Gravitational Axions as Dark Matter

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Abstract

A hypothesis is developed for cosmic QCD axions, as gravitationally and gravitoelectromagnetically active topological spacetime remnants, derived from inflational scale *cosmological* events and existing as a quasiparticle excitation spectrum of a ground state bosonic superfluid, interacting directly with the baryons. The guiding principle is axion Higgs electrodynamics in condensed matter physics systems, and the hypothetical axion behavior is justified through both observational and experimental methods.

Introduction

The existence and nature of dark matter is one of the most enduring of mysteries of theoretical physics. First formally postulated by Fritz Zwicky in 1933,[1] and then formally observed by Vera Rubin in 1977,[2] dark matter manifests itself through its gravitational mass interactions with ordinary galactic matter, where it is primarily observed as sparse galactic mass halos with increasing structure towards galaxies, and appears to be primarily smooth and flat towards intergalactic interstitial spaces and cosmic voids.

Dark matter is hypothesized to be new and as yet undiscovered beyond standard model particles, and more recently modifications of gravitational theories such as MOGs, MONDs and entropic gravities. Detection of dark matter has consumed significant amounts of funding and efforts across the entire mass-energy spectrum with no definitive results besides exclusion constraints and no-go theorems.

The purpose of this report is to document modern dark matter research from the unique perspective of condensed matter physics, using the most blunt hypothesis exclusion tools currently available, and to develop a viable hypothesis of dark matter closely aligned with astronomical observational evidence, while satisfying analogue constraints provided by recent developments in quantum topological physics. The goal of this report is to produce a path to dark matter detection, quickly yielding conclusive results. The author of this report admits an intrinsic bias in this research; that of a condensed matter physicist.

Supersymmetry is Dead

Supersymmetry is dead. Although the mathematical basis of supersymmetry and various string theories remains intrinsically sound, the absence of low energy evidence for supersymmetric partner particles in high energy experiments either pushes the relevance of these theories to up near the Planck scale and/or resolves to simulating their physics in condensed matter experiments and cold atom analogue systems.

Peccei Quinn Axions Exist

For immediate progress to occur in dark matter research, vast swaths of theory space must summarily be eliminated, excluded, constrained or voided by fundamental morphological reasoning in the spirit of Fritz Zwicky. In this manner, the ΛCDM concordance cosmological model is thus invoked, where only legitimate standard model fields and particles are considered, which yields the Peccei Quinn axion.[3, 4, 5] The axion was thus named after a commonly advertised detergent, since it *cleaned up* QCD theory,[6, 7] by explaining the lack of CP (charge parity) violation within quantum chromodynamics, and thus the extreme smallness of the axion angle and neutron electric dipole moment within the standard model. Therefore, QCD axions are guaranteed to exist, and have become the defacto standard for dark matter.

The Peccei Quinn QCD Axion Decay Constant is Large

After a great deal of cosmological model building over the decades utilizing the QCD axion concept, in the last year or so actual lattice QCD calculations have been performed with ever increasing power and resolution, in an effort to pin down an axion mass for new microwave detection strategies.[8, 9, 10, 11, 12, 13, 14] More recently, alternative approaches to QCD equation of state calculations have confirmed the basic veracity of this approach.[15, 16] In all of these approaches to axion mass determination, the goal has been to calculate topological susceptibility in QCD, using an instanton gas model at relatively low energies, which has refined the axion mass into the microwave region from 50 to 1500 μeV. with a very large so called *axion decay constant*, or f_a, of the order of 10^9 to 10^{12} GeV, or roughly half way to Planck scale.

This result renders the axion very weakly coupled in all standard model sectors, besides gravitationally. This also assumes that the mass of the hypothesized QCD axion holds in globally flat spacetime, which is Minkowski space, such as what may most appropriately apply to the cosmic voids between galaxies. In such regions of space, ordinary baryonic particle density is very low, and gravitational perturbations are very weak. Therefore it's now clear that the axions are primordial and cosmic, and the vast majority are still very cold and relatively pristine and unexcited since their formation within the early universe.

