CURRICULUM VITAE

NAME : **AMRUTA MISHRA**

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ACADEMIC AND EMPLOYMENT RECORD :

- Bachelor of Science (Hons.) Physics major subject, Utkal University (1984) (**Best Graduate** of Utkal Univ.), other subjects were Mathematics, Chemistry and English.
- Master in Science (Physics), Utkal University, Bhubaneswar (1986) (1st class), Result was out in March, 1987.
- Joined as a Doctoral Scholar with C. S. I. R. fellowship in Department of Physics, Utkal University, Bhubaneswar in July, 1987. Submitted the thesis for Ph. D. on 5th May, 1993.
- Physical Research Laboratory, Ahmedabad, India as a post doctoral fellow from 1st November, 1993 to 31st October 1995.
- Ph. D. in Physics (Utkal University) in October,1994.
- Mehta Research Institute, Allahabad, India as a CSIR Research Associate from November, 1995 to March,1996.
- Alexander von Humboldt Fellow in Institüt für Theoretische Physik, University of Frankfurt, Germany from June 1996 to May 1997.

- Visitor, Theory Division, Physical Research laboratory, Ahmedabad from July 1997 to June 1998.
- Post Doctoral fellow, Theory Group, Institute for Plasma Research, Gandhinagar from July 1998 to July 2000.
- Visiting Scientist, Institute for Plasma Research, Gandhinagar from October 2000 to February 2001
- Alexander von Humboldt Fellow in Institüt für Theoretische Physik, University of Frankfurt, Germany, from 1st May, 2001 till October, 2001.
- Scientific Associate at the Institüt für Theoretische Physik, University of Frankfurt, Germany from November, 2001 till February, 2004.
- Joined as Assistant Professor in Physics Department, I.I.T, Delhi, India since April, 2004 and continuing (**present basic pay Rs. 14940/−** in the pay scale 12,000-18,000).
- Visited Frankfurt Institute of Advanced Studies (FIAS), University of Frankfurt, Germany, under Alexander von Humboldt Fellow follow-up program from 1st June till 30th June, 2005.
- Visited Frankfurt Institute of Advanced Studies (FIAS), University of Frankfurt, Germany, under Alexander von Humboldt Fellow follow-up program from 20th May till 20th July, 2007.
- Visited Frankfurt Institute of Advanced Studies (FIAS), University of Frankfurt, Germany, under Alexander von Humboldt Fellow follow-up program from 1st June to 30th June, 2009.

TITLE OF THESIS :

A field theoretical study of hadron structure

THESIS SUPERVISOR : Professor Niranjan Barik, Mayurbhanj Professor of Physics, Physics Department, Utkal University, Bhubaneswar- 751 004, India.

AREA OF RESEARCH :

Non-perturbative variational methods in quantum field theory, in particular Vacuum structure in QCD, QCD at finite temperatures and/or baryon densities in the context of Quark gluon plasma and neutron and/or quark stars, Chiral symmetry breaking, Color superconductivity, Super fluidity in ultra cold atoms, Ground and Excited states of Nuclear matter, Dense matter equation of state and neutron star properties, Magnetic field structure in rotating compact objects, Properties of Mesons in hot hadronic matter and their effects on observables of ultra-relativistic heavy ion collision experiments.

COMPUTATIONAL EXPERIENCE :

Familiarity with programming in Fortran and Mathematica as a user.

AWARDS/HONOURS:

- **Best Graduate** of Utkal University in 1984.
- Awarded **Alexander von Humboldt** fellowship in 1995.
- Awarded the **Regular Associateship of The Abdus Salam International Centre for Theoretical Physics**, Italy, from 1st January, 2006 until 31st December, 2011.

TEACHING EXPERIENCE :

I designed and taught the courses on **Nuclear Physics** and on **Quantum Electrodynamics** to the M.Sc. students at IIT, Delhi. I was involved in teaching of the course '**Fields and Waves**' (comprising of Electrodynamics, Optics and Modern Physics) (summer semester 2004-2005 and I-semester 2004-2005, II Sem 2007-2008 and summer semester, 2008) for the B. Tech. students. I also taught a course on **Quantum Mechanics** and **Mathematical Physics** to the B. Tech. students, **Advanced topics in Quantum Mechanics** and **Electrodynamics** to the M.Sc. students.

This apart I gave **a series of lectures (three)** on *Chiral effective Theories* on an workshop on Chiral Field Theory held at Saha Institute of Nuclear Physics, Kolkata (Feb-March, 2005) to Ph.D. students and post doctoral fellows. I also gave **a set of lectures (four)** on 'Hadron spectroscopy' in the **3rd DST-SERC school on Nuclear Physics** that was organised at Institute of Physics during the period from 18th December, 2006 to 6th January, 2007.

Sponsored Projects

1. DST-SERC project on **Hadron properties of hot and dense hadronic matter** since May 2007 for 3 years of an amount of Rs. 9,77,000/-. One student (Mr. Arvind Kumar) is working for Ph.D. under this project.
2. Completed the project under new faculty grant (IRD) for 18 months of Rs. 100,000/- after joining IIT,Delhi.
3. A research associate (Ms. Raje Bhagirathee) working with me under the women scientist project of DST.

Organisational Experience

1. I was in **the national organising committee** for the 20th International Conference on ultra-relativistic Nucleus-Nucleus Collisions **Quark Matter 2008** held in Jaipur, India in February, 2008.
2. I was one of the organizers for the one day **workshop on Engineering Challenges for Future Accelerators**, jointly held by IUAC and I.I.T.,Delhi on the 13th of March, 2006.

Lectures delivered outside IIT,Delhi

1. Gave a series of lectures (three) on **Chiral effective Theories** on an workshop on Chiral Field Theory held at Saha Institute of Nuclear Physics, Kolkata (Feb-March, 2005) to Ph.D. students and post doctoral fellows.

2. Gave a set of lectures (four) on **'Hadron spectroscopy'** in the **3rd DST-SERC school on Nuclear Physics** organised at Institute of Physics during the period from 18th December, 2006 to 6th January, 2007.

Scientific Visits outside India after joining IIT,Delhi

1. Visited FIAS, University of Frankfurt, Germany for a month in June, 2005 with Alexander von Humboldt follow-up program.

2. Visited FIAS, University of Frankfurt, Germany for two months (20th May, 2007 to 20th July, 2007) with Alexander von Humboldt follow-up program.

3. Visited Frankfurt Institute of Advanced Studies (FIAS), University of Frankfurt, Germany, under Alexander von Humboldt Fellow follow-up program from 1st June to 30th June, 2009.

SOME RECENT INVITED TALKS:

- *"D-mesons in asymmetric nuclear matter"*, **Invited talk** given in "the Workshop in heavy Quarkonia", held during 24-29 May, 2009, at ECT, Trento, Italy.

- *"D-mesons in asymmetric nuclear matter"*, **Invited talk** given at Quark Gluon Plasma (QGP) meet, 2008, during 25-27 November, 2008 at VECC, Kolkata, India.

