Ice and gas in protostellar clouds and planet-forming disks: a combined laboratory and observational study

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Publications

Refereed publications

1. *Quantification of O_2 formation during UV photolysis of water ice - H_2O and H_2O:CO_2 ices*
   Bulak, M., Paardekooper, D.M., Fedoseev, G., Chuang, K.-J., **Terwisscha van Scheltinga, J.**, Eistrup, C., and Linnartz, H. 2021, accepted for publication in Astronomy & Astrophysics.

2. *Infrared spectra of complex organic molecules in astronomically relevant ice matrices. III. Methyl formate and its tentative solid-state detection*
   Terwisscha van Scheltinga, J., Marcandalli, G., McClure, M.K., Hogerheijde, M.R., Linnartz, H. 2021, Astronomy & Astrophysics, 651, A95.

3. *An inherited complex organic molecule reservoir in a warm planet-hosting disk*
   Booth, A.S., Walsh, C., **Terwisscha van Scheltinga, J.**, van Dishoeck, E.F., Ilee, J.D., Hogerheijde, M.R., Kama, M., Nomura, H. 2021, Nature Astronomy, 5. 684-690.

4. *The TW Hya Rosetta Stone Project. IV. A hydrocarbon-rich disk atmosphere*
   Cleeves, L.I., Loomis, R.A., Teague, R., Bergin, E.A., Wilner, D.J., Bergner, J.B., Blake, G.A., Calahan, J.K., Cazzoletti, P., van Dishoeck, E.F., Guzmán, V.V., Hogerheijde, M.R., Huang, J., Kama, M., Öberg, K.I., Qi, C., **Terwisscha van Scheltinga, J.**, Walsh, C. 2021, The Astrophysical Journal, 911, 29.

5. *The TW Hya Rosetta Stone Project. III. Resolving the gaseous thermal profile of the disk*
   Calahan, J.K., Bergin, E.A., Zhang, K., Teague, R., Cleeves, L.I., Bergner, J.B., Blake, G.A., Cazzoletti, P., Guzmán, V.V., Hogerheijde, M.R., Huang, J., Kama, M., Loomis R.A., Öberg, K.I., Qi, C., van Dishoeck, E.F., **Terwisscha van Scheltinga, J.**, Walsh, C., Wilner D.J. 2021, The Astrophysical Journal, 908, 8.

6. *The TW Hya Rosetta Stone Project. II. Spatially resolved emission of formaldehyde hints at low-temperature gas-phase formation*
   Terwisscha van Scheltinga, J., Hogerheijde, M.R., Cleeves, L.I., Loomis, R.A., Walsh, C., Öberg, K.I., Bergin, E.A., Bergner, J.B., Blake, G.A., Calahan, J.K., Cazzoletti, P., van Dishoeck, E.F., Guzmán, V.V., Huang, J., Kama, M., Qi, C., Teague, R., Wilner, D.J. 2021, The Astrophysical Journal, 906, 111.

7. *The TW Hya Rosetta Stone Project. I. Radial and vertical distributions of DCN and DCO^+*
Öberg, K.I., Cleeves, L.I., Bergner, J.B., Cavanaro, J., Teague, R., Huang, J., Loomis, R.A., Bergin, E.A., Blake, G.A., Calahan, J.K., Cazzoletti, P., Guzmán, V.V., Hogerheijde, M.R., Kama, M., **Terwisscha van Scheltinga, J.**, Qi, C., van Dishoeck, E.F., Walsh, C., Wilner, D.J. 2021, The Astronomical Journal, 161, 38.

8. *Infrared spectra of complex organic molecules in astronomically relevant ice mixtures. II. Acetone*
Rachid, M.G., **Terwisscha van Scheltinga, J.**, Koletzki, D., Linnartz, H. 2020, Astronomy & Astrophysics, 639, A4.

9. *Effect of molecular structure on the infrared signatures of astronomically relevant PAHs*
Bouwman, J., Castellanos, P., Bulak, M., **Terwisscha van Scheltinga, J.**, Cami, J., Linnartz, H., Tielens, A.G.G.M. 2019, Astronomy & Astrophysics, 621, A80.

10. *The formation of peptide-like molecules on interstellar dust grains*
Ligterink, N.F.W., **Terwisscha van Scheltinga, J.**, Taquet, V., Jørgensen, J.K., Cazaux, S., van Dishoeck, E.F., Linnartz, H. 2018, Monthly Notices of the Royal Astronomical Society, 480, 3.

11. *Methanol ice co-desorption as a mechanism to explain cold methanol in the gas-phase*
Ligterink, N.F.W., Walsh, C., Bhuin, R.G., Vissapragada, S., **Terwisscha van Scheltinga, J.**, Linnartz, H. 2018, Astronomy & Astrophysics, 612, A88.

