

Dark Energy Production by Star Formation Processes in the Observable Universe

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Abstract

The main content of the presented work is devoted to the study of the dynamics of the growth of dark energy of gravitational radiation due to intense collidings and mergers of dark matter of primordial black holes in the processes of star formation.

It is shown that measurements based on the analysis of the cosmic microwave background (CMB) carry information about very early dark energy, while measurements based on the analysis of the brightness of Cepheids and Type Ia supernovae carry information about the dark energy surrounding them, including both its early component and the component associated with current star formation processes.

This, in particular, removes the so-called "Hubble tension" problem, based on the unfounded belief in the constancy of dark energy, and also understands the important role played by dark matter in the star formation processes themselves. As it turns out, it is involvement of dark matter in these very important processes that significantly accelerates the formation of early galaxies, as convincingly demonstrated by sensational discoveries of James Webb telescope.

Keywords: Dark Matter, Primordial Black Holes, Dark Energy Production, Star Formation Process, "Hubble Tension" Problem, Early Galaxies

Introduction

The so-called "Hubble tension" problem continues to trouble the astrophysicist community, as it affects the foundations of standard Lambda-CDM cosmology. Moreover, it is to be questioned the very existence of dark matter and dark energy, which form the basis of this well-established cosmology.

The essence of this problem, which has puzzled astrophysicists for nearly a quarter of a century, is that measurements of the Hubble parameter based on the Cosmic Microwave Background (CMB) and those using nearby objects such as Cepheids and Type Ia supernovae yield significantly different results. But this doesn't necessarily

cast doubt on the very existence of dark matter and dark energy, which perfectly explain non-Keplerian galactic rotations, gravitational lensing, "bullet cluster"-type effects, and the accelerated expansion of the observable universe.

The real problem isn't the discrepancy between these objective measurement results, which shouldn't be in doubt. The real problem is to understand, based on data from other space explorations, which physical processes determine the dynamics of the Universe and how.

This is precisely the main goal of our work, based on modern experimental and observational data, as well as well-tested physical theories.

Methodology / Theoretical Framework

The main obstacle to the successful solution of this problem is to establish the real physical nature of dark matter and dark energy, as well as how they are interconnected in the process of dynamic expansion and development of the observable Universe.

Recently, an increasing number of astrophysicists and cosmologists are beginning to believe that dark matter consists of primordial black holes, predicted by the eminent physicist and cosmologist Stephen Hawking back in 1971. This confidence is based on numerous considerations arising from cosmic observations.

Moreover, it was he who succeeded in proving the famous "area theorem", which precisely established the energy of gravitational radiation produced by the colliding and merging of black holes, and which was successfully confirmed by a thorough analysis of gravitational waves according to the LIGO/Virgo collaboration data [1,2].

On the other hand, another outstanding physicist, P.W. Anderson, impressed by the remarkable discoveries of this collaboration, put forward an exceptionally important and theoretically sound idea that it is gravitational radiation that is the carrier of dark energy. Moreover, he convincingly showed that modern cosmology is obliged to take these discoveries very seriously [3].

From these premises it immediately follows that a decrease in the amount (density) of dark matter by colliding and merging primordial black holes is directly related to an increase in the amount (density) of dark energy produced in the Universe. This is precisely the methodological and theoretical basis of our study.

It remains to prove, based on well-tested theoretical premises, and to show, based on numerous astrophysical data, that the dynamics of star-forming processes determines the dynamics of dark energy production, starting from the scale of the formation of our Solar System and ending with the scale of the entire observable Universe.

Results and Discussion

“Numbers don’t rule the world, but they show how the world is ruled.”
(J. W. von Goethe)

From a historical point of view, the outstanding physicist and astronomer Karl Schwarzschild in 1916 was the first who not only obtained an exact solution to Einstein’s equations [4], but also, in fact, was the first to pose a still unanswered question: what real physical substance are black holes made of? The fact is that he obtained his famous solution based on the model of a “sphere” (now we call it a “black hole”), consisting of a certain “uncompressible fluid”. It was from this physical postulate that he derived his famous exact solution for the gravitational radius of a black hole:

$$R_s = \frac{2G}{c^2} M_s = \frac{2G}{c^4} E_s \quad (1)$$

where R_s is gravitational radius, M_s is black hole mass, $E_s = M_s c^2$ is its rest energy.

