P odd Universe, Dark Energy, Large Scale Magnetic Field and QCD

(based on works done with Federico Urban, 2010, see e.g. arXiv: 1011.2425)

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1. P -parity odd universe (observations)

- Cosmological observations on the largest scales exhibit a solid record of un- expected anomalies and alignments, apparently pointing towards a large scale violation of statistical isotropy, violation of P- and CP- symmetries.

- These include a variety of CMB measurements, large scale magnetic field as well as alignments of quasar polarization vectors (radio and optical measurements).

2. Sky alignments and anomalies from distant quasars and CMB (observations)

- Significant correlation in the linear polarization angles of photons in the optical spectrum over huge distances of order of Gpc. The rotation fits linearly to redshift at the rate of 0.5 radian/Gpc

- CMB: there is a statistically very unlikely planarity between quadrupole and octopole, which is seen in different releases of the data as well as in different statistical analyses.

- CMB: There is evidence for an hemispherical asymmetry in the power spectrum

- CMB spectrum exhibits an excess (respectively lack) of power for P-odd (even) multipoles $L < 22$

3.Large scale magnetization of the Universe (observations).

- Ever increasing correlation lengths:
1. Galaxies- $B \sim \mu G$ on (1-30) kpc scale
2. Cluster of galaxies- similar strengths have been observed over distances reaching Mpc scale.
3. Fields are not associated with individual galaxies.
4. Recent hints on magnetization (with similar intensity) of <u>gigantic superclusters</u> (~1 Mpc)
5. Evidence for the <u>magnetic field in IGM</u> (~10 Mpc)

- High redshifts: $B \sim \mu G$ field were present at much earlier epoch, z~5 when dynamo mechanism has not had enough time to operate.

- Conventional theoretical models (including inverse cascade) <u>fail to explain</u> such correlation lengths with similar strengths at all scales.

4. Dark Energy as the main source of large scale (E&M-related) anomalies.

- Several pieces of observations as reviewed above tend to indicate that our Universe is not invariant under P-parity.

- More than that: the observations require a mechanism operating on unbelievably large scales (Gpc), which generates coherence among disparate light signals from diverse sources.

- The main goal of this talk is to argue that all the essential ingredients which are required to explain these observational puzzles are in fact already present in our Dark Energy proposal which is <u>entirely rooted in the standard model (SM) of particle physics, without any new fields and/or new coupling constants.</u>

5. Dark Energy proposal.

- DE in this model arises as a <u>deviation from</u> Minkowski space-time geometry, in the form of a time-dependent vacuum energy shift, similar to the Casimir effect, therefore it is proportional to the rate of expansion, the Hubble constant $H \sim 10^{-33}$ eV

- The energy density in this framework must be proportional to H, estimated as $\rho_\Lambda \approx H \Lambda_{QCD}^3 \sim (10^{-3} \text{eV})^4$

- all local interactions and coupling constants are fixed in our framework--they are SM parameters, and they are the same in a curved background and in Minkowski space-time. New elements emerge when the system is promoted to a curved/time- dependent background, such that all new effects proportional to $H \sim 10^{-33}$ eV

- **WHY DOES THE DIFFERENCE IN ENERGY OCCUR IN FLRW UNIVERSE IN COMPARISON WITH FLAT SPACE-TIME? CONVENTIONAL QFT-SUBTRACTION CONSTANT-->FUNCTION**

- **FORMALLY : THE GUPTA-BLEULER-LIKE CONDITION (SIMILAR TO QED CONDITIONS IMPOSED ON UNPHYSICAL PHOTON'S POLARIZATIONS) CAN NOT BE MAINTAINED THROUGHOUT THE WHOLE SPACE IN FLRW UNIVERSE.**

- **FLRW UNIVERSE:** $(\phi_2 - \phi_1)^{(+)} |\mathcal{H}_{\mathrm{phys}}\rangle \sim H \neq 0$

- **MINKOWSKI SPACE-TIME:** $(\phi_2 - \phi_1)^{(+)} |\mathcal{H}_{\mathrm{phys}}\rangle = 0$

- **THE FIELDS ϕ_1 and ϕ_2 ARE THE VENEZIANO GHOST AND ITS PARTNER. WE KNOW ABOUT THEM FROM QCD. THIS IS THE PLACE WHERE SMALL PARAMETER $H/\Lambda_{QCD} \sim 10^{-41}$ ENTERS THE SYSTEM (WITHOUT ANY NEW FIELDS & INTERACTIONS).**

- Typical wavelengths contributing to the "ghost" fluctuations is $k \sim H^{-1} \sim 10^{10} yr$. This type of matter (large wavelengths) is drastically different from anything else in the Universe as it does not clump.

