Gaia Benchmark stars (GBS)

Paula Jofre (Univ. Diego Portales) Sara Vitali (Univ. Diego Portales)
Caroline Soubiran (Univ. Bordeaux), Natalie Brouillet (Univ. Bordeaux), Laia Casamiquela (Univ Bordeaux), Ulrike Heiter (Univ. Uppsala), Clare Worley (Univ. Cambridge)

"Gaia Benchmark" vs other Reference?

Jofre+2018 and references therein.
See also Jofre, Heiter & Soubiran 2019, ARA&A

They have interferometric radii

$$T_{\mathrm{eff}} = \left(\frac{F_{\mathrm{bol}}}{\sigma}\right)^{0.25} (0.5\,\theta_{\mathrm{LD}})^{-0.5}.$$

To have a zero point for the Temperature.

e.g. Accuracy

"Gaia Benchmark" vs other Reference?

Jofre+2018 and references therein.
See also Jofre, Heiter & Soubiran 2019, ARA&A

They have interferometric radii

$$T_{\rm eff} = \left(\frac{F_{\rm bol}}{\sigma}\right)^{0.25} (0.5\,\theta_{\rm LD})^{-0.5}.$$

To have a zero point for the Temperature.

e.g. Accuracy

Anything else we'd like to "trust"

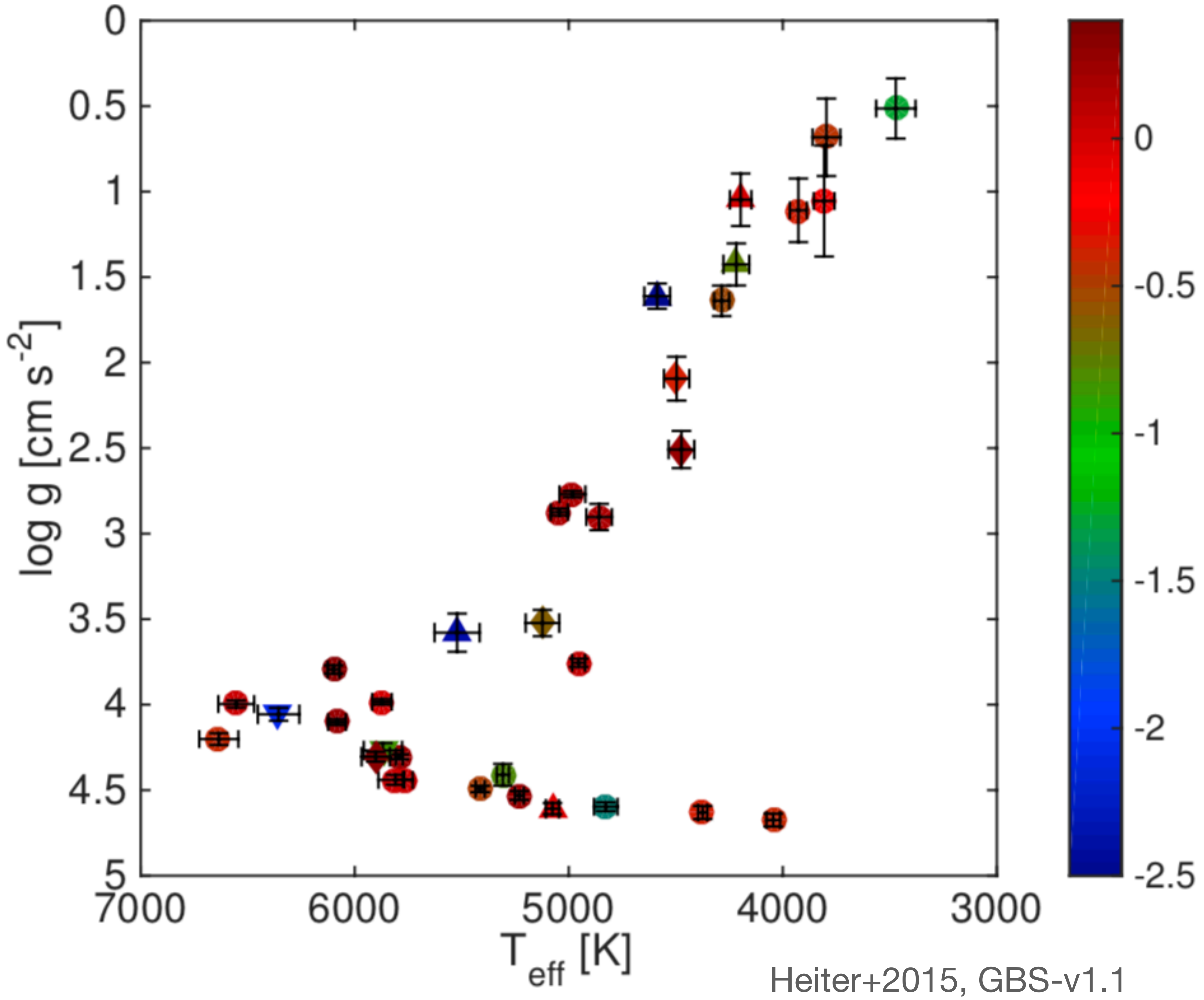
- Sun and solar-twins
- Seismic stars
- Planet hosts
- Cluster stars
- Wide binaries
- Radial velocity standards
- Bright stars with lots of literature

Assessing different parameters

Gaia Benchmark stars in 2014-15
GBS-v1
(fundamental pillars for GES/RAVE/GALAH)

Gaia Benchmark stars in 2014-15

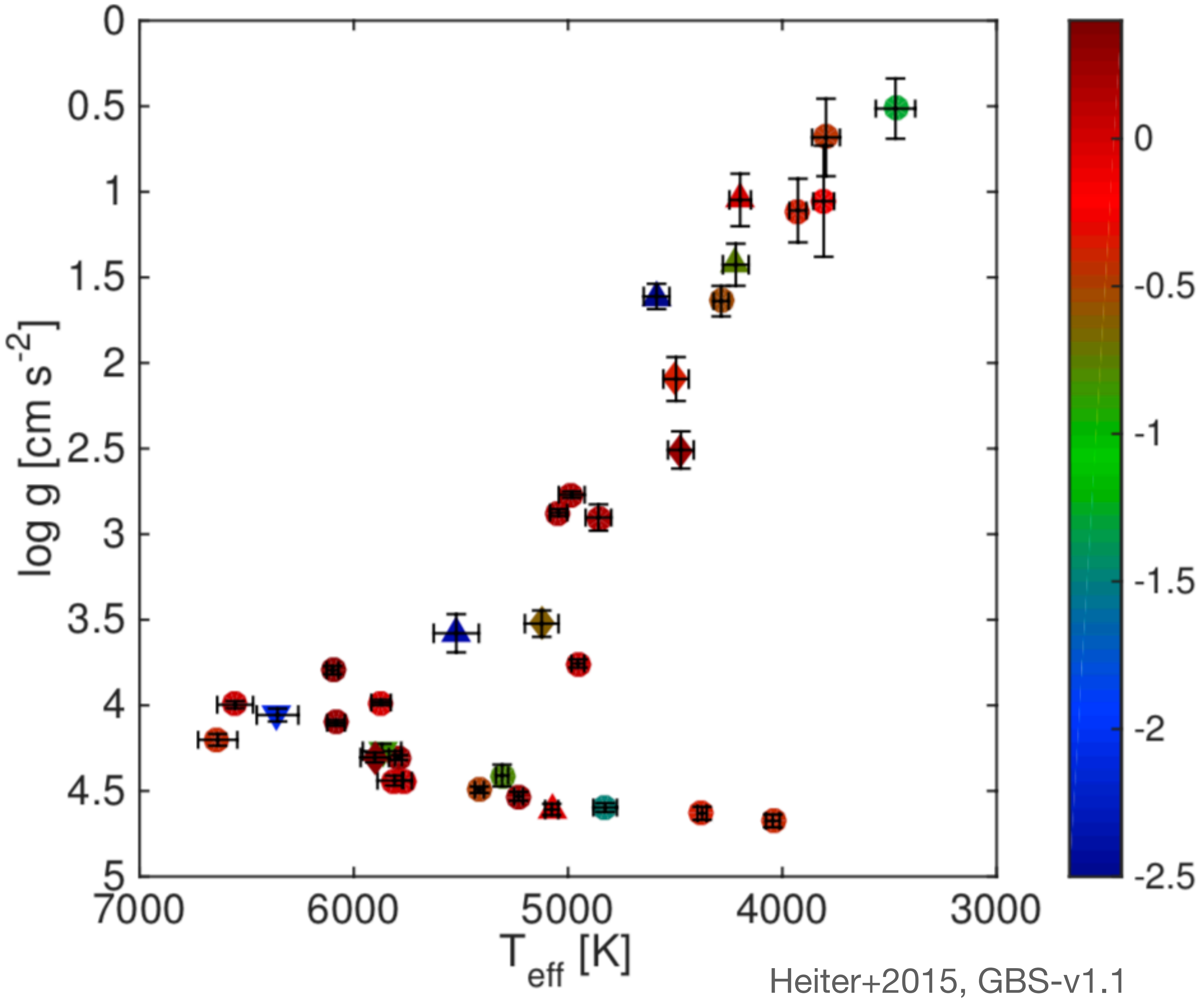
Starting point for our GBS is they have angular diameters



