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TECHNICAL PROGRESS REPORT

A. Publications Dec. 1988 – Dec. 1989

1. "QCD–Based Effective Lagrangian Including Quark Mass Effects: Calculations of f_K", H. Munczek and D. McKay, *Phys. Rev.* **D39**, 883, (1989).

2. "Bright Dark Matter: Evidence for Radiative Neutrino Decay", D. McKay and J. Ralston, *Proceedings of Neutrino 88: The 13th International Conference on Neutrino Physics and Astrophysics* (Boston, 1988), edited J. Schneps, T. Kafka, A. Mann and P. Nath, (World Scientific, Singapore, (1989) p. 717.

3. "The Exact Bethe–Salpeter Equation and Comparison of Different Composite Effective Actions", D.W. McKay and H. Munczek, *Proceedings of "Beyond the Standard Model"*, (Ames, 1988) edited by K. Whisnant and B.-Young. (World Scientific, 1989) p. 480.

4. "Signals of Dark Matter Radiative Decay," D.W. McKay and J.P. Ralston, *Particle Astrophysics: Forefront Experimental Issues* (Berkeley, CA 1988) edited by E.B. Norman (World Scientific, 1989).

5. "Composite Operator Effective Action Considerations on Bound States and Corresponding S–Matrix Elements," Douglas W. McKay and Herman J. Munczek, *Phys. Rev. D* **40**, Dec. 15, 1989.

6. "ICEMAND: Microwave Detection of Ultra–High Energy Neutrinos in Ice," J.P. Ralston and D.W. McKay, *Proceedings of the UALR – U.C. Irvine Workshop on High Energy Particle Astrophysics* (Little Rock, AK, 1989) (to be published in *Nucl. Phys. B.* special issue). (Also reprinted in *Proceedings of the Bartol Workshop on Cosmic Rays and Astrophysiccs at the South Pole* (Newark, DE 1989) (AIP, in press)).

7. "On Derivation of Propagator and Bound State Equations and S–Matrix Elements for Composite States", H. Munczek and D. McKay, *Proceedings of the Vth Workshop on Nonlinear Evolution Equations and Dynamical Systems* (Crete, 1989) (Springer Verlag, in press).

8. "Current Evidence for Dark Matter Radiative Decay", D.W. McKay and J.P. Ralston, (*Proceedings of the 10th Annual Grand Unification Workshop* (Chapel Hill, 1989) (World Scientific, in press).

9. "Nambu and Jona–Lasinio Approach to Complete, Low Energy Technicolor Lagrangian with Vector Mesons", R. Johnson, B.-L. Young and D. McKay, *Physical Review D* (submitted).

10. "Electric Curvature and the Time–Component of the Adiabatic Connection," J.P. Ralston, *Phys. Rev.* **A40**, 5400 (1989).

11. "Model Dependence of Astrophysical Lower Bounds on the Neutrino Mass," J.P. Ralston, *Phys. Rev. Lett.* **63**, 1038 (1989).

12. "Berry's Phase and the Symplectic Structure of Quantum Time Evolution", J.P. Ralston, *Phys. Rev. A* **40**, 4872 (1989).

13. "Coherence and Color Transparency," B. Pire and J.P. Ralston, Kansas Preprint (1989), to be published in *Proceedings of NPAS Topical Conference on Electronuclear Physics with Internal Targets* (Stanford, 1989) (World Scientific, in press).

14. "Nuclear Filtering of Strong Interactions," J.P. Ralston and B. Pire, (Kansas preprint, 1989) to be published in *Proceedings of the 24^{th} Rencontre de Moriond* (Les Arcs, 1989) edited by J. Tran Thanh Van (Editions Frontiers, in press).

15. "Color Transparency and Mini–Hadron Dynamics," B. Pire and J.P. Ralston, to be published in *Procedings of European Physical Society–International Conference on High Energy Physics* (Madrid, 1989). (*Nuc. Phys.* **B**, in press).

