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著者(和文)	小泉陽平
Author(English)	Yohei Koizumi
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Characterization of M-type Dwarfs

（M型矮星の特性決定）

Department of Earth and Planetary Sciences

Tokyo Institute of Technology

東京工業大学大学院　理学院　地球惑星科学コース

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Yohei Koizumi

小泉　陽平

Supervisor: Prof. Bun'ei Sato

An M-type dwarf is a cool and small star in the main sequence and it has been gathering attention as a promising target for detecting Earth-like small planets. Since the estimation of planetary properties strongly depends on the properties of the host star, understanding its stellar properties such as temperature, radius, mass, and metallicity is vital for planet search projects and for understanding planetary systems. Although the characterization of a Solar-like star is generally performed via comparisons of a high resolution spectrum with a synthetic model atmosphere, that for the M-type dwarf is significantly more complicated than that for the Sun-like FGK type star. The spectrum of an M type dwarf has strong and complex atomic and molecular absorption bands, which result in significantly blended spectral lines and unclear continuum regions. The current model atmosphere of low mass stars suffers from incomplete knowledge of stellar physics, line opacity, and other issues. Therefore, the estimation based on a synthetic model atmosphere may fail to yield accurate stellar properties. Recently, several studies have suggested that machine learning tasks can provide model-independent stellar properties for M-type dwarfs. However, in order to apply these data-driven methods, the spectra must be obtained with the same spectrograph. This work presents the methods to estimate the stellar parameters of low mass stars based on various observations.

In Chapter 2, the temperatures and radii of M-type dwarfs are revised based on the optical spectra and photometric observations with the latest parallaxes. The optical spectra are obtained in the target selection observation of the planet search program. This observation is conducted using several instruments. Therefore, the temperatures are calculated by comparing the optical spectra with the synthetic spectra. To estimate the precise temperatures, the fitting procedure is calibrated by using the M-type dwarfs whose temperatures are well-determined. For spectra with limited or narrow wavelength coverages, it is found that the temperature estimation is refined by utilizing only VO absorption features if available. Combining near infrared spectra with the optical spectra in this work will enable us to obtain more robust temperature estimations. Even if the synthetic model atmosphere is poorly constrained, selecting the suitable wavelength region and fitting the synthetic model spectra are still useful in order to estimate temperatures. The temperatures and radii of M-type dwarfs are also calculated via spectral energy distributions with the latest Gaia parallaxes. The Comparison of the resulting radii with the empirical ones and those from the stellar evolution model suggests that the radii are larger than the empirical and theoretical predictions.

The stellar properties of M-type dwarfs are determined using the data-driven method of optical low-resolution spectra in Chapter 3. Sparse modeling, which is a machine learning task, can be used to determine the model-independent stellar properties. The stellar properties are modeled as liner function of spectral indices, which are calculated as flux ratio and the prediction functions are trained via sparse approximation with stars whose properties are well-determined. The temperatures and metallicities can be obtained with precision of ~ 50 K and 0.09 dex, respectively. The sparse approximation of optical spectra can provide accurate metallicity for metal-poor stars. However, a metallicity discrepancy is observed in higher metallicity regions. This suggests that the low resolution spectroscopy does not contain sufficient resolution power to estimate higher metallicity values.

Further, the sparse approximation is also applied to M-type dwarfs that have near infrared high-resolution spectra and provides temperatures, radii, masses and metallicities in Chapter 4. The proposed method can obtain the properties of M-type dwarfs with the precision of 109 K in temperature, 6% in radius, 6% in mass, and 0.07 dex in metallicity. Similar to the sparse modeling of low-resolution spectroscopy, the stellar properties are modeled as liner function of equivalent width and the presented method does not utilize the synthetic spectra of low mass stars that suffer from the incomplete knowledge of the stellar atmosphere. While the sparse approximation does not provide better temperature estimation, the estimation of metallicity with a high-resolution spectra yields better results than that with low-resolution spectra. The resulting metallicities are consistent with reference values and no discrepancy is observed in this analysis.

Chapter 5 shows a metallicity correlation of CARMENES planets, which is a planet survey project using near infrared high-dispersion spectrograph. The proposed sparse method can derive the metallicity values of the planet-host M-type dwarfs and it confirms a correlation between planetary mass and stellar metallicity. The result supports the scenario that a metal-rich star tends to have dust-rich disks and it results in more gas giants around those stars. The absence of Earth-like planets is observed in metal-rich star regime. It must be noted that the number of planets is still small and the further analysis will be required to confirm planet–metallicity correlation.

The characterization of M-type dwarfs remains challenging. However, combining various types of observations enable us to provide accurate stellar properties. This study emphasizes that the data-driven methods can help achieve breakthroughs in stellar characterization because sparse modeling does not make use of the synthetic model atmosphere which suffers from the incomplete knowledge of stellar physics. Currently, M-type dwarfs are one of the primary targets not only in radial velocity surveys but also in the transit survey. Several planet search projects are planning or conducting their observations. Without accurate stellar properties, understanding planetary systems and constraining planet formation theory cannot be achieved. This research is expected to make a significant contribution to such planet survey projects and to understanding planetary systems.