Precise Stellar Parameters for 10,000+ APOGEE M dwarfs

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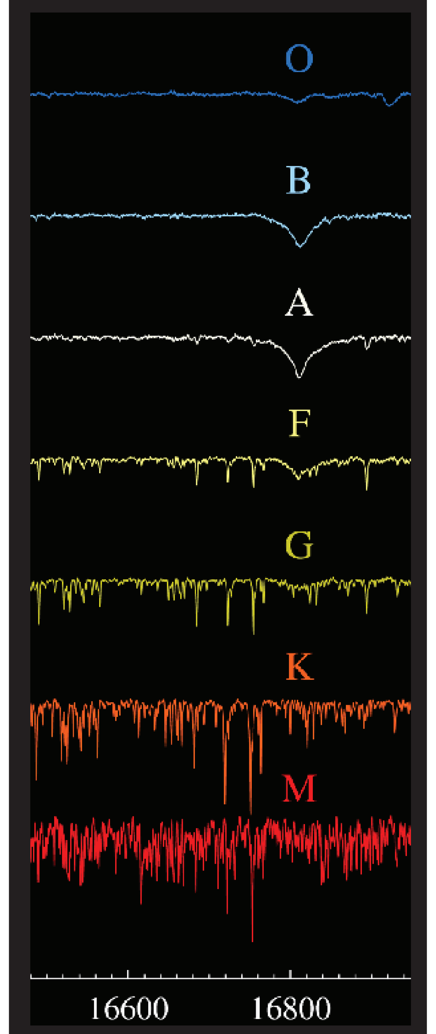
Overview

Motivation: M dwarfs which are atmospheric temperatures of 2500-4200K make up ~70% of the galaxy [3] and have lifespans over 10^{12} yrs [8] making them unique probes of galactic structure & evolution [3]. Low masses, small radii and short orbital periods facilitate easier detection of their exoplanets by radial velocity and transit methods [13,2].

Data: The Apache Point Observatory Galactic Evolution (APOGEE) survey [9]: >250,000 stars, 1.5 - 1.7 μm, R~22,500, primarily targeting bright, giant sources.

Challenge: Numerous blended features → difficult to deconvolve & measure equivalent widths of individual lines [12]. Atmospheric models limited by incomplete line lists & opacities [1].

Objective: Extract precise atmospheric parameters (temperatures and metallicity abundances) from high-res M dwarf spectra using data-driven models.

