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Numerical study of a 1D model for DDT at the tip of a flame in narrow channels

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Recent experiments and numerical simulations [1,2] evidence that DDT may occur in laminar flames more amenable to theoretical analysis.

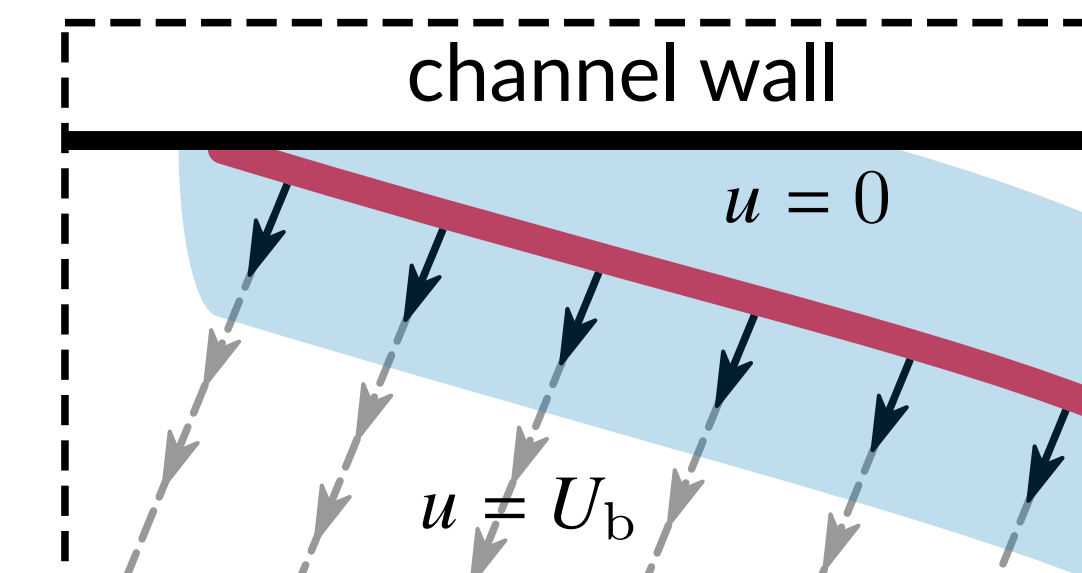
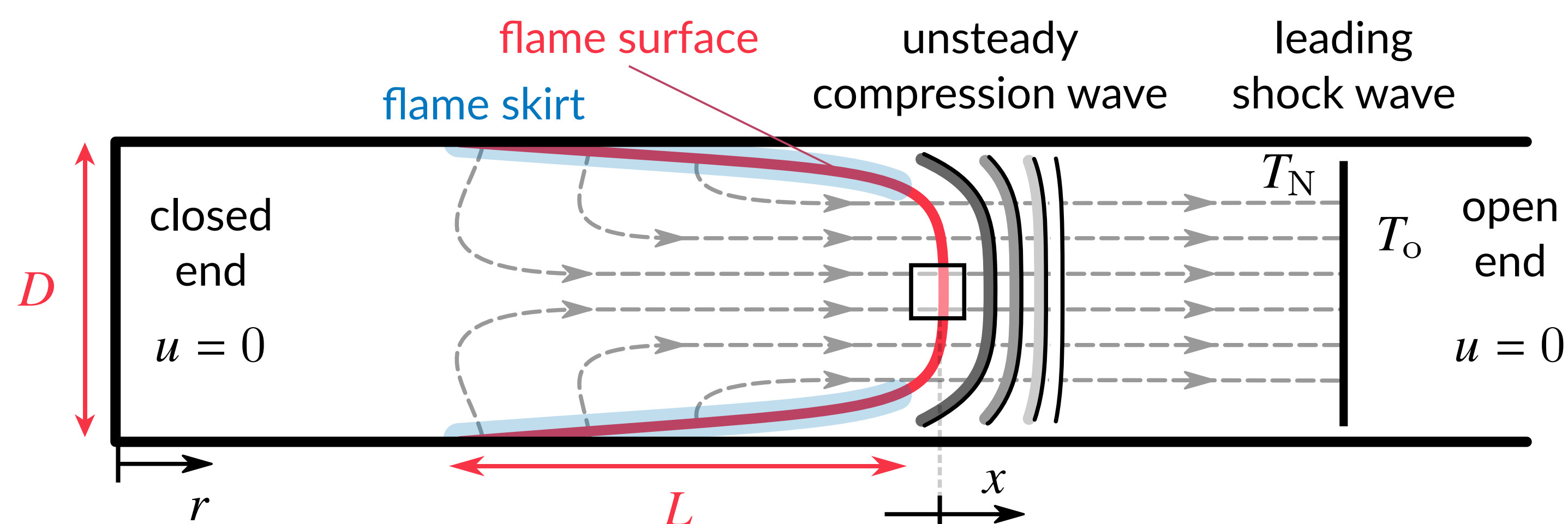
A novel 1D model for the tip of elongated flames has been proposed that yields results consistent with experimental and numerical observations of DDT [3].

