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THE HUNT FOR EXTRASOLAR PLANETS AT MCDONALD OBSERVATORY

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RESUMEN

Actualmente los mayores telescopios en el Observatorio de McDonald se usan para la búsqueda de planetas extrasolares. Hacemos una reseña de los diferentes programas de búsqueda. En particular describimos en detalle los levantamientos Doppler de alta precisión en el telescopio de 2.7-m Harlan J. Smith y en el Telescopio Hobby-Eberly (HET). El punto sobresaliente del programa HET fue el descubrimiento el año pasado de un “Nepturno caliente” en el sistema planetario de ρ^1 Cancri. Este objeto, de apenas 17 masas terrestres, demuestra nuestra capacidad de detección de planetas extrasolares de masas inferiores a las de los planetas gigantes.

ABSTRACT

Currently every major telescope at McDonald Observatory is utilized in the search for extrasolar planets. We review the different planet search efforts and present the results of these programs. In particular we describe in detail the on-going precise Doppler surveys at the Harlan J. Smith 2.7 m telescope and at the Hobby-Eberly Telescope (HET). The highlight of the HET program was last year’s discovery of a “Hot Neptune” in the ρ^1 Cancri planetary system. With a mass of only 17 Earth masses this object demonstrates our ability to detect extrasolar planets with masses below the gas giant range.

Key Words: **STARS: PLANETARY SYSTEMS — TECHNIQUES: RADIAL VELOCITIES**

1. INTRODUCTION

The search for extrasolar planets has a long standing tradition at the McDonald Observatory in the Davis Mountains in West Texas. Already in the 1980’s, the first radial velocity (RV) survey of nearby solar-type stars was begun using the Harlan J. Smith 2.7 m telescope and its high resolution coudé spectrograph. The observational efforts to detect planetary companions to other stars have grown ever since at this site. Currently every major telescope is utilized for planet search and the parameter space for target host stars as well as the sample sizes have increased steadily.

The focus of the RV program has now moved to the Hobby-Eberly Telescope (HET) and its High Resolution Spectrograph (HRS). The HET queue scheduled observing mode makes this telescope an ideal facility for planet hunting. The RV program at the 2.7 m telescope has also continued and expanded over the years and a sub-sample of 36 stars enjoys already a total time baseline of more than 15 years. This will allow us to derive first constraints on the frequency of solar system analoges (i.e. Jovian class planets at orbital separations of $\approx$ 5 AU and with periods of $\approx$ 12 years).

But planet hunting at McDonald Observatory is also done by means other than RV measurements. A timing survey is currently in progress at the Otto Struve 2.1 m telescope. This program is using high speed photometry of stably pulsating white dwarf stars to search for the change in arrival times of these pulses caused by the orbital reflex motion due to planetary companions (Mullally et al. 2003).

TeMPEST (Baliber & Cochran 2003) is a photometric transit search using the 0.8 m telescope to monitor more than 14,000 stars for transits of close-in giant planetary companions.

2. THE HARLAN J. SMITH 2.7 M TELESCOPE SURVEY

The search for extrasolar planets by the means of highly precise RV measurements using the Harlan J. Smith 2.7 m telescope at McDonald Observatory began in 1988. Phase 1 of this program used telluric O_2 lines as the velocity metric. In 1992 we switched to a temperature stabilized iodine (I_2) absorption cell as the velocity metric for phase 2, using a single order of the coudé echelle spectrograph. We began phase 3 of the RV survey in July 1998, using the same I_2 cell in combination with the cross-dispersed echelle spectrograph, which allowed us to use the entire bandwidth of the I_2 absorption band. This resulted in a major improvement in our RV measurement precision, as well as greatly reduced exposure times.

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Phases 1 and 2 of the 2.7 m telescope program surveyed 36 bright, nearby stars, and resulted in the discovery of a planetary companion to 16 Cygni B (Cochran et al. 1997). Data collected in phases 1 through 3 led to the discoveries of the planets around ϵ Eridani (Hatzes et al. 2000) and γ Cephei (Hatzes et al. 2003). The fact that γ Cephei is a relatively tight binary system ($a \approx 18$ AU), with a planet orbiting the primary at $a = 2.1$ AU, makes this system very interesting from a dynamical as well as from a planet formation standpoint. The very long time baseline of the RV data for γ Cephei enabled us to determine a double Keplerian orbital solution, solving simultaneously for the stellar orbit as well as for the planet.

The current phase 3 target list contains more than 250 stars, most of them F,G,K-type main sequence stars.

2.1. *An oasis in the brown dwarf desert*

It is in the nature of a search program that some of its findings are unexpected and surprising. One of our recent results gives an excellent example for this: the companion to HD 137510 (G0 IV) is a *rare* bona-fide brown dwarf companion (see Fig. 1). The gap in the mass function of spectroscopic binaries which separates the planetary regime from the stellar companions is generally dubbed the "brown dwarf desert." The $m \sin i$ value of 26 $\mathrm{M_{Jup}}$ for the secondary makes HD 137510 a true oasis in this desert. This object was independently discovered by the Tautenburg planet search program and both data sets were combined to publish the orbital solution (Endl et al. 2004).

