PURSuing the planet–debris disk connection: analysis of upper limits from the anglo-australian planet search

Robert A. Wittenmyer1,2 and Jonathan P. Marshall1,2
1 School of Physics, UNSW Australia, Sydney 2052, Australia; rob@phys.unsw.edu.au
2 Australian Centre for Astrobiology, UNSW Australia, Sydney 2052, Australia
Received 2014 November 3; accepted 2015 January 8; published 2015 February 2

ABSTRACT

Solid material in protoplanetary disks will suffer one of two fates after the epoch of planet formation; either being bound up into planetary bodies, or remaining in smaller planetesimals to be ground into dust. These end states are identified through detection of sub-stellar companions by periodic radial velocity (or transit) variations of the star, and excess emission at mid- and far-infrared wavelengths, respectively. Since the material that goes into producing the observable outcomes of planet formation is the same, we might expect these components to be related both to each other and their host star. Heretofore, our knowledge of planetary systems around other stars has been strongly limited by instrumental sensitivity. In this work, we combine observations at far-infrared wavelengths by IRAS, Spitzer, and Herschel with limits on planetary companions derived from non-detections in the 16 year Anglo-Australian Planet Search to clarify the architectures of these (potential) planetary systems and search for evidence of correlations between their constituent parts. We find no convincing evidence of such correlations, possibly owing to the dynamical history of the disk systems, or the greater distance of the planet-search targets. Our results place robust limits on the presence of Jupiter analogs which, in concert with the debris disk observations, provides insights on the small-body dynamics of these nearby systems.

Key words: circumstellar matter – infrared; stars – planetary systems – stars: solar-type – techniques: radial velocities

1. INTRODUCTION

Circumstellar debris disks around main-sequence stars are composed of second-generation dust produced by the attrition of larger bodies (Backman & Paresce 1993), which are remnants of primordial protoplanetary disks (Hernández et al. 2007). Exoplanets form early in the history of these systems, with \( \sim 10 \, M_\oplus \) planets required to capture a gas envelope from the protoplanetary disk before it dissipates (typically within 3–10 Myr; Hernández et al. 2007; Ribas et al. 2014), whereas terrestrial planet formation by hierarchical growth (Lissauer 1995; Pollack et al. 1996) may continue over longer timescales of a few tens of Myr (e.g., Earth–Moon forming collision at \( \sim 40 \) Myr; Canup 2008, 2012).

Planet formation requires the hierarchical growth of dust grains to pebbles and thereafter to larger bodies eventually ending up at asteroids and comets—the planetesimals from which exoplanets form (Perryman 2011, p. 426; Armitage 2013). At the same time, collisions between these planetesimals produce the dust grains we observe as the visible components of debris disks. Since planetesimals are key to production of both planets and dusty debris, one might expect the properties of planets and debris around a star to be mutually dependent. This expectation has been strengthened by the direct imaging of several exoplanet systems around debris disk host stars and indirectly by the structural features observed in many debris disks (warsps, off-sets, asymmetries), which are often inferred to be due to the gravitational perturbation of the debris by one or more unseen exoplanet(s) (see reviews by Wyatt 2008; Krivov 2010; Moro-Martín 2013).

Observations of nearby Sun-like stars at far-infrared wavelengths by the Spitzer (Werner et al. 2004) and Herschel (Pilbratt et al. 2010) space telescopes revealed evidence for several correlations between planets and debris. Herschel observations determined that a higher statistical incidence of exoplanets around debris disk host stars is seen, explicitly linking these two components of planetary systems (Bryden et al. 2013). Further correlations between the presence of both a debris disk and low-mass planets around low (sub-solar) metallicity stars (Wyatt et al. 2012; Marshall et al. 2014), and between the presence of a debris disk and cold (distant) Jovian planet(s) (Maldonado et al. 2012), have also been identified. Such correlations can be understood, and even expected, within a picture of planet formation via core accretion, and the subsequent dynamical interaction between planet(s) and planetesimal belts.

