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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 novel 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 time dilation is added as a scalar sum, instead of the vector sum used in Newtonian gravity. Adding fields as a scalar sum avoids the cancelling out that comes with vectors pointed in different directions, leading to increased gravitational acceleration. This effect could explain galaxy rotation dynamics and the gravitational lensing of galaxies without the need for dark matter. Additionally, the ESF 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. © *2022 Physics Essays Publication*. [http://dx.doi.org/10.4006/0836-1398-35.1.27]

Résumé: Le facteur d'échelle de l'entropie (ESF) est une nouvelle théorie proposant que l'échelle du temps et de l'espace change en fonction de l'entropie, et que ce changement est à la base de la relativité restreinte, la gravité et l'expansion de l'espace. Dans la relativité restreinte, plus la vitesse relative des objets augmente, plus il y a de combinaisons possibles de vitesse et de position dans un cadre mobile en raison du principe d'incertitude. Cette augmentation des micro-états possibles représente une augmentation de l'entropie, qui peut être mise en relation avec la dilatation du temps et la contraction de la longueur de la relativité restreinte. Le ESF prévoit qu'un observateur dans une région vide de l'espace prenant des mesures à proximité d'un objet entropique verra le temps s'écouler plus lentement et les longueurs paraîtront plus longues dans la direction de l'entropie. Ces changements d'échelle déformeraient l'espace-temps, engendrant la gravité. Pour les objets à faible accélération, la gravité peut être estimée uniquement par la composante de dilatation temporelle. Pour une seule étoile, cette approximation prédit un champ gravitationnel similaire à celui de la gravité newtonienne. Pour une constellation d'étoiles, le ESF prédit que la gravité sera plus forte que dans la gravité newtonienne, car la dilatation du temps est ajoutée comme une somme scalaire, au lieu de la somme vectorielle utilisée dans la gravité newtonienne. Ajouter des champs comme une somme scalaire évite l'annulation qui vient avec des vecteurs pointés dans différentes directions, conduisant à une accélération gravitationnelle accrue. Cet effet pourrait expliquer la dynamique de rotation des galaxies et la lentille gravitationnelle des galaxies, sans avoir besoin de matière noire. De plus, le ESF entraînera l'expansion de l'espace à mesure que l'entropie de l'univers augmente. C'est parce que l'entropie d'une délimitation sphérique change seulement la dimension radiale, de sorte que l'entropie de la délimitation augmente le temps dans

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la limite ralentit plus rapidement que le volume diminue. Étant donné la vitesse constante de la lumière, un observateur à l'intérieur d'une telle frontière connaîtra l'augmentation du rapport volume-temps à la mesure de l'expansion de l'espace. En conséquence, l'augmentation rapide de l'entropie dans l'univers primitif provoquerait une expansion rapide de l'espace, ce qui expliquerait peut-être l'homogénéité de la structure à grande échelle de l'univers sans la nécessité de l'inflation cosmique. Dans notre univers récent, l'augmentation de la production d'entropie due aux trous noirs peut expliquer l'expansion accélérée de l'espace, sans avoir besoin d'énergie noire.

Key words: General Relativity; Entropy; Dark Matter; Inflation.

I. INTRODUCTION

There are a number of long-standing mysteries in astrophysics. The outer reaches of galaxies rotate too quickly. Galaxies have too much gravitational lensing. The cosmic microwave background is too even. The expansion of space is unexpectedly accelerating. Various explanations have been proposed for these phenomena, including dark matter, inflation, and dark energy, yet none have been universally accepted.[1–3] Alternatively, it is possible that all of these phenomena may be explained by a change in our understanding of gravity.

The scale of spacetime is known to change depending on reference frame, gravitational field, 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. This theory predicts 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 paper 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.

II. ENTROPY AND SPECIAL RELATIVITY

The Heisenberg microscope is a thought experiment that has objects in two different reference frames: the rest frame of the observer and the moving frame of the recoil electron. In this experiment, the Compton scattering off an electron is measured by an idealized microscope. The Heisenberg microscope has been criticized for using classical physics to explain a quantum phenomenon, but it still provides useful insights.[4] This experiment is typically used to show the limits of simultaneously measuring the position and momentum of the electron, but it can also be used to show how relative velocity results in entropy.

Consider a Heisenberg microscope setup to maximize measurements of direct hits from photons (those with a scattering angle of 180°). In the rest frame, the energy of the scattered photon is given by the following equation, where $h\nu_0$ is the energy of the incident photon

$$h\nu' = h\nu_0 \left(\frac{1}{1 + \dfrac{h\nu_0}{0.511\,\mathrm{MeV}}(1 - \cos\theta)} \right). \tag{1}$$

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 $<0.256\,\mathrm{MeV}$. This contrasts with the momentum of the recoil electron, which increases nearly as fast as the momentum of the incident photon.

