

Eigenvalue-based Linear Stability Analysis of Thermodiffusively Unstable H₂-Air Flames

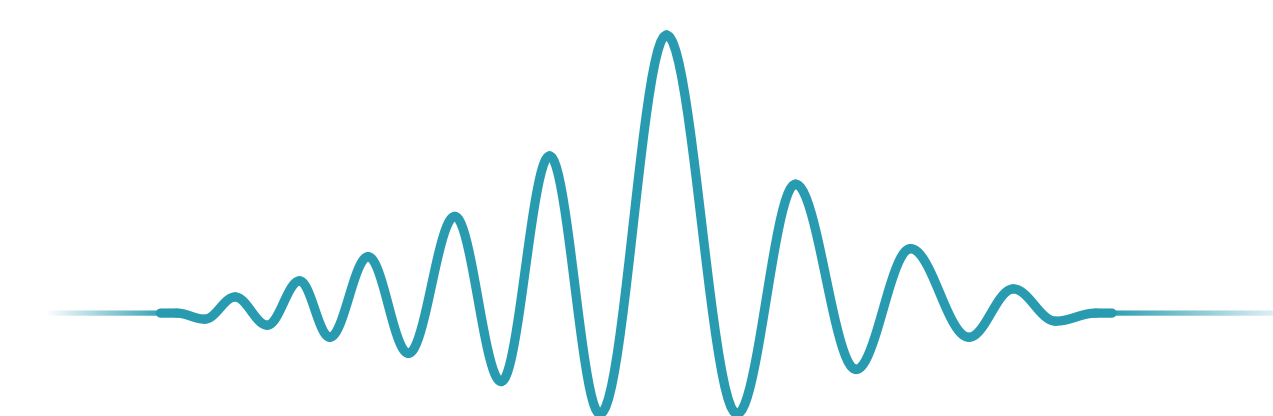
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Modelling and Simulation
of Thermo-Fluid Systems



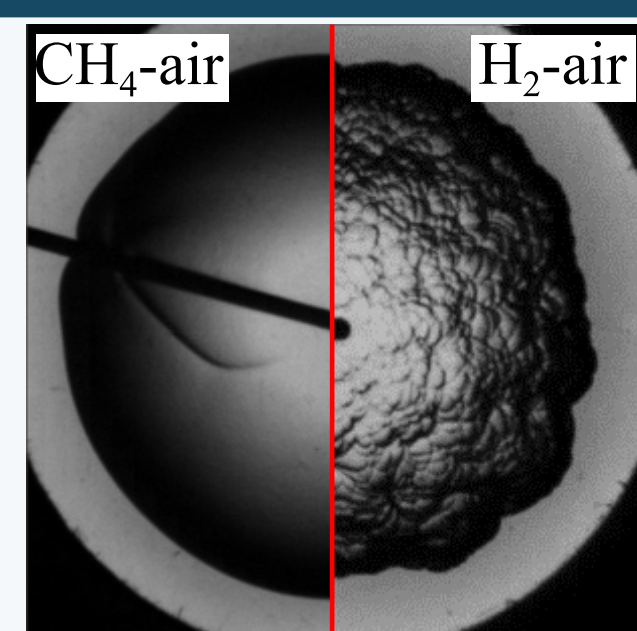
Abstract

Thermodiffusive instabilities (TDIs) wrinkle the front

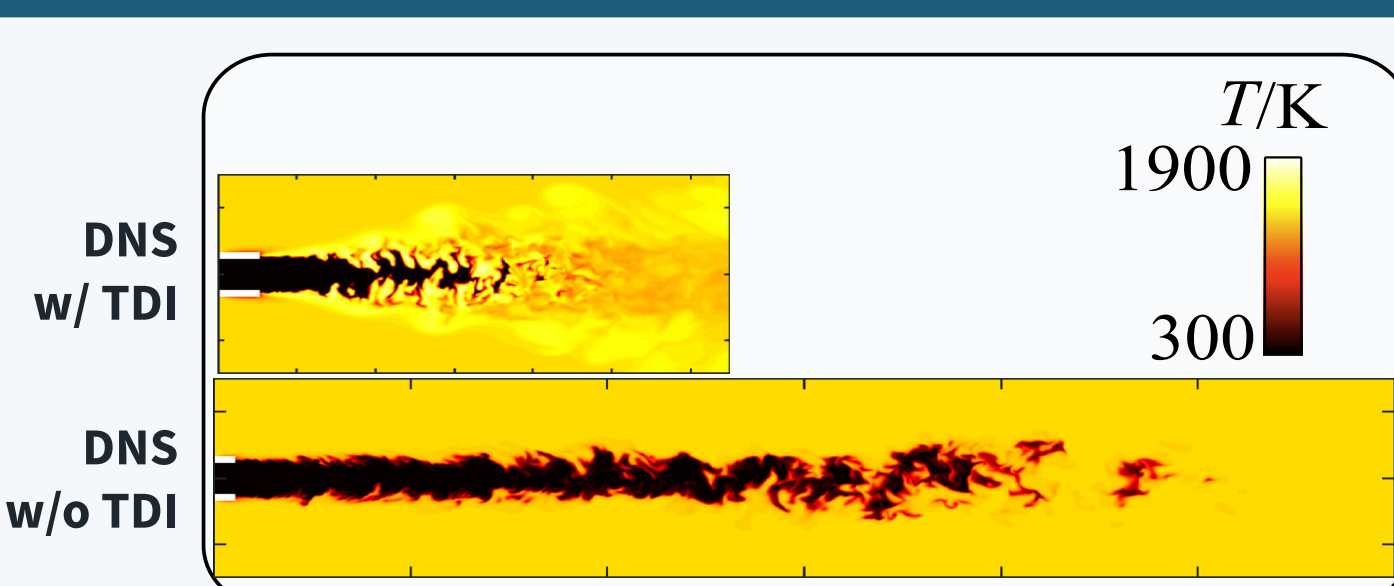
Wrinkles are small $\Rightarrow$ model for LES needed

