

Quantum Gravity

K. Sreeman Reddy

E-mail: sreeman@brandeis.edu

ABSTRACT: These are some short notes on quantum gravity. I will try to review all relevant topics briefly. Perturbative string theory is the only UV finite quantum gravity theory we have (excluding toy models like SYK). Non-perturbative information can be extracted from the AdS/CFT correspondence, D-branes, and string field theory, but non-perturbative string theory is not yet properly understood. Alternative approaches are very, very incomplete compared to string theory. But I will also briefly discuss some of them. I will be continuously updating these notes when I learn new things. Which topic gets more importance will be biased based on what I am interested in. These notes are useful only to revise stuff that you already know, not for first time learning. Whenever many reviews are cited, assume that the first reference is the best. For frameworks that are already empirically verified (QM, GR, and QFT), check notes at ksr.onl/FP.

My current research area is section 8.2.

Please email me any mistakes you find.

Currently, these notes are in the beginning stage and are only useful to see the references cited under each section.

Contents

1	Introduction	2
1.1	Problems	2
1.2	Expected properties	3
1.3	History	3
1.4	QFT in curved spacetime	3
1.4.1	Unruh radiation in flat space	4
1.4.2	Hawking radiation	4
1.4.3	The information paradox	4
1.4.3.1	The small corrections theorem	4
1.4.3.2	AMPS firewall	4
1.5	GR as an EFT	4
I	String theory	5
2	Conformal field theory	5
2.1	$D \geq 3$	5
2.1.1	Conformal transformations	5
2.1.2	Representations of the conformal group	6
2.1.3	Radial quantization	6
2.2	$D = 2$	6
2.2.1	Conformal transformations	6
2.2.2	Primary fields	6
2.2.3	OPE	6
2.2.4	Ward identities	6
2.2.5	Free boson	6
2.2.6	Free fermion	6
2.2.7	The bc theory	6
2.2.8	The $\beta\gamma$ theory	6
2.2.9	CFT on the Disk	6
2.2.10	CFT on the Torus	6
2.2.11	Bosonization	6
2.2.12	Entanglement entropy	6
2.3	Bootstrap	6
2.4	Axiomatic CFT	6
3	Bosonic string theory	6
3.1	Classical	6
3.2	Quantize	6
3.2.1	Canonical quantization	6

3.2.2	Light-cone quantization	6
3.2.3	Covariant path integral quantization	6
3.2.4	BRST quantization	6
3.3	Scattering amplitudes	6
3.3.1	Tree-level amplitudes	6
3.3.2	One-loop amplitudes	6
4	Supersymmetry	6
4.1	SUSY QM	6
4.2	SUSY QFT	7
4.2.1	Superspace	7
4.2.2	Gauge theories	7
4.3	SUGRA	7
4.3.1	11D	7
4.3.2	10D	7
4.3.3	4D	7
5	Superstring theory	7
5.1	Classical	7
5.2	Type II string theories	7
5.3	Type I string theory	7
5.4	Heterotic string theories	7
5.5	Vertex operators	7
5.6	Scattering amplitudes	7
5.6.1	Tree-level amplitudes	7
5.6.2	One-loop amplitudes	7
5.6.3	UV finiteness	7
5.7	String dualities	7
5.7.1	T-duality	7
5.7.2	S-duality	7
5.7.3	F-theory	7
6	String landscape	8
6.1	String compactifications	8
6.2	Nongeometric compactifications	8
6.3	String cosmology	8
6.3.1	de-Sitter vacua	8
6.3.2	String inflation	8
6.3.3	Brane cosmology	8
6.4	Particle phenomenology	8
6.5	Swampland	8

7	<i>D</i>-branes	8
7.1	Effective actions	8
7.2	As BPS SUGRA solitons	8
7.3	D-branes moving and merging	8
7.4	Creation/Annihilation of D-branes	8
7.5	Multiple coincident D-branes	8
7.6	D-brane geometry	8
8	Holography	9
8.1	Stringy AdS/CFT	9
8.1.1	Dictionary	9
8.1.2	Correlation functions	9
8.1.3	Finite temperature	9
8.1.4	Solitons	9
8.1.5	The pp wave correspondence	9
8.1.6	Different dimensions	9
8.1.6.1	AdS_3 compactifications	9
8.1.7	Orbifolds and orientifolds	9
8.1.8	Integrability	9
8.1.9	Higher spin duality (tensionless limit)	9
8.1.10	Fluid/gravity correspondence	9
8.1.11	Nonrelativistic limit	9
8.2	It from Qubit AdS/CFT	9
8.2.1	Holographic entanglement entropy	9
8.2.1.1	Classical gravity from entanglement	9
8.2.1.2	Quantum extremal surfaces	9
8.2.1.3	Derivation of RT, HRT, QES from gravity path integral	9
8.2.1.4	Holographic entropy cone	10
8.2.1.5	Bit threads	10
8.2.1.6	Islands	10
8.2.1.7	Quantum extremal surface perturbation theory	10
8.2.2	Tensor networks	10
8.2.3	Error correction	10
8.2.4	Chaos	10
8.2.5	Complexity	10
8.2.6	SYK	10
8.2.7	JT	10
8.2.8	DSSYK	10
8.2.9	von Neumann algebras	10
8.3	Flat space holography	10
8.3.1	Celestial holography	10
8.3.2	Carrollian holography	10
8.4	de Sitter holography approaches	11

8.4.1	dS/CFT	11
8.4.2	Static patch holography	11
8.4.3	$T\bar{T}$ deformation	11
9	Stringy maths (inspired from or related to strings)	11
9.1	Mirror symmetry	11
9.2	Modular forms	11
9.3	Monstrous moonshine	11
9.4	Knot theory	11
9.5	Geometric Langlands correspondence	11
9.6	K-theory	11
9.7	p-adic strings	11
9.8	Higher structures	11
9.8.1	Higher gauge theory	11
9.8.2	Higher category theory	11
9.9	Noncommutative geometry	11
9.9.1	Noncommutative algebraic geometry and mirror symmetry	12
9.9.2	Noncommutative quantum field theory	12
10	M-theory	12
10.1	Membrane theory	12
10.2	Matrix theory	12
10.2.1	BFSS matrix model	12
10.2.2	IKKT matrix model	12
10.3	AdS/CFT approach	12
10.3.1	$AdS_4 \times S^7/\mathbb{Z}_k$ & ABJM CFT	12
10.4	Miscellaneous	12
11	String field theory	12
11.1	Off-shell string theory	12
11.2	Bosonic string field theory	12
11.2.1	Open	12
11.2.2	Closed	12
11.2.3	Open-Closed	12
11.2.4	Background independence	12
11.3	Superstring field theory	12
11.4	Tachyon condensation	12
12	Miscellaneous	13
12.1	Chern-Simons theories	13
12.1.1	Superconformal Chern-Simons matter theories	13
12.1.2	Quantum Gravity in 2+1 Dimensions	13
12.2	Topological string theory	13
12.2.1	Twistor string theory	13

12.2.1.1	Amplituhedron	13
12.3	More on scattering amplitudes	13
12.3.1	Double copy	13
12.4	Localization techniques	13
12.5	Generalized symmetries	14
12.6	Pure spinor formalism	14
12.7	Worldline formalism (∞ tension limit)	14
12.8	2D string theory	14
12.9	Liouville theory	14
12.10	Metastring theory and modular spacetime	14
II	Other approaches	15
13	Twistor theory	15
13.1	Real slices and reality structures	15
13.2	$\mathbb{M}_{\mathbb{C}}$'s conformal structure = \mathbb{PT} 's complex structure	15
13.3	Penrose transform	15
13.4	Gauge theory	15
13.5	Ambitwistors and $d > 4$	15
13.6	Mini-Twistor theory	15
13.7	Miscellaneous	15
14	Canonical quantum gravity	15
14.1	ADM formalism	15
14.2	Wheeler–DeWitt equation	15
15	Loop quantum gravity	15
15.1	Ashtekar variables	15
15.2	Quantum Riemannian geometry	15
15.3	Spin foams	15
15.4	Loop quantum cosmology	15
16	Weinberg's asymptotic safety	16
17	Causal set theory	16
18	Causal fermion systems	16
19	Causal dynamical triangulation	16
20	Group field theory	16
21	Unimodular gravity	16
22	Hořava–Lifshitz gravity	16

A Miscellaneous math	17
References	18
Acknowledgements	38

1 Introduction

Nevertheless, due to the inneratomic movement of electrons, atoms would have to radiate not only electromagnetic but also gravitational energy, if only in tiny amounts. As this is hardly true in nature, it appears that **quantum theory would have to modify** not only Maxwellian electrodynamics, but also the new theory of gravitation.

Albert Einstein (1916) [1]

Gravity couples to the stress-energy tensor. So, gravity couples to everything. Except for gravity, we know that everything else in the physical world is fundamentally quantum in nature. It is probably not possible or at least inelegant to consistently couple classical gravity to quantum fields. So, we are compelled to quantize gravity.

Since it couples to everything, in principle, every calculation that we make to predict something about reality must include corrections coming from quantum gravity. For example, if you have a scalar field theory, we know how to solve the QFT if we neglect the scalar field interaction with gravity, but there will always be corrections due to the interaction between the scalar field and gravity. You can do semiclassical physics (QFT in curved spacetime), but there will still be quantum gravity corrections. But, in practice, quantum gravity effects are notoriously hard to detect in experiments. The Planck length is 10^{16} times smaller than the smallest scale that our species probed. In a loose sense, any approach to quantum gravity is a theory of everything since quantum gravity is *necessary* to understand anything exactly. But usually, the term theory of everything is reserved for theories like string theory where the theory is hoped to be *sufficient* to explain all physical phenomena.

We have figured out how to quantize fields with spin $0, \frac{1}{2}, 1$. But quantizing the spin 2 gravitational quantum field turned out to be hard or impossible due to the perturbative nonrenormalizability of gravity. It is unlikely that there is a nontrivial UV fixed point for gravity; see section 16. So, it seems highly likely that the framework of QFT is insufficient for quantum gravity, and we have ... [to go... even further beyond!](#)

I learned very early the difference between knowing the name of something and knowing something.

Richard Feynman

When I started these notes, I knew the *names* of most topics related to quantum gravity. My goal now is to properly understand them instead of just knowing the names.

1.1 Problems

[15–19]

Some of the many problems that we encounter when we try to quantize gravity are:

Perturbative nonrenormalizability:

Unitarity of black hole evaporation:

Causality and chronology protection conjecture:

Singularities and cosmic censorship:

Problem of time:

Failure of classical spacetime: If we try to probe a distance smaller than the Planck scale, then due to the Heisenberg uncertainty principle, the momentum and energy will be so large that this region will collapse into a black hole. So, the classical spacetime that we understand well breaks down at the Planck scale. What is the nature of quantum spacetime from which the classical spacetime emerges? Is it noncommutative geometry [9.9](#)?

Holographic description: Does the fact that black hole entropy scales like area really imply that quantum gravity must have a lower dimensional field theory description? Is holography limited to asymptotically AdS spacetimes (AdS/CFT)? Or is it a property of all spacetimes?

Framework: All approaches to quantum gravity indirectly use the framework of QFT or GR. For example, worldsheet string theory is $2D$ CFT, and holography is $D \geq 2$ CFT. Is there a more natural mathematical framework for quantum gravity instead of QFT?

Quantum gravity is notoriously a subject where problems vastly outnumber results.

Sidney Coleman (1989)

1.2 Expected properties

These are some expected properties of quantum gravity. Some things, like *no global symmetries*, *weak gravity conjecture*, can also be included here, but I will discuss them under the swampland conjectures in [6.5](#).

Unitarity:

No local observables: [\[21\]](#).

UV complete: [\[89\]](#)

IR complete: [\[22, 89, 171\]](#). Although IR divergences are normally considered to be less serious than ultraviolet ones, they certainly cannot be ignored.

Holography: [\[23–25\]](#). Historically, holography was first argued [\[26\]](#) based on black hole thermodynamics without invoking string theory.

1.3 History

[\[27–36\]](#)

I do not want to discuss history. But check the above references. There are many interesting historical facts like how string theory was originally developed to explain the strong force instead of quantum gravity.

1.4 QFT in curved spacetime

[\[37–55\]](#)

Even though Hawking radiation has not yet been experimentally observed, almost every reasonable physicist believes in its validity. So, this section could be, in principle, moved to my [FP](#) notes. But it is highly relevant to quantum gravity.

