

Cosmological implications of P and CP-odd phenomena in QCD

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P and CP odd effects in Hot and Dense matter

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1. SOME HISTORICAL REMARKS

■ THE $\theta \frac{\alpha_s}{8\pi} G_{\mu\nu}^a \tilde{G}^{\mu\nu a}$ TERM IS A KEY PLAYER IN STRONGLY INTERACTING QCD

■ $\theta \frac{\alpha_s}{8\pi} G_{\mu\nu}^a \tilde{G}^{\mu\nu a} = \theta \partial_\mu K^\mu$ IS TOTAL DERIVATIVE, DOES NOT CHANGE THE EQUATION OF MOTION. STILL, IT LEADS TO THE PHYSICALLY OBSERVABLE EFFECTS: DIPOLE MOMENT, $\eta' \rightarrow 2\pi$

■ $\theta < 10^{-9}$ MUST BE SMALL (NOW) AS IT VIOLATES P, CP INVARIANCE IN STRONG INTERACTIONS.

■ STILL, θ PARAMETER MAY PLAY A CRUCIAL ROLE DURING THE QCD PHASE TRANSITION IN EARLY UNIVERSE

2. QUANTUM ANOMALY, θ , AND *Charge Separation Effect (Little Bang).*

- FOR THE UNIFORM MAGNETIC FIELD THE ELECTRIC FIELD WILL BE INDUCED ALONG \mathbf{B} IN THE PRESENCE OF θ

$$L^2 E_z^{ind} = - \left(\frac{e \theta}{2\pi} \right) l, \quad \text{where} \quad l = \frac{e}{2\pi} \int d^2 x_{\perp} B_z^{ext}$$

- THE INDUCED ELECTRIC FIELD WILL LEAD TO THE INDUCED CURRENTS AND TO THE SEPARATION OF CHARGES ALONG \mathbf{B}

$$[Q(z = +L) - Q(z = -L)] \sim \left(\frac{e \theta}{2\pi} \right) l$$

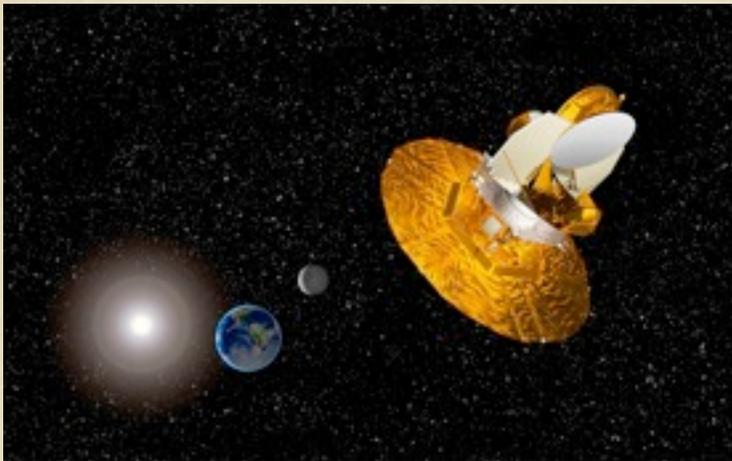
- A SIMILAR PHENOMENON HAPPENS WHEN THE SYSTEM IS ROTATING (IT EFFECTIVELY REPLACES THE MAGNETIC FIELD \mathbf{B}). THEREFORE: AN UPPER HEMISPHERE CAN THUS HAVE EITHER EXCESS OF QUARKS OVER ANTI-QUARKS OR VICE-VERSA.

3. OBSERVATIONAL COSMOLOGICAL PUZZLES AND *Charge Separation Effect (Big Bang)*

- SEVERAL INDEPENDENT OBSERVATIONS OF THE GALACTIC CORE SUGGEST UNEXPLAINED SOURCES OF ENERGY:
- THE MOST KNOWN CASE IS THE 511 KEV LINE (INTEGRAL) WHICH HAS PROVEN VERY DIFFICULT TO EXPLAIN WITH CONVENTIONAL ASTROPHYSICAL POSITRON SOURCES.
- A SIMILAR, BUT LESS KNOWN MYSTERY IS THE EXCESS OF GAMMA-RAY PHOTONS DETECTED BY COMPTEL ACROSS A BROAD ENERGY RANGE 1-20 MEV. SUCH PHOTONS HAVE BEEN FOUND TO BE VERY DIFFICULT TO PRODUCE VIA KNOWN ASTROPHYSICAL SOURCES



