Hydrodynamics of the dark superfluid: IV. Cosmological model

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Abstract In our previous works about the hydrodynamics of the dark superfluid[1] (dark energy + dark matter) we have addressed issues concerning particle physics, nature and propagation of light, quantum gravity and relativity. Here we want to test the convenience of a cosmological model based on such a dark superfluid. We obtain a solution to the cosmological redshift that matches the set of available data, including distant supernovae, without resorting to an expanding universe. The correct redshift seems to be due to the density of the dark superfluid fading out over large distances in spherical distribution. The model seems also suitable to solve baryon asymmetry and to let us better understand the nature of dark energy and of light itself. Still critical issues as the Big Bang, cosmic inflation and accelerated expansion of the universe would vanish, opening up new prospects.

Keywords Standard model of cosmology · cosmological redshift · quantum cosmology · superfluid vacuum · light propagation · dark energy

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Introduction

The standard FLRW ΛCDM big-bang model presents, as known, many unsolved criticalities, as also recently remarked by López-Corredoira [1]. Cosmic inflation is for instance a necessary complementary theory to the model but itself not justified resorting to current physics. These problems range from the issues of homogeneity, flatness and magnetic monopoles (as we know, artificially solved by introducing inflation) up to baryon asymmetry, galaxy structure formation, dwarf galaxies scarcity, necessity of accelerated expansion, stable density of vacuum energy despite expansion etc. Nevertheless, the general acceptance of the standard model and the numerous efforts to make it work properly, are due to the fact that we have currently found a single valid explanation to the redshift observed by E. Hubble, that of an expanding universe. However, after decades, the feeling is now to insist on a path which is maybe not correct. As Hossenfelder has recently stated [23], "science needs reason to be trusted". We therefore believe that we need to reinterpretate the cosmological redshift, by starting from a better understanding of the physical vacuum and of the nature of light, as previously discussed in [2,3]. The results are encouraging. Since the universe is filled at 95% with dark energy and dark matter (the dark superfluid (DS)), light has to propagate through them rather than through a real, Newtonian vacuum. A foaming quantum vacuum where particle-antiparticle pairs continuously appear and annihilate is perhaps nothing but the stochastic quantum hydrodynamic oscillation in the order parameter of the DS, in which vortex-antivortex pairs form and annihilate [2], as also observed in liquid helium when cooled under a critical temperature and in polaritons superfluids [6], even at room temperatures [11]. We have speculated that a photon too might be a quantum hydrodynamic perturbation of the DS, a *phonon* propagating through it, since we know that phonons also propagate through fluids and superfluids, even as transversal waves [36] and possess wave-particle duality such as photons. Furthermore, the speed of sound in dilatant fluids cannot be surpassed, thus, by hypothesizing a dilatant behavior of the DS (due to its granular, quantum nature) under shear stress occurring in a relativistic regime, we would also explain the reason why the speed of light cannot be surpassed [3]. Once it has transiently passed to a solid state, only sound, i.e. light in this case, can still propagate through it and this would pave the way

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[1] See ref. [2–4]

to merging special relativity with quantum physics, specifically with quantum hydrodynamics (see chart and details in [3], Sect. 4). Once taken into account the existence of the DS, the analogies photon-phonon were too many to make us desist from re-investigating the nature of light. In this case the speed of light would be dependent on the density of the DS.

By taking into account this dependence, we obtain an exact solution to the complete data set concerning the cosmological redshift with a single equation, which indeed describes the speed of light through the DS. This without resorting to expanding and accelerating universe and obtaining a simpler and effective cosmological model (see table in the annex for a model comparison). Here the energy density of free space coincides with that of dark energy (whose value is still debated, see Sect. 2) that permeates the whole cosmos and we believe it possess, along with dark matter, superfluid features, analogous to those of a Bose-Einstein condensate [38], at the average temperature of the cosmic microwave background (CMB). As known, in cosmology it is indeed useful to treat the universe as a fluid, which some authors let coincide with dark energy [5,8,2], if a single-fluid model is taken into account.

