



Universiteit
Leiden
The Netherlands

Dynamics of coupled quantum systems

Ohanesjan, V.

Citation

Ohanesjan, V. (2024, February 7). *Dynamics of coupled quantum systems*. *Casimir PhD Series*.

Version: Publisher's Version

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

Downloaded from:

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

Bibliography

- [1] Marcos Rigol, Vanja Dunjko, and Maxim Olshanii. “Thermalization and its mechanism for generic isolated quantum systems”. In: *Nature* 452.7189 (Apr. 2008), pp. 854–858. DOI: [10.1038/nature06838](https://doi.org/10.1038/nature06838).
- [2] J. M. Deutsch. “Quantum statistical mechanics in a closed system”. In: *Phys. Rev. A* 43 (4 Feb. 1991), pp. 2046–2049. DOI: [10.1103/PhysRevA.43.2046](https://doi.org/10.1103/PhysRevA.43.2046).
- [3] Mark Srednicki. “Chaos and quantum thermalization”. In: *Phys. Rev. E* 50 (2 Aug. 1994), pp. 888–901. DOI: [10.1103/PhysRevE.50.888](https://doi.org/10.1103/PhysRevE.50.888).
- [4] Luca D’Alessio et al. “From quantum chaos and eigenstate thermalization to statistical mechanics and thermodynamics”. In: *Advances in Physics* 65.3 (May 2016), pp. 239–362. DOI: [10.1080/00018732.2016.1198134](https://doi.org/10.1080/00018732.2016.1198134).
- [5] Andrew Hallam, James Morley, and Andrew G. Green. “The Lyapunov Spectrum of Quantum Thermalisation”. In: *Nature Communications* 10.1 (2019), p. 2708. ISSN: 2041-1723. DOI: [10.1038/s41467-019-10336-4](https://doi.org/10.1038/s41467-019-10336-4). arXiv: [1806.05204](https://arxiv.org/abs/1806.05204) [[cond-mat](#), [physics:quant-ph](#)].
- [6] Stefan Trotzky et al. “Probing the Relaxation towards Equilibrium in an Isolated Strongly Correlated 1D Bose Gas”. In: *Nature Physics* 8.4 (2012), pp. 325–330. ISSN: 1745-2473, 1745-2481. DOI: [10.1038/nphys2232](https://doi.org/10.1038/nphys2232). arXiv: [1101.2659](https://arxiv.org/abs/1101.2659) [[cond-mat](#), [physics:quant-ph](#)].
- [7] Tim Langen et al. “Local Emergence of Thermal Correlations in an Isolated Quantum Many-Body System”. In: *Nature Physics* 9.10 (2013), pp. 640–643. ISSN: 1745-2473, 1745-2481. DOI: [10.1038/nphys2739](https://doi.org/10.1038/nphys2739). arXiv: [1305.3708](https://arxiv.org/abs/1305.3708) [[cond-mat](#), [physics:quant-ph](#)].
- [8] Govinda Clos et al. “Time-Resolved Observation of Thermalization in an Isolated Quantum System”. In: *Physical Review Letters* 117.17 (2016), p. 170401. ISSN: 0031-9007, 1079-7114. DOI: [10.1103/PhysRevLett.117.170401](https://doi.org/10.1103/PhysRevLett.117.170401). arXiv: [1509.07712](https://arxiv.org/abs/1509.07712) [[quant-ph](#)].
- [9] Adam M. Kaufman et al. “Quantum Thermalization through Entanglement in an Isolated Many-Body System”. In: *Science* 353.6301 (2016), pp. 794–800. ISSN: 0036-8075, 1095-9203. DOI: [10.1126/science.aaf6725](https://doi.org/10.1126/science.aaf6725). arXiv: [1603.04409](https://arxiv.org/abs/1603.04409) [[cond-mat](#), [physics:physics](#), [physics:quant-ph](#)].
- [10] C. Neill et al. “Ergodic Dynamics and Thermalization in an Isolated Quantum System”. In: *Nature Physics* 12.11 (2016), pp. 1037–1041. ISSN: 1745-2473, 1745-2481. DOI: [10.1038/nphys3830](https://doi.org/10.1038/nphys3830). arXiv: [1601.00600](https://arxiv.org/abs/1601.00600) [[quant-ph](#)].
- [11] Yijun Tang et al. “Thermalization near Integrability in a Dipolar Quantum Newton’s Cradle”. In: *Physical Review X* 8.2 (2018), p. 021030. ISSN: 2160-3308. DOI: [10.1103/PhysRevX.8.021030](https://doi.org/10.1103/PhysRevX.8.021030). arXiv: [1707.07031](https://arxiv.org/abs/1707.07031) [[cond-mat](#), [physics:physics](#), [physics:quant-ph](#)].

