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Testing Radiation-Flow Physics and Shock Breakout (U)

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Radiative shocks are important in a wide variety of astrophysical problems, especially in the modeling of shock breakout or shock emergence in supernovae. In core-collapse supernovae, as the shock from the explosion "breaks out" of the star, the radiative shock transitions from a regime where the radiation is trapped in the flow to a regime where the shock front is optically thin to radiation. Similarly, in thermonuclear supernovae, as the white dwarf star expands, the radiation dominated explosion also transitions from an optically thick to an optically thin explosion. Understanding this transition is critical to understanding the subsequent evolution of the shock and the explosion and is required if we are to take advantage of the wealth of observational data of supernovae to better understand the engine behind these cosmic explosions. But this understanding requires accurate simulations of this difficult-to-model transition in radiation hydrodynamics. Analytic approximations of this transition have been shown to be incorrect by orders of magnitude in many examples. To achieve precision calculations, we must develop more accurate means to test our codes.

The University of Michigan radiation-shock experiment is designed to test the progress of a radiative shock, following it through the transition from a flow where the radiation is trapped to an optically thin flow. Such an experiment is ideally suited to test numerical algorithms designed to model radiation-hydrodynamics. To take advantage of such a test requires both an accurate treatment of the initial conditions in this experiment and a detailed modeling of the experimental diagnostics. Here we show simulations of this experiment using the Cassio code, outlining the relevant physics and the difficulties in modeling the initial conditions (a contributor, we believe, to the initial disagreement of the University of Michigan CRASH calculations). To take full advantage of this experiment, we must also directly compare the simulations to the observed diagnostics. We present new methods to calculate these diagnostics, demonstrating the importance of these diagnostic models on this radiation-flow experiment. With these diagnostics, we verify our radiation hydrodynamics algorithms and discuss how future experiments in this vein can be designed to further test our radiation-hydrodynamics codes.

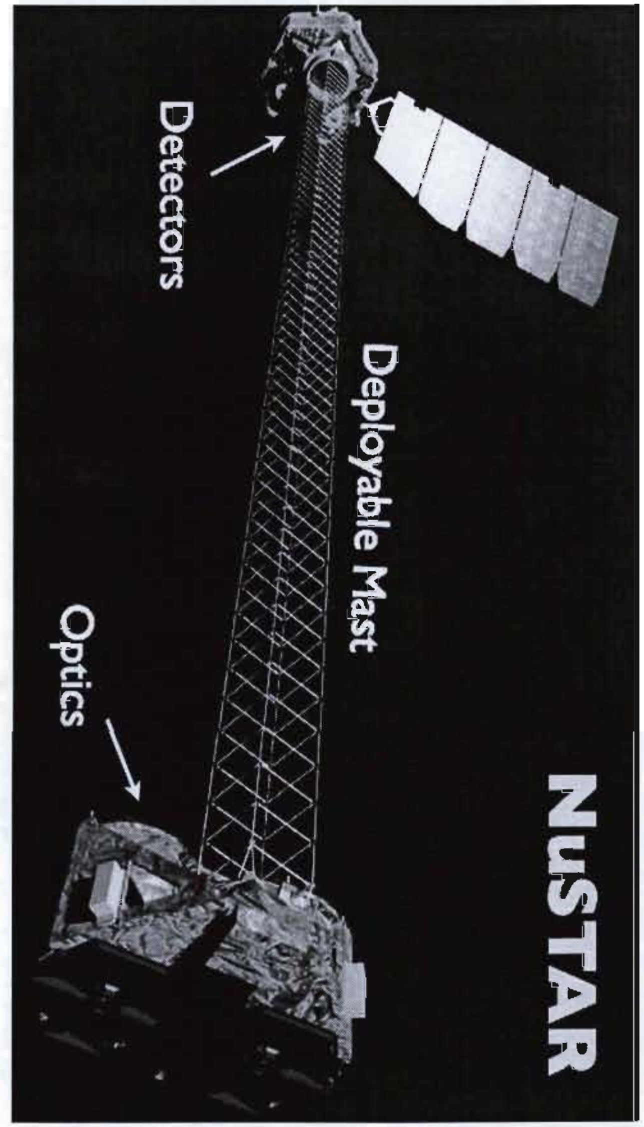
Testing Radiation-Flow Physics and Shock Break-Out

Chris Fryer (LANL)

- Shock Breakout and Transient Astronomy
- Why study Shock Breakout Physics
- U Michigan Experiment: Problems, Simulations, Current Status

