



Universiteit
Leiden

The Netherlands

Focal-plane wavefront sensors for direct exoplanet imaging: theory, simulations and on-sky demonstrations

Bos, S.P.

Citation

Bos, S. P. (2021, September 30). *Focal-plane wavefront sensors for direct exoplanet imaging: theory, simulations and on-sky demonstrations*. Retrieved from <https://hdl.handle.net/1887/3214244>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/3214244>

Note: To cite this publication please use the final published version (if applicable).

Publication list

Refereed publications

1. *Imaging the water snow-line during a protostellar outburst*
L.A. Cieza, S. Cassassus, J.J. Tobin, **S.P. Bos**, J.P. Williams, S. Perez, Z. Zhu, C. Caceres, H. Canovas, M.M. Dunham, A. Hales, J.L. Prieto, D.A. Principe, M.R. Schreiber, D. Ruiz-Rodriguez, A. Zurlo
2016, *Nature*, 535(7611), 258-261
2. *The Envelope Kinematics and a Possible Disk Around the Class 0 Protostar within BHR7*
J.J. Tobin, **S.P. Bos**, M.M. Dunham, T.L. Bourke, N. Van der Marel
2018, *The Astrophysical Journal*, 856(2), 164.
3. *Spatial Linear Dark Field Control and Holographic Modal Wavefront Sensing with a vAPP Coronagraph on MagAO-X*
K.L. Miller, J.R. Males, O. Guyon, L.M. Close, D.S. Doelman, F. Snik, E.H. Por, M.J. Wilby, C.U. Keller, C. Bohlman, K. Van Gorkom, A. Rodack, J. Knight, J. Lumbres, **S.P. Bos**, N. Jovanovic
2019, *Journal of Astronomical Telescopes, Instruments, and Systems*, 5(4), 049004
4. *Focal-plane wavefront sensing with the vector-Apodizing Phase Plate*
S.P. Bos, D.S. Doelman, J. Lozi, O. Guyon, C.U. Keller, K.L. Miller, N. Jovanovic, F. Martinache, F. Snik
2019, *Astronomy & Astrophysics*, 632, A48
5. *Vector speckle grid: instantaneous incoherent speckle grid for high-precision astrometry and photometry in high-contrast imaging*
S.P. Bos
2020, *Astronomy & Astrophysics*, 638, A118
6. *On-sky verification of Fast and Furious focal-plane wavefront sensing: Moving forward toward controlling the island effect at Subaru/SCEXAO*
S.P. Bos, S. Vievard, M.J. Wilby, F. Snik, J. Lozi, O. Guyon, B.R.M. Norris, N. Jovanovic, F. Martinache, J.F. Sauvage, C.U. Keller
2020, *Astronomy & Astrophysics*, 639, A52
7. *Detection of polarization neutral points in observations of the combined corona and sky during the Aug. 21 2017 total solar eclipse*
F. Snik, **S.P. Bos**, S.A. Brackenhoff, D.S. Doelman, E.H. Por, F. Bettonvil, M. Rodenhuis, D. Vorobiev, L.M. Eshelman, J.A. Shaw
2020, *Applied Optics*, 59(21), F71-F77
8. *Laboratory Demonstration of Spatial Linear Dark Field Control For Imaging Extrasolar Planets in Reflected Light*
T. Currie, E. Pluzhnik, O. Guyon, R. Belikov, K.L. Miller, **S.P. Bos**, J.R. Males, D. Sirbu, C. Bond, R. Frazin, T. Groff, B. Kern, J. Lozi, B.A. Mazin, B. Nemati, B. Norris, H. Subedi, S. Will
2020, *Publications of the Astronomical Society of the Pacific*, 132(1016), 104502

