An Approach to Analyzing Long Mean-Free-Path Effects on First-Wall Ion Threat Spectra

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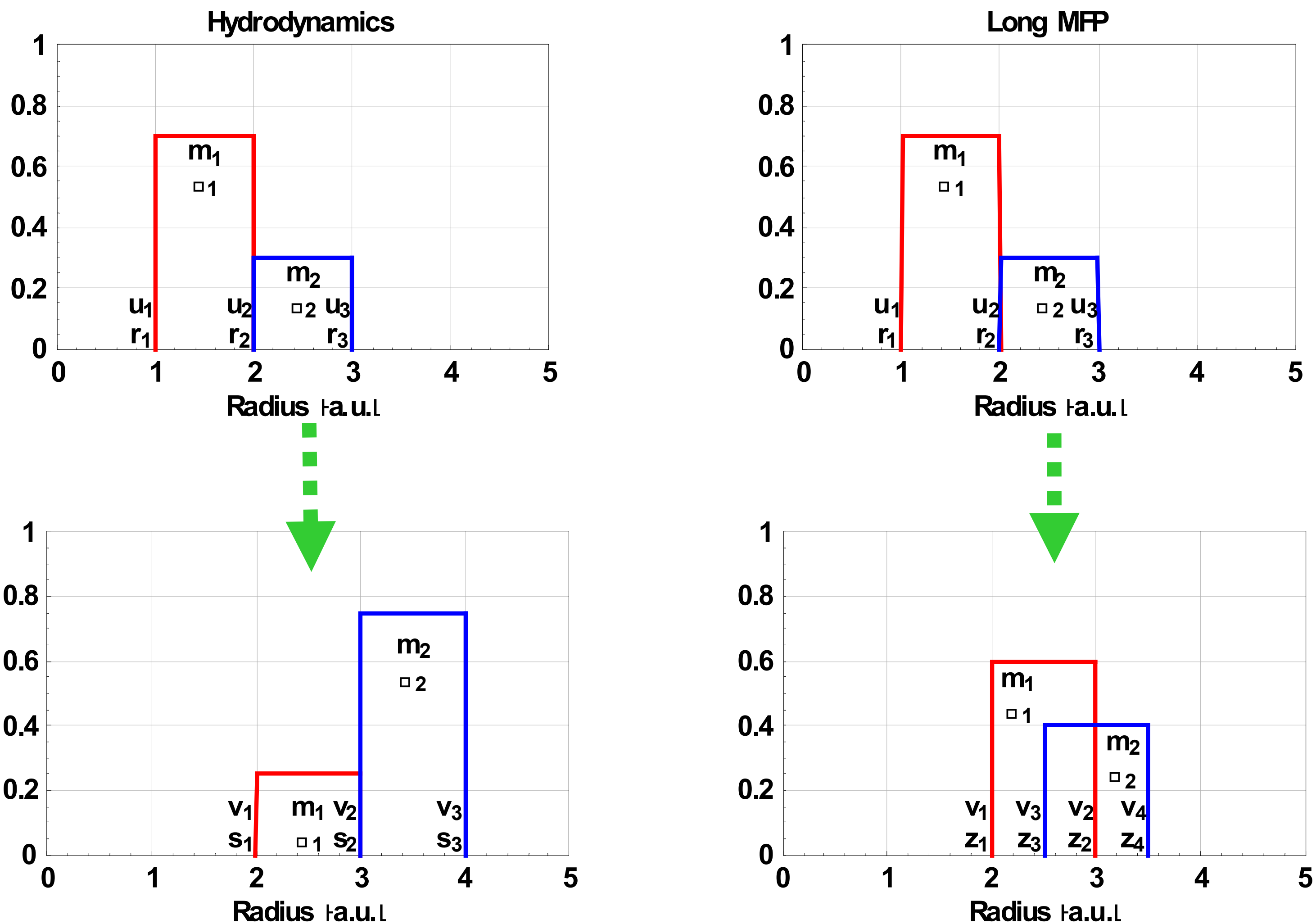
Why is Hydrodynamics Not Sufficient for Predicting the Ion Threat Spectra on the First Wall?

