The InfraRed Flux Method for PLATO

Luca Casagrande

Australian National University

in collaboration with J González Hernández and WP122300.

Partly based on PLATO-ANU-PSPM-TN-0055.

Seven Sisters Walking. Copyright Alma Nungarrayi Granites.

What is the InfraRed Flux Method (IRFM)?

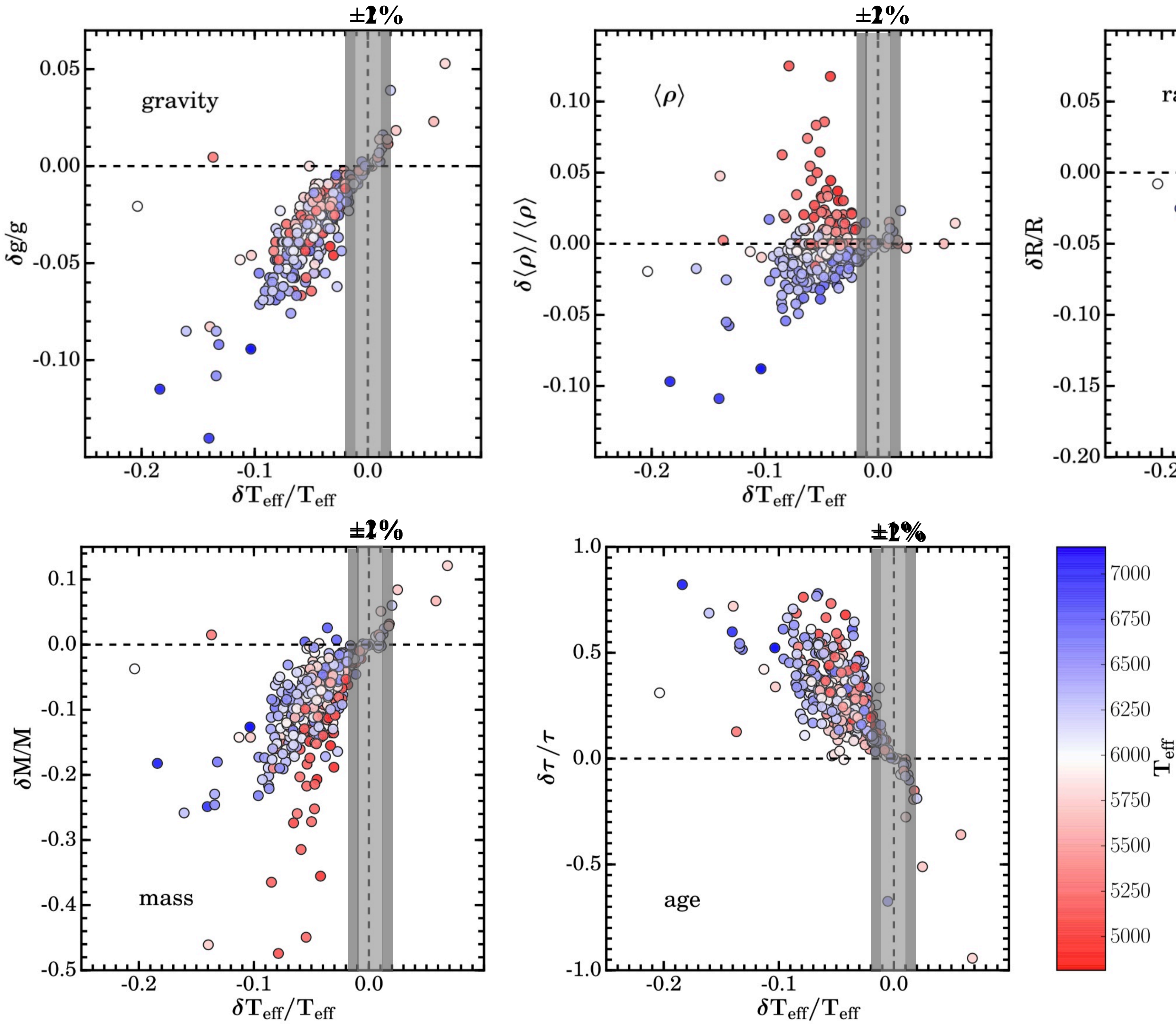
- A method to determine effective temperatures, angular diameters and bolometric fluxes in stars (A**FGK**M type).
- Based on photometry.

Why the IRFM?

- Arguably, the second most direct method to determined T_{eff} after interferometry.
- Computationally cheap, all you need is good photometry.

What can the IRFM do for PLATO?

Impact of T_{eff} on seismic parameters



APOKASC catalog of Kepler dwarf and subgiant stars (Serenelli et al. 2017).

See also e.g., Valle et al. (2018), Bellinger et al. (2019).

