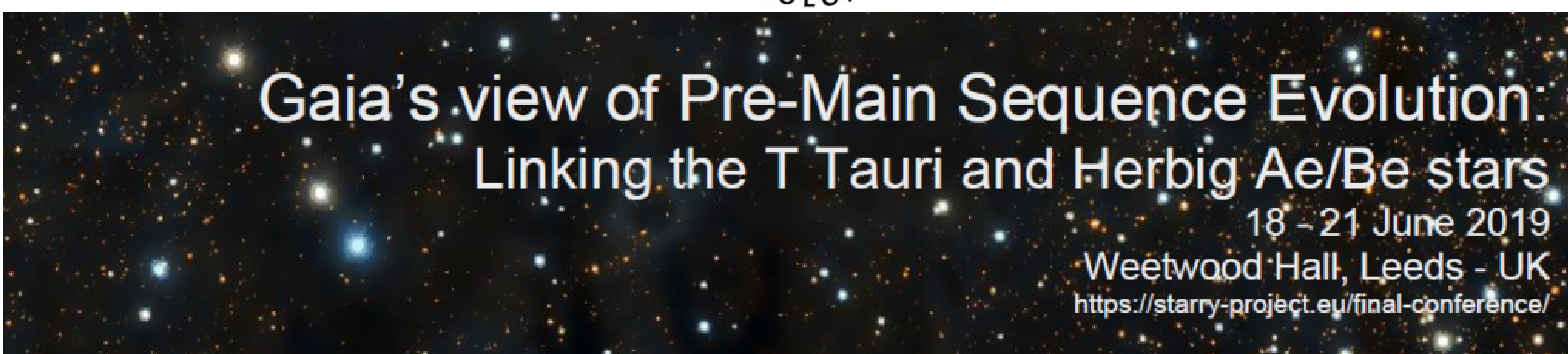
Rotational Evolution of T Tauri and Herbig Ae/Be stars

Giovanni Pinzón

(and J. Hernández, S. Matt, R. Avendaño, A. García, Y. Osorio)

Observatorio Astronómico
Universidad Nacional de Colombia, Bogotá



Motivation

Does magnetospheric accretion scenario depend on mass?

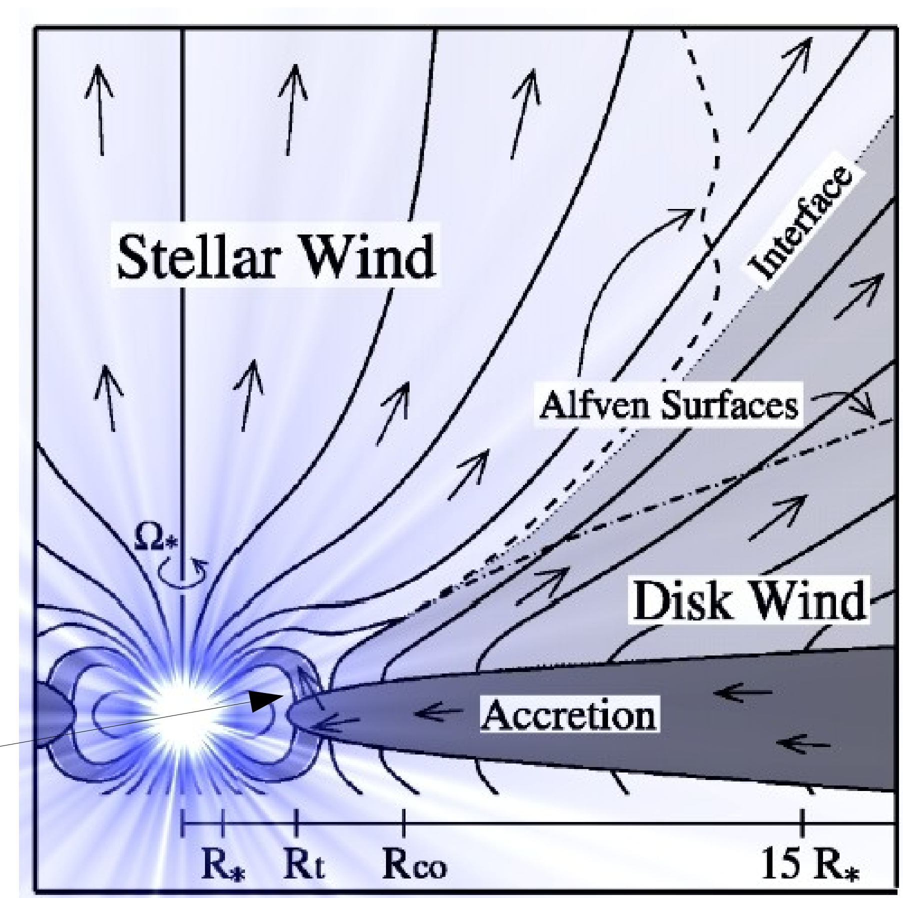
Context

CTTs ≤ 2Mo (Classical T Tauri stars)

HAeBes > 2-10Mo (Intermediate Mass stars)

(Matt+2012)

- Both : Are young, exhibit IR and UV excesses, mass inflow and outflows, variability, magnetic activity, multiplicity, X-ray emission.



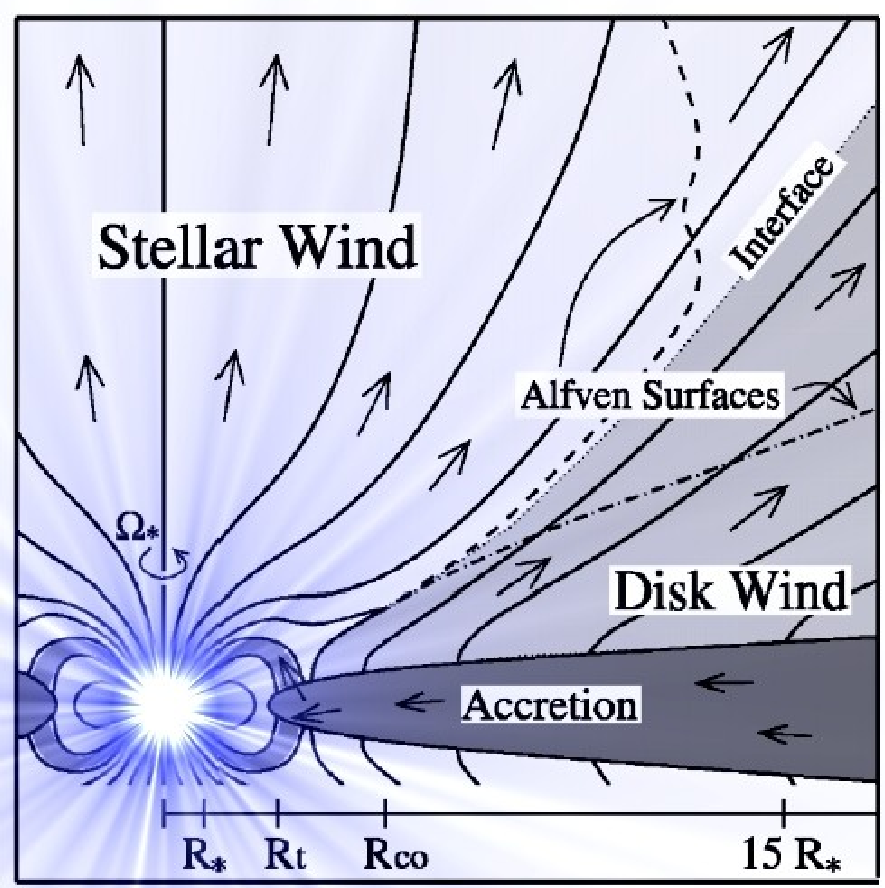
The accretion power shakes up open field lines setting off Alfven waves which end up driving gas away - different gas than the those that is accreted.

Context

- HAeBes are crossing the region in the HR diagram where the convective envelope dissapear. On the contrary, CTTs are fully convective.

- Absence of simultaneous occurrences of red(blue)-shifted absorption features in Herbig Bes is interpreted as Bes <u>accrete disk material</u> in a different way (Cauley+2015), **challenging the idea of a unique paradigm i.e. Magnetospheric Accretion, over the whole mass spectrum.**

(Matt+2012)



The accretion power shakes up open field lines setting off Alfven waves which end up driving gas away - different gas than the those that is accreted.

