

RELATIVISTIC ATOMIC PHYSICS:

FROD CLOCK SYNCHRONIZATION

TOWARDS RELATIVISTIC ENTANGLEMENT

AND SPACE PHYSICS WITH POST-NEWTONIAN GRAVITY

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LUSANNA - THE CHRONOGEOMETRICAL STRUCTURE OF SPECIAL AND GENERAL RELATIVITY: A REVISITATION OF CANONICAL GEOMETRODYNAMICS

42 KARPACZ WINTER SCHOOL INT. J. GEOM. METHODS MOD. PHYS. 4 (2007) 79
GR-06/0604120

ALBA-LUSANNA - GENERALIZED RADAR-COORDINATES AND EQUAL TIME CAUCHY SURFACES FOR ARBITRARY ACCELERATED OBSERVERS

INT. J. MOD. PHYS. D16 (2007) 1149 gr-qc/0501090

ALBA-LUSANNA-PAURI - CENTERS OF MASS AND ROTATIONAL KINEMATICS FOR THE RELATIVISTIC N-BODY PROBLEM IN THE REST-FRAME INSTANT FORM

J. MATH. PHYS. 43 (2002) 1677 hep-th/0102087

CRATER-LUSANNA - THE REST-FRAME DARWIN POTENTIAL FROM THE LIENARD-WIECHERT SOLUTION IN THE RADIATION GAUGE

ANN. PHYS. 289 (2001) 87

ALBA-CRATER-LUSANNA - HAMILTONIAN RELATIVISTIC 2-BODY PROBLEM: CENTER OF MASS AND ORBIT RECONSTRUCTION

J. PHYS. A 40 (2007) 9535 gr-qc/0610200

ALBA-LUSANNA-CRATER - TOWARDS RELATIVISTIC ATOMIC PHYSICS. I. THE REST-FRAME INSTANT FORM OF DYNAMICS AND A CANONICAL TRANSFORMATION FOR A SYSTEM OF CHARGED PARTICLES PLUS THE ELECTROMAGNETIC FIELD
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II. COLLECTIVE AND RELATIVE RELATIVISTIC VARIABLES FOR A SYSTEM OF CHARGED PARTICLES PLUS THE ELECTROMAGNETIC FIELD IN PREPARATION

III. CLOCK SYNCHRONIZATION, QUANTIZATION AND RELATIVISTIC ENTANGLEMENT IN PREPARATION

ICES { ESA FIRENZE (2008) FTP://CACCIAPUOTI:1n73m0@FTP.ESAC.ESA.IT/
ESA MUNICH GEODESY (2008) <http://www.iapf.bv.tam.de/12735-naces-programme.htm>

GRAVITY LUSANNA - THE REST-FRAME INSTANT FORM OF PERI GRAVITY GRG 33 (2001) 1579

DE PIETRI-LUSANNA-PARTUCCI-RUSSO - ... TETRAD GRAVITY GRG 34 (2002) 877

ALBA-LUSANNA - YORK MAP GRG 39 (2007) 2149 gr-qc/0604086

LUSANNA-PAURI - DYNAMICAL 3-SPACE AND HOLE ARGUMENT

GRG 38 (2006) 187 and 229 gr-qc/0403081, 0407007

HISTORY AND PHILOSOPHY OF MODERN PHYSICS 37 (2006) 692 gr-qc/0604087

CLASSICAL AND QUANTUM THEORIES

PDE PREDICTABILITY $\rightarrow$ CAUCHY PROBLEM

$\downarrow$
INSTANTANEOUS 3-SPACE
 $\parallel$
CLOCK SYNCHRONIZATION

1) GALILEI SPACE-TIME

$\left\{ \begin{array}{l} \text{INERTIAL FRAMES} \\ \text{NON-INERTIAL FRAMES} \end{array} \right.$

2) MINKOWSKI SPACE-TIME

3+1 SPLITTINGS
AND THEIR GAUGE EQUIVALENCE

$\left\{ \begin{array}{l} \text{INERTIAL FRAMES} \\ \text{NON-INERTIAL FRAMES} \end{array} \right.$

ISOLATED SYSTEMS (PARTICLES, STRINGS, FIELDS, FLUIDS)

RELATIVISTIC CENTER OF MASS AND POINCARÉ GROUP

QUANTUM REL. MECHANICS

REL. ATOMIC PHYSICS

REL. ENTANGLEMENT

$\downarrow$ QUANTIZATION IN NON-INERTIAL FRAMES

3) EINSTEIN SPACE-TIMES

3+1 SPLITTINGS

ONLY NON-INERTIAL FRAMES
EQUIVALENCE PRINCIPLE

ACES - CLOCK SYNCHRONIZATION IN SOLAR SYSTEM (PN GRAVITY)

YORK MAP - INERTIAL AND TIDAL EFFECTS IN CANONICAL GRAVITY

COSMOLOGY - FRW PARADIGM

$\left\{ \begin{array}{l} \text{GR} \rightarrow \text{DARK MATTER (RELATIVISTIC INERTIAL EFFECT?)} \\ \text{GR} \rightarrow \text{DARK ENERGY (BACKREACTION? BUCHERT, ELLIS, \dots)} \end{array} \right.$

$\left\{ \begin{array}{l} \text{GR} \rightarrow \text{DARK ENERGY (BACKREACTION? BUCHERT, ELLIS, \dots)} \end{array} \right.$

$\rightarrow$ CAUCHY PROBLEM, CLOCK SYNCHRONIZATION

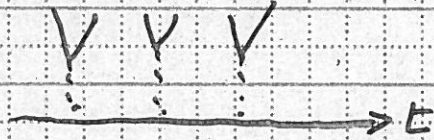
3+1
1+3
VIEWPOINTS - BOTH NON FACTUAL

NON-RELATIVISTIC PHYSICS

(NEWTON'S THEORY IN GALILEI SPACETIME)

ABSOLUTE TIME

ABSOLUTE 3-SPACE (EUCLIDEAN)



ABSOLUTE SIMULTANEITY AND SPATIAL DISTANCE

GALILEI LAW OF INERTIA $\rightarrow$ INERTIAL OBSERVERS

GALILEI RELATIVITY PRINCIPLE - INVARIANCE IN FORM OF $\vec{p} = m\vec{a}$ IN INERTIAL FRAMES
(CENTERED ON INERTIAL OBSERVERS) WITH CARTESIAN
3-COORDINATES - KINEMATICAL GALILEI GROUP

NEWTON'S GRAVITY - A-A-A-D INTERACTION WITH GALILEI EQUIVALENCE PRINCIPLE

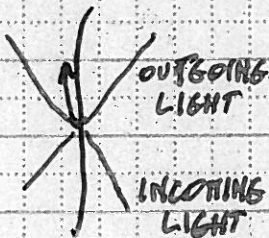
$$m\vec{a} = \vec{F}_G = m_G \vec{g} \quad m = m_G$$

INERTIAL FRAMES - IDEAL LIMIT

RIGID NON-INERTIAL FRAMES CENTERED - INERTIAL FORCES $\propto$ INERTIAL MASS
ON ACCELERATED OBSERVERS

$$\vec{a} = \frac{\vec{F}}{m} = \underbrace{\vec{w}(t)}_{\text{LINEAR}} + \underbrace{\vec{x} \times \frac{d\vec{\omega}(t)}{dt}}_{\text{JACOBI}} + \underbrace{2 \frac{d\vec{x}}{dt} \times \vec{\omega}(t)}_{\text{CORIOLIS}} + \underbrace{\vec{\omega}(t) \times [\vec{x} \times \vec{\omega}(t)]}_{\text{CENTRIFUGAL}}$$

SPECIAL RELATIVITY (MINKOWSKI SPACETIME)



ABSOLUTE FLAT SPACETIME

$$ds^2 = [c^2 dt^2 - d\vec{x}^2] = \eta_{\mu\nu} dx^\mu dx^\nu$$

$$\eta_{\mu\nu} = \varepsilon (+---), \varepsilon = \pm 1$$

CARTESIAN 4-COORDINATES

ONLY THE
CONFORMAL STRUCTURE
(THE LIGHT CONE) IS
INTRINSICALLY GIVEN

NO NOTION OF

INSTANTANEOUS 3-SPACE, SPATIAL DISTANCE
SIMULTANEITY (SYNCHRONIZATION OF DISTANT CLOCKS NEEDED)
CAUCHY 3-SURFACE FOR MAXWELL EQS
1-WAY VELOCITY OF LIGHT (2 SYNCHRONIZED CLOCKS NEEDED)

LIGHT POSTULATES - THE 2-WAY (OR ROUND TRIP; ONLY 1 CLOCK NEEDED) VELOCITY OF
LIGHT IS A) ISOTROPIC B) CONSTANT $c = 2.997924580 \cdot 10^8 \text{ m s}^{-1}$

METROLOGY - c and standard of time

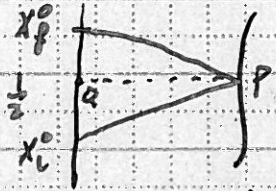
$$L = \frac{1}{2} c \Delta t$$

$\rightarrow$ but curved 3-space?

LAW OF INERTIA → INERTIAL OBSERVERS

SPECIAL RELATIVISTIC RELATIVITY PRINCIPLE - INVARIANCE IN FORM OF PHYSIC'S LAWS
IN INERTIAL FRAMES (CENTERED ON INERTIAL OBSERVERS) WITH CARTESIAN
4-COORDINATES - KINETICAL POINCARÉ GROUP

IDENTIFIED BY EINSTEIN'S $\frac{1}{2}$ CONVENTION FOR CLOCK SYNCHRONIZATION

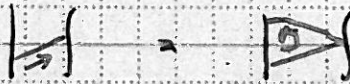


$$x_P^0 \stackrel{\text{def}}{=} x_Q^0 = x_L^0 + \frac{1}{2}(x_R^0 - x_L^0) = \frac{1}{2}(x_R^0 + x_L^0)$$



1/(INERTIAL) B (NON-INERTIAL) 3 SPACES = EUCLIDEAN $x^0 = ct = \text{CONST}$ HYPERPLANES

1-WAY = 2-WAY = c



INERTIAL OBSERVERS = IDEAL LIMIT → ACCELERATED OBSERVERS

$$\begin{aligned} \text{ACCELERATION LENGTH} \quad & \left\{ \begin{aligned} \lambda &= c^2/a && \text{TRANSLATIONAL} && (\sim 1 \text{ LY}) \\ \lambda &= \frac{c^2}{\omega} && \text{ROTATIONAL} && (\sim 20 \text{ AU}) \end{aligned} \right. \end{aligned}$$

LOCALITY HYPOTHESIS - an accelerated observer is a succession of instantaneously comoving inertial observers

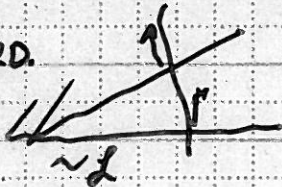
$\lambda > \lambda$ PROBLEMS

1+3 POINT OF VIEW

ONLY THE OBSERVER'S WORLDLINE AND 4-VELOCITY ARE GIVEN

NO KNOWN METHOD TO DEFINE GLOBAL INSTANTANEOUS 3-SPACES (CAUCHY SURFACES)

FERNI COORD.