But here’s what’s interesting: Einstein, who called a sphere of this radius the “Schwarzschild Singularity”, came to the disappointing conclusion that this solution was physically realizable. However, the irony of great discoveries manifested itself in the most unexpected way when, in 2010, German physicists discovered the Bose-Einstein condensate (BEC) of photons (condensed light) [5], the existence of which Einstein himself had predicted almost a century earlier. This condensate turned out to be the only candidate for the mysterious Schwarzschild “incompressible fluid,” and here’s why.

Firstly, having a stationary rest energy, according to Einstein, this photon condensate must inevitably have a non-zero mass [6].

Secondly, the Compton wavelength λ_{sm} of each of the condensed photons of the same rest mass M_{sm} and rest energy E_{sm} must satisfy the natural geometric equality [7]:

$$\lambda_{sm} = 2\pi R_s \quad (2)$$

that connected quantum theory with Einstein’s general relativity for quantum black holes.

By definition of Compton wavelength

$$\lambda_{sm} = \frac{2\pi\hbar}{M_{sm}c} \quad (3)$$

and by (2) we find

$$M_{sm} = \frac{2\pi\hbar}{\lambda_{sm}c} = \frac{2\pi\hbar}{2\pi R_s c} = \frac{\hbar}{R_s c}; E_{sm} = M_{sm}c^2 = \frac{\hbar c}{R_s}. \quad (4)$$

From (1) and (4) we easily find the number of photons of condensed light in a quantum black hole:

$$N_s = E_s/E_{sm} = \frac{c^4}{2G} R_s / \left(\frac{\hbar c}{R_s}\right) = \frac{R_s^2 c^3}{2\hbar G} = \frac{A_s}{8\pi l_p^2} \quad (5)$$

where $A_s = 4\pi R_s^2$ is the area of "stretched horizon", $l_p = \sqrt{\frac{\hbar G}{c^3}} = 1.616 \times 10^{-33} \text{ cm}$ is Planck length.

Note, that from these simple, but very important definitions and equations we can easily express the area of black hole (A_s) through its mass (M_s):

$$A_s = 16\pi G^2 M_s^2 / c^2 \quad (6)$$

The most amazing thing is that we have unexpectedly but naturally obtained an equation that connects quantum theory (Compton wavelength) with gravity (Schwarzschild radius). We especially note that all these photons are uniformly "smeared" over the surface of the black hole. This is fully consistent with the well-tested model of simple excision of a black hole in 3+1 numerical relativity [8].

Thirdly, each photon of the quantum condensate has only two possible states ($|0\rangle$ and $|1\rangle$ in Paul Dirac's notation). This means that each photon is a carrier of exactly one bit of quantum information. In other words, the total amount of information (I_s) contained in a black hole is exactly equal to the number of photons that form it:

$$I_s = N_s = \frac{A_s}{8\pi l_p^2} (\text{bit}). \quad (7)$$

Fourth, using the law of conservation of information we easily find theoretical confirmation for the famous Hawking "area theorem" for binary black hole collidings, which was brilliantly confirmed by the analysis of data from the LIGO/Virgo collaboration.

Let us take in consideration the gravitationally bound system of N black holes with set of masses

$$\{M_{sj}\}, j = 1, 2, \dots, N \quad (8)$$

with total initial mass

$$M_{s,N} = \sum_{j=1}^N M_{sj}, \quad (9)$$

where each black hole is located at a very large distance from the others. Note, that the lifetime of each black hole is considered to be much larger than the system collapse time.

By N binary colliding and merger events this system must inevitably turn into a residual black hole of a much smaller mass than total initial mass $M_{s,n}$ of such system. The whole point is that the enormous work of gravitational field of a collapsing system will cause exactly the same energy of gravitational radiation in form of Einstein's gravitational waves.

