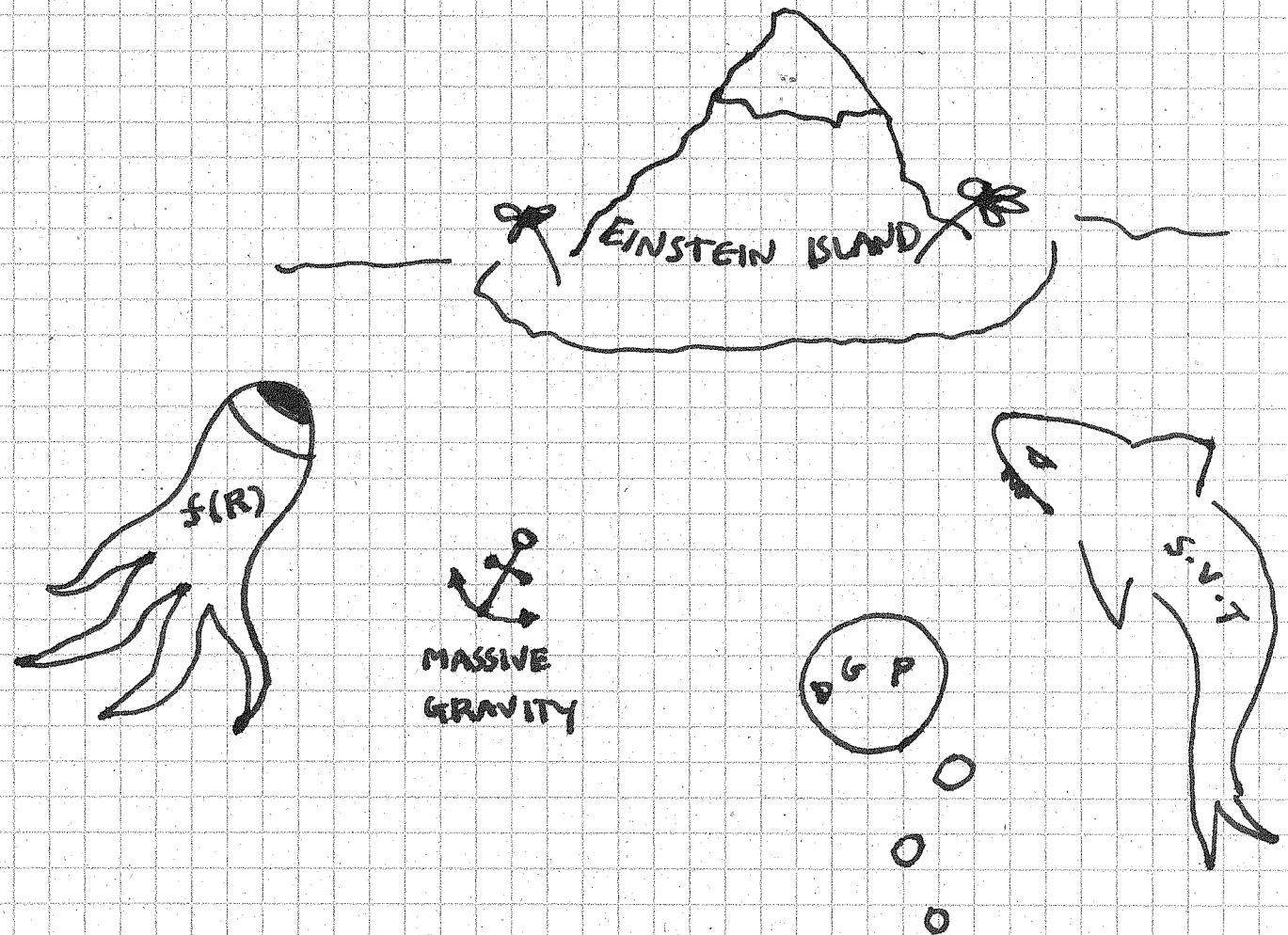


# DARK ENERGY :

## FRAMES & FORCES



R. CALDWELL

GGI · 2 MARCH 2009

IS DARK ENERGY AN "AETHER" ?