9. *The polarization-modulated self-coherent camera*
S.P. Bos
2021, *Astronomy & Astrophysics*, 646, A177
10. *Spatial linear dark field control on Subaru/SCExAO: Maintaining high contrast with a vAPP coronagraph*
K.L. Miller, **S.P. Bos**, J. Lozi, O. Guyon, D.S. Doelman, S. Vievard, A. Sahoo, V. Deo, N. Jovanovic, F. Martinache, F. Snik, T. Currie
2021, *Astronomy & Astrophysics*, 646, A145
11. *The vector-apodizing phase plate coronagraph: design, current performance, and future development*
D.S. Doelman, F. Snik, E.H. Por, **S.P. Bos**, G.P.P.L. Otten, M. Kenworthy, S.Y. Haffert, M.J. Wilby, A.J. Bohn, B.J. Sutcliffe, K.L. Miller, M. Ouellet, J. de Boer, C.U. Keller, M.J. Escuti, S. Shi, N.Z. Warriner, K.J. Hornburg, J.L. Males, K.M. Morzinski, L.M. Close, J. Codona, J. Long, L. Schatz, J. Lumbres, A. Rodack, K. Van Gorkom, A. Hedglen, O. Guyon, J. Lozi, T. Groff, J. Chilcote, N. Jovanovic, S. Thibault, C. de Jonge, G. Allain, C. Vallée, D. Patel, O. Côté, C. Marois, P. Hinz, J. Stone, A. Skemer, Z. Briesemeister, A. Boehle, A.M. Glauser, W. Taylor, P. Baudoz, E. Huby, O. Absil, B. Carlomagno, C. Delacroix
2021, *Applied Optics*, 60(19), D52-D72
12. *First on-sky demonstration of spatial Linear Dark Field Control with the vector-Apodizing Phase Plate at Subaru/SCExAO*
S.P. Bos, K.L. Miller, J. Lozi, O. Guyon, D.S. Doelman, S. Vievard, A. Sahoo, V. Deo, N. Jovanovic, F. Martinache, T. Currie, F. Snik
Accepted for publication in *Astronomy & Astrophysics*.
13. *Circular polarimetric imaging at planetary-system scales by hacking SPHERE-IRDIS: Full-Stokes observations of the asymmetric nebula surrounding VY CMa*
K.N. Strelow, D. Abbink, R.G. van Holstein, **S.P. Bos**, Z. Wahhaj, J. de Boer, C. Ginski, J. Milli, F. Ménard, F. Snik
In preparation.
14. *Polarization-dependent beam shifts upon metallic reflection in high-contrast imagers and telescopes*
R.G. van Holstein, C.U. Keller, F. Snik, **S.P. Bos**, H.M. Schmid
In preparation.

Conference proceedings

1. *Rigorous vector wave propagation for arbitrary flat media*
S.P. Bos, S.Y. Haffert, C.U. Keller
2017, *Proc. of SPIE Vol. 10407, Polarization Science and Remote Sensing VIII*, 1040709
2. *A review of high contrast imaging modes for METIS*
M. Kenworthy, O. Absil, B. Carlomagno, F. Snik, T. Agócs, E.H. Por, B.R. Brandl,

