Visualization and Analytics Approaching the Exascale for Core-Collapse Supernova Simulation

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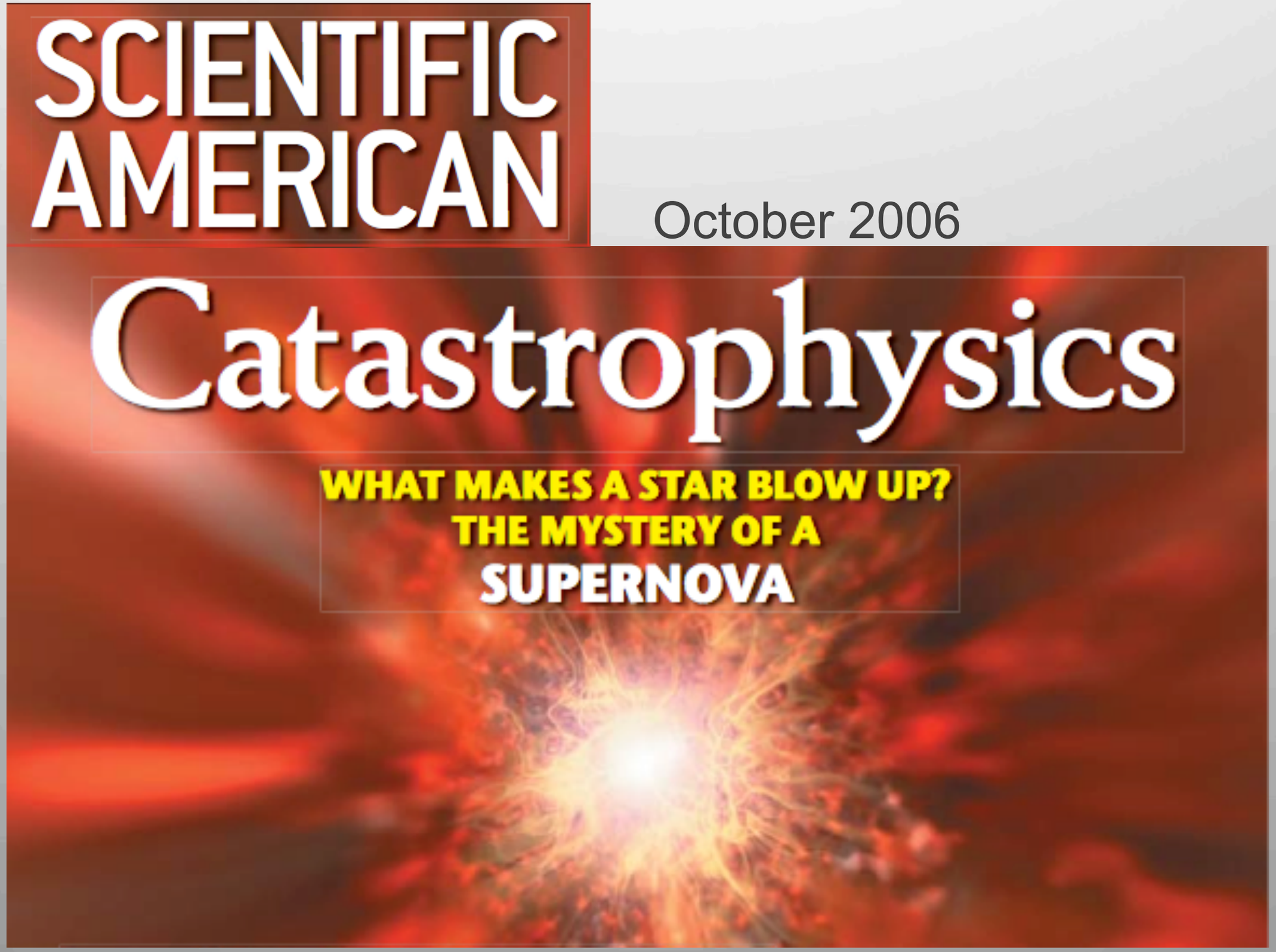
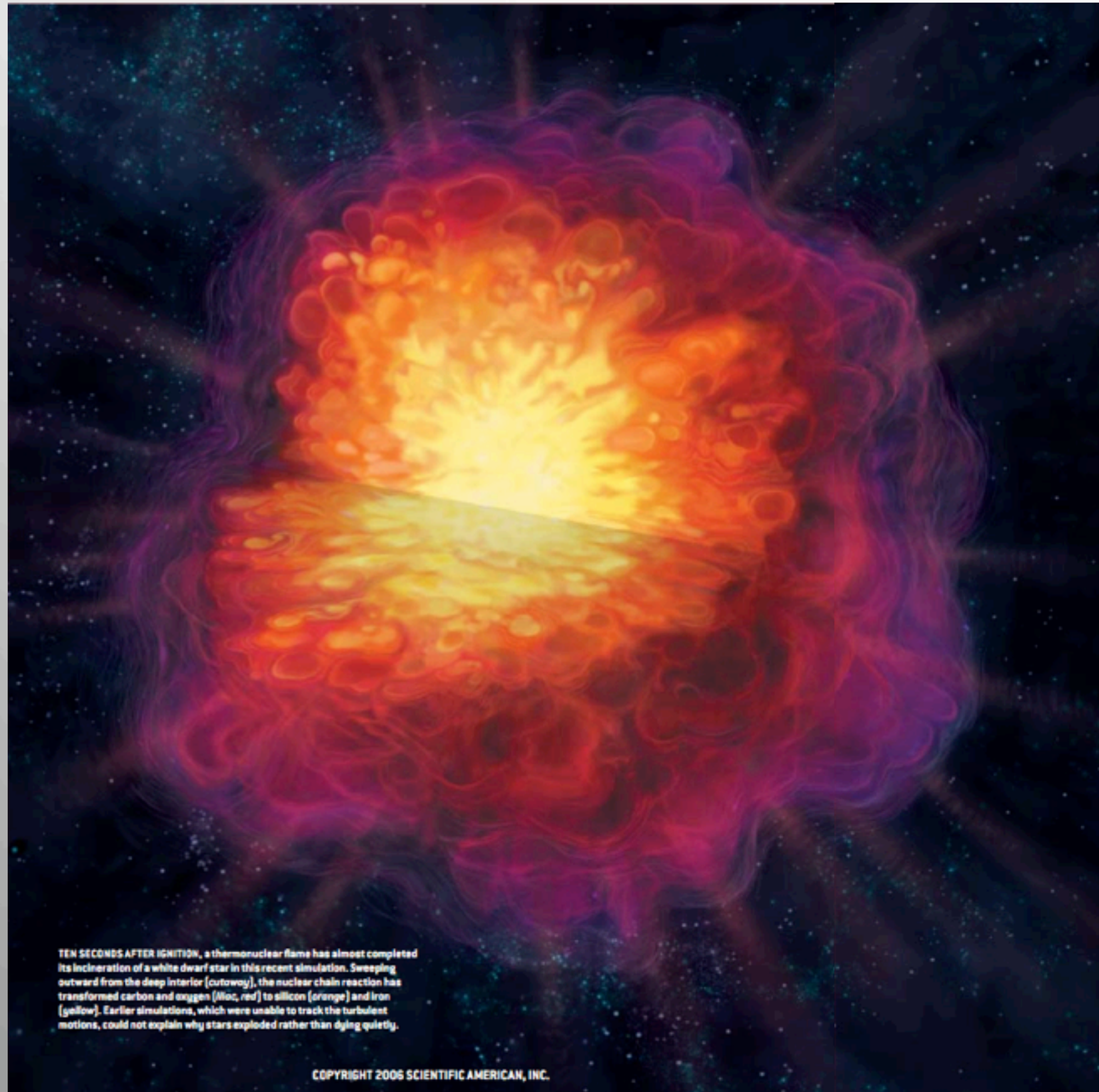
University of Tennessee


SCIENTIFIC AMERICAN
October 2006
Catastrophysics
WHAT MAKES A STAR BLOW UP?
THE MYSTERY OF A
SUPERNOVA



TEN SECONDS AFTER IGNITION, a thermonuclear flame has almost completed its incineration of a white dwarf star in this recent simulation. Sweeping outward from the deep interior (*cutaway*), the nuclear chain reaction has transformed carbon and oxygen (*blue, red*) to silicon (*orange*) and iron (*yellow*). Earlier simulations, which were unable to track the turbulent motions, could not explain why stars exploded rather than dying quietly.

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How to Blow Up a Star

By Wolfgang Hillebrandt, Hans-Thomas Janka and Ewald Müller

It is not as easy as you would think. Models of supernovae have failed to reproduce these explosions—until recently

On November 11, 1572, Danish astronomer and nobleman Tycho Brahe saw a new star in the constellation Cassiopeia, blazing as bright as Jupiter. In many ways, it was the birth of modern astronomy—a shining disproof of the belief that the heavens were fixed and unchanging. Such "new stars" have not ceased to surprise. Some 400 years later astronomers realized that they briefly outshine billions of ordinary stars and must therefore be spectacular explosions. In 1934 Fritz Zwicky of the California Institute of Technology coined the name "supernovae" for them. Quite apart from being among the most dramatic events known to science, supernovae play a special role in the universe and in the work of astronomers: seeding space with heavy elements, regulating galaxy formation and evolution, even serving as markers of cosmic expansion.

