# CURRICULUM VITÆ

**NAME : HIRANMAYA MISHRA**

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1. **PERSONAL DATA:**

   Nationality : Indian
   Date of Birth : July 17, 1962
   Sex : Male

2. **EMPLOYMENT RECORD :**

Permanent position

- **Senior Professor** from 1st July 2018
- **Professor** from 1st January, 2013-June 2018
- **Associate Professor** from 1st January 2008 till 31st Dec2012.
- **Reader** from 1st July 2001 to 31st Dec. 2007, in Physical Research Laboratory Ahmedabad.
- **Scientist D** from July 1997 to June 2001.

Visiting positions/ Post Doctoral Fellow

- Visiting Professor, **School of Physics, Jawaharlal Nehru University, New Delhi** July 2008 till 15th May 2009 (on sabbatical leave from PRL).
- Visiting Scientist, Department of Physics, **University of Bielefeld, Germany** from July 15th 2001 till July 14th 2002 on sabbatical from PRL, Ahmedabad sponsered by **Humboldt Foundation, Germany**.
- **Alexander von Humboldt Fellow**, Physics Department, **University of Bielefeld, Germany**, April 1996, July 1997
- Post Doctoral Fellow at **Physical Research Laboratory, Ahmedabad** from July 1993 to July 1995.

Visiting positions for more than a month

- **Visiting Scientist**, Institute for Theoretical Physics, J W Goethe University, Frankfurt, 1-30thJune 2011, sponsered by **Humboldt Foundation**.
- **Visiting Scientist**, Institute for Theoretical Physics, J W Goethe University, Frankfurt, 1-30June 2010, sponsered by **Humboldt Foundation**.
- **Visiting Scientist**, Institut for Theoretical Physics, J W Goethe University, Frankfurt, May 2008–July 2008.
- CSIR Research Associate, HarishChandra Research Institute , Allahabad, August 1995-March 1996

Academic record

- Ph.D. in Science (PHYSICS) from Institute of Physics, Bhubaneswar, Utkal University, April 94.
- Diploma in Advanced Physics, Institute of Physics, Bhubaneswar(1985), **First** position in the batch.
- Master in Science (Physics), Indian Institute of Technology, Kharagpur (1984) (First class), **Third position** in the batch.
- Bachelor of Science (Hons. with Distinction), Physics Honours, (1982), (First class), other subjects were Mathematics, Chemistry and English, **First Class First** in Sambalpur University.

## SCHOLARSHIPS/ AWARDS

- **National Scholarships** throughout (From Class VII till M. Sc.).
- **L. K. Panda Award** for securing first position in Dip. In Advance Physics course at Institute of Physics, Bhubaneswar.
- **Alexander von Humboldt** fellowship .

**PhD students and post doctoral fellows**
**Five** students have been awarded PhD degree.

- Dr. V. Sreekanth, Theisis title *"Properties of strongly interacting matter at high temperature and density"*
- Dr. Bhaswar Chatterjee, Thesis title *"A Field theoretic study of matter under extereme condition"*
- Dr. Guruprakash Kadam, Thesis title *"Phenomenological studies of strongly interacting matter under extreme conditions"*
- Dr. Aman Abhshek, Thesis title *"Phenomenological studies of strongly interacting matter under extreme conditions"*
- Dr. Balbeer Singh, Thesis title *"Dynamics of heavy quarks in a medium"*

Apart from them one more student Mr. Deepak Kumar is pursuing his PhD with me.
Postdoctoral fellows

- Dr. T.K. Jha
- Dr. Purnendu Chakraborty
- Dr. Ranjita K Mohapatra
- Dr. Lata Thakur
- Dr. Arpan Das
- Dr. Aman Abhishek
- Dr. Surasree Majumder
- Dr. Balbeer Singh

**Teaching experience**

I gave courses on **Mathematical Physics** in the years 1997-98 and 1998-99 to the graduate students' course work at Physical Research Laboratory, Ahmedabad. This apart I also gave lectures on **Mathematical Physics** to college teachers' training program held at Physical Research Laboratory, Ahmedabad in June 2000. I also gave course to the graduate students on **Classical Electrodynamics** for the session 2002-2003. I am teaching the course on **Classical Electrodynamics** for the session 2006-2007. I am also teaching a course on **Statistical Physics** to the graduate students of our laboratory for the year 2015-2016.

This apart I have given a series of lectures on **"Thermal Field Theory"** to PhD students/PDFs in the **DST- SERC school on Theoretical High Energy Physics** held in IIT Mumbai in Feb 2008 as a part of the **main courses** offered in this school.