16. "Hollow Galactic Halos of Fermionic Dark Matter", J.P. Ralston and L.L. Smith, *Astrophysical Journal (submitted).*

IIB. Narrative of Research Progress

Dec. 1988 – Dec. 1989

1) Effective Actions and the S–Matrix for Bound States

Moving beyond their earlier focus on spontaneous symmetry breaking issues within the development of bilocal field effective Lagrangians,[1] McKay and Munczek showed[2] that this formalism provides a unified framework for the study of the bound state equation and the S–Matrix for bound state scattering. The effective action as defined by Cornwall, Jackiw and Tomboulis[3] (CJT) was shown to be the one which most naturally generalizes the local field case. Our result is equivalent to the Nishijima[4] and Mandelstam[5] prescriptions.

Alternative effective actions,[6] dubbed the "auxiliary field" actions, were shown to be equivalent to each other but differ in form from the CJT action. In QED–like cases, McKay and Munczek argued that the two actions lead to the same S–Matrix elements. In a general case where higher order gluon Green's functions are required, the S–matrix elements are not necessarily the same when calculated from the different actions, and the CJT version is proposed as the preferred tool. These results are reported in *Phys. Rev. D*, Dec. 15, 1989. We also reported some of these and related results at the Ames Conference and the Crete Conference.[2]

2) McKay collaborated with Bob Johnson and Bing–Lin Young (Iowa State) on building a complete and unified low energy technicolor Lagrangian with techni–pseudoscalar and vector mesons.[7] We argued that the Nambu and Jona–Lesinio version of a non–Abelian, confining technicolor theory can be obtained by integrating out the techni–gluons and then truncating and localizing the resulting gluon Green's function expansion.[8] The weak (*i.e* $SU(3) \times SU_L(2) \times XU(1)$) gauge bosons are introduced at the technifermion level.[9] The natural way in which the Higgs mechanism works and techni–vector meson dominance arises is emphasized. We develop the consequences on the ρ–parameter, the techni–ω and the techni–ρ couplings and their enhancement of the W and Z production cross sections from our approach.[10] The lack of techni–omega decays which are analogs of $\omega \to \pi\gamma$, for example, is a general feature of the techni–scheme and is transparent in our formalism.[1] The extended technicolor interactions are included and some phenomenological implications worked out. In particular, we demonstrate that techni–ρ enhancement mechanism recently proposed[12] looks unworkable. A long manuscript detailing these developments has been submitted to *Physical Review D.*

3) Neutrino Astrophysics

Ralston and McKay put together their results on ultra high energy (UHE) neutrino cross sections[13] with a reanalysis of early work by Askaryan[14] on coherent microwave emission by electromagnetic showers.[15] Our conclusion supports the optimistic estimates by *e.g.* Markov and Zheleznyk,[16] on detectability of microwave pulses emitted by showers initiated by UHE neutrino cosmic rays stopping in the ice. We proposed that an array of 50 antennas could give up to several hundred events per year, enough to verify a signal and start some limited directionality, timing and physics studies.

Our "first look" at the very detailed problem of shower development and microwave coherence revealed a previously unrecongized log enhancement factor, $\ell n(E_o/E_>)$, for producing coherent emission when E_o is shower energy and $E_>$ is an effective threshold energy. This increases the detectability by an order of magnitude. We plan to follow up with a detailed study in collaboration with experimentalists at KU and elsewhere. These results were reported at the Little Rock Conference on particle astrophysics,[15] and were reprinted by invitation of the organizers in the proceedings of the Bartol meeting.[15]

Any results on neutrino collisions with energies above 100 TeV coming from point astrophysical sources will be electrifying in both the particle physics and astrophysics communities.

4) Color Transparency and Nuclear Target Effects in Hadron Scattering

Following earlier work[17,18] on Color Transparency, Ralston and Pire have found a number of new effects of QCD coherence in high energy scattering of hadrons in nuclear targets. The mechanism proposed was tested by using interference between "large" hadrons, in which the quarks are separated by large impact parameter, and small ones. The resulting prediction[19] for the transparency ratio (which is the ratio of elastic scattering off a particle in a nuclear target to the same process on a free particle) was shown to fit the energy dependence of the data[20] with no adjustable parameters. More recently, we fit data on $\pi p \rightarrow \pi p$ to predict oscillations[21] (180°out of phase) in the πA data.

