We report the discovery of an extrasolar planet detected from the combined data of a microlensing event OGLE-2015-BLG-0051 acquired by two microlensing surveys. Despite the fact that the short planetary signal occurred in the very early Bulge season during which the lensing event could be seen for just about an hour, the signal was continuously and densely covered. From the Bayesian analysis using models of the mass function, and matter and velocity distributions, combined with information on the angular Einstein radius, it is found that the host of the planet is located in the Galactic bulge. The planet has a mass $0.72^{+0.07}_{-0.05} M_J$ and it is orbiting a low-mass M-dwarf host with a projected separation $d_p = 0.73 \pm 0.08$ au. The discovery of the planet demonstrates the capability of the current high-cadence microlensing lensing surveys in detecting and characterizing planets.

Key words: gravitational lensing: micro – planetary systems

1. INTRODUCTION

Since the first discovery by Wolszczan & Frail (1992) followed by Mayor & Queloz (1995), many exo-planets have been discovered. With the Kepler mission, the number of known planets explosively increased and now exceeds ~3000, according to the Extrasolar Planets Encyclopedia. Most of them were discovered by either the transit, e.g., Tenenbaum et al. (2014), or radial-velocity methods, e.g., Pepe et al. (2011).

Planets have also been discovered using the microlensing method. Due to the fact that these planetary systems are detected through their gravitational fields rather than their radiation, this method makes it possible to detect planets around faint stars and even dark objects. Furthermore, microlensing is sensitive to planets in wide orbits beyond the snow line, which separates regions of rocky planet formation from regions of icy planet formation, while other major planet detection techniques are sensitive to close-in planets. As it is able to detect planets that are difficult to detect with other techniques, this method is important for comprehensive understanding of planet formation (Gaudi 2012).

The number of known microlensing planets at the time of writing this paper is 46, which is relatively small compared to the number of planets detected by other major methods. There are two main reasons for the small number of microlensing planets. The first reason is the rarity of microlensing events. The optical depth to microlensing, which represents the average probability of a star to be gravitationally lensed at a given moment, toward the Galactic bulge field is of order $10^{-6}$ (Sumi et al. 2003, 2006). Then, observation cadences of survey experiments were limited because they should monitor a large area of sky in order to maximize the number of observing stars. The second reason is the short duration of planetary microlensing signals. A planetary companion to a stellar lens exhibits its presence through a short-term perturbation to the smooth and symmetric lensing light curve induced by the host star (Mao & Paczynski 1991; Gould & Loeb 1992). It was difficult to cover such short planetary signals with early-generation lensing surveys that had ~1/2–1 day observation cadences. To detect short planetary signals, earlier lensing experiments adopted a strategy where lensing events were detected by wide-field surveys and events detected by surveys were intensively monitored using multiple narrow-field telescopes (Albrow et al. 1998). However, only a small fraction of ongoing events, which exceeds several hundreds during an observing season, could be observed by approximately a dozen follow-up telescopes. As a result, the detection efficiency of
microlensing planets under the survey/follow-up mode observation had been low.

However, the past few years have witnessed great changes in microlensing surveys. With the start of the fourth phase survey experiment, the Optical Gravitational Lensing Experiment (OGLE: Udalski et al. 2015) group significantly increased the observation cadence by broadening the field of view of their camera from 0.4 deg$^2$ into 1.4 deg$^2$. The Microlensing Observation in Astrophysics (MOA: Bond et al. 2001) group also plans to upgrade their camera to widen the current 2.2 deg$^2$ field of view into 4 deg$^2$ (T. Sumi 2016, private communication). There were additions of instruments to microlensing surveys. The WISE team (Shvartzvald et al. 2014) joined microlensing surveys in 2011 using its 1.0 m telescope. The Korea Microlensing Telescope Network (KMTNet) survey, which is composed of three globally distributed telescopes equipped with large-format cameras, started microlensing observation in the 2015 season. With the continuous and dense coverage of lensing events achieved by the instrumental upgrade of existing survey groups and the addition of new surveys, microlensing planet search is entering a new phase where planets can be detected by survey-mode observations alone.