- Delivered a talk on *"Kaons and antikaons in asymmetric nuclear matter"* in Workshop in High Energy Physics Phenomenology (WHEPP) held at Insititute of Mathematical Sciences (IMSc) at Chennai, India during 2nd to 13th January, 2008.

- Delivered four lectures on *"Hadron spectroscopy"* in the 3rd DST-SERC school on Nuclear Physics organised at Institute of Physics, Bhubaneswar, December, 2006-January, 2007.

- *"Kaons and antikaons in dense hadronic matter"*, **Invited talk** given at DAE-BRNS workshop on physics and astrophysics of hadrons and hadronic matter, Visva Bharati University, Shantiniketan, Nov. 6-11,2006.

- *"Hadrons in hot and dense hadronic matter"*, **Talk** given at Institute of Physics, Bhubaneswar, June 2006.

- *"Hadrons in hot and dense hadronic matter"*, **Talk** given at Variable Energy Cyclotron Center (VECC), Kolkata, June 2006.

- *"Kaons and antikaons in hot hadronic matter"*, **invited talk** in QGP meet,06 at VECC, Kolkata, 5-7 Feb., 2006.

- *'Mesons in hot hadronic matter'*, **colloquium** at the Frankfurt Institute of Advanced Studies (FIAS), University of Frankfurt, Germany, June, 2005.

- *"Chiral effective theories"*, **Three lectures** given in the workshop on chiral field theory, Saha Institute of Nuclear Physics, Kolkata, India, Feb-March 2005.

- *" Medium modifications of meson properties and their effects on experimental observables"*, **Invited talk** given at DAE symposium on Nuclear Physics, Banaras Hindu Unversity,Banaras, India, Dec 2004.

- *" Meson properties in hot and dense matter"*, **invited talk** given at workshop on QGP, QGP04 at Institute of Physics, Bhubaneswar, India, October 2004.

- "*Chiral symmetry breaking, Color superconductivity and gapless modes in color neutral matter*, Talk given at International winter meeting on Nuclear Physics, Bormio, Italy, Jan 26-31, 2004.

- *" Mass modification of D mesons in hot and dense matter"*, Talk given at International winter meeting on Nuclear Physics, Bormio, Italy, Jan 26-31, 2004.

- "*In-medium vector meson properties and low mass dilepton production from hot hadronic matter*",**Invited talk** QGP meet'03, held at VECC, Kolkata, India, 5 May - 7 May, 2003

- "*In-medium vector meson properties and low mass dilepton production from hot hadronic matter*", **invited talk** in workshop on "Mesons and Quarks", held at BARC, Mumbai, India, 28 Jan- 1 Feb, 2003.

- Quark Matter 2002, held at Nantes, France, 18-24 July, 2002 (presented posters on "*Vertex corrections and color superconducting gap*" and "*In-medium vector meson properties and low mass dilepton production from hot hadronic matter*").

Details about courses taught/teaching in IIT Delhi:

1. M. Sc. Course on Nuclear Physics (PHL 569) (I Semester 2009-2010)
2. Course on Electrodynamics (PHL 552) (II Semester 2008-2009)
3. Course on Advanced topics in Quantum Mechanics (PHL 744) (I Semester 2008-2009)
4. Course on Nuclear Physics (PHL 569) (I Semester 2008-2009)
5. Course on Fields and Waves (PHL110) (Summer Semester 2008)
6. Course on Fields and Waves (PHL110) (II-Semester 2007-2008)
7. Course on QED and Particle Physics (PHL 741) (I-Semester 2007-2008)
8. elective course on Advanced Quantum Mechanics (PHL 744) (II-Semester 2006-2007)
9. B.Tech. course on Mathematical Physics (EPL 103) (I-Semester 2006-2007)
10. B.Tech course on Quantum Mechanics (EPL 202) (II-Semester 2005-2006)
11. Elective course on QED and Particle Physics (PHL 741) (I Semester 2005-2006).
12. M.Sc. course (PHL 514) Nuclear Physics (II-Semester 2004-2005).
13. B.Tech course Fields and Waves (PHL110) (I semester, 2004-2005).
14. B.Tech course Fields and Waves (PHL110) (summer semester, 2004).

M.Sc. Projects supervised/under supervision: 9

1. M.Sc.project ("Strange mesons in hot hadronic matter") of Mr. Ram Krishna Deewanjee under supervision (2009-2010).
2. M.Sc.project ("Charmed mesons in hadronic matter") of Mr. Arshdeep Singh Bhatia under supervision (2009-2010).
3. M.Sc.project ("Kaon condensation in neutron stars") of Mr. Shashikant Kumar under supervision (2009-2010).
4. M.Sc.project ("Strange mesons in the medium") of Ms. Sudeshna Ganguly, under supervision (2008-2009).
5. M.Sc.project ("Charmed mesons in the medium") of Mr. Arindam Mazumder in 2007-2008.
6. M.Sc.project (title "kaons and antikaons in hot and dense hadronic matter") of Mr. Sambuddha Sanyal in 2007-2008.
7. M.Sc.project (title "Dilepton emission rates from hot hadronic matter") of Mr. Apurva Soumya in 2005-2006.

8. M.Sc.project (title "K-mesons in hot and dense matter") of Mr. Mukul Kumar Dubey in 2005-2006.

9. M.Sc.project (title "Equation of state and dense matter properties of neutron stars") of Mr. Ujjwal Sinha in 2005-2006.

B. Tech. Projects supervised:

1. Mini project on 'Superfluidity in ultra cold atoms', by Mr. S. Bhuvanesh and Ms. Abha Rajan during II Semester, 2008-2009.

Ph. D. supervision:

1. Supervising a Ph.D. student (Mr. Arvind Kumar) since July, 2007.
2. Supervising a Ph.D. student (Mr. Sushil Kumar) since January, 2009.

Research Associate supervision:

1. A research associate (Ms. Raje Bhagirathee) working with me under the women scientist project of DST.

Other Institute responsibilities undertaken

1. A member of the Departmental Research Committee (DRC) from Aug,2005- September,2007.
2. IIT representative for DRDO,2004, JEE screening test, 2005, JEE, 2006, JMET, 2007; and, **Confidential operations** for DRDO, 2004, GATE, 2005, JAM, 2005, GATE, 2007.

'Strongly interacting matter' has been broadly the area of my research. We had been studying strongly interacting systems in quantum field theory in a nonperturbative manner, since the perturbative techniques become invalid due to the large value of the coupling constant. This has been done using equal time algebra and then minimising the energy density, free energy or thermodynamic potential, as the case may be, with a variational ansatz for the determination of the ground state as a quantum realignment of the perturbative vacuum.

The techniques have been applied to phase transitions, equations of state in Quantum Chromodynamics (QCD) with and without quarks, equation of state of nuclear matter, structure of neutron and hybrid stars including rotating stars with magnetic field. We give below a short description of the same.

