論文の内容の要旨

Discovery and characterization of transiting exoplanets with diverse radii and ages

(多様な半径・年齢を持つトランジット太陽系外惑星の発見と特徴づけ)

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Kepler is the predecessor of the *K2* mission which observed a single patch of sky continuously for 4 years to look for planets around Sun-like (~FGK) stars using the transit technique. In contrast to the *Kepler* mission, *K2* observed different patches of the sky along the ecliptic in a series of "campaigns" for ~80 days each to look for planets primarily around late-type stars. Altogether, both missions discovered more than 2800 transiting exoplanets to date. Despite the overwhelming number of planets already known however, hundreds more remain to be discovered in the *K2* mission alone. Based on the original *Kepler* catalog, Dotson et al. (2019) predicted 1317±61 detectable exoplanets in the *K2* data set but only about 1/3 of this prediction are validated or confirmed *K2* planets. In this work, we set out to validate a number of planet candidates orbiting 72 host stars using a suite of follow-up observations including reconnaissance spectroscopy with McDonald/TULL, adaptive optics (AO) imaging with Subaru/IRCS, and speckle imaging with WIYN/NESSI. Because campaign 5 (C5) overlaps with C16 & C18, and C6 overlaps with C17, this provides light curves with baselines as long as 3 years. This allowed us to measure the transit ephemeris very precisely, revisit single transit candidates identified in earlier campaigns, and search for additional transiting planets with longer periods leveraging multiple *K2* campaigns for the first time. Using a robust statistical framework taking into account our follow-up data as constraints, we validate 35 planet candidates, 31 of which were also detected in previous catalogs and 4 are new detections found in this work. We also measure rotation periods for 42 stars in our sample, and report additional non-transiting candidates found via transit timing variations. These planets have a typical size of 2.2 $R_\oplus$ and orbital periods between 2.0 and 51.7 days. We highlight interesting systems including a sub-Neptune with the longest period with more than two transits detected with *K2*, (b) rare sub-Neptune-sized planets orbiting F-type stars, and (c) a variety of multi-planet systems in various architectures. This work, combined with our previous works (Livingston et al. 2018a, Livingston et al. 2018b, Castro-Gonzales et al. 2020) validated a cumulative number of 156 small planets which helped meet the expected yield of *K2*.

A large fraction of planet candidates (PCs) presented in this study could not be validated because of their large radii ($R_p>8$ $R_\oplus$) comparable to that of dwarf stars which are common sources of false positives. The standard solution to differentiate between the planetary and stellar scenario is confirming the companion's mass via radial velocity (RV) technique or astrometry but both methods are impractical or observationally expensive especially for planets orbiting faint (Vmag>13) host stars. An alternative method to constrain the companion's mass from the light curve itself is through phase curve modeling. Moreover, when coupled with constraints from multi-band transit photometry these complementary techniques become suitable to validate the majority of giant planets around faint stars. With this in mind, we conducted

several follow-up multi-band transit observations of EPIC 9937 b--a large planet candidate orbiting a K dwarf star every 3.4 days, using various facilities including OAO/MuSCAT, TNT/ULTRASPEC, PROMPT-8 and TRT-GAO. These observations are useful to confirm that the transit depth does not depend on the passband (i.e. achromatic) which rules out eclipses from stellar companions as well as provides constraint on the effective temperature of the orbiting companion. These constraints are folded into the phase curve model which includes the effects of ellipsoidal variations, reflection, thermal emission, and Doppler beaming. Consequently, we are able to rule out false positive scenarios and constrain the mass of the companion below Mp<13 Mjup and hence validate EPIC 9937 b as a rare inflated planet.

So far, the newly discovered planets are found to orbit mature host stars. However, there is a dearth of known planets around young stars with age<1 Gyr which inhabit a very important part of the evolutionary timescale, where formation mechanisms, accretion, migration and dynamical interactions can significantly change the shape of observed planetary systems. The main reason for the rarity of known young planets is the strong stellar activity of young stars, which makes it hard to find the subtle planetary signal in the face of large stellar variations. Despite the challenges, the young planet population is an emerging field that is expected to yield highly impactful scientific results. Therefore, by compiling a statistically significant sample of well-characterized exoplanets with precisely measured ages, we should be able to begin identifying the dominant processes governing the time-evolution of exoplanet systems. In this light, we present the discovery and validation of a sub-Neptune orbiting the young (~300-800 Myr old) star HD 18599. Complementary to *TESS* data, we utilized a suite of follow-up data including photometry with Spitzer/IRAC, IRSF/SIRIUS, speckle imaging with Gemini/Zorro, and high resolution spectroscopy from ESO 2.2m/FEROS, LCO 2m/NRES, SMARTS 1.5m/CHIRON, and MKO 6x0.7m/MINERVA Australis. By implementing a similar validation framework and analyses presented previously, we found that the planet has an orbital period of 4.3 days, a radius of 2.6 $R_{\oplus}$ and a mass <0.5 Mjup. What is unique about the host star is not only it is relatively young, it is also nearby (*d*~40 pc) and bright (Vmag=9, Jmag=7) which should facilitate detailed characterization of its interior composition via precise RV mass measurements and atmosphere via transmission spectroscopy.

Altogether, this work presented the discovery of new transiting planets with diverse radii and ages. Our validation of a large number of K2 planets would facilitate future occurrence studies of K2 planets as well as follow-up studies of the unique systems highlighted in this study. Moreover, our demonstration of the use of multi-band photometry and phase curve modeling to validate a number of remaining large planet candidates orbiting faint host stars would be proven more useful as we continue to conduct our follow-up observations of similar systems applicable not only in K2 but also in the TESS era. Finally, our discovery of a young planet amenable for detailed mass and atmospheric characterization provides a glimpse of the scientific opportunities possible with our on-going young planet search survey. With the advent of high precision astrometry from Gaia DR3 and wider sky coverage of TESS, we would be able to find more young and similarly interesting systems to provide important insights in theories of planet formation and evolution.