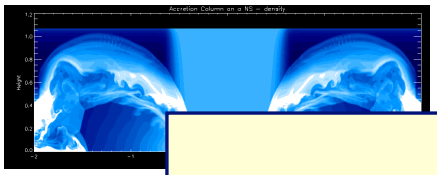
FLASH Code and Science

Don Q. Lamb
DOE NNSA/ASC and Office of Science/ASCR
Flash Center for Computational Science

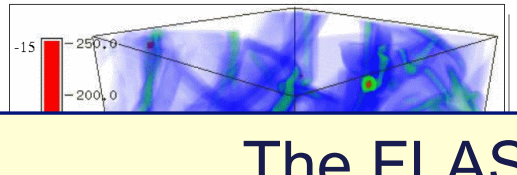
NVIDIA
11 February 2011

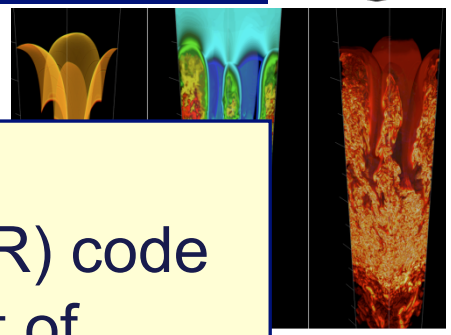
Flash Center for Computational Science
University of Chicago

FLASH Capabilities Span a Broad Range



Shortly: Relativ





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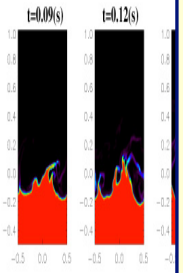
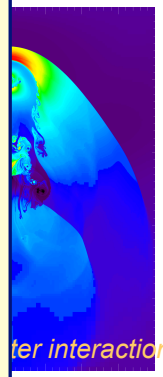


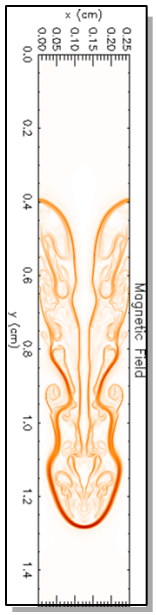
Wave breaking

The FLASH code

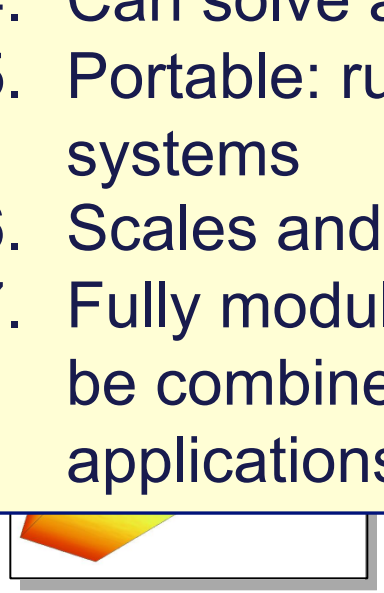
1. Parallel, adaptive-mesh refinement (AMR) code
2. Block structured AMR; a block is the unit of computation
3. Designed for compressible reactive flows
4. Can solve a broad range of problems
5. Portable: runs on many massively-parallel systems
6. Scales and performs well
7. Fully modular and extensible: components can be combined to create many different applications



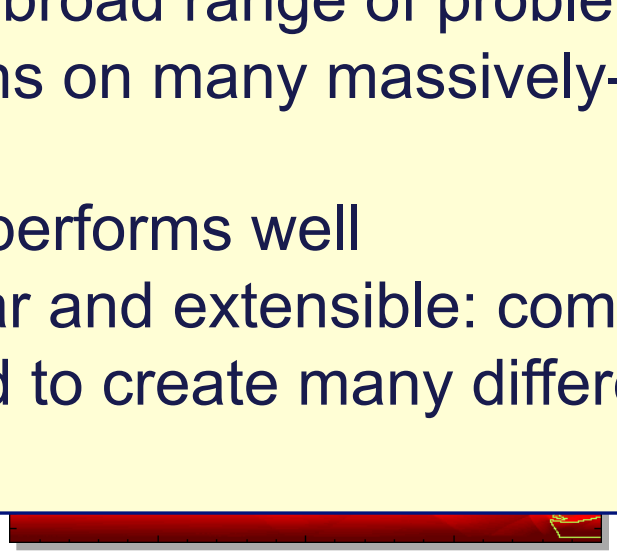
ter interactions



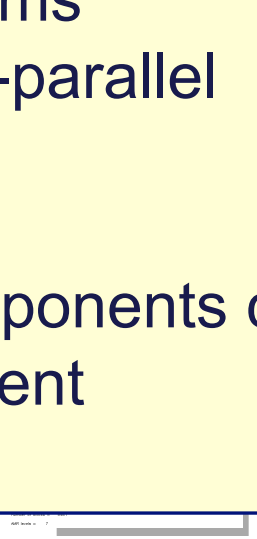
Magnetic Rayleigh-Taylor



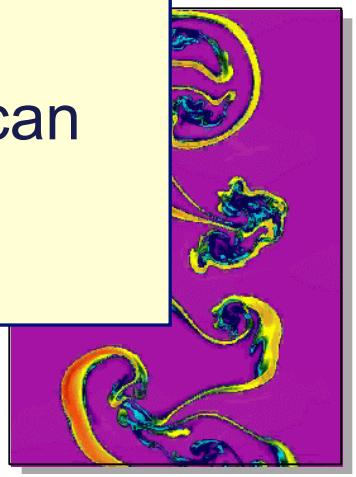
Cellular detonation



Helium burning on neutron stars



Orzag/Tang MHD vortex



Richtmyer-Meshkov instability

FLASH is used by groups throughout the world

Munich University Observatory

CAST

Computational Astrophysics Group

Germany

http://www.usm.uni-muenchen.de/CAST/people.html

Pawel Ciecielag: Planets formation: planetesimals accretion, gas drag, disk-planet interaction; Cosmology: large scale velocity fields, density-velocity comparisons; Numerical methods: direct n-body (Nbody4++ code, special purpose hardware - GRAPE), hydro (PPM, AMR, FLASH code).

Steffi Walch: Star formation with emphasis on the formation of protostellar disks, evolution and fragmentation of protoplanetary disks and the evolution of their spectral energy distributions. Numerical Methods: hydrodynamics (FLASH code)

Practical FLASH Notes 10/14/2005 04:14 PM

Learning and Testing FLASH: Practical Notes

This page is intended for members of the Computational Astrophysics group at McMaster University who whish to learn and be involved with the testing of the FLASH code. The code was developed at the ASCI/Alliances Center for Astrophysical Thermonuclear Flashes at the University of Chicago.

