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

Miguel Vioque, René D. Oudmaijer and Deborah Baines

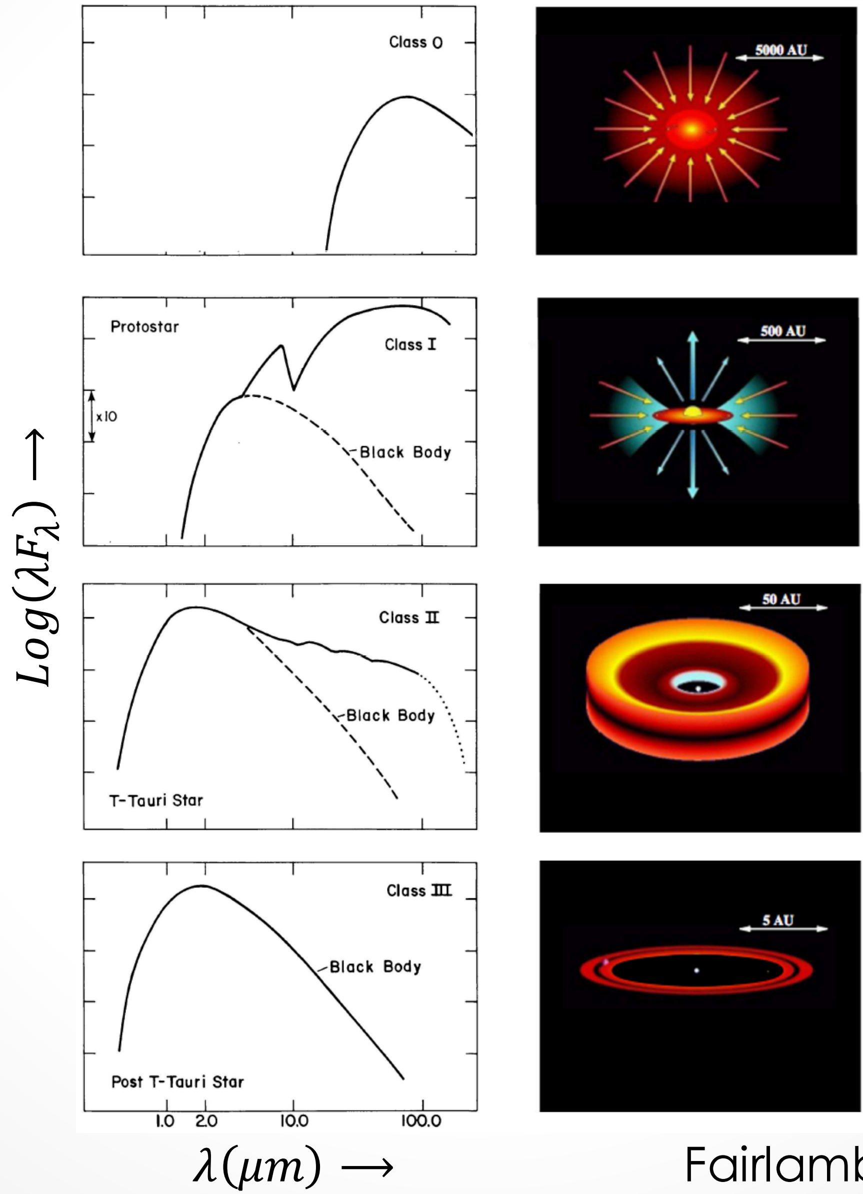
STARRY
STARS THAT 'R' YOUNG

MARIE CURIE ACTIONS

Isdefe

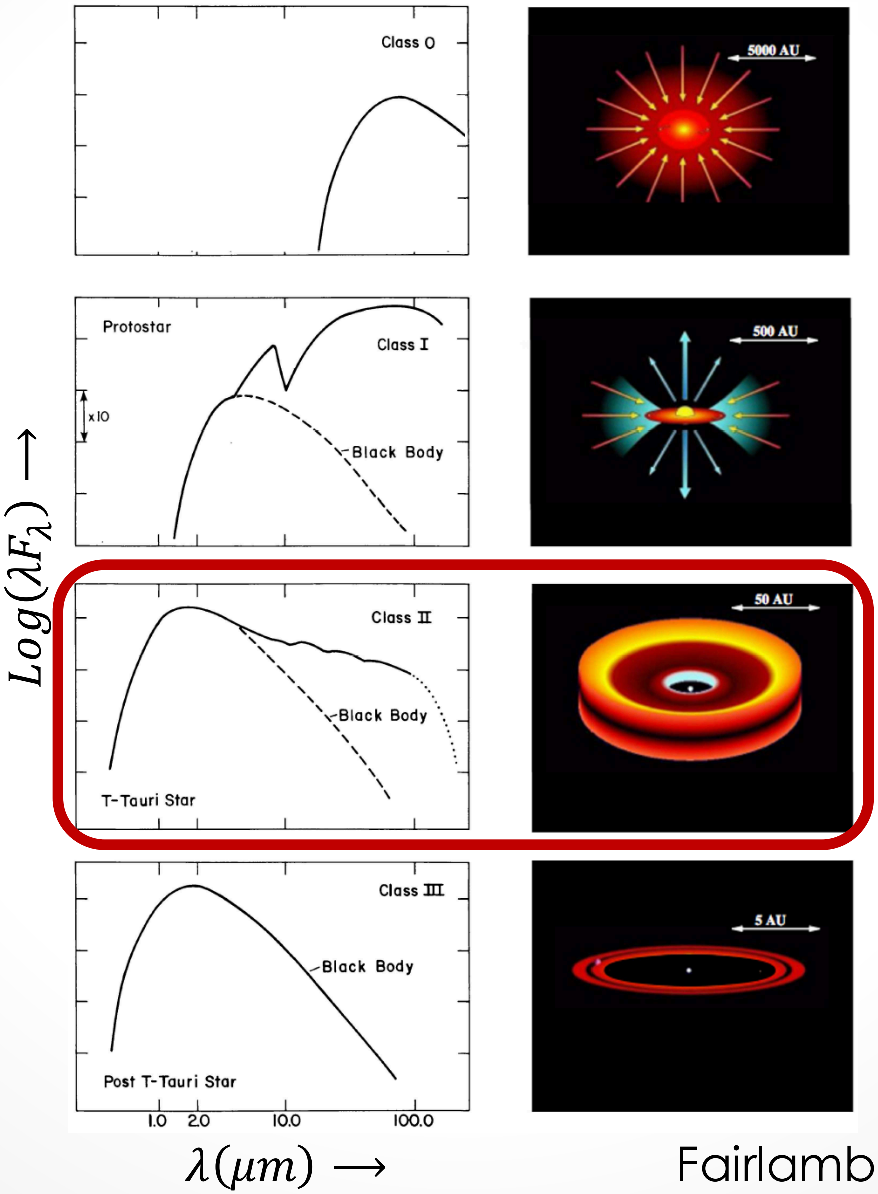
UNIVERSITY OF LEEDS

Herbig Ae/Be stars



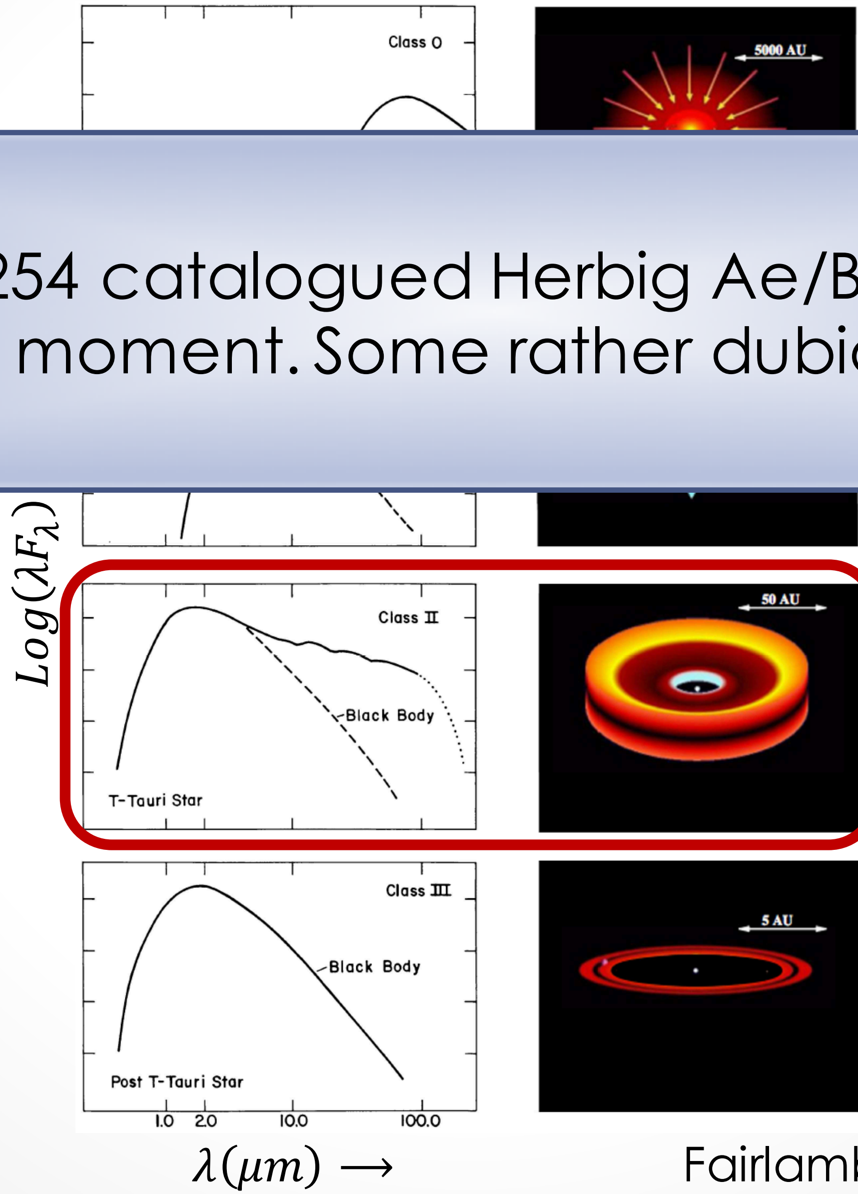
Fairlamb J.R. thesis. 2015

Herbig Ae/Be stars



Fairlamb J.R. thesis. 2015

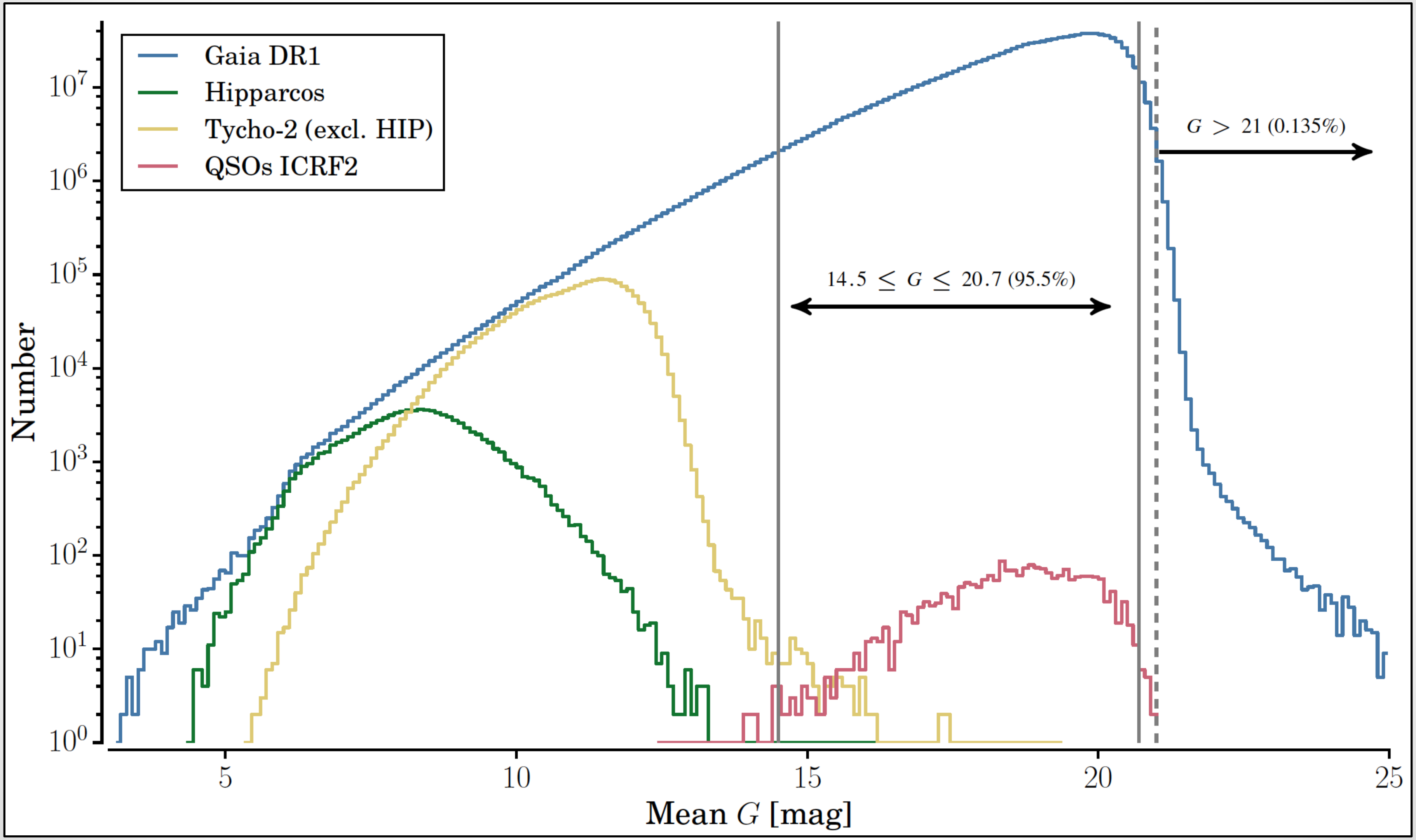
Herbig Ae/Be stars



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

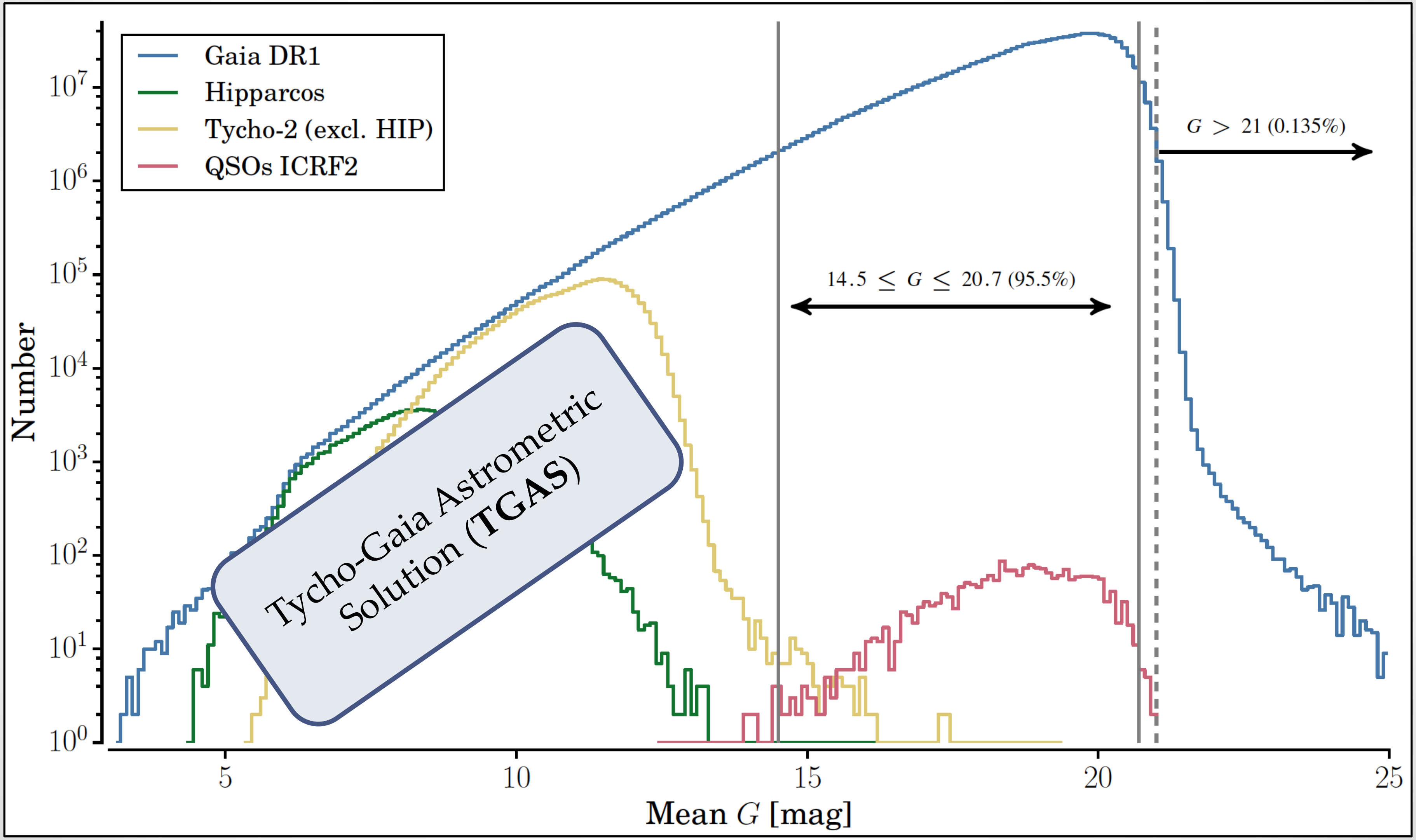
Fairlamb J.R. thesis. 2015

Gaia



Gaia Collaboration. 2016, *A&A*, 595, A2

Gaia



Gaia Collaboration. 2016, *A&A*, 595, A2

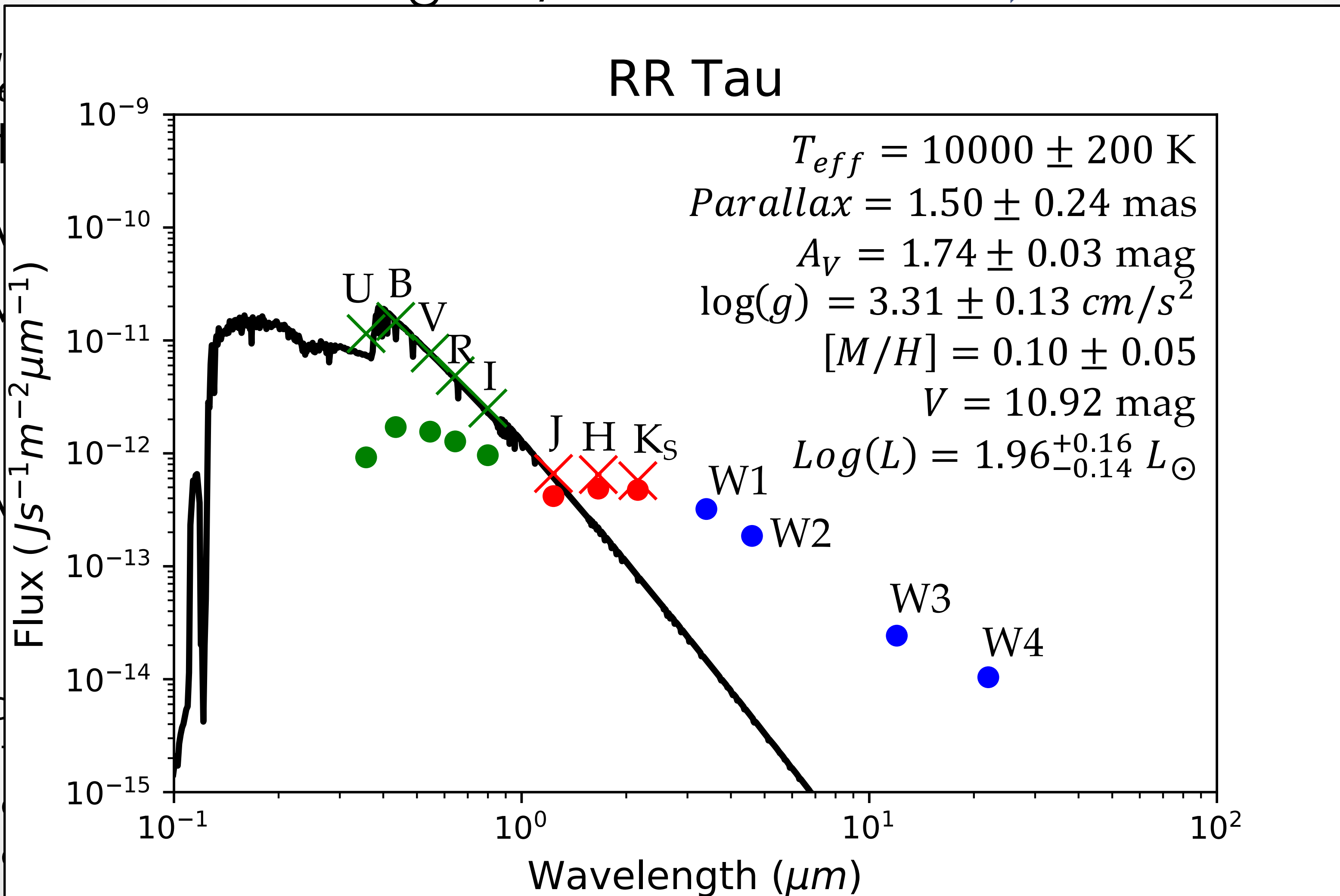
HR diagram

- 254 known Herbig Ae/Be stars ⟹ 108 in TGAS.
- T_{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.

Fairlamb J.R. *et al*. 2015, *MNRAS*, 453, 976