Exactly as Maxwell derived his equation for the speed of light from the density and the elasticity of the hypothesized ether, translated into the magnetic permeability and permittivity of vacuum, we use in our computations a formula for the speed of light based on its propagation through the DS. In superfluid quantum gravity (SQG) [4], the ether wind – or, to be precise, the flow of DS due to Bernoulli pressure exerted by massive particles being quantum vortices in the DS [2,4] – corresponds to the gravitational field, as previously hypothesized also by other authors [32,33]. In this case, the premise of the Michelson-Morley test (relative motion Earth-ether) [28] would have been inappropriate and no ether could be detected. The negative result of that test has forced us to reject the existence of a dark medium permeating the physical vacuum and this despite growing evidences from quantum physics (quantum vacuum) and cosmology (dark energy) about the non-existence of a real, Newtonian vacuum [2,7,19,20,22,38] as also investigated in recent works [34,35], and on the contrary about the existence of a dark medium owning superfluid features which photons might propagate through as quasi-particles [3], i.e. as quantized waves which possess a momentum.

With this different premise, let us come back to the interpretation of the cosmological redshift and we will see that an exact law for the observed redshift (including the distant supernovae) may be obtained from the role of density on light propagation, without critical side-effects and apparently solving various other issues of modern cosmology, as summarized in the annex.

1 Structure of the universe

Here we assume that the dark superfluid be distributed in a spherical volume and that its density fades out in distance, up to be zero at its boundary. In the present model, the universe is therefore a bubble of dark superfluid showing a $1/r$ density decrease (see Fig. 1). By assuming that this bubble is not expanding, we obtain in Sect. 3 the correct chart for the cosmological redshift. Outside of this bubble nothing, nor light can propagate. By approaching the edge of the universe, light would progressively lose energy, redshifting up to vanish. In the model the spherical volume filled with dark superfluid is also spinning and we therefore agree with Longo [15], who hypothesizes a rotating primordial universe. A spinning bubble (at least previously spinning) is not necessary for our redshift computations but helps to solve other well-known issues. As for laboratory superfluids, where single-handed vortices emerge from a rotating superfluid (Fig. 1), such a rotation would explain baryogenesis without antimatter, solving the baryon asymmetry and also explaining the statistical one-handed bias of spiral galaxies [15] and the left-handed bias of life molecules [18]. About the reasons for considering massive fundamental particles as quantized vortices in the DS see [2]. As regards baryon asymmetry, the decay of B mesons is indeed predicted to favor the production of matter over antimatter but not enough to explain the huge preponderance of matter in the present universe. Recent tests at the LHCb [16] showed that baryons too seem to violate the CP symmetry by following different decay paths but stronger data are necessary and this phenomenon is likely too rare in nature. Thus, with the present knowledge, baryon asymmetry remains unsolved in the standard ΛCDM big-bang model. On the contrary, Fig. 1 shows how a rotating superfluid could generate only same-handed particles, explaining the observable absence of antimatter in the universe.

2 The problem of vacuum energy density

From measurements of the WMAP probe, the energy density of vacuum (we assume dark energy) results to be $\sim 6\times10^{-9}\,\mathrm{J/m^3}$. However, in our model, as long as quantum vortices do not form in the DS [2,4], dark energy does not exert gravitational pull. This is clear also considering the fact that in a detected flat universe ($\Omega = 1$) accelerated expansion cannot occur (as on the contrary necessary in the standard model). Thus, assuming that dark energy at rest (not hydrodynamically perturbed [2,4]) does not exert gravitational pull, the measurement of the WMAP probe would not be correct. It appears to be first necessary to better theorize what dark energy is and how it behaves, to decide its role in gravitation. And it is also necessary to understand the quantum foundation of gravity, which could exactly bring

