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PURSUING THE PLANET–DEBRIS DISK CONNECTION: ANALYSIS OF UPPER LIMITS FROM THE ANGLO-AUSTRALIAN PLANET SEARCH

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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 ~ 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 (warps, 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-Martin 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 ~250 nearby solar-type stars (Butler et al. 2001; Tinney et al. 2001). It has achieved a consistent velocity precision of 2–3 m 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 ~40 planets diskovered 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 diskoveries, 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_amoromar_1 (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	
GJ 832	39	5465	5.7	AAT	Wittenmyer et al. (2014c)
…	54	1089	1.9	HARPS	Wittenmyer et al. (2014c)
…	16	818	1.7	PFS	Wittenmyer et al. (2014c)
Total	109	5569	3.5		
HD 142	86	5667	11.3	AAT	
HD 1581	110	5668	3.3	AAT	
HD 2039[a]	46	4780	14.0	AAT	
HD 3823[a]	75	5668	5.6	AAT	
HD 4308	41	680	1.7	HARPS	Udry et al. (2006)
…	109	5669	3.8	AAT	
Total	150	5669	3.3		
HD 7570	53	5665	6.3	AAT	
HD 9280[a]	30	4970	12.6	AAT	
HD 10360	64	5668	4.7	AAT	
HD 10647	51	5134	10.7	AAT	
HD 10700	248	5726	3.0	AAT	
…	638	8800	7.1	Lick	Fischer et al. (2014)
Total	886	9511	6.2	…	
HD 11112[a]	37	5724	15.8	AAT	
HD 12387[a]	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[a]	23	5104	8.5	AAT	
HD 19632[a]	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	Lick	Fischer et al. (2014)
Total	182	6941	6.1	…	
HD 27274	28	4114	7.0	AAT	
HD 27442	96	5724	7.3	AAT	
HD 30177	36	5438	18.5	AAT	
HD 30295[a]	33	4850	9.2	AAT	
HD 31827[a]	29	5265	8.1	AAT	
HD 33811[a]	26	4878	8.8	AAT	
HD 36108[a]	34	5549	4.0	AAT	
HD 38283[a]	64	5883	4.0	AAT	
HD 38382[a]	45	5936	5.4	AAT	
HD 38973[a]	43	5882	5.2	AAT	
HD 39091	69	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	…	
HD 42902[a]	17	4840	24.6	AAT	
HD 43834	131	5880	6.1	AAT	
HD 44120[a]	39	5882	3.8	AAT	
HD 44594[a]	43	5937	6.8	AAT	
HD 45289[a]	34	5941	5.1	AAT	
HD 52447[a]	24	3689	15.8	AAT	

Table 1
(Continued)

Star	N	ΔT (days)	rms (m s^{-1})	Telescope	Reference
HD 53705[a]	130	5880	4.3	AAT	
HD 53706[a]	45	5881	3.3	AAT	
HD 55720[a]	28	5634	3.8	AAT	
HD 59468[a]	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[a]	30	5637	4.8	AAT	
HD 73121[a]	43	5961	5.9	AAT	
HD 73524[a]	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[a]	38	5788	8.6	AAT	
HD 80635[a]	23	4784	10.6	AAT	
HD 83443[a]	23	1211	10.2	AAT	
HD 83529A[a]	31	5964	4.9	AAT	
HD 86819[a]	34	5844	10.2	AAT	
HD 88742[a]	35	5941	12.3	AAT	
HD 92987[a]	51	5935	5.3	AAT	
HD 93385[a]	45	5845	7.8	AAT	
HD 96423[a]	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)

Table 1
(Continued)