(a) Work during Ph.D. (1987-1993):

The method was first applied to the Gross-Neveu model in 1+1 dimension as a test case [1]. It was shown that the usual nonperturbative vacuum emerges as a solution corresponding to the solution considered earlier, here *without* resorting to a sum over infinite number of Feynman diagrams. Phase transition here was also generalised to the corresponding 1+1 dimensional supersymmetric model as test case at zero temperature as well as at finite temperature [3], with supersymmetry breaking or restoration.

The ansatz functions considered here were rather similar to the construction of coherent states in field theory. Thus it was thought that it may be possible to simulate some of the classical mean field results of Walecka. To verify this we applied the method to symmetric nuclear matter [2], where it was seen that the scalar isoscalar pion condensate can simulate the σ-meson of Walecka. This analysis has been further continued by our group to consider hot nuclear matter as well as neutron matter and hybrid stars.

Consideration of phase transitions as vacuum destabilisation was also applied for Salam Weinberg symmetry breaking [4]. At finite temperatures, the Higgs potential was obtained in a self-consistent manner with the temperature dependent Higgs mass being constrained so that the same as a parameter of the Bose distribution function becomes equal to the double derivative at the minimum of the potential. The potential here *did not* involve any high temperature expansion or perturbation expansion. There appears to be some evidence that a few peculiar cosmic ray events like chiron events or halo events might arise as a signature of local vacuum destabilisation in high energy cosmic ray collisions. The vacuum realignment occurs here below the critical temperature for a phase transition, like change in Fermi surface of a metal with temperature *without* a phase transition.

Chiral symmetry breaking is an important concept in strong interaction physics. For this purpose we first examined if this symmetry breaking for quarks can arise [7] from the phenomenological quark anti-quark potentials of hadron spectroscopy. Our consideration of symmetry breaking as explicit vacuum realignment yielded that the pion wave function gets determined in terms of the ansatz function describing the vacuum structure. It was seen that the potentials do give rise to chiral symmetry breaking, but that the vacuum structure as arising from the same is *inconsistent* with the experimentally measured value of the the charge radius of the pion.

We then considered [8] chiral symmetry breaking with a *phenomenological ansatz* as a *Gaussian* distribution in the nonperturbative vacuum, with a single parameter, which could be determined from pion decay constant. This then yielded some low energy hadronic properties, with the relativistic corrections for the quarks being determined from the vacuum structure itself.

The method has been used to tackle various problems in QCD in a series of papers [5, 6, 9, 10, 12]. First, the nontrivial vacuum structure here was attempted with a variational ansatz, as earlier using only equal time algebra, similar to that of Gross-Neveu model, at zero temperature with only gluon condensates [5]. Minimisation of the energy density yielded that for a coupling $g^2/4\pi$ greater than a critical value of 0.39, there is a phase transition and the QCD vacuum becomes nontrivial. The condensate scale was determined by identifying $< GG >$ with the numerical value of the SVZ parameter. This was next extended to finite temperature [6] using thermo field dynamics where the expectation value of the free energy density was minimised, and, to the case of finite baryon density at finite temperature [9] by minimising the expectation value of the thermodynamic potential. The results in all these cases were similar to those of lattice calculations, showing the continued existence of nonperturbative effects.

(b) Post-doctoral work at PRL and MRI, Allahabad (1993-1996):

Earlier, we had considered vacuum realignment with only quark condensates for chiral symmetry breaking, and with only gluon condensates in QCD, which we extended to include both condensates [12]. This yielded a bag constant generally in the same range as the experimental value of the same, and the correct charge radius of the pion.

These techniques were then generalised to consider some problems in astrophysics using Tolman-Oppenheimer-Volkoff equations [10], and equation of state of quark matter and neutron matter as derived by us. This gave rise to hybrid stars with a neutron crust, with quark matter inside being in equilibrium with neutron matter, where the density of neutron matter at the phase boundary is only about three times the nuclear density.

We also derived quark matter equation of state taking explicitly confinement into account in a relativistic harmonic oscillator model [11]. Using a phenomenological equation of state for neutron matter a phase transition is obtained for density around 4 to 5 times the nuclear density.

(c) Post-doctoral work at Frankfurt as Humboldt Fellow (1996-1997):

We calculated the effective potential for scalar theory at finite temperature with a squeezed coherent state construction for the ground state [13]. This method essentially consists of optimising the field operator basis at zero and finite temperatures. The resulting gap equation becomes identical to summing an infinite series of daisy and super daisy graphs of conventional perturbation theory and the effective potential includes multi-loop effects agreeing with that obtained through composite operator formalism at finite temperature. This work started in India and was completed at Frankfurt.

The idea of condensates was also used to consider vacuum polarisation effects in nuclear matter [14]. The contribution arising from a ground state structure with baryon anti-baryon condensates yields the results of relativistic Hartree approximation of summing tadpole diagrams for the baryon propagator. Such a vacuum is then generalised to include quantum effects from meson fields through scalar-meson condensates. This leads to a softer equation of state giving a lower value of the incompressibility than would be reached without quantum effects.

Nuclear matter was considered at finite temperature with a direct quark meson coupling as a phenomenological model [15], similar to Walecka model incorporating quark degrees of freedom, where the equation of state and effective masses of the hadrons were calculated. Here apparently nucleon mass increased with temperature.

(d) Work at PRL (1997-1998):

Rotating neutron as well as hybrid stars endowed with magnetic fields were considered [16] with Hartle-Thorn equations as possible phenomenological models of pulsars along with the structure of magnetic fields in the interior of the same.

(e) Work at IPR (1998–2001):

The work described so far had been dealing with static problems. Our research interests at IPR had been to study the strongly interacting dynamical systems, e.g., dusty plasmas, quark gluon plasmas (QGP). For studying the dynamical evolution of QGP formed in relativistic heavy ion collisions, an attempt was made to develop a relativistic generalisation of the viscoelastic formalism, a framework for studying strongly coupled plasmas. The numerical calculations for the problem, however, remains to be done.

Dusty plasmas are of great current research interest because of their possible applications to a variety of fields such as plasma astrophysics of interplanetary and interstellar matter, fusion research etc. The strong Coulomb coupling in the dusty plasma leads to many novel physical effects such as formation of dust plasma crystals, modified dispersion of the compressional waves and the existence of transverse shear waves. We have investigated the instability of the low frequency shear mode in a strongly coupled dusty plasma. This instability is related to the charging of the dust particles by the inflow of plasma currents in an inhomogeneous plasma sheath and the finite charging time of the dust grains. The calculations, carried out in the generalised hydrodynamic viscoelastic formalism, also bring out important modifications to the dispersion relations arising due to the coupling of the shear mode to the compressional mode [17].

The nonperturbative method of Ref.[14] for nuclear matter is generalised to study the vacuum polarisation effects in hyperon rich dense matter. The equation of state (EOS) for electrically charge neutral dense matter is derived. The effect of such an EOS on the structure of neutron stars is also studied [19].