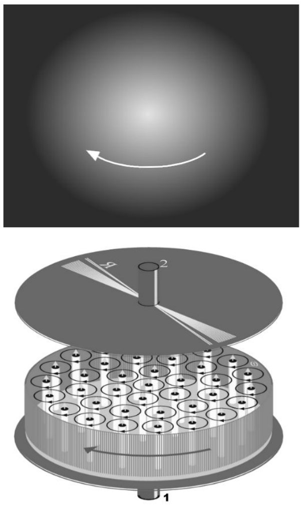

Fig. 1 Above: in this superfluid model the universe, here imaginarily observed from an outer point of view, appears as a non-expanding, spinning bubble of dark superfluid, whose density fades out from the center as $1/r$. It is not excluded that other universes may exist next to it but light (and any other kind of information) could not travel between them. The decreasing density would explain the redshift of distant supernovae and its rotation may justify the baryogenesis without antimatter and the formation of the indirectly observed cosmic web of dark matter [26] (the scaffolding of the universe) as a hydrodynamic perturbation of the DS (Fig. 2). Below: the formation of single-handed quantum vortices [2] in a rotating superfluid as the probable reason for baryon asymmetry and for the single-handed bias observed in spiral galaxies [15] and organic molecules [18].

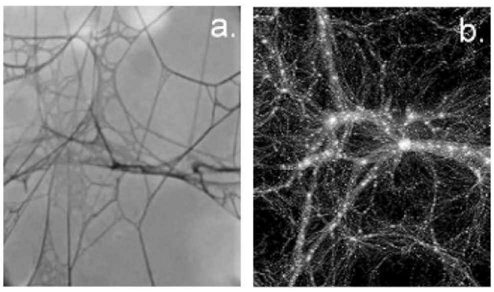

Fig. 2 Left: (a) Metal atoms trapped in superfluid helium vortices highlight a structure of vortex filaments [24]; (b) galactic filaments of dark matter [26] which baryon matter aggregates on forming stars and galaxies. Here the relationship between dark energy and dark matter is the same existing between superfluid helium and the vortex filaments which manifest in it, i.e. we suppose dark matter is a hydrodynamic manifestation of superfluid dark energy [8,20].

into play dark energy [4]. With the DS at rest only pressure is exerted (from its energy density, $\mathrm{J/m^3} \Rightarrow \mathrm{Pa}$) which balances the gravitation of baryon and dark matter. Since in a superfluid a quantum vortex is a topological defect where the field density drops to zero in a region having radius ξ (which refers to the vortex healing length, see [2,7]), it is very likely in our model that the value for vacuum's energy density could be extremely high and finite, surely closer to the calculations of quantum field theory than to those of the WMAP spacecraft. If we imagine fundamental massive particles as bubbles in a fluid (also in a bubble, as in a vortex, the fluid density drops to zero) it is easy to understand how vacuum can possess a much higher density than ordinary matter, even of that of a neutron star, since the neutron is represented in our superfluid approach [2] as a three-vortex system (three quarks) and in each vortex we have field density $|\psi|^2 = 0$. Baryon matter is not more dense than the DS but is rather a small part of it possessing great kinetic energy (i.e. spin, as a particle's total internal kinetic energy [29,30, 2]). We perceive the vortex and its action through the medium (gravity, electromagnetism), not the medium directly, since it interacts with us through its topological defects (particles) and the forces they generate. This is in our opinion the reason why we cannot directly detect dark energy. We have to search for its manifestations and the most evident may be light itself [3]. Thus, the reason why we cannot detect the gravitational pull of this enormous amount of dark energy at rest is because no gravity is exerted unless stable (not the ephemeral vacuum's fluctuations) vortices arise. By way of comparison, we could say that we cannot detect the air around us unless it is perturbed. And if it is not, this does not mean we live in a vacuum. So, the question with dark energy is "what we expect to observe". We think that the universe, hence the observer himself [2], are quantum hydrodynamic manifestations of the DS. We could be what we are trying to observe.

3 Exact law for cosmological redshift without expansion

We use here the model of photon [3] as a quasi-particle (transverse phonon, respecting its wave-particle duality) which acoustically propagates through the DS. Superfluid light in bulk nonlinear media has been described by Carusotto [27] and a superfluid behavior of photons has been observed in exciton-polariton condensates [9,10]. Also the DS would be a sort of dark Bose-Einstein condensate [38], at the temperature of the CMB radiation[2]. If light is the acoustic excitation of the DS, a sound that we "hear" with our eyes, we can therefore use the formula for the speed of sound in a fluid medium, $v_s = \sqrt{K/\rho}$, expressing the ratio bulk modulus to density, and resort to the isentropic compressibility, $\beta = 1/K$, to define the speed of light as

$$c = \frac{1}{\sqrt{\beta_d \rho_d}} \tag{1}$$

[2] In our model the CMB radiation is not the residual radiation from recombination (no Big Bang) but the intrinsic average temperature ($\sim 2.725K$) of the dark superfluid at rest, similar to that of other superfluids ($\sim 2.172K$ for phase transition in ^{4}He). Indeed, in a rotating superfluid universe (Fig. 1) baryon matter can form without Big Bang and without producing antimatter. This helps to solve baryon asymmetry.

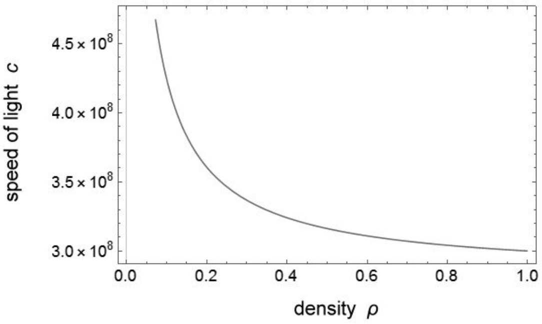

Fig. 3 Speed of light-density plot. The scale has been set by way of example acting on the arbitrary constants P_{d_0} and k, in the interval between $\rho_d \longrightarrow 0$ and $\rho_d = 1$.

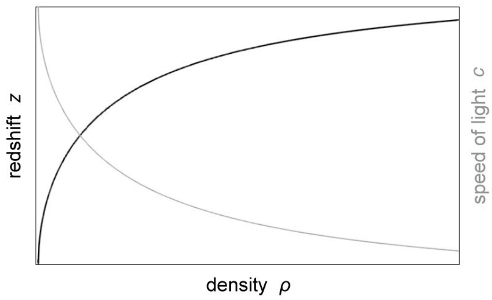

Fig. 4 Redshift caused by decreasing speed of light due to the density of the DS fading out with distance. As the curve suggests, the known value for c may be valid with good approximation only within cosmologically short distances.

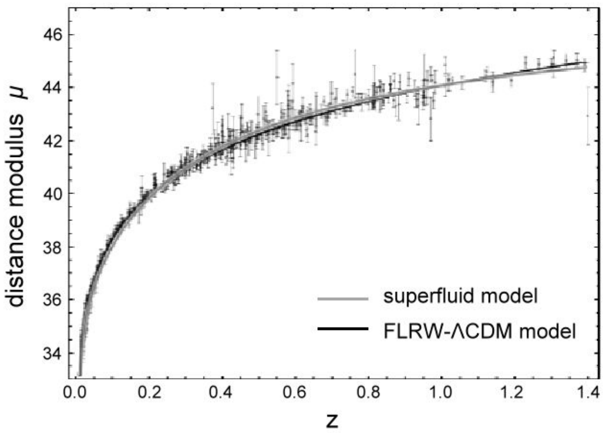

Fig. 5 Distance modulus-redshift plot. Data including the supernova Union2 compilation [17].

analogous to $c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$, where ρ_d is the density of the DS and β_d its isentropic compressibility. Here, as Maxwell did (though in the reverse direction to eliminate the concept of ether) and recently also Gremaud [12–14], we assume the identity $\varepsilon_0 \mu_0 = \beta_d \rho_d$. Since $\beta_d = (\rho_d(\partial P_d/\partial \rho_d))^{-1}$ we can pass to the equivalent definition

$$c = \sqrt{\frac{\partial P_d}{\partial \rho_d}}. \tag{2}$$

as also in [5]. As expected, we see that the speed of light is inversely proportional to the density of the DS. Let us plot (Fig. 3) $c = \sqrt{P_d/\rho_d}$ with $P_d = P_{d_0} + k\rho_d$, where P_{d_0} and k are arbitrary constants, to observe how the speed of light varies with density. Since we assumed that density decreases moving away from the center of the universe (Fig. 1), the speed of light will increase in distance equally in all directions from a central point of observation. The most distant a galaxy or a supernova, the more redshift its light will undergo at detection. Here it is important to specify that once light reaches our instruments on Earth or in the space, it settles on the local value of speed, i.e. the known $c = 299972458$ m/s, the value allowed by the local density (where *local* might be approximatively extended to beyond the solar system, considering the cosmic distances involved in the redshift measurement). A frequency deviation from that at the source has therefore occurred (due to the lower velocity in our frame of reference), which is detected as a redshift (Fig. 4) and this also applies to distant supernovae, as ascertainable from Fig. 5. In short, the curve of the observed redshift is nothing but the reciprocal of the speed of light and this is the core of the present model.

Also in Hubble's law, $z = H_0 D/c$, the $1/c$ dependence appears, albeit there c is a constant. And this is the problem, since the law is in that case linear and does not fit the observations, being not a suitable mathematical law for the cosmological redshift. In our formula the variation of distance is implicit in the varying $(1/r)$ value of density and the Hubble parameter disappears, substituted if anything by a simple coefficient that also eliminate the units or we can otherwise measure the redshift in [s/m]. Abandoning the expanding Big Bang universe, the use of FLRW metric becomes invalid and we explain the observations gaining a dramatic simplification in the mathematics.

Eventually, to conclude our speculative reasoning, it is interesting to see what happens if the point of observation (Earth) is not exactly in the center of the bubble-universe. Fig. 6 shows that this fact would add deviations from the predicted redshift curve, since the measurement would not be anisotropic anymore, as regards the chosen direction of observation. For instance, observing along r, would yield different redshift data for some equidistant galaxies, e.g. those located at the equidistant points D and K. This can in part explain the deviation from the theoretical curve which, for some objects, is much higher than expected.

4 Galaxy formation

Structure formation at the level of single galaxies is another weak spot of the standard model. Starting from a conjecture by Lathrop [7, 31] we think that galaxies have formed from

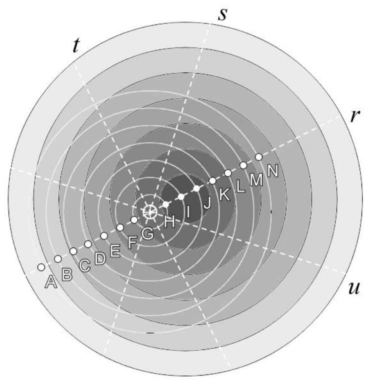

Fig. 6 deviations of the observed redshift from the predicted curve (Fig. 4, 5) due to the position of the point of observation (Earth) in the universe. Concentric grey circles express a discretized variation of density in distance and white circles represent equidistant points from the Earth (⊕). We notice that equidistant galaxies (e.g. B and M) may show a different redshift. This could explain part of the observed deviations (Fig. 5). However, taking into account all the possible different directions (observing for instance along *s, t, u*) the predicted curve is on average respected, with more or less deviation, assuming the observer is not excessively decentralized toward the edge of the universe. This means that our galaxy is relatively central and that the observation of the sky from peripheral regions of the universe would be strongly anisotropic. An analysis of redshift deviations to verify the hypothesis illustrated in Fig. 6 is suggested and could yield an approximate position of the Earth in the superfluid, finite, cosmos).

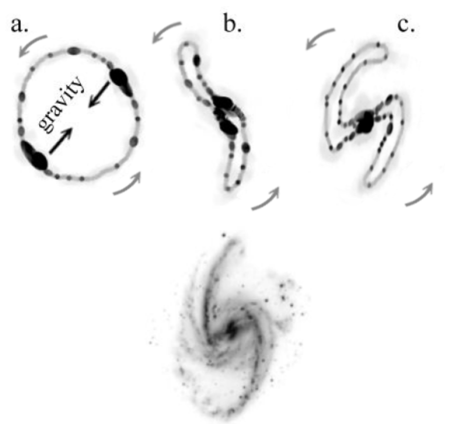

Fig. 7 Structure formation of a spiral galaxy (here NGC 1365) in a superfluid universe. Elaboration from an idea by Lathrop [31,7], compatible with the superfluid model. A giant vortex of dark matter in the DS attracts dust (also gravity is here considered as a quantum hydrodynamic phenomenon in the DS, see SQG [4]) which clumps and accretes on the vortex (we say due to Bernoulli pressure [4,25,7]). Because of the gravitational interaction, baryon clumps attract each other toward the center of the vortex, forming a black hole.

gas and dust accretion onto large vortices of dark matter, due to gravitational interaction (here interpreted as the action of Bernoulli pressure [4] therefore again a hydrodynamic phenomenon in the DS). This framework is illustrated in Fig. 7. The rotation of a galaxy would directly derive from that of the original vortex. The accreted clumps of baryon matter attract each other, moving toward the center of the ring. This originates a black hole, believed to be present at the center of galaxies. The way clumps are distributed on the ring would determine the shape of the galaxy. It is interesting to note that since a uniform distribution is unlikely, galaxies have generally assumed a spiral shape, while elliptical galaxies derive from merged galaxies. Irregular galaxies would have formed due to baryon and dark matter clustering without a "pilot-vortex". About the anomalous redshift deviations from galaxies in the Virgo cluster, Arp [37] thinks that there seem to be no alternative explanation other than a dependence on morphological galaxy types, where Sc galaxies show the largest redshift and the Sb the smallest value. Within our model, we argue it may depend on the different distribution and concentration of dark matter in galaxies depending on their shape. Also in this case, different density in the DS would therefore affect the equation of light (2).

5 Conclusion

As summarized in the table (see annex), our investigation shows that a cosmological model assuming a (once?) rotating, superfluid, approximatively spherical, universe whose density fades out as $1/r$ and where light corresponds to its acoustic excitation [3] is simpler and at first glance more effective than the FLRW ΛCDM big bang model, to justify the ontogeny of our universe and the observed redshift according to the available data set [17], without the necessity of complementary theories. Just taking into account the dependence of the speed of light on the density of the DS, we obtain a law for the redshift, without resorting to an expanding universe and to the mathematics of general relativity (which also has to get along with quantum theory and the framework becomes increasingly critical). On the contrary, this superfluid model predicts an approximately static universe, where galaxies have not formed from primordial fluctuations which have then expanded but *in loco*, due to quantum hydrodynamic perturbations of the DS. We deduce that the DS has existed ever since [39], letting it obey the principle of energy conservation, and its history is maybe older than the universe itself, without an adimensional singularity containing all the energy-mass of the universe which, at some point, decided to instantly swell and then to continue its (accelerated) expansion.

A superfluid model seems able to also justify the indirectly observed cosmic web of dark matter (Fig. 2), baryon asymmetry (Fig. 1), the statistically relevant single-handed bias of spiral galaxies [15] and that of organic molecules [18], the small amount of dwarf galaxies, the structure formation of single galaxies (Fig. 7) and the reason why the speed of light cannot be surpassed [3]. Dark energy theory should be improved in that dark energy would not exert gravitational pull (nor a supposed "negative gravity") as long as vortices (massive particles) do not form in it [4,2]:

at rest, dark energy only exerts repulsive pressure (as energy density) able to balance the gravitation of baryon matter and to avoid a gravitational collapse. The present model suggests that quantum cosmology does not need to reconcile general relativity with quantum physics. Even because such a reconciliation seems to lead us anyway to the superfluid approach, where curved spacetime gives way to the hydrodynamics of the DS [4].

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A — Model comparison

Issue	FLRW big-bang model	Superfluid model
horizon problem	needs inflation theory	not present; homogeneity is part of the model; CMB radiation is the average temperature of the cosmic superfluid
magnetic monopoles problem	needs inflation theory	not present; no primordial ultra hot universe predicted
cosmic inflation	necessary for the model but not justified yet	not present
gravitational singularity before Planck e-poch ($< 10^{-43}$s)	general relativity necessary but here theory breaks down due to quantum effects	not present; no singularities
oldness problem	not explained. Small deviances from ρ_c should have been grown in time.	not present; flat universe
$\Omega = 1$ **problem**	a detected flat universe should not expand but accelerated expansion is necessary to explain the observed redhift	an expanding universe is excluded and a flat universe is compatible with the model. The sphere of DS does not refer to spacetime geometry but to the distribution of the DS in a flat space.
dark energy	it is zero in Friedmann universes or otherwise why does it not exert normal gravitational pull?	dark energy is the main component of the superfluid and cannot exert gravitational pull when at rest. Gravity is a quantum hydrodrodynamic phenomenon [4] (perturbation of DS is needed) produced by vortices (massive particles [2]) in the DS and due to Bernoulli pressure; thus, on the contrary, dark energy density ($\mathrm{J/m^3} \Rightarrow \mathrm{Pa}$) balances the gravitation of baryon and dark matter, so the exerted force is repulsive
dark energy density invariance problem	from WMAP observations the density of dark energy paradoxically does not vary with the expansion of the universe	no expansion of the universe; dark energy density fades out in large distances as a Gaussian gradient, not in time, justifying the redshift of distant supernovae
dwarf galaxy problem (dark matter)	based on dark matter evolution model the small number of dwarf galaxies cannot be explained	not present; the dark matter web on which galaxies form arises from the hydrodynamic perturbation of the cosmic superfluid, with no prevalence of dwarf galaxies
baryogenesis	due to the Big bang and linked to its criticalities	due to the rotation of the cosmic superfluid massive fundamental particles arise and possess spin; this also solves several issues of particle physics [2]
baryon asymmetry and one-handed bias	not explained	cosmic superfluid spinning in a single direction justifies the absence of antimatter in the universe, the statistical one-handed bias of spiral galaxies [15], and the left-handed bias of life-molecules [18]
redshift of distant supernovae	not explained by linear Hubble's law. Accelerated expansion necessary.	explained by a single equation, no accessory hypotheses needed
galaxy structure formation	not explained	from gravitatonal accretion of dust onto great vortices in the cosmic superfluid (according to Lathrop). This explains the shape of galaxies, their rotation and the presence of a black hole at their center
future evolution of the universe	big crunch or thermal death depending on ρ_c	approximatively static universe where the gravitation of baryon and dark matter[4] is balanced by the internal pressure of dark energy
speed of light as upper limit to acceleration	not explained	due to the dilatancy of the cosmic superfluid under shear stress occurring in relativistic regime ($v \to c$) [3]
nature of light problem	light as an odd wave without propagation medium which is also a particle and has a constant speed everywhere in the universe	light corresponds to transverse phonons through the quasi-lattice of the dark superfluid, i.e. to the acoustic excitation of dark energy. Actually, a photon is therefore a quasi-particle (phonon) still owning wave-particle duality (due to possessing quantized momentum). The speed of light depends on the density of the DS and is therefore *not* constant in different parts of the universe. The speed increases with the radius of the spherical universe, following the decrease in density.