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Thermohaline Instabilities Induced by Heavy Element Accretion onto White Dwarfs: Consequences on the Derived Accretion Rates.

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Abstract. Heavy elements are observed in the atmospheres of many DA and DB white dwarfs, and their presence is attributed to the accretion of matter coming from debris disks. Several authors have deduced accretion rates from the observed abundances, taking into account the mixing induced by the convective zones and the gravitational settling. The obtained values are different for DA and DB white dwarfs. Here we show that an important process was forgotten in all these computations: thermohaline mixing, induced by the inverse μ -gradient built during the accretion process. Taking this mixing into account leads to an increase of the derived accretion rates, specially for DA white dwarfs, and modifies the conclusions.

1. Introduction: heavy elements accretion onto white dwarfs

An increasing number of DA and DB white dwarfs observed with Spitzer show infrared excess due to circumstellar disks (Farihi (2011); Xu & Jura (2012); Girven et al. (2012); Brinkworth et al. (2012)). In the mean time, high-resolution spectroscopy reveals the presence of heavy elements in the spectra of many white dwarfs (reclassified as DAZ and DBZ) with effective temperatures below 25000 K (Zuckerman et al. (2007); Klein et al. (2010b), Klein et al. (2010a); Vennes et al. (2010); Zuckerman et al. (2011); Dufour et al. (2012)). This was unexpected in such stars because heavy elements rapidly diffuse in the deep layers as a result of the very short gravitational settling time scales. The radiative accelerations which can balance gravity and support some heavy elements in hot white dwarfs (Vauclair et al. (1979); Chayer et al. (1995)) is no longer operating in such cooler white dwarfs. These observations support the idea that heavy elements are presently being accreted from circumstellar debris disks. The tidal disruption of asteroid-like bodies may be the source of the disk material polluting the white dwarf atmospheres (Jura (2003)). The determination of the abundances of the heavy elements present in white dwarfs atmospheres may lead to an evaluation of the accretion rates, with the help of stellar models. It is then possible to determine the mass and composition of the body whose disruption is at the origin of the pollution. Up to now, such estimates have been obtained with the assumption that the accreting material is mixed into the outer convective zone and diffuses at its bottom due to gravitational settling. The derived accretion rates differ by several orders of magnitude between DAZ and DBZ (Farihi et al. (2012)), which is difficult to understand and does not seem to have

any physical meaning. Here we show that these derived accretion rates are not correct, because a fundamental physical process has been forgotten in all these previous studies: thermohaline convection due to the accretion-induced inverse μ -gradient. As a consequence, the mixed zone is much deeper than the classical convective zone, and the accretion rates are larger than those presently determined. We show here an example of computations of this effect for a DA white dwarf. Due to the initial μ value, larger for helium than for hydrogen, and to the different internal structure, thermohaline mixing is less efficient in DB than in DA white dwarfs, for the same amount of accreted matter. This will be discussed in a forthcoming paper. We expect that this may reconcile the accretion rates needed to account for the observations of DAZ and DBZ white dwarfs.

2. Thermohaline convection in stars

Thermohaline convection, well known in oceanography, is now recognized as a major mixing process which occurs in stars in the presence of an inverse μ -gradient associated with a stable temperature gradient, so that the medium as a whole is dynamically stable. If a blob begins to move down, the heat exchange with its surroundings occurs more rapidly than the particle exchange so that the blob goes on falling, thereby triggering the instability (see Vauclair (2004), Vauclair & Théado (2012), and references therein).

Various situations may lead to thermohaline convection in stellar interiors. One of them is the accretion of heavy matter onto the star, which may be due to planetary material (Vauclair (2004), Garaud (2011), Théado & Vauclair (2012)) or to an evolved companion in a binary system (e.g. Stancliffe et al. (2007), Thompson et al. (2008)). Thermohaline convection develops if:

$$1 \leq R_0 \leq \frac{1}{\tau} \quad (1)$$

where:

$$R_0 = \frac{\nabla_{ad} - \nabla}{|\nabla_\mu|} \quad (2)$$

and τ is the inverse Lewis number, equal to the ratio of the particle diffusivity to the thermal diffusivity. Here ∇_{ad} and ∇ are the usual temperature gradients and ∇_μ stands for $d \ln \mu / d \ln P$.