Heiter+2015, GBS-v1.1

Gaia Benchmark stars in 2014-15

Starting point for our GBS is they have angular diameters



Heiter+2015, GBS-v1.1

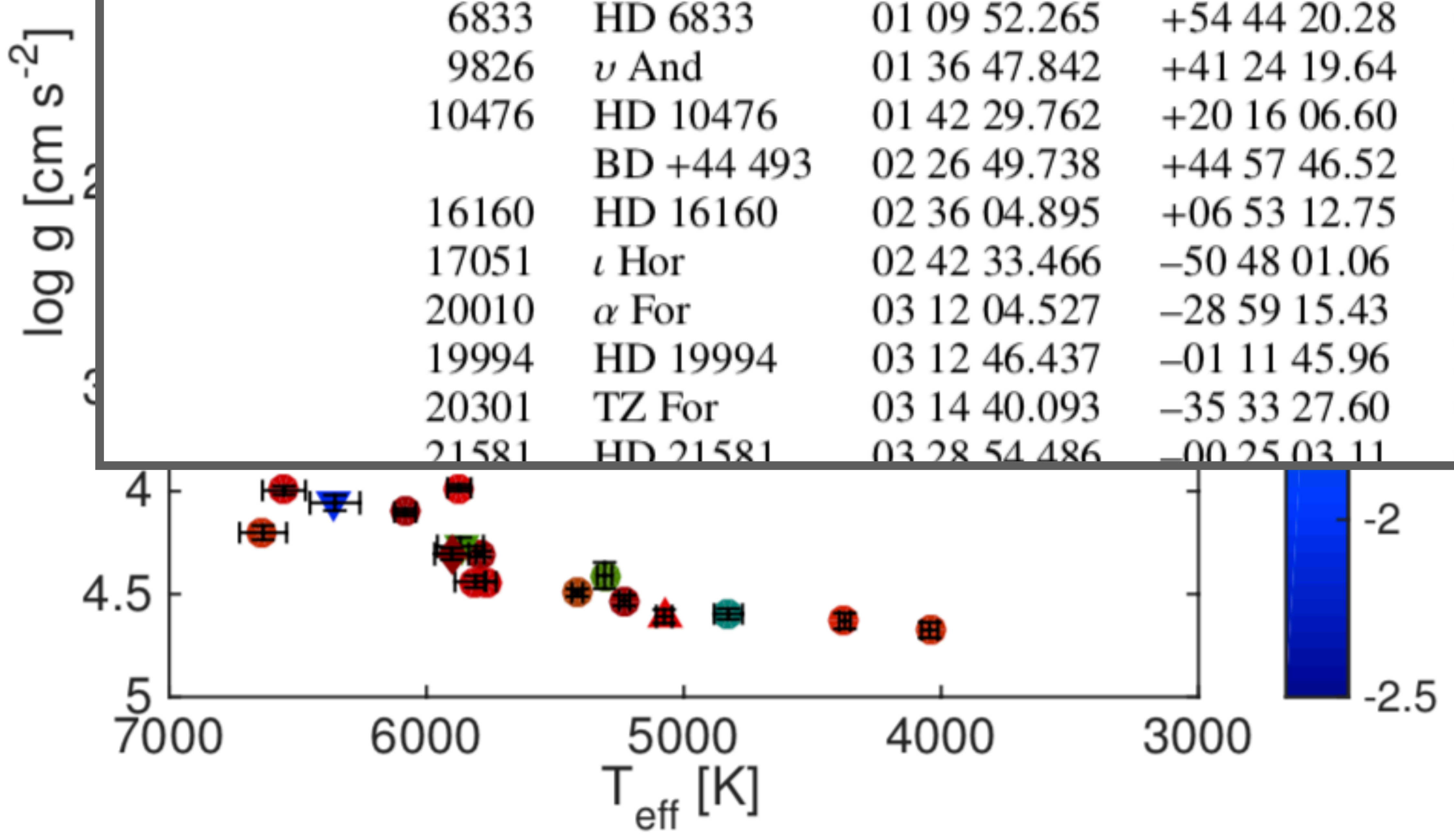
Name	T_{eff}	$u(T_{eff})$ [K]	$\%u(T_{eff})$	log g	$u(\log g)$ [cm s^{-2}]
F dwarfs					
Procyon	6554	84	1.28	4.00	0.02
HD 84937	6356	97	1.52	4.06	0.04
HD 49933	6635	91	1.38	4.20	0.03
FGK subgiants					
δ Eri	4954	30	0.61	3.76	0.02
HD 140283	[5522]	[105]	[1.91]	3.58	0.11
ϵ For	5123	78	1.53	[3.52]	[0.08]
η Boo	6099	28	0.45	3.79	0.02
β Hyi	5873	45	0.77	3.98	0.02
G dwarfs					
α Cen A	5792	16	0.27	4.31	0.01
HD 22879	5868	89	1.52	4.27	0.04
Sun	5771	1	0.01	4.4380	0.0002
μ Cas	5308	29	0.54	[4.41]	[0.06]
τ Cet	5414	21	0.39	[4.49]	[0.02]
α Cen B	5231	20	0.38	4.53	0.03
18 Sco	5810	80	1.38	4.44	0.03
μ Ara	[5902]	[66]	[1.12]	4.30	0.03
β Vir	6083	41	0.68	4.10	0.02
FGK giants					
Arcturus	4286	35	0.82	[1.64]	[0.09]
HD 122563	4587	60	1.31	1.61	0.07
μ Leo	4474	60	1.34	2.51	0.11
β Gem	4858	60	1.23	2.90	0.08
ϵ Vir	4983	61	1.21	2.77	0.02
ξ Hya	5044	40	0.78	2.87	0.02
HD 107328	4496	59	1.32	2.09	0.13
HD 220009	[4217]	[60]	[1.43]	[1.43]	[0.12]
M giants					
α Tau	3927	40	1.01	1.11	0.19
α Cet	3796	65	1.71	0.68	0.23
β Ara	[4197]	[50]	[1.20]	[1.05]	[0.15]
γ Sge	3807	49	1.28	1.05	0.32
ψ Phe	[3472]	[92]	[2.65]	[0.51]	[0.18]
K dwarfs					
ϵ Eri	5076	30	0.60	4.61	0.03
Gmb 1830	[4827]	[55]	[1.14]	4.60	0.03
61 Cyg A	4374	22	0.49	4.63	0.04
61 Cyg B	4044	32	0.78	4.67	0.04

Gaia Benchmark stars in 2

Starting point for our GBS is they have a

Table B.1. Basic information for stars suggested for future extension of the *Gaia* FGK benchmark stars sample.