DETECTION BY THE CHANDRA SATELLITE OF DIFFUSE X-RAY EMISSION FROM ACROSS THE GALACTIC BULGE PROVIDES A PUZZLING PICTURE: AFTER SUBTRACTING KNOWN X-RAY SOURCES ONE FINDS A RESIDUAL DIFFUSE THERMAL X-RAY EMISSION CONSISTENT WITH VERY HOT PLASMA ($T = 10$ KEV). SOURCE OF ENERGY FUELING THIS PLASMA IS A MYSTERY.



THE WMAP EXPERIMENT HAS REVEALED AN EXCESS OF MICROWAVE EMISSION, $23 < W < 61$ GHz FROM THE CENTER OF OUR GALAXY. THIS EXCESS, WHICH IS UNCORRELATED TO THE KNOWN FOREGROUNDS, IS KNOWN AS THE "WMAP HAZE".

ORIGIN OF THIS EXCESS REMAINS A MYSTERY AS ALL CONVENTIONAL SOURCES FOR THIS DIFFUSE EMISSION HAVE BEEN RULED OUT.

- I ARGUED (BNL TALK, 2009 WORKSHOP, POSTED) THAT WE ARE WITNESSING THE RARE EVENTS OF ANNIHILATIONS RESULTED FROM CHARGE SEPARATION EFFECT WHICH TOOK PLACE 14 BILLION YEARS AGO.
- ALL RELATIVE INTENSITIES (MENTIONED ABOVE) OF EXCESSES IN GAMMA DIFFUSE EMISSIONS WITH FREQUENCIES RANGING OVER 13 ORDERS OF MAGNITUDE ARE FIXED BY KNOWN, WELL-ESTABLISHED PHYSICS.
- CHARGE SEPARATION EFFECT DOES IMPLY THE STRONG P AND CP VIOLATION. THESE CONDITIONS AT RHIC MAY MIMIC THE EARLY UNIVERSE DURING THE QCD PHASE TRANSITION AT NONZERO θ .

4. ANOTHER θ -RELATED CONNECTION...

- THE θ DEPENDENCE IN QCD DETERMINES THE η' MASS (WITTEN, VENEZIANO, 1979)

$$L = \frac{1}{2} \partial_\mu \eta' \partial^\mu \eta' - \frac{1}{\chi} Q^2 - \left(\theta - \frac{\eta'}{f_{\eta'}} \right) Q + N_f m_q | \langle \bar{q}q \rangle | \cos \left[\frac{\eta'}{f_{\eta'}} \right]$$

$$Q \equiv \frac{\alpha_s}{8\pi} G_{\mu\nu}^a \tilde{G}^{\mu\nu a}, \quad \chi = -\frac{\partial^2 \epsilon_{vac}(\theta)}{\partial \theta^2} = i \int d^4x \langle T\{Q(x), Q(0)\} \rangle$$

- THE TOPOLOGICAL SUSCEPTIBILITY $\chi \neq 0$ DOES NOT VANISH IN SPITE OF THE FACT THAT OPERATOR Q IS TOTAL DERIVATIVE
- SIGN OF $\chi < 0$ IS NEGATIVE (IT IS OPPOSITE TO WHAT ONE SHOULD EXPECT FROM A PHYSICAL DEGREE OF FREEDOM)-- SO THE TERM “THE VENEZIANO GHOST”
- INTEGRATING OUT Q FIELD PRODUCES η' MASS WITH NO ANY TRACES OF MASSLESS (UNPHYSICAL) GHOSTS.