Operator-based stability analysis captures perturbation growth at DNS accuracy, up to $10^6 \times$ cheaper in 2D ($10^8 \times$ in 3D).

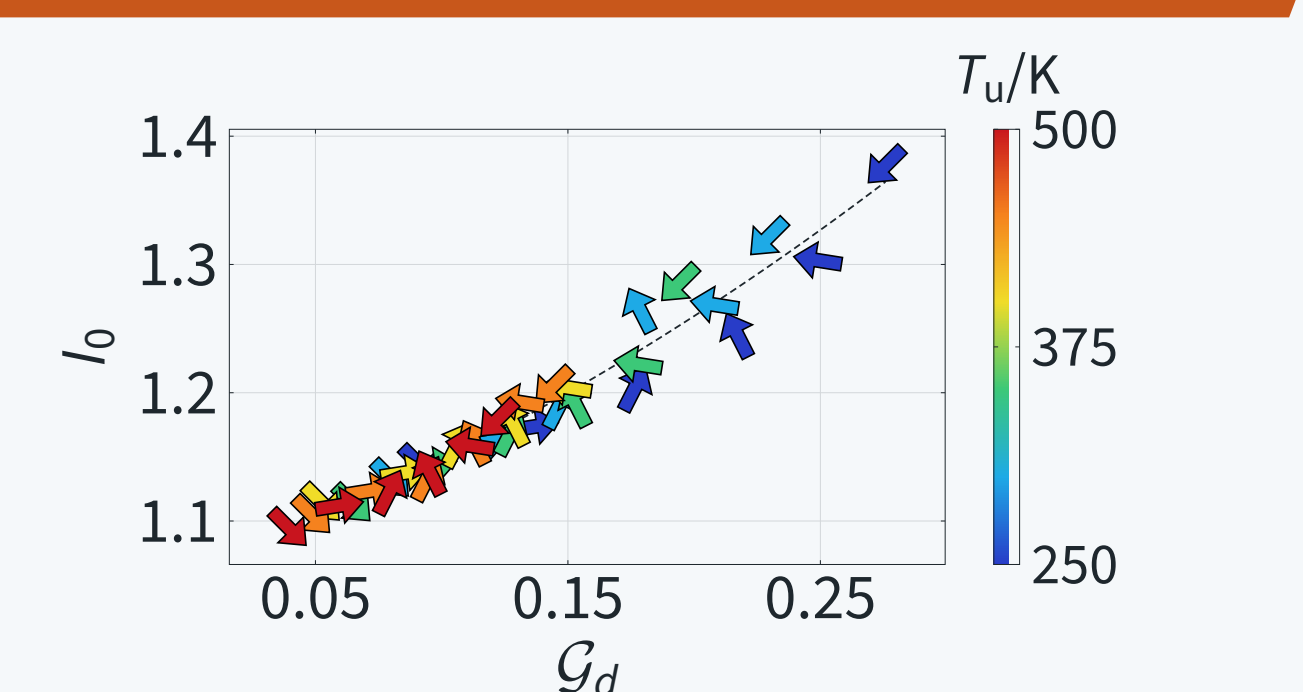
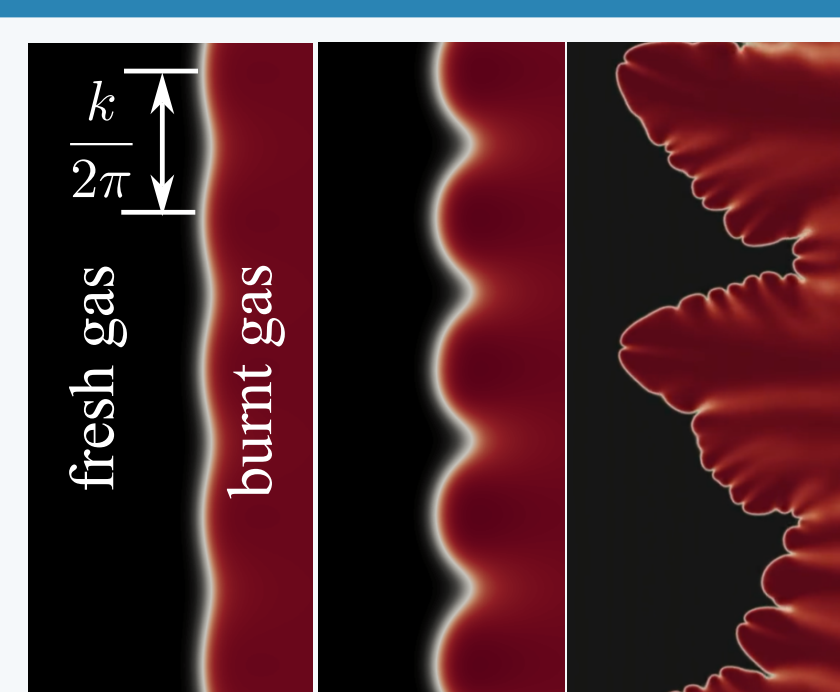
Findings link directly to LES models of thermodiffusive instabilities