Stellar Rotation in accreting stars

CTTs

- Half of CTTs in larger samples are slow rotators. Spin down via star-disk interaction (Bouvier+1997,2013) and Stellar Winds (Matt+2012).
- <u>The restant fraction are fast rotators usually assumed diskless stars.</u>

HAeBes

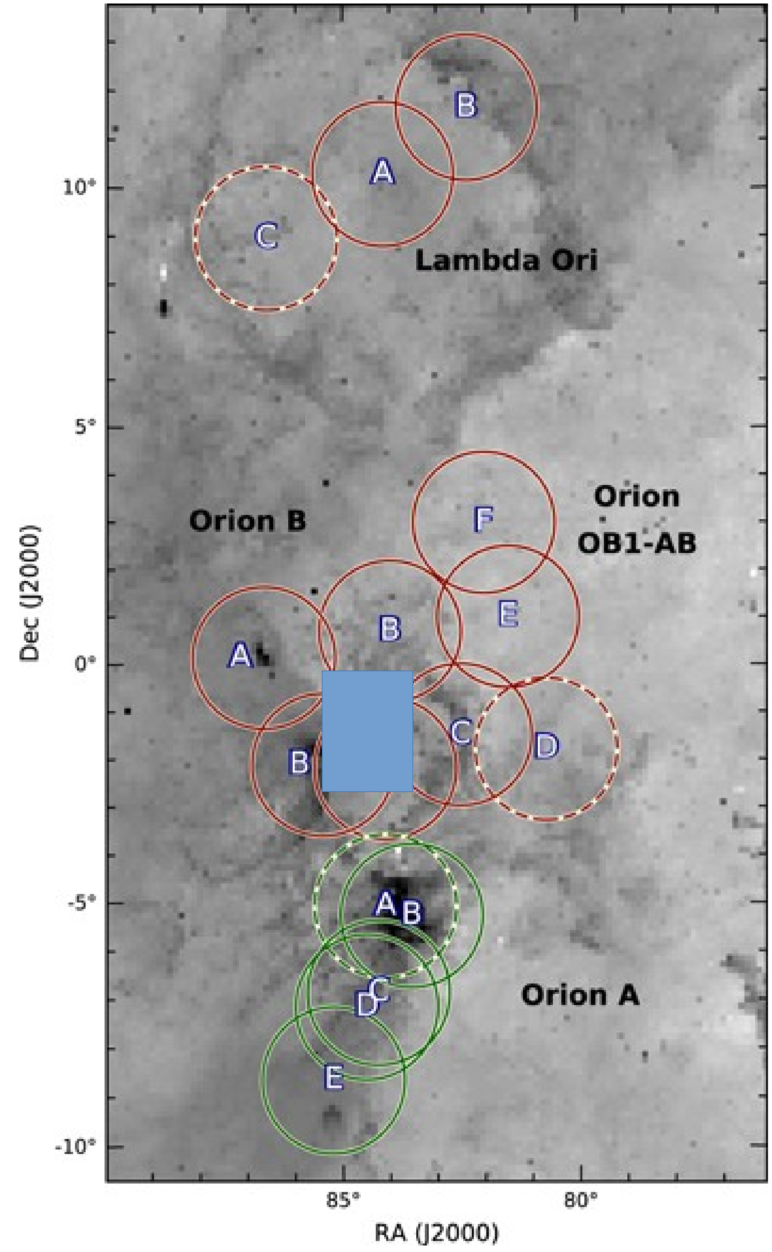
- Rotate faster due to they are bigger and with weaker magnetic fields (only 7-10% of positive detections) (Alecian+2013). **However, a more efficient braking is noted for magnetic HAeBes.**

  Thus, it seems plausible that the loss of Angular Momentum (AM) is occurring under same mechanisms than in CTTs.

- Moreover, HAeBes are the progenitors of the Ap/Bp MS stars which have periods of a few days (Zorec+2012)

Our Approach

We take to the limit the main assumptions used for describing the spin evolution in CTTs, extending them up to higher masses. For this purpose we consider an **approximately coeval sample** of young stars covering the mass interval 0.2 to 4.0 Mo belonging to the Orion molecular complex.

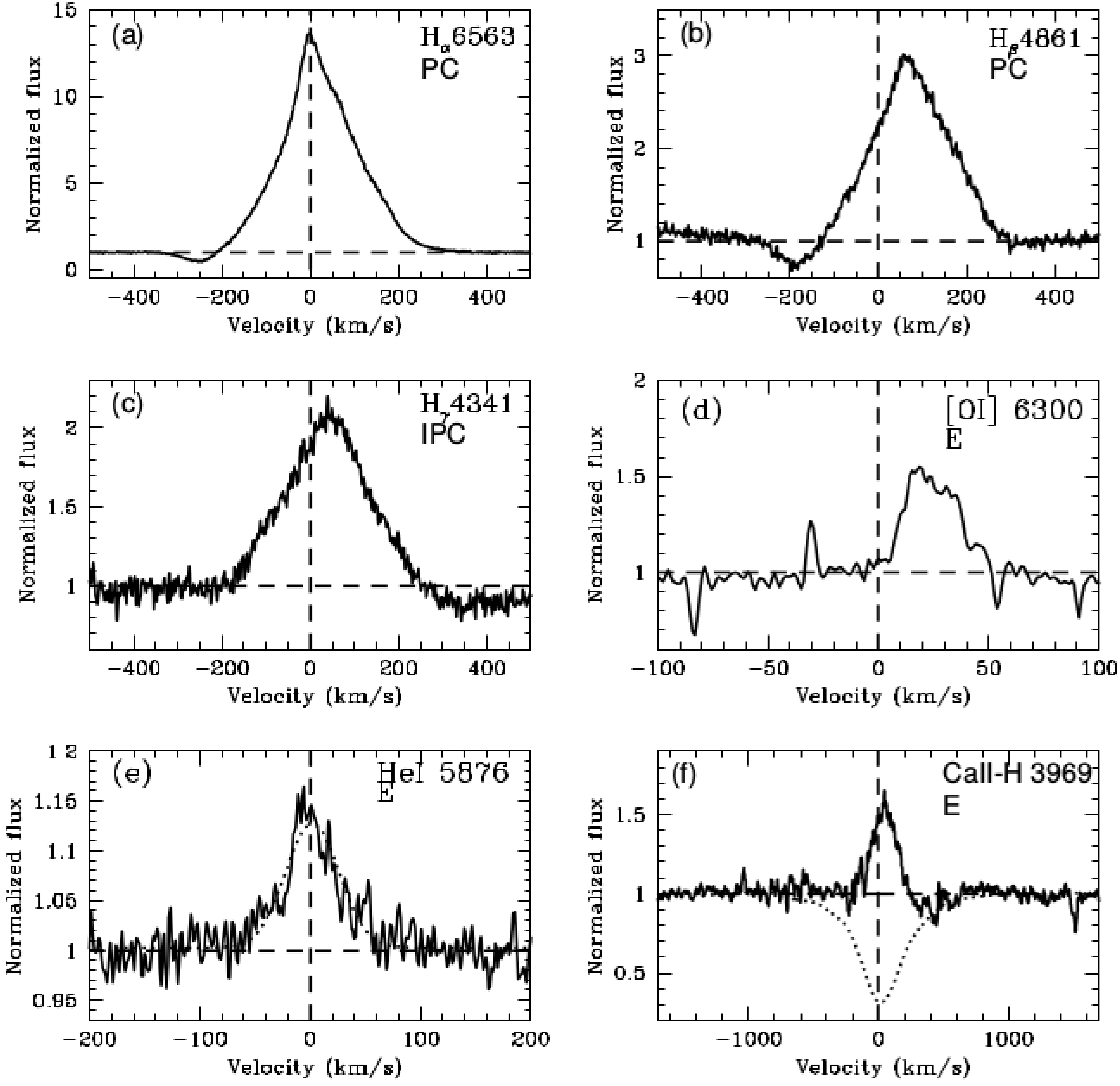


Our Approach

- We selected 6 HAeBes belonging to Orion Star formation Complex (~1My) and acquired High Resolution spectra with **FIES** spectrograph (R~68000) (3680 – 7270A) at **Nordic Optical Telescope** 2.5m. We measured ($v_e$sini) and conducted detailed analysis of line profiles .

