Ice giant exoplanets – current status and future prospects

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Understanding of planet formation and evolution requires finding exoplanets similar to the Solar System planets. While thousands of exoplanets are known, only very few of them have orbits similar to Uranus and Neptune. Detecting such planets around solar-type stars presents a challenge because of their extremely long orbital periods. Currently, planets on orbits similar to Uranus and Neptune can be found only using the microlensing technique. In particular, the OGLE project has made large contribution to studies of such planets. In the near future, the NASA flagship WFIRST satellite will make a major contribution.

1 Introduction

Full understanding of planetary system formation and evolution cannot be achieved without understanding how different types of planets, including ice giants, have formed. A simple in-situ formation model is not able to reproduce Uranus and Neptune masses, compositions, and orbital separations (Pollack et al., 1996). There were a few attempts to explain formation of Uranus and Neptune using other models (Thommes et al., 1999; Goldreich et al., 2004; Tsiganis et al., 2005), however, validation of these models requires knowing more ice giants than the two known in the Solar System. There are around 4000 exoplanets currently known, but very few of them are similar to the Solar System ice giants. Extrasolar analogs of Uranus and Neptune are hard to discover primarily due to their long orbital periods, or equivalently large projected separations.

There are a few exoplanet detection methods and they have different biases. Most of the exoplanets known today were discovered using the transit technique, however, secure detection of exoplanet ice giants with the transit technique would require high-precision photometry spanning more than a human lifetime and covering a large number of targets. The radial velocity technique gives secure detections if the length of the dataset is similar to the planet orbital period. The three exoplanets with well-characterized radial velocity signals and the longest periods (longer than 20 yr) all have semi-amplitudes larger than 35 m s^{-1} (Sahlmann et al., 2016; Wittenmyer et al., 2017; Blunt et al., 2019). This is much larger than a few m s^{-1} required for Uranus- or Neptune-analog detection. The long-term stability of spectrographs is an important factor limiting the radial velocity detection of extrasolar ice giants. The third widely-used planet detection technique is direct imaging. While wide-separation makes direct imaging easier, the extrasolar ice giants have contrast ratios well below capabilities of current and near-future high-resolution imaging instruments. Since it turns out that none of these three techniques allows detecting ice giants, only the gravitational microlensing can detect ice giants. For a review of microlensing planet detection technique see Gaudi (2012).

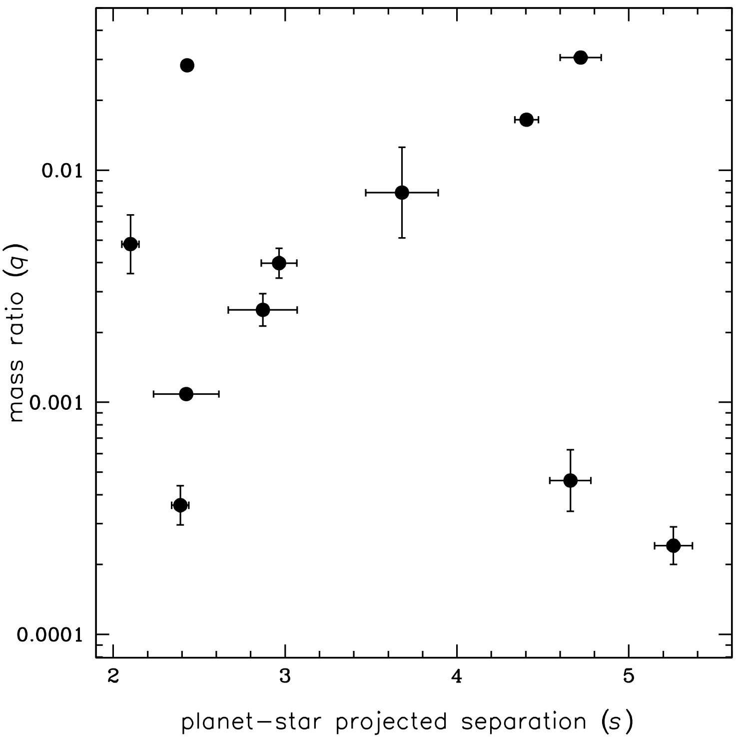

Fig. 1: Directly measured properties of wide-orbit microlensing planets. The objects shown are listed in Poleski et al. (2018) plus Hwang et al. (2019) and Han et al. (2020).

2 Current status

For microlensing planets, the parameters that are directly measured are: q – planet to star mass ratio and s – planet-star projected separation relative to Einstein ring radius (θ_{E}). Typical value of θ_{E} corresponds to the projected separation of ≈ 2.5 AU. More than 80 microlensing exoplanets have been detected so far. Microlensing is most sensitive to planets with $s \approx 1$ and can detect planet with separations up to a few times larger. At these largest separations, the detected planets are similar to Uranus and Neptune. The widest orbit planet currently known has $s = 5.3$ and $q = 2.4 \times 10^{-4}$ (OGLE-2008-BLG-092LAb; Poleski et al., 2014). Thus, this planet is a Uranus analog. It was discovered by the Optical Gravitational Lensing Experiment (OGLE), which is currently in its fourth phase (Udalski et al., 2015). The orbit of OGLE-2008-BLG-092LAb is so wide that for random source trajectories producing planetary signal, only about half of them show a detectable signal from the host star. Hence, similar planets can be mistaken for free-floating planets, which are found as short-lasting and apparently single-lens microlensing events. Population of free-floating planet candidates was recently studied by the OGLE survey (Mróz et al., 2017) and a few high-quality candidates were also published (Mróz et al., 2018, 2019). In order to find what fraction of free-floating planet candidate events are caused by bound planets we have to measure population statistics of wide-orbit planets. This subject is actively investigated.

In Fig. 1 we show currently known microlensing planets and brown dwarfs (i.e., objects with $0.01 \lesssim q \lesssim 0.1$) in q vs. s plane. We see that for the widest-orbit objects ($s \gtrsim 4$) we do detect both low mass ratio objects ($q < 10^{-3}$) and high mass ratio objects ($q > 10^{-1}$) but there is no detection for intermediate mass ratios. This can be caused by statistical noise or a dearth of Jupiter-mass wide-orbit planets (Poleski et al., 2018). Note that detection efficiency increases with increasing mass ratio.

3 Future prospects

Future breakthrough in wide-orbit and free-floating microlensing planet studies will be possible by the high-cadence near-infrared satellite surveys. Microlensing program is part of a core science of NASA flagship mission Wide Field Infrared Survey Telescope (WFIRST; Penny et al., 2019). It is possible that the Euclid satellite constructed by ESA will also conduct a microlensing survey (Penny et al., 2013). Currently, planned launch dates are 2025 and June 2022, respectively.

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