Zwicky and his colleague Walter Baade speculated that the explosive energy comes from gravity. Their idea was that

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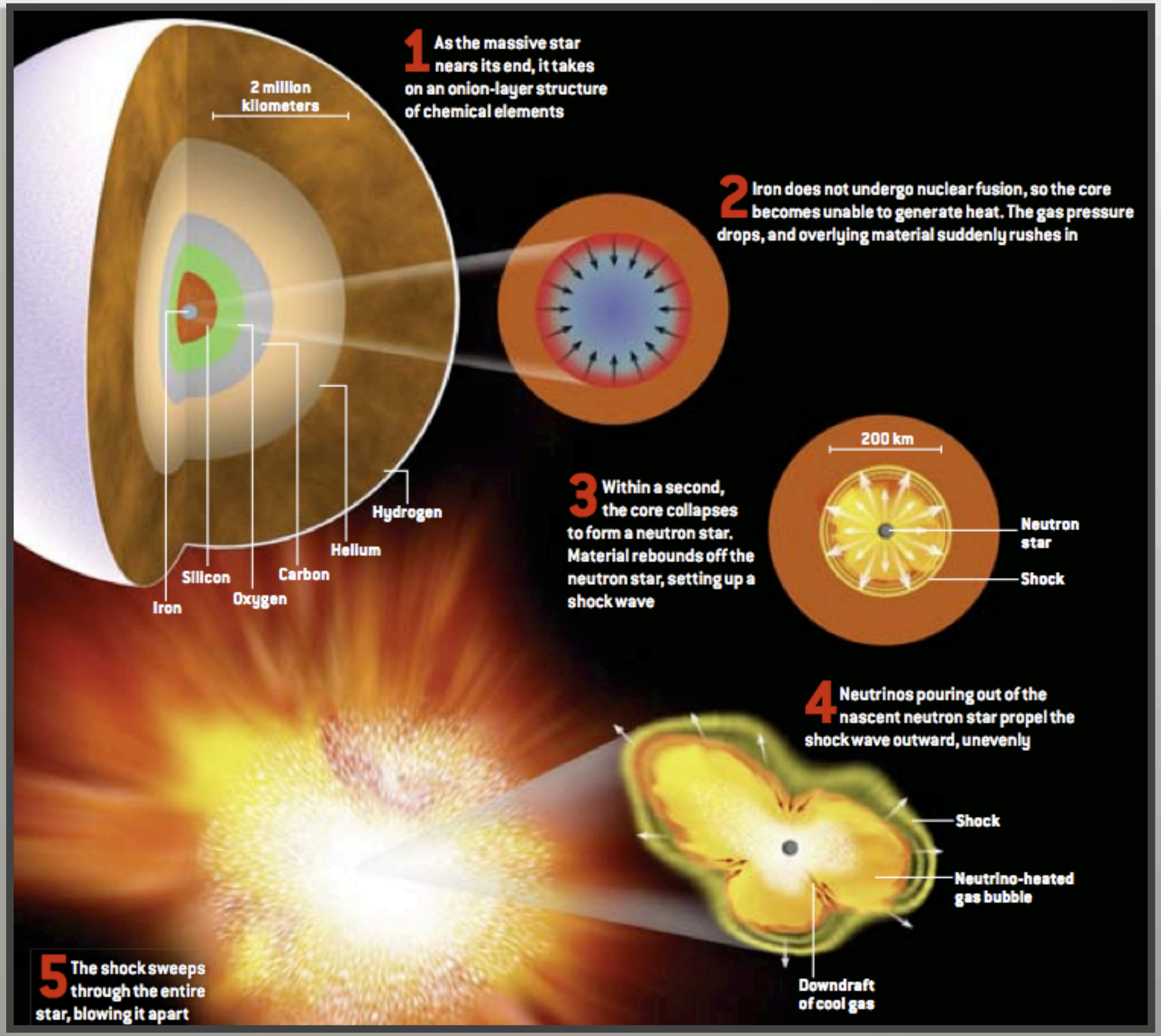
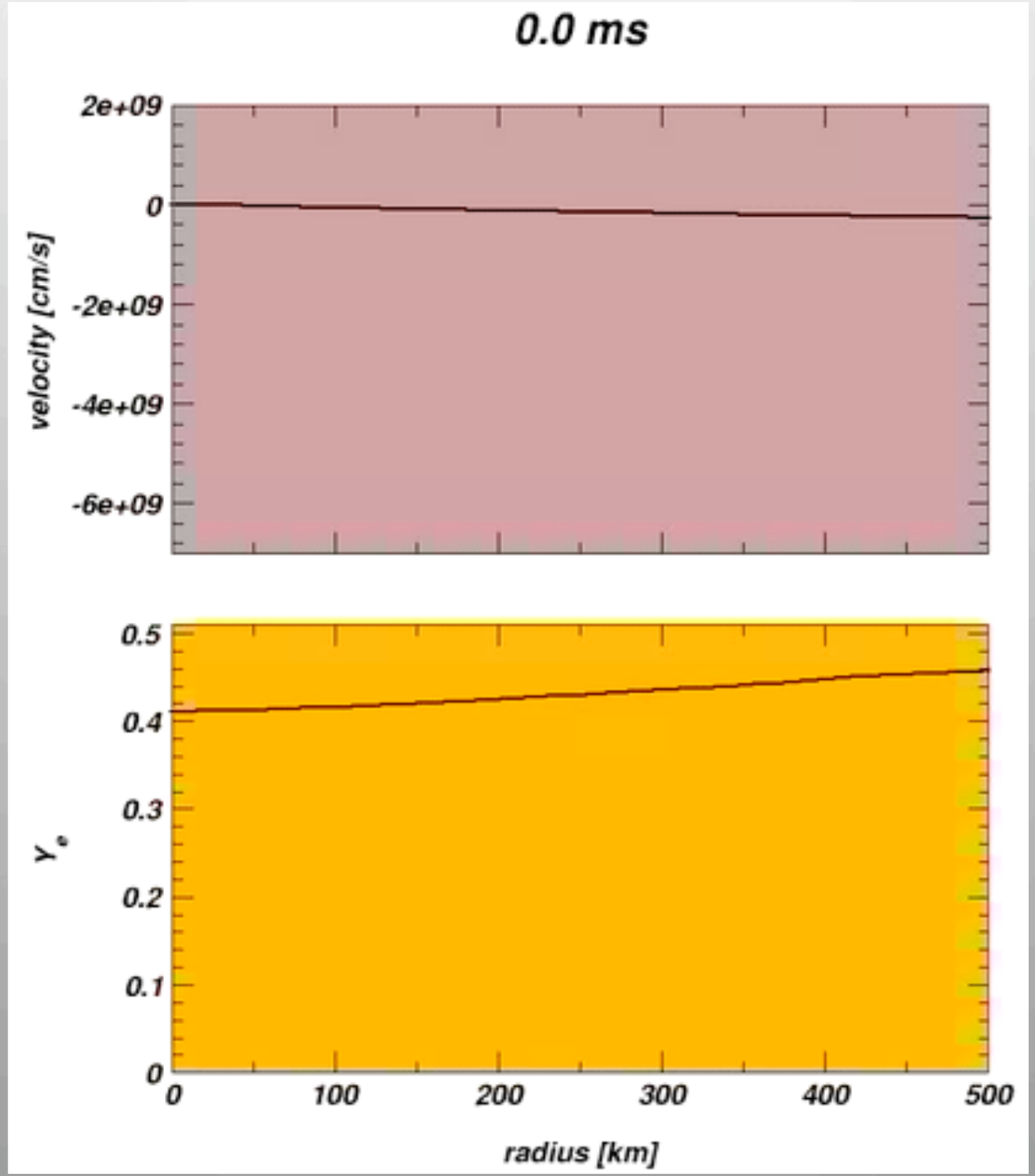


Hillebrandt & Janka 200 (Sci Am)

Spherically symmetric collapse

Messer(2000)

Spherically symmetric collapse



Messer(2000)

Current Workhorse

CHIMERA

- Ray-by-ray MGFLD transport (E_ν)
- 3D (magneto)hydrodynamics
- 14-150 species nuclear network

The "Exascale Workhorse"

GenASiS

- Full 3D Boltzmann transport (E_ν,θ,φ)
- 3D (magneto)hydrodynamics
- 150-300 species nuclear network
- +AMR

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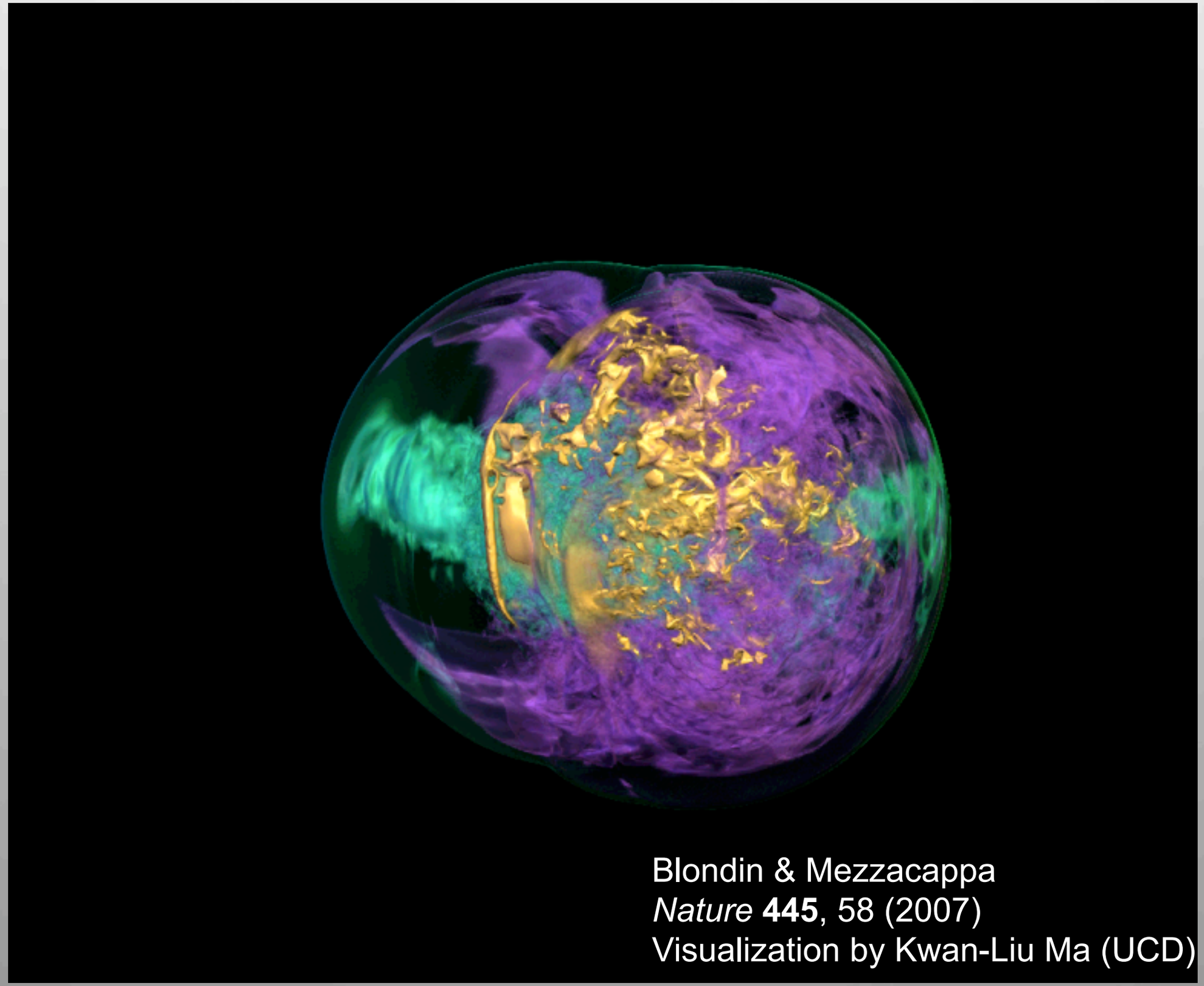
25 M⊙ progenitor

