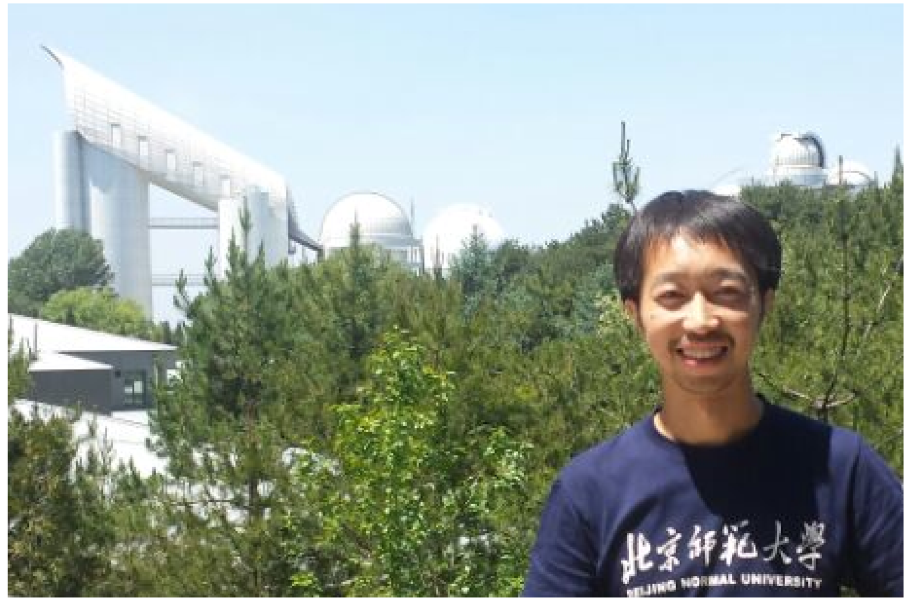
LAMOST observations in the *Kepler* field.
Analysis of the stellar parameters measured with the LASP based on the low-resolution spectra[*]

Anbing Ren[1], **Jianning Fu**[1], **Peter De Cat**[2], **Jianrong Shi**[3], **Ali Luo**[3], **Subo Dong**[4], **Ruyuan Zhang**[1], **et al.**

1. Department of Astronomy, Beijing Normal University
2. Royal observatory of Belgium
3. Key Lab for Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences
4. Kavli Institute for Astronomy and Astrophysics, Peking University

Anbing.Ren@gmail.com

[*] Based on observations collected with the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) located at the Xinglong Observatory, China.



Abstract

All of the 14 subfields of the *Kepler* field have been observed at least once with the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST, Xinglong Observatory, China) during the 2012-2014 observation seasons. There are 88,628 reduced spectra with SNR_g (signal-to-noise ratio in g band) ≥ 6 in the database of the LAMOST-*Kepler* project (LK-project). By adopting the upgraded version of the LAMOST Stellar Parameter pipeline (LASP), we have determined the atmospheric parameters (T_{eff}, $\log g$, and $[\mathrm{Fe/H}]$) and heliocentric radial velocity v_{rad} for 51,406 stars with 61,226 spectra. Compared with atmospheric parameters derived from both high-resolution spectroscopy and asteroseismology method for common stars in Huber et al. (2014), an external calibration of LASP atmospheric parameters was made, leading to the determination of external errors for the giants and dwarfs, respectively. Multiple spectroscopic observations for the same objects were used to estimate the internal uncertainties of the atmospheric parameters as a function of SNR_g with the unbiased estimation method. The LASP atmospheric parameters were calibrated based on both the external and internal uncertainties for the giants and dwarfs, respectively. A general statistical analysis of the stellar parameters leads to discovery of 106 candidate metal-poor stars, 9 candidate very metal-poor stars, and 18 candidate high-velocity stars. Fitting formulae were obtained segmentally for both the calibrated atmospheric parameters of the LK-project and the KIC parameters with the common stars. The calibrated atmospheric parameters and radial velocities of the LK-project will be useful for studying stars in the *Kepler* field.

