

Patrick Barth



Title

The role of lightning for early life on Earth and exoplanets: connecting experiments and simulations

Abstract

Previous experiments have shown that in N₂-dominated atmospheres lightning can lead to the formation of nitrate (NO₃⁻) and nitrite (NO₂⁻), which could not only have facilitated the origin of life but also sustained the earliest ecosystems. This hypothesis has been difficult to test with the available rock record because geochemical fingerprints of this fixed nitrogen source have not been developed. We present new results from spark discharge experiments in varying atmospheric compositions corresponding to different points of time in Earth's evolution. We find substantial amounts of nitrate are produced in an N₂/CO₂ atmosphere. Furthermore, we investigate the effect of lightning on the isotopic composition of the resulting nitrogen oxides in solution. Our fixed nitrogen is depleted in heavy ¹⁵N in comparison to atmospheric N₂, in line with rock samples older than 3.2 billion years. For the first time we can assess to what degree lightning chemistry may have influenced the origin and early evolution of life. However, the spark in our experiment is much smaller and cooler than lightning channels in Earth's atmosphere. To extrapolate our experimental results to full-scale planetary atmospheres we complement them with a complex kinetic chemistry network which we use to simulate the atmospheric chemistry of exoplanets and Earth. We simulate the temperature decay both in a hot lightning channel and a cool spark channel, predicting the production rates of nitrogen oxides and other molecules. This allows us to extend our experiments to real lightning conditions and develop observable tracers for lightning chemistry in exoplanetary atmospheres.

Curriculum Vitae of Patrick Barth

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Contact

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Work experience

Since 2019 **Postgraduate Researcher**
University of St Andrews, School for Physics and Astronomy & School for Earth
and Environmental Sciences, UK
[St Andrews Centre for Exoplanet Science](#)

Feb. - July 2017 **Student Research Assistant**
[Max Planck Institute for Astronomy](#), Heidelberg, Germany

Education

Since 2019 **PhD in Astronomy**
University of St Andrews, School for Physics and Astronomy & School for Earth
and Environmental Sciences, UK
[St Andrews Centre for Exoplanet Science](#)
Supervisor: Prof. Christiane Helling & Dr. Eva Stüeken

2017 - 2018 **International Student**
University of Washington, Seattle, United States of America

2017 - 2019 **Master of Science in Physics** (2-year program)
Final Grade: 1.1 (very good), University of Heidelberg, Department of Physics and
Astronomy, Germany

2013 - 2017 **Bachelor of Science in Physics**
Final grade: 1.7 (good), University of Heidelberg, Department of Physics and As-
tronomy, Germany

2013 **Abitur**
Final grade: 1.1 (very good), Karl-Friedrich-Gymnasium Mannheim, Germany

Awards

2021	Student Presentation Award NoRCEL Meeting, 29-31 March 2021, St Andrews, UK (online)
2019 - 2023	St Leonard's Interdisciplinary Doctoral Scholarship University of St Andrews, UK
2017 - 2018	Baden-Württemberg-Stipendium Scholarship for distinguished students studying abroad
2013	High School Graduation Award of the German Physical Society (DPG)

Students

since 2020	Lukas Rossmann Undergraduate research assistant, spark experiments and analysis, co-supervision with Dr. Eva Stüeken
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Teaching & Organisation

Since 2019	Host and organizer of the Journal Club St Andrews Centre for Exoplanet Science
Autumn 2021	Demonstrator for “Astronomy and Astrophysics 1” lab held by Dr. Alexander Scholz, School of Physics and Astronomy, University of St Andrews, UK
Spring 2021	Guest lecture for “Chemistry of the Solar System” lecture held by Dr. Paul Savage and Prof. Christiane Helling, School of Earth and Environmental Sciences, University of St Andrews, UK
Spring 2021	Tutor for “Computational Astrophysics” lecture held by Dr. Peter Woitke, Dr. Christiane Helling, and Dr. Martin Dominik, School of Physics and Astronomy, University of St Andrews, UK
Autumn 2020	Demonstrator for “Astronomy and Astrophysics 1” lab held by Dr. Alexander Scholz, School of Physics and Astronomy, University of St Andrews, UK
Spring 2020	Tutor for “Computational Astrophysics” lecture held by Dr. Peter Woitke, Dr. Christiane Helling, and Dr. Martin Dominik, School of Physics and Astronomy, University of St Andrews, UK

Publications

- Raymond, S. N., et al., incl. **Barth, P.**, 2021, *An upper limit on late accretion and water delivery in the TRAPPIST-1 exoplanet system*, Nature Astronomy 2021. [DOI](#), [arXiv](#).
- **Barth, P.** et al., 2021, *Magma Ocean Evolution of the TRAPPIST-1 planets*, Astrobiology 21, 11. [DOI](#), [arXiv](#), [GitHub](#).
- **Barth, P.** et al., 2021, *MOVES IV. Modelling the influence of stellar XUV-flux, cosmic rays, and*

stellar energetic particles on the atmospheric composition of the hot Jupiter HD 189733b, MNRAS, 502, 6201. [DOI](#), [arXiv](#).

- Woitke, P., et al., incl. **Barth, P.**, 2021, *Coexistence of CH₄, CO₂ and H₂O in exoplanet atmospheres*, A&A 646, A43. [DOI](#), [arXiv](#).
- Barnes, R., et al., incl. **Barth, P.**, 2020, *VPLanet: The Virtual Planet Simulator*, PASP, 132, 024502. [DOI](#), [arXiv](#), [GitHub](#).
- Carone, L., Baeyens, R., Mollière, P., **Barth, P.**, et al., 2020, *Equatorial retrograde flow in WASP-43b elicited by deep wind jets?*, MNRAS, 496, 3582. [DOI](#), [arXiv](#).

