Toward the Explosion Mechanism for Core-Collapse Supernovas: An Emerging Picture

Presented by

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SC07

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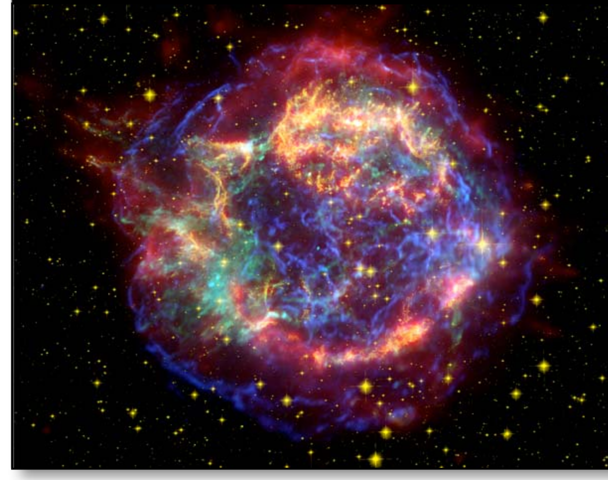
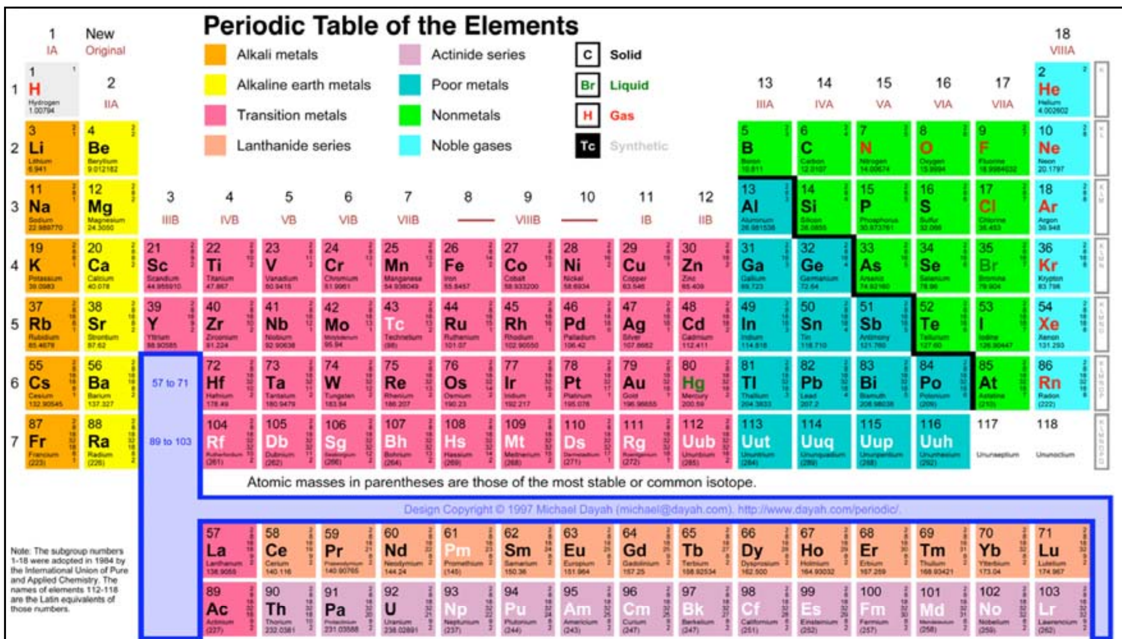
Core-collapse supernovas

- What are they?
  - Explosions of massive stars
- How often do they occur?
  - About twice per century in our galaxy
- Why are they important?
  - Dominant source of elements in the universe

Cas A Supernova Remnant
(Chandra Observatory)