Axions have had roughly 13.8 billion years in which their initial dispersion and structure has had ample chances to evolve considerably, subject to their gravitational self attraction as well as ordinary baryonic gravitational attraction. And their standard model interactions, however weakened by the factor of $1/f_a$, still apply in a universe of ever increasing particle and energy density due to gravitational aggregation and nuclear forces. These interactions include, of course, electromagnetism and weak and strong forces, since our present universe now includes topological spacetime defects in the form of many black holes, as well as the dense and energetic generational objects such as neutron stars, hot bright stars and heavy planets, including the highly energetic cosmic rays and neutrinos resulting from their cosmic evolution. That cosmic evolution includes being ripped to shreds by immense forces while entering black holes, and now with gravitational wave detection via LIGOs, the merger of very large black holes themselves. It's precisely these very weak standard model interactions that allows the physical detection of axions.

Axions are Bosons with an Average Mass Near the Cosmic Microwave Background (CMB)

Quantum bosons, whether elementary or composite, gauge bosons or Goldstone bosons, pseudo-bosons physical bosons, or collective excitations emerging from some underlying quantum many body field, or lattice, or gas of particles, are the ideal candidate statistics for cosmic axions. Dark matter appear to be mostly localized throughout the universe, and the axions are able to exist in cold and condensed states, whether physically excited to a gas, or to an excitonic plasma over time, or not. For the most part axion reasoning is speculative at best. Given that axions are primarily gravitational and cold, with relatively unknown mixings and couplings to electromagnetism and the weak and strong forces, and from a quantum field theoretical point of view the only thing definitely known about axions is their Peccei-Quinn symmetry breaking behavior, then physical detection of the axions is of the utmost importance.

Next generation axion detection schemes will focus on the most probable energy range indicated by lattice QCD, which right now sits from 50 to 500 μeV, which spans across the CMB (or the cosmic microwave background frequency) at 235 μeV. Nearby and slightly cooler sits the superfluid transition temperature of ^{4}He, marked by its second order phase transition temperature at 187 μeV, or 2.172 K. This energy range has traditionally presented volume and scaling difficulties with microwave detection, and new dielectric haloscopes have been proposed and developed to overcome these difficulties.[17, 18, 19] One instrument in particular is designed to search again at 110 μeV, an energy of a previous and highly controversial Josephson junction detection technique involving an observed anomalous Shapiro step.[20] Since dark matter axions, like ^{4}He, are composed of bosons, although the specific heat is discontinuous, the superfluid transition temperature is not, and therefore the ground state of the axion condensate and the mass of the individual axion could be 1.1 K or below, where the bulk of axions could be condensed.

Axions are in Thermal Equilibrium with the Cosmic Microwave Background Radiation (CMB)

If the average mass of the axion is somewhere down near the cosmic microwave background radiation, then the question is what is the average temperature of the universe, commonly assigned to the CMB, and then subsequently what is the excited thermal state of any cold bosonic superfluid after 13.8 billion years of continuous microwave irradiation. Above the CMB, up to arbitrarily high temperatures, are the baryons and other fundamental particles, excited to relatively high temperatures by their gravitationally induced high energy nuclear reactions, and to a lesser extent, the high energy collisions between highly energetic objects. The size and mass of these objects range from nuclei to neutron stars and black holes, and the combined momentum ranges from direct particle collisions at near the speed of light, up to and including energetic neutron star collisions and massive black hole mergers, as well as the static induced reactions at ambient pressures inside of extremely heavy objects such as hotly burning main sequence stars and dense planets. Energetic particle jets emanating from rotating and revolving energetic objects are another source of the high energy excitation of particles and a higher overall average temperature of the total (local and global) mass-energy of the universe. as presumably measured by the frequency of the cosmic microwave background radiation, which itself is slowly falling towards absolute zero as the universe continues to expand and cool, and the microwave radiation is red shifted further downwards.

