Max-Planck-Institut für Astrophysik

THE NEUTRINO TURNS 60

TUM LMU Excellence Cluster Universe

INT-16-61W: "Flavor Observations with Supernova Neutrinos"

INT @ UW, Seattle, WA, August 15-19, 2016

Diagnosing Supernova Dynamics and Neutron-Star Properties by Neutrinos

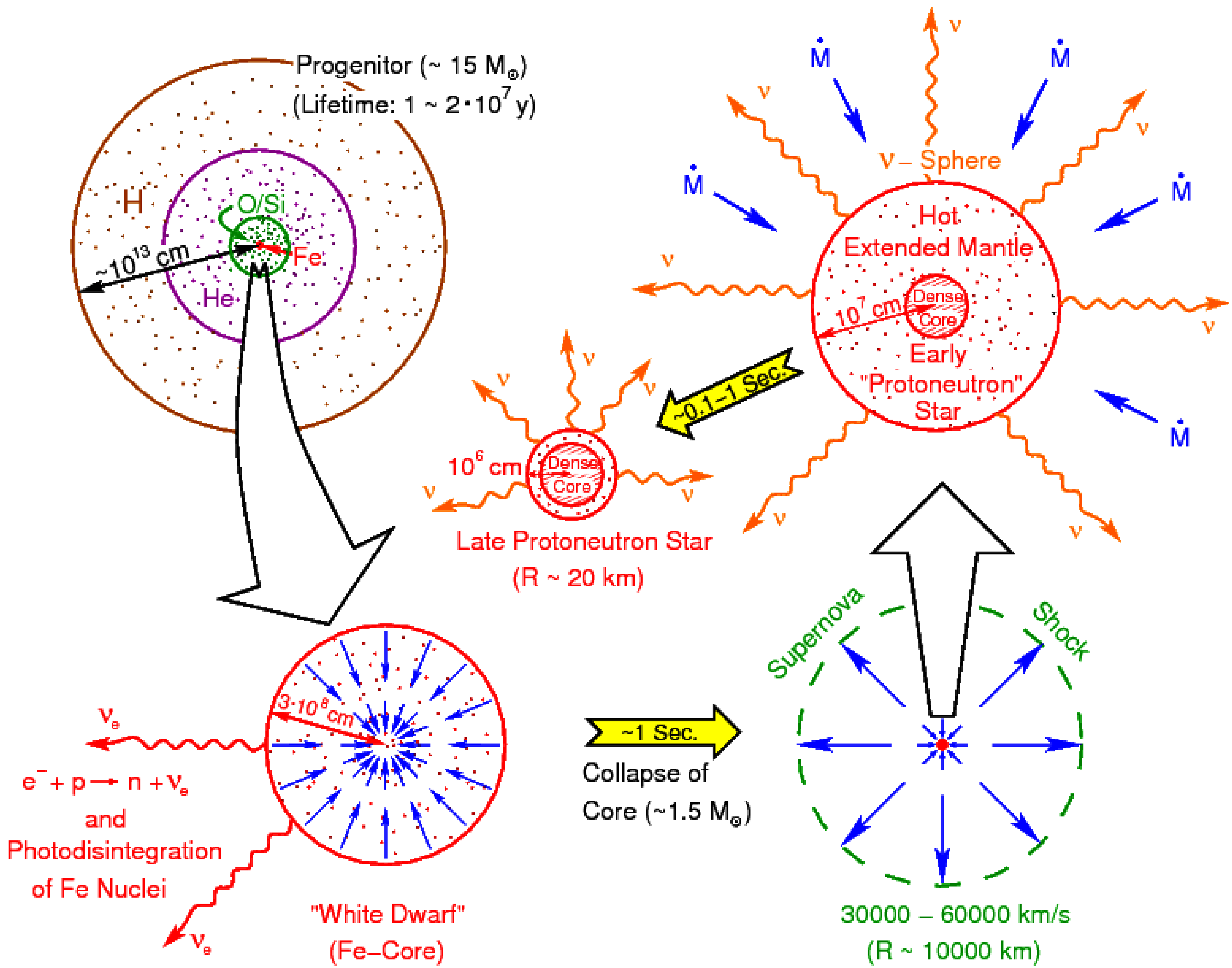
Hans-Thomas Janka

(Max Planck Institute for Astrophysics Garching)

European Research Council
Established by the European Commission
Supporting top researchers from anywhere in the world

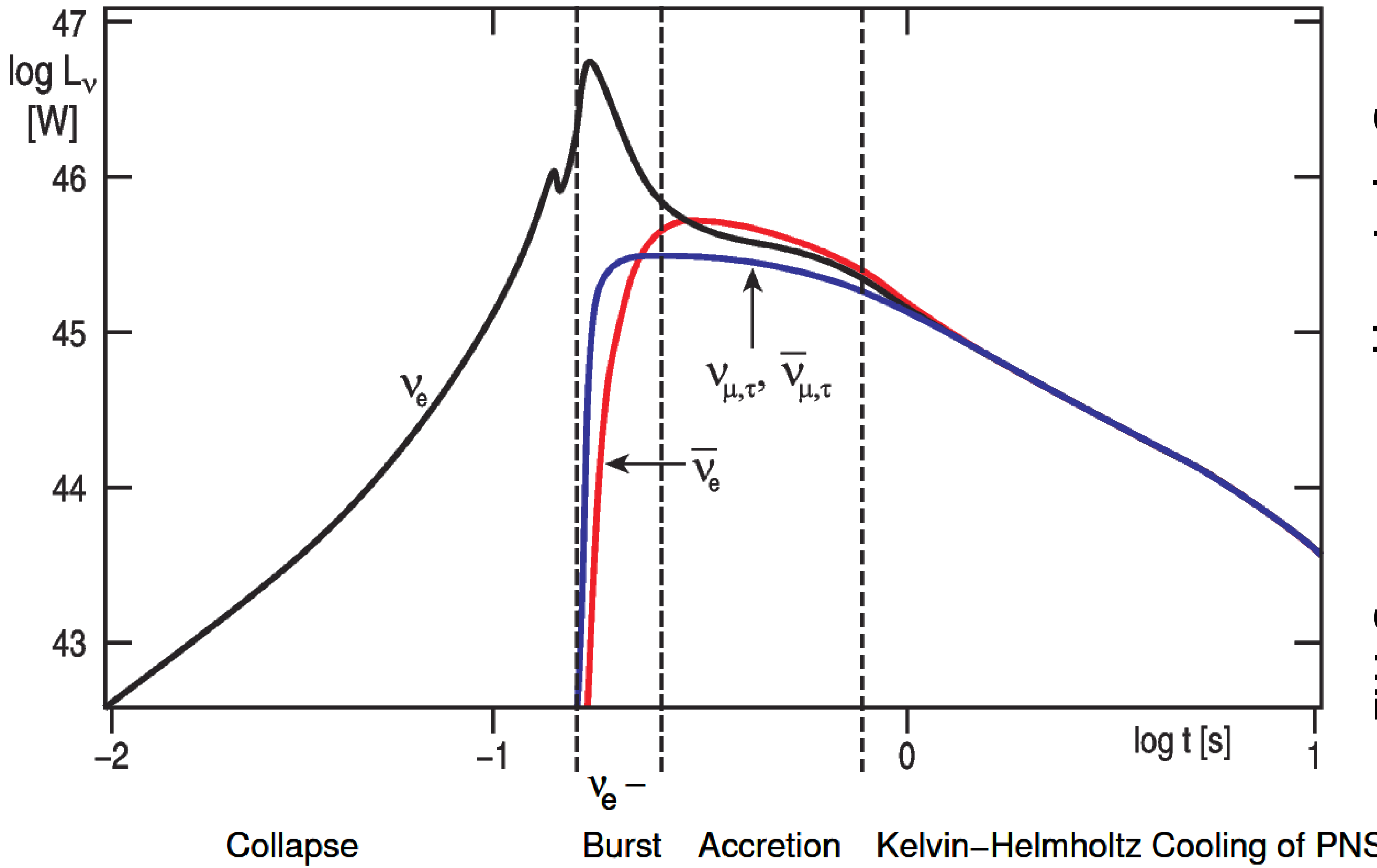
COCO2CASA

Stellar Collapse and Supernova Stages



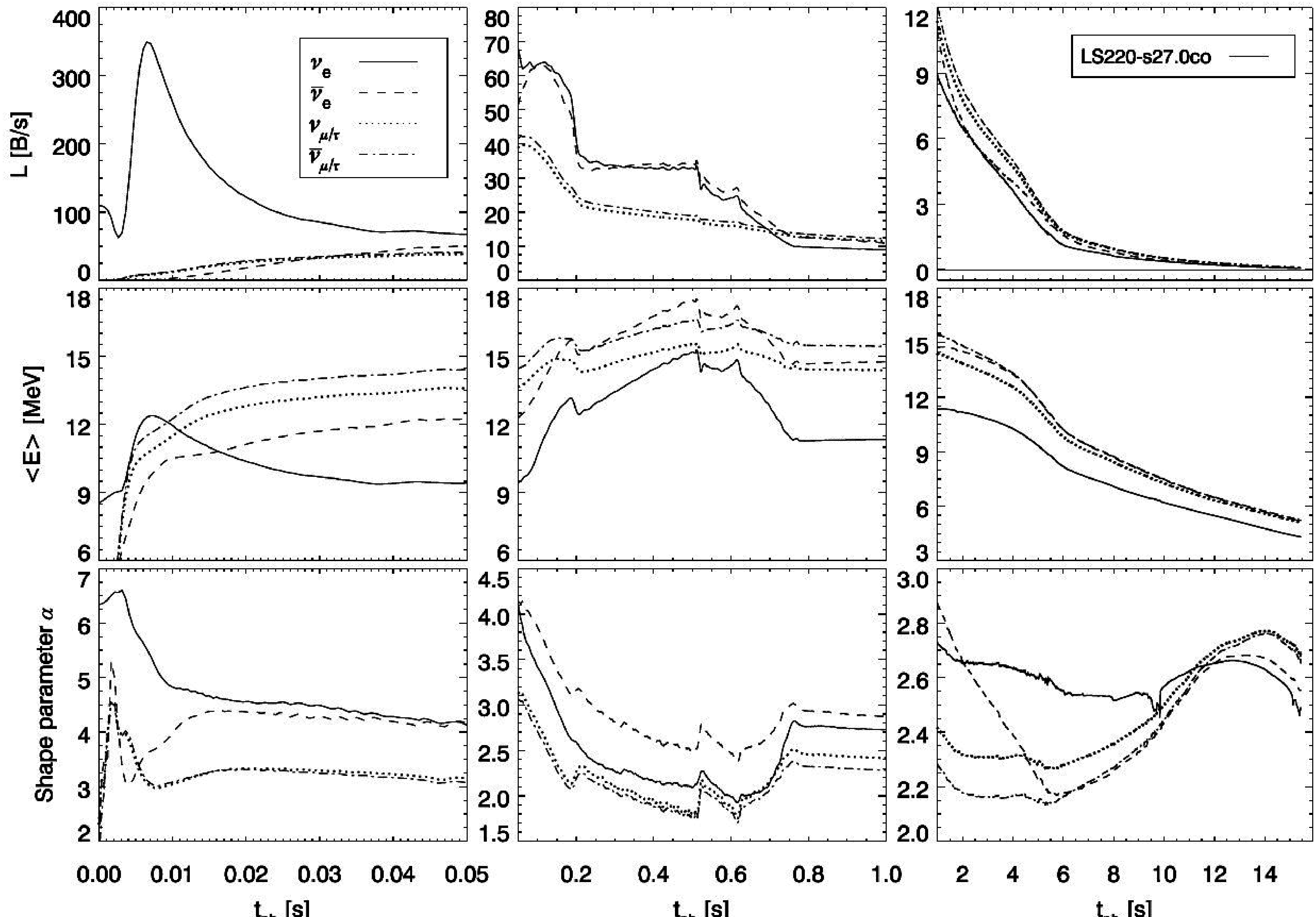
adapted from A. Burrows (1990)

Neutrino Emission Phases



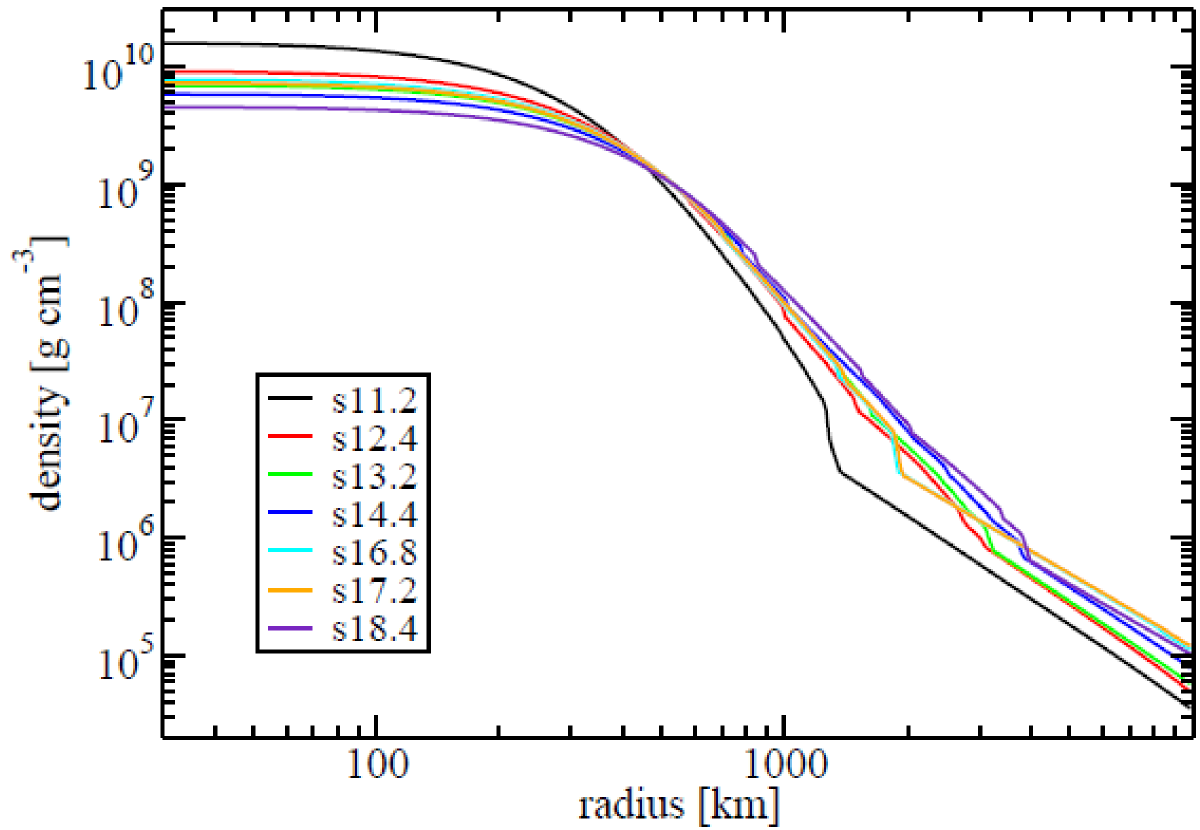
THJ, Supernovae und kosmische Gammablitze, Springer Spektrum (2011)

