SYNERGY BETWEEN ASTEROSEISMOLOGY AND HIGH-RESOLUTION SPECTROSCOPY

Giada Casali

Postdoc at the University of Bologna

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ASTERO CHRONOMETRY

ALMA MATER STUDIORUM
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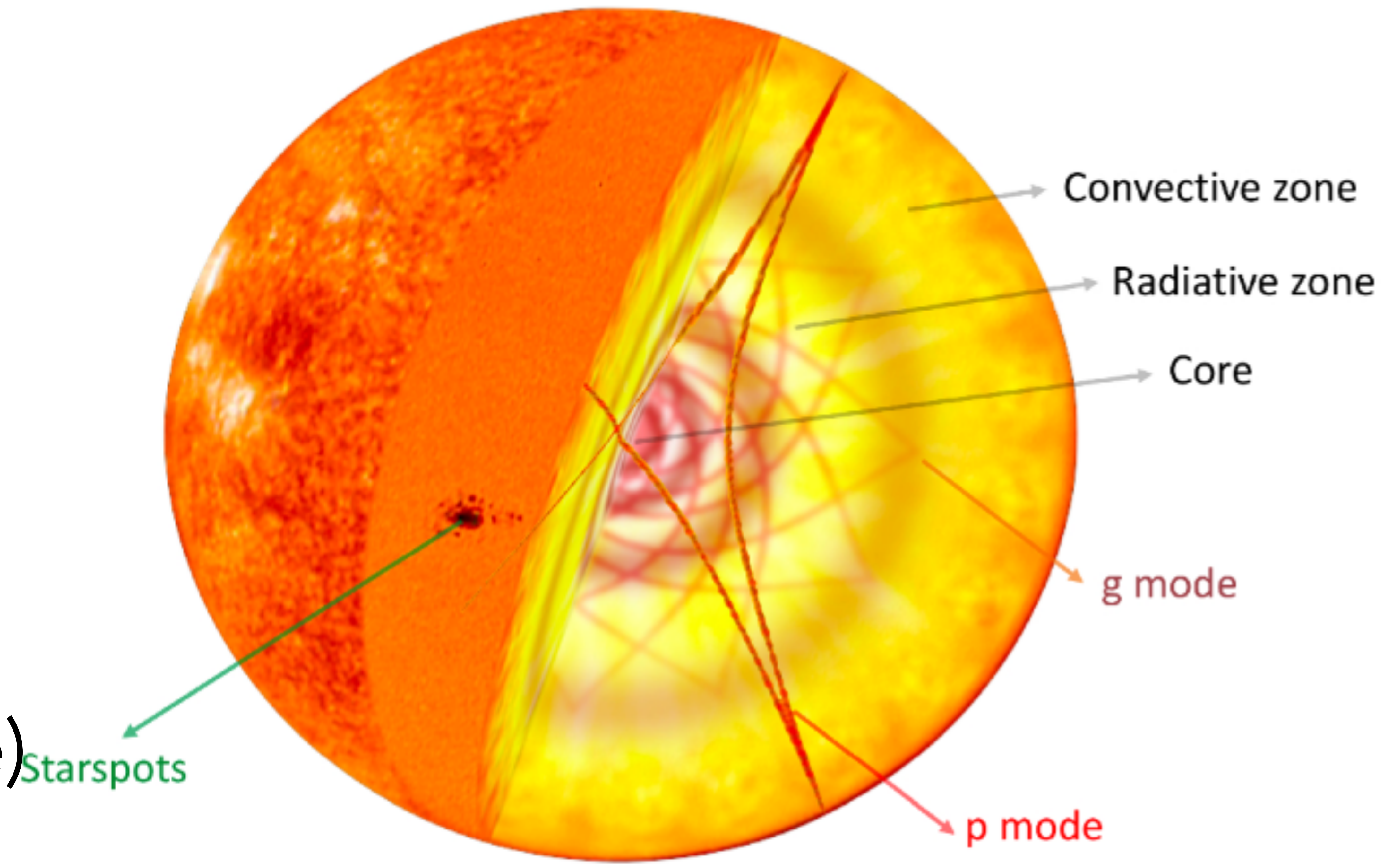
ASTEROSEISMOLOGY

- It studies the oscillation frequencies of a star to measure its internal properties.

- It is able to infer fundamental stellar parameters (e.g., mass, radius, logg and age) using T_{eff} and chemical composition.



