School of Physics and Astronomy
FACULTY OF MATHEMATICS AND PHYSICAL SCIENCES

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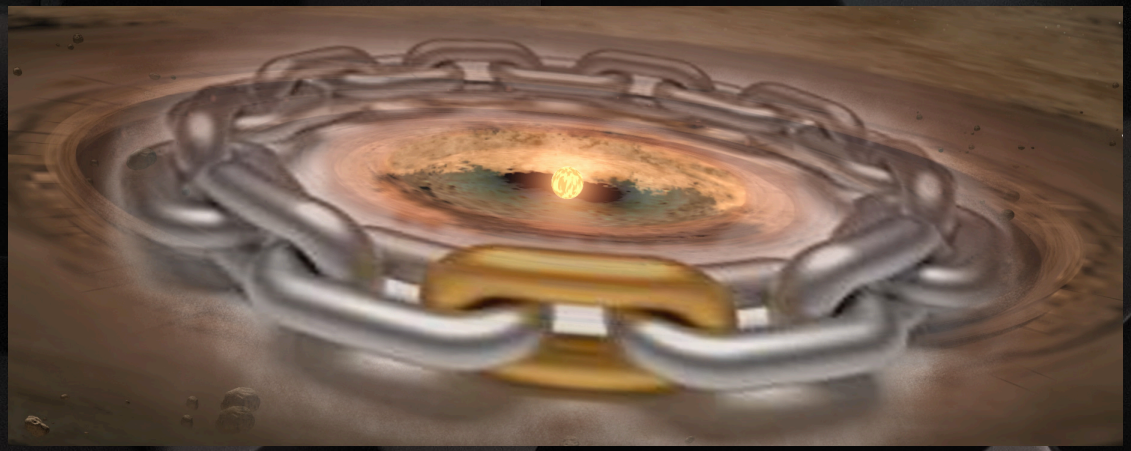
Formation and evolution of the intermediate mass Herbig Ae/Be pre-main sequence stars

René Oudmaijer

(Leeds, UK)



John Fairlamb, Karim Ababakr, Miguel Vioque, Alice Perez (Leeds), Ignacio Mendigutia, Deborah Baines (Madrid), Mario van den Ancker, Willem-Jan de Wit (ESO), Jorick Vink (Armagh), John Ilee (Cambridge)

Low mass vs. high mass star formation
Is magnetospheric accretion acting?

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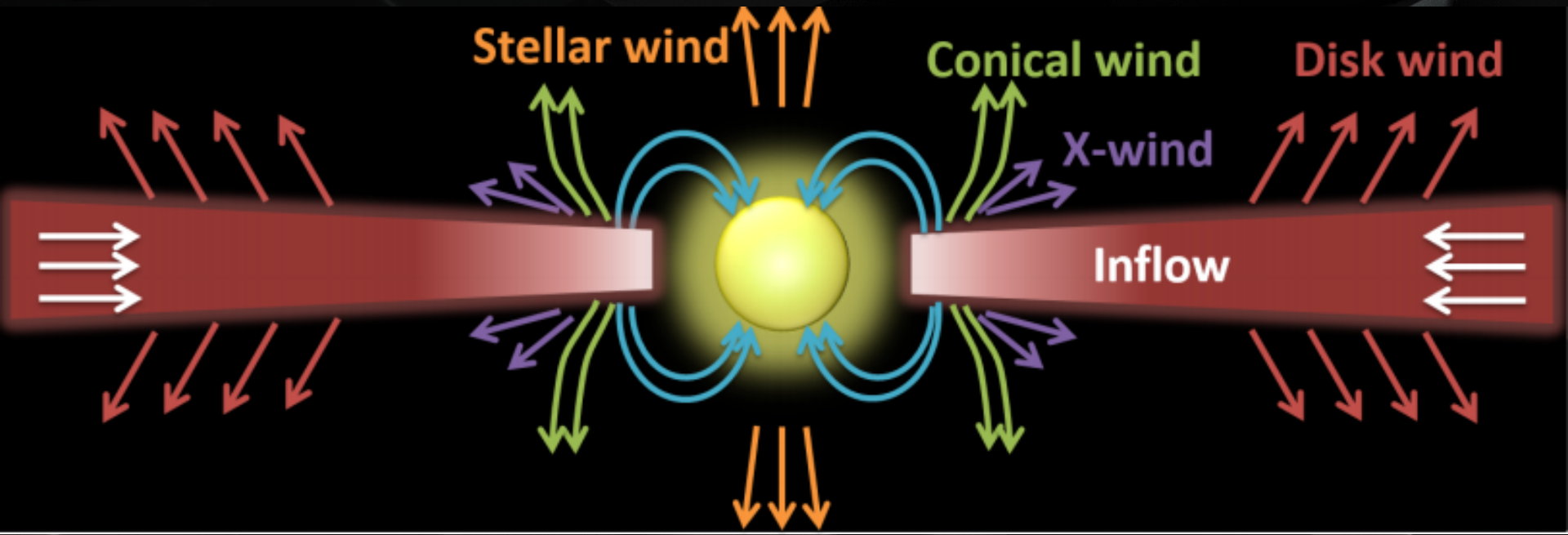

- Stars of spectral type A and earlier have radiative envelopes, so expect no magnetic dynamo
- Only about 10% of intermediate mass stars found to have *B*-fields (Alecian+ 2013)
- How does matter accrete onto more massive stars?

Pre-main sequence stars

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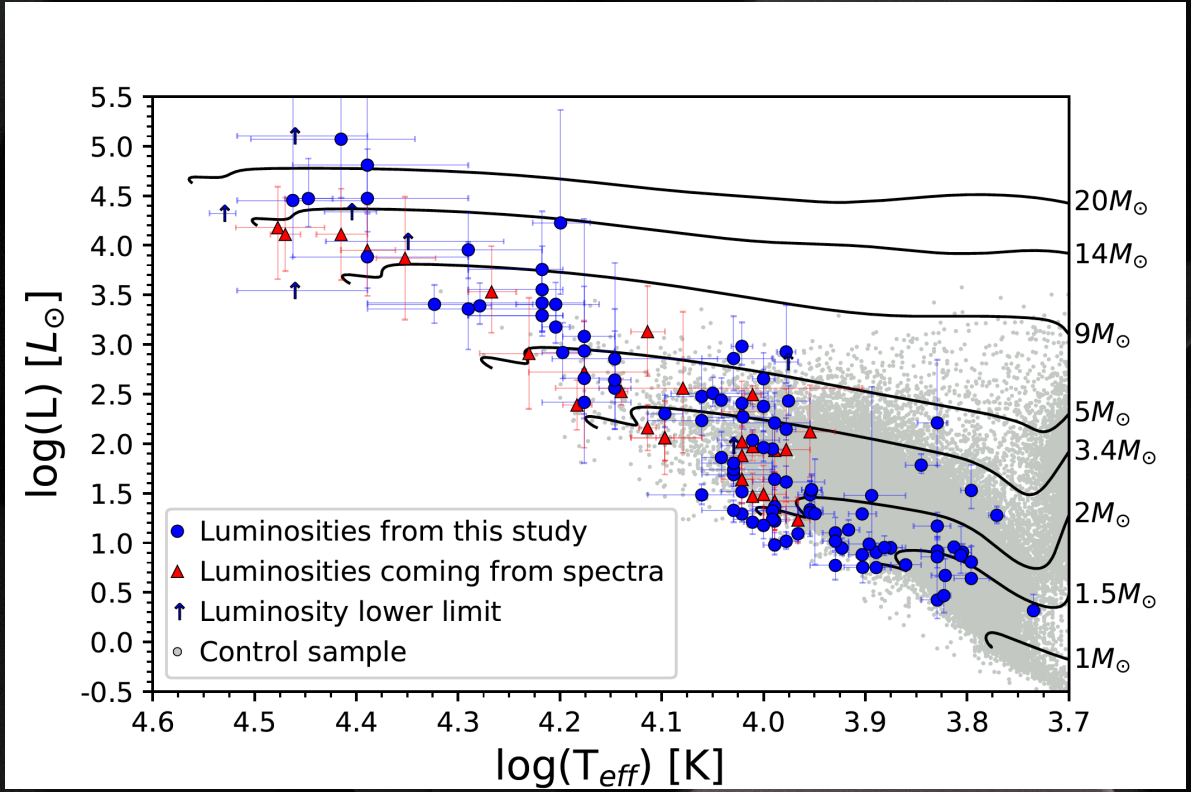
T Tauri stars : solar mass, magnetically controlled

accretion, veiling, optically visible

Herbig Ae/Be stars : intermediate mass,

optically visible

Massive Young Stellar Objects : massive, rare, elusive, obscured (Leeds RMS)



