Muhammed Saleem Cholayil

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1 Employment

- Weinberg Institute Postdoctoral Fellow, Aug 2024 - present
  Center for Gravitational Physics, Weinberg Institute of theoretical Physics, University of Texas at Austin, Austin, TX 78712

- Post Doctoral Associate, Sept 2020 - Aug 2024,
  University of Minnesota, 116 Church Street SE, Minneapolis, MN 55454, United States.

- Visiting Fellow, March 2018 - Aug 2020,
  Chennai Mathematical Institute, SIPCOT IT Park, Sirusseri, Chennai 603 103.

- Research Associate, December 2017 - March 2018,
  Indian Institute of Technology, Bombay,
  Powai, Mumbai, Maharashtra 400076.

2 Education

- Ph.D in Physics, January 2012 - November 2017,
  IISER-Thiruvananthapuram, Kerala, India
  Title: "*Parameter estimation of gravitational waves from compact binaries and astrophysical implications*"
  Advisor: Prof. Archana Pai
  Awarded : June 2018

- Junior Research Fellow, August 2011 - December 2011,
  Institute for Plasma Research (IPR), Gandhinagar, Gujarat

- Msc Physics, July 2007 - September 2009,
  St. Albert's College Ernakulam, Mahatma Gandhi University Kottayam, Kerala.

- Bsc Physics, June 2004 - May 2007,
  MES Mampad College, University of Calicut, Kerala, India

3 Research Interests

- **Broad interests**: Gravitational wave physics and astronomy, Multi-messenger astronomy, Data analysis, Stochastic gravitational wave background, Machine learning applications in real-time astronomy.

- **Specific interests**:

  - Using observed gravitational wave data to test general relativity and other alternative theories, gaining insights into the fundamental nature of gravity.

- Utilizing observed gravitational wave data as a tool to investigate the physical nature of the source objects, discerning whether they are black holes, neutron stars, or other exotic compact objects.
- Exploring the synergies between gravitational wave astronomy and electromagnetic astronomy; for example, investigating the implications of the association between short gamma-ray bursts and gravitational waves, to gain insights into the complex physics powering them.
- Detecting the gravitational energy density dispersed in the universe known as the stochastic gravitational wave background, by accumulating several months of observed gravitational wave data, and use them to study astrophysics and cosmology.
- Developing more accurate and efficient data analysis methods for gravitational wave astronomy; for example, machine learning architectures for noise regression and Bayesian inference for detecting and inferring the population of astrophysical binary black holes.

4 Expertises

- Analyzing Gravitational wave data to estimate parameters and astrophysical inferences such as merger rates and population properties.
- Proficient in using Machine Learning for noise regression, and developing custom neural network architectures.
- Skilled in designing and implementing workflows and pipelines for efficient processing of Gravitational wave data.
- Experienced in multi-messenger modeling of binary neutron star mergers, combining information from multiple observations to enhance understanding.

5 Computing Skills

- Programming languages: Python, C, C++, MATLAB, Octave, Mathematica, HTML.
- Familiar applications: Condor Job scheduler, Git, LaTeX.
- Operating Systems: Linux (knowledge of bash scripting), Mac OS, Windows.
- Data analysis packages:

  - *DeepClean*: A Machine Learning-based noise-regression algorithm for LIGO data denoising .
  - *LALInference*: A Bayesian toolkit to perform parameter estimation and model selection using gravitational waves.
  - *Bilby*: A Bayesian inference library for gravitational wave data analysis as well as compatible for generic applications.
  - *BoxFit*: A hydrodynamic simulation package to simulate and fit GRB afterglow lightcurves.

6 Publications

1. Xiao-Xiao Kou, Muhammed Saleem, Vuk Mandic, Colm Talbot, Eric Thrane
   "Progress toward the detection of the gravitational-wave background from stellar-mass binary black holes: a mock data challenge", arXiv pre-print:2506.14179

2. R. Weizmann Kiendrebeogo, Muhammed Saleem, Marie Anne Bizouard, Andy H.Y. Chen, Nelson Christensen, Chia-Jui Chou, Michael W. Coughlin, Kamiel Janssens, S. Zacharie Kam, Jean Koulidiati, Shu-Wei Yeh. "Application of Non-Linear Noise Regression in the Virgo Detector", arXiv pre-print:2410.06220