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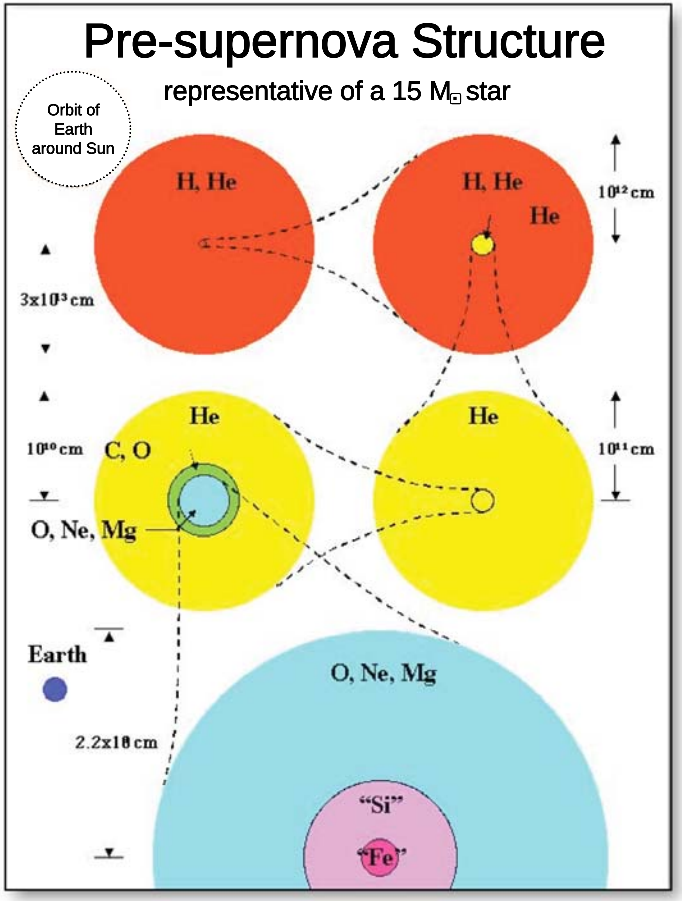
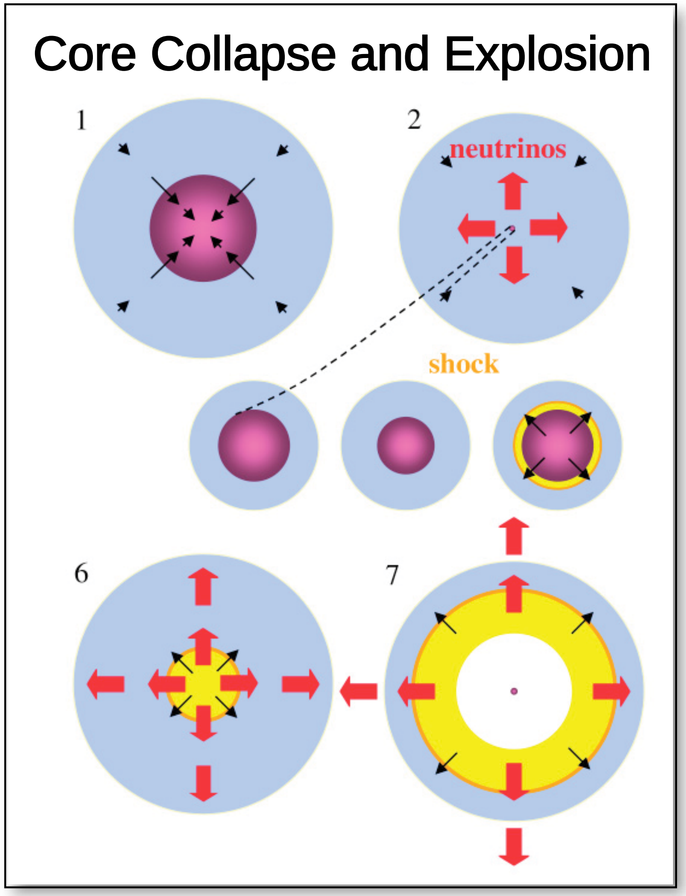
Core-collapse supernova paradigm





The star's iron core becomes unstable, collapses, rebounds, and launches a shock wave into the star, which stalls.

