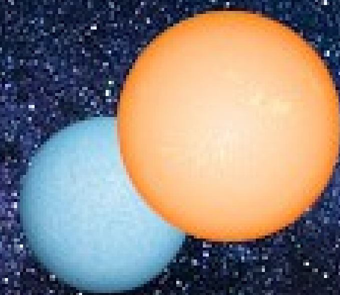
Parameters and chemical composition of stars or binary systems components based on analysis of high-resolution spectra



Cezary Gałan

Annual Report 2024,
January 23, 2025

Publications and conference presentations

PAPERS:

- "Precise physical parameters of three late-type eclipsing binary giant stars in the Large Magellanic Cloud", Rojas García, G.; Graczyk, D.; Pietrzyński, G.; Gałan, C.; et al., 2025, A&A 692, 110

- "Surface brightness-colour relations of dwarf stars from detached eclipsing binaries - II. Extension of calibrating sample", Graczyk, D.; Pietrzyński, G.; Gałan, C.; et al., 2025, A&A, accepted in print

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CONFERENCE PRESENTATIONS:

@ ”Galactic and Extragalactic Distances for the Hubble constant. Araucaria Collaboration Meeting 2024”,
Paris Observatory, France, September 2-6, 2024:

- ”Spectral analysis of the candidates for non-pulsating stars in the Cepheid instability strip”, Gałan, C.; (oral presentation)

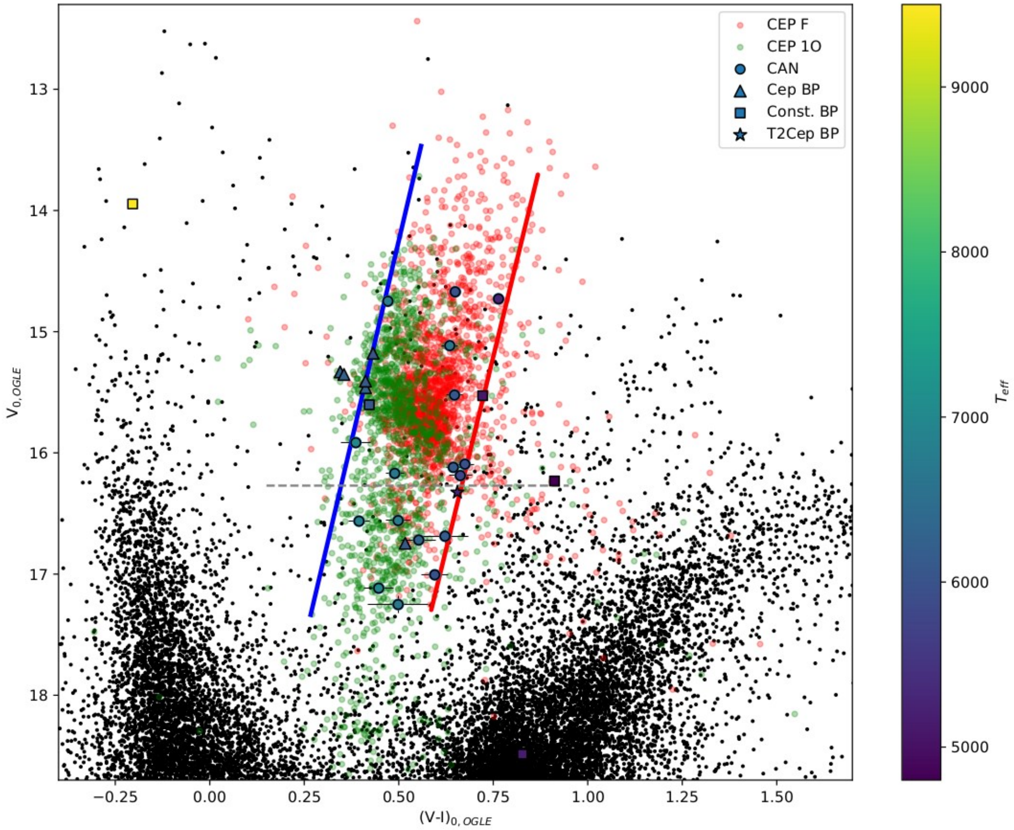
@ ”Symbiotic stars, weird novae, and related embarrassing binaries”,
Faculty of Mathematics and Physics of Charles University, Prague, Czech Republic, June 3-7, 2024:

- ”Chemical abundances and kinematics of symbiotic giants in S-type systems”, Gałan, C.; (oral presentation)
- ”HRS monitoring of symbiotic stars with yellow giants and active systems during outbursts”, Gałan, C.; Mikołajewska, J.; Monard, B.; Pietrzyński, G.; Wielgórski, P.; Kicia, M.; (poster)
- ”Chemical abundances of the stripped giant in the X-ray binary GX 339-4”, Gałan, C.; Mikołajewska, J.; Zdziarski, A.; (poster)

Spectral analysis of the candidates for non-pulsating stars in the Cepheid instability strip

Candidates among LMC Cepheids.

Parameters: T_{eff}, [Fe/H], and log g derived from the Strömgren photometry.



MIKE spectrograph

6.5 m Clay telescope

Las Campanas Observatory

Slit 0.7”, R_{blue} ~ 41000, R_{red} ~ 32000.

Name	No. of obs.	Dates	Radial Vel. [km/s]	S/N
Can-01	1	2019-12-23	267.92 ± 0.30	45
Can-03	2	2019-12-23 2020-02-24	271.47 ± 0.38 271.36 ± 0.43	70
Can-07	1	2019-12-24	241.66 ± 0.26	40
Can-08	1	2019-12-23	252.96 ± 1.26	43
Can-09	1	2019-12-24	268.21 ± 0.34	45
Can-10	3	2019-12-23 2020-02-24 2021-12-08	285.74 ± 0.97 285.28 ± 0.99 284.81 ± 1.09	95
Can-11	1	2019-12-23	244.08 ± 0.29	48
Can-13	1	2019-12-24	265.43 ± 0.34	43
Can-14	2	2019-12-23 2020-02-24	259.37 ± 0.38 259.70 ± 0.40	65
Can-16	1	2019-12-24	278.71 ± 0.78	40
Can-17	3	2019-12-23 2020-02-24 2021-12-10	263.62 ± 0.60 263.33 ± 0.60 263.12 ± 0.48	90

These stars appear to be photometrically stable at the level of a few mmag!

