Young stars in WEAVE

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WEAVE Science on Young Stars

WEAVE will provide us with homogeneous data for a large number of stars in different regions of young open clusters (YOCs; age ≤ 500 Myr) and Star forming Regions (SFRs) from their cores to their outskirts.

Unprecedented impact on our understanding of:

- the formation and early evolution of stars and planetary systems;
- accretion disks, their lifetimes, environmental effects;
- cluster's properties (kinematic and chemical);
- dynamical evolution (formation and early evolution).

Thanks to the synergies with Gaia and other surveys and with photometric monitoring programs from Earth and space (e.g. K2).

WEAVE Science on Young Stars

WEAVE spectroscopy of YOCs and SFRs will allow to derive:

- Radial velocity (*RV*) with accuracy of ~ 0.3 km/s or better;
- Lithium abundance;
- Projected rotational velocity ($v\sin i$) accuracy of ~ 1-2 km/s ;
- Mass accretion rates ($\dot{M}_{\rm acc}$);
- Chromospheric activity indicators;
- Atmospheric parameters ($T_{\rm eff}$, log*g*, [Fe/H]).

This data set has an outstanding value on its own.

WEAVE Science on Young Stars

The combination with Gaia and photometric monitoring data will provide:

- equatorial rotational velocity;
- stellar spin inclination;
- stellar radius;
- 3D position in the cluster;
- 3D kinematics.

Data of clusters at different age will allow tracing, in a statistical sense, the evolution of these parameters.

Young Open Clusters

Preliminary selection (Dias et al. catalogue)

CLUSTER	b	(m-M)v	E(B-V)	Age	Z	diam	Notes
IC348	-17.80	10.81	0.929	44	-117.7	7.0	Prior=II, very compact
Collinder70	-17.35	8.09	0.04	5	-116.6	180.0	Prior=I
NGC1647	-16.77	9.81	0.370	144	-155.8	40.0	Prior=I
Praesepe	32.48	6.39	0.009	729	100.4	70.0	Prior=I
Stock1	2.26	7.99	0.15	…	12.6	80.0	Prior=I
Stock2	-1.69	8.59	0.38	170	-9.0	45.0	Prior=I
α Per	-5.86	6.61	0.090	71	-18.9	300.0	Prior=I
σ Ori	-17.35	8.16	0.05	7	…	10.0	Prior=I
Coma	84.02	4.95	0.013	449	95.5	120.0	Prior=I, low density
M34	-15.61	8.71	0.070	177	-134.3	35.0	Prior=I
Collinder359	12.52	7.58	0.193	32	54.0	240.0	Prior=I
NGC2232	-7.54	7.87	0.030	53	-47.1	45.0	Prior=I
NGC7092	-2.24	7.61	0.013	279	-12.8	29.0	Prior=I
Roslund5	0.27	8.25	0.098	68	1.9	50.0	Prior=I
NGC2281	16.88	8.93	0.063	358	162.0	25.0	Prior=II
Briceno1=25Ori	-18.29	…	…	…	…	….	Prior=II
IC4665	17.08	8.27	0.174	43	103.4	70.0	Prior=II
Trumpler3	4.50	10.12	0.30	70	54.1	60.0	Prior=II
Hyades	-22.34	3.30	0.010	787	-17.1	330.0	Prior=I

SFRs: U Sco, Per OB1, Cygnus Rift

WEAVE Science on Young Stars

The experience gained by our group with the analysis of GES data, but also with X-Shooter (Italian GTO) and *Kepler*-LAMOST data, is fundamental for WEAVE.

The Gaia-ESO Survey

http://www.gaia-eso.eu/

Spectrum Extraction Pipelines

- **WG7:** GIRAFFE Reduction; UVES Reduction;
- **WG8:** Radial Velocities;
- **WG9:** Discrete Classification;

Spectrum Analyses

- **WG10:** FGK Stars: GIRAFFE (HR10+HR21 for MW; HR15N for OCs);
- **WG11:** FGK Stars: UVES (580+520);
- **WG12:** Pre-Main-Sequence stars: UVES (580+520) + GIRAFFE (HR15N)
- …

The Gaia-ESO Survey

http://www.gaia-eso.eu/

WG 12 Products

- Atmospheric parameters (T_{eff}, log$g$, [Fe/H], ξ);
- Other parameters (Sp.Type, $v$sin$i$);
- Lithium *EW* and abundance;
- “Accretion” parameters ($EW_{\mathrm{H\alpha}}$; $10\%W_{\mathrm{H\alpha}}$; $\dot{M}_{\mathrm{acc}}$; *veil*);
- Chromospheric parameters ($EW^{chr}_{\mathrm{H\alpha}}$; $EW^{chr}_{\mathrm{H\beta}}$; $F_{\mathrm{H\alpha}}$; $F_{\mathrm{H\beta}}$);
- Element abundance (from UVES spectra only).

Atmospheric Parameters and *v*sin*i*: ROTFIT

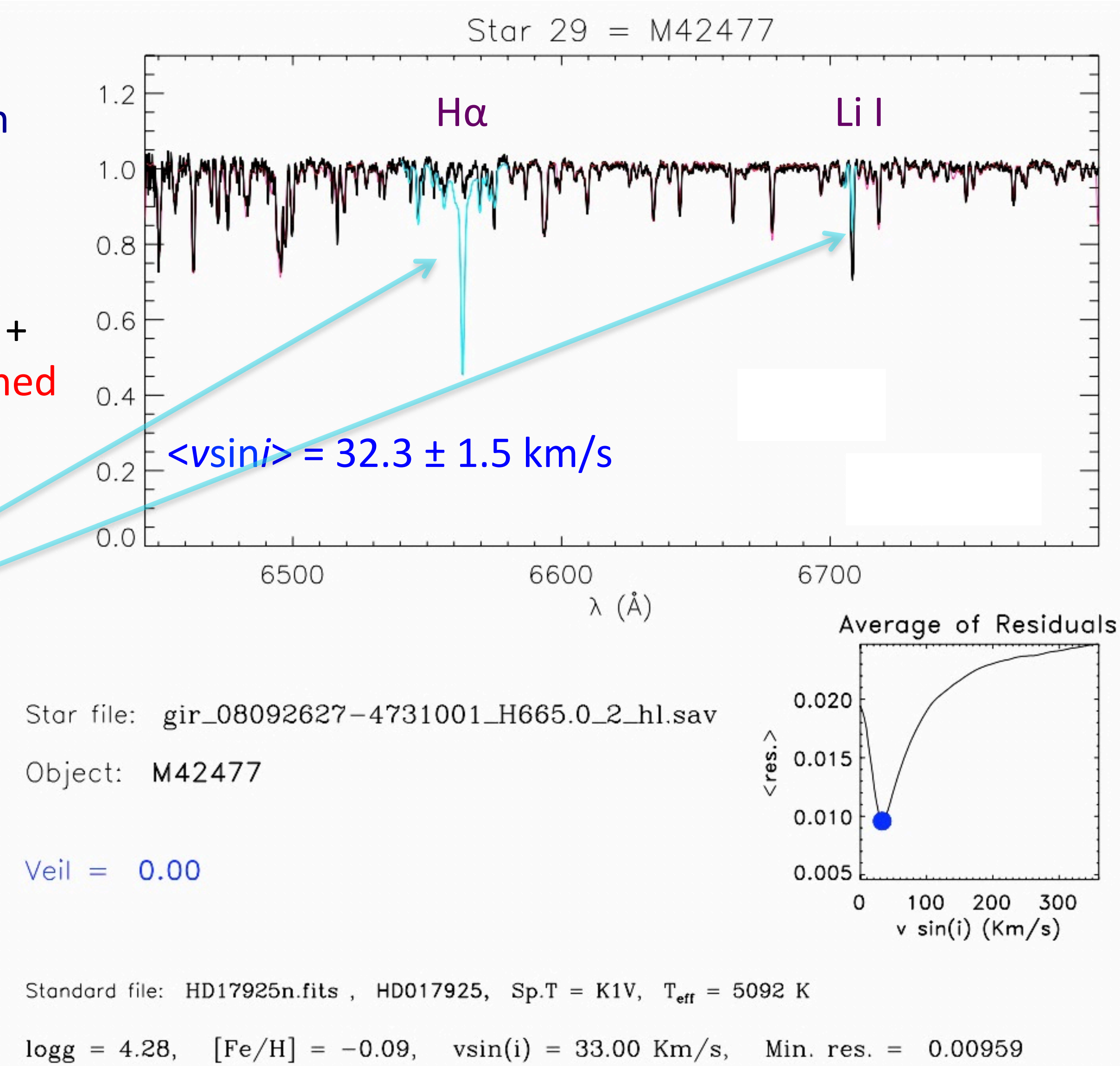
- IDL code originally designed for measuring *v*sin*i* and get an MK classification (e.g., Frasca et al. 2006, A&A 454, 301; 2015, A&A 575, A4);
- Fully automatic determination of T_{eff}, log*g*, [Fe/H], and *v*sin*i* by the comparison with template spectra (χ^2 minimization);
- The UVES spectra are split in 100Å-wide segments independently analysed;
- Minimum of residuals (or χ^2) is found and the templates are sorted according to it;
- Weighted averages of the parameters and standard errors;
- The weight includes the "amount of information" contained in each segment, which is quantified by the total line absorption;
- All the spectral range for Giraffe HR15N, eventually masking Hα & LiI.