GAIA

Vioque+ 2017, poster 79

Herbig Ae/Be stars even host planets

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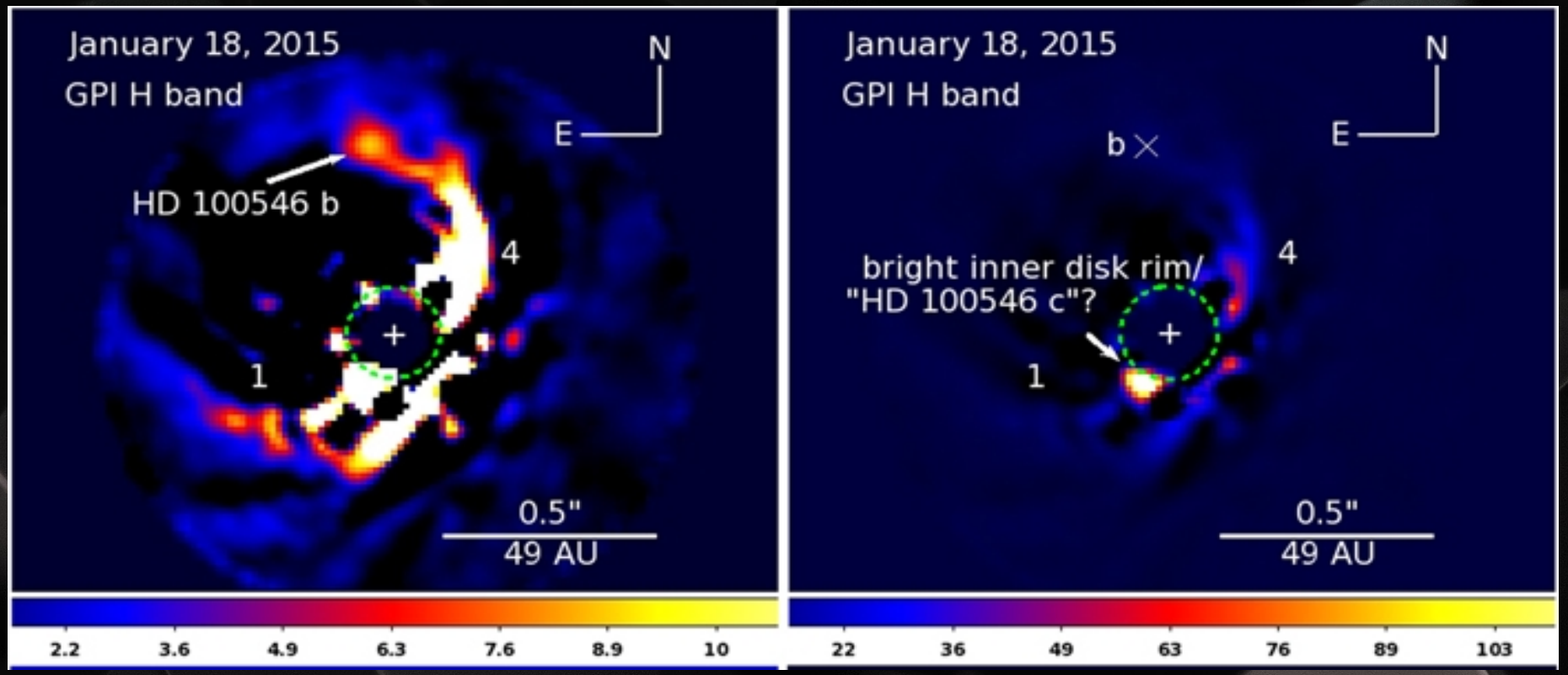

HD 100546 : Thayne Currie+ 2015, see also Mendigutia+ 2015, 2017

Herbig Ae/Be stars even host planets
HD 100546:

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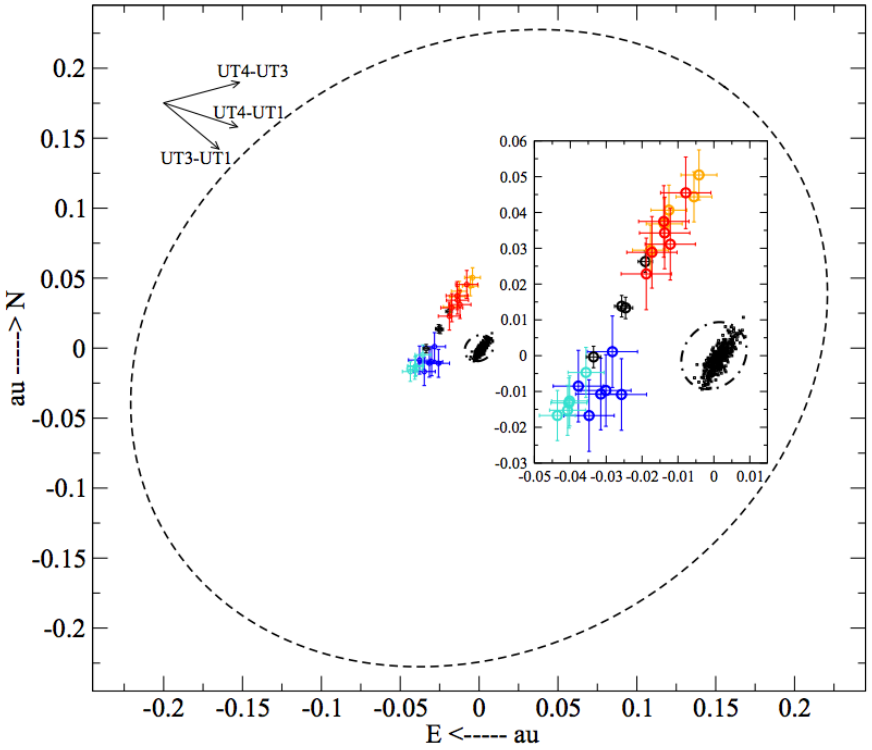
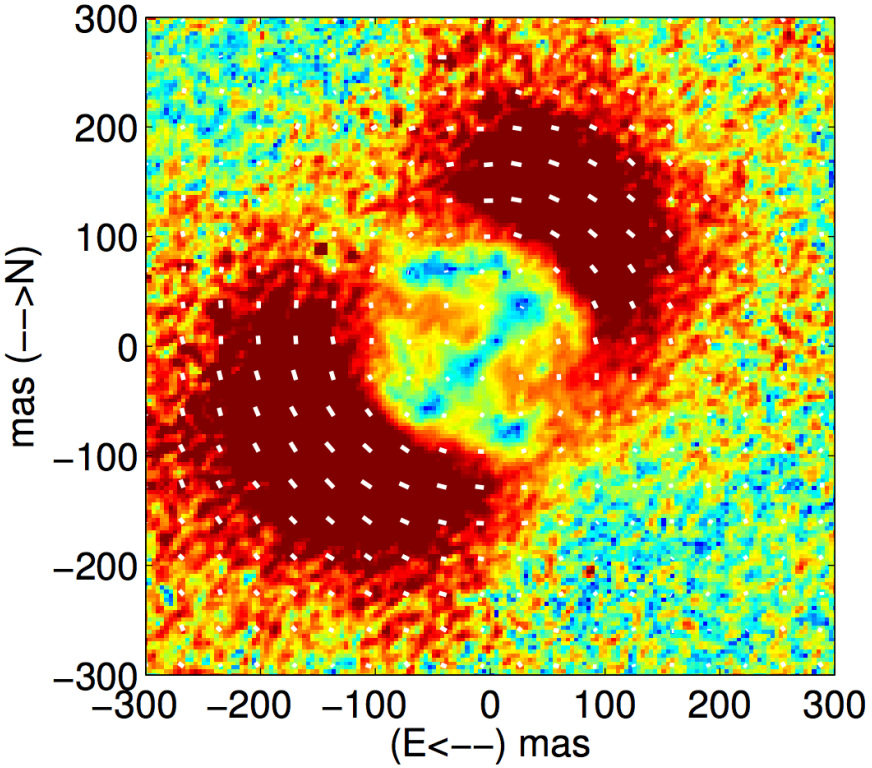




