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## Unveiling the nature of giant radio galaxies

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# List of publications

## First author publications

1. ‘Discovery of giant radio galaxies from NVSS: radio and infrared properties’, Dabhade, P., Gaikwad, M., Bagchi, J., Pandey-Pommier, M., Sankhyayan, S., & Raychaudhury, S. (2017), MNRAS, 469, 2886.  
DOI:10.1093/mnras/stx860
2. ‘Giant radio galaxies in the LOFAR Two-metre Sky Survey. I. Radio and environmental properties’, Dabhade, P., Röttgering, H. J. A., Bagchi, J., Shimwell, T. W., Hardcastle, M. J., Sankhyayan, S., Morganti, R., Jamrozy, M., Shulevski, A., & Duncan, K. J. (2020), A&A, 635, A5.  
DOI:10.1051/0004-6361/201935589
3. ‘Search and analysis of giant radio galaxies with associated nuclei (SAGAN). I. New sample and multi-wavelength studies’, Dabhade, P., Mahato, M., Bagchi, J., Saikia, D. J., Combes, F., Sankhyayan, S., Röttgering, H. J. A., Ho, L. C., Gaikwad, M., Raychaudhury, S., Vaidya, B., & Guiderdoni, B. (2020), A&A, 642, A153.  
DOI:10.1051/0004-6361/202038344
4. ‘Search and analysis of giant radio galaxies with associated nuclei (SAGAN). II. Molecular gas content of giant radio galaxies’, Dabhade, P., Combes, F., Salomé, P., Bagchi, J., & Mahato, M. (2020), A&A, 643, A111.  
DOI:10.1051/0004-6361/202038676
5. ‘Barbell shaped giant radio galaxy with  $\sim 100$  kpc kink in jet’, Dabhade, P et al. 2021- In preparation.

## Co-authored publications

1. ‘Tracking Galaxy Evolution Through Low-Frequency Radio Continuum Observations using SKA and Citizen-Science Research using Multi-Wavelength Data’, Hota, A., Konar, C., Stalin, C. S., Vaddi, S., Mohanty, P. K., Dabhade, P., Dharmik Bhoga, S. A., Rajoria, M., & Sethi, S. (2016), *Journal of Astrophysics and Astronomy*, 37, 41.  
DOI:10.1007/s12036-016-9415-8
2. ‘Saraswati: An Extremely Massive 200 Megaparsec Scale Supercluster’, Bagchi, J., Sankhyayan, S., Sarkar, P., Raychaudhury, S., Jacob, J., & Dabhade, P. (2017), *ApJ*, 844, 25.  
DOI:10.3847/1538-4357/aa7949
3. ‘‘Zwicky’s Nonet’: a compact merging ensemble of nine galaxies and 4C 35.06, a peculiar radio galaxy with dancing radio jets’, Biju, K. G., Bagchi, J., Ishwara-Chandra, C. H., Pandey-Pommier, M., Jacob, J., Patil, M. K., Kumar, P. S., Pandge, M., Dabhade, P., Gaikwad, M., Dhurde, S., Abraham, S., Vivek, M., Mahabal, A. A., & Djorgovski, S. G. (2017), *MNRAS*, 471, 617.  
DOI:10.1093/mnras/stx1476
4. ‘MACS J0553.4-3342: a young merging galaxy cluster caught through the eyes of Chandra and HST’, Pandge, M. B., Bagchi, J., Sonkamble, S. S., Parekh, V., Patil, M. K., Dabhade, P., Navale, N. R., Raychaudhury, S., & Jacob, J. (2017), *MNRAS*, 472, 2042.  
DOI:10.1093/mnras/stx2028
5. ‘AGN Feedback in Galaxy Groups: A Detailed Study of X-Ray Features and Diffuse Radio Emission in IC 1262’, Pandge, M. B., Sonkamble, S. S., Parekh, V., Dabhade, P., Parmar, A., Patil, M. K., & Raychaudhury, S. (2019), *ApJ*, 870, 62.  
DOI:10.3847/1538-4357/aaf105
6. ‘GMRT observations of extragalactic radio sources with steeply inverted spectra’, Mhaskey, M., Gopal-Krishna, Dabhade, P., Paul, S., Salunkhe, S., & Sirothia, S. K. (2019), *MNRAS*, 485, 2447.  
DOI:10.1093/mnras/stz335
7. ‘A low-frequency study of recently identified double-double radio galaxies’, Nandi, S., Saikia, D. J., Roy, R., Dabhade, P., Wadadekar, Y., Larsson, J., Baes, M., Chandola, H. C., & Singh, M. (2019), *MNRAS*, 486, 5158.  
DOI:10.1093/mnras/stz1184
8. ‘GMRT observations of a first sample of ‘Extremely Inverted Spectrum Extragalactic Radio Sources (EISERS)’ candidates in the Northern sky’, Mhaskey, M., Gopal-Krishna, Paul, S., Dabhade, P., Salunkhe, S., Bhagat, S., & Bendre, A. (2019), *MNRAS*, 489, 3506.  
DOI:10.1093/mnras/stz2379

