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RESEARCH ACTIVITY AND MAIN RESULTS:

1. Analysis of the time measurements in Quantum Mechanics. I have shown that for a given 2-dimensional plane P, the question "What is the probability that a particle in quantum state ψ will pass through P within the time interval $[t_0, t_1]$?" cannot be answered in terms of the standard probability current J considered in Quantum mechanics. I have introduced the "time operator" related with P and shown that it is uniquely determined by a few natural properties of the time measurement. Moreover, I have proved the Heisenberg uncertainty principle between the energy and the transition time through P (see positions 8, 9 of my publication list).

Most important publications among them:
[9] *On the time operator in quantum mechanics and the Heisenberg uncertainty relation for energy and time*, Rep. Math. Phys. **6** (1974) p. 361-386.
[103] *On the "arrival time" in quantum mechanics*, Phys. Rev. **A 59** (1999) p. 897 – 899

Recently: J. G. Muga published a volume entitled "Arrival time in quantum mechanics" (Physic Reports 338 (2000) 353 – 438) where he discusses among others the history of the problem and recent results. He writes in the Introduction:

A key result was due to Kijowski in 1974, who, instead of starting with the time operator, introduced an arrival-time distribution by imposing a number of conditions motivated by the classical mechanical case ...

Recently: I published a new paper in this domain:
[135] *Comment on "Time operator": the challenge persists*, Concepts of Phys. **2** (2005) pp. 99 – 102.

2. Analysis of the canonical structure of field theories. I introduced the notion of a *multi-symplectic manifold*. Multisymplectic field theory was later used by J. Marsden, M. Gotay, J. Isenberg and many others. It became one of the standard approaches to canonical field theory and the geometric formulation of the calculus of variations and is still used. Also, I am a co-author of a symplectic interpretation of variational principles in terms of symplectic relations and their generating functions (see positions 6, 7, 10, 11, 12, 16, 20, 22, 24, 28 of my publication list).

Most important ones among them:
[7] *A finite dimensional canonical formalism in classical field theory*, Comm. Math. Phys. **30** (1973) p. 99-128.
and
[20] *A symplectic framework for field theories* (together with W. M. Tulczyjew), Springer Lecture Notes in Physics, vol. **107** (1979), 257 pages.

3. Geometric Quantization. I contributed to the analysis of the compatibility of Quantum Mechanics and Quantum Field Theory with a possible non-flat structure of space-time and with the complete canonical structure of classical phase spaces (see positions 13, 15, 16, 17, 18, 39, 47).

Most typical one among them:
[16] *Symplectic geometry and second quantization*, Rep. Math. Phys. **11** (1977) p. 97-109.

4. Variational and canonical structure of General Relativity. I invented a new ("purely affine") variational principle for Einstein equations (see positions 19, 24, 25, 26, 27, 30, 31, 34). I have proved that, virtually, all "generalizations of General Relativity" (e. g. based on torsion, non-metric connection or non-linear Lagrangians) are *equivalent* to the standard, Einsteinian theory of the metric field interacting with additional matter fields. This way *all* dynamical effects obtained by such generalizations may be obtained by introducing additional matter fields in the conventional framework of General Relativity (see positions 42, 46, 49, 50 of my publication list).

Most typical publications among them:
[19] *On a new variational principle in general relativity and the energy of gravitational field*, GRG Journal **9** (1978), p. 857-881.
[83] *Unconstrained variational principle for relativistic elasticity theory* (together with G. Magli), Rep. Math. Phys. **39** (1997) p. 99-112

5. Formulation of classical and quantum theory of gauge fields in terms of gauge invariants. For many physically important models of gauge fields interacting with matter fields (e. g. Higgs fields) I have found a fully gauge-invariant formulation of both the canonical structure and the dynamics (see positions 28, 36, 38, 40, 51, 54, 64, 72, 77 of my list of publications).

