

# Nandini Sahu

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## Professional Appointments

Sept 2022–	<b>Postdoctoral Fellow</b> (AGEL- ASTRO3D), University of New South Wales, Sydney, Australia.
Sept 2021– May 2022	<b>Postdoctoral Researcher</b> , Swinburne University of Technology, Melbourne, Australia.

## Education

<b>PhD</b> 2017- 2021	<b>Centre for Astrophysics and Supercomputing</b> , Swinburne University of Technology, Melbourne, Australia <b>PhD in Astrophysics</b> <b>Thesis Title:</b> “ <a href="#">Morphology-Dependent Black Hole Mass Scaling Relations</a> ” (thesis <a href="#">link</a> ) <b>Primary Supervisor:</b> Prof. Alister W. Graham <b>Co-Supervisors:</b> Dr. Benjamin L. Davis, A/Prof. Edward (Ned) Taylor
Masters+Bachelors 2012-2017	<b>Indian Institute of Technology</b> (BHU) Varanasi, India 5-year Integrated Masters Degree in Engineering Physics <b>Master’s Thesis Title:</b> “ <a href="#">Variation of Optical Depth of the Interstellar Medium Against the Supernovae Remnants</a> ” <b>Supervisor:</b> A/Prof. Prasun Dutta <b>Bachelor’s Thesis Title:</b> “ <a href="#">Image Formation in Gravitational Lensing</a> ” <b>Supervisor:</b> A/Prof. Prasun Dutta

## Publications

First author	<ul style="list-style-type: none"><li>• <b>Sahu, N.</b> et al. 2021, “The (Black Hole Mass)-(Spheroid Stellar Density) Relations: <math>M_{\text{BH}}-\mu</math> (<math>M_{\text{BH}}-\Sigma</math>) and <math>M_{\text{BH}}-\rho</math>.” (<a href="#">ApJ, 927, 67</a>)</li><li>• <b>Sahu, N.</b> et al. 2020, “Defining the (Black Hole)–Spheroid Connection with the Discovery of Morphology-dependent Substructure in the <math>M_{\text{BH}}-n_{\text{sph}}</math> and <math>M_{\text{BH}}-R_{\text{e,sph}}</math> Diagrams: New Tests for Advanced Theories and Realistic Simulations”, <a href="#">ApJ, 903, 97</a>.</li><li>• <b>Sahu, N.</b> et al. 2019b, “Revealing Hidden Substructures in the <math>M_{\text{BH}}-\sigma</math> Diagram, and Refining the Bend in the <math>L-\sigma</math> Relation”, <a href="#">ApJ, 887, 10</a>.</li><li>• <b>Sahu, N.</b> et al. 2019a, “Black Hole Mass Scaling Relations for Early-type Galaxies. I. <math>M_{\text{BH}}-M_{*,\text{sph}}</math> and <math>M_{\text{BH}}-M_{*,\text{gal}}</math>”, <a href="#">ApJ, 876, 155</a>.</li></ul>
Co- Author	<ul style="list-style-type: none"><li>• Ackley, K. et al. including <b>Sahu, N.</b> 2020, “Neutron Star Extreme Matter Observatory: A kilohertz-band gravitational-wave detector in the global network” <a href="#">PASA, 37, 47A</a>.</li><li>• Martin, G. et al. including <b>Sahu, N.</b> 2021, “Preparing for low surface brightness science with the Vera C. Rubin Observatory: characterisation of LSB tidal features from mock images”. (<a href="#">MNRAS, 513, 1459</a>)</li></ul>

## Conference Proceedings

First author	<ul style="list-style-type: none"><li>• <b>Sahu N.</b>, et al. 2021, “Morphology-dependent Black Hole–Host Galaxy Correlations: A consequence of Physical Formation Processes”, Proceedings of the Crimean-2021 AGN Conference. (Acta Astrophysica Taurica 5)</li></ul>
Co- Author	<ul style="list-style-type: none"><li>• Davis, B., <b>Sahu N.</b>, 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, <a href="#">Vol 15, S359, pp. 37-39</a>.</li><li>• Sinha, T., <b>Sahu N.</b> et al. “The Characterization of Thick Gas Electron Multiplier (THGEM)”, published in the proceedings of the 60th DAE –BRNS Symposium on Nuclear Physics 2015 (<a href="http://sympnp.org/proceedings/60/G36.pdf">http://sympnp.org/proceedings/60/G36.pdf</a>).</li></ul>

