Frontera Fellowship Research Statement: Sean Christian Lewis

Star formation is a complex, multi-physics process taking place over millions of years and extending across spatial scales of several parsecs down to fractions of an AU. Although observational techniques allow snapshot inferences of star cluster formation, detailed and powerful simulations must be designed to accurately examine the process from start to finish. As such, the simulation and study of star forming regions is a very active area of research, with innovations in simulation techniques occurring every year. My research utilizes one such innovation. *Torch* (Wall et al., 2019) is a novel simulation technique that bridges gas dynamics with collisional N-body dynamics and individual stellar feedback. It accomplishes this by pairing the magnetohydrodynamics Eulerian grid code FLASH (Fryxell et al., 2000) and the N-body stellar evolution code AMUSE (Portegies Zwart & McMillan, 2019). *Torch* combines the physics of gas heating through a wide range of densities, magnetic fields, dynamical effects between individual stars and their natal gas cloud, formation of binaries and higher order systems, and stellar feedback in the form of radiation, winds, and supernovae. Such a unique combination is extraordinarily powerful and allows for the exploration of many topics within the star formation process. With the computing power provided by the Frontera Fellowship, and the innovative atmosphere of the Texas Advanced Computing Center, I will examine the effects of massive star formation in embedded star clusters, and whether their stellar feedback has significant effects on a cluster’s formation and evolution.

Lada & Lada (2003) found that 90% of all local embedded star clusters are ultimately destroyed before they become unembedded. Our sun is thought to be a remnant of one such destructive episode. The mechanism for this destruction is commonly hypothesized to be natal gas expulsion. But whether massive O-type stars are especially effective at removing surrounding natal gas *and* significantly disrupt the stellar cluster is still a topic of debate. More broadly: are there any consistent energetic and dynamical patters due to O-star formation? My research will begin to answer such questions. *Torch* is the perfect environment for such a study: not only does its inclusion of extensive multi-physics allow for data-dense and insightful simulations, it also operates with a dynamic data architecture that I am able to easily manipulate. With *Torch*, I will create a set of controlled experiments of a star forming region where I will alter the formation time of massive O-type stars while keeping initial conditions and included physics constant. More specifically, I will design and run 24 simulations (12 pairs). Each pair will evolve a 10,000 solar mass cloud with identical initial conditions, but I will manually force an O-type star to form early in one simulation and not at all in the other. By creating a collection of simulations in this way and through analysis of cluster and gas structure, dynamics, and energetics, I will be able to examine if any resulting patterns are largely stochastic or generated by the O-star formation.

*Torch’s* adaptive mesh refinement (AMR) computational space allows for high levels of resolution in regions of interest. In the case of star formation, such regions are those of Jean’s unstable gas (Jeans, 1902) collapsing to form stars which can extend a few hundredths of a parsec, about one thousand times smaller than the scale off the full simulation space. Therefore, the star forming regions constitute a large number of computational grid cells. Each grid cell interacts gravitationally with surrounding cells, are heated by background radiation, and employ a hydrodynamical Reimann solver for each grid face to determine gas flow. In addition, star-gas, gas-star, and star-star interactions must be calculated. Finally, the computational domain must be evolved thousands of times per simulation run. Each simulation will therefore be very computationally expensive and parallelization across Frontera’s HPC architecture is absolutely necessary. I have designed my plan of research to utilize the allotted 50,000 computer hours to their full capacity. A typical simulation will constitute 2,000 hours of computation time across 20 to 40 processors. In my test runs, 2,000 computer hours generally corresponds to 1.5 Myr simulation time—a point when collapsing regions of gas have been established and the first few dozen stars have formed. At this point, an estimated 100 Gigabytes of data per simulation will have been generated. My remaining computation time will be spent performing the necessarily parallelized data analysis and image processing. Data visualization is vital to this research as it will allow me to compare simulated gas and stellar distributions with observational data captured by the likes of the Hubble Telescope and ALMA. To efficiently process my simulation data, I will employ the Python data visualization package *yt* (Turk et al., 2011).

My research, although currently self-contained, has been developing along-side other graduate students and faculty in addition to my advisor Dr. Stephen McMillan. Aaron Tran of Columbia University has done an extraordinary amount of work refactoring *Torch* into the readable and modular form it takes today. My committee member Dr. Mordecai-Mark Mac Low of Columbia University and the American Museum of Natural History has consistently lent me his support and astrophysical knowledge. Also, graduate students Claude Cournoyer-Cloutier of McMasters University and Sabrina Appel of Rutgers University are currently developing branches of *Torch;* implementing stellar jets and primordial binary formation respectively. Together, we hope to continue to our active collaboration and keep *Torch* a thriving source of new research opportunities.

The volume of data and insights received from my simulations will provide numerous starting points for other research projects. I expect to mentor one or more Drexel undergraduate students while they use aspects of my datasets for analysis projects and senior theses. By allowing me to design, process, and analyze two dozen simulations, the Frontera Fellowship will provide a critical stepping stone towards my thesis goals.

The effects of O-type star formation in embedded stellar clusters

Abstract: In a controlled set of simulations, I follow the formation and evolution of embedded star clusters and the effects of O-type star formation. To do this, I use the newly developed magnetohydrodynamic and N-body physics software suite *Torch*. I design two simulation pairs—each have identical initial conditions, but one is predetermined to form O-type stars early and the other will form none at all. The evolution of the star clusters in each simulation is then analyzed to determine how O-type star radiation, winds, and supernovae affect the surrounding star cluster and natal gas.

This project will follow the formation and evolution of embedded star clusters as a controlled set of experiments. To do so, I use the newly developed magnetohydrodynamic and N-body physics software suite *Torch*. I design twelve simulation pairs—each have identical initial conditions, but one is predetermined to form O-type stars early and the other will form none at all. The evolution of the star clusters in each simulation is then analyzed to determine how O-type star radiation, winds, and supernovae affect the surrounding star cluster and natal gas.