



Rotation and Chromospheric activity in the young clusters IC4665 and NGC2547



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Outline

- Selection of members of these clusters:
Lithium, RV, H α emission;
- Projected rotation velocity ($v\sin i$);
- Indicators of chromospheric activity (CE):
 $EW_{H\alpha}$, $F_{H\alpha}$ and $R'_{H\alpha}$;
- Dependence of CE on stellar parameters;
- Conclusions.

IC 4665

Coarse young cluster.
Diameter ~ 41 arcmin
Distance = 370 pc
 $A_V = 0.59$ mag
Age = 30–40 Myr
28 Myr from LDB
(Manzi et al. 2008)

GES Observations **DR3**:
545 stars with Giraffe
34 stars with UVES
12 in common



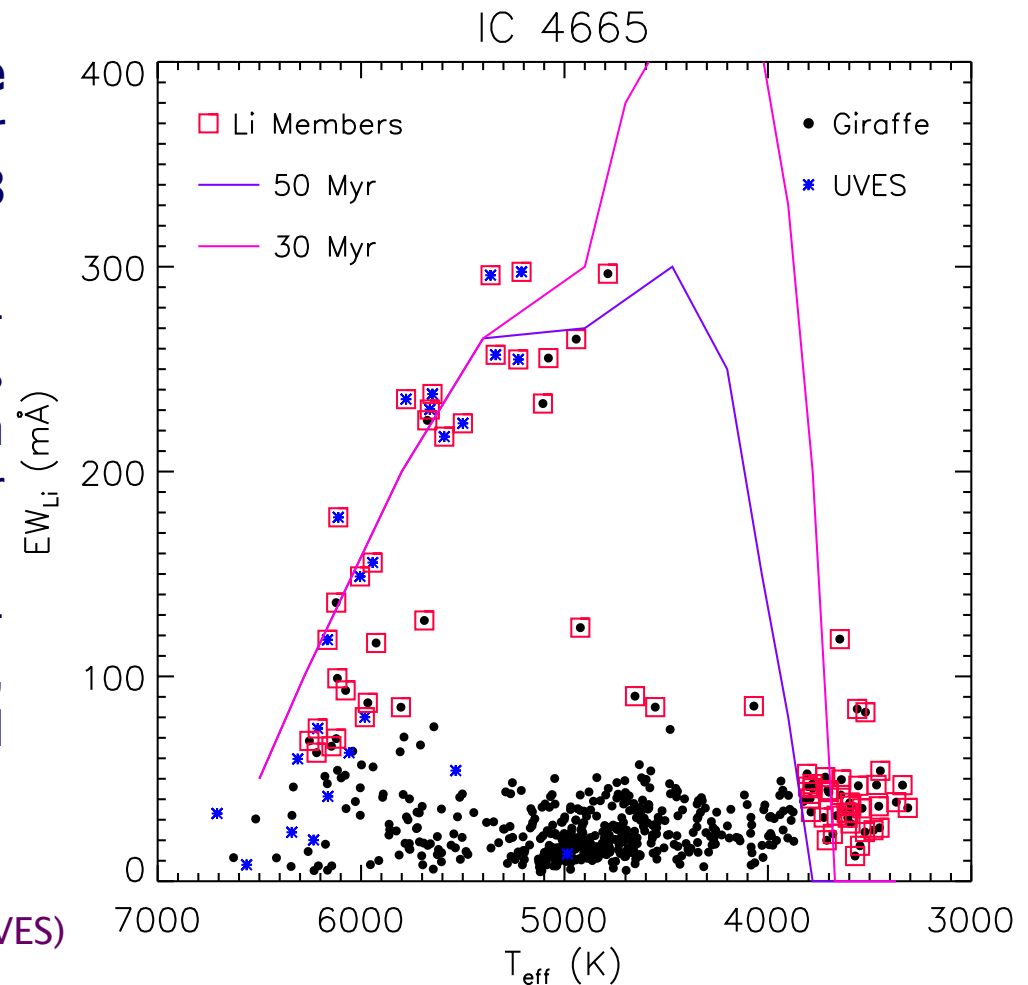
<http://www.jthommes.com/Astro/IC4665.htm>

WG12 “recommended” parameters

IC 4665 - Member selection

- Pre-selection of **candidate members** to the IC4665 cluster based on the EW of lithium 6708 Å line ("**Li members**").
- We adopted a simple, most-inclusive criterion (all sources beyond the Li depletion boundary, $EW > 80$ mÅ for higher T_{eff}).
- A contamination by non-members is still possible: e.g., Li-rich giants, young field stars.

57/545 Li members for Giraffe
(excluding 8 stars observed also with UVES)
15/34 for UVES



Baraffe et al. (2002, A&A 382, 563) Li isochrones
adapted from Jeffries et al. (2009, MNRAS 400, 317).

IC 4665 - Member selection

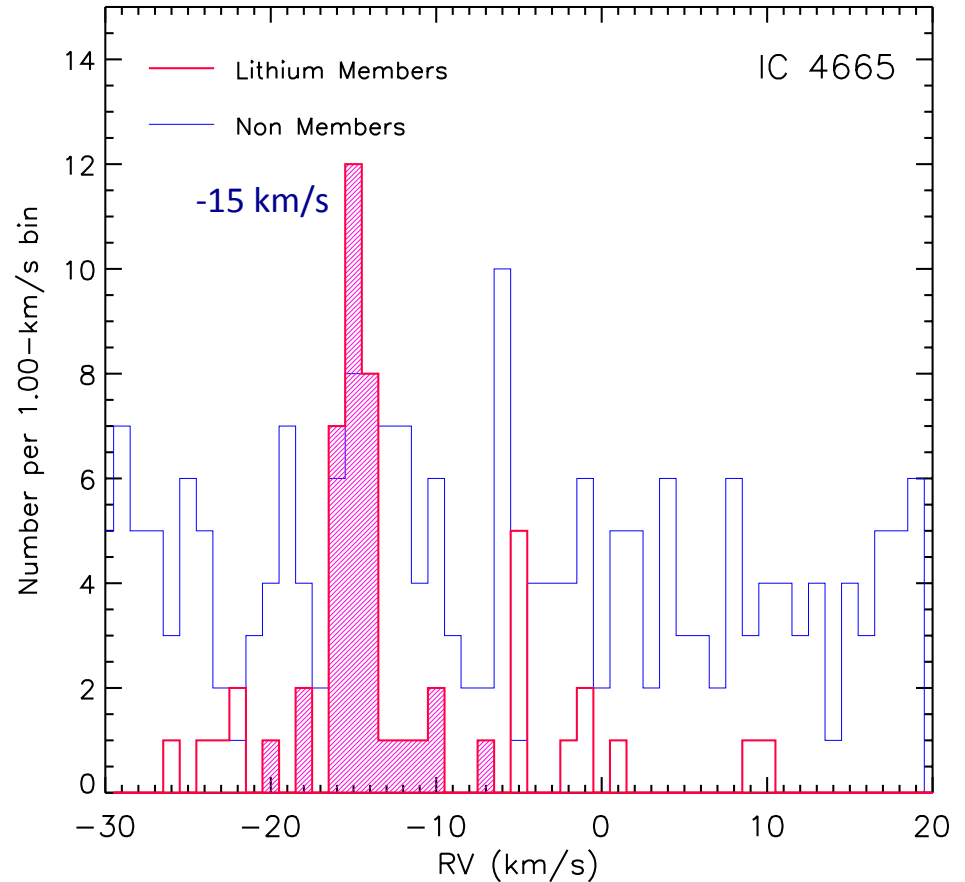
The “final” members (hatched area) are selected among the candidates from their radial velocity:

$$-21 \leq RV \leq -6 \text{ km/s.}$$

22 Giraffe members

Excluding 6 stars observed also with UVES

14 UVES members



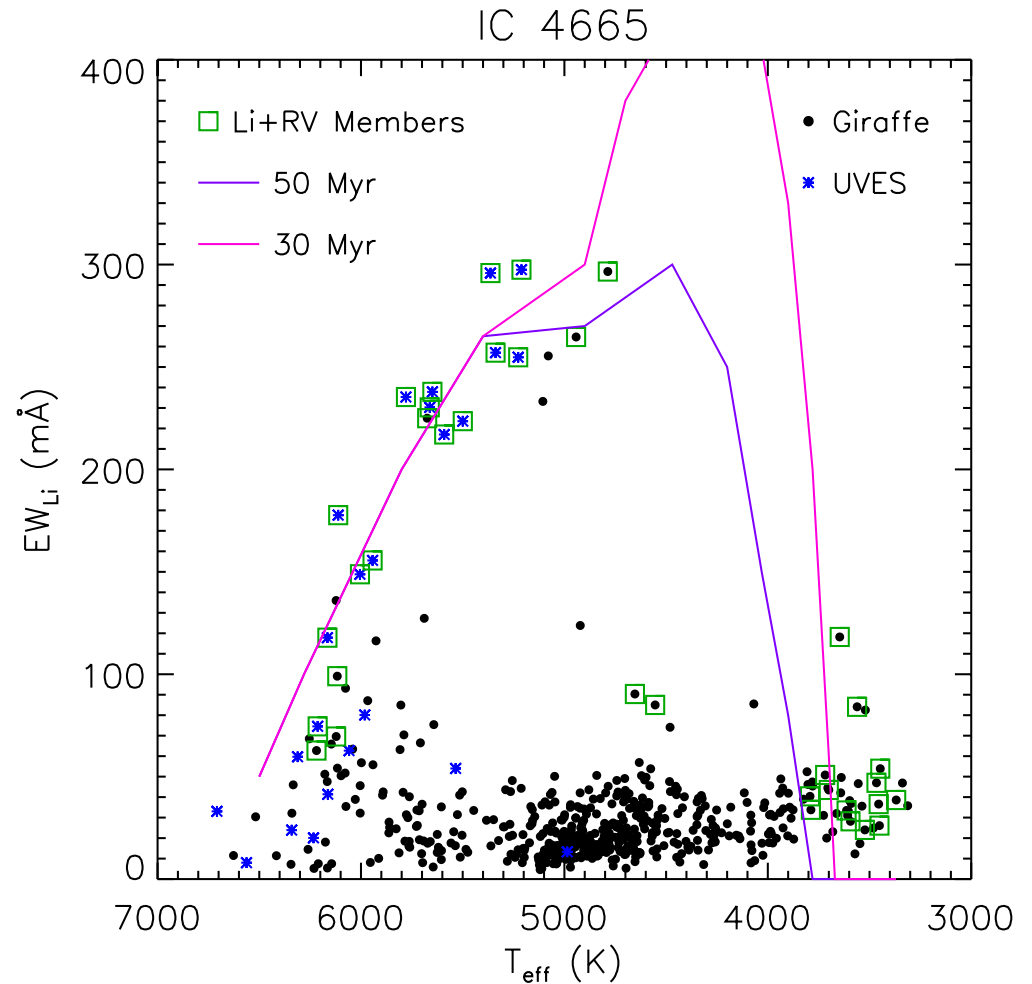
RV distribution for the members peaked at about -15 km/s.