Introduction

A large number of uninterrupted time-series has been obtained for pulsating stars of all kinds and flavors, the *Kepler* mission provides an unprecedented opportunity to study stellar oscillations. However, a reliable asteroseismic modeling requires reliable basic stellar physical parameters. Unfortunately, the atmospheric parameters as given in the *Kepler* Input Catalogue (KIC[1]) are not always unsuited for a successful asteroseismic modelling. Moreover, KIC atmospheric parameters are missing for a significant fraction of the *Kepler* objects.

We therefore initiated the LAMOST-*Kepler* project (LK-project)[1] to acquire LAMOST spectra for as many objects in the *Kepler* field as possible and to characterize them in terms of spectral classification, atmospheric parameters (T_{eff}, $\log g$, $[\mathrm{Fe/H}]$), rotation rate ($v \sin i$[2]) and radial velocity (v_{rad}).

Observations

The *Kepler* field is relatively large (105 deg^2). Fourteen circular LAMOST-*Kepler* fields (LK-fields) with a diameter of 5 degrees are needed for a close-to-full coverage of the *Kepler* field. In total, the 14 LK-fields were observed with 35 plates during 25 nights in the July 2012 - September 2014 observations seasons (Tab. 1).

Table 1: The progress of observation and achieved parameters during the 2012-2014 observations seasons for the LK-project. #: the observed LK-fields; KO: objects were observed by the *Kepler*.

LK-field	R.A.(2000)	Dec.(2000)	Cluster	Date	#	Spectra	Parameters	KO
LK01	19:03:39.258	+39:54:39.24		2014/06/02	2	4944	3481	1851
LK02	19:36:37.977	+44:41:41.77	NGC6811	2012/06/04	1	506	315	195
				2014/09/13	2	6365	4903	3166
LK03	19:24:09.919	+39:12:42.00	NGC6791	2012/06/15	3	8490	6085	4169
LK04	19:37:09.862	+40:12:49.63	NGC6819	2012/06/17	3	7612	4172	2861
LK05	19:49:18.139	+41:34:56.85		2013/10/05	2	5744	3845	2346
				2014/05/22	1	2336	883	683
LK06	19:40:45.383	+48:30:45.10		2013/05/22	1	2480	1486	1145
				2013/05/23	1	1989	798	670
				2013/09/14	1	2745	2212	1543
LK07	19:21:02.816	+42:41:13.07		2013/05/19	1	3136	2160	1652
				2013/09/26	1	2922	2412	1818
LK08	19:59:20.425	+45:46:21.15	NGC6866	2013/09/25	2	5464	4079	1757
				2013/10/02	1	2494	436	5
				2013/10/17	1	2427	1286	617
				2013/10/25	1	2708	2057	827
LK09	19:08:08.340	+44:02:10.88		2013/10/04	1	2856	2387	1618
LK10	19:23:14.829	+47:11:44.80		2014/05/20	2	2785	1802	1239
LK11	19:06:51.499	+48:55:31.77		2014/09/18	1	2852	2563	1619
LK12	18:50:31.041	+42:54:43.72		2013/10/07	1	2643	2347	1284
LK13	18:51:11.993	+46:44:17.52		2014/05/02	1	2548	1917	1074
				2014/05/29	2	4697	3553	1901
LK14	19:23:23.787	+50:16:16.64		2014/09/17	1	2821	2605	1391
				2014/09/27	1	2457	1578	803
				2014/09/29	1	2607	1864	951
Total					35	88628	61226	37185
Unique							51406	30110
1x							42773	23950
2x							7550	5325
3x							986	762
4x							92	68
+5x							5	5

Spectra

CCD Raw images from the LK-project were reduced and analyzed by the standard LAMOST automated data reduction and analysis system including the 2-dimension (2D) reduction pipeline[3], the 1-dimension (1D) pipeline[4,5]. A total of 61,226 flux- and wavelength-calibrated, sky-subtracted low-resolution (R=1800) spectra and the signal-to-noise ratio (SNR) in the Sloan Digital Sky Survey (SDSS) u, g, r, i and z bands is shown in Fig. 1.