Getting Started:

Canada

THE FLASH CODE AT OAPA 10/14/2005 01:21 PM

·step spoon-feed for
ıs along the way.

OSSERVATORIO ASTRONOMICO DI PALERMO GIUSEPPE S. VAIANA

The FLASH code at OAPA

Italy

The Osservatorio Astronomico di Palermo is one of the test sites for the very accurate FLASH code, a 3-dimensional astrophysical hydrodynamic code for supercomputers mainly developed at the "Flash Center", the University of Chicago.

Palermo is the test site in which FLASH has been ported to Compaq architectures. The FLASH code solves the compressible Euler equations on a block-structured adaptive mesh, and its modular design permits the introduction of additional physics and of different solvers.

The Palermo team collaborates with the Flash Center to upgrade and to apply extensively FLASH to astrophysical systems.

The group in Palermo also develops new modules for FLASH which extend the field of applicability of the code to other problems in astrophysics, from solar and stellar coronae, to supernova remnants, and to galaxy clusters halos. In particular, the new modules so far developed and tested include:

1. the non-equilibrium ionization effects of the most abundant elements in astrophysical plasmas
2. the thermal conduction according to the formulation of Spitzer (1962)
3. the radiative losses from an optically thin plasma according to the Raymond spectral code and Peres et al. (1982) for the chromosphere.
4. the viscosity according to the formulation of Spitzer (1962)

In this project, the Palermo team takes advantage of its long experience in developing hydrodynamic codes for modeling astrophysical plasma and in optimizing the codes for efficient parallel execution on high performance computers. The group has recently acquired and uses, for the FLASH development, a high performance computing (HPC) cluster of 16 powerful alpha EV67 processors distributed in 4 compaq ES40 (interconnected with a highly efficient Memory Channel II), entirely dedicated to HPC projects (for more information see the SCAN facility homepage).

http://www.astropa.unipa.it/FLASH/ Page 1 of 1

The Astrophysical Journal, 628:205–209, 2005 July 20

US

SUPERNOVA BLAST WAVES IN LOW-DENSITY HOT MEDIA: A MECHANISM FOR SPATIALLY DISTRIBUTED HEATING

Shiki Tang and Q. Daniel Wang

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Received 2004 December 17; accepted 2005 April 11

ABSTRACT

Most supernovae are expected to explode in low-density hot media, particularly in galactic bulges and elliptical galaxies. The remnants of such supernovae, although difficult to detect individually, can be profoundly important in heating the media on large scales. We characterize the evolution of this kind of supernova remnant, based on analytical approximations and hydrodynamic simulations. We generalize the standard Sedov solution to account for both temperature and density effects of the ambient media. Although cooling can be neglected, the expansion of such a remnant deviates quickly from the standard Sedov solution and asymptotically approaches the ambient sound speed as the swept-up thermal energy becomes important. The relatively steady and fast expansion of the remnants over large volumes provides an ideal mechanism for spatially distributed heating, which may help to alleviate the overcooling problem of hot gas in groups and clusters of galaxies, as well as in galaxies themselves. The simulations were performed with the FLASH code.

Subject headings: cooling flows — galaxies: clusters: general — galaxies: ISM — ISM: structure — supernova remnants

Online material: color figures

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10/14/2005 01:30 PM

FLASH Code Development

ım Members:

ı Boss (DTM)
abeth Myhill, Justin Domes (Marymount University)
rl Vanhala (Challenger Center)

US

: FLASH Adaptive Mesh Refinement Hydrodynamics Code

seek to study the dynamics of mixing and transport processes in the presolar cloud and in the solar ıla, in the context of isotopic heterogeneity introduced either by shock-triggered collapse of the presolar d or by infall from an x-wind outflow, the two leading explanations for the widespread evidence of t-lived radioactivities in chondritic refractory inclusions and, much more rarely, in chondrules. Myhill Domes are leading our effort to develop a new hydrodynamical code for studying these problems, the SH adaptive mesh refinement code. FLASH will allow the problem of shock-wave triggering and ction to be studied with an unprecedented degree of high spatial resolution, which is likely to be critical e question of simultaneous triggering and injection when nonisothermal shock front thermodynamics is loyed. We will work with Vanhala to define a nonisothermal shock test case to be calculated with both FLASH code and Vanhala's EVH-1 code. In addition, the FLASH code will permit extending these stigations down to the scale of the solar nebula, where nebular transport and mixing processes can be ied in general terms, applicable to isotopically heterogeneous grains falling onto the nebular surface as a lt of either shock-triggered collapse or x-wind outflows. We will seek in part to learn whether spatial temporal heterogeneity inherited from such sources can survive subsequent nebular mixing processes can help to explain certain isotopic abundance patterns seen in the inner Solar System and the asteroid The development of the FLASH code should also prove useful for Boss's studies of the formation of t planets by the disk instability mechanism.

3D AMR Simulations of Point-Symmetric Nebulae

Erik-Jan Rijkhorst, Vincent Icke, and Garrelt Mellema, Sterrewacht Leiden, The Netherlands
http://www.strw.LeidenUniv.nl/AstroHydro3D/

Numerical Implementation

We used the three-dimensional hydrocode *Flash* [6] to model the interaction between a spherical wind and a warped disk. This parallelized code implements block-structured adaptive mesh refinement (AMR) [7] (see images below) and a PPM type hydrosolver [8].

We added to the code the proper initial conditions for the wind-di… warped disk, Eq. (1) was combined with a constant 'wedge angle … was given a constant density . The spherical wind was implemen… 1/r² density profile and a constant velocity. The pressure was ca… constant Poisson index γ.

Netherlands

Monthly Notices of the Royal Astronomical Society
Volume 355 Issue 3 Page 995 - December 2004
doi:10.1111/j.1365-2966.2004.08381.x

UK

Quenching cluster cooling flows with recurrent hot plasma bubbles
Claudio Dalla Vecchia[1], Richard G. Bower[1], Tom Theuns[1,2], Michael L. Balogh[1], Pasquale Mazzotta[3] and Carlos S. Frenk[1]

EVENTS & CALENDAR

FLASH Workshop

Canada

Workshop
Wed, Mar 23, 2005, 9:00 AM
Location: MP1318A

Workshop on the FLASH code: a general-purpose, parallel, adaptive mesh, reactive astrophysical hydrodynamics code that is available to the research community

Tentative Schedule

Abstract:

On March 23 and 24th, CITA will host a mini-workshop on the FLASH code: a general-purpose, parallel, adaptive mesh, reactive astrophysical hydrodynamics code that is available to the research community. The FLASH code has been applied to problems from burning in or on compact objects, to the efficiency of cooling flows in galaxy clusters, to cosmological simulations.