Atmospheric Parameters and *vsini*: GIRAFFE

Early-K active star in Gamma Vel cluster ≈10 Myr

Observed spectrum + rotationally broadened template

Masked regions



vsini: X-Shooter

Mid-K star in Lupus SFR (≈3 Myr)

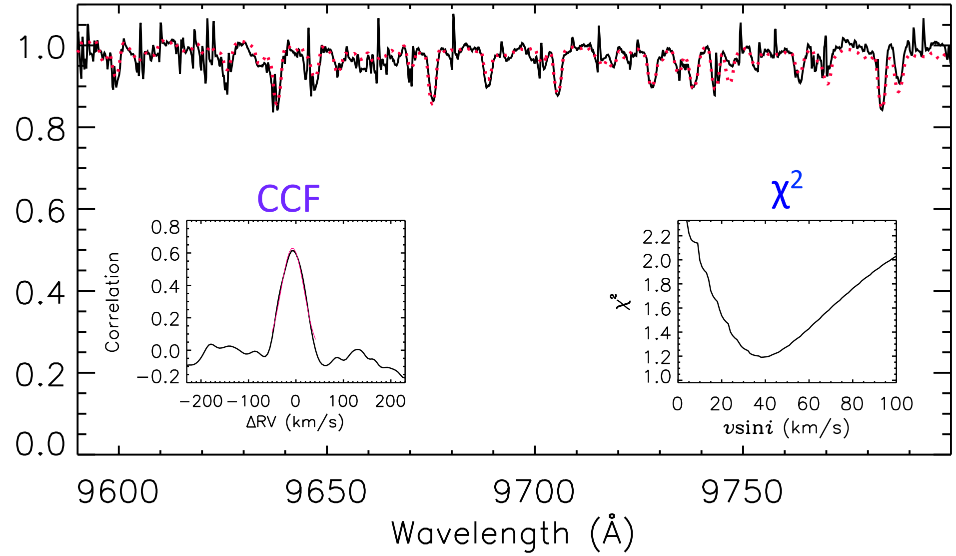
Observed spectrum + rotationally broadened BT-Settl template

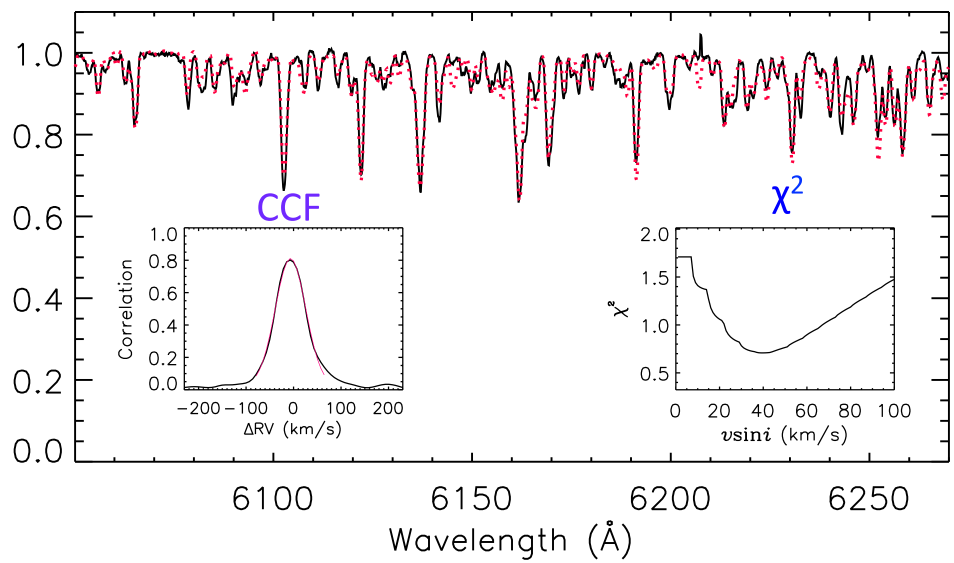
The best spectral regions for *vsini* are those with strong but relatively narrow lines.

Suitable also for T_{eff}, log*g* and [Fe/H].

<*vsini*> = 39.6 ± 1.2 km/s

Frasca et al. in prep.



