Carl Edward Fields, Jr. - Research Statement

Stars explode. Supernovae (SNe), or stellar explosions, can occur through the ignition of a degenerate white dwarf (WD) star, a star that is supported by quantum electron degeneracy pressure, or by the core collapse of a massive star. Recent transient surveys, such as The *Dark Energy Survey* have discovered and imaged thousands of supernovae since 2013 including the anomalous SNe DES13S2cmm. The forthcoming *Large Synoptic Survey Telescope* will further these efforts utilizing a three billion pixel digital camera to cover more than 20,000 deg^2 of the night sky. However, even with this wealth of observational data, many aspects of the evolution and subsequent explosion of massive stars remain unknown.

My background in theoretical astrophysics has prepared me to aide in the advancement of these efforts. **I propose to investigate the stellar structure and evolution of massive stars, core collapse supernovae explosion (CCSNe) mechanisms, and implications for cosmic chemical evolution and gravitational wave radiation.** The confluence of advancements in multiple fields will provide the empirical basis needed to accomplish these goals. The focused efforts proposed are summarized as follows: (i) getting the progenitor right, (ii) supernova explosion mechanisms, and (iii) nucleosynthetic yields and gravitational wave bursts. Advancement in our understanding of massive stars can lead to furthering our knowledge of the cosmic chemical evolution of the Universe and provide direct tests of Einstein's General Theory of Relativity (GR).

Getting the progenitor right. The star that will eventually explode as a CCSNe is often referred to as the progenitor. Computational modeling of the progenitor star can lead to the insight of how a star will end its life, or allow one to infer the initial progenitor of an observed supernova. Recent 3D hydrodynamic simulations of radiation dominated envelopes in massive stars and internal magnetic field strengths of order $\sim 10^5$ Gauss, suggest the need for further investigation [4]. **I will investigate the uncertainties associated with the structure and evolutionary properties of massive stars that will end their lives as CCSNe explosions.** Using a state of the art stellar evolution code, Modules for Experiments in Stellar Astrophysics, I will focus on uncertainties due to the nuclear reaction rates, compositional mixing, and the effects of rotation and induced magnetic dynamos.

Specific steps include the sampling of new Monte Carlo nuclear reaction rate distributions for key nuclear reactions using the recently constructed rate library, STARLIB [5], and performing a quantitative assessment of the effect of varying strengths of compositional mixing and rotational values. The utilization of new measurements of nuclear reaction rates at astrophysically relevant energies forthcoming from the *Facility for Rare Isotopes Beams* will also be paramount in this effort. **My background in stellar astrophysics, especially my past published work on modeling super asymptotic giant branch stars [2]**, will allow me to play a productive role towards modeling more physically accurate stellar models that can address fundamental questions in stellar and galactic evolution.

Supernova explosion mechanisms. Collapse of the iron core within a massive star initiates the CCSNe explosion. The inner core is then halted once densities exceed that of nuclear matter, resulting in core bounce launching a shock towards the still collapsing outer core. However, the shock is not strong enough to blow up the star and is usually halted. This stalled shock has led to the so-called 'failed supernovae' problem and has left many scientist trying to determine the mechanism which allows for the efficient explosion of CCSNe observed. Contemporary approaches favor neutrino transport as an efficient means of reheating, or adding energy to, the stalled shock allowing for a successful explosion. Recent studies suggest a correlation between the local neutrino heating rate and successful explosion [1].

I propose to continue this effort by investigating various explosion mechanisms of CCSNe and addressing uncertainties therein. My primary numerical instrument will be the 3D adaptive mesh hydrodynamic code, FLASH. The computational resources available at my proposed graduate institution, California Institute for Technology, will make these efforts feasible, while the expertise of the group I wish to join will provide the neccessary support to successfully address these scientific questions.

Nucleosynthetic yields and gravitational wave bursts. Successful CCSNe explosions are also known to produce iron-group elements and experience bursts of gravitational wave radiation. **I propose to investigate gravitational wave bursts caused by CCSNe as well as the associated nucleosynthetic yields.**

Minutes after the Big Bang, the Universe began to synthesize light isotopes such as ^{1}H and ^{4}He. However, uncertainties still lie within the steps taken to arrive at the mélange of isotopes in our interstellar medium today. The next step towards understanding the cosmic chemical evolution of our Universe is to move towards a deeper understanding of the nucleosynthetic yields of CCSNe. **My current NSF-supported work with Dr. Frank Timmes at Arizona State University on nucleosynthetic yields in WDs [3] is preparing me** to address aspects of forging the elements during my graduate work.

Furthermore, with the recent upgrade of The Laser Interferometer Gravitational-Wave Observatory (LIGO) complete, direct detection of gravitational waves (GWs) is imminent. These ripples in spacetime can occur during asymmetric collapse to a black hole of CCSNe and provide direct tests of GR. A new field of astrophysics is upon us and requires necessary interplay between astronomy and theoretical physics. **While participating in the NSF LIGO summer research program I simulated GWs emitted by compact binary systems in an effort to test the strong-field dynamics of General Relativity** and this experience has prepared me to play a large role in this effort.

Here I present a framework for maintaining successful completion of these efforts. In years 1-2 of my graduate studies, I will work on focused effort, *Getting the progenitor right*, with successful completion corresponding to a peer-reviewed journal publication. Years 3-4 will focus on *Supernova explosion mechanisms*, again with successful completion corresponding to a peer-reviewed journal publication. Lastly, I will spend my final year considering *Nucleosynthetic yields and gravitational wave bursts*, with the culmination of this project resulting in a publication and successful completion of my Ph.D.

The focused efforts presented here would result in the advancement of our understanding of the evolution and subsequent explosion of massive stars, leading to advancements in the fields of cosmology, astronomy, and theoretical physics. These are immense, broad questions that require expertise in multiple backgrounds as well as interdisciplinary collaborative efforts. Being supported by the NSF through the GRFP would accelerate my goals by allowing me to begin research my first year and be invaluable in preparing me for a successful career.

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[2] Farmer, R., Fields, C. E., & Timmes, F. X. 2015, The Astrophysical Journal, 807, 184

[3] Fields et al. 2016, The Astrophysical Journal, in prep.

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[5] Sallaska, A. L., Iliadis, C., Champange, A. E., et al. 2013, ApJS, 207, 18