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MEMORANDUM

To: All concerned

From: Peter Fisher

Subject: The difference between dark matter and dark energy

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Those outside the field are frequently curious about the difference between dark matter and dark energy. In both cases, "dark" refers to a lack of interaction with light and both have been observed only via the response of normal matter their gravitational influence.

Dark energy appears to be uniformly distributed throughout the universe with a mass density of Λ =9 proton masses per cubic meter. Einstein's field equations relate the mathematical object that describes the expansion of the universe with the energy density of the matter in the universe plus a dark energy term proportional to Λ. The dark energy density does not change as the universe expands, making further expansion of the universe energetically favorable – the unchanging dark energy density drives the expansion exponentially with time. The dark energy term in the field equations was added to explain observations that distant super novas recede more rapidly that predicted by the Hubble Law.

The constant dark energy density is characteristic of the zero point motion of a quantum field. Despite considerable theoretical speculation, there is no workable quantum theory of gravity and there is no viable quantum mechanical explanation for dark energy.

Dark matter acts like a collection of particles – it flows towards concentrations of matter under the force of gravity. There is a fixed number of dark matter particles in the universe, so as the universe expands, the dark matter becomes more dilute. Normal matter and photons behave in the same way. As they become more dilute as the universe expands, both dark and normal matter drive the expansion of the universe much more slowly than dark energy. If the total energy density is below a certain critical amount, the expansion of the universe stops and it begins to contract.

Dark matter concentrates in galaxies, exerting a dominant influence on the observable motion of normal matter in galaxies. For example, the Milky Way contains between 0.6 and 3 trillion solar masses of dark matter, while the total stellar mass of the Milky Way is around 60 billion solar masses, 2-5% of the dark matter mass. On average in the universe, this is about 0.01 proton mass of dark matter per cubic meter, while near Earth, there are about 300,000 proton masses of dark matter per cubic meter.

Dark matter enters into the Einstein field questions the same way normal matter does – there is no special dark matter term that needs to be added.

What dark matter and dark energy have in common is that, aside from gravitationally, they do not interact with normal particles, at least not very much. Neutrinos have the weakest known interaction strength of any particle – they can pass through the Earth without interacting at all. Measurements indicate dark matter has an interaction strength less than a ten billionth of a neutrino.

Finally, there are very well studied extensions to the Standard Model of particle physics that include particles that could be dark matter. There is no experimental evidence that any of these extensions are correct descriptions of nature, but experiments are looking for evidence of dark matter particles predicted by these extensions to the Standard Model.

In summary, dark matter has an easy way of being added to our successful model of particle interactions, while dark energy does not. Dark energy is uniformly distributed across the universe, while dark matter clumps in galaxies and clusters of galaxies. The dark energy density is constant with time while the dark matter density decreases with time as the universe expands. Both dark matter and dark energy interact gravitationally, but, at most, their interactions are much more feeble than those of the neutrino, the most weakly interacting particle currently known.