- [12] “7th Les Houches School in Computational Physics: Dynamics of Complex Quantum Systems, from Theory to Computation”. In: (2021).
- [13] Pengfei Zhang. “Evaporation dynamics of the Sachdev-Ye-Kitaev model”. In: *Phys. Rev. B* 100 (24 Dec. 2019), p. 245104. DOI: [10.1103/PhysRevB.100.245104](https://doi.org/10.1103/PhysRevB.100.245104).
- [14] Juan Maldacena and Alexey Milekhin. *SYK wormhole formation in real time*. 2020. arXiv: [1912.03276](https://arxiv.org/abs/1912.03276) [[hep-th](#)].
- [15] Ahmed Almheiri, Alexey Milekhin, and Brian Swingle. “Universal Constraints on Energy Flow and SYK Thermalization”. In: (2019). arXiv: [1912.04912](https://arxiv.org/abs/1912.04912) [[hep-th](#)].
- [16] Daniel L. Jafferis et al. “Relative entropy equals bulk relative entropy”. In: *Journal of High Energy Physics* 2016.6 (June 2016). DOI: [10.1007/jhep06\(2016\)004](https://doi.org/10.1007/jhep06(2016)004).
- [17] B. Keimer et al. “From quantum matter to high-temperature superconductivity in copper oxides”. In: *Nature* 518.7538 (Feb. 2015), pp. 179–186. ISSN: 1476-4687. DOI: [10.1038/nature14165](https://doi.org/10.1038/nature14165).
- [18] N. F. Balm et al. “T-linear resistivity, optical conductivity, and Planckian transport for a holographic local quantum critical metal in a periodic potential”. In: *Physical Review B* 108.12 (Sept. 2023). DOI: [10.1103/physrevb.108.125145](https://doi.org/10.1103/physrevb.108.125145).
- [19] Aavishkar A. Patel, Michael J. Lawler, and Eun-Ah Kim. “Coherent Superconductivity with a Large Gap Ratio from Incoherent Metals”. In: *Physical Review Letters* 121.18 (Oct. 2018). DOI: [10.1103/physrevlett.121.187001](https://doi.org/10.1103/physrevlett.121.187001).
- [20] Peter Cha et al. “Linear resistivity and Sachdev-Ye-Kitaev (SYK) spin liquid behavior in a quantum critical metal with spin-1/2 fermions”. In: *Proceedings of the National Academy of Sciences* 117.31 (July 2020), pp. 18341–18346. DOI: [10.1073/pnas.2003179117](https://doi.org/10.1073/pnas.2003179117).
- [21] Michael A. Nielsen and Isaac L. Chuang. *Quantum Computation and Quantum Information*. Cambridge University Press, 2009. DOI: [10.1017/cbo9780511976667](https://doi.org/10.1017/cbo9780511976667).
- [22] Sebastian Deffner and Steve Campbell. *Quantum Thermodynamics*. Morgan & Claypool Publishers, 2019. ISBN: 978-1-64327-658-8. DOI: [10.1088/2053-2571/ab21c6](https://doi.org/10.1088/2053-2571/ab21c6).
- [23] Ken Funo, Yu Watanabe, and Masahito Ueda. “Thermodynamic work gain from entanglement”. In: *Phys. Rev. A* 88 (5 2013), p. 052319. DOI: [10.1103/PhysRevA.88.052319](https://doi.org/10.1103/PhysRevA.88.052319).
- [24] Anatoly I. Larkin and Yu. N. Ovchinnikov. “Quasiclassical Method in the Theory of Superconductivity”. In: *Journal of Experimental and Theoretical Physics* (1969).
- [25] Juan Maldacena, Stephen H. Shenker, and Douglas Stanford. “A bound on chaos”. In: *Journal of High Energy Physics* 2016.8 (Aug. 2016). ISSN: 1029-8479. DOI: [10.1007/jhep08\(2016\)106](https://doi.org/10.1007/jhep08(2016)106).
- [26] Aurelio Romero-Bermúdez, Koenraad Schalm, and Vincenzo Scopelliti. “Regularization dependence of the OTOC. Which Lyapunov spectrum is the physical one?” In: *Journal of High Energy Physics* 2019.7 (July 2019). DOI: [10.1007/jhep07\(2019\)107](https://doi.org/10.1007/jhep07(2019)107).
- [27] M.L. Mehta and M. Gaudin. “On the density of Eigenvalues of a random matrix”. In: *Nuclear Physics* 18 (1960), pp. 420–427. ISSN: 0029-5582. DOI: [https://doi.org/10.1016/0029-5582\(60\)90414-4](https://doi.org/10.1016/0029-5582(60)90414-4).

- [28] Thomas Guhr, Axel Müller–Groeling, and Hans A. Weidenmüller. “Random-matrix theories in quantum physics: common concepts”. In: *Physics Reports* 299.4-6 (June 1998), pp. 189–425. DOI: [10.1016/s0370-1573\(97\)00088-4](https://doi.org/10.1016/s0370-1573(97)00088-4).
- [29] Freeman J. Dyson. “Statistical Theory of the Energy Levels of Complex Systems. I”. In: *Journal of Mathematical Physics* 3.1 (Dec. 2004), pp. 140–156. ISSN: 0022-2488. DOI: [10.1063/1.1703773](https://doi.org/10.1063/1.1703773). eprint: https://pubs.aip.org/aip/jmp/article-pdf/3/1/140/8157927/140_1_online.pdf.
- [30] Freeman J. Dyson. “Statistical Theory of the Energy Levels of Complex Systems. II”. In: *Journal of Mathematical Physics* 3.1 (Dec. 2004), pp. 157–165. ISSN: 0022-2488. DOI: [10.1063/1.1703774](https://doi.org/10.1063/1.1703774). eprint: https://pubs.aip.org/aip/jmp/article-pdf/3/1/157/8158003/157_1_online.pdf.
- [31] Freeman J. Dyson. “Statistical Theory of the Energy Levels of Complex Systems. III”. In: *Journal of Mathematical Physics* 3.1 (Dec. 2004), pp. 166–175. ISSN: 0022-2488. DOI: [10.1063/1.1703775](https://doi.org/10.1063/1.1703775). eprint: https://pubs.aip.org/aip/jmp/article-pdf/3/1/166/8157965/166_1_online.pdf.
- [32] Michel Gaudin. “Sur la loi limite de l’espacement des valeurs propres d’une matrice ale’atoire”. In: *Nuclear Physics* 25 (1961), pp. 447–458. ISSN: 0029-5582. DOI: [https://doi.org/10.1016/0029-5582\(61\)90176-6](https://doi.org/10.1016/0029-5582(61)90176-6).
- [33] O. Bohigas, M. J. Giannoni, and C. Schmit. “Characterization of Chaotic Quantum Spectra and Universality of Level Fluctuation Laws”. In: *Phys. Rev. Lett.* 52 (1 Jan. 1984), pp. 1–4. DOI: [10.1103/PhysRevLett.52.1](https://doi.org/10.1103/PhysRevLett.52.1).
- [34] Lea F. Santos and Marcos Rigol. “Onset of quantum chaos in one-dimensional bosonic and fermionic systems and its relation to thermalization”. In: *Physical Review E* 81.3 (Mar. 2010). DOI: [10.1103/physreve.81.036206](https://doi.org/10.1103/physreve.81.036206).
- [35] Ranjan Modak and Subroto Mukerjee. “Finite size scaling in crossover among different random matrix ensembles in microscopic lattice models”. In: *New Journal of Physics* 16.9 (Sept. 2014), p. 093016. DOI: [10.1088/1367-2630/16/9/093016](https://doi.org/10.1088/1367-2630/16/9/093016).
- [36] M. V. Berry and M. Tabor. “Level Clustering in the Regular Spectrum”. In: *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences* 356.1686 (1977), pp. 375–394. ISSN: 00804630.
- [37] Ahmed A. Elkamshishy and Chris H. Greene. “Observation of Wigner-Dyson level statistics in a classically integrable system”. In: *Physical Review E* 103.6 (June 2021). DOI: [10.1103/physreve.103.062211](https://doi.org/10.1103/physreve.103.062211).
- [38] Y. Alhassid. “The statistical theory of quantum dots”. In: *Rev. Mod. Phys.* 72 (4 Oct. 2000), pp. 895–968. DOI: [10.1103/RevModPhys.72.895](https://doi.org/10.1103/RevModPhys.72.895).
- [39] Subir Sachdev and Jinwu Ye. “Gapless spin-fluid ground state in a random quantum Heisenberg magnet”. In: *Phys. Rev. Lett.* 70 (21 May 1993), pp. 3339–3342. DOI: [10.1103/PhysRevLett.70.3339](https://doi.org/10.1103/PhysRevLett.70.3339).
- [40] A. Kitaev. *A simple model of quantum holography*. KITP Program: Entanglement in Strongly-Correlated Quantum Matter, 2015.
- [41] Julian Sonner and Manuel Vielma. “Eigenstate thermalization in the Sachdev-Ye-Kitaev model”. In: *JHEP* 11 (2017), p. 149. DOI: [10.1007/JHEP11\(2017\)149](https://doi.org/10.1007/JHEP11(2017)149). arXiv: [1707.08013](https://arxiv.org/abs/1707.08013) [hep-th].
- [42] Ahmed Almheiri and Joseph Polchinski. *Models of AdS₂ Backreaction and Holography*. 2014. DOI: [10.48550/ARXIV.1402.6334](https://doi.org/10.48550/ARXIV.1402.6334).