(f) Work at ITP, University of Frankfurt (2001-2004) and at IIT, Delhi (2004 onwards):

The effect of temperature on the EOS within the nonperturbative framework including quantum correction effects has also been attempted in a variational manner using Walecka model. The temperature- and density- dependent nucleon and scalar meson masses are obtained in a self-consistent manner. We then study the liquid gas phase transition as well as examine for a possible chiral symmetry restoration at high temperatures [18]. The effect of such quantum corrections on the vector meson masses [20] has been studied. The effect of such quantum corrections on dilepton production in relativistic heavy ion collisions [21] is investigated which is seen to lead to appreciable broadening of the resonant peaks in the dilepton spectrum. The dynamical evolution of fireball resulting from a nuclear collision is modeled [27] and the space time integrated dilepton emission rates are calculated. The results are compared to those from other hadronic scenarios as well as the CERES data. The related problem of computing photon emission rates resulting from heavy ion collisions as modified due to quantum effects, is also being pursued.

The density dependence of the dilepton spectra are also studied [21] which may be relevant for highly compressed matter at the early stage of a heavy ion collision. These calculations are particularly important for heavy ion collision experiments which look for medium properties at high densities and temperatures that are being planned at GSI, Darmstadt, Germany and is complimentary to the experiments at RHIC, Brookheaven.

The medium modifications of hadronic properties have been studied using a chiral SU(3) model [24,25]. Their effects on experimental observables like dilepton rate and particle multiplicities are presently under investigation.

The chiral SU(3) model has been generalised to chiral SU(4) to study the medium modification of the D-meson mass [26] in hot and dense matter. This can have important phenomenological consequences for the production of open charm and the suppression of J/psi in heavy ion collision experiments and, can be explored in experiments, e.g., in the future accelerator facility at GSI. The in-medium properties of kaons and antikaons in hot hadronic matter in different hadronic scenarios and their effects on their production and flow pattern observed in the heavy ion collision experiments are also investigated [28]. These can be used to determine the medium modification of kaons and antikaons in the hot and dense hadronic matter from the experimental side in the near future at GSI.

The spectral properties of D-mesons in the nuclear medium have also been studied recently using a self-consistent coupled channel calculation [29]. The DN interaction is seen to generate the resonance Λ_c (2593) dynamically, which is the charm counterpart of the resonance Λ (1405) arising from $\bar{K}N$ interaction in the I=0 channel.

This apart, I am also looking at matter at high density in terms of quark and gluon degrees of freedom. It appears strongly interacting matter in terms of these degrees of freedom can have a very interesting and rich phase structure at high baryon densities like color superconducting phase [22,30], chiral crystallization. We have looked into the case of color superconductivity that could be possible for the matter in the neutron star interiors. The conditions of electrical as well as color charge neutrality leads to cooper paring of quarks which under certain conditions can lead to gapless super conductivity- namely a nonzero gap but with gapless quasi particle modes for certain momenta. Such an interesting phenomenon of gapless modes can also be there due to mismatch of fermi momenta for systems that can be realised in laboratory- namely for cold atoms. We have suggested such 'breached pairing' and its detection for ultracold atoms [23].

I have also been looking within perturbative QCD the effect of vertex corrections on the color superconducting gap in a resummed dense loop approximation scheme. Further, I plan to look into color superconducting gap equation in Coulomb gauge QCD including also the possibility of having quark–antiquark condensates. These phenomena can have interesting consequences in extreme astrophysical situations like neutron star interior, neutron star collisions, core of collapsing stars. This can also give an insight to nuclear physics coming down from the high density side. The above stated problems constitute my current and future research interests.

NAME : AMRUTA MISHRA

LIST OF PUBLICATIONS:

Articles in published in refereed journals

1. *"Kaon and antikaon optical potnetials in isospin asymmetric hyperonic matter"*, **Amruta Mishra**, Arvind Kumar, Sambuddha Sanyal, Stefan Schramm, arxiv:0808.1937 (nucl-th), Eur. Phys. J. A41, 203-213 (2009).

2. *"D mesons in asymmetric nuclear matter"*, **Amruta Mishra** and Arindam Mazumdar, Phys. Rev. C 79, 024908 (2009).

3. *"LOFF and breached pairing with cold atoms"*, **Amruta Mishra**, Hiranmaya Mishra, Eur. Phys. Jour. D53, 75-87 (2009).

4. *"Relativistic BCS-BEC crossover - A variational approach"*, Bhaswar Chatterjee, Hiranmaya Mishra and **Amruta Mishra**, arxiv:0804.1051 (hep-ph), Phys. Rev. D 79, 014003 (2009).

5. *"Pairing in spin polarized two species fermionic mixtures with mass asymmetry"*, S.A. Silotri, D. Angom, H. Mishra and **A. Mishra**, arxiv: 0805.1784 (cond-mat), published in Eur. Phys. J. D49 , 383-390 (2008).

6. *"Kaons and antikaons in asymmetric nuclear matter"*, **Amruta Mishra**, Stefan Schramm and Walter Greiner, arxiv:0802.0363 (nucl-th), Phys. Rev. C 78, 024901, 2008.

7. *"Isospin dependent kaon and antikaon optical potentials in dense hadronic matter"*,**Amruta Mishra** and Stefan Schramm, arXiv: nucl-th/0607050, Phys. Rev. C 74, 064904, 2006.

8. *"Color superconductivity with determinant interaction in strange quark matter"*, **Amruta Mishra** and Hiranmamya Mishra, arXive: hep-ph/0605223, Phys. Rev. **D74**, 054024, 2006.

9. *"Color superconducting 2SC+s quark matter and gapless modes at finite temperatures"*, **Amruta Mishra**, Hiranmamya Mishra, arXive: hep-ph/0412213 Phys Rev **D71**,074023,2005.

10. *" Properties of D-mesons in nuclear matter within a self-consistent coupled channel approach"*, L. Tolos, J. Schaffner-Bielich and **A. Mishra**, nucl-th/0404064, Phys Rev.C**70**, 025203,2004.

11. *"Dilepton emission rates from hot hadronic matter"*, Thorsten Renk and **Amruta Mishra**, nucl-th/0312039, Phys. Rev. **C 69**, 054905, 2004.

12. *"Kaons and anti-kaons in hot and dense matter"*, **A.Mishra**, E.L. Bratvaskaya, J. Schaffner-Beilich, S.Schramm, H. Stocker, Phys. Rev **C70**, 044904,2004.

13. *"Medium modification of D-meson mass in hot and dense matter"*, **A. Mishra**, E. Bratkovskaya, J. Schaffner-Bielich, S. Schramm and H. Stoecker, nucl-th/0308082, Phys Rev C 69, 015202, 2004.

14. *"Effects of Dirac sea polarization on hadronic properties- A chiral SU(3) approach"*, **A. Mishra**, K. Balazs, D. Zschiesche, S. Schramm, H. Stoecker and W. Greiner, **nucl-th/0308064**, Phys. Rev. C 69, 024903, 2004.

