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A Theory of Dark Matter

Nima Arkani-Hamed, Douglas Finkbeiner, Tracy Slatyer, and Neal Weiner (AFSW) have published a paper on the arXiv called, “A Theory of Dark Matter,” which models dark matter as a heavy WIMP with a mass of 500-800 GeV that, in spite of its mass, annihilates into leptons rather than hadrons. These particles interact through a new force that is confined to the dark sector and is mediated by a new force carrier with a mass less than 1 GeV. The dark matter annihilates into the new force carrier, whose light mass precludes its annihilation into hadrons, resulting in predominantly leptons as final annihilation products, thereby explaining the positron excesses observed by several recent experiments.

In the inflaton spacetime model, the dark matter is an exotic, but standard-model-related particle that is very heavy and annihilates with itself. It interacts only gravitationally and only with itself, so it appears to exchange a force carrier that is different from the graviton exchanged by ordinary matter. Gravity is actually the law of spin and statistics at work, whether the particles involved are ordinary matter or dark matter, but the appearance is of two different force carriers. Thus, one can say that the dark matter sector in the inflaton spacetime model does fit the model proposed by AFSW, at least in this respect. In this note, I’ll explore this similarity, but first I’ll talk about dark matter as it appears in the inflaton spacetime model, since this model is unfamiliar to most physicists,

Dark Matter in the Inflaton Spacetime Model

In this model, spacetime is a combination of fermionic and bosonic fields, which are coupled as a result of mixing, that is, as a result of each point's having some probability of being either a boson or a fermion on any given observation (time tick). The coupling gives the fermions some bosonic behavior: they feel the force of gravity. Similarly, some fermionic behavior is imparted to the bosonic points as a result of the same coupling.

Fermions obey Fermi-Dirac statistics: there is zero probability that any two identical fermions can occupy the same position. The apparent force that keeps them apart is called *degeneracy pressure*. As a result, they form a lattice or Fermi gas, and because they are indistinguishable and spacetime looks the same whether they move or not, there is some probability that they do move. They have two velocity eigenvalues, zero (not moving) and the speed of light, c (moving). The vacuum expectation value of the electroweak Higgs field determines the ratio of 0 points to c points at any time tick. Over time, fermionic points can be mixtures of these two states, so they can have any velocity between zero and c.

How does the coupling to the fermionic field affect the bosonic field? In the absence of the fermionic field, the bosonic field would assume a minimum-energy configuration in which all bosonic points would be in the same quantum state and move at the speed of light. However, as a result of the coupling to the fermionic field, the bosonic spacetime field feels a kind of friction derived from the degeneracy pressure felt by the fermionic field, so on any time tick some of the bosonic points will not be able to move. Therefore, like the fermionic points, which have two velocity eigenvalues, zero and c, the speed of light, the bosonic points also have two velocity eigenvalues, 0 and c. The bosonic spacetime field has its own version of the Higgs field, which settles to some vacuum expectation value that determines the ratio of bosonic 0 points to bosonic c points.

The bosonic and fermionic fields differ when it comes to the ability of points or particles to move at velocities between 0 and c. Particles are points that are in a resonant state, above their ground state or zero-point energy. At the end of the inflationary period of the early universe, when the oscillations in the mean free path of the fermionic points decay into particles and radiation, some of the fermionic and bosonic points absorb this energy and resonate, forming particles. Particles are modeled as excited points whose excess energy above the ground state is vested in a creation time that oscillates around the global or observer's time ticks.

As explained elsewhere, fermionic spacetime is a lattice of point quads. Each quad consists of spin up and spin down forward-time points and spin up and spin down backward-time points. It doesn't matter which four points are in any point quad as long as they are the right kinds. The points need not have any special relationship to each other because, whether they do or not, spacetime looks the same. Thus, as spacetime takes a step forward in time and a step backward, the forward-time and backward-time images of a given point do not have to remain at the same position. It simply doesn't matter. When a point moves, there will always be a point of opposite type at its new position, guaranteeing that spacetime remains time neutral and charge neutral. A point or particle moving at an arbitrary velocity can therefore be modeled as a mixed state of 0 and c velocity eigenstates.

