On the composition of interstellar gas

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Abstract. The modified first law of thermodynamics with consideration of the gravitational field and the equation for working with consideration of anti-gravity are formulated. It is shown that the difference in the equations of state of different gases leads to the absence of local thermodynamic equilibrium. Photons resulting from the Unruh effect are suggested to play the role of background radiation, an approximate value of the Hubble constant in the recombination epoch is obtained. It is shown that dark matter can be formed by cosmic dust of a special kind.

Keywords: entropy, gravity, expansion, equilibrium, temperature

Introduction

The possibility of using a thermodynamic approach to the Universe runs up against well-known difficulties. A thermodynamic system is a system of many particles that are divided into groups of identical particles (atoms or molecules). These particles are constantly colliding with each other, which allows you to enter the mean free path and the mean square of the velocity. Thermodynamics of solids is based on the presence of several types of identical many particles vibrating about an equilibrium position. The thermodynamics of liquids, including plasma, implies the presence of such relationships as the equation of continuity, heat transfer equations, etc. For a system or two, three, *n* contacting systems, the concepts of equilibrium, thermostat and temperature can be introduced.

There are no collisions in the universe in the thermodynamic sense. One part of space is filled with galaxies, whose masses range from 10^1 billion to 10^3 billion solar masses. In total, there are about $3 \cdot 10^{22}$ stars in the visible part (there are 10^{11} stars in our galaxy), about 10^{11} galaxies. Galaxies merge into clusters, 90% of galaxies - in clusters. Of these, 10^7 – are superclusters of thousands of galaxies, $2{,}5 \cdot 10^{10}$ – are galactic groups, $3{,}5 \cdot 10^{11}$ - are giant galaxies, $0{,}7 \cdot 10^{13}$ - are dwarf galaxies, and this is only a small part, because 9/10 galaxies are hidden from us. The number of asteroids is uncountable.

Superclusters and individual galaxies form chains (galactic filaments, filaments), for example, the Markarian chain - the largest structures in the Universe, with an average length of 60-80 Mpc. Filoments are filled with very hot (millions and tens of millions of degrees) and very rarefied (1-10 atoms per m^3) gas. According to the standard model of the evolution of the Universe, galactic threads are formed and follow along the network-like streams of dark matter. Other parts of the Universe, voids, hundreds of Mpc in size, are empty. The chains are located between the voids. Chains and voids sometimes form what are called walls, such as Sloan's Great Wall.

The Great Wall CfA2, located at a distance of 200 million light years from us, is 15 million light years thick and about 500 million light years long. The wall "Giant group of quasars" has a size of 4 billion light years, the Great Wall of Hercules - the Northern Crown - 10 billion light years. Finally, they suggest the existence of the yet-to-be-discovered Great Attractor, a cluster of many superclusters attracting matter from our sector of the Universe, to which the Milky Way is tending at a speed of 400 km/s.

It was recently discovered that the number of galaxies was previously underestimated by a factor of 10–20. incorrectly determined the rate of formation of galaxies in the early Universe. There are separate cold and warm clouds surrounded by hotter gas, as well as relic black holes.

It is assumed that on a scale of the order of 300 Mpc, the Universe is practically homogeneous and is a set of filamentous clusters of galaxies, between which there are voids.

In the direction of the constellation Eridanus, there is a cold spot, 70 μK colder than the average temperature of the CMB (greater than the rms deviation of the CMB of 18 μK). Its diameter is about 10 angular degrees, it is assumed that it is a supervoid with a diameter of about 150-500 Mpc, which is 2-3 Gpc from Earth.

Internally, the Galaxies are almost collisionless. That is, it is difficult to use the laws of thermodynamics inside galaxies. The galaxies themselves collide more often. If we proceed from the frequency of collisions of molecules in a gas, the frequency of collisions of galaxies is of the order of 10-14 per year, in reality it is two orders of magnitude lower. In addition, collisions of galaxies do not have the character of collisions between molecules; in the event of their merging (merging), the process of star formation is activated in them. Consequently, standard thermodynamics does not apply to galaxy systems.

Part of the Universe is ordinary matter, 5%, of which the mass of neutrinos is 0.1%, part is dark energy, 75%, part is dark matter, 20%. Dark energy cannot participate in thermodynamic processes in the Universe.