15. *"In-medium vector meson masses in a Chiral SU(3) model"*, D. Zscheische, **A. Mishra**, S. Schramm, Horst Stöcker and Walter Greiner, Phys. Rev **C70**,045202,2004.

16. *"Interior gap superfluidity in a two-component Fermi gas of atoms"*, B. Deb, **A. Mishra**, H. Mishra, P. K. Panigrahi, **Rapid Communication**, Phys. Rev. **A70**, 011604(R),2004.

17. *"Chiral symmetry breaking, color superconductivity and color neutral quark matter: a variational approach"*, **A. Mishra** and H. Mishra, Phys Rev. D69,014014, 2004.

18. *"In-medium vector meson properties and low–mass dilepton production from hot hadronic matter"* **Amruta Mishra**, Joachim Reinhardt, Horst Stöcker and Walter Greiner, Phys. Rev. **C 66**, 064902 (2002).

19. *"Vector meson masses in hot nuclear matter: the effect of quantum corrections"* **Amruta Mishra**, Jitendra C. Parikh and Walter Greiner, Jour. Phys. **G 28** 151 (2002).

20. *"Vacuum polarisation effects in hyperon rich dense matter– a nonperturbative treatment"*, **Amruta Mishra**, P.K. Panda and W. Greiner, Jour. Phys. **G 28** 67 (2002).

21. *"Quantum vacuum in hot nuclear matter– a nonperturbative treatment"* **Amruta Mishra**, P.K. Panda and W. Greiner, Jour. Phys. **G 27**, 1561 (2001).

22. *"Instability of shear waves in an inhomogeneous strongly coupled dusty plasma"*, **Amruta Mishra**, P.K. Kaw and A. Sen, Phys. of Plasmas, 7, 3188 (2000).

23. *"Rotating compact objects with magnetic fields"*, Anshu Gupta, **Amruta Mishra**, Hiranmaya Mishra and A.R. Prasanna, Class. and Quant. Grav. 15, 3131 (1998).

24. *"Hot nuclear matter in the quark meson coupling model"*, P.K. Panda, **A. Mishra**, J.M. Eisenberg and W. Greiner, Phys. Rev. C56, 3134 (1997).

25. *"Structure of Vacuum in Nuclear Matter– A nonperturbative approach"*, **A. Mishra**, P. K. Panda, S. Schramm, J. Reinhardt and W. Greiner, Phys. Rev. C56, 1380 (1997).

26. *"Vacuum Structure and Effective Potential at Finite Temperature: A Variational Approach"*, **Amruta Mishra** and Hiranmaya Mishra, Jour. Phys. G23, 143 (1997).

27. *"Vacuum structure in QCD with quark and gluon condensates"*, **A. Mishra**, H. Mishra, Varun Sheel, S.P. Misra and P. K. Panda, Int. J. Mod. Phys. E5, 93 (1996).

28. *"Confinement, Quark Matter Equation of State and Hybrid Stars"*, S. B. Khadkikar, **A. Mishra**, H. Mishra, Modern Physics Letters A10, 2651 (1995).

29. *"Gluon Condensates,Quark Matter Equation of State and Quark Stars"*, **A. Mishra**, H. Mishra, S. P. Misra and P. K. Panda, Z. Phys. C63, 681 (1994).

30. *"Gluon Condensates at finite baryon densities and temperature"*, **A. Mishra**, H. Mishra and S. P. Misra, Z. Phys. C59, 159 (1993).

31. *"Gluon Condensates, Chiral Symmetry Breaking and Pion Wave Function"*, **A. Mishra** and S. P. Misra, Z. Phys. C58, 325 (1993).

32. *"Effective Potentials in QCD and Chiral Symmetry Breaking"*, **A. Mishra**, H. Mishra and S. P. Misra, Z. Phys. C57, 241 (1993).

33. *"QCD at finite temperatures: A variational approach"*, **A. Mishra**, H. Mishra, S. P. Misra and S. N. Nayak, Z. Phys. C57, 233 (1993).

34. *"A non-perturbative variational approach to vacuum structure in quantum chromodynamics"*, **A. Mishra**, H. Mishra, S. P. Misra and S. N. Nayak, Pramana(Jou. of Phys.)37, 59 (1991).

35. *"Higgs particles production through vacuum excitations"*, **A. Mishra**, H. Mishra, S. P. Misra and S. N. Nayak, Phys. Rev D44,110 (1991).

36. *"1+1 dimensional supersymmetry at finite temperature : a variational approach"*, **A. Mishra**, H. Mishra, S.P. Misra and S.N. Nayak, Phys. Lett. B251, 541 (1990).

37. *"Nuclear matter with constituent meson quanta"*, **A.Mishra**, H.Mishra and S. P. Misra, Int. Jou.of Mod. Phys.A5, 3391 (1990).

38. *"A variational approach to Gross-Neveu Model"*, **A. Mishra**, H. Mishra and S. P. Misra, Int. Jou. of Mod. Phys.A 2331 (1988)

Articles submitted for publication in refereed journals

1. *"Kaon properties in (proto) neutron stars"*, **Amruta Mishra**, Arvind Kumar, Sambuddha Sanyal, V. Dexheimer and Stefan Schramm, arXiv:0905.3518[nucl-th].

Published contributions to academic conferences/workshops/schools

1. Talk on 'Kaons and antikaons in asymmetric nuclear matter', by A. Mishra, published in the working group report of Quark Gluon plasma, in the proceedings of Workshop on High Energy Physics Phenomenology (WHEPP) held at Institute of Mathematical Sciences, Chennai during 2-13 January, 2008, published in Pramana- Journal of Physics, Volume 72, No. 1, pg 290, January, 2009.

2. 'Colour Superconductivity at moderate densities', By A. Mishrra and H. Mishra, published in the working group report of Quark Gluon Plasma, in the proceedings of Workshop on High Energy Physics Phenomenology (WHEPP-X), held at Institute of Mathematical Sciences, Chennai during 2-13 January, 2008, published in Pramana-Journal of Physics, Volume 72, No. 1, pg. 290, January, 2009.

3. "Kaons and Antikaons in dense hadronic matter in Lecture Series on 'Physics and Astrophysics of Hadrons and Hadronic Matter', Narosa Publishing House Pvt. Ltd, 2008, pages 179-193, Editor A. B. Santra. This was presented in the International Workshop on 'Physics and Astrophysics of Hadrons and Hadronic Matter', held during 6-11 November, 2006 at the Department of Physics, Visva Bharati University,Shantiniketan, India.

4. 'Hadron Spectroscopy', by A. Mishra published in Lecture Note Series on 'Quark Gluon Plasma and Hadron Physics', Narosa Publishing House Pvt. Ltd., 2009, Editors: P.K. Sahu, S.C. Phatak, Y.P.Viyogi, pages 241-250. These lectures (series of four) were presented at the IIIrd DST-SERC school on Nuclear Physics held at Institute of Physics, Bhubaneswar during December, 2006 –January, 2007.

