Entropy Scale Factor May Explain Gravity, Dark Matter and the Expansion of Space

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Abstract

The entropy scale factor (ESF) is a recently published theory proposing that the scale of time and space change depending on entropy, and that this change underlies special relativity, gravity and the expansion of space. In special relativity, as the relative velocity of objects increases there are more possible combinations of momentum and position within the moving frame due to the uncertainty principle. This increase in possible microstates represents an increase in entropy, which can be correlated with the time dilation and length contraction of special relativity. The ESF predicts that an observer in an empty region of space taking measurements near an entropic object will measure time to run more slowly and lengths to appear longer in the direction of entropy. These changes in scale would warp of spacetime, causing gravity. For objects with low acceleration gravity can be approximated by the time dilation component only. For a single star, this approximation predicts a gravitational field similar to that of Newtonian gravity. For a constellation of stars, the ESF predicts that gravity will be stronger than in Newtonian gravity, because the constellation has additional entropy associated with its configuration. Constellation entropy is a result of uncertainty in the relative position and momentum of the individual stars and black holes within a constellation. This additional source of entropy would cause the gravitational field from ESF to be higher for constellations than for the sum of their individual objects, which could explain galaxy rotation dynamics and the gravitational lensing of galaxies, without the need for dark matter. Additionally, the entropy scale factor would cause space to expand as the entropy of the universe increases. This is because the entropy of a spherical boundary changes only the radial dimension, so as the entropy encoded on the boundary increases time within the boundary slows down more quickly than the volume decreases. Given the constant speed of light, an observer inside such a boundary will experience the increasing volume to time ratio as the expansion of space. Accordingly, the rapid increase in entropy in the early universe would cause a rapid expansion of space, possibly explaining the homogeneity of the large-scale structure of the universe without the need for inflation. In our recent universe, the increasing rate of entropy production due to black holes may explain the accelerating expansion of space, without the need for dark energy.

1. Introduction

The predictions of general relativity have been confirmed in a broad array of tests, including gravitational time dilation of the earth, gravitational lensing of the sun and direct observation of a black hole, among others. These tests have been all done in simple systems. General relativity has failed to make accurate predictions in more complicated systems, like galaxies or the universe as a whole. Discordant phenomena have been explained by theories such as dark matter, inflation and dark energy, although it is possible that a new theory of gravity could make the same predictions as general relativity for simple systems, while performing better in complicated systems.

The scale of spacetime is known to change depending on reference frame, gravitational fields and the expansion of the universe. The entropy scale factor (ESF) is a new theory that proposes that a change in entropy underlies all of these changes in scale.[1,2] This theory has predictions that diverge from general relativity for complicated systems. These predictions include an increase in the strength of gravity for constellations of stars, rapid expansion of space in the inflationary epoch, and accelerating expansion of space in our recent universe. These changes may explain phenomena that have been attributed to dark matter, inflation and dark energy.

This essay defines the ESF and discusses examples involving special relativity, black holes, and gravity. It applies the ESF to phenomena attributed to dark matter, inflation and dark energy. It explains why these changes have not been detected in tests of general relativity and suggests areas for future study.

2. Entropy and Special Relativity

Applying thermodynamics to special relativity is a long-standing problem in physics.[3] Investigators have typically assumed that entropy is independent of reference frame, but this paper shows that reference frames have their own entropy. In statistical mechanics, the entropy of a system is described by how the measurable macrostate is spread out over all the possible microstates. Each microstate is defined by the position and momentum of the molecules in the system. If increased relative motion between two reference frames results in more possible microstates for the particles in the moving frame, then this change can be interpreted as an increase in entropy.

To see how motion can affect entropy consider the Heisenberg microscope thought experiment, which has objects in two different reference frames: the rest frame of the observer and the moving frame of the recoil electron. In this experiment, Compton scattering off an electron is measured by an idealized microscope. If the experiment is set up to maximize measurements of direct hits from photons (those with a scattering angle of 180°), the rest frame the energy of the scattered photon is given by the following equation, where hv_0 is the energy of the incident photon (Eq. 1).

$$hv' = hv_0\left(\frac{1}{1 + \frac{hv_0}{0.511\ \text{MeV}}(1 - \cos\theta)}\right)$$

Eq. 1

In the case of a direct hit, the energy of the scattered photon increases much more slowly than the energy of the incident photon, and has a maximum energy of < 0.256 MeV. This contrasts with the momentum of the recoil electron, which increases nearly as fast as the momentum of the incident photon.

In this experiment, the entropy of the recoil electron's reference frame would depend on how many ways the momenta and positions of the electron and the photon can be divided up. As the recoil electron's frame gains velocity there would be a small decrease in the number of possible locations, due to the slow change in the scattered light's wavelength, compared to the energy of the incident light. There would also be a much larger increase in the possible combinations of momentum, due to the rapid increase in the recoil electron's momentum. This imbalance leads to an increase in the total number of possible microstates and represents an increase in entropy due to the hidden information in the moving frame. This entropy is related to the velocity of the moving object, and not Compton scattering specifically, as any photon interacting in two frames with high relative velocity will have a large number of possible microstates.

