NEAR-INFRARED CONSTRAINTS ON THE PRESENCE OF WARM DUST AT METAL-RICH, HELIUM ATMOSPHERE WHITE DWARFS

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ABSTRACT

We present near-infrared spectroscopic observations of 15 helium atmosphere, metal-rich white dwarfs obtained at the NASA Infrared Telescope Facility. While a connection has been demonstrated between the most highly polluted, hydrogen atmosphere white dwarfs and the presence of warm circumstellar dust and gas, their frequency at the helium atmosphere variety is poorly constrained. None of our targets shows excess near-infrared radiation consistent with warm orbiting material. Adding these near-infrared constraints to previous near- and mid-infrared observations, the frequency of warm circumstellar material at metal-bearing white dwarfs is at least 20% for hydrogen-dominated photospheres, but could be less than 5% for those effectively composed of helium alone. The lower occurrence of dust disks around helium atmosphere white dwarfs is consistent with Myr timescales for photospheric metals in massive convection zones. Analyzing the mass distribution of ten white dwarfs with warm circumstellar material, we search for similar trends between the frequency of disks and the predicted frequency of massive planets around intermediate-mass stars, but find the probability that disk-bearing white dwarfs are more massive than average is not significant.

Key words: circumstellar matter – infrared: stars – white dwarfs

Online-only material: color figures

1. INTRODUCTION

High gravity, in the absence of radiative forces, together with significant convection zones, allows the downward sedimentation of heavy elements to proceed rapidly in cool white dwarfs (Schatzman 1958). Therefore, even if heavy elements are accreted, they will sink to the bottom of the photosphere quickly, typically leaving behind a near-pure hydrogen or helium atmosphere. On the other hand, a recent survey of nearby cool DA (hydrogen-rich) white dwarfs by Zuckerman et al. (2003) found that up to 25% of the isolated white dwarfs in their sample show trace amounts of heavy elements (mainly calcium, type DAZ).[6] Since the diffusion timescales for heavy elements are shorter than the white dwarf evolutionary timescales, the source of the metals observed in the photospheres of these white dwarfs cannot be primordial.

The interstellar medium (ISM) seems like a natural candidate for the source of metals in white dwarf atmospheres. However, the Sun is located in a very low density region, and the volume-filling factor of clouds in the local ISM is much less than 25%, the percentage of DA stars showing metallic features in the nearby white dwarf sample. In addition, Zuckerman et al. (2003) and Kilic & Redfield (2007) found no correlation between the accretion density required to supply metals observed in DAZ white dwarfs with the densities observed in their interstellar environment, indicating that ISM accretion alone cannot explain the presence of metals in these nearby degenerates. Helium-rich white dwarfs with metals (type DBZ) do not show a correlation with the local ISM clouds, either (Aannestad et al. 1993). Jura (2006) demonstrates there are several DBZ stars with carbon abundances at least an order of magnitude below solar, which is inconsistent with accretion from the ISM.

A more exciting possibility for the atmospheric metals is accretion from circumstellar disks. Until recently, there was only a single metal-rich white dwarf known to have a debris disk, G29-38 (Graham et al. 1990; Zuckerman & Becklin 1987; Koester et al. 1997). Kilic et al. (2005) and Becklin et al. (2005) both independently discovered the second known debris disk around a metal-rich white dwarf star, GD 362. Recently, seven more dust disks have been discovered around metal-rich white dwarfs with space- and ground-based observations (Kilic et al. 2006; Kilic & Redfield 2007; von Hippel et al. 2007; Jura et al. 2007; Farihi et al. 2008a), while no disks were indicated in sensitive space-based observations of $N \approx 120$ non-metal-bearing white dwarfs (Mullally et al. 2007).

For the white dwarfs with debris disks, the presence of metals in the atmosphere is almost certainly related to the circumstellar material at these stars. If the source of the photospheric metals observed in several DAZ stars is accretion from circumstellar disks, there is no *a priori* reason to assume that the same mechanism does not work for DBZ white dwarfs. It is perhaps noteworthy that the fraction of metal-bearing to non-metal-bearing stars is similar for both hydrogen and helium atmosphere white dwarfs (Koester et al. 2005a). However, because helium is relatively transparent compared to hydrogen, DB stars and their cooler counterparts have photospheres which are more readily contaminated than DA stars (Zuckerman et al. 2003). Additionally, these heavy contaminants can stay present in cool helium atmospheres for Myr timescales, owing to massive convection zones (Paquette et al. 1986). Still, a similar mechanism may explain both the DAZ and DBZ stars.

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[6] Koester et al. (2005a) found a lower frequency of DAZs ($\approx 5\%$) among their DA white dwarf sample. Different biases contribute to the varying percentages between the Zuckerman et al. (2003) and Koester et al. studies. Since the biases for these two surveys have not been accounted for, a definitive fraction of DAZ versus DA has yet to be determined.

