Atul Kedia

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Current Research

My research interests are in theoretical astrophysics and cosmology. I am working with Prof. Grant Mathews and we are 1) currently investigating Equations of states of neutron stars by developing numerical simulations of binary neutron star merger using the open source code Einstein Toolkit. We also aim to add neutrino transport mechanism to better describe the process. 2) Recently we completed an investigation on the effect of electron energy distribution on proton energy distribution during Big bang nucleosynthesis (BBN). We solved the Multi-component relativistic Boltzmann equation which revealed the true proton distribution during BBN. We independently also developed a Multi-component relativistic thermalization simulation for protons in electron background to verify our analytic solution.

Education

2022 **Graduate studies**, *University of Notre Dame*, Physics.

2016 **Graduation**, *Indian Institute of Technology Bombay*, B.Tech. in Engineering Physics with Honors in Physics.

2015 **Exchange Semester**, *University of Toronto*, Physics, Spring 2015.

Research Experience

Neutron Star Mergers and the Nuclear Equation of State *(2019 - present)*

Collaborators: Prof. Grant Mathews, Dr. In-Saeng Suh

University of Notre Dame

- Abstract: With the recent observations of gravitational wave signals from binary neutron star mergers, relativistic hydrodynamics has become testable by numerical simulations. Numerous simulations currently exist exploring parameters of binaries such as mass ratio, distance, spins, and equations of states of the constituent Neutron stars. Different numerical approaches exist such as the BSSN or BSSNOK formalisms, and the conformally flat approximation that solve the Einstein equation efficiently on computers. In this work, we use the open source code Einstein Toolkit to study binary neutron star merger simulations for various equations of state and relativistic solutions in an attempt to regenerate the observed signal. The goal is to better constrain the equation of state of neutron matter.

Relativistic electron scattering and Big Bang Nucleosynthesis *(Jan 2017 - 2019)*

Collaborators: Prof. Grant Mathews, Dr. Nishanth Sasankan, & Prof. Motohiko Kusakabe

University of Notre Dame

- Abstract: Big-bang nucleosynthesis (BBN) is a valuable tool to constrain the physics of the early universe and is the only probe of the radiation-dominated epoch. A fundamental assumption in BBN is that the nuclear velocity distributions obey Maxwell-Boltzmann (MB) statistics as they do in stars. In this paper, however, we suggest that there could be a difference between stellar reaction rates and BBN reaction rates, arising due to their fundamentally different environments. Specifically, the BBN epoch is characterized by a dilute baryon plasma for which the velocity distribution of nuclei is mainly determined by the dominant Coulomb elastic scattering with mildly relativistic electrons. One must therefore deduce the momentum distribution for reacting nuclei from the multi-component relativistic Boltzmann equation. However, the full multi-component relativistic Boltzmann equation has only recently been analyzed and its solution has only been worked out in special cases. Here, we construct the relativistic Boltzmann equation in the context of BBN. We also derive a Langevin model and perform relativistic Monte-Carlo simulations which clarify the baryon distribution during BBN. We show by these analyses that, contrary to our previous claim, the imposition of pressure equilibrium leads to a nuclear distribution that remains very close to MB statistics even during the most relativistic environment relevant to BBN. Hence, the predictions of standard BBN remain unchanged.
- ArXiv articles 1810.05976 [astro-ph.CO] 1909.01245 [astro-ph.CO] 1911.07334 [nucl-th]

Scales to cosmic homogeneity with multiple tracers *(May 2014 - November 2016)*

Advisors: Prof. Subhabrata Majumdar & Dr. Prakash Sarkar

Tata Institute of Fundamental Research, India

- Abstract: We carry out multifractal analyses of multiple tracers namely the main galaxy sample, the LRG sample and the quasar sample from the SDSS to test the assumption of cosmic homogeneity and identify the scale of transition to homogeneity, if any. We consider the behavior of the scaled number counts and the scaling relations of different moments of the galaxy number counts in spheres of varying radius R to calculate the spectrum of the Minkowski-Bouligand general dimension $D_q(R)$ for $-4 \leq q \leq 4$. The present analysis provides us the opportunity to study the spectrum of the generalized dimension $D_q(R)$ for multiple tracers of the cosmic density field over a wide range of length scales and allows us to confidently test the validity of the assumption of cosmic homogeneity. Our analysis indicates that the SDSS main galaxy sample is homogeneous on a length scales of $80h^{-1}Mpc$ and beyond whereas the SDSS quasar sample and the SDSS LRG sample show transition to homogeneity on an even larger length scales at $\sim 150h^{-1}Mpc$ and $\sim 230h^{-1}Mpc$ respectively. These differences in the scale of homogeneity arise due to the effective mass and redshift scales probed by the different tracers in a Universe where structures form hierarchically. Our results reaffirm the validity of cosmic homogeneity on large scales irrespective of the tracers used and strengthens the foundations of the Standard Model of Cosmology.
- ArXiv article 1611.07915 [astro-ph.CO]

Stability of non-Relativistic Magnetized Astrophysical Jets *(Summer 2015)*

Advisors: Prof. Dinshaw Balsara, Dr. Jinho Kim and Dr. Sudip Garain

University of Notre Dame, United States

- Studied the non-relativistic MagnetoHydrodynamics(MHD) equations and numerically solved them by linearizing for a jet-like structure.
- Jet stability was analysed using different velocity profiles and in both the presence and absence of magnetic field. Jets were assumed to have no net electric current and surface currents. Codes were developed on Mathematica with a colleague.