Montesinos B. *et al*. 2009, *A&A*, 495, 901
Hernández J. *et al*. 2004, *AJ*, 127, 1682
Mendigutía I. *et al*. 2012, *A&A*, 543, A59
Chen P.S. *et al*. 2016, *New A*, 44, 1

HR diagram

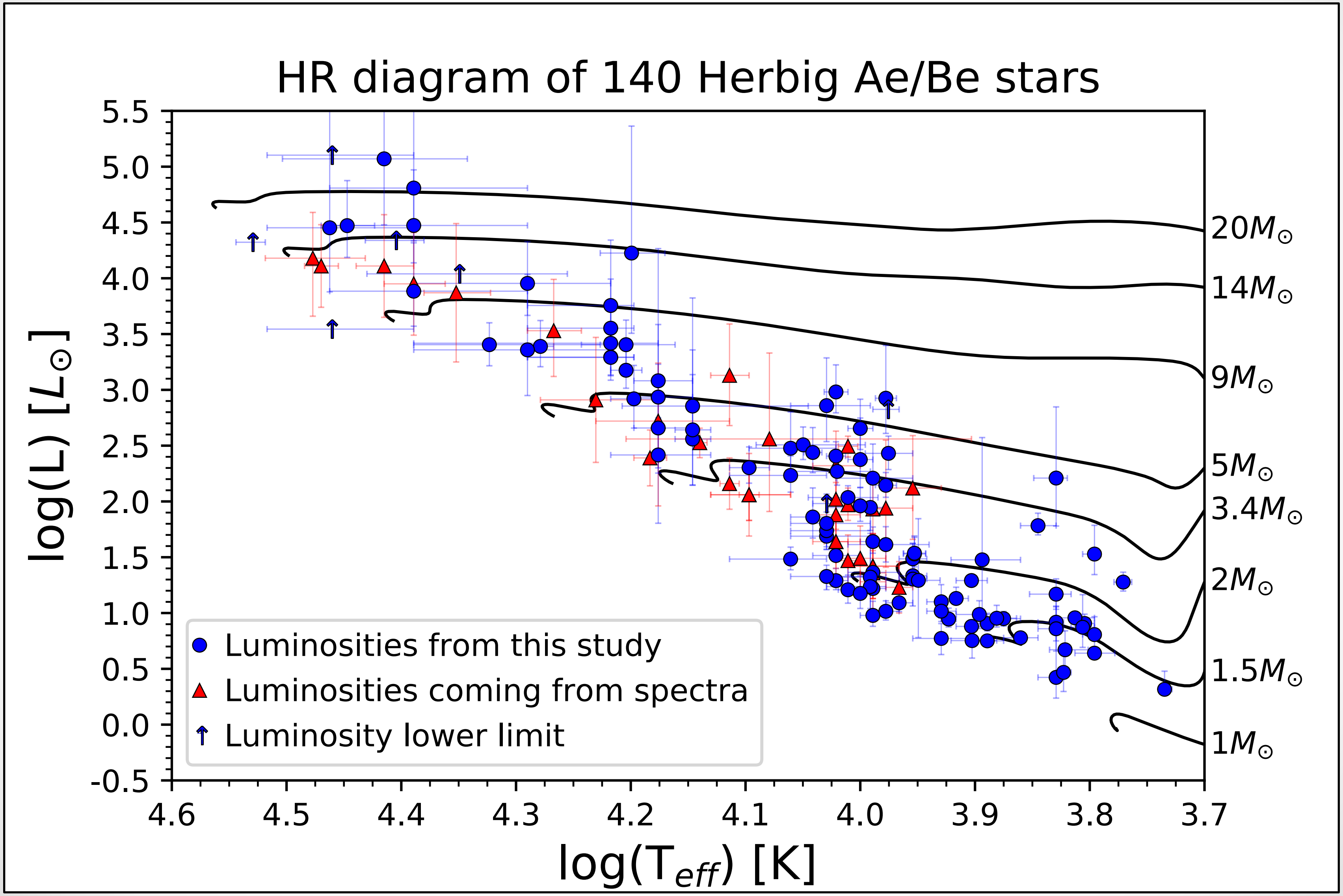
- 254 known Herbig Ae/Be stars ⟹ 108 in TGAS.
- T_e ... lit
- W ... w
- P
- A ... E.



Fairlo
Mon
Hern
Men
Chen J. et al. 2018, New A, 44, 1

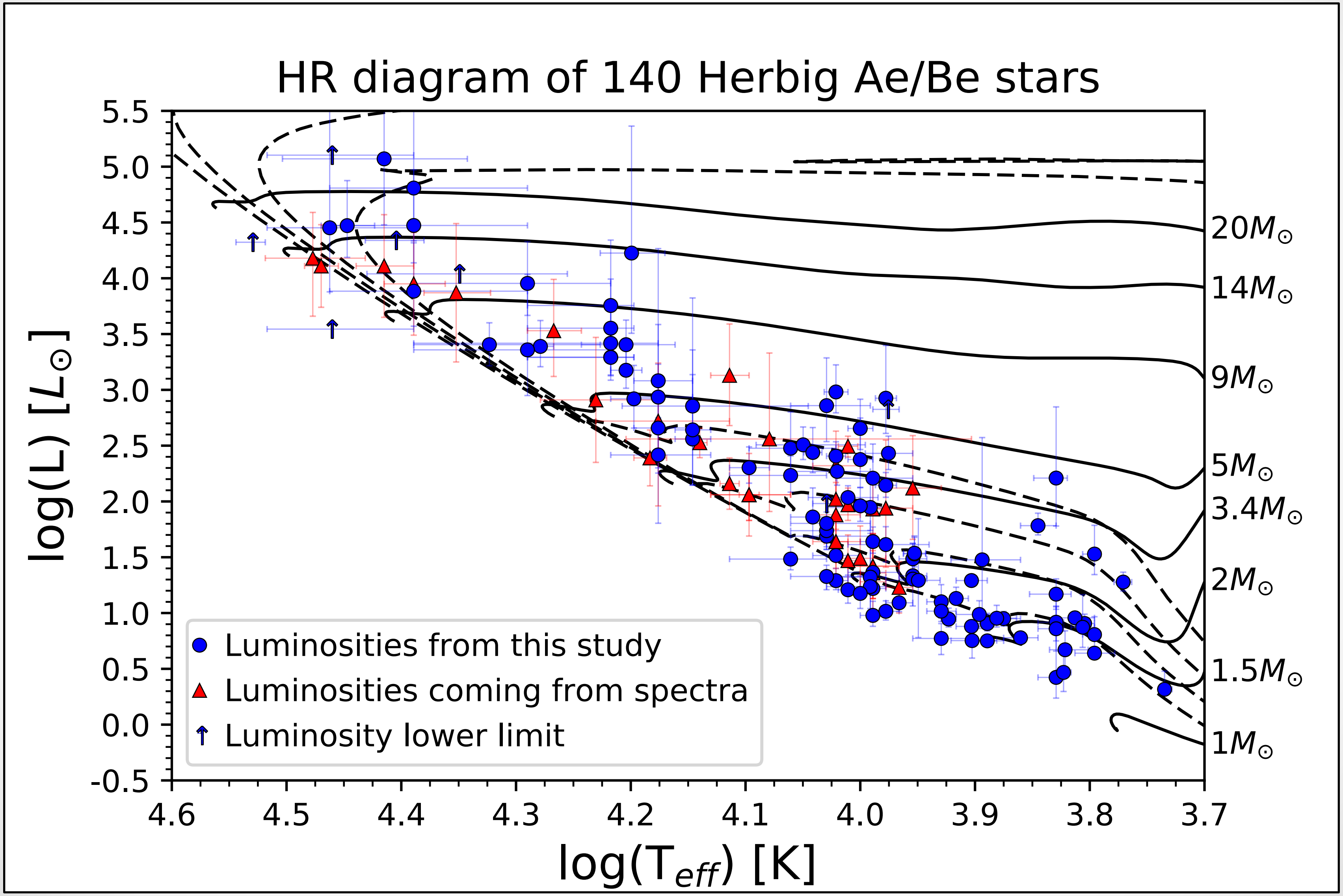
Castelli F., Kurucz R.L. 2004.

HR diagram



Luminosities from spectra: Fairlamb *et al.* (2015) & Montesinos *et al.* (2009)

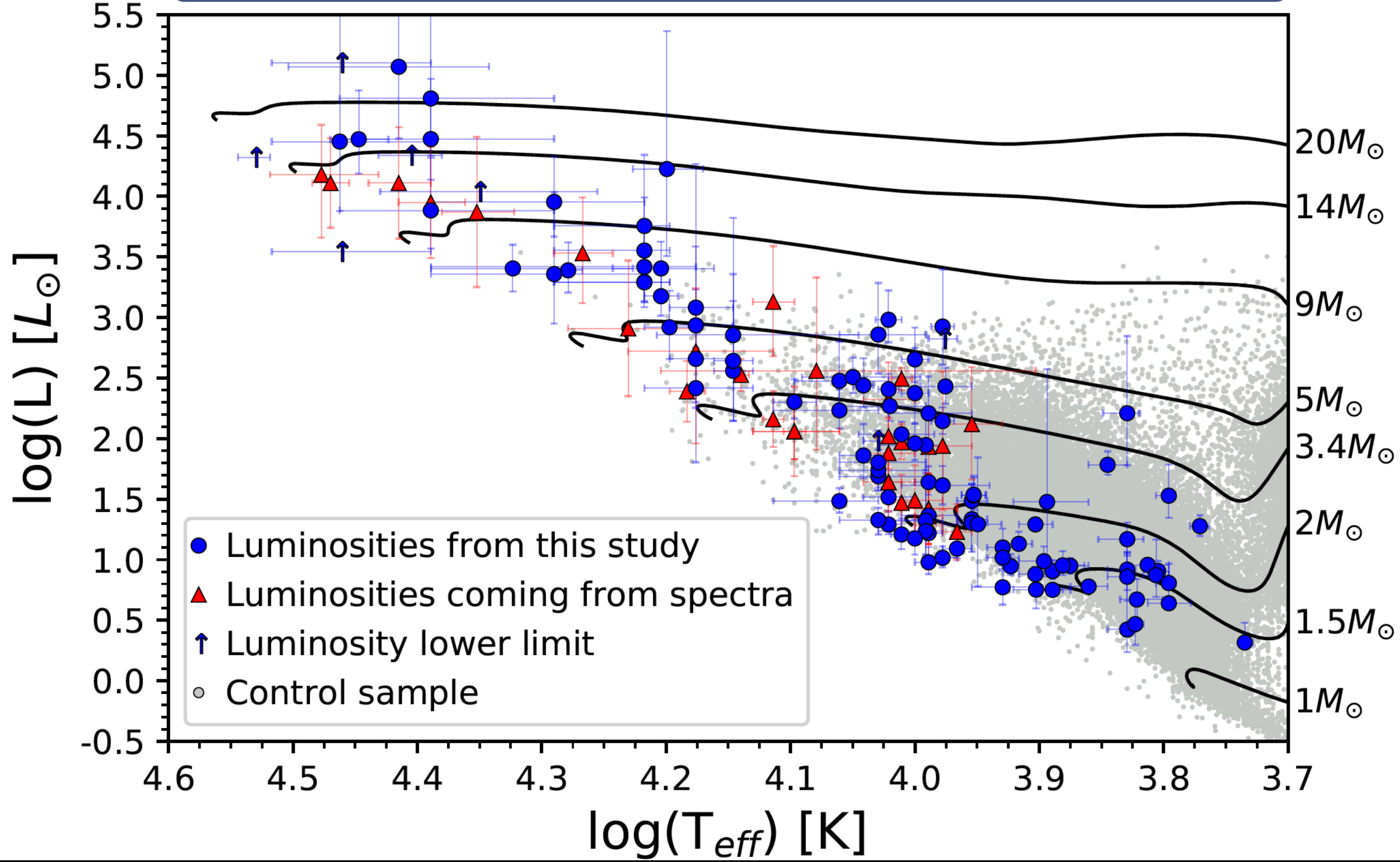
HR diagram



Isochrones: Bressan A. *et al.* 2012, *MNRAS*, 427, 127

HR diagram

Similar procedure for 73240 TGAS sources



McDonald I. *et al*. 2012, *MNRAS*, 427, 343

Identify Herbig Ae/Be stars

- Herbig G.H. 1960, *ApJS*, 4, 337:
  - 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.