I also taught the course on **Subatomic Physics** to the **M.Sc.** students in **School of Physics, Jawaharlal Nehru University (JNU)** where I took a sabbatical leave from PRL, Ahmedabad.
I gave a course on Quantum Field Theory to PhD students in the year 2009-2010. and **Statistical Mechanics** to PhD. students in the year 2012-2013.

*Given a chance, I can also teach the following courses to under graduate students, Masters students and pre PhD students-:***Quantum Mechanics, Quantum field theory, Particle physics, Nuclear physics, Electromagnetic theory**.

**AREA OF RESEARCH :**

Non-perturbative variational methods for studying bound states in quantum field theory, Vacuum structure in QCD, Finite temperature quantum field theory, Nuclear matter and QCD at finite temperatures in the context of Quark gluon plasma, Phase transitions, Chiral symmetry breaking, Solvable models in field theory, magnetic field structure in neutron stars, hybrid stars, phase structure of strongly interacting matter, correlation functions in QCD, QCD sum rules at finite temperature, color superconductivity, superconductivity with cold fermionic atoms. BCS-BEC crossover transition in cold fermionic atoms, QGP hydrodynamics in the context of heavy ion collision , Nonequllibrium field theory, Baryogenesis, Dark matter, Neutron star structure, transport coefficients of strongly interacting matter.

**TITLE OF THESIS :** Composite and extended objects in quantum field theory : a reappraisal

**THESIS SUPERVISOR :** Professor S. P. Misra

**SOME INVITED TALKS/Lectures**

A: Plenary talks in International Conferences:

(a) " Estimating of transport coefficients in effective models of QCD", Invited plenary talk given at the International workshop on 'Myriad colorful ways of understanding QCD matter", ICTS, Bengaluru, 4th April 2019.

(b) " Domain growth in quark matter", at International workshop on Critical Point and Onset of Deconfinement (**CPOD 2013**), March 11-15th 2013,**Napa, Sanfransisco, California (Proceedings to appear in Proceedings of Science)**.

(c) "Kinetics of chiral transition in quark matter", in Gribov-80 Memorial meeting on QCD and beyond, **ICTP, Trieste, May 2010**. Proceedings published in QCD and Beyind, World Scientific, Singapore 2011.

(d) "Color superconducting strange quark matter at finite temperature", **Plenary talk** given at International Conference on Physics and Astrophysics of Quark Gluon Plasma-05", Kolkata 7-12 Feb. 2005. Proceedings published in Journal of Physics G, Conference series 50, 223-229 2006.

Invited Talks:

(a) "Color superconductivity in dense matter: an NJL model approach", Invited talk at Nambu Centennial Symposium at Univ of Hyderabad, Jan 20 2021.

(b) "Color superconductivity in magnetized quark matter", Talk at Institute of Physics at Institute of Physics, Bhubaneswar, Decemebr 27th 2019.

(c) " Superconductivity in magnetized quark matter", **Colloquium** at Institute for Mathematical Sciences (IMSc.), Chennai, 28 March 2019.

(d) " Properties of matter under extreme conditions", Invited talk at "3rd Goa Researchers meet', Goa University, 2nd March 2019.

(e) "Hot and dense matter", Talk given at Department Physics IIT Goa, November 2018.

(f) " Matter under extreme condition", Talk given at conference on "Frontiers in experimental and theoretical physics", Center of Engineering and Technology, Bhubaneswar 24-27 April 2018.

(g) "Transport coefficients in Polyakov loop quark meson coupling model", Invited talk at **International conference on Critical point and onset of deconfinement, CPOD2017, 7-11 August 2017, Stony Brook University, USA**

(h) " Matter under extreme conditions", Invited talk at 34th Annual convention of Odisha Physical Society,11-12 Feb. 2017 Berhampur University

(i) " Viscosity coefficients in quark matter", Theory Conference- ten Years of IISER Kolkata 20-21 Jan 2017.

(j) " Transport coefficients of hot and dense quark matter", **International nuclear Physics conference 2016(INPC 2016), Adelaide, Australia**, Sept 11-16 2016.

(k) " Transport coefficients in hot and dense matter", Workshop on High Energy Physics Phenomenology, (WHEPP), IIT Kanpur, 4-13 Dec 2015.

(l) "Transport Coefficients in Hadron Resonance Gas model", Conference on Advances in Nuclear Physics' at Institute of Physics bhubaneswar, 26-30 June 2015.

(m) "Kinetics of chiral transition in quark matter", Invited talk at "Discussion meeting on Phase diagram of QCD", NISER, Bhubaneswar, 8-10 July, 2013.