- ***Entropy is the de facto default variable to "observe"***

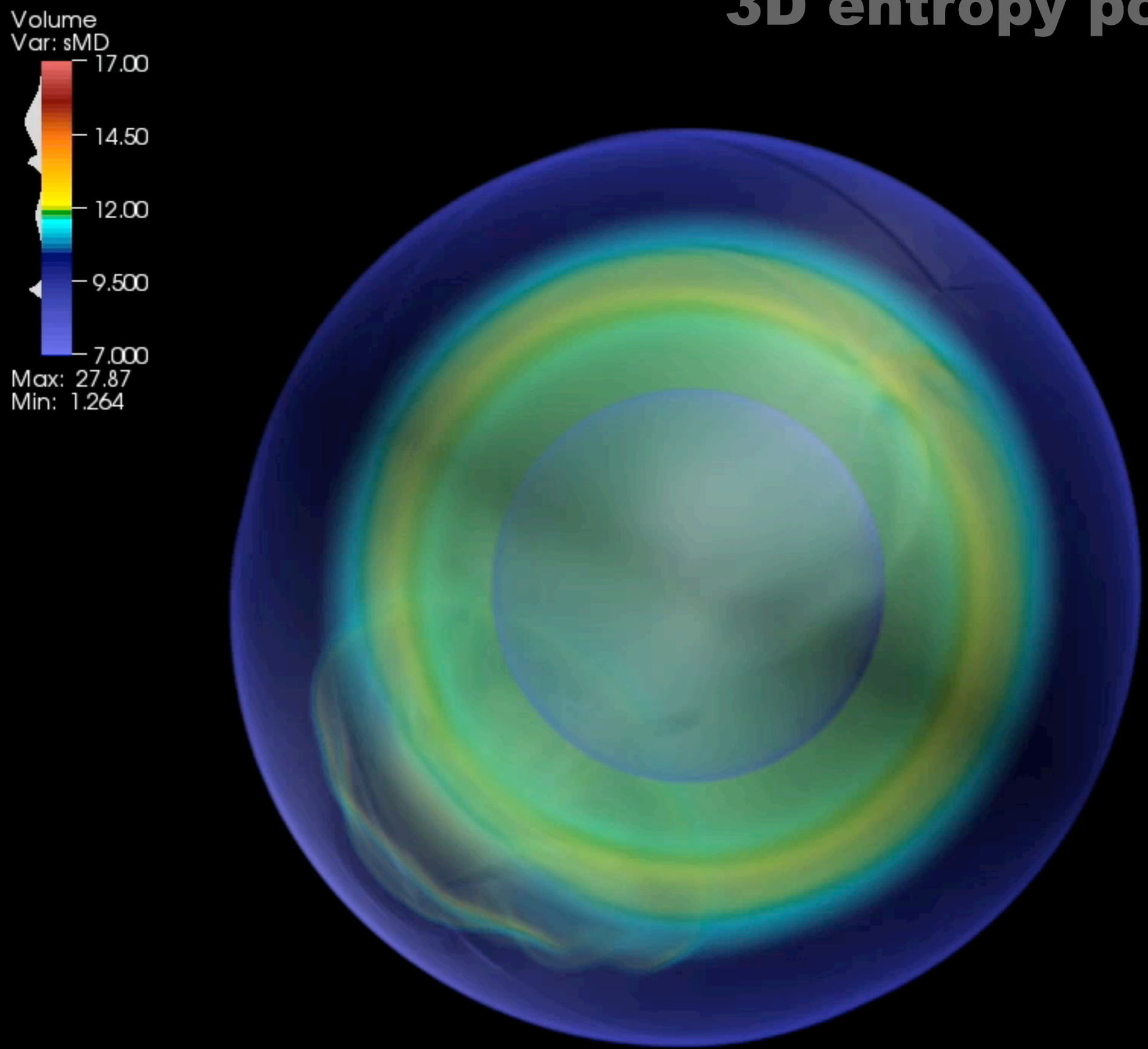
Standing Accretion Shock Instability 3D

Blondin & Mezzacappa
Nature **445**, 58 (2007)
Visualization by Kwan-Liu Ma (UCD)

Standing Accretion Shock Instability 3D



3D entropy post-bounce



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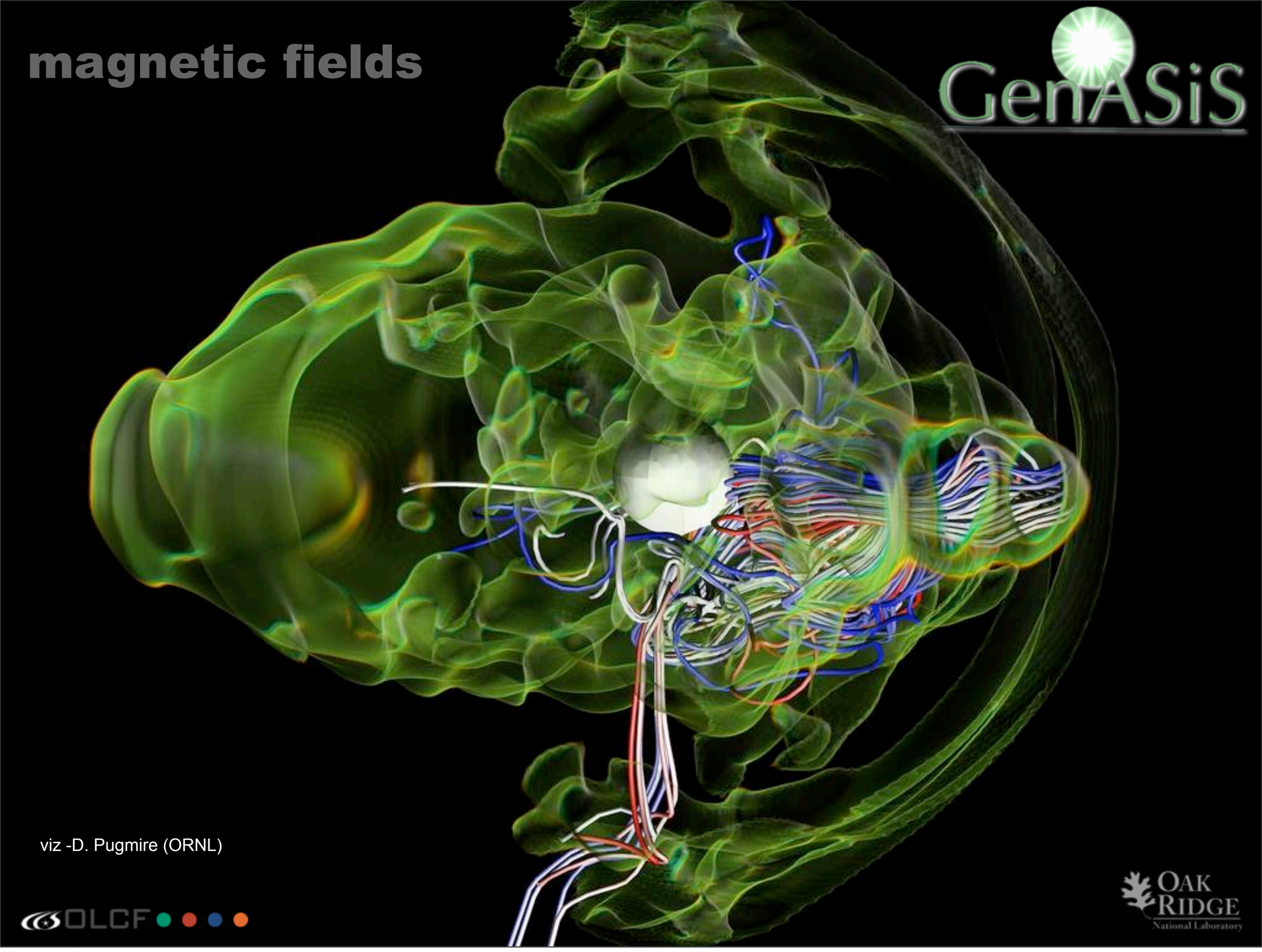
magnetic fields