Table 1
Metal-Rich, Helium Atmosphere White Dwarfs Observed in the Infrared

Object	$T_{\rm eff}$(K)	$\log g$	$\log({\rm Ca/He})$	$\log({\rm H/He})$	Spectral type	Source	Reference
WD 0002+729	13750	8.00	−9.6	−6.0	DBZ	*Spitzer*	W02
WD 0300−013 (GD 40)	15200	8.00	−6.7	−6.0	DBZA	IRTF/*Spitzer*	F99, V07
HE 0449−2554	12200	8.20	−7.2	. . .	DBAZ	IRTF	F00
J080537.64+383212.4	10470	8.82	. . .	. . .	DZ	IRTF	E06
	10660	8.00	−10.03	< −6.0			D07
J093942.29+555048.7	10090	7.51	. . .	. . .	DZA	IRTF	E06
	8680	8.00	−8.51	−4.20			D07
J103809.19−003622.5	10080	7.28	. . .	. . .	DZ	IRTF	E06
	6770	8.00	−9.44	< −5.0			D07
WD 1225−079	10500	8.00	−7.9	. . .	DZAB	IRTF	W02
J124703.28+493423.6	16810	8.21	. . .	. . .	DBAZ	IRTF	E06
J131336.95+573800.5	10090	8.82	. . .	. . .	DZ	IRTF	E06
	8900	8.00	−9.39	−4.70			D07
HE 1349−2305	18300	8.13	−8.0	−4.9	DBAZ	IRTF	K05
J135118.47+425316.0	10080	8.82	. . .	. . .	DZ	IRTF	E06
	6770	8.00	−11.35	< −3.0			D07
WD 1352+004	15300	8.48	−9.3	−4.8	DBAZ	IRTF	K05
WD 1425+540	14100	. . .	−10.3	−4.2	DBAZ	IRTF	D93
WD 1709+230	19700	8.17	−8.0	−4.2	DBAZ	IRTF	K05
WD 1729+371 (GD 362)	10540	8.24	−6.24	−1.14	DAZB	IRTF/*Spitzer*	Z07
WD 1822+410	17000	7.90	−8.15	−4.0	DBAZ	*Spitzer*	W02
WD 2142−169	15900	7.93	−9.1	−4.5	DBAZ	IRTF	K05
WD 2144−079	16500	7.90	−8.5	. . .	DBZ	*Spitzer*	K05
WD 2322+118	12000	. . .	−8.7	−5.2	DZA	IRTF	D93
WD 2354+159	19000	7.91	−8.1	. . .	DBZ	*Spitzer*	K05

Notes. The IRTF and *Spitzer* observations are from: this study; Kilic et al. (2005); Mullally et al. (2007); and Jura et al. (2007). The IRTF observations are sensitive for excess emission from the disks in the *H* and *K* bands, whereas the *Spitzer* observations are sensitive up to 8 μm.
References. D93 (Dupuis et al. 1993); D07 (Dufour et al. 2007); E06 (Eisenstein et al. 2006); F99 (Friedrich et al. 1999); F00 (Friedrich et al. 2000); K05 (Koester et al. 2005a); V07 (Voss et al. 2007); W02 (Wolff et al. 2002); and Z07 (Zuckerman et al. 2007).

Jura et al. (2007) obtained *Spitzer* IRAC and MIPS photometry of the carbon-deficient DBZ, GD 40 and found it to have a disk, while two other DBZ stars in the same program did not show any evidence for warm or cool dust. Moreover, high-resolution optical spectroscopy of GD 362 reveals it has a significant amount of helium, and a more accurate spectral type is DAZB (Zuckerman et al. 2007; Koester et al. 2005b). The Mullally et al. (2007) sample contains only two DBZ stars, neither of which shows mid-infrared excess. There has not yet been a systematic search for debris disks around these helium-rich, externally polluted stars.

We present near-infrared spectroscopic observations of 15 helium atmosphere, metal-rich white dwarfs selected from the literature (Dupuis et al. 1993; Koester et al. 2005a; Eisenstein et al. 2006). The physical characteristics of our sample are presented in Table 1, our observations are discussed in Section 2, and the results and analysis of the spectroscopic data are presented in Section 3.

2. OBSERVATIONS

We used the 0.8–5.4 μm Medium-Resolution Spectrograph and Imager (SpeX; Rayner et al. 2003) on the NASA Infrared Telescope Facility (IRTF) to perform near-infrared spectroscopy on 15 helium atmosphere, metal-rich white dwarfs and one DAZ white dwarf, HE 0106−3253. The prism mode was employed with a 0.5″ slit to produce spectra with a resolving power of 90–210 (average of 150) over the 0.8–2.5 μm range. Our observations were performed under conditions of thin cirrus and partly cloudy skies on 2007 March 5–6 and November

3–4. To remove the dark current and the sky signal from the data, the observations were taken at two different positions on the slit separated by 10″. Internal calibration lamps (a 0.1 W incandescent lamp and an argon lamp) were used for flat-fielding and wavelength calibration, respectively. In order to correct for telluric features and flux calibrate the spectra, nearby bright A0V stars were observed at an airmass similar to the target star observations. We used an IDL-based package, Spextool version 3.4 (Cushing et al. 2004), to reduce our data.