IC 4665 - “Final” Members

22/545 “Final” (Li+RV)
members for Giraffe
(excluding 6 observed also with UVES)

14/34 for UVES

~ 7 %



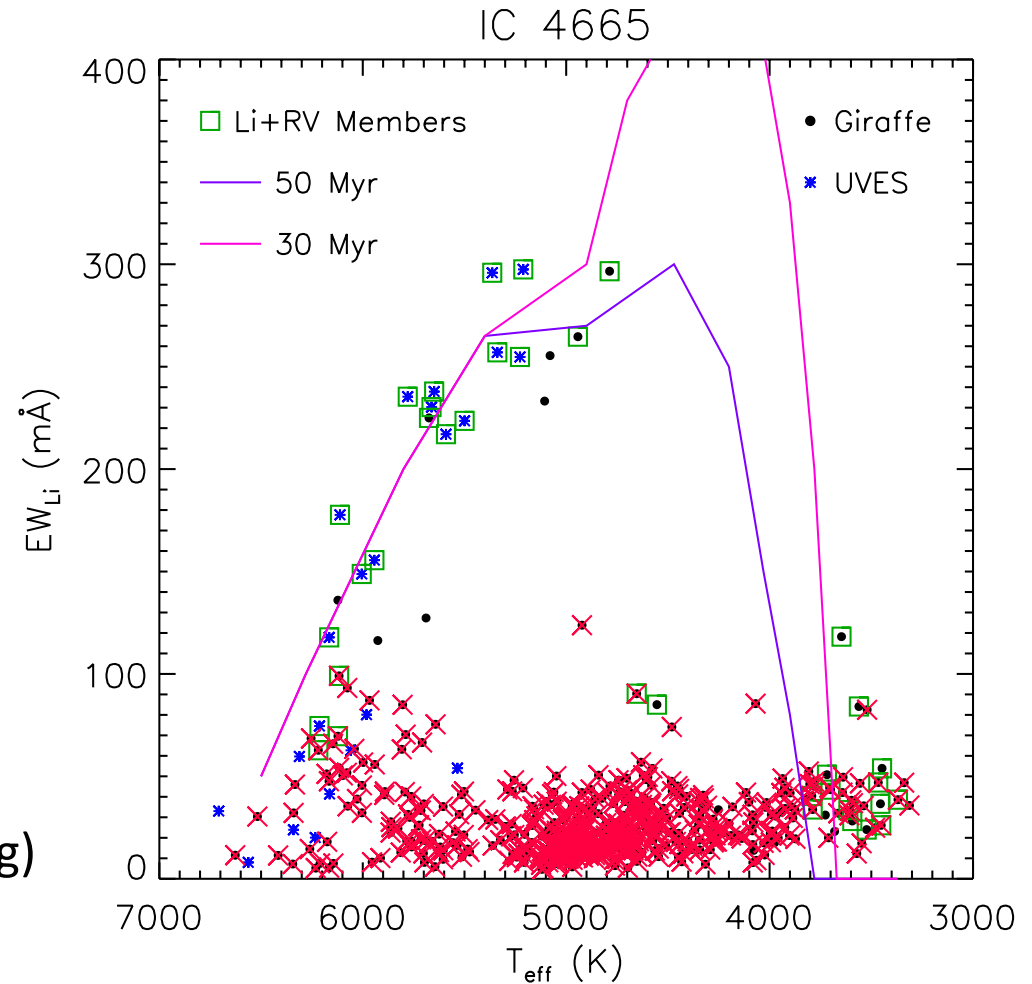
IC 4665 - “Final” Members

22/545 “Final” (Li+RV)
members for Giraffe
(excluding 6 observed also with UVES)

14/34 for UVES

~ 7 %

✗ = no H α emission (or filling)



NGC 2547

~2 deg south of γ^2 Vel.

Diameter ~ 20 arcmin

Distance = 350–470 pc

$A_V \approx 0.12$ mag

Age = 35 Myr from LDB
(Oliveira et al. 2003)



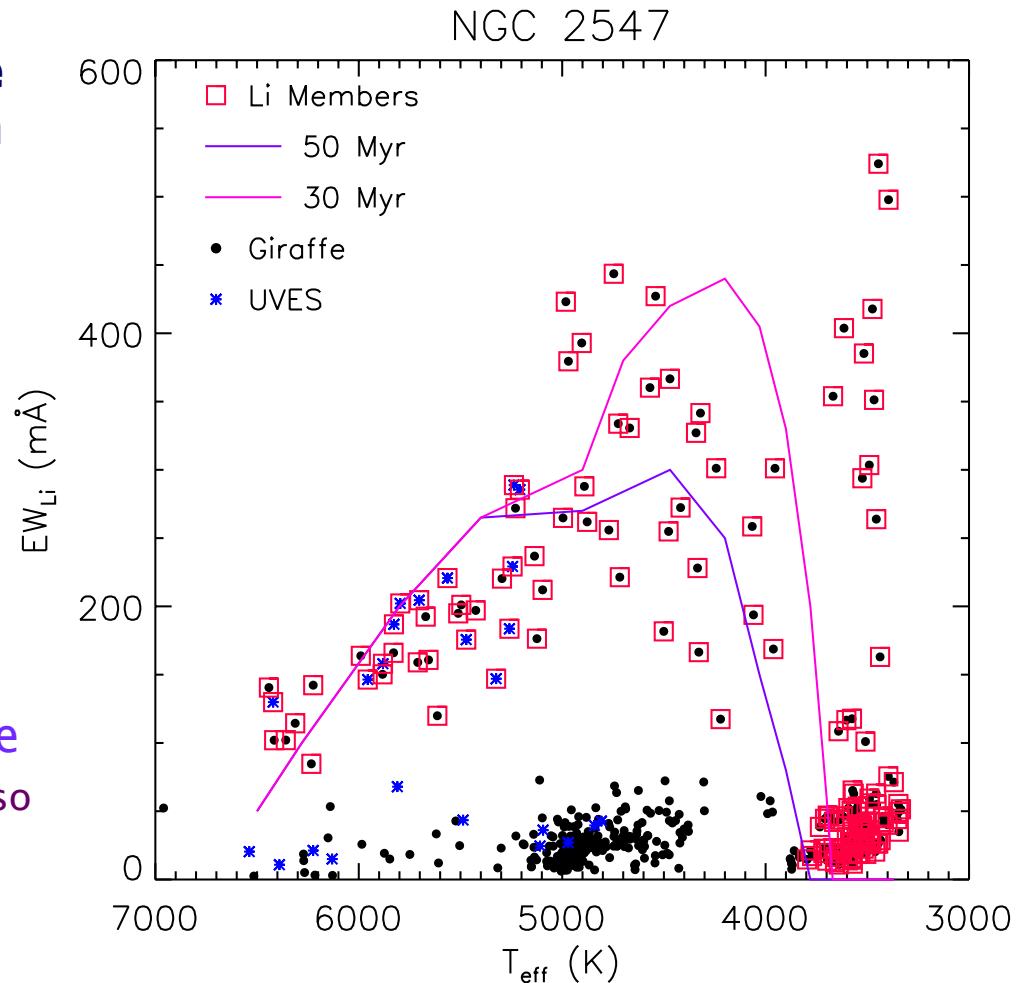
GES Observations DR2:
450 stars with Giraffe
26 stars with UVES
21 in common

NGC 2547 - Member selection

- Pre-selection of **candidate members** to NGC2547 based on lithium EW.
- All sources cooler than the Li depletion boundary, and $EW > 80 \text{ m\AA}$ for larger T_{eff} .
- Higher values of EW_{Li} , on average, compared to IC4665

144/450 Li members for Giraffe
(excluding 12 members observed also with UVES)

13/26 for UVES



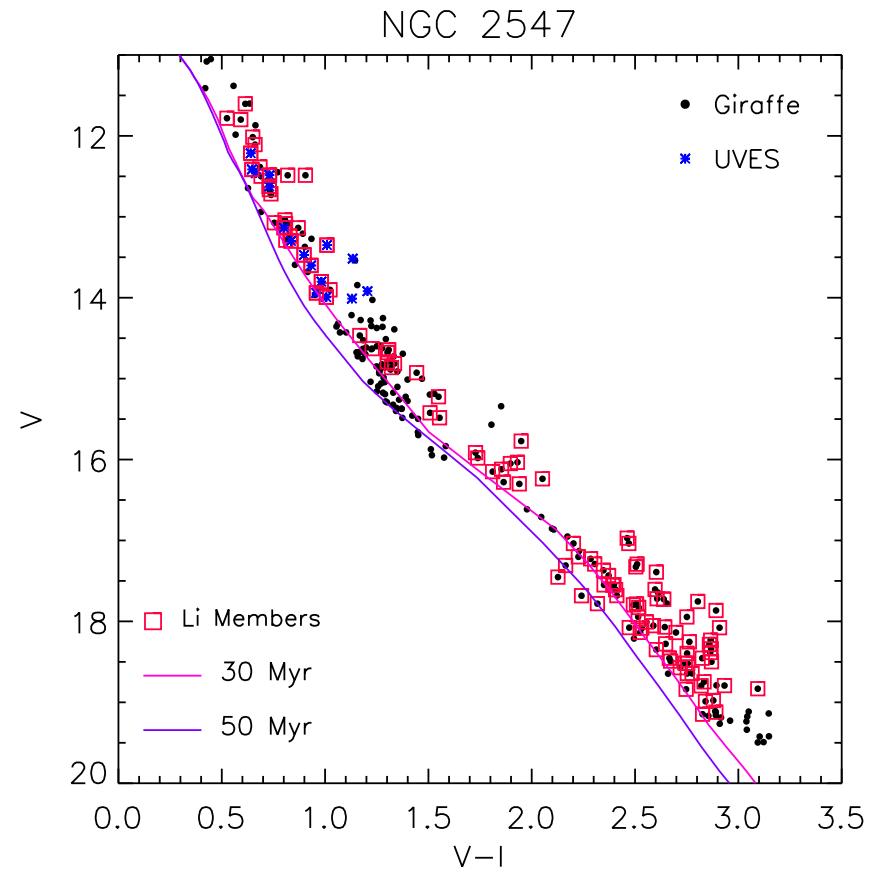
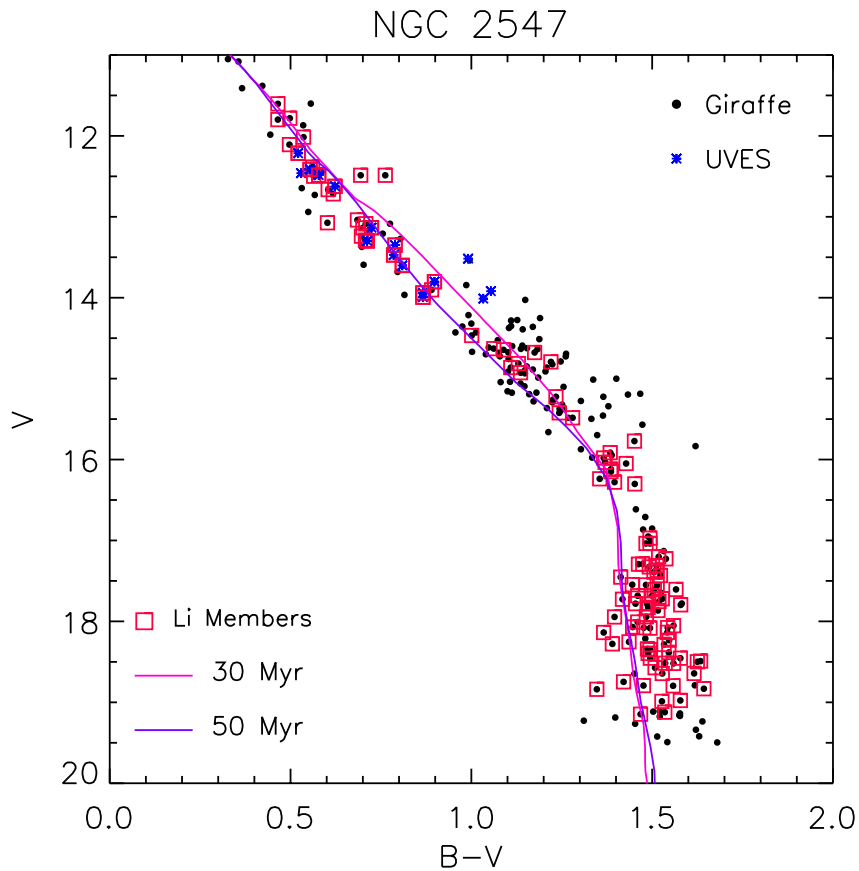
Baraffe et al. (2002, A&A 382, 563) Li isochrones adapted from Jeffries et al. (2009).

NGC 2547 - Member selection

BVI_C Photometry ~ 250 stars (Johnson-Cousins)

$D=400$ pc; $A_V=0^m.12$

PARSEC isochrones (Bressan et al. 2012)



Not all the candidates have optical photometry in the header

NGC 2547 - Member selection

The “final” members (**Population A**) are selected among the candidates from their radial velocity:

$$5 \leq RV \leq 16.5 \text{ km/s.}$$

105 Giraffe members

Excluding 10 stars observed also with UVES

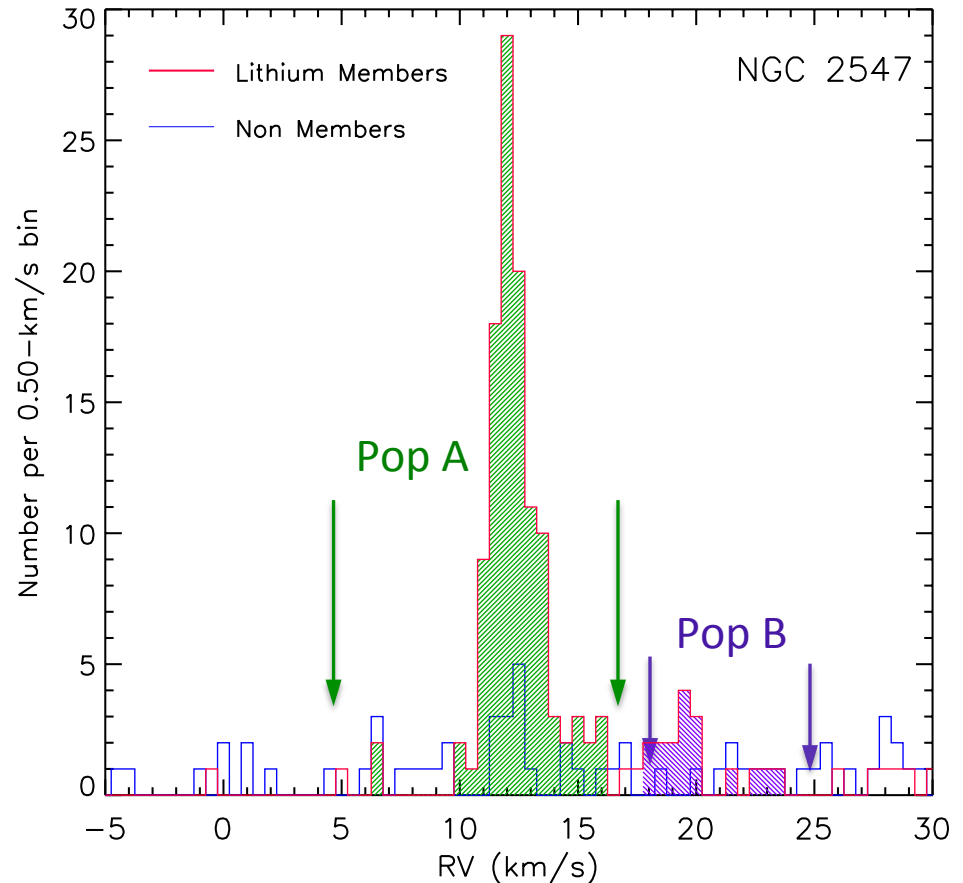
11 UVES members

Population B:

$$17.5 \leq RV \leq 25 \text{ km/s.}$$

17 Giraffe members

No UVES



RV distribution for the members peaked at about +12 km/s plus a second smaller peak (Pop B) likely associated to the nearby γ Vel cluster or Vela OB2 association (Sacco et al. 2014).