The goal of this study is to investigate the internal flame structure on the basis of this 1D model.



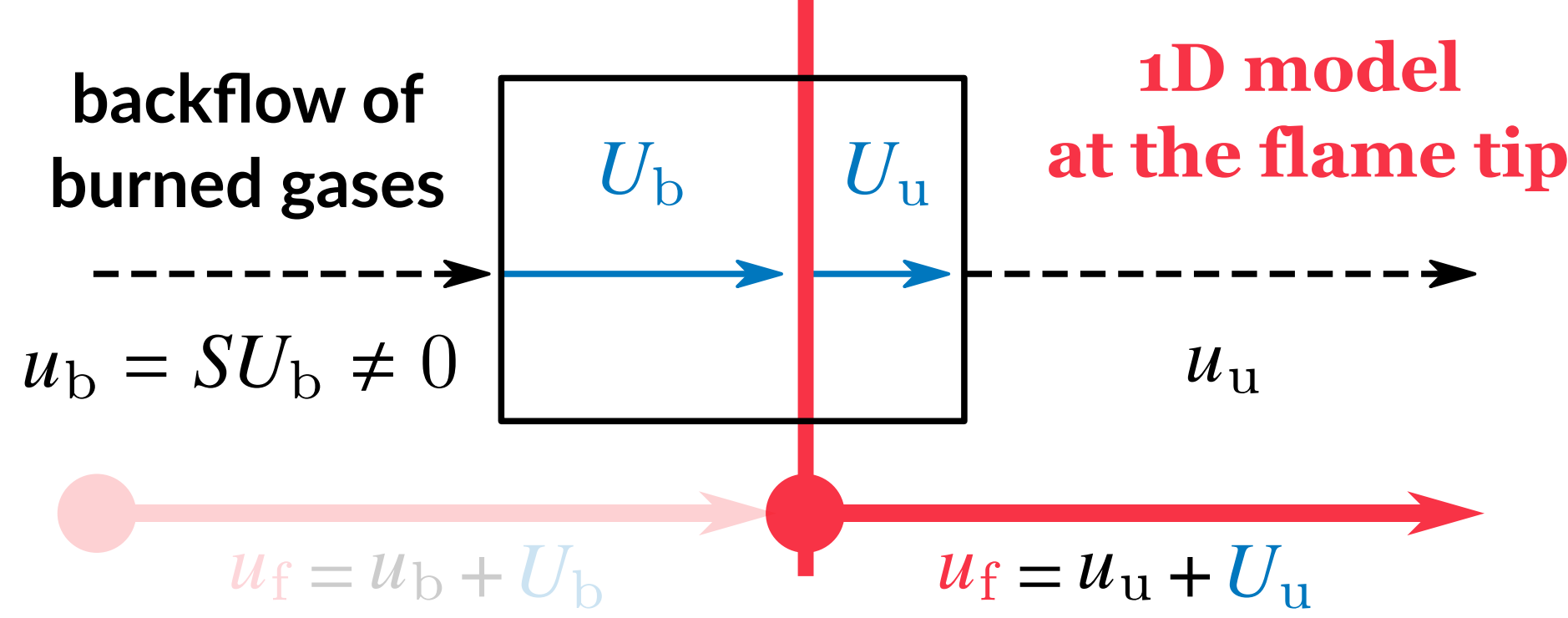
Elongated flames in narrow channels

1. Gas flow interaction with the walls distorts the flame surface, which adopts an elongated shape with a quasi-planar front at the tip of the flame [4].

