Until the late 1800’s, the atom was thought to be indivisible. Since then, research motivated by curiosity has led to important technologies such as nuclear energy and radiation treatments that have changed the face of humanity. This demonstrates the value of pursuing research into the fundamental nature of matter even without knowledge of the uses it will provide. Atoms have since been shown to be composed of protons and neutrons, which, more recently, have been found to be composed of even more fundamental particles called quarks.

I am currently using non-relativistic fluid dynamics to simulate unitary Fermi gases and compare the results against experimental data (e.g. [4]) for several different physical approximations of the fluid. Theoretical values for the fluid viscosity and other material parameters can be extracted from these simulations. These simulations also verify my non-relativistic methods experimentally, and so provide a solid foundation for my future relativistic methods. The next step in my research is to develop a relativistic fluid model out of my existing simulations of the unitary Fermi gas in order to simulate quark-gluon plasmas. Central to achieving this goal is the development of accurate and efficient computational algorithms for relativistic fluid dynamics. I hope to contribute to the theoretical study of viscosity in quark-gluon plasmas and to the efficient implementation of relativistic hydrodynamics in my undergraduate thesis.

the simulations of cold Fermi gases are hoped to provide a basis for simulating quark-gluon plasmas that is more precise than direct fitting of fluid simulations to experimental data in quark-gluon plasma research could provide.

My research explores one possible solution to this problem, which is to develop a fluid-dynamical relationship between quark-gluon plasma and another fluid that is easier to study experimentally, use solutions to the fluid dynamics of that system as an experimentally-verifiable *approximate* solution to the fluid dynamics of quark-gluon plasmas, and therefore calculate the material properties of quark-gluon plasma with more precision than the uncertain experimental data for quark-gluon plasma itself would allow.

The catch is that it remains difficult to determine many things about them with any certainty because the experimental procedures and data analysis are exceptionally complex. My research seeks to solve the part of the problem that is interested in determining the physical / material properties (such as viscosity) of the quark-gluon plasma. Our method is to use computational fluid dynamics (i.e. by writing fluid dynamics simulations) to model a fluid that has been shown ([2], [3]) to be similar to quark-gluon plasma in order to verify the accuracy of our fluid / physical approximations against low-uncertainty experiment, and then to use a similar physical model to simulate quark-gluon plasma.

My research seeks to solve part of this problem by

As recently as the late 1800’s, even the atom was thought to be indivisible. Studies of the atom revealed that it was composed of protons, neutrons, and electrons. This discovery yielded many important practical applications, including nuclear energy and radiation treatments, even though the study of the atom was conducted purely for curiosity and the purposes of fundamental physics. Protons and neutrons are now known to be composed of quarks and gluons. Although quarks are of modern interest for their importance in better understanding the fundamental forces at play in our universe, they are certain to have eventual applications.

Until the late 1800’s, the atom was thought to be an indivisible unit. However, thanks to research motivated by curiosity, not only has this been shown to be untrue, but has also led to useful technologies we use today such as blah blah blah. This goes to demonstrate the value of pursuing research into the fundamental nature of matter despite lack of precise examples of future utility. Similarly, nowadays we know that even protons and neutrons are composed

Why you should care paragraph. There is no reason why you should care about splitting atoms until you do it, and get nuclear energy, radiation treatment, etc. Something about how mankind’s insatiable curiosity leads to great developments. Even without some further idea of the eventual applications, a better understanding of the fundamental forces at play in our universe have without fail (?) improved the quality of life of mankind. Whether you’re driven by curiosity of by desire for quantifiable gain, theoretical physics research is a valuable (and rewarding!) pursuit (!)

Start off with “The flow of quark-gluon plasma is indicative of the interactions between free quarks and gluons…” and put this paragraph before the previous one. Thus… fluid dynamics is a promising method for the theoretical study of quark-gluon plasmas. The flow characteristics of a fluid convey abundant information about the microscopic interactions between fluid particles. In this case, the flow of quark-gluon plasma is indicative of the interactions between free quarks and gluons, which are of great fundamental interest. An advantage of studying quark-gluon plasma and the interaction between free quarks and gluons with fluid dynamics is that fluids that exhibit similar macroscopic flow properties demonstrate that they obey similar fluid dynamics. Therefore, although the microscopic interactions (between quarks and gluons) are not well understood, it is possible to draw valid analogies (in the context of fluid dynamics) between fluids that exhibit similar macroscopic flow even if it is not known how each is interacting microscopically. For quark-gluon plasmas, these analogies provide an experimentally-verifiable context in which to test theoretical methods.