DOES IT INDICATE A SPECIAL REFERENCE FRAME ?

VIOLATE LORENTZ INVARIANCE ?

RESULT IN NEW FORCES ?

# FUNDAMENTAL LORENTZ INVARIANCE VIOLATION

HORAVA, 0901.3775

"QUANTUM GRAVITY AT A LIFSHITZ POINT"

VISSER, 0902.0590

"LORENTZ SYMMETRY BREAKING AS A LEFT REGULATOR"

A THY. W/ HIGHER SPATIAL DERIVATIVES IS L.I.V  
BUT CAN CURE UV DIVERGENCES

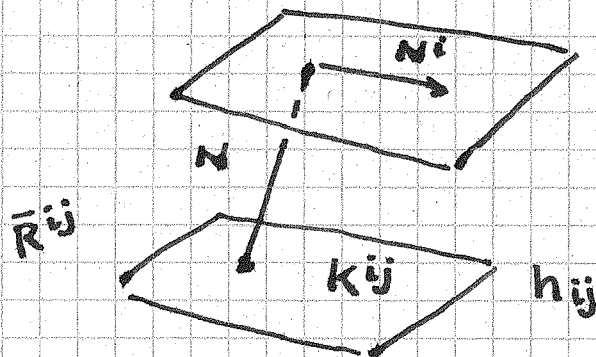
$$S = \int dt d^3x \left[ \dot{\phi}^2 - \phi (-\nabla^2)^z \phi + \sum_{n=1}^z g_n \phi^n \right]$$

$z = 3$ : UV FINITE, BUT TIME IS SPECIAL

APPLY TO GRAVITY?

PREFERRED FOLIATION

BREAK DIFFEOMORPHISM INVARIANCE



DESCRIBE GRAVITY IN  
ADM-LIKE LANGUAGE

KINETIC ENERGY

$$S_K = \frac{2}{\kappa^2} \int dt d^3x \sqrt{h} N \left[ K_{ij} K^{ij} - \lambda K^2 \right]$$

$$K_{ij} = \frac{1}{2N} \left( \partial_t h_{ij} - \bar{\nabla}_i N_j - \bar{\nabla}_j N_i \right)$$

$\lambda$ : DYNAMICAL COUPLING, SUSCEPTIBLE TO QM CORRECTIONS

POTENTIAL ENERGY

$$S_V = - \int dt d^3x \sqrt{h} N Q^{ij} G_{ijkl} Q^{kl}$$

$$Q^{ij} = (\text{3rd DERIVATIVE TERMS})$$

$$- \mu \left( \bar{R}^{ij} - \frac{1}{2} \bar{R} h^{ij} + \Lambda_B h^{ij} \right)$$

$$G_{ijkl} = \frac{1}{2} (h_{ik} h_{jl} + h_{il} h_{jk}) - \lambda h_{ij} h_{kl}$$

$$\text{AT LOW ENERGY, } S_K + S_V \approx S_{EH} = \int dt d^3x \sqrt{h} N \left[ K_{ij} K^{ij} - K^2 + R - 2\Lambda \right]$$

$$\text{GR: } \lambda = \mu = 1$$

COMMENT: • SPEED OF LIGHT IS "EMERGENT", •  $\Lambda_B$  IS CONSTRAINED,

• COSMOLOGY w/  $\lambda, \mu \neq 1$  RESEMBLES MODIFIED GRAVITY

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# SPONTANEOUS VIOLATION OF THE STRONG EQUIVALENCE PRINCIPLE

DARK ENERGY COUPLES TO GRAVITY

$$S = \int d^4x \sqrt{-g} \left( \frac{R}{16\pi G} - \left[ \frac{1}{2} \nabla_\mu \phi \nabla^\mu \phi + V(\phi) \right] + L_{\text{INT}} \right)$$