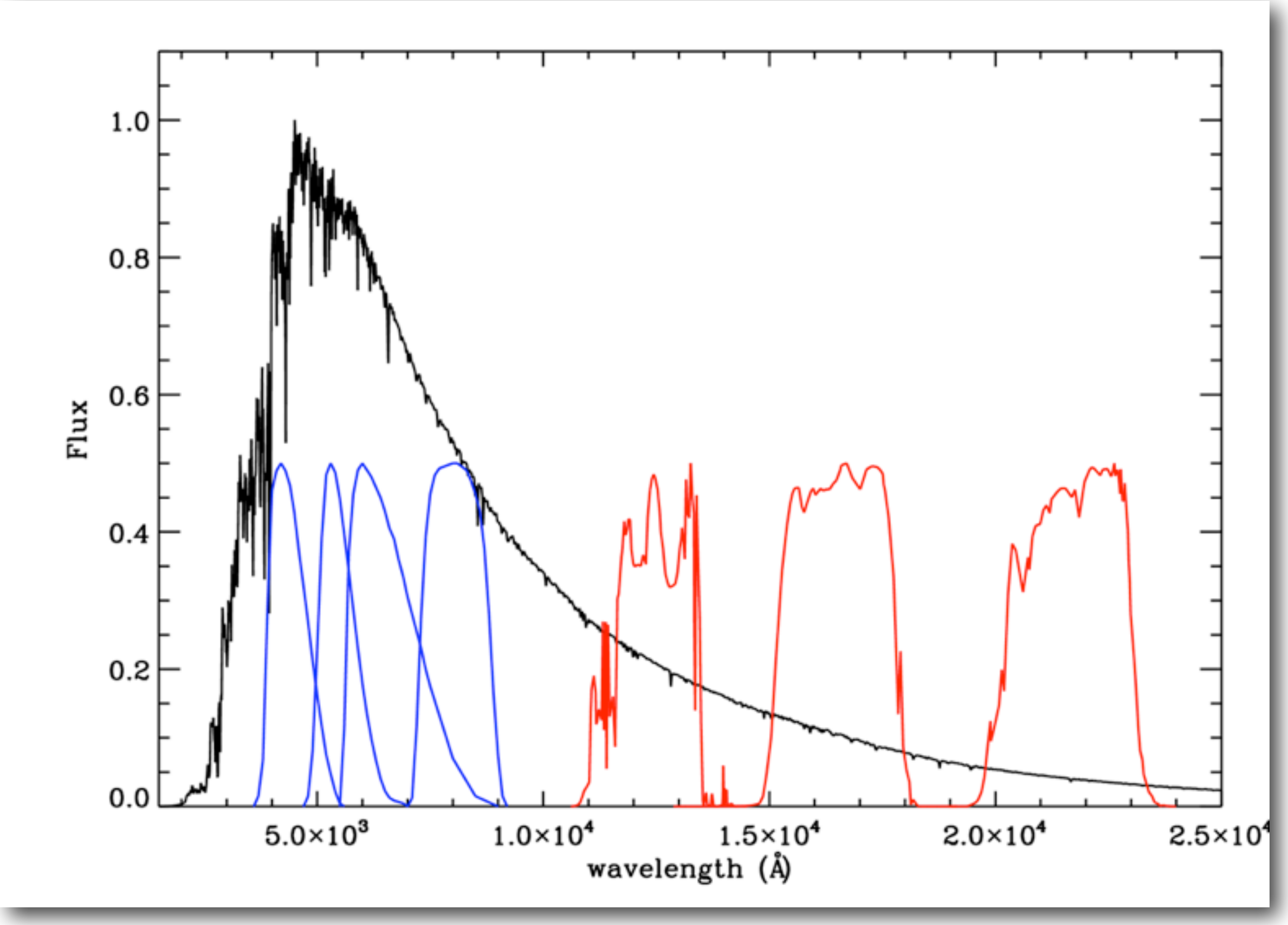
IRFM in a nutshell

see e.g., Casagrande et al. (2006, 2010), González-Hernández & Bonifacio (2009).

- Mostly empirical (80%)
- weak sensitivity of broad-band photometry to logg and [Fe/H].

$$\leftarrow \quad \frac{\mathcal{F}_{Bol}(\mathrm{Earth})}{\mathcal{F}_{\mathrm{IR}}(\mathrm{Earth})} = \frac{\sigma T_{\mathrm{eff}}^4}{\mathcal{F}_{\mathrm{IR}}(\mathrm{model})} \quad \rightarrow$$

Rayleigh-Jeans tail.



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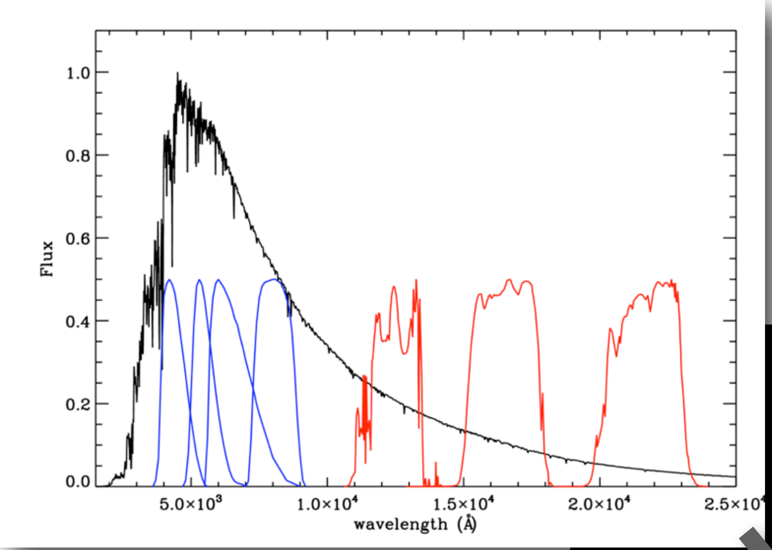
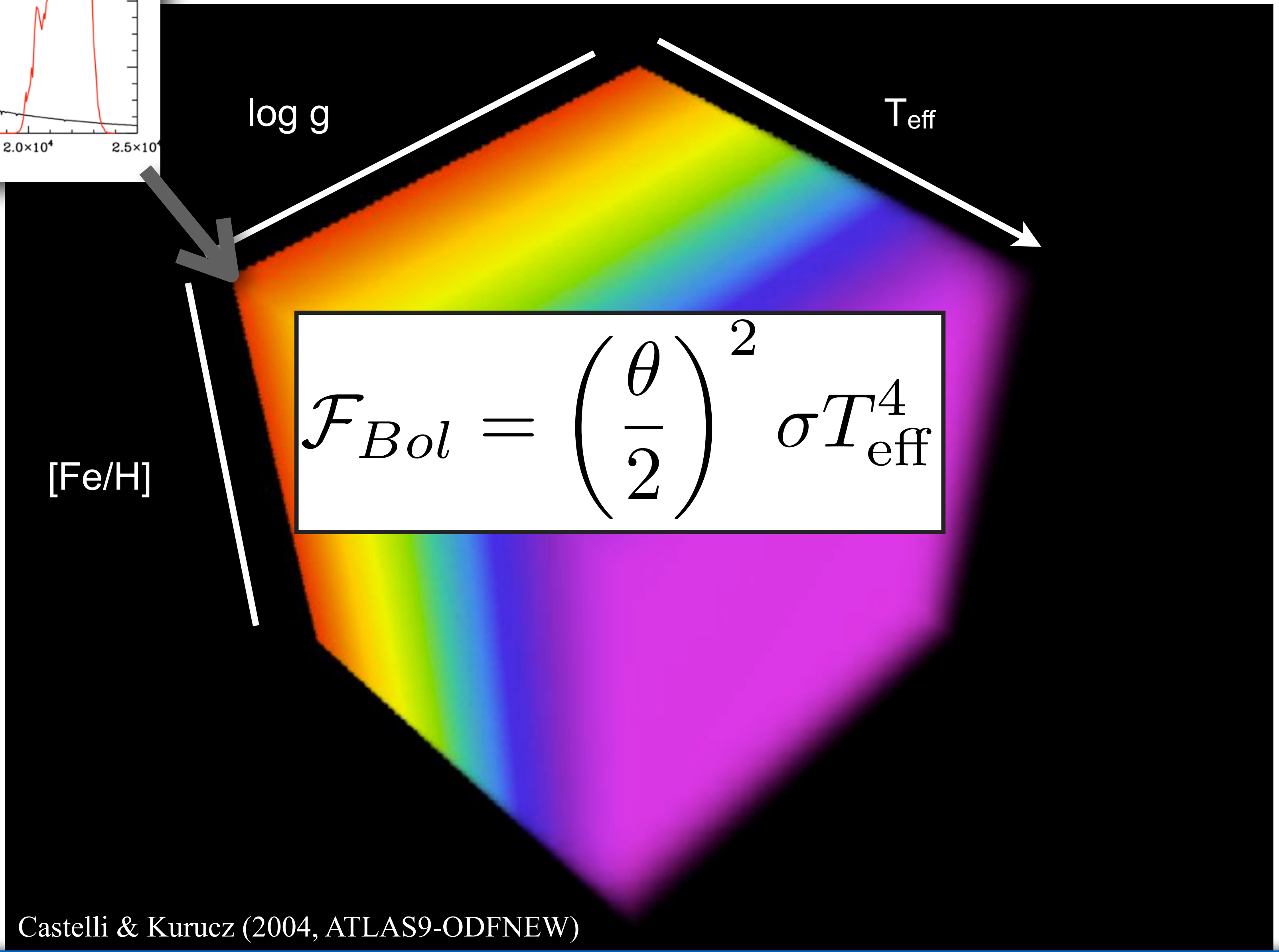
IRFM in a nutshell

see e.g., Casagrande et al. (2006, 2010), González-Hernández & Bonifacio (2009).



$$\frac{\mathcal{F}_{Bol}(\text{Earth})}{\mathcal{F}_{\text{IR}}(\text{Earth})} = \frac{\sigma T_{\text{eff}}^4}{\mathcal{F}_{\text{IR}}(\text{model})}$$