Paragraphs 3 and 5 have the same topic sentence; quark-gluon plasmas are hard to study. Devin’s thought: flop paragraphs 3 and 4, talk about theory, say they’re hard to do experimentally, then say “since they are hard to study experimentally, more stable analogs are needed to verify theoretical results”.

First paragraph seems to fly conceptually. Another sentence between sentence 2 and 3?

Last sentence of second paragraph doesn’t seem to fit with the rest of the paragraph. Maybe that sentence would go better in the intro, and replace it with another background sentence on quarks and gluons.

The only matter that contains free quarks and gluons – by definition QGP, so kinda awkward. Maybe rephrase to “Study of quark-gluon plasmas is a unique opportunity to study the individual quarks, as opposed to composites of quarks”.

Keep in mind that it is a little funny that cold atomic gases and hot QGP would be analogous. Maybe touch briefly on this to help everybody. Possibly talking about the temperature and pressure requirements for degeneracy might help bridge the gap.

Sentences about “my research” are awkward; an abrupt change of content. Consider grabbing all of the various scattered sentences about your research and grouping them into one paragraph.

Experimental data suggests that quark-gluon plasma may have the lowest viscosity ever observed. The fluid that is thought to have the next lowest viscosity is a cold atomic gas called the unitary Fermi gas, which is an ultra-cold collection of fermions (typically Lithium) under the conditions in which the atoms exhibit the strongest coupling [2].

However, a primary challenge in the theoretical study of systems, like quark-gluon plasmas, that have high experimental uncertainty is finding ways to verify theoretical methods experimentally.

However, a major concern and challenge in the theoretical study of systems that have high uncertainty in the experimental data is experimental verification to make sure the methods are working correctly and there are no significant numerical errors. Therefore, as a first step in my research, I am studying the fluid dynamics of a related physical system.

The presence of quark-gluon plasma in a collision theoretically suppresses the creation of certain other particles that can be detected directly, so the statistical presence of these particles is used to infer whether quark-gluon plasma was created in the collision.

However, uncertainty in experimental data for the flow of quark-gluon plasmas suggests the importance of finding additional ways to verify the research results experimentally.

Toward this end I am currently studying the fluid dynamics of cold atomic gases, which have very similar material properties to quark-gluon plasmas but have been studied with relatively low experimental uncertainty. My research in the fluid dynamics of cold Fermi gases is exploring the physical approximations that best model the flow that has been observed in experiment. In this context I am verifying both the fluid dynamics and the numerical methods used in my simulations. This forms a solid foundation on which I will develop simulations of quark-gluon plasmas in the future.

Quark-gluon plasmas and cold atomic gases are proposed to have analogous material properties because they both exhibit a unique fluid-flow phenomenon called elliptic flow. Fluids with these flow characteristics expand non-uniformly from their initial state, so a density distribution that is initially elliptical will expand much more quickly in one direction than in the other. Elliptic flow is a characteristic of strongly-coupled quantum fluids with anomalously low viscosity. The observation of elliptic flow in quark-gluon plasmas in 2005 was very important because it first allowed parallels to be drawn between quark-gluon plasmas and other fluids that are easier to study experimentally [1].

My research is focused on one particular cold atomic gas, the unitary Fermi gas, which is an ultra-cold collection of fermions (often Lithium) under the conditions in which the atoms exhibit the strongest coupling. Experimental data suggests that quark-gluon plasma may have the lowest viscosity of any fluid yet observed, and the unitary Fermi gas has the second lowest [2]. Therefore the fluid dynamics of unitary Fermi gases and quark-gluon plasmas are expected to be very similar. The primary difference in modelling quark-gluon plasmas is that they expand from a heavy-ion collision at a significant fraction of the speed of light, and have very high energy-density.

