PLATO benchmark stars

WP 125500

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and many others

What is a benchmark star?

A **benchmark star** is a star with very well determined **properties** useful to:

- calibrate pipelines and models before (DEV phase)
- validate results after the operations start (OPS phase)

The PLATO benchmark group is in charge to build a database of benchmark stars that satisfy the requirements of the various WPs within WP120000

PLATO-OCA-PSPM-TN-0079

Requirements

- Not all the requirements need to be fulfilled simultaneously
- Some requirements need higher precision for some of the parameters

- masses in the range [0.08, 3] $M_\odot$ with a $\Delta M/M \leq 5\%$
- radii with $\Delta R/R \leq 5\%$
- luminosities with $\Delta L/L \leq 5\%$
- age with $\Delta\tau/\tau \leq 10\%$
- $T_{\rm eff}$ in the range [2300, 7500] K with $\Delta T_{\rm eff} \leq 100$ K
- $\log g \geq 2.5$ with $\Delta \log g \leq 0.1$
- metallicity in the range [−2.50, 0.5] with Δ[Fe/H]≤ 0.1

Data collection: accuracy from well-studied stars

- Single stars
  - Gaia Benchmark stars v3 (Soubiran+ 2023): ~100 ✫
  - Titans I & II benchmark stars (Giribaldi+ 2021, 2023): ~55 ✫
  - Interferometric angular diameters:
    - FGK bright single stars with angular diameters from SPICA/CHARA: ~20 ✫
    - M-type stars with interferometric radii (Boyajian+ 2012, etc.)
  - Solar analogs (e.g. 18 Sco Bazot+ 2011): a few

- Close binaries
  - Eclipsing and/or spectroscopic components
    (e.g. α Cen A, B Kervella+ (2017), AI Phe Maxted+ 2020)
  - Eclipsing components from DEBcat (Southworth+ 2015): ~ 200 ✫
  - EBLM: Eclipsing binaries with low-mass companion (e.g. TOI-1338 Kostov+ 2020)

- Wide binaries
  - Visual components with high accuracy on masses and radii (Serenelli+ 2021): ~60 ✫
  - Also for M dwarfs (e.g. Kervella+ 2016, Rains+2024)

Data collection: precision from large catalogues

- SPOCS (Valenti & Fischer 2005):
  $\Delta t/t \leq 10\%$ & $\Delta M/M \leq 5\%$ & $\Delta R/R \leq 5\%$ & T_{eff} in [2500, 7500] K & logg > 2.5 & [Fe/H] in [-2.5, 0.5] ➔ 10 ☆

- XHIP (Anderson & Francis 2012):
- $\Delta t/t \leq 10.0\%$ and Δ[Fe/H] ≤ 0.1 and Tc in [40, 80[(FGKM) and Lc > 2 (III, IV, V, VI) ➔ 360 ☆

- Kepler mission (Mathur+ 2012, Creevey+ 2017, Silva Aguirre+ 2017): ➔ 100 ☆

- Gaia-Kepler (Berger+ 2020):
  $\Delta t/t \leq 10.0\%$ & $\Delta M/M \leq 5.0\%$ & $\Delta R/R \leq 5.0\%$ & ΔTeff ≤ 100 K & Δ[Fe/H] ≤ 0.12 & T_{eff} in [2500, 7500] K & logg> 2.5 & [Fe/H] in [-2.5, 0.5] ➔ 30 ☆

- APOGEE-Kepler (Claytor+ 2020):
  $\Delta t/t \leq 10.0\%$ and $\Delta M/M \leq 5.0\%$ and $\Delta R/R \leq 5.0\%$ ➔ 30 ☆

- GALAH DR3 (Buder+ 2021):
  $\Delta t/t \leq 10.0\%$ & $\Delta M/M \leq 1.0\%$ & $\Delta R/R \leq 1.0\%$ & ΔTeff ≤ 50 K & Δ[Fe/H] ≤ 0.1 & |[Fe/H]| ≤ 0.5 & isredclump ≤ 0.01 & Flagsp = 0 & T_{eff} in [2300, 7500] K & logg > 2.5 & Δlogg ≤ 0.193 ➔ 190 ☆

- And more...

Definitions of benchmark levels: B1 – B2 – B3

Definitions

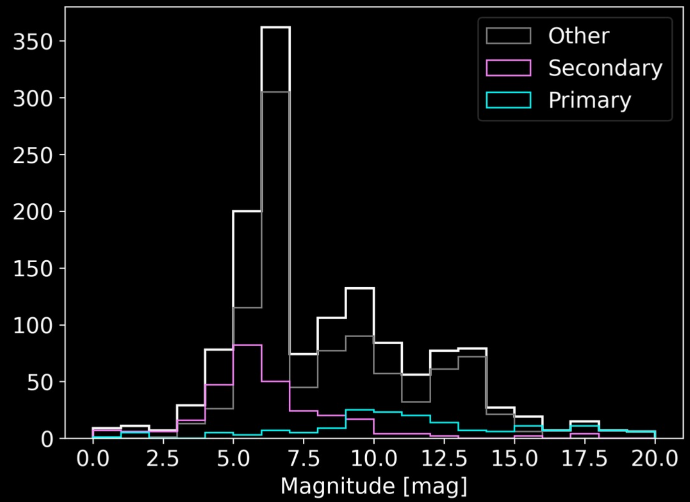
- **Level B1**: directly measured model-independent parameter
- **Level B2**: parameter inferred using stellar models or other theoretical inputs where the level of systematic errors due to the model dependence is well understood
- **Level B3**: parameter inferred from empirical relations

Benchmark levels are per parameter!