In addition to our IRTF observations, we obtained near-infrared spectra of another DAZ, WD 1150−153, on the United Kingdom Infrared Telescope (UKIRT). Two separate sets of observations were performed on 2007 June 13 and 2008 January 9 in service mode (Service Program 1659) using the UKIRT 1–5 μm Imager Spectrometer (UIST; Ramsay Howat et al. 2004) with the *HK* grism and a 0.6″ slit, yielding spectra over 1.4–2.5 μm with a resolving power of 400. A nearby F0V standard, HD 96220, was observed for flux calibration and telluric correction.

3. RESULTS

Figure 1 presents the flux-calibrated spectra of nine DBZ stars, ordered by $T_{\rm eff}$, compared to the predicted photospheric fluxes for each star. Blackbody spectral energy distributions (SEDs) are suitable for warm helium-rich atmosphere white dwarfs, and are therefore used here. Most of our targets have reliable Two Micron All Sky Survey (2MASS) *J*-band photometry, while some also have *H*- and *K*-band data. The 2MASS photometry is shown as filled circles with error bars;
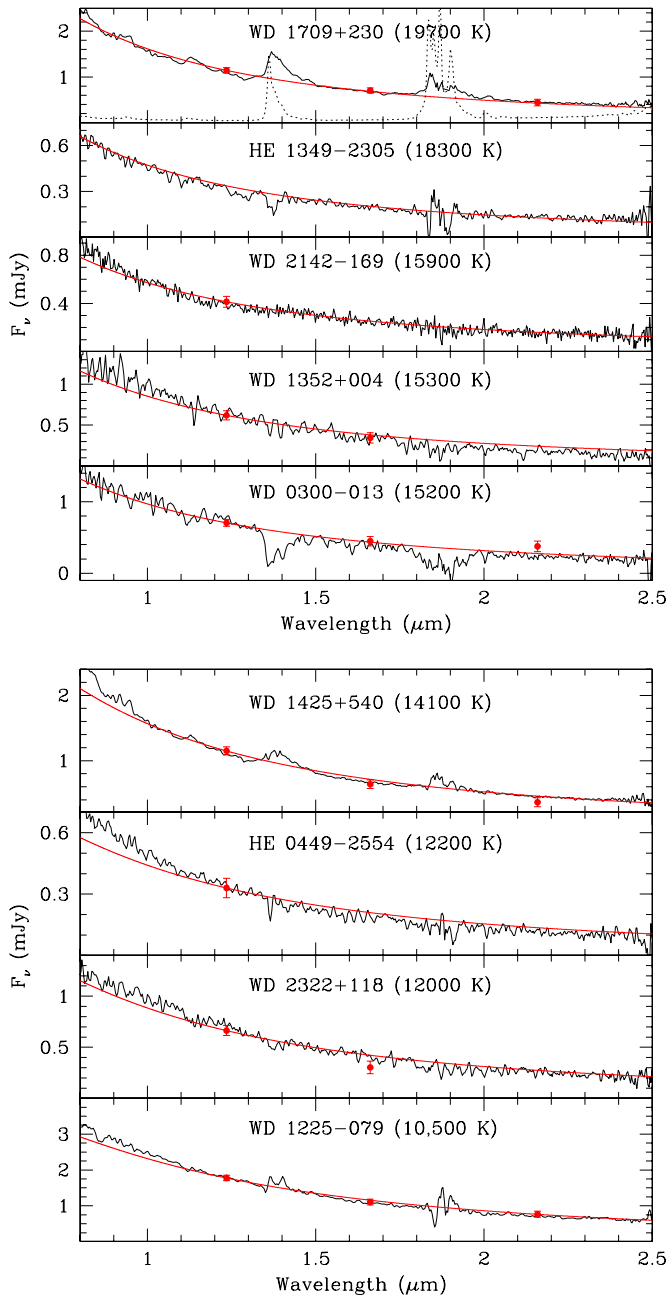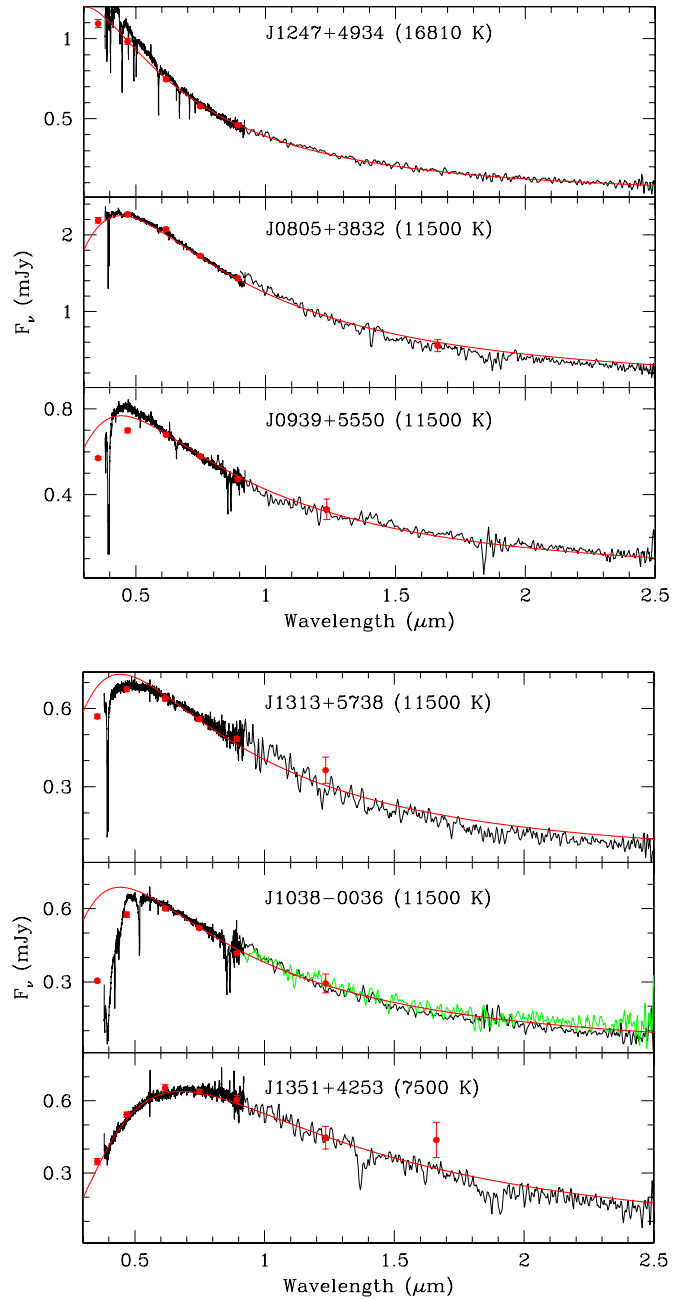
Figure 1. Flux-calibrated spectra of the helium atmosphere white dwarfs in our sample (black lines, ordered in $T_{\rm eff}$) compared to models (red lines). The 2MASS photometry is shown as filled circles with error bars. Telluric spectrum obtained from observations of WD 1709+230 is shown (dotted line) in the top panel.