HD	Name	RA (J2000)	Dec (J2000)	Spectral type	V mag	[Fe/H]	σ([Fe/H])
2665	HD 2665	00 30 45.446	+57 03 53.63	G5IIIw	7.7	–2.00	0.09
2796	HD 2796	00 31 16.915	–16 47 40.80	Fw	8.5	–2.32	0.13
4306	HD 4306	00 45 27.163	–09 32 39.79	KIIvw	9.0	–2.70	0.19
4628	HD 4628	00 48 22.977	+05 16 50.21	K2.5V	5.7	–0.26	0.05
6980	AI Phe	01 09 34.195	–46 15 56.09	K0IV+F7V	8.6	–0.14	0.10
6755	HD 6755	01 09 43.065	+61 32 50.19	F8V	7.7	–1.55	0.05
6860	β And	01 09 43.924	+35 37 14.01	M0III	2.0	–0.04	
6833	HD 6833	01 09 52.265	+54 44 20.28	G9III	6.7	–0.88	0.11
9826	υ And	01 36 47.842	+41 24 19.64	F9V	4.1	0.08	0.05
10476	HD 10476	01 42 29.762	+20 16 06.60	K1V	5.2	–0.04	0.04
	BD +44 493	02 26 49.738	+44 57 46.52	G5IV	9.1	–3.68	0.11
16160	HD 16160	02 36 04.895	+06 53 12.75	K3V	5.8	–0.12	0.06
17051	ι Hor	02 42 33.466	–50 48 01.06	F8V	5.4	0.13	0.10
20010	α For	03 12 04.527	–28 59 15.43	F6V+G7V	3.9	–0.28	0.06
19994	HD 19994	03 12 46.437	–01 11 45.96	F8V	5.1	0.19	0.07
20301	TZ For	03 14 40.093	–35 33 27.60	G8III+F7IV	6.9	0.10	0.15
21581	HD 21581	03 28 54.486	–00 25 03.11	G0	8.7	–1.69	0.09



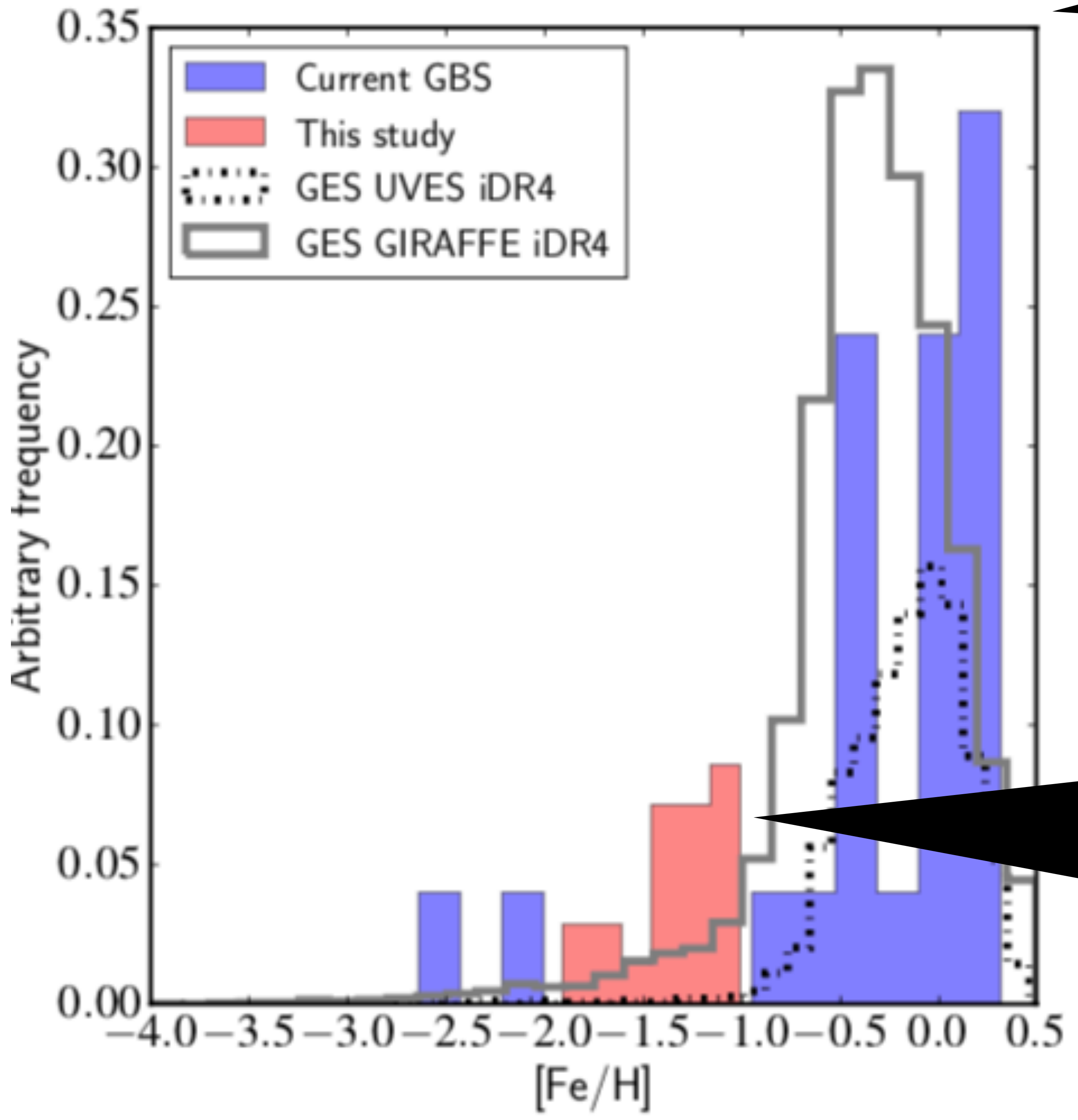
Name	T_{eff}	$u(T_{eff})$ [K]		
α Tau	3927	40		
α Cet	3796	65		
β Ara	[41			
γ Sge				
ψ Phe				
ε Eri	50			
Gmb 1830	[4827]			
61 Cyg A	4374	22		
61 Cyg B	4044	32	0.78	

Too few metal-poor stars - particularly dwarfs

Some interferometric radii too uncertain.