- [43] Kristan Jensen. “Chaos in AdS₂ Holography”. In: *Physical Review Letters* 117.11 (Sept. 2016). DOI: [10.1103/physrevlett.117.111601](https://doi.org/10.1103/physrevlett.117.111601).
- [44] Julius Engelsöy, Thomas G. Mertens, and Herman Verlinde. “An investigation of AdS₂ backreaction and holography”. In: *JHEP* 07 (2016), p. 139. DOI: [10.1007/JHEP07\(2016\)139](https://doi.org/10.1007/JHEP07(2016)139). arXiv: [1606.03438](https://arxiv.org/abs/1606.03438) [[hep-th](#)].
- [45] Subir Sachdev. “Holographic Metals and the Fractionalized Fermi Liquid”. In: *Phys. Rev. Lett.* 105 (15 Oct. 2010), p. 151602. DOI: [10.1103/PhysRevLett.105.151602](https://doi.org/10.1103/PhysRevLett.105.151602).
- [46] Subir Sachdev. “Bekenstein-Hawking Entropy and Strange Metals”. In: *Phys. Rev. X* 5 (4 Nov. 2015), p. 041025. DOI: [10.1103/PhysRevX.5.041025](https://doi.org/10.1103/PhysRevX.5.041025).
- [47] Yingfei Gu et al. “Notes on the complex Sachdev-Ye-Kitaev model”. In: *J. High Energy Phys.* 2020 (2020), p. 157. DOI: [10.1007/JHEP02\(2020\)157](https://doi.org/10.1007/JHEP02(2020)157).
- [48] Chenyuan Li, Subir Sachdev, and Darshan G. Joshi. “Superconductivity of non-Fermi liquids described by Sachdev-Ye-Kitaev models”. In: *Physical Review Research* 5.1 (Jan. 2023). DOI: [10.1103/physrevresearch.5.013045](https://doi.org/10.1103/physrevresearch.5.013045).
- [49] Pasquale Calabrese, Fabian H. L. Essler, and Maurizio Fagotti. “Quantum Quench in the Transverse-Field Ising Chain”. In: *Physical Review Letters* 106.22 (June 2011). DOI: [10.1103/physrevlett.106.227203](https://doi.org/10.1103/physrevlett.106.227203).
- [50] Subir Sachdev. *Quantum Phase Transitions*. 2nd ed. Cambridge University Press, 2011. DOI: [10.1017/CB09780511973765](https://doi.org/10.1017/CB09780511973765).
- [51] Shenglong Xu and Brian Swingle. “Accessing scrambling using matrix product operators”. In: *Nature Physics* 16.2 (Nov. 2019), pp. 199–204. DOI: [10.1038/s41567-019-0712-4](https://doi.org/10.1038/s41567-019-0712-4).
- [52] Ben Craps et al. “Lyapunov growth in quantum spin chains”. In: *Physical Review B* 101.17 (May 2020). DOI: [10.1103/physrevb.101.174313](https://doi.org/10.1103/physrevb.101.174313).
- [53] James R. Garrison and Tarun Grover. “Does a Single Eigenstate Encode the Full Hamiltonian?” In: *Physical Review X* 8.2 (Apr. 2018). DOI: [10.1103/physrevx.8.021026](https://doi.org/10.1103/physrevx.8.021026).
- [54] J. Karthik, Auditya Sharma, and Arul Lakshminarayan. “Entanglement, avoided crossings, and quantum chaos in an Ising model with a tilted magnetic field”. In: *Physical Review A* 75.2 (Feb. 2007). DOI: [10.1103/physreva.75.022304](https://doi.org/10.1103/physreva.75.022304).
- [55] Juan Maldacena and Douglas Stanford. “Remarks on the Sachdev-Ye-Kitaev model”. In: *Phys. Rev. D* 94 (10 Nov. 2016), p. 106002. DOI: [10.1103/PhysRevD.94.106002](https://doi.org/10.1103/PhysRevD.94.106002).
- [56] D A Trunin. “Pedagogical introduction to the Sachdev–Ye–Kitaev model and two-dimensional dilaton gravity”. In: *Physics-Uspekhi* 64.3 (June 2021), pp. 219–252. DOI: [10.3367/ufne.2020.06.038805](https://doi.org/10.3367/ufne.2020.06.038805).
- [57] Andreas Eberlein et al. “Quantum quench of the Sachdev-Ye-Kitaev model”. In: *Phys. Rev. B* 96 (20 Nov. 2017), p. 205123. DOI: [10.1103/PhysRevB.96.205123](https://doi.org/10.1103/PhysRevB.96.205123).
- [58] Irina Aref'eva et al. “Replica-nondiagonal solutions in the SYK model”. In: *Journal of High Energy Physics* 2019.7 (July 2019). DOI: [10.1007/jhep07\(2019\)113](https://doi.org/10.1007/jhep07(2019)113).
- [59] Antonio M. García-García et al. *Replica Symmetry Breaking and Phase Transitions in a PT Symmetric Sachdev-Ye-Kitaev Model*. 2021. DOI: [10.48550/ARXIV.2102.06630](https://doi.org/10.48550/ARXIV.2102.06630).