(n) " Strong magnetic field and chiral transition in hot and dense matter", Talk given at "Discussion meeting on Phase diagram of QCD", at VECC, Kolkata, 10-12 Jan 2012.(Prodeedings not published)

(o) " Kinetics of chiral transition–a toy model", Working group talk at Workshop on High Energy Physics Phenomenology, (WHEPP-12), 02-08 January, 2012, Mahabaleswar, India, (Proceedings to appear)

(p) "Domain growth and ordering kinetics in quark matter ", **Invited talk** in workshop on Critical Phenomena in QCD **CPOD-10, JINR, Dubna, Russia,** August 2010. Proceedings in Yad. Fiz. 75, 739 (2012).

(q) "Ground state structure and superfluidity in Cold atoms", **two** invited lectures given at workshop on cold atoms held at IISER Kolkata, Kalyani, West Bengal 12-13 Dec. 2008. Proceedings not pulished.

(r) " Relativistic BCS-BEC Crossover– A variational approach", Invited talk given at International Conference on Cold Atoms 2008", IISER, Kolkata, Kalyani, West Bengal, 14-16 Dec. 2008, edings not published.

(s) "Relativistic BCS-BEC crossover in Quark matter", **Invited Talk** given at Workshop on High Energy Physics Phenomenology (WHEPP X), Jan 2-Jan 13, 2008, Institute for Mathematical Sciences, Chennai. Proceedings published in Pramana, 72, 2009.

(t) " QCD and dense matter in QCD from lattices to stars", Institute for Nuclear Theory program INT04-1, 5-9 April, 2004, Seattle, USA. (Proceedings not published)

(u) "Color neutral quark matter and gapless modes'**Invited talk** given at conference 'QGP meet'03', held at VECC, Kolkata, India, 5 May - 7 May, 2003. (Proceedings not published)

(v) "Chiral symmetry breaking, color superconductivity and color neutral quark matter'**Invited talk** given at *workshop on quarks and Mesons, BARC, Mumbai* Feb 2003. (Proceedings published in "Mesons and Quarks, Ed. A.B. Santra,Narosa Publishing House, Pgs 306-320, 2004,ISBN-13: 9788173195891)

(w) "Color superconductivity in charge neutral quark matter" **Invited Talk** given at 'Visitors' Program', Physics Department, Delhi University, June 2003. (Proceedings not published)

(x) " Quark matter phase diagram, Color superconductivity and astrophysical implications" **Invited talk** given at *workshop on Nuclear Astrophysics, IUCAA, Pune* September 2000. (Proceedings not published)

**B: Recent Talks in Institutes/Universities:**

(a) "Hot and dense matter", Talk given at Department Physics IIT Goa, November 2018.

(b) " Matter under extreme condition", Talk given at conference on "Frontiers in experimental and theoretical physics", Center of Engineering and Technology, Bhubaneswar 24-27 April 2018.

(c) " Transport properties of quark matter", Talk given at BITS Pillani, Goa Campus, Dec 2017.

(d) " Lectures on Quantum Field Theory" six lectures given at, Physics Department, Berhampur University, Bhanjabihar, Berhampur, Feb 2015.

(e) "Kinetics of chiral trnsitions in quark matter", Talk given at Institute of Physics, Bhubanswar, June 6, 2013.

(f) " Chiral symmetry breaking in magnetized quark matter", Talk given at IISER, Kolkata, May 22nd, 2013.

(g) " Matter under extreme conditions", Invited talk at seminar on "Current trends in Physics", Kendrapara college, Odisha, 16-17 Jan 2013.

(h) " Matter under extreme conditions and chiral symmetry breaking", Talk given at BITS Pillani, Goa Campus, July 2012.

(i) "Chiral symmetry breaking in hot and dense matter in strong field", Talk given at Institute of Physics Bhubaneswar, Dec. 26, 2011

(j) " Strong interactions in extreme conditions", **Six** lectures given at Academic Staff College, Sambalpur University, Jyotivihar, Burla, India Dec 2010.

(k) "Superfluidity in quark matter and ultracold atoms", Lecture given at Academic Staff College, Jawaharlal Nehru University, February 2009.

(l) "Relativistic BCS-BEC crossover in fermionic matter", Seminar in AstroPhysics group, Institute for Theoretical Physics, Univ. of Frankfurt, June 2008

(m) "Gapless superconductivity : from Quark matter to ultracold atoms", **Theory Colloquium**, given at TIFR, Mumbai 18 September, 2007.

