Sean Couch

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BIO SKETCH

Sean Couch joined the MSU faculty in June 2015 with joint appointments in the Department of Computational Mathematics, Science, and Engineering, and the Department of Physics and Astronomy, as well as an adjunct appointment in the Facility for Rare Isotope Beams/National Superconducting Cyclotron Laboratory.

Prior to arriving at MSU, Couch was a Senior Postdoctoral Scholar at the California Institute of Technology and a Hubble Fellow at the University of Chicago. Couch received his PhD in Astrophysics from the University of Texas at Austin in 2010. In just the last few years, Couch and his collaborators have made paradigm-shifting contributions to the theoretical investigation of CCSNe.

RESEARCH INTERESTS

Core-collapse supernovae; stellar evolution; computational astrophysics; nuclear astrophysics

LAB(S)/GROUP(S)

Facility for Rare Isotope Beams, National Superconducting Cyclotron Laboratory, Joint Institute for Nuclear Astrophysics

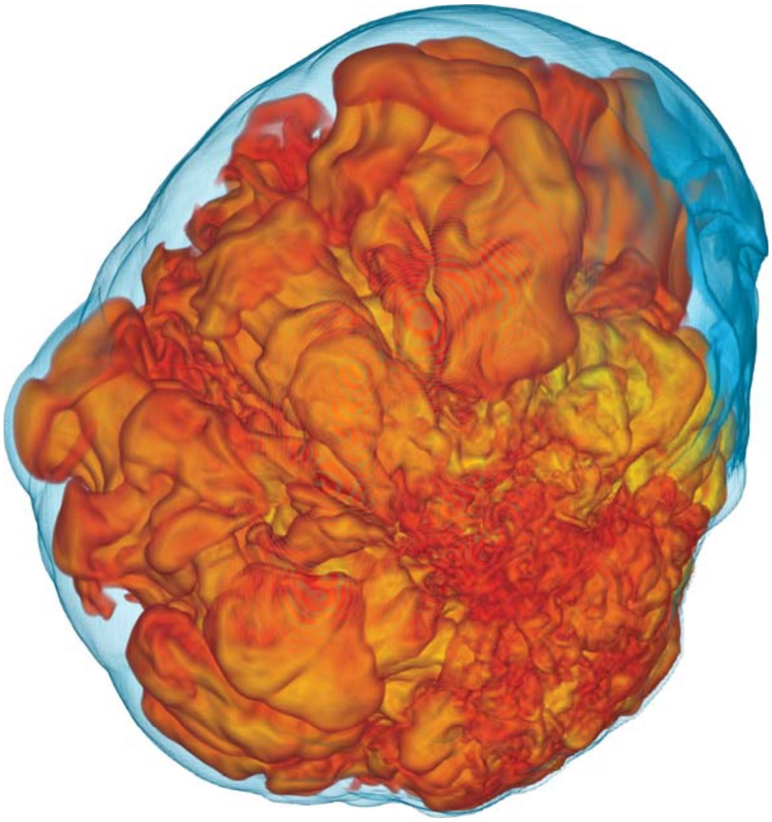

FIGURE 1. Strong turbulent convection behind the stalled shock of a 3-D rotating, magnetic core-collapse supernova simulation. Simulations such as this one are being used to understand the role of turbulence in aiding successful supernova explosions.

WEBSITE

www.pa.msu.edu/~couch

CURRENT RESEARCH FOCUS

Couch's research is centered on unraveling the mystery of how massive stars explode at the end of their lives. Such core-collapse supernova (CCSN) explosions are responsible for the production of most of the elements beyond hydrogen and helium throughout the universe and play a crucial role in providing feedback mechanisms to galaxy and star formation. While CCSNe are observed routinely to occur in galaxies near and far, the physical mechanism that drives these energetic explosions remains unclear. Couch's group at MSU is advancing the state-of-the-art in the study of the CCSN mechanism through the application of cutting-edge computational science executed on the world's largest supercomputers.

Turbulence in stellar explosions. The most promising candidate for the CCSN explosion mechanism is the so-called "delayed neutrino heating" mechanism. Neutrinos carry away nearly all of the gravitational binding energy released via the collapse of the stellar core, about 100 times the energy necessary to drive robust supernova explosions. The trouble is that neutrinos have an incredibly tiny cross section for interaction, making extracting much of this copious energy extremely difficult. The most sophisticated 1-D simulations have, for decades, shown that the neutrino mechanism fails in spherical symmetry. The situation is somewhat more promising in 2-D and 3-D wherein a handful of self-consistent explosions have been obtained, but these explosions tend to be marginal.

A perennial question has been what phenomena in 2-D and 3-D aid explosion as compared to 1-D? While many hydrodynamic instabilities seem to help the neutrinos in driving CCSN explosions, Couch and his collaborators recently showed that by far the most important difference is the presence of turbulence in 2-D and 3-D. Turbulence behind the stalled supernova shock, driven by the neutrino heating, is extremely strong and violent. This turbulence exerts an effective pressure on the stalled shock that can revival the background thermal pressure. This is a huge effect that is completely missing from 1-D calculations! Couch showed that 2-D and 3-D calculations require much less neutrino heating to reach explosions precisely because of this turbulent pressure helping to push the shock out. This realization represents a sea change in our thinking about what aids explosions in multidimensional simulations and points the way toward a robust model for successful CCSN explosions.

