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

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

- Stars of spectral type A and earlier have radiative envelopes, so no magnetic dynamo expected
- Only about 10% of intermediate mass stars found to have $B$-fields (Alecian+ 2013 – no difference in emission properties Reiter+ 2018)
- How does matter accrete onto more massive stars?
Pre-main sequence stars

**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, see talk Lumsden)

GAIA DR2 Vioque+ 2018
Herbig Ae/Be stars even host planets

HD 100546 : Thayne Currie+ 2015, see also Mendigutia+ 2015, 2017
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 with inner disk hole of several stellar radii

Large sample of 56 objects:
Trend with spectral type (Ababakr+ 2017)

Break/change in properties around $3M_\odot$. 
Investigate accretion properties across mass range

- Obtained X-Shooter data of a large sample of 90 Herbig Ae/Be stars
- 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.
- Fairlamb+ 2015
A large sample: accretion rates

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

Accretion rate correlates with mass

But: different slope Ae and Be objects
Break at around 3 solar masses

Occurs at similar mass as other such findings Vink+ 2002 (see also Muzerolle+ 2004, Grady+ 2010, Oudmaijer+ 2011, Cauley & Johns-Krull 2015, Scholler+ 2016)

Also, some early B-types have UV excesses that cannot be reproduced with magnetospheric accretion
Need another mechanism.
Boundary layer accretion instead?
Mendigutia+ in prep; Fairlamb+ 2015

See poster 4C by Wichittanakom
Emission line luminosities correlate with accretion luminosity.

Can be used as accretion diagnostic

$L_{\text{acc}}$ determination much easier than using UV excess

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

Fairlamb+ 2017

The HR diagram – GAIA DR2 results
Parallaxes + Total Fluxes → Luminosities

200+ objects could be placed on HR diagram.

PMS tracks → Masses & Isochrones → Ages

Vioque+ 2018
There appears a break at $7M_\odot$. Dusty environment different for early Herbig Be stars.

Related to more efficient dust evaporation at higher temperatures/brightnesses.

See also Albi+ 2009, Gorti+ 2009
Variability derived from GAIA data vs. Mass

Same break at around 7 solar masses.

25% of all Herbig Ae/Be stars strongly variable.
Variability vs. Infrared excess

of the strongly variable Herbig Ae/Be stars show double-peaked Hα emission. None show a single-peaked line profile.

UXOR phenomenon

Grinin+ 1996, 2000
Ongoing: GAIA: Herbig Ae/Be stars as link between low and high mass stars – Clusters stats: Testi, Palla+ 97, 98, 99

Fig. 7. Stellar volume densities derived from $N_K$ (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.

See Poster 1G by Perez
Conclusions

- 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
- GAIA DR2 200+ objects in HR Diagram
- Herbig Ae stars similar to T Tauri stars in spectropolarimetry
- Specpol + $M_{\text{acc}}$: tracing gas close to star: change at around 3 solar masses (mid to late B-type). Different accretion mode?
- GAIA – dust tracing material further from star: change at 7 solar mass (photo-evaporation).
- Variability linked to edge-on disks – UXOR phenomenon
- Disk accretion mechanism in massive objects – Boundary Layer?

The STARRY project receives funding from the European Union’s Horizon 2020 Marie Skłodowska-Curie Actions (MSCA) programme under ITN_EID Grant Agreement No 676036.