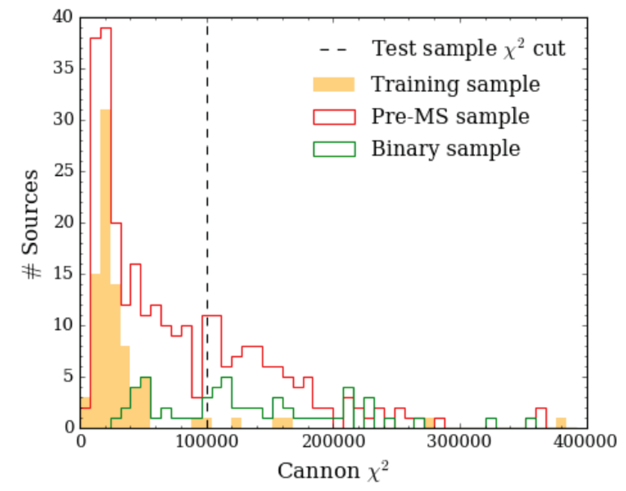


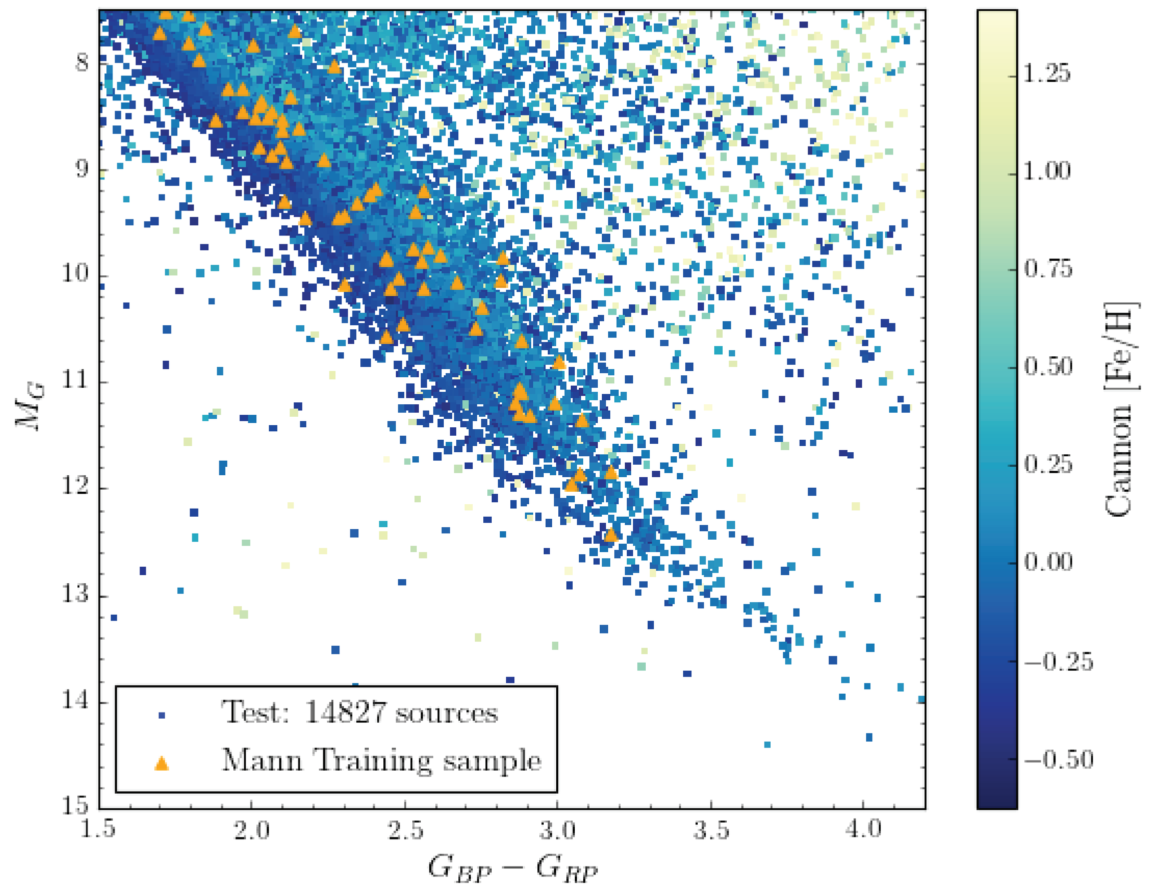
Methods & Sample Selection

Method: Using The Cannon [11] framework, we construct a regression model for predicting the flux at each pixel as a function of stellar labels. This method employs no line lists & effectively transfers labels from a training sample with known labels to a test sample.

Training Sample: 89 sources with calibrated temperature & metallicity measurements from Mann et al. 2015, spanning 2850 < Teff < 4200K and -0.5 < [Fe/H] < 0.5