1.4.1 Unruh radiation in flat space

1.4.2 Hawking radiation

1.4.3 The information paradox

1.4.3.1 The small corrections theorem
[\[44–46\]](#)

1.4.3.2 AMPS firewall

1.5 GR as an EFT

[\[56–59\]](#)

Part I

String theory

References: [2, 3] are the standard references. [4, 5] are also very good and cover later understanding of non-perturbative and holographic stuff. Also see [6–14][183]

Why string theory? I will briefly mention some promising reasons. Check [60–62] for more.

- 1.

2 Conformal field theory

[63–71]

The worldsheet descriptions of bosonic/superstring theories are 2D CFTs. $D > 2$ CFTs are the holographic duals of superstring theories with more than 3 noncompact dimensions. So, both cases are important.

2.1 $D \geq 3$

2.1.1 Conformal transformations

A conformal transformation is a specific combination of a general coordinate and a **Weyl transformation** that leaves the metric intact. Usually, this metric is the flat Minkowski metric.

Almost everywhere, people specify that conformal transformation is a type of coordinate transformation. **But it is not.** The first time I saw this definition was in [122] in my undergrad final year, and it resolved my longstanding confusion about this definition. Every physical theory (not only general relativity) has diffeomorphism invariance, and you can check the beginning of the General relativity chapter in my [FP notes](#) if you want to know why every physical theory from Newtonian mechanics has diffeomorphism invariance. If conformal transformation is just a subset of coordinate transformation, then conformal symmetry will be present in every theory, and that is nonsense. A **mere coordinate transformation** can never change distances, as ds^2 is invariant under coordinate transformations. So, you can never scale distances with them. But a **Weyl transformation changes the distances** because it directly changes the metric without changing the coordinates. Weyl symmetry **implies** conformal symmetry, but the converse is not true.

2.1.2 Representations of the conformal group

2.1.3 Radial quantization

2.2 $D = 2$

2.2.1 Conformal transformations

2.2.2 Primary fields

2.2.3 OPE

2.2.4 Ward identities

2.2.5 Free boson

2.2.6 Free fermion

2.2.7 The bc theory

2.2.8 The $\beta\gamma$ theory

2.2.9 CFT on the Disk

2.2.10 CFT on the Torus

2.2.11 Bosonization

2.2.12 Entanglement entropy

2.3 Bootstrap

2.4 Axiomatic CFT

[71–73][66]

3 Bosonic string theory

3.1 Classical

3.2 Quantize

For this part [9] is the best.

3.2.1 Canonical quantization

3.2.2 Light-cone quantization

3.2.3 Covariant path integral quantization

3.2.4 BRST quantization

3.3 Scattering amplitudes

3.3.1 Tree-level amplitudes

3.3.2 One-loop amplitudes

4 Supersymmetry

4.1 SUSY QM

[74, 75, 78, 183]

4.2 SUSY QFT

[76–82]

4.2.1 Superspace

4.2.2 Gauge theories

4.3 SUGRA

[83–88]

4.3.1 11D

[85, 86]

4.3.2 10D

4.3.3 4D

5 Superstring theory

There are no open strings in IIA, IIB in perturbation theory around the vacuum.

Type II does include open strings. However, they don't show up in the vacuum perturbation theory, they are only there in connection with non-perturbative effects like D-branes.

5.1 Classical

[7]

5.2 Type II string theories

5.3 Type I string theory

5.4 Heterotic string theories

5.5 Vertex operators

5.6 Scattering amplitudes

5.6.1 Tree-level amplitudes

5.6.2 One-loop amplitudes

5.6.3 UV finiteness

[89]

5.7 String dualities

5.7.1 T-duality

5.7.2 S-duality

5.7.3 F-theory

[90]

6 String landscape

6.1 String compactifications

[91–97]

Freund–Rubin compactification

6.2 Nongeometric compactifications

[98–100]

6.3 String cosmology

[101–110]

6.3.1 de-Sitter vacua

[102, 103]

6.3.2 String inflation

[104, 105]

6.3.3 Brane cosmology

6.4 Particle phenomenology

[111–113]

The previous section was on the phenomenology of cosmology. Unlike other quantum gravity theories, string theory, being a ToE, must also answer questions of particle phenomenology.

6.5 Swampland

[114–118]

7 *D*-branes

[5, 119, 120]

7.1 Effective actions

7.2 As BPS SUGRA solitons

7.3 *D*-branes moving and merging

7.4 Creation/Annihilation of *D*-branes

7.5 Multiple coincident *D*-branes

7.6 *D*-brane geometry

[244]

8 Holography

8.1 Stringy AdS/CFT

[5, 121–127]

8.1.1 Dictionary

8.1.2 Correlation functions

8.1.3 Finite temperature

8.1.4 Solitons

[128]

8.1.5 The pp wave correspondence

8.1.6 Different dimensions

8.1.6.1 AdS_3 compactifications

[129, 130]

8.1.7 Orbifolds and orientifolds

8.1.8 Integrability

[131]

8.1.9 Higher spin duality (tensionless limit)

[132–136]

8.1.10 Fluid/gravity correspondence

[137]

8.1.11 Nonrelativistic limit

[138, 139]

8.2 It from Qubit AdS/CFT

[140]

8.2.1 Holographic entanglement entropy

[140–145]

8.2.1.1 Classical gravity from entanglement

8.2.1.2 Quantum extremal surfaces

8.2.1.3 Derivation of RT, HRT, QES from gravity path integral

[140, 143]. Original articles are [146–148]

8.2.1.4 Holographic entropy cone

8.2.1.5 Bit threads

8.2.1.6 Islands

[140, 143]. Criticism about massive islands etc is discussed in [54, 149–152]

8.2.1.7 Quantum extremal surface perturbation theory

[153]

8.2.2 Tensor networks

[140, 154, 155]

8.2.3 Error correction

[154–156]

8.2.4 Chaos

[157–159]

8.2.5 Complexity

[140, 160, 161]

8.2.6 SYK

[163, 164]

8.2.7 JT

[162–164]

8.2.8 DSSYK

[165]

8.2.9 von Neumann algebras

[166–168] these are holography related. For math [169]

8.3 Flat space holography

8.3.1 Celestial holography

[170–175]

8.3.2 Carrollian holography

[176–178]

8.4 de Sitter holography approaches

[179, 180]

8.4.1 dS/CFT

8.4.2 Static patch holography

8.4.3 $T\bar{T}$ deformation

[181]

9 Stringy maths (inspired from or related to strings)

[182]

9.1 Mirror symmetry

[183–195]

9.2 Modular forms

[196][192]

9.3 Monstrous moonshine

[197–200]

9.4 Knot theory

[201, 202]

9.5 Geometric Langlands correspondence

[203–206]

9.6 K-theory

[207, 208]

9.7 p-adic strings

[209–212]

9.8 Higher structures

[213–219, 311]

9.8.1 Higher gauge theory

9.8.2 Higher category theory

9.9 Noncommutative geometry

[220–222]

9.9.1 Noncommutative algebraic geometry and mirror symmetry

[223][190]

9.9.2 Noncommutative quantum field theory

[224–244, 258–260]

10 M-theory

10.1 Membrane theory

[245–255]¹

10.2 Matrix theory

[256–262] [233, 234]

10.2.1 BFSS matrix model

10.2.2 IKKT matrix model

10.3 AdS/CFT approach

[263–267]

10.3.1 $AdS_4 \times S^7/\mathbb{Z}_k$ & ABJM CFT

10.4 Miscellaneous

[268–271]

11 String field theory

[14, 272–281]

11.1 Off-shell string theory

11.2 Bosonic string field theory

11.2.1 Open

11.2.2 Closed

11.2.3 Open-Closed

11.2.4 Background independence

11.3 Superstring field theory

11.4 Tachyon condensation

[282–286]

¹Fun fact: [245] was posted on arXiv on the same day I was born (23rd Jan 2002) just few hours after I was born.

Doubt: Is there a holographic dual of bosonic string theory? The bosonic string is unstable non-perturbatively. So, it might not have a holographic dual. Sen's conjecture and instability of the D25-branes. But maybe there is still some unstable CFT with tachyons that is its dual? The R symmetry of the boundary theory will match to the symmetry of the compact dimensions. Since here we don't have R symmetry does that mean the bulk has no compactification? Does that mean the boundary theory is a 25-dimensional unstable CFT?

12 Miscellaneous

12.1 Chern-Simons theories

[\[287–290\]](#)

12.1.1 Superconformal Chern-Simons matter theories

[\[291\]](#)

12.1.2 Quantum Gravity in 2+1 Dimensions

[\[292–296\]](#)

12.2 Topological string theory

[\[297–299\]](#)

12.2.1 Twistor string theory

[\[328\]](#)

12.2.1.1 Amplituhedron

[\[300, 301\]](#)

12.3 More on scattering amplitudes

[\[302–305\]](#)

12.3.1 Double copy

[\[306\]](#)

12.4 Localization techniques

[\[307\]](#)

12.4.1 Gromov-Witten invariants

[\[308\]](#)

12.4.2 F-Theorem and F-Maximization

[\[309\]](#)

12.4.3 Localization and AdS/CFT

[\[310\]](#)

12.5 Generalized symmetries

[\[311, 312\]](#)

12.6 Pure spinor formalism

[\[313, 314\]](#)

12.7 Worldline formalism (∞ tension limit)

[\[315–318\]](#)

12.8 $2D$ string theory

[\[319, 320\]](#)

12.9 Liouville theory

[\[321\]](#)

12.10 Metastring theory and modular spacetime

[\[322\]](#)

Part II

Other approaches

13 Twistor theory

[323–329][7, 227]

13.1 Real slices and reality structures

13.2 $\mathbb{M}_{\mathbb{C}}$'s conformal structure = $\mathbb{P}\mathbb{T}$'s complex structure

13.3 Penrose transform

13.4 Gauge theory

13.5 Ambitwistors and $d > 4$

[330]

13.6 Mini-Twistor theory

[331–335]

13.7 Miscellaneous

[336–338]

14 Canonical quantum gravity

[339, 340]

14.1 ADM formalism

[341]

14.2 Wheeler–DeWitt equation

15 Loop quantum gravity

[342–350]

15.1 Ashtekar variables

15.2 Quantum Riemannian geometry

15.3 Spin foams

15.4 Loop quantum cosmology

[351]

16 Weinberg's asymptotic safety

[352–354]

Also called nonperturbative renormalizability.

17 Causal set theory

[355, 356]

18 Causal fermion systems

[357, 358]

19 Causal dynamical triangulation

[359]

20 Group field theory

[360, 361]

21 Unimodular gravity

[362]

22 Hořava–Lifshitz gravity

[363]