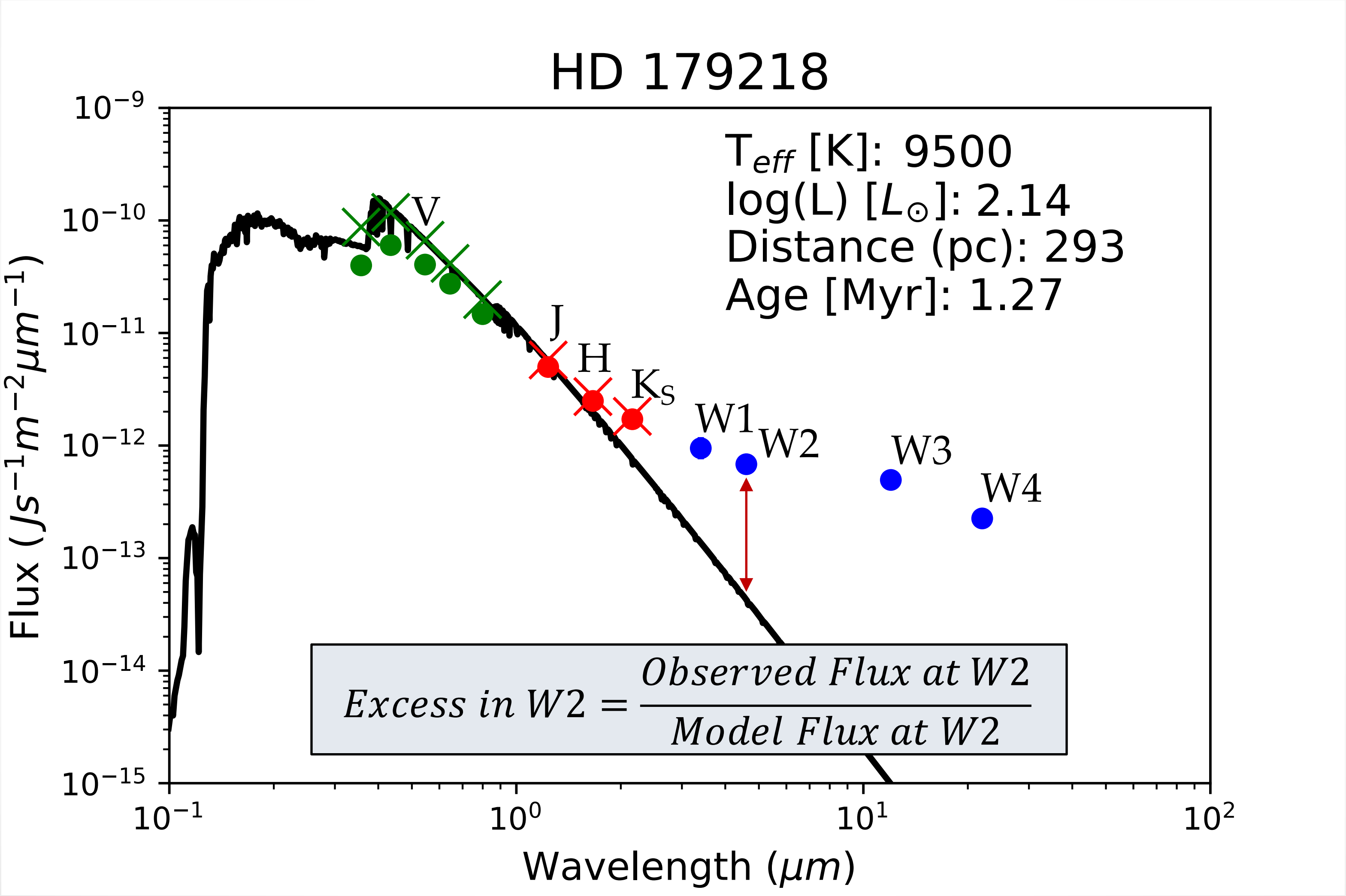
Infrared Excess
Variability
$H\alpha$ Emission

Identify Herbig Ae/Be stars

- Herbig G.H. 1960, *ApJS*, 4, 337:
  - 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.

$\boxed{\text{Infrared Excess}}$
Variability
$H\alpha$ Emission

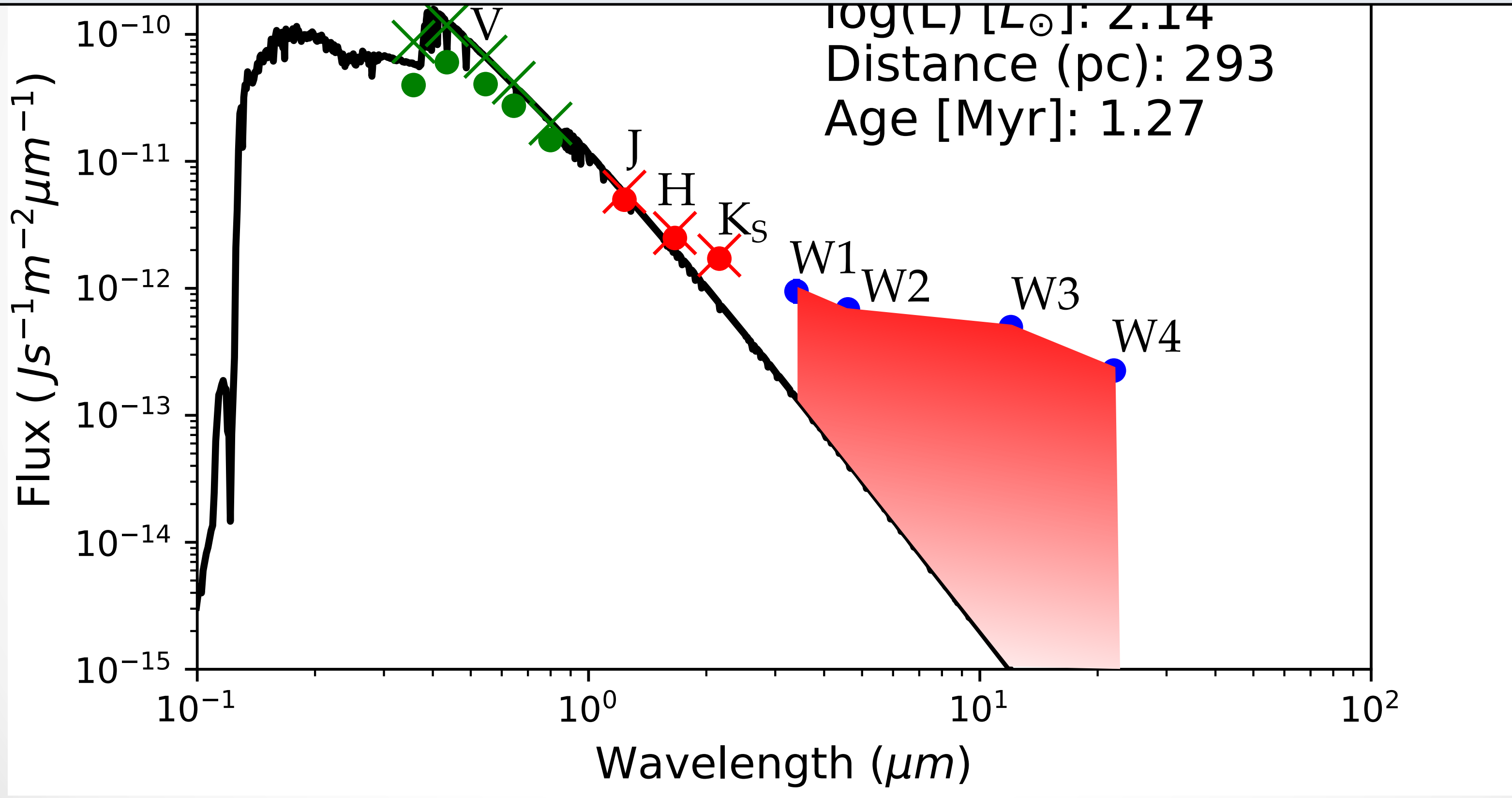
Infrared Excess



McDonald I. *et al*. 2012, *MNRAS*, 427, 343

Infrared Excess

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

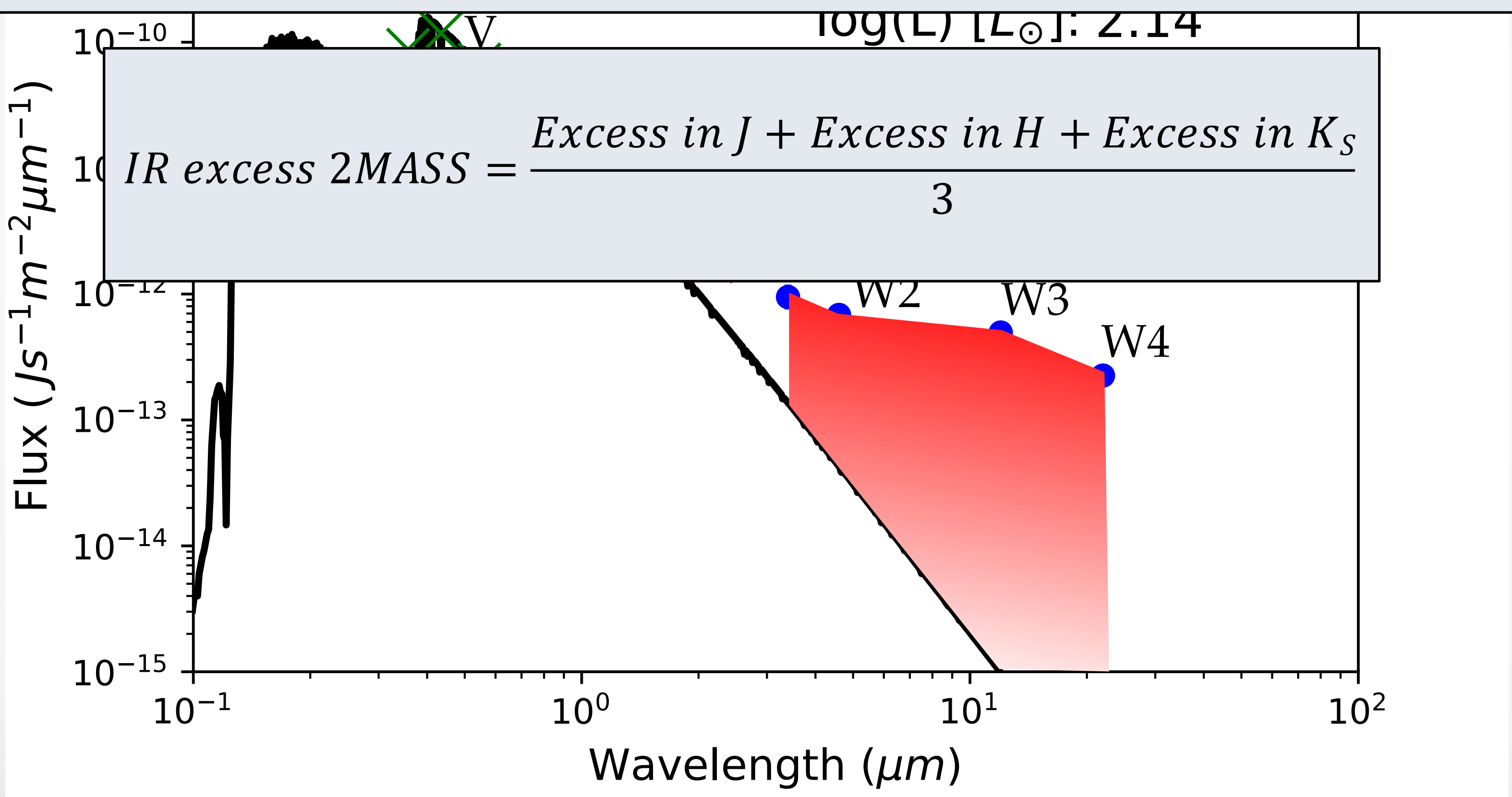


McDonald I. *et al*. 2012, *MNRAS*, 427, 343

Infrared Excess

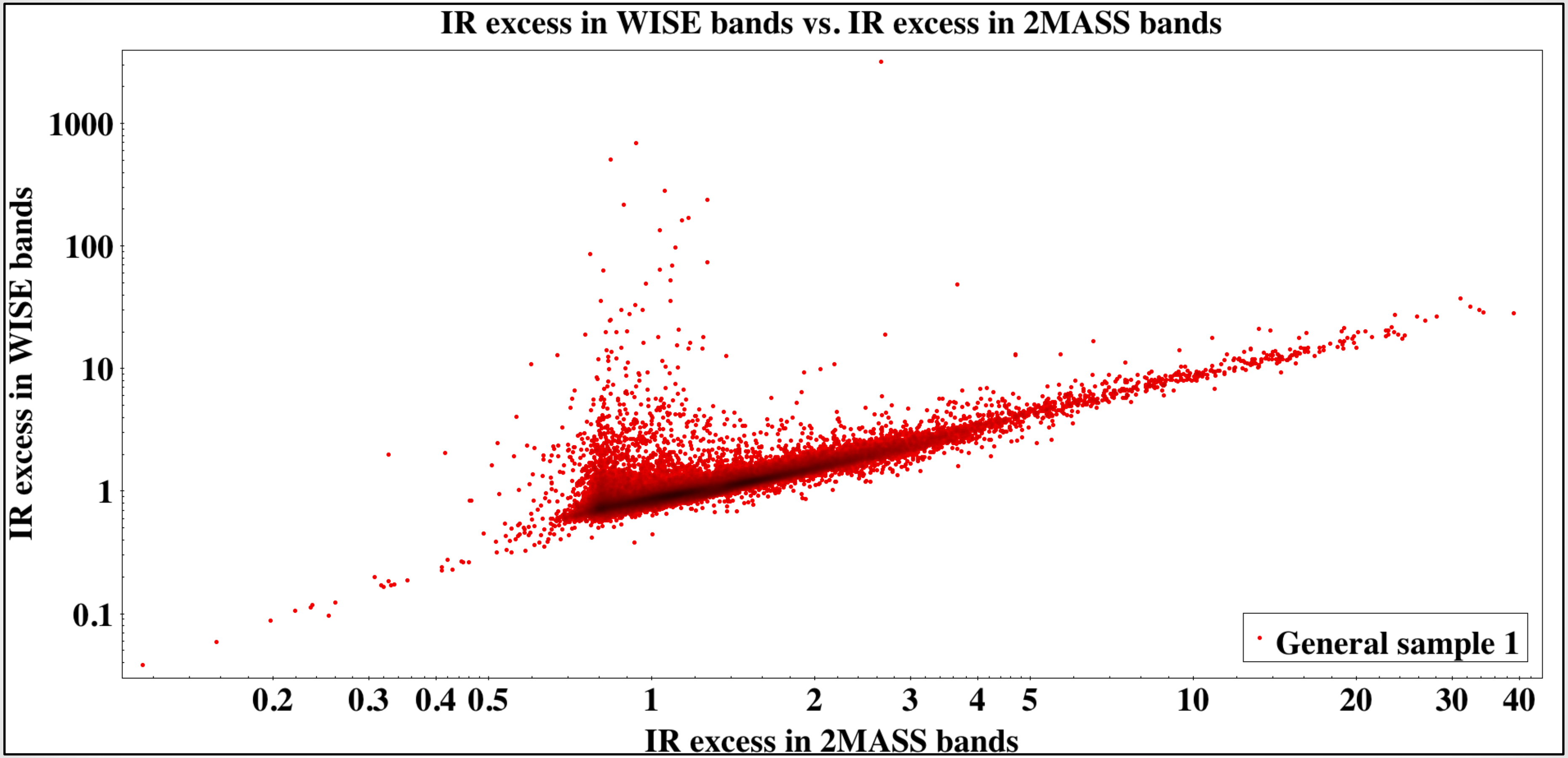
$$IR\ excess\ WISE = \frac{Excess\ in\ W1 + Excess\ in\ W2 + Excess\ in\ W3 + Excess\ in\ W4}{4}$$

$$IR\ excess\ 2MASS = \frac{Excess\ in\ J + Excess\ in\ H + Excess\ in\ K_S}{3}$$



