

## Boy Lankhaar



### Title

Tracing cosmic magnetic fields using molecules

### Abstract

Understanding the magnetic field strength and morphology of astrophysical regions is of great importance in understanding their dynamics. There exist a number of methods astronomers can employ to trace magnetic field structures, and each have their own limitations. A promising technique to trace the magnetic field morphology around evolved stars, or on the smallest scales of (high-mass) star forming regions, is (sub-)millimeter spectral line polarization observations. Line (linear) polarization can either arise in association with maser radiative transfer, or alternatively, molecular lines polarize through the Goldreich-Kylafis effect. In both cases, the polarization angle traces the magnetic field with a 90-degree ambiguity. In order to remove this ambiguity, and to estimate the observational viability of particular line polarization measurements, polarized line radiative transfer needs to be employed.

In this talk, I present

- (i) polarized radiative transfer tools that quantify the polarization of maser radiation,
- (ii) a three-dimensional polarized line radiative transfer tool: PORTAL. PORTAL simulates the emergence of thermal molecular line polarization in astrophysical objects of arbitrary geometry and magnetic field morphology,
- (iii) A novel polarization mechanism: collisional polarization. Which provides the possibility of directly detecting ambipolar diffusion in disks through the polarization of molecular ions,

and I will discuss observations of molecular line polarization around evolved stars and on the smallest scales of (high-mass) star forming regions



# Boy Lankhaar

*Curriculum Vitae*

## PERSONAL DETAILS

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*Birth* April 25, 1991  
*Address* Vasagatan 10A, 411 24 Göteborg  
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## EDUCATION

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### BSc. Chemistry

2009-2013

*Radboud University Nijmegen*

Minor in physics. The main part of my studies revolved around quantum chemistry, mathematics and computational solutions to chemical problems. Thesis: The Equation-of-Motion Coupled-Cluster Technique; ab-initio calculations on the electron-attached state of  $\text{NaHe}^+$  and  $\text{ScHe}^+$ . Final grade: 7.5/10

### MSc. Theoretical Chemistry

2013-2015

*Radboud University Nijmegen*

Minor in physics. I followed advanced courses in condensed matter theory, theoretical chemistry and molecular physics. As my major research project, I worked on the Zeeman effect and hyperfine structure of methanol. This included performing electronic structure calculations, working out the molecular dynamics including the internal rotation and computing the hyperfine spectrum (J. Chem. Phys. 145, 244301. (2016)). Final grade: 9/10

*Thesis was awarded the 'KNCV Master Award 2015', the prize for the best master thesis in chemistry in the Netherlands.*

### Postdoctoral research Student

2015-2015

*University of Warwick*

As a part of the Radboud University honours programme (Beyond the Frontiers), I was a visiting student in the group of dr. Scott Habershon. We investigated quantum-mechanical smoothing of aqueous nano droplets by means of path-integral molecular dynamic techniques. Final grade: 9/10

### PhD. student

2016-

*Chalmers University of Technology*

Investigating the effect of magnetic fields on molecules and their spectral manifestation (Nat. Astr. 2, 145. (2018)). Developing numerical tools that assist in the interpretation of maser polarization observations (Astron. Astrophys. 628, A14. (2019)). And development of the first three-dimensional line-polarization code (Astron. Astrophys. in prep.). Side activities: leading work seminars for 'basår' students, outreach and assisting in APEX telescope observations.

## WORK EXPERIENCE

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### Teacher's Assistant

2011-2014

*Montessori College Nijmegen*

I assisted in educating natural sciences to a class of first and second year HAVO-VWO students (13-15 years old). I helped to devise experiments and answer questions of pupils about subjects ranging from physics to biology.

### Librarian

2011-2014

*Library of Science, Radboud University Nijmegen*

I helped students to find literature and was of assistance in case of malfunctioning equipment at the Library of Science, the library of the Faculty of Science and Mathematics of the Radboud University Nijmegen.

### Student Assistant

2013-2015

*Radboud University Nijmegen*

I lead work seminars for university courses in mathematics, classical mechanics and quantum mechanics. Also, I assisted in writing the quantum mechanics course syllabus, exercises and model answers.

### Project Assistant

2015-2016

*Chalmers University of Technology*

At the Onsala Space Observatory, I assisted in the interpretation of astronomical observations as a theoretical chemist.