The mass of interstellar gas, including radiation, makes up 99% of all matter in the Universe, 60% of baryonic matter in intergalactic space. Interstellar gas consists of protons, electrons, hydrogen, helium, their ions, and the radiation of stars. It is this part, despite the absence of a heat conduction mechanism, can be considered in some problems as a thermodynamic system.

Interstellar gas

There is no local thermodynamic equilibrium in the Universe, it is impossible to introduce the concept of equilibrium as a whole, since there is no thermostat, therefore, it is impossible to introduce such an intense parameter as temperature. We can only talk about thermodynamics, for example, of electrons, their energy spectrum is described by the Maxwell distribution, about the thermodynamics of relict radiation (the Stefan-Boltzmann equation), about the Boltzmann velocity distribution, about the thermodynamics of gas clouds, for which the first law of thermodynamics can be written.

By the number of particles with non-zero rest mass, cosmic rays are 92% protons, 6% helium nuclei, about), 0.1% -1% of the number of atoms are O, C, N, Ne, S, Ar, Fe, and about 1% is accounted for by electrons. In addition - aliphatic carbon compounds, compounds of a fatty series, similar to resins, formed in some stars. It is believed that 30% of the interstellar carbon that fills outer space may be composed of these fats. In addition, micrometeorites from 1 to 180 μm (cosmic dust) - 1% of the mass of interstellar gas, plus neutrinos from supernovae and relic radiation, the density of which is about 10-34 g/cm3 (0.25 eV/cm^3 or 4 10− 14 J/m^3 or

400-500 photons/cm^3), which is 4 orders of magnitude less than the estimates of the density of matter in the Universe, electromagnetic diffuse background, photons of the visible spectrum, X-rays and gamma quanta. Some galaxies, such as the Milky Way, emit gamma rays in the form of bubbles.

Cosmic rays consist of 43% of the energy of protons, 23% of the energy of alpha particles and 34% of the energy carried by the rest of the particles.

Interplanetary space contains about 10 molecules of hydrogen and helium per 1 cm^3; the intergalactic space contains 10^{-6} molecules per 1 cm^3.

According to other data, the average density of the interstellar medium is less than 1 atom of matter per 1 cm^3 [1, 2].

Thus, the mean free path $l = 1/n\sigma$, where n is the concentration of particles, and σ - is the effective cross section, is extremely large, on the order of 10^{12} m, and the scattering probability $P = r/l$, where r – is the average distance between particles, is vanishingly small. Accordingly, for spherical particles of diameter d, in particular, for hydrogen or helium, the relation $kT = \sqrt{2}\pi n d^2 pl$ following from the Clapeyron-Mendeleev law $pV = nRT$, where the pressure p is of the order of 10^{-14} Pa (the gas-kinetic cross section of elastic scattering of atoms or molecules through a large angle at thermal energies has a value of the order of 10^{-19}/m^2).

The ratio is fulfilled if we take other data [3-5], according to which the concentration of interstellar gas particles is 10^3/cm^3. However, in this case, the mass of the interstellar medium is 1-2 orders of magnitude higher than the estimated mass of the Universe 10^{52} kg, if its radius is about 10^{26} m.

In an ordinary gas, the collision model is just a rough approximation, for example, a molecule does not necessarily hit the wall of the volume, in reality it flies up to it, holds on to it for some time and flies off. In this case, on average, the law of conservation of momentum is fulfilled. Therefore, despite the extremely rare number of collisions of interstellar gas particles, a temperature can be introduced for it, which is proportional to the rms velocity of gas particles $T \sim m\overline{v^2}$, which, unlike stars and galaxies, can exert pressure on the walls of a sufficiently large volume, like a stellar wind.

The temperature of interstellar molecular gas is in the range from -269 to -167°C, in interstellar shock waves (see, for example, [6]) the temperature can exceed 1 billion K, in galaxy clusters typical temperatures are in million K, in In the crowns of galaxies of various ages, over 10 billion years, the temperature increased from 200000 K to 2 million K. At the same time, the temperature of the Boomerang nebula in the constellation Centaurus, located 5,000 light-years from Earth due to rapid expansion, is only 1 K, below the temperature of the relic radiation. Recently, filaments of dense gas from highly ionized oxygen atoms at a temperature of 60 million K have been discovered, which make up 30% of all baryonic matter [7].

