Statement of Objectives

Pierre-Antoine Graham *PSI Master Program*

We live in a golden age where science opens up the craziest possibilities and brings minds from all across the world in brilliant collaborations. As a 21st century physicist, I want to thrive in these countless research opportunities. To do it, I need to explore physics further and meet the people that make the breakthroughs possible. This is why I am applying to Perimeter Scholars International; I know the program will allow me to find my place within the scientific community.

My physics journey has led me to many different branches of physics and I feel like PSI is the natural next step in my exploration. Initially driven by outreach events, I focused on communicating theoretical ideas ranging from classical electromagnetism to cosmology. Then I had the chance to collaborate with three different theoretical four-month undergraduate internships. While the first two increased my appreciation of condensed matter physics, from cuprates to topological materials, the last one sparked my interest in gravitation. The PSI program provides core courses that will sharpen my knowledge of these subjects while making me rediscover classical mechanics and statistical mechanics from an advanced point of view. I am applying to the program to shine a new light on my past and future research.

My first theoretical research experience took place in Prof. André-Marie Tremblay's group. I was tasked to treat data from two-particle self-consistent approach simulations of electron-doped cuprates. At the beginning of the project, I had little knowledge of many-body physics and I demonstrated my learning abilities by efficiently teaching myself the basics. Then, with rigorous data analysis, I devised a procedure to approximate the temperature at which the antiferromagnetic pseudogap appears. I used this temperature to locate the quantum critical point of the electron-dopped phase diagram. My analysis allowed me to determine the effect of a simple implementation of disorder on the quantum critical point and helped orient further research that would lead to a publication in Physical Review B. Overall, the internship made me realize how thrilling a very active material sciences field can be. It is the idea that my abstract theoretical work could lead directly or indirectly to new technologies and experiments that made the research so engaging for me. When I picture the career ahead of me I see myself doing research combining aspects of many-body physics with other disciplines. One path I am interested in is the use of the AdS/CFT correspondence which connects gravity and condensed matter in a setting with experimental prospects. I look forward to the AdS/CFT course to learn more about the correspondence and add it to my toolkit. Another path I could follow would revolve around machine learning methods for many-body physics. The numerical methods and machine learning courses provide a unique opportunity to explore this field and develop my computer science skills.

The thrill of material sciences became even more vivid with my next internship project. This time, I was working with Prof. Ion Garate on an adaptation of the Van Roosbroeck system of partial differential equations providing a semi-classical description of Weyl semimetals. The goal of the project was to solve the equations to gain insight into the semi-classical role of the chiral anomaly. Throughout the internship, I produced animations of the numerical evolution of charge densities through time. They allowed getting intuition about the general behavior of the system. While building this intuition, I constantly discussed the limitations of the model and the measurability of our predictions with Prof. Garate. Once I was convinced of the experimental prospects of our approach, I found a way to decouple the equations further using Ampère's law. Approximating their solutions allowed me to compare them with my numerical results. In the end, we identified the presence of photoinduced plasma oscillations leading to a paper currently submitted to Physical Review Letters. After the internship, I started a more general exploration of the literature about topological materials. This exploration led me to the Chern-Simons theory and I am excited to take the course about it. I am attracted not only to the elegance of the theory but also to the viewpoint on the role of topology in physics it will give me.

Although my first internships were connected to quantum materials, my curiosity pushed me to join Prof. Valerio Faraoni's group to work with modified theories of gravity. The prototypical idea of the project was to study a notion of temperature associated with scalar-tensor gravity. The first part of my work focused on a family of cosmological solutions which had ill-defined temperatures. With perturbation theory, I showed that the problematic solutions were either unphysical or unstable and explained why the temperature was ill-defined in the first place. These results led to a publication in Physical Review D. In the second half of the internship, I proposed an extension of the formalism to multi-scalar tensor gravity, by introducing the idea of an effective multi-fluid described in a paper currently submitted to European Physical Journal C. While exploring this extension, I took part in passionate discussions that taught me how to express and blend in my ideas.

To complete my undergraduate experience, I took part in the PSI-Start summer courses. Even if it was an online school, it gave me a taste of the environment at Perimeter Institute and I liked every aspect of it. The program allowed me to meet motivated and curious people with whom I felt I could access another level of problem-solving. It had a positive impact on my way to ask questions and participate in academic activities. During my last undergraduate semester, I asked more interesting questions and engaged in more frequent deep discussions with my collegues. I wish to keep growing in this direction with the PSI program and help others grow with me. The professors I met had a clear passion and dedication that resonated with mine. In particular, I had the chance to work on a mini-project about quantum clocks with Dr. Flaminia Giacomini. This subject blew my mind to the point I animated the main concepts for an outreach contest last fall. I was particularly fascinated by the connections between relativistic effects and entanglement which make me deeply interested in the relativistic quantum information course. The course would also be an opportunity to expand my knowledge of the Unruh effect I learned about with Pr. Faraoni.

In a general sense, I look forward to making meaningful connections with the great minds of Perimeter Institute. Collaboration and exchange are central to launching a stimulating career I will be proud of. I am convinced Perimeter Institute's professors and students will allow me to reach my full potential in this century of great scientific opportunities.

Sincerely,

Pierre-Antoine Graham