Lapenna et al. (2023)



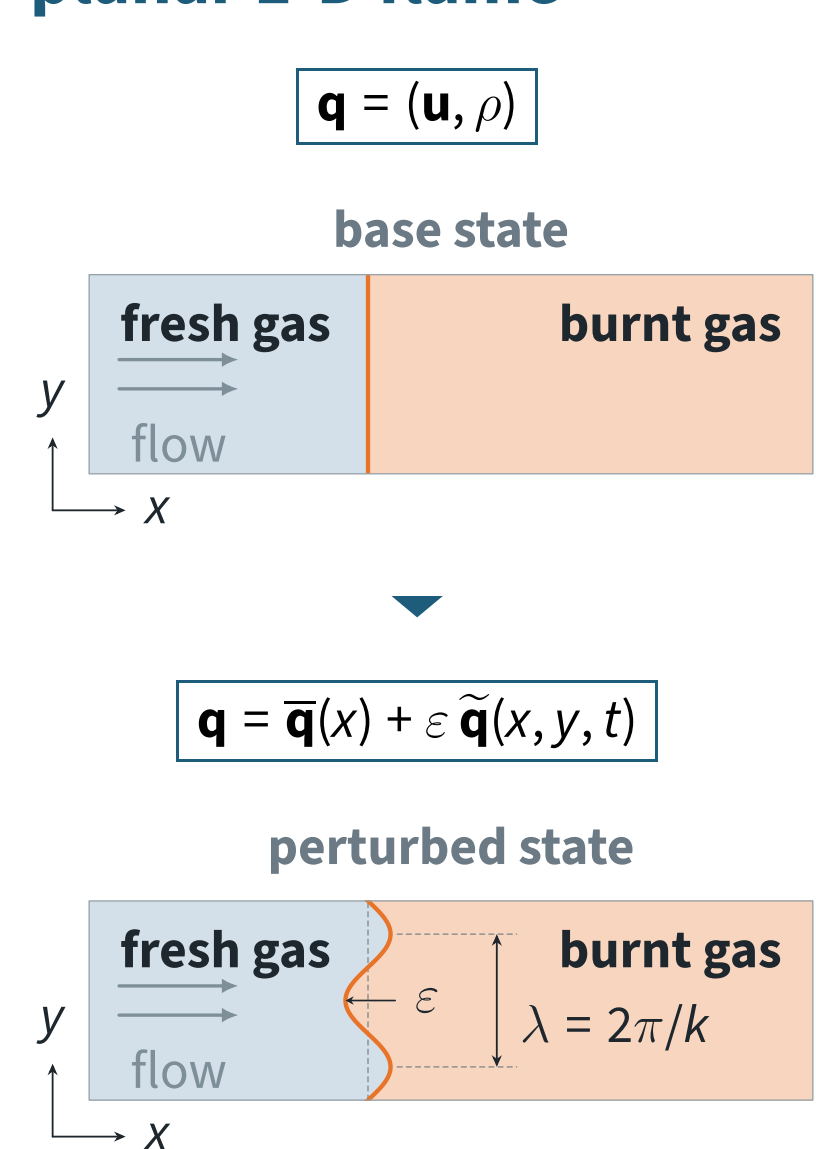
Berger et al. (2022)