2.2. *A planet around a massive giant star*

Another recent result of the 2.7 m telescope RV survey is the co-discovery of a massive planetary (or low mass brown dwarf) companion to the K giant star HD 13189 (Hatzes et al. 2005). The giant status (K2 II) of the host star makes this discovery exceptional. Based on a comparison with evolutionary tracks we estimate a mass between 2 and 7 $\mathrm{M_\odot}$ for the parent star. HD 13189 may be the most massive star known to possess an extrasolar planet. This also demonstrates that planet formation can occur around massive early-type stars. The mass of the companion ranges from $m \sin i = 8$ to 20 $\mathrm{M_{Jup}}$, depending on the true mass of the giant star. Figure 2 displays the RV data coming from the Tautenburg, 2.7 m telescope and HET planet search programs along with the orbital solution for the companion. The large residual scatter around this orbit is probably caused by stellar oscillations, which are typical for K giants.

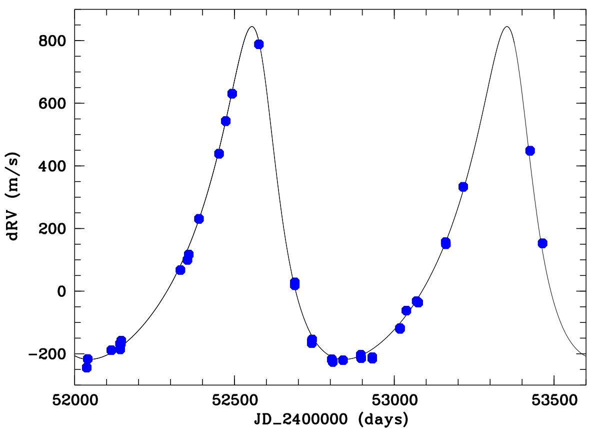

Fig. 1. The 2.7 m telescope RV measurements for the G0 subgiant HD 137510 (1.3 $\mathrm{M_\odot}$) showing the high amplitude Keplerian motion (solid line) caused by a rare brown dwarf companion ($m \sin i = 26$ $\mathrm{M_{Jup}}$) in an eccentric orbit with a semi-major axis of 1.85 AU.

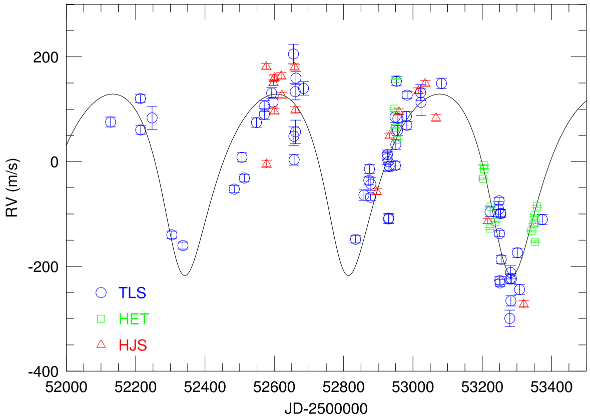

Fig. 2. RV data for the massive K2 II star HD 13189 obtained by the Tautenburg Observatory planet search (circles), the 2.7 m telescope (triangles) and the HET (squares). The solid line denotes the best Keplerian orbital solution (from Hatzes et al. 2005).

3. THE HOBBY-EBERLY TELESCOPE (HET) PROGRAMS

The HET is a large aperture, low cost, specially built telescope consisting of 91 hexagonal 1 m mirror segments, mounted on a rotatable truss with a fixed tilt (35° zenith distance). The HET was specifically designed for the task to carry out large spectroscopic surveys (Ramsey et al. 1998).

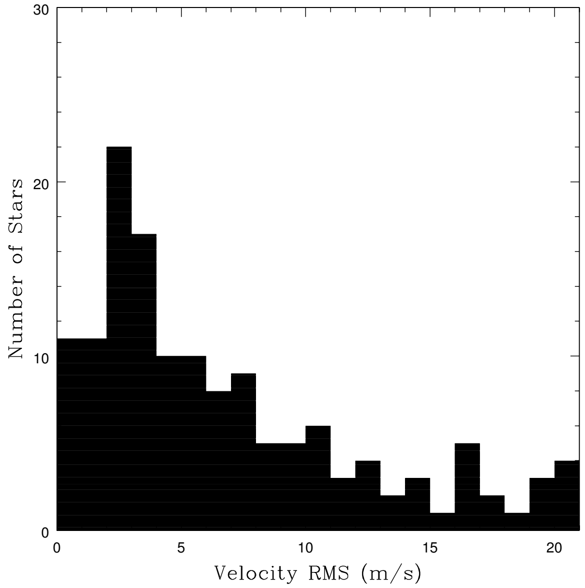

Fig. 3. The histogram of the total rms RV scatter for 142 stars observed with the HET/HRS (from Cochran et al. 2004).