Mendigutia+ 2015 ***AMBER:***

- Much Br gamma emission from volume outside magnetosphere
- Inner disk would be depleted in < 1 yr, needs to be replenished

Mendigutia+ 2017 subm. ***SPHERE***

Polarized light

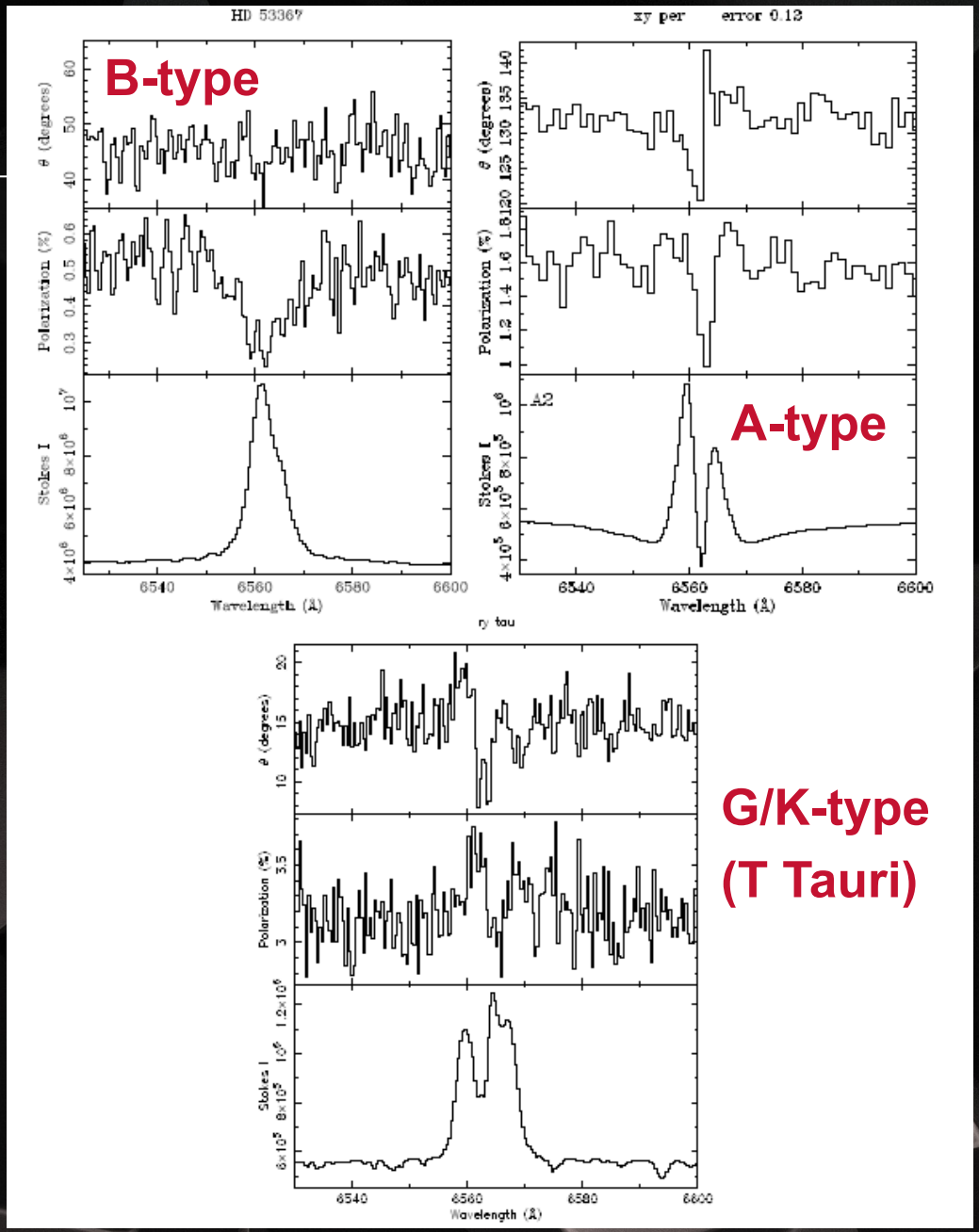
Linear Spectropolarimetry

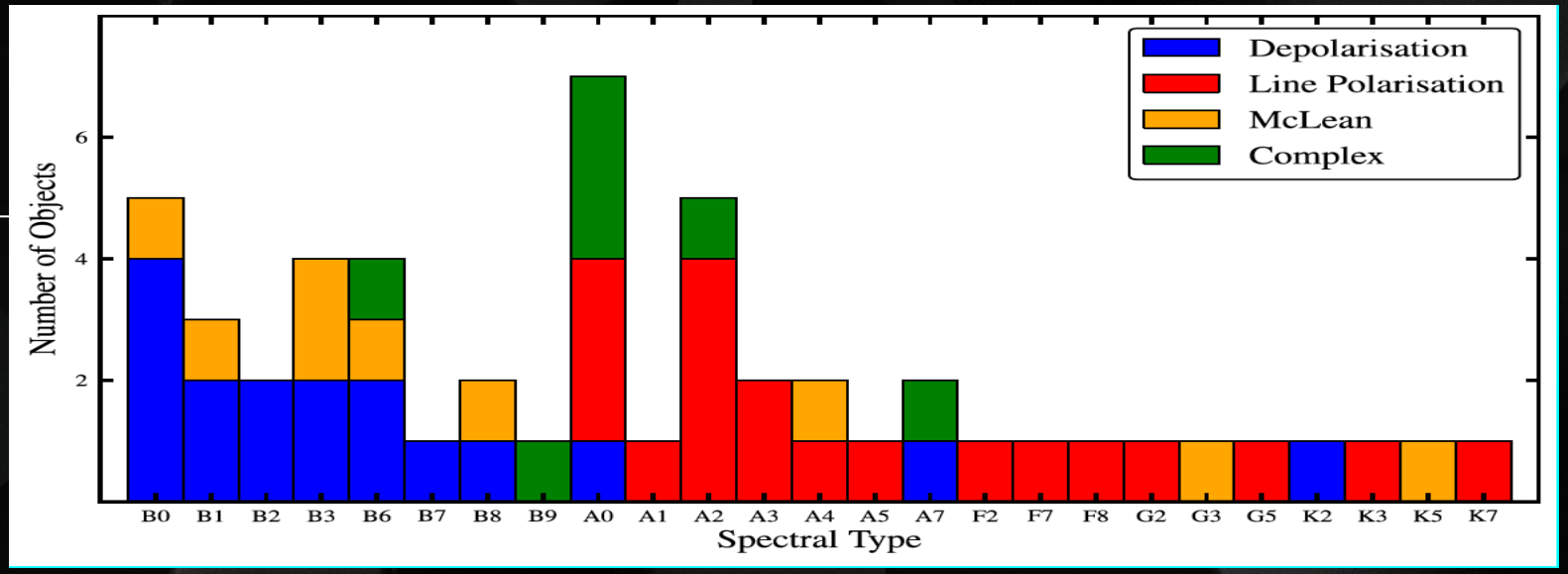
Reveals presence of small scale disks

Herbig Be stars consistent with disk reaching to close to star

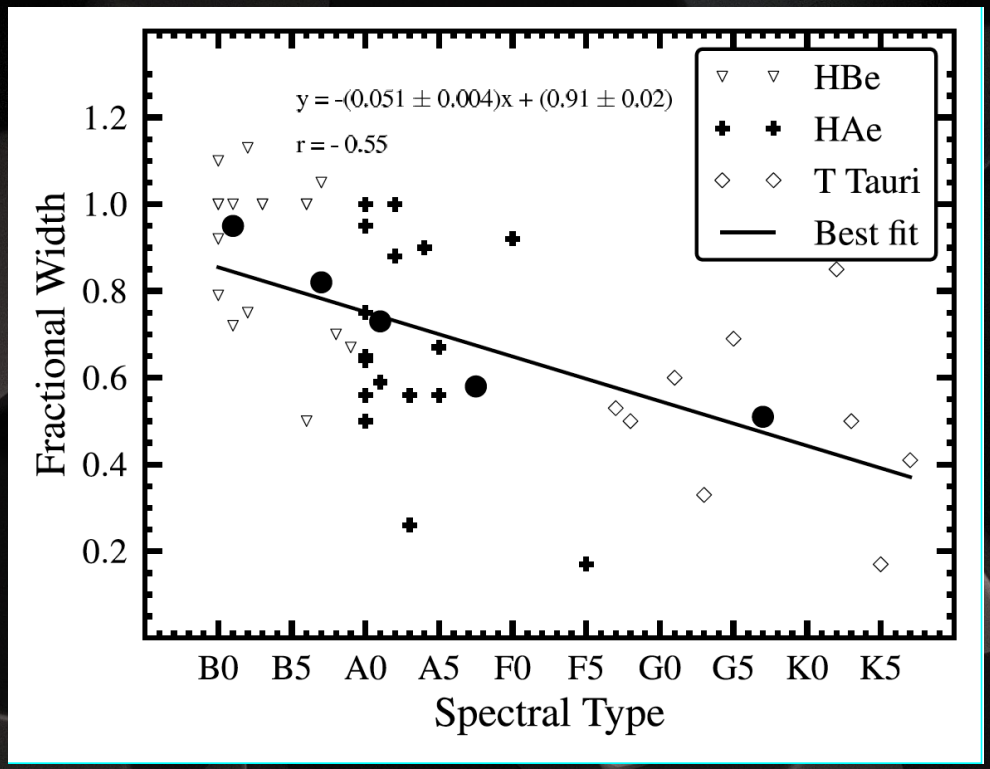
Herbig Ae stars similar to the T Tauri stars