This theoretical approach shows much promise, but there is also much progress to be made before quark-gluon plasmas can be modelled accurately with fluid dynamics. In particular, derivations of conventional fluid dynamics (method that are used, for example, to model the flow of air around an airplane wing) assume that classical physics can be used to describe the physics of the fluid in question. In the case of heavy-ion collisions, quark-gluon plasmas are moving at a significant fraction of the speed of light, and have very high energy (temperature). Therefore the physics of this system must be accounted for using Einstein’s theory of relativity. The essential equations of fluid dynamics must change to take this into account.

One new theoretical approach to studying quark-gluon plasmas is using the fact that they seem to behave fluid-dynamically like a nearly-ideal Fermi liquid. My current research is to study the characteristics of quark-gluon plasmas through the fluid dynamics of this experimentally-verifiable system. This evades (temporarily) the trials of relativistic fluid dynamics, while otherwise testing the computational methods against experimental data.

My research involves the use of fluid dynamics to calculate values for the material properties of quark-gluon plasmas, like the viscosity, that determine how it flows and expands after a heavy ion collision. In the absence of definitive experimental data, some characteristics of quark-gluon plasmas can be understood through the fluid dynamics of related physical systems.

My current research is to study the characteristics of quark-gluon plasmas through the fluid dynamics of another system, the cold Fermi gas.

My future research is to develop relativistic hydrodynamic methods in order to study quark-gluon plasmas directly.

The observation of elliptic flow in quark-gluon plasmas was a major step forward because it demonstrated that quark-gluon plasmas have similar dynamics to several other fluids. Elliptic flow is a phenomenon in which the wide dimension of an elliptical density profile changes with time, and is a characteristic of strongly-coupled quantum fluids with anomalously low viscosity. The observation of elliptic flow in quark-gluon plasmas implies that analogies can be drawn with other systems that exhibit elliptic flow, but which are easier to study experimentally. Fluids that flow elliptically exhibit similar fluid transport and diffusion characteristics and therefore are expected to have similar material properties [1].

Several strongly-coupled atomic fluids exhibit elliptic flow and are promising parallels for the study of quark-gluon plasmas. One such system is the unitary Fermi gas, which is an ultra-cold collection of fermions (often Lithium) in the limit (called unitarity) where the Fermi gas exhibits the strongest coupling. Experimental data suggests that quark-gluon plasma may have the lowest viscosity of any fluid yet observed, and the unitary Fermi gas has the second lowest [2]. Hydrodynamics is a natural method for studying the relationship between the material properties of unitary Fermi gases and quark-gluon plasmas because it deals explicitly with the fluid transport and diffusion on which our analogy is based.

Under the direction of Dr. Paul Romastchke, I am developing a set of hydrodynamic simulations of unitary Fermi gases from which to extract their material properties (such as viscosity). The expansion and elliptic flow of unitary Fermi gases has been observed in several experiments (e.g. [3]) and occurs on the scale of hundreds of microseconds. Density profiles of the fluid can be imaged many times over the lifetime of the expansion, and so the data is thorough and has relatively low experimental uncertainty. Studying the unitary Fermi gas allows me to compare the results of my simulations with experiment, analyze deviations, and revise my algorithms if necessary. The limited experimental data set for the expansion of quark-gluon plasmas does not make a similar analysis possible for this system.

Although quark-gluon plasmas and unitary Fermi gases share analogous material properties, heavy ion collisions and quark-gluon plasmas are a relativistic system while unitary Fermi gases are not. The behavior of matter that has exceptionally high mass or energy is not described accurately by classical physics and must be analyzed using Einstein’s theory of relativity. Quark-gluon plasmas are expanding at a significant fraction of the speed of light, and the energy density in these collisions is also very large. For these reasons, an accurate model of quark-gluon plasmas will incorporate the effects of relativity.