NGC 2547 - “Final” Members

Population A:

105/450 “Final” (Li+RV)
members for Giraffe
(excluding 10 observed also with
UVES)

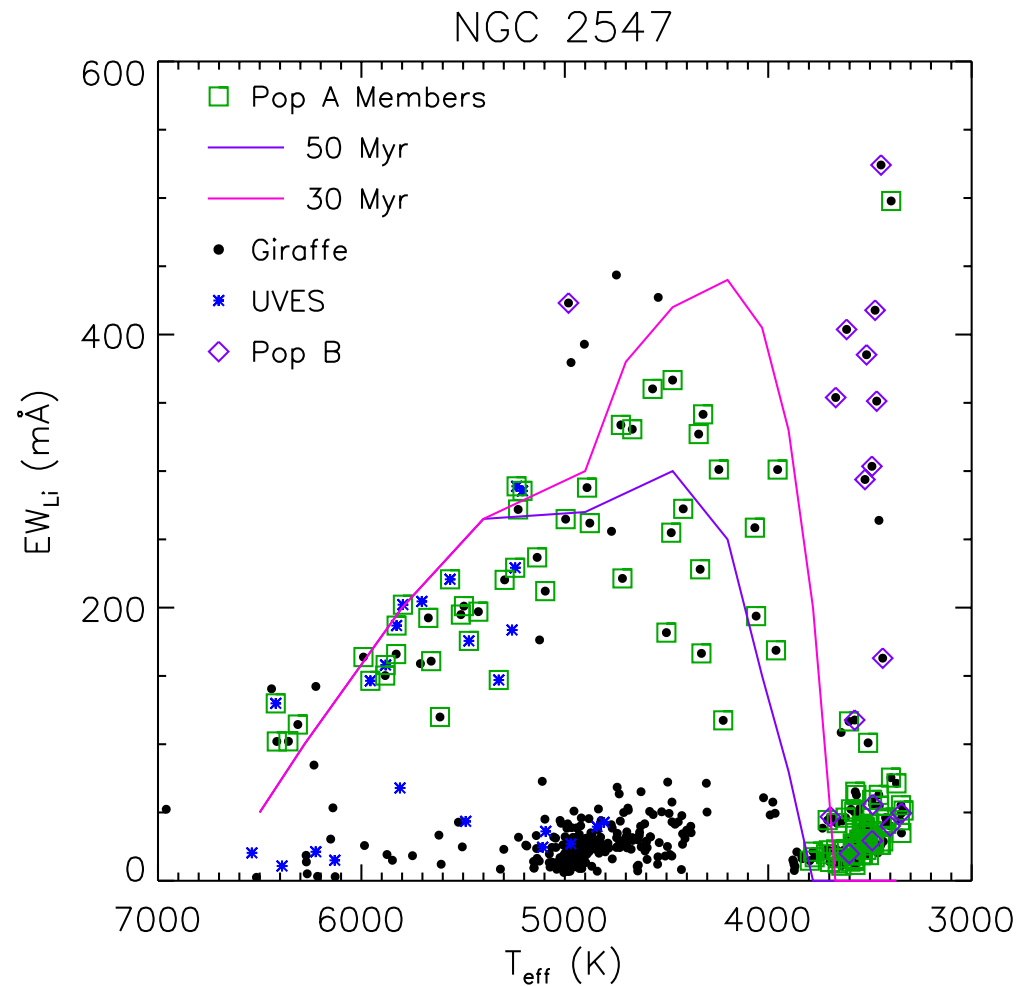
11/26 for UVES

Population B:

$17.5 \leq RV \leq 25$ km/s.

17 Giraffe members

No UVES



NGC 2547 - “Final” Members

Population A:

105/450 “Final” (Li+RV)
members for Giraffe
(excluding 10 observed also with
UVES)

11/26 for UVES

Population B:

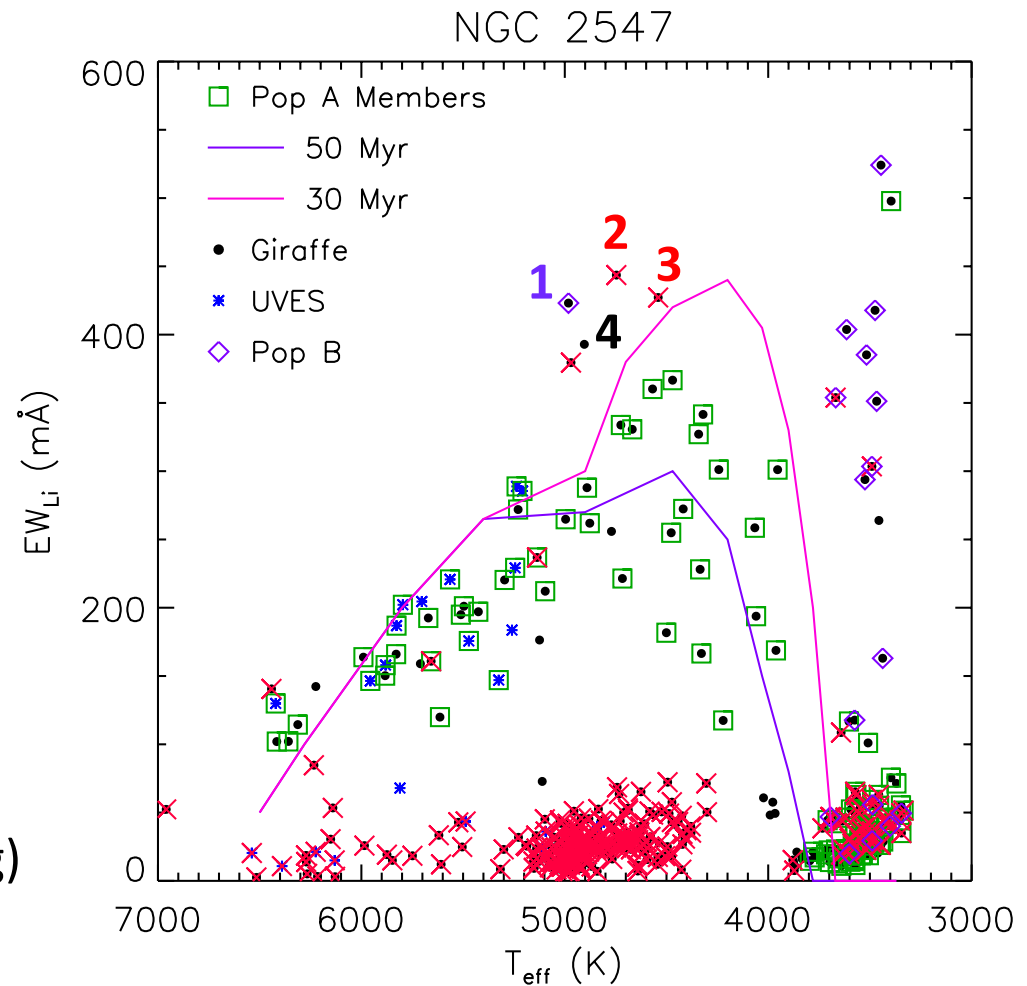
$17.5 \leq RV \leq 25$ km/s.

17 Giraffe members

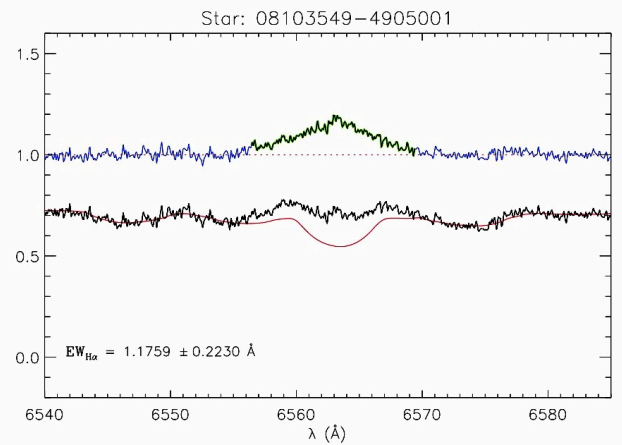
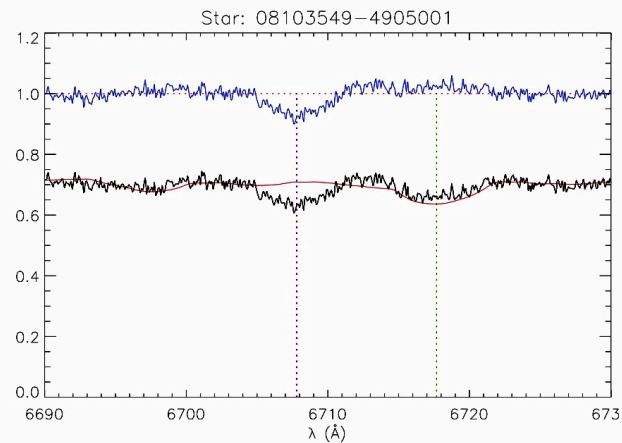
No UVES

✗ = no H α emission (or filling)

Or no H α data

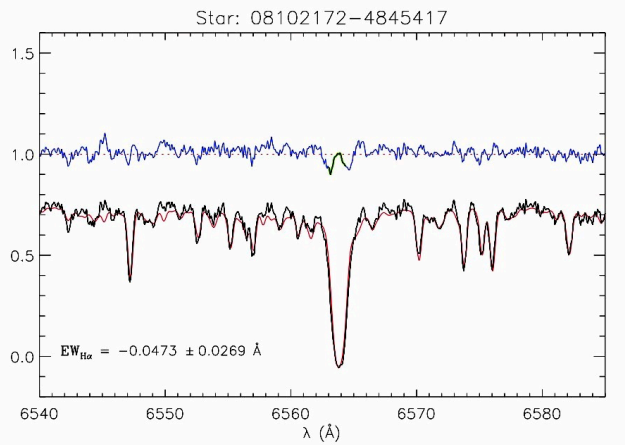
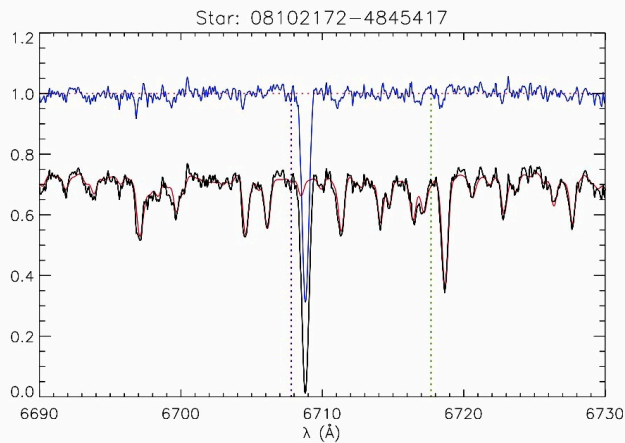