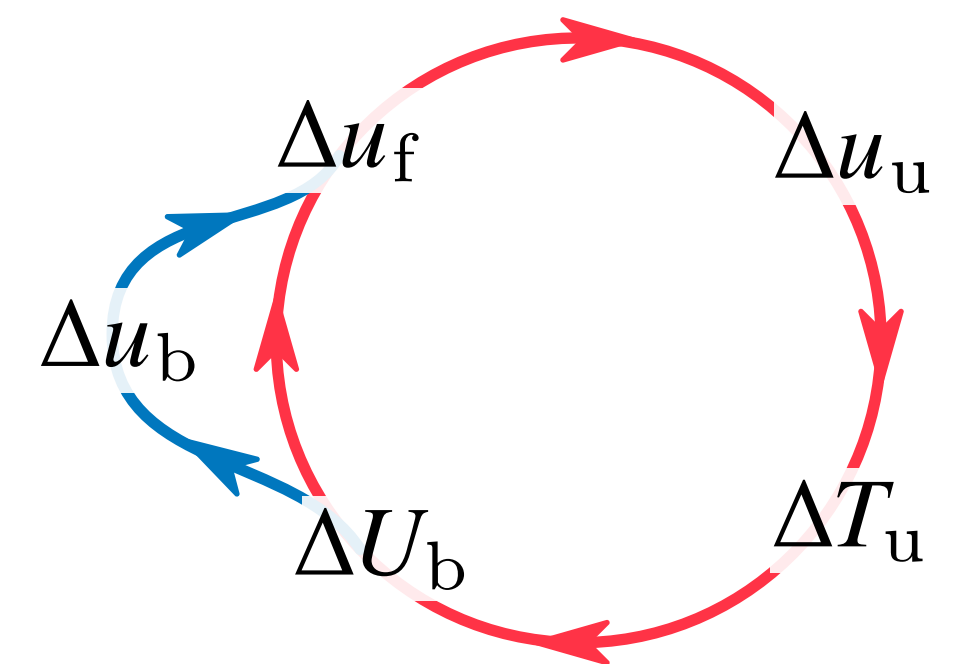


2. A mass production term models the expansion of the combustion products on the flame skirt [5].

3. Integration of the mass production term, neglecting unsteady and compressible effects in the burned gas region, results in a burned gases backflow proportional to a flame elongation parameter $S \propto L/D$.



4. Thermal feedback of compression waves on the flame [6] is coupled with the additional feedback loop of the burned gases backflow and the flame burning velocity.



Double-discontinuity solution

Nonlinear relationship between the flame velocity and the flame elongation determined for

- ▶ a leading shock wave as a discontinuity satisfying the Rankine-Hugoniot jump conditions $u_N, T_N = RH(M_o)$
- ▶ a flame as a reactive isobaric discontinuity with a strongly temperature-sensitive velocity $U_b \propto \exp\left(-\frac{E_a}{2k_B T_b}\right)$

assuming the flow between the flame and the shock wave to be

- ▶ uniform (i.e. $T_u = T_N$ and $u_u = u_N$) for constant backflow
- ▶ isentropic for elongating flames.

Numerical integration

- ▶ 1D reactive compressible Navier-Stokes equations
- ▶ ν -th order single-step reaction model

are numerically integrated following a Strang splitting algorithm

$$\mathbf{u}^{n+1} = \mathcal{D}(\Delta t/2) \mathcal{G}(\Delta t) \mathcal{D}(\Delta t/2) (\mathbf{u}^n)$$

