

# PAULO BEDAQUE

Physics Department

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## **Employment**

Professor, University of Maryland, 2013-present

Associate Professor, University of Maryland, 2007-2013

Assistant Professor, University of Maryland, 2006-2007

Senior Scientist: Lawrence-Berkeley Laboratory, 2006

Divisional Fellow: Lawrence-Berkeley Laboratory, 2001-2006

Research Assistant Professor: Institute for Nuclear Theory, University of Washington, 1999-2001

Research Associate: Institute for Nuclear Theory, University of Washington, 1996-1999

Post-Doctoral Associate: Massachusetts Institute of Technology, 1994-1996

## **Education**

**Ph.D.:** University of Rochester, Rochester, 1994, Physics

**M.S.:** Universidade de Sao Paulo, Brazil, 1989, Physics

**B.S.:** Universidade de Sao Paulo, Brazil, 1985, Physics

## **Grants and Fellowships**

Co-PI of “Theoretical Studies in Hadronic and Nuclear Physics, DoE grant, (2013-2016) Co-PI of “Theoretical Studies in Hadronic and

Nuclear Physics, DoE grant, \$2,199,000 (2010-2012)  
NCSA Teragrid: 500.000 processor hours, 2006

SciDAC: 1.500.000 processor hours at the Fermilab cluster, 2005  
LOFAR, University of Groningen: about 60 teraflop weeks of computer time, 2005  
SciDAC: 700.000 processor hours at the JLab cluster, 2005

Laboratory Directed Research and Development program (LDRD):  
“Effective Field Theory for Few-Nucleon Systems”, 2003

Laboratory Directed Research and Development program (LDRD):  
“Effective Field Theory for Few-Nucleon Systems”, 2002

Research and Teaching Assistantship, University of Rochester  
(1989-1994) Scholarship for Studies Abroad, CAPES, Brazil, 1989-1993  
Scholarship for Studies Abroad, CNPq, Brazil, 1989

## **Conference and Workshop Organization**

International Advisory Board, “Chiral Dynamics”

Co-convener of Few-Body working group, “Chiral Dynamics 2009”,  
Bern, Switzerland

Steering Committee, National Nuclear Physics Summer School, 2009-  
present

Editorial Board, PMC Physics A - 2011-2014

International Advisory Board, “VIII Latin American Symposium on  
Nuclear Physics and Applications”, Chile, 2009

Co-Organizer of the “2005 National Nuclear Physics Summer School”,  
Berkeley, June 2005

Co-Organizer of the ECT\* “Effective Theories in Nuclear Physics and  
Lattice QCD”, Trento, Italy, July 2005

Organizer of “Berkeley Summer of Lattice”, Berkeley, 2004

Organizer of “Berkeley Effective Summer”, Berkeley, 2003

Co-convener of Few-Body Systems Workgroup of “Chiral Dynamics  
2003”, Bonn, Germany, 2003

Co-organizer of INT Workshop on Effective Field Theory and Nuclear Physics, Seattle, 1999

## **Teaching and Mentoring**

Advisor:

graduate student Neill Warrington (2015-present)

graduate student Michael Buchoff (graduated in 2010)

Evan Berkowitz (graduated in 2013)

Srimoyee Sen (graduated in 2015)

undergraduate student Danielle Allor (UMD),

undergraduate student Charles Stebbens (MIT) (summer 2006)

undergraduate student Nathan Ng (UMD)

undergraduate student Gregory Ridgway (2015-present)

Research Experience for Undergraduates (REU) summer students Michael Kesden (1999) and James McGuire (2000), University of Washington

Instructor: multiple graduate and undergraduate classes

Supervisor:

Postdoctoral Fellow Gokce Basar

Postdoctoral Fellow Amy Nicholson

Postdoctoral Fellow Simin Mahmoodifar

Postdoctoral Fellow Brian Tiburzi

Postdoctoral Fellow Andre Walker-Loud

Postdoctoral Fellow Gautam Rupak (2001-2003)

Visiting Researcher Heron Caldas (2003), Lawrence-Berkeley Laboratory

## **Invited Talks (after 2000)**

“Going with the flow: solving the sign problem with thimbles”,  
Institute of Nuclear Theory, University of Washington, March 2016

“Mini-Course in Effective Field Theory and Applications”, IFT, Sao  
Paulo, Brazil, August 2015