Further work by Couch and his collaborators showed that even the highest resolution multidimensional CCSN simulations do a very poor job of resolving the turbulence behind the stalled shock. Crucially, this implies that we are not accurately

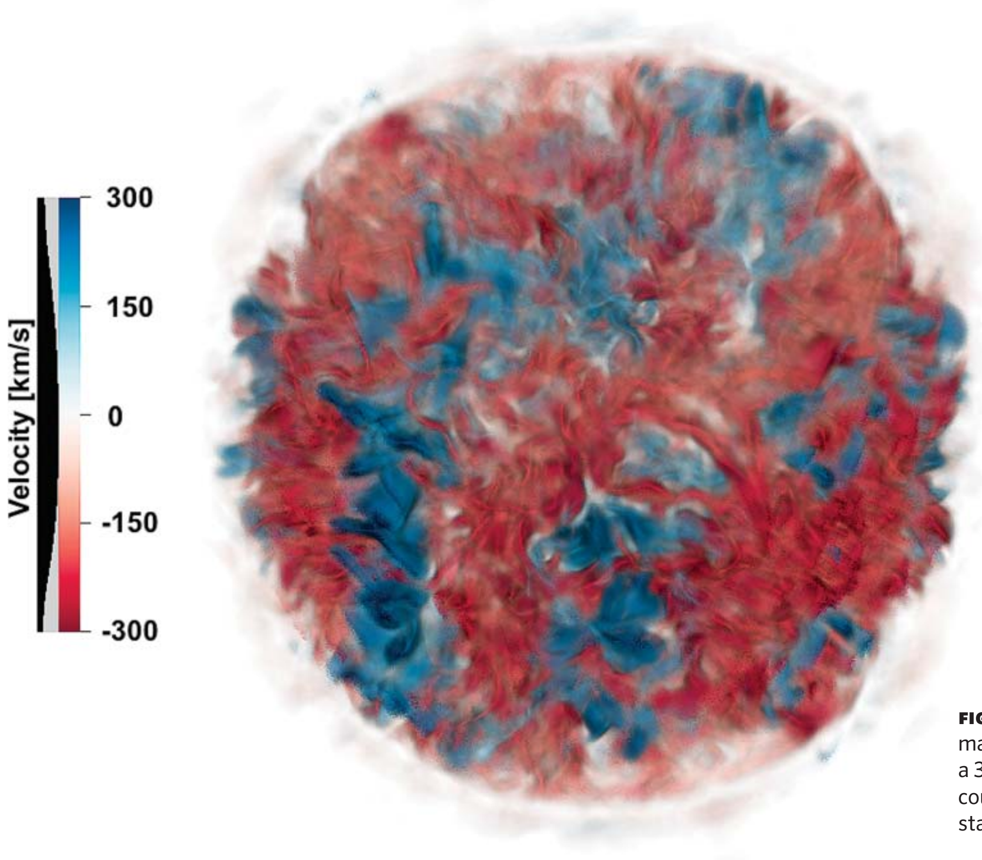

FIGURE 2. The final seconds in the life of a very massive star, captured in 3-D. This is the first time a 3-D model of such a star has been developed and could lead to a better understanding of why these stars blow up as supernovae.

modeling this very important physical process in our most sophisticated simulations. Couch is now leading an effort to address these issues directly. Couch is PI of a DOE INCITE computing allocation to carry out CCSN simulations with nearly an order of magnitude greater resolution than has ever been achieved in 3-D simulations. Couch is also leading efforts to develop sub-grid models of CCSN turbulence that could be used in simulations that lack sufficient resolution to accurately model the turbulence directly.

3-D massive stellar evolution. One critical aspect of the role of turbulence in the CCSN mechanism is its connection to the presence of non-spherical structure in the progenitor stars. Recently, Couch and his colleagues showed that the presence and strength of convection in the pre-collapse progenitor star directly impacts the strength of the turbulence behind the stalled supernova shock: the stronger the progenitor convection, the stronger the resulting turbulence. How strong such progenitor convection is in real massive stars was, however, completely unknown since the state-of-the-art in CCSN progenitor calculations is still 1-D models. Couch and his colleagues made the first steps forward in addressing these issues by carrying out the world's first 3-D CCSN progenitor simulation, directly calculating the final three minutes in the life of a massive star all the way to the point of gravitational core collapse. Couch showed that the resulting strongly aspherical progenitor structure was more favorable for successful CCSN explosion than an otherwise identical 1-D progenitor. This work has paradigm-shifting potential for the theoretical study of CCSN because it implies that the trouble all along may not have been with the neutrino heating mechanism, per se, but with the initial conditions we have been using.

Together with collaborators around the country, Couch is leading a cutting-edge effort to produce the world's first and most realistic 3-D CCSN progenitor models. This work involves the combination of best-in-class open-source stellar evolution modeling codes with Couch's 3-D nuclear combustion hydrodynamics code, and the world's fastest supercomputers.

RECENT PUBLICATIONS

S.M. Couch, E. Chatzopoulos, W.D. Arnett, F.X. Timmes, "The Three-dimensional Evolution to Core Collapse of a Massive Star," *Astrophysical Journal Letters*, 808, L21 (2015).

S.M. Couch, C.D. Ott, "The Role of Turbulence in Neutrino-driven Core-collapse Supernova Explosions," *Astrophysical Journal*, 799, 5 (2015).

S.M. Couch, E.P. O'Connor, "High-resolution Three-dimensional Simulations of Core-collapse Supernovae in Multiple Progenitors," *Astrophysical Journal*, 785, 123 (2014).

S.M. Couch, C.D. Ott, "Revival of the Stalled Core-collapse Supernova Shock Triggered by Precollapse Asphericity in the Progenitor Star," *Astrophysical Journal Letters*, 778, L7 (2013).