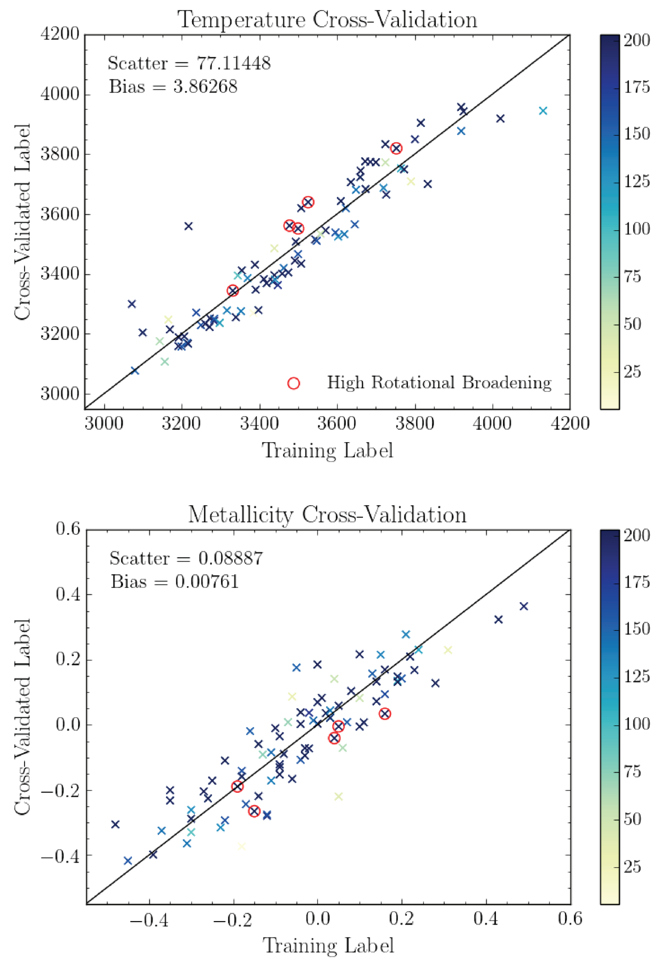
Test Sample: Using 2MASS/Gaia CMD cuts and Cannon model fits, we minimize pre-main sequence, K dwarf & subdwarf sources resulting in a sample of 10,311 M dwarfs.