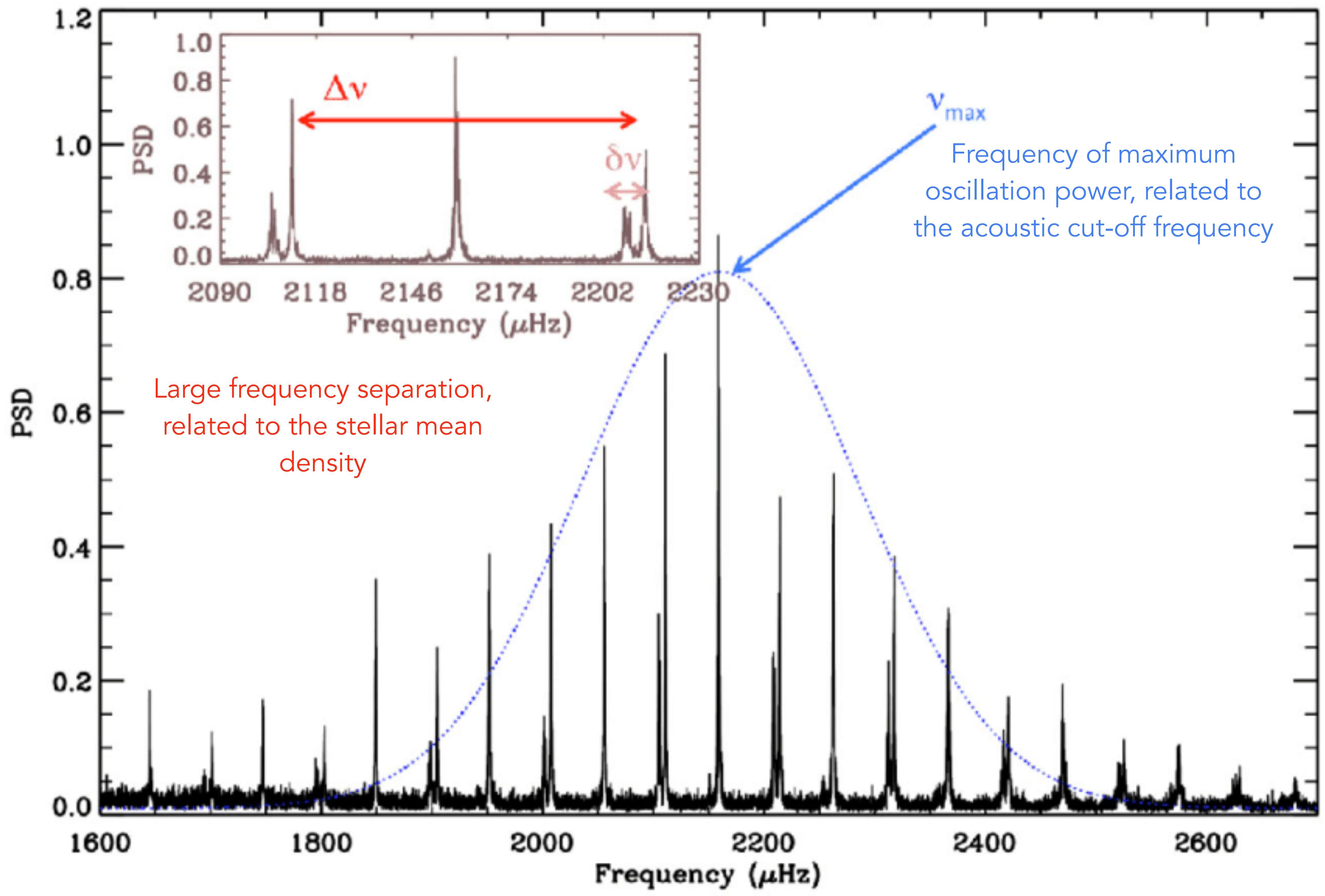
García & Ballot 2019

ASTEROSEISMOLOGY

$$\frac{M}{M_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^3 \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{3/2}$$

$$\frac{R}{R_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right) \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1/2},$$

$$\log g = \log g_\odot + \log\left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right) + \frac{1}{2}\log\left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)$$



García & Ballot 2019

Ref: . Stello et al. 2008; Kallinger et al. 2010; Belkacem et al. 2011; Mosser et al. 2010; Miglio et al 2012; Morel & Miglio 2012 + many more

SPEC LOGG DETERMINATION

- logg for late-type stars can suffer from systematic errors of the order of 0.2 dex (Morel & Miglio 2012; Heiter et al. 2015; Takeda & Tajitsu 2015; Takeda et al. 2016). Possible causes:
  - use of different techniques by different authors;
  - adoption of inaccurate atomic parameters;
  - assumption of local thermodynamical equilibrium (LTE) and 1-D conditions;
  - degeneracies and noisy or ill continuum-normalised spectra.
- As a consequence: inaccurate estimates of T_{eff}, chemical abundances, distances and stellar age.

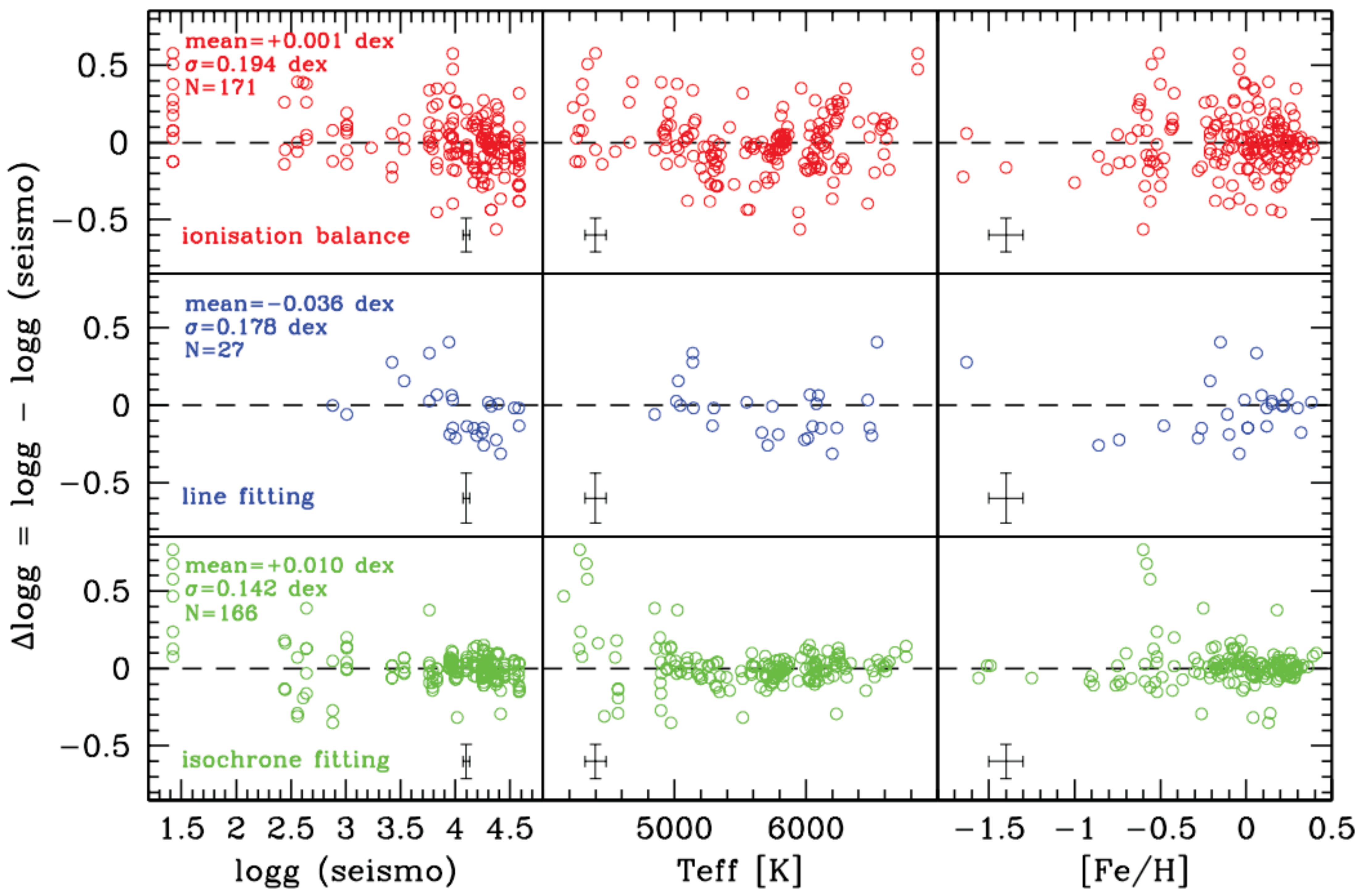
ASTEROSEISMOLOGY → SPECTROSCOPY

- The seismic surface gravity proved to be more precise and accurate than that derived using only spectroscopy (Thygesen et al 2012; Morel & Miglio 2012; Creevey et al. 2013; Hekker et al. 2013; Huber et al. 2013; Morel et al. 2014; Heiter et al. 2015; Hawkins et al 2016 + many more).

This seismic logg can be used as a powerful tool for testing the adopted spectroscopic pipelines and, eventually, calibrating them.

