Planetary systems around young stars

– an alternative approach –

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Introduction

White dwarfs come in two main varieties – those with hydrogen atmospheres (spectral type DA) and those with helium atmospheres (DO, DB and others). All heavier elements are absent or at most present as tiny traces with abundances much below their solar abundance. The standard explanation for these spectral types is gravitational settling: all heavy elements sink down in the extremely high gravitational fields, and only the lightest element present floats to the top. This separation is a diffusion process and the diffusion timescales are always very short compared to evolutionary timescales, from a few days for hot and young white dwarfs to millions of years at the cool end of the evolutionary sequence.

Why do we then see some white dwarfs with heavy metals at all? Traditionally, these have been a few "freaks", but with the larger telescopes the number has been growing steadily, reaching now numbers of 25 or even 50%.

What is the source of these metals?

The most obvious idea, dominating for several decades because of the lack of a real alternative, has been the assumption of accretion from the interstellar medium. This could partly explain the observations, but there have always been at least two serious problems:
- the needed accretion rates could only be reached in dense ISM clouds, but these are absent in the solar neighborhood, were all the brighter white dwarfs are found
- hydrogen is generally not accreted, at least not in the proportions of the ISM (this can be determined for the DB white dwarfs, where hydrogen should accumulate at the top). Attempts to explain this have not been convincing

Paradigm change and new chances

In the last decade with powerful infrared telescopes in space and on the ground, infrared excesses from dusty disks were detected around about 30 white dwarfs. All of these white dwarfs were also "polluted" by heavy metals, making the connection between the two observations unavoidable. Since the disks are always within the tidal radius of the white dwarf (approximately one solar radius) it is now common consensus within the white dwarf community that the dust originates from the tidal disruption of a rocky remnant ("asteroid") of a planetary system around the progenitor star. **This opens up a completely new avenue for the study of exoplanetary systems, in particular their chemical composition.** A general first order result so far is that this composition is very similar to Bulk Earth composition, dominated by the elements oxygen, silicon, magnesium, and iron, which together are about 95% of the Bulk Earth composition. Since Siyi Xu at this workshop will talk about the aspect of composition, I will here emphasize the statistics of planet formation from the white dwarf point of view.

A COS/HST snapshot survey (PI Boris Gänsicke)

We conducted the largest survey for metal pollution in DA white dwarfs using the Cosmic Origins Spectrograph on-board the Hubble Space Telescope in the far ultraviolet range between 1130 and 1435 Å. With a resolution of 0.1 Å and good S/N this search was even more efficient than optical searches with VLT and Keck, because of the strong lines of SiII, CII, and OI in this range in white dwarfs between 17000 and 25000 K. We analyzed the spectra with theoretical models and determined the element abundances in the photosphere.

Of the 85 DAs analyzed, 48 (56%) show photospheric silicon. In 23 (27%) the metals must come from current accretion. In the remaining 25 silicon can be currently supported in the atmosphere by radiative levition; we argue, however, that also in these accretion must have occured very recently, because the support was not efficient enough in earlier evolutionary phases. With our current understanding of the origin of these metals from circumstellar debris disks, **we thus conclude that between 27 and 56% of white dwarfs show the remnants of a former planetary system**.