3. Christina Reissel, Siddharth Soni, Muhammed Saleem, Michael Coughlin, Philip Harris, Erik Katsavounidis. "Coherence DeepClean: Toward autonomous denoising of gravitational-wave detector data", arXiv pre-print:2501.04883

4. D Chatterjee, E Marx, W Benoit, R Kumar, M Desai, E Govorkova, A Gunny, E Moreno, R Omer, R Raikman, M Saleem, S Aggarwal, M W Coughlin, P Harris and E Katsavounidis. "Rapid likelihood free inference of compact binary coalescences using accelerated hardware", *Mach. Learn.: Sci. Technol. 5 045030 (2024)* arXiv pre-print:2407.19048

5. E Marx, W Benoit, A Gunny, R Omer, D Chatterjee, Ricco C. Venterea, L Wills, M Saleem, Eric Moreno, R Raikman, E Govorkova, D Rankin, M. W. Coughlin, P Harris, E Katsavounidis. "A machine-learning pipeline for real-time detection of gravitational waves from compact binary coalescences", Phys. Rev. D 111, 042010 (2025) arXiv pre-print:2403.18661

6. Soumyadeep Bhattacharjee, Smaranika Banerjee, Varun Bhalerao, Paz Beniamini, Sukanta Bose, Kenta Hotokezaka, Archana Pai, Muhammed Saleem, and Gaurav Waratkar
"Joint gravitational wave-short GRB detection of Binary Neutron Star mergers with existing and future facilities", *Monthly Notices of the Royal Astronomical Society* 528 (3), 4255–4263 (2024), arXiv pre-print:2401.13636

7. Divyajyoti, N. V. Krishnendu, Muhammed Saleem, Marta Colleoni, Aditya Vijaykumar, K. G. Arun, and Chandra Kant Mishra. "Effect of double spin-precession and higher harmonics on spin-induced quadrupole moment measurements", Phys. Rev. D 109 (2024) 2, 023016, arXiv pre-print:2311.05506

8. Muhammed Saleem, Alec Gunny, Chia-Jui Chou, Li-Cheng Yang, Shu-Wei Yeh, Andy H. Y. Chen, Ryan Magee, William Benoit, Tri Nguyen, Pinchen Fan, Deep Chatterjee, Ethan Marx, Eric Moreno, Rafia Omer, Ryan Raikman, Dylan Rankin, Ritwik Sharma, Michael Coughlin, Philip Harris, and Erik Katsavounidis.
"Demonstration of Machine Learning-assisted real-time noise regression in gravitational wave detectors", *Class. Quantum Grav.* **41** 195024 (2024), arXiv pre-print:2306.11366

9. Varun Bhalerao *et al* "Science with the Daksha High Energy Transients Mission", Exp Astron 57, 23 (2024), arXiv pre-print:2211.12052
(Contribution: Computed Daksha's projected detection rates of long and short gamma-ray bursts)

10. Alec Gunny, Dylan Rankin, Philip Harris, Erik Katsavounidis, Ethan Marx, Muhammed Saleem, Michael Coughlin and William Benoit, "A Software Ecosystem for Deploying Deep Learning in Gravitational Wave Physics", FlexScience 22: Proceedings of the 12th Workshop on AI and Scientific Computing at Scale using Flexible Computing Infrastructures https://doi.org/10.1145/3526058.3535454

11. Sayantani Datta, M. Saleem, K. G. Arun and B. S. Sathyaprakash. "Multiparameter tests of general relativity using principal component analysis with next-generation gravitational wave detectors", (Accepted for publication in Phys. Rev. D), Phys.Rev.D 109 (2024), 044036, arXiv pre-print:2208.07757

12. M. Saleem, N. V. Krishnendu, Abhirup Ghosh, Anuradha Gupta, 6 W. Del Pozzo, Archisman Ghosh, and K. G. Arun
"Population inference of spin-induced quadrupole moments as a probe for nonblack hole compact binaries", Phys.Rev.D 105 (2022) 10, 104066 arXiv pre-print:2111.04135

13. M. Saleem, Sayantani Datta, K. G. Arun and B. S. Sathyaprakash
"Parametrized tests of post-Newtonian theory using principal component analysis", Phys.Rev.D 105 (2022) 8, 084062 arXiv pre-print:2110.10147

14. N. K. Johnson-McDaniel, A. Ghosh, S. Ghonge, Muhammed Saleem, N. V. Krishnendu, and J. A. Clark. *et al.* "Investigating the relation between gravitational wave tests of general relativity", Phys.Rev.D 105 (2022) 4, 044020 arXiv pre-print:2109.06988

