CURRICULUM VITAE

1. Personal data

- **Surname:** Megías Fernández **First name:** Eugenio
- **Date and Place of Birth:** 14th May 1978, Granada, Spain.
- **Citizenship:** Spanish.
- **Marital Status:** Single.
- **Current Position:** Research Associate, Institute for Theoretical Physics,
  University of Heidelberg (Germany).
  Alexander von Humboldt Research Fellowship.
- **Mailing address:** Institute for Theoretical Physics,
  Philosophenweg 19,
  D-69120 Heidelberg (Germany).
  Phone.: (0049)-6221-549438
  Fax.: (0049)-6221-549331
- **E-mail address:** emegias@ugr.es, emegias@tphys.uni-heidelberg.de
- **Homepage:** http://www.ugr.es/∼emegias
  http://www.tphys.uni-heidelberg.de/∼emegias

2. Academic degrees

- **Jun 1997:** Graduate studies in Music at the Conservatory (Intermediate level). Royal School of Music Victoria Eugenia, Granada (Spain).
- **Jun 2001:** Undergraduate studies of Physics at the University of Granada (Spain). Specialty: Theoretical Physics.
- **Sep 2003:** Master Thesis Research (*Heat Kernel expansion at Finite Temperature. Effective action of QCD and Chiral Quark Models*). Supervisor: Prof. L.L. Salcedo. University of Granada (Spain).
  Mark: Sobresaliente (with honours).
- **Jun 2006:** PhD Thesis (*Finite Temperature and Curvature effects in QCD and Chiral Quark Models*). Supervisors: Profs. E. Ruiz Arriola and L.L. Salcedo. University of Granada (Spain).
  Mark: Sobresaliente Cum Laude with unanimity. (It is the highest mark in Spain.)

3. Professional employment

- **2 Jul 2001- 15 Sep 2001**: Young research assistant.
  Institute of Astrophysics of Canarias-IAC, Tenerife (Spain).
  Under the support of the IAC.

- **16 Sep 2001 - 31 Dec 2001**: Young research assistant.
  Institute of Astrophysics of Andalucía (Spanish National Research Council-CSIC), Granada (Spain).
  Under the support of the CSIC.

- **1 Jan 2002 - 31 Dec 2005**: Research assistant.
  Department of Atomic, Molecular and Nuclear Physics, University of Granada (Spain).
  Under the support of the Spanish Ministry of Education.

- **1 Jan 2006 - 31 Dec 2006**: Research assistant.
  Department of Atomic, Molecular and Nuclear Physics, University of Granada (Spain).
  Under the support of the University of Granada.

- **1 Apr 2007 - 31 Mar 2009**: Postdoctoral position, Research Associate.
  Nuclear Theory Group, Physics Department, Brookhaven National Laboratory (USA).
  Under the joint support of the Spanish Ministry of Education and Science (Spain) and the Fulbright Program of the U.S. Department of State (USA).

- **1 Apr 2009 - Present**: Postdoctoral position, Research Associate.
  Institute for Theoretical Physics, University of Heidelberg (Germany).
  Under the support of the Alexander von Humboldt Foundation (Germany).

4. Academic honors, prizes and merits:

- Gold Medal at the VII National Physics Olympiad,
  Madrid, Spain, April 1996.
  (Approx. 150 High school students from Spain).

- Honourable Mention at the XXVII International Physics Olympiad,
  Oslo, Norway, July 1996.
  (Approx. 270 High school students from 55 countries).

- Graduated first in my year (out of approx. 300 students) in Physics,
  University of Granada, June 2001.
  (Average 9.72 out of 10, with 20 passed subjects with honours (out of 23)).

- 2nd National Award for Graduate Students in Physics corresponding to the academic year 2000/2001,
  Madrid, Spain, July 2002.

- I was awarded a Fulbright Research Scholar Fellowship for 2 years in the USA. I was awarded after my application obtained the mark of "*excellent*" and passed an interview with experts of the Fulbright Commission in Spain.
  Madrid, Spain, March 2007.
  (40 Fulbright Research Scholars in Spain out of approx. 1000 applicants.)
- Nominated for Exceptional Award in Doctoral Degree corresponding to the academic year 2005/2006 (University of Granada, Spain).
  Granada, Spain, May 2009.
  (This prize is awarded to only one out of twelve PhD Theses passed with the highest mark *"Sobresaliente Cum Laude with unanimity"*. The awarded thesis is not known yet.)

5. Teaching experience

- February - June 2005: Teaching Assistant for Problems in Quantum Physics.
  6th semester in Physics Degree, University of Granada (Spain).

6. Work as Referee in International Journals

- Referee of Physical Review D (Particles, Fields, Gravitation and Cosmology) since 2006.

7. Stays in institutions out of the University of Granada

- Institute of Astrophysics of Canarias, IAC.
  2 July - 15 September , 2001, Tenerife, Spain.
- Institute of Astrophysics of Andalucía, IAA-CSIC.
  16 September - 31 December, 2001, Granada, Spain.
- Institute of Nuclear Physics Henryka Niewodniczańskiego.
  1 May - 30 June, 2003, Cracow, Poland.
- Institut für Theoretische Physik, Universität Heidelberg.
  2 - 8 October, 2006, Heidelberg, Germany.
- Brookhaven National Laboratory.
  1 April, 2007 - 31 March, 2009, New York, USA.
- Institut für Theoretische Physik, Universität Heidelberg.
  1 April, 2009 - Present, Heidelberg (Germany).

