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Search for extra-solar Planets using SALT

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Abstract. From our experience with the follow-up of transiting planet candidates from the Optical Gravitational Lensing Experiment (OGLE) we report here on our plans for using SALT in our own search for extra-solar planets.

1. Introduction

The detection of planets outside the solar system is a long-standing goal of astronomy. Since the detection of the first gas giant planet around a solar type star (Mayor & Queloz 1995), a multitude of search projects using various methods have been started (Schneider 2001)[1].

Out of the over one hundred presently known planets, the vast majority has been detected with Doppler-velocity measurements of the planets' host stars. Together with the limited time spent (relative to e.g. Jupiter's orbital period) for extensive planet search projects, this gives an observational bias towards massive planets and tight planetary orbits. Nevertheless, the observed quantities of the extra-solar planets have a strong impact on our understanding of planet formation and evolution.

The known extra-solar planets and planetary systems are quite markedly different from our own solar system. About a third of these planets are Jupiter-sized objects with orbits smaller than the one of Mercury, about a half have orbits smaller than 1 AU. While the eccentricity of the solar planets is low, extra-solar planets are found with a large scatter in eccentricities up to nearly unbound orbits (Naef et al. 2001). Surprisingly, planets have also been found in binary systems (Cochran et al. 1997). Down to the detection limit of 0.12 Jupiter masses, the mass distribution seems to favor low mass planets (Marcy et al. 2003).

2. From candidates to confirmed planets

2.1. Transiting planets

The orbital inclination of one of the extra-solar planets found using the Doppler-velocity method, HD 209458B, allowed the measurement of the eclipse of the

[1]see http://www.obspm.fr/encycl/catalog.html for an up-to-date overview

host star by the planet (Charbonneau et al. 2000, Henry et al. 2000). Such a planetary transit permits the detection of additional important quantities. First of all, the orbital inclination can be determined precisely from the eclipse light curve, which then allows one to determine a true planetary mass (Mazeh et al. 2000) instead of a lower mass limit as from Doppler-velocity measurements alone. Second, the eclipse light curve also provides the planetary radius (Mazeh et al. 2000, Brown et al. 2001). Combined with the mass, this gives the planet's mean density and these quantities can be confronted with the theory of structure and evolution of gas giant planets (Guillot et al. 1996, Burrows et al. 2000). Finally, the light of the primary star shining through the planetary atmosphere during the eclipse allows one to investigate some atmospheric properties (Charbonneau et al. 2002).

2.2. OGLE

The successful first-detection of an extra-solar planet with the transit method was made by the Optical Gravitational Lensing Experiment (OGLE) (Udalski et al. 1992, 1997)[2]. OGLE is designed to investigate dark matter via microlensing events. The required large field, photometric precision, and data analysis can, however, also be used for secondary science goals like stellar variability. Among those, the search for transiting low luminosity objects (Udalski et al. 2002a,b,c, 2003) is of special interest since the so-called transit method is capable of detecting extra-solar planets. In two campaigns, 137 stars with low luminosity companions (i.e. the secondary eclipse is not present in the light curve) have been found. Whether these companions are M stars, brown dwarfs or extra-solar planets cannot be decided from the photometric monitoring alone. The light curve provides the radius ratio from the depth of the primary eclipse, with weak constraints for the primary radius. The radius of the secondary can therefore be consistent with stellar as well as sub-stellar sizes of the companions. Additional observations as described in 2.4-2.6 are therefore necessary to derive the nature of the low luminosity companions (Dreizler et al. 2002, 2003, Konacki et al. 2003).

2.3. MONET

The University Göttingen is currently erecting two 1.2 m robotic telescopes, the **MO**nitoring **NE**twork of **T**elescopes (MONET), funded by the Alfried Krupp von Bohlen und Halbach Foundation[3]. One telescope will be operated at McDonald Observatory, Texas (MONET-North), the other at the South African Astronomical Observatory (SAAO, MONET-South). MONET-North is expected to start operation in summer 2004, MONET-South about half a year later. Göttingen will have 80% of the observing time, SAAO and McDonald will have about 10% each. A requirement for the grant from the Krupp foundation is an intensive public educational outreach. This is obtained by offering schools access to high quality astronomical observations. Half of the Göttingen share, i.e. 40%, is devoted to this educational aspect. The telescopes will be equipped

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[2]see also http://sirius.astrouw.edu.pl/~ogle/index.html for an overview

[3]see also http://www.uni-sw.gwdg.de/~hessman/MONET/

with CCD cameras covering about 22'×22' for a 13μ pixel chip, and the pixel scale will be about 0.32" per pixel.

The main motivation for the large field is the search for extra-solar planets via the transit method. MONET is ideally suited for a transit search project since numerous repeated observations of a small number of fields can be easily implemented in the planned robotic operation. Besides candidates from the continued transit search from OGLE, we will therefore be able to select low luminosity transiting objects from our MONET search. Like the OGLE candidates, the MONET candidates need further follow-up observations in order to confirm or disprove their planetary nature. The typical brightness of these candidates is between 14^{m} and 17^{m}, further, especially high resolution spectroscopy therefore requires large telescopes.