1



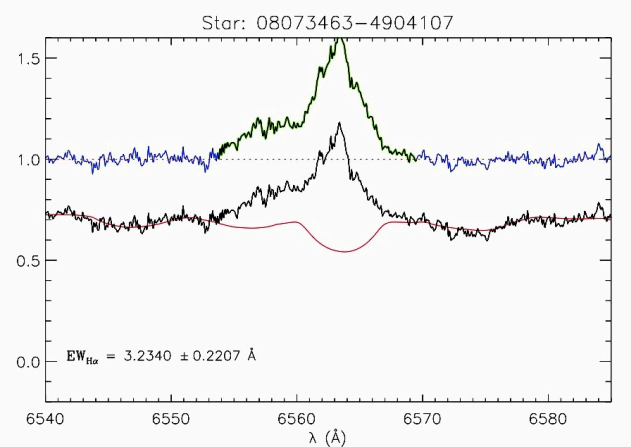
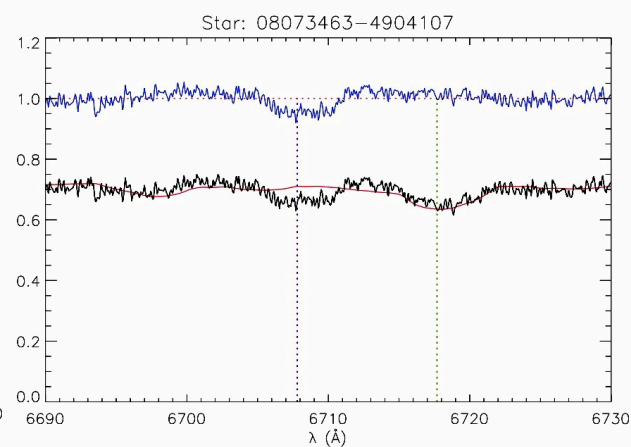
Member of Pop B

3



Lithium-rich Giant

4



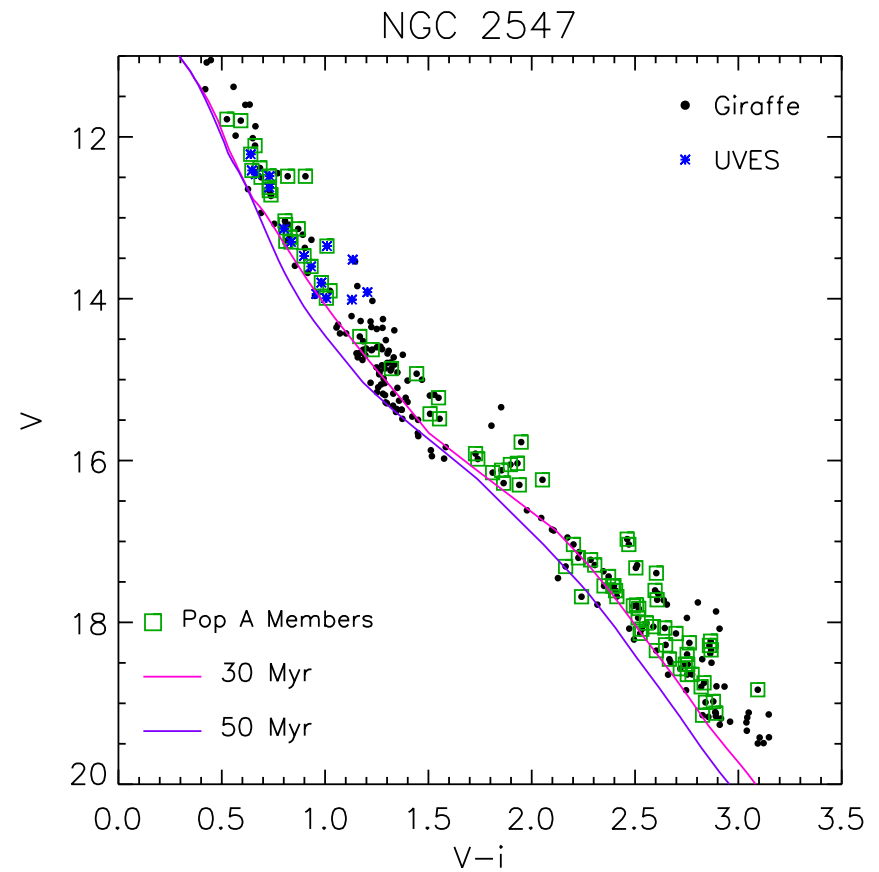
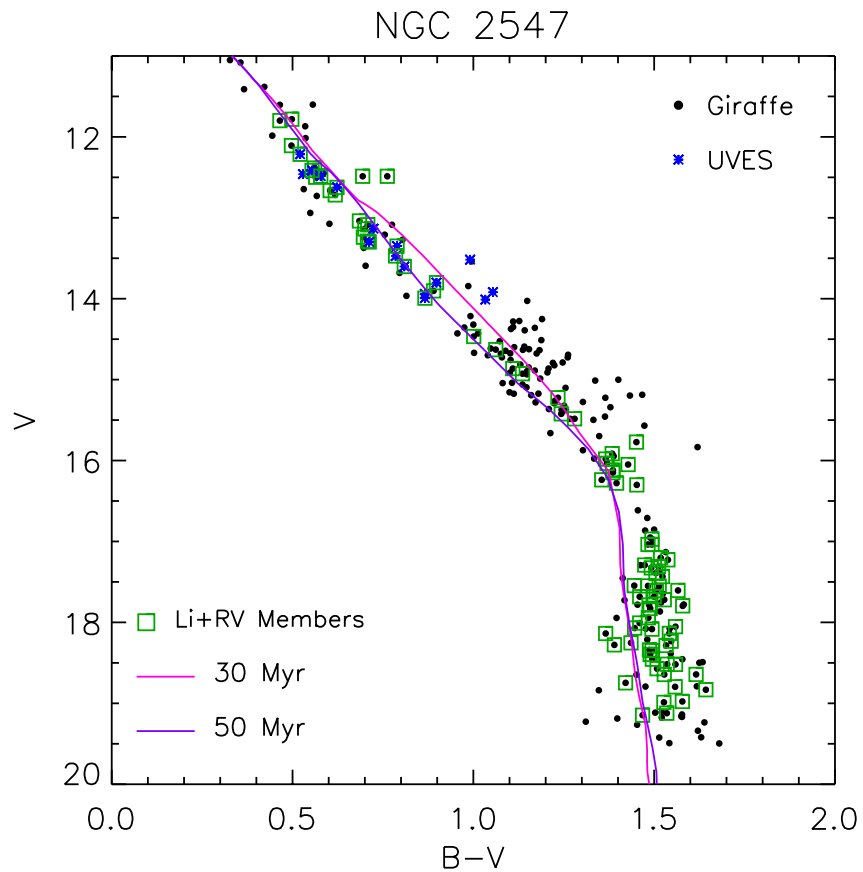
RV= 62.5 km/s, SB?

NGC 2547 - "Final" members

BVI_C Photometry ~ 250 stars (Johnson-Cousins)

$D=400$ pc; $A_V=0^m.12$

PARSEC isochrones (Bressan et al. 2012)

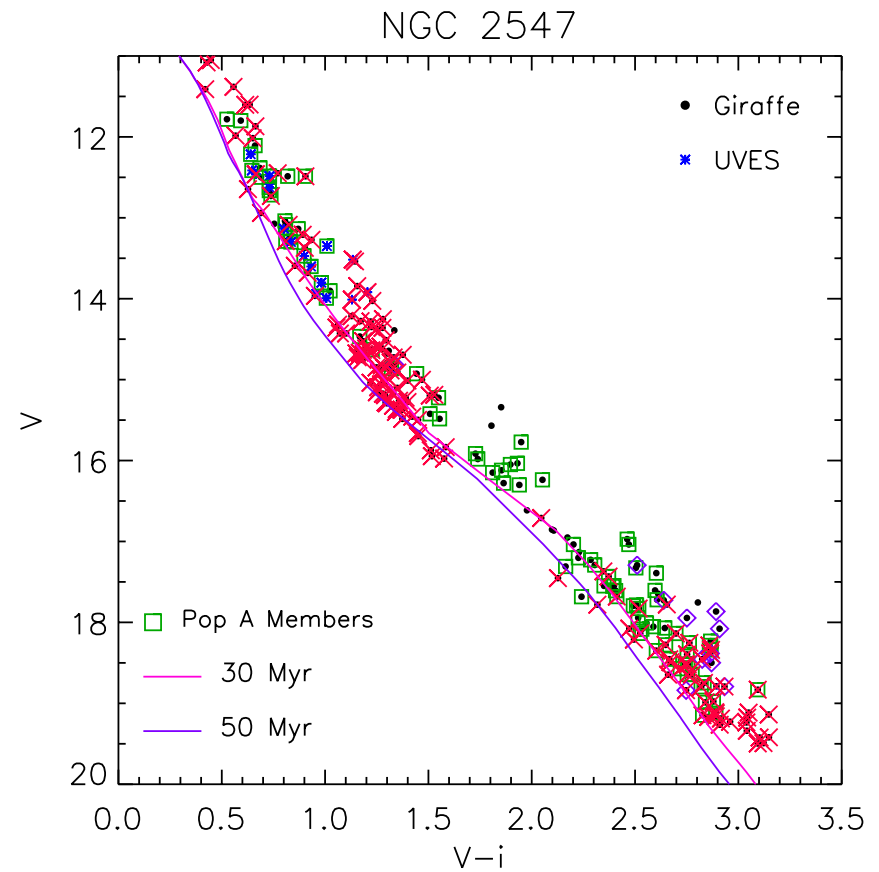
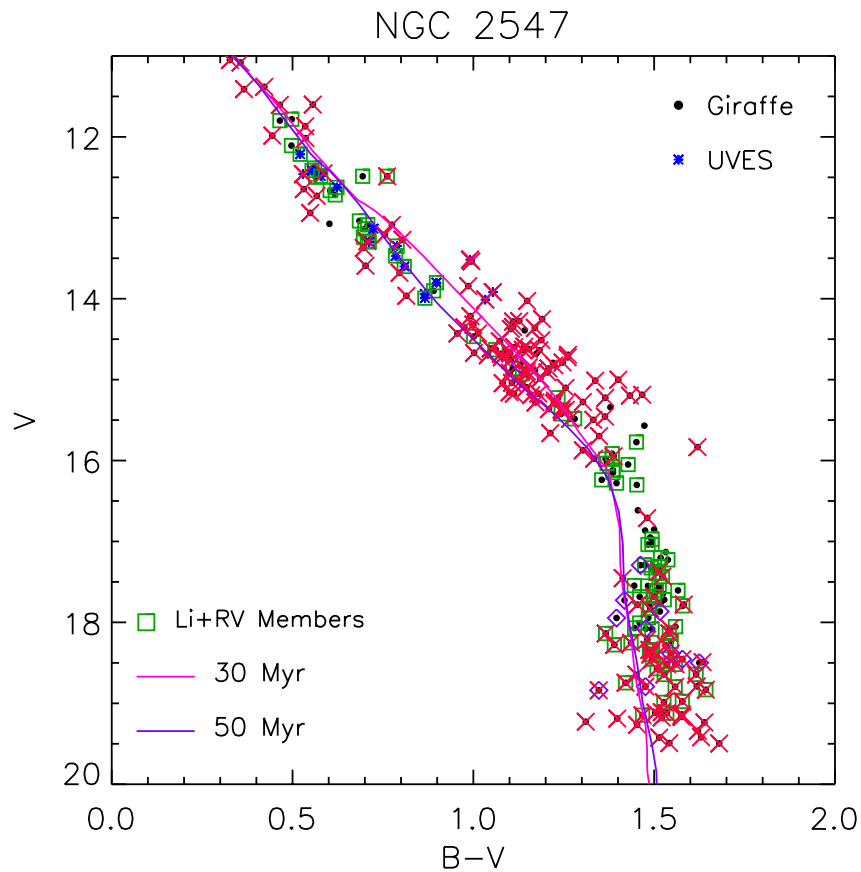