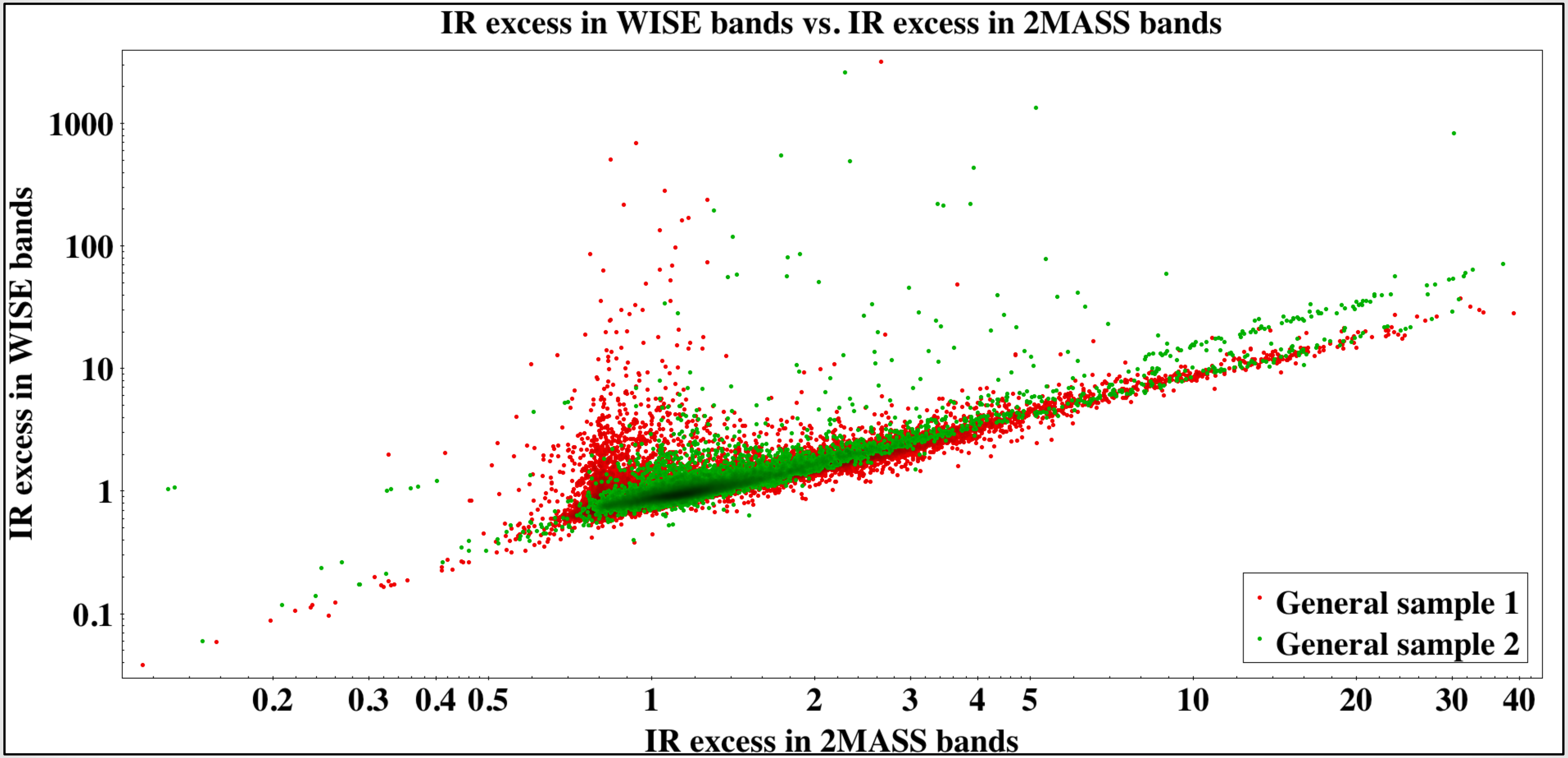
McDonald I. *et al*. 2012, *MNRAS*, 427, 343

Infrared Excess



Red dots: McDonald I. *et al*. 2012, *MNRAS*, 427, 343

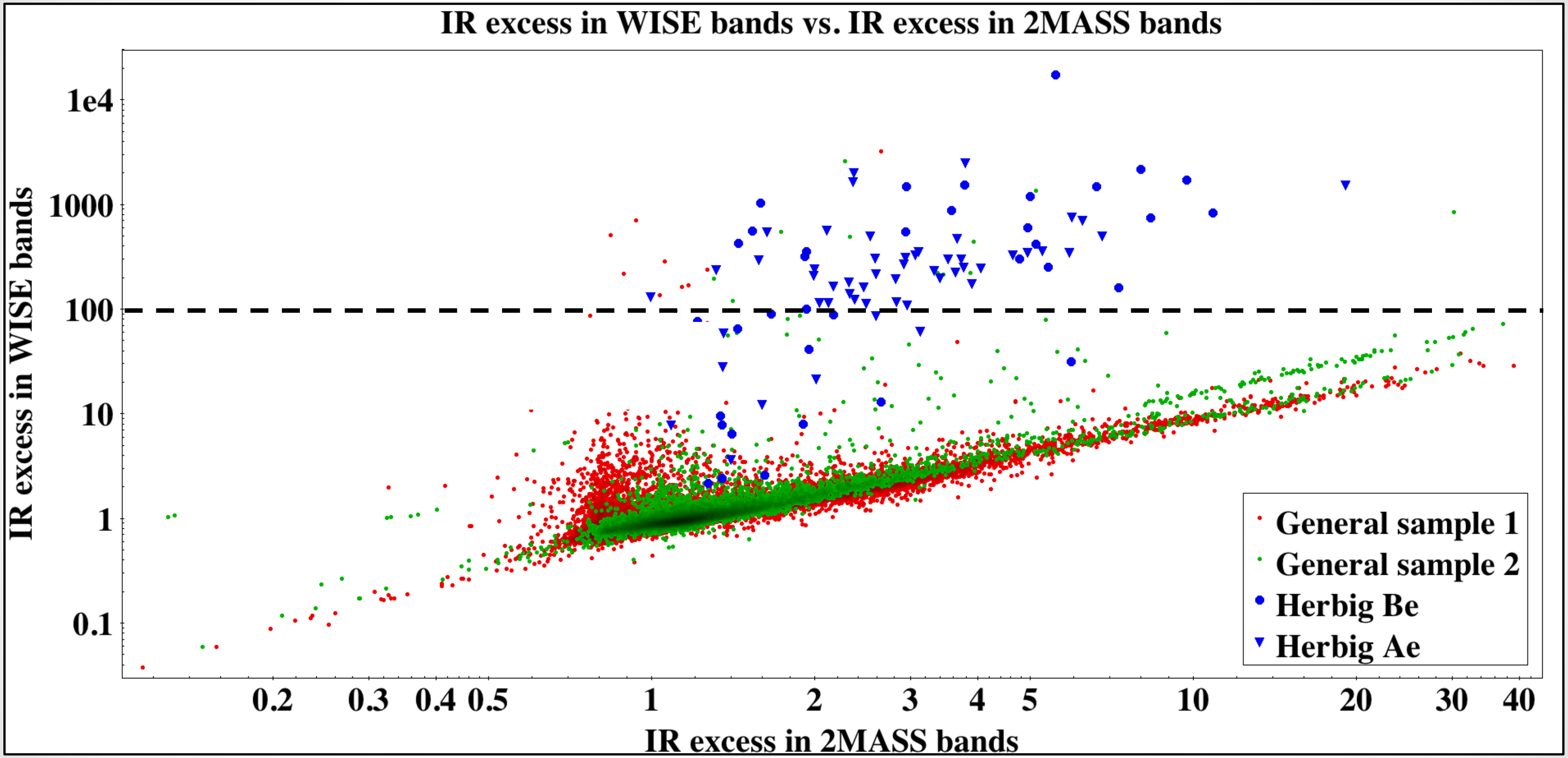
Infrared Excess



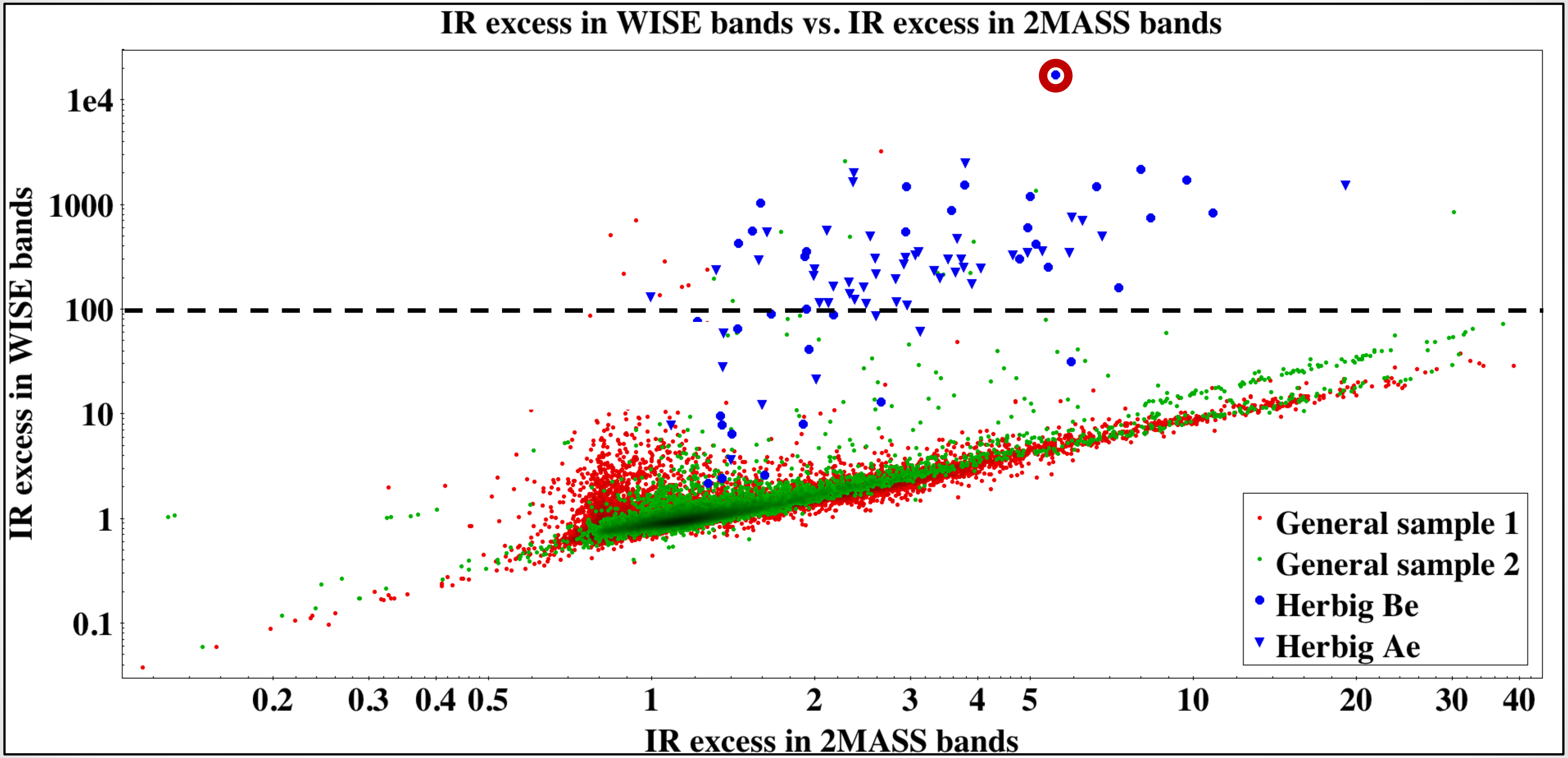
Green dots: The PASTEL catalogue; Soubiran C. *et al*. 2016, *A&A*, 591A, 118

Red dots: McDonald I. *et al*. 2012, *MNRAS*, 427, 343

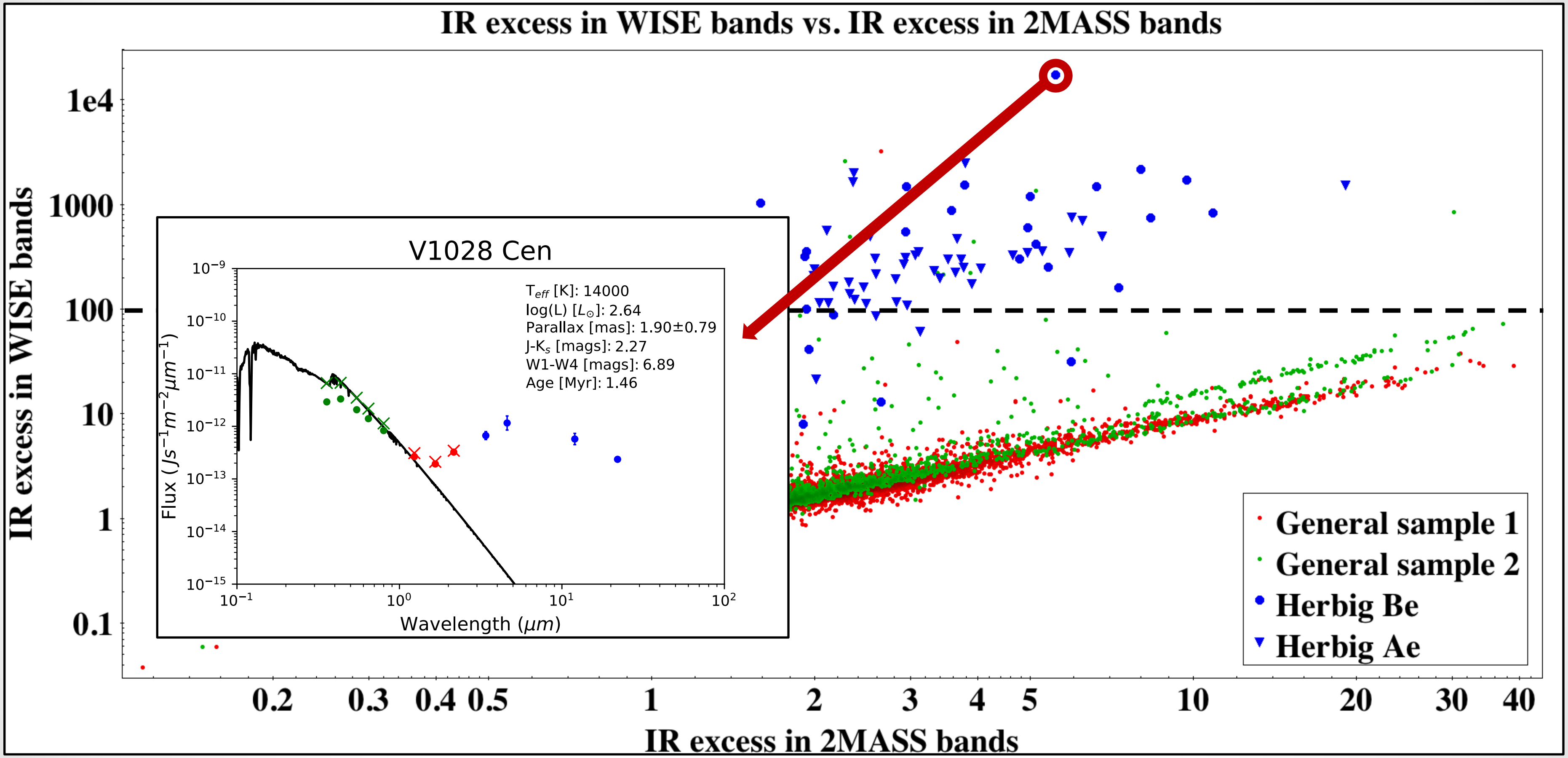
Infrared Excess



Infrared Excess



Infrared Excess



What else looks like this?

