Nandini Sahu

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Education

2017- 2021 **Centre for Astrophysics and Supercomputing,** Swinburne University of Technology, Melbourne, Australia
PhD in Astrophysics

Thesis Title: "Morphology-Dependent Black Hole Mass Scaling Relations"

(PhD dissertation VIVA/defense qualified on 16th November 2021)

Primary Supervisor: Prof. Alister W. Graham
Co-Supervisors: Dr. Benjamin L. Davis, A/Prof. Edward (Ned) Taylor

2012-2017 **Indian Institute of Technology** (BHU) Varanasi, India
5-year Integrated Masters Degree in Engineering Physics

Master's Thesis Title: "Variation of Optical Depth of the Interstellar Medium Against the Supernovae Remnants"

Supervisor: A/Prof. Prasun Dutta

Bachelor's Thesis Title: "Image Formation in Gravitational Lensing"

Supervisor: A/Prof. Prasun Dutta

Professional Appointments

Sept 2021 – May 2022 **Postdoctoral Researcher,** Swinburne University of Technology, Melbourne, Australia

Publications

First author

- **Sahu, N.** et al. 2021, "The (Black Hole Mass)-(Spheroid Stellar Density) Relations: M_{BH}–μ (M_{BH}–Σ) and M_{BH}–$\boldsymbol{\rho}$." (Submitted to ApJ, arXiv link)
- **Sahu, N.** et al. 2020, "Defining the (Black Hole)–Spheroid Connection with the Discovery of Morphology-dependent Substructure in the M_{BH}–n_{sph} and M_{BH}–$R_{e,sph}$ Diagrams: New Tests for Advanced Theories and Realistic Simulations", ApJ, 903, 97.
- **Sahu, N.** et al. 2019b, "Revealing Hidden Substructures in the M_{BH}–σ Diagram and Refining the Bend in the L–σ Relation", ApJ, 887, 10.
- **Sahu, N.** et al. 2019a, "Black Hole Mass Scaling Relations for Early-type Galaxies. I. M_{BH}–$M_{*,sph}$ and M_{BH}–$M_{*,gal}$", ApJ, 876, 155.

Co- Author

- Ackley et al. including **Sahu, N.** 2020, "Neutron Star Extreme Matter Observatory: A kilohertz-band gravitational-wave detector in the global network" PASA, 37, 47A.

Proceedings

First author

- **Sahu N.**, et al. 2021, "Morphology-dependent Black Hole–Host Galaxy Correlations: A consequence of Physical Formation Processes", Proceedings of the Crimean-2021 AGN Conference. (Submitted to the peer reviewed journal Acta Astrophysica Taurica)

Co- Author

- Davis, B., **Sahu N.**, Graham W. A., 2020 , "Substructure in black hole scaling diagrams and implications for the coevolution of black holes and galaxies", Proceedings of the International Astronomical Union, Vol 15, S359, pp. 37-39.
- Sinha, T., **Sahu N.** et al. "The Characterization of Thick Gas Electron Multiplier (THGEM)", published in the proceedings of the 60th DAE –BRNS Symposium on Nuclear Physics 2015 (http://sympnp.org/proceedings/60/G36.pdf).

Talks: Conferences, Meetings, Live sci-com interview

Sept 2021	Galaxies with Active Nuclei on Scales from Black Hole to Host Galaxy, Crimean. (Contributed talk)
March 2021	Astrophysics group meeting University of Queensland, Australia. (Invited talk)
Dec 2020	Supermassive Black Holes, Chile. (Contributed online talk)
Oct 2020	Live interview with Astro Roxy, "The supermassive black hole and galaxy correlations". (Link)
Oct 2020	Star Clusters and Galaxies meeting at University of Queensland, Australia. (Invited talk)
Sept 2020	The Royal Astronomical Society's Early Career Poster Exhibition. (Contributed poster)
Sept 2020	The 13th International LISA Symposium. (Contributed online talk)
July 2020	Annual scientific meeting of Astronomical Society of Australia (ASA). (Contributed online talk)
June 2020	236th American Astronomical Society (AAS) meeting. (Contributed online talk , Session 307.2)
Feb 2020	2nd Australia-ESO joint conference at Perth, WA. (Contributed talk)
Jan 2020	235th AAS meeting at Honolulu, Hawaii, USA. (Contributed talk)
July 2019	ASA Annual Scientific Meeting at Brisbane. (Contributed talk)
Dec 2018	OzGrav Annual Retreat and ECR Workshop at Perth. (Contributed poster)
June 2018	ASA Annual Scientific Meeting at Melbourne, VIC. (Contributed poster)

Expertise

- Expert in photometric image reduction and the two dimensional galaxy modeling.
- Expert in the multi-component decomposition of galaxy light.
- Confident with statistical regression and error propagation analysis.
- Experienced in 2D spectral data reduction, extraction, telluric correction, and flux calibration.
- Astronomical software and statistical regressions: IRAF, ISOFIT, CMODEL, Profiler, DS9, SourceExtractor, CASA, Topcat, BCES regression (python-based), FITEXY regression (IDL-based), Bayesian routine (R-based).
- Programming languages: Python, Mathematica, Matlab, and C/C++.

