Sensitivity of He Flames in X-ray Bursts to Nuclear Physics

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INTRODUCTION

An X-ray burst (XRB) is a thermonuclear runaway caused by the ignition of the accreted fuel on the surface of a neutron star. XRBs found with a mixture of hydrogen and helium fuel layers show bursts with ~ 5 sec rise time, while a pure helium layer is typically more explosive and shows bursts with shorter rise times (~ 1 sec). The burst oscillation behavior observed during the rise-time of the burst and difference between the accretion and burst timescales both suggest that nuclear ignition is likely to begin in a localized region (hotspot), and spread to the rest of the neutron star.

Continuing our previous works [1, 2], we employ a 2D model to study the sensitivity of Helium flames in X-ray burst.

INITIAL MODEL

- 2D r-z cylindrical coordinate system assuming azimuthal-symmetry.
- Corotating frame with consideration of Coriolis force.
- Pure Helium-4 accretion layer
- Employed a hydrostatic initial model to represent the neutron star's initial thermodynamic conditions.

Overall 2D Hydrostatic Profile:

- Isothermal base with $T = T_*$ and pure ^{56}Ni composition for $0 < z < H_*$ to represent the underlying neutron star.
- A transition phase with prescribed temperature and composition profiles that blend the base and atmosphere for $H_* < z < H_* + 3\delta_{atm}$.
- Isentropic atmosphere with pure ^{4}He composition for $z > H_* + 3\delta_{atm}$ to represent the accretion layer.
- A temperature perturbation on the left part of the domain to drive a rightward propagating flame, a spreading hotspot for our geometry.

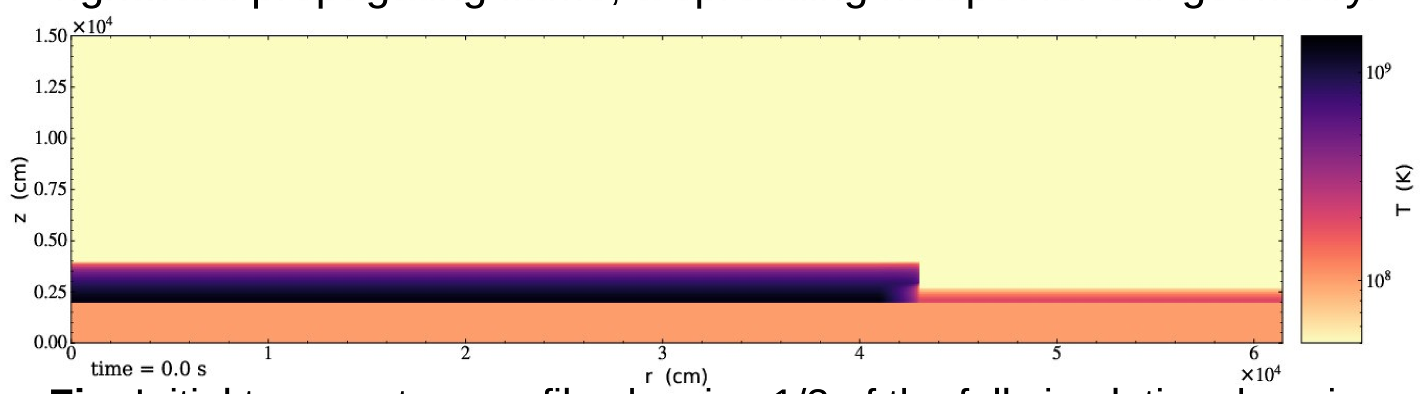


Fig: Initial temperature profile showing 1/3 of the full simulation domain.

