

# Lennart Balkenhol

## Curriculum Vitae

lennart.balkenhol@iap.fr — <https://lbalkenhol.github.io> — +33 06 56 68 68 08

### RESEARCH INTERESTS

- Cosmic microwave background anisotropies
- Physics beyond the standard model
- Cosmological structure formation
- Analysis methods in astrophysics and cosmology
- Machine learning applications in cosmology
- Cosmological concordance

### RESEARCH & EDUCATION

<b>POSTDOCTORAL FELLOW</b> Institut d'Astrophysique de Paris Advisor: Silvia Galli Project: NEUCosmoS (ERC consolidator grant)	03/2023 - 02/2026
<b>DOCTOR OF PHILOSOPHY</b> University of Melbourne Advisory Committee: Christian Reichardt, Rachel Webster, Raymond Volkas Thesis: 'Constraining Cosmology with SPT-3G'	06/2019 - 01/2023
<b>MASTER OF SCIENCE IN PHYSICS</b> University of Melbourne Advisor: Christian Reichardt	02/2017 - 12/2018
<b>BACHELOR OF SCIENCE WITH HONOURS IN PHYSICS WITH ASTROPHYSICS</b> University of Sussex Advisor: Robert E. Smith	09/2013 - 06/2016

### PROFESSIONAL ACTIVITIES, SERVICE TO THE COMMUNITY

Author and maintainer of <code>candl</code> ( <a href="https://github.com/Lbalkenhol/candl">https://github.com/Lbalkenhol/candl</a> ) <ul style="list-style-type: none"><li>• First and only public library of differentiable cosmic microwave background likelihoods (Python w/ JAX)</li><li>• Extensive documentation, including pedagogical tutorial notebooks</li></ul>	Since 2024
Member of the SPT-3G Collaboration <ul style="list-style-type: none"><li>• Analysis coordinator of 60-person 'Theory and Likelihood' working group (since 2024)</li><li>• Organised and chaired high-level analysis session of multiple collaboration meetings.</li></ul>	Since 2019
Member of the CMB-S4 Collaboration	Since 2023
Member of the 'Comité contre le harcèlement et les discriminations', Institut d'Astrophysique de Paris <ul style="list-style-type: none"><li>• Organised an institute-wide seminar related to diversity, equity, and inclusion (2025)</li></ul>	Since 2024
Organiser of the cosmology journal club, University of Melbourne	2020 - 2022

### MENTORING

Aline Vitrier (PhD candidate, Institut d'Astrophysique de Paris) <ul style="list-style-type: none"><li>• Fisher forecasting, likelihood analysis, and Bayesian inference</li><li>• Use of public cosmology software I developed and maintain (<code>candl</code>)</li><li>• Helped achieve first-author publication and South Pole Telescope collaboration paper</li></ul>	Since 2023
Madeline Casas (MSc student, Institut d'Astrophysique de Paris) <ul style="list-style-type: none"><li>• Guiding learning in Bayesian inference and different contemporary cosmological data sets</li></ul>	2025

## SKILLS

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- **Programming:** Python incl. JAX (Advanced), Objective-C (Intermediate), Fortran (Intermediate), C (Basic), HTML & CSS (Basic), Unix scripting (Basic)
- **Technical:** machine learning (Gaussian processes, neural networks), differentiable computing, MCMC sampling (Cobaya, CosmoMC, MontePython, BlackJAX, flowMC), cosmological theory codes and emulators (CAMB, CLASS, CosmoPower, Capse.jl), HEALPix, pip distribution, supercomputing using CPUs and GPUs, version control, data visualisation, signal processing, statistical interpretation
- **Languages:** German (native), English (bilingual), French (B2)

## AWARDS AND SCHOLARSHIPS

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2022 Dr Albert Shimmins Postgraduate Writing-Up Award  
2022 Laby PhD Travelling Scholarship  
2021 Laby PhD Travelling Scholarship  
2019 Melbourne Research Scholarship  
2017 International Postgraduate Coursework Scholarship  
2016 Andrew J. Symonds Memorial Award  
2013 Scholar of the German National Academic Foundation