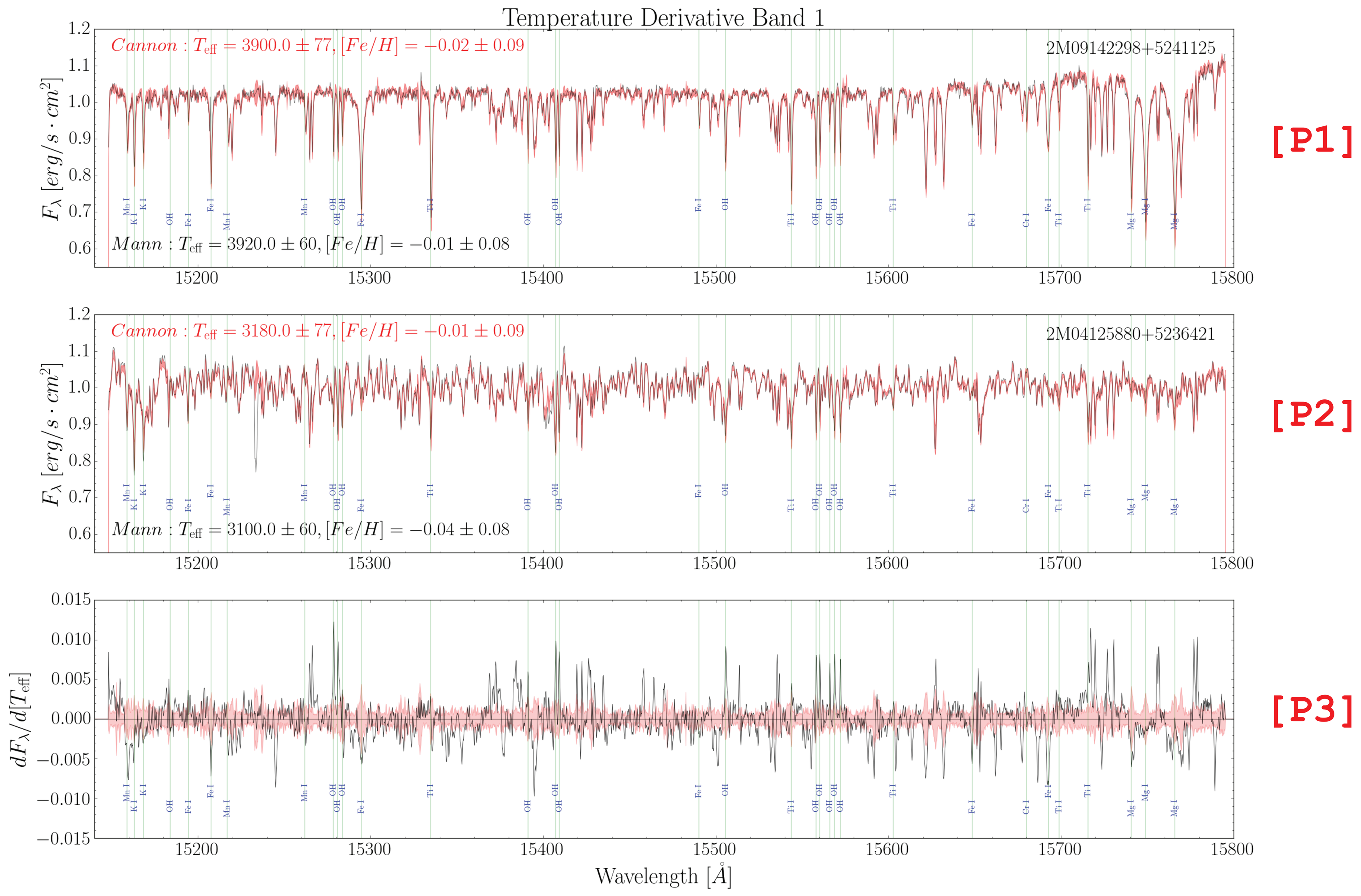


Color-magnitude diagram (CMD) of 14,827 sources selected from the APOGEE-Gaia cross-match. Overplotted in orange are the 89 training sources.

Data-Driven Models



Training labels compared to the Cannon model cross-validated labels.

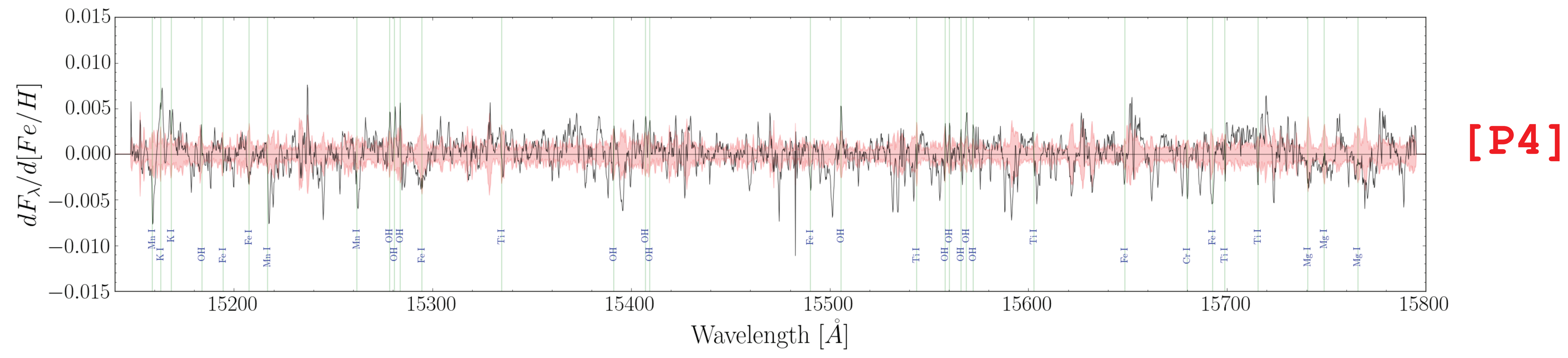


How does our model extract information?