5. *"Color superconducting strange quark matter at finite temperature"*, **Amruta Mishra** and Hiranmya Mishra, J. Phys. G 50, 223-229, 2006, in the proceedings of International Conference on Physics and Astrophysics of Quark Gluon Plasma, Saha Institute of Nuclear Physics, Kolkata Feb.7-11, 2005, Kolkata, India.

6. *"In-medium meson properties and experimental observables"* appeared at the Proceedings of DAE symposium on nuclear physics, Banaras Hindu University, Banaras, India, 2005.

7. *" D- mesons in dense nucler matter"*, L.Tolos, J. Schaffner-Beilich,**A. Mishra**, published in the proceedings of International conference on Hard and Electromagnetic probes of High Energy Nuclear Collisions (HP2004), Ericeira, Portugal 4-10 nov. 2004, Eur. Phys. J. C 43, 127-130, 2005.

8. *" Properties of D-mesons in dense matter"*, L.Tolos, J. Schaffner-Beilich,**A. Mishra**, published in the proceedings of 8th International conference on Strangeness in Quark matter (SQM 2004), Cape town, South Africa; 15-20 Sept. 2004,hep-ph/0411256, J. Phys. G 31, S1213, 2005.

9. *" Mass modifications of D mesons in hot hadronic matter"*,A. Mishra, E. Bratkovskaya, J. Schaffner-Bielich, S. Schramm and H. Stoecker, in the proceedings of XLII International winter meeting on Nuclear Physics, Bormio, Italy, Jan.26-31 2004, supplemento. N. 123, Ed. I. Iori (pg. 198-213).

10. *"Chiral symmetry breaking, color superconductivity and gapless modes in color neutral matter"*, A. Mishra and H. Mishra in the proccedings of XLII International winter meeting on Nuclear Physics, Bormio, Italy, Jan.26-31 2004, supplemento. N. 123, Ed. I. Iori (pg. 124-140).

11. *"Chiral symmetry breaking, color superconductivity and color neutral quark matter"*, A. Mishra and H. Mishra in the proceedings of Workshop on "Mesons and Quarks", held at BARC, Mumbai, India (2003).

12. *"In-medium vector meson properties and low mass dilepton production from hot hadronic matter"*, A. Mishra, J. Reinhardt, H. Stoecker and W. Greiner, to appear in the proceedings of Workshop on "Mesons and Quarks", held at BARC, Mumbai, India, 28 Jan- 1 Feb, 2003.

13. *"Vacuum structure in QCD with quark and gluon condensates"*, A. Mishra in Proceedings of XI DAE symposium on High Energy Physics, 28th December,1994 to 2nd January, 1995, Shantiniketan, India (1995).

14. *"Gluon condensates at finite baryon densities and temperatures"*, A. Mishra, H. Mishra, and S.P. Misra(1993): Proceedings of the second International Conference on Physics and Astrophysics of Quark Gluon Plasma at Calcutta, India, January 1993.

RESEARCH WORK DURING LAST FIVE YEARS: A SYNOPSIS

'Strongly interacting matter' has been broadly the area of my research. We had been studying strongly interacting systems in quantum field theory in a nonperturbative manner. During the last five years, I have mostly been working on properties of hadrons in hot and dense matter, which is of great relevance for the present as well as upcoming relativistic heavy ion collision experiments, e.g., at SIS, GSI, Germany; at AGS, Brookhaven National laboratory, U.S.A., SPS, CERN, Switzerland, RHIC at Brookhaven National Lab. (U.S.A); CBM experiment at FAIR project at the future facility at GSI (Germany), as well as the upcoming Large Hadron Collider at CERN, Switzerland.

The medium modifications of hadronic properties have been studied using a chiral SU(3) model as well as other hadronic models like Walecka model and Quark meson coupling model. Their effects on experimental observables like dilepton rate and yield and propagation of the particles, like kaons, D-mesons in the hot and dense matter resulting from heavy ion collision experiments have been some topics of my research interest. This apart, I am also looking at matter at high density in terms of quark and gluon degrees of freedom. It appears that the strongly interacting matter in terms of these degrees of freedom can have a very interesting and rich phase structure at high baryon densities like various exotic phases of color superconductivity, which could be present in the interior of neutron stars, arising from the various degrees of freedom (color, flavor,spin) available for the quarks. These exotic phases can be realised in laboratory- namely for ultracold atoms. We have suggested such a phase ('breached pairing') for ultracold atoms.

FUTURE RESEARCH PLAN

Matter under extreme conditions of density and temperature has been my area of specialization. The future work that I intend to do will be in the context of (A) the properties of hadrons in matter that is relevant for the upcoming heavy ion collision experiments and (B) astrophysical implications of new phases of matter from neutron star interior. Below, I give in some detail the planned proposal to study these.

(A) **Hadrons in hot and dense matter**

The study of properties of hadrons in extreme conditions of temperature and density is an important and challenging topic of the present strong interaction physics research. In the recent past, substantial experimental and theoretical efforts have been undertaken in this topic. Through heavy ion collision experiments, the strongly interaction matter is created in the laboratory, and the varying experimental conditions like the collision energy, impact parameter and the colliding ions give a broad regime in the temperature and density of this excited nuclear matter. Experiments have been performed at Schwer-Ionen-Sunchrotron (SIS) at

Gesellschaft für Schwerionenforschung(GSI) in Darmstadt, Germany, Alternating Gradient Synchrotron (AGS) in Brookhaven National Laboratory (BNL) in U.S.A., at Super-proton-Synchrotron (SPS) at CERN, Geneva, at the Relativistic Heavy Ion Collider (RHIC) at BNL, and the forthcoming experiments at Large Hadron Collider (LHC) at CERN, and at the future Facility for Antiproton and Ion Research (FAIR) at GSI, Germany, which will be operational in the near future. The study of the properties of the hadrons as modified in the hot and dense matter, which have direct implications on the experimental observables in these heavy ion collision experiments, is the purpose of the present proposal.

The properties of hadrons in hot and dense hadronic matter is a topic of intense research in strong interaction physics, both theoretically and experimentally. The medium modifications of hadrons are directly linked to the experimental observables in the high energy heavy ion collision experiments. The study of the vector meson masses in hot and dense matter [1, 2, 3], has been an active field of research interest, because of its relevance in heavy ion collision experiments, where the dilepton and photon production rates from the highly compressed strongly interacting matter (fireball) are affected by the in-medium vector meson properties. An enhancement of the dilepton production at SPS, CERN by the CERES collaboration [4] is attributed to the medium modification of the ρ and ω vector mesons. The dilepton spectra have been studied [5, 6] taking into account effects from the in-medium properties of vector mesons within the Walecka model [7, 8] as well as using a chiral SU(3) model [9, 10]. As a future plan, the dilepton emission rates will be studied relevant for various experimental conditions relevant for SIS at GSI, Germany, SPS at CERN, RHIC at BNL, USA, as well as the forthcoming experiments LHC at CERN and FAIR at GSI.

