Expanding Bubbles from Holography

Mikel Sanchez Garitaonandia

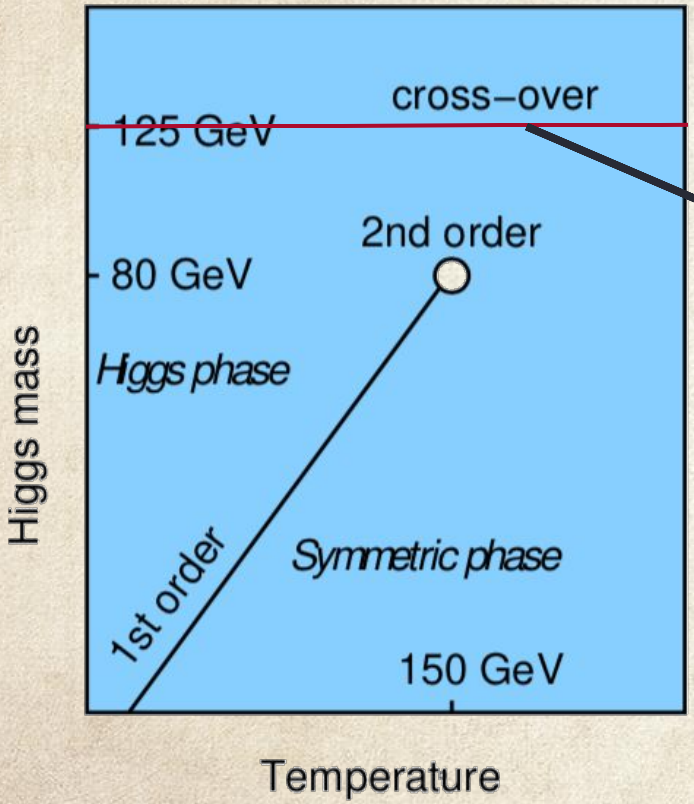
Universitat de Barcelona

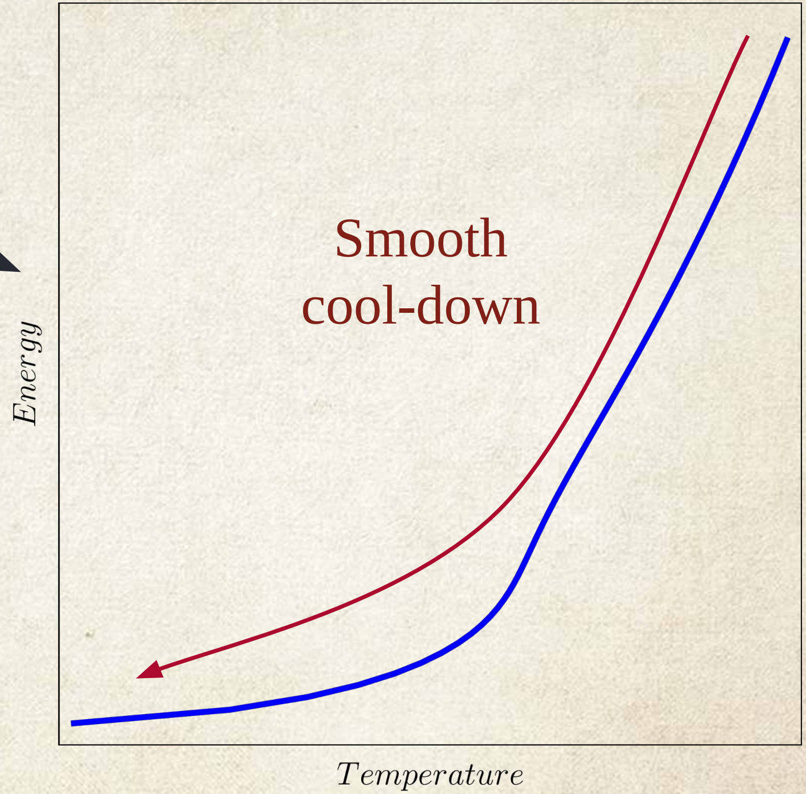
Y. Bea, J.Casalderrey-Solana, T. Giannakopoulos, D. Mateos, M. Zilhão