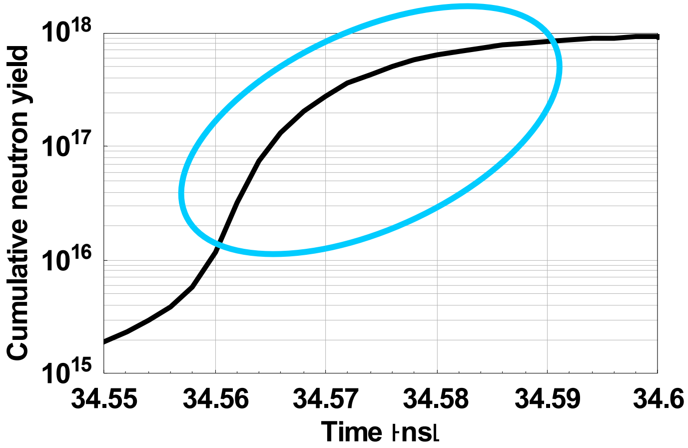
- The hydrodynamic approximation breaks down for particles with mean free paths longer than the scale lengths of interes.
- For HAPL, two classes of ions violate the hydrodynamic assumptions for some fraction of the shot duration:
  - Shock wave passing through background plasma, and
  - Maxwellian ion distribution tails.
- The explosion cannot efficiently accelerate ions with mean free paths longer than the shock thickness or, for some ions, the plasma extent.

"Perfect" Momentum Transfer Characterizes Hydrodynamics, but Not Long MFP Situations

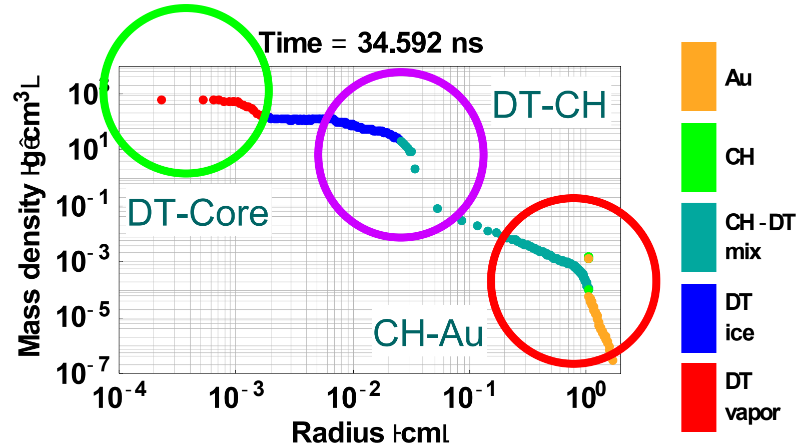


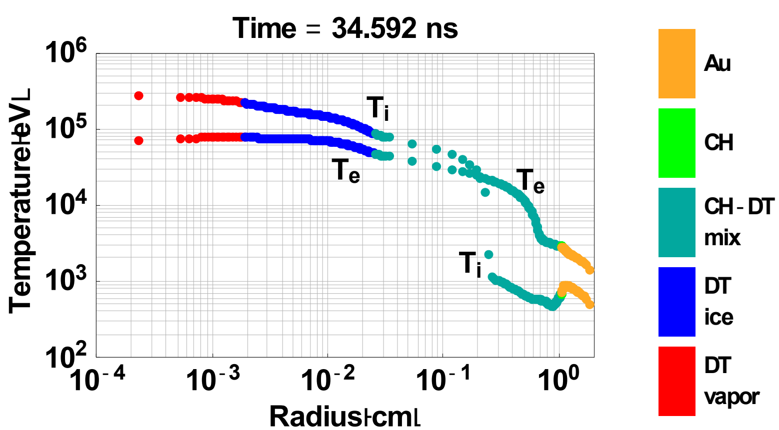
DT Core, DT-CH Shock, and CH-Au Shock Will Exemplify the Issues

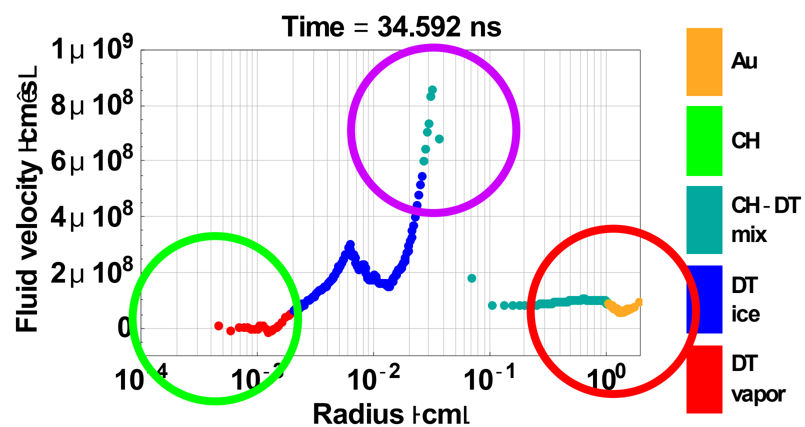
- Neutrons get produced within ~30 ps.