15. Alec Gunny, Dylan Rankin, Jeffrey Krupa, Muhammed Saleem, Tri Nguyen et al. *et al.* "Hardware-accelerated Inference for Real-Time Gravitational-Wave Astronomy", Nature Astron. 6 (2022) 5, 529-536 arXiv pre-print:2108.12430

16. M. Saleem, Javed Rana, V Gayathri, Aditya Vijaykumar, Srashti Goyal, Surabhi Sachdev, Jishnu Suresh, S Sudhagar, Arunava Mukherjee, Gurudatt Gaur, Bangalore Sathyaprakash , Archana Pai, Rana X Adhikari, P Ajith and Sukanta Bose.
"The Science Case for LIGO-India", Class. Quantum Grav. 39 025004 (2022) arXiv pre-print:2105.01716

17. Siddharth R. Mohite, Priyadarshini Rajkumar, Shreya Anand, David L. Kaplan, Michael W. Coughlin, Ana Sagués-Carracedo, Muhammed Saleem, *et al*. "Inferring kilonova population properties with a hierarchical Bayesian framework I : Non-detection methodology and single-event analyses", Astrophys.J. 925 (2022) 1, 58 arXiv pre-print:2107.07129

18. S Mohan, M. Saleem, L Resmi "Detectability of Electromagnetic counterparts from Neutron Star mergers: prompt emission vs afterglow", *Monthly Notices of the Royal Astronomical Society* 511 (2), 2356–2366 (2022). arXiv pre-print: 1912.09436

19. Abbott et al.,"Tests of general relativity with binary black holes from the second LIGO-Virgo gravitational-wave transient catalog", Physical Review D, 103(12), 122002 (2021), arXiv pre-print:2010.14529 (Contribution: Analysis and writing of the section V.B of the paper, about the test of black hole nature of LIGO detections using the measured spin-induced deformations)

20. M. Saleem "Prospects of joint detections of neutron star mergers and short-GRBs with Gaussian structured jets", Monthly Notices of the Royal Astronomical Society 493 (2), 1633–1639 (2020), arXiv pre-print:1905.00314

21. M. Saleem, L. Resmi, K. G. Arun, S. Mohan "On the energetics of a possible relativistic jet associated with the binary neutron star merger candidate S190425z", *The Astrophysical Journal, 891(2), (2020) p.130.*. arXiv pre-print:1905.00337

22. Shilpa Kastha, M. Saleem, K G Arun "Imprints of the redshift evolution of double neutron star merger rate on the signal to noise ratio distribution", Monthly Notices of the Royal Astronomical Society 496 (1), 523–531 (2020), arXiv pre-print:1801.05942

23. N. V. Krishnendu, M. Saleem, A. Samajdar, K. G. Arun, W. Del Pozzo, Chandra Kant Mishra "Constraints on the binary black hole nature of GW151226 and GW170608 from the measurement of spin-induced quadrupole moments", *Phys. Rev. D 100, 104019,* (2019), arXiv pre-print:1908.02247

24. M. Saleem, L. Resmi, Kuntal Misra, Archana pai, KG. Arun "Exploring short-GRB afterglow parameter space for observations in coincidence with gravitational waves", *Monthly Notices of the Royal Astronomical Society*, 474(4), 5340-5350 (2018). arXiv pre-print:1710.06102

25. M. Saleem, Archana Pai, Kuntal Misra, L Resmi, KG Arun "Rates of Short- GRB afterglows in association with Binary Neutron Star mergers", *Monthly Notices of the Royal Astronomical Society* 475(1), 699-707, (2018), arXiv pre-print:1710.06111

26. Abbott et al.,"GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral", Physical Review Letters, 119, 161101 (2017) (Contribution: Analysis of the associated GRB and interpretation of the multi-messenger nature of the detection)

27. Abbott et al.,"Gravitational waves and gamma-rays from a binary neutron star merger: GW170817 and GRB 170817A", The Astrophysical Journal Letters, 848(2), L13 (2017) (Contribution: Analysis related to the Jet structure of the GRB)

28. Abbott et al., "Binary black hole mergers in the first advanced LIGO observing run", Physical Review X, 6(4), 041015 (2016) (Contribution: Analysis related to the parametrized tests of general relativity).