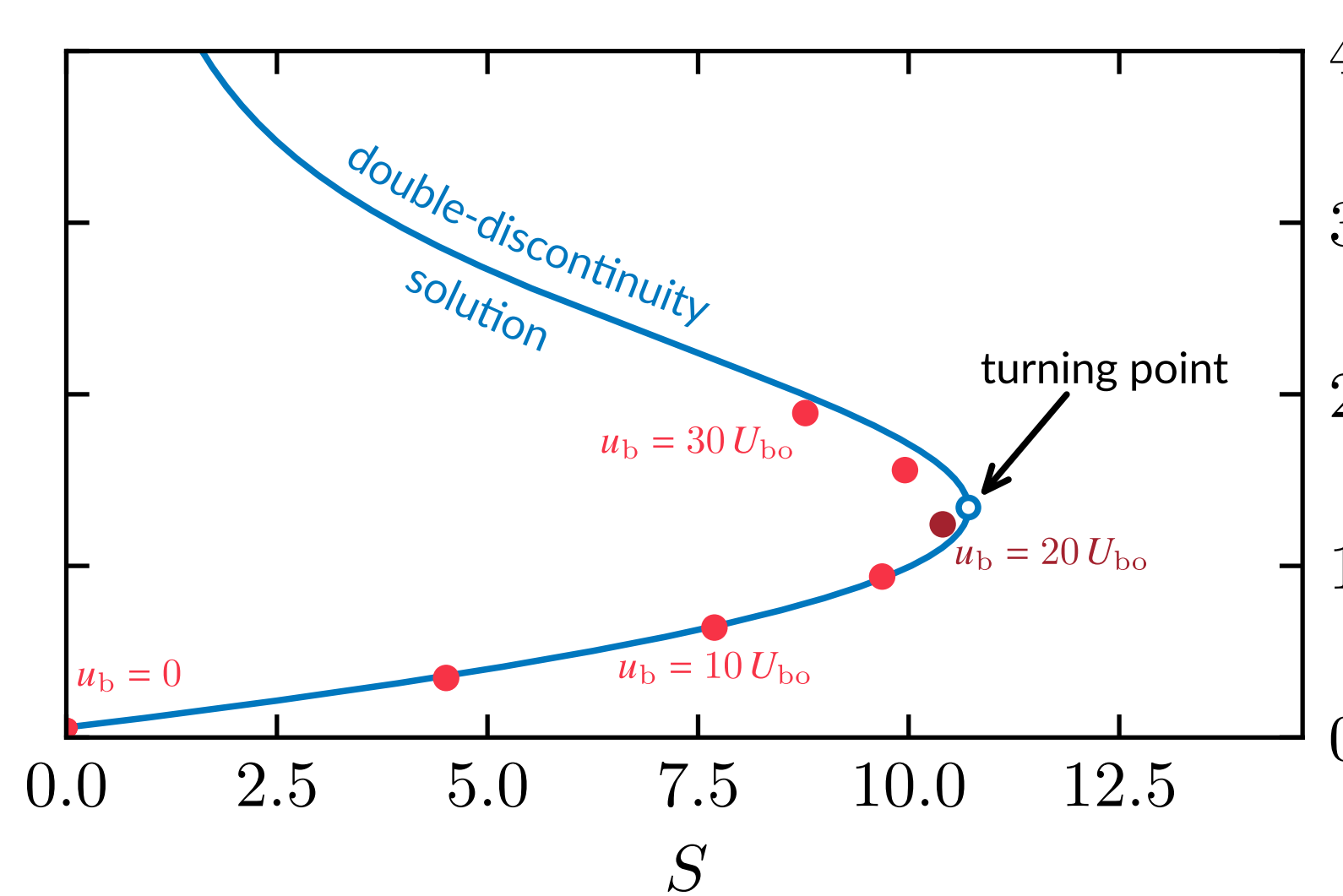
- ▶ Kurganov-Tadmor [7] solver is applied to the convective subproblem
- ▶ Implicit finite difference scheme is applied to the reaction-diffusion subproblem integrating the reactive terms explicitly

Results

for the set of thermochemical parameters: $Pr = 0.7$, $Le = 1$, $\gamma = 1.4$, $q_m/(c_p T_o) = 7$, $\beta = 10$, $\nu = 2$ and $U_{bo}/a_{bo} = 2 \times 10^{-2}$