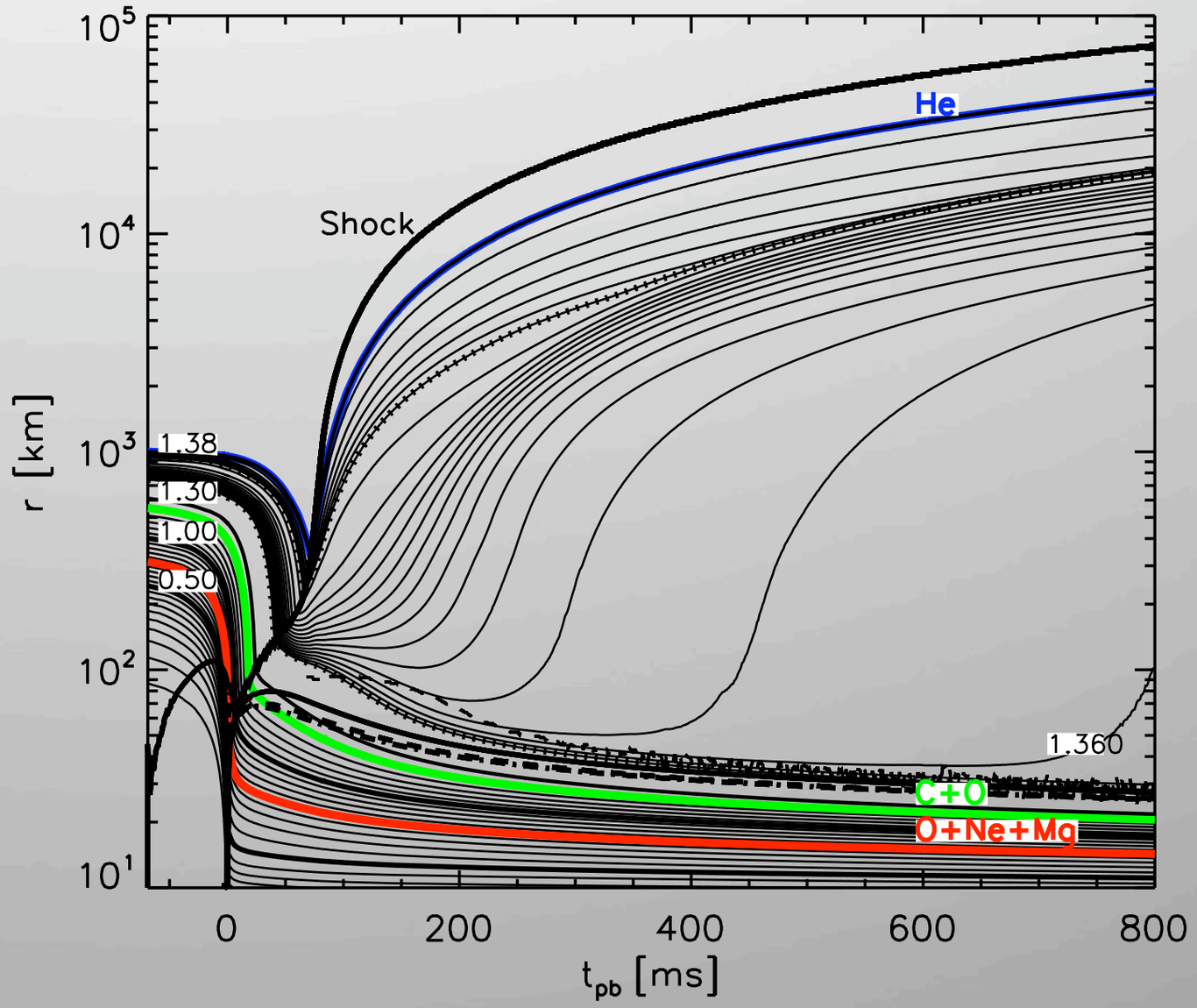


Assumptions

- Limited memory per MPI task will significantly curtail the march of strong scaling we have seen for the past few years.
  - This is regardless of adopted swim lane
- The 10 PF platforms will, in many respects, look more like the 1 EF platform than they do jaguar.
- Storage, both “on-line” and “off-line” will continue to be significantly underfunded relative to the heart of the “big iron.”
  - *In situ* analysis comes to the fore, but I have to be able to “play.”

Composition (XNET)

- Deceptively easy in 1D
- 2- & 3-D?



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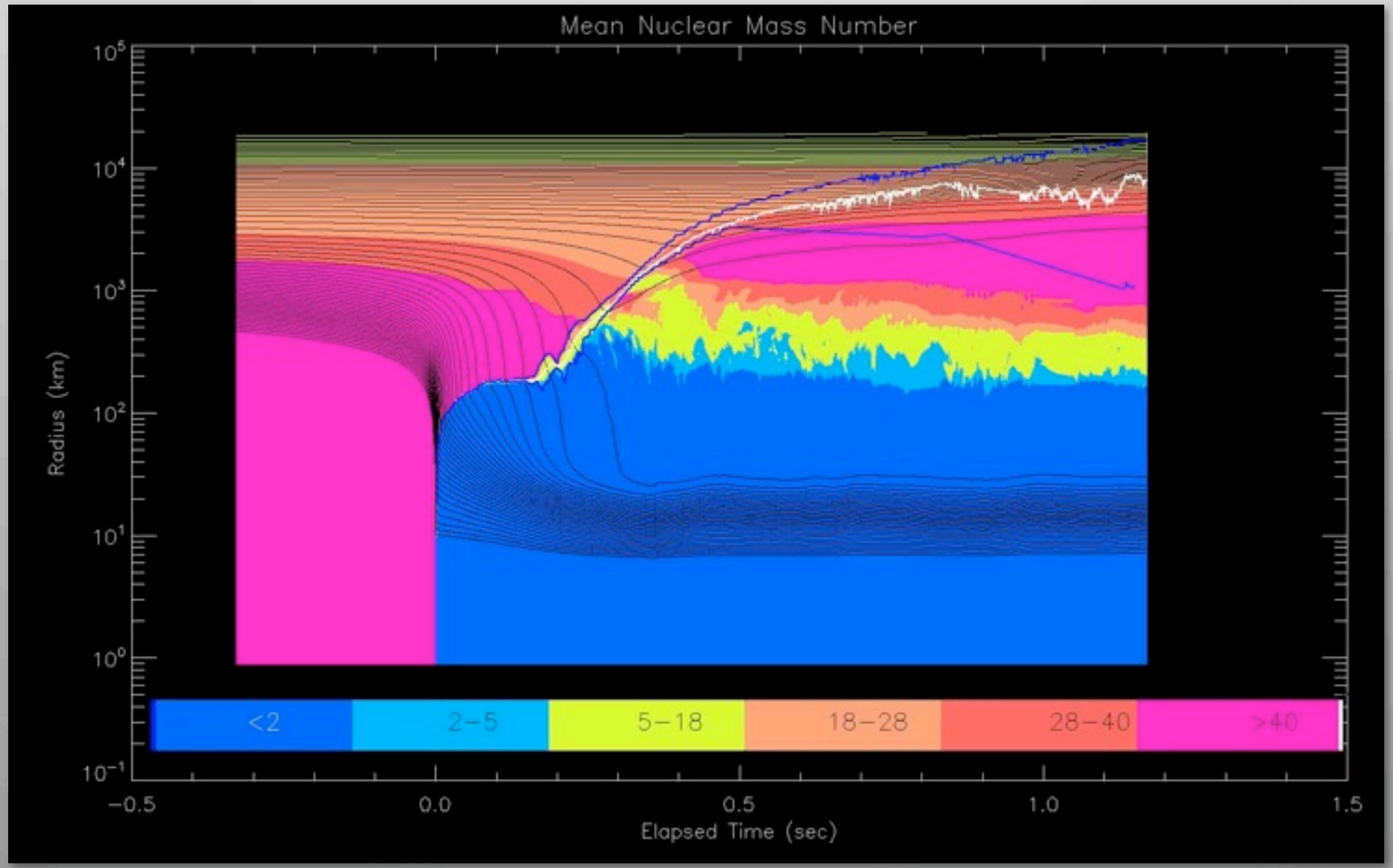
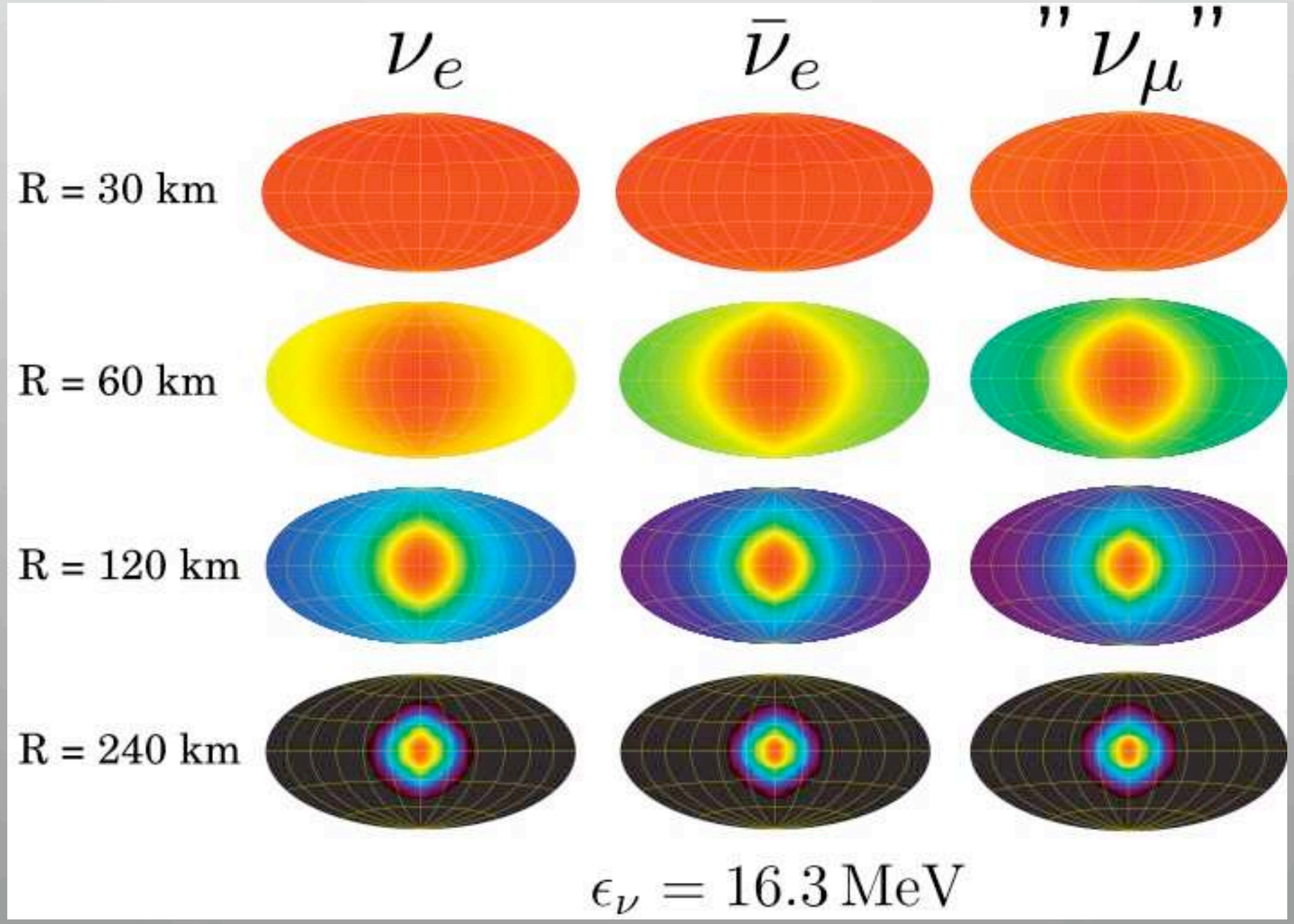
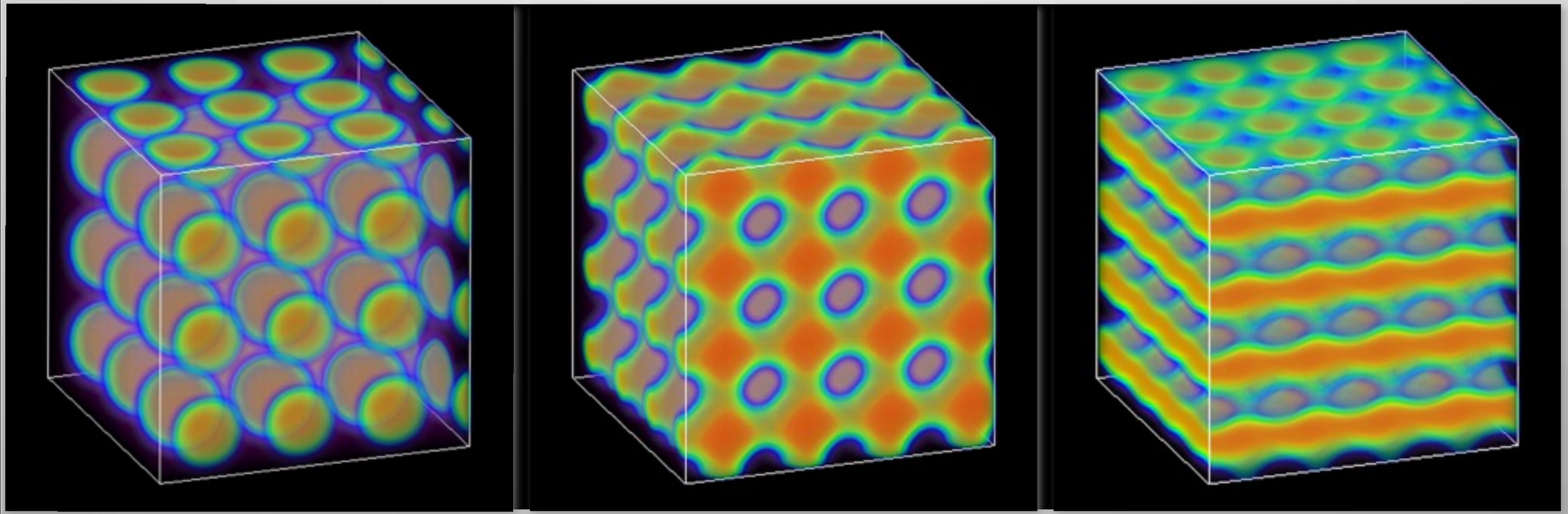


