

BIBLIOGRAPHIC NOTES

This section provides references to works described by Joe in the main text of the memoir. It is by no means an exhaustive list for each of the topics discussed. Review articles and/or books will be included for some general topics mentioned without reference in the main text.

CHAPTER 2

2.2

Bill Zajc got his head start by reading Richard P. Feynman, Robert B. Leighton, and Matthew L. Sands, *The Feynman Lectures on Physics* (Reading, MA: Addison-Wesley, 1963).

2.8

Joe mentions that he learned QFT using the old text by James D. Bjorken and Sidney David Drell, *Relativistic Quantum Mechanics* (New York: McGraw-Hill, 1964). I'd personally recommend some of the newer standard texts such as Mark Srednicki, *Quantum Field Theory* (Cambridge: Cambridge University Press, 2007), for its clarity and explicitness, and Michael E. Peskin and Dan V.

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Schroeder, *An Introduction to Quantum Field Theory* (Boulder, CO: Westview Press, 1995), for its high focus on physical reasoning.

The Big Black Book of GR is Charles W. Misner, Kip S. Thorne, and John Archibald Wheeler, *Gravitation* (San Francisco, CA: W. H. Freeman, 1973). The more standard way of learning GR nowadays is through Robert M. Wald, *General Relativity* (Chicago: University of Chicago Press, 1984), or the more accessible Sean M. Carroll, *Spacetime and Geometry: An Introduction to General Relativity* (Cambridge: Cambridge University Press, 2019).

CHAPTER 3

3.3

Diagnosing confinement via the Wilson loop was proposed in Kenneth Wilson, “Confinement of Quarks,” *Physical Review D* 10 (1974). The electromagnetic dual of this operator, the ’t Hooft vortex operator, was discussed in Gerard ’t Hooft, “On the Phase Transition towards Permanent Quark Confinement,” *Nuclear Physics B* 138 (1978). Joe’s construction of the ’t Hooft operator can be found in his dissertation: Joseph Polchinski, “Vortex Operators in Gauge Field Theories” (PhD diss., University of California, Berkeley, 1980). As Joe says, this problem was not completely solved until the work of Kapustin, found in Anton Kapustin, “Wilson-’t Hooft Operators in Four-Dimensional Gauge Theories and S-Duality,” *Physical Review D* 74 (2006).

3.6

More books on QFT include K. Nishijima, *Fields and Particles: Field Theory and Dispersion Relations*, 4th ed. (San Francisco, CA: Benjamin Cummings, 1998); Raymond F. Streater and Arthur S.

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Wightman, *PCT, Spin and Statistics, and All That* (Princeton, NJ: Princeton University Press, 2000); and N. N. Bogoliubov and D. V. Shirkov, *Introduction to the Theory of Quantized Fields* (Geneva: Interscience Publishers, 1959), the last of which used to be the standard text for learning about renormalization.

The advances in QFT in the 1970s include the discovery of monopoles in QFT found in Gerard 't Hooft, "Magnetic Monopoles in Unified Gauge Theories," *Nuclear Physics B* 79 (1974), and Alexander M. Polyakov, "Particle Spectrum in the Quantum Field Theory," *Journal of Experimental and Theoretical Physics Letters* 20 (1974), and the discovery of instantons in Alexander A. Belavin et al., "Pseudoparticle Solutions of the Yang-Mills Equations," *Physics Letters B* 59 (1975). The rediscovery of bosonization was shown in Sidney Coleman, "Quantum Sine-Gordon Equation as the Massive Thirring Model," *Physical Review D* 11 (1975).

Coleman's lectures, compiled in his book *Aspects of Symmetry: Selected Erice Lectures* (Cambridge: Cambridge University Press, 1988), is a highly recommended resource for any serious student of QFT.

CHAPTER 4

4.1

Coleman's theorem forbidding spontaneous breaking of continuous symmetry in $1+1$ -dimensional QFT, due to its propagators being IR divergent, is proven in Sidney Coleman, "There Are No Goldstone Bosons in Two Dimensions," *Communications in Mathematical Physics* 31 (1973).