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.

Analogously, in the Heisenberg microscope, the entropy of the recoil electron's frame would depend on how many ways the momenta and positions of the electron and the photon can be divided up. As the frame of the recoil electron gains velocity, the number of possible microstates of location would decrease, due to the optical resolution of microscopes and the lower wavelength of the scattered light. The decrease in possible locations would be limited, however, by the slow change in the scattered light's wavelength, compared to the energy of the incident light. As the energy of the incident light increases, there would 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 contraction of special relativity. If the same change in scale occurs with other forms of entropy, then black holes offer a useful framework for exploring its effects.

III. 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.

$$Ws \equiv \frac{t_p}{t_{P0}} \propto \frac{l_p}{l_{P0}}. \qquad (2)$$

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 there is length contraction 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. At first glance, this "length dilation" appears to be the opposite of the length contraction of special relativity, but it actually represents a similar process. In special relativity, using a Lorentz transformation on spatial coordinates results in a bigger difference in coordinates than a Galilean transformation would. It is only when spacetime is examined, instead of just the spatial dimension, that length contraction occurs. This is because measuring length requires measuring two points simultaneously. As the speed of an object increases, time dilation makes the speed of light in the moving frame appear to be slower, yet the speed of light in the rest frame remains constant. This mismatch means that the time it takes light from different parts of the object to reach an observer will depend on the object's velocity relative to the observer. This relativity of simultaneity results in length contraction, with length decreasing as the velocity of the moving object increases.

In the ESF, a measuring rod near a star could be motionless. In this situation, the ESF could cause an apparent increase in length, similar to a Lorentz transformation, without motion causing length contraction.

Black holes give further insights into the changes of scale in the ESF. The surface area of black holes depends on their entropy, but their volume is undefined by general relativity.[5,7] 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

$$r_s = l_p\sqrt{\frac{S}{\pi k_B}}. \qquad (3)$$

Assuming that the radius of all black holes is one Planck length, the Planck length can be substituted for the Schwarzschild radius and both sides 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

$$W_S = \sqrt{\frac{S}{\pi k_B}}. \qquad (4)$$

For spheres centered on a black hole in empty space, the entropy per unit of surface area decreases as the size of the sphere increases. This is because the larger spheres contain the same entropy yet have a larger surface area. The surface areas of spheres change with the inverse square of their radii, so the following relationship can be used to estimate the magnitude of the ESF a given distance from this black hole:

$$W_S \propto \frac{\sqrt{\frac{S}{\pi k_B}}}{x^2}. \qquad (5)$$

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. These changes in scale must occur outside a black hole, because translational symmetry would be violated if they only occurred within. The time dilation and length dilation from the ESF would be strongest near black holes, or other entropic objects, and fall off with distance. Both time dilation and length dilation contribute to the warping of spacetime. These changes would cause gravity in the direction of an entropic object, discussed in Sec. IV.

IV. ENTROPY SCALE FACTOR AND GRAVITY

The entropy scale factor would cause gravity in the direction of entropy. This can be seen by examining the Schwarzschild metric from general relativity. In this equation, ds^2 is the metric, which is similar to the gravitational potential in Newtonian gravity, G is the gravitational constant, t is time, r is radius, and c is the speed of light[8]

$$ds^2 = -\left(1 - \frac{2GM}{c^2 r}\right)(c\,dt)^2 + \left(1 - \frac{2GM}{c^2 r}\right)^{-1} dr^2 + r^2\left(d\theta^2 + \sin\theta\, d\varphi^2\right). \qquad (6)$$

Since dt is multiplied by the speed of light, and dr is not, change in time dominates gravity in systems that do not have high acceleration. 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 time dilation from the ESF is added as a scalar sum, instead of the vector sum used to add fields from different objects in Newtonian gravity. Adding fields as a scalar sum avoids the cancelling out from vectors pointed in different directions, increasing the strength of gravity. For example, consider the acceleration of a test mass in a system of two identical stars the same distance from the x-axis (Fig. 1).