SEISMIC & SPEC LOGG

- Good agreement between the seismic and spec logg ⇒ applicability of the logg scaling law
- Typical seismic logg uncertainties: 0.05 vs 0.15-0.20 dex from spec.
  (Chaplin & Miglio 2013)



Morel & Miglio et al 2012

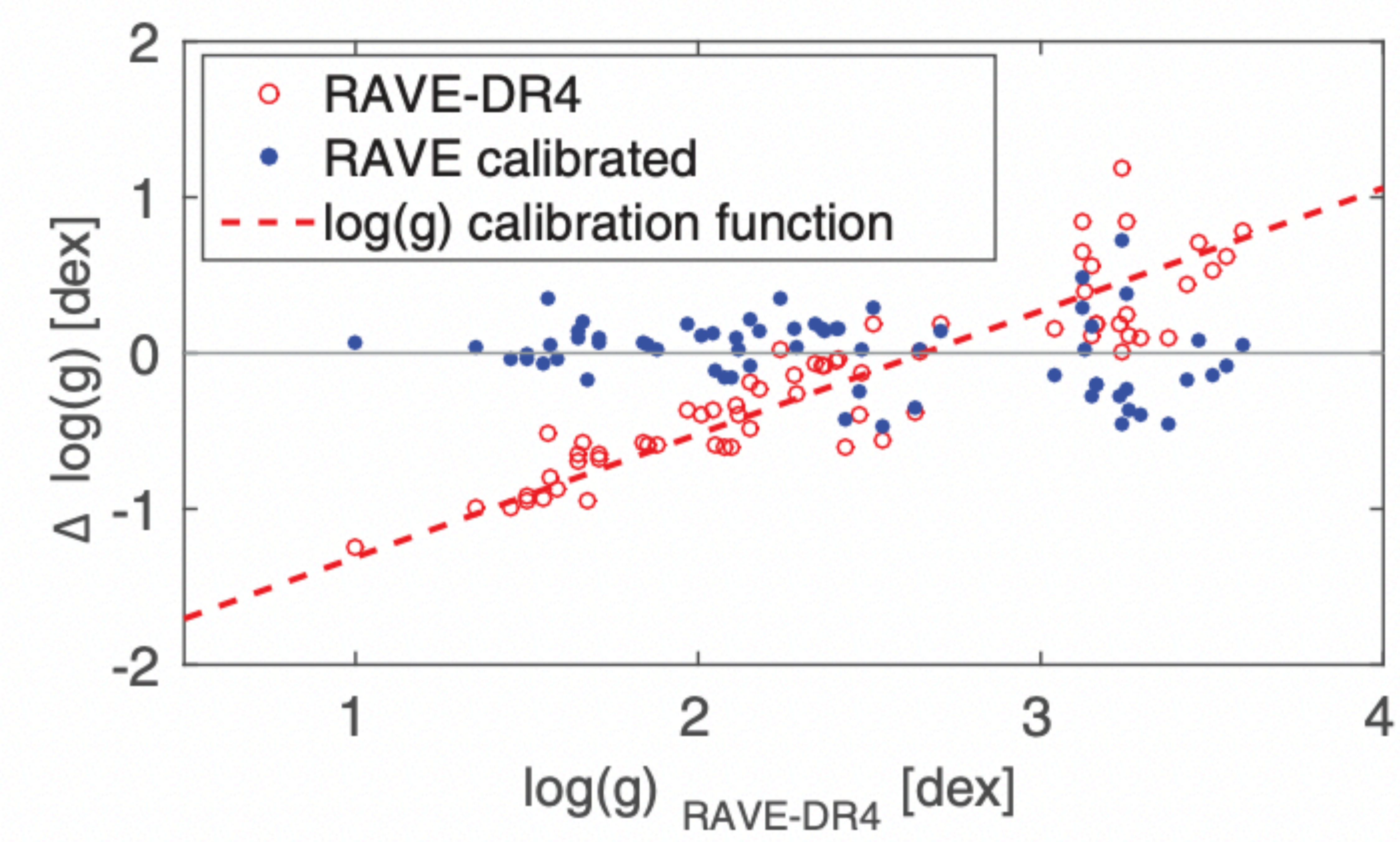
UNCERTAINTIES WITH/NO SEISMO

Quantity	Spectroscopy High Resolution			Spectroscopy Low Resolution		
	Model Requir.	No seismo	With Seismo	Model Requir.	No seismo	With Seismo
T_{eff}	50 K	75 K	40 K	80 K	110 K	65 K
$\log g$	<0.1 dex	0.12 dex	0.02 dex	0.2 dex	0.3 dex	0.02 dex
[Fe/H]	<0.1 dex	0.1 dex	0.02 dex	<0.1 dex	0.2 dex	<0.1 dex
[αelement/Fe]	<0.1 dex	0.1 dex	0.03 dex	<0.2 dex	0.2 dex	<0.1 dex
[n − capt./Fe]	<0.1 dex	0.1 dex	0.03 dex	<0.2 dex	0.3 dex	<0.1 dex

Valentini 2018 (proceedings)

SEISMIC LOGG - T_{eff}-logg DEGENERACY

- Seismic logg can be useful in case of strong T_{eff}-logg degeneracy, e.g. in the case of RAVE survey.
- Reasons:
  - Low resolution (R< 10,000)
  - Small wavelength coverage



