

Final Report

Title: **Research in Theoretical
High-Energy Physics**

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Grant No: DE-FG03-92ER40711

Duration: 2/1/1992 - 4/30/2015

The closeout of grant DE-FG03-92ER40711 does not end the DOE supported research by the Principal Investigators Greensite and Golterman. This research continues to be supported under a new grant number DE-SC0013682, and the project proceeds as before. The cause of the closeout of DE-FG03-92ER40711, which precipitates this report, was an error by a staff member of our research office at San Francisco State University, who caused our proposal for grant renewal to be submitted after the deadline. Since it is DOE policy that no grants will be considered if they are submitted after the deadline, the grant was terminated. The following year we again submitted a grant proposal, and this proposal was successful. So in reality the DOE support of our research effort continues, only under another number. Nevertheless, since grant DE-FG03-92ER40711 is formally closed, we are submitting this report in compliance with DOE policy.

The personnel supported by this grant, in the period 2/1/1992 to 4/30/2015 were Jeff Greensite and Maarten Golterman, both professors at San Francisco State University, and varying numbers of graduate students.

Greensite's research, carried out under grant support since 1992, has concentrated mainly on issues in quantum gravity (in the period 1992-1997), and non-perturbative QCD. In quantum gravity the focus was on novel quantization procedures for square-root actions, new Hamiltonian formulations and the problem of time, a reformulation of general relativity as geodesic motion in superspace, and the suggestion of a dynamical origin for the Lorentzian signature of spacetime. In QCD the main results concern the confinement problem. Very strong evidence in favor of the center vortex theory of confinement was obtained over the course of more than a decade, and presented in a long string of articles. The results were eventually summarized in an invited review article ("The Confinement Problem in Lattice Gauge Theory," Prog. Part. Nucl. Phys. **51**, 1 (2003)) and a book (*Introduction to the Confinement Problem*, Springer Publishing, 2011). Special aspects of confinement in Coulomb gauge were also studied in some detail, along with investigations of the structure of the Yang-Mills vacuum wave functional. In recent years, the primary focus has been on the sign problem in QCD at high densities.

The results of all these investigations were reported in 112 refereed articles and published conference proceedings, listed below, along with the book just mentioned.

Golterman's research, carried out under grant support since 1992, has covered the following principal areas: the application of Chiral Perturbation Theory (ChPT) to Lattice QCD, the construction of chiral gauge theories on the lattice and non-perturbative gauge fixing, fermion methods in Lattice QCD (including domain-wall, overlap, and staggered fermions), the algebraic renormalization of supersymmetric gauge theories, the study of quark-hadron duality in QCD, the determination of the strong coupling from hadronic tau-lepton decays, the precision computation of hadronic contributions to the muon anomalous magnetic moment, and the application of lattice gauge theory techniques to the study of composite Higgs models. A comprehensive introduction to the application of ChPT to

lattice QCD was presented in his lectures at the Les Houches Summer School “Modern perspectives in lattice QCD” in August of 2009.

The results of all these investigations were reported in 144 refereed articles and published conference proceedings, listed below, along with the lectures published in the proceedings of the Les Houches Summer School mentioned above.

Publication List (Jeff Greensite)

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3. Dynamical Origin of the Lorentzian Signature of Spacetime, Phys. Lett. B300 (1993) 34.
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12. Creutz Ratios From Color-Truncated Lattice Configurations, Phys. Rev. D52 (1995) 6620, with G. Fleming.
13. Casimir Scaling vs. Abelian Dominance in QCD String Formation, Phys. Rev. D53 (1996) 5891, with L. Del Debbio, M. Faber, and S. Olejnik.
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