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Sizing up protoplanetary disks

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LIST OF PUBLICATIONS

Refereed publications

1. Far-infrared HD emission as a measure of protoplanetary disk mass
Trapman, L., Miotello, A., Kama, M., van Dishoeck, E. F., Bruderer, S. 2018, A&A, 605, A69
2. Gas versus dust sizes of protoplanetary discs: effects of dust evolution
Trapman, L., Facchini, S., Hogerheijde, M. R., van Dishoeck, E. F., Bruderer, S. 2019, A&A, 629, A79 [Chapter 2]
3. Constraining the radial drift of millimeter-sized grains in the protoplanetary disks in Lupus
Trapman, L., Ansdell, M., Hogerheijde, M. R., Facchini, S., Manara, C. F., Miotello, A., Williams, J. P., Bruderer, S. 2020, A&A, 638, A38 [Chapter 3]
4. Observed sizes of planet-forming disks trace viscous spreading
Trapman, L., Rosotii, G., Bosman, A. D., Hogerheijde, M. R., van Dishoeck, E. F. 2020, A&A, 640, A4 [Chapter 4]
5. Mass constraints for 15 protoplanetary disks from HD 1-0
Kama, M., **Trapman, L.**, Fedele, D., Bruderer, S., Hogerheijde, M.R., Miotello, A., van Dishoeck, E. f., Clarke, C., Bergin, E. A. 2020, A&A, 638, A88 [Chapter 6]
6. ALMA Survey of Lupus protoplanetary disks. II. Gas disk radii
Ansdell, M., Williams, J. P., **Trapman, L.**, van Terwisga, S. E., Facchini, S., Manara, C. F., van der Marel, N., Miotello, A., Tazzari, M., Hogerheijde, M., Guidi, G., Testi, L., van Dishoeck, E. F. 2018, ApJ, 859, 21
7. V1094 Scorpii: A rare giant multi-ringed disk around a T Tauri star
van Terwisga, S. E., van Dishoeck, E. F., Ansdell, M., van der Marel, N., Testi, L.; Williams, J. P., Facchini, S., Tazzari, M., Hogerheijde, M. R., **Trapman, L.**, Manara, C. F., Miotello, A., Maud, L. T., Harsono, D. 2018, A&A, 616, A88
8. Methanol and its relation to the water snowline in the disk around the young outbursting star
van 't Hoff, M. L. R., Tobin, J. J., **Trapman, L.**, Harsono, D., Sheehan, P. D., Fischer, W. J., M., Thomas, S., van Dishoeck, E. F. 2018, ApJL, 864, L23

9. The ALMA Lupus protoplanetary disk survey: evidence for compact gas disks and molecular rings from CN
van Terwisga, S. E., van Dishoeck, E. F., Cazzoletti, P., Facchini, S., **Trapman, L.**, Williams, J. P., Manara, C. F., Miotello, A., van der Marel, N., Ansdell, M., Hogerheijde, M. R., Tazzari, M., Testi, L. 2019, *A&A*, 623, A150

CURRICULUM VITAE

I was born on Februari 5th in Amsterdam to Joris Trapman en Rita Bakker. Before my second birthday we had already moved on to Lelystad, which is where I would spend most of my childhood. Here I would be joined by a younger brother, Bart, who was and has remained a constant source of excitement (and some headaches). As it turns out, it would take a while for my interest in Astronomy to fully manifest itself. As a kid I had many interests over the years that are common to many at that age: firetrucks, astronauts and space, knights. It was my interest with dinosaurs, fueled by documentaries like *Walking With Dinosaurs*, that made it clear to me that I wanted to be a paleontologist (or an archaeologist in a pinch).

This changed during my years at the Scholengemeenschap Lelystad where I followed my secondary education. During primary education it had already become clear that I had a knack for arithmetic, and now physics, chemistry and mathematics could be added to that list. Despite that, I was still convinced that I wanted to become a paleontologist until, during a visit to a job/study market, it became clear that my childhood vision of the job did not fully match with the real world. It was at this point that my brain decided to pick astronomy as the logical alternative. It is still not fully clear to me what made me pick astronomy, but I have not regretted it since.