In this paper, we report the discovery of a giant planet from the joint data acquired by the OGLE and KMTNet survey experiments. The short-duration planetary signal occurred in the very early Bulge season, during which the event could be seen for just about an hour. Nevertheless, the signal was densely and continuously covered by the two surveys experiments, enabling the detection and characterizing the planetary system.

The paper is organized as follows. In Section 2, we describe the observation of the planetary microlensing event using survey experiments and acquired data. In Section 3, we give a description of the modeling procedure conducted to analyze the observed lensing light curve. We provide the estimated physical parameters of the discovered planetary system in Section 4. Finally, we summarize the results and briefly discuss the result in Section 5.

2. OBSERVATION AND DATA

The planet was discovered from the observation of the microlensing event OGLE-2015-BLG-0051 which occurred on a star located toward the Galactic bulge field. The equatorial coordinates of the lensed star (source) are (R.A., decl.) = (17$^h$58$^m$39$^s$.01, $-$28$^o$01$'$54$''$.1), corresponding to the Galactic coordinates ($l$, $b$) = ($2^\circ$24$'$2$''$.0). The event was discovered by the OGLE Early Warning System (EWS: Udalski et al. 2015) on 2015 February 13 from observations using the 1.3 m Warsaw telescope at the Las Campanas Observatory in Chile. On 2015 March 2, an anomaly in the event was noticed and an alert was issued to the microlensing community for follow-up observations. However, the alert was issued when the anomaly was almost finished and thus the majority of the anomaly could not be covered by follow-up observations.

The event was analyzed in real time throughout its progress. From the modeling one of us (C.H.) conducted during the anomaly, it was pointed out that the anomaly is possibly of planetary origin, although other binary interpretations could not be completely excluded. Continued modeling conducted after the anomaly by C.H. and other modelers (V.B. and M.D.A.) reached the consistent result that the anomaly was produced by a planetary companion to the lens.

Although the event could not be observed by follow-up observations, it was densely observed by the KMTNet lensing survey, which is designed to monitor a large area of the Galactic bulge field with high cadences using large-format cameras equipped on multiple telescopes. The KMTNet survey started its test observation in 2015 February, which matches the occurrence time of the event. The event was dubbed KMT-2015-BLG-0048 in the KMT event list. The survey uses three identical telescopes located at the Cerro Tololo Interamerican Observatory in Chile (KMT CTIO), South African Astronomical Observatory in South Africa (KMT SAAO), and Siding Spring Observatory in Australia (KMT SSO). At the time of the event, KMT SSO was not online and the event was observed by two telescopes, KMT CTIO and KMT SAAO. Each telescope has a 1.6 m aperture and is equipped with a mosaic camera composed of four 9K $\times$ 9K CCDs. Each CCD has a pixel size of 10 microns corresponding to 0.4 arcsec pixel$^{-1}$ and thus the camera has a 4 deg$^2$ field of view (Kim et al. 2016). For the major fields, the observation cadence of the survey is $\sim$10 minutes. This cadence is high enough to detect signals produced by Earth-mass planets considering that the perturbation time of the signal is $\sim$3 hr.

In our analysis, we use combined data acquired by the OGLE and KMTNet surveys. The OGLE data are composed of 1167 $I$-band images. The KMTNet data consist of 786 $I$-band and 54 $V$-band images obtained from KMT CTIO observations and 1117 $I$-band images acquired from KMT SAAO observations. The main use of the KMT CTIO $V$-band data is to constrain the source star but they are not used for the light curve analysis because (1) the amount of data is small and (2) the photometry is relatively poor due to extinction. There exist data taken by the MOA group but we do not use them in our analysis not only because the perturbation region covered by the data overlaps with that covered by the combined OGLE + KMTNet data but also because the photometry quality is relatively poor.