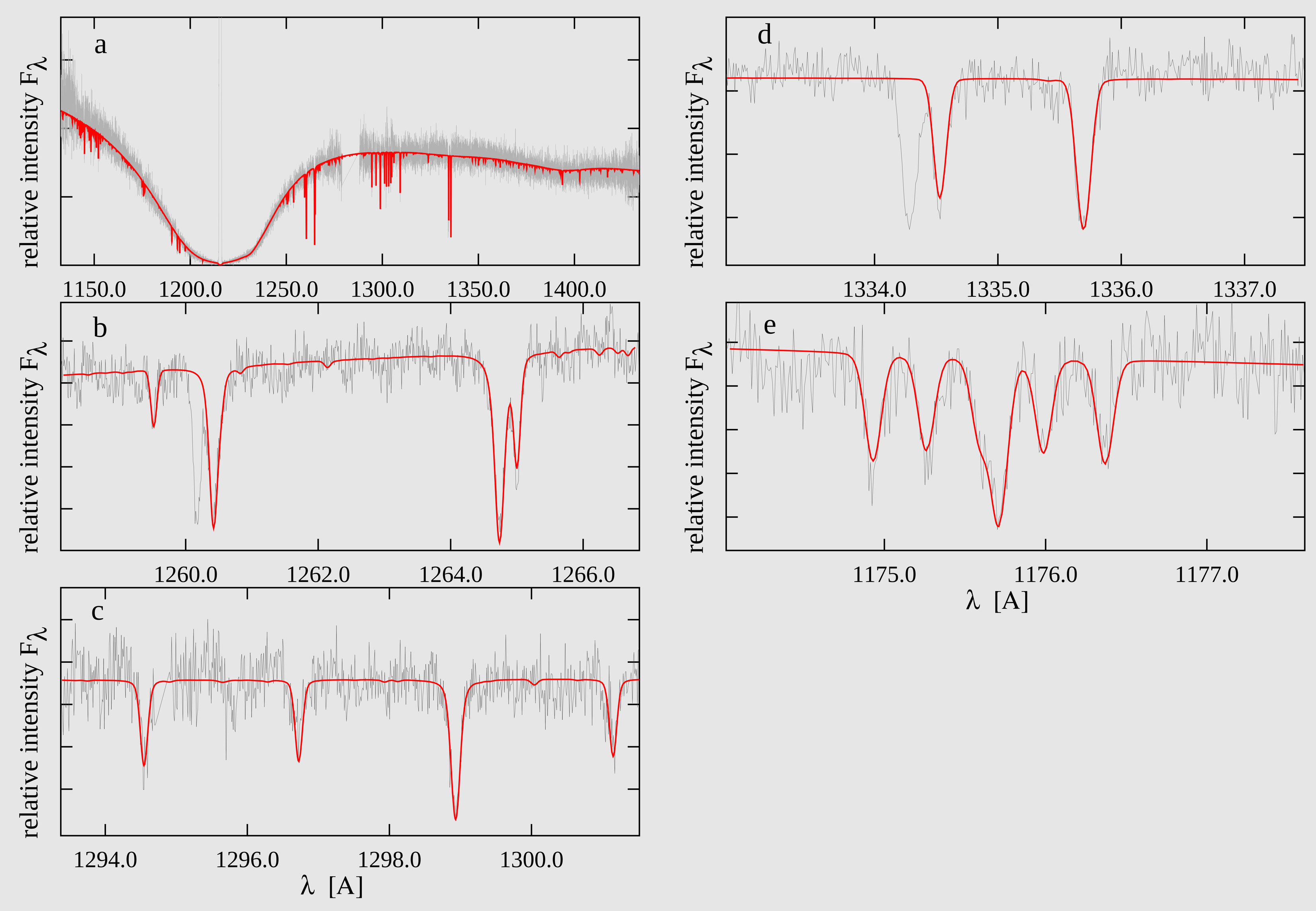

Fig. 1: Example spectra with the important lines for this work. The panels show:
a) complete COS spectral range for WD 1943+163 with typical signal-to-noise and relatively large Si and C abundances.
b) SiII 1260.422, 1264.738, 1265.002 Å. Note the strong blue-shifted interstellar component of the resonance line 1260.422 Å. The sulfur SI 1259.519 Å line is also visible at the photospheric position.
c) SiII 1294.545, 1296.726, 1298.892, 1298.946, 1301.149 Å lines.
d) CII 1334.530, 1335.660, 1335.708 Å lines, with interstellar component of the resonance line 1334.530 Å.
e) CIII 1174.930, 1175.260, 1175.590, 1175.710, 1175.987, 1176.370 Å lines.
The continuous (red) lines are the theoretical model.

Figure 1 shows a typical spectrum with the most important spectral lines. From the atmospheric abundances we determine the composition of the accreted material, using the equations of diffusion equilibrium (mass flux = constant = accreted flux. Figure 2 shows the total mass accretion fluxes derived from this work (red), together with data from the literature (black). The total accretion rates occupy a constant range between $10^{5.5}$ to $18^{8.5}$ g/s over a huge range of stellar parameters: effective temperatures from 5000 to 25000 K, ages from 20 to 5000 Myr, and diffusion timescales from days to Myrs.

