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Molecular inheritance from cloud to disk: a story of complex organics and accretion shocks

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Citation

Gelder, M. L. van. (2022, November 24). *Molecular inheritance from cloud to disk: a story of complex organics and accretion shocks*. Retrieved from <https://hdl.handle.net/1887/3487189>

Version: Publisher's Version

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Note: To cite this publication please use the final published version (if applicable).

Publications

1. *N-bearing complex organics toward high-mass protostars. Constant ratios pointing to formation in similar pre-stellar conditions across a large mass range*
Nazari, P., Meijerhof, J. D., **van Gelder, M. L.**, Ahmadi, A., van Dishoeck, E. F., Tabone, B., Langeroodi, D., Ligterink, N. F. W., Jaspers, J., Beltrán, M. T., Fuller, G. A., Sánchez-Monge, Á., Schilke, P., 2022, accepted for publication in *Astronomy & Astrophysics*.
2. *Methanol deuteration in high-mass protostars*
van Gelder, M. L., Jaspers, J., Nazari, P., Ahmadi, A., van Dishoeck, E. F., Beltrán, M. T., Fuller, G. A., Sánchez-Monge, Á., Schilke, P., 2022, accepted for publication in *Astronomy & Astrophysics*, *Chapter 4*.
3. *Importance of source structure on complex organics emission II. Can disks explain lack of methanol emission from some low-mass protostars?*
Nazari, P., Tabone, B., Rosotti, G. P., **van Gelder, M. L.**, Meshaka, R., van Dishoeck, E. F., 2022, *Astronomy & Astrophysics*, 663, A58.
4. *Importance of source structure on complex organics emission. I. Observations of CH₃OH from low-mass to high-mass protostars*
van Gelder, M. L., Nazari, P., Tabone, B., Ahmadi, A., van Dishoeck, E. F., Beltrán, M. T., Fuller, G. A., Sakai, N., Sánchez-Monge, Á., Schilke, P., Yang, Y.-L., Zhang, Y., 2022, *Astronomy & Astrophysics*, 662, A67, *Chapter 3*.
5. *Imaging the water snowline around protostars with water and HCO⁺ isotopologues*
van 't Hoff, M. L. R., Harsono, D., **van Gelder, M. L.**, Hsieh, T.-H., Tobin, J. J., Jensen, S. S., Hirano, N., Jørgensen, J. K., Bergin, E. A., van Dishoeck, E. F., 2022, *The Astrophysical Journal*, 924, 5.
6. *Which molecule traces what: Chemical diagnostics of protostellar sources*
Tychoniec, Ł., van Dishoeck, E. F., van 't Hoff, M. L. R., **van Gelder, M. L.**, Tabone, B., Chen, Y., Harsono, D., Hull, C. L. H., Hogerheijde, M. R., Murillo, N. M., Tobin, J. J., 2021, *Astronomy & Astrophysics*, 655, A65.

7. *Modeling accretion shocks at the disk-envelope interface. Sulfur chemistry*
van Gelder, M. L., Tabone, B., van Dishoeck, E. F., Godard, B., 2021, *Astronomy & Astrophysics*, 653, A159, *Chapter 5*.
8. *Complex organic molecules in low-mass protostars on Solar System scales. II. Nitrogen-bearing species*
Nazari, P., **van Gelder, M. L.**, van Dishoeck, E. F., Tabone, B., van 't Hoff, M. L. R., Ligterink, N. F. W., Beuther, H., Boogert, A. C. A., Caratti o Garatti, A., Klaassen, P. D., Linnartz, H., Taquet, V., Tychoniec, Ł., 2021, *Astronomy & Astrophysics*, 650, A150.
9. *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., van Dishoeck, E. F., 2021, *Astronomy & Astrophysics*, 646, A3.
10. *Complex organic molecules in low-mass protostars on Solar System scales. I. Oxygen-bearing species*
van Gelder, M. L., Tabone, B., Tychoniec, Ł., van Dishoeck, E. F., Beuther, H., Boogert, A. C. A., Caratti o Garatti, A., Klaassen, P. D., Linnartz, H., Müller, H. S. P., Taquet, V., 2020, *Astronomy & Astrophysics*, 639, A87, *Chapter 2*.
11. *VLT/X-shooter spectroscopy of massive young stellar objects in the 30 Doradus region of the Large Magellanic Cloud*
van Gelder, M. L., Kaper, L., Japelj, J., Ramírez-Tannus, M. C., Ellerbroek, L. E., Barbá, R. H., Bestenlehner, J. M., Bik, A., Gräfener, G., de Koter, A., de Mink, S. E., Sabbi, E., Sana, H., Sewilo, M., Vink, J. S., Walborn, N. R., 2020, *Astronomy & Astrophysics*, 636, A54.

