Hayley J. Macpherson

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Education

PhD in Astrophysics, March 2016 - September 2019
Monash University, Clayton, Victoria, Australia
Thesis: Inhomogeneous cosmology in an anisotropic universe

Bachelor of Science (Honours), 2015
Monash University, Clayton, Victoria, Australia
Thesis: Inhomogeneous cosmology in an anisotropic universe

Bachelor of Science, 2012 - 2014
Monash University, Clayton, Victoria, Australia
Major: Astrophysics

Employment

NASA Einstein Fellow November 2022 - present
Kavli Institute for Cosmological Physics (KICP)
University of Chicago, Chicago, Illinois, USA

Herchel Smith Fellow October 2019 - October 2022
Department of Applied Mathematics and Theoretical Physics (DAMTP)
University of Cambridge, Cambridge, United Kingdom

Teaching Experience

Teaching Associate, Physics & Astronomy 2015 - 2019
Monash University, Clayton, Victoria, Australia
I worked as a teaching associate during my PhD for the following units offered as part of an Astrophysics major

- *ASP2011 - Astronomy.*
- *ASP2062 - Introduction to astrophysics.*
- *ASP3051 - Relativity and cosmology.*
- *ASP3162 - Computational astrophysics and the extreme universe.*

For all of these I took control of the weekly tutorial/laboratory classes, helping students with questions regarding content, marking weekly question sheets and exam marking.

PhD supervision May 2021 - present
Co-supervision of PhD candidate Michael Williams at the University of Canterbury, New Zealand (Main supervisor: Prof. David Wiltshire). Thesis title: *"Numerical Simulations in Relativistic Cosmology"*

Undergraduate supervision November 2020 - June 2022

- Co-supervision of summer research project with student Michael Williams at the University of Canterbury, New Zealand (Main supervisor: Prof. David Wiltshire) from November 2020 - March 2020. Project title: *"Cosmic structures from numerical solution of Einstein's equations"*
- Co-supervision of Part III student Jessica Cowell's research project at the Institute of Astronomy (IoA), Cambridge, (Co-supervised by Dr. Suhail Dhawan) from October 2021 - June 2022. Project title: *"Quantifying low-redshift cosmological anisotropy"*

- Co-supervision of Jessica Cowell's 8-week summer project preparing a publication of her Part III work in August and September 2022.

Publications

- **Macpherson, H. J.**, *Cosmological distances with general-relativistic ray tracing: framework and comparison to cosmographic predictions*, 2022, *arXiv e-prints*, arXiv:2209.06775 (submitted to JCAP)
- Dhawan, S., Borderies, A., **Macpherson, H. J.** and Heinesen, A., *The quadrupole in the local Hubble parameter: first constraints using Type Ia supernova data and forecasts for future surveys*, 2022, *arXiv e-prints*, arXiv:2205.12692 (submitted to MNRAS)
- Heinesen, A., **Macpherson, H. J.**, *A prediction for anisotropies in the nearby Hubble flow*, 2022, JCAP, 2022, 057
- Ota, A., **Macpherson, H. J.**, Coulton, W. R., *Covariant transverse-traceless projection for secondary gravitational waves*, 2021, *arXiv e-prints*, arXiv:2111.09163 (accepted for publication in Phys. Rev. D)
- **Macpherson, H. J.**, Heinesen, A., *Luminosity distance and anisotropic sky-sampling at low redshifts: a numerical relativity study*, 2021, Phys. Rev. D, 104, 023525
- Adamek, J., Barrera-Hinojosa, C., Bruni, M., Li, B., **Macpherson, H. J.**, and Mertens, J. B., *Numerical solutions to Einstein's equations in a shearing-dust Universe: a code comparison*, 2020, Classical and Quantum Gravity, 37(15):154001
- **Macpherson H. J.**, Price D. J., Lasky P. D., *Einstein's Universe: Cosmological structure formation in numerical relativity*, 2019, Phys. Rev. D., 99, 063522
- **Macpherson H. J.**, Lasky P. D., Price D. J., *The trouble with Hubble: Local versus Global Expansion Rates in Inhomogeneous Cosmological Simulations with Numerical Relativity*, 2018, ApJ, 865, L4
- **Macpherson H. J.**, Lasky P. D., Price D. J., *Inhomogeneous cosmology with numerical relativity*, 2017, Phys. Rev. D, 95, 064028
- De Silva G. M., Carraro G., D'Orazi V., Efremova V., **Macpherson H.**, Martell S., Rizzo L., *Binary open clusters in the Milky Way: photometric and spectroscopic analysis of NGC 5617 and Trumpler 22*, 2015, MNRAS, 453, 106

