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EXPERIMENTALLY OBSERVED DARK MATTER CONFINEMENT CLARIFIES A DISCREPANCY IN ESTIMATING THE UNIVERSE'S EXPANSION SPEED

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Abstract. It is well known the our Universe is expanding. In principle, we can estimate the expansion speed either directly, by observing the current state of the Universe, or indirectly, by analyzing the cosmic background radiation. Surprisingly, these two estimates lead to somewhat different expansion speeds. This discrepancy is a important challenge for cosmologists. Another challenge comes from recent experiments that show that, contrary to the original idea that dark matter and regular (baryonic) matter practically do not interact, dark matter actually "shadows" the normal matter.
In this paper, we show that this "dark matter confinement" can explain the discrepancy between different estimates of the Universe's expansion speed. It also explains the observed ratio of dark matter to regular matter.

Keywords: dark matter, Universe's expansion speed.

1. Dark Matter: What Is It, and What Is Known About It

Newton's law of gravitation: brief reminder. One of the main discoveries of Isaac Newton was that the motion of each celestial body A is described by the equation

$$m_A \cdot \vec{a}_A = \vec{F}_A = \sum_B \vec{F}_{AB} = \sum_B G \cdot \frac{m_A \cdot m_B}{r_{AB}^3} \cdot \vec{r}_{AB},$$

where m_A is the mass of the body A, $\vec{a}_A$ is its acceleration, G is the gravitational constant, $\vec{r}_{AB}$ is a vector connecting the celestial bodies, and r_{AB} is the length of this vector, i.e., the distance between the bodies A and B.

By dividing both sides of this formula by m_A, we conclude that

$$\vec{a}_A = \sum_B G \cdot \frac{m_B}{r_{AB}^3} \cdot \vec{r}_{AB}.$$

By observing the motion of different celestial bodies, we can calculate their accelerations and thus, determine the corresponding masses.

In particular, by observing planets orbiting a star, we can determine the mass of this star; by observing satellites orbiting a planet, we can determine the mass of this planet, etc.

What is dark matter. In many galaxies, all the stars rotate around the galaxy's center (and, by the way, our Sun is no exception). In principle, by observing the acceleration of stars at different distance r from the galaxy's center, we can determine the overall mass of all the matter at distance $\leq r$ from the galaxy center.

On the other hand, we know what the galaxies are made of, so we can estimate the same mass by counting different stars – and adding up their masses, by counting the gases (which can be estimated by how much they emit or block the light from the stars), by estimating how many dead stars and planets there can be, etc.

It turns out that all possible matter constitutes only about 20% of the mass needed to explain the rotation. In other words, to explain the observed rotation, we need to conclude that, in addition to the usual mass, there is an additional "unusual" mass, mass that does not emit light or radio-waves and which is therefore not directly visible on the usual astronomical instruments such as telescopes and radio-telescopes. In a telescope, the area filled only with such an unusual matter is invisible (dark). Because of this fact, such unusual matter is called the *dark matter.*

Comment. To avoid possible confusion, we should mention that a similar deficiency appears if we compare the acceleration of galaxies on a cosmological scale with the overall mass of galaxies and other celestial bodies – the only difference is that on the cosmological scale, one needs to use Einstein's equations of General Relativity Theory instead of the approximate Newton's equations. The resulting missing mass is known as the *dark energy.*

In this paper, we only consider dark matter.

What is the proportion of usual vs. dark matter. According to current estimates, the usual matter forms $\approx 5\%$ of the Universe's mass and dark matter forms $\approx 27\%$ [4].

The original idea: dark matter and usual matter practically do not interact. Since the only observable effect of dark matter is its gravitational effect on the usual matter, researchers previously concluded that there is no other interaction between these two types of matter.

In other words, the only interaction between these two types of matter is the gravitational one – which, by the way, is drastically weaker than any other type of interaction; see, e.g., [2].

Because the only interaction between the two types of matter is very weak, it was assumed that, in general, these two types of matter practically do not affect each other. In particular, it was assumed that the spatial distributions of the usual matter and of the dark matter are very weakly correlated.

An unexpected empirical fact: dark matter follows the usual matter. Surprisingly, a recent spatial analysis of galaxy's velocity and usual mass distributions showed that there is a strong spatial correlation between the usual matter and the dark matter [3].

While on the local level, the distributions of the dark matter may be practically independent from the distribution of the usual matter, on a larger scale, the distribution of the dark matter seems to follow the distribution of the usual matter – and vice versa.

In other words, while on a medium-size distance scale, that may be no interaction between the usual and the dark matter, something prevents them from separating beyond a certain distance.

2. This Experimentally Observed Dark Matter Confinement Can Clarify a Discrepancy Between Estimates of the Universe' Expansion Speed

From the physical viewpoint, such a "confinement" is not unusual. The above phenomenon is not usual – a similar *quark confinement* is a known fact; see, e.g., [2]. Within short distances, quarks within a baryon practically do not interact with each other, but once they reach a certain distance, they become more and more attracted to each other – to the extent that they cannot separate beyond a certain distance.