- S.P. Bos**
2018, Proc. of SPIE Vol. 10702, Ground-based and Airborne Instrumentation for Astronomy VII, 10702A3
3. *High Contrast Imaging for Python (HCIPy): an open-source adaptive optics and coronagraph simulator*
E.H. Por, S.Y. Haffert, V.M. Radhakrishnan, D.S. Doelman, M. van Kooten, **S.P. Bos**
2018, Proc. of SPIE Vol. 10703, Adaptive Optics Systems VI, 1070342
 4. *On-sky results of the Leiden EXoplanet Instrument (LEXI)*
S.Y. Haffert, M.J. Wilby, C.U. Keller, I.A.G. Snellen, D.S. Doelman, E.H. Por, M. van Kooten, **S.P. Bos**, J. Wardenier
2018, Proc. of SPIE Vol. 10703, Adaptive Optics Systems VI, 1070323
 5. *Fully broadband vAPP coronagraphs enabling polarimetric high contrast imaging*
S.P. Bos, D.S. Doelman, J. de Boer, E.H. Por, B. Norris, M.J. Escuti, F. Snik
2018, Proc. of SPIE Vol. 10706, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation III, 107065M
 6. *New NIR spectro-polarimetric modes for the SCEXAO instrument*
J. Lozi, O. Guyon, N. Jovanovic, B. Norris, T. Groff, J. Chilcote, J. Kasdin, T. Kudo, M. Tamura, J. Zhang, **S.P. Bos**, F. Snik, D.S. Doelman, S. Vievard, A. Sahoo, T. Currie, F. Martinache
2019, Proc. of AO4ELT 6
 7. *Status of the SCEXAO instrument: recent technology upgrades and path to a system-level demonstrator for PSI*
J. Lozi, O. Guyon, S. Vievard, A. Sahoo, N. Jovanovic, B. Norris, B. Mazin, A. Walter, P. Tuthill, T. Kudo, H. Kawahara, T. Kotani, M. Ireland, N. Cvetojevic, E. Huby, S. Lacour, T.D. Groff, J. Chilcote, J. Kasdin, F. Martinache, R. Laugier, J. Knight, **S.P. Bos**, F. Snik, D.S. Doelman, E. Bendek, R. Belikov, T. Currie, Y. Minowa, C. Clergeon, N. Takato, M. Tamura, H. Takami, M. Hayashi
2019, Proc. of AO4ELT 6
 8. *Overview of focal plane wavefront sensors to correct for the Low Wind Effect on SUBARU/SCEXAO*
S. Vievard, **S.P. Bos**, F. Cassaing, A. Ceau, O. Guyon, N. Jovanovic, C.U. Keller, J. Lozi, F. Martinache, A. Montmerle-Bonnefois, L. Mugnier, M. N'Diaye, B. Norris, A. Sahoo, J.F. Sauvage, F. Snik, M.J. Wilby, A. Wong
2019, Proc. of AO4ELT 6
 9. *New NIR spectro-polarimetric modes for the SCEXAO instrument*
J. Lozi, O. Guyon, T. Kudo, J. Zhang, N. Jovanovic, B. Norris, M.A. Martinod, T.D. Groff, J. Chilcote, M. Tamura, **S.P. Bos**, F. Snik, S. Vievard, A. Sahoo, V. Deo, F. Martinache, J. Kasdin
2020, Proc. of SPIE Vol. 11448, Adaptive Optics Systems VII, 114487C

10. *Status of the SCExAO instrument: recent technology upgrades and path to a system-level demonstrator for PSI*
J. Lozi, O. Guyon, S. Vievard, A. Sahoo, V. Deo, N. Jovanovic, B. Norris, M.A. Martinod, B. Mazin, A. Walter, N. Fruitwala, S. Steiger, K. Davis, P. Tuthill, T. Kudo, H. Kawahara, T. Kotani, M. Ireland, T. Anagnos, C. Schwab, N. Cvetojevic, E. Huby, S. Lacour, K. Barjot, T.D. Groff, J. Chilcote, J. Kasdin, F. Martinache, R. Laugier, M. N'Diaye, J. Knight, J.R. Males, **S.P. Bos**, F. Snik, D.S. Doelman, K.L. Miller, E. Bendek, R. Belikov, E. Pluzhnik, T. Currie, M. Kuzuhara, T. Uyama, J. Nishikawa, N. Murakami, J. Hashimoto, Y. Minowa, C. Clergeon, Y. Ono, N. Takato, M. Tamura, H. Takami, M. Hayashi
2020, Proc. of SPIE Vol. 11448, Adaptive Optics Systems VII, 114480N
11. *Validating advanced wavefront control techniques on the SCExAO testbed/instrument*
O. Guyon, J. Lozi, S. Vievard, R. Belikov, E. Bendek, **S.P. Bos**, T. Currie, V. Deo, M. Fitzgerald, D. Gratadour, T. Groff, N. Jovanovic, H. Kawahara, T. Kotani, T. Kudo, C. Lopez, H. Ltaief, J.R. Males, F. Martinache, M.A. Martinod, B.A. Mazin, K.L. Miller, B. Norris, M. N'diaye, E. Pluzhnyk, A. Sahoo, A. Sevin, N. Skaf, F. Snik, M. Tamura, A. Wong
2020, Proc. of SPIE Vol. 11448, Adaptive Optics Systems VII, 114481Z
12. *Adaptive optics real-time control with the compute and control for adaptive optics (Cacao) software framework*
O. Guyon, A. Sevin, F. Ferreira, H. Ltaief, J.R. Males, V. Deo, D. Gratadour, S. Centre, F. Martinache, J. Lozi, S. Vievard, N. Fruitwala, **S.P. Bos**, N. Skaf
2020, Proc. of SPIE Vol. 11448, Adaptive Optics Systems VII, 114482N
13. *MagAO-X first light*
J.R. Males, L.M. Close, O. Guyon, A.D. Hedglen, K. Van Gorkom, J.D. Long, M. Kautz, J. Lumbres, L. Schatz, A. Rodack, K.L. Miller, D.S. Doelman, F. Snik, **S.P. Bos**, J.M. Knight, K. Morzinski, V. Gasho, C.U. Keller, S.Y. Haffert, L. Pearce
2020, Proc. of SPIE Vol. 11448, Adaptive Optics Systems VII, 114484L
14. *Focal plane wavefront sensing on SUBARU/SCExAO*
S. Vievard, **S.P. Bos**, F. Cassaing, T. Currie, V. Deo, O. Guyon, N. Jovanovic, C.U. Keller, M. Lamb, C. Lopez, J. Lozi, F. Martinache, K.L. Miller, A. Montmerle-Bonnefois, L.M. Mugnier, M. N'Diaye, B. Norris, A. Sahoo, J.F. Sauvage, N. Skaf, F. Snik, M.J. Wilby, A. Wong
2020, Proc. of SPIE Vol. 11448, Adaptive Optics Systems VII, 114486D
15. *Calibration of the instrumental polarization effects of SCExAO-CHARIS' spectropolarimetric mode*
R.G. van Holstein, **S.P. Bos**, J. Ruigrok, J. Lozi, O. Guyon, B. Norris, F. Snik, J. Chilcote, T. Currie, T.D. Groff, N. Jovanovic, J. Kasdin, T. Kudo, F. Martinache, B. Mazin, A. Sahoo, M. Tamura, S. Vievard, A. Walter, J. Zhang
2020, Proc. of SPIE Vol. 11447, Ground-based and Airborne Instrumentation for Astronomy VIII, 114475B

