M DWARF CATALOG OF THE LAMOST PILOT SURVEY

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ABSTRACT

We present a spectroscopic catalog of 58,360 M dwarfs from the Large Sky Area Multi-Object Fiber Spectroscopic Telescope pilot survey. For each spectrum in the catalog, spectral subtype, radial velocity, Hα emission lines. The molecular band indices included in this catalog are sensitive to temperature and metallicity, and can be used for further study of the physical properties of M dwarfs. This M dwarf catalog is available on the Web site http://sciwiki.lamost.org/MCatalogPilot/.

Key words: catalogs – methods: analytical – stars: late-type

Online-only material: color figures

1. INTRODUCTION

M dwarfs are the most common stars in the Galaxy (Bochanski et al. 2010), and their main-sequence lifetime is even longer than the age of the universe (Laughlin et al. 1997). Therefore, M dwarfs can be used to trace the structure and evolution of the Milky Way. M dwarfs are also important for identifying potentially habitable extrasolar planets (Charbonneau et al. 2009). Many previous studies have been carried out on M dwarfs, for instance, tracing the Galactic disk kinematics (Hawley et al. 1996; Gizis et al. 2002; Lépine et al. 2003; Bochanski et al. 2005, 2007a, 2010), studying the structure of the Galaxy (Reid et al. 1997; Kerber et al. 2001; Woolf & West 2012), and computing the stellar initial mass function (Covey et al. 2008; Bochanski et al. 2010). To research these scientific topics, some fundamental and preliminary analyses need to be performed in advance, including spectral type classification (Kirkpatrick et al. 1991, 1999; Reid et al. 1995a; Martin 1999; Cruz & Reid 2002), radial velocity measurements (Bochanski et al. 2007b), metallicity estimation (Gizis 1997; Lépine et al. 2003, 2007; Woolf & Wallerstein 2006), and analysis of magnetic activity (Reid et al. 1995b; Hawley et al. 1996; Gizis et al. 2000; West et al. 2004, 2011; West & Hawley 2008).

Due to the difficulty of obtaining spectra of these faint objects, studies of M dwarfs a decade ago were limited by the number of M dwarf spectra (e.g., Delfosse et al. 1998, 1999, with 118 M stars). However, with the development of modern astronomical facilities, the number of M dwarf spectra increases dramatically. Reid et al. (1995a) obtained a spectroscopic catalog of 1746 stars, containing primarily M dwarf spectra and a small number of A – K spectra. The Sloan Digital Sky Survey (SDSS; York et al. 2000) later sharply increased the number of M dwarf spectroscopic samples. West et al. (2008) presented a spectroscopic catalog of more than 38,000 M dwarfs from SDSS Data Release 5 (Adelman-McCarthy et al. 2007) and then as a part of the Sloan Extension for Galactic Understanding and Exploration survey (SEGUE; Yanny et al. 2009), over 50,000 additional M dwarf candidates provided new insight for probing the structure, kinematics, and evolution of the Milky Way. West et al. (2011, hereafter West2011) presented the latest spectroscopic catalog including 70,841 M dwarf spectra from SDSS Data Release 7 (Abazajian et al. 2009), providing fundamental parameters of M dwarfs for future use of the sample in probing galactic chemical evolution.