Previous studies to determine the underlying connections between these distinct components of planetary systems—stars, planets and debris—have concentrated on analysis of target samples consisting of known exoplanet host stars with or without debris (Beichman et al. 2006; Moro-Martín et al. 2007; Kóspál et al. 2009; Bryden et al. 2009). Little regard was given to the potential that any given star may in fact host a planet below the threshold of current detection capabilities. In this work we take account of the threshold upper limits for companions orbiting stars targeted by the Anglo-Australian Planet Search (AAPS), some of which are already known to host planetary companions.

The AAPS is an ongoing, 16 year high-precision radial-velocity survey of \( \sim 250 \) nearby solar-type stars (Butler et al. 2001; Tinney et al. 2001). It has achieved a consistent velocity precision of \( 2–3 \, \text{m} \, \text{s}^{-1} \) for its lifetime, making the AAPS a world leader in the detection of long-period planets analogous to Jupiter. These “Jupiter analogs” are among the more recent of the \( \sim 40 \) planets disovered by the AAPS, (e.g., Wittenmyer et al. 2012, 2014b), and are the focus of ongoing observations and simulation work (Wittenmyer et al. 2011a, 2013). In addition to the planet discoveries, the AAPS data are useful for
setting limits on the presence of undetected planets (e.g., O’Toole et al. 2009; Wittenmyer et al. 2010, 2011b).

In this paper, we use the AAPS data, including non-detections, to further explore the connection between debris disks and planets. For the first time, we include the detection limits for targets that have debris disk observations but as yet no known planets. In Section 2, we describe the sample and detection-limit technique. Section 3 presents the results, and we give our conclusions in Section 4.

2. OBSERVATIONS AND THE STELLAR SAMPLE

The stellar physical parameters used in the analysis, i.e., luminosity, photospheric temperature, age, and metallicity, were taken from Takeda (2007) and Valenti & Fischer (2005). The distances were taken from the re-reduction of the Hipparcos catalog by van Leeuwen (2007).

2.1. Far-infrared Observations

Of the 141 AAPS stars analyzed here, 54 were observed at far-infrared wavelengths by the Herschel Space Observatory (Pilbratt et al. 2010) with the Photodetector Array Camera and Spectrometer instrument (PACS; Poglitsch et al. 2010; Balog et al. 2013) through a combination of the Guaranteed Time debris disks program, the Open Time Key Programmes “Disc Emission via a Bias-free Reconnaissance in the Infrared/Submillimetre” (DEBRIS; Matthews et al. 2010) and “DUst around NEarby Stars” (DUNES; Eiroa et al. 2013), and the Open Time programs “Search for Kuiper Belts Around Radial-velocity Planet Stars” (SKARPS; Bryden et al. 2013; Kennedy et al. 2013) and program OT1_paniomeromar1 (PI: A. Moro-Martín). A further 11 stars were observed at 70 μm by the Spitzer Space Telescope (Werner et al. 2004) with its “Multi-band Imaging Photometer for Spitzer” instrument (MIPS; Gordon et al. 2007). Finally, upper limits at 60 μm were taken from the IRAS Faint Source Catalogue for an additional 39 targets. A total of 104/141 AAPS stars therefore have some measure of the presence (or absence) of debris in their circumstellar environment. Of these, 21 stars have detected infrared excesses.

Herschel flux densities were taken from the literature where available (Lestrade et al. 2012; Eiroa et al. 2013; Marshall et al. 2014). For targets without published measurements, the PACS data were reduced and analyzed using the Herschel Interactive Processing Environment (HIPE; Ott 2010) using the standard data reduction scripts and following the method laid out in Eiroa et al. (2013). Spitzer flux densities were taken from the literature, namely Trilling et al. (2008) and Bryden et al. (2009).

