FLASH Verification & Validation Topics

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Outline

FLASH Center Overview

Center-specific activities

- V&V in astrophysics
- V&V in computational methods
  - Case study: shock-cylinder interaction
    - Are 2-D experiments truly two-dimensional?
    - AMR and vortex-dominated flows
    - New message from Courant, Friedrichs, & Lewy
- SQA in code development

Summary

- Changing culture in astrophysics
- Improving computational machinery

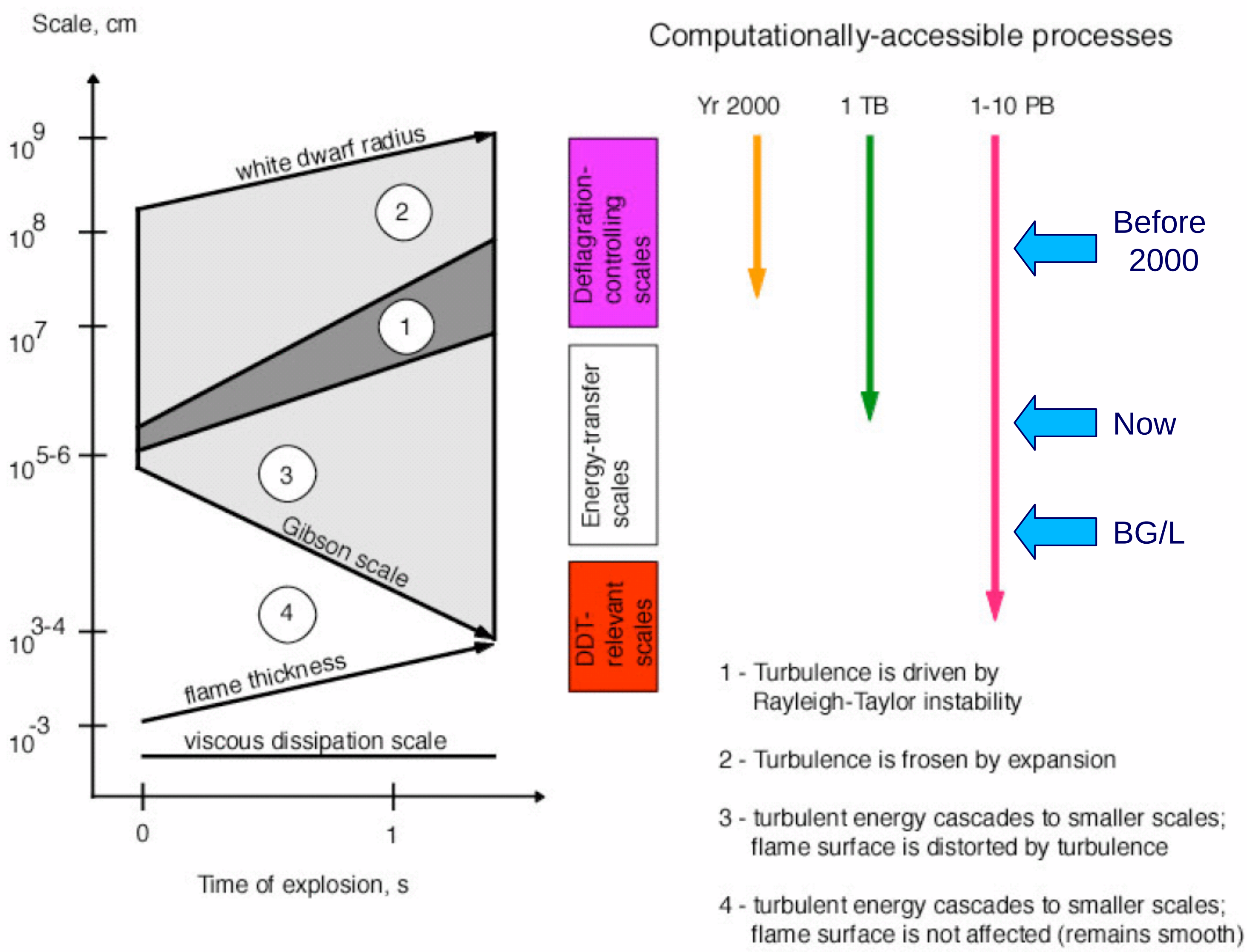
Target Applications

- Compact accreting stars (white dwarf, neutron star)
- Reactive hydrodynamics (DNS or subgrid model)
- Initial conditions close to hydrostatic equilibrium (self-gravity)
- Complex EOS (dense nuclear matter)

Example: Type Ia Supernova

- Massive white dwarf
- Subgrid model for nuclear flame
- Self-gravity
- Degenerate EOS

Length scales in White Dwarf Deflagration



V&V and Astrophysics

- Verification ranging from simple analytic problems to code-code comparison.
- No direct access to experiments: use scaling laws
- Absolutely **NO** culture of validation!

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ON VALIDATING AN ASTROPHYSICAL SIMULATION CODE

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ABSTRACT

We present a case study of validating an astrophysical simulation code. Our study focuses on validating FLASH, a parallel, adaptive-mesh hydrodynamics code for studying the compressible, reactive flows found in many astrophysical environments. We describe the astrophysics problems of interest and the challenges associated with simulating these problems. We describe methodology and discuss solutions to difficulties encountered in verification and validation. We describe verification tests regularly administered to the code, present the results of new verification tests, and outline a method for testing general equations of state. We present the results of two validation tests in which we compared simulations to experimental data. The first is of a laser-driven shock propagating through a multilayer target, a configuration subject to both Rayleigh-Taylor and Richtmyer-Meshkov instabilities. The second test is a classic Rayleigh-Taylor instability, where a heavy fluid is supported against the force of gravity by a light fluid. Our simulations of the multilayer target experiments showed good agreement with the experimental results, but our simulations of the Rayleigh-Taylor instability did not agree well with the experimental results. We discuss our findings and present results of additional simulations undertaken to further investigate the Rayleigh-Taylor instability.

Subject headings: hydrodynamics — instabilities — methods: numerical — shock waves

V&V and Computational Methods

- Verification exploits elementary tests with known analytic solutions or "converged" numerical solutions (not strict but practical).

  Example: advection-diffusion-reaction subgrid model for evolution of the nuclear flame.
- Access to experiments: collaborations with LANL (shock-tube) and LLNL (high-energy density laser) experiments.