29. Abbott et al., "Tests of general relativity with GW150914", Physical Review Letters, 116(22), 221101 (2016) (Contribution: Analysis on parametrized tests of GR).

30. Abbott, et al., "Observation of gravitational waves from a binary black hole merger", Physical Review Letters, 116(6), 061102 (2016) (Contribution: Tests of General Relativity analyses)

7 As a referee in peer-reviewed journals

- Physical Review Letters, and Physical Review D of American Physical Society
- Classical and Quantum gravity (IOP Publishing)
- Monthly Notices of Royal Astronomical Society (MNRAS)

8 Courses taught

- Graduate-level elective course "Gravitational waves" (January-April 2019) at Chennai Mathematical Institute. Course code: PGE046
- Graduate-level elective course "Basics of Gravitational wave data analysis" (January-April 2020) at Chennai Mathematical Institute. Course code: PGE018
- Conducted a Half-day technical workshop on "Introduction to noise regression using Machine Learning" at the School of Physics and Astronomy, University of Minnesota. Attendees: Undergrad, masters and graduate students.

9 Mentoring Experiences

- Andrew Ramirez, undergraduate student at University of Texas at Austin, during 2025 -present.
- Brooke Anne Williams, undergraduate student at University of Texas at Austin, during 2025 -present.
- Cole Panzer, undergraduate student at University of Minnesota, during 2021 May-August.
- Vinaya Valsan, undergraduate student at Chennai Mathematical Institute, during Jan-May 2018.
- Divyaa Sree, undergraduate student at Chennai Mathematical Institute, (September 2019 - August 2020),

10 Awards and Achievements

- Co-recipient of 2016 Special breakthrough prize in fundamental physics for the discovery of Gravitational waves (shared with members in LIGO Scientific Collaboration). Link to prize announcement
- Gruber cosmology prize 2016 by Gruber foundation (shared with members in LIGO Scientific Collaboration).
- Bruno Rossi Prize "for the first direct detections of gravitational waves, for the discovery of merging black hole binaries and for beginning the new era of gravitational-wave astronomy" (shared with LIGO Scientific collaboration).

11 Direct Contribution to LIGO scientific collaboration (LSC)

- Chairing a committee that reviews the software infrastructures and results it produces for the real-time noise subtraction in the fourth observing run of LIGO-Virgo-KAGRA detectors.
- Leading a sub-group that works on estimating the stochastic background of binary blackholes from LVK data using a novel Bayesian approach.
- Parametrized tests of GR with GW events GW150914 and GW151226.
- Estimation of background distribution of NSBH systems for parametrized tests of GR.
- Study on effects of waveform systematics in the parametrized tests of GR.
- Assessing the jet properties of the event GW170817 under uniform top hat model using observations from GW and EM windows.
- Member of the team for the parameter estimation follow-up of the GW triggers from O3 obserations of Advanced LIGO and Advanced Virgo.
- Advocate for signing off public alerts for the electromagnetic follow-up of gravitational wave triggers.

12 Memberships in professional collaboration

- LIGO Scientific Collaboration (2013 - present).
- IndIGO-LSC (2013-2020), currently known as LIGO-India Science Collaboration.
- Actively involved in the science study of "Daksha", a proposed space-based gamma-ray telescope dedicated for the follow-up of gravitational wave triggers.

13 Conference Presentations and Talks

- Invited talk on "Denoising gravitational wave data using Deep Learning methods" at the Center for Gravitation, Cosmology & Astrophysics at the University of Wisconsin Milwaukee (28, April, 2023)
- Oral presentation at the "AcceleratingPhysicsWithML@MIT" at Massatusetts Institute of Technology (Jan 2023) *"Denoising gravitational wave data using Machine Learning"*.
- Oral presentation at the "A3D3 Fast ML meeting" at Southern Methodist University, Dallas, Texas, United states (October 2022) *"DeepClean: Machine Learning-assisted data de-noising in LIGO"*.

- Poster presentation at the "The Gravitational Wave Physics and Astronomy Workshop" at HANNOVER, GERMANY, (December 2021) *"An Optimal Search for the gravitational wave background of unresolved binary black-hole mergers"*.

- Oral presentation at the "14th Edoardo Amaldi Conference on Gravitational Waves" (July 19-23, 2021) *"The Science case for LIGO India"*.

- Invited talk at the "Chennai Symposium on Gravitation and Cosmology " at IIT Madras, India (January 2020) *"Multi-messenger astronomy with gravitational waves"*.