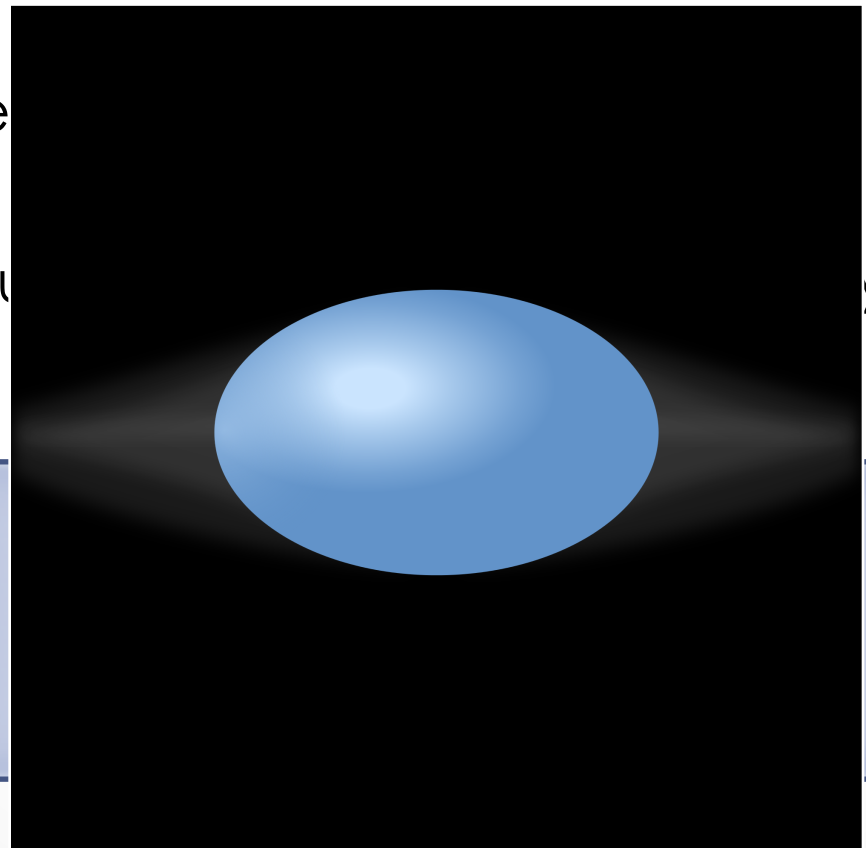
- Herbig G.H. 1960, *ApJS*, 4, 337:
  - Spectral type A or earlier, with emission lines.
  - The stars lies in an obscured region.
  - The stars illuminates fairly bright luminosity in its immediate vicinity.

Infrared Excess
Variability
$H\alpha$ Emission

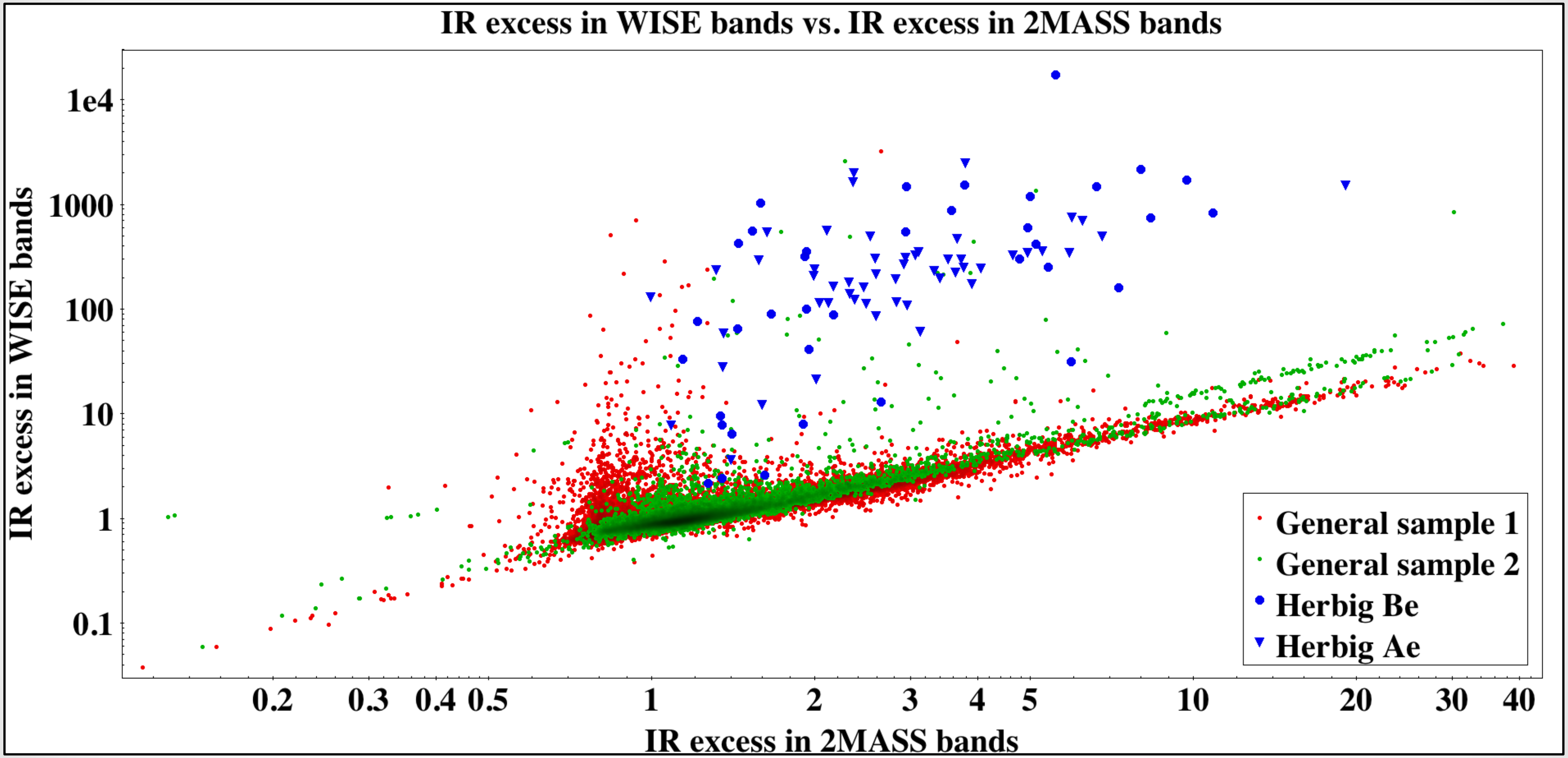
What else looks like this?

Be stars

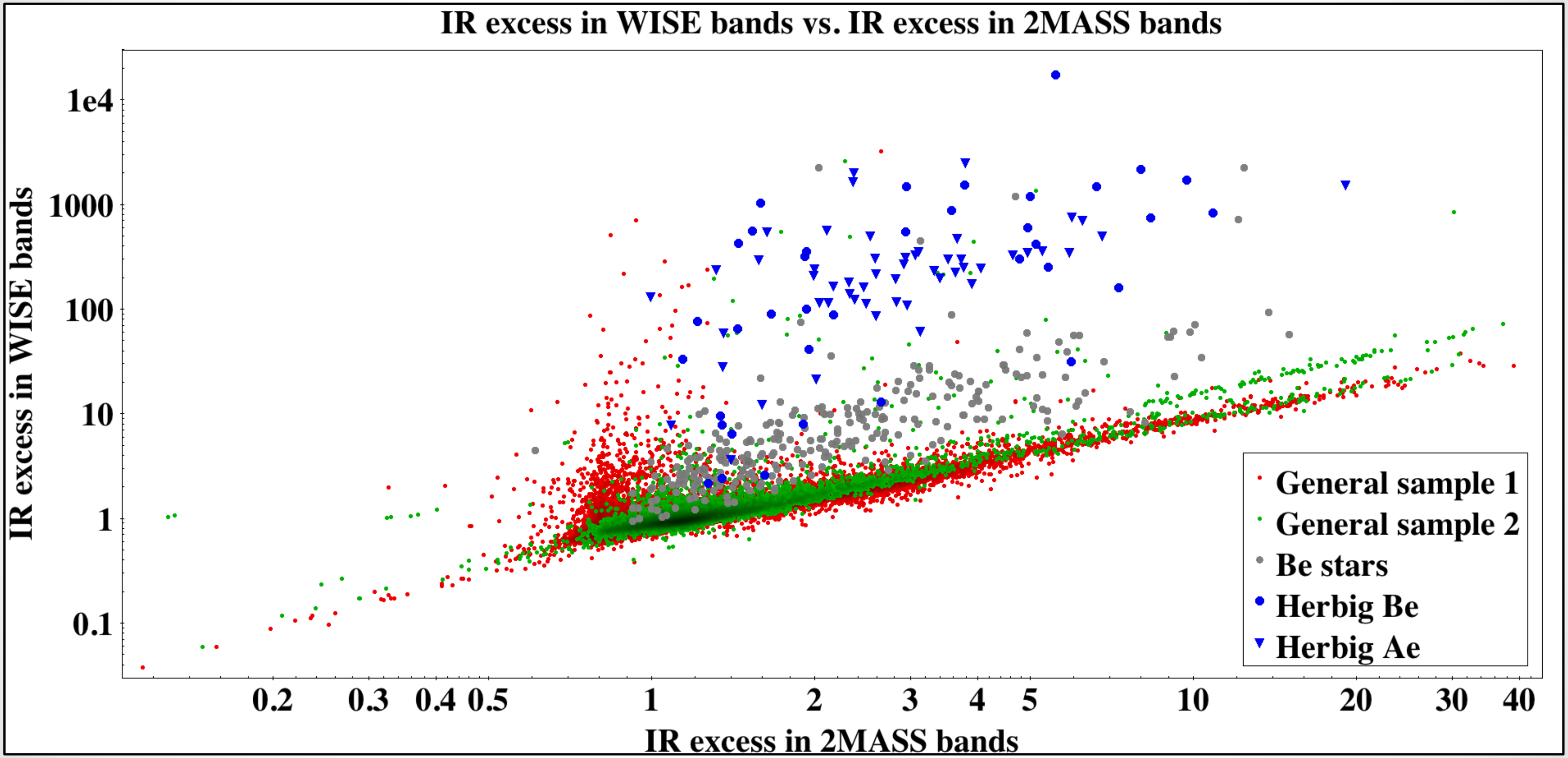
- He
  - Spectral type A or earlier, with emission lines.
  - The stars lie
  - The stars illu y in its immediate vicinity.



Infrared Excess

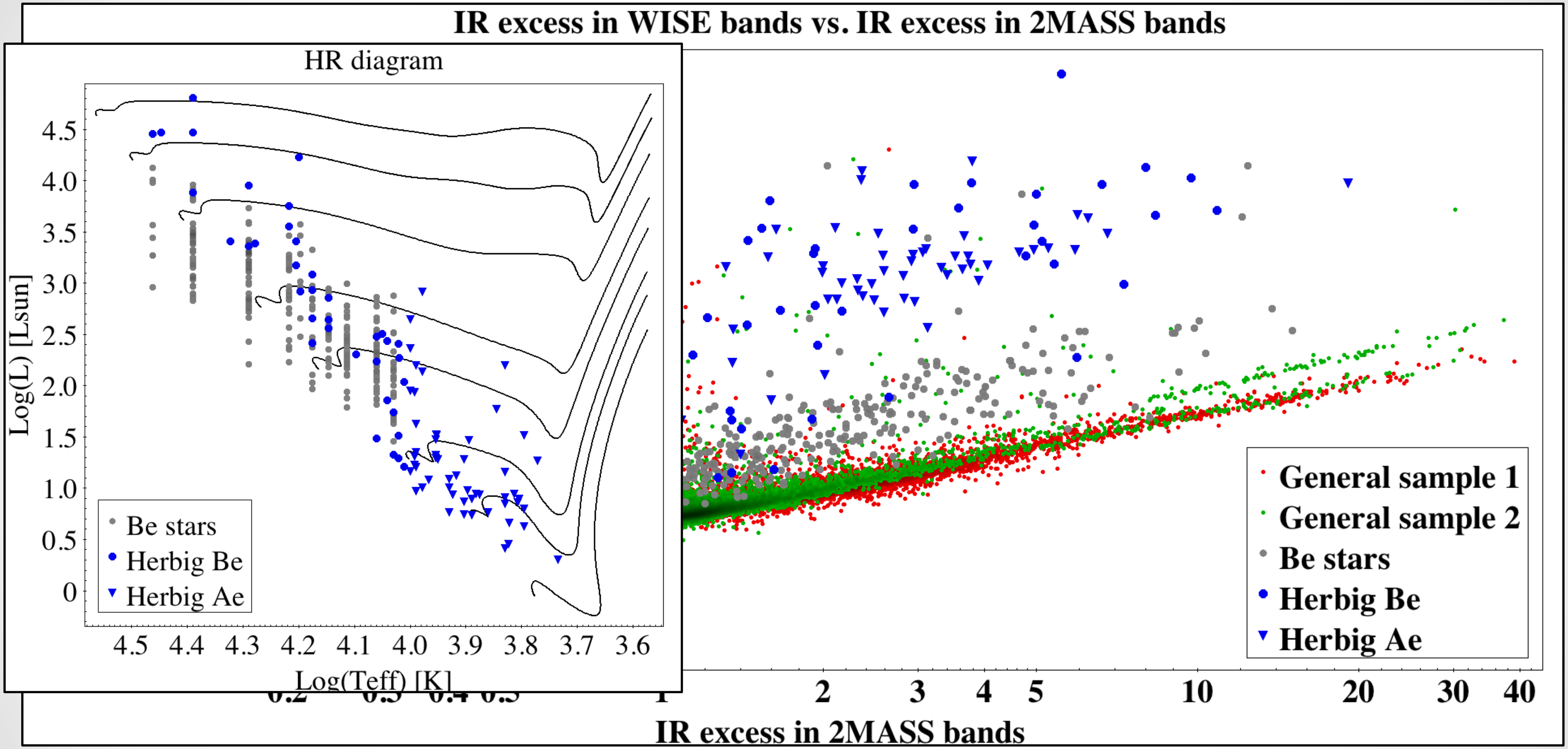


Infrared Excess



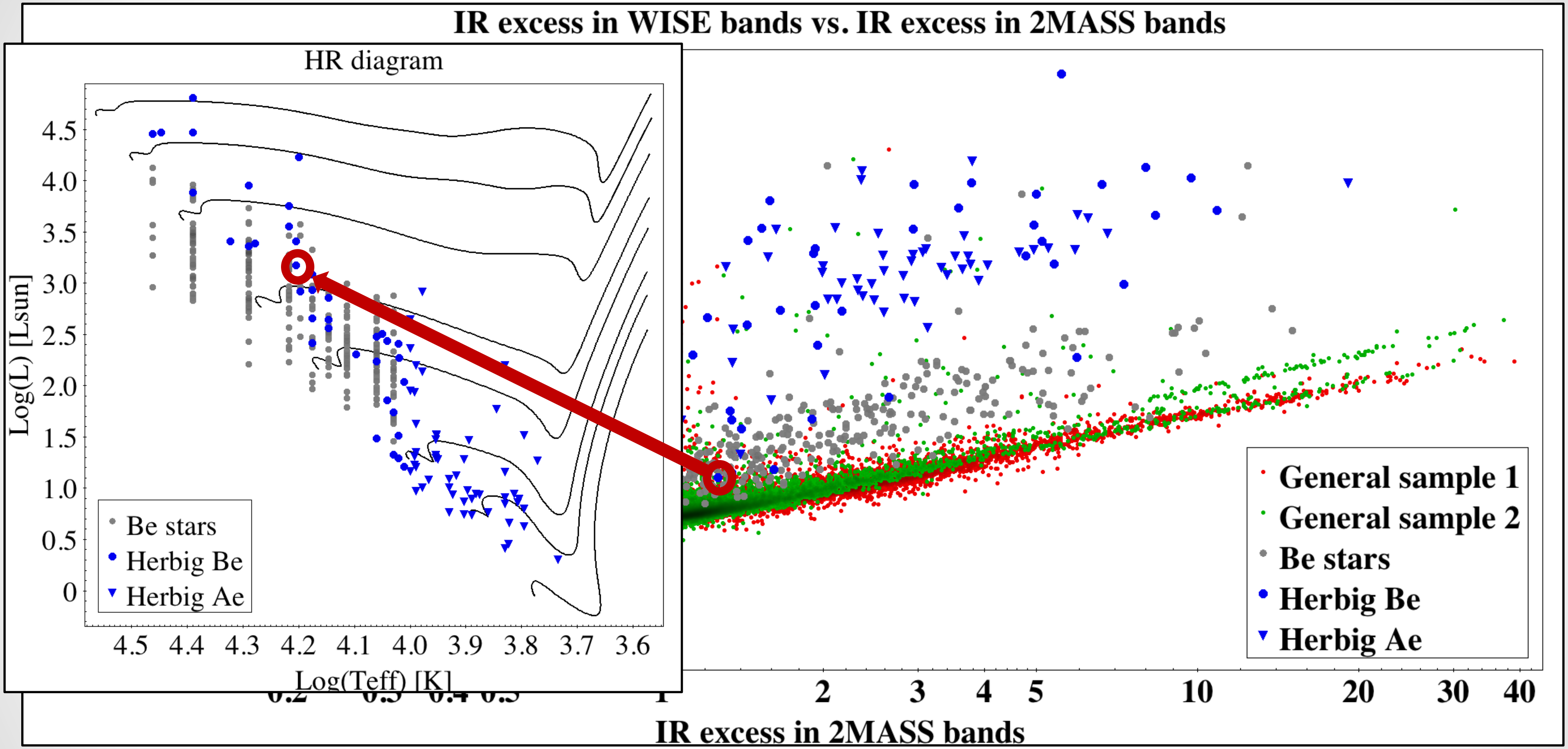
Be stars: Jaschek M., Egret D. 1982, *IAUS*, 98, 261