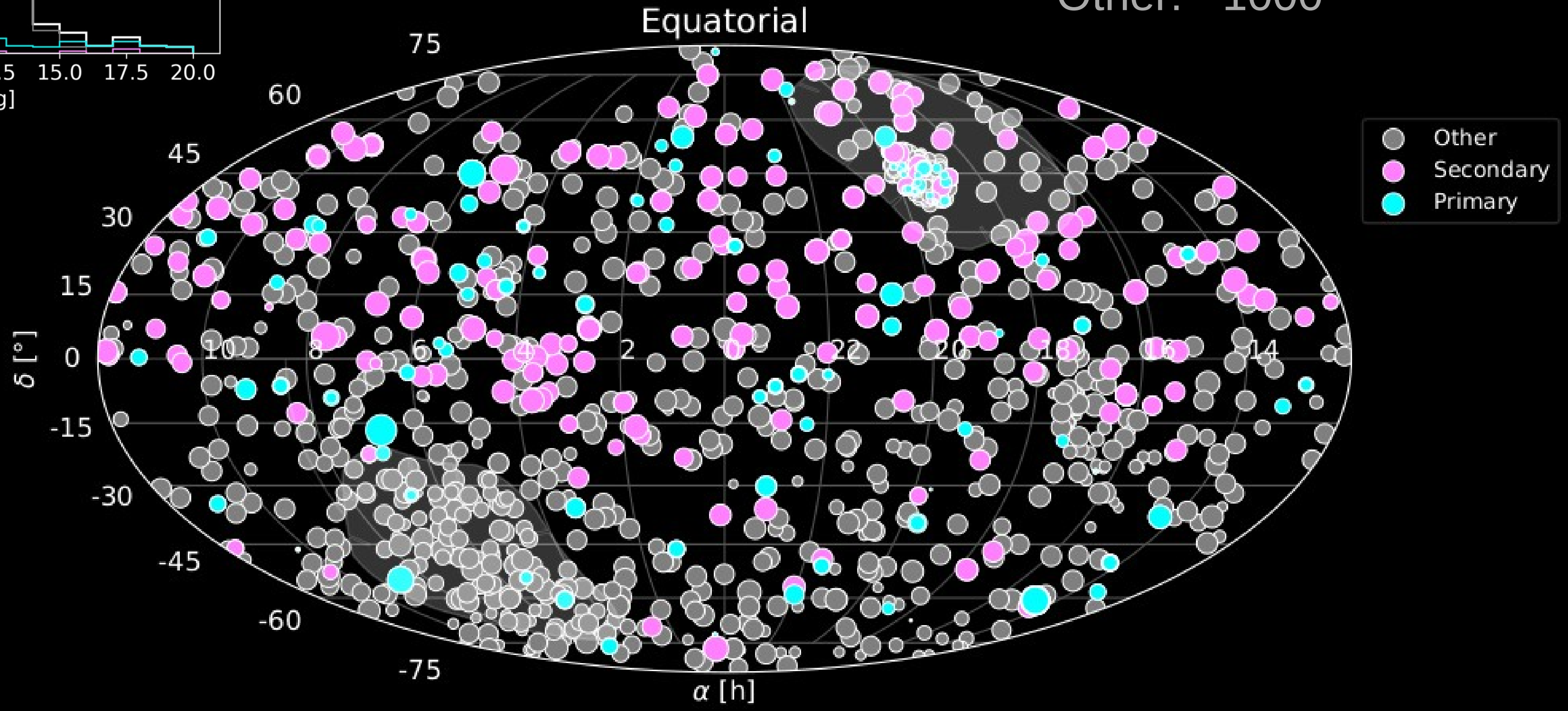
Example

- the **radius** of star from its measured angular diameter and parallax is B1
- the **mass** of the same star estimated from stellar isochrones is B2
- the **age** of the same star from its rotation rate is B3