REFERENCES

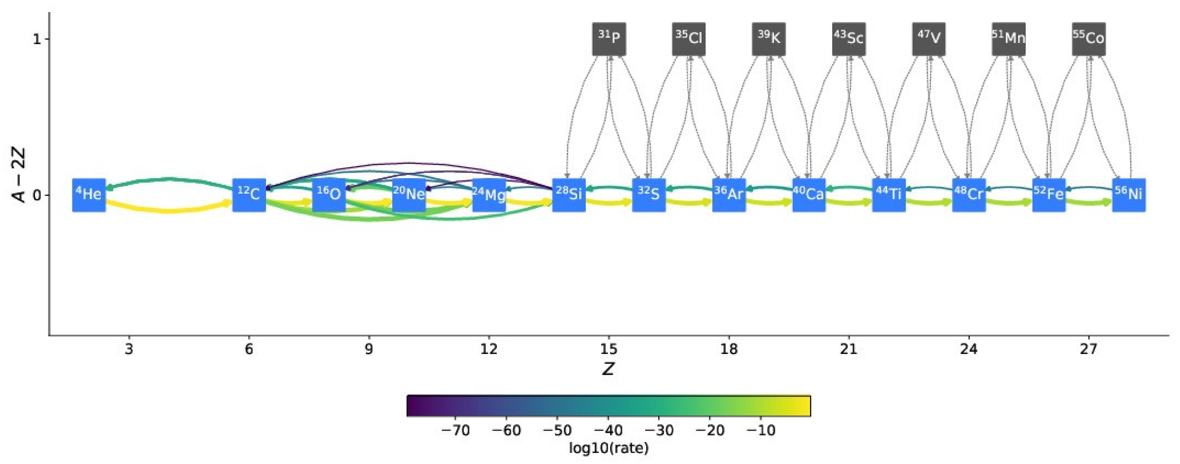
[1] Eiden, K., Zingale, M., Harpole, A., Willcox, D., Cavecchi, Y., & Katz, M. P. (2020). DOI: 10.3847/1538-4357/ab80bc.
[2] Harpole, A., Ford, N. M., Eiden, K., Zingale, M., Willcox, D. E., Cavecchi, Y., & Katz, M. P. (2021). doi:10.3847/1538-4357/abee87
[3] K. J. Shen and L. Bild, DOI: 10.1088/0004-637x/699/2/1365.
[4] N. N. Weinberg, L. Bildsten, and H. Schatz, DOI: 10.1086/499426.

CODE

Castro | https://github.com/AMReX-Astro/Castro
Microphysics | https://github.com/AMReX-Astro/Microphysics
Pynucastro | https://github.com/pynucastro/pynucastro

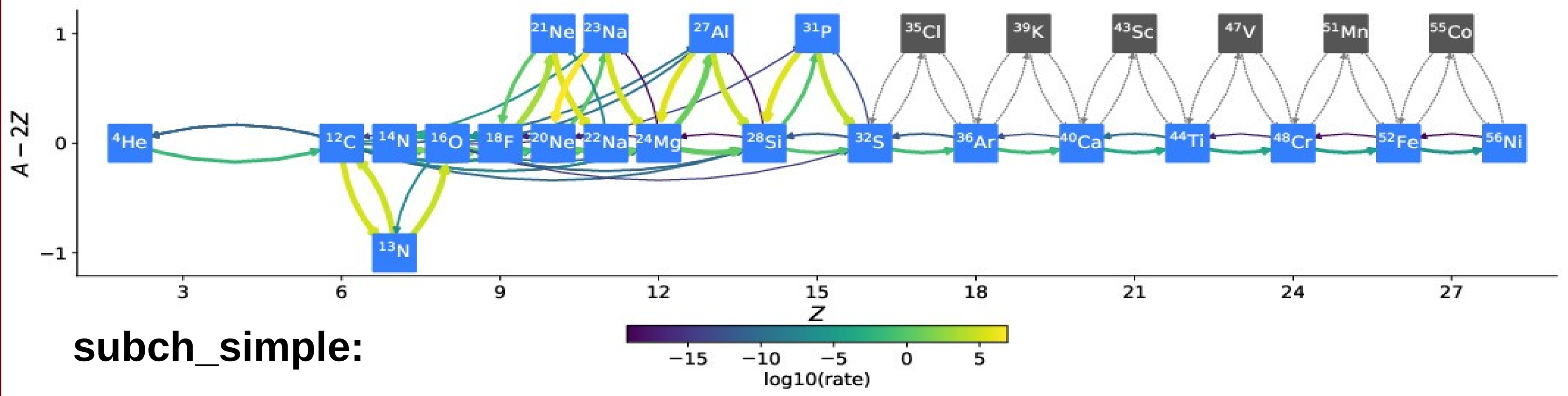
New Contributions Are Welcome!