The physics of separating large and small hadrons with a nuclear filter is rather general. At several meetings[21–23] predictions were made for:

a) Spin observables, *e.g.* $\mathcal{A}$ and $\mathcal{A}_{NN}$ in a nuclear medium. The prediction is that these will return to the perturbative value for large momentum transfer $|\, t \,| >> GeV^2$ and nuclear number $A >> 1$. The prediction for the analyzing power $\mathcal{A}$ should be easy to test.

b) Inclusive reactions, *e.g.* the polarization of inclusive hyperons. This should go to zero at fixed $P_\perp$ for $A >> 1$.

c) Diffractive ρ production: The data is inconsistent, but the prediction is that the ρ polarization should be equal its perturbative value for $A >> 1$.

d) $\pi p \to \rho p$. The transverse ρ polarization should vanish for large $|t| >> GeV^2$ and $A >> 1$.

These predictions and others were discussed in invited talks at the Topical Meeting on *Electronuclear Physics with Internal Targets* (SLAC, January 1989), the 24^{th} *Rencontre de Moriond* (Les Arcs, March 1989) and the *Gordon Conference on Nuclear Physics* (Tilton, NH June 1989). In addition, Ralston presented colloquia on these subjects and Color Transparency at the College of William and Mary, Michigan State University and Ohio State University. A longer paper with Pire is in preparation.

5) Neutrino Dark Matter and Galactic Dynamics

For some time there have existed theoretical lower bounds for the mass of neutrinos (or other fermions) composing galactic halos. The bounds[24] are all based on Fermi statistics, in the sense that the phase space density should be less than a certain value of order $1/\hbar^3$. The most sophisticated of these bounds, by Tremaine and Gunn,[25] has been used to argue that galactic halos cannot be made of massive neutrinos. Applying this bound with data from certain dwarf galaxies, the lower bound was found to be larger than the upper bounds $\Sigma m_\nu \lesssim 100$ eV from big bang cosmology.[26]

In these previous studies the neutrino phase space was presumed to be isotropic and closely related to that of visible stars or hydrogen gas in the galaxy. Ralston[27] investigated the collisionless self–consistent dynamics for an anisotropic neutrino velocity distribution. The reason for considering this is that the velocity in the radial direction of a spherical galaxy halo could be larger than other components. This would spread the neutrinos over a larger phase space volume, weakening the bound.

Velocity anisotropy is allowed for a collisionless system in steady state. The phase space density f studied was of the fermi form

$$f(\mathcal{E}, L) = \frac{1}{1+e^{\beta(\mathcal{E}-\mu)}} g(L^2/L_o^2)$$
$$g(L^2/L_0^2) = N\exp(-L^2/2L_0^2) \ .$$

where L is the magnitude of the angular momentum and $\mathcal{E}$ the non-relativistic energy. In this expression μ can be identified as the neutrino Fermi energy. The limit $\beta\mu >> 1$, a degenerate Fermi distribution, was studied. Then, after solving for a self-consistent, spherically symmetric halo, the mass bounds were re-examined. The previous bounds, *e.g.* of Tremaine and Gunn[25] take the form

$$m_\nu^4 \lesssim \frac{\rho\hbar^3}{(\sigma^2)^{3/2}}$$

where ρ is a central mass density and σ^2 a measurable star r.m.s. "temperature" *i.e.* velocity dispersion. The new bound[27] is of the form

$$m_\nu^4 \lesssim \frac{\rho\hbar^3}{\mu^{3/2}} \ .$$

If the neutrino Fermi energy μ is much larger than the star velocity dispersion then the new bound is much weaker than the old one. Thus no contradiction between neutrinos in galactic halos and the big bang cosmology actually exists. This result was published[27] in *Physical Review Letters.*

Extending this work, Ralston and Smith[28] retained the degenerate Fermi energy distribution but considered the multiparameter family of anisotropy distributions

$$g(L^2/L_o^2) = (AL^2/L_o^2 + B)e^{-L^2/L_o^2}$$

A more detailed analysis of the self-consistency was undertaken. This enters through a non-linear integro-differential equation for the potential $\psi(r)$:

$$\nabla^2\psi(r) = 4\pi G\, m_\nu \int d^3v \;\; f(\mathcal{E}, L) \;\; ;$$
$$\mathcal{E} = \vec{v}^2/2 + \psi(r)$$