- [60] Elliott Lieb, Theodore Schultz, and Daniel Mattis. “Two soluble models of an antiferromagnetic chain”. In: *Annals of Physics* 16.3 (Dec. 1961), pp. 407–466. DOI: [10.1016/0003-4916\(61\)90115-4](https://doi.org/10.1016/0003-4916(61)90115-4).
- [61] M. C. Bañuls, J. I. Cirac, and M. B. Hastings. “Strong and Weak Thermalization of Infinite Nonintegrable Quantum Systems”. In: *Physical Review Letters* 106.5 (Feb. 2011). DOI: [10.1103/physrevlett.106.050405](https://doi.org/10.1103/physrevlett.106.050405).
- [62] Geoff Penington et al. “Replica wormholes and the black hole interior”. In: (Nov. 2019). arXiv: [1911.11977](https://arxiv.org/abs/1911.11977) [hep-th].
- [63] Geoffrey Penington. “Entanglement Wedge Reconstruction and the Information Paradox”. In: *JHEP* 09 (2020), p. 002. DOI: [10.1007/JHEP09\(2020\)002](https://doi.org/10.1007/JHEP09(2020)002). arXiv: [1905.08255](https://arxiv.org/abs/1905.08255) [hep-th].
- [64] Ahmed Almheiri, Raghu Mahajan, and Juan Maldacena. “Islands outside the horizon”. In: (2019). arXiv: [1910.11077](https://arxiv.org/abs/1910.11077) [hep-th].
- [65] Ahmed Almheiri et al. “The Page curve of Hawking radiation from semiclassical geometry”. In: *JHEP* 03 (2020), p. 149. DOI: [10.1007/JHEP03\(2020\)149](https://doi.org/10.1007/JHEP03(2020)149).
- [66] Gabor Sarosi. “AdS₂ holography and the SYK model”. In: *Proceedings of XIII Modave Summer School in Mathematical Physics — PoS(Modave2017)*. Sissa Medialab, Mar. 2018. DOI: [10.22323/1.323.0001](https://doi.org/10.22323/1.323.0001).
- [67] Roman Jackiw. “Lower dimensional gravity”. In: *Nuclear Physics B* 252 (1985), pp. 343–356. ISSN: 0550-3213. DOI: [https://doi.org/10.1016/0550-3213\(85\)90448-1](https://doi.org/10.1016/0550-3213(85)90448-1).
- [68] Claudio Teitelboim. “Gravitation and hamiltonian structure in two spacetime dimensions”. In: *Physics Letters B* 126.1 (1983), pp. 41–45. ISSN: 0370-2693. DOI: [https://doi.org/10.1016/0370-2693\(83\)90012-6](https://doi.org/10.1016/0370-2693(83)90012-6).
- [69] Daniel Grumiller and Robert McNees. “Thermodynamics of black holes in two (and higher) dimensions”. In: *Journal of High Energy Physics* 2007.04 (Apr. 2007), pp. 074–074. DOI: [10.1088/1126-6708/2007/04/074](https://doi.org/10.1088/1126-6708/2007/04/074).
- [70] Juan Maldacena, Douglas Stanford, and Zhenbin Yang. *Conformal symmetry and its breaking in two dimensional Nearly Anti-de-Sitter space*. 2016. arXiv: [1606.01857](https://arxiv.org/abs/1606.01857) [hep-th].
- [71] N. V. Gnedzilov et al. “Ultrafast dynamics of cold Fermi gas after a local quench”. In: *Phys. Rev. A* 107.3 (2023), p. L031301. DOI: [10.1103/PhysRevA.107.L031301](https://doi.org/10.1103/PhysRevA.107.L031301). arXiv: [2108.12031](https://arxiv.org/abs/2108.12031) [cond-mat.quant-gas].
- [72] V. Ohanesjan et al. “Energy dynamics, information and heat flow in quenched cooling and the crossover from quantum to classical thermodynamics”. In: *arXiv preprint:2204.12411* (2022).
- [73] Y. Cheipesh et al. “Quantum tunneling dynamics in a complex-valued Sachdev-Ye-Kitaev model quench-coupled to a cool bath”. In: *Phys. Rev. B* 104.11 (2021), p. 115134. DOI: [10.1103/PhysRevB.104.115134](https://doi.org/10.1103/PhysRevB.104.115134). arXiv: [2011.05238](https://arxiv.org/abs/2011.05238) [cond-mat.str-el].
- [74] C. W. J. Beenakker. “Electron-hole entanglement in the Fermi sea”. In: *arXiv preprint:cond-mat/0508488* (2005).
- [75] C. W. J. Beenakker et al. “Proposal for Production and Detection of Entangled Electron-Hole Pairs in a Degenerate Electron Gas”. In: *Phys. Rev. Lett.* 91 (14 2003), p. 147901. DOI: [10.1103/PhysRevLett.91.147901](https://doi.org/10.1103/PhysRevLett.91.147901).

