

Education

- 2017-present **Swinburne University of Technology**, Melbourne, Australia
PhD candidate in Astrophysics
Thesis Title: “Morphology-Dependent Black Hole Mass Scaling Relations and The Pursuit of Long-Wavelength Gravitational Waves”
Primary Supervisor: Prof. Alister W. Graham
Co-Supervisors: A/Prof. Edward (Ned) Taylor, Dr. Benjamin L. Davis
- 2012-2017 **Indian Institute of Technology (BHU)** Varanasi, India
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
Bachelors Thesis Title: “Image formation in Gravitational lensing”
Supervisor: A/Prof. Prasun Dutta

Research Experience

- 2017-present **PhD Candidate:** Morphology-Dependent Black Hole Mass Scaling Relations and The Pursuit of Long-Wavelength Gravitational Waves
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 with galaxy properties, search the most fundamental relation using the largest to date sample of directly measured black hole masses, and further apply the latest scaling relations to improve the predictions for detection of the long wave-length gravitational wave signals by ground based and space based detectors.
- 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 ($M_{*,\text{sph}}$) 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-(log)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. (Published in ApJ)
- Project 2:** Investigated the correlation between black hole mass 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 $M_{*,\text{gal}}-\sigma$ diagram. This work discovered a break in the $M_{\text{BH}}-\sigma$ diagram due to Sersic (gas abundant /wet merger driven) and core-Sersic (dry merger driven) galaxies and also recovers 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_{BH} reduce the alleged offset. (Published in ApJ)
- Project 3:** Extending the project 1, this work searches for correlations between M_{BH} and the basic spheroid properties (Sersic index, central concentration index, effective size) obtained during the image analysis. The results reinforced the morphological dependence of correlations of black hole scaling relations with galaxy properties with substructures consistent with $M_{\text{BH}}-M_{*,\text{sph}}$ relations. (Accepted in the ApJ)
- Project 4:** In this project we numerically calculate (using vectorized *Mathematica* script) the de-projected (3D) internal (spatial) density profiles of galactic spheroids using their projected Sersic profile obtained in project 1. This work also reveals morphology dependent correlations between black hole mass and spheroid internal density at various radii, along with the correlations of black hole mass with project densities, which are consistent with the substructure found the $M_{\text{BH}}-M_{*,\text{sph}}$ diagram. (To be submitted in the ApJ)

Project 5: This work is going to use our latest morphology-dependent black hole scaling relations and the latest morphology-aware galaxy mass function to improve the strain model for gravitation wave background specifically in the low frequency (micro-nano Hertz) regime. This model will then be used to improve the constraints (amplitude, event rate) for the detection of long-wavelength gravitational waves by pulsar timing arrays and laser interferometer space antenna (LISA).

2016-2017 **Master's thesis :** Variation of Optical Depth of the inter-stellar medium 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 Microwave 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 ($l=111.73$, $b=-0.02.13$) is consistent with that of shelled nebulae Cassiopeia A ($l=184.56$, $b=-0.05.78$) measured at the same scale ($\lesssim 1$ pc). This implies similar scale dependence of opacity fluctuation and 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 objects 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 ($2.16 \mu\text{m}$) emission line.
- 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 on 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.
- Experience gained: This was my first ever research exposure to astrophysics which lead me to pursue it further. Here, I used python for the first time.

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 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 radiations emitted by Fe^{55} (Photo-peak and Escape peak) 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 60th DAE-BRNS Symposium on Nuclear Physics.
- Experience gain: 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.

Publications

First author	<p>Sahu, N. et al. 2020, “Defining the (Black Hole)–Spheroid Connection with the Discovery of Morphology-dependent Substructure in the $M_{\text{BH}}-n_{\text{sph}}$ and $M_{\text{BH}}-R_{\text{e,sph}}$ Diagrams: New Tests for Advanced Theories and Realistic Simulations”.</p> <p>Sahu, N. et al. 2019b, “Revealing Hidden Substructures in the $M_{\text{BH}}-\sigma$ Diagram, and Refining the Bend in the $L-\sigma$ Relation”, ApJ, 887, 10.</p> <p>Sahu, N. et al. 2019a, “Black Hole Mass Scaling Relations for Early-type Galaxies. I. $M_{\text{BH}}-M_{*,\text{sph}}$ and $M_{\text{BH}}-M_{*,\text{gal}}$”, ApJ, 876, 155.</p>
Co- Author	<p>Ackley et al. including Sahu, N. 2020, “Neutron Star Extreme Matter Observatory: A kilohertz-band gravitational-wave detector in the global network”. (Ackley et al. 2020, accepted)</p> <p>Sinha, T., Sahu N. et al. “The Characterization of Thick Gas Electron Multiplier (THGEM)”, Published in the Proceedings of 60th DAE –BRNS Symposium on Nuclear Physics 2015 (http://sympnp.org/proceedings/60/G36.pdf).</p>

Conferences/ Meetings/ Talks

Sept 2020	The RAS Early Career Poster Exhibition. (Contributed poster)
Sept 2020	The 13th International LISA Symposium. (Contributed online talk)
July 2020	ASA Annual Scientific Meeting. (Contributed online talk)
June 2020	236 th AAS meeting. (Contributed online talk)
Feb 2020	2 nd Australia-ESO joint conference at Perth, WA. (Contributed talk)
Jan 2020	235 th 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, cosmic correction, masking.
- ❖ Expert in the two dimensional galaxy modeling.
- ❖ Expert in the multi-component decomposition of galaxy light.
- ❖ Expert in statistical regression and error propagation analysis.
- ❖ Well versed in 2D spectral data reduction, extraction, telluric correction, and flux calibration.
- ❖ Astronomical softwares: IRAF, ISOFIT, Profiler, DS9, SourceExtractor, CASA, Topcat.
- ❖ Scripting: Python, Mathematica, C/C++, Matlab.

Awards and Honours

- ❖ Recipient of the SUPRA scholarship to pursue PhD at Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Melbourne, Australia.
- ❖ Won first prize in the OzSTAR image competition 2018 at Swinburne University.
- ❖ Awarded IIT (BHU) Varanasi gold medal in 2017 for exceptional academic performance during the five year Integrated Masters Degree in engineering physics.
- ❖ Awarded Junior Research Fellowship by Indian Academy of Sciences (IAS) to work at SINP in summer 2015.
- ❖ Won the first prize on Institute day- 2016 at department level 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.
- ❖ Recipient of Scholarship from GAIL (India) Limited in association with CSRL for first four years of Integrated Masters Degree (IMD) program.

Teaching Experience and Positions of Responsibility Held

2019	Tutor for the course Energy and Motion at Swinburne University.
2016	TA for the course Quantum Physics at IIT-BHU Varanasi.
2016	TA for the course Classical, Quantum, and Relativistic Mechanics at IIT-BHU Varanasi.
2015	TA for the course Electrodynamics and Optics at IIT-BHU Varanasi.
2014-15	Joint Secretary of Aero-modeling Club, IIT-BHU Varanasi.
2014	TA for the course Classical, Quantum, and Relativistic Mechanics at IIT-BHU Varanasi.

Extracurricular Activities

- ❖ Participated in Inter-IIT sports meet 2013 at Guwahati as a part of girls basketball team representing IIT -BHU.
- ❖ Participated in UDGOSH 2013 (the annual sports festival of IIT Kanpur) as a part of girls basketball team, representing IIT- BHU.
- ❖ Secured 1st position in the event- Nukkad of Kashi Yatra 2013 (cultural festival of IIT BHU) themed on women empowerment.

References

- Reference 1 Prof. Alister Graham
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