8. Conferences and Presentations

1. **Galaxies, the Third Dimension.**
   Cozumel, Mexico, 3 - 7 December, 2001. Organized by IA-UNAM.
   Talk: IDA: A new software facility for Integral Field Spectroscopy Data Analysis.
   - Poster: IFS of the Starburst galaxy NGC 2782.
   - Poster: Stellar and Ionized Gas Kinematics of NGC 4388.
   - Poster: Interactions, triggering activity in Seyfert Galaxies?
2. **First Graduate School in Physics at Colliders.**
   Torino, Italy, 2 - 6 October, 2001. Organized by the European Commission, contract HPRN-CT-2000-00149, and ISATSU (International School of Advanced Studies of the University of Torino).
3. **7th Granada Seminar on Computational and Statistical Physics.**
   Granada, Spain, 2 - 7 September, 2002. Organized by the Institute Carlos I of Theoretical and Computational Physics (University of Granada).
4. **School in Applications of Effective Field Theories.**
   Milano, Italy, 3 - 8 February, 2003. Organized by the University of Milano.
   - Talk: The Heat Kernel expansion at Finite Temperature.
5. **Cracow School of Theoretical Physics, XLIII Course, 2003.**
   Zakopane, Poland, 30 May - 8 June, 2003. Organized by Institute of Physics (Jagellonian University of Cracow), Institute of Nuclear Physics (Cracow), University of Minig and Metallurgy (Cracow), Academia Polaca de las Artes y las Ciencias (Cracow).
6. **Institute of Nuclear Physics Henryka Niewodniczańskiego.**
   Cracow, Poland, 12 June, 2003.
   - Talk: The Heat Kernel expansion at Finite Temperature.
7. **Chiral Dynamics of Hadrons and Hadrons in a Medium.**
   Valencia, Spain, 26 - 28 June, 2003. Organized by the Department of Theoretical Physics, University of Valencia and IFIC.
8. **17th International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, (Quark Matter 2004).**
   Oakland, California, USA, 11 - 17 January, 2004. Organized by Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL), Brookhaven National Laboratory (BNL), Department of Energy Office Science of USA, National Science Fundation (NSF).
   - Poster: The Effective Action of QCD at High Temperature.

9. **9th Hadron Physics and 7th Relativistic Aspects of Nuclear Physics: A Joint Meeting on QCD and QGP (HADROM-RANP 2004).**
   Angra dos Reis, Rio de Janeiro, Brazil, 28 March - 3 April, 2004. Organized by Universidade do Estado do Rio de Janerio (UERJ), Universidade Federal do Rio de Janeiro (EFRJ), Comissão Nacional de Energia Nuclear (CNEN).
   - Poster: One-loop Effective Action of QCD at High Temperature using the Heat kernel Method.
10. **2004 International Conference on Quarks and Nuclear Physics.**
   Bloomington Indiana, USA, 23 - 28 May, 2004. Organized by Indiana University.
   - Talk: Low Energy Chiral Lagrangians in curved space-time from Chiral Quark Models and Quark-Hadron Duality.
11. **Mini-WorkShop on Quark Dynamics: Bled 2004.**
   Bled, Slovenia, 12 - 19 July, 2004. Organized by Jozef Stefan Institute and Department of Physics, University of Ljubljana.
   - Talk: Polyakov Loop at Finite Temperature In Chiral Quark Models.
12. **6th Conference on Quark Confinement and the Hadron Spectrum.**
   Villasimius, Sardinia, Italy, 21 - 25 September, 2004.
   - Talk: Chiral Lagrangians at Finite Temperature and the Polyakov Loop.
13. **29th Johns Hopkins Workshop on Current Problems in Particle Physics: Strong Matter in the Heavens.**
   Budapest, Hungary, 1 - 3 August, 2005. Organized by Johns Hopkins University (Baltimore), Eötvös University (Budapest), University of Florence, University of Heidelberg.
   - Talk: Polyakov Loop at Low and High temperatures.
14. **18th International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, (Quark Matter 2005).**
   Budapest, Hungary, 4 - 9 August, 2005. Organized by Eötvös University (Budapest), Hungary Academy of Sciences (Budapest).
   - Poster: Non-Perturbative contributions to the Polyakov Loop above the Deconfinement Phase Transition.
15. **Workshop on Quark-Gluon Plasma Thermalization.**
   Viena, Austria, 10 - 12 August, 2005. Organized by Technical University of Wien.
   - Poster: Dimension two condensates and the Polyakov Loop above the Deconfinement Phase Transition.
16. **4th International Conference on Quarks and Nuclear Physics (QNP06). And International Complutense Seminar: Matter under Extreme Conditions.**
   Madrid, Spain, 5 - 10 June, 2006. Organized by Complutense University of Madrid.

