Erratum and Addendum: Entropy scale factor may explain gravity, dark matter, and the expansion of space [Phys. Essays 35, 27 (2022)]

Christopher N. Watson[a)]
1300 East 86th Street, Suite 14, Indianapolis, Indiana 46240, USA

(Received 21 January 2022; accepted 15 February 2022; published online 8 March 2022)

 [http://dx.doi.org/10.4006/0836-1398-35.1.99]

The article of Ref. 1 incorrectly said that in Newtonian gravity, fields are added as a vector sum. Gravitational potential is a scalar quantity, and fields made of gravitational potential should be added as scalar quantities. Gravitational acceleration from two objects is added as a vector quantity, but gravitational acceleration represents a gradient in the field, not the field itself.

Additionally, Eq. (9) in the article is incorrect. Time dilation fields should be added the same way as in Newtonian gravity. Since time dilation fields from different objects are added the same way as gravitational fields in Newtonian gravity, scalar addition cannot account for the "constellation effect," where the gravity of two objects adds up to a stronger gravitational field than would be expected in Newtonian gravity.

Instead, the constellation effect can be explained by entropy. This is because the entropy of a system of gravitational objects is higher than the sum of the objects' individual entropy. This is true because 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.

Constellation entropy can be explained by comparing it with a star's entropy. The entropy of a star describes how many possible microstates could add up to the measurable macrostate of the star. Each microstate represents a possible combination of position and momentum for the star's particles. Similarly, constellations entropy represents the number of possible combinations of position and momentum for the objects in the system that adds up to the measurable macrostate of the constellation.

For example, consider a constellation of two black holes. Each black hole has its own entropy, which is associated with a temperature.[2] One way to interpret the temperature of black holes is as uncertainty about exact position of segments of the event horizon.[3] This uncertainty comes from quantum fluctuations of spacetime. Knowledge about the position and momentum of a black hole is limited not only by the uncertainty principle but also 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 the position and momentum of the black hole. For a constellation of two black holes, an interaction near the surface of one black hole is redshifted from both black holes' gravitational fields, resulting in greater uncertainty than if the nearby black hole was by itself.

Uncertainty about the position and momentum of individual black holes and stars in a constellation results in multiple possible microstates, which would add up to the measurable macrostate of the system. This 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 gravitational fields can result in many possible microstates, as in the black hole example above.

Constellations can also be complicated. The Milky Way has been estimated to contain one billion stars.[4] 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. With increased gravity due to constellation entropy, the entropy scale factor may be able to explain phenomena that have been attributed to dark matter, including galaxy rotation dynamics, galaxy cluster dynamics, and the gravitational lensing of galaxies.

[1]C. N. Watson, Phys. Essays **35**, 27 (2022).
[2]S. W. Hawking, Commun. Math. Phys. **43**, 199 (1975).
[3]C. Rovelli, *Reality is Not What it Seems: The Journey to Quantum Gravity* (Riverhead Books, New York, 2017).
[4]The Gaia Collaboration, Astron. Astrophys. **595**, A1 (2016).

[a)]chriswatsonmd@gmail.com