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ORIGINAL ARTICLE

Turbulence model for simulation of the flame front propagation in SNIa

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Abstract Turbulence significantly influences the dynamics of flame in SNIa. The large Reynolds number makes impossible the direct numerical simulations of turbulence, and different models of turbulence have to be used. Here we present the simulations with the k–ϵ model. The turbulence is generated by the RTL instability and crucially influences flame front velocity, resulting in $v_{\mathrm{flame}} \sim 300$ km/s. The model reproduces turbulent properties in low-dimensional simulations and can be used for the low-cost studies.

Keywords Supernovae Ia · Turbulence · Flame propagation

1 Introduction

The problem of a nuclear flame propagation in the SNIa is still controversial and is one of the fundamental questions in astrophysics and the theory of burning. These flashes are considered to be the thermonuclear explosions of a white dwarf close to Chandrasekhar limit in binary systems. There exist three popular scenarios of SNIa events: single-degenerate, double-degenerate and sub-Chandrasekhar explosions (see, e.g. Hillebrandt and Niemeyer 2000). The first depends crucially on flame physics: to meet observations it requires two stages of burning propagation, slow burning (the deflagration) and the detonation. The effective mechanism of deflagration to detonation transition (DDT) should exist Khokhlov et al. (1997), Lisewski et al. (2000), Seitenzahl et al. (2013) and is an essential part of the single-degenerate scenario considered here, when the progenitor of the explosion is a white dwarf (WD) in a binary system with a non-degenerate companion star.

The flame in conditions of a white dwarf is negligibly thin compared to any other spatial scale (Timmes and Woosley 1992). Such a flame is subject to many instabilities (Hillebrandt and Niemeyer 2000; Niemeyer and Woosley 1997; Glazyrin 2013). The effects of such instabilities are in changing the character of the flame propagation (like the change of its velocity) or turbulization of medium (and influence on flame through turbulence). The latter is considered in this paper. The flame velocity acceleration close to the speed of sound is an essential part of DDT and turbulence could do it effectively.

Though several effects lead to turbulization, only one instability is considered in this paper as it plays the dominating role in SNIa. This is the instability of the surface separating two mediums with different densities in gravitational field. For the non-interacting mediums it is called the Rayleigh–Taylor instability, and for flames it was first considered by Landau (1944) (the famous Landau–Darries instability was also introduced in that paper), so we will use below the term Rayleigh–Taylor–Landau instability (RTL) for flames. The surface can be unstable when density gradient and gravitational acceleration satisfy: $\mathbf{g}\nabla\rho < 0$, what is true for a flame spreading outwards the centre of a star.

The turbulent flames in SNIa were considered in a number of papers. In the paper by Niemeyer and Hillebrandt (1995) the subgrid-scale model for turbulence was implemented, the main source of turbulence was the RTL instability, as in our work. It was shown that the turbulence increases flame velocity to ∼2 % of the sound speed. This

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