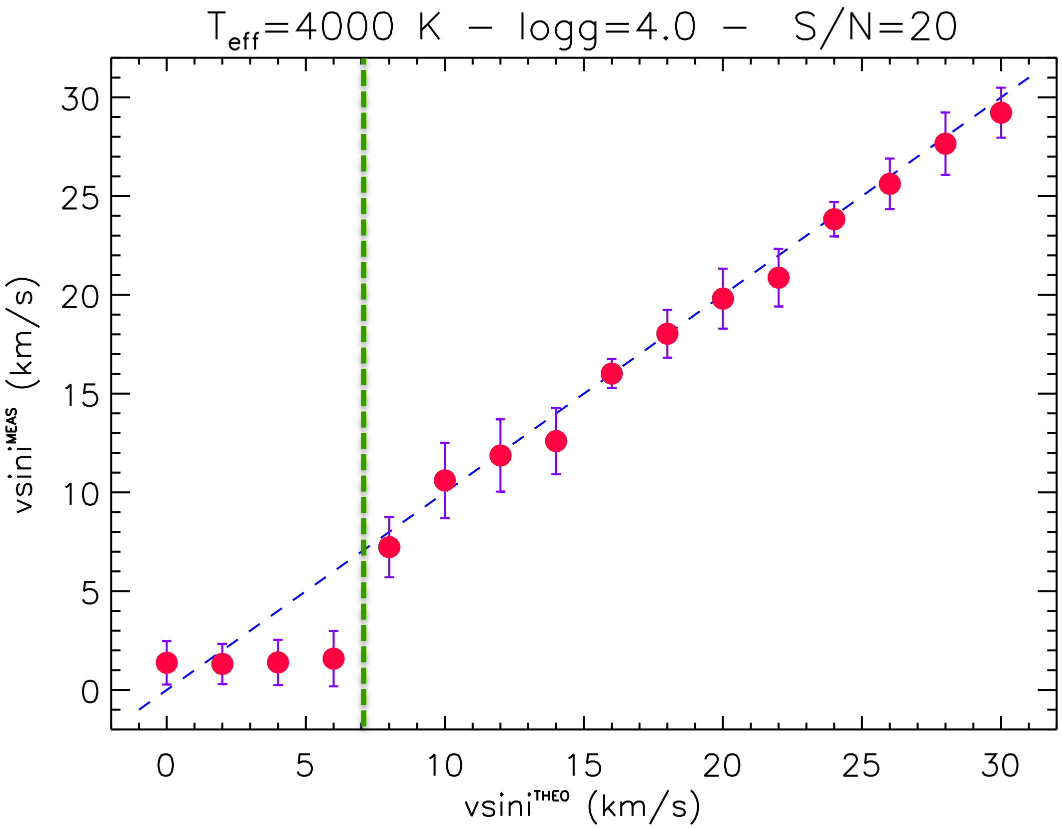


vsini: WEAVE

Monte Carlo simulations

R=20,000

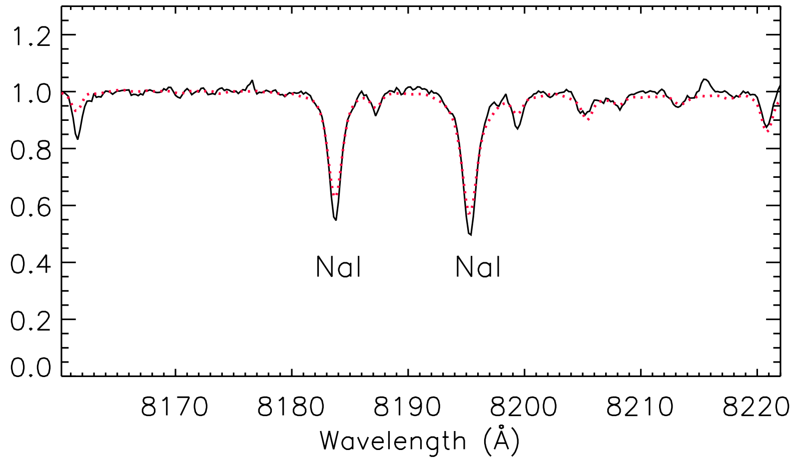
595-685 nm spectrum



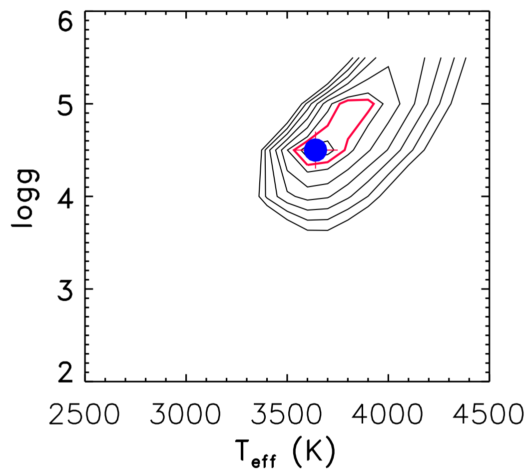
Minimum *vsini* ≈ 7-8 km/s. Error ≈ 1-3 km/s

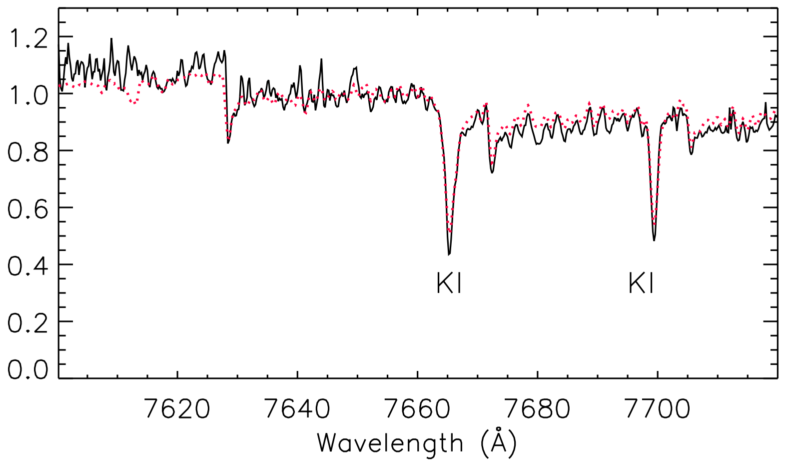
Atmospheric Parameters: X-Shooter

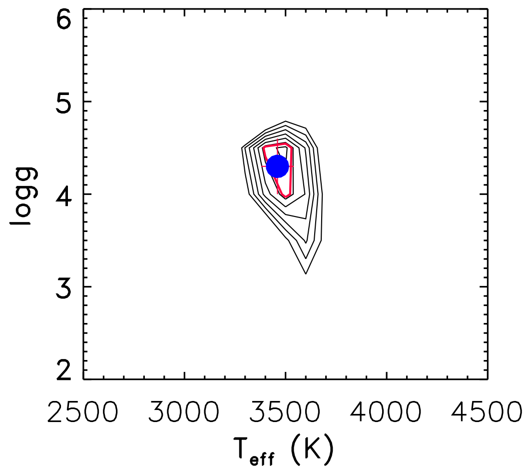
Target + template



χ^2 maps



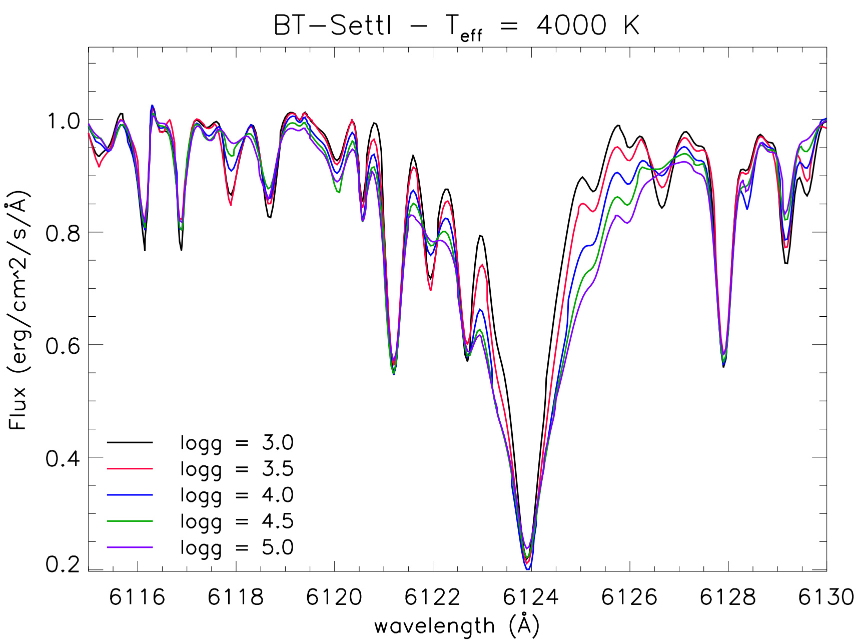


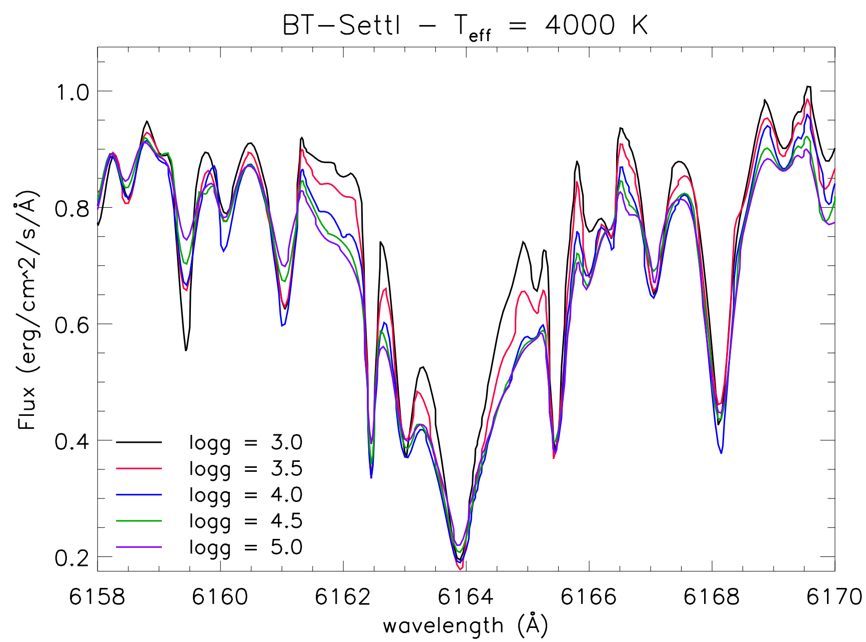


Frasca et al. in prep.