Methods

Spectrum synthesis

GSSP code (Tkachenko 2015)
SynthV radiative transfer code (Tsymbal 1996)

MEASURED: T_{eff}, [M/H], ξ, V_{rot}, abundances

MODEL ATMOSPHERES:
LLMODELS (Shulyak et al., 2004)
MARCS (Gustafsson et al., 2008)

[M/H] (dex)	Δ[M/H] (dex)	T_{eff} (K)	ΔT_{eff} (K)	log *g* (dex)	Δlog *g* (dex)
		MARCS			
[-1.0, 1.0]	0.1	[2 500, 5 500]	100	[1.0, 5.0]	0.1
		LLMODELS			
[-0.8, 0.8]	0.1	[5 600, 10 000]	100	[2.5, 5.0]	0.1
		[10 000, 25 750]	250	[3.0, 5.0]	
		[25 750, 30 000]		[3.3, 5.0]	
		[30 000, 33 000]	500	[3.5, 5.0]	
		[33 000, 34 000]		[4.0, 5.0]	

PROBLEM:
the lack of models for log *g* < 2.5 dex
(adopted log *g* = 2.5 for all objects).

Equivalent width method

MOOG v2019 code (Sneden 1973)
ARES v2 code (Sousa et al., 2015)

log *g*, T_{eff}, [M/H], ξ, ~~V_{rot}~~, abundances

Kurucz (ATLAS code; Kurucz 1993)

ADVANTAGES:
- can be faster (focused on a specific lines),
- ARES enables authomatic measuremet of EW,
- Fully authomatic continuum determination.

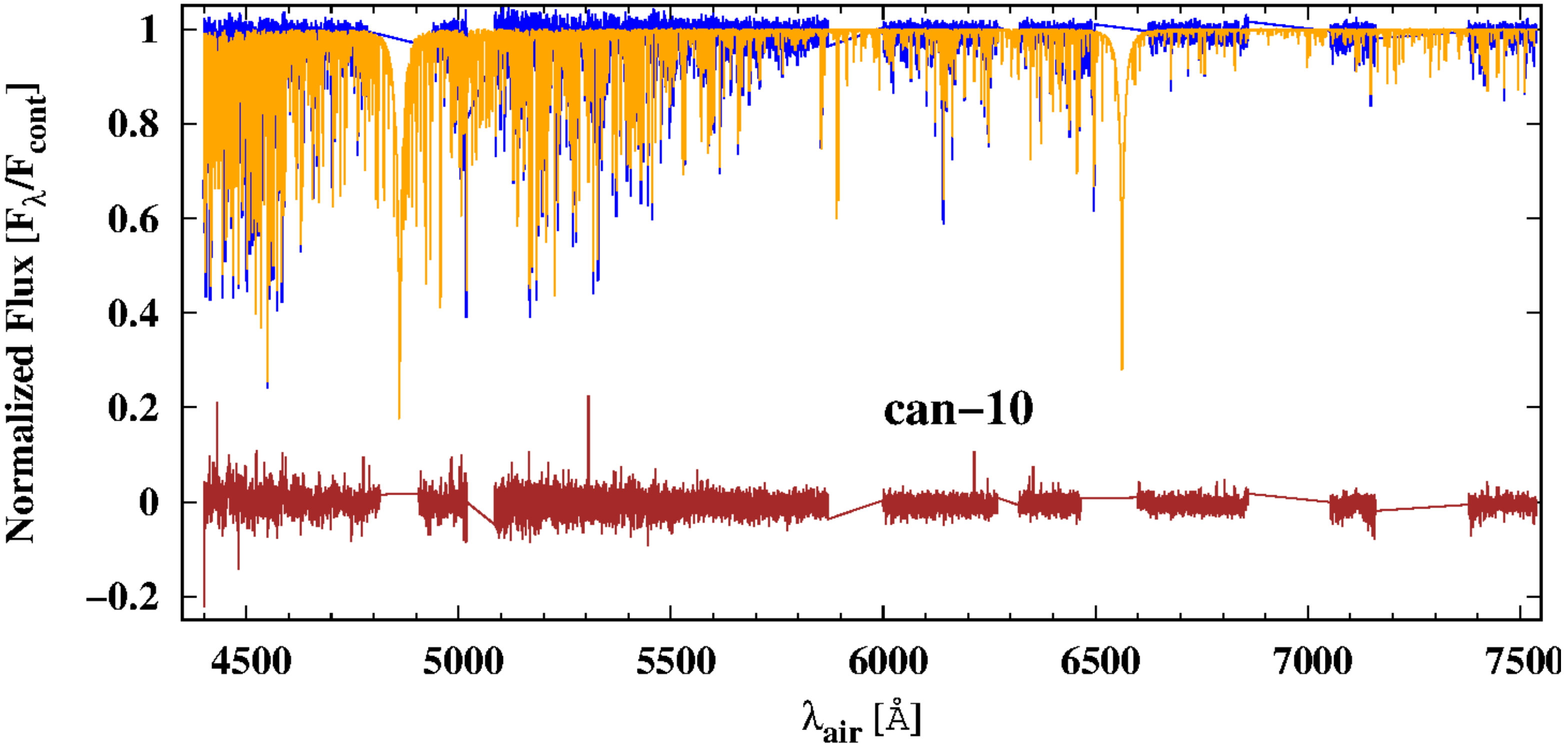
WEAKNESSES:
- Blending of lines makes a problem
(this may lead to inaccurate results),
- Caution in lower resolution data (R < 20000),
- Avoid fast rotators (V sini >~15 Km/s).

