Astronomía
FACULTAD DE CIENCIAS FÍSICAS Y MATEMÁTICAS UNIVERSIDAD DE CHILE

SPECIES:

Spectroscopic Parameters and atmosphEric ChemIstriEs of Stars

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Precision Spectroscopy 2017

HOW IT ALL BEGAN...

We wanted to study planets orbiting different types of stars.

In most of the cases, we only observe the star, not the planet directly.

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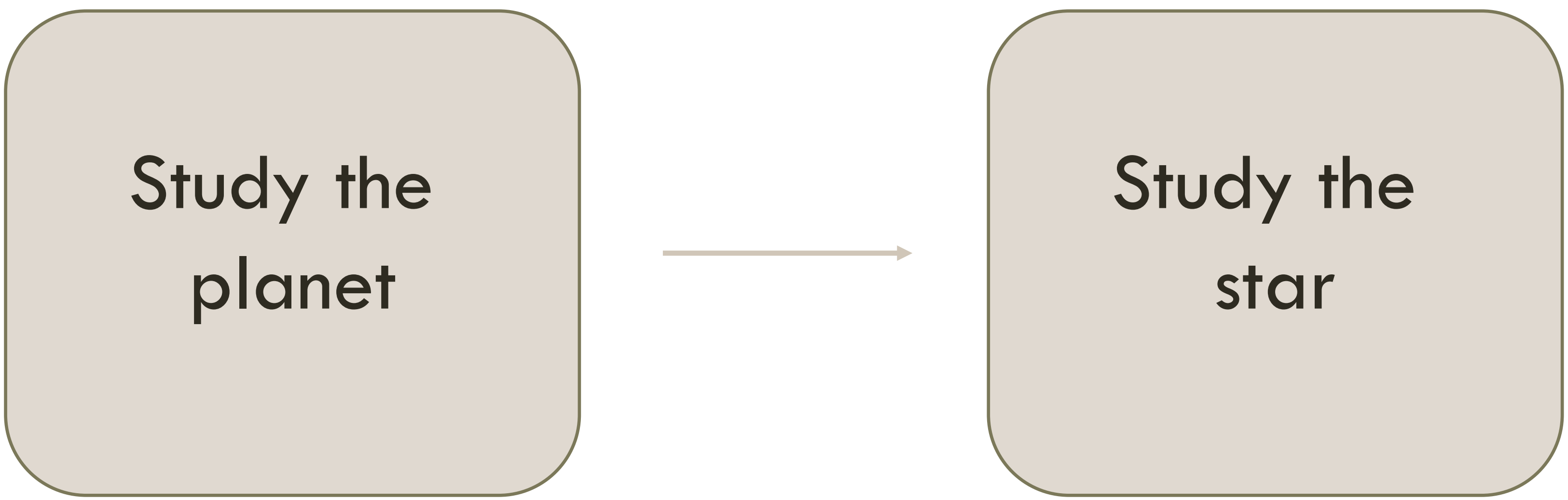

HOW IT ALL BEGAN…

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In most of the cases, we only observe the star, not the planet directly.

Study t
plane

- Mass
- Temperature
- Age
- Evolutionary stage
- etc…

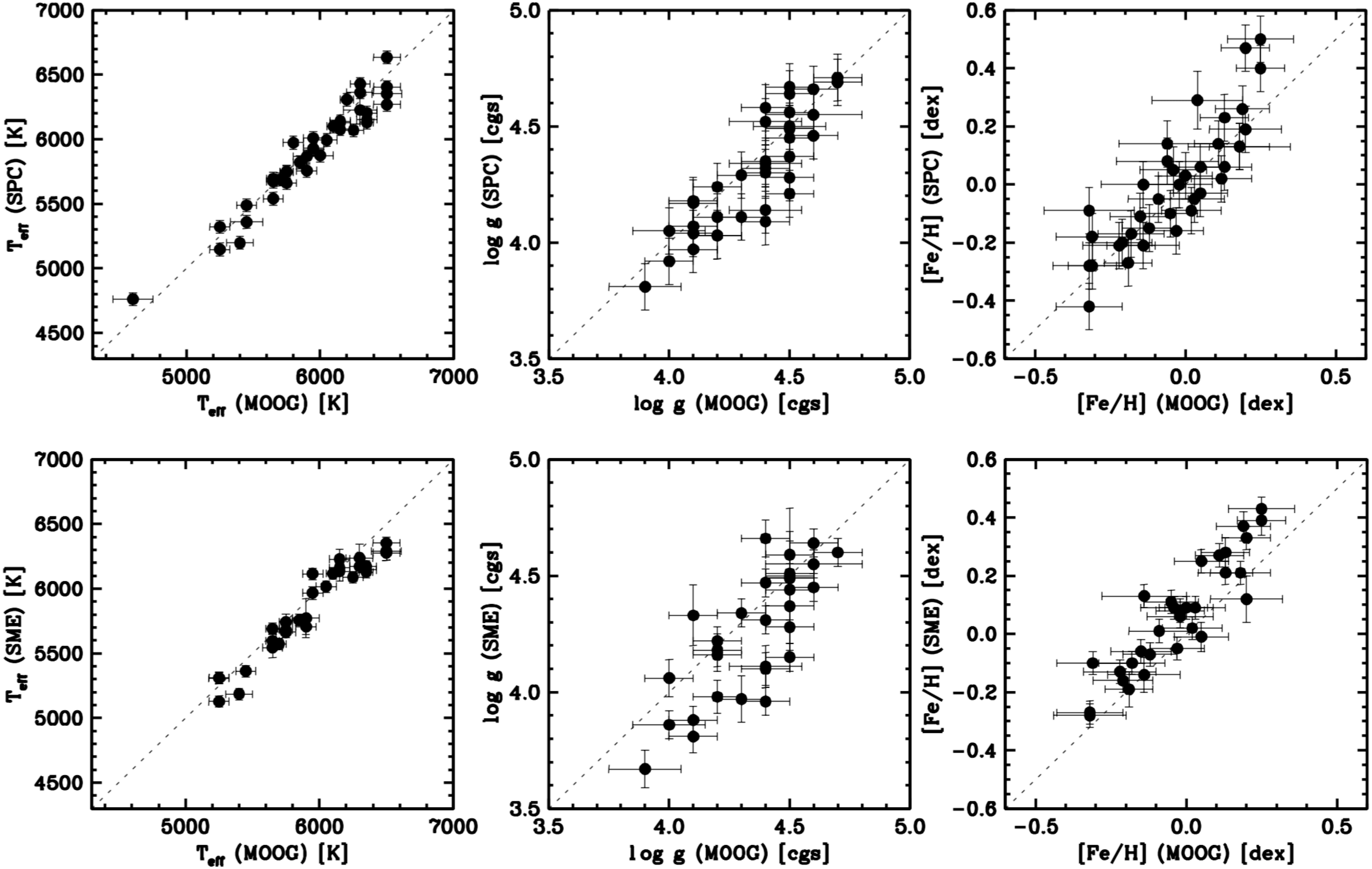
udy the
star

STELLAR PARAMETERS IN THE LITERATURE

Issues:

- Derived using different methods

→ systematic differences in the parameters.



Torres et al. 2012

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Obtain stellar parameters in a homogeneous and automated way

