A Spitzer Warm Mission Proposal To Survey Single White Dwarfs

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Abstract. At least 2% of single white dwarfs with 10,000 K < T < 20,000 K have an infrared excess at 3.6 μm and 4.5 μm. A Spitzer warm mission survey of 1000 white dwarfs can enable an improved characterization of the occurence of an excess as a function of white dwarf properties such as age, mass and composition. The tidal-disruption of an asteroid is the most promising model to explain an infrared excess around a cool, single white dwarf, and thus this survey can help improve our understanding of extrasolar planetary systems.

Keywords: Spitzer Space Telescope, infrared astronomical observations, white dwarfs, stellar ages, stellar masses
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1. INTRODUCTION

An infrared excess produced by dust orbiting the white dwarf G29-38 was discovered 20 years ago (Zuckerman and Becklin [1]). It took 18 years for the second excess, that around GD 362, to be found (Becklin et al. [2], Kilic et al. [3]). Progress during the past year has been dramatic; there are now eight white dwarfs known to have an infrared excess (Mullally et al. [4], Farihi et al. [5], Jura et al. [6], Kilic et al. [7], Kilic and Redfield [8]). The Spitzer warm mission can be used to continue to improve our understanding of dust orbiting white dwarfs.

2. BACKGROUND

The most promising model to explain an excess around a white dwarf is that a minor-body is perturbed (Debes and Sigurdsson [9]) to orbit within the tidal radius of the star where it is destroyed and a dusty disk is produced (Jura [10]). Besides producing an infrared excess, accretion from this disk can pollute the white dwarf. Gravitational settling of heavy elements is so effective in white dwarfs cooler than 20,000 K that their atmospheres are expected to be pure hydrogen or pure helium (Paquette et al. [11]), and the $\sim$ 20% of these stars which exhibit photospheric metals are thought to be externally polluted. Since the gravitational settling times in a white dwarf's atmosphere for different elements vary by less than a factor of 2 (Paquette et al. [11]), the metal composition of the white dwarf directly measures the composition of the accreted material. Therefore, the atmospheres of white dwarfs with an infrared excess may provide a unique and powerful tool for studying the bulk compositions of extrasolar

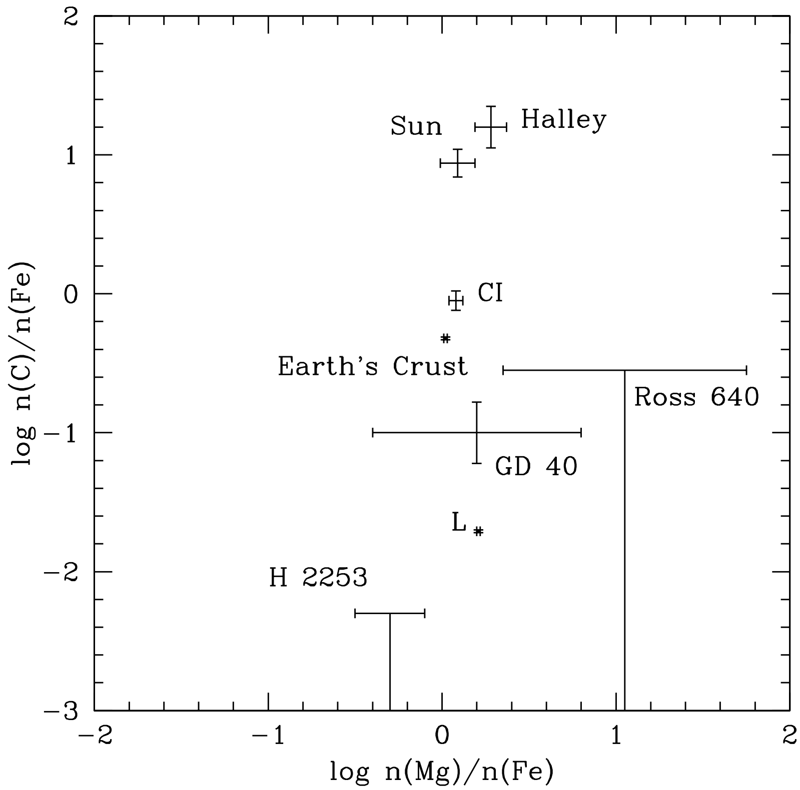

FIGURE 1. Abundance ratio of carbon to iron vs. magnesium to iron in the Sun, Halley's comet, the Earth's crust, CI chondrites, L chondrites and three externally-polluted white dwarfs (see Jura [12]). The accreted material onto white dwarfs is markedly deficient in carbon. From Jura [12]. Reproduced by permission of the AAS.

minor planets. Recent work shows that similar to both the Earth and even the most primitive meteorites, carbon is deficient relative to refractory atoms by more than a factor of 10 in the atmospheres of six white dwarfs[1].

