Measuring accretion rates of Herbig Ae/Be stars

The UX Ori type stars and related topics

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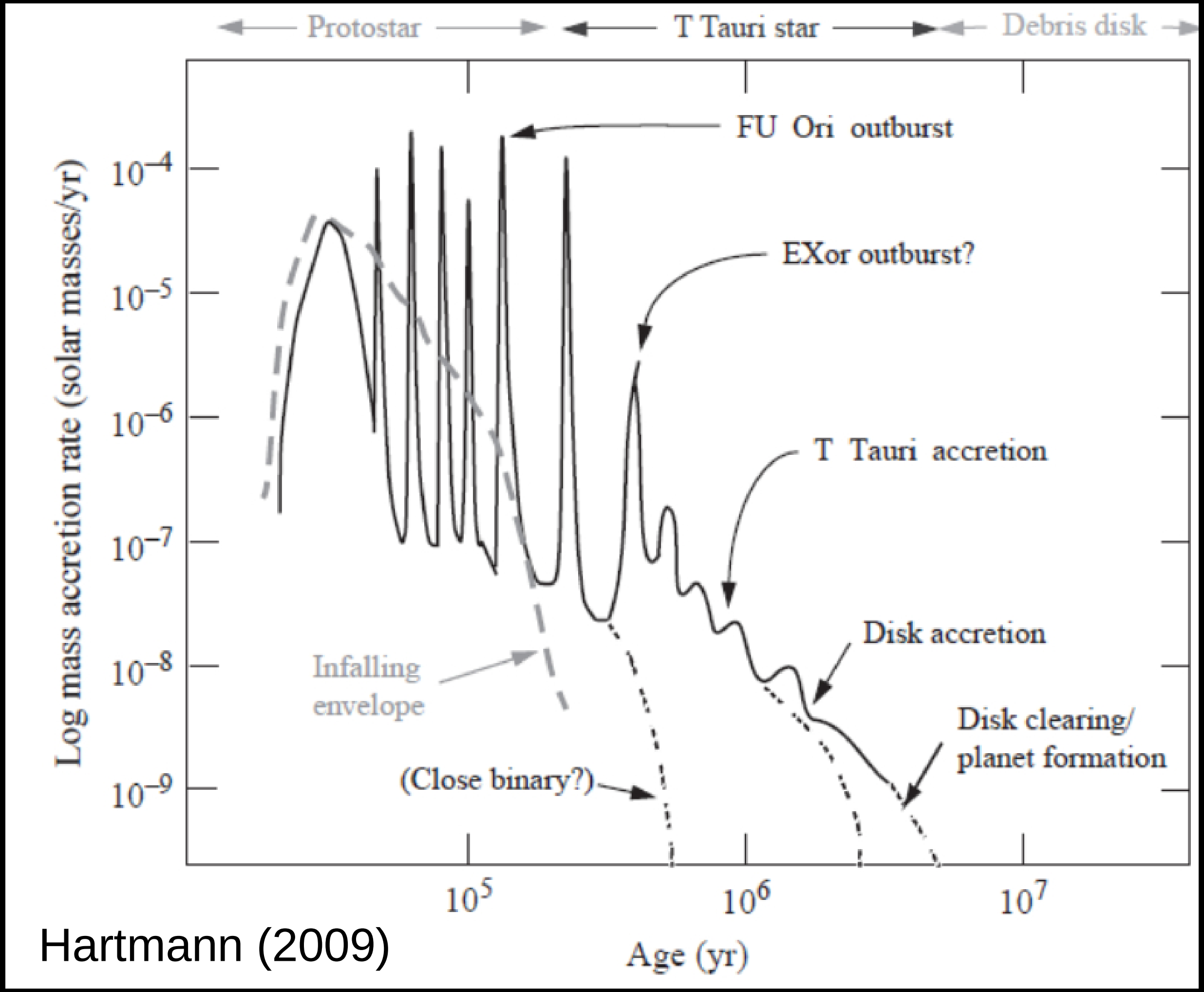
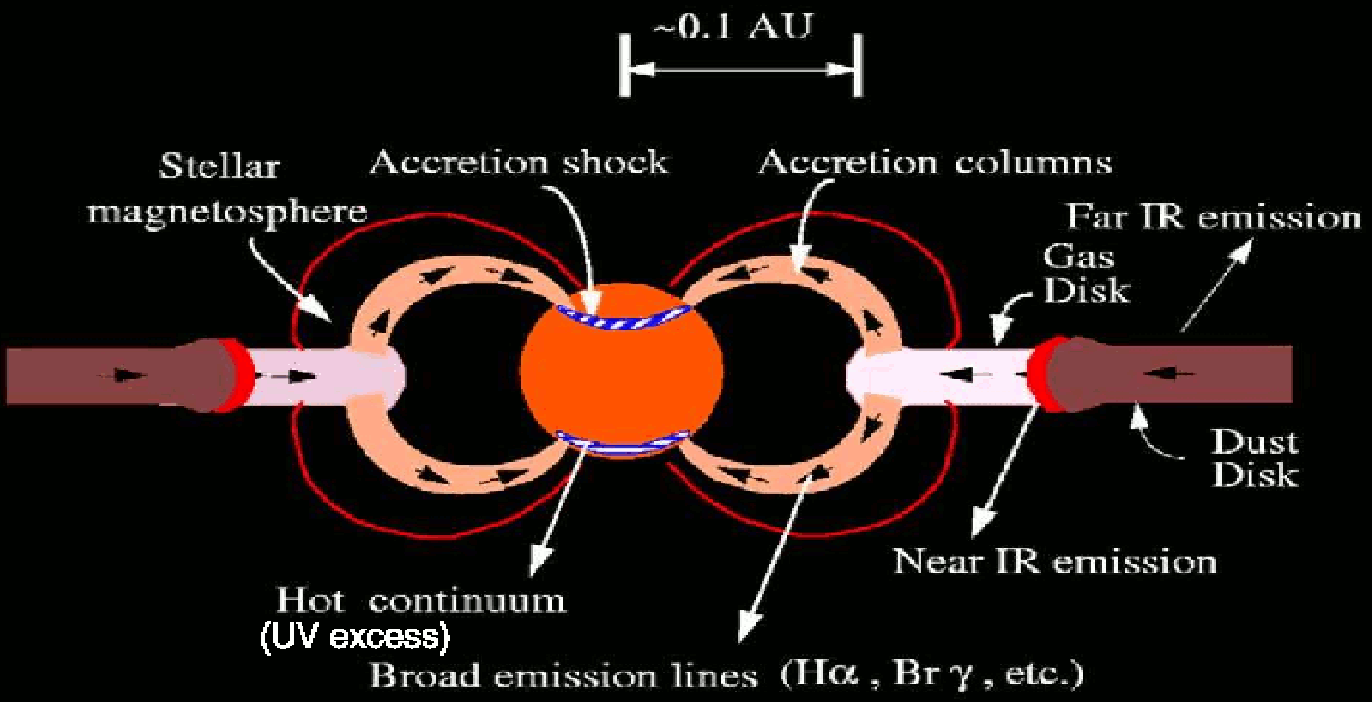
Why accretion?