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST, also called Guo Shou Jing Telescope) is a National Major Scientific project undertaken by the Chinese Academy of Science (Wang et al. 1996; Cui et al. 2012). LAMOST has a field of view as large as 20 square degrees, and at the same time a large effective aperture that varies from 3.6 to 4.9 m in diameter. The magnitude limit of LAMOST can reach as faint as 19 mag in the SDSS photometric r band at resolution $R = 1800$. The main aims of LAMOST include the extragalactic spectroscopic survey of galaxies (to study the large-scale structure of the universe) and the stellar spectroscopic survey of the Milky Way (to study the structure and evolution of the Galaxy; Cui et al. 2012; Liu et al. 2013). Based on these scientific goals, the LAMOST survey contains two main parts: the LAMOST ExtraGalactic Survey, and the LAMOST Experiment for Galactic Understanding and Exploration (LEGUE) survey of Milky Way stellar structures (see Deng et al. 2012 for the detailed science plan of LEGUE). From 2011 October to 2012 June, LAMOST completed the pilot survey and released 319,000 spectra (Luo et al. 2012). Since the fall of 2012, LAMOST has begun the regular survey. Within 4–5 yr, LAMOST will observe at least 2.5 million stars in a contiguous area in the Galactic halo, and
more than 7.5 million stars in the low galactic latitude areas around the plane. The spectra collected for such a huge sample of stars will provide a legacy that allows us to learn detailed information about stellar kinematics, chemical compositions well beyond SDSS/SEGUE. There is a detailed description of the LAMOST spectra survey in Zhao et al. (2012), the survey science plan of LEGUE in Deng et al. (2012) and Liu et al. (2013), and input catalog descriptions in Yang et al. (2012), Zhang et al. (2012), Chen et al. (2012), and Liu et al. (2013). The up-to-date complete lists of LAMOST technical and scientific publications are available at http://www.lamost.org/publication.

Among the spectra that the LAMOST pilot survey obtained, M-type spectra account for nearly 10% of all stellar spectra (LAMOST one-dimensional (1D) pipeline recognized as stellar spectra, regardless of signal-to-noise ratio, S/N). In terms of this proportion, the total number of M dwarf spectra in the entire survey will be several hundred of thousands. Such a large sample will enable a number of research topics to explore the evolution and structure of the Milky Way. As the countless molecule bands lead to peculiar morphology of M-type stellar spectra, during the process of LAMOST data analysis, M-type spectra have to be treated separately to derive fundamental parameters, while other stellar spectra are input to the ULYSS program (Wu et al. 2011) for parameters of effective temperature, surface gravity, and metal abundance. We focus on deriving accurate fundamental parameters from M dwarf spectra obtained in the LAMOST pilot survey. This will lay the foundation for further research on the Galactic structure and kinematics.

In this paper, we describe the M dwarf spectra from the LAMOST pilot survey and the methods adopted to derive fundamental parameters, including spectral subtype, radial velocity (RV), equivalent width (EW) of Hα, a number of prominent molecular band indices, the metal-sensitive parameter ξ, and their corresponding uncertainties. In Section 2, we describe the spectra observed by LAMOST and our sample selection. In Section 3, we discuss how to determine the spectral types and RVs for M dwarfs, and to measure magnetic activity, molecular band indices, and the metal-sensitive parameter. Our results are discussed in Section 4.

2. DATA AND SAMPLE SELECTION

In the LAMOST pilot survey, the resolution of the spectra is $R = 1800$ over a wavelength coverage of 3690–9100 Å. Two arms of each spectrograph cover the entire wavelength range with 200 Å of overlap. The spectral coverage of blue is 3690–5900 Å while that of red is 5700–9100 Å. The red side has higher throughput than the blue. Therefore, it is easy to obtain higher quality spectra of M dwarfs than other types of stars because most of the light of M dwarfs is in the red band. The raw data has been reduced with LAMOST two-dimensional (2D) and 1D pipelines (Luo et al. 2004), including bias subtraction, cosmic-ray removal, spectral tracing and extraction, flat-fielding, wavelength calibration, sky subtraction, and classification. The LAMOST 1D pipeline performs the $\chi^2$ fitting to match the observed spectra to the templates, which were constructed by linear combinations of eigen spectra (from decomposition of a set of SDSS spectra) and low-order polynomials (Luo et al. 2012). Most M-type stellar spectra were correctly recognized by the 1D pipeline, but nearly one-fifth of the M-type stellar spectra (mainly M0, M1) were misclassified as K7 dwarfs. Therefore, all K7-type spectra require visual inspection to search for M-type spectra. Thus, we selected the spectra that were classified as M or K7 by the LAMOST 1D pipeline. The total number of the candidates is 98,887. Through visual inspection using a modified Hammer spectral typing facility (original Hammer: Covey et al. 2007; see Section 3.1 for a description of the modified Hammer), we excluded K7-type spectra, spectroscopic binaries, bad spectra, and spectra observed repeatedly. We ignored giant contamination on account of the low rate of giants (not more than 4% estimated by the color J-H according to Bessell & Brett 1988). We gathered the remaining spectra to form the catalog, ignoring $S/N$ because for many M-type stellar spectra, even with a lower $S/N$ (in the $r$ band), they can be correctly identified and assigned appropriate spectral types. Finally, our M dwarf catalog contains 58,360 M dwarfs.