Atmospheric Parameters: WEAVE

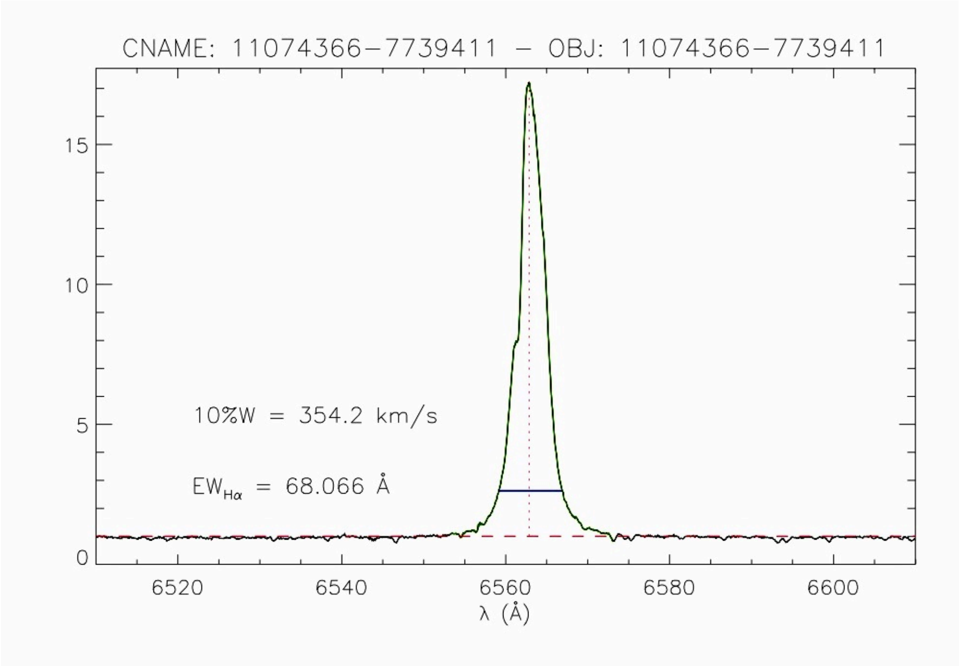
In the high resolution mode (R≈20,000), the two spectral ranges covered by WEAVE (4040-4650 Å and 5950-6850 Å) are suitable for determination of *v*sin*i*, T_{eff}, and log*g*. They also contain broad lines, e.g. CaI lines, whose wings are good diagnostics of log*g*.





Accretion diagnostics: GES

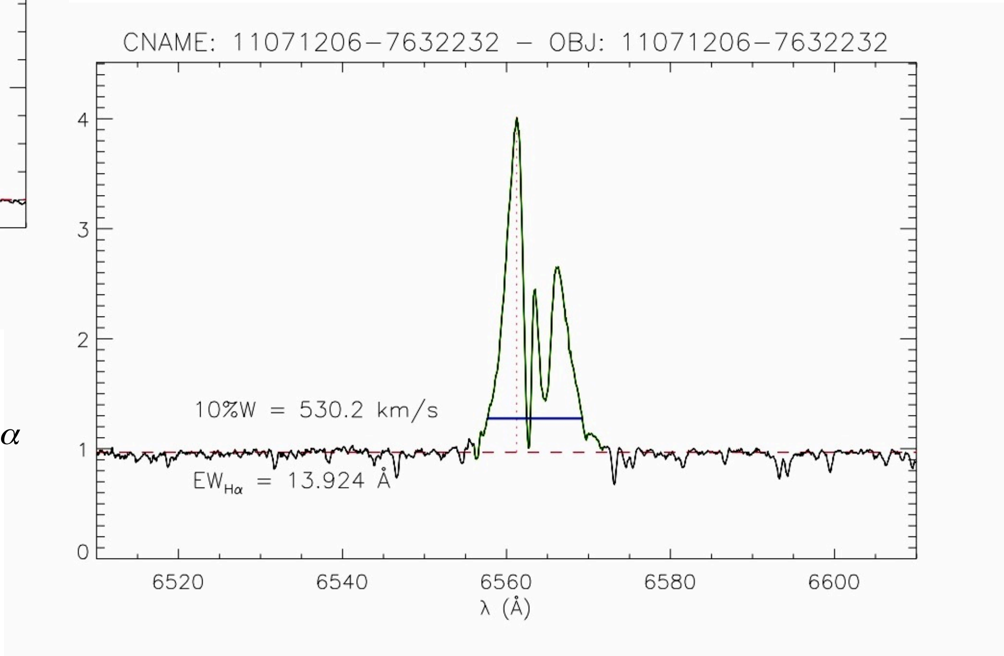
$EW_{H\alpha}$ and 10% $W_{H\alpha}$ for two members of Cha I



Useful for selection of accretor candidates

$$\log \dot{M}_{acc} = -12.89 + 9.7\times10^{3}\cdot 10\% W_{H\alpha}$$

Natta et al. (2004, A&A 424, 603)



Accretion diagnostics: GES

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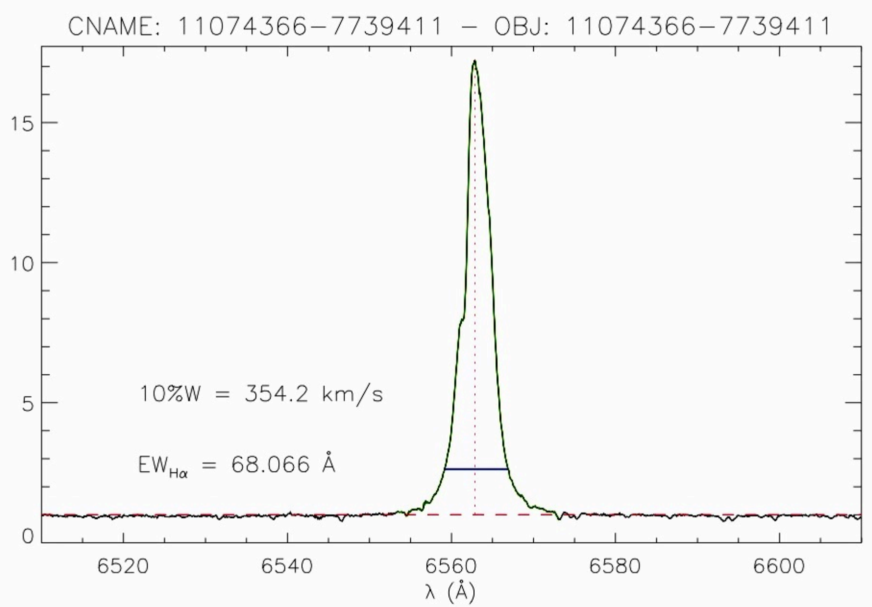
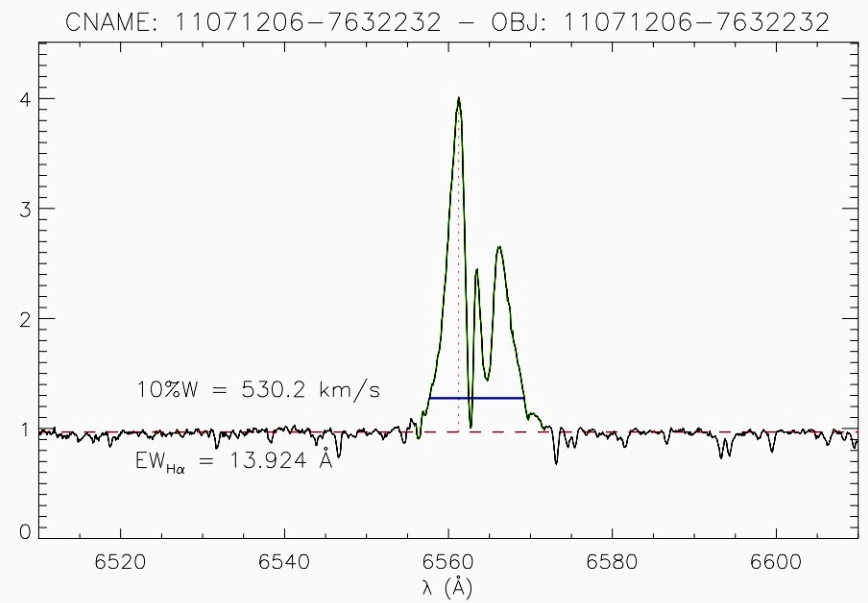


