30 Years of the McDonald Observatory Planet Search

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Abstract

The McDonald Observatory Planet Search began its current radial velocity survey on the Harlan Smith Telescope’s 2d-coudé Tull Spectrograph in 1998, with older RV observations dating back more than 20 years. The survey has monitored the RVs of hundreds of nearby stars over 15 years, and is sensitive to true Jupiter analogs. We present a brief history of the survey, and present some new results. We have recently discovered new Jupiter analogs around the solar-type stars HD 95872 and ψ1 Draconis B, and have also discovered periodic RV signals for β Virgini and HD 10086 that appear to be massive exoplanets, but are actually caused by long-period magnetic cycles.

1 History of the McDonald Observatory Planet Search

The McDonald Observatory Planet Search, or MOPS, began in September 1987 and is still ongoing. The program began on the coudé spectrograph of the 2.7 m Harlan J. Smith telescope, and has expanded to include the High Resolution Spectrograph (HRS; Tull 1998) on the 10 m Hobby-Eberly Telescope (HET; Ramsey et al. 1998).

Figure 1: MOPS Phase I RV observations (large filled circles) of the low-mass companion to HD 114762 (from Cochran et al. 1991), compared to those from the original discovery by Latham et al. (1989). The Phase I RVs were wavelength calibrated using telluric O2 lines.
Phase I of the MOPS program used the 6 foot camera to isolate a single échelle order of the Smith Telescope’s coudé spectrograph, and referenced the telluric O$_2$ band at 6300Å as the velocity standard (see, e.g. Hatzes et al. 2000). This configuration provided RV precisions of $15 - 20$ m s$^{-1}$ on bright ($V < 6$) stars, but experience systematic errors associated with velocity changes of the atmosphere above McDonald Observatory. The addition of an I$_2$ absorption cell in the fall of 1990 marked the beginning of Phase II, improving stability, and enabling the program’s first exoplanet discovery–16 Cygni Bb (Cochran et al. 1997). The survey began in its current configuration (Phase III) in the summer of 1998 when observations were moved to the cross-dispersed 2d-coudé Tull Spectrograph (Tull et al. 1995), also at the coudé focus of the Smith Telescope. The Tull Spectrograph is a white-pupil spectrograph with wavelength coverage from $\sim 375 - 1000$ nm. Typical RV observations are taken at resolving power $R \sim 60000$, and are wavelength calibrated with an I$_2$ cell.

Since migrating to the Tull Spectrograph in 1998, the MOPS program has surveyed approximately 200 stars for RV variability, as compared to 36 for the first two phases of the survey. Its targets are typically brighter than $V = 10$, and are of primarily FGK spectral types. The spectrograph achieves single-measurement RV precisions of 4-7 m s$^{-1}$ for the majority of its targets. The MOPS team has performed 1-2 observing runs (typically 4-9 nights long) per month from the beginning of the survey to present day, resulting in an observational time baseline exceeding all but a few other RV programs.

RV observations with HET/HRS began in 2001. The HRS design–white pupil, I$_2$ cell, typical RV mode $R \sim 60000$–offers many of the same capabilities as the Tull Spectrograph, but the larger aperture of the HET enables high-precision RV observations of fainter targets. Furthermore, the HET’s queue-scheduled operation offers flexibility for initiatives such as observations at quadrature (e.g. for Kepler follow-up, Endl et al. 2011) and Rossiter-McLaughlin studies (e.g. Cochran et al. 2008) not available to classically-scheduled surveys. The primary HET/HRS survey contribution to the MOPS program has been the M dwarf survey, which has monitored $\sim 100$ M stars–nearly all of which are too faint for precision RV observations with the Smith Telescope–over 12 years (Endl et al. 2003; Robertson et al. 2013a). While close-in giant planets are rarer for M dwarfs than for more massive stars...
The observational time baseline of the MOPS survey is perhaps its defining characteristic. The survey's combination of baseline and RV precision makes it sensitive to true Jupiter analogs—gas giants of low or moderate eccentricity that remain at large orbital separation after their systems' epoch of planetary migration has ended. This unique capability offers empirical constraints on topics such as the frequency of giant planets, the percentage of giant planets that migrate inward after formation, the prevalence of giants in multi-planet systems, and the dependence of giant planet properties on host star characteristics.

2 New Results

The MOPS program has been quite successful in discovering extrasolar Jupiter analogs (e.g. Hatzes et al. 2000; Cochran et al. 2007; Wittenmyer et al. 2007; Robertson et al. 2012). The survey continues to produce new long-period exoplanets, the most recent of which are detailed in Endl et al. (2015) and Johnson et al. (2016).

Endl et al. (2015) announces the discovery of two new long-period giant planets: HD 95872b and ψ1 Draconis Bb. HD 95872b has a minimum mass of $4.6 M_J$ and a semimajor axis of 5.2 AU, while ψ1 Dra Bb orbits at $a = 4.4$ AU with a minimum mass of $1.5 M_J$. Both of these planets have wide enough orbits to qualify as Jupiter analogs.

![Figure 3: Tull Spectrograph RV observations and orbital fits for HD 95872b (left) and ψ1 Dra Bb (right) from Endl et al. 2015.](image)

The ψ1 Dra B system is particularly interesting for a number of reasons. First, the star is the secondary member of a hierarchical triple star system; the primary, ψ1 Dra A, has a low-mass stellar companion, which is detected directly in speckle imaging. Additionally, the RV curve of ψ1 Dra B shows a long-period trend which is likely caused by a second substellar companion, thus making its planetary system a potential analog to the Jupiter-Saturn pair.

As is becoming increasingly typical of all long-term RV surveys, MOPS has discovered several RV signals that resemble those created by Jupiter analogs, but are instead likely caused by magnetic activity cycles analogous to the 11-year cycle observed for the Sun. Endl et al. (2015) details two such examples. For HD 10086, we observe an $\sim 8$-year activity cycle, which creates a $K = 11$ m s$^{-1}$ RV signature. Similarly, for β Virginis, we observe a 2000-day RV signal that mimics an eccentric giant planet. However, a strong correlation with the $S_{HK}$ Ca II activity index betrays the signal as being caused by magnetic activity.

A more harmonious interplay between RV and stellar activity is presented in Johnson et al. (2016), wherein we leverage the outstanding cadence and baseline of the MOPS survey to provide complete coverage of the 12-year magnetic activity cycle of HD 219134. HD 219134 was recently shown by Motalebi et al. (2015) and Vogt et al. (2015) to be a multi-planet system containing a Jupiter analog and several low-mass interior planets. While both studies verified that the RVs of the outer planet were uncorrelated with $S_{HK}$, neither had complete coverage of the magnetic cycle. The MOPS observations clearly resolved both the outer planet and the full activity cycle, eliminating any concern that the planet signal was in fact caused by stellar activity.
Figure 4: The 12-year activity cycle of HD 219134, as observed in $S_{HK}$ by the MOPS survey (from Johnson et al. 2016). Complete coverage of the cycle adds confidence to the detection of the Jupiter analog in the HD 219134 system, as the periods of the planet and cycle are completely distinct.

3 Conclusion

The McDonald Observatory Planet Search is one of the world’s oldest exoplanet surveys, and it continues to provide valuable observations of the outer planetary systems of the nearest Sunlike stars. We anticipate the discovery of even more Jupiter analogs as we continue to collect data and improve our RV pipeline. These results will place more stringent empirical constraints on the fraction of giant planets which remain beyond the ice line, as compared to the close-in population of gas giants.

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