## SKILLS

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<i>Languages</i>	Dutch (mother tongue) English (fluent) Swedish (fluent) German (elementary proficiency) French (elementary proficiency)
<i>Software</i>	MATLAB/SCILAB, L <sup>A</sup> T <sub>E</sub> X, PERL, FORTRAN, MICROSOFT OFFICE, WINDOWS, UBUNTU

## **PUBLICATIONS**

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### **First Author**

**Lankhaar, B.**, Groenenboom, G.C., van der Avoird, 2016. Hyperfine interactions and internal rotation in methanol. *Journal of Chemical Physics* 145, 244301. doi: 10.1063/1.4972004

**Lankhaar, B.**, Vlemmings, W.H.T., Surcis, G., van Langevelde, H.J., Groenenboom, G.C., van der Avoird, A., 2018. Characterization of methanol as a magnetic field tracer in star-forming regions. *Nature Astronomy* 2, 145–150. doi: 10.1038/s41550-017-0341-8

**Lankhaar, B.**, Vlemmings, W.H.T., 2019. Characterizing maser polarization: effects of saturation, anisotropic pumping, and hyperfine structure. *Astronomy & Astrophysics* 628, A14. doi: 10.1051/0004-6361/201935064

**Lankhaar, B.**, Vlemmings, W.H.T., 2020. PORTAL: Three-dimensional polarized (sub) millimeter line radiative transfer. *Astronomy & Astrophysics* 636, A14. doi: 10.1051/0004-6361/202037509

**Lankhaar, B.**, Vlemmings, W.H.T., 2020. Collisional polarization of molecular ions: a signpost of ambipolar diffusion. *Astronomy & Astrophysics* 638, L7. doi: 10.1051/0004-6361/202038196

### **co-Author**

Dall’Olio, D., Vlemmings, W.H.T., Surcis, G., Beuther, H., **Lankhaar, B.**, Persson, M.V., Richards, A.M.S., Varenus, E., 2017. Methanol masers reveal the magnetic field of the high-mass protostar IRAS 18089-1732. *Astronomy & Astrophysics* 607, A111. doi: 10.1051/0004-6361/201731297

Vlemmings, W.H.T., Khouri, T., O’Gorman, E., de Beck, E., Humphreys, E., **Lankhaar, B.**, Maercker, M., Olofsson, H., Ramstedt, S., Tafuya, D., Takigawa, A., 2017. The shock-heated atmosphere of an asymptotic giant branch star resolved by ALMA. *Nature Astronomy* 1, 848-853. doi: 10.1038/s41550-017-0288-9

Larsson, R., **Lankhaar, B.**, Eriksson, P., 2019. Updated Zeeman effect splitting coefficients for molecular oxygen in planetary applications *Journal of Quantitative Spectroscopy and Radiative Transfer*, 224, 431-438. doi: 10.1016/j.jqsrt.2018.12.004

Khouri, T., Velilla-Prieto, L., De Beck, E., Vlemmings, W. H. T., Olofsson, H., **Lankhaar, B.**, Black, J. H., Baudry, A., 2019. Detection of highly excited OH towards AGB stars. A new probe of shocked gas in the extended atmospheres *Astronomy & Astrophysics* 623, L1. doi: 10.1051/0004-6361/201935049

Vlemmings, W.H.T., **Lankhaar, B.**, Cazzoletti, P., Ceccobello, C., Dall’Olio, D., van Dishoeck, E.F., Facchini, S., Humphreys, E.M.L., Persson, M.V., Testi, L., Williams, J.P., 2019. Stringent limits on the magnetic field strength in the disc of TW Hya. ALMA observations of CN polarisation. *Astronomy & Astrophysics* 624, L7. doi: 10.1051/0004-6361/201935459

Larsson, R., **Lankhaar, B.**, 2020. Zeeman effect splitting coefficients for ClO, OH and

NO in some Earth atmosphere applications *Journal of Quantitative Spectroscopy and Radiative Transfer*, 250, 107050. doi: 10.1016/j.jqsrt.2020.107050

D. Dall'Olio, W. H. T. Vlemmings, **Lankhaar, B.** and G. Surcis, 2020. Polarization properties of methanol masers. *Astronomy & Astrophysics* 644, A122. doi: 10.1051/0004-6361/202039149