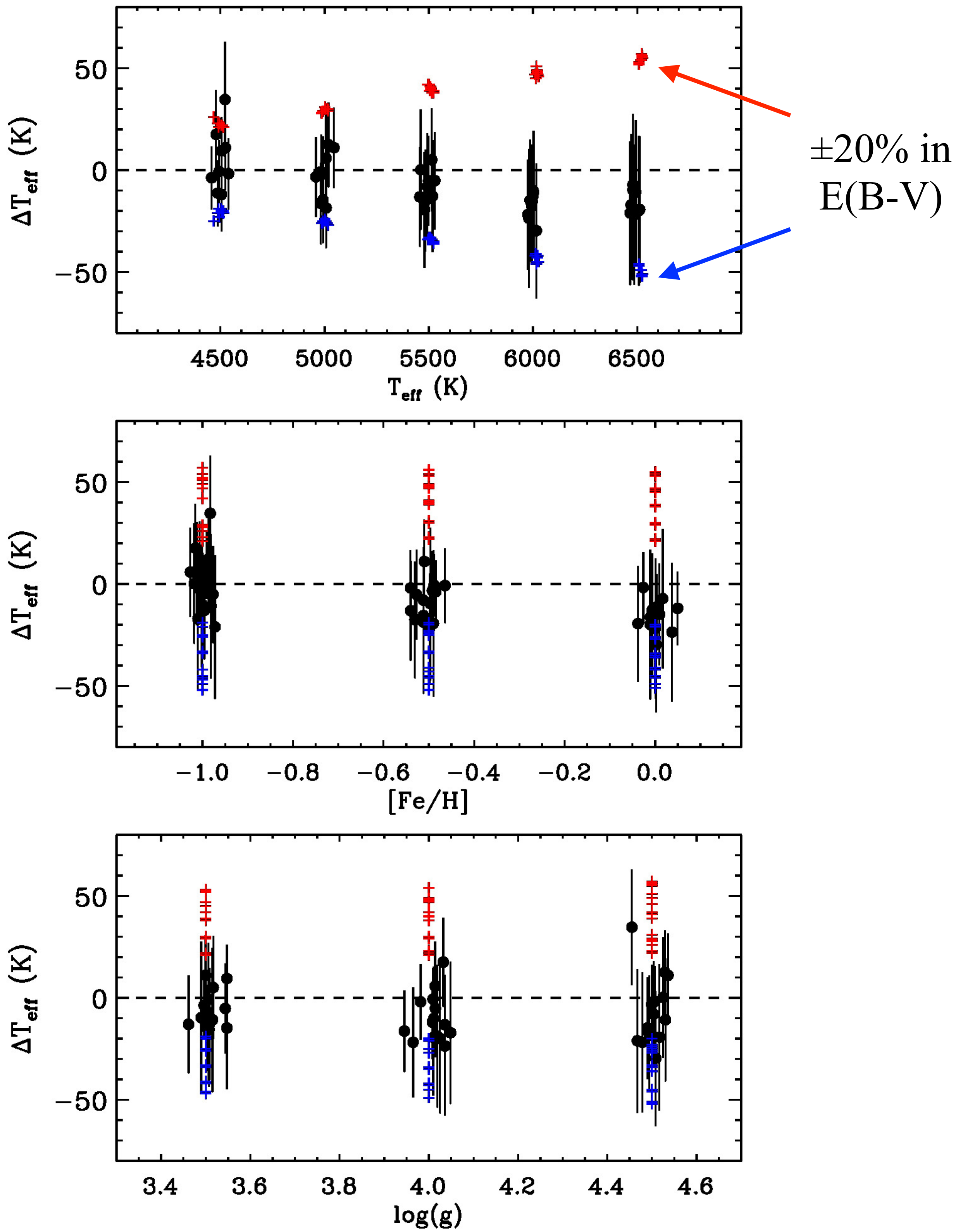
$$\mathcal{F}_{Bol} = \left(\frac{\theta}{2}\right)^2 \sigma T_{\text{eff}}^4$$

Castelli & Kurucz (2004, ATLAS9-ODFNEW)

IRFM in a nutshell

Error budget:

- zero-point (1% in flux → 20K).
- model fluxes: ~20 K.
- photometry (Montecarlo): 30-50 K.
- log(g): ± 0.5 dex → ~20 K.
- [Fe/H]: ± 0.1dex → ~20 K.
- beyond local bubble, reddening is the largest source of uncertainty.



IRFM in a nutshell

Different grids of model fluxes are implemented:
MARCS and ATLAS9-ODFNEW are currently used. Differences are typically a few K only.

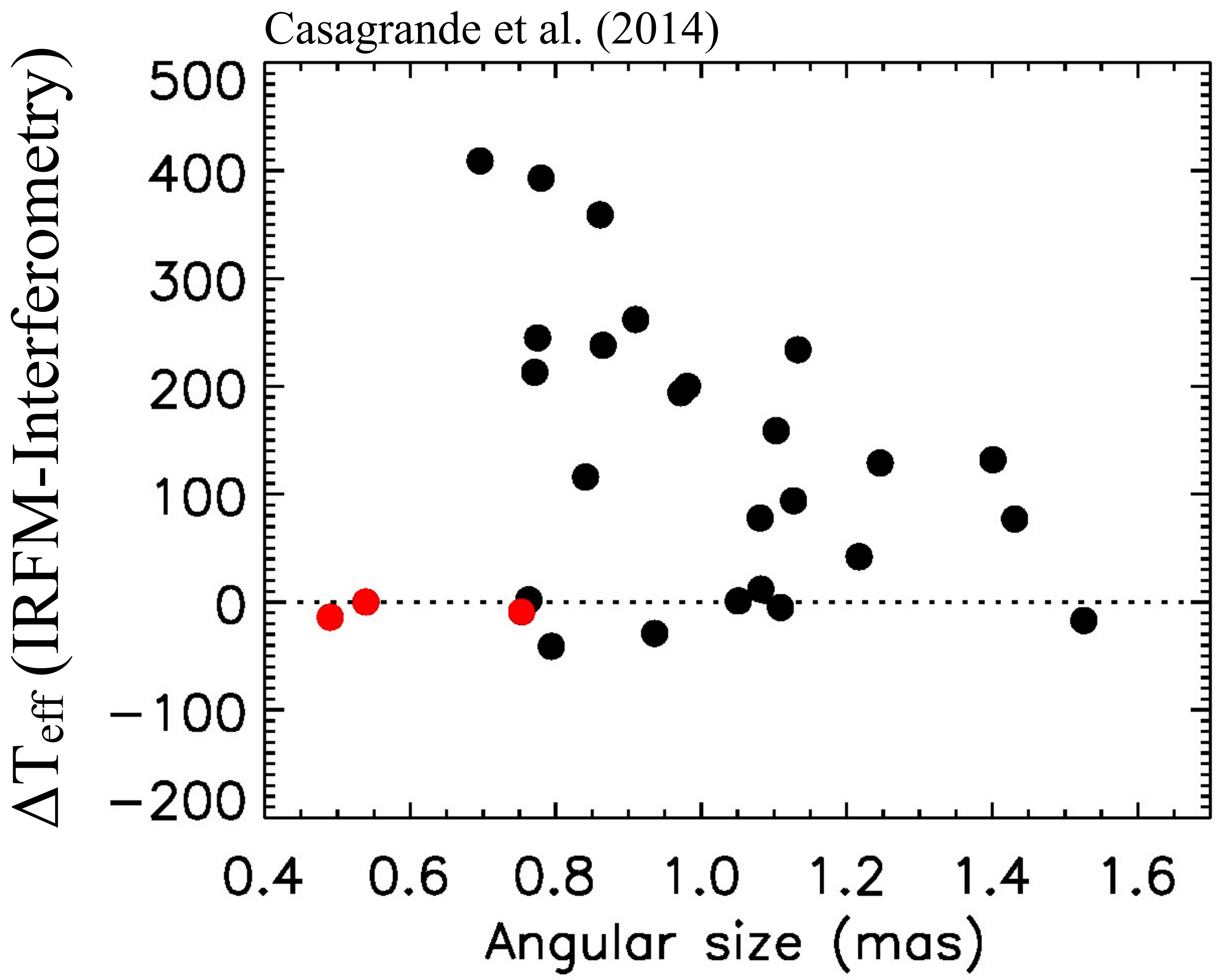
Different photometric systems are implemented:
OPTICAL: **Gaia, Tycho2**, SkyMapper, APASS, Johnson-Cousins.
INFRARED: **2MASS**, SAAO.