According to the law of conservation of quantum information, under the above restrictions, we can formulate the following information equation for the collapsing system:

$$I_{s,res} = \sum_{j=1}^N I_{sj}, \quad (10)$$

where

$$I_{s,res} = \frac{A_{s,res}}{8\pi l_p^2}, \quad (11)$$

is amount of quantum information contained in residual black hole, $A_{s,res}$ – its surface area,

$$I_{sj} = \frac{A_{sj}}{8\pi l_p^2} \quad (12)$$

is amount of quantum information contained in a initial black hole with index j and A_{sj} is its surface area.

It is easy to see that equation (10) can be reformulated as

$$A_{s,res} = \sum_{j=1}^N A_{sj}, \quad (13)$$

which exactly corresponds to Hawking's "area theorem" for binary collidings and its resolutions for masses and energies. Taking into account expression (6), from the area law (13) we obtain the following remarkable accurate formula for the mass of the resulting black hole:

$$M_{s,res} = \sqrt{\sum_{j=1}^N M_{sj}^2} \quad (14)$$

We would like to especially note, that the validity of this formula was convincingly confirmed through careful analysis of LIGO/Virgo data mentioned above. This is also of great importance as the confirmation of the quantum gravity theory of black holes presented here.

The main difference between our result and Hawking's remarkable "area theorem" is that his expression for the area law is given as an inequality. Whereas we obtained an exact equality, since it follows from the fundamental law of conservation of quantum information and precise initial condition. Another difference is that we extend Hawking's result from binary systems to any number of primordial black holes.

From the defect of masses ΔM_{DM} produced by the work of gravitational field of a collapsing black holes system we obtain the exact value of the energy of gravitational radiation, in other words, the dark energy produced:

$$\Delta E_{DE} = \Delta M_{DM} c^2 = \sum_{j=1}^N M_{sj} - \sqrt{\sum_{j=1}^N M_{sj}^2}, \quad (15)$$

where

$$\Delta M_{DM} = M_{s,N} - M_{s,res} \quad (16)$$

is a difference between initial mass $M_{s,n}$ and final mass $M_{s,res}$ of the system.

For our further conclusions we will need a number of parameters of the primordial black holes that form dark matter in the observable Universe [9]:

- Typical mass $M_s^{DM} = 1.6 \times 10^{18}$ gr
- Typical size $R_s^{DM} = 4.8 \times 10^{-11}$ cm
- Typical temperature $T_s^{DM} = 4.6 \times 10^{18}$ °K
- Space numerical density is 10^{41} less than that of protons

The cloud of such dark matter is a best candidate for gravitational lensing and a suitable object for calculation of the dynamics of a collapsing system of a very large number of primordial black holes.

Using the typical value method, we significantly simplify the calculation expressions (14) and (15) for a gravitationally bound system of N primordial black holes of dark matter:

$$M_{s,res} = M_{sDM} \times \sqrt{N} \quad (17)$$

$$\Delta E_{DE}(N) = M_{sDM} c^2 N (1 - 1/N). \quad (18)$$

The main thing we see is that at large N number, as a result of gravitational collapse, almost all the mass of dark matter is converted into gravitational radiation, that is, into dark energy.

Now we are completely ready to begin solving our main problem, first for our Solar System.

In the distant past, it was a cloud of unionized gas and dust, immersed in a halo of dark matter. What happened next and where did this halo with a mass an order of magnitude greater than this cloud of "ordinary matter" go?

The calculations based on (18) show that practically all of our former dark matter halo has "evaporated" through colliding and merging in the form of dark energy.

If all this were not so, then all distant planets would not rotate according to Kepler's laws, which we, naturally, do not observe.

However, there still remains a small remnant of collapsed dark matter (17) in the central part of our Sun in the form of a black hole with a mass of about half the mass of Mercury:

$$M_{s,res} = 1.6 \times 10^{18} \text{ gr} \sqrt{\frac{85\%}{100\% - 85\%} \times 2 \times 10^{33} \text{ gr} / 1.6 \times 10^{18} \text{ gr}} = 1.35 \times 10^{26} \text{ gr} \quad (19)$$

where the calculation is based on the equation (17); expression under the square root refer to the characteristic N for the Sun, where the multiplier $85\%/(100\% - 85\%)$ is

based on the widely accepted percentage of dark matter mass (85% of all matter Universe), 2×10^{33} gr is the mass of the Sun, $M_s^{DM} = 1.6 \times 10^{18}$ gr.