- Each point represents a Lagrangian zone of constant mass.





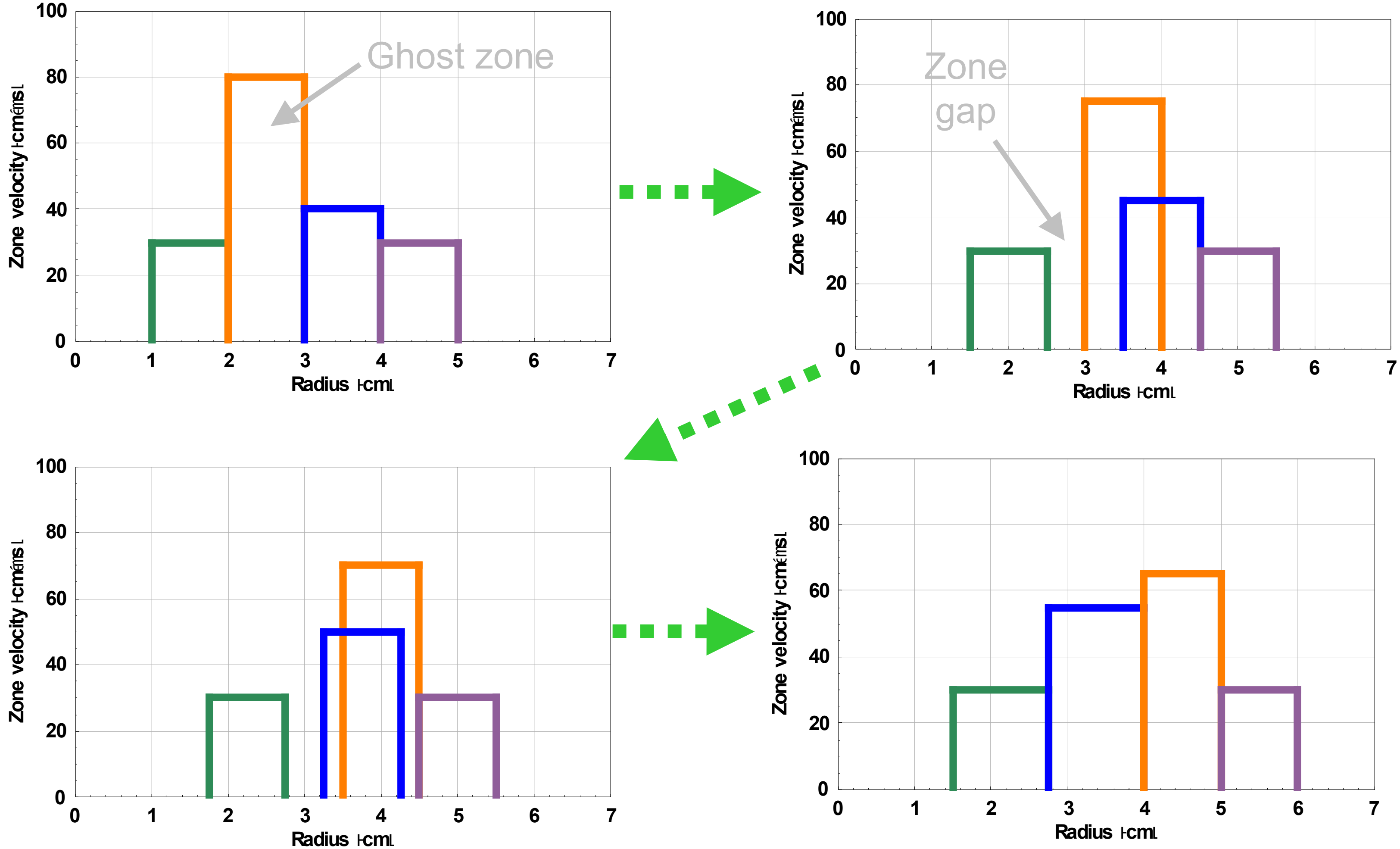


At 34.592 ns, the DT-CH Shock Thickness and Incoming Ion Mean Free Paths Become Comparable