## Talks: Conferences, Meetings, Live sci-com interview

Jan 2022	Hypatia Colloquium Series <a href="#">2022</a> (Invited talk, <a href="#">Link</a> )
Dec 2021	Morphology-dependent Black Hole Scaling relations invited colloquium at the Hamburg Observatory.
Sept 2021	Galaxies with Active Nuclei on Scales from Black Hole to Host Galaxy, Crimean. ( <a href="#">Contributed talk</a> )
March 2021	Astrophysics group meeting University of Queensland, Australia. ( <a href="#">Invited talk</a> )
Dec 2020	Supermassive Black Holes, Chile. ( <a href="#">Contributed online talk</a> )
Oct 2020	Live interview with Astro Roxy, “The supermassive black hole and galaxy correlations”. ( <a href="#">Link</a> )
Oct 2020	Star Clusters and Galaxies meeting at University of Queensland, Australia. ( <a href="#">Invited talk</a> )
Sept 2020	The Royal Astronomical Society’s Early Career Poster Exhibition. ( <a href="#">Contributed poster</a> )
Sept 2020	The 13th International LISA Symposium. ( <a href="#">Contributed online talk</a> )
July 2020	Annual scientific meeting of Astronomical Society of Australia (ASA). ( <a href="#">Contributed online talk</a> )
June 2020	236 <sup>th</sup> American Astronomical Society (AAS) meeting. ( <a href="#">Contributed online talk</a> , <a href="#">Session 307.2</a> )
Feb 2020	2 <sup>nd</sup> Australia-ESO joint conference at Perth, WA. ( <a href="#">Contributed talk</a> )
Jan 2020	235 <sup>th</sup> AAS meeting at Honolulu, Hawaii, USA. ( <a href="#">Contributed talk</a> )
July 2019	ASA Annual Scientific Meeting at Brisbane. ( <a href="#">Contributed talk</a> )
Dec 2018	OzGrav Annual Retreat and ECR Workshop at Perth. ( <a href="#">Contributed poster</a> )

## 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 Fellowships/Scholarships Achieved

- ❖ **Trottier Chair Astrophysics postdoctoral fellowship** at McGill University. (2021, declined in favour of an ongoing project at Swinburne).
- ❖ **Swinburne University Postgraduate Research Award (SUPRA)** scholarship to pursue PhD at the Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Melbourne, Australia. (2017- 2021)
- ❖ Four year **scholarship from Gas Authority of India Ltd. (GAIL)** in association with CSRL during Integrated Masters Degree (IMD) program. (2013-2016)
- ❖ Centre for Social Responsibility and Leadership (CSRL), **Super 30 Scholarship** for preparation of the competition IIT-JEE. (2011-2012)
- ❖ Seven year **scholarship from Ministry of Education, 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

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

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

## Research Experience

August 2021

### **PhD Thesis:** [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. ([Link](#))

**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 ( $M_{\text{BH}}$ ) taken from literature. Our image analysis provided us with stellar mass associated with each galaxy component including bulge ( $M_{*,\text{sph}}$ ) and total galaxy stellar mass ( $M_{*,\text{gal}}$ ) 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  $> 1$ )  $M_{\text{BH}}-M_{*,\text{gal}}$  and  $M_{\text{BH}}-M_{*,\text{sph}}$  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 ( $\sigma$ ) of host galaxies, luminosity ( $L$ ) versus  $\sigma$  relation, and the issue of claimed offset between galaxies with and without dynamically measured  $M_{\text{BH}}$  in the  $M_{*,\text{gal}}-\sigma$  diagram. This work discovered a break in the  $M_{\text{BH}}-\sigma$  diagram due to Sérsic (gas abundant /wet merger driven) and core-Sérsic (dry merger driven) galaxies and also recovered this bend in the  $L_{\text{gal}}-\sigma$  relation using our NIR-band data. Additionally, our (bent)  $M_{*,\text{gal}}-\sigma$  relation for galaxies with dynamically measured  $M_{\text{BH}}$  reduces the offset seen in Shankar et al. (2016). ([ApJ, 887, 10](#))

**Project 3:** Expanding on project 1, here we searched for correlations between  $M_{\text{BH}}$  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  $M_{\text{BH}}-M_{*,\text{sph}}$  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  $M_{\text{BH}}-M_{*,\text{sph}}$  diagram. ([ApJ, 927, 67](#))

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. ([DOI: 10.13140/RG.2.2.21934.02889](#))
- 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- $\gamma$  (2.16  $\mu\text{m}$ ) emission line. ([DOI: 10.13140/RG.2.2.15951.71845](https://doi.org/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](https://doi.org/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  $\text{Fe}^{55}$  (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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- Reference 2 **Dr. Benjamin L. Davis**  
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