“Dense matter and angulons”, talk at the Institut de Physique Nucléaire,  
Orsay, France, January 2014

“Dense matter and angulons”, talk at the “Effective Field Theory and  
Quantum Many Body Systems” workshop, Madrid, Spain, January 2014

“Triplet condensed neutron matter and angulons”, talk at the University  
of Minnessotta, November 2013

“Triplet condensed neutron matter and angulons”, talk at the Ohio  
University, April 2013 “High density nuclear condensates”, talk  
presented at JLab, May 2012

“The densest matter in the Universe”, Colloquium at the George  
Washington University, April 2011

Plenary talk at "INT @ 20 years: The future of nuclear physics and its  
intersections", Seattle, July 2010 Colloquium, March 2010

“The densest matter”, Mississippi State university

TRIUMF, invited talk on the “Workshop on the Future Directions on  
Nuclear Physics”, Vancouver, Canada, November 2010

Confinement 2010, “Superfluid deuterium”, invited talk, September  
2010, Madrid, Spain

Invited talk, Argonne, December 2009, “Quarks on a hyperdiamond  
lattice”

Confinement 2008, “Few-body lattice calculations”, plenary talk,  
September 2008 TNT Colloquium, North Carolina State University,  
“Nuclear Forces and Lattice QCD”, February 2007

Colloquium at George Washington University, Washington D.C.,  
“Hadron

Interactions from Lattice QCD, February 2007

Invited talk at the “APS Topical Group on Hadronic Physics Meeting”,  
Nashville, “Nuclear Physics with Lattice QCD”, November 2006

Invited talk at “Chiral Dynamics: Theory and Experiment”, “ $\pi\pi$   
Scattering from Mixed Action Lattice QCD”, Durham, September 2006

Invited talk at the “Few-Body Conference”, Brazil, “Nuclear Forces and  
Lattice QCD”, July 2006

Invited talk at the “Workshop on New Developments in Quantum  
Gases”, August 2005

Lecturer: RIA Summer School on Exotic Beam Physics, July 2005  
Invited talk at the APS Spring Meeting 2005, “Nuclear Lattice QCD”,  
Tampa April

Invited talk at the University of Maryland, “Nuclear Forces and QCD”,  
February 2005

Invited talk at the “Physics of Nuclei with the 12 GeV upgrade  
Workshop”, JLab, November 2004

Invited talk at the MIT, “Nuclear Forces from Lattice QCD”, October  
2004

Invited talk at the University of Maryland, “Bohm-Aharonov Effect and  
Nuclear Forces on the Lattice”, October 2004

Invited talk at the Institute for Nuclear Theory, “Angulon Cooling of  
Neutron Stars”, Seattle, April 2004

Plenary talk at “Chiral Dynamics 2003”, Bonn, Germany, September 2003  
Invited talk at Caltech, “Effective Theory and Three-body

Systems”, March 2003  
Invited talk at the Institute for Nuclear Theory, “Model Independency in Three-Nucleon Systems”, December 2003

Invited talk at “The 17th International IUPAP Conference on Few-Body Problems in Physics”, “Three-Body Scattering”, Durham, June 2003

Invited talk at the APS Spring Meeting 2003, Philadelphia, “Nuclear Effective Field Theory”, April 2003

Invited talk at the University of Sao Paulo, Brazil, “Color Superconductivity”, December 2002

Invited talk at the University of Rochester, “Kaon Condensation in Quark Matter”, December 2002

Invited talk at Ohio State University, “What is the Ground State of Quark Matter?”, December 2002

Invited talk at the Los Alamos National Laboratory, “Color Superconductivity”, November 2002

Invited Talk at the ETSIM Workshop, “Kaon Condensation in Quark Matter”, Manchester, UK, July 2002

Invited talk at Ohio State University, “Effective Field Theory and the Running of the Three Body Force”, November 2001

TNT Colloquium, Duke University, “The Ground State of Really Squeezed Matter”, April 2001

Invited talk at Caltech, “The Triton Lives on a Limit Cycle”, November 2000  
Invited talk at the Institute for Nuclear Theory, Seattle, “3-Body Physics in Effective Field Theory”, August 2000

Colloquium at McGill University, Montreal, Canada, “Effective Theories for Dense QCD”, June 2000