## TEACHING

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### TEACHING ASSISTANT

University of Melbourne

- Introduction to Life, Earth and Universe 2021
- From the Solar System to the Cosmos 2020
- Physics First Year Laboratory 2017-2020, 2022

### TEACHING ASSISTANT

University of Sussex

- Introduction to Scientific Python Programming 2015-2016

## PROFESSIONAL EXPERIENCE

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### DATA ANALYST

08/2018-06/2019

Crypton Capital 96 Pelham St, Carlton VIC 3053, Australia

- Cleaned and structured high-volume, noisy data for emerging start-up
- Trained and optimised machine-learning models to deliver profitable predictive systems

### DEVELOPMENT INTERN

07/2014-02/2015

Touch Fantastic Werks Central, 15-17 Middle Street, Brighton BN1 1AL, United Kingdom

- Quickly built the technical expertise to contribute high-quality code in a dynamic start-up environment
- Contributed core features to the Sparkjar classroom app and refined UX through feedback sessions with teachers

## INTERESTS

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- **Fencing:** Levallois Sporting Club (since 2023), University of Melbourne Elite Athlete Scholarship (2017 - 2022), Melbourne University full blue award (2019), British coaching qualification, Australian referee accreditation, University of Sussex Fencing Club secretary (2015-2016)
- **Inclusion & Sustainability:** active member of the 'Comité contre le harcèlement et les discriminations' and work with the climate committee of the Institut d'Astrophysique de Paris
- **Scientific outreach:** presentation to and engagement with hobby astronomers of the 'Sternfreunde Menden', Germany (2024), Telescopes in schools volunteer, University of Melbourne (2018 - 2022)

## PRESENTATIONS AT SCIENTIFIC CONFERENCES

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\* = Talk; Inv. = Invited talk; Sem. = Seminar

- 2026 April, Progress on Old and New Themes in Cosmology (PONT 2026), Avignon, France  
Inv. — *‘Review of the latest SPT results’*
- 2026 February, CosmoForward, San Cristóbal de La Laguna, Spain — *‘The added value of new methods’*
- \* 2025 December, Inflation 2025, Institut d’Astrophysique de Paris, France — *‘Implications for inflation of the CMB-BAO tension’*
- Sem. 2025 November, Institut d’Astrophysique de Paris, France — *‘Cosmology from the SPT-3G D1 T&E CMB power spectra’*
- Sem. 2025 November, Imperial College London, UK — *‘SPT-3G D1’*
- \* 2025 October, Colloque National CMB-France, Institut d’Astrophysique de Paris, France — *‘SPT-3G D1: CMB Temperature and Polarization Power Spectr and Cosmology from 2019-2020 Observations of the SPT-3G Main Field (III)’*
- Sem. 2025 June, South Pole Telescope Release Webinar — *‘SPT-3G D1: CMB power spectra and cosmology from 2019 and 2020 observations of the SPT-3G Main field’*
- Sem. 2025 April, Postdoc day, Institut d’Astrophysique de Paris, France — *‘CMB Analysis with a Differentiable Pipeline’*
- \* 2025 February, Cosmology on the steep rise, Sexten Center for Astrophysics Riccardo Giacconi, Italy — *‘Changing the way we analyse CMB data with candl’*
- Sem. 2024 December, Swinburne Institute of Technology, Australia — *‘Changing the way we analyse CMB data with candl’*
- Sem. 2024 December, University of Melbourne, Australia — *‘Changing the way we analyse CMB data with candl’*
- Sem. 2024 November, RWTH Aachen, Germany — *‘CMBlite with Automatic Differentiation’*
- Inv. 2024 November, CMB-S4 maps to power spectra working group — *‘Changing the way we analyse CMB data with candl’*
- Inv. 2024 November, GDR CoPhy Tools, Institut d’Astrophysique de Paris, France — *‘Changing the way we analyse CMB data with candl’*
- \* 2024 October, Cosmo24, Kyoto University, Japan — *‘Constraining Cosmology with the South Pole Telescope’*
- \* 2024 May, GDR CoPhy Episode 2, IP2I Lyon, France — *‘candl: CMB Analysis with a differential likelihood’*
- Sem. 2024 April, RWTH Aachen, Germany — *‘Changing the way we analyse CMB data with candl’*
- \* 2024 April, Rencontres de Moriond, La Thuile, Italy — *‘candl: CMB Analysis with a differential likelihood’*
- Sem. 2024 March, Postdoc day, Institut d’Astrophysique de Paris, France — *‘candl: CMB Analysis with a differential likelihood’*
- \* 2023 December, Colloque National CMB-France, Institut d’Astrophysique de Paris, France — *‘candl: CMB Analysis with a Differentiable Likelihood’*
- Sem. 2023 October, Laboratoire Univers et particules de Montpellier, France — *‘A Differentiable Likelihood for CMB Data Analysis’*
- \* 2023 September, Cosmo23, Instituto de Física Teórica, Spain — *‘SPT-3G 2018 TT/TE/EE Power Spectrum and Future Likelihood’*
- Sem. 2023 March, Simons Observatory maps2cell working group — *‘SPT-3G 2018 TT/TE/EE Power Spectrum’*
- Sem. 2023 March, Institut d’Astrophysique de Paris, France — *‘Cosmic Microwave Background Power Spectrum Measurements from SPT-3G 2018 Data’*
- Inv. 2022 July, Intriguing Inconsistencies in the Growth of Structure over Cosmic Time, Sexten Center for Astrophysics, Italy — *‘Constraints on Structure Growth from SPT-3G Power Spectrum Measurements’*
- Sem. 2022 July, Imperial College London, UK — *‘Searching for Physics Beyond the Standard Model with Planck, SPT, and ACT data’*
- Sem. 2022 June, University of Cambridge, UK — *‘Searching for Physics Beyond the Standard Model with Planck, SPT, and ACT data’*

