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Cosmic depth and detail: advancing LOFAR imaging workflows to unveil the deep high-resolution universe

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List of publications

First author

1. *Benford's Law in the Gaia Universe*
J.M.G.H.J. de Jong, J.H.J. de Bruijne, J. De Ridder
Astronomy & Astrophysics, Volume 642, A205, 16 pp., 2020
2. *Deep Study of A399-401: Application of Wide-Field Facet Calibration*
J.M.G.H.J. de Jong, R.J. van Weeren, A. Botteon, J.B.R. Oonk, G. Brunetti,
T.W. Shimwell, R. Cassano, H.J.A. Röttgering, C. Tasse
Astronomy & Astrophysics, Volume 668, A107, 19 pp., 2022
3. *Cosmic Evolution of FRI and FRII Sources out to $z = 2.5$*
J.M.G.H.J. de Jong, H.J.A. Röttgering, R. Kondapally, B. Mingo, R.J. van
Weeren, P.N. Best, L.K. Morabito, M. Magliocchetti, J.B.R. Oonk, A. Villarrubia-
Aguilar, F.F. Vecchi
Astronomy & Astrophysics, Volume 683, A23, 17 pp., 2024
4. *Into the Depths: Unveiling ELAIS-N1 with LOFAR's Deepest Sub-Arcsecond
Wide-Field Images*
J.M.G.H.J. de Jong, R.J. van Weeren, F. Sweijen, J.B.R. Oonk, T.W. Shimwell,
A.R. Offringa, L.K. Morabito, H.J.A. Röttgering, R. Kondapally, E.L. Escott,
P.N. Best, M. Bondi, H. Ye, J.W. Petley
Astronomy & Astrophysics, Volume 689, A80, 32 pp., 2024
5. *Unlocking Ultra-Deep Wide-Field Imaging with Sidereal Visibility Averaging*
J.M.G.H.J. de Jong, R.J. van Weeren, T.J. Dijkema, J.B.R. Oonk, H.J.A.
Röttgering, F. Sweijen
Astronomy & Astrophysics, Volume 694, A98, 9 pp., 2025
6. *Advanced Strategy for Deep Sub-Arcsecond Wide-Field Facet Calibration with
LOFAR*
J.M.G.H.J. de Jong, L. Veefkind, R.J. van Weeren, R.J. Schlimbach, J.B.R.
Oonk, D.N.G. Kampert, H.J.A. Röttgering, M. van der Wild
To be submitted.

Contributing author

1. *Abell 0399–Abell 0401 radio bridge spectral index: First multi-frequency detection*
G.V. Pignataro, A. Bonafede, G. Bernardi, F. de Gasperin, G. Brunetti, T. Pasini, F. Vazza, N. Biava, **J.M.G.H.J. de Jong**, R. Cassano, A. Botteon, M. Brüggen, H.J.A. Röttgering, R.J. van Weeren, and T.W. Shimwell
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2. *Characterization of the decametre sky at sub-arcminute resolution*
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Nature Astronomy, Volume 8, p. 786-795, 2024
3. *1-arcsecond imaging of ELAIS-N1 field at 144MHz using the LoTSS survey with international LOFAR telescope*
H. Ye, F. Sweijen, R.J. van Weeren, W.L. Williams, **J.M.G.H.J. de Jong**, L.K. Morabito, H.J.A. Röttgering, T.W. Shimwell, P.N. Best, M. Bondi, M. Brüggen, F. de Gasperin, C. Tasse
Astronomy & Astrophysics, Volume 691, A347, 18 pp., 2024
4. *A hidden Active Galactic Nuclei population: the first radio luminosity functions by physical process*
L.K. Morabito, R. Kondapally, P.N. Best, B.-H. Yue, **J.M.G.H.J. de Jong**, F. Sweijen, M. Bondi, D.J. Schwarz, D.J.B. Smith, R.J. van Weeren, H.J.A. Röttgering, T.W. Shimwell, I. Prandoni
Monthly Notices of the Royal Astronomical Society: Letters, Volume 536, Issue 1, Pages L32–L37, 2025
5. *The LOFAR Two-metre Sky Survey: Deep Fields Data Release 2*
T.W. Shimwell, C.L. Hale, P.N. Best, A. Botteon, A. Drabent, M.J. Hardcastle, V. Jelić, **J.M.G.H.J. de Jong**, R. Kondapally, H.J.A. Röttgering, C. Tasse, R.J. van Weeren, W.L. Williams, A. Bonafede, M. Bondi, M. Brüggen, G. Brunetti, J.R. Callingham, K.J. Duncan, C. Horellou, S. Iyer, I. de Ruiter, K. Małek, D.G. Nair, L.K. Morabito, I. Prandoni, A. Rowlinson, J. Sabater, A. Shulevski1, D.J.B. Smith
Astronomy & Astrophysics, Volume 695, A80, 20 pp., 2025

