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It's just a phase: high-contrast imaging with patterned liquid-crystal phase plates to facilitate characterization of exoplanets

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List of Publications

Refereed Publications

1. *Simultaneous phase and amplitude aberration sensing with a liquid-crystal vector-Zernike phase mask*
Doelman, D. S.; Fagginger Auer, F.; Escuti, M. J.; Snik, F.
Optics letters, 44(1), 17-20 (2019)
2. *Multi-color holography with a two-stage patterned liquid-crystal element*
Doelman, D. S.; Escuti, M. J.; Snik, F.
Optical Materials Express 9 (3), 1246-1256 (2019)
3. *Minimizing the polarization leakage of geometric-phase coronagraphs with multiple grating pattern combinations*
Doelman, D. S.; Por, E. H.; Ruane, G.; Escuti, M. J.; Snik, F.
PASP, 132(1010), 045002 (2020)
4. *First light of a holographic aperture mask: Observation at the Keck OSIRIS Imager*
Doelman, D. S.; Wardenier, J. P.; Tuthill, P.; Fitzgerald, M. P.; Lyke, J.; Sallum, S.; Norris, B.; Warriner, N. Z.; Keller, C. U.; Escuti, M. J.; Snik, F.
Accepted for publication in A&A (2021)
5. *The vector-apodizing phase plate coronagraph: design, current performance, and future development*
Doelman, D. S.; Snik, F.; Por, E. H.; Bos, S. P.; Otten, G. P. P. L.; Kenworthy, M.; Haffert, S. Y.; Wilby, M.; Bohn, A. J.; Sutlief, B. J.; Miller, K.; Ouellet, M.; de Boer, J.; Birkby, J. L.; Keller, C. U.; GPL team; MagAO team; MagAO-X team; SCEXAO team; HiCIBaS team; LMIRcam/ALES team; ERIS team; MICADO team; METIS team
Accepted for publication in Applied Optics (2021)
6. *Focal-plane wavefront sensing with the vector-Apodizing Phase Plate*
Bos, S. P.; **Doelman, D. S.**; Lozi, J.; Guyon, O.; Keller, C. U.; Miller, K. L.; Jovanovic, N.; Martinache, F.; Snik, F.
A&A, 632, A48 (2019)
7. *Detection of polarization neutral points in observations of the combined corona and sky during the 21 August 2017 total solar eclipse*
Snik, F.; Bos, S. P.; Brackenhoff, S. A.; **Doelman, D. S.**; Por, E. H.; Bettonvil, F.; Rodenhuis, M.; Vorobiev, D.; Eshelman, L. M.; Shaw, J. A.
Applied Optics, 59 (21), F71-F77
8. *Spatial linear dark field control on Subaru/SCEXAO-Maintaining high contrast with a vAPP coronagraph*
Miller, K. L.; Bos, S. P.; Lozi, J.; Guyon, O.; **Doelman, D. S.**; Vievard, S.; Sahoo, A.; Deo, V.; Jovanovic, N.; Martinache, F.; Snik, F.; Currie, T.
A&A, 646, A145

9. *The Single-mode Complex Amplitude Refinement (SCAR) coronagraph II. Lab verification, and toward the characterization of Proxima b*
Haffert, S. Y.; Por, E. H.; Keller, C. U.; Kenworthy, M. A.; **Doelman, D. S.**; Snik, F.; Escuti, M. J.
A&A, 635, A56 (2020)
10. *Spatial linear dark field control and holographic modal wavefront sensing with a vAPP coronagraph on MagAO-X*
Miller, K. ; Males, J. R.; Guyon, O.; Close, L. M.; **Doelman, D. S.**; Snik, F.; Por, E. H.; Wilby, M. J.; Keller, C.; Bohlman, C.; Van Gorkom, K.; Rodack, A.; Knight, J.; Lumbres, J.; Bos, S. P.; Jovanovic, N.
JATIS, V5 (4), 049004 (2019)
11. *First Images of the Protoplanetary Disk around PDS 201*
Wagner, K.; Stone, J.; Dong, R.; Ertel, S.; Apai, D.; **Doelman, D.S.**; Bohn, A.; Najita, J.; Brittain, S.; Kenworthy, M.; Keppler, M.; Webster, R.; Mailhot, E.; Snik, F.
The Astronomical Journal 159 (6), 252
12. *METIS high-contrast imaging: design and expected performance*
Carlomagno, B.; Delacroix, C.; Absil, O.; Cantalloube, F.; de Xivry, G. O. ; Pathak, P.; Agocs, T.; Bertram, T.; Brandl, B.; Burtscher, L.; **Doelman, D. S.**; Feldt, M.; Glauser, A.; Hippler, S.; Kenworthy, M.; Por, E. H.; Snik, F.; Stuik, R.; van Boekel, R.
JATIS, V6 (4), 049801 (2020)
13. *Cryogenic characterization of the grating vector Apodizing Phase Plate coronagraph for the Enhanced Resolution Imager and Spectrograph at the Very Large Telescope*
Boehle, A.; **Doelman, D. S.**; Konrad, B. S.; Snik, F.; Glauser, A. M.; Warriner, N. Z.; Shi, S.; Escuti, M. J.; Kenworthy, M. A.; Quanz, S.
Submitted to JATIS