NGC 2547 - "Final" members

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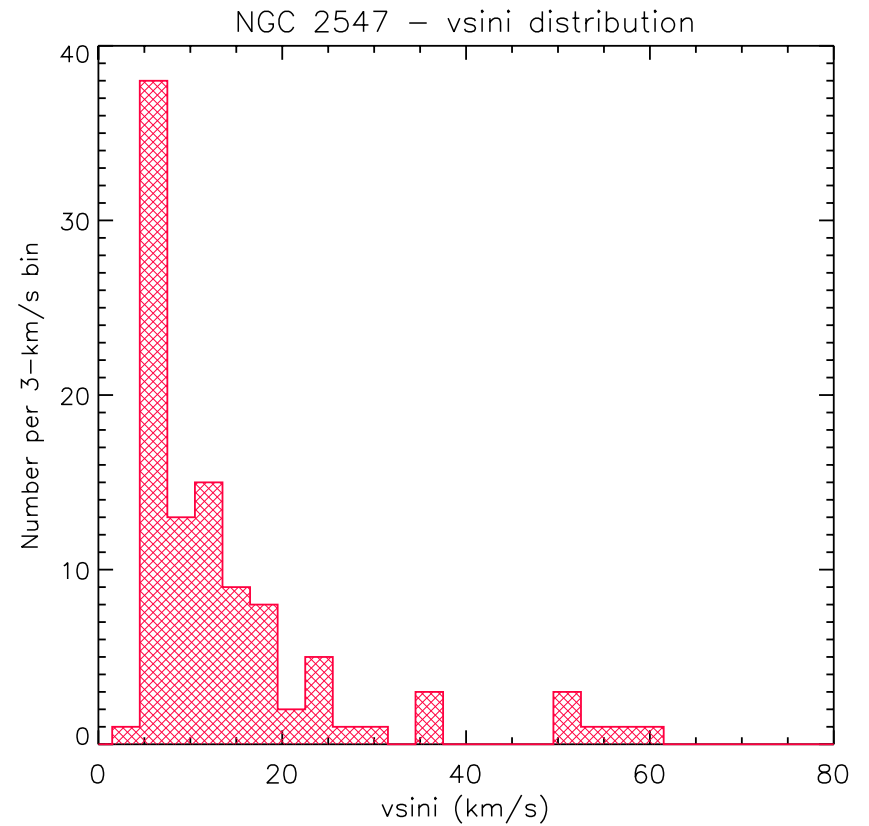
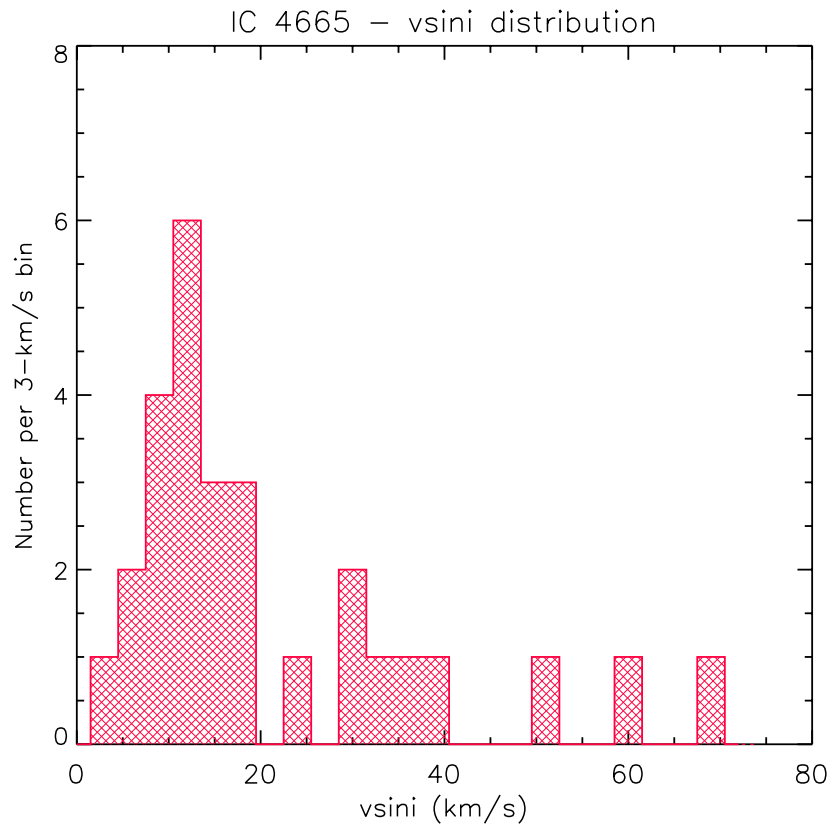
$D=400$ pc; $A_V=0^m.12$

PARSEC isochrones (Bressan et al. 2012)

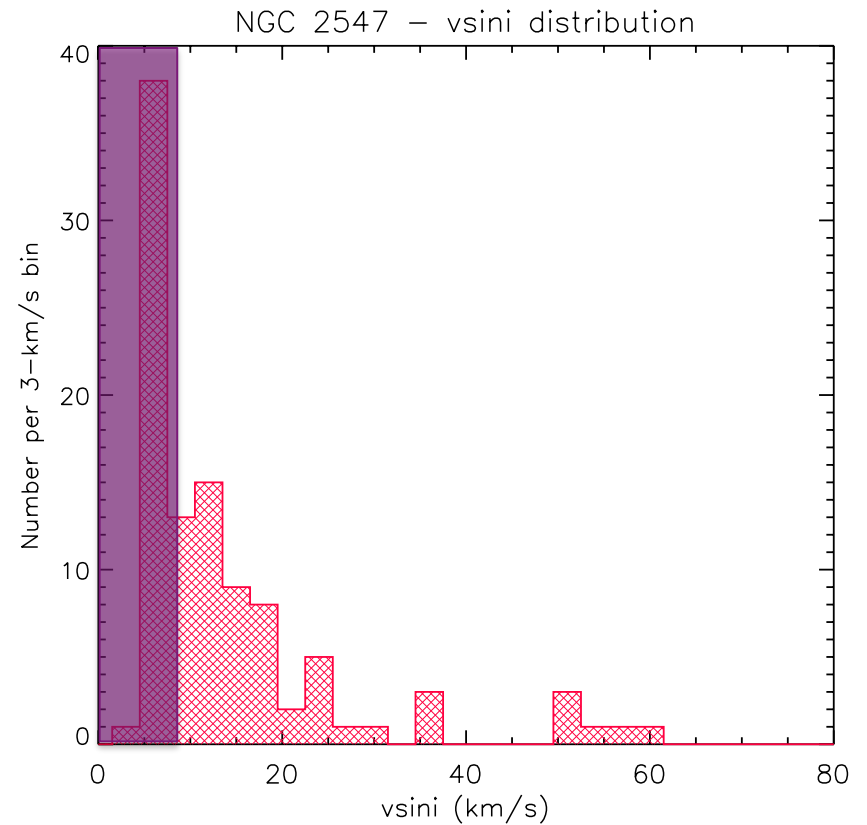
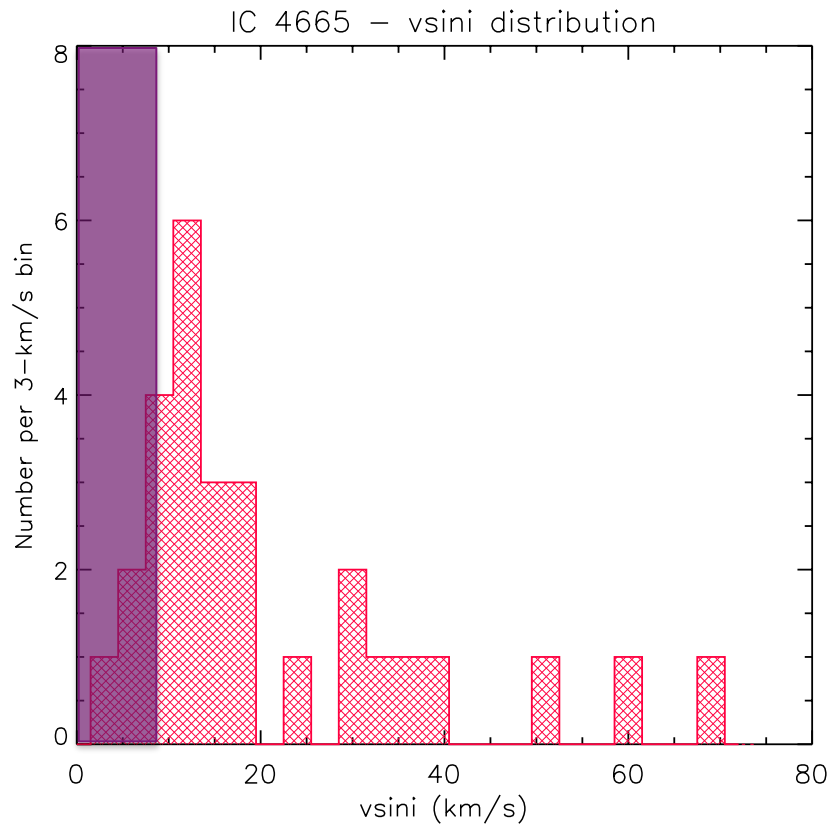


✗ = no H α emission (or filling)

vsini Distributions

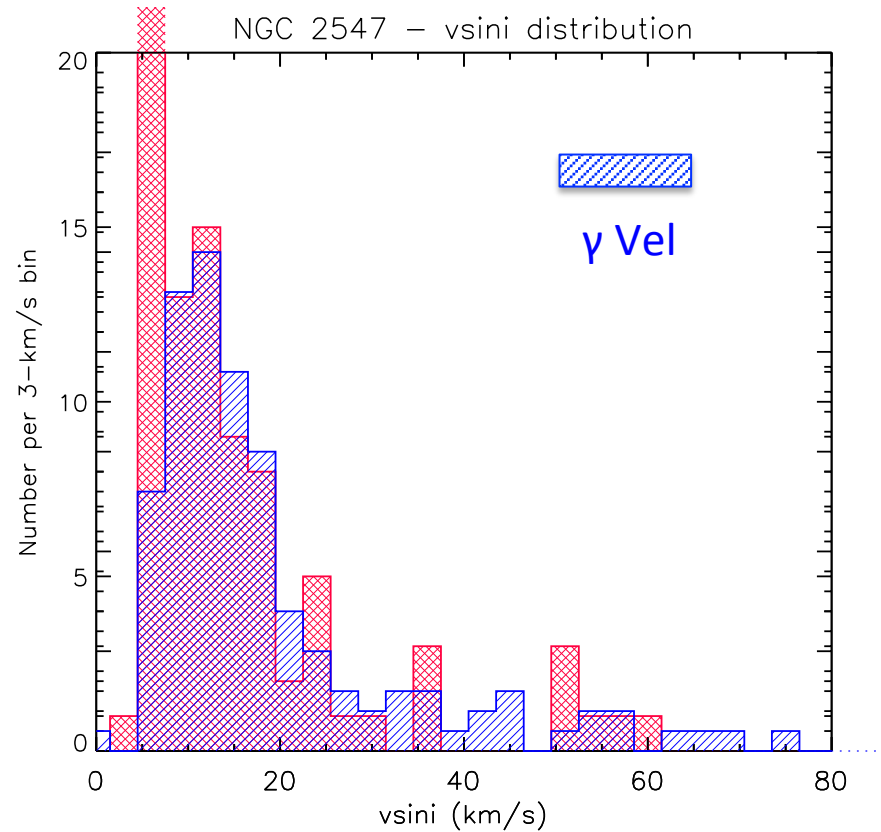
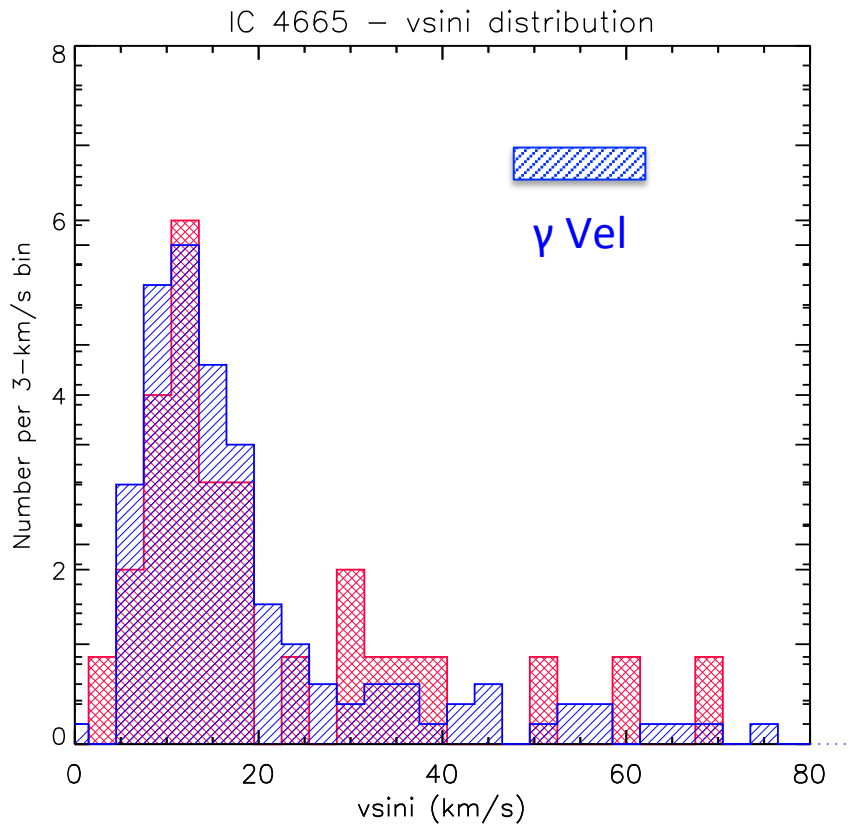


vsini Distributions



vsini upper limit ≈ 7 km/s for Giraffe spectra (Frasca et al. 2014)