3. METHODS

3.1. Spectral Types

The spectral subtype of an M dwarf, which is one of the most important fundamental parameters, is related to the temperature and the mass of the M dwarf. There are two primary approaches to classify an M dwarf by its spectrum. The first method uses the overall slope of the spectrum, which requires accurate spectrophotometric calibration over the full optical wavelength. The second approach matches the relative strength of atomic and molecular features in the spectrum, which has been normalized by being divided by an estimated local continuum. Considering the flux uncertainty of LAMOST M dwarf spectra, we choose the second method to derive the spectral types of the LAMOST M dwarfs.

The Hammer (Covey et al. 2007) is an IDL code that uses the relative strength of features. It has been widely used for classifying stellar spectra (Lee et al. 2008; West et al. 2011; Woolf & West 2012; Dhill et al. 2012), especially for M dwarf spectra. For classification of late-type stars, the Hammer computes 16 molecular band head indices of each spectrum, including the indices of Ca i, Mg i, CaH3, TiO5, V O, Na i, Cs, CrH, and Ca ii, and the wavelength of the indices covers 4000–9100 Å. The Hammer matches these indices with the indices computed from the templates, and the spectral type of the closest template is selected as the spectral type of the observed spectra. However, as described in the previous findings, the automatic Hammer tends to classify some spectra that are later than M5 as an earlier subtype (West et al. 2011).

In order to revise the late M classification problem of the Hammer code, we first tested the Hammer code with template spectra derived by Bochanski et al. (2007b, hereafter Bochanski2007b), We use the Hammer to automatically classify the Bochanski2007b templates and the results are shown in the second column of Table 2. In contrast to the first column of the table, M1, M5, M6, M7, and M9 templates are allocated with the modified Hammer: Covey et al.2007; see Section 3.1 for a description of the modified Hammer, WC7 dwarfs. Therefore, all K7-type spectra require visual inspection to search for M-type spectra. Thus, we selected the spectra that were classified as M or K7 by the LAMOST 1D pipeline. The
The important features (the numerators of important indices) supplied by the RF method are shown in Figure 1. As a large number of LAMOST spectra are not of high quality in the blue part, and most of the obvious features of M dwarfs that can help distinguish between the spectral subtypes located in 6000–9000 Å, the spectral range we care about is limited to 6000–9000 Å. According to the importance list of the features, we adjusted the indices of the Hammer by adding three new indices and keeping the original Hammer indices that are in 6000–9000 Å. The three indices and their corresponding wavelength ranges are shown in Table 1. The features in the numerator range of CaH6385 and TiO8250 are sensitive to temperature. The numerator range of index 6545 is near Hα and is often used as a part of the continuum to compute the EW of Hα. So we take the index 6545 as a pseudo-continuum index, and name it Color6545. Table 1 shows the wavelength ranges of each index. The original Hammer indices Ca i, Mg i, and Color1 are removed because they are out of the wavelength of 6000–9000 Å. After adjusting the indices of the Hammer, there are still 16 indices. The 16 index values of the Hammer M dwarf template are calculated again. Figure 2 shows the values of the indices; points of the same color are index values in the same subtype. Lines from red to blue correspond to the subtypes of M0–M9. This figure indicates that the three new indices are good at identifying subtypes of M dwarf spectra.