- THIS IS THE OLD AND WELL-KNOWN STORY WHEN THE THEORY IS FORMULATED IN INFINITE MINKOWSKI SPACE.
- WHAT WOULD HAPPEN IF THE THEORY IS DEFINED ON A FINITE MANIFOLD SIZE $L \sim 1/H \sim 10^{10}$ YEARS, OR/AND IF THE UNIVERSE IS SLOWLY EXPANDING WITH RATE H (FRLW UNIVERSE)?
- FOR LITTLE BANG: $L \sim 10\text{fm}$, H (EXPANSION RATE) $\sim T$
- IS IT POSSIBLE TO STUDY THIS DELOCALIZED ENERGY (EVENTUALLY WE SHALL IDENTIFY THIS ENERGY IN THE UNIVERSE WITH **DARK ENERGY**) AT RHIC?
- IMPORTANT: THIS ENERGY IS ORIGINATED FROM THE (P-ODD) Q-FIELD SENSITIVE TO THE BOUNDARIES L AND EXPANSION RATE H

5. OBSERVATIONS: P- VIOLATION ON VERY LARGE SCALES IN THE UNIVERSE. CMB

P PARITY ASYMMETRY OF WMAP

$$\vec{x}' = -\vec{x},$$

$$\vec{x}' = \vec{x} - 2\vec{n}(\vec{x} \cdot \vec{n})$$

REFLECTION SYMMETRY

MIRROR SYMMETRY

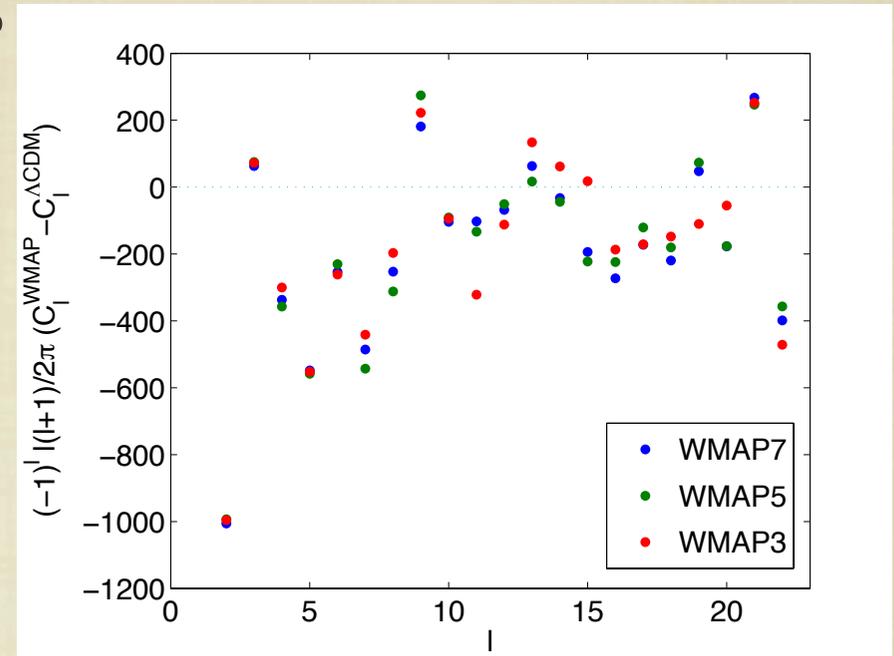


FIG. INDICATES: THERE EXISTS POWER DEFICIT (EXCESS) AT MOST EVEN (ODD) MULTIPOLES AS IT IS WEIGHTED WITH $(-1)^l l(l+1)$.

100+ PAPERS ON ASYMMETRY WITH TYPICAL TITLES: “ IS THE UNIVERSE ODD?”, “ ANOMALOUS PARITY ASYMMETRY...” ETC (THE PLOT IS FROM PAPER BY NASELSKY ET AL, 2010)

6. LARGE SCALE MAGNETIZATION OF UNIVERSE (P-ODD EFFECT). OBSERVATIONS.

■ EVER INCREASING CORRELATION LENGTHS:

■ 1. GALAXIES- $B \sim \mu\text{G}$ 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 GIGANTIC SUPERCLUSTERS (~ 100 MPC).

ALSO: ALIGNMENT OF QUASAR POLARIZATION (~ 1.5 GPC).

■ HIGH REDSHIFTS: $B \sim \mu\text{G}$ FIELD WERE PRESENT AT MUCH EARLIER EPOCH, $z \sim 5$ WHEN DYNAMO MECHANISM DID NOT HAVE ENOUGH TIME TO OPERATE

■ CONVENTIONAL THEORETICAL MODELS (INCLUDING INVERSE CASCADE) FAIL TO EXPLAIN SUCH CORRELATION LENGTHS WITH SIMILAR STRENGTHS AT ALL SCALES.