Awards

- NASA Hubble Fellowship Program Einstein Fellowship at the University of Chicago (2022-2025)
- Charlene Heisler Prize from the Astronomical Society of Australia (ASA) for the most outstanding PhD thesis in astronomy (2020)
- Robert Street Doctoral Prize in Physics for the best PhD thesis in the School of Physics & Astronomy at Monash University (2020)
- Mollie Holman Medal for the best PhD thesis in the Faculty of Science, Monash University (2020)
- Research Associateship, Fitzwilliam College, Cambridge (2020 & 2021)
- Herchel Smith Postdoctoral Fellowship (2019-2022)
- Monash University's Faculty of Science Young Science Leader Award (2018)
- Australian Postgraduate Award PhD scholarship (2016-2019)
- J.L William scholarship from the School of Physics & Astronomy (2016-2019)
- Monash Centre for Astrophysics top honours student prize (2015)

Invited Talks

- *"Luminosity distance and anisotropic sky-sampling at low redshifts: A numerical relativity study"* AAPPS-DACG workshop on Astrophysics, Astroparticle Physics, Cosmology and Gravitation (online) from November 14-17th
- *"Numerical relativity as a tool to study inhomogeneous cosmology"* European Einstein Toolkit meeting, University College Dublin, Ireland from August 29th-September 2nd, 2022
- *"Low-redshift cosmic anisotropy in simulations using numerical relativity"* Monash University Astrophysics seminar, Melbourne, Australia, July 19th, 2022
- *"Low-redshift cosmic anisotropy in simulations using numerical relativity"* University of Milano-Bicocca AstroBicocca seminar, Milan, Italy, June 16th, 2022
- *"Low-redshift cosmic anisotropy in simulations using numerical relativity"* University College London cosmology and extra-galactic seminar (online), June 1st, 2022
- *"Luminosity distance and anisotropic sky-sampling at low redshifts: A numerical relativity study"* Institute of Theoretical Astrophysics colloquium at the University of Oslo, May 13th, 2022
- *"Luminosity distance and anisotropic sky-sampling at low redshifts: A numerical relativity study"* Liverpool John Moores University ARI seminar, March 23rd, 2022
- *"Numerical relativity as a tool for cosmology"* Plenary talk at ACGRG11 at the University of Tasmania, Australia, February 2-4, 2022
- *"Luminosity distance and anisotropic sky-sampling at low redshifts: A numerical relativity study "* Queen Mary University of London cosmology seminar (online), December 15th, 2021
- *"Luminosity distance and anisotropic sky-sampling at low redshifts: A numerical relativity study"* Institute for Cosmology and Gravitation Portsmouth seminar (online), October 6th, 2021
- *"Low-redshift cosmic anisotropy in simulations using numerical relativity"* MIT Brown Bag Lunch talk (online), October 4th, 2021
- *"Luminosity distance and anisotropic sky-sampling at low redshifts: a numerical relativity study"* Cambridge/LMU Munich joint journal club seminar, June 11th, 2021
- *"How much are local anisotropies biasing our measurements?"* Cosmology Talks online seminar (joint with Asta Heinesen) on YouTube, June 3rd, 2021
- *"Luminosity distance and anisotropic sky-sampling at low redshift: a numerical relativity study"* DAMTP General Relativity seminar, Cambridge (on Zoom), May 28th, 2021
- *"Numerical relativity as a tool to study inhomogeneous cosmology"* CIRM Theory of Gravitation and Variation in Cosmology Virtual Research School, April 12-16th, 2021
- *"Luminosity distance and anisotropic sky-sampling at low redshift: a numerical relativity study"* University of Hawaii online seminar, April 1st, 2021
- *"The importance of anisotropy in sky-sampling of cosmological data"* University of Leicester online seminar, March 10th, 2021
- *"An improved calculation of cosmological backreaction in simulations with numerical relativity"* University of Helsinki online seminar, November 11th, 2020
- *"Einstein's Universe: Cosmological structure formation in numerical relativity"* DAMTP Cosmology Seminar, University of Cambridge, February 24th, 2020