The specificity of interstellar gas is, firstly, in the attraction of galaxies, and secondly, in the process of star formation, both processes lead to local heating against the background of the expanding Universe.

Gravitational attraction and gravitational repulsion

By definition, a perpetual motion machine of the second kind is an infinitely long operating machine, which, if put into operation, would turn into work all the heat extracted from the surrounding bodies. The impossibility of realizing a perpetual motion machine of the second kind is postulated in thermodynamics as one of the equivalent formulations of the second law of thermodynamics: in all irreversible processes, the entropy of an isolated system invariably increases: $dS > 0$.

The universe, being an isolated system, does not exchange heat, therefore $\delta Q = 0$, hence, $dS = 0$ and $S = const$.

The adiabatic process, in which *S=const*, is reversible. In addition, unlike the expansion of a gas into a void, there is no void in the case of the expansion of the Universe. That is, the idea of the impossibility of a perpetual motion machine of the 2nd kind is limited by local systems.

In [8, p. 64, 119], the law of conservation of entropy in the accompanying one is formulated, that is, expanding system, $sa^3 = const$, where s - is the entropy density, which decreases with increasing radius a. This confirms the conclusion about the conservation of entropy in the volume of the entire Universe. This, it would seem, confirms the validity of the previous statement. However, it is indicated in [8] that this is a covariant law. But the fact is that *S* is an additive quantity, therefore, this relation is valid for any expanding isolated systems. Thus, the version of the thermal death of the Universe due to the growth of entropy or the laws of thermodynamics of gases is untenable.

The introduction of only the classical gravitational field violates the 2nd law of thermodynamics (in the well-known problem of heating two balls, on a support and on a thread, see [9]. The law can be preserved, as is proposed in [10], by introducing the energy of the balls into the gravitational field of the Earth into internal energy.Therefore, in general, the internal energy

$$U \to U + \frac{1}{2}\int \rho\varphi dV \,,$$

Where ρ - is the density, φ - is the potential of the external gravitational field. Then you can write the modified 1st law of thermodynamics:

$$\delta Q = d(U + \frac{1}{2}\int \rho\varphi dV) + \delta A$$

In the Universe, the role of van der Waals forces is played by the forces of gravity. It is possible to represent the pressure in the van der Waals equation as the internal pressure, determined by the Hubble law, as the antigravity force according to Gliner. If we imagine the Universe in the form of a ball, the entire mass of which is in the center, then in the classical case and approximately the work done during the expansion of the Universe:

$$dA = \int_S \rho(\frac{GM}{r^2} + H\dot{r})drds$$

However, the inclusion of the gravitational field does not exhaust the difficulties. The fact is that, on the one hand, the volume parameter does not obey thermodynamic laws, but is set from the outside by the Hubble law; it cannot be argued that the volume increases with temperature.

On the other hand, the system contains internal sources of heat that are switched on and off, for example, in the form of thermonuclear reactions, i.e. the process is not adiabatic.

The contradiction is that any space system, any selected volume in the Universe is not closed, since it gives off heat to a constantly expanding volume, but this emerging volume is "simultaneously" included in the system.

Relict radiation

The relict radiation predicted by Gamow is separated from matter during the epoch of recombination. According to the first estimates of Gamow, the temperature of cosmic radiation is about 3-7 K [11]. In 1955, Tigran Shmaonov experimentally discovered noise microwave radiation with a temperature of about 3 K. In 1964, A. Penzias and R. Wilson discovered the cosmic background of radiation and measured its temperature - 3 K.

By definition, displacement $z = (\lambda - \lambda_0) / \lambda_0$, from Wien's law $\lambda_{\max} = 0,29 / T$ we get $T = T_0(1 + z)$.

Accordingly, for distant galaxies, the background radiation temperature is higher; using the Keck telescope, spectra of two quasars with redshifts *z*=1.776 and *z*=1.973 were obtained, which show that they are irradiated with thermal radiation with a temperature of 7.4±0.8 K and 7.9±1.1 K, which corresponds to the calculated data *T*(1.776) = 7.58 K and *T*(1.973) = 8.11 K.

It would seem that thereby Gamow's theory was confirmed.