(n) "Superconductivity in neutron stars", Talk given at Department of Physics, Berhampur University, August 17, 2007.

(o) "Gapless superconductivity : from Quark matter to ultracold atoms", Talk given at Center for Theoretical Physics, Jamia Milia Islamia, Delhi, 17 August 2006.

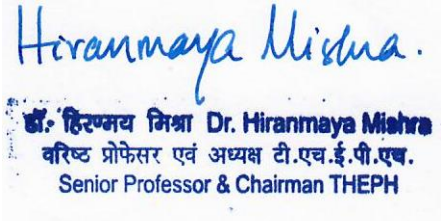
(p) "Superconductivity : from Quark matter to ultra cold atoms", Colloquium given at Institute of Physics Bhubaneswar, 26 June 2006.

(q) "Gapless superconductivity :from Quark matter to cold atoms", Talk given at Indian Association for Cultivation of Science, Kolkata, 15 June 2006.

(r) "Gapless superconductivity : from Quark matter to cold atoms", Talk given at Saha Institute of Nuclear Physics, Kolkata, June13th , 2006

(s) " Gapless superconductivity: from quark matter to cold atoms", Talk given at School of Physics, Jawaharlal Nehru University, April 19th, 2006.

(t) " Chiral symmetry breaking, color superconductivity and quark matter phase diagram"– Talk given at *Center for theoretical studies, Bangalore*- September 2000.



# Science Administration

(a) I am now the **Area Chairman** of the theory division of PRL that I took over since March 2015.

The responsibility has been, among otherthings, (i) managing the department of about ten faculty members, forty students and post doctoral fellows, (ii) course work structure for PhD program, (iii) hiring faculty members, and, (iv) mentoring younger faculty members regarding their progress and promotion.

(b) I have been involved in evaluating projects for department of scince and technology, DAE BRNS projects, ISRO RESPOND program projects. This apart, I have also been involved in evaluating and recommending projects under CEFIPRA (Indo French Collaborative projects), FCT ( Deapartment of scince and technology) Portugal

(c) I have been in the **academic committee** of PRL, Ahmedabad for two years whose responsibility is to look after the the Phd and post doctoral research program in our laboratory.

(d) I am in the committee of faculty appointments,review and recommendation committee of Physical research laboratory whose responsiblity is regarding faculty appointment at all levels, their promotion of the whole laboratory having about 100 faculty members.

(e) I have been in faculty selection committes of Baroda University physics department, IIIT Baroda,

(f) I am in the **Interview Committee of PRL** for recruiting Ph.D. students in our laboratory almost every year since 1997. I am also involved in setting question papers for the written tests for these selections.

(g) I am member of review committees for PhD as well as Post Doctoral fellows in our laboratory regularly.

(h) I have been one of the referees for reviewing various project proposals from DST as well as DAE BRNS.

(i) I have been **PhD thesis examiner** for Viswabharati University, Shantiniketan, Kalyani University, Utkal University, Berhampur University , Sardar Patel University, Anand, Gujurat and Institute of Physics, Bhubaneswar, IIT Roorkee, IISER Kolkata, VECC, Kolkata, Jadavpur University, NISER Bhubaneswar, Saha Institute of Nuclear Physics, Kolkata, Sambalpur University, Calcutta University, NIIT Shibpur Kolkata, NIT Rourkela.

**Scintific duties as related to workshop/school/conferences‘**

(a) Member, national organising committee, DAE symposium NISER Dec 2020

(b) Scientific coordinator, Heavy ion group WHEPP at IISER Bhopal 2014.

(c) Member, National Advisory committee, International conference on physics and astrophysics of quark gluon plasma (ICPA QGP), Kolkata 2010., International Conference on Quark Matter Jaipur 2008

(d) Co-Director of DST SERC School in Theoretical High Energy Physics organised by PRL in 2006.

(e) Member, National Organising Committee, DAE-BRNS Workshop on Hadronic Physics, Aligarh 2008.

(f) Coordinator of Heavy Quarkonia Group in the workshop on Relativistic heavy Ion Collision Nov. 2005, TIFR, Mumbai.

(g) Member of Organising committee of International Workshop on Physics and Astrophysics of Hadronic Matter, Nov. 6–11, Shantiniketan, India.

**Referee for the journals**

(a) Physical Review D

(b) European Journal of Physics A

(c) Journal of Physics G

(d) International j. of Mod. Phys A, E

(e) Pramana

**A summary of recent research work**

**NAME: Hiranmaya Mishra**

During last few years my research work broadly focussed on behavior of matter under extreme conditions of temperature, density as well as external fields. Most of the work is in relation to quark hadron phase transition related to heavy ion collisions and the matter in the core of ultra compact astrophysical objects like neutron star. Recent work of mine has been on estimating different transport coefficients of hot and dense matter.