- Also used data with similar resolution for 142 members of Sigma-Ori cluster (~3My) obtained with **HECTOECHELLE** fiber fed multiobject spectrograph at the 6.5m Telescope of the MMT Observatory (MMTO). We measured ($v_e$sini) for 60 of them which exhibit Li I in absorption.

FIES line profiles of HIP26955



Stellar or disk winds ?

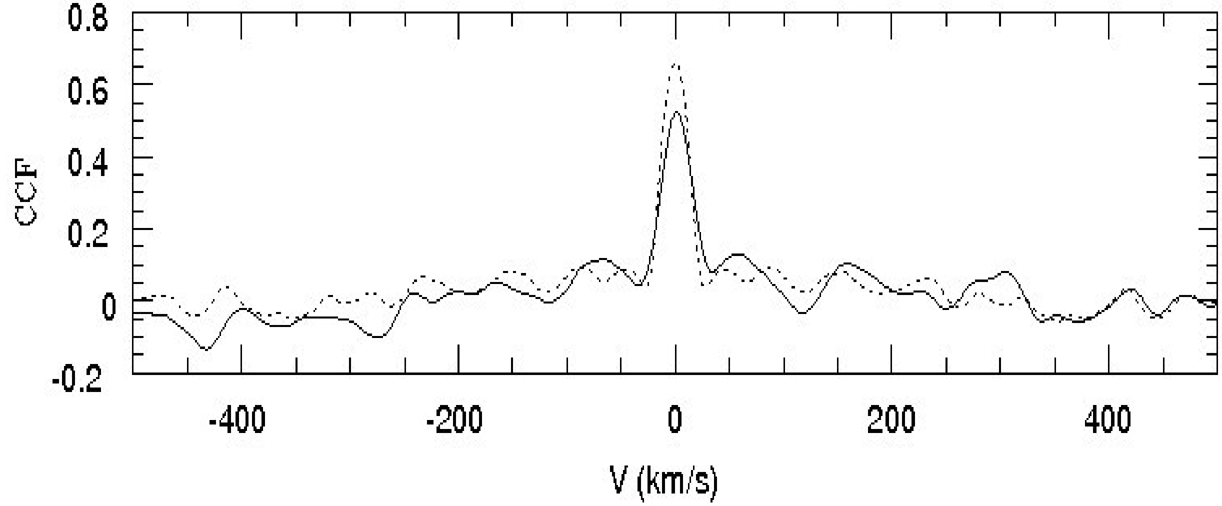
Stellar Parameters

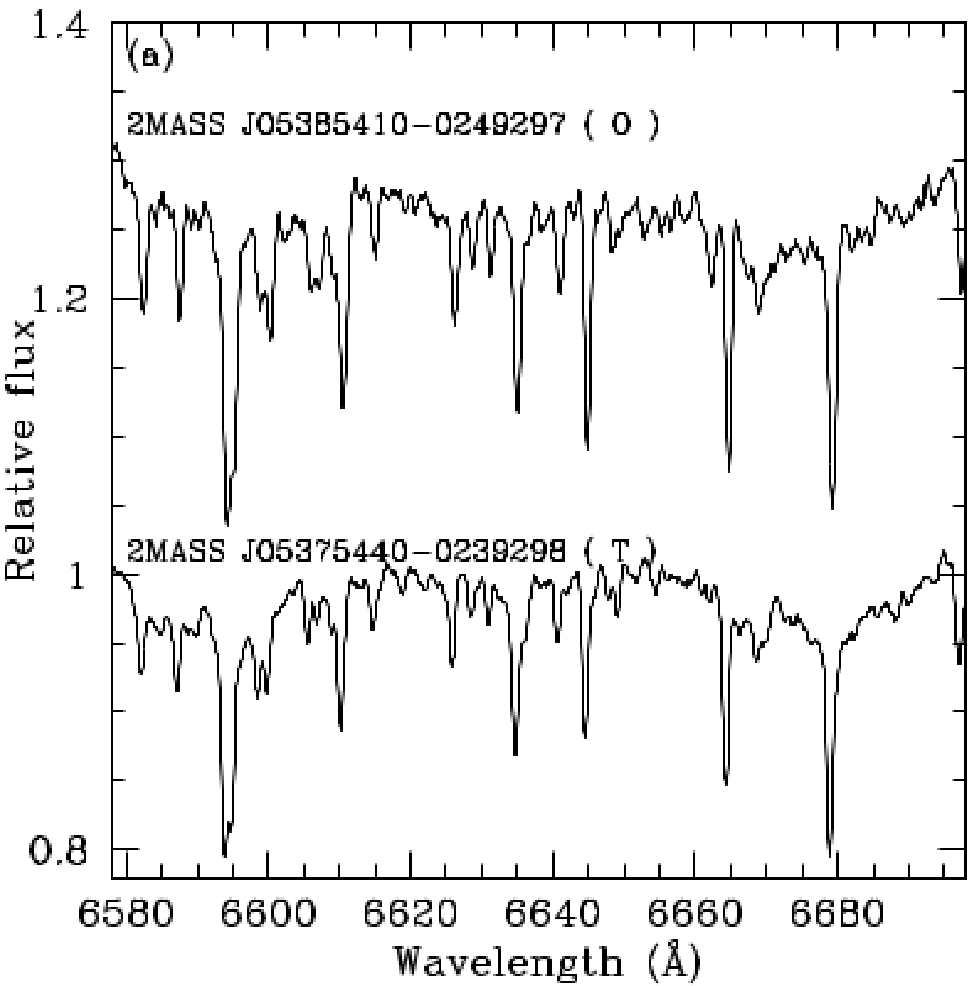
- **Mass, radius and age** for each star were obtained by interpolating $(B\text{-}V)_o$ and M_V in (Siess+2000) and using **GAIA DR2 parallaxes**
- Mass outflow / inflow diagnostics (FIES)
- **Projected rotational velocities ($v_e \sin i$)**

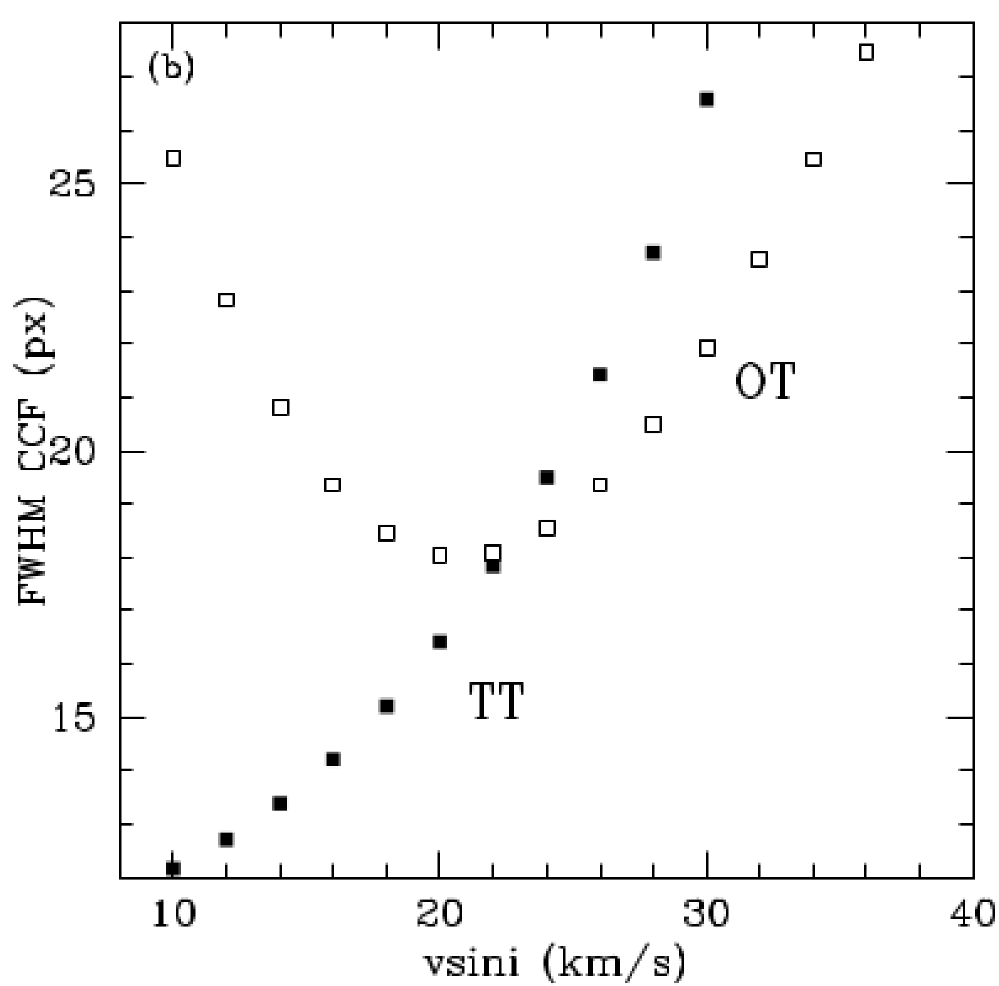
Computed through CCF of each star with one comparison spectrum with similar SpT, artificially broadened at different velocities.