However, it is this black hole that will subsequently determine the fate of the Sun when all the thermonuclear fuel will burn out.

It should be emphasized that these calculations are universal: for any star, it is sufficient to indicate its mass instead of the mass of the Sun.

Let's consider how all this happened from the point of view of cosmic processes.

It should be especially noted that traditional views on star formation processes did not take into account the role of dark matter. In general, the mechanism of star formation seemed quite simple and, at first glance, convincing: extremely dense and high-temperature protostars formed from clouds of cosmic gas and dust under the influence of gravity. With further gravitational compression, thermonuclear reactions spontaneously arose, the pressure of which stopped further gravitational compression. Everything seemed logical and convincing, but as observational technologies and physical theories developed, new, difficult-to-resolve questions arose. For example, it became unclear how so-called "Herbig-Haro objects" with their sharp, long jets of extremely hot matter, characteristic only of black holes, arose around newly forming stars for a short time (only about a thousand years). It is important to note that the Herbig-Haro objects represent the final stage of the star formation according to NASA experts [10].

Understanding the origin of these astonishing jets and the entire dynamics of star formation is possible only if we consider how the primordial dark matter halo, consisting of primordial asteroid-mass black holes, determines these dynamics. It all begins with the cloud of initial molecular gas and the dark matter cloud permeating it, beginning to condense around their common center of gravity, eventually acquiring a spherical shape. However, as gravitational compression proceeds, the cloud of ordinary matter begins to ionize, and the temperature and pressure of the resulting plasma increase, which begin to resist gravitational compression. At the same time, nothing prevents the spherical swarm of primordial dark matter holes from rapidly compressing under the influence of the overall gravity, of which it accounts for the largest share (as we know, about 85%). As a result, the rate of compression of the spherical dark matter swarm begins to significantly outpace the gravitational compression of the plasma cloud.

And here we come to the crucial moment of understanding what a colossal role dark matter plays in the process of star formation.

Rapidly contracting in size, a massive swarm of primordial black holes accelerates the compression of the plasma of ordinary baryon matter, which significantly accelerates the process of star formation.

Finally, a moment comes when, as a result of gravitational contraction, when the numerical density of dark matter (which was initially 41 decimal orders less than the numerical density of ordinary matter!), begins to approach the numerical density of

the plasma, the swarm of primordial black holes (each of the order of an asteroid's mass) begins to act as a single black hole of stellar mass.

It is at this moment that an accretion disk begins to form around such a super-dense spherical swarm of primordial black holes and two powerful jets in different directions flare up, accompanied by a powerful rotating magnetic field. A powerful Herbig-Haro object forms around a nascent star. Astronomers estimate that the lifetime of such cosmic objects (judging by the lengths of observed jets) is only about a thousand years, which is very short on cosmic scales. However, it is during this time that an avalanche-like process of collisions and mergers of primordial black holes occurs, resulting in the release of colossal gravitational energy, contributing to the overall increase in the density of dark energy in the observable Universe.

As we see, accounting for dark matter in star formation processes not only leads us to a convincing solution to the so-called "Hubble tension" problem, but also leads us to the conclusion that star formation processes last not hundreds of millions of years (as previously believed), but at least no more than tens of millions of years. This is precisely what we are convinced of by the sensational observational data from the James Webb telescope, which discovered "incredible" mature galaxies in a very early observable Universe [11].

Let us move on to solve the main problem using the cumulative effect of dark energy production from the individual stars formation level to the entire Universe evolution level. Now we can easily calculate the irreversible increase in dark energy density by accurately determining the amount of dark energy produced by primordial black holes as a result of the collapse of dark matter during star formation. From the Recombination epoch to present days this part of dark energy density grows to a value

$$\Delta\Omega_{DE} = \frac{85\%}{100\%-85\%} \times \Omega_{stars} = 5.7 \times 0.005 = 0.0285, \quad (20)$$

where $85\%/(100\%-85\%) = 5.7$ is mentioned above initial dark and ordinary mass relation, $\Omega_{stars}^R = 0.005$ is the rest energy density of all stars in the Universe estimated by NASA's WMAP Science Team.