NUCLEAR REACTION NETWORKS



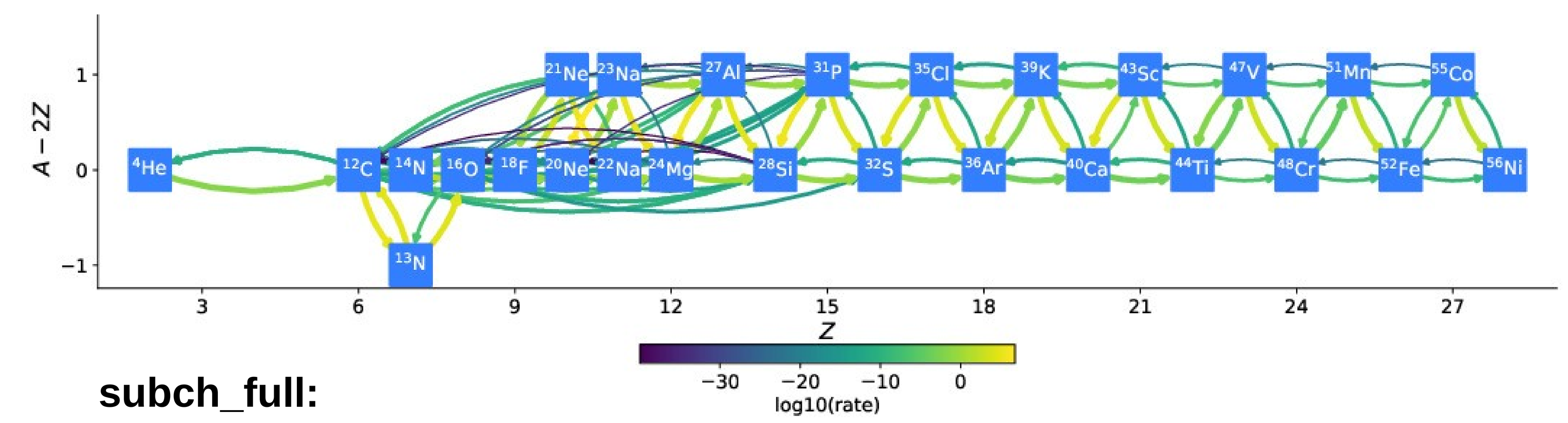
aprox13:

- (α, p)(p, γ) approximation.
- 13 isotopes, 31 rates.



subch_simple:

- (α, p)(p, γ) approximation for heavy isotopes.
- The reverse rates of all ^{12}C + ^{12}C, ^{16}O + ^{16}O, and ^{16}O + ^{12}C are removed.
- Forward and reverse rates of ^{12}C + ^{20}Ne , ^{23}Na(α, γ)^{27}Al, and ^{27}Al(α, γ)^{31}P removed.
- 22 isotopes, 57 rates.



subch_full:

- No (α, p)(p, γ) approximation.
- Additional rates, such as ^{12}C(^{12}C, p)^{23}Na to give complete representation on carbon and oxygen burning.
- Additional rates, ^{14}N(α, γ)^{18}F(α, p)^{21}Ne and ^{12}C(p, γ)^{13}N(α, p)^{16}O, discussed in Shen & Bildsten 2009 and Weinberg 2006 [3], [4].
- 28 isotopes, 107 rates.

subch_full_mod:

- Identical to subch full but ^{12}C(p, γ)^{13}N(α, p)^{16}O rates are disabled.
- 27 isotopes, 103 rates.