Selected Conference Proceedings

1. *Patterned liquid-crystal optics for broadband coronagraphy and wavefront sensing*
Doelman, D. S.; Snik, F.; Warriner, N. Z.; Escuti, M. J.
SPIE 10400, 104000U (2017)
2. *Multiplexed holographic aperture masking with liquid-crystal geometric phase masks*
Doelman, D. S.; Tuthill, P.; Norris, B.; Wilby, M. J.; Por, E. H.; Keller, C. U.; Escuti, M. J.; Snik, F.
SPIE 10701, 107010T (2018)

3. *New concepts in vector-apodizing phase plate coronagraphy*
Bos, S. P.; **Doelman, D. S.**; Miller, Kelsey L.; Snik, Frans
SPIE 11448, 114483W (2020)
4. *Fully broadband vAPP coronagraphs enabling polarimetric high contrast imaging*
Bos, S. P.; **Doelman, D. S.**; de Boer, J.s; Por, E. H.; Norris, B.; Escuti, M. J.; Snik, F.
SPIE 10706, 107065M (2018)
5. *A snapshot full-Stokes spectropolarimeter for detecting life on Earth*
Snik, F.; Keller, C. U.; **Doelman, D. S.**; Kühn, J.; Patty, C. H. L.; Hoeijmakers, H. J.; Pallichadath, V.; Stam, D. M.; Pommerol, A.; Poch, O.; Demory, B.
SPIE 11132, 111320A (2019)
6. *High Contrast Imaging for Python (HCIPy): an open-source adaptive optics and coronagraph simulator*
Por, E. H.; Haffert, S. Y.; Radhakrishnan, V. M.; **Doelman, D. S.**; van Kooten, M.; Bos, S. P.
SPIE 10703, 1070342 (2018)
7. *MagAO-X first light*
Males, J. R.; Close, L. M.; Guyon, O.; Hedglen, A. D.; Van Gorkom, K.; Long, J. D.; Kautz, M.; Lumbres, J. Schatz, L.; Rodack, A.; Miller, K.; **Doelman, D. S.**; Snik, F.; Bos, S.; Knight, J. M.; Morzinski, K.; Gasho, V.; Keller, C.U.; Haffert, S. Y.; Pearce, L.
SPIE 11448, 114484L (2020)
8. *On-sky results of the Leiden EXoplanet Instrument (LEXI)*
Haffert, S. Y.; Wilby, M. J.; Keller, C. U.; Snellen, I. A. G.; **Doelman, D. S.**; Por, E. H.; van Kooten, M.; Bos, S. P.; Wardenier, J.
SPIE 10703, 1070323 (2018)
9. *HiCIBaS: A precursor mission for high contrast imaging balloon systems*
Marchis, F.; Thibault, S.; Côté, O.; Brousseau, D.; Allain, G.; Lord, M. P.; Ouellet, M.; Patel, D.; Vallée, C.; Belikov, R.; Bendek, E.; Blain, C.; Bradley, C.; **Doelman, D.S.**; Daigle, O.; Doyon, R.; Grandmont, F. J.; Helmbrecht, M.; Kenworthy, M.; Lafrenière, D.; Marois, C.; Montminy, S.; Snik, F.; de Jonge, C.; Vasisht, G.; Veran, J. P.; Vincent, P.
AGU Fall Meeting, P41C-3747 (2018)
10. *Cryogenic characterization of the grating vector APP coronagraph for the upcoming ERIS instrument at the VLT*
Boehle, A.; Glauser, A. M.; Kenworthy, M. A.; Snik, F.; **Doelman, D.S.**; Quanz, S. P.; Meyer, M. R.
SPIE 10702, 107023Y (2018)

11. *SCEXAO, an instrument with a dual purpose: perform cutting-edge science and develop new technologies*
Lozi, J.; Guyon, O.; Jovanovic, N.; Goebel, S.; Pathak, P.; Skaf, N.; Sahoo, A.; Norris, B.; Martinache, F.; N'Diaye, M.; Mazin, B.; Walter, A. B.; Tuthill, P.; Kudo, T.; Kawahara, H.; Kotani, T.; Ireland, M.; Cvetojevic, N.; Huby, E.; Lacour, S.; Vievard, S.; Groff, T. D.; Chilcote, J. K.; Kasdin, J.; Knight, J.; Snik, F.; **Doelman, D.S.**; Minowa, Y.; Clergeon, C.; Takato, N.; Tamura, M.; Currie, T.; Takami, H.; Hayashi, M.

