Spectroscopic investigation of selected λ Boo – type stars

Joanna Molenda-Żakowicz[1], Richard O. Gray[2], Christopher J. Corbally[3], Simon J. Murphy[4], Drew Chojnowski[5], Sten Hasselquist[5], Ewa Niemczura[1], Ernst Paunzen[6] and Chris Koen[7]

1. Astronomical Institute, University of Wrocław, Kopernika 11, 51–622 Wrocław, Poland
2. Department of Physics and Astronomy, Appalachian State University, Boone, NC 26808, USA
3. Vatican Observatory Research Group, Steward Observatory, Tucson, AZ, 85721–0065 USA
4. Sydney Institute for Astronomy (SIfA), School of Physics, University of Sydney, NSW 2006, Australia
5. Department of Astronomy, New Mexico State University, Box 30001, MSC 4500, Las Cruces NM 88003, USA
6. Department of Theoretical Physics and Astrophysics, Masaryk University, Kotlárská 2, CZ-611 37 Brno, Czech Republic
7. Department of Statistics, University of the Western Cape, Private Bag X17, Bellville, 7535 Cape Town, South Africa

We present the first results of our programme of high-resolution, high signal-to-noise spectroscopic observations of selected λ Boo stars. Observations acquired in the framework of this project will be used to derive the relative abundances of chemical elements on the surface of the star. This information then will be used in detailed asteroseismic analysis aiming to answer the long-standing question whether the λ Boo stars are peculiar only on the surface or throughout the whole star. This research may also help us to address larger problems of star formation and evolution, and gain insights into planet formation and planet – debris disk interaction.

1 Introduction

The λ Boo stars form a small sub-group of chemically peculiar stars on the upper main-sequence (see: Murphy et al., 2015; Gray et al., 2017) characterized by under-abundances of iron-peak elements and near-solar abundances of the volatile elements C, N, O, and S (Kamp et al., 2001). Even though ,they have been known for more than 70 years, their structure, origin of the peculiarity, and their evolutionary status still remains a puzzle. That is partly due to the fact that many λ Boo stars lack high-resolution spectroscopic observations which would confirm their classification and allow us to study the properties of this class in more detail.

In order to address the question of the origin of the peculiar abundance pattern of the λ Boo stars we launched a programme of high-resolution, high signal-to-noise (S/N) spectroscopic observations of the selected λ Boo stars. The information which we will derive from those spectra will include $v \sin i$ values and detailed surface abundance pattern. Such information then will be used in detailed asteroseismic studies, based on the photometric observations acquired with the *Kepler* space telescope via the K2 mission and the future TESS space mission, which will allow us to address the question of the origin of the peculiar abundance pattern of λ Boo stars. Our expectation that the TESS observations will allow us to discover and study the pulsational variability of many stars from our sample is supported by the fact that λ Boo stars are more likely to pulsate than normal stars and often show richer pulsation spectra than normal δ Sct stars (Murphy, 2014).

Table 1: A summary of observations of 75 stars classified as λ Boo or λ Boo candidates obtained with the HRS@SALT (stars with HD numbers) or the ARCES@3.5m (stars with KIC numbers) instruments.