Talks

- 15 Sept. 2021 **“Tracking the role of lightning-produced nitrate for early life with nitrogen isotopes in spark discharge experiments”**
[AbGradCon 2021](#), ELSI, Japan (online)
- 9 July 2021 **“Tracking the role of lightning-produced nitrate for early life with nitrogen isotopes in spark discharge experiments”**
[Goldschmidt 2021](#), Lyon, France (online)
- 28 May 2021 **“Magma Ocean Evolution of the TRAPPIST-1 planets”**
NASA ‘Quantifying Habitability’ Science Working Group (online)
- 29 April 2021 **“Modelling the influence of high-energy radiation on the atmospheric composition of the hot Jupiter HD 189733b”**
[vEGU21](#) (online)
- 31 March 2021 **“Understanding the role of lightning in the formation of organic molecules on early Earth”**
[NoRCEL](#) Meeting, St Andrews, UK (online)
- 26 Nov. 2020 **“Modelling the influence of high-energy radiation on the atmospheric composition of HD 189733b”**
CHAMELEON kick-off meeting, University of St Andrews, UK (online)
- 17 Nov. 2020 **“What’s the role of lightning in the origin of life”**
Out Thinkers (LGBT+ STEM Week 2020), University of St Andrews, UK (online)
- 21 Oct. 2020 **“Modelling the influence of high-energy radiation on the atmospheric composition of HD 189733b”**
Scottish Exoplanet and Brown Dwarf Meeting, University of Edinburgh, UK (online)
- 24 July 2020 **“MOVES IV: Modelling the influence of high-energy radiation on the atmospheric composition of HD 189733b”**
NOVO Nordisk Meeting, Niels Bohr Institute, University of Copenhagen, Denmark (online)
- 23 June 2020 **“MOVES IV: Modelling the influence of high-energy radiation on the atmospheric composition of HD 189733b”**
Summer Meeting, St Andrews Centre for Exoplanet Science, UK (online)
- 18 Dec. 2019 **“Magma Ocean Model for Terrestrial (Exo)Planets”**
PSF-Coffee, MPIA, Heidelberg, Germany

- 10 Oct. 2019 **“Magma Ocean Model for Terrestrial (Exo)Planets”**
VPL Meeting, University of Washington, Seattle, US
- 23 Aug. 2019 **“Magma Ocean Model for Terrestrial (Exo)Planets”**
Summer Meeting, St Andrews Centre for Exoplanet Science, UK
- 27 March 2019 **“Coupled Atmosphere-Interior Model for Terrestrial Planets - Application to Early Earth”**
General Meeting SPP 1833 Habitable Earth, DFG, Cologne, Germany
- 30 April 2017 **“Zirkulation mit Wolkenbildung in planetaren Atmosphären”**
(G)Astro-Seminar, jDPG, Bad Kreuznach, Germany
- 11 Jan. 2017 **“Large-Scale Circulation with Cloud Formation in Planetary Atmospheres”**
PSF-Coffee, MPIA, Heidelberg, Germany

Posters

- Sept. 2020 **“X-rays, UV, and co: detrimental or beneficial to the origin of life?”**
[Royal Astronomical Society Early Career Poster Exhibition 2020](#)
- 26 Aug. 2020 **“X-rays, UV, and co: detrimental or beneficial to the origin of life?”**
The STEM Village Virtual Symposium 2020
- 27-31 July 2020 **“MOVES IV: Modelling the influence of high-energy radiation on the atmospheric composition of HD 189733 b”**
[Exoplanet 3](#), Heidelberg, Germany (online)
- 6-8 April 2020 **“MOVES IV: Modelling the influence of stellar XUV-flux and cosmic rays on the atmospheric composition of HD 189733 b”**
UKEXOM, Birmingham, UK (cancelled due to COVID-19)
- 9-13 March 2020 **“MOVES IV: Modelling the influence of stellar XUV-flux and cosmic rays on the atmospheric composition of HD 189733 b”**
Cloud Academy II, Les Houches, France (cancelled due to COVID-19)
- 15-20 Sept. 2019 **“Desiccation of the TRAPPIST-1 Planets During Their Magma Ocean Phase”**
EPSC-DPS Joint Meeting, Geneva, Switzerland (presented by Ludmila Carone)
- 24-28 June 2019 **“Desiccation of the TRAPPIST-1 Planets During Their Magma Ocean Phase”**
Astrobiology Science Conference, Seattle, WA, USA (presented by Rory Barnes)
- 24-28 June 2019 **“Desiccation of the TRAPPIST-1 Planets During Their Magma Ocean Phase”**
“Star-planet interaction” workshop, Ringberg, Germany (presented by Ludmila Carone)

Outreach

- Since 2020 [STEM Ambassador, STEM Learning, UK](#)
- Since 2019 [Mobile Planetarium](#)
University of St Andrews, School for Physics and Astronomy

Programming Skills

- Intermediate: Python, C
- Basics: Fortran

Languages

- Native language: German
- Fluent: English
- Basics: Spanish, French

Volunteer Experience

Since 2020	University of St Andrews Liberal Democrats Treasurer
	St Andrews Whisky Society
Since 2021	Secretary
2019 - 2021	Ordinary Committee member SaintsLGBT+, University of St Andrews Student Association
2019 - 2021	Postgraduate Officer Hector-Seminar Alumni Association, Germany
2019 - 2021	Vice President
2015 - 2019	Secretary
2013 - 2019	Election Worker in Mannheim, Germany