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Title: iFP simulations for Omega experiments studying implosions about the cryogenic vapor pressure of 0.3 mg/cc

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iFP simulations for Omega experiments studying implosions about the cryogenic vapor pressure of 0.3 mg/cc

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Outline

- **Brief summary of iFP**
 - Model: Hybrid ion-VFP and fluid electrons
 - Nonlinearly implicit solver
 - Adaptive and conservative phase-space grid
- **MIT exploding pusher experiments**
 - IC and BC
- **Results and discussions**
 - YOC in good agreement
 - Inferred temperature also closer to experiment

iFP: A hybrid 1D2V VFP code for spherical implosion simulations of ICF capsules

- Hybrid VFP ion (arbitrary species) and fluid electron with quasi-neutrality and ambipolarity

$$\partial_t f_\alpha + \nabla_x \cdot (\vec{v} f_\alpha) + \nabla_v \cdot (\vec{a} f_\alpha) = \nabla_v \cdot \left[\overline{\overline{D}}_\beta \cdot \nabla_v f_\alpha - \vec{A}_\beta f_\alpha \right]$$

$$\frac{3}{2} \partial_t P_e + \frac{5}{2} \nabla_x \cdot (\vec{u}_e P_e) - \vec{u}_e \cdot \nabla_x P_e = \sum_{\alpha}^{N_s} W_{e\alpha}$$

$$n_e = \sum_{\alpha}^{N_s} q_{\alpha} n_{\alpha} / q_e \quad \vec{u}_e = \sum_{\alpha}^{N_s} n_{\alpha} \vec{u}_{\alpha} / q_e n_e$$

- 1D2V spherical radial and cylindrical velocity space
- Electrostatic (Ohm's law)

Nonlinearly implicit time-stepping and adaptive phase-space grid

- **Nonlinearly implicit Solver:**
 - $\Delta t_{exp} \sim O(10^{-12} \text{ ns})$ (dynamically irrelevant)
 - $\tau_{dyn} \sim O(10^{-3} \text{ ns})$
- **Adaptive and conservative phase-space grid**
 - Static uniform grid : $O(10^{12})$ unknowns in 1D2V
 - Adaptive grid : $O(10^5)$ unknowns

The implementation is massively parallel and scalable as well

W.T. Taitano *et al.*, JCP 297 (2015)

iFP has been benchmarked rigorously against a broad suite of analytical and semi-analytical theory

- Correct self-similar solution¹ obtained for $t \gg \tau_{\text{col}}$
- Test of implicit solver with $\Delta t = 4 \times 10^4 \tau_{\text{col}}$
- Successfully benchmarked against VPIC²

1. K. Molvig *et al.*, PRL 113 (2014)
2. Yin *et al.*, Phys. Plasmas, 23, 112302 (2016)

M=1.5 Multispecies Shock (fluid regime)

B. Keenan *et al.*, Phys. Rev. E, **96** (2018)

M=5 Multispecies Shock (fluid regime)

Single-species (verification)

Vidal *et al.*, Phys. Fluids B, **5** (9) (1993)

Keenan *et al.*, PRE, **96** (2017)

Spherical Guderley problem

Taitano *et al.*, Comp. Phys. Comm., **263** (2021)

LILAC simulations are used to initialize and drive iFP simulations

- iFP is driven by time-dependent Maxwellian with rad-hydro state variables:

$$f_{iFP,B} = \frac{n_H}{\pi^{3/2} v_{th,H}^3} e^{-\frac{(\vec{v} - \vec{u}_H)^2}{v_{th,H}^2}}$$

- n_H , u_H , $v_{th,H}$ all obtained from radhydro simulation at Lagrangian zone inside the pusher

Observations: Kinetically enhance pusher mix, as well as fuel ballistically streaming out of the core

Significant mix of glass shell into core at bang time. lim effects in X-ray image from rad-hydro is not present

Good agreement in YOC up until the lowest fill pressure

Inferred (neutron spectrum) ion temperatures in closer agreement with experiments, relative to LILAC (driver for iFP), but DUED performs better at higher fill

Immediate and future work

- **Isolation of dominant physics that iFP is capturing correctly:**
 - Interface mixing
 - Tail depletion
 - Increased heat capacity due to shell mixing
- **Missing physics in current simulation:**
 - Kinetic electrons:
 - Nonlocal electron heat-transport and kinetic instabilities role in implosion dynamics?
 - Capability currently being tested in iFP with shot 86639. Numerical issues are being ironed out.
 - Electron EOS:
 - For higher fill pressures, could play a role particularly in pusher.
 - Self-consistent radiation drive:
 - Currently, testing gray radiation diffusion (for indirect drive).
 - Laser driver for direct drive will be more relevant for this collaboration.