Thermohaline convection must clearly occur at the bottom of the outer convective zone in accreting white dwarfs. This process strongly modifies the downward mixing of the accreted matter and must be taken into account for determining the accretion rates. Here we present preliminary results obtained for the computation of thermohaline time scales in a DA white dwarf model, with parameters representative of the star G29-38: $M_*/M_\odot=0.59$, $M_H/M_*=5 \times 10^{-10}$, $M_{He}/M_*=2.5 \times 10^{-2}$, $L/L_\odot=0.0026$, $T_{eff}=11100$ K as derived from asteroseismology (Romero et al. (2012)). These results can already lead to the conclusion that the effect is very important for DAZ and may increase the derived accretion rate by several orders of magnitude

3. Consequences for accreting white dwarfs

The accretion/mixing process described in section 2 is expected to occur in white dwarfs in the same way as in accreting main sequence stars. When a DA or DB white dwarf accretes heavy matter from a debris disk, the same events as described in Vauclair (2004) occur successively. The new chemical elements are mixed in the convective zone, but they do not stay inside this zone because of the induced inverse μ -gradient. First dynamical convection occurs below the Schwarzschild zone, as predicted by the “Ledoux criterion”, until the R_0 ratio becomes equal to one. Then thermohaline convection begins, and the accreted matter is diluted far below the dynamical convective zone.

For the considered DA model, we have computed the gravitational diffusion time scale for calcium, in the same way as in Théado et al. (2009), and the thermohaline convection time scale, computed with the Vauclair & Théado (2012) thermohaline mixing coefficient, as a function of the external mass, between the bottom of the convective zone and the H-He transition zone. The thermohaline time scale is computed as the time needed for the accreted matter to reach the considered layer. We find that the thermohaline time scale is several orders of magnitude smaller than the gravitational diffusion time scale, as expected. The values below the convective zone may be as low as a few minutes for the thermohaline time scales, compared to a few years for the diffusion time scale. At the bottom of the hydrogen zone they become closer, of the order of one year for thermohaline, ten years for diffusion. This means that the accreted matter is rapidly mixed in all the hydrogen layer. Thermohaline mixing is completely stopped at the transition region, because of the μ increase induced by the increasing amount of helium.

These preliminary computations prove that the accretion rates needed to account for the heavy element abundance observations are much larger than generally assumed. Reaching a present μ value of 0.5005 as observed in G29-38 would need an original μ value as large as 0.532. This is probably too large to correspond to a single accretion episode. Time dependent computations with several smaller accretion episodes are needed to go further. This is a work in progress.

4. Conclusion

We have shown that the accretion of heavy elements onto white dwarfs induces a thermohaline instability due to the created inverse μ -gradient. The accreted material is mixed down in a much deeper part of the star than the usually considered convective zone. In our preliminary study of this effect in a representative DAZ model close to G29-38, the accreted heavy elements are diluted in a fractional mass of the star 10^3 larger than the mass of the convective zone. It follows that accretion rates should be 10^3 larger to produce the observed abundances of heavy elements. The effects of thermohaline instabilities in DAZ with larger hydrogen mass fractions and in DBZ are under study. We expect the thermohaline convection to be less efficient in DB than in DA white dwarfs due to the different initial μ value and the different internal structure. In any case, we demonstrate that this special convection process has to be taken into account in all computations of the accretion rates needed to account for the observations. It will reduce and may even suppress the differences in the accretion rates needed to

account for the observations of DAZ and DBZ stars. This will be presented in a forthcoming paper.

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