12. *Infrared spectra of complex organic molecules in astronomically relevant ice matrices. I. Acetaldehyde, ethanol, and dimethyl ether*
Terwisscha van Scheltinga, J., Ligterink, N.F.W., Boogert, A.C.A., van Dishoeck, E.F., Linnartz, H., 2018, Astronomy & Astrophysics, 611, A35.

Submitted publications

1. *Formation of CO_2 through consumption of gas-phase CO on vacuum-UV irradiated water ice*
Terwisscha van Scheltinga, J., Ligterink, N.F.W., Bosman, A.D., Hogerheijde, M.R., Linnartz, H. Submitted to Astronomy & Astrophysics.

2. *Ice Age: Chemo-dynamical modeling of Cha-MMS1 to predict new solid-phase species for detection with JWST*
Jin, M., Lam K.H., McClure, M.K., **Terwisscha van Scheltinga, J**, Li, Z.-Y., Boogert, A.C.A., Herbst, E., Davis, S.W., Garrod, R.T. Submitted to The Astrophysical Journal.

Curriculum Vitae

My first independent breath of air was on Wednesday the 26$^{\text{th}}$ of December 1990. When growing up, my father made and repaired as much as possible by himself. It is thus no surprise that I as kid always wanted to take things apart and see how they worked. This was a great clue that I should become a scientist, but my ambitions as a kid were different, I wanted to build houses.

During my time at high school there was not much that grabbed my attention and I decided that academia was not for me, oh the irony. One thing that I did enjoy during that time was working on my moped. Taking it apart, repairing it, and making it go faster. Sorry mom, it went a lot faster than I said. This interest in mechanics and electronics lead to me enrolling at the "Vak Technische Opleidings Centrum *Fokker*". Here I was trained in the craft of maintaining, troubleshooting, and repairing avionic aircraft systems. As a follow-up of this training I joined the Royal Netherlands Air Force, but that part of my career was rather short as I quickly realized it was not for me. At that time I was 21 and the commercial aviation industry was in a depression, which meant no one was hiring and left me with the question what do I do now?

Having become slightly more mature since high school and having regained some of my curiosity about wanting to know how stuff works, I decided to continue studying. After a chat with the study advisor of Applied Physics, Nico van der Houwen at the Haagse Hogeschool, I was convinced that I wanted to be an engineer. I finished the first year cum laude, but was caught off guard when I got offered a job at a company at which I initially applied. I decided to take the job at AAR Aircraft Component Services. Here I learned to work with electronics at the component level and repair automatic pilot, navigation, and communication systems. However, after a year it no longer satisfied my curiosity and I went back to Applied Physics at the Haagse Hogeschool.

For my internship I got the opportunity to work at ESA-ESTEC with Olivier Witasse and Fabrice Cipriani. This was for me the first exposure to an academic environment and I truly enjoyed it. I worked on a Direct Simulation Monte Carlo model in which the effects of Mars and Solar wind on the regolith of Phobos were simulated. This project left me wanting more and in my final year of Applied Physics I asked my graduation project coordinator, Arjan Lock, if he knew a place where I could dip my toes in the academic world. He got me in touch with Prof. Harold Linnartz of the then Sackler Laboratory of Astrophysics at Leiden University. Impressed with all the scientific equipment and the big questions at play there was no doubt for me, this was the place for me. I wrote my thesis on the characterization of vibrational spectra of ethanol in pure form and astronomically relevant ice matrices. After this, I joined the group as a research assistant to expand my work and prepare it for a scientific publication. I contemplated getting a masters degree in astronomy, but decided that

student life was no longer for me and it was time for me to look for a full-time job. This decision did not align with the plan Harold had for me. I remember vividly sitting in his office when I got the question, would you like to start a PhD with me and Michiel Hogerheijde? How could I say no to a once in a life-time opportunity? Arranging the paper work for this unusual situation was going to take some time, and I decided to travel through Southeast Asia in the mean time. On the 7^{th} of June 2017 the plane I was in landed in Hanoi Vietnam and unsuspectingly I turned off airplane mode. Filled with joy, and a bit of disbelief, I read that within a month I would be a scientist who would work on improving the general knowledge about molecules during star and planet formation.