6. *A decade of sub-arcsecond imaging with the International LOFAR Telescope* L.K. Morabito, N. Jackson, **J.M.G.H.J. de Jong**, E.L. Escott, C. Groeneveld, V.H. Mahatma, J.W. Petley, F. Sweijen, R. Timmerman, R.J. van Weeren
Springer Nature (Astrophysics and Space Science), Volume 370, article number 19, 2025
7. *The relationship between morphology and host galaxy properties of RLAGN in LoTSS DR2*
L. Clews, J.H. Croston, H. Dickinson, B. Mingo, B. Barkus, M.J. Hardcastle, **J.M.G.H.J. de Jong**
Submitted for publication in Monthly Notices of the Royal Astronomical Society.

Published software

1. LOFAR helpers

Python package with several tools to work with LOFAR data. This code has been developed and used for most of the chapters in this thesis.

https://github.com/jurjen93/lofar_helpers

2. Advanced Astro Visualization

Python code to produce videos and posters of fits images. It was used during a press release in 2021 to demonstrate LOFAR high-resolution imaging.

https://github.com/jurjen93/advanced_astro_visualization

3. Redshifting

Python package to move radio sources to higher redshifts in the image plane. This software has been used to simulate the appearance of FRI and FRII sources at different redshifts.

<https://github.com/jurjen93/redshifting>

4. Sidereal Visibility Averaging

Python package to average visibilities for similar baseline coordinates. This software is currently being used to enhance imaging when combining multiple LOFAR observations for ultra-deep imaging.

https://github.com/jurjen93/sidereal_visibility_avg

Curriculum Vitae

I was born on May 26, 1993, in Hulst, a city in the Dutch province Zeeland. While I had great teachers at primary school at Basisschool de Ark, my main teacher growing up was my older brother, who, being 7.5 years older, constantly inspired me with stories about history, science, and everything he learned at school himself. Navigating secondary school at Het Reynaertcollege in Hulst was challenging, largely due to the fear to speak up because of my stutter. Nevertheless, I found great joy in following mathematics classes, which was further reinforced by participating in the national Mathematics Olympiads. Eventually, I finished secondary school in 2011, but was unsure about what to do next.

Since engineering seemed to offer diverse career opportunities, I chose to pursue a bachelor's degree in mechanical engineering at Avans Hogeschool in Breda. However, during my first year, I quickly realised I had 'two left hands' – as we often say in Dutch – since I performed worse in my class in practical assignments on topics like drilling, milling, and welding. More theory-focused subjects like mathematics, mechanics, and material science appealed to me far more, which led me to decide to complete the propaedeutics and leave mechanical engineering to pursue a university degree instead.

In 2012, I started a bachelor's degree program in mathematics at the University of Utrecht, where I enjoyed in my first year courses on fundamental mathematics and added additional courses from other programs to feed my interest in philosophy, history, and physics. By the second year, I decided to pursue a full bachelor's degree in physics next to mathematics, alongside a minor in the history and philosophy of science. I completed these studies with a double bachelor's thesis under the supervision of dr. Steven Wepster. This work was focused on interpreting the ancient Indian mathematical-astronomical work “Ganita-Yukti-Bhāṣā”, which had recently been translated from Malayalam to English. In my research, I sought to connect this ancient work to modern mathematics and astronomy. This research project marked my first direct academic interaction with astronomy.