A Miscellaneous math

References

- [1] A. Einstein, “Approximative Integration of the Field Equations of Gravitation,” *Sitzungsber. Preuss. Akad. Wiss. Berlin (Math. Phys.)* **1916**, 688-696 (1916)
 - [2] J. Polchinski, “String theory. Vol. 1: An introduction to the bosonic string,” Cambridge University Press, 2007, ISBN 978-0-511-25227-3, 978-0-521-67227-6, 978-0-521-63303-1 [doi:10.1017/CBO9780511816079](https://doi.org/10.1017/CBO9780511816079)
 - [3] J. Polchinski, “String theory. Vol. 2: Superstring theory and beyond,” Cambridge University Press, 2007, ISBN 978-0-511-25228-0, 978-0-521-63304-8, 978-0-521-67228-3 [doi:10.1017/CBO9780511618123](https://doi.org/10.1017/CBO9780511618123)
 - [4] E. Kiritsis, “String Theory in a Nutshell: Second Edition,” Princeton University Press, 2019, ISBN 978-0-691-15579-1, 978-0-691-18896-6 doi.org/10.2307/j.ctvc4hd1
 - [5] C. V. Johnson, “D-Branes,” [doi:10.1017/9781009401371](https://doi.org/10.1017/9781009401371)
 - [6] S. Cecotti, “Introduction to String Theory,” *Theor. Math. Phys.* **9783031365300**, pp. (2023) Springer, 2023, ISBN 978-3-031-36529-4, 978-3-031-36530-0 [doi:10.1007/978-3-031-36530-0](https://doi.org/10.1007/978-3-031-36530-0)
 - [7] P. West, “Introduction to strings and branes,” Cambridge University Press, 2012, ISBN 978-0-521-81747-9, 978-1-139-41529-3, 978-0-521-81747-9 [doi:10.1017/CBO9781139045926](https://doi.org/10.1017/CBO9781139045926)
 - [8] K. Becker, M. Becker and J. H. Schwarz, “String theory and M-theory: A modern introduction,” Cambridge University Press, 2006, ISBN 978-0-511-25486-4, 978-0-521-86069-7, 978-0-511-81608-6 [doi:10.1017/CBO9780511816086](https://doi.org/10.1017/CBO9780511816086)
 - [9] R. Blumenhagen, D. Lüst and S. Theisen, “Basic concepts of string theory,” Springer, 2013, ISBN 978-3-642-29496-9 [doi:10.1007/978-3-642-29497-6](https://doi.org/10.1007/978-3-642-29497-6)
 - [10] L. E. Ibanez and A. M. Uranga, “String theory and particle physics: An introduction to string phenomenology,” Cambridge University Press, 2012, ISBN 978-0-521-51752-2, 978-1-139-22742-1 [doi:10.1017/CBO9781139018951](https://doi.org/10.1017/CBO9781139018951)
 - [11] Pierre Deligne, Pavel Etingof, Daniel S. Freed, Lisa C. Jeffrey, David Kazhdan, John W. Morgan, David R. Morrison, Edward Witten, “Quantum Fields and Strings: A Course for Mathematicians. Vol. 1,” ias.edu/math/qft
 - [12] Pierre Deligne, Pavel Etingof, Daniel S. Freed, Lisa C. Jeffrey, David Kazhdan, John W. Morgan, David R. Morrison, Edward Witten, “Quantum Fields and Strings: A Course for Mathematicians. Vol. 2,” ias.edu/math/qft
 - [13] D. Tong, “Lectures on String Theory,” <http://www.damtp.cam.ac.uk/user/tong/string/string.pdf>
 - [14] H. Erbin, “String Field Theory: A Modern Introduction,” *Lect. Notes Phys.* **980**, 1-421 (2021) 2021, ISBN 978-3-030-65320-0, 978-3-030-65321-7 [doi:10.1007/978-3-030-65321-7](https://doi.org/10.1007/978-3-030-65321-7) [arXiv:2301.01686 [hep-th]]. Latest at <https://harolderbin.com/science-books/>
-
- [15] S. B. Giddings, “The deepest problem: some perspectives on quantum gravity,” [arXiv:2202.08292 [hep-th]].
 - [16] C. Kiefer, “Quantum Gravity,” Oxford University Press, 2007, ISBN 978-0-19-921252-1 [doi:10.1093/acprof:oso/9780199585205.001.0001](https://doi.org/10.1093/acprof:oso/9780199585205.001.0001)

- [17] D. Oriti, “Approaches to quantum gravity: Toward a new understanding of space, time and matter,” Cambridge University Press, 2009, ISBN 978-0-521-86045-1, 978-0-511-51240-7 doi:[10.1017/CBO9780511575549](https://doi.org/10.1017/CBO9780511575549)
- [18] C. Kiefer, “Quantum gravity - an unfinished revolution,” [[arXiv:2302.13047](https://arxiv.org/abs/2302.13047) [gr-qc]].
- [19] R. Loll, G. Fabiano, D. Frattulillo and F. Wagner, “Quantum Gravity in 30 Questions,” PoS **CORFU2021**, 316 (2022) doi:[10.22323/1.406.0316](https://doi.org/10.22323/1.406.0316) [[arXiv:2206.06762](https://arxiv.org/abs/2206.06762) [hep-th]].
- [20] L. Smolin, “How far are we from the quantum theory of gravity?,” [[arXiv:hep-th/0303185](https://arxiv.org/abs/hep-th/0303185) [hep-th]].
- [21] Luboš Motl, “Diff(M) as a gauge group and local observables in theories with gravity,” Physics Stack Exchange <https://physics.stackexchange.com/a/4360/264772>
- [22] P. Berglund, L. Freidel, T. Hubsch, J. Kowalski-Glikman, R. G. Leigh, D. Mattingly and D. Minic, “Infrared Properties of Quantum Gravity: UV/IR Mixing, Gravitizing the Quantum – Theory and Observation,” [[arXiv:2202.06890](https://arxiv.org/abs/2202.06890) [hep-th]].
- [23] S. B. Giddings, “Holography and unitarity,” JHEP **11**, 056 (2020) doi:[10.1007/JHEP11\(2020\)056](https://doi.org/10.1007/JHEP11(2020)056) [[arXiv:2004.07843](https://arxiv.org/abs/2004.07843) [hep-th]].
- [24] D. Marolf, “Holography without strings?,” Class. Quant. Grav. **31**, 015008 (2014) doi:[10.1088/0264-9381/31/1/015008](https://doi.org/10.1088/0264-9381/31/1/015008) [[arXiv:1308.1977](https://arxiv.org/abs/1308.1977) [hep-th]].
- [25] T. Jacobson and P. Nguyen, “Diffeomorphism invariance and the black hole information paradox,” Phys. Rev. D **100**, no.4, 046002 (2019) doi:[10.1103/PhysRevD.100.046002](https://doi.org/10.1103/PhysRevD.100.046002) [[arXiv:1904.04434](https://arxiv.org/abs/1904.04434) [gr-qc]].
- [26] G. 't Hooft, “Dimensional reduction in quantum gravity,” Conf. Proc. C **930308**, 284-296 (1993) [[arXiv:gr-qc/9310026](https://arxiv.org/abs/gr-qc/9310026) [gr-qc]].
-
- [27] S. Carlip, D. W. Chiou, W. T. Ni and R. Woodard, “Quantum Gravity: A Brief History of Ideas and Some Prospects,” Int. J. Mod. Phys. D **24**, no.11, 1530028 (2015) doi:[10.1142/S0218271815300281](https://doi.org/10.1142/S0218271815300281) [[arXiv:1507.08194](https://arxiv.org/abs/1507.08194) [gr-qc]].
- [28] P. Di Vecchia, “The Birth of string theory,” Lect. Notes Phys. **737**, 59-118 (2008) [[arXiv:0704.0101](https://arxiv.org/abs/0704.0101) [hep-th]].
- [29] J. H. Schwarz, “The Early History of String Theory and Supersymmetry,” [[arXiv:1201.0981](https://arxiv.org/abs/1201.0981) [physics.hist-ph]].
- [30] S. Mukhi, “String theory: a perspective over the last 25 years,” Class. Quant. Grav. **28**, 153001 (2011) doi:[10.1088/0264-9381/28/15/153001](https://doi.org/10.1088/0264-9381/28/15/153001) [[arXiv:1110.2569](https://arxiv.org/abs/1110.2569) [physics.pop-ph]].
- [31] J. Polchinski, “Memories of a Theoretical Physicist,” MIT Press, 2022, ISBN 978-0-262-54344-6, 978-0-262-36890-2 [[arXiv:1708.09093](https://arxiv.org/abs/1708.09093) [physics.hist-ph]].
- [32] J. Polchinski, “Dualities of Fields and Strings,” Stud. Hist. Phil. Sci. B **59**, 6-20 (2017) doi:[10.1016/j.shpsb.2015.08.011](https://doi.org/10.1016/j.shpsb.2015.08.011) [[arXiv:1412.5704](https://arxiv.org/abs/1412.5704) [hep-th]].
- [33] M. J. Duff, “M-history without the M,” Contemp. Phys. **57**, 83 (2016) doi:[10.1080/00107514.2014.992964](https://doi.org/10.1080/00107514.2014.992964) [[arXiv:1501.04098](https://arxiv.org/abs/1501.04098) [physics.hist-ph]].
- [34] C. Rovelli, “Notes for a brief history of quantum gravity,” [[arXiv:gr-qc/0006061](https://arxiv.org/abs/gr-qc/0006061) [gr-qc]].
- [35] W. Siegel, “Particles, Strings, & Other Things,” insti.physics.sunysb.edu/~siegel/PSOT.pdf
- [36] S. Deser, “Forks in the Road A Life in Physics,” doi:[10.1142/12205](https://doi.org/10.1142/12205)

-
- [37] T. Jacobson, “Introduction to quantum fields in curved space-time and the Hawking effect,” doi:10.1007/0-387-24992-3_2 [arXiv:gr-qc/0308048 [gr-qc]].
- [38] S. Hollands and R. M. Wald, “Quantum fields in curved spacetime,” Phys. Rept. **574**, 1-35 (2015) doi:10.1016/j.physrep.2015.02.001 [arXiv:1401.2026 [gr-qc]].
- [39] S. Carlip, “Black Hole Thermodynamics,” Int. J. Mod. Phys. D **23**, 1430023 (2014) doi:10.1142/S0218271814300237 [arXiv:1410.1486 [gr-qc]].
- [40] T. Jacobson, “Introductory Lectures on Black Hole Thermodynamics,” physics.umd.edu/grt/taj/776b/lectures.pdf
- [41] D. Marolf, “The Black Hole information problem: past, present, and future,” Rept. Prog. Phys. **80**, no.9, 092001 (2017) doi:10.1088/1361-6633/aa77cc [arXiv:1703.02143 [gr-qc]].
- [42] T. Hartman, “Lectures on Quantum Gravity and Black Holes,” hartmanhep.net/topics2015/gravity-lectures.pdf
- [43] D. Harlow, “Jerusalem Lectures on Black Holes and Quantum Information,” Rev. Mod. Phys. **88**, 015002 (2016) doi:10.1103/RevModPhys.88.015002 [arXiv:1409.1231 [hep-th]].
- [44] S. D. Mathur, “What the information paradox is not,” [arXiv:1108.0302 [hep-th]].
- [45] S. D. Mathur, “The Information paradox: A Pedagogical introduction,” Class. Quant. Grav. **26**, 224001 (2009) doi:10.1088/0264-9381/26/22/224001 [arXiv:0909.1038 [hep-th]].
- [46] S. D. Mathur, “What Exactly is the Information Paradox?,” Lect. Notes Phys. **769**, 3-48 (2009) doi:10.1007/978-3-540-88460-6_1 [arXiv:0803.2030 [hep-th]].
- [47] P. H. Lambert, “Introduction to Black Hole Evaporation,” PoS **Modave2013**, 001 (2013) doi:10.22323/1.201.0001 [arXiv:1310.8312 [gr-qc]].
- [48] J. Polchinski, “The Black Hole Information Problem,” doi:10.1142/9789813149441_0006 [arXiv:1609.04036 [hep-th]].
- [49] A. Almheiri, T. Hartman, J. Maldacena, E. Shaghoulian and A. Tajdini, “The entropy of Hawking radiation,” Rev. Mod. Phys. **93**, no.3, 035002 (2021) doi:10.1103/RevModPhys.93.035002 [arXiv:2006.06872 [hep-th]].
- [50] J. Kaplan, sites.krieger.jhu.edu/jared-kaplan/files/2020/01/QuantumGravityLectureNotes.pdf
- [51] D. N. Page, “Hawking radiation and black hole thermodynamics,” New J. Phys. **7**, 203 (2005) doi:10.1088/1367-2630/7/1/203 [arXiv:hep-th/0409024 [hep-th]].
- [52] J. H. Traschen, “An Introduction to black hole evaporation,” [arXiv:gr-qc/0010055 [gr-qc]].
- [53] A. C. Wall, “A Survey of Black Hole Thermodynamics,” [arXiv:1804.10610 [gr-qc]].
- [54] S. Raju, “Lessons from the information paradox,” Phys. Rept. **943**, 1-80 (2022) doi:10.1016/j.physrep.2021.10.001 [arXiv:2012.05770 [hep-th]].
- [55] B. S. Kay, “Quantum Field Theory in Curved Spacetime (2nd Edition),” [arXiv:2308.14517 [gr-qc]].
-
- [56] J. F. Donoghue, “Quantum General Relativity and Effective Field Theory,” doi:10.1007/978-981-19-3079-9_1-1 [arXiv:2211.09902 [hep-th]].