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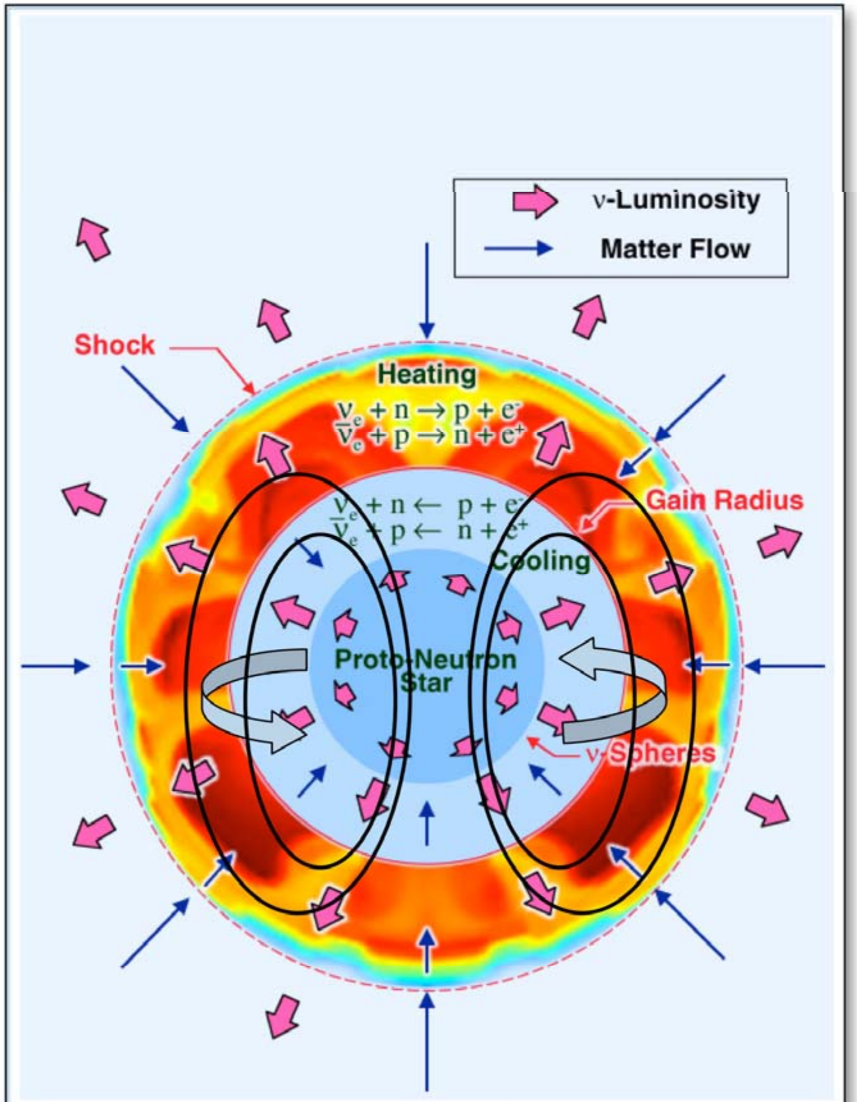
How is the supernova shock wave revived?



The most fundamental question in supernova theory

- Neutrino (radiation) heating
- Convection
- **Shock instability**
- Nuclear burning
- Rotation
- Magnetic fields