Four people will be coming from the Chicago FLASH centre to give one day of talks on the capabilities of the code, and will be available to schedule meetings with on the second day for more focused, less formal discussions on applying the FLASH code to problems of interest to local projects.

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The Astrophysical Journal, 630:740–749, 2005 September 10

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Germany

ACTIVE GALACTIC NUCLEI HEATING AND DISSIPATIVE PROCESSES IN GALAXY CLUSTERS

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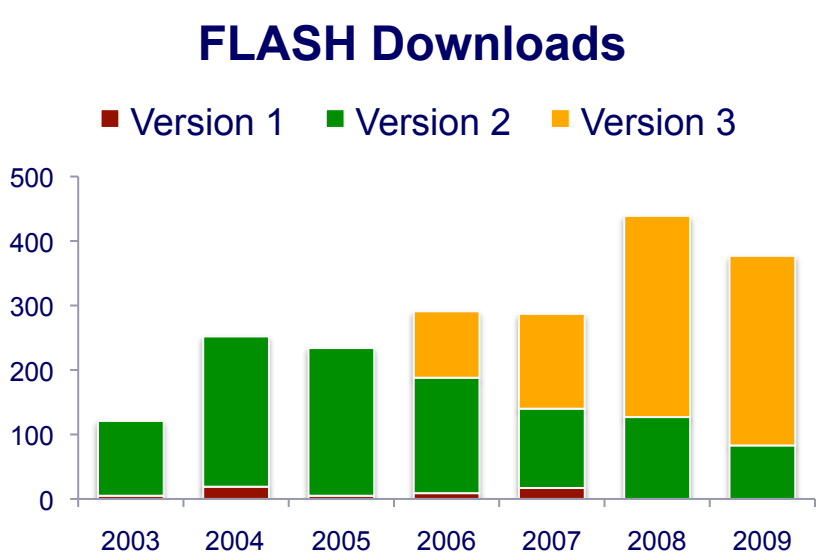
Received 2005 January 10; accepted 2005 May 22

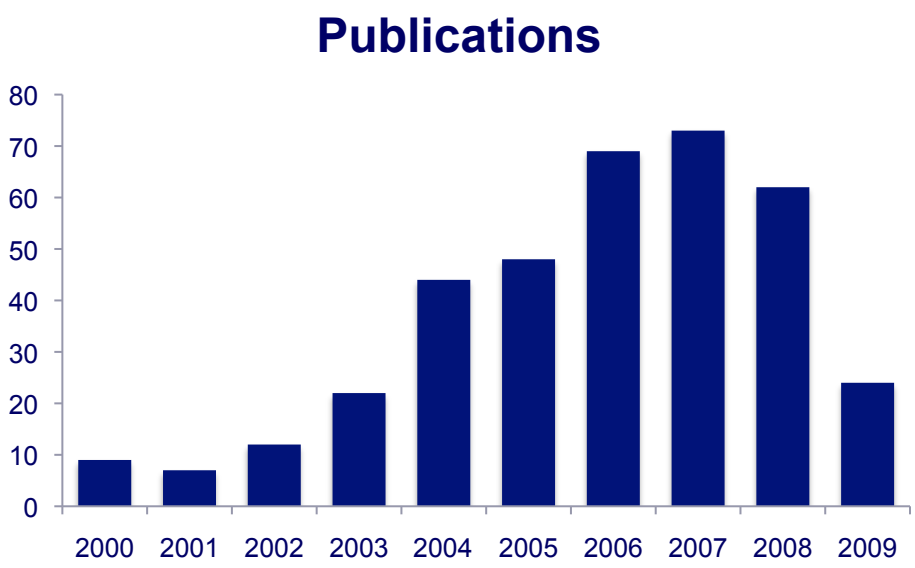
ABSTRACT

Recent X-ray observations reveal growing evidence for heating by active galactic nuclei (AGNs) in clusters and groups of galaxies. AGN outflows play a crucial role in explaining the riddle of cooling flows and the entropy problem in clusters. Here we study the effect of AGNs on the intracluster medium in a cosmological simulation using the adaptive mesh refinement FLASH code. We pay particular attention to the effects of conductivity and viscosity on the dissipation of weak shocks generated by the AGN activity in a realistic galaxy cluster. Our three-dimensional simulations demonstrate that both viscous and conductive dissipation play an important role in distributing the mechanical energy injected by the AGNs, offsetting radiative cooling and injecting entropy to the gas. These processes are important even when the transport coefficients are at a level of 10% of the Spitzer value. Provided that both conductivity and ty are suppressed by a comparable amount, conductive dissipation is likely to dominate over viscous dissipation. heless, viscous effects may still affect the dynamics of the gas and contribute a significant amount of dissipation red to radiative cooling. We also present synthetic *Chandra* observations. We show that the simulated buoyant s inflated by the AGN, and weak shocks associated with them, are detectable with the *Chandra* observatory.

t *headings:* cooling flows — galaxies: active — galaxies: clusters: general — X-rays: galaxies