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Figure 2. Flux-calibrated spectra of the SDSS DBZ and DZ white dwarfs (black lines) compared to models (red lines). The SDSS and 2MASS photometry are shown as filled circles with error bars.
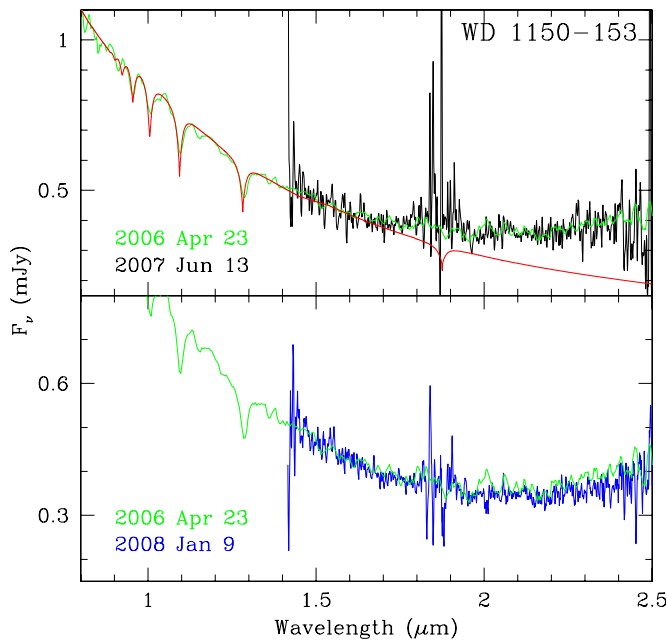
(A color version of this figure is available in the online journal)

the blackbody and observed spectra are normalized to match the 2MASS photometry in the J band. A typical telluric spectrum observed at the IRTF is presented in the top panel. The features observed in several stars in the range 1.35–1.45 μm and 1.80–2.05 μm are telluric correction residuals.

Figure 2 presents our IRTF spectra of six DBZ stars found in the Sloan Digital Sky Survey (SDSS) along with their optical photometry and spectroscopy. The red lines show the appropriate blackbody SEDs. Only one of these stars, J1247+4934, is hot enough to show helium lines and therefore classified DBZ. Optical helium lines disappear below $T_{\rm eff} \approx 12,000$ K in white dwarf atmospheres, and hence one can conclude that these five

stars are cooler than this; they are classified as either DZ or DZA. Even though blackbody SEDs do not reproduce the observed spectra shortward of 0.5 μm due to strong metal lines, they reproduce the near-infrared SEDs fairly well. Fitting their optical and near-infrared colors with blackbody colors, we find that four of the stars are consistent with $T_{\rm eff} \approx 11,500$ K, and one of them, J1351+4253, with $T_{\rm eff} \approx 7500$ K.

