

# GOODNESS IN THE AXIS OF EVIL

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## ABSTRACT

An unexpected alignment of 2-4-8-16 cosmic microwave background spherical harmonic directions with the direction of a surprisingly large WMAP temperature minimum, a large radio galaxy void, and an unexpected alignment and handedness of galaxy spins have been observed. The alignments point to  $RA = 202^\circ, \delta = 25^\circ$  and are termed the “Axis of Evil”. Already many authors have commented about how the AE impacts our understanding of how structure emerged in the Universe within the framework of  $\Lambda$ CDM, warm dark matter, string theory, and hydro-gravitational dynamics (HGD). The latter uniquely predicts the size scales of the voids and matter condensations, based upon estimates of fluid forces in the early phases of structure formation. Reported departures from simple Gaussian properties of the WMAP data favor two regimes of turbulent structure formation, and from these we make predictions of the nature of finer structure expected to be measured with the PLANCK spacecraft. From HGD, friction has limited the expansion of superclusters to 30 Mpc but supervoids have expanded with the universe to 300 Mpc.

*Subject headings:* Cosmology: theory – Galaxy: halo, dark matter, turbulence

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## 1. What is the Axis of Evil (AE)?

Since the first publication of the 1-year and 3-year WMAP measurements of the Cosmic Background Radiation, it has been recognized that the quadrupole and octupole moments of the brightness distribution have an unexpected property. If this map of remnant radiation intensity projected back onto the plane (sphere) of the sky is analyzed for its lowest order moments, a surprisingly large quadrupole and co-aligned octupole moment are found (Schwarz et al. 2004). Soon it was also found that the axis points toward an unexpectedly large low-temperature structure in the background radiation (Vielva et al. 2004), and then that this void is very significantly deficient in radio galaxies (McEwen et al. 2006, 2007; Rudnick et al. 2007). Finally, polarizations of quasars (Hutsemekers et al 2005) and analysis of the spins of spiral galaxies catalogued in the SDSS, showed that they display a statistically significant alignment, in the sense that observed spiral structure in galaxies prefers a significant sense (handedness) along this same axis (Longo 2007). Because these observations are so strongly at variance with the seemingly entrenched  $\Lambda$ CDMHC model, the observed exceptional direction has become known as the Axis of Evil (AE) (Land & Magueijo 2005).

We take the opposite point of view, The currently accepted cosmological theory has been strained by many diverse observations, leaving many to ask what observations might allow discrimination between alternative cosmological models. The purpose of the present manuscript is to ask which cosmological models might be FAVORED by the AE. So in the paragraphs to follow, we ask what the alternative cosmological theories predict about the existence of structure having the characteristic scales presently attributed to the AE. Thus in §2 we note that the  $\Lambda$ CDMHC model cannot accomodate voids on the scale of 300 Mpc diameter, and has never made a prediction that collimated galaxy spins should be aligned over 30 Mpc scales. String theory advocates §3 consider that the existence of structure on such large scales indicates the interference of our universe with its nearest neighbors (Holman & Mercini-Houghton, 2006 a,b) but that the aligned spins are a violation of the cosmological principle. And although warm dark matter §4 does not by itself predict AE structure, Hydro-Gravitational-Dynamics theory §5 does (Gibson & Schild 2007).

Throughout this manuscript we adopt the theory of inflation and standard values of the expansion rate (Hubble Constant) and all fundamental constants.

## 2. $\Lambda$ CDMHC and voids

The predictions of  $\Lambda$ CDMHC theory are well known, but so also are problems with the theory for structure on the scale of the largest voids. Thus Peebles (2001) has discussed the

measured void properties as a “crisis” for CDM theory. Rudnick et al. (2007), in describing the largest ( $\approx 300$  Mpc) void coinciding with its imprint on the WMAP measurements, shows that the AE is in strong conflict with  $\Lambda$ CDMHC Theory (Hoyle & Vogeley 2004), and Longo (2007) describes the alignment of galaxy spins on  $\approx 30$  Mpc supercluster scales as a violation of the cosmological principle. Hutsemekers et al (2005) found from quasar polarization the existence of cells with co-aligned polarizations on 1.5 Gpc scales. Confirmation of the existence of the AE would probably be conclusive proof of failure of  $\Lambda$ CDMHC theory.