Analysis.

Example of solution for CAN-10 using single version of GSSP code

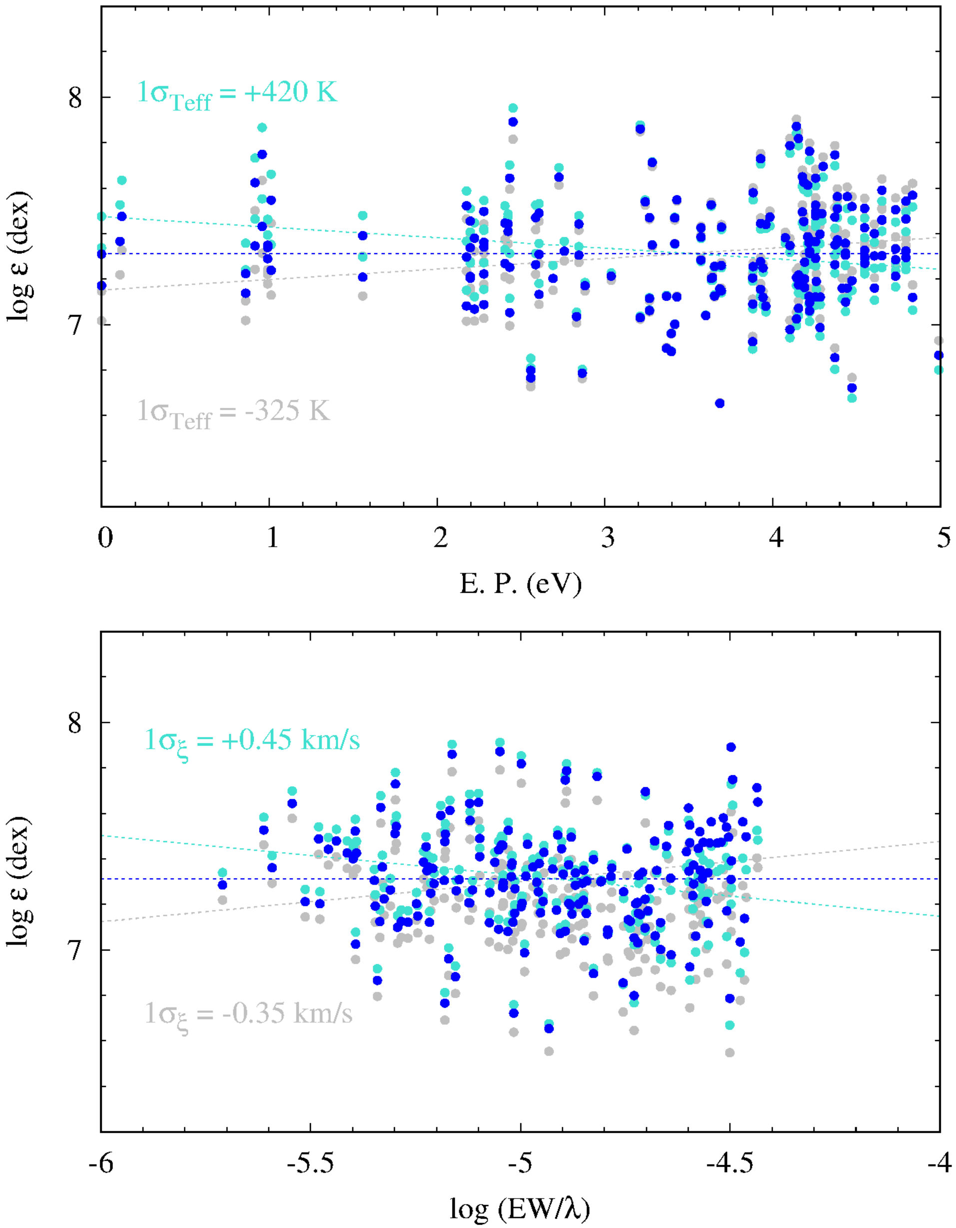
```
# ADOPTED:

 logg = 2.5 dex
 Vmacro =  8.0 km/s

# Grid best parameters:

[M/H]  = -0.1 dex
Teff   =  7300 K
Vmicro =  4.70 km/s
Vsini  =  23.0 km/s
Chi2_red_min =       7.9004
chi2_red_1sigma =    7.9614

# Best fit parameters:

[M/H]  = -0.113 +0.062/-0.067  dex
Teff   =  7273  +/-45          K
Vmicro =  4.782 +0.172/-0.174  km/s
Vsini  =  23.46 +0.82/-0.81    km/s
```

Synthetic fit (orange) compared to the observed spectra (blue).



Analysis.

Example of solution for CAN-11 using ARES + MOOG



Iterative proces:
After each step, outlier points were rejected using the ±3σ criterion.

The final parameters:

T_{eff} = 6410 ± 375 K

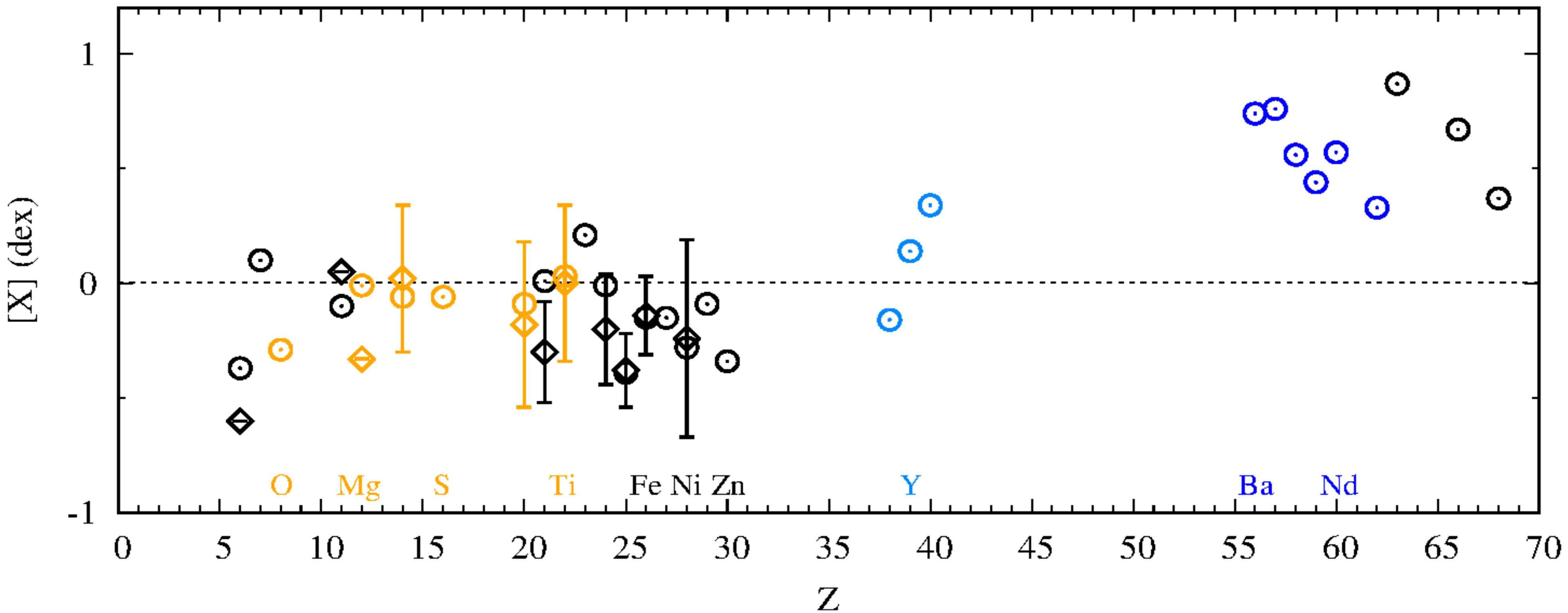
log g = 1.55 ± 0.62 dex

[Fe/H] = -0.14 ± 0.17 dex

ξ = 3.33 ± 0.40 km/s

Abundances of chemical elements in CAN-11

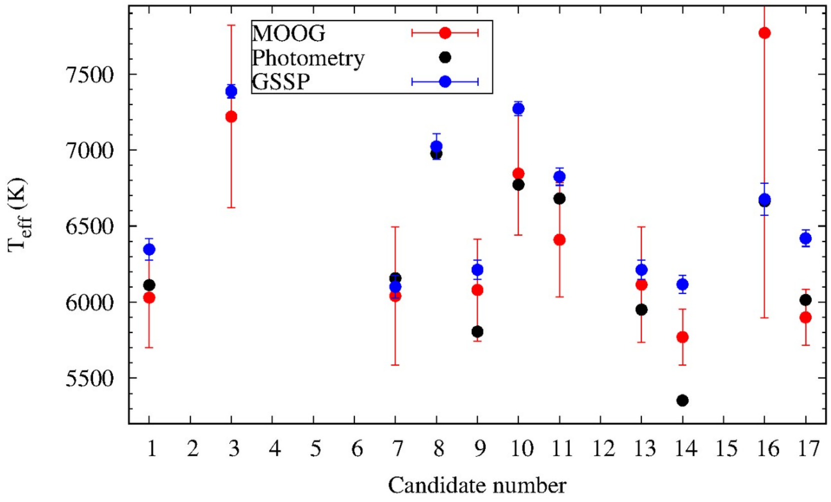
Relative to solar the values of abundances obtained with GSSP (circles) and MOOG (diamonds).

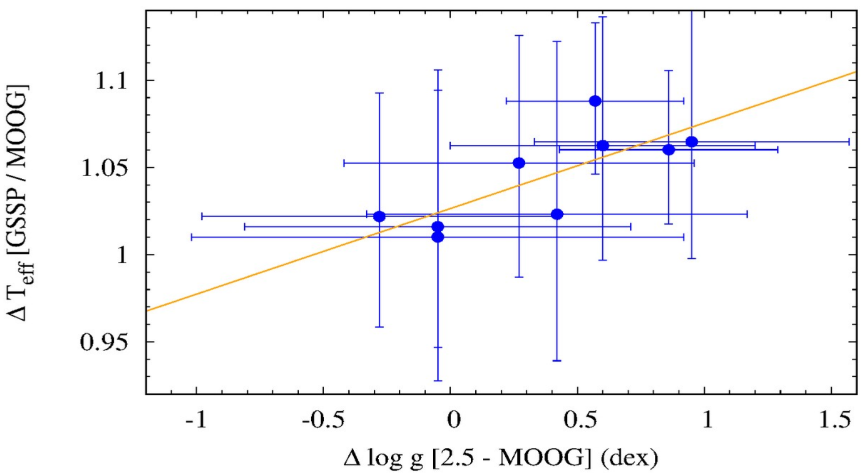


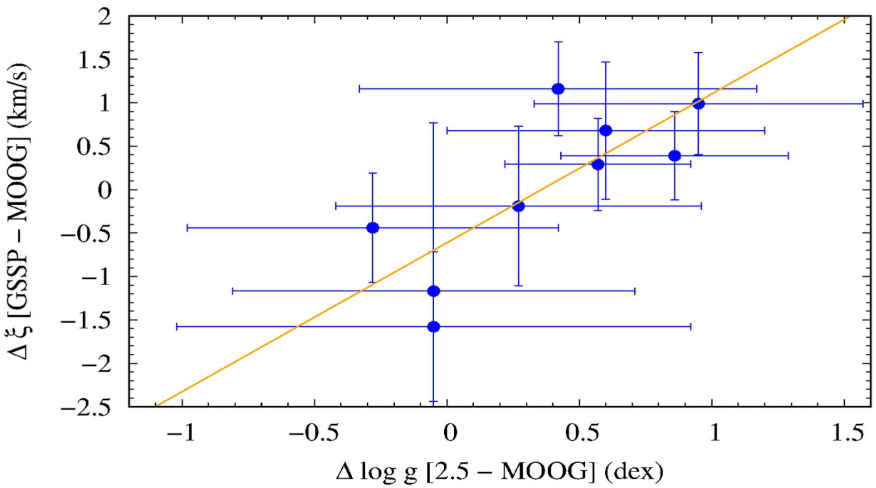
Significantly enhanced heavy (Barium – peak) s-process elements: Ba, La, Ce, Pr, Nd, Sm; and frequently also light (Zirconium – peak) s-process elements: Zr, Y.