I started my Bachelor in Astronomy at the Leiden University in 2011. For someone who breezed through secondary education without having to put much effort in, the transition to university was a bit of a shock but also a welcome challenge. I finished my Bachelor doing a research project together with Leindert Boogaard, under the supervision of Michiel Hogerheijde. Together we looked at ALMA data of transition disks, which are protoplanetary disks with a clear inner cavity. It is obvious that I enjoyed this topic, as I would eventually return to it.

After my Bachelor I decided to continue with a Master in Astronomy in Leiden. During my Masters I shared an office with Arthur, Bavo, David, David⁵, Kasper, Matthias and Leindert, with whom I formed a tightly-knit group for studying, scientific discussions and the odd christmas tree decorating. For my first research project I looked at methods for measuring gravitational lensing, under the supervision of Henk Hoekstra, Massimo Viola and Ricardo Herbonnet. I did my second research project in the group of Ewine van Dishoeck. Here I returned to the topic of protoplanetary disks. Under the supervision of Anna Miotello and Mihkel Kama I dove into the world of thermochemical modeling and investigated hydrogen deuteride as potential disk gas mass tracer. I was very happy to find out that I finished my Masters cum laude.

By the end of my Master it was clear to me that I wanted to continue in research and in astronomy. I was fortunate to be invited for the PhD interviews in both Leiden and Amsterdam. Over the five years of my Bachelor and Master I kept my fascination

⁵no that's not a typo, there were two Davids

for protoplanetary disks, so when Michiel Hogerheijde offered me a PhD position to work with him on this topic I did not hesitate to accept it.

When I started in 2016, the plan for my PhD was to work on the so-called “icelines”, locations in protoplanetary disks where molecules transition from being mostly gaseous to being frozen out on dust grains. Obtaining the necessary observations turned out to be difficult. While we successfully got our observing proposal(s) accepted each year (currently a three-year streak) it has so far not resulted in any observations. Instead I joined the Lupus collaboration - Jonathan Williams, Megan Ansdell, Stefano Facchini, Carlo Manara, Anna Miotello, Marco Tazzari, Leonardo Testi, Michiel Hogerheijde, Ewine van Dishoeck and others - just as they were starting to look at their new ALMA observations. I worked together with Megan Ansdell on measuring gas and dust outer radii of protoplanetary disks in the Lupus star-forming region. This turned out to be a rich vein of interesting science, which lead directly and indirectly to several articles you can find elsewhere in this thesis. Also early in my PhD I started working together with Mihkel Kama on a side project involving unpublished HD 1-0 flux upper limits. This turned out to be a long and eventful journey that at some point reached near mythical status. Having clearly found my home in modeling, I finished of my PhD with two projects on the evolution of protoplanetary disks. During my PhD I also had the opportunity to travel abroad and visit other scientific institutes. I made several work trips to the MPE in Germany, attended schools in the Netherlands and France, and presented my work at conferences in Göteborg and Boston.

As part of my PhD I also had the pleasure to supervise two Master students, Lisa Dombrovsky and Yapeng Zhang and two bachelor students, Ivana van Leeuwen and Yke Rusticus. In addition, I worked as a teaching assistant for the course Pre-university college Astronomy⁶, where we presented high school students with an overview of astronomy and gave them a taste of what it is like to study astronomy at Leiden University. Finally, I was part of the Education Committee of the Astronomy Master, where we gather feedback from the students and use that to provide advice to the University on how to improve the astronomy Master. After completing my PhD I will work as a postdoc researcher with Ke (Coco) Zhang at the University of Wisconsin-Madison in the United States.

⁶previously known as Laptopp

ACKNOWLEDGEMENTS

The thesis that you see here before has been four years in the making. That sounded like a long time when I started working on it, but now that I am at the end I am amazed at how quickly it all has gone by. These four years have been a journey, with twists and turns, ups and downs. But more than the work itself, it is also a collection of memories: of challenges, places, but most importantly, of people. Without the people around me it would not nearly have been this much fun. Thank you all for helping to make this happen.

First of all, I want to thank my supervisor, Michiel, for taking me on this journey. Throughout my PhD you have taught me a great deal of science, but also life lessons that will be useful wherever I might end up. And most importantly, your door was always open for any questions, no matter what the topic was. And thank you Ewine, for your positive attitude as well as your detailed insights. Our meetings were always invaluable for keeping my research focused on the big questions, especially when I sometimes got lost in the details.