Star	N	ΔT (days)	rms (m s^{-1})	Telescope	Reference
HD 155974	50	5878	9.6	AAT	
HD 159868	49	4077	6.6	AAT	Wittenmyer et al. (2012)
...	34	1593	4.4	Keck	Wittenmyer et al. (2012)
Total	83	4077	5.8		
HD 160691	172	5581	2.6	AAT	
	40	2483	7.7	CORALIE	Pepe et al. (2007)
...	86	980	1.7	HARPS	Pepe et al. (2007)
Total	298	5581	3.5		
HD 161612	50	5874	4.4	AAT	
HD 164427	44	5079	6.2	AAT	
HD 177565	165	3501	3.1	AAT	
HD 179949	68	5085	12.2	AAT	
HD 183877	43	5673	5.8	AAT	
HD 187085	69	5434	12.0	AAT	
HD 189567	88	5345	5.5	AAT	
HD 191408	177	5497	3.9	AAT	
HD 192310	158	5377	3.1	AAT	
HD 192865	44	5345	10.4	AAT	
HD 193193	52	5652	5.8	AAT	
HD 193307	79	5377	4.4	AAT	
HD 194640	78	5377	4.8	AAT	
HD 196050	55	5021	7.7	AAT	
HD 196068	35	5375	11.8	AAT	
HD 196761	45	3010	5.7	AAT	
HD 196800	38	5675	6.6	AAT	
HD 199190	52	5521	4.8	AAT	
HD 199288	80	5521	5.1	AAT	
HD 199509	32	5732	4.6	AAT	
HD 202628	30	4367	10.9	AAT	
HD 204385	38	5465	6.5	AAT	
HD 205536	27	5432	4.1	AAT	
HD 205390	33	5521	9.6	AAT	
HD 207129	120	5433	4.9	AAT	
HD 207700	33	5522	5.4	AAT	
HD 208487	46	5433	8.5	AAT	
HD 208998	34	5054	7.8	AAT	
HD 209653	40	5462	5.0	AAT	
HD 210918	68	5521	5.0	AAT	
HD 211317	41	5433	5.1	AAT	
HD 212168	47	5464	5.4	AAT	
HD 212330	31	5218	3.7	AAT	
HD 212708	35	4069	4.3	AAT	
HD 213240	35	4487	5.0	AAT	
HD 214759	30	5465	5.7	AAT	
HD 214953	78	5464	4.2	AAT	
HD 216435	74	4723	6.5	AAT	
HD 216437	51	5668	4.6	AAT	
...	21	865	8.0	CORALIE	Mayor et al. (2004)
Total	72	5668	5.8	...	
HD 217958	35	4727	9.2	AAT	
HD 219077	69	5635	4.8	AAT	
HD 220507	27	5464	4.2	AAT	
HD 221420	79	5960	4.0	AAT	
HD 222237	30	5431	4.6	AAT	
HD 223171	58	5464	6.0	AAT	

[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 semiamplitude 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 determine detectability, gaps in data sampling can conspire to make some trial periods fail to produce a significant peak even for very large amplitudes (K_{max} = 200 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_{min} = 1 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 (~12 year) within the total timespan of the AAPS data (16 year).[3]

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 $m \sin i > 0.2\,M_{Jup}$ 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

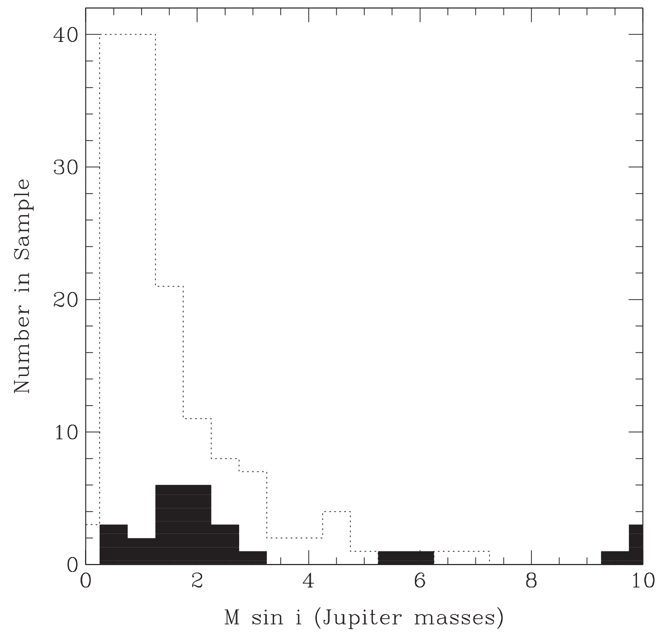

Figure 1. Dashed histogram: planetary detection limits at 5 AU for the 141 stars in this sample. Filled histogram: known planets in the sample with $a > 1$ AU and $m \sin i > 0.2\,M_{Jup}$.

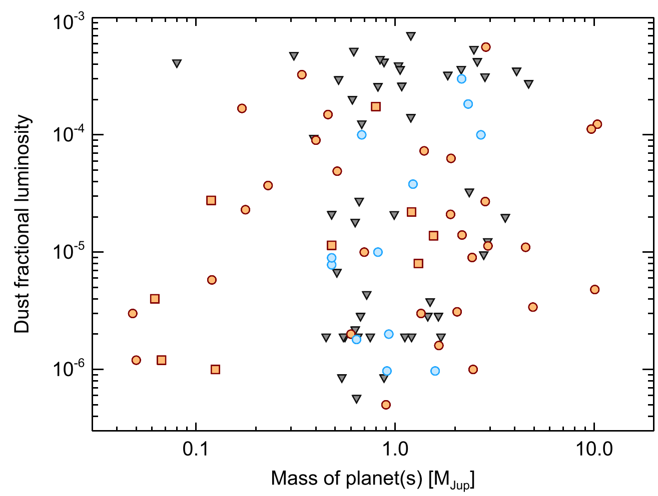

Figure 2. Dust fractional luminosity as a function of the total mass of planets in the system. Triangles: upper limits for both dust and planets. Blue circles: stars with dust disks and no known planets. Red circles: stars with both detected dust and planets. Red squares: stars with planets but no dust.

