Research Statement

Motivation: Highly energetic, magnetized plasma is continuously being ejected from the Sun. This phenomenon has been of interest to generations of scientists, and is responsible for events such as the northern lights. The study of this accelerated plasma made a major leap in 1958, when Prof. Eugene Parker successfully proved the existence of sub- to super-sonic flows of gas near the solar surface, which he coined as "solar wind" [5]. Since then, scientists have expanded on Parker's work, studying the different physical phenomenon related to the solar wind.

Despite decades of effort, however, fundamental questions related to the solar wind remain. One of the most puzzling problems is why the ions in the solar wind are so much hotter than our theoretical models predict. In general, one expects the electrons in plasma to be hotter than the ions, but this was surprisingly contradicted by observations of the corona and the solar wind. Stranger still, the minor ion species to proton temperature ratio has been observed to reach and, in some cases, exceed, the species to proton mass ratio, which suggests that ions are being *preferentially* heated compared to electrons [4]. **The mechanism by which ions are being preferentially heated is not yet understood**.

Advanced magnetohydrodynamic (MHD) simulations have been developed to explore the underlying heating mechanisms at play in the solar wind [2,8]. While these simulations provide some insight into the underlying plasma physics, key components are excluded, thus creating an incomplete picture of the full turbulent dynamics. **I am already writing up a mathematical formulation of the solar wind in an upcoming paper [1], and plan to further develop this analysis by undertaking an MHD simulation to gain a more complete understanding of the solar wind.** My computational and data analysis skills developed during previous work in astronomy make me well equipped to take on this project.

Relevant Background: Magnetized plasma has at least two characteristic speeds: the speed of sound and the Alfvén speed. The Alfvén speed is the propagation speed of Alfvén waves (AWs), which are phenomenon that are caused by the co-fluctuations of ions in plasma and the magnetic field. The distance at which the solar wind achieves Alfvén speed forms a spherical surface around the star, denoted as the Alfvén surface [2]. MHD simulations have identified the Alfvén surface as the region where large-scale MHD turbulence first manifests, which could indicate a change in heating mechanisms [3]. **This makes the Alfvén surface a naturally occurring focal point in the study of heating processes in the solar wind.** Therefore, simulating the solar wind from the photosphere to a distance outside the Alfvén surface will allow for direct comparison of its thermodynamic properties in both regimes, resulting in a more complete picture of the solar wind.

Project Aim: In the three year term of this grant, **my main objective is to build upon current MHD simulation techniques to study the heating mechanisms of the solar wind.** Principle omissions in the most recent models of the solar wind are (*i*) the parametric decay of AWs into slow magnetosonic waves and counter-propogating AWs and (*ii*) the effects of nonlinear compressive and non-compressive coupling of fluctuations. The former, when excluded, leads to anomalies in the spectrum of outward-propagating fast solar wind [2]; the latter drastically affects the propagation and dissipation of turbulent energy [6]. **Understanding both of these effects are integral in understanding the underlying heating mechanisms in the solar wind.** Therefore, the primary outcomes of my project will be:

(O1) Building upon existing models to include the effects of parametric decay of AWs in the solar wind. This aim presents a golden opportunity to join two independently developed approaches. In [2], a MHD simulation was developed to consider kinetic heating effects, but failed to include the decay of AWs; the opposite is true of [8]. Thus, a natural next step is to combine the two approaches into one succinct model of the solar wind.

(O2) Develop new programs to account for compressive and non-compressive coupling in fluctuations. Unlike (O1), I am unaware of any existing programs that take into account these effects. **Thus, developing new software that accounts for these effects will lead to a substantial advancement in our understanding of the solar wind.**

I plan to make the full simulation suite open source upon completion, which will allow others to use and improve upon the techniques implemented in this project.

Intellectual Merit: The results of this project will **push forward the frontiers of MHD simulations of the solar wind**, while also providing valuable information on the physics of solar wind by forming a more complete picture of the full dynamics. Another motivation for this project is to compare numerical results to observational data. In 2018, NASA launched the Parker Space Probe (PSP), which by 2020 will be the first spacecraft to travel inside the solar Alfvén surface [4]. **Therefore, development of theoretical and numerical models to compare with our observations is urgent**; key measurements taken by the PSP, such as electric and magnetic field strengths, as well as proton and electron properties, will further shed light on the heating mechanisms of the solar wind [7]. This work also has interdisciplinary implications, as the solar wind provides **an excellent laboratory for studying plasma physics, especially plasma kinetics and turbulence**. Information gathered from this project can be applied to other analogous phenomenon, such as the accretion disks of black holes.

Broader Impacts: This work will shed light on the key mechanisms at play in the solar wind, which is of interest to both the astrophysics and plasma physics communities. **Thus, the results of this work will promote constructive collaboration between plasma physicists, stellar astrophysicists, and observational astronomers**. Accurate simulation results produced in this project can be compared against observational data, which in turn can be used to better understand the underlying plasma physics.

My dedication to scientific education and outreach has led to my involvement in many different programs. In an effort to reach underrepresented groups, I have built new demonstrations for programs such as Physics Discovery that will have a lasting impact. My interest in teaching has led to my position as an undergraduate teaching assistant, which has given me pedagogical skills that will be vital for my success as an instructor in graduate school and beyond. I have also been involved in improving and reforming physics education by putting forth new assignments to help students with test anxiety showcase their talents. *The NSF GRFP will give me the resources to continue my research work, while also making an impact in my community, regardless of where I attend graduate school.*

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