Conferences and Summer schools attended

- **October 2019** Midwest Relativity Meeting at GVSU, Grand Rapids, Michigan.
- **June 2019** Einstein Toolkit North American Workshop at RIT, Rochester, NY.
- **April 2019** APS April Meeting at Denver, Colorado. Travel supported by APS-DAP travel grant and GSU-Conference Presentation Grant.
- **Oct 2018** Interplay between Particle and Astroparticle physics (IPA) 2018 at Cincinnati, Ohio.
- **May 2018** Neutron Star Merger summer school at FRIB, Michigan State University with funding support.
- **April 2018** APS April Meeting at Columbus, Ohio. Travel supported by APS-DNP Student travel grant.
- **Sept 2017** Midwest Theory Get-Together at Argonne National Laboratory with funding support.
- **Sept 2017** Chemical Evolution of the Universe, GMT community science meeting at Tarrytown, New York.
- **July 2017** National Nuclear Physics Summer School at University of Colorado Boulder with partial funding support.
- **July 2017** Invited for ICTP-SAIFR School on Open Problems in Cosmology at Sao Paulo, Brazil.
- **June 2017** Fourth Azarquiel School of Astronomy, on Nuclear Astrophysics and Astroparticle physics at Sicily, Italy with partial funding support.
- **Nov 2016** GPS Annual Conference at University of Notre Dame.

Talks and Presentations

- **April 2019** "Relativistic electron scattering and Big Bang Nucleosynthesis" at APS April Meeting.
- **Dec 2018** Poster title "Relativistic particle scattering and Big Bang Nucleosynthesis" at COSE-JAM 2018.
- **Oct 2018** "Relativistic particle scattering and Big Bang Nucleosynthesis" at the Biophysics group lead by Prof. Vural at iCeNSA, University of Notre Dame.
- **Oct 2018** "Relativistic particle scattering and Big Bang Nucleosynthesis" at IPA 2018.
- **April 2018** Poster title "Proton distribution function during Big Bang Nucleosynthesis" at APS April Meeting.
- **June 2017** "Probing homogeneity of the Cosmos using Quasars" at Fourth Azarquiel School of Astronomy.
- **Nov 2016** Poster title "Probing homogeneity of the Cosmos using Quasars" at GPS Annual Conference.

Teaching Experience

- **Summer 2019** Adjunct Faculty at Indiana University South Bend, teaching Physics 2 Electromagnetism labs.
- **Feb 2019** Lectured two classes on Engineering Physics I for Prof. Howk at University of Notre Dame.
- **March 2018** Lectured a class on Math Methods for Physics II for Prof. Vural at University of Notre Dame.
- **Jan 2017** Lectured a class on Elementary Cosmology for Prof. Jessop at University of Notre Dame.
- **2016-present** Teaching Assistant for physics 1 lab for pre-med students (fall 16, spring 18), physics 2 lab for pre-med students (spring 17, summer 17), physics 1 course tutor (summer 17, 18, fall 19), physics 2 course tutor (summer 18, fall 18, spring 19), Descriptive Astronomy and Elementary Cosmology (fall 17), Particles and Cosmology (spring 18), Graduate Classical Mechanics (fall 18), and Special and General Relativity (spring 19).
- **2015** Teaching Assistant for online course on Engineering physics by IIT Bombay and *Teach 10k Teachers* for physics teachers at engineering colleges in India.

University service

2017-18 Graduate international students committee member at the Physics Department, University of Notre Dame.

March 2017, 2019 Judge for high school and elementary school students' physics projects at Northern Indiana Regional Science & Engineering Fair(NIRSEF).

2016-18 Volunteer for Our Universe Revealed events and Stargazing events at the University of Notre Dame.

Skill Set

Programming Languages :- C, C++, Python and Arduino.

Software Packages :- MATLAB, Mathematica, and LaTeX.

Operating Systems :- Windows and Ubuntu(Linux).

Languages :- Fluent in English and Hindi. Working knowledge of French, German, and Bengali.

Advisors

Prof. Grant Mathews
Professor of Physics, Director of CANDU, University of Notre Dame, USA.
Contact - gmathews@nd.edu
Webpage - physics.nd.edu/people/faculty/grant-j-mathews/

Prof. Subhabrata Majumdar
Professor of Theoretical Physics, Tata Institute of Fundamental Research, India.
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Webpage - theory.tifr.res.in/pheno/people.html