Relativistic hydrodynamics is a developing field with important applications across several branches of physics, including astrophysics, magneto-hydrodynamics, and high-energy condensed matter physics. It describes how fluids behave near very massive objects (like stars) or when they are exceptionally high in energy. In non-relativistic hydrodynamics, viscous flows are typically modeled by the Navier-Stokes equations. These methods are well understood and strike a balance between computability and accuracy. Unfortunately, relativistic formulations of the Navier-Stokes equations are not useful because they violate causality, the directionality of time [4]. Various techniques for re-working this model have been proposed, but the equations remain very complicated and numerical solutions are prohibitively computationally-intensive in most cases. Advances in hydrodynamic modeling of quark-gluon plasmas and other high-energy matter will require improvements in the computational efficiency of relativistic hydrodynamic methods.

In order to apply my study of elliptic flow in unitary Fermi gases to the study of quark-gluon plasmas, I will need to incorporate relativistic hydrodynamics into my simulations. Solving the issue of computability and accuracy in relativistic hydrodynamics will be central to the effective simulation of quark-gluon plasmas, and is also an open problem across several other areas of physics. I hope to contribute to the resolution of this important issue in my undergraduate thesis.

One topic of particular interest is the characteristics of the flow of quark-gluon plasmas, because the fluid flow is a macroscopic property that conveys abundant information about the microscopic interactions between fluid particles, in this case quarks and gluons, that is very important to understanding the forces governing quarks and gluons. My current research is using theoretical and computational fluid dynamics to calculate values for the material properties of quark-gluon plasmas, like viscosity, that determine how it flows and expands after a heavy-ion collision. Fluid viscosity is particularly important because it is closely correlated to the strength of the interactions between fluid particles on the microscopic level.

Quark-gluon plasma is the only matter ever created that contains quarks that are not bound inside of other particles, so it is of fantastic importance to the study of quarks independently of the study of the composite particles that are formed from quarks. Quark-gluon plasma is also thought to have been the state of matter shortly after the Big Bang, and therefore to have had a defining impact on the early evolution of our universe.

Recent experiments at CERN and at Brookhaven’s Relativistic Heavy Ion Collider have realized a state of matter with such high energy that quarks and gluons cannot form fundamental nuclear particles like protons and neutrons. Unbound quarks and gluons form plasma that has fantastic experimental and theoretical importance. Quark-gluon plasma is thought to have been the state of matter very shortly after the Big Bang, and thus is thought to have had an important impact on the early evolution of our universe. It is also suspected to exist at the core of neutron stars.

The interest in studying quarks is that they are the fundamental building block of all matter. The experimental realization of quark-gluon plasma is revolutionizing modern physics because it is the only matter ever created that contains free quarks. therefore the interest in studying quarks is analogous to the interest in studying protons and neutrons once it was discovered that the atom is divisible. Quark-gluon plasma is of fundamental importance in physics because it is the only known state of matter in which quarks are not confined inside of other particles, so in the same way we wanted to split atoms to discover how their constituents behaved, we now want to split nuclear particles to see how their constituents behave. (Since quarks are now thought to be the smallest unit from which all matter is created, this interest is analogous to the interest of studying protons and neutrons once it was discovered that the atom was divisible). Quark-gluon plasma is formed when matter is too high in energy for neutrons and protons to be stable, so they break apart into their constituent particles, quarks and gluons. Quark-gluon plasma is of fundamental theoretical importance in physics because in all other matter it is the only known state of matter in which quarks and gluons are not confined within particles The energy of these collisions

Quark-gluon plasma is a state of matter that is created in the aftermath of heavy ion collisions. It was first realized experimentally in 2005 (CHECK REFERENCE). The study of quark-gluon plasmas is of significant theoretical importance in many areas of physics. Its characteristics

Because fluid dynamics is extremely computationally-intensive, it is always necessary to make physical approximations. Unfortunately it is not always clear which approximations will be best for a particular fluid.

One difficulty in modelling quark-gluon plasmas reliably with fluid dynamics is that the experimental data has large uncertainty. Fluid dynamics is notoriously computationally-intensive, so some approximations must always be made. Often, we learn about the physics of a fluid by trying many approximations, seeing which fits the experimental data best, and revising our approximations. Large experimental uncertainty in data for the flow of quark-gluon plasmas makes this method not particularly reliable. Therefore I am currently studying the fluid dynamics of a system that is widely accepted to have analogous material properties

I am currently studying the fluid dynamics of a system that is proposed to have analogous material