	DT Core	DT-CH Shock	CH-Au Shock
r_{shock} (cm)	< 0.001	0.026	1.1
Δr_{shock} (cm)	< 0.001	0.02	0.004
v_{shock} (cm/s)	6.6×10^6	5.5×10^8	8.6×10^7
n_i (cm^{-3})	1.5×10^{26}	5.1×10^{24}	5.0×10^{18}
T_i (keV)	276	86	2.8
T_e (keV)	72	47	0.69
Ave. charge state	1	DT 1 CH 1	CH 1 Au 36
Δr_{shock} / mfp	> 1000	1.1	0.001

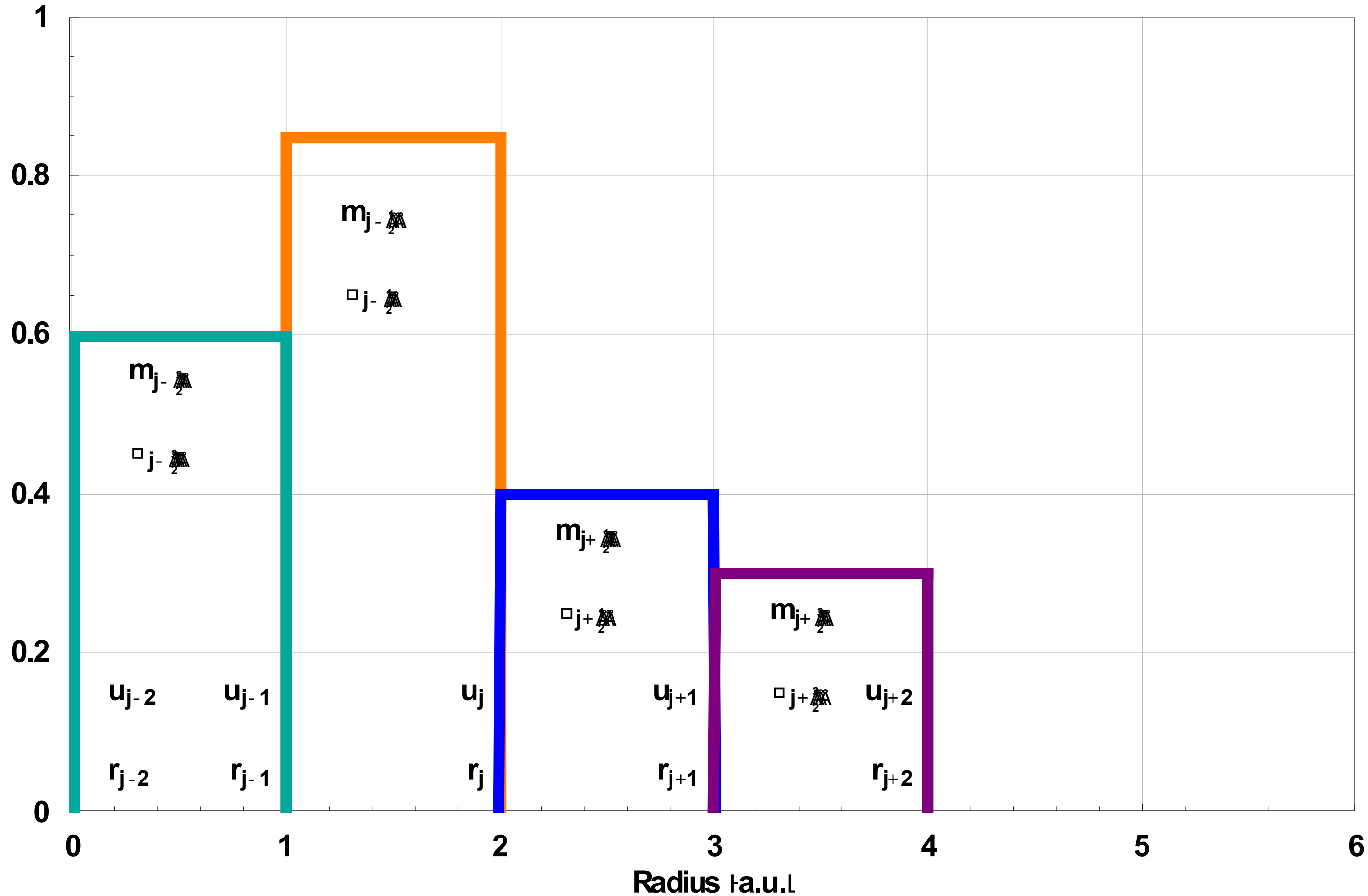
In the Present Approach, “Ghost” Zones Move through Hydro Zones

- Ghost zones interact with zone boundaries, but only as they pass through them.



