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The hunt for frozen organic molecules in space: a laboratory approach

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Publications

Refereed publications

1. *An Ice Age JWST inventory of dense molecular cloud ices. Nature Astronomy*
McClure, M., Rocha, W.R.M., Pontoppidan, K., Crouzet, N., Chu, L., Dartois, E., Lamberts, T., Noble, J., Pendleton, Y., Perotti, G., Qasim, D., **Rachid, M. G.**, Smith, Z. L., Sun, F., Beck, T.L., Boogert, A.C.A., Brown, W.A., Caselli, P., Charnley, S.B., Cuppen, H.M., Dickinson, H., Drozdovskaya, M. N., Egami, E., Erkal, J., Fraser, H., Garrod, R.T., Harsono, D., Ioppolo, S., Jiménez-Serra, I., Jin, M., Jørgensen, J. K., Kristensen, L.E., Lis, D. C., McCoustra, M. R. S., McGuire, B. A., Melnick, G. J., Öberg, K. I., Palumbo, M. E., Shimonishi, T., Sturm, J. A., van Dishoeck, E. F. & Linnartz, H., 2023, *Nature Astronomy*, <https://doi.org/10.1038/s41550-022-01875-w>
2. *LIDA - The Leiden Ice Database for Astrochemistry*
Rocha, W., **Rachid, M. G.**, B. Olsthoorn, E. F. van Dishoeck, M. K. McClure, H. Linnartz, 2022, *Astronomy & Astrophysics*, 668, A63.
3. *Infrared spectra of complex organic molecules in astronomically relevant ice mixtures - V. Methyl cyanide (acetonitrile)*
Rachid, M. G., Rocha W., Linnartz, H., 2022, *Astronomy & Astrophysics*, 665, A89.
4. *Refractive index and extinction coefficient of vapor-deposited water ice in the UV-vis range*
He, J., Diamant, S. J., Wang, S., Yu, H., Rocha, W. R., **Rachid, M. G.**, & Linnartz, H., 2022, *The Astrophysical Journal*, 925(2), 179.
5. *Infrared spectra of complex organic molecules in astronomically relevant ice mixtures - IV. Methylamine*
Rachid, M. G., Brunken, N., De Boe, D., Fedoseev, G., Boogert, A. C. A., Linnartz, H., 2021, *Astronomy & Astrophysics*, 653, A116.

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6. *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.
7. *Processing of 72-K water-rich ices by keV and MeV oxygen ions: implications for the Saturnian moon Enceladus*
Rachid, M. G., Pilling, S., Rocha, W. R. M., Agnihotri, A., Rothard, H., & Boduch, P., 2020, *Monthly Notices of the Royal Astronomical Society*, 494(2), 2396-2409.
8. *Searching for stable fullerenes in space with computational chemistry*
Candian, A., **Gomes Rachid, M.**, MacIsaac, H., Staroverov, V. N., Peeters, E., & Cami, J., 2019, *Monthly Notices of the Royal Astronomical Society*, 485(1), 1137-1146.
9. *Destruction of C₂H₄O₂ isomers in ice-phase by X-rays: Implication on the abundance of acetic acid and methyl formate in the interstellar medium.*
Rachid, M. G., Faquine, K., & Pilling, S., 2017, *Planetary and Space Science*, 149, 83-93.
10. *Systematic theoretical study of non-nuclear electron density maxima in some diatomic molecules*
Terrabuio, L. A., Teodoro, T. Q., **Rachid, M. G.** & Haiduke, R. L., 2013, *The Journal of Physical Chemistry A*, 117(40), 10489-10496.

Submitted/About to be submitted

1. *Morphological changes in CO ices probed by interference measurements*
Rachid, M. G., He, J., Cenic, R., Rocha, W., Slavicinska, K., Henning, T. & Linnartz, H., A&A.
2. *The hunt for formamide in interstellar ices - Laboratory infrared spectra in astronomically relevant ice mixtures and comparisons to ISO, Spitzer, and JWST observations*
Slavicinska, K., **Rachid, M. G.**, Rocha, W., Chuang, K.-J., van Dishoeck, E.F. & Linnartz, H., A&A

About the author

I was born in Rio Claro, in the countryside of São Paulo state, in Brazil, on August 16th, 1989. My full education has taken place in public schools, and while I have to thank some passionate teachers that helped develop my interest in science, it was my father who truly nurtured my passion for learning. Through our weekly visits to the city library, he sparked in me a deep passion for reading and learning. In an interesting way, my fascination with chemistry and physics was revealed at the age of 11, when I received disciplinary action for running in the school corridors. As part of my "punishment", I was assigned to create a comprehensive homework on the topic of "the atom."