The benchmark stars database

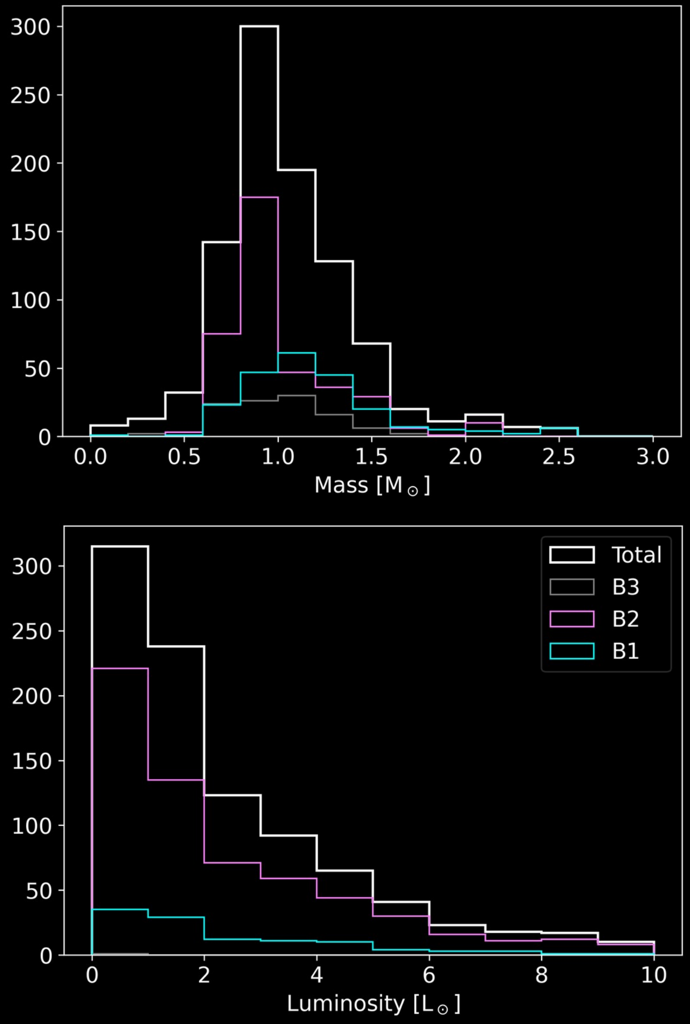


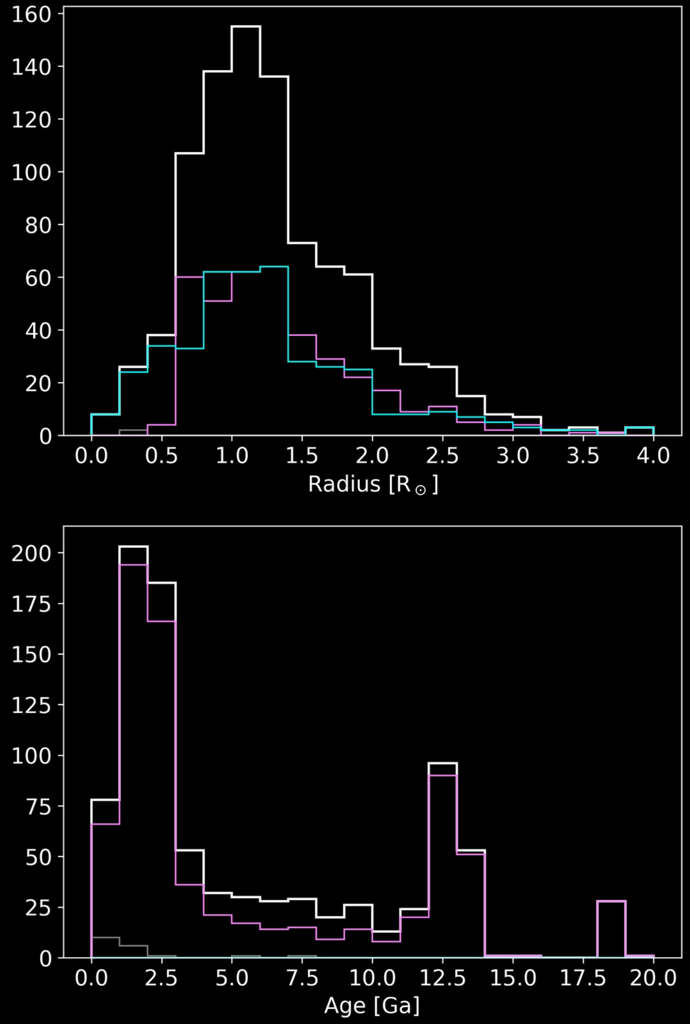
Primary: ~140
Secondary: ~240
Other: ~1000