- [57] A. Rocci and T. Van Riet, “The Quantum Theory Of Gravitation, Effective Field Theories, and Strings: Yesterday And Today,” [[arXiv:2403.14008](https://arxiv.org/abs/2403.14008) [[physics.hist-ph](#)]].
- [58] C. P. Burgess, “Quantum gravity in everyday life: General relativity as an effective field theory,” *Living Rev. Rel.* **7**, 5-56 (2004) doi:10.12942/lrr-2004-5 [[arXiv:gr-qc/0311082](https://arxiv.org/abs/gr-qc/0311082) [[gr-qc](#)]].
- [59] C. P. Burgess, “Introduction to Effective Field Theory,” Cambridge University Press, 2020, ISBN 978-1-139-04804-0, 978-0-521-19547-8 doi:10.1017/9781139048040
- [60] J. Polchinski, “String theory to the rescue,” [[arXiv:1512.02477](https://arxiv.org/abs/1512.02477) [[hep-th](#)]].
- [61] J. Polchinski, “Why trust a theory? Some further remarks (part 1),” [[arXiv:1601.06145](https://arxiv.org/abs/1601.06145) [[hep-th](#)]].
- [62] J. Conlon, “Why string theory?,” CRC Pr., 2016, ISBN 978-1-4822-4247-8 doi:10.1201/9781315272368
-
- [63] J. D. Qualls, “Lectures on Conformal Field Theory,” [[arXiv:1511.04074](https://arxiv.org/abs/1511.04074) [[hep-th](#)]].
- [64] A. N. Schellekens, <https://www.nikhef.nl/t58/CFT.pdf>
- [65] R. Blumenhagen and E. Plauschinn, “Introduction to conformal field theory: with applications to String theory,” *Lect. Notes Phys.* **779**, 1-256 (2009) doi:10.1007/978-3-642-00450-6
- [66] M. Gillioz, “Conformal field theory for particle physicists,” Springer, 2023, ISBN 978-3-031-27085-7, 978-3-031-27086-4 doi:10.1007/978-3-031-27086-4 [[arXiv:2207.09474](https://arxiv.org/abs/2207.09474) [[hep-th](#)]].
- [67] S. Rychkov, “EPFL Lectures on Conformal Field Theory in $D \geq 3$ Dimensions,” doi:10.1007/978-3-319-43626-5 [[arXiv:1601.05000](https://arxiv.org/abs/1601.05000) [[hep-th](#)]].
- [68] D. Simmons-Duffin, <https://github.com/davidsd/ph229/blob/master/ph229-notes.pdf>
- [69] S. Nawata, R. Tao and D. Yokoyama, “Fudan lectures on 2d conformal field theory,” [[arXiv:2208.05180](https://arxiv.org/abs/2208.05180) [[hep-th](#)]].
- [70] A. M. Evans, A. Miller and A. Russell, “A Conformal Field Theory Primer in $D \geq 3$,” [[arXiv:2309.10107](https://arxiv.org/abs/2309.10107) [[hep-th](#)]].
- [71] M. Schottenloher, “A mathematical introduction to conformal field theory,” *Lect. Notes Phys.* **759**, 1-237 (2008) doi:10.1007/978-3-540-68628-6
- [72] P. Kravchuk, J. Qiao and S. Rychkov, “Distributions in CFT. Part I. Cross-ratio space,” *JHEP* **05**, 137 (2020) doi:10.1007/JHEP05(2020)137 [[arXiv:2001.08778](https://arxiv.org/abs/2001.08778) [[hep-th](#)]].
- [73] P. Kravchuk, J. Qiao and S. Rychkov, “Distributions in CFT. Part II. Minkowski space,” *JHEP* **08**, 094 (2021) doi:10.1007/JHEP08(2021)094 [[arXiv:2104.02090](https://arxiv.org/abs/2104.02090) [[hep-th](#)]].
-
- [74] D. Tong, “Lectures on Supersymmetric Quantum Mechanics,” <http://www.damtp.cam.ac.uk/user/tong/susyqm.html>
- [75] David Skinner, “Supersymmetry,” <http://www.damtp.cam.ac.uk/user/dbs26/SUSY.html>
- [76] D. Tong, “Lectures on Supersymmetry,” <http://www.damtp.cam.ac.uk/user/tong/susy.html>
- [77] M. Bertolini, <https://people.sissa.it/~bertmat/teaching.htm>

- [78] D. S. Freed, “Five lectures on supersymmetry,” AMS, 1999, ISBN 978-0-8218-1953-1 bookstore.ams.org/FLS
- [79] K. A. Intriligator and N. Seiberg, “Lectures on supersymmetric gauge theories and electric-magnetic duality,” Nucl. Phys. B Proc. Suppl. **45BC**, 1-28 (1996) doi:10.1016/0920-5632(95)00626-5 [[arXiv:hep-th/9509066](https://arxiv.org/abs/hep-th/9509066) [hep-th]].
- [80] D. S. Berman and E. Rabinovici, “Supersymmetric gauge theories,” [[arXiv:hep-th/0210044](https://arxiv.org/abs/hep-th/0210044) [hep-th]].
- [81] S. S. Razamat, E. Sabag, O. Sela and G. Zafrir, “Aspects of 4d supersymmetric dynamics and geometry,” SciPost Phys. Lect. Notes **78**, 1 (2024) doi:10.21468/SciPostPhysLectNotes.78 [[arXiv:2203.06880](https://arxiv.org/abs/2203.06880) [hep-th]].
- [82] M. Aghand, G. Arias-Tamargo, A. Mininno, H. Y. Sun, Z. Sun, Y. Wang and F. Xu, “The hitchhiker’s guide to 4d $\mathcal{N} = 2$ superconformal field theories,” SciPost Phys. Lect. Notes **64**, 1 (2022) doi:10.21468/SciPostPhysLectNotes.64 [[arXiv:2112.14764](https://arxiv.org/abs/2112.14764) [hep-th]].
- [83] H. Nastase, “Introduction to Supergravity,” [[arXiv:1112.3502](https://arxiv.org/abs/1112.3502) [hep-th]].
- [84] E. Sezgin, “Survey of supergravities,” [[arXiv:2312.06754](https://arxiv.org/abs/2312.06754) [hep-th]].
- [85] H. Samtleben, “11D Supergravity and Hidden Symmetries,” doi:10.1007/978-981-19-3079-9_45-1 [[arXiv:2303.12682](https://arxiv.org/abs/2303.12682) [hep-th]].
- [86] A. Miemiec and I. Schnakenburg, “Basics of M-theory,” Fortsch. Phys. **54**, 5-72 (2006) doi:10.1002/prop.200510256 [[arXiv:hep-th/0509137](https://arxiv.org/abs/hep-th/0509137) [hep-th]].
- [87] B. de Wit, “Supergravity,” [[arXiv:hep-th/0212245](https://arxiv.org/abs/hep-th/0212245) [hep-th]].
- [88] W. Taylor, “TASI Lectures on Supergravity and String Vacua in Various Dimensions,” [[arXiv:1104.2051](https://arxiv.org/abs/1104.2051) [hep-th]].
- [89] A. Sen, “Ultraviolet and Infrared Divergences in Superstring Theory,” [[arXiv:1512.00026](https://arxiv.org/abs/1512.00026) [hep-th]].
- [90] T. Weigand, “TASI Lectures on F-theory,” PoS **TASI2017**, 016 (2018) [[arXiv:1806.01854](https://arxiv.org/abs/1806.01854) [hep-th]].
-
- [91] T. Van Riet and G. Zoccarato, “Beginners lectures on flux compactifications and related Swampland topics,” Phys. Rept. **1049**, 1-51 (2024) doi:10.1016/j.physrep.2023.11.003 [[arXiv:2305.01722](https://arxiv.org/abs/2305.01722) [hep-th]].
- [92] L. B. Anderson and M. Karkheiran, “TASI Lectures on Geometric Tools for String Compactifications,” PoS **TASI2017**, 013 (2018) doi:10.22323/1.305.0013 [[arXiv:1804.08792](https://arxiv.org/abs/1804.08792) [hep-th]].
- [93] L. McAllister and F. Quevedo, “Moduli Stabilization in String Theory,” [[arXiv:2310.20559](https://arxiv.org/abs/2310.20559) [hep-th]].
- [94] M. Grana, “Flux compactifications in string theory: A Comprehensive review,” Phys. Rept. **423**, 91-158 (2006) doi:10.1016/j.physrep.2005.10.008 [[arXiv:hep-th/0509003](https://arxiv.org/abs/hep-th/0509003) [hep-th]].
- [95] M. R. Douglas and S. Kachru, “Flux compactification,” Rev. Mod. Phys. **79**, 733-796 (2007) doi:10.1103/RevModPhys.79.733 [[arXiv:hep-th/0610102](https://arxiv.org/abs/hep-th/0610102) [hep-th]].
- [96] A. Font and S. Theisen, “Introduction to string compactification,” Lect. Notes Phys. **668**, 101-181 (2005) [10.1007/11374060_3](https://doi.org/10.1007/11374060_3)

- [97] S. Alexandrov, “Twistor Approach to String Compactifications: a Review,” *Phys. Rept.* **522**, 1-57 (2013) doi:10.1016/j.physrep.2012.09.005 [[arXiv:1111.2892 \[hep-th\]](#)].
- [98] E. Plauschinn, “Non-geometric backgrounds in string theory,” *Phys. Rept.* **798**, 1-122 (2019) doi:10.1016/j.physrep.2018.12.002 [[arXiv:1811.11203 \[hep-th\]](#)].
- [99] B. Wecht, “Lectures on Nongeometric Flux Compactifications,” *Class. Quant. Grav.* **24**, S773-S794 (2007) doi:10.1088/0264-9381/24/21/S03 [[arXiv:0708.3984 \[hep-th\]](#)].
- [100] Y. Kimura, “Eight-dimensional non-geometric heterotic strings and enhanced gauge groups,” *Eur. Phys. J. ST* **232**, no.23-24, 3697-3704 (2023) doi:10.1140/epjs/s11734-023-00889-3 [[arXiv:2305.09240 \[hep-th\]](#)].
- [101] M. Cicoli, J. P. Conlon, A. Maharana, S. Parameswaran, F. Quevedo and I. Zavala, “String cosmology: From the early universe to today,” *Phys. Rept.* **1059**, 1-155 (2024) doi:10.1016/j.physrep.2024.01.002 [[arXiv:2303.04819 \[hep-th\]](#)].
- [102] G. K. Leontaris and P. Shukla, “Seeking de Sitter vacua in the string landscape,” *PoS CORFU2022*, 058 (2023) doi:10.22323/1.436.0058 [[arXiv:2303.16689 \[hep-th\]](#)].
- [103] P. Berglund, T. Hübsch and D. Minic, “On de Sitter Spacetime and String Theory,” *Int. J. Mod. Phys. D* **32**, 2330002 (2023) doi:10.1142/S0218271823300021 [[arXiv:2212.06086 \[hep-th\]](#)].
- [104] D. Baumann and L. McAllister, “Inflation and String Theory,” Cambridge University Press, 2015, ISBN 978-1-107-08969-3, 978-1-316-23718-2 doi:10.1017/CBO9781316105733 [[arXiv:1404.2601 \[hep-th\]](#)].
- [105] D. Baumann, “Inflation,” doi:10.1142/9789814327183_0010 [[arXiv:0907.5424 \[hep-th\]](#)].
- [106] J. Polchinski, “The Cosmological Constant and the String Landscape,” [[arXiv:hep-th/0603249 \[hep-th\]](#)].
- [107] R. Bousso, “TASI Lectures on the Cosmological Constant,” *Gen. Rel. Grav.* **40**, 607-637 (2008) doi:10.1007/s10714-007-0557-5 [[arXiv:0708.4231 \[hep-th\]](#)].
- [108] E. Silverstein, “TASI lectures on cosmological observables and string theory,” doi:10.1142/9789813149441_0009 [[arXiv:1606.03640 \[hep-th\]](#)].
- [109] R. Brandenberger, “Superstring cosmology — a complementary review,” *JCAP* **11**, 019 (2023) doi:10.1088/1475-7516/2023/11/019 [[arXiv:2306.12458 \[hep-th\]](#)].
- [110] J. Erdmenger, “String cosmology: Modern string theory concepts from the Big Bang to cosmic structure,” doi:10.1002/9783527628063
- [111] F. Marchesano, G. Shiu and T. Weigand, “The Standard Model from String Theory: What Have We Learned?,” doi:10.1146/annurev-nucl-102622-01223 [[arXiv:2401.01939 \[hep-th\]](#)].
- [112] M. Cvetič, J. Halverson, G. Shiu and W. Taylor, “Snowmass White Paper: String Theory and Particle Physics,” [[arXiv:2204.01742 \[hep-th\]](#)].
- [113] F. Marchesano, B. Schellekens and T. Weigand, “D-brane and F-theory Model Building,” [[arXiv:2212.07443 \[hep-th\]](#)].
-
- [114] N. B. Agmon, A. Bedroya, M. J. Kang and C. Vafa, “Lectures on the string landscape and the Swampland,” [[arXiv:2212.06187 \[hep-th\]](#)].
- [115] E. Palti, “The Swampland: Introduction and Review,” *Fortsch. Phys.* **67**, no.6, 1900037 (2019) doi:10.1002/prop.201900037 [[arXiv:1903.06239 \[hep-th\]](#)].