Infrared Excess



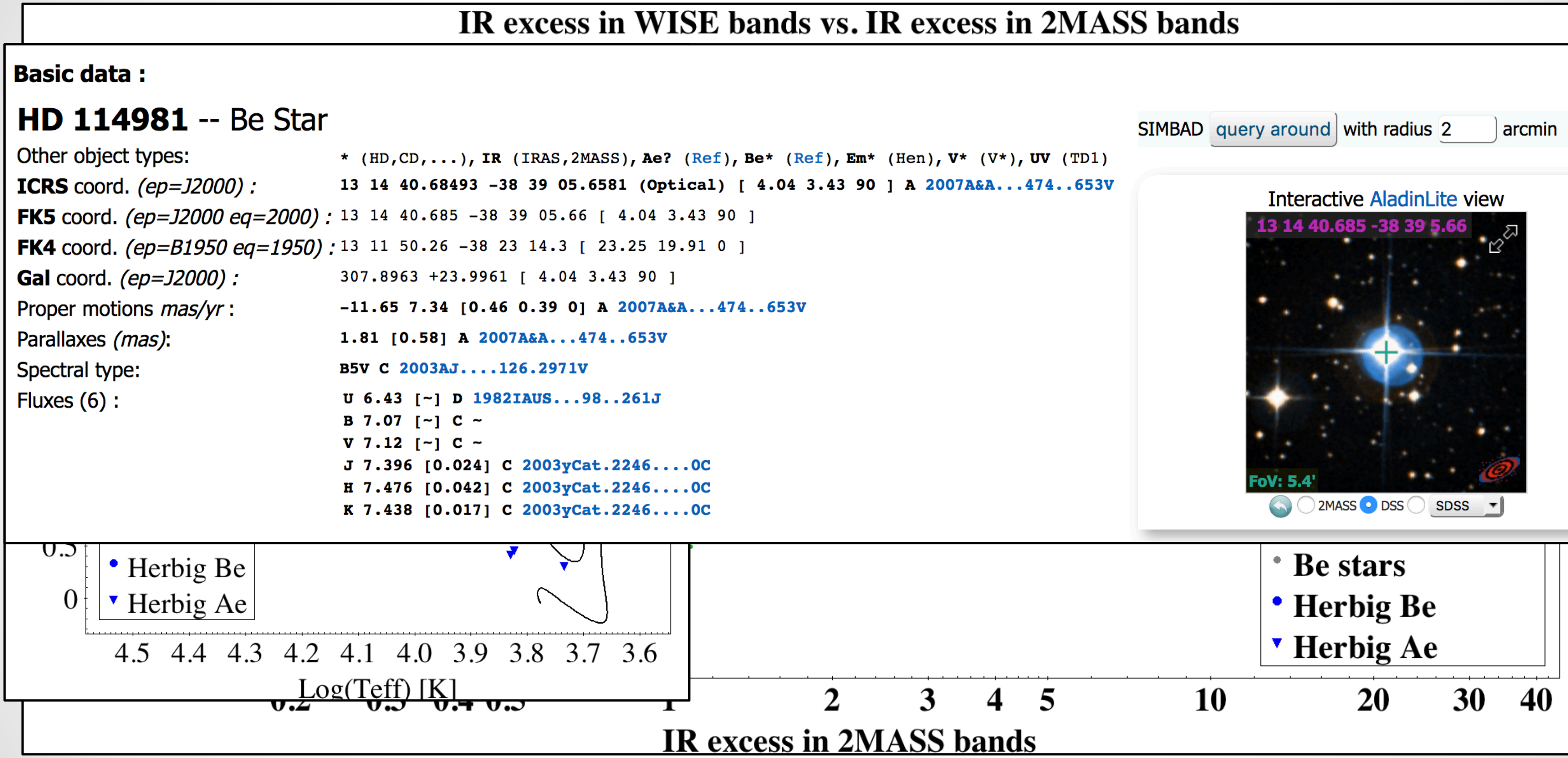
Be stars: Jaschek M., Egret D. 1982, *IAUS*, 98, 261

Infrared Excess



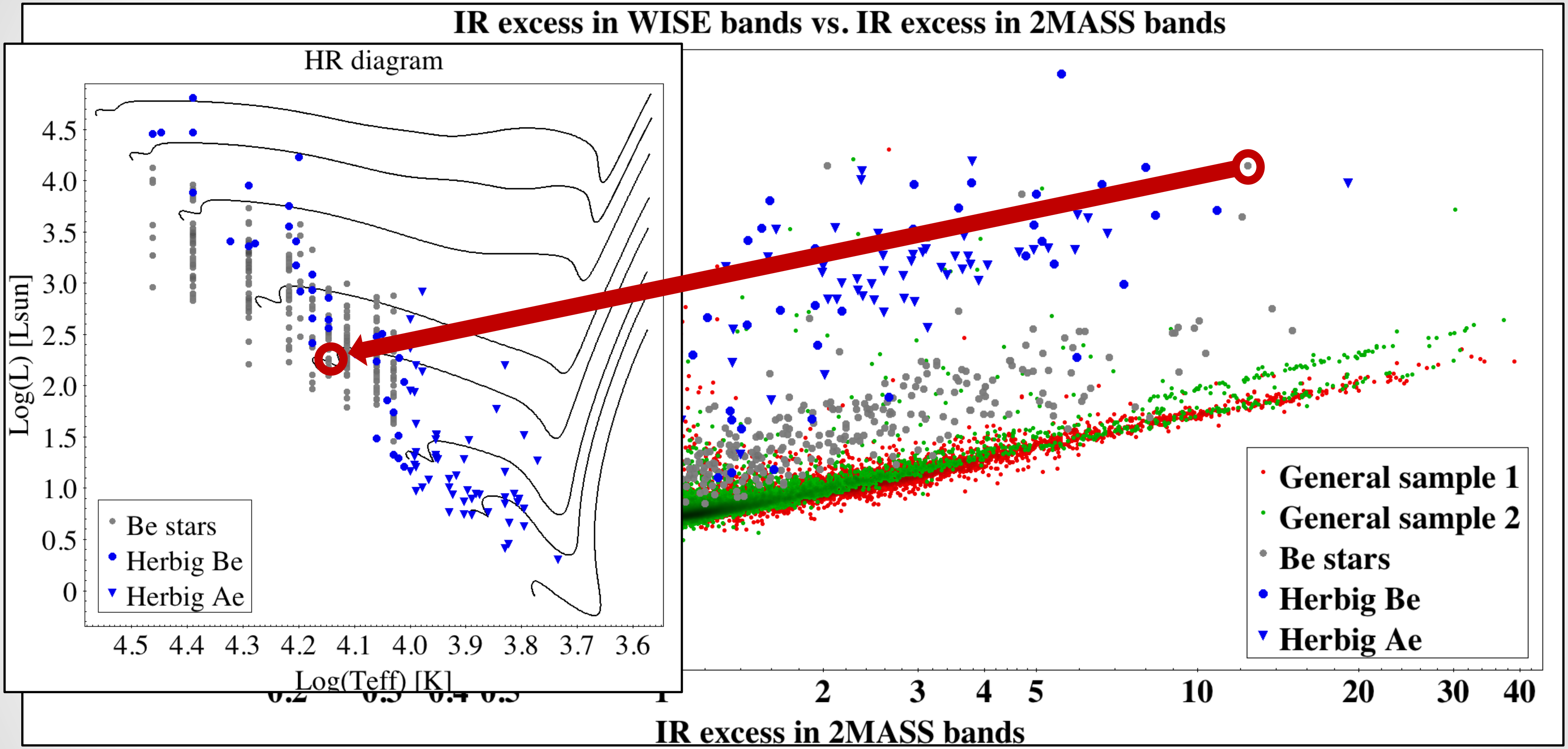
Be stars: Jaschek M., Egret D. 1982, *IAUS*, 98, 261