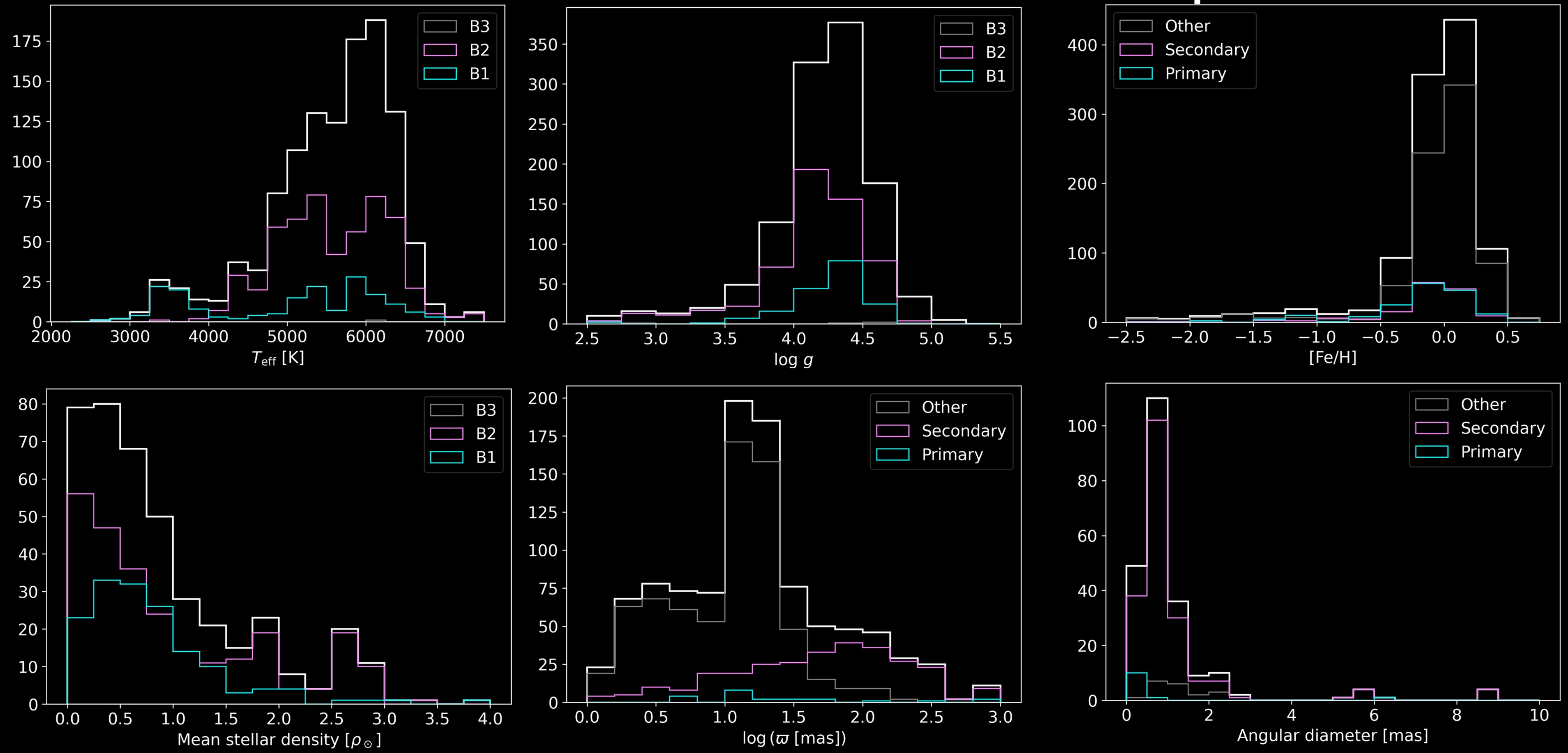
2024-07-04

Fundamental parameters

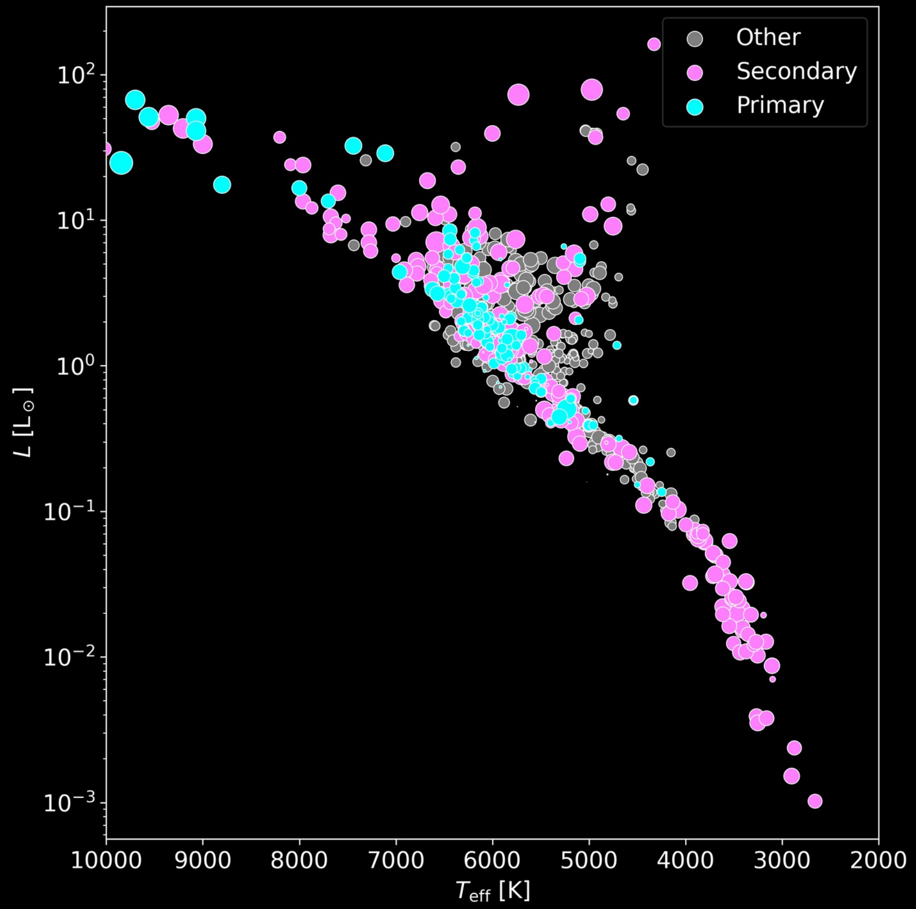


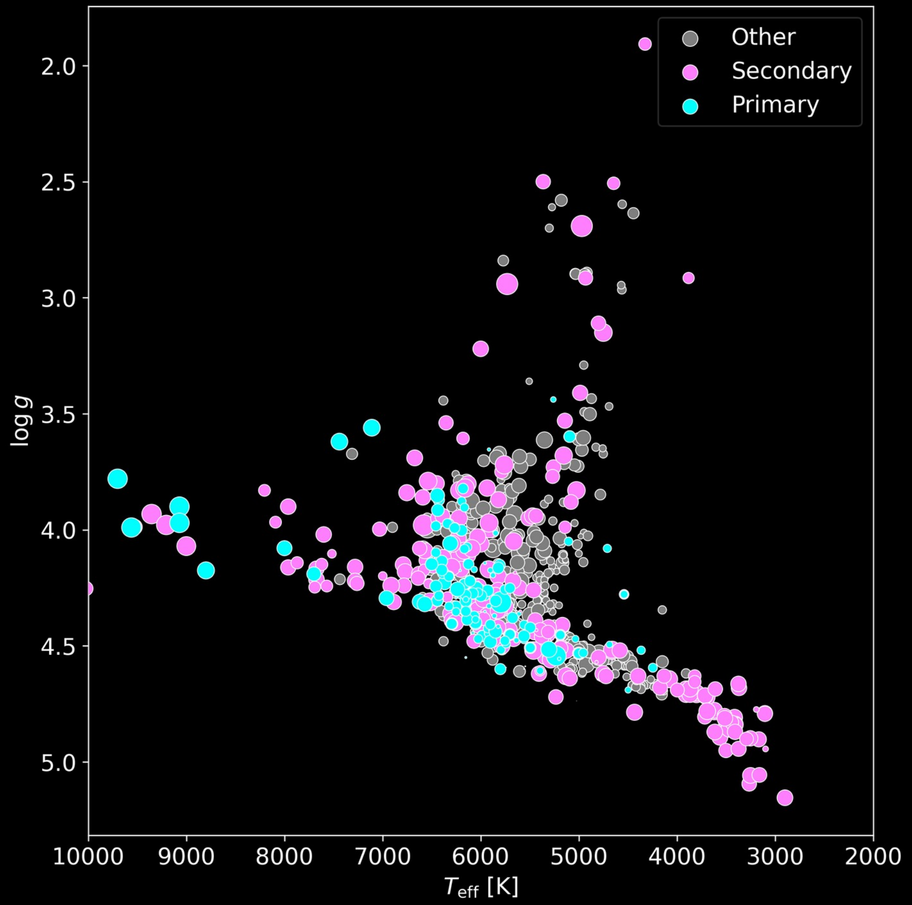


Other parameters

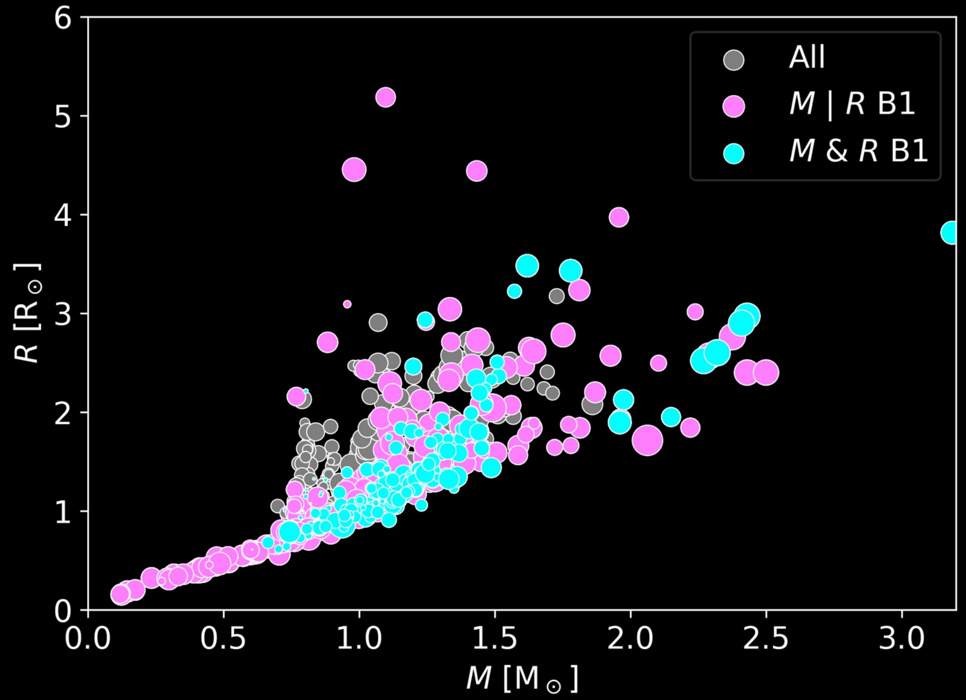


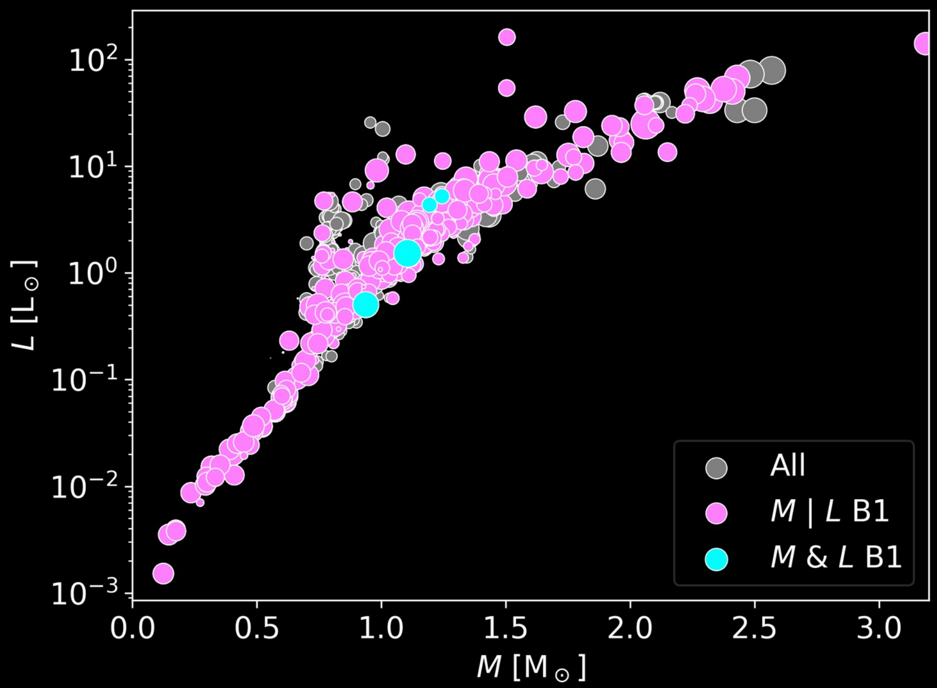
Hertzsprung-Russel and Kiel diagrams





Mass-radius and mass-luminosity relations





Summary

- The PLATO benchmark stars database is still work in progress:
  - 4 fundamental parameters (mass, radius, luminosity and age)
  - Atmospheric parameters (T_{eff}, log*g*, mean density & limb darkening)
  - Ancillary parameters: [Fe/H], [α/Fe], parallax, extinction, angular diameter, bolometric flux, rotational period, etc.

- Currently, there are about 1500 entries (with possible duplicates):
  - Primary benchmark (mass and radius are B1): ~140 ✫
  - Secondary benchmark (at least 1 B1 parameter): ~240 ✫
  - Other (no B1 parameters): ~1000 ✫