16. *New concepts in vector-Apodizing Phase Plate coronagraphy*
S.P. Bos, D.S. Doelman, K.L. Miller, F. Snik
2020, Proc. of SPIE Vol. 11448, Adaptive Optics Systems VII, 114483W
17. *“Fast” and Furious focal-plane wavefront sensing at W.M. Keck Observatory*
S.P. Bos, M. Bottom, S. Ragland, J.R. Delorme, S. Cetre, L. Pueyo
In preparation.
18. *Full characterization of the instrumental polarization effects of the spectropolarimetric mode of SCExAO/CHARIS*
J. 't Hart, R.G. van Holstein, **S.P. Bos**, J. Ruigrok, F. Snik, J. Lozi, O. Guyon, T. Kudo, J. Zhang, N. Jovanovic, B. Norris, M.A. Martinod, T.D. Groff, J. Chilcote, T. Currie, M. Tamura, S. Vievard, A. Sahoo, V. Deo, K. Ahn, F. Martinache, J. Kasdin
In preparation.

Curriculum Vitae

I was born on May 8th, 1993 in Delft, the Netherlands, the place where I also grew up. From 2005 to 2011 I attended the Stanislascollege Westplantsoen in Delft with a specialization in the natural sciences and technology. During this period I was a member of the Stanislas Tech Team and participated with this team in the FIRST Tech Challenge, which is a robotics competition for high-school students. We became national champions of the Netherlands and qualified for the world championships in Atlanta, USA, in which we participated in 2010. My interest in astronomy developed during my high school period while reading books and internet pages on space travel, stars, galaxies and the universe.

Due this to interest I decided to start the Bachelor's program in astronomy at Leiden University in September, 2011. During this time I got more and more interested in astronomical instrumentation. This led in the summer of 2014 to a six week internship at the opto-mechatronics department of TNO in Delft studying the feasibility of a tip/tilt mirror to counteract atmospheric turbulence for the BlackGEM telescope. I finished my Bachelor's in 2015 with a research project on "Achromatic liquid crystal linear polarization modulation" supervised by Frans Snik in the group of Christoph Keller. In the following summer I attended the summer school "Introduction to Astronomical Instrumentation" in Toronto, Canada organized by the Dunlap Institute.

To deepen my knowledge on instrumentation I joined in August, 2015 the Master's program at Leiden University in the specialization "Astronomy & Instrumentation". To deepen my knowledge on optics I also followed some courses at the Technical University in Delft, which turned out to be essential for my later research projects. My minor research project was on "Determining the masses and disk sizes of the youngest protostars and proto-binary stars" supervised by John Tobin in the group of Ewine van Dishoeck. I got the opportunity to present this work during the *Nederlandse Astronomen Conferentie* in 2016. My graduation project was "Rigorous vector diffraction for arbitrary flat surfaces" supervised by Sebastiaan Haffert in the group of Christoph Keller.