### 3. String Theory

The string theory community has already commented upon the AE implications and predictions (Holman et al. 2006; Holman & Mersini-Houghton, 2006; see also New Scientist, 24 Nov. 2007, p.23). Voids on the scale of 200 Mpc would result from neighboring universes having bumped into and interacted with ours during the inflationary period. This would leave our shape-distorted universe entangled with neighboring universes for all time. The HGD theory to be discussed below differs by tracing the origin of the largest voids to the post-inflationary time of  $10^{12}$  seconds, which precedes the recombination event at  $10^{13}$  sec. Thus, accepting the observations of the scale of the voids and CMB temperature anomalous structures called the AE precludes the simplest form of  $\Lambda$ CDMHC and opens a door to string theory and HGD.

Moreover, in string theory the northern void should also be paired with a comparable southern void, and the void defects should be stronger in matter density than in temperature (Hannestad & Mersini-Houghton, 2005), whereas HGD predicts the same fluctuations in matter and temperature. Moreover, in String Theory the temperature anomalies would be systematically located in a quadrupole or multipole sense (Inoue & Silk 2006), whereas in HGD voids would be randomly distributed. These may be viewed as reasonably firm predictions of string theory amenable to observational test with data that will soon be available.

### 4. Warm Dark Matter

A frequently discussed variant of the  $\Lambda$ CDMHC theory is a Warm Dark Matter theory, wherein a fitted interaction length scale is introduced to effect the early interaction processes related to galaxy and star formation (Gao et al. 2005, 2007). However, in common with the  $\Lambda$ CDMHC theory it is posited that structure formation begins as a power-law distribution

of primordial fluctuations. This theory is primarily structured to study early structure formation related to star formation from baryonic matter. Unsurprisingly the theory predicts similar structure formation on cosmological scales, including the familiar pattern of filaments, condensations, and voids seen in  $\Lambda$ CDMHC simulations and observations.

Because this theory treats voids in much the same way as the  $\Lambda$ CDMHC theory, and because the principal attribute of the AE is in the observed properties of voids, in the following we simply treat the Warm Dark Matter theory as a variant of the  $\Lambda$ CDMHC theory, sharing the problematic void properties.

## 5. Hydro Gravitational Dynamics (HGD)

An important new perspective on the standard structure formation scenario has come forward from the hydrodynamics community. Published primarily in the hydrodynamics literature (Gibson 1996; Gibson 2000; Gibson 2004; Gibson 2005; Gibson 2008), it traces structure formation to processes that occurred early, during the plasma epoch. And their existence is found in the WMAP texture (Rudnick et al. 2007).

To first order it is found that WMAP temperature anomalies have Gaussian properties (Creminelli et al, 2007). The amplitudes of the fluctuations follow a Gaussian distribution for any size scale and the observed distribution of size scales for cosmic structures also is Gaussian. However, Gaussian size scales and temperatures are not unique to the  $\Lambda$ CDMHC theory, where it is simply assumed and fitted to various observations and parameters. Gaussian velocities, temperatures and structure sizes are also observed for turbulence, turbulent mixing and post-turbulence (fossil turbulence) hydrophysical fields (Monin & Yaglom 1975), with an important caveat. For all turbulent and post-turbulence cases, higher moments of hydrophysical fields depart from the simple Gaussian case, and provide tests for a turbulent origin of the observed WMAP texture by statistical comparisons to Kolmogorovian universal similarity parameters of turbulence and turbulent mixing (Gibson 1991). From HGD, primordial plasma turbulence is driven by vorticity  $\vec{\omega}$  produced by baroclinic torques at rate  $\partial\vec{\omega}/\partial t = \nabla\rho \times \nabla p/\rho^2$  near gravitationally expanding superclustervoid boundaries.

