Untangling cosmic collisions: a study of particle acceleration and magnetic fields in merging galaxy clusters

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List of Publications

Part of this thesis.

First Author

1. **E. Osinga**, R. J. van Weeren, L. Rudnick, F. Andrade-Santos, A. Bonafede, T. Clarke, K. Duncan, S. Giacintucci, Tony Mroczkowski, H. J. A. Röttgering, *Probing cluster magnetism with embedded and background radio sources in Planck clusters*, A&A to be submitted.

2. **E. Osinga**, R. J. van Weeren, G. Brunetti, R. Adam, K. Rajpurohit, A. Botteon, J. R. Callingham, V. Cuciti, F. de Gasperin, G. K. Miley, H. J. A. Röttgering, T. W. Shimwell, *Probing particle acceleration in Abell 2256: from to 16 MHz to gamma rays*, A&A submitted.

3. **E. Osinga**, R. J. van Weeren, F. Andrade-Santos, L. Rudnick, A. Bonafede, T. Clarke, K. Duncan, S. Giacintucci, Tony Mroczkowski, H. J. A. Röttgering, *The detection of cluster magnetic fields via radio source depolarisation*, A&A, 665, A71 (2022)

4. **E. Osinga**, R. J. van Weeren, J. M. Boxelaar, G. Brunetti, A. Botteon, M. Brüggen, T. W. Shimwell, A. Bonafede, P.N. Best, M. Bonato, R. Cassano, F. Gastaldello, G. di Gennaro, M. J. Hardcastle, S. Mandal, M. Rossetti, H. J. A. Röttgering, J. Sabater, C. Tasse, *Diffuse radio emission from galaxy clusters in the LOFAR Two-metre Sky Survey Deep Fields*, A&A, 648, A11 (2021)

5. **E. Osinga**, G. K. Miley, R. J. van Weeren, T. W. Shimwell, K. J. Duncan, M. J. Hardcastle, A. P. Mechev, H. J. A. Röttgering, C. Tasse, W. L. Williams, *Alignment in the orientation of LOFAR radio sources.*, A&A, 642, A70 (2020)

Contributing author

1. C. J. Riseley, N. Biava, G. Lusetti, A. Bonafede, E. Bonnassieux, A. Botteon, F. Loi, G. Brunetti, R. Cassano, **E. Osinga**, K. Rajpurohit, H. J. A. Rottgering, T. Shimwell, R. Timmerman, R. J. van Weeren, *A MeerKAT-meets-LOFAR study of Abell 1413: a moderately disturbed non-cool-core cluster hosting a* $\sim$ *500 kpc mini-halo*, MNRAS, 524, 4 (2023).

1. M. Simonte, H. Andernach, M. Brüggen, P. N. Best, **E. Osinga**, *Revisiting the alignment of radio galaxies in the ELAIS-N1 field*, A&A, 672, A178 (2023)

2. K. Rajpurohit, **E. Osinga**, M. Brienza, A. Botteon, G. Brunetti, W. R. Forman, C. J. Risely, F. Vazza, A. Bonafede, R. J. van Weeren, M. Brüggen, S. Rajpurohit, A. Drabent, D. Dallacasa, M. Rossetti, A. S. Rajpurohit, M. Hoeft, E. Bonnassieux, R. Cassano, G. K. Miley, *Deep low-frequency radio observations of Abell 2256. II. The ultra-steep spectrum radio halo*, A&A, 669, A1 (2023)

3. K. Rajpurohit, R. J. van Weeren, M. Hoeft, F. Vazza, M. Brienza, W. R. Forman, D. Wittor, P. Dominguez-Fernandez, S. Rajpurohit, C.J. Risely, A. Botteon, **E. Osinga**, G. Brunetti, E. Bonnassieux, A. Bonafede, A.S. Rajpurohit, C. Stuardi, A. Drabent, M. Brüggen, D. Dallacasa, T.W. Shimwell, H. J. A. Röttgering, F. de Gasperin, G. K. Miley, M. Rossetti, *Deep Low-frequency Radio Observations of A2256. I. The Filamentary Radio Relic*, ApJ, 927, 1 (2022)

4. G. di Gennaro, R. J. van Weeren, R. Cassano, G. Brunetti, M. Brüggen, M. Hoeft, **E. Osinga**, A. Botteon, V. Cuciti, F. de Gasperin, H. J. A. Röttgering, C. Tasse, *A LOFAR-uGMRT spectral index study of distant radio halos*, A&A, 654, A166 (2021)

5. D. N. Hoang, T. W. Shimwell, **E. Osinga**, A. Bonafede, M. Brüggen, A. Botteon, G. Brunetti, R. Cassano, V. Cuciti, A. Drabent, C. Jones, H. J. A. Röttgering, R. J. van Weeren, *LOFAR detection of a low-power radio halo in the galaxy cluster Abell 990*, MNRAS, 501, 1 (2020)