Photometry of the images are conducted using the customized pipelines of the individual groups. Both pipelines are based on the Difference Imaging Analysis method (Alard et al. 1998; Woźniak 2000; Albrów et al. 2009). Since data are taken by different telescopes and processed by different photometry codes, we renormalize the error bars of the individual data sets using

$$\sigma' = k (\sigma_0^2 + \sigma_{\min}^2)^{1/2},$$

where $\sigma_0$ is the error estimated from the pipeline, $\sigma_{\min}$ is a factor used to make the cumulative distribution function of $\chi^2$ as a function of lensing magnification linear, and $k$ is a scaling factor to make the $\chi^2$ per degree of freedom unity. Photometric precision improves as the source star is magnified, and the factor $\sigma_{\min}$ is needed to make the scatter of data points be consistent with the error bars of the source brightness. The scaling factor $k$ is needed to ensure that each data set is fairly weighted according to its error bars. We note that the error-bar normalization parameters vary as the lensing model varies. We iterate the normalization process and the final parameters are set when the model is stable. In Table 1, we present the

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13 http://astroph.chungbuk.ac.kr/~kmtnet
estimated normalization parameters of the individual data sets. Although the event was observed in the early season, we find no systematic trend in the photometry caused by airmass trends.

In Figure 1, we present the light curve of OGLE-2015-BLG-0051/KMT-2015-BLG-0048. Compared to the continuous and symmetric light curve of a single-mass event, the light curve exhibits a short-term perturbation during $7080.0 \leq \text{HJD} \leq 7082.5$. The perturbation shows a feature that is composed of a depression centered at HJD $\sim 7081.5$ and brief bumps at both edges of the depression. Such dips, usually surrounded by two bumps, are a generic feature of lensing systems with small mass ratios $q \ll 1$ and normalized planet–star separations $s < 1$, i.e., planets inside the Einstein ring, which represents the source image caused by the exact alignment of the source, lens, and observer. When a source is lensed by the host of a planet, the host star’s gravity generates two images, one inside and the other outside the Einstein ring. The former, being a saddle point on the time delay surface, is easily suppressed if the planet lies in or near the path, thereby causing relative demagnification, and hence a dip in the light curve (Gaudi 2012).

Besides the main feature of the anomaly, there appears to exist a weak anomaly at HJD $\sim 2457075$, where four data points show a $\sim 0.02$ mag level deviation. We consider it as a fluctuation in the data because (1) the deviation is consistent with a $3\sigma$ level of photometry, (2) the region is sparsely observed, and (3) a two-body model cannot explain both of these weak and the main anomaly features.

The major structure of the anomaly feature was well covered by the survey data despite the short time window toward the field. See the zoom of the light curve around the planetary perturbation presented in Figure 2. During the time of the perturbation when the Bulge field could be seen only for approximately an hour, the OGLE survey obtained two images per night and the KMTNet survey obtained up to 20 images per night using its two telescopes. Since the OGLE and KMT CTIO telescopes are located at the sites with similar longitudes, the coverage of the perturbation by the two telescopes is similar. Although the KMT SAAO data missed the depression part of the perturbation due to poor weather conditions, they cover the second bump thanks to the $\sim 6.1$ hr longitude difference from the Chilean telescopes.

### 3. ANALYSIS

Keeping in mind that the anomaly pattern is likely to be produced by a binary lens with a low-mass ratio, we conduct binary-lens modeling. For the description of a binary-lensing light curve, one needs seven principal parameters for the lensing system and two flux parameters for each observatory. The first three of the principal parameters describe the source approach with respect to the lens, including the time of closest}

### Table 1

| Data Set | $k$  | $\sigma_{\text{min}}$ (mag) |
|----------|------|-----------------------------|
| OGLE     | 1.749| 0.001                       |
| KMT CTIO | 1.366| 0.005                       |
| KMT SAAO | 1.162| 0.002                       |

Figure 1. Light curve of the microlensing event OGLE-2015-BLG-0051/KMT-2015-BLG-0048. The solid curve superposed on the data is the model light curve based on the planetary model, while the dashed curve is based on the point-source point-lens (PSPL) model. Residuals of the KMT data sets are daily binned.