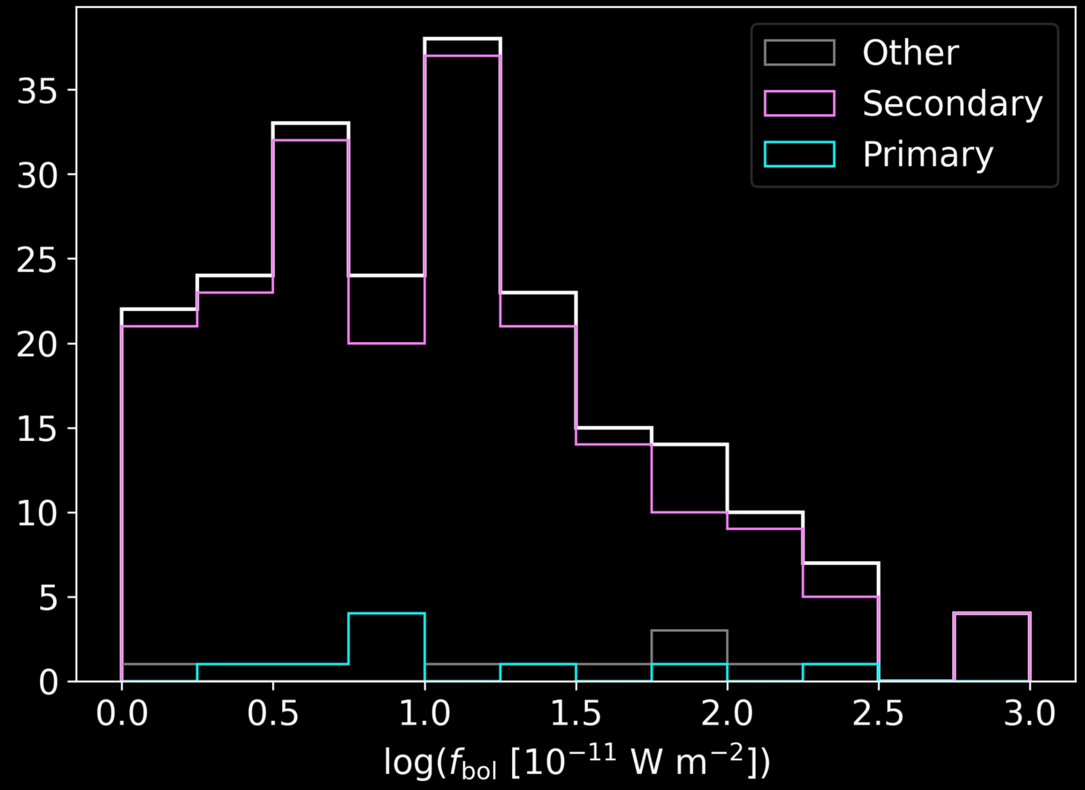
- Benchmark levels
  - B1: 1300
  - B2: 3800
  - B3: 140
  - But many not yet assess

Next steps

- Homogenisation of nomenclature, spectral type and luminosity class using e.g. update of Pecaut & Mamajek (2013)
- Add if a benchmark star is member of a cluster using e.g. Hunt & Reffert (2023)
- Correct the zero-point parallaxes (using Lindegren+ 2021 or Groenewegen 2023)
- Update radii, luminosities and bolometric fluxes with updated parallaxes (from Gaia DR3 or from orbital parallaxes)
- Check consistencies between parameters
- Article in preparation

