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NICS

3D – The Next Crucial Step in Core-Collapse Supernova Simulations

CASTRO!

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Overview

The mechanism by which the cores of massive stars as they die launch supernova explosions has been studied for many years but has not been unambiguously determined

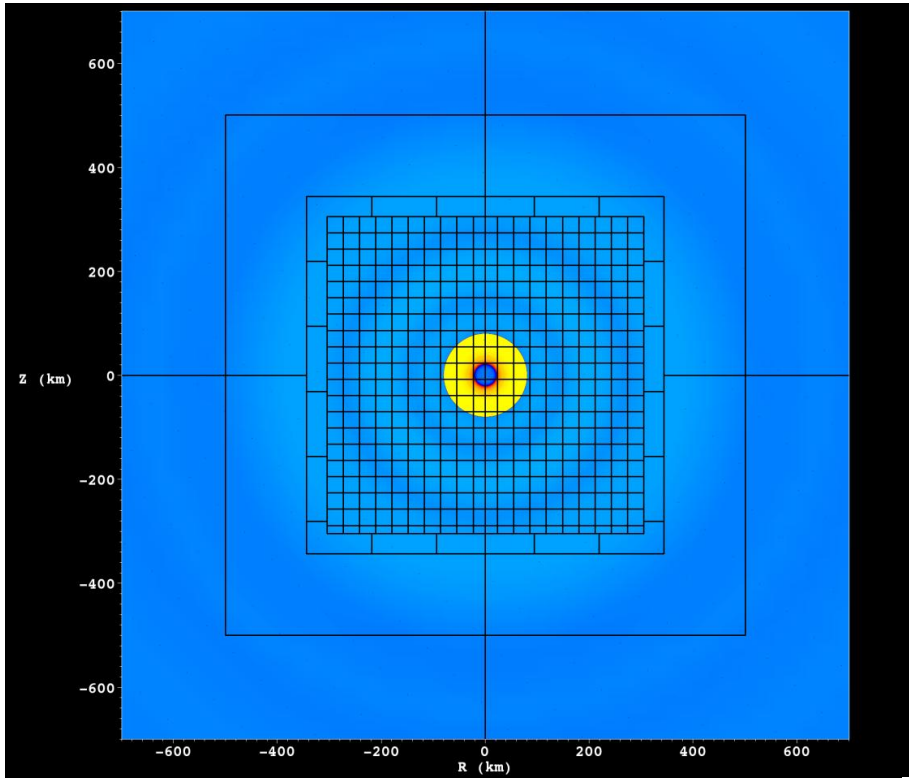
At the confluence of nuclear, particle, and gravitational physics, and a numerical challenge of the first order, this puzzle has confounded theorists in no small measure due to its complexity. Some of this complexity is due to its multidimensional character—the dynamics experiences many hydrodynamic instabilities, and the explosions are not spherical

Hence, the associated computational complexity of multidimensional simulations has retarded progress, but with the recent advent of fast and large parallel computers, the multidimensional character of core-collapse supernovae may soon be captured. Whereas in the past, 1D and 2D simulations could be performed, 3D simulation capabilities are emerging. The movies here of early 3D simulations provide a glimpse at the character of the results to come

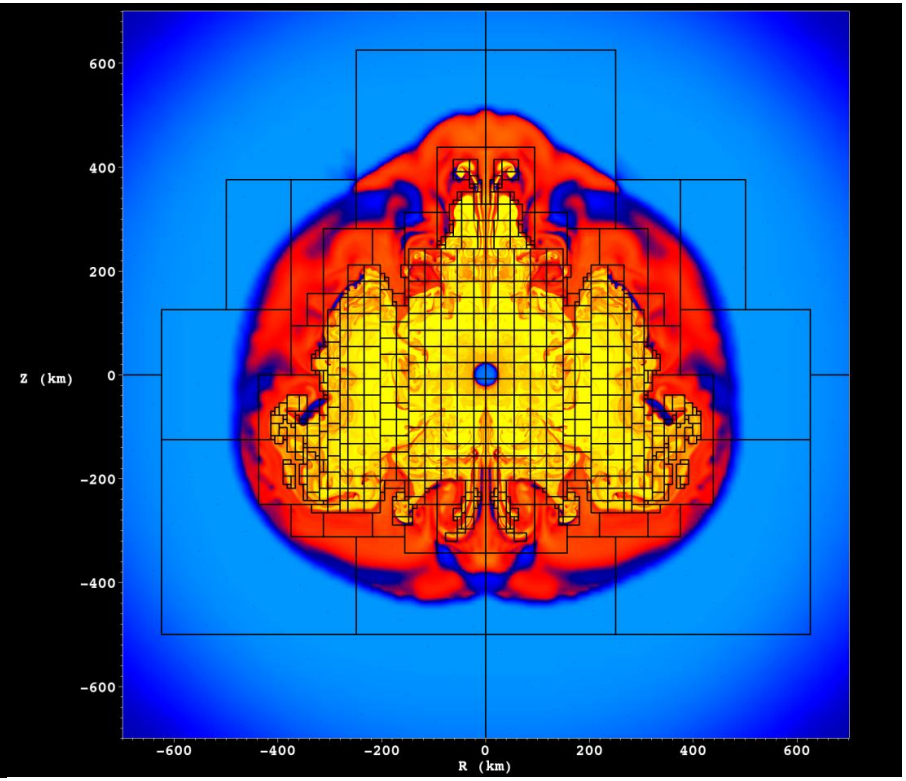
CASTRO – 3D AMR, multigroup radiation-hydrodynamic supernova code

