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The astrochemical factory: A solid base for interstellar reactions

Ligterink, N.F.W.

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Publications

Published papers

- *Protostellar and cometary detections of organohalogenes*
Fayolle, E.C.; Öberg, Karin I.; Jørgensen, J.K.; Altwegg, K.; Calcutt, H.; Müller, H.S.P.; Rubin, M.; van der Wiel, M.H.D.; Bjerkeli, P.; Bourke, T.L.; Coutens, A.; van Dishoeck, E.F.; Drozdovskaya, M.N.; Garrod, R.T.; **Ligterink, N.F.W.**; Persson, M.V.; Wampfler, S.F.; Rosina Team
- *The ALMA-PILS survey: detection of CH₃NCO towards the low-mass protostar IRAS 16293–2422 and laboratory constraints on its formation*
Ligterink, N.F.W.; Coutens, A.; Kofman, V.; Müller, H.S.P.; Garrod, R.T.; Calcutt, H.; Wampfler, S.F.; Jørgensen, J.K.; Linnartz, H.; van Dishoeck, E.F.; 2017, Monthly Notices of the Royal Astronomical Society, Volume 469, Issue 2
- *The (w)hole survey: An unbiased sample study of transition disk candidates based on Spitzer catalogs*
van der Marel, N.; Verhaar, B. W.; van Terwisga, S.; Mern, B.; Herczeg, G.; **Ligterink, N. F. W.**; van Dishoeck, E. F.; 2016, Astronomy & Astrophysics, Volume 592
- *The ALMA-PILS survey: First detections of deuterated formamide and deuterated isocyanic acid in the interstellar medium*
Coutens, A.; Jørgensen, J. K.; van der Wiel, M. H. D.; Müller, H. S. P.; Lykke, J. M.; Bjerkeli, P.; Bourke, T. L.; Calcutt, H.; Drozdovskaya, M. N.; Favre, C.; Fayolle, E. C.; Garrod, R. T.; Jacobsen, S. K.; **Ligterink, N. F. W.**; Öberg, K. I.; Persson, M. V.; van Dishoeck, E. F.; Wampfler, S. F.; 2016, Astronomy & Astrophysics, Volume 590
- *UV Photodesorption of Methanol in Pure and CO-rich Ices: Desorption Rates of the Intact Molecule and of the Photofragments*
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- *Controlling the emission profile of an H₂ discharge lamp to simulate interstellar radiation fields*
Ligterink, N. F. W.; Paardekooper, D. M.; Chuang, K.-J.; Both, M. L.; Cruz-Diaz, G. A.; van Helden, J. H.; Linnartz, H.; 2015, Astronomy & Astrophysics, Volume 584
- *Laboratory Photo-chemistry of PAHs: Ionization versus Fragmentation*
Zhen, J.; Castellanos, P.; Paardekooper, D.M.; **Ligterink, N.F.W.**; Linnartz, H.; Nahon, L.; Joblin, C.; Tielens, A.G.G.M.; 2015, The Astrophysical Journal Letters, Volume 804, Issue 1

- *Search for methylamine in high mass hot cores*
Ligterink, N. F. W.; Tenenbaum, E. D.; van Dishoeck, E. F.; 2015, *Astronomy & Astrophysics*, Volume 576

Submitted papers

- *Interstellar bromine depletion matches cometary ices from Rosetta*
Ligterink, N.F.W. & Kama, M.; 2017, submitted for publication in *Astronomy & Astrophysics*
- *The ALMA-PILS survey: Stringent limits on small amines and nitrogen-oxides towards IRAS 16293–2422B*
Ligterink, N.F.W.; Calcutt, H.; Coutens, A.; Bourke, T.L.; Drozdovskaya, M.N.; Kristensen, L.E.; Müller, H.S.P.; Wampfler, S.F.; van der Wiel, M.H.D.; van Dishoeck, E.F.; Jørgensen, J.K.; 2017, submitted for publication in *Astronomy & Astrophysics*
- *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.; 2017, submitted for publication in *Astronomy & Astrophysics*
- *Methanol ice co-desorption as a mechanism to explain cold methanol in the gas-phase*
Ligterink, N. F. W.; Walsh, C.; Bhui, R.G.; Vissapragada, S.; Terwisscha van Scheltinga, J.; Linnartz, H.; 2017, submitted for publication in *Astronomy & Astrophysics*

Curriculum Vitae

Most of my early life I spent in and around Vinkeveen, a small village just south of Amsterdam. From 2001 to 2007 I attended secondary school at the Alkwin Kollege in Uithoorn. Here I followed the exact sciences track “Natuur & Techniek” at Gymnasium level. I was mostly interested in chemistry and after graduating decided to study chemistry at the Vrije Universiteit Amsterdam. During my bachelor I got more interested in the fundamental molecular interactions and in the field of physics and in the final year I did a research project in the physical chemistry group of Prof. Maurice Janssen. This led me to continue with the master specialization Physical Chemistry and do a master research project in femtosecond (10^{-15} seconds) chemistry under supervision of Dr. Stefan Lehmann, again in the group of Prof. Maurice Janssen. Near the end of my time as a master student I did a second research project in attosecond (10^{-18} seconds) physics at the Max Born Institute in Berlin. This work was supervised by Dr. Jesse Klei and Dr. Christian Neidel in the group of Prof. Marc Vrakking. During my times as a bachelor and master student I did not take courses in astronomy and it was thus by chance that I got into contact with Harold Linnartz at the Leiden Observatory and was introduced to the world of astronomy. After working for a few months in the Sackler Laboratory for Astrophysics as a technician, I was offered, and accepted, a PhD position under supervision of Ewine van Dishoeck and Harold Linnartz on the laboratory and observational investigation of nitrogen-bearing complex organic molecules as formed in the inter- and circumstellar medium.