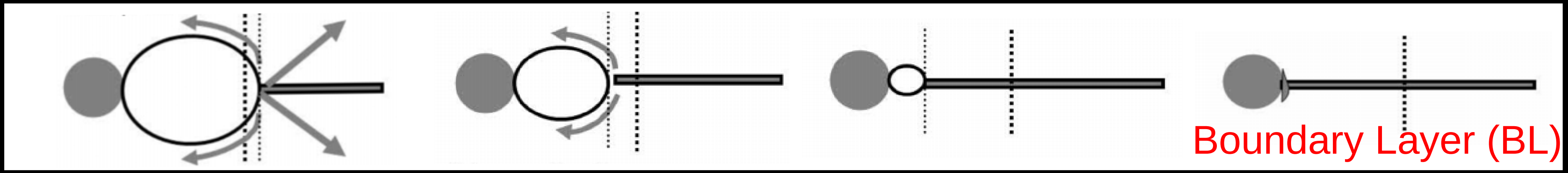
- $\dot{M}_{acc}$ traces the evolution of YSOs (Hartmann+1998; Fedele+2010, Sicilia-Aguilar+2010...)
- $\dot{M}_{acc}$ probes the gas reservoir --> Alternative M_{disk} (Hartmann+1998; Dong+2018….)
- $\dot{M}_{acc}$ is an input parameter necessary for detailed disk modelling (e.g Woitke+2016)
- ***Inferring $\dot{M}_{acc}$ requires understanding the physics of the star-disk interface***

Does magnetospheric accretion (MA) also work in HAeBes?



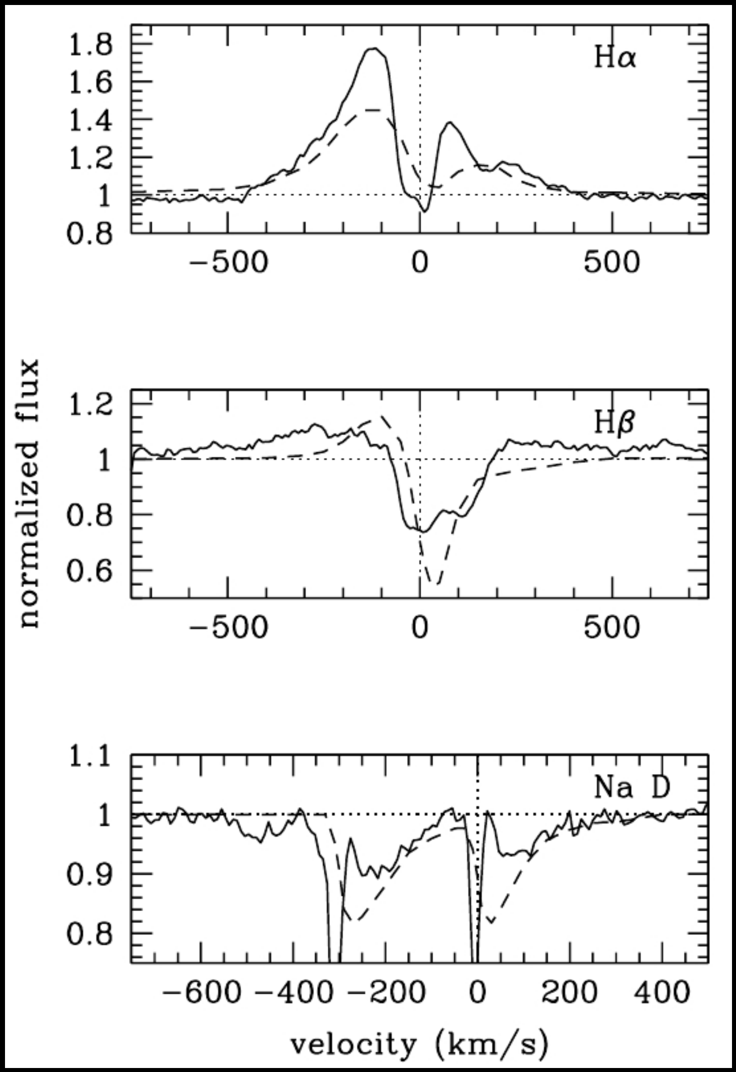
$B_{field} \sim M_*^{5/6} \times \dot{M}_{acc}^{1/2} \times v_{rot*}^{-7/6} \times R_*^{-11/6}$ (e.g. Johns-Krull+99)
TTs need kG, HAeBes need ≤ 100 x G

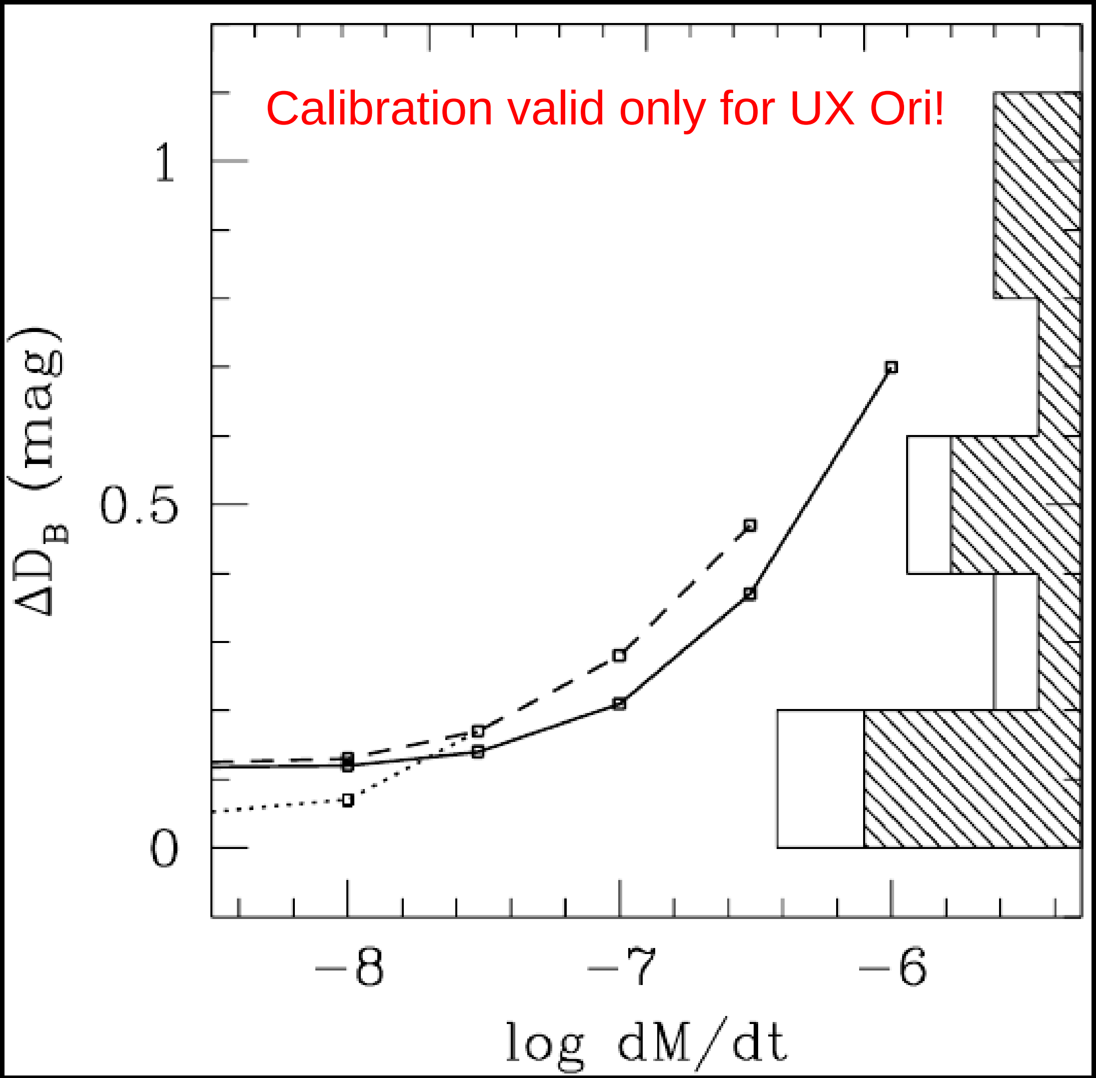
Small B field → small disk truncation radius (~ 5R$_*$ for TTs; ~ 2.5R$_*$ for HAeBes)