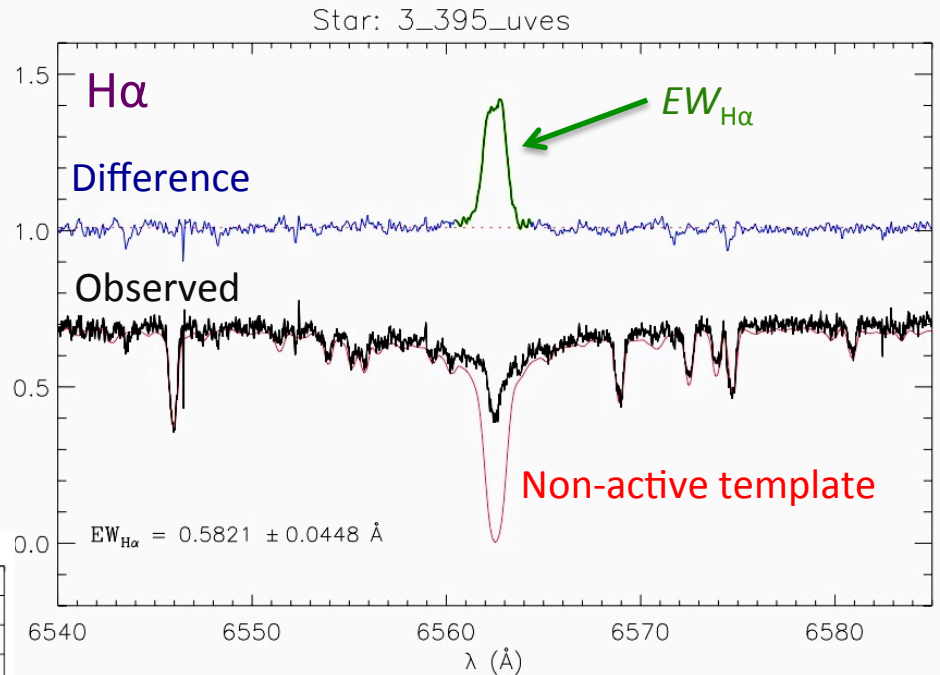
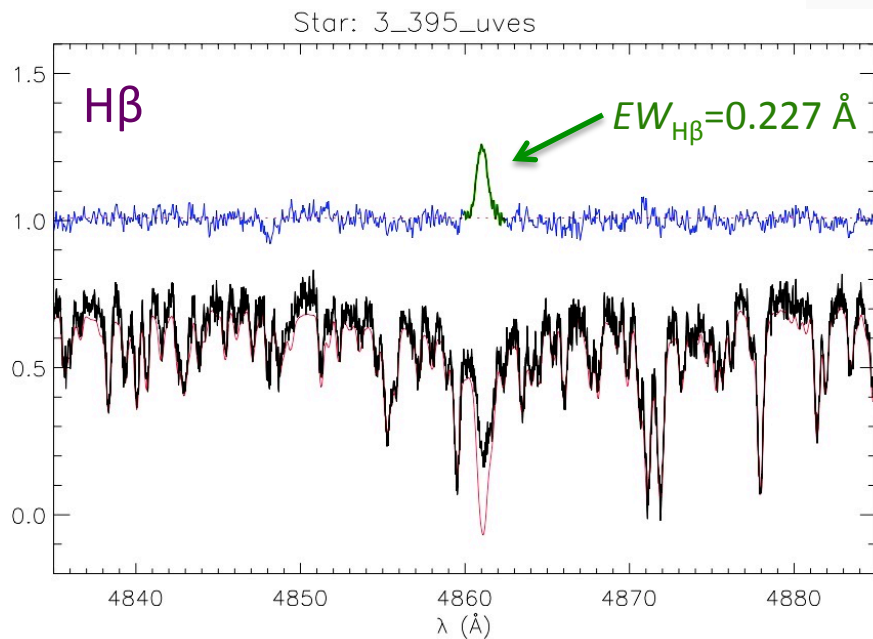
vsini Distributions



Marginal difference with respect to the younger (10 Myr) cluster γ Vel.
Less slow rotators, more fast rotators ($vsini > 30$ km/s)

Chromospheric Activity: spectral subtraction

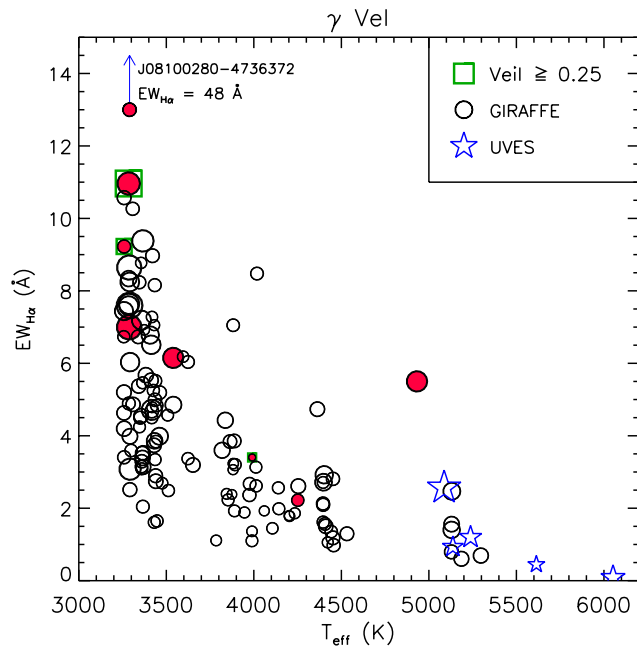
Removal of photospheric profile
→ Subtraction of a “non-active template”:
a spectrum of a **low-activity standard star** degraded to the Giraffe/UVES resolution, rotationally broadened and Doppler-shifted.



K0V active star member of IC4665
observed with UVES.

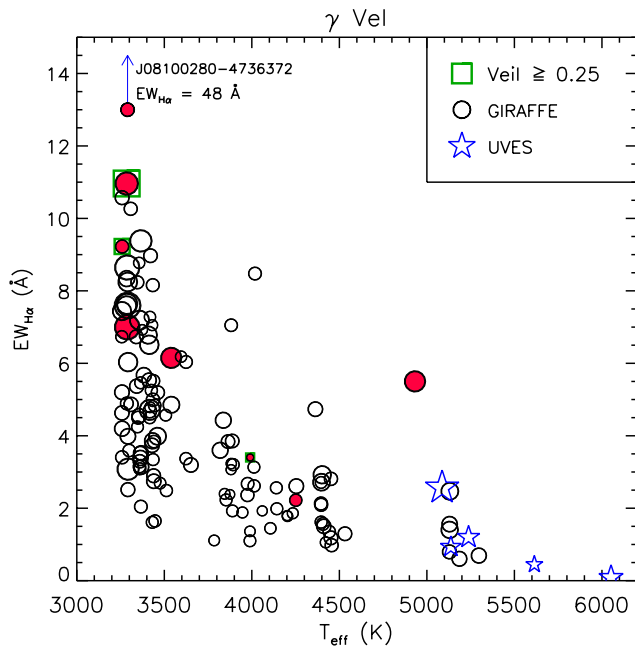
$T_{\text{eff}} = 5360 \text{ K}$; $v \sin i = 13 \text{ km/s}$

Chromospheric Activity: $EW_{H\alpha}$, $F_{H\alpha}$, $L_{H\alpha}/L_{bol}$

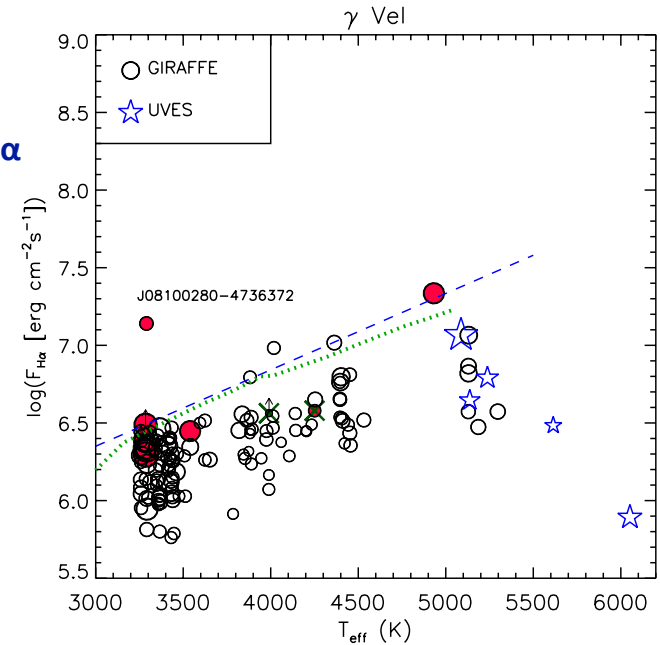


Largest $EW_{H\alpha}$ for cooler stars. Contrast effect: $H\alpha$ emission stands out against a low continuum.

Chromospheric Activity: $EW_{H\alpha}$, $F_{H\alpha}$, $L_{H\alpha}/L_{bol}$



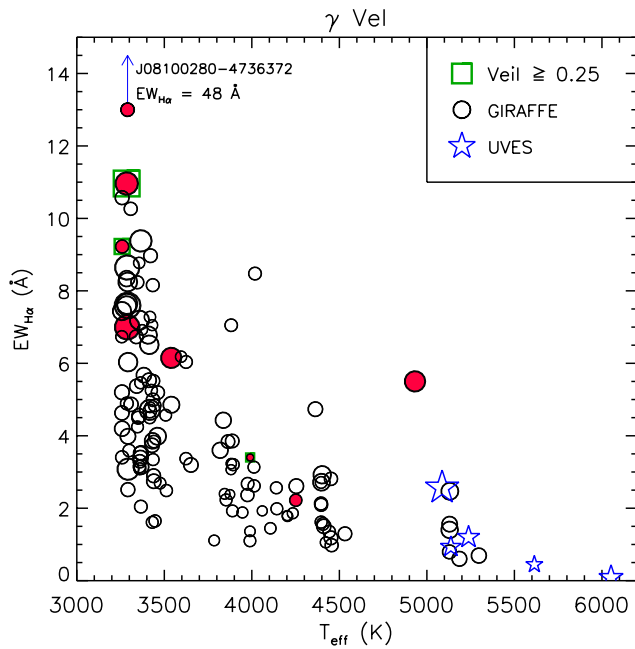
$$F_{H\alpha} = F_{cont} * EW_{H\alpha}$$



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

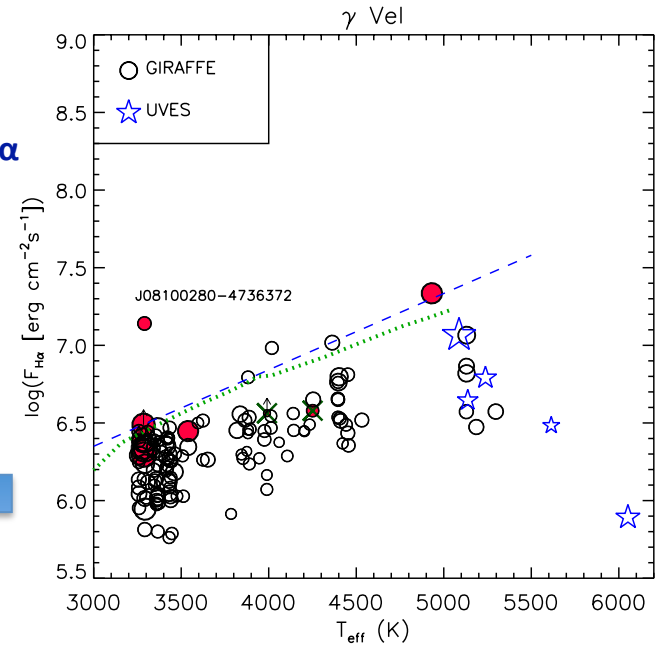
When converted into flux, the nearly exponential behaviour with T_{eff} disappears.