2016: Towards GBS v2.1

Trying to fill the metal-poor gap



Patch solution because stars hadn't angular diameters measured directly

Hawkins+2016

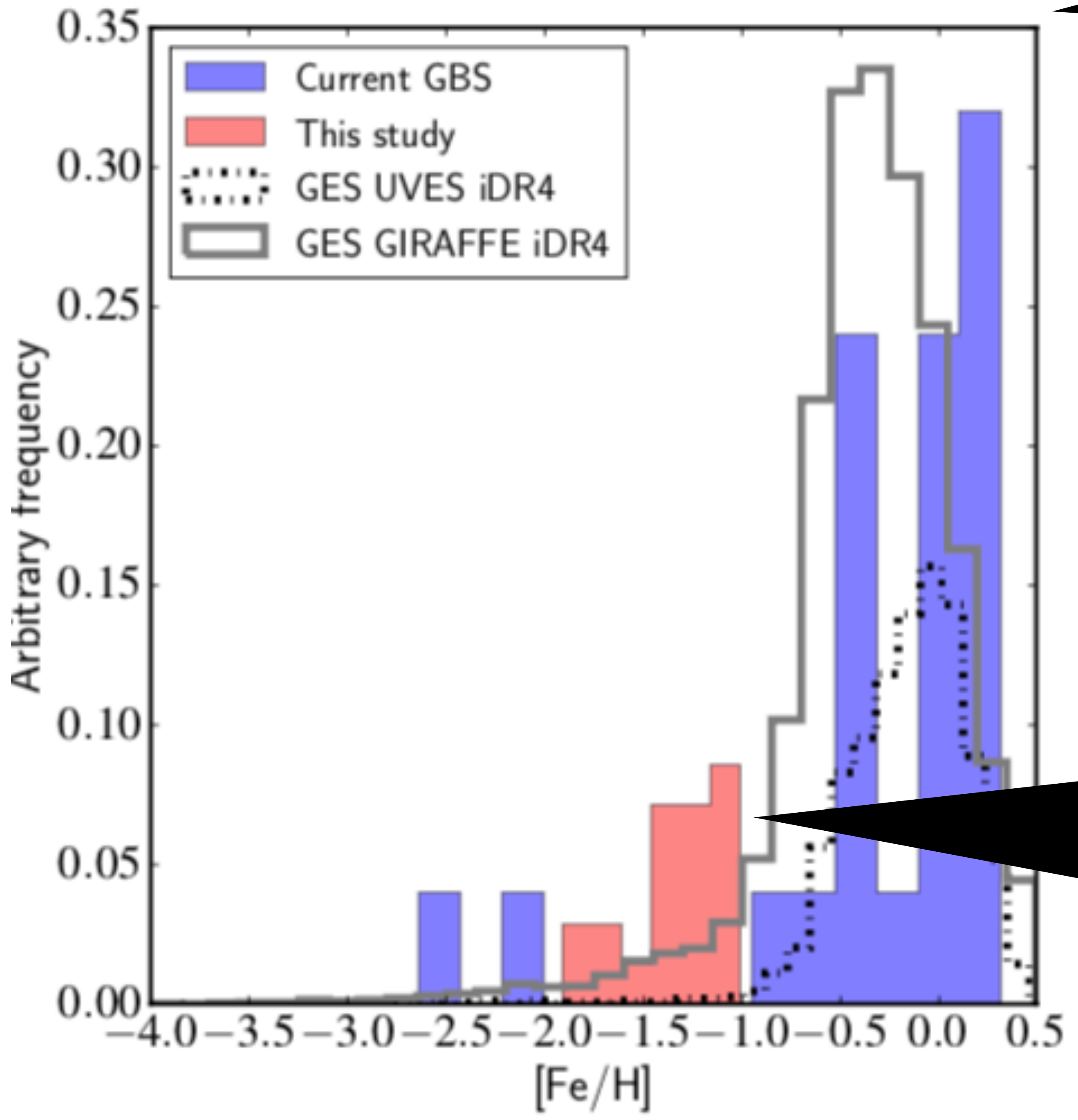
THE *Gaia* FGK BENCHMARK STARS VERSION 2.1*

Paula Jofré,[1] Ulrike Heiter,[2] Marcelo Tucci Maia,[1] Caroline Soubiran,[3] C. Clare Worley,[4] Keith Hawkins,[5] Sergi Blanco-Cuaresma,[6] and Carlos Rodrigo[7,8]

[1] *Núcleo de Astronomía, Facultad de Ingeniería y Ciencias, Universidad Diego Portales, Ejército 441, Santiago de Chile*
[2] *Department of Physics and Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden*

In CDS VizieR - VO - Jofre+2018 summary: recommended stars form all works to date + parameters determined by these works

2016: Towards GBS



Hawkins+2016

Table 4. Measured or calibrated angular diameters and bolometric fluxes, and their uncertainties (absolute, u, and in percent, $\%u$) for *Gaia* FGK benchmark stars.

Heiter+2015

Name	θ_{LD} [mas]	$u(\theta_{LD})$	$\%u(\theta_{LD})$	Band	Ref(θ_{LD})	F_{bol} [10^{-9} W m^{-2}]	$u(F_{bol})$	$\%u(F_{bol})$	Ref(F_{bol})
F dwarfs									
Procyon	5.390	0.030	0.6	K	Ch	17.8600	0.8900	5.0	A
HD 84937	0.153	0.005	3.0	–	K04*	0.0127	0.0001	1.1	B98
HD 49933	0.445	0.012	2.7	735 nm	B11	0.1279	0.0014	1.1	B98
FGK subgiants									
δ Eri	2.394	0.029	1.2	K	T	1.1500	0.0008	0.1	Bo13
HD 140283	0.353	0.013	3.7	720 nm	C15	0.0386	0.0008	2.0	A96*
ϵ For	0.788	0.016	2.0	–	K04*	0.1425	0.0066	4.6	H*
η Boo	2.189	0.014	0.6	K	vB	2.2100	0.0282	1.3	vB
β Hyi	2.257	0.019	0.8	700 nm	N07	2.0190	0.0525	2.6	B98
G dwarfs									
α Cen A	8.511	0.020	0.2	K	K	27.1600	0.2670	1.0	Bo13
HD 22879	0.382	0.011	3.0	–	K04*	0.0577	0.0006	1.1	B98
μ Cas	0.973	0.009	0.9	K'	Bo08	0.2504	0.0028	1.1	B98
τ Cet	2.015	0.011	0.5	K'	D	1.1620	0.0128	1.1	B98
α Cen B	6.000	0.021	0.4	K	B06	8.9800	0.1220	1.4	Bo13
18 Sco	0.676	0.006	0.9	700 nm	Ba	0.1734	0.0090	5.2	Bo13
μ Ara	0.763	0.015	2.0	–	K04*	0.2354	0.0047	2.0	A95*
β Vir	1.450	0.018	1.2	700 nm	N09	0.9590	0.0105	1.1	B98
FGK giants									
Arcturus	21.050	0.210	1.0	H	L	49.8000	1.2948	2.6	G
HD 122563	0.940	0.011	1.2	K	C12	0.1303	0.0061	4.7	H*
μ Leo	2.930	0.040	1.4	–	C99*	1.1458	0.0530	4.6	H*
β Gem	7.980	0.080	1.0	opt	M	11.8200	0.5319	4.5	M
ϵ Vir	3.280	0.030	0.9	opt	M	2.2100	0.0994	4.5	M
ξ Hya	2.386	0.021	0.9	K	T	1.2280	0.0319	2.6	B98
HD 107328	1.740	0.020	1.1	–	C99*	0.4122	0.0195	4.7	H*
HD 220009	2.045	0.034	1.7	800 nm	Tp	0.4409	0.0206	4.7	H*
M giants									
α Tau	20.580	0.030	0.1	K	RR	33.5700	1.3500	4.0	RR
α Cet	12.200	0.040	0.3	K	W4	10.3000	0.7000	6.8	W4
β Ara	5.997	0.037	0.6	K	Tp	3.7179	0.1718	4.6	H*
γ Sge	6.060	0.020	0.3	K	W3	2.5700	0.1300	5.1	W3
ψ Phe	8.130	0.200	2.5	K	W2	3.2000	0.3000	9.4	W2
K dwarfs									
ϵ Eri	2.126	0.014	0.7	K'	D	1.0000	0.0200	2.0	A96*
Gmb 1830	0.679	0.015	2.2	K	C12	0.0834	0.0009	1.1	B98
61 Cyg A	1.775	0.013	0.7	K	K08	0.3844	0.0051	1.3	M13
61 Cyg B	1.581	0.022	1.4	K	K08	0.2228	0.0032	1.4	M13