Results from different methods:
Spectrum synthesis (GSSP), EW (MOOG), and Strömgren photometry

- T_{eff} (EW) ~ T_{eff} (Photometry)
- Small precission from the method of EW
- Significant correlations between log *g* and T_{eff}, ξ, and [M/H].







- T_{eff} will probably not differ significantly from those obtained from Strömgren photometry – suspected physical reason for the observed behavior!
- The next step: the spectral synthesis repeated using *Kurucz* model atmospheres with free log *g*.

HRS monitoring of symbiotic stars with yellow giants, and active systems around outbursts

Gałan C., Mikołajewska J., Monard B., Pietrzyński G., Wielgórski P., Kicia M.

Id No[a]	Name	JD_{1st}	$JD_{last-1st}$	$N_{obs.}$	$P_{orb.}$ [d]	$(JD_{last-1st})/P_{orb.}$
-	StHa 63	2458446	1977	16	-	-
25	WRAY 15-157	2458446	1978	17	-	-
28	AS 201	2458439	1985	19	-	-
32	SS73 29	2458473	1957	19	-	-
40	Hen 3-863	2458487	1937	31	526 [b]	3.68
41	St 2-22	2458530	1891	27	918	2.06
43	V840 Cen	2458494	1935	23	8.096 [b]	239
50	V417 Cen	2458497	1917	27	1652	1.16
51	BD-21 3873	2458505	1560	27	281.6	5.54
55	HD 330036	2458517	1906	27	1678	1.14
65	Hen 3-1213	2458559	1864	35	533 [b]	3.50
112	AS 255	2459009	1412	11	-	-
116	AS 269	2458664	1772	12	-	-
-	PN G001.7-03.6	2458617	1408	5	-	-
122	Hen 3-1591	2458602	1821	13	2350	0.77
s22	V618 Sgr	2458544	1844	23	703	2.62
126	PN Ap 1-9	2458574	1858	10	-	-
s25	Hen 2-379	2458559	1878	15	-	-
-	SS383	2458576	1847	20	385 [b]	4.80
153	MWC 960	2458577	1862	19	-	-
-	StHa 176	2458581	1840	25	241 [b]	7.63
182	CD-43 14304	2458442	1978	25	1448	1.37
184	StHa 190	2458617	1820	18	-	-

AIMS:

- Abundances, evolutionary status, mass transfer
- Radial velocity monitoring → spectroscopic orbits
- Monitoring of SySt in active states

OBSERVATIONS:

- HRS/SALT (R~40000, 3900 – 8800 Å)

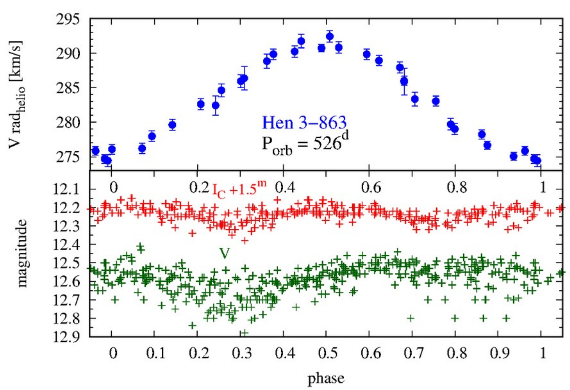
Programs: 2019-1-MLT-008 & 2018-2-SCI-021.

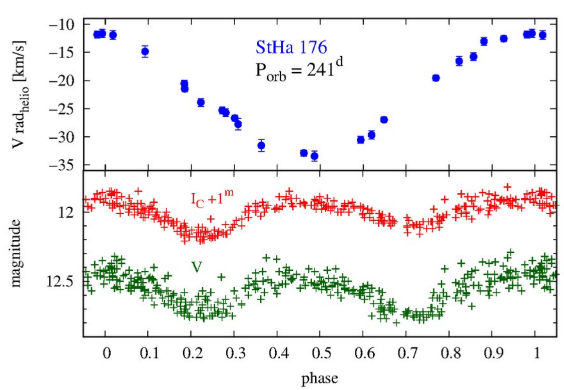
- *V*, R_C, I_C photometry (35 cm Meade RCX400)

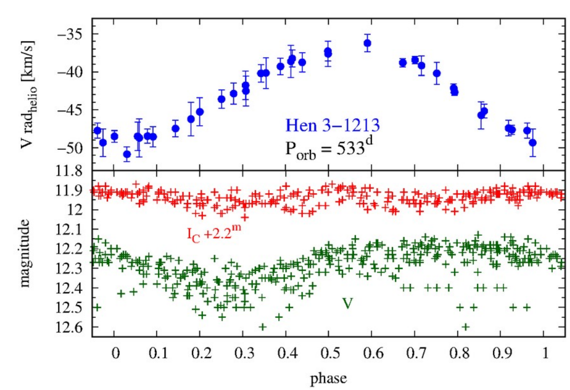
Berto Monard, Kleinkaroo Observatory, Sout Africa

- *V*, I_C photometry (80 cm 'Zibi' Telescope)