After finishing my bachelor's degrees in math and physics within three years, I moved to the University of Ghent in Belgium in 2015 to pursue a master's degree in mathematics with a specialisation in mathematical (astro)physics. This was where I took a few introductory courses in astrophysics. During my second year, I went on an Erasmus+ exchange to Uppsala (Sweden) where I took a few more courses in astronomy and remotely worked under the supervision of prof. dr. Maarten Baes

on my master's degree thesis, which involved deriving analytical Fox-H functions for the Nuker model in galactic dynamics.

After a year in Sweden, I was ready for a new adventure and spent the summer of 2017 in Tunis (Tunisia), where I worked as a summer intern at Engineering Procurement and Project Management (EPPM), as part of the Belgian IAESTE program. There, I derived formulas to calculate stresses on storage tanks and pipeline constructions. After returning, I graduated with my first master's degree and began an advanced master's program in Space Studies at the University of Leuven in Belgium. This one-year program provided a comprehensive overview of the space industry and space-related research, covering topics such as space law, space biology, exoplanet research, rocket science, and general engineering. I had the privilege of learning from experts, including former astronaut Frank De Winne, who inspired me by showing that even though you have physically been in space, you can still be down to Earth. To apply the knowledge I gained across various subjects, I also took on a side job during this time, writing popular science articles for *Scientias*. The articles I wrote covered a wide range of topics, including mathematics, physics, astronomy, quantum computing, and space exploration.²⁶

In the summer of 2018, I was fortunate to be awarded a small scholarship to study Mandarin in Tainan (Taiwan). This was an enjoyable and challenging side step out of my comfort zone, since I learned much about new cultures, while it showed me that I was not gifted with skills for learning foreign languages. A few days after returning to Europe, I began, with financial support from a scholarship from the Flemish government (foreign affairs), a three-month internship at the European Space Agency (ESA). At ESA, I did research with the brand new second data release from the Gaia space telescope under the supervision of dr. Jos de Bruijne. I applied Benford's law to identify patterns in the data corresponding to distances between stars, which led to my master's thesis and the completion of the Space studies program. This work was later converted into my first first-authored scientific publication.

Having completed 2 bachelor's degrees and 2 master's degrees, I decided that I was done with collecting university degrees for now and started with a traineeship in data science at Matrixian Group. This transitioned into a full-time role as a data scientist and machine learning engineer. During this time, I gained experience beyond science and programming as well, such as working with clients, thinking about business models, meeting strict deadlines and dependencies, and collaborating with colleagues from diverse backgrounds. When the COVID-19 pandemic hit at the start of 2020, I took in March of that year the last plane from the Netherlands to Iceland, where my girlfriend was living at the time. I ended up staying there for

²⁶You can still find my articles here <https://scientias.nl/author/jurjen-de-jong>.

four months, which gave me time to reflect on my future. While I enjoyed my work as a data scientist, I missed the academic challenges...

Thankfully, I remained in contact with Anniek Gloudemans, a former colleague from my internship at ESA, who introduced me to her supervisor, prof. dr. Huub Röttgering. After a few interviews, he offered me a PhD position in Leiden, and although I had no prior experience with radio astronomy, the opportunity to work in the field of radio astronomy with a focus on the computational data processing side as well was appealing. On January 1st, 2021, under the supervision of prof. dr. Huub Röttgering, dr. Reinout van Weeren, and dr. Raymond Oonk, I embarked on my PhD journey. Despite the lockdowns keeping me home for much of the first year, I focused on mastering the calibration and imaging of LOFAR data, while studying galaxy cluster pre-mergers and radio galaxy evolution. Later on, my focus moved to pushing the wide-field sub-arcsecond imaging pipeline with LOFAR forward to open up new windows for the study of the universe at the smallest angular scales and greatest depths. All this work eventually resulted in the work presented in this thesis.

While my career has let me zigzag across the world and disciplines, I feel very fortunate to have the opportunity to continue working for the coming years as a postdoc in Leiden with Huub, Reinout, Raymond, and many others who have made the work outlined in this thesis possible.