$L_{H\alpha} \rightarrow L_{acc}$

Alcalà et al. (2014, A&A 561, A2)



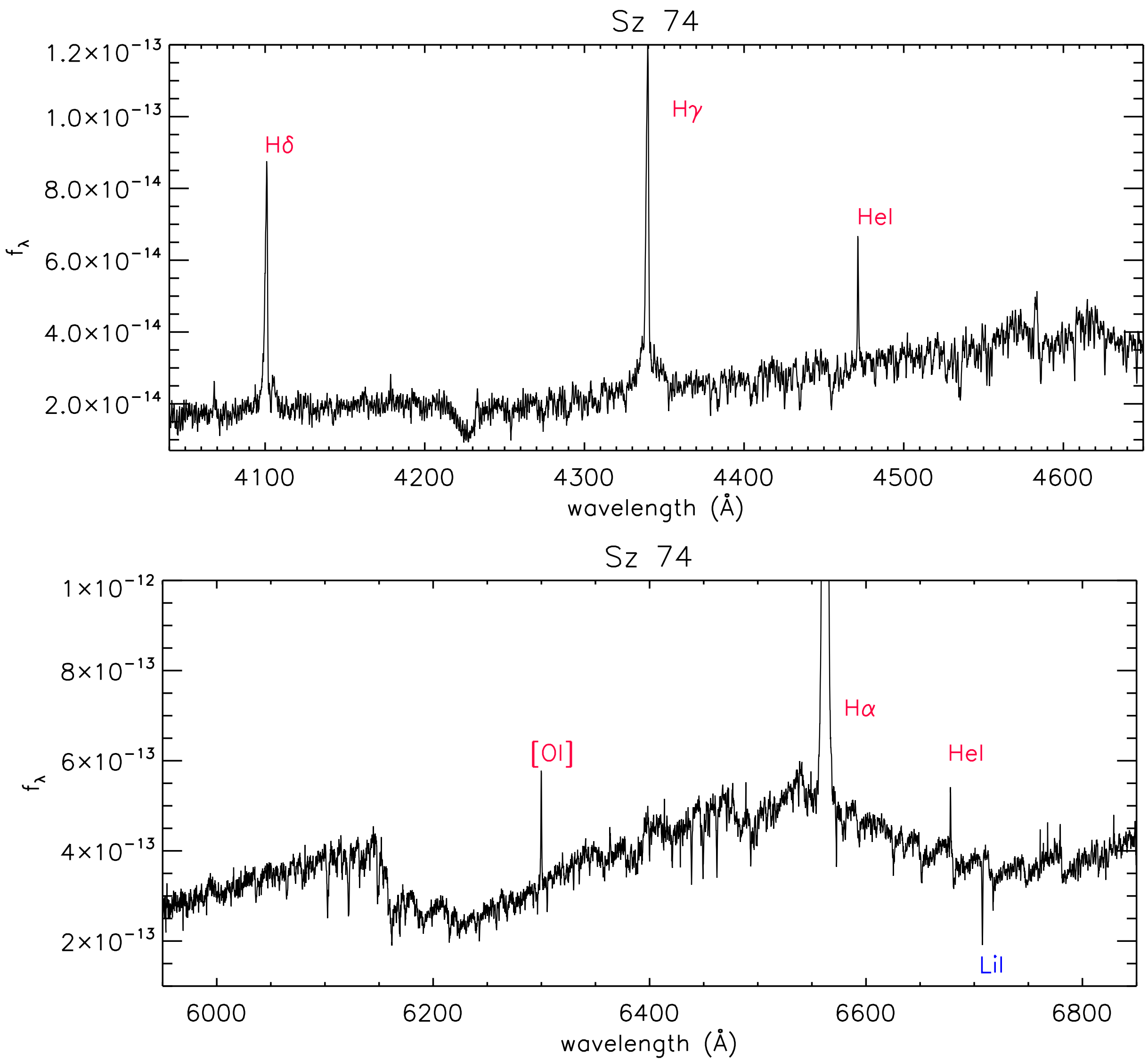
$$\dot{M}_{acc}^{EW} = \left(1 - \frac{R_*}{R_{in}}\right)^{-1} \frac{L_{acc} R_*}{G M_*}$$

$R_{in} = 5 R_*$

Hartmann et al. (1998, ApJ 495, 385)

Accretion diagnostics: WEAVE

More accretion diagnostics in the WEAVE ranges



Accreting M3.5 star in Lupus.

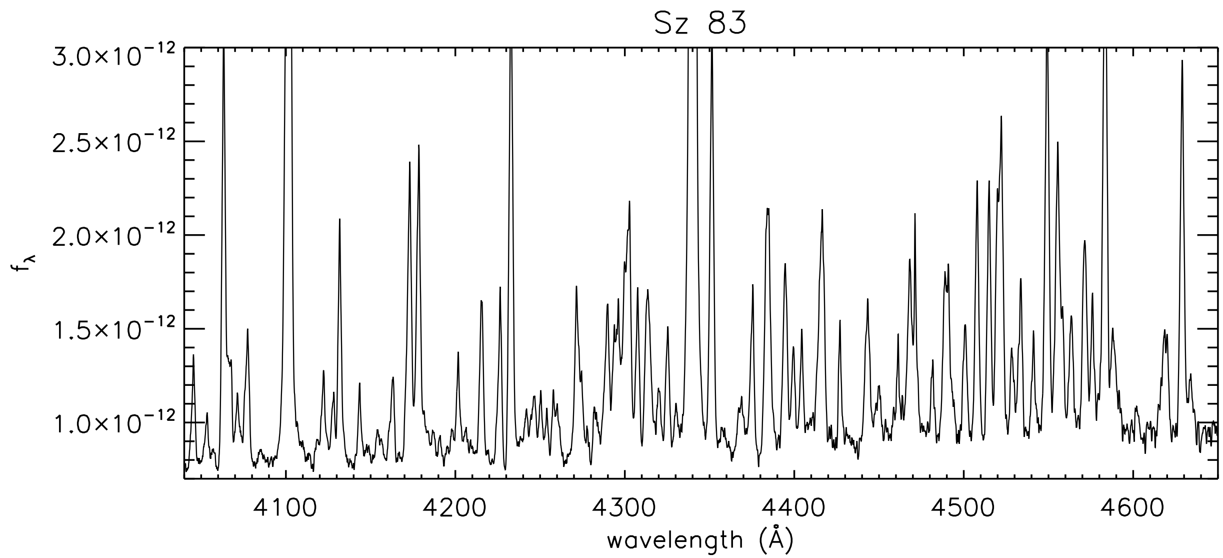
X-Shooter spectrum

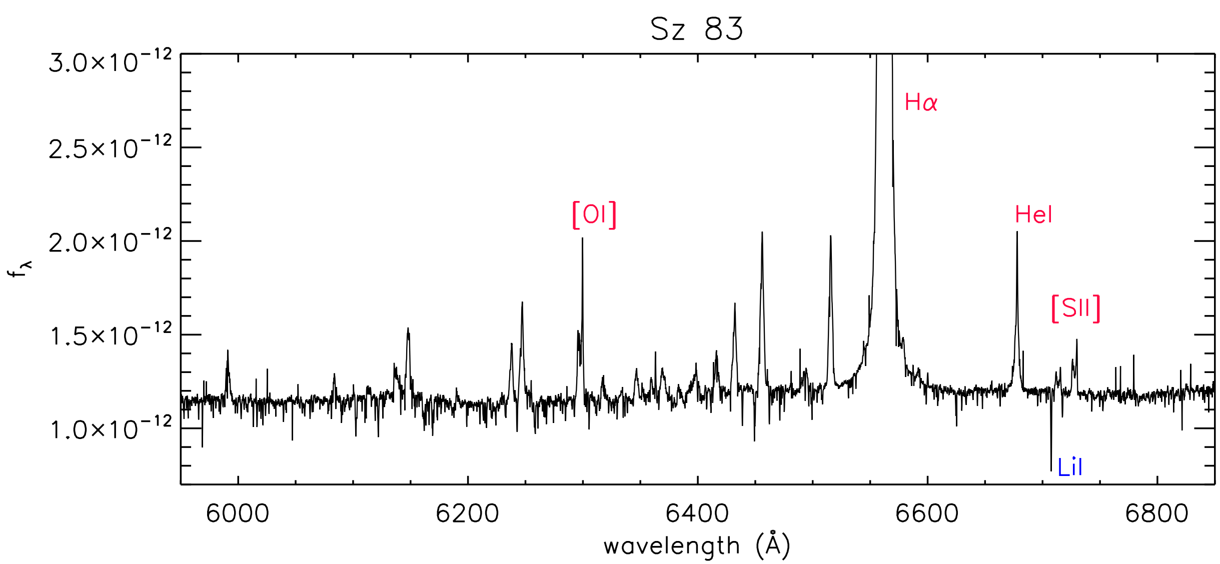
$\log(M_{acc}[M_{\odot}/yr]) = -8.1$

Alcalà et al. 2014, A&A 561, A2

Accretion diagnostics: WEAVE

More accretion diagnostics in the WEAVE ranges





Accreting K7 star in Lupus.