Little sensitivity to adopted log(g) and [Fe/H]:
It can be applied to all PLATO targets, as long as they have photometry.

Fundamentally tied to absolute fluxes and/or interferometry.

Reddening:
Currently the main limitation … or maybe not!

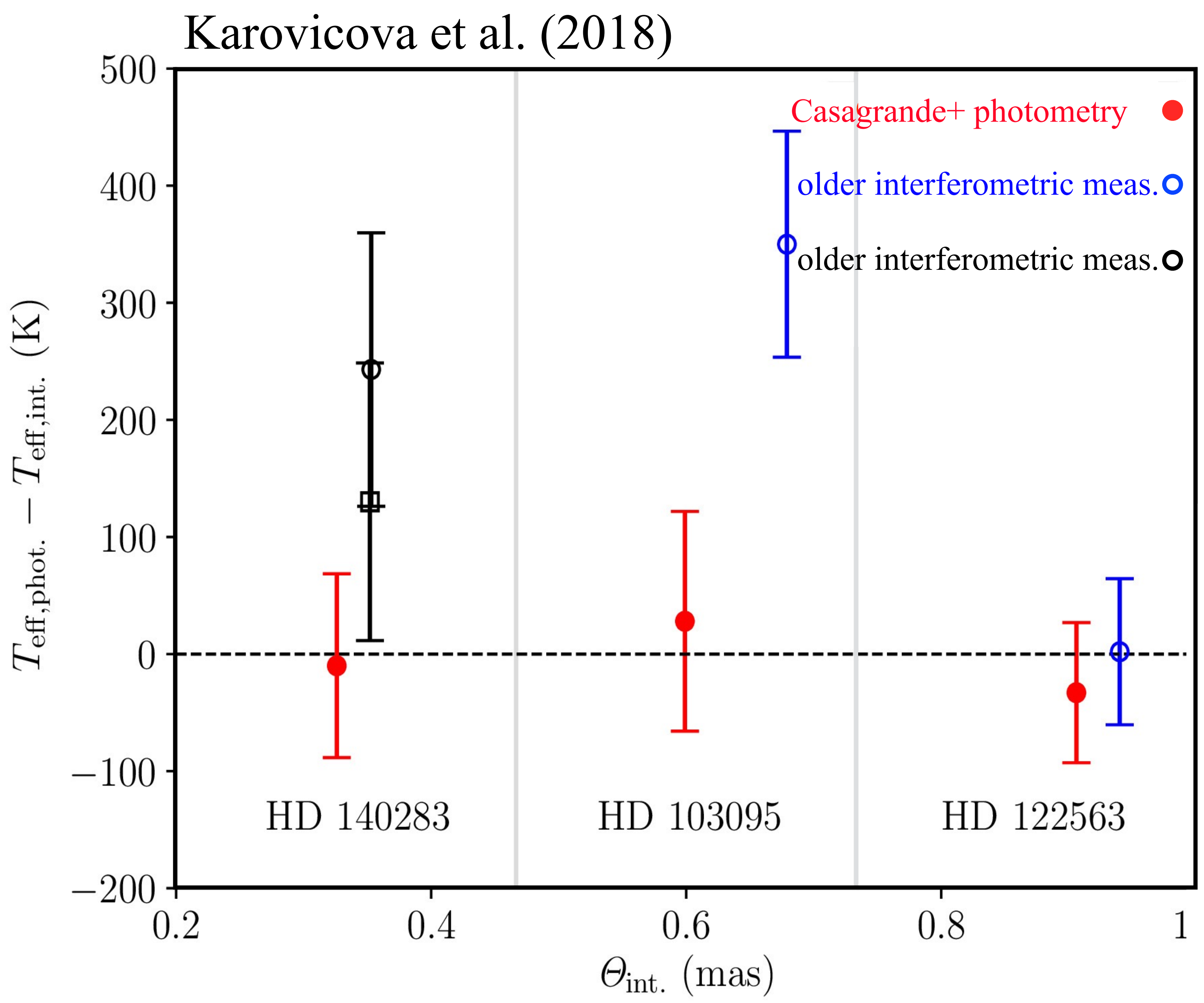
Comparing T_{eff} from interferometry



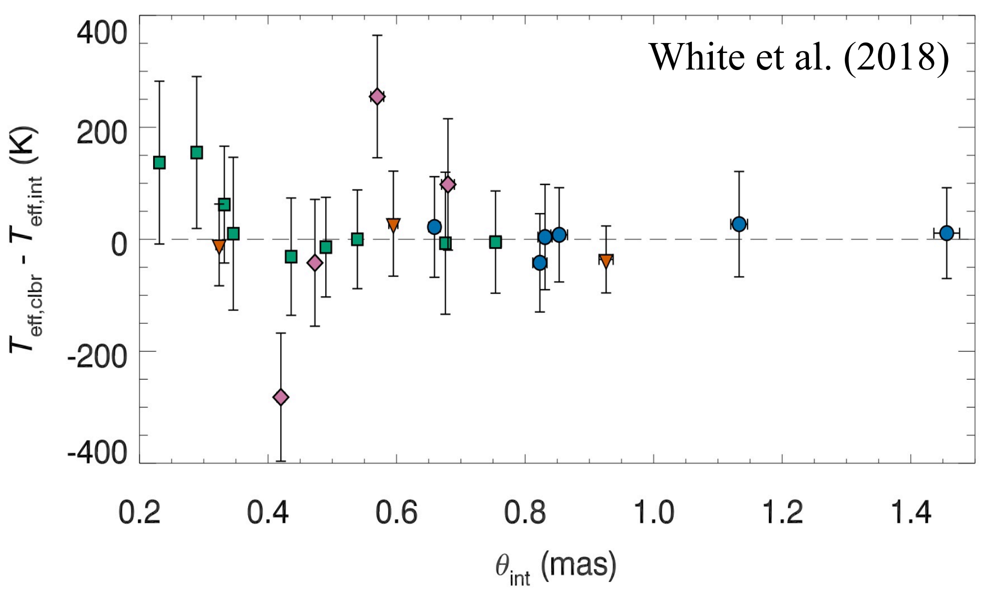
Discrepancy between interferometric and IRFM T_{eff} increases as angular diameters gets smaller (Boyajian et al. 2012).

Agreement when stars are interferometrically well resolved (White et al. 2013).

