HYDROGEN BURNING ON A WHITE DWARF ACCRETING HYDROGEN IN A BINARY SYSTEM

S. A. GLASNER, G. RAKAVY, and Y. TUCHMAN
Department of Theoretical Physics, Racah Institute of Physics, Hebrew University, Jerusalem, Israel

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Abstract. We follow the accretion of hydrogen-rich matter onto the surface of a white dwarf in a close binary system. Two phases of accretion are assumed. First—slow accretion from the interstellar clouds, second—fast accretion from the companion.

Hydrogen is ignited at the interface between the fast and slowly accreted layers. After a short runaway burning continues in the form of quasistationary deflagration front propagating inwards. The features of this front are discussed. A possibility of mass loss is indicated.

1. Introduction

We consider a binary system with a white dwarf as one of its components. As long as the companion star does not overflow its Roche lobe, the white dwarf accretes matter from interstellar clouds. In this process of slow accretion a non negligible hydrogen rich envelope is formed. When the companion emerges from its Main Sequence state, it expands and overflows its Roche lobe, the accretion rate on the white dwarf becomes much faster. When the accreted envelope becomes thick enough, hydrogen is ignited.

In the literature, hydrogen accretion with a single rate, usually the slow one, was considered (Giannone and Weigert, 1967; Taam and Faulkner, 1975; Taam, 1979; Sugimoto et al., 1979; Kutter and Sparks, 1980). In these calculations the hydrogen is always ignited at the base of the envelope.

In the process we consider here, accretion in two phases, a new kind of phenomena arises; hydrogen burning is ignited near the interface between the old, slowly accreted, and the new, fast accreted, hydrogen (hereafter the SFA interface). Ignition is far above the core's surface. After a short thermal runaway a burning shell is created in the form of a stationary deflagration front propagating downwards into the unburnt fuel. This behaviour differs considerably from the phenomena following ignition at the base of the envelope, considered in previous publications.

2. The Accretion Process

We start with a helium white dwarf of $0.76 M_\odot$. The initial model has a point source of $3 \times 10^{-2} L_\odot$ at the center. At time $t = 0$ we remove the heat source and let the star relax until the luminosity is $2.5 \times 10^{-2} L_\odot$. At this stage we start the accretion process.

Accretion rates for slow accretion are in the range of $3 \times 10^{-15} - 3 \times 10^{-13} \, M_\odot \, yr^{-1}$ (Bondi, 1952). Truran et al. (1977) showed that statistically an average white dwarf has a probability of 10% to accrete matter from the interstellar clouds at a rate equal or higher than $10^{-13} \, M_\odot \, yr^{-1}$. We use this rate for the slow accretion phase. The accretion process is assumed to be quasistatic; i.e., matter is added to the white dwarf's surface with zero velocity and with an entropy equal to the prevailing value. The slow accretion process has only minor effects on the cooling of the white dwarf. The accretion luminosity $L_{\text{acc}} = \frac{GM_\odot \dot{M}}{R} = 1.6 \times 10^{-4} \, L_\odot$ is indeed negligible. All along this phase the envelope is almost in thermal equilibrium; i.e., the radiation flux is almost position independent.

After $1.85 \times 10^9 \, yr$, a period corresponding to the evolution time of a 1.5–2.0 $M_\odot$ Main Sequence star, the accretion process is assumed to become faster. The fast accretion rate is taken to be $10^{-7} \, M_\odot \, yr^{-1}$, a value which is consistent with the accretion rates in close binary systems as estimated by Nather and Warner (1969).

At the moment the accretion becomes fast, the white dwarf has accumulated a hydrogen rich envelope of $1.85 \times 10^{-4} \, M_\odot$ and its luminosity has dropped to $0.175 \times 10^{-2} \, L_\odot$.

3. Hydrogen Ignition

Immediately after the beginning of the fast accretion, a maximum in the temperature profile develops near the SFA interface. In order to understand the formation of this maximum we examine a limiting model of extreme fast accretion. In this model heat conduction can be neglected. The whole envelope is, therefore, adiabatically compressed. The accreted matter, according to our assumption is added with the surface entropy of the existing envelope. Thus an entropy profile of the form shown in Figure 1 or Figure 2 (the lines marked $\alpha$) is obtained. In Figure 2 lines of constant temperature are marked. It is seen that the temperature is highest at the cusp of the entropy profile; i.e., at the SFA interface.

For an accretion rate of $10^{-7} \, M_\odot \, yr^{-1}$ as assumed in this work heat conduction cannot be completely ignored. The actual entropy profile tends to become flatter due to heat transfer, see Figure 1 lines b and c. However, the main features of the extreme-fast accretion model are retained. The only effect of the heat conduction is a small shift in the position of the maximum of the temperature profile, it appears a bit above the SFA interface.

As the fast accretion continues, the maximum in the temperature profile increases. After the accumulation of $2.1 \times 10^{-4} \, M_\odot$ in this phase of fast accretion, the maximal temperature is high enough to ignite hydrogen. A thermal runaway is initiated. As shown in Figure 3, curves d and e, the hydrogen is ignited near the SFA interface.