Interpretation of the Tadpole VV29 Merging Galaxy System using Hydro-Gravitational Theory

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ABSTRACT

Hubble Space Telescope (HST/ACS) images of the galaxy merger Tadpole (VV29=Arp 188=UGC 10214) are interpreted using the hydro-gravitational theory of Gibson 1996-2000 (HGT) that predicts galaxy masses within about 100 kpc ($3.1 \times 10^{21}$ m) are dominated by dark halos of planetary mass primordial-fog-particles (PFPs) in dark proto-globular-star-clusters (PGCs). According to our interpretation, stars and young-globular-clusters (YGCs) appear out of the dark as merging galaxy components VV29cdef move through the baryonic-dark-matter halo of the larger galaxy VV29a creating luminous star-wakes. Frozen PFP planets are evaporated by radiation and tidal forces of the intruders. Friction from the gas accelerates an accretional cascade of PFPs to form larger planets, stars and YGCs of the filamentary galaxy VV29b. Star-wakes show that galaxy VV29c, identified as a blue dwarf by radio telescope observations of gas density and velocity (Briggs et al. 2001), with companions VV29def entered the dark halo of the larger VV29a galaxy at a radius $4 \times 10^{21}$ m and then spiraled in on different tracks toward frictional capture by the VV29a core. A previously dark dwarf galaxy is identified from a Keck spectrographic study showing a VV29c star-wake dense cluster of YGCs aligned to 1° in a close straight row (Tran et al. 2003).

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1. Introduction

The peculiar filamentary galaxy Tadpole (VV29=Arp 188=UGC 10214) at distance $4 \times 10^{24}$ m and the similar merging galaxy system with a long luminous tail Mice (NGC 4676) at distance $3 \times 10^{24}$ m were chosen to be among the first images obtained by the HST/ACS Hubble Space Telescope, taking advantage of the wide angle field of view of the newly installed Advanced Camera for Surveys (April 30, 2002, press release) to provide better information about the origins of these distant mysterious systems. It was speculated (Trentham et al. 2001) that the long Tadpole tail might reflect the presence of a nearby, non-baryonic, cold-dark-matter (CDM) “Dark-Matter” halo by forming a tidal bridge of stars from VV29a extending toward a massive, but invisible, CDM halo object. However, “CDM Halos” are excluded by HGT cosmology because non-baryonic dark matter (NBDM) by its weakly collisional nature is highly diffusive with long mean free paths for collision so it cannot possibly form the gravitationally bound “CDM Halo” objects required by CDM cosmologies. According to HGT cosmology the NBDM diffuses to form outer halos of large galaxies or galaxy clusters. NBDM halos have smaller densities than inner baryonic-dark-matter (BDM) galaxy halos even though they have larger masses. Sand et al. 2002 have constrained the density profile of a lensing galaxy cluster within 100 kpc to a form that excludes the steep universal CDM density profiles predicted by CDM cosmological simulations at the 98% CL, strongly contradicting the CDM paradigm for galaxy formation.

The radio telescope measurements (Briggs et al. 2001) clearly demonstrate the existence of a blue dwarf galaxy VV29c embedded in the VV29a image with velocity different than the rapid VV29a rotation velocity of about $330$ km s$^{-1}$, so the massive CDM halo interpretation of VV29b (Trentham et al. 2001) becomes unnecessary. Briggs et al. 2001 propose a different (Toomre and Toomre 1972) tidal tail interpretation of Tadpole where the blue dwarf galaxy VV29c enters from the Northwest, experiences a close encounter with VV29a, ejects (“slings”) the filamentary galaxy VV29b to the Southeast, and then departs away from the observer along the VV29a line of sight to a distance comparable to the length of VV29b about $4 \times 10^{21}$ m. The CDM-halo tidal bridge interpretation (Trentham et al. 2001) is not excluded by the (Briggs et al. 2001) title, “Did VV 29 collide with a dark Dark-Matter halo?” Both of these “tidal tail” interpretations are based on the Toomre & Toomre 1972 collisionless gravity tidal force models, and are inconsistent with HGT and with numerous previously unseen details revealed by HST/ACS images such as Figure 1.
Thin tidal tails in frictionless tidal models are the result of thin galaxy disks ejected so that by coincidence some portion is edgewise to the observer, resulting in tidal lion or beaver tails that are bushy or paddle-like at one or both ends (Mihos 2001) rather than the thin and pointed tadpole and mice tails observed in Tadpole, Mice and Antennae galaxy mergers which we interpret as star wakes of merging galaxy cores moving through each other’s baryonic-dark-matter halos. Random sprays of collisionless particles in N body computer simulations must be ignored in fitting tidal tail simulations to galaxy merger observations. No collisionless galaxy merger simulation that matches the Tadpole geometry is presented or referenced by Briggs et al. 2001. Furthermore, we see from the highest resolution HST/ACS images that the disk of VV29c is perpendicular to the VV29b tail rather than parallel as required, with VV29c embedded in VV29a, not far in the background as proposed (Briggs et al. 2001) assuming a frictionless galaxy interaction. The VV29c galaxy disk is intact and has not been flung forward edgewise to form VV29b as expected for a collisionless tidal tail model involving a merging galaxy with a thin disk.

From the HST/ACS images VV29c and its companions VV29def have been captured by frictional forces of VV29a, and the star-wake VV29b cannot be described by any version of the collisionless (Toomre and Toomre 1972) ejected tidal tail model. The oval features previously interpreted as spiral arms of VV29a confute this pattern in the HST/ACS images and appear instead as cylindrical luminous star-wakes. The outermost star-wake shows a spiral path that wraps once around VV29a and terminates with VV29cf at half its initial distance from the VV29a center. A smaller and shorter star-wake splits into two fragments VV29de about half way around before these objects plunge toward VV29a at two thirds the way around and half way to the center. One of the fragments VV29e apparently possesses an active nucleus that creates a spray of star formation extending $4 \times 10^{20}$ m to the Northeast, well away from the VV29a nucleus that lacks any such AGN signature. A similar spray of star formation from AGN radiation into a baryonic-dark-matter halo appears in a background galaxy $2 \times 10^{21}$ m on the plane due East of VV29a to illustrate this phenomenon that is natural to assume from HGT but would otherwise be mysterious.

The present frictional accretion merger and star wake interpretation of the HST/ACS Tadpole images is explained by viscous-turbulent-diffusional hydro-gravitational fluid mechanics that excludes CDM cosmologies and collisionless fluid mechanics assumptions that are the basis of the frictionless flung disk (Briggs et al. 2001) and CDM dark halo (Trentham et al. 2001) tidal tail interpretations. In the following, we briefly review the hydro-gravitational theory and the evidence in its support and then compare its predictions with the HST/ACS images. Finally, some conclusions are provided.
2. Hydro-Gravitational Theory Prediction of the Baryonic Dark Matter Form

Detailed evidence and analysis (Gibson & Schild 2003) supporting the hydro-gravitational theory (HGT) of self-gravitational structure formation (Gibson 1996), and its prediction that the interstellar medium and baryonic dark matter masses of galaxies should be dominated by primordial-gas-planets (PFPs), are beyond the scope of the present paper. This prediction of HGT was reached as a conclusion independently (Schild 1996) from observed twinkling frequencies of galaxy lensed quasar images, leading to the interpretation that the mass of the lensing galaxy was dominated by “rogue planets ... likely to be the missing mass”. Length scales and acronyms relevant to self-gravitational structure formation are given in Tables 1 and 2. The Jeans length $L_J$ is the scale for which pressure gradients in a self-gravitating ideal gas are smoothed by acoustic wave propagation. It is not a minimum scale for structure formation. The “pressure support” argument used to bolster the Jeans 1902 gravitational instability criterion fails because pressure forces depend on pressure gradients, and these vanish by acoustic propagation on scales smaller than $L_J$. Non-acoustic density perturbations on scales smaller than the Jeans length are absolutely unstable to gravitational structure formation unless resisted by viscous forces, turbulence forces or diffusion of the fluid particles. Sub-Jeans scale self-gravitational instabilities appear in numerical simulations in a stagnant gas (Truelove et al. 1997). However, these are dismissed as numerical artifacts (“artificial fragmentation”) based on the erroneous Jeans 1902 criterion, and a Jeans scale digital filter is invented. Jeans number digital filters (with Jeans number $J \equiv \Delta x / L_J \leq 0.25$, where $\Delta x$ is the cell size) are recommended versus numerical viscosity normally used to suppress $L \leq L_J$ instabilities in gravitohydrodynamic simulations. We believe that the calculations prove the HGT claim that a nearly stagnant gas is absolutely unstable to the formation of self-gravity driven condensations and voids on predictable sub-Jeans scales (Table 1).

As indicated in Table 1, magnetic and other forces were negligible in the viscous primordial plasma and buoyancy dominated gas (Gibson 2000). The first structures appeared at $L_{SV} \approx L_{ST}$ scales by gravitational fragmentation in the plasma epoch, soon after the energy density of the hot plasma matched the matter density ($\rho_E \approx \rho_M \approx 10^{-15}$ kg m$^{-3}$) at $t \approx 7.5\times10^{11}$ s (25,000 years) with small amplitude ($\delta \rho / \rho \leq 10^{-5}$) limited by the diffusive separation of the non-baryonic dark matter to fill the voids and cut off the gravitational forcing. The photon viscosity was so large ($4 \times 10^{26}$ m$^2$ s$^{-1}$) that the plasma turbulence was weak or non-existent. The first structures were at the horizon scale $L_H \equiv ct \approx L_{SV} \approx L_{ST} \approx 3 \times 10^{20}$ m, where $c$ is the speed of light. The baryonic density was $\approx 3 - 2 \times 10^{-17}$ kg m$^{-3}$ so the first objects to form were protosupercluster fragments. Further fragmentation continued to protogalaxy masses, just before the plasma to gas transition at 300,000 years. Turbulence was damped by buoyancy forces at the Ozmidov scale $L_R \equiv [\xi / N^3]^{1/2}$ of the self-gravitational structures, with stratification frequency $N$, starting at $t \approx 10^{12}$ s (30,000 years) and the
density and rate-of-strain at that time were preserved as fossils of the earlier hydrodynamic state (Gibson 1999), which determined the density of globular star clusters ($\approx 10^{-17}$ kg m$^{-3}$), $L_{SV}$, and the PFP masses. CDM condensations were impossible because $L_{SD_{CDM}} \gg L_H$.

Because the transition viscosity $\nu$ decreased by a factor of $\approx 10^{12}$, the fragmentation length scale decreased by a factor of $\approx 10^6$ (Table 1), giving a primordial gas fragmentation mass of $10^{-6} M_\odot$ to produce primordial fog particles. The gaseous proto-galaxies also fragmented at the Jeans scale to form proto-globular-cluster PGCs, but not for the reasons suggested by Jeans 1902. $L_J$ was considerably smaller than the proto-galaxy scale at decoupling, so pressures could not equilibrate as gravitational structures formed. The initially isothermal gas developed $L_J$ scale temperature fluctuations smoothed by radiative heat transfer, giving $L_J$ scale non-acoustic fragmentation sites. Thus the proto-galaxies fragmented into Jeans-mass PGC clouds of primordial-fog-particle (PFP) fragments that comprise the baryonic-dark-matter and ISM mass of all galaxies. Most of the BDM ($\approx 97\%$) remains dark, in $10^6 M_\odot$ PGC clouds of frozen $10^{-6} M_\odot$ PFP micro-brown-dwarf “rogue planets”. The present high resolution wide angle HST/ACS observations of the Tadpole galaxy merger provide excellent evidence of star wakes and YGCs triggered by objects merging through galactic baryonic dark matter halos comprised of PGC clumps of dark PFPs, as predicted by HGT. The observations contradict previous interpretations of Tadpole based on cold-dark-matter halos, collisionless mergers, collisionless tidal tails, and CDMHCC.

3. Tadpole Observations

Besides the eponymous tail, the most striking features of the very high resolution wide angle HST/ACS images of Tadpole are the two well defined luminous ovals around VV29a which we interpret as star formation wakes in the dark halo above and below the disk of VV29a (Figure 2) rather than ordinary spiral arms in the disk. The outermost star-wake is labeled VV29c at the bottom of Fig. 2 because it is a direct continuation of the VV29b star-wake and is readily extrapolated around VV29a to the embedded galaxy VV29c. The inner oval pattern extends the center of the West Plume (Briggs et al. 2001) of stars that apparently were triggered into formation by the merging galaxy components VV29def, and appears to terminate at VV29e and some sort of AGN plasma jet (labeled “Polar Stream” in the Briggs et al. 2001 inventory of structures Fig. 13).

The inferred galaxy component VV29d leaves a dark dust wake plunging toward the VV29a center in Figure 3. VV29e also leaves a dark dust wake, suggesting strong turbulence and short lived massive stars were triggered by its passage. Component VV29f entered the inner dark halo of VV29a closest to VV29c and left no stars small enough to remain
luminous for more than the $\approx 5 \times 10^8$ years since its passage. The dust trail of VV29f leaves a narrow shadow over the bright oval of VV29de and terminates with the bright clump of star clusters labeled VV29f in Fig. 2, maintaining a distance of about $1.5 \times 10^{20}$ from VV29c throughout their spiral descent toward VV29a. This interpretation is supported by the radio telescope observations (Briggs et al. 2001) showing large integral HI (neutral hydrogen) column densities with velocity opposite to that of the VV29a rotation and VV29c star wake. The VV29c and VV29f objects are in front of and obscure the VV29b star-wake in the HST/ACS images, contrary to the (Briggs et al. 2001) interpretation that these objects are $\approx 4 \times 10^{21}$ m in the background of VV29a using a frictionless tidal tail scenario.

The edge of the VV29a baryonic dark matter halo is clearly shown by the high resolution HST/ACS images, as in Figure 4 (dashed line at bottom right). Above the boundary we see numerous young globular clusters, especially along the star-wakes of VV29cdef but also all around them, but no stars and no YGCs below. A gas patch with $0.6 \times 10^{24}$ H atoms m$^{-2}$ and with the constant $+100$ km/s velocity measured for the gas of VV29b is shown in Fig. 1 of Briggs et al. 2001 at the beginning of the VV29cdef star-wakes shown in Fig. 4 for the present HGT interpretation. Another patch with double the column density is shown to the west of VV29a which can be identified with a patch of stars, presumably formed by halo-halo tides, in the high resolution HST/ACS images. Larger gas surface densities up to $3.6 \times 10^{24}$ H atoms m$^{-2}$ were reported near the cluster of YGCs shown near the top of Fig. 4, and even larger values at VV29a itself. Such high gas column densities in star wakes only about $10^{20}$ m wide suggest H-He mass densities $\approx 4 \times 10^{-23}$ kg m$^{-3}$ exist in the dark baryonic halo of VV29a. This gives a total baryonic-dark-matter inner halo mass of order $10^{43}$ kg, which is an order of magnitude larger than the mass of the central galaxy. A similar conclusion results if one takes a typical PGC separation in the inner halo (within $4 \times 10^{21}$ m) to be about $3 \times 10^{19}$ m based on the separation of bright objects taken to be YGCs shown in the star-wake region of Fig. 4.

Keck telescope spectroscopy confirms our assumption that the bright blue objects in the VV29b filamentary galaxy are YGCs. Figure 5 shows the slit location for the 42 YGC candidates identified (Tran et al. 2003). The brightest clump is described as a super-star-cluster (SSC), but with such a large half light diameter ($\approx 10^{19}$ m) that it must either be unbound or very “cold”. The YGCs are aligned precisely (within $\approx 1^o$) with the track of VV29c toward the beginning of its spiral star-wake produced during capture by VV29a. Our interpretation from hydro-gravitational-theory is that the large clump of massive bright blue stars (SSC) represents the first stars of to be triggered into formation from PFPs in a clump of dark PGCs by the near passage of the dense central core of VV29c. Such massive stars likely form in PGC cores at large turbulent Schwarz scales, reflecting maximal dissipation rates $\varepsilon$ in gas evaporated from PFPs by VV29c as it passed through a dense portion of the
baryonic dark galaxy-halo of VV29a, revealing a dark galaxy-halo dwarf-galaxy. Frictional forces of the observed gas explain why the apparent SSC is bound. Our star formation process from pre-existing pre-stellar and proto-cluster condensations (PGCs), formed much earlier in the universe and constituting the BDM, also explains why such bright clusters of large stars can form, without any evidence in the HST/ACS images of the giant \((10^6 M_\odot)\) molecular clouds (GMCs) ordinarily seen in Galactic regions of star formation with ages of several million years (see the excellent summary of embedded cluster formation in GMCs by Lada & Lada, 2003), with the 3 – 10 million year ages estimated by Tran et al. (2003). From HGT, the mysterious GMCs, identified as the site of most star formation in our Galaxy (Lada & Lada 2003), are PGCs captured by the Galaxy disk, with large stars of embedded clusters \((\approx 50 M_\odot)\) reflecting the large \(\varepsilon\) and \(L_{ST}\) values of star formation determined by strong resulting turbulence. New infrared observational capabilities such as SIRTF will test our suggestion that star formation processes in dark PGCs and GMCs are closely related.

For comparison with the large gas concentrations in VV29, Briggs et al. 2001 point out that no gas is detectable in the near companion elliptical galaxy MCG 09-26-54. From HGT it is easy to understand why gas appears in merging galaxy systems like Tadpole as frozen PFP planetoids evaporate, and not in quiescent galaxy cores like MCG 09-26-54 where ambient gas freezes out on the same objects. It is also easy to understand the appearance of stars triggered by the passage of galaxy components through BDM halos if stars are formed by increased accretion rates of PFPs caused by increased levels of gas friction. It is impossible to understand how collisionless, frictionless, tidal tail ejections of any kind produced the high concentrations of gas observed in Tadpole, the spiral star trails, the narrow filaments of YGCs without OGCs, or YGCs clustered in straight lines pointing to the spiral star trails.

### 4. Conclusions

The wealth of morphological details in the high resolution HST/ACS images makes any frictionless tidal tail interpretation of the Tadpole system untenable. A tidal bridge to an invisible CDM halo (Trentham et al. 2001) as the explanation of VV29b would require that the CDM halo rotate precisely with VV29a and that the VV29c star-wake near VV29a be ignored. Tidal forces in this CDM scenario should expel a symmetric trail of stars on the opposite side of VV29a that is not observed. Similarly, the suggestion (Briggs et al. 2001) that VV29c entered from the Northwest rather than the Southeast and is far in the background moving away seems quite implausible in view of the HST/ACS images that show VV29c and other companion components VV29def are firmly embedded in, and merging with, VV29a. No evidence of dust extinction caused by the spiral arms of VV29a is seen on
the face of VV29c in the HST/ACS images (eg Fig. 2) as one would expect if VV29c were far in the background. CDM halos smaller than 100 kpc are ruled out by hydro-gravitational-theory and cosmology, and are not supported by observations (Sand et al. 2002). Frictionless galaxy collisions and tidal tails are also ruled out by HGT, and are not supported by the great quantities of gas observed in Tadpole (Briggs et al. 2001). Spectroscopic observations using the Keck telescope (Tran et al. 2003) show dense concentrations of young globular clusters aligned closely in a star trail pointing toward the merging spiral star wake at the central galaxy. The 3-10 Myr ages of the YGCs found $2 \times 10^{21}$ m from VV29a proves they were formed in place and not 300 Myr later by unknown processes after ejection at reasonable speed. Their precise alignment with the vector toward the merging spiral star-wake of VV29c around VV29a proves they were formed as a wake and not ejected.

From the HST/ACS images the Tadpole galaxy can best be interpreted as a frictional galaxy merger producing baryonic-dark-matter star wakes, young-globular-star-clusters, and dSphs (dwarf galaxies) from PFPs and PGCs rather than any sort of collisionless galaxy merger flinging out tidal tails. Gas that provides the friction and triggers the star formation is produced by evaporating frozen primordial-fog-particles in proto-globular-clusters comprising the baryonic-dark-matter halos of the merging galaxies in Tadpole, as in the BDM halos similarly revealed for the Mice and Antennae merging galaxy systems. The location of the edge of the VV29a baryonic dark matter halo is clearly shown by the HST/ACS images giving a Tadpole BDM halo radius of $\approx 4 \times 10^{21}$ m (120 kpc). From the observed gas densities and velocities (Briggs et al. 2001) and the YGC separation distances it appears that the baryonic-dark-matter halo mass is at least an order of magnitude larger than the mass of the luminous stars of VV29a. Thus the HST/ACS images of Tadpole support the existence of massive baryonic-dark-matter galaxy halos composed of about a million dark proto-globular-clusters (PGCs) of dark primordial-fog-particles (PFPs), as predicted by the hydro-gravitational theory and cosmology of Gibson 1996-2000 and confirmed by the quasar microlensing interpretation of Schild 1996.

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Fig. 1.— Interpretation of HST/ACS Tadpole image (April 30, 2002 press release) using the Gibson 1996-2000 hydro-gravitational structure formation cosmology, where the merging galaxy structures VV29cdef enter the VV29a dark halo at lower right (dashed line) and merge along luminous trails of star formation triggered by radiation and tidal forces acting on the PGCs and PFPs of the dark halo of VV29a. The VV29b galaxy is interpreted as a star-wake of VV29cdef merging galaxy components in the VV29a dark baryonic halo, and not as any sort of collisionless tidal tail. Star formation regions (visible in higher resolution images) triggered in the baryonic-dark-matter by AGN jets of VV29e and a background galaxy are shown by arrows. A previously dark dwarf galaxy is revealed by a straight row of closely spaced YGCs (Tran et al. 2003) pointing toward the VV29c entry star-wake (see Fig. 5). North is to the left and East is to the bottom.
Fig. 2.— Close-up of HST/ACS Tadpole image (April 30, 2002 press release) showing that the VV29c blue dwarf galaxy and its companion VV29f are merging with and embedded in the larger spiral galaxy VV29a. Most of the bright objects are probably young globular clusters formed from dark PGCs by the merger event. North is to the left and East is to the bottom.
Fig. 3.— Close-up of HST/ACS Tadpole image (April 30, 2002 press release) showing star wakes of merging dwarf galaxies VV29def. VV29e apparently contains an active galactic nucleus to explain the plume of stars observed in the direction of the bottom arrow. Note the dark VV29def dust wakes expected from massive stars formed in highly turbulent regions. North is to the left and East is to the bottom.
Fig. 4.— Close-up of HST/ACS Tadpole image (April 30, 2002 press release) showing the edge of the baryonic dark matter halo of galaxy VV29a as indicated by the beginning of the star-wakes and young globular clusters (YGCs) triggered by the entry to the halo by galaxy components VV29cdef. If the dark halo is spherical with a homogeneous distribution of PGCs separated by $\approx 3 \times 10^{19}$ m corresponding to the YGC separation shown, the dark halo mass is about $10^{43}$ kg, with density $\rho \approx 4 \times 10^{-23}$ kg m$^{-3}$. The dynamical mass of VV29a from its rotation velocity within radius $7 \times 10^{20}$ m (Briggs et al. 2001) is $\approx 10^{12}$ kg. North is to the left and East is to the bottom.
Fig. 5.— Bright linear clump of YGCs in VV29b examined spectroscopically by Tran et al. 2003 using the Keck telescope. The 1 ” Echellette slit used is shown with a loose super-star-cluster SSC (arrow on left, see text). Ages of the 42 clusters identified range from 3-10 Myr. The aligned clusters point precisely along the arrow (right, labeled) to the beginning of the spiral star wake of VV29c in its capture, with companions, by VV29a. The large stellar mass density $\rho \approx 10^{-21}$ kg m$^{-3}$ and the straightness of the cluster row suggests it is a star trail triggered by VV29c passing through an $\approx 10^{39}$ kg dark dwarf galaxy in the VV29a BDM halo (see Fig. 1). North is to the left and East is to the bottom.
Table 1. Length scales of self-gravitational structure formation

| Length scale name       | Symbol | Definition          | Physical significance            |
|-------------------------|--------|---------------------|----------------------------------|
| Jeans Acoustic          | $L_J$  | $V_S/[\rho G]^{1/2}$| ideal gas pressure equilibration|
| Schwarz Diffusive       | $L_{SD}$ | $[D^2/\rho G]^{1/4}$ | $V_D$ balances $V_G$             |
| Schwarz Viscous         | $L_{SV}$ | $[\gamma \nu / \rho G]^{1/2}$ | viscous force balances gravitational force |
| Schwarz Turbulent       | $L_{ST}$ | $\varepsilon^{1/2}/[\rho G]^{3/4}$ | turbulence force balances gravitational force |
| Kolmogorov Viscous      | $L_K$  | $[\nu^3/\varepsilon]^{1/4}$ | turbulence force balances viscous force |
| Ozmidov Buoyancy        | $L_R$  | $[\varepsilon/N^3]^{1/2}$ | buoyancy force balances turbulence force |
| Particle Collision      | $L_C$  | $m\sigma^{-1}\rho^{-1}$ | distance between particle collisions |
| Hubble Horizon          | $L_H$  | $ct$                | maximum scale of causal connection |

$V_S$ is sound speed, $\rho$ is density, $G$ is Newton’s constant, $D$ is the diffusivity, $V_D \equiv D/L$ is the diffusive velocity at scale $L$, $V_G \equiv L[\rho G]^{1/2}$ is the gravitational velocity, $\gamma$ is the strain rate, $\nu$ is the kinematic viscosity, $\varepsilon$ is the viscous dissipation rate, $N \equiv [g\rho^{-1}\partial\rho/\partial z]^{1/2}$ is the stratification frequency, $g$ is self-gravitational acceleration, $z$ is in the opposite direction (up), $m$ is the particle mass, $\sigma$ is the collision cross section, $c$ is light speed, $t$ is the age of universe.

Magnetic and other forces (besides viscous and turbulence) are negligible for the epoch of primordial self-gravitational structure formation (Gibson 1996).
Table 2. Acronyms

| Acronym | Meaning | Physical significance |
|---------|---------|-----------------------|
| BDM     | Baryonic Dark Matter | PGC clumps of PFPs from HGT |
| CDM     | Cold Dark Matter | an erroneous concept |
| CDMHCC  | CDM HCC | nested erroneous concepts |
| HCC     | Hierarchical Clustering Cosmology | an erroneous concept |
| HCG     | Hickson Compact Galaxy Cluster | Stephan’s Quintet (SQ=HGC 92) |
| HGT     | Hydro-Gravitational Theory | corrects Jeans 1902 |
| ISM     | Inter-Stellar Medium | mostly PFPs and gas from PFPs |
| NBDM    | Non-Baryonic Dark Matter | possibly neutrinos |
| OGC     | Old Globular star Cluster | PGC forms stars at $t \approx 10^6$ yr |
| PFP     | Primordial Fog Particle | planet-mass protogalaxy fragment |
| PGC     | Proto-Globular star Cluster | Jeans-mass protogalaxy fragment |
| SSC     | Super-Star Cluster | a cluster of YGCs |
| YGC     | Young Globular star Cluster | PGC forms stars at $t \approx$ now |