Comparing T_{eff} from interferometry



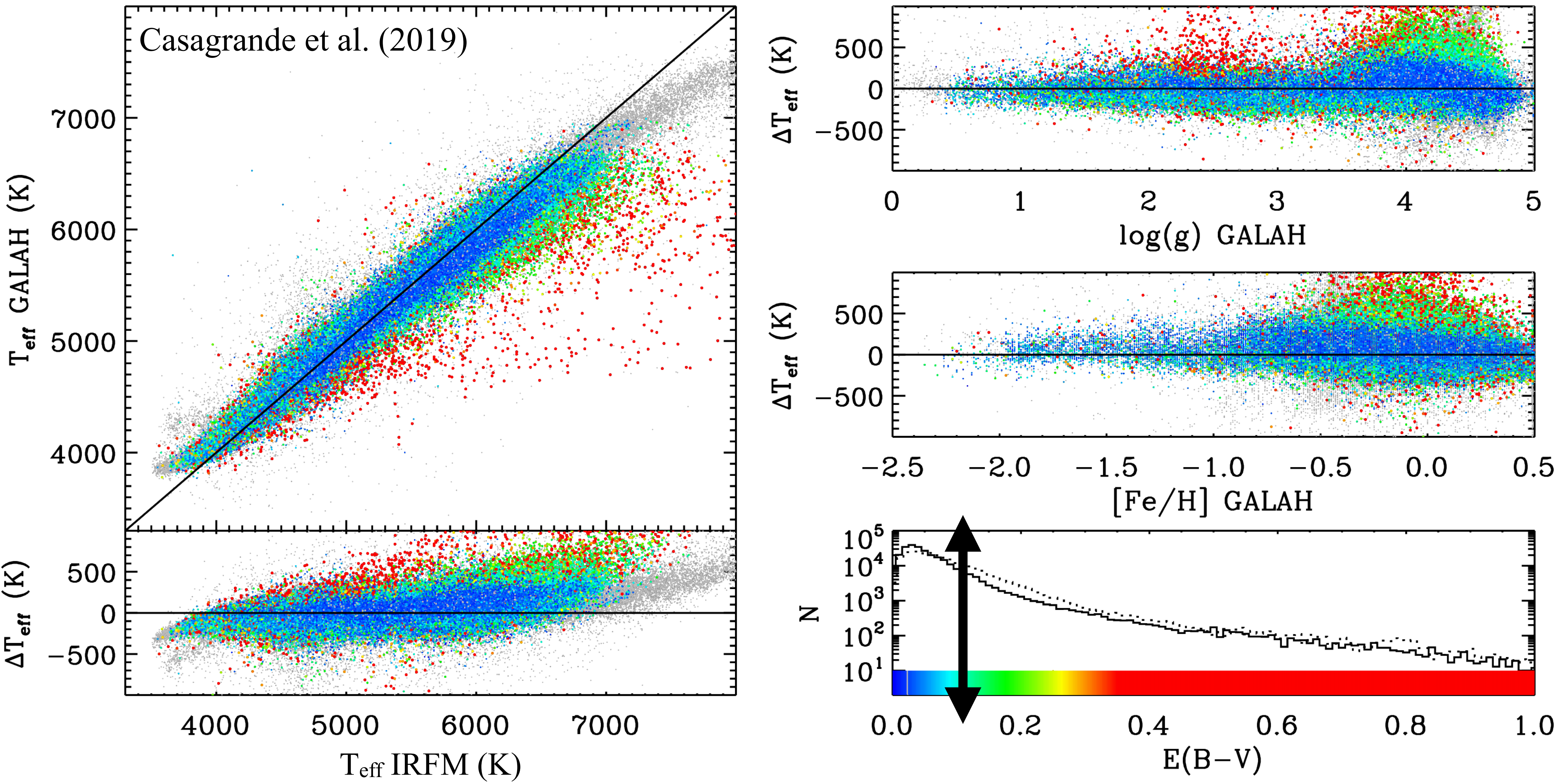
Trend predicted by the IRFM now confirmed by newer interferometric measurements (better sampling of visibilities and larger number of calibrators used).



Reddening

Reddening

IRFM on 0.5 million stars from the Galah Spectroscopic Survey.
Simple assumptions on reddening (rescaling of SFD98 map, using clump stars as standard crayons).