- *"Einstein's Universe: Cosmological structure formation in numerical relativity"* Kenyon College, Columbus, OH, USA, February 21st, 2020
- *"Einstein's Universe: Cosmological structure formation in numerical relativity"* DAMTP General Relativity Seminar, University of Cambridge, November 29th, 2019
- *"Einstein's Universe: Cosmological structure formation in numerical relativity"* School of Physics & Astronomy, Queen Mary University of London, November 20th, 2019
- *"Cosmological simulations of large-scale structure with numerical relativity"* at the "From Dark Energy to Bright Synergies" workshop, Sexten Centre for Astrophysics, Sesto-Sexten, Italy, July 23-27 2018
- *"Cosmological simulations of large-scale structure with numerical relativity"* at the "General relativistic effects in cosmological large-scale structure" workshop, Sexten Centre for Astrophysics, Sesto-Sexten, Italy, July 16-20 2018
- *"The trouble with H_0: a general relativistic point of view"* Centre for Astrophysics & Supercomputing, Swinburne University of Technology, Melbourne, May 16th 2018
- *"General Relativistic cosmological structure formation"* at the 9th Australasian Conference on General Relativity and Gravitation, Gingin, Perth, November 27-30 2017
- *"Inhomogeneous cosmology in an anisotropic Universe"* Institute of Cosmology and Gravitation, University of Portsmouth, United Kingdom, July 12th 2017
- *"Inhomogeneous cosmology in an anisotropic Universe"* Department de Physique Theorique, Universite de Geneve, Switzerland, June 30th 2017
- *"Inhomogeneous cosmology with the Einstein Toolkit"* Department of Physics, University of Trento, Italy, June 20th 2016

Conference Presentations

Here is a selection (not necessarily exhaustive) of contributed conference presentations I have given.

- *"Precision cosmological modelling in nonlinear general relativity "* at the NASA Hubble Fellowship Program (NFHP) fellows symposium (hybrid; presented online) at STScI in Baltimore, Maryland, USA
- *"Fully nonlinear ray-tracing in cosmological simulations with numerical relativity"* at the General Relativistic effects in observing the Large Scale Structure of the Universe workshop, Porto, Portugal, June 20-23, 2022
- *"FLRWSolver: realistic cosmological initial conditions for the Einstein Toolkit"* at the North American Einstein Toolkit summer school on Zoom (hosted by the University of Illinois Urbana-Champaign), July 26-30th, 2021
- *"The General Luminosity Distance 'Hubble Law' for Model-Independent Cosmological Analysis"* (joint talk with Asta Heinesen) at Cosmology From Home, July 5-15th, 2021
- *"Hubble's law in general space-times: a framework for model-independent cosmological data analysis"* (joint talk with Asta Heinesen) at the Relativistic Aspects of Large Scale Structure on Zoom (hosted by Zurich), April 3-5, 2021
- *"Simulations of large-scale structure formation with numerical relativity"* at the Euclid Consortium end of year meeting (online) Dec. 14 & 15, 2020
- *"Cosmological backreaction in simulations with numerical relativity"* at the GR Simulations in Cosmology workshop on Zoom (hosted by QMUL), September 7 & 8 2020

- *"The trouble with Hubble: a general relativistic point of view"* at the 30th Texas Symposium on Relativistic Astrophysics, Portsmouth, United Kingdom, December 16-20 2019
- *"Cosmological structure formation with numerical relativity"* at the 13th ANITA Theory Workshop, Swinburne University of Technology, Melbourne, February 4-8 2019
- *"Inhomogeneous cosmological simulations with numerical relativity"* at the Inhomogeneous Cosmologies III workshop, Jagiellonian University, Kraków, Poland, September 16-21 2018
- *"Inhomogeneous cosmology in an anisotropic Universe"* at the Inhomogeneous Cosmologies workshop, Nicolaus Copernicus University, Torun, Poland, July 1-7 2017
- *"Inhomogeneous cosmology with numerical relativity"* at the 11th ANITA Theory Workshop, University of Tasmania, February 9-10 2017
- *"Formation of structures in the Universe: A full General-Relativistic treatment"* at CAASTRO Diving into the Dark: Bridging Cosmological Theory & Observation, Cairns, July 18-22 2016
- *"Cosmology with the Einstein Toolkit"* at the Einstein Toolkit EU School and Workshop, University of Trento, Italy, June 13-17 2016
- *"Formation of structures in the Universe: A full General-Relativistic treatment"* at the 10th ANITA Theory Workshop, Monash University, February 11-12 2016
- *"Formation of structures in the Universe: A full General-Relativistic treatment"* at the Eighth Australasian Conference on General Relativity and Gravitation (ACGRG8), Monash University, December 2-4 2015

