Photospheric Ca and Mg line-strength variations in G29-38

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Abstract. Temporal variations in metal-line strengths in H-atmosphere white dwarfs hold the potential to test the timescales of gravitational settling theory. These short timescales, in turn, require that DAZs are currently accreting. Such temporal variations would also indicate that accretion from a circumstellar dust disk can be episodic. We are compiling increasing evidence for time-variable Ca and Mg line-strength variations in the best studied DAZ, G29-38. Our evidence to date supports the gravitational settling timescales of Koester & Wilken (2006) and episodic accretion from G29-38’s debris disk. Furthermore, we have detected evidence for time-variable accretion with a timescale \( \leq 24 \) hours, and typical variability of \( \sim 4\% \) during the 100 days of our autumn 2007 monitoring campaign.

1. Introduction

The presence of heavy elements in the photospheres of many hydrogen-dominated (DA) white dwarfs (WDs) runs counter to our expectation. The high surface gravities of WDs cause their atmospheres to become highly stratified, and for \( T_{\text{eff}} < 22,000 \) K, heavy elements should settle out of the photosphere on timescales of \( 10^{-2} \) to \( 10^{9} \) years (Dupuis et al. 1992; Koester & Wilken 2006), depending on the mass and surface temperature of the white dwarf. Yet most WDs are old, and almost every known DAZ, as these stars are now called (Sion et al. 1983), has been cooling as a WD for at least \( 10^{8} \) years. DAZ stars must be currently accreting heavy elements. We have argued elsewhere (von Hippel et al. 2007) that most DAZs, and perhaps all, are accreting from circumstellar dust disks, rather than from the interstellar medium. We will not reconsider that argument here, as our focus is on G29-38, a DAZ with a known dust disk. (Where the dust disk is detected as an infrared excess, we abbreviate the system DAZd, DZd, DBZd, etc.) In this paper, we will focus on the accretion process from the disk to the WD’s photosphere.
1.1. What is reasonably understood
We understand that the major constituent of WD disks is silicates (Reach et al. 2005; Farihi, et al. 2009), and that this material is accreted from disks onto WDs at a rate of order $10^{-17} M_\odot$ yr$^{-1}$ (Koester & Wilken 2006, with the rate corrected for circumstellar rather than ISM accretion). This material is refractory-rich, C-poor (Jura 2006; Zuckerman et al. 2007), and grossly underabundant in H and He (Reach et al. 2005; Gänsecke et al. 2006). We do not expect the luminosity, radius, or effective temperature of an accreting WD to be noticeably affected, since the accretion luminosity is only of order $10^{-10} L_\odot$.

1.2. What is not understood
Theory substantially lags observation for DZd systems. At present, we do not know how these disk were formed, though we believe that the tidal destruction of asteroids or other minor planetary bodies played a key role (Jura 2003). We do not know how the complex set of dynamical interactions that take place after the mass-losing AGB phase could yield so many DZd systems, especially if this mechanism is responsible for all DZs, which account for ~ 25% of all WDs (Zuckerman & Reid 1998). If we could understand the dynamical history of DZd systems, we would probably discover important new constraints on the prevalence and architecture of planetary systems. We may also learn more about AGB mass loss.

The WD disks themselves are poorly understood. While an optically thick, physically thin disk model approximately fits many of these systems (von Hippel et al. 2005; Jura, Farihi, & Zuckerman 2007), other systems do not fit this simple model (Jura et al. 2007). Nor do we know if the disk evolves through viscous dissipation, Poynting-Robertson drag, or some form of magnetic instability. Without this knowledge, we do not know if these disks start out as relatively massive entities that erode with time, or whether they have short lifetimes but are often replaced by new infalling material.

We also do not know the dominant accretion mechanism that moves material from the disks to the WD photospheres. None of the DAZd WDs are known magnetics, though magnetic fields could play a key role. At present, there are only two constraints on the accretion mechanism, besides the accretion rate itself. One is the preliminary result reported by Montgomery, Thompson, & von Hippel (2008) that G29-38 is accreting onto its equator, rather than uniformly, or onto its poles. The other is that G29-38 is accreting episodically (von Hippel & Thompson 2007). We follow up on the latter discovery in this conference paper.

2. The case for metal-line variability in G29-38
The case for metal-line variability in G29-38 was first made by von Hippel & Thompson (2007), then questioned by Debes & Lopez-Morales (2008). Here we present our further efforts to demonstrate that G29-38 is accreting in a time-variable manner, and characterize that variation.

In the spirit of a conference, our data and analysis represent a work in progress. Indeed, as we submit this article, we are still acquiring more data on G29-38’s Ca and Mg abundances at both Gemini North and the Hobby-Eberly Telescope.

Figures 1 and 2 presents our preliminary Ca and Mg EWs from our autumn 2007 monitoring program. Each data point has two sets of error bars. The inner set of error bars represent the 1σ scatter in the equivalent width (EW) measurement due to Poisson noise in the spectrum and any sky subtraction issues. The outer set of error bars includes these effects, as well as a conservative 1σ estimate of surface temperature variations affecting the line strengths during the exposure. We have not yet taken continuum measurement errors into account, which we estimate could increase the total error bar by as much as 50%. Assuming our errors are approximately correct, the distribution of points is completely inconsistent with constant Ca and Mg line strengths, and therefore inconsistent with steady-state accretion from the disk.
Figure 1. Ca EW as a function of time. The normalization has been adjusted upward by 4.7% for the HET data, which compensates for differences in how our technique measures EW between the moderate resolution Gemini and high resolution HET data. These were our best error estimates as of the conference. On-going analysis indicates that there may be an increase in these errors by as much as 50% due to noise in the continuum.