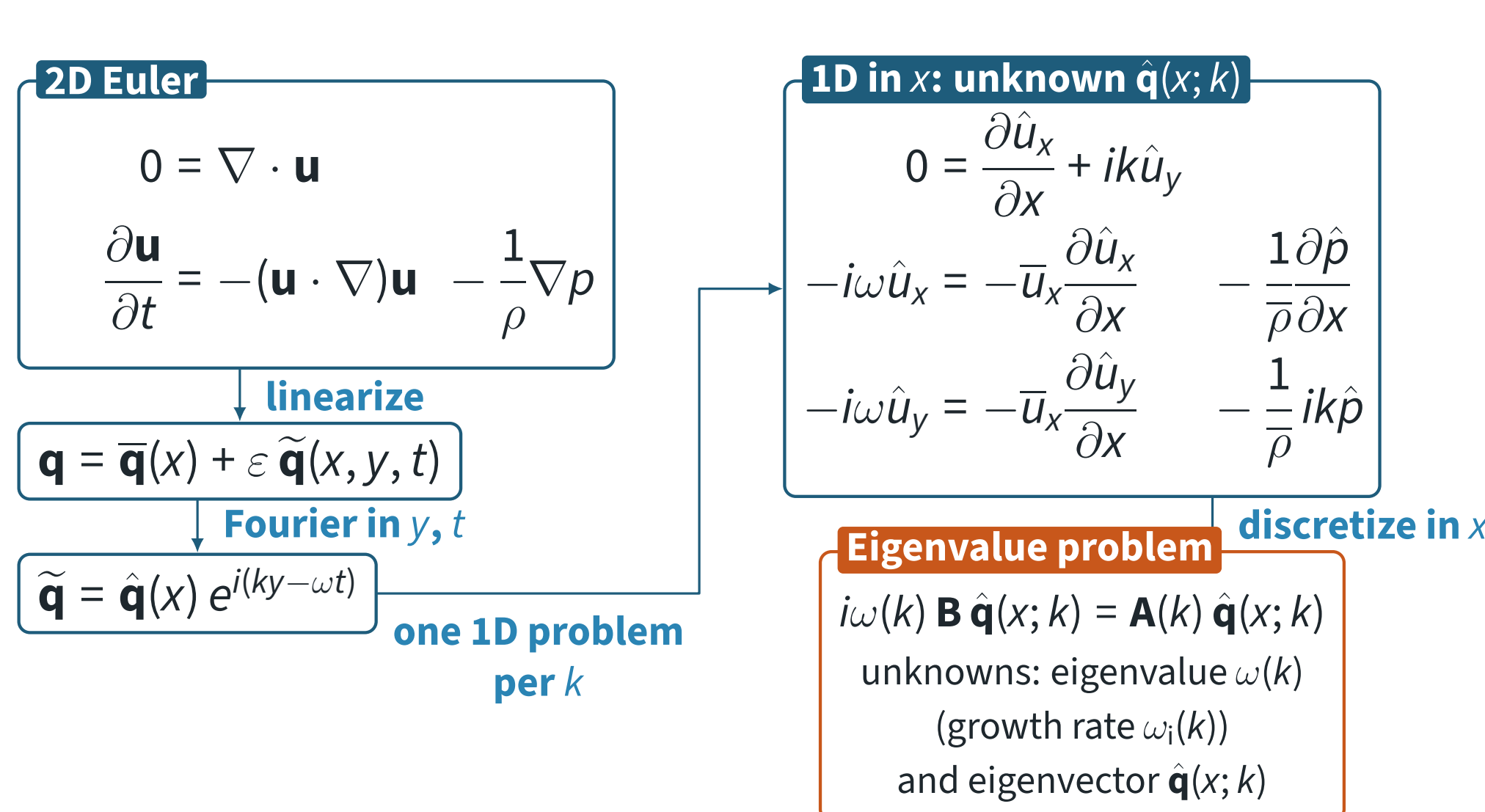
① The idea: replace an expensive 2D/3D DNS by one 1D eigenvalue problem per wave number k

Proof of concept: the LSA reproduces Landau's analytical growth rate and eigenmodes

