Giant Planets and Variable Stars in Globular Clusters

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For my Parents, who have been there since day one...

Disclaimer

The work described in this thesis is that of the candidate alone, with the exception of the Colour Magnitude Diagram dataset, which was obtained by K.Freeman and M.Doherty.

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Abstract

Over the last decade, 135 extrasolar planets have been discovered, the vast majority found by ongoing radial velocity searches. Of the stars sampled in these searches, $\sim$1% have 'Hot Jupiter' planets associated with them. Having masses equivalent to Jupiter yet orbital periods of only a few days, this new class of planet is clearly unlike anything in our Solar System.

Hot Jupiters present us with an intriguing prospect. If the orientation of the planetary orbit is close to edge-on, the planet will periodically transit across the face of its star, resulting in a small drop in brightness. This transit phenomenon has been successfully used for planet detection over the last couple of years, allowing determination of the planetary radius and accurate mass estimates when coupled with radial velocity observations.

To aid understanding of the effect stellar environment plays on Hot Jupiter formation and survivability, this thesis presents the results of a wide-field search for transiting Hot Jupiters in the globular cluster 47 Tucanae. This cluster presents many thousands of stars in a moderate field of view and provides the perfect target for a search of this nature. One previous transit search has been made in the central core of 47 Tuc; using the HST for 8.3 continuous days, Gilliland et.al (2000) expected 17 transits yet found none. This null result suggests that either system metallicity or stellar density may be inhibiting Hot Jupiter formation or survivability in the cluster.

This thesis presents a search for transits with a field of view 250 times larger than the HST search and samples the uncrowded outer halo of the cluster (previously unsampled for transits), providing important constraints on the effect of environment on Hot Jupiter formation. If planets are found, then stellar density would seem responsible for the Gilliland et.al (2000) core null result. If no planets are found to a significant level, the survey would provide strong evidence that system metallicity is the dominant factor. Using the ANU 40″ (1m) telescope at Siding Spring Observatory, a 30.4 night observing run was executed and photometry was derived via differential imaging. The dataset numbers 109,000 cluster (and field) stars for photometric analysis, of which 22,000 are suitable for the transit search. With a custom-written transit detection algorithm and extensive Monte Carlo simulations to model the dataset, seven planets should be detectable if the occurrence rate of Hot Jupiters is the same in the cluster as in the Solar Neighbourhood.

Despite a detailed search, no transit signatures were identified. This result strongly indicates that the low metallicity of the cluster is the dominant factor inhibiting planet formation in 47 Tuc. Current results in the Solar Neighbourhood show that planet frequency is strongly biased towards stars of high metallicity.

This thesis shows that the metallicity trend is likely a universal phenomenon, not only limited to the immediate Solar Neighbourhood and raises questions of whether planets were much rarer in the earlier Universe.

As a side result of the search, 100 variable stars were identified in the field, 69 of which are new discoveries. Subsequent analysis reveals a strong period segregation among the cluster eclipsing binaries, indicating previously unobserved dynamical effects in the cluster. Distance estimates for both 47 Tuc and the SMC are in agreement with previously published values and an independent identification of the binary period-colour relation was observed. Two binaries seem to have low-luminosity companions worthy of followup and one variable is likely a star in the early phases of planetary nebula formation. All of the results presented in this thesis have been published in three separately refereed research papers.

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