9. ‘[The LOFAR view of intergalactic magnetic fields with giant radio galaxies](#)’, Stuardi, C., O’Sullivan, S. P., Bonafede, A., Brüggen, M., Dabhade, P., Horellou, C., Morganti, R., Carretti, E., Heald, G., Iacobelli, M., & Vacca, V. (2020), *A&A*, 638, A48.  
DOI:10.1051/0004-6361/202037635
10. ‘[Exploring the hot gaseous halo around an extremely massive and relativistic jet launching spiral galaxy with XMM-Newton](#)’, Mirakhor, M. S., Walker, S. A., Bagchi, J., Fabian, A. C., Barth, A. J., Combes, F., Dabhade, P., Ho, L. C., & Pandge, M. B. (2020), *MNRAS*,.  
DOI:10.1093/mnras/staa3404

\* [List in NASA-ADS](#) \*

## Conference Proceedings

- ‘[New results on the exotic galaxy ‘Specs’ and discovering many more Specs with RAD@home network](#)’, Hota, A., Croston, J. H., Ohyama, Y., Stalin, C. S., Hardcastle, M. J., Konar, C., Aravind, R. P., Agarwal, S. M., Dharmik Bhoga, S. A., Dabhade, P., et al. (2014), *Astronomical Society of India Conference Series*, 13, 141.

## News articles / highlights

- ‘[Giant radio galaxies: the cosmic behemoths](#)’, P. Dabhade and M. Mahato, *Nature Astronomy Community*, Sept 10, 2020.
- ‘[Large sample of giant radio galaxies discovered](#)’, P. Dabhade, *MNRAS OUP blog*, July 2, 2017.
- ‘[LoTSS of giants](#)’, *Nature Astronomy (Research Highlights)*, Feb 03, 2020.



## Curriculum Vitae

I was born on 13<sup>th</sup> June 1989 in a town located in central part of Maharashtra state of India, called Jalna (~400 km from Mumbai). Most of my childhood summer time was spent at my maternal grandparent's house in Jalna, where there was hardly any light pollution, allowing me to gaze at the majestic star filled night sky. However, this privilege was not granted in the ever growing skylines of Mumbai, where I have spent most of my life under the loving care of my parents, Anand Sampatrao Dabhade and Bharati Anand Dabhade along with my sister Dr. Rachana Dabhade (Ophthalmologist). I also spent six formative years of my childhood in the lovely city of Indore, located in central Indian state of Madhya Pradesh, where I became proficient in the Hindi language and was exposed to the north Indian culture. Growing up I had huge interest in science-fiction and sports like cricket, football and table-tennis. I managed to play district level football league in Mumbai, which I discontinued after joining for bachelors studies.

I completed my schooling from Lok Puram Public school, followed by junior college from Saraswati Education Society College in Thane, Maharashtra state. In 2009, I joined the D.G.Ruparel College in Mumbai for my bachelors in physics, where I came in contact with inspiring and encouraging teachers. Fortunately in the same year of 2009 I was introduced to the fascinating field of Astrophysics via public talks at the Nehru planetarium as part of the IAU's International year of Astronomy program.