Story of the Ancient Universe

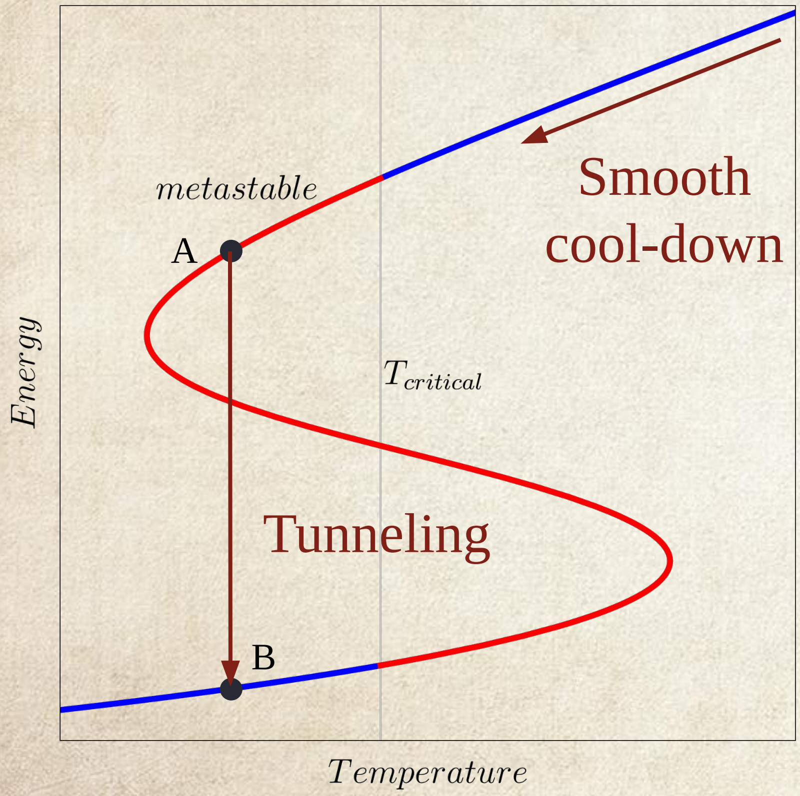
Standard Model

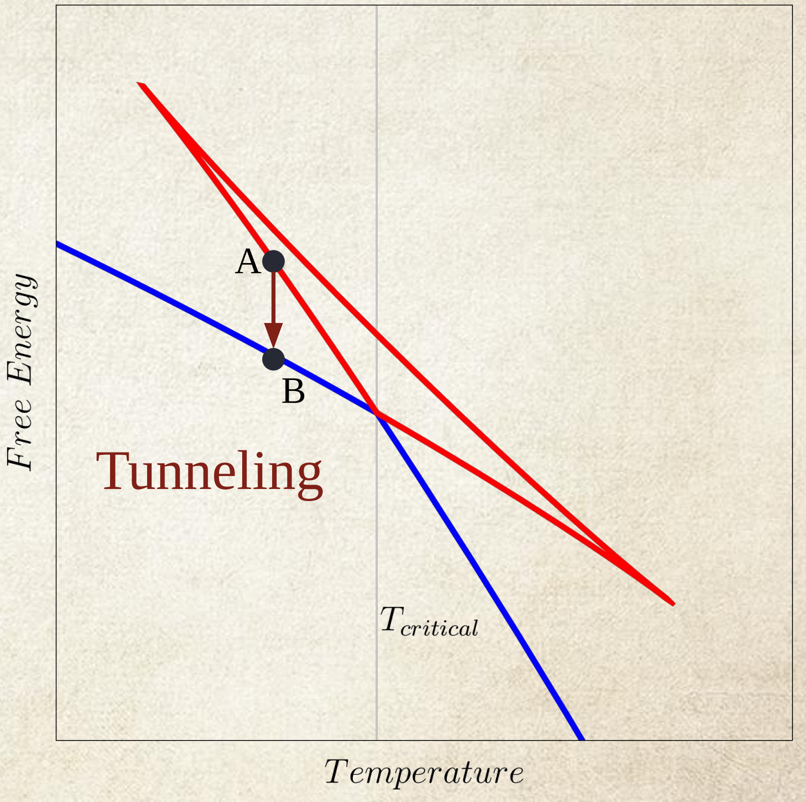
[Hindmarsh, Lüben, Lumma, Pauly 2021]

