Statement of purpose

In graduate study, I am mostly interested in **gravitational physics and Cosmology**. The successful detection of gravitational waves from black hole mergers by LIGO in 2016 has motivated extensive efforts to model the general relativistic effects of compact objects. However, the analytical solution of the Einstein field equations remains an incredibly challenging task due to its inherent nonlinearity and a high degree of coupling. To date, within the limits of human capability, accurately modeling gravitational waves from binary neutron star mergers can only be achieved through discretizing spacetime and solving the field equation step by step. This is also the case for high energy astrophysics due to the complexity of the Navier-Stokes equation. Some astrophysical phenomena that are hard to be directly observed or measured can be revealed by the higher performances of numerical simulation codes and then provide valuable guidance for observational studies. Several code packages have been developed and refined, such as HARM for black hole accretion, Gadget for cosmological N-body/SPH simulations and Athena++ for MHD simulation.

Among them, **Prof. David Radice** focuses on numerical relativity, especially modeling the binary neutron star merger. As early as 2014, he developed the first higher-than-second-order GR hydrodynamic simulation code, `WhiskyTHC`. Years later, with the help of this module, he conducted the largest set of NS simulations and studied the merger's dynamical ejecta, nucleosynthesis and EM counterparts. In 2020, he discovered that a high-mass ratio of NS binary tends to cause tidal disruption and successive accretion and finally, form a prompt collapsed BH. In recent years, he also participated in the simulation of Black Hole binaries with the aim of meeting the precision requirements of future GW detectors. After reading through a substantial number of his papers, I can sense his remarkable ability to focus on a specific topic for years, steadily building a series of accomplishments that ultimately culminate in significant breakthroughs. Therefore, I am eager to conduct simulation study of compact object mergers. I would also like to apply the simulation codes to the simulation study of Tidal Disruption Event. My previous research experience in the simulation of BH accretion is very helpful to Prof. Radice, and I am confident that I will become one of his star pupils. Besides, I am also interested in working with Prof. **Eugenio Bianchi** to study the general-relativistic statistical mechanics. There are also some professors in Astrophysics and Astronomy that match my research interests, such as **Yuexing Li** and **Steinn Sigurdsson**. My story is below.

My journey began during a visit to the Fuxian Lake Solar Observatory in Kunming, where I was introduced to MHD for studying the Sun's interior by Prof. Chun Xia. There, I witnessed how the activity of the sun influence on Earth. Exploring the application of fluid dynamics during my undergraduate ignited my passion for astrophysics. My excellent academic performance in my freshman year earned me a place in the Fudan University Joint-Cultivated Undergraduate Program. At Fudan, I strengthened my understanding of theory foundations. Although this program was interrupted by the *2022 Spring Shanghai Lockdown*. I continued pursuing study opportunities at the University of Notre Dame and UC Santa Barbara. These study and research experiences shaped my research taste and laid a foundation for my future academic career.

In my junior year, I initiated a research project on extreme super-Eddington BH accretion in AGN. It is well known that the accreting material piled at the surface of a neutron star or white dwarf will go through thermonuclear fusion and shine in X-ray band. Why is then the accreting black hole cannot induce such a burst? What is the difference between a black hole accretion and a neutron star? On the other hand, fast accretion BH is thought to form in the disk of AGN. Small BH mass with a fast accretion will bring a hotter and denser ambient. Based on these questions and analysis, we started from the basic advection-dominated accretion flow model and explored the effect of thermonuclear fusion on fast accretion. In energy equation, we considered the heat released by two types of hydrogen burning and Helium burning. In order to learn more about nuclear reactions, I studied advanced courses at UCSB as an exchange student. I was also introduced to the Modules for Experiments in Stellar Astrophysics (MESA). After I returned, with my supervisor's help, I developed a 4th-order Runge-Kutta method using Python to solve the disk structure. The result shows that heat released by fusion is still negligible, mainly due to the low density and high *advection* cooling rate. After our discussions, my answer to the initial question is that BH has no clear physical surface to deposit the material, therefore, cannot make it as dense and as hot as those in NS or WD. After that, I decided to employ an open-source code(the workhorse of MESA) to compute the nuclear reaction network. Significant metal enrichment has been reproduced. If these elements are carried by the outflow of the disk, we may explain the supersolar metallicity observed in the broad line region. During this research, I

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greatly enhanced my skills in numerical simulation and parallel computing on a Linux server. This work culminated in a paper accepted by *MNRAS* (See the link).

In the summer of 2023, I participated in the International Summer Undergraduate Research Experience at the University of Notre Dame, where I worked with Prof. Boja Anguiano to study the kinematical and chemical properties of the M33 galaxy. Using spectra of approximately 100 clusters obtained with the Hectospec instrument at the MMT Observatory, I processed the data with Python to classify the clusters into young($\lesssim 3 \times 10^8$yr), intermediate and old($> 8 \times 10^8$yr) populations. Subsequently, I calculated metallicity, velocity, and spatial distributions to identify statistical patterns. Our analysis revealed that young clusters are more metal-rich ([Z/H] $\sim$ −0.1), while older clusters exhibit greater scatter in metallicity and weaker correlations with age. Furthermore, we observed that the velocity dispersion relative to local disk motion increases with cluster age, and rotational velocities decline with age. It is also noticed that young clusters are concentrated in the inner disc regions (< 4 kpc), while older clusters are more evenly distributed. This experience allowed me to understand the typical workflow of data analysis in the field of galaxy evolution, as well as the importance of observational study in guiding theoretical research.

In this fall quarter, I finished several graduate courses at UCSB; one was High Energy Astrophysics conducted by Prof. Omer Blase. I also finished a course project entitled Repeated TDEs(link). I surveyed the observational and theoretical progress in explaining repeated TDEs and concentrated on the promising models. Hills Mechanism and Kozai-Lidov Mechanism are two promising directions, both trying to introduce a third body's perturbation to drag the star near the disruptor. This course has not only pushed me to the most cutting-edge and active research directions in the field but also deepened my understanding of radiation mechanisms in high energy astrophysics. I also finished a project related to planet formation theory under the instruction of Prof. Ben Mazin at UCSB.(Link)

In addition to astrophysics, I am also interested in statistical mechanics. I conducted a project entitled Phase Transitions in the 2D Ising Model with Prof. Bo Zheng. Using Monte Carlo method, I simulated the Paramagnetism-Ferromagnetism transition of the system using Python. I analyzed the order parameters of the system and compared the convergence and robustness of two strategies. Wolff Algorithm displayed enhanced accuracy and speed as the system expanded, owing to its multi-particle flipping strategy. I also made an animation that shows the transition of the symmetry breaking of the lattice. This research deepened my understanding of how different algorithmic strategies can significantly improve computational efficiency. I believe that my solid theoretical foundation and multidisciplinary research experience will greatly benefit me in my graduate study.

Apart from my research background, I cherish my commitment to astronomy outreach. As astronomers push our knowledge and technologies to the limits, we shall never leave behind the general public who share the same passion for astronomy. I was a member of the Yunnan University Astronomy Club since my freshman year. During my final year, I organized science outreach events at Yunnan University in collaboration with other members of the Astronomy Club, inviting high school students to visit the observatory. We taught visitors how to use the optical telescope to locate and identify typical celestial objects such as Jupiter and Saturn, and shared knowledge about traditional Chinese calendrical systems. Noticing that some of the visitors were international tourists from Southeastern Asia, I prepared bilingual (Chinese and English) scripts for the Yunnan Observatory tours and established a standard protocol for guided visits. I was proud of our efforts since we are promoting astronomy to people who do not have any related background. At PSU, I also aim to contribute to initiatives that support underrepresented students in physics and astronomy, such as mentorship programs for international students and serving as a teaching assistant for students facing academic challenges. My journey from an under-resourced village to the front gate of a top-tier graduate program reflects resilience and a commitment to equitable access to education, and I hope to inspire similar transformations in others.

Overall, the Department of Astronomy and Astrophysics, the Department of Physics, the Institute for Gravitation and the Cosmos at Penn State offer a broad range of research topics pursued by various scholars. This interdisciplinary environment fosters intellectual stimulation and encourages collaboration across different fields, enabling us to tackle scientific challenges in unexpected and innovative ways. Therefore, I am deeply enthusiastic about starting my graduate studies at PSU. In the long run, I am going to be a theoretical and numerical astrophysicist aspiring to build models of gravitational physics that better align with observational data and adhere more closely to physical intuition.

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