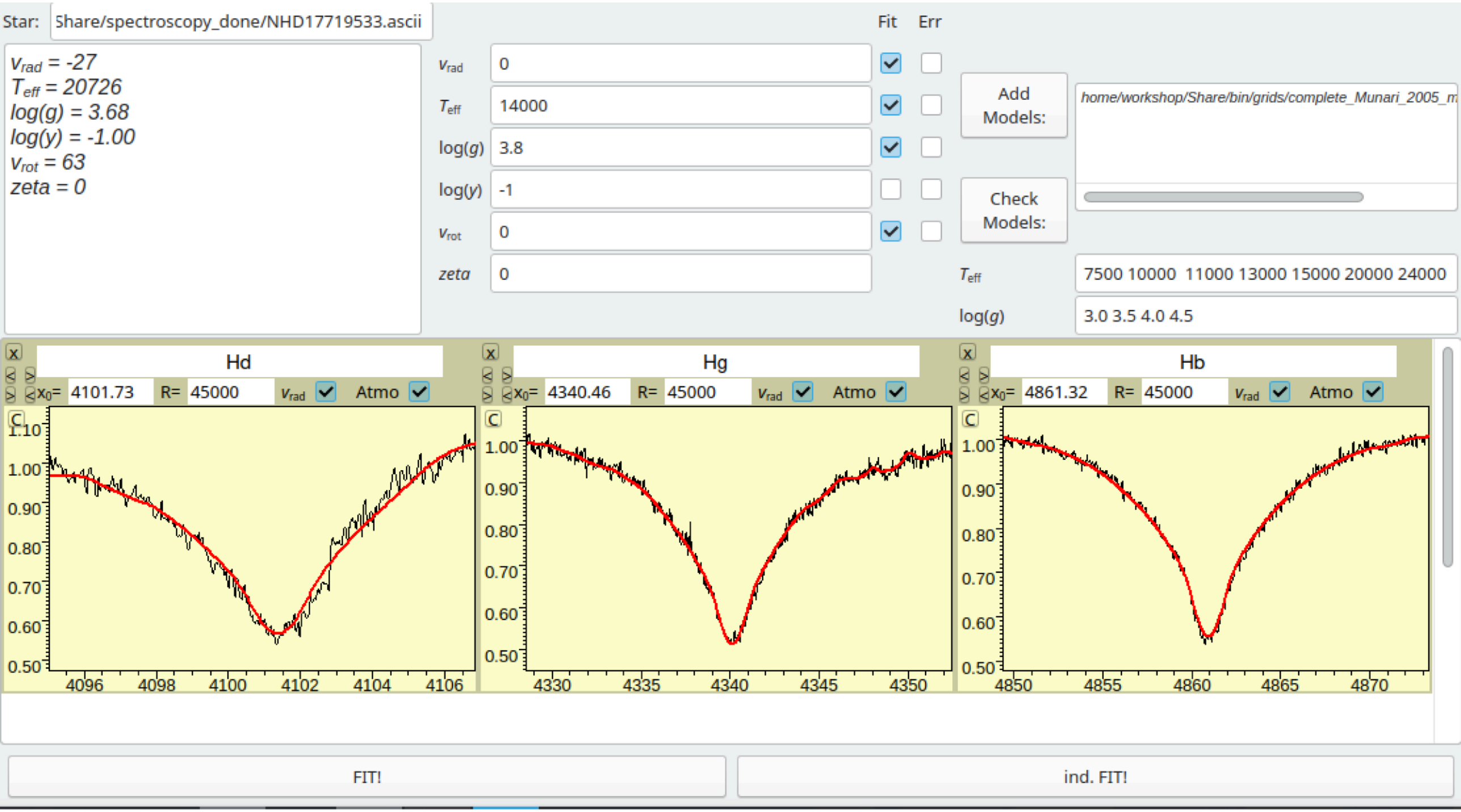
With model grid

SPAS — RV fitting with grids



With model grid

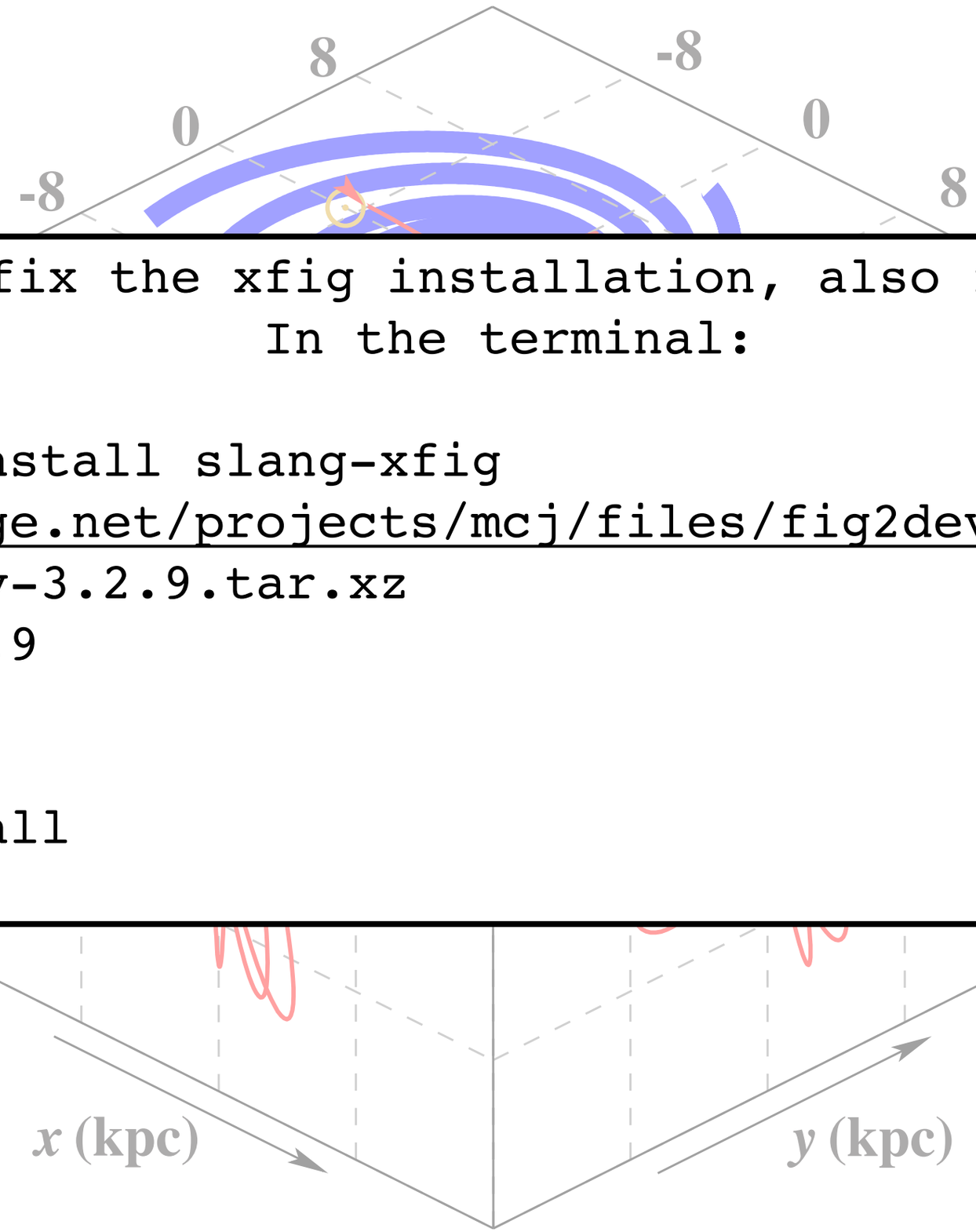
SPAS — RV fitting with grids



With model grid

Galactic kinematics