- Sem. 2022 June, University of Sussex, UK — *‘Searching for Physics Beyond the Standard Model with Planck, SPT, and ACT data’*
- Sem. 2022 June, Max Planck Institute for Astrophysics, Germany — *‘Searching for Physics Beyond the Standard Model with Planck, SPT, and ACT data’*
- \* 2022 June, Colloque National CMB-France, Institut d’Astrophysique de Paris, France — *‘Searching for Physics Beyond the Standard Model with Planck, SPT, and ACT data’*
- Sem. 2022 February, Institut d’Astrophysique de Paris, France — *‘Constraints on Cosmological Parameters from SPT-3G 2018’*
- \* 2021 August, Cosmo21, University of Illinois, USA — *‘Constraints on Cosmology from the SPT-3G 2018 EE/TE Power Spectra’*
- \* 2021 July, ASA2021, University of Melbourne, Australia — *‘Constraints on Cosmology from the SPT-3G 2018 EE/TE Power Spectra’*
- Inv. 2021 June, Six week summer webinar series on the growth of structure over cosmic time — *‘CMB Measurements of the Growth of Structure from SPT’*
- Sem. 2021 May, University of Sussex, UK — *‘Constraints on Cosmology from the SPT-3G 2018 EE/TE Power Spectra’*
- Sem. 2021 April, KIPAC Tea Talk, Stanford University, USA — *‘Constraints on  $\Lambda$ CDM Extensions from the SPT-3G 2018 EE/TE Power Spectra and their Implications for the Hubble Constant’*
- \* 2019 December, AIP Summer Meeting 2019, RMIT, Australia — *‘Preparing Next-Generation CMB Experiments for Big Data Challenges Using Extreme Digitisation’*
- \* 2018 June, ASA 2018, Swinburne University, Australia — *‘Using Extreme Digitisation to Combat Data Challenges in CMB Observations’*

# Lennart Balkenhol

## List of Publications

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### REFEREED JOURNAL ARTICLES

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1,337 total citations of published works, average of 51.4 per paper, h-index of 16, according to Inspire.<sup>1</sup>

### PROJECTS LEAD OR WITH MAJOR CONTRIBUTION

I have lead the following projects or made major contributions to them.