Infrared Excess

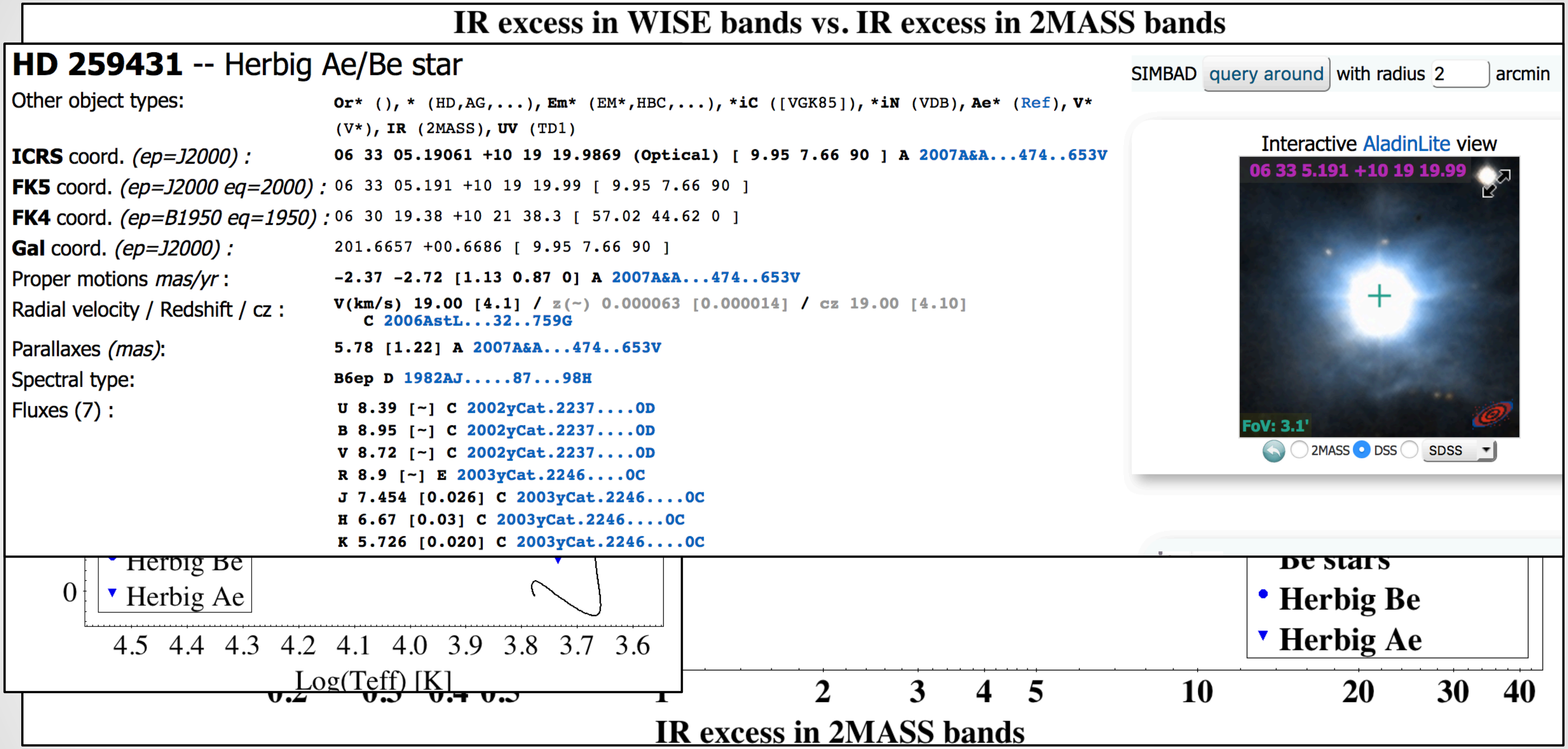


Be stars: Jaschek M., Egret D. 1982, *IAUS*, 98, 261

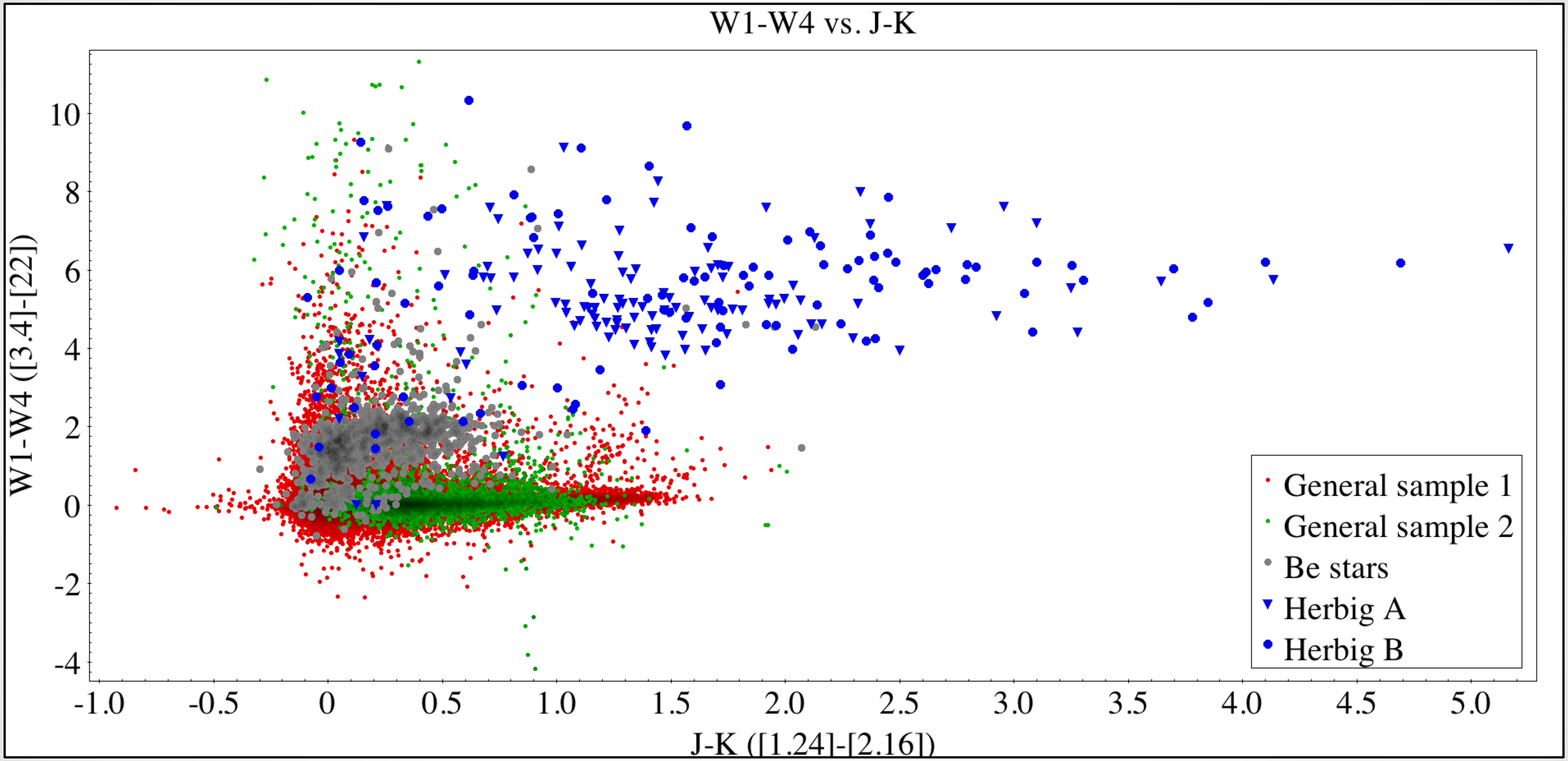
Infrared Excess



Infrared Excess

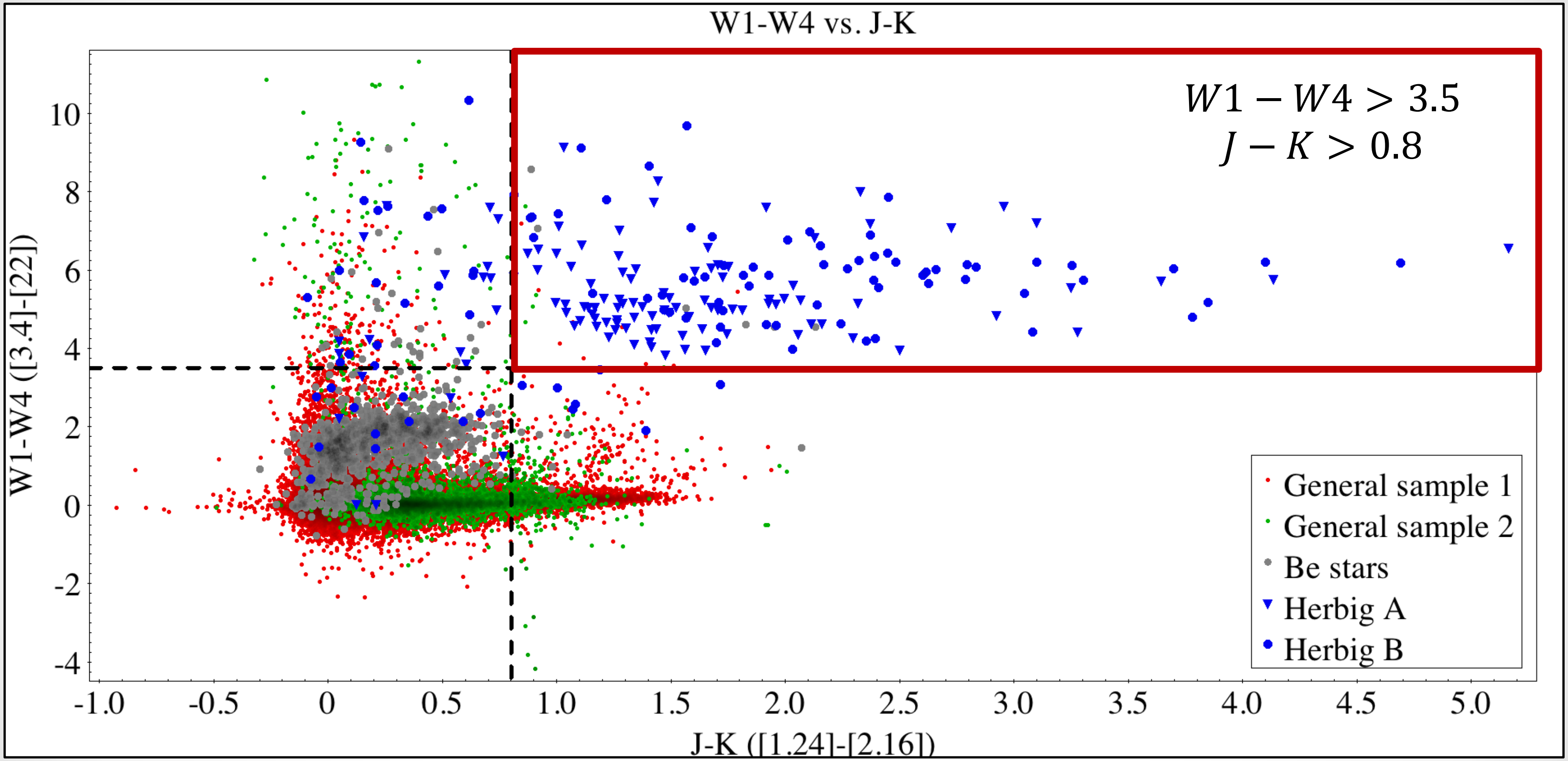


Infrared Excess



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

Infrared Excess

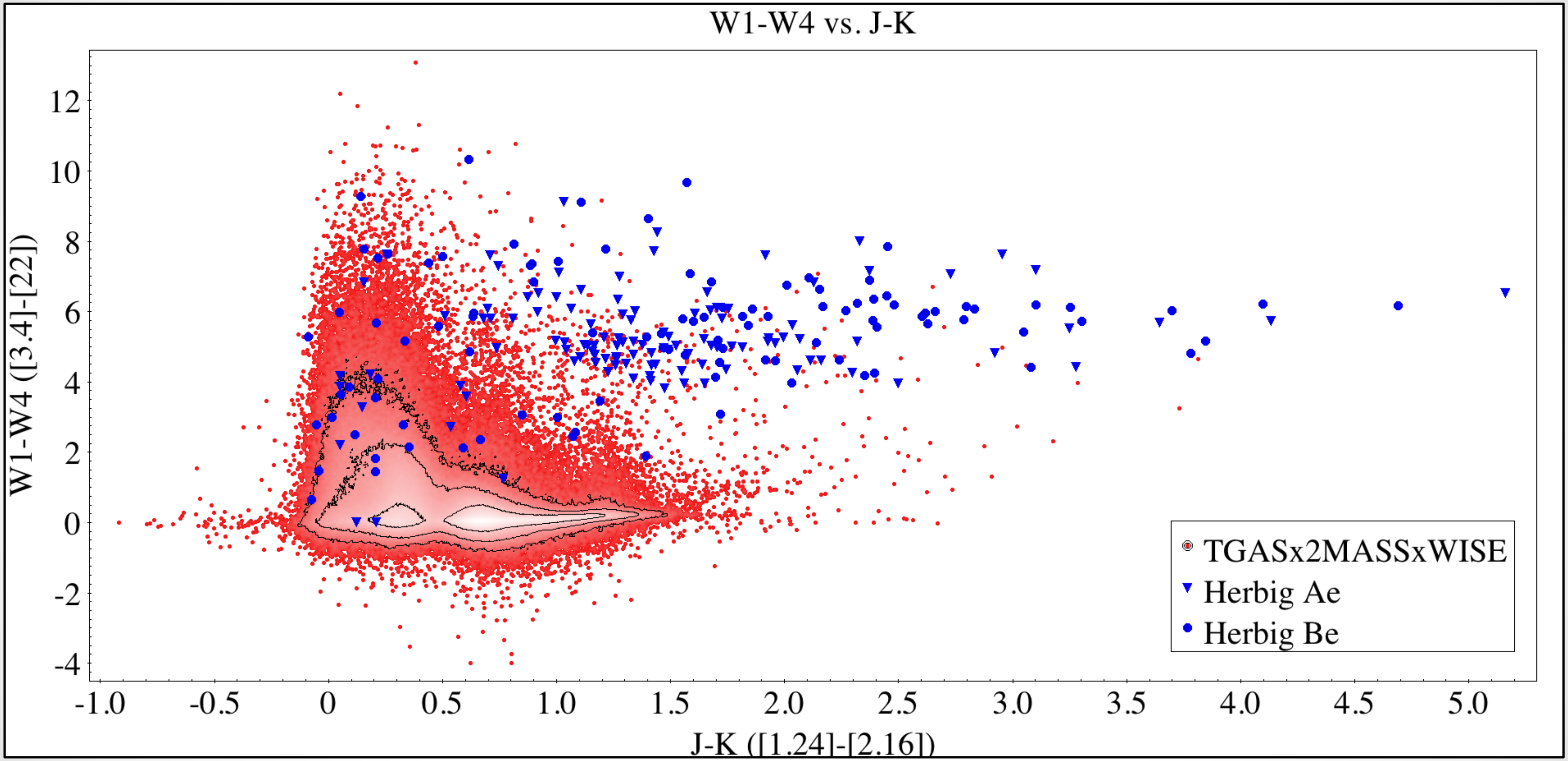


- 95/115 Herbig Ae
- 66/103 Herbig Be
- 6/951 Be stars
- 10/96328 General sample 1
- 5/17251 General sample 2

Infrared Excess

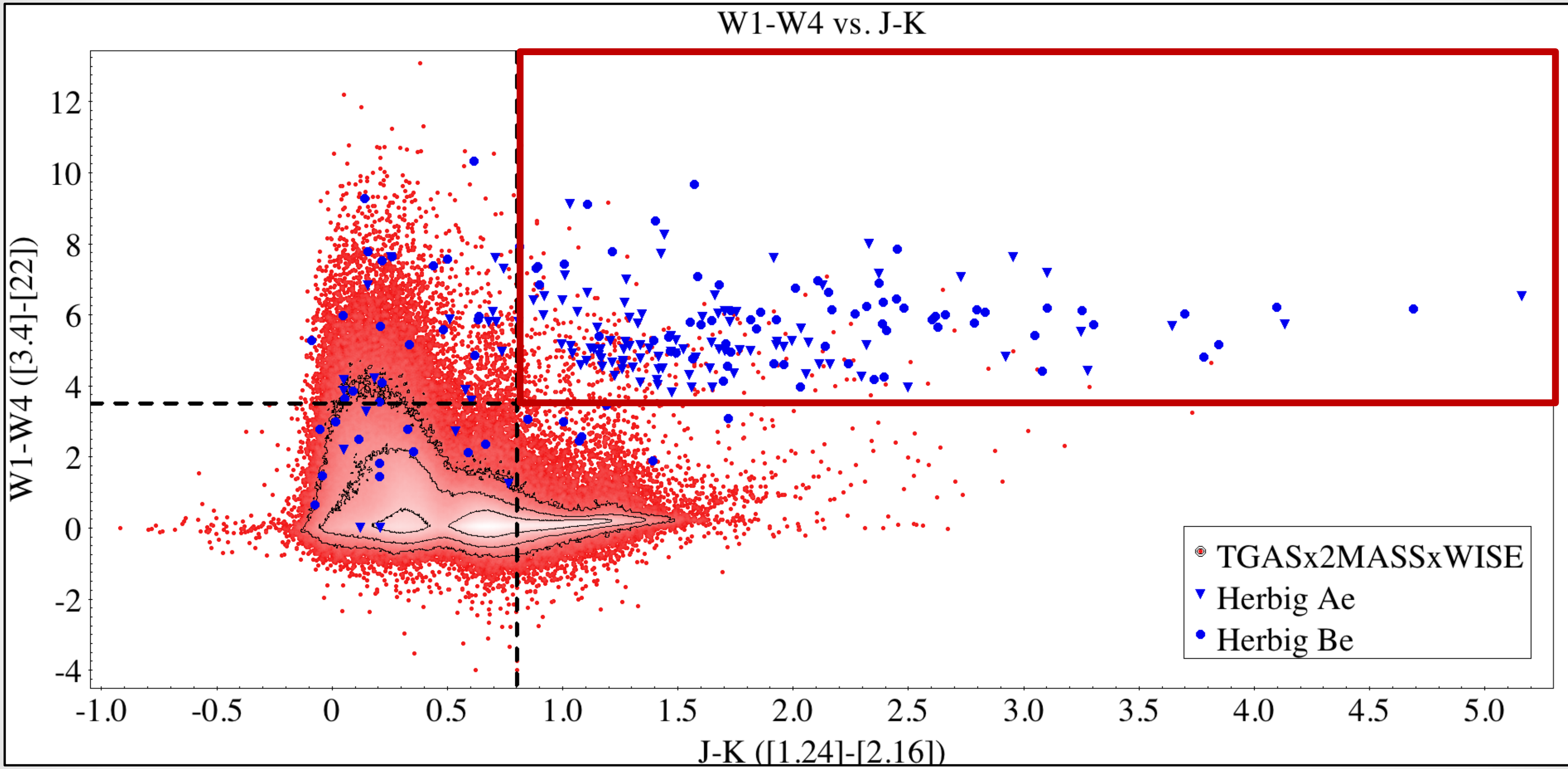
- From an input catalogue of 114748 sources, imposing $W1 - W4 > 3.5$ and $J - K_S > 0.8$:
    - 74% of Herbig Ae/Be stars recovered.
        - 83% of Herbig Ae stars.
        - 64% of Herbig Be stars.
    - 0.6% of Be stars recovered.
    - 0.01% of general sources.

Infrared Excess



- 218 Herbig Ae/Be
- 1017635 input catalogue

Infrared Excess



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

74%

0.03%

Variability

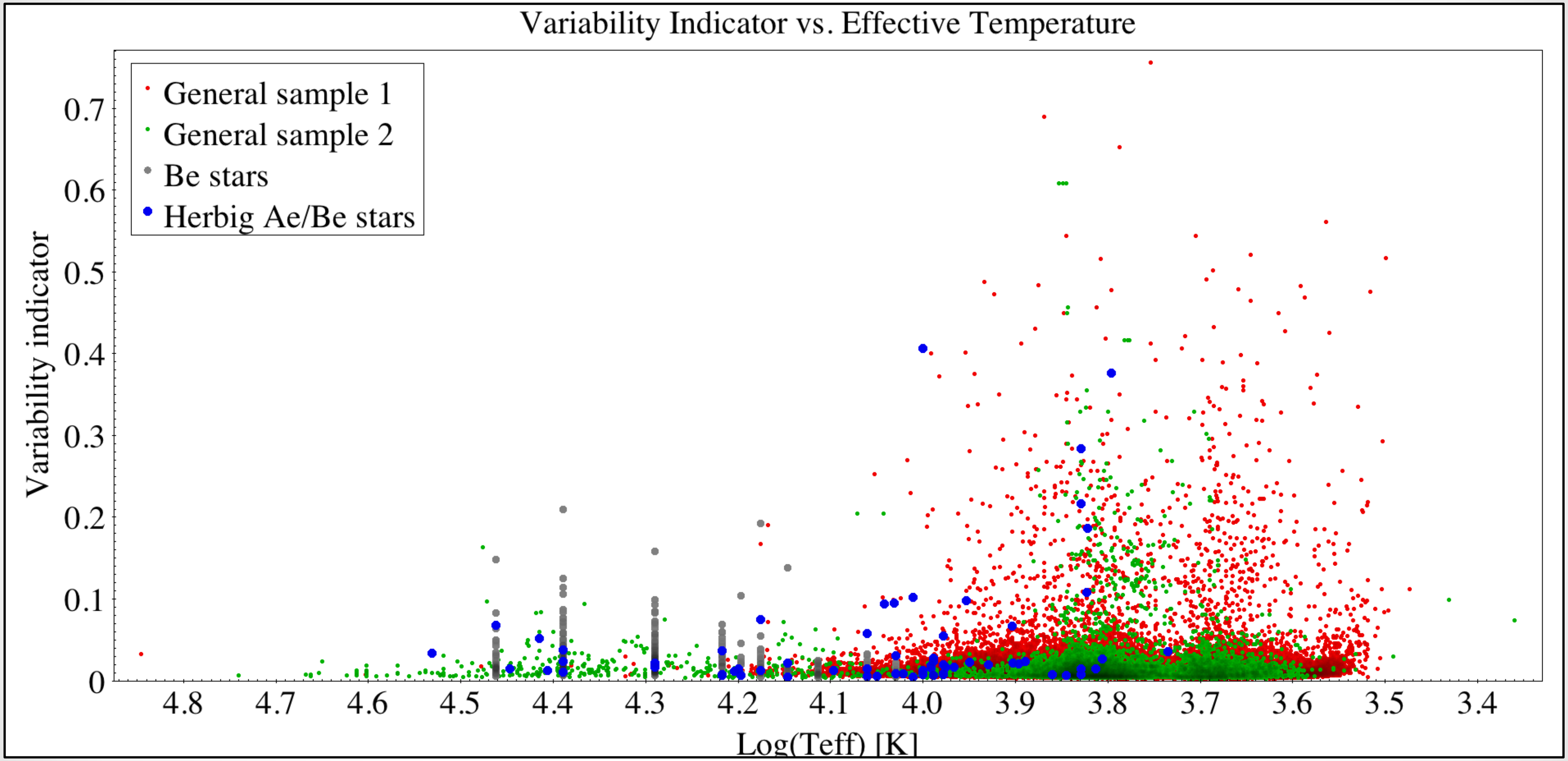
- In general, Gaia Data Release 1 has no explicit variability information.
- In Gaia Data Release 1 sources were observed several tens to hundreds of times.
    - It is possible to extract variability information from the repeated observations.

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

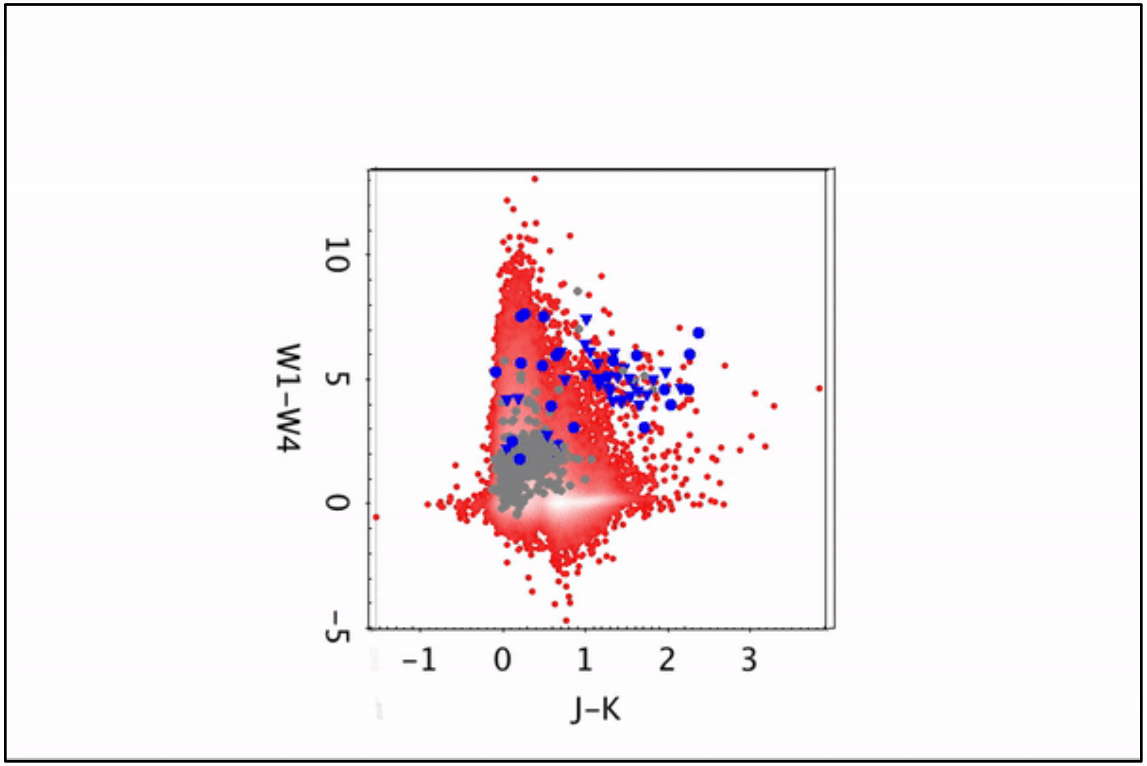
N_{obs} is the number of CCD crossings, F is the flux in the G band, $\sigma(F)$ is the flux error.