List of Selected Presentations

1. *Patterned liquid-crystal optics for broadband coronagraphy and wavefront sensing*
SPIE Optical Engineering + Applications, August 2017, San Diego, United States (oral)
2. *The world of vAPP: creating dark holes in PSFs all over the world*
Netherlands Astronomy Conference, May 2018, Nijmegen, The Netherlands (poster, 2nd prize)
3. *Advanced wavefront sensing techniques enabled by patterned liquid-crystal technology*
SPHERE upgrade workshop, May 2018, Grenoble, France (oral)
4. *Multiplexed holographic aperture masking with liquid-crystal geometric phase masks*
SPIE Astronomical Telescopes & Instrumentation, June 2018, Austin, United States (oral)
5. *First light for the vAPP on SCEXAO/CHARIS*
SPIE Astronomical Telescopes & Instrumentation, June 2018, Austin, United States (oral)
6. *The world of vAPP: creating dark holes in PSFs all over the world*
Exoplanets II, July 2018, Cambridge, United Kingdom (poster)
7. *Liquid crystals for high-contrast imaging*
NYRIA, Oct 2018, Leiden, The Netherlands (oral, LOC)
8. *The vector-Apodizing Phase Plate coronagraph*
Spirit of Lyot, Oct 2019. Tokyo, Japan (oral)

Curriculum Vitae

David Sebastiaan Doelman was born on July 30th, 1993 in Amsterdam (The Netherlands) to Jollette Drogendijk and Gerard Doelman, only a few minutes after his sister (Eline) and brother (Matthijs). Together with his other brothers (Christiaan and Michiel, 1995), he grew up in Haarlem and later Heemstede. He came into contact with natural sciences and space in part through his grandfather, who intrigued him with his large collection of model spacecraft and later the science magazines he would bring. This interest expressed itself at College Hageveld, where he graduated with a specialization in the natural sciences in 2011.

In that same year he started a double Bachelor in Physics and Astronomy at Leiden University. He specifically enjoyed the practica of physics, the topics of astronomy, and observing with the Isaac Newton Telescope at La Palma. His interest in optics was sparked by his Bachelor research project, where he worked on shaping an optical beam profile to create ring-shaped plasma under the supervision of Dirk Bouwmeester and Chris Smiet. He graduated both Bachelor's in 2014.

He continued with a Master in Astronomy specializing in astronomical instrumentation, taking courses both in Leiden and Delft. During the Master's study he first worked on determining dust and gas distributions in two protoplanetary disks to look for radial drift using cycle-0 data of the *Atacama Large Millimeter Array* (ALMA), under supervision of Michiel Hogerheijde. For his second research project he optimized vector-Apodizing Phase Plate (vAPP) coronagraph designs using simulated annealing under supervision of Christoph Keller and Michael Wilby. One design for the *Large Binocular Telescope* (LBT) was selected for fabrication and installed in the LMIRcam instrument. He received his Master's degree *Cum Laude* in 2016.

In September 2016, he started his PhD under supervision of Frans Snik and Christoph Keller, where he developed novel concepts with liquid-crystal technology for diffraction limited optical and infrared high-contrast imaging instruments, to find and characterize extra-solar planets. He designed liquid-crystal optics currently used, or soon implemented, in 8 different instruments at ground-based telescopes. For most of these projects he was heavily involved in manufacturing, installation, the calibration, and on-sky testing. After observations with the vAPP at the LBT, he also led the data reduction efforts and retrieved the first-ever spectra of the HR 8799 planets in the thermal infrared. Finally, he worked on a liquid-crystal wavefront sensor and coronagraph for the next generation space-based high-contrast imaging instruments which soon will be tested at the Jet Propulsion Laboratory. He presented his work at many workshops and international conferences and during public talks.

He started the next phase as a postdoctoral researcher in the group of Frans Snik to further develop the liquid-crystal technology, focussing on space-based applications in collaboration with SRON.

Acknowledgements

It is just a phase. And now it is over. The result is this thesis, which can be seen as a token of a transformation into an independent researcher. However, if this thesis shows anything, it is that research requires collaboration. I have had the pleasure to work with many amazing people on diverse projects, in addition to enjoying the full support of friends, colleagues, and family. I would like to thank you personally.