In September, 2017 I started a PhD under the supervision of Frans Snik in the instrumentation group of Christoph Keller at Leiden Observatory. The original goal of the project was to integrate the vector-Apodizing Phase Plate coronagraph with polarimetry, spectroscopy and focal-plane wavefront sensing. But this slowly evolved towards the development and on-sky demonstration of new focal-plane wavefront sensors for the direct imaging of exoplanets. In the autumn of 2017 I went to Raleigh, USA for a six weeks visit to the Geometric-Phase Photonics Lab led by Michael Escuti to learn all about liquid-crystal technology. I made another trip to the USA during the last few months of 2018 when I spent two months with the SCEXAO team in Hawaii. During this time I learned to operate the SCEXAO high-contrast imaging instrument and tested my first focal-plane wavefront sensor on this instrument. I presented my work during multiple in-person and digital conferences in Europe, North America and Japan. During my PhD I have given multiple talks on the search for exoplanets for the general public and assisted in multiple outreach activities of the observatory and university. I have been a teaching assistant of the first-year Bachelor's course *planetenstelsels* for five years, and (co-)supervised six Bachelor's and four Master's students.

During my time at Leiden Observatory I have served in various committees. During my Master I was a member of the *Onderwijs Faciliteiten* committee. In my PhD I joined

the social committee and soon after became its chairman, been a member of the Institute Council and (briefly) of the Social Support committee. In 2018 I was one of the organizers of the annual workshop of the Network of Young Researchers in Instrumentation for Astronomy when it was held in Leiden. I have also been a member of the board of editors of the *Nederlands Tijdschrift van de Natuurkunde*.

I had the opportunity to observe with some of the world's largest optical telescopes during my time in astronomy. For a Bachelor's course I observed with the Isaac Newton Telescope on La Palma, Spain to look for a bridge of stars between two star clusters. I joined two observation runs with the LEXI instrument led by Sebastiaan Haffert at the William Herschel Telescope, La Palma during my Master's and PhD. Later on in my PhD I observed with the Subaru telescope and Keck telescope at Hawaii, USA during engineering nights to test new focal-plane wavefront sensors. Other highlights of my PhD were the 2017 and 2019 solar eclipses in the USA and Chile respectively, the launch of the balloon-based HiCIBaS telescope in Timmins, Canada, and looking down on the ALMA telescope while standing on the summit of Cerro Toco, Chile.

I will start working as Design Engineer at ASML in the EUV Projection group on July 1st, 2021.

Acknowledgements

It feels good to be typing the last words of this PhD thesis. It marks the end of a journey with many ups and downs. From the moment when I had no idea of what I was doing and everything seemed to simultaneously go wrong, to celebrating the successful on-sky demonstration of a new algorithm. All these moments are precious to me, because without the one you cannot truly appreciate the value of the other. I could not have completed this journey, with its ups and downs, on my own. Many people have contributed in some way and I would like to thank them here.

First of all, I would like to thank Frans for all the adventures around the world during the last few years and giving me encouragements and the freedom to pursue my own ideas. And Christoph, thank you for your help in the last months when it was most necessary.

Within Leiden Observatory there are many people that make sure that everything runs smoothly. Erik, Eric and David, thank you for your support with computer related issues. Marjan, Monica, Susanne, Hafize, Els, Alexandra and Evelijn, thank you for all your help with practical matters that come up during a PhD.

I spent the majority of my time in the instrumentation group, and have seen many of its members come and go. David, Rob and Alex thanks for all the fun times drinking beer and eating pizza, and especially for the fun night in Tokyo. I think that we have to improve our rapping skills before we can attempt another Eminem song during karaoke. Sebastiaan and Emiel, you have taught me so much about programming and optics. Your knowledge and insights have always been very valuable to me. Maaïke and Kelsey, thank you for being the co-members of the gurl squad during our trip to Quebec and introducing me to *How I met your mother*. Can't wait to try another of those vanilla soft serve cones with white chocolate dip! Mireille, I'm glad that you came to join us in Leiden after your balloon adventures, and I enjoyed our time being officemates. Rico, Willeke, Floor, Elina and Thijs, thank you for bringing new energy into the group. Your presence made the last year so much more enjoyable. And all the other members of the research group: Olivier, Patrick, Fedde, Dirk, Dora, Mike, Vikram, Jos, Christian, Schuyler, Remko, Matt, Bernard, Rudolf, Leo and Chad, thank you for the interesting discussions during the meetings, and the relaxed and friendly environment.