In the context of heavy ion collision I along with my collaborators worked on dissipative effects in quark gluon matter formed after a heavy ion collision. In this context the heavy flavors- the charm and bottom quarks and their bound states play an important role in characterising the properties of quark gluon matter. We looked into the estimation of drag and diffusion coefficients of heavy quarks in a thermalised medium of light quarks and gluons in a background of Polyakov loop,the socalled semi QGP. The quark thermasses and the gluon Debye masses were calculated in a nontrivial Polyakovloop background.The constituent quark mass and the Polyakov loop parameters weere estimated from different effective models as well as lattice QCD simulated. The temperature and momentum dependences of the heavy quark drag and diffusion coefficients were estimated and it was observed that the temperature dependence of the drag coefficients is quite weak which can have interesting consequences on the heavy quark observables at RHIC and LHC energies. These calculations were also extended to include the effects of viscosities (shear and bulk) on drag and diffusion coefficients . It is observed that shear viscosity effects reduces the drag while bulk viscosity effects work in the opposite way. Further, we stududied the effects of the strong magnetic field on the heavy quark energy loss in a partonic medium. It is observed that the dominant contribution to energy loss arise from the Compton scatterring process i.e. $Qg \to Qg$. On the otherhand, the Coulomb scatterring $Qq \to Qq$ is sensitive to th estrength of magnetic field. The corrections due to the magnetic field are of the same order to the case with out the magnetic field and can be imporatant for jet quenching phenomena in heavy ion collsion experiments.

The experiments from RHIC indicated that the matter at high temperature makes a crossover from hadronic to strongly interacting quark gluon liquid which is almost ideal. While there have been many studies on the reason for quick local thermalisation hence applicability of hydrodynamics has been addressed to, we on the other hand asked the complementary question– that is after what time during the hydro evolution, hydrodynamic description breaks down and if so what could be the consequences. We studied this using the Israel and Stewart formulation of 2nd order relativistic viscous hydrodynamics. It turns out that, viscous effects can lead to a negative longitudinal pressure and hence breakup of the system into droplets. Beyond such a cavitation time during the evolution, the applicability of hydrodynamics breaks down. In the RHIC scenario what triggers cavitation is is the bulk viscosity which become large near the critical temperature. We have also considered temperature dependent shear viscosity to entropy ratio which could be more physical. It turns out that different prescription for shear viscosity temperature dependence can drive cavitation for LHC energies. The effect of cavitation was also studied by us regarding the particle production from the QGP phase in heavy ion collision. In particular we studied the photon and dilepton production from QGP when effects of cavitation are

taken into account. We also incorporated the another effect of viscosity– namely modification of the equilibrium thermal distribution functions. We investigated the limitation of the applicability of Grad's method for calculation of viscous modification of the distribution function. These works have been reported in various international conferences like quark matter 2011 meeting in France, PANIC meeting at MIT, USA as well as in seminars in various universities/institutes of Europe( Vienna, Darmstadt, Rome, Budapest and Dubna) and USA (Stoney-brook) and were appreciated. Apart from international conferences, these work were reported in various national conferences.

Apart from dissipative effects in quark matter, I,along with my collaborators, also looked into dissipative effects in hadronic matter in the context of matter in the core of neutron stars in the context of r-mode instability. This mode can couple with gravitational radiation and can reduce the angular momentum of the star through emission of gravitational waves, unless, these modes are damped by viscosity of the stellar matter. We used a chiral Lagrangian including the lowest lying octet of baryons to extract the equation of state of hyperonic matter. The parameters of the model are constrained by the flow data in heavy ion collision, nuclear matter properties as well as observed high mass neutron stars. We computed the coefficient of bulk viscosity of the hyperonic matter. It turns out that the hyperon induced bulk viscosity is effective in damping the instability at low temperatures.