(Vink+ 2003, 2005, Mottram+ 2007, Ababakr+ 2017)



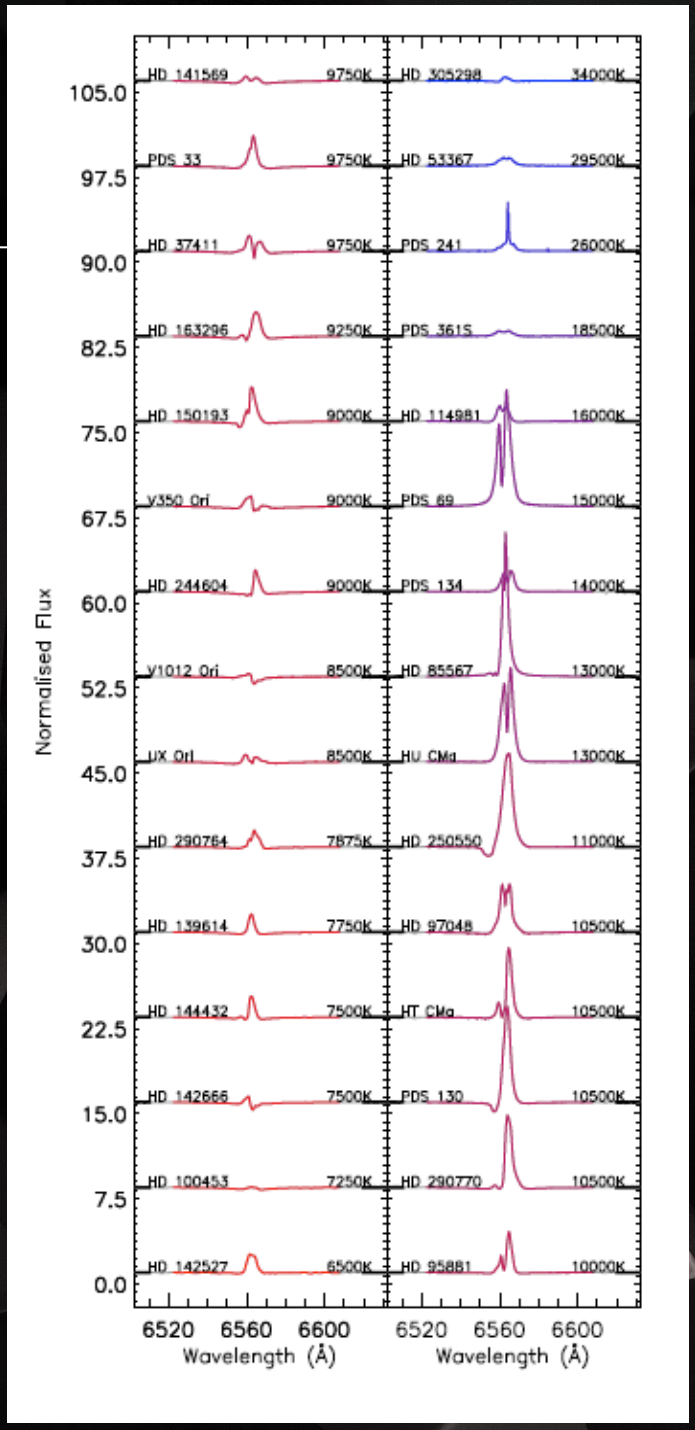


Trend with spectral type (Ababakr+ subm., 2017)



Investigate accretion properties across mass range

- Obtained X-Shooter data of a large sample of 90 Herbig Ae/Be stars – almost all known
- Spectra cover optical – near-infrared wavelength range (400nm – 2.4micron) in one shot, no issue with variability
- Determined stellar parameters in homogeneous manner for all objects
- Worked out accretion rate.
- Results from Fairlamb+ 2015