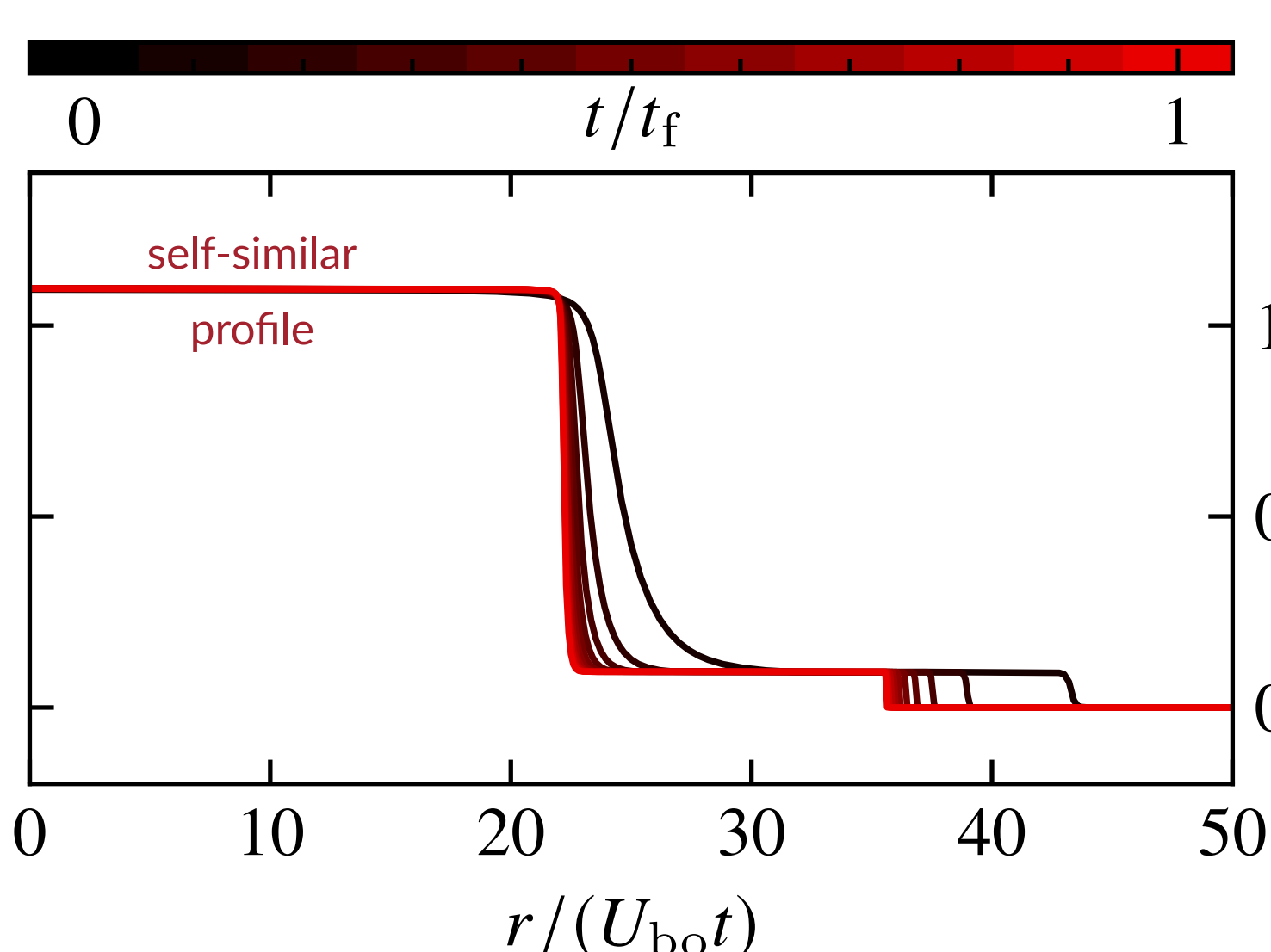
