From physics to astrophysics and back again …

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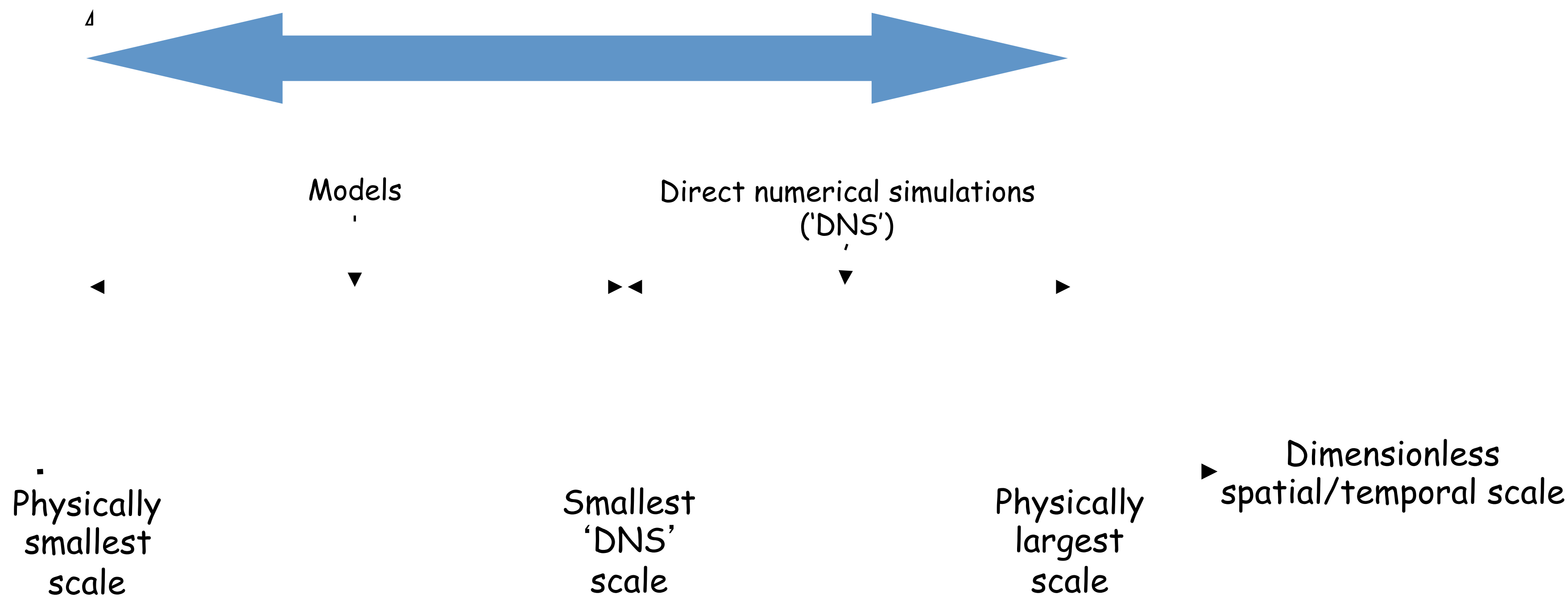
Astronomy & Astrophysics and Physics

What is it that makes theoretical/computational astrophysics so challenging, but also fun?

- **As an astrophysical discipline, it is a ‘remote sensing’ science**
  - Controlled experiments are not a possibility …
- **As an astrophysical discipline, it is ‘phenomena-focused’**
  - The phenomena are typically multi-scale in both time and space …
  - Models are heavily ‘scenario-based’ …
    - Enormous disparities in astrophysical temporal and spatial scales, and multiple physical processes, make it difficult to construct complete ‘first-principles’ models/theories
      - Typically one cannot model all of the phenomenology …
      - Great resemblance to science-based engineering
    - As a result, physically well-motivated aspects are commonly connected by more speculative (and more poorly modeled and understood) ‘storylines’
- **What is changing?**
  - New avenues for laboratory-based studies of plasma phenomena relevant to astrophysics …
  - Remarkably more capable computer-based simulation tools …
  - Totally new horizons: dark matter & energy, gravitational waves, …