The chiral SU(3) model has been used to study the properties of kaons (antikaons) in the medium, which have direct implications on their production and flow pattern observed in the heavy ion collision experiments [11]. The particle spectra as well as the collective flow of kaons (antikaons) have been studied for low energies relevant for SIS energies (around few AGeV) [12]. However, the kaon and antikaons were assumed to be at rest, which may not be so in the high energy heavy ion collision experiment. Using a chiral SU(3) model, we have studied the dispersion relations for the kaons and antikaons at finite momentum. The effect of isospin asymmetry on the optical potentials of the kaons and antikaons has also be investigated at finite densities and zero temperatures [13, 14]. The generalizations to finite temperature of the optical potentials of kaons and antikaons, as well as to include the effects of coupled channels are amongst the topics to be investigated in the future. These will be of importance in isospin asymmetric nuclear collisions, e.g., at the forthcoming experiments at the new international accelerator facility to study compressed baryonic matter at FAIR (Facility for Antiproton and Ion Research) at Gessellschaft für Schwerionenforschung (GSI, Germany), where more neutron rich beams are planned to be adopted.

The modification of the D-mesons in the medium have been a topic of great interest since the $K^{\pm}$ in the strange sector shows close analogy to the open charm sector ($D^{\pm}$) resulting from exchanging strange/antistrange quarks by the anticharm/charm quarks. The D-meson mass modifications have been earlier studied using QCD sum rule calculations. It was found that due to the presence of the light quark in the D-meson, the D-mass has a large contribution from the light quark condensates. To investigate the D-meson mass modification, we generalized the chiral SU(3) model to chiral SU(4) to derive the interaction of D-mesons to the light hadron sector, and the mass modifications of the D-mesons have been studied within the chiral effective theory as well as using the interaction Lagrangian of the chiral perturbation theory [15]. In the proposed research project, we plan to generalize the earlier work [15] where the D-meson was assumed to be at rest, to derive the spectral functions of the D-mesons in different hadronic models, like the chiral effective model as well as the chiral perturbation theory. The spectral functions have also been studied for the isospin asymmetric nuclear matter at zero temperatures [16]. The production and the collective flow of the D-mesons are important observables related to the medium modification of the D-mesons. The density as well as temperature effects on the D-meson will be particularly looked into in the Compressed baryonic matter (CBM) experiment of the proposed project FAIR at GSI, Germany, as well as the temperature effects can be compared with the existing and future experimental data at RHIC and LHC.

The spectral properties of the D-mesons in a nuclear medium have also been studied using a self-consistent coupled channel approach [17] which generates the resonance $\Lambda_c(2593)$ dynamically due to the attractive DN interaction, analogous to the dynamical generation of the $\Lambda(1405)$ due to the KN interaction. The separable potential for the DN interaction as used here can be improved by using relativistic potentials as well as by incorporating chiral constraints on the bare hadronic interactions, which we plan to do in the future.

To summarize, the future research plan to study broadly the following aspects of hot and dense matter–

(i) to study the dilepton emission rates from heavy ion collision experiments, using chiral SU(3) model;

(i) the derive the optical potentials the K ($\bar{\mathrm{K}}$) relevant for various experimental conditions in heavy ion collision experiments and the effects on their production and flow, using various hadronic models,

(ii) the study of the D-meson spectral function, calculated in a coupled channel approach with improved baryon meson potentials, as well as their effect on their production and propagation in heavy ion collision experiments.

(B) **Dense hadronic matter – some astrophysical implications**
The understanding of dense hadronic matter is important to study compact stellar objects such as neutron stars. The equation of state of the neutron star matter determines the gross properties of the neutron star [18]. The compact star with high central energy densities could have a quark core with a neutron matter crust, and with still higher central energy densities could even be a quark star [19].

In the presence of a quark core, the charge neutral quark matter in the compact star could also exhibit different possible color superconducting phases. Color superconductivity, i.e. Cooper pairing of quarks at high density has become a fascinating topic of research during last few years. At sufficiently high baryon densities, when nucleons get converted to quark matter, the resulting quark matter is expected to be in one kind or the other of the many different possible color superconducting phases at low enough temperatures [20]. The rich phase structure is essentially due to the fact that the quark–quark interaction is not only strong and attractive in many channels, but also many degrees of freedom become possible for quarks like color, flavor and spin. Studying the properties of color superconducting phases in heavy ion collision experiments seems unlikely in the present accelerators as one cannot avoid producing large entropy per baryon in heavy ion collisions and hence cannot produce the dense and cold environment that is needed to support the formation of superconducting phases. However, in the future accelerator facility planned at GSI for compressed baryonic matter experiments, one possibly can hope for observing fluctuations signifying precursory phenomena of color superconducting phase [21].

On the other hand, it is natural to expect some color superconducting phases to exist in the core of compact stars where the densities are above nuclear matter densities and temperatures are of the order of tens of KeV. However, to consider quark matter for neutron stars, color and electrical charge neutrality conditions need to be imposed for the bulk quark matter. This leads to various scenarios for the phase structure for dense quark matter.

Such an attempt has been made in Ref.[22] as well as in Ref. [23], where the lighter up and down quarks form the two flavor color superconducting (2SC) matter while the strange quarks do not participate in pairing. A model independent analysis was done in Ref. [22] that is valid in the limit $m_s << \mu$ and $\Delta \sim m_s^2/\mu$, where, Δ is the pairing gap and μ is the quark chemical potential. It has been shown, based upon the comparison of free energies that such a two flavor color superconducting phase would be absent in the core of neutron stars [22]. Within Nambu Jona-Lasinio (NJL) model in Ref. [23] it has been argued that such conclusions are consistent except for a small window in density range where superconducting phase is possible. It was further observed that the imposition of neutrality conditions lead to pairing of quarks with different Fermi momenta giving rise to gapless modes [24, 25]. Within a Nambu Jona Lasinio model, the two flavor superconducting quark matter (2SC) was shown to exhibit gapless modes (g2SC) arising due to the difference in the Fermi momenta of the pairing quarks, when charge and color neutrality conditions are imposed. Superconducting quark matter with unpaired strange quarks (2SC+s) was shown to exhibit gapless superconductivity (g2SC+s) within a window of about 80 MeV in baryon chemical potential [25, 26].

A variational approach was used to study the chiral symmetry breaking as well as color superconductivity for the quark matter [25, 26, 27]. The calculations were carried out for the NJL model with the minimisation of the free energy density to study which condensate will exist at what density. Charge neutrality conditions were introduced through the introduction of appropriate chemical potentials. Further, it was shown by us that the determinant interaction for the quarks play an important role enhancing the importance of light flavor condensates. Within this scenario it is important to investigate the kind of signatures that one can expect to get from observations from neutron stars to rule out the possibilty of non hadronic matter in the core of the neutron stars.

In this context I would like to consider the mass radius relationship for the neutron stars using the superconducting quark matter equation of state for the quark matter core and a suitable hadronic matter equation of state for the neutron matter crust. A mixed phase construction for the quark matter and hadronic matter shall be used to get the equation of state at all densities and it will be used to calculate the mass radius relations.

