Personal Statement

I am proposing to be a Frontera Computational Science Fellow because I seek critical support for my research studying [this thing] using novel techniques and software to create cutting-edge simulations

My research experience began in undergraduate at Cal Poly San Luis Obispo with Dr. Vardha Bennert where I attempted to determine the most accurate fitting technique for the o[III] emission spectra of 80 local active galaxies. Ultimately, my contributions are now published in Bennert et al. 2018 which investigates the possibility of using the o[iii] line width as a surrogate for galactic core velocity dispersion. At the same time I was also the Treasurer of the physics honors society Sigma Pi Sigma.

My research experience as a graduate student at Drexel University has extended beyond my successful Oral Qualification exam. I presented a research poster detailing the survivability of globular cluster close encounters with supermassive binary black holes at the 2019 AAS winter meeting. Now I am working with a group of ~a half dozen other graduate students using and developing a bridged magnetohydrodynamical n-body star formation software suite TORCH. Currently I am using the supercomputing cluster Draco at Drexel University as my basis for performing simulations, multiprocessor image and data analysis. In addition, I am the Treasurer and Co-Event Coordinator of the physics graduate student organization PGSA where I have allocated funds for and planned public outreach programs such as the Drexel Scholar Share event, participation at the Philadelphia Science Festival, and community activities such as the Graduate Student camping trip and bimonthly PGSA student lectures.

The TORCH software suite is extensive enough that multiple individual projects are currently ongoing. But cohesiveness, cooperation, and communication are all still necessary. As a team, researchers and advisors meet bimonthly to discuss progress, problems, and predictions. I also attended a multiday meeting at the Simons Foundation Center for Computational Astrophysics in NYC. As an individual, my research tasks are to create a set of simulations that

Five years in the future, after receiving my doctorate degree, I see myself participating in a research team focusing on fluid simulations, hydrodynamics. Either in industry or scientific field.

I would make an Outstanding Frontera Fellow for a few reasons, firstly, my current and continuing research is well established, with a concrete end goal facilitating progress on a daily basis. My expertise in using supercomputing clusters at Drexel and my concrete understanding of star formation environments, processes, etc. and my eagerness to communicate, share, and learn from others lends to a cohesive and productive work environment

Research Statement

Nearly all stars form within a cluster of 100s to 1000s of stars. Stellar clusters begin as a giant molecular cloud containing 1e4 – 1e7 solar masses of molecular hydrogen and traces of CO within which a complex interplay of turbulence, magnetic fields, and heating/cooling creates gravitationally unstable regions that will collapse, fragment and collapse further to produce compact stellar cores, birthing 100s of stars in a region of less than a parsec in diameter. The newly born stars, still embedded within their natal gas, now affect their environment gravitationally and radiatively potentially promoting or halting future star formation in the region.

Heirarchal star formation is a significantly complicated Multiphysics process extending over millions of years and throughout spatial scales of many parsecs down to fractions of an AU. Observational techniques of star birthing regions are held back by limitiations caused by timescales, spatial resolution, and light extinction: the hiding of important dynamical and energetic features within the early moments of star formation.

This naturally represents an ideal system to employ computer simulations and utilize the power of modern supercomputing, multiprocessing capabilities. My research utilizes such a star formation simulation software known as *Torch* (Wall+19). *Torch* is an AMR mesh eulerian grid code significant due to it’s explicit functionality in bridging the software suites FLASH (magnetohydrodynamics) and AMUSE (N-body dynamics) allowing for the placement of star particles sampled from the IMF into the natal gaseous environment, the modeling of gas-star and star-gas gravitational dynamics as well as stellar feedback evolving along with the individual stellar life cycle. Such a detailed modeling requires highly parallelized processing on powerful computing clusters the likes that TACC is able to offer.

*Torch* is a novel method for star formation simulation and boasts high stability, portability, and is modular. EXPLAIN EACH OF THESE

How much time does one simulation take? How will I use the 50k computer hours?

4 simulations taking ~10k hours each to complete

Remaining time to process data, creating image series (videos) from plot file output using yt-project

How much data space does a typical simulation run need? ~200G, 50G to first star formation

Supernovae: we have the capability, let’s see what happen! No more accurate simulations run long enough to detonate a star.