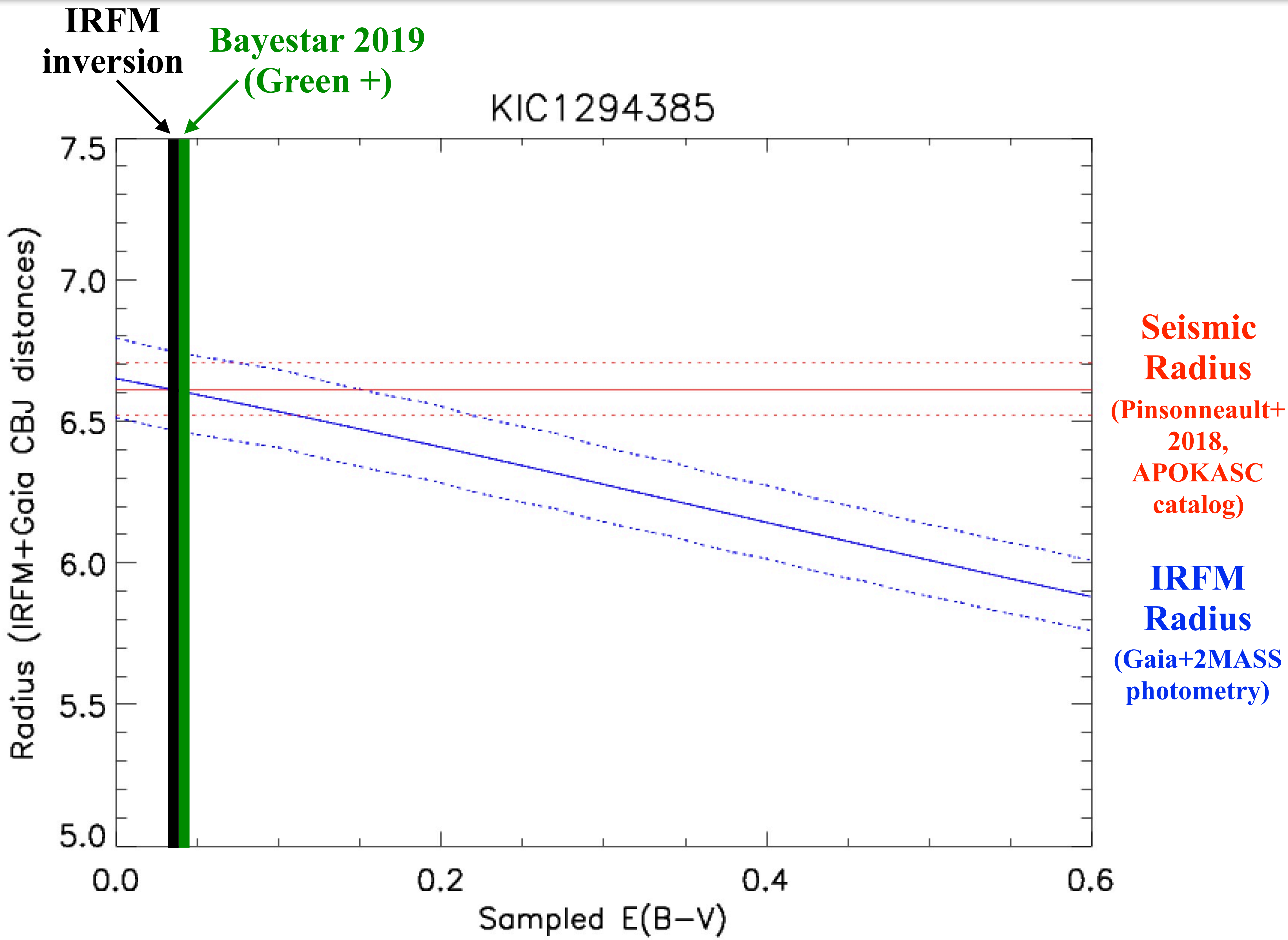
Reddening

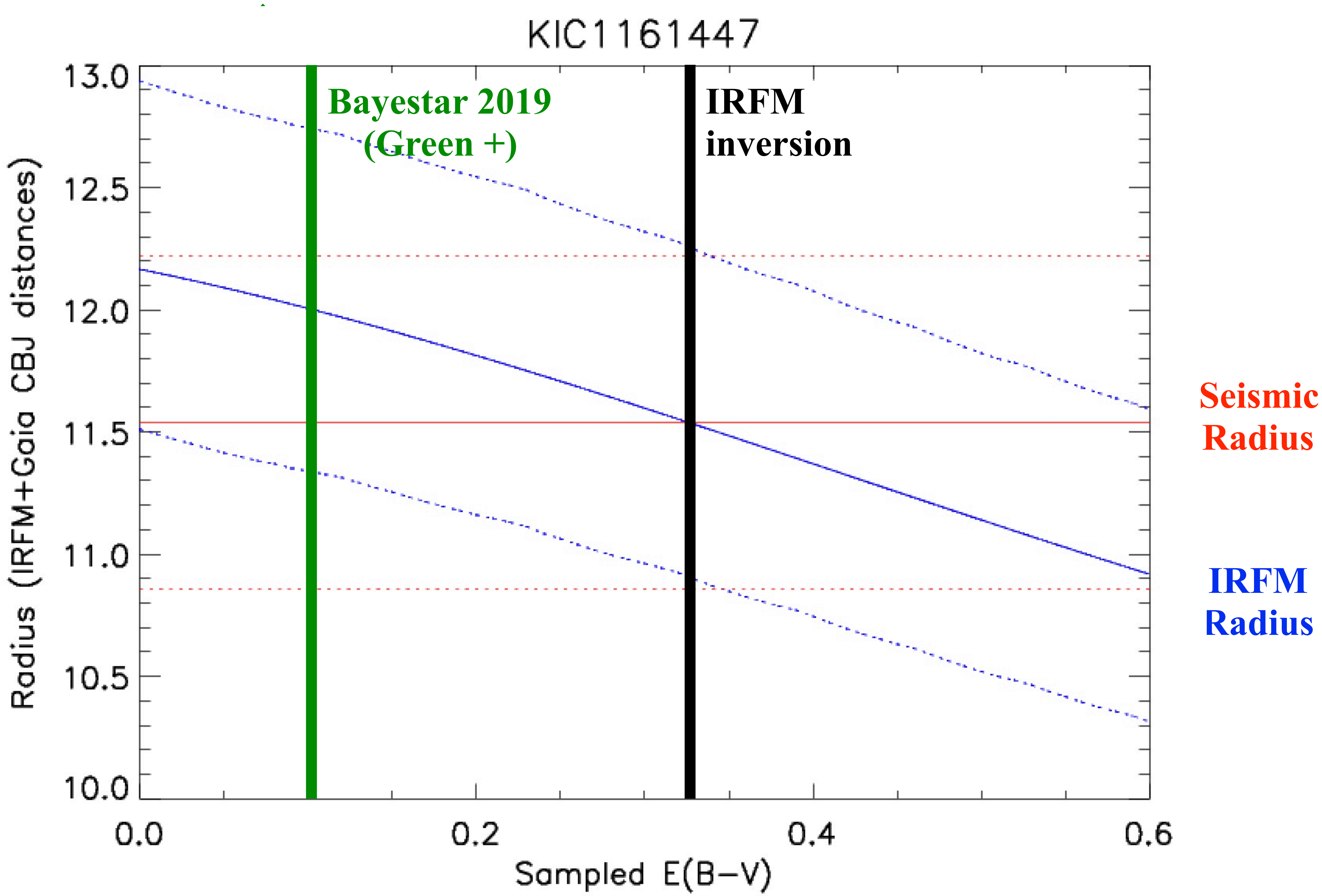
If reddening is (reasonably) known:

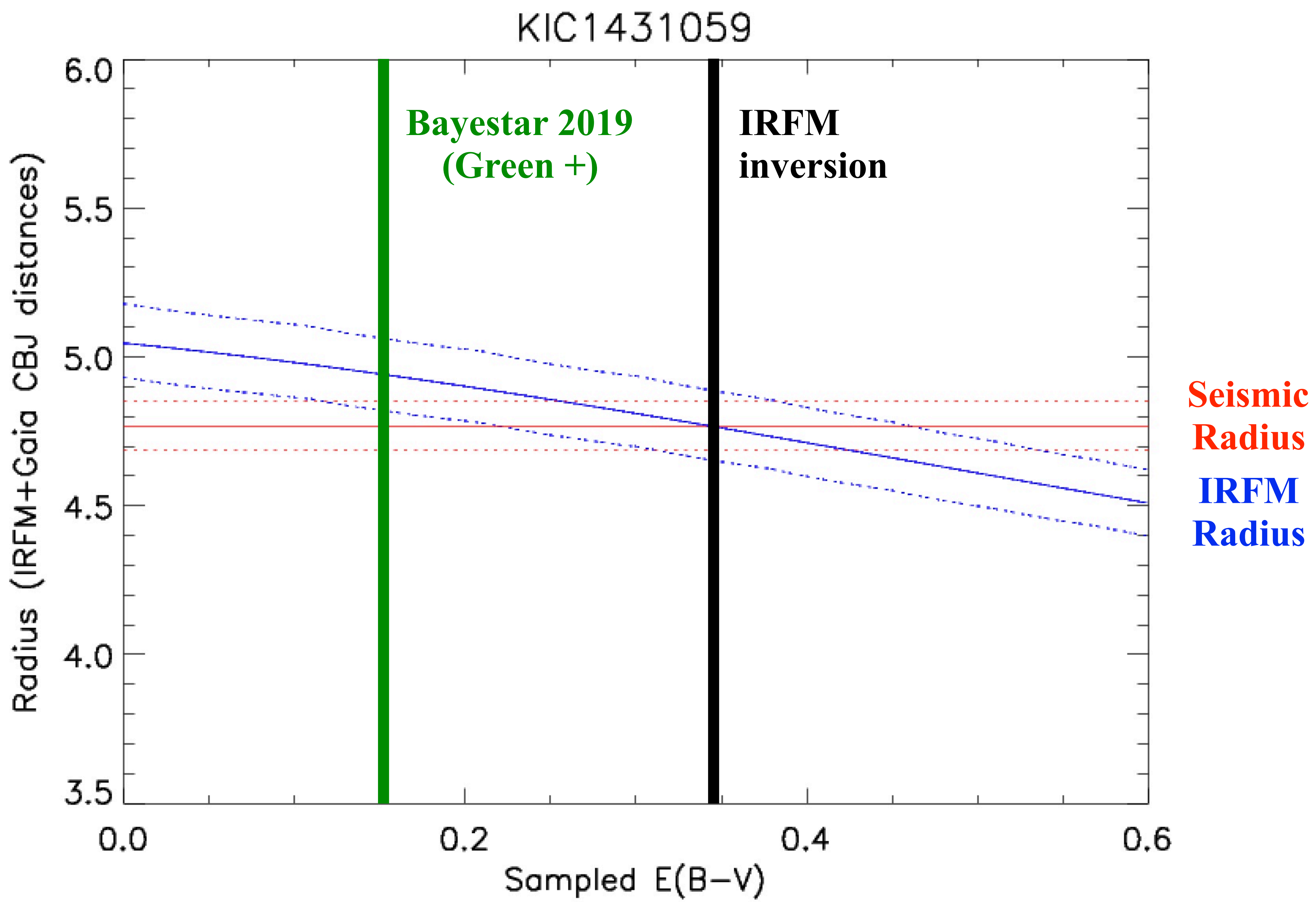
From the IRFM all quantities in this relation $F_{\mathrm{Bol}} = \left(\frac{\theta}{2}\right)^2 \sigma T_{\mathrm{eff}}^4$ are known. Since $\frac{\theta}{2} = \frac{R}{d}$ where R is stellar radius and d is stellar distance. If R is determined independently (asteroseismology), then distances can be derived. See e.g. Silva Aguirre et al. (2012), Casagrande et al. (2014).