FLASH Users



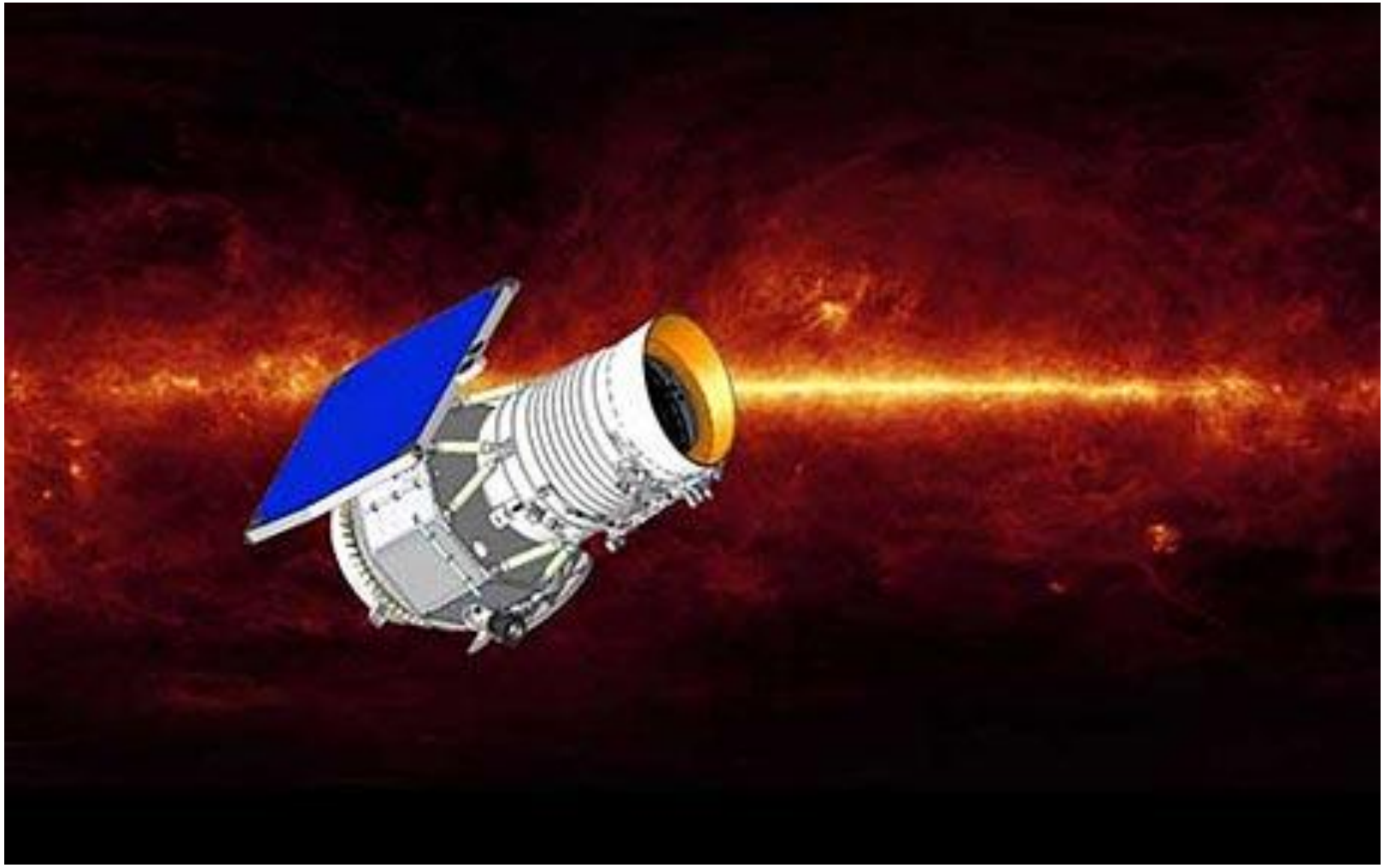


- FLASH has been downloaded more than 2000 times
- More than 700 scientists have been co-authors on more than 400 papers published using FLASH

Current Major Flash Center Projects

- High-Energy Density Physics Initiative *(ASC Program in DOE NNSA and ASCR in DOE Office of Science)*
- Flash High-Energy Density Physics Exascale Co-Design Center *(ASCR in DOE Office of Science)*
- Petascale Computing of Thermonuclear Supernova Explosions *(NSF Astronomy & Astrophysics Program)*
- Petascale Algorithms for Multi-Body, Fluid-Structure Interactions in Incompressible Flows (Whole Blood Flow) *(NSF CyberInfrastructure PetaApps Program)*

