The PennState/Toruń Center for Astronomy Search for Planets around Evolved Stars.

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Abstract. We present the motivation for and the first results from a large radial velocity search for planets around red giants with the 9.2-m Hobby-Eberly Telescope.

Introduction

Since the discovery of the first extrasolar planetary system (Wolszczan & Frail 1992) and the first planet orbiting a Sun-like star (Mayor & Queloz 1995) more than 200 planets have been detected beyond the Solar System. Aside from the most successful surveys of solar type stars, a spectacular progress has been made in searches for planets around low-mass dwarfs, which, among other goals, have been driven by the anticipation that Earth-mass planets can be found in their habitable zones (Marcy et al. 2005; Mayor et al. 2005). However, over time, it has become apparent that to achieve a truly satisfying level of understanding of planet formation and evolution, the surveys have to be extended to other types of stars. For example, surveys of white dwarfs, which probe ancient planetary systems - survivors of the evolution of their parent stars - exemplify an extension of planet searches to the endpoint of stellar evolution (e.g. Kepler et al. 2005; Silvotti et al. 2007). In addition, searches for neutron star planets can provide information on planets around massive stars (Thorsett & Dewey 1993) and on planet formation in extreme, post-supernova environments (Konacki & Wolszczan 2003; Wang et al. 2006).

More than a decade ago, precision radial velocity (RV) studies have established that GK-giant stars exhibit RV variations ranging from days to many hundreds of days (e.g. Walker et al. 1989; Hatzes & Cochran 1993, 1994). Enough observational evidence has been accumulated to identify three distinct sources of this variability, namely stellar pulsations, surface activity, and a presence of substellar companions. As Doppler searches for planets around main sequence (MS) stars become inefficient for spectral types earlier than F6-F8, because of paucity of spectral features and their rotational broadening, extending studies of planetary system formation and evolution to stellar masses substantially larger than 1 M$_\odot$ is observationally difficult. A potentially very efficient, indirect way to remove this difficulty is to conduct surveys of post-MS giants. These evolved stars have cool atmospheres and many narrow spectral lines, which can
be utilized in RV measurements to give an adequate precision level (<10 m s\(^{-1}\)). Discoveries of planets around post-MS giants, in numbers comparable to the current statistics of planets around MS-dwarfs (e.g. Butler et al. 2006), will most certainly provide the much needed information on planet formation around intermediate mass MS-progenitors (\(\geq 1.5M_\odot\)) and they will create an experimental basis with which to study dynamics of planetary systems orbiting evolving stars (e.g. Duncan & Lissauer 1998). Sufficiently large surveys of post-MS giants should furnish enough planet detections to meaningfully address the problem of a long-term survival of planetary systems around stars that are off the MS and on their way to the final white dwarf stage.

**Strategy and observations**

In order to address the above issues, we have joined the existing surveys (e.g. Hatzes et al. 2006; Sato et al. 2007, and references therein) with our own long-term project to search for planets around evolved stars with the 9.2-m Hobby-Eberly Telescope (HET) (Ramsey et al. 1998) and its High Resolution Spectrograph (HRS) (Tull 1998). The sample of stars we have been monitoring since early 2004 is composed of two groups, approximately equal in numbers. The first one falls in the “clump giant” region of the HR-diagram (Jimenez et al. 1998), which contains stars of various masses over a range of evolutionary stages. The second group comprises stars, which have recently left the MS and are located \(\sim 1.5\) mag above it. Generally, all our targets, a total of >900 GK-giants brighter than \(\sim 11\) mag, occupy the area in the HR-diagram, which is approximately defined by the MS, the instability strip, and the coronal dividing line (a narrow strip in the HR-diagram marking the transition between stars with steady hot coronae and those with cool chromospheric winds (Linsky & Haish 1979)). If the frequency of occurrence of planets around MS-progenitors of GK-giants is similar to that of planets around solar-type stars, our survey should detect 50-100 planets and planetary systems, which, together with the detections from similar projects, will provide a firm basis for studies of planetary system formation and evolution around \(> 1M_\odot\) stars.

Observations were made in the queue scheduled mode (Shetrone et al. 2007). The HRS was used in the R=60,000 resolution mode with a gas cell (\(I_2\)) inserted into the optical path, and it was fed with a 2 arcsec fiber. Typically, the signal-to-noise ratio per resolution element (at 594 nm) was \(\sim 200\) for the stellar spectra taken with the gas cell, and \(\geq 250\) for the templates.