Figure 2. Lens system geometry. The upper panel shows the source trajectory (straight line with an arrow) with respect to the lens components (marked by $M_1$ and $M_2$) and caustics (closed concave curve), and the lower panel shows the light variation with the progress of the source position. Lengths are scaled to the Einstein radius, and the source trajectory is aligned so that the progress of the source matches the light curve shown in the lower panel. The inset in the upper panel shows the wide view and the major panel shows the enlarged view around the caustic. The empty circles on the source trajectory represent the source positions at the times of observation and their size indicates the source size. The dotted curve in the lower panel is the light curve expected for a point source. The inset in the middle panel shows the zoom of the light curve affected by finite-source effects.
source approach to a reference position on the lens $t_0$, the lens–source separation at that moment $t_0$ (impact parameter), and the time for the source to cross the angular Einstein radius $\theta_E$ of the lens $\theta_0$ (Einstein timescale). For the reference position of the lens, we use the barycenter of the binary lens. The other three principal parameters describe the binary lens including the projected separation $s$ and the mass ratio $q$ between the binary components, and the angle between the source trajectory and the binary axis, $\alpha$. We note that the impact parameter $t_0$ and the binary separation $s$ are normalized to $\theta_E$. The other parameter defined as the ratio of the angular source radius to the Einstein radius, $\rho = \theta_0/\theta_E$, is needed to describe light curve deviations affected by finite-source effects. For the graphical presentation of the binary-lensing parameters, see Figure 6 of Jung et al. (2015). The flux parameters $f_s$ and $f_b$ represent the fluxes from the source and blend, respectively.

For some lensing events, observed data exhibit subtle residuals from the best-fit model based on the principal lensing parameters due to higher-order effects. The known causes of such deviations include the parallax effect (Gould 1992) and the lens–orbital effect (Albrow et al. 2000; An et al. 2002; Jung et al. 2013). The parallax effect is caused by the positional change of the observer due to the orbital motion of the Earth around the Sun. On the other hand, the lens–orbital effect is caused by the positional change of the lens due to its orbital motion. Such effects are important for long timescale events where the duration of the event comprises a significant fraction of the orbital period of either the Earth or the lens. For OGLE-2015-BLG-0051/LMT-2015-BLG-0048 with an Einstein timescale $\theta_E \sim 11$ days, we find that these higher-order effects are negligible.

Our light-curve modeling proceeded in several steps. In the first step, we conducted a preliminary grid search for solutions in the parameter space of $(s, q, \alpha)$, for which lensing light curves vary sensitively to the change of the parameters. In this process, other parameters, for which the light curve varies smoothly with the change of the parameters, are searched for by using a downhill approach. For downhill $\chi^2$ minimization, we use the Markov Chain Monte Carlo (MCMC) method. The ranges of the $s$ and $q$ parameters inspected by the grid search are $-1.0 < \log s \leq 1.0$ and $-4.0 < \log q \leq 1.0$, respectively, and they are divided into $70 \times 70$ grids. The range of the source trajectory angle is $0 < \alpha \leq 2\pi$ and it is divided into 15 grids. We note that $\alpha$ is allowed to vary from each starting point while $s$ and $q$ are fixed during the model search. In the second step, we investigated possible local solutions in the parameter space in order to check for the existence of degenerate solutions where different combinations of the lensing parameters result in similar light curves. In this process, we refined local solutions by allowing all parameters, including the grid parameters $s$, $q$, and $\alpha$ in the preliminary search, to vary. Finally, we searched for the global solution by comparing $\chi^2$ values of the identified local solutions.

