Freezing conditions in warm disks: snowlines and their effect on the chemical structure of planet-forming disks

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Publications

Refereed publications as first author

1. *A major asymmetric ice trap in a planet-forming disk. IV. Nitric oxide gas and a lack of CN tracing sublimating ices and a C/O ratio <1*
Leemker, M., Booth, A. S., van Dishoeck, E. F., van der Marel, N., Tabone, B., Ligterink, N. F. W., Brunken, N. G. C., and Hogerheijde, M. R., 2023, Astronomy & Astrophysics, 673, 7.

2. *Gas temperature structure across transition disk cavities*
Leemker, M., Booth, A. S., van Dishoeck, E. F., Pérez-Sánchez, A. F., Szulágyi, J., Bosman, A. D., Bruderer, S., Facchini, S., Hogerheijde, M. R., Paneque-Carreño, T., and Sturm, J. A., 2022, Astronomy & Astrophysics, 663, 23.

3. *Chemically tracing the water snowline in protoplanetary disks with HCO^+*
Leemker, M., van 't Hoff, M. L. R., Trapman, L., van Gelder, M. L., Hogerheijde, M. R., Ruíz-Rodríguez, D. A., and van Dishoeck, E. F., 2021, Astronomy & Astrophysics, 646, 3.

Submitted publications as first author

1. *Chemistry across dust and gas gaps in protoplanetary disks: modelling the co-spatial molecular rings in the HD 100546 disk*
Leemker, M., Booth, A. S., van Dishoeck, E. F., Wölfer, L., and Dent, B., submitted to Astronomy & Astrophysics.

Refereed publications as co-author

1. *Constraining the gas mass of Herbig disks using CO isotopologues*
Stapper, L. M., Hogerheijde, M. R., van Dishoeck, E. F., Lin, L., Ahmadi, A.,

Booth, A. S., Grant, S. L., Immer, K., **Leemker, M.**, and Pérez-Sánchez, A. F., accepted for publication in Astronomy & Astrophysics.

2. *Tracing snowlines and C/O ratio in a planet-hosting disk. ALMA molecular line observations towards the HD 169142 disk*
Booth, A. S., Law, C. J., Temmink, M., **Leemker, M.**, and Macías, E., 2023, Astronomy & Astrophysics, 678, 146.

3. *Deuterium-enriched water ties planet-forming disks to comets and protostars*
Tobin, J. J., van 't Hoff, M. L. R., **Leemker, M.**, van Dishoeck, E. F., Paneque-Carreño, T., Furuya, K., Harsono, D. Persson, M. V., Cleeves, L. I., Sheehan, P. D., and Cieza, L., 2023, Nature, 615, 7951.

4. *Disentangling the protoplanetary disk gas mass and carbon depletion through combined atomic and molecular tracers*
Sturm, J. A., Booth, A. S., McClure, M. K., **Leemker, M.**, and van Dishoeck, E. F., 2023, Astronomy & Astrophysics, 670, 12.

5. *A chemical map of the outbursting V883 Ori system: vertical and radial structures*
Ruíz-Rodríguez, D. A., Williams, J. P., Kastner, J. H., Cieza, L., **Leemker, M.**, and Principe, D. A., 2022, Monthly Notices of the Royal Astronomical Society, 515, 2.

6. *The young embedded disk L1527 IRS: Constraints on the water snowline and cosmic-ray ionization rate from HCO^+ observations*
van 't Hoff, M. L. R., **Leemker, M.**, Tobin, J. J., Harsono, D., Jørgensen, J. K., and Bergin, E. A., 2022, The Astrophysical Journal, 932, 1.

7. *A major asymmetric ice trap in a planet-forming disk. III. First detection of dimethyl ether*
Brunken, N. G. C., Booth, A. S., **Leemker, M.**, Nazari, P., van der Marel, N., and van Dishoeck, E. F., 2022, Astronomy & Astrophysics, 659, A29.