ROTATING DISK



$$\omega R = c \Rightarrow g_{00}(y^0, \vec{y}) = \omega R \hat{n} = c \hat{n} = 0$$

↓ $x^\mu \rightarrow y^\mu(x), \eta_{\mu\nu} \rightarrow g_{\mu\nu}(y)$
SAGNAC EFFECT

COORDINATE SINGULARITIES

PARAMETRIZED MINKOWSKI THEORIES

WORLD-LINE OF AN ACCELERATED OBSERVER (TIRELIKE)

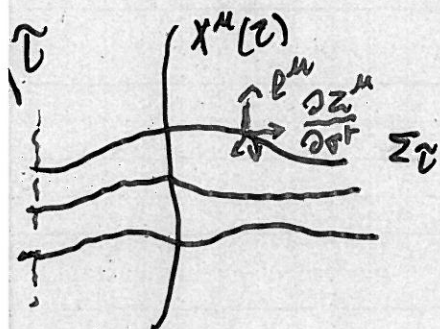
→ 3+1 SPLITTING OF MINKOWSKI SPACETIME

(= NICE FOLIATION WITH SPACELIKE 3-SURFACES =

= CLOCK SYNCHRONIZATION CONVENTION =

= DEFINITION OF THE INSTANTANEOUS 3-SPACE)

⇒ GLOBAL NON-INERTIAL FRAME CENTERED ON THE ACCELERATED OBSERVER



FRAME-AND OBSERVER-DEPENDENT, LORENTZ-SCALAR

RADAR 4-COORDINATES (BONDI) (τ, σ^A)

[DIFFERENTLY FROM FERMI COORDINATES, THEY CAN BE OPERATIONALLY DEFINED]

ASYMPTOTIC INERTIAL OBSERVER

$$\left\{ \begin{array}{l} x^\mu \mapsto \sigma^A(x) = (\tau, \sigma^A) \\ \sigma^A \mapsto x^\mu = z^\mu(\tau, \sigma^A) \end{array} \right.$$

x^μ CARTESIAN 4-COORD. IN AN INERTIAL FRAME

EMBEDDING OF Σ_τ

$$\eta_{\mu\nu} \rightarrow g_{AB}[z(\tau, \sigma^A)] = \frac{\partial z^\mu(\sigma^A)}{\partial \sigma^A} \eta_{\mu\nu} \frac{\partial z^\nu(\sigma^B)}{\partial \sigma^B}$$

NORMAL TO Σ_τ

$$\frac{\partial z^\mu(\tau, \sigma^A)}{\partial \tau} = N(\tau, \sigma^A) l^\mu(\tau, \sigma^A) + N^\tau(\tau, \sigma^A) \frac{\partial z^\mu(\tau, \sigma^A)}{\partial \sigma^A}$$

$$l^\mu = \frac{1}{\sqrt{g}} \epsilon^\mu_{\alpha\beta\gamma} z_1^\alpha z_2^\beta z_3^\gamma$$

LAPSE

SHIFT

$\hookrightarrow = z^\mu_\tau(\tau, \sigma^A)$ TANGENT TO Σ_τ

MÖLLER ADMISSIBILITY CONDITIONS FOR THE 3+1 SPLITTINGS

$$g_{\tau\tau}(\tau, \sigma^A) > 0, \quad g_{\tau A}(\tau, \sigma^A) < 0, \quad \det g_{AB}(\tau, \sigma^A) < 0$$

↓
NO RIGID REL. ROTATIONS

$$\begin{vmatrix} g_{\tau\tau} & g_{\tau s} \\ g_{s\tau} & g_{ss} \end{vmatrix}(\tau, \sigma^A) > 0$$

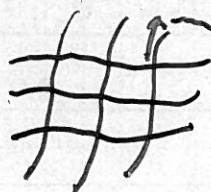
Σ_τ SPATIAL INFINITY
SPACELIKE HYPER PLANE

2 CONGRUENCES OF ACCELERATED OBSERVER ASSOCIATED TO EVERY 3+1 SPLITTING



NORMAL = 4-VELOCITY
SURFACE-FORMING

EULERIAN OBSERVERS



$\frac{dz^\mu}{d\sigma^A} = 4$ -VELOCITY

NON-SURFACE-FORMING
(ROTATING DISK)

ISOLATED SYSTEM (PARTICLES, STRINGS, FLUIDS, FIELDS) WITH LAGRANGIAN DESCRIPTION
(CONFIGURATIONS WITH THE 10 POINCARÉ GENERATORS FINITE)

COUPLING TO EXTERNAL GRAVITATIONAL FIELD $g_{\mu\nu}(x)$ $\mathcal{L}(\text{matter}, g_{\mu\nu})$

$$g_{\mu\nu}(x) \mapsto g_{AB}[z^A(\tau, \vec{\sigma})] \Rightarrow S = \int d\tau d^3\sigma \tilde{\mathcal{L}}(\text{matter}, z(\tau, \vec{\sigma}))$$

ACTION PRINCIPLE FOR MATTER AND EMBEDDING $z^A(\tau, \vec{\sigma})$

S INVARIANT UNDER FRAME-PRESERVING DIFFEOMORPHISMS
(SPECIAL RELATIVISTIC GENERAL COVARIANCE)

4 FIRST-CLASS CONSTRAINTS (DEPARAMETRIZED ANALOGUES OF THE SUPER-HAM. AND SUPER-MOMENTUM CONSTRAINTS OF GR)

$$\mathcal{H}^A(\tau, \vec{\sigma}) = \underbrace{S^A(\tau, \vec{\sigma})}_{\substack{\uparrow \\ \text{4-POTENTIAL} \\ \text{OF } z^A(\tau, \vec{\sigma})}} - \underbrace{e^A(\tau, \vec{\sigma})}_{\substack{\uparrow \\ \text{MATTER} \\ \text{ENERGY} \\ \text{DENSITY}}} T^{\hat{t}\hat{t}}(\tau, \vec{\sigma}) - \underbrace{z^M(\tau, \vec{\sigma})}_{\substack{\uparrow \\ \text{MATTER} \\ \text{3-POTENTIAL} \\ \text{DENSITY}}} T^{\hat{t}\hat{M}}(\tau, \vec{\sigma}) \approx 0$$

$$\{ \mathcal{H}^A(\tau, \vec{\sigma}_1), \mathcal{H}^A(\tau, \vec{\sigma}_2) \} \approx 0$$

$\Rightarrow z^A(\tau, \vec{\sigma})$ GAUGE VARIABLES $\Rightarrow$ GAUGE EQUIVALENCE OF ADMISSIBLE
NON-INERTIAL FRAMES (I.E. OF CLOCK SYNCHRONIZATION CONVENTIONS
AND OF CHOICE OF 3-COORDINATES ON THE
INSTANTANEOUS 3-SPACES)

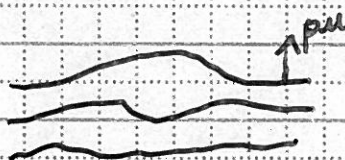
REST-FRAME INSTANT FORM OF DYNAMICS

INERTIAL 3+1 SPLITTING CENTERED ON AN INERTIAL OBSERVER (DESCRIBING
THE COLLECTIVE VARIABLES OF THE ISOLATED SYSTEM)

WHOSE INSTANTANEOUS 3-SPACES ARE ORTHOGONAL TO THE 4-POTENTIAL
OF THE ISOLATED SYSTEM (INTRINSICALLY DEFINED BY ITS CONFIGURATIONS)

$$\begin{array}{c} \uparrow p^\mu \\ \text{---} \\ \text{---} \end{array} \quad z^A(\tau, \vec{\sigma}) = x^A(\tau) + \varepsilon_F^A(p) \sigma^\mu$$

NON-INERTIAL REST FRAMES



ASYMPTOTIC INERTIAL
OBSERVERS = FIXED STAR

ISOLATED SYSTEMS IN THE REST-FRAME INSTANT FORM

STANDARD DESCRIPTION - POINCARÉ GENERATORS $P^\mu, J^{\mu\nu}$ FINITE

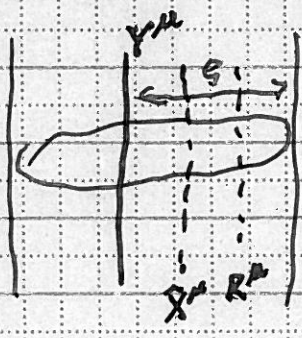
- NON-LOCAL QUANTITIES - THEY KNOW THE WHOLE INSTANTANEOUS 3-SPACE $P^\mu = \int_{\Sigma_t} d^3x \dots$
- LORENTZ BOOSTS; INTERACTION-DEPENDENT $[P^\mu, K^\nu] = \delta^\mu_\nu P^0$
- $\neq$ GALILEI BOOSTS

$P^\mu, J^{\mu\nu} \rightarrow$ 3 NOTIONS OF COLLECTIVE VARIABLES

- $\tilde{X}^\mu = (\tilde{x}^0; \tilde{\vec{x}})$ NON-COVARIANT CANONICAL CENTER OF MASS (CENTER OF SPIN)
- $Y^\mu = (\tilde{x}^0; \vec{y})$ COVARIANT NON-CANONICAL FOKKER-PRYCE CENTER OF INERTIA
- $R^\mu = (\tilde{x}^0; \vec{R} = -\frac{\vec{K}}{\pi_C})$ NON-COVARIANT NON-CANONICAL MÖLLER CENTER OF ENERGY

$\rightarrow$ NEWTON CENTER OF MASS
C.M.