In Newtonian gravity, the acceleration towards each star is given by the following equation, where G is the gravitational constant, M is the mass of the star, and $\hat{r}$ is the unit vector:

$$g = -\frac{GM}{r^2}\hat{r}. \tag{7}$$

In the above example, acceleration along the y-axis would cancel out, so the acceleration along the x-axis can be calculated by solving for the x-axis vector component, then multiplying by two to account for the presence of two stars. The unit vector was dropped, because acceleration is given to be along the x-axis

$$g = -\frac{2GM\cos\theta}{y^2 + x^2}. \tag{8}$$

In the ESF, the mass of the stars is replaced by the square root of their entropy, S. This is because time dilation is proportional to the square root of entropy, as in Eq. (5). The gravitational field from the ESF would be approximated by the following equation, where G represents a new gravitational constant that is dependent on the square root of entropy, instead of on mass

$$g = -\frac{2G\sqrt{S}\cos\theta}{y^2 + x^2} - \frac{2G\sqrt{S} - 2G\sqrt{S}\sin\theta}{y^2 + x^2}. \tag{9}$$

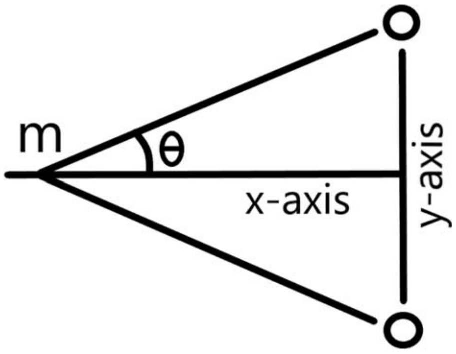

FIG. 1. Two identical stars, represented by circles, are equidistant from the x-axis. They attract a test mass, m, on the x-axis.

The new gravitational constant can be found by multiplying the Newtonian gravitational constant by the mass of a Schwarzschild black hole (to get its standard gravitational parameter) then dividing by the square root of the black hole's entropy. This yields a value of $\sim 1.1 \times 10^{-7}$ m^3 K$^{0.5}$ J$^{-0.5}$ s^{-2}.

The entropy of stars, planets, and objects on earth are dependent on their mass, so entropy would increase proportionately with mass in most situations.[9] If the gravitational field for a single star in the ESF is indistinguishable from the Newtonian prediction, then the *cos* θ expression in Eq. (9) should be equivalent to Eq. (8). The *sin* θ expression would then represent the increase in gravity predicted by the ESF, because the y-axis component would not cancel out like it does in Newtonian 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 two entropic objects interact with a third object, as in the example with two stars above. Tests involving only two objects, such as laser lunar ranging or binary pulsars, are not sensitive tests of ESF, because they study how the two objects affect each other, not how the combination of the two fields would affect a third object some distance away.[10,11]

V. 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 $\sim 10^{19}$ when a star collapses into a black hole.[15] This means that galaxies with black holes may have significantly more gravitational lensing than would be expected based on their mass alone.

The Bullet Cluster is a famous example of gravitational lensing around galaxies.[14] In this system, a collision of two galaxy clusters left most of the matter as intragalactic gas in the space between the clusters. Gravitational lensing is stronger in the galaxies than for the more massive intragalactic gas. Although a precise estimate of the Bullet Cluster's structures' entropy is not available, a survey of the universe estimated that the entropy of all black holes is $\sim 10^{25}$ times larger than that of all interstellar matter and intragalactic matter, combined.[9] If the Bullet Cluster's composition reflects the universal average, then there should be more entropy in the galaxy clusters, even though the intragalactic gas is more massive. Additionally, the relatively compact size of the galaxies, compared to the intragalactic gas cloud, may allow for more overlap of time dilation fields, leading to more constellation effects. With the high entropy of the galaxies due to black holes, and the galaxies' small size increasing gravity from the ESF, this theory may be able to explain gravitational lensing in the Bullet Cluster without the need for dark matter.

VI. 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.[16] Second, the rate of expansion of the more recent universe appears to be increasing, instead of decreasing due to gravitational attraction.[17,18] These phenomena have been attributed to inflation and dark energy, 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 will cause there to be less volume in the sphere, in the same way that length dilation causes a black hole to have less volume than is expected based on its surface area. As entropy increases, time dilation will cause time to run more slowly in the sphere. Time will change faster than volume, because length dilation only affects the radial dimension, while time dilation affects all spatial dimensions.

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 expands as the entropy of the sphere increases.

The entropy of the universe is always increasing, but it does not always increase at a constant rate.[9] 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.

VII. CONCLUSIONS

The entropy scale factor is similar to modified Newtonian dynamics in that it proposes an increase in the strength of gravity that has not been ruled out by tests of general relativity and does not break any accepted symmetry of nature, such as translational symmetry.[19] It is different in that it depends on entropy, not mass, which may better explain phenomena like the Bullet cluster.

The expansion of the universe has been previously linked to its entropy, both in the inflationary epoch and in the accelerating universe.[20,21] The ESF 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 that would be a powerful argument for this theory.

The ESF's possible connections to multiple problems, like the ones listed above, create a rigid framework for testing this idea. 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. 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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