

Statement of Research Interests

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My research investigates the geometric and analytic structures of scattering amplitudes and correlation functions in quantum field theory, string theory, and cosmology. A common theme is to find representations in which mathematical structure guides the calculation. I combine geometry and cohomology with the study of special functions to organise integrals, uncover relations among them, and clarify their analytic structure. These connections help me obtain compact expressions and investigate how more complicated quantities can be reconstructed from simpler limits and physical constraints. This interplay between mathematical structure and physical questions runs through three principal directions of my research: cosmological wavefunctions and correlators; string amplitudes and their field-theory limits on nodal spheres; and energy correlators at strong coupling.

In cosmology, my collaborators and I have developed graphical coactions [1, 2] and systematic expansions in multiple polylogarithms (MPLs) [3], and obtained compact representations of de Sitter wavefunctions using cluster algebra structures [4, 5]. In string theory, I have shown how to reconstruct one-loop superstring correlators from field-theory data [6, 7]. For energy correlators, I have computed strong-coupling corrections from AdS string amplitudes [8, 9]. Together, these results form a foundation for my broader research at the interface of mathematics and theoretical physics.

Cosmological wavefunctions and mathematical structures

Cosmological wavefunctions encode the interactions of quantum fields in an expanding universe. Developments such as cosmological polytopes and kinematic flow have revealed geometric principles underlying their analytic structure [10, 11]. My work turns this structure into systematic analytic representations.

With A. McLeod and A. Pokraka, I developed a graphical coaction for the time integrals of conformally coupled scalar theories in Friedmann–Robertson–Walker (FRW) backgrounds [1, 2]. Here, **twisted (co)homology** provides a geometric framework for organising integrands and integration contours. The resulting graph rules describe derivatives and discontinuities at arbitrary multiplicity and loop order (at the loop-integrand level). In subsequent work with A. Pokraka, I determined how the physical integration contour decomposes into basic cycles, enabling systematic MPL expansions of FRW integrals [3]. This connects the graphical coaction to explicit function representations.

Moreover, in de Sitter space, we find that these explicit function representations take a simpler form, organised by the underlying **cluster algebra** structures. With collaborators, I obtained compact representations for chain and loop graphs in (generalized) quadrangular polylogarithms [4, 5]. These results provide explicit analytic expressions, including information not captured by their symbols, and make the cluster structure useful for calculations.

I plan to extend these analytic methods to massless and massive fields beyond the conformally coupled case, building on preliminary results for mass deformations and reductions to conformally coupled integrals. I will also investigate whether cluster algebra structures can simplify the representations of wavefunction coefficients and correlators for more general graphs at the function level. In the longer term, I aim to incorporate spatial loop-momentum integration and relate the elliptic and more general classes of functions that can arise to the underlying graph geometry.

String amplitudes from nodal spheres

The worldsheet formulation of string theory connects quantum gravitational scattering to the geometry of Riemann surfaces. However, computing string amplitudes becomes increasingly difficult beyond tree level. My work reconstructs worldsheet correlators from their simpler field-theory limits. At

one loop, this connection is realised on **nodal spheres**, which arise when the torus degenerates. With Y. Geyer, J. Guo, and R. Monteiro, I developed a map from field-theory BCJ numerators to one-loop superstring correlators [6]. In subsequent work with R. Monteiro, I constructed a systematic worldsheet basis and extended this reconstruction through fifteen points [7]. The construction also reveals constraints on BCJ numerators imposed by the worldsheet geometry. With collaborators, I also explored **double-copy structures** of string amplitudes via twisted (co)homology, using worldsheet integral families at arbitrary genus [12, 13].

Building on the one-loop reconstruction of worldsheet correlators, I aim to extend this programme to two loops, starting with the known five-point superstring correlator [14]. Using higher-genus integration kernels and their degeneration rules [15], I will test whether field-theory BCJ numerators, together with worldsheet constraints, determine the full correlator. The five-point case will provide a basis for studying six points and higher multiplicity.

Energy correlators at strong coupling

Energy correlators measure angular correlations of energy flow, probing how interactions shape the final state of an event. My work uses holography to study how string dynamics modifies these distributions in planar $\mathcal{N} = 4$ super Yang–Mills theory at strong coupling [16]. I use worldsheet representations to organise and compute string corrections, and aim to reconstruct these representations directly from analytic and physical constraints.

With B. Wang and C. Wen, I developed a **worldsheet representation** of the energy-energy correlator (EEC) from the AdS Virasoro–Shapiro amplitude [8, 17]. This expresses string corrections to the EEC as worldsheet integrals involving single-valued MPLs and allows their direct evaluation. With M. Jackson, B. Wang, and C. Wen, I subsequently computed higher-order corrections and extended the calculation to states created by half-BPS operators of arbitrary protected dimension [9]. An independent approach using low-energy amplitude data provides a cross-check. Together, these methods establish a consistent prescription for extracting the EEC from AdS amplitudes, with predictions that can be compared with non-perturbative conformal collider bootstrap bounds [18].

Since energy detectors probe only part of the information in a local correlator, I plan to pursue a **direct bootstrap** of the EEC worldsheet representation, using factorisation and string spectral data. I will test this approach against known lower-order results before applying it to higher-order corrections. The goal is to determine the observable without reconstructing the full AdS amplitude. I will also investigate energy flow in states created by heavy, large-charge operators, to understand which features of the distribution retain information about the initial state and which are universal at strong coupling.

References

- [1] A. McLeod, A. Pokraka, and L. Ren, “A Graphical Coaction for FRW Wavefunction Coefficients,” [arXiv:2603.25703](#).
- [2] A. McLeod, A. Pokraka, and L. Ren, “A Graphical Coaction for FRW Integrals from Partial/Relative Twisted (Co)homology,” [arXiv:2606.13627](#).
- [3] A. Pokraka and L. Ren, “Zonotope Expansion,” to appear.
- [4] L. Ferro, T. Łukowski, L. Ren, M. Spradlin, A. Volovich, H. Weng, and Y. Zhang, “de Sitter Wavefunction from Quadrangular Polylogarithms: Chain Graphs,” [arXiv:2605.06542](#).
- [5] L. Ferro, T. Łukowski, S. Paranjape, L. Ren, M. Spradlin, A. Volovich, H. Weng, and Y. Zhang, “de Sitter Wavefunction from Quadrangular Polylogarithms: Polygon Graphs,” [arXiv:2610.06772](#).
- [6] Y. Geyer, J. Guo, R. Monteiro, and L. Ren, “Superstring amplitudes from BCJ numerators at one loop,” JHEP **03** (2025) 017, [arXiv:2410.19663](#).
- [7] R. Monteiro and L. Ren, “Superstring amplitudes from the field-theory limit: an n-point map at one loop,” JHEP **01** (2026) 057, [arXiv:2510.02455](#).
- [8] L. Ren, B. Wang, and C. Wen, “Energy-energy correlator from the AdS Virasoro-Shapiro amplitude,” Phys. Rev. D **113** (2026) 106013, [arXiv:2601.05312](#).
- [9] M. Jackson, L. Ren, B. Wang, and C. Wen, “Energy-Energy Correlators at Strong Coupling,” [arXiv:2607.21139](#).
- [10] N. Arkani-Hamed, P. Benincasa, and A. Postnikov, “Cosmological Polytopes and the Wavefunction of the Universe,” [arXiv:1709.02813](#).
- [11] N. Arkani-Hamed, D. Baumann, A. Hillman, A. Joyce, H. Lee, and G. Pimentel, “Differential equations for cosmological correlators,” JHEP **09** (2025) 009, [arXiv:2312.05303](#).
- [12] R. Bhardwaj, A. Pokraka, L. Ren, and C. Rodriguez, “A double copy from twisted (co)homology at genus one,” JHEP **07** (2024) 040, [arXiv:2312.02148](#).
- [13] A. Pokraka, L. Ren, and C. Rodriguez, “A double copy from twisted (co)homology at genus g ,” [arXiv:2509.01598](#).
- [14] E. D’Hoker, C. Mafra, B. Pioline, and O. Schlotterer, “Two-loop superstring five-point amplitudes I: Construction via chiral splitting and pure spinors,” JHEP **08** (2020) 135, [arXiv:2006.05270](#).
- [15] M. Biancotto, E. D’Hoker, A. Kleinschmidt, M. Santagata, and O. Schlotterer, “Degenerations of flat connections on Riemann surfaces,” [arXiv:2607.05656](#).
- [16] D. Hofman and J. Maldacena, “Conformal collider physics: Energy and charge correlations,” JHEP **05** (2008) 012, [arXiv:0803.1467](#).
- [17] L. Alday and T. Hansen, “The AdS Virasoro-Shapiro amplitude,” JHEP **10** (2023) 023, [arXiv:2306.12786](#).
- [18] R. Dempsey, R. Karlsson, S. Pufu, Z. Zahraee, and A. Zhiboedov, “Conformal collider bootstrap in $\mathcal{N} = 4$ SYM,” [arXiv:2512.10796](#).