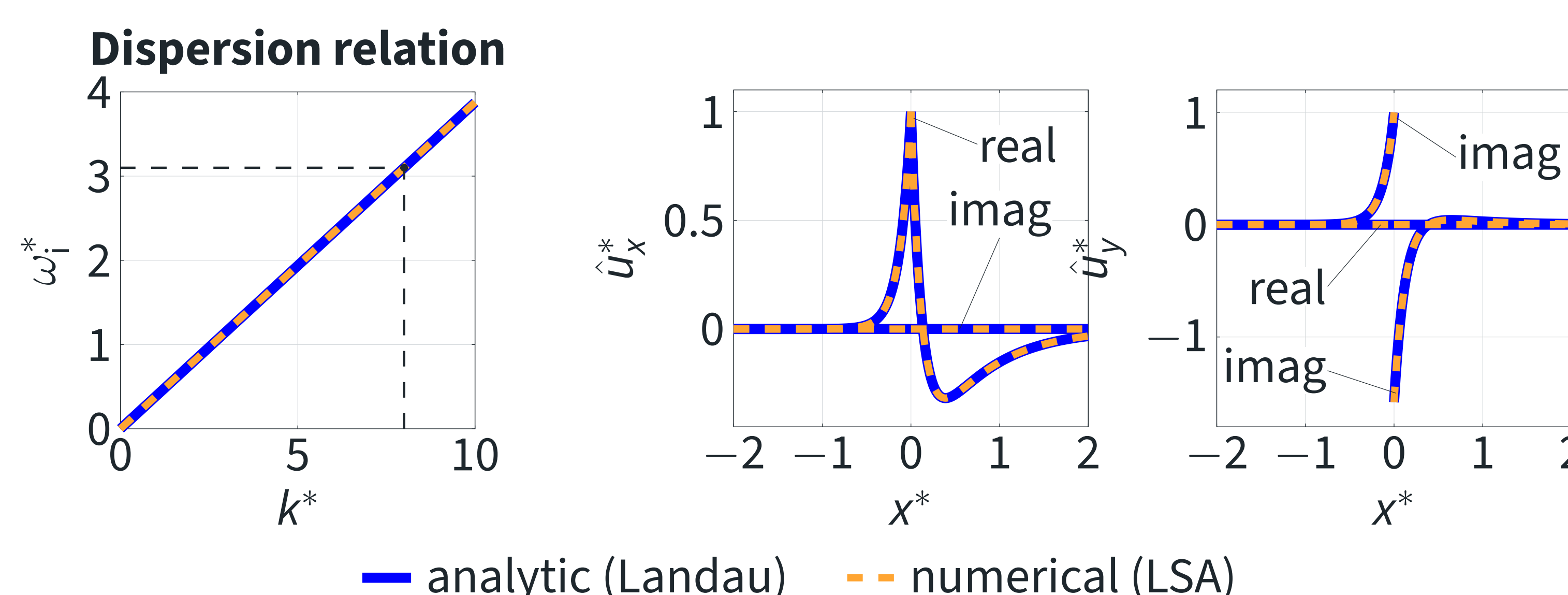
Linearize around the planar 1-D flame



Darrieus-Landau flame (1944): the flame as a discontinuity



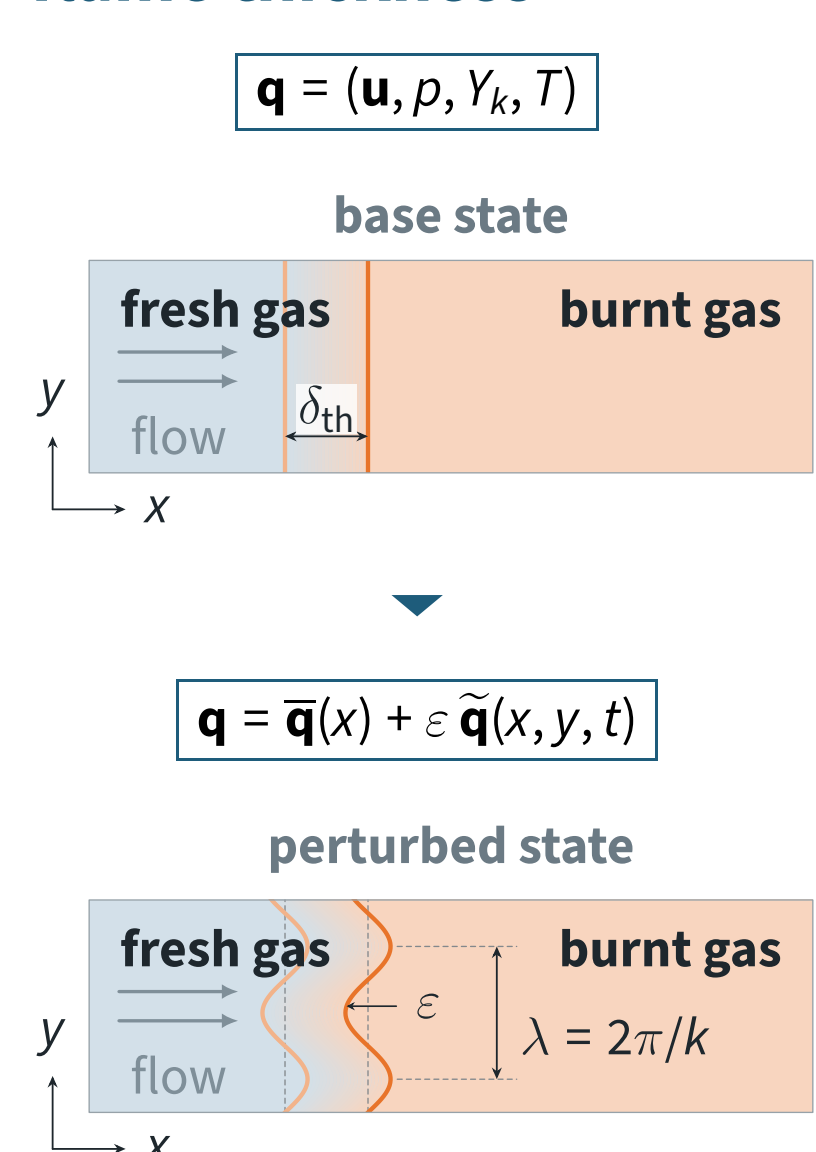
LSA dispersion relation and eigenmodes = Landau's analytical solution ($\sigma = 2$; modes at $k_y^* = 8$)