THE *Gaia* FGK BENCHMARK STARS

Paula Jofré,[1] Ulrike Heiter,[2] Marcelo Tucci Maia,[1] Caroline Soubiran
Sergi Blanco-Cuaresma,[6] and Carlos Ro

[1]*Núcleo de Astronomía, Facultad de Ingeniería y Ciencias, Universidad Dieg*
[2]*Department of Physics and Astronomy, Uppsala University, Bo*

In CDS VizieR - VO - Jofre+2018 summary: recommended
parameters determined by these w

Progress since 2016

Progress since 2016

Not a patch solution for metal-poor stars anymore!

Fundamental stellar parameters of benchmark stars from CHARA interferometry

I. Metal-poor stars

2020

I. Karovicova[1,2], T. R. White[3,4], T. Nordlander[5,6], L. Casagrande[5,6], M. Ireland[5], D. Huber[7], and P. Jofré[8]

The JMMC Stellar Diameters Catalog v2 (JSDC): A New Release Based on SearchCal Improvements

L. Bourgès,[1] S. Lafrasse,[1] G. Mella,[1] O. Chesneau,[2] J.-B. Le Bouquin,[1] G. Duvert,[1] A. Chelli,[1] and X. Delfosse[1]

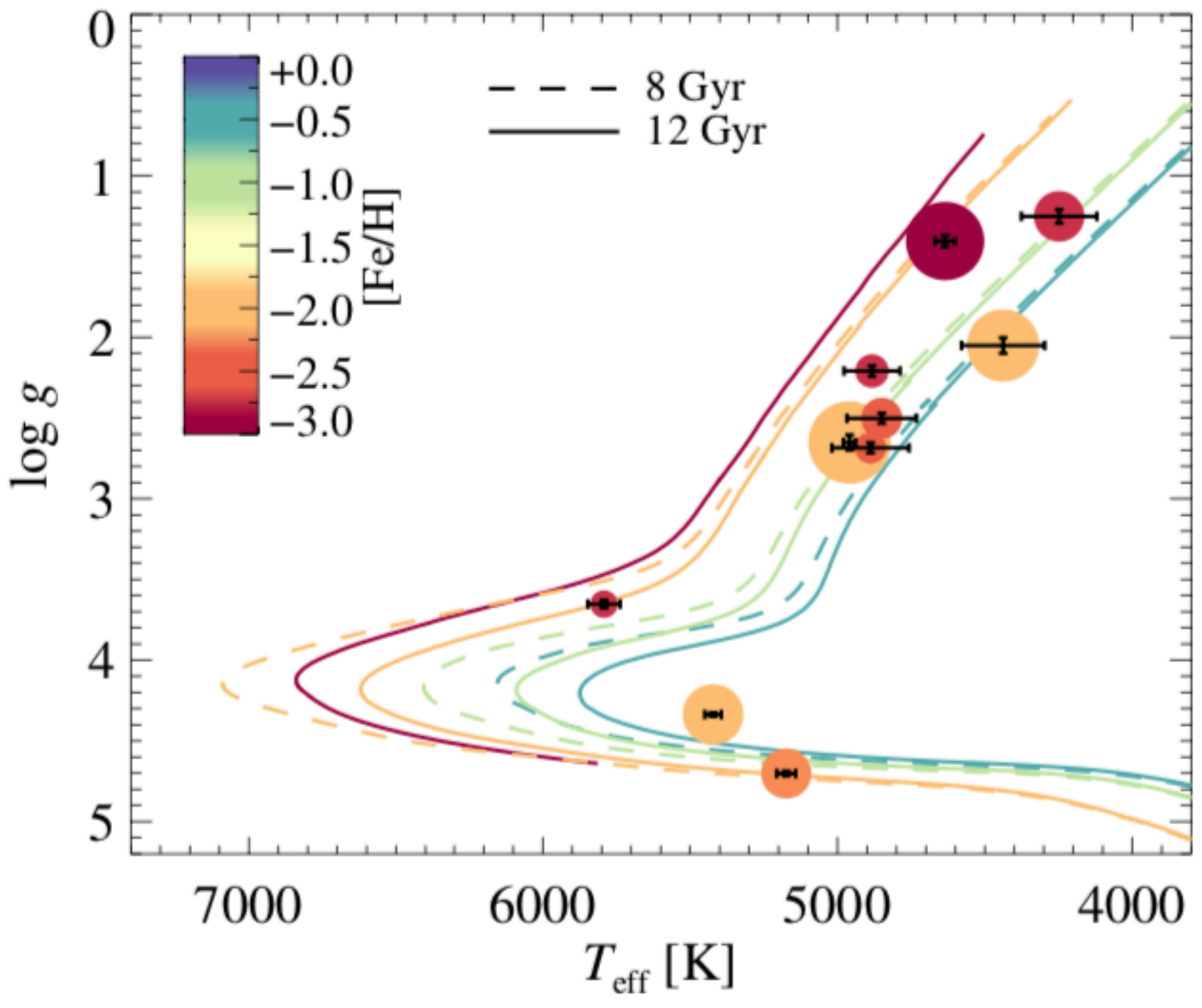
[1]*UJF-Grenoble 1 / CNRS-INSU, Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), UMR 5274, Grenoble, F-38041, France*

[2]*Laboratoire Lagrange, UMR 7293, Université de Nice Sophia-Antipolis, CNRS, Observatoire de la Côte d'Azur, Bd. de l'Observatoire, 06304 Nice, France*

~900 stars - assembly from literature with updates in Vizier

The 07-Feb-2020 version includes 1672 measurements

And Gaia new parallaxes!!!



A bloody F star - Creevey :)

The subgiant HR 7322 as an asteroseismic benchmark star

Amalie Stokholm,[1★] Poul Erik Nissen,[1] Víctor Silva Aguirre,[1] Timothy R. White,[1,2] Mikkel N. Lund,[1,3], Jakob Rørsted Mosumgaard[1], Daniel Huber[4,5,6,1], and Jens Jessen-Hansen[1]

[1]*Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark.*
[2]*Research School of Astronomy and Astrophysics, Australian National University, Canberra, ACT 2611, Australia*
[3]*School of Physics & Astronomy, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK*
[4]*Institute for Astronomy, University of Hawai'i, 2680 Woodlawn Drive, Honolulu, HI 96822, USA*
[5]*Sydney Institute for Astronomy (SIfA), School of Physics, University of Sydney, NSW 2006, Australia*
[6]*SETI Institute, 189 Bernardo Avenue, Mountain View, CA 94043, USA*

2019

Calibrating the surface brightness – color relation for late-type red giants stars in the visible domain using VEGA/CHARA interferometric observations

2020

N. Nardetto[1], A. Salsi[1], D. Mourard[1], V. Hocdé[1], K. Perraut[2], A. Gallenne[1,3,4,5], A. Mérand[6], D. Graczyk[3,4], G. Pietrzynski[4], W. Gieren[3], P. Kervella[7], R. Ligi[8], A. Meilland[1], F. Morand[1], P. Stee[1], I. Tallon-Bosc[9], and T. ten Brummelaar[10,11]