1. '*Probing Anisotropic Cosmic Birefringence with Foreground-Marginalised SPT B-mode Likelihoods*'  
**L. Balkenhol**, A. Coerver, C. L. Reichardt, J. A. Zebrowski  
The Open Journal of Astrophysics, V8 2025
2. '*SPT-3G D1: CMB temperature and polarization power spectra and cosmology from 2019 and 2020 observations of the SPT-3G Main field*'  
E. Camphuis, W. Quan, **L. Balkenhol**, ... et al. [108 authors]  
Submitted to Physical Review D, arXiv:2506.20707
3. '*Compressed 'CMB-lite' Likelihoods Using Automatic Differentiation*'  
**L. Balkenhol**  
The Open Journal of Astrophysics V8 2025
4. '*candl: Cosmic Microwave Background Analysis with a Differentiable Likelihood*'  
**L. Balkenhol**, C. Trendafilova, K. Benabed, S. Galli  
Astronomy & Astrophysics, V686 (June 2024), A10
5. '*A Measurement of the CMB Temperature Power Spectrum and Constraints on Cosmology from the SPT-3G 2018 TT/TE/EE Data Set*'  
**L. Balkenhol**, D. Dutcher, A. Spurio Mancini, A. Doussot, K. Benabed, S. Galli, ... et al. [87 authors]  
Physical Review D 108 (2023) 2, 023510
6. '*The Parameter-Level Performance of Covariance Matrix Conditioning in Cosmic Microwave Background Data Analyses*'  
**L. Balkenhol** and C. L. Reichardt  
Monthly Notices of the Royal Astronomical Society vol. 512 (2022), no. 3, pp.4394-4403
7. '*Constraints on  $\Lambda$ CDM extensions from the SPT-3G 2018 EE and TE power spectra*'  
**L. Balkenhol**, D. Dutcher, ... et al. [120 authors]  
Physical Review D 104 (2021) 8, 083509
8. '*Measurements of the E -mode polarization and temperature-E -mode correlation of the CMB from SPT-3G 2018 data*'  
D. Dutcher, **L. Balkenhol**, ... et al. [121 authors]  
Physical Review D 104 (2021) 2, 022003
9. '*Extreme digitization for ground-based cosmic microwave background experiments*'  
**L. Balkenhol** and C. L. Reichardt  
Monthly Notices of Royal Astronomical Society vol. 487 (2019), no. 3, pp. 3279–3287

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<sup>1</sup>Further statistics available on:

NASA ADS: <https://ui.adsabs.harvard.edu/search/q=author%3A%22Balkenhol%2C%20Lennart>

Inspire: <https://inspirehep.net/authors/1883019>

ORCID: <https://orcid.org/0000-0001-6899-1873>

## MODEST CONTRIBUTION

I have made limited contributions to the following projects.

1. *'Towards constraining cosmological parameters with SPT-3G observations of 25% of the sky'*  
A. Vitrier, K. Fichman, **L. Balkenhol**, ... et al. [98 authors]  
Submitted to Physical Review D, arXiv:2510.24669
2. *'SPT-3G D1: Axion Early Dark Energy with CMB experiments and DESI'*  
A. R. Khalife, **L. Balkenhol**, ... et al. [107 authors]  
Submitted to Physical Review D, arXiv:2507.23355
3. *'The BAO-CMB Tension and Implications for Inflation'*  
E. G. M. Ferreira, E. McDonough, **L. Balkenhol**, R. Kallosh, L. Knox, A Linde  
Submitted to Physical Review D, arXiv:2507.12459
4. *'OLÉ – Online Learning Emulation in Cosmology'*  
S. Günther, **L. Balkenhol**, C. Fidler, A. R. Khalife, J. Lesgourgues, M. R. Mosbech, R. K. Sharma  
Accepted in the Journal of Cosmology and Astroparticle Physics
5. *'Hints of Early Dark Energy in Planck, SPT, and ACT data: new physics or systematics?'*  
T. Smith, M. Lucca, V. Poulin, G. Abellan, **L. Balkenhol**, K. Benabed, S. Galli, and R. Murgia  
Physical Review D 106 (2022) 4, 043526
6. *'Consistency of Planck, ACT and SPT constraints on magnetically assisted recombination and forecasts for future experiments'*  
S. Galli, L. Pogosian, K. Jedamzik, and **L. Balkenhol**  
Physical Review D 105 (2022) 2, 023513

## COLLABORATION WORK

I am a co-author of the papers below as part of the SPT collaboration.