The discrepancy in the Universe's expansion speed. While all observations confirm that the Universe expands, different measurements lead to different values of the expansion rate:

- supernova and quasar measurements estimate the expansion rate as 72–73 km/sec per megaparsec; see, e.g., [1], while
- measurements of the cosmic microwave background result in the smaller expansion rate of 67 km/sec per megaparsec [5].

From the physical viewpoint, cosmic background rational measurements correspond to early stages of the Universe, while supernova and quasar measurements reflect the current state of the Universe. Thus, the above discrepancy means that at present, the Universe expands faster than in the past.

Until now, there was no good theoretical explanation for this discrepancy.

Dark matter confinement can explain this discrepancy. The observed phenomenon of dark matter confinement shows that at reasonably short distances, there is a strong attraction force between dark matter and regular (baryonic) matter.

At present, the confinement distance – which is commeasurable with the galaxy sizes – is much smaller than the size of the Universe. Thus, these forces do not affect processes on the cosmological level of the Universe as a whole. On the other hand, on the early stages of the Universe, the distance was commeasurable with the Universe's size. Thus, this additional attraction force prevented the Universe from expanding – and, a consequence, the Universe expanded slower than at present.

This is exactly what we observe.

3. From Qualitative to Quantitative Explanation

Need for quantitative explanation. Qualitative explanation is a good start, but it is definitely desirable to come up with a quantitative explanation of observations. In this section, we provide such an explanation.

Dark matter confinement explains the discrepancy between different estimates of the Universe's expansion speed. In the dark matter confinement model, at the early stages of the Universe, there is a strong attraction between dark matter and regular matter, so strong that it prevents the dark matter from moving beyond a certain distance.

In effect, this means that at these stages, the dark and regular matter do not contribute to the expansion. Overall, both types of matter form $27\% + 5\% \approx 32\%$ part of the Universe's mass. Since the gravitational interaction is proportional to the product of the interacting masses, the interaction between dark matter and normal matter forms $0.32 \times 0.32 \approx 0.10$ part of the overall force. Thus, it is reasonable to expect that the expansion speed measured at the early stage of the Universe – e.g., by the cosmic background radiation – is approximately 10% smaller than the speed measured at present – e.g., by supernova and quasars.

A 10% decrease from 73 km/sec gives us 66 km/sec, which is in good accordance with the observe value of ≈ 67 km/sec per megaparsec.

4. Additional Result: Dark Matter Confinement Explains, in the First Approximation, the Observed Ratio of Dark Matter to Regular Matter

We know that dark matter "shadows" the regular matter. What is the configuration of dark matter in comparison with the usual matter?

- To each particle x of the normal matter, there can be a particle of dark matter nearby.
- We can also have several other particles of dark matter at some distance from the original particle x.

In nature, everything tries to move to a configuration with the smallest value of potential energy. Energy does not change if we swap different distance dark-matter particle. Thus, if we assume that there is one optimal configuration, then this optimal configuration should have the same symmetry as the energy expression. In other words, the configuration should not change if replace some of these distance dark-matter particles. This means, in the particular, that the distance between every two different dark-matter particles must be the same.

In the 3-D space, we can have no more than 4 points A_1, A_2, ..., with the property that $d(A_i, A_j) = \text{const}$ for all $i \neq j$. These points form a regular tetrahedron.

In the resulting configuration, to every particle of the usual matter, there correspond *five* dark-matter particles:

- one close one and
- four distance ones.

This first-approximation ratio of dark matter to normal matter is in good accordance with the observed ratio of $27\%/5\% \approx 5.4$.

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References

1. V. Bonvin et al., "H0LiCIW – V. New COSMOGRAIl time delays of HE 0435–1223: H_0 to 3.8 per cent precision from strong lensing in a flat ΛCDM model", *Monthly Notices of the Royal Astronomical Society*, 2017, Vol. 465, pp. 4914–1930.
2. R. Feynman, R. Leighton, and M. Sands, *The Feynman Lectures on Physics*, Addison Wesley, Boston, Massachusetts, 2005.
3. S. S. McGaugh, F/ Lelli, and J. M. Schombert, "Radial acceleration relation in rotationally supported galaxies", *Physical Review Letters*, 2016, Vol. 117, Paper 201101.
4. Planck Collaboration, "Planck 2013 results. I. Overview of products and scientific results", *Astronomy and Astrophysics*, 2014, Vol. 571, Paper A1.
5. Planck Collaboration, "*Planck* intermediate results. XLVI. Reduction of large-scale systematic effects in HFI polarization maps and estimation of the reionization optical depth", *Astronomy and Astrophysics*, 2016, Vol. 596, Paper A107.