8. *A major asymmetric ice trap in a planet-forming disk. II. Prominent SO and SO_2 pointing to $C/O < 1$*
Booth, A. S., van der Marel, N., **Leemker, M.**, van Dishoeck, E. F., and Ohashi, S, 2021, Astronomy & Astrophysics, 651, L6.

9. *A major asymmetric ice trap in a planet-forming disk. I. Formaldehyde and methanol*
van der Marel, N., Booth, A. S., **Leemker, M.**, van Dishoeck, E. F., and Ohashi, S., 2021, Astronomy & Astrophysics, 651, L5.

Submitted publications as co-author

1. *An ALMA molecular inventory of warm Herbig Ae disks: I. Molecular rings, asymmetries and complexity in the HD 100546 disk*

Booth, A. S., **Leemker, M.**, van Dishoeck, E. F., Evans, L., Ilee, J. D., Kama, M., Keyte, L., Law, C. J., van der Marel, N., Temmink, M., Nomura, H., Notsu, S, Öberg, K. I., and Walsh., C., submitted to the Astrophysical Journal.

2. *An ALMA molecular inventory of warm Herbig Ae disks: II. Abundant complex organics and volatile sulphur in the IRS 48 disk*
Booth, A. S., Temmink, M., van Dishoeck, E. F., Evans, L., Ilee, J. D., Kama, M., Keyte, L., Law, C. J., **Leemker, M.**, van der Marel, N., Nomura, H., Notsu, S., Öberg, K. I., and Walsh., C., submitted to the Astrophysical Journal.

Curriculum Vitae

On April second 1996, a day with typical Dutch weather semi-cloudy and cold, I was born in Zwijndrecht in the Netherlands. Not too long after that I moved to Ridderkerk to spend half of my weekends with my dad and step-mom, and to The Hague to spend the rest of the time with my mom. During this time I got to enjoy a big city near the sea and a small and quiet town with a house and a garden. I also remember watching TV shows about the universe and science after school when I was not swimming, doing gymnastics, making jigsaw puzzles or postcards. I was always interested in the questions starting with 'why' and 'how' things work.

The choice of my favourite high school was not difficult after I spent hours making jewellery, seeing a shape memory alloy, i.e., a piece of metal that you could bend in a certain shape, but would return to its original form when heated, and other things at the open day of the 'Christelijk College De Populier' in The Hague, right till I had to leave the building because the open day had ended already some time ago. This also, unsurprisingly, turned out to be my favourite course during the first three years. In addition to this science course, I loved all the courses that used numbers in one way or another and were challenging me to think about the problem I was solving, like math, physics, and chemistry but also biology and natural sciences. In addition to my regular high school classes, I took two courses offered by the LAPTop program of Leiden University. In my fifth year I took physics and in my final year I took Astronomy, both of which I enjoyed a lot.

Choosing what I was going to study after graduating from high-school was a challenge. I knew I liked to apply mathematics to solve difficult problems, but many of my study tests just confirmed to me that I chose the right courses in high school and would not narrow down the choice of studies. Then I realised that Leiden offered a double bachelor in Physics and Astronomy, the perfect choice for me as I enjoyed these LAPTop courses as a high-school student. During my second year I got the opportunity to go to La Palma to take my first astronomical observations that got published by another student in 2021. During the second half of my studies I helped bachelor students with their first year course work and I always enjoyed it when their eyes lit up when they grasped a difficult assignment. It was also around this time that one of my hobbies was taken to the next level with the start of an 18000 piece jigsaw puzzle that I would finish a little less than

a decade later.