We adopted as $v_e \sin i$ the value at which occurs the minimum of the FWHM of the parabola that better fits the peak of the CCF

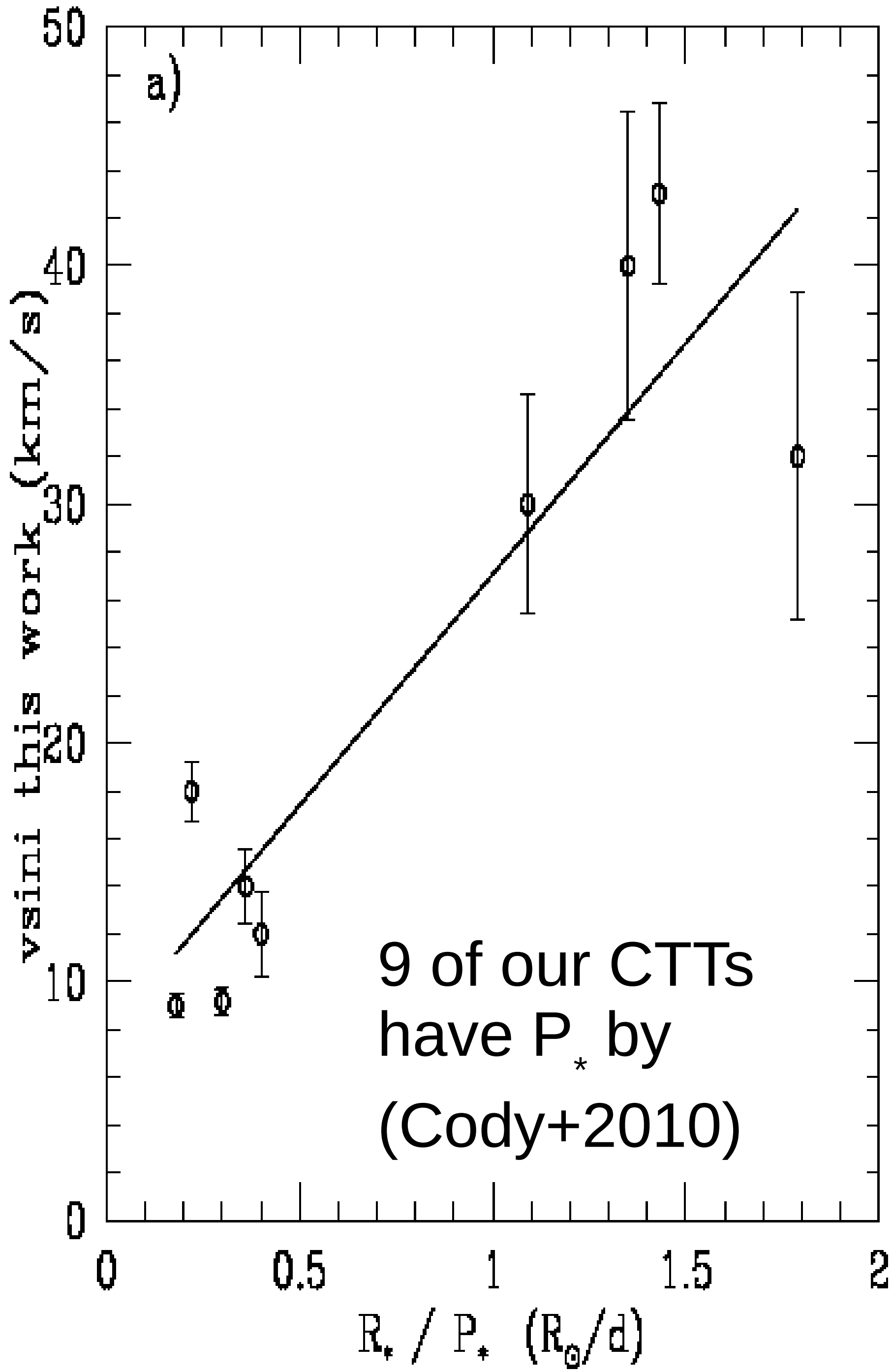
$v_e \sin i$ measurements



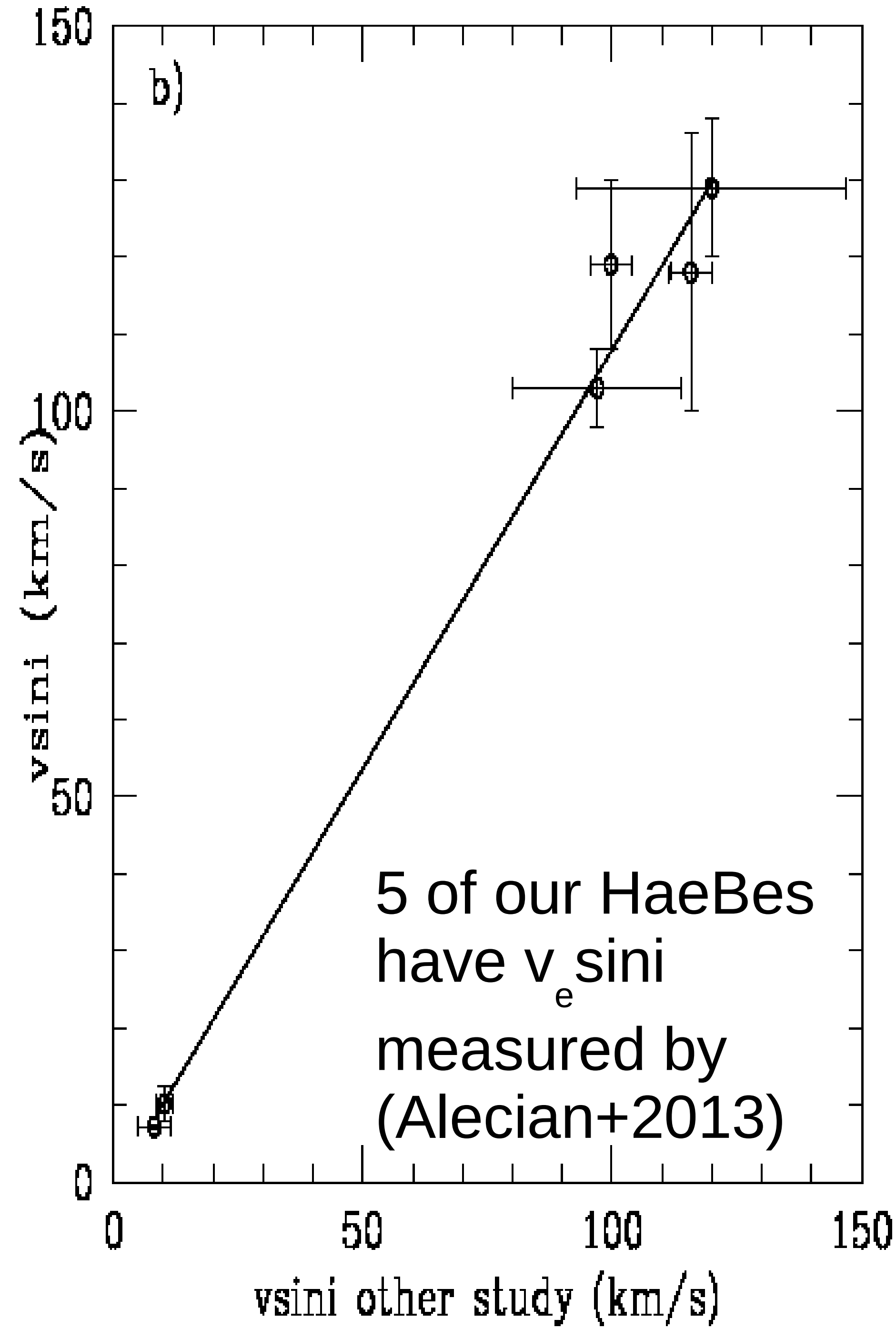




Comparison with other studies



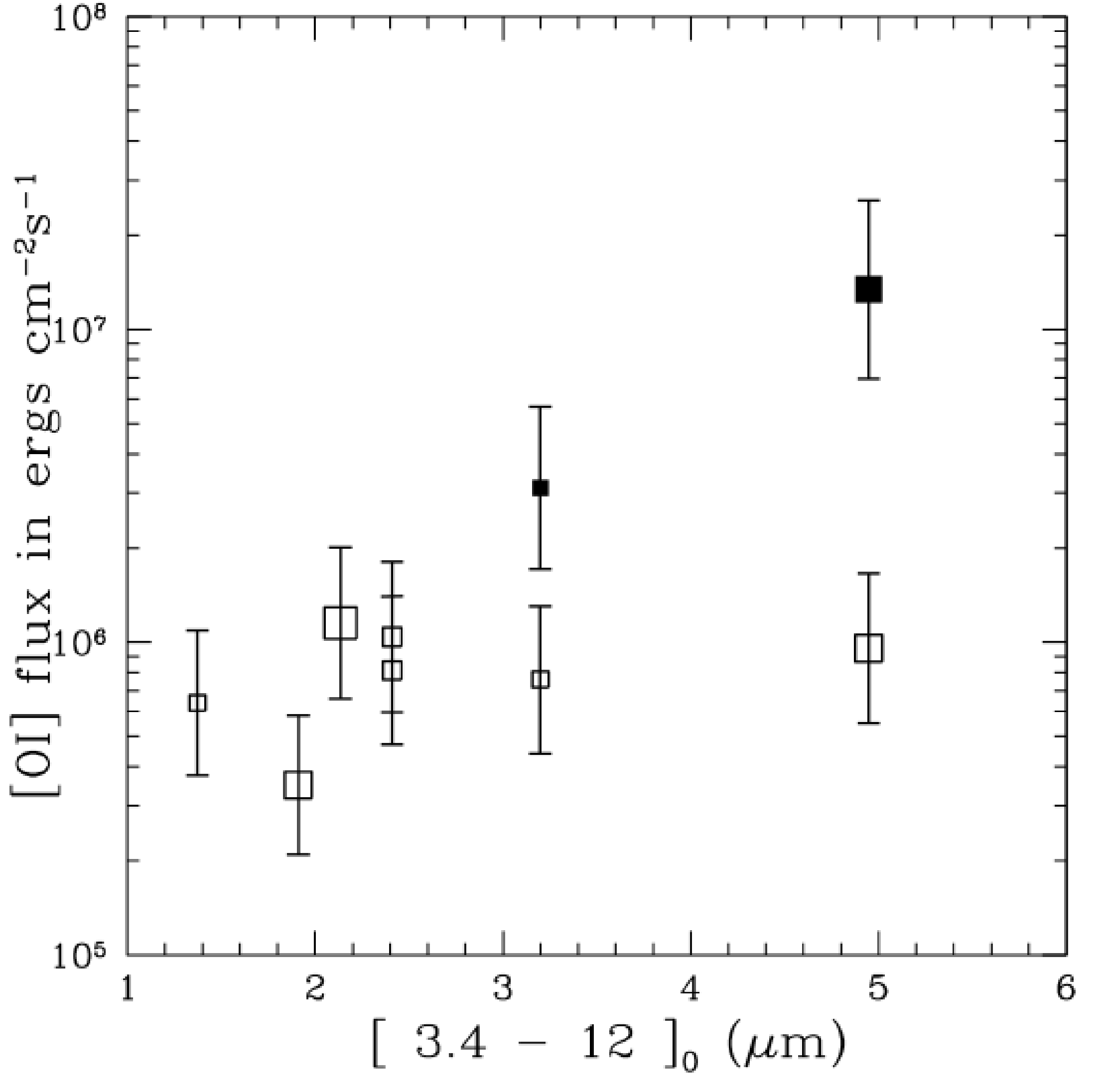
9 of our CTTs have P_* by (Cody+2010)



5 of our HaeBes have $v_e$sini measured by (Alecian+2013)

- **We used a spin evolution model carefully parametrized in order to explain the rotation measurements obtained in HAeBes by assuming that rotation of both CTTs and HAeBes is governed by the same physics**

Stellar winds powered by accretion in HAeBes ?



Rotational evolution for stars with 0.13 – 7 Mo

Assuming that the stars rotate as a solid bodies, the angular momentum equation evolution can be computed for distinct masses in terms of :