Chromospheric Activity: $EW_{H\alpha}$, $F_{H\alpha}$, $L_{H\alpha}/L_{bol}$



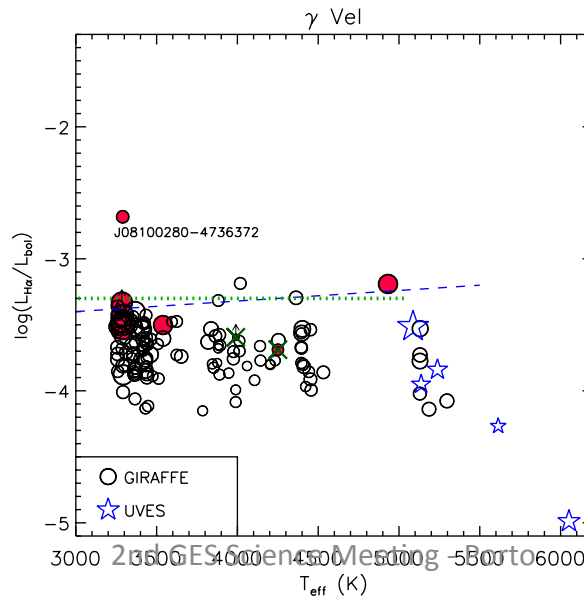
$$F_{H\alpha} = F_{cont} * EW_{H\alpha}$$

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

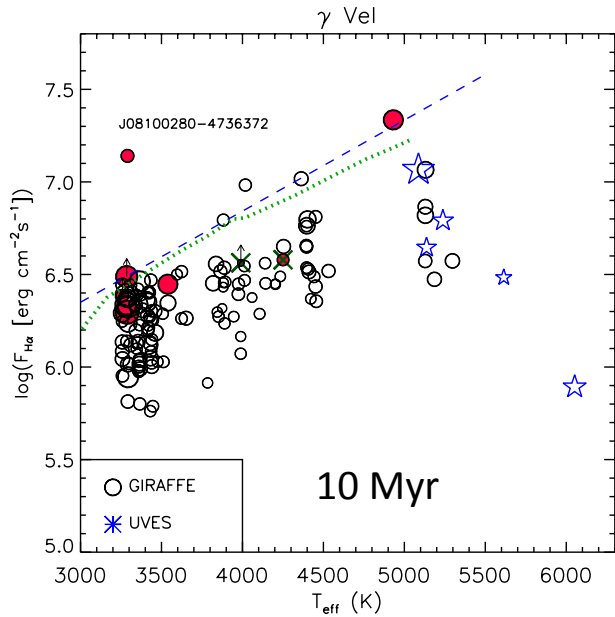


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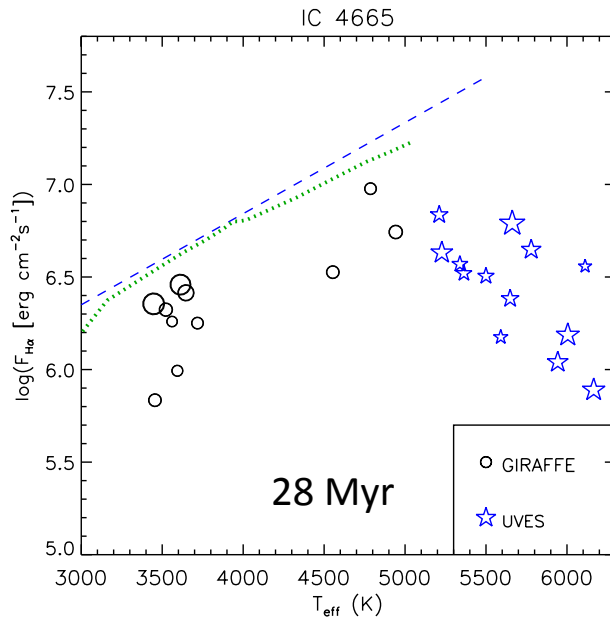


Chromospheric Activity vs. T_{eff}



----- Saturation limit (Barrado & Martin 2003)

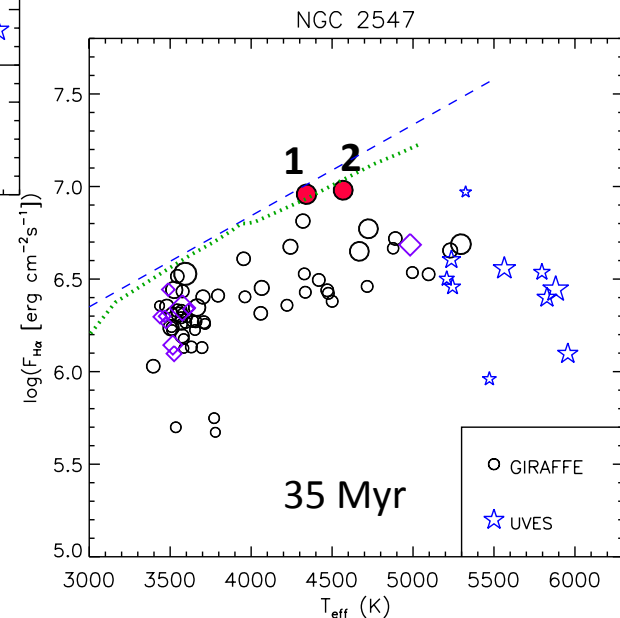
----- Dividing line accretion/chrom. (Frasca et al. 2014)



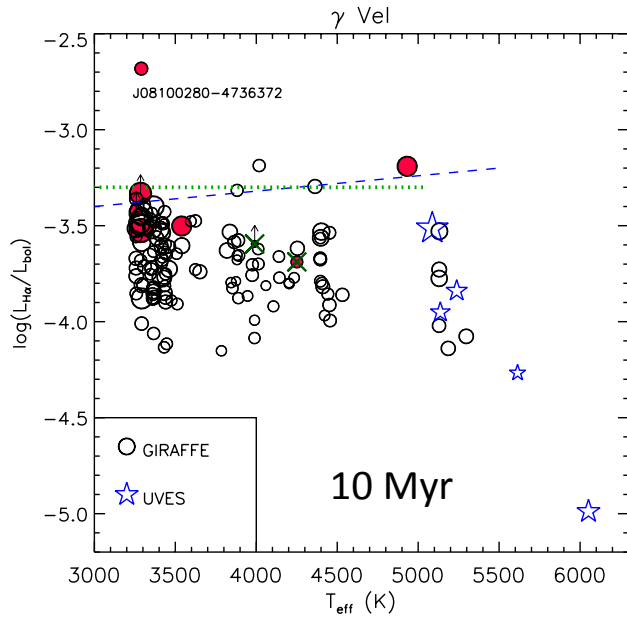
$F_{\text{H}\alpha}$

Less (or no) accretor candidates ($W_{10\%} > 270$ km/s) at older ages.

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



Chromospheric Activity vs. T_{eff}



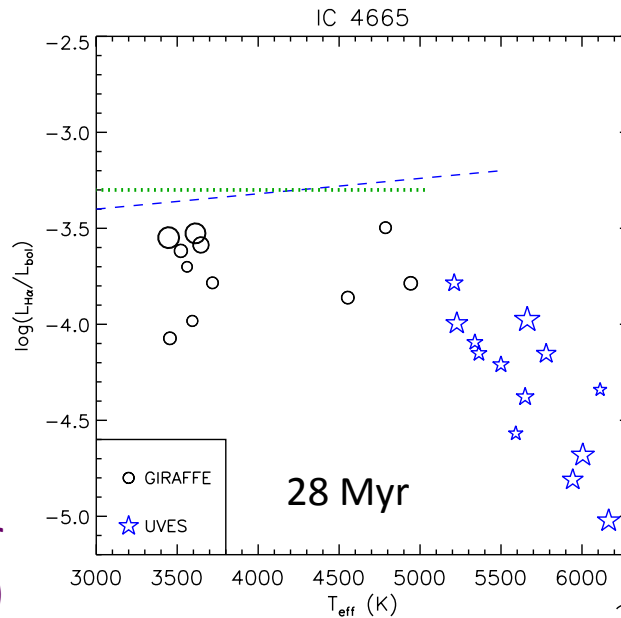
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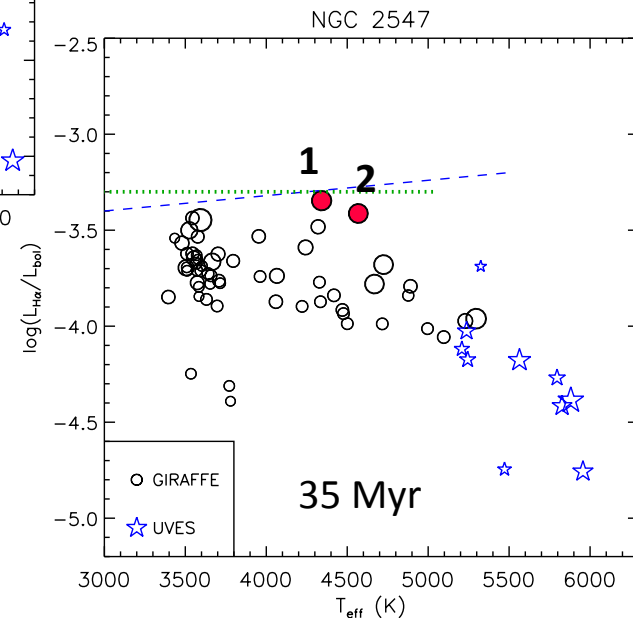
12/11/14

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

----- Dividing line accretion/chrom. (Frasca et al. 2014)

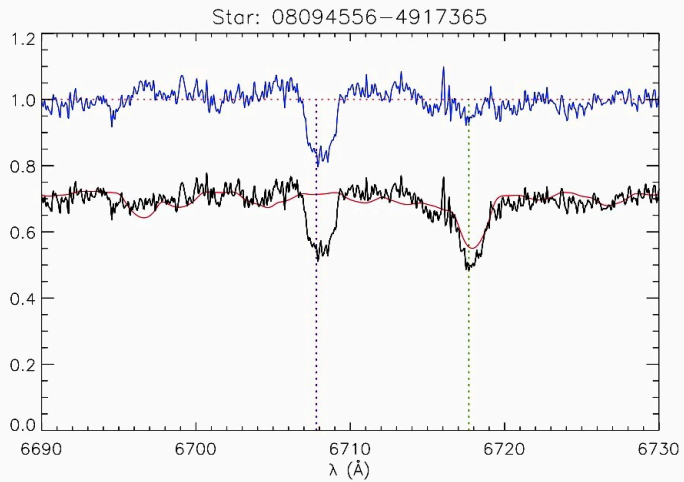


$$R'_{\text{H}\alpha} = L_{\text{H}\alpha}/L_{\text{bol}}$$

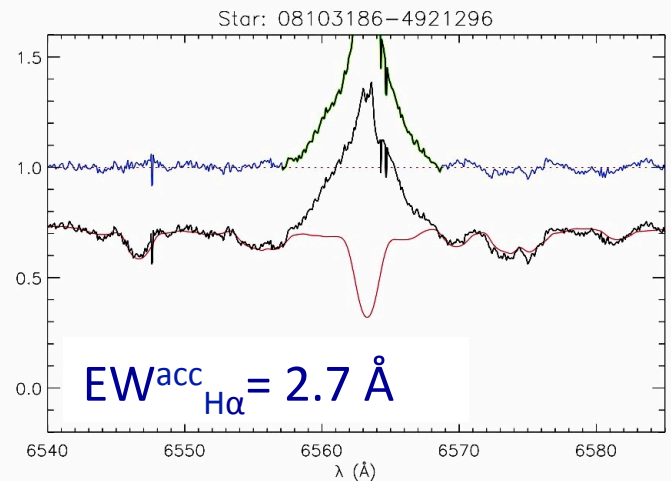
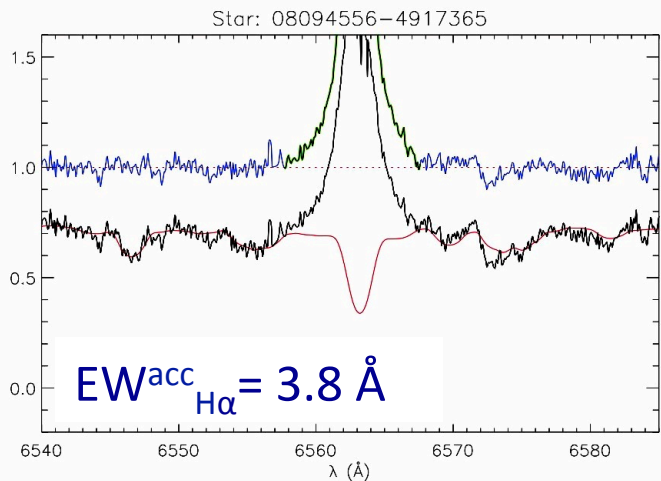
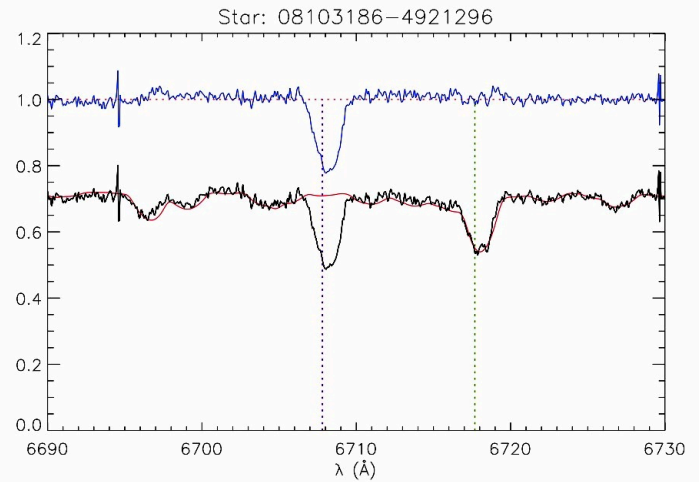