To date, the white dwarfs with definite infrared excesses all possess dust as warm as 1000 K. A representative result showing a marked excess at both 3.5 μm and 4.6 μm is shown in Fig. 2 for GD 40, an externally polluted white dwarf with m_K = 15.6 mag and a value of *n*(C)/*n*(Fe) more than a factor of 30 below Solar.

Approximately 200 white dwarfs have been observed with the IRAC camera on Spitzer, and 8 stars are known to display infrared excesses. However, because of selection effects, the true frequency of white dwarfs with an infrared excess is unknown; a conservative bound is that at least 2% of white dwarfs with $10,000K < T_{eff} < 20,000K$ have an excess.

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[1] *n*(C)/*n*(Fe) is shown for three stars in Figure 1. GD 362 (Zuckerman et al. [13]) also has a markedly low value of *n*(C)/*n*(Fe) while GD 61 and PHL 962 are externally-polluted carbon-deficient white dwarfs with low values of *n*(C)/*n*(Si) (Desharnais et al. in preparation).

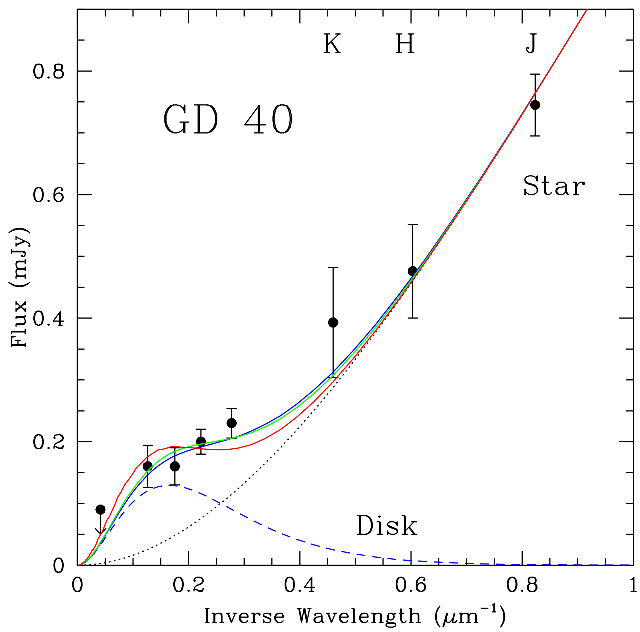

FIGURE 2. Comparison of models and data (2 errors) for GD 40. The plot shows the contribution from the stellar photosphere (dotted line), one disk model (dashed line) and totals for three models described in Jura et al. [6]. A representative model has an inner disk temperature of 1200 K and an outer disk temperature of 600 K; the dust lies well within the star's tidal radius. From Jura et al. [6]. Reproduced by permission of the AAS.

There are now enough white dwarfs with an infrared excess that it is possible to begin to discern some patterns. First, all the white dwarfs with an infrared excess also display atmospheric metals. Thus, it is highly plausible that the stars are accreting from reservoirs of circumstellar material. Second, Kilic et al. [7], Farihi et al. [5], Kilic and Redfield [8] have shown that the stars with relatively high calcium abundances also tend to display an infrared excess. Third, the stars with an infrared excess all have effective temperatures greater than $\sim$ 9500 K and white dwarf cooling ages less than $\sim$ 1 Gyr [2]. Figure 3 (taken from Jura et al. [6]) presents a comparison of $\dot{M}_{dust}$ vs. effective temperature for DAZs with IRAC photometry, distinguishing between those with and without excess emission.