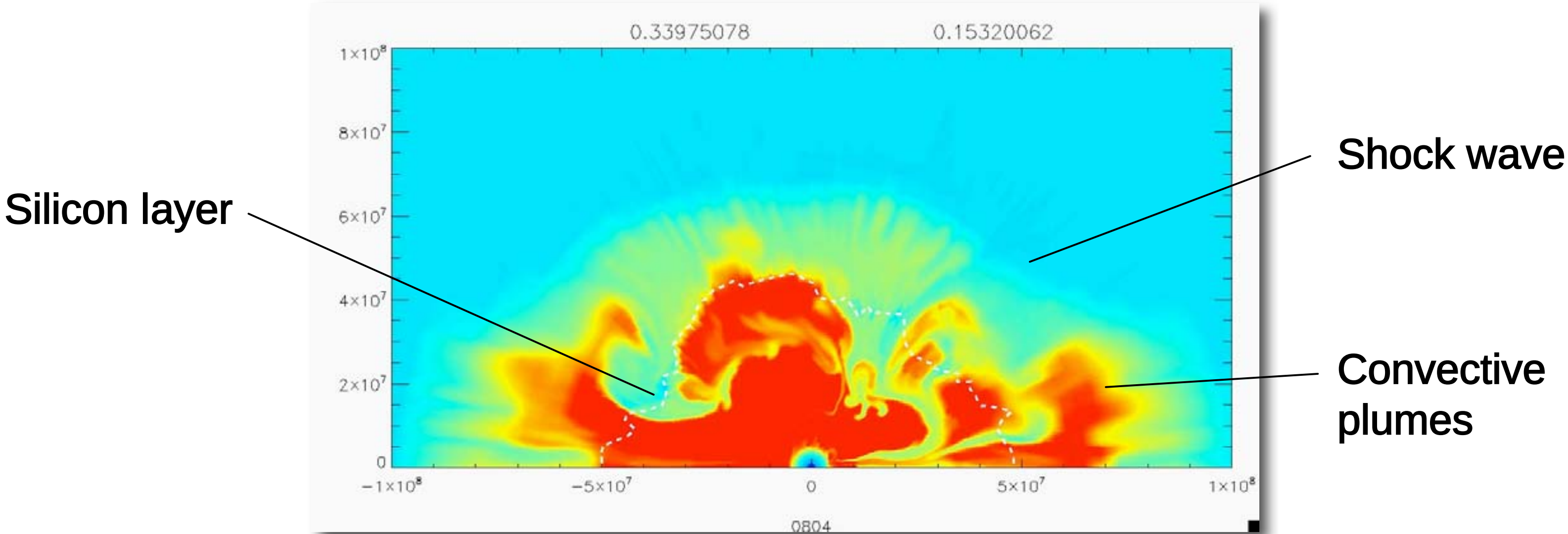
**New ingredient*

Conservative Hydrodynamics with Implicit Multi-Energy Radiation Algorithms

CHIMERA Code

- Size:
  - 150,000 lines of executable code
- Language:
  - Fortran 90
- Parallel programming model:
  - MPI (some OpenMP)
- Major components:
  - Hydrodynamics: MVH3 (latest version of VH-1)
  - Neutrino Transport: MGFLD_TRAN
  - Nuclear Network: XNET
- Libraries:
  - LAPACK
  - HDF5, pNETCDF

An emerging picture from 2-D multiphysics models



11-Solar-Mass Star

- Shock powered in part by neutrino (radiation) heating from below, aided by convection.
- Improved/additional neutrino interactions increase the neutrino heating.
- Shock distorted into cigar shape in part by the shock instability (SASI), which precipitates shock's arrival in silicon and oxygen layers (marked by white dashed line), where nuclear burning can occur behind the shock, further powering it.
- Density ahead of the shock decreases rapidly when it reaches the oxygen layer (less for the shock to plow through).

Confluence of neutrino heating with improved neutrino interactions, convection, the SASI, nuclear burning, and drop in density lead to an explosion.