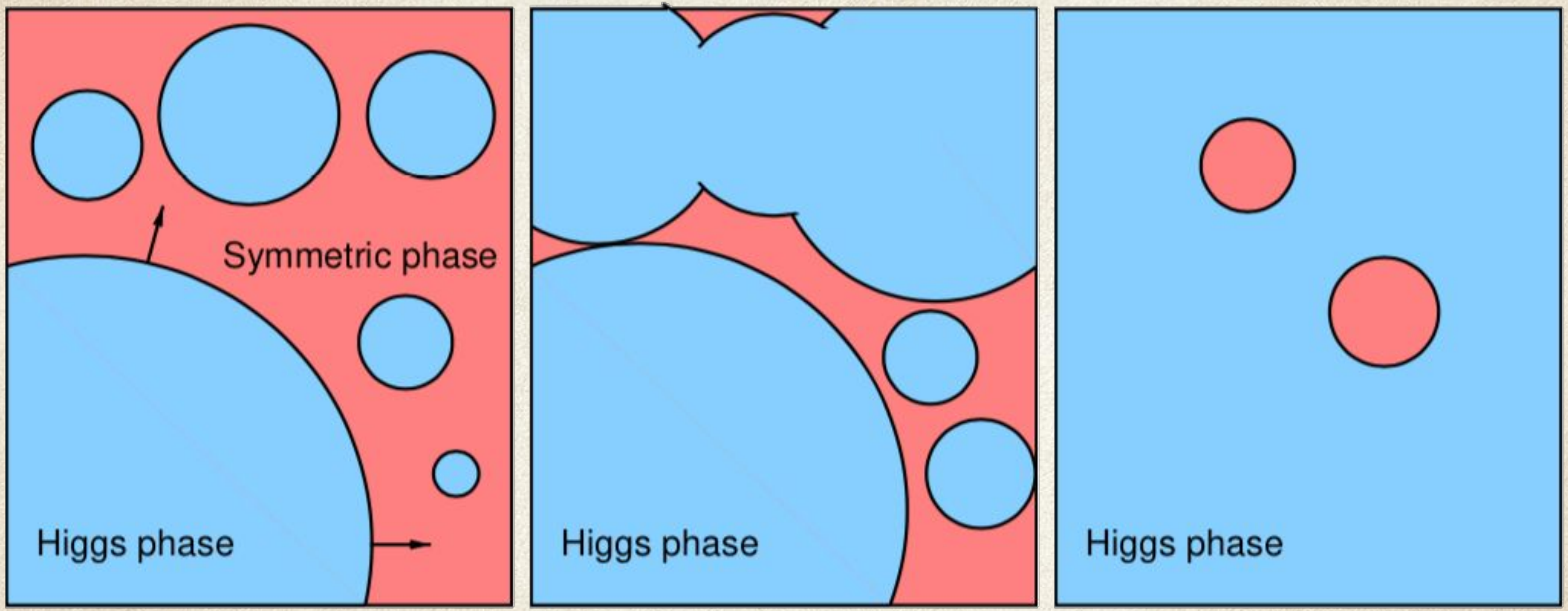




Extensions of the SM







[Hindmarsh, Lüben, Lumma, Pauly 2021]

Nice story… Why should we care?