Spectroscopic Parameters and atmosphEric ChemIstriEs of Stars

↓

SPECIES

SPECIES

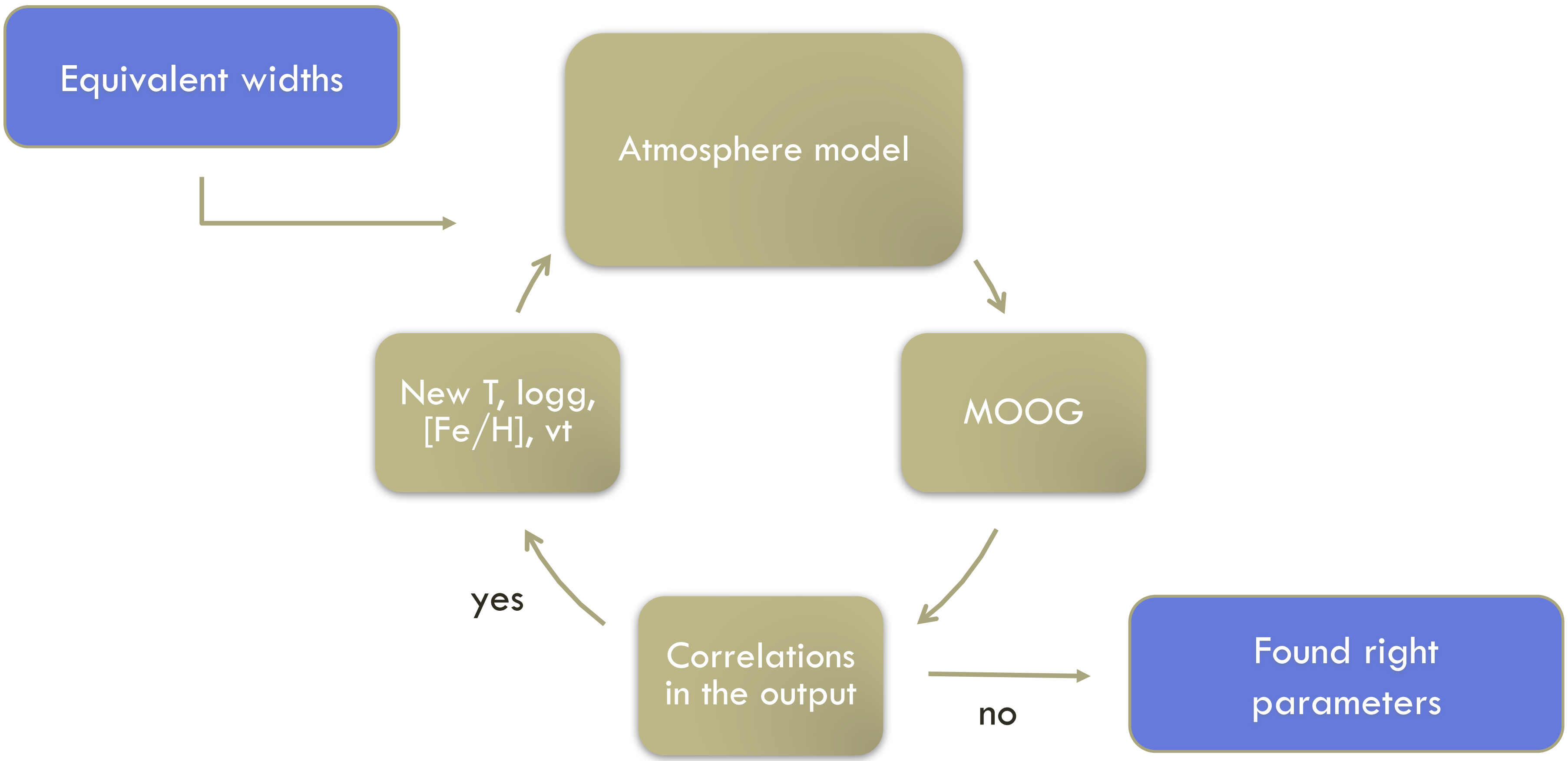
Input:
- High resolution echelle spectra for each star.

Output:
- Temperature
- Metallicity
- Surface gravity.
- Microturbulent velocity.
- Macroturbulent velocity.
- Rotational velocity.
- Abundances for Na, Mg, Al, Si, Ca, Ti, Cr, Mn, Ni, Cu, Zn.
- Mass.
- Age.

SPECIES: ATMOSPHERIC PARAMETERS

- T_{eff}, log g, [Fe/H] and microturbulence are derived using equivalent widths (EW) for the set of Fe I and FeII lines.
- Solve the radiative transfer equation assuming local thermodynamic equilibrium (LTE) conditions, using MOOG.
- The EWs were measured using the ARES code.
- The atmosphere models were obtained by interpolating through a grid of ATLAS9 atmosphere models.

SPECIES: ATMOSPHERIC PARAMETERS



SPECIES: UNCERTAINTY ESTIMATION

$$\sigma^2_{\xi_t} = \left(\left. \frac{\partial \xi_t}{\partial S_{RW}} \right|_{S_{RW}=0} \right)^2 \sigma^2_{S_{RW}}$$

$$\sigma^2_T = \left(\left. \frac{\partial T}{\partial \xi_t} \right|_{\xi_t} \right)^2 \sigma^2_{\xi_t} + \left(\left. \frac{\partial T}{\partial \chi_I} \right|_{\chi_I=0} \right)^2 \sigma^2_{\chi_I}$$

$$\sigma^2_{[Fe/H]} = \left(\left. \frac{\partial [Fe/H]}{\partial \xi_t} \right|_{\xi_t} \right)^2 \sigma^2_{\xi_t} + \left(\left. \frac{\partial [Fe/H]}{\partial T} \right|_{T} \right)^2 \sigma^2_T + \sigma^2_{FeI}$$

$$\sigma^2_{\log g} = \left(\left. \frac{\partial \log g}{\partial T} \right|_{T} \right)^2 \sigma^2_T + \left(\left. \frac{\partial \log g}{\partial FeII} \right|_{FeII} \right)^2 \sigma^2_{FeII}$$

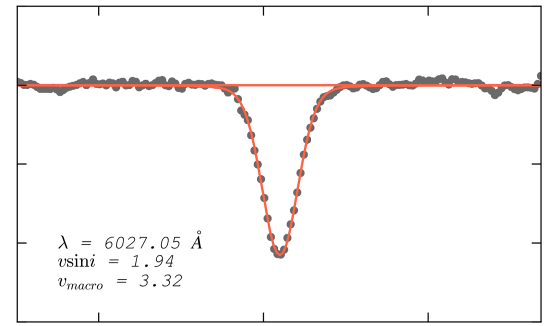
SPECIES: ROTATION AND MACROTURBULENCE

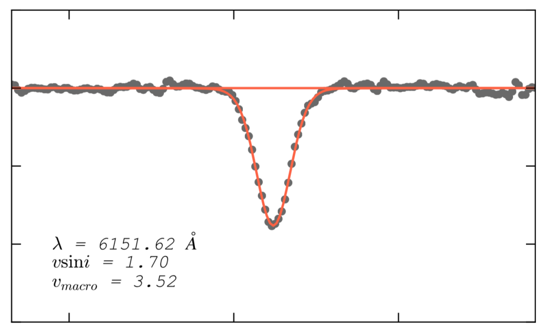
- Macroturbulence is found by using temperature scales.

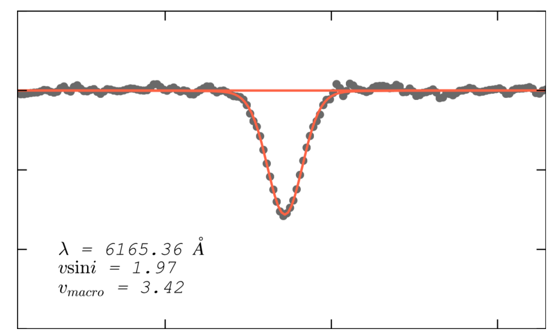
$$
\begin{aligned}
v_{mac,\lambda} = v^{\odot}_{mac,\lambda} \\
&+ 10.0 - 0.00707\,T_{\rm eff} \\
&+ 9.2422 \times 10^{-7} T^2_{\rm eff} \\
&+ k_1(\log \mathrm{g} - 4.44) + k_2
\end{aligned}
$$

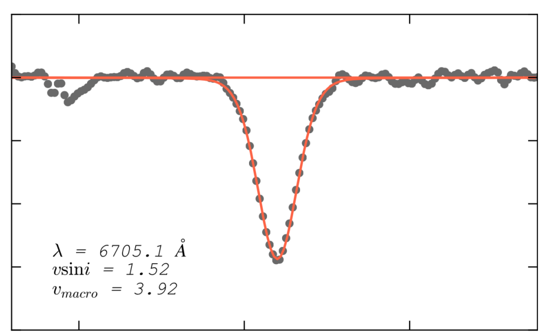
Dos Santos et al. 2016

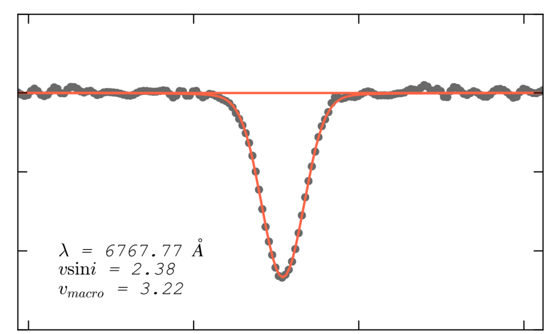
- Rotational velocity is found by fitting the line profiles of five absorption lines with synthetic spectra.