Major Scholarships Achieved

- Trottier Chair Astrophysics postdoctoral fellowship at McGill University. (2021, declined in favour of an ongoing project at Swinburne).
- Recipient of the SUPRA scholarship to pursue PhD at Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Melbourne, Australia. (2017-2021)
- Recipient of Scholarship from GAIL (India) Limited in association with CSRL for first four years of Integrated Masters Degree (IMD) program. (2013-2016)
- Recipient of CSRL Super 30 Scholarship for preparation of the competition IIT-JEE. (2011-2012)
- Recipient of seven-year scholarship from MHRD, Government Of India, for schooling at Jawahar Navodaya Vidyalaya Faizabad, UP, India. (2004-2011)

Awards and Honours

- Won first prize in the OzSTAR image competition 2018 at Swinburne University of Technology.
- Awarded **IIT (BHU) Varanasi gold medal** in 2017 for exceptional academic performance during the five-year Integrated Masters Degree (IMD) in Engineering Physics.
- **Junior Research Fellowship** by Indian Academy of Sciences (IAS) to work at SINP in summer 2015.
- First prize on Institute day-2016 at department level at IIT-BHU for poster presentation of my work on THGEM.
- Got funded to attend IIST Astronomy and Astrophysics school (IAAS-2015) at the Indian Institute of Space Technologies, Trivandrum, Kerala.

Teaching Experience and Positions of Responsibility Held

2019	Tutor for 1st year physics course "Energy and Motion" at Swinburne University.	(sem 1, 24 students)
2016	TA for 2nd year physics course "Quantum Physics" at IIT-BHU Varanasi.	(sem 1, 40 students)

2016/14 TA for 1st year physics course "Classical, Quantum, and Relativistic Mechanics" at IIT-BHU. (sem 1, 40 students)
2015 TA for 1st year course "Electrodynamics and Optics" at IIT-BHU Varanasi. (sem 1, 40 students)
2014-15 Joint Secretary of Aeromodeling Club, IIT-BHU Varanasi.

Research Experience

August 2021 **PhD Candidate:** Morphology-Dependent Black Hole Mass Scaling Relations
ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav)
Centre for Astrophysics and Supercomputing (CAS)
Swinburne University of Technology, Melbourne, Australia

Thesis Aims: Investigate the correlation of central black hole mass with galaxy properties, explore the connection of these correlations with the galaxy morphology, and search for the most fundamental relation using the largest to date sample of directly measured black hole masses.

Project 1: Performed the image analysis (reduction, masking, 2D isophotal modeling, and multi-component decomposition) using near-infrared (NIR)-dominated large field of view and high-resolution images of galaxies with directly (dynamically) measured black hole masses (M_{BH}) taken from literature. Our image analysis provided us with stellar mass associated with each galaxy component including bulge ($M_{*,sph}$) and total galaxy stellar mass ($M_{*,gal}$) and the detailed morphology (presence of bar/stellar disk/ring/nuclear components/spiral arms) of our galaxies. We then investigated the correlation between black hole mass and both the bulge stellar mass and total galaxy stellar mass. This work revealed tight super-linear (slope > 1) M_{BH}–$M_{*,gal}$ and M_{BH}–$M_{*,sph}$ relations which turn out to depend on galaxy morphology. (ApJ, 876, 155)

Project 2: Investigated the correlation between black hole mass and central stellar velocity dispersion (σ) of host galaxies, luminosity (L) versus σ relation, and the issue of claimed offset between galaxies with and without dynamically measured M_{BH} in the $M_{*,gal}$--σ diagram. This work discovered a break in the M_{BH}--σ diagram due to Sérsic (gas abundant /wet merger driven) and core-Sérsic (dry merger driven) galaxies and also recovered this bend in the L_{gal}--σ relation using our NIR-band data. Additionally, our (bent) $M_{*,gal}$--σ relation for galaxies with dynamically measured M_{BH} reduces the offset seen in Shankar et al. (2016). (ApJ, 887, 10)

Project 3: Expanding on project 1, here we searched for correlations between M_{BH} and the basic spheroid properties (Sérsic/central concentration index, effective size) obtained during the image analysis. The results reinforced the morphological-dependence of black hole scaling relations with galaxy properties, with substructures consistent with M_{BH}–$M_{*,sph}$ relations. (ApJ, 903, 97)