- First order phase transitions naturally induces a departure from equilibrium, required to explain matter-antimatter asymmetry

- This violent physics could source observable Gravitational Waves, shedding light into possible new physics (extensions of the SM)

- Problem of the expansion of a single bubble is important to predict the gravitational wave emission of bubble collision
- Formulas assume a thin wall bubble and the wall speed is required as input parameter
- No simulation based on first principles yet, we have relied on hydrodynamics so far (does not predict the wall speed)
- Far from equilibrium problem → Holography

Questions:

1. Is the wall thin?

2. Does the wall move at constant speed?

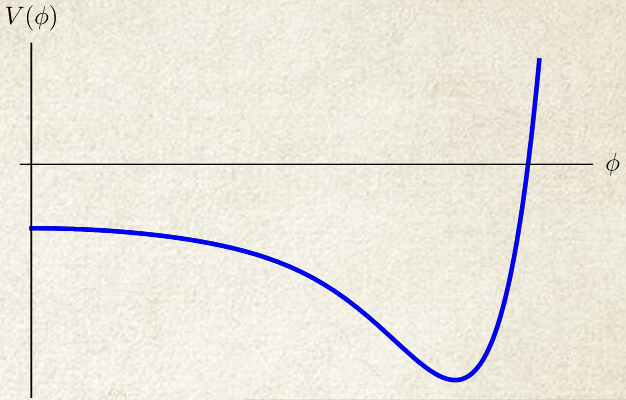
3. Unique bubble for a given nucleation temperature?