Towards the end of my first years of bachelors I got the opportunity to attend a summer school at IUCAA in Pune, which is one the premier institutes of astronomy in India. This summer school in 2010 opened altogether a new exciting world for me, where I decided to be an astronomer exploring the secrets of the Universe. I will forever be indebt to IUCAA for providing me this opportunity and changing the course of my life. During my second year of bachelors in 2010 I was generously offered a project by Prof Joydeep Bagchi to work on construction of Cosmic ray muon detector at IUCAA. This allowed me to grasp concepts of special theory relativity, particle and astro-particle physics. I completed the construction and calibration of the muon detector by summer of 2011 with the help of my friend and project partner. Consequently, we have been collecting muon data ever since in the radio physics lab of IUCAA and the experiments with this setup were included in the master's astrophysics lab course of Pune University (now Savitribai Phule Pune University).

The topic for master's thesis at Pune University was search for spiral host

radio galaxies and giant radio galaxies, which involved checking thousands of objects manually along with cross checking with several catalogs of radio and optical bands. The project really helped me several key concepts of radio astronomy as well as programming. In 2013, I also became the part of RAD@home Astronomy Collaboratory, which is India's first citizen science research platform in astronomy. Based on the work done on searches from TIFR-GMRT Sky Survey data as part of their camps I presented my research work for the first time at the annual Astronomical society of India's meeting in Mohali in 2014.

Having completed my masters in Physics from Pune University in 2015, I was selected for the position of 'junior research fellow' at IUCAA to work on a Indo-French CEFIPRA project with Prof Joydeep Bagchi and collaborators. Under this position I started to work on giant radio galaxies exclusively and in 2016 I was given opportunity by Prof Huub Röttgering to work with the LOFAR collaboration and consequently registered in University of Leiden as a PhD student. In the last five years I have spent time in Europe (Leiden and Paris) and at IUCAA working in a joint collaboration.

I have been associated with the radio physics lab of IUCAA for nearly a decade now, during which I have participated in various lab activities initially and later on organised them as well (e.g. winter school, science day, public talks, conducting masters practicals and projects students).

I will continue my journey in research career as a post-doctoral fellow in Paris working with Prof Francoise Combes at the Observatoire de Paris.



# Acknowledgements

“ There is no such thing as a self-made man/woman. We are made up of thousands of others. Every one who has ever done a kind deed for us, or spoken one word of encouragement to us, has entered into the make-up of our character and of our thoughts, as well as our success. ”

- George Matthew Adams

Here, I attempt to acknowledge a long list of people who have helped me in various stages of life so far and have knowingly or unknowingly contributed to whom I am today. I shall be forever grateful to all of them.

I begin by acknowledging my parents (Anand Dabhade and Bharati Dabhade) for their eternal support, limitless love and for believing in me. I thank my sister (Dr. Rachana Dabhade) for always leading by example when it came to academics and career, as growing up with her I always learnt to aim higher.

I thank Prof. Joydeep Bagchi for kick-starting my journey into the research field by generously offering projects to work on since my bachelors and for his teaching, guidance and support in the past decade. More importantly, thank you for inculcating and encouraging independent working.

This thesis would not have been possible without the financial and logistical support from the Indo-French CEFIPRA project, IUCAA, and Leiden University. I am thankful to all the people involved. I would like to thank Prof. Somak Raychaudhury, the director of IUCAA, for his support, guidance and encouragement during my tenure at IUCAA. I must mention the important role of Dr. V Chelathurai, who allowed me to attend IUCAA summer school back in 2010, which paved way for my research career.

As an observational astronomer, I had the wonderful opportunities of visiting various observatories in India and Europe for observations, where I met very kind people who made the observations and my stay memorable. Hence, I thank the hardworking staff of GMRT, ASTRON (LOFAR), HCT (IIA), IRAM, and DOT (ARIES).

I was fortunate to interact with the late Prof. Govind Swarup on several occasions, where he inspired me with his ideas and enthusiasm. He was quite pleased to know that my work has resulted in the finding hundreds of GRGs and they are being followed up by GMRT, one of the great telescopes he built.

As a CEFIPRA (Indo-French project) junior research fellow, I was able to travel to Paris and Lyon in France a couple of times for collaborative work, where I learnt a lot about millimetre-wave astronomy from Prof. Francoise Combes. She has been very instrumental in my research career.