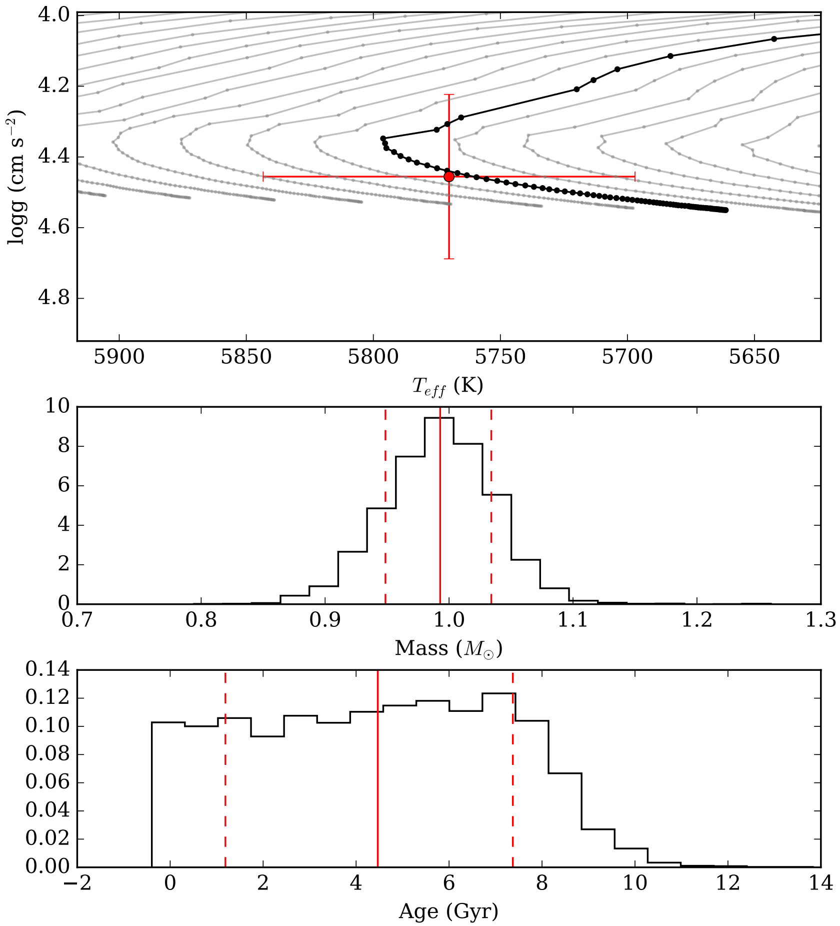








SPECIES: MASS AND AGE



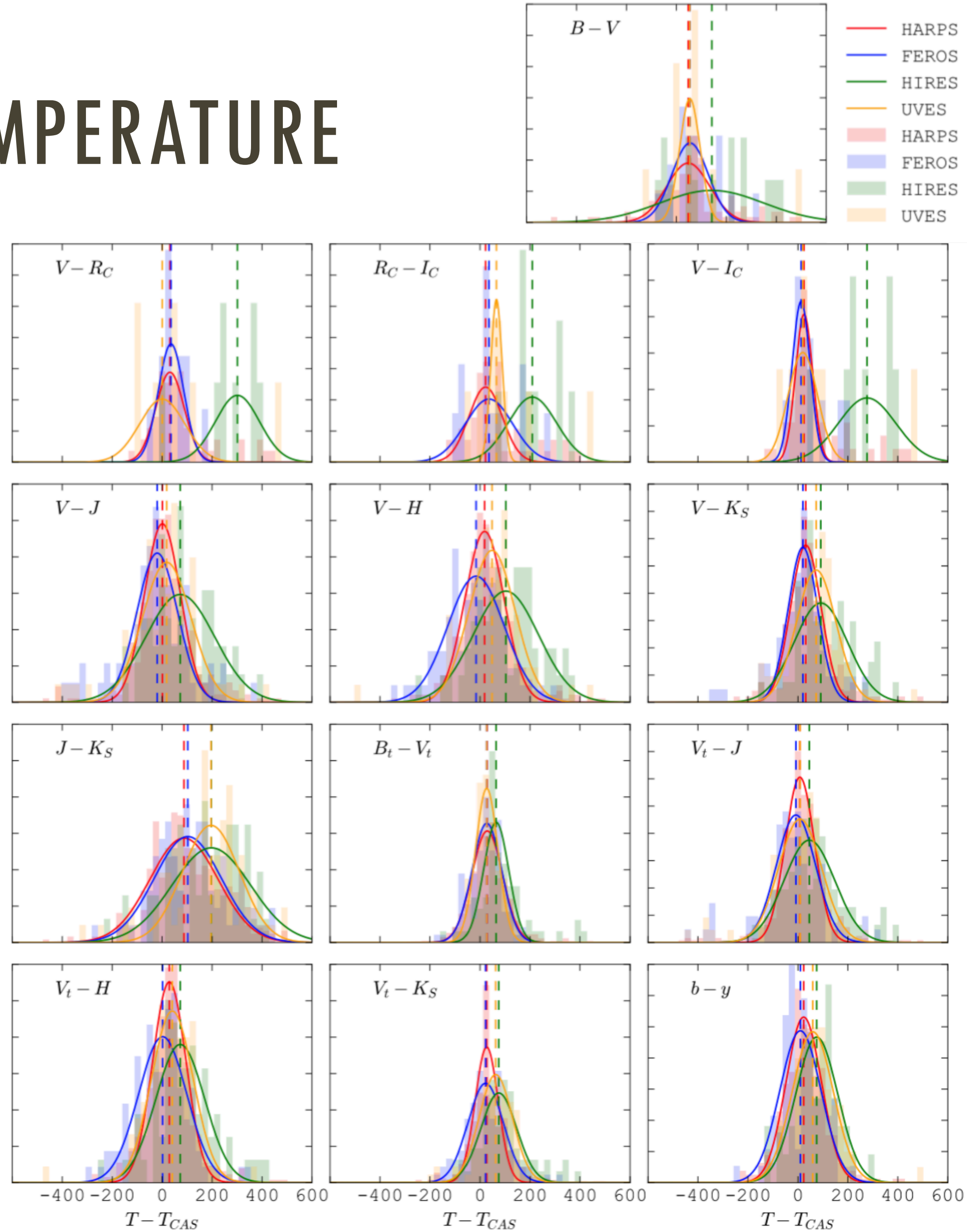
- Mass and age are found by interpolating through a grid of isochrones.
- Input values are metallicity, temperature and surface gravity.
- In this case we used the Dartmouth database.

RESULTS: COMPARISON WITH DIFFERENT WORKS

- We used a sample of ~450 stars from Sousa et al. 2008. and ~150 stars from Ivanyuk et al. 2017.

- Data from four spectragraphs:
  - HARPS (R ~ 115000)
  - FEROS (R ~ 48000)
  - UVES (R ~ 110000)
  - HIRES (R ~ 67000)