Neutrino Emission Phases: Simulation



Mirizzi, Tamborra, THJ, et al., La Rivista del Nuovo Cimento, 39, (2016) 1

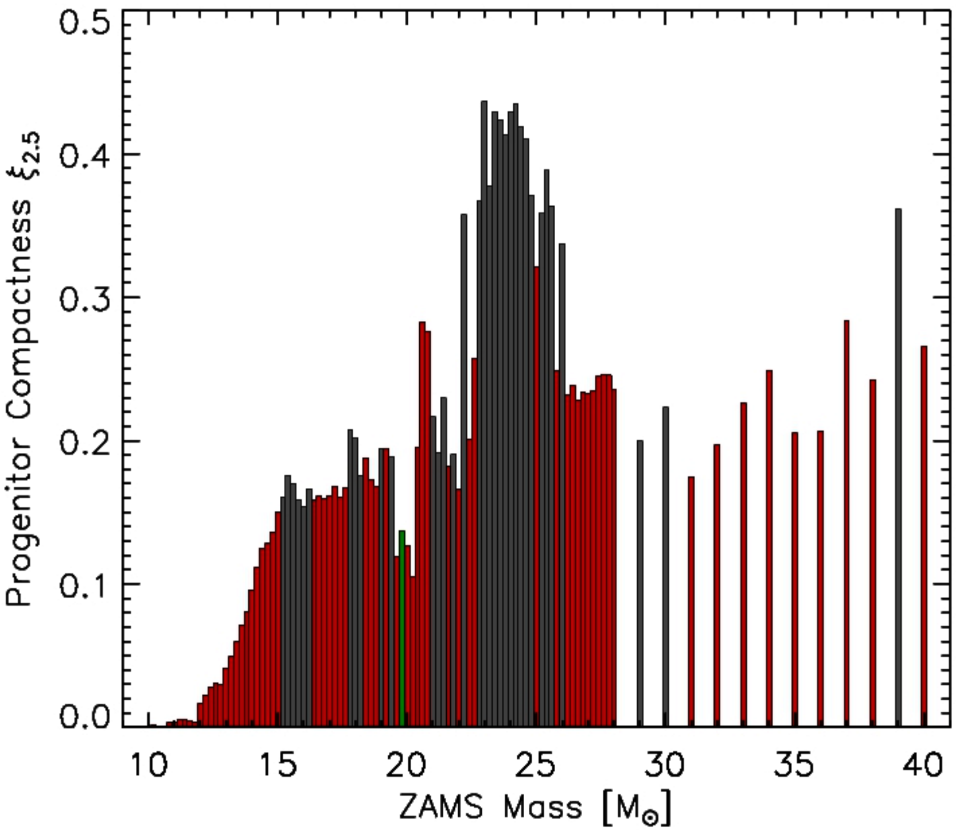
Progenitor Stars: Density Profiles



Progenitor models at onset of stellar core collapse:
Woosley, Heger & Weaver, RMP (2002)

Stellar Compactness and Explosion

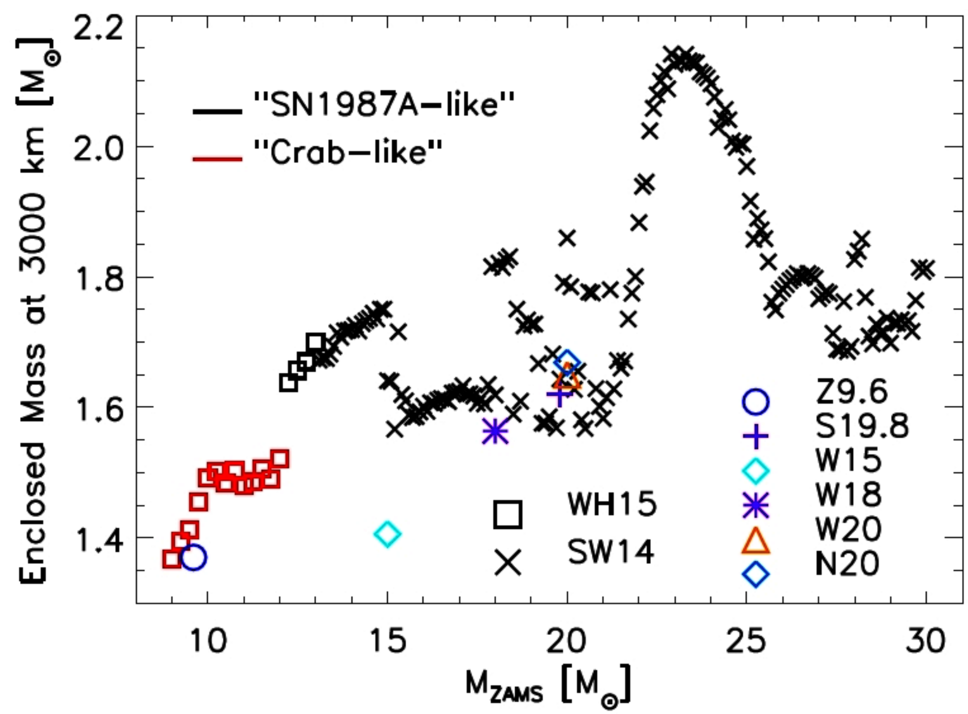
Core compactness can be nonmonotonic function of ZAMS mass



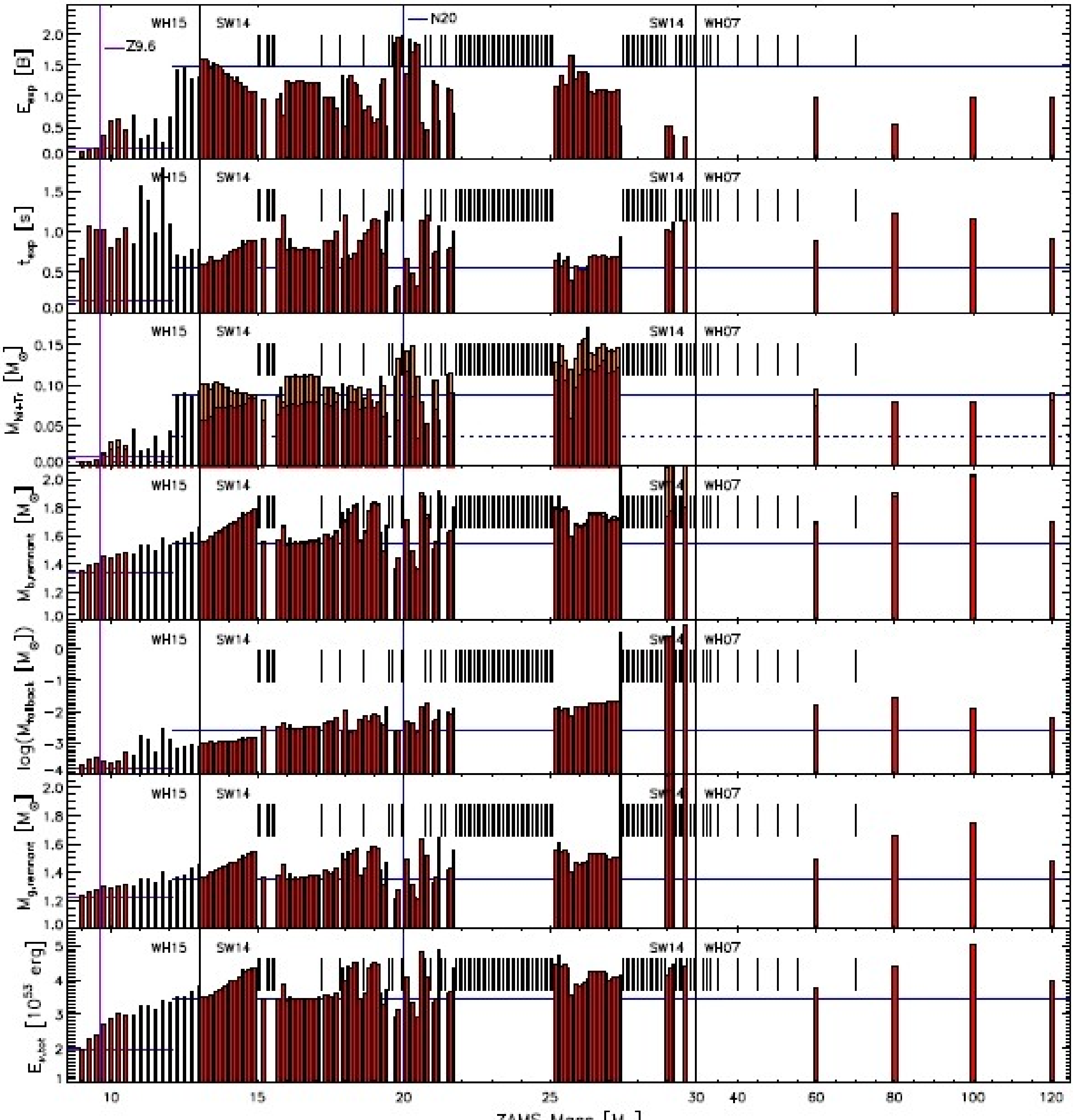
$$\xi_{2.5} \equiv \frac{M/M_\odot}{R(M)/1000\,\mathrm{km}}, \quad \text{mass } M = 2.5\ M_\odot$$

O'Connor & Ott, ApJ 730:70 (2011)

Progenitor models:
Woosley et al. (RMP 2002), Sukhbold & Woosley (2014), Woosley & Heger (2015)



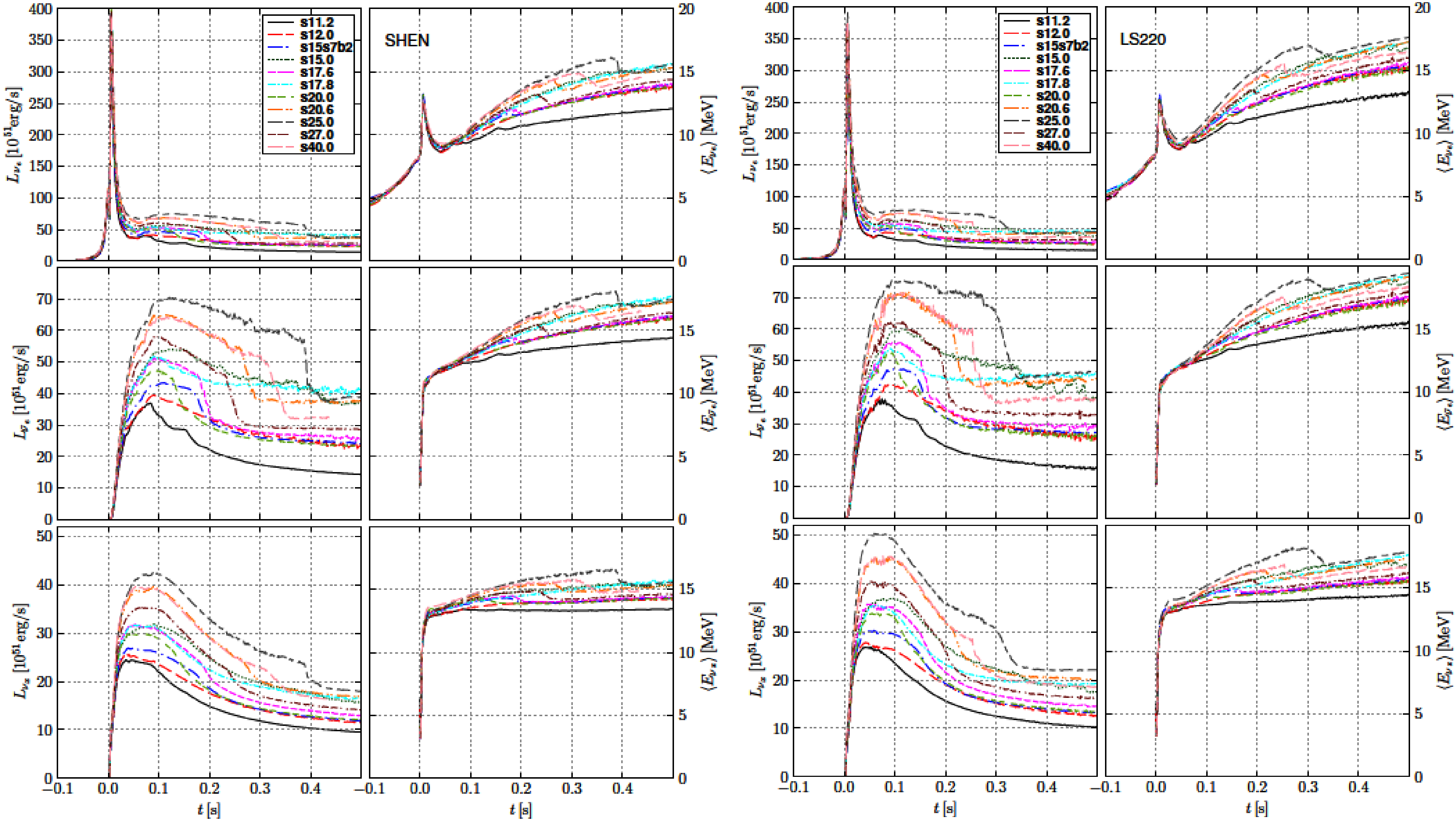
(Ugliano et al., ApJ 757 (2012) 69;
Ertl et al., ApJ 818 (2016) 124;
Sukhbold, Ertl et al., ApJ 821 (2016) 38)



(Sukhbold, Ertl, Woosley, Brown, and Janka, arXiv:1510.04643)

Neutrino Signal Dependence on Progenitor and EOS

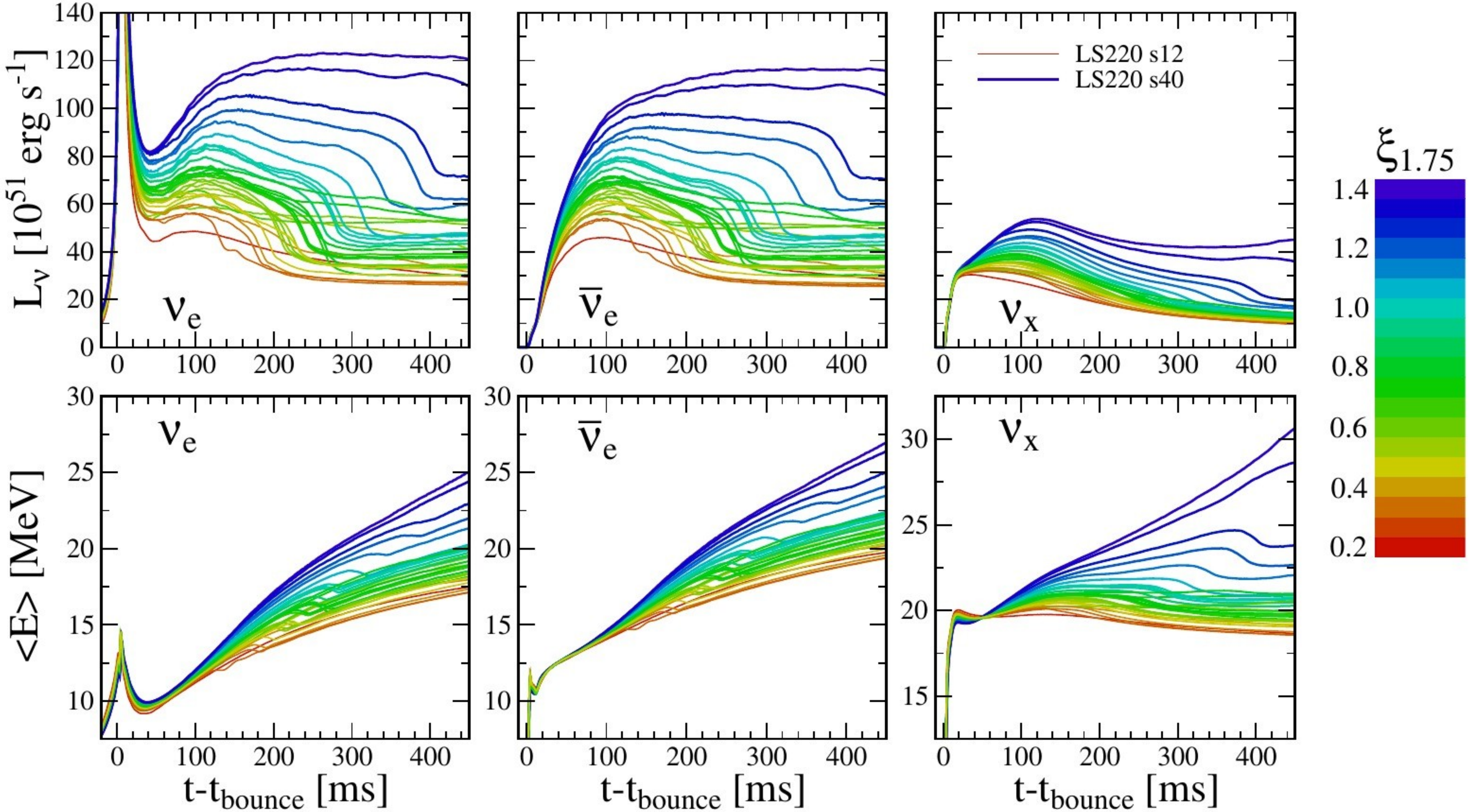
Pre-explosion accretion phase



Janka et al., PTEP, Vol. 2012, id.01A309; L. Hüdepohl, PhD Thesis, TUM (2013)