**Figure 2.** Modified Hammer indices, including 13 original Hammer indices in 6000–9000 Å and three newly added indices. The three newly added indices are CaH6385, TiO8250, and Color6545. Each line corresponds to a different subtype. Lines from red to blue represent subtypes from M0 to M9. If a certain index value monotonically increases or decreases with the type from M0 to M9, it indicates that the index is a good spectral type tracer and it is suitable for spectral type classification. For example, VO7912, TiOB, TiO8250, and Color6545 are good spectral type tracers.
We then classified the Bochanski2007b template using the modified Hammer. The results are shown in the third column of Table 2. The classification result of each template is correct now. In order to verify the performance of Hammer after adjusting the indices, we further tested the code with 70,841 spectra from the SDSS DR7 M dwarf catalog (West et al. 2011). The results are shown in Figure 3. The top panel of the figure is the difference distribution of all spectral subtypes for the 70,841 total spectra. It shows a number of spectra that were misclassified as a later subtype by the original Hammer, and now are partially corrected by the modified Hammer. The accuracy of the modified Hammer is greater than the original Hammer. The bottom panel shows the difference distributions of subtypes for spectra later than M5 and indicates that the original Hammer classifies a larger fraction of late-type M dwarfs as an earlier subtype (as indicated by West et al. 2011). This is greatly
remedied by the improved Hammer. According to the statistical results of all the data, the mean subtype difference is 1 subtype before adjusting the indices, while the mean subtype difference is 0.6 subtypes for the modified Hammer.

### 3.2. Radial Velocity

The radial velocity of each M dwarf is measured by the cross-correlation method. Each observed spectrum is cross-correlated with the Bochanski2007b M dwarf template of the best matched subtype. In order to decrease the impact of inaccurate flux calibration, we use a cubic polynomial to rectify the observed spectra to the best fitted template spectra. We constrain the range of RVs to $-500$ km s$^{-1}$ to $+500$ km s$^{-1}$ in 2 km s$^{-1}$ steps. After each move, the observed spectra are multiplied by an optimal cubic polynomial to cross-correlate the observed spectrum, with the corresponding template fitting all correlation values to produce a Gaussian peak. The corresponding RV of the Gaussian peak is chosen as our final RV. A bootstrap estimate is conducted to access the internal error of the RV estimation.

We use spectra from the SDSS DR7 M dwarf catalog to test our RV measurement method. Figure 4 shows the results. The left panel shows the comparison of our measured RV values to the values of West2011. The right panel shows the distribution of RV differences, in which 67,843 RV differences between $-100$ km s$^{-1}$ and $+100$ km s$^{-1}$ are shown. Figure 4 indicates that the RVs we measured generally agree with the RVs West2011 measured. The mean of two RV differences is $0.17$ km s$^{-1}$, while the standard deviation is $6.4$ km s$^{-1}$, which is less than the reported uncertainties of West2011. The larger scatter of RVs around the center of the figure is due to the low S/N of the spectra, which can be seen in Figure 5. It is intrinsically difficult to derive accurate RVs from these spectra with low S/N. We further select a subsample consisting of 479 spectra to examine the performance of our method by checking the Na doublet at 8183 Å and 8195 Å. In this subsample, the S/Ns are between 10 and 20 and the differences between the two RVs are between 50 and 200. We correct each spectrum of this subsample with its corresponding two RVs, respectively. The result is that for some spectra, our RVs are more accurate and for others, West’s are better. Both measurements have their own advantages and their accuracies are close. We also inspect the points in the bottom of the left panel of Figure 4, and we find for this subsample our RVs are more accurate. Our comparisons indicate that our RV measurements of M dwarf spectra are generally accurate.
3.3. Magnetic Activity, Molecular Band Indices, and the Metallicity Indicator \( \zeta \)

The H\( \alpha \) emission line is the best indicator of chromospheric magnetic activity in M dwarfs due to their red colors. Thus, we estimate the magnetic activity of M dwarfs following the methods of West et al. (2004, 2011). We use a 14 Å wavelength region to calculate the EW of H\( \alpha \). The central wavelength is 6564.66 Å in vacuum with 7 Å on either side. The continuum regions are 6555.0–6560.0 Å and 6570.0–6575.0 Å. Our magnetic activity criteria are similar to the West2011 criteria. As our sample contained all M dwarf spectra from the LAMOST pilot survey irrespective of S/N, we add an additional S/N (marked up with HASN2 in our catalog) constraint to obtain a more clean sample. The S/N constraint is that the average S/N of the spectral regions 6500–6550 Å and 6575–6625 Å should be larger than 10. From this clean sample, if a star is classified as active, its spectrum needs to satisfy the four criteria listed below.