The temperature of the relict radiation is 2.7 K., while the average temperature of the interstellar gas is 4 K. Let's imagine the space of the Universe as a vessel in which partitions were removed between different gases. The temperature of the gas mixture is determined by the formula:

$$T = \sum_i \frac{p_i V_i}{C_{pi} / C_{vi} - 1} \left(\sum_j \frac{T_j p_j V_j}{C_{pj} / C_{vj} - 1} \right)^{-1} \text{ or } T = \sum_{i \neq j} \rho_i T_j \left(\sum_k \rho_k \right)^{-1}$$

For monatomic gases, when the sum of internal energies does not change, the equilibrium temperature is determined from the easily obtained ratio:

$$T = \frac{\sum_i (T_i m_i^{-1})}{\sum_k m_k^{-1}} \text{ or } T = \overline{m_i / Ti} \cdot \overline{m_k}$$

where $\overline{x}$ - is the harmonic mean of x. Meanwhile, the temperature of interstellar space is 4 *K*, while the temperature of the relict radiation is 2.7 *K*, i.e. for billions of years, equilibrium has not been established (see [12], also [13, p. 150-151]). Thus, the temperatures of the CMB and the rest of the interstellar gas should have leveled off.

Usually, among the reasons for the absence of local thermodynamic equilibrium indicate that, for example, the electron and ion temperatures of the interstellar gas can be very different from each other, because energy exchange during collision occurs extremely rarely. In addition, in the interstellar medium, the forward and reverse processes of ionization and recombination are of a different nature, and therefore a detailed balance cannot be established. The small optical thickness for hard radiation and fast charged particles leads to the fact that the energy released in any region of space is carried away over long distances, and cooling occurs throughout the volume at once, and not in local space, expanding at the speed of sound in the medium. Heating occurs in a similar way, and the heat conduction mechanism is not able to transfer heat from a distant source.

However, all of the above has nothing to do with the balance between the relict radiation and the rest of the interstellar gas, which should have been established over more than 13 billion years.

If the temperature of the relict radiation turned out to be lower, due to the inverse Compton effect indicated by Zeldovich, the energy of relict photons should increase, and over billions of years the temperature of the relict radiation should have become equal to the temperature of interstellar matter.

Expansion of gases

In gas clouds, the temperature can be different for different gas layers. Let *ni* be the number of particles in the *i*-th layer, *ni/Ti* be the optical thickness of the *i*-th layer, the sum of the optical thicknesses equal to the total number of atoms divided by the average temperature, respectively, the average temperature

$$T = \sum_i n_i (\sum_j n_j / T_j)^{-1}$$

Consider the equation of state for the interstellar medium outside clouds and galaxies. At nonrelativistic velocities, due to the low density of matter, the interstellar medium is classical.

The expansion of the Universe is an adiabatic process, the system does not give off heat and does not receive it from the outside. Let us denote the ratio of the specific heats $\gamma = C_p / C_v$ Under the adiabatic expansion of an ideal gas $pV^\gamma = k$, where *k* – is a constant. In an ideal gas, during adiabatic expansion, the temperature drops depending on the value of $\gamma = C_p / C_v$. From the first law of thermodynamics $\delta Q = c_v dT + pdV$ it is easy to obtain the dependence of the temperature decrease on the volume in the absence of heat transfer:

$TV^{\gamma-1} = const$.

That is, for an ideal gas, as the volume increases, the temperature slowly decreases. The equation for the internal energy is: $dE = -kV^{-\gamma}dV$. Hence $E = -kV^{1-\gamma}/(1-\gamma) + c_1$.

The internal energy of a van der Waals gas consists of its kinetic energy (the energy of the thermal motion of molecules) and potential:

$$E = c_v T - kV^{1-\gamma}/(1-\gamma) + c_1$$

Since gravitational forces are many orders of magnitude weaker than van der Waals forces, one can imagine the Universe as an ideal gas. However, the fact is that if we imagine the contents of the Universe as an ideal gas, then its internal energy during expansion does not depend on volume, as was shown by Joule in 1845. In van der Waals gas $(V-b)(p + a\nu^2/V^2) = \nu RT$. Van der Waals constants *a* and *b* take into account the attraction between molecules at large distances (constant *a*) and strong repulsion at small ones (constant *b*). This repulsion makes the inner space of the molecule inaccessible to other molecules and reduces the total free volume.