4. How reliable is hydrodynamics?

Set-Up

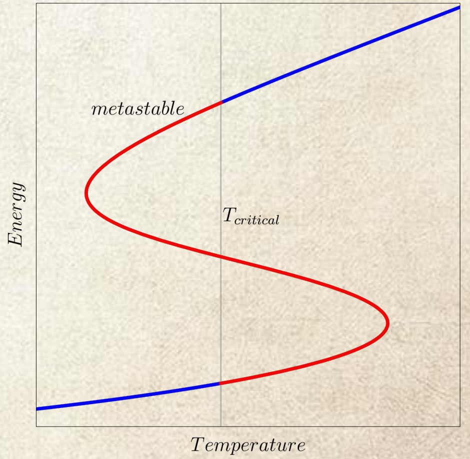
In the bulk

$$S = \int d^5x\sqrt{-g}(R + \partial\phi^2 + V(\phi))$$



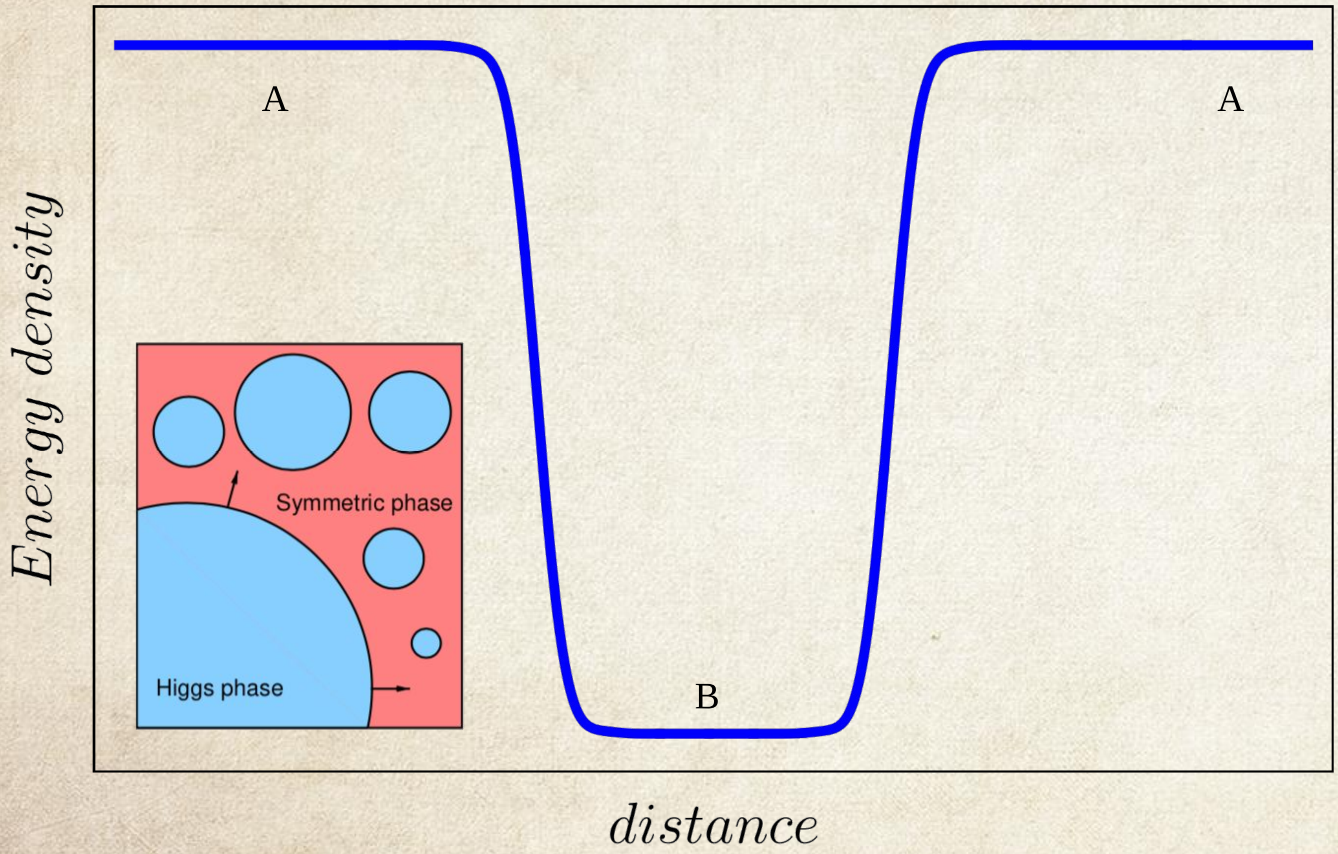
$V(\phi)$: Simple polynomial with 2 parameters

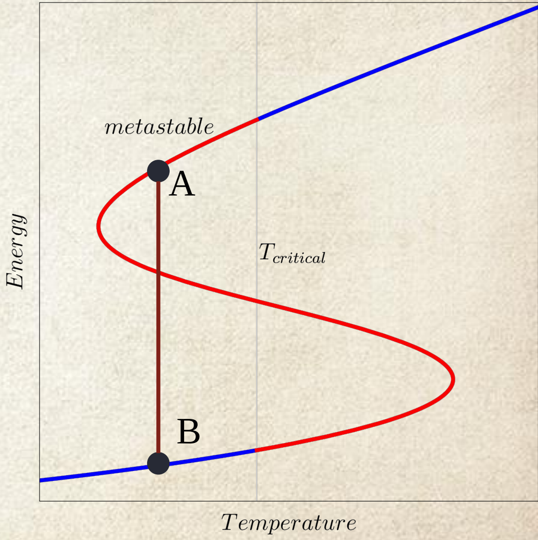
On the boundary



Deformation of the CFT with a single energy scale Λ (~ QCD) and a first order thermal phase transition