Simulation of Vortex–Dominated Flows Using the FLASH Code

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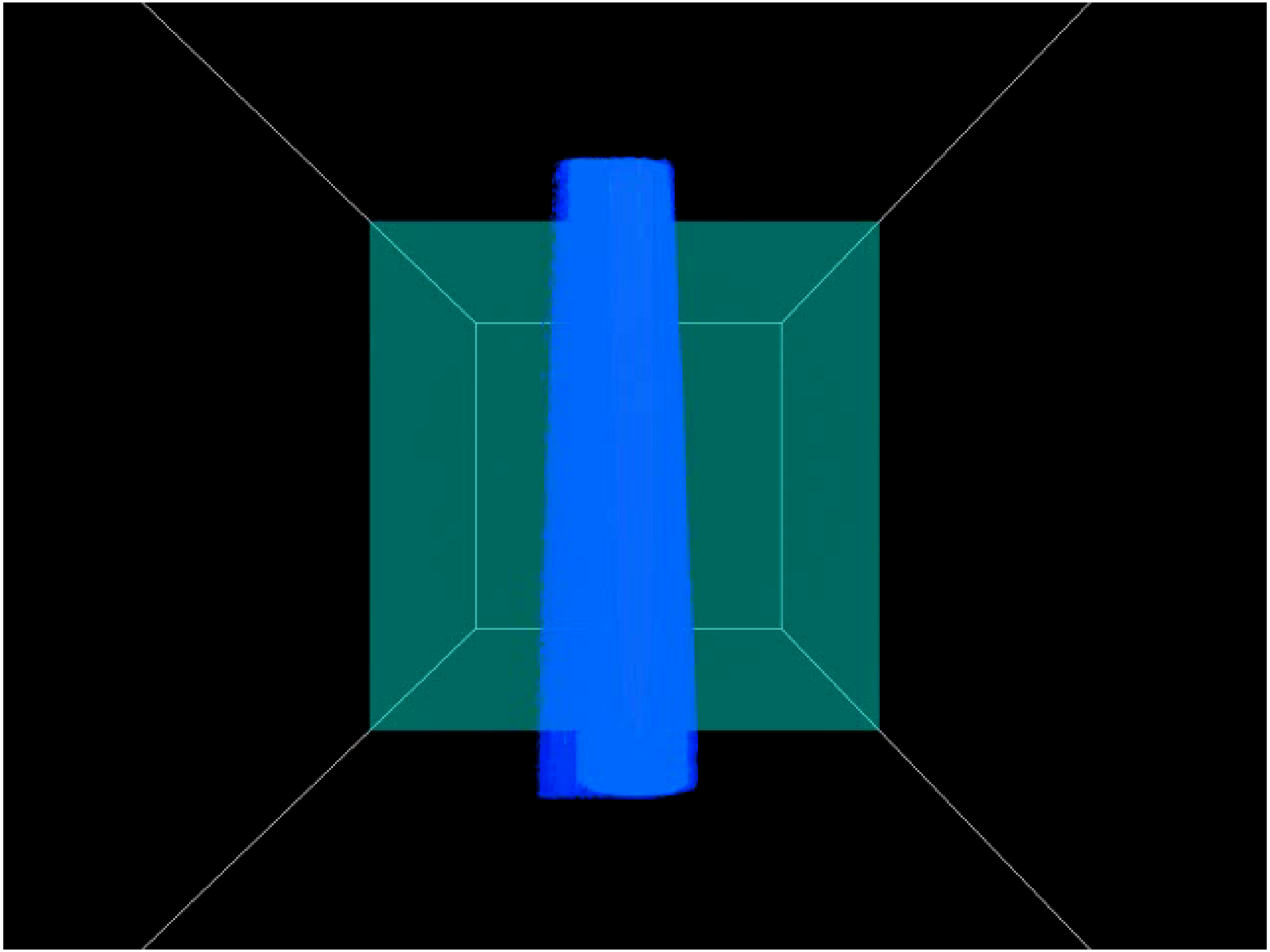
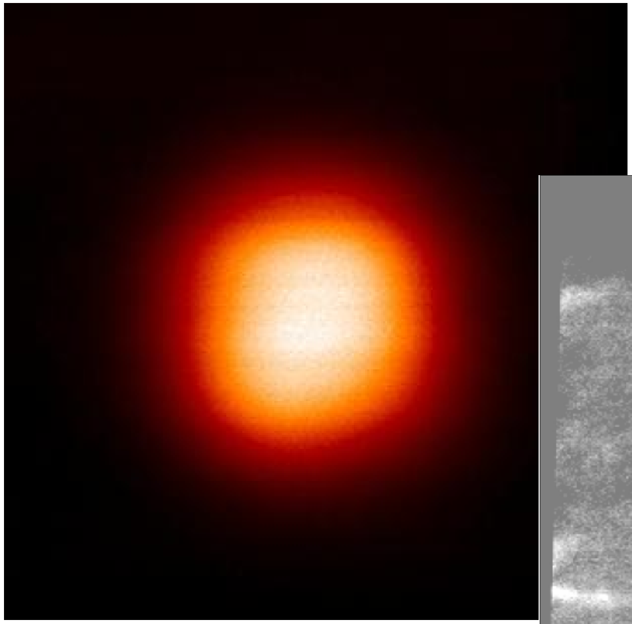
1 Abstract