- Oral presentation at the "International Conference in Gravitation and Cosmology " at IISER Mohali, India (December 2019) *"Constraining the properties of electromagnetic counterparts of Binary Neutron Star mergers"*.

- Oral presentation at the "The Indian Association for General Relativity and Gravitation " conference at BITS Pilani, Hyderabad, India (January 2019) *"Stealth biases in gravitational wave parameter estimation due to exotic nature of compact binaries"*.

- Invited panelist in the PAX4 meeting for the discussion on "Analysis challenges in gravitational wave astronomy" at IUCAA during Aug 7-10, 2018.

- Oral presentation at the "Astronomical Society of India" meeting at Osmania University, Hydrabad, India (February 2018) *"Short-GRB afterglows in coincidence with gravitational waves from Binary Neutron Star mergers"*.

- Poster presentation at the "Astronomical Society of India" meeting at Jaipur, India (March 2017) "Prospects of LIGO-India in probing masses, spins and source location of compact binaries".

- Poster presentation at the "International Conference on Gravitation and Cosmology" at IISER Mohali, India (December 2015) *"Measuring Binary inclination angle: connection to short GRB jet opening angle"*.

- Oral presentation at the "The Indian Association for General Relativity and Gravitation" conference at RRI, Bangalore, India (March 2015) *"Improving GW parameter estimation accuracy of inclination angle using short GRB observations"*.

14   Workshops, Meetings, Schools and Visits

- *GWPAW* meeting at *Albert Einstein Institute, Hannover* during Dec, 2021.

- *14th Edoardo Amaldi* Conference on Gravitational Waves, 19-23 July 2021.

- *Future of GW astronomy* meeting at *ICTS Bangalore* during Aug 19-22, 2019.

- *ICTS School on GW astronomy* at *ICTS Bangalore* during Aug 13-24, 2018.

- ICTS discussion meeting: *Future of GW astronomy* at ICTS Banglore, 4-8 April, 2016.

- *Workshop on Astronomy, Cosmology and Fundamental Physics with Gravitational Waves* at Chennai Mathematical Institute, 2-4 March 2015.

- Visit to Cardiff University during December 1-4, 2014.

- Visit to University of Birmingham for *collaboration works on parametrized tests of GR* during November 6 − 30, 2014.

- *ICTS Winter School on Experimental Gravitational-Wave Physics, RRCAT Indore*, Dec 23-28, 2013.

- *Gravitational Wave Physics and Astronomy Workshop* 2013, 17-20 December, 2013, IUCAA, Pune, India.

- *ICTS School on Numerical Relativity* at *ICTS Bangalore* during June 10-21, 2013.

- Workshop on GW Data Analysis at *BITS Pilani Goa* Campus during 2012 Dec 17-21.

- *Astrod 5* meeting at *Raman Research Institute, Bangalore* (2012 July 11-13).

15   Education and Public Outreach Activities

- Conducted a half-day technical workshop on *Use of Machine Learning in gravitational wave data denoising* for graduate students at University of Minnesota (April 3rd, 2023).

- Outreach talk *"Discovery of Gravitational waves: Listening to the symphony of Universe"* at Zamorin's Guruvayoorappan college, Calicut, 2016 February 29.

- Outreach talk *"Discovery of Gravitational waves: Listening to the symphony of Universe"*, at Unity women's college, Manjeri, 2016 March 01.

- Outreach talk *"Gravitational waves: Listening the Black-hole symphony"* at MES Mampad college, Malappuram, 2017 January 14.

- Took part in conducting an exhibition "Discovery of Gravitational waves" at IISER Trivandrum in (February 2016).

- Lead a team which conducted an exhibition on gravitational wave astronomy as part of the KSCSTE workshop on Gravitational waves, at Planetarium, Trivandrum (2016 May)

- Took part in conducting an exhibition on "Discovery of Gravitational waves" at IIST Trivandrum (March 2016).

- Lead a team which conducted an outreach activity "Selfie with Gravitational Waves" as part of "Techconnect", the tech fest of IIT Bombay (2017 December).

- Nobel lecture in physics *"Gravitational waves: Einstein's messengers from distant Universe"*, at Unity women's college, Manjeri, 2018 February 21.

- Outreach talk *"Gravitational waves: Einstein's messengers from distant Universe"*, at Malabar Christian college , Calicut, 2019 January.