Although stuttering had various effects on my life, I am proud to mention that next to my scientific career, I co-founded with friends the non-profit organisation ‘Stamily’, during the first years of my PhD. This association fosters a global community and provides a supportive safe space for people who stutter, as having a stutter can impact many aspects of people’s lives. I was elected as the first chair and took on a leadership role in establishing the foundation, organizing both in-person and online events, making contact with other associations, and maintaining the website. On the day I write these words, Stamily has over 150 members from 35 different countries, has been featured in national media in the Netherlands and local media in other countries,²⁷ and is organizing each year several camps and weekends for people who stutter around Europe.

²⁷<https://www.stamily.org/in-the-media>

Acknowledgements

The work presented in this thesis would not have been possible without the support of many people over the past four years. First and foremost, I want to thank Huub, Reinout, and Raymond. They took on the challenge of supervising a PhD student with little to no prior knowledge of radio astronomy. I am grateful for the trust you placed in me to complete this journey successfully. I am thankful to Reinout for his endless patience, support, and daily mentorship throughout these four years; to Raymond, who, despite his busy schedule, always made time to help me when I reached out with computing issues or when I just asked for advice; and to Huub for encouraging me to think critically and stay focused on the bigger picture of my research as well. I really appreciate all the help and support you three provided throughout my PhD, as well as the effort you have put into guiding me toward my future career. I am very happy that we will continue working together.

I could not have started this PhD without Anniek, who connected me with Huub. Thank you so much for this. A special thanks to my former office mate and patient colleague, Frits. Thank you for opening the heavens for high-resolution wide-field imaging with LOFAR and for always being ready to help out. I also want to thank my dear colleagues and travel companions from the first few years of my PhD: Christian, Erik, María, and Roland. I really enjoyed having the opportunity to visit my first astronomical conferences with you and explore new parts of the world. I will never forget (or perhaps partly) our dance night out in Seoul and our hunt for spotting the big five at Pilanesberg.

I would like to thank everyone from Leiden's LOFAR group with who I shared the excitement of working with data from this amazing instrument: Andrea, Bohan, Emanuele, Gabriella, George, Haoyang, Ian, James, Jinyi, Joe, Joshiwa, Lars, Luca, Marco, Martijn, Rafael, Sai, Sarah, Scott, Tong, Wendy, Xuechen, and others. Many thanks to everyone from the LOFAR VLBI working group as well: Alexander, Aleksandra, Cyril, Deepika, Emmy, Etienne, Jonny, Jort, Gulay, Henrik, Leah, Nadia, Neal, Marcin, Marco, Matthijs, Rishi, Sagar, Shane, Tom, Vijay, and many others. It was a real joy to spend weeks with you hacking LOFAR software and doing amazing things at my favourite LOFAR resolution. Especially, the week in a castle in Durham and the catacombs in Paris are experiences I will never forget. Of course, I have to thank the guys from Surf – Duncan, Lars, and Robert Jan – who have not only improved the work presented in this thesis but also enriched my coding and machine learning knowledge.

A big thanks to Michiel, Osmar, and Tim for making my experience as a teaching assistant in the radio astronomy course such a rewarding experience. Developing the Cantenna interferometer with you each year was a great learning experience and lots of fun. Thanks to Jelle and Thomas for sharing Office 460 with me. I hope our extended LOFAR brainstorming sessions were not too distracting. Rico, Tong, and Willeke, I enjoy our time together in our new office as well. Good (or perhaps bad) news: I will stay there with you. To all my Cosmos United teammates – Alfred, Amy, Andrew, Christiaan, Dario, Elia, Joey, Josh, Kayou, Kevin, Mojtaba, Murat, Osmar, and everyone else who came out (un)injured – thank you for being part of the same team during the eventful matches in the beautiful indoor football stadium from the USC. If our scores had been adjusted for age, we would have won the league after all. I also want to thank the IT group and secretaries for always being ready to help with technical, practical, or organizational issues. It is difficult to list all the names from everyone I have met over the years at Leiden Observatory and other institutes who have supported me throughout my PhD journey. But I am very thankful for all your time, help, and support, or just for spending time together during borrels, coffee breaks, and other non-scientific activities.

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Finally, and most importantly, I am so grateful for the love and support from Satu. I am so proud of you and you inspire me with your ability to never give up. Without you, I would have no idea where I would have been. At least not in Leiden, writing the last few words of my PhD thesis.