MÖLLER
WORLD-TUBE
OF NON-COVARIANCE
(LORENTZ SIGNATURE)



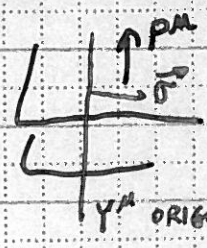
MÖLLER RADIUS

$$S \approx \frac{\sqrt{-W^2}}{P^2_C} = \frac{|\vec{S}|}{\pi_C}$$

$S \sim$ COMPTON WAVELENGTH
OF ISOLATED SYSTEM
REMNANT OF ENERGY CONDITION
OF GENERAL RELATIVITY

REST-FRAME INSTANT FORM

WIGNER INSTANTANEOUS 3-SPACES



Σ EXACT REST TIME
(LORENTZ SCALAR)

Y^μ ORIGIN OF 3-COORD.

$$Z^\mu(\Sigma; \vec{h}) = Y^\mu(\Sigma) + \Sigma P^\mu(\vec{h}) \sigma^\mu$$

$$P^\mu = \pi_C(\sqrt{1+\vec{h}^2}, \vec{h}) = L^\mu_\nu(P, \vec{h}) P^\nu$$

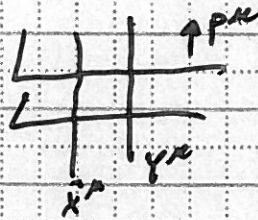
$$\vec{P}^\mu = \pi_C(1; \vec{h}), \pi_C = \sqrt{P^2} \quad \downarrow \text{WIGNER BOOST FOR TIGHTLY BOUND}$$

POSITIVE ENERGY PARTICLES $X^\mu_i(\Sigma) = Z^\mu(\Sigma; \vec{h}_i(\Sigma)) = Y^\mu(\Sigma) + \Sigma P^\mu(\vec{h}_i) \sigma^\mu$

$\tilde{X}^\mu(\Sigma), Y^\mu(\Sigma), R^\mu(\Sigma)$ KNOWN FUNCTIONS OF $\Sigma, \pi, \vec{S}$, and of the FROZEN JACOBI DATA $\vec{Z}, \vec{h}$ OF THE EXTERNAL CENTER OF MASS

$$\vec{X}_{NW} = \frac{\vec{S}}{\pi_C} \quad \text{NEWTON-WIGNER POSITION}$$

ISOLATED SYSTEM



- 1) NON-COVARIANT DECOUPLED EXTERNAL CENTER OF MASS
(DESCRIBED BY THE FROZEN JACOBI DATA) CARRYING A POLE-DIPOLE
STRUCTURE : M INTERNAL MASS, $\vec{S}$ REST SPIN
(UNIVERSAL BREAKING OF LORENTZ COVARIANCE BUT DECOUPLED)

EXTERNAL
POINCARÉ GENERATORS

$$P^0 = \sqrt{1+h^2} \pi c \quad P^i = \pi c h^i$$

$$\vec{J} = \vec{Z} \times \vec{h} + \vec{S} \quad \vec{K} = \sqrt{1+h^2} \vec{Z} + \frac{\vec{S} \times \vec{h}}{1+\sqrt{1+h^2}}$$

- 2) INSIDE THE INSTANTANEOUS WIGNER 3-SPACE THERE ARE THE WIGNER-^{RM} DATA
VARIABLES OF THE ISOLATED SYSTEM (INTERNAL SPACE)
AND A UNFAITHFUL INTERNAL REALIZATION OF THE POINCARÉ GROUP

$\tau = cT$ LORENTZ-SCALAR REST TIME

$$\left\{ \begin{array}{l} \pi c = c \int d^3\sigma T^{00}(v, \vec{\sigma}) \\ \vec{P} \approx 0 \quad \text{REST-FRAME CONDITION} \quad \vec{P} = \int d^3\sigma T^{0i}(v, \vec{\sigma}) \\ \vec{J} \approx \vec{S} \quad \vec{S} = \frac{1}{2} \epsilon^{\mu\nu} \int d^3\sigma \sigma^{\mu\nu} T^{00}(v, \vec{\sigma}) \\ \vec{K} \approx 0 \quad \text{(INTERACTION-DEPENDENT) ELIMINATION OF THE INTERNAL 3-CENTER OF MASS} \\ \vec{K} = - \int d^3\sigma \sigma^i T^{0i}(v, \vec{\sigma}) \end{array} \right.$$

POSITIVE-ENERGY SCALAR FREE PARTICLES $\vec{\eta}_L(t), \vec{K}_L(t)$

$$\pi c = \sum_L \sqrt{m_L^2 c^2 + \vec{K}_L^2}, \quad \vec{P} = \sum_L \vec{K}_L \approx 0, \quad \vec{S} = \sum_L \vec{\eta}_L \times \vec{K}_L, \quad \vec{K} = - \sum_L \vec{\eta}_L \sqrt{m_L^2 c^2 + \vec{K}_L^2} \approx 0$$

$$\Rightarrow \vec{\eta}_L, \vec{K}_L, L=1, \dots, N \text{ FUNCTIONS ONLY OF RELATIVE VARIABLES } \vec{S}_a, \vec{T}_a, a=1, \dots, N$$

2-BODY CASE - ORBIT RECONSTRUCTION

$$X_L^\mu(t) = Y^\mu(t) + (-)^{L+1} \epsilon_F^\mu(\vec{h}) \frac{\sqrt{m_L^2 c^2 + \vec{\pi}_{L2}^2}}{\sum_K \sqrt{m_K^2 c^2 + \vec{\pi}_{K2}^2}} \vec{S}_{12}(t) \xrightarrow{c \rightarrow \infty} \left\{ \vec{X}_{(N)} + (-)^{L+1} \frac{m_{L+1}}{m_L + m_2} \vec{P}_{(N)} = \vec{X}_{(N)} \right.$$

- COVARIANT WORLD LINES - DERIVED NON-CANONICAL QUANTITIES
 $\{X_L^\mu, X_J^\nu\} \neq 0$ PREDICTIVE COORDINATES
VIOLATION OF MICROCAUSALITY
- DERIVED P_L^μ SATISFY $P_L^2 = m_L^2 c^2$ ALSO IN PRESENCE OF INTERACTIONS

THE SIMPLEST INTERACTING 2-BODY SYSTEM

$$\left\{ \begin{array}{l} M = \sqrt{m_1^2 + \vec{K}_1^2 + \phi(\vec{S}^2)} + \sqrt{m_2^2 + \vec{K}_2^2 + \phi(\vec{S}^2)} \quad \vec{S} = \vec{\eta}_1 - \vec{\eta}_2 \\ \vec{P} = \vec{K}_1 + \vec{K}_2 \approx 0 \\ \vec{J} = \vec{S} = \vec{\eta}_1 \times \vec{K}_1 + \vec{\eta}_2 \times \vec{K}_2 \\ \vec{K} = -\vec{\eta}_1 \sqrt{m_1^2 + \vec{K}_1^2 + \phi(\vec{S}^2)} - \vec{\eta}_2 \sqrt{m_2^2 + \vec{K}_2^2 + \phi(\vec{S}^2)} \approx 0 \end{array} \right.$$

THE INTERNAL POINCARÉ ALGEBRA IS SATISFIED

$$\Pi \approx M = \sqrt{m_1^2 + \vec{\Pi}^2 + \phi(\vec{S}^2)} + \sqrt{m_2^2 + \vec{\Pi}^2 + \phi(\vec{S}^2)} \quad \text{HAMILTONIAN FOR THE RELATIVE MOTION}$$

$$m_0 = \sqrt{m_1^2 + \vec{\Pi}^2} + \sqrt{m_2^2 + \vec{\Pi}^2}$$

$$\vec{K} \approx 0$$

$$\Rightarrow \vec{q} \approx \vec{q}(\vec{S}, \vec{\Pi}) = \frac{m_1^2 - m_2^2}{2} \left(\frac{1}{m_0^2} - \frac{1}{m^2} \right) \vec{S}$$

$$\Rightarrow \vec{\eta}_L \approx \frac{(-1)^{L+1}}{2} \left(1 - \frac{m_1^2 - m_2^2}{m^2} \right) \vec{S} \xrightarrow{c \rightarrow \infty} (-1)^{L+1} \frac{m_1}{m_1 + m_2} \vec{S}$$

IN THE PAPER THERE ARE THE ORBITS FOR COULOMB-LIKE POTENTIALS

$$\phi(\vec{S}^2) = -2\mu \frac{e^2}{\sqrt{\vec{S}^2}}$$

N.B. FOR $\Pi = \sqrt{m_1^2 + \vec{K}_1^2} + \sqrt{m_2^2 + \vec{K}_2^2} + \frac{e^2}{4\pi |\vec{\eta}_1 - \vec{\eta}_2|}$ (REAL COULOMB POTENTIAL)

IT IS NOT KNOWN THE FORM OF THE INTERNAL BOOST $\vec{K}$

(IT IS NOT KNOWN THE LAGRANGIAN, FROM WHICH TO GET THE ENERGY-MOMENTUM TENSOR.)

NON-RELATIVISTIC QUANTUM MECHANICS

2-BODY PROBLEM

$$\vec{x}_{(1)i}, \vec{p}_{(1)i} \rightarrow \vec{x}_{(1)}, \vec{p}_{(1)}, \vec{x}_{(2)}, \vec{p}_{(2)}$$

$$\begin{aligned} m_1, m_2 \\ m = m_1 + m_2 \\ \mu = m_1 m_2 / m \end{aligned}$$

GALILEI GENERATORS

$$\begin{cases} E \approx H = H_{com} + H_{rel}, & H_{com} = \frac{\vec{P}_{(1)}^2}{2m}, & H_{rel} = \frac{\vec{q}_{(1)}^2}{2\mu} + V(\vec{r}_{(1)}) \\ \vec{P} \approx \vec{P}_{(1)} = \sum_i \vec{p}_{(1)i} \\ \vec{L} \approx \sum_i \vec{x}_{(1)i} \times \vec{p}_{(1)i} = \vec{x}_{(1)} \times \vec{p}_{(1)} + \vec{S}_{(1)}, & \vec{S}_{(1)} = \vec{r}_{(1)} \times \vec{q}_{(1)} \\ \vec{K} \approx -m \vec{x}_{(1)} + \vec{p}_{(1)} t \end{cases}$$

REST FRAME CENTERED IN $\vec{x}_{(1)}$

EXTERNAL C.O.P. $\vec{x}_{(1)}, \vec{p}_{(1)}$ DECOUPLED WITH POLE-DIPOLE STRUCTURE: $H_{rel}, \vec{S}_{(1)}$
 → EXTERNAL GALILEI GROUP