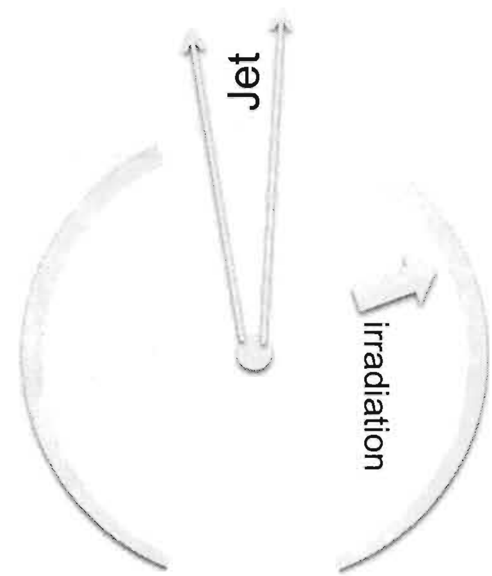
Transient Astronomy – the New Frontier

- Time domain astronomy (outbursts, flashes, etc.) has become a focus point in observational astronomy: Palomar Transient Factory, Large Synoptic Survey Telescope, Swift, Fermi, Nuclear Spectroscopic Telescope Array, …
- These explosions provide ideal tests of our code physics.



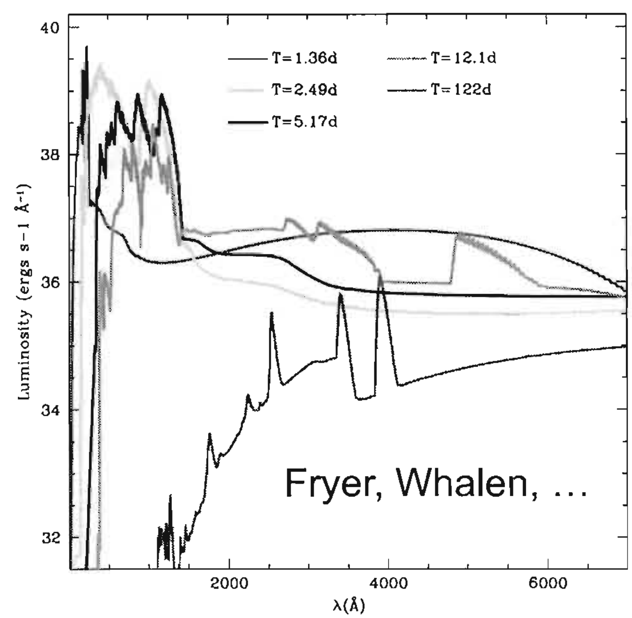
Radiation Hydrodynamics

- Laboratory radiation-hydrodynamics capabilities are ideally suited to modeling a wide variety of astrophysical transients.
- Example 1: LANL models of matter irradiation and re-radiation allowed LANL scientists to come up with a picture of XRF 122510 – Nature 2011.
- Example 2: LANL spectral calculations for pair-unstable SNe allow us to predict signals for the James Webb Telescope (successor to Hubble)
- Accurate atomic opacities allow us to calculate detailed spectra from these explosions.
- Code comparisons critical to finding errors in ASC codes.
- The post-process techniques used to calculate astrophysics spectra were modified and are now used to do diagnostic calculations for Campaign experiments.



