“The ability to simplify means to eliminate the unnecessary so that the necessary may speak.”
— *Hans Hofman*

▣ A Personal Sketch.

As the son of chemists, I grew up wanting to be a scientist. However, this was sort of a vacuous sentiment at the time—I had no idea what it meant to actually “do science”, what a science was or where I could get one. In fact, while I was nose-deep in popular science books, the reality of science was as far removed from me as is the second-nearest star cluster from Earth.

In my second year of high school, I took AP Physics on a whim with no real expectations. However, the impression of the subject left on me by my physics teacher, Mrs. Eibeck, was transformative. Through her dedication to the subject and its simple yet powerful methods, I discovered two lasting ideas which continue to guide my journey today:

(1) The elegance of the ability of simple physics to describe a wide range of phenomena in our universe, and
(2) the joy of communicating physics to others.

▣ Intellectual Merit.

While I have had a number of varied interests over the last few years, I am generally fascinated by applied and emergent consequences of the kind of fundamental physics one studies in their first year of college. Though more technically demanding, advanced-level physics consistently surprises me with its enduring linkages to elementary concepts in physics and mathematics. Maxwell’s equations take me back to first-year multivariable, the classical Lagrangian to high school calculus, the Riemann curvature tensor to eighth grade geometry. Though always expanding my physical knowledge through coursework on quantum information, atomic physics, fluid dynamics, and beyond, I am constantly reminded of the universality of a few basic concepts whose often unintuitive consequences pave the frontier of scientific discovery.

From 2016-2019, under the supervision and guidance of Professor Jessica Lu, ***I used stellar proper motions from the WFC3-IR instrument on the Hubble Space Telescope to identify members of the Quintuplet star cluster from a crowded and highly reddened field***[1], work which led to a first-author publication. The cluster’s young age and close proximity to the Galactic Center makes it a picture-perfect example of star formation in environmental conditions taken at their apex. However, the very properties that make the Quintuplet cluster so scientifically fascinating are the very same properties that make its study so difficult. To combat the Galactic Center field’s enormous optical extinction, I constructed a reddening map by locating and dereddening “standard crayon” background red clump stars. Seeking an accurate stellar census of the cluster in the face of extreme background densities, I performed numerous artificial star injection tests to estimate stellar incompleteness as a function of detector position and brightness. After combining these analyses, calculating stellar proper motions, and determining cluster membership through a sophisticated nested sampling approach, I was able to extract critical dynamical information about the cluster: calculating its number density profile out to 3.2 pc (covering an area ~19× more than had ever been explored), putting the strongest constraint to date on the cluster’s core radius, finding signs of mass segregation, and confirming the approximate spherical symmetry of the cluster. I approached the Quintuplet’s intense natal struggle with utmost captivation, shared by students and faculty who attended my Astronomy Department lunch talk and first Physics Department Undergraduate Seminar.

In the summer of 2019, my exploration of star clusters transitioned from the study of young clusters in the Milky Way’s Galactic Center to old globular clusters in the Milky Way halo.

Working with Professor Fred Rasio at Northwestern University, ***I developed a scheme for using the observed surface brightness and velocity dispersion profiles to locate a "best-fit" model within a recent, unprecedently large grid of globular cluster simulations***[2]. Using this method, which I optimized by preprocessing simulation data for fast readout, I peered inside the expected stellar distributions of real clusters, elucidating the dynamical formation of compact and double black hole binaries in globular clusters with physically realistic parameters. In particular, I showed that globulars which had undergone rapid runaways in stellar densities (so-called "core-collapsed" clusters) were much less likely to dynamically assemble cataclysmic variable systems than their non-collapsed counterparts, though collapsed clusters were disproportionately more likely to create recycled millisecond pulsars. In studying the theoretical late-time behavior of such many-body systems and contextualizing them in real observations, I realized that, however simple it seems, Newton's Law of Universal Gravitation implies a wealth of counterintuitive emergent physics, better examples for which nature could not possibly have provided. At my second Undergraduate Seminar and Illinois Space Grant Seminar, I shared this exciting work in stellar dynamics with undergraduates at Berkeley and in Northwestern's NSF REU program.