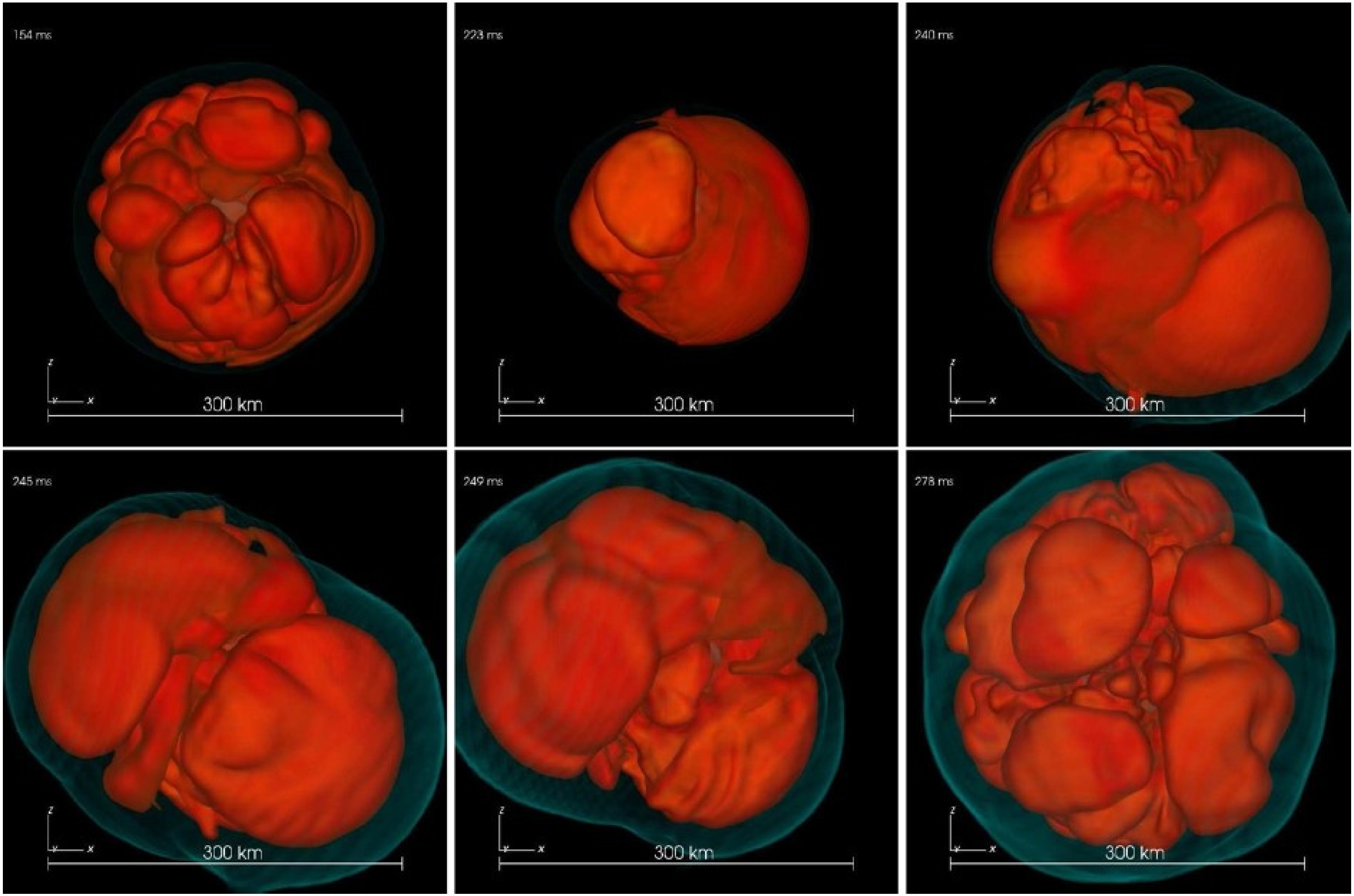
Neutrino Signal Dependence on Progenitor and EOS

Progenitor compactness can be used as ordering parameter



O'Connor & Ott, ApJ 762 (2013) 126

SASI in the Postshock Accretion Layer



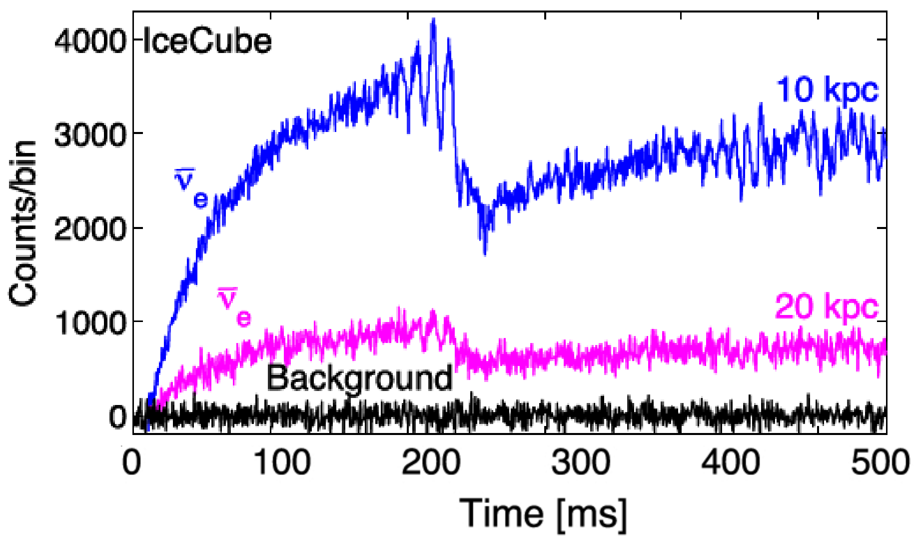
27 M_{sun} progenitor (WHW 2002)

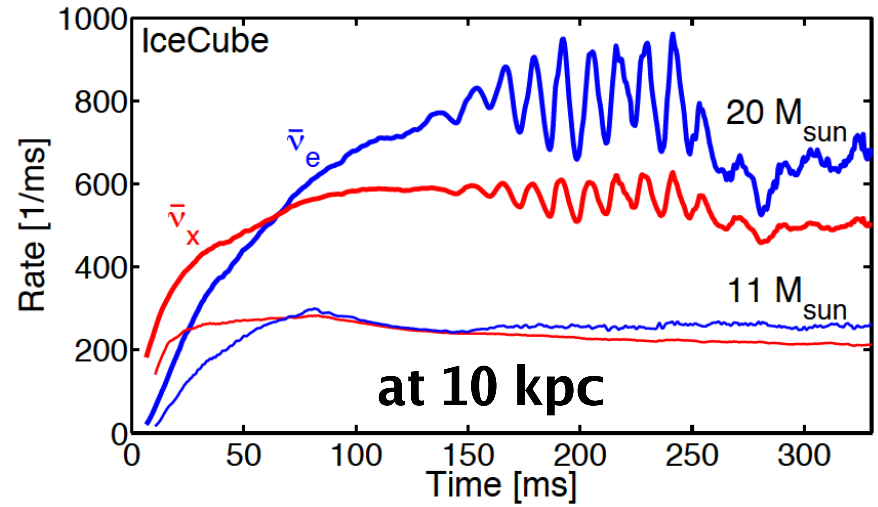
F. Hanke et al., ApJ 770 (2013) 66

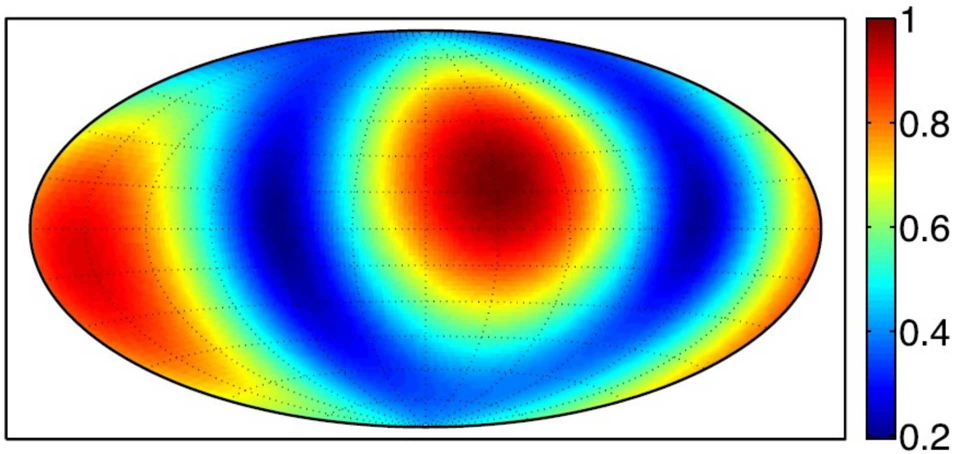
3D Core-Collapse Models: Neutrino Signals

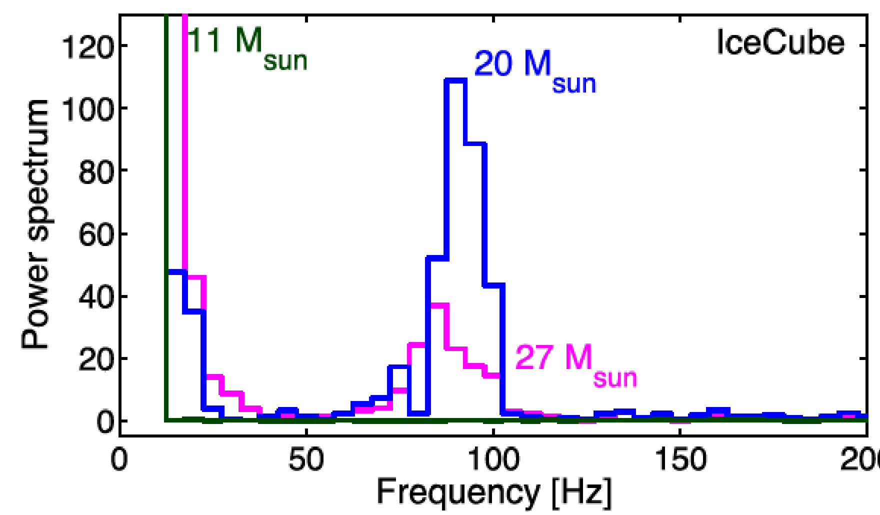
11.2, 20, 27 M_{sun} progenitors (WHW 2002)

SASI produces modulations of neutrino emission and gravitational-wave signal.





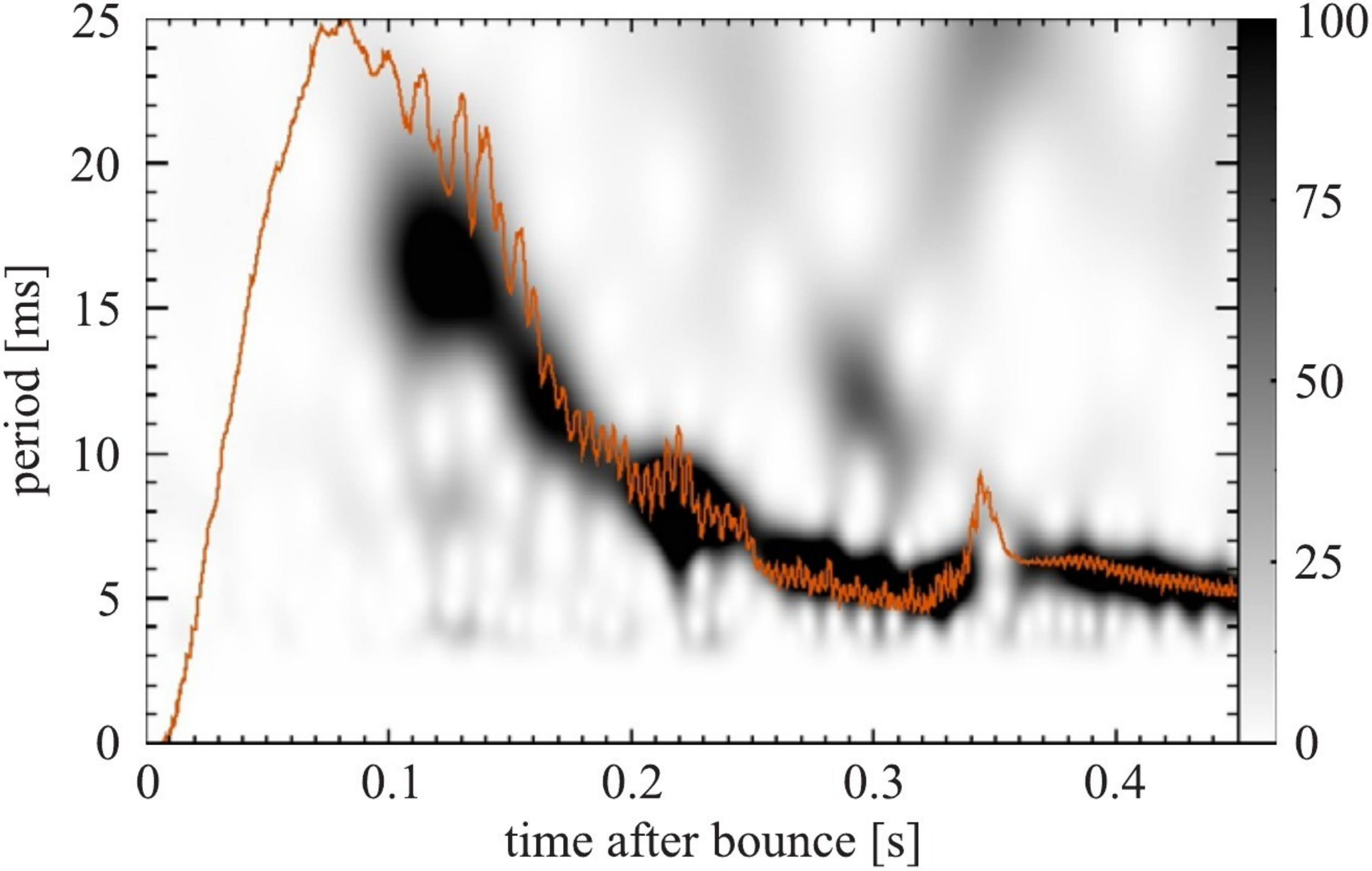




Tamborra et al., PRL 111, 121104 (2013); PRD 90, 045032 (2014)

$$f_{\rm SASI}^{-1} \sim \int_{R_{\rm NS}}^{R_{\rm S}} \frac{dr}{|v|} + \int_{R_{\rm NS}}^{R_{\rm S}} \frac{dr}{c_{\rm S} - |v|}$$