Valentini et al 2017

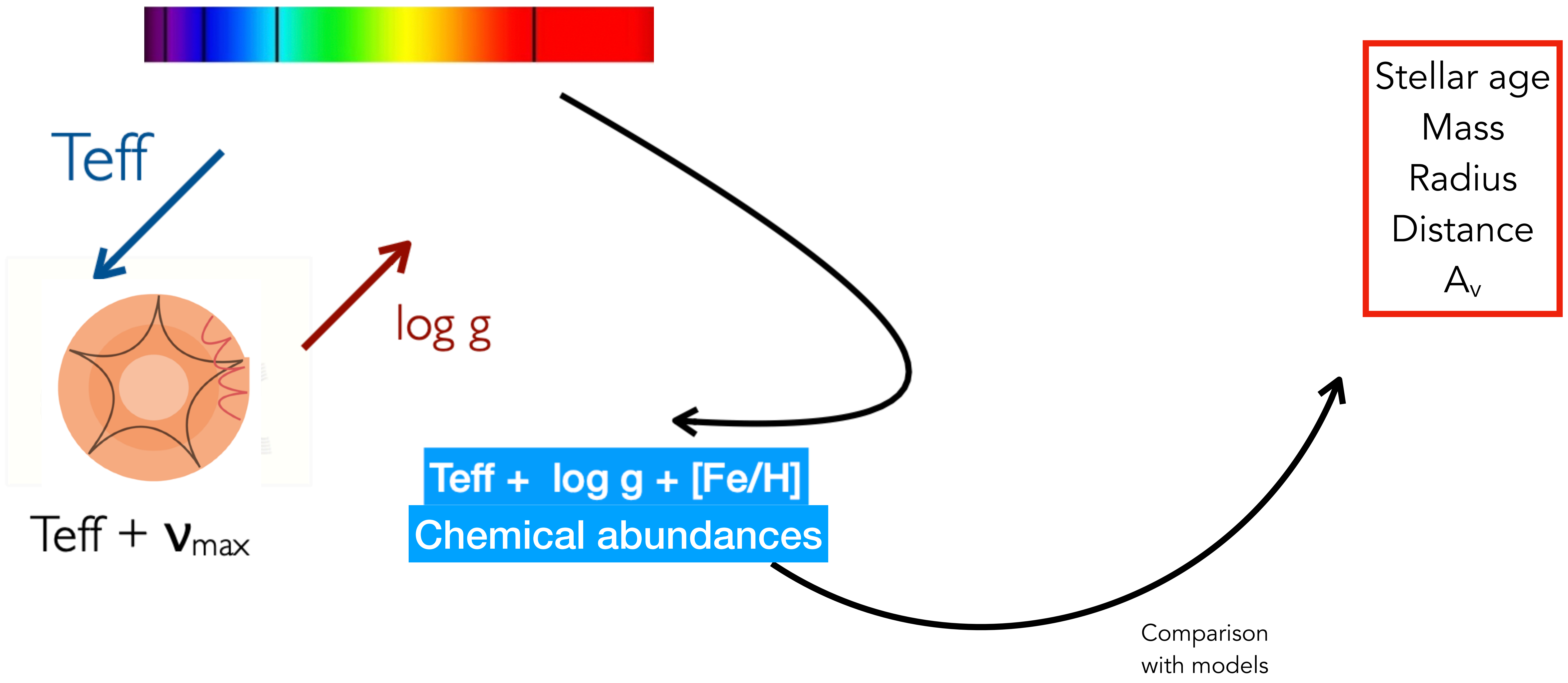
SPECTROSCOPY → ASTEROSEISMOLOGY

- Spectroscopy can provide effective temperature and chemical composition necessary to estimate important parameters through the asteroseismology:

  - **Stellar age**

These two fields are therefore closely connected and can greatly benefit from each other.

ASTEROSEISMOLOGY-SPECTROSCOPY INTERATION



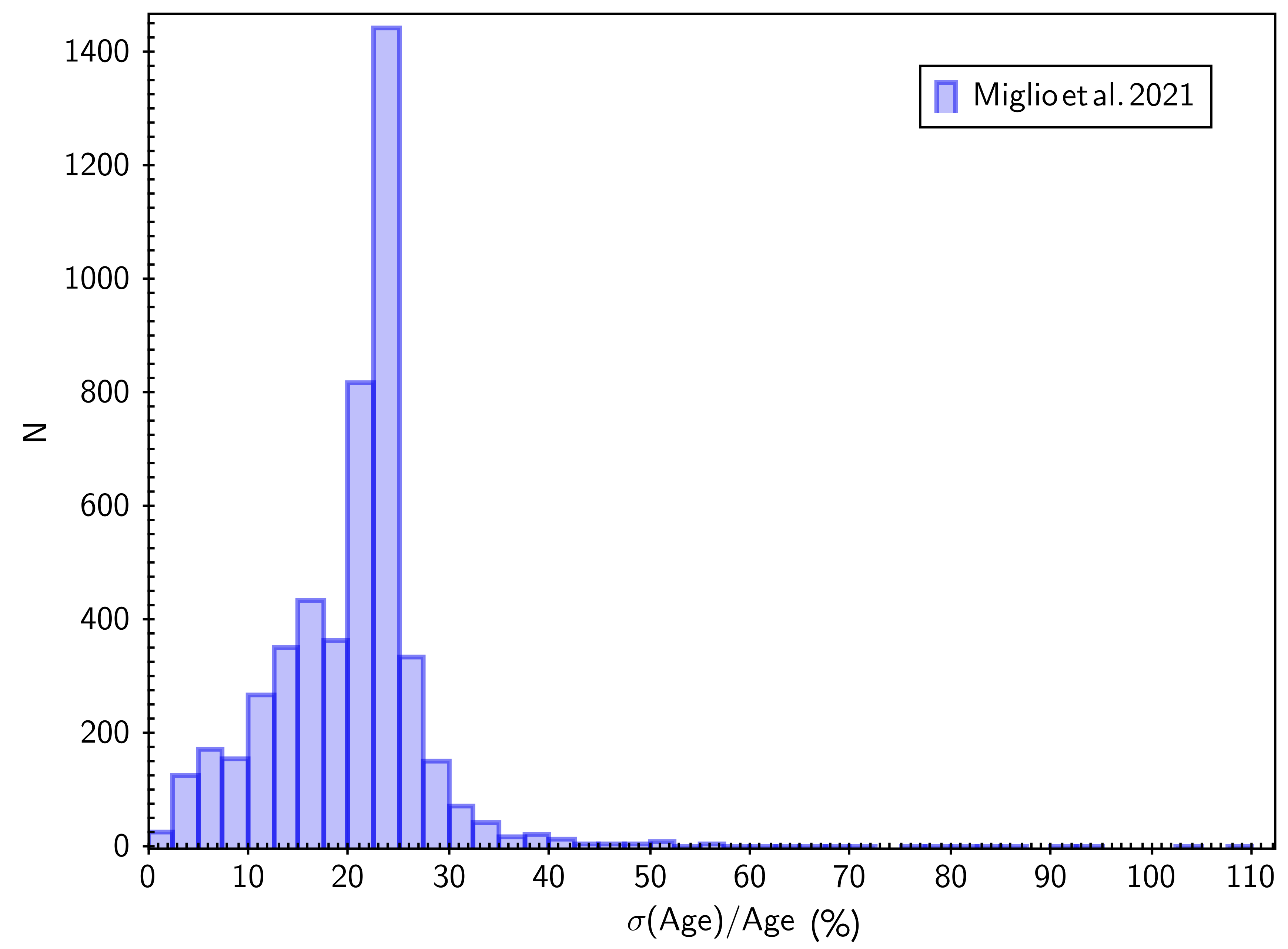
SEISMIC STELLAR AGE

Asteroseismic constraints, coupled with information on chemical abundances and T_{eff}, give us the ability to measure accurate mass, radius and age for RGB stars, using suitable tools (e.g. PARAM, astroNN).
(Anders et al. 2017; Silva Aguirre et al. 2018; Rendle et al. 2019a; Valentini et al. 2019; Miglio et al 2021; Montalban et al 2021; Das & Sanders 2019; Mackereth et al 2019, 2020 + many more)