Star	α_{2000}	δ_{2000}	V (mag)	Date	$t_{\rm exp}$ (s)	Seeing (arc sec)	S/N @5500Å	Weather conditions
HD 319	00:07:46.90	-22:30:30.8	5.93	2017-08-31	125	1.1	220	foggy
HD 3922	00:40:46.14	-68:11:11.1	8.37	2017-06-18	525	2.1	160	clear
HD 4158	00:43:54.05	-20:23:59.3	9.58	2017-06-12	1825	1.3	190	clear
HD 6870	01:08:03.97	-61:52:17.8	7.48	2017-09-02	325	1.4	200	clear
HD 7908	01:18:25.37	-23:00:47.6	7.31	2017-09-11	325	1.6	95	thick clouds
HD 11413	01:50:54.43	-50:12:22.1	5.95	2017-08-07	25	2.1	90	clear
HD 13755	02:12:47.09	-44:29:20.5	7.87	2017-07-14	325	2.0	150	humid
HD 15165	02:26:45.65	+10:33:55.1	6.69	2017-10-02	125	2.1	95	clouds
HD 16179	02:35:48.67	-00:20:59.1	8.62	2017-08-08	725	1.2	120	clouds
"	"	"	"	2017-09-04	925	2.5	160	hazy
HD 17341	02:45:55.66	-31:25:11.7	9.34	2017-07-10	1525	2.2	160	clear
HD 23392	03:44:32.72	-08:35:12.5	8.24	2017-09-06	925	2.2	150	clear
HD 23828	03:47:45.95	-08:36:41.4	9.58	2017-09-26	1825	1.3	170	clear
HD 28490	04:29:20.10	-05:30:39.0	9.53	2017-09-26	1825	1.4	180	clear
HD 28548	04:29:27.25	-15:01:51.1	9.24	2017-08-06	1265	1.1	210	cirruses
HD 30422	04:46:25.75	-28:05:14.8	6.18	2017-09-27	125	2.8	195	thin clouds
HD 31508	04:48:00.47	-75:46:55.5	9.60	2017-09-23	1825	1.8	130	clear
HD 34799	05:18:46.06	-28:52:20.7	8.26	2017-08-09	525	1.7	200	clear
HD 35242	05:23:31.07	+05:19:23.1	6.34	2017-10-23	125	1.4	85	clear
HD 36726	05:33:51.73	-00:04:36.3	8.82	2017-09-09	925	1.6	170	clear
HD 38043	05:38:02.18	-64:54:33.7	9.50	2017-09-30	1725	2.5	180	thin clouds
HD 41958	06:05:02.77	-53:12:47.1	8.80	2017-04-21	925	1.4	250	clear
HD 42503	06:09:02.56	-41:07:04.7	7.46	2017-09-30	225	2.3	160	thin clouds
HD 43533	06:14:58.46	-38:42:22.2	9.65	2017-09-09	1925	2.0	70	clear
"	"	"	"	2017-09-20	1925	1.7	160	thin clouds
HD 44930	06:23:58.80	-13:12:25.3	9.46	2017-10-10	1725	2.0	170	clear
HD 46722	06:33:46.55	-27:57:21.9	9.31	2017-04-22	1425	1.5	170	clear
HD 47425	06:37:20.32	-27:28:30.1	9.55	2017-04-20	1825	1.5	170	clear
HD 76097	08:53:59.04	-07:31:03.4	9.59	2017-05-07	1825	1.6	200	thin clouds
HD 83041	09:34:56.55	-28:52:39.3	8.83	2017-05-31	825	1.5	155	thin clouds
HD 84159	09:42:52.66	-10:41:43.6	9.54	2017-05-10	1725	1.2	140	clear
HD 296828	10:42:32.98	-45:31:20.2	9.58	2017-06-11	1825	1.6	45	thick clouds
HD 94326	10:52:33.34	-46:13:02.1	7.79	2017-05-07	325	1.5	115	thin clouds
HD 94390	10:53:07.83	-44:49:13.5	8.99	2017-06-02	925	1.3	150	clear
HD 100546	11:33:25.44	-70:11:41.2	6.70	2017-05-08	125	1.3	100	thin clouds
HD 103701	11:56:26.04	-48:47:41.8	8.76	2017-06-05	825	1.6	170	clear
HD 111786	12:51:57.90	-26:44:17.8	6.17	2017-05-15	125	1.3	300	clouds
HD 112682	12:58:58.83	-40:27:40.0	9.70	2017-05-04	1925	1.4	170	clear
HD 112948	13:00:42.81	-36:09:05.8	9.37	2017-06-12	1425	1.6	170	clear
HD 125508	14:20:39.21	-33:41:09.4	9.17	2017-06-15	1225	1.4	180	thin clouds
HD 125889	14:23:15.75	-35:49:55.0	9.84	2017-07-12	2175	1.4	180	clear
HD 126627	14:29:38.00	-66:24:42.3	9.04	2017-06-09	925	2.6	85	thick clouds
HD 127659	14:35:40.01	-66:42:19.7	9.36	2017-05-21	1525	1.4	150	clear
HD 128336	14:36:37.23	-12:29:37.3	9.12	2017-06-02	1125	1.5	170	clear
HD 132777	15:01:23.69	-16:53:11.7	9.29	2017-05-17	1325	1.3	220	clear
HD 133214	15:03:38.43	-09:49:58.7	9.45	2017-05-18	1725	1.2	220	clear
HD 136463	15:22:13.90	-40:09:37.4	9.55	2017-09-06	1825	2.0	150	clear
HD 139614	15:40:46.38	-42:29:53.5	8.27	2017-06-12	525	1.2	150	clear
HD 141569	15:49:57.75	-03:55:16.3	7.13	2017-07-14	125	1.5	155	clear
HD 141444	15:50:11.47	-28:42:15.6	8.94	2017-09-02	925	1.2	170	clear
HD 142994	15:59:10.90	-38:44:55.0	7.21	2017-05-07	125	1.1	190	clear
HD 153747	17:02:53.83	-38:27:36.8	7.43	2017-05-17	225	1.4	210	cirruses
HD 154153	17:05:48.47	-44:06:18.1	6.21	2017-05-14	125	1.3	240	clear
HD 159021	17:37:48.13	-68:10:12.6	8.70	2017-05-19	1425	1.3	270	clear
HD 160928	17:44:42.01	-42:43:45.5	5.89	2017-04-30	125	2.5	230	thick clouds
HD 162193	17:53:33.94	-59:42:25.4	8.69	2017-04-25	825	1.5	200	some clouds
HD 168947	18:24:30.06	-44:11:56.7	8.14	2017-05-04	425	1.3	190	clear
HD 168740	18:25:31.63	-63:01:17.5	6.15	2017-05-14	125	1.2	200	clear
HD 169346	18:26:51.46	-50:19:30.5	9.27	2017-09-08	1425	1.3	200	clear
HD 174005	18:48:39.49	-06:00:15.5	6.50	2017-10-03	125	2.1	110	thick clouds
HD 176387	19:02:12.28	-46:39:12.1	8.95	2017-08-27	925	2.1	130	clear
HD 183324	19:29:00.99	+01:57:01.6	5.79	2017-09-12	125	2.6	20	cloudy
KIC 9289960	19:41:23.01	+45:46:07.7	11.86	2017-06-16	1800	0.8	65	clear
KIC 8246833	19:45:18.48	+44:08:03.8	11.98	2017-06-16	1800	0.8	55	clear
KIC 11973705	19:46:42.59	+50:21:01.3	9.09	2017-06-16	1200	0.8	115	clear
KIC 6463047	19:49:29.85	+41:51:45.4	10.11	2017-06-16	1800	0.8	85	clear
HD 188164	19:58:52.98	-68:45:45.3	6.38	2017-09-04	125	2.0	180	hazy
HD 193256	20:20:26.57	-29:11:28.7	7.55	2017-08-14	225	1.5	160	thin clouds
HD 198160	20:51:38.47	-62:25:45.6	6.21	2017-09-03	125	1.6	220	clear
HD 198161	20:51:38.76	-62:25:44.9	6.56	2017-09-04	125	1.5	160	hazy
HD 201019	21:09:04.56	-55:17:36.3	8.43	2017-06-14	525	1.3	120	clear
HD 203709	21:25:39.73	-50:12:21.1	9.61	2017-05-18	1825	1.1	230	clear
HD 204041	21:25:51.58	+00:32:03.6	6.46	2017-09-07	125	1.5	180	clear
HD 210111	22:08:42.64	-33:07:32.5	6.41	2017-07-19	125	1.7	150	clear
HD 213669	22:34:18.67	-54:17:52.5	7.44	2017-04-29	225	1.7	170	clear
HD 214582	22:40:28.89	-57:50:23.2	9.51	2017-06-18	1625	1.6	110	clear
HD 223352	23:48:55.55	-28:07:49.0	4.57	2017-05-14	125	1.1	680	clear