None of the 15 helium atmosphere, metal rich white dwarfs in our sample, including GD 40 (WD 0300−013), shows near-infrared excess. The 2MASS photometry of GD 40 is slightly brighter in the K band than predicted by our spectroscopy. Jura et al. (2007) discovered a mid-infrared excess around GD 40, and were able to model the observed excess with a flat disk extending
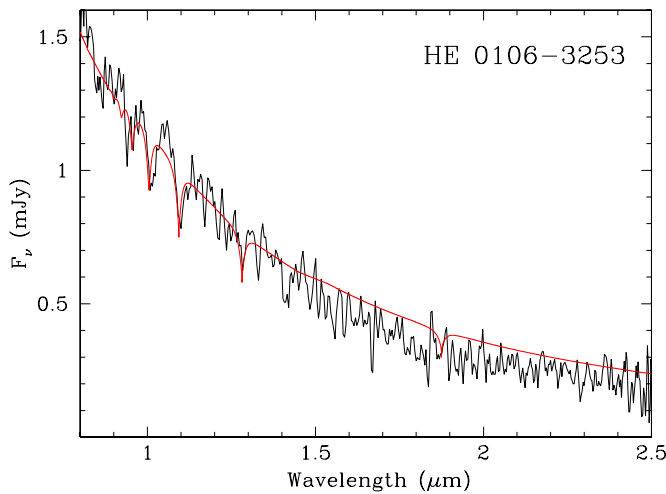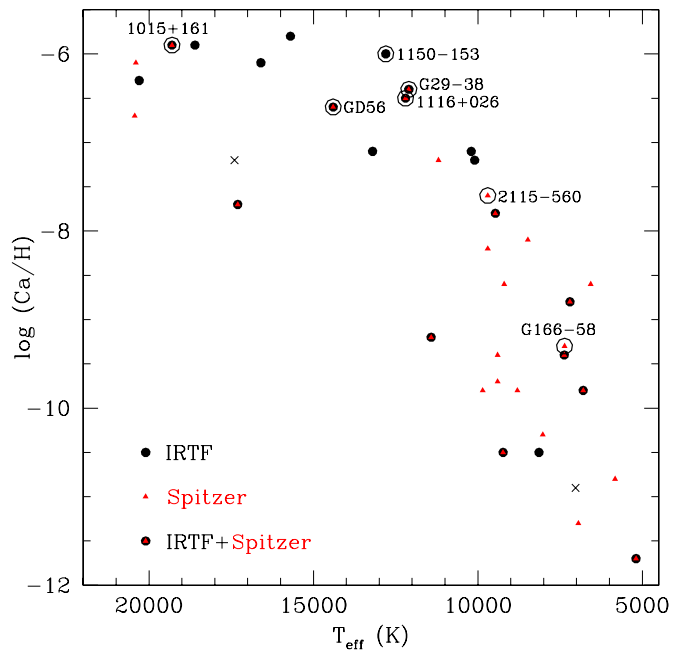
Figure 3. Near-infrared spectrum of HE 0106−3253 (black line) compared to a $T_{eff} = 15,700$ K DA white dwarf model kindly provided by D. Koester (2007, private communication, red line).

Figure 4. Near-infrared spectra of WD 1150−153 obtained on 2006 April 23 (IRTF, green line), 2007 June 13 (UKIRT, black line), and 2008 January 9 (UKIRT, blue line). The red line shows the expected photospheric flux from the white dwarf.

Figure 5. Calcium abundance versus effective temperature for the DAZ stars observed at the IRTF (filled circles; Kilic et al. 2006, Kilic & Redfield 2007, this study) and *Spitzer*/IRAC (filled triangles; von Hippel et al. 2007, Debes et al. 2007, Farihi et al. 2008a). The remaining DAZ white dwarfs from Koester & Wilken (2006) are shown as crosses. White dwarfs with circumstellar debris disks are labeled and marked with open circles.

variable with a dominant period of 250 s and an optical pulsation amplitude of 0.8% (Gianninas et al. 2006; Koester & Voss 2006), expected to be an order of magnitude smaller in the near-infrared. Normalizing each spectrum by the average flux between 1.44 μm and 1.82 μm (the 2MASS H band), the total K-band flux increased by 0.2% in 2007, and decreased by 4.3% in 2008, relative to the total flux observed in 2006. However, this level of variability is well within a typical 3–5% photometric error for a single near-infrared observation in clear weather conditions, which we did not have. Therefore, it is likely that these differences are due to calibration errors caused by variations in sky brightness and extinction due to non-photometric conditions. Further photometric observations are needed to rule out possible changes in the disk. Kilic & Redfield (2007) reported two near-infrared spectroscopic observations of GD 362 separated by nearly one year, which did not reveal any variations.

4. DISCUSSION

4.1. Helium versus Hydrogen Atmospheres

Like their DAZ counterparts, most DBZ white dwarfs do not show near-infrared excess due to dust disks. The only reported helium-rich white dwarf with a clear K-band detectable (disk) excess is GD 362, yet this star is also very hydrogen-rich and DAZ-like, both in its spectral (Gianninas et al. 2004), compositional (log(H/He) = −1.1; Zuckerman et al. 2007), and physical properties (B. Hansen 2008, private communication). In order to better constrain the fraction of dusty white dwarfs among spectral types DBZ and DAZ, we now consider all such stars with published IRTF and *Spitzer* observations. Figure 5 presents a plot of T_{eff} versus calcium abundance for 39 DAZ stars (Koester et al. 2005a; Zuckerman et al. 2003), 37 of which have now been observed at the IRTF and/or with *Spitzer*. There

from 20 to 30 R_*. Their model predicts little or no excess in the K band, at odds with the 2MASS K-band photometry, but consistent with our IRTF spectrum. Figure 3 presents the near-infrared spectrum of the most metal-rich DAZ in the Koester & Wilken (2006) sample, HE 0106−3253, compared to the model-predicted photospheric flux. Perhaps surprisingly, it does not have an excess, indicating a warm dust disk.