Accretor candidates

1

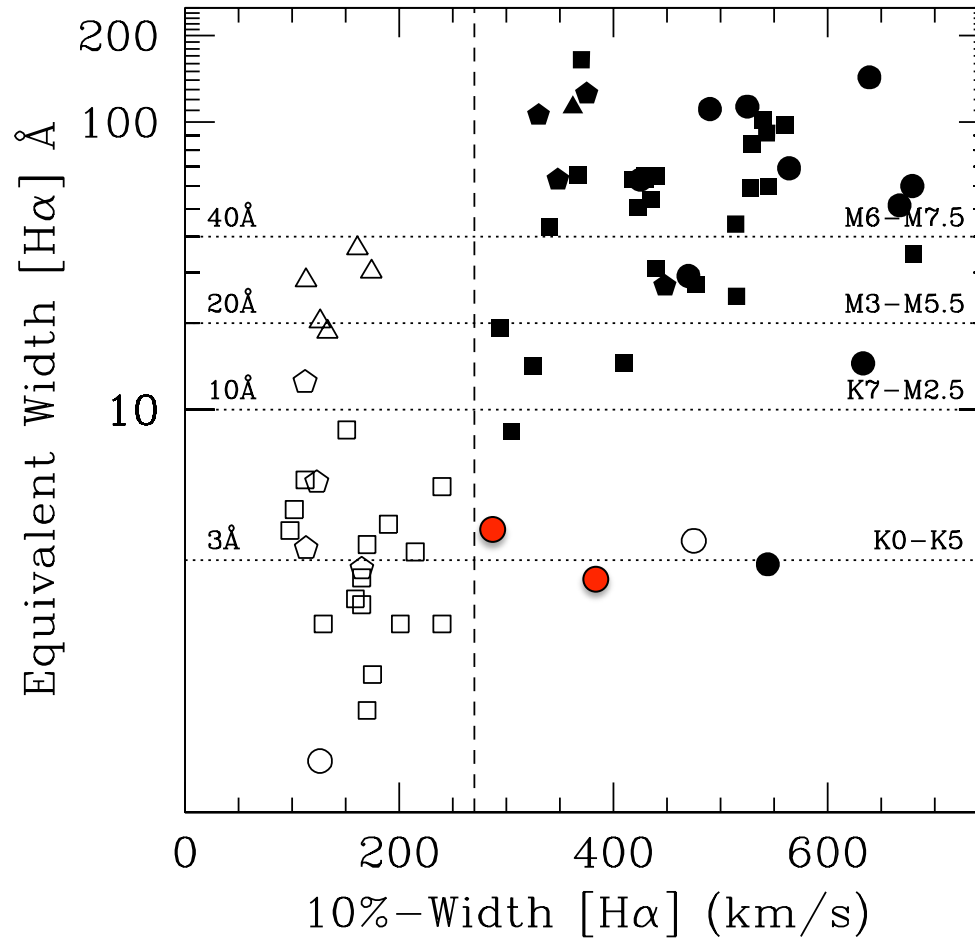


2



K5; $T_{\text{eff}} = 4340 \text{ K}$; $W_{10\%} = 291 \text{ km/s}$

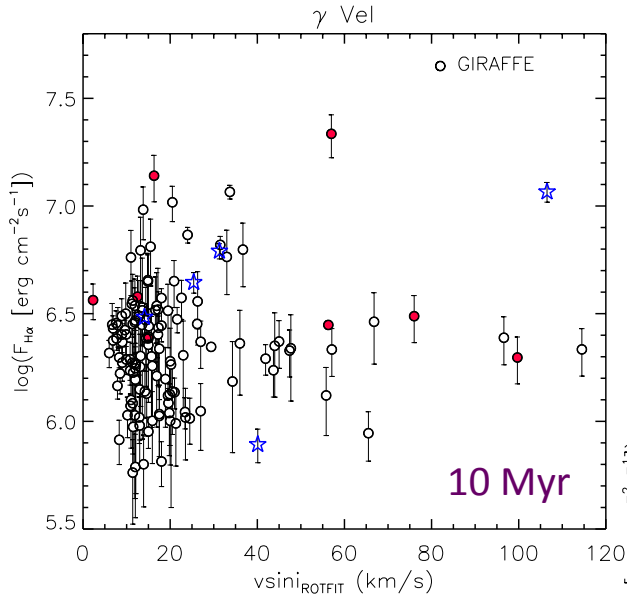
K5; $T_{\text{eff}} = 4570 \text{ K}$; $W_{10\%} = 374 \text{ km/s}$



From White & Basri
(2003, ApJ, 582, 1109)

Border-line objects

Chromospheric Activity vs. $v\sin i$

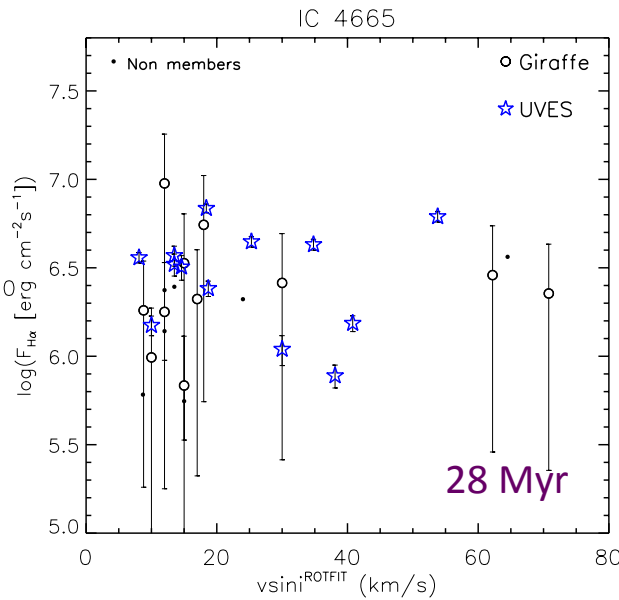


Rank Correlation

$$\rho = 0.057$$

$$\sigma = 0.519$$

$F_{H\alpha}$

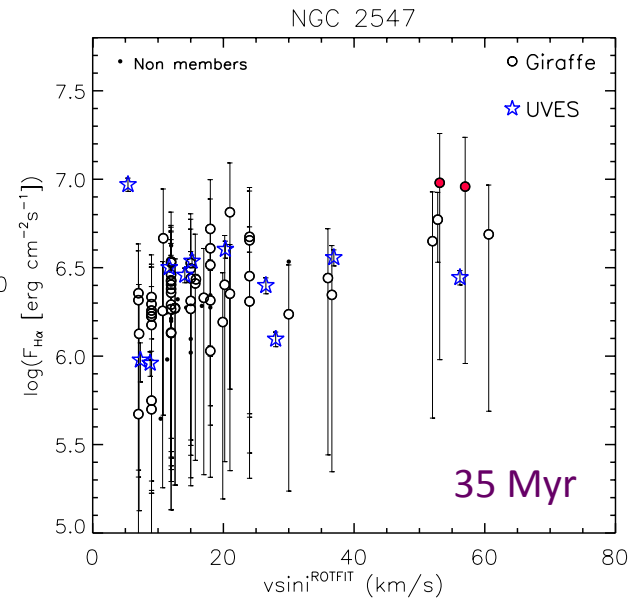


$$\rho = 0.045$$

$$\sigma = 0.835$$

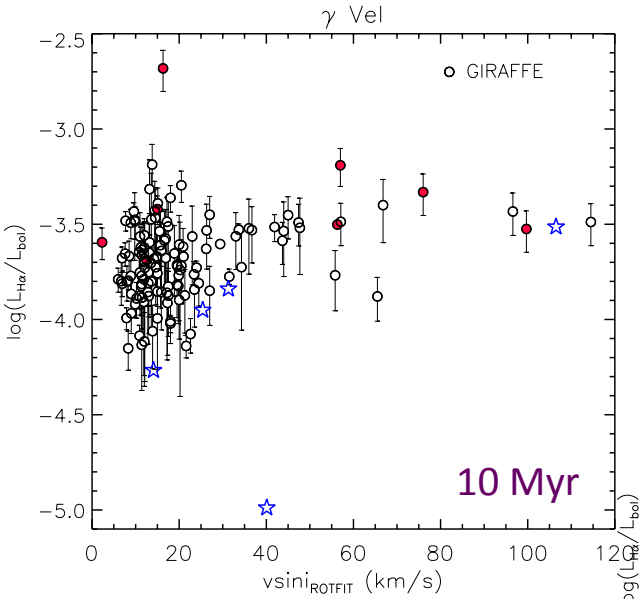
$$\rho = 0.467$$

$$\sigma = 5.9e-5$$



Chromospheric Activity vs. $v\sin i$

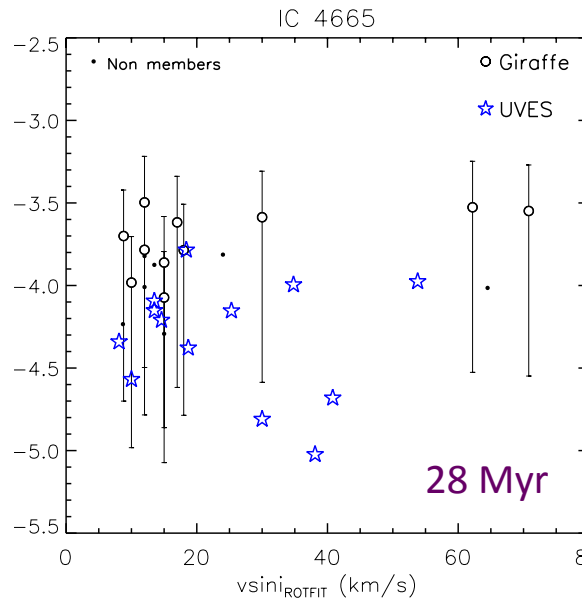
$$R'_{\text{H}\alpha} = L_{\text{H}\alpha} / L_{\text{bol}}$$



Rank Correlation

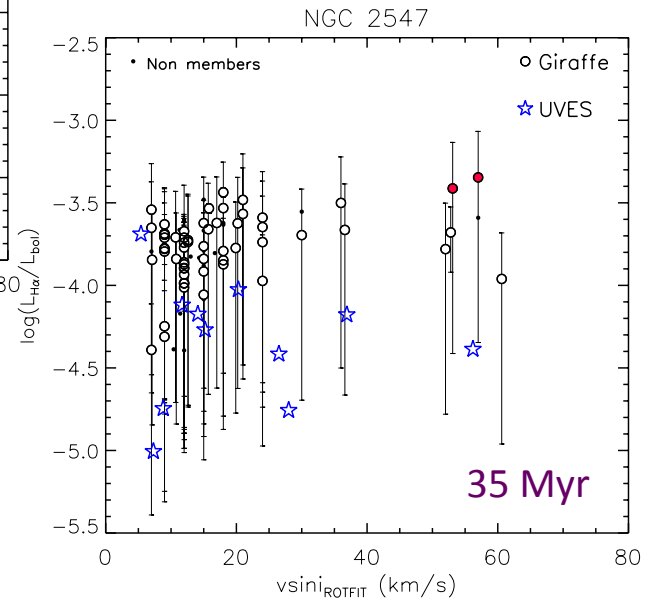
$\rho = 0.217$

$\sigma = 0.013$



$\rho = 0.027$

$\sigma = 0.902$



$\rho = 0.158$

$\sigma = 0.198$

Conclusions and perspectives

- Chromospheric activity ($H\alpha$ emission) is an additional tool for member selection;
- $v\sin i$ distributions: marginal difference between 10 Myr (Y Vel) and IC4665 (30 Myr) \rightarrow more fast rotators;
- Till to ~ 30 Myr all the stars cooler than about 4500 K are near the saturation of activity;
- Hotter stars display a flux $F_{H\alpha}$ and a $R'_{H\alpha}$ decreasing with the increasing T_{eff} ;
- Only 2 possible accretors in NGC2547 (Pop. A);
- A significant correlation between $F_{H\alpha}$ and $v\sin i$ only for NGC2547.
- Extend this analysis to all the nearby GES clusters with ages till to a few 100 Myr.