The classification of electric and magnetic fluxes by 't Hooft that Joe was interested in is Gerard 't Hooft, "A Property of Electric

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and Magnetic Flux in Nonabelian Gauge Theories,” *Nuclear Physics B* 153 (1979). The lattice model which seemed to contradict its results was discussed in Gerhard Mack and Valentina B. Petkova, “Comparison of Lattice Gauge Theories with Gauge Groups $Z(2)$ and $SU(2)$,” *Annals of Physics* 123 (1979), and Laurence G. Yaffe, “Confinement in $SU(N)$ Lattice Gauge Theories,” *Physical Review D* 21 (1980). Joe’s work showing how these models are in fact consistent with ’t Hooft’s conditions when all the fluxes are correctly accounted for is Joseph Polchinski, “Order Parameters in a Modified Lattice Gauge Theory,” *Physical Review D* 25 (1982).

On the comparison between the short, slick physics argument versus the long, rigorous proof, Joe brings up Alexander M. Polyakov, “Quark Confinement and Topology of Gauge Theories,” *Nuclear Physics B* 120 (1977) versus Markus Göpfert and Gerhard Mack, “Proof of Confinement of Static Quarks in 3-Dimensional $U(1)$ Lattice Gauge Theory for All Values of the Coupling Constant,” *Communication in Mathematical Physics* 82 (1982), respectively. The general argument for the difficulty of proving confinement is given in Gerard ’t Hooft, “On the Phase Transition towards Permanent Quark Confinement,” *Nuclear Physics B* 138 (1978).

4-3

A description of the standard model and its possible extensions, including supersymmetry, can be found in the more modern QFT texts given above.

Unifying the forces of the standard model into a single grand unified theory was proposed in Howard Georgi and S. L. Glashow, “Unity of All Elementary-Particle Forces,” *Physical Review Letters* 32 (1974).

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4.4

Witten's work on cancellation of D -term corrections is in Edward Witten, "Mass Hierarchies in Supersymmetric Theories," *Physics Letters B* 105 (1981). Joe's collaborative work demonstrating the cancellation of quantum corrections and the charge sum rule is Willy Fischler, Hans-Peter Nilles, Joseph Polchinski, Stuart Raby, and Leonard Susskind, "Vanishing Renormalization of the D -Term in Supersymmetric $U(1)$ Theories," *Physical Review Letters* 47, (1981).

4.5

An example construction of realistic SUSY models of physics is Luis Álvarez-Gaumé, Mark Claudson, and Mark Wise, "Low-Energy Supersymmetry," *Nuclear Physics B* 207 (1982).

The stability of the various energy scales under SUSY breaking was studied in Joseph Polchinski and Leonard Susskind, "Breaking of Supersymmetry at Intermediate Energy," *Physical Review D* 26 (1982). Further analysis of this question was pursued by Joe in Joseph Polchinski, "Gauge-Fermion Masses in Supersymmetric Hierarchy Models," *Physical Review D* 26 (1982), and Joseph Polchinski, "Effective Potentials for Supersymmetric Three-Scale Hierarchies," *Physical Review D* 27 (1983).

Susskind's work on the connection between information loss and energy nonconservation is Thomas Banks, Leonard Susskind, and Michael Peskin, "Difficulties for the Evolution of Pure States into Mixed States," *Nuclear Physics B* 244 (1984).

4.6

The project Joe worked on during his stop at Aspen is Mary K. Gaillard, Lawrence J. Hall, Bruno Zumino, Francisco del Aguila,

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Joseph Polchinski, and Graham G. Ross, “Light Scalars in $N = 1$ Locally Supersymmetric Theories,” *Physics Letters B* 122 (1983).

CHAPTER 5

5.1

Joe’s “initiation” project at Harvard was published in Joseph Polchinski and Mark B. Wise, “On the Generality of the Mass Sum Rule,” *Nuclear Physics B* 218 (1983).