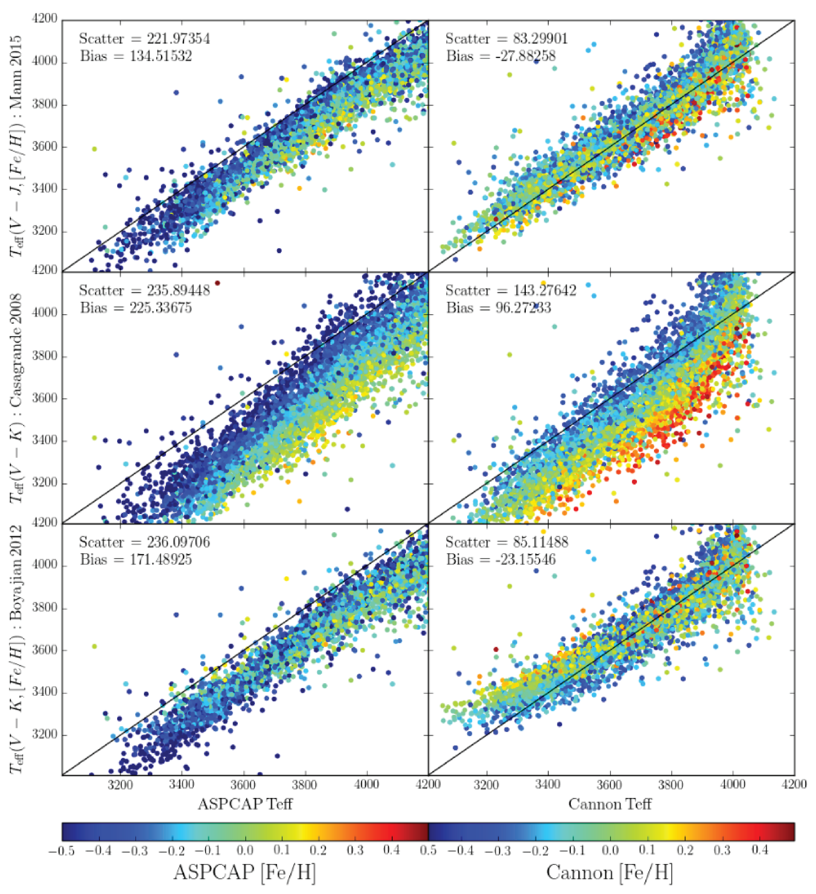
Panels [P1] and [P2] demonstrate our model fits for two sources different temperatures and near solar metallicities for the 1.51-1.58 μm band spectrum. Overplotted are atomic and molecular lines identified by [12].

[P3] shows the derivative of our model with respect to temperature and [P4] the derivative with respect to metallicity. A 1-σ jackknife error interval is overplotted in red, indicating which features significantly contribute to the model.

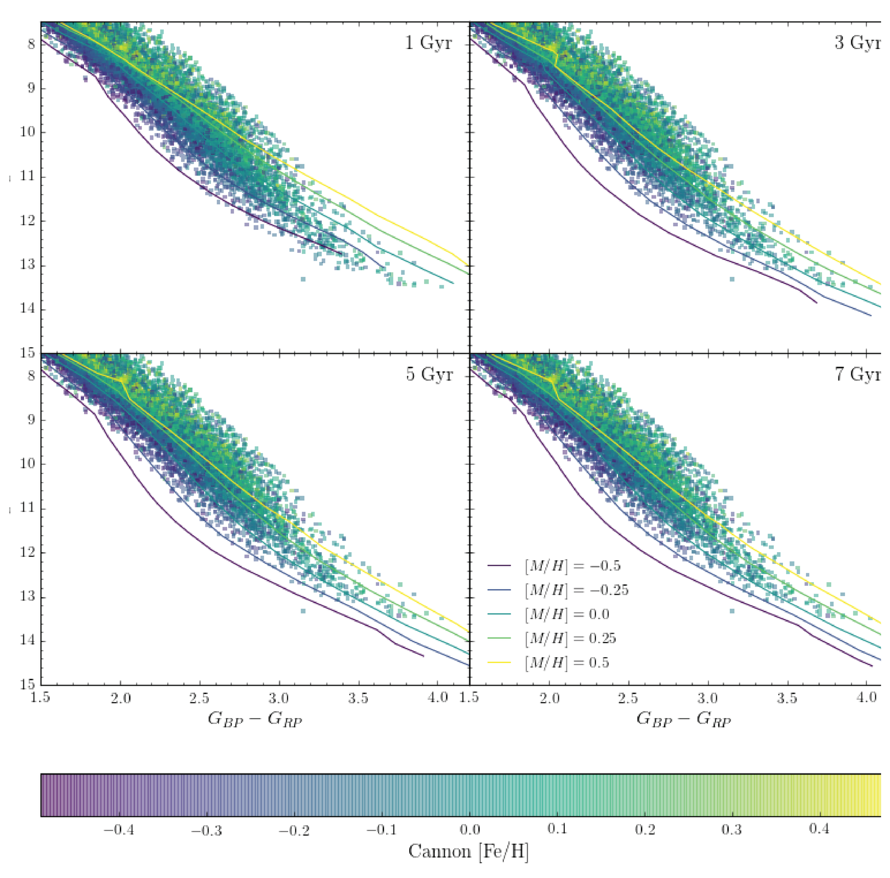
Our model finds OH, Mn I, Fe I, FeH, Si I lines to be the strongest indicators of temperature. In our [Fe/H] derivative we find less significant metallicity indicators (OH, Fe I, Mn I, Si I), and an insignificant correlation with FeH lines, indicating our model may be picking up low-level metallicity infomation from many weak lines.