SASI Period Measures Shock Radius Evolution

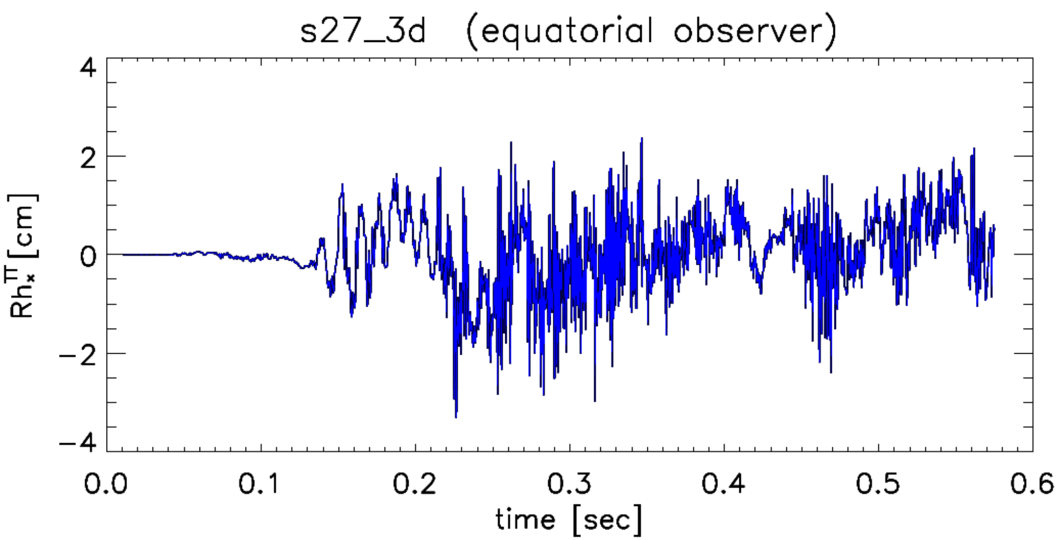


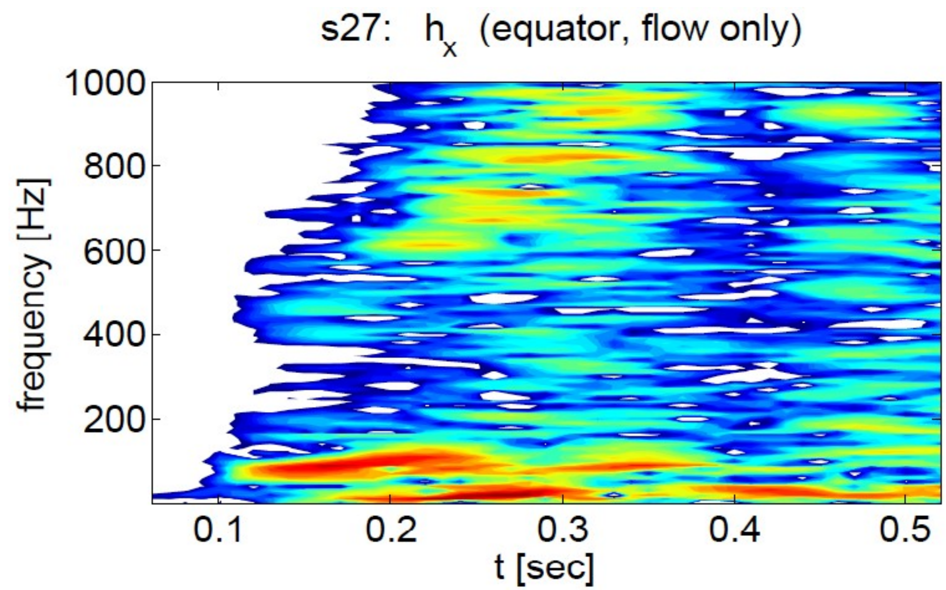
Müller & THJ, ApJ 788 (2014) 82

$$T_{\rm SASI} = 19\,{\rm ms}\left(\frac{r_{\rm sh}}{100\,{\rm km}}\right)^{3/2}\ln\left(\frac{r_{\rm sh}}{r_{\rm PNS}}\right)$$

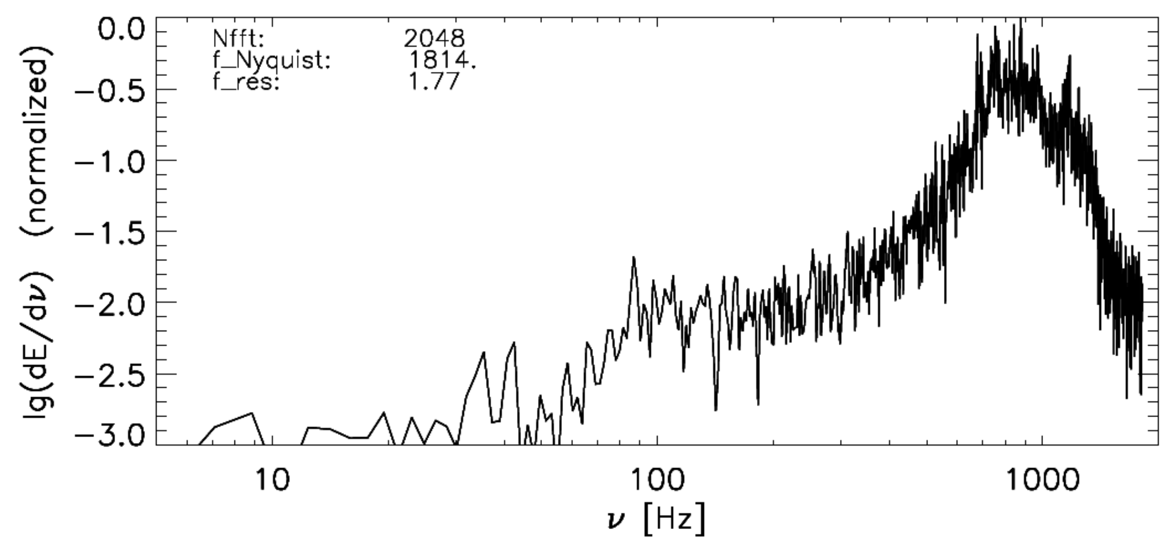
3D Core-Collapse Models: Gravitational Waves

27 M_{sun} progenitor (WHW 2002)





Preliminary analysis by E. Müller of 27 M_{sun} 3D SN simulation by F. Hanke et al., ApJ 770 (2013) 66; Andresen et al., arXiv



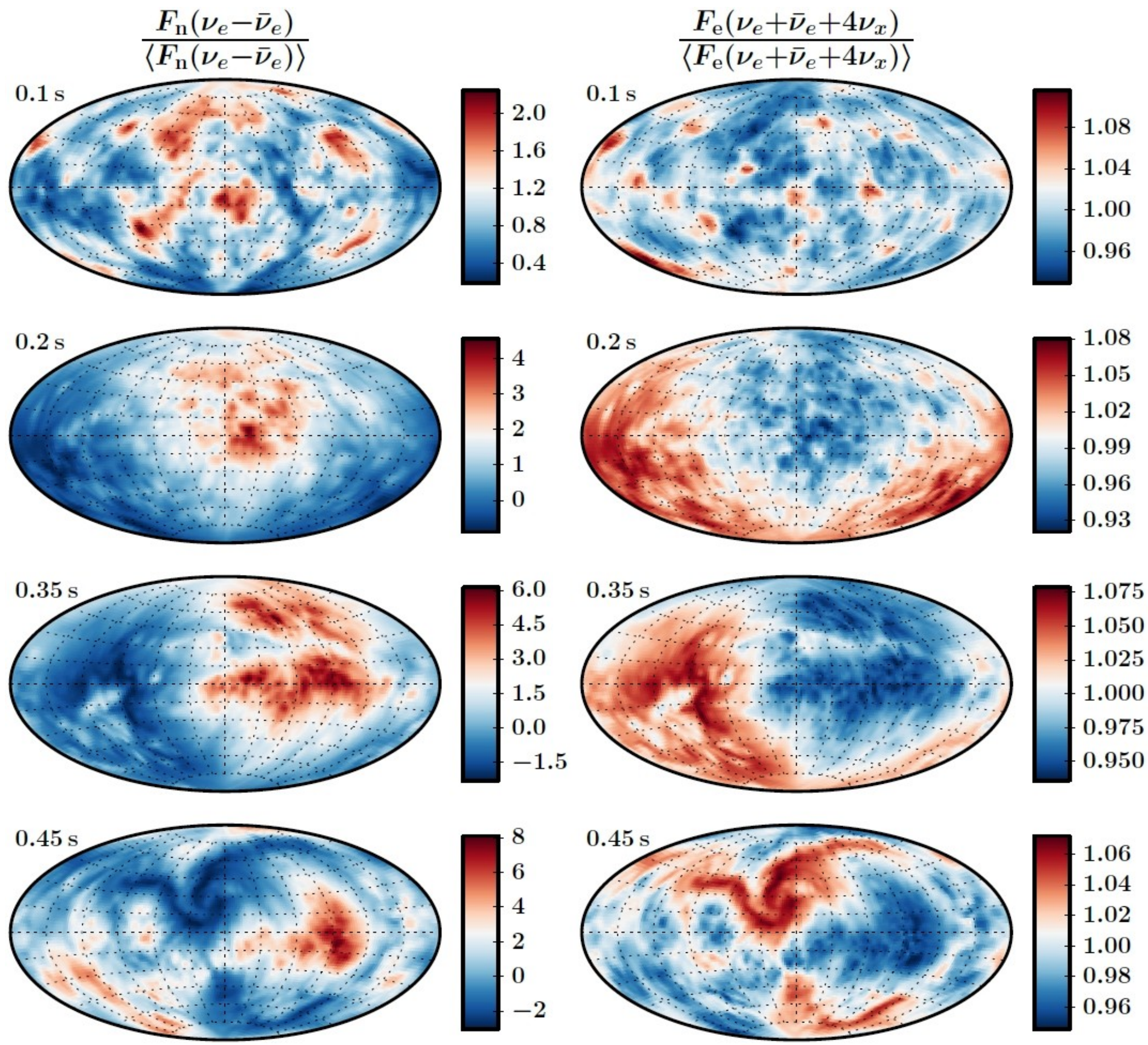
A New Nonradial 3D Instability

Dipole asymmetry of lepton-number emission (LESA)

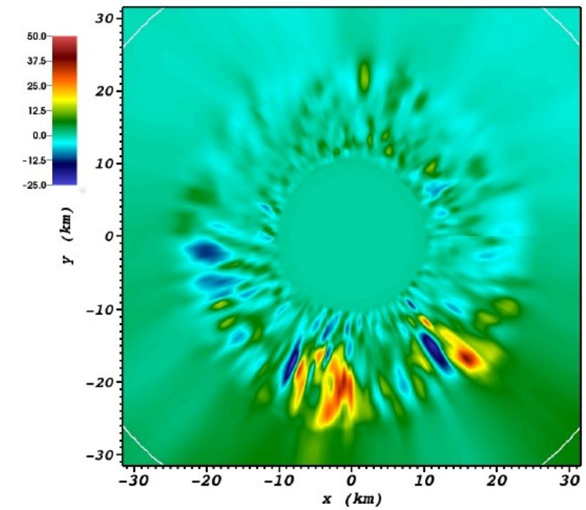
Lepton number flux:
ν_e minus anti-ν_e

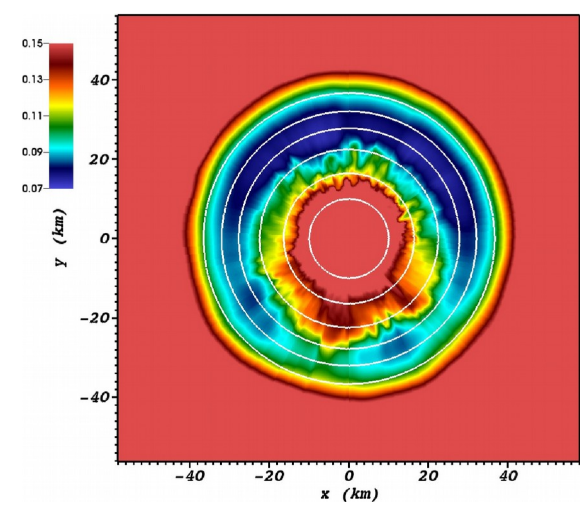
$$(F_{\nu_e} - F_{\bar{\nu}_e})/\langle F_{\nu_e} - F_{\bar{\nu}_e}\rangle$$

Total energy flux:
ν_e plus anti-ν_e plus heavy-lepton neutrinos



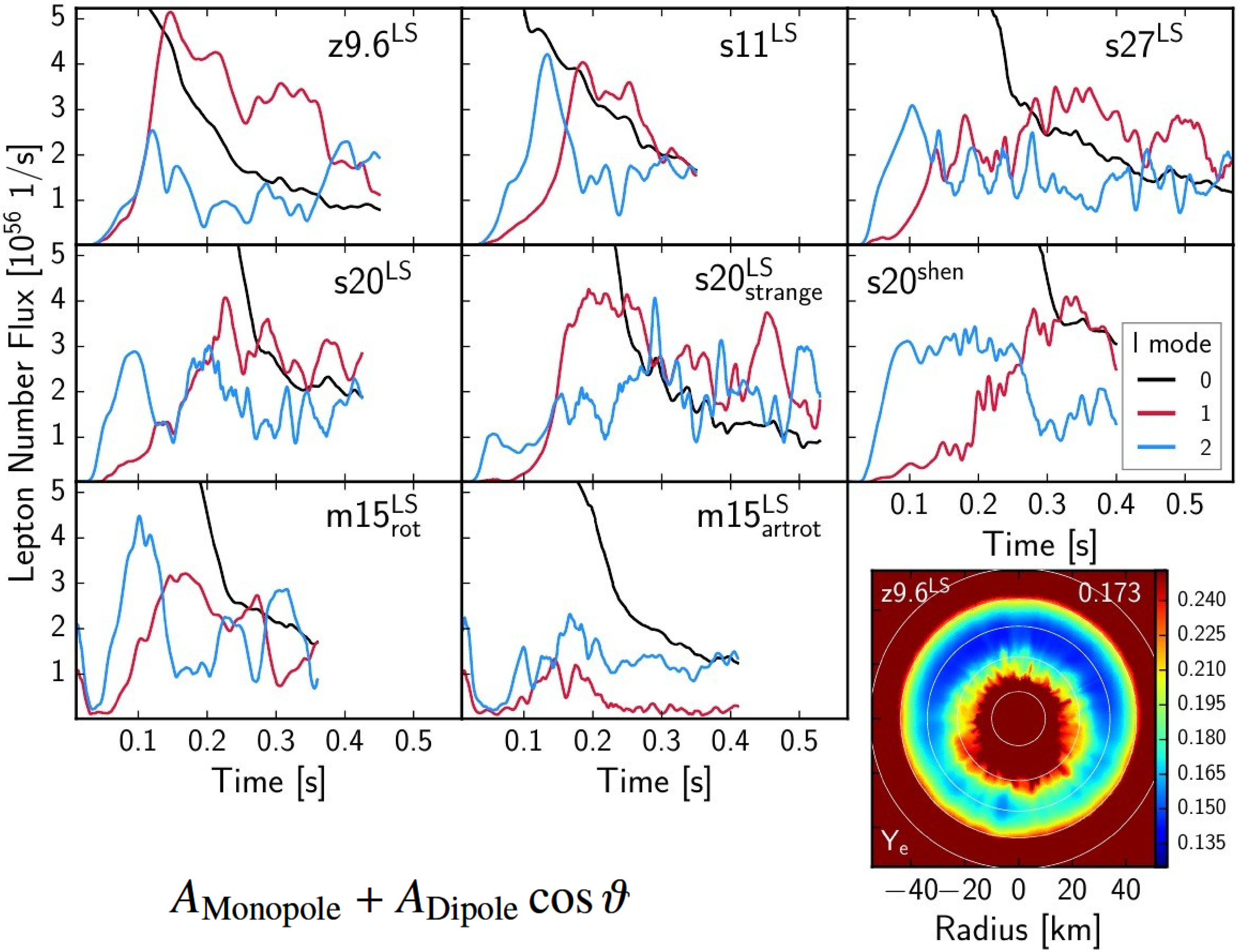
Anisotropic convection inside the proto-neutron star





Tamborra, Hanke, THJ, et al., ApJ 792, 96 (2014);
THJ et al., ARNPS 66 (2016)

