Herbig Ae/Be stars with TGAS parallaxes in the HR diagram

Miguel Vioque, René D. Oudmaijer and Deborah Baines
Herbig Ae/Be stars

\[ \lambda \mu \text{m} \rightarrow \log(\lambda F_{\lambda}) \rightarrow L_\text{og} \]

Fairlamb J.R. thesis. 2015
Herbig Ae/Be stars

Fairlamb J.R. thesis. 2015
Herbig Ae/Be stars

Around 254 catalogued Herbig Ae/Be stars at the moment. Some rather dubious.
Gaia

Gaia DR1
Hipparcos
Tycho-2 (excl. HIP)
QSOs ICRF2

Number

$\log_{10}$ [Number]

Mean $G$ [mag]

$14.5 \leq G \leq 20.7$ (95.5%)

$G > 21$ (0.135%)

HR diagram

• 254 known Herbig Ae/Be stars → 108 in TGAS.
• $T_{\text{eff}}, \log(g)$ and metallicity were taken from the literature.
• We used multi epoch and simultaneous photometry when possible.
• Photometry was dereddened using a $R_V = 3.1$.
• All sources were crossmatched with 2MASS and WISE.

Chen P.S. et al. 2016, New A, 44, 1
254 known Herbig Ae/Be stars → 108 in TGAS.

- $T_{eff} = 10000 \pm 200$ K
- $Parallax = 1.50 \pm 0.24$ mas
- $A_V = 1.74 \pm 0.03$ mag
- $\log(g) = 3.31 \pm 0.13$ cm/s$^2$
- $[M/H] = 0.10 \pm 0.05$
- $V = 10.92$ mag
- $Log(L) = 1.96^{+0.16}_{-0.14} L_\odot$
HR diagram of 140 Herbig Ae/Be stars

Similar procedure for 73240 TGAS sources

**Luminosities from this study**

**Luminosities coming from spectra**

**Luminosity lower limit**

**Control sample**
Identify Herbig Ae/Be stars

• Herbig G.H. 1960, ApJS, 4, 337:
  
  o Spectral type A or earlier, with emission lines.
  
  o The star lies in an obscured region.
  
  o The star illuminates fairly bright luminosity in its immediate vicinity.

Infrared Excess
Variability
$H\alpha$ Emission
Identify Herbig Ae/Be stars

  - Spectral type A or earlier, with emission lines.
  - The star lies in an obscured region.
  - The star illuminates fairly bright luminosity in its immediate vicinity.

**Infrared Excess Variability**

*Hα Emission*
Infrared Excess

HD 179218

T_{eff} [K]: 9500
log(L) [L_\odot]: 2.14
Distance (pc): 293
Age [Myr]: 1.27

Excess in W2 = \frac{Observed Flux at W2}{Model Flux at W2}

Infrared Excess

\[
IR \text{ excess } WISE = \frac{Excess \ in \ W1 + Excess \ in \ W2 + Excess \ in \ W3 + Excess \ in \ W4}{4}
\]

\[
\log(L) \ [L_\odot] : 2.14
\]

Distance (pc): 293

Age [Myr]: 1.27

Infrared Excess

\[ IR \text{ excess } WISE = \frac{\text{Excess in } W1 + \text{Excess in } W2 + \text{Excess in } W3 + \text{Excess in } W4}{4} \]

\[ IR \text{ excess } 2\text{MASS} = \frac{\text{Excess in } J + \text{Excess in } H + \text{Excess in } K_s}{3} \]

Infrared Excess

IR excess in WISE bands vs. IR excess in 2MASS bands

Infrared Excess

Infrared Excess

IR excess in WISE bands vs. IR excess in 2MASS bands

- General sample 1
- General sample 2
- Herbig Be
- Herbig Ae
Infrared Excess
Infrared Excess

IR excess in WISE bands vs. IR excess in 2MASS bands

V1028 Cen
- $T_{\text{eff}} [K]$: 14000
- log($L$) [$L_\odot$]: 2.64
- Parallax [mas]: 1.90±0.79
- J-K$_s$ [mags]: 2.27
- W1-W4 [mags]: 6.89
- Age [Myr]: 1.46

- General sample 1
- General sample 2
- Herbig Be
- Herbig Ae
What else looks like this?

  - Spectral type A or earlier, with emission lines.
  - The stars lies in an obscured region.
  - The stars illuminates fairly bright luminosity in its immediate vicinity.