There are many unknowns:

- Do stars with T < 10,000 K display infrared excesses as frequently as stars with T > 10,000 K? Cooler white dwarfs are older, and their asteroid belts may have been depleted.
- How robust is the correlation, based on a handful of stars, between accretion rate

[2] GD 362 previously was thought to be hydrogen-rich and have a relatively low luminosity and therefore a cooling age well in excess of 1 Gyr (Gianninas et al. [14]). However, the star is now known to be helium-rich and have a much larger luminosity and correspondingly shorter cooling age (Zuckerman et al. [13]).

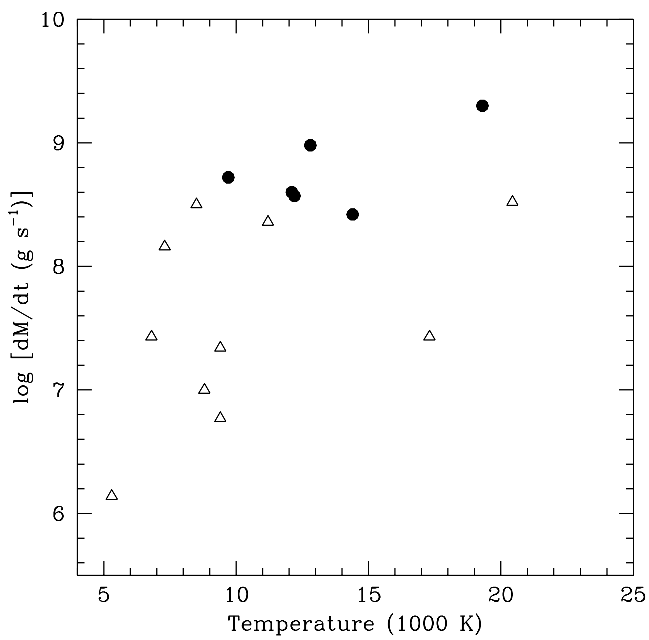

FIGURE 3. Mass accretion rates vs. effective temperature for hydrogen-rich white dwarfs with an excess (solid circles) and without an excess (open triangles) in published Spitzer data. GD 133 and PG 1015+161 (Jura et al. [6]), GD 56 (Jura et al. [6], Kilic et al. [7]), G29-38 (Zuckerman and Becklin [1]), WD 2115-560 (Mullally et al. [4], von Hippel et al. [16]), WD 1150-153 (Kilic and Redfield [8]) have an excess while EC 12043-1337, HE 1225+038, and HE 1315-1105 (Jura et al. [6]), WD 1202-232, WD 1337+705 and WD 2149+021 (Mullally et al. [4]), and WD 0208+396, WD 0243-026, WD 0245+541, and WD 1257+278 (Debes and Sigurdsson [17]) do not. Two helium-rich white dwarfs (GD 40 and GD 362) that also display an excess are not shown here. From Jura et al. [6]. Reproduced by permission of the AAS.

and the presence of an infrared excess? Why do some externally-polluted white dwarfs display an excess, but most do not? Are there different modes of accretion?

- Is there any correlation between having an infrared excess and the mass of the white dwarf?
- Is there any difference between the fraction of helium-rich and hydrogen-rich white dwarfs with an infrared excess?
- Is there any correlation between having an infrared excess and the chemical composition of the accreted material? Are all externally-polluted stars also carbon deficient? What is the fraction of white dwarfs with detectable gaseous disks (Gaensicke et al. [15]) and do these stars also have infrared excesses?

3. EXTENDED-MISSION PROPOSAL

A survey of the $\sim$ 1000 single white dwarfs that are brighter than $m_K \approx$16 mag to measure 3.6 μm and 4.5 μm fluxes of 100 μJy is possible with the Spitzer warm mission. (The IRAC data shown in Fig. 1 for GD 40 (m_K = 15.6 mag) were obtained with a total of 600 seconds of integration time.) To date, the most extensive IRAC survey of white dwarfs was by Mullally et al. [4] who observed 124 white dwarfs at 4.5 μm and 7.9 μm. A preliminary estimate is that the proposed survey requires $\sim$200 hours of telescope time. By substantially increasing the number of observed stars, it should be possible to understand better the origin and evolution of dust orbiting white dwarfs. In turn, spectroscopic studies of these stars can enable a better quantitative measure of the bulk compositions of extrasolar minor planets.

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