Earliest suggestions that MA could work at least in HAes (not in HBes):
Vink+(2002); Eisner+(2004)

First MA characterization of a HAeBe star: UX Ori
(Muzerolle et al. 2004)



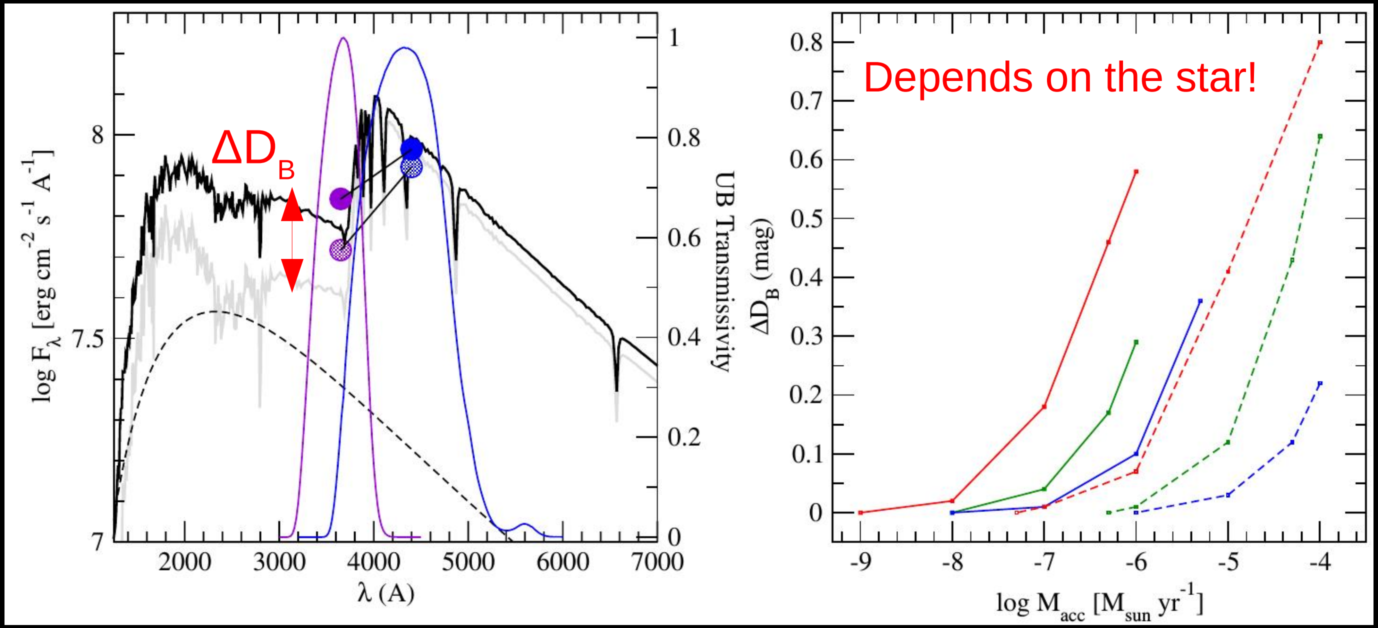


Accretion rates can be inferred from spectral line and accretion shock (ΔD_B) modelling

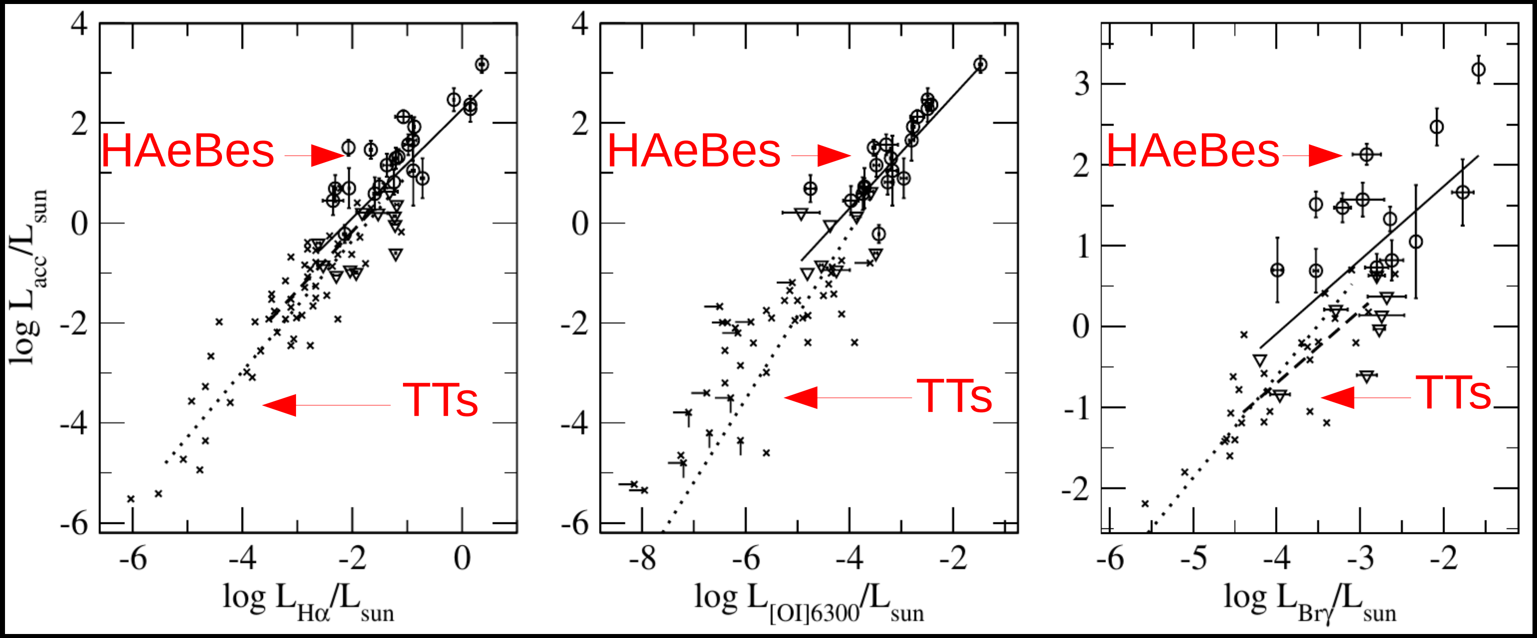
(see also Calvet+2004; Garcia-Lopez+2006 for IMTTs)