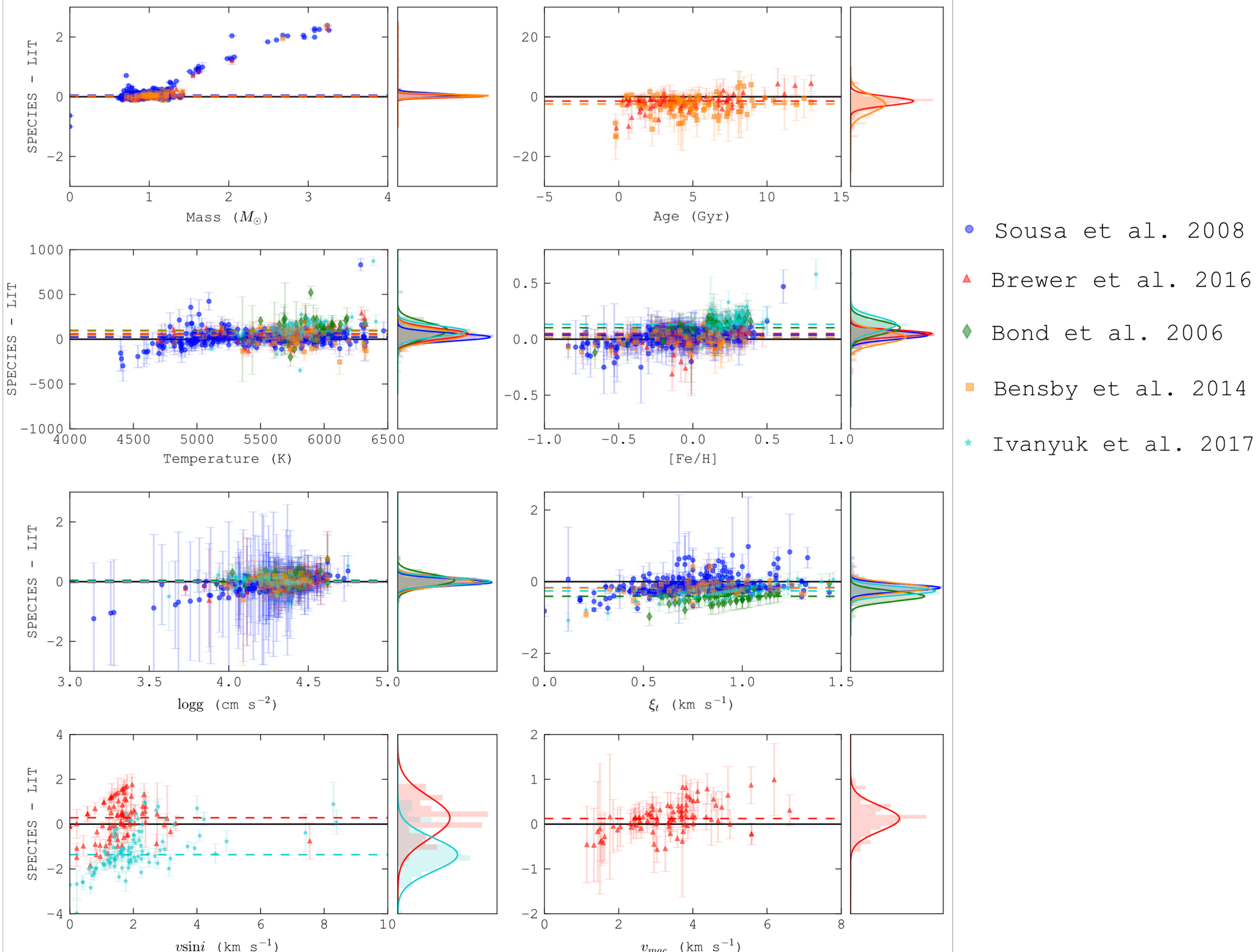
PHOTOMETRIC TEMPERATURE RELATIONS



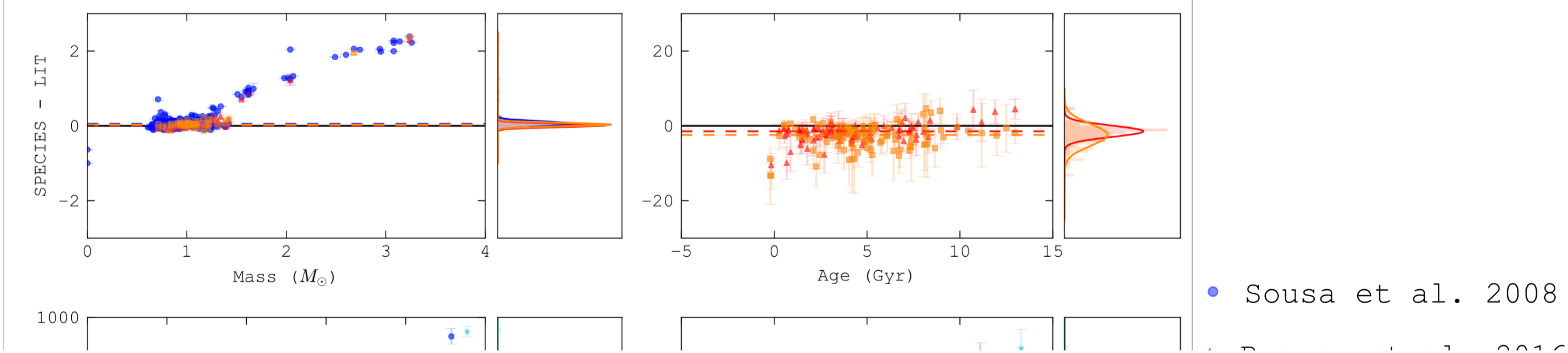
- Compared our temperatures with the ones derived using photometric temperature calibrations.
- Used the relations from Casagrande et al. 2010.
- Photometry is obtained from several catalogues in Vizier, automatically.

RESULTS: COMPARISON WITH DIFFERENT WORKS

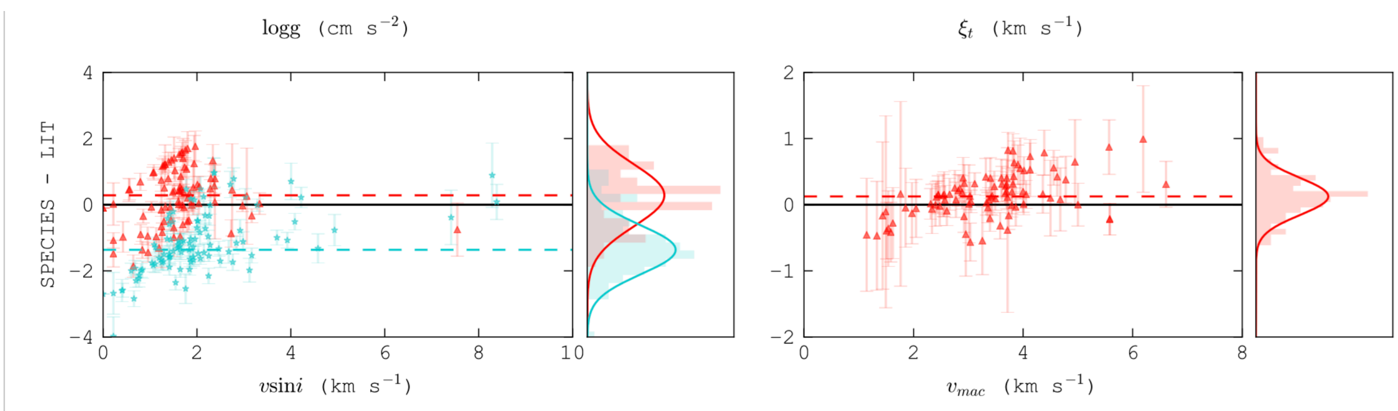
- Compare against the following catalogues:
  - Brewer et al. 2016 : Spectral synthesis method, and Y2 isochrones.
  - Sousa et al. 2008 : Same method than used here.
  - Bond et al 2006 : Similar method than used here, but using a photometric scale for the temperature.
  - Bensby et al. 2014: Similar method than in this work, but using the MARCS code, EW from iraf, and Y2 isochrones.
  - Ivanyuk et al. 2017: Infrared Flux Method (IRFM) calibration to derive temperatures.

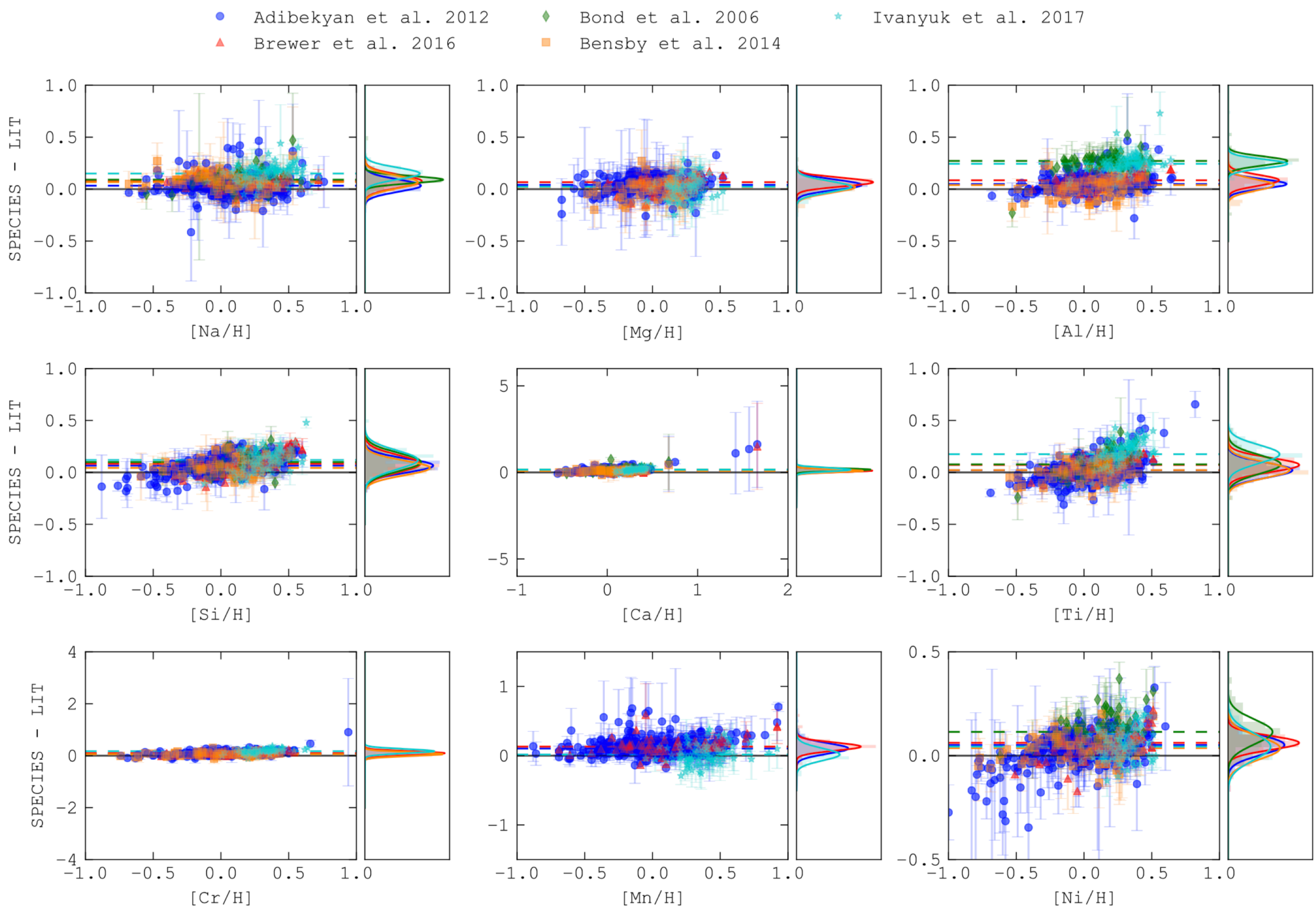


SPECIES - LIT
Mass ($M_\odot$)
Age (Gyr)
Temperature (K)
[Fe/H]
logg (cm s^{-2})
ξ_t (km s^{-1})
$v$sin$i$ (km s^{-1})
v_{mac} (km s^{-1})
Sousa et al. 2008
Brewer et al. 2016
Bond et al. 2006
Bensby et al. 2014
Ivanyuk et al. 2017