The spectra consisted of 46 echelle orders recorded on the “blue” CCD chip (407.6-592 nm) and 24 orders on the “red” one (602-783.8 nm). The spectral data used for RV measurements were extracted from the 17 orders, which cover the 505 to 592 nm range of the \(I_2\) cell spectrum.

Because the HRS spectra extend far beyond the range occupied by the \(I_2\) lines, we were able to measure variations of line profiles to monitor stellar activity in the same spectra which were used for radial velocity determination. To avoid any contamination by the \(I_2\) spectrum, we have selected lines in the wavelength range redwards of 660 nm. We have measured two line parameters, the line bisector span and its curvature (Nowak & Niedzielski, this volume). The “blue” high SNR template spectra, exposed without gas cell were used to
obtain rotational velocities via cross-correlation with a slow rotator, (Nowak & Niedzielski, this volume).

The observing strategy has been optimized for the HET taking into account the fact that the number of targets is large, about 2/3 of them are fainter than 8 mag, and that they are approximately randomly distributed over the sky. Measurements of a particular target star begin with 2-3 exposures, typically 3-6 months apart, to check for any RV variability exceeding a 30-50 m s\(^{-1}\) threshold. The interval between observations also matches the HET ability to point at a given object, usually no more than 1-2 times per night, thus favoring the expected long term RV variations. If a significant variability is detected, the star is scheduled for more frequent observations, and, if the RV variability is confirmed, it becomes part of the high priority list.

The data reduction was performed using IRAF\(^1\) scripts. Radial velocities were measured by means of the commonly used \(I_2\) cell calibration technique (Butler et al. 1996). A template spectrum was constructed from a high-resolution Fourier Transform Spectrometer (FTS) \(I_2\) spectrum and a high signal-to-noise stellar spectrum measured without the \(I_2\) cell. Doppler shifts were derived from least-square fits of template spectra to stellar spectra with the imprinted \(I_2\) absorption lines. The resultant radial velocity measurement for each epoch was derived as a mean value of the independent determinations from the 17 usable echelle orders. The corresponding uncertainties of these measurements were calculated assuming that errors obeyed the Student’s t-distribution and they typically fell in a 4-5 m s\(^{-1}\) range at 1\(\sigma\)-level. Radial velocities were referred to the Solar System barycenter using the Stumpff (1980) algorithm.

**First results.**

Since the beginning of this survey, 4 years ago, over 600 stars of our sample have been observed. More than 300 of them have been observed at multiple epochs. For all stars for which enough data exist, the rms scatter in RV can be calculated. The distribution of this scatter shows a maximum between 10 and 20 m/s, which we interpret as representing the typical intrinsic RV jitter of the red giants. Based on this result, we consider a red giant to be RV-stable, if its \(\sigma_{RV}\)\(\leq\)40 m/s. According to this criterion, \(\sim\) 55% of our sample stars can be considered as RV stable. Another \(\sim\) 20% of the program stars show RV variations with \(\sigma_{RV}\geq\)250 m/s and we assume that they are binaries with a stellar companion. Yet another 20% of them show \(\sigma_{RV}\) between 40 and 250 m/s and these are the stars which constitute our sample of candidates for substellar companions.

We have detected a periodic RV signal in about one-half of the stars, which belong to the group of planetary companion candidates. Typically, the estimated periods are longer than one year and only a very few stars show shorter periodicities. Our current approach is that only stars with the suspected substellar companions, for which at least 3 consistent orbital periods have been

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\(^1\)IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
observed, are considered for prompt publication. This is to ensure a reliable rejection of all sources of observed RV variations other than the presence of a low-mass companion.

Our first discovery is a sub-stellar companion to the red giant HD 17092 (Niedzielski et al. 2007). In the absence of any correlation of the observed 360-day periodicity in radial velocities with the standard indicators of stellar activity, the observed radial velocity variations are most plausibly explained in terms of a Keplerian motion of a planetary-mass body around the star. With the estimated stellar mass of 2.3M_☉, the minimum mass of the planet is 4.6M_J. The planet’s orbit is characterized by a mild eccentricity of e=0.17 and a semi-major axis of 1.3 AU. This is the tenth published detection of a planetary companion around a red giant star.

Acknowledgments. The project is supported in part by the Polish Ministry of Science and Higher Education grant 1P03D 007 30. AW also acknowledges a partial support from the NASA Astrobiology Program. The Hobby-Eberly Telescope (HET) is a joint project of the University of Texas at Austin, the Pennsylvania State University, Stanford University, Ludwig-Maximilians-Universität München, and Georg-August-Universität Göttingen. The HET is named in honor of its principal benefactors, William P. Hobby and Robert E. Eberly.

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