Since there is no penetration into internal spaces in the Universe, the constant *b* can be set equal to zero. Moreover, constant a ceases to be constant: $a \sim 1/\mathrm{r}^2$, $a \to a'$, and

$$V(p + a'\nu^2/V^{8/3}) = \nu RT,$$

where *r* – radius of the universe, ν - number of moles, a' - new constant. Those. in the initial stage of expansion, when the $a'/V^{8/3}$, term plays the main role, the temperature drops rapidly. At large volumes, when the 2nd term in the right-hand side is small, the temperature decreases slowly, because pressure decreases with increasing volume.

In the case of adiabatic expansion of van der Waals gas $dT = \frac{a}{c_v}\frac{dV}{V^2}$. I.e. the temperature $T \sim V^{-1}$ falls in inverse proportion to the volume, which clearly does not correspond to reality.

In the Dieterichi $pV = RT\exp(-a/RTV)$, model, which is more adequate for low pressures, i.e. at b = 0, the picture is approximately the same: since the interaction between the atoms of a rarefied gas is small, the relation for an ideal gas $pV^{\gamma} = const$, $T = \frac{const}{V^{\gamma-1}}\exp(a/RTV)$ can be used and, taking into account that at large volumes the exponential exponent tends to zero, we see that the temperature slowly decreases with increasing volume in the same way as in ideal gas.

In a real gas, when it expands into a void, the average distance between molecules increases, the forces of attraction do negative work, and the potential energy increases. Since the total internal energy remains constant, the kinetic energy of the molecules, and hence the temperature of the gas, decreases. The slowness of the decrease is due to the weak interaction between the gas particles. Thus, all parts of the interstellar medium cool extremely slowly with the expansion of the Universe, including the relic radiation, but cool in different ways.

The thermodynamics of a photon gas is significantly different, the equation of its state

$$pV = \frac{1}{3}E$$

Since E is additive, pressure is independent of volume.

The internal energy of a photon gas is directly proportional to the volume, while the energy of an ordinary gas is proportional to the volume to the power $(1-\gamma)$.

The density of different components of the medium also changes in different ways. Since$S$ = *const*, from the equations $dE = pdV$ and $\rho = E/V$ we obtain the dependence of the density on the radius of the Universe (or the scale factor) $d\rho + 3(p+\rho)dr/r = 0$; for the radiation density $\rho \sim r^{-4}$, since the energy is inversely proportional to the wavelength $E \sim 1/\lambda \sim 1/r$, for the rest of the gas $\rho \sim r^{-3}$.

Therefore, with the expansion of the Universe, the photon gas and the rest of the interstellar gas should have different temperatures.

Fulling - Davis - Unruh effect

Unruh's photon gas appears every moment of time and cannot come into equilibrium with the environment. Therefore, one could assume that the measured CMB is in fact the Unruh radiation.

By virtue of the principle of relativity, the Milky Way is the same galaxy as the rest - it is also moving away with acceleration from other galaxies. In such a case, the Milky Way must be pierced by radiation. By virtue of the principle of relativity, the temperature of Unruh radiation is the same at any point in the Universe. All galaxies located at distances less than the radius of the Universe make a smaller energy contribution to the Unruh radiation.

The temperature of the observed Unruh radiation is expressed by the same formula as the temperature of Hawking radiation, but depends not on surface gravity, but on the acceleration of the reference frame a:

$$T = \frac{\hbar a}{2\pi kc} \approx 4 \cdot 10^{-21} \cdot a$$

The energy of the photon gas is - $E = \frac{8\pi^5 k^4}{15c^3h^3}VT^4$, the number of photons is - $N = \frac{2k^3\varsigma(3)}{c^3h^3\pi^2}VT^3$. We use Hubble's law $v = Hr, a = H^2 r$, where r - is the radius of the Universe. Let us estimate the energy of the modern photon Unruh on Earth, taking the Hubble constant equal to 10^{-18}:

$$E_{Унру} = \frac{E}{N} \approx 4,2kT \approx \frac{2\hbar H^2 r}{\pi c} \sim 10^{-52} \text{Дж} \quad (1)$$

The angular acceleration of the rotation of the disk of the Milky Way gives the energy of the Unruh photon of the order of 10^{-34} J, the acceleration of the rotation of the Local Group - by several orders of magnitude less.

