Spitzer Search for Mid-IR excesses Around Five DAZs

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Abstract. Hydrogen atmosphere white dwarfs with metals, so-called DAZs, require external accretion of material to explain the presence of weak metal line absorption in their photospheres. The source of this material is currently unknown, but could come from the interstellar medium, unseen companions, or relic planetesimals from asteroid belt or Kuiper belt analogues. Mid-infrared photometry of these white dwarfs provide additional information to solve the mystery of this accretion and to look for evidence of planetary systems that have survived post main sequence evolution. We present Spitzer IRAC photometry of five DAZs and search for excesses due to unseen companions or circumstellar dust disks. Three of our targets show unexpected deficits in flux, which we tentatively attribute to absorption due to SiO and CO.

1. Introduction

White dwarfs have long been used to probe the low mass end of the IMF to look for low mass stars and brown dwarfs (Probst & Oconnell 1982; Zuckerman & Becklin 1992; Farihi et al. 2005). With the advent of more sensitive ground- and space-based imaging at longer wavelengths, the direct detection of substellar objects and planets with a few times Jupiter’s mass is now possible (Ignace 2001; Burleigh et al. 2002; Friedrich et al. 2005; Debes et al. 2005a,b).

Searching a subset of white dwarfs that harbor markers for substellar objects can maximize the return of such a survey. Nearby hydrogen white dwarfs with metal line absorption (DAZs) may fit this criterion. Three hypotheses have been put forth to explain the presence of DAZs: interstellar matter (ISM) accretion (Dupuis et al. 1992, 1993a,b), unseen companion wind accretion (Zuckerman et al. 2003), and accretion of volatile poor planetesimals (Alcock et al. 1986; Debes & Sigurdsson 2002; Jura 2003). Accretion of planetesimals is certainly the explanation for the disks around GD 362 and G 29-38, as well as other candidate dust disks found with near-IR excesses (Kilic et al. 2006). It is less clear that is the explanation for those white dwarfs without any noticeable near-IR excess.

With the launch of Spitzer an unprecedented sensitivity is now possible to further constrain the presence of companions in close orbits, as well as the presence of dusty disks around white dwarfs. A large interest in infrared excesses...
Table 1. Properties of the Target White Dwarfs

| WD              | $T_{\text{eff}}$ (K) | $t_{\text{cool}}$ (Gyr) | D (pc) | $M_i$ (M$_\odot$) | $t_{\text{cool}} + t_{\text{MS}}$ (Gyr) | References |
|-----------------|----------------------|-------------------------|--------|------------------|--------------------------------------|------------|
| 0208+396        | 7310                 | 1.4                     | 17     | 2.1              | 3.2                                  | 1          |
| 0243-026        | 6820                 | 2.3                     | 21     | 3.2              | 2.8                                  | 1          |
| 0245+541        | 5280                 | 6.9                     | 10     | 4.6              | 7.2                                  | 1          |
| 1257+278        | 8540                 | 0.9                     | 34     | 1.7              | 3.3                                  | 1          |
| 1620-391        | 24406                | 0.1                     | 12     | 3.1              | 0.7                                  | 2,3        |

(1) Bergeron et al. (2001) (2) Bragaglia et al. (1995) (3) van Altena et al. (2001)

around white dwarfs in general is evidenced by the many surveys of white dwarfs with Spitzer (Hansen et al. 2006; Kilic et al. 2006).

In this paper we present results of our search with Spitzer of five nearby DAZs with no known excesses for companions and circumstellar disks.

2. Observations

Table 1 shows our target DAZs, complete with known $T_{\text{eff}}$, log $g$, distances, and ages. Cooling ages were taken from the literature and initial masses and main sequence lifetimes were calculated by the equations of Wood (1992):

\[
M_i = 10.4 \ln \frac{M_{WD}}{0.49 M_\odot} \quad (1)
\]

\[
t_{\text{MS}} = 10M_i^{-2.5} \quad (2)
\]

Each target was observed with the four IRAC channels, with nominal wavelengths of $\sim$3.6, 4.5, 5.6, and 8.0 $\mu$m (Fazio et al. 2004). The observations were carried out in the mapping mode, with 30 random point dithers for each pair of channels. At each dither point, the camera integrated for 96 seconds, for a total of 2880 seconds in each band. The exception to this was WD 1620-391, which is a much brighter source. It had exposure times of 30 s per dither with 75 dithers for a total integration of 2250 s.

In order to obtain photometry with an accuracy of $\sim$3%, we followed the prescription laid out in Reach et al. (2005). With the exception of WD 0208+396, we took each target’s (BCD) files, divided them by correction files to negate array position dependent sensitivity, registered them, and median combined them to obtain a final image using the MOPEX package (Makovoz & Marleau 2005). We performed aperture photometry with a 5 pixel radius ($\sim$6") and used a 10 pixel wide annulus starting 10 pixels away from the source for background subtraction. Aperture corrections appropriate for this size source radius and background annulus were applied, as well as calibration factors and flux conversions as mentioned in Reach et al. (2005). Additionally, the change in total flux as a function of location within a pixel was accounted for in the 3.6$\mu$m channel. No obvious interstellar cirrus was noted for any of our targets in the 8$\mu$m channel.
For two of our targets, WD 0245+541 and WD 0208+396, we used smaller source apertures of 2 and 3 pixels respectively. For WD 0208+396, there appeared to be a large increase in flux as a larger radius was used, possibly due to two resolved background objects earlier reported in [Debes et al. (2005a, 2006)]. For WD 0245+541, several background objects are located at separations > 3" so the smallest aperture size was used to minimize their contribution to the flux. These two cases demonstrate why high spatial resolution sensitive imaging at shorter wavelengths must be performed for a believable claim of an excess, in order to rule out the small contribution from redder background sources.

