Neutron Star Merger Simulations

To whom it may concern:

It is my pleasure to have thes opportunity to write this essay describing my dissertation research and my professional goals. I hope by reading this essay you will be as exited as I am of the potential and actual scientific result of my dissertation research, and able to appreciate my professional aspiration and goals.

I am a doctoral candidate in computational astrophysics. My dissertation topic is about creating computer simulation of neutron stars merger. I will explain what this is and why this is an important and exciting scientific endeavor.

In the late 1960s, U.S. satellites Vela originally built to detect nuclear weapon test after the Nuclear Test Ban Treaty started registering gamma radiation pulses, radiation commonly also emitted by nuclear weapon. Long story short, the scientists who analyzed the data finally realized that the sources of this gamma radiation where of cosmic origin, randomly distributed on the sky. These are now known as Gamma-Ray Bursts (GRB).

There are two different kind of GRB: long bursts that last anywhere from 2 seconds to several minutes, and short bursts that last only up to one second or less. Although we currently do not know the actual mechanisms that produce GRBs, we have indirect evidences that the latter are associated with neutron stars mergers event. One goal of my dissertation research is to explore the possible mechanisms of the production of short GRB through computer simulation of neutron star mergers.

Neutron stars are astronomical objects that have been observed in nature, both as a star in isolation, and also in a binary system, where two neutron stars orbit each other. When a star that has mass more than 8-10 times the mass of our Sun runs out of its fuel, it undergoes gravitational collapse that results in a massive explosion known as core-collapse supernova that shreds all of the star outer-layer. The remnant of this event, at its core, is a very dense object: a neutron star.

There is another interesting physical phenomena associated with neutron star mergers, namely gravitational wave. According to Einstein's theory of relativity, gravity is not a mysterious action-at-a-distance, rather gravity is actually the effect of the space-time “topography”. Therefore, an object influence other object gravitationally by making a curvature in the space-time itself. Another consequence of this is that: massive objects that move through the space-time produces a ripple through the space-time itself: gravitational wave.

Observing gravitational wave directly will be a significant scientific achievement for mankind. However, gravitational wave is very hard to detect directly because it is extremely weak. Efforts to detect gravitational wave have had a long history, but only recently have we advanced enough scientifically and technologically to have a real chance of the detection of gravitational wave. These efforts are currently done by international collaborations such as LIGO, VIRGO, and others. Gravitational wave astronomy will be a very novel way to observe nature because of its property. Because it is the ripple of the space-time itself, gravitational wave propagation can continue unabated through large distance, giving us information that we cannot glimpse just from electromagnetic wave such as visible lights, infrared, or x-ray. Just as we learn so much more when we started to see not only in visible light but also infrared, ultraviolet, and x-ray, being able to “see” in gravitational wave will be a new way to do astronomy and learn about nature.

Neutron stars in a binary system do not stay in orbit of each other forever. As they move, they loose their energy through the production of gravitational waves. Eventually they will spiral toward each other and collapse forming a black hole. Because of their masses and velocity, as they are collapsing they produce the strongest kind of gravitational wave, the best candidate for the detection of gravitational wave currently. However, the detection of the gravitational wave from these mergers require that we know some templates such as frequency and spectrum of wave. This will enable the extraction of the observed gravitational wave from other background noise. To provide these templates for experimental observation based on characteristics of the binary system is another goal of my research dissertation.

A realistic computer simulations of neutron star mergers is a large-scale computational problem. A simulation system or “software” for this problem will have to incorporate many physical theory to represent the multi-physics nature of the problem. A simulation system like this requires the use of supercomputers or large computational clusters to run, and therefore has to be designed and developed with this requirement from the start. As part of my research, I am currently developing such simulation system, called GenASiS for General Astrophysics Simulation System, with my scientific adviser Dr. Christian Cardall. Our computational resources includes the supercomputers at the National Center for Computational Sciences at the Oak Ridge National Laboratory. I will use GenASiS for the simulation of neutron star mergers for my dissertation work. This work will explore the possible mechanisms for short Gamma Ray Bursts associated with neutron star merges, and provides templates of gravitational wave from such events which are necessary for direct observation. The development of GenASiS also lays the ground work for further exploration of other astrophysical problems such as the mechanisms of core-collapse supernovae through computer simulations.

My professional goal is to be a research scientist and an educator in my present field. I enjoy my current research work as a doctoral candidate, and I hope to be able to continue doing it professionally. I hope to be on the leading edge of science for new discovery as I feel that I presently am while working on my dissertation. However, that is not the end it. I strongly feel that it is our responsibility to educate and make science and discovery accessible to everyone. Not only that we need to attract and educate the next generations of scientists, but we also needs to be able to communicate scientific advancement to the general public, and therefore raise scientific awareness and excitement of the general public. I hope and am certain that in my professional career after my finishing my degree I will be involved in this role as an educator.