Deason A.J. *et al.* 2017. *MNRAS*, 467, 2636

Variability

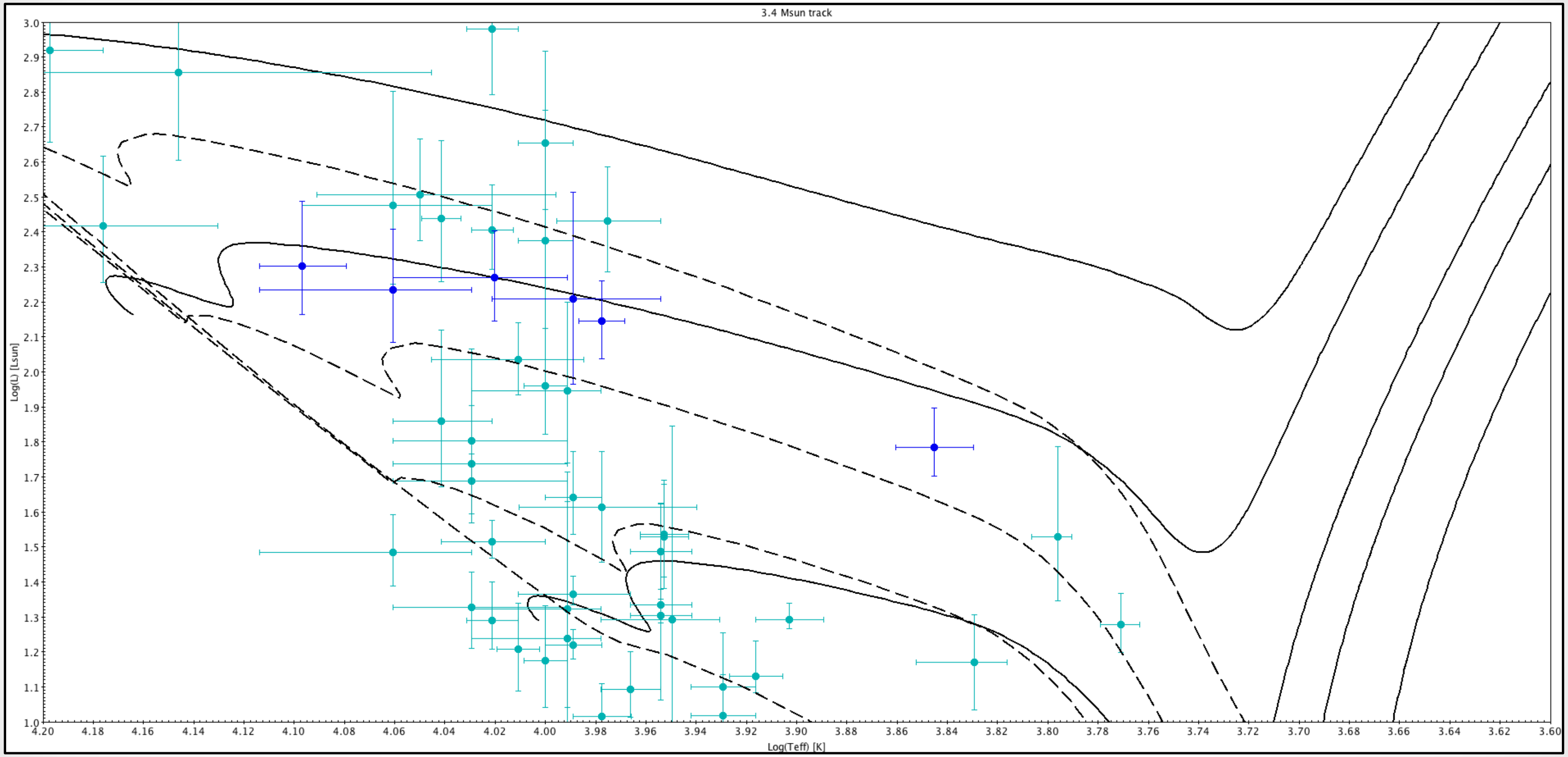


Variability & IR Excess

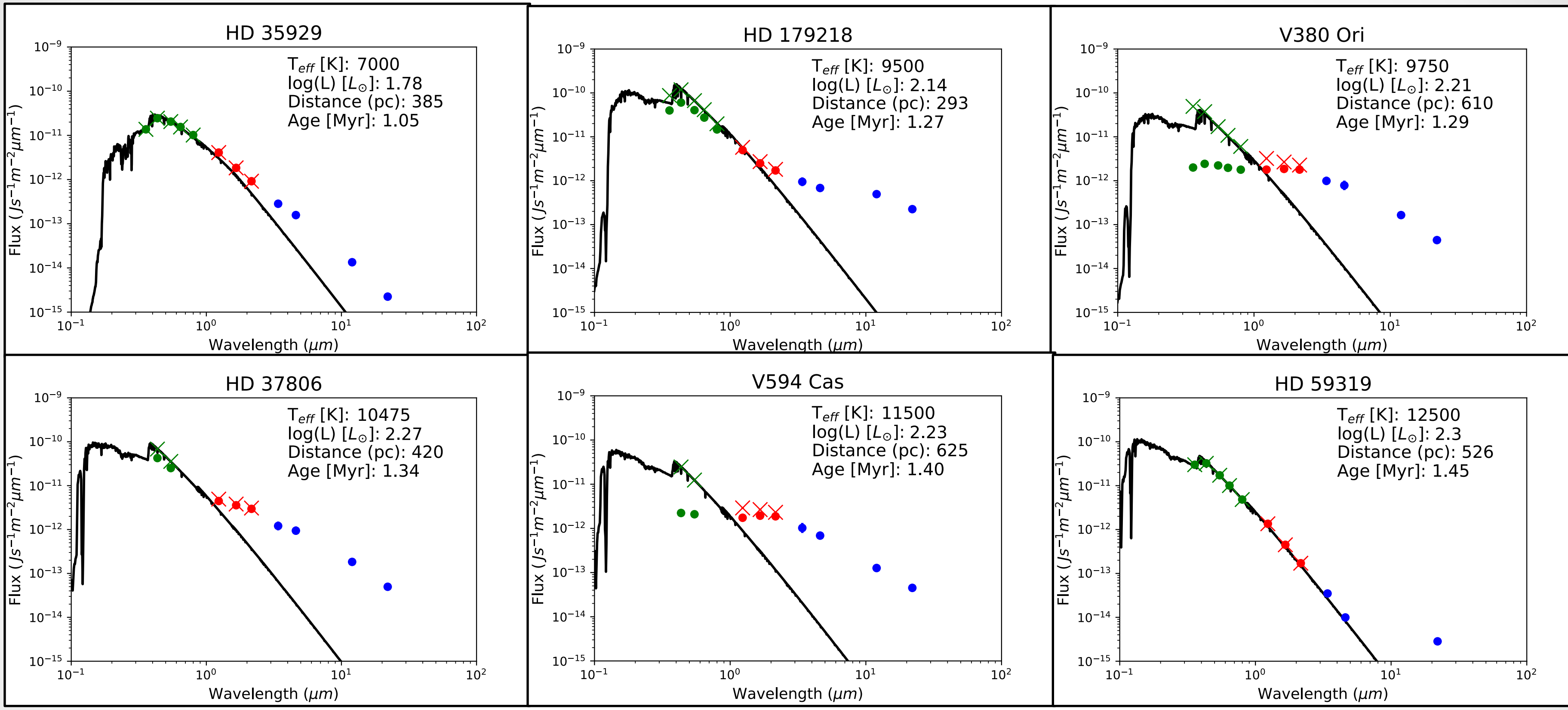


- 33 Herbig Ae
- 22 Herbig Be
- 497 Be stars
- 671478 TGAS sources

3.4 $M_{\odot}$ track



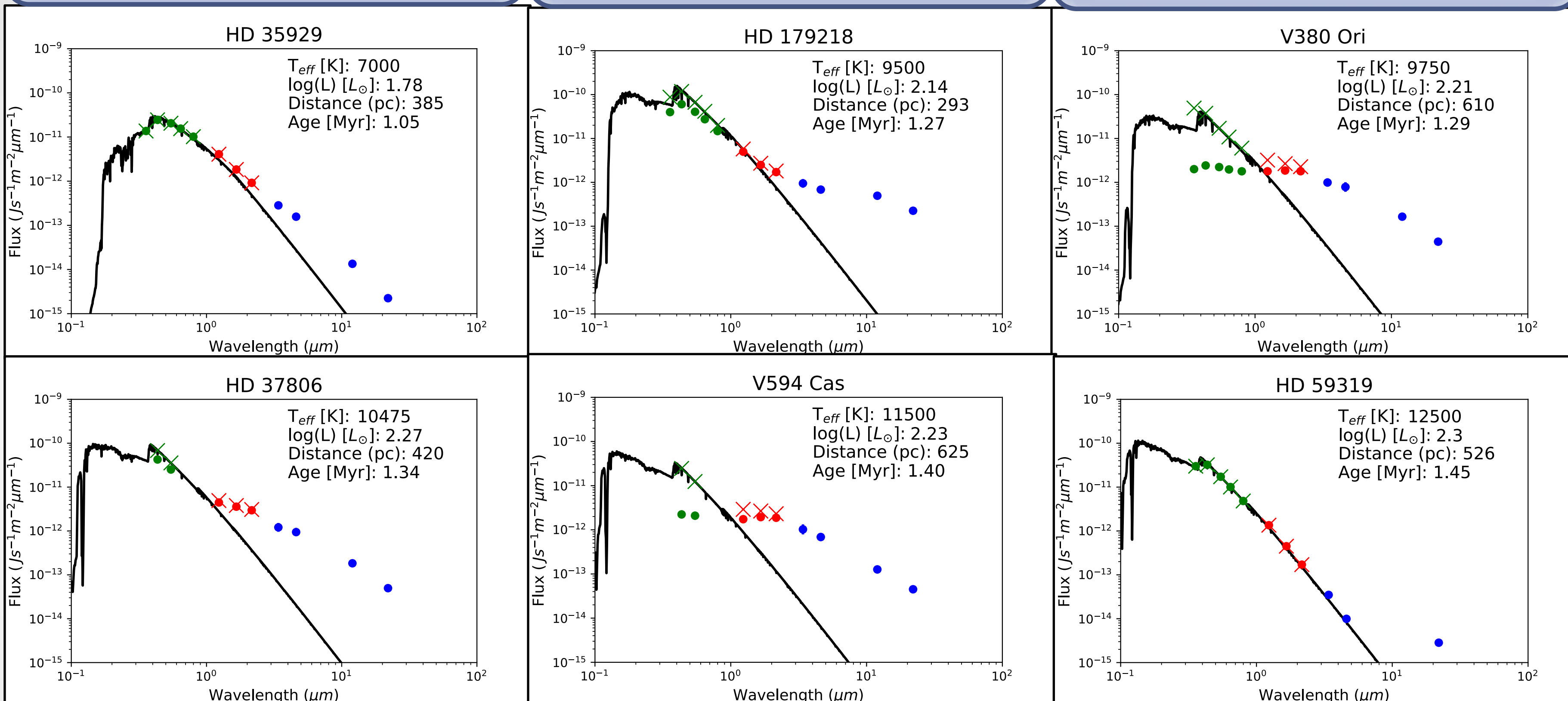
3.4 $M_\odot$ track



IR excess 2MASS = 1.60
IR excess WISE = 12.6

IR excess 2MASS = 1.63
IR excess WISE = 560

IR excess 2MASS = 6.78
IR excess WISE = 509



IR excess 2MASS = 4.78
IR excess WISE = 299

IR excess 2MASS = 11.9
IR excess WISE = 824

IR excess 2MASS = 1.14
IR excess WISE = 33.3

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.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under MSCA ITN-EID grant agreement No 676036.

More STARRY

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.

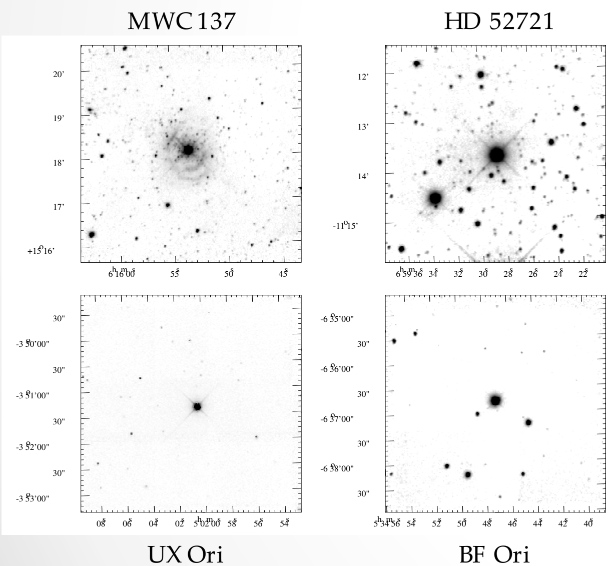


Figure 1 K band images of four Herbig stars. The upper section of the figure shows the Herbig stars surrounded by a large number of companions and the lower section of the figure the Herbig stars appear single and isolated. Figure taken from **Testi et al. (1997).**

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

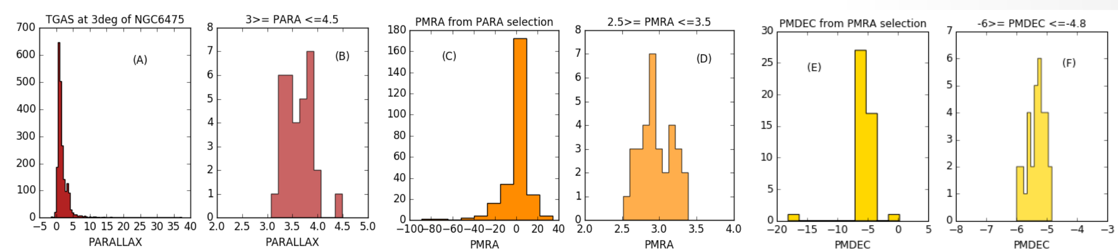


Table 2: Astrometric parameters of the cluster NGC6475

Source	Parallax mas	Pmra mas/yr	Pmdec mas/yr
Gaia Collaboration., et al. 2017	3.57	3.10	-5.32
This project	3.60	2.98	-5.35

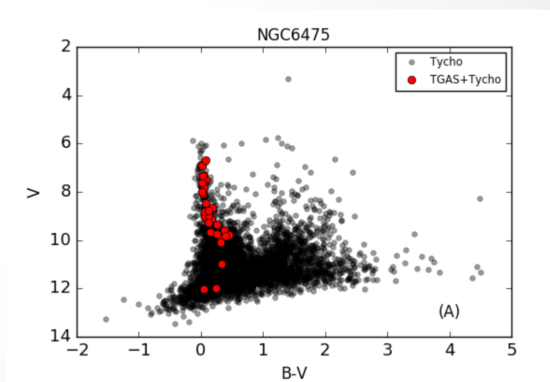


Figure 3 Colour - Magnitude diagram of the cluster NGC6475. In figure A the black points represent the data from Tycho in a circular area with a radius of 3 degrees around the center and the red points are the cross-match between the result of the selection in parallax and proper motions from TGAS and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

Testi, L., Palla, F., Prusti, T., Natta, A., & Maltagliati, S. 1997, A&A, 320, 159
Gaia Collaboration, van Leeuwen, F., Vallenari, A., et al. 2017, arXiv:1703.01131