6. A. Botteon, R. J. van Weeren, G. Brunetti, F. de Gasperin, H.T. Intema, **E. Osinga**, G. di Gennaro, T.W. Shimwell, A. Bonafede, M. Brüggen, R. Cassano, V. Cuciti, D. Dallacasa, F. Gastaldello, S. Mandal, M. Rossetti, H. J. A. Röttgering, *A giant radio bridge connecting two galaxy clusters in Abell 1758*, MNRAS Letters, 499, 1 (2020)

Curriculum Vitæ

Erik Osinga

I was born on 28 December 1995 in Amsterdam, the Netherlands, and grew up in the nearby city of IJmuiden. Perhaps I was subconsciously influenced to pursue astronomy because I lived in a neighbourhood full of streets named after constellations or asterisms. I grew up in the *Lierstraat* (Lyra street), just adjoining streets such as the *Perseusstraat* and the *Herculesstraat*, and attended a primary school called *de Pleiaden* (The Pleiades). When I was 12, we moved to Drachten, Friesland, where I went to high school and started to be consciously interested in astronomy. I remember the elective course *Natuur, Leven en Technologie* (Nature, Life and Technology), which really sparked my interest in (astro)physics as we could study any subject we wanted. I wrote a report on time dilation, the fact that time flows differently for observers who are experiencing different gravitational forces or are moving with respect to each other. The fact that the Universe legitimately adheres to these bizarre rules that seem like science fiction made a big impression on me, which has never really gone away.

After high school, I started the Bachelor's program in astronomy at Leiden University in 2014. In the first year, I came into contact with programming and realised its importance in modern astronomy. Luckily, I loved that as well and thus pursued a minor in Data Science. I graduated with a Bachelor of Science in 2017. Opportunely, that year was the first year that the Master's programme *Astronomy & Data Science* was offered, which I immediately signed up for. During my Master's programme, I was introduced to scientific research through various projects. I did a research project in the Low-Frequency Array (LOFAR) group on the alignment of radio galaxy jets, which was the seed that sparked my interest in a PhD and would develop into the first publication of my PhD two years later. I graduated (cum laude) in 2019, with a graduation project on using machine learning to extract the optimal amount of information from future weak lensing surveys.

My PhD started in October 2019, a study of magnetic fields and particle acceleration in galaxy clusters with state-of-the-art radio telescopes, supervised by Prof. Huub Röttgering and Dr. Reinout van Weeren. I worked mainly with LOFAR and The Karl G. Jansky Very Large Array but have also had the opportunity to observe on-site with the Isaac Newton Telescope on La Palma and the IRAM 30m telescope on the Sierra Nevada mountain range in Spain. During my PhD, I supervised various students: two Master's students, one Bachelor's student and a summer student as part of LEAPS. In the spring of 2022, I spent just over two months in Bologna visiting the INAF-IRA Istituto di Radioastronomia, where I worked with Dr. Gianfranco Brunetti on theoretical models of particle acceleration in galaxy clusters. In the first half of my PhD, many conferences were online due to the COVID-19 pandemic, but I was fortunate enough to be able to present my work at various

in-person conferences as well, such as the LOFAR KSP meeting in Turin (Italy), the GLOW meeting in Garching (Germany), the LOFAR Family meeting in Cologne (Germany), the IAU General Assembly in Busan (South-Korea), and SPARCS XI near Johannesburg (South Africa). I had a lot of fun in various other activities as well, such as managing the setup of the Radio Galaxy Zoo: LOFAR citizen science project, for which I have given a few interviews, writing a Zenit article on my PhD research, organising the PhD talks at the Sterrewacht, and organising scavenger hunts and various other social activities for new PhD students.

Starting in December 2023, I will move to Toronto, Canada, to work as a postdoctoral researcher as part of the POSSUM (Polarisation Sky Survey of the Universe's Magnetism) collaboration. There, I will continue studying magnetic fields in galaxy clusters and the Universe.

Acknowledgments

As with many acknowledgements, the list of people to thank is too long, and written too hastily in the stressful final stages of finishing a draft, to not inadvertently miss a few people. I hope I have referenced everyone, but if not, please know that I value all the interactions I had during my PhD.

First, I have to thank my supervisors, Huub and Reinout. During the applications for a PhD, I was in doubt about which of your projects I would put highest on the preference list, but in the end, decided to go with the project more focused on radio astronomy. I am happy that I did, not just because of the science, but also because I feel like this way I got the best of having you both as supervisors. Huub, thanks for always being critical, stimulating discussions and showing me how to think bigger. Reinout, I cannot thank you enough for your input, enthusiasm, and incredible engagement. In my opinion, you are the best supervisor walking around the Sterrewacht. I do not know how you do it but, as Gabriella once hypothesised, I would not be surprised if you reveal at some point that you were actually twins the whole time, like in *The Prestige*.