7. θ -RELATED VACUUM ENERGY

■ WHAT WOULD HAPPEN TO THE TOTAL (DELOCALIZED) ENERGY IF THE SYSTEM IS DEFINED ON A FINITE MANIFOLD SIZE $L \sim 1/H \sim 10$ G YEARS, OR/AND IF THE UNIVERSE IS SLOWLY EXPANDING WITH RATE H (FRLW UNIVERSE)?

■ ``NAIVE ANSWER``: THE CORRECTIONS DUE TO A FINITE SIZE OR EXPANSION ($\sim H$) SHOULD BE EXTREMELY SMALL AS ALL PHYSICAL DEGREES OF FREEDOM ARE MASSIVE

$$\exp(-L\Lambda_{QCD}) \sim \exp\left(-\frac{\Lambda_{QCD}}{H}\right) \sim \exp(-10^{41})$$

■ IN REALITY, THE PHYSICS COULD BE MUCH MORE INTERESTING/COMPLICATED DUE TO THE TOPOLOGICAL NATURE OF THE θ VACUA (SENSITIVITY TO BOUNDARIES)

8. EXAMPLE: 2D SCHWINGER MODEL

- THE θ DEPENDENCE, THE U(1) ANOMALY, THE ANOMALOUS WARD IDENTITIES, η' MASS PROBLEM... ARE FORMULATED/ SOLVED EXACTLY IN THE SAME WAY AS IN 4D QCD.
- THE KOGUT-SUSSKIND GHOST (KS, 1975) HAS PRECISELY CORRECT PROPERTIES (INCLUDING $\chi < 0$) TO SOLVE ALL THOSE PROBLEMS.
- KS-GHOST ϕ_1 , ITS PARTNER ϕ_2 , THE MASSIVE PHYSICAL η' THE θ DEPENDENCE... ARE DESCRIBED BY KS LAGRANGIAN:

$$\begin{aligned} \mathcal{L}_{KS} &= \frac{1}{2} \partial^\mu \eta' \partial_\mu \eta' + \frac{1}{2} \partial^\mu \phi_2 \partial_\mu \phi_2 - \frac{1}{2} \partial^\mu \phi_1 \partial_\mu \phi_1 - \frac{m_{\eta'}^2}{2} \eta'^2 \\ &- m_q \langle \bar{q} q \rangle \cos(\theta + 2\sqrt{\pi}(\eta' + \phi_2 - \phi_1)) \end{aligned}$$

■ **KS GHOST IS UNPHYSICAL (ϕ_1 IS CANCELLED BY ϕ_2). STILL, KS GHOST CONTRIBUTES TO THE VACUUM ENERGY, TOPOLOGICAL SUSCEPTIBILITY, SATURATES WI, SOLVES $U(1)_A$**

■ **ONE CAN EXACTLY COMPUTE THE θ DEPENDENT PORTION OF THE ENERGY WITH EXACT RESULT**

$$\Delta E \equiv E(L) - E_{Minkowski} = E \left(1 + O\left(\frac{1}{m_{\eta'} L}\right) \right)$$

■ **THE MODEL HAS A SINGLE PHYSICAL MASSIVE η' . STILL, ENERGY CORRECTION IS LINEAR IN L^{-1} , NOT $\exp(-L)$.**

■ **THE CASIMIR-LIKE EFFECT OCCURS IN THE MODEL WITH A SINGLE MASSIVE PHYSICAL DEGREE OF FREEDOM!**

9. THE VENEZIANO GHOST IN 4D. $T=0$. CONVENTIONAL PICTURE IN MINKOWSKI SPACE.

ONE CAN EXPLICITLY DEMONSTRATE THAT THE LOW ENERGY LAGRANGIAN FOR $U(1)_A$ DEGREES OF FREEDOM IN 4D QCD IS IDENTICAL TO THE 2D KOGUT-SUSSKIND LAGRANGIAN (INCLUDING θ TERM AND KS GHOST).

$$\mathcal{L} = \frac{1}{2} \partial_\mu \eta' \partial^\mu \eta' + \frac{1}{2} \overset{\text{Veneziano ghost's partner}}{\partial_\mu \phi_2 \partial^\mu \phi_2} - \frac{1}{2} \partial_\mu \phi_1 \overset{\text{Veneziano ghost}}{\partial^\mu \phi_1} - \frac{1}{2} m_{\eta'}^2 \eta'^2 + m_q | \langle \bar{q} q \rangle | \cos \left[\theta + \frac{\eta' + \phi_2 - \phi_1}{f_{\eta'}} \right]$$

THE VENEZIANO GHOST IS INTRODUCED TO ACCOUNT FOR THE “WRONG” SIGN IN χ . IT GIVES THE SAME PHYSICS AS THE WITTEN’S CONTACT TERM AND PROVIDES THE η' MASS.