2.2. Dust Limits

Dust fractional luminosities, or upper limits in the case of non-detection at far-infrared wavelengths, of the AAPS target stars were calculated from fitting of a modified blackbody (Wyatt 2008) to the Spitzer MIPS measurements at 70 μm (compiled from Trilling et al. 2008; Bryden et al. 2009) and Herschel PACS measurements at 70 and/or 100 and 160 μm, along with optical, near- and mid-infrared and submillimeter measurements (where available) taken from the literature, following the approach of Marshall et al. (2014). In the case of targets with only upper limits on their emission at far-infrared wavelengths, a dust temperature of 50 K was assumed for the

### Table 1: Summary of Radial-velocity Data

| Star     | N   | ΔT (days) | rms (m s⁻¹) | Telescope | Reference |
|----------|-----|-----------|-------------|-----------|-----------|
| GJ 729   | 30  | 3218      | 20.7        | AAT       | Wittenmyer et al. (2014a) |
| GJ 832   | 39  | 5465      | 5.7         | AAT       | Wittenmyer et al. (2014a) |
| ...      | 54  | 1089      | 1.9         | HARPS     | Wittenmyer et al. (2014a) |
| ...      | 16  | 818       | 1.7         | PFS       | Wittenmyer et al. (2014a) |
| Total    | 109 | 5569      | 3.5         | AAT       |         |
| HD 142   | 86  | 5667      | 11.3        | AAT       |         |
| HD 1581  | 110 | 5668      | 3.3         | AAT       |         |
| HD 2039* | 46  | 4780      | 14.0        | AAT       |         |
| HD 3823* | 75  | 5668      | 5.6         | AAT       |         |
| HD 4308  | 41  | 680       | 1.7         | HARPS     | Udry et al. (2006) |
| ...      | 109 | 5569      | 3.8         | AAT       |         |
| Total    | 150 | 5569      | 3.3         | AAT       |         |
| HD 7570  | 53  | 5665      | 6.3         | AAT       |         |
| HD 9280* | 30  | 4970      | 12.6        | AAT       |         |
| HD 10360 | 64  | 5668      | 4.7         | AAT       |         |
| HD 10647 | 51  | 5134      | 10.7        | AAT       |         |
| HD 10700 | 44  | 5726      | 3.0         | AAT       |         |
| ...      | 638 | 8800      | 7.1         | AAT       | Liebert et al. (2014) |
| Total    | 886 | 9511      | 6.2         | AAT       |         |
| HD 11112 | 37  | 5724      | 15.8        | AAT       |         |
| HD 12387 | 25  | 4403      | 8.0         | AAT       |         |
| HD 13445 | 64  | 5724      | 5.9         | AAT       |         |
| HD 14412 | 26  | 2561      | 3.4         | AAT       |         |
| HD 16417 | 117 | 5724      | 3.8         | AAT       |         |
| HD 17051 | 36  | 4843      | 18.0        | AAT       |         |
| HD 18709*| 23  | 5104      | 8.5         | AAT       |         |
| HD 19632*| 30  | 3863      | 24.8        | AAT       |         |
| HD 20201 | 31  | 5105      | 8.0         | AAT       |         |
| HD 20766 | 50  | 5881      | 6.5         | AAT       |         |
| HD 20782 | 53  | 5520      | 5.8         | AAT       |         |
| HD 20807 | 91  | 5724      | 4.4         | AAT       |         |
| HD 23079 | 37  | 5132      | 5.6         | AAT       |         |
| HD 23127 | 44  | 4850      | 11.6        | AAT       |         |
| HD 23484 | 19  | 2976      | 14.0        | AAT       |         |
| HD 26965 | 104 | 3046      | 4.4         | AAT       |         |
| ...      | 78  | 5016      | 7.8         | AAT       |         |
| Total    | 182 | 6941      | 6.1         | AAT       |         |
| HD 27274 | 28  | 4114      | 7.0         | AAT       |         |
| HD 27442 | 96  | 5724      | 7.3         | AAT       |         |
| HD 30177 | 36  | 5438      | 18.5        | AAT       |         |
| HD 30295*| 33  | 4850      | 9.2         | AAT       |         |
| HD 31827*| 29  | 5265      | 8.1         | AAT       |         |
| HD 33811*| 26  | 4878      | 8.8         | AAT       |         |
| HD 36108*| 34  | 5549      | 4.0         | AAT       |         |
| HD 38283*| 64  | 5883      | 4.0         | AAT       |         |
| HD 38382*| 45  | 5936      | 5.4         | AAT       |         |
| HD 38973*| 43  | 5882      | 5.2         | AAT       |         |
| HD 39091 | 49  | 5879      | 6.4         | AAT       |         |
| HD 40307 | 28  | 5882      | 5.8         | AAT       |         |
| ...      | 345 | 1912      | 1.1         | HARPS     | Tuomi et al. (2013) |
| Total    | 373 | 5882      | 1.9         | AAT       |         |
| HD 42902*| 17  | 4840      | 24.6        | AAT       |         |
| HD 43834 | 131 | 5880      | 6.1         | AAT       |         |
| HD 44120*| 39  | 5882      | 3.8         | AAT       |         |
| HD 44594*| 43  | 5937      | 6.8         | AAT       |         |
| HD 45289*| 34  | 5941      | 5.1         | AAT       |         |
| HD 52447*| 24  | 3689      | 15.8        | AAT       |         |
| Star      | N  | \(\Delta T\) (days) | rms (m s\(^{-1}\)) | Telescope | Reference                  |
|-----------|----|----------------------|---------------------|-----------|-----------------------------|
| HD 53705  | 130| 5880                 | 4.3                 | AAT       |                             |
| HD 53706  | 45 | 5881                 | 3.3                 | AAT       |                             |
| HD 55720  | 28 | 5634                 | 3.8                 | AAT       |                             |
| HD 59468  | 45 | 5881                 | 5.0                 | AAT       |                             |