Once entropy is calculated for the relative velocity of objects this entropy can be correlated with the time dilation and length dilation of Lorentz transformations. If the same change in scale occurs with other forms of entropy, then black holes offer a useful framework for exploring its effects.

3. Entropy Scale Factor and Black Holes

The entropy scale factor is defined by the change in the scale of time due to entropy and is proportional to the change in length due to entropy. The ESF can be quantified by comparing a standard unit in a region with entropy to the same unit in empty space. This paper will use the Planck time (t_p) and the Planck length (l_p) as the standard unit of comparison, due to the importance of the Planck length in black hole thermodynamics. Accordingly, the ESF is defined by the Planck time over the Planck time in empty space, which is proportional to the Planck length over the Planck length in empty space (Eq. 2).

$$W_S \equiv \frac{t_P}{t_{P0}} \propto \frac{l_P}{l_{P0}}$$

Eq. 2

The ESF predicts that t_p and l_p will increase due to entropy. The Planck time is the time it takes for light to travel one Planck length, so as t_p increases time dilation will increase. This means that a clock near a high entropy object will tick more slowly than the clock of an observer in empty space.

The ESF also predicts a change in scale in one of the three spatial dimensions, the dimension towards or away from a region of entropy. This is analogous to how in special relativity Lorentz transformations result in length dilation in the direction of motion, but not in the perpendicular directions. As l_p increases length will appear to increase, so a measuring rod near such an object will appear longer in the direction of entropy.

Black holes offer a way to quantify changes in scale due to entropy. The surface area of black holes depends on their entropy, but their volume is undefined by general relativity.[4-6] The ESF predicts length dilation along the radius of the black hole, but not in the circumferential direction. By asymmetrically changing the scale of space only along the direction of the radius, the volume of a black hole can be changed without upsetting the relationship between its surface area and entropy.

The ESF changes space in this way to predict that all Schwarzschild black holes have the same radius. Locations within a black hole cannot be distinguished, so the ESF treats the radius of all Schwarzschild black holes as one quantum of length. To an observer, the radius of a more entropic black hole will appear larger, but this is because there is more length dilation associated with the higher entropy of the larger black hole.

Particles cannot be located more precisely than the Planck length, so the maximum amount of length dilation in the ESF would be to assume that the radius of every Schwarzschild black hole is one Planck length. This conflicts with the traditional radius of a black hole. For example, in general relativity a Planck mass black hole has a radius of two Planck lengths. The ESF explains this discrepancy by saying that the entropy encoded on the event horizon of a Planck mass black hole causes a scale factor two, so that the size of a Planck length within the black hole would appear to be twice as large as a Planck length in empty space.

The Hawking equation can be rearranged to give the radius of a Schwarzschild black hole in general relativity (Eq. 3).

$$r_s = l_p\sqrt{\frac{S}{\pi k_B}}$$

Eq. 3

Assuming that the radius of all black holes is one Planck length, the Planck length can be substituted for the Schwarzschild radius and both side can be divided by the Planck length in empty space. The resulting equation gives the ESF for a black hole radius depending on its entropy (Eq. 4).

$$W_S = \sqrt{\frac{S}{\pi k_B}}$$

Eq. 4

Transitional symmetry would be violated if changes in scale only occurred within a black hole. A sphere centered on a black hole in empty space will have the same entropy as the black hole, but a larger surface area. The surface area of the sphere changes with the inverse square of its radius, so the following relationship can be used to estimate the magnitude of the ESF a given distance from this black hole (Eq. 5).

$$W_S \propto \frac{\sqrt{\frac{S}{\pi k_B}}}{x^2}$$

Eq. 5

According to this relationship, time would move more slowly and lengths perpendicular to the surface of the black hole would appear longer in the space surrounding the black hole, not just within it. The time dilation and length dilation from the ESF would be strongest near black holes, or other entropic objects, and fall off with distance. These changes would cause gravity in the direction of an entropic object, discussed in the next section.

4. Entropy Scale Factor and Gravity

The entropy scale factor would cause gravity in the direction of entropy. This can be seen because in general relativity, in systems with low acceleration gravity is in the direction of time dilation. For example, in a weak field the metric can be approximated by the following equation, where φ(x) is the Newtonian potential (Eq. 6).[7]

$$ds^2 = \left(1 + 2\varphi(x)\right)dt^2 - dx^2$$

Eq. 6

In this equation, the metric is strongly correlated with dt^2, and dt^2 increases with time dilation. Since gravity is in the direction of time dilation, and the ESF predicts time dilation around entropic objects, the ESF also predicts that gravity will be in the direction of entropic objects.

For a single entropic object, like a black hole or a star, Newtonian gravity and the ESF predict similar gravitational fields, because gravitational acceleration falls off as an inverse square in both theories. However, for constellations of entropic objects the predictions will diverge. This is because the entropy of a system of gravitational objects is higher than the sum of the objects' individual entropy. Each constellation of gravitational objects has its own entropy, which depends on the entropy and arrangement of objects in the system. The total entropy of a gravitational system is the constellation entropy, plus the entropy of the individual stars and black holes in that system. If gravity depends on entropy, as predicted by the entropy scale factor, then constellation entropy should cause the gravitational field of a system to be stronger than what would be predicted based on the entropy of its objects alone.