5.2

While avoiding SUSY, Coleman was busying himself with magnetic monopoles in Sidney Coleman, “The Magnetic Monopole Fifty Years Later,” in *Proceedings, Les Houches Summer School in Theoretical Physics: Gauge Theories in High Energy Physics*, ed. Mary K. Gaillard and Raymond Stora (Les Houches, 1981), 461–552; with ‘t Hooft anomaly cancellation in Sidney Coleman and Bernard Grossman, “‘t Hooft’s Consistency Condition as a Consequence of Analyticity and Unitarity,” *Nuclear Physics B* 203 (1982); and with topological solitons in Sidney Coleman, “Q-Balls,” *Nuclear Physics B* 262 (1985).

5.4

Joe’s work on finding a realistic model of supergravity is in Luis Álvarez-Gaumé, Joseph Polchinski, and Mark B. Wise, “Minimal Low-Energy Supergravity,” *Nuclear Physics B* 221 (1983). As is footnoted in the main text, some results had already been discovered in Luis Ibáñez and Graham G. Ross, “ $SU(2)_L \times U(1)$ Symmetry Breaking as a Radiative Effect of Supersymmetry Breaking

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in GUTs,” *Physics Letters B* 110 (1982). The follow-up work is Benjamin Grinstein, Joseph Polchinski, and Mark B. Wise, “W and Z Decays in Low Energy Supersymmetry,” *Physics Letters B* 130 (1983).

5.5

Joe’s seminal work on renormalization is Joseph Polchinski, “Renormalization and Effective Lagrangians,” *Nuclear Physics B* 231 (1984).

Balaban’s proof of asymptotic freedom culminates in Tadeusz Balaban, “Large Field Renormalization. 2: Localization, Exponentiation, and Bounds for the R Operation,” *Communications in Mathematical Physics* 122 (1989). The entire series is included in this paper’s bibliography.

5.6

The presence of magnetic monopoles in GUTs was first shown in Gerard ’t Hooft, “Magnetic Monopoles in Unified Gauge Theories,” *Nuclear Physics B* 79 (1974), and Alexander M. Polyakov, “Particle Spectrum in the Quantum Field Theory,” *Journal of Experimental and Theoretical Physics Letters* 20 (1974).

Baryonic size controlling of the rate of baryon number violating processes was shown in Valery A. Rubakov, “Adler-Bell-Jackiw Anomaly and Fermion-Number Breaking in the Presence of a Magnetic Monopole,” *Nuclear Physics B* 203 (1982), and Curtis G. Callan, Jr., “Dyon-Fermion Dynamics,” *Physical Review D* 26 (1982). Joe’s toy model for this is in Joseph Polchinski, “Monopole Catalysis: The Fermion-Rotor System,” *Nuclear Physics B* 242 (1984).

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The other Rubakov work on baryon number violation at high temperatures is in Vadim A. Kuzmin, Valery A. Rubakov, and Mikhail E. Shaposhnikov, “On the Anomalous Electroweak Baryon Number Nonconservation in the Early Universe,” *Physics Letters B* 155 (1985). The work involving Joe trying to understand this is Michael Dine, Olaf Lechtenfeld, Bunji Sakita, Willy Fischler, and Joseph Polchinski, “Baryon Number Violation at High Temperature in the Standard Model,” *Nuclear Physics B* 342 (1990).

Rubakov and Shaposhnikov investigated the braneworld idea in Valery A. Rubakov and Mikhail E. Shaposhnikov, “Do We Live Inside a Domain Wall?,” *Physics Letters B* 125 (1983).

5-7

The work Joe reported on was his work with Álvarez-Gaumé and Wise (referenced in section 5.4 above).

The attempt to explain monojets using supersymmetry was in Lawrence J. Hall and Joseph Polchinski, “Implications of Supersymmetric Origins for Monojets,” *Physics Letters B* 152 (1985).