The High Resolution Spectrograph (HRS; Tull 1998) is located below the telescope in an insulated room. An optical fiber connects the HRS with the tracker package on top of the HET. Again, we use a temperature controlled I_2 cell for precise RV measurements. Currently, we achieve a *routine* RV precision of $2-4$ $\mathrm{m\,s^{-1}}$ for slowly rotating F,G,K and M stars down to $V=10$ (Fig. 3).

Observations at the HET are carried out in service mode by resident astronomers. A typical night is not dedicated to a particular project, the observing "queue" rather consists of many individual entries coming from different programs, ranked according to their priorities and visibilities. This queue scheduling offers the flexibility to obtain the data exactly at the time when they are needed. This, of course, is ideal for RV planet hunting, because observations of critical orbital phases can now be more efficiently performed than before.

3.1. *HD 37605: the first HET planet*

The queue scheduled observing mode helped us for instance to quickly characterize the orbit of the first planet discovered by the HET: the companion to HD 37605 (Cochran et al. 2004). This planet resides in an eccentric ($e=0.68$) orbit with a period of 55 days and has a mass of $m\sin i = 2.3$ $\mathrm{M_{Jup}}$. The high eccentricity leads to a sharp "spike" in the RV curve of HD 37605 (see Fig.4). By using the HET we were able to schedule observations at the time of RV minimum to cover this crucial orbital phase and to determine the RV amplitude and thus mass of the companion.

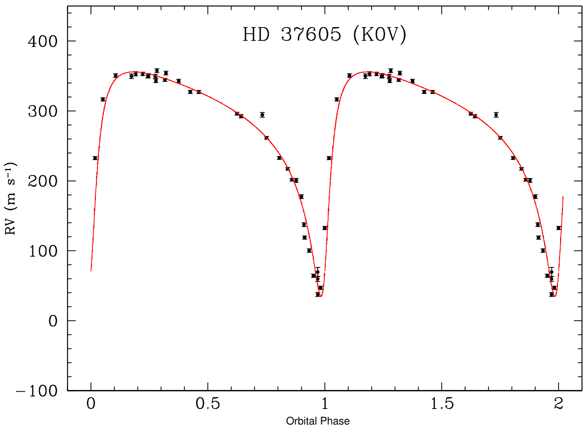

Fig. 4. The highly eccentric orbit (solid line) of the planetary companion to HD 37605, the first extrasolar planet discovered by the HET. HET observations (points) were scheduled successfully to cover the critical phase around the periastron passage of the planet.

3.2. *Exploring the M dwarf realm*

Over the past 3 years we have monitored more than 60 fainter ($V=9$ to 12) M dwarf stars with the HET to search for giant planetary companions (Endl et al. 2003), but found none. This result points toward a generally lower frequency for Jovian planets around M dwarfs, as compared to earlier spectral types (≈ 8% of G-type stars have giant planets detectable by the RV technique). A lower M dwarf giant planet frequency is also suggested by theoretical model computations (e.g. Laughlin et al. 2004).

3.3. *Discovery of a hot Neptune in the ρ^1 Cancri system*

The high RV precision we attain with the HRS instrument combined with the dense temporal sampling made possible by the queue scheduling mode allows also to search for very low amplitude RV signals caused by extremely low mass planets. Our discovery of the fourth and innermost planet with a mass comparable to Neptune ($m=17$ $\mathrm{M_{Earth}}$) in the ρ^1 Cancri planetary system (McArthur et al. 2004) demonstrates the feasibility of using the HET/HRS to detect planets with masses below the gas giant mass range. This object was found using more than 100 HET observations of ρ^1 Cancri (G8 V). We detected the low amplitude RV signal (see Fig. 5) of the

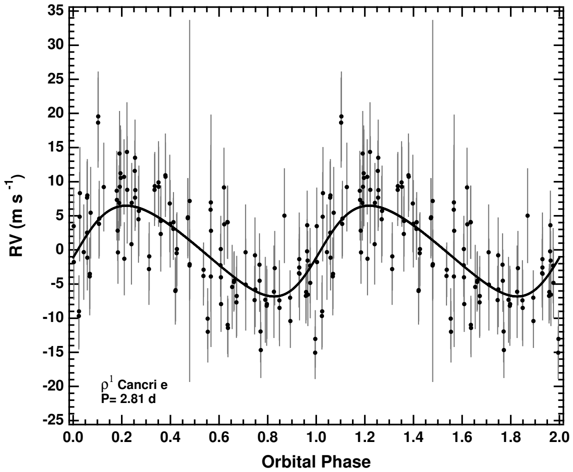

Fig. 5. The HET/HRS RV data for ρ^1 Cancri after subtraction of the three known giant planets and phased to the orbital period (2.8 days) of the hot Neptune (from McArthur et al. 2004).

4th companion in the RV residuals after subtracting the already known 3 giant planets in this system. This planet is a member of a new class of extrasolar planets, the so-called “hot Neptunes,” which presumably are giant planet cores consisting predominantly of rocky material mixed with volatiles such as H_2O, NH_3 and CH_4. Hot Neptunes were also found by other groups around the M dwarf Gliese 436 (Butler et al. 2004) and the G5 V star μ Ara (Santos et al. 2004).

A new HET program specifically designed to search for hot Neptunes in known planetary systems is currently in progress.

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