Cerro Murphy Observatory, Chile



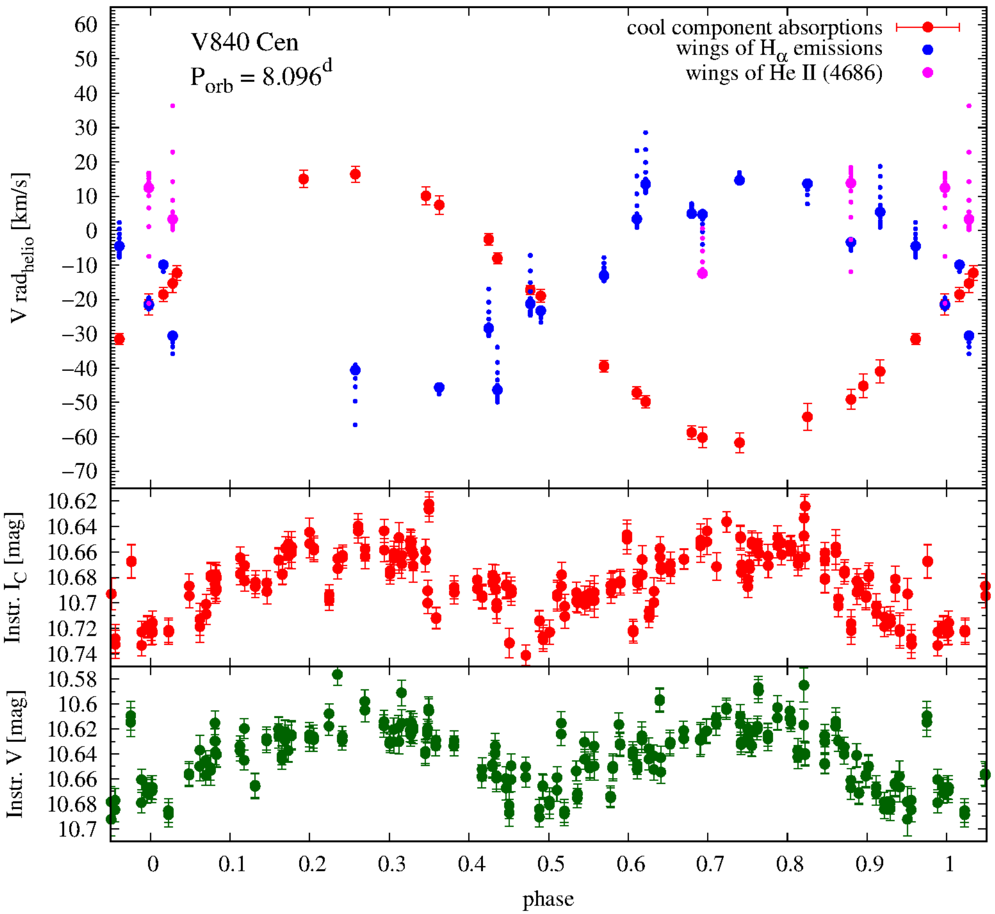




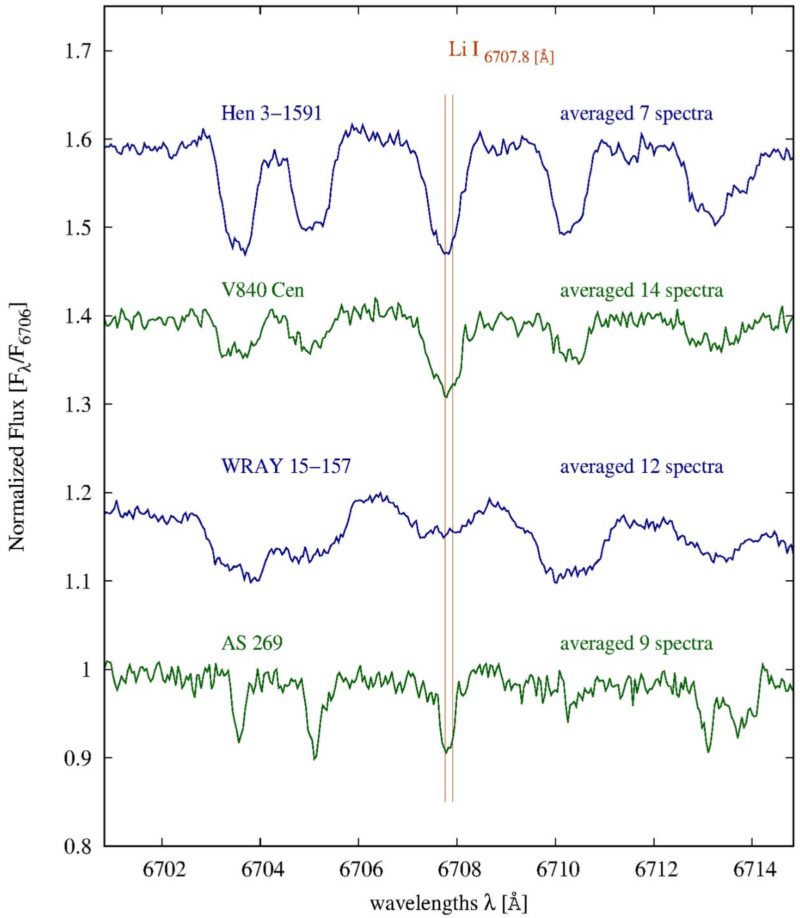
V840 Cen

P_{orb} ~ 8.096 days

Radial velocity curves of both components, and ellipsoidal variations



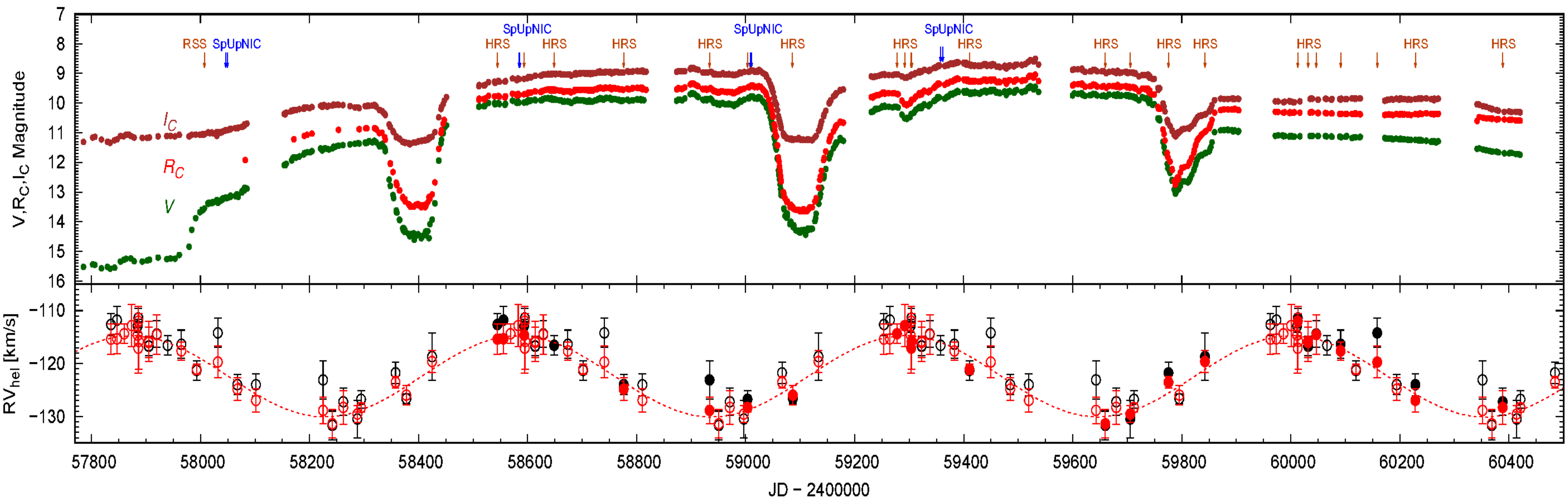
Lithium (6707.8 Å) line



V618 Sgr

eclipsing symbiotic Nova

Radial velocities rom 23 HRS/SALT spectra (around three eclipses).