2.1. Could rotation with spots cause Ca/Mg EW variability?
G29-38 is rotating with a velocity, \( v \sin(i) = 11–28 \text{ km s}^{-1} \) (Berger et al. 2005). This corresponds to a rotation period of 900–2400 s or 2000–5000 s, assuming a radius consistent with \( \log(g) = 8.14 \) (Bergeron et al. 1995) or 7.9 (Koester et al. 2005), respectively. Our VLT and Keck time-series observations cover 4.72 and 6.14 hours, respectively, so if the star had a strong spot, any metal-line modulation caused by the spot would have to have been meaningfully longer than 6 hours, which is inconsistent with the measured rotation rate. Additionally, the Ca and Mg variations should be modulated on the same timescale, for which we see no evidence.

3. The data at face value: implications
In the following, we assume that 1) the metals are accreting onto G29-38 uniformly over the surface, 2) gravitational settling theory is correct, and 3) that accretion never stops, but may decrease or increase. While item #1 may be incorrect (see Montgomery et al. 2008), our calculations are meant to serve only as a guideline. Further refinements, of the order of the area of the accretion surface divided by the total surface area of the WD, can be made once we learn more about the accretion geometry. Since there have been no observational tests of item #2 to date, with the exception of the general consistency of the observed variability (von Hippel & Thompson 2007) at an appropriate timescale, we assume the timescales of Koester & Wilken (2006). Item #3 just states that we do not assume that accretion ever shuts off, and therefore a
3.1. Decreases in Ca & Mg line strengths
Since we have not yet fully inter-calibrated the HET and Gemini EWs, we restrict our comparisons of EW variations to be within either the HET or Gemini data sets. We find three instances where the Ca EW declines, two within the HET data and one within the Gemini data. In those three cases, we find that the timescale for Ca depletion is ≤ 32.4, ≤ 39.8, and ≤ 52.3 days. We find one such instance involving 3 epochs for the Mg EWs within the Gemini data where we find the timescale for Mg depletion is ≤ 66 days. The calculations of Koester & Wilken predict settling timescales (depending on which \( \log(g) \) value is used) of \( \sim 13–23 \) days for Ca and \( \sim 20–36 \) days for Mg, respectively. Our data support these timescales.

3.2. Increases in Ca & Mg line strengths
The fastest rise in accretion occurred between epochs 5 & 6 in the HET data. This was an increase from 220 ± 11 to 249 ± 8 mA in 0.99 days, or 13% (though only a marginal 2.1\( \sigma \) result). If we compare this relative accretion rate change with the theoretical accretion rate (Koester & Wilken 2006, again reduced by 50 × assuming G29-38 is only accreting metals, not the Solar mixture), this corresponds to an increase of \( \sim 130 \) metric tons per second. Assuming a porous silicate structure with density \( \sim 2 \) g cm\(^{-3} \), this corresponds to accreting one extra 2.5 m radius rock per second or one extra 112 m boulder in the unobserved 24 hour period. We do not know, however, if this accretion takes place quickly enough to happen in the solid phase, or
whether this material is slowly brought in as gas.

3.3. How variable was accretion (while we were looking)?

The mean Ca EW difference between adjacent epochs (e.g., epoch1 − epoch2 or epoch4 − epoch5) was 13 mA for the Gemini data, whereas the average error bar was 7 mA. Subtracting these numbers in quadrature yields an average variation of 11 mA, or 4%, between epochs. (Increasing the error bars by 50% would mean an average variation of 8 mA, or 3%). The HET data also yield an average variation of 11 mA. The maximum observed variation was 31 mA (11%) in the Gemini data and 39 mA (16%) in the HET data.

The mean difference between adjacent epochs for Mg from the Gemini data was 10 mA with an average error of 4 mA, or a result of 9 mA (18%). The largest Mg change was 20 mA (41%), though Mg is weaker and more difficult to measure, and therefore the results are not as firm.

If we just use the (more conservative) Ca numbers, then G29-38 had typical accretion variations of only 4% during this period. If we imagine the accretion process to be a series of discrete rocks or dust blobs all of the same mass hitting the surface, then we can estimate the number and mass of rocks/blobs hitting the surface with simple Poisson statistics. The 4% scatter we see would imply \( \sim (4\%)^{-2} = 625 \) discrete Ca sources per typical inter-epoch period of 8 days. More likely, a power-law source of rocks or dust blobs is responsible, rather than a Poisson distribution, and this number would be characteristic of the larger accreted rocks/blobs.

4. Conclusions

The convincing measurement of time-variable metal-line strengths in any DAZ would indicate both that the timescales for gravitational settling theory are broadly correct and that accretion from the dust disk is episodic. The former is important, since it is the primary motivator for the interpretation of on-going accretion and the mystery of the DZ phenomenon. The latter may offer some insights into the accretion physics, which at present are not even sketched out. We are compiling increasing evidence for time-variable metal-line strength variations in the best studied DAZ, G29-38. Our evidence to date broadly supports the gravitational settling timescales of Koester & Wilken (2006) and episodic accretion from G29-38’s debris disk. Furthermore, we have detected evidence for time-variable accretion with a timescale \( \leq 24 \) hours, and typical variability of \( \sim 4% \) during the 100 days of our autumn 2007 monitoring campaign.

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