The Axion Superfluid Ground State Condensate Temperature '*Is Less Than Or Equal To*' the Superfluid Transition Temperature and Lambda λ Transition Point of Superfluid Helium 4 – ^{4}He.

Therefore the axion quasiparticle excitation spectrum and the dispersion of the axion condensate is thus presumed to be cold and bosonic, at or below the superfluid condensation temperature of helium – ^{4}He. Axions are excited out of that bosonic ground state condensate into a myriad of unknown states and structures by gravitational and baryonic interactions, individually, in pairs, and collectively, coherently and incoherently, into states very weakly interacting gravitoelectromagnetically and within the standard model, and mixing only weakly into simulated electrodynamical axions within a similar energy range.[21]

There are indeed legitimate reasons for how and why Peccei–Quinn symmetry breaking at a high QCD scale traverses through electroweak standard model physics and thus becomes directive and observable down at the superfluid transition temperature of liquid helium. The quantum superfluid phase transition of helium is directly dependent upon the electric dipole interactions of its constituent nucleons and/or nuclei, which are in turn dependent upon the near vanishing electric dipole moment of the neutron.[22] [23]

The proximity of the axion condensate and its excitation spectrum to the bosonic superfluid helium I/II transition and the cosmic microwave background radiation solves the axion detection problem, in that therein lies a rich set of diverse coherent quantum mechanical electronic, ionic and nuclear transitions traversing the entire temperature region down to at least the hyperfine transition of hydrogen at 21 cm, and ultimately, well into the nanoKelvin realm of optical, laser trapped, cold atom experimental setups. These very weak coupling interaction mixings can be leveraged into axion detection schemes, based upon what can be predicted from what is known about their properties, as a field of quantum bosons within a given mass, density and temperature regime, with known high energy interaction pathways.

Axions Interact Gravitoelectromagnetically and Electromagnetically in Condensed Matter Physics Analogue Systems as Goldstone Bosons Coupled to Artificial Higgs Mode Excitations

An immediate question legitimately asked is – are axion excitations truly bosonic quasiparticles? [24] Axions, axion angles and axion physics are already well known within condensed matter physics.[25, 26, 27] Within quantum topological physics the machinery of gravitoelectromagnetism has been explicitly invoked in an effort to understand the anomalous thermal Hall effect in topological superconductors. Strongly correlated thermal and electronic transport properties of topological superconductors are now well described by axionic concepts. Therefore, it is proposed that *gravitational axions* are unifying.

Credible detection strategies for cosmic microwave axions have already been elaborated, including the mixing of ambient axions with simulated condensed matter analogue axions, through their proximity in energy, and their well established electronic, thermal, and indeed, mass transport cross correlations.[28] Helium 3 (^{3}He) analogue physics systems have suddenly become particularly useful in this regard,[29, 30] and it's clear now that liquid helium systems will be vital for future axion detection and manipulation,[31] although not in the far lower energy range first envisioned for ultra light axions found in string theories.

Conclusions

Gravitational axions are proposed as dark matter – new quantum bosons of the Peccei-Quinn variety,[32] with additional properties derived from their primordial cosmic origin and nature. Cosmic QCD axions as proposed here, interact strongly with gravitation, but weakly gravitoelectromagnetically within the quantum topological superfluid systems known from condensed matter physics, and very weakly with weak and strong forces through symmetry breaking resulting from early *quantum cosmological* events.

The axion unifying concepts as outlined above, derived from known and testable axion Higgs physics within theoretical and experimental advances now well underway within condensed matter physics and cold atom experiments, begs for the application of this new physical paradigm to a new quantum field theory of gravitation and *cosmogenesis*, within the entirely new emerging field of *quantum cosmology*. Detection of microwave axions in the indicated energy range should be of the highest national priority, since axions, as a new bosonic superfluid, may be excited to as high an energy and density as desired.

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Companion Essays

Gravitational Axions in Quantum Gravity and Cosmology

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The Cosmic Evolution of Autobiogenesis

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