In the context of high energy heavy ion collisions experiments I, along with my collaborators, studied nonequllibrium effects in the kinetics of phase transition which becomes important if the expansion dynamics is very fast. In this context we studied the far from equilibrium kinetics for chiral transition i.e. the evolution of the system after a quench from a disordered phase to an ordered phase with quark-anti quark condensates. Depending upon the nature of the quench the system evolves via either spinodal decomposition or nucleation and growth. It turns out that if the system is nearly equillibriated the features of coarsening morphologies will be similar for quenches through both 1st order or second order transition. However, if the equilibrium time scales are larger than the life time of the fireball, the morphology is very different for 1st order transitions with the system evolving through nucleation of bubbles. Consequences of signatures of such 1st order transitions is of relevance for the search of the critical point of QCD that has become very relevant in the context of planned heavy ion experiments in RHIC beam energy scan in USA, FAIR at Darmstadt as well as NICA at Dubna in Russia. This work has also been reported in different important international conferences ( Gribov80 meeting at ICTP, Italy; CPOD 10 in Dubna) as well as in WHEPP meeting at Mahabaleswar in India.

Ultra strong magnetic field (eB $\sim m_\pi^2$) is expected to be produced in off central heavy ion collision experiments. Strong magnetic fields could be there in the neutron stars. This prompted us to look into the behavior of hot and dense matter under strong magnetic fields. We used Nambu Jona Lasinio model with external magnetic field to study the chiral symmetry breaking and the phase structure of dense matter. It turns out that the effect of magnetic field at finite temperature and vanishing chemical potential lies in cayalysing quark anti quark condensation. On the other hand, we observe 'inverse magnetic catalysis' at finite baryon chemical potential. In the context of neutron star matter, we also find that the pressure becomes anisotropic when there is significant magnetization of the quark matter. Within the model such effects starts showing for field strengths greater than about $10^{16}$ gauss. This work has also been reported in international conferences (Int. conf. on QGP in Phys and AstroPhys., Goa2011, STAR collaboration meeting, Kolkata) and national

conferences like DAE symposium at Jaipur.

I, alongwith my collaborators, also investigated dissipative effects in the context of warm inflationary cosmology. In warm inflation models there is the requirement of generating large dissipative couplings of the inflaton with radiation, while at the same time, not de-stabilizing the flatness of the inflaton potential due to radiative corrections. One way to achieve this without fine tuning unrelated couplings is by super symmetry. In contrast, we show that if the inflaton and other light fields are Pseudo-Nambu-Goldstone Bosons then the radiative corrections to the potential are suppressed and the thermal corrections are small as long as the temperature is below the symmetry breaking scale. In such models it is possible to fulfill the contrary requirements of an inflaton potential which is stable under radiative corrections and the generation of a large dissipative coupling of the inflaton field with other light fields. We construct a warm inflation model which gives the observed CMB-anisotropy amplitude and spectral index where the symmetry breaking is at the GUT scale.

Strong interaction is known to respect space time symmetry but the QCD interaction in principle permit a CP violating term - the so called theta term. Even if CP is not violated in QCD vacuum, it is possible that it can be violated for QCD matter at finite temperature and density. We investigated chiral symmetry breaking and CP violating effects in the phase diagram of strongly interacting matter. We observe spontaneous CP violation occurs for $\theta = \pi$ which is restored through a second order transition while the same at finite density is a turns out to be a first order transition.

At asymptotically high density, the ground state of QCD is known to be a superconductor from first principle QCD calculations due to asymptotic freedom. However, for the extreme density available in the neutron stars are not high enough where perturbative QCD can be applied. Here one take recourse to effective field theories like Nambu-Jona Lasinio models. However, approximations made here still remain uncontrolled. It is natural to expect that at strong coupling the coherence length of the super-conducting pair can be of the same order as their inter particle separation and quark quark condensates can be considered as a localized bosonic bound state. We investigated this BCS BEC crossover in relativistic fermionic matter in a simple model with two species of fermions allowing for density imbalance. We showed that, the antiparticle degrees of freedom in relativistic system plays a an important role in the dynamics of BCS-BEC crossover as the coupling increases. We also show that with imbalanced population, thermodynamically stable gap less modes are possible in the strong coupling BEC regime both for fermions as well as antifermions. The effect of fluctuation of condensates are also studied which play an important role near the crossover. This was also reported in International conference on cold atoms at IISER, Kolkata.

The color super conducting phase of quark matter shows a very rich phase structure. The reason being, apart from spin, there are flavor and color degrees of freedom available here. Further, external conditions like charge neutrality ( both color as as electromagnetic) can allow for various possibilities of BCS pairing in the super conducting phases. What is even more exciting is that some of these phases that arise due to different ways in which fermions can pair, can be achieved in the laboratory experiments with cold fermionic atoms. In this context, we investigated the Cooper pairing of fermionic atoms with mismatched Fermi surfaces using a variational construct for the ground state. We determined the state for different values of the mismatch of chemical potential for weak as well as strong coupling regimes including the BCS BEC cross over region. We considered Cooper pairing with both

zero and finite net momentum - the so called LOFF phase. Within the variational approximation for the ground state and comparing the thermodynamic potentials, we showed that (i) the LOFF phase is stable in the weak coupling regime, (ii) the LOFF window is maximum on the BEC side near the Feshbach resonance and (iii) the existence of stable gap less states with a single fermi surface for negative average chemical potential on the BEC side of the Feshbach resonance.