Bosonic spacetime does not form a point quad lattice. Points can have any position. For spacetime to remain time neutral, there must be a guarantee that when a bosonic point moves, it will not remain in any position for more than one time tick unless it is paired with an opposite-time point wherever it lands. In other words, speed-of-light bosonic points are acceptable by themselves, but to guarantee time and therefore charge neutrality, stationary bosonic points must be paired—*every stationary forward-time bosonic point must be paired with a stationary backward-time bosonic point*. The two points form a *bound state*—they are tightly coupled electromagnetically. Moreover, they must always have the same position. The position of such a pair can only change through quantum fluctuations, which means that it can move, but very slowly. In the bosonic spacetime field, neither points nor particles can be in a mixed state of 0 and c eigenstates. Only pure velocity eigenstates are possible. This is because the 0 eigenstate is a bound pair of forward-time and backward-time points, so it cannot mix with points in the c eigenstate, which are single, unpaired points. The degeneracy pressure affects only the paired, stationary points. Thus, the inability of the 0 and c velocity eigenstates of bosonic points to mix splits the bosonic spacetime field into two separate fields. The quanta of one are extremely sluggish and feel degeneracy pressure, while the quanta of the other all move at the speed of light.

Why don’t fermionic points form bound states? Any stationary point has an electromagnetic charge, so stationary bosonic points will immediately pair up, with opposite charges bound together by electromagnetic attraction. But any fermionic point is completely surrounded by oppositely charged points, so the net electromagnetic force on it is zero. Bosonic points, on the other hand, are mostly c velocity points, which are massless and chargeless, so those that are stationary are strongly attracted to any oppositely charged points that happen to be nearby.

The Sloton. A bosonic resonance can be a forward-time or backward-time resonance or both. A resonance or particle is identified by a creation-time difference between a point and the global or observer's time. If the resonance is of an unpaired forward-time bosonic point, it is a photon and the resonating point moves at the speed of light. It is indistinguishable from a resonance of an unpaired backward-time point moving in the opposite direction. Therefore, the photon is its own antiparticle.

If the forward-time and backward-time points of a stationary bosonic point pair resonate, they do it as a single unit because they constitute a bound state, and the resonance is a stationary boson with zero charge and zero spin. No such particles are known to exist. However, it is possible in the inflaton spacetime model because the forward-time and backward-time components of a stationary point are collocated, so they can resonate synchronously. This particle cannot move at all, except for quantum fluctuations of its position, which means that it can move, but very slowly.

The resonance of a bosonic stationary point pair is a particle that is related to the photon, since it is something like a bound state of a photon and an antiphoton. The photon has spin $J = 1$, and therefore should have three helicity states: $J_3 = +1$, 0, and -1. The photon and its antiparticle (itself) account for the +1 and -1 states. The 0 state is not known to exist because the photon always moves at the speed of light. If a photon were to have zero helicity it would have to be standing still. But this is just what the new particle does! Thus, we can conclude that here we have *the previously unknown zero-helicity state of the photon, which exists only in combination with its antiparticle* (the photon and the antiphoton are indistinguishable physically, but in the inflaton spacetime model they are different particles). The particle and antiparticle do not annihilate because they form a single resonance of a stationary bosonic point pair, and points do not annihilate like particles do.

Now we can suggest a name for our new particle. I will refer to it as the *sloton*, for "slow photon." It is a massive boson, has zero charge, acts like a zero-spin or scalar particle, interacts only gravitationally, and feels degeneracy pressure. It is very cold, that is, slow-moving, because it moves only by quantum fluctuations of its position, and it is obviously very heavy. It is a good candidate for the dark matter that is known to form massive halos around galaxies and clusters. In fact, it is thought that these halos formed first, and galaxies formed within them. This would indicate that at the end of the inflationary period, when all particles were formed, there were quantum fluctuations in the sloton density that grew gravitationally to form large regions of greater and lesser sloton density.