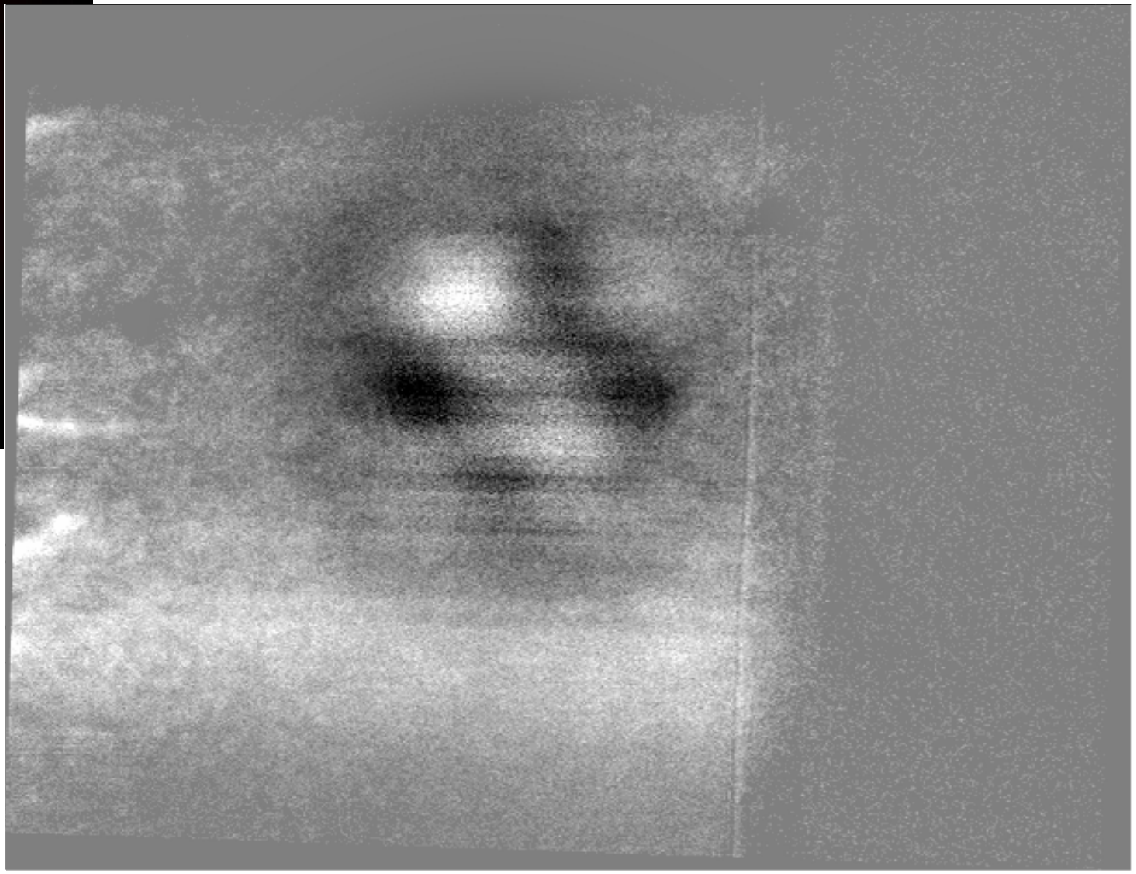
We compare the results of two–dimensional simulations to experimental data obtained at Los Alamos National Laboratory in order to validate the FLASH code. FLASH is a multi–physics, block–structured adaptive mesh refinement code for studying compressible, reactive flows in various astrophysical envi-