$$L_{\text{INT}} = \lambda^2 \nabla_\mu \phi \nabla_\nu \phi R^{\mu\nu}$$

SCOTT DANIEL, RC 0709.0009

FULLY COVARIANT, BUT COSMIC SCALAR IDENTIFIES A SPECIAL FRAME

$$\phi = \phi_0(t)$$

$$L = \frac{1}{16\pi G} R^{\mu\nu} (g_{\mu\nu} + 16\pi G \lambda^2 \nabla_\mu \phi \nabla_\nu \phi)$$

$$\tilde{g}_{\mu\nu} = g_{\mu\nu} + 16\pi G \lambda^2 \nabla_\mu \phi \nabla_\nu \phi$$

"DISFORMAL" TRANSFORMATION

IN COSMIC FRAME  $t$ -COMPONENTS AFFECTED

MOVING W/RT COSMIC FRAME  $\phi(t) = \phi(\tau(t' + vx'))$

$t$ ,  $tx$ ,  $xx$ -COMPONENTS AFFECTED



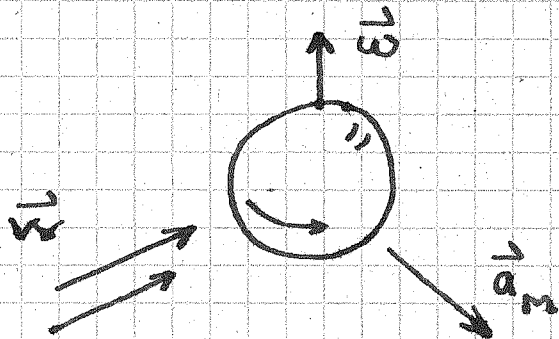
## MODIFICATION OF KEPLERIAN METRIC

$$g_{tt} \Rightarrow -1 + 2u + 2\alpha_3 \vec{w} \cdot \vec{v}$$

$$\alpha_3 = 32\pi G \lambda^2 \dot{\phi}_c^2$$

$\vec{w}$  = VELOCITY OF FRAME RELATIVE  
TO COSMIC FRAME

$$\vec{v} = \sum_i m_i \vec{v}_i / |\vec{x} - \vec{x}_i|$$



## ANOMALOUS ACCELERATION OF SPINNING BODY

$$\vec{a}_M = -\frac{1}{3} \frac{E_G}{M} \vec{w} \times \vec{\omega}$$

(NORDVEDT & WILL '72)

$\alpha_3 \neq 0$  WILL CAUSE BINARY SYSTEMS  
TO GROW ECCENTRIC!

$$|\alpha_3| \lesssim 10^{-19}$$

(SPLANER ET AL, '05)

# SPONTANEOUS LORENTZ and PARITY VIOLATION

## DARK ENERGY COUPLES TO ELECTROMAGNETISM

$$S = \int d^4x \sqrt{-g} \left( \frac{R}{16\pi G} - \left[ \frac{1}{2} \nabla_\mu \phi \nabla^\mu \phi + V(\phi) \right] - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + L_{\text{INT}} \right)$$

$$L_{\text{INT}} = \beta \frac{\phi}{4M} F_{\mu\nu} \tilde{F}^{\mu\nu} \quad \text{LIKE THE AXION}$$

CARROLL (1990)  $\nabla^\mu \phi \rightarrow p^\mu$  STATIC 4-VECTOR  
L-, R-CIRCULAR POLARIZED EM WAVES  
ROTATE DIFFERENTLY