THE NEGATIVE SIGN IN THE LAGRANGIAN DOES NOT LEAD TO ANY PROBLEMS (UNITARITY, CAUSALITY...) WHEN AUXILIARY (SIMILAR TO GUPTA-BLEULER IN QED) CONDITIONS ON THE PHYSICAL HILBERT SPACE ARE IMPOSED:

$$(\phi_2 - \phi_1)^{(+)} |\mathcal{H}_{\text{phys}}\rangle = 0. \quad \textit{positive frequency part enters this condition!}$$

THE HAMILTONIAN HAS SIGN MINUS FOR THE GHOST. HOWEVER, THE EXPECTATION VALUE FOR ANY PHYSICAL STATE VANISHES AS A RESULT OF GB CONDITION,

$$H = \sum_k \omega_k (b_k^\dagger b_k - a_k^\dagger a_k). \quad \langle \mathcal{H}_{\text{phys}} | H | \mathcal{H}_{\text{phys}} \rangle = 0.$$

IT IS SIMILAR TO WHAT HAPPENS IN QED WHEN TWO UNPHYSICAL PHOTON'S POLARIZATIONS CANCEL EACH OTHER AS A RESULT OF GUPTA-BLEULER CONDITIONS.

I USE THE VENEZIANO (RATHER THAN THE WITTEN'S) APPROACH AS IT CAN BE EASILY GENERALIZED FOR A TIME DEPENDENT, ACCELERATING BACKGROUND WHEN $T \neq 0$.

10. ACCELERATING SYSTEM.

UNRUH EFFECT. $T \neq 0$

- THE MINKOWSKI SEPARATION (OF POSITIVE FREQUENCY MODES FROM NEGATIVE ONES) IS MAINTAINED THROUGHOUT THE WHOLE SPACE AS A CONSEQUENCE OF POINCARÉ INVARIANCE.
- A TRANSITION FROM A COMPLETE ORTHONORMAL SET OF MODES TO DIFFERENT ONE (THE SO-CALLED BOGOLUBOV'S TRANSFORMATIONS) IN ACCELERATING SYSTEM WILL ALWAYS MIX POSITIVE FREQUENCY MODES WITH NEGATIVE FREQUENCY ONES.
- AS A RESULT OF THIS MIXTURE, THE VACUUM STATE DEFINED BY A PARTICULAR CHOICE OF THE ANNIHILATION OPERATORS WILL BE FILLED WITH PARTICLES IN A DIFFERENT SYSTEM (UNRUH EFFECT).

11. VENEZIANO GHOST IN RINDLER SPACE. UNRUH EFFECT. $T \neq 0$

- THE RINDLER METRIC DESCRIBES A CONSTANTLY ACCELERATING SYSTEM WHEN L(R)-OBSERVERS DO NOT EVER HAVE ACCESS TO THE ENTIRE SPACE-TIME