Case Study: Shock-Cylinder Interaction

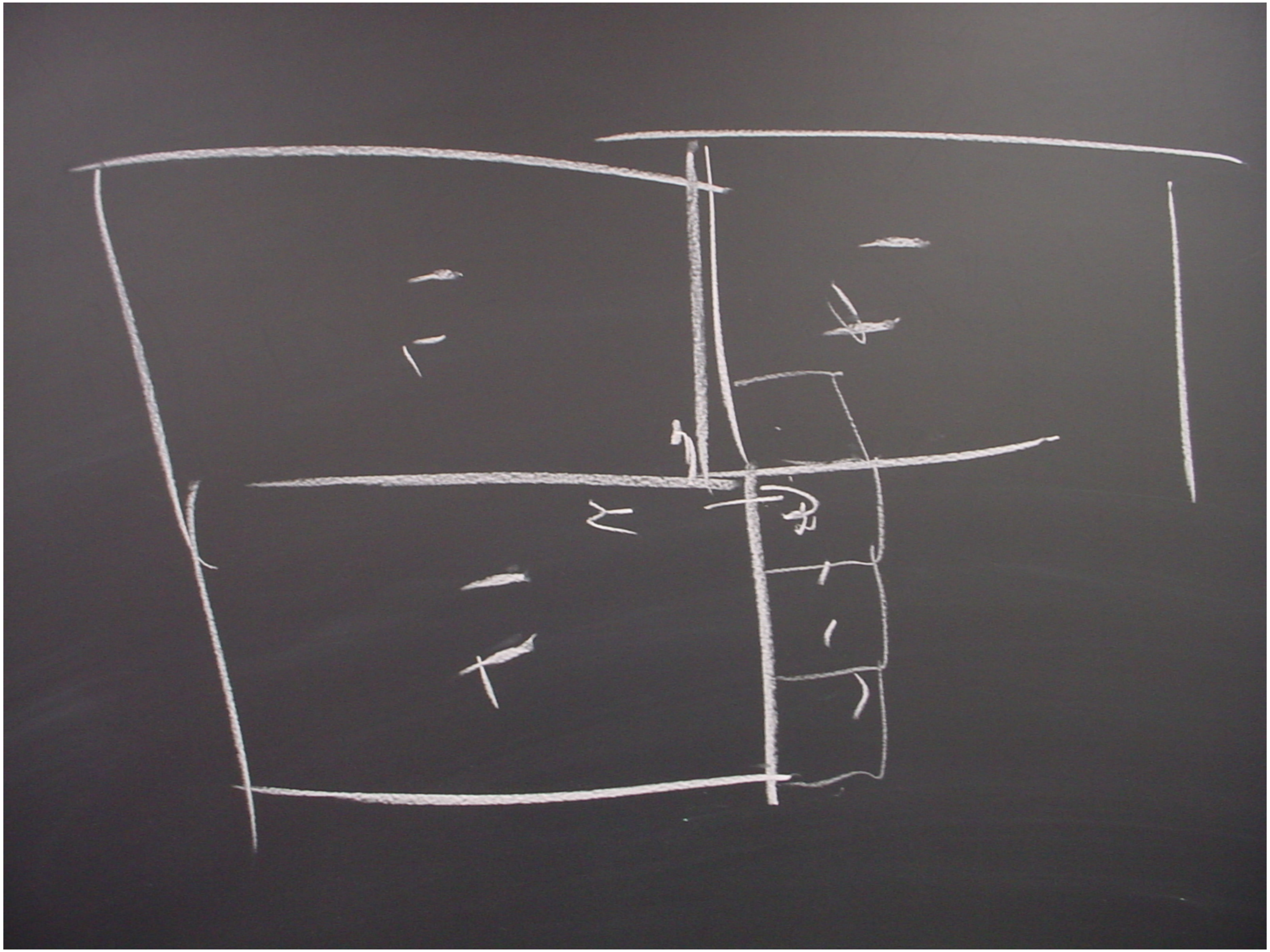


Initial Conditions: Cylinder Cross-section





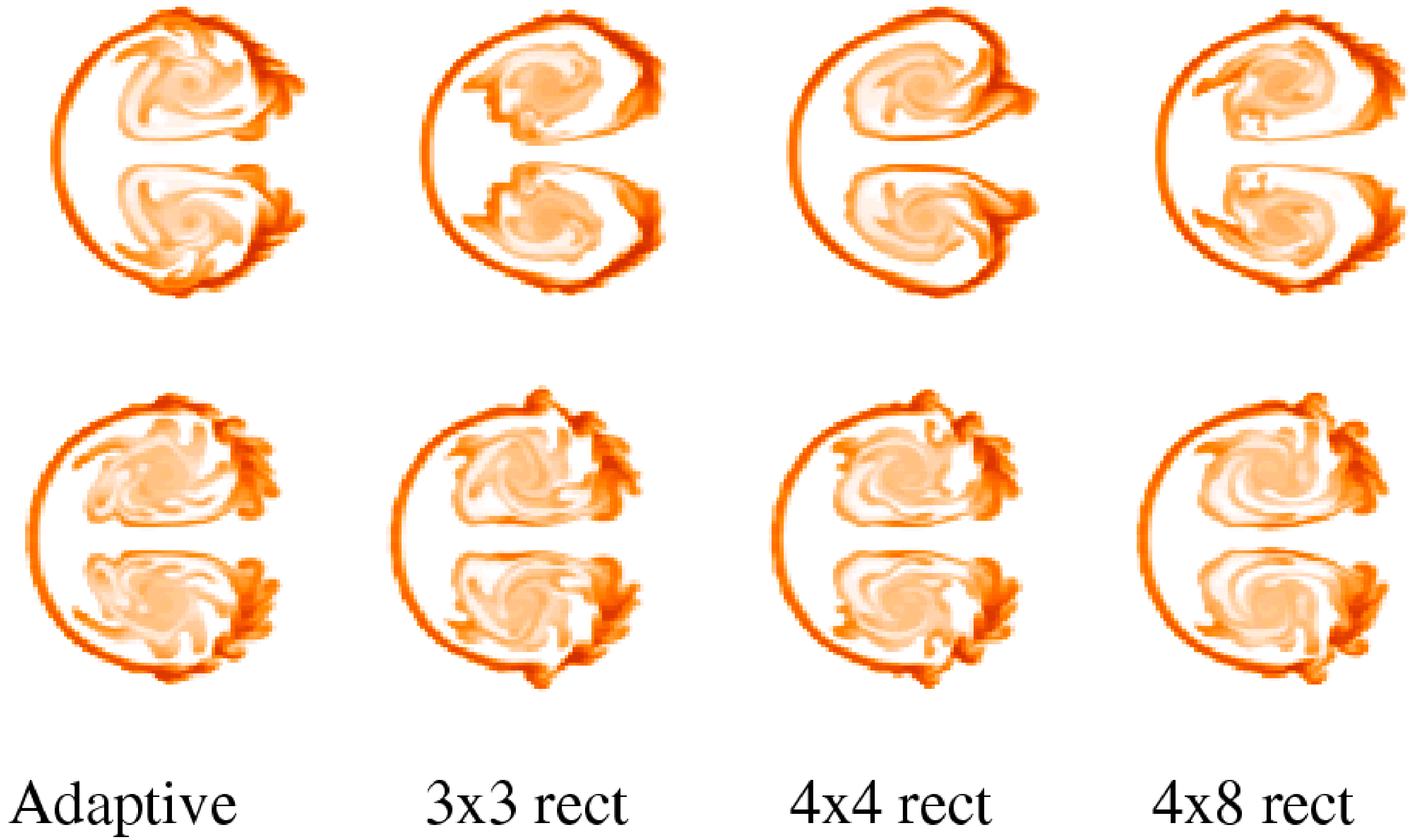
FLASH Code is the AMR code



CFL dependency

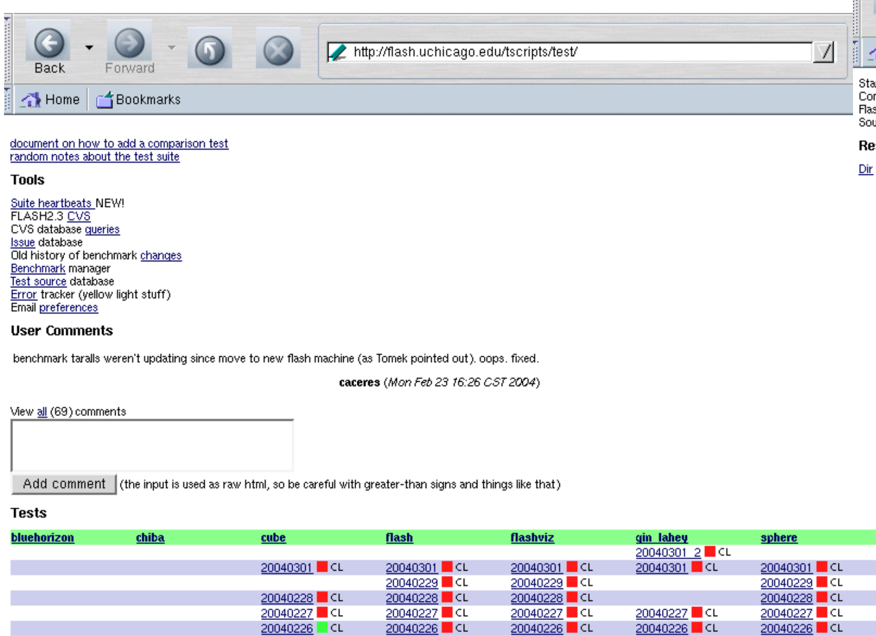
CFL=0.8

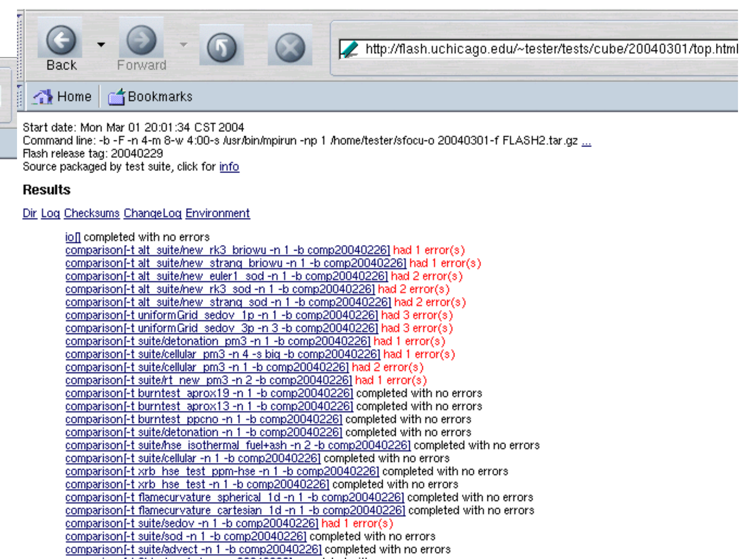
CFL=0.2



Software Quality Assurance

- Pure sciences rarely offer formal education or training: hands-on approach.
- SQA begins with code design: follow standards, design guidelines, specifications, etc. (FLASH2 -> FLASH3)
- Has to be a daily practice, encouraged/enforced by use of automated monitoring tools (FLASH test suite).





Summary

- V&V is an essential component of the Center’s work.
- The Center introduced V&V methodology to astrophysics, promotes and truly builds V&V-related consciousness among astrophysicists.
- Interaction with the National Laboratories, especially DP Labs, is crucial for the V&V effort (direct access to experiments, use of predictive power of the simulation tools, aiding in experiment design).
- Software Quality Assurance is a daily practice of the Center’s work supported by specialized, developed in-house software and guided by design rules and custom programming standards.