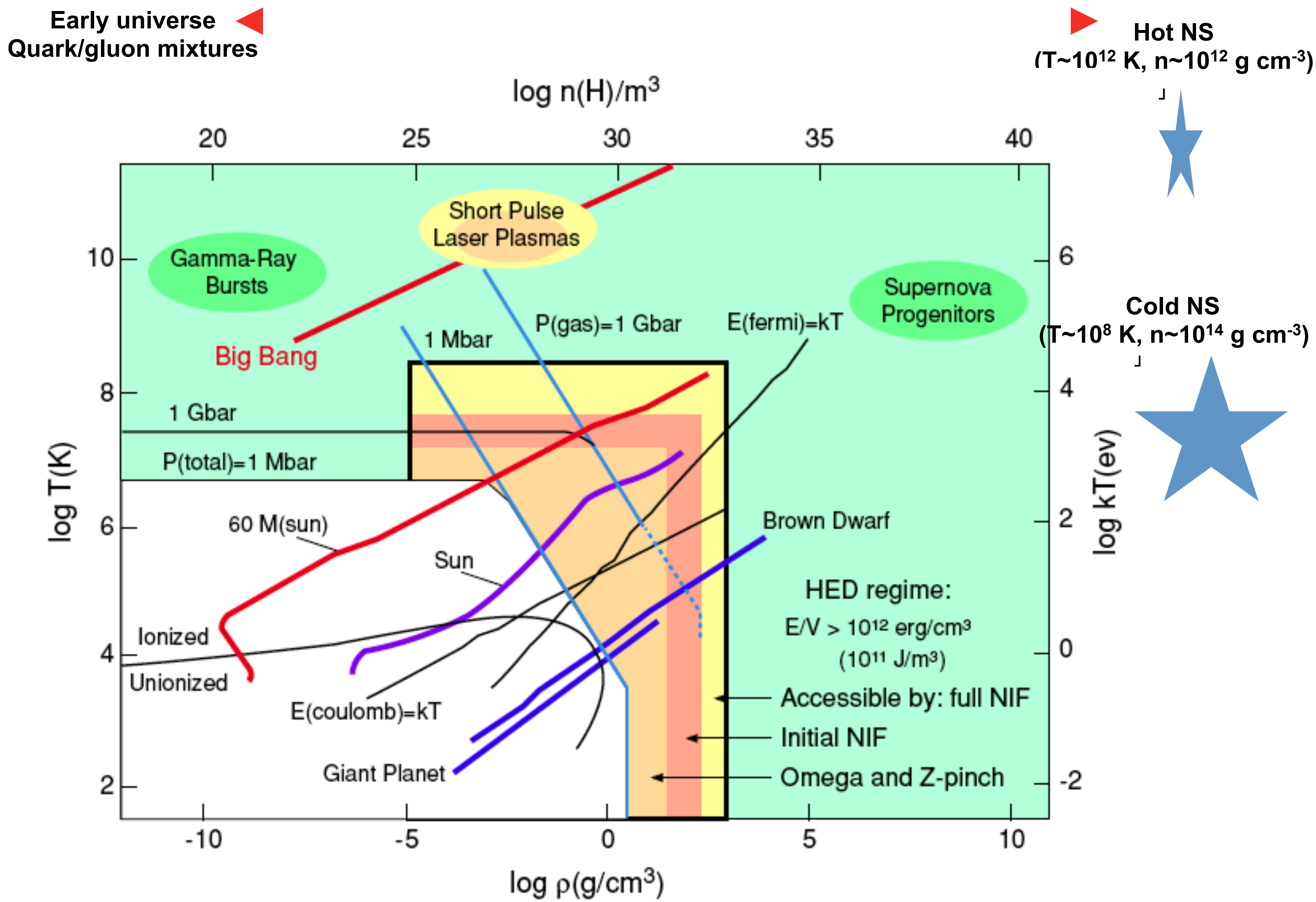
Computational astrophysics unavoidably depends on models for the unresolved scales …

Computational [HED] astrophysics



- "Sub-grid" models require experimental validation …
- In the inviscid limit, we can scale our problems from astrophysics to the lab …

How does plasma astrophysics connect with (lab) physics?

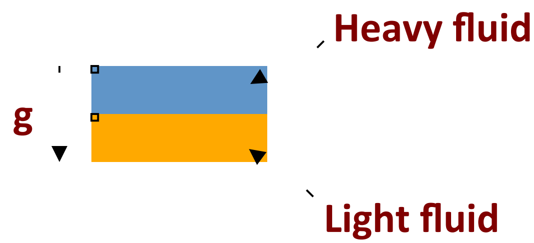


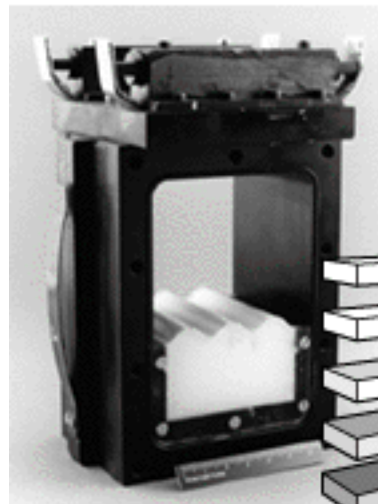
… and the new HED facilities offer the chance to reproduce these conditions – and to experiment with them!