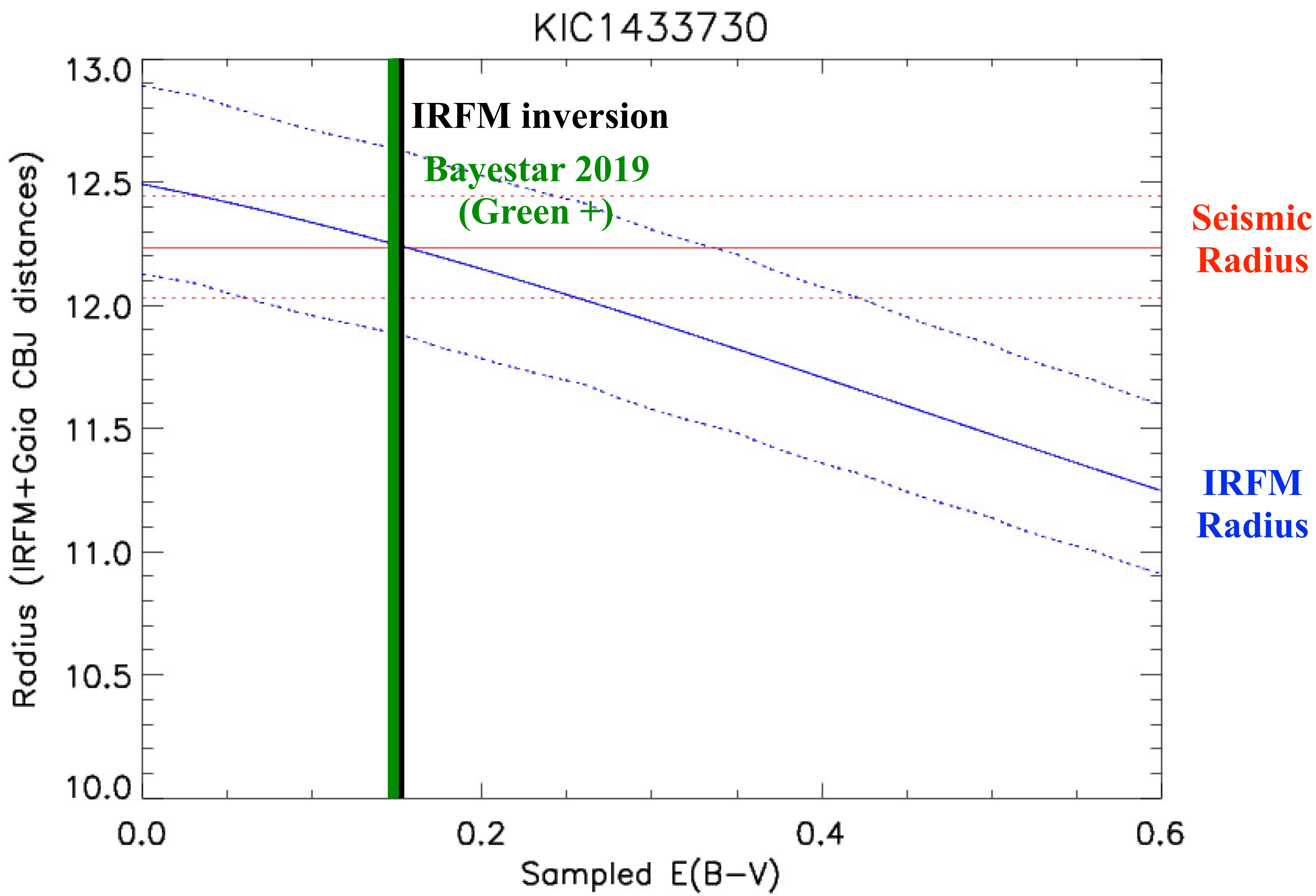
If reddening is unknown:

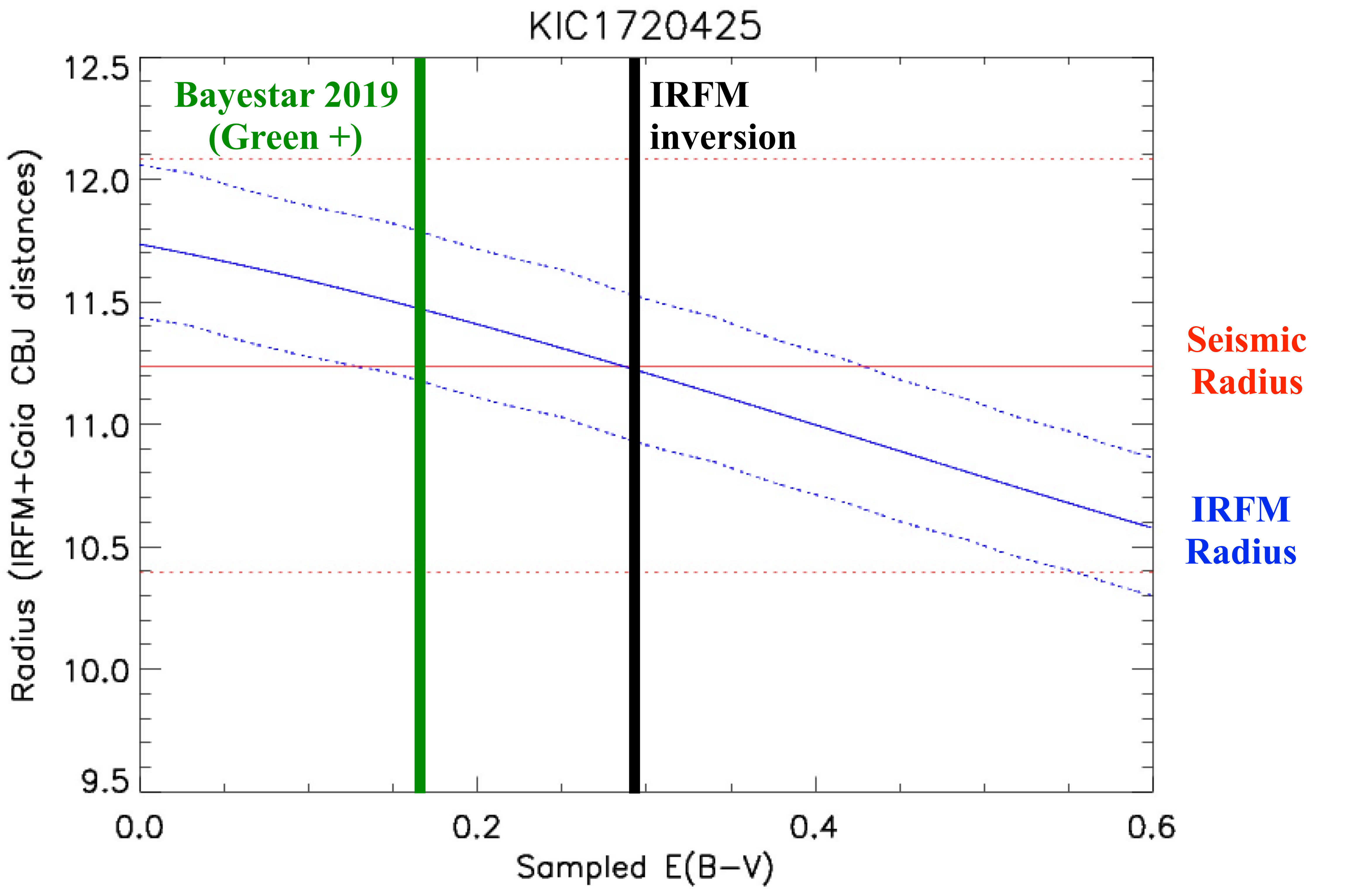
Angular diameters can be computed from Gaia distances and seismic radii (modulo the precision at which distances and seismic radii are known). Thus reddening can be sampled so that angular diameters from the IRFM match those inferred from Gaia distances and seismic radii.