$$\frac{d\Omega_*}{dt} = \frac{T_*}{I_*} - \Omega_* \left(\frac{\dot{M}_a}{M_*} + \frac{2}{R_*} \frac{dR_*}{dt} \right)$$

(Siess+2000)

$$T_* = \begin{cases} \dot{M}_a \delta J + \int_{R_T}^{R_{out}} \gamma(R) \frac{\mu^2}{R^4} dR - \dot{M}_w \Omega_* r_A^2 & \text{if } t < \tau_D \\ 0 & \text{if } t > \tau_D \end{cases}$$

$\gamma(R)$: B_ϕ / B_z

r_A:

$$\frac{r_A}{R_*} = K \left(\frac{B_*^2 R_*^2}{\dot{M}_w v_{esc}} \right)^m$$

(Matt+2008)

Rotational evolution for stars with 0.13 – 7 Mo

Stellar Accretion

The simplest way is consider that decays exponentially on time from an initial value at τ :

$$\dot{M}_a = \dot{M}_{a,0} e^{-\frac{(t-\tau_0)}{\tau_a}}$$

(Vidotto+2014)

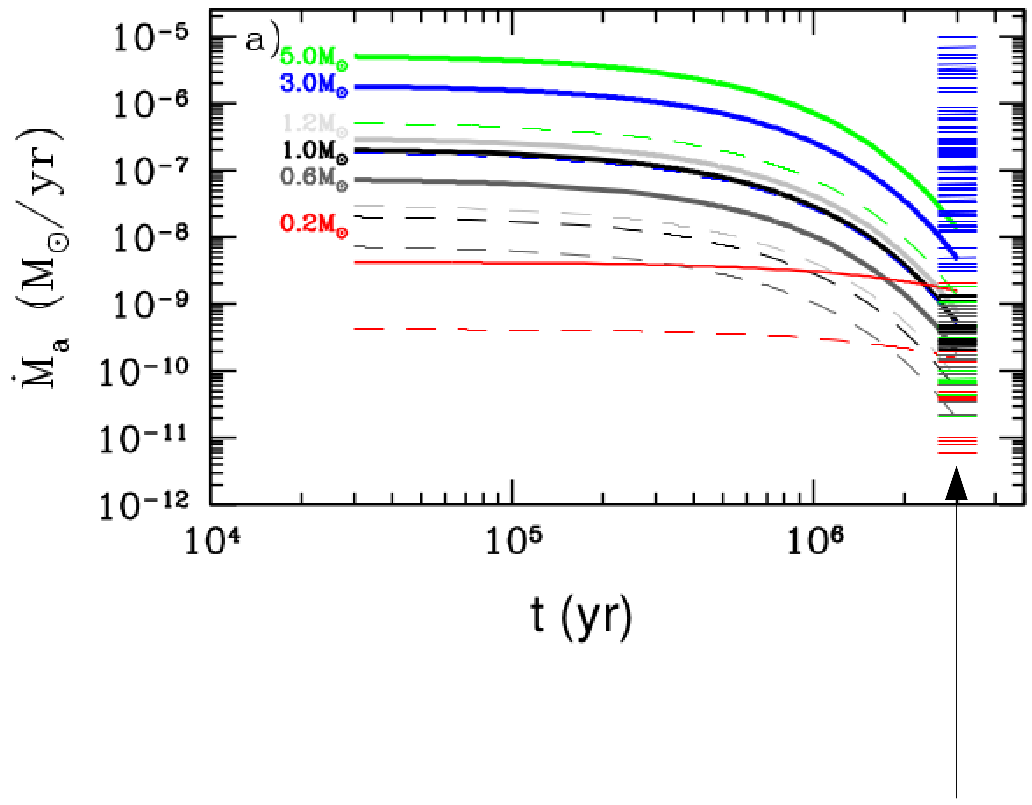
Magnetic field strength

(Landin+2010)