A large sample: accretion rates

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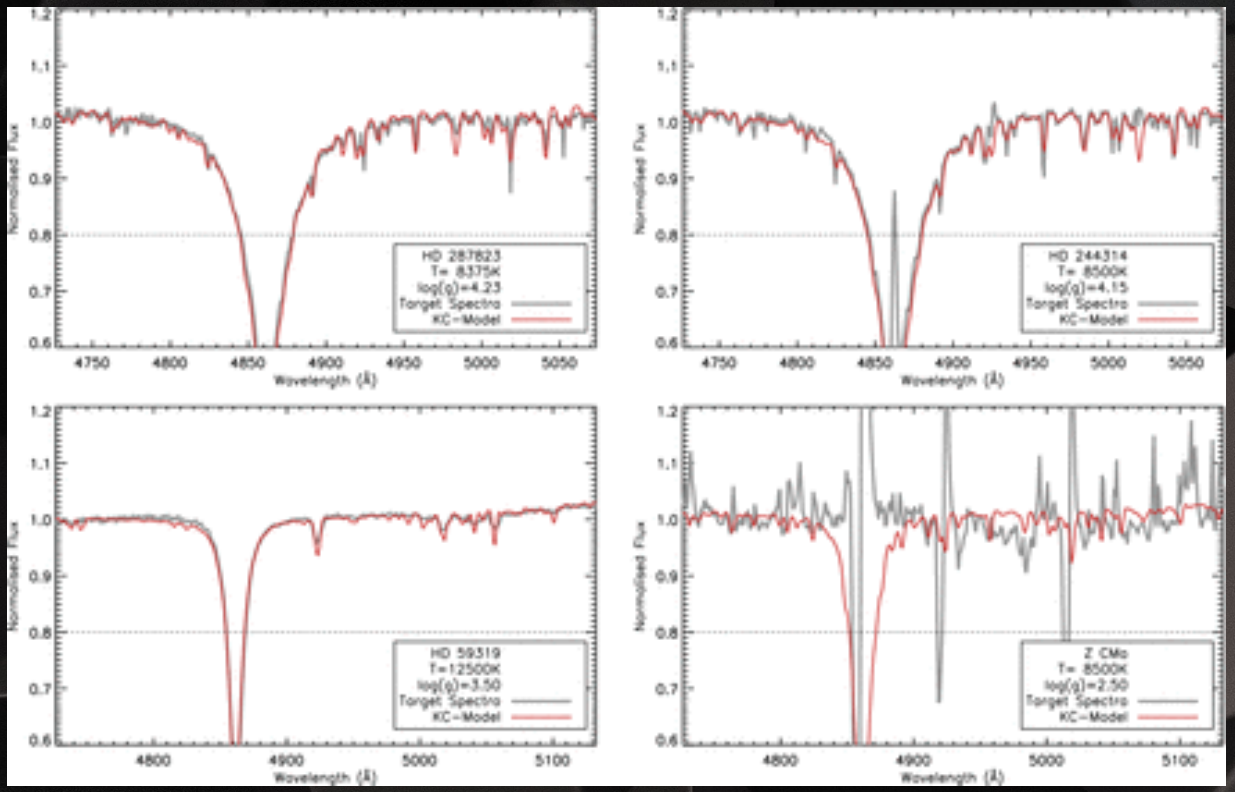
Only “direct” measure: Balmer excess: continuum emission due to accretion shock

Determine stellar parameters, spectral type, temperature, gravity, reddening



A large sample: accretion rates

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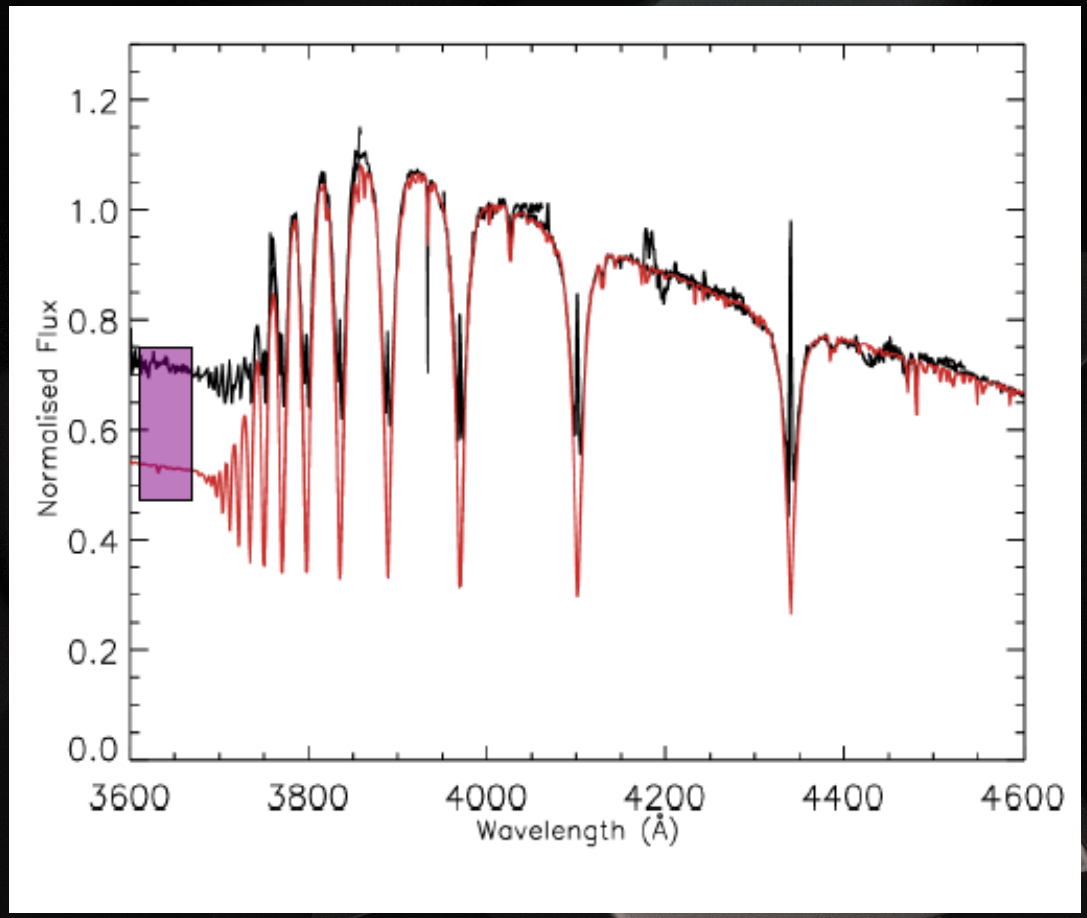
Only “direct” measure: Balmer excess: continuum emission due to accretion shock

- Determine UV excess
- Magnetospheric accretion model: accretion luminosity
- Stellar radius and mass: accretion rate

- Cf. Calvet & Gullbring 1998 (T Tauri) Muzerolle+2004, Donehew & Brittain 2011 (Herbig Ae/Be)