- [116] T. D. Brennan, F. Carta and C. Vafa, “The String Landscape, the Swampland, and the Missing Corner,” PoS **TASI2017**, 015 (2017) doi:10.22323/1.305.0015 [[arXiv:1711.00864](#) [[hep-th](#)]].
- [117] M. van Beest, J. Calderón-Infante, D. Mirfendereski and I. Valenzuela, “Lectures on the Swampland Program in String Compactifications,” Phys. Rept. **989**, 1-50 (2022) doi:10.1016/j.physrep.2022.09.002 [[arXiv:2102.01111](#) [[hep-th](#)]].
- [118] M. Graña and A. Herráez, “The Swampland Conjectures: A Bridge from Quantum Gravity to Particle Physics,” Universe **7**, no.8, 273 (2021) doi:10.3390/universe7080273 [[arXiv:2107.00087](#) [[hep-th](#)]].
- [119] K. Hashimoto, “D-brane: Superstrings and new perspective of our world,” Springer, 2012, ISBN 978-3-642-23573-3 doi:10.1007/978-3-642-23574-0
- [120] C. Bachas, “D-branes,” [[arXiv:2311.18456](#) [[hep-th](#)]].
-
- [121] O. Aharony, S. S. Gubser, J. M. Maldacena, H. Ooguri and Y. Oz, “Large N field theories, string theory and gravity,” Phys. Rept. **323**, 183-386 (2000) doi:10.1016/S0370-1573(99)00083-6 [[arXiv:hep-th/9905111](#) [[hep-th](#)]].
- [122] H. Nastase, “Introduction to the ADS/CFT Correspondence,” Cambridge University Press, 2015, ISBN 978-1-107-08585-5, 978-1-316-35530-5 doi:10.1017/CBO9781316090954
- [123] M. Ammon and J. Erdmenger, “Gauge/gravity duality: Foundations and applications,” Cambridge University Press, 2015, ISBN 978-1-107-01034-5, 978-1-316-23594-2 doi:10.1017/CBO9780511846373
- [124] J. Polchinski, “Introduction to Gauge/Gravity Duality,” doi:10.1142/9789814350525_0001 [[arXiv:1010.6134](#) [[hep-th](#)]].
- [125] J. Kaplan, sites.krieger.jhu.edu/jared-kaplan/files/2016/05/AdSCFTCourseNotesCurrentPublic.pdf
- [126] S. De Haro, D. R. Mayerson and J. N. Butterfield, “Conceptual Aspects of Gauge/Gravity Duality,” Found. Phys. **46**, no.11, 1381-1425 (2016) doi:10.1007/s10701-016-0037-4 [[arXiv:1509.09231](#) [[physics.hist-ph](#)]].
- [127] V. E. Hubeny, “The AdS/CFT Correspondence,” Class. Quant. Grav. **32**, no.12, 124010 (2015) doi:10.1088/0264-9381/32/12/124010 [[arXiv:1501.00007](#) [[gr-qc](#)]].
- [128] D. Tong, “TASI lectures on solitons: Instantons, monopoles, vortices and kinks,” [[arXiv:hep-th/0509216](#) [[hep-th](#)]].
- [129] P. Kraus, “Lectures on black holes and the AdS(3) / CFT(2) correspondence,” Lect. Notes Phys. **755**, 193-247 (2008) [[arXiv:hep-th/0609074](#) [[hep-th](#)]].
- [130] C. T. Ma, “AdS₃ Einstein gravity and boundary description: pedagogical review,” Class. Quant. Grav. **41**, no.2, 023001 (2024) doi:10.1088/1361-6382/ad17f0 [[arXiv:2310.04665](#) [[hep-th](#)]].
- [131] N. Beisert, C. Ahn, L. F. Alday, Z. Bajnok, J. M. Drummond, L. Freyhult, N. Gromov, R. A. Janik, V. Kazakov and T. Klose, *et al.* “Review of AdS/CFT Integrability: An Overview,” Lett. Math. Phys. **99**, 3-32 (2012) doi:10.1007/s11005-011-0529-2 [[arXiv:1012.3982](#) [[hep-th](#)]].

- [132] S. Giombi, “Higher Spin CFT Duality,” doi:10.1142/9789813149441_0003 [[arXiv:1607.02967](#) [[hep-th](#)]].
- [133] Andrea Campoleoni and Stefan Fredenhagen, “Higher-spin gauge theories in three spacetime dimensions,” [[arXiv:2403.16567](#) [[hep-th](#)]].
- [134] X. Bekaert, N. Boulanger, A. Campoleoni, M. Chiodaroli, D. Francia, M. Grigoriev, E. Sezgin and E. Skvortsov, “Snowmass White Paper: Higher Spin Gravity and Higher Spin Symmetry,” [[arXiv:2205.01567](#) [[hep-th](#)]].
- [135] R. Rahman and M. Taronna, “From Higher Spins to Strings: A Primer,” [[arXiv:1512.07932](#) [[hep-th](#)]].
- [136] A. Sagnotti, “Notes on Strings and Higher Spins,” *J. Phys. A* **46**, 214006 (2013) doi:10.1088/1751-8113/46/21/214006 [[arXiv:1112.4285](#) [[hep-th](#)]].
- [137] V. E. Hubeny, S. Minwalla and M. Rangamani, “The fluid/gravity correspondence,” [[arXiv:1107.5780](#) [[hep-th](#)]].
- [138] G. Oling and Z. Yan, “Aspects of Nonrelativistic Strings,” *Front. in Phys.* **10**, 832271 (2022) doi:10.3389/fphy.2022.832271 [[arXiv:2202.12698](#) [[hep-th](#)]].
- [139] S. Baiguera, “Aspects of non-relativistic quantum field theories,” *Eur. Phys. J. C* **84**, no.3, 268 (2024) doi:10.1140/epjc/s10052-024-12630-y [[arXiv:2311.00027](#) [[hep-th](#)]].
-
- [140] B. Chen, B. Czech and Z. z. Wang, “Quantum information in holographic duality,” *Rept. Prog. Phys.* **85**, no.4, 046001 (2022) doi:10.1088/1361-6633/ac51b5 [[arXiv:2108.09188](#) [[hep-th](#)]].
- [141] M. Headrick, “Lectures on entanglement entropy in field theory and holography,” [[arXiv:1907.08126](#) [[hep-th](#)]].
- [142] M. Rangamani and T. Takayanagi, “Holographic Entanglement Entropy,” *Lect. Notes Phys.* **931**, pp.1-246 (2017) Springer, 2017, doi:10.1007/978-3-319-52573-0 [[arXiv:1609.01287](#) [[hep-th](#)]].
- [143] N. Callebaut, “Entanglement in Conformal Field Theory and Holography,” *Lect. Notes Phys.* **1022**, 239-271 (2023) doi:10.1007/978-3-031-42096-2_10 [[arXiv:2303.16827](#) [[hep-th](#)]].
- [144] T. Nishioka, “Entanglement entropy: holography and renormalization group,” *Rev. Mod. Phys.* **90**, no.3, 035007 (2018) doi:10.1103/RevModPhys.90.035007 [[arXiv:1801.10352](#) [[hep-th](#)]].
- [145] E. Witten, “APS Medal for Exceptional Achievement in Research: Invited article on entanglement properties of quantum field theory,” *Rev. Mod. Phys.* **90**, no.4, 045003 (2018) doi:10.1103/RevModPhys.90.045003 [[arXiv:1803.04993](#) [[hep-th](#)]].
- [146] A. Lewkowycz and J. Maldacena, “Generalized gravitational entropy,” *JHEP* **08**, 090 (2013) doi:10.1007/JHEP08(2013)090 [[arXiv:1304.4926](#) [[hep-th](#)]].
- [147] X. Dong, A. Lewkowycz and M. Rangamani, “Deriving covariant holographic entanglement,” *JHEP* **11**, 028 (2016) doi:10.1007/JHEP11(2016)028 [[arXiv:1607.07506](#) [[hep-th](#)]].
- [148] X. Dong and A. Lewkowycz, “Entropy, Extremality, Euclidean Variations, and the Equations of Motion,” *JHEP* **01**, 081 (2018) doi:10.1007/JHEP01(2018)081 [[arXiv:1705.08453](#) [[hep-th](#)]].

- [149] H. Geng, A. Karch, C. Perez-Pardavila, S. Raju, L. Randall, M. Riojas and S. Shashi, “Inconsistency of islands in theories with long-range gravity,” *JHEP* **01**, 182 (2022) doi:10.1007/JHEP01(2022)182 [arXiv:2107.03390 [hep-th]].
- [150] E. J. Martinec, “Trouble in Paradox,” [arXiv:2203.04947 [hep-th]].
- [151] B. Guo, M. R. R. Hughes, S. D. Mathur and M. Mehta, “Contrasting the fuzzball and wormhole paradigms for black holes,” *Turk. J. Phys.* **45**, no.6, 281-365 (2021) doi:10.3906/fiz-2111-13 [arXiv:2111.05295 [hep-th]].
- [152] I. Bena, E. J. Martinec, S. D. Mathur and N. P. Warner, “Fuzzballs and Microstate Geometries: Black-Hole Structure in String Theory,” [arXiv:2204.13113 [hep-th]].
- [153] N. Engelhardt and S. Fischetti, “Surface Theory: the Classical, the Quantum, and the Holographic,” *Class. Quant. Grav.* **36**, no.20, 205002 (2019) doi:10.1088/1361-6382/ab3bda [arXiv:1904.08423 [hep-th]].
- [154] A. Jahn and J. Eisert, “Holographic tensor network models and quantum error correction: a topical review,” *Quantum Sci. Technol.* **6**, no.3, 033002 (2021) doi:10.1088/2058-9565/ac0293 [arXiv:2102.02619 [quant-ph]].
- [155] T. Kibe, P. Mandayam and A. Mukhopadhyay, “Holographic spacetime, black holes and quantum error correcting codes: a review,” *Eur. Phys. J. C* **82**, no.5, 463 (2022) doi:10.1140/epjc/s10052-022-10382-1 [arXiv:2110.14669 [hep-th]].
- [156] D. Harlow, “TASI Lectures on the Emergence of Bulk Physics in AdS/CFT,” *PoS TASI2017*, 002 (2018) doi:10.22323/1.305.0002 [arXiv:1802.01040 [hep-th]].
- [157] V. Jahnke, “Recent developments in the holographic description of quantum chaos,” *Adv. High Energy Phys.* **2019**, 9632708 (2019) doi:10.1155/2019/9632708 [arXiv:1811.06949 [hep-th]].
- [158] P. Saad, “TASI lectures on random matrix universality in AdS/CFT,” *PoS TASI2021*, 011 (2023) doi:10.22323/1.403.0011
- [159] A. Bhattacharyya, L. K. Joshi and B. Sundar, “Quantum information scrambling: from holography to quantum simulators,” *Eur. Phys. J. C* **82**, no.5, 458 (2022) doi:10.1140/epjc/s10052-022-10377-y [arXiv:2111.11945 [hep-th]].
- [160] L. Susskind, “Three Lectures on Complexity and Black Holes,” Springer, 2020, ISBN 978-3-030-45108-0, 978-3-030-45109-7 doi:10.1007/978-3-030-45109-7 [arXiv:1810.11563 [hep-th]].
- [161] S. Aaronson, “The Complexity of Quantum States and Transformations: From Quantum Money to Black Holes,” [arXiv:1607.05256 [quant-ph]].
- [162] T. G. Mertens and G. J. Turiaci, “Solvable models of quantum black holes: a review on Jackiw–Teitelboim gravity,” *Living Rev. Rel.* **26**, no.1, 4 (2023) doi:10.1007/s41114-023-00046-1 [arXiv:2210.10846 [hep-th]].
- [163] G. Sárosi, “AdS₂ holography and the SYK model,” *PoS Modave2017*, 001 (2018) doi:10.22323/1.323.0001 [arXiv:1711.08482 [hep-th]].
- [164] D. A. Trunin, “Pedagogical introduction to the Sachdev–Ye–Kitaev model and two-dimensional dilaton gravity,” *Usp. Fiz. Nauk* **191**, no.3, 225-261 (2021) doi:10.3367/UFNe.2020.06.038805 [arXiv:2002.12187 [hep-th]].