Model for XRF 122510

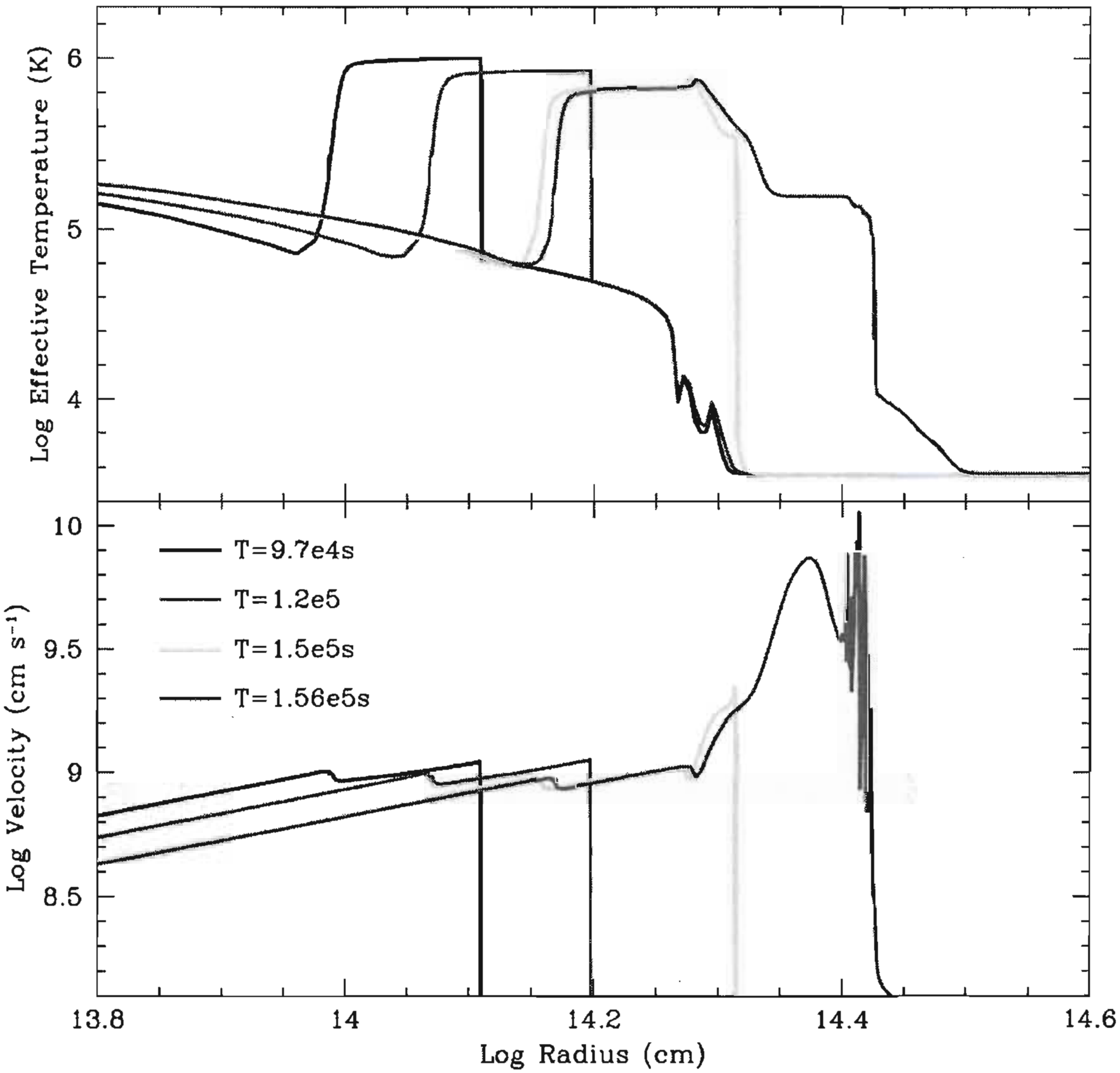
Even et al. 2011



Spectra from Pair-Instability Supernovae

Shock Breakout is a true Rad-Hydro Problem

- Even when the radiation is trapped, it can lead the shock – the shock position moves faster than Sedov solution would predict.
- After breakout, the radiation begins to decouple from the material.