My project started with the construction of an upgraded version of the CryoPAD set-up (creatively named CryoPAD2), an ultra high vacuum experiment in which photochemistry and physics of thin ice layers are studied. Also, I was given the chance to participate in an observational project and go on an observing run at the William Herschel Telescope at the island of La Palma. These last two experiences were a real eye opener and greatly raised my interest in observational astrochemistry and astronomy as a whole. Afterwards, laboratory work and observational analysis occurred mostly simultaneously, often complementary to each other, and resulted in the varied thesis that you are reading now.

The work in this thesis has been presented at various conferences in The Netherlands, United States, Spain, Switzerland, France, Denmark and Chile, awarded highlighted publication of year 2015 in Astronomy & Astrophysics (Chapter 3) and been the subject of an ESO press release (Chapter 6). Next to my research, I supervised two bachelor and a master student in laboratory projects, performed teaching duties for the course “Inleiding astrofysica” and organised the Astrochem Seminar.

Afterword

My experience as a PhD student can largely be characterized by the words “new” and “diverse”. I came from the field of chemistry and had to adapt to this new world of astronomy, of which in the beginning I only understood the laboratory techniques. A steep learning curve followed in which basic astronomy, star formation theory and telescope techniques were covered. My affection for astronomy grew and eventually resulted in a number of observational chapters in this thesis. This transformation from chemist to astronomer did teach me that there are almost no limits to what you can do as long as you keep listening, reading and learning.

When it comes to learning, astronomy is a fantastic environment. It is a diverse field which also touches upon chemistry, physics, biology and mathematics as well as many technical aspects. There is always a challenge to be found and something new to do and learn. This shows in this thesis which covers a wide variety of subjects ranging from solid-state physics and chemistry to interferometric observations of interstellar gas-phase molecules. I have also been fortunate enough to work at and see some very different scientific facilities, such as the William Herschel Telescope at La Palma, the SOLEIL synchrotron in Paris and the Very Large Telescope in the Atacama desert in Chile. I can not imagine many other fields of study where one gets to go to such a variety of high-end instruments.

The PhD experience has been a great enrichment of my life and it goes without saying that many people have contributed to this. The first two of those people are Ewine and Harold, who not just hired me, but more importantly gave me the freedom to explore the astrochemical possibilities in the laboratory and observations in my own way. In some cases this is the long way around to get scientific results, but for me an experience that helped me to better understand the many aspects of astrochemistry and science.

A large group of colleagues, collaborators and friends helped me with various projects. At the start of my PhD Edith showed me the ropes of laboratory astrochemistry on the original CryoPAD set-up (and, yes, gave me the nickname snowflake). Subsequently, Martijn has been essential in the construction of the upgraded CryoPAD2 set-up, but also in adventures in- and outside the lab (like on French highways). Aart has always been keeping a watchful eye on the organisation of the lab and if enough jokes are being told. Also, of course, the fine mechanical and electronics departments, glass workshop and computer group as well as administrative support, because without them my work and (laboratory) astrochemistry would be a lot more difficult.

Throughout the years I have worked together with many great, fun and knowledgeable collaborators. Especially Daniel P., Mihkel, Audrey, Catherine and Hannah contributed to a significant portion of the scientific work that you see in this thesis.

The input of group members have been just as important in establishing this thesis. There were many discussions on the ins and outs of laboratory experiments with Junfeng, Thanja, Gleb, Dongfeng and Jordy, introductions and

advanced courses in observational astronomy by Daniel H., Vianny, Nienke and Magnus, post-doc guidance by Gustavo and Radha, office buddy support from Kirsten, Vincent and Ko-Ju (best of luck to these three in finishing their own theses!) and a variety of discussions and fun times with Anton, J.B., Xavier, Pablo, Danna, Michal, Gwen, Andreas, Steven, Arthur, Maria, Irene, Joe, Lukasz, Merel, Paolo, Stefano, Sierk, Christian, Anna, Alvaro and Nadia.

The Protostellar Interferometric Line Survey (PILS) team has played a major part in transforming me into an observational astronomer. Jes, Matthijs, Holger, Susanne, Lars, Steffen and the rest of the team have been of great help and I very much enjoyed the team meetings we have had.

As a "teacher" I have guided Miriam, Marin and Jeroen TvS. (also my successor on CryoPAD2, best of luck in your future endeavours!) in their internships. Student supervision was often just as much a learning experience for me, but I am very happy with the successes and results of 'my' students.

The past few years would have been quite different without the observatory members who make for such a good atmosphere and in this way contributed to this thesis. With Eva, Heather, Jeroen F., Nico, Ricardo, Henriette, Ann-Sofie, Emanuelle, Mher and many, many others there never had to be a dull moment inside, but also outside, the workplace.

Last but not least are all the people that are not in astronomy or science, but made for the every now and then much needed distraction of science. Martial arts are a big part of my life and training and competing with the kickboxers of Team Atlas, the fighters of Gym Hoofddorp (where I received my blue belt in Brazilian jiu-jitsu) and the many martial artists and trainers of other gyms, has been a welcome pastime. Family and friends from Vinkeveen, Leiden and throughout The Netherlands have always been a welcome sight and were the greatest support throughout these years.

I thank you all for helping me in completing this thesis.