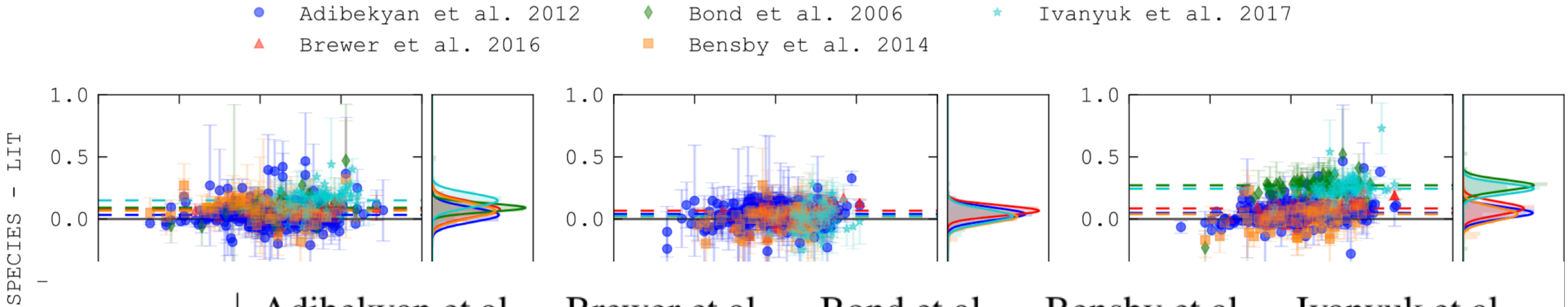


	Sousa et al. (2008)		Brewer et al. (2016)		Bond et al. (2006)		Bensby et al. (2014)		Ivanyuk et al. (2017)	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
M ($M_\odot$)	0.05	0.07	0.01	-0.04			0.03	-0.05		
Age (Gyr)			-1.38	1.51			-2.53	3.07		
T (K)	24.85	43.23	57.99	54.62	98.15	86.57	47.00	59.08	109.32	62.46
[Fe/H]	0.04	0.04	0.05	0.03	0.10	0.06	0.02	0.05	0.15	0.07
log g	-0.02	0.12	0.04	0.13	0.05	0.20	0.01	0.14	0.07	0.12
ξ_t (km s^{-1})	-0.17	0.10			-0.41	0.14	-0.16	0.13	-0.18	0.11
$v \sin i$ (km s^{-1})			0.28	1.94					-1.36	0.74
v_{mac} (km s^{-1})			0.11	0.22						

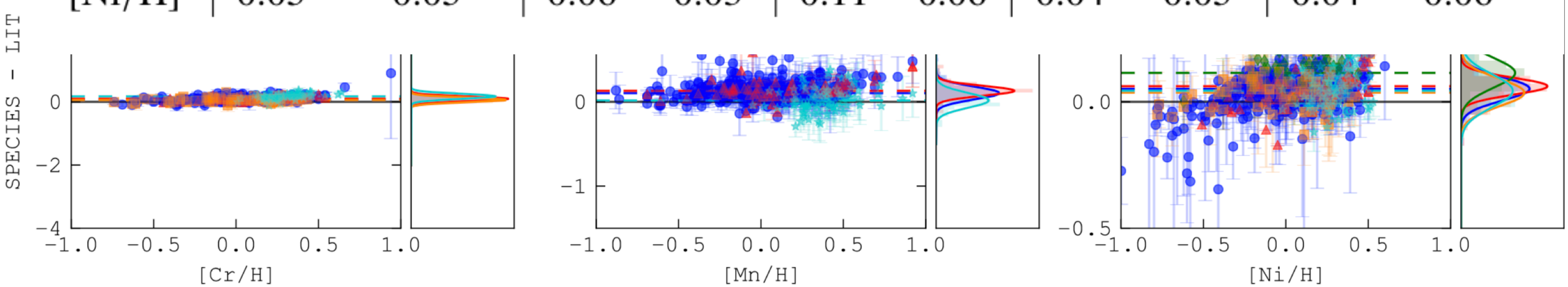




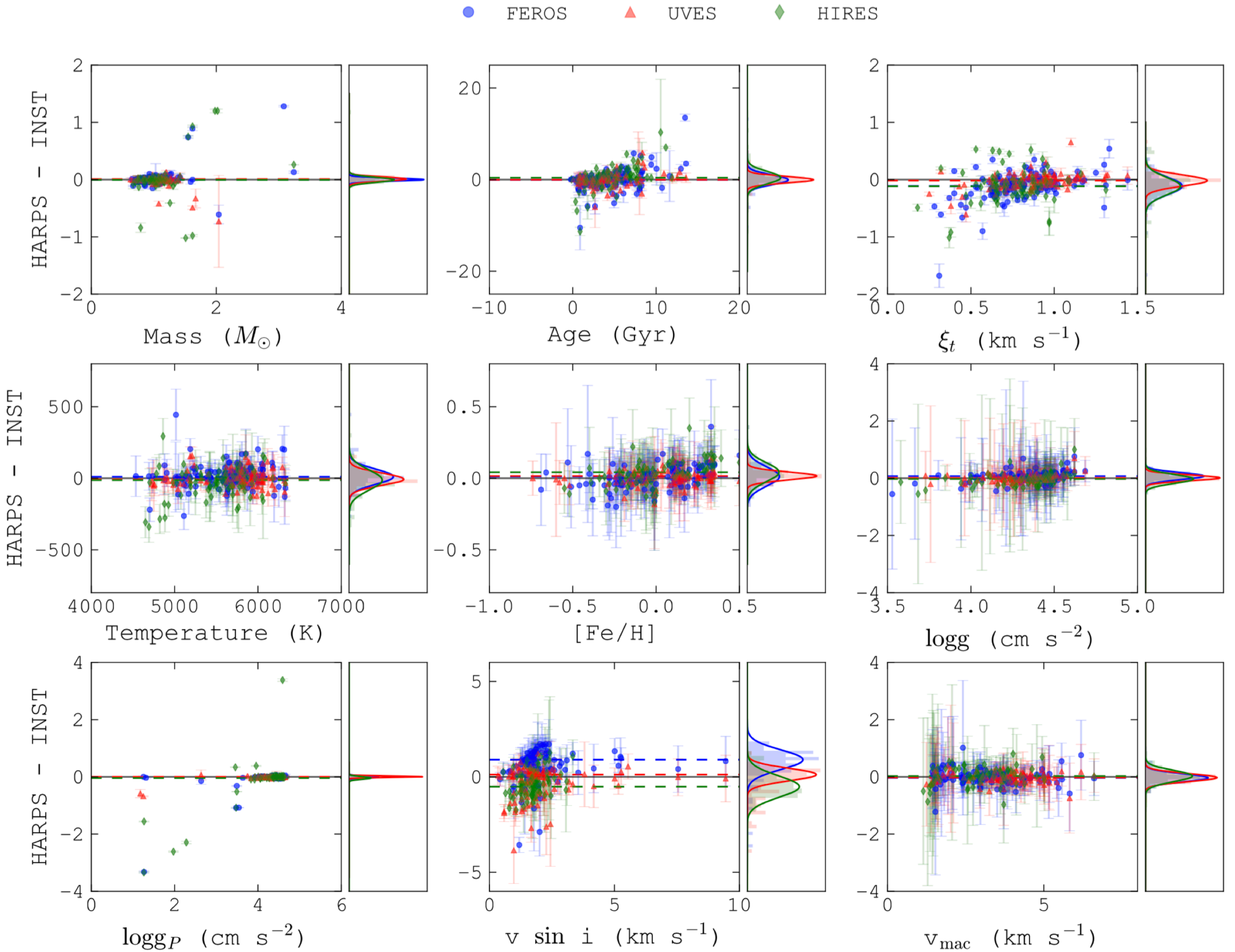
Adibekyan et al. 2012
Bond et al. 2006
Ivanyuk et al. 2017
Brewer et al. 2016
Bensby et al. 2014
SPECIES - LIT
[Na/H]
[Mg/H]
[Al/H]
[Si/H]
[Ca/H]
[Ti/H]
[Cr/H]
[Mn/H]
[Ni/H]