After my double bachelor, I decided to start with an Astronomy Cosmology master to combine Physics and Astronomy while continuing to help students with their courses. My first research project was fully theoretical with the goal to model tidal truncation of protoplanetary disks in a stellar cluster in the group of Prof. Dr. S. F. Portegies Zwart. One of the courses that I took was 'Star and Planet Formation' by Prof. Dr. E. F. van Dishoeck. I enjoyed this course so much that I decided to switch the specialisation of my masters to a research master so I could do my second research project in her group. This second project was a true joy with Merel van 't Hoff helping me on a daily basis, teaching me about chemistry and radiative transfer, and the regular discussions with Prof. Dr. E. F. van Dishoeck about the progress I had made. While I was doing this project I learned that I wanted to pursue a career in Astronomy and I applied for PhD positions. When I got offered a position in Leiden I accepted it immediately, even before Ewine could inform the rest of the group that she had made me an offer.

During my PhD I got the chance to look both at the hot cavities of transition disks and the somewhat colder region where water sublimates tracing its snowline. In addition, I enjoyed the fun of exploring all possible outcomes of thermo-chemical models to solve the puzzle of why the observations look like they are, why do we see the molecules that we detect? This continued during my work as a teaching assistant for the Astrochemistry, Radiative Transfer, and Observational and Molecular Astronomy courses, and during the co-supervision of two master students, Nashanty Brunken and Dylan Natoewal, with Dr. A. S. Booth. Despite COVID19 cancelling many conferences during my PhD, I still got the opportunity to travel and present my work in London, Leeds, Heidelberg, Ringberg, Garching, Berlin, Kyoto, and Milan. After writing many ALMA proposals I am now awaiting my first A-rated program that will be observed around Christmas, one of the best work-related presents ALMA could have given me. I will continue doing my research with Prof. Dr. Stefano Facchini as a postdoc at the University of Milan.

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During my my eleven years in Leiden, nine of which full-time, I met many great people that showed me the beauty and privilege of doing Astronomy. Your support has helped me to complete this thesis in the form it is now. I would like to thank you all for making Leiden Observatory a nice and warm place.

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It was great to be embedded in a large research group with expertise on many different aspects of the field from young objects to the older ones and from line rich sources to studies of samples of disks. Lucas, it was always great to turn around in the office and chat about the results we found in our research and help each other. I am very happy that we got to share an office and so much more during our PhDs. Lisa, we first met during a DALI workshop that we would repeat many more times. Even though we spend most of our PhDs in different countries it was always great to chat with you over a (virtual) lunch about everything that happend in our lives. Martijn, it was great being your paranymph. Thank you for all your help with removing emitting lines from an observed spectrum of the V883 Ori disk or doing the opposite and help me to squeeze as many as we could into one ALMA proposal. Ardjan, I enjoyed our morning coffee breaks to start up our days. Andrés, the kinks and spirals in your disks always twisted and turned my view of protoplanetary disks. Merel, thank you for always having an answer to my questions. Andrew and Sierk, you learned me a lot about random things like country codes for cell phones. Alex, Arthur, and Daniel, it was great to have you as pre-pandemic office mates. Arthur and Leon, thank you for helping me with all my DALI questions.

Nashanty, it was great to co-supervise you as a master student with Alice and I am very proud that you are now analyzing JWST data as a PhD student in the

group. Sierra, Giulio, Paolo, and Nico, even though most of our meetings were through a big LG-telecon screen, I enjoyed our meetings and chats when we met in person. Tere, I'm impressed with how fast you can speak in Spanish. You were a great roommate for the Berlin conference. Marissa, Milou, and Logan, it was great to work with you during the final year of my PhD. Pooneh, your excitement was always contagious and Yuan it was fun to go to the summer school in Heidelberg together.

Danny and Ioannis, your presence always lit up the conversation. It was great to go for lunch with the group where we also accreted some PhD students of other groups, like Maite, Luna, and Sam. Maite, I would like to thank you for making sure I would stop working at 17:00 sharp on Wednesdays to go for a fun dinner at either of our places. Fedde, thank you for making me go running at least semi-regularly. I would also like to thank all the PhD students of my year, Andrés, Anniek, Dora, Erik, Evgenii, Fedde, Maite, Marta, Morgan, Pooneh, Roland, Shun-Sheng, Yapeng, Zhenlin, and Yu for the games and our trip to the Efteling.

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