Accretion luminosity correlates with stellar luminosity

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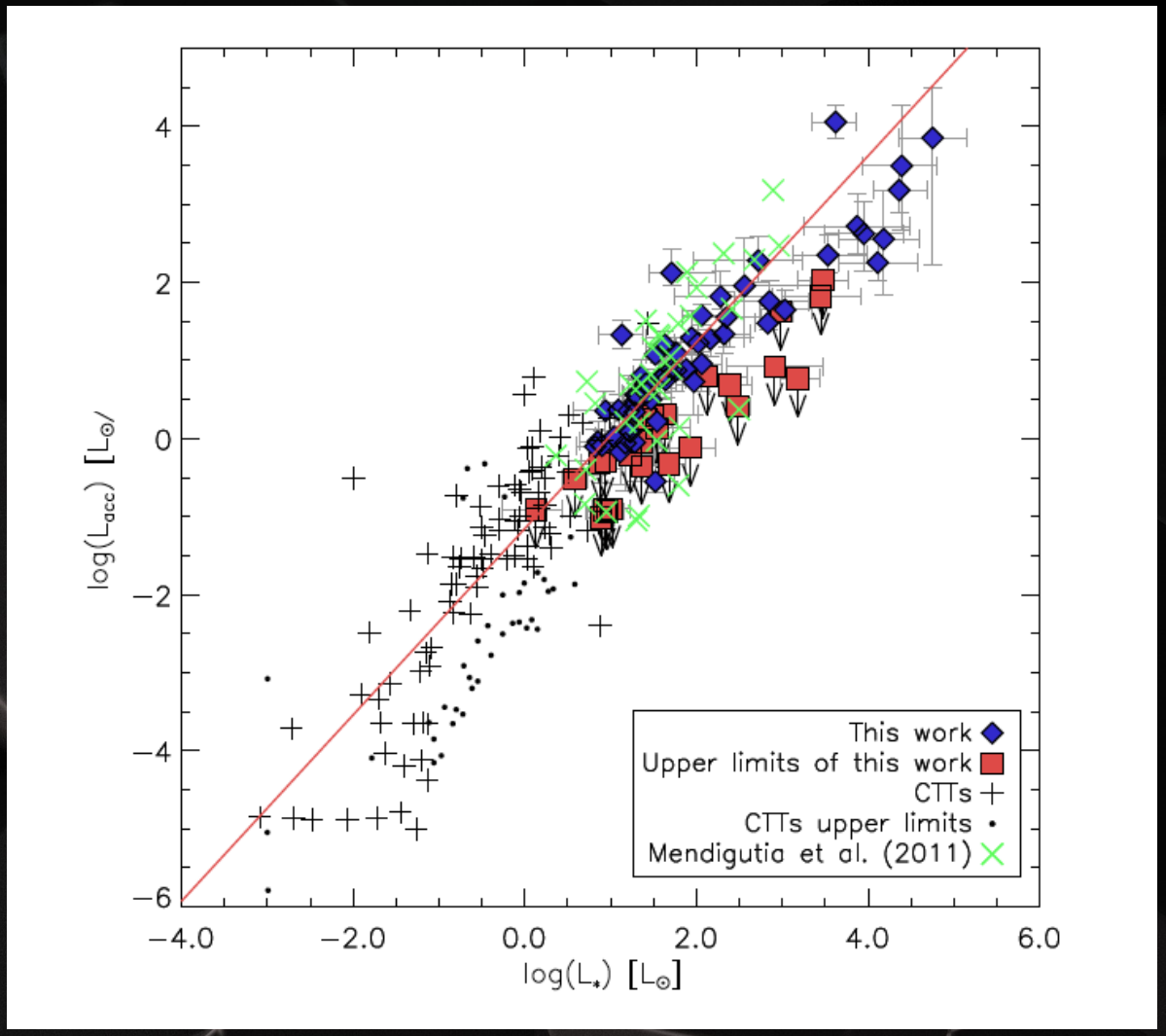

Across many orders of magnitude in luminosity.

Mendigutia+ 2011, Natta+ 2006

Accretion rate decreases with age

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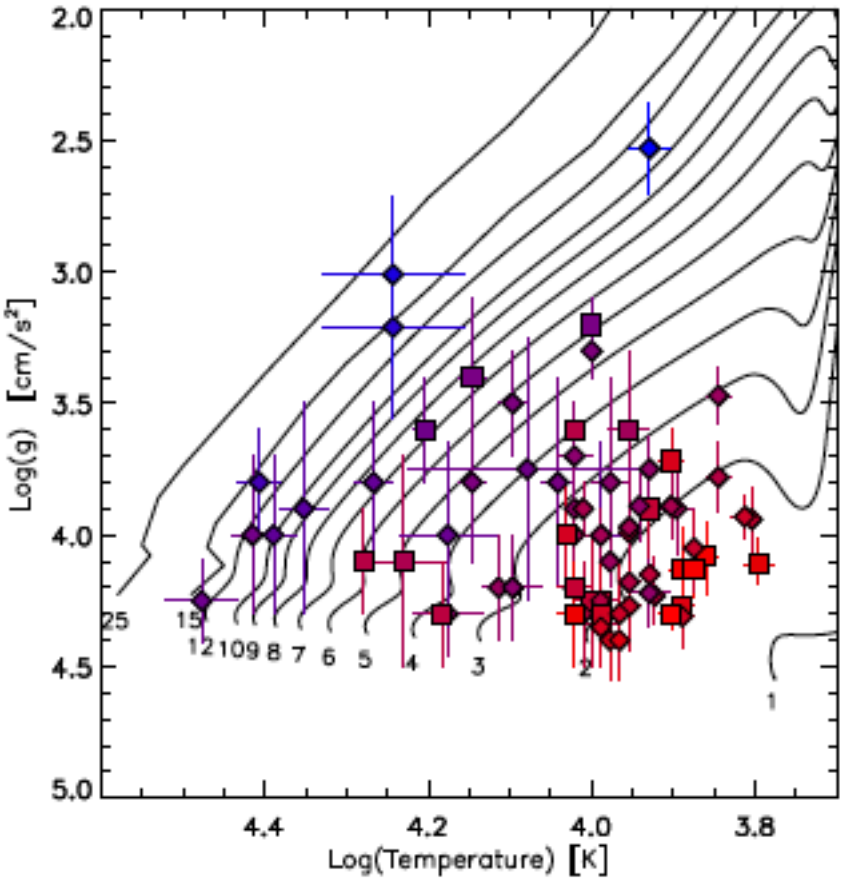