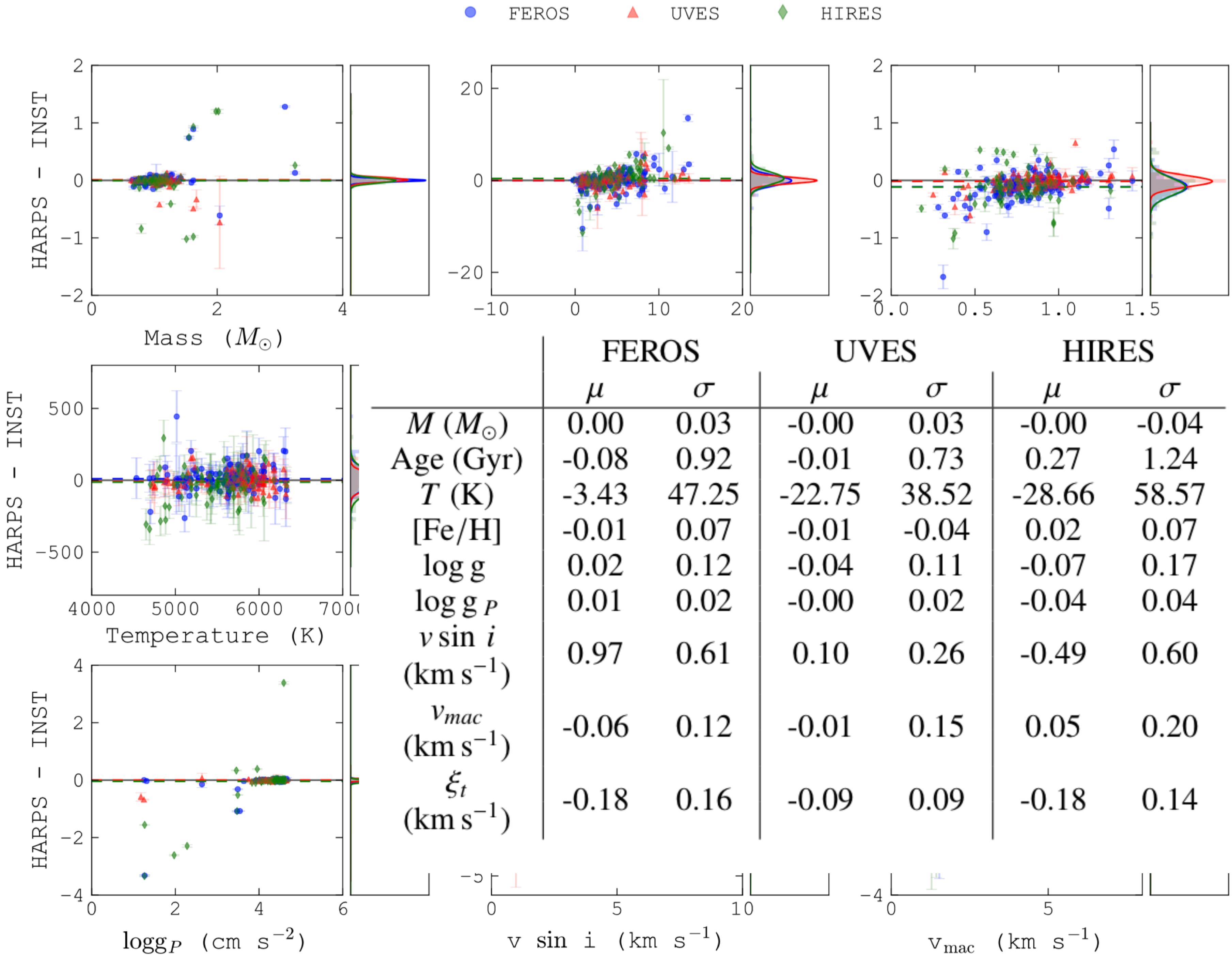
	Adibekyan et al. (2012)		Brewer et al. (2016)		Bond et al. (2006)		Bensby et al. (2014)		Ivanyuk et al. (2017)	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
[Na/H]	0.03	0.06	0.08	0.06	0.09	0.03	0.07	0.06	0.15	0.06
[Mg/H]	0.04	0.05	0.07	0.04			0.02	0.05	0.02	0.05
[Al/H]	0.05	0.05	0.09	0.05	0.27	0.04	0.04	0.05	0.24	0.04
[Si/H]	0.07	0.07	0.08	0.08	0.10	0.09	0.04	0.07	0.12	0.09
[Ca/H]	0.10	0.08	0.10	0.07	0.16	0.07	0.08	0.08	0.15	0.10
[Ti/H]	0.07	0.07	0.07	0.08	0.09	0.02	0.08	0.18	0.09	
[Cr/H]	0.08	0.08	0.10	0.07			0.06	0.07	0.17	0.08
[Mn/H]	0.10	0.08	0.13	0.06					0.02	0.09
[Ni/H]	0.05	0.05	0.06	0.03	0.11	0.06	0.04	0.05	0.04	0.06



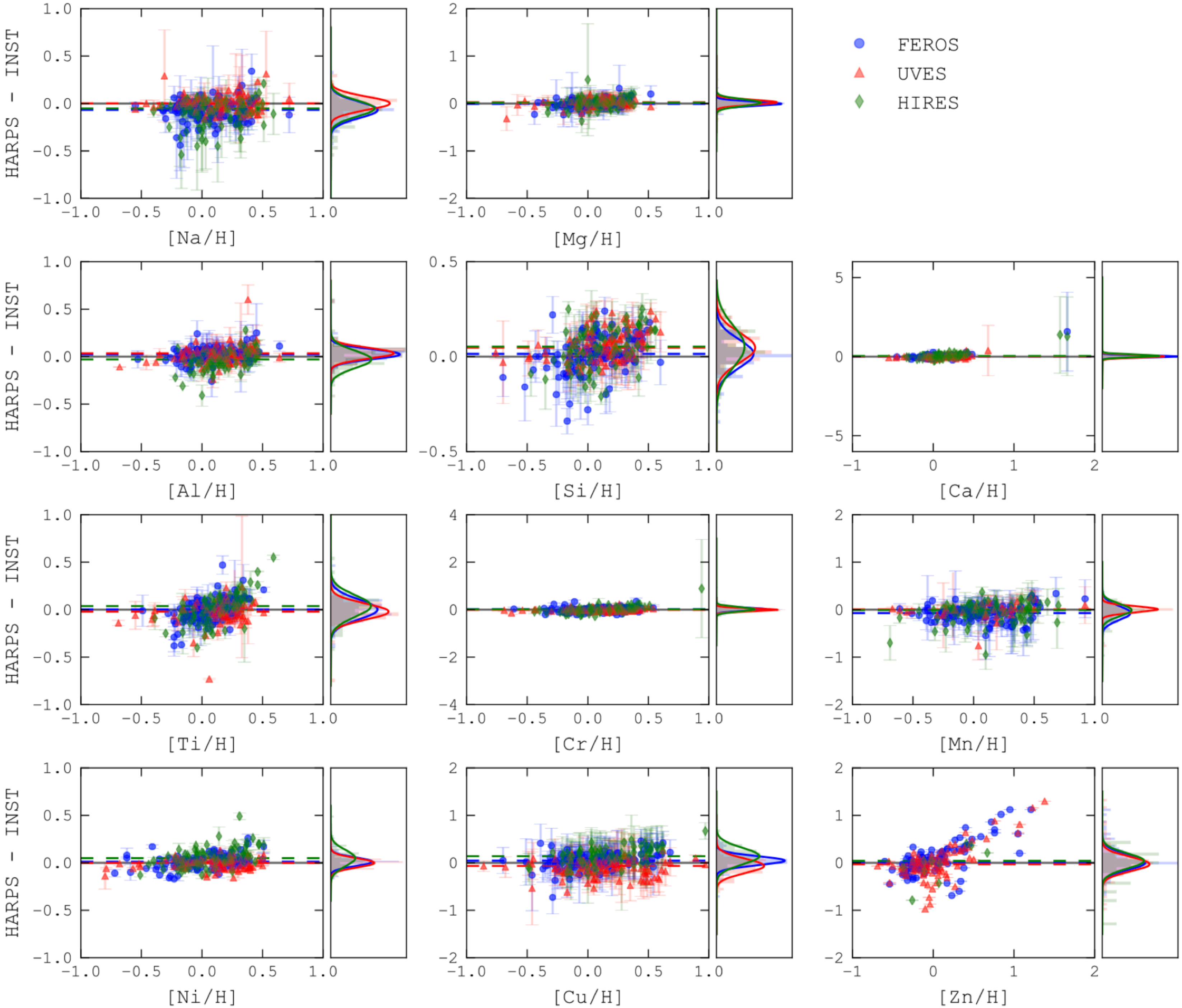
RESUTS: COMPARISON WITH DIFFERENT INSTRUMENTS