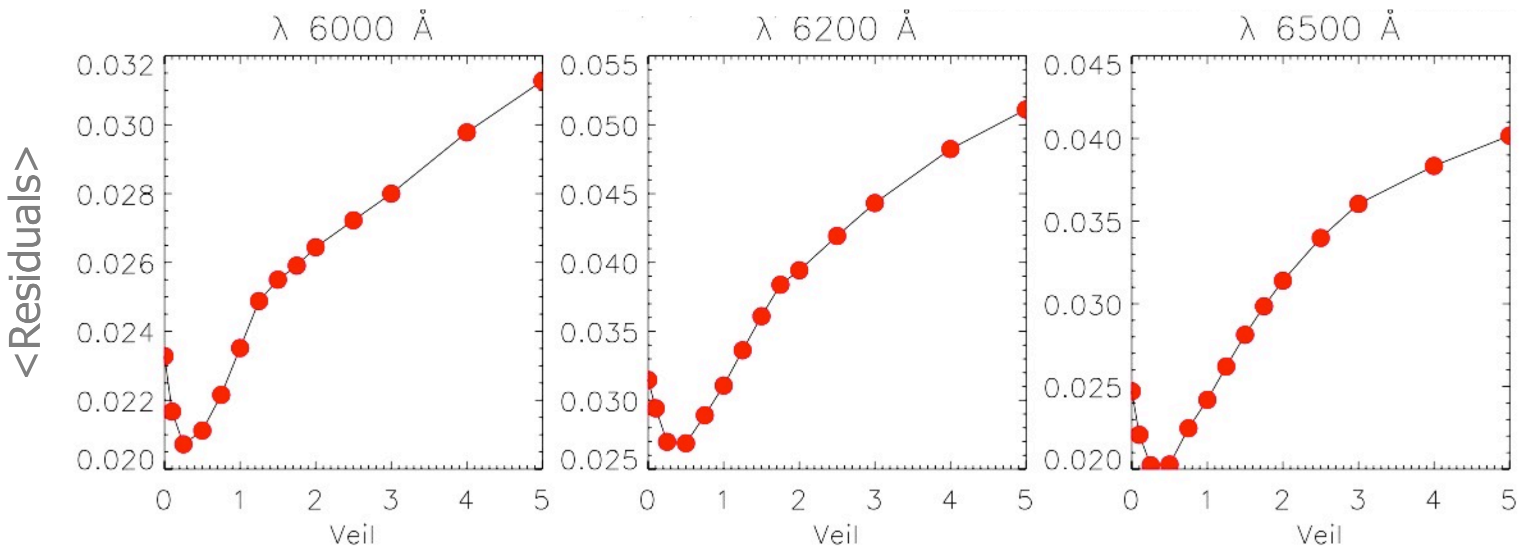
X-Shooter spectrum

$\log(M_{acc}[M_{\odot}/yr]) = -7.4$

Alcalà et al. 2014, A&A 561, A2

Veiling

For accretor candidates ($10\%W_{H\alpha} \geq 270$ km/s) we can run the code with another free parameter: the ***veil*** *(r)* in continuum units.



Assumption: veil constant over a limited wavelength range (100 Å for UVES, ≈ 300 Å for GIRAFFE). Templates progressively artificially "veiled"

$$\frac{F_\lambda^{veil}}{F_C} = \frac{\frac{F_\lambda}{F_C} + veil}{1 + veil}$$

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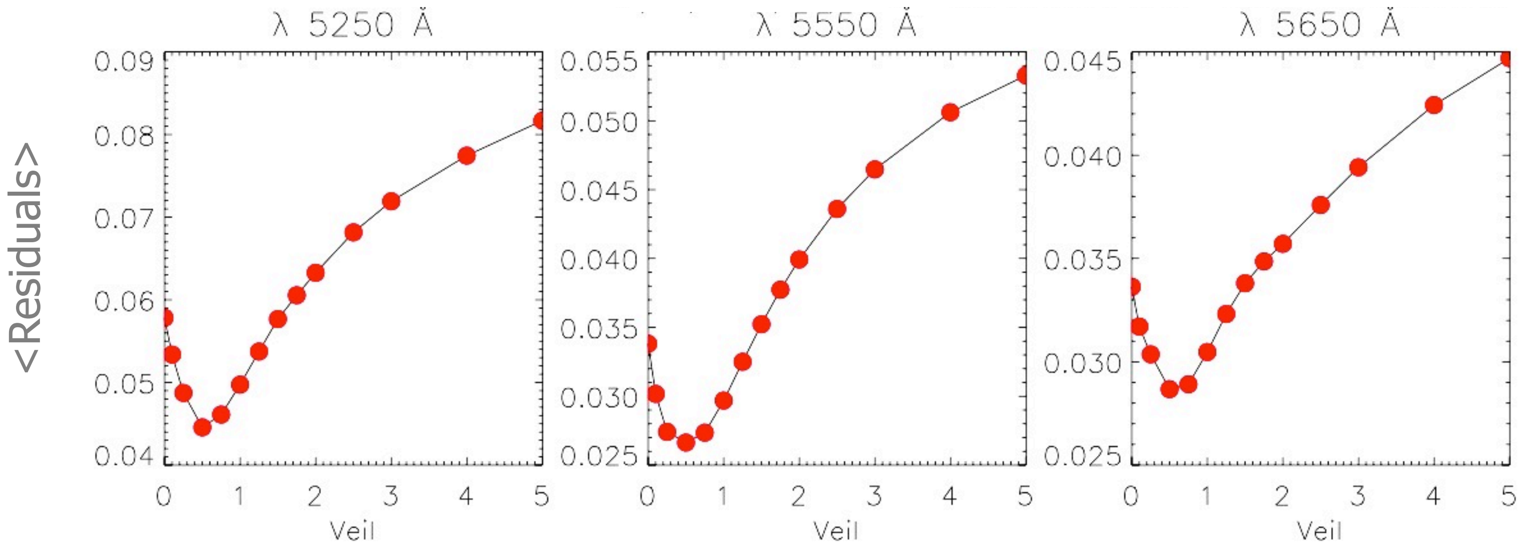