LVE et al (1999) ROTATE E  $\rightarrow$  B POLARIZATION OF CMB

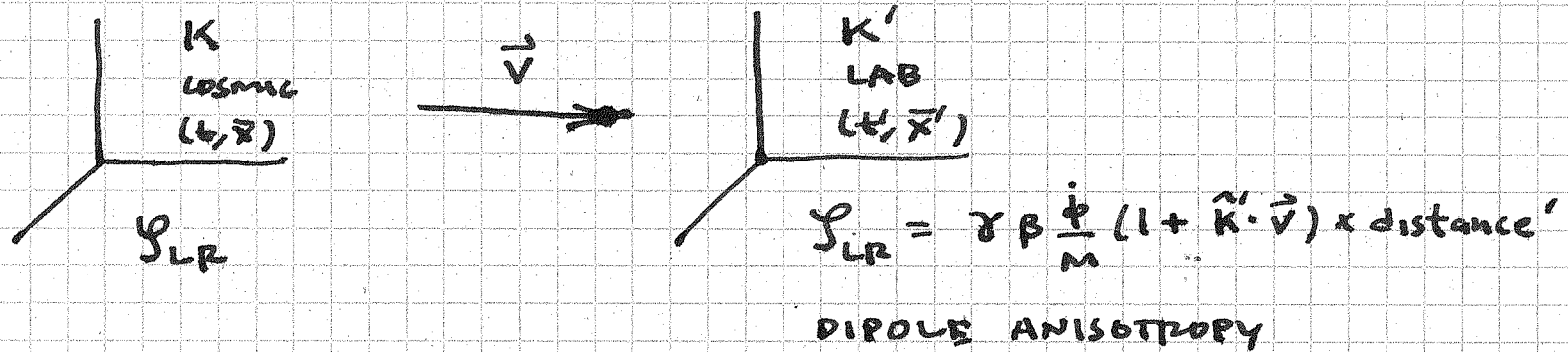
CMB LIMITS

$$\varphi_{LR} = \beta \frac{\dot{\phi}}{M} \times \text{DISTANCE} \lesssim 2^\circ$$

$$\chi \equiv \beta \frac{\dot{\phi}}{M} < 2 \times 10^{-43} \text{ GeV} \approx 0.1 \text{ H}_0$$

WMAP 0803.0547  
QUAD 0811.0618

## COSMIC SCALAR DEFINES A PREFERRED FRAME



## MAXWELL EQUATIONS

$$\vec{\nabla} \cdot \vec{B} = 0, \quad \vec{\nabla} \times \vec{E} + \frac{\partial \vec{B}}{\partial t} = 0$$

$$\vec{\nabla} \cdot \vec{E} = \rho + \frac{\rho}{M} \vec{\nabla} \phi \cdot \vec{B}$$

$$\vec{\nabla} \times \vec{B} - \frac{\partial \vec{E}}{\partial t} = \vec{j} + \frac{\rho}{M} (\vec{E} \times \vec{\nabla} \phi - \vec{B} \frac{\partial \phi}{\partial t})$$

NEW SOURCES,  
CURRENTS!

## FRAME EFFECTS:

$$K \text{ (LOSMIC)} \quad \partial_t \phi = \dot{\phi} \approx H \phi, \quad \vec{\nabla} \phi = 0$$

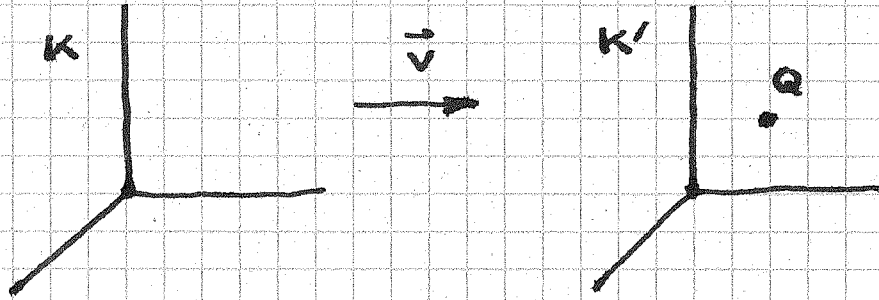
$$K' \text{ (LAB)} \quad \partial_{t'} \phi = \gamma \dot{\phi} \approx \gamma H \dot{\phi},$$

$$\vec{\nabla}' \phi = -\gamma \vec{v} \dot{\phi} \approx -\gamma \vec{v} H \phi$$

TANGIBLE EFFECT OF MOTION!