More giants of sub solar metallicities

Towards GBS v3

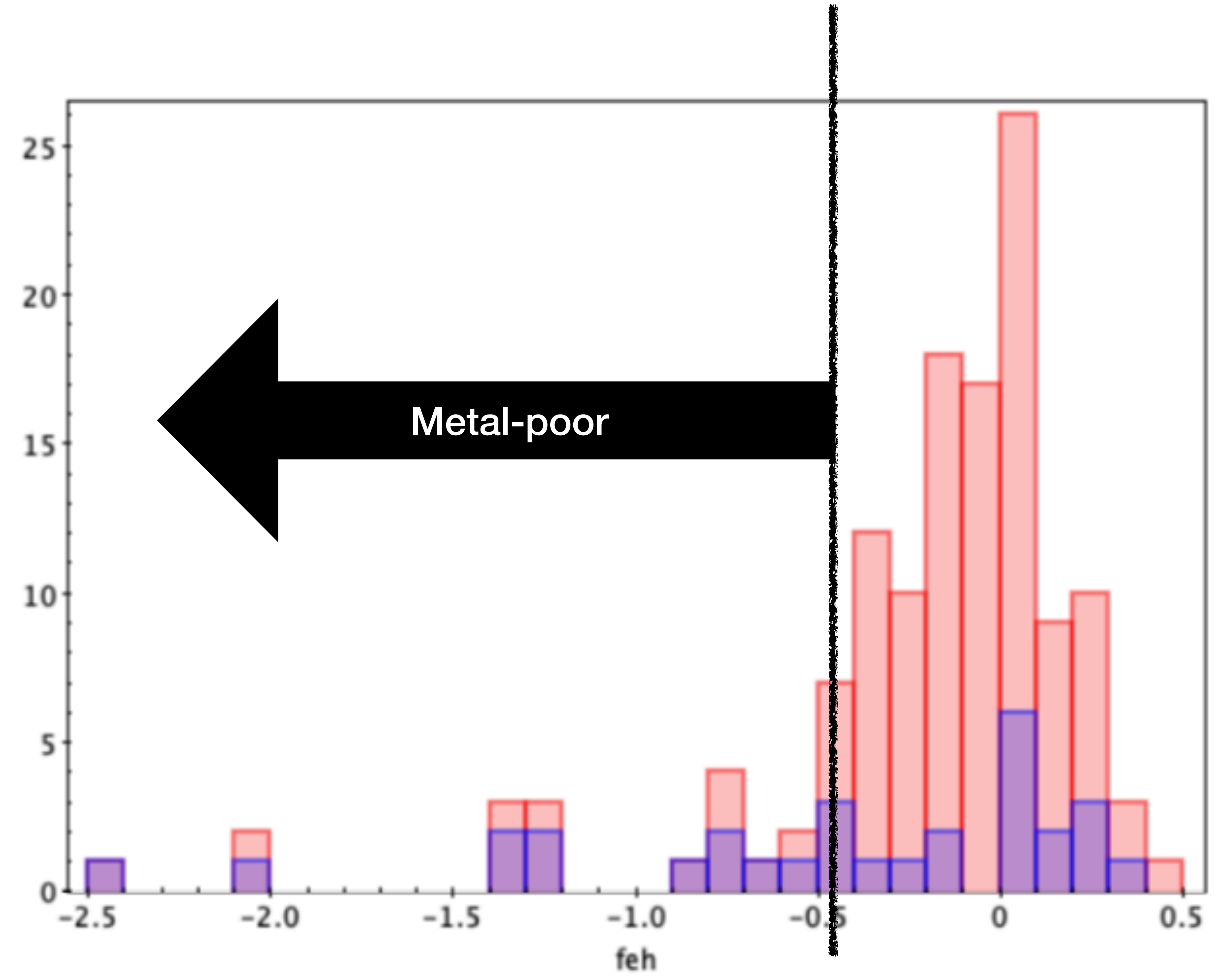
Towards GBS v3

Clean JMDC catalogue:

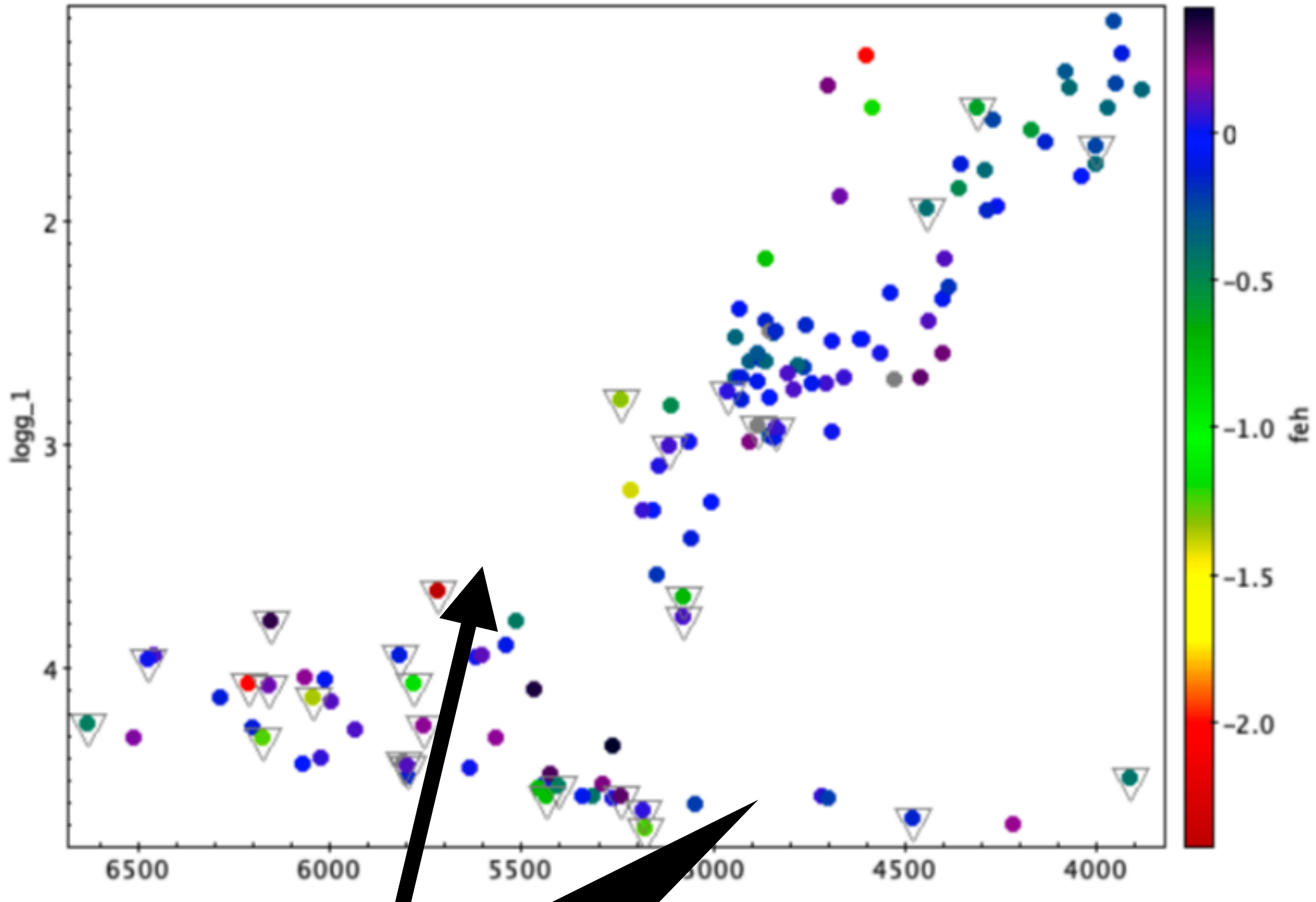
- following Selsi+2020
  - Remove Variables, Miras, Cepheids, etc.
  - Remove uncertain angular diameters (too disperse if >1 measurement, uncertainty reported > 8%, bad observing conditions, etc)
  - Remove stars with uncertain photometry
  - Keep the FGK type
- Add our own special stars
  - Metal-poor Karovicova + Nardetto + Stockholm + favourites from GBS v2.1 & few more