- 2nd-order, Eulerian, unsplit, compressible hydro
- PPM and piecewise-linear methodologies
- Multigrid Poisson solver for gravity
- Multicomponent advection scheme with reactions
- Adaptive Mesh Refinement (AMR) – flow control, memory management, grid generation
- Block-structured hierarchical grids
- Subcycles in time (multiple timestepping – coarse, fine)
- Sophisticated synchronization algorithm
- BoxLib software infrastructure, with functionality for serial distributed and shared memory architectures
- 1D (Cartesian, cylindrical, spherical); 2D (Cartesian, cylindrical); 3D (Cartesian)
- Transport is a conservative implementation of the mixed-frame method of Hubeny & Burrows (2007), with v/c terms and inelastic scattering
- Uses scalable linear solvers (e.g., hypre) with high-performance preconditioners that feature parallel multigrid and Krylov-based iterative methods
- Developers: John Bell, Ann Almgren, Louis Howell, Mike Singer, Jason Nordhaus, Adam Burrows – LBNL, LLNL, Princeton

Sample block grid structures of CASTRO

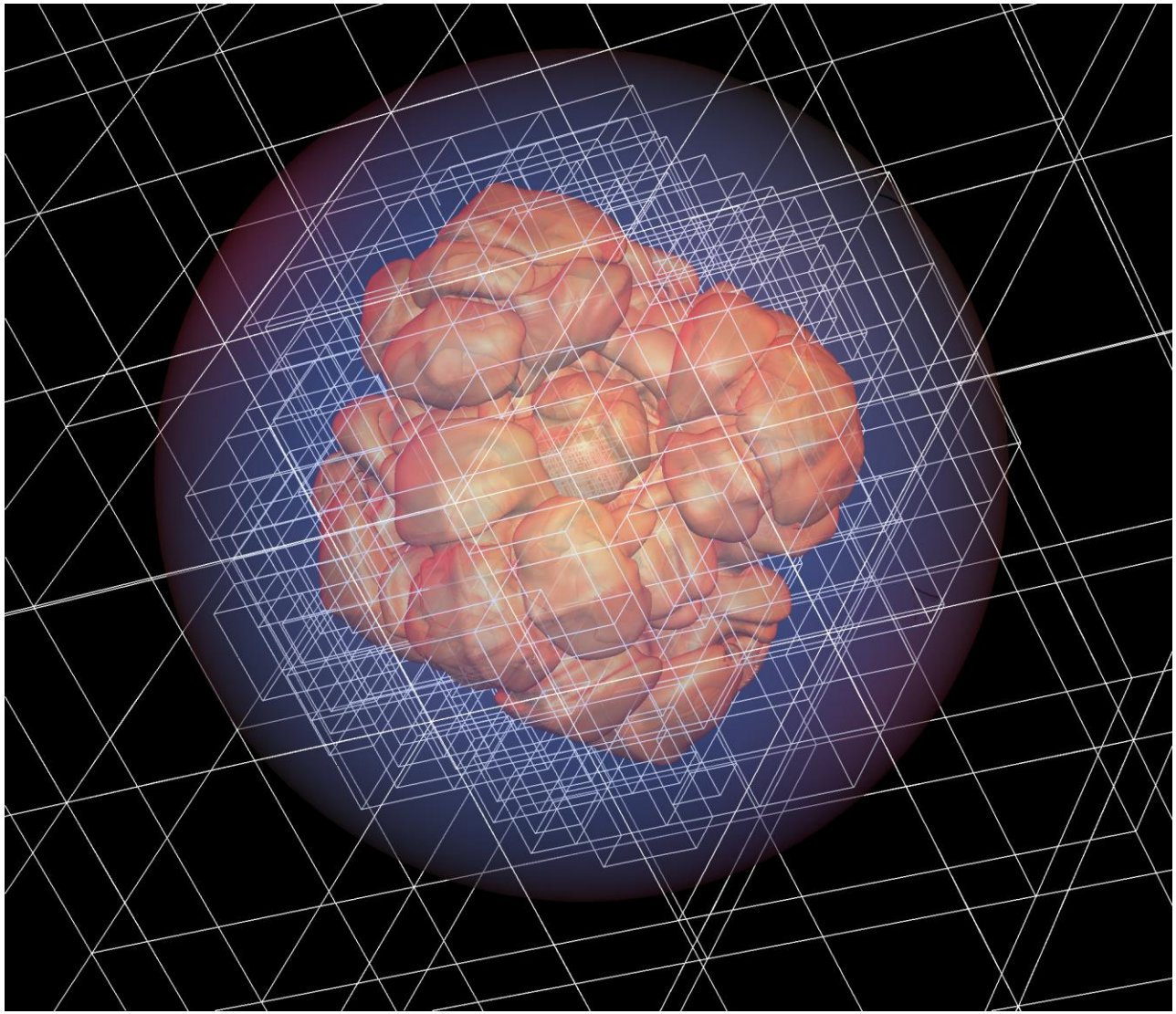


Precollapse



Postcollapse

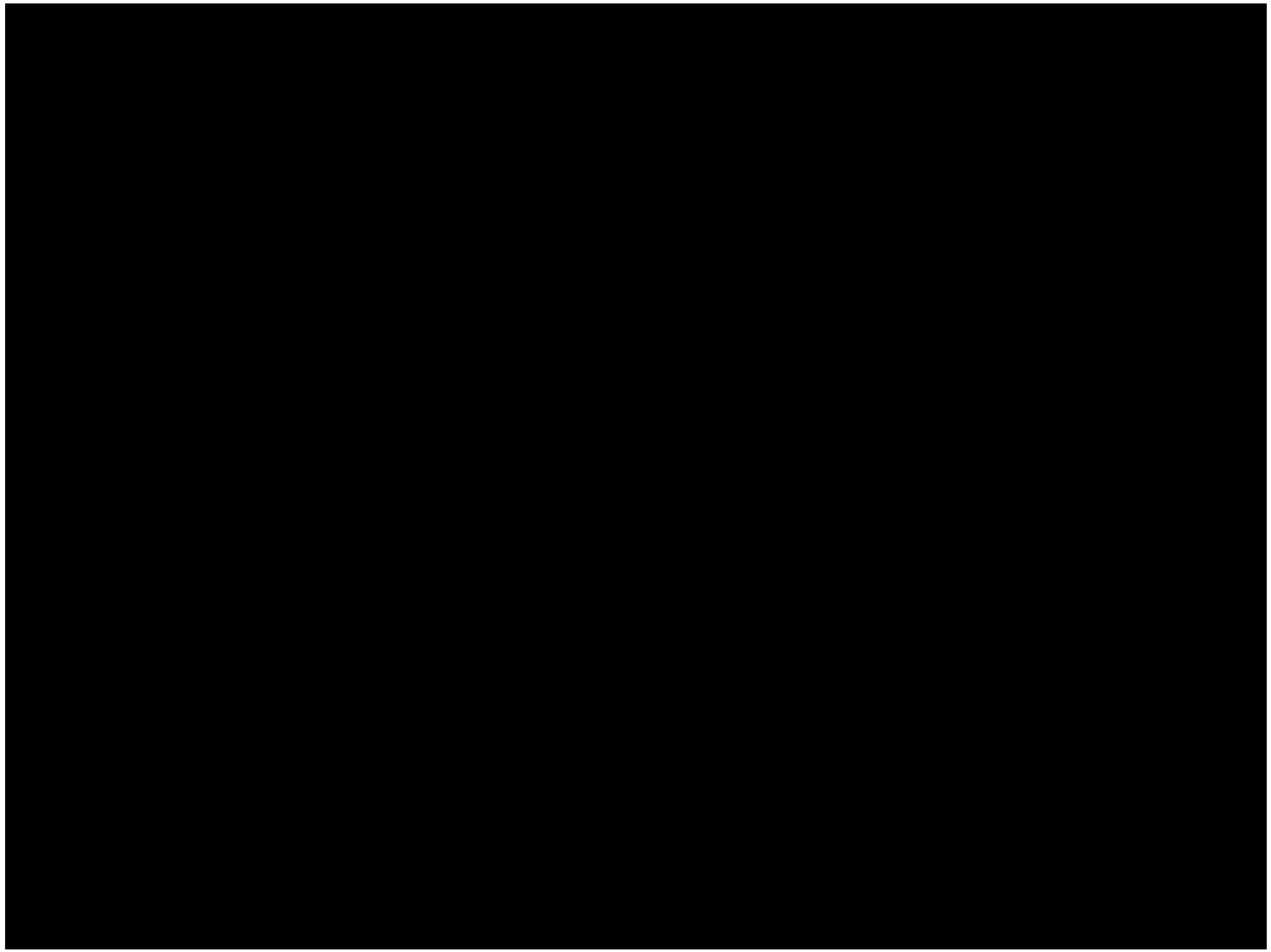
CASTRO 3D AMR mesh: Explosion model



The movie depicts an isoentropy contour of an exploding shell of the core of the star. The fracturing into small structures is evident to a degree not readily apparent in corresponding 2D simulations, suggesting the importance of 3D effects. At the end of the simulation, the camera rotates the debris to reveal its heterogeneity

Same simulation, but depicts the shell of material moving at a positive (hence exploding) speed of 5000 kilometers per second. The matter interior to it is moving more slowly, while that exterior to it is moving faster. The tattered character of this interface demonstrates the gross asphericities created during explosion, and the camera rotation of the structure at the end of the movie reveals the nested character of the speed contours. 2D simulations could not reveal this behavior

BLAST morphology sequence in 3D



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