Invited talk at the APS Spring Meeting 2000, “Three-Body Physics and Effective Field Theory”, Long Beach, April 2000

## **Book**

“Nuclear Physics with Effective Theories”, P. Bedaque, M. Savage, U. van Kolck and R. Seki (editors), World Scientific, 2000

## **Professional Associations**

Fellow of the American Physical Society (2010)

## **Publication List**

**“Sign problem and Monte Carlo calculations beyond Lefschetz thimbles”**, Andrei Alexandru, Gokce Basar, Paulo F. Bedaque, Gregory W. Ridgway, Neill C. Warrington, e-Print: arXiv:1512.08764

**“Monte Carlo algorithm for simulating fermions on Lefschetz thimbles”**, Andrei Alexandru, Gökçe Basar, Paulo Bedaque, *Phys.Rev. D*93 (2016) 1, 014504.

**“An Upper Bound on Neutron Star Masses from Models of Short Gamma-ray Bursts ”**, S. Lawrence, J. Tervala, P. Bedaque and C. Miller, *Astrophys.J.* 808 (2015) 2, 186

**“Hypernuclei and the hyperon problem in neutron stars”**, P. Bedaque and A. Steiner, *Phys.Rev. C*92 (2015) 2, 025803.

**“Massive and massless modes of the triplet phase of neutron matter”**, P. Bedaque, A. Nicholson and S. Sen, *Phys.Rev.* C92 (2015) 3, 035809.

**“Sound velocity bound and neutron stars”**, P. Bedaque and A. Steiner, *Phys.Rev.Lett.* 114 (2015) 3, 031103

**“Neutrino emissivity from Goldstone boson decay in magnetized neutron matter”**, Paulo Bedaque, Srimoyee Sen, *Phys.Rev.* C89 (2014) 3, 035808 [arXiv:1312.6632[nucl-th]]

**“A new crystalline phase in magnetar crusts”**, Paulo F. Bedaque, Simin Mahmoodifar, Nathan Ng, Srimoyee Sen, [arXiv: 1312.0591[astro-ph]]

**“Goldstone modes in the neutron star core”**, Paulo F. Bedaque and Sanjay Reddy, *Phys.Lett.* B735 (2014) 340-343 [arXiv:1387.8183[nucl-th]]

**“Friedel crystals and the outer crust of magnetars”**, Paulo F. Bedaque, Simin Mahmoodifar, Srimoyee Sen, *Phys. Rev* C88 (2013) 055881

**“The low lying modes of triplet-condensed neutron matter and their effective theory”**, P. Bedaque and Amy Nicholson, *Phys.Rev.* C87 (2013) 5, 055807 [arXiv: 1212.1122[nucl-th]]

**“Thermodynamics of nuclear condensates and phase transitions in white dwarfs”**, P. Bedaque, E. Berkowitz and S. Sen, *Phys.Rev.* D89 (2014) 4, 045010 [arXiv: 1206.1059[astro-ph]]

**“Neutrino emission from helium white dwarfs with condensed cores”**, Paulo F. Bedaque, Evan Berkowitz, Aleksey Cherman, [arXiv: 1102.4795[nucl-th]]



**“Electron shielding of vortons in high density quark matter”**, Paulo F. Bedaque, Evan Berkowitz, Geoffrey Ji and Nathan Ng, *Phys. Rev D* 85 (2012) 043008, [arXiv: 1112.1386[nucl-th]]

**“Stable vortex loops in two-species BEC’s”**, Paulo F. Bedaque, Evan Berkowitz and Srimoyee Sen, [arXiv:1111.4507] [cond-mat.quant-gas]

**“Nuclear condensate and helium white dwarfs”**, Paulo F. Bedaque, Evan Berkowitz, Aleksey Cherman, *Astrophys. J.* 749 (2012) 5, [arXiv: 1111.1343[nucl-th]]

**“Vortons in dense quark matter”**, Paulo F. Bedaque, Evan Berkowitz, Aleksey Cherman, [arXiv:1102.4795[nucl-th]]

**“Quark mass variation constraints from Big Bang Nucleosynthesis”**, Paulo F. Bedaque, Thomas Luu and Lucas Platter [arXiv: 1012.3840[nucl-th]][nucl-th]

**“The complexities of simplicity”**, an invited "Viewpoint" article on the Atomic and Molecular section of the APS online journal "Physics"

**“The phases of deuterium at extreme densities”**, Paulo F. Bedaque, Michael I Buchhoff and Aleksey Cherman [arXiv:1007.1972 [hep-ph]]

**“Meson-Baryon Scattering Parameters from Lattice QCD with an Isospin**

**Chemical Potential”**, P. F. Bedaque, M. I. Buchhoff and B. C. Tiburzi, *Phys. Rev. D* 80, 114501 (2009), [arXiv:0910.4595 [hep-lat]].