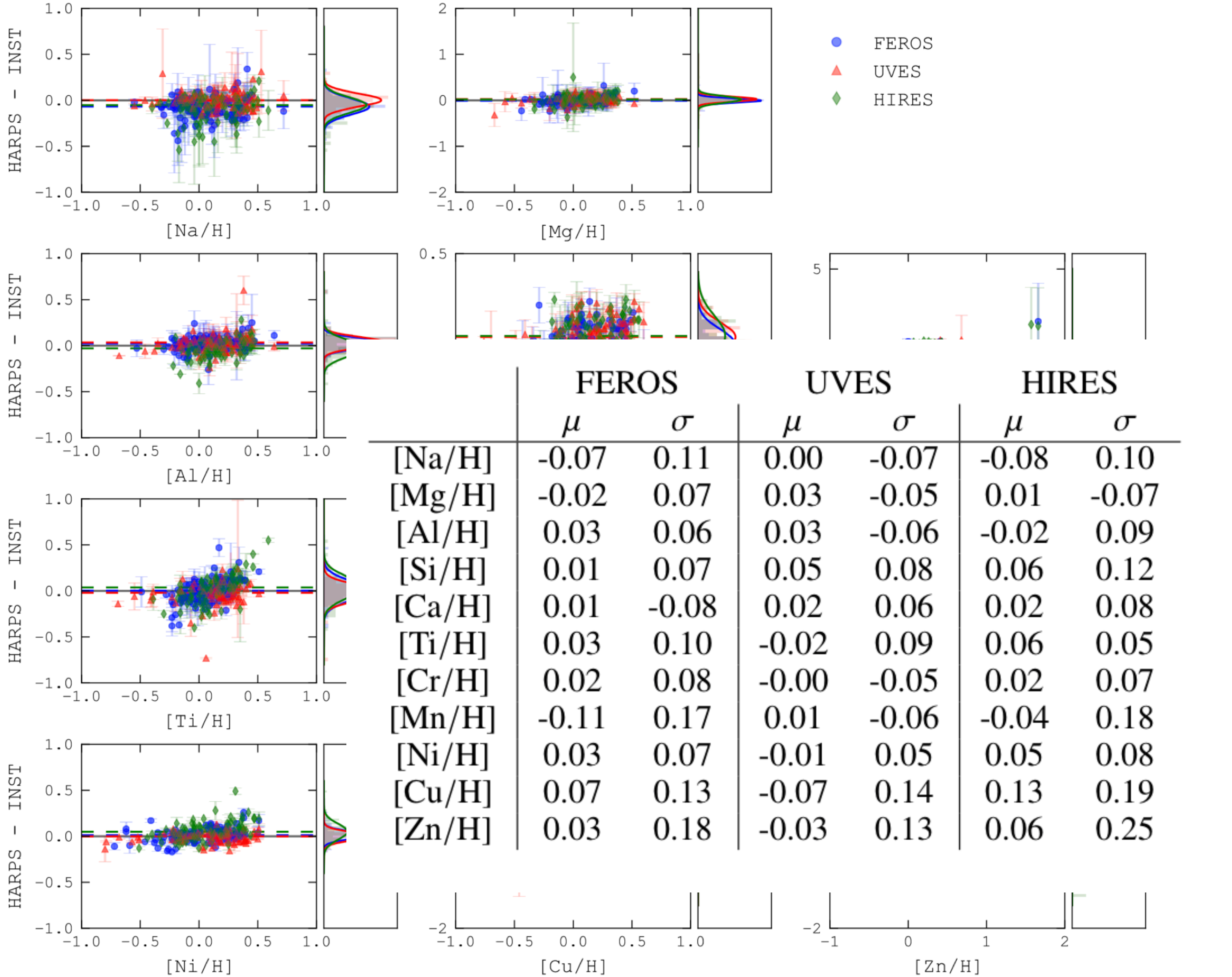
FEROS
UVES
HIRES
HARPS - INST
Mass ($M_\odot$)
Age (Gyr)
ξ_t (km s^{-1})
Temperature (K)
[Fe/H]
logg (cm s^{-2})
logg$_P$ (cm s^{-2})
v sin i (km s^{-1})
v$_{\rm mac}$ (km s^{-1})



	FEROS		UVES		HIRES	
	μ	σ	μ	σ	μ	σ
M ($M_\odot$)	0.00	0.03	-0.00	0.03	-0.00	-0.04
Age (Gyr)	-0.08	0.92	-0.01	0.73	0.27	1.24
T (K)	-3.43	47.25	-22.75	38.52	-28.66	58.57
[Fe/H]	-0.01	0.07	-0.01	-0.04	0.02	0.07
log g	0.02	0.12	-0.04	0.11	-0.07	0.17
log g $_P$	0.01	0.02	-0.00	0.02	-0.04	0.04
$v \sin i$ (km s^{-1})	0.97	0.61	0.10	0.26	-0.49	0.60
v_{mac} (km s^{-1})	-0.06	0.12	-0.01	0.15	0.05	0.20
ξ_t (km s^{-1})	-0.18	0.16	-0.09	0.09	-0.18	0.14



FEROS
UVES
HIRES
HARPS - INST
[Na/H]
[Mg/H]
[Al/H]
[Si/H]
[Ca/H]
[Ti/H]
[Cr/H]
[Mn/H]
[Ni/H]
[Cu/H]
[Zn/H]



	FEROS		UVES		HIRES	
	μ	σ	μ	σ	μ	σ
[Na/H]	-0.07	0.11	0.00	-0.07	-0.08	0.10
[Mg/H]	-0.02	0.07	0.03	-0.05	0.01	-0.07
[Al/H]	0.03	0.06	0.03	-0.06	-0.02	0.09
[Si/H]	0.01	0.07	0.05	0.08	0.06	0.12
[Ca/H]	0.01	-0.08	0.02	0.06	0.02	0.08
[Ti/H]	0.03	0.10	-0.02	0.09	0.06	0.05
[Cr/H]	0.02	0.08	-0.00	-0.05	0.02	0.07
[Mn/H]	-0.11	0.17	0.01	-0.06	-0.04	0.18
[Ni/H]	0.03	0.07	-0.01	0.05	0.05	0.08
[Cu/H]	0.07	0.13	-0.07	0.14	0.13	0.19
[Zn/H]	0.03	0.18	-0.03	0.13	0.06	0.25

SUMMARY

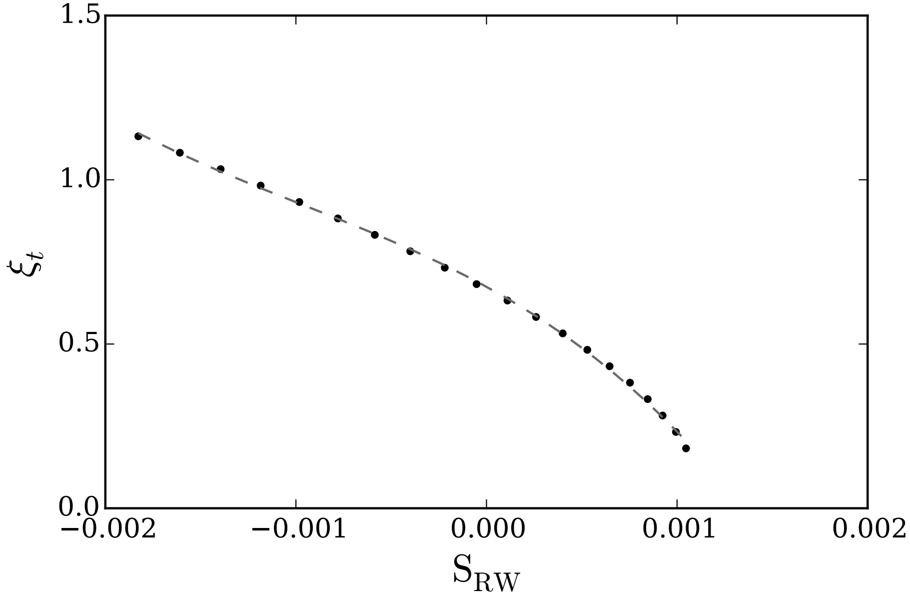
- **SPECIES is an automated code to compute stellar parameters.**
- Written mostly in python.
- **All input needed in a high S/N, high resolution spectra.**
- Propose analytic relations between the atmospheric parameters.
- Tested for dwarf and subgiant stars.
- More information in **Soto et al. 2017 in prep.**
- Available to the community in https://github.com/msotov/SPECIES

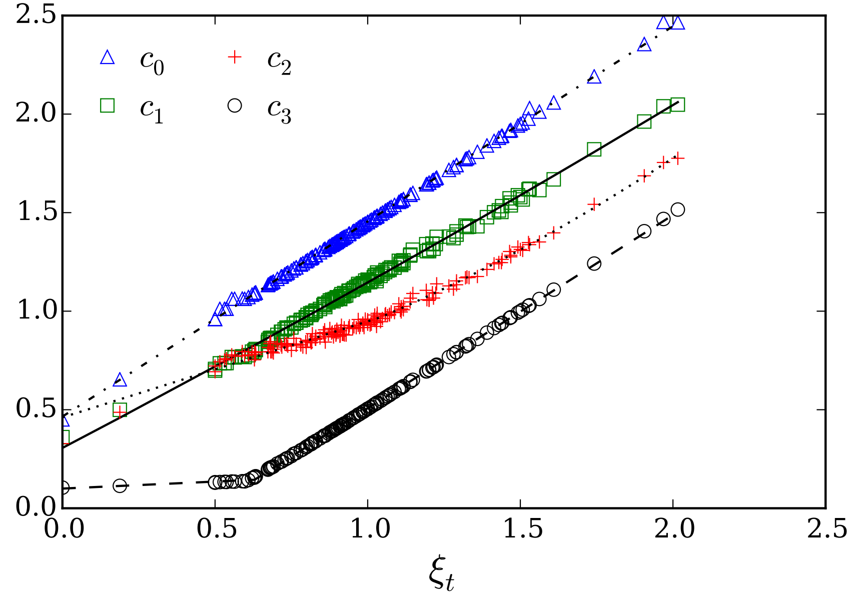
WHAT'S IN THE FUTURE

- Perform analysis for M-dwarfs.
- Test SPECIES with low-resolution spectra.
- Test SPECIES with low signal-to-noise spectra.