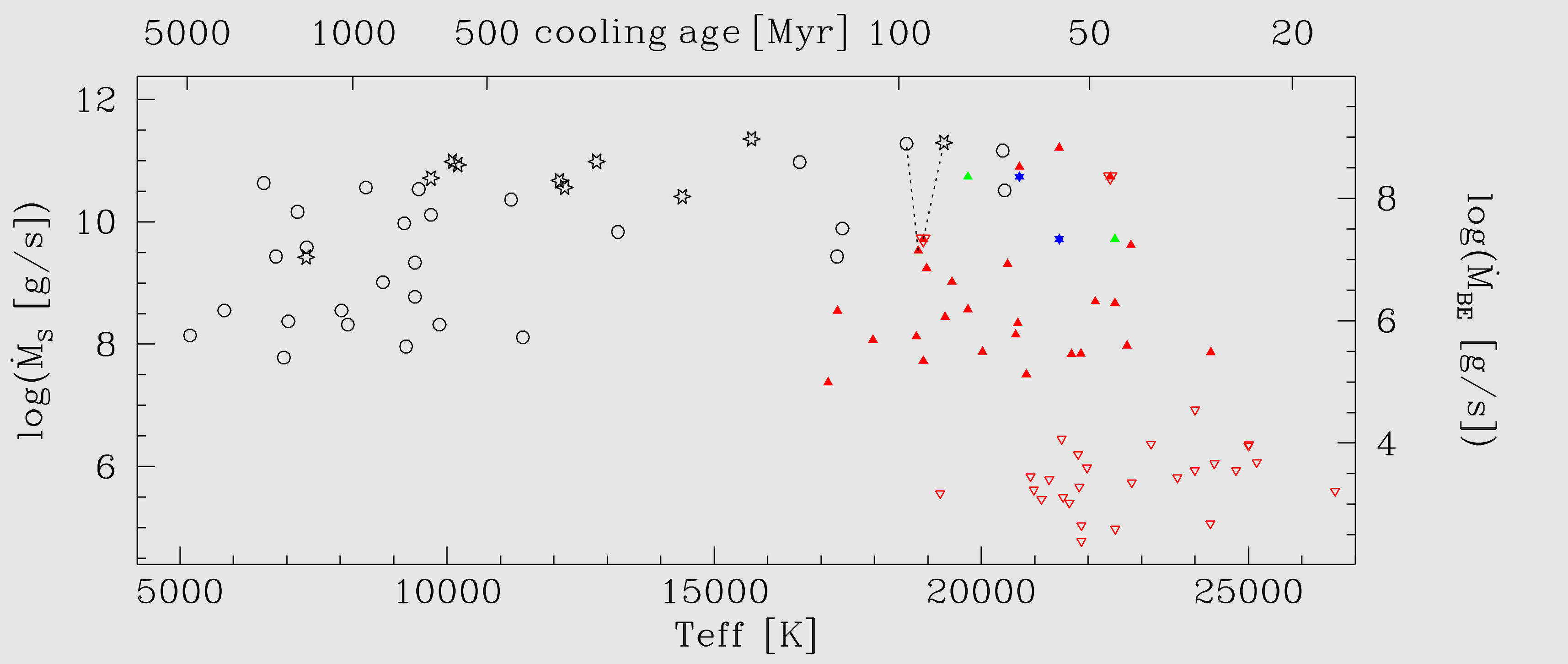

Fig. 2: Total accretion fluxes for polluted DA white dwarfs derived using the standard assumption of molecular diffusion (right scale assumes Bulk Earth ratios). Note the constant range over a very large range of stellar parameters and observed Ca or Si abundances from 10^{-12} to $10^{-4.5}$. The open triangles in the lower right show Si supported by radiative levitation, where the accretion fluxes are upper limits and can be zero.