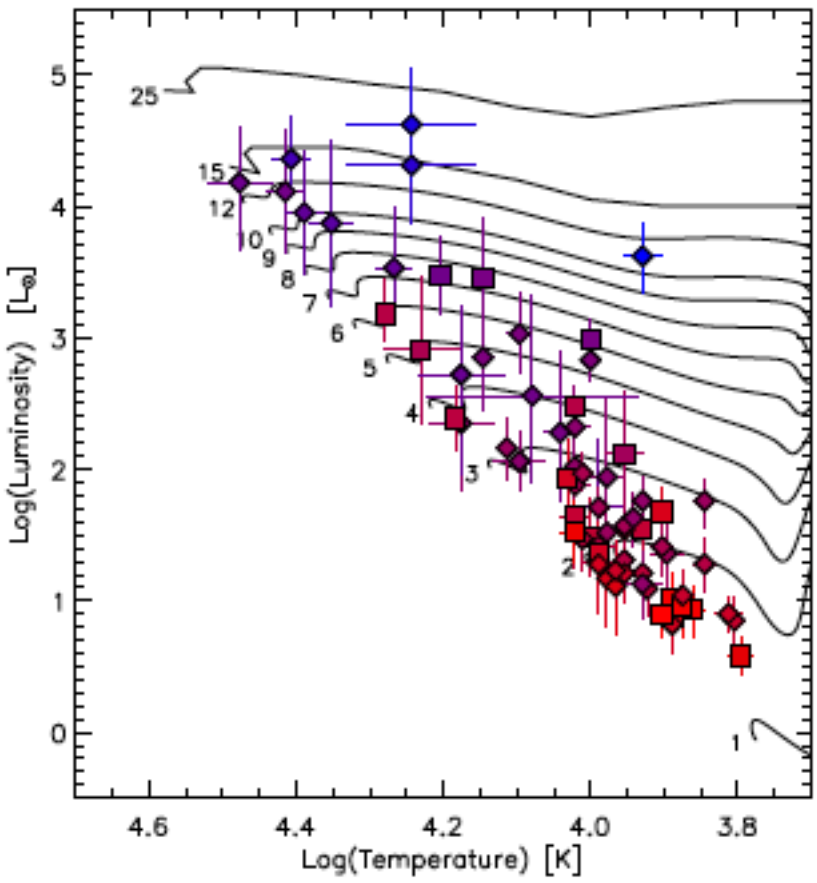

Accretion rate correlates with mass

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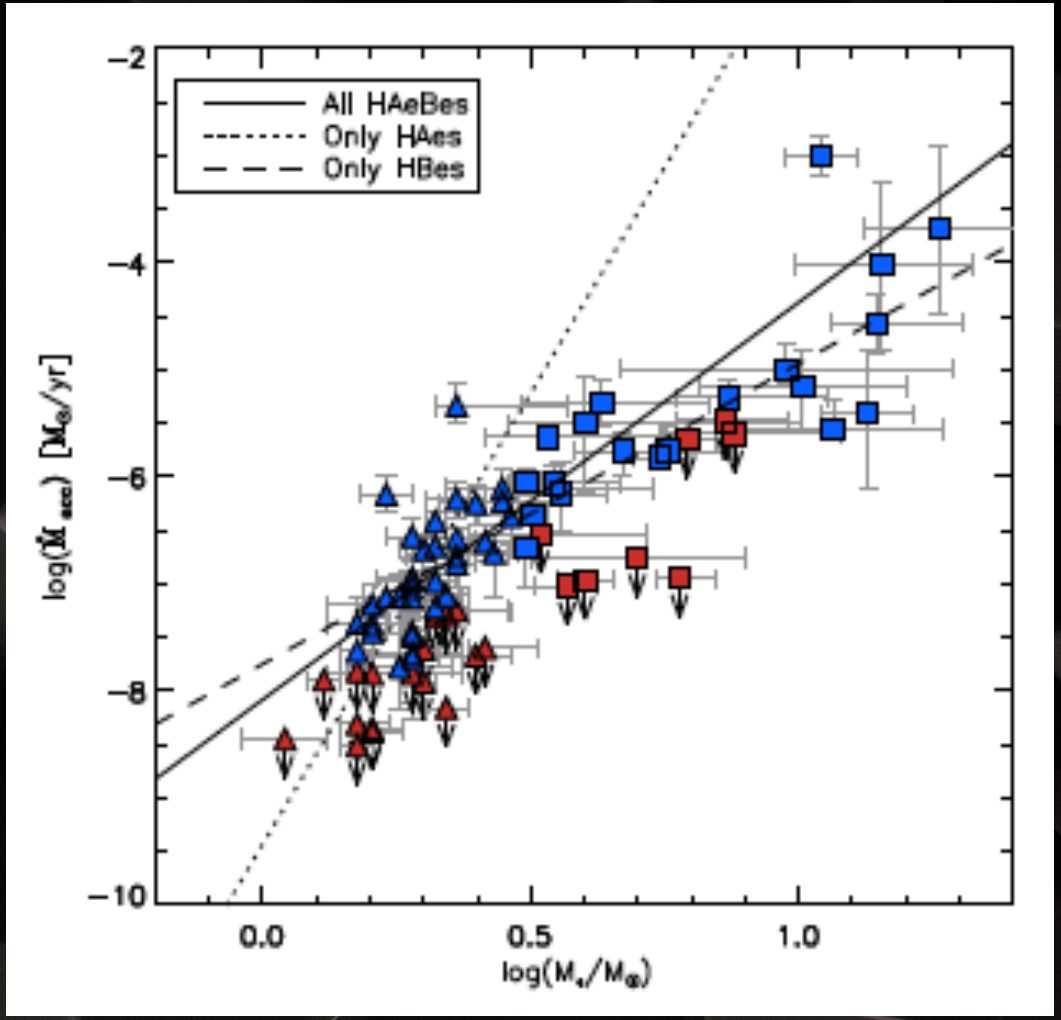


But: different slope Ae and Be objects

Occurs at similar mass as other such findings Vink+ 2002 (see also Muzerolle+ 2004, Grady+ 2010, Oudmaijer+ 2011, Alecian+ 2013, Cauley & Johns-Krull 2015)

Also, some early B-types have UV excesses that can not be reproduced with magnetospheric accretion

Need another mechanism.

Boundary layer accretion instead?

Mendigutia+ in prep; Fairlamb+ 2015

Emission line luminosities correlate with accretion luminosity.

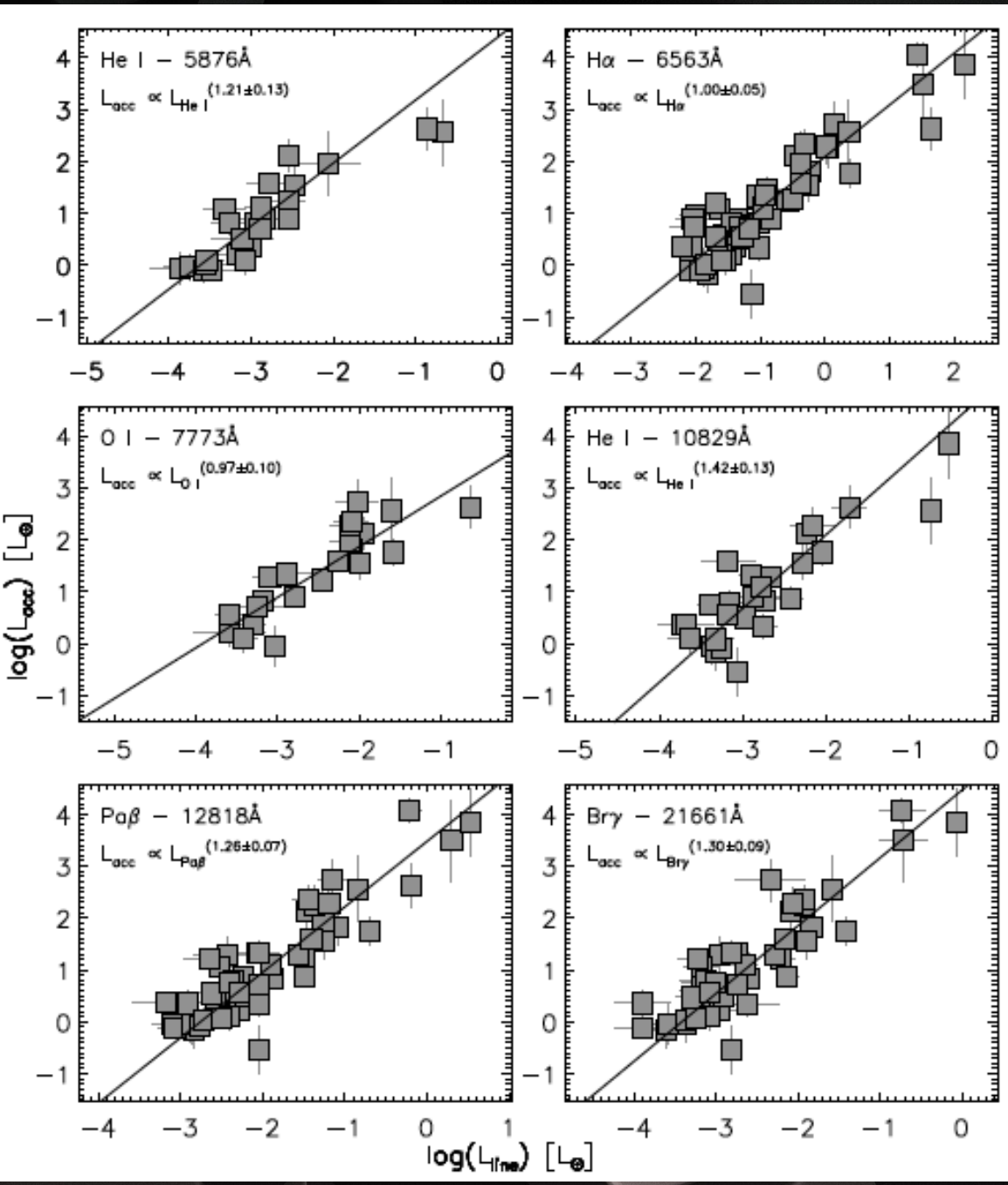
Can be used as accretion diagnostic

L_{acc} determination much easier than using UV excess

Extended the number of calibrated lines to entire X-Shooter spectral range

Fairlamb+ 2017

Mendigutia+2011, Garcia-Lopez+ 2005, Muzerolle+2004, Donehew & Brittain 2011, Rigliaco+2012