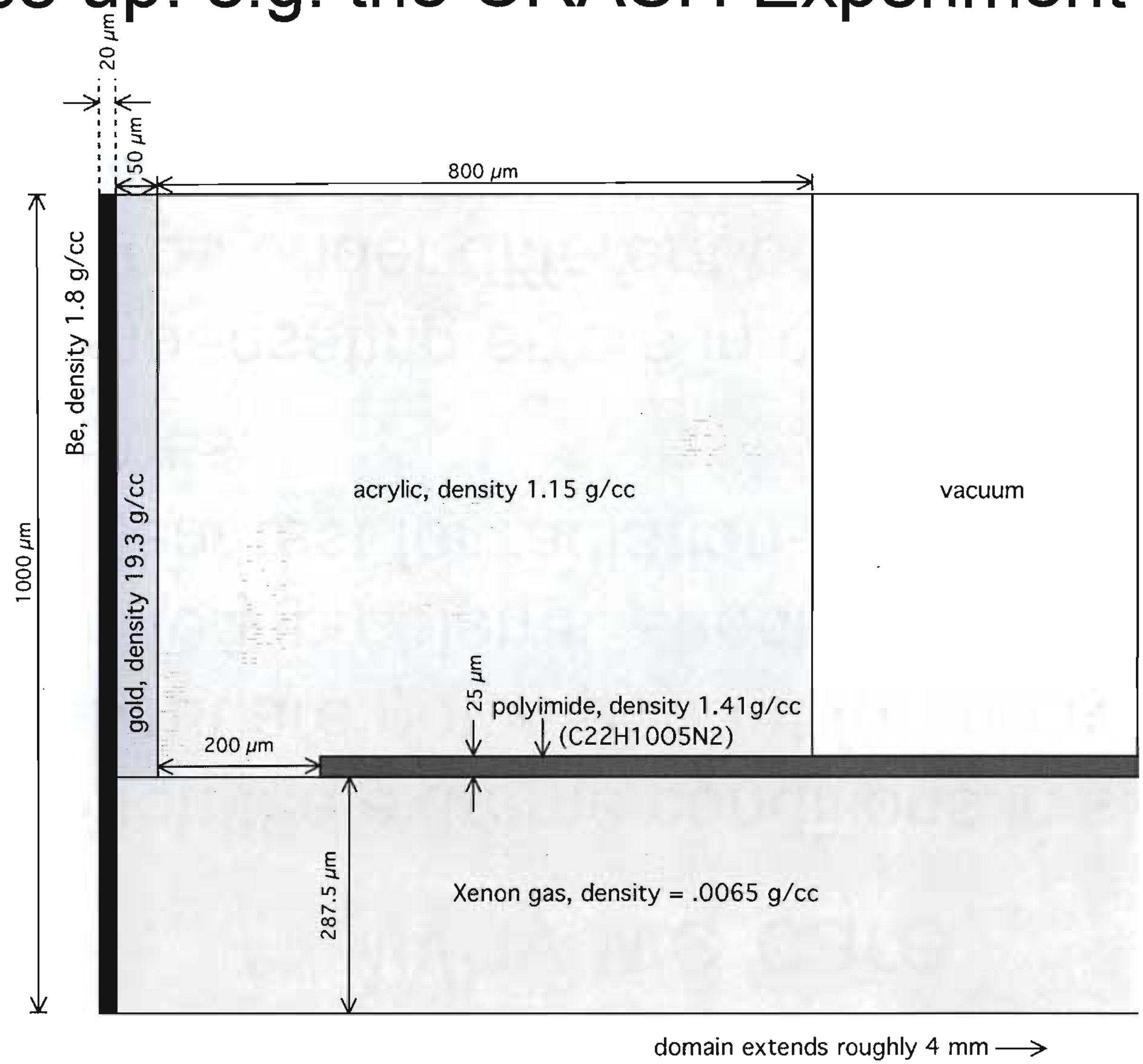


Why we care

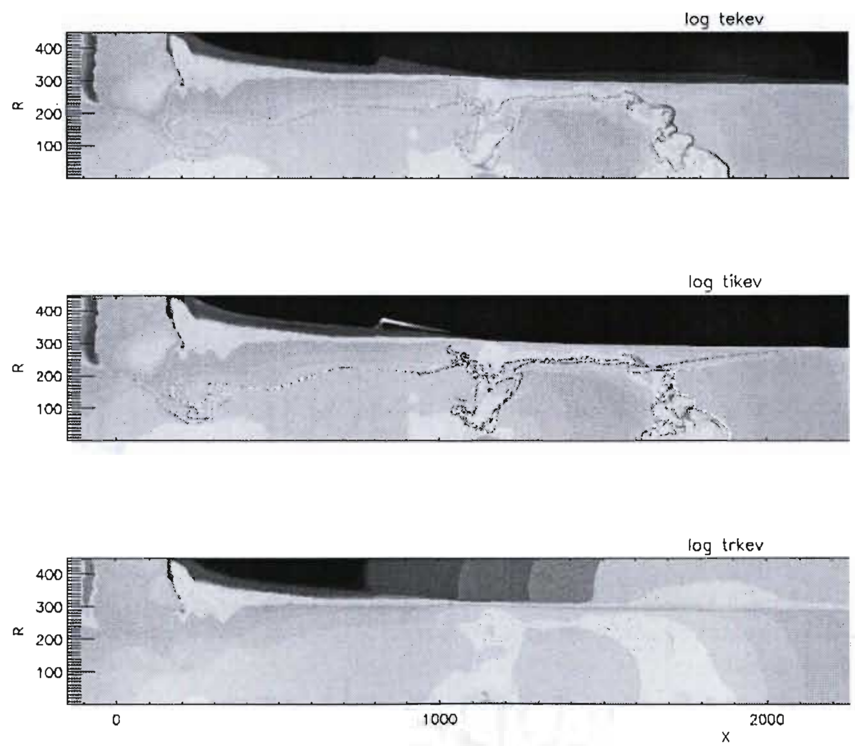
Although the extreme conditions in shock breakout are not important for many laboratory problems, shock breakout is an excellent test for radiation-hydrodynamics schemes.