Figure 4 presents three near-infrared spectra of WD 1150−153 obtained in 2006 (Kilic & Redfield 2007), 2007, and 2008 (this paper), which were taken to search for variability. The timescale for Poynting–Robertson drag at the inner disk edge of such a $T_{eff} \approx 12,000$ K DAZ is close to 30 days (von Hippel & Thompson 2007), and if the process which replenishes the warmest dusty material is not continuous, it could result in K-band flux variations. WD 1150−153 is a ZZ Ceti

are seven observed stars which have debris disks, corresponding to an overall fraction of $18.9^{+8.0}_{-4.8}\%$. Due to small sample size, we used a binomial probability distribution to derive statistical uncertainties for the frequency of disks. Since the probability distribution is not symmetric about its maximum value, we report the range in frequency that delimits 68% of the integrated probability function as error bars. These error bars are equivalent to 1σ limits for a Gaussian distribution (see the discussions in McCarthy & Zuckerman 2004 and Burgasser et al. 2003). If we include the DAZ analog GD 362, the fraction of DAZ white dwarfs with disks goes up to $21.1^{+7.9}_{-5.1}\%$. Only one nearly pure DB white dwarf with metals is known to have a dust disk, the recently reclassified DBAZ GD 40 (log(H/He) = −6.0; Voss et al. 2007), corresponding to one of 19 stars in Table 1 with log(H/He) < −4 (abundances typical for DB white dwarfs with hydrogen; Voss et al. 2007), or $5.3^{+10.2}_{-1.7}\%$. If we limit our sample to ground-based observations only, this value goes down to $2.6^{+4.3}_{-2.6}\%$ for hydrogen-poor white dwarfs and $14.3^{+10.8}_{-4.6}\%$ for hydrogen-rich white dwarfs. Dust disks appear less frequent among helium versus hydrogen atmosphere white dwarfs, and the difference appears to be significant at the 2σ level.

If the observed difference in the frequency of dusty DAZ and DBZ stars is real, and the above analysis supports that conclusion, then this result is consistent with the difference in their respective, typical diffusion timescales. The diffusion timescales for metals are a few to several orders of magnitude longer in helium-rich atmospheres compared to hydrogen-rich analogs. For a $0.6\,M_\odot$, 10,000 K helium atmosphere white dwarf, the diffusion timescale for calcium is on the order of 10^5 yr (Paquette et al. 1986), whereas it is only 10^2 yr for a DAZ of the same temperature. Therefore, a lower fraction of dust disks around helium-rich degenerates may imply the disk lifetimes are shorter than the metal diffusion timescales, a scientifically interesting constraint on these poorly understood compact disks. While there may once have existed circumstellar dust around some or many polluted, helium-rich white dwarfs, these have either completely dissipated (become fully consumed by the star), or remain in gaseous phase and hence undetectable in the infrared. Any photospheric metal remnants should persist for Myr timescales in the relatively massive convection zones of these helium degenerates, and, in principle, could even be periodically replenished by the ISM.

Recently, Farihi et al. (2007) announced the discovery of a dust disk around another helium-rich white dwarf, GD 16, which also possesses significant amounts of atmospheric hydrogen. GD 16 is classified DAZB (as GD 362) with log(H/He) = −2.89 (Koester et al. 2005b). The presence of appreciable amount of hydrogen in a helium-dominated atmosphere can shorten the diffusion timescales for heavy elements significantly, presumably due to the outermost layers being dominated by the lighter gas. Both GD 362 and GD 16 probably behave more like DAZ stars in terms of their diffusion timescales (B. Hansen 2008, private communication). Hence, the discovery of disks around these particular helium- and hydrogen-rich stars may not be surprising, as the stars are more likely to be presently accreting in order that the observed metal lines are present in their optical spectra.

GD 40, the only nearly pure DB with a dust disk, also has trace amounts of hydrogen. However, the hydrogen abundance in GD 40 is lower by 3–5 orders of magnitude relative to GD 16 and GD 362. Voss et al. (2007) found that 55% of DB white dwarfs in the temperature range 10,000–30,000 K show hydrogen at a similar level to GD 40 (log(H/He) $\lesssim$ −4). This fraction goes

Table 2
Possible Progenitor Masses for White Dwarfs with Circumstellar Disks

Object	T_{eff}(K)	log g	$M_{\mathrm{final}}(M_\odot)$	$M_{\mathrm{initial}}(M_\odot)$	Reference
WD 0408−041	15070	7.96	0.59	1.8	K01
WD 1015+161	19540	8.04	0.65	2.3	L05
WD 1116+026	12290	8.05	0.63	2.2	L05
WD 1150−153	12260	7.83	0.51	1.1	K01
WD 1455+298	7390	7.97	0.58	1.7	L05
WD 2115−560	9940	8.13	0.66	2.4	B95
WD 2326+049	11820	8.15	0.70	2.8	L05
GD 362	10540	8.24	0.74	3.2	Z07
J1043+0855	18330	8.09	0.67	2.5	G07
J1228+1040	22290	8.29	0.81	3.8	G07

Notes. References given are for the white dwarf mass, as determined primarily via Balmer line spectroscopy.
**References.** K01 (Koester et al. 2001); L05 (Liebert et al. 2005); B95 (Bragaglia et al. 1995); Z07 (Zuckerman et al. 2007); and G07 (Gänsicke et al. 2007).

up to 62% for the temperature range of our sample (10,000–20,000 K). It is therefore reasonable to assume that the source of hydrogen in GD 40 is also responsible for its presence in other DB white dwarfs (see Voss et al. 2007 for a thorough study and discussion of this poorly understood phenomenon).