I was quite fortunate to get Prof. D.J. Saikia in my neighbouring office at IUCAA, nearly three years back. This led to our interaction and eventual fruitful collaboration. His vast knowledge of radio galaxies and his humble nature combined with his patience has been very inspiring and helpful for me.

I am thankful to Prof. Ishwar Chandra (NCRA radio astronomy schools) for introducing me to AIPS and for fruitful discussions on radio galaxies and imaging. I thank Dr Huib Intema for creating and teaching me SPAM (radio imaging made simple). The project with the LoTSS data would not have been possible without great help from Dr Timothy Shimwell for which I am very grateful. I thank and appreciate Prof. Ananda Hota for creating and making me part of RAD@home Astronomy Collaboratory (citizen-science research platform) early on during my masters. It was very exciting to learn new techniques to find objects from TGSS.

I would also like to thank Prof. Madkaikar and Prof. Londhe from D.G. Ruparel college (Bachelors) for encouragement and guidance to take up research. They both introduced me to Prof. S Prabhu (TIFR), who was instrumental in providing me timely advice and direction with respect to higher education and research.

Tejas Kale, thank you for supporting and guiding me at my low points of life. I have always looked up to you. Your suggestion to take up basic sciences has done wonders for me. Madhuri Gaikwad, thank you for making the time in our bachelors and masters so great with all discussions and projects. Thank you for always being supportive of my ideas in our joint projects, for your patience, and for always being there for me.

The turning point in my life was attending IUCAA summer school in 2010, which would not have happened without my cousin Pravin Maghade who very graciously hosted me in Pune for a month and introduced me to the lifestyle of Pune. I will forever be thankful to him.

A major part of my PhD was spent at IUCAA, where numerous people made this journey very memorable. The hardships of PhD were made quite bearable by my friend and collaborator Shishir Sankhyayan who stood by me throughout. It was great working with you and thank you for being the brother I never had before. It is very crucial to understand the telescopes very well in radio astronomy especially if you are an observational astronomer. Over the years Ashish Mhaske not only has been a great friend but also has cleared my numerous technical doubts about radio telescopes which lead to some epic discussions for future projects. Junior turned collaborator turned friend- Mousumi Mahato- you have been of exceptional help to me during my crucial second half of my PhD. It has been an absolute pleasure working with you and thank you for being patient with me.

Radio physics lab at IUCAA was the place where I spent most of my time joyfully working alongside Shishir, Ashish, Mousumi, and Jameer Manur. It was great to have Jameer as a friend and colleague who always ensured smooth working of the lab and providing us all with amazing home-cooked food.

It was amazing to see Ajay Vibhute's computing and managerial skills at work. I learned a lot about Linux and computing from him, and he always had a solution

to my computing problems.

On my first visit to IUCAA during my bachelors, Dr Prashant Samantray showed me that being PhD student does not demand you to be nerdy all the time. Thank you for your timely guidance and for inspiring me with your work and fitness ethics.

I am grateful to Dr Biju K.G and Dr Joe Jacob for their support and inspiring me with their zeal to learn. It was refreshing to attend conferences with you both and spend joyful time at IUCAA during your visits.

From being my seniors at Pune University (masters) to great friends, Bhooshan Gadre and Shabbir Shaikh made times at IUCAA more joyous and always had sound advice for me. From trying new food with Bhooshan to taking late-night walks with Shabbir, there was always scope to have discussions on any topic with both of them.

Sharmad Navelkar always ensured that I had enough outings in the month so that I didn't burn out, thank you for a great time. Those outings were made epic by the company of Reju Sam John, Swagat Mishra, Sorabh Chhabra and many more (apologies for forgetting some names). Physics discussions and admiring rock music with Swagat Mishra were always gratifying, who always impressed me with his endearing passion for physics. A very essential skill that I developed during my PhD is cooking (my mother would be equally proud about this) and much of the credit goes to Sangeetha CR and Vidushi Sharma. I am grateful to them for always pushing to cook new dishes, which ensured I get the needed break from work. Vidushi's impromptu plans for cooking or outing or work discussions always broke the monotonous routine. In the past few years, I had some very scintillating discussions with Sayak Datta and Siddharth Maharana, which often gave me an interesting perspective on certain matters.

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