- [76] Israel Klich. “Lower entropy bounds and particle number fluctuations in a Fermi sea”. In: *J. Phys. A: Math. Gen.* 39 (2006), p. L85. DOI: [10.1088/0305-4470/39/4/102](https://doi.org/10.1088/0305-4470/39/4/102).
- [77] Israel Klich and Leonid Levitov. “Quantum Noise as an Entanglement Meter”. In: *Phys. Rev. Lett.* 102 (10 2009), p. 100502. DOI: [10.1103/PhysRevLett.102.100502](https://doi.org/10.1103/PhysRevLett.102.100502).
- [78] John Cardy. “Measuring Entanglement Using Quantum Quenches”. In: *Phys. Rev. Lett.* 106 (15 2011), p. 150404. DOI: [10.1103/PhysRevLett.106.150404](https://doi.org/10.1103/PhysRevLett.106.150404).
- [79] Dmitry A. Abanin and Eugene Demler. “Measuring Entanglement Entropy of a Generic Many-Body System with a Quantum Switch”. In: *Phys. Rev. Lett.* 109 (2 2012), p. 020504. DOI: [10.1103/PhysRevLett.109.020504](https://doi.org/10.1103/PhysRevLett.109.020504).
- [80] Rajibul Islam et al. “Measuring entanglement entropy in a quantum many-body system”. In: *Nature* 528 (2015), p. 77. DOI: [10.1038/nature15750](https://doi.org/10.1038/nature15750).
- [81] T. Sagawa. “Second Law-Like Inequalities with Quantum Relative Entropy: An Introduction”. In: *Kinki University Series on Quantum Computing*. World Scientific, 2012, p. 125. DOI: [10.1142/9789814425193_0003](https://doi.org/10.1142/9789814425193_0003).
- [82] R. Dorner et al. “Emergent Thermodynamics in a Quenched Quantum Many-Body System”. In: *Phys. Rev. Lett.* 109 (16 2012), p. 160601. DOI: [10.1103/PhysRevLett.109.160601](https://doi.org/10.1103/PhysRevLett.109.160601).
- [83] Michele Campisi and Rosario Fazio. “Dissipation, correlation and lags in heat engines”. In: *J. Phys. A: Math. Theor.* 49 (2016), p. 345002. DOI: [10.1088/1751-8113/49/34/345002](https://doi.org/10.1088/1751-8113/49/34/345002).
- [84] Takahiro Sagawa and Masahito Ueda. “Minimal Energy Cost for Thermodynamic Information Processing: Measurement and Information Erasure”. In: *Phys. Rev. Lett.* 102 (25 2009), p. 250602. DOI: [10.1103/PhysRevLett.102.250602](https://doi.org/10.1103/PhysRevLett.102.250602).
- [85] Wojciech H. Zurek. “Decoherence and the Transition from Quantum to Classical”. In: *Physics Today* 44 (1991), p. 36. DOI: [10.1063/1.881293](https://doi.org/10.1063/1.881293).
- [86] Maria Popovic, Mark T. Mitchison, and John Goold. “Thermodynamics of decoherence”. In: *arXiv preprint:2107.14216* (2021).
- [87] Wojciech Hubert Zurek and Juan Pablo Paz. “Decoherence, chaos, and the second law”. In: *Phys. Rev. Lett.* 72 (16 1994), p. 2508. DOI: [10.1103/PhysRevLett.72.2508](https://doi.org/10.1103/PhysRevLett.72.2508).
- [88] Wojciech Hubert Zurek. “Decoherence, einselection, and the quantum origins of the classical”. In: *Rev. Mod. Phys.* 75 (3 2003), p. 715. DOI: [10.1103/RevModPhys.75.715](https://doi.org/10.1103/RevModPhys.75.715).
- [89] Davide Rossini et al. “Quantum Advantage in the Charging Process of Sachdev-Ye-Kitaev Batteries”. In: *Phys. Rev. Lett.* 125 (23 Dec. 2020), p. 236402. DOI: [10.1103/PhysRevLett.125.236402](https://doi.org/10.1103/PhysRevLett.125.236402).
- [90] Robert Alicki and Mark Fannes. “Entanglement boost for extractable work from ensembles of quantum batteries”. In: *Phys. Rev. E* 87 (4 2013), p. 042123. DOI: [10.1103/PhysRevE.87.042123](https://doi.org/10.1103/PhysRevE.87.042123).
- [91] Karen V. Hovhannissyan et al. “Entanglement Generation is Not Necessary for Optimal Work Extraction”. In: *Phys. Rev. Lett.* 111 (24 2013), p. 240401. DOI: [10.1103/PhysRevLett.111.240401](https://doi.org/10.1103/PhysRevLett.111.240401).