+ INTERNAL SPACE WITH $\vec{\eta}_{(1)i} = \vec{x}_{(1)i} |_{\vec{x}_{(1)}=0}, \vec{K}_{(1)i} = \vec{p}_{(1)i} |_{\vec{p}_{(1)}=0}$ $\vec{\eta}_{(1)1} - \vec{\eta}_{(1)2} = \vec{r}_{(1)}$

and unfaithful Galilei realisation $H_{rel}, \vec{P} \approx 0, \vec{S}_{(1)}, \vec{K} \approx 0$ $\begin{cases} \vec{\eta}_i \rightarrow \vec{\eta}_{(1)i} \\ \vec{K}_L \rightarrow \vec{K}_{(1)i} \end{cases}$

$$\boxed{H \approx H_1 \otimes H_2 = H_{com} \otimes H_{rel}}$$

COMPOSITE SYSTEM SEPARABILITY (ZEROth POSTULATE of QM, ZEN)
 $\Psi(t, \vec{x}_{(1)i}) \Psi(t, \vec{x}_{(2)i})$

UNITARY TRANSF. DICTATED BY SEPARATION OF VARIABLES IN SCHR. EQ
 $\Psi(t, \vec{x}_{(1)}) \Phi(t, \vec{p}_{(1)})$

$$\begin{cases} i \frac{\partial}{\partial t} \Psi(t, \vec{x}_{(1)}, \vec{p}_{(1)}) = (\hat{H}_{com} + \hat{H}_{rel}) \Psi(t, \vec{x}_{(1)}, \vec{p}_{(1)}) \\ i \frac{\partial}{\partial t} (e^{-i \frac{\vec{P}_{(1)}^2}{2m} t} \Psi_P(\vec{x}_{(1)})) = \hat{H}_{com} (e^{-i \frac{\vec{P}_{(1)}^2}{2m} t} \Psi_P(\vec{x}_{(1)})) & \Psi_P(\vec{x}_{(1)}) \sim e^{i \vec{x}_{(1)} \cdot \vec{p}_{(1)}} \\ i \frac{\partial}{\partial t} (e^{-i \varepsilon_{rel} t} \Phi_{new}(\vec{p}_{(1)})) = \hat{H}_{rel} (e^{-i \varepsilon_{rel} t} \Phi_{new}(\vec{p}_{(1)})) \end{cases}$$

HAMILTON-JACOBI FOR CENTER OF MASS

FROZEN JACOBI DATA $\vec{x}_{(1)}(0), \vec{p}_{(1)}$ FOR COM
 INTERNAL SPACE $\vec{p}_{(1)}, \vec{q}_{(1)}$

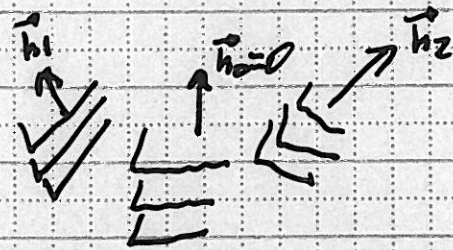
$$\begin{cases} \hat{\vec{P}} \Psi_P(\vec{p}_{(1)} | t, \vec{r}_{(1)}) \\ i \frac{\partial}{\partial t} \Psi_P(\vec{p}_{(1)} | t, \vec{r}_{(1)}) = \hat{H}_{rel} \Psi_P(\vec{p}_{(1)} | t, \vec{r}_{(1)}) \end{cases} \quad H_{com} \xrightarrow{e^{i \hat{S}}} 0 \quad S \approx -H_{com} t$$

QUANTIZATION OF THE REST-FRAME INSTANT FORM

$$H = H_{com} \otimes H_{int} \neq H_1 \otimes H_2 \quad \begin{array}{l} \text{Tensor Product of 2} \\ \text{Klein-Gordon} \end{array}$$

ALL THE IMPLICATIONS OF POINCARÉ GROUP
TAKEN INTO ACCOUNT

$$P^\mu = \pi c(\sqrt{1+\vec{h}^2}; \vec{h})$$



REFERENCE INERTIAL FRAME

GLOBAL (NOT LOCALLY DEFINED)

CLOSED UNIVERSE $\vec{h} \rightarrow$ CONSTANT OF MOTION

1) H_{com} NON-COVARIANT FROZEN JACOBI DATA $\vec{z}, \vec{h}$ OF EXTERNAL CENTER OF MASS $[\vec{z}, \vec{h}] = i\hbar \delta^3$

PREFERRED $\vec{h}$ -BASIS FOR DEFINITION OF INSTANTANEOUS WIGNER 3-SPACE

$$\vec{h} \psi_p(\vec{h}) = \vec{k} \psi_p(\vec{h}) \quad \psi_p(\vec{h}) = \delta^3(\vec{h} - \vec{k})$$

$$\vec{x}_{NW} = \frac{\vec{z}}{\pi c} \quad \text{DEPENDS ON MASS EIGENVALUE}$$

$$\langle \psi_1 | \psi_2 \rangle = \int \frac{d^3 h}{1+\vec{h}^2} \psi_1^*(\vec{h}) \psi_2(\vec{h})$$

$\vec{h} \rightarrow$ CONSTANT OF MOTION - $\vec{z}$ NOT MEASURABLE (WIGNER-ARAKI-YAMASE TH.)

CLOSED UNIVERSE

$$\psi_p(\vec{z}) = \int d^3 h e^{-i\vec{h} \cdot \vec{z}} \psi_p(\vec{h}) = e^{-i\vec{k} \cdot \vec{z}}$$

COM WAVE PACKETS

a) ALLOWED? (ALSO SUPERPOSITION OF 3-SPACES)

b) FORBIDDEN FROM SUPERSELECTION RULE? (LIKE IN CANONICAL GRAVITY - GIULINI, MAROLF)

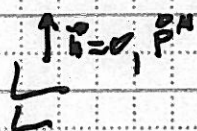
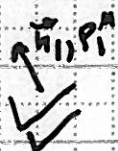
WHO WILL OBSERVE THE WAVE FUNCTION OF THE UNIVERSE?

FROZEN JACOBI DATA - NO EVOLUTION OF COM - NO INSTANTANEOUS SPREADING

OF COM WAVEPACKETS (WAY OUT OF HEGGERFELDT'S THEOREM)

2) UNIVERSAL INTERNAL SPACE H_{int} DUE TO WIGNER COVARIANCE

$$P^\mu = \pi c(1;0)$$



$$P^\mu = L^\mu_\nu(P_1, \vec{P}) \vec{P}^\nu = \pi c L^\mu_0(\vec{P}_1, \vec{P}), \quad h^\mu_i = L^\mu_0(P_1, \vec{P})$$

$$\eta^\mu_L \xrightarrow{\Lambda} R^\mu_\nu(P, \Lambda) \eta^\nu_L$$

$$\Lambda = L(P, \vec{P})$$

$$R(P, L(P, \vec{P})) = 1$$

$$\eta_L \rightarrow \eta_L$$

$$H_{rel} = \bigoplus_{\vec{k} \approx 0} H_{\vec{k}} \Big|_{\vec{p} \approx 0, \vec{k} \approx 0} = \bigoplus_a H_{\vec{s}_a}$$

INTERMEDIATE UNPHYSICAL
HILBERT SPACE

$$\langle \phi_1, \phi_2 \rangle = \int \pi_a d^3 \vec{s}_a \phi_1^*(t, \vec{s}_a) \phi_2(t, \vec{s}_a)$$

$$i \frac{\partial}{\partial t} \phi(t, \vec{s}_a) = \hat{H}_c \phi(t, \vec{s}_a)$$

$$\langle \psi_1, \psi_2 \rangle = \int \pi_L d^3 \vec{q}_L \psi_1^*(t, \vec{q}_L) \psi_2(t, \vec{q}_L)$$

$$i \frac{\partial}{\partial t} \psi(t, \vec{q}_L) = \hat{H}_c \psi(t, \vec{q}_L)$$

INTERACTION
DEPENDENT

GUPTA-BLEULER FOR REST-FRAME CONDITIONS

$$\langle \text{PHYS} | \vec{P} | \text{PHYS} \rangle = \langle \text{PHYS} | \vec{R} | \text{PHYS} \rangle = 0$$

$$\begin{cases} \hat{H}_c \phi_{nem}(\vec{s}_a) = \varepsilon_n \phi_{nem} \\ \hat{S}_2 \phi_{nem} = \ell(\ell+1) \phi_{nem} \\ \hat{S}_3 \phi_{nem} = m \phi_{nem} \end{cases}$$

ELEMENTARY
SOLUTIONS

WAVE PACKETS

$$\psi_{R,nem}(\vec{q}_L | t, \vec{s}_a) = \psi_R(\vec{q}_L) e^{-i\varepsilon_n t} \phi_{nem}(\vec{s}_a)$$

$$\xrightarrow{\vec{q}_L \rightarrow 0} e^{-imc^2 t} \left(\begin{array}{l} \text{NON-REL} \\ \text{WAVE FUNCTION IN HAMILTON-JACOBI} \end{array} \right) \text{ FOR COM}$$

STANDARD ATOMIC PHYSICS - $O(\frac{1}{c})$ - NEITHER GALILEI NOR POINCARÉ GROUP

RELATIVISTIC ATOMIC PHYSICS - EFFECTIVE THEORY FOR $E < \text{THRESHOLD FOR PAIR PRODUCTION}$

FIXED NUMBER OF POSITIVE-ENERGY SCALAR (OR SPINNING) PARTICLES
WITH COULOMB MUTUAL INTERACTION +
+ TRANSVERSE ELECTRO-MAGNETIC FIELD (RADIATION GAUGE)

ISOLATED SYSTEM IN THE REST-FRAME INSTANT FORM

GRASSMANN-VALUED ELECTRIC CHARGES $Q_i^2 = 0, Q_L Q_j = Q_j Q_L \neq 0$ for $L \neq j$

UV REGULARIZATION OF SELF-ENERGIES

IR REGULARIZATION (NO SOFT PHOTON EMISSION)