Neutrinos (MGFLD-TRANS)

- Attempt from recent SciDAC contribution of Ott et al.



Microscopic degrees of freedom (EOS)



increasing density

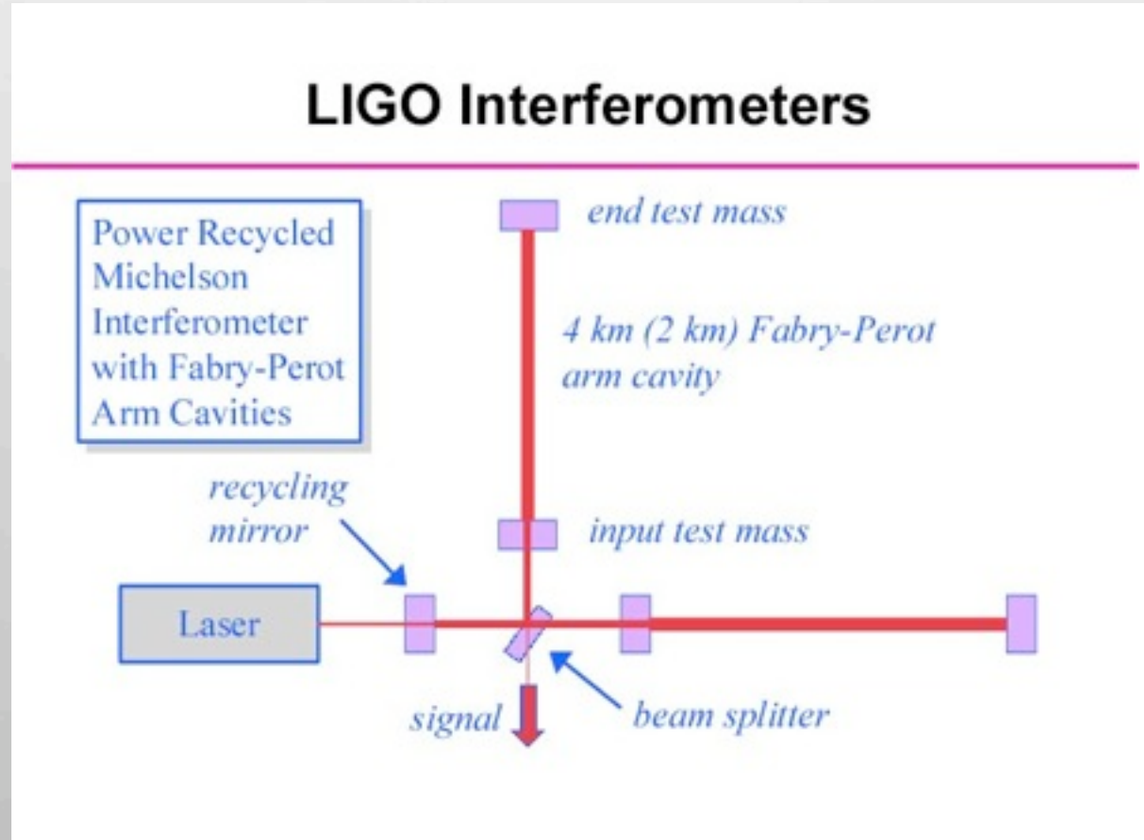
Evolution of dense matter during collapse.
“nuclear pasta”

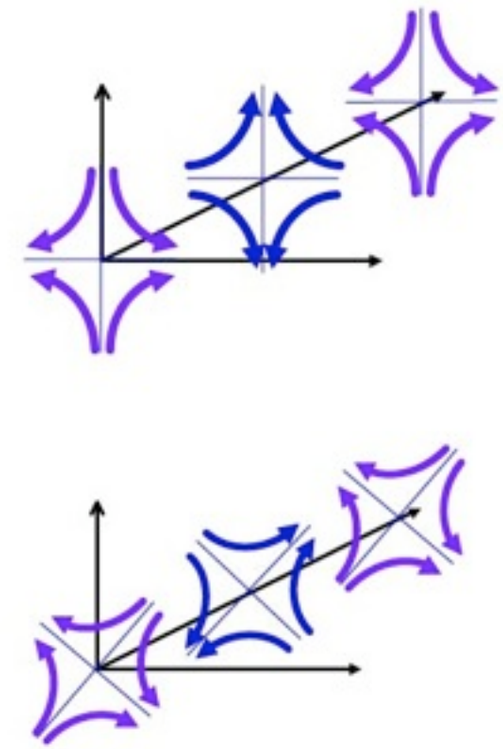
Newton, Stone, and Mezzacappa,
Journ. Phys. Conf. Ser., **46**, 408 (2006)
Viz: Ross Toedte (ORNL)

The Advent of Gravitational Wave Astronomy
Laser Interferometric Gravitational Wave Observatory