Leindert, Leon, Stijn, and Kirsty, sorry for all the instrumentation talk all day, every day. We sometimes tend to forget that there are more things in astronomy than exoplanets and instruments. Thank you for your friendship, the fun chats during the borrels and coffee breaks on either the 11th or the 5th floor.

Harold, Michiel, Marijn en Anthony, there was always pleasant cooperation when organizing and teaching the *Planetenstelsels* course. Jens, Vincent and all the other teaching assistants, thank you for all the laughs when grading the (sometimes endless) streams of homework. I would also like to thank the students that I have (co-)supervised: Stefanie, Pieter, David, Nicky, Daphne, Kira, Jasper, Alex, Andy and Joost. Good luck with your future studies!

Although we only briefly shared an office at the start of my PhD, Jorrit and Geert-Jan, thank you for teaching me a thing or two about transit observations of exoplanets and those galaxies really far far away.

A big thanks to the members of the SCEAO team. During my visit to Hilo I really en-

joyed all the Hawaiian adventures that you took me on, and the weekly volleyball matches were perfect for testing the reaction time of my reptile brain. Those two months were the absolute highlight of my PhD. I can't wait to come back and eat a delicious sandwich at the Le Yellow Sub and some tasty pork ribs at Jackie Rey's. Especially Olivier, Julien, Sebastian, Nemanja and Ananya, without your hard work, help, and fruitful discussions the majority of my thesis would not be here today.

Although the results did not make it into this thesis, I would also like to thank Michael, Sam, Jacques and Sylvain for their help with the on-sky demonstration of Fast&Furious at the Keck telescope. Our sessions during my evening and your morning were always pleasant and it was very satisfying when we finally managed to crack the convergence problem.

Michael, Shuoja, Zane and all the others at the Geometric Phase Lab, thank you for the warm welcome during my visit to Raleigh and teaching me all about the wonders of liquid-crystal technology.

Tot slot is het prettig om dit proefschrift in het Nederlands te kunnen eindigen. Vincent, Fré, Sam, Falko en Sebastiaan, aan de dagen dat we tot diep in de nacht aan calculus opdrachten zaten heb ik toch merkwaardig goede herinneringen overgehouden. Bavo en Kasper, dank voor alle goede gesprekken en de gezelligheid wanneer we weer eens naar Delft afreisden om te leren hoe het nou eigenlijk precies zit met Fourier optica.

Ik wil graag de mannen bedanken uit de verscheidene waterpoloteams bij LZ 1886, ZVL 1886 en d'Elft. Niks is beter om de gedachten van werk te halen dan 1,5 uur keihard trainen en ballen op het goal te knallen.

Daarnaast zijn er nog vele vrienden die allemaal heel erg belangrijk voor mij zijn. Ik dank jullie allemaal voor jullie vriendschap, de gezelligheid en het aanhoren van al mijn eindeloze verhalen over sterrenkunde.

Mijn broertje en zusje, Tom en Dorine, bedankt hoe jullie altijd klaar staan voor mij. Ik waardeer jullie hulp echt enorm en ben zo trots op wat jullie al hebben bereikt en nog gaan bereiken in de toekomst. Pap en Mam, zonder jullie was dit nooit allemaal gelukt. Erg dankbaar ben ik voor al de aandacht, het advies, de steun en stimulans om mijn eigen pad te kiezen. Ook waardeer ik de moeite die jullie steken in het begrijpen van mijn werk, want dat is lang niet altijd eenvoudig.

Als laatste wil ik mijn lieve vriendin Charlotte bedanken. Zonder jouw liefde, enthousiasme en steun door dik en dun zou het me nooit gelukt zijn om dit proefschrift te schrijven. Wij hebben het altijd zo leuk samen en zijn altijd aan het lachen. Ik kijk zo enorm uit naar al onze toekomstige avonturen, want samen gaan we de wereld veroveren!