- The nature of small parameter $H/\Lambda_{QCD} \sim 10^{-41}$ is not a result of supersymmetry or any other extra symmetries imposed on the system (there are in fact, none), but it comes about from the auxiliary conditions on the physical Hilbert space which accommodate the gigantic span of scales.

- ϕ_1 and ϕ_2 fields are P-odd parity fields (originated from the topological density operator in QCD). They are not asymptotic states, do not violate unitarity, do not mix with photons. However, these fields do fluctuate: the "ghost condensate".

6. Fine tuning without ``fine tuning''.

- A number of fine tuning issues such as coincidence problem, drastic separation of scales, etc may find a simple and universal explanation within this framework, without new fields, new interactions, new symmetries...

- For example, vacuum energy is determined by the deviation from Minkowski flat space-time,

$$\Delta E = [E(L, H) - E(L = \infty, H = 0)] \sim H\Lambda_{QCD}^3 \sim (10^{-3}\text{eV})^4$$

- Why does it happen now?

$$3H^2 M_{PL}^2 \sim \Delta E \implies \tau \sim H^{-1} \sim \frac{M_{PL}^2}{\Lambda_{QCD}^3} \sim 10 \text{ Gyr}$$

7. Interaction of the DE with light

- Standard triangle anomaly unambiguously fixes the interaction between DE fields and Electromagnetic field in SM,

Irrelevant for cosmology field

$$\mathcal{L}_{(\phi_2-\phi_1)\gamma\gamma} = \frac{\alpha}{4\pi} N_c \sum Q_i^2 \left(\frac{\eta' + \phi_2 - \phi_1}{f_{\eta'}} \right) F_{\mu\nu} \tilde{F}^{\mu\nu} \ .$$

- In Minkowski space the relevant expectation value vanishes- no effects occur due to the constraint:

$$\langle \mathcal{H}_{\mathrm{phys}} | (\phi_2 - \phi_1) | \mathcal{H}_{\mathrm{phys}} \rangle = 0.$$

- However, this constraint can not be globally maintained in the entire space in a time-dependent background, resulting in the <u>interaction of DE and EM fields.</u> This coupling leads to generation of EM energy from the -DE fields. It also leads to many other effects such as rotation of polarization, etc.

- THIS COUPLING AT THE FUNDAMENTAL LEVEL DOES NOT VIOLATE P INVARIANCE. HOWEVER, P IS EFFECTIVELY BROKEN AS LONG AS WE ARE CONFINED TO A SINGLE OSCILLATION OF φ FIELD WITH $\lambda \sim H^{-1}$ ~ GPC SCALE.

- THE SAME DE-E&M INTERACTION CAN BE WRITTEN IN CHERN-SIMONS FORM

$$\mathcal{L}_{CS} = -\frac{1}{2} p_\mu A_\nu \tilde{F}^{\mu\nu}, \qquad p_\mu \equiv g \partial_\mu \varphi, \qquad \varphi \sim (\phi_1 - \phi_2)$$

- p_μ -VECTOR CAN BE TREATED AS (ALMOST) CONSTANT VECTOR ON THE SCALES $\lambda \sim H^{-1}$ ~GPC. THE P, CP AND LORENTZ SYMMETRIES ARE LOCALLY VIOLATED ON THIS SCALE WITH EFFECTIVE COUPLING $|p_\mu| \sim H \sim 10^{-33}$ EV.

- IT LEADS TO SOME <u>OBSERVABLE EFFECTS IF IT COHERENTLY BUILDS UP FOR A VERY LONG TIME</u> ~ H^{-1} ~ 10 GYR.

8. Magnetic field generation on Gpc scale

- Magnetic field which will be generated will have a typical Fourier mode $k^{EM} \simeq k \simeq H$, higher frequencies being exponentially suppressed.

- Magnetic fields will be generated at all times, even at higher redshifts, though their magnitudes will experience a standard $1/a^2(t)$ suppression due to the expansion of the universe. There is no need for seeds to feed a dynamo with, as the largest scales are generated last.

- The simplest way to see this generation of E&M field is to analyze the dispersion relation in the presence of Maxwell and Chern-Simons terms:

$$\omega^2 = \vec{k}^2 \pm \left(p_0 |\vec{k}| - \omega |\vec{p}| \cos\theta \right), \quad \text{unstable modes with } \omega^2 < 0 \text{ are: } |\vec{k}| \leq |p_0| \sim H$$

- This leads to the following estimate for the EM energy pumped from DE fields:
$$B^2 \simeq (\frac{\alpha}{2\pi})^2 H\Lambda_{QCD}^3 \sim (\frac{\alpha}{2\pi})^2 \rho_{DE}, \quad \text{where} \quad \rho_{DE} \sim (10^{-3}\text{eV})^4$$

- The result is a very reasonable numerical estimate without a single fitting parameter:
$$B \simeq \frac{\alpha}{2\pi}\sqrt{H\Lambda_{QCD}^3} \sim \text{nG}$$

- interaction does not violate P invariance on the fundamental level, similarly to $\pi^0 \to 2\gamma$ decay. However, such a violation occurs locally, on large correlation scales $\lambda_k \sim H^{-1}$.

- The estimated intensity should be treated as initially generated fields. They are the subject for further evolution/dumping with time (work in progress).

- Fields are predicted to be <u>helical</u>, correlated on huge Gpc-scales, <u>not isotropical</u>, <u>not homogeneous</u>.

9. DE-E&M COUPLING: OTHER APPLICATIONS

- Early universe large scale magnetic fields may have a profound impact on the mechanisms of structure formation. In fact, the observations suggest (see e.g. Kronberg, 1994) that galactic systems have evolved in environment where $B \gtrsim \mu G$.

- Impact to the travelling light signals from such distance sources as quasars. In fact, it has been claimed (see e.g. Hutsemekers, 1998, 2001, 2005) that the polarization vectors are aligned over huge regions ~ Gpc. Mean polarization angle β rotates with redshift at the rate of $30°$ per Gpc.

- This fact seems to not be related to the local environment we are immersed in. The symmetry of the $(\beta - z)$ relation is mirror like: β rotating clockwise in NGP, and counter-clockwise in SGP.
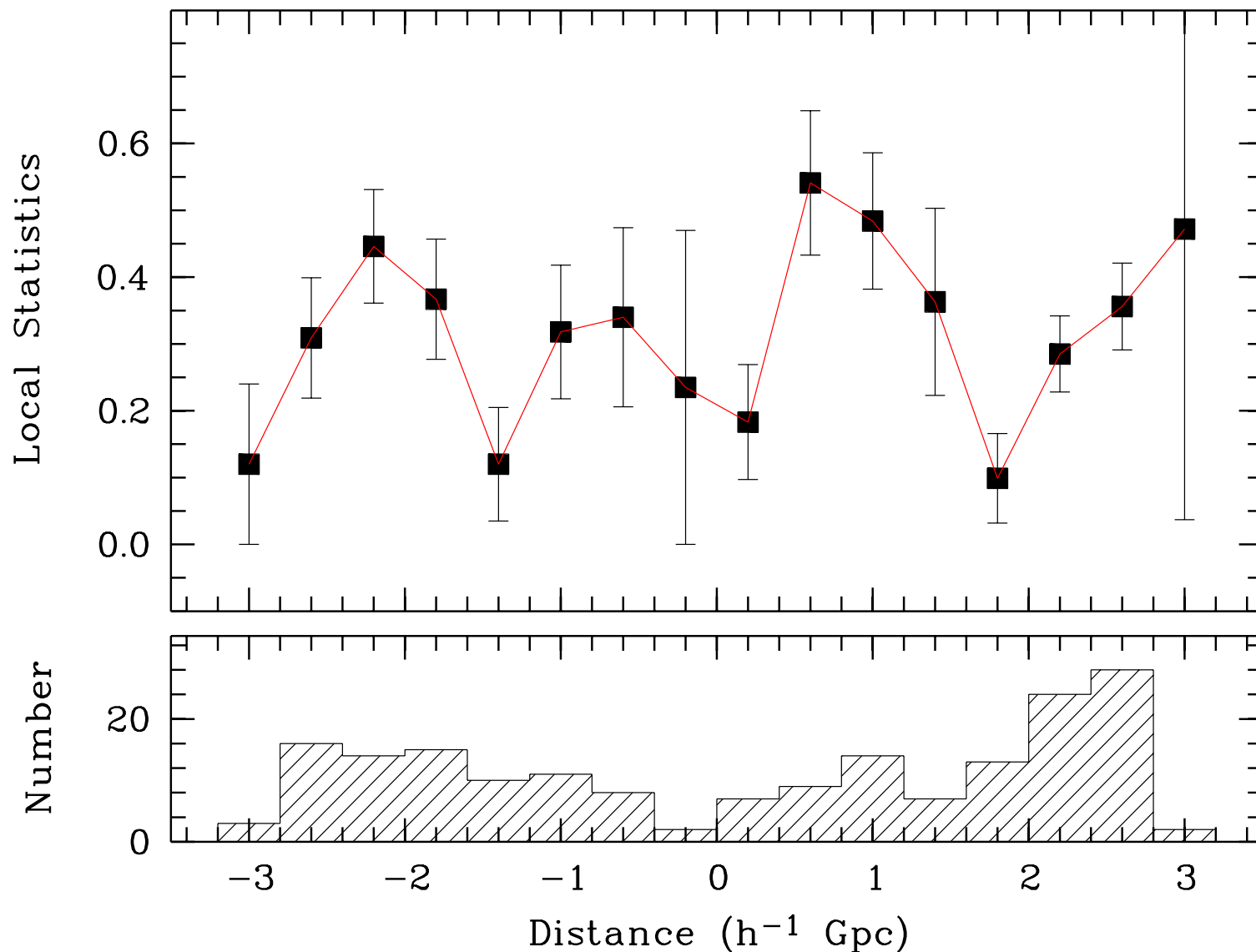
Plot from Hutsemekers, 2005.

Highest values of reading S_i indicate the strongest departure from uniform distributions of polarization angle. Redshifts are positive (+) for objects located in the North Galactic Pole (NGP) regions and minus (-) for SGP regions. Bin size is $\Delta r = 0.4 h^{-1} \mathrm{Gpc}$
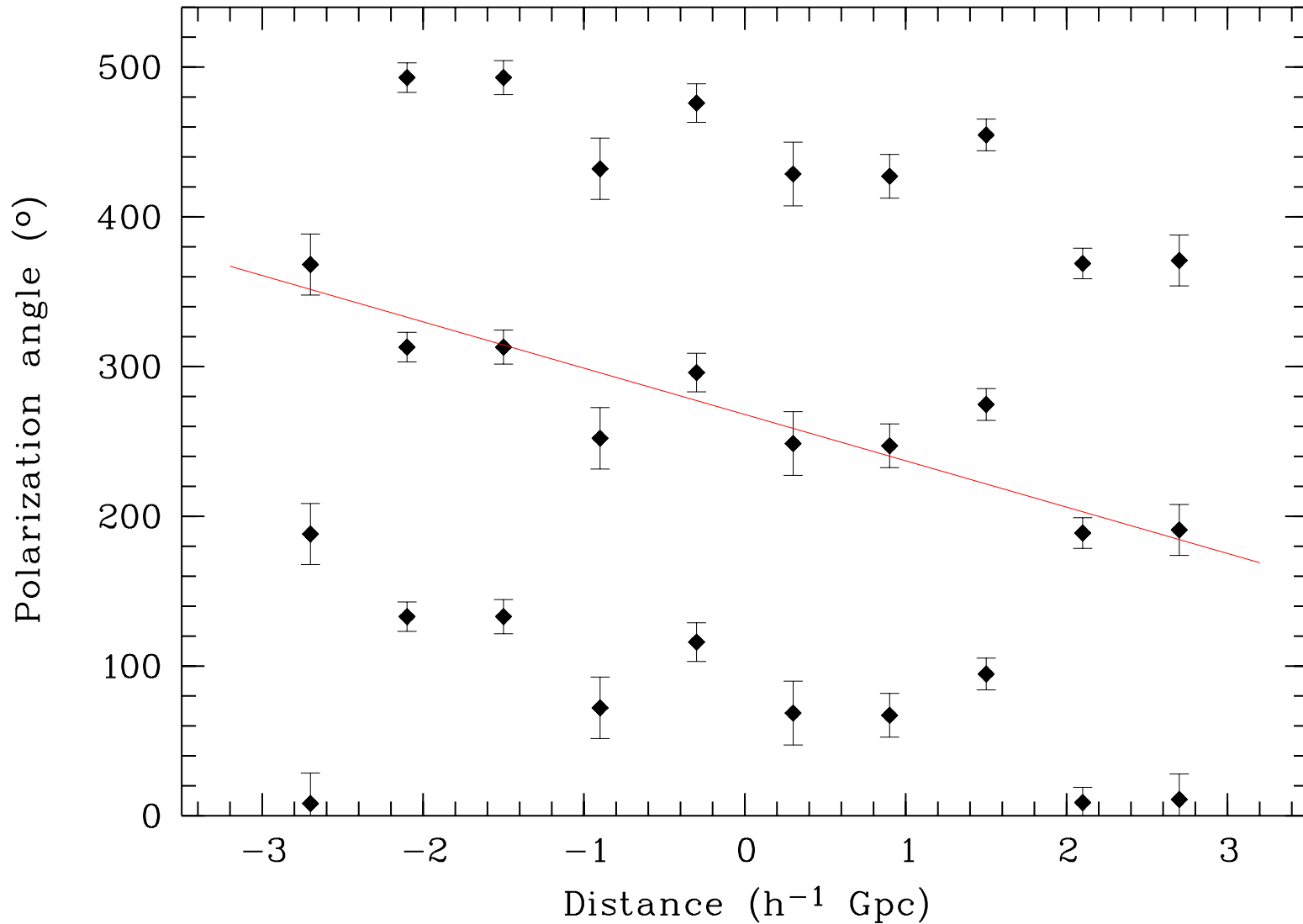
Plot from Hutsemekers, 2005.
Quasar polarization angles as a function of co-moving distance. Bin size is $\Delta r = 0.6 \ h^{-1} \ \mathrm{Gpc}$. Data points (z, β) are replicated $(z, \beta + 180°), (z, \beta + 360°)$ to facilitate detection of pattern.

In our framework the rotation of polarization is determined by the integral being taken along the path travelled by the photon

$$\beta = \frac{1}{2} \int p_\mu dx^\mu, \qquad p_\mu \equiv\; <g\partial_\mu\varphi>$$

Effect is order of one because of the coherent propagation of light. There are no any new small parameters involved as long as distance is ~1/H:

$$p_\mu \equiv \langle g\partial_\mu\varphi\rangle \sim H \sim 10^{-33}\text{eV}, \quad \text{but:} \int dx^\mu \sim H^{-1} \sim \text{Gpc}$$

The preferred direction is parametrized by the gradient $\vec{p} = -\vec{\nabla}\varphi$ of DE field in our framework and is identified in [Hutsemekers, 2005] as $(l \approx 267°,\; b \approx 69°)$.

The mirror like symmetry (rotating clockwise in NGP, and counter-clockwise in SGP) is due to the correlation $\vec{k} \cdot \vec{p} \equiv -\vec{k} \cdot \langle g\vec{\nabla}\varphi\rangle$ when photon $\vec{k}$ changes its direction while DE- field $\vec{p} \equiv -\langle g\vec{\nabla}\varphi\rangle$ stays constant

10. DE-E&M COUPLING: P- VIOLATION IN CMB

- ROTATION EFFECTS IN QUASARS SERVE AS OUR "NORMALIZATION" OF DE-E&M COUPLING $|\langle g\vec{\nabla}\varphi\rangle| \sim H$

- IT SHOULD BE CONSISTENTLY USED IN ALL OTHER ESTIMATES, E.G. IN CONTEXT OF CMB.

- P-ODD EFFECTS IN CMB WILL BE SUPPRESSED (IN COMPARISON WITH ROTATION EFFECTS IN QUASARS) BECAUSE CMB-PHOTONS TRAVELLED Z~1100 REDSHIFTS WITH DIFFERENT ORIENTATIONS OF P-ODD DOMAINS. THEREFORE, ESTIMATIONS FOR P-ODD SPECTRA (TB, EB)

$$\int dx^\mu \langle g\partial_\mu\varphi(z)\rangle \sim \frac{\beta(z \simeq 1)}{\sqrt{z_{1100}}} \sim \frac{\beta(z \simeq 1)}{33} \sim 1°,$$

- P-ODD EFFECTS ARE ORDER OF ONE AT Z~1100 (SIMILAR TO ROTATION OF POLARIZATION FROM QUASARS), NOT NOW.

ASYMMETRY OF WMAP \<TT\> POWER SPECTRUM:

DIFFERENT TYPES OF P ODD EFFECTS IN CMB STUDIED FROM \<TT\> SPECTRA (IN CONTRAST WITH \<TB\>, \<EB\>) IS NOT A SUBJECT OF SUPPRESSION (AS \<TT\> IS NOT SENSITIVE TO THE SIGN OF DE-E&M COUPLING).
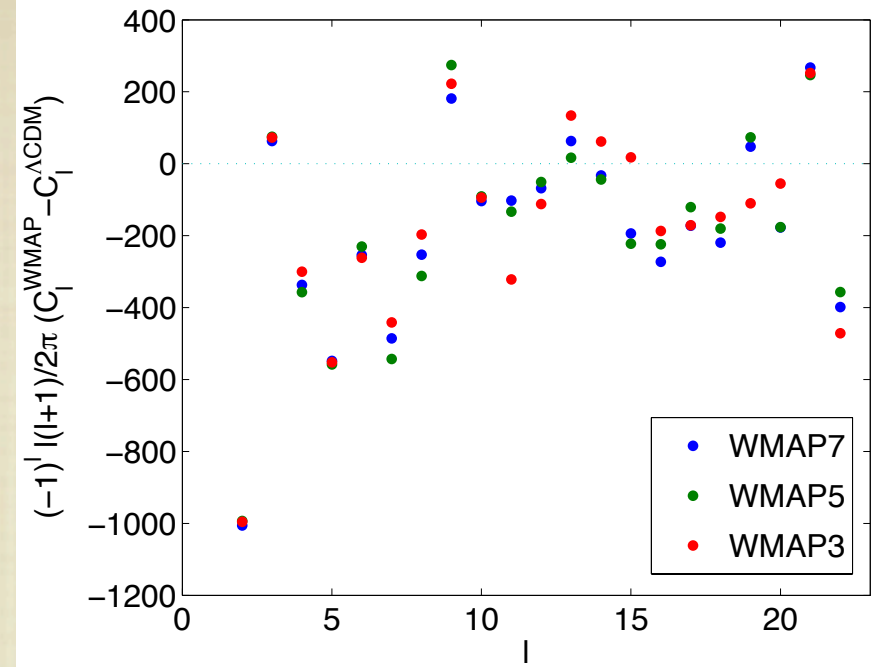

FIG. ABOVE INDICATES: THERE EXISTS POWER DEFICIT (EXCESS) AT MOST EVEN (ODD) MULTIPOLES AS IT IS WEIGHTED WITH $(-1)^l l(l+1)$.

100+ PAPERS ON ASYMMETRY WITH TYPICAL TITLES: " IS THE UNIVERSE ODD?", " ANOMALOUS PARITY ASYMMETRY..." ETC (THE PLOT IS FROM PAPER BY KIM AND NASELSKY, 2010)

Instead of Conclusion

- A new paradigm: the "renormalized cosmological constant" to be zero in Minkowski vacuum where the Einstein equations are consistently satisfied.

- It defines our "point of normalization" where subtraction is being made. The behaviour of the system is unambiguously predicted for any other geometry slightly deviated from Minkowski ~H.

- the DE observed in our universe might be a result of mismatch between the vacuum energy computed in slowly expanding universe and in flat Minkowski space

$$\Delta E_{vac} \sim H \Lambda_{QCD}^3 \sim (10^{-3} \mathrm{eV})^4$$

- A number of fine tuning problems is automatically resolved as a result of auxiliary conditions on the physical Hilbert space which accommodate the gigantic span of scales without a new symmetry.

- Direct consequences of the DE-E&M coupling:
  1. large correlation scales of helical magnetic field in the universe with the largest scales are generated last (consistent with observations of magnetic field in IGM, Neronov, Vovk, 2010).
  2. P-odd correlations in CMB as consequence of P-odd nature of the DE field. Current data are signalling on inconsistencies with the standard cosmological model (homogeneous & isotropic).
  3. Observations of rotations of the linear polarizations from quasars (z~2).

- Testing these ideas on the lattice (i.e. testing the subtraction constant in topological susceptibility) $\sim 1/L$ instead of $\sim \exp(-L)$. Preliminary result: the Casimir like effect is present for 4d QCD (AZ & M. Polikarpov, ITEP).

- Local violation of P- symmetry has been observed at RHIC (Brookhaven), where P odd domains can be experimentally produced/studied (AZ & Kharzeev, Brookhaven, Stony Brook).