Explaining the putative new signal using wave-function effects was done in Joseph Polchinski, Stephen R. Sharpe, and Ted Barnes, “Bound State Effects in $\Upsilon \rightarrow \zeta(8.3) + \gamma$,” *Physics Letters B* 148 (1984), and James Pantaleone, Michael E. Peskin, and S.-H. Henry Tye, “Bound-State Effects in $\Upsilon \rightarrow \gamma + \text{Resonance}$,” *Physics Letters B* 149 (1984).

CHAPTER 6

6.3

It goes without saying that *the* authoritative text on string theory is Joe’s very own *String Theory*, which was published in the two

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volumes: Joseph Polchinski, *String Theory: An Introduction to the Bosonic String*, vol. 1 (Cambridge: Cambridge University Press, 1998), and Joseph Polchinski, *String Theory: Superstring Theory and Beyond*, vol. 2 (Cambridge: Cambridge University Press, 1998). A useful supporting document to this is Joe's string theory course notes titled *Joe's Little Book of String*, found online at <https://www.kitp.ucsb.edu/sites/default/files/users/joep/JLBS.pdf>.

The cancellation of anomalies in superstring theories with chiral fermions is found in Michael B. Green and John H. Schwarz, "Anomaly Cancellations in Supersymmetric $D=10$ Gauge Theory and Superstring Theory," *Physics Letters B* 149 (1984).

Heterotic string theory, which could accommodate something like the standard model, was discovered in David J. Gross, Jeffrey A. Harvey, Emil Martinec, and Ryan Rohm, "Heterotic String," *Physical Review Letters* 54(1985).

Solutions of compactified string theory on Calabi-Yau spaces was first found in Philip Candelas, Gary T. Horowitz, Andrew Strominger, and Edward Witten, "Vacuum Configurations for Superstrings," *Nuclear Physics B* 258 (1985).

Work on effective strings in any dimension, not those required by actual strings, was done in Joseph Polchinski and Andrew Strominger, "Effective String Theory," *Physical Review Letters* 67 (1991).

Joe's papers on the Polyakov path integral include Joseph Polchinski, "Evaluation of the One Loop String Path Integral," *Communications in Mathematical Physics* 104 (1986); Joseph Polchinski, "Vertex Operators in the Polyakov Path Integral," *Nuclear Physics B* 289 (1987); and Joseph Polchinski, "Factorization of Bosonic String Amplitudes," *Nuclear Physics B* 307 (1988).

Joe's collaborations on aspects of the Polyakov path integral regarding off-shell amplitudes and supersymmetry are Andrew

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Cohen, Gregory Moore, Philip Nelson, and Joseph Polchinski, "Semi-Off-Shell String Amplitudes," *Nuclear Physics B* 281 (1987), and Gregory Moore, Philip Nelson, and Joseph Polchinski, "Strings and Supermoduli," *Physics Letters B* 169 (1986). Erratum: *Physics Letters B* 201 (1988).

6.4

The breaking of $N = 2$ down to $N = 1$ by vortices was shown in David Lancaster, "Instanton Contributions to Supersymmetric Ward Identities," *Nuclear Physics B* 238 (1984). Joe's work with Hughes on working out the four-dimensional action of $N = 2$ to $N = 1$ breaking is in James Hughes and Joseph Polchinski, "Partially Broken Global Supersymmetry and the Superstring," *Nuclear Physics B* 278 (1986), and James Hughes, Jun Liu, and Joseph Polchinski, "Supermembranes," *Physics Letters B* 180 (1986). The extension to the case of $D = 6$ to $D = 4$ is in James Hughes, Jun Liu, and Joseph Polchinski, "Virasoro-Shapiro from Wilson," *Nuclear Physics B* 316 (1989).

The supposed no-go theorem precluding the breaking of SUSY from $N = 2$ to $N = 1$ in four dimensions uses the argument in Rudolf Haag, Martin Sohnius, and Jan T. Łopuszański, "All Possible Generators of Supersymmetries of the S-Matrix," *Nuclear Physics B* 88 (1975).