- [92] Javier M. Magán. “Black holes as random particles: entanglement dynamics in infinite range and matrix models”. In: *J. High Energy Phys.* 2016 (Aug. 2016), p. 81. DOI: [10.1007/jhep08\(2016\)081](https://doi.org/10.1007/jhep08(2016)081).
- [93] Geoffrey Penington. “Entanglement wedge reconstruction and the information paradox”. In: *J. High Energy Phys.* 2020 (2020), p. 2. DOI: [10.1007/jhep09\(2020\)002](https://doi.org/10.1007/jhep09(2020)002).
- [94] Ahmed Almheiri et al. “The entropy of bulk quantum fields and the entanglement wedge of an evaporating black hole”. In: *J. High Energy Phys.* 2019 (2019), p. 63. DOI: [10.1007/JHEP12\(2019\)063](https://doi.org/10.1007/JHEP12(2019)063).
- [95] Ahmed Almheiri et al. “The Page curve of Hawking radiation from semiclassical geometry”. In: *J. High Energy Phys.* 2020 (Mar. 2020), p. 149. DOI: [10.1007/jhep03\(2020\)149](https://doi.org/10.1007/jhep03(2020)149).
- [96] V. Oshanesjan *et al.* *in preparation*.
- [97] John Goold et al. “The role of quantum information in thermodynamics—a topical review”. In: *Journal of Physics A: Mathematical and Theoretical* 49.14 (Feb. 2016), p. 143001. ISSN: 1751-8121. DOI: [10.1088/1751-8113/49/14/143001](https://doi.org/10.1088/1751-8113/49/14/143001).
- [98] Sebastian Deffner and Steve Campbell. *Quantum Thermodynamics: An introduction to the thermodynamics of quantum information*. 2019. arXiv: [1907.01596](https://arxiv.org/abs/1907.01596) [[quant-ph](#)].
- [99] Hong Zhe Chen et al. “Evaporating Black Holes Coupled to a Thermal Bath”. In: (2020). arXiv: [2007.11658](https://arxiv.org/abs/2007.11658) [[hep-th](#)].
- [100] Anel Larzul, Steven J Thomson, and M Schiro. “Are fast scramblers good thermal baths?” In: (2022). arXiv: [2204.06434](https://arxiv.org/abs/2204.06434) [[cond-mat](#)].
- [101] Ahmed Almheiri. “Holographic Quantum Error Correction and the Projected Black Hole Interior”. In: (Oct. 2018). arXiv: [1810.02055](https://arxiv.org/abs/1810.02055) [[hep-th](#)].
- [102] N. V. Gnedilov et al. *Information to energy conversion in quantum composite systems at finite temperature*. 2021. arXiv: [2108.12031](https://arxiv.org/abs/2108.12031) [[quant-ph](#)].
- [103] Berry Groisman, Sandu Popescu, and Andreas Winter. “Quantum, classical, and total amount of correlations in a quantum state”. In: *Physical Review A* 72.3 (Sept. 2005). ISSN: 1094-1622. DOI: [10.1103/physreva.72.032317](https://doi.org/10.1103/physreva.72.032317).
- [104] Akram Touil and Sebastian Deffner. “Quantum scrambling and the growth of mutual information”. In: *Quantum Science and Technology* 5.3 (May 2020), p. 035005. ISSN: 2058-9565. DOI: [10.1088/2058-9565/ab8ebb](https://doi.org/10.1088/2058-9565/ab8ebb).
- [105] Akram Touil and Sebastian Deffner. “Information Scrambling versus Decoherence—Two Competing Sinks for Entropy”. In: *PRX Quantum* 2.1 (Jan. 2021). ISSN: 2691-3399. DOI: [10.1103/prxquantum.2.010306](https://doi.org/10.1103/prxquantum.2.010306).
- [106] Benjamin Doyon et al. “Non-equilibrium steady states in the Klein-Gordon theory”. In: *J. Phys. A* 48.9 (2015), p. 095002. DOI: [10.1088/1751-8113/48/9/095002](https://doi.org/10.1088/1751-8113/48/9/095002). arXiv: [1409.6660](https://arxiv.org/abs/1409.6660) [[cond-mat.stat-mech](#)].
- [107] Denis Bernard and Benjamin Doyon. “Energy flow in non-equilibrium conformal field theory”. In: *J. Phys. A* 45 (2012), p. 362001. DOI: [10.1088/1751-8113/45/36/362001](https://doi.org/10.1088/1751-8113/45/36/362001). arXiv: [1202.0239](https://arxiv.org/abs/1202.0239) [[cond-mat.str-el](#)].
- [108] Denis Bernard and Benjamin Doyon. “Non-Equilibrium Steady States in Conformal Field Theory”. In: *Annales Henri Poincaré* 16.1 (2015), pp. 113–161. DOI: [10.1007/s00023-014-0314-8](https://doi.org/10.1007/s00023-014-0314-8). arXiv: [1302.3125](https://arxiv.org/abs/1302.3125) [[math-ph](#)].