# Proposed research plan

The study of matter under "extreme" conditions such as high temperatures, high densities or ultra strong fields is one of the most exciting and challenging problems in strong interaction physics. While study of matter at high temperature behaviour of strongly interacting matter is relevant for the physics of early universe, an understanding of the same at high baryon densities is relevant for physics of compact stellar objects such as neutron stars. Heavy ion collision experiments gives an unque opportunity to study the properties of such matter in the laboratory. This apart effect of strong field both in dense matter as well in the matter produced in off central heavy ion collisions is also relevant. My future research plan is related to the properties of such excited matter.At present there are three different facets of this study that I wish to pursue in the imeediate future. These are (i) transport properties of heavy flavors in quark gluon plasma; (ii) inhomogeneous phase structure of quark matter in the presence of magnetic field and (iii) equation of state dense matter and constarints from gravitational wave data. Below I briefly describe each of these aspects.

- **Transport properties of heavy flavors and vacuum structure of QCD**
  Heavy flovors are useful probes for the QCD vacuum structure with different properties of heavy mesons getting related to vacuum expectation values of quarks and gluons. They are also useful probes of the excited QCD matter. The objective of the proposal is to investigate the nonperturbative effects arising from nontrivial Polyakov loop and chiral symmetry breaking in the transport properties of heavy quarks that result in the spectra of the heavy flavor mesons. The study of the drag and diffusion coefficients of heavy quarks will be the deatiled insightful study of heavy quark transport. In view of the upcoming heavy ion collision experiments at finite baryon densities, the plan is to investigate the usefulness of the heavy quarks to probe various phases of matter at finite densities and/or temperature. The metodology will use the matrix model of semi QGP which includes some nonperturbative features of having a Polyakov loop back ground. Further, the phenomenological implications of of these nonperturbative effects like the nuclear modification factor $R_{AA}$ and the elleiptic flow $v_2$. It ought to be mentioned that it is challenging in almost all the models on heavy quark dynamics to describe the data on both these variables. Apart from this, we would like to study the effect of strong fields on the transport of the heavy quarks. Since the heavy quarks are produced in the early stage of collision when the field is very high, it is reasonable to argue that their dynamics is affected by strong field till their detection as a heavy meson. We would like to estimate the transport coefficients and the heavy quark dynamics in presence of strong magnetic field.

- **Inhomogeneous phase structure of quark matter**
  The phase structure of matter at high densities is extremely challenging and exciting. At asymptotically high densities, color superconductivity is inevitable as the one gluon exchange potential is attactive in certain channels leading to cooper pair formation. However, realistic densities that could be there in the core of the neutron stars or that could be achieved in the planned heavy ion collision experiments are not asymptotically high. At the moment we do not have any approximation scheme that is valid and well controlled at such intermediate densities where the couplings are large.While diquark condensates related to color superconductivity has been quite extensively studied, the pairing of particle and hole near the fermisurface to form a condensate of non zero momentum can break chiral symmetry. It can be energetically favorable to have such condensate when there is a net nonzero momentum of the condensate. Such condensates are thus inhomegeneous and the order parameter can be a plane wave or a

standing wave given as $\langle\bar{\psi}(\mathbf{x})\psi(\mathbf{x})\rangle = \Delta\cos(\mathbf{q}\cdot\mathbf{x})$; and, $\langle\bar{\psi}(\mathbf{x})\gamma_5\tau^i\psi(\mathbf{x})\rangle = \mathbf{e}^i\Delta\sin(\mathbf{q}\cdot\mathbf{x})$; with $\mathbf{e}^i$ being an unit vector in the isospin space. uch sates are similar to Larkin-Ovchinnikov-fulde-Ferrel (LOFF) states of suerconductivity but for the chiral order parameter. It is proposed to investigate the effect of magnetic fields on the inhomogeneous condensates both in quark antiquark channel as well as diquark channels and will perhaps add to our understanding of phase diagram of QCD.