My eagerness to learn has also taken me from the study of the very large to the very small—in the summer after my sophomore year, I explored solid-state diamond defects under Professor Norman Yao. In a way, this was a metaphorical transition from first-year classical dynamics to first-year electromagnetism and optics. After developing a code routine for identifying individual nitrogen-vacancy centers through fluorescence autocorrelation, I became increasingly interested in their promise as nanoscale sensors of electromagnetic[3] and strain fields. Under this broad goal, ***I performed an extensive literature search of existing high-pressure magnetometers to quantify the advantages presented by nitrogen-vacancy metrology methods***, a review which motivated a diamond-anvil cell study which has been accepted to *Science*[4]. Most recently, I have worked on building and maintaining a new experimental setup to measure the strain response of the lesser-explored silicon-vacancy (SiV) center, whose zero-order electric susceptibility and nice optical properties make it a prime candidate for local measurements of the strain tensor in high pressure experiments. Over the past few months, I have performed low-temperature measurements of the optical spectrum of pressurized microdiamonds implanted with SiVs to measure the hydrostatic shift of the zero-phonon line. In collaboration with the Center for Nanoscale Materials, I spent four days performing x-ray diffraction experiments to image the strain distribution inside of defect-implanted diamond anvils which had been permanently, plastically deformed by pressurization in order to subject the ingrown SiVs to interesting strain distributions which would produce a measurable optical strain response. During regular experimental updates, I present these findings to the experimental group, having become the de facto resident expert in the study of silicon-vacancy centers under high pressure. When working on solid-state defects and their metrological applications, I am in awe that these vibrant physical phenomena follow from basic quantum mechanics and symmetry.

▣ Broader Impacts.

Aware of the warm welcome I received when I came to Berkeley, I am a tireless advocate for community in our local Physics and Astronomy Departments. Throughout college, I have worked through Berkeley's chapter of the Society of Physics Students to increase department inclusivity and promote public outreach. As outreach coordinator, I organized undergraduate volunteers for numerous outreach events to local elementary schools and festivals such as the Bay Area Science Festival and Engineering 4 Kids Day, fascinating countless young students (and their parents) with our captivating library of physics demonstrations. During my tenure as vice president from 2018-2019, I supervised numerous club events, overhauled our chapter's website (sps.berkeley.edu), and wrote the annual chapter report to the national organization for which our chapter will be featured in the national organization's magazine, *The Observer*. This year, ***as president of Berkeley's chapter of SPS, I have been working to increase our social media presence, expand participation in the International Physics Tournament to other universities in the United States, and collaborate with the Mathematics Undergraduate Student Association (MUSA) and the Society of Engineering Sciences (SES) to hold the first ever Integration Bee at Berkeley***. Under my direction, we are also piloting a new mentorship program which pairs two upper division students with a group of lower division students and new transfers, which has already shown incredible success at making our department more welcoming to new students, women, and underrepresented minorities.

My desire to share physics and astronomy with others also extends through my love of teaching. In the spring semesters of 2018 and 2019, I instructed the *Python for Astronomers* course—an introduction to the Python programming language for astrophysics majors—delivering lectures as well as writing and grading weekly homework assignments and long-term coding projects. As Berkeley's astrophysics major has no formal coding requirement, this course serves as the officially endorsed coding introduction in the department. Using lessons learned from this first teaching experience, ***I designed an original Berkeley course from scratch called the*** **Beginner's Guide to the Universe*****, which aims to promote physics literacy among non-major students at a qualitative level***. Touching on selected topics from quantum field theory to cosmology, this course has challenged me to translate rigorous physical derivations into simple explanations without sacrificing the intrinsic beauty of the subject. Over the past two semesters through Splash at Berkeley, I brought these enthralling physics concepts to high school students through one-session courses on quantum mechanics, special and general relativity, and complex numbers, making my lecture notes publicly available on my personal website (nicholasrui.com). On the fiftieth anniversary of the Apollo 11 moon landing for an Astronomer Evening event at Northwestern, I even read up about solar system moons and space exploration, topics outside my direct areas of expertise, in order to make my public presentation on the subjects as effective and scientifically relevant as possible. By finding clearer and more succinct ways of explaining concepts I take for granted, I not only broaden the understanding of my students but also my own.

Through outreach and teaching, I hope to pay forward the incredible guidance of my PIs—Fred, Norm, Jessica—as well as Mrs. Eibeck back in high school and, ultimately, my parents, whose unyielding support originally kindled my childhood curiosity.

▣ Goals.

Taking with me the fundamental lessons I live by, I plan to continue research in graduate school with the ultimate goal of becoming a university professor, to pursue high-quality scientific discoveries and to educate students and the public about physics and astronomy.

References: [1] **N. Z. Rui**, M. W. Hosek Jr., J. R. Lu, et al. *The Quintuplet Cluster: Extended Structure and Tidal Radius*. Astrophys. J., 2019. DOI: 10.3847/1538-4357/ab17e0. [2] K. Kremer, C. S. Ye, **N. Z. Rui**, N. Weatherford, et al. *Modeling Dense Star Clusters in the Milky Way and Beyond with the CMC Cluster Catalog* (in preparation). [3] T. Mittiga, S. Hsieh, C. Zu, …, **N. Z. Rui**, et al. *Imaging the local charge environment of nitrogen-vacancy centers in diamond*. Phys. Rev. Lett., 2018. DOI: 10.1103/PhysRevLett.121.246402. [4] S. Hsieh; P. Bhattacharyya, C. Zu, …, **N. Z. Rui**, et al. *Imaging stress and magnetism at high pressures using a nanoscale quantum sensor*. arXiv:1812.08796, to be published in *Science*, 2019.