1. *'Detection of Millimeter-Wavelength Flares from Two Accreting White Dwarf Systems in the SPT-3G Galactic Plane Survey'*  
Y. Wan, J. D. Vieira, P. M. Chichura, T. J. Maccarone, ... **L. Balkenhol**, ... et al. [99 authors]  
Submitted to the Astrophysical Journal, arXiv:2509.08962
2. *'Millimeter-wave observations of Euclid Deep Field South using the South Pole Telescope: A data release of temperature maps and catalogs'*  
M. Archipley, A. Hryciuk, L. E. Bleem, K. Korneelje, M. Klein, ... **L. Balkenhol**, ... et al. [112 authors]  
Submitted to Astronomy & Astrophysics, arXiv:2506.00298
3. *'Constraints on Inflationary Gravitational Waves with Two Years of SPT-3G Data'*  
J. A. Zebrowski, C. L. Reichardt, ... **L. Balkenhol**, ... et al. [109 authors]  
Submitted to Physical Review D, arXiv:2505.02827
4. *'Unified and consistent structure growth measurements from joint ACT, SPT and Planck CMB lensing'*  
Frank J. Qu, Fei Ge, W. L. Kimmy Wu, Irene Abril-Cabezas, Mathew S. Madhavacheril, Marius Millea, ... **L. Balkenhol**, ... et al. [157 authors]  
Accepted in Physical Review Letters, arXiv:2504.20038
5. *'The SPT-Deep Cluster Catalog: Sunyaev-Zel'dovich Selected Clusters from Combined SPT-3G and SPTpol Measurements over 100 Square Degrees'*  
K. Korneelje, L. E. Bleem, E. S. Rykoff, ... **L. Balkenhol**, ... et al. [210 authors]  
Submitted to the Astrophysical Journal, arXiv:2503.17271

6. *'Measurements of the Temperature and E-mode Polarization of the Cosmic Microwave Background from the Full 500-square-degree SPTpol Dataset'*  
T.-L. Chou, ... **L. Balkenhol**, ... et al. [63 authors]  
Physical Review D 111 (2025) 12, 123513
7. *'Pointing Accuracy Improvements for the South Pole Telescope with Machine Learning'*  
P. M. Chichura, A. Rahlin, ... **L. Balkenhol**, ... et al. [103 authors]  
Journal of Astronomical Instrumentation, V14, 2550001
8. *'Cosmology From CMB Lensing and Delensed EE Power Spectra Using 2019-2020 SPT-3G Polarization Data'*  
F. Ge, M. Millea, E. Camphuis, C. Daley, N. Huang, Y. Omori, W. Quan, ... **L. Balkenhol**, ... et al. [96 authors]  
Physical Review D 111 (2025) 8, 083534
9. *'Detection of Thermal Emission at Millimeter Wavelengths from Low-Earth Orbit Satellites'*  
A. Foster, A. Chokshi, ... **L. Balkenhol**, ... et al. [92 authors]  
The Open Journal of Astrophysics, V8 2025
10. *'Measurement and Modeling of Polarized Atmosphere at the South Pole with SPT-3G'*  
A. Coerver, J. A. Zebrowski, S. Takakura, W. L. Holzapfel, ... **L. Balkenhol**, ... et al. [105 authors]  
The Astrophysical Journal, 982, (2025) 1
11. *'Mass calibration of DES Year-3 clusters via SPT-3G CMB cluster lensing'*  
B. Ansarinejad, S. Raghunathan, ... **L. Balkenhol**, ... et al. [145 authors]  
Journal of Cosmology and Astroparticle Physics 07 (2024) 024
12. *'Testing the  $\Lambda$ CDM Cosmological Model with Forthcoming Measurements of the Cosmic Microwave Background with SPT-3G'*  
K. Prabhu, S. Raghunathan, M. Millea, G. Lynch, ... **L. Balkenhol**, ... et al. [101 authors]  
The Astrophysical Journal 973 (2024) 4
13. *'First Constraints on the Epoch of Reionization Using the non-Gaussianity of the Kinematic Sunyaev-Zel'dovich Effect from the South Pole Telescope and Herschel-SPIRE Observations'*  
S. Raghunathan, ... **L. Balkenhol**, ... et al. [124 authors]  
Physical Review Letters 133, 121004
14. *'Flaring Stars in a Non-targeted mm-wave Survey with SPT-3G'*  
C. Tandoi, S. Guns, A. Foster, ... **L. Balkenhol**, ... et al. [99 authors]  
The Astrophysical Journal 972 (2024) 6
15. *'A Measurement of Gravitational Lensing of the Cosmic Microwave Background Using SPT-3G 2018 Data'*  
Z. Pan, F. Bianchini, W. L. K. Wu, ... **L. Balkenhol**, ... et al. [136 authors]  
Physical Review D 108 (2023) 12, 122005
16. *'A measurement of the mean central optical depth of galaxy clusters via the pairwise kinematic Sunyaev-Zel'dovich effect with SPT-3G and DES'*  
E. Schiappucci, F. Bianchini, ... **L. Balkenhol**, ... et al.  
Physical Review D 107 (2023) 4, 042004
17. *'Searching for axion-like time-dependent cosmic birefringence with data from SPT-3G'*  
K. R. Ferguson, A. J. Anderson, N. Whitehorn, ... **L. Balkenhol**, ... et al. [81 authors]  
Physical Review D 106 (2022) 4, 042011
18. *'Asteroid Measurements at Millimeter Wavelengths with the South Pole Telescope'*  
P. M. Chichura, A. Foster, C. Patel, N. Ossa-Jaen, ... **L. Balkenhol**, ... et al. [144 authors]  
The Astrophysical Journal 936 (2022) 2, 173

