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The Search For Planets Around Pulsating White Dwarf Stars

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Abstract. We are implementing a proven technique to search for extrasolar planets with a different sensitivity from other methods, using the pulsations of white dwarf stars as intrinsic clocks. We will search more than one hundred stars over the next decade for the effects of reflex orbital motion in changing light travel times and accelerations caused by any planets orbiting these stars.

To become a white dwarf, a main sequence star must pass through the red giant phase, which might consume its inner planets but is likely to leave more distant ones intact. Our technique is sensitive to parent stars with progenitors of 1-4 solar masses, a range of metallicities, and planets in the range 2-20 AU. This range of parameters is largely unexplored and is likely to remain so until space based missions are launched.

1. A New Search for Planetary Systems Dynamically Similar to Our Own

From the known oscillating white dwarf stars and those uncovered by the ongoing Sloan Digital Sky Survey, we will select targets with sufficiently stable oscillations (approximately one fourth of the known pulsators qualify) with frequency stabilities exceeding those of most millisecond pulsars and the claimed stability of the NIST atomic clocks (e.g. Kepler et al. 2000). Theory indicates we can expect a slow drift in frequency from cooling of the star, and our current measurements bear this out. We will search for periodic variations in this slow frequency drift, and analyze them by fitting the variations to models of orbiting planets. Should we find no evidence of planets at all, we can set useful limits on the number of planets formed with their parent stars in the early universe.

We developed this technique in the course of studying the period stability of two pulsating white dwarf stars. We were forced to include the effects of first Jupiter, then Saturn, then other planets in our solar system as our constraints on the stability improved. We showed that the effects of a planet with Saturn's mass and distance are still more than an order of magnitude above our noise of measurement (Kepler et al. 1982, 1990, 1991, 2000). Our search will give information about planetary systems in post-main sequence stars. If the theoretical estimates on the survivability of the outer planets during the post-main sequence phases are correct, this survey will allow us to place constraints on the frequency of planetary systems with masses and orbital separations similar to our own solar system.

Figure 1 shows the sensitivity of our search in the (log planetary mass, log semi-major axis) plane. The upper half plane is the region of detection. Ultimately any planets above the solid lines will be detected, and any planets to the left of the dashed line will be detected early through the curvature in the (O-C) diagram for the pulse arrival times.

Figure 2 simulates the effects on the (O-C) diagram of single and multiple planets. As with the Doppler spectroscopic method, multiple planets will not be difficult to detect. Figure 3 illustrates how measurement of the rate of period change through measuring curvature allows an early warning of the presence of planets with long-period orbits and allows the early characterization of the orbits.

We regard this survey as a long-term project, for which we have established the basic search technology. As we find evidence for planets we intend to make this information public promptly, so others can pursue the needed follow-up observations. We will also encourage others to adopt this survey technology in order to widen the search beyond what we can manage with our resources. We welcome both independent and collaborative efforts.

2. Argos High-Speed Photometry

We have improved our ability to perform time-series photometric measurements on faint white dwarf stars by about 2.5 magnitudes on the 82-in telescope, from about magnitude 17 with PMT detectors to about magnitude 19.5 with the CCD (Argos) system. In addition to the improvement in quantum efficiency from $\sim 25\%$ to $\sim 75\%$, we also benefit from fewer optical surfaces between the detector and the star by mounting the camera at prime focus. The shorter focal length concentrates the image, so dark count is dominated by the counts from a moonless sky, and the effects of image motion are minimized by our need to take short exposures (typically 5-10 seconds) to time-resolve the pulsations we study.

A typical HDAV star has a dominant period near 200 s, with amplitudes of approximately 0.02 in fractional intensity. With the Argos system we can obtain pulse timings on magnitude 19.5 stars accurate to 1 second in one observation; this corresponds to the fainter star limit in Figure 1. We can reach the limit of 0.1 second in Figure 1 for the magnitude 17.5 stars and brighter.

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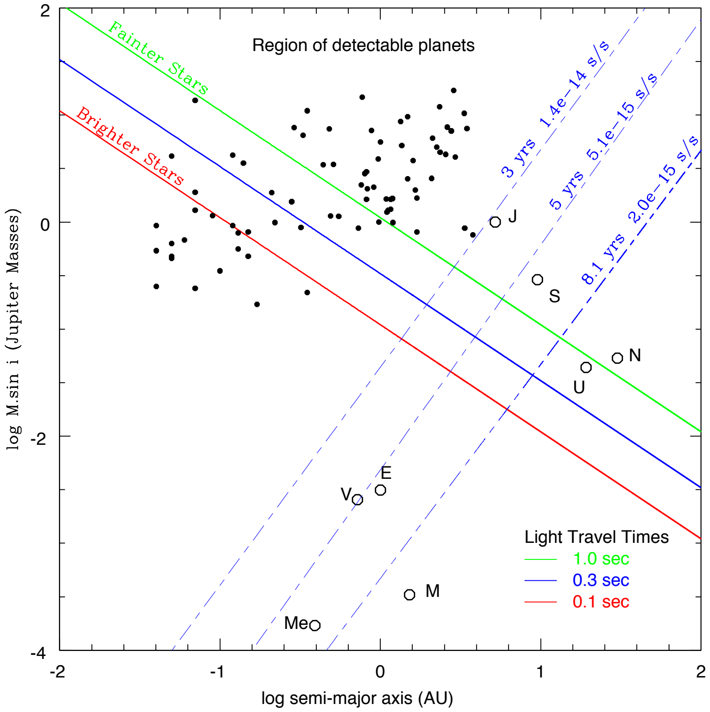