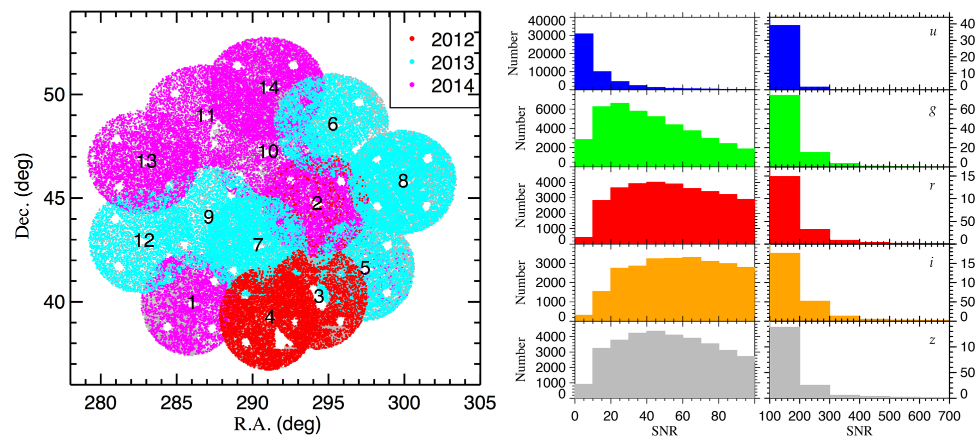


Figure 1: The spatial distribution of all targets and their SNR in different bands.

Stellar Parameter

The LAMOST stellar parameter pipeline (LASP) was used to automatically determine the stellar atmospheric parameters (T_{eff}, $\log g$ and $[\mathrm{Fe/H}]$) and radial velocity (v_{rad}) from the selected 61,226 reduced spectra. As a fraction of the observed stars have multiple LAMOST observations, the 61,226 analysed LAMOST spectra correspond to 51,406 unique targets, including 671 A-type stars, 18,937 F-type stars, 25,847 G-type stars, and 5,952 K-type stars. In Tab. 2, we give the observed objects and their LASP parameters.

Table 2: The catalogue of the LASP stellar parameters for the LK-project. Obsid: The unique spectra ID; Kp: The magnitude in the KIC.

Obsid / Subclass	Filename / SNR_g	Target / T_{eff} (K)	R.A. (deg) / $\log g$ (dex)	Dec. (deg) / $[\mathrm{Fe/H}]$ (dex)	Kp / v_{rad} (kms^{-1})
52201011	spec-56083-IF04_B56083_sp01-011	KIC07042868	294.51886	42.549595	9.117
G5	76.73	4852.00±51.72	2.658±0.470	-0.021±0.082	1.98±12.52
52201018	spec-56083-IF04_B56083_sp01-018	KIC06957157	294.34372	42.407665	10.106
G5	50.72	4742.09±64.08	2.497±0.455	-0.002±0.098	6.07±11.74
…	…	…	…	…	…
250016248	spec-56930-KP192323N501616V03_sp16-248	KIC12933571	289.32538	52.398720	13.307
K5	19.47	4480.25±49.50	2.678±0.333	-0.266±0.077	-89.24±8.66
250016249	spec-56930-KP192323N501616V03_sp16-249	KIC12883443	289.20694	52.250880	13.460
K0	18.22	5286.27±102.40	3.808±0.468	0.035±0.138	-49.52±13.55

Calibration of Stellar Parameters

External Calibration

The stellar atmospheric parameters in Tab. 2 are compared with the common targets in a sub-sample of Huber et al. (2014)[6] (H14) to perform an external calibration of LASP atmospheric parameter uncertainties for the giants ($\log g < 3.5$ dex) and dwarfs ($\log g \geq 3.5$), respectively (Fig. 2).

