Turbulence in The Big Bang

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Abstract

Observations show that the statistical distribution of galaxies and their clusters are chaotic and homogenous, suggesting that something about the big bang mechanism was capable of structure formation in patterns characteristic of high Reynolds number. Turbulence arises in a hot big-bang epoch at Planck scales and is characterized by the fundamental constants $c$, $h$, $G$, and $k$. Planck mass, length, time, temperature, energy, power, viscous dissipation rate, specific entropy, density, gravitational force, and inertial vortex force scales can be derived by dimensional analysis. Due to scales, the Reynolds number in the Planck epoch is $R_e \sim 10^6$, above the critical number for turbulent conditions. Big bang turbulence arises from physical mechanisms such as quantum tunneling, prograde accretion and energy release, small to large scale energy cascade, fluid instabilities, and finally inflation due to extremely high Reynolds’s stresses. Temperature fluctuations are preserved as the first fossil turbulence in the cosmic microwave background radiation pattern and analysis of the pattern fluctuations and observable extremely large scale structures in the Universe support the theory and indications of strong turbulence and departures from Gaussianity.
**Introduction**

*Classical View*

The Big Bang theory is the leading cosmological theory on the evolution of the universe in which it expanded from an extremely compact, dense, and hot state. Historically, cosmic fluids are generally taken to be inviscid and their flows ideal, linear, and acoustical. The model for cosmic fluids is historically based Jean’s instability theory (1902) derived from the Euler equations, and relate the expansion or collapse of space to the balance between gravity and local internal pressure. Only Jean’s insatiability theory on acoustic waves in ideal fluids is considered relevant by most cosmological reverences. Certainly, the Euler equations are inviscid, and most cosmology books do not have the terms “viscosity, diffusivity, and turbulence” in their index or contents [1]. However, a different view is that the self-gravitational condensation of structures in the universe is limited primarily by viscous and turbulence forces, and that quantum gravitational turbulence powered the big bang [2]

*Big Bang Turbulence (BBT)*

Observations show that the statistical distribution of galaxies and their clusters are chaotic and homogenous, suggesting that something about the big bang mechanism was capable of randomly producing and distributing the energy density seeds required to trigger nucleosynthesis and gravitational structure formation in patterns characteristic of high Reynolds number [3]. It is suggested that fluid mechanics must be considered along with other physical theories such as general relativity, M-superstring theory, and quantum mechanics to fully describe the mechanisms of the big bang and universe formation as seen in Figure 1. This literature review summarizes some of the theories of the primary researcher in big bang turbulence in that turbulence arises at Planck scales, produces the first irreversible entropy, and continues for a brief time in between the big bang and the strong force freeze out temperature before quarks and gluons could damp out the turbulence (like photons damp out turbulence in electron ion plasma) [1].
Governing Equations and Turbulence Definitions

Characteristics

Turbulence often escapes a universal, exact definition and is still a topic of intense research and discovery. Big bang turbulence relies on principles that many would agree with such as that turbulence is an irreversible process, and that turbulence is an eddy-like state of fluid motion where the inertial forces of the eddies are larger than any forces that dampen the eddies out. The momentum conservation equations are shown in Figure 2 below, and the narrow definition of big bang turbulence suggests the inertial vortex force per unit mass $\vec{v} \times \vec{w}$ is the universal nonlinear force that causes turbulence and turbulent cascade, forming when the gradient of the Bernoulli group is negligible as are the buoyancy, Coriolis forces etc. [4]. Why is turbulence relevant in the big bang? The inertial vortex force at Planck scales $(5.7 \times 10^{51} \text{ m/s}^2)$ matches the gravitational Planck force and therefore ranks as a new fundamental fifth force of nature along with the strong, weak, gravitational, and electromagnetic forces [1].

$$\frac{\partial \vec{v}}{\partial t} = -\nabla B + \vec{v} \times \vec{\omega} + \vec{F}_b + \vec{F}_c + \vec{F}_v + \cdots$$

Energy Cascade

BBT requires a turbulence cascade from small scales to large (many turbulence definitions assume the reverse). As described in subsequent sections, the mechanisms for big bang turbulence starts with rotation at the very small scales, such as the source shown in Figure 3. A series of shear layers form concentric to the rotating cylinder that are unstable and break up to form larger and larger eddies [1]. Planck inertial vortex forces balance gravitational forces as the Planck turbulence cascades...
to larger scales and the universe expands and cools. Turbulent mixing of temperature fluctuations and viscous dissipation of turbulent kinetic energy provide irreversibility necessary to sustain the process, and meeting the definition of turbulence for the BBT theory [3].

Figure 3. Turbulence Cascade, Small to Large

Conditions of The Quantum Gravitation Dynamic Epoch

Planck Particles

When the universe is small and hot enough that relativity and quantum mechanics break down, only Planck particles and monopoles can exist so viscosity is low [5]. A Planck particle is a hypothetical particle defined as a tiny black hole with Planck mass and Schwarzschild radius Planck length. Also present are Plank-Kerr particles which are Plank particles with spin. Small, weakly collisional particles like gluons, neutrinos, and photons that inhibit turbulence by viscous stresses cannot exist during the quantum gravitational dynamic (QGD) epoch temperatures, and cannot appear until the cooler temperatures of the strong force freeze out [3].

Scales, Properties

Turbulence arises in a hot big-bang QGD scenario at Planck scales. The Planck era is characterized by the fundamental constants $c$, $h$, $G$, and $k$ (speed of light, Planck constant, Newton’s constant, and Boltzmann’s constant). The Planck mass, length, time and temperature scales were found by dimensional analysis from these constants. Planck energy, power, viscous dissipation rate, specific entropy, density, gravitational force, and inertial vortex force scales can be derived by combinations of the Planck mass, length, time, and temperature [4]. These scales, properties, and parameters are summarized in Figure 4 below. Due to scales, the Reynolds number in the QGD epoch is $Re \sim 10^6$, above the critical number for turbulent conditions.
Big Bang Turbulence

Production Mechanism Steps

Big Bang Turbulence arises in the period of hot time before the strong force freeze-out period in which quarks could form and damp turbulence. Turbulence irreversibility is proposed as the likely mechanism by which the highly reversible quantum vacuum oscillations of the quantum gravitational dynamics (QCD) epoch produced the first entropy [4] and created space-time. Turbulence arises from these reversible vacuum oscillations at Planck length scales which allow for a small possibility for Planck particles and Planck anti-particles to appear spontaneously by quantum tunneling. Once they increase the possibility of the production of more Planck particles pairs due to their enormous Planck
temperatures. A second critical stop of the big bang process occurs if a Planck particle-antiparticle pair become misaligned as they collapse and form an extreme Planck-Kerr black hole with spin, producing the first stable quantum spinning state. A unique aspect of Kerr black holes is the large amount of energy released as they absorb matter, especially if the matter approaches the spinning black hole in a prograde orbit [1]. Prograde accretions of Planck particles on these objects trigger a turbulent Planck gas with vorticity matching the spin of the pinwheel like source, as shown in Figure 5.

![Figure 5. Plank Pair Production by Prograde Accretion](image)

Energy release from these particles falling in is 42% of the rest mass energy or more, and this release increases entropy and the probability for more Planck particles to form. This energy release and results in a highly exothermic production of turbulent Planck gas [5] with chaotic, eddy-like motions which cascade from the Planck scale of $10^{-35}$m to the larger, cooler quark-gluon scales which damp the turbulence. A Planck-Kerr instability gives rise to high Reynolds number ($R_e \sim 10^6$) turbulent combustion, formation of space-time-energy entropy, and turbulent mixing [4]. These physical processes are depicted in Figure 6 below. Planck turbulence generates Reynolds stress at $1.31 \times 10^{121}$ Pa per unit mass. From general relativity space-time is created/expands by sufficiently large negative pressure such as the BBT Reynolds stress and these large negative turbulent Reynolds stresses rapidly stretch space until the turbulent fireball cools to the strong force freeze-out temperature where quarks and gluons form. Then their viscosity damps out the turbulence, increase negative stresses and combined with the false vacuum energy lead to the great inflation period of the universe [5], [6]. The big-bang cascade terminates when the temperatures decrease to the strong force freeze-out or Grand unification temperature (GUT) of $T \sim 10^{28}$ K at $t=10^{-35}$ seconds [4].
BBT Evidence in Fossil Turbulence

Fossil Turbulence

Turbulence irreversibility is reflected in the persistence of turbulence fossils. Fossil turbulence is any fluctuation in a hydro-physical field produced by turbulence that is no longer turbulent at the scale of the fluctuation, such as airplane contrails, skywriting, or milk patches in weakly stirred coffee (Figure 7), where buoyancy forces damp the large scale turbulence [1].
Batchelor-Obukhov-Corison temperature fluctuations are preserved as the first fossil turbulence, since inflation stretches the patterns beyond the horizon $ct$ of casual connection. During the inflation period all lengths were stretched by the inflation factor $10^{25}$ [6]. Since during the time of this turbulence only Planck particles can exist, momentum and heat transport are the same mechanism. The Prandtl number is 1 and fluid fluctuations are equivalent to temperature fluctuations [1]. The smallest scale fluctuation of temperature at Planck length would be stretched, thus the temperature fluctuations up the inflated freeze-out (GUT) scale of $10^{-2}m$ represent the first fossil turbulence because all these fluctuations were caused by turbulence but actual turbulent interactions are no longer possible because they are outside the horizon scale of causal connection [1]. This forms the cosmic microwave background (CMB) pattern of the sky, first observed from space by the Cosmic Background Explorer (COBE) satellite, depicted in Figure 8 below [7].
CMB Analysis

Analysis of the cosmic microwave background (CMB) pattern fluctuations support the BBT theory and indications of strong turbulence and departures from Gaussianity. Fingerprints of high Reynolds number turbulence have been observed in the CMB temperature anisotropies using extended self-similarity coefficients (ESS) [3], [8]. Extended self-similarity coefficients plot structure function as a function of separation distance $S_n(R)$ in certain way, such that you can plot get a much longer range of representation by the power law. The trend of the temperature fluctuations in the CMB match the ESS of known high Reynolds turbulence but not known non-turbulent flows such Benard convection and the magnetohydrodynamic solar wind [3]. The coefficients of the temperature structure functions are shown in Figure 9 (CMB shown in circles, high Reynolds number turbulence as x’s, solar wind as triangles, and Benard convection as squares).

\[ \langle |\delta T(r)|^p \rangle \sim r^{-\xi_p} \]

Figure 9. Extended Self-Similarity Coefficients
In addition, the observed CMB temperature power spectra is consistent with several theories including BBT, Figure 10. CMB spectra support the interpretation that big-bang turbulence fossils triggered fragmentation of the viscous plasma, as discussed in the subsequent section.

![Figure 10. CMB Spectra Observations and Theories](image)

**Galaxy Structure Formation**

Observations from the Hubble Space Telescope show proto-galaxies in linear clusters as seen in Figure 11, reflecting their likely fragmentation on vortex lines of the big bang turbulence. The BBT stresses caused an inflation of space, which produced fossil density turbulence remnant that triggered gravitational instability at protosupercluster masses of $10^46$ kg, $\Delta \rho \to$ gravitational instability. The first gravitational structures occurred by fragmentation at density minima along the plasma vortex lines to form protogalaxy masses of $10^{42}$ kg, just before the transition from plasma to gas [5]. Big Bang turbulence mixing and inflation gave the random energy density seeds required to trigger nucleosynthesis, gravitational structure formation, and the chaotic lognormal distribution of galactic density observed at scales larger than causal horizon $ct$ [4].
Conclusion

A variety of indicators suggest that the big bang was not only turbulent but strongly turbulent before inflation, even though that time period was short and the length scales small. Other than turbulence and its effects, no other strong sources of irreversibility exist during the QGD epoch where the temperatures are extremely high and oscillations of the vacuum produce little or no entropy [3]. The mechanisms, conditions, and energy cascade direction at the Planck scales in the beginning of the universe satisfy the primary researcher’s definition of turbulence. Planck-Kerr instabilities produce small scale vorticity and subsequently space-time is driven to inflation by increasing Reynolds stresses and negative pressure viscous effects. Inflation fossilized the turbulent fluid and temperature fluctuations
by stretching the local and global length scales beyond the horizon at which they can ever again interact. These fluctuations have been detected by observations of large scale structures as well as the microscale analysis of cosmic microwave background radiation which match identically certain properties of high Reynolds number turbulence and mixing.
References