In the four years of my PhD, I worked on the experimental devices CryoPAD2 and HV setup, both cryogenic setups that exploit Fourier transform infrared spectroscopy. Additionally, the CryoPAD2 setup has a quadrupole mass spectrometer and microwave-discharge hydrogen-flow lamp. This allows for investigation of photoprocesses in analogue interstellar ices. Part of my PhD consisted of working with data from the Atacama Large Millimeter/submillimeter Array. This data was part of a large collaboration, the "TW Hya Rosetta Stone" project. As part of this project, I visited the University of Virginia and the National Radio Astronomy Observatory in Charlottesville Virginia. The experimental and observational research in this thesis has been presented during conferences and visits in The Netherlands, The United Kingdom, Italy, and the United States of America. During my time in the Laboratory for Astrophysics I have supervised three students (Giulia Marcandalli, Daniel Koletzki, and Stefan van der Giessen) and was mentor to two PhD students (Marina G. Rachid and Tara Bründl). Additionally, I was the teaching assistant for the master colloquia in which I supervised MSc students in presenting their work. After the defense of my thesis, I will continue as a VICO fellow at the University of Virginia in Charlottesville.

Acknowledgements

Although I am the author of this book, non of it would have been written without the trust and support of many people along the way. It is easy to forget how much small things matter. Asking someone to join for a coffee or lunch, listening to their struggles, racing a piece of furniture around the top floor of a building, or just a simple smile. For everyone who did that for me, thank you.

I feel very fortunate to have received the opportunity to pursue a PhD. I am especially grateful to Harold Linnartz and Michiel Hogerheijde who believed that I could succeed without the standard prerequisites. You stuck your necks out for me and this has swayed my life into a direction I could never have imagined. Thank you for all the supervision and patience, and Michiel, I promise that one day I will write the conclusion at the beginning of the paragraph.

Another person who played a fundamental role in my PhD is Niels Ligterink. He supervised me as a BSc student, but was also a great PhD mentor who taught me the ropes of astrochemistry and CryoPAD2. Even after you left to Bern, you were always available for scientific sparring and helping me wrap my head around the mind-boggling struggles that come with a PhD. For the majority of my PhD I have been roomies with Michał Bulak. It was great to have someone to share laboratory struggles with, but also boerenkool with way too much mustard or a good party. Thank you for all the fun and your patience, zapiekanka. Alex, Arthur, Leon, and Merel, you have supported me tremendously. No question was too silly, and (remarkably) no borrel conversation was too weird for you.

No (laboratory) PhD student survives without technical support. I would like to thank David, Eric, Erik, Huib, and Leonardo for all their IT support over the years. However, there is one person from IT who I would like the give a special thanks, Aart Vos. Besides the countless times he helped me or ordered parts for me, he also taught me a great deal in "practical" skills, for example, moving a 5 meter long wooden crate through two university buildings and up five floors. It was not easy, but we managed. A je to! How many golfers does it take to change a light bulb? FORE! If you want more jokes like this, Aart is a great supplier. Martijn Witlox, where would I have been without your mechanical support. Always ready to fix the mess we create in the lab or thinking of ways in which we can improve our science. You are truly a master of scientific machining. Peter van Veldhuizen and Raymond Koehler, thank you for all the electronic support, and trusting me with your precious equipment so that I could figure it out by myself.

Through the years I have worked with many people in the Laboratory for Astrophysics at Leiden Observatory. Andreas, Carlos, Daniel P., Danna, Old Gregg, Gleb, Gwen, Helgi, Jerry, Jiao, Jordy, Julia, Kirstin, Ko-Ju, Marina, Michał, Morgan, Nicolas, Niels, Pablo, Pranjal, Radha, Sanjana, Sergio, Tara, Thanja, Vincent, Will,

Xavier, and Yu thank you for all the enlightening conversation, the games of dominoes, and drinks.

Besides working in the laboratory, I have also worked with ALMA in the group of Michiel. Eva, Leon, Mason, and Vachail (Nico), thank you for all the support and making a lab rat feel welcome in the world of ALMA. I would also like to thank Ewine van Dishoeck who welcomed me in her group meetings and retreats. I have learned a tremendous amount about star and planet formation through those interactions. Alex, Alice, Alvaro, Andres, Anna M., Ardjan, Arthur, Benoit, Christian, Daniel H., Giovanni, Leon, Lisa, Lucas, Łukasz, Margot, Martijn, Melissa, Merel, Nadia, Paolo, Pooneh, Sierk, and Teresa thank you for always being patience and explaining the trivial and nontrivial gaps in my knowledge. I have also had the pleasure to be part of the ALMA collaboration "TW Hya Rosetta Stone" project. This project was lead by Ilse Cleeves and I am very grateful I was able to join. The data reduction was far from standard, but with the help of the ARC node Allegro and Ryan Loomis a beautiful data set was created. The entire team has made my first adventure with ALMA a great success and they have taught me a lot. It gave me the nudge to aspire an academic career, and I could not have been happier when Ilse told my I could join her group as a VICO fellow to work with her. See you soon!

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