Evolution of Dipole Strength and Direction

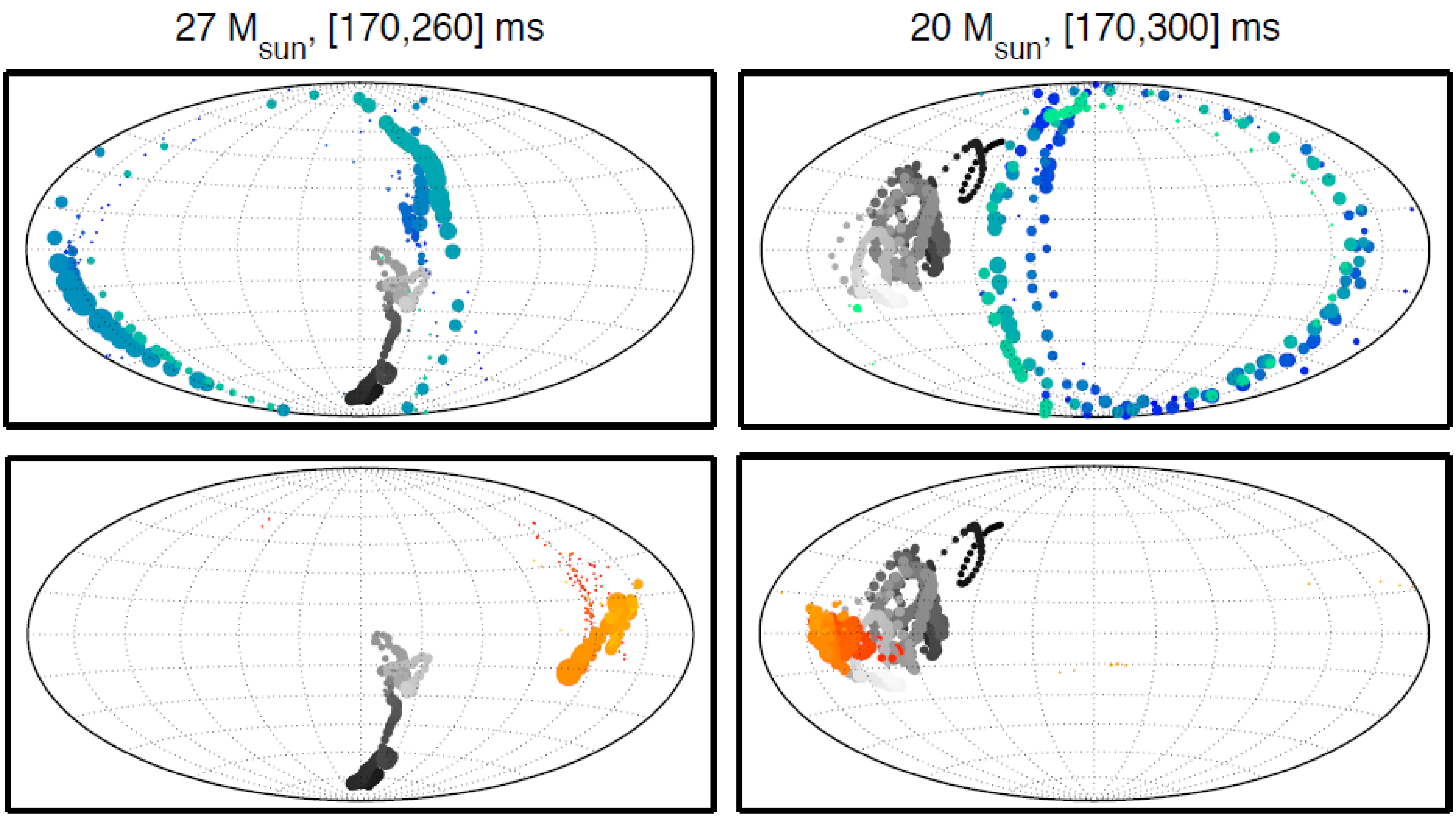


$$A_{\text{Monopole}} + A_{\text{Dipole}} \cos\vartheta$$

Janka, Melson, & Summa, ARNPS 66 (2016); arXiv:1602.05576

LESA-SASI-Interference

Drifting of LESA direction during first SASI episode

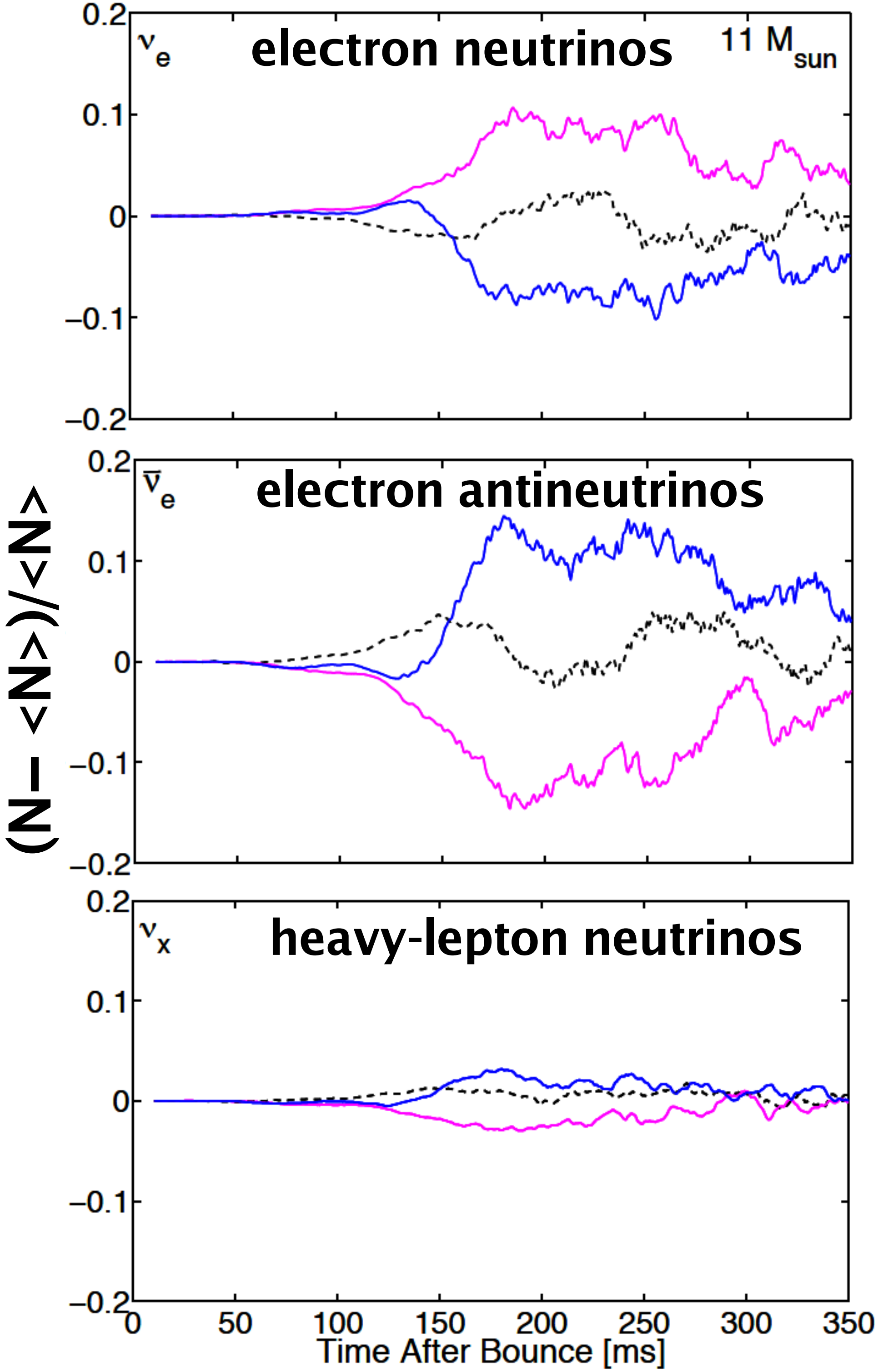


Tamborra, Hanke, Janka, et al., ApJ 792 (2014) 96

A New Nonradial 3D Instability

Dipole asymmetry of lepton-number emission

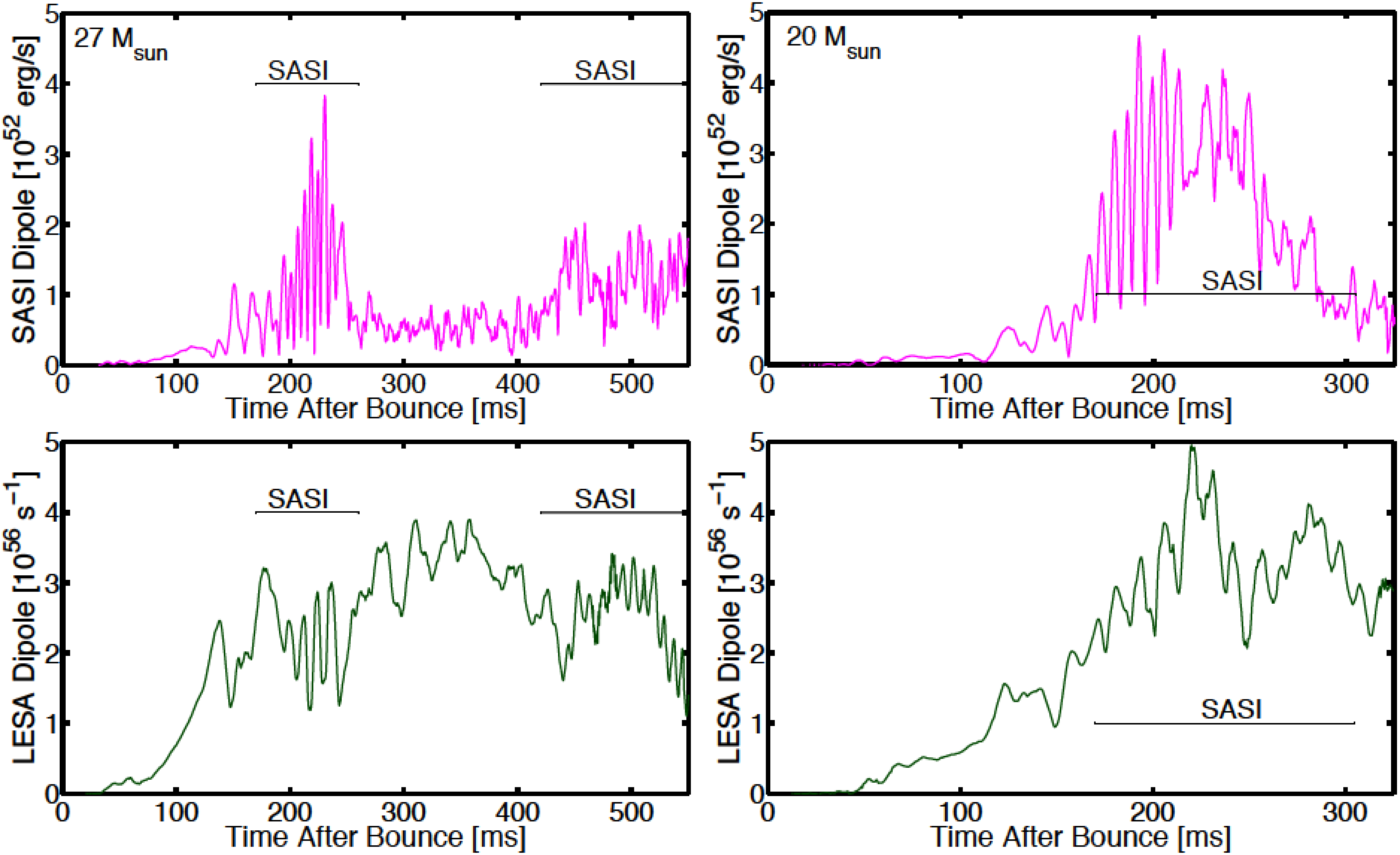
11.2 M_{sun} progenitor (WHW 2002)



Tamborra, Hanke, Janka, et al., ApJ 792 (2014) 96

LESA and SASI Effects in Neutrino Emission

Time evolution of dipole amplitudes of total neutrino luminosity and of lepton-number emission



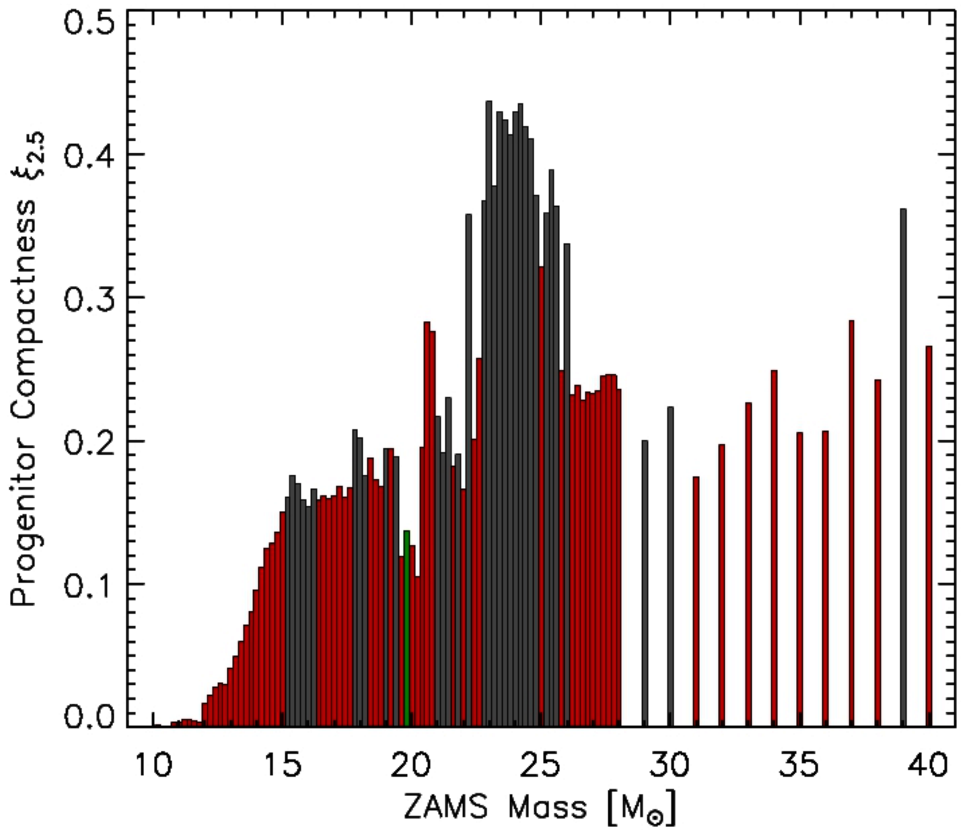
Tamborra et al., PRD 90 (2014) 045032

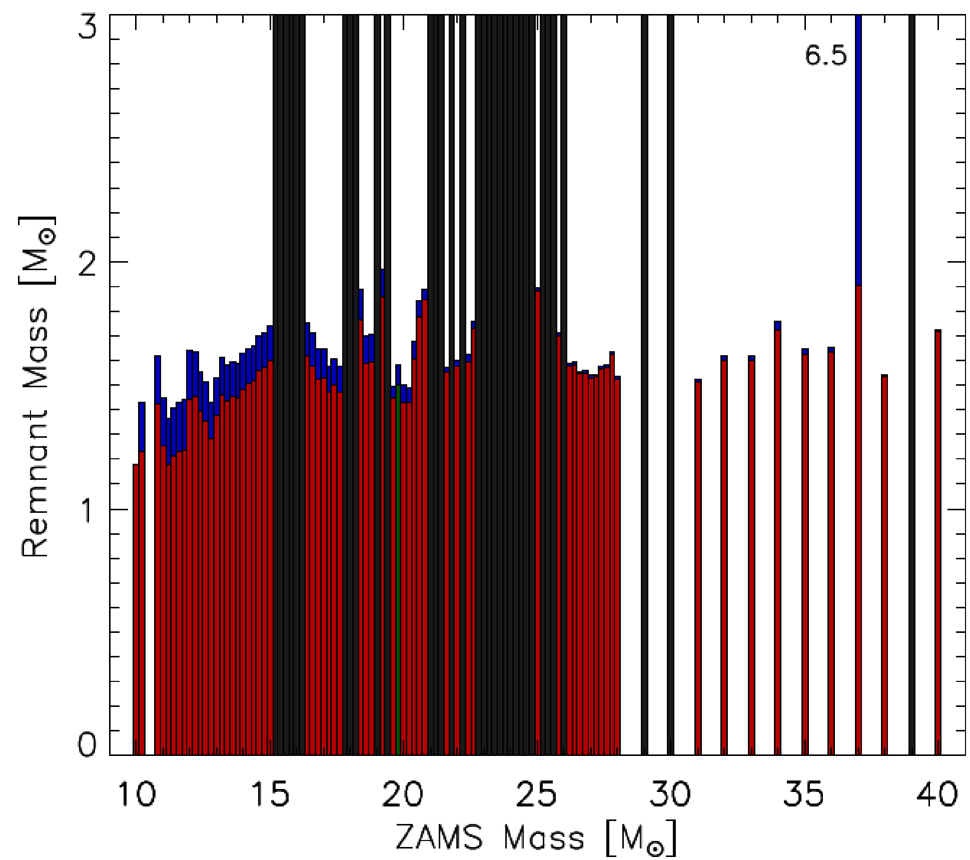
Black-Hole Formation

Stellar Compactness and Explosion

Core compactness can be nonmonotonic function of ZAMS mass

Progenitor models: Woosley et al. (RMP 2002)