Preliminary solution for the circular orbit:

T_0 = (2458405.5 ±3.9) + (708.9 ±0.23) • E, K = 7.7 ±0.4 km/s

Ephemeris is in good agreement with 3 minima observed in 1930's (Swope 1940)

M_{WD} ~0.5–0.6 M⊙

Chemical abundances of the stripped giant in the X-ray binary GX 339-4

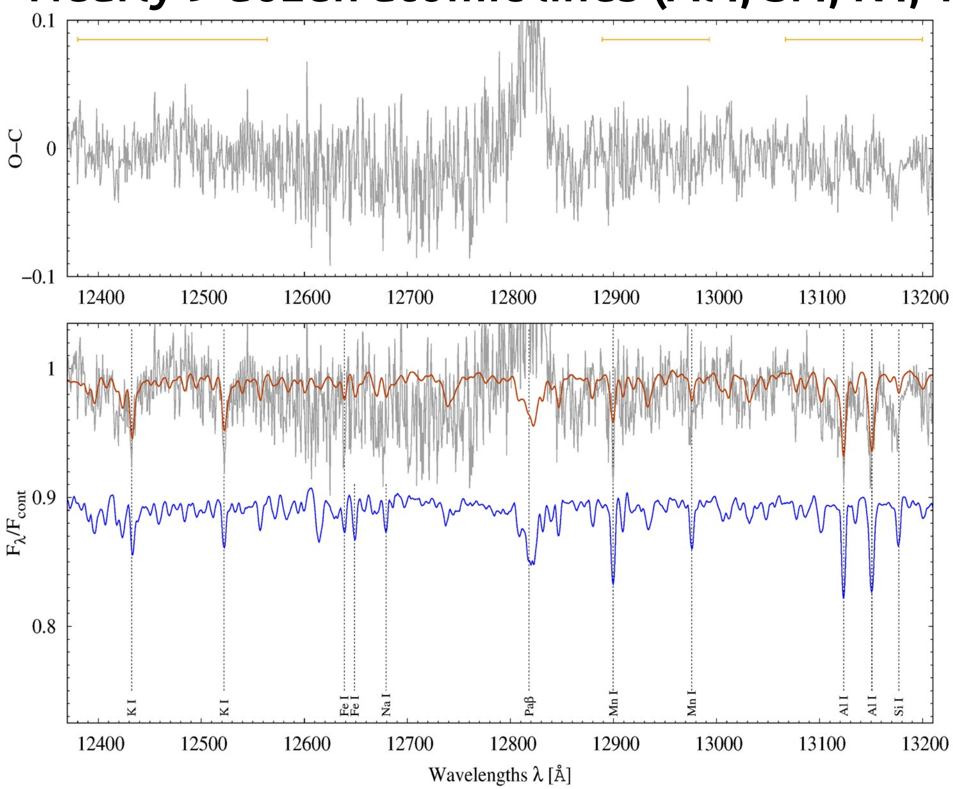
Cezary Gałan, Joanna Mikołajewska, Andrzej Zdziarski