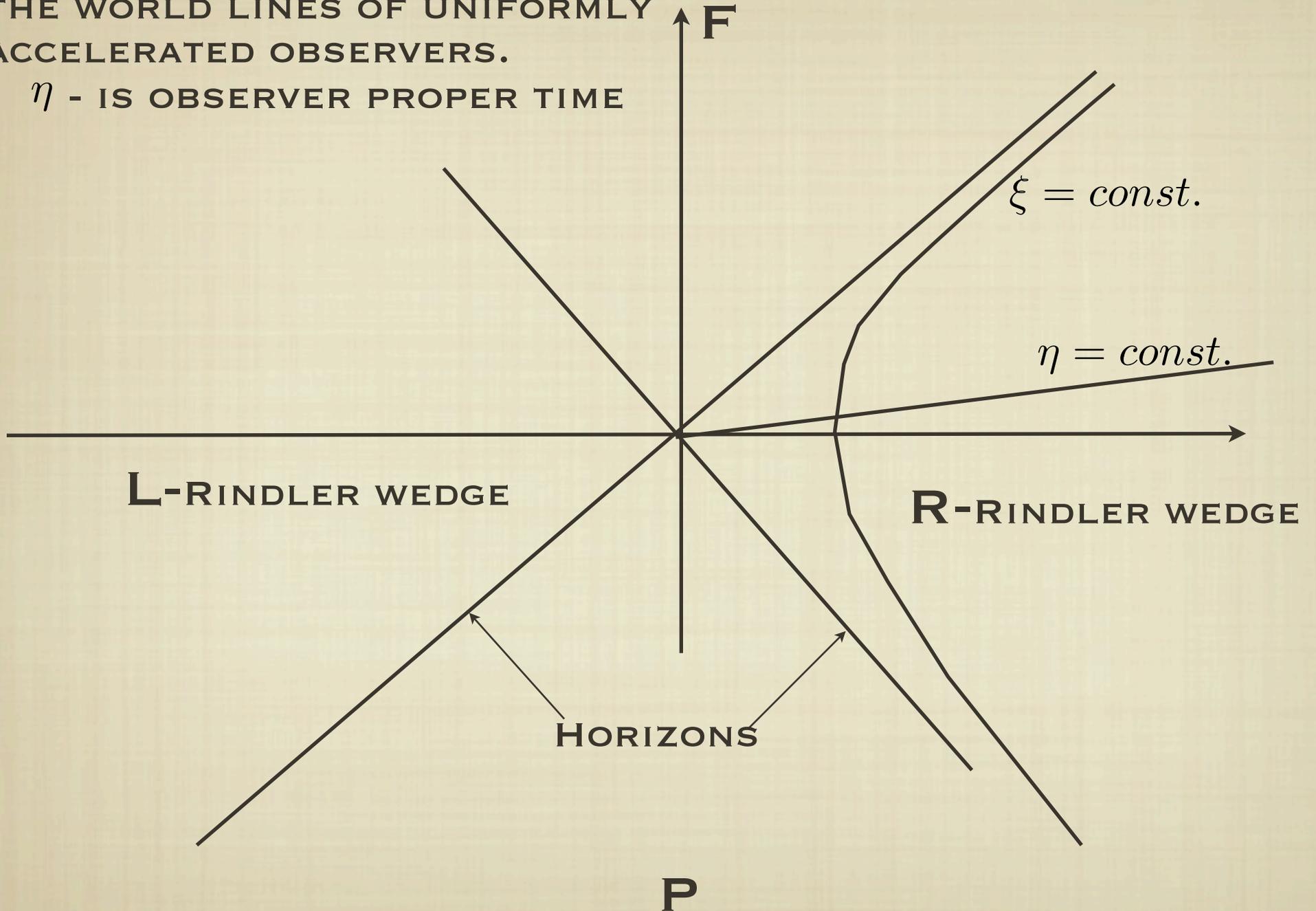
$$ds^2 = e^{2a\xi} (d\eta^2 - d\xi^2), \quad t = \frac{e^{a\xi^R}}{a} \sinh a\eta^R, \quad x = \frac{e^{a\xi^R}}{a} \cosh a\eta^R$$

- BOGOLUBOV'S COEFFICIENTS ARE KNOWN EXACTLY FOR THIS CASE (MIXING THE POSITIVE AND NEGATIVE MODES).
- THE CANCELLATION BETWEEN THE VENEZIANO GHOST AND ITS PARTNER DOES NOT HOLD FOR THE ACCELERATING RINDLER OBSERVER.

$$\langle 0 | \omega_k \left(b_k^{(R,L)\dagger} b_k^{(R,L)} - a_k^{(R,L)\dagger} a_k^{(R,L)} \right) | 0 \rangle = \frac{2\omega}{(e^{2\pi\omega/a} - 1)}.$$

$\xi = const.$ CORRESPONDS TO
THE WORLD LINES OF UNIFORMLY
ACCELERATED OBSERVERS.