| HD 69655  | 30 | 4754                 | 5.6                 | AAT       |                             |
| HD 69830  | 19 | 1181                 | 4.4                 | AAT       |                             |
| ...       | 32 | 3451                 | 7.8                 | Lick      | Fischer et al. (2014)       |
| Total     | 51 | 4848                 | 6.7                 | ...       |                             |
| HD 70642  | 41 | 5882                 | 4.4                 | AAT       |                             |
| HD 72769  | 30 | 5637                 | 4.8                 | AAT       |                             |
| HD 73121  | 43 | 5961                 | 5.9                 | AAT       |                             |
| HD 73524  | 84 | 5935                 | 5.4                 | AAT       |                             |
| HD 73526  | 36 | 5226                 | 7.7                 | AAT       | Wittenmyer et al. (2014a)  |
| ...       | 20 | 856                 | 2.8                 | PFS       | Wittenmyer et al. (2014a)  |
| Total     | 56 | 5226                 | 6.3                 | ...       |                             |
| HD 75289  | 46 | 5879                 | 6.6                 | AAT       |                             |
| HD 76700  | 43 | 4785                 | 6.4                 | AAT       |                             |
| HD 78429  | 38 | 5788                 | 8.6                 | AAT       |                             |
| HD 80635  | 23 | 4784                 | 10.6                | AAT       |                             |
| HD 83443  | 23 | 1211                 | 10.2                | AAT       |                             |
| HD 83529A | 31 | 5964                 | 4.9                 | AAT       |                             |
| HD 86842  | 35 | 5941                 | 12.3                | AAT       |                             |
| HD 92977  | 51 | 5935                 | 5.3                 | AAT       |                             |
| HD 93385  | 45 | 5845                 | 7.8                 | AAT       |                             |
| HD 96423  | 38 | 5464                 | 5.1                 | AAT       |                             |
| HD 100623 | 95 | 3305                 | 3.7                 | AAT       |                             |
| HD 102117 | 59 | 5766                 | 4.7                 | AAT       |                             |
| HD 102365 | 178| 5881                 | 2.7                 | AAT       |                             |
| HD 102438 | 53 | 5881                 | 4.1                 | AAT       |                             |
| HD 103932 | 18 | 2978                 | 5.5                 | AAT       |                             |
| HD 105328 | 52 | 5961                 | 6.2                 | AAT       |                             |
| HD 106453 | 36 | 3014                 | 10.7                | AAT       |                             |
| HD 108147 | 56 | 5166                 | 13.0                | AAT       |                             |
| ...       | 118| 1076                 | 16.0                | CORALIE   | Pepe et al. (2002)          |
| Total     | 174| 5166                 | 15.0                | ...       |                             |
| HD 108309 | 66 | 5961                 | 4.7                 | AAT       |                             |
| HD 114613 | 235| 5965                 | 3.9                 | AAT       |                             |
| HD 114853 | 57 | 5962                 | 6.9                 | AAT       |                             |
| HD 115617 | 153| 3228                 | 3.1                 | AAT       |                             |
| ...       | 78 | 1682                 | 2.3                 | Keck      | Vogt et al. (2010)         |
| Total     | 231| 3228                 | 3.1                 | ...       |                             |
| HD 117618 | 73 | 5881                 | 5.7                 | AAT       |                             |
| HD 120690 | 11 | 1176                 | 4.5                 | AAT       |                             |
| HD 122862 | 100| 5961                 | 4.7                 | AAT       |                             |
| HD 128620 | 102| 4926                 | 3.5                 | AAT       |                             |
| HD 128621 | 119| 5725                 | 3.7                 | AAT       |                             |
| HD 134060 | 95 | 5876                 | 6.3                 | AAT       |                             |
| HD 134330 | 44 | 5549                 | 6.2                 | AAT       |                             |
| HD 134987 | 73 | 5579                 | 3.0                 | AAT       |                             |
| HD 140901 | 113| 5551                 | 12.1                | AAT       |                             |
| HD 142415 | 22 | 2687                 | 17.0                | AAT       |                             |
| ...       | 137| 1529                 | 14.6                | CORALIE   | Mayor et al. (2004)         |
| Total     | 159| 3808                 | 14.8                | ...       |                             |
| HD 143114 | 40 | 5878                 | 6.2                 | AAT       |                             |
| HD 147722 | 66 | 5879                 | 17.8                | AAT       |                             |
| HD 154857 | 42 | 4109                 | 3.2                 | AAT       | Wittenmyer et al. (2014b)  |