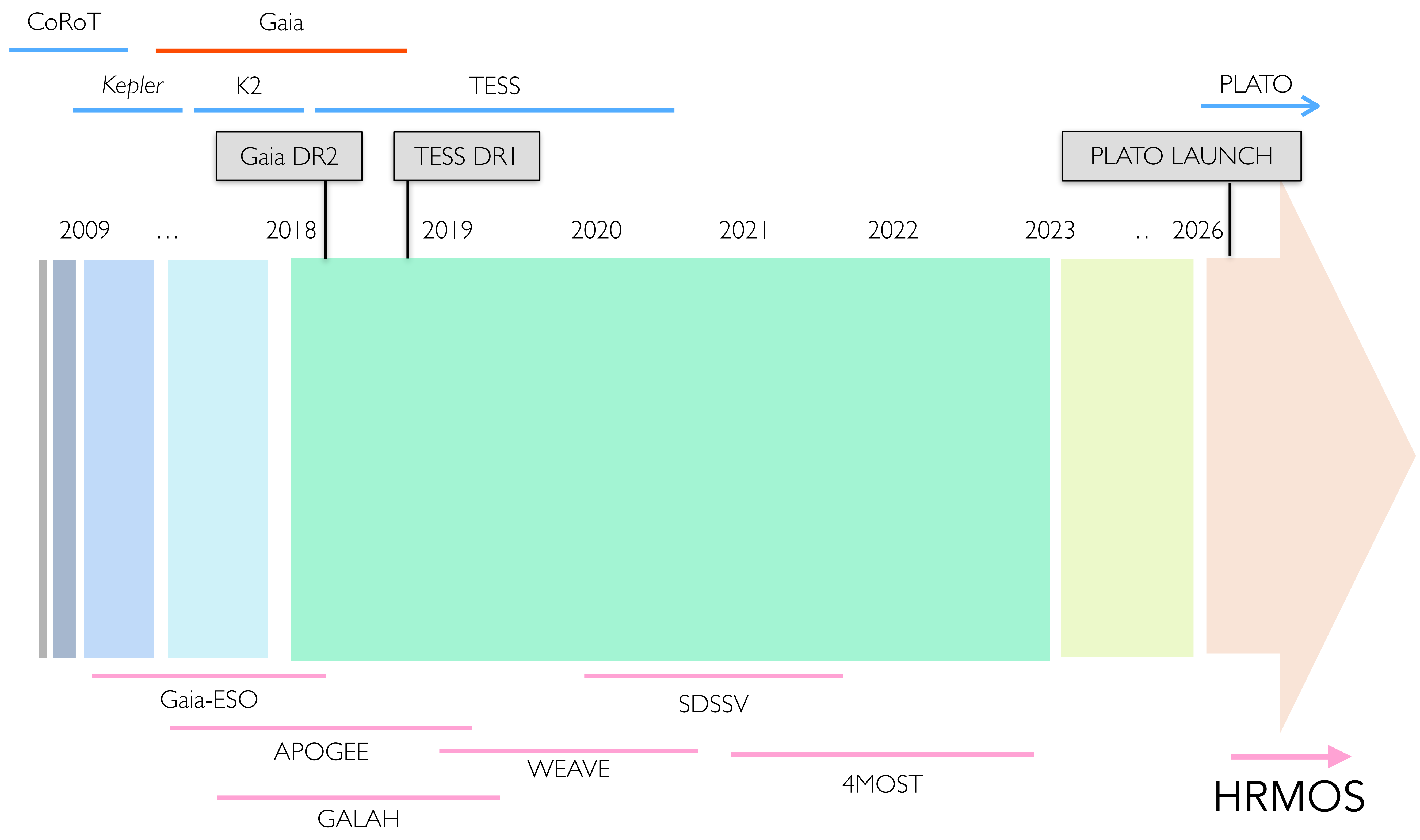
Typical uncertainties: ~20-25% (vs. > 80% for isochrones)

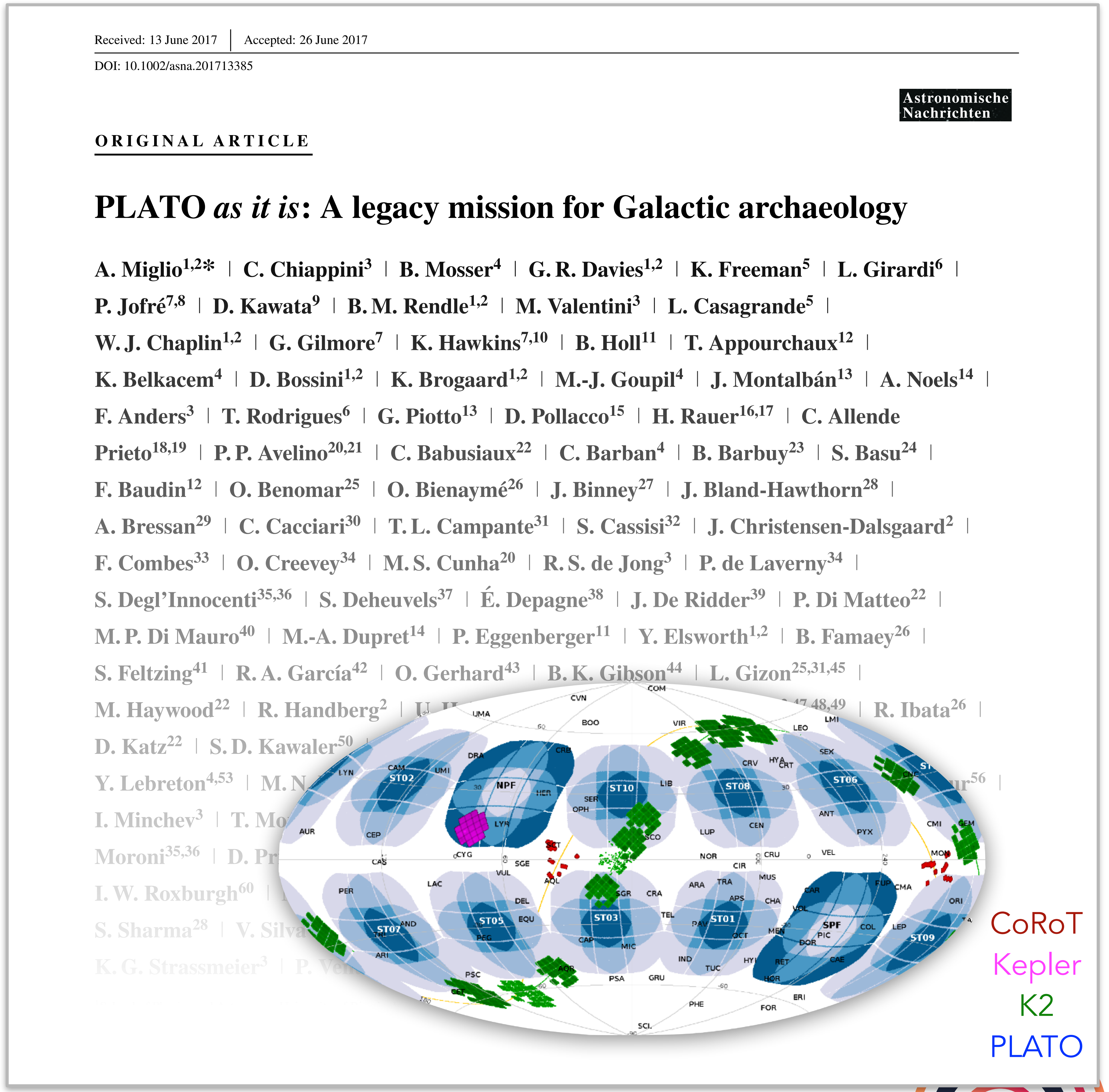
Improvable up to ~10% using HR and individual freq.