Ex.



POINT CHARGE AT REST IN LAB

$$\vec{E}' = \frac{Q}{(r')^3} \vec{r}' + \mathcal{O}(\beta) \quad (\beta \equiv v/c)$$

$$\vec{B}' = -\frac{1}{2} \beta \times \frac{Q}{(r')^3} [ (r')^2 \vec{v} + \vec{r}' (\vec{r}' \cdot \vec{v}) ]$$

$$\propto \frac{1}{r'} !$$

ANOMALOUS MAGNETIC FIELD!

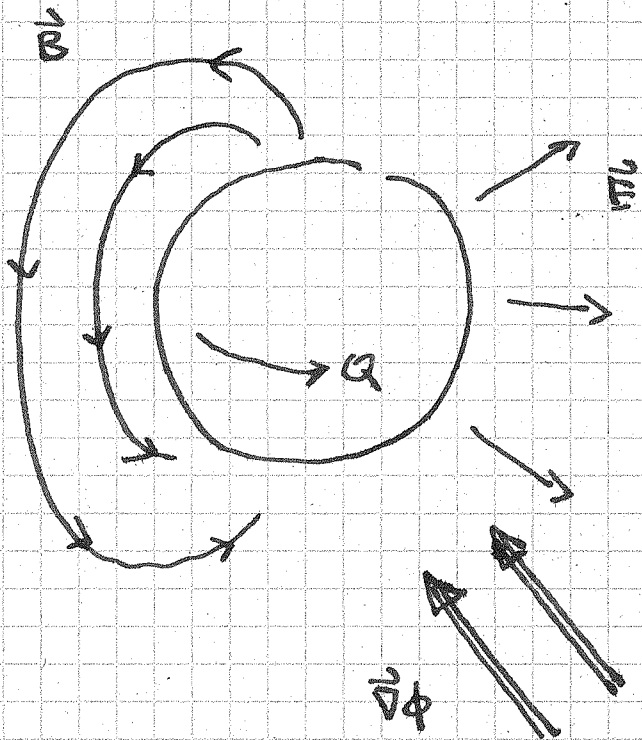
DETECTABLE?  $\beta$  IS SO TINY...

# PREFERRED FRAME: ANOMALOUS TORQUE

S-E TENSOR:  $\Theta_{\mu\nu} = F_{\mu\alpha} F_{\nu}{}^{\alpha} - \frac{1}{4} g_{\mu\nu} F^2$

BUT  $J^{\mu} \Theta_{\mu\nu} = J_{\alpha} F_{\nu}{}^{\alpha} + \underbrace{\frac{\beta}{4m} \nabla_{\mu} \phi F^{\mu}{}_{\nu}}_{\text{A NEW FORCE ON BODIES CARRYING } \vec{E} \cdot \vec{B} \text{ "CHARGE"}}$

A NEW FORCE ON BODIES CARRYING  $\vec{E} \cdot \vec{B}$  "CHARGE"



TORQUE  $\vec{\tau} = \int d^3x' \vec{r}' \times \vec{f}(\vec{x}')$

$\vec{f} = \gamma \mathbf{I} \vec{v} (\vec{E} \cdot \vec{B})$

CANDIDATES?

+ MAGNETAR?  $\Omega \approx 10^{18}$  Hz

+ ELECTRON?  $\Omega \approx 10$  Hz

[ 9-2 EXP'TS TRAP ELECTRONS FOR 10'S OF SECONDS! ]

# TESTING DARK ENERGY - PREFERRED FRAMES, DARK FORCES