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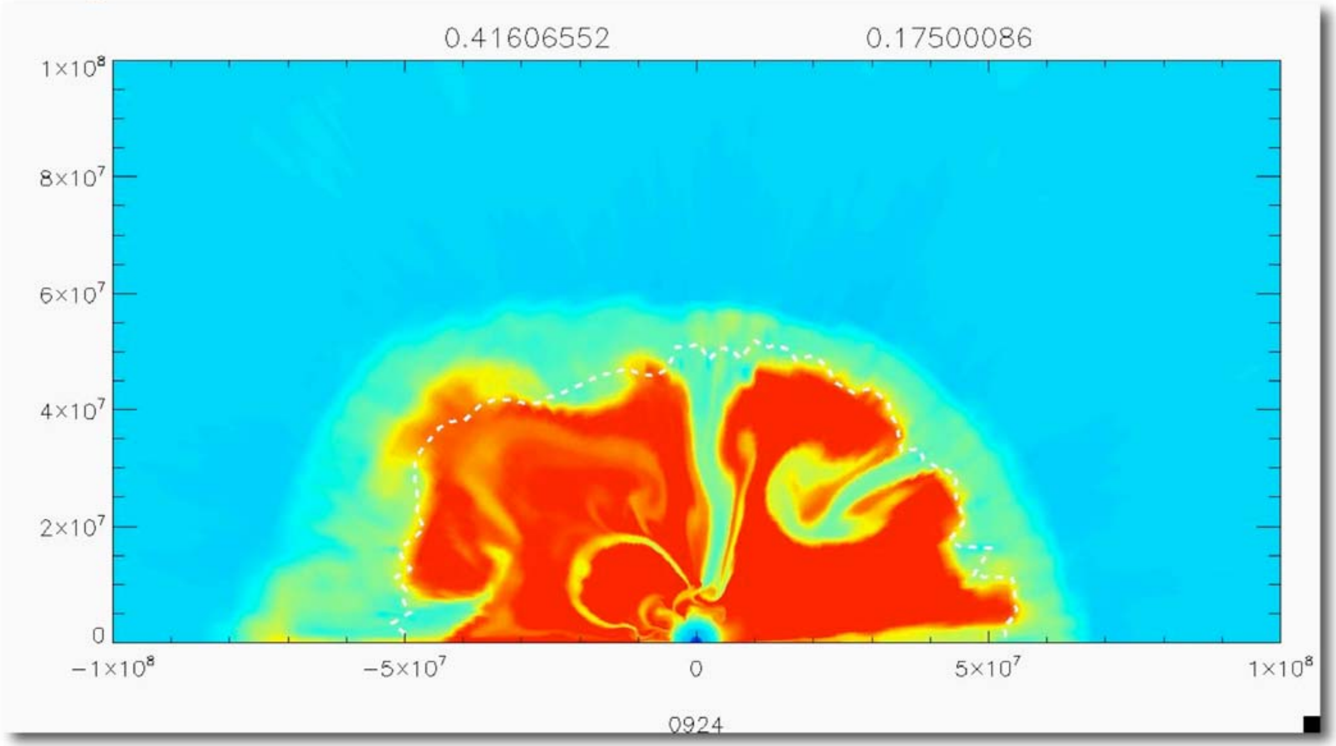
An emerging picture for 2-D multiphysics models



Bruenn et al., *J. Phys. Conf. Ser.*, **46**, 393 (2006)
Mezzacappa et al., *AIP Conf. Proc.*, **924**, 234 (2007)

20-Solar-Mass Star

- Explosion occurs in this case as well.
- Two-dimensional results are very promising given they occur for a range of massive stars.

N.B. Progenitor for supernova SN1987A was a 20-Solar-mass star.