First, I would like to thank Frans Snik. Your endless enthusiasm and the many opportunities you provided always encouraged me to make the most of my PhD. I would also like to thank Christoph Keller. You always made time to discuss issues and put me back on track. Both of you have also given me a lot of freedom to pursue projects and my own ideas, which helped me becoming an independent researcher.

Luckily, the PhD experience is a shared one, and I could not have done it without all my colleagues from the instrumentation group. Steven, Maaike, Rob, Sebastian, Emiel, Alex, Mireille, Kelsey, Olivier, Patrick and many others, you have made my PhD a wonderful adventure. I am grateful for all the knowledge, support, conversation, and inspiration you have given me during these years. I particularly enjoyed our many trips together, where, after the serious part, there was always plenty of time for exploration, relaxation, and enjoyment. To the students I supervised, Fedde and Joost, your energy was highly infectious and your work was excellent. I am happy to see you both pursuing an academic career, no doubt with great success. During the pandemic I also got to know some of the new members of our research group. Willeke, Floor, and Elina, it was a delight to have you as (safely distanced) company during the last few months of my PhD.

I find the high-contrast imaging community to be a welcoming one and I have been fortunate enough to collaborate with many incredible people from many institutes all around the globe. I can't name you all personally, so I want to thank the SCE_xAO, MagAO-X, HiCIBaS, LMIRcam, OSIRIS, ERIS, MICADO, and METIS teams. You were extremely helpful and accommodating, and even though the Zoom meetings were at dreadful times some days, I thoroughly enjoyed working together. In particular, I want to thank the people from the Geometric-Phase Photonics Lab, Michael Escuti, Shuojia Shi, Zane Warriner, and, Kathryn Hornburg. Our team-up has been a fruitful one, not in the least due to your generosity and hard work. I have fond memories of the two longer visits to Raleigh, testing all kind of crazy ideas with the liquid-crystal plates, experiencing Halloween, getting an electric shock from the lab door, and getting beaten at airhockey in the arcade hall. Here, I also want to thank Lucas and Steven, who also kept me company during these visits to Raleigh. The nights playing bingo at Ba-Da Wings with cajun fries and PBR were legendary.

I also want to thank my friends from outside of the research group, some of whom I have known for a very long time. Stijn, Leindert, and Leon, we have travelled a long road together. Since our first lecture as first year students, we have shared notes, offices, beers and friendship. Bavo, Kasper, and David, you inspire me ever since we met in office 101. Kirsty, you get a special thanks from my cats, yet I want

to thank you for enduring the technobabble at the morning coffees and forcing me to watch sports and drink beer at 6am in the morning. During my PhD I also helped organize a NYRIA workshop, and four of the observatory staff members went out of their way to help us. Monica, Marjan, Hafize, and Els, without your help we never would have been able to make it work.

Tot slot wil ik nog een aantal mensen bedanken die mijn leven buiten mijn promotie kleur hebben gegeven. Lieve leden van het dispuut Terra F., ik heb een geweldige tijd met jullie beleefd. Mede door jullie gezelligheid, alle activiteiten en schelvispekel heb ik mij geen moment verveeld. Ook nu ik geen PhD-student meer ben zal er nog minder stuko in de stukoburgers zitten. Maar, Kevin, Dionne, Lianne en Martijn, ons gouden leventje is nog niet voorbij. Graag wil ik ook mijn schoonfamilie bedanken. Eric, Hanja en Roy, vanaf het eerste moment ben ik altijd welkom bij jullie. Ik heb jullie leren kennen als gedreven mensen met een hechte band, en ik voel me bevoorrecht om een onderdeel te zijn van jullie gezin. Aan het eind van dit avontuur wil ik ook de ruimte maken om mijn ouders, broers en zus te bedanken. Mam, Pap, jullie hebben ons altijd gestimuleerd en geholpen ons onze dromen na te jagen, wat met vijf kinderen vast niet altijd makkelijk was. Jullie hebben mij altijd gesteund en waren er altijd voor me als ik het moeilijk had. Ook hebben jullie mij geleerd dat je door hardwerken en vastberadenheid alles kan bereiken. Jullie zijn een inspiratie.

Als onderdeel van een drieling is het moeilijk te omschrijven hoeveel jullie voor mij hebben betekend. Eline, ik wil je bedanken voor je zorgzaamheid maar ook alle gekkigheid die we hebben beleefd in bij SSR en daarbuiten. Matthijs, onze eeuwige competitie haalt het beste in mij naar boven. Nu ben jij weer aan zet. Christiaan en Michiel, we hebben het elkaar niet altijd even makkelijk gemaakt, maar weet dat ik ontzettend trots op jullie ben.

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