The era of inflation lasted from 10^{-42} to 10^{-36} seconds. At this time $10^{42} сек^{-1} > H > 10^{36} сек^{-1}$, the radius is about 10^{-2}. Let us take a smaller value, then at the end of the inflationary epoch the energy of the Unruh photon is about 10^{30} J.

Let's estimate the energy of the relic radiation:

$$E_{реликт} = \hbar\omega \sim 10^{-22} дж$$

If we choose a period of 380000 years, when the radiation separated from matter, and even the moment after the Dark Ages 550 million years from the Big Bang, then, integrating Hubble's law, it is easy to see that the energy of Unruh's photons is not much different from the modern one, since the exponent with a small value the Hubble constant is close to unity.

You can find a time point when the density of interstellar gas abruptly becomes so low that collisions with photons become critically rare. This is the time of the formation of stars in 550 - 800 thousand years, but even after this period of time, if we consider the size of the Universe in accordance with the Hubble law, the energy of Unruh's photons has hardly changed. However, the Unruh mechanism generated particles during the entire period of the expansion of the Universe. That is, there should be parameters *H* and *r* intermediate in magnitude, at which the energy of the Unruh photon is equal to the energy of the relict photon.

Obviously, high-energy Unruh photons should have disappeared due to the formation of multiple pairs of particles, but the question arises about the disappearance of the spectrum of low-energy photons, which should be continuous. They are removed if the value of the Hubble constant has decreased in an extremely short period of time.

380000 years after the Big Bang, the redshift is - $z \sim 1000$, the temperature of the relict gas is in equilibrium with the rest of the environment - $T \sim 3000K$, the density of the relict gas is about $4 \cdot 10^{11}$ /cm^3.

Since at the moment of separation of radiation from baryonic matter, the radiation temperature is 3000 K, and the dimensions of the Universe were about 1000 times smaller than the modern ones, from the assumption that the temperature of the Unruh gas is in order of magnitude to the temperature of the relict gas, it is possible to estimate the intermediate value of the Hubble coefficient at the moment of time 380000 years from the Big Bang:

$$H_{recombination} \approx 4 \cdot 10^{-5} c^{-1}$$

Thus, Unruh photons can play the role of background radiation with a temperature of 2.7 K.

The evolution of the Universe is represented as follows: white dwarfs will cool down to 1 K in 10^{17} years. After 10^{19} years, neutron stars will cool down to 30 K. After 10^{32} years, matter will decay into photons and neutrinos. The most massive black holes at the centers of galaxies will evaporate within 10^{96} years. But this is an incomplete picture.

According to Hubble's law, galaxies scatter with acceleration. It has decreased by tens of orders of magnitude during the epoch of inflation, but since the epoch of 5-6 billion years, the magnitude of the acceleration is slowly increasing. The further away the galaxy is, the higher its speed becomes. With acceleration, the Fulling-Unruh effect arises, the creation of pairs of particles from a vacuum.

The Milky Way is just like the rest of the galaxy - it is also accelerating away from other galaxies. In this case, when the acceleration of the Milky Way reaches a certain value, the galaxy will be permeated with radiation. Based on the Hubble law, the acceleration $a = H^2 r$, $r = r_0 \exp(Ht)$, taking into account that the modern radius of the Universe is $r \sim 10^{27}$, and assuming for the assessment that the Hubble constant increased uniformly over 7 billion years to the present value of 10^{-18}, we can calculate when the acceleration reaches the indicated level: $t^2 \exp(10^{-36} t) \sim 10^{64} c^2$, whence $t \sim 3 \cdot 10^{24}$ yours. That is, after the cooling of white dwarfs and neutron stars, but long before the disintegration of matter, galaxies will begin to gradually heat up.

Dark matter

Dark matter, which makes up about 25% of the mass-energy of the Universe, does not participate in electromagnetic interaction, therefore, it is inaccessible to direct observation, manifests itself only in gravitational interaction and affects the expansion rate of the Universe. The concept of dark matter was introduced to explain the problem of hidden mass in the effects of anomalously high rotation speed of the outer regions of galaxies and gravitational lensing; they involve a substance whose mass is much greater than the mass of ordinary visible matter. Dark matter is thought to be composed of Weakly Interacting Massive Particle (WIMP), hypothetical weakly interacting massive particles. The WIMP mass should be at least several tens of times greater than the proton mass $M_p = 10^{-27}$ kg. At the same time, wimps are not included in the Standard Model. Stable neutralinos are also considered in supersymmetric theories. In various unconfirmed experiments, a possible signal from WIMPs with a mass of the order of 4-19 M_p was observed.

Dark or absorption nebulae, types of interstellar clouds, are not dark matter, they are so dense that they absorb visible light from emission or reflection nebulae (such as the Horsehead Nebula) or stars (such as the Coal Bag nebula), behind. Stars are born in the inner parts of dark nebulae, and other active processes take place. However, it is possible that a special kind of cosmic dust can form dark matter.

Space dust particles range in size from a few molecules to 0.2 microns. Solar system dust includes cometary dust, asteroid dust, Kuiper belt dust, and interstellar dust passing through the solar system. The density of the dust cloud through which the Earth passes is approximately 10^{-6} dust particles per m^3. According to various estimates, from 5 to 300 tons of cosmic matter, including dust, enter the Earth's atmosphere per day. Dust particles interact with electromagnetic radiation, the nature of the reflected radiation depends on the particle size, cross section, structure, refractive index, wavelength of electromagnetic radiation, etc. The density of interplanetary dust particles in the Earth's stratosphere is 1-3 g/cm³ with an average value about 2.0 g/cm³. Near-star dust is composed of CO molecules, silicon carbide, silicates, polycyclic aromatic hydrocarbons, ice, and polyformaldehyde. Frequent components of dust particles are graphite, aluminum oxide, spinel, etc., which condense at high temperatures from the cooled gas that occurs during stellar winds or during decompression of the inner part of a supernova.

The Schrödinger equation refers to the energy of an electron in the electric field of the nucleus. If we replace it with a gravitational one, then the gravitational Bohr radius –

$$r_{grav}(n) = \left(\frac{n\hbar}{\pi}\right)^2 (GMm^2)^{-1}$$

For a proton and an electron, the first Bohr radius is greater than the radius of the Universe, 10^{28} m. If we assume that quantum properties manifest themselves at distances of the order of the 1st Bohr radius 10^{-10} - 10^{-11} m, then

$$2a + b = -(43\text{-}44),$$

where a and b – exponents, for example: $m \sim 10^a$. The terms can take the following values: - 15 and - 13, - 16 and - 11, or - 16 and -12, - 15 and -14, etc., which are included in the range of cosmic dust masses - from 10^{-16} kg to 10^{-4} kg. That is, in cosmic dust there should be connected states that do not emit electromagnetic waves, since dust particles are neutral, and for the transition from orbit to orbit they interact not with the electromagnetic, but with the gravitational vacuum.

Compounds of the macromolecule type, as well as formed under the action of van der Waals intermolecular interaction, dipole-dipole, the potential energy of which decreases with radius $U_{orient} \sim -1/r^6$, dipole-dipole induced ($U_{ind} \sim -1/r^6$), London dispersive and dispersive Slater - Kirkwood ($U_{disp} \sim -1/r^6$) with different coefficients proportionality and in the first type with a dependence on temperature, cannot be dark matter, since they are capable of emitting and absorbing electromagnetic waves.

It is possible that such dark matter regions of cosmic dust arise due to mass separation by the centrifugal force arising from the rotation of galaxies, thus separating them from the rest of the cosmic dust.

Conclusion

The modified 1st law of thermodynamics allows one to take into account the contribution of dark matter to local thermodynamic processes. The expression for work allows you to calculate the contribution of antigravity to the internal energy of the Universe. An analysis of the equations of thermodynamics shows that the cooling of the interstellar medium in the Universe slows down with expansion. Taking Unruh photons into account makes it possible to expand the scope of the thermodynamic approach to the Universe. If the assumption about Unruh's photons as radiation is correct, then the observed background cannot be one of the confirmations of the theory of a hot Universe. If the assumption of connected states in cosmic dust matches reality, it could be a step towards constructing quantum gravity.

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