Infrared Excess
Variability
$H\alpha$ Emission
Be stars

- Spectral type A or earlier, with emission lines.
- The stars lie in an obscured region.
- The stars illuminate fairly bright luminosity in its immediate vicinity.
Infrared Excess

IR excess in WISE bands vs. IR excess in 2MASS bands

- General sample 1
- General sample 2
- Herbig Be
- Herbig Ae
Infrared Excess

IR excess in WISE bands vs. IR excess in 2MASS bands

Be stars: Jaschek M., Egret D. 1982, IAUS, 98, 261
Infrared Excess

Be stars: Jaschek M., Egret D. 1982, IAUS, 98, 261
Infrared Excess

Be stars: Jaschek M., Egret D. 1982, IAUS, 98, 261
Infrared Excess

IR excess in WISE bands vs. IR excess in 2MASS bands

Basic data:

**HD 114981 -- Be Star**

**Other object types:**

- (HD,CD,...), IR (IRAS,2MASS), Ae? (Ref), Be* (Ref), Em* (Hen), V* (V*), UV (TD1)

**ICRS coord. (ep=J2000):**

- 13 14 40.68493 -38 39 05.6581 (Optical) [ 4.04 3.43 90 ] A 2007A&A...474..653V

**FK5 coord. (ep=J2000 eq=2000):**

- 13 14 40.685 -38 39 05.66 [ 4.04 3.43 90 ]

**FK4 coord. (ep=B1950 eq=1950):**

- 13 11 50.26 -38 23 14.3 [ 23.25 19.91 0 ]

**Gal coord. (ep=J2000):**

- 307.8963 +23.9961 [ 4.04 3.43 90 ]

**Proper motions mas/yr:**

- 11.65 7.34 [ 0.46 0.39 0 ] A 2007A&A...474..653V

**Parallaxes (mas):**

- 1.81 [0.58] A 2007A&A...474..653V

**Spectral type:**

- B5V C 2003AJ....126.2971V

**Fluxes (6):**

- U 6.43 [ - ] D 1982AUS...98...261J
- B 7.07 [ - ] C 2003yCat.2246....0C
- V 7.12 [ - ] C 2003yCat.2246....0C
- J 7.396 [0.024] C 2003yCat.2246....0C
- H 7.476 [0.042] C 2003yCat.2246....0C
- K 7.438 [0.017] C 2003yCat.2246....0C

Be stars: Jaschek M., Egret D. 1982, IAUS, 98, 261
Infrared Excess

HR diagram

IR excess in WISE bands vs. IR excess in 2MASS bands

- Be stars
- Herbig Be
- Herbig Ae

General sample 1
General sample 2
Be stars
Herbig Be
Herbig Ae

Log(L) [L\(_\odot\)] vs. Log(Teff) [K]
IR excess in 2MASS bands

0 1 2 3 4 5 10 20 30 40
Infrared Excess

IR excess in WISE bands vs. IR excess in 2MASS bands

HD 259431 -- Herbig Ae/Be star

Other object types:
- Or* (e.g., * (HD,AG,...)), Em* (EM*,HBC,...), *IC ([VKG85]), *in (VDB), Ae* (Ref), V*

ICRS coord. (ep=J2000):
- 06 33 05.19661 +10 19 19.9869 (Optical) [ 9.95 7.66 90 ] A 2007A&A...474..653V

FK5 coord. (ep=J2000 eq=2000):
- 06 33 05.191 +10 19 19.99 [ 9.95 7.66 90 ]

FK4 coord. (ep=BJ1950 eq=1950):
- 06 30 19.38 +10 21 38.3 [ 57.02 44.62 0 ]

Gal coord. (ep=J2000):
- 201.6657 +00.6686 [ 9.95 7.66 90 ]

Proper motions mas/yr:
- -2.37 -2.72 [1.13 0.87 0] A 2007A&A...474..653V

Radial velocity / Redshift / cz:
- V(km/s) 19.00 [4.1] / z(-) 0.000063 [0.000014] / cz 19.00 [4.10]

C 2006AstL...32...759G

Parallaxes (mas):
- 5.78 [1.22] A 2007A&A...474..653V

B6ep D 1982AJ.....87...98H

Spectral type:
- B6ep

Fluxes (7):
- U 8.39 [-] C 2002yCat.2237.....0D
- B 8.95 [-] C 2002yCat.2237.....0D
- V 8.72 [-] C 2002yCat.2237.....0D
- R 8.9 [-] E 2003yCat.2246.....0C
- J 7.454 [0.026] C 2003yCat.2246.....0C
- H 6.67 [0.03] C 2003yCat.2246.....0C
- K 5.726 [0.020] C 2003yCat.2246.....0C

IR excess in 2MASS bands

0 1 2 3 4 5 10 20 30 40

Log(Teff) [K]

Herbig Be

Herbig Ae

Be stars
- Herbig Be
- Herbig Ae

0.5 0.4 0.3 0.2

Log(Teff) [K]
Infrared Excess

- 115 Herbig Ae
- 951 Be stars
- 103 Herbig Be
- 96328 General sample 1
- 17251 General sample 2
Infrared Excess