First systematic MA estimates for HAeBe stars

Mendigutía et al. 2011: M_{acc} for 38 northern HAe(Bes); ~ 10^{-7} $M_{\odot}$/yr , but depends on M_*



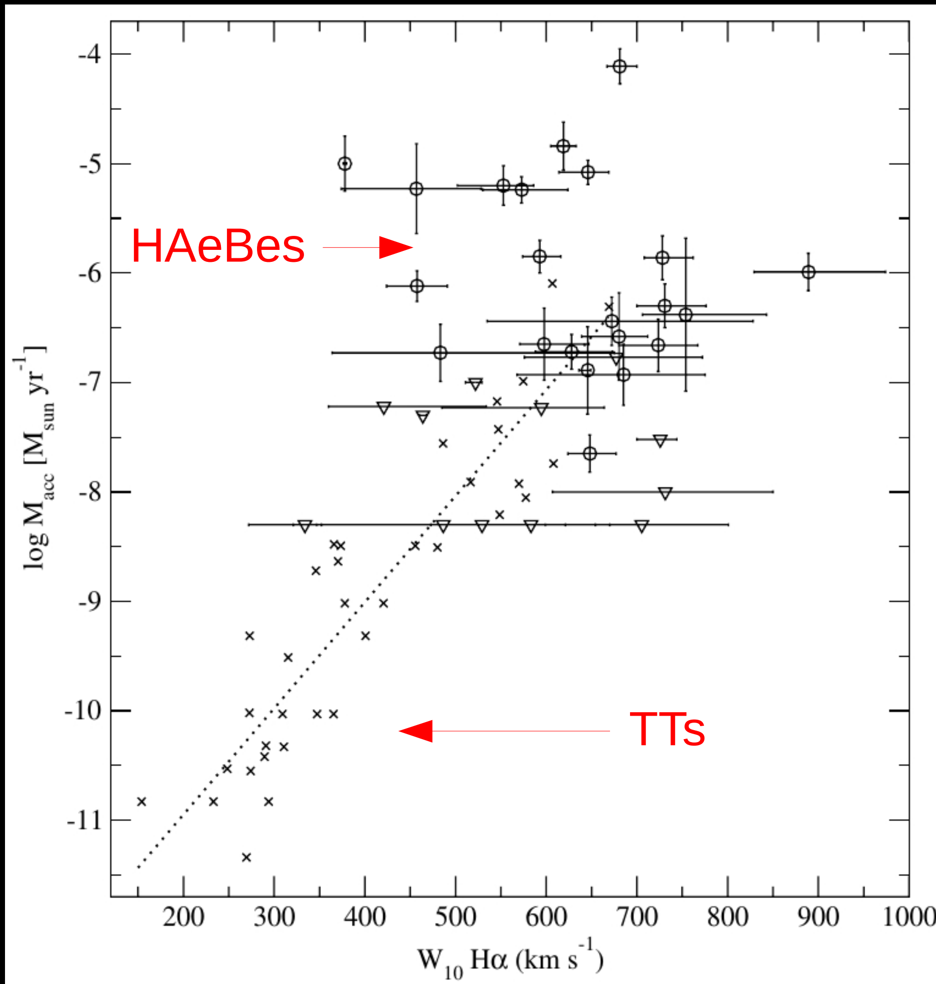
<±0.5 dex accuracy

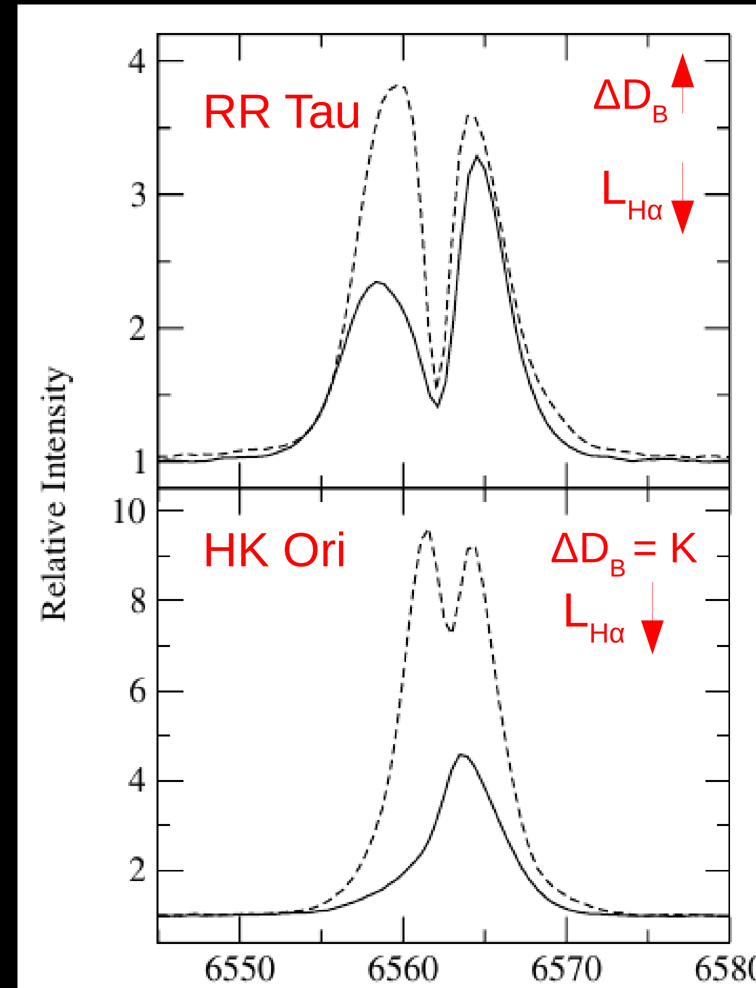


±1 dex accuracy

(see also Donehew & Brittain 2011, Pogodin+2011)

Invalid accretion tracers for HAeBe stars (Mendigutía et al. 2011, 2013)





Hα 10% width valid for TTs (Natta+2004), not for HAeBes (large v sini). First suggested by Boley+2009 for a HBe star.