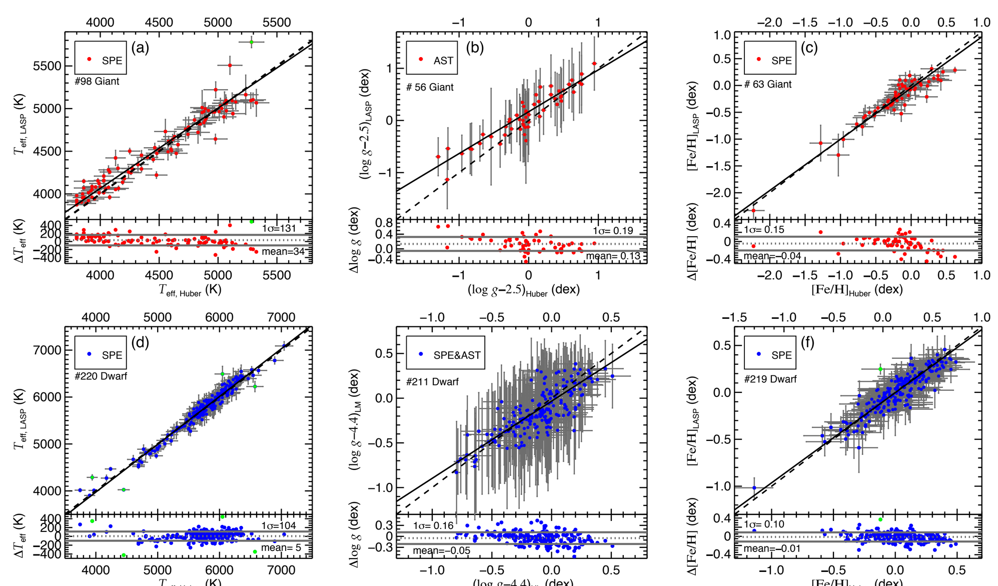


Figure 2: Comparison of the T_{eff}, $\log g$ and $[\mathrm{Fe/H}]$ as determined by LASP with the stellar parameters were derived by the method of spectroscopy (SPE) and asteroseismology (AST) in H14 (categories C1, C2, C5, C7, C8, and C9 of their Table 1; X-axis). The stars located outside the 3 σ region around the mean difference are given in green.

Internal Calibration

Multiple observation targets in the parameter catalogue of the LK-project are used to calculate the internal calibration of stellar atmospheric parameters uncertainties by using the method of the unbiased estimator:

$$\Delta P_i = \sqrt{n/(n-1)}(P_i - \bar{P}) \quad (1)$$

with i = 1, 2, ..., n, where i is one of the individual measurements and n is the total number of measurements for parameter P. The values of the unbiased estimations for ΔT_{eff}, $\Delta \log g$ and $\Delta[\mathrm{Fe/H}]$ versus SNR_g of the LAMOST spectra are shown in Fig. 3, respectively.

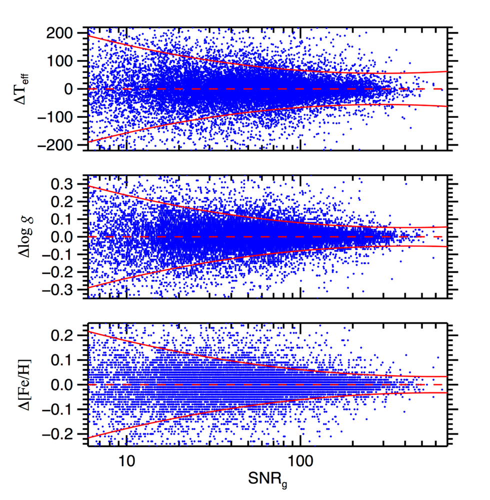


Figure 3: The unbiased estimation for the multiple observation targets as a function of SNR_g (blue dots). The 1σ levels are fitted with a second-order polynomial (red solid lines).

Calibration of LASP Stellar Parameters

The dispersions of the LASP stellar atmospheric parameter uncertainties (green lines), taking both internal and external uncertainties into account, are calculated for the giants (left panels) and dwarfs (right panels) in Fig. 4, respectively. The mean biases are indicated by the black dashed lines when compared with the published values in H14.