**“Sommerfeld enhancement from Goldstone pseudo-scalar exchange,”** P.F.Bedaque, M.I.Buchhoff and R.K.Mishra, *JHEP* 0911, 046 (2009), [arXiv:0907.0235 [hep-ph]].

**“Can fermions save large N dimensional reduction?”**, P.F.Bedaque, M.I.Buchhoff, A. Cherman and R. P. Springer, *JHEP* 0910, 070 (2009), [arXiv:0904.0277 [hep-th]].

**“Restless pions from orbifold boundary conditions: an explicit construction for noise reduction in lattice QCD,”** P. F. Bedaque and A. Walker-Loud, [arXiv:

0811.2127].

**“Search for Fermion Actions on Hyperdiamond Lattices,”** P. F. Bedaque, M. I. Buchoff, B. C. Tiburzi and A. Walker-Loud, *Phys. Rev. D* **78**, 017502 (2008), [arXiv: 0804.1145 [hep-lat]].

**“Broken Symmetries from Minimally Doubled Fermions”**, P. F. Bedaque, M. I. Buchoff, B. C. Tiburzi and A. Walker-Loud, *Phys. Lett. B* **662**, 449 (2008), [arXiv: 0801.3361 [hep-lat]].

**“Effective Field Theory for the Anisotropic Wilson Lattice Action”**, P. F. Bedaque, M. I. Buchoff and A. Walker-Loud, *Phys. Rev. D* **77**, 074501 (2008), [arXiv:0708.2254 [hep-lat]].

**“Restless pions: orbifold boundary conditions and noise suppression in**

**lattice QCD”**, P. F. Bedaque and A. Walker-Loud, *Phys. Lett. B* **660**, 369 (2008), [arXiv:0708.0207 [hep-lat]].

**Fitting two nucleons inside a box: exponentially suppressed corrections to the Luscher's formula**, Paulo F. Bedaque and Ikuro Sato, *Phys. Rev. D* **76** (2007) 034502, *hep-lat/0702021*

**Hyperon-Nucleon Scattering from Fully-Dynamical Lattice QCD**, by Silas R. Beane, Paulo F. Bedaque, Thomas C. Luu, Kostas Orginos, Elisabetta Pallante, Assumpta Parreno, Martin J. Savage, *Nucl. Phys. A* **794** (2007) 62-72, *hep-lat/0612026*

**A New class of quantum bound states: Diprotons in extreme magnetic fields**, by Danielle Allor, Paulo Bedaque, Thomas D. Cohen, Charles T. Sebens, *Phys. Rev. C* **75**:034001, 2007.

**$\pi K$  scattering in full QCD with domain-wall valence quarks**, by Silas R. Beane, Paulo F. Bedaque, Thomas C. Luu, Kostas Orginos, Elisabetta Pallante, Assumpta Parreno, Martin J. Savage, *Phys.Rev.D74:114503,2006*.

**$f(K)/f(\pi)$  in Full QCD with Domain Wall Valence Quarks.**, by S.R. Beane, P.F. Bedaque, K. Orginos, M.J. Savage, *Phys.Rev. D75 (2007) 094501, hep-lat/0606023*

**Superfluid phases of the three-species fermion gas**, by Paulo F. Bedaque, Jose P. D'Incao, *Annals Phys.* 324 (2009) 1763-1768, *cond-mat/0602525*

**Nucleon-nucleon scattering from fully-dynamical lattice QCD**, by S.R. Beane, P.F. Bedaque, K. Orginos, M.J. Savage, *Phys.Rev.Lett.* 97:012001,2006.

**Finite volume corrections to  $\pi$ - $\pi$  scattering**, by Paulo F. Bedaque, Ikuro Sato, Andre Walker-Loud, *Phys.Rev.D73:074501,2006*.