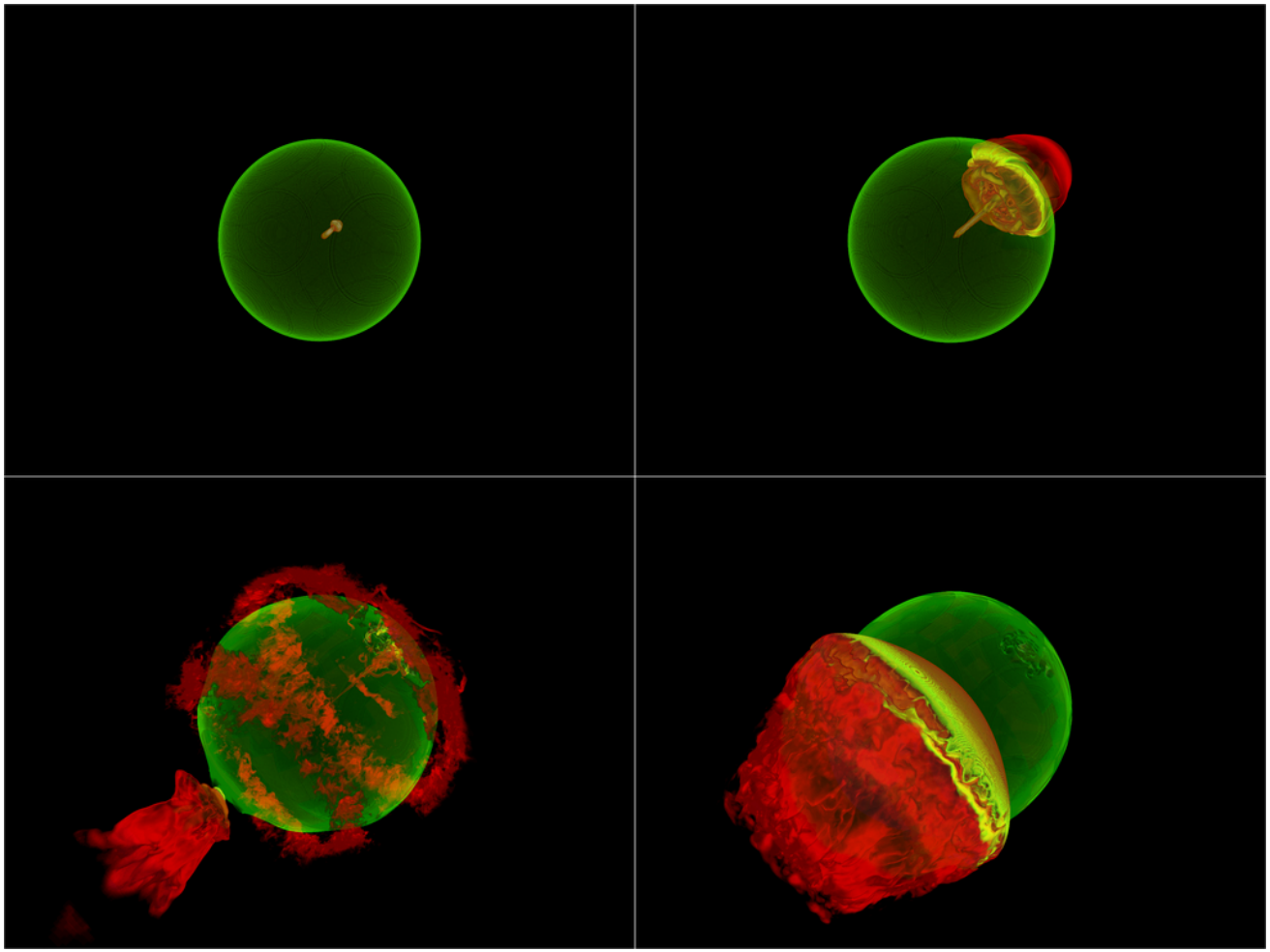
Wide-Field Infrared Red Space Telescope



Partnership with SDSS-II Supernova Survey to Validate Type Ia Supernova Models

SDSS Supernova Project has spectroscopically identified more than 500 Type Ia supernovae, and obtained high-quality light curves and spectra for many of them *(Holtzman et al. 2009, Kessler et al. 2009)*

Discovery of Entirely New Mechanism for Thermonuclear-Powered Supernovae



Calder et al. (2003); Plewa, Calder and Lamb (2004); Townsley et al. (2007); Jordan et al. (2008); Meakin et al. (2009)

The Center for Astrophysical Thermonuclear Flashes

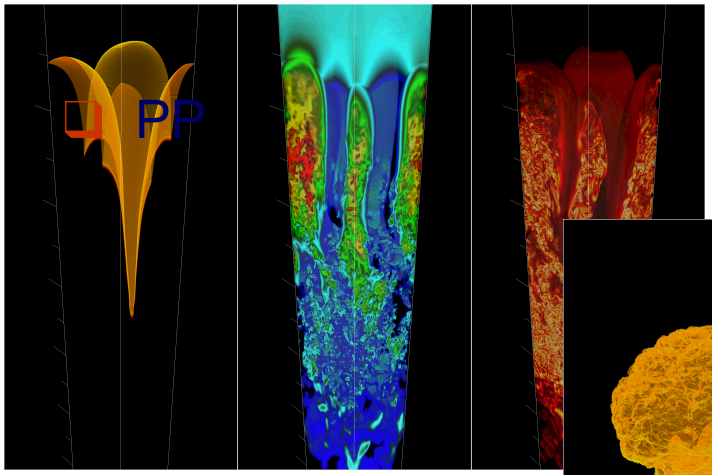
Simulation of the Deflagration and Detonation Phases of a Type Ia Supernovae

Ignition occurs 40 km from the center of the star.
Hot material is shown in color and stellar surface in green.

This work was supported in part at the University of Chicago by the DOE NNSA ASC ASAP and by the NSF. This work also used computational resources at LBNL NERSC awarded under the INCITE program, which is supported by the DOE Office of Science.

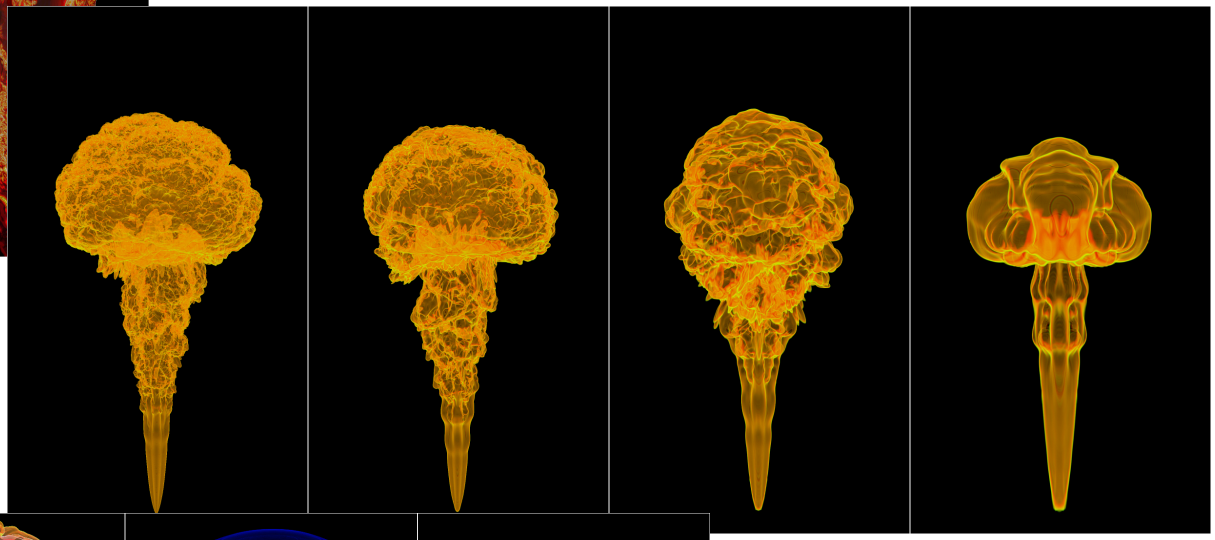
An Advanced Simulation and Computation (ASC)
Academic Strategic Alliances Program (ASAP) Center
at The University of Chicago

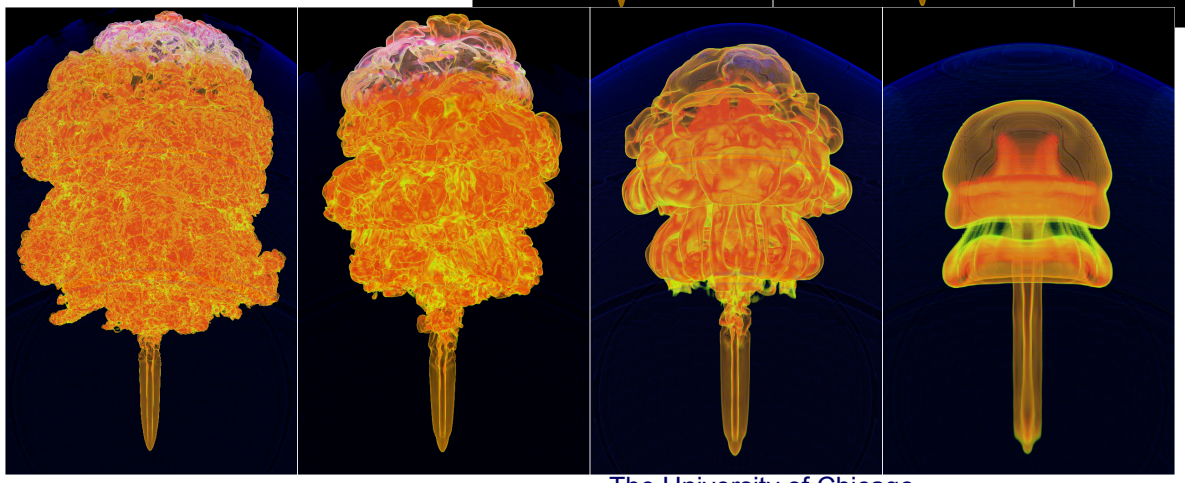
3D Verification Simulations of Buoyancy-Driven Turbulent Nuclear Combustion