Curriculum Vitae

It was in the afternoon of February 8th 1994 that I was born to Erik van Gelder and Ellen Niggebrugge in the “hofstad” of the Netherlands, The Hague. I am the youngest of three children, with my brother Jeroen and sister Pauline both being four years older (yes, they are twins). Already from a very young age, they would be great examples of what to do and also what things one should not do. It was a great pleasure to grow up in the Vogelwijk of The Hague with many green areas to play around as well as the dunes, beach, and sea very close.

With a dad who had studied experimental physics and a mom who had studied chemistry, it was not unexpected that math and physics were very interesting to me already at a very young age. Numbers were just more interesting to work with than, for example, languages. It was thus also no surprise that on my elementary school, the Nutsschool Laan van Poot, I passed the math classes with little effort but that I hated parsing Dutch sentences.

For my high school I chose the Christelijk gymnasium Sorghvliet, a rather small school at about a 15 minute bike ride. Also at high school, my main interest in the natural sciences (physics, chemistry, biology, math) grew. Since physics was the most interesting course and also the one for which I had the highest grades, I decided to start studying Physics and Astronomy at Utrecht University in 2012.

At Utrecht university, however, the first thing I was told was: “if you are here to study astronomy, that’s bad luck because the > 400 year old astronomy department has been removed from the university due to budget cuts”. Most of my bachelor’s studies were therefore focused on many aspects of physics with only two astronomy courses available in Utrecht. Nevertheless, my interest in astronomy resulted in me doing my Bachelor’s research project at SRON (then still in Utrecht) under supervision of dr. Elisa Costantini and dr. Tom Prokopec. The topic was on X-ray absorption spectroscopy of the hot interstellar medium near the Galactic center. It was during this research project that my interest in astronomy manifested itself and I decided to pursue my master in Astronomy and Astrophysics at the Anton Pannekoek Institute of the University of Amsterdam. Of course, first a 4 month backpack trip through Australia was necessary to explore the world.

The journey of my master started in 2016 with many courses covering topics from black holes and general relativity to stellar structure and evolution. However,

it was the star and planet formation course that attracted me most. I was grateful that I could participate in the La Palma observing project, where we were allowed to take our own observations with the Mercator telescope. For my MSc project, I started with a project under the supervision of prof. dr. Lex Kaper on X-shooter observations of massive young stellar objects in the 30 Doradus region of the Large Magellanic Cloud. I graduated cum laude from the University of Amsterdam in the summer of 2018. Both the observational project and the master project convinced me that I really liked working with observational data and that I wanted to keep doing so in the future. Therefore I decided that I was going to apply for PhD positions in astronomy.

I was fortunate enough to receive an offer for a PhD position from prof. dr. Ewine van Dishoeck from Leiden Observatory. The topic of astrochemistry during star and planet formation caught my eye, as well as the fact that I could start working with the newest data from the newest telescope, the James Webb Space Telescope (JWST). Unfortunately, the launch of JWST was delayed by more than three years, but that did not mean that no observational data were available. Plenty of data from the Atacama Millimeter/submillimeter Array were taken to pursue my main research topics: complex organic molecules and accretion shocks in young protostellar systems. Finishing this PhD thesis would not have been possible without my daily supervisor across from me in the office, dr. Benoît Tabone. Throughout the four years of my PhD I presented at various conferences, both in person and online, and learned how to setup and do a research project. Toward the end, also the world of outreach has opened itself up to me, with a talk at Astronomy on Tap and many demonstrations with the beautiful 1:10 scale model of JWST.

The next stop in my career will actually not be far away. I will stay at Leiden Observatory for an additional two years as a postdoctoral researcher. Now, I finally get to work with the newest data from the newest telescope as part of the JOYS, JWST Observations of Young protoStars, team.

Acknowledgements

This PhD thesis would not have been possible without the support and friendship of many people around me. Especially during the years of the pandemic when we were locked up in our houses, all social interactions were a great support.

First of all, I would like to thank you Ewine for giving me the opportunity and the framework to pursue a PhD in (mostly) observational astronomy. Your guidance, knowledge, and support have made it possible to pursue the projects covered during my PhD. I am also grateful that you offered me a postdoc position in Leiden to (finally) work with the JWST data for which I was originally hired as a PhD student. Michiel, you were always very kind to help with various issues that I had, especially related to ALMA data. Last but definitely not least: Benoît, thank you for always answering all my questions in a very clear way. I will really miss our discussions on both science and non-science topics, as well as the occasional French swear words. I am grateful for the PEACHES and ALMAGAL teams that I could use their ALMA data for the various projects of this thesis. Also a great thank you to the Allegro team for helping me with the ALMA datasets presented in this work.