Due to a large rate of solar protons, the observations of WD 0208+396 were degraded by a large flux of cosmic ray events. In this case median combination may mistakenly return a larger flux due to repeated cosmic ray strikes. For each channel, each dither point was visually inspected for obvious cosmic rays and if one was present near the target the image was rejected. The resulting collection of “good” images were median combined to give a final image. In addition to the standard errors in photometry, we added a 3% factor to account for the overall uncertainty in the flux calibrations quoted by [Reach et al. (2005)].

In order to detect a bona fide excess, one must compare the observed flux with an expected flux. In order to compare our observations we took the models of [Bergeron et al. (1995)] as well as the $BVRIJK$ photometry of [Bergeron et al. (2001)] for four of the five targets. WD 1620-391 was not part of [Bergeron et al. (2001)]’s survey and so we used a combination of USNOB, Hipparcos, and 2MASS photometry. We compared the photometry and predicted models to ensure a good fit, and then extrapolated the observed fluxes from the model K flux out to longer wavelengths under the assumption of blackbody emission using the model $T_{eff}$. The error in the extrapolation then comes solely from the error in the effective temperature. Since most of the observed BLR data fit within 1-$\sigma$ of the model, we required that a significant excess (deficit) be > three times the photometric error above (below) the calculated model flux in at least one channel.

3. Results

3.1. Significant Deficits

Figures 2 and 1 show the model fluxes and the measured fluxes for two of our DAZs, as well as the residuals. Three of the target DAZs show significant deficits in the four channels, namely WD 0208+396, WD 0245+541, and WD 0243-026. Their effective temperatures range from 5280 K to 7310 K, in a similar range to deficits detected in other DA stars within that temperature range [Kilic et al. (2006)]. We tentatively claim that the source of the opacity is non-LTE absorption by silicon monoxide, with possibly some contribution from carbon monoxide. Absorption due to fundamental and overtone rotational-vibrational bands of SiO and CO in late type stars is well known [Cohen et al. (1992)]. The dissociation temperature of SiO is high enough that it could persist at the temperatures of the stars in our sample, and CO could be present in the cooler stars. However, the absorption inferred is significantly higher than expected for LTE absorption at those temperatures and gravities.
We conjecture that SiO is formed above the white dwarf photospheres through photodissociation of silicon dioxide (and any CO present is similarly formed through photodissociation of carbonates) from refractory dust which sublimes as it is brought down to the the white dwarf surface through photon drag. The resulting SiO is formed at low densities above the photosphere, and is far from local thermodynamic equilibrium, with much larger absorption strengths than inferred from photospheric LTE.

3.2. Limits to Companions

For IRAC, very cool substellar objects can be detected as excesses, especially due to a “bump” of flux for brown dwarfs and planets at $\sim 4.5 \mu m$. While theoretical models predict the $4.5 \mu m$ flux to be large, observations of cool brown dwarfs suggest that the spectral models overestimate this flux by a factor of $\sim 2$ (Golimowski et al. 2004).

In order to place upper limits on the types of unresolved companions present around our DAZs, we compared predicted IRAC fluxes for cool brown dwarfs by convolving the IRAC filters with the models of Burrows et al. (2003) appropriate for the particular age of each target DAZ and its distance. For the $4.5 \mu m$ channel we assumed that the resultant flux was a factor of two smaller than predicted. We then compared our $4.5 \mu m$ $3\sigma$ limits to those models in order to determine a mass limit.

In all cases we improve the unresolved companion limits to these objects over Debes et al. (2005a) by a factor of 2-4. For WD 0208+395, WD 0243, and
2.0

2.5

3.0

3.5

4.0

log $\mu$Jy

Figure 2. SED of WD compared to predicted model values and the residuals. There is a deficit between the measured and expected flux.

WD 1620-391 we rule out all but planetary mass objects $<15 M_J$ for separations $<2.4''$. The other two DAZs have limits of $\sim 25 M_J$. In light of the fact that some of our sample have anomalous deficits, it should be noted that these limits may change as the source of the deficit is better understood.

4. Conclusions

Five DAZ white dwarfs have been observed with the Spitzer Telescope for excesses due to companions or dusty disks. We find no evidence of excesses, but we do find deficits in the flux on the order of 10-20% between 3.6 and 8 $\mu$m. These deficits require more study, either through spectroscopy of the white dwarfs or by better modeling of the white dwarf fluxes in the mid-IR. We plan to more carefully determine the expected flux of the white dwarfs by using models that extend into the mid-IR. The non-LTE behavior of dust grains impacting a white
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dwarf atmosphere is a new avenue of study that should provide further observational diagnostics of the type of material DAZs with no excess are accreting.

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