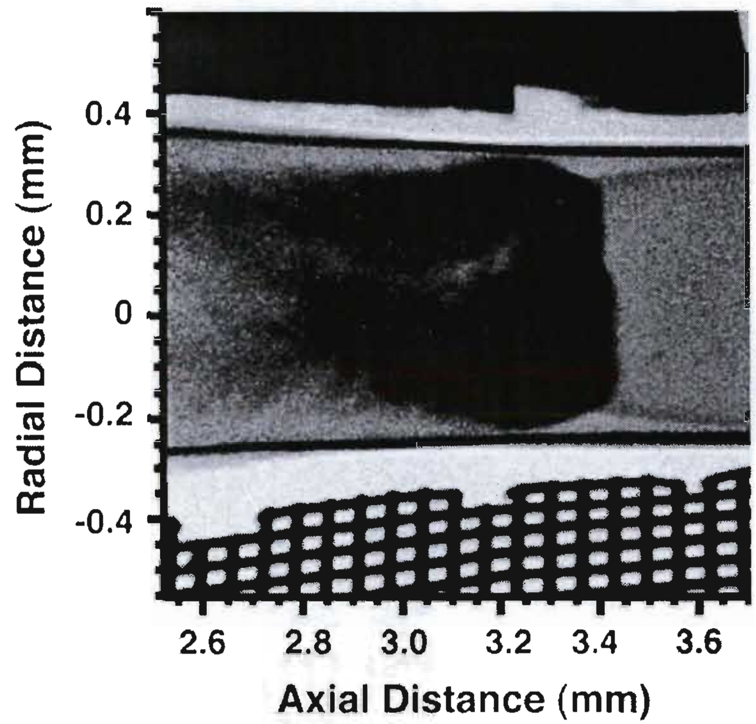
- Compensating errors in one regime will diverge under different conditions.
- Extreme conditions can enlarge 10% errors (difficult to track down) to 100% (easy to track down)

Experiments allow us to see shock breakout close up: e.g. the CRASH Experiment at MSU



The Problem: CRASH Simulations Show much more structure than the experiment





nx=321472, 1, it= 6263, time= 1.3001e-08

Experimental Modeling

Physics

- Transport
- Non-Thermal Electrons
- Equation of State
- Opacities

Numerics

- Eulerian vs. Lagrangian
- Resolution

Setup

- Laser Drive
- Materials

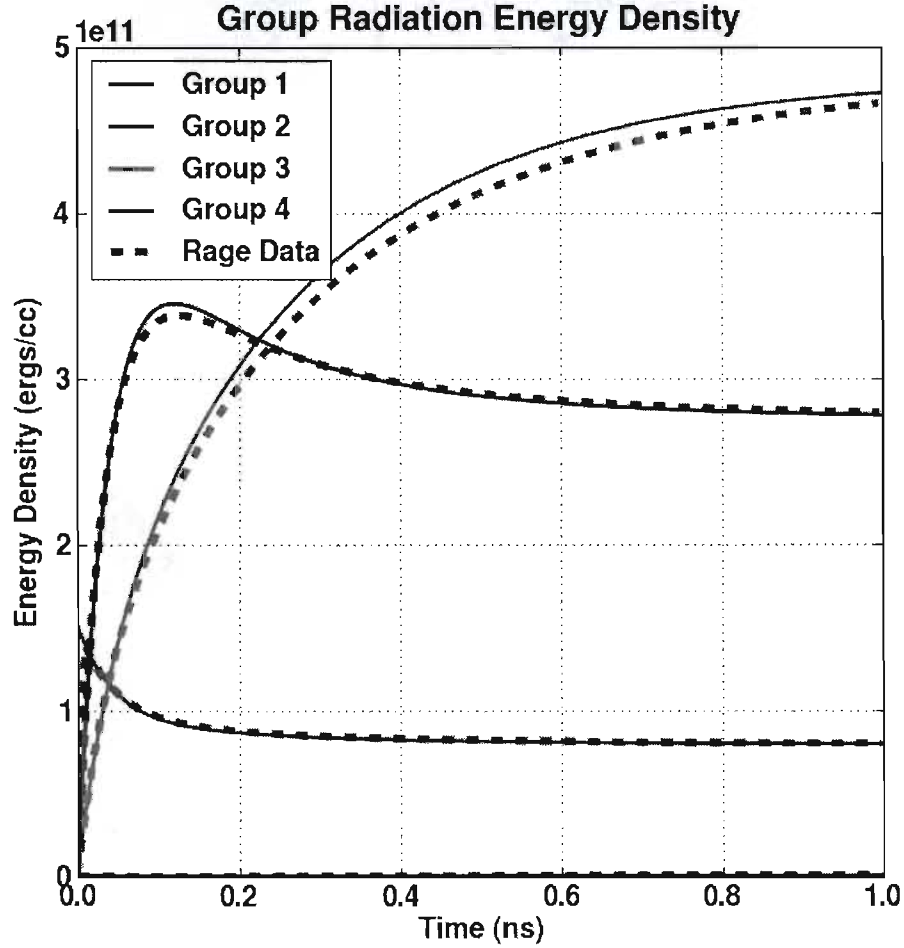
To understand the different results and to try to disentangle the different physics, detailed code comparisons were needed.