It was a great pleasure to be part of the large astrochemistry research group. Łukasz, thanks for the joint adventure in supervising our first master students and for getting me up to speed in the group. Also thanks for letting me use your apartment as an office in the beginning of pandemic, I hope this evens the times I opened the door for you when you lost the keys. Pooneh, thank you for all the endless discussions on COMs and for always being so happy and energetic. Margot, thanks for always seeing humor in everything and jointly complaining about various aspects of science and life. I have never used DALI, but now know its pros and even more of its cons. Alice, your little dances always cheer me up. You will never have to change arm poses in my pictures. Lisa, you always found time for a talk and discuss the various aspects of life, thank you for helping me with the German trains. Ardjan, your down to earth mentality is very useful for the times when I was stressed. Lucas, you have taken over the L-G meetings in a great manner. Logan, next time you can smuggle your own beer mug past an angry German airport security lady. Arthur and Alex, the corridors on the fifth floor are so quiet without your laughter. Merel, you were a great office mate, thank you for answering all my basic questions. Nadia, Daniel, our discussions as embedded

task force will not be forgotten. Sierk, thank you for showing me how to run the L-G meeting. Leon, keep making the nice cocktails. Giovanni, I always liked our talks about both science and life. Sierra, Giulio, Teresa, Andrés, you were great hosts during our recent group retreat in Garching, it's always nice to see you in 3D again. To 'my' master students Yuan, Micha, Jeroen, Jurrian, Gabriëlla, and Nelleke, it was an honor to supervise you during your master projects. Yuan, I am proud that you joined our group again as a PhD student. Jerry, although we do not have a 'private' office anymore, I will still find time to talk. Milou, Marissa, Logan, thank you for releasing me from my private office with Jerry. Thank you also to everyone that helped with the demo's with our big JWST model.

The fortunate part of our group was to also share the floor with the lab. Jeroen, you were always easy to find, thank you all the rather interesting conversations during borrels. Pranjal, our borrel talks were always of significant quality. Marina, your beers always taste amazing. Katie, your logo for JOYS is beautiful. Will, you are a great guru for ice observations. Dana, Gleb, Ko-Ju, Michal, Julia, many thanks for the many discussions on COMs.

Ofcourse, also the interaction with various other people at the observatory have made the PhD life much more pleasant. Anna, Mantas, it was a great honor to serve the great Big Dipper together. Fraser, thank you enjoyable discussions and for cleaning up after borrel. Marta, although I agree the Dutch weather is not great, it can be sunny occasionally. Anniek, great to see a fellow UvA student coming to Leiden. Kirsty, thanks for the many weird conversations. Hidido, you were always very happy and Frisian. Also to the many other people at the Observatory, Andrés, Andrew, Aida, Bas, Danny, Dario, Dilovan, Folkert, Frits, Gabriëlla, Josh, Lýdia, Martijn, Matthieu, Nicco, Roland, and many people I am very likely forgetting, thank you for the coffee breaks, borrels, and everything else.

Also outside of the observatory, I was fortunately surrounded by many friends. Jeroen, great that you have arranged it with the PhD, thanks for keeping me caffeinated with our many 'plonko' breaks. Jesse, I promise I will be online more often, thanks for the many adventures over the past decade. Marijn, we'll visit you more often in Deventer. Mirjam, Wouter, Anne-Bibi, Baptiste, Rianne, Justin, I loved our regular online pub quizzes during the pandemic as well as the new year's parties. Ariane, Chris, David, Hessel, Jan, Jay, Jasper, Joost, Sjoerd, thank you for the many enjoyable moments during our studies in Utrecht, and also afterwards. Frank, I can never eat broccoli, corn, leek, radish, and tomato again without thinking back at our Europe interrail trip. Wieger, Floris, Koen, Max, I will never forget our many adventures in The Hague.

Tenslotte, pap, mam, Jeroen, Pauline, Eric, dank jullie wel voor de onvoorwaardelijke support gedurende mijn hele leven. Ik zal Nederland goed bewaken gedurende jullie avonturen in het buitenland. Isaac, voor als je over enkele jaren hebt leren lezen: je bent een geweldig leuke toevoeging aan de familie. Trudy, Hans, Ivar, Arvid, Diana, BA, ik voel me altijd direct thuis bij jullie in 's Gravenzande. Birgit, ik kan je niet genoeg bedanken voor alle support en liefde die je me geeft. Zonder jou was dit allemaal niet mogelijk geweest.