**$I = 2$   $\pi$ - $\pi$  scattering from fully-dynamical mixed-action lattice QCD**, by NPLQCD Collaboration (Silas R. Beane *et al.*), *Phys.Rev.D73:054503,2006*.

**Twisted valence quarks and hadron interactions on the lattice**, by Paulo F. Bedaque, Jiunn-Wei Chen, *Phys.Lett.B616:208-214,2005*.

**A Nucleon in a tiny box**, by Paulo F. Bedaque, Harald W. Griesshammer, Gautam Rupak, *Phys.Rev.D71:054015,2005*.

**Aharonov-Bohm effect and nucleon nucleon phase shifts on the lattice**, by Paulo F. Bedaque, *Phys.Lett.B593:82-88*, 2004.

**Two Nucleons on a Lattice**, by S. Beane, P. F. Bedaque, M. Savage and A. Parreno, *Phys.Lett.B585:106-114*, 2004.

**Exploring Hyperons and Hyper Nuclei with Lattice QCD**, by S. Beane, P. F. Bedaque, M. Savage and A. Parreno, *Nucl.Phys.A747:55-74*, 2005.

**Phase Separation In Asymmetrical Fermion Superfluids**, by Paulo F. Bedaque, Heron Caldas and Gautam Rupak, *Phys.Rev.Lett.* 91:247002, 2003.

**Goldstone Bosons In The  $^3P_2$  Superfluid Phase Of Neutron Matter And Neutrino Emission**, by Paulo F. Bedaque, Gautam Rupak and Martin J. Savage, *Phys.Rev.C68:065802*, 2003.

**Narrow Resonances In Effective Field Theory**, by P.F. Bedaque, H.W. Hammer and U. van Kolck, *Phys.Lett.B569:159-167*, 2003.

**Atomic Molecular Condensates With Large Positive Scattering Length**, by Aurel Bulgac and Paulo F. Bedaque, *cond-mat/0210217*

**Quantum Corrections To Dilute Bose Liquids**, by Paulo F. Bedaque, Aurel Bulgac and Gautam Rupak, *Phys.Rev.A68:033606*, 2003.

**Low-Energy Expansion In The Three-Body System To All Orders And The Triton Channel**, by Paulo F. Bedaque, Gautam Rupak, Harald W. Griesshammer and Hans- Werner Hammer, *Nucl.Phys.A714:589-610*, 2003

**Dilute Resonating Gases And The Third Virial Coefficient**, by Paulo F. Bedaque and Gautam Rupak, *Phys.Rev.B67:174513*, 2003.

**Effective Field Theory For Few Nucleon Systems**, by Paulo F. Bedaque and Udirajara van Kolck, *Ann.Rev.Nucl.Part.Sci.52:339-396*,

2002

**Charged Kaon Condensation In High Density Quark Matter**, by Paulo F. Bedaque, *Phys.Lett.B524:137-143, 2002*

**High Density Quark Matter Under Stress**, by Paulo F. Bedaque and Thomas Schafer, *Nucl.Phys.A697:802-822, 2002*

**Towards A Perturbative Theory Of Nuclear Forces**, by S.R. Beane, Paulo F. Bedaque, M.J. Savage and U. van Kolck, *Nucl.Phys.A700:377-402, 2002*

**Singular Potentials And Limit Cycles**, by S.R. Beane, Paulo F. Bedaque, L. Childress, A. Kryjevski, J. McGuire and U. van Kolck, *Phys.Rev.A64:042103, 2001*

**From Hadrons To Nuclei: Crossing The Border**, by Silas R. Beane, Paulo F. Bedaque, Wick C., Daniel R. Phillips and Martin J. Savage in the Boris Ioffe Festschrift, ed. by M. Shifman, World Scientific

**How To Renormalize The Gap Equation In High Density QCD**, by Silas R. Beane and Paulo F. Bedaque, *Phys.Rev.D62:117502, 2000*

**Renormalization Group Improved Gap Equation For Color Superconductors**, by Silas R. Beane, Paulo F. Bedaque and Martin J. Savage, *Nucl.Phys.A688:931-938, 2001*

**Three Body Recombination In Bose Gases With Large Scattering Length**, by Paulo F. Bedaque, E. Braaten and H.W. Hammer,

*Phys.Rev.Lett.85:908-911, 2000*

**Meson Masses In High Density QCD**, by Silas R. Beane, Paulo F. Bedaque and Martin J. Savage, *Phys.Lett.B483:131-138, 2000*