Cooper pairing of quarks having different fermi momenta (which is expected to be the case for neutron star matter which is both electrically and color charge neutral) leads to various interesting phases like the gapless phase. In this phase while the superconducting gap is nonzero, their excitation energy vanishes at certain momenta. Therefore these modes will be the dominant modes regarding the transport properties of such superconducting matter. The other possible manifestation of quark matter at intermediate densities when the strange quark mass is large, is a crystalline color superconductor in which quark with different Fermi surface pair with nonzero momentum, resulting in an inhomogeneous but spatially periodic order parameter. This leads to characteristic dispersion relations. The effect of these dispersion relations can be reflected the cooling behavior of neutron stars which is also an observable. The cooling rate depends both on the neutrino emissivity as well as on the specific heat of the quark phase. These quantities depends sensitively on the dispersion relations of the quarks and the dominant contribution will come from the modes where the dispersion vanishes leading to characteristic behavior regarding cooling rates of the neutron stars. A detailed calculations regarding cooling rate of neutron stars with a quark core shall be attempted.

Neutron stars are also endowed with strong magnetic fields. The effect of these magnetic fields on the pairing of colored quarks is an interesting theoretical problem which can have phenomenological consequences. Some recent calculations indicate that the magnetic fields favor color superconductivity with a larger gap. We would like to investigate the effect of magnetic field on superconductivity within the variational ansatz that has been developed for color superconductivity.

To summarise, part of the future research plans will focus on the following astrophysical aspects of color superconductivity phase of dense matter –

(i) to study the mass radius relationship of neutron stars with a color superconducting quark matter core.

(ii) Cooling rates of neutron stars with a superconducting quark matter core.

(iii) Effect of magnetic field on Cooper pairing of colored quarks.

References

[1] **A. Mishra**, P.K. Panda, S. Schramm, J. Reinhardt and W. Greiner, Phys. Rev. C56, 1380

(1997).

[2] **A. Mishra**, P. K. Panda and W. Greiner, Jour. Phys. G27, 1561 (2001)

[3] **A. Mishra**, P. K. Panda and W. Greiner, J. Phys. G28, 67 (2002).

[4] G. Agakichiev et al, Phys. Rev. Lett. 175, 1272 (1005); ibid; Phys. Lett. B 422, 405 (1998); ibid, Nuclear Physics 661, 23 (1999).

[5] **A. Mishra**, J. Reinhardt, H. Stöcker and W. Greiner, Phys. Rev. C 66, 064902 (2002); **A. Mishra**, J. C. Parikh and W. Greiner, Jour. Phys. G28, 151 (2002).

[6] T. Renk and **A. Mishra**, nucl-th/0312039, Phys. Rev. C 69, 054905 (2004).

[7] J. D. Walecka, Ann. of Phys. 83, 491 (1974); B. D. Serot and J. D. Walecka, Adv. Nucl. Phys. 16, 1 (1986).

[8] H.-C. Jean, J. Piekarewicz and A. G. Williams, Phys. Rev. C49, 1981 (1994); H. Shiomi and T. Hatsuda, Phys. Lett. B334, 281 (1994).

[9] D. Zscheische, **A. Mishra**, S. Schramm, H. Stöcker and W. Greiner, nucl-th/0302073, Phys. Rev. C 70, 045202 (2004).

[10] **A. Mishra**, K. Balazs, D. Zscheische, S. Schramm, H. Stöcker, nucl-th/0308064, Phys. Rev. C 69, 024903 (2004).

[11] M. Menzel et al, KaoS collaboration, Phys. Lett. B 495, 26 (2000); N. Herrmann et al, FOPI collaboration, Nucl. Phys. A 610, 49c (1996); B. Hong et al, Phys. Rev. C 57, 244 (1998).

[12] **A. Mishra**, E. Bratkovskaya, J. Schaffner-Bielich, S. Schramm and H. Stoecker, nucl-th/0402062, Phys. Rev. C 70, 044904 (2004).

[13] **Amruta Mishra** and Stefan Schramm, arXiv: nucl-th/0607050, Phys. Rev. C 74, 064904, 2006.

[14] **Amruta Mishra**, Stefan Schramm and Walter Greiner, arxiv:0802.0363 (nucl-th), Phys. Rev. C 78, 024901, 2008; **Amruta Mishra**, Arvind Kumar, Sambuddha Sanyal, Stefan Schramm, arxiv:0808.1937 (nucl-th), Eur. Phys. J. A41, 203-213 (2009).

[15] **A. Mishra**, E. Bratkovskaya, J. Schaffner-Bielich, S. Schramm and H. Stoecker, nucl-th/0308082, Phys. Rev. C 69, 015202 (2004).

[16] **Amruta Mishra** and Arindam Mazumdar, Phys. Rev. C 79, 024908 (2009).

[17] L. Tolos, J. Schaffner-Bielich and **A. Mishra**, nucl-th/0404064, Phys. Rev. C 70, 025203 (2004).

[18] **Amruta Mishra**, P.K. Panda and W. Greiner, Jour. Phys. **G 28** 67 (2002); Anshu Gupta, **Amruta Mishra**, Hiranmaya Mishra and A.R. Prasanna, Class. and Quant. Grav. 15, 3131 (1998).

[19] **A. Mishra**, H. Mishra, S. P. Misra and P. K. Panda, Z. Phys. C63, 681 (1994).

[20] For reviews see K. Rajagopal and F. Wilczek, arXiv:hep-ph/0011333; D.K. Hong, Acta Phys. Polon. B32,1253 (2001); M.G. Alford, Ann. Rev. Nucl. Part. Sci 51, 131 (2001); G. Nardulli, Riv. Nuovo Cim. 25N3, 1 (2002); S. Reddy, Acta Phys Polon.B33, 4101(2002); T. Schaefer arXiv:hep-ph/0304281; D.H. Rischke, Prog. Part. Nucl. Phys. 52, 197 (2004); H.C. Ren, arXiv:hep-ph/0404074; M. Huang, arXiv: hep-ph/0409167; I. Shovkovy, arXiv:nucl-th/0410191.

[21] M. Kitazawa, T. Koide, T. Kunihiro and Y. Nemoto, Phys. Rev. D **65**, 091504 (2002), D.N. Voskresensky, arXiv:nucl-th/0306077.

[22] M. Alford and K. Rajagopal, JHEP 0206,031,(2002)

[23] A.W. Steiner, S. Reddy and M. Prakash, Phys. Rev. D **66**, 094007 (2002).

[24] Igor Shovkovy, Mei Huang, Phys. Lett. B **564**, 205 (2003).

[25] Amruta Mishra and Hiranmaya Mishra, Phys. Rev. D **69**, 014014 (2004).

[26] A. Mishra and H. Mishra, Phys. Rev. D **71**, 074023 (2005).

[27] H. Mishra and J.C. Parikh, Nucl. Phys. **A679**, 597 (2001).

[28] E.J.Ferrer, V. Incera and C. Manuel, Phys. Rev. Lett:152002,2005.