19. *'Improving cosmological constraints from galaxy cluster number counts with CMB-cluster-lensing data: Results from the SPT-SZ survey and forecasts for the future'*  
P. S. Chabul, C. L. Reichardt, N. Gupta, ... **L. Balkenhol**, ... et al. [43 authors]  
The Astrophysical Journal 931 (2022) 2, 139
20. *'The Design and Integrated Performance of SPT-3G'*  
J. A. Sobrin, A. J. Anderson, A. N. Bender, B. A. Benson, D. Dutcher, A. Foster, N. Goeckner-Wald, J. Montgomery, A. Nadolski, A. Rahlin, ... **L. Balkenhol**, ... et al. [123 authors]  
The Astrophysical Journal Supplement Series 258 (2022) 2, 42
21. *'Performance and characterization of the SPT-3G digital frequency-domain multiplexed readout system using an improved noise and crosstalk model'*  
J. Montgomery, ... **L. Balkenhol**, ... et al. [121 authors]  
Journal of Astronomical Telescopes, Instruments, and Systems 8 (2022), 014001
22. *'Detection of Galactic and Extragalactic Millimeter-Wavelength Transient Sources with SPT-3G'*  
S. Guns, A. Foster, C. Daley, A. Rahlin, N. Whitehorn, ..., **L. Balkenhol**, ... et al. [122 authors]  
The Astrophysical Journal 916 (2021) 2, 98
23. *'Searching for Anisotropic Cosmic Birefringence with Polarization Data from SPTpol'*  
F. Bianchini, W. L. K. Wu, ... **L. Balkenhol**, ... et al. [72 authors]  
Physical Review D 102 (2020) 8, 083504

## THESES

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1. *'Constraining Cosmology with SPT-3G'*  
PhD Thesis, 2022  
Available at: <https://minerva-access.unimelb.edu.au/items/4b67dae4-60f1-416b-80a7-d60d580d899c/full>
2. *'Few-Bit Digitisation for Ground-Based Cosmic Microwave Background Experiments'*  
MSc Thesis, 2018  
Available upon request.
3. *'Analytical Aperture Mass Models and Tools of Gravitational Lensing in Python'*  
BSc Thesis, 2016  
Available upon request.