- Talk: Dimension two condensates and Polyakov Chiral Quark Models.

17. **7th International Conference on Quark Confinement and the Hadron Spectrum.**
Ponta Delgada, Azores (Portugal), 2 - 7 September, 2006. Organized by the Technical University of Lisbon (IST).
    - Talk: The Quantum and Local Polyakov loop in Chiral Quark Models at Finite Temperature.

18. **Mini-Workshop on Polyakov action.**
Heidelberg (Germany), 4 October, 2006. Organized by Institute for Theoretical Physics, University of Heidelberg.
    - Talk: Polyakov effects in chiral quark models and QCD.

19. **International Workshop on High Energy QCD: from RHIC to LHC.**
Villazano, Trento (Italy), 9 - 13 January, 2007. Organized by the European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*).
    - Talk: Non-Perturbative effects above the Deconfinement Phase Transition.

20. **40th Anniversary Symposium of the Yang Institute for Theoretical Physics.**
Stony Brook, New York (USA), 2 - 5 May, 2007. Organized by the Stony Brook University.

21. **Brookhaven National Laboratory.**
New York, USA, 10 May, 2007.
    - Talk: Polyakov loop effects in QCD and chiral quark models.

22. **Exploring QCD:Deconfinement, extreme environments and holography.**
Cambridge (United Kingdom), 20 - 24 August, 2007. Organized by the Isaac Newton Institute for Mathematical Sciences.
    - Talk: A new approach to the Polyakov-loop chiral quark model and QCD.

23. **Electron Ion Collider Collaboration Meeting.**
Stony Brook, New York (USA), 7 - 8 December, 2007. Organized by the Stony Brook University.

24. **Quark Gluon Plasma Winter School 2008.**
Jaipur (India), 1 - 3 February, 2008. Organized by the Variable Energy Cyclotron Centre, Kolkata, India.

25. **20th International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, (Quark Matter 2008):**
Jaipur (India), 4 - 10 February, 2008. Organized by the Variable Energy Cyclotron Centre, Kolkata, India.
    - Poster: Trace Anomaly and dimension two condensate above the phase transition.

26. **Workshop on Hot and Dense Matter in the RHIC-LHC Era:**
    Mumbai (India), 12 - 14 February, 2008. Organized by the Tata Institute of Fundamental Research.

    - Poster: Implications of the dimension two gluon condensate on the deconfined phase of QCD.

27. **Workshop on Theory-Experiment Collaboration for Hot QCD Matter.**
    Brookhaven National Laboratory, New York (USA), 6 - 7 May, 2008. Organized by Brookhaven National Laboratory, New York, USA.

28. **14th International Conference in QCD (QCD 08).**
    Montpellier (France), 7 - 12 July, 2008. Organized by Laboratoire de Physique Theorique et d'Astroparticules, Université de Montpellier and Centre National de la Recherche Scientifique (CNRS).

    - Talk: The Powers of deconfinement.

29. **34th International Conference on High Energy Physics (ICHEP 08).**
    Philadelphia (USA), 20 July - 5 August, 2008. Organized by Princeton University and University of Pennsylvania.

    - Poster: Dimension two condensates and scale symmetry breaking in high temperature QCD.

30. **3rd Workshop for Young Scientists on the Physics of Ultrarelativistic Nucleus-Nucleus Collisions (Hot Quarks 08).**
    Estes Park, Colorado (USA), 18 - 23 August, 2008. Organized by Brookhaven National Laboratory, Duke University, Yale University, University of Colorado at Boulder, Torino/INFN, Strasbourg/IPHC, Universita di Roma "La Sapienza".

    - Talk: A phenomenological description of broken scale invariance in QCD.

31. **Seminar on Hadrons and chiral symmetry in honor of Prof. Klaus Goeke**
    Bochum (Germany), 16 March, 2009. Organized by Institute for Theoretical Physics II, Rurh-University Bochum.

    - Talk: Thermal Power Corrections in the deconfined phase.

32. **Institute for Theoretical Physics, University of Heidelberg.**
    Heidelberg, 22 April, 2009.

    - Talk: Dilatons and transport coefficients in high temperature QCD.

33. **Transregional Collaborative Research Centre TRR 33 Meeting "The Dark Universe".**
    Heidelberg, 18 - 20 June, 2009. Organized by University of Heidelberg, University of Bonn and LMU Munich.

34. **Conference on Constructive and Multiscale Methods in Quantum Theory.**
    Heidelberg, 28 - 30 July, 2009. Organized by University of Heidelberg.

35. **Institute for Theoretical Physics, University of Heidelberg.**
Heidelberg, 7 August, 2009.

- Talk: Non Perturbative QCD at high temperature: AdS-QCD and Gluon Condensates.

9. Organization of Conferences

1. **EMMI International Workshop on String theory approach to QCD-thermodynamics and kinetics.**
To be held in Heidelberg (Germany) on March 2010 for the period of four days. Organization in collaboration with Prof. Hans-Jürgen Pirner (University of Heidelberg).