Parameter Validation



Temperatures from the ASCAP pipeline [7] (left) and The Cannon (right), each compared to three color-temperature relations [4,6,10]. Cannon temperatures agree within ~85K.



Gaia color-magnitude diagram, colored by Cannon metallicities. Overplotted are PARSEC isochrones [5] at varying metallicities and ages. Note the binary sequence on upper slice of main sequence.

Take-Aways

Large samples of M dwarf physical parameters are useful for constraining exoplanet conditions and tracing galactic structure in kinematics. Our sample contains Teff, [Fe/H], Masses, Radii, 6D kinematics.

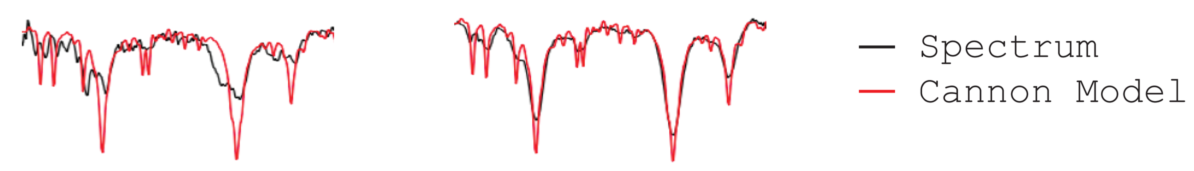
The data-driven modeling approach circumvents the challenge of incomplete line lists in theoretical models + we identify Teff & [Fe/H] sensitive indices.

Our data-driven model achieves very high temperature/metallicity precisions of 77K/0.09 dex. Models is accurate in the spectral domain to ~1%.

Stay tuned for our paper **Birky et al. (In prep)**!

Future Work

Model improvements:



Spectroscopic Binaries   Rapid Rotators

Seach for spectral indicators of magnetic activity?

Applications:

Spectral models of other surveys (2,748 LAMOST sources).

Properties of exoplanet hosts (4,586 TESS sources).

Color-magnitude-temperature-metallicity relations.

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[2] Ballard, S. 2018, arXiv:1801.04949
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[4] Boyajian, T. S. et al. 2012, ApJ, 757, 112
[5] Bressan, A., et al. 2012, MNRAS, 427, 127
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[7] Garcia Pérez, et al. 2016, AJ, 151, 144
[8] Laughlin, G., et al. 1997, ApJ, 482, 420
[9] Majewski, S. R. et al. 2015, AJ, 154, 94
[10] Mann, A. W. et al. 2015, ApJ, 804, 64
[11] Ness, M. et al. 2015, ApJ, 808, 16
[12] Souto, D. et al. 2017, ApJ, 835, 239
[13] Trifonov et al. 2018, A&A, 609, A117

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