To the great people of the 2019 PhD year: Anniek, Evgenii, Maite, Margot, Marta, Pooneh, Roland, Sun-Sheng, Yapeng, and Zhenlin, I am glad to have made this journey with you all. I really enjoyed our weekend getaways where we tried to figure out who was lying when they said they were liberal. Marta, we had some great workouts together, and I'm very glad that after some doubts you decided to come on the PhSki trip to be part of the best ski house. Anniek, Roland, my LOFAR siblings, I am very happy to have started and finished the journey of the PhD with you both so closely. Anniek, I loved all the (friendly) competitions we had, from board games to bowling, and *I know it is not a competition but...* congratulations on winning the PhD by finishing first. Roland, you are one great guy, I was absolutely sure of that when, after having only just met, you showed up to my birthday in Drachten during the Christmas break to party with random people. It is unfortunate that you have such poor taste in what constitutes a great MOBA, but your movie night hosting skills make up for it. Many thanks also to Christian and Jurjen (completing *Reinout's Radio Rascals*), with whom we four make a pretty good travel gang that knows how to make the best use of a conference trip. I particularly appreciated the ease with which we all just clicked when travelling together, and I hope we will still get to do that in the next few years.

The LOFAR group has many layers, and the Leiden group is quite a close family within the whole collaboration, with many people to thank. Frits, I am glad we shared the intimate moment of your first kapsalon. Maria, thanks for your yoga sessions in lunch breaks while on safari. Rafael and Martijn, the philosophical discussions we had during the LOFAR Family meeting have really stuck with me, but unfortunately COVID kind of got in the way of spending more time together. Andrea, Gabriella, Joe, Kim, Sarah, Tim, Wendy and George, thanks for being great examples to look up to on how to be a good researcher and person. The broader European LOFAR collaboration was also a great family to be in. I cannot name everyone here as the list would be too long, but if we shared a drink at

one of the LOFAR Family Meetings, you know who you are. One highlight was getting to know the Italian side of the collaboration and in particular, visiting Bologna. Gianfranco, many thanks for hosting me (and Reinout & Huub for pushing me to go) and Luca thanks for being a great host. I should also thank the whole gang of PhDs there for the instant inclusion of me (and Tjissa) in their group, and Xavi for teaching us how to lead climb!

The Sterrewacht in Leiden is a great place to work. The astronomy department, although of course not perfect, is a social bundle of joy with many activities and borrels. I am grateful to the IT department for keeping everything running so smoothly, and for their very rapid response time to all my questions. I also want to express my gratitude to the secretariat for so seamlessly managing all the administrative work that I rarely had to worry about it. Some highlights of my time at the Sterrewacht were the barbecues (including swimming at the beach), playing secret Sinterklaas, and random or themed house parties, I thank everyone with whom I have shared those moments. A big highlight was the ski trip, where I first learned how to ski together with Silvia, Alessia, Josh, Marta and Timo, and had a great time in house Gryffindor thanks to Amy, Anniek, Chris, Billy, Jelle, Mantas and Marta. Mantas, also thanks to you in particular for being my thesis design sempai, but that does not mean I will go easy on you next time.

Although nearly forgotten, I also had a life at the Sterrewacht before the PhD. To the *Bierspons* gang, who have been with me since I first stepped foot into the observatory nine long years ago, and without whom I would probably not have made it into the PhD: thanks Auke, Chris, Couzy, Jelle, Joey, Len and last but not least: Jonah (it's you and me, baby, let's destroy the Universe together). Thanks for all the good times and rants we shared about professors, coursework, cosmology and Karels. I love the hiking trips we take together (except the Toubkal before lunch), and honestly can anyone name a more iconic duo than astronomers and mountains?

It is also greatly important to be surrounded by non-astronomers. To the set of friends I made for exploring my new hobby of bouldering and dungeons: Tom, Noah, Stefan, Guilia, Marije, Daan and Wessel: thanks for the good times, (on the subject of bouldering, it is still impossible to avoid astronomers, so I should say I am also grateful for the fun sessions with Billy, Elia, Jinyi, Thijs and Timo). Thanks to the boys from *de Klik* for a great place to blow off steam with all the great 'workouts': Jivan, Jorik, Boudewijn, Dick, Guido, Pieter, Stan, Siem, Lennart and Emile. And of course, Steef for keeping the old guard together, and focused on our touring life. To friends that have stuck with me from *the before times* even throughout the PhD, especially Axel, Floris and Robin, you guys are real life-long friends. Although I am not the best at keeping in touch, I will try my best to keep those friendships alive and thriving.

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