Project 4: In this project, we numerically calculated the de-projected (3D) internal (spatial) density profiles of galactic spheroids using inverse Abel transformation upon their projected (Sérsic) surface brightness profiles, obtained in project 1. This work revealed morphology-dependent correlations between black hole mass and spheroid internal density at various radii, including the black hole's sphere of influence, which offers many direct applications. We also present the morphology-dependent scaling relations of black hole mass with the projected luminosity and mass density at various spheroid radii, including the half-light radius. These diagrams have divisions consistent with the substructure found in the M_{BH}–$M_{*,sph}$ diagram. (Submitted, arXiv link)

2016-2017 **Master's thesis :** Variation of Optical Depth of the Interstellar Medium (ISM) Against the Supernovae Remnants
Indian Institute of Technology (BHU) Varanasi, India

- Thesis Aim: this project was aimed at measuring the optical depth of ISM against the CRAB nebula, using the HI 21cm absorption line. We used the data observed with the Giant Meterwave Radio Telescope (GMRT), and analysed using the Common Astronomy Software Application package (CASA).
- Outcome: We found that the power-law index of the optical depth of cold neutral medium (CNM) towards CRAB nebula (l=184.56, b= -5.78) is consistent with that of shelled nebulae Cassiopeia A (l=111.74, b= -2.14) measured at the same scale ($\lesssim$ 1 pc) by Roy et al. (2010). This implies a similarity in the scale dependence of opacity fluctuation and further similar density structure and temperature of the CNM along the two different galactic co-ordinates in the Milky Way.
- Experience gained: Learnt to reduce and analyse (radio) visibility data using CASA, and application of Chi-square analysis.

2016 **Research intern:** Near-Infrared (NIR) Spectroscopy of Young Stellar Objects
Indian Institute of Space science and Technology (IIST) Trivandrum
Supervisor: A/Prof. Sarita Vig

- Aim: My objective was to reduce and extract the NIR HK spectra of stellar members in proto-cluster IRAS 18511+0146, and recognize the features of evolving young stars.
- Outcome: I produced a manual describing the detailed procedure of NIR spectral reduction, spectrum extraction, telluric correction, and flux calibration using the NIR spectra of the stars in the IRAS 18511+0146 cluster, taken using Son OF Issac (SOFI) instrument onboard ESO 3.6 m New Technology Telescope (NTT). Seven out of 10 stellar objects show a rising spectral energy density, with three of them showing Brackett-γ (2.16 μm) emission line. (DOI: 10.13140/RG.2.2.15951.71845)
- Experience gained: This was my firsthand experience with real astronomical data. I learnt the whole rigorous spectral reduction and extraction process using IRAF and added to my knowledge of star formation and evolution.

2015-2016 **Bachelors thesis :** Image Formation in Gravitational Lensing
Indian Institute of Technology (BHU) Varanasi, India

- Thesis Aim: In this exploratory project, my aim was to formulate the gravitational lensing caused by point mass and extended objects (galaxies/clusters), and form images of lensed sources using the corresponding gravitational potential models.
- Outcome: I simulated those formalisms using a Python script, where I applied the Rayshooting method to solve the lens equation to obtain the source position corresponding to the image position for various approximated lensing potential models (point mass, isothermal sphere, softened isothermal sphere, and non-circularly symmetric lens models), and also compared some images of lensed sources with the actual observations. (DOI: 10.13140/RG.2.2.12121.13924)
- Experience gained: This was my first ever research exposure to astrophysics which lead me to pursue it further.

2015 **Research intern:** The Characterization of Thick Gas Electron Multiplier
Saha Institute of Nuclear Physics (SINP) Kolkata
Supervisors: Prof. Sukalyan Chattopadhyay and Dr. Tinku Sinha

- Aim: Thick Gaseous Electron Multiplier (THGEM), is a modern high-efficiency ionization detector. My aim was to study the performance of indigenously designed and fabricated THGEM in the single-mode configuration, where it was used to detect the radiation emitted by Fe^{55} (Photo-peak 5.9 keV) in a gaseous medium of 9:1 mixture of Argon and Carbon-di-Oxide.
- Outcome: Gain of the detector was found to depend on input voltage and geometric properties of THGEM which can be tailored to obtain the optimum gain, suggesting that THGEM is an upcoming high-efficiency and high-resolution radiation detector. This work has been published in the proceedings of the 60th DAE-BRNS Symposium on Nuclear Physics. (Link)
- Experience gained: In addition to learning about conventional and advanced nuclear radiation detectors, on which I wrote a detailed report, this was my first experimental project where I learnt to calibrate/operate high energy equipments and data (signal) acquisition.

References

Reference 1
Prof. Alister Graham
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Email: agraham@swin.edu.au

Reference 2
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