One way to interpret the entropy of black holes is as uncertainty about the position and momentum of the black hole.[8] Knowledge about these quantities is limited not only by the uncertainty principle, but by each black holes' gravitational field. Photons from interactions near the surface of a black hole have gravitational redshift when observed at a distance from the black hole. This redshift decreases the spatial resolution for the observer, increasing uncertainty about both position and momentum.

For an observer measuring a constellation of two black holes, gravitational redshift not only results in uncertainty in the position and momentum of each two black holes relative to the observer, but also results in even greater uncertainty in the position and momentum of the black holes relative to each other. This additional uncertainty represents constellation entropy.

Constellation entropy is higher when the system's objects have stronger gravitational fields, and when they are closer together, resulting in more overlap of their gravitational fields. Although constellations can be simple, their constellation entropy can be relatively large because strong gravitational fields can result in large amounts of uncertainty, as in the black hole example above.

Constellations can also be complicated. The Milky Way has been estimated to contain 100 billion stars.[9] Such a complicated system has many possible microstates, which corresponds with significant entropy. In the entropy scale factor, this constellation entropy would increase the strength of gravity, compared to theories like Newtonian gravity and general relativity where constellation entropy does not influence gravity.

To be a useful theory of nature, the entropy scale factor will have to agree with tests of general relativity. To the author's knowledge all precise tests of general relativity have been done in systems with one or two entropic objects. The ESF diverges most from general relativity when a constellation of two or more entropic objects interacts with another object. Tests involving only two objects, such as laser lunar ranging or binary pulsars, are not sensitive tests of ESF because they do not measure how constellation entropy affects gravity.[10,11]

5. Entropy Scale Factor and Dark Matter

The entropy scale factor may be helpful in explaining some of the phenomena that have been attributed to dark matter. These phenomena include galaxy rotation rates and gravitational lensing around galaxies.

Galaxy rotation curves show that the outer reaches of galaxies rotate faster than would be expected with general relativity.[12,13] The ESF could explain this phenomenon because it predicts that the gravitational fields of constellations will be stronger than in Newtonian gravity, as explained above. This same mechanism could apply to other phenomena that have been attributed to dark matter as well, including globular cluster and galaxy cluster dynamics.

Dark matter has also been invoked to explain gravitational lensing around galaxies, which is stronger than expected. The ESF may be able to explain this phenomenon without dark matter, because the strength of gravitation lensing would be increased by constellation effects, and because black holes have entropy that is disproportionally higher than other forms of matter. Entropy increases by a factor of ~10^{19} when a star collapses into a black hole.[14] This means that galaxies with black holes may have significantly more gravitational lensing than would be expected based on their mass alone.

6. Entropy Scale Factor and the Expansion of Space

There are two features of the universe's expansion that are not well explained by general relativity. First, the early universe had an unexplained period of rapid expansion.[15] Second, the rate of expansion of the more recent universe appears to be increasing, instead of decreasing due to gravitational attraction.[16,17] These phenomena have been attributed to inflation and dark energy, respectively, although it is possible that both phenomena are better explained by the entropy scale factor.

To see how the ESF causes the expansion of space, imagine a spherical volume with increasing entropy. As entropy increases length dilation would cause there to be less volume in the sphere. Time dilation would cause time to slow down, and this change would dominate over length contraction because time affects all dimension, while length dilation just affects one. The speed of light is constant, so an observer at the center of the sphere will measure nearby space to have a higher volume-to-time ratio than space further away, which is to say space expanding over time.

The entropy of the universe is always increasing, but it does not always increase at a constant rate.[18] Right after the big bang there was a huge increase in entropy due to the formation of particles and radiation. This period was followed by a slower increase in entropy, driven by the evolution of stars. Entropy is increasing faster again, driven by the growth of black holes. According to the ESF the rapid increase in entropy in the early universe would cause a rapid increase in the size of the universe. This effect may explain the homogeneity of the large-scale structure of the universe, without the need for inflation. In our recent universe, the increasing rate of entropy production due to black holes may explain the accelerating expansion of space, without the need for dark energy.

7. Conclusions

The expansion of the universe has been previously linked to its entropy, both in the inflationary epoch and in the accelerating universe.[19,20] The entropy scale factor is different because it offers a mechanism for this expansion, and because it may explain other phenomena including special relativity, gravity and those attributed to dark matter.

The ESF may also be linked to other problems as well. Solar corona heating and the power of relativistic jets are both unsolved problems that involve entropic objects. If either of these phenomena can be explained by the ESF, then they would represent additional arguments for this theory.

Numerous studies will need to be done to see if the entropy scale factor agrees with existing data and can explain unsolved mysteries in a consistent system. The ESF's possible connections to multiple problems, like the ones listed above, create a rigid framework for testing this idea. This theory has not had the time for elaboration that has been afforded to theories like dark matter, inflation and dark energy. It is worth further study because it has not been ruled out by tests of gravity and because it has the potential to offer a breakthrough with relevance to many problems in physics.

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