Zone Evolution

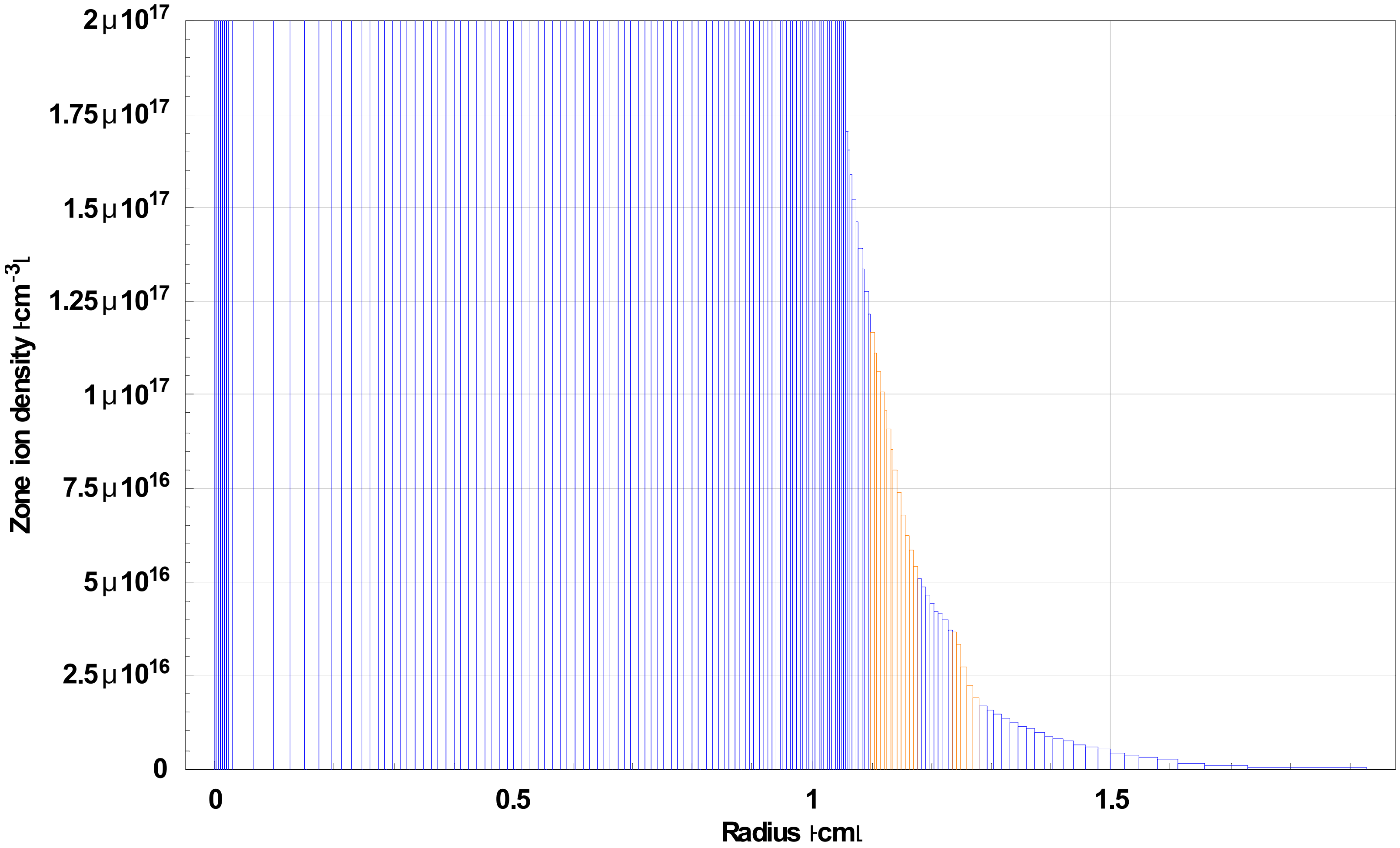
• The gold zone is a ghost zone with respect to the blue zone. The green and violet zones always interact in a hydrodynamic manner with all other zones.