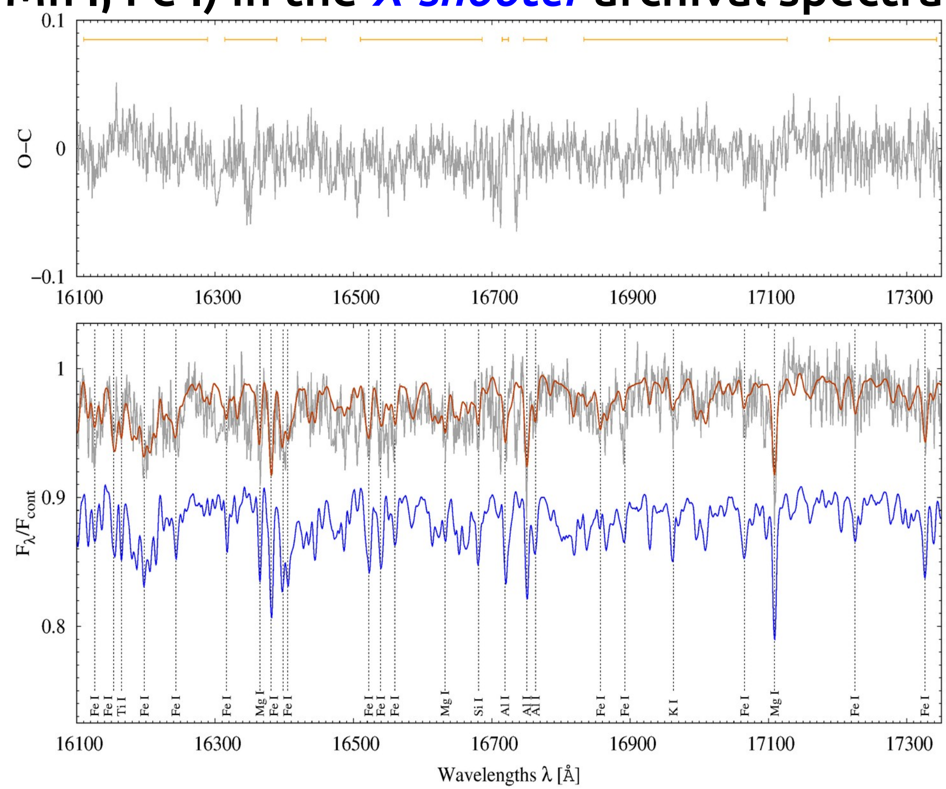
Black Hole: $M_{BH} \approx 2.3–9.5\ M_\odot$,

$P_{orb} = 1.76$ days, Heida et al. (2016).

Red Giant: $M_g \approx 0.5–1.4\ M_\odot$, Zdziarski et al. (2019).

Nearly 9 dozen atomic lines (Al I, Si I, K I, Ti I, Mn I, Fe I) in the *X-shooter* archival spectra.





Spectral synthesis and results

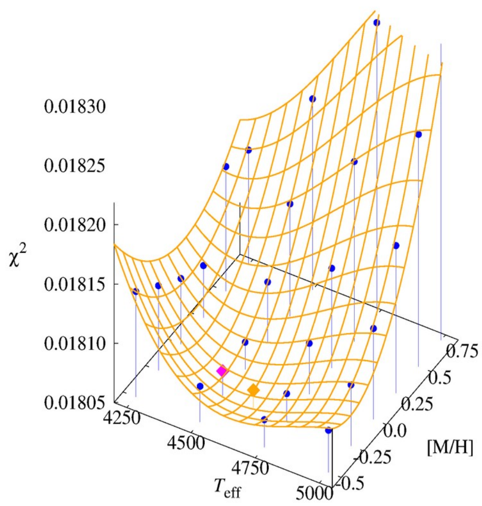
The spectrum synthesis method: *Turbospectrum.v19* code (Plez 2012).

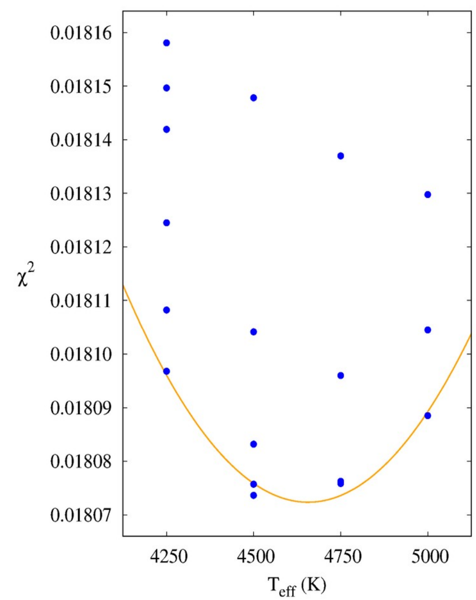
Grid of 72 models: T_{eff} = 4250–5000 K, log g = +2.5–+3.5 dex, [M/H] = -0.5 – +0.75 dex.

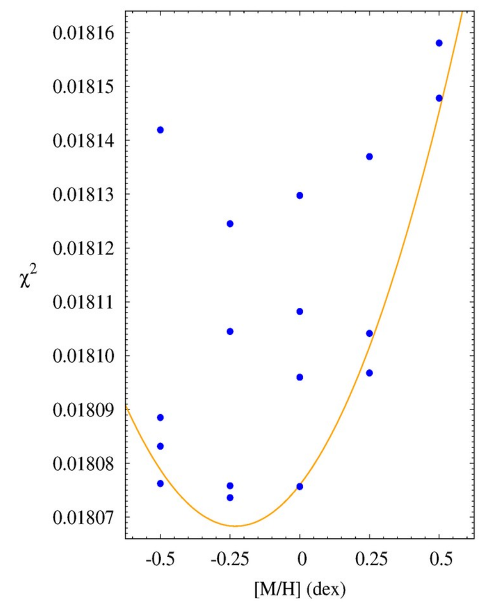
The best fit parameters: T_{eff} = 4500 K, log g = 3.5 dex, [M/H] = -0.25 dex.

Exceptionally high abundance of potassium (K I): [X] ~ +1.9 dex !

Element	**log ϵ (*X*)**	**[*X*]**
C	8.72 ± 0.04	+0.29
Mg	7.98 ± 0.08	+0.39
Al	7.20 ± 0.21	+0.77
Si	7.96 ± 0.08	+0.45
K	6.96 ± 0.37	+1.92
Ca	6.72 ± 0.26	+0.40
Ti	5.69 ± 0.18	+0.76
Mn	5.41 ± 0.28	-0.01
Fe	7.71 ± 0.04	+0.24
Ni	6.99 ± 0.12	+0.79








Thank you