**Notes for all editors - PLEASE READ BEFORE EDITING**

* Thank you for taking the time out of your day to provide comments on my graduate school materials. I recognize that your time is important, and I am very grateful for any feedback you can provide
* Please, be honest. If something stinks, let me know. I want to showcase the best representation of me to these schools. If that is not present here, I want to know about it.
* There are three sections of my personal statement. I would like to make this statement as concise as possible. Two pages is the maximum length dictated by the [GRFP guidelines](https://www.nsf.gov/pubs/2021/nsf21602/nsf21602.pdf)
* I am debating including my current spectrograph work in this statement. LLAMAS is not as powerful as DESI, but it would be a natural extension of what I’m currently doing

**Notes for editors who are unfamiliar with the structure of an NSF GRFP personal statement**

There are three components to an NSF GRFP research statement

The evaluation criteria is **bold** below and fully detailed [here in](https://www.nsf.gov/pubs/2021/nsf21602/nsf21602.pdf) section VI.

* **Intellectual merit**
  + What is the potential for the proposed activity to advance knowledge and understanding within its own field or across different fields?
* **Broader impacts**
  + What is the potential for the proposed activity to benefit society or advance desired societal outcomes?
  + In general, THIS EVALUATION CRITERIA (**broader impacts**) is what earns people the fellowship. There are a lot of people who can research at a high level, but not a lot of people who can impact the world outside of their lab.
* Future goals
  + How will the NSF GRFP help me reach personal and professional goals?

Additional evaluation criteria that apply to both **intellectual merit** and **broader impacts**

* To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?
* Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale?
* Does the plan incorporate a mechanism to assess success?
* How well qualified is the individual, team, or organization to conduct the proposed activities?
* Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?

Some of these criteria I am trying to answer in just the research statement, some criteria I am trying to answer in the personal statement, others in both. If there is an opportunity to answer the evaluation criteria strongly in either supplement that I am missing, please point it out.**Research Statement Sean MacBride**

**Quantifying the Evolution of Baryonic Structure in the Dark-Energy Dominated Universe**

**Abstract**: Galaxies are diverse tracers of the fabric of the universe, comprised of stars and the interstellar medium. Integrated observations of galaxies provide information about the macroscopic properties of these galaxies but lack information about different sub-structures of the galaxy. The capability of observational facilities is rapidly increasing with the recently commissioned *Dark Energy Spectroscopy Instrument* (DESI) and soon to be commissioned *Large Lenslet Array Magellan Spectrograph* (LLAMAS) ushering in a golden age of cosmology-driven galaxy surveys. The *Bright Galaxy Survey* (BGS)of DESI will obtain spectra from over ten million galaxies in the dark-energy dominated universe.[[1]](#footnote-0) This improves the sample size of galaxies from the *Sloan Digital Sky Survey* (SDSS) tenfold.[[2]](#footnote-1) Prior surveys of interstellar content and galactic observables have provided an incomplete picture of interstellar medium evolution in a cosmological context due to high sample observations being comprised of integrated spectra while spatially resolved spectra are available in only low samples. **I propose a study to study the relationships between different galactic properties in the dark-energy-dominated universe by extending conclusions from spatially resolved galactic spectra to infer properties missing from integrated spectra.** To ensure that the next generation of spectroscopic surveys has a large impact on this effort, it is necessary to 1) determine the macroscopic scaling relationships of molecular gas and dust in galaxies using integrated spectra, 2) compare the global relationships to high angular observations of galaxies to search for local variations in dust and gas evolution, 3) utilize BGS and LLAMAS observations with previous calibrations to investigate what integrated observations do not capture about baryonic evolution of galaxies. The combination of these measures will lead to enormous leaps in our understanding of galactic evolution in the cosmos.

**Intellectual Merit**: Integrated spectra of nearby galaxies using the *eXtended CO Legacy Database for the GALEX Arecibo SDSS Survey* (xCOLD GASS) have led to inferences regarding themolecular gas content, star formation, and other mechanisms involved in galaxy growth.[[3]](#footnote-2) I will apply a similar methodology to characterize dust evolution in galaxies using observations from the *JCMT dust and gas In Nearby Galaxies Legacy Exploration* (JINGLE) survey[[4]](#footnote-3) and extend these investigations to quantify the physical parameters that drive molecular gas evolution in galaxies. I conducted a preliminary analysis using these surveys, showing that Balmer emission in galaxies has a strong correlation with molecular gas and dust.[[5]](#footnote-4) These results are set to be tested within separate galaxy surveys (SDSS, legacy surveys for DESI[[6]](#footnote-5)) to look for discrepancies and further improvements for the model by determining the observables that affect gas conversion into stars and the biases that impact observations.

While global calibrations derived from integrated spectroscopy provide a solid foundation for studying galaxy formation, they do not account for diverse stellar populations that exist in galaxies. The *Physics at High Angular Resolution in Nearby GalaxieS* (PHANGS) survey is a spectroscopic and photometric survey to image nearby galaxies at high resolution.[[7]](#footnote-6) Starting with the global scaling relationships from the xCOLD-GASS and JINGLE surveys, I will apply a similar methodology to spectra from the PHANGS-MUSE (Multi Unit Spectroscopic Explorer) survey to look for variations in gas, dust, and star formation evolution within different galactic structures. Understanding the variations in substructure evolution provides an in-depth probe of the star formation and dust accretion processes in galaxies. To examine the influence of these mechanisms, I will design new analyses and classification codes in Python to determine radial dependencies, evaluate individual clouds, and assess the impact of motion on gas and dust evolution.

PHANGS-MUSE observations are limited to a relatively small sample of galaxies (19 ALMA + VLT/MUSE targets). To remedy this, I will apply the conclusions from these observations to LLAMAS observations.[[8]](#footnote-7) LLAMAS will be commissioned in 2022 and is capable of spatial spectroscopy of galaxies to redshift z<1 with a similar spectral range and resolution as DESI. Observations from DESI can be complemented with faster observations (14 min for LLAMAS vs. 29 min for DESI) to further refine our models ahead of the deeper survey catalogs from DESI.

The ultimate goal of this study is to use observations from DESI and LLAMAS with models of interstellar content from PHANGS, JINGLE, and xCOLD GASS to evaluate galactic evolution in a cosmological context. The Bright Galaxy Survey of DESI will obtain multi-wavelength photometry and optical spectroscopy using integrated spectra. I will search for biases in DESI observations and then apply previously derived calibrators from xCOLD GASS and JINGLE to DESI observations. This will form a comprehensive picture of matter evolution by using conclusions from spatially-resolved observations to better understand evolutionary processes not obvious from integrated spectra.

The proposed investigation is an organic extension of my previous research with Prof. Amélie Saintonge. We derived interstellar medium evolution in JINGLE and xCOLD GASS galaxies. Developing and modifying models to test observational data against previous results has thoroughly prepared me to execute techniques pertinent to understanding galaxy evolution. My experience at Rutgers University prepared me with the data analysis tools to study large astronomical datasets through the creation and amendment of a data pipeline for use with Gaia astrometry. I have also integrated and tested the LLAMAS spectrograph, which has provided me with the background to understand the intricacies of fiber-fed spectrographs used in cosmological surveys.

An optimal location to execute this project is Harvard University, with a strong combination of faculty expertise and privileged facility access. As a consortium member of DESI, faculty are directly involved in the instrument development and observing program (D. Eisenstein), along with others actively contributing to studies of galaxy evolution and cosmology (D. Finkbeiner, C. Conroy). In addition, Harvard is a consortium member of the Magellan Telescopes - one of which will host LLAMAS.

**Study Overview**

**Year 1**: While DESI begins observing, I will finalize and publish dust and cold-gas scaling relations of integrated spectra obtained by xCOLD GASS and JINGLE surveys.

**Year 2**:I will apply methodology from xCOLD GASS calibration to the PHANGS survey and create new classification tools to investigate local galactic evolution behavior.

**Year 3:** I will use LLAMAS observations to perform initial tests to accurately inform galaxy evolution models forthcoming from DESI.

**Year 4**: I will apply the dust and cold-gas calibrators to BGS spectroscopy and compare BGS measurements to insights from xCOLD GASS, JINGLE, PHANGS, and LLAMAS surveys.

**Year 5**: I will consider the impact of this investigation on our understanding of both local and global galaxy evolution in the dark-energy universe, in culmination with the completion of my Ph.D.

**Broader Impacts:** The proposed work will advance our understanding of interstellar medium and galactic evolution, setting standards for future studies of baryonic structure growth. The DESI collaboration will also produce galaxy-clustering data and mock catalogs for constraining the dark-matter halos that host galaxies. Utilizing the proposed study and analysis of galaxy-clustering would result in a comprehensive and precise understanding of the evolution of structure in the dark-energy-dominated universe. The combination of these analyses would facilitate constructive collaboration between observational astronomers, theoretical cosmologists, and computational astrophysicists.

Widespread interdisciplinary scientific participation is essential to promoting universal academic and social good. The implementation of machine-learning methods is integral to extracting fundamental insights from over 30 million galaxy spectra. While astronomy has reaped benefits from machine learning, similar algorithms have transformed analyses in biology, chemistry, economics, and other disciplines. To facilitate the dissemination of advanced analytical resources, I will host newly developed tools on GitHub for public utilization by other scientists. Additionally, I will provide context for each technique with a public website and leverage the platform to encourage contributions from researchers in other disciplines.

1. [The DESI Experiment Part I: Science,Targeting, and Survey Design](https://arxiv.org/abs/1611.00036) 31 Oct. 2016 [↑](#footnote-ref-0)
2. [Panchromatic properties of 99000 galaxies detected by SDSS, and (some by) ROSAT, GALEX, 2MASS, IRAS, GB6, FIRST, NVSS and WENSS surveys](https://ui.adsabs.harvard.edu/abs/2006MNRAS.370.1677O/abstract) Aug. 2006 [↑](#footnote-ref-1)
3. [A new empirical method to estimate the molecular gas mass in galaxies](https://arxiv.org/abs/1905.02214) 6 May 2019 [↑](#footnote-ref-2)
4. [JINGLE V: Dust properties of nearby galaxies derived from hierarchical Bayesian SED fitting](https://arxiv.org/abs/1909.05266) 11 Sep. 2019 [↑](#footnote-ref-3)
5. [MCMC-Dust-Gas-SF-Gal · GitHub](https://github.com/seanmacb/MCMC-Dust-Gas-SF-Gal) [↑](#footnote-ref-4)
6. [Overview of the DESI Legacy Imaging Surveys](https://iopscience.iop.org/article/10.3847/1538-3881/ab089d) 17 Aug. 2021. [↑](#footnote-ref-5)
7. [The Physics at High Angular resolution in Nearby GalaxieS (PHANGS) Surveys](https://ui.adsabs.harvard.edu/abs/2019Msngr.177...36S/abstract) Sep. 2019 [↑](#footnote-ref-6)
8. [LLAMAS: ​​A Facility Integral Field Spectrograph for the Magellan Telescopes](http://www.mit.edu/people/rsimcoe/Llamas_pocketguide_rA.pdf). Aug. 2021. [↑](#footnote-ref-7)