Lensing magnifications are affected by finite-source effects when the source is located close to or over caustics, which represent the positions on the source plane where the lensing magnification of a point source becomes infinite. Caustics of binary lenses form either a single curve or multiple closed curves, where each curve is composed of concave curves that meet at cusps. For the computation of lensing magnifications affected by finite-source effects, we use the ray-shooting method. In this method, rays are uniformly shot from the lens plane, bent by the lens equation, and then collected on the source plane to make a ray map. The lens equation of a binary lens is expressed as

$$\zeta = z - \frac{\epsilon_1}{z - z_{1,1}} - \frac{\epsilon_2}{z - z_{1,2}}. \tag{2}$$

where $\epsilon_1$ is the mass fraction of each lens component; $\zeta$, $z$, and $z_{l,1}$ denote the positions of the source, image, and lens expressed in complex notation in units of the angular Einstein radius, respectively; and $\bar{z}$ represents the complex conjugate of $z$ (Witt 1990). Once a ray map is constructed, a finite-source magnification for a given source position is computed as the number density ratio of rays that arrived on the source surface to the ray density on the image plane. In the initial grid search, we apply the map-making method (Dong et al. 2006), where a single map for a combination of the binary parameters $s$ and $q$ is used to produce many light curves resulting from different source trajectories. In the step to refine local solutions, the map-making method cannot be used because the parameters $s$ and $q$ are allowed to vary. In order to accelerate computation, we first apply semi-analytic hexadecapole approximations (Gould 2008; Pejcha & Heyrovský 2009), except when the source is on the caustic. We also minimize the number of rays by shooting rays that will arrive at regions around the caustic. Finally, we use customized codes developed for parallel computing, where multiple CPUs simultaneously compute model magnifications for the individual data points instead of computing the magnification of each data point one by one.

In computing finite-source magnifications, we consider the surface-brightness variation of the source star. For this, we model the surface-brightness profile as

$$S_\lambda \propto 1 - \Gamma_\lambda \left(1 - \frac{3}{2} \cos \phi \right), \tag{3}$$

where $\Gamma_\lambda$ is the linear limb-darkening coefficient and $\phi$ is the angle between the line of sight toward the source and the normal to the source surface. We adopt $\Gamma_\lambda = 0.46$ from Claret (2000) based on the de-reddened color and brightness of the source. See Section 4 for details about the procedure to determine the color and magnitude.

From the search for a solution, we find a unique solution with a companion/primary mass ratio corresponding to a planetary case. We find no degenerate solution with a $\chi^2$ value that is comparable to the best-fit solution. This can be seen in Figure 3, where we present the $\Delta \chi^2$ map in the $(s, q)$ parameter space obtained from the preliminary grid search. By refining the solution, it is estimated that the planet–host mass ratio is $q = (6.80 \pm 0.18) \times 10^{-3}$ and the projected planet–host separation is $s = 0.954 \pm 0.004$. In Table 2, we present the best-fit lensing parameters. In Figure 4, we also present the distributions of the lensing parameters on the MCMC chain in order to show the covariances between the lensing parameters. The MCMC run is stopped by visually inspecting the posterior distributions in the parameter space. The uncertainty of each parameter is estimated from the scatter of the MCMC chain.

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14 Those who want to reanalyze the event can download the MCMC chain and the light curve data at http://astroph.chungbuk.ac.kr/~cheongho/OB150051/data.html.
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4. PHYSICAL PARAMETERS

Since finite-source effects are clearly detected, it is possible
to determine the angular Einstein radius from the relation

θE = θs / ρ.

(4)

The normalized source radius ρ is measured from the analysis
of the light curve around the planetary perturbation. The angular radius of the source star, θs, is estimated from the
source type that is determined based on the de-reddened color
(V − I)0 and brightness I0.