IRFM inversion
Bayestar 2019 (Green +)
KIC1294385
7.5
7.0
6.5
6.0
5.5
5.0
Radius (IRFM+Gaia CBJ distances)
0.0
0.2
0.4
0.6
Sampled E(B−V)
Seismic Radius
(Pinsonneault+ 2018, APOKASC catalog)
IRFM Radius
(Gaia+2MASS photometry)

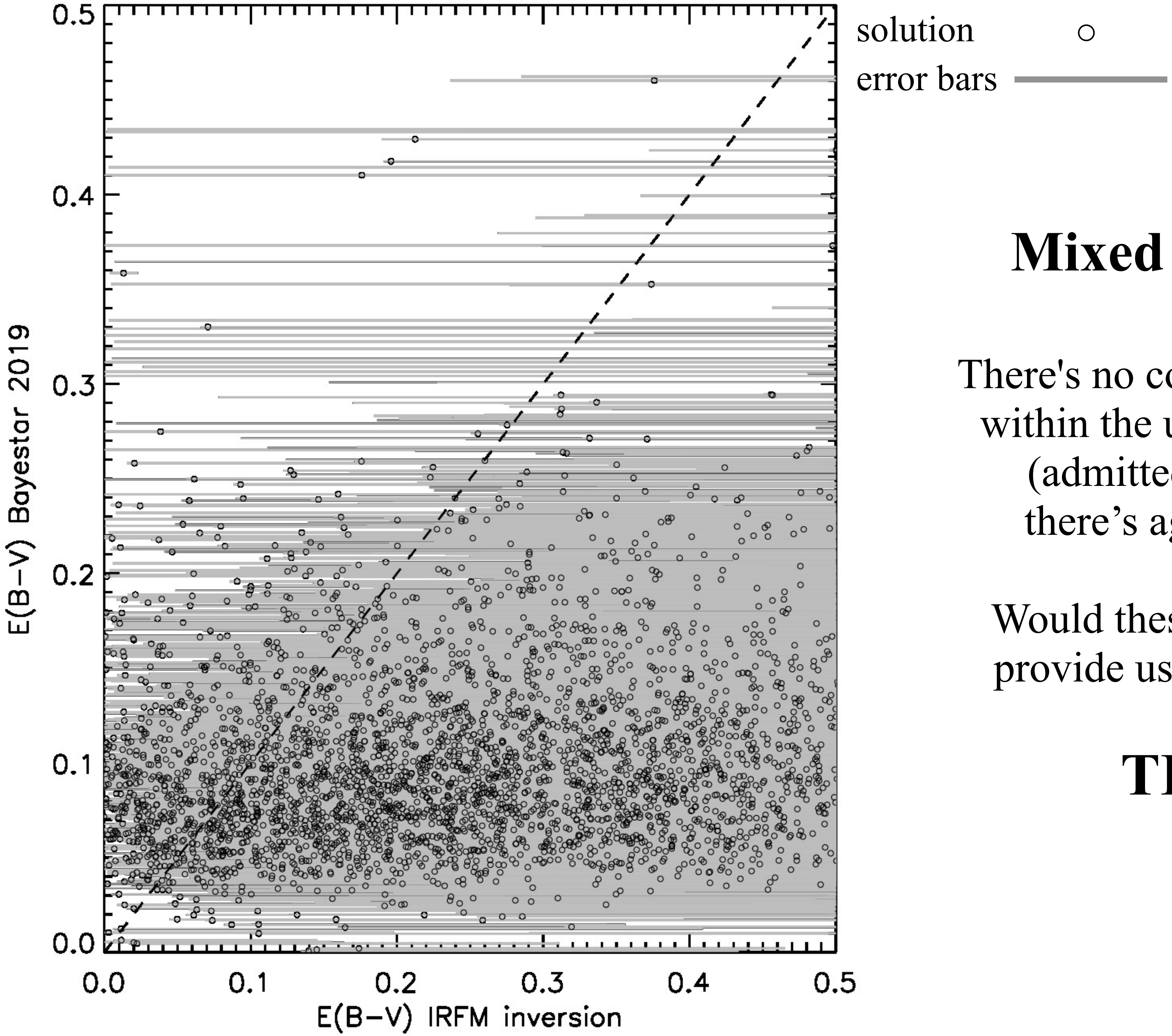

KIC1161447
Bayestar 2019
(Green +)
IRFM
inversion
Radius (IRFM+Gaia CBJ distances)
13.0
12.5
12.0
11.5
11.0
10.5
10.0
0.0
0.2
0.4
0.6
Sampled E(B−V)
Seismic
Radius
IRFM
Radius


KIC1431059
Bayestar 2019
(Green +)
IRFM
inversion
Seismic
Radius
IRFM
Radius
Radius (IRFM+Gaia CBJ distances)
Sampled E(B−V)
6.0
5.5
5.0
4.5
4.0
3.5
0.0
0.2
0.4
0.6


KIC1433730
IRFM inversion
Bayestar 2019
(Green +)
Seismic Radius
IRFM Radius
Radius (IRFM+Gaia CBJ distances)
13.0
12.5
12.0
11.5
11.0
10.5
10.0
0.0
0.2
0.4
0.6
Sampled E(B–V)


KIC1720425
Bayestar 2019
(Green +)
IRFM
inversion
Seismic
Radius
IRFM
Radius
Radius (IRFM+Gaia CBJ distances)
Sampled E(B−V)
12.5
12.0
11.5
11.0
10.5
10.0
9.5
0.0
0.2
0.4
0.6

6500 stars later …



Mixed results.

There's no correlation, but within the uncertainties (admittedly large) there's agreement.

Would these estimates provide useful priors?

TBD

Conclusions

The Infrared Flux Method is a **robust and well tested** technique.

It can be readily **applied to any star**, and to **large sample of stars**, provided good photometry is available.

This is very much the case nowadays, with well standardised photometry and absolute calibrations (the need for <1% absolute fluxes is cosmology driven, but stellar astrophysics benefits from it too).
The IRFM in the **Gaia+2MASS** system is now implemented and **ready to go**.

Absolute fluxes are now good enough that the IRFM can **predict angular diameters** from first principles (in the "famous" work of Alonso+ 1996 absolute fluxes were calibrated onto angular diameters). As a results, the IRFM has **uncovered systematic errors in a number of interferometric measurements**.