POTENTIAL IN CAUCHY PROBLEM OF 1-PHOTON EXCHANGE I

LIENARD-WIECHERT POTENTIALS = FUNCTIONS OF $\vec{q}_L, \vec{R}_L$ INDEPENDENT

OR RETARDED, ADVANCED, ... GREEN FUNCTIONS

CLASSICAL CANONICAL TRANSF

$\vec{q}_L, \vec{R}_L$ + COULOMB

$\vec{q}_L, \vec{R}_L$ (COULOMB DRESSED) + COULOMB + DARWIN

BEING
SALPETER

$\vec{A}_L, \vec{E}_L$ INTERPOLATING

$\vec{A}_L, \vec{E}_L$ IN, OUT FREE FIELDS (NR. HAAG THEOREM)

$$\begin{aligned}
 M_C &= \sum_i \sqrt{m_i^2 c^2 + (\vec{K}_i - \frac{q_i}{c} \vec{A}_i(\vec{r}_i, \vec{\eta}_i(t)))^2} + \sum_{i < j} \frac{q_i q_j}{4\pi |\vec{\eta}_i(t) - \vec{\eta}_j(t)|} \\
 &+ \frac{1}{2} \int d^3\sigma [\vec{\Pi}_\perp^2 + \vec{B}^2](\vec{r}, \vec{\sigma}) \\
 \vec{P} &= \sum_i \vec{K}_i(t) + \frac{1}{c} \int d^3\sigma (\vec{\Pi}_\perp \times \vec{B})(\vec{r}, \vec{\sigma}) \approx 0 \\
 \vec{J} = \vec{S} &= \sum_i \vec{\eta}_i(t) \times \vec{K}_i(t) + \frac{1}{c} \int d^3\sigma [\vec{\sigma} \times (\vec{\Pi}_\perp \times \vec{B})](\vec{r}, \vec{\sigma}) \\
 \vec{K} &= - \sum_i \vec{\eta}_i(t) \sqrt{m_i^2 c^2 + (\vec{K}_i - \frac{q_i}{c} \vec{A}_i(\vec{r}_i, \vec{\eta}_i(t)))^2} + \\
 &+ \frac{1}{c} \sum_{i < j} q_i q_j \left(\frac{1}{4\pi} \frac{\partial C(\vec{\eta}_i(t) - \vec{\eta}_j(t))}{\partial \vec{\eta}_j} - \vec{\eta}_j(t) C(\vec{\eta}_i(t) - \vec{\eta}_j(t)) \right) \\
 &+ \sum_i \frac{q_i}{c} \int d^3\sigma \vec{\Pi}_\perp(\vec{r}, \vec{\sigma}) C(\vec{\sigma} - \vec{\eta}_i(t)) - \\
 &- \frac{1}{2c} \int d^3\sigma \vec{\sigma} (\vec{\Pi}_\perp^2 + \vec{B}^2)(\vec{r}, \vec{\sigma}) \approx 0
 \end{aligned}$$

CRATER - LL - ANN. PHYS. 289(2001)37
 hep-th/0001046
 ALBA, CRATER, LL
 INT. J. MOD. PHYS. A16(2001)3365
 hep-th/0103109

2 PARTICLES WITH DARWIN POTENTIAL

$$\begin{aligned}
 M_C &= \sqrt{m_1^2 c^2 + \vec{K}_1^2(t)} + \sqrt{m_2^2 c^2 + \vec{K}_2^2(t)} + \frac{q_1 q_2}{4\pi |\vec{\eta}_1(t) - \vec{\eta}_2(t)|} + V_{\text{DARWIN}} \\
 \vec{P} &= \vec{K}_1(t) + \vec{K}_2(t) \approx 0 \\
 \vec{J} = \vec{S} &= \vec{\eta}_1(t) \times \vec{K}_1(t) + \vec{\eta}_2(t) \times \vec{K}_2(t) \\
 \vec{K} &= - \sum_i \vec{\eta}_i(t) \sqrt{m_i^2 c^2 + \vec{K}_i^2(t)} \cdot \left[\frac{1}{2} \frac{\partial K_{12}}{\partial \vec{S}} - 2 \vec{A}_{1s1}(\vec{K}_1, \vec{S}) \right] \\
 &- \frac{q_1 q_2}{2c} \left[\vec{\eta}_1 \frac{\vec{K}_1}{\sqrt{m_1^2 c^2 + \vec{K}_1^2}} \cdot \left(\frac{1}{2} \frac{\partial K_{12}}{\partial \vec{S}} - 2 \vec{A}_{1s2}(\vec{K}_2, \vec{S}) \right) + \vec{\eta}_2 \frac{\vec{K}_2}{\sqrt{m_2^2 c^2 + \vec{K}_2^2}} \cdot \left(\frac{1}{2} \frac{\partial K_{12}}{\partial \vec{S}} - 2 \vec{A}_{2s1}(\vec{K}_1, \vec{S}) \right) \right] \\
 &- \frac{q_1 q_2}{2c} \left(\sqrt{m_1^2 c^2 + \vec{K}_1^2} \frac{\partial}{\partial \vec{K}_1} + \sqrt{m_2^2 c^2 + \vec{K}_2^2} \frac{\partial}{\partial \vec{K}_2} \right) K_{12}(\vec{K}_1, \vec{K}_2, \vec{S}) - \\
 &+ \frac{q_1 q_2}{4\pi c} \int d^3\sigma \left(\frac{\vec{\Pi}_{1s1}(\vec{\sigma} - \vec{\eta}_1, \vec{K}_1)}{|\vec{\sigma} - \vec{\eta}_1|} + \frac{\vec{\Pi}_{1s2}(\vec{\sigma} - \vec{\eta}_2, \vec{K}_2)}{|\vec{\sigma} - \vec{\eta}_2|} \right) - \\
 &- \frac{q_1 q_2}{c} \int d^3\sigma \left[\vec{\Pi}_{1s1}(\vec{\sigma} - \vec{\eta}_1, \vec{K}_1) \cdot \vec{\Pi}_{1s2}(\vec{\sigma} - \vec{\eta}_2, \vec{K}_2) + \vec{B}_{s1}(\vec{\sigma} - \vec{\eta}_1, \vec{K}_1) \cdot \vec{B}_{s2}(\vec{\sigma} - \vec{\eta}_2, \vec{K}_2) \right] \approx 0
 \end{aligned}$$

IMPLICATIONS FOR RELATIVISTIC ENTANGLEMENT

ISOLATED SYSTEMS - CLOSED UNIVERSE

CLOCK SYNCHRONIZATION (INSTANTANEOUS 3-SPACE, CAUCHY PROBLEM)

KINEMATICAL NON-LOCALITY - THE RELATIVISTIC CENTER OF MASS IS A GLOBAL QUANTITY NOT LOCALLY MEASURABLE

+ PREFERRED $\vec{n}$ -BASIS
(3-SPACE)

SEE NEWTON-WIGNER LOCALIZATION PROBLEM
THE NW POSITION OPERATOR CANNOT BE BUILT WITH
LOCAL OR QUASI-LOCAL OPERATORS

$\Rightarrow$ NON-COVARIANCE OF $\vec{Z} = m\vec{c}\vec{x}_{NW}$ IRRELEVANT

KINEMATICAL SPATIAL NON-SEPARABILITY

$$H \approx H_{\text{com}} \otimes H_{\text{rel}} \neq H_1 \otimes H_2 \otimes \dots$$

POSITION OR MOMENTUM BASES KINEMATICALLY PREFERRED

PREFERRED ROBUST POINTER BASES
IN H_{rel} FROM DECOHERENCE

NO ZEROth POSTULATE ON COMPOSITE
SYSTEMS, NO EINSTEIN SEPARABILITY

ONLY RELATIVE VARIABLES (WEAK RELATIONISM $\neq$ ROVELLI)

THESE RELATIVISTIC PROPERTIES BEFORE QUANTUM NON-LOCALITY (ENTANGLEMENT)

NON-LOCALITY (FAKE A-A-D INTERACTION) - FROM KINEMATICS OF Poincaré GROUP
(NO SUPERLUMINAL SIGNALS)

NO EINSTEIN REALISM - LOCAL HIDDEN VARIABLES RULED OUT BY EXPERIMENTS
SUPERPOSITION OF MACROSCOPIC OBJECTS (DOUBLE SLIT
EXPERIMENT WITH FULLERENE MOLECULES) SHIELDED FROM
RELEVANT ENVIRONMENT

REALITY? - PROBABILISTIC RULES + PROBLEM OF OUTCOMES (COLLAPSE
AND EIGENVECTOR-EIGENVALUE LINK OR SPONTANEOUS COLLAPSE
OR EVERETT OR BOHN)

INTERPRETATION OF THE REDUCED DENSITY MATRIX

(IMPROPER MIXTURE)

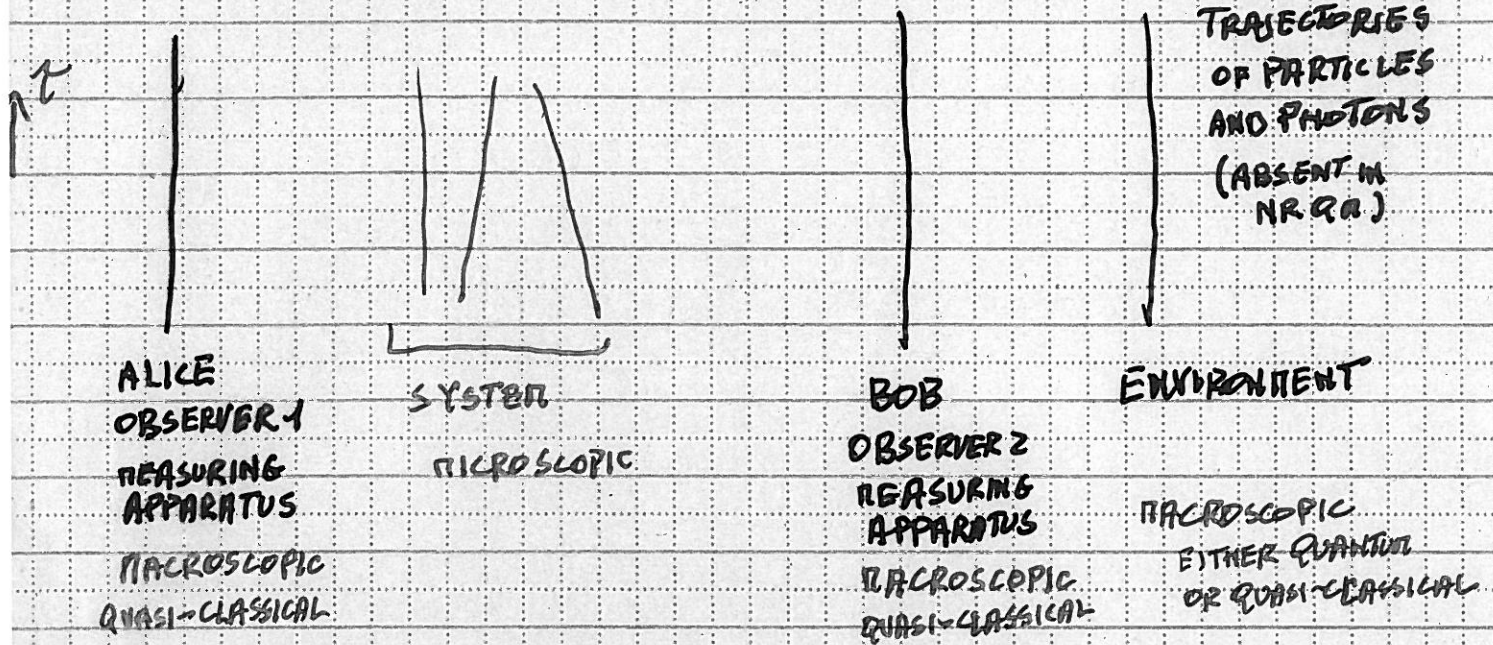
DECOHERENCE - OPEN SUBSYSTEMS, BREAKING OF UNITARITY, PREFERRED ROBUST POINTER
BASES (BUT SPECIAL INTERACTIONS, SCHRÖDINGER DECOMPOSITION, 3 SUBSYSTEMS?)
NO SOLUTION TO PROBLEM OF OUTCOMES