Microturbulence

$$\sigma_{\xi_t}^2 = \left(\frac{\partial \xi_t}{\partial S_{RW}} \bigg|_{S_{RW}=0} \right)^2 \sigma_{S_{RW}}^2$$



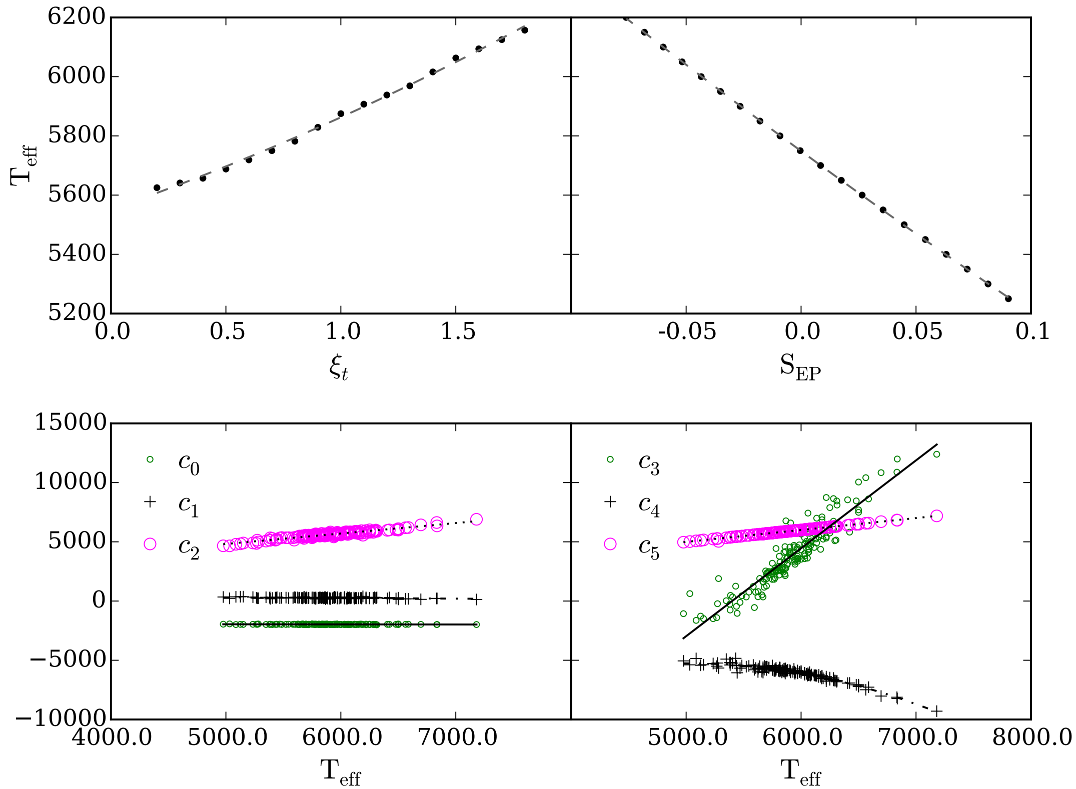


Temperature

$$\sigma_T^2 = \left(\frac{\partial T}{\partial \xi_t}\bigg|_{\xi_t} \right)^2 \sigma_{\xi_t}^2 + \left(\frac{\partial T}{\partial \chi_I}\bigg|_{\chi_I=0} \right)^2 \sigma_{\chi_I}^2$$

$$T = c_0 \cdot \xi_t^2 + c_1 \cdot \xi_t + c_2$$

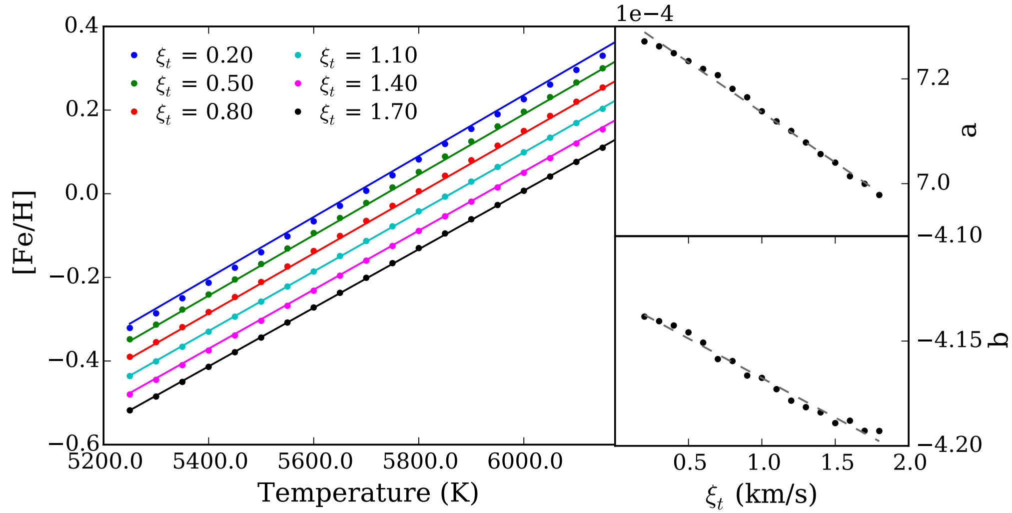
$$T = c_3 \cdot \chi_I^2 + c_4 \cdot \chi_I + c_5$$

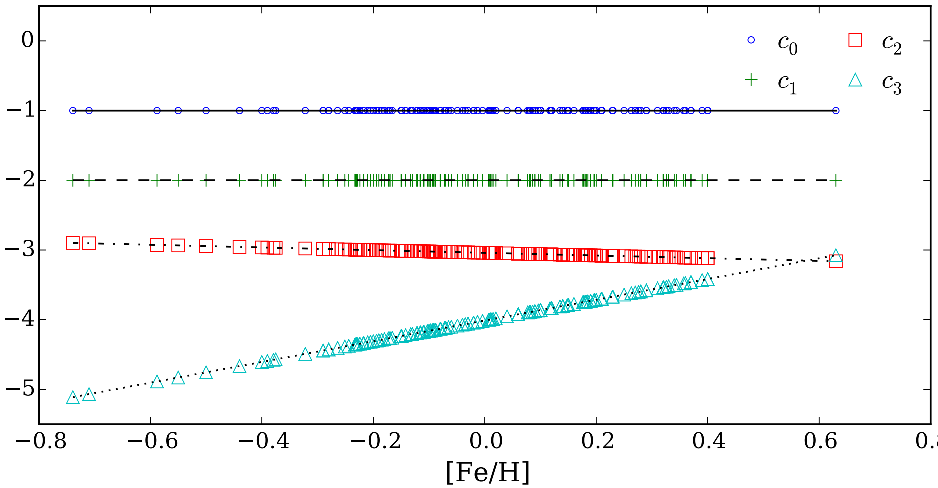


- Metallicity

$$\sigma^2_{[Fe/H]} = \left(\frac{\partial [Fe/H]}{\partial \xi_t} \bigg|_{\xi_t} \right)^2 \sigma^2_{\xi_t} + \left(\frac{\partial [Fe/H]}{\partial T} \bigg|_{T} \right)^2 \sigma^2_{T} + \sigma^2_{FeI}$$

$$[Fe/H] = (c_0 \cdot \xi_t + c_1) \cdot T + (c_2 \cdot \xi_t + c_3)$$





- logg

$$\sigma^2_{\log g} = \left(\frac{\partial \log g}{\partial T} \bigg|_T \right)^2 \sigma^2_T + \left(\frac{\partial \log g}{\partial FeII} \bigg|_{FeII} \right)^2 \sigma^2_{FeII}$$

$$\log g = c_0 \cdot FeII + c_1$$

$$\log g = c_2 \cdot T^2 + c_3 \cdot T + c_4$$