- [165] M. Berkooz, M. Isachenkov, V. Narovlansky and G. Torrents, “Towards a full solution of the large N double-scaled SYK model,” *JHEP* **03**, 079 (2019) doi:10.1007/JHEP03(2019)079 [[arXiv:1811.02584 \[hep-th\]](#)].
- [166] J. Sorce, “Notes on the type classification of von Neumann algebras,” *Rev. Math. Phys.* **36**, no.02, 2430002 (2024) doi:10.1142/S0129055X24300024 [[arXiv:2302.01958 \[hep-th\]](#)].
- [167] E. Witten, “Algebras, Regions, and Observers,” [[arXiv:2303.02837 \[hep-th\]](#)].
- [168] S. Hollands, “GGI Lectures on Entropy, Operator Algebras and Black Holes,” [[arXiv:2209.05132 \[hep-th\]](#)].
- [169] F. Hiai, “Concise lectures on selected topics of von Neumann algebras,” [[arXiv:2004.02383 \[math.OA\]](#)].
-
- [170] L. Donnay, “Celestial holography: An asymptotic symmetry perspective,” [[arXiv:2310.12922 \[hep-th\]](#)].
- [171] A. Strominger, “Lectures on the Infrared Structure of Gravity and Gauge Theory,” [[arXiv:1703.05448 \[hep-th\]](#)].
- [172] S. Pasterski, M. Pate and A. M. Raclariu, “Celestial Holography,” [[arXiv:2111.11392 \[hep-th\]](#)].
- [173] A. M. Raclariu, “Lectures on Celestial Holography,” [[arXiv:2107.02075 \[hep-th\]](#)].
- [174] S. Pasterski, “Lectures on celestial amplitudes,” *Eur. Phys. J. C* **81**, no.12, 1062 (2021) doi:10.1140/epjc/s10052-021-09846-7 [[arXiv:2108.04801 \[hep-th\]](#)].
- [175] S. Pasterski, “A Chapter on Celestial Holography,” [[arXiv:2310.04932 \[hep-th\]](#)].
- [176] A. Bagchi, P. Dhivakar and S. Dutta, “Holography in Flat Spacetimes: the case for Carroll,” [[arXiv:2311.11246 \[hep-th\]](#)].
- [177] L. Donnay, A. Fiorucci, Y. Herfray and R. Ruzziconi, “Bridging Carrollian and celestial holography,” *Phys. Rev. D* **107**, no.12, 126027 (2023) doi:10.1103/PhysRevD.107.126027 [[arXiv:2212.12553 \[hep-th\]](#)].
- [178] L. Donnay, A. Fiorucci, Y. Herfray and R. Ruzziconi, “Carrollian Perspective on Celestial Holography,” *Phys. Rev. Lett.* **129**, no.7, 071602 (2022) doi:10.1103/PhysRevLett.129.071602 [[arXiv:2202.04702 \[hep-th\]](#)].
-
- [179] D. A. Galante, “Modave lectures on de Sitter space & holography,” *PoS Modave2022*, 003 (2023) doi:10.22323/1.435.0003 [[arXiv:2306.10141 \[hep-th\]](#)].
- [180] M. Spradlin, A. Strominger and A. Volovich, “Les Houches lectures on de Sitter space,” [[arXiv:hep-th/0110007 \[hep-th\]](#)].
- [181] Y. Jiang, “A pedagogical review on solvable irrelevant deformations of 2D quantum field theory,” *Commun. Theor. Phys.* **73**, no.5, 057201 (2021) doi:10.1088/1572-9494/abe4c9 [[arXiv:1904.13376 \[hep-th\]](#)].
-
- [182] I. Bah, D. S. Freed, G. W. Moore, N. Nekrasov, S. S. Razamat and S. Schafer-Nameki, “A Panorama Of Physical Mathematics c. 2022,” [[arXiv:2211.04467 \[hep-th\]](#)].

- [183] K. Hori, S. Katz, A. Klemm, R. Pandharipande, R. Thomas, C. Vafa, R. Vakil and E. Zaslow, “Mirror symmetry,” AMS, 2003, <https://www.claymath.org/library/monographs/cmim01.pdf>
- [184] P. S. Aspinwall, T. Bridgeland, A. Craw, M. R. Douglas, A. Kapustin, G. W. Moore, M. Gross, G. Segal, B. Szendrői and P. M. H. Wilson, “Dirichlet branes and mirror symmetry,” AMS, 2009, <https://www.claymath.org/library/monographs/cmim04.pdf>
- [185] Denis Auroux, <https://ocw.mit.edu/courses/18-969-topics-in-geometry-mirror-symmetry-spring-2009/pages/lecture-notes/>,
- [186] M. Alim, “Lectures on Mirror Symmetry and Topological String Theory,” [arXiv:1207.0496 [hep-th]].
- [187] K. Hori, “Trieste lectures on mirror symmetry,” ICTP Lect. Notes Ser. **13**, 109-202 (2003) <https://inspirehep.net/files/045fe862f3e8ab7b15300626a281ffaf>
- [188] A. Kapustin and D. Orlov, “Lectures on mirror symmetry, derived categories, and D-branes,” Russ. Math. Surveys **59**, 907 (2004) doi:10.1070/RM2004v059n05ABEH000772 [arXiv:math/0308173 [math.AG]].
- [189] S. Hosono, A. Klemm and S. Theisen, “Lectures on mirror symmetry,” Lect. Notes Phys. **436**, 235-280 (1994) doi:10.1007/3-540-58453-6_13 [arXiv:hep-th/9403096 [hep-th]].
- [190] M. R. Ballard, “Meet homological mirror symmetry,” Fields Inst. Commun. **54**, 191-224 (2008) [arXiv:0801.2014 [math.AG]].
- [191] C. Quigley, “Mirror Symmetry in Physics: The Basics,” Fields Inst. Monogr. **34**, 211-278 (2015) doi:10.1007/978-1-4939-2830-9_7 [arXiv:1412.8180 [hep-th]].
- [192] B. Haghighat, “Mirror Symmetry and Modularity,” [arXiv:1712.00601 [hep-th]].
- [193] A. Imparato, “Towards Homological Mirror Symmetry,” [arXiv:2108.03931 [math.SG]].
- [194] A. Imparato, “About Homological Mirror Symmetry,” [arXiv:2306.13589 [math.AG]].
- [195] B. Webster and P. Yoo, “3-dimensional mirror symmetry,” [arXiv:2308.06191 [math-ph]].
-
- [196] E. D’Hoker and J. Kaidi, “Lectures on modular forms and strings,” [arXiv:2208.07242 [hep-th]].
- [197] V. Anagiannis and M. C. N. Cheng, “TASI Lectures on Moonshine,” PoS **TASI2017**, 010 (2018) doi:10.22323/1.305.0010 [arXiv:1807.00723 [hep-th]].
- [198] S. M. Harrison, J. A. Harvey and N. M. Paquette, “Snowmass White Paper: Moonshine,” [arXiv:2201.13321 [hep-th]].
- [199] J. F. R. Duncan, J. A. Harvey and B. C. Rayhaun, “An Overview of Penumbral Moonshine,” [arXiv:2109.09756 [math.RT]].
- [200] V. Tatitscheff, “Monstrous Moonshine: A Short Introduction,” Reson. **27**, no.12, 2107-2126 (2022) doi:10.1007/s12045-022-1508-x [arXiv:1902.03118 [math.NT]].
- [201] S. Gukov and I. Saberi, “Lectures on Knot Homology and Quantum Curves,” doi:10.1090/conm/613/12235 [arXiv:1211.6075 [hep-th]].
- [202] S. Nawata and A. Oblomkov, “Lectures on knot homology,” Contemp. Math. **680**, 137 (2016) doi:10.1090/conm/680/13702 [arXiv:1510.01795 [math-ph]].
- [203] E. Witten, “Geometric Langlands From Six Dimensions,” [arXiv:0905.2720 [hep-th]].

- [204] E. Witten, “Mirror Symmetry, Hitchin’s Equations, And Langlands Duality,” doi:10.1093/acprof:oso/9780199534920.003.0007 [[arXiv:0802.0999 \[math.RT\]](#)].
- [205] E. Witten, “Geometric Langlands And The Equations Of Nahm And Bogomolny,” [[arXiv:0905.4795 \[hep-th\]](#)].
- [206] K. G. Schlesinger, “A Physics perspective on geometric Langlands duality,” [[arXiv:0911.4586 \[hep-th\]](#)].
- [207] J. Evslin, “What does(n’t) K-theory classify?,” [[arXiv:hep-th/0610328 \[hep-th\]](#)].
- [208] R. J. Szabo, “D-branes and bivariant K-theory,” [[arXiv:0809.3029 \[hep-th\]](#)].
- [209] P. G. O. Freund, “p-adic strings and their applications,” AIP Conf. Proc. **826**, no.1, 65-73 (2006) doi:10.1063/1.2193111 [[arXiv:hep-th/0510192 \[hep-th\]](#)].
- [210] B. Dragovich, A. Y. Khrennikov, S. V. Kozyrev and I. V. Volovich, “On p-Adic Mathematical Physics,” Anal. Appl. **1**, 1-17 (2009) [[arXiv:0904.4205 \[math-ph\]](#)].
- [211] S. S. Gubser, C. Jepsen and B. Trundy, “Spin in p -adic AdS/CFT,” J. Phys. A **52**, no.14, 144004 (2019) doi:10.1088/1751-8121/ab0757 [[arXiv:1811.02538 \[hep-th\]](#)].
- [212] B. Dragovich, A. Y. Khrennikov, S. V. Kozyrev, I. V. Volovich and E. I. Zelenov, “ p -Adic Mathematical Physics: The First 30 Years,” Anal. Appl. **9**, 87-121 (2017) doi:10.1134/S2070046617020017 [[arXiv:1705.04758 \[math-ph\]](#)].
- [213] L. Borsten, M. J. Farahani, B. Jurco, H. Kim, J. Narozny, D. Rist, C. Saemann and M. Wolf, “Higher Gauge Theory,” [[arXiv:2401.05275 \[hep-th\]](#)].
- [214] B. Jurčo, C. Saemann, U. Schreiber and M. Wolf, “Higher Structures in M-Theory,” Fortsch. Phys. **67**, no.8-9, 1910001 (2019) doi:10.1002/prop.201910001 [[arXiv:1903.02807 \[hep-th\]](#)].
- [215] D. Fiorenza, H. Sati and U. Schreiber, “The Rational Higher Structure of M-theory,” Fortsch. Phys. **67**, no.8-9, 1910017 (2019) doi:10.1002/prop.201910017 [[arXiv:1903.02834 \[hep-th\]](#)].
- [216] T. Yoneya, “Lectures on Higher-Gauge Symmetries from Nambu Brackets and Covariantized M(atrix) Theory,” [[arXiv:1612.08513 \[hep-th\]](#)].
- [217] C. Saemann, “Lectures on Higher Structures in M-Theory,” doi:10.1142/9789813144613.0004 [[arXiv:1609.09815 \[hep-th\]](#)].
- [218] Yuri Ximenes Martins, Rodney Josué Biezuner, “Higher Category Theory and Hilbert’s Sixth Problem,” 2020 [[hal:02909681](#)].
- [219] H. Sati and U. Schreiber, “Mathematical foundations of quantum field theory and perturbative string theory,” Am. Math. Sci., 2011, ISBN 978-0-8218-5195-1
-
- [220] M. Khalkhali, “Lectures on noncommutative geometry,” [[arXiv:math/0702140 \[math.QA\]](#)].
- [221] V. Ginzburg, “Lectures on noncommutative geometry,” [[arXiv:math/0506603 \[math.AG\]](#)].
- [222] F. D’Andrea, “Topics in Noncommutative Geometry,” [[arXiv:1510.07271 \[math.QA\]](#)].
- [223] Snigdhasyan Mahanta, “On some approaches towards non-commutative algebraic geometry,” [[arXiv:math/0501166 \[math.QA\]](#)].
- [224] P. Vitale, M. Adamo, R. Dekhil and D. Fernández-Silvestre, “Introduction to noncommutative field and gauge theory,” [[arXiv:2309.17369 \[hep-th\]](#)].