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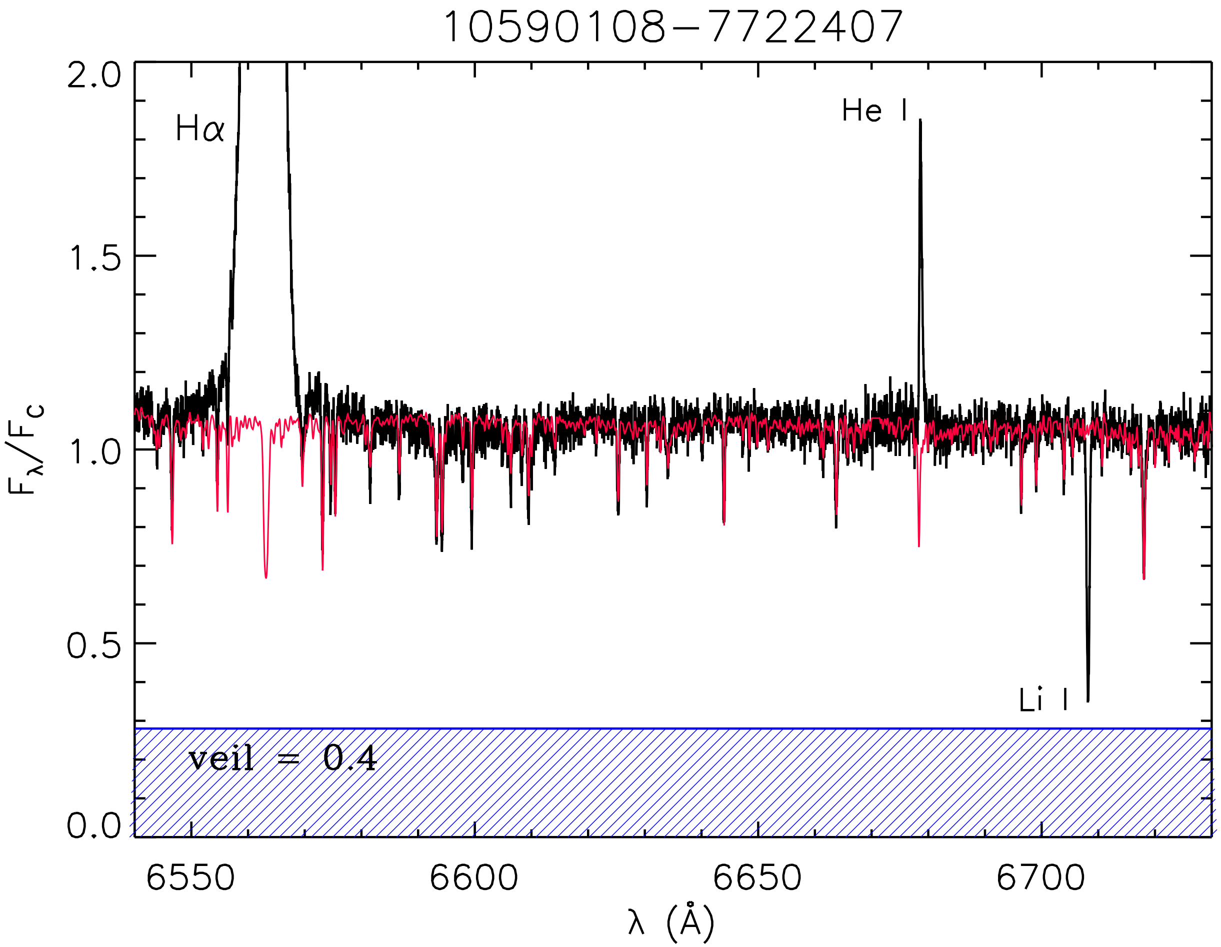
Veiling



Accreting K8 star in Cha I.

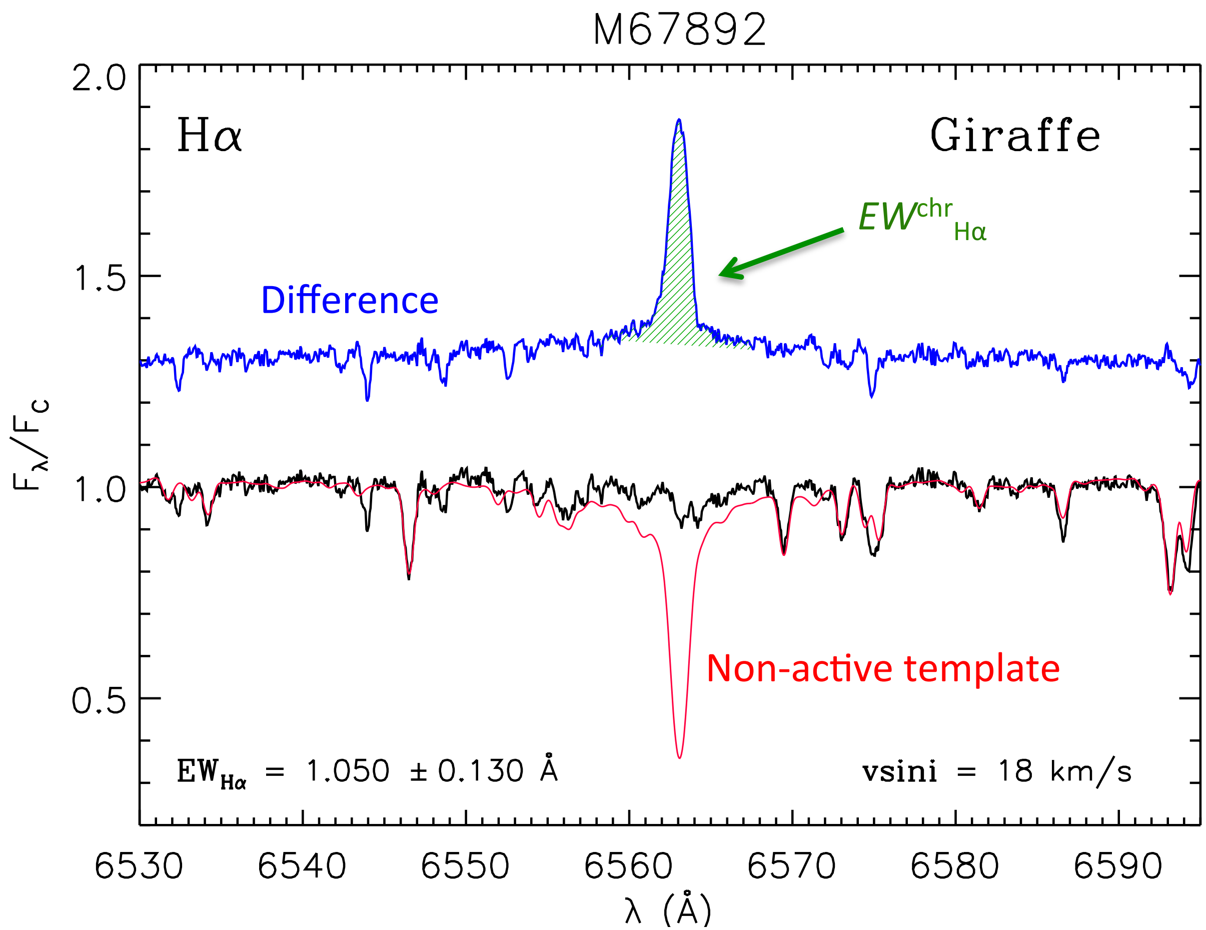
$T_{\rm eff}$= 4130 K

$v\sin i$ = 9 km/s

UVES spectrum

Frasca et al. 2015, A&A 575, A4

Chromospheric Activity: spectral subtraction

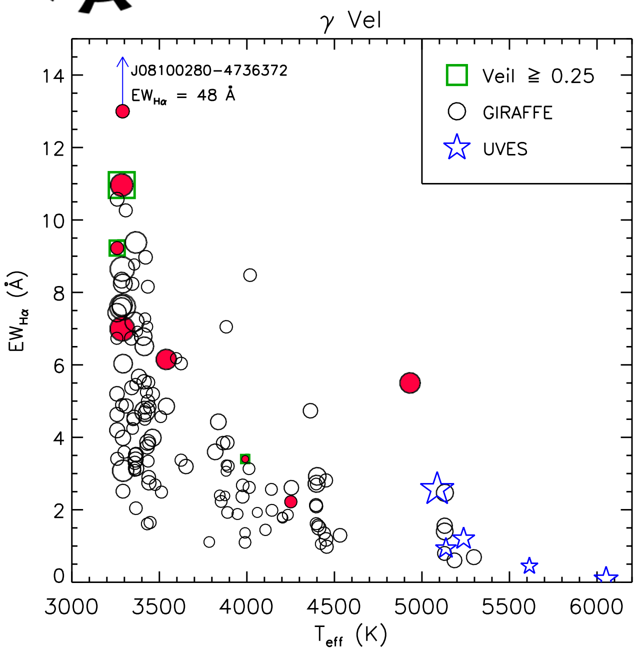


K1V active star member of Y Vel. The Hα line is totally filled by emission.