SIMULATION RESULTS

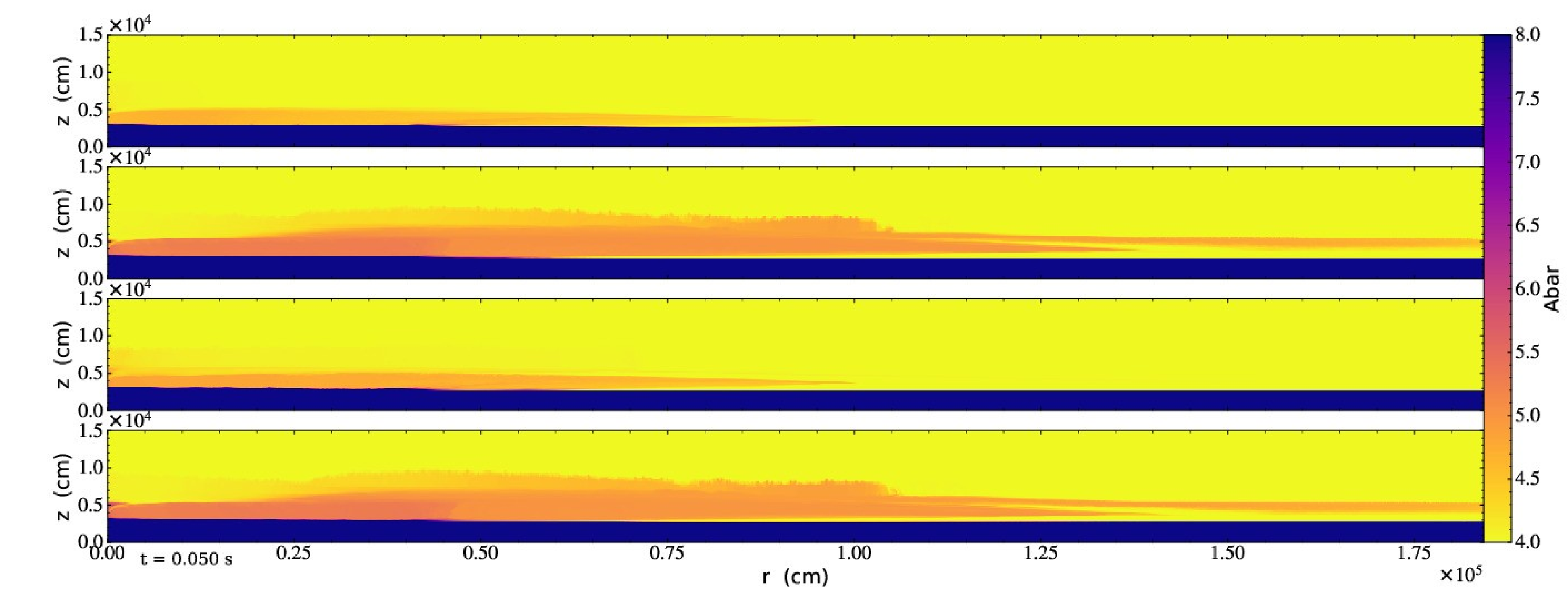


Fig: Slice plots of the flame propagation comparing average atomic weight, Abar, for aprox13 (top panel), subch full (second panel from top), subch full mod (third panel), and subch simple (last panel) at 50ms.