- [109] M. J. Bhaseen et al. “Far from equilibrium energy flow in quantum critical systems”. In: *Nature Phys.* 11 (2015), p. 5. DOI: [10.1038/nphys3220](https://doi.org/10.1038/nphys3220). arXiv: [1311.3655](https://arxiv.org/abs/1311.3655) [hep-th].
- [110] Andrea De Luca et al. “Nonequilibrium thermal transport in the quantum Ising chain”. In: *Phys. Rev. B* 88.13 (2013), p. 134301. DOI: [10.1103/PhysRevB.88.134301](https://doi.org/10.1103/PhysRevB.88.134301). arXiv: [1305.4984](https://arxiv.org/abs/1305.4984) [cond-mat.str-el].
- [111] Benjamin Doyon. “Lecture notes on Generalised Hydrodynamics”. In: *SciPost Physics Lecture Notes* (Aug. 2020). ISSN: 2590-1990. DOI: [10.21468/scipostphyslectnotes.18](https://doi.org/10.21468/scipostphyslectnotes.18).
- [112] Márton Kormos. “Inhomogeneous quenches in the transverse field Ising chain: scaling and front dynamics”. In: *SciPost Physics* 3.3 (Sept. 2017). DOI: [10.21468/scipostphys.3.3.020](https://doi.org/10.21468/scipostphys.3.3.020).
- [113] Brian Swingle. “Unscrambling the physics of out-of-time-order correlators”. In: *Nature Physics* 14.10 (Oct. 2018), pp. 988–990. DOI: [10.1038/s41567-018-0295-5](https://doi.org/10.1038/s41567-018-0295-5).
- [114] Vedika Khemani, Ashvin Vishwanath, and D. A. Huse. “Operator spreading and the emergence of dissipation in unitary dynamics with conservation laws”. In: *Phys. Rev. X* 8.3 (2018), p. 031057. DOI: [10.1103/PhysRevX.8.031057](https://doi.org/10.1103/PhysRevX.8.031057). arXiv: [1710.09835](https://arxiv.org/abs/1710.09835) [cond-mat.stat-mech].
- [115] Antonio M. García-García et al. “Quantum chaos transition in a two-site Sachdev-Ye-Kitaev model dual to an eternal traversable wormhole”. In: *Physical Review D* 100.2 (July 2019). arXiv: [1901.06031](https://arxiv.org/abs/1901.06031) [hep-th]. ISSN: 2470-0029. DOI: [10.1103/physrevd.100.026002](https://doi.org/10.1103/physrevd.100.026002).
- [116] S. W. Hawking. “Black hole explosions?” In: *Nature* 248 (1974), pp. 30–31. DOI: [10.1038/248030a0](https://doi.org/10.1038/248030a0).
- [117] S. W. Hawking. “Breakdown of predictability in gravitational collapse”. In: *Phys. Rev. D* 14 (10 Nov. 1976), pp. 2460–2473. DOI: [10.1103/PhysRevD.14.2460](https://doi.org/10.1103/PhysRevD.14.2460).
- [118] Don N. Page. “Information in black hole radiation”. In: *Phys. Rev. Lett.* 71 (23 Dec. 1993), pp. 3743–3746. DOI: [10.1103/PhysRevLett.71.3743](https://doi.org/10.1103/PhysRevLett.71.3743).
- [119] D. I. Pikulin and M. Franz. “Black Hole on a Chip: Proposal for a Physical Realization of the Sachdev-Ye-Kitaev model in a Solid-State System”. In: *Phys. Rev. X* 7 (3 July 2017), p. 031006. DOI: [10.1103/PhysRevX.7.031006](https://doi.org/10.1103/PhysRevX.7.031006).
- [120] Aaron Chew, Andrew Essin, and Jason Alicea. “Approximating the Sachdev-Ye-Kitaev model with Majorana wires”. In: *Phys. Rev. B* 96 (12 Sept. 2017), 121119(R). DOI: [10.1103/PhysRevB.96.121119](https://doi.org/10.1103/PhysRevB.96.121119).
- [121] Ipei Danshita, Masanori Hanada, and Masaki Tezuka. “Creating and probing the Sachdev-Ye-Kitaev model with ultracold gases: Towards experimental studies of quantum gravity”. In: *PTEP* 2017.8 (2017), p. 083I01. DOI: [10.1093/ptep/ptx108](https://doi.org/10.1093/ptep/ptx108).
- [122] Chenan Wei and Tigran A. Sedrakyan. “Optical lattice platform for the Sachdev-Ye-Kitaev model”. In: *Phys. Rev. A* 103 (1 Jan. 2021), p. 013323. DOI: [10.1103/PhysRevA.103.013323](https://doi.org/10.1103/PhysRevA.103.013323).
- [123] Anffany Chen et al. “Quantum Holography in a Graphene Flake with an Irregular Boundary”. In: *Phys. Rev. Lett.* 121 (3 July 2018), p. 036403. DOI: [10.1103/PhysRevLett.121.036403](https://doi.org/10.1103/PhysRevLett.121.036403).

-
- [124] L. García-Álvarez et al. “Digital Quantum Simulation of Minimal AdS/CFT”. In: *Phys. Rev. Lett.* 119 (4 July 2017), p. 040501. DOI: [10.1103/PhysRevLett.119.040501](https://doi.org/10.1103/PhysRevLett.119.040501).
- [125] Zhihuang Luo et al. “Quantum simulation of the non-fermi-liquid state of Sachdev-Ye-Kitaev model”. In: *npj Quantum Information* 5 (June 2019), p. 53. DOI: [10.1038/s41534-019-0166-7](https://doi.org/10.1038/s41534-019-0166-7).
- [126] Ryan Babbush, Dominic W. Berry, and Hartmut Neven. “Quantum simulation of the Sachdev-Ye-Kitaev model by asymmetric qubitization”. In: *Phys. Rev. A* 99 (4 Apr. 2019), 040301(R). DOI: [10.1103/PhysRevA.99.040301](https://doi.org/10.1103/PhysRevA.99.040301).
- [127] N. V. Gnedilov, J. A. Hutasoit, and C. W. J. Beenakker. “Low-high voltage duality in tunneling spectroscopy of the Sachdev-Ye-Kitaev model”. In: *Phys. Rev. B* 98 (8 Aug. 2018), 081413(R). DOI: [10.1103/PhysRevB.98.081413](https://doi.org/10.1103/PhysRevB.98.081413).
- [128] Oguzhan Can, Emilian M. Nica, and Marcel Franz. “Charge transport in graphene-based mesoscopic realizations of Sachdev-Ye-Kitaev models”. In: *Phys. Rev. B* 99 (4 Jan. 2019), p. 045419. DOI: [10.1103/PhysRevB.99.045419](https://doi.org/10.1103/PhysRevB.99.045419).
- [129] Alexander Altland, Dmitry Bagrets, and Alex Kamenev. “Sachdev-Ye-Kitaev Non-Fermi-Liquid Correlations in Nanoscopic Quantum Transport”. In: *Phys. Rev. Lett.* 123 (22 Nov. 2019), p. 226801. DOI: [10.1103/PhysRevLett.123.226801](https://doi.org/10.1103/PhysRevLett.123.226801).
- [130] Alexander Kruchkov et al. “Thermoelectric power of Sachdev-Ye-Kitaev islands: Probing Bekenstein-Hawking entropy in quantum matter experiments”. In: *Phys. Rev. B* 101 (20 May 2020), p. 205148. DOI: [10.1103/PhysRevB.101.205148](https://doi.org/10.1103/PhysRevB.101.205148).
- [131] Andrei I. Pavlov and Mikhail N. Kiselev. “Quantum thermal transport in the charged Sachdev-Ye-Kitaev model: Thermoelectric Coulomb blockade”. In: *Phys. Rev. B* 103 (20 May 2021), p. L201107. DOI: [10.1103/PhysRevB.103.L201107](https://doi.org/10.1103/PhysRevB.103.L201107).
- [132] Dmitri V. Khveshchenko. “One SYK single electron transistor”. In: *Lithuanian Journal of Physics* 60 (Aug. 2020), p. 3. DOI: [10.3952/physics.v60i3.4305](https://doi.org/10.3952/physics.v60i3.4305).
- [133] Dmitri V. Khveshchenko. “Connecting the SYK Dots”. In: *Condensed Matter* 5.2 (June 2020), p. 37. DOI: [10.3390/condmat5020037](https://doi.org/10.3390/condmat5020037).
- [134] Alex Kamenev. “Course 3 Many-body theory of non-equilibrium systems”. In: *Nanophysics: Coherence and Transport*. Ed. by H. Bouchiat et al. Vol. 81. Les Houches. Elsevier, 2005, pp. 177–246. DOI: [https://doi.org/10.1016/S0924-8099\(05\)80045-9](https://doi.org/10.1016/S0924-8099(05)80045-9).
- [135] Ritabrata Bhattacharya, Dileep P. Jatkar, and Nilakash Sorokhaibam. “Quantum quenches and thermalization in SYK models”. In: *J. High Energy Phys.* 2019.7 (July 2019), p. 66. DOI: [10.1007/JHEP07\(2019\)066](https://doi.org/10.1007/JHEP07(2019)066).
- [136] Clemens Kuhlenskamp and Michael Knap. “Periodically Driven Sachdev-Ye-Kitaev Models”. In: *Phys. Rev. Lett.* 124 (10 Mar. 2020), p. 106401. DOI: [10.1103/PhysRevLett.124.106401](https://doi.org/10.1103/PhysRevLett.124.106401).
- [137] Arijit Haldar et al. “Quench, thermalization, and residual entropy across a non-Fermi liquid to Fermi liquid transition”. In: *Phys. Rev. Research* 2 (1 Mar. 2020), p. 013307. DOI: [10.1103/PhysRevResearch.2.013307](https://doi.org/10.1103/PhysRevResearch.2.013307).
- [138] Xue-Yang Song, Chao-Ming Jian, and Leon Balents. “Strongly Correlated Metal Built from Sachdev-Ye-Kitaev Models”. In: *Phys. Rev. Lett.* 119 (21 Nov. 2017), p. 216601. DOI: [10.1103/PhysRevLett.119.216601](https://doi.org/10.1103/PhysRevLett.119.216601).