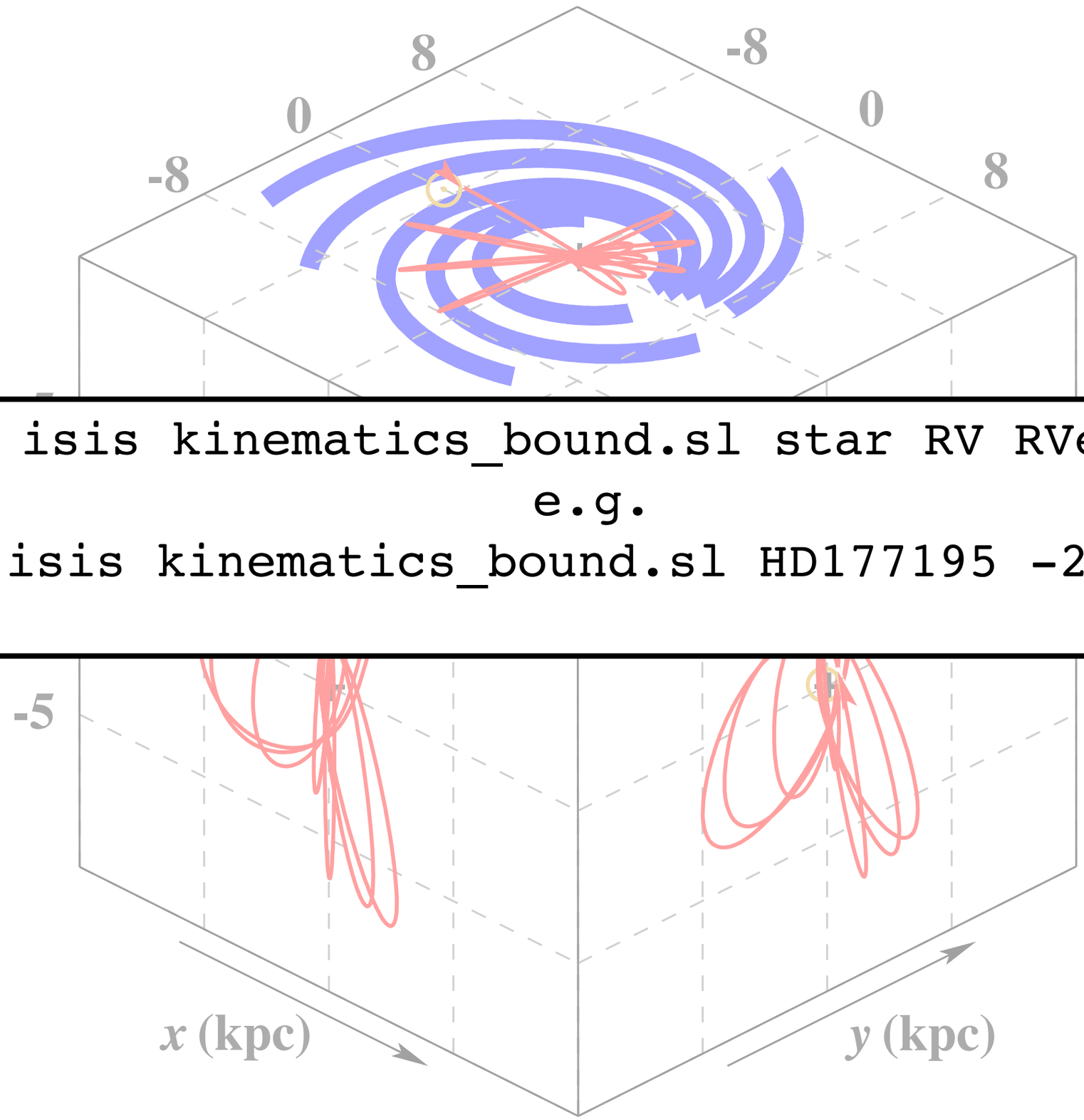
Radial velocity — v_{rad}



First fix the xfig installation, also for SEDs
In the terminal:

```
sudo apt-get install slang-xfig
wget sourceforge.net/projects/mcj/files/fig2dev-3.2.9.tar.xz
tar -xf fig2dev-3.2.9.tar.xz
cd fig2dev-3.2.9
bash configure
make
sudo make install
```

Radial velocity — v_{rad}




```
isis kinematics_bound.sl star RV RVerr
e.g.
isis kinematics_bound.sl HD177195 -27 5
```