**Higher Partial Waves In An Effective Field Theory Approach To Nd Scattering**, by Fabrizio Gabbiani, Paulo F. Bedaque and Harald W. Griesshammer, *Nucl.Phys.A675:601-620, 2000*

**Color Superconductivity In Asymmetric Matter**, by Paulo F. Bedaque, *Nucl.Phys.A697:569-577, 2002*

**Parity Violation In Gamma Polarized Compton Scattering**, by Paulo F. Bedaque and Martin J. Savage, *Phys.Rev.C62:018501, 2000*

**Quartet S Wave Neutron Deuteron Scattering In Effective Field Theory**, by Paulo F. Bedaque and Harald W. Griesshammer, *Nucl.Phys.A671:357-379, 2000*

**Effective Theory Of The Triton**, by Paulo F. Bedaque, H.W. Hammer and U. van Kolck, *Nucl.Phys.A676:357-370, 2000*

**The Three Boson System With Short Range Interactions**, by Paulo F. Bedaque, H.W. Hammer and U. van Kolck, *Nucl.Phys.A646:444-466, 1999*

**Renormalization Of The Three-Body System With Short Range Interactions**, by Paulo F. Bedaque, H.W. Hammer and U. van Kolck,

*Phys.Rev.Lett.82:463-467, 1999*

**Effective Theory For Neutron Deuteron Scattering: Energy Dependence**, by Paulo F. Bedaque, H.W. Hammer and U. van Kolck, *Phys.Rev.C58:641-644, 1998*

**Nucleon Deuteron Scattering From An Effective Field Theory**, by Paulo F. Bedaque and U. van Kolck, *Phys.Lett.B428:221-226, 1998*

**Cutting Rules At Finite Temperature**, by Paulo F. Bedaque, Ashok K. Das and Satchidananda Naiak, *Mod.Phys.Lett.A12:2481-2496, 1997*

**Chiral Perturbation Theory Analysis Of Baryon Temperature Mass Shifts**, by Paulo F. Bedaque, *Phys.Lett.B387:1-8, 1996*

**Baryon Masses At Second Order In Large N Chiral Perturbation Theory**, by Paulo F. Bedaque and Markus A. Luty, *Phys.Rev.D54:2317-2327, 1996*

**Thermalization And Pinch Singularities In Nonequilibrium Quantum Field Theory**,

by Paulo F. Bedaque, *Phys.Lett.B344:23-28, 1995*

**Annihilation Diagrams In Two-Body Nonleptonic Decays Of Charmed Mesons**, by

Paulo F. Bedaque, A.K. Das and V.S. Mathur, *Phys.Rev.D49:1339-1341, 1994*

**Two-Body Nonleptonic Decays Of Charmed Mesons**, by Paulo F. Bedaque, A.K. Das

and V.S. Mathur, *Phys.Rev.D49:269-274, 1994*

**Out-Of-Equilibrium Phase Transitions And A Toy Model For Disoriented Chiral Condensates**, by Paulo F. Bedaque and Ashok K. Das, *Mod.Phys.Lett.A8:3151-3164, 1993*

**On The Analytic Structure Of The Selfenergy For Massive Gauge Bosons At Finite Temperature**, by Peter Arnold, Stamatis, Paulo F. Bedaque and Ashok K. Das, *Phys.Rev.D47:4698-4704, 1993*

**Delta Expansion And Selfconsistent Calculation**, by Paulo F. Bedaque and Ashok K. Das, *hep-th/9211101*

**Two-Dimensional Baryons In The Large N Limit**, by Paulo F. Bedaque, I. Horvath and S.G. Rajeev, *Mod.Phys.Lett.A7:3347-3356, 1992*

**Feynman Parametrization And The Degenerate Electron Gas**, by Paulo F. Bedaque and Ashok K. Das, *Phys.Rev.D47:601-607, 1993*

**On The Zero Momentum Limit Of Feynman Amplitudes At Finite Temperature**, by Paulo F. Bedaque and Ashok K. Das, *Phys.Rev.D45:2906-2910, 1992*

**Generalized Schwinger Model And A Theory Of Interacting Photons And Majorana Fermions**, by Paulo F. Bedaque, Ashok K. Das and Wen-Jui Huang, *Phys.Rev.D44:1818-1824, 1991*