LIGO Hanford

LIGO Livingston





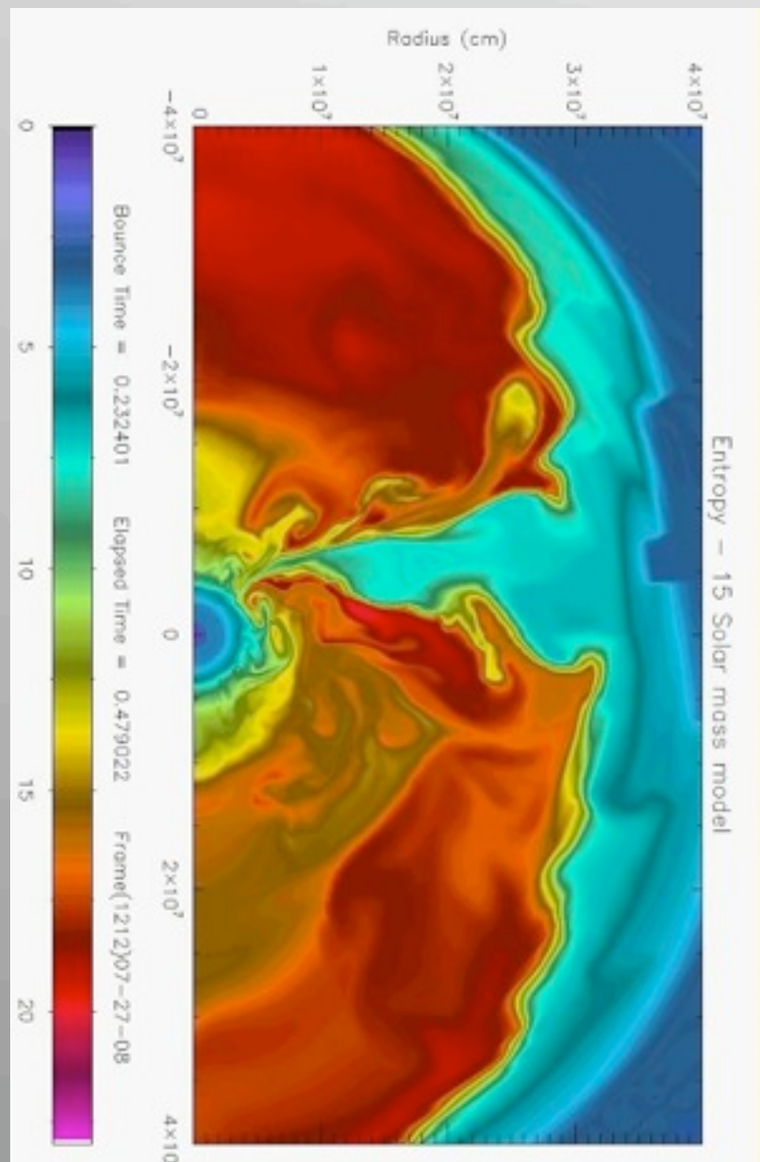
Gravitational waves are quadrupolar. Test masses will move 1 trillionth the width of a human hair.

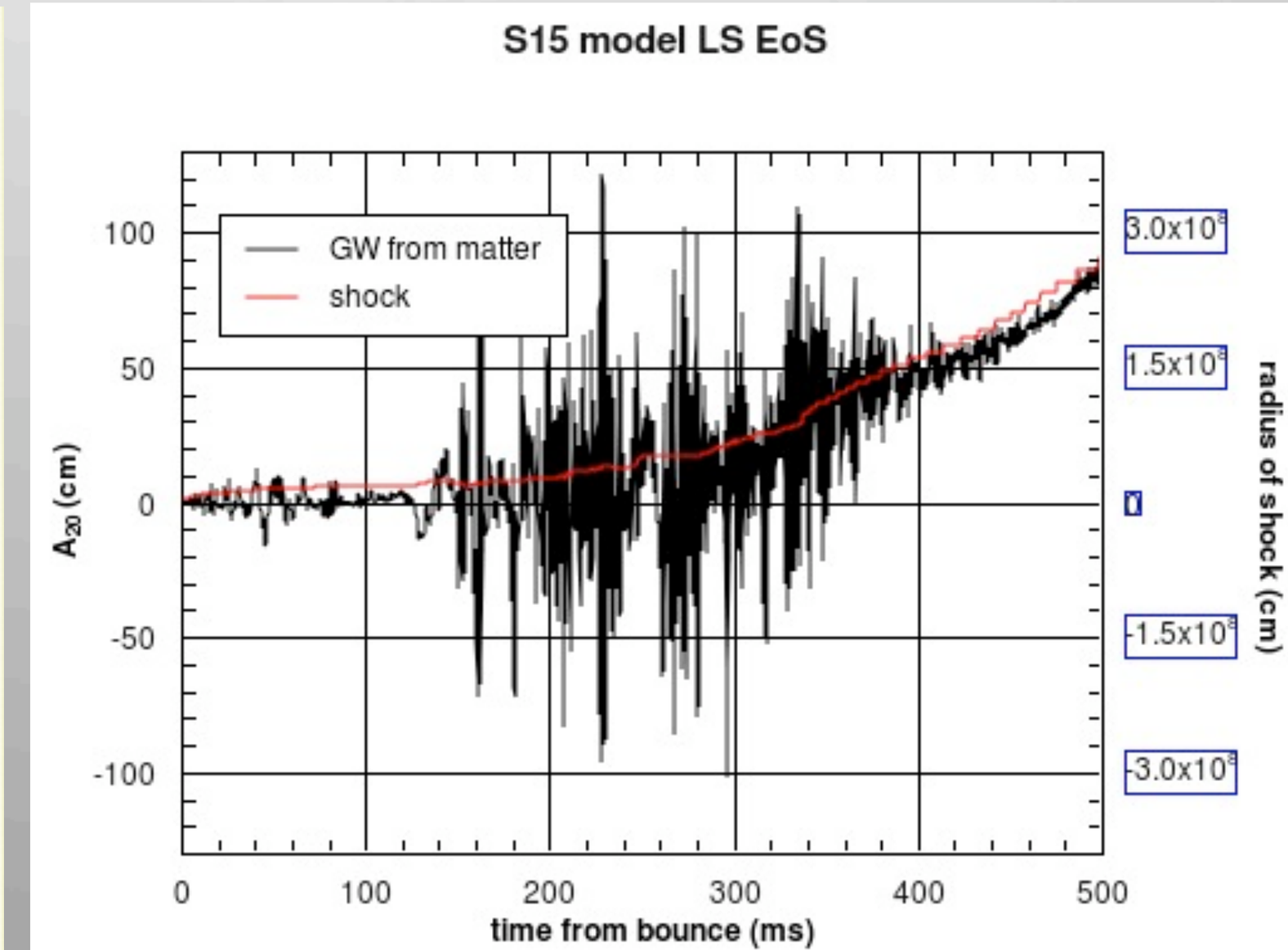
Other Observatories: TAMA, VIRGO, GEO, LISA, …

Sources: Core-Collapse Supernovae, Neutron-Star Mergers, Black Hole Mergers

GW's from matter motion

- High frequency signal from convective motions superposed on SASI 'sloshing'

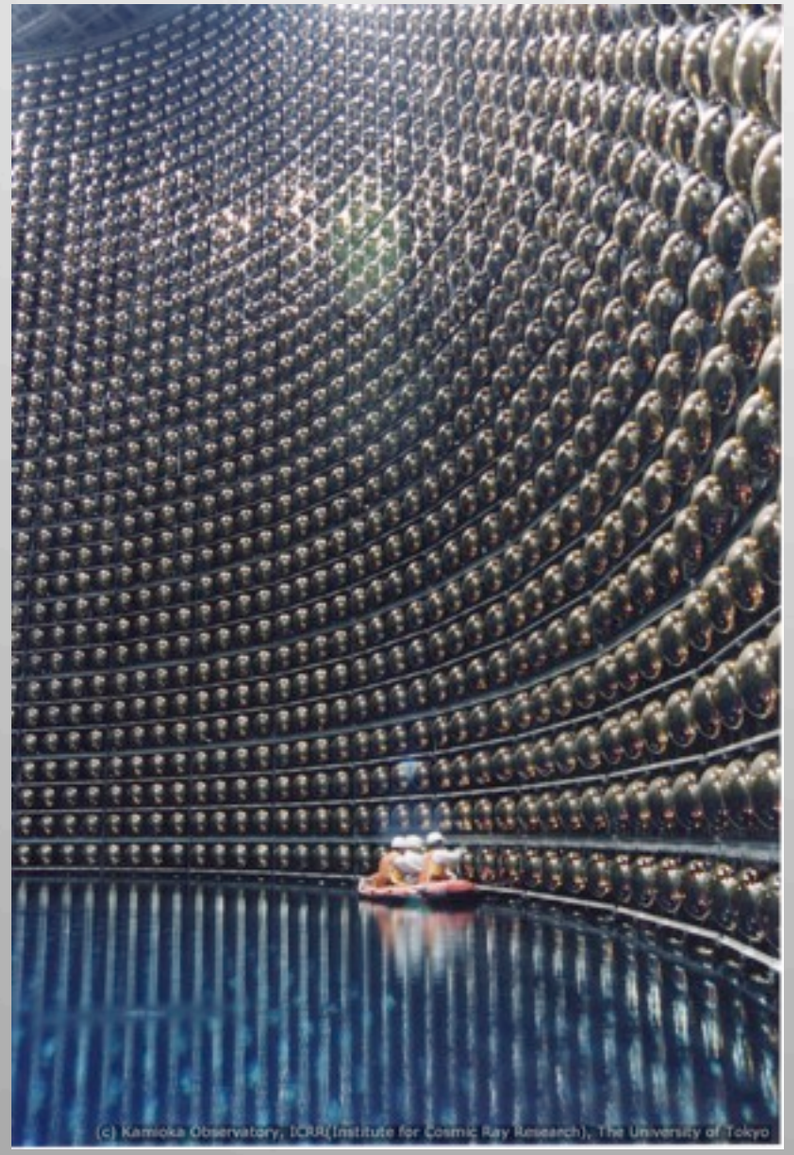




K. N. Yakunin, P. Marronetti, A. Mezzacappa, S. W. Bruenn, C-T. Lee, M. A. Chertkow, W. R. Hix, J. M. Blondin, E. J. Lentz, O. E. B. Messer, and S. Yoshida. Classical and Quantum Gravity **27**, 194005 (2010).