Sloton Gravity. The sloton has very peculiar gravitational properties. It is a boson, so over time it will gravitate towards other slotons, but it does this very slowly, as if subject to friction. *It does not interact gravitationally with other types of particles*! Gravity is the result of the bosonic spacetime points tending towards the same state (Bose-Einstein statistics) and dragging the fermionic spacetime points with them. This only happens if the points are indistinguishable. A bound state of a bosonic point and a bosonic antipoint is *not* indistinguishable from a single bosonic point. Thus, there is no gravitational attraction between these two types of points, and therefore, there is no gravitational attraction between slotons and other particles. At *long distances*, a sloton and a baryon or lepton will *seem* to gravitate towards each other because, as explained elsewhere, gravity acts throughout spacetime but is unobservable until it is revealed by the presence of particles. Even the presence of a sloton will reveal that a baryon is attracted towards the region of space around the sloton. However, it is not attracted to the sloton itself. It just seems that way. At close range, it becomes obvious that there is no attraction between slotons and normal particles. Observationally, slotons would obey Newton's law when interacting with each other, but with other types of particles, their interaction would seem to obey Newton's law at long distances and decrease to zero at zero distance. If gravity is an exchange of gravitons for ordinary matter, it would then appear that dark matter particles exchange some different force carrier, as the AFSW theory suggests.

Dark Matter Halo Density Profiles

The existence of dark matter is inferred from measurements of the rotation velocity of gas and isolated stars far outside the luminous cores of galaxies. Here the rotation velocity at a distance r from the center of the galaxy, according to Newton's law, should be given by $v^2 = GM/r$, where G is Newton's constant and M is the mass of the luminous galaxy. Outside the luminous core, there should be almost no matter, so M should be constant and v^2 should fall off as 1/r. In fact, *v^2 falls off much more slowly*. Measurements indicate that the velocity is nearly constant, implying a linear increase of mass with radius. Since no matter can be seen that would account for this increase of mass, it is attributed to a halo of *dark matter* surrounding the galaxy.

Dark matter researchers seek to predict the mass density profile of dark matter halos via computer simulations and then confirm these predictions by observing actual galaxies. At large distances there is fairly good agreement. Some recent measurements seem to confirm the mass density profile seen in simulations of the model called *collisionless cold dark matter*. For small r, near the center of the galaxy, the collisionless cold dark matter simulations indicate that the halo density becomes very high near the core of the galaxy (a *cuspy* halo). Some observations appear to confirm this, and others find that the core density appears to flatten out near r = 0. A major problem with the cold dark matter model is that the simulations show much more clumping or fine structure in dark matter halos than is actually observed. The simulations assume that dark matter particles attract each other according to Newton's law. Observations consist of measurements on the visible, baryonic matter in galaxies. The dark matter density profile is then computed from these measurements, assuming that baryons and dark matter particles also attract each other according to Newton's law.

F. Piazza and C. Marinoni (*Phys. Rev. Lett.*, **91** 141301, 2003) have recently found that the observations and the simulations can be reconciled if it is assumed that interactions between the dark matter and the baryonic matter do *not* obey Newton's law. They propose a modified gravitational potential between dark matter and baryons that obeys Newton's law at large distances but goes to zero at close range.

Does the sloton of the inflaton spacetime model have the right properties to be the dark matter? It is very cold, and it is collisionless in that it does not interact with normal matter at close range. We have seen that the sloton appears to interact gravitationally with baryonic matter according to the kind of law proposed by Piazza and Marinoni, which gives a better fit to the observational data than the standard cold dark matter model for many galaxies. The sloton is not collisionless with respect to itself, because slotons feel degeneracy pressure. This means that while its core density can be very high, as predicted by the simulations, it can never be infinite because of the degeneracy pressure, which tends to keep slotons apart. Because of this degeneracy pressure, sloton density profiles should not be very clumpy or fine-structured; this agrees with observations.

Annihilation. A last word about degeneracy pressure as felt by slotons: Degeneracy pressure for slotons is not the same as for fermions. It is a rather weak force that tends to keep slotons apart *on the average*. It is more of a bulk effect than an individual particle effect. Thus, a sloton will be repelled by a large cloud of slotons, but if two slotons get close enough, gravity will overcome the degeneracy pressure and pull them together. Since a sloton is its own antiparticle, two slotons that collide will annihilate into photons or leptons, in the same way that matter and antimatter annihilate into photons. (It is the resonances or particles that annihilate, not the underlying points. Points do not annihilate.) This means that if the sloton is the dark matter, we might be able to detect gamma rays or leptons from dark matter annihilation. In fact excesses of both gamma rays and leptons have been detected in our galaxy, and there is strong suspicion that these may be products of dark matter annihilation.