1. The S/N of the continuum near H\( \alpha \) is larger than 3.
2. The EW of H\( \alpha \) must be larger than 1.
3. The EW of H\( \alpha \) is larger than three times its error.
4. The height of the H\( \alpha \) emission line is larger than three times the noise in the adjacent continuum.

The only difference between our criteria and West’s is criterion 2. We carefully inspect our sample and find that it is more reasonable to use 1 as the boundary of the H\( \alpha \) EW. When a star from our clean sample is classified as inactive, its spectra should meet criterion 1, and the spectrum should have no detectable emission.

We have also measured the important molecular band features TiO1–TiO3, CaH1–CaH3, and CaOH following the wavelength ranges defined by Reid et al. (1995a, Table 2). The errors of these indices are given as well.

A rough indicator of metallicity \( \zeta \) is computed, which was initially defined by Lépine et al. (2007). The definition of \( \zeta \) is based on the strength of the TiO5, CaH2, and CaH3 molecular bands. This indicator was designed to divide main-sequence M into different metallicity classes: dwarf, subdwarf, extreme dwarf, and ultra subdwarf (Lépine et al. 2007). Dhital et al. (2012) refined the index \( \zeta \), which can better fit their observed M sample consisting of more M0–M3 dwarf spectra. Mann et al. (2013) found that the \( \zeta \) parameter is correlated with [Fe/H] for super-solar metallicities and it does not always correctly identify metal-poor M dwarfs. Lépine et al. (2013) found that the metallicity mentioned in Lépine et al. (2007) overestimated the metallicity at earlier subtypes, while the Dhital et al. (2012) calibration tends to underestimate metallicity, so they recalibrated \( \zeta \). We measure the parameter \( \zeta \) and its error following the latest definition of \( \zeta \) by Lépine et al. (2013).

4. RESULTS AND DISCUSSION

We have estimated all of the parameters of the M dwarfs in our catalog with carefully verified methods. Figure 6 shows the positions of 58,360 M dwarfs in our catalog and 70,841 M dwarfs in SDSS DR7 (West et al. 2011). The S/N (HASN2) distribution of M dwarf spectra in our catalog is shown in Figure 7. The wavelength range of measuring HASN2 has been described in Section 3.3, and this S/N is also used in following discussions.

4.1. Spectral Types

Spectral types of M dwarfs in our catalog are derived using the modified Hammer method and then confirmed by a visual check. As the LAMOST pilot survey is a test run of the telescope system, all celestial spectra, not just M dwarf spectra, have been visually inspected to ensure the instruments and processing pipeline work well. During visual inspection, roughly one-fifth of the automatic classification results are modified, and this classification bias is caused primarily by spectral noise and part-flux absence in the wavelength range of the adopted indices. The average difference between the automatic classification and the visually inspected classification is 0.26 spectral types. Figure 8 shows the spectral type distribution of LAMOST M dwarfs, in which early-type M dwarfs account for a large proportion and the peak spectral subtype is around M1–M2. Late-type M dwarfs from M6 to M9 are few (only 599), of which only 157 meet the S/N constraint of being larger than 10. This is likely due to target selection effects and the magnitude limitation of the LAMOST telescope.

4.2. Radial Velocity

We have measured RVs and errors for all spectra of our catalog with our tested method described in Section 3.2. Although many factors may cause RV uncertainties, we try to reduce the unfavorable effects on the RV. We use the best matched spectral type template and cross-correlate it with the observed spectra, which minimizes the error introduced by spectral type
mismatch. In order to reduce the effect of inaccuracy of the spectral flux, we use an optimal cubic polynomial to calibrate the observed spectra. The mean internal error of our RVs is 11.5 km s\(^{-1}\), estimated by a Monte Carlo method. Because we specifically consider M dwarf spectra instead of all stellar spectra, our measurement results are more accurate than the LAMOST 1D pipeline. Using our measured RVs, we correct all spectra of this catalog to zero RV for measurements of the H\(\alpha\) emission line and molecular band indices.