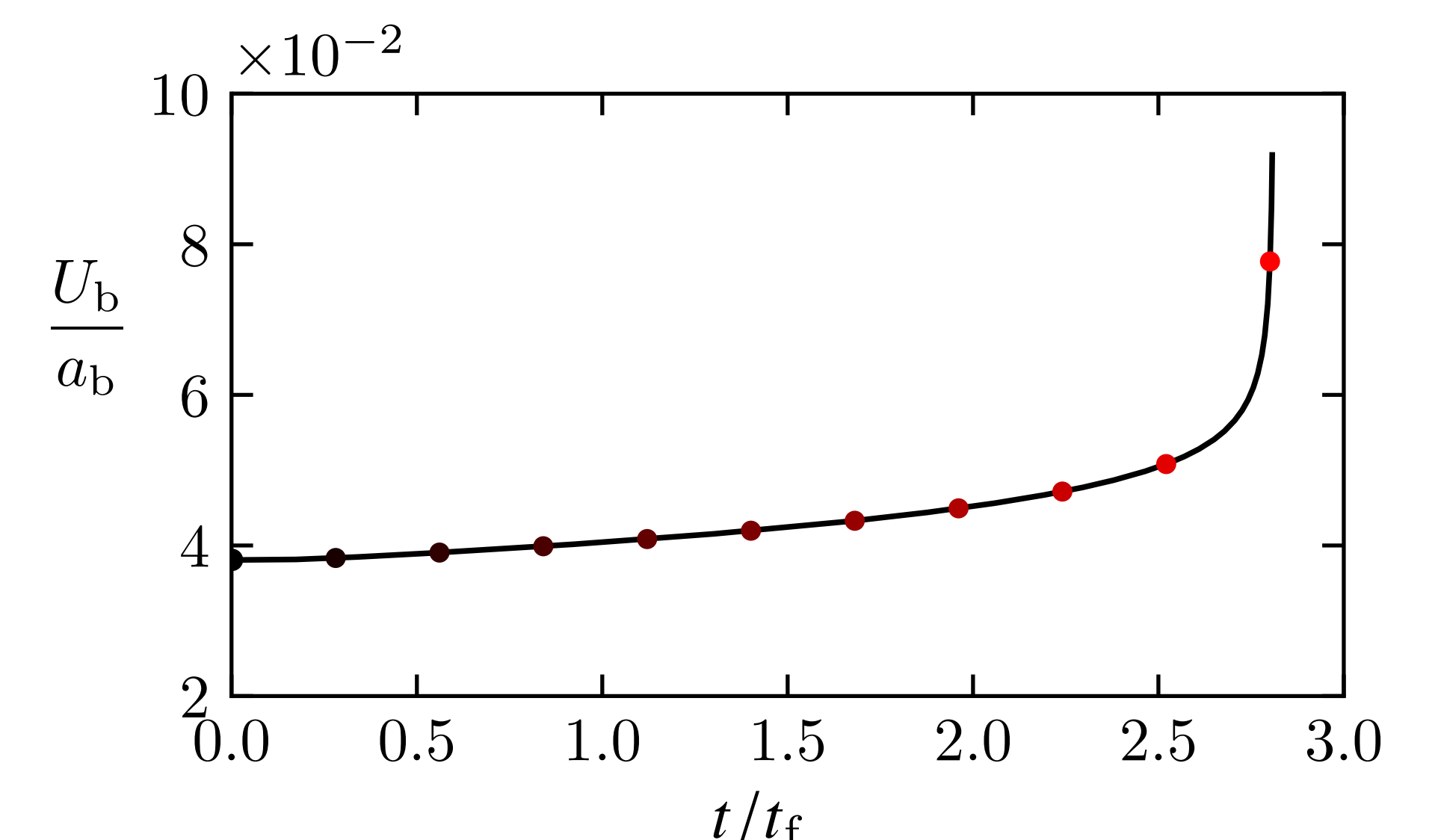