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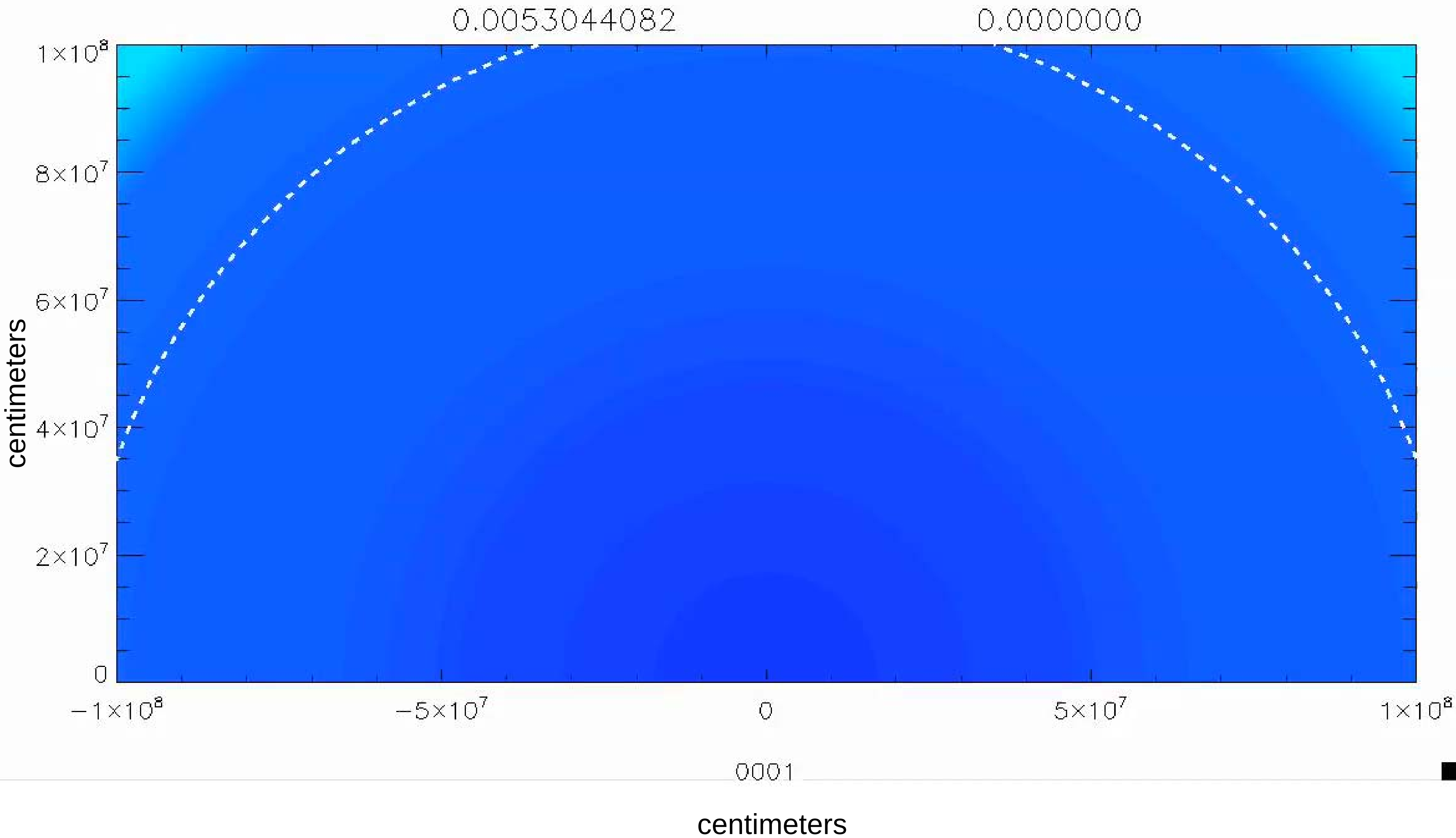