EMERGENCE OF QUASI-CLASSICAL MACROSCOPIC OBJECTS (Ehrenfest, GAUSSIAN MINIMAL UNCERTAINTY
WAVE PACKETS, WITH POSITIVE WIGNER FUNCTION) - OPEN PROBLEM

O. PESSOA JR - WE NEED AN ENVIRONMENT-INDUCED COLLAPSE (MANY-BODY PROBLEM)

ISOLATED SYSTEM IN REST-FRAME QM

$$H_{com} \otimes H_{rel}$$



LOOK FOR THE SET OF CANONICAL RELATIVE VARIABLES MORE SUITABLE TO THE PROTOCOL OF THE EXPERIMENT (BELL INEQUALITIES, TELEPORTATION)

LIKE IN MOLECULAR PHYSICS - CANONICAL JACOBI COORDINATES MOST SUITABLE TO DESCRIBE THE STRONGEST CHEMICAL BONDS INSIDE THE MOLECULE (THE OTHERS TREATED WITH PERTURBATION THEORY)

MAX. NUMBER OF CONSTANTS OF MOTION PREFERRED MACROSCOPIC OBJECTS

STUDY $\langle \hat{x}_i^2(t) \rangle$ OF PREDICTIVE WORLDLINES (NOT COMMUTING) TO RECOVER CLASSICAL TRAJECTORIES

NO MICROCAUSALITY BUT CLUSTER DECOMPOSITION (CRITICISM TO LOCAL QFT - UNSHARP MEASUREMENTS)

ENTANGLEMENT WITH EXTERNAL NON-LOCAL CENTER OF MASS NOT MEASURABLE

SUPERSELECTION RULE?

$$\psi = \psi_{com} \otimes \prod_a \psi(\vec{r}_a, \vec{p}_a)$$

$$H_{rel} = \otimes_a H_{sa} \text{ OR } \otimes_i H_{\vec{r}_i} | \vec{p}_{\approx 0} \vec{r}_{\approx 0} \text{ (INTERACTION-DEPENDENT)}$$

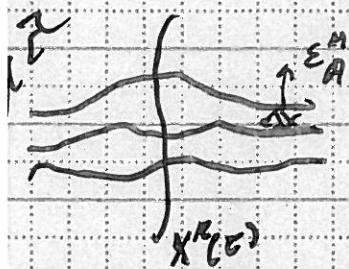
STUDY SIMPLE EXAMPLES

WITH MACROSCOPIC BODIES $\vec{r}_{\approx 0}$ MAY BE APPROXIMATED WITH $\vec{r}_{INT. CO.}$ AND WE MAY WORK IN THE SEPARABLE UNPHYSICAL HILBERT SPACE $\otimes_i H_{\vec{r}_i}$ RESTRICTED AT THE END ($\vec{p}_{\approx 0}, \vec{r}_{\approx 0}$)

ATOMIC PHYSICS - RAY OF LIGHT + POLARIZATION (IN NRQM ONLY POLARIZATION) SPINNING PARTICLES

TELEPORTATION TO SPACE STATION - DIFFICULT CONTROL OF POLARIZATION DUE TO ATMOSPHERE

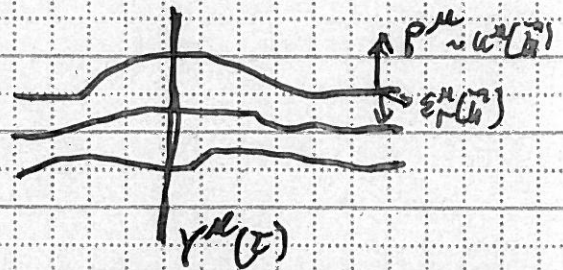
NON-INERTIAL FRAMES IN EINSTEIN SPACETIME



$$Z^A(t, \vec{\sigma}) \approx X^A(t) + F^A(t, \vec{\sigma})$$

$$F^A(t, 0) = 0$$

$$F^A(t, \vec{\sigma}) = \epsilon^A_A \Lambda^A_B(t, \vec{\sigma}) \sigma^B$$



IN EACH POINT

LINEAR ACCELERATION HYPOTHESIS) NOT NECESSARILY

ANGULAR VELOCITY (RESTRICTION ON ANGULAR VELOCITY)

$$g_{FAB} = \epsilon \begin{pmatrix} \eta_F^2 - h_F^{rs} \eta_F^r \eta_F^s & -h_F^{ru} \eta_F^u \\ -h_F^{su} \eta_F^u & -h_F^{rs} \end{pmatrix}$$

NON-INERTIAL REST FRAMES AND REST-FRAME INSTANT FORM

$$Z^A(t, \vec{\sigma}) = Y^A(t) + U^A(t) g(t, \vec{\sigma}) + \epsilon_F^A(t) [\sigma^r + g^r(t, \vec{\sigma})]$$

INERTIAL FORCES ON PARTICLES IN NON-COVARIANT RADIATION GAUGE

$$m_i \frac{d}{dt} \left(\frac{h_F^{rs} (\dot{y}_L^r + \eta_F^r)}{\sqrt{\eta_F^2 - h_F^{ru} (\dot{y}_L^u + \eta_F^u) (\dot{y}_L^u + \eta_F^u)}} (y_L^r(t)) \right) = q_L [\vec{E}_L + \dot{\vec{y}}_L(t) \times \vec{B}] (y_L^r(t)) + q_L \frac{\partial W}{\partial y_L^r} +$$

NON-INERTIAL (GOLD)

$$+ \left(\frac{m_i}{\sqrt{\eta_F^2 - h_F^{ru} (\dot{y}_L^u + \eta_F^u) (\dot{y}_L^u + \eta_F^u)}} \left[\frac{\partial \eta_F^u}{\partial y_L^r} h_F^{ru} (\dot{y}_L^u + \eta_F^u) - \frac{\partial \eta_F}{\partial y_L^r} + \frac{\partial h_F^{ru}}{\partial y_L^r} \frac{(\dot{y}_L^u + \eta_F^u) (\dot{y}_L^u + \eta_F^u)}{\eta_F} \right] \right) (y_L^r(t))$$

IDENTIFY THE RELATIVISTIC INERTIAL FORCES

$$\downarrow c \rightarrow \infty$$

$$m_L \ddot{\vec{x}}_L(t) = \vec{F} + m_i \left[-\vec{w}(t) + \vec{x}_L(t) \times \frac{d\vec{\omega}(t)}{dt} + 2 \dot{\vec{x}}_L(t) \times \vec{\omega}(t) + \vec{\omega}(t) \times (\vec{x}_L(t) \times \vec{\omega}(t)) \right]$$

LINEAR AC. JACOBI CORIOLIS CENTRIFUGAL

CANONICAL GRAVITY

EQUIVALENCE PRINCIPLE

DISENTANGLE RELATIVISTIC INERTIAL EFFECTS FROM TIDAL EFFECTS (grav. waves, graviton --)

QUANTUM MECHANICS OF SCALAR AND SPINNING PARTICLES IN NON-INERTIAL FRAMES
ALBA, L.L. hep-th/0502060 INT. J. MOD. P. 41 (2006) 2731

MULTITEMPORAL QUANTIZATION - QUANTIZE THE PARTICLES BUT NOT THE INERTIAL APPEARANCES [$Z^A(t, \vec{\sigma})$ C-NUMBERS]

ATOMIC SPECTRA OK

NON-REL QM

ALBA, hep-th/0504060

INT. J. MOD. PHYS. 21 (2006) 3913

QUANTUM MECHANICS OF SCALAR AND SPINNING PARTICLES IN NON-INERTIAL FRAMES

D. ALISA and L.L.
INT. J. MOD. PHYS
21(2006)2781 relativistic
21(2006)3917 non-relativistic
hep-th/0502060
0504060

MULTITEMPORAL QUANTIZATION

QUANTIZE ONLY THE PARTICLES BUT NOT

THE INERTIAL APPEARANCES [$Z''(t, \vec{x})$ C-NUMBER]

NON-INERTIAL REST-FRAME INSTANT FORM



INERTIAL EFFECTS ON

PARTICLES + TRANSVERSE
ELECTRO-MAGNETIC FIELD
COMPARISON WITH CANONICAL
EINSTEIN-RAWELL (EQUIVALENCE)
PRINCIPLE

TORRE-VARADARAJAN - CLASS. QUANT. GRAV 16(1999)2651

FRAGGORGIS, EARRAN, RUETSONG
STUDIES HIST. PHIL. MODERN PHYS
33(2002)151

OPEN PROBLEM

QUANTIZATION OF KG FIELD IN NON-INERTIAL FRAMES

WITH THE PREVIOUS MULTITEMPORAL METHOD → STANDARD PARTICLE MODEL
IN NON-INERTIAL FRAMES

AVOID THE TORRE-VARADARAJAN NO-GO THEOREM (NO
UNITARY EVOLUTION IN THE TONONOGA-SCHWINGER FORMALISM)

EVOLUTION (KATULTONIAN) ONLY IN A 3+1 SPLITTING → FOURIER TRANSFORMATION
INSTANTANEOUS 3-SPACES → FOCK SPACE

1) 3+1 SPLITTINGS WITH LEAVES ADMITTING FOURIER TRANSFORM INSTEAD OF
DETECTORS REPLACING
PARTICLES
(QFT IN CURVED
SPACETIMES)

$$\begin{array}{c} \uparrow \\ \text{Diagram of two horizontal lines with a vertical arrow pointing up between them} \end{array} \quad \begin{array}{l} a(\vec{k}_1, t_2) \dots \\ a(\vec{k}_1, t_1) \dots \end{array}$$

↑ BOGOLUBOV
↓ TRANSFORMATION

$$a_{\vec{k}}' = \sum_{\vec{q}} [\alpha_{\vec{k}\vec{q}} a_{\vec{q}} + \beta_{\vec{k}\vec{q}} a_{\vec{q}}^\dagger]$$

2) FIND 3+1 SPLITTINGS WITH HILBERT-SCHWIDT $\sum_{\vec{k} \in E} |\beta_{\vec{k}}|^2 < \infty$

3) UNITARY EQUIVALENCE OF HS 3+1 SPLITTINGS



TRY TO REFORMULATE THE STANDARD MODEL OF ELEMENTARY
PARTICLES IN NON-INERTIAL FRAMES (THE ONLY ONES
EXISTING IN EINSTEIN GLOBALLY HYPERBOLIC SPACETIME DUE TO
THE EQUIVALENCE PRINCIPLE)

GENERAL RELATIVITY (EINSTEIN SPACETIMES)

GEOMETRICAL VIEW OF THE GRAVITATIONAL FIELD

EVERYTHING IS DYNAMICAL

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}$$

SPACETIME $\approx$ GRAVITATIONAL FIELD

$\Rightarrow$ CAUCHY SURFACE NEEDED

DOUBLE ROLE OF THE METRIC TENSOR $g_{\mu\nu}(x)$ [x^μ 4-COORDINATES IN A CHART OF THE ATLAS OF π_4]

A) POTENTIAL OF THE GRAVITATIONAL FIELD

B) DYNAMICAL CHRONOGEOMETRICAL STRUCTURE OF SPACETIME $ds^2 = g_{\mu\nu}(x) dx^\mu dx^\nu$

$g_{\mu\nu}(x)$ TEACHES RELATIVISTIC CAUSALITY TO THE OTHER FIELDS!