Plan of research:

Ultimately, I will create a set/series of controlled experiments by using the same dynamics and structure of the initial GMC and using consistent physics throughout each simulation (global heating, cooling, and photoionization rates) leaving the order in which stars are formed to be the main source of randomness in the simulation. I then will look for and explore any common patterns in star cluster structure, regions of formation, expulsion of natal gas, star formation efficiency. Since I have direct control over the star forming future of all Jeans unstable regions of gas, I will investigate whether specific sequences of star forming events lead to patterns; notably I will compare/analyze the effects of early O-star formation.

In addition, I would also like to explore the extent to which the GMC initial conditions (gas structure, energy budget, velocity field) affect star cluster formation, stellar and gas dynamics. Currently, the GMC initial conditions are simplified and not realistic (especially the GMC structure). It may be that simple initial conditions and complex alternatives result in very different or similar cluster formation and cluster/gas behavior. \

*Torch* provides a stable, portable, and modular computational software suite used to simulate star cluster formation from initial conditions and using physics that are easily controllable by the user. *Torch’s* method of bridging the AMR Eulerian grid magnetohydrodynamics code FLASH with the n-body dynamics software engine AMUSE provides a novel computational structure on which the feedback and dynamical effects of individual stars can be followed. This uniquely detailed and controlled modeling of the physical processes that govern star cluster formation will allow the exploration of the specific dynamic and energetic effects of early massive O-type star formation. *Torch* is no longer in the development phase and such simulations are currently possible and are being conducted given enough computing power and time.

When a star forming region is detected in *Torch*, the region is assigned a list of stars that are to be produced there as mass is accreted into the region. By manipulating this list, we are able to control in what order stars form and what mass (and therefore feedback properties) a star has. At TACC, Sean will conduct a series of controlled experiments of a self-gravitating 10,000 solar mass gas cloud. The 4 simulations (two pairs) will be used to specifically investigate the effects on star formation and giant molecular cloud structure by manipulating when and where O-star formation occurs. To do this, the first simulation pair will have identical initial conditions (thereby ensuring a star forming region will occur in the same location) and once a star forming region is identified, one simulation will be set to produce an O-type star right away, while the other will be manipulated to avoid O-star formation. The second pair of simulations will perform the same task but will have different initial conditions (randomized gas velocity field) to promote star formation in a different location within the natal cloud. Ultimately, Sean will examine any resulting patterns in star formation location, and cloud/star cluster disruptions to determine if the patterns are largely stochastic or if they are driven by the specific event of an O-type star forming. And, perhaps more broadly, Sean will use the produced dataset to answer: what patters does massive star feedback consistently lead to?

A typical simulation will begin forming stars at 600-1000 hours of computation time, using 25-40 processors. The data output at this point averages 20 Gigabytes per simulation, and if pushed for another 4000 hours will typically approach 200G with ~150 stars forming. As such, the majority of TACC’s allotted 50k computational hours will be devoted towards processing the four simulations, 10k computer hours each. On an important note; *Torch* simulations are designed such that a checkpoint file is written to disk at a user-defined frequency. A checkpoint contains all simulation data and state information and so can be restarted from that point without consequence or loss of information. In addition, such a restart can be performed on a computing system separate from the one used to begin the simulation. Therefore, we will be able to continue simulations at TACC as well as continue the simulations initiated at TACC. The remaining computation time will be devoted to the data reduction and analysis of each simulation. Using the yt-project python package, the physical data within *Torch’s* output files may be processed and converted into visual representations of the star forming regions where the dynamics and energy budget of the molecular gas as well as the dynamics and feedback of the individual stars can be examined. Such images/movies are critical to understanding the accuracy of the simulations as simple visual comparisons to observational data is a powerful tool. Sean has already written some rudimentary versions of *Torch* image processing and data analysis algorithms and has generalized and parallelized them such that any set of *Torch* data files can be processed across any number of processors. As further optimizations and development is needed here, the computationally focused environment at TACC will lend valuable assistance on this front.

Overall, Sean’s current work with *Torch* will be amplified by the computational opportunity provided by the Frontera Fellowship and the innovative and passionate environment fostered at the Texas Advanced Computing Center.