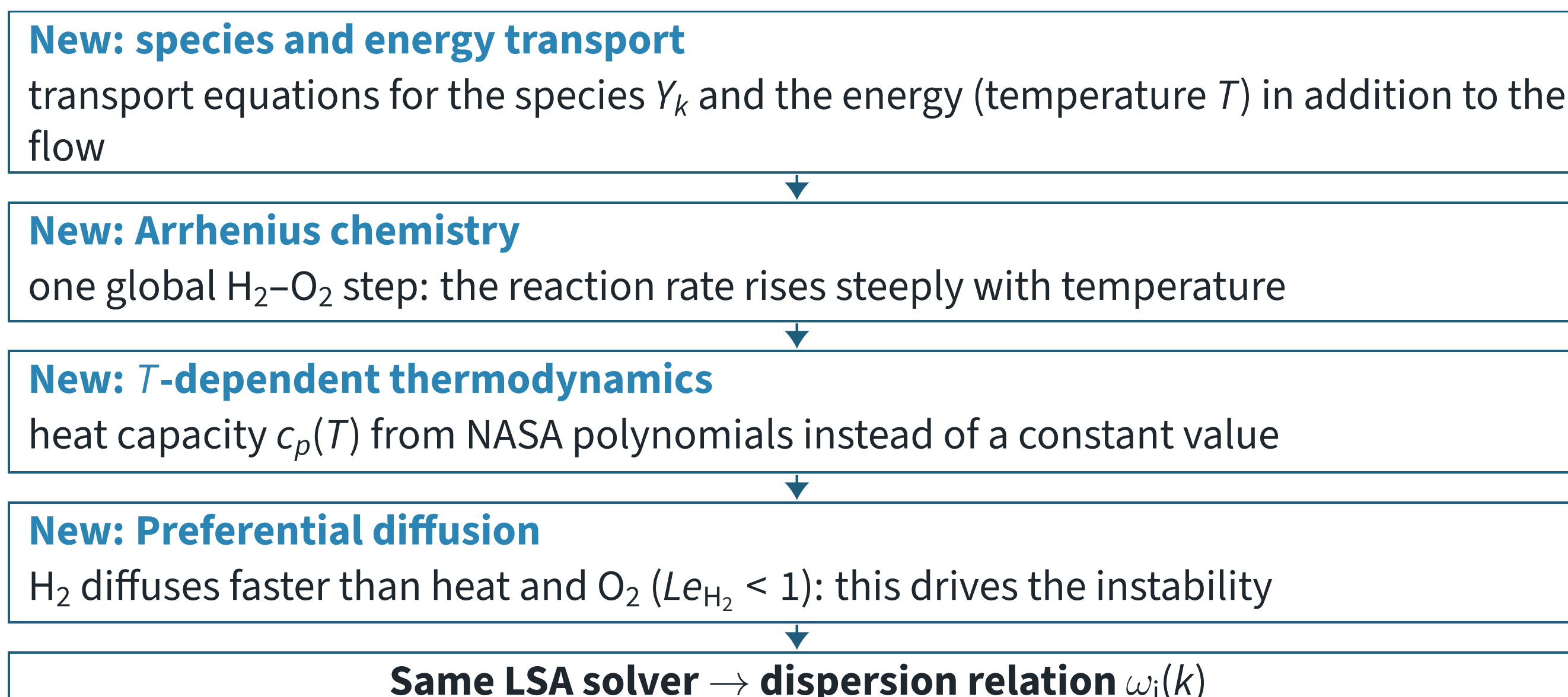
② The step up: LSA for an H₂-air flame using one-step chemistry, including preferential diffusion

LSA growth rates match DNS, at $10^6 \times$ lower cost

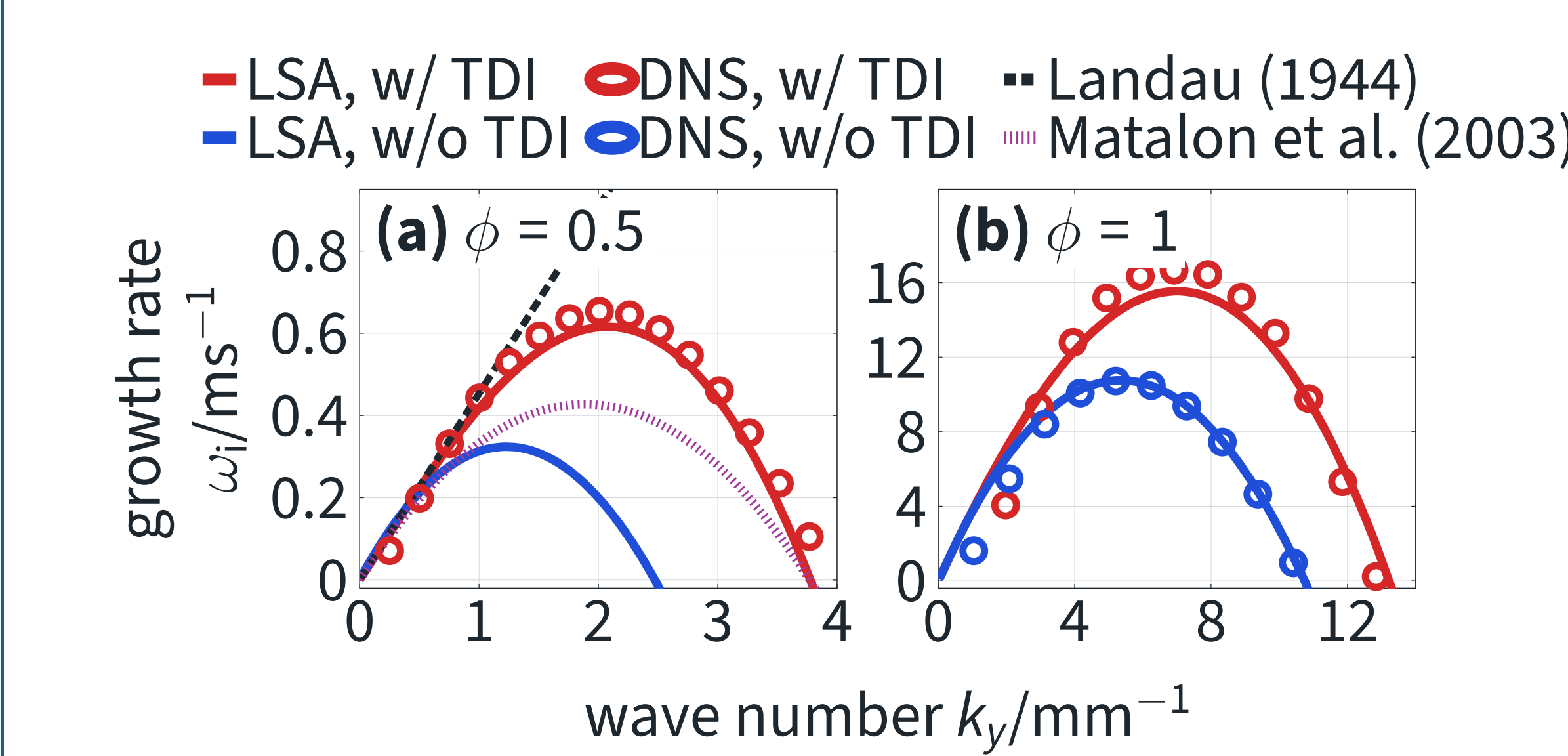
Same linearization, finite flame thickness