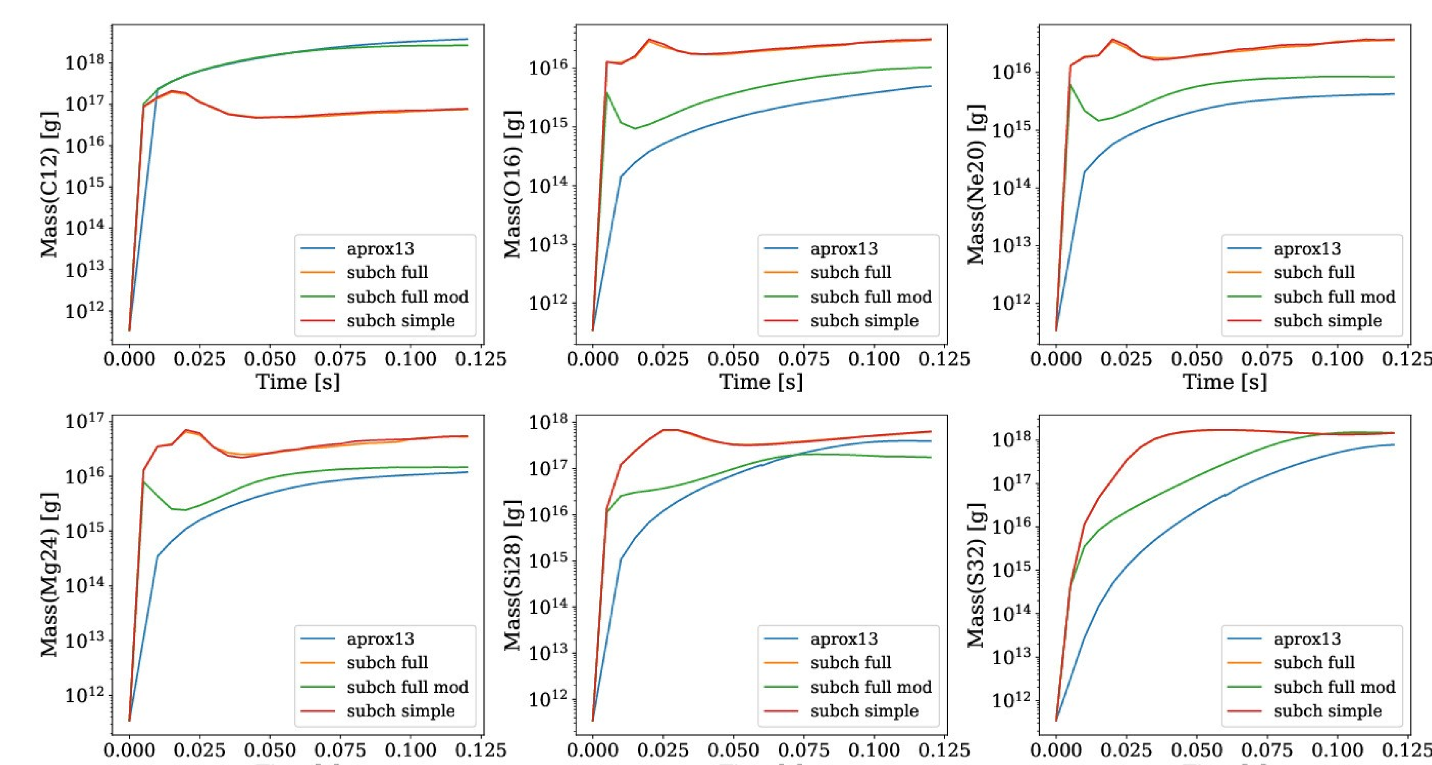


Fig: The evolution of the total mass for ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si, and ^{32}S.