10. List of Publications

1. **IDA: A new software tool for INTEGRAL Field Spectroscopy Data Analysis.**
B. García-Lorenzo, J.A. Acosta-Pulido and E. Megías-Fernández, ASP Conference Proceedings, Vol. 282. Edited by M. Rosado, L. Binette and L. Arias. ISBN: 1-58381-125-7. San Francisco: Astronomical Society of the Pacific, 2002., p. 501.
Galaxies: The Third Dimension (2001).

2. **The Polyakov loop and the heat kernel expansion at finite temperature.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo, Physics Letters B 563 (2003) 173-178. [*arXiv: hep-th/0212237*].

3. **Thermal heat kernel expansion and the one-loop effective action of QCD at finite temperature.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo, Physical Review D 69 (2004) 116003. [*arXiv: hep-ph/0312133*].

4. **Low-energy chiral lagrangian from the spectral quark model.**
E. Megías, E. Ruiz Arriola, L.L. Salcedo and W. Broniowski, Physical Review D 70 (2004) 034031. [*arXiv: hep-ph/0403139*].

5. **One-loop effective action of QCD at high temperature using the heat kernel method.**
E. Megías, American Institute of Physics Conference Proceedings 739: 443-445 (2005). [*arXiv: hep-ph/0407052*].
9th Hadron Physics and 7th Relativistic Aspects of Nuclear Physics: A Joint Meeting on QCD and QGP (HADRON-RANP 2004).

6. **Polyakov loop at finite temperature in chiral quark models.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo, "Bled 2004, Quark Dynamics" Vol. 5, No. 1, Pag. 1-6. [*arXiv: hep-ph/0410053*].
Mini-WorkShop on Quark Dynamics: Bled 2004.

7. **Chiral lagrangians at finite temperature and the Polyakov Loop**
E. Megías, E. Ruiz Arriola and L.L. Salcedo, American Institute of Physics Conference Proceedings 756: 436-438 (2005). [*arXiv: hep-ph/0411293*].
Quark Confinement and the Hadron Spectrum: Sardinia 2004.

8. **The energy momentum tensor of chiral quark models at low energies.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo, Physical Review D 72 (2005) 014001. [*arXiv: hep-ph/0504271*].

9. **Dimension two condensates and the Polyakov loop above the deconfinement phase transition.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo, JHEP 0601 (2006) 073. [*arXiv: hep-ph/0505215*].

10. **Non-Perturbative contributions to the Polyakov loop above the deconfinement phase transition.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo. Romanian Reports in Physics, Vol. 58, No. 1, Pag. 81-85. [*arXiv: hep-ph/0510114*].
18th International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, (Quark Matter 2005).

11. **Polyakov loop at low and high temperatures.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo. Journal of High Energy Physics Proceedings of Science, PoS(JHW2005)025. [*arXiv: hep-ph/0511353*].
29th Johns Hopkins Workshop on Current Problems in Particle Physics: Strong Matter in the Heavens.

12. **Polyakov loop in chiral quark models at finite temperature.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo. Physical Review D 74 (2006) 065005. [*arXiv: hep-ph/0412308*].

13. **Chiral lagrangian at finite temperature from the Polyakov-chiral quark model.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo. Physical Review D 74 (2006) 114014. [*arXiv: hep-ph/0607338*].

14. **The Quantum and Local Polyakov loop in Chiral Quark Models at Finite Temperature.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo. American Institute of Physics Conference Proceedings 892: 444-447 (2006). [*arXiv: hep-ph/0610095*].
7th International Conference on Quark Confinement and the Hadron Spetrum, (QCHS7).

15. **Dimension 2 condensates and Polyakov Chiral Quark Models.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo. The European Physical Journal A 31 (2007) 553-556. [*arXiv:hep-ph/0610163*].
4th International Conference on Quarks and Nuclear Phsics (QNP06).

16. **Power corrections in the quark-antiquark potential at finite temperature.**
E. Megías, E. Ruiz Arriola and L.L. Salcedo. Physical Review D75 (2007) 105019. [*arXiv: hep-ph/0702055*].

17. **Trace anomaly and dimension two gluon condensate above the phase transition.**

    E. Megías, E. Ruiz Arriola and L.L. Salcedo. To be published by Indian Journal of Physics (2008), *eprint: arXiv 0805.4579[hep-ph].*

    20th International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions, (Quark Matter 2008).

18. **The powers of deconfinement.**

    E. Megías, E. Ruiz Arriola and L.L. Salcedo. Nuclear Physics B Proc. Suppl. 186: 256-259 (2009). [*eprint: arXiv 0809.2044[hep-ph]*]

    14th International Conference in QCD (QCD 08).