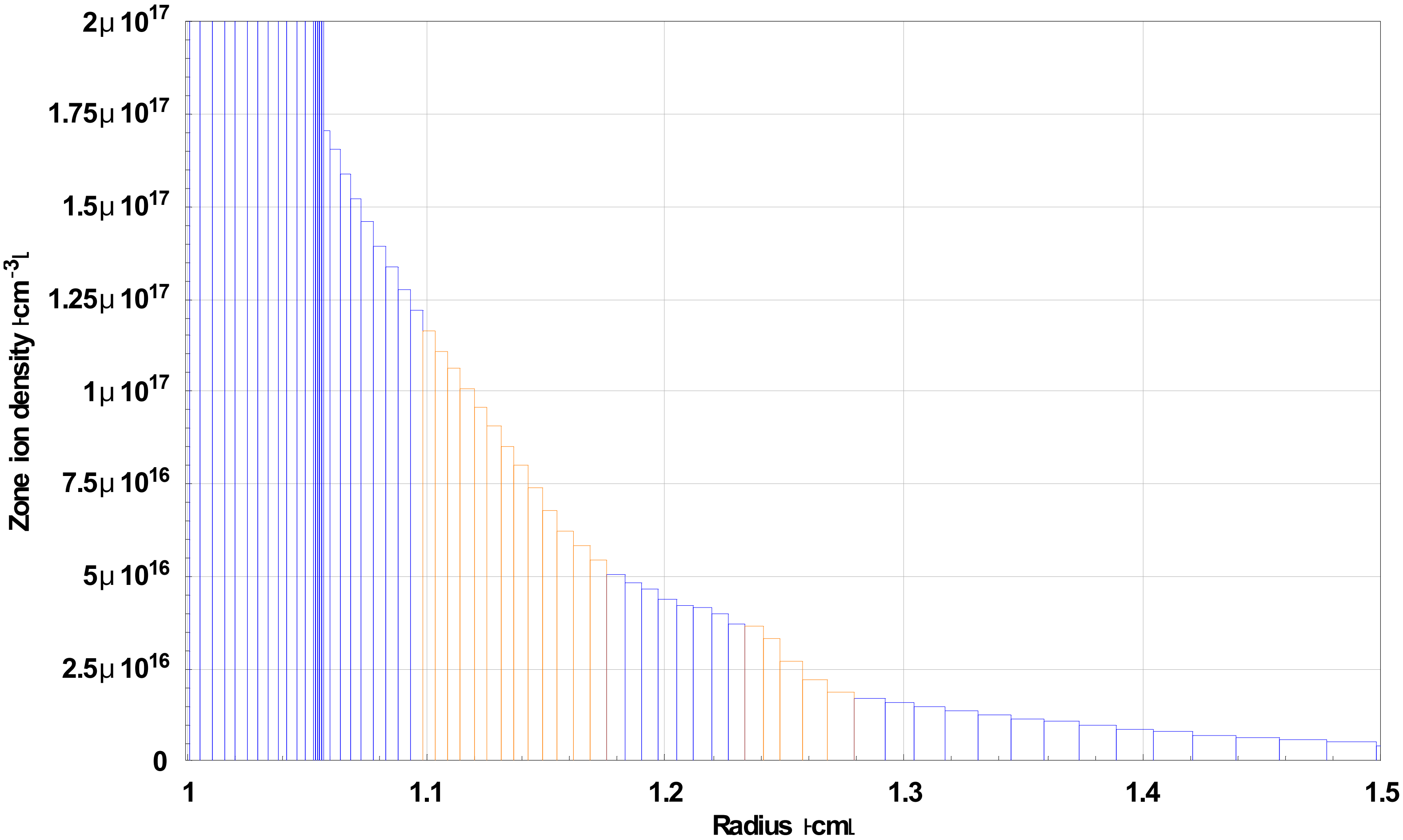
Computational Approach to Modeling Long Mean-Free Paths

1. Test algorithms in Mathematica® using a simplified Lagrangian code [$\partial u/ \partial t+ \partial p/ \partial m=0$; $\partial e/ \partial t+p(\partial V/ \partial t)=0$]:
   a. Perform zone-by-zone check for long mean-free path zones (*ghosts*) relative to adjacent zones.
   b. Move ghost zones a hydro time step *dt* through a series of partial time steps, δt, set by intersecting zone boundaries.
      - Check ghost/hydro status at each δt.
   c. Move hydro zones for time step *dt*.
   d. Update plasma, control, and time parameters.
   e. Reattach ghost zones that return to hydro status & renumber.
2. Implement modified algorithms in BUCKY.