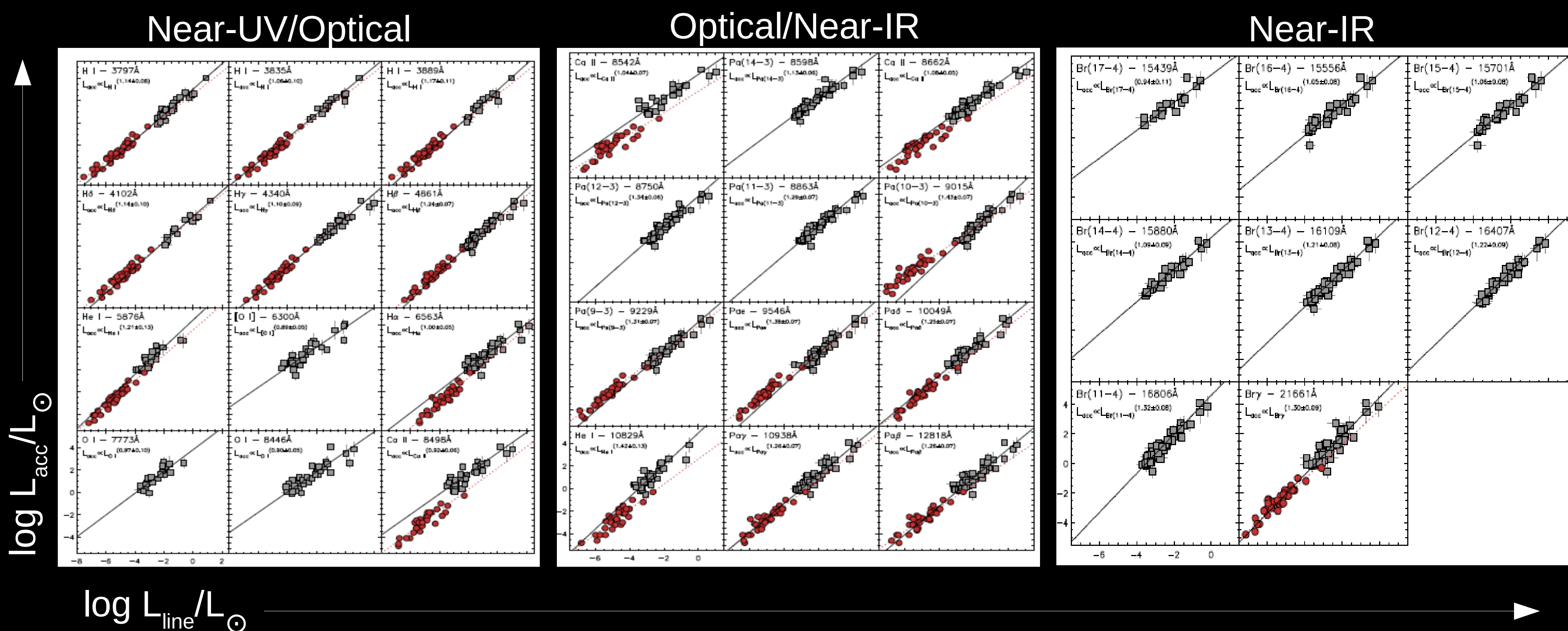
Same for spectroscopic line veiling (Muzerolle+ 2004: $T_{shock} \sim T_* \sim 10000$ K)

Accretion & line variabilities decoupled! → Careful spectro-photometric monitoring needed (e.g. Dupree+2012, 2013)

More recent MA estimates for HAeBes

Fairlamb et al. 2015: $\dot{M}_{acc}$ for 91 southern HAeBes from ΔD_B modelling based on X-Shooter spectra → stellar parameters

Fairlamb et al. (2017): L_{acc} from ΔD_B and L_{line} from X-Shooter spectra (**TTs, Alcalá+2014**; **HAeBes, Fairlamb+2015**)



$\log L_{acc}/L_\odot = A + B \times \log L_{line}/L_\odot$ (~ ±1 dex accuracy)

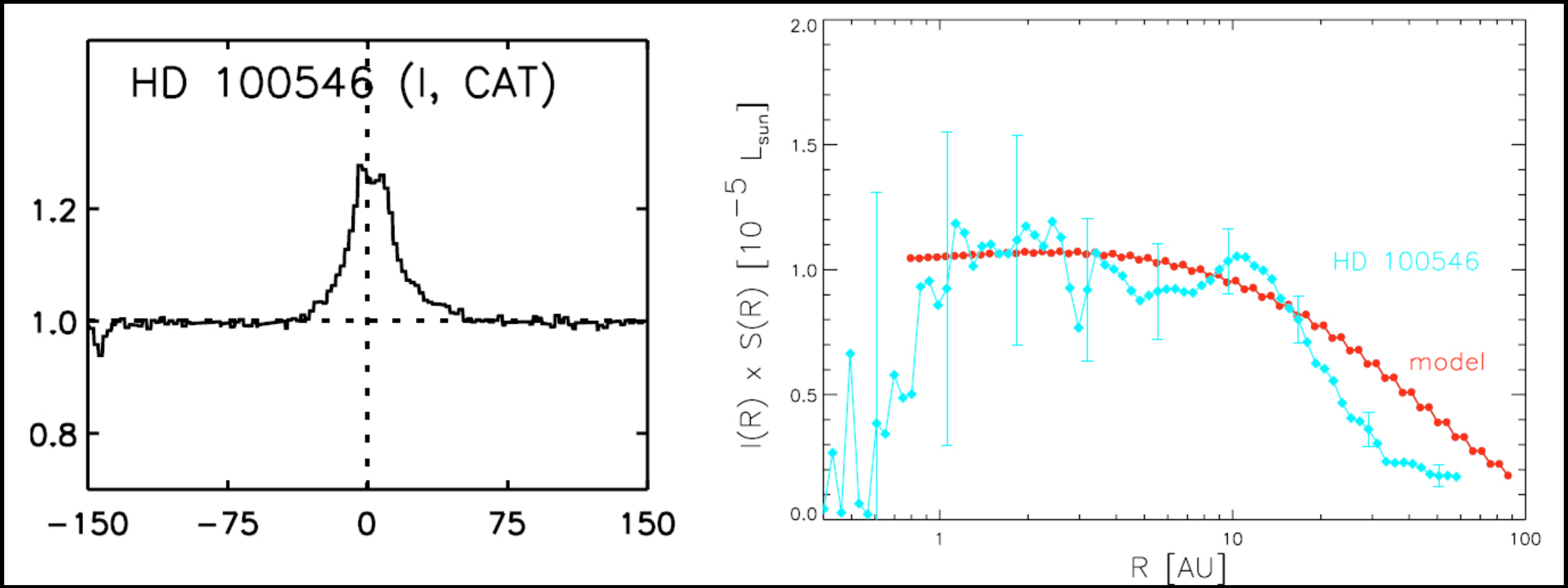
All emission line luminosities serve to estimate accretion rates...

