

Nandini Sahu



Title

Morphology-dependent Black Hole Mass Scaling Relations

Abstract

For decades, astronomers have been investigating the connection between supermassive black holes (SMBH) and their host galaxies.

I will talk about my work based on the largest-yet sample of galaxies with dynamically measured central SMBH masses, which adds another step to this study. We measured the host galaxy properties using state-of-the-art two-dimensional isophotal modeling and the multi-component photometric-decomposition, incorporating the kinematic evidence for the presence of stellar disks. These decompositions allowed us to accurately estimate the galactic spheroid properties and reliably identify the galaxy morphologies. We investigated the BH mass scaling relations for various sub-morphological classes of galaxies, i.e., galaxies with and without a disk, early-type versus late-type galaxies, barred versus non-barred galaxies, and Sersic (gas-abundant accretion/wet merger) versus core-Sersic (depleted-core, dry merger) galaxies.

Consequently, we have discovered significantly modified correlations of BH mass with galaxy properties, e.g., the spheroid stellar mass, total galaxy stellar mass, central stellar velocity dispersion, bulge central light concentration, bulge size, and the bulge projected and internal stellar. The final scaling relations are dependent on galaxy morphology, fundamentally linked with galaxy formation and evolutionary paths. These relations provide consistent predictions for the very recent directly measured BHs. The morphological dependence of BH scaling relations poses ramifications for the virial factor and offers tests for simulations and theories for BH-galaxy co-evolution. These relations provide an easier way to estimate BH merger time scales, morphology-aware BH mass function, and improved characteristic strain model for the ground- and space-based detection of long-wavelength gravitational waves generated by merging SMBHs.

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Title

Black Hole—Galaxy Correlations Depend on Galaxy Morphology

Abstract

Since the consensus that a massive black hole (BH) resides at the center of almost every galaxy (local quiescent as well as the distant active galaxies), astronomers have tried to determine the correlations between BH mass and host galaxy properties, as evidence of the BH-galaxy co-evolution.

I will talk about the latest BH-galaxy correlations we observed, which significantly advance this study. We used the largest-yet sample of galaxies with dynamically measured central supermassive BH masses. We measured the host galaxy properties using two-dimensional isophotal modeling and the multi-component photometric-decomposition incorporating the kinematic evidence for the presence of stellar disks and bars. This process leads to accurate estimation of the galactic spheroid properties and detailed galaxy morphologies.

We investigated the BH mass scaling relations for various sub-morphological classes of galaxies, i.e., early-type versus late-type galaxies, galaxies with and without a stellar disk, Sersic (gas-abundant accretion/wet merger) versus core-Sersic (depleted-core, dry merger) galaxies, and barred versus non-barrred galaxies. Consequently, we have discovered significantly modified correlations of BH mass with galaxy properties, e.g., the spheroid stellar mass, total galaxy stellar mass, central stellar velocity dispersion, bulge central light concentration, bulge size, and the bulge projected and internal stellar mass density. We find that the BH scaling relations are dependent on galaxy morphology, fundamentally linked with galaxy formation and evolutionary paths.

These relations provide consistent predictions for the very recent directly measured BH masses. The morphological dependence of BH scaling relations poses ramifications for the virial factor and offers tests for simulations and theories for BH-galaxy co-evolution. These relations provide an easier way to estimate BH merger time scales, morphology-aware BH mass function, and improved characteristic strain model for the ground- and space-based detection of long-wavelength gravitational waves generated by merging supermassive BHs.

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](#)”
(Approved for the award of the degree of Doctor of Philosophy on 10th December 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– Present **Postdoctoral Researcher**, Swinburne University of Technology, Australia

Publications

- First author
- **Sahu, N.** et al. 2021, “The (Black Hole Mass)-(Spheroid Stellar Density) Relations: $M_{\text{BH}}-\mu$ ($M_{\text{BH}}-\Sigma$) and $M_{\text{BH}}-\rho$.” ([Accepted to be published in ApJ](#), [arXiv link](#))
 - **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”, [ApJ, 903, 97](#).
 - **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](#).
 - **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](#).
- Co- Author
- Ackley, K. et al. including **Sahu, N.** 2020, “Neutron Star Extreme Matter Observatory: A kilohertz-band gravitational-wave detector in the global network” [PASA, 37, 47A](#).
 - Martin, G. et al. including **Sahu, N.** 2021, “Preparing for low surface brightness science with the Vera C. Rubin Observatory: characterisation of LSB tidal features from mock images”. ([Submitted to MNRAS](#))

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

Jan 2022	Hypatia Colloquium 2022 (Upcoming , 25 th January)
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. (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	236 th American Astronomical Society (AAS) meeting. (Contributed online talk , Session 307.2)
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)

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 1 st year physics course “Energy and Motion” at Swinburne University.	(sem 1, 24 students)
2016	TA for 2 nd 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 Aero-modeling Club, IIT-BHU Varanasi.

References

- Reference 1 Prof. Alister Graham
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- Reference 2 Dr. Benjamin L. Davis
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- Reference 3 A/Prof. Prasun Dutta
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