So far ~150 stars

Parameter coverage taken from PASTEL (Soubiran+2018)



7 new metal-poor stars
Lots of new metal rich stars
Blue: GBS v2.1
Red: GBS v3

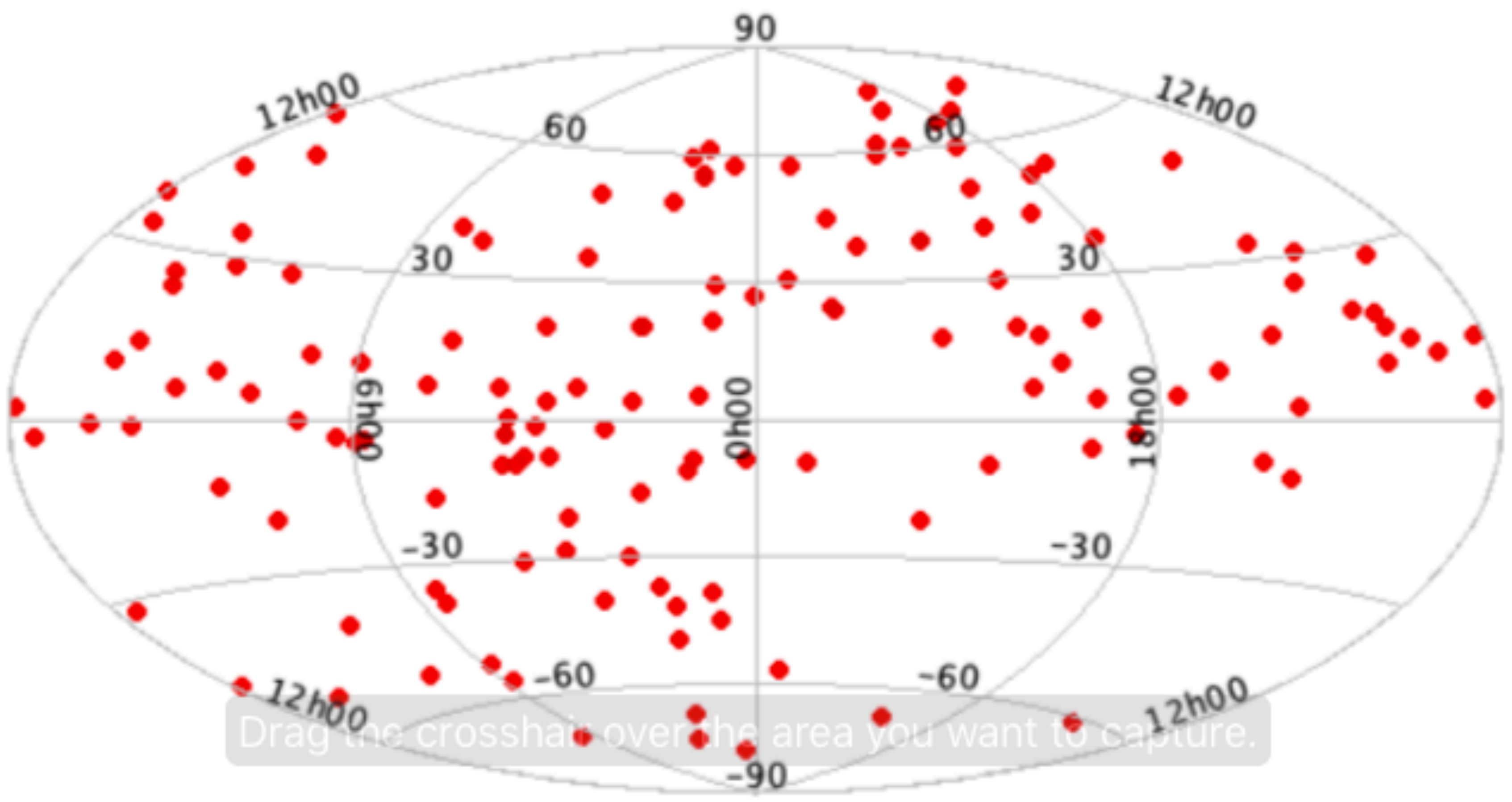


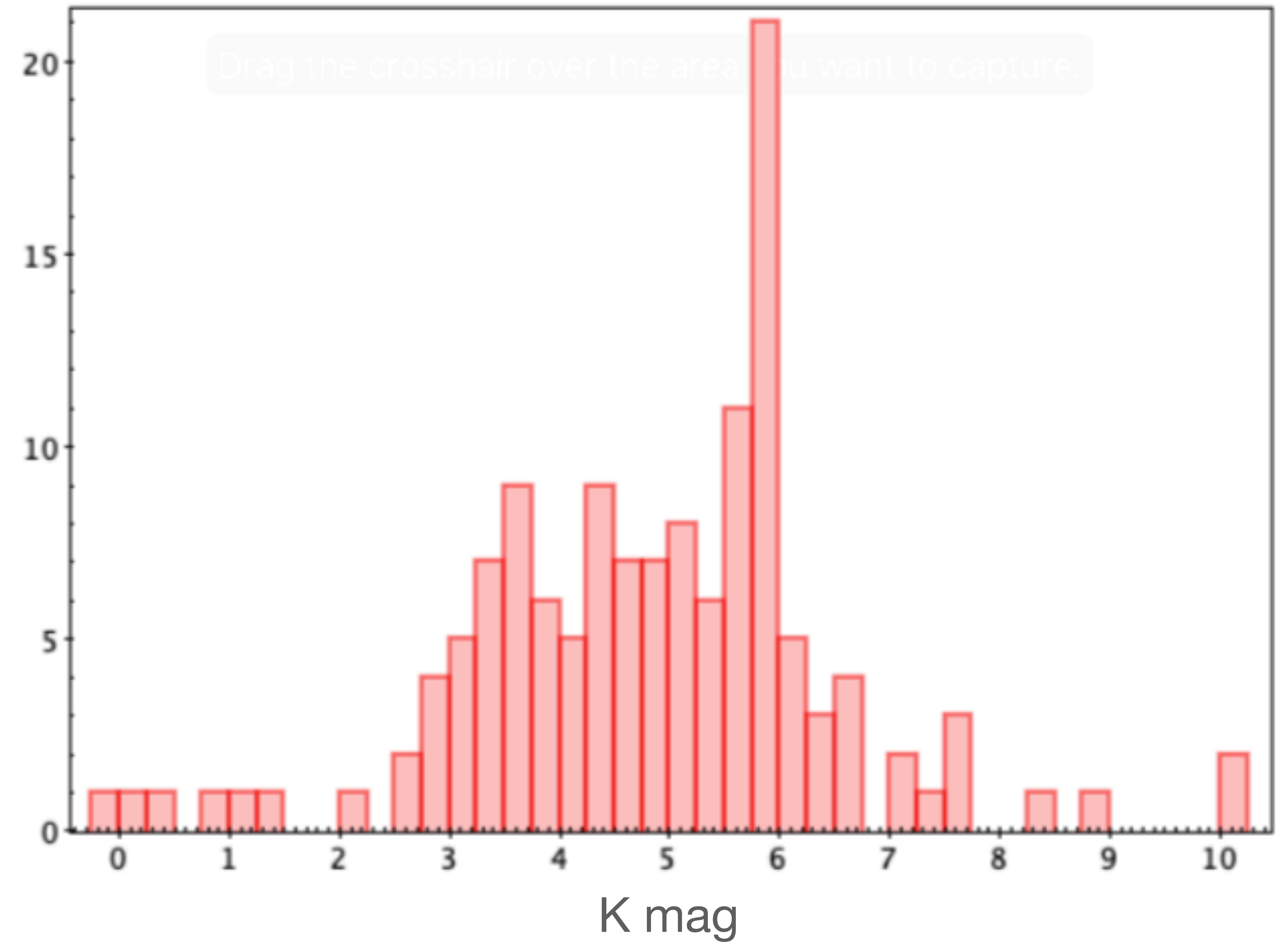
Triangles GBS v2.1

Still some gaps that might be filled by looking into JMDC and changing the "cleaning steps"

So far ~150 stars

Sky and magnitude coverage taken VizieR & Simbad





~ half of the sample has high res spectra from public archives
Effort to get spectra from both hemispheres

Beyond 2021

Beyond
SPICA

https://lagrange.oca.eu/fr/spica-project-overview

The CHARA/SPICA project aims at providing the astronomical community with a large and homogeneous set of measured stellar parameters over the Hertzsprung-Russel (HR) diagram.

It is based on a survey of ~1000 stars that will be observed with a new visible interferometric instrument *CHARA/SPICA (Stellar Parameters and Images with a Cophased Array)* assisted by a near-infrared fringe tracker.

… moreover preparing the arrival of new data on brighter systems with *K2, TESS, CHEOPS, and PLATO*, supports the idea of massively exploring this field of research.
Our project aims at establishing a **homogeneous catalogue of about 1000 stellar diameters over the whole HR diagram**.

6 - Effect of metallicity on stellar fundamental parameters, LD and SBCR:

- **WP13 – Galactic Archeology:** ***C. Soubiran, O. Creevey, P. de Laverny, N. Nardetto***