19. **Trace anomaly, thermal power corrections and dimension two condensates in the deconfined phase.**

    E. Megías, E. Ruiz Arriola and L.L. Salcedo. Physical Review D80 (2009), 056005. [*eprint: arXiv 0903.1060[hep-ph]*].

20. **Phenomenology of AdS/QCD and Its Gravity Dual.**

    B. Galow, E. Megías, J. Nian and H.J. Pirner. *eprint: arXiv 0911.0627[hep-ph]*, (2009).

- **Regular articles in preparation:**

To be sent within 1 month:

21. **Broken scale invariance, massless dilatons and transport coefficients at finite temperature.**

    E. Megías, D. Kharzeev and E. Levin. Preprint (2009). To be sent to Physics Letters B or JHEP.

22. **Correlations between Perturbation Theory and Power Corrections at zero and finite temperature.**

    E. Megías, E. Ruiz Arriola and L.L. Salcedo. Preprint (2009). To be sent to Physics Letters B.

23. **The Heavy Quark Potential at $T < T_c$ in AdS/QCD.**

    K. Veschgini, E. Megías, J. Nian and H.J. Pirner. Preprint (2009). To be sent to Physics Letters B.

To be sent within 4 months:

24. **Gauge/string duality at finite temperature.**

    E. Megías, H.J. Pirner and E.M. Ilgenfritz. Preprint (2009). To be sent to Physical Review D.

11. Participation in Research Projects

1. **Dynamics of the Hadronic Systems in Nuclear Physics at intermediate energies.**
   - Financial organization: DGI and Feder funds, BFM2002-03218.
   - Participants: University of Granada.
   - Duration: from 1.10.2003 to 1.10.2005.
   - Amount: 129790 euros.
   - Responsible researcher: Juan Miguel Nieves Pamplona.
   - Number of participant researchers: 10.5.
2. **Nuclear Physics at Intermediate Energies.**
   - Financial organization: Junta de Andalucía (FQM-0225).
   - Participants: Universidad de Granada.
   - Duration: from 1997 to 2003.
   - Amount: 53500 euros.
   - Responsible researcher: Antonio M. Lallena Rojo.
   - Number of participants researchers: 12-19.
3. **Nuclear Physics at Intermediate Energies.**
   - Financial organization: Junta de Andalucía (FQM-0225).
   - Participants: University of Granada.
   - Duration: from 2004 to 2006.
   - Amount: 24816 euros.
   - Responsible Researcher: Carmen GarcÃa Recio.
   - Number of participant researchers: 9.
4. **Structure and Dynamics of Hadrons.**
   - Financial organization: UE, I3HP N5-Theory Network, contract number RII3-CT-2004-506078.
   - Participants: Tens of Universities and European Research Centers.
   - Duration: from 2003 to 2006.

- Amount: 122000 euros (Barcelona).
- Responsible researcher: C. Guaraldo. In Barcelona, where is included the Granada's group, the responsible researcher is A. Ramos.
- Number of participant researchers: 27.8 (Barcelona).

5. **Dynamics of the Hadronic Systems in Nuclear Physics at intermediate energies.**
    - Financial organization: MEC and Feder funds, FIS2005-00810.
    - Participants: University of Granada.
    - Duration: from 15.10.2005 to 14.10.2008.
    - Amount: 99960 euros.
    - Responsible researcher: Juan Miguel Nieves Pamplona.
    - Number of participant researchers: 9.
6. **Special Functions, Quantum Entropies and its applications in Bio- and Nano-Technologies.**
    - Financial organization: Junta de Andalucía (Research project with excellence), FQM-481.
    - Participants: Universities of Granada, Sevilla and Almería.
    - Duration: from 2006 to 2006.
    - Amount: 85000 euros.
    - Responsible researcher: Jesús Sánchez-Dehesa Moreno-Cid.
    - Number of participant researchers: 24.
7. **BIOMAT: Study of Models of Cellular and Tumoural development and mobility.**
    - Financial organization: Junta de Andalucía (Research project with excellence), FQM-1268.
    - Participants: University of Granada.
    - Duration: from 2006 to 2006.
    - Amount: 85000 euros.
    - Responsible researcher: Juan Soler Vizcaíno.
    - Number of participant researchers: 16

8. **Orthogonality, non-linearity and theory of information: interactions and physical, clinical and nano-technologic applications.**

   - Financial organization: Junta de Andalucía (Research project with excellence), P06-FQM-01735.
   - Participants: University of Granada, Sevilla and Almería.
   - Duration: from 01.06.2007 to 31.05.2010.
   - Responsible researcher: Andrei Martínez-Finkelshtein.
   - Number of participant researchers: 23

9. **Dynamics of the Hadronic Systems in Nuclear Physics at intermediate energies.**

   - Financial organization: MEC and Feder funds, FIS2008-01143.
   - Participants: University of Granada.
   - Duration: from 15.10.2008 to 14.10.2011.
   - Responsible researcher: José Enrique Amaro Soriano.

12. Research Interests

Note: The numeric references correspond to my list of publications.

My research deals with the properties of nuclear matter under extreme conditions. In this regime, the elementary constituents of nuclear matter (quarks and gluons), become the active degrees of freedom: with increasing energy density, one expects indeed nuclear matter to undergo a phase transition in which quarks and gluons, usually confined inside hadrons, are liberated to form the quark-gluon plasma (QGP). This new state of matter was experimentally produced recently at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), USA, and it will be further analyzed at the Large Hadron Collider (LHC) at CERN, Switzerland, as well as at the proposed FAIR facility at GSI in Darmstadt, Germany. It is therefore important to have a good theoretical understanding of the quark-gluon plasma in order to confront our expectations to the present and future experimental data.