Classification of all possible membranes was performed in the seminal works Eric Bergshoeff, Ergin Sezgin, and Paul K. Townsend, "Superstring Actions in $D = 3, 4, 6, 10$ Curved Superspace," *Physics Letters B* 169 (1986), and Eric Bergshoeff, Ergin Sezgin, and Paul K. Townsend, "Supermembranes and Eleven-Dimensional Supergravity," *Physics Letters B* 189 (1987).

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Understanding the potential anomaly in superstring theory and its cancellation from the perspective of the fundamental string was done in Joseph Polchinski and Yunhai Cai, "Consistency of Open Superstring Theories," *Nuclear Physics B* 296 (1988).

6.5

The monotonicity of the scale transformation was shown in Alexander B. Zamolodchikov, "'Irreversibility' of the Flux of the Renormalization Group in a 2D Field Theory," *JETP Letters* 43 (1986), which Joe used to prove that scaling symmetry implies conformal symmetry in Joseph Polchinski, "Scale and Conformal Invariance in Quantum Field Theory," *Nuclear Physics B* 303 (1988).

Witten analyzed the production of cosmic strings in superstring theory in Edward Witten, "Cosmic Superstrings," *Physics Letters B* 153 (1985).

On the question of strings passing through each other, the numerical analysis on GUTs strings was done in Richard A. Matzner, "Interaction of $U(1)$ Cosmic Strings: Numerical Intercommutation," *Computers in Physics* 2 (1988), while the analytic study for the fundamental string was done by Joe in Joseph Polchinski, "Collision of Macroscopic Fundamental Strings," *Physics Letters B* 209 (1988). The follow-up with open strings is Jin Dai and Joseph Polchinski, "The Decay of Macroscopic Fundamental Strings," *Physics Letters B* 220 (1989).

The work on mirror symmetry is Philip Candelas, Xenia C. De La Ossa, Paul S. Green, and Linda Parkes, "A Pair of Calabi-Yau Manifolds as an Exactly Soluble Superconformal Theory," *Nuclear Physics B* 359 (1991).

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Weinberg's work on string theory vertex operators is Steven Weinberg, "Coupling Constants and Vertex Functions in String Theories," *Physics Letters B* 156 (1985), and on the finiteness of the bosonic open string is Steven Weinberg, "Cancellation of One-Loop Divergences in $SO(8|192)$ String Theory," *Physics Letters B* 187 (1987).

Cancellations in the dilaton energy between string amplitudes and loop divergences were studied in Willy Fischler and Leonard Susskind, "Dilaton Tadpoles, String Condensates and Scale Invariance," *Physics Letters B* 171 (1986), and Willy Fischler and Leonard Susskind, "Dilaton Tadpoles, String Condensates and Scale Invariance II" *Physics Letters B* 173 (1986).

The work by the "international students" on the low energy effective action of the string is Clifford P. Burgess, Anamaría Font, and Fernando Quevedo, "Low-Energy Effective Action for the Superstring," *Nuclear Physics B* 272 (1986).

CHAPTER 7

7.1

The book on string theory utilizing mostly the light-cone methods is Michael B. Green, John H. Schwarz, and Edward Witten, *Superstring Theory*, vols. 1 and 2 (Cambridge: Cambridge University Press, 1987).

The work on heavy quark theory that Joe "regretted" missing out on was Nathan Isgur and Mark B. Wise, "Weak Decays of Heavy Mesons in the Static Quark Approximation," *Physical Letters B* 232 (1989).

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7.2

Joe's seminal work with his students introducing D-branes and connecting different string theories via T -duality is Jin Dai, Robert G. Leigh, and Joseph Polchinski, "New Connections between String Theories," *Modern Physics Letters A* 4 (1989). Earlier work showing that the two type II theories were T -dual is Michael Dine, Patrick Y. Huet, and Nathan Seiberg, "Large and Small Radius in String Theory," *Nuclear Physics B* 322 (1989).

The works Joe refers to by Hořava and Green in a footnote are Petr Hořava, "Background Duality of Open String Models," *Physics Letters B* 231 (1989), and Michael B. Green, "Modifying the Bosonic String Vacuum," *Physics Letters B* 201 (1988).

p -Branes were introduced in Ana Achucarro, Jonathan M. Evans, Paul K. Townsend, and David L. Wiltshire, "Super p -Branes," *Physical Letters B* 198 (1987).