Neutrino “Telescopes”

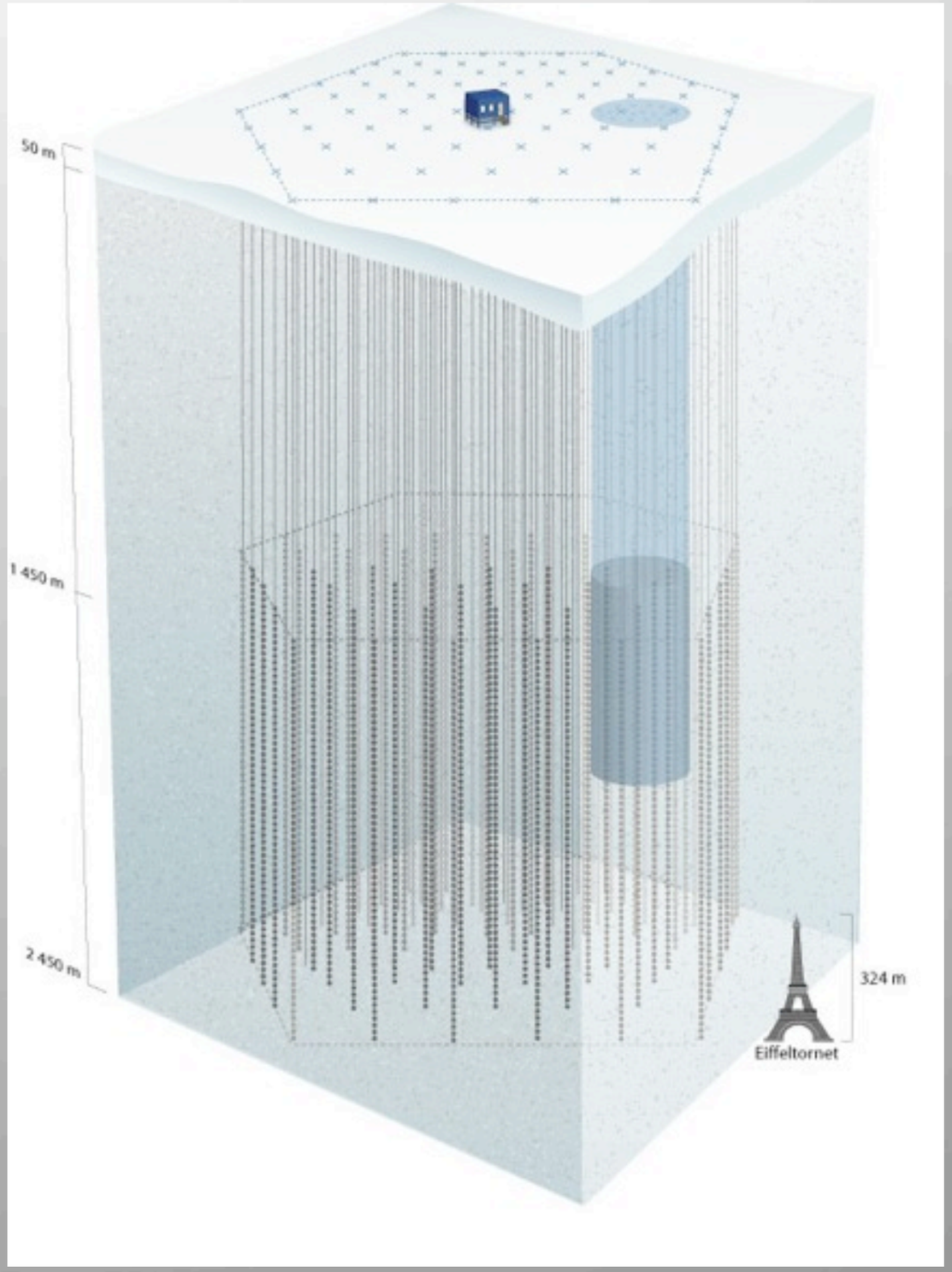
Super-Kamiokande (Kamioka Mine, Japan)



50 ktons water

Neutrino interactions with water/ice produce charged particles that radiate Cerenkov radiation, detected by photomultiplier tubes.

IceCube (South Pole)

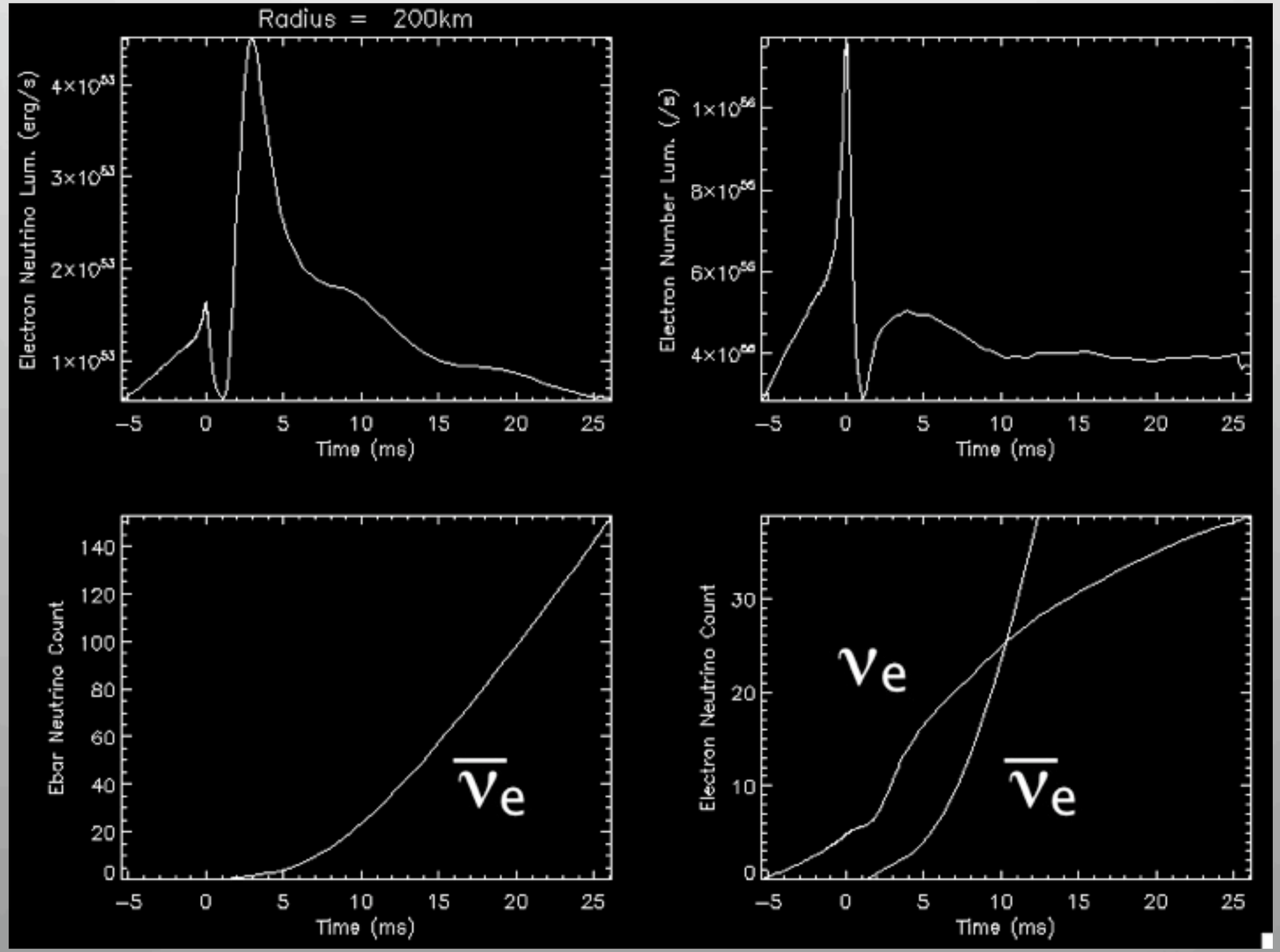


1 billion tons of ice

1 km^3

ν signatures in terrestrial detectors

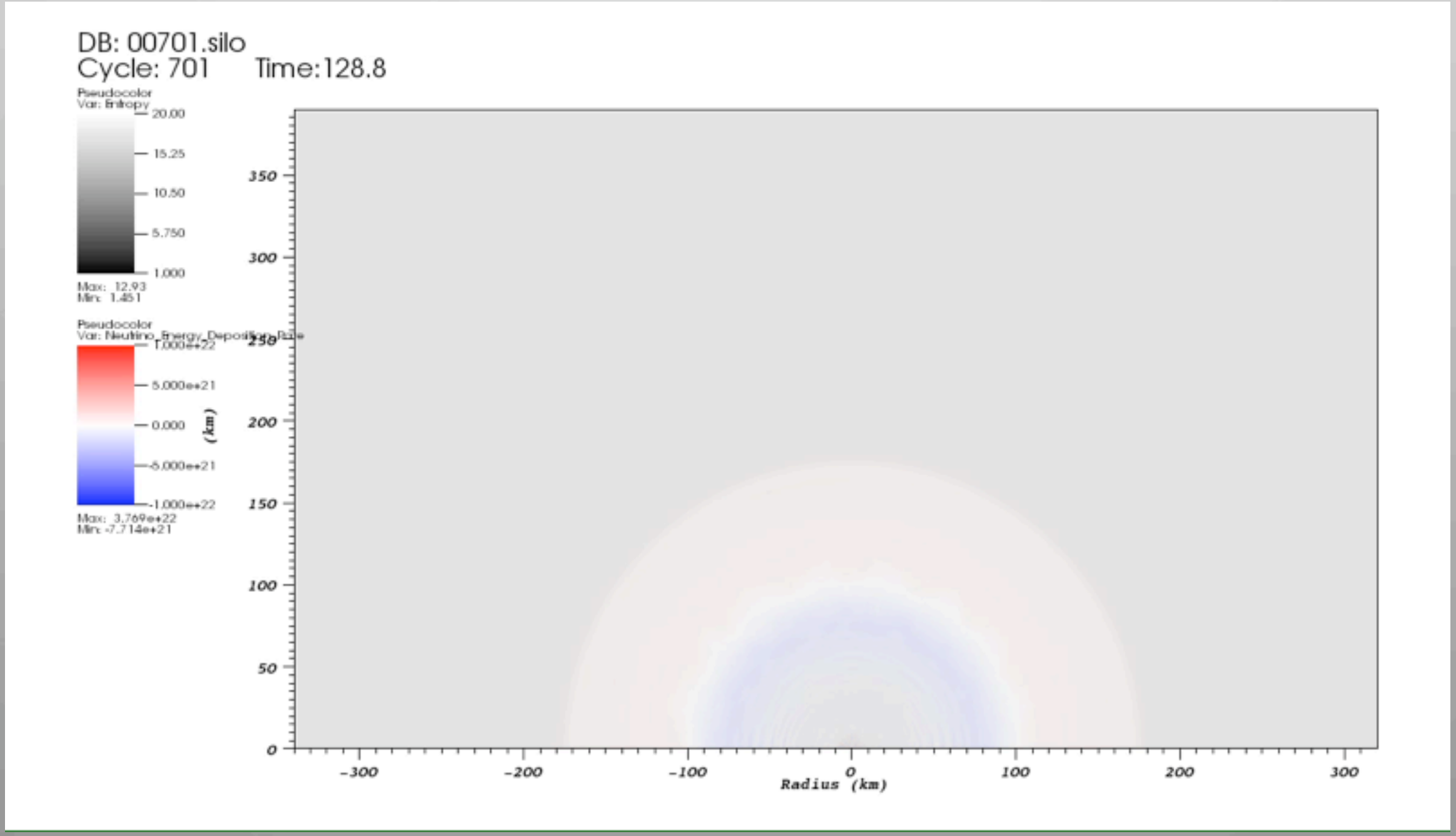
Shock breakout in Super-Kamiokande;15 $M_\odot$ progenitor,10 kpc