Anna and Mihkel, thank you for supervising my master project, which introduced me to the wondrous world of disk modeling. Our project together made it clear to me that this is what I wanted to do for the next four years. And Mihkel, who would have guessed where that conversation in a cafe in Cambridge would lead to? I am looking forward to our next, hopefully slightly shorter, project. To Megan, Jonathan, Anna, Carlo, Stefano, Marco, Leonardo, Sierk, Michiel, Ewine and all the others on the Lupus team: I could not think of a better group for my first international collaboration. I would also like to thank the LKBF for funding three of my work visits abroad, two of which were instrumental for my development as a researcher, while the third was unfortunately canceled due to the current situation in the world.

My fellow group members, Eva, Nico and Mason, you welcomed me with open arms into the group. Thanks for helping me to get started with my PhD. Eva, I enjoyed our shared lunches, which came with their own eleven-flights-of-stairs exercise regime. Jeroen, it was nice to have a fellow partner in crime (i.e. group member) again. Thanks for all your energy, humor and borrel conversations.

I also became an honorary member of Ewine's research group, where I was so readily accepted that people kept forgetting that I was not actually a member of the group. I cannot thank you guys enough for that. I have enjoyed our many scientific discussions, but also the myriad of topics that were discussed over beers during our Friday afternoon borrels. Arthur, you were a constant stream of knowledge, tech-support and (in-)jokes. I'm convinced you probably are a wizard [citation needed]. Merel, I enjoyed our conversations both N_2H^+ related or otherwise. And I still owe you that thing we discussed during our bike ride. Giovanni, thanks for kick-starting my interest in the evolution of disks. I have thoroughly enjoyed working together

so far, and based on our current plans, I have the feeling that we will continue to do so for a while. Alex, your positive attitude is infectious. Please keep reminding me that planets are important, not just for the introduction of my papers. On the flip side, thank you Alvaro for reminding me of the big picture. Łukasz, what about outflows? Joking aside, I always enjoyed our conversations, especially over one of your special coffee brews. Benoit, thank you for explaining to me the dark arts of MHD disk wind simulations. Beside that, it was always gezellig to join you for beers at the borrel. Sierk, it was really nice to have someone from the Lupus team also in Leiden, especially in the beginning. Margot, supervising you and answering your many questions over the last year has been fun and has also kept me sharp. Good luck with the rest of your doctorate. Martijn, thanks for the smooth organization of the telecons, but more importantly, thanks for providing ample beers during the Friday borrels. Pooneh, it has always been great to see your excitement on all matters inside and outside of science. To all of the new people in Leiden, Alice, Lucas and Ardjan: good luck and have fun, I know that you are in good hands.

And to the Garching side of the group, Stefano, Paolo, Lisa and now also Andres, you made me immediately feel at home whenever I came to visit the MPE. Stefano, you helped making my second project go smoothly while my first project was stuck in the dirt. Thank you Paolo for letting me see a PhD defense from the front row before I have to do my own. Lisa, I hope that you will enjoy Leiden next year as much as I have. And good luck Andres, I have no doubt that you can make it to the end of your PhD.

The observatory is of course much bigger than just two research group. To my fellow PhDs on the 11th floor, David, Steven, Maaïke, Alex, Rob, Emiel, Sebas, thanks for all of our morning coffees. And thanks Leindert, Stijn and Kirsty for being willing to come up to the 11th floor to join said coffees. Leindert, in terms of astronomy topic you and I have somewhat diverged after our Bachelor research project. You have nevertheless remained a constant source of friendship and scientific discourse. Arthur, Bavo, David, David, Kasper, Matthias and Leindert: check out the latest release of 101 productionsTM! And to all of the others at the observatory that I might be forgetting right now: thanks for creating this amazing atmosphere that is both stimulating to work in and relaxing when at the end of the week we all join for the Friday borrel.

Last but not least, there are also some people outside of the astronomy world that I would like to thank. It is quite special to not only live in the same house for nine years, but also to do so with basically the same group of housemates. Kay, Maartje, Marijke, thanks for all the late night conversations, our movie nights, our shared dinners and just all of our adventures in general. Maartje, you and I have lived in the same house now for close to nine years and I have enjoyed every minute of it. Kay, with you around there is never a dull moment. Marijke, thanks for reminding me that there is more than one point of view on life. Als laatste wil ik ook mijn ouders en mijn broer bedanken. Jullie zijn er altijd voor me geweest en hebben me altijd gesteund, zelf wanneer dat lastig was. Dankjulliewel voor alles.