- Very dense plasmas – orders of magnitude above ordinary solid matter densities, up to 10^{24}-10^{26} cm^{-3}, at temperatures up to 100's of eV
- Relativistic plasmas
  - Neutral electron-positron plasmas, up to densities ~ 10^{18} cm^{-3} (in 2-3 yrs)
- Very strong (possibly radiative, possibly relativistic) shocks, well beyond what can be done in ordinary hydro experiments
- Radiation-dominated plasmas
- Very strong magnetic fields – well above 10^6 Gauss
- High Reynolds numbers – not quite astrophysical, but getting there
  - $Re > 10^6$
  - $Re_m > 10^3$
    - We may be able to finally reach MHD turbulence conditions, in which the turbulent generation of magnetic fields might be explored!

An example: Can code comparisons reveal whether the astrophysics simulation codes are "correct"?

- The 'alpha group' code focused on the nonlinear evolution of the Rayleigh-Taylor (R-T) instability





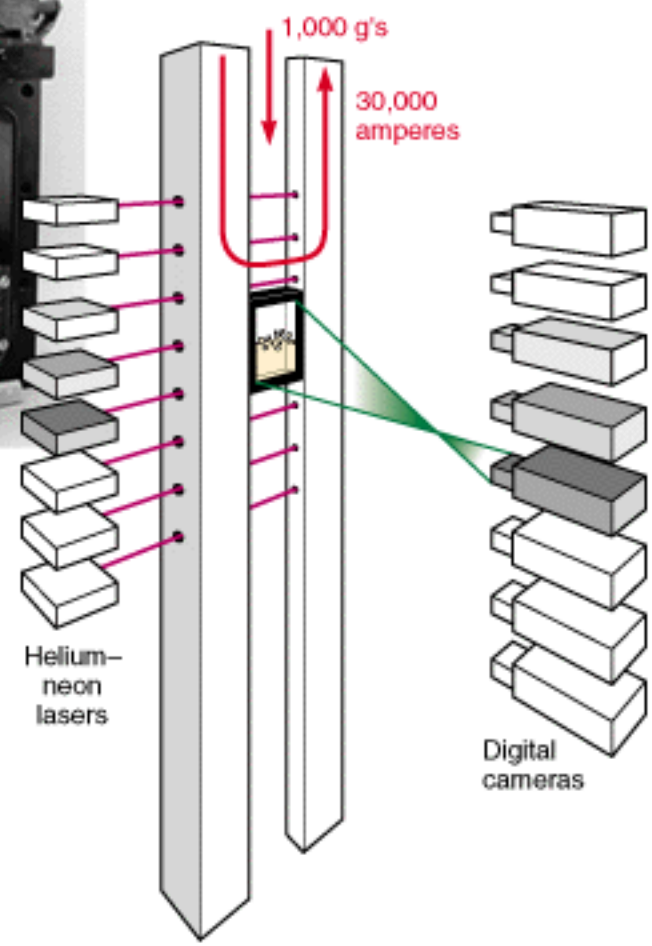
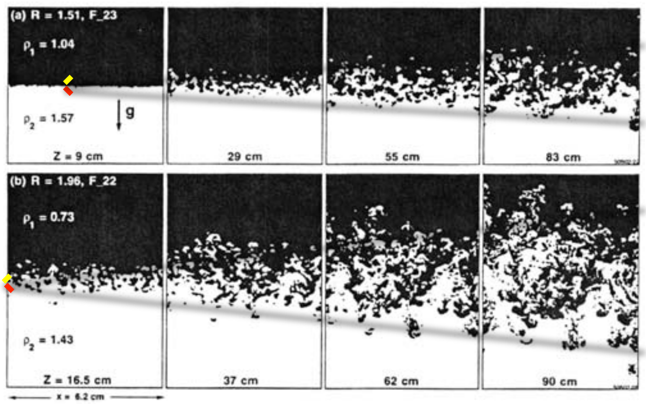


Figure 1. A schematic of the linear electric motor and close-up of the cell.

Guy Dimonte

The idea …

- Guy Dimonte designed the experiment, and carried it out. He measured the width of the mixing zone as a function of time.

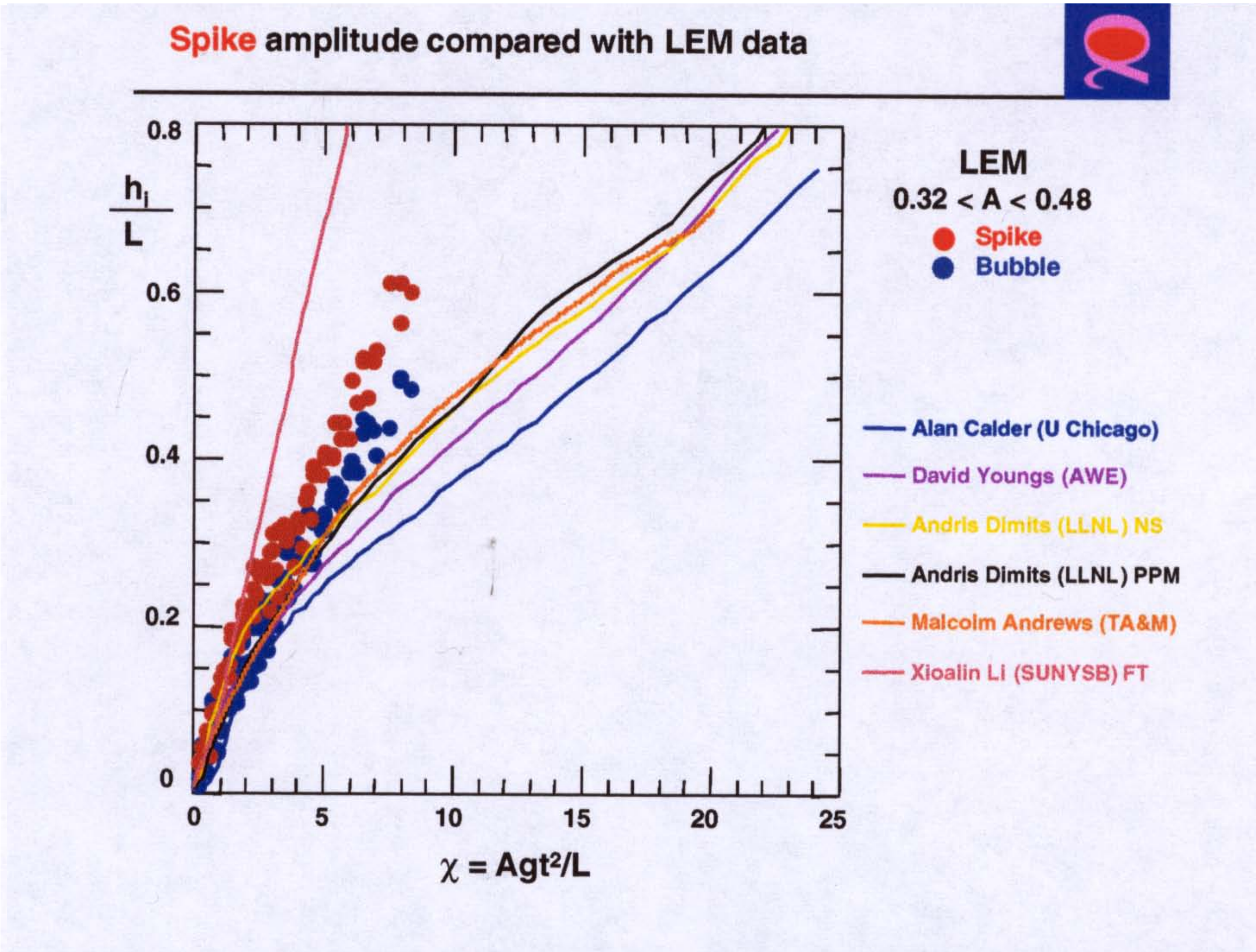


The mixing layer width: h ~ **α**gAt^2,
A ~ "density ratio", **α** is what we're after …

- Six different code groups simulated this experiment, and computed the mixing layer width as a function of time, allowing an estimate of **α** from the simulations …

- We then compared (by overlaying transparent foils/viewgraphs)
  - The 6 code results
  - The 6 code results with the experimental data

Unfortunately, successful comparison of codes cannot increase confidence in the results … but they can identify aspect of physics we've missed or mis-understood …



The data-modeling comparison strongly suggests that the effective density contrast (which is related to the buoyancy driving) is too low in the simulations …

- This suggests that the simulations are too diffusive when compared to the real world, e.g., the upward and downward-going bits are diffusing into one another, reducing the density contrast ...
- Thus, we need to reduce or eliminate diffusion in the simulations ...

A Comparative Study of the Turbulent Rayleigh-Taylor (RT) Instability Using High-Resolution 3D Numerical Simulations: The Alpha-Group Collaboration Dimonte, G., Youngs, D.L., Dimits, A., Weber, S., Marinak, M., Wunsch, S., Garasi, C., Robinson, A., Andrews, M.J., Ramaprabhu, P., Calder, A.C., Fryxell, B., Biello, J., Dursi, L.J., MacNeice, P., Olson, K., Ricker, P., Rosner, R., Timmes, F.X., Tufo, H., Young, Y.-N., & Zingale, M. 2004, *Phys. Fluids*, **16**(5), 1668-1693.

Discussion/questions/…