\(^{a}\) No far-IR observations available.
fitting process. We compare the AAPS results presented here with results from the Herschel-observed radial-velocity planet host sample from Marshall et al. (2014) (see Figure 2).

2.3. Planetary Detection Limits

Among the 141 AAPS stars examined here, 43 are previously known to host one or more companions. For the targets known to host planets, we fit for and removed the signals of those planets, making use of additional velocity data from the literature where available. The stars considered here and the characteristics of the velocity data are given in Table 1. The detection limit was determined by adding a fictitious Keplerian signal to the data, then attempting to recover it via a generalized Lomb–Scargle periodogram (Zechmeister & Kürster 2009). Here, we have assumed circular orbits; for each combination of period $P$ and radial-velocity semi-amplitude $K$, we tried 30 values of orbital phase. The radial-velocity amplitude $K$ of the injected planet is increased until 99% of orbital configurations at a given $P$ are recovered with a false-alarm probability (Sturrock & Scargle 2010) of less than 1%. This approach is virtually identical to that used in our previous work (e.g., Wittenmyer et al. 2006, 2009, 2011a). Because this approach uses a periodogram to determinate detectability, gaps in data sampling can conspire to make some trial periods fail to produce a significant peak even for very large amplitudes ($K_{\text{max}} = 200 \text{ m s}^{-1}$). These situations result in allegedly undetectable trial signals (Wittenmyer et al. 2010). We compensate for this artifact in the following way: if an injected signal at a trial period $P$ fails to be detected for all $K$ values, the algorithm switches from the periodogram to the F-test, starting again at $K_{\text{min}} = 1 \text{ m s}^{-1}$ and increasing $K$ until all trial configurations at that $(P,K)$ combination result in an rms that differs from the original data at the 99% significance level. The upper limits on planetary companions were computed in this way for all 141 stars. We choose the detection limit at 5 AU as a representative figure of merit, being the approximate orbital radius of Jupiter, and being at an orbital period ($\sim 12$ year) within the total timespan of the AAPS data (16 year).