Professional Activities

- Judging panel for the Kerr Prize for best student talk at ACGRG11 in Hobart, Australia (February 2022)
- Delivered a tutorial on use of FLRWSolver and the Einstein Toolkit at the GR Simulations in Cosmology Workshop (September 7&8 2020)
- Organiser for the GR Simulations in Cosmology Workshop, held online and hosted by Queen Mary University of London (September 7&8 2020)
- Co-organiser for the Cambridge Cosmology group meetings (2020-2022)
- Organiser for the DAMTP Racism Discussion Group (2020)
- Local organising committee member for the 13th Australian National Institute for Theoretical Astrophysics (ANITA) annual science workshop in Melbourne, February 4th-8th (2019)
- Delivered a tutorial (4 hours total) on using the Einstein Toolkit numerical relativity code at the Inhomogeneous Cosmologies III workshop in Kraków, Poland (2018)
- Scientific organising committee member for the Inhomogeneous Cosmologies III workshop in Kraków, Poland (2018)
- Local organising committee member for the 1st Phantom Users Workshop in Melbourne, February 19-23 (2018)
- Member of the Postgraduate Committee (PGC) and representative for students within the School of Physics & Astronomy (2017)
- Steering committee member for the Monash University Graduate Research Conference in Melbourne, November 17 (2017)

- Local organising committee member for the ADACS Data Intensive Astronomy Workshop in Melbourne, August 7-9 (2017)
- Scientific organising committee member for the 1st Inhomogeneous Cosmologies workshop in Torun, Poland (2017)

Grants

I was the Principle Investigator on the DiRAC project *Einstein's Universe: Using numerical relativity to unveil the general-relativistic signatures in our cosmological observations* from October 2021 - April 2022. The project was allocated 1.35 million CPU hours on the COSMA8 machine in Durham, UK.

My project *Inhomogeneous cosmology in an anisotropic Universe (INCA)* was awarded the following allocations in the National Computational Merit Allocation Scheme (NCMAS):

- 1 million CPU hours on the Magnus machine at the Pawsey Supercomputing centre in Perth, Western Australia (December 2016 and 2017 round)
- 100 thousand CPU hours on Multi-modal Australian ScienceS Imaging and Visualisation Environment (MASSIVE) M2 machine in Melbourne (December 2016 round)

Skills

- Extensive use of the Einstein Toolkit numerical relativity code based on the Cactus infrastructure
- Proficient in modern Fortran and Python programming
- Basic usage of Mathematica including the Riemannian Geometry and Tensor Calculus (RGTC) package
- Over 2.5 million CPU hour usage of supercomputer resources

Outreach

- *"Listen carefully: how astronomers can hear gravitational waves in space"* online YouTube livestream talk for Astronomy on Tap, Cambridge, February 25th, 2021
- *"The Big Bang and Black Holes: In Celebration of Stephen Hawking's Birthday"* online YouTube livestream with the Centre for Theoretical Cosmology (leader of panel discussion), January 8th, 2021
- *"How to build a Universe"* online YouTube livestream for the Institute of Astronomy Wednesday open evenings, December 2nd, 2020
- *"Newton vs Einstein: battle of the brains"* kids talk online YouTube stream for the IoA Cambridge, June 30th, 2020
- *"How to make a Universe"* talk at Astronomy on Tap, Cambridge, February 27th, 2020
- Organiser for "*Astronomy on Tap*" Cambridge (2019 - present)
- Co-founder of the School of Physics and Astronomy Women in Physics & Astronomy mentoring program, Monash University, Melbourne (2017-2019)
- Panel member for Science Week Q&A session at "The Academy" Catholic Girls Secondary School, Melbourne, August 14th (2019)
- Live science demonstrations for "Science Night" at Overport Primary School, Melbourne (2017 & 2019)
- Participant in running the Monash Centre for Astrophysics outreach stand at the Astrolight Festival at Scienceworks, Melbourne (2017)
- Skype discussion with primary school students in Tawa, New Zealand about space and Astronomy (2016)

- Monash University open day talk to high school students encouraging Physics & Astronomy (2015)