Initially Planar Flame
In Rectilinear Domain
at Constant *g* and *ρ*

Flame Bubble in Rectilinear
Domain at Constant *g* and *ρ*





Flame Bubble
in White Dwarf Star

The Center for Astrophysical Thermonuclear Flashes

Simulation of Buoyancy-Driven Turbulent Nuclear Burning for a Froude Number of 0.010

This work was supported in part at the University of Chicago by the DOE NNSA ASC ASAP and by the NSF. This work also used computational resources at LBNL NERSC awarded under the INCITE program, which is supported by the DOE Office of Science.

An Advanced Simulation and Computation (ASC)
Academic Strategic Alliances Program (ASAP) Center
at The University of Chicago

FLASH Code Contributors

- Current CS-Applications Group:
  - Sachin Bhargara, Sean Couch, Colin Cross, Chris Daley, Milad Fatenejad, Norbert Flocke, Carlo Graziani, Dongwook Lee, Klaus Weide, and Anshu Dubey
- Other Current Contributors:
  - Paul Ricker, Dean Townsley, Cal Jordan, John Zuhone, Kevin Olson, Marcos Vanella
- Past Major Contributors:
  - Katie Antypas, Alan Calder, Jonathan Dursi, Robert Fisher, Murali Ganapathy, Timur Linde, Tomek Plewa, Lynn Reid, Paul Rich, Katherine Riley, Andrew Siegel, Dan Sheeler, Frank Timmes, Natalia Vladimirova, Greg Weirs, Mike Zingale

FLASH Basics

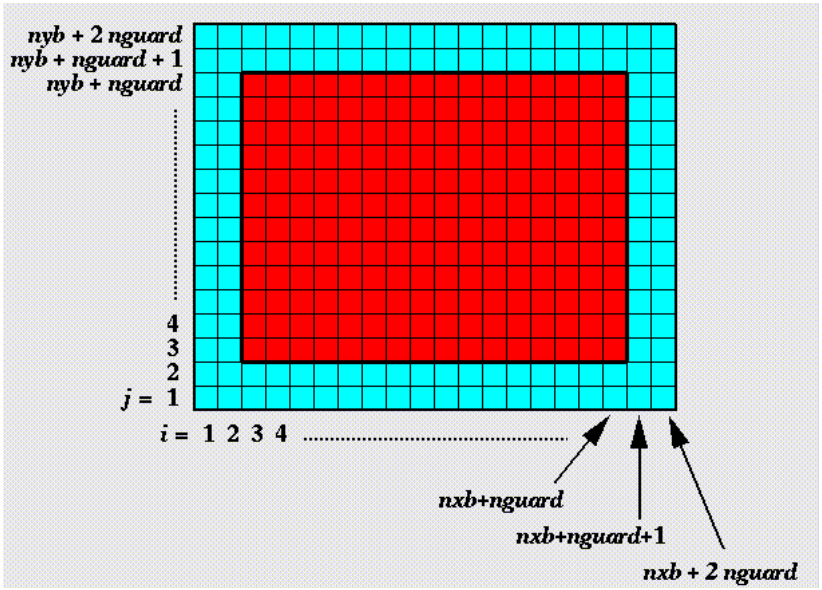
- An application code, composed of units/modules. Particular modules are set up together to run different physics problems.
- Fortran, C, Python, …
  - More than 500,000* lines of code, 75% code, 25% comments
- Very portable, scales to tens of thousand processors

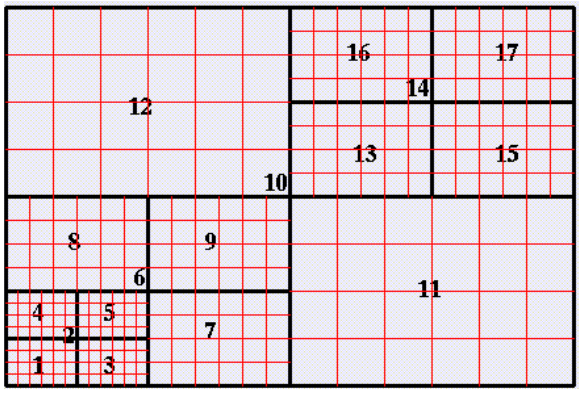
Capabilities

- Infrastructure
  - Configuration (setup)
  - Mesh Management
  - Parallel I/O
  - Monitoring
    - Performance and progress
  - Verification
    - FlashTest
      - Unit and regression testing
- Physics
  - Hydrodynamics, MHD, RHD
  - Equation of State
  - Nuclear Physics and other Source Terms
  - Gravity
  - Particles, active and passive
  - Material Properties
  - Cosmology