4.2. Planet versus Disk Frequency

Laws et al. (2003) and Fischer & Valenti (2005) both suggest an increase in the incidence of planetary and substellar companions orbiting relatively more massive stars. For planet masses $m > 0.8\,M_\mathrm{J}$ and semimajor axes $a < 2.5$ AU, Johnson et al. (2007) find the frequency of planets increases from 4.2% for $0.7\,M_\odot < M \leqslant 1.3\,M_\odot$ stars, to 8.9%, for $1.3\,M_\odot < M \leqslant 1.9\,M_\odot$ primaries. The analogs of these planets around the progenitors of white dwarfs would almost certainly be engulfed on the asymptotic giant branch (AGB), and the frequency of planets around intermediate-mass stars at wider separations is currently unknown. However, a comparable numbers of planets may exist at wider separations. Kennedy & Kenyon (2008) suggest a model in which the frequency of gas giant planets increases linearly with stellar mass from $0.4\,M_\odot$ to $3\,M_\odot$ and decreases for higher-mass primaries. Recent surveys for planets around white dwarfs revealed a possible planet around a white dwarf with $M_{\mathrm{initial}} \approx 2\,M_\odot$ (Mullally et al. 2008) and no massive planets around several dozen white dwarfs with $M_{\mathrm{initial}} \geqslant 3\,M_\odot$ (Farihi et al. 2008b; see also Burleigh et al. 2008; Friedrich et al. 2007; Debes et al. 2005, 2006). If the white dwarf disks arise as a result of planetary system interactions, a correlation with degenerate stellar mass is possible.

von Hippel et al. (2007) studied the ensemble characteristics of four DAZ stars with debris disks. Including the recently discovered disk-bearing DAZ and DBZ stars, there are now nine white dwarfs with dusty disks and two white dwarfs with gaseous disks (Gänsicke et al. 2007). Table 2 presents T_{eff}, log g, initial and final masses for these white dwarfs, excepting GD 40 which has no mass estimate available in the literature. A typical error in these spectroscopic masses is around $0.03\,M_\odot$ (Liebert et al. 2005). The initial masses for the progenitors of these white dwarfs are estimated using the relation given by Kalirai et al. (2008), ranging from $1.1\,M_\odot$ to $3.8\,M_\odot$ with an average of $2.3\,M_\odot$. The use of an independent initial-to-final mass relation would change these mass estimates slightly. For example, employing the relation of Dobbie et al. (2006),
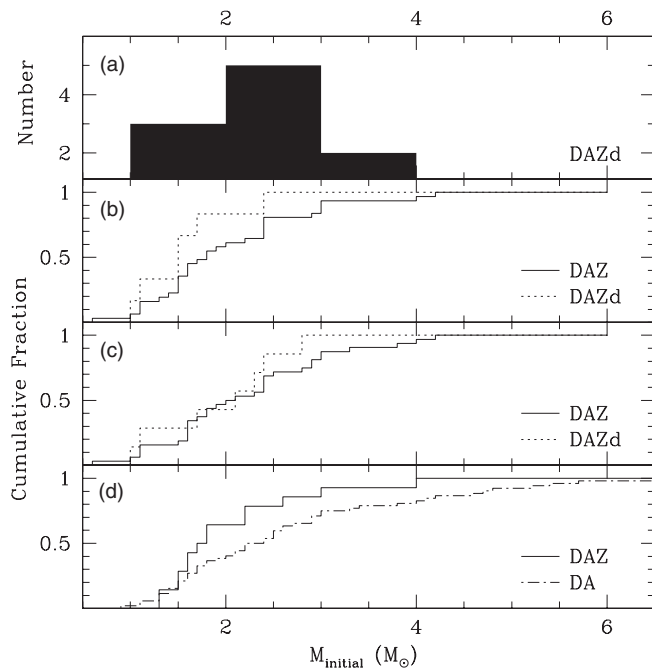
Figure 6. Panel (a): the mass distribution for the progenitors of ten white dwarfs with circumstellar disks. Panels (b), (c), (d): the cumulative mass distributions for the DA, DAZ, and DAZd white dwarfs analyzed by Koester & Wilken (2006), Bergeron et al. (2001), and Zuckerman et al. (2003), respectively.

Williams (2007), or Weidemann (2000) increases the initial mass estimates on average by 0.1–0.3 $M_\odot$ compared to the Kalirai et al. (2008) relation.