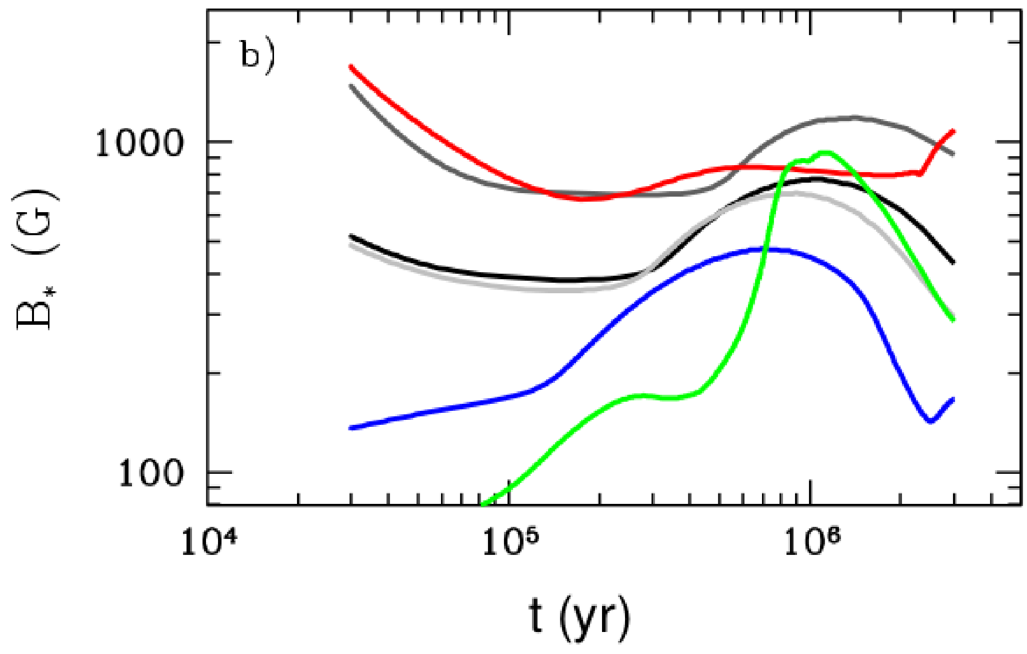
$$B_* = \begin{cases} B_0(\Omega_*) \dfrac{\tau_{c,*}(M_*,t)\Omega_*(M_*,t)}{\tau_{c,\odot}\Omega_\odot} & \text{for } 0.6 < M_* < 1.2Mo \\ C(M_*) \dfrac{\Omega_*(M_*,t)}{\Omega_\odot} & \text{for } M_* < 0.6 \text{ and for } M_* > 1.2Mo \end{cases}$$