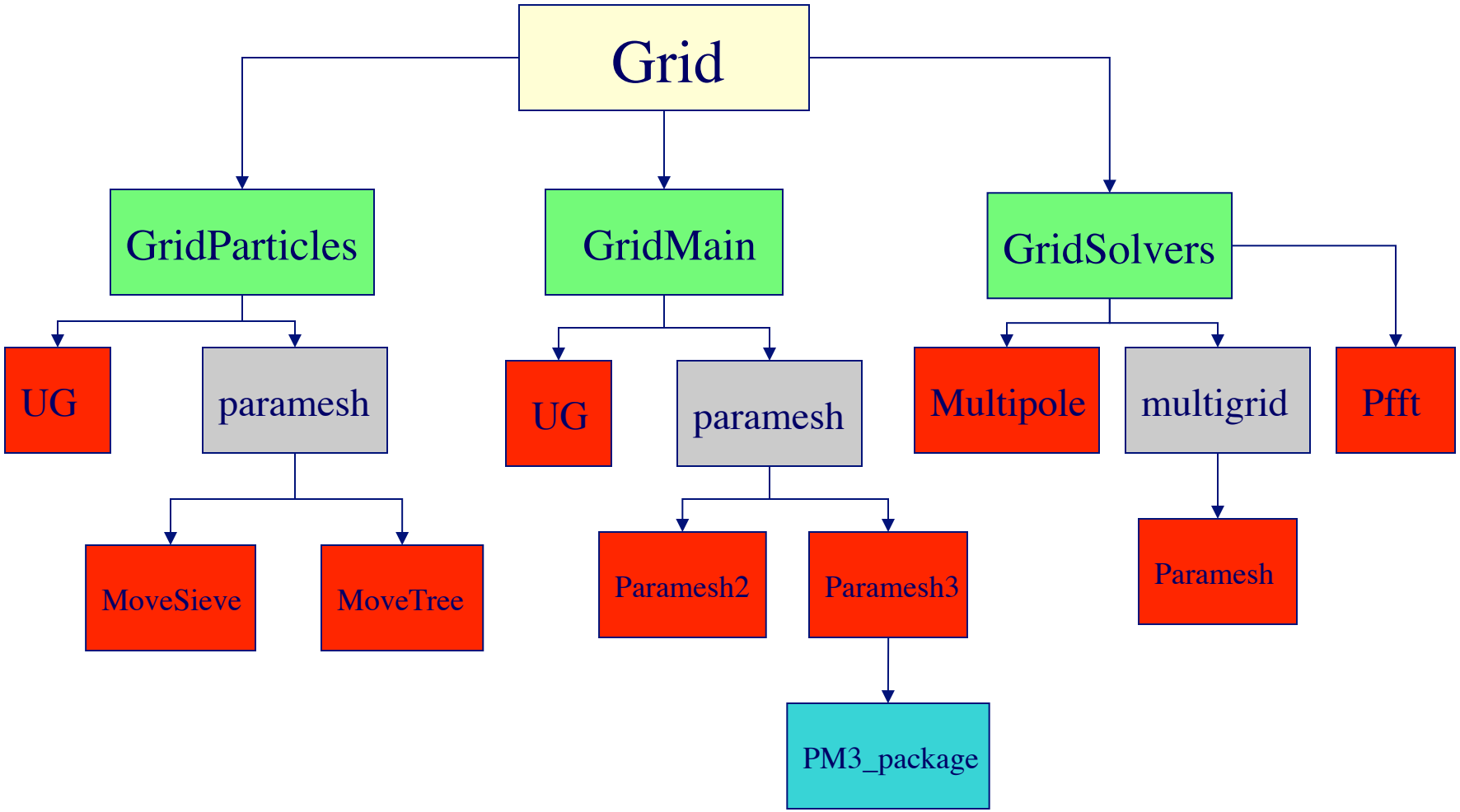
Basic Computational Unit: Block

- The grid is composed of blocks
- Cover different fraction of the physical domain.
- In AMR blocks at different levels of refinement have different grid spacing.





Example of a Unit - Grid



FLASH Setup Script: Implements Architecture

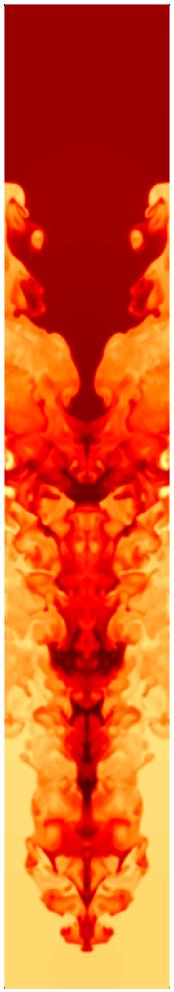
Python code links together needed physics and tools for a problem

- Parses Config files to
  - Determine a self consistent set of units to include
  - If a unit has multiple implementations, finds out which implementation to include
  - Get list of parameters from units
  - Determines solution data storage
- Configures Makefiles properly
  - For a particular platform
  - For included Units
- Implements inheritance with unix directory structure
- Provides a mechanism for customization

Hydrodynamics and MHD

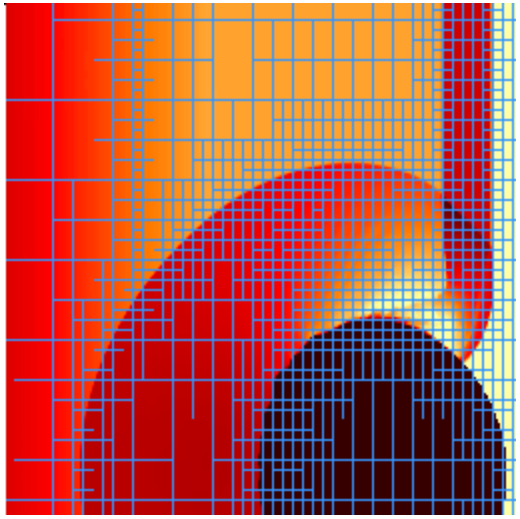
PPM (Piecewise Parabolic Method)

- Based on the Prometheus code of Fryxell
- 2nd-order Strang split in time



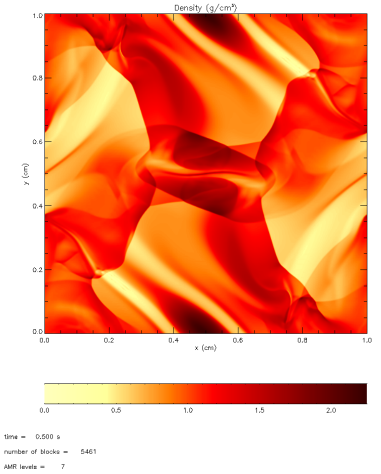
Relativistic Hydrodynamics

- Module based on the Pluto code of A. Mignone



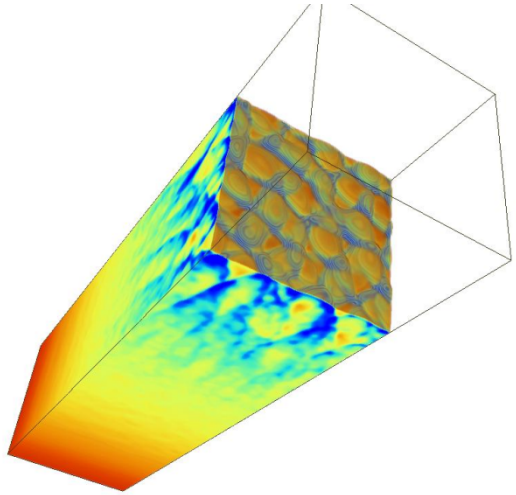
MHD

- Original implementation based on Powell et al. 1999
- New staggered mesh directionally unsplit implementation in FLASH3 by Dongwook Lee