Figure 1. Our survey limits for a $0.55 M_\odot$ white dwarf—corresponding to a $1 M_\odot$ main sequence star. The solid lines represent the light travel time across the reflex orbit of the pulsating white dwarf star. This corresponds to the amplitude of the periodic variations in the $(O-C)$ diagram. Planets above these lines are detectable. The top line will be easily reached for the fainter stars in our sample, the bottom line for the brighter stars (see section 2.3). The dashed lines correspond to the estimated time necessary to detect curvature in the $(O-C)$ diagram—an early warning of a possible planetary companion. The lines are labelled with a corresponding rate of period change, and an estimated time to reach that limit for a typical star in our sample. For comparison, we plot planets detected using the Doppler spectroscopy method with solid dots and Solar system planets with hollow dots and letter labels.

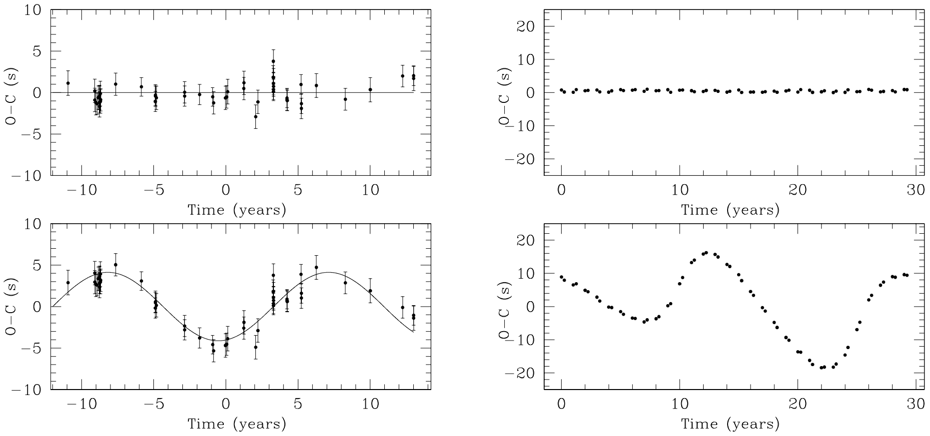

Figure 2. **Left:** Easy detectability of a 1 M_J planet: The top panel shows real $O-C$ data of G117-B15A with the parabola (due to cooling) removed. The lower panel shows the effect of superposing a 1 M_J planet at 5.2 AU in a circular orbit. **Right:** Multiple Planets: The top panel shows simulated $O-C$ data with a timing uncertainty of 1s and the effect of cooling removed. The lower panel shows multiple planets; a 1 M_J planet at 8 AU in a circular orbit, and a 3 M_J planet in an elliptical orbit ($e = 0.4$) at 5 AU around a 0.55 $M_{\odot}$ white dwarf.

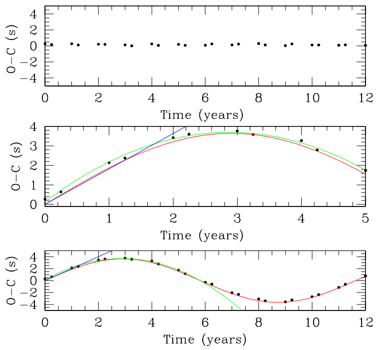

Figure 3. Detecting Jupiter in 3-4 years: The top panel shows simulated $O-C$ data with a timing uncertainty of 0.3s and the effect of cooling removed. The middle and lower panels show the effect of a 1 M_J planet in a circular orbit at 4.2 AU from a 0.55 $M_{\odot}$ white dwarf. The sinusoid in both these panels indicates the effects due to a planet in a circular orbit. The straight line helps the eye to see curvature in the O-C data, which is an early warning of a possible planetary companion. We are thus warned of a possible planet detection in 2-3 years. The parabola quantifies the curvature, it is our best fit to 5 years of the O-C data with the planet superposed. We can see a significant deviation of the parabola from the sinusoid in 6 years, a fraction of the total orbit. Hence, we do not need a complete orbit to report a planet detection.

References

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Discussions at the Poster Session