It was during this task that I was introduced to the fascinating domain of atoms, orbitals, and molecules. It was like a whole new world had opened up to me! Ever since that moment, I knew that I wanted to know more about those tiny particles and become a scientist when I grew up.

In 2005, I passed an exam to enroll in the highly-regarded school "ETEC Prof. Armando Bayeux da Silva" for my high school studies. Upon completing high school in 2008, I was accepted into the chemistry bachelor's program at the University of São Paulo (USP), in São Carlos. It was during this time that I became captivated by astronomy and was fortunate to have the guidance of Prof. Luiz Vitor de Souza Filho, who graciously accepted me as a guest student in his group. During the final year of my bachelor's program, I conducted a research project on theoretical chemistry, studying the electronic structure of various diatomic molecules under the supervision of Prof. Roberto Luiz Andrade Haiduke. After completing my chemistry degree, in 2012, I opted not to pursue a master's degree immediately. Instead, I decided to broaden my academic horizons by studying physics and astronomy to explore various career paths. To this end, I relocated to São Paulo and enrolled in a physics program, also at the USP. During my time there, I engaged in several research projects until I discover a fascination for astrochemistry. At that time, I had been awarded a prestigious undergraduate scholarship from FAPESP, the research agency of São Paulo

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state, to work with Prof. Eduardo Janot Pacheco on a project related to the infrared absorption spectra of nucleobases. During this period, I faced health challenges that resulted in extended hospitalizations, delaying the completion of my studies. With the encouragement and support of those around me and my professors, I concluded my physics degree, and in 2016, after a break to work as a teacher, baker, and traveling in South America, I enrolled in a master's program at the Universidade do Vale do Paraiba, in São Jose dos Campos.

I obtained my master's degree with the support of a FAPESP scholarship and guidance from Prof. Sergio Pilling. My master's research focused on the impact of energetic ions on interstellar ice analogs and their implications for Solar System chemistry. During my scholarship, I had the opportunity to conduct experimental work on ion irradiation at GANIL in Caen-France, working with Prof. Philippe Boduch and Prof. Herman Rothard. Also during my master, I was selected to participate in a LEAPS project in Leiden. Under the supervision of Dr. Alessandra Candian, I conducted a computational study to analyze the IR spectra and stability of fullerenes.

I was admitted to a Ph.D. program at the Laboratory for Astrophysics in the Leiden Observatory in 2018, where I worked under the guidance of Prof. Harold Linnartz and Prof. Ewine van Dishoeck in the field of experimental and observational astrochemistry. My primary responsibility during my Ph.D. was to develop IRASIS (InfraRed Absorption Setup for Ice Spectroscopy), an upgrade to an existing laboratory setup designed for studying the infrared spectra and characteristics of interstellar ice analogs. Alongside Dr. Jiao He, I also worked on the characterization of visible-ultraviolet properties of ice using the OASIS (Optical Absorption Setup for Ice Spectroscopy) setup. In addition to the laboratory work, I have been involved in the upgrade of the Leiden Ice Database for Astrochemistry, a project led by Dr. Will Rocha, and in the analysis of the first interstellar ice observations from the JWST ERS program Ice Age, led by Dr. Melissa McClure. I am presently involved in the observation of COMs in star-forming regions using ALMA observations with Prof. Ewine van Dishoeck. This thesis is the outcome of my laboratory and computational work and has been presented at conferences and symposiums in the Netherlands and abroad. Also during my Ph.D., I was the daily supervisor of many bachelor students working on experimental projects and the teaching assistant of experimental physics.

In April 2023, I joined the research team of Prof. Sander Woutersen at the Van 't Hoff Institute for Molecular Sciences at the University of Amsterdam as a postdoctoral researcher.

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I feel lucky to have been surrounded by many supportive and inspiring people on my journey. While the list of those who have played a significant role in my life is lengthy, I would like to thank here those who have been particularly present over the last four years. Please accept my apologies if there are any omissions, they are not a result of disregard on my part.

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Folkert - I have to thank the Leiden Observatory for having allowed me to meet

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