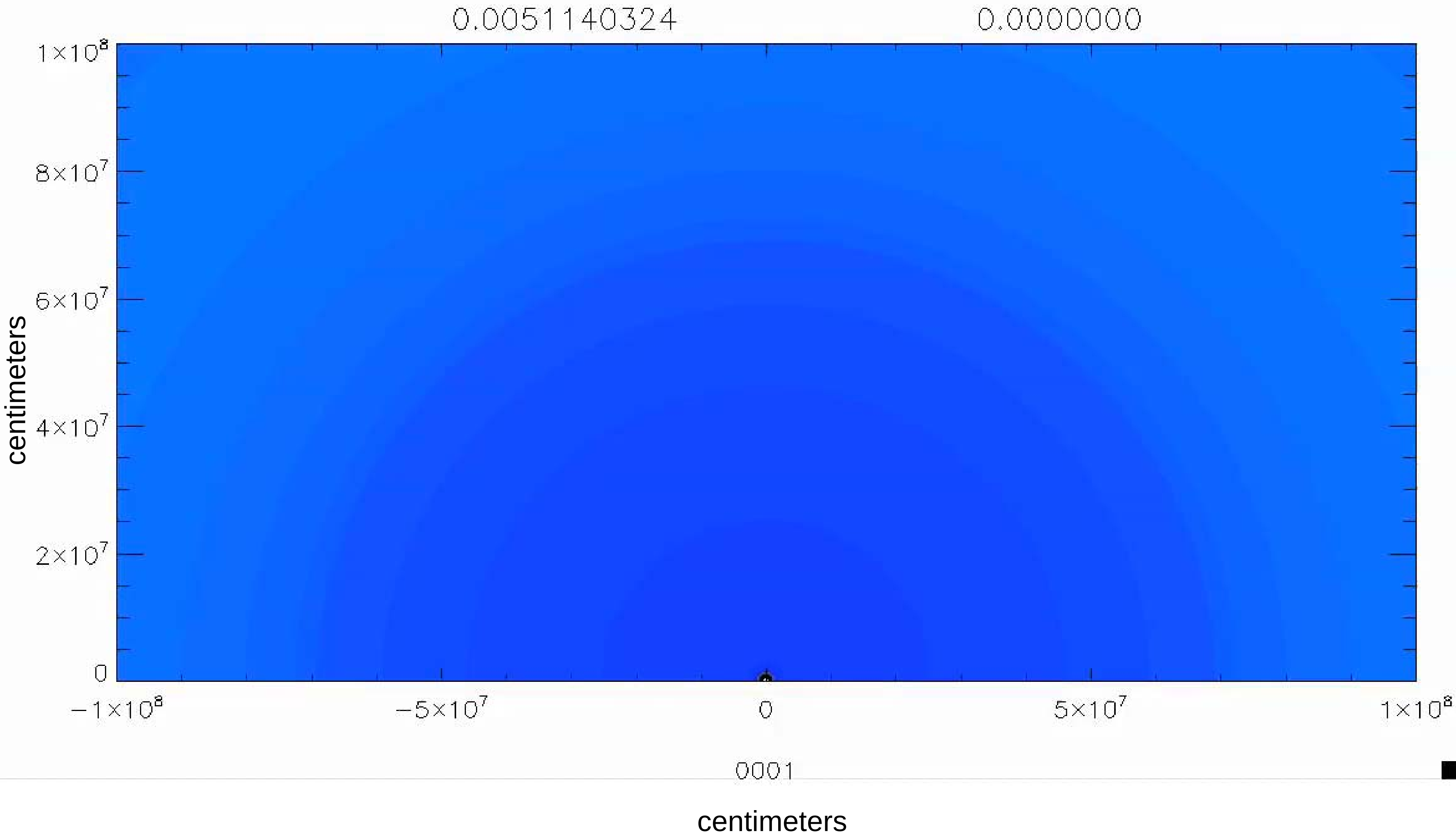
11-Solar-mass model