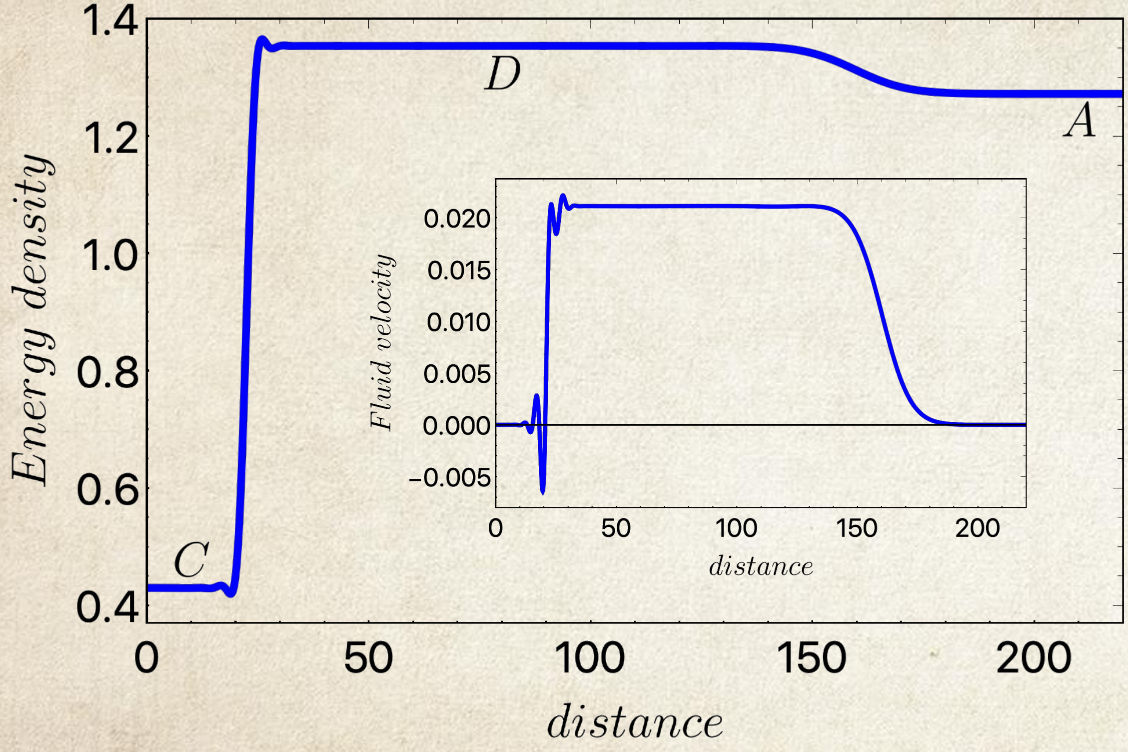
INITIAL STATE

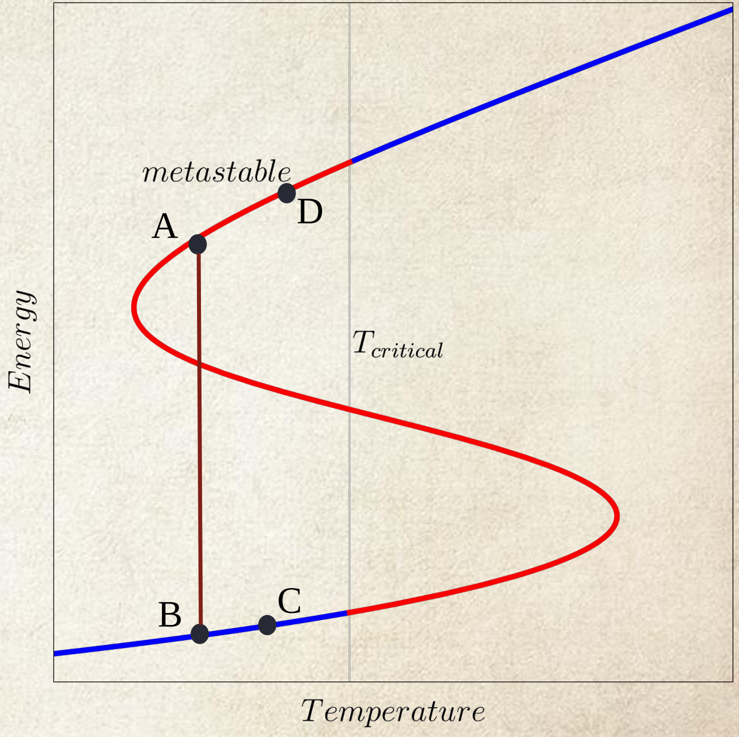




Results

Stationary Regime





- The wall moves at constant speed as a rigid body ($v_{wall} \leq 0.033$)