- [225] M. R. Douglas and N. A. Nekrasov, “Noncommutative field theory,” *Rev. Mod. Phys.* **73**, 977-1029 (2001) doi:10.1103/RevModPhys.73.977 [[arXiv:hep-th/0106048 \[hep-th\]](#)].
- [226] R. J. Szabo, “Quantum field theory on noncommutative spaces,” *Phys. Rept.* **378**, 207-299 (2003) doi:10.1016/S0370-1573(03)00059-0 [[arXiv:hep-th/0109162 \[hep-th\]](#)].
- [227] V. P. Nair, “Noncommutative mechanics, Landau levels, twistors and Yang-Mills amplitudes,” *Lect. Notes Phys.* **698**, 97-138 (2006) doi:10.1007/3-540-33314-2_3 [[arXiv:hep-th/0506120 \[hep-th\]](#)].
- [228] P. Aschieri and L. Castellani, “Noncommutative gauge and gravity theories and geometric Seiberg–Witten map,” *Eur. Phys. J. ST* **232**, no.23-24, 3733-3746 (2023) doi:10.1140/epjs/s11734-023-00831-7 [[arXiv:2209.03774 \[hep-th\]](#)].
- [229] R. J. Szabo and M. Tirelli, “Noncommutative instantons in diverse dimensions,” *Eur. Phys. J. ST* **232**, no.23-24, 3661-3680 (2023) doi:10.1140/epjs/s11734-023-00840-6 [[arXiv:2207.12862 \[hep-th\]](#)].
- [230] A. P. Balachandran, S. Kurkuoglu and S. Vaidya, “Lectures on fuzzy and fuzzy SUSY physics,” [[arXiv:hep-th/0511114 \[hep-th\]](#)].
- [231] B. Ydri, “Lectures on Matrix Field Theory,” *Lect. Notes Phys.* **929**, pp.1-352 (2017) Springer, 2017, ISBN 978-3-319-46002-4, 978-3-319-46003-1 doi:10.1007/978-3-319-46003-1 [[arXiv:1603.00924 \[hep-th\]](#)].
- [232] I. Y. Arefeva, D. M. Belov, A. A. Giryavets, A. S. Koshelev and P. B. Medvedev, “Noncommutative field theories and (super)string field theories,” doi:10.1142/9789812777317.0001 [[arXiv:hep-th/0111208 \[hep-th\]](#)].
- [233] H. Steinacker, “Emergent Geometry and Gravity from Matrix Models: an Introduction,” *Class. Quant. Grav.* **27**, 133001 (2010) doi:10.1088/0264-9381/27/13/133001 [[arXiv:1003.4134 \[hep-th\]](#)].
- [234] H. Steinacker, “Non-commutative geometry and matrix models,” *PoS QGQGS2011*, 004 (2011) doi:10.22323/1.140.0004 [[arXiv:1109.5521 \[hep-th\]](#)].
- [235] F. Lizzi, “Noncommutative Geometry and Particle Physics,” *PoS CORFU2017*, 133 (2018) doi:10.22323/1.318.0133 [[arXiv:1805.00411 \[hep-th\]](#)].
- [236] W. D. van Suijlekom, “Noncommutative geometry and particle physics,” Springer, 2015, ISBN 978-94-017-9161-8, 978-94-017-9162-5 doi:10.1007/978-94-017-9162-5
- [237] L. Bubuianu, D. Singleton, S. I. Vacaru and E. V. Veliev, “Nonassociative Geometric and Quantum Information Flows and R-Flux Deformations of Wormhole Solutions in String Gravity,” *Fortsch. Phys.* **72**, no.3, 2300212 (2024) doi:10.1002/prop.202300212 [[arXiv:2402.10993 \[hep-th\]](#)].
- [238] R. Blumenhagen and E. Plauschinn, “Nonassociative Gravity in String Theory?,” *J. Phys. A* **44**, 015401 (2011) doi:10.1088/1751-8113/44/1/015401 [[arXiv:1010.1263 \[hep-th\]](#)].
- [239] R. Blumenhagen and M. Fuchs, “Towards a Theory of Nonassociative Gravity,” *JHEP* **07**, 019 (2016) doi:10.1007/JHEP07(2016)019 [[arXiv:1604.03253 \[hep-th\]](#)].
- [240] D. Viennot, “Metrics and geodesics on fuzzy spaces,” [[arXiv:2305.15095 \[math-ph\]](#)].
- [241] G. Manolakos, P. Manousselis, D. Roumelioti, S. Stefas and G. Zoupanos, “Matrix-Formulated Noncommutative Gauge Theories of Gravity,” *PoS CORFU2021*, 285 (2022) doi:10.22323/1.406.0285 doi:10.22323/1.406.0285

- [242] G. Manolakos, P. Manousselis, D. Roumelioti, S. Stefas and G. Zoupanos, “Intertwining noncommutativity with gravity and particle physics,” *Eur. Phys. J. ST* **232**, no.23-24, 3607-3624 (2023) doi:10.1140/epjs/s11734-023-00830-8 [[arXiv:2305.11785 \[hep-th\]](#)].
- [243] A. H. Chamseddine, A. Connes and W. D. van Suijlekom, “Noncommutativity and physics: a non-technical review,” *Eur. Phys. J. ST* **232**, no.23-24, 3581-3588 (2023) doi:10.1140/epjs/s11734-023-00842-4 [[arXiv:2207.10901 \[hep-th\]](#)].
- [244] M. R. Douglas, “Two lectures on D-geometry and noncommutative geometry,” [[arXiv:hep-th/9901146 \[hep-th\]](#)].
-
- [245] A. Dasgupta, H. Nicolai and J. Plefka, “An introduction to the quantum supermembrane,” *Grav. Cosmol.* **8**, 1 (2002) [[arXiv:hep-th/0201182 \[hep-th\]](#)].
- [246] M. J. Duff, “Supermembranes,” [[arXiv:hep-th/9611203 \[hep-th\]](#)].
- [247] H. Nicolai and R. Helling, “Supermembranes and M(atric) theory,” [[arXiv:hep-th/9809103 \[hep-th\]](#)].
- [248] J. Hoppe, “Recent progress on Membrane Theory,” *PoS CORFU2021*, 258 (2022) doi:10.22323/1.406.0258 [inspirehep.net/files/c6839f351370b7328bd22bd19c381a20](#)
- [249] M. Cederwall, “Thoughts on membranes, matrices and non-commutativity,” [[arXiv:hep-th/0410110 \[hep-th\]](#)].
- [250] P. S. Howe and E. Sezgin, “The Supermembrane revisited,” *Class. Quant. Grav.* **22**, 2167-2200 (2005) doi:10.1088/0264-9381/22/11/017 [[arXiv:hep-th/0412245 \[hep-th\]](#)].
- [251] M. P. Garcia del Moral, “Dualities as symmetries of the Supermembrane Theory,” [[arXiv:1211.6265 \[hep-th\]](#)].
- [252] M. J. Duff, J. X. Lu, R. Percacci, C. N. Pope, H. Samtleben and E. Sezgin, “Membrane Duality Revisited,” *Nucl. Phys. B* **901**, 1-21 (2015) doi:10.1016/j.nuclphysb.2015.10.003 [[arXiv:1509.02915 \[hep-th\]](#)].
- [253] P. K. Townsend, “The eleven-dimensional supermembrane revisited,” *Phys. Lett. B* **350**, 184-187 (1995) doi:10.1016/0370-2693(95)00397-4 [[arXiv:hep-th/9501068 \[hep-th\]](#)].
- [254] G. Linardopoulos, “Classical Strings and Membranes in the AdS/CFT Correspondence,” [users.uoa.gr/ glinardo/Thesis.pdf](#)
- [255] Fiona K. Seibold and Arkady A. Tseytlin, “Scattering on the supermembrane,” [[arXiv:2404.09658 \[hep-th\]](#)].
-
- [256] W. Taylor, “M(atric) Theory: Matrix Quantum Mechanics as a Fundamental Theory,” *Rev. Mod. Phys.* **73**, 419-462 (2001) doi:10.1103/RevModPhys.73.419 [[arXiv:hep-th/0101126 \[hep-th\]](#)].
- [257] W. Taylor, “The M(atric) model of M theory,” *NATO Sci. Ser. C* **556**, 91-178 (2000) doi:10.1007/978-94-011-4303-5_3 [[arXiv:hep-th/0002016 \[hep-th\]](#)].
- [258] B. Ydri, “Review of M(atric)-Theory, Type IIB Matrix Model and Matrix String Theory,” [[arXiv:1708.00734 \[hep-th\]](#)].
- [259] A. Konechny and A. S. Schwarz, “Introduction to M(atric) theory and noncommutative geometry,” *Phys. Rept.* **360**, 353-465 (2002) doi:10.1016/S0370-1573(01)00096-5 [[arXiv:hep-th/0012145 \[hep-th\]](#)].

- [260] A. Konechny and A. S. Schwarz, “Introduction to M(atr)ix theory and noncommutative geometry. Part 2.,” [[arXiv:hep-th/0107251 \[hep-th\]](#)].
- [261] D. Bigatti and L. Susskind, “Review of matrix theory,” NATO Sci. Ser. C **520**, 277-318 (1999) [[arXiv:hep-th/9712072 \[hep-th\]](#)].
- [262] T. Banks, “TASI lectures on matrix theory,” [[arXiv:hep-th/9911068 \[hep-th\]](#)].
-
- [263] N. B. Copland, “Introductory Lectures on Multiple Membranes,” [[arXiv:1012.0459 \[hep-th\]](#)].
- [264] J. Bagger, N. Lambert, S. Mukhi and C. Papageorgakis, “Multiple Membranes in M-theory,” Phys. Rept. **527**, 1-100 (2013) doi:10.1016/j.physrep.2013.01.006 [[arXiv:1203.3546 \[hep-th\]](#)].
- [265] I. R. Klebanov and G. Torri, “M2-branes and AdS/CFT,” Int. J. Mod. Phys. A **25**, 332-350 (2010) doi:10.1142/S0217751X10048652 [[arXiv:0909.1580 \[hep-th\]](#)].
- [266] N. Lambert, “M-Branes: Lessons from M2’s and Hopes for M5’s,” Fortsch. Phys. **67**, no.8-9, 1910011 (2019) doi:10.1002/prop.201910011 [[arXiv:1903.02825 \[hep-th\]](#)].
- [267] K. Hosomichi, “M2-branes and AdS/CFT: A Review,” PTEP **2020**, no.11, 11B102 (2020) doi:10.1093/ptep/ptaa060 [[arXiv:2003.13914 \[hep-th\]](#)].
- [268] R. Dijkgraaf, S. Gukov, A. Neitzke and C. Vafa, “Topological M-theory as unification of form theories of gravity,” Adv. Theor. Math. Phys. **9**, no.4, 603-665 (2005) doi:10.4310/ATMP.2005.v9.n4.a5 [[arXiv:hep-th/0411073 \[hep-th\]](#)].
- [269] P. C. West, “E(11) and M theory,” Class. Quant. Grav. **18**, 4443-4460 (2001) doi:10.1088/0264-9381/18/21/305 [[arXiv:hep-th/0104081 \[hep-th\]](#)].
- [270] G. T. Horowitz and L. Susskind, “Bosonic M theory,” J. Math. Phys. **42**, 3152-3160 (2001) doi:10.1063/1.1376160 [[arXiv:hep-th/0012037 \[hep-th\]](#)].
- [271] K. S. Kim, A. Mitra, D. Mukherjee and S. Ryu, “Monotonicity of renormalization group flow, Perelman’s entropy functional, and emergent dual holography in the worldsheet nonlinear σ model,” [[arXiv:2404.09122 \[hep-th\]](#)].
-
- [272] C. Maccaferri, “String Field Theory,” [[arXiv:2308.00875 \[hep-th\]](#)].
- [273] C. de Lacroix, H. Erbin, S. P. Kashyap, A. Sen and M. Verma, “Closed Superstring Field Theory and its Applications,” Int. J. Mod. Phys. A **32**, no.28n29, 1730021 (2017) doi:10.1142/S0217751X17300216 [[arXiv:1703.06410 \[hep-th\]](#)].
- [274] T. Erler, “Four Lectures on Closed String Field Theory,” Phys. Rept. **851**, 1-36 (2020) doi:10.1016/j.physrep.2020.01.003 [[arXiv:1905.06785 \[hep-th\]](#)].
- [275] T. Erler, “Four lectures on analytic solutions in open string field theory,” Phys. Rept. **980**, 1-95 (2022) doi:10.1016/j.physrep.2022.06.004 [[arXiv:1912.00521 \[hep-th\]](#)].
- [276] E. Fuchs and M. Kroyter, “Analytical Solutions of Open String Field Theory,” Phys. Rept. **502**, 89-149 (2011) doi:10.1016/j.physrep.2011.01.003 [[arXiv:0807.4722 \[hep-th\]](#)].
- [277] Y. Okawa, “Analytic methods in open string field theory,” Prog. Theor. Phys. **128**, 1001-1060 (2012) doi:10.1143/PTP.128.1001
- [278] W. Taylor, “String field theory,” [[arXiv:hep-th/0605202 \[hep-th\]](#)].
- [279] L. Rastelli, “String field theory,” [[arXiv:hep-th/0509129 \[hep-th\]](#)].

