Statement of Purpose

MIT Department of Physics · PhD Program · Fall 2024

Introduction

My first set of simulation results at NASA were initially puzzling. Unexpected bifurcations had emerged from the dispersed vehicle trajectories, and with hundreds of models by thousands of engineers integrated into the code, I was unsure where to begin my investigation. I soon learned to pull hints from (internal) flight dynamics reports, and use linear & nonlinear analysis methods to find the models responsible for the macro-dynamical effects.

As an aspiring computational scientist, I hope to use dynamical analysis techniques to explain the processes behind galactic dynamics, the universe's large scale structure, and stellar formation. I am excited to apply for the opportunity to learn from leaders in the field of astrophysics at MIT's Department of Physics. I hope to be considered for graduate advisement by **Dr. Vogelsberger**, **Dr. Necib**, and **Dr. Frebel**.

Computation links my graduate astrodynamics research, my experience writing performant `C++` for dexterous manipulators, and my simulation studies at NASA. I believe these skills will translate productively to computational astrophysics research. Thank you for your time and consideration.

Research Experience

As Dr. Dave Akin's core robot software lead, I lived in 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. My implementation of one of Ranger's kinematic **solvers** produced a performance hurdle: the computation required several intermediate-Jacobian solutions per-cycle, 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; along the way, I contributed the required **fixes** to `Symbolics.jl`. SSL projects taught me to write performant software for computationally demanding applications. During graduate course projects, under Mr. Barbee's guidance, I learned how computation extends into 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. After failing to find guidance in literature for selecting from flavors of a particular halo orbit solver, I delivered a decision tree which mapped desired orbit characteristics to compatible flavors of differential correction, several open source Julia **packages**, and over 130k **initial conditions** for periodic orbits. 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`, and described on my personal website: `loopy.codes`. Professionally, scientific software has been critical to my role as an integrated GN&C analyst in NASA's Artemis Program. I have used linear analysis, model reduction, and parameter sweeps to explain & improve results in tens of thousands of monte-carlo simulations. 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 change 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 categories of dynamics, i.e. further quantifying galaxy formation's sensitivity to rates of stellar formation and Lyman-α 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. Julia's ease of expression, in combination with Dr. Rackauckas' surrogate modeling & differentiable simulation codes, may allow for faster cosmological & galactic model exploration. 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.