Most important results in:
[51] *The functional integral on the gauge orbit space for a non-Abelian Higgs model* (together with G. Rudolph), Nuclear Physics. B **325** (1989) p. 211-224.
[77] *Functional Integral of QED in Terms of Gauge-Invariant Quantities* (together with G. Rudolph and M. Rudolph), Lett. Math. Phys. **33** (1995) p. 139-146
and
[91] *Effective Bosonic Degrees of Freedom for One-Flavour Chromodynamics* (together with G. Rudolph and M. Rudolph), Ann. Inst. H. Poincaré **68** (1998) p. 285 – 313

6. Lattice Gauge Field Theory I proposed a new description of gauge fields on the lattice (see positions 29, 37, 45, 48, 58, 72, 84). The last paper contains a complete analysis of the superselection sectors for the lattice version of Quantum Electrodynamics. In particular, it was shown that the theory may by expressed in terms of the algebra of observables (i. e. gauge invariant quantities only). The uniqueness of the irreducible representations of this algebra was proved.

Typical publication among them:
[37] *New lattice approximation of gauge fields* (together with G. Rudolph), Phys. Rev. D **31** (1985) p.859-864.
and
[82] *Algebra of Observables and Charge Superselection Sectors for QED on the Lattice* (together with G. Rudolph and A. Thielmann), Comm. Math. Phys. **188** (1997) p. 535 – 564

7. Positivity and quasi-localizability of gravitational energy. I gave a new proof of the "positive mass conjecture". For this purpose I developed a new technique of splitting initial data in General Relativity into the gauge part and the "true degrees of freedom" part. Comparing with other approaches (i. e. the one due to York) this method is quasi-local. Moreover, the "true degrees of freedom" are described by four unconstrained functions. The total field energy (A. D. M. mass at infinity) may be explicitly written in terms of a volume integral containing initial data. The gauge conditions which I use, *annihilate automatically* all terms under the integral, which are not explicitly positive. This way the positivity of the total energy becomes much more explicit than in other proofs (see positions 35, 41, 44, 55, 63 of my list of publications).

Typical publications among them:
[44] *Positivity of total energy in general relativity* (together with J. Jezierski), Phys. Rev. D. 36 (1987) p. 1041-1044.
and
[81] *A simple Derivation of Canonical Structure and quasi-local Hamiltonians in General Relativity*, Gen. Relat. Grav. Journal **29** (1997) p. 307-343

Recently: During the GR 17 conference (Dublin, July 2004) the plenary talk by P. Chruściel, devoted to "Recent results in mathematical gravity", contained several references to my results and a detailed discussion of the properties of the "Kijowski mass", a concept which I have introduced in 1997 (cf. paper [81] on my publication list) and later (in 2003) rediscovered by C. M. Liu and S.-T. Yau (cf. the paper *New definition of quasilocal mass and its positivity* by these authors, arXiv:gr-qc/0303019). The talk was published in the Proceedings of GR 17. It is also available as an arXiv:gr-qc/0411008 publication).

There was also an interesting comment to the "Kijowski mass" by O'Murhadha, Szabados and Tod: *Coment "Positivity of Quasilocal Mass"*, Phys. Rev. Letters, **92** (2004) p. 259001-1.

Recently: My approach to quasilocal definition of the gravitational energy was thoroughly analyzed by Laszlo Szabados in: *Quasi-local Energy-momentum and Angular Momentum in GR: A Review Article*, Living Rev, Relativity **7** (2004), 4, (available on the Web: http://www.livingreviews.org/lrr-2004-4).

8. Relativistic mechanics of continuous media and relativistic thermodynamics. I gave a consistent formulation of relativistic elasticity theory. An interesting astrophysical application leads to relatively simple models of crusts of neutron stars (see positions 60, 61, 62, 65, 68, 76 of my list of publications). I introduced the "material time" as the potential for relativistic temperature (see positions 32, 54, 57 of my list of publications).

Typical publications among them:

[60] *Relativistic elastomechanics as a lagrangian field theory* (together with G. Magli), Journ. Geometry and Phys. **9** (1992) p. 207-223

[90] *Lagrangian and Hamiltonian Formalism for Discontinuous Fluid and Gravitational Field* (together with P. Hájíček), Phys. Rev. **D57** (1998) p. 914 – 935

[98] *Unconstrained hamiltonian formulation of General Relativity with thermo-elastic sources* (together with Giulio Magli), Class. Quantum Grav. **15** (1998) p. 3891 – 3916

[104] *Covariant gauge fixing and Kuchař decomposition* (together with P. Hájíček), Phys. Rev. **D 61** (1999) p. 024037-1 – 024037-13

Recently: I was asked to write a review article discussing the status of variational principles in relativistic continuum mechanics and thermodynamics:

[127] *Variational Formulations of Relativistic Elasticity and Thermo-elasticity* (together with G. Magli), in *Variational and Extremum principles in Macroscopic Systems*, Eds.: S. Sieniutycz, H. Farkas, Elsevier (2005); Part 1, Chapter 5, p. 97 – 114.