The original argument precluding the standard model from type IIA, B was presented in Lance J. Dixon, Vadim Kaplunovsky, and Cumrun Vafa, "On Four-Dimensional Gauge Theories from Type II Superstrings," *Nuclear Physics B* 294 (1987).

The effective field theory for the D-branes was worked out in Robert G. Leigh, "Dirac-Born-Infeld Action from Dirichlet Sigma Model," *Modern Physics Letters A* (1989).

Showing that the two heterotic theories are T -dual was done in Kumar S. Narain, "New Heterotic String Theories in Uncompactified Dimensions < 10 ," *Physical Letters B* 169 (1986).

7.3

The ability to formulate string theory in dimensions other than 10 and nonzero vacuum energy was shown in Robert C. Myers,

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“New Dimensions for Old Strings,” *Physical Letters B* 199 (1987). Joe’s work on trying to construct examples with small CC is in Shanta P. de Alwis, Joseph Polchinski, and Rolf Schimmrigk, “Heterotic Strings with Tree Level Cosmological Constant,” *Physical Letters B* 218 (1989).

The physics of spacetime wormholes in quantum gravity was analyzed in Sidney R. Coleman, “Black Holes as Red Herrings: Topological Fluctuations and the Loss of Quantum Coherence,” *Nuclear Physics B* 307 (1988); Steven B. Giddings and Andrew Strominger, “Axion Induced Topology Change in Quantum Gravity and String Theory,” *Nuclear Physics B* 306 (1988); and Steven B. Giddings and Andrew Strominger, “Loss of Incoherence and Determination of Coupling Constants in Quantum Gravity,” *Nuclear Physics B* 307 (1988). Coleman’s application of those ideas to address the CC problem is in Sidney R. Coleman, “Why There Is Nothing Rather than Something: A Theory of the Cosmological Constant,” *Nuclear Physics B* 310 (1988).

Lenny’s ambition, along with not finding evidence for a peak at zero CC, was realized in Willy Fischler, Igor Klebanov, Joseph Polchinski, and Leonard Susskind, “Quantum Mechanics of the Gogolplexus,” *Nuclear Physics B* 327 (1989).

The idea of addressing the CC problem by sourcing the CC with a four-form field strength was proposed in Stephen W. Hawking, “The Cosmological Constant Is Probably Zero,” *Physical Letters B* 134 (1984). This is related to earlier work in Michael J. Duff and Peter van Nieuwenhuizen, “Quantum Inequivalence of Different Field Representations,” *Physical Letters B* 94 (1980), and Antonio Aurilia, Hermann Nicolai, and Paul K. Townsend, “Hidden Constants: The Theta Parameter of QCD and the Cosmological Constant of $N = 8$ Supergravity,” *Nuclear Physics B* 176 (1980).

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Getting energy from tunneling was analyzed by Joe and collaborators in Willy Fischler, Daniel Morgan, and Joseph Polchinski, "Quantum Nucleation of False Vacuum Bubbles," *Physical Review D* 41 (1990), and Willy Fischler, Daniel Morgan, and Joseph Polchinski, "Quantization of False Vacuum Bubbles: A Hamiltonian Treatment of Gravitational Tunneling," *Physical Review D* 42 (1990). The general idea had been argued before in Edward Farhi and Alan H. Guth, "An Obstacle to Creating a Universe in the Laboratory," *Physical Letters B* 183 (1987).

Morgan's work on black holes with a cutoff placed on the maximum allowed curvature is Daniel Morgan, "Black Holes in Cutoff Gravity," *Physical Review D* 43 (1991).