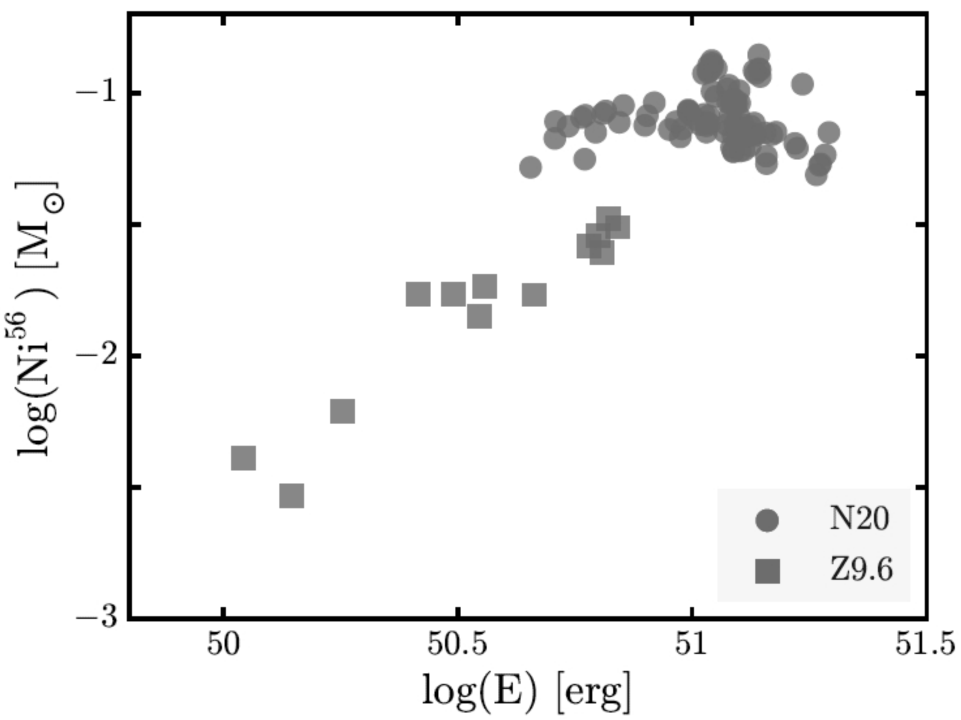
$$\xi_{2.5} \equiv \frac{M/M_\odot}{R(M)/1000\,\mathrm{km}}\,, \quad \text{mass } M = 2.5\ M_\odot$$

O'Connor & Ott, ApJ 730:70 (2011)

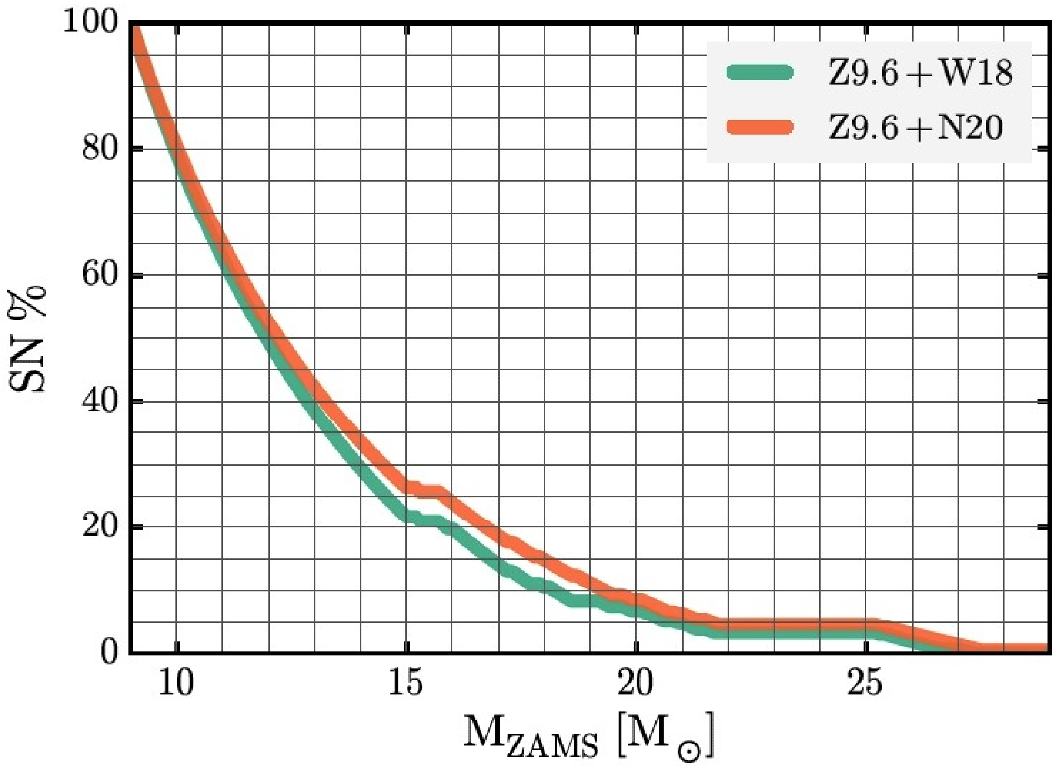
(Ugliano, THJ, Marek, Arcones, ApJ 757, 69 (2012))

Supernova Explosion Properties

Energy-Nickel Mass Correlation

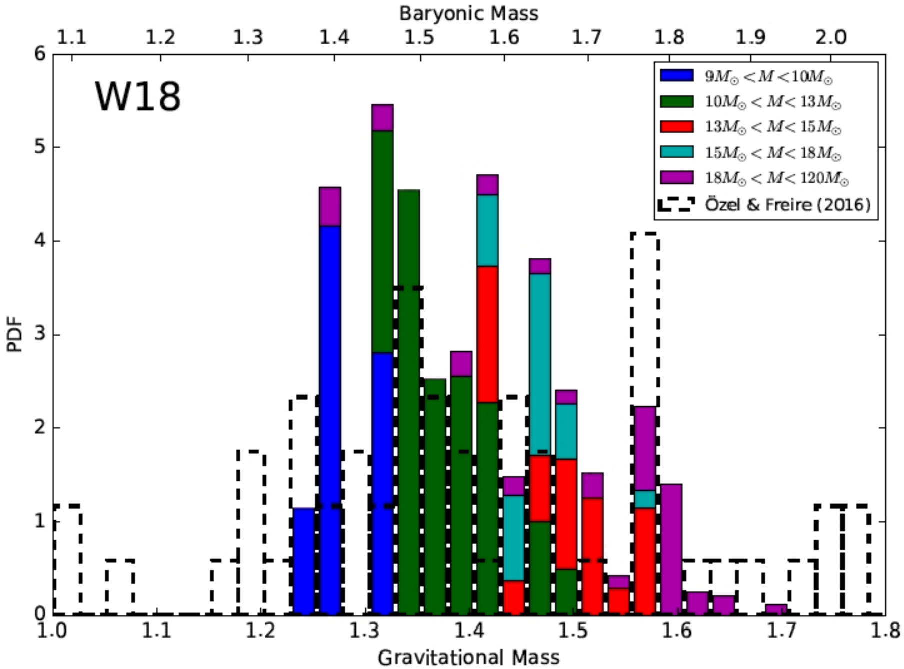


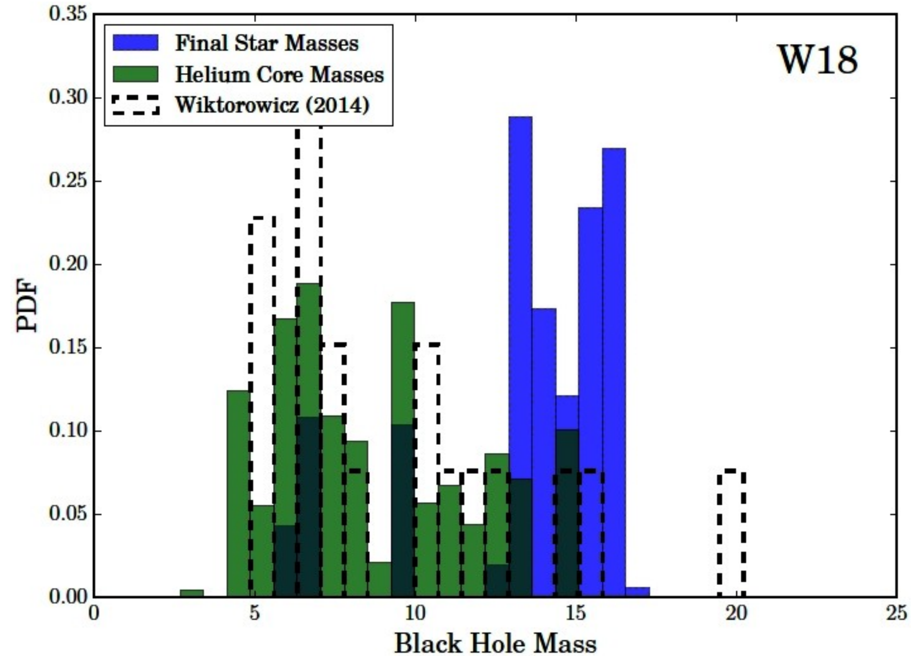
Supernova Percentage vs ZAMS Mass

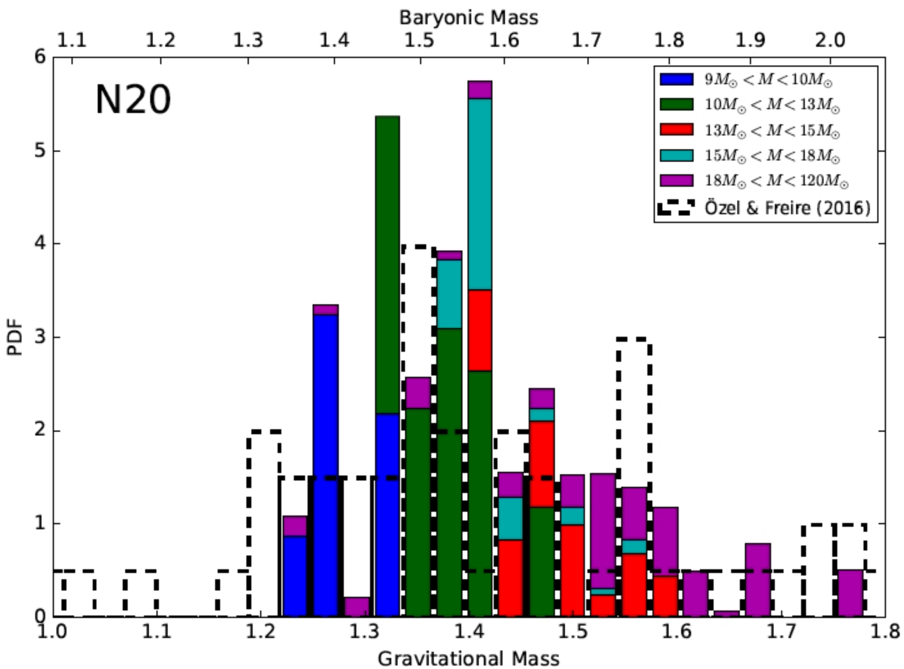


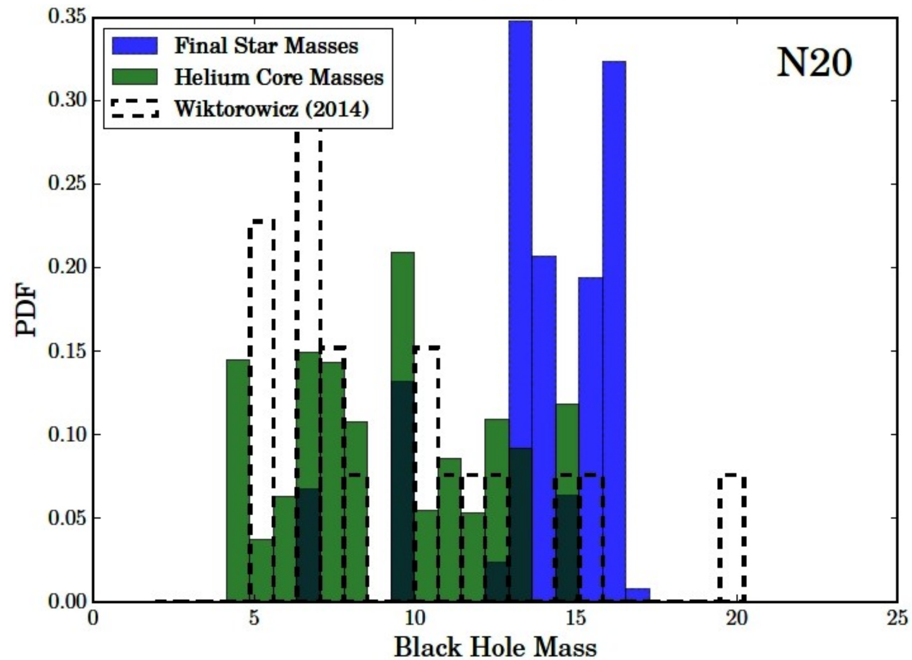
(Sukhbold, Ertl et al., ApJ 821 (2016) 38)

Birth-Mass Distributions of NSs and BHs



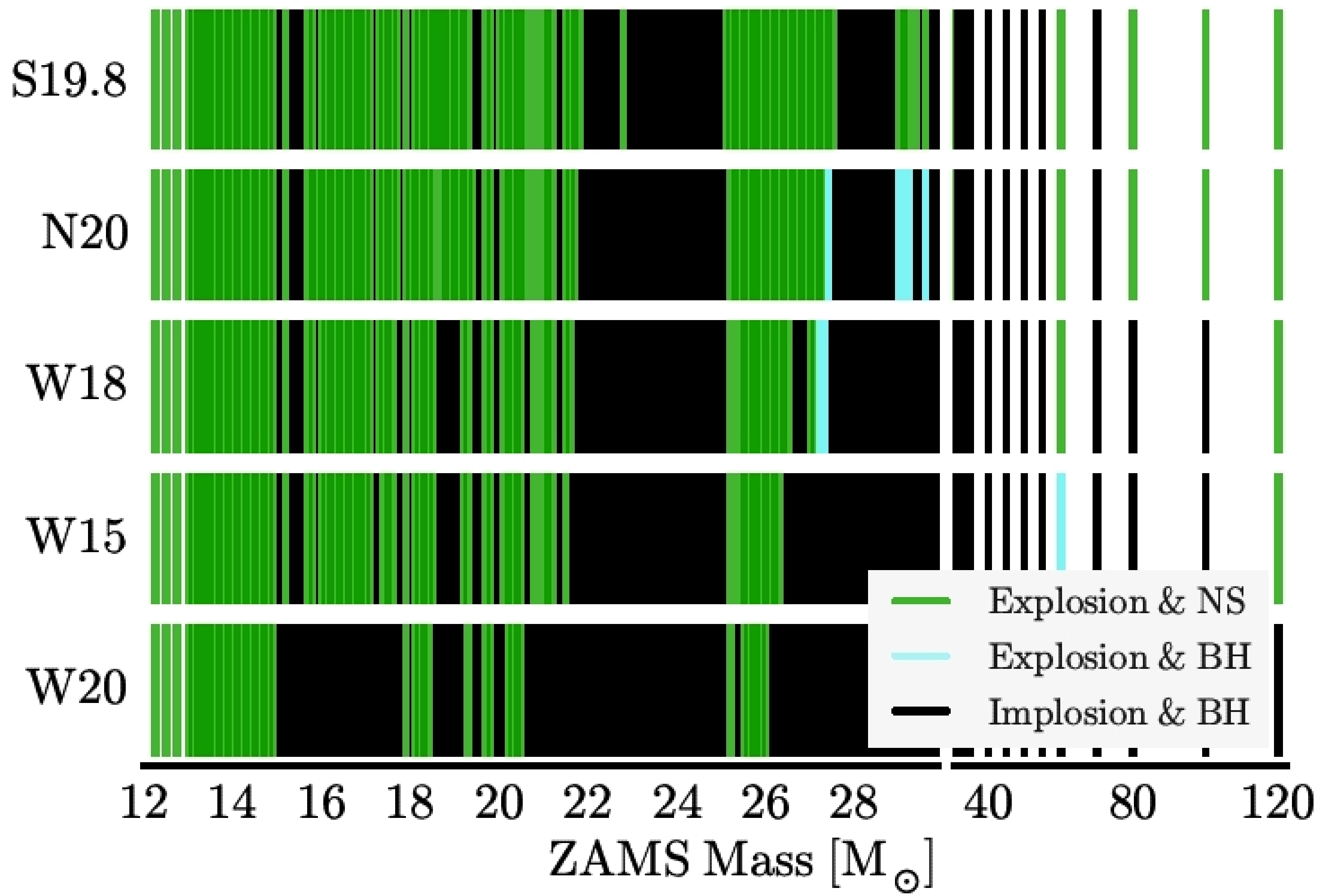






(Sukhbold, Ertl et al., ApJ 821 (2016) 38)

BH Formation for Different SN 1987A Engines



77% SN expl.