Rotational evolution for stars with 0.13 – 7 Mo

Stellar Accretion

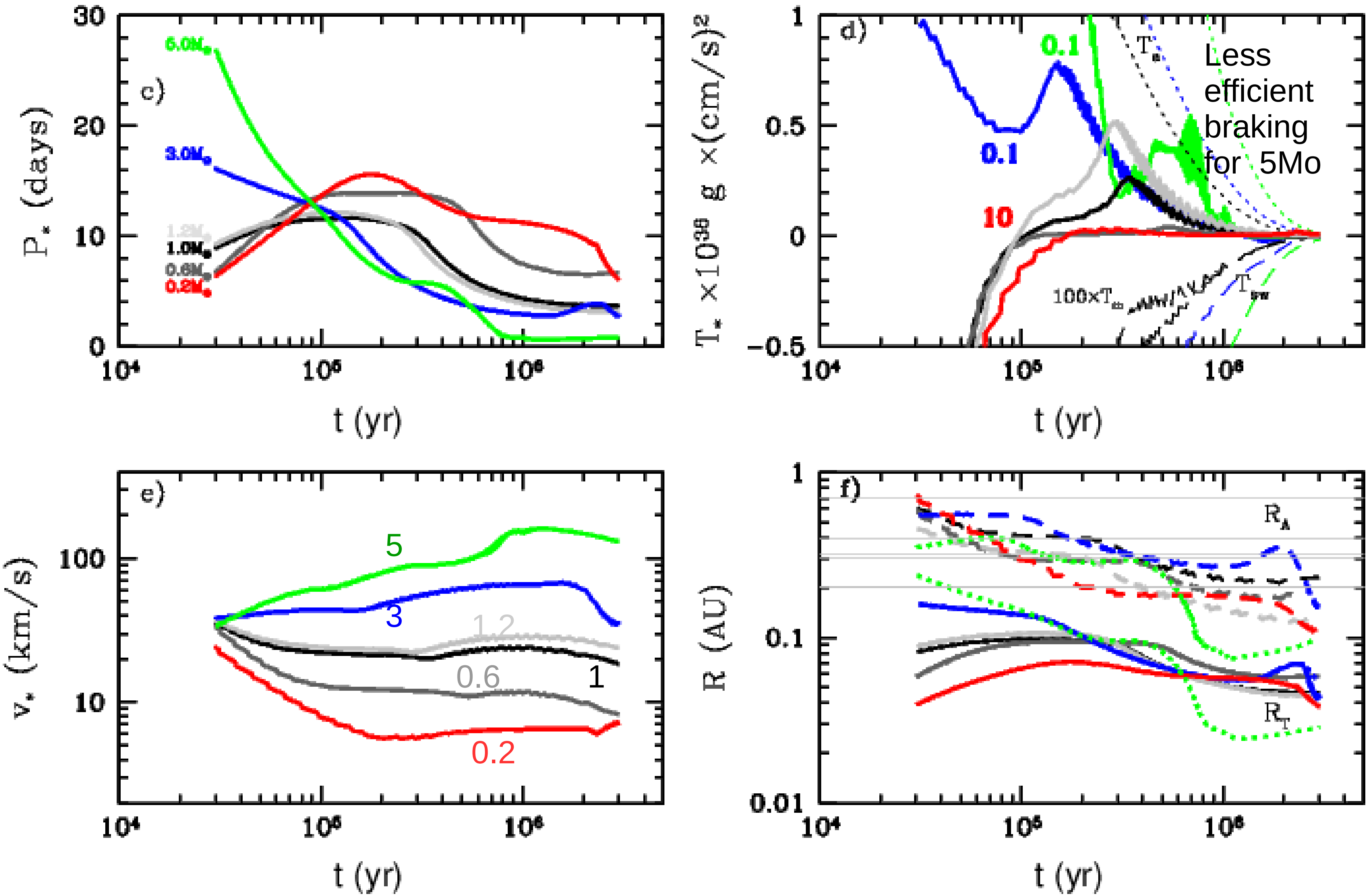


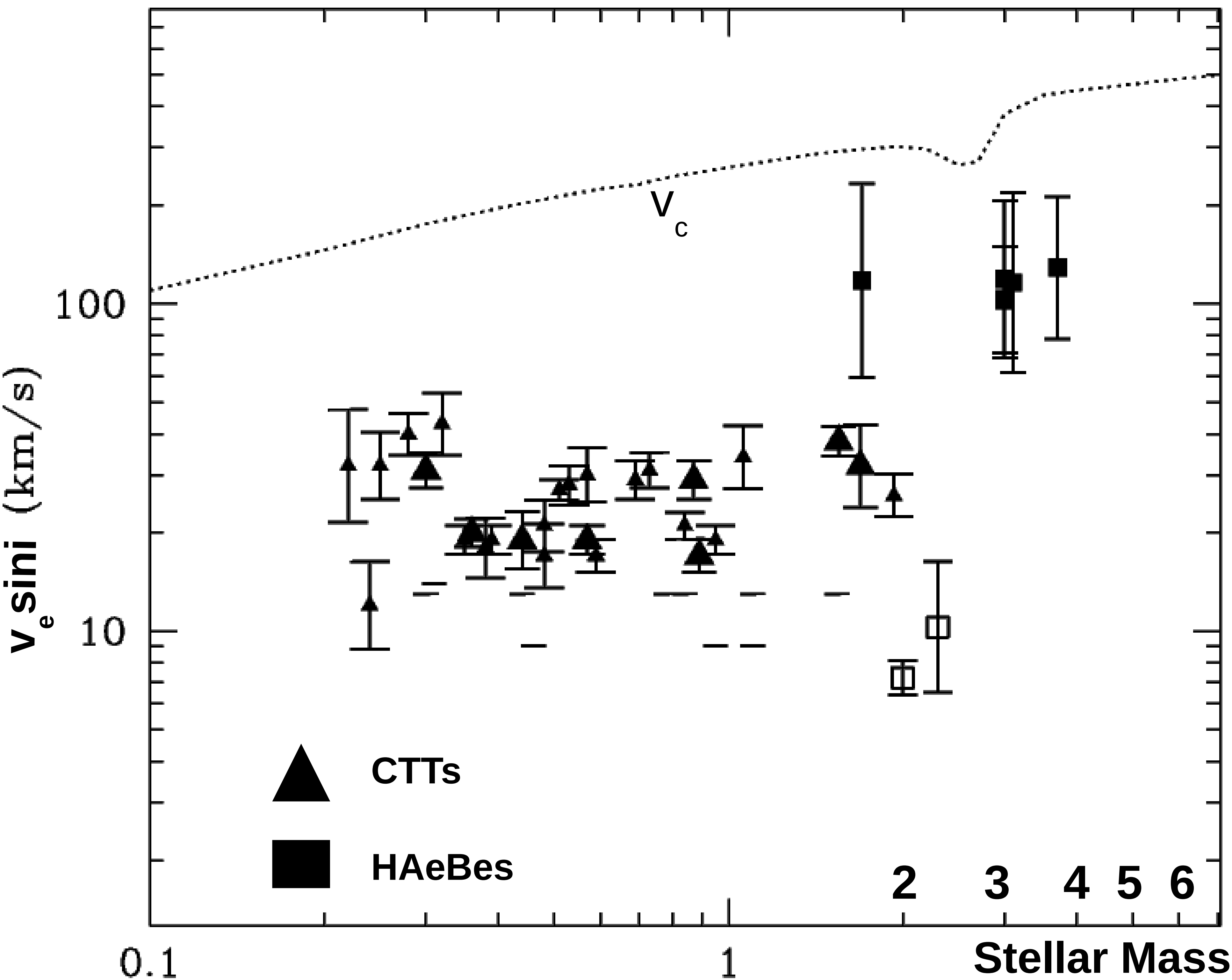
Magnetic field strength



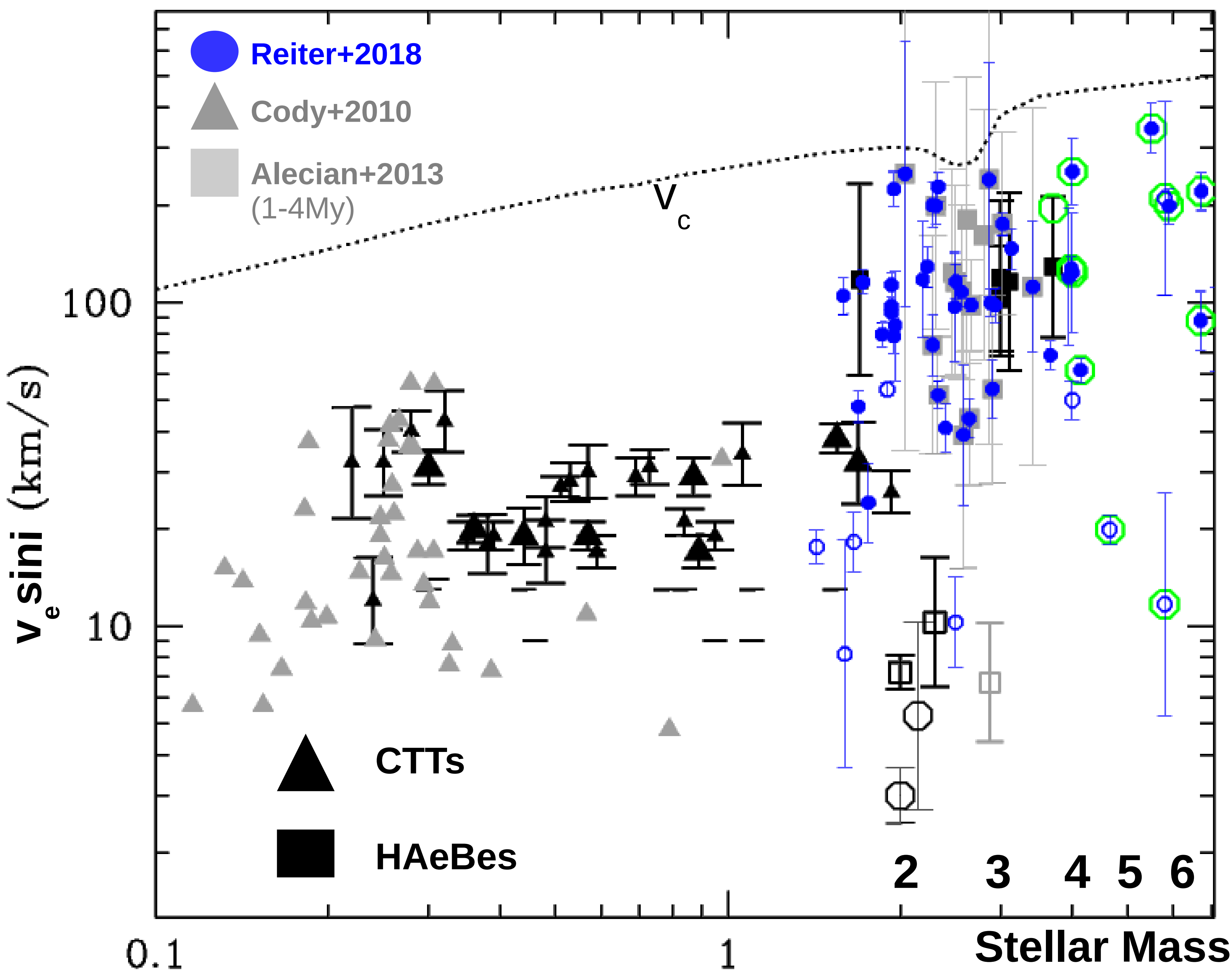
(Maucó+2016)