GLUONS...

$\swarrow \searrow$ ~~NON~~ NULL GEODESICS ($ds^2=0$) VARYING WITH THE POINT (TRAJECTORIES OF PHOTONS)

PT, STRING - FIX BACKGROUND - B) LOST - NON GEOMETRICAL VIEW (FEYNMAN), GRAVITON $m=0, h=2$

RELATIVITY PRINCIPLE $\rightarrow$ PRINCIPLE OF GENERAL COVARIANCE - $G_{\mu\nu}$ 4-TENSOR

POINCARÉ GROUP $\rightarrow$ DIFFEOMORPHISM GROUP

$\rightarrow$ INVARIANCE IN FORT

EQUIVALENCE PRINCIPLE $\rightarrow$ GLOBAL INERTIAL FRAMES DO NOT EXIST!

ONLY FREE FALL



SPACETIMES

PARTICLE PHYSICS - CHAPTER OF THE THEORY OF REALIZATIONS

OF THE POINCARÉ GROUP IN INERTIAL FRAMES IN BINKOWSKI SR

$\pi_4 = \mathbb{R}^3 \times \mathbb{R}$

A) GLOBALLY HYPERBOLIC (TIME), SPATIALLY NON-COMPACT, TOPOLOGICALLY TRIVIAL

$\hookrightarrow$ AND HAMILTONIAN FORMULATION

B) ASYMPTOTICALLY FLAT AT SPATIAL INFINITY AND WITHOUT TRANSLATION

SUPER-

$\hookrightarrow$ ASYMPTOTIC ADM POINCARÉ GROUP



GLOBAL NON-INERTIAL FRAMES CENTERED ON ACCELERATED OBSERVERS

ASYMPTOTIC INERTIAL OBSERVERS (FIXED STARS)

REST FRAME OF THE 3-UNIVERSE

$g_{\mu\nu}(x) \xrightarrow{\text{SPATIAL INFINITY}} \eta_{\mu\nu}$

ASYMPTOTIC BACKGROUND

ASYMPTOTICALLY MINKOWSKIAN SPACETIME

(G) DEPARAMETRIZATION TO THE REST-FRAME INSTANT FORT $P_{ADM}^A \rightarrow P^A$

LOOP QUANTUM GRAVITY - SPATIALLY COMPACT SPACETIME -

IN ABSENCE OF MATTER CHRISTODOULOU-KLAINTERMAN SPACETIMES

$J_{ADM}^A \rightarrow J^A$

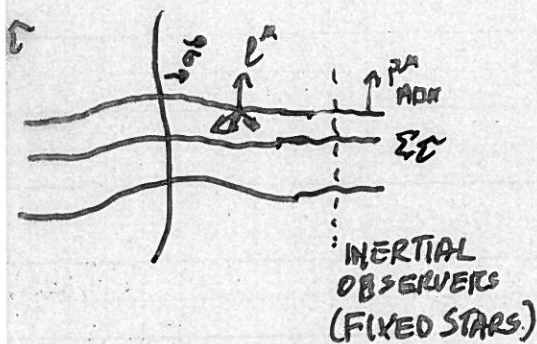
$\hookrightarrow$ PARTICLE PHYSICS?

HAMILTONIAN FORMULATION TO DISENTANGLE THE GAUGE VARIABLE FROM THE PHYSICAL DEGREES OF FREEDOM OF THE GRAVITATIONAL FIELD

$\Rightarrow$ FIXED GAUGE WITH DETERMINISTIC HAMILTON EQS AND A WELL POSED CAUCHY PROBLEM

TETRAID GRAVITY (FERIONS) $\gamma_{AB}(t, \vec{x}) = E_A^{(\mu)}(t, \vec{x}) \gamma_{(\mu)(\nu)} E_B^{(\nu)}(t, \vec{x})$

USE ADM ACTION



$$g_{AB}(t, \vec{x}) = E_A^{(\alpha)}(t, \vec{x}) \eta_{(\alpha)(\beta)} E_B^{(\beta)}(t, \vec{x})$$

TETRAD GRAVITY (FERRIONS)

16 + 16 = 32
 14 CONSTRAINTS, GENERATORS OF GAUGE TRANS.
 14 GAUGE VARIABLES (INERTIAL EFFECTS)
 2+2 d.o.f. OF GRAVIT. FIELD (TIDAL EFFECTS)

YORK CANONICAL BASIS

$\phi_{(a)}$	$\alpha_{(a)}$	n	$\bar{n}_{(a)}$	θ^r	ϕ^2	$R_{\bar{a}}$
≈ 0	≈ 0	≈ 0	≈ 0	$\pi_r^{(0)}$	π_ϕ	$\pi_{\bar{a}}$

EIGENVALUES OF 3-METRIC WITH $\det g = 1$

DIAGONAL ELEMENTS OF SHEAR

$\phi = (3g)^{1/2}$ 3-VOLUME ELEMENT - from super-hamiltonian constraint

$\pi_r^{(0)}$ - from the super-momentum constraints
 NON-DIAGONAL ELEMENTS OF SHEAR

LICHNEROWICZ EQ.

GAUGE VARIABLES

$\alpha_{(a)}, \phi_{(a)}$ - D(3,1) gauge freedom of tetrads - CHOICE OF 3 GYROSCOPES AND THEIR TRANSFORM LAW FROM OBSERVERS

θ^r - gauge freedom of 3-COORDINATES ON $\Sigma_t \Rightarrow$ CORIOLIS ...
 $\bar{n}_{(a)}$ - " " in GRAVITO-MAGNETISM (it depends on the choice of 3-rod)
 $\Rightarrow$ GRAVITOMAGNETIC EFFECTS

$\pi_\phi \approx 3K$ - " " in the CHOICE OF 3-SPACE, I.E. OF the CLOCK SYNCHRONIZATION CONVENTION
 $\Rightarrow$ INERTIAL FORCE NOT EXISTING IN NEWTON THEORY
 n - " " culture LOCAL UNIT OF PROPER TIME $\Rightarrow$ TIME INERTIAL FORCE

$$E_A^{(\alpha)} = L^{(\alpha)}_{(a)}(\phi_{(a)}) \left(\frac{1+n}{\phi} \right) + L^{(\alpha)}_{(a)}(\phi_{(a)}) \left(\frac{n_{(a)}}{3e_{(a)r}} \right)$$

$$3e_{(a)r} = R_{(a)(b)}(\alpha_{(a)}) V_{ra}(\theta^r) \phi^2 e^{\bar{z}\bar{a}} \delta_{\bar{a}a} R_{\bar{a}}$$

$$g_{rs} = \sum_a 3e_{(a)r} 3e_{(a)s} = \phi^4 \sum_a V_{ra}(\theta^r) V_{sa}(\theta^s) e^{\bar{z}\bar{a}} \delta_{\bar{a}a} R_{\bar{a}}$$

$$g_{tr} = 3e_{(a)r} n_{(a)} \quad g_{tt} = (1+n)^2 - n_{(a)} n_{(a)}$$

$$H = E_{ADM} \quad H_n = \left(d^2 \sqrt{E_{ADM}}(t, \vec{x}) + n(t, \vec{x}) \mathcal{H}(t, \vec{x}) + \bar{n}_{(a)} \mathcal{H}_{(a)}(t, \vec{x}) \right)$$

12 ADM EQUATIONS $\xrightarrow{\text{YORK}}$ $\left\{ \begin{array}{l} 4 \text{ CONTRACTED BIANCHI IDENTITIES } \partial_t \phi, \partial_t \pi_i^j \\ 4 \text{ EQUATIONS FOR GAUGE VARIABLES } \partial_t \theta^a, \partial_t \tau_a \\ 4 \text{ EQUATIONS FOR TIDAL VARIABLES } \partial_t R_a, \partial_t \pi_a \end{array} \right.$

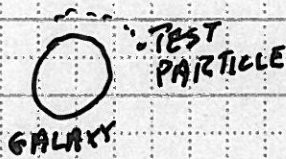


ASYMPTOTIC FLAT BACKGROUND

ADD PARTICLES
+ EM FIELD

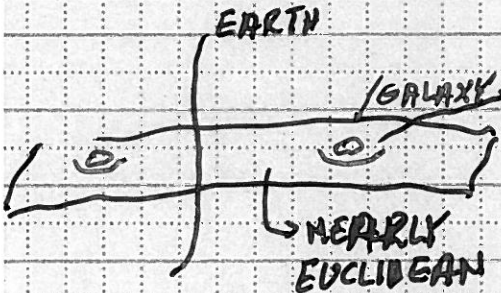
LINEARIZATION
WITHOUT $g \approx \eta + h$

RESONANCE OF PN EXPANSION
RELATIVISTIC QUADRUPOLE EMISSION
FORMULA
PARTICLE EQUATIONS OF MOTION
WITH RELATIVISTIC INERTIAL FORCES
REPLACING KEPLER EQUATIONS



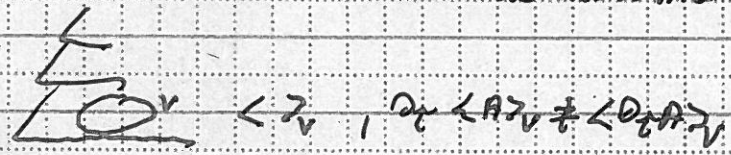
INVERSE PROBLEM

FIX THE GAUGE BUT NOT $\pi_a^k = {}^3K$: LEAVE IT AS A FREE FUNCTION
- FIT 3K TO ROTATION CURVES OF GALAXIES



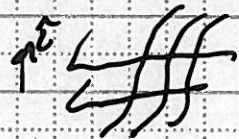
DARK MATTER
AS A

RELATIVISTIC INERTIAL EFFECT?