In order to determine the calibrated color and brightness of
the source star, we use the method of Yoo et al. (2004).

following the method, we first locate the source star in the
instruments (uncalibrated) color–magnitude diagram of neighboring
stars in the same field. We then calibrate the color and
brightness from the offsets between the positions of the source
star and the centroid of the giant clump (GC), for which its
dereiddened color (V − I)0,GC and brightness I0,GC are known
(Nataf et al. 2013). In Figure 5, we present the source position
in the instrumental color–magnitude diagram with respect to the
GC centroid. By adopting (V − I)0,GC = 1.06 (Bensby et al.
2011) and I0,GC = 14.4 accounting for a variation with Galactic
longitude (Nataf et al. 2013), we find that

(V − I, I0 = (0.77 ± 0.05, 14.5 ± 0.03). This indicates that
the source is a G-type giant star. We then convert V − I into
V − K using the color–color relation of Bessell & Brett (1988)
and finally determine θs using the color–angular radius relation
of Kervella et al. (2004). We find that the angular source radius is
θs = 4.40 ± 0.38 μas. We note that the two principal
sources of uncertainty in estimating θs are the uncertainty of the
dereiddened color, σ(V − I0) ∼ 0.05 mag and the magnitude
uncertainty in the determined position of GC, ∼0.1 mag.

These two sources combined yield a ∼7% uncertainty in the
estimated θs. On the other hand, the uncertainty in the color–
size relation is small compared to the principal sources of error
(Gould 2014). The angular Einstein radius estimated from θs is
then

θE = 0.093 ± 0.008 mas.

(5)

Combined with the Einstein timescale measured from the light
curve modeling, the relative lens–source proper motion is
determined as

μ = θE / τE = 3.15 ± 0.28 mas yr−1.

(6)

As expected from the large ρ, the estimated Einstein radius is
significantly smaller than ∼0.5 mas for typical events produced
by low-mass stars.

For the unique determination of the mass M and distance Dl
to the lens, one needs both the lens parallax τE and the Einstein
radius θE (Gould 1992) that are related to the physical

Table 2

Lensing Parameters

| Parameters | Values |
|------------|--------|
| χ2         | 3057.1 |
| I0 (HJD)   | 2457083.081 ± 0.003 |
| u0         | 0.224 ± 0.002 |
| τE (days)  | 10.81 ± 0.07 |
| s          | 0.963 ± 0.002 |
| q (10−3)   | 7.43 ± 0.13 |
| α (rad)    | 5.358 ± 0.002 |
| β (10−3)   | 45.3 ± 0.6 |
| fs/fs*     | 0.01 ± 0.01 |

We note that the shape of the light curve resembles that of
MOA-2007-BLG-192 (Bennett et al. 2008). For MOA-2007-
BLG-192, the observational coverage of the planetary deviation
is sparse and incomplete and thus there exist multiple
possible solutions. On the other hand, the coverage of the
deviation of OGLE-2015-BLG-0051 is dense and complete,
thanks to high-cadence observation from multiple distributed
locations, leading to unambiguous characterization of the
planetary system.

In the upper panel of Figure 2, we present the geometry of
the lens system corresponding to the best-fit solution. Due to
the resonance of the projected separation to θE, i.e., s ∼ 1, the
lens system forms a single caustic around the host of the planet.
The source passed the backside of the arrowhead-shaped
caustic. The depression in the light curve occurred when the
source was in the demagnification valley between the two
protruding cusps that caused the brief bumps on both sides of
the depression. The source crossed the tip of one of the cusps
during which the light curve shows a clear finite-source
signature from which we accurately measure the normalized
parameters by

\[ M = \frac{\theta_E}{\kappa \pi_E}, \quad D_L = \frac{\text{au}}{\pi_B \theta_E + \pi_S}, \]

where \( \kappa = 4G/(c^2\text{au}) \simeq 8.1 \text{ mas}/M_\odot \) and \( \pi_S = \text{au}/D_S \) is the parallax of the source star located at a distance \( D_S \). For OGLE-2015-BLG-0051/KMT-2015-BLG-0048, the lens parallax cannot be measured due to the short timescale of the event and thus the physical parameters cannot be uniquely determined.