Rotational histories for stars with long-lived disks

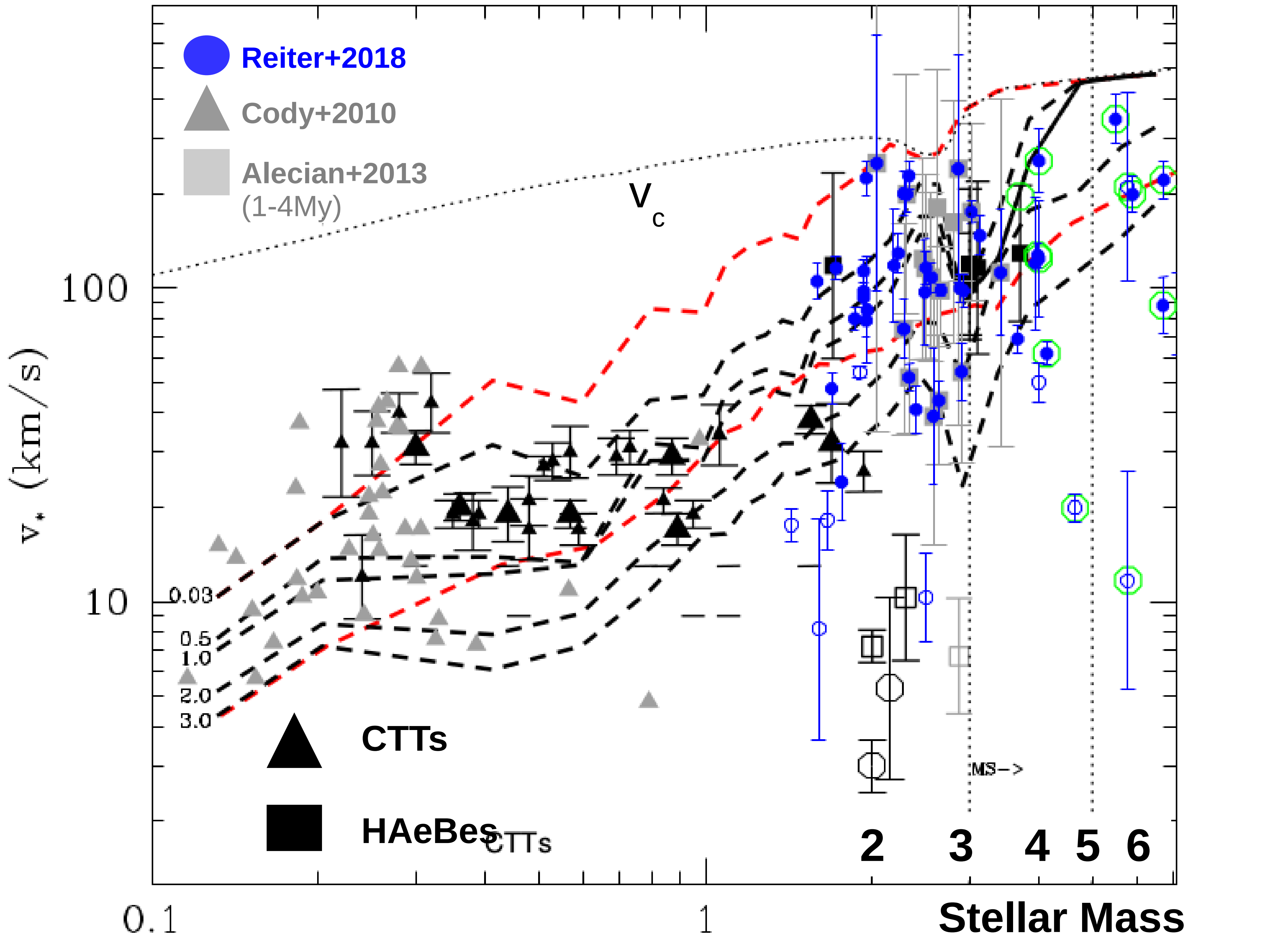




V_c
100
10
$v_e$sini (km/s)
CTTs
HAeBes
2
3
4
5
6
0.1
1
Stellar Mass



Reiter+2018
Cody+2010
Alecian+2013
(1-4My)
V
c
CTTs
HAeBes
100
10
$v_e$sini (km/s)
0.1
1
2
3
4
5
6
Stellar Mass



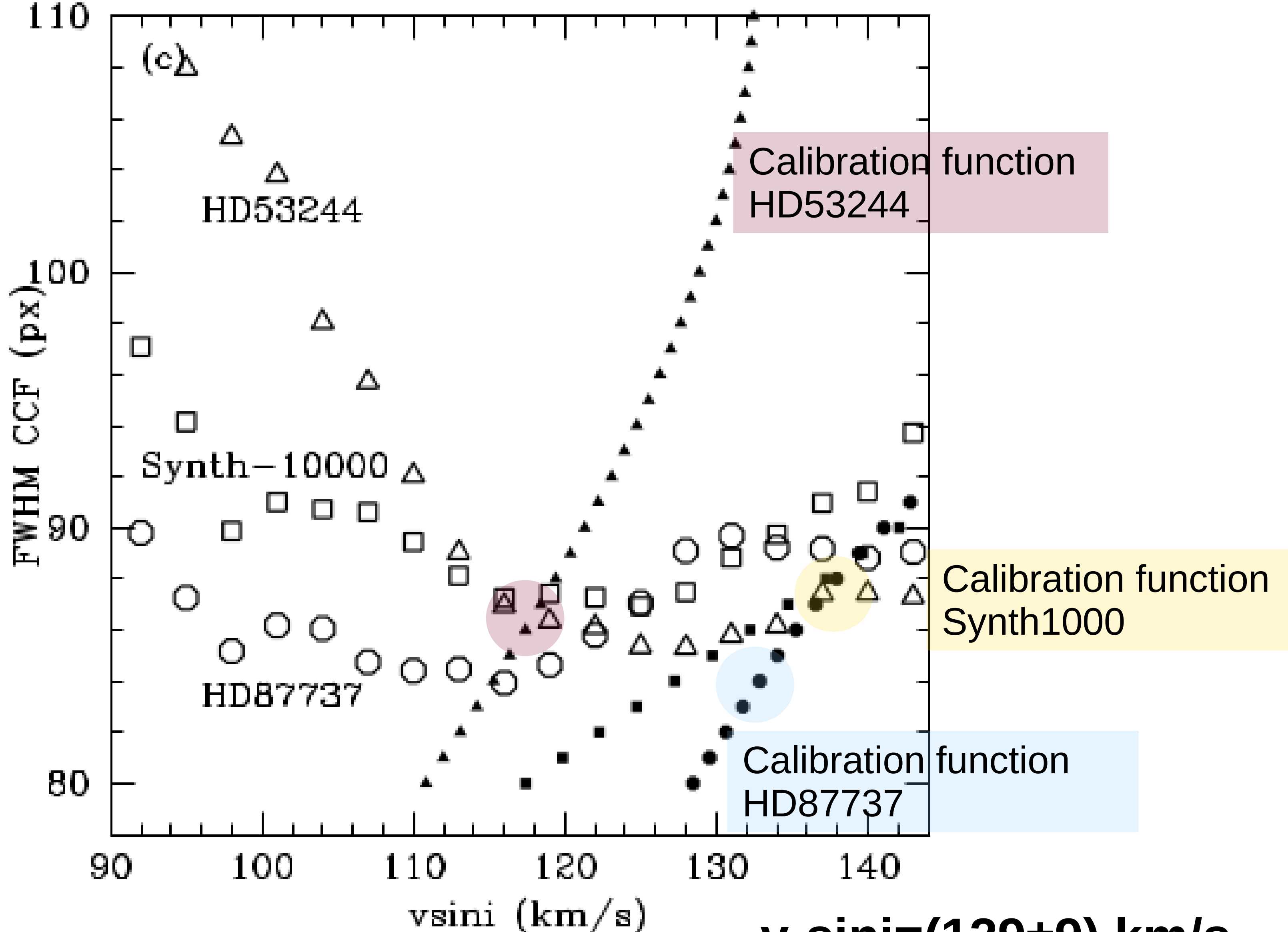
Reiter+2018
Cody+2010
Alecian+2013
(1-4My)
Vc
100
10
0.03
0.5
1.0
2.0
3.0
CTTs
HAeBes
CTTs
MS-->
2
3
4
5
6
0.1
1
Stellar Mass
v* (km/s)

Conclusions

- The extension of a spin evolution model for one solar mass toward higher masses, is able to explain the high rotation rates in HAeBes within the uncertainties of our measurements.
- A lack of efficiency for the wind launching mechanism is noted however as mass increases, in particular for 5Mo. This seems in agreement with recent studies that suggest that the CTTs paradigm for rotation is not valid in Herbig Bes (Cauley+2105,Fairlamb+2104,+2105).
- This adds more evidence for a break of MA for higher masses.

Many thanks !

$v_e$sini measurements



$v_e$sini=(129±9) km/s

Balmer excesses