Backup

Histogram of bolometric fluxes



The excel working sheet

Target identifier	RAJ2000	DEJ2000	Component	Spectral type	Magnitude Value	Band	Radius [solar radius] Value	Error_lo	Error_hi	Level	Method	%	Source
G[illegible]	[illegible]	[illegible]	[illegible]	M2V	5.25	J	0.3874	0.0023	0.0023	B1	Interf	0.59	2012ApJ...757..112B
G[illegible]	[illegible]	[illegible]	[illegible]	M2V	5.25	J	0.3849	0.0019	0.0019	B1	Interf	0.50	this work, from ang. diam. a
HD 36395	82.9	-3.7	N/A	M1.5Ve	4.83	J	0.5735	0.0044	0.0044	B1	Interf	0.77	2012ApJ...757..112B
HD 36395	82.9	-3.7	N/A	M1.5Ve	4.83	J	0.5782	0.0025	0.0025	B1	Interf	0.42	this work, from ang. diam. a
HD 79210	138.6	52.7	A	K7V	4.89	J	0.5773	0.0131	0.0131	B1	Interf	2.27	2012ApJ...757..112B
HD 79210	138.6	52.7	A	K7V	4.89	J	0.5930	0.0102	0.0102	B1	Interf	1.72	this work, from ang. diam. a
HD 79211	138.6	52.7	B	M0V	4.779	J	0.5673	0.0137	0.0137	B1	Interf	2.41	2012ApJ...757..112B
HD 79211	138.6	52.7	B	M0V	4.779	J	0.5828	0.0109	0.0109	B1	Interf	1.87	this work, from ang. diam. a
BD+44 2051	166.4	43.5	A	M1.0V	5.538	J	0.3982	0.0091	0.0091	B1	Interf	2.29	2012ApJ...757..112B
BD+44 2051	166.4	43.5	A	M1.0V	5.538	J	0.4028	0.0090	0.0090	B1	Interf	2.23	this work, from ang. diam. a
Ross 128	176.9	0.8	N/A	M4V	6.505	J	0.1960	0.01	0.01	B1	Interf	5.10	2019MNRAS.484.2674R
Ross 128	176.9	0.8	N/A	M4V	6.505	J	0.1959	0.0105	0.0105	B1	Interf	5.37	this work, from ang. diam. a
HD 119850	206.4	14.9	N/A	M2V	5.18	J	0.4840	0.0084	0.0084	B1	Interf	1.74	2012ApJ...757..112B
HD 119850	206.4	14.9	N/A	M2V	5.18	J	0.4878	0.0082	0.0082	B1	Interf	1.68	this work, from ang. diam. a
BD+68 946	264.1	68.3	N/A	M3.0V	5.335	J	0.4183	0.007	0.007	B1	Interf	1.67	2012ApJ...757..112B
BD+68 946	264.1	68.3	N/A	M3.0V	5.335	J	0.4202	0.0068	0.0068	B1	Interf	1.63	this work, from ang. diam. a
HD 173739	280.7	59.6	A	M3V	5.189	J	0.3561	0.0039	0.0039	B1	Interf	1.10	2012ApJ...757..112B
HD 173739	280.7	59.6	A	M3V	5.189	J	0.3549	0.0030	0.0030	B1	Interf	0.85	this work, from ang. diam. a
HD 173740	280.7	59.6	B	M3.5V	5.721	J	0.3232	0.0061	0.0061	B1	Interf	1.89	2012ApJ...757..112B
HD 173740	280.7	59.6	B	M3.5V	5.721	J	0.3223	0.0057	0.0057	B1	Interf	1.76	this work, from ang. diam. a
HD 180617	289.2	5.2	A	M3-V	5.583	J	0.5260	0.032	0.032	B1	Interf	6.08	2006ApJ...644..475B
HD 180617	289.2	5.2	A	M3-V	5.583	J	0.5315	0.0324	0.0324	B1	Interf	6.10	this work, from ang. diam. a
HD 199305	313.3	62.2	N/A	M1.0V	5.429	J	0.5472	0.0067	0.0067	B1	Interf	1.22	2012ApJ...757..112B
HD 199305	313.3	62.2	N/A	M1.0V	5.429	J	0.5464	0.0061	0.0061	B1	Interf	1.11	this work, from ang. diam. a
HD 216899	344.1	16.6	N/A	M1.5V	5.429	J	0.5477	0.0048	0.0048	B1	Interf	0.88	2012ApJ...757..112B
HD 216899	344.1	16.6	N/A	M1.5V	5.429	J	0.5492	0.0030	0.0030	B1	Interf	0.54	this work, from ang. diam. a
HD 95735	165.8	36.0	N/A	M2+V	4.2	J	0.3921	0.0037	0.0037	B1	Interf	0.94	2012ApJ...757..112B
HD 95735	165.8	36.0	N/A	M2+V	4.2	J	0.3920	0.0036	0.0036	B1	Interf	0.91	this work, from ang. diam. a
HD 285968	70.7	19.0	N/A	M2.5V	6.462	J	0.4567	0.0214	0.0214	B1	Interf	4.69	this work, from ang. diam. a
Ross 905	175.5	26.7	N/A	M3V	6.9	J	0.4381	0.0137	0.0137	B1	Interf	3.12	this work, from ang. diam. a
BD-07 4003	229.9	-7.7	N/A	M3V	6.706	J	0.3020	0.0095	0.0095	B1	Interf	3.14	this work, from ang. diam. a
BD+25 3173	254.5	25.7	N/A	M2V	6.448	J	0.5406	0.0134	0.0134	B1	Interf	2.48	this work, from ang. diam. a
Barnard's star	269.5	4.7	N/A	M4V	5.244	J	0.1871	0.0010	0.0010	B1	Interf	0.53	this work, from ang. diam. a
BD-15 6290	343.3	-14.3	N/A	M3.5V	5.934	J	0.3746	0.0045	0.0045	B1	Interf	1.21	this work, from ang. diam. a
HD 225213	1.4	-37.4	N/A	M2V	5.328	J	0.3794	0.0023	0.0023	B1	Interf	0.62	this work, from ang. diam. a
BD+01 2447	157.2	0.8	N/A	M2V	6.176	J	0.4266	0.0159	0.0159	B1	Interf	3.72	this work, from ang. diam. a
Proxima Centauri	217.4	-62.7	N/A	M5.5Ve	5.357	J	0.1544	0.0010	0.0010	B1	Interf	0.63	this work, from ang. diam. a
CD-46 11540	262.2	-46.9	N/A	M3V	5.711	J	0.3607	0.0181	0.0181	B1	Interf	5.02	this work, from ang. diam. a
HD 204961	323.4	-49	N/A	M2/3V	5.349	J	0.4346	0.0053	0.0053	B1	Interf	1.23	this work, from ang. diam. a
HD 88230	152.8	49.5	N/A	K7V	3.97	J	0.6414	0.0047	0.0047	B1	Interf	0.73	this work, from ang. diam. a
BD+05 1668	111.9	5.2	N/A	M3.5V	5.714	J	0.3187	0.0041	0.0041	B1	Interf	1.28	this work, from ang. diam. a
BD-12 4523	247.6	-12.7	N/A	M3V	5.95	J	0.3061	0.0065	0.0065	B1	Interf	2.12	this work, from ang. diam. a