⇒ Unprecedented constraints for our understanding of the MW!



AVAILABLE SYNERGIES





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ORIGINAL ARTICLE

PLATO *as it is*: A legacy mission for Galactic archaeology

A. Miglio[1,2*] | C. Chiappini[3] | B. Mosser[4] | G. R. Davies[1,2] | K. Freeman[5] | L. Girardi[6] | P. Jofré[7,8] | D. Kawata[9] | B. M. Rendle[1,2] | M. Valentini[3] | L. Casagrande[5] | W. J. Chaplin[1,2] | G. Gilmore[7] | K. Hawkins[7,10] | B. Holl[11] | T. Appourchaux[12] | K. Belkacem[4] | D. Bossini[1,2] | K. Brogaard[1,2] | M.-J. Goupil[4] | J. Montalbán[13] | A. Noels[14] | F. Anders[3] | T. Rodrigues[6] | G. Piotto[13] | D. Pollacco[15] | H. Rauer[16,17] | C. Allende Prieto[18,19] | P. P. Avelino[20,21] | C. Babusiaux[22] | C. Barban[4] | B. Barbuy[23] | S. Basu[24] | F. Baudin[12] | O. Benomar[25] | O. Bienaymé[26] | J. Binney[27] | J. Bland-Hawthorn[28] | A. Bressan[29] | C. Cacciari[30] | T. L. Campante[31] | S. Cassisi[32] | J. Christensen-Dalsgaard[2] | F. Combes[33] | O. Creevey[34] | M. S. Cunha[20] | R. S. de Jong[3] | P. de Laverny[34] | S. Degl'Innocenti[35,36] | S. Deheuvels[37] | É. Depagne[38] | J. De Ridder[39] | P. Di Matteo[22] | M. P. Di Mauro[40] | M.-A. Dupret[14] | P. Eggenberger[11] | Y. Elsworth[1,2] | B. Famaey[26] | S. Feltzing[41] | R. A. García[42] | O. Gerhard[43] | B. K. Gibson[44] | L. Gizon[25,31,45] | M. Haywood[22] | R. Handberg[2] | ... R. Ibata[26] | D. Katz[22] | S. D. Kawaler[50] ... Y. Lebreton[4,53] | M. N ... I. Minchev[3] | T. Mo ... Moroni[35,36] | D. Pr ... I. W. Roxburgh[60] ... S. Sharma[28] | V. Silv ... K. G. Strassmeier[3] | P. Ve ...

FUTURE: PLATO - HRMOS

- The spectroscopic follow-up of PLATO's targets by HRMOS

1. calibration of spectroscopic analysis procedures

2. precise chemical abundance determinations → precise stellar properties (in particular age), to testing:

   - stellar models

   - Galactic chemical evolution models

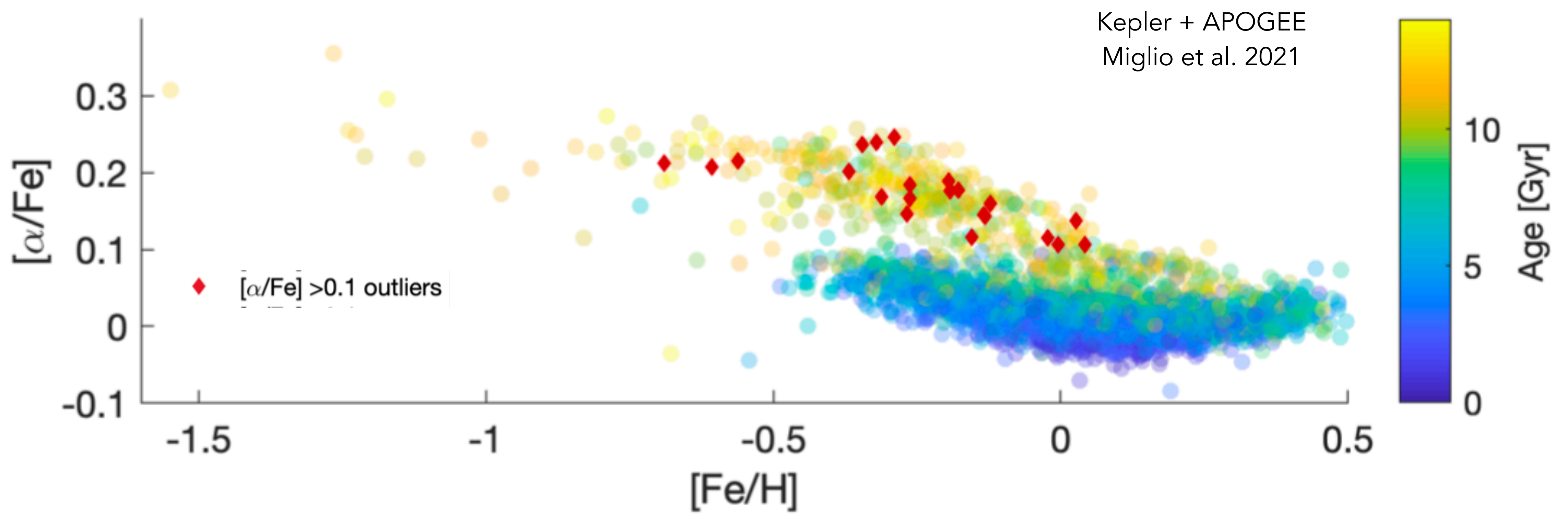
3. breakthrough science for **Galactic** and **Local Group Archaeology, Stellar Astrophysics** and **Exoplanet studies**.

SCIENCE IN G.A.