- [280] A. Sen, “String Field Theory as World-sheet UV Regulator,” JHEP **10**, 119 (2019) doi:10.1007/JHEP10(2019)119 [arXiv:1902.00263 [hep-th]].
- [281] W. Siegel, “Introduction to string field theory,” Adv. Ser. Math. Phys. **8**, 1-244 (1988) [arXiv:hep-th/0107094 [hep-th]].
- [282] A. Sen, “Tachyon dynamics in open string theory,” Int. J. Mod. Phys. A **20**, 5513-5656 (2005) doi:10.1142/S0217751X0502519X [arXiv:hep-th/0410103 [hep-th]].
- [283] M. Headrick, S. Minwalla and T. Takayanagi, “Closed string tachyon condensation: An Overview,” Class. Quant. Grav. **21**, S1539-S1565 (2004) doi:10.1088/0264-9381/21/10/027 [arXiv:hep-th/0405064 [hep-th]].
- [284] W. Taylor and B. Zwiebach, “D-branes, tachyons, and string field theory,” doi:10.1142/9789812702821_0012 [arXiv:hep-th/0311017 [hep-th]].
- [285] W. Taylor, “Lectures on D-branes, tachyon condensation, and string field theory,” doi:10.1007/0-387-24992-3_4 [arXiv:hep-th/0301094 [hep-th]].
- [286] J. Gomis, “Lectures on tachyon condensation: Towards time-dependent backgrounds and holography,” Class. Quant. Grav. **22**, S107-S124 (2005) doi:10.1088/0264-9381/22/8/004
-
- [287] D. Grabovsky, “Chern–Simons Theory in a Knotshell,” <https://web.physics.ucsb.edu/~davidgrabovsky/files-notes/CS%20and%20Knots.pdf>
- [288] G. V. Dunne, “Aspects of Chern-Simons theory,” [arXiv:hep-th/9902115 [hep-th]].
- [289] J. M. F. Labastida, “Chern-Simons gauge theory: Ten years after,” AIP Conf. Proc. **484**, no.1, 1-40 (1999) doi:10.1063/1.59663 [arXiv:hep-th/9905057 [hep-th]].
- [290] R. K. Kaul, T. R. Govindarajan and P. Ramadevi, “Schwarz type topological quantum field theories,” [arXiv:hep-th/0504100 [hep-th]].
- [291] D. Gaiotto and X. Yin, “Notes on superconformal Chern-Simons-Matter theories,” JHEP **08**, 056 (2007) doi:10.1088/1126-6708/2007/08/056 [arXiv:0704.3740 [hep-th]].
- [292] S. Carlip, “Quantum Gravity in 2+1 Dimensions,” [arXiv:2312.12596 [gr-qc]].
- [293] S. Carlip, “Conformal field theory, (2+1)-dimensional gravity, and the BTZ black hole,” Class. Quant. Grav. **22**, R85-R124 (2005) doi:10.1088/0264-9381/22/12/R01 [arXiv:gr-qc/0503022 [gr-qc]].
- [294] S. Carlip, “Quantum gravity in 2+1 dimensions,” Cambridge University Press, 2003, ISBN 978-0-521-54588-4, 978-0-511-82229-2 doi:10.1017/CBO9780511564192
- [295] S. Carlip, “Quantum gravity in 2+1 dimensions: The Case of a closed universe,” Living Rev. Rel. **8**, 1 (2005) doi:10.12942/lrr-2005-1 [arXiv:gr-qc/0409039 [gr-qc]].
- [296] S. Carlip, “Lectures on (2+1) dimensional gravity,” J. Korean Phys. Soc. **28**, S447-S467 (1995) [arXiv:gr-qc/9503024 [gr-qc]].
- [297] M. Vonk, “A Mini-course on topological strings,” [arXiv:hep-th/0504147 [hep-th]].
- [298] A. Neitzke and C. Vafa, “Topological strings and their physical applications,” [arXiv:hep-th/0410178 [hep-th]].
- [299] A. Klemm, “Topological string theory on Calabi-Yau threefolds,” PoS **RTN2005**, 002 (2005) doi:10.22323/1.019.0002

- [300] L. Ferro and T. Lukowski, “Amplituhedra, and beyond,” *J. Phys. A* **54**, no.3, 033001 (2021) doi:10.1088/1751-8121/abd21d [[arXiv:2007.04342 \[hep-th\]](#)].
- [301] E. Herrmann and J. Trnka, “The SAGEX review on scattering amplitudes Chapter 7: Positive geometry of scattering amplitudes,” *J. Phys. A* **55**, no.44, 443008 (2022) doi:10.1088/1751-8121/ac8709 [[arXiv:2203.13018 \[hep-th\]](#)].
- [302] Z. Bern and J. Trnka, “Snowmass TF04 Report: Scattering Amplitudes and their Applications,” [[arXiv:2210.03146 \[hep-th\]](#)].
- [303] G. Travaglini, A. Brandhuber, P. Dorey, T. McLoughlin, S. Abreu, Z. Bern, N. E. J. Bjerrum-Bohr, J. Blümlein, R. Britto and J. J. M. Carrasco, *et al.* “The SAGEX review on scattering amplitudes,” *J. Phys. A* **55**, no.44, 443001 (2022) doi:10.1088/1751-8121/ac8380 [[arXiv:2203.13011 \[hep-th\]](#)].
- [304] J. J. M. Carrasco, “Gauge and Gravity Amplitude Relations,” doi:10.1142/9789814678766_0011 [[arXiv:1506.00974 \[hep-th\]](#)].
- [305] J. J. Carrasco, “TASI 2022 lectures on scattering amplitudes – an addendum,” *PoS TASI2022*, 002 (2024) doi:10.22323/1.439.0002
- [306] T. Adamo, J. J. M. Carrasco, M. Carrillo-González, M. Chiodaroli, H. Elvang, H. Johansson, D. O’Connell, R. Roiban and O. Schlotterer, “Snowmass White Paper: the Double Copy and its Applications,” [[arXiv:2204.06547 \[hep-th\]](#)].
- [307] V. Pestun, M. Zabzine, F. Benini, T. Dimofte, T. T. Dumitrescu, K. Hosomichi, S. Kim, K. Lee, B. Le Floch and M. Marino, *et al.* “Localization techniques in quantum field theories,” *J. Phys. A* **50**, no.44, 440301 (2017) doi:10.1088/1751-8121/aa63c1 [[arXiv:1608.02952 \[hep-th\]](#)].
- [308] D. R. Morrison, “Gromov–Witten invariants and localization,” *J. Phys. A* **50**, no.44, 443004 (2017) doi:10.1088/1751-8121/aa6f65 [[arXiv:1608.02956 \[hep-th\]](#)].
- [309] S. S. Pufu, “The F-Theorem and F-Maximization,” *J. Phys. A* **50**, no.44, 443008 (2017) doi:10.1088/1751-8121/aa6765 [[arXiv:1608.02960 \[hep-th\]](#)].
- [310] K. Zarembo, “Localization and AdS/CFT Correspondence,” *J. Phys. A* **50**, no.44, 443011 (2017) doi:10.1088/1751-8121/aa585b [[arXiv:1608.02963 \[hep-th\]](#)].
- [311] C. Cordova, T. T. Dumitrescu, K. Intriligator and S. H. Shao, “Snowmass White Paper: Generalized Symmetries in Quantum Field Theory and Beyond,” [[arXiv:2205.09545 \[hep-th\]](#)].
- [312] L. Bhardwaj, L. E. Bottini, L. Fraser-Taliente, L. Gladden, D. S. W. Gould, A. Platschorre and H. Tillim, “Lectures on generalized symmetries,” *Phys. Rept.* **1051**, 1-87 (2024) doi:10.1016/j.physrep.2023.11.002 [[arXiv:2307.07547 \[hep-th\]](#)].
- [313] M. Cederwall, “Pure Spinors in Classical and Quantum Supergravity,” doi:10.1007/978-981-19-3079-9_47-1 [[arXiv:2210.06141 \[hep-th\]](#)].
- [314] N. Berkovits and C. R. Mafra, “Pure Spinor Formulation of the Superstring and Its Applications,” doi:10.1007/978-981-19-3079-9_63-1 [[arXiv:2210.10510 \[hep-th\]](#)].
- [315] O. Corradini, C. Schubert, J. P. Edwards and N. Ahmadinia, “Spinning Particles in Quantum Mechanics and Quantum Field Theory,” [[arXiv:1512.08694 \[hep-th\]](#)].
- [316] J. P. Edwards and C. Schubert, “Quantum mechanical path integrals in the first quantised approach to quantum field theory,” [[arXiv:1912.10004 \[hep-th\]](#)].

- [317] C. Schubert, “Perturbative quantum field theory in the string inspired formalism,” Phys. Rept. **355**, 73-234 (2001) doi:10.1016/S0370-1573(01)00013-8 [[arXiv:hep-th/0101036 \[hep-th\]](#)].
- [318] Vyacheslav Lysov, “Spinors and SUSY on a worldline,” [groups.oist.jp/system/files/WL_SUSY.pdf](#).
- [319] E. J. Martinec, “Matrix models and 2D string theory,” [[arXiv:hep-th/0410136 \[hep-th\]](#)].
- [320] P. H. Ginsparg and G. W. Moore, “Lectures on 2-D gravity and 2-D string theory,” [[arXiv:hep-th/9304011 \[hep-th\]](#)].
- [321] S. Chatterjee and E. Witten, “Liouville Theory: An Introduction to Rigorous Approaches,” [[arXiv:2404.02001 \[hep-th\]](#)].
- [322] L. Freidel, R. G. Leigh and D. Minic, “Modular Spacetime and Metastring Theory,” J. Phys. Conf. Ser. **804**, no.1, 012032 (2017) <https://doi.org/10.1088/1742-6596/804/1/012032>
-
- [323] T. Adamo, “Lectures on twistor theory,” PoS **Modave2017**, 003 (2018) doi:10.22323/1.323.0003 [[arXiv:1712.02196 \[hep-th\]](#)].
- [324] M. Atiyah, M. Dunajski and L. Mason, “Twistor theory at fifty: from contour integrals to twistor strings,” Proc. Roy. Soc. Lond. A **473**, no.2206, 20170530 (2017) doi:10.1098/rspa.2017.0530 [[arXiv:1704.07464 \[hep-th\]](#)].
- [325] T. Adamo, “Twistor actions for gauge theory and gravity,” [[arXiv:1308.2820 \[hep-th\]](#)].
- [326] T. Adamo, M. Bullimore, L. Mason and D. Skinner, “Scattering Amplitudes and Wilson Loops in Twistor Space,” J. Phys. A **44**, 454008 (2011) doi:10.1088/1751-8113/44/45/454008 [[arXiv:1104.2890 \[hep-th\]](#)].
- [327] M. Wolf, “A First Course on Twistors, Integrability and Gluon Scattering Amplitudes,” J. Phys. A **43**, 393001 (2010) doi:10.1088/1751-8113/43/39/393001 [[arXiv:1001.3871 \[hep-th\]](#)].
- [328] F. Cachazo and P. Svrcek, “Lectures on twistor strings and perturbative Yang-Mills theory,” PoS **RTN2005**, 004 (2005) doi:10.22323/1.019.0005 [[arXiv:hep-th/0504194 \[hep-th\]](#)].
- [329] Ljudmila Kamenova, “Twistor spaces and compact manifolds admitting both Kähler and non-Kähler structures,” [[arXiv:1711.07948 \[math.DG\]](#)].
- [330] Y. Geyer and L. Mason, “The SAGEX review on scattering amplitudes Chapter 6: Ambitwistor Strings and Amplitudes from the Worldsheet,” J. Phys. A **55**, no.44, 443007 (2022) doi:10.1088/1751-8121/ac8190 [[arXiv:2203.13017 \[hep-th\]](#)].
- [331] M. Dunajski, “Twistor Theory and Differential Equations,” J. Phys. A **42**, 404004 (2009) doi:10.1088/1751-8113/42/40/404004 [[arXiv:0902.0274 \[hep-th\]](#)].
- [332] T. Adamo, D. Skinner and J. Williams, “Minitwistors and 3d Yang-Mills-Higgs theory,” J. Math. Phys. **59**, no.12, 122301 (2018) doi:10.1063/1.5030417 [[arXiv:1712.09604 \[hep-th\]](#)].
- [333] M. