

# MICHAEL J. COONS

## CURRICULUM VITAE



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### CONTACT AND PERSONAL INFORMATION

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Citizenships: Australia, USA

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### CAREER PROGRESSION

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| 2019 –      | Deputy Editor-in-Chief<br>Journal of the Australian Mathematical Society  |
| 2019 –      | Associate Professor of Mathematics<br>The University of Newcastle, Australia  |
| 2018        | Visiting Professor<br>Forschungsschwerpunkt Mathematische Modellierung, Universität Bielefeld, Germany  |
| 2017 – 2018 | Visiting Researcher<br>Alfréd Rényi Institute of the Hungarian Academy of Sciences, Budapest, Hungary   |
| 2015 – 2018 | Senior Lecturer of Mathematics<br>The University of Newcastle, Australia  |
| 2014 – 2016 | Distinguished Early Career Research Fellow (DECRA)<br>Australian Research Council, The University of Newcastle, Australia   |
| 2012 – 2014 | Lecturer of Mathematics<br>The University of Newcastle, Australia   |
| 2009 – 2012 | Fields–Ontario Postdoctoral Fellow<br>Fields Institute and University of Waterloo, Canada<br>Hosts: Kevin Hare and Cameron L. Stewart   |
| 2006 – 2009 | Ph.D. in Mathematics, Simon Fraser University, Burnaby, British Columbia, Canada<br>Thesis: <i>Parity, transcendence, and multiplicative functions</i><br>Advisors: Peter Borwein and Stephen Kwok-Kwong Choi |
| 2005 – 2006 | Fulbright Scholar<br>Alfréd Rényi Institute of the Hungarian Academy of Sciences, Budapest, Hungary<br>Host: János Pintz  |
| 2005 – 2006 | Visiting Student<br>Central European University, Budapest, Hungary  |
| 2004 – 2005 | M.S. in Mathematics, Baylor University, Waco, Texas, USA<br>Thesis: <i>General moment theorems with applications</i><br>Advisor: Klaus Kirsten  |
| 1999 – 2003 | B.A. in Mathematics, The University of Montana, Missoula, Montana, USA  |

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### AWARDS, HONOURS, AND SCHOLARSHIPS

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| 2020 | Plenary Speaker, Number Theory Down Under VIII, University of Melbourne;<br><b>Simons Foundation Visiting Professor</b> , Math. Forsch. Oberwolfach, Germany. |
| 2019 | Keynote Speaker, Dynamics and Number Theory, University of Sydney;<br>Invited Lecturer, AMSI Summer School, UNSW.   |

- 2017      **Mahony–Neumann–Room Prize**, Australian Mathematical Society (with J. P. Bell and K. G. Hare, for the best paper in the Bulletin of the Australian Mathematical Society in 2011–2016).
- 2016      Chair, Early Career Plenary Session, Australian Math. Soc. Meeting, ANU.
- 2014      **Australian IMU Delegate** to the *General Assembly of the IMU/ICM*, Gyeongju, Korea; Keynote Speaker, Australian Mathematical Sciences Student Conference; **Discovery Early Career Research Award**, Australian Research Council (2014–2016).
- 2013      Australian Mathematical Society Early Career Workshop, invited research presenter.
- 2012      Australian Mathematical Society representative to *Science meets Parliament*.
- 2010      Simon Fraser University Nominee for 2010 CMS Doctoral Prize (essentially, the departmental award for best PhD thesis of 2009).
- 2009      **Fields–Ontario Postdoctoral Fellowship** (2009–2012); Graduate Fellowship, Simon Fraser University.
- 2008      President’s PhD Research Stipend, Simon Fraser University; Graduate Fellowship, Simon Fraser University; Research Travel Award, Simon Fraser University.
- 2007      Second Place Poster Prize, CECM Summer Meeting.
- 2005      **Fulbright Scholar**, Alfréd Rényi Institute, Budapest, Hungary; Best Student Paper Prize, MAA Regional Meeting, Texas Section.
- 2003      Dean’s List, University of Montana; Pi Mu Epsilon, National Honors Society of Mathematics; Phi Kappa Phi, National Honors Society; Undergraduate Research Fellow, University of Montana; Scholar of the College of Arts and Sciences, University of Montana.
- 2000      Phi Theta Kappa, National Honors Society.

## PUBLICATIONS (MANY OF MY PREPRINTS ARE AVAILABLE AT [arXiv.org](https://arxiv.org).)

### Preprints

- [53] (with J. Evans and N. Mañibo) *Beyond substitutions: the spectral theory of regular sequences*, preprint.
- [52] (with J. Evans) *A sequential view of self-similar measures, or, what the ghosts of Mahler and Cantor can teach us about dimension*, preprint.
- [51] (with M. Baake, J. Evans and P. Gohlke) *On a family of singular continuous measures related to the doubling map*, preprint.

### Accepted

- [50] (with M. Baake) *Scaling of the diffraction measure of  $k$ -free integers near the origin*, **Michigan Mathematical Journal**, to appear.
- [49] *A diffraction abstraction*, in “2019 MATRIX Annals”, **MATRIX Book Ser.**, Springer, to appear.
- [48] (with M. Baake, U. Grimm, J. A. G. Roberts and R. Yassawi) *Aperiodic order meets number theory: Origin and structure of the field*, in “2019 MATRIX Annals”, **MATRIX Book Ser.**, Springer, to appear.

### Published

- [47] *Degree-one Mahler functions: asymptotics, applications and speculations*, **Bulletin of the Australian Mathematical Society** **102** (2020), no. 3, 399–409.
- [46] (with M. Baake and N. Mañibo) *Constant-length binary substitutions and Mahler measures of Borwein polynomials*, in “From Analysis to Visualization: A Celebration of the Life and Legacy of Jonathan M. Borwein”, 303–322, **Springer Proceedings in Math. & Stat.**, Vol. 13, Springer, 2020.

- [45] (with Y. Bugeaud) *A Mahler Miscellany*,  
**Documenta Mathematica** (2019), Extra Vol., Mahler Selecta, 179–190.
- [44] (with M. Baake, J. M. Borwein and Y. Bugeaud) *Introduction*,  
**Documenta Mathematica** (2019), Extra Vol., Mahler Selecta, 3–11.
- [43] (co-edited with M. Baake and Y. Bugeaud) *The Legacy of Kurt Mahler: A Mathematical Selecta*,  
**Documenta Mathematica** (2019), Extra Vol., Mahler Selecta.
- [42] (with J. P. Bell, F. Chyzak and P. Dumas) *Becker’s conjecture on Mahler functions*,  
**Transactions of the American Mathematical Society** **372** (2019), no. 5, 3405–3423.
- [41] (with L. Spiegelhofer) *Number theoretic aspects of regular sequences*,  
in “Sequences, Groups, and Number Theory”, 37–87, **Trends Math.**, Birkhäuser/Springer, 2018.
- [40] *Mahler takes a regular view of Zaremba*,  
**Integers** **18A** (2018), #A6, 1–15.
- [39] (with M. Baake) *A natural probability measure derived from Stern’s diatomic sequence*,  
**Acta Arithmetica** **183** (2018), no. 1, 87–99.
- [38] *Proof of Northshield’s conjecture concerning an analogue of Stern’s sequence for  $\mathbb{Z}[\sqrt{2}]$* ,  
**Australasian Journal of Combinatorics** **71(1)** (2018), 113–120.
- [37] *Extension of theorem of Duffin and Schaeffer*,  
**Journal of Integer Sequences** **20** (2017), Article 17.9.4, 1–4.
- [36] *An asymptotic approach in Mahler’s method*,  
**New Zealand Journal of Mathematics** **47** (2017), 27–42.
- [35] (with Y. Tachiya) *Transcendence over meromorphic functions*,  
**Bulletin of the Australian Mathematical Society** **95** (2017), no. 3, 393–399.
- [34] *Regular sequences and the joint spectral radius*,  
**International Journal of Foundations of Computer Science** **28** (2017), no. 2, 135–140.
- [33] (with L. Spiegelhofer) *The maximal order of hyper-(b-ary)-expansions*,  
**Electronic Journal of Combinatorics** **24** (2017), no. 1, #P1.15, 1–8.
- [32] (with J. P. Bell) *Transcendence tests for Mahler functions*,  
**Proceedings of the American Mathematical Society** **145** (2017), no. 3, 1061–1070.
- [31] *A Problem With A Regular Outlook*,  
**Notes of the Canadian Mathematical Society** **49** (2017), no. 1, 14–15.
- [30] *Zero order estimates for Mahler functions*,  
**New Zealand Journal of Mathematics** **46** (2016), 83–88.
- [29] (with M. Hussain and B.-W. Wang) *A dichotomy law for the Diophantine properties in  $\beta$ -dynamical systems*,  
**Mathematika** **62** (2016), no. 3, 884–897.
- [28] (with E. Catt and J. Velich) *Strong normality and generalised Copeland–Erdős numbers*,  
**Integers** **16** (2016), #A11, 1–10.
- [27] (with J. P. Bell and K. Hare) *Growth degree classification for finitely generated semigroups of integer matrices*,  
**Semigroup Forum** **92** (2016), no. 1, 23–44.
- [26] (with R. P. Brent and W. Zudilin) *Algebraic independence of Mahler functions via radial asymptotics*,  
**International Mathematics Research Notices** (2016), no. 2, 571–603.
- [25] (with H. Winning) *Powers of two modulo powers of three*,  
**Journal of Integer Sequences** **18** (2015), Article 15.6.1, 1–9.
- [24] (with J. P. Bell and Y. Bugeaud) *Diophantine approximation of Mahler numbers*,  
**Proceedings of the London Mathematical Society** (3) **110** (2015), no. 5, 1157–1206.
- [23] *Addendum to: On the rational approximation of the sum of the reciprocals of the Fermat numbers*,  
**The Ramanujan Journal** **37** (2015), no. 1, 109–111.
- [22] (with J. Borwein and Y. Bugeaud) *The Legacy of Kurt Mahler*,  
**Notices of the American Mathematical Society** **62** (2015), no. 5, 526–531.

- [21] (with J. Tyler) *The maximal order of Stern's diatomic sequence*,  
**Moscow Journal of Combinatorics and Number Theory** **4** (2014), iss. 3, 3–13.
- [20] (with J. P. Bell and K. Hare) *The minimal growth of a  $k$ -regular sequence*,  
**Bulletin of the Australian Mathematical Society** **90** (2014), no. 2, 195–203.
- [19] *An arithmetical excursion via Stoneham numbers*,  
**Journal of the Australian Mathematical Society** **96** (2014), no. 3, 303–315.
- [18] (with J. Borwein and Y. Bugeaud) *The Legacy of Kurt Mahler*,  
**Australian Mathematical Society Gazette** **41** (2014), no. 1, 11–21.
- [17] (with J. Borwein and Y. Bugeaud) *The Legacy of Kurt Mahler*,  
**Newsletter of the European Mathematical Society** **91** (2014), 19–23.
- [16] (with J. P. Bell and E. Rowland) *The rational-transcendental dichotomy of Mahler functions*,  
Special Issue in Honour of the 60th Birthday of Jean-Paul Allouche  
**Journal of Integer Sequences** **16** (2013), Article 13.2.10, 1–11.
- [15] *On the rational approximation of the sum of the reciprocals of the Fermat numbers*,  
**The Ramanujan Journal** **30** (2013), no. 1, 39–65.
- [14] *Transcendental solutions of a class of minimal functional equations*,  
**Canadian Mathematical Bulletin** **56** (2013), no. 2, 283–291.
- [13] *A correlation identity for Stern's diatomic sequence*,  
**Integers** **12** (2012), #A3, 1–5.
- [12] *A note on two conjectures associated to Goldbach's problem*,  
**Publicationes Mathematicae Debrecen** **80** (2012), 1–3.
- [11] (with J. P. Bell and N. Bruin) *Transcendence of generating functions whose coefficients are multiplicative*,  
**Transactions of the American Mathematical Society** **364** (2012), no. 2, 933–959.
- [10] (with P. Vrbik) *An irrationality measure for regular paperfolding numbers*,  
**Journal of Integer Sequences** **15** (2012), Article 12.1.6, 1–10.
- [9] *Extension of some theorems of W. Schwarz*,  
**Canadian Mathematical Bulletin** **55** (2012), no. 1, 60–66.
- [8] (with J. Shallit) *A pattern sequence approach to the Stern sequence*,  
**Discrete Mathematics** **311** (2011), 2630–2633.
- [7] *On some conjectures concerning Stern's sequence and its twist*,  
**Integers** **11** (2011), #A35, 1–14.
- [6] (with S. R. Dahmen) *On the residue class distribution of the number of prime divisors of an integer*,  
**Nagoya Mathematical Journal** **202** (2011), 15–22.
- [5] *(Non)Automaticity of number theoretic functions*,  
**Journal de Théorie des Nombres de Bordeaux** **22** (2010), no. 2, 339–352.
- [4] (with P. Borwein and S. K. K. Choi) *Completely multiplicative functions taking values in  $\{-1, 1\}$* ,  
**Transactions of the American Mathematical Society** **362** (2010), no. 12, 6279–6291.
- [3] *The transcendence of series related to Stern's diatomic sequence*,  
**International Journal of Number Theory** **6** (2010), no. 1, 211–217.
- [2] (with P. Borwein) *The transcendence of power series for some number theoretic functions*,  
**Proceedings of the American Mathematical Society** **137** (2009), no. 4, 1303–1305.
- [1] (with K. Kirsten) *General moment theorems for non-distinct unrestricted partitions*,  
**Journal of Mathematical Physics** **50** (2009), no. 1, 19 pages.

#### Other contributions and theses

- x. (with J. Borwein, Y. Bugeaud, and J. van der Poorten) *The Kurt Mahler Archive*,  
a website dedicated to the mathematical life and collected works of Kurt Mahler,  
available at <http://carma.newcastle.edu.au/mahler/>
- ix. *On the multiplicative Erdős discrepancy problem*,  
10 pages (permanent preprint not intended for publication, available on my webpage).

- viii. *Yet another proof of the infinitude of primes, I*,  
4 pages (permanent preprint not intended for publication, available on my webpage).
- vii. *Hendrik Lenstra: Distinguished Lecture Series*,  
**Fields Notes**, Vol. 10:2 (2010), pages 3 and 14–15.
- vi. *Workshop on Discovery and Experimentation in Number Theory*,  
**Fields Notes**, Vol. 10:2 (2010), pages 6 and 17.
- v. *Some aspects of analytic number theory: parity, transcendence, and multiplicative functions*,  
Ph.D Thesis, xii+94 pages, ISBN: 978-0494-59811-5, Simon Fraser University, 2009.
- iv. Translation of Edmund Landau's Dissertation, *New proof of the equation  $\sum \mu(k)/k = 0$* ,  
preliminary version (2007), preprint. (Available at <http://arxiv.org/pdf/0803.3787v1>)
- iii. *The Emergence of Modern Number Theory in Hungary*,  
**Hungarian Fulbright Student Conference Papers**, TypoTEX Ltd. Electronical Publishing Co.,  
Budapest, 2009, 181–192.
- ii. *General moment theorems with applications*,  
vi+77 pages, Master's Thesis, Baylor University, 2005.
- i. *Numerical Methods for Left-Ventricular Contractility*,  
32 pages, Bachelor's Thesis, University of Montana, 2003.

## EVENT ADMINISTRATION AND ORGANISATION

- Organiser, *Number Theory Online Conference (NTOC2020)*, held online hosted by CARMA, University of Newcastle, 3–5/6/2020.
- Program Committee, 2019 Australian Mathematical Society Meeting, held at Monash University, Victoria, 12/2019.
- Organiser, *Aperiodic Order Meets Number Theory*, held at MATRIX, University of Melbourne, Creswick, Victoria, 25/2/2019–1/3/2019.
- Organiser, CARMA Colloquia and Seminars, University of Newcastle, 2019–2020.
- Director/Organiser, *2018 Australian Mathematical Society Early Career Workshop*, held at the Barcoo Function Centre, West Beach, Adelaide, South Australia, 12/2018.
- Organiser, University of Newcastle Mathematics Colloquium, 1/2017–6/2017.
- Organiser, *Special Session in Number Theory*, 60th meeting of the Australian Mathematical Society, held at the Australian National University, Australian Capital Territory, 12/2016.
- Director/Organiser, *2016 Australian Mathematical Society Early Career Workshop*, held at the Australian Academy of Sciences, Australian Capitol Territory, 12/2016.
- Organiser, *Number Theory Down Under 4*, held at the University of Newcastle, New South Wales, 9/2016.
- Organiser, *Special Session in Number Theory*, 59th meeting of the Australian Mathematical Society, held at the Flinders University, South Australia, 9/2015.
- Director/Organiser, *2015 Australian Mathematical Society Early Career Workshop*, held at the Flinders University, South Australia, 9/2015.
- Organiser, *Number Theory Down Under 3*, held at the University of Newcastle, New South Wales, 9/2015.
- Organiser, *2015 Australian Mathematical Sciences Institute (AMSI) Summer School*, held in Newcastle, New South Wales, 1/2015.
- Organiser, *Special Session in Number Theory*, 58th meeting of the Australian Mathematical Society, held at the University of Melbourne, Victoria, 8/12/2014–12/12/2014.
- Organiser, *Special Session in Analytic methods in Diophantine equations*, Summer meeting of the Canadian Mathematical Society, held in Winnipeg, Manitoba, 6/6/2014–9/6/2014.

- Organiser, *Number Theory Down Under*, a one-day meeting for number theory (which will hopefully become annual), held at the Harbourview Function Centre in Newcastle, New South Wales, 5/10/2013.
- Organiser, *Special Session in Number Theory*, 57th meeting of the Australian Mathematical Society, held at the University of Sydney, New South Wales, 30/9/2013–3/10/2013.
- Organiser, *Special Session in Number Theory*, 56th meeting of the Australian Mathematical Society, held at the University of Ballarat, Victoria, 9/24–27/2012.
- Organiser, Formal Languages and Automata Seminar (School of Computer Science), 1/2012–4/2012. (University of Waterloo)
- Organiser, Fields/IRMACS workshop, *Discovery and Experimentation in Number Theory*, held jointly at the Fields Institute in Toronto and the IRMACS Centre in Burnaby, 9/22–26/2009.
- Organiser, Mathematics Graduate Research Seminar, 1/2007–12/2007. (Simon Fraser University)

## SPECIAL PROGRAMS, INVITED CONFERENCES, AND OTHER VISITS

- 2020      *Almost Periodicity in Aperiodic Order*, to be held at the Banff International Research Station (BIRS) in Banff, Alberta. (7/2020) (*Cancelled–COVID*)  
             *Diophantische Approximationen*, to be held at Mathematisches Forschungsinstitut Oberwolfach, Germany, 19–25/4/2020. (*Cancelled–COVID*)
- 2019      *Ergodic Theory, Diophantine Approximation and Related Topics*, held at MATRIX, University of Melbourne, Creswick, Victoria, 21/6/2019.  
             *Dynamics and Number Theory*, held at the University of Sydney, Sydney, New South Wales, 12/6/2019–14/6/2019.  
             *Aperiodic Order Meets Number Theory*, held at MATRIX, University of Melbourne, Creswick, Victoria, 25/2/2019–1/3/2019.  
             *Asia–Australia Algebra Conference*, held at the University of Western Sydney, Parramatta, New South Wales, 20/1/2019–26/1/2019.  
             *AMSI Summer School*, held at the University of New South Wales, Randwick, New South Wales, 7/1/2019–1/2/2019.
- 2018      *Informal Workshop on Aperiodic Order*, Universität Bielefeld in Bielefeld, Germany. (12/2018)  
             *Research Visit*, Hochschule für Technik Stuttgart, Germany. (11/2018)  
             *Research visit*, University of Waterloo in Ontario, Canada. (11/2018)  
             *Research visit*, University of York, United Kingdom. (10/2018)  
             *Diophantine Approximation and Transcendence*, a conference held at CIRM/Luminy in Marseille, France. (9/2018)  
             *Model Sets and Aperiodic Order*, a conference held at Durham University in Durham, United Kingdom. (9/2018)  
             *Research visit*, Université de Lorraine in Nancy, France. (5/2018)  
             *Research visits*, Universität Bielefeld in Bielefeld, Germany. (1/2018, 5/2018, 9/2018–1/2019)  
             *Workshop on Words and Complexity*, Université de Lyon in Lyon, France (2/2018)
- 2017      *Denmark Australia Diophantine Approximation Day*, a conference held at Aarhus University in Aarhus, Denmark. (12/2017)  
             *Research visit*, Institut Henri Poincaré in Paris, France. (11/2017)  
             *Research visit*, INRIA in Paris, France. (11/2017)  
             *Research visits*, Universität Bielefeld in Bielefeld, Germany. (8/2017, 9/2017, 10/2017)  
             *Research visit*, Alfréd Rényi Institute of the Hungarian Academy of Sciences in Budapest, Hungary. (7/2017–2/2019)  
             *Diophantine Approximation and Algebraic Curves*, a conference held at the Banff International Research Station (BIRS) in Banff, Alberta. (7/2017)  
             *Research visit*, Universiteit Leiden in Leiden, The Netherlands. (1–2/2017)

- 2016 *Normal Numbers: Arithmetic, Computational and Probabilistic Aspects*, a conference held at the Erwin Schrödinger International Institute for Mathematics and Physics (ESI) in Vienna, Austria. (11/2016)  
*International Alumni Meeting*, a conference held at the Hungarian Academy of Sciences organised by the Hungarian Ministry of Human Capacities in Budapest, Hungary. (10/2016)
- 2015 *The Geometry, Algebra and Analysis of Algebraic Numbers*, a conference held at the Banff International Research Station (BIRS) in Banff, Alberta. (10/2015)  
*Research visit*, Dalhousie University in Halifax, Canada. (6/2015)  
*Automatic Sequences*, a conference held at the University of Liège, Belgium. (5/2015)  
*Research visit*, Australian National University in Canberra, Australia. (5/2015)  
*Algebraic, Number Theoretic and Graph Theoretic Aspects of Dynamical Systems*, a conference held at UNSW, Sydney, Australia. (2/2015)
- 2014 *2014 General Assembly of the IMU*, International Congress of Mathematicians, a conference held in Gyeongju, Korea. (8/2014, funded attendance from AustMS and AMSI)  
*Research visit*, University of Waterloo in Waterloo, Ontario. (9–15/6/2014)  
*Research visit*, University of Calgary in Calgary, Alberta. (19/5/2014–5/6/2014)
- 2013 *Australian Mathematical Society Early Career Workshop*, a workshop held at Waldorf Leura Garden Resort, Blue Mountain NSW. (29–30/9/2013)  
*Research visit*, University of British Columbia in Vancouver, British Columbia. (12–26/9/2013)
- 2011 *3rd Montréal–Toronto Workshop in Number Theory: new developments in analytic number theory*, a conference held at the Fields Institute in Toronto, Ontario. (10/7/2011–10/9/2011)  
*Analytic Aspects of L-functions and Applications to Number Theory*, a conference held at the University of Calgary in Calgary, Alberta. (6/29/2011–6/3/2011)
- 2010 *Diophantine Approximation and Transcendence*, a conference held at CIRM/Luminy in Marseille, France. (9/6/2010–9/10/2010)  
*Diophantine Approximation and Analytic Number Theory: A Tribute to Cam Stewart*, a conference held at the Banff International Research Station (BIRS) in Banff, Alberta. (5/30/2010–6/4/2010)
- 2009 *Foundations of Computational Mathematics*, thematic program held at the Fields Institute in Toronto, Ontario. (7/1/2009–12/31/2009)
- 2008 Fields Institute Summer School in *Analytic Number Theory and Diophantine Approximation* held at the University of Ottawa in Ottawa, Ontario. (6/30/2008–7/11/2008)
- 2005–2006 *Fulbright Scholar*, Alfréd Rényi Institute of the Hungarian Academy of Sciences, Budapest, Hungary. (8/1/2005–6/30/2006)  
*Visiting Student*, Central European University, Budapest, Hungary. (8/1/2005–6/30/2006)

PRESENTATIONS (**Bold**#=INVITED AND SPECIALISED, REGULAR#=CONTRIBUTED AND HOME SEMINARS)

## 2020

- 107.** *Fractal aspects of regular sequences: a paradigm in progress*,  
 Number Theory Down Under VIII (Melbourne, VIC), 7/10/2020.
- 106.** *Some curious infinite products*,  
 Number Theory Seminar, University of New South Wales (Sydney, NSW), 4/3/2020.
- 105.** *Some curious infinite products*,  
 Mathematics Colloquium, University of Tasmania (Hobart, TAS), 19/02/2020.

**2019**

- 104. *Integer sequences, asymptotics and diffraction*,  
Symmetry in Newcastle, University of Newcastle (Callaghan, NSW), 6/9/2019.
- 103. *Integer sequences, asymptotics and diffraction*,  
Pure Mathematics Seminar, University of New South Wales (Sydney, NSW), 16/7/2019.
- 102. *A diffraction abstraction distraction, I*, Ergodic Theory, Diophantine Approximation and Related Topics,  
MATRIX, University of Melbourne, Creswick, Victoria, 21/6/2019.
- 101. *Scaling of the diffraction measure of  $k$ -free integers: A diffraction abstraction distraction, II*,  
Dynamics and Number Theory, University of Sydney (Sydney, NSW), 14/6/2019.
- 100. *Mahler's methods: theorems, speculations and variations*,  
CARMA Colloquium, University of Newcastle (Newcastle, Australia), 14/3/2019.
- 99.  *$\pi$ , an irrational love story*,  
Newcastle Maths Students Society, University of Newcastle (Newcastle, Australia), 14/3/2019.

**2018**

- 98. *Mahler's methods: theorems, speculations and variations*,  
Informal Workshop on Aperiodic Order, University of Bielefeld (Bielefeld, Germany), 8/12/2018.
- 97. *Mahler's methods: theorems, speculations and variations*,  
Mathematics Colloquium, Hochschule für Technik Stuttgart (Stuttgart, Germany), 29/11/2018.
- 96. *Mahler's methods: theorems, speculations and variations*,  
Pure Mathematics Colloquium, University of Waterloo (Waterloo, Canada), 5/11/2018.
- 95. *Stern measures: something more must be done!*,  
Number Theory Seminar, University of York (York, United Kingdom), 17/10/2018.
- 94. *One regular problem*,  
Forschungsschwerpunkt Math. Model. Seminar, Universität Bielefeld (Bielefeld, Germany), 21/9/2018.
- 93. *Two regular problems*,  
Diophantine approximation and transcendence, CIRM (Luminy, France), 14/9/2018.
- 92. *A regular journey at the interface of number theory and computer science*,  
Mathematics Colloquium, Universität Bielefeld (Bielefeld, Germany), 24/5/2018.
- 91. *Regular sequences via a paradigmatic example*,  
Séminaire Théorie des Nombres, Université de Lorraine (Nancy, France), 17/5/2018.
- 90. *Automatic sequences and Mahler's measure*,  
Workshop on Words and Complexity, Université de Lyon (Lyon, France), 21/2/2018.

**2017**

- 89. *2-automatic sequences, Lyapunov exponents and a dynamical analogue of Lehmer's Mahler measure problem*,  
Denmark–Australia Diophantine Approximation Day, U. Aarhus (Aarhus, Denmark), 8/12/2017.
- 88. *2-automatic sequences, Lyapunov exponents and a dynamical analogue of Lehmer's Mahler measure problem*,  
Seminar "Computations and Proofs" at SpecFun, INRIA (Paris, France), 20/11/2017.
- 87. *Binary substitutions of constant length and Mahler measures of Borwein polynomials*,  
Jonathan M. Borwein Commemorative Conference (Newcastle, NSW), 27/9/2017.
- 86. *A problematic excursion at the interface of number theory and analysis*,  
Diophantine Approximation and Algebraic Curves at BIRS (Banff, AB), 3/7/2017.
- 85. *Variations on a theme of Mahler*,  
Algebra and Number Theory Seminar, University of Leiden (Leiden, Netherlands), 13/2/2017.

**2016**

- 84. *An analytic view of transcendence*,  
University of New South Wales Number Theory Seminar (Sydney, NSW), 5/10/2016.
- 83. *The Erdős Discrepancy Problem*,  
Discrete Mathematics Seminar, University of Newcastle (Callaghan, NSW), 30/3/2016.
- 82. *Minimal growth of some structured  $\pm 1$ -sequences*,  
Discrete Mathematics Seminar, University of Newcastle (Callaghan, NSW), 16/3/2016.

**2015**

- 81. *The benefits of a regular outlook*,  
CARMA Number Theory Seminar (Callaghan, NSW), 20/10/2015.



- 80. *Asymptotics of Mahler functions*,  
The Geometry, Algebra and Analysis of Algebraic Numbers at BIRS (Banff, AB), 4/10/2015.
- 79. *Radial asymptotics and algebraic independence in Mahler's method*, Applied Mathematics, Modeling and Computational Science Conference AMMCS-CAIMS 2015 (Waterloo, ON), 12/6/2015.
- 78. *Algebraic independence results related to an automatic sequence*,  
CMS Summer Meeting (Charlottetown, PEI), 8/6/2015.
- 77. *Hypertranscendence of Stern's function*,  
Dalhousie University Number Theory Seminar (Halifax, NS), 1/6/2015.
- 76. *Algebraic independence results related to an automatic sequence*,  
Workshop on Automatic Sequences, Université de Liège (Liège, Belgium), 26/5/2015.
- 75. *Randomness in digital expansions of real numbers, or not*,  
MSI Number Theory Seminar, ANU (Canberra, ACT), 12/5/2015.
- 74. *Variations on a theme of Mahler*,  
Maths Colloquium, University of Wollongong (Wollongong, NSW), 8/5/2015.
- 73. *Variations on a theme of Mahler*,  
MSI Colloquium, ANU (Canberra, ACT), 7/5/2015.
- 72. *A function related to Mahler's method*, Algebraic, Number Theoretic and Graph Theoretic Aspects of Dynamical Systems, UNSW (Sydney, NSW), 3/2/2015.

## 2014

- 71. *Growth degree classification for regular sequences*,  
Number Theory Down Under II (Newcastle, NSW), 25/10/2014.
- 70. *From rational to regular*,  
Victorian Algebra Conference, VAC31, Monash University (Melbourne, VIC), 3/10/2014.
- 69. *Variations on a theme of Mahler*,  
CARMA Colloquium (Newcastle, NSW), 25/9/2014.
- 68. *Variations on a theme of Mahler*,  
University of New South Wales Number Theory Seminar (Sydney, NSW), 10/9/2014.
- 67. *Research at CARMA*,  
CARMA Retreat 2014 (Newcastle, NSW), 30/8/2014.
- 66. *My life in  $\$math mode$* ,  
Australian Mathematical Sciences Student Conference (Newcastle, NSW), 2/7/2014.
- 65. *Growth and gaps in regular sequences*,  
Canadian Number Theory Association XIII Meeting (Ottawa, ON), 16/6/2014.
- 64. *Growth and gaps in regular sequences*,  
University of Waterloo (CS Dept.) Formal languages and automata sem. (Waterloo, ON), 11/6/2014.
- 63. *Transcendence and algebraic independence of regular functions*,  
Number Theory Nosh, University of Calgary (Calgary, AB), 3/6/2014.
- 62. *Diophantine approximation: automatic numbers and their generalisations*,  
University of Montana Colloquium (Missoula, MT), 21/5/2014.
- 61. *Growth and gaps in regular sequences*,  
Pacific Northwest Number Theory Conference (Burnaby, BC), 17/5/2014.

## 2013

- 60. *Mind the gap*,  
Victorian Algebra Conference, VAC31, University of Melbourne (Melbourne, VIC), 29/11/2013.
- 59. *Mahler and me, a one-sided love story*,  
Australian Mathematical Society Early Career Workshop (Blue Mountain, NSW), 29/9/2013.
- 58. *Mahler's method, digital expansions, and algebraic numbers (or not)*,  
Joint UBC-SFU Number Theory Seminar (Burnaby, BC), 26/9/2013.
- 57. *Un pas de Mahler (pas de malheur, hein?)*,  
CARMA Retreat 2013 (Newcastle, NSW), 17/8/2013.
- 56. *Automatic for the people! (if you're a number theorist)*,  
University of Newcastle Mathematics Taster Talks (Callaghan, NSW), 8/8/2013.
- 55. *Mahler's method: an introspective retrospective*,  
University of Queensland Colloquium (Brisbane, QLD), 27/5/2013.
- 54. *Arithmetic and Diophantine properties of low-complexity numbers*,  
University of Melbourne Number Theory and Algebra Seminar (Melbourne, VIC), 22/3/2013.

53. *An arithmetic excursion via Stoneham numbers*,  
Monash University Colloquium (Melbourne, VIC), 21/3/2013.

## 2012

52. *The rational-transcendental dichotomy of Mahler functions*,  
Optimisation, Analysis and Number Theory Seminar, CARMA (Callaghan, NSW), 15/10/2012.
51. *A hierarchy of complexity in the context of Mahler's method*,  
CARMA Retreat 2012 (Newcastle East, NSW), 18/8/2012.
50. *A functional introduction to Mahler's method*,  
CARMA Colloquium, University of Newcastle (Callaghan, NSW), 9/8/2012.
49. *A hierarchy of complexity in the context of Mahler's method*,  
Canadian Number Theory Association XII Meeting (Lethbridge, AB), 6/17/2012.
48. *On a theorem of Randé*,  
University of Waterloo (CS Dept.) Formal languages and automata sem. (Waterloo, ON), 6/13/2012.
47. *The rational-transcendental dichotomy of Mahler functions*,  
CMS Summer Meeting (Regina, SK), 6/3/2012.
46. *Rational approximation of Mahler numbers*,  
University of Newcastle Colloquium (Callaghan, NSW), 4/23/2012.
45. *Diophantine approximation of Mahler numbers*,  
University of Lethbridge Special Colloquium (Lethbridge, AB), 4/10/2012.
44. *Rational approximations of regular numbers*,  
University of Waterloo (CS Dept.) Formal languages and automata sem. (Waterloo, ON), 4/4/2012.
43. *Diophantine approximation: automatic numbers and their generalisations*,  
Institute of Science and Technology Austria Colloquium (Klosterneuburg, Austria), 2/23/2012.
42. *Diophantine approximation: automatic numbers and their generalisations*,  
State University of New York Special Colloquium (New Paltz, NY), 2/14/2012.
41. *Diophantine approximation: automatic numbers and their generalisations*,  
University of Waterloo Number Theory Seminar (Waterloo, ON), 2/2/2012.
40. *Some problems and results concerning Stern's diatomic sequence*,  
University of Waterloo (CS Dept.) Formal languages and automata sem. (Waterloo, ON), 1/18/2012.
39. *An irrationality measure for Mahler numbers*,  
AMS–MAA Joint Mathematics Meetings (Boston, MA), 1/6/2012.

## 2011

38. *An irrationality measure for Mahler numbers*,  
CMS Winter Meeting (Toronto, ON), 12/11/2011.
37. *New proof of a theorem of Nishioka*,  
University of Toronto Number Theory Seminar (Toronto, ON), 11/9/2011.
36. *New proof of a theorem of Nishioka*,  
University of Waterloo (CS Dept.) Formal languages and automata sem. (Waterloo, ON), 11/7/2011.
35. *Some problems and results concerning Stern's diatomic sequence*,  
Applied Math., Modeling and Computational Sci. Conf. AMMCS-2011 (Waterloo, ON), 7/27/2011.
34. *Rational approximation of automatic and regular numbers II*,  
University of Waterloo (CS Dept.) Formal languages and automata sem. (Waterloo, ON), 6/20/2011.
33. *An irrationality exponent related to Fermat numbers*,  
CMS Summer Meeting (Edmonton, AB), 6/05/2011.
32. *Traversing transcendence: irrationality for the rationally minded*,  
University of Lethbridge Special Colloquium (Lethbridge, AB), 4/21/2011.
31. *On the rational approximation of ruler numbers*,  
University of Waterloo Number Theory Seminar (Waterloo, ON), 3/24/2011.
30. *Rational approximation of automatic and regular numbers I*,  
University of Waterloo (CS Dept.) Formal languages and automata sem. (Waterloo, ON), 3/04/2011.

## 2010

29. *On the distribution of  $\Omega(n)$  modulo  $m$* ,  
Seventh Midwest Num. Theory Conf. for Students and Recent PhDs (Ann Arbor, MI), 11/13/2010.
28. *The automatic multiplicative Erdős discrepancy problem*,  
University of Waterloo (CS Dept.) Formal languages and automata sem. (Waterloo, ON), 11/05/2010.

- 27. *Multiplicative functions and the rational-transcendental dichotomy*,  
University of Waterloo Colloquium (Waterloo, ON), 10/25/2010.
- 26. *Multiplicative functions, transcendence, and automaticity*,  
University of Lethbridge Number Theory and Combinatorics Seminar (Lethbridge, AB), 7/22/2010.
- 25. *Multiplicative functions and automaticity*,  
Canadian Number Theory Association XI Meeting (Wolfville, NS), 7/13/2010.
- 24. *The Erdős discrepancy problem*,  
Pacific Northwest Number Theory Conference (Burnaby, BC), 5/9/2010.

**2009**

- 23. *The residue class distribution of  $\Omega(n)$* ,  
CMS Winter Meeting (Windsor, ON), 12/7/2009.
- 22. *Some problems and results concerning multiplicative functions*,  
University of Waterloo Number Theory Seminar (Waterloo, ON), 11/19/2009.
- 21. *(Non)automaticity of number-theoretic functions*,  
McMaster University Arithmetic Geometry Seminar (Hamilton, ON), 11/12/2009.
- 20. *The Riemann hypothesis: celebrating 150- $\varepsilon$  years*,  
Fields Institute Postdoctoral Seminar Series (Toronto, ON), 11/09/2009.
- 19. *Multiplicative functions and transcendence*,  
AMS Eastern Sectional Meeting at Penn State (State College, PA), 10/24/2009.
- 18. *Parity, primes, and zeta-functions*,  
SFU Mathematics Graduate Research Seminar (Burnaby, BC), 2/10/2009.
- 17. *Transcendence and functional equations*,  
Joint UBC-SFU Number Theory Seminar (Burnaby, BC), 1/15/2009.

**2008**

- 16. *(Non)automaticity of number-theoretic functions*,  
Joint UBC-SFU Number Theory Seminar (Burnaby, BC), 10/9/2008.
- 15. *Transcendence of various numbers and series*,  
Canadian Number Theory Association X Meeting (Waterloo, ON), 7/17/2008.
- 14. *Some Properties of Completely Multiplicative Signatures*,  
Second Canada-France Congress (Montréal, QC), 6/4/2008.
- 13. *Sums of completely multiplicative signature functions*,  
The Mathematical Interests of Peter Borwein Conference (Burnaby, BC), 5/15/2008.

**2007**

- 12. *A density-residue theorem*,  
Pure Math Graduate Student Conference (Burnaby, BC), 10/12/2007.
- 11. *A General Result on Conditionally Convergent Series*,  
SFU Mathematics Graduate Research Seminar (Burnaby, BC), 10/09/2007.
- 10. *On the density of integers bi-representable as the sum of two cubes*,  
CECM Summer Meeting (Burnaby, BC), 8/08/2007 (Poster, Second Prize in Poster Competition).
- 9. *The Wonderful World of Primes*,  
CMS-PIMS Summer Math Camp (Burnaby, BC), 7/05/2007.
- 8. *On the density of integers bi-representable as the sum of two cubes*,  
CMS-MITACS Joint Conference (Winnipeg, MB), 5/31/2007. (Poster)
- 7. *A "Cubic" Excursion in Additive Number Theory*,  
Western Canadian Conference for Young Researchers in Mathematics (Calgary, AB), 5/05/2007.
- 6. *Sequences and Divergent Series*,  
SFU Mathematics Graduate Research Seminar (Burnaby, BC), 2/08/2007.

**2006**

- 5. *General Moment Theorems for Non-Distinct Unrestricted Partitions*,  
Joint UBC-SFU Number Theory Seminar (Burnaby, BC), 10/19/2006.
- 4. *The Emergence of Modern Number Theory in Hungary*,  
Hungarian Fulbright Student Conference (Budapest, Hungary), 4/21/2006.

**2005**

3. *On the Number of Partitions of an Integer as a Sum of Summands of a General Spectrum*,  
MAA Texas Section (Arlington, TX), 4/15/2005.

**2003**

2. *Mathematics of the Heart: Producing Left-Ventricular Pressure-Volume Loops using Cubic Spline Functions*,  
Montana Academy of Sciences (Missoula, MT), 5/26/2003.
1. *Cordae Tendinae and Contractility in Sheep*,  
University of Montana Conference for Undergraduate Research (Missoula, MT), 5/5/2003. (Poster)

**SUPERVISION****Postdoctoral Fellows**

- Mumtaz Hussain (PhD, University of York, UK), 2014–2016.  
Now Senior Lecturer at La Trobe University.
- Paul Vrbik (PhD, University of Western Ontario, Canada), 2014–2016.  
Now Lecturer at the University of Queensland.

**Research Higher Degree (PhD and Masters)**

- James Evans, PhD Candidate (expected 2023), University of Newcastle  
Topic: *Spectral Methods in Aperiodic Order and Diophantine Approximation*  
Supervisors: M. Coons (principal), F. Breuer (co)
- Zhenlin Ran, PhD Candidate (expected 2023), University of Newcastle  
Topic: *The André-Oort Conjecture*  
Supervisors: F. Breuer (principal), M. Coons (co)
- Matthew Skerrett, PhD (2020), University of Newcastle  
Thesis: *Some Iterative Algorithms in Experimental Mathematics*  
Supervisors: M. Coons (principal), R. Brent (co)
- Daniel Sutherland, PhD (2015), University of Newcastle  
Thesis: *Arithmetic Applications of Hankel Determinants*  
Supervisors: M. Coons (principal), W. Zudilin (co), J. Borwein (co)

**Honours**

- Zachary Groth, BMATH Honours, Univ. of Newcastle, 7/2020–present  
Project: *Fractal aspects of regular sequences*.
- Aaron Ting, BMATH Honours, Univ. of Newcastle, 1/2019–present  
Project: *Combinatorics on Words*.
- Siddharth Iyer, BMATH Honours, Univ. of Newcastle, 1/2020–12/2020  
Project: *On rational approximation with restricted denominators*.

**Undergraduate****2015–2016**

- Egan Meek, MAPS Summer Research Scholarship, Univ. of Newcastle, 12/2015–2/2016.
- Joshua Hartigan, MAPS Summer Research Scholarship, Univ. of Newcastle, 12/2015–2/2016.
- Joseph Gurr, MAPS Summer Research Scholarship, Univ. of Newcastle, 12/2015–2/2016.
- Jordan Velich, MAPS Summer Research Scholarship, Univ. of Newcastle, 12/2015–2/2016.

**2014–2015**

- Jordan Velich, CARMA Summer Research Student, Univ. of Newcastle, 12/2014–2/2015.

**2013–2014**

- Heath Winning, CARMA Winter Research Student, Univ. of Newcastle, 7/2014;  
CARMA Summer Research Student, Univ. of Newcastle, 12/2013–2/2014.

**2008**

- Lawrence Ng, NSERC–USRA summer student, Simon Fraser University, 5/2008–8/2008.
- Amy Wiebe, NSERC–USRA summer student, Simon Fraser University, 5/2008–8/2008.

**TEACHING EXPERIENCE****University of Newcastle, Australia**

2020	Linear Algebra (MATH2320); Number Theory (MATH3170); Mathematical Discovery 1 (MATH1210); Fractal Geometry (MATH3210 Directed Studies/Honours Course, taught twice).
2019	Combinatorics on Words (Honours Course); Number Theory (MATH3170); Discrete Mathematics (MATH1510); Algebra (MATH3120).

**AMSI Summer School, Australian Mathematical Sciences Institute, Australia**

2019	Analytic Number Theory (Honours Course)
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**University of Newcastle, Australia**

2017	Number Theory (MATH3170); Preparatory Studies in Mathematics (MATH1001); Calculus of Science and Engineering (MATH2310).
2015	Analytic Number Theory (Honours Course)
2013	Transcendental Number Theory (Honours Course); Complex Analysis (MATH 3242); Engineering Mathematics (MATH 2420); Analysis (MATH 2330); Mathematical Discovery 1 (MATH 1210).
2012	Mathematics 2 (MATH 1120); Mathematics 1 (MATH 1110).

**University of Waterloo, Canada**

2012	Algebra for Honours Mathematics (MATH 135).
2011	Algebraic Number Theory (PMATH 441/641 (Graduate)).
2010	Analytic Number Theory (PMATH 740 (Graduate)); Elementary Number Theory (PMATH 340).

**Simon Fraser University, Canada**

2007–2009	Elementary Number Theory (MATH 342); Hitchhiker’s Guide to Everyday Math (MATH 197).
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**Baylor University, USA**

2004–2005	Pre–calculus (MATH 1304, taught twice).
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**ACADEMIC SERVICE** (IN ADDITION TO EVENT ADMINISTRATION AND ORGANISATION)
**International**

- Australian Delegate to the *General Assembly of the International Mathematical Union (IMU)*, Gyeongju, Korea, 8/2014.

**National**

- Early Career Representative, Australian Mathematical Society, 2014–2018.
- B. H. Neumann Prize Committee, Australian Mathematical Society, 2013, 2014 and 2019.
- Representative of the Australian Mathematical Society to *Science meets Parliament*, 9/2012.

**University**

- Organiser, CARMA Colloquia and Seminars, 2019–2020.
- Faculty Research Committee, Faculty of Science, University of Newcastle, 2019.
- Honours and RHD Coordinator, Mathematics, University of Newcastle, 1–4/2019.
- Member of ERA 2018 Cluster Advisory Group of Mathematical, Information and Computing Sciences, University of Newcastle, 2017–2018.
- Organiser, University of Newcastle Mathematics Colloquium, 1–6/2017.
- Deputy Director, CARMA, 1–8/2016.
- Member of CARMA Executive Committee, 4/2014–8/2016.
- Member of Academic Senate, University of Newcastle, 2014–2015.
- Member of CARMA Prize Nomination Committee, 26/9/2012–8/2016.
- Faculty Research Committee, Faculty of Science and IT, University of Newcastle, 2015.
- Member of Faculty Board, Faculty of Science and IT, University of Newcastle, 2013–2014.
- School Research Committee, Math. and Physical Sciences, University of Newcastle, 2015.
- Library Liaison, for the School of Math. and Physical Sciences, Univ. of Newcastle, 2013.

**Profession**

- External Thesis Examiner, Max Lewis (PhD in Mathematics, University of Queensland, 2020).
- Deputy Editor-in-Chief, Journal of the Australian Mathematical Society, 2019–present.
- External Thesis Examiner, C. Neil Mañibo (PhD in Mathematics, Universität Bielefeld, Germany, 2019).
- External Thesis Examiner, Topi Törmä (PhD in Mathematics, University of Oulu, Finland, 2018).
- Associate Editor, Journal of the Australian Mathematical Society, 2017–2019.
- External Thesis Examiner, Randell Heyman (PhD in Mathematics, University of New South Wales, 2015).
- Founding Member, Number Theory Down Under, Special Interest Group of the Aust. Math. Society, 2015.
- Internal Thesis Examiner, Salma Alghawi (Masters in Mathematics, University of Waterloo, 2011).
- Internal Thesis Examiner, Veronika Koltunova (Masters in Mathematics, University of Waterloo, 2010).
- Internal Thesis Examiner, Rishikesh (PhD in Mathematics, University of Waterloo, 2010).
- Treasurer, Mathematics Graduate Caucus, 1/2007–6/2008. (Simon Fraser University).
- Speaker, CMS–PIMS High School Math Camp, 7/2007 (Simon Fraser University).

- Referee for: American Mathematical Monthly, Algorithmic Number Theory Symposium, Archiv der Mathematik, Australian Research Council (ARC), Bulletin of the Australian Mathematical Society, Bulletin of the London Mathematical Society, Designs Codes and Cryptography, Developments in Language Theory (CS Conference Series), Electronic Journal of Combinatorics, Experimental Mathematics, Finite Fields and their Applications, Functiones et Approximatio, Illinois Journal of Mathematics, Integers Journal, International Journal of Number Theory, International Mathematics Research Notices (IMRN), Journal of Integer Sequences, Journal de Théorie des Nombres de Bordeaux, Journal of the Australian Mathematical Society, Journal of the London Mathematical Society, Journal of Number Theory, Mathematical Intelligencer, Mathematische Annalen, Monatshefte für Mathematik, National Sciences and Engineering Research Council of Canada (NSERC), Proceedings of the London Mathematical Society, Proceedings of the American Mathematical Society, Quaestiones Mathematicae, Ramanujan Journal, Rocky Mountain Journal of Mathematics, WILF80 Proceedings (Springer).
- Reviewer for: AMS Math Reviews, Zentralblatt MATH.

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## PROFESSIONAL AFFILIATIONS AND SOCIETIES

- Australian Mathematical Society, Sustaining Member, since 2012.
- Canadian Mathematical Society, 2006–2018.
- CARMA (Priority Research Centre for Computer–Assisted Research Math. and its Appl.), 2012–2020.
- IRMACS (Interdisciplinary Research in the Math. and Comput. Sciences Centre, Canada), 2006–2009.
- Victorian Algebra Group, Special Interest Group of the Aust. Math. Society, since 2013.
- Number Theory Down Under, founding member, Special Interest Group of the AustMS, since 2015.
- Early- and Mid-Career Researcher (EMCR) Forum, Australian Academy of Science, since 2019.

In Newcastle, Australia, on 16 December 2020