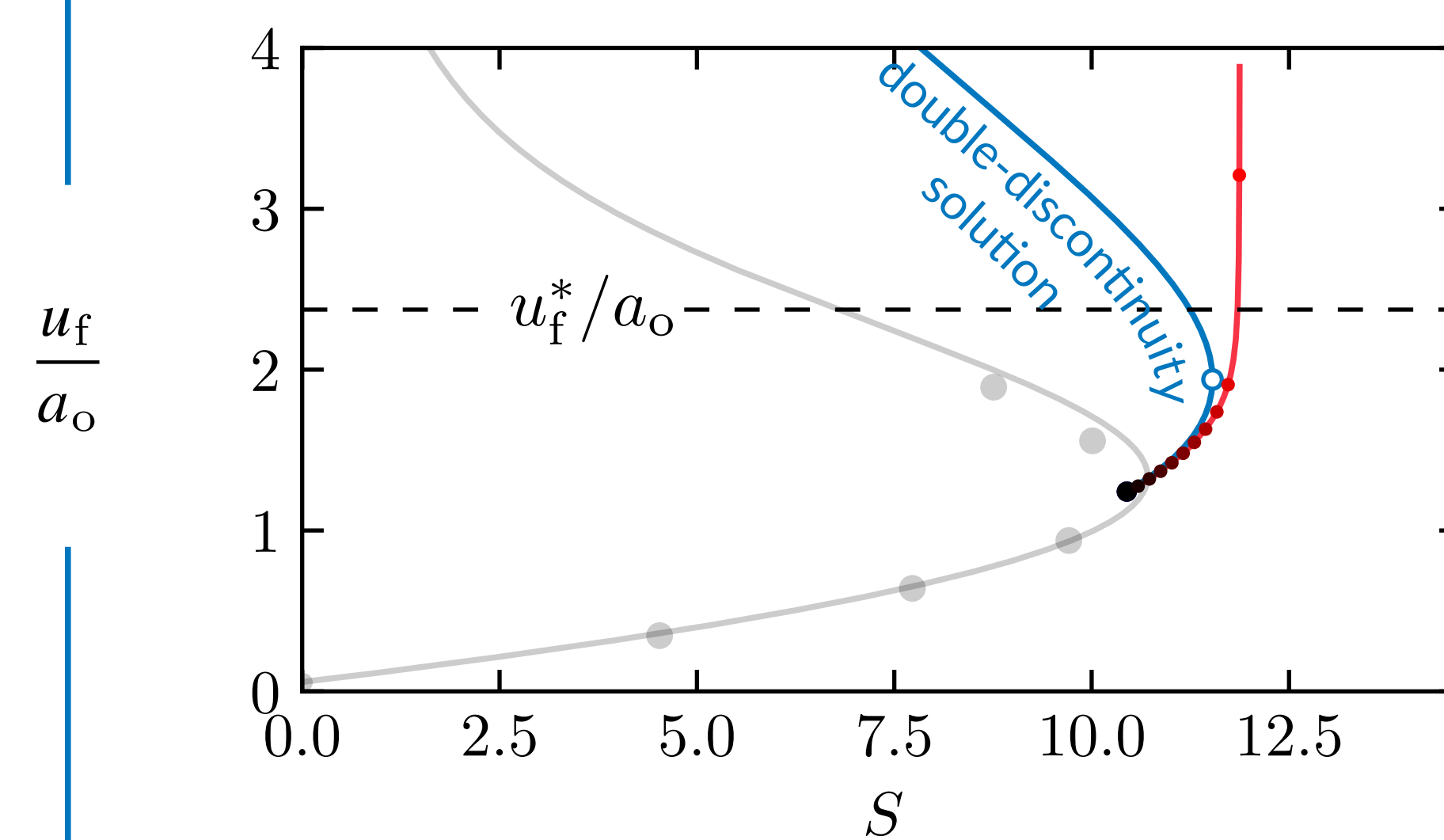
parametric study

$$du_b/dt = dS/dt = 0$$

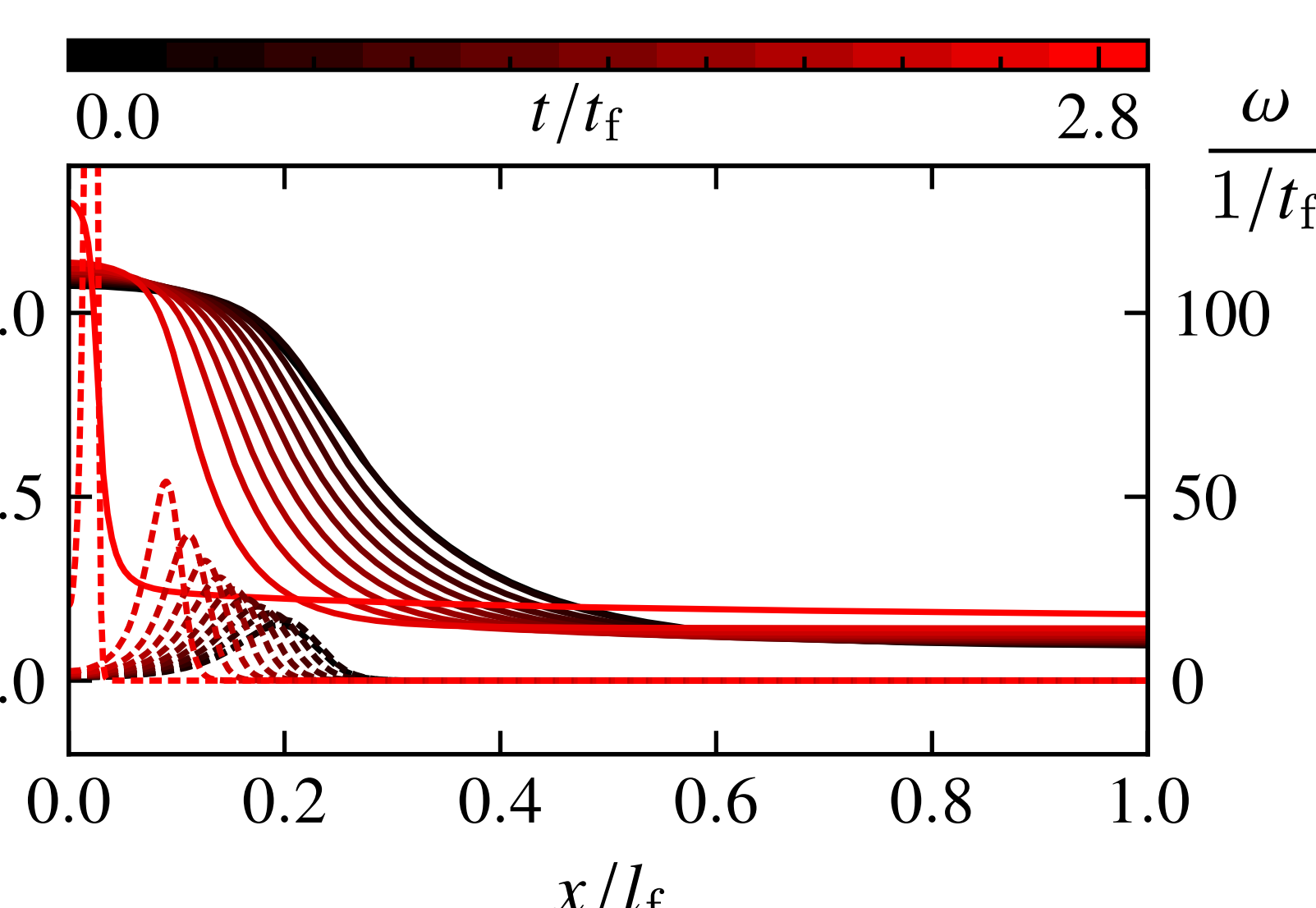


time-dependent flame elongation

$$S(t) = S_0 (1 + \varepsilon t/t_f) \text{ with } \varepsilon = 5 \times 10^{-2}$$



$$\theta \equiv \frac{T - T_o}{T_{bo} - T_o}$$



Conclusions

- ▶ There is no steady/quasi-steady solution above a critical flame elongation associated with a finite-time singularity [8].
- ▶ If the critical elongation is exceeded, the flame undergoes a limitless acceleration accompanied by flame shrinkage.
- ▶ Abrupt flame acceleration occurs well before the CJ condition can be reached.
- ▶ Under strong flame acceleration and shrinkage, dissipation mechanisms are expected to form a shock wave triggering the onset of a detonation.

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