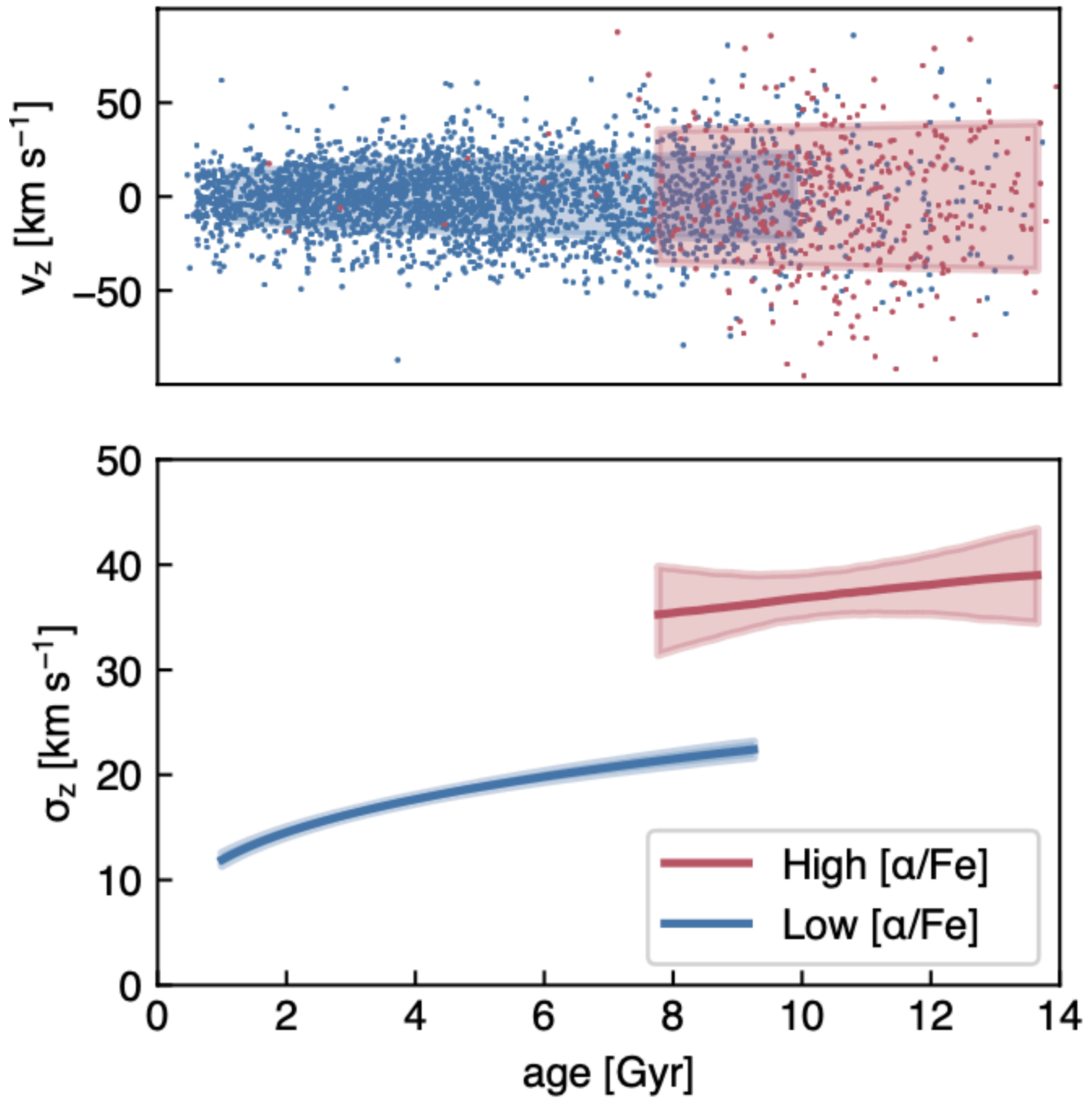
- Formation and evolution of the thin and thick discs of our Galaxy, and in particular to identify the transition between α-rich and α-poor discs

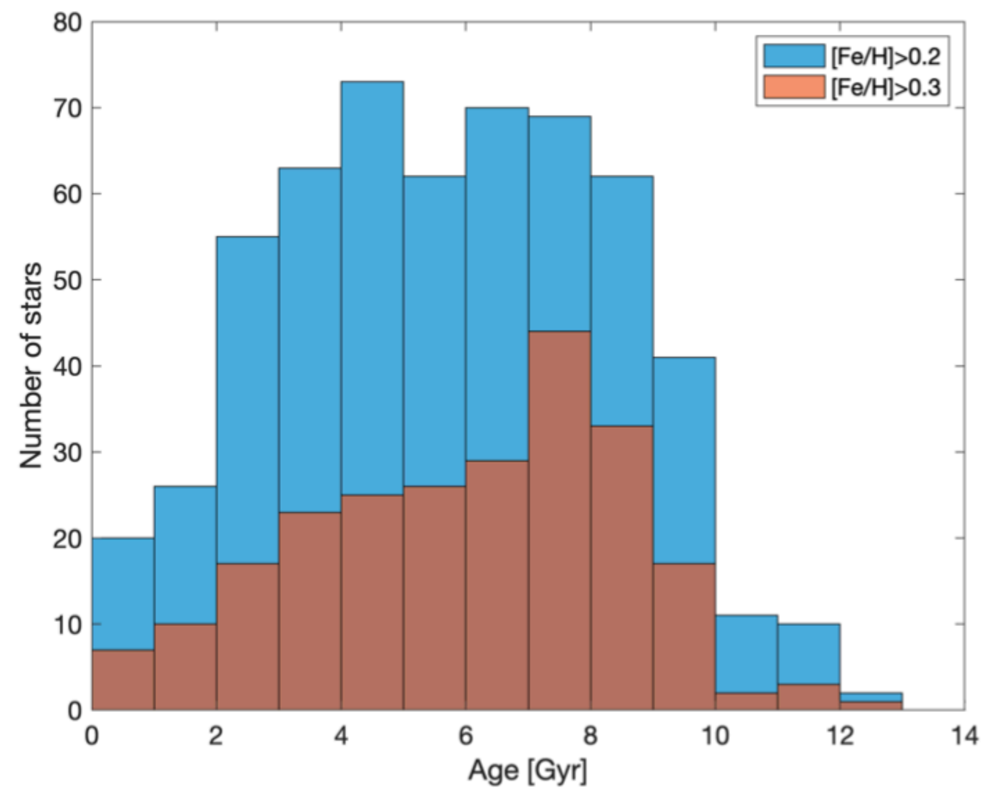
- Radial migration → presence of old metal-rich stars in solar vicinity

- Chemical discontinuity in the [α/Fe] vs [Fe/H] diagram seems to correspond to an abrupt change in the velocity dispersion at old ages