Darrieus-Landau flame + new physics = H₂-air flame



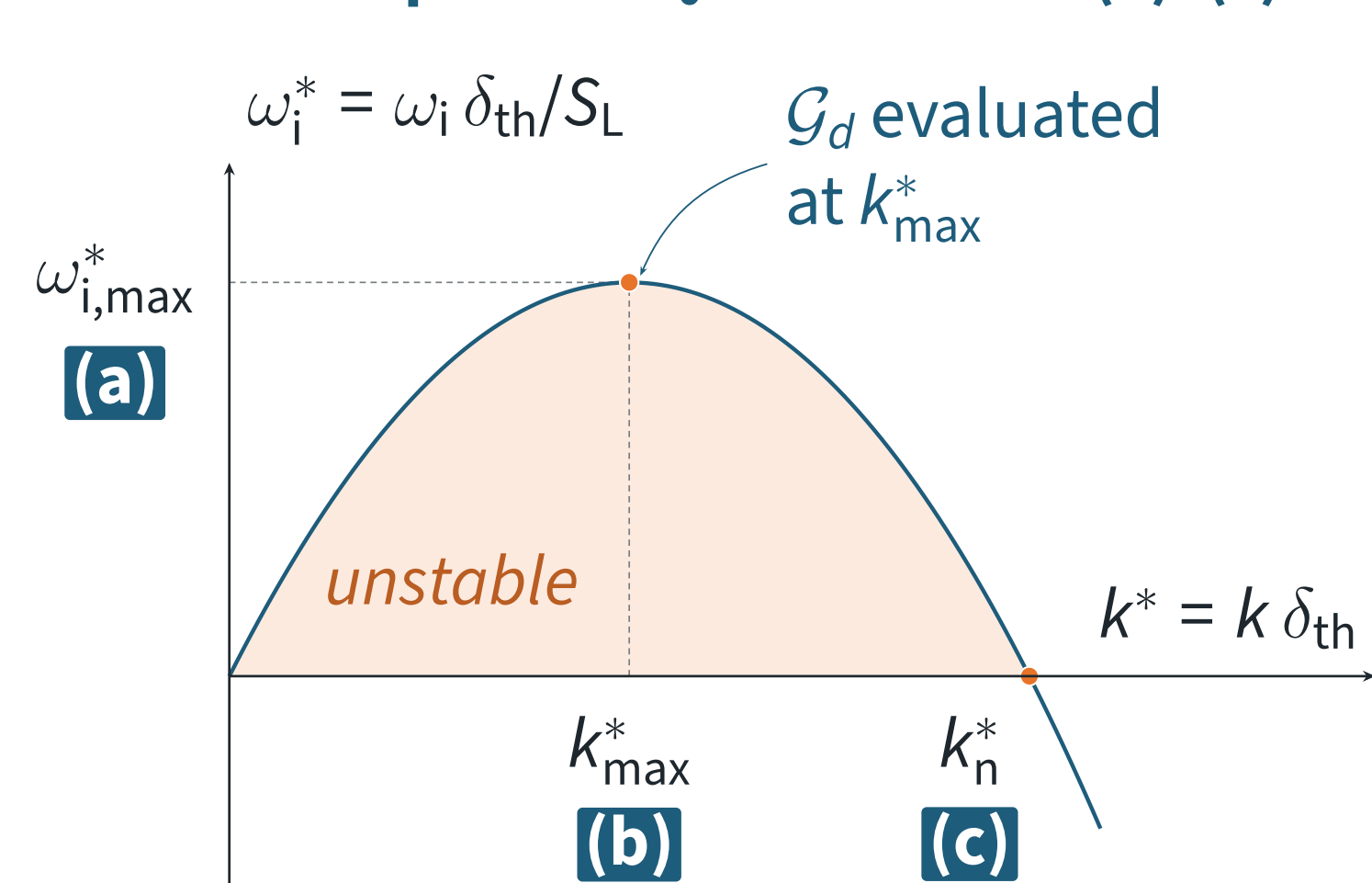
LSA growth rates match DNS (TDI = thermodiffusive instabilities)