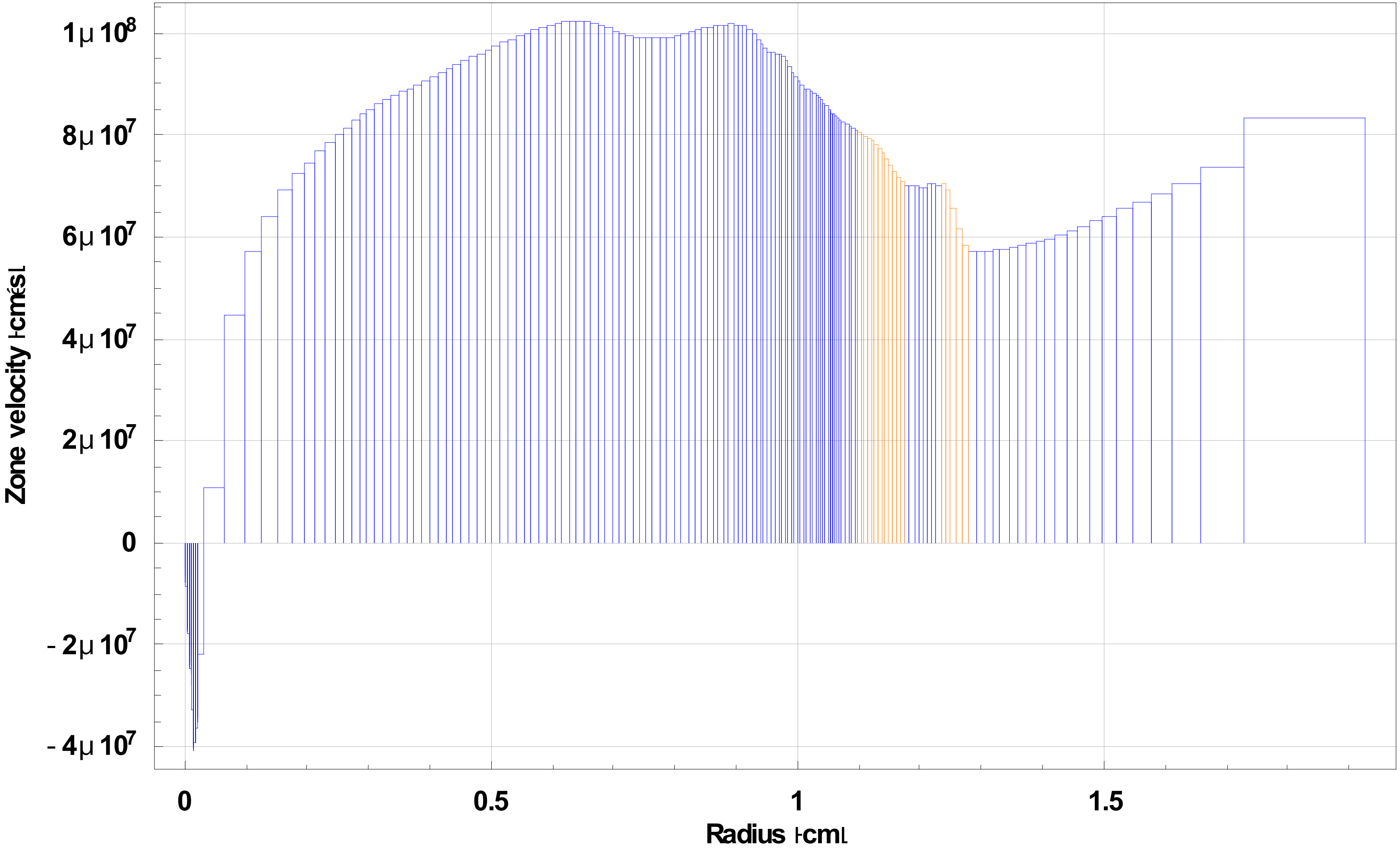
Lagrangian Zone Ion Density Falls Steeply in the