### 4.2. Magnetic Activity

Using our magnetic activity criteria, 1971 of 58,360 M dwarfs are H\(\alpha\) active while 22,987 are H\(\alpha\) inactive. The H\(\alpha\) activity fractions of M0–M5 are listed in Table 3. We confirm that later subtypes have higher active fractions. The fraction values are not very consistent with those from West2011; however, the trend of the active fraction from M0 to M5 is in good agreement with West2011, as shown in Figure 9. The number of late-type M dwarfs is too small (as mentioned in Section 4.1) to produce a reasonable activity fraction when using the same magnetic activity criteria. Therefore, the activity fraction of M6–M9 was not provided here.

### 4.4. Molecular Band Indices

The important molecular band indices and their errors (as mentioned in Section 3.3) are measured and included in our catalog. In this section, we assess the accuracy of these quantities and discuss the impact of spectral flux uncertainties and noise on the accuracy of these quantities.

We compare the nine molecular band indices with those from the SDSS DR7 M dwarf catalog (West et al. 2011), as shown in Figure 10, where indices of each molecular band are averaged after grouping by spectral subtypes. The error bars in blue and red in Figure 10 represent the standard deviation of LAMOST indices and SDSS indices, respectively, at each spectral type. The spectral indices with spectral types later than M5 are not presented here because the spectral number is not enough for completeness. In general, for all nine indices in this figure, the LAMOST average indices at each spectral subtype match well with those of SDSS. This good consistency confirms that the LAMOST M dwarf spectral sample and the SDSS M dwarf spectral sample are similar and allow us to be confident in the correctness of these quantities. Furthermore, the error bars of LAMOST and SDSS display a similar trend, that is, with an increase in spectral type, error bars get larger. It should be known that the intrinsic differences of M dwarf spectra also play a role in the size of error bars. However, the CaH1 and CaOH indices of LAMOST have larger error bars than those of SDSS, which can be due to noise effect and spectral flux uncertainties.

In order to find the influence of spectral noise on the measured indices in our catalog, we examine the TiO5 index distribution at each spectral type with different S/\(N\)s. Figures 11–14 show the changes in TiO5 by S/\(N\). In each figure, we show the TiO5 index distribution at each spectral type with S/\(N\) (HASN2) below 5, 5–10, 10–20, and 20 and above, respectively. Given a spectral type, the difference “diff” gradually declines with increasing S/\(N\). Specifically, at SPT (spectral type) = 0 the “diff” are 0.064, 0.031, and 0.016 for S/\(N\)/5 < 5, 5 < S/\(N\)/\(\leq\)10, and 10 < S/\(N\)/\(\leq\)20, respectively, and at other spectral types the trends are the same. The standard deviations of TiO5 indices also decline with increasing S/\(N\). At SPT = 0, the standard deviations are 0.12, 0.09, 0.06, and 0.05 for S/\(N\)/5 < 5, 5 < S/\(N\)/\(\leq\)10, 10 < S/\(N\)/\(\leq\)20, and S/\(N\)/\(\leq\)20, respectively. These indicate that spectral noise does affect index accuracy and that the lower the S/\(N\), the less reliable the indices are. For S/\(N\)/5 < 5, standard deviations of TiO5 indices are around 0.14, while for S/\(N\)/5 > 5, they are almost below 0.1; for this S/\(N\) most “diff” are below 0.03, which means the average index offset to the corresponding ones of SDSS is not more than 5%. However, the S/\(N\) should be larger than 10 for more reliable indices.

We exclude low S/\(N\) spectra to estimate the influence from LAMOST spectral flux uncertainties. Using S/\(N\)/5 > 15 spectra of LAMOST and SDSS, we compare the nine molecular indices again, as shown in Figure 15. For TiO indices, the LAMOST indices are generally in agreement with SDSS. However, for other indices at later spectral types, the consistency between LAMOST and SDSS indices does not appear to be as good, which is caused by flux uncertainties. We estimate that the index
Figure 10. Average molecular band indices as a function of spectral type for M0–M5. LAMOST mean indices are plotted as blue stars, while SLOAN DR7 M dwarf indices (West et al. 2011) are plotted as red open circles. Error bars indicate the standard deviation of LAMOST indices and SLOAN indices at each spectral type. Two kinds of indices at each subtype are separated with an interval of 0.3 subtypes to show their error bars clearly.

(A color version of this figure is available in the online journal.)