3. RESULTS AND DISCUSSION

Planetary detection limits in the sample of 141 stars are shown as a histogram in Figure 1; for comparison, known planets with $a > 1$ AU and $m \sin i > 0.2 M_{\text{Jup}}$ are shown as a filled histogram. In Figure 2, the AAPS stars are presented as colored or black data points, while those taken from literature sources are in grayscale. Broadly speaking, two distinct regions dominate the parameter space illustrated in Figure 2: systems with high fractional luminosities and no known planets (of any given age) occupy the top left (with masses derived from sub-mm flux densities), while systems with low dust luminosities (or only upper limits) and massive Jovian exoplanets occupy the bottom right. This is suggestive that massive, cool Jovian planets preclude a peaceful coexistence with a debris belt (Maldonado et al. 2012). Exceptions to this trend do exist including HD 95086 and HR 8799 with bright disks and massive exoplanets at comparable orbital radii (e.g., Marois et al. 2008, 2010; Moór et al. 2013; Rameau et al. 2013a, 2013b; Matthews et al. 2014), but such cases are usually young (<100 Myr) and A-type stars. For a summary of A-star debris population statistics, see, e.g., Su et al. (2006) and Thureau et al. (2014). Such systems are quite different from the targets of the AAPS survey which are mature ($t_{\text{age}} > 1$ Gyr), Sun-like (FGK type) stars. For a summary of debris around FGK stars, see e.g., Bryden et al. (2009), Maldonado et al. (2012), and Eiroa et al. (2013).

In the search for any correlation between the planets and debris it should be noted that only the brightest ends of the distributions of both planet mass (modulo orbital radius/instrument sensitivity) and dust luminosity have heretofore been measured. That we are able to discern any correlation between these components of planetary systems, however tentatively, is perhaps unexpected (Maldonado et al. 2012; Wyatt et al. 2012; Marshall et al. 2014). It is as yet impossible to detect direct dusty analogs to our solar system, due to the
faintness of its cool debris disk, the Edgeworth–Kuiper Belt, $(L_{\text{IR}}/L_* \sim 1.2 \times 10^{-7})$, Vitense et al. 2012. Long term radial-velocity programs monitoring exoplanet host stars are still only in their third decade, with the AAPS being the longest currently running exoplanet survey, although the now defunct Lick survey still holds the record for longest duration (Fischer et al. 2014). The solar system was speculated to be at the fainter end of the dust brightness distribution (among the bottom 10%; Greaves & Wyatt 2010), although subsequent Herschel observations suggest it may in fact lie close to the average disk brightness (Moro-Martin et al. 2015).

3.1. Statistical Analysis

Recent analysis of results from Spitzer (Maldonado et al. 2012; Wyatt et al. 2012) and Herschel (Bryden et al. 2013; Marshall et al. 2014) have identified correlations between the presence of debris and exoplanets around Sun-like stars, finding that debris disks are more common around stars with known planetary companions (Bryden et al. 2013) and that low-mass planet hosts favor the presence of debris over those stars with Jovian-mass companions (Wyatt et al. 2012; Marshall et al. 2014). In this section, we apply the Kolmogorov–Smirnov (KS) and Fisher exact tests to the sample of AAPS stars presented here, looking for similar correlations.

We consider the dust fractional luminosities, or $3\sigma$ upper limits, derived from either Spitzer MIPS 70 $\mu$m or Herschel PACS 100 $\mu$m measurements assuming a disk temperature of 50 K, with a preference for Herschel values if both are available due to the superior angular resolution of the PACS instrument over that of MIPS. The mass upper limits at 5 AU for the stars are derived in this work. For the purposes of statistical analysis in this work, any star with a mass limit $<1 M_{\text{Jup}}$ and no known Jovian-mass companion is ruled to be a potential low-mass planet host star, while those stars with mass limits $\geq 1 M_{\text{Jup}}$ (or host a known Jovian-mass companion) may potentially harbor a Jupiter analog planet and are therefore potential high-mass planet hosts in this analysis.

In the AAPS sample presented here there is a total of 141 stars. Among these, 43 stars host known substellar companions of which nine also host a cool debris disk. Of the remainder, 12 stars are known to host a debris disk without exhibiting any evidence of planets, while the remaining 87 stars in the sample have no observational evidence of a companion planetary system.