Milky Way Mapper SDSS-V
All kinds of stars (APOGEE-BOSS) for mapping the Galaxy
(Jennifer Johnson)

Abundances Working Group
Paula Jofre & Szabolcz Meszaros

Building our reference sample:
Using the know-how from previous experiences

GALAH DR3 - APOGEE DR17 - Gaia-ESO

Building our reference sample:
Using the know-how from previous experiences

GALAH DR3 - APOGEE DR17 - Gaia-ESO

gold: cut in parallax/ mag, etc…

Gold term is currently under debate

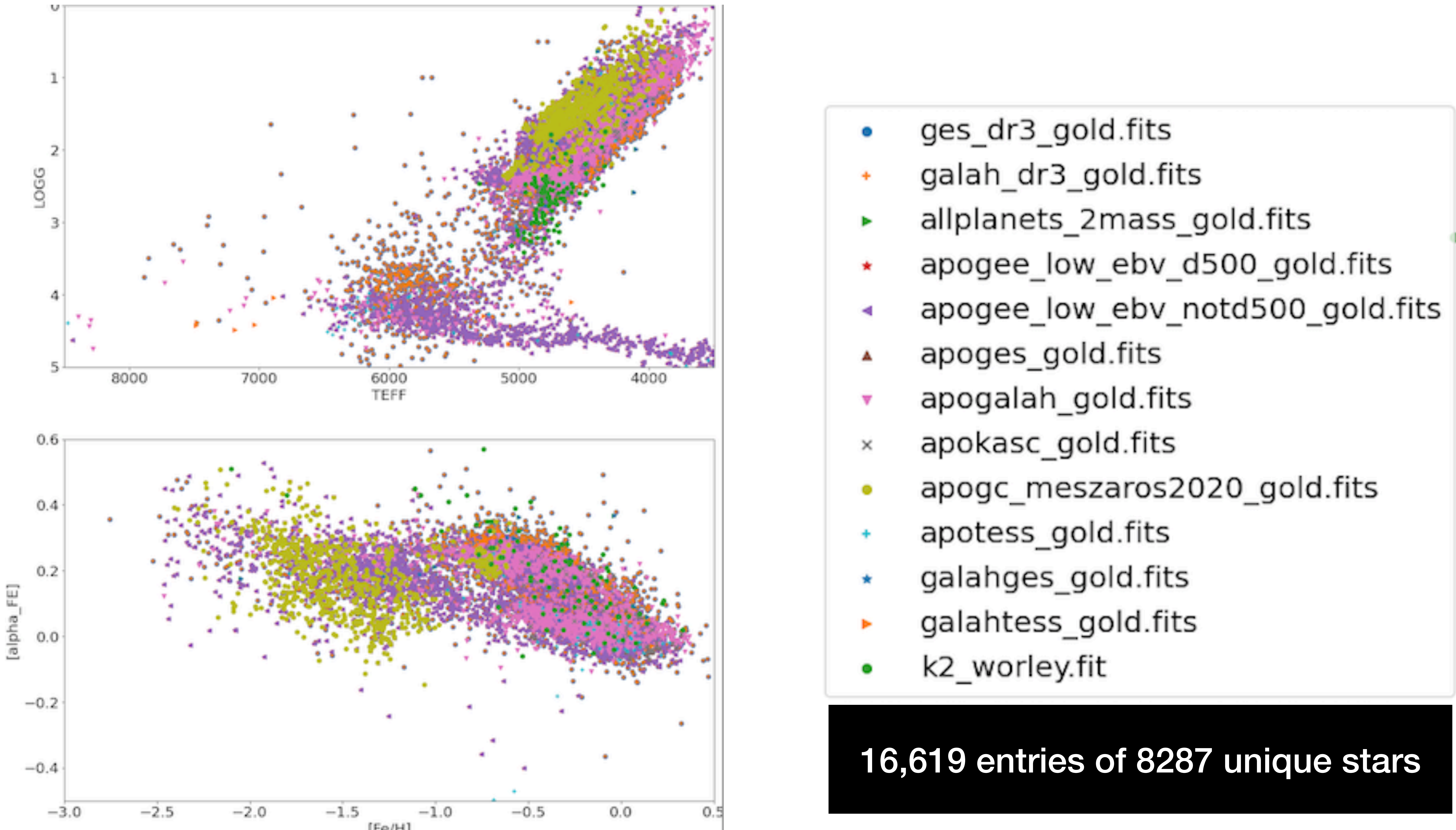
16,619 entries of 8287 unique stars

Building our reference sample:
Using the ow-how from previous experiences

WORK
IN PROGRESS

GALA APOGEE DR17 - Gaia-ESO

What is a reasonable size? How to get to it?
HELP !!!



16,619 entries of 8287 unique stars

Final remarks

A reference set for next gen surveys

- It is our duty (the survey makers) to get the spectral data right - not the duty of the user to apply zero point calibrations
- The variety of stars, instruments and expertise will make us progress in mapping our Galaxy greatly if:
  - We reach a consensus on the reference stars we want to adopt to develop our own diverse pipelines.
    - We shall dispute on the true value of our reference stars, but not on the sample! Let's use our experience from GALAH/GES/APOGEE and collaborate as much as we can in building this reference set.
  - **Thanks Dianne & Gregor** for this initiative, this step is key.