With comparisons, we began to simplify. These comparisons led to a number of discoveries, e.g.:

•"0-D" relaxation calculations (electron-ion, electron-ion-radiation) discovered a bug in the RAGE's tabular values of the Planck integral.

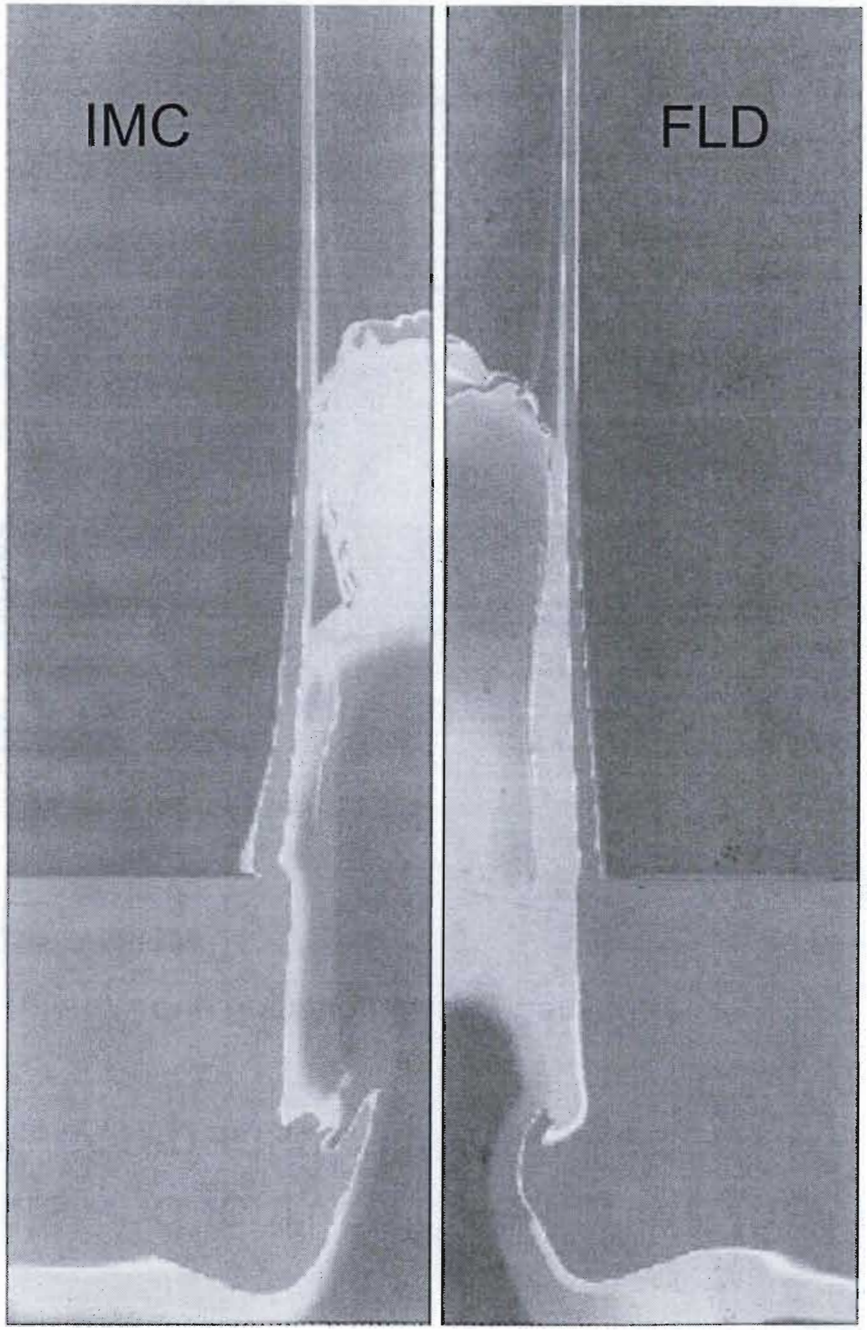
•The flash codes exponential relaxation scheme allows larger timesteps (faster) than RAGE's scheme.