Lagrangian Zone Evolution for Mean Free Paths ≳ Shock Thickness



Lagrangian Zone Evolution for Mean Free Paths ≥ Shock Thickness



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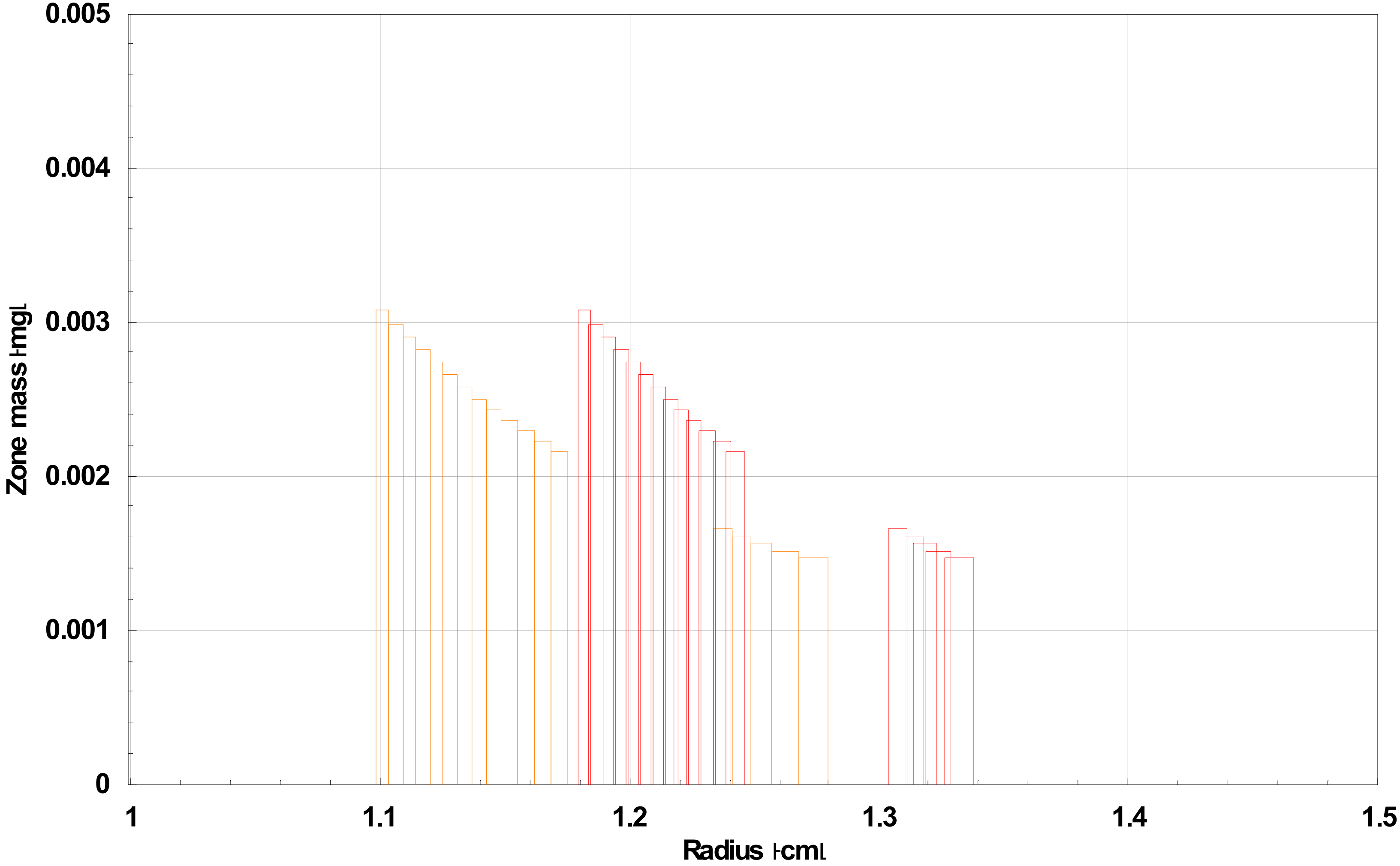

Status and Summary

- Developed an algorithm for velocity transfer between zones of long relative mean-free paths.
- In final stages of debugging this method in a Mathematica® code, originally written for simplified hydrodynamics:
  - Zel'dovich and Raizer problem of supernova shock wave into an exponentially decreasing stellar atmosphere.
  - HAPL problem, starting ~30 ps after start of burn.
- Work remains to implement the long mfp algorithms in BUCKY, in order to include radiation transfer, equations of state, and other effects.