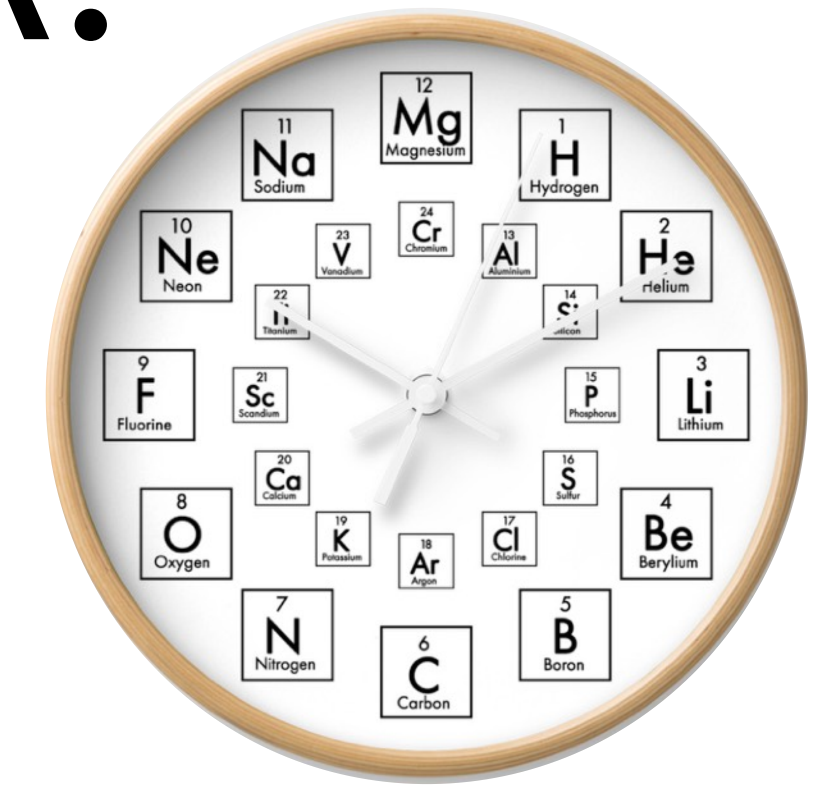


Miglio et al 2021





SCIENCE IN G.A.

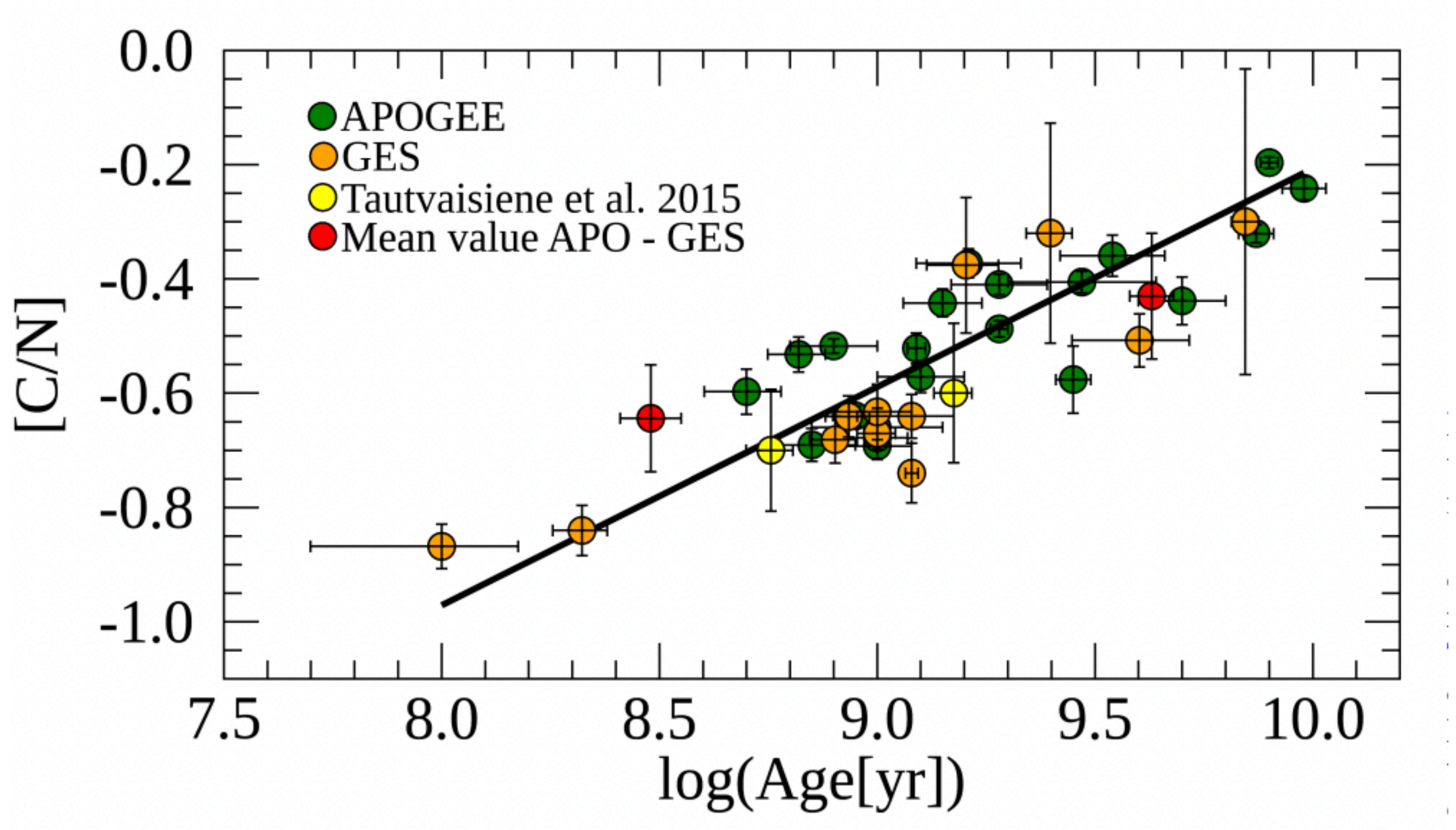


<u>A possible application of PLATO-HRMOS synergy:</u>

Calibration of chemical clocks relations using stars with precise seismic age and chemical abundances.

PLATO-HRMOS stars can extend the chemical clocks relations to older age than other calibrators, such as open clusters.

Moreover, knowing the evolutionary state of stars from asteroseismology allow us to investigate possible chemical variations due to the stellar evolution.



Casali et al 2019

CONCLUSIONS

- A detailed spectroscopic analysis has so far been carried out for only a tiny fraction of all the stars observed by CoRoT, K2, TESS and *Kepler*. Much more is expected in the near future.
- Seismic targets are currently used as benchmark stars in various large-scale surveys, such as APOGEE, Gaia-ESO and GALAH. In future: WEAVE, 4MOST, HRMOS
- The combination of HR spectroscopic data with asteroseismic ones will be of great relevance for investigating the properties of the stellar populations constituting our Galaxy.