2 Observations

The observations were obtained with two instruments (i) the High Resolution Spectrograph (HRS, $R = 65,000$) mounted at the 11-m Southern African Large Telescope (SALT) at the South African Astronomical Observatory (SAAO, South Africa) in the framework of the observing proposal 2017-1-SCI-010; and (ii) ARC Echelle Spectrograph (ARCES, $R = 31,500$) mounted at the 3.5-m telescope at the Apache Point Observatory (APO, NM, USA). Using HRS@SALT, we observed 71 bright southern stars, most of which were recently classified as λ Boo by Gray et al. (2017). Using ARCES@3.5m, we observed four faint northern λ Boo stars, which we selected as the most promising targets for asteroseismic investigation from the list of new λ Boo stars classified by Corbally et al. (2016). This large sample of targets will allow us to investigate the statistical properties of the whole λ Boo class and to join the discussion on different possible channels for producing the λ Boo peculiarity (see: Murphy & Paunzen, 2017).

We succeeded in obtaining $S/N \geq 100$ at λ=5500 Å for almost all targets. The spectra with the lowest S/N were acquired for HD 183324 and HD 296828 on two cloudy nights at SAAO. These stars may be re-observed since our programme of spectroscopic observations of bright southern λ Boo stars with HRS@SALT is being continued in the second semester of 2017 (proposal 2017-2-SCI-021). The details of the observations acquired with HRS@SALT in the framework of the proposal 2017-1-SCI-010 (stars with HD numbers) and with ARCES@3.5m (stars with KIC numbers) are provided in table 1.

Acknowledgements. J.M.-Ż and EN acknowledge the Polish National Science Center grant No. 2014/13/B/ST9/00902. J.M.-Ż acknowledges the Wrocław Centre for Networking and Supercomputing grant No. 224.

References

Corbally, C. J., Murphy, S. J., Gray, R. O. (2016), URL http://www.star.uclan.ac.uk/stars2016/posters/Corbally.pdf

Gray, R. O., et al., *AJ* **154**, 31 (2017)

Kamp, I., et al., *A&A* **375**, 899 (2001)

Murphy, S. J., *Investigating the A-Type Stars Using Kepler Data*, Ph.D. thesis, Jeremiah Horrocks Institute, University of Central Lancashire, Preston, UK (2014)

Murphy, S. J., Paunzen, E., *MNRAS* **466**, 546 (2017)

Murphy, S. J., et al., *PASA* **32**, e036 (2015)