I am interested in the physics of phase transitions of gauge theories. For the electroweak and strong theories, phase transitions occur at certain values of temperature and baryon chemical potential. In Quantum Chromodynamics (QCD) there are two phase transitions: the confinement-deconfinement phase transition and the restoration of chiral symmetry. The first one is driven by the breaking of the discrete global symmetry $\mathcal{Z}(N_c)$, which is the center of the usual color gauge group $\mathrm{SU}(N_c)$. For heavy quarks, they become static sources and there is a general consensus that the order parameter for this transition can be taken to be the Polyakov loop or thermal Wilson line. Lattice data shows that these two transitions occur very close together, at least for zero baryon chemical potential.

The dynamics of the Polyakov loop has been a key ingredient in my research work. I have some experience in the Matusubara formalism of quantum field theory at finite temperature, where there are periodic or antiperiodic boundary conditions in the Euclidean time direction, and for example, it could be very fruitful to apply this formalism for gauge theories with extra dimensions.

The study of effective actions to describe the QGP phase has been of interest during the last 30 years, in particular the effective potential which includes the Debye mass to describe the screening of the chromoelectric interaction, and the quartic term to describe the self-interaction of the chromoelectric gluons. I obtained terms of mass dimension 6 in the chromoelectric and chromomagnetic sectors in my PhD Thesis [3,5]. For this purpose I considered as a mathematical tool the Heat Kernel expansion at finite temperature [2]. The Polyakov loop must be included in this expansion in order to maintain gauge invariance order by order. The Heat Kernel constitutes a very general formalism to compute effective actions of gauge theories at zero and finite temperature.

It is remarkable that even if the QGP is produced, the states which are detected in a collider are hadrons created in a hot enviroment. Thus, it make sense to study the properties of hadrons in a medium which can undergo a confinement-deconfinement phase transition. In the low temperature regime of QCD the effective degrees of freedom are hadrons. Such a phase is non perturbative and so the treatment is difficult. At low energies a systematic treatment is Chiral Perturtation Theory (ChPT), where the effective degrees of freedom are pions, that is, the Goldstone bosons of the spontaneously chiral symmetry breaking. The parameters of the Lagrangian are obtained after integration of quarks and gluons. In practice there is no efficient procedure to compute these parameters, and they must be adjusted to the experiment. In addition, there exist some constituent chiral quark models, which use pions (and other mesons) and effective quarks as degrees of freedom. If the constituent quarks are integrated, the chiral Lagrangian is obtained with a prediction for the parameters. This was an important part of my PhD Thesis. I studied some chiral quark models at finite temperature (Constituent Quark Model, Nambu–Jona-Lasinio and Spectral Quark Model), by considering the coupling of the Polyakov loop in a minimal way [6,7,12,13,14,15] and including corrections beyond mean field approximation. The inclusion of the gluonic Polyakov loop incorporates large gauge invariance, and this generates an effective theory of quarks and Polyakov loops as basic degrees of freedom. The net result is that, contrary to standard chiral quark model calculations at finite temperature, no single quark excitations are allowed due to triality conservation. More generally, the leading thermal corrections, which are provided by pion thermal loops, start at temperatures near the deconfinement transition, and we have named this effect "*Polyakov cooling*" of the quark excitations.

The renormalization of the Polyakov loop is an open problem, and only recently different ways of measuring renormalized Polyakov loops on the lattice have been proposed by Kaczmarek et al. [PLB543, 41 (2002); PRD77, 034503 (2008)] and Dumitru et al. [PRD70, 034511 (2004)]. Perturbation theory can only describe the region of high temperature (above $6T_c$), and non perturbative contributions become important below this regime. I have proposed in [9,10,11] a phenomenological model to describe the available lattice data for the Polyakov loop in the region just above the deconfinement phase transition. These data exhibit unequivocal inverse power temperature corrections driven by a dimension 2 gluon condensate. The model was applied also for the heavy quark free energy in [16], and it predicts a decomposition in a perturbative term plus a non perturbative power correction. A similar decomposition holds for the well established $q\overline{q}$ potential at zero temperature. On the other hand, it is noteworthy that the same shape for the Polyakov loop can also be obtained within the instanton approach at finite temperature along the lines of [E.Gava et al., NPB200, 107 (1982)]. The relation between instantons and dimension 2 gluon condensates at zero temperature was suggested in [M.Hutter, hep-ph/0107098] and fruitfully exploited in recent lattice simulations to extract, via cooling techniques, the infrared behaviour of the running coupling constant [P.Boucaud et al., PRD70, 114503 (2004)]. In this regard, it might be rather interesting to isolate the purely non perturbative instantonic contributions on the lattice and determine whether, after cooling, our shape extends also below the phase transition.