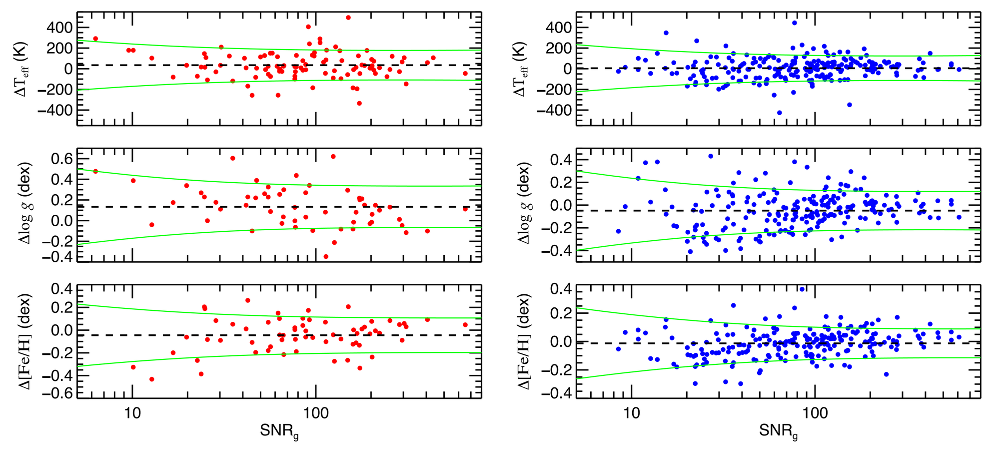


Figure 4: The dispersions of the LASP stellar atmospheric parameter uncertainties.

The external and internal uncertainties of the LASP parameters are combined to redefine the systematic deviation and the errors of stellar atmospheric parameters within the LK-project. The calibrated relations are given by:

$$\begin{cases} P_i = (P_{i,\mathrm{LASP}} - a)/b \\ \sigma = \sqrt{\sigma_{in}^2 + \sigma_{ex}^2} \end{cases} \quad (2)$$

where P_i denotes the calibrated stellar parameters, $P_{i,\mathrm{LASP}}$ is the LASP value while a and b are the zero and slope of the linear functions as given in Formulae (1)∼(6), σ is the calibrated errors of atmospheric parameters, σ_{in} and σ_{ex} is the inner and external deviation, respectively.

Based on these calibrated relations, we recalculated the LASP stellar parameters and their errors as listed in Tab. 3.

Table 3: The catalog of calibrated LASP stellar atmosphere parameters.

Obsid	Target	SNR_g	Subclass	T_{eff} (K)	$\log g$ (dex)	$[\mathrm{Fe/H}]$ (dex)
52201011	KIC07042868	76.73	G5	4844±149	2.485±0.211	0.031±0.165
52201018	KIC06957157	50.72	G5	4727±155	2.284±0.220	0.051±0.173
…	…	…	…	…	…	…
250016248	KIC12933571	19.47	K5	4448±178	2.510±0.259	-0.227±0.202
250016249	KIC12883443	18.22	K0	5086±161	3.742±0.242	0.036±0.171

A general statistical analysis of the calibrated LASP parameters (T_{eff}, $\log g$ and $[\mathrm{Fe/H}]$) and the LASP v_{rad} for all 51,399 *Kepler* stars in the LK-project are shown in Fig. 5. The mean errors of the measured stellar parameters are 2.75% in T_{eff}, 0.215 dex in $\log g$, 0.152 dex in $[\mathrm{Fe/H}]$, and 18 $\mathrm{km\,s^{-1}}$ in v_{rad}.

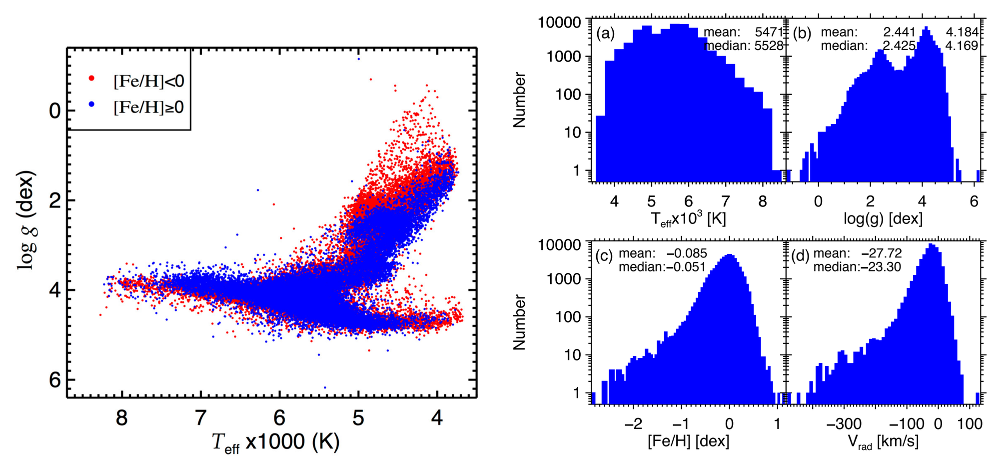


Figure 5: The HR diagram and the histogram distributions of the parameters.