Figure 11. TiO5 index distribution at each spectral type from 0 to 5 for LAMOST M dwarf spectra with S/N < 5. Each panel shows the histogram distribution of LAMOST TiO5 index values at a given spectral type. “mean” and “std” in each panel are the mean and standard deviation, respectively, and “Diff” is the difference between this mean and that of SDSS at corresponding spectral types. The bold black line is the mean-level line, while the red dashed line describes SDSS’s mean level.

(A color version of this figure is available in the online journal.)
Figure 12. TiO5 index distribution at each spectral type from 0 to 5 for LAMOST M dwarf spectra with 5 < S/N < 10. Each panel shows the histogram distribution of LAMOST TiO5 index values at a given spectral type. “mean” and “std” in each panel are the mean and standard deviation, respectively, and “Diff” is the difference between this mean and that of SDSS at corresponding spectral types. The bold black line is the mean-level line, while the red dashed line describes SDSS’s mean level. (A color version of this figure is available in the online journal.)

Figure 13. TiO5 index distribution at each spectral type from 0 to 5 for LAMOST M dwarf spectra with 10 < S/N < 20. Each panel shows the histogram distribution of LAMOST TiO5 index values at a given spectral type. “mean” and “std” in each panel are the mean and standard deviation, respectively, and “Diff” is the difference between this mean and that of SDSS at corresponding spectral types. The bold black line is the mean-level line, while the red dashed line describes SDSS’s mean level. (A color version of this figure is available in the online journal.)
**Figure 14.** TiO5 index distribution at each spectral type from 0 to 5 for LAMOST M dwarf spectra with S/N > 20. Each panel shows the histogram distribution of LAMOST TiO5 index values at a given spectral type. “mean” and “std” in each panel are the mean and standard deviation, respectively, and “Diff” is the difference between this mean and that of SDSS at corresponding spectral types. The bold black line is the mean-level line, while the red dashed line describes SDSS’s mean level. (A color version of this figure is available in the online journal.)

**Figure 15.** Comparisons between LAMOST indices and SDSS indices for S/N > 15 spectra. The average molecular band indices as a function of spectral type for M0–M5 are shown. LAMOST mean indices are plotted as blue stars, while SDSS DR7 M dwarf indices (West et al. 2011) are plotted as red open circles. Error bars indicate the standard deviation of LAMOST indices and SDSS indices at each spectral type. (A color version of this figure is available in the online journal.)
bias of the LAMOST pilot survey may be introduced by flux uncertainties by comparing the index differences. In this figure, the largest difference between LAMOST and SDSS appears in CaH indices at SPT = 5; the index difference between LAMOST and SDSS is 0.07, about 10% of that of SDSS. Currently, LAMOST uses a relative flux calibration method (Song et al. 2012) due to the lack of a high-precision companion. LAMOST and SDSS is 0.07, about 10% of that of SDSS.

In summary, the molecular band indices in our catalog have been measured correctly and these quantities are generally accurate. We have discussed the impact of the spectral noise and flux uncertainties on the accuracy of these indices. We suggest a S/N > 10 cutoff for more accurate indices.

5. SUMMARY

We present a spectroscopic M dwarf catalog from the LAMOST pilot survey, which consists of 58,360 M dwarfs and their spectral parameters. In this catalog, spectral subtypes, RVs, magnetic activity, EWs of Hα, and nine molecular band indices, as well as the metal-sensitive parameter ζ, are provided. We measured these quantities in proper ways and the correctness of these quantities are verified by comparison with those of SDSS.

The M dwarf catalog of the LAMOST pilot survey provides the first glimpse of LAMOST M-type stellar spectra. By examining the spectral parameters of our sample, we get a clearer understanding of M dwarf spectra from LAMOST and prepare for the LAMOST regular survey. The LAMOST regular survey has released data release one (DR1), containing over 1.2 million spectra with S/N larger than 10, including spectra of the pilot survey and spectra of the first year of the regular survey. LAMOST will enlarge the sample of M dwarfs rapidly and even get the largest spectroscopic sample of M dwarfs, which may enable more scientific studies of M dwarfs and provide more statistically significant results to explore the structure and evolution of the Milky Way.

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Yi et al.