If we add our estimate of the increase in the dark energy density to the best estimate of the early dark energy density obtained by the Planck-2018 collaboration (using the CMB analysis) then we will find a result close to the estimates based on the analysis of the brightness of Cepheids and Type Ia supernovae:

$$\Omega_{DE}(Planck2018) + \Delta\Omega_{DE} = 0.6847 + 0.0285 = 71.32. \quad (21)$$

Clearly, this result, like any results based on the brightness analysis of Cepheids and Type Ia supernovae, is subject of some uncertainty. Nevertheless, it provides a highly reliable reflection of the connection between dark matter and dark energy in the observable Universe.

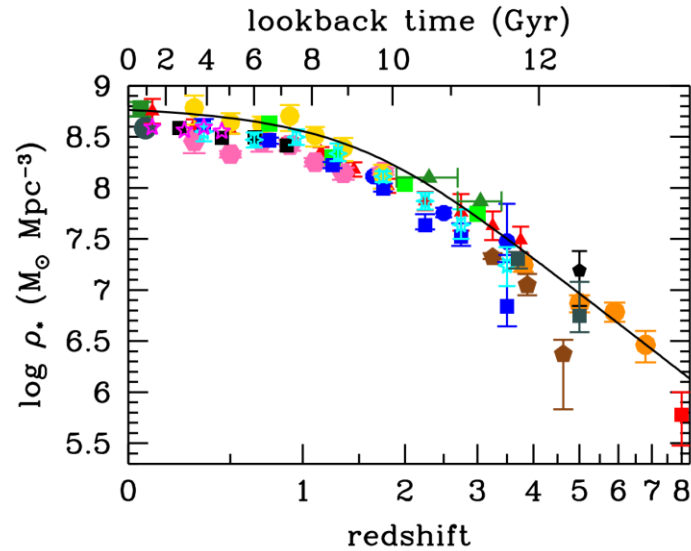


Figure 1: The Evolution of the Stellar Mass Density

The solid line shows the global stellar mass density obtained by integrating the best-fit instantaneous star-formation rate density. (Piero Madau, Mark Dickinson, Cosmic Star Formation History, arXiv:1403.0007v3)

But here's what's particularly interesting about our discovery of a direct link between the mass density of stars and the density of dark energy they produce during dark matter collapse during star formation.

Figure 1 shows the evolution of stellar mass density over time, based on a retrospective analysis of numerous astrophysical observations [12]. This directly provides a clear picture of the cumulative dynamics of dark energy production. Moreover, all conclusions cosmologists draw regarding the dynamics of star formation are directly related to the dynamics of dark energy production from the Recombination epoch to the present day. For example, the peak intensity of dark energy production was observed approximately 9–10 billion years ago, whereas over the past 1–2 billion years, it has sharply declined due to the weakening of star formation sources.

Undoubtedly, this observationally founded information, associated with the undeniable growth of dark energy in the observable Universe, reveals the true background of the "Hubble tension" dynamics.

Presented results reveal exciting connections between different areas of space research and open new ways for mutually beneficial cooperation.

Conclusions

The main goal of the presented work is to prove, based on numerous and diverse space research, that the dark energy of the observable Universe is an irreversibly increasing quantity.

Moreover, it was possible to show how the dynamics of star formation processes directly determines the dynamics of dark energy production. This provides the key to

solving the so-called “Hubble tension” problem, the essence of which lies in the unfounded initial belief in the constancy of dark energy.

But what is interesting is that our study showed that in the last billions of years this growth has decreased so much that, given the errors of modern measurements, it can create a false impression of the “constancy” of the Hubble parameter.

The main advantage of our work is that its results are based on the analysis of cosmic measurements of the dynamics of stellar mass growth in the Universe.

The theoretical background of our research is the further development of Stephen Hawking’s early work on gravitational radiation generated by collisions and mergers of black holes, as well as the development of new views on the nature of primordial black holes, dark matter and dark energy.

Particularly important is the revelation of the decisive role of dark matter in the star formation processes, indicating the much faster formation of early galaxies. This is precisely what the sensational discoveries of James Webb telescope demonstrate.

The results of our research further confirm the enduring value of interdisciplinary scientific and practical research in the field of modern astrophysics and cosmology.

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