9. Problem of motion in classical electrodynamics (beyond the "test particle approximation"). I found a local and causal renormalization procedure of classical, Maxwell electrodynamics with point-like sources. As a result, I proposed a self-consistent, relativistic theory of a physical system composed of point-like particles interacting with the Maxwell field. The particles are not treated as test particles: they are not only influenced by the field but they influence the field themselves. The theory is local and causal (see positions 69, 73, 74, 79 of my list of publications).

Typical publications among them:

[73] *Electrodynamics of moving bodies*, GRG Journal **26** (1994) p. 167-201

[99] *The Relativistic Dynamics of the Combined Particle-Field System in Nonlinear Renormalized Electrodynamics* (together with Hans-Peter Gittel and Eberhard Zeidler), Comm. Math. Phys. **198** (1998) p. 711 – 736

and

[105] *Head or tail: the dilemma of electrodynamics* Proceedings of the International Symposium "Quantum Theory and Symmetries" (Goslar, 18-22 July 1999); Editors H.-D. Doebner, V.K. Dobrev, J.-D. Hennig and W. Luecke; World Scientific

Recent publications in this field:

[92] *Generation of multipole moments by external field in Born-Infeld non-linear electrodynamics* (together with D. Chuściński), J. Phys. A: Math. Gen. **31** (1998) p. 269 – 276.

[97] *A Gauge-invariant Hamiltonian Description of the Motion of Charged Test Particles* (together with D. Chruściński), Journal Geom. Phys. **27**, (1998) p. 49 – 64.

[108] *Asymptotic expansion of the Maxwell field in a neighbourhood of a multipole particle* (together with M. Kościelecki), Acta. Phys. Polon. **B 31** (2000) p. 1691 – 1707

[117] *Born renormalization in classical Maxwell electrodynamics* (together with Piotr Podleś), Journal Geom. Phys. **48** (2003) p. 369 – 384.
[129] *On stability of renormalized classical electrodynamics* (together with M. Kościelecki), physics/0305123, Acta Physica Polonica B **36** (2005) p. 75 – 107.

Research activity in last few years:

10. Superselection rules in QED and QCD. In context of the lattice version of Quantum Electrodynamics we have examined thoroughly the "total charge" *versus* "the distribution of the electric flux at spatial infinity" superselection rules. We have proved that irreducible representations of the Observable Algebra are actually numbered by the value of the total charge: representations which differ only by the distribution of fluxes at the boundary, but correspond to the same value of the total charge, are equivalent. A similar analysis, consisting in the analysis of the Observable Algebra and its representations, was later applied to the lattice QCD model. Here, the Z_3-valued charge, numbering irreducible representations of the Observable Algebra, was found and the role of boundary data in the field quantization was analyzed.

Principal publications in this field:
[82] *Algebra of Observables and Charge Superselection Sectors for QED on the Lattice* (together with G. Rudolph and A. Thielmann), Comm. Math. Phys. **188** (1997) p. 535 – 564.
[93] *On the Structure of the Observable Algebra for QED on the Lattice* (together with G. Rudolph and C. Śliwa), Lett. Math. Phys. **43** (1998) p. 299 – 308.
[112] *On the Gauss law and global charge for quantum chromodynamics* (together with G. Rudolph), Jour. Math. Phys. **43** (2002) p. 1796 – 1808
[118] *Charge Superselection Sectors for Scalar QED on the Lattice* (together with G. Rudolph and C. Śliwa), Ann. Inst. H. Poincaré, **4** (2003) p. 1136 – 1167.
[128] *Charge Superselection Sectors for QCD on the Lattice* (together with G. Rudolph), Journ. Math. Phys. **46** (2005) p. 032303-1 – 032303-32, hep-th/0404155.
[133] *On the Structure of the Observable Algebra of QCD on the Lattice* (together with P. Jarvis and G. Rudolph), hep-th/0412143, J. Phys. A, **38** (2005) pp. 5359 – 5377.