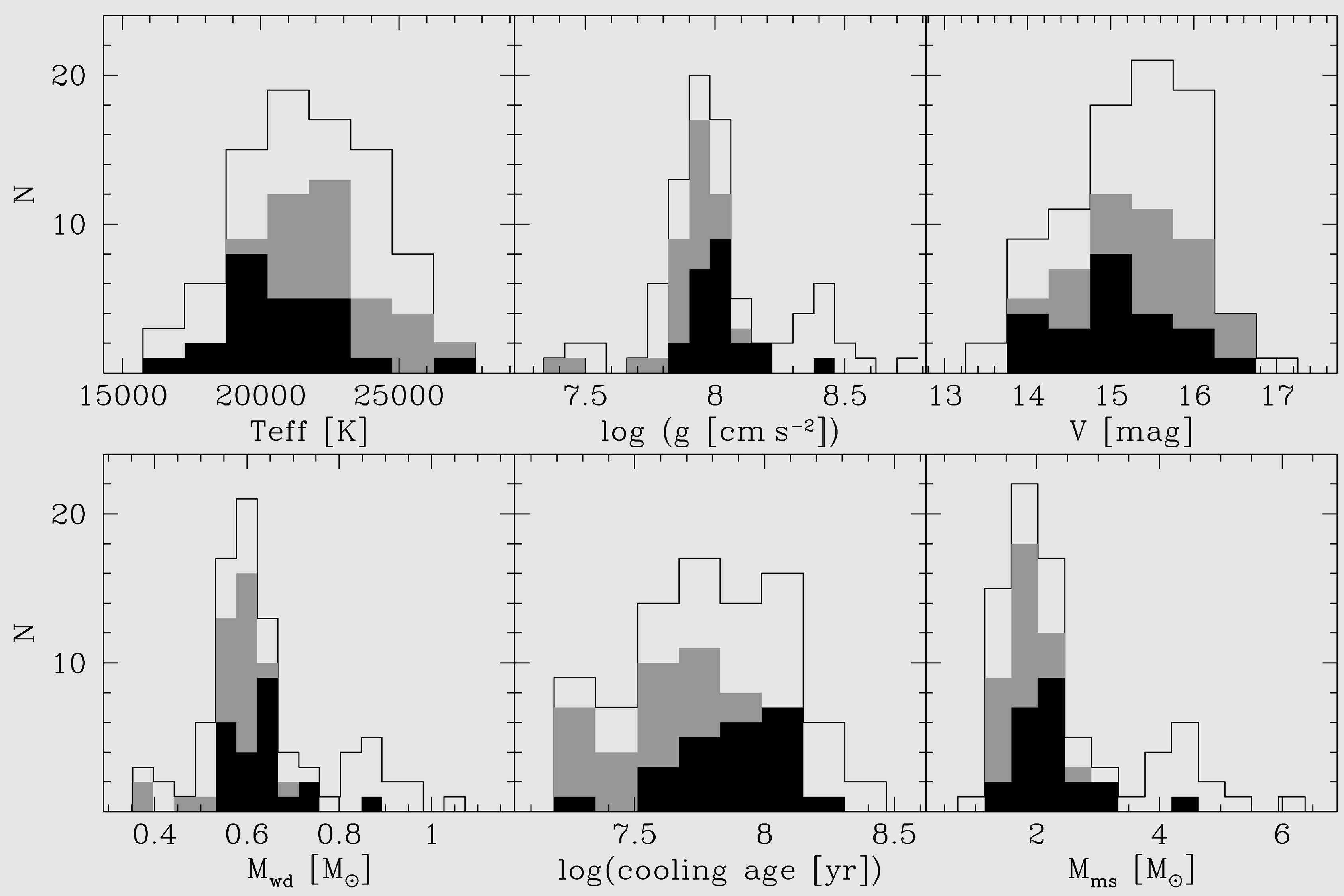

Fig. 3: Fundamental properties of the DA stars observed in this HST/COS far-ultraviolet spectroscopic survey. From top left to bottom right: effective temperature and surface gravity, V-band magnitude, white dwarf mass and cooling age computed from $T_{\rm eff}$ and $\log g$ using cooling models, and the main-sequence progenitor mass computed with an initial-to-final mass relation. The full sample is indicated by the outlined histogram. 48 white dwarfs where at least photospheric Si has been detected are shown with the filled histograms, of which 23 must be currently accreting (black). The remaining 25 (grey) have Si abundances consistent with support from radiative levitation alone, and have very likely accreted in the recent past.

Results and conclusions

Many objects show several more metals beyond Si. The abundance ratios provide information about the composition of the accreted material, which is then compared to known rocky material in our own system. Results are published in separate papers **(note also talk by Siyi Xu at this workshop!)**
In the present context we emphasize one statistical result of this large study. The vast majority of exoplanet searches have focused on FGK type host stars, with masses of 0.5-1.5 $M_\odot$. Consequently, our current knowledge of the frequency of planet hosts with $M > 1.5\,M_\odot$ is limited. As Fig. 3 shows, the host masses of our sample are in the range 1.5-4.5 $M_\odot$, with a median of 2 $M_\odot$.
We can thus conclude that at least 27%, more likely 56% of main sequence stars in this mass range produce rocky material around them, which survives evolution until the final stage. It appears that the formation of planetary systems is common around 2-3 $M_\odot$ late B- and A-type stars.

Collaborators and literature

This particular study was conducted with Boris Gänsicke (University of Warwick, UK), and Jay Farihi (University of Cambridge, UK). Further collaborators in the general field of metal pollution, accretion, exoplanetary composition are Ben Zuckerman, Mike Jura, Beth Klein (UCLA, US), Siyi Xu (ESO), and many others.
More details of this work, as well as many references, can be found in
D. Koester, B.T. Gänsicke, J. Farihi (2014, Astron. Astrophys., 566, A34)
"The frequency of planetary debris around young white dwarfs".