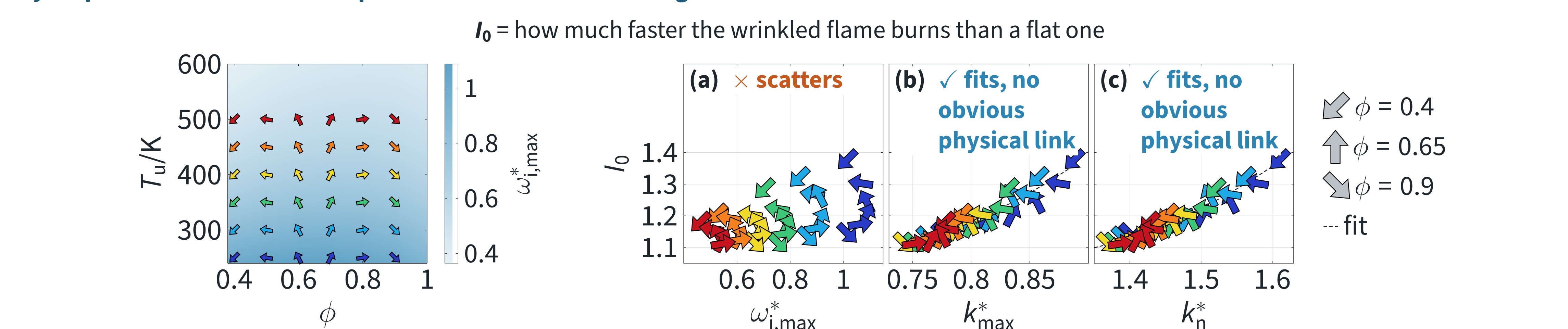
③ Implications for LES modelling: from linear flame response to a model for enhanced burning intensity due to preferential diffusion (I_0)

One physics-based factor $\mathcal{G}_d$ collapses 35 DNS cases onto a single curve for I_0

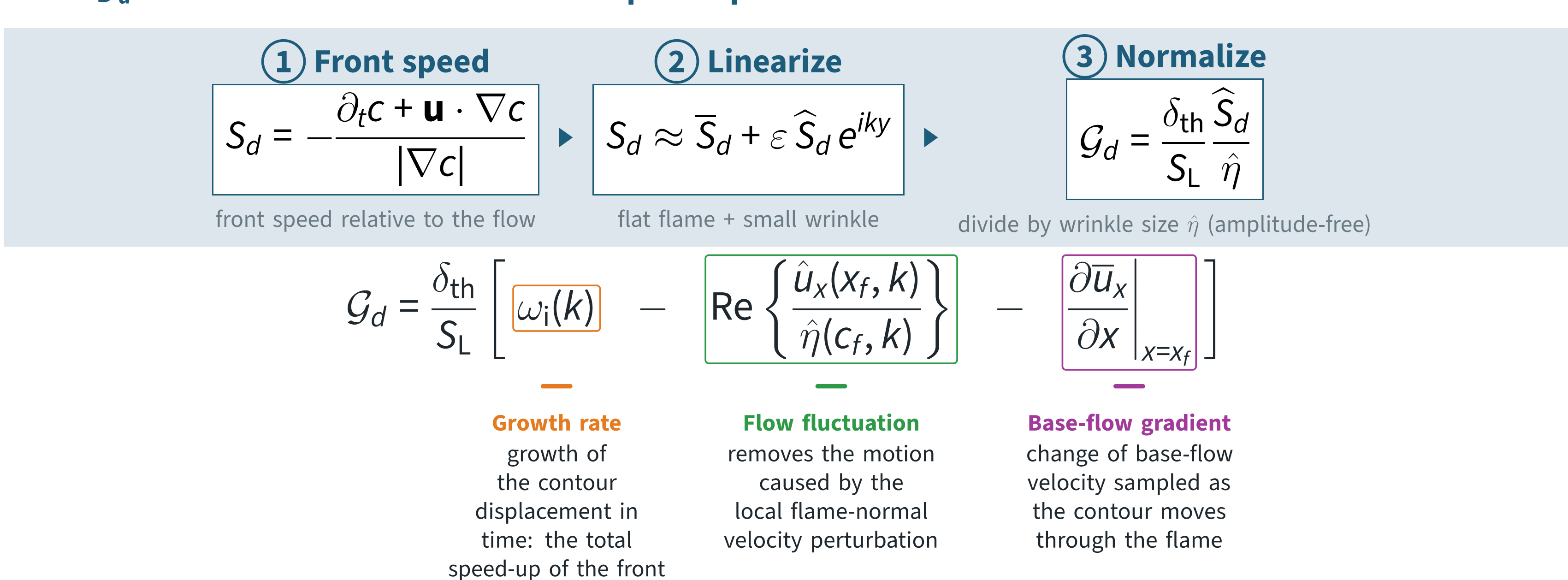
Which result predicts I_0 ? Candidates (a)-(c)



Try 1: quantities read off the dispersion relation are not enough



Idea: $\mathcal{G}_d$ measures the flame front's own speed-up



Test: 35 DNS cases ($\phi = 0.4-0.9$, $T_u = 250-500$ K, $Le_{H_2} = 0.5$), I_0 follows $\mathcal{G}_d$ on one curve