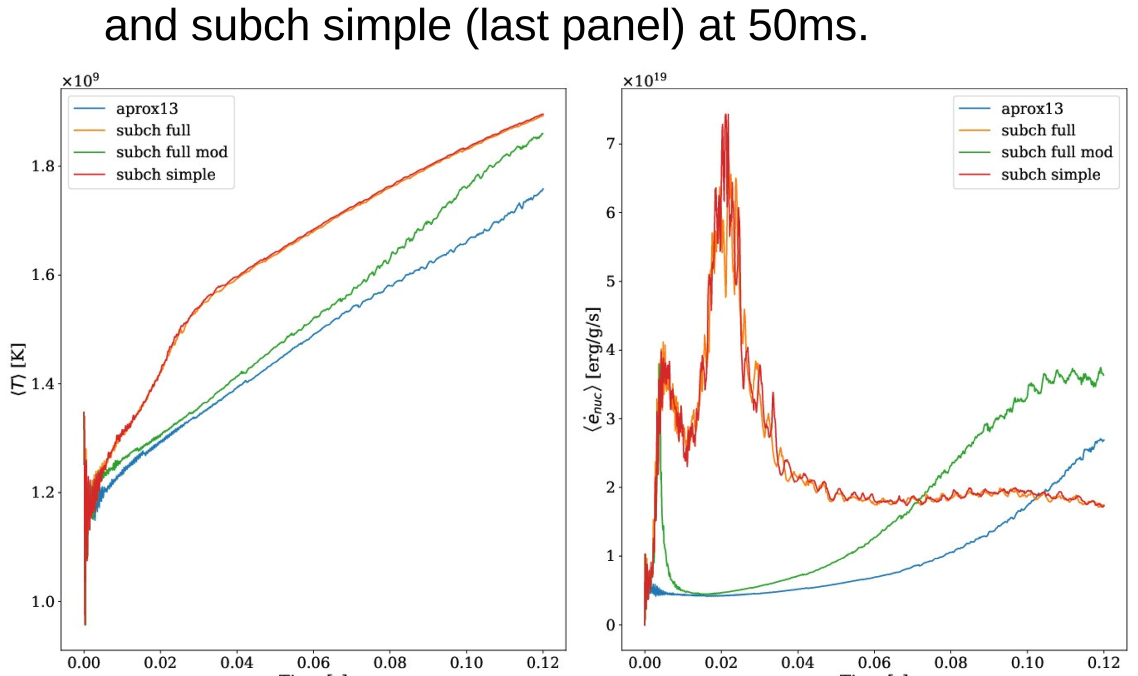


Fig: Left: The weighted temperature time profile. Right: The weighted nuclear energy generation rate time profile.

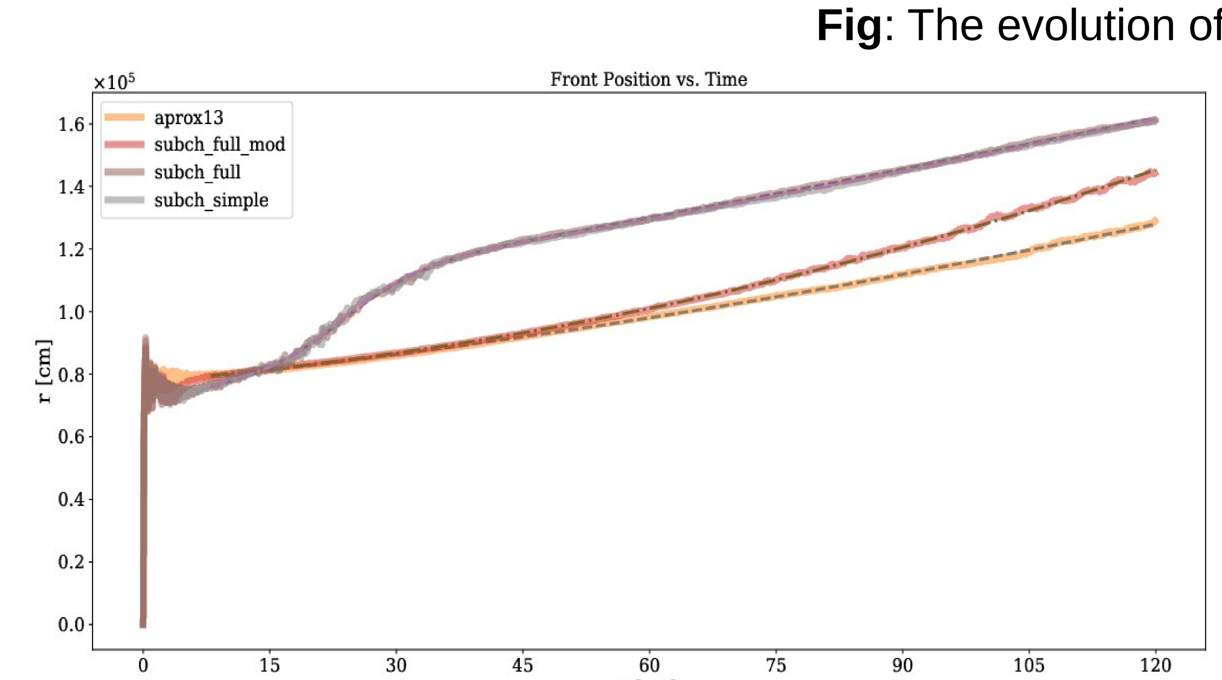


Fig: The flame front position as a function time. Solid Lines: Data. Dashed lines: fit

Name	v_{23} [km/s]	v_{100} [km/s]	t_{10} [s]
aprox13	3.369 ± 0.016	5.234 ± 0.027	0.7647
subch_full	20.732 ± 0.284	5.411 ± 0.105	0.9917
subch_full_mod	3.468 ± 0.017	7.975 ± 0.029	0.4873
subch_simple	21.095 ± 0.332	5.521 ± 0.120	0.8483

Table: Instantaneous flame propagation speeds at t = 23 ms and t = 100 ms calculated using the fitting function. t_{10} is the expected time for the flame to reach r = 10 km using the fitting function.

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