• The answers are now starting to converge to the same solution.

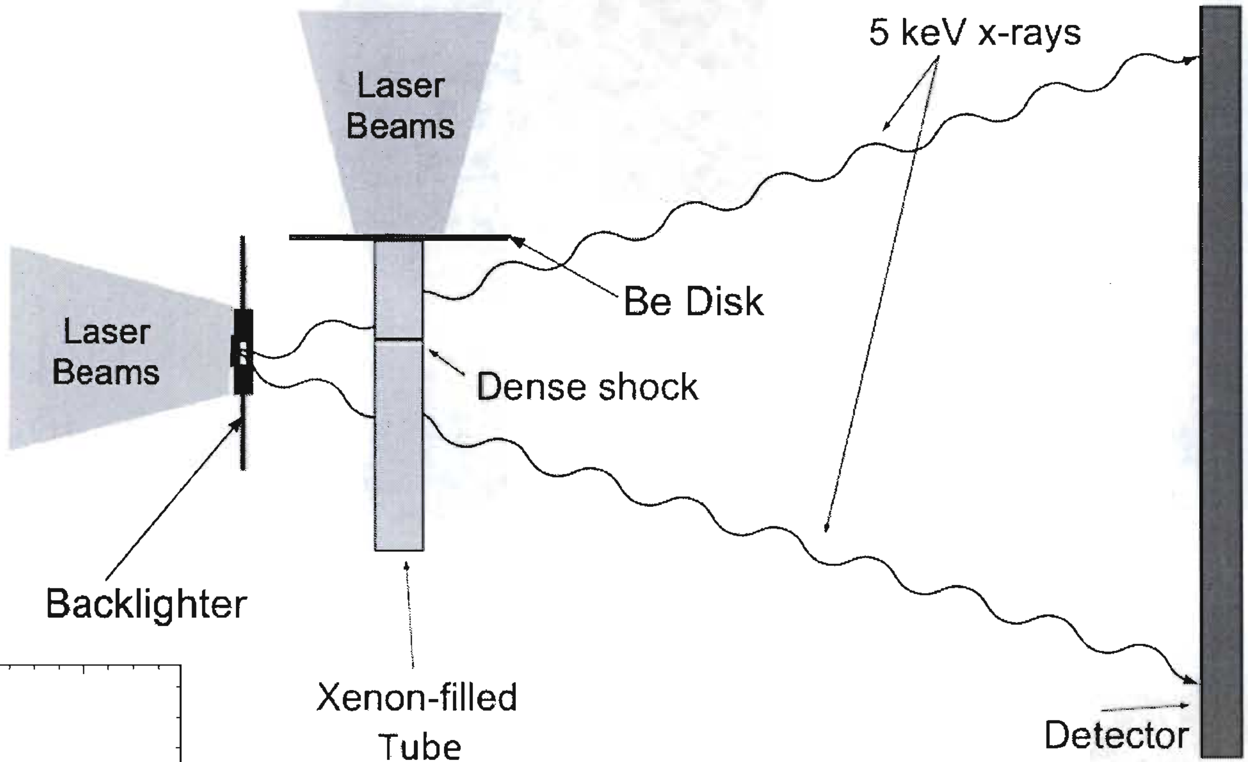


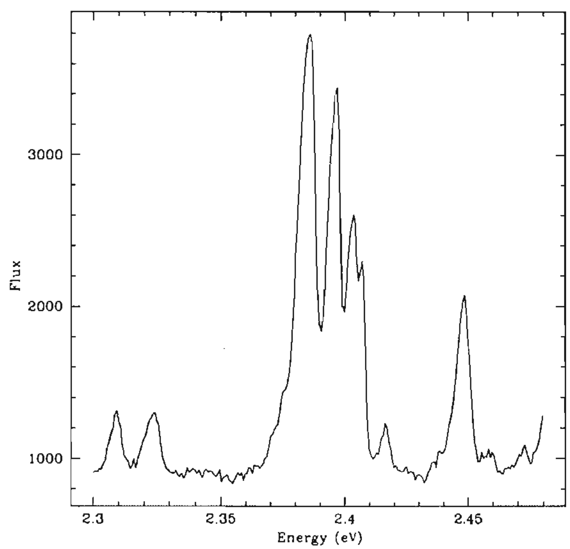
Some resolutions:

- Eulerian codes are fully capable of matching the experiment.
- The CRASH simulations used a Hyades single-group set-up. Many of the artifacts were due to this setup.
- But even with these corrections, differences persist between IMC and FLD. Is this RAGE's FLD or is it true of FLD in general?



To model the backlighter diagnostic, we'd ideally calculate the opacity to the entire backlighter spectrum

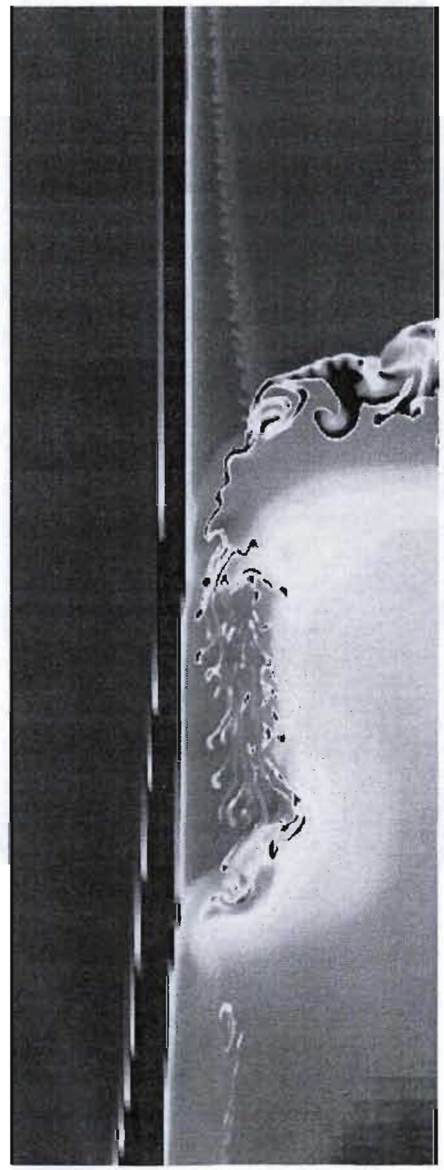


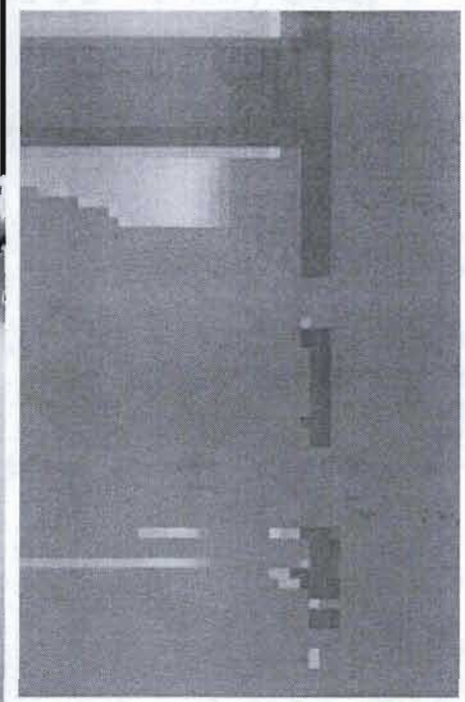


We map the 2D simulation into 3D and calculate the opacities (using the 14,900 group TOPS opacities) and run the full spectrum through the experiment.

As we increase the resolution, the simulation becomes increasingly turbulent. However, the radiograph will not easily detect this turbulence!

The University of Michigan team has pursued this experiment, running more shots and increasing the data.





Summary – It's All in the Details

- Agreement with experiment can be obtained with careful initial conditions and detailed diagnostic comparisons.
- Detailed comparisons have uncovered code errors and have identified ways to improve physics and performance.
- Repeated shots and improved diagnostics are crucial in making experiments useful for complex physics.