The perturbative series of the free energy of QCD has a problem of convergence for temperatures below $10T_c$, which could mean a lack of analyticity near the phase transition. There have also been numerous attempts to resum perturbation theory in order to get a better convergence of the result, one of the most developed techniques being the Hard Thermal Loop (HTL) perturbation theory, first proposed in [E.Braaten et al, NPB337, 569 (1990)]. But even when much mathematical efforts have been made for a long time in the computation of the equation of state of QCD using these resummations, the result is clearly unsatisfactory. As a matter of fact the HTL computation up to 2 loops order give a very small and smooth behavior for the trace anomaly density in the strong-QGP regime, in contrast to the violent behavior predicted by lattice data [E.Braaten et al, PRD66, 085016 (2002)]. Many perturbative studies based on the computation of the three-dimensional effective theory of QCD on the lattice lead once again to the same conclusion [A.Hietanen et al, PRD79, 045018 (2009)]. In order to firmly establish the need for a non perturbative description of the equation of state just above T_c, I have studied in [19] the improvement of the perturbative series in the computation of the free energy of QCD based on Renormalization Group (RG) arguments. The perturbative series then writes in a manifestly RG invariant form expressed in terms of a single invariant. I have extended this analysis to the Polyakov loop and heavy quark-antiquark free energy in [22], and in all cases the results confirm that perturbation theory is not a correct description near T_c.

There have been many approximations to characterize the non perturbative contributions in the equation of state of QCD just above the phase transition. Some of them introduce a gluon mass [Meisinger et al, PLB585: 149 (2004)]. Given the success of our model for the description of the Polyakov loop and heavy quark free energy, I have studied the extension of this model to compute the equation of state in quenched QCD [19]. In addition to the standard parameters of the dimensional reduced theory (Debye mass, chromo-electric and chromo-magnetic effective couplings, etc), the model incorporates a new mass parameter that could be seeing as a tachyonic gluon mass. It signals an explicit breaking of scale invariance. While the model might be improved, taken at face value it provides a unified and coherent description of gluodynamics thermal observables in terms of a dimension two gluon condensate.

The appearance of a tachyonic mass was first stablished in the computation of QCD sum rules at the non perturbative level [K.G. Chetyrkin et al, NPB550, 353 (1990)]. One important point is to clarify the origin of this tachyonic mas in the gluon propagator, or equivalently the dimension two gluon condensate. One possibility is that it appears as a consequence of the dimensional reduction of QCD. Another possibility is that it is a consequence of an infrared renormalization of the Schwinger-Dyson equation for the gluon, as it was proposed in [V.Gogokhia PLB618, 103-114 (2005)]. I have studied this problem and tried to give an answer. Although this is a difficult issue, some clues have been obtained in [20].

Although the origin of power corrections in QCD is not clear, many efforts have been devoted to put some light on this problem. Of interest is a recently conjectured scenario pointed out in [S.Narison et al, PLB679, 355 (2009)], namely a duality between condensates and perturbative contributions. This duality concerns the properties of large order perturbative series which includes expansion in the strong running coupling constant, and it establishes that they are dual to non perturbative power corrections. At the practical level, this means that if one considers a short perturbative series then one should add the leading power correction by hand. Only when one uses long perturbative series there is no reason to add power corrections. I have proposed an approach to check the validity of this conjecture, based on the computation of correlations between the perturbative series and power corrections for observables both at zero and finite temperature. In addition to the existence of a strong correlation, a preliminary analysis suggests that there is a smaller contribution from power corrections at increasing perturbative orders [22], and so this result is in the line with the duality.

An interesting symmetry present in Gluodynamics and in QCD in the chiral limit is *"scale invariance"*, which means invariance with respect to rescaling of coordinates. The QCD Lagrangian is scale invariant at the classical level in four space-time dimensions, but this invariance is lost in real world (the hadrons possess finite masses and sizes). Quantum corrections break this symmetry because a scale has to be introduced in the theory after the necessary regularization of ultraviolet divergences. Unlike chiral symmetry, the scale invariance is broken not spontaneously but explicitly, and so there is no limit in which the dilaton can become massless. Nevertheless, the corresponding effective theory can still be formulated [J. Schechter, PRD21, 3393 (1980); D.Kharzeev et al, PRD70, 054005 (2004)]. I have extended this effective theory to finite temperature in [20], and related the powers corrections of the unconfined phase of QCD to the existence of chromo-electric flux tubes in the vacuum, which could eventually lead to confinement.

Using this model I have studied the hydrodynamical properties of the quark gluon plasma, and in particular the behavior of the transport coefficients computed in the context of the effective kinetic theory dictated by the Boltzmann equation [P. Arnold et al, JHEP01 (2003) 030]. A diagramatic computation was applied for the shear and bulk viscosities, the lowest order coefficients, and predicted a behavior in the non-perturbative regime in very good agreement with recent lattice data [H.Meyer PRD76 (2007), PRL100 (2008)]. This regime is the one corresponding to current experiments at RHIC and LHC. This model could be easily applied to compute other transport coefficients, such as the energy loss of high energy jets.