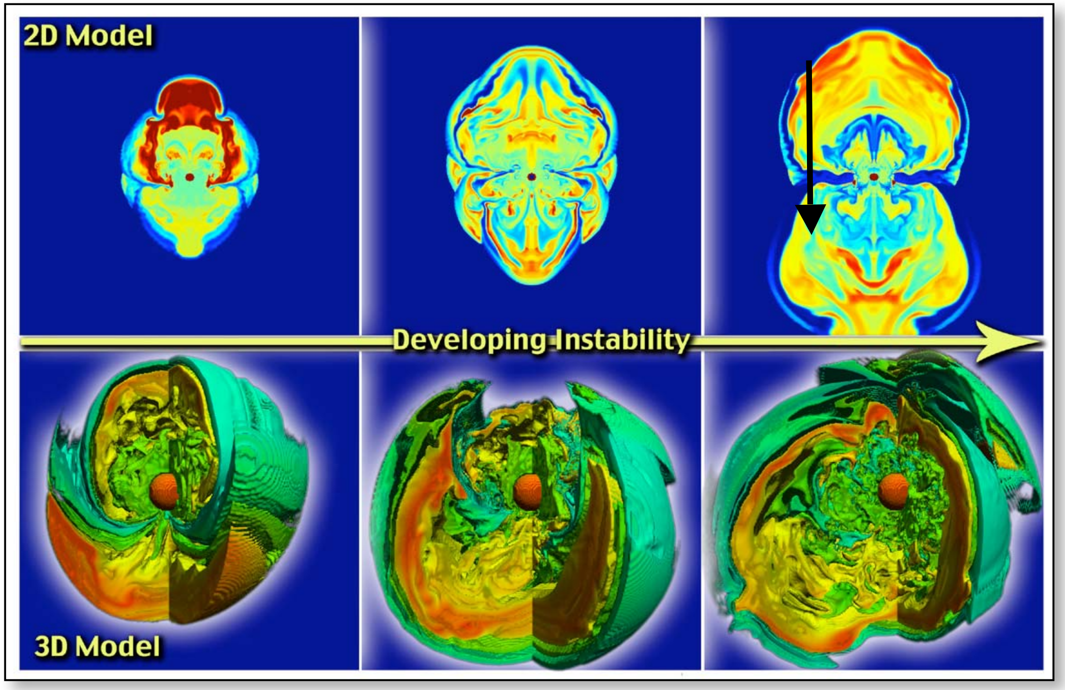


20-Solar-mass model



Need for 3-D

- Simulations of the SASI in 2-D and 3-D reveal new modes/dynamics in 3-D that qualitatively alter simulation outcomes.



Blondin, Mezzacappa, and DeMarino, *Ap.J.* **584**, 971 (2003)

> Promising 2-D simulations reported here must be performed in 3-D.

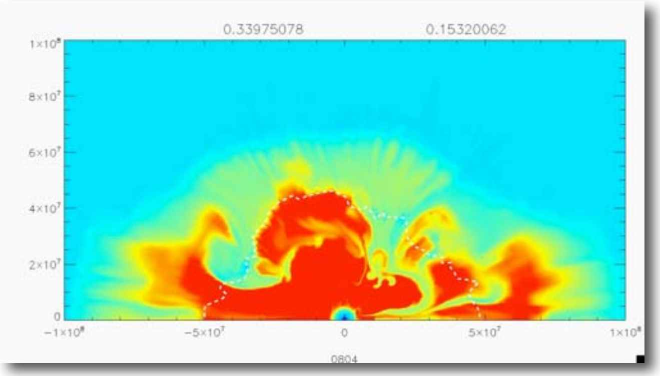
- SASI has axisymmetric and nonaxisymmetric (3-D) modes that are both linearly unstable!
  - Blondin and Mezzacappa, *Ap.J.* **642**, 401 (2006)
  - Blondin and Shaw, *Ap.J.* **656**, 366 (2007)

Summary and prospects

- Two-dimensional models

  Confluence of neutrino heating with improved neutrino interactions, convection, the SASI, nuclear burning, and sufficient simulation time for shock to reach silicon/oxygen layers leads to explosions over a range of supernova progenitors.

- Three-dimensional (SASI, hydrodynamics-only) models
  - Demonstrate how different 2-D and 3-D are.
  - Two-dimensional multiphysics models reported here must be performed in 3-D.



- Ongoing and planned 3-D multiphysics simulations
  - Preliminary low-resolution 3-D simulations ongoing at the Leadership Computing Facility (LCF).
  - Higher-resolution models will require 32,768 cores and are planned for the 250 TF LCF platform.

- Longer term
  - What role will magnetic fields play?

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Collaboration

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FAU — Bruenn, Marronetti

NC State University — Blondin

UCSD — Fuller

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