A variety of higher moment WMAP texture parameters have been compared to those of laboratory and computer simulated (DNS) turbulence (Bershanskii and Sreenivasan 2002; Bershanskii and Sreenivasan 2003; Bershanskii 2006). The agreement is precise in all cases. In the hydrodynamics community, this property is called “intermittency” “The fingerprints of Kolmogorov are all over the sky” (Bershanskii, 2001 personal communication to CHG).

What is the origin of the CMB turbulence? Is it big bang turbulence or plasma epoch

turbulence? Kolmogorovian intermittency parameters are Reynolds number dependent, and a significant difference exists between  $Re_\lambda \approx 10^3$  expected for big bang turbulence (Gibson 2004; Gibson 2005) and  $Re_\lambda \gtrsim 40$  near the transition to turbulence expected for the plasma epoch (Gibson 2000). An indicator of Reynolds number is the intermittency exponent  $\alpha(Re_\lambda)$  in

$$\delta T_{rms} \sim r^{-\alpha}. \quad (1)$$

The root-mean-square  $\delta T$  represents any hydrophysical field affected by turbulence (such as temperature). The intermittency parameter  $\alpha$  expanded as a Taylor series in  $1/\ln Re_\lambda$  (Barenblatt & Goldfield 1995; Sreenivasan & Bershadskii 2006) gives

$$\alpha(Re_\lambda) = a(\infty) + a_1/\ln Re_\lambda + a_2/(\ln Re_\lambda)^2 + \dots \quad (2)$$

where  $a(\infty) \approx 0.1$  and only the linear term in  $1/\ln Re_\lambda$  contributes for wind tunnel and atmospheric values for  $200 \leq Re_\lambda \leq 20000$ . Extrapolations of these  $\alpha = 0.3 - 0.4$  measurements to CMB measurements of  $\alpha \approx 0.45$  from eq. 1 give  $(Re_\lambda)_{CMB} \approx 100$ . Such a small Reynolds number near transition is consistent with the weak-plasma-epoch-turbulence dominated by photon viscosity and buoyancy effects of gravitational structure formation predicted by HGD.

It is also predicted that evidence for post-turbulent structure will be found in 3-dimensional maps of cosmic structure to be developed in the future, and apparently already has been seen in maps showing co-aligned quasar polarization structures (Hutsemekers et al 2005)

### 5.1. Successful Predictions

Further analysis of the turbulent properties of the early universe have originated in the hydrodynamics community. These are now confirmed in the AE observations.

In the astrophysics community, fluid properties of the expanding universe or other fluid mechanical systems are treated in mega-giga-particle simulations. But when turbulence is encountered, the simulation stops “because our grid is too coarse and too many compute cycles would be required.” But the fluid and its motion do not end, and the fluid mechanics community has found methods to describe the further evolution of the fluid (gas). The successful approach entails adopting a Kolmogorov post-turbulent spectrum for the fluid, and carefully analyzing the forces acting within the fluid to identify the size scales at which the eddy-like post-turbulent fluid motions will survive or not against self-gravity.

This approach has been undertaken by Gibson (1996) who follows standard fluid-mechanical-turbulence methodology by defining nonlinear Schwarz viscous, turbulence and

diffusion scales as criteria for self-gravitational structure formation in astrophysical fluids of the expanding universe, instead of solely the linear criterion of Jeans 1902 responsible for  $\Lambda$ CDMHC theory. Whereas Bershanskii (2006) attributes WMAP turbulence signatures to fluid forces at the time of recombination  $10^{13}$  sec after the big bang, Gibson (1996) attributes turbulent temperature signatures to earlier fluid forces and vorticity production during the plasma epoch from fragmentation and void formation (§6) giving the following predictions:

1. Structure on the largest scales originated by fragmentation at  $t \approx 10^{12}$  seconds with density  $\rho_0 \approx 10^{-17}$  kg m<sup>-3</sup> and strain-rate and spin  $\gamma_0 \approx \omega_0 \approx t^{-12}$  at the  $10^{-2}$  Mpc horizon scales of causal connection  $ct$  to form protosuperclustervoids. These have expanded to the 300 Mpc supervoids observed (Rudnick et al. 2007) at the present time, larger than the 30 Mpc supercluster scales estimated from AE and other observations. Since the largest scale condensations were turbulent vortexes isolated from other vortexes by the expanding voids, the primordial turbulence should be preserved as the aligned spins  $\omega$  and magnetic fields of condensations (galaxies) formed on these scales, as found by Longo (2007). Structure on scales from supercluster voids to galaxies further formed between  $10^{12}$  and  $10^{13}$  sec (recombination). HGD predicts non-gaussian statistical parameters such as  $\alpha$  for small scale CMB texture will reflect  $Re_\lambda \approx 1000$  (fig. 1) values corresponding to big bang turbulence. Remnants of this structure should be seen in the PLANCK spacecraft high-resolution maps.

2. The enormous  $\times 10^{-13}$  decrease of kinematic viscosity at recombination freed up the expanding primordial plasma to fragment at small gas scales, limited by viscosity to planetary mass  $\approx M_\oplus$ , so the entire baryonic mass of the universe fragmented into primordial fog clouds that cooled and condensed with a droplet (Primordial Fog Particle, PFP) mass  $10^{-6}M_\odot \approx M_\oplus$  (Gibson 1996). This is the origin of the "rogue planets" discovered in quasar microlensing by Schild (1996). Note that the universal collapse of the baryonic matter to become dark matter primordial planetoids was predicted before its observational discovery.

3. Simultaneous gas fragmentations were favored by acoustic and radiative heat transfer effects within the protogalaxy gas at Jeans mass scales of  $10^6 M_\odot$  with density  $\rho_0$  termed protoglobularstarcusters (PGCs), each containing a trillion PFPs. These are the condensations of PFPs that formed globular clusters seen today in all galaxies both as primordial and as young cluster objects. Stars form from clustering of the PFPs within the  $\rho_0$  PGCs, and the many young globular clusters found by the thousands in galaxy collisions seem to us to be fairly shouting that the baryonic dark matter is sequestered away in such dark clusterings (Gibson & Schild 2003).

## 6. The Axis of Evil scorecard.

We finally examine the success of our featured cosmological theories in the context of the available AE properties in Table 1.

By any scoring, the Hydro-Gravitational-Dynamics theory is winning. Particularly troubling to the  $\Lambda$ CDMHC theory is the observation of large scale regions devoid of galaxies, since these are the last structures formed by hierarchical clustering of growing CDM halos driven by decreasing density differences with increased gravitational free fall times. To form such large supervoids would require an average velocity 7.5% of light speed  $c$  over the full age of the universe and an average velocity  $c$  during the last Gyr of time while superclusters have existed from  $\Lambda$ CDMHC, which is highly improbable (Hoyle & Vogeley 2004).

From HGD theory, supervoids are the first structures to form, not the last, starting  $10^{12}$  s after the big bang and growing with sound speed  $c/3^{1/2}$ , as shown in Fig. 1 (Gibson & Schild 2007). Voids of this scale predicted by Gibson (1996) result from gravitational fragmentation and void expansion at plasma sonic velocities  $c/3^{1/2}$  with turbulence produced at void boundaries until the recombination event at  $10^{13}$  seconds. The predicted turbulent structures preserve their rotational vorticity up to supercluster scales, and impart it to all substructure forming within. Consistent with the postulated homogeneity of the universe at the largest scales, other voids must exist on 300 Mpc scales, probably already seen in 3-Dimensional quasar polarization maps (Hutsemekers et al 2005)

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Table 1. Axis of Evil Score Card

AE Structure	$\Lambda$ CDMHC	String Theory	HGD
Aligned CMB multipoles	XX	OK	OK
Galaxy void $\gtrsim 300$ MPc	XX	XX	OK
Turbulent signatures in WMAP data	XX	XX	OK
Galaxy spin alignments in local 30 MPc	XX	XX	OK

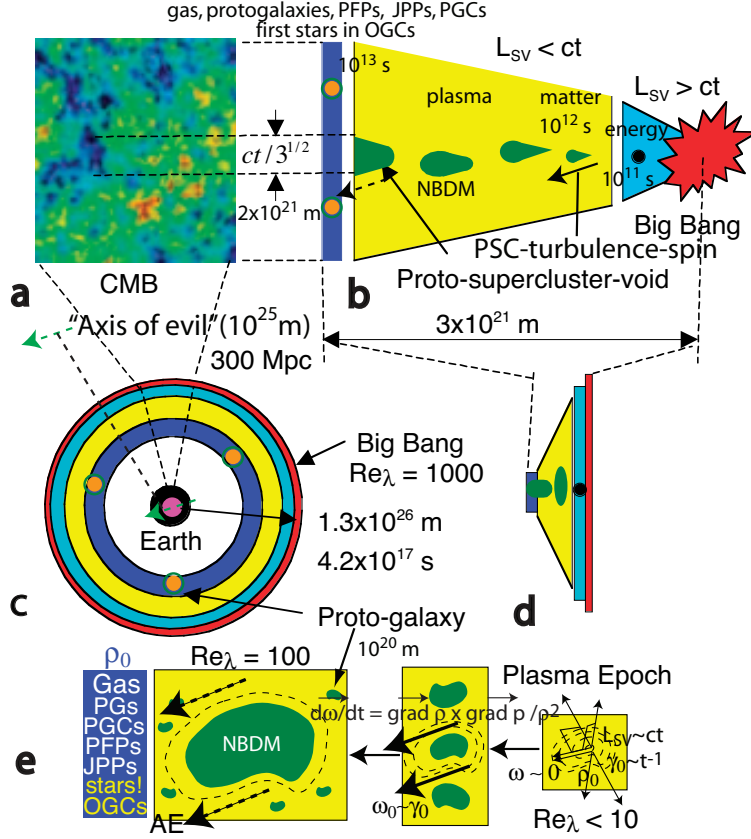


Fig. 1.— Hydro-Gravitational-Dynamics (HGD) description (Gibson & Schild 2007) of the formation of structure (Gibson 2005; Gibson 2004). The CMB (a) viewed from the Earth (b) is distant in both space and time and stretched into a thin spherical shell along with the energy-plasma epochs and the big bang (c and d). Fossils of big-bang turbulent-temperature nucleosynthesis-fossil-density-turbulence patterns are preserved in the H-He density (black dots). These trigger gravitational  $L_{SV} \approx L_{ST}$  scale structures in the plasma epoch as proto-supercluster (PSC)-voids. These remain filled with NBDM (green, probably neutrinos) by diffusion as the voids grow. Baroclinic torques on expanding plasma-void boundaries produce vorticity and weak turbulence as they smooth the void surface, so the PSCs fragment along vortex lines at straining maxima and density minima. (e) The PSC spin fossilizes and accounts for the CMB “axis of evil” (Land & Magueijo 2005) as well as spin-axis and galaxy-handedness on 30 Mpc supercluster scales (Longo 2007). The smallest structures emerging from the plasma epoch are linear chains of fragmented  $L_N$  scale proto-galaxies (Gibson 2008). These fragment into  $L_J$  scale density  $\rho_0$  PGC clumps of  $L_{SV}$  scale PFP Jovian planets that freeze to form the baryonic dark matter (Gibson 1996; Schild 1996).