Target identifier	Mass [solar mass] Value	Error_lo	Error_hi	Level	Method	%	Source	Luminosity [solar luminosity] Value	Error_lo	Error_hi	Level	Source
G[illegible]	0.423	0.0423	0.0423	N/A	Other	10%	2012ApJ...757..112B	0.02173	0.00021	0.00021	B2	2012ApJ...757..112B
G[illegible]	0.423	0.0423	0.0423	N/A	Other	10%	2012ApJ...757..112B	0.02149	0.00017	0.00017	B2	this work, from bol. flux and
HD 36395	0.615	0.0615	0.0615	N/A	Other	10%	2012ApJ...757..112B	0.06163	0.00088	0.00088	B2	2012ApJ...757..112B
HD 36395	0.615	0.0615	0.0615	N/A	Other	10%	2012ApJ...757..112B	0.06285	0.00033	0.00033	B2	this work, from bol. flux and
HD 79210	0.622	0.0622	0.0622	N/A	Other	10%	2012ApJ...757..112B	0.06974	0.00213	0.00213	B2	2012ApJ...757..112B
HD 79210	0.622	0.0622	0.0622	N/A	Other	10%	2012ApJ...757..112B	0.07376	0.00064	0.00064	B2	this work, from bol. flux and
HD 79211	0.6	0.06	0.06	N/A	Other	10%	2012ApJ...757..112B	0.06465	0.00194	0.00194	B2	2012ApJ...757..112B
HD 79211	0.6	0.06	0.06	N/A	Other	10%	2012ApJ...757..112B	0.06837	0.00046	0.00046	B2	this work, from bol. flux and
BD+44 2051	0.403	0.0403	0.0403	N/A	Other	10%	2012ApJ...757..112B	0.02129	0.00026	0.00026	B2	2012ApJ...757..112B
BD+44 2051	0.403	0.0403	0.0403	N/A	Other	10%	2012ApJ...757..112B	0.02186	0.00017	0.00017	B2	this work, from bol. flux and
Ross 128	0.174	0.004	0.004	N/A	Other	2.3	2019MNRAS.484.2674R	0.00390	0.0003	0.0003	B2	2019MNRAS.484.2674R
Ross 128	0.174	0.004	0.004	N/A	Other	2.3	2019MNRAS.484.2674R	0.00393	0.00032	0.00032	B2	this work, from bol. flux and
HD 119850	0.52	0.052	0.052	N/A	Other	10%	2012ApJ...757..112B	0.03603	0.00051	0.00051	B2	2012ApJ...757..112B
HD 119850	0.52	0.052	0.052	N/A	Other	10%	2012ApJ...757..112B	0.03672	0.00028	0.00028	B2	this work, from bol. flux and
BD+68 946	0.413	0.0413	0.0413	N/A	Other	10%	2012ApJ...757..112B	0.02128	0.00023	0.00023	B2	2012ApJ...757..112B
BD+68 946	0.413	0.0413	0.0413	N/A	Other	10%	2012ApJ...757..112B	0.02155	0.00014	0.00014	B2	this work, from bol. flux and
HD 173739	0.318	0.0318	0.0318	N/A	Other	10%	2012ApJ...757..112B	0.01531	0.00018	0.00018	B2	2012ApJ...757..112B
HD 173739	0.318	0.0318	0.0318	N/A	Other	10%	2012ApJ...757..112B	0.01527	0.00002	0.00002	B2	this work, from bol. flux and
HD 173740	0.235	0.0235	0.0235	N/A	Other	10%	2012ApJ...757..112B	0.00871	0.00012	0.00012	B2	2012ApJ...757..112B
HD 173740	0.235	0.0235	0.0235	N/A	Other	10%	2012ApJ...757..112B	0.00868	0.00005	0.00005	B2	this work, from bol. flux and
HD 180617	0.484	0.0484	0.0484	N/A	Other	10%	2006ApJ...644..475B	0.03261	0.0017	0.0017	B3	2006ApJ...644..475B
HD 180617	0.475	0.047	0.047	N/A	Other	9.9	2015ApJ...804...64M	0.03298	0.00025	0.00025	B2	this work, from bol. flux and
HD 199305	0.573	0.0573	0.0573	N/A	Other	10%	2012ApJ...757..112B	0.04990	0.00062	0.00062	B2	2012ApJ...757..112B
HD 199305	0.573	0.0573	0.0573	N/A	Other	10%	2012ApJ...757..112B	0.04992	0.00042	0.00042	B2	this work, from bol. flux and
HD 216899	0.569	0.0569	0.0569	N/A	Other	10%	2012ApJ...757..112B	0.05112	0.00074	0.00074	B2	2012ApJ...757..112B
HD 216899	0.569	0.0569	0.0569	N/A	Other	10%	2012ApJ...757..112B	0.05159	0.00025	0.00025	B2	this work, from bol. flux and
HD 95735	0.403	0.0403	0.0403	N/A	Other	10%	2012ApJ...757..112B	0.01989	0.00014	0.00014	B2	2012ApJ...757..112B
HD 95735	0.403	0.0403	0.0403	N/A	Other	10%	2012ApJ...757..112B	0.01994	0.00012	0.00012	B2	this work, from bol. flux and
HD 285968	0.486	0.011	0.011	N/A	Other	2.3	2019MNRAS.484.2674R	0.03581	0.00089	0.00089	B2	2020A&A...642A.115C
Ross 905	0.472	0.0472	0.0472	N/A	Other	10%	2012ApJ...757..112B	0.02431	0.00034	0.00034	B2	2020A&A...642A.115C
BD-07 4003	0.297	0.0297	0.0297	N/A	Other	10%	2012ApJ...757..112B	0.01235	0.00026	0.00026	B2	2020A&A...642A.115C
BD+25 3173	0.517	0.013	0.013	N/A	Other	2.5	2019MNRAS.484.2674R	0.0447	0.002	0.002	B2	2020A&A...642A.115C
Barnard's star	0.146	0.0146	0.0146	N/A	Other	10%	2012ApJ...757..112B	0.003523	9.10E-05	9.10E-05	B2	2020A&A...642A.115C
BD-15 6290	0.409	0.01	0.01	N/A	Other	2.4	2019MNRAS.484.2674R	0.01271	0.00025	0.00025	B2	2020A&A...642A.115C
HD 225213	0.39	0.01	0.01	N/A	Other	2.6	2019MNRAS.484.2674R	0.02214	0.00043	0.00043	B2	this work, from bol. flux and
BD+01 2447	0.42	0.03	0.03	B3	Evolution mo	7.1	2018ApJ...858...71S	0.02505	0.00051	0.00051	B2	this work, from bol. flux and
Proxima Centauri	0.124	0.003	0.003	N/A	Other	2.4	2019MNRAS.484.2674R	0.00152	0.00011	0.00011	B2	this work, from bol. flux and
CD-46 11540	0.352	0.008	0.008	N/A	Other	2.3	2019MNRAS.484.2674R	0.01582	0.00150	0.00150	B2	this work, from bol. flux and
HD 204961	0.447	0.011	0.011	N/A	Other	2.5	2019MNRAS.484.2674R	0.02590	0.00087	0.00087	B2	this work, from bol. flux and
HD 88230	0.66	0.066	0.066	N/A	Other	10%	2012ApJ...757..112B	0.10274	0.00069	0.00069	B2	this work, from bol. flux and
BD+05 1668	0.293	0.007	0.007	N/A	Other	2.4	2019MNRAS.484.2674R	0.01025	0.00053	0.00053	B2	this work, from bol. flux and
BD-12 4523	0.3	0.007	0.007	N/A	Other	2.3	2019MNRAS.484.2674R	0.01091	0.00039	0.00039	B2	this work, from bol. flux and