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Gravitational hydrodynamics of large-scale structure formation

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Abstract – The gravitational hydrodynamics of the primordial plasma with neutrino hot dark matter is considered as a challenge to the bottom-up cold-dark-matter paradigm. Viscosity and turbulence induce a top-down fragmentation scenario before and at decoupling. The first step is the creation of voids in the plasma, which expand to 37 Mpc on the average now. The remaining matter clumps turn into galaxy clusters. At decoupling galaxies and Jeans clusters arise; the latter constitute the galactic dark-matter halos and consist themselves of earth mass milli brown dwarfs. Frozen milli brown dwarfs are observed in microlensing and white-dwarf-heated ones in planetary nebulae. The approach explains the Tully-Fisher and Faber-Jackson relations, and cosmic microwave background temperature fluctuations of sub-milli-kelvins.

Introduction. – Structure formation in the Universe starts in the plasma of protons, electrons, He atoms and neutrinos, that exists up to some 400000 yr after the Big Bang, the time of decoupling (dc) of photons from matter (last scattering (L) or recombination). Then the plasma transforms to a neutral gas of H and 24% by weight ^{4}He, with the neutrinos remaining free streaming. As this occurs at about four thousand degrees kelvin, a moderate plasma temperature, we shall seek an explanation in terms of plasma physics and gravitational hydrodynamics alone. This embodies a return to the top-down scenario of large-scale structure formation.

Currently it is assumed that cold dark matter (CDM) also exists and, clustered before decoupling, has set seeds for baryon condensation. The so-called the concordance or ΛCDM model involves also a cosmological constant or dark energy. It describes a hierarchical bottom-up approach to structure formation, stars first, then galaxies, clusters, and, finally, voids.

But observations of dense clumps of ancient small stars in old globular clusters (OGCs) in all galaxies contradict the ΛCDM predictions that star formation should begin only after about 300 million years of dark ages and that the first stars should be 100–1000 $M_\odot$ population-III superstars. OGCs do not spin rapidly so they cannot be condensations, and their small stars imply gentle flows inconsistent with superstars. Other difficulties are posed by empty supervoids with size up to 300 Mpc reported from radio telescope measurements [1], dwarf galaxies with a lot of dark matter [2] and a preferred axis of evil spin direction (AE) that appears at scales extending to 1.5 Gpc, a tenth of the horizon scale [3]. Nearly every month new observations arise that pose further challenges to the ΛCDM paradigm: Correlations in galaxy structures [4]; absence of baryon acoustic oscillations in galaxy-galaxy correlations [5]; galaxies formed already when the universe was 4–5 billion years old [6] or even 1 billion [7]; dwarf satellites that swarm our own galaxy just like its stars [8].

The recent conclusion by one of us that dark-matter particles must have mass of a few eV and probably are 1.5 eV neutrinos [9], means that dark matter is hot (HDM), urging once more for an explanation of structure formation from baryons alone, without a cold-dark-matter trigger.

We shall discuss such baryonic clustering due to a viscous instability in the plasma, overlooked by the currently popular linear models of structure formation. CDM is assumed not to exist, while HDM, though, next to inflation, important to maintain the homogeneity of the plasma, has no role in the structure formation.

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Central in our discussion will be the huge plasma viscosity $\nu \sim 6 \cdot 10^{27}\,\mathrm{m^2\,s^{-1}}$ arising from photons that scatter from free electrons. This makes the plasma increasingly viscous, while it is expanding with space. At some age before the decoupling an instability creates the first structures, proto-voids and proto-galaxy-clusters. At decoupling the viscosity drops to hot gas values $\sim 10^{13}\,\mathrm{m^2\,s^{-1}}$, which creates further structures at the Jeans scale and at the new, small viscous scale.

The plan of this letter is to review modern theory of gravitational hydrodynamical structure formation, to evaluate the estimates for various fragmentation scales within Friedman cosmology, and to compare with observations.

Hydrodynamics. – The description of gravitational structure formation starts with Jeans 1902. He proposes that scales for gravitational condensation of a uniform fluid of mass density ρ must be larger than the Jeans acoustic scale $L_\mathrm{J} = V_\mathrm{S}/(\rho G)^{1/2}$, where $V_\mathrm{S} \sim c/\sqrt{3}$ is the sound speed of the plasma and $G = 6.67 \cdot 10^{-11}\,\mathrm{m^3/kg\,s^2}$ is Newton's constant. As the plasma Jeans scale is always larger than the horizon scale of causal connection, this forbids gravitational structure formation before decoupling. The Jeans criterion reflects a linear gravitational instability from acoustics, but it neglects the fact that self-gravitational instability of a gas is absolute [10]. All density variations will grow or decrease unless prevented by the viscous forces, turbulent forces and diffusion effects.

Conservation of the specific momentum in a fluid is expressed by the Navier-Stokes equation,

$$\frac{\partial \vec{v}}{\partial t} = \nabla B + \vec{v} \times \vec{\omega} + \vec{F}_\mathrm{viscous} + \vec{F}_\mathrm{other}, \tag{1}$$

averaged over system control volumes exceeding the momentum collision length scale. B is the Bernoulli group of mechanical energy terms $B = p/\rho + \frac{1}{2}v^2 + lw$ and the viscous force is $\vec{F}_\mathrm{viscous} = \nu_\mathrm{s}\nabla^2\vec{v} + (\frac{1}{3}\nu_\mathrm{s} + \nu_\mathrm{b})\nabla \cdot (\nabla \cdot \vec{v})$, with kinematic shear viscosity $\nu_\mathrm{s} = \eta/\rho$ and bulk viscosity $\nu_\mathrm{b} = \zeta/\rho$, while other fluid forces may arise. The inertial-vortex force per unit mass $\vec{v} \times \vec{\omega}$, with $\vec{\omega} = \nabla \times \vec{v}$, produces turbulence if it dominates the other forces; for example, $\mathrm{R_e} \equiv |\vec{v} \times \vec{\omega}|/|\vec{F}_\mathrm{viscous}|$ is the Reynolds number. A large viscosity corresponds to a small Reynolds number, with universal critical value $\mathrm{R_e^c} \sim 25$–100. For adiabatic flows the "lost work" term lw due to frictional losses is negligible so the enthalpy p/ρ decreases or increases to compensate for changes in the kinetic energy per unit mass $\frac{1}{2}v^2$.

The turbulence problem is put in a new perspective by Gibson [11]. Universal similarity laws are explained in terms of the inertial vortex forces $\vec{v} \times \vec{\omega}$. From eq. (1), turbulence is defined as an eddy-like state of fluid motion where the inertial-vortex forces of the flow are larger than any other forces that tend to damp the eddies out [12,13]. By this definition, irrotational flows are non-turbulent. All turbulence then cascades from small scales to large because vorticity is produced at small scales and adjacent eddies with the same spin induce inertial vortex forces that cause the eddies to merge and form bigger structures. Thus, turbulent motions and energy always cascade from small scales to large, contrary to standard turbulence theories that include in turbulence also irrotational flows and motions dominated by other forces.

Gravitohydrodynamics (GHD). – In his approach with hydrodynamic and diffusive modelling, Gibson 1996 [11] derives several gravitational Schwarz length scales for structure formation by Kolmogorian dimensional analysis. With $\tau_\mathrm{g} = 1/\sqrt{\rho G}$ the gravitational free-fall time in the Jeans length $L_\mathrm{J} = V_\mathrm{S}\tau_\mathrm{g}$, there occurs first the viscous length $L_\mathrm{SV} = \tau_\mathrm{g}\sqrt{\gamma\nu}$, where ν is the kinematic viscosity and γ is the rate of the strain, *i.e.*, the magnitude of $e_{ij} = \frac{1}{2}(\partial v_i/\partial x_j + \partial v_j/\partial x_i)$. Second, there is the turbulent length $L_\mathrm{ST} = (\varepsilon\tau_\mathrm{g}^3)^{1/2}$, where ε is the rate of energy dissipation per unit mass, and third, the diffusive length $L_\mathrm{SD} = \sqrt{D\tau_\mathrm{g}}$, where D is the diffusion coefficient. Within the acoustic horizon scale, $d_\mathrm{H}^\mathrm{ac} \sim ct$ structures can form at scale L if $d_\mathrm{H}^\mathrm{ac} \geqslant L \geqslant \max(L_\mathrm{SV}, L_\mathrm{ST}, L_\mathrm{SD})$.

We shall evaluate these scales within the flat Friedman metric $\mathrm{d}s^2 = c^2\mathrm{d}t^2 - a^2(t)\mathrm{d}\mathbf{r}^2$. The Friedman equation for baryonic and neutrino matter reads

$$\frac{\dot{a}^2}{H_0^2 a^2} \equiv \Omega(a) = \Omega_\Lambda + \frac{\Omega_B + \Omega_\nu}{a^3} + \frac{\Omega_\gamma}{a^4}, \tag{2}$$

where $\Omega_\nu = -\Omega_{\nu,0}\frac{\mathrm{d}}{\mathrm{d}\tau}\log\int_0^\infty \mathrm{d}x\sqrt{x}e^{-\tau\sqrt{1+x}}$ with $\tau = am_\nu c^2/k_\mathrm{B}T_0$ becomes a-dependent around the Compton temperature $\sim$17000 K. With $\mathrm{d}t = \mathrm{d}a/H_0 a\sqrt{\Omega(a)}$ the age is $\int_0^t \mathrm{d}t$, while the "angular" distance to an object at redshift $z = 1/a - 1$ reads $d_A(z) = [c/(1+z)]\int_t^{t_0}\mathrm{d}t/a$.

We adopt the Hubble parameter $h = H_0/[100\,\mathrm{km/s\,Mpc}] = 0.744$ favored in ref. [9], so that $m_\nu = 2^{3/4}(G_\mathrm{F})^{1/2}m_e^2 = 1.4998\,\mathrm{eV}$ and $\Omega_\nu = 0.111/h^{3/2} = 0.173$. For baryons we take $\Omega_B = 0.02265/h^2 = 0.0409$ from WMAP5 [14], while for photons $\Omega_\gamma = 2.47 \cdot 10^{-5}/h^2 = 4.46 \cdot 10^{-5}$. Finally, $\Omega_\Lambda = 1 - \Omega_\nu - \Omega_B - \Omega_\gamma = 0.786$ assures a flat space.

Viscous instability in the plasma. – GHD starts with acknowledging the importance of the photon viscosity. Because it strongly increases in time, already before decoupling the plasma becomes too viscous to follow the expansion of space [11]. Thus a gravitational instability occurs, that tears the plasma apart at density minima, thus creating voids. Cosmic (super)voids surround us at any distance and the furthest observable ones are located at the decoupling redshift. Presently, voids have a 20 times under-density with respect to the critical density. In between voids the galaxy clusters are located on "pancakes" that join in superclusters.

The shear viscosity $\nu \equiv \nu_\mathrm{s}$ reads for $k_\mathrm{B}T \ll m_e c^2$ [15]

$$\nu = \frac{\eta}{\rho_B} = \frac{1}{\rho_B}\,\frac{5m_e^2\zeta(3)(k_\mathrm{B}T)^4}{9\pi^3\hbar^5 c^2\alpha_\mathrm{em}^2 n_e}, \tag{3}$$

with m_e the electron mass, $\alpha_\mathrm{em} = 1/137$ the fine-structure constant and $n_e = 0.76\rho_B/m_N$ the electron density. With $n_e \sim \rho_B \sim T^3$, ν increases as $1/T^2$. At WMAP5 values for decoupling it reaches the huge value $5.85 \cdot 10^{27}\,\mathrm{m}^2/\mathrm{s}$, while the bulk viscosity $\sim 10^{14}\,\mathrm{m}^2/\mathrm{s}$ is much smaller. In the plasma the acoustic speed $V_\mathrm{S} = c/\sqrt{3(1+R_z)}$ with $R_z = 3\Omega_B/4\Omega_\gamma(1+z)$ [16] sets the acoustic horizon scale

$$d_\mathrm{H}^\mathrm{ac}(z) = \frac{1}{1+z}\int_0^{t(z)} \mathrm{d}t' \frac{V_\mathrm{S}(t')}{a(t')}. \tag{4}$$

At WMAP5 decoupling it takes the value $d_\mathrm{H}^\mathrm{ac} = 128\,\mathrm{kpc}$ but, estimating $\gamma = V_\mathrm{S}/d_\mathrm{H}^\mathrm{ac}$, the viscous length $L_\mathrm{SV} = (\nu V_\mathrm{S}/G\rho_B d_\mathrm{H}^\mathrm{ac})^{1/2}$ is then only $76\,\mathrm{kpc}$, showing that an instability has occurred. This causes an often overlooked baryonic structure formation in the plasma [11]. The crossover of L_SV and d_H^ac occurs when $d_\mathrm{H}^\mathrm{ac} = (V_\mathrm{S}\nu/G\rho_B)^{1/3}$. This happens at $z_\mathrm{vf} = 5120$, where $d_\mathrm{H}^\mathrm{ac} = 7.3\,\mathrm{kpc}$ is the initial void scale. It expands by a factor $1 + z_\mathrm{vf}$ to become 37 Mpc now, a typical void size, smaller than the supervoids of 50–300 Mpc observed by radio telescopes. ΛCDM models predict such voids formed last and full of debris, rather than first and empty as observed [1]. Foreground voids will play a role in the cosmic microwave background (CMB) structure at large angles [17], especially due to their neutrino depletion at $z \sim 7$ [9]. Voids occur next to condensations with baryonic clustering mass

$$M_\mathrm{cl} = \frac{\pi}{6}\rho_B (d_\mathrm{H}^\mathrm{ac})^3 = \frac{\pi V_\mathrm{s}\nu}{6G} = 1.7 \cdot 10^{14}\, M_\odot, \tag{5}$$

which corresponds to the baryonic mass of fat galaxy clusters (cl). The Reynolds number becomes

$$\mathrm{R_e} = \frac{d_\mathrm{H}^\mathrm{ac} V_\mathrm{S}}{\nu} = \frac{9\pi^3\hbar^5 c^2 \alpha_\mathrm{em}^2}{5 m_e^2 \zeta(3)} \frac{d_\mathrm{H}^\mathrm{ac} V_\mathrm{s} n_e \rho_B}{(k_\mathrm{B}T)^4}. \tag{6}$$

At z_vf it equals 158, somewhat above critical. At the boundaries of the clumps it is much smaller, $\mathrm{R_e}(r,z) = \mathrm{R_e}(z)[\rho_B(r,z)/\rho_B(z)]^2$, where z codes the redshift, r the local position and the uniform terms refer to the would-be uniform state. While $\mathrm{R_e} = 158$ at z_vf is already not large, fragmentation leads to small values at the boundaries, which enhances the turbulence. As the voids expand, baroclinic torques at their boundaries produce vorticity and turbulence due to misalignment of pressure gradients and density gradients. Pressure gradients will be normal to void boundaries, but density gradients need not. The rate of vorticity and turbulence production at the expanding protosupercluster boundaries is $\partial\vec{\omega}/\partial t = \nabla\rho \times \nabla p/\rho^2$. Observations of the Hubble Ultra Deep Field [18] show chains of protogalaxies and spiral clump clusters, as well as DM filaments, formed in this way.

A connection to turbulence was established [19] in a study of the CMB temperature difference between two points at angular separation r, *viz.* $\langle|\Delta T|^p\rangle \sim r^{\zeta_p}$, where the average is taken over angles between 0.9° and 4°. For $0.1 < p \leqslant 3$ the exponent reads $\zeta_p \approx p/3$, as in turbulence. A test of Gaussianity in CMB, $\langle|\Delta T|^p\rangle \sim \langle|\Delta T|^3\rangle^{\zeta_p}$ reveals a marked deviation from the Gaussian value $\zeta_p = p/3$ in the interval $3 < p < 12$, with $\zeta_{12} \approx 2.8$, and coinciding with the ζ_p of turbulence [20]. In ref. [21] it is deduced that the data for the first CMB peak involve $\mathrm{R_e} \sim 100$, in striking agreement with our estimate ~ 158.

The pancaked structure of matter in between large voids arises dynamically since voids expand more than matter.

Towards decoupling. – In the period near last scattering, helium is already formed, so the density of protons plus H-atoms is $n = 0.76\,\rho_B/m_N$. The fractional ionization $X = n_e/n$ evolves according to eq. (2.3.27) of [16],

$$\frac{\mathrm{d}X}{\mathrm{d}T} = \frac{n\alpha}{HT}\frac{X^2 - (1-X)/S}{1+A} + \left(3 - \frac{T}{n}\frac{\mathrm{d}n}{\mathrm{d}T}\right)\frac{X}{T}, \tag{7}$$

$$\begin{aligned} S &= n\lambda_\mathrm{T}^3 e^{157{,}894\,K/T}, \qquad \lambda_\mathrm{T} = \hbar\sqrt{\frac{2\pi}{m_e k_\mathrm{B} T}}, \\ \alpha &= \frac{1.4377 \cdot 10^{-16}(T/K)^{-0.6166}}{1 + 5.085\cdot 10^{-3}(T/K)^{0.5300}}\,\frac{\mathrm{m}^3}{\mathrm{s}}, \\ A &= \frac{\alpha\lambda_\mathrm{T}^{-3} e^{-39{,}474\,K/T}}{\Gamma_{2s} + 8\pi H/[\lambda_\alpha^3 n(1-X)]}. \end{aligned} \tag{8}$$

Here S is the Saha function and λ_T the thermal length, while α and A are factors involving $\Gamma_{2s} = 8.22458\,\mathrm{s}^{-1}$ the two-photon decay rate of the H_{2s} level and $\lambda_\alpha = 1215\,\mathrm{\AA}$ the Ly_α wavelength. We added the last term in (7) in order to allow that $n \neq \mathrm{const}\cdot T^3$. Baryonic matter will expand less after clusters have formed. Let us take the geometric mean between no and full expansion, thus assuming that the matter clumps expand up till last scattering at z_L by a factor $\sqrt{a/a_\mathrm{vf}} \leqslant 2.2$, implying $\rho_B = (a_\mathrm{vf}/a)^{3/2}\rho_B^\mathrm{vf}$.

Initially $S \ll 1$, so the Saha law $X = 1 - SX^2$ continues to hold. H formation makes X decrease appreciably, from where on we have to solve eq. (7). The condition for maximal probability of last scattering [16] can be formulated as $\mathrm{d}J/\mathrm{d}T = J^2$, where $J = c\sigma_T nX/HT$ involves the Thomson cross-section $\sigma_T = 6\pi(\hbar/\alpha_{em} m_e c)^2 = 6.6525 \cdot 10^{-29}\mathrm{m}^2$. This fixes the surface of last scattering at $T_L = 2862\,\mathrm{K}$, $z_L = 1050$, compared to $z_\mathrm{dc} = 1090$ from WMAP5, and taking place at age $t_L = 408000$ yr. The clump size $L_\mathrm{cl} = d_\mathrm{H}^\mathrm{ac}(z_\mathrm{vf})\sqrt{a_L/a_\mathrm{vf}}$ corresponds to an angle $\theta_\mathrm{cl} = 180° L_\mathrm{cl}/\pi d_A(z_L) = 0.84°$, or spherical index $\ell_\mathrm{cl} = 180°/\theta_\mathrm{cl} = 215$, which agrees with the first CMB peak. At this moment $X = 0.01$ makes the Reynolds number as low as 0.12, thus exhibiting turbulence throughout the bulk, and predicting more CMB turbulence at smaller lengths.

Magnitude of CMB temperature fluctuations. – The smallness of CMB fluctuations, $\delta T/T \sim 10^{-4}$–10^{-5} is one of the mysteries of cosmology. Indeed, how can it be consistent with a mass contrast of almost 100% between clumps and voids? Presently it is described by inflation, where its size is adjusted in the initial fluctuation spectrum [16]. In order to explain it from a physical mechanism, let us notice that not all clump energy can associate with temperature fluctuation, since in empty space the temperature already decays with the redshift, $T(z) = (z+1)T_0$. Compared to voids, extra energy of a clump that is available for photons must mainly stem from the $E_1 = 13.6\,\text{eV}$ energy release of H formation. The H density is low, at decoupling $\sim(1+z_{\rm dc})^3\Omega_B\rho_c/m_N \sim 300$/cc with $\rho_c = 1.04\cdot 10^{-26}\text{kg/m}^3$ the critical density. At a temperature $T < T_{\rm vf}$ this amounts to an excess energy density $f\Omega_B E_1(1+z_{\rm vf})^3\rho_c/m_N$, where $f\sim 2$ accounts for having the matter in plasma clumps. By scatterings this heats the local photons, while opaqueness prevents it to also heat the voids. Thus it causes a perturbation in the photon energy density at last scattering $\delta u_\gamma(z_L) = 4\Omega_\gamma\rho_c c^2(z_L+1)^4(\delta T/T)_L$ and yields

$$\left.\frac{\delta T}{T}\right|_L = \frac{f\Omega_B E_1(z_{\rm vf}+1)^3}{4\Omega_\gamma m_N c^2(z_L+1)^4}. \tag{9}$$

For $z_{\rm vf} = 5120$, $z_L = 1050$ we find $\delta T/T|_L = 1.4\cdot 10^{-6}$, which corresponds presently to $\delta T_{\rm cl} \equiv T_{\rm cl} - T_{\rm void} = +3.9\,\mu$K. Given the strong $(1+z_{\rm vf})^3$-dependence this can be adapted to the right order of magnitude. Voids do not have this baryonic content, which explains the observed connection hot spots – (super)clusters, cold spots – voids.

Fragmentation in the gas at two scales. – At last scattering, the plasma turns into a neutral gas and further baryonic structures form. The free fall time is $\tau_{\rm g} = 1.68$ Myr, while the age is $t_L = 0.41$ Myr. The sound speed of a monoatomic gas is $V_{\rm S} = \sqrt{5p/3\rho}$. For H with 24% weight of He, $p = 0.82\rho k_{\rm B}T/m_N$ yields $V_{\rm S} = 5.68$ km/s. The gas fragments at the Jeans scale $L_{\rm J} = V_{\rm S}\tau_{\rm g} = 9.78$ pc into Jeans clusters (JCs) or Proto-Globular Clusters (PGCs) with Jeans mass

$$M_{\rm JC} = \frac{\pi}{6}\rho_B L_{\rm J}^3 = \frac{\pi V_{\rm S}^3}{6G^{3/2}\rho_B^{1/2}} = 38000\,M_\odot. \tag{10}$$

This Jeans mechanism is well known, but not always welcomed, since so few globular clusters are observed. In our approach it is a standard process, that fragments all gas in Jeans clumps, so they should be very frequent – see below.

At decoupling the viscosity decreases from photon viscosity values to hot-gas values. The He viscosity can be estimated as $\eta_{\rm He}(T_L) = 5.9\cdot 10^{-5}$ kg/ms. For the 76:24 H-He mixture it will be about $0.76/8 + 0.24/4 = 0.155$ of this. The viscous length $L_{\rm SV} = (V_{\rm S}\eta/G\rho_B^2)^{1/3} = 3.9\cdot 10^{14}$ m implies a further condensation into masses of order

$$M = \frac{\pi}{6}\rho_B L_{\rm SV}^3 = \frac{\pi V_{\rm S}\eta}{6G\rho_B} = 13\,M_\oplus = 3.9\cdot 10^{-5}\,M_\odot. \tag{11}$$

We may call these objects MBDs, Primordial Fog Particles or milli brown dwarfs. Their mass is in good agreement with estimates from microlensing of a distant quasar [22,23] and so-called cometary knots in the Helix nebula [24–26]. It was anticipated independently by theory of Gibson [11] and observations of Schild [22] that galactic dark matter is composed from such MBDs. Each JC contains about a billion of them.

Galaxies. – We may relate galaxies to the Jeans mechanism at the end of the plasma epoch. The sole relevant aspect is then the decrease of the speed of sound from plasma values to hot gas values. Taking the geometric mean velocity $\overline{V}_{\rm S} = (V_{\rm S}^{\rm plasma}V_{\rm S}^{\rm gas})^{1/2} = 874\,\text{km/s}$, we get the Jeans scale $L_{\rm J} = 1.5$ kpc and corresponding mass

$$M_{\rm gal} = \frac{\pi}{6}\rho_B L_{\rm J}^3 = \frac{\pi\overline{V}_{\rm S}^3}{6G^{3/2}\rho_B^{1/2}} = 1.4\cdot 10^{11}M_\odot. \tag{12}$$

The corresponding CMB angle is $\theta_G = 4.7'$ and the angular index is $\ell_G = 2300$. For this mass regime the formation time is limited, because the sound speed continues to decrease to gas values, from where on JCs are formed. This explains why a lot of baryons are not locked up in galaxies with their baryonic dark matter, but located in intracluster and intercluster X-ray gas. That gas has become hot, with temperatures up to 100 keV ($1\,\text{keV}/k_{\rm B} = 1.16\cdot 10^7$ K), due to virialization after neutrino condensation on clusters at $z\sim 7$ or $t_{\nu c} = 120$ Myr [9]. At such high temperatures the gas may allow nuclear fusion up to tellurium [27].

Role of Jeans clusters. – In some of them, still warm, collision processes quickly lead to star formation, basically without a dark period, thus transforming them into OGCs. Other JCs transform in ordinary stars. In the major part of the JCs the MBDs freeze and they still persist without stars. These JCs are in virial equilibrium and act as ideal gas particles that constitute the galactic dark matter. Their physical presence explains why the isothermal model describes the basic features of galactic rotation curves so well, that is, linear growth at small radius, plateau at large radii. To improve the fit, one may consider mixtures with several isothermal components [9].

In the centers of galaxies the near passings of JCs will cause tidal forces which heat their planets and induce star formation. Since this is mainly a two-particle effect, the luminosity of a galaxy is expected to relate to the JC mass density as $L\sim\int \mathrm{d}^3r\,\rho_{\rm JC}^2$. In the isothermal model $\rho_{\rm JC} = \sigma_v^2/2\pi G r^2$, where σ_v is the velocity dispersion, so the $1/r^4$ fall off of the integrand makes the luminosity finite. This results in the scaling $L\sim\sigma_v^4/R$, *i.e.*, the Faber-Jackson relation [28], with an additional characteristic bulge scale R. The Tully-Fisher relation is likewise explained, as it involves the rotation velocity, which scales with σ_v.

In several instances the matrix of dark JCs is revealed by new star formation. When agitated by tidal forces the collision frequency of the MBDs will increase causing re-evaporation of the frozen gases, increased size and friction, and the possibility of planet mergers to produce larger MBDs and eventually new stars. The existence of galaxy dark matter in the form of clumps of frozen primordial MBDs is clearly revealed in photographs of galaxy mergers such as Tadpole, Mice and Antennae. On the respective photographs one can see numerous bright clusters of comparable size, that are identified here as JCs turned into young globular clusters. They are located in star wakes as the merging galaxies enter each others dark-matter halos and heat up the MBDs in the JCs on their path through the dark matrix. The effect exists only within a certain radius, the boundary of the JC cloud of the host galaxy.

Role of milli brown dwarfs (MBDs). – From the GHD scenario following decoupling, the first stars form gently by a frictional binary accretion of still warm MBDs to form larger planet pairs and finally small stars as observed in OGCs. Thereby they create an Oort cavity as clearly exposed in *e.g.* the Helix planetary nebula. Slow turbulent mixing from the rain of planets will not mix away the dense carbon core. By conservation of angular momentum the star spins rapidly as it compresses producing strong spin radiation along the spin axis and at the star equator. Stars can form as binaries in JC clumps.

At decoupling the entire baryonic universe turns to a fog of earth mass MBDs. Due to the expansion they cool and the freezing temperature of hydrogen and helium occurs at redshift $z \approx 30$ a few hundred million years later, producing the frozen dark baryonic MBDs in clumps predicted as the galaxy dark matter [11]. Neutrino condensation at $z \sim 7$ comes later, showing that the extra-galactic MBDs reionize to become hot X-ray gas. That the dark matter of galaxies should be objects of earth mass was independently proposed by the Schild 1996 interpretation of 5 h twinkling periods in quasar microlensing observations [22,23]. Thousands of these planet crossings have been observed.

As the universe expands the MBDs that did not turn into stars freeze and the JCs become less collisional and diffuse out of the 3 kpc scale protogalaxies to form the observed typical $R = 100\,\mathrm{kpc}$ dark matter halos with a basically isothermal distribution. Consistency of this picture is shown by the isothermal estimate $M_{\mathrm{gal}} = 2\sigma_v^2 R/G \sim 1.9 \cdot 10^{12}\, M_\odot$ for $\sigma_v = 200\,\mathrm{km/s}$.

When frozen, the MBDs are too small to dim light, even from remote sources, but they can account for dimming when they are heated. Warm atmosphere diameters are $\approx 10^{13}$ m, the size of the solar system out to Pluto, bringing them out of the dark. The separation distance between MBDs is $\approx 10^{14}$ m, as expected if the JC density of MBDs is the primordial density $\rho_0 = 2 \times 10^{-17}\,\mathrm{kg\,m^{-3}}$. In planetary nebula such as such as the nearby Helix, dark MBDs at the boundary of the 3×10^{15} m Oort cavity are evaporated. HST optical images of Helix show $\approx 10^4$ "cometary knots", gaseous planet atmospheres $\approx 10^{13}$ m which we identify as MBDs with metallicity, and Spitzer shows $\geqslant 10^5$ in the infrared from the $10^3\, M_\odot$ available [13]. Meaburn *et al.* determine for cometary knots in Helix a mass of $1 \cdot 10^{-5}\, M_\odot$, and conclude that the globules and tails are dusty [24], and later report a mass of $2 \cdot 10^{-5}\, M_\odot$ [25]. Huggins *et al.* [26] measure a mass of $5 \cdot 10^{-6}\, M_\odot$ via the radio measurement of CO emission. These findings support the GHD prediction of earth mass MBDs as the baryonic dark-matter repository.

Dimming by dense 10^{13} m planet atmosphere gases or realistic quantities of dust is negligible at the 20% levels observed [29]. Such large dimming of obscured lines of sight observed in a planetary nebula (*e.g.* Helix) requires post turbulent electron density forward scattering [30] as observed by radio telescope pulsar scintillation spectra, embedded in the Kolmogorovian "great power law on the sky" [12], which can now be understood from GHD as remnants of supernova powered turbulent mixing in our local PGC [30]. The planet atmosphere cross-section for SNe Ia dimming $\sigma \approx 10^{26}\,\mathrm{m}^2$ gives a photon mean free path $1/n\sigma \approx 3 \times 10^{15}$ m from the primordial PFP number density n_0, comparable to the observed Helix planetary nebula shell thickness and consistent with $\approx$5% of the SNe Ia lines of sight unobscured. Clouds of warm MBDs can be responsible for the Ly_α forest – not hydrogen clouds that have remained undetected.

Conclusion. – Within gravitational hydrodynamics (GHD) for a flat space Friedman cosmology with (hot) neutrino cluster dark matter we have described various structures that form due to hydrodynamic instabilities in the baryonic plasma. The approach accounts for a wealth of observations and relations between them.

The first step, when photon scattering from free electrons makes the plasma too viscous, is the creation of proto-voids at $z_{\mathrm{vf}} = 5120$, before decoupling, that expand to present average cosmic voids. Proto-supervoids occur too, but are rare. The matter condenses in proto-galaxy-clusters. The coincidence of turbulence properties in the CMB and turbulent fluids supports the GHD model. Pancaked galaxy (cluster) structures in between large voids arise dynamically, since the voids expand faster, while the matter remains gravitationally bound.

The assumption that the ionization energy of the H-formation is redistributed to the photons, explains the milli-kelvin scale of CMB fluctuations and the connection cold spots – voids, hot spots – (super)clusters.

At very large scales the homogeneity of temperature is explained by inflation. Before the viscous instability the plasma was quite homogeneous, due to the free streaming neutrinos that damped inhomogeneities at the free streaming scale of 10 kpc at z_{vf}. So, irrespective of their location on the sky, the fluctuations caused by the viscous instability have the same order of magnitude. This known large-angle correlation is in GHD an effect of simultaneity (of void formation in the plasma), not of causality.

At decoupling first galaxies are formed and later primordial globular clusters (Jeans clusters, JCs) of about 38000 solar masses. Some of them turn into old globular clusters (OGCs) and others form the stars in galaxy bulges. But most JCs, millions per galaxy, remain dark and constitute the galactic dark matter as an ideal gas, which explains why the isothermal model describes galactic rotation curves well. A galactic dark JC matrix also accounts for numerous young globular clusters seen in galaxy mergers. Near JC crossings in the center of galaxies will form stars, which explains the Tully-Fisher and Faber-Jackson relations.

At decoupling the viscous scale becomes much smaller which turns all matter into MBDs of a few earth masses. Some of them coalesce to form the first small stars, but most freeze to earth scale. The MACHO [31] and EROS [32] collaborations have searched in vain for such objects. Still, they are not excluded because they do not occur uniformly but in PGC clumps. Theoretical descriptions of clumped MACHOs in the dark halo were started in [33]. But thousands of planets have been observed in microlensing [22,23] and, reheated, forty thousand in planetary nebula such as Helix [24–26,34]. Hot MBD atmospheres may dim distant supernovas.

In this letter we analyzed previous results by two of us within in Friedman cosmology, explained CMB temperature fluctuations from H formation, and we connected to the isothermal distribution of JCs and the Tully-Fisher relation. We have adopted one set of cosmological parameters, which performed rather well, but not attempted an optimization. While in the CDM model the main cause of clustering is dark matter with baryons a second-order effect, the GHD scales will be rather sensitive to the precise baryonic parameter values. Large scale numerical hydrodynamics simulations of separate steps of the fragmentation process are expected to result in precise fits for the mass fractions of baryons and neutrinos, and the Hubble constant. We have not considered the large scale power spectrum [16], this should be set by inflation. We may recall that there are reasons to question whether baryons trace the neutrino dark matter well [9].

Let us sortly connect to the numerical work on the Cold-Dark-Matter model by Shapiro *et al.* [35]. These authors find that the Inter Galactic Medium must have contained a substantical amount of the baryon density of the Universe during and after its reionization epoch, in agreement with our wide distribution of JCs around galaxies. Their problem with quasar absorption lines may be explained by absorption by hot gas MBD atmospheres. The authors do not find a reheating of the Inter Galactic Medium, also not by quasars. In our picture it is achieved by the condensation of neutrinos on *e.g.* galaxy clusters.

Let us finally see how some problems of the ΛCDM paradigm mentioned in the introduction are solved naturally in GHD. There are not a few but very many Jeans clusters. Population-III stars may have been rare, since reionization may find its origin in neutrino condensation on galaxy clusters [9]. Dwarf galaxies with a lot of (baryonic!) dark matter may pertain to JCs with incomplete star formation. The related fact that OGCs often exhibit stars formed at several epochs is likewise explained by further sets of reheated, pre-existing MBDs. Correlations in galaxy structures are expected since they all form early; baryon acoustic oscillations do not show up in GHD. Galaxy formation when the universe was 4–5 billion years young may refer to proto-galaxies with late-stage star formation by close PGC encounters. Dwarf satellites that swarm our galaxy just like its stars may just relate to single JCs with modest star formation and still many dark MBDs, popping out of the matrix of dark JCs that surrounds the Galaxy.

We have shown that the concordance model, though successful in explaining *e.g.* the CMB fluctuations, cannot be right since it overlooks a plasma instability.

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