η - IS OBSERVER PROPER TIME



Technical reason for non-cancellation:

■ THE GROUND STATE FOR MINKOWSKI OBSERVER IS DEFINED AS USUAL

$$a_k |0\rangle = 0, \quad b_k |0\rangle = 0, \quad \forall k.$$

■ THE VACUUM FOR R-RINDLER OBSERVER IS DEFINED AS

$$a_k^L |0_R\rangle = 0, \quad a_k^R |0_R\rangle = 0, \quad b_k^L |0_R\rangle = 0, \quad b_k^R |0_R\rangle = 0, \quad \forall k.$$

■ THE BOGOLUBOV'S COEFFICIENTS ARE KNOWN TO MIX POSITIVE AND NEGATIVE FREQUENCY MODES:

$$a_k^L = \frac{e^{-\pi\omega/2a} a_{-k}^{1\dagger} + e^{\pi\omega/2a} a_k^2}{\sqrt{e^{\pi\omega/a} - e^{-\pi\omega/a}}}$$

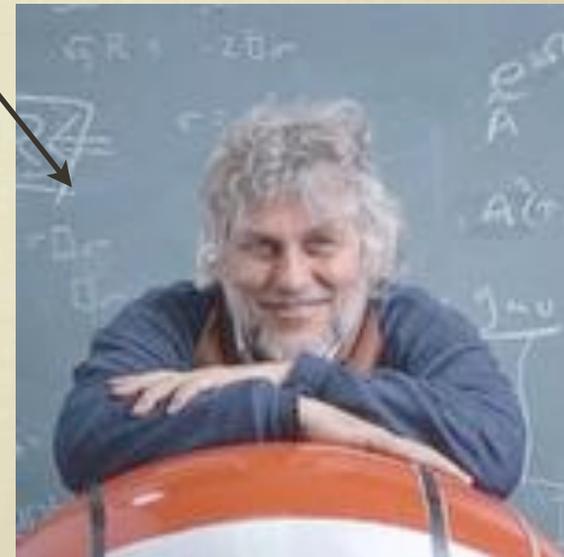
$$b_k^L = \frac{e^{-\pi\omega/2a} b_{-k}^{1\dagger} + e^{\pi\omega/2a} b_k^2}{\sqrt{e^{\pi\omega/a} - e^{-\pi\omega/a}}}$$

$$a_k^R = \frac{e^{-\pi\omega/2a} a_{-k}^{2\dagger} + e^{\pi\omega/2a} a_k^1}{\sqrt{e^{\pi\omega/a} - e^{-\pi\omega/a}}}$$

$$b_k^R = \frac{e^{-\pi\omega/2a} b_{-k}^{2\dagger} + e^{\pi\omega/2a} b_k^1}{\sqrt{e^{\pi\omega/a} - e^{-\pi\omega/a}}}.$$

- NO CANCELLATION BETWEEN THE VENEZIANO GHOST AND ITS PARTNER COULD OCCUR AS A RESULT OF OPPOSITE SIGN (-) IN COMMUTATION RELATIONS AND NEGATIVE SIGN (-) IN HAMILTONIAN.
- IF WE HAD STARTED WITH A CONVENTIONAL SCALAR FIELD WE WOULD DERIVE A WELL-KNOWN FORMULA FOR PLANK SPECTRUM FOR RADIATION AT $T = a/(2\pi)$ OBSERVED BY A RINDLER OBSERVER IN MINKOWSKI VACUUM WHICH IS CONVENTIONAL UNRUH EFFECT

THE CANCELLATION FAIL TO HOLD FOR THE ACCELERATING RINDLER OBSERVER BECAUSE THE PROPERTIES OF THE OPERATOR WHICH SELECTS THE POSITIVE FREQUENCY MODES WITH RESPECT TO MINKOWSKI TIME t AND OBSERVER'S PROPER TIME η ARE NOT EQUIVALENT.



12. VENEZIANO GHOST IN ACCELERATING SYSTEM. $T \neq 0$. INTERPRETATION.

■ ONE CAN STUDY THE SAME SYSTEM USING BRST QUANTIZATION FOR SELECTION OF THE PHYSICAL HILBERT SPACE (INSTEAD OF GUBTA- BLEULER FORMULATION). THE RESULT IS THE SAME: THE BRST OPERATOR AS CONSTRUCTED BY THE RINDLER OBSERVER DOES NOT ANNIHILATE THE MINKOWSKI VACUUM STATE.