- So far deflagrations: $v_{wall} < c_s$ far away outside the bubble

- Only fluid in motion is right ahead of the wall, warming the fluid above nucleation temperature

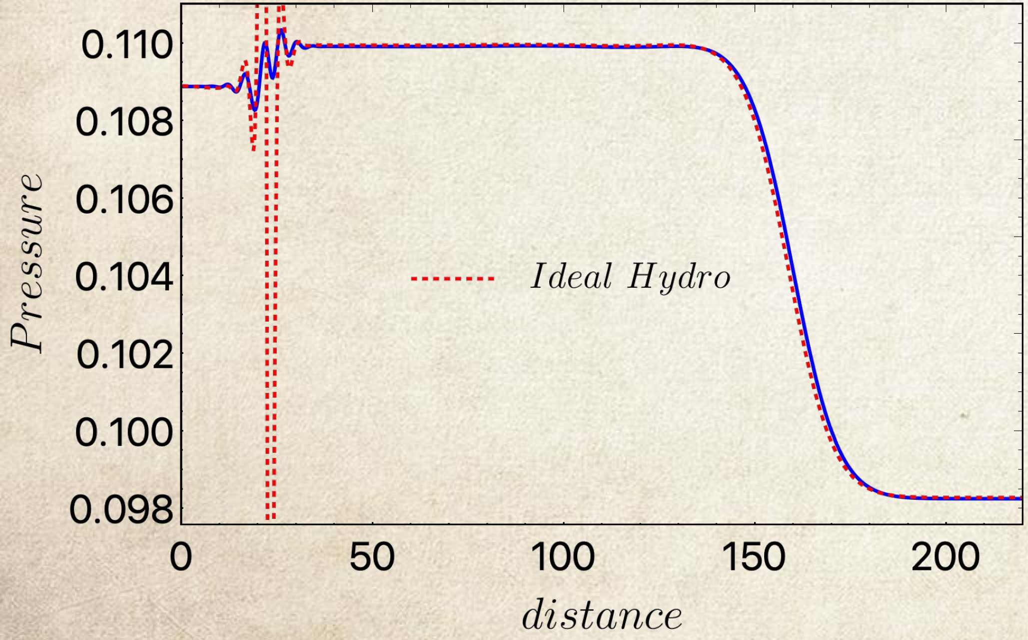
- States inside the bubble and ahead of the wall are determined solely by the nucleation temperature (unique bubble)

- Size of the regions grows linearly with time while the wall shape is fixed, we end up with a thin wall

Hydrodynamics

Change in the properties is very small, so there is a chance that ideal hydro (rest frame equilibrium) can describe a big part of the plasma

$$T^{\mu\nu} = \mathcal{E} u^\mu u^\nu + \mathcal{P}(\mathcal{E}) \eta^{\mu\nu}$$



It explains everything but the wall

To obtain the wall, including the wall velocity, we require a more fundamental approach

Every story comes to an end

1. Is the wall thin?
   The wall does not change shape, it becomes thin with time

2. Does the wall move at constant speed?
   It does in the stationary regime

3. Unique bubble for a given nucleation temperature?
   Yes, data seems to support a unique bubble

4. How reliable is hydrodynamics?
   Ideal hydro describes the whole fluid except for the wall itself

Future Directions

- Explore scenarios in which detonation might happen: bubble expands faster than the speed of sound in that medium

- Extend the study to higher dimensions (2+1): learn about expansion when the bubble is not big

- Simulate collisions of expanding bubbles


Thank You