Although unique determinations are difficult, one can statistically constrain the physical lens parameters based on the measured Einstein radius \( \theta_E \) and the relative lens–source proper motion \( \mu \) combined with a Galactic model. For this, we conduct a Bayesian analysis using models of the mass function, and matter and velocity distributions. The Galactic model is based on Han & Gould (1995). In this model, the matter distribution is based on a double-exponential disk and a triaxial bulge. The disk velocity distribution is assumed to be Gaussian about the rotation velocity, and the bulge velocity distribution is a triaxial Gaussian with components deduced from the flattening via the tensor virial theorem. The mass function is based on the Gould (2000) model, which includes stars, brown dwarfs, and stellar remnants of white dwarfs, neutron stars, and black holes. Based on the the Galactic model, we produce a large number \( (6 \times 10^6) \) of artificial Galactic microlensing events and compute the relative probability of the individual events. From the lensing parameter distribution of artificial

\[ \text{Figure 4. Distributions of the lensing parameters. The color coding represents points on the MCMC chains within 1\sigma (red), 2\sigma (yellow), 3\sigma (green), 4\sigma (cyan), and 5\sigma (blue) of the best-fit value.} \]

\[ \text{Figure 5. Source position in the instrumental color–magnitude diagram of nearby stars with respect to the centroid of the giant clump. The diagram is constructed based on stars in the KMT subfield (140° \times 140° area) including the source star.} \]

events, we then estimate the range of the lens mass and distance corresponding to the measured \( t_E \) and \( \theta_E \).

\[ \text{Figure 6 shows the posterior distributions of the lens mass and distance obtained from Bayesian analysis. The mass and} \]

The snow line distance of the host star is \( s \) while the measurement of distance to the Galactic center is \( D \). We note that the mean value of the estimated mass function, one cannot exclude the possibility that the host of the lens mass peaks just above the lower limit of the assumed mass range. However, considering that the likelihood of small masses and low luminosities of M dwarfs provide leverage on conditions of planet formation, enabling the validity of existing formation theories to be checked and surviving theories, e.g., Ida & Lin (2005) and Boss (2006), to be refined. With improved survey capability, future microlensing planet sample will include planets not only in greatly increased number but also in a wide spectrum of hosts and planets, helping us to have a better and comprehensive understanding about the formation and evolution of planets.

5. SUMMARY AND DISCUSSION

We reported the discovery of an extrasolar planet that was detected from the combined data of a microlensing event OGLE-2015-BLG-0051/KMT-2015-BLG-0048 acquired by the OGLE and KMTNet surveys. Continuous and dense coverage of the short planetary signal by the survey data collected during the short time window in the early bulge season enabled unambiguous detection and characterization of the planetary system. We find that the planet has a mass about twice that of Jupiter and it is orbiting a low-mass host star located in the Galactic bulge. The discovery of the planet well demonstrates the capability of the current lensing surveys with enhanced observation cadence achieved by the instrumental upgrade of existing surveys and the addition of new surveys.

Cool M dwarfs far outnumber Sun-like stars and thus understanding the process of planet formation around them is important. Furthermore, small masses and low luminosities of M dwarfs provide leverage on conditions of planet formation, enabling the validity of existing formation theories to be checked and surviving theories, e.g., Ida & Lin (2005) and Boss (2006), to be refined. With improved survey capability, future microlensing planet sample will include planets not only in greatly increased number but also in a wide spectrum of hosts and planets, helping us to have a better and comprehensive understanding about the formation and evolution of planets.

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