■ THE NATURE OF THE EFFECT (EXTRA AMOUNT OF THE VACUUM ENERGY OBSERVED BY THE ACCELERATING OBSERVER IN COMPARISON WITH THE MINKOWSKI OBSERVER) IS THE SAME AS THE CONVENTIONAL UNRUH EFFECT WHEN THE MINKOWSKI VACUUM $|0\rangle$ IS RESTRICTED TO THE RINDLER WEDGE WITH NO ACCESS TO THE ENTIRE SPACE TIME.

■ WE INTERPRET THE EXTRA CONTRIBUTION TO THE ENERGY OBSERVED BY AN ACCELERATING OBSERVER AS A RESULT OF FORMATION OF THE SQUEEZED STATE WHICH CAN BE COINED AS THE “GHOST CONDENSATE” RATHER THAN A PRESENCE OF “FREE PARTICLES” AT $T = a/2\pi$ PREPARED IN A SPECIFIC MIXED STATE.

$$|0\rangle = \prod_k \frac{1}{\sqrt{(1 - e^{-2\pi\omega/a})}} \exp \left[e^{-\pi\omega/a} \left(b_k^{R\dagger} b_{-k}^{L\dagger} - a_{-k}^{R\dagger} a_k^{L\dagger} \right) \right] |0^R\rangle \otimes |0^L\rangle$$

■ WE INTERPRET THE GHOST CONTRIBUTION TO THE ENERGY AS A CONVENIENT WAY TO ACCOUNT FOR A NONTRIVIAL INFRARED PHYSICS AT THE HORIZON AND/OR THE BOUNDARY(THERE ARE NO ASYMPTOTIC GHOST STATES).

■ IT IS POSSIBLE THAT THE SAME PHYSICS, IN PRINCIPLE, CAN BE DESCRIBED WITHOUT THE GHOSTS (SUCH A DESCRIPTION HOWEVER WOULD BE MUCH MORE TECHNICALLY COMPLICATED).

13. IMPLICATIONS. DARK ENERGY FROM (P-ODD) VANEZIANO GHOST?

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,

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

TYPICAL WAVELENGTHS CONTRIBUTING TO THE “GHOST CONDENSATE” IS $k \sim H^{-1} \sim 10^{10} \text{yr}$. THIS TYPE OF MATTER (LARGE WAVELENGTH) IS DRASTICALLY DIFFERENT FROM ANYTHING ELSE IN THE UNIVERSE AS IT DOES NOT CLUMP.

14. LARGE SCALE MAGNETIC FIELD AND DE

STANDARD TRIANGLE ANOMALY UNAMBIGUOUSLY FIXES THE INTERACTION BETWEEN DE FIELDS AND ELECTROMAGNETIC FIELD,

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

ONE CAN ESTIMATE THE EM ENERGY AND MAGNETIC FIELD B INDUCED BY THIS INTERACTION:

$$\rho_{EM} \simeq \langle \vec{B}^2 \rangle \simeq \frac{\alpha}{2\pi} H \Lambda_{QCD}^3, \quad \text{where } \rho_{DE} \simeq H \Lambda_{QCD}^3$$

$$\langle B \rangle \sim \sqrt{\frac{\alpha}{2\pi} H \Lambda_{QCD}^3} \sim \mu\text{G}$$

OUR PICTURE SUGGESTS THAT INDEED $B \sim \mu\text{G}$ WILL BE CORRELATED ON ARBITRARY LARGE SCALES (CONSISTENT WITH OBSERVATIONS). NO ANY FITTING PARAMETERS ARE INVOLVED IN OUR ESTIMATE OF $B \sim \mu\text{G}$.

INSTEAD OF CONCLUSION

- CONJECTURE: P-ODD EFFECT (OBSERVED AT RHIC) COULD BE INTERPRETED AS A RESULT OF ACCELERATION a WITH TEMPERATURE $T = \frac{a}{2\pi}$
- ACCELERATION a HAS BEEN ESTIMATED BY DIMA: $a \sim Q_s$ WHERE Q_s IS SATURATION SCALE. HORIZON SCALE HAS ALSO BEEN ESTIMATED: IT IS A FM SCALE
- OTHER P-ODD OBSERVABLES TO SUPPORT (RULE OUT) THE PICTURE?