74% SN expl.

67% SN expl.

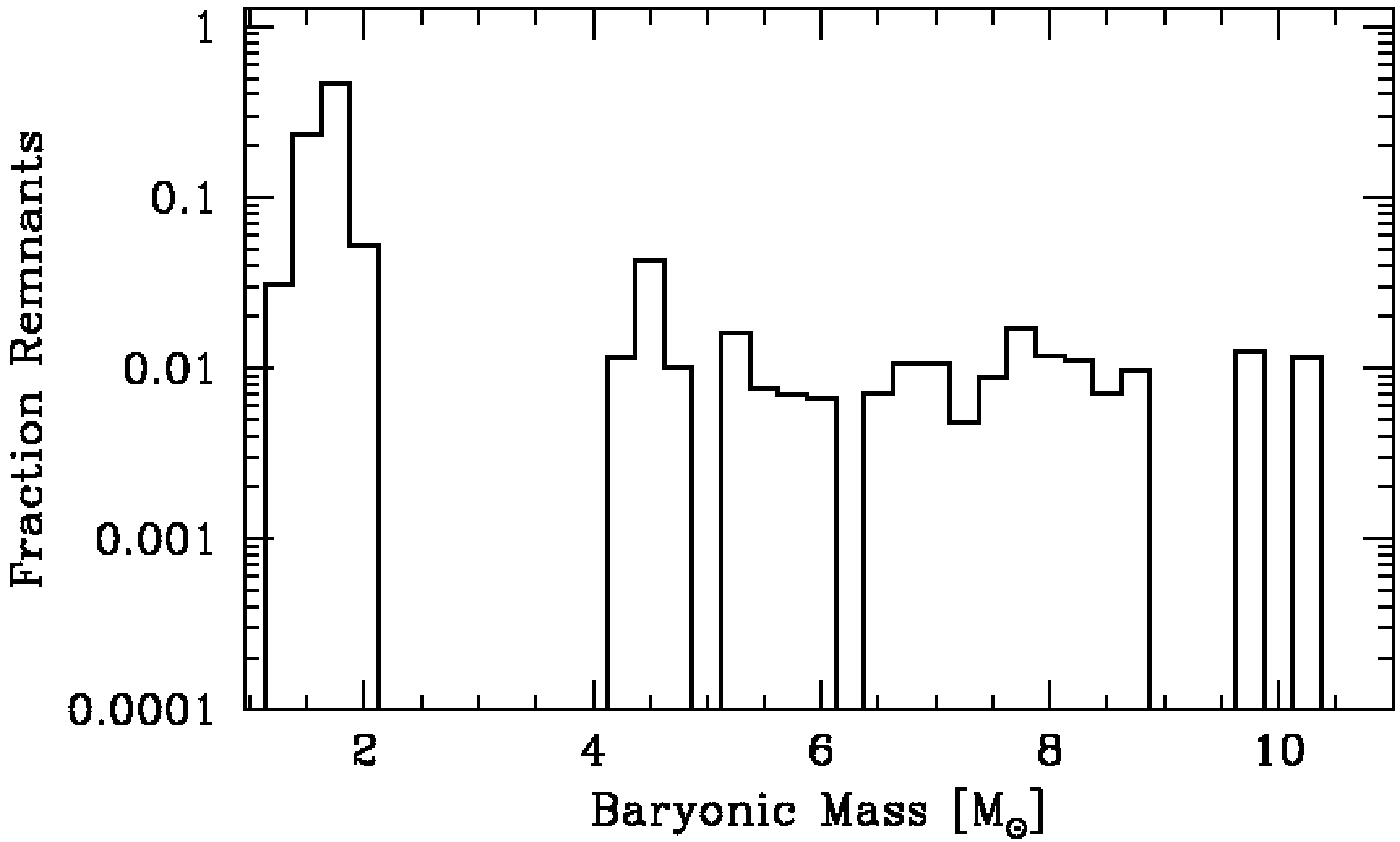
66% SN expl.

55% SN expl.

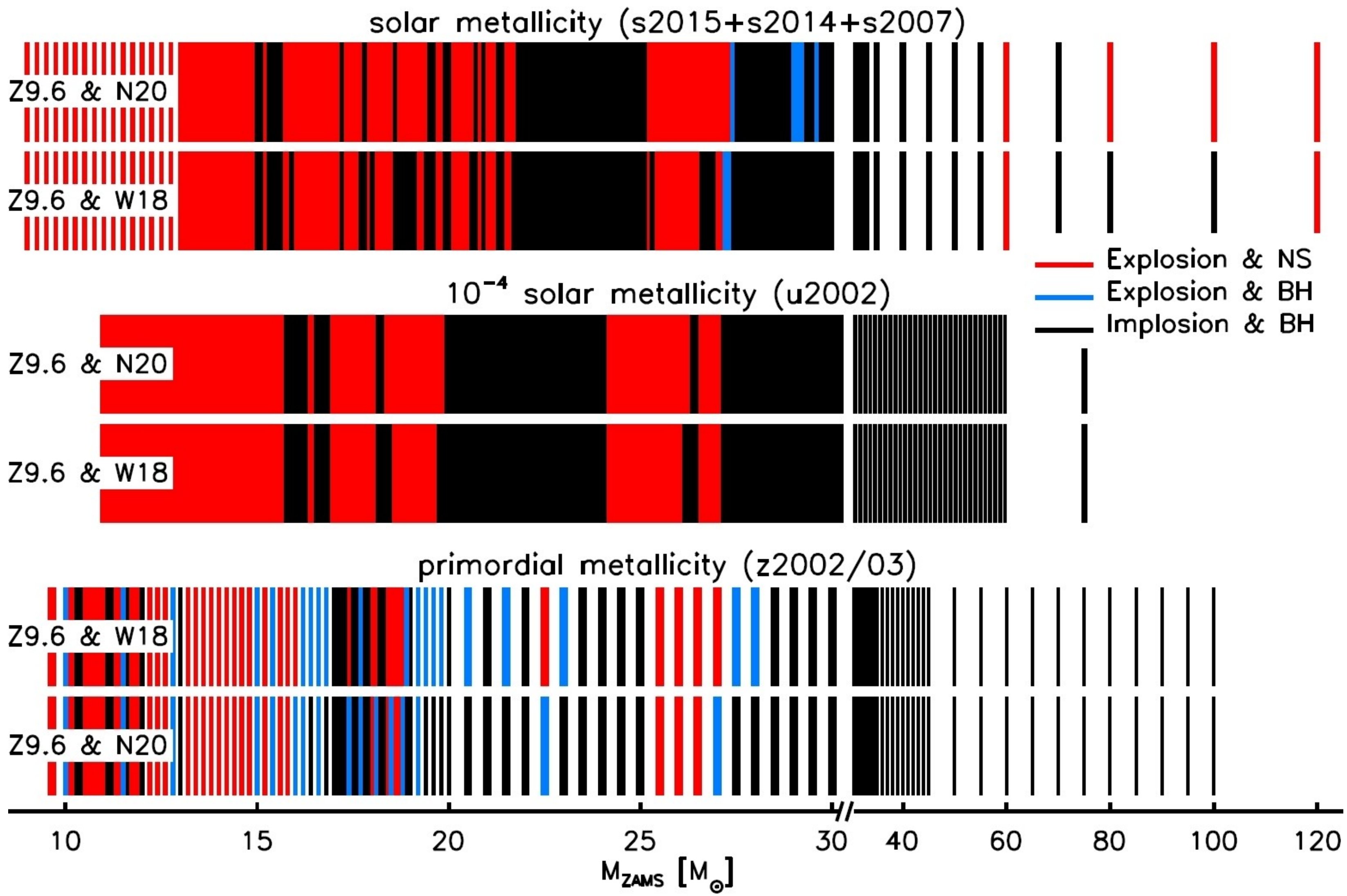
Sukhbold, Ertl, Woosley, Brown & Janka, ApJ, 821 (2016) 38

Theoretical Remnant Mass Distribution

Our model results reproduce possible gap
in the observed distribution of NS and BH masses if
H-shell stripping for BH formation without SN is included.



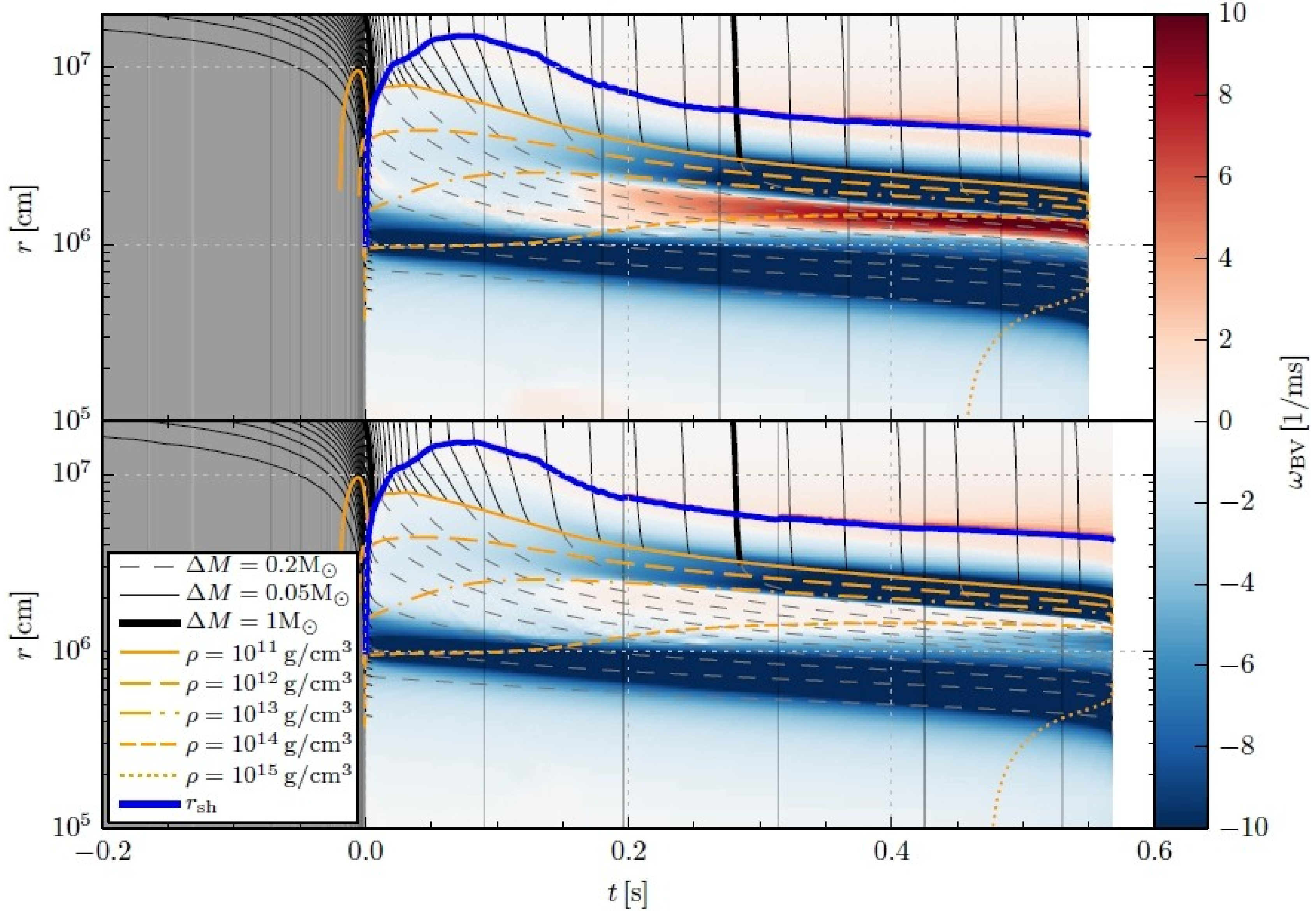
BH Formation for Different SN 1987A Engines and Metallicities



Sukhbold, Ertl et al., ApJ 821 (2016) 38; Th. Ertl, PhD Thesis (2016)

Convection in Proto-NSs evolving to BHs

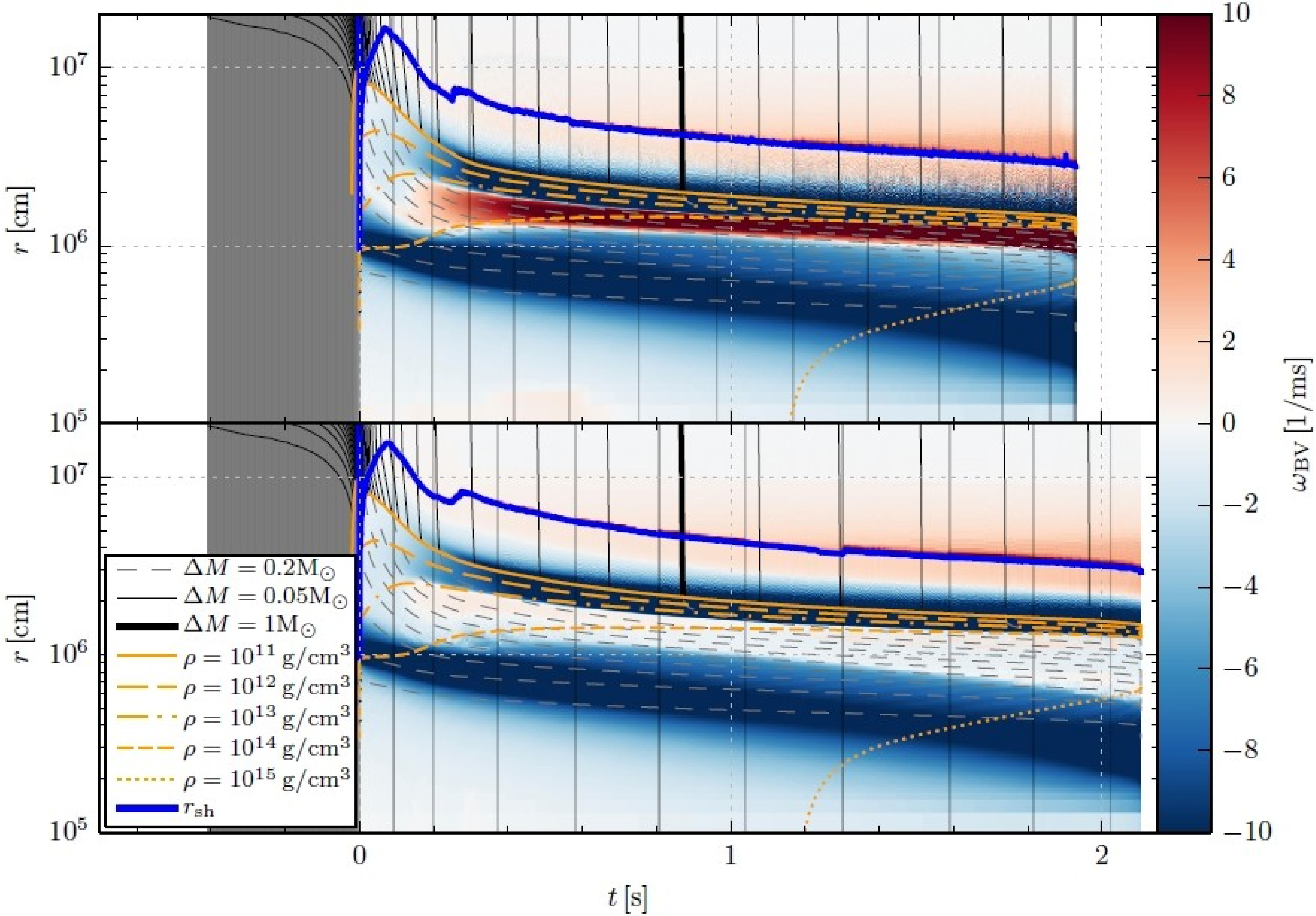
Model s40s7b2 (Woosley & Weaver 1997)