Comparison with KIC

The comparisons between the LASP and KIC parameters are shown in Fig. 6.

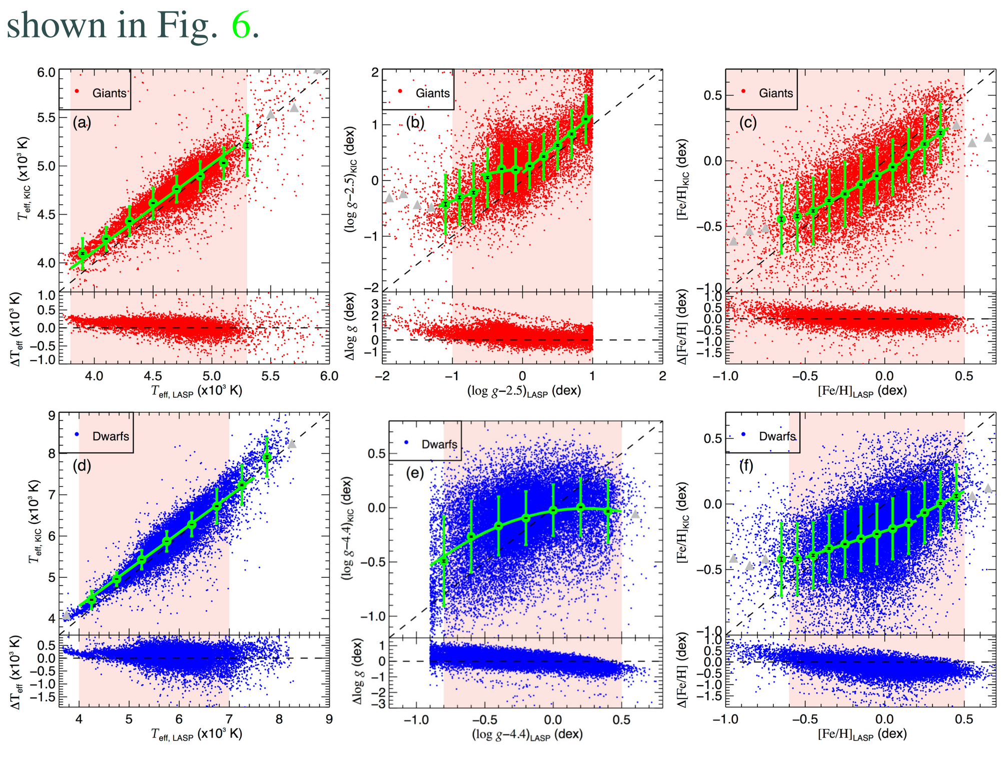


Figure 6: Comparison of the calibrated T_{eff}, $\log g$ and $[\mathrm{Fe/H}]$ as determined by LASP (LASP X-axis) with those from KIC (KIC, Y-axis of the upper panels).

2015 observations for the LK-project

A great progress has been made in 2015 as 32 additional plates, covering the whole *Kepler* field except for one subfield (LK01), have been observed during 18 nights. Finally, we obtained a total of 97,666 reduced spectra and 79,387 stellar parameters after the second round of observations for the LK-project, these parameters correspond to 75,825 unique stars in the *Kepler* field.

Reference: [1] De Cat, P., Fu, J. N., Ren, A. B., et al. 2015, ApJS, 220, 19; [2] http://arxiv.org/abs/1606.09149; [3] Luo, A.-L., Zhang, Y.-X., & Zhao, Y.-H. 2004, Proc. SPIE, 5496, 756; [4] Wu, Y., Du, B., Luo, A., Zhao, Y., & Yuan, H. 2014a, IAU Symposium, 306, 340; [5] Luo, A.-L., Zhao, Y.-H., Zhao, G., et al. 2015, Research in Astronomy and Astrophysics, 15, 1095; [6] Huber, D., Silva Aguirre, V., Matthews, J. M., et al. 2014, ApJS, 211, 2