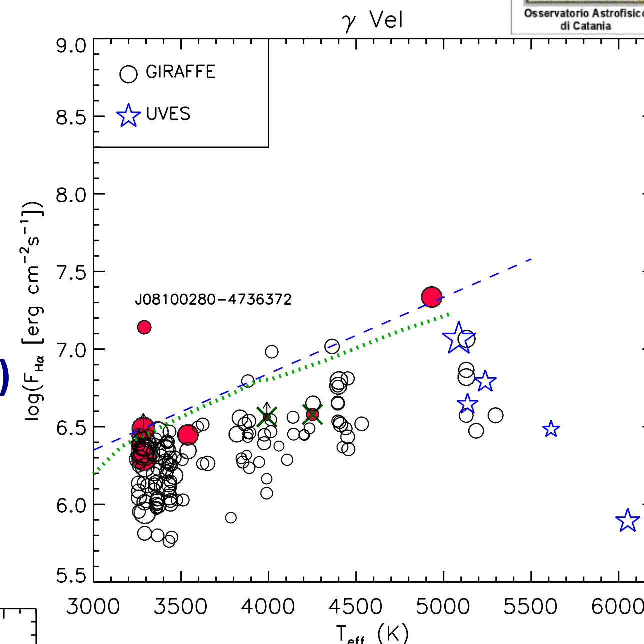
Frasca et al. 2015, A&A 575, A4

Removal of photospheric profile → Subtraction of a "non-active template": a spectrum of a low-activity standard star degraded to the Giraffe resolution, rotationally broadened and Doppler-shifted.

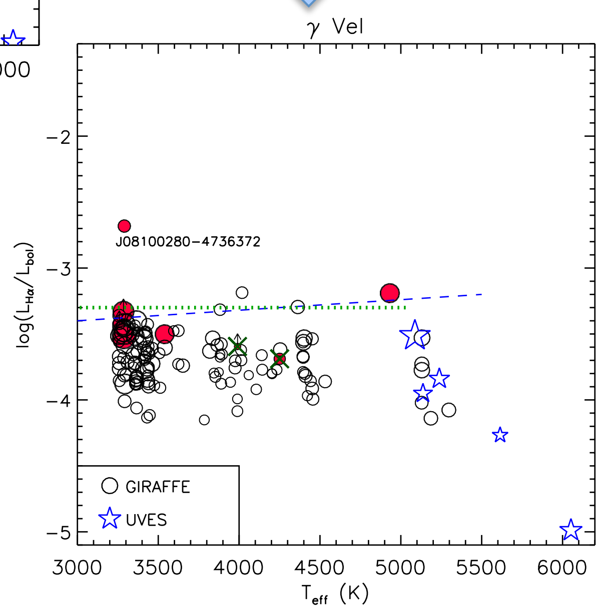
Chromospheric Activity: $EW_{H\alpha}$, $F_{H\alpha}$, $R'_{H\alpha}$



$$F_{H\alpha} = F_{cont} * EW_{H\alpha}$$



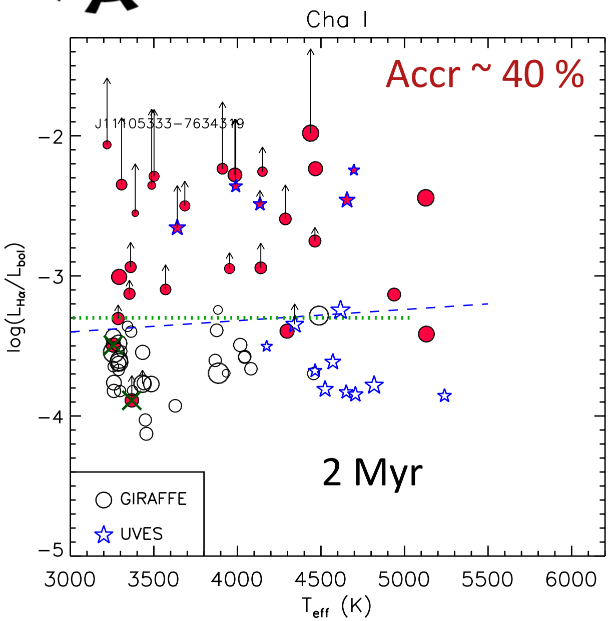
$$R'_{H\alpha} = L_{H\alpha}/L_{bol} = F_{H\alpha}/(\sigma T_{eff}^4)$$



Largest $EW_{H\alpha}$ for cooler stars. Contrast effect: Hα emission stands out against a low continuum.

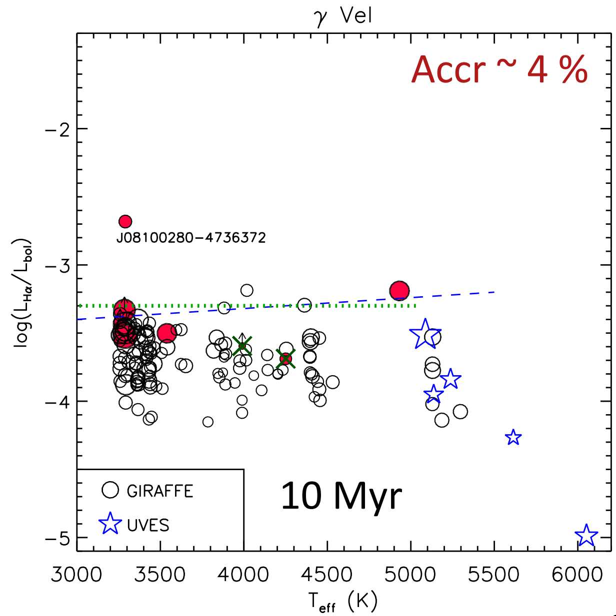
When converted into flux, the nearly exponential behaviour with T_{eff} disappears.

Evolution of Chromospheric Activity and Accretion



Saturation limit $R'_{H\alpha}$=-3.2 (Barrado & Martin 2003)

Dividing line accretion/chrom. (Frasca et al. 2015)



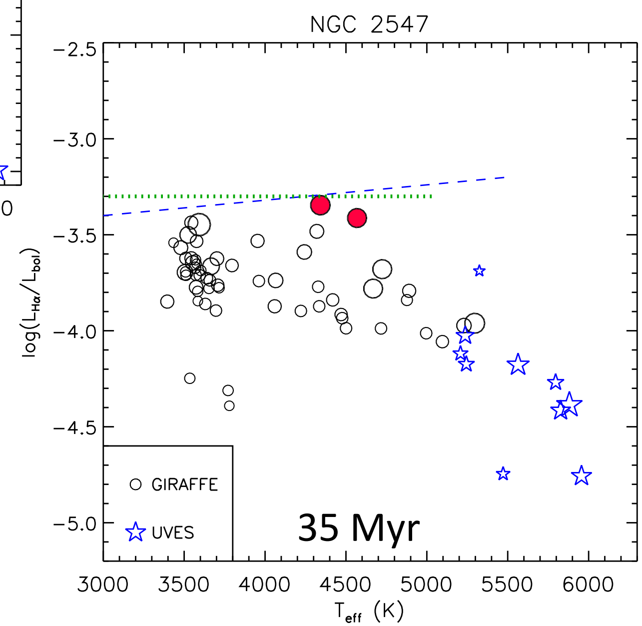
$\log R'_{H\alpha} = -3.4 + 0.00008(T_{eff} - 3000)$

$$R'_{H\alpha} = L_{H\alpha}/L_{bol}$$

Accretor candidates ($W_{10\%}$ > 270 km/s) occupy a different region from chromospherically active stars.

Less (or no) accretor candidates at older ages.

Fluxes and luminosities progressively lower than the limit, especially for T_{eff} > 4500-5000 K



Summary

- WEAVE is an ideal instrument for the study of young OCs and SFRs due to its very large FoV and multi-object capabilities;
- Formation and early kinematical evolution of SFRs and YOCs;
- Substructures in YOCs;
- Large stellar samples for the analysis of *v*sin*i,* chromospheric activity, accretion, etc.;
- Time evolution of angular momentum and activity as a function of stellar mass;
- Stellar radii and spin orientations;
- …

Thanks for your attention