- 95/115 Herbig Ae
- 66/103 Herbig Be
- 6/951 Be stars
- 10/96328 General sample 1
- 5/17251 General sample 2

\[ W1 - W4 > 3.5 \]
\[ J - K > 0.8 \]
Infrared Excess

- From an input catalogue of 114748 sources, imposing $W_1 - W_4 > 3.5$ and $J - K_s > 0.8$:
  - 74% of Herbig Ae/Be stars recovered.
    - 83% of Herbig Ae stars.
    - 64% of Herbig Be stars.
  - 0.6% of Be stars recovered.
  - 0.01% of general sources.
Infrared Excess

- 218 Herbig Ae/Be
- 1017635 input catalogue
Infrared Excess

- 161/218 Herbig Ae/Be
- 337/1017635 input catalogue

74%

0.03%
Variability

- In general, Gaia Data Release 1 has no explicit variability information.
- In Gaia Data Release 1 sources were observed several tens to hundreds of times.
  - It is possible to extract variability information from the repeated observations.

\[
\text{Variability indicator} = \sqrt{N_{\text{obs}} \sigma(F)/F}
\]

\(N_{\text{obs}}\) is the number of CCD crossings, \(F\) is the flux in the G band, \(\sigma(F)\) is the flux error.

Variability

Variability Indicator vs. Effective Temperature

- General sample 1
- General sample 2
- Be stars
- Herbig Ae/Be stars
Variability & IR Excess

- 33 Herbig Ae
- 22 Herbig Be
- 497 Be stars
- 671478 TGAS sources
3.4 $M_\odot$ track
3.4 $M_\odot$ track

**HD 35929**
- $T_{\text{eff}}$ [K]: 7000
- log($L$) [$L_\odot$]: 1.78
- Distance (pc): 385
- Age [Myr]: 1.05

**HD 179218**
- $T_{\text{eff}}$ [K]: 9500
- log($L$) [$L_\odot$]: 2.14
- Distance (pc): 293
- Age [Myr]: 1.27

**V380 Ori**
- $T_{\text{eff}}$ [K]: 9750
- log($L$) [$L_\odot$]: 2.21
- Distance (pc): 610
- Age [Myr]: 1.29

**HD 37806**
- $T_{\text{eff}}$ [K]: 10475
- log($L$) [$L_\odot$]: 2.27
- Distance (pc): 420
- Age [Myr]: 1.34

**V594 Cas**
- $T_{\text{eff}}$ [K]: 11500
- log($L$) [$L_\odot$]: 2.23
- Distance (pc): 625
- Age [Myr]: 1.40

**HD 59319**
- $T_{\text{eff}}$ [K]: 12500
- log($L$) [$L_\odot$]: 2.3
- Distance (pc): 526
- Age [Myr]: 1.45
<table>
<thead>
<tr>
<th>Star</th>
<th>IR excess 2MASS</th>
<th>IR excess WISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD 35929</td>
<td>1.60</td>
<td>12.6</td>
</tr>
<tr>
<td>HD 179218</td>
<td>1.63</td>
<td>560</td>
</tr>
<tr>
<td>V380 Ori</td>
<td>6.78</td>
<td>509</td>
</tr>
<tr>
<td>HD 37806</td>
<td>4.78</td>
<td>299</td>
</tr>
<tr>
<td>V594 Cas</td>
<td>11.9</td>
<td>824</td>
</tr>
<tr>
<td>HD 59319</td>
<td>1.14</td>
<td>33.3</td>
</tr>
</tbody>
</table>
Conclusions

- Infrared excesses have proved to be a very powerful tool for identifying Herbig Ae/Be stars.
- Variability is not a good tracer of Herbig Ae/Be stars, but it will be useful in combination with other parameters.
- Current analysis on the HR diagram do not allow us to draw any solid conclusion, except that infrared excesses are not very dependent of evolutionary status.
- It is necessary to keep adding dimensions to the selection criteria to be as much prepared as possible for Gaia DR2.
The clustering properties of intermediate mass young stars

Perez-Blanco A. et al.

Characterization cluster properties Herbig Ae/Be stars, by identifying the cluster environment around the target stars and determining the clusters’ astrophysical parameters.

Figure 1 K band images of four Herbig stars. The upper section of the figure shows the Herbig stars surrounded by a large number of companions and the lower section of the figure the Herbig stars appear single and isolated. Figure taken from Testi et al. (1997).

Figure 2 Selection process of the stars in the cluster NGC6475.

Table 2: Astrometric parameters of the cluster NGC6475

<table>
<thead>
<tr>
<th>Source</th>
<th>Parallax</th>
<th>Pmra</th>
<th>Pmdc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaia Collaboration., et al.</td>
<td>3.57</td>
<td>3.10</td>
<td>-5.32</td>
</tr>
<tr>
<td>This project</td>
<td>3.60</td>
<td>2.98</td>
<td>-5.35</td>
</tr>
</tbody>
</table>

Figure 3 Colour - Magnitude diagram of the cluster NGC6475. In figure A the black points represent the data from Tycho in a circular area with a radius of 3 degrees around the center and the red points are the cross-match between the result of the selection in parallax and proper motions from TGAS and Tycho.