Stellar properties: comparing the stellar properties of the AAPS sample with the volume limited radial-velocity planet hosts sample from Marshall et al. (2014) using the Fisher exact test, we find $p$-values in the range 0.5–1.0 for their effective temperatures, $T_{\text{eff}}$, ages, and metallicities. The results are plotted in Figure 3. The stellar composition of the two samples are therefore similar, to be expected as they are both comprised of HD 164427 is a brown dwarf (Tinney et al. 2001).
of targets from radial velocity planet searches. However, a comparison of the distance distributions shows a marked dissimilarity, with a p-value of 0.057 as the AAPS stars, by and large, lie beyond 20 pc. The dust upper limits are a strong function of the stellar distance with only weak constraints on the presence of debris beyond 25 pc (in the range 10$^{-5}$–10$^{-4}$), but the p-value for dust incidence comparison of the AAPS sample presented here with Eiroa et al. (2013) is 0.599, so the two samples are indistinguishable regarding the presence of debris.

**Planetary mass (limits):** stars with sub-Jovian mass limits are preferentially low (sub-solar) metallicity, suggesting that these stars do not have high mass planetary companions, as seen in Marshall et al. (2014). The significance of this correlation is low, as the low metallicity stars in the sample are older and closer than the average for the sample, such that bias plays a role there.

**Debris brightness:** looking at the distribution of detected debris disks in the sample, cool Jupiter host stars seem to favor the presence of a bright debris disk over low mass planet host stars, a trend identified by Maldonado et al. (2012). Checking this correlation in our sample with the KS test, we obtain a p-value of 0.17 which is suggestive, but not conclusive, of a correlation between cool Jupiter mass planets and debris. The strength (weakness) of the correlation is heavily influenced by the presence of HD 207129, a large, bright debris disk host star (Krist et al. 10; Marshall et al. 2011; Löhne et al. 2012), in the potential low-mass-planet hosts subgroup. If we omit this star, then the p-value of the KS test drops to 0.05, strengthening the significance of the (potential) correlation.

4. CONCLUSIONS

We have analyzed a sample of AAPS stars, combining upper limits (ruling out Jovian analogs around several stars) with radial velocity detections, and have been able to identify a weak trend of debris brightness with planet mass. Further analysis, searching for other previously identified trends, is hampered by the weak upper limits on the presence of debris due to the larger distances to most of the stars in our sample than those of other samples, which typically concentrate on nearby stars (d < 25 pc).

The absence of any strong trends between planets and debris may be a function of the dynamical history of these systems wherein the chaotic dynamical evolution of planets (including migration and scattering) dominates the observed disk brightness. Any correlations visible in more strictly defined stellar samples, wherein we have a better understanding of the relative incidences of their component parts as a function of the stellar and planetary properties is thereby diluted. For a statistical analysis of a well-characterized sample, we direct the interested reader to the forthcoming work by Moro-Martin et al. (2015).

This research is supported by Australian Research Council grants DP0774000 and DP130102695. JPM is supported by a UNSW Vice-Chancellor’s Fellowship. We have made use of NASA’s Astrophysics Data System (ADS), and the SIMBAD database, operated at CDS, Strasbourg, France. This research has also made use of the Exoplanet Orbit Database and the Exoplanet Data Explorer at exoplanets.org (Wright et al. 2011).
Wittenmyer, R. A., Horner, J., Tuomi, M., et al. 2012, ApJ, 753, 169
Wittenmyer, R. A., Tinney, C. G., Horner, J., et al. 2013, PASP, 125, 351
Wittenmyer, R. A., Tan, X., Lee, M. H., et al. 2014a, ApJ, 780, 140
Wittenmyer, R. A., Horner, J., Tinney, C. G., et al. 2014b, ApJ, 783, 103
Wittenmyer, R. A., Tuomi, M., Butler, R. P., et al. 2014c, ApJ, 791, 114
Wright, J. T., Fakhouri, O., Marcy, G. W., et al. 2011, PASP, 123, 412
Wyatt, M. C. 2008, ARA&A, 46, 339
Wyatt, M. C., Kennedy, G., Sibthorpe, B., et al. 2012, MNRAS, 424, 1206
Zechmeister, M., & Kürster, M. 2009, A&A, 496, 577