Herbig Ae/Be stars as link between low and high mass stars – Clusters stats: Testi, Palla+ 97, 98, 99

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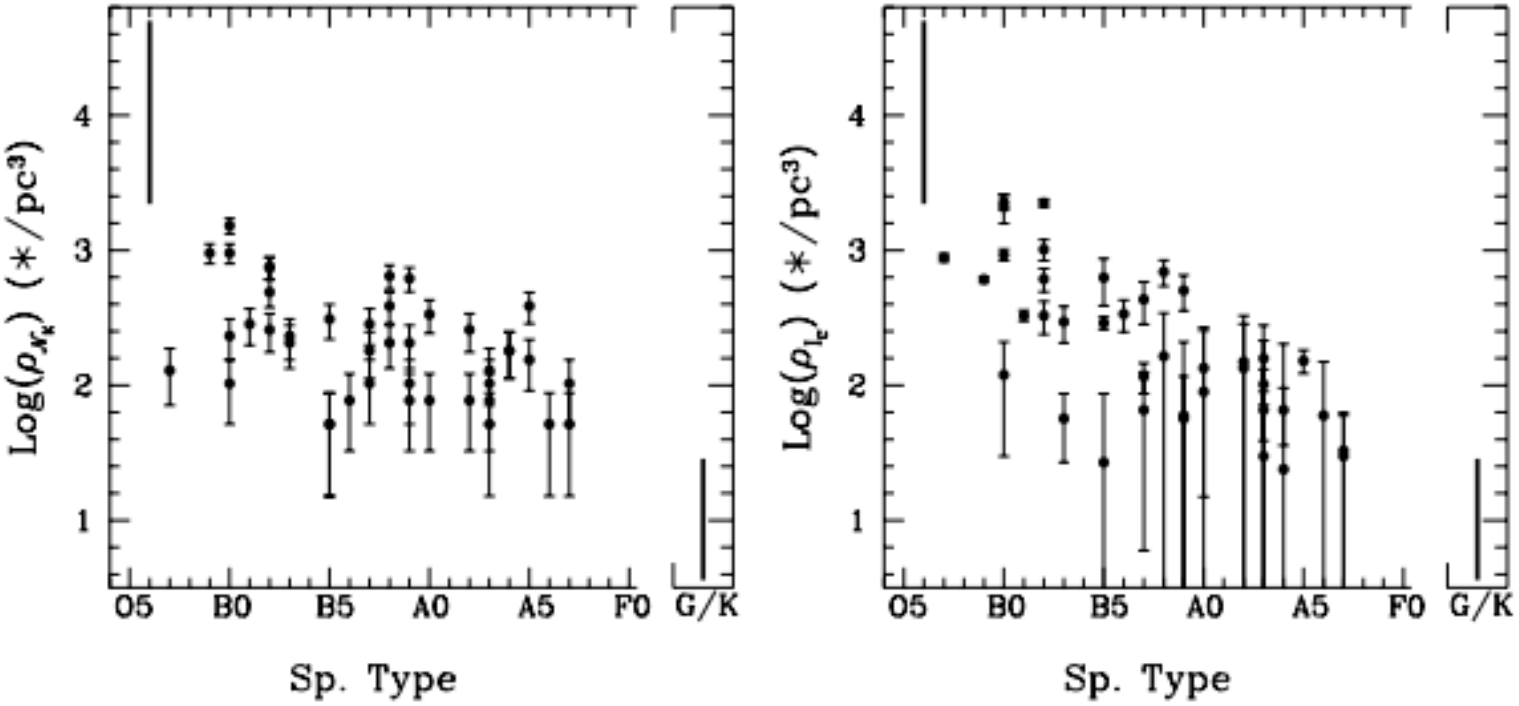
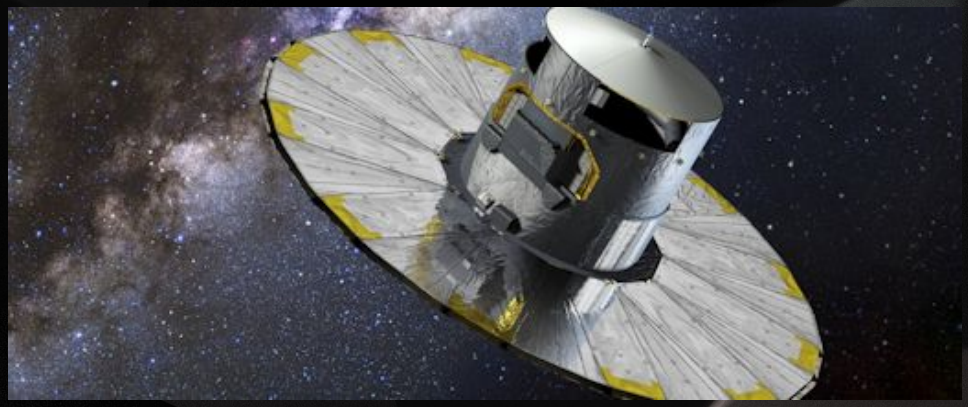


Fig. 7. Stellar volume densities derived from $\mathcal{N}_K$ (*left*) and from I_C (*right*) versus spectral type of the central star. Stars with $I_C < 0$ have been excluded. The heavy vertical line at O6 represents the range of stellar densities found in the Trapezium cluster, whereas that at G/K (not to scale) represents the densities of stellar groups in Taurus-Auriga.

Aim is to find more about the intermediate mass stars – no follow-on studies of large samples since 1999

Need more and better defined Herbig Stars Find and characterize clusters around them

STARRY
STARS THAT 'R' YOUNG



- GAIA satellite will provide fundamental information on a billion of stars
- Using HR diagrams, STARRY project will deliver new Herbig Ae/Be stars and their clusters
- STARRY will deliver "search and identify" tools and, if applicable, automatic cluster characterization.
- Great for all kinds of stars.
- See posters by Vioque (poster 79) and Perez (poster 89)

Conclusions

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- Herbig Ae/Be stars bridge the gap between low and high mass young stars and cover the mass where change in accretion occurs.
- Collected largest dataset of linear spectropolarimetry (56 objects)
- Conducted largest spectral survey – 0.4 – 2.4 micron of 90 objects
- Determined spectral types, temperatures, radii and accretion rates "directly" from UV excess or line flux.
- Presented relations to allow accretion rates to be determined from line luminosities instead. Large spectral range.
- Herbig Ae stars similar to T Tauri stars in spectropolarimetry
- Specpol + M_{acc}: Appears to be a change in accretion mode **at around 3 solar masses** (mid to late B-type)
- Future work: GAIA , new samples, clustering.
- Disk accretion mechanism in massive objects – Boundary Layer?