- **Equation of state of dense hadronic matter under strong field and constraints from the gravitational wave data**
  In the recent past astrophysical observations from X-ray,radio and gravitational wave of neutron stars have provided useful insights about the equation of state of the neutron stars. The discovery of two solar mass neutron stars indicated that the pressure of the matter from the core of the star is large. The detection of gravitional wave from neutron star megers placed an upper limit on the tidal deformation which limited the radius of the star to be less than 13.5 km which require the pressure of the outer core has to be small. Taken together the spped of sound of the matter in the core of the star should increase rapidly. There are various models which try to explain this sudden spike in the velocity of sound in the neutron star core. In this context we would like to consider effect of magnetic field on the equation of state of dense hyperonic matter and examine whether the soft EOS ruled out by neglecting the magnetic field can actually be consistent with the large mass neuron star and other results from tidal deformability.

# List of publications

**NAME : HIRANMAYA MISHRA**

**Communicated for publication**

1. **"Critical exponents and transport properties near the QCD critical endpoint from the statistical bootstrap model"**
   G. Kadam, H. Mishra and M. Panero.
   arXiv:2011.02171 [hep-ph]

2. **"Thermoelectric transport coefficients of quark matter"**
   A. Abhishek, A. Das, D. Kumar and H. Mishra.
   arXiv:2007.14757 [hep-ph]

3. **"Momentum broadening of heavy quark in a magnetized thermal QCD medium"**
   B. Singh, M. Kurian, S. Mazumder, H. Mishra, V. Chandra and S. K. Das.
   arXiv:2004.11092 [hep-ph]

4. **"Transport coefficients of hadronic matter in a van der Walls hadron resonance gas model"**
   R. K. Mohapatra, H. Mishra, S. Dash and B. K. Nandi.
   arXiv:1901.07238 [hep-ph]

**Articles in refereed journals**

1. **"In medium properties of axion within a Polyakov loop enhanced Nambu-Jona-Lasinio model"**
   Aman Abhishek, Arpan Das, Ranjita K Mohapatra and Hiranmaya Mishra
   arXiv:2006.15727 [hep-ph](To appear in Phys. Rev D)

2. **"Effects of hadronic repulsive interactions on the fluctuations of conserved charges"**
   S. Pal, G. Kadam, H. Mishra and A. Bhattacharyya.
   arXiv:2010.10761 [hep-ph] (To appear in Phys. Rev D)

3. **"Thermo electric transport coefficients in hot and dense QCD matter"**
   Arpan Das and Hiranmaya Mishra
   Invited review article to European journal of Physics, Special topics on Quark-gluon plasma and heavy ion phenomenology ((EPJST) , To appear)

4. **"An Equation of State for Magnetized Neutron Star Matter and Tidal Deformation in Neutron Star Mergers"**
   N. K. Patra, T. Malik, D. Sen, T. K. Jha and H. Mishra.
   DOI:10.3847/1538-4357/aba8fc
   Astrophys. J. **900**, no. 1, 49 (2020).

5. **"Magneto-Seebeck coefficient and Nernst coefficient of a hot and dense hadron gas"**
   A. Das, H. Mishra and R. K. Mohapatra.
   arXiv:2004.04665 [hep-ph]
   DOI:10.1103/PhysRevD.102.014030
   Phys. Rev. D **102**, no. 1, 014030 (2020)

6. **"HQ Collisional energy loss in a magnetized medium"**
   B. Singh, S. Mazumder and H. Mishra.
   arXiv:2002.04922 [hep-ph]
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7. **"Heavy quark transport in a viscous semi QGP"**
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8. **"Transport coefficients of hot and dense hadron gas in a magnetic field: a relaxation time approach"**
   A. Das, H. Mishra and R. K. Mohapatra.
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   Phys. Rev. D **100**, no. 11, 114004 (2019)

9. **"Chiral susceptibility in the NambuJona-Lasinio model: A Wigner function approach"**
   A. Das, D. Kumar and H. Mishra.
   arXiv:1907.12332 [hep-ph]
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10. **"Electrical conductivity and Hall conductivity of hot and dense quark gluon plasma in a magnetic field: a quasi particle approachElectrical conductivity and Hall conductivity of a hot and dense quark gluon plasma in a magnetic field: A quasiparticle approach"**
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12. **"Viscosity calculations from Hadron Resonance Gas model: Finite size effect"**
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A. Abhishek, A. Das, H. Mishra and R. K. Mohapatra.
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A. Abhishek and H. Mishra.
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19. **"Thermoelectric effect and Seebeck coefficient for hot and dense hadronic matter"**
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20. **"Estimating transport coefficients of interacting pion gas with K-matrix cross sections"**
G. Kadam, S. Pawar and H. Mishra.
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