2.4. Low resolution spectroscopy

The first step in the confirmation process is low resolution spectroscopy in order to determine the spectral types of the primary stars, allowing an estimate of their radius. The depth of the eclipse obtained from the photometric light curve provides the radius ratio. In combination with the primary radius, the radius of the low luminosity companion can then be derived. Companion radii above $0.2\,\mathrm{R}_\odot$ clearly indicate a stellar companion, since only very young sub-stellar objects can be that large, making a detection during that very short phase extremely unlikely. For smaller objects, the mass-radius degeneracy doesn't allow one to discriminate between a low mass M-star (below about $0.2\,\mathrm{M}_\odot$), a brown dwarf, or a gas giant planet. The earth-bound photometric precision limits the detection to about Saturn-sized gas giants. While such a small companion radius would rule out a stellar nature, further confirmation is necessary also for such systems in order to discriminate against possible blends.

PFIS[4] is a suitable instrument, especially in multi-object mode, because the search method will provide several targets in relatively small fields. An infrared extension would be extremely valuable because M-star companions could be rejected also from an IR excess in the spectral distribution.

2.5. Medium resolution spectroscopy

All candidates passing the radius criterion have to be finally confirmed by a dynamical mass determination in order to discriminate planets from brown dwarfs and very low-mass M-stars. A few medium resolution spectra at phases of expected maximum radial velocity are sufficient to detect the remaining low-mass M-stars. A solar like primary would typically reveal radial velocity variations of about $20\,\mathrm{km\,s}^{-1}$ or larger for the low-mass M-stars assuming orbital periods in the order of days, which will be the favored orbital periods found in transit searches. Again, PFIS in its highest resolution mode would be suitable and very limited observing time is needed to reject all stellar companions. While these binary systems containing an eclipsing M-star companion can be further investigated for an improvement of the mass-radius relation of low mass main sequence

[4]http://www.sal.wisc.edu/PFIS/

objects, we will skip that discussion here and refer to the work of Lopez-Morales (these proceedings and Lopez-Morales & Clemens 2004).

2.6. High resolution spectroscopy

The final step towards a confirmation of a planet is a dynamical mass determination via high precision measurements of the tiny radial velocity variations. While brown dwarfs around solar like stars would induce radial velocity variations of a few $\mathrm{km\,s^{-1}}$ (again assuming orbital periods of the order of days), a Jupiter-mass planet requires precision down to at least $100\,\mathrm{m\,s^{-1}}$, an internal precision of an order of magnitude lower would significantly improve this work. The planned high resolution spectrograph for SALT will therefore be able to provide radial velocity curves for all candidates down to about 17th magnitude.

The co-added spectra can be analysed in order to derive a spectroscopic mass and radius of the primary star improving the light curve as well as the radial velocity variation analysis compared to the spectral type determination from the low resolution spectroscopy. One can also derive the metallicity of the primary star in order to check the metal dependency of planet formation.

While a positive detection of a radial velocity variation with a period consistent with the photometric periodicity will give a final confirmation of the planetary nature, a non-detection needs further investigation. The mass of the companion could be below the detection limit or a shallow eclipse in the light curve in combination with a non-detection of radial velocity variations can be due to blends, where an eclipsing binary is diluted be a tertiary star either physically belonging to the system, i.e. in a wider orbit, or by incidentally being in the line of sight. Coarsely, one can divide the blending in two types: The first type consists of a faint binary system and a bright third star. The spectrum of the dominating third star would then be absolutely undisturbed and further information could only be obtained from very high precision photometry. The second type consists of an eclipsing binary system where the primary is of comparable brightness as the third star. In that case, the high resolution spectra would reveal periodic line shifts or line asymmetries detectable from the time resolved high resolution spectra obtained for the Doppler-measurements.

The final outcome is therefore a dynamical mass for the low luminosity companion confirming a planet in the optimal case. In the case of non-detection of radial velocity variations, the observations provide information to discriminate between a blend or a non-detection due to the velocity amplitude falling below the detection limit.

3. Summary and conclusion

Current (OGLE) and future (MONET) searches for transiting planets will provide a large number of low luminosity objects resulting in many planets with precisely know masses, radii and densities. The combination with MONET as a pathfinder telescope makes SALT a very interesting instrument for such a project. In order to confirm the planetary nature, a staged procedure going from imaging to low and then to high resolution spectroscopy is needed. The faintness of the targets in combination with the necessary precision require a 10 m class telescope like SALT.

Besides the large aperture and the available and future instrumentation, the queue scheduling of SALT is an important aspect for this kind of work. In mixed service and visitor mode scheduling, repeated observations are periodically interrupted by visitor mode blocks, resulting in long gaps in e.g. radial velocity variation measurements. This causes unnecessary difficulties in the analysis which are prevented in a pure queue scheduling mode. The effectivity of the proposed measurements of radial velocity variations can be significantly improved when observations with SALT are combined with those from the VLT in order to reduce the daily gaps.

The combination of large aperture, flexible scheduling, and a rich collection of instrumentation combined with dedicated input from smaller robotic telescopes promises to make SALT the ideal platform for discovering extra-solar planets.

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