ADD FLUID - STUDY BACKREACTION WITH YORK-ADM EQUATIONS

VELOCITY FIELD OF FLUID - CONGRUENCE OF TIRELIKE OBSERVERS
IN GENERAL NOT SURFACE-FORMING



IMPOSE RESTRICTION ON SOLUTIONS OF FLUID-EINSTEIN EQUATION

$\text{VORTICITY OF FLUID CONGRUENCE} = 0 \Rightarrow$ EXISTENCE OF PRIVILEGED
3-SPACES DETERMINED BY MATTER
CMB OBSERVERS

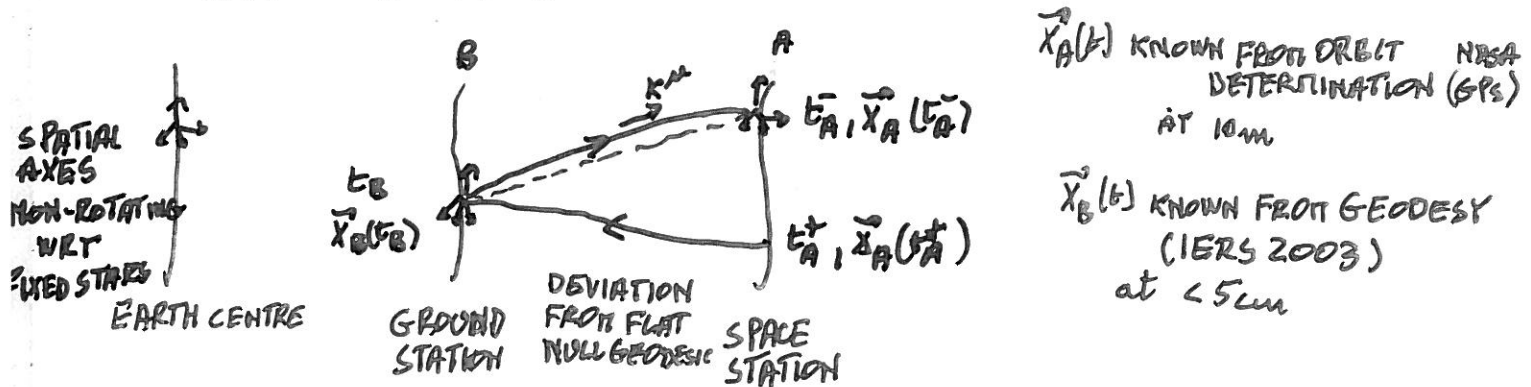
ACES - ESA MISSION

2013?

HIGH PRECISION ^{NICROWAVE} ATOMIC CLOCK (PHARAO) WITH RELATIVE ACCURACY 10^{-16} /day (GPS 10^{-16}) ON SPACE STATION

2-WAY LINK WITH ATOMIC CLOCKS IN EARTH STATIONS (IN THE FUTURE ^{NICROWAVE} OPTICAL CLOCKS 10^{-18})

MAIN MEASUREMENT GRAVITATIONAL REDSHIFT FROM THE POST-NEWTONIAN GRAVITATIONAL POTENTIAL OF THE EARTH (IAU 2000 CONVENTIONS) IN THE GEOCENTRIC CELESTIAL REFERENCE FRAME CENTER IN THE CENTRE OF THE GEOID



t - GEOCENTRIC TIME

$t = \text{const}$ INST. 3-SPACE (NON-EUCLIDEAN $O(\frac{1}{c^2})$)

SALONON, TEYSSANDIER, WOLF, BLANCHET (2001)

$$\frac{\delta\nu}{\nu} = \frac{1}{c^2} \left[U_B - U_A - \frac{1}{2} \vec{v}_{AB}^2 - \vec{r}_{AB} \cdot \vec{a}_B \right] \cdot \left(1 + \frac{\vec{n}_{AB} \cdot \vec{v}_{AB}}{c} \right)$$

$\sim 5 \cdot 10^{-17}$

GRAV. REDS. OF GEOID ($\sim 5 \cdot 10^{-11}$)

2nd ORDER DOPPLER SHIFT ($\sim 3 \cdot 10^{-10}$)

SAGNAC ($\sim 7 \cdot 10^{-13}$)

LIKE A FIRST ORDER DOPPLER SHIFT ($\sim 10^{-9}$)

$+ O(\frac{1}{c^2})$ ($< 10^{-17}$)

STATIC SPHERICAL GEOPOTENTIAL

FURTHER CORRECTIONS FROM EARTH MULTIPOLES

IT IS POSSIBLE TO EXPRESS t_B IN TERMS OF

t_A^+ EMISSION TIME
 t_A^- ARRIVAL TIME
 $\hat{n}^+|_{t_A^+}$ TANGENT AT THE NULL GEODESIC AT THE EMISSION TIME
 $=$ EMISSION ANGLES θ_A^+, ϕ_A^+
 $\vec{v}_A, \vec{a}_A$ - A VELOCITY AND ACCELERATION AT THE EMISSION TIME

WITH A STRAIGHTFORWARD CALCULATION

$$t_B = t_A^+ + \frac{1}{2} \left[1 - \left\{ \frac{1}{c} \left(\vec{v}_A \cdot \hat{n}_+ + \vec{a}_A \cdot \hat{n}_+ (t_A^- - t_A^+) \right) - \frac{2}{c^2} \left(\vec{v}_A^2 - (\vec{v}_A \cdot \hat{n}_+)^2 \right) \right\} (t_A^- - t_A^+) \right]$$

$\approx 10 \text{ nsec}$ $\approx 0.1 \text{ psec}$

$\mathcal{E}(t_A^-, t_A^+, \hat{n}_+, \vec{v}_A, \vec{a}_A) \neq \frac{1}{2}$ SPECIAL RELATIVISTIC CORRECTIONS AT $\mathcal{E} = \frac{1}{2}$

$$\hat{n}_+ = \frac{\vec{x}_B - \vec{x}_A(t_A^+)}{R_A^+} + \frac{G\pi}{c^2} \hat{\alpha}_+$$

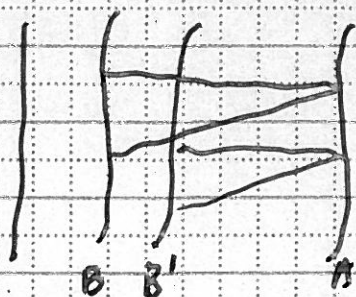
$\hookrightarrow$ GENERAL RELATIVISTIC CORRECTION TO $\mathcal{E}$
 AT ORDER $\frac{1}{c^2}$

$\Rightarrow$ POSSIBILITY OF ABSOLUTE SYNCHRONIZATION OF THE CLOCKS IN THE EARTH STATION WITH THE CLOCK IN THE SPACE STATION AT THE LEVEL OF 1 nsec OR LESS IN THE GEOCENTRIC NON-INERTIAL FRAME (ACES 100PS)
 TILL NOW $\mathcal{E} = \frac{1}{2}$ IS USED IN THE MICROWAVE LINK!
 (2-WAY TIME TRANSFER, T2L2)

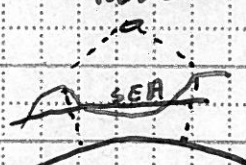
NO DATA!
 TILL NOW
 ONLY ESTIMATES



COMPARISON OF TWO EARTH CLOCKS



GPS RECEIVER ON SPACE STATION NEEDED



MOVABLE OPTICAL CLOCKS REPLACING GRAVIMETERS

RELATIVISTIC GEODESY!
(SVELLA)

THEORY OF HEIGHTS WRT FLAT GPS DESCRIPTION OF EQUIPOTENTIAL SURFACES OVER THE REFERENCE ELLIPSOID

COSMIC MICRO WAVE BACKGROUND (OBSERVERS SEEING A BLACK BODY RADIATION)

LUMINOSITY DISTANCE

PAST LIGHT CONE AS EQUAL TIME SURFACE

NULL 4-COORD

GALAXY (SPIR)

RAY OF LIGHT

STAR COORD.

BCRS NON-ROTATING WET FIXED STARS

SUN Σ_B NON-EUCLIDIAN O(123)

IAU CONVENTIONS 2000

PN 4-METRIC [O(123) in E] SOLUTION OF EINSTEIN EQS IN HARMONIC 4-COORD.

HOW MUCH DARK MATTER AND DARK ENERGY IS A RELATIVISTIC INERTIAL EFFECT?

QUANTUM GRAVITY? PARTICLE PHYSICS IN CURVED SPACETIMES?

HAMILTONIAN 2-BODY PROBLEM IN TETRAD GRAVITY POST-NEWTONIAN GRAV. WAVES AND A-A-A-D POTENTIALS

GRAVITATIONAL FIELD TIDAL EFFECTS (GRAY WAVES)

INERTIAL EFFECTS (APPEARANCES)

A-A-A-D IN MATTER (NAVTON AND GRAVITOMAGNETIC POTENTIALS)

EQUIVALENCE PRINCIPLE ONLY NON-INERTIAL FRAMES EXIST

OBSERVABLES?

3+1 SPLITTINGS TIMELINE OBSERVERS

CLOCK SYNCHRONIZATION FUNDAMENTAL

ACES - GRAY REDSHIFT, SHAPED TIME DELAY, SPACIAL $1/c^2$ IN REL. GEODESY (TORBIT OF HEIGHTS)

REL. ENTANGLEMENT FROM REL. ATOMIC PHYSICS

QUANTIZATION

NON-INERTIAL FRAMES

FIELDS (TORSION-VARIATION NO GO THEOREM) PARTICLE PHYSICS IN NON-INERTIAL FRAMES?

N-BODY PROBLEM IN MINKOWSKI SP.

REL. ORBITS

INERTIAL FRAMES IN MINKOWSKI SP.

ATOMIC PHYSICS (etc)

ON EARTH CLOCK SYNCHRONIZATION N.E. ENTANGLEMENT, EPR (TELEPORTATION)

IRRELEVANT

REL. PARTICLE PHYSICS

1ERS CONVENTIONS 2003

ROTATING

GCES GRS

NON-ROTATING WET FIXED STARS

SPACE STATION

PROCESSION ROTATION EARTH AXIS NON-REL