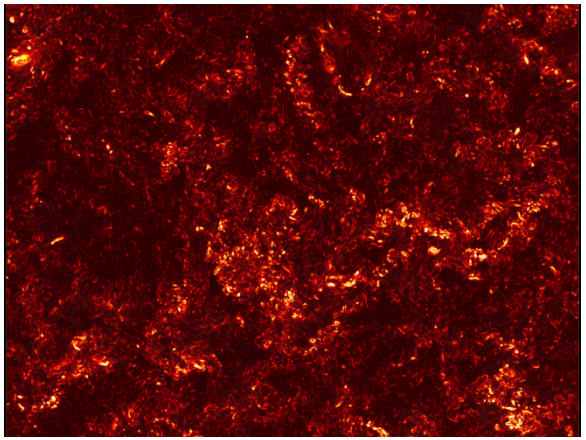


Source Terms and Equations of State

- Source Terms
  - Nuclear Burning
  - Ionization
  - Stir
  - Heat
  - Cool

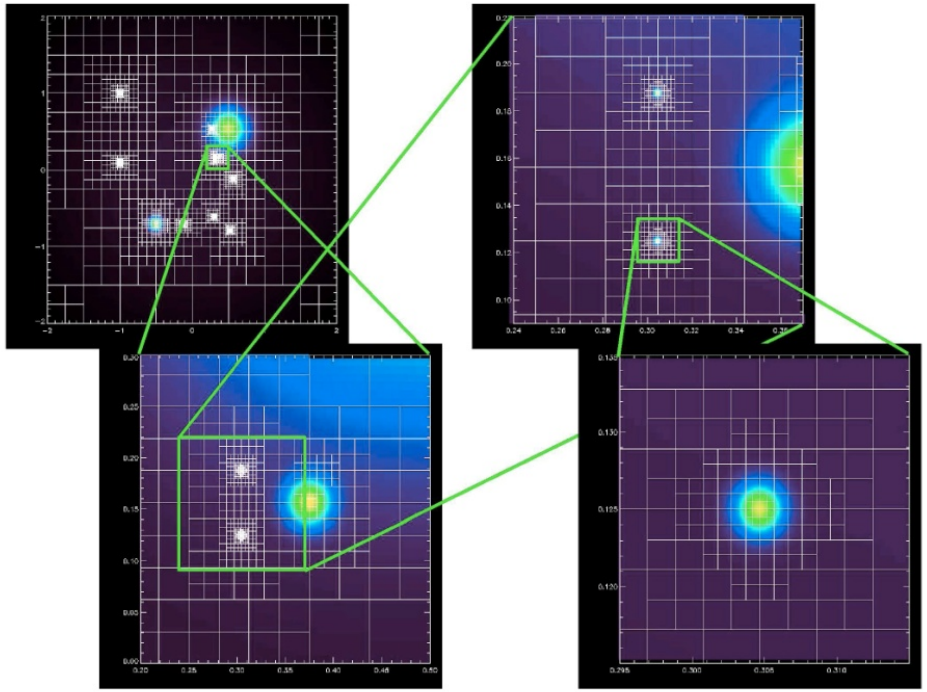


- Equations of State
  - Gamma Law
  - Multi-Gamma Law
  - Helmholtz EOS for degenerate matter



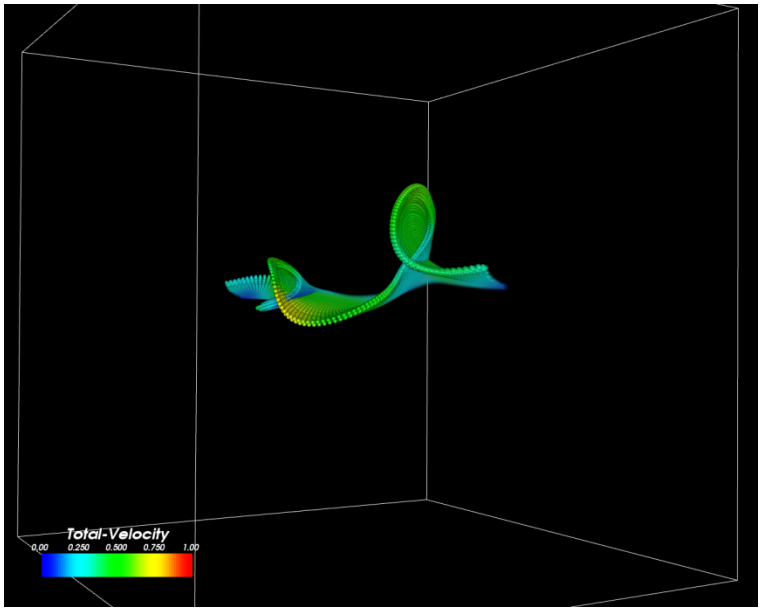
Gravity

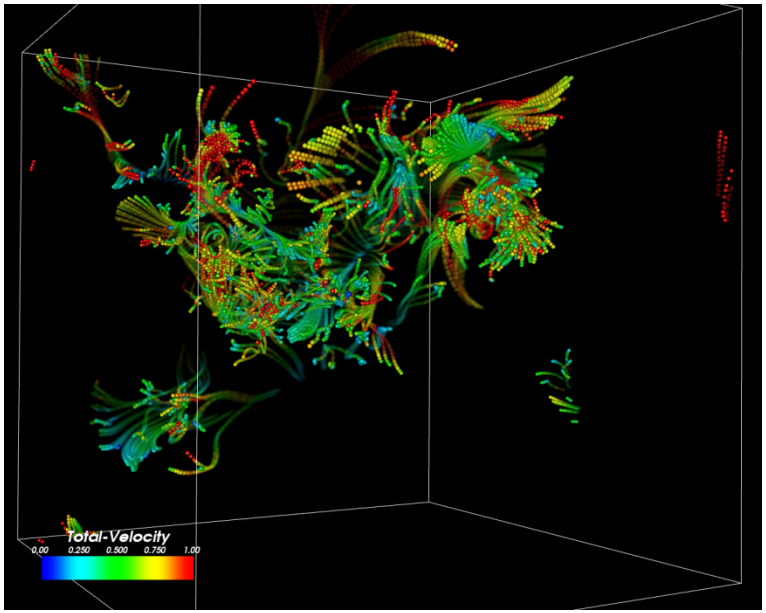
- Constant
- Pointmass
- Plane parallel
- Newtonian self gravity (elliptic solver)
  - Barnes-Hut Tree
  - Multipole
  - Multigrid



Particles

- Active particles to simulate dark matter
  - Long-range and short-range forces
- Active particles to simulate photons
- Lagrangian tracer particles





… which brings us to

Questions and Discussion