The other possibilities for explaining the CC Joe mentions in passing are Tom Banks, "TCP, Quantum Gravity, the Cosmological Constant and All That . . .," *Nuclear Physics B* 249 (1985); Laurence F. Abbott, "A Mechanism for Reducing the Value of the Cosmological Constant," *Physics Letters B* 150 (1985); J. David Brown and Claudio Teitelboim, "Dynamical Neutralization of the Cosmological Constant," *Physics Letters B* 195 (1987); and J. David Brown and Claudio Teitelboim, "Neutralization of the Cosmological Constant by Membrane Creation," *Nuclear Physics B* 297 (1988). Aspects of the latter two are discussed further in chapter 9.

Weinberg's seminal paper on bounding the CC using anthropics is Steven Weinberg, "Anthropic Bound on the Cosmological Constant," *Physical Review Letters* 59 (1987).

7.4

Work by Thorne and collaborators on closed time-like curves via boosted wormholes is Michael S. Morris, Kip S. Thorne, and Ulvi Yurtsever, "Wormholes, Time Machines, and the Weak Energy

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Condition,” *Physical Review Letters* 61 (1988). Their work studying the “Polchinski Paradox” of a billiard ball striking itself is Fernando Echeverria, Gunnar Klinkhammer, and Kip S. Thorne, “Billiard Balls in Wormhole Space-Times with Closed Timelike Curves: Classical Theory,” *Physical Review D* 44 (1991).

Some problems with nonlinear extensions of quantum mechanics were studied by Joe in Joseph Polchinski, “Weinberg’s Nonlinear Quantum Mechanics and the EPR Paradox,” *Physical Review Letters* 66 (1991), and also in Nicolas Gisin, “Stochastic Quantum Dynamics and Relativity,” *Helvetica Physica Acta* 62 (1989).

7.5

7.5.1 Attempts at defining string theory nonperturbatively include Edward Witten, “Noncommutative Geometry and String Field Theory,” *Nuclear Physics B* 268 (1986); Ashoke Sen, “Tachyon Condensation on the Brane Anti-Brane System,” *Journal of High Energy Physics* 8 (1998) (for a more recent review, see Ashoke Sen, “Tachyon Dynamics in Open String Theory,” *International Journal of Modern Physics A* 20 [2005]); and Barton Zwiebach, “Closed String Field Theory: Quantum Action and the B-V Master Equation,” *Nuclear Physics B* 390 (1993).

Work on solvable matrix models and $1+1$ -dimensional string theory is David J. Gross and Alexander A. Migdal, “Nonperturbative Two-Dimensional Quantum Gravity,” *Physical Review Letters* 64 (1990); Michael R. Douglas and Stephen H. Shenker, “Strings in Less than One Dimension,” *Nuclear Physics B* 335 (1990); and Edouard Brezin and Vladimir A. Kazakov, “Exactly Solvable Field Theories of Closed Strings,” *Physical Letters B* 236 (1990).

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The size of nonperturbative effects in string theory was studied in Stephen H. Shenker, “The Strength of Nonperturbative Effects in String Theory,” in *The Large N Expansion in Quantum Field Theory and Statistical Physics: From Spin Systems to Two-Dimensional Gravity*, ed. E. Brezin and S. R. Wadia (Singapore: World Scientific, 1993), 809–819.

7.5.2 Joe’s work with Bryce on searching for a UV fixed point for quantum gravity was done in Jorge de Lyra, Bryce S. DeWitt, See Kit Foong, Timothy Gallivan, Rob Harrington, Arie Kapulkin, Eric Myers, and Joseph Polchinski, “The Quantized $O(1,2) / O(2) \times Z(2)$ Sigma Model Has No Continuum Limit in Four-Dimensions. 1. Theoretical Framework,” *Physical Review D* 46 (1992), and Jorge de Lyra, Bryce S. DeWitt, See Kit Foong, Timothy Gallivan, Rob Harrington, Arie Kapulkin, Eric Myers, and Joseph Polchinski, “The Quantized $O(1,2) / O(2) \times Z(2)$ Sigma Model Has No Continuum Limit in Four-Dimensions. 2. Lattice Simulation,” *Physical Review D* 46 (1992).