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_{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 diskern 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

[3] For the median stellar mass 1 $M_\odot$, $a_{5\,AU} \sim 12$ year. The range in this sample is 0.45–1.72 $M_\odot$, or $a_{5\,AU} \sim 16.9$–8.5 year, respectively.

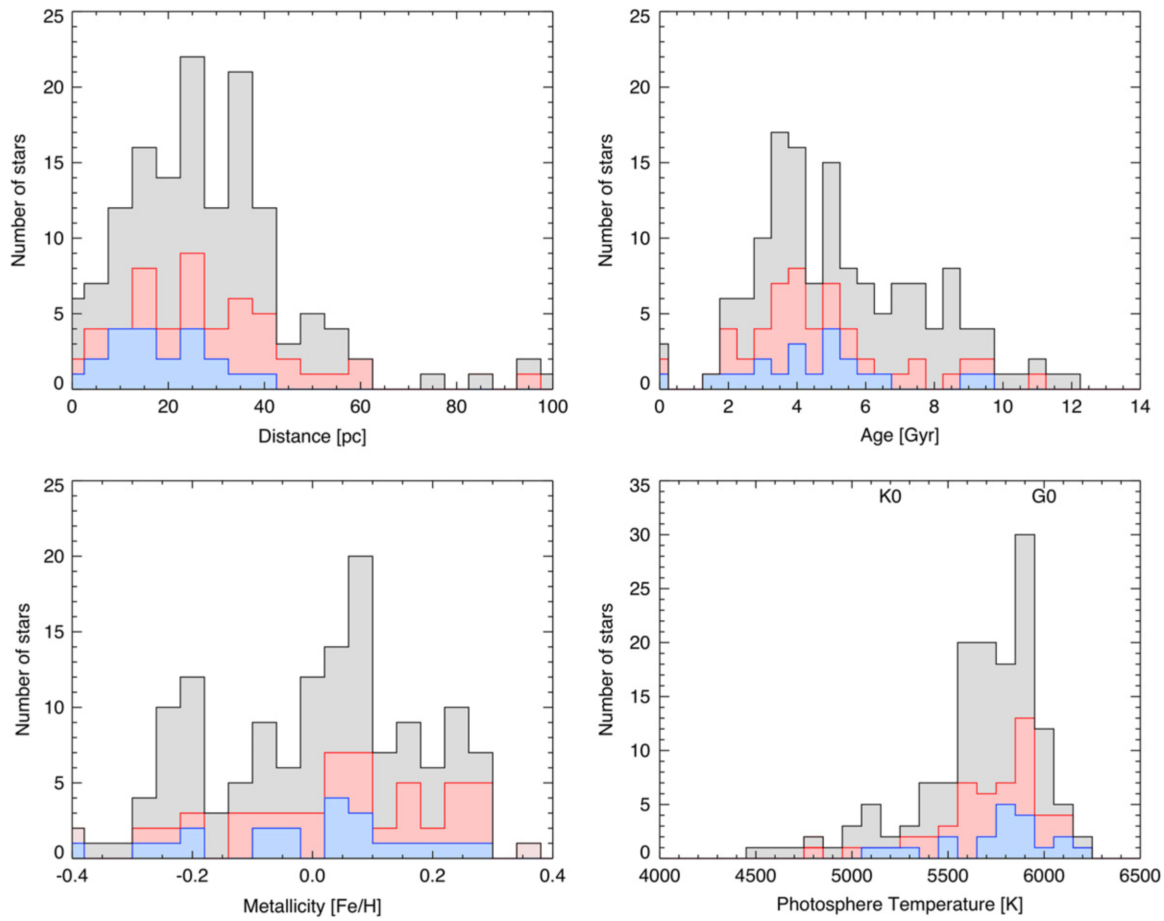

Figure 3. Distribution of the distance, age, metallicity, and $T_{\rm eff}$ for the 141 AAPS stars considered here. Gray histogram: total sample. Blue histogram: stars with detected debris ($N = 21$). Red histogram: stars with known planets and no debris ($N = 120$).

faintness of its cool debris disk, the Edgeworth–Kuiper Belt, ($L_{\rm IR}/L_{\star} \sim 1.2 \times 10^{-7}$, 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 3σ upper limits, derived from either *Spitzer* MIPS 70 μm or *Herschel* PACS 100 μm 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 $M_{\rm Jup}$ and no known Jovian-mass companion is ruled to be a potential low-mass planet host star, while those stars with mass limits $\geqslant 1$ $M_{\rm Jup}$ (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[4] 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, $T_{\rm eff}$, 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

[4] 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. 2010; 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).

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