...but not all emission lines probe accretion

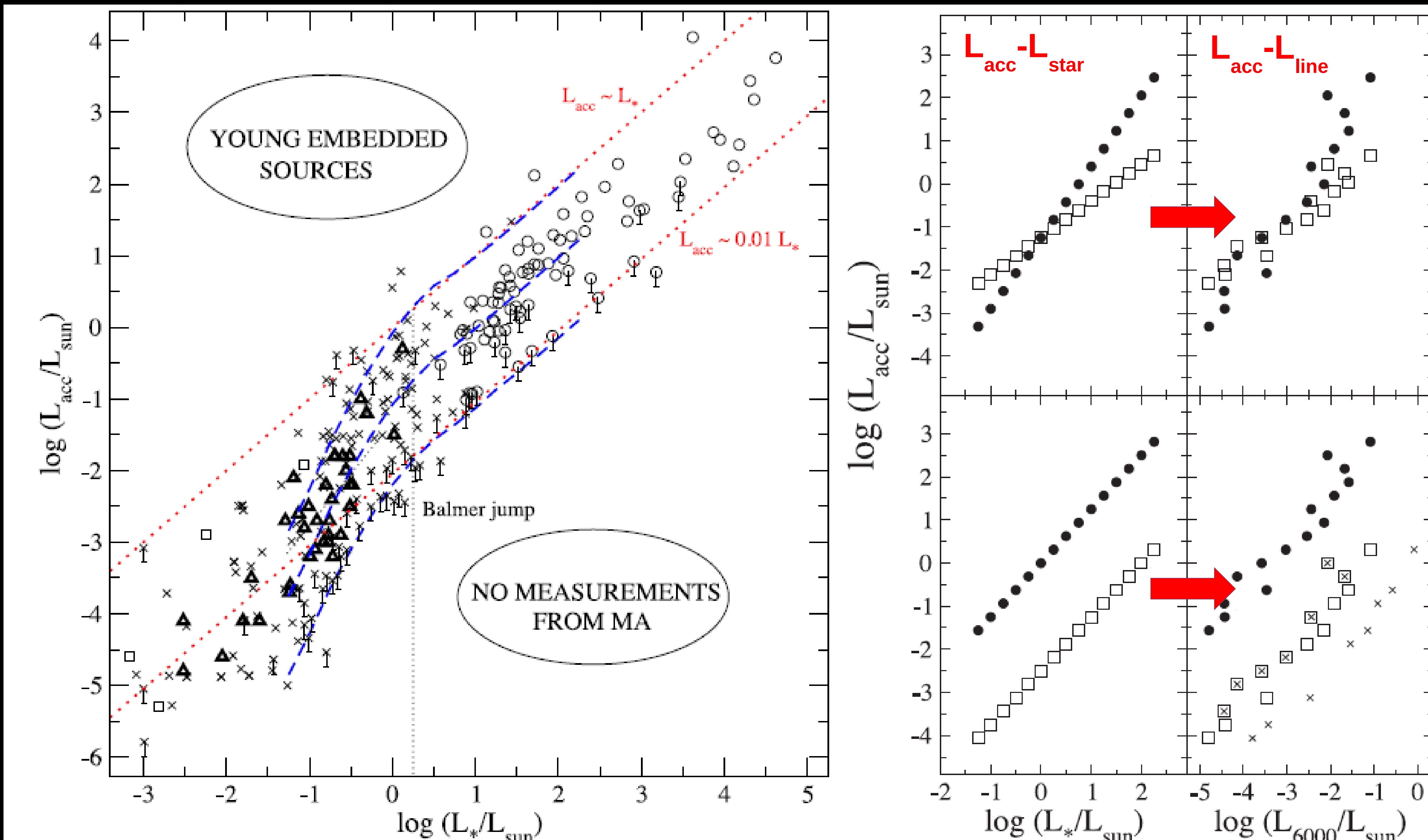
1) Accretion variability (from ΔD_B) generally decoupled from simultaneous spectral line variations

2) The main Brγ & Hα emitting regions are larger than the accreting region in many HAeBes (Kraus+2008; Garcia Lopez+2015, 2016; Mendigutía+2015, 2017; Tambovtseva+2016; Kurosawa+2016; Kreplin+2018...)

3) The physical origin of some lines is not related to accretion (e.g. [OI]6300 comes from the disk in HAeBes, Acke +2005; Acke & van den Ancker 2006)



Caution: L_{acc} correlates with L_{line} regardless of its physical origin, because of the correlation with L_* (Mendigutía et al. 2015)



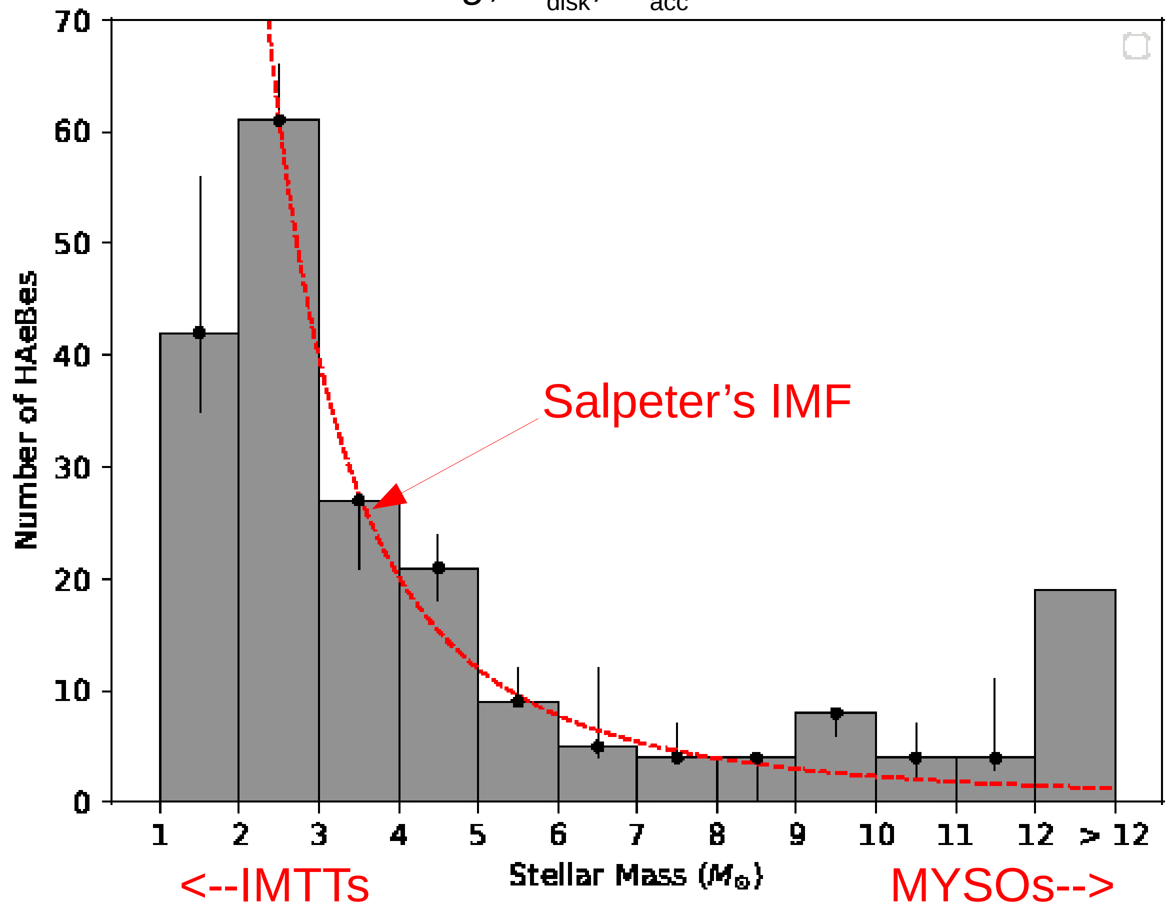
...Thus, L_* can also be used to estimate L_{acc} (~ ±1 dex accuracy)

Present and future: Gaia

Gaia distances to re-determine stellar parameters of HAeBes: > 200 known to date (Vioque+2018), and increasing (Vioque+, in prep.)