7.5.3 The quantum mechanics text that Joe used is A. S. Davydov, *Quantum Mechanics* (New York: Pergamon Press, 1965).

Joe’s seminal paper on Fermi surfaces is Joseph Polchinski, “Effective Field Theory and the Fermi Surface,” in *Recent Directions in Particle Theory: From Superstrings and Black Holes to the Standard Model*, Proceedings of the 1992 Theoretical Advanced Study Institute in Elementary Particle Physics, ed. Jeffrey Harvey and Joseph Polchinski (Singapore: World Scientific, 1993), 235–274.

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7.6

The work on T -duality in time-dependent solutions is Eric Smith and Joseph Polchinski, "Duality Survives Time Dependence," *Physical Letters B* 263 (1991). Smith's work analyzing $1+1$ strings is Eric Smith, "Light Cone Gauge for $(1+1)$ Strings," *Nuclear Physics B* 382 (1992).

Minic's work on solutions to $1+1$ -dimensional string theory is in Djordje Minic, Joseph Polchinski, and Zhu Yang, "Translation Invariant Backgrounds in $(1+1)$ -Dimensional String Theory," *Nuclear Physics B* 369 (1992), and Djordje Minic and Zhu Yang, "Is $S=1$ for $c=1$?" *Physical Letters B* 274 (1992). His work on quark dynamics is in Duane A. Dicus, Djordje Minic, Ubirajara van Kolck, and Roberto Vega, "The Axial Vector Coupling and Magnetic Moment of the Quark," *Physical Letters B* 284 (1992). The work on the Luttinger liquid is Djordje Minic, "On the Theory of the One-Dimensional Luttinger Liquid," *Modern Physical Letters B* 7 (1993). His work on $1+1$ -dimensional black holes is in Shyamoli Chaudhuri and Djordje Minic, "On the Black Hole Background of Two-Dimensional String Theory," *Physical Letters B* 312 (1993).

Natsuume's first project from Joe on noncritical strings is Makoto Natsuume, "Nonlinear Sigma Model for String Solitons," *Physical Review D* 48 (1993). His second on the high-dimensional string S -matrix is Makoto Natsuume, "Natural Generalization of Bosonic String Amplitudes," preprint, submitted February 26, 1993. <https://arxiv.org/abs/hep-th/9302131>. The work he did on the S -matrix in $1+1$ dimensions is Makoto Natsuume, "Zero Mode Divergence Problem in String Theory," *Modern Physical Letters A* 9 (1994). His work on corrections to string theory black holes is Makoto Natsuume, "Higher Order Correction to the GHS String

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Black Hole,” *Physical Review D* 50 (1994). Including Joe, the work on gravity in the $1+1$ -dimensional string theory is Makoto Natsuume and Joseph Polchinski, “Gravitational Scattering in the $c=1$ Matrix Model,” *Nuclear Physics B* 424 (1994).

A list of Makoto’s popular articles and books can be found on his personal website at <https://research.kek.jp/people/natsuume/activities-e.html>.

CHAPTER 8

8.1

A highly recommended resource for physicists, novice and veterans alike, is the KITP website <https://www.kitp.ucsb.edu>, which keeps an audio/video archive of all its conferences and workshops.

The rather amusing book on the history of the IAS is Ed Regis, *Who Got Einstein’s Office? Eccentricity and Genius at the Institute for Advanced Study* (New York: Perseus Publishing, 1987).

8.2

Hawking’s discovery that black holes evaporate via pair creation at the horizon is in Stephen W. Hawking, “Particle Creation by Black Holes,” *Communications Mathematical Physics* 43 (1975). He then argued that it led to a loss of information in Stephen W. Hawking, “Breakdown of Predictability in Gravitational Collapse,” *Physical Review D* 14 (1976).

The famous CGHS model of an evaporating black hole in two dimensions was introduced in Curtis G. Callan, Jr., Steven B. Giddings, Jeffrey A. Harvey, and Andrew Strominger, “Evanescent Black Holes,” *Physical Review D* 45 (1992).

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CHAPTER 12

12.1

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