Hüdepohl, PhD Thesis (2013); Mirizzi, Tamborra, THJ, et al., La Rivista del Nuovo Cimento, 39, (2016) 1

Convection in Proto-NSs evolving to BHs

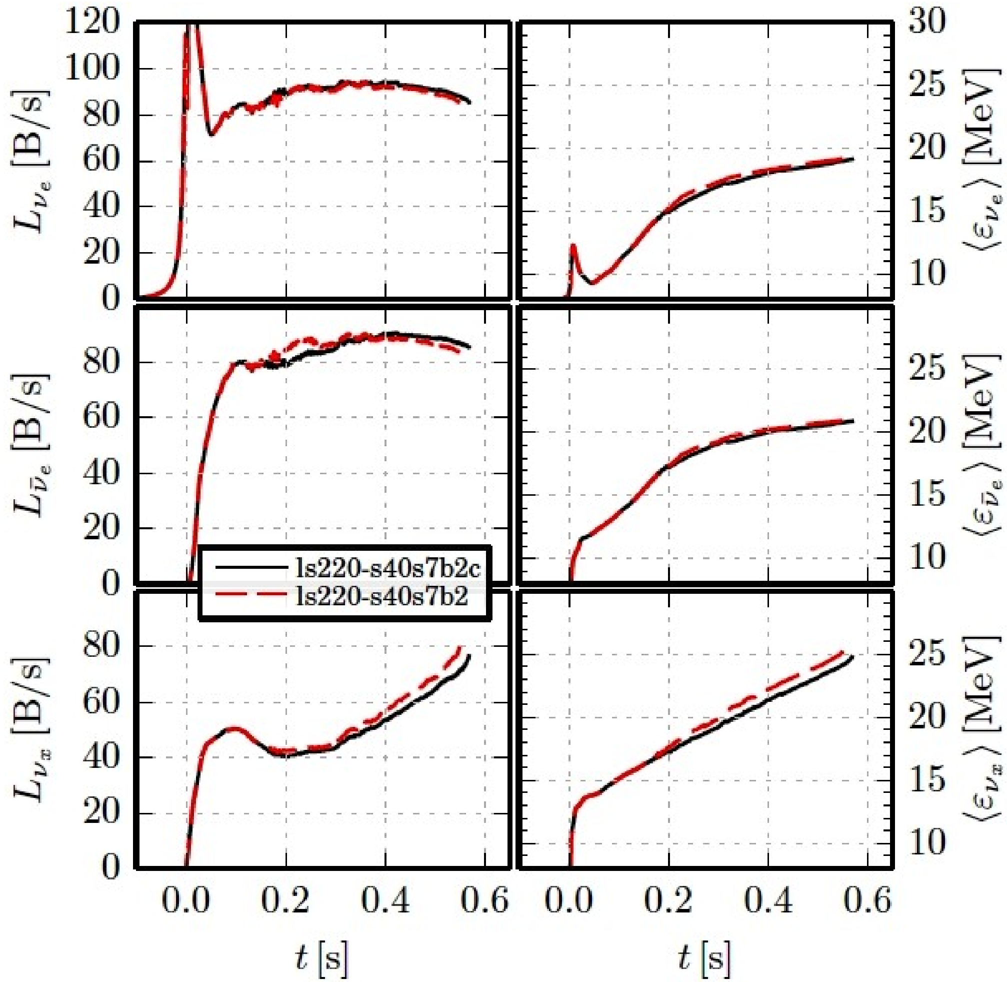
Model s40.0 (Woosley et al. (2002)



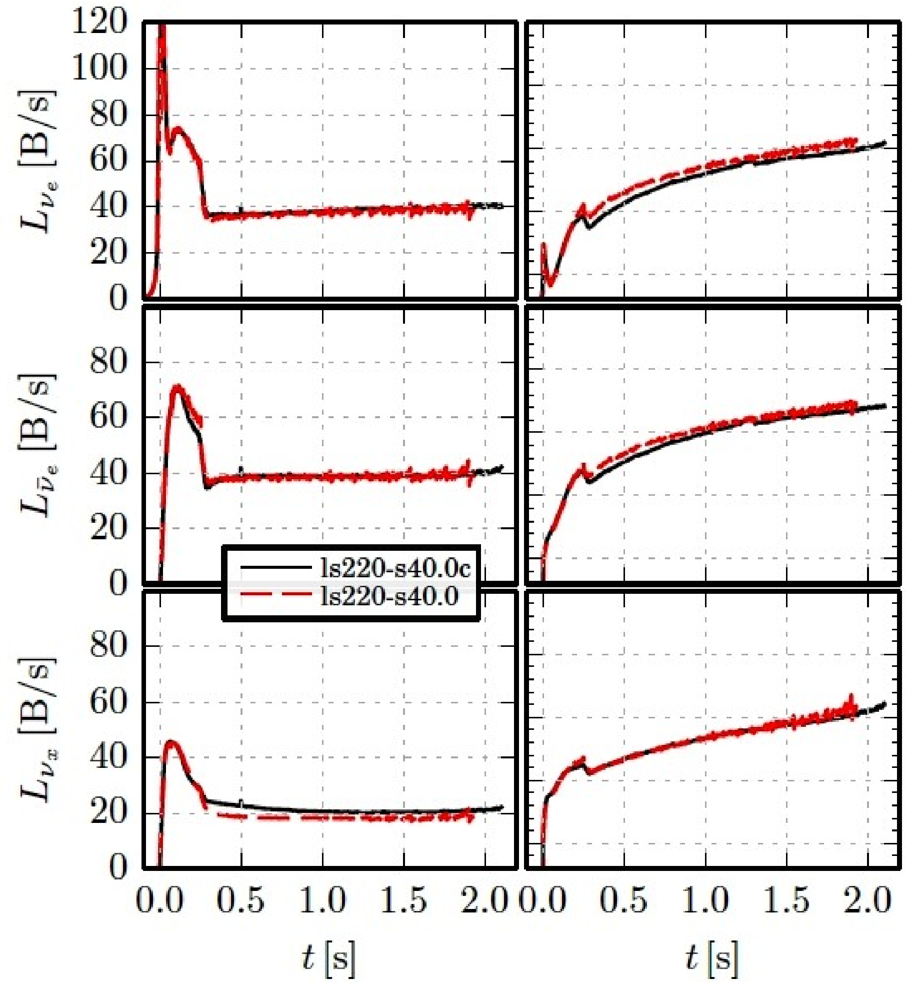
Hüdepohl, PhD Thesis (2013); Mirizzi, Tamborra, THJ, et al., La Rivista del Nuovo Cimento, 39, (2016) 1

Convection in Proto-NSs evolving to BHs

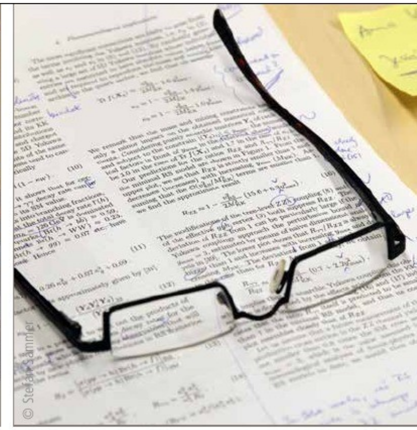
Model s40s7b2
(Woosley & Weaver 1997)



Model s40.0
(Woosley et al. (2002)



Hüdepohl, PhD Thesis (2013); Mirizzi, Tamborra, THJ, et al., La Rivista del Nuovo Cimento, 39, (2016) 1


Mainz Institute for Theoretical Physics

Supernova Neutrino Observations: What can we learn and do?

Hans-Thomas Janka **MPI for Astrophysics,** Georg Raffelt **MPI for Physics,** Lutz Köpke, Michael Wurm **JGU**

October 9-13, 2017

Garching CCSN Data Archive

Max Planck Institute
for Astrophysics

MPA Homepage

The Garching Core-Collapse Supernova Research

Core-Collapse Supernova Data Archive

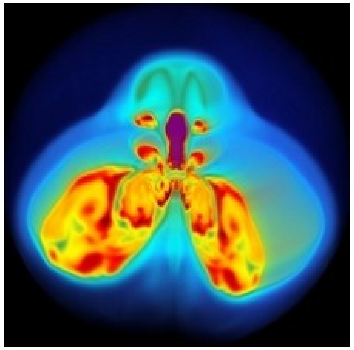
Core-Collapse Supernova Movie Archive

People contributing to this archive

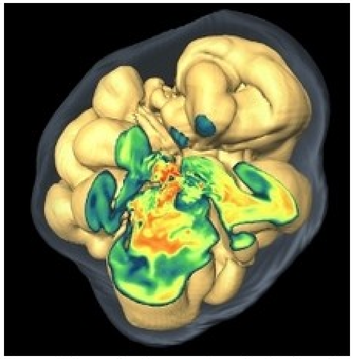
Gravitational core-collapse events and supernova explosions are among the most powerful cosmic phenomena, releasing more energy within seconds than stars like the sun produce in billions of years. They terminate the lives of massive stars, giving birth to neutron stars or stellar-mass black holes, and are responsible for the production of about half of the chemical elements heavier than iron. By far most of the energy release occurs in the form of elusive neutrinos, elementary particles that are abundantly produced when the hot, compact remnant settles and cools. Though only a small fraction of the gravitational binding energy are converted to gravitational waves, supernovae are among the most intense sources of these spacetime perturbations. Both neutrinos and gravitational waves are unique probes of the physical processes that take place in the deep interior of dying stars. Huge experimental facilities, neutrino detectors in the eternal ice shield of the South Pole and in deep underground laboratories as well as kilometer-scale interferometric gravitational-wave antennae are therefore continuously searching for such signals of stellar catastrophies.

Crab Supernova Remnant: NASA, ESA and Allison Loll/Jeff Hester (Arizona State University), thanks to: Davide De Martin (ESA/Hubble)

Stellar explosions are generically multi-dimensional phenomena. This fact has been concluded for the first time from observations of Supernova 1987A, but all of its implications are recognized only as computational models of supernova explosions become increasingly more sophisticated and begin to be advanced to the third dimension and to longer evolution periods. This has led to a better understanding of the role of neutrinos for driving the explosion, to new insights into the characteristics of the neutrino and gravitational-wave emission of supernovae, and to the discovery of links between pulsar kicks and spins, supernova nucleosynthesis, and the origin of asymmetries seen in the gaseous remnants of stellar explosions.



Two-dimensional computer simulation of the explosion of a 15 solar-mass star 0.70 seconds after core bounce; diameter of displayed region: 1500 km (A. Marek, M. Rampp (RZG), see Marek & Janka, ApJ 694 (2009) 664).



Three-dimensional computer simulation of the explosion of a 15 solar-mass star 0.50 seconds after core bounce; diameter of displayed region: about 4000 km (L. Scheck, PhD Thesis 2007; see Woosley & Janka, Nature Physics 1 (2005) 147).

The Core-Collapse Modeling Group at the Max Planck Institute for Astrophysics participates at the forefront of worldwide theoretical modeling efforts of stellar collapse and explosions and of their observable signals (neutrinos, gravitational waves, heavy elements), using state-of-the-art numerical tools and being linked to national and international collaborations. It is funded by the Deutsche Forschungsgemeinschaft (DFG) through two Transregional Collaborative Research Centres (SFB/TR 7 and SFB/TR 27) and the Cluster of Excellence for Fundamental Physics (EXC 153). Computer time grants are kindly provided by the Rechenzentrum Garching (RZG), the High Performance Computing Center Stuttgart (HLRS), the Leibniz-Rechenzentrum (LRZ), the John von Neumann Institut für Computing (NIC Jülich), and the Distributed European Infrastructure for Supercomputing Applications Consortium (DEISA).

www.mpa-garching.mpg.de/ccsnarchive/

Garching CCSN Data Archive

www.mpa-garching.mpg.de/ccsnarchive/

Max Planck Institute
for Astrophysics

MPA Homepage > CCSN Homepage

The Garching Core-Collapse Supernova Archive

Using the data in this archive is permitted for non-commercial purposes under the condition of citing this WWW page and the corresponding publication where one exists. If these data are used for a scientific publication, we appreciate a short notification. All efforts have been made to eliminate errors, but no warranty whatsoever is provided. Please inform us of any errors or inconsistencies that you may detect.

Some of the archives are password protected. Please get in touch if you need to use these data.

Contact address and responsibility: Hans-Thomas Janka (thj@mpa-garching.mpg.de)

+ General archives, catalogs, and applications
+ Data and supplementary material of parameterized 1D simulations with HotB
+ Data and supplementary material of parameterized long-time 3D simulations with HotB
+ Data and supplementary material of 1D simulations with PROMETHEUS-VERTEX
+ Data and supplementary material of 2D and 3D simulations with PROMETHEUS-VERTEX
+ Data and supplementary material of 2D simulations with COCONUT-VERTEX
+ Data and supplementary material for 2D simulations of compact binary mergers

www.mpa-garching.mpg.de/ccsnarchive/

+ General archives, catalogs, and applications

+ Data and supplementary material of parameterized 1D simulations with HotB

+ Data and supplementary material of parameterized long-time 3D simulations with HotB

– Data and supplementary material of 1D simulations with PROMETHEUS-VERTEX

Proto-neutron star neutrino cooling signals (2016)

Simulations done by Robert Bollig

Neutrino data

Neutrinos from the Formation, Cooling, and Black Hole Collapse of Neutron stars (2014)

Neutrino signals from models of the PhD Thesis of Lorenz Hüdepohl, TU München 2014

Neutrino data

Spherically symmetric simulations of the accretion phase for a set of progenitors and EoS (2012)

Simulations done by Lorenz Hüdepohl

Partially published in Phys. Rev. D 85, 085031 (2012), arXiv eprint 1111.4483.

Data

Neutrino intensity for a 15 solar-mass star core collapse (2012)

Simulations done by Lorenz Hüdepohl

The simulation data are used in Phys. Rev. Lett. 108, 061101 (2012) (arXiv eprint 1109.3601) and in Phys. Rev. D 85, 113007 (2012) (arXiv eprint 1204.0971).

Data

Neutrino intensity for a set of progenitors (2012)

Simulations done by Lorenz Hüdepohl (unpublished)

In the one-dimensional simulations, progenitor models from Woosley, Heger & Weaver (2002) and the EOS by Lattimer & Swesty (1991) are used.

Neutrino data

Neutrino Signal of Electron-Capture Supernovae from Core Collapse to Cooling (2010)

Hüdepohl, L., Müller, B., Janka, H.-T., Marek, A., & Raffelt, G. G.

Physical Review Letters 104, 251101 (2010), arXiv eprint 0912.0260

PRL models

Additional data

+ Data and supplementary material of 2D and 3D simulations with PROMETHEUS-VERTEX

+ Data and supplementary material of 2D simulations with COCONUT-VERTEX

+ Data and supplementary material for 2D simulations of compact binary mergers