The entire dependence on the neutrino mass, Planck's constant, the maximum phase space density, and the halo Fermi-energy turn out to be contained in a dimensionless constant K_o:

$$K_o = \frac{1}{4\pi}\frac{L_o^2}{\hbar^2}\frac{m_\nu}{M_p^2}\frac{c}{\sqrt{\mu}} \ ,$$

where $M_p = 1.2 \times 10^{19} GeV$ is the planck mass. Amazingly, the numerical value of K_o is close to 1 for a typical galaxy halo, while $K_o << 1$ follows for dwarf galaxies or anisotropic halos. Previous neutrino mass limits are equivalent to the unwarranted statement that $K_o \gtrsim 1$. For $K_o << 1$ solutions exist and it was shown analytically by Ralston and Smith that:

a) $K_o \ll 1$ generically will give a flat rotation curve for stars moving in the dark matter halo. This shows not only that the dark matter is observable, but answers the question of why its distribution consistently shows some structure.

b) The halos for $K_o \ll 1$ generally have a hollow core, an unexpected phenomenon not very familiar to galactic dynamicists.

c) There is no lower bound on m_ν in any galactic halo. Thus neutrinos are a viable elementary particle for dark matter. These analytic results were confirmed by detailed numerical solutions to be non-linear equations. The paper has been submitted to *Astrophysical Journal.*

6) Berry's Phase and Symplectic Structure

Ralston studied Berry's phase[29] by embedding quantum dynamics in a classical canonical formalism. This is not the usual operator swindle, but a direct and literal interpretation of all the degrees of freedom in a quantum system as classical ones.

The procedure begins with a Lagrangian $L(q, \dot{q})$ where $q_i(t)$, $i = 1 \ldots N$ is the coordinate with N degrees of freedom and $\dot{q}$ is its time derivative. The most general bilinear Lagrangian can be written down in matrix notation,

$$L(q, \dot{q}) = \frac{1}{2}\dot{q}M\dot{q} - \Phi(q) + \dot{q}A(q)$$
$$\Phi(q) = \frac{1}{2}qVq \quad ; \quad A(q) = \Lambda q \quad .$$

where M, V, and Λ are $N \times N$ matrices of time-dependent coefficients. This system transform like a gauge interaction, *i.e.* a classical particle in an N-dimensional electric and magnetic field. Then by making some canonical transformations and definitions, Hamilton's equations for the q's and p's are the Schroedinger equation for the Schroedinger picture wave function $\psi(t)$. Interestingly, this shows that the symmetry group of quantum dynamics is Sp(2N), the sympletic group of canonical transformations. A certain subgroup, the intersection of Sp(2N) and O(2N) operating on the p's and q's is shown to be the usual U(N) unitary group. The Sp(2N) transformations are used to help solve some simple problems. After solving the problems with "illegal" Sp transformations, not included in the conventionally allowed unitary group, the results are transformed back to standard coordinates.

The Berry phase turns out to be a classical quantity, equal to the cumulative change of phase of the action-angle coordinates in the adiabatic approximation. It is related to but not the same as what is called Hannay[30] holonomy. The curvature of Berry's connection is related to a certain canonical invariant. There turns out to be another curvature and invariant, an electric-like curvature.[31] This quantity seems to have been neglected in most previous studies, but is more apparent in the symplectic formalism. These results were published[31,32] in two articles in *Physical Review* **A.**

7. Bosonization and the meaning of Equivalence

So far in the literature, claims of $1+1$ dimensional QCD bosonization have been discussed in the framework of the path integral approach. Ambiguities intrinsic to the path integral method result in the vagueness of the correct form of bosonized QCD Lagrangian.

A similar situation existed for the free fermionic model prior to Knizhnik and Zamolodchikov's[33] explicit calculation of the multipoint correlation functions. Their work has greatly substantiated Witten's[34] original claim.

For the QCD case, it has been found that the same calculation simply cannot be done. Tse's program on this issue is more restricted. Tse is doing the semi-classical calculation of the various bosonized versions of QCD and is comparing them with the calculation of the low energy spectrum of QCD by 't Hooft.[36] The calculation, when completed, will give a much firmer meaning to the equivalence of bosonic and fermionic versions of $1+1$ dimensional QCD. It will also clear up the ambiguities in the various claims of bosonized versions of QCD. The results of this calculation and implications for equivalence will be reported in a forthcoming preprint.