- [139] Milton Abramowitz and Irene Stegun. *Handbook of Mathematical Functions, With Formulas, Graphs, and Mathematical Tables*, New York: Dover Publications, Inc., 1964.
- [140] Yura Malitsky. “Golden ratio algorithms for variational inequalities”. In: *Mathematical Programming* 184 (2020), pp. 383–410. DOI: [10.1007/s10107-019-01416-w](https://doi.org/10.1007/s10107-019-01416-w).
- [141] Y. Chepesh et al. “Reentrant superconductivity in a quantum dot coupled to a Sachdev-Ye-Kitaev metal”. In: *Phys. Rev. B* 100 (22 Dec. 2019), 220506(R). DOI: [10.1103/PhysRevB.100.220506](https://doi.org/10.1103/PhysRevB.100.220506).
- [142] Olivier Parcollet et al. “Overscreened multichannel $SU(N)$ Kondo model: Large- N solution and conformal field theory”. In: *Phys. Rev. B* 58 (7 Aug. 1998), pp. 3794–3813. DOI: [10.1103/PhysRevB.58.3794](https://doi.org/10.1103/PhysRevB.58.3794).
- [143] A. V. Lunkin, K. S. Tikhonov, and M. V. Feigel'man. “Sachdev-Ye-Kitaev Model with Quadratic Perturbations: The Route to a Non-Fermi Liquid”. In: *Phys. Rev. Lett.* 121 (23 Dec. 2018), p. 236601. DOI: [10.1103/PhysRevLett.121.236601](https://doi.org/10.1103/PhysRevLett.121.236601).
- [144] Oguzhan Can and Marcel Franz. “Solvable model for quantum criticality between the Sachdev-Ye-Kitaev liquid and a disordered Fermi liquid”. In: *Phys. Rev. B* 100 (4 July 2019), p. 045124. DOI: [10.1103/PhysRevB.100.045124](https://doi.org/10.1103/PhysRevB.100.045124).
- [145] Debanjan Chowdhury et al. “Translationally Invariant Non-Fermi-Liquid Metals with Critical Fermi Surfaces: Solvable Models”. In: *Phys. Rev. X* 8 (3 July 2018), p. 031024. DOI: [10.1103/PhysRevX.8.031024](https://doi.org/10.1103/PhysRevX.8.031024).
- [146] Maria Tikhanovskaya et al. “Excitation spectra of quantum matter without quasiparticles. I. Sachdev-Ye-Kitaev models”. In: *Phys. Rev. B* 103 (7 Feb. 2021), p. 075141. DOI: [10.1103/PhysRevB.103.075141](https://doi.org/10.1103/PhysRevB.103.075141).
- [147] L. S. Levitov and G. B. Lesovik. “Charge distribution in quantum shot noise”. In: *JETP Lett.* 58 (3 1993), p. 230.
- [148] Leonid S. Levitov, Hyunwoo Lee, and Gordey B. Lesovik. “Electron counting statistics and coherent states of electric current”. In: *Journal of Mathematical Physics* 37.10 (1996), pp. 4845–4866. DOI: [10.1063/1.531672](https://doi.org/10.1063/1.531672).
- [149] C.M. Varma, Z. Nussinov, and Wim van Saarloos. “Singular or non-Fermi liquids”. In: *Physics Reports* 361.5-6 (May 2002), pp. 267–417. DOI: [10.1016/s0370-1573\(01\)00060-6](https://doi.org/10.1016/s0370-1573(01)00060-6).