...but, what does the “shape” of the flux look like?

It is the totality of the observables, and their interconnections, that holds the most info

- How to quickly "grok" correlations (or lack thereof) between neutrino radiation field, composition, entropy, and matter motion?



Data Volumes

Code	# Variables	Resolution	# Dumps	Total Volume	Runtime	Machine
CHIMERA 1.0	~ 200	576X96X192	3000	~50 TB	~ 3 Months	1 PF
CHIMERA 2.0	~ 350 (expanded nuclear network α to 150-species)	576X96X192	3000	~90 TB	~ 3 Months	20 PF
GenASiS	~5000	512X512X512	3000	~30 PB	?	1 EF

- GenASiS data get large quickly as we move from moments of the distribution function to the distribution function itself
- Otherwise, data sizes increase modestly
  - The exascale machine will be a “strong scaling” platform (relative dearth of memory)

bellerophon - “one stop shopping”

Bellerophon

Regression Test Explorer | SVN Statistics On-Demand | Browse Chimera Trac Repository | View Chimera Trac Wiki

bellerophon

Welcome to Bellerophon

Select a feature from the top row to begin. Enabling popup wind

Regression Test Explorer

Revision: 261

Index: 216

Date: 04/28/10

Owner: -

Platform: -
Jaguar XT4
Jaguar XT5
Smoky
Genasis
Kraken
Newton

Reload Test Table

Explore Test Data

Repo Heatmap

Development Statistics for /trunk/RadHyd3D

Start Date: 2010-03-27
End Date: 2010-04-26

This chart is an applet, it shows all files in a hierarchic
The bigger the file, the bigger the box and the colour

[root]
Ancillary_Files_3D
Array_Dimensions
Convect
Data3_Files
E_Advection
Edit
Edit_Global
Edit_HDF
Edit_MD
Equation_of_State
Execute
FullNet
GR
Hydro_EVH1
Lapack
MGFLD
Makefiles
Nuclear
Particle
Plot
RadHyd95
Restart

This page uses JTreeMap

Bellerophon

Regression Test Explorer | SVN Statistics On-Demand | Browse Chimera Trac Repository | View Chimera Trac Wiki | Log Out and Quit Bellerophon

SVN statistics generation is complete!

View Generated SVN Statistics

Generate SVN Statistics for Another Revision

Applet net.sf.jtreemap.swing.example.JTreeMapAppletExample started

272	272	04/17/10	Bellerophon	Jaguar XT4	Execution Success
271	266	04/12/10	Bellerophon	Jaguar XT4	Execution Success
270	271	04/16/10	Bellerophon	Jaguar XT4	Execution Success
269	268	04/14/10	Bellerophon	Jaguar XT5	Execution Success
268	272	04/17/10	Bellerophon	Jaguar XT5	Execution Success
267	266	04/11/10	Bellerophon	Jaguar XT5	Execution Success
266	268	04/13/10	Bellerophon	Jaguar XT4	Execution Success
265	270	04/15/10	Bellerophon	Jaguar XT5	Execution Success
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263	266	04/09/10	Bellerophon	Jaguar XT4	Execution Success
262	266	04/07/10	Bellerophon	Jaguar XT4	Execution Success
261	266	04/08/10	Bellerophon	Jaguar XT4	Execution Success
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258	266	04/05/10	Bellerophon	Smoky	Execution Failure
257	266	04/06/10	Bellerophon	Jaguar XT4	Execution Success
256	266	04/07/10	Bellerophon	Jaguar XT5	Execution Success
255	266	04/05/10	Bellerophon	Jaguar XT4	Execution Success
254	266	04/05/10	Bellerophon	Jaguar XT5	Execution Success
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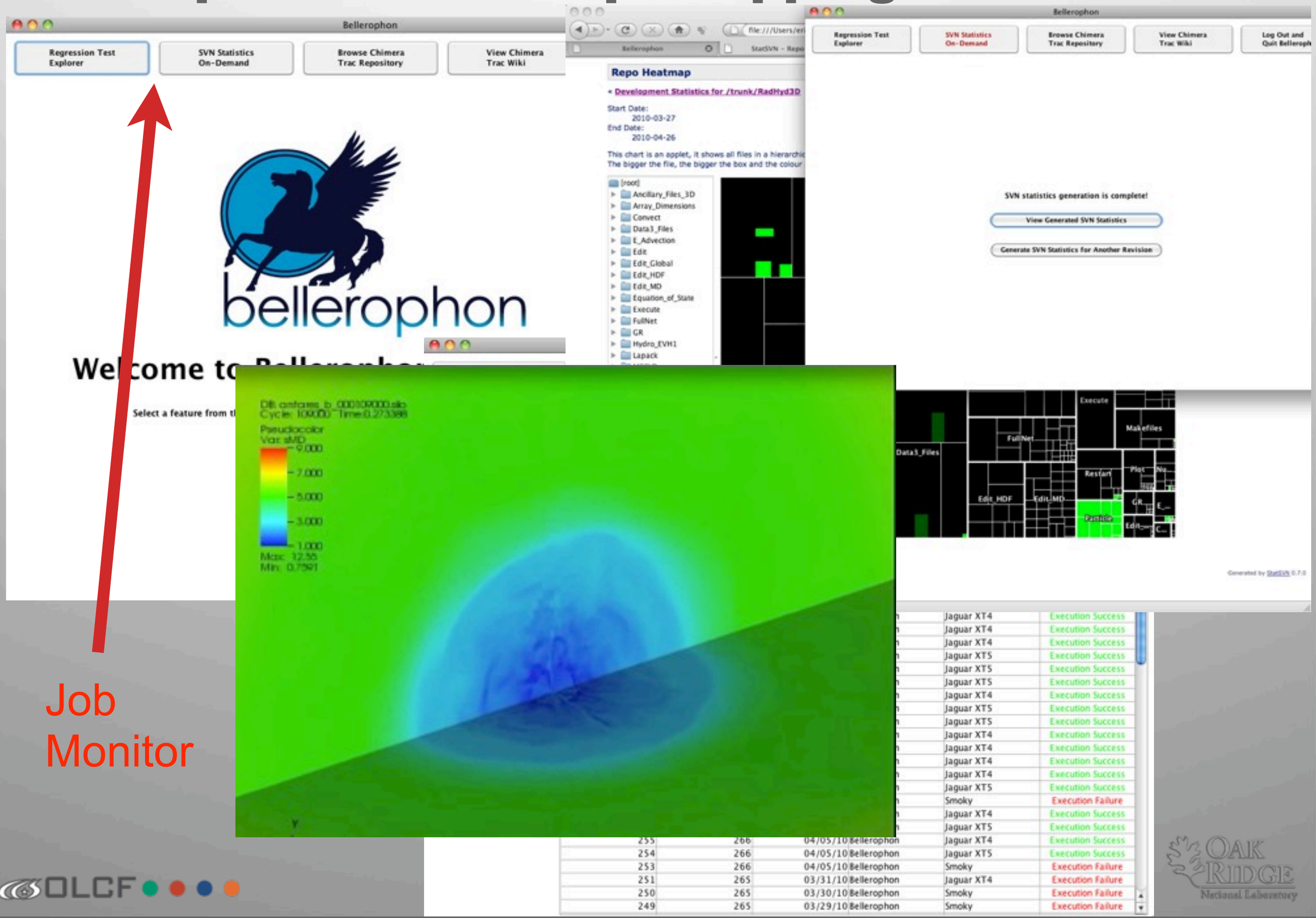
bellerophon - “one stop shopping”



Job Monitor

Summary

- From 180 to >4500 DOF per grid point in CHIMERA/GenASiS simulations in roughly 3 "groups"
  - hydro scalars
  - neutrino distribution functions
  - nuclear species
- Correlations important and hard to see
- Neutrino field and nuclear composition "solutions" are currently lacking
- MHD coming online now => magnetic field visualization
- Job monitoring viz needs to provide as much diagnostic power as possible
- Robust, versatile scripting/evaluation syntax needed
  - One of the only places a lack of expressiveness is limiting current work