Arun et al. (2019): $\dot{M}_{acc}$ for 106 HAeBes from $L_{H\alpha}$
(and increasing; 163 HAeBes from $L_{H\alpha}$ in Wichittanakom+, *poster 10*)

Guzmán-Díaz+, in prep: homogeneous stellar parameters from *SED fitting*, M_{disk}, M_{acc}...for 221 HAeBes

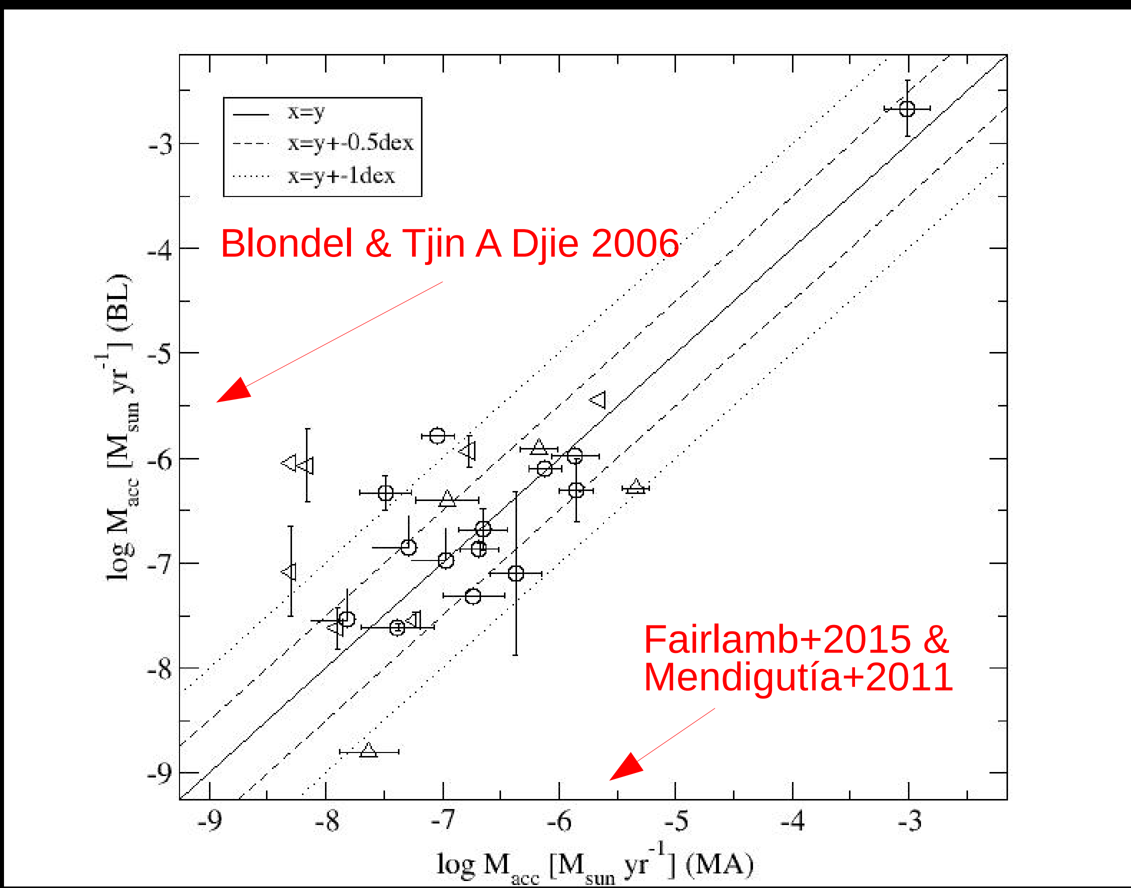


MA works in HAes

- Statistics on spectral lines (Cauley & Johns-Krull 2015, 2014)
- Multi-epoch spectra (Schoeller+2019, 2016; Costigan+2014; Mendigutía+2011a)
- Spatially-resolved (Eisner+2010, 2004)
- Line/shock modelling (Tambovtseva+2016; Fairlamb+2015; Mendigutía+2011b; Muzerolle+2004...)
- Spectro-polarimetry (Ababakr+2017; Mottram+2007, Vink+2002, 2003, 2005)
- ...

MA does not work in HAes

- Reiter+2018 (HeI10830 similar in 5 magnetic and 59 non-magnetic HAeBes)
- Aarnio+2017 (multi-epoch 1 HBe + 1 HAe)
- Blondel & Tjin A Djie 2006 ($\dot{M}_{acc}$ from BL for 39 F & A stars)



What if MA estimates are wrong?

Preliminary test

MA and BL estimates of HAe stars differ ≤ ± 1 dex (best case scenario)

In general $\dot{M}_{acc}$ (BL) > $\dot{M}_{acc}$ (MA)

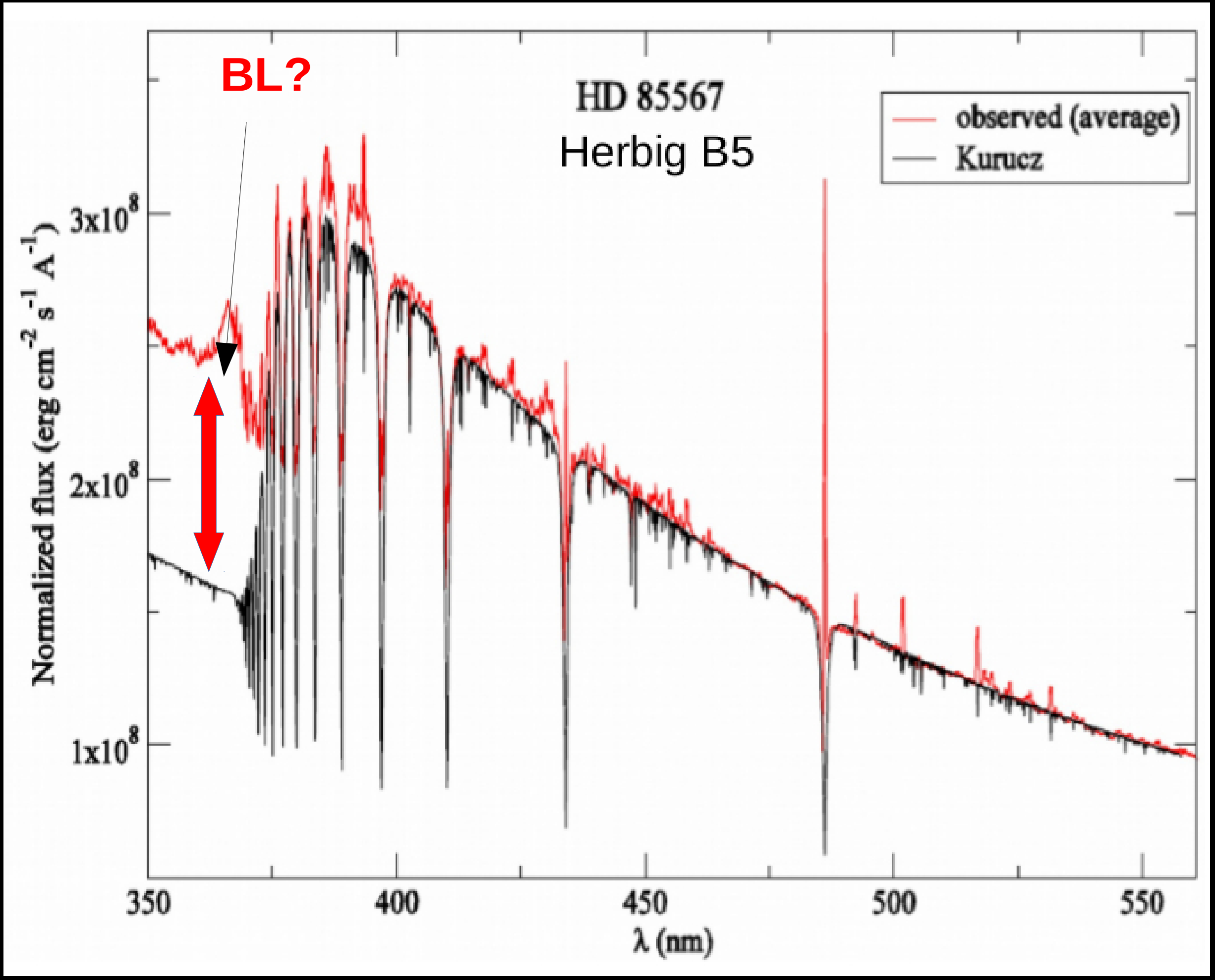
HAes and HBes behave differently (e.g. Oudmaijer, SFNewsletter, Jan 2019), moreover:

MA does not work in several HBe stars

Mendigutía+(2011) and Fairlamb+(2015) identified > 20 HBes for which MA shock modelling hardly reproduces the observed ΔD_B (covering fractions ≥ 50-100%)

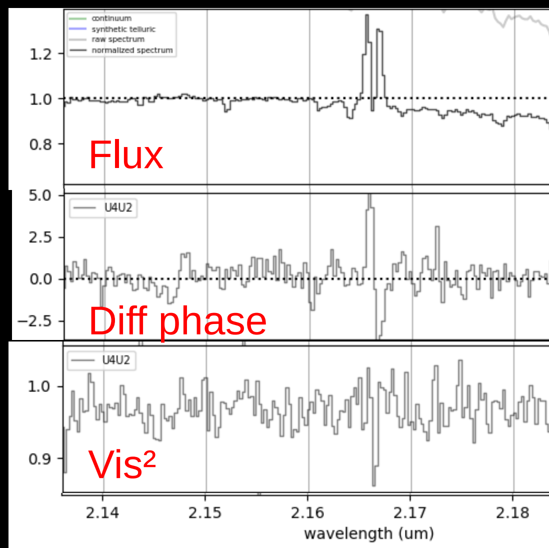
“Non-magnetospheric” HBes

VY Mon
R Mon
PDS 133
HD 85567
HD 305298
DG Cir
HD 141926
VV Ser
LkHa 234
HD 53367
V380 Ori
V590 Mon
GU Cma
Z Cma (A4)
PDS 27
PDS 281
PDS 286
PDS 37
HD 94509
HD 96042
PDS 69
MWC 297
AS 442



Work in progress

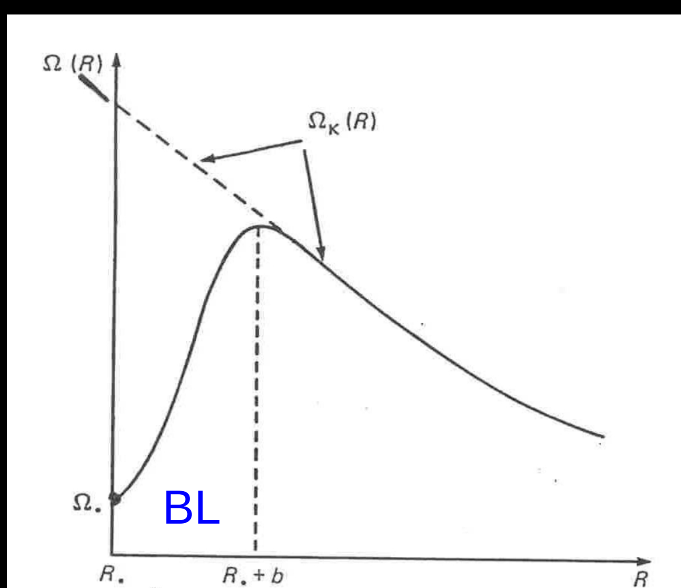
1) GRAVITY/VLTI data of 6 “non-magnetospheric” HBe stars under analysis (Marcos-Arenal+, in prep.)

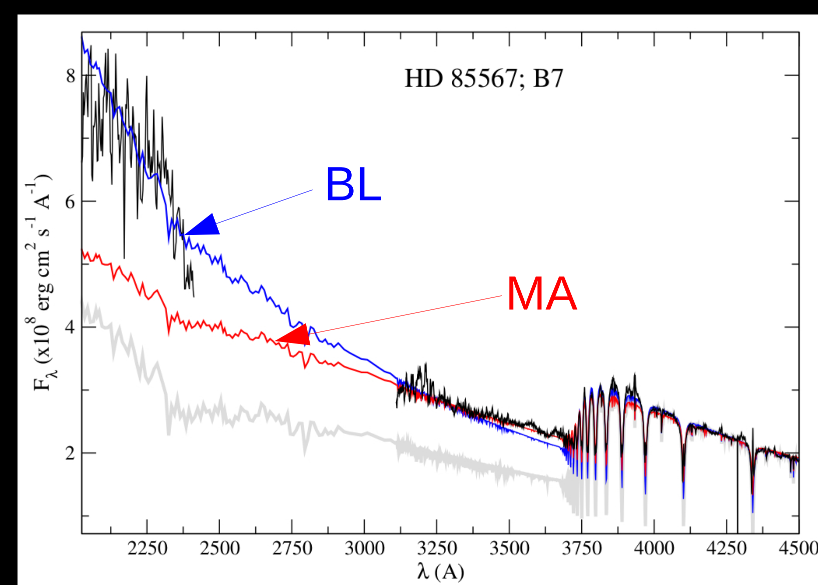


HD 94509, Herbig Be, 12000 K, 11$M_\odot$

λ/2B ~ 2 mas, R ~ 4000, 4 UTs

2) UV spectra could be key to disentangle between MA and BL (IUE, Hubble, WSO...)





Conclusions

- $\dot{M}_{acc}$ is not a direct observation → needs an underlying model.

- Numerous indications suggesting that MA is valid for HAes and some HBes (but not yet a consensus)

- MA estimates: $\dot{M}_{acc}$ ~ 10^{-7} $M_{\odot}$/yr (dependence on M_*).

* Accuracy < ± 0.5 dex from direct estimates (near-UV excess)
* Accuracy ~ ± 1 dex from indirect estimates (correlations with L_{line} or L_*)
* Emission line modelling strongly depends on relatively free parameters

- $\dot{M}_{acc}$(BL) scarce but ≥ $\dot{M}_{acc}$(MA) for HAes

- Alternatives to reproduce near-UV excess of several HBes: BL?; other accretion scenarios? (e.g. Takasao+2018); winds?