11. Radiation problem in classical field theory and in General Relativity. I have proved that the time evolution of the field data at null-infinity (called usually the "scri"surface) may be described in terms of the conventional Hamiltonian dynamics with the so called "Bondi-mass" (or Bondi-energy) playing role of the total energy of the system. It was shown that the existence and unusual properties of the Bondi-mass are not specific gravitational phenomena but are rather an example of a general theory of radiation, which applies to any hyperbolic field theory, like e. g. Klein-Gordon (also its non-linear version) or electrodynamics. This leads to a substantial simplification of the classical Bondi theory, but also to its considerable extension, where not only radiation of energy but also of momentum and the angular-momentum may be simply described in the hamiltonian framework. Main results of this theory were published in the book:
[111] *Hamiltonian Field Theory in the Radiating Regime* (together with P. Chruściel and J. Jezierski), monograph (174 pages), volume **70** of the series: Springer Lecture Notes in Physics, Monographs (2001).

These results were later applied to various problems. An example:
[132] *Boundary data in canonical gravity and thermodynamics of black holes* (together with J. Jezierski and E. Czuchry), Nuovo Cimento. **119 B** (2004) pp. 733 – 748

This paper is related with another problem which occupied me during last years, namely:

12. Geometry of light-fronts and the thermodynamics of black holes. I have proposed a new, gauge-invariant definition of the external curvature of a null-like surface (a "wave front"). This leads to a simple, geometric formulation of the singular initial value problems in general relativity (i. e. dynamics of the gravitational field within a wave front). As a simple consequence of this approach the so called "first law of thermodynamics of

black holes" is derived easily from first principles, as a fundamental property of Einstein equations, without usual *ad hoc* assumptions. Main results of this analysis were published in the following papers:
[109] *Geometry of null-like surfaces in General Relativity and its application to dynamics of gravitating matter* (together with J. Jezierski and E. Czuchry), Rep. Math. Phys. **46** (2000) p. 399 – 418.
[126] *Dynamics of gravitational field within a wave front and thermodynamics of black holes* (together with J. Jezierski and E. Czuchry), Phys. Rev. D **70** (2004) p. 124010-1 – 124010-14

13. Thin shells in general relativity and quantum cosmology.

Thin shells play an important role in both classical and quantum gravity. They were introduced by W. Israel as a practically unique tractable model of the gravitational collapse. Moreover, they provide a convenient toy-model of quantum gravity (known also as "quantum cosmology") where many properties of the "would be" quantum gravity may be tested or, at least, illustrated. Despite of the enormous interest in the shell theory, no derivation of its variational and Hamiltonian structure was known until few years ago. I proposed such a derivation recently for both the massive and light-like shells. Principal papers containing these results for the massive case are:
[95] *"True degrees of freedom" of a spherically symmetric, self-gravitating dust shell* , Acta Phys. Polon. **B 29** (1998) p. 1001 – 1013.
[107] *Spherically symmetric dust shell and the time problem in Canonical Relativity* (together with P. Hájíček), Phys. Rev. **D 62** (2000) p. 044025-1 – 044025-5.
[136] *Dynamics of a self-gravitating shell of matter* (together with E. Czuchry), Phys. Rev. D **72** (2005) pp. 084015-1 – 084015-12
[137] *Relativistic dynamics of spherical timelike shells*, (together with G. Magli and D. Malafarina), General Relat. Grav. (in print),
[138] *A new derivation of the variational principle for the dynamics of a gravitating spherical shell*, (together with G. Magli and D. Malafarina), Phys. Rev. D **74** (2006) pp. 084017-1 – 084017-11

whereas for the light-like case:
[113] *Dynamics of a self gravitating light-like matter shell: a gauge-invariant Lagrangian and Hamiltonian description* (together with J. Jezierski and E. Czuchry), Phys. Rev. **D 65** (2002), 064036-1 – 064036-20.