Panel (a) of Figure 6 presents the mass distributions for the progenitors of the ten white dwarfs presented in Table 2. The average and standard deviation for these disk-bearing white dwarf masses, including an assumed measurement error of 0.03 $M_\odot$, is 0.65 ± 0.09 $M_\odot$. Although slightly higher, this value is consistent within the errors with the mean mass for the field DA (0.60 ± 0.13 $M_\odot$; Liebert et al. 2005) and DB (0.60 ± 0.07 $M_\odot$ (Voss et al. 2007) white dwarf samples. One caveat, however, is the outstanding problem of DA white dwarf mass estimates from spectroscopy for effective temperatures less than 12,000 K (for a thorough review of this problem, see Kepler et al. 2007). In a nutshell, the presence of unseen helium (and possibly other neutral particles) can skew cooler DA masses toward higher values, perfectly exemplified by the mass estimate for GD 362 prior to the high-resolution detection of atmospheric helium (Zuckerman et al. 2007; Gianninas et al. 2004). There are only a few targets in Table 2 which belong in this category, and our results are unlikely to be affected by the situation, but we mention it for completeness and due to the fact that DA field white dwarf mass measurements purposefully exclude stars in this temperature range (Liebert et al. 2005). Therefore, we cannot say whether a trend exists between disk frequency and white dwarf mass, but a larger sample of such stars, combined with parallaxes to remove any mass estimate ambiguity introduced via spectroscopy for cooler DA type stars, may prove more insightful on this astrophyscially important topic. Based on previous works on white dwarfs with disks, it appears probable that the circumstellar material should be associated with surviving planetary system bodies, and hence any correlation between disks and host mass would imply a correlation between planetary systems and host mass.

The cumulative mass distributions for hydrogen- and metal-rich white dwarfs with (DAZd) and without (DAZ) disks from

the Koester & Wilken (2006) analysis are shown in panel (b) of Figure 6. A Kolmogorov–Smirnov (K-S) test indicates that there is a 48% probability that the DAZd white dwarfs are randomly drawn from the general distribution of DAZ white dwarfs. About half of these DAZ stars are also analyzed by P. Bergeron in various papers (e.g., Liebert et al. 2005; Bergeron et al. 2001); panel (c) shows the DAZ mass distribution using these mass estimates. A K-S test shows that the probability that the DAZ and DAZd distributions are similar is 81%. Thus, based on the seven DAZd white dwarfs, there is no apparent correlation between the frequency of disks and degenerate mass. Panel (d) of Figure 6 shows the cumulative mass distributions for the DA and DAZ white dwarfs analyzed by Zuckerman et al. (2003). Masses for these white dwarfs are derived from the quoted stellar parameters, where known (i.e., log g = 8 not assumed), and Bergeron et al. (1995) tabulated models. A K-S test shows that the null hypothesis is 28% probable; we do not find a significant difference between the DA and DAZ mass distributions.

If all metal-rich white dwarfs accrete from dusty or gaseous circumstellar material, and if there is a connection between white dwarf disks and planets, then we might expect metal-rich white dwarfs to be more massive than normal white dwarfs if planets occur more frequently around intermediate mass stars. However, there exists theoretical and now some empirical evidence that certain types of planetary systems may induce significant mass loss on the first and asymptotic giant branches (Siess & Livio 1999a, 1999b). Nelemans & Tauris (1998) proposed a scenario to explain the formation of single, low-mass white dwarfs via enhanced mass loss due to planets or brown dwarfs which spiral into the first ascent giant envelope; this is essentially analogous to the standard (binary) formation scenario for low-mass, helium-core white dwarfs and subdwarf B stars (Han et al. 2002). Moreover, the 3 M_J planet orbiting the sdB star V 391 Pegasi (Silvotti et al. 2007) may have belonged to a multiple-planet system in which the innermost planet(s) were cannibalized to create the 0.5 $M_\odot$ helium-burning primary, which should evolve directly into a low-mass white dwarf. Therefore, any correlation between stellar mass and planet-disk frequency could be erased or marginalized by similar processes.

5. CONCLUSIONS

Our search for near-infrared excess at 15 metal-rich, helium atmosphere white dwarfs did not reveal any new evidence for disks. We tentatively conclude that circumstellar material is responsible for the photospheric metals in at least 20% of the hydrogen-rich white dwarfs and no more than 5% of the hydrogen-poor white dwarfs. The lower frequency of disks at externally polluted, helium-rich yet hydrogen-poor white dwarfs possibly reflects a typical disk lifetime which is at least an order of magnitude shorter than the 10^4–10^6 yr diffusion timescales for metals in pure helium atmospheres. On the other hand, the higher discovery rate of disks around metal-contaminated, hydrogen-rich white dwarfs (including types DAZ and DAZB) analogously reflects short diffusion times compared to disk lifetimes, which favor discovery of disks in metal line DA white dwarfs.

In addition, we searched for K-band flux variations in the DAZ WD 1150−153, and did not observe significant changes within 1.7 yr, implying that the warmest emitting material at the inner edge of the disk remains largely unchanged. We also studied the mass distribution of metal-rich white dwarfs

with disks in order to search for similar trends between the frequency of disks and the predicted frequency of gas giants around intermediate-mass stars, but given the current small number statistics and errors, the probability that dusty white dwarfs are more massive than normal white dwarfs is not significant.

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