There has been a breakthrough in understanding the dynamics of supersymmetric conformal Yang-Mills theory based on the holographic correspondence between the field theory describing behavior on 4D Minkowski boundary and the supergrativy in the 5D Anti-de Sitter space [J.M.Maldacena ATMP 2, 231-252 (1998)], and known as AdS/CFT correspondence. The AdS metric is unique if we want to extend Minkowski boundary space into the fifth dimension preserving the conformal invariance, but in principle there is some freedom in an extension that breaks conformal invariance. Of importance in this correspondence is the duality between the strongly-coupled Yang-Mills theory and the weakly coupled gravity that can be treated by semi-classical methods. This allows to translate some hopelessly difficult field-theoretical problems into treatable exercises in classical gravity. The finite temperature is introduced on the gravity side by putting a black hole in the center of the AdS. The temperature and the entropy density of the Yang-Mills plasma are thus associated with a Hawking temperature of the black hole and the entropy associated with its even horizon. Many efforts in this issue are been doing recently.

A first step towards a more QCD-like theory is obtained by deforming the AdS metric, in such a way that it captures the non-conformal nature of QCD. The strategy of such a deformation is the following: one uses an asymptotically AdS-space in the ultraviolet regime, in order to accommodate the conformal behavior of QCD at high momenta. The deep bulk region, corresponding to the infrared physics, is then taken to deviate from AdS, in order to model confinement. This was first realized in the so-called hard-wall models [J. Polchinski et al, PRL88 (2002)]. I have studied a different model based on the modification of the AdS metric in a smooth way by an additional factor [21], which is in the context of the more fruitful soft-wall models. The infrared properties of the metric can be phenomenologically determined by either fitting to the glueball spectrum [E. Kiritsis et al, JHEP02 (2008)] or to the heavy quark potential which I considered in my computation. A detailed analytical computation of the heavy quark potential at short distances allows a direct comparison with perturbation theory, and serves as a tool for a precise determination of the string length and other relevant parameters of the metric. We found that AdS/QCD can describe QCD much better than the accepted 10 % to 25 % accuracy.

I have explored also some of the features of a heavy quark-antiquark at finite temperature and the thermodynamics of the deconfined phase of QCD within AdS/QCD [23]. Using a consistent treatment based on 5D Einstein-dilaton gravity with a dilaton potential, the computation of the Einstein equations leads to two solutions: the thermal graviton gas solution corresponding to a confined phase, and the black hole solution which is characterized by the existence of an horizon, corresponding to a deconfined phase [E.Kiritsis et al, JHEP05 (2009)]. The second solution gives very careful results for the expectation value of the Polyakov loop and equation of state. This is a remarkable fact, because this means that the formalism incorporates in a natural way power corrections, and it allows for a perfectly invariant way to introduce condensates of dimension two.

My research deals also with the study of QCD in presence of curvature (that is, quarks and gluons coupled to a metric). In QCD, the energy momentum tensor operator probes the interaction of quarks and gluons to gravitons. As an example, the gravitational pion form factor can be used to determine the width of a light Higgs boson into two pions, and also the decay of a scalar glueball into two pions. In that case, after integration of the underlying degrees of freedom, we obtain a chiral Lagrangian coupled to the metric and new operators which don't appear in the flat space case. I studied in [4,8] the low energy structure of the energy momentum tensor (EMT) in several chiral quark models in presence of external gravitational fiels.

Needless to say, I am always open to new developments and ideas in theoretical and nuclear physics, and it would be a pleasure for me to collaborate in other fields where my experience and knowledge could be useful.

13. References

- **Prof. Enrique Ruiz Arriola**
  Departamento de Física Atómica, Molecular y Nuclear. Universidad de Granada. Campus de Fuentenueva s/n, E-18071 Granada, Spain. Tel.: +34 958 246170.
  email: earriola@ugr.es

- **Prof. Lorenzo Luis Salcedo**
  Departamento de Física Atómica, Molecular y Nuclear. Universidad de Granada. Campus de Fuentenueva s/n, E-18071 Granada, Spain. Tel.: +34 958 240772.
  email: salcedo@ugr.es

- **Prof. Wojciech Broniowski**
  Department of Theory of Structure of Matter, H. Niewodnizański Institute of Nuclear Physics, Cracow, Poland. Tel.: +48 12 662 8431.
  email: Wojciech.Broniowski@ifj.edu.pl

- **Prof. Robert D. Pisarski**
  Nuclear Theory Group, Physics Department, Bldg. 510A, Brookhaven National Laboratory, Upton, New York 11973, USA. Tel.: +1 631 344 5161.
  email: pisarski@quark.phy.bnl.gov

- **Prof. Dmitri Kharzeev**
  Nuclear Theory Group, Physics Department, Bldg. 510A, Brookhaven National Laboratory, Upton, New York 11973, USA. Tel.: +1 631 344 7231.
  email: kharzeev@bnl.gov

- **Prof. Eugene Levin**
  Department of Particle Physics, School of Physics and Astronomy Raymond and Beverly Sackler Faculty of Exact Science, Tel Aviv University, Tel Aviv, 69978, Israel. Tel.: +972 - 3 - 640 6740.
  email: leving@post.tau.ac.il

- **Prof. Hans-Jürgen Pirner**
  Institute for Theoretical Physics, Philosophenweg 19, D-69120 Heidelberg, Germany. Tel.: +49 6221 54 9441.
  email: pir@tphys.uni-heidelberg.de

Heidelberg, Germany, 4 November, 2009.

Dr. Eugenio Megías.