FLASH accomplishments--
Scientific Simulation and Prediction
for turbulence workshop

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Summary

Our turbulence work is connected with an astrophysical computation center called ASC-FLASH.

I concentrate my attention upon the physical content of our simulations, showing how they can explore possible scenarios for the hydrodynamics of stellar explosions.

my usual scientific role is, in part, to explain and criticize the FLASH efforts.

Here I stand in for Don Lamb, the Program Director, because he has a longstanding European engagement. He says “hi” and “sorry”.
Background

ASC is an alliance of universities and DOE weapons labs aimed at improving scientific computations as a support for the program of stockpile stewardship. FLASH is Chicago’s part of this program. We work on simulating and understanding novae and supernovae events. DOE gives us regular and occasional access to very large computers.

We seized an occasional opportunity to do a homogeneous and isotropic turbulence simulation because it helped expand our horizons. It provides familiar territory in its Eulerian aspect, but unbroken ground in its Lagrangian aspects. We intend to make these results available to the community.
But First Let’s Look at the Science we (FLASH) has done so far:

- Rayleigh-Taylor Instability
- Nova
- Type Ia Supernova
- Flame Lab
Rayleigh Taylor Instability

Source of Instability

cooler more dense, fluid

hotter, less dense, fluid

Very important for DOE. They saw variability in early studies; they therefore sponsored 15+ major studies of this instability through ASC program.
The Raleigh Taylor Instability.

A high density fluid sits on top of a lower density one. Small deviations from perfect surface flatness triggers an instability. The two fluids penetrate into one another. Dimensional analysis suggests a penetration distance

\[ h = \alpha A g t^2 \]

with \( A \) being the Atwood's number (density contrast) and \( \pm \) being dimensionless---and also Universal (!?).

Kai Kadau...Berni Alder, “Nanohydrodynamics simulation of R-T Instability”, ‘04. 1.3•108 particles
Almost 15 groups have measured or calculated . Their results are important for us (a DOE supported astrophysics group) because the instability occurs on the surface of an exploding star. It is also important to the DOE nuclear weapons program who sponsored the studies.

Summary of Different Studies


The ‘b’ refers to the bubble, which is the mode of penetration of the light fluid. The heavy fluid penetrates as spikes.
Resolution Study  \( d=2 \)

Calder et al
The same $d=3$
Result

Don’t trust the value of $\alpha$
It is not universal and depends on the details of the calculation being done

Don’t trust any Rayleigh Taylor calculation with zero surface tension. Mathematically, it’s an ill posed problem and answers depend upon details of what happens at the earliest time.
Nova and Supernova

Unburned material from an ordinary star accretes onto a white dwarf star. The material is then ready to undergo a very rapid burn.

In a nova, the burn is preceded by a mixing which we argue is caused by wave action in the upper layers of the white dwarf.

cartoon by NASA
Nova: Mixing makes burn possible

Breaking carbon/oxygen waves on a solar mass white dwarf. The waves are driven by a resonance interaction with a wind in the overlying accreted hydrogen layer, analogously to terrestrial ocean waves. This carbon/oxygen spray helps catalyze the hydrogen thermonuclear burning that powers classical novae.

We do not know enough about wind velocity, etc. for a good check of theory against observation.

A. Alexakis, et al., Astrophysical Journal, in press. Visualization was done by ANL/Futures Laboratory
On to type Ia’s Supernovae: a really hard problem

A supernova is a white dwarf with nuclear material all mixed up and ready. It needs a really good push to get the nuclear detonation started. It’s hard to see where that push comes from. Furthermore, if we detonate it in its natural state, still the result is poor because the outcome is mostly heavier elements and does not include the lighter elements actually observed in the explosion.
Step I: A new kind of trigger. A local fluctuation produces a hot bubble which rises through the material. Instabilities produce a very unsymmetric bubble.
The Bubble

Step II: **Inertial focusing**

But after a time it was noted that the direct effect of this surfacing was not a detonation. Through insight and simulation Plewa et. al. showed that hot material would shoot up from the bubble, fly across the star, dredge up unburnt material, and the whole mess would refocus on the other side. **BOOM**
Flames Propagate through Star studied with “flame laboratory”

The volume swept by the flame is the product of surface area, as modified by turbulence, and flame speed. When perturbations cannot be resolved, enhanced flame speed is used to compensate for the reduced surface area. Current model is based on RT rates - was confirmed by simulations of flame in a box.

Shimon Asida
Resolution study: flame surface
Where do we go from here?

We hope to:

1. continue to test supernovae simulations against observational data to get a better hand on using the Type Ia’s as a tool for testing astrophysical theories.

2. test our simulations against “laboratory” experiments to further investigate the validity of the simulations.

3. continue to develop the FLASH simulation package for the simulation community.

4. contribute to fundamental knowledge of hydrodynamics by drawing the community in to analyze the results of our simulations. Specifically to make data available from our very large homogeneous turbulence simulation. Let’s hear about that!