

# STATEMENT OF PURPOSE

MIT DEPARTMENT OF PHYSICS · PHD PROGRAM · FALL 2024

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## INTRODUCTION

I am an aerospace engineer and scientific software developer who is passionate about computational dynamics. I have been fortunate to have had the opportunity to exercise this background in support of human space exploration projects at NASA. I aspire to learn as much as possible about the physical world, and work to expand our knowledge through astrophysical dynamics research.

I am particularly interested in topics relating to galactic dynamics, large scale structure formation, and stellar formation. I hope to be considered for graduate advisement by **Dr. Vogelsberger**, **Dr. Necib**, and **Dr. Frebel**. I am eager to apply the skills I have gained through computational research, scientific software development, and large-scale dynamical studies, to astrophysics research projects within MIT's Department of Physics, and the Kavli Institute.

## RESEARCH EXPERIENCE

My graduate research assistant experience under Dr. Dave Akin brought me into the weeds of constrained, performant software development. The University of Maryland's Space Systems Lab (**SSL**) develops and maintains an 8DOF serial manipulator (**Ranger**) for satellite servicing and dexterous manipulation research. I independently developed interfaces (C++ templates) and implementations for kinematic solvers and Cartesian controllers. One **solver's** implementation introduced a performance hurdle: the computation required several intermediate-Jacobian solutions, which I initially solved-for iteratively. I substantially improved the time-performance

of each intermediate-Jacobian solve by using Julia's **Symbolics.jl** to print analytical Jacobian solutions to performant, non-allocating C++ functions; I contributed the required **build\_function** target **fixes** to **Symbolics.jl**. This experience at SSL, and others, taught me to write performant software for computationally demanding applications. Graduate course projects, under Mr. Barbee's guidance, showed me how computation can extend to physical discovery.

For the term project of my graduate Interplanetary Navigation & Guidance course, I replicated halo orbit and invariant manifold computations as summarized by Megan Rund's **thesis** on low-cost interplanetary transfer techniques. Multiple flavors of the chosen halo orbit solver algorithm existed in literature, but I found no guidance in selecting one flavor over another. My project delivered a decision tree which mapped desired orbit characteristics to compatible flavors of differential correction, alongside open source Julia **packages**, and over 130k **initial conditions** for periodic orbits. Julia's dynamic qualities allowed me to quickly explore the emergent consequences of perturbation parameter changes, and eventually find intersections between three-body manifolds. I was thrilled to have used computation to find true low-energy paths through the solar system, and I soon discovered a vibrant community of like-minded scientific software developers. After **presenting** the foundations of my project at JuliaCon 2021, I was added to the **JuliaSpace** GitHub organization. I was later invited to a **seminar** on dynamical reachability. I continued to develop and explore scientific software in personal time, and in my professional roles at NASA.

## SCIENTIFIC COMPUTING

All of my astrodynamics research codes are available as a series of Julia **packages**. I have enjoyed developing other scientific convenience packages in spare time, such as **SPICEKernels.jl**. My open source software projects are hosted at [github.com/cadojo](https://github.com/cadojo), and described on my personal website: **loopy.codes**. Professionally, scientific software has been critical to my role as an integrated GN&C analyst in the Artemis Program. I routinely execute thousands of monte-carlo simulations on HPC clusters, and analyze that data to better understand dynamical conditions which emerge during simulated atmospheric flight; in 2022, I wrote over 150 pages of technical reports which documented such investigations. While I have enjoyed contributing to human space exploration projects, and I am eager to apply similar computational investigations to scientific research.

## RESEARCH ASPIRATIONS

I believe that my simulation studies at NASA echo MIT's massive astrophysical simulation projects, i.e. **IllustrisTNG**. While different in scope and purpose, both aim to study emergent dynamical consequences of known or hypothesized physical laws. At NASA, I frequently disable specific dynamical models to determine their effect on simulated vehicle trajectories. I have been encouraged to find similar methods used in astrophysics research, such as Josh Borrow's **characterization** of the impact of the epoch of reionization on simulated galactic formation. As an astrophysics student, I hope to discuss similar such studies with my advisor, and work to characterize the sensitivity of astrophysical phenomena to other dynamical effects, i.e. galaxy formation's sensitivity to rates of stellar formation and Lyman- $\alpha$  radiation dynamics.

In my view, cosmological & galactic simulation codes have two distinct roles: fast implementations for research, and convenient interfaces for education. Fitting my graduate astrodynamics coursework into convenient open source software was an incredibly productive educational exercise, and I plan to similarly explore my astrophysics coursework through software. When appropriate, I hope to publish astrophysics codes to help undergraduate and early-graduate students learn foundational concepts through computational exploration. Julia, and its package ecosystem, provide excellent tools for such a computational playground. MIT's **Julia Lab** is revolutionizing scientific computing, and I am interested in applying their novel codes to astrophysical contexts. Might exploratory studies with **Dr. Rackauckas'** unique surrogate modeling & differentiable simulation codes help scope future high-fidelity simulation studies? If an advisor found similar ideas promising, I would welcome such interdisciplinary research opportunities. I have been delighted to find astrophysics research methods which align with my technical skill set: dynamical analysis and scientific computing. I look forward to learning more about our universe, and growing new technical skills as a scientist.

## FUTURE PLANS

I will continue to learn about topics in modern astrophysics by reading **astrobites'** paper summaries, the Simons Foundation's **Quanta Magazine**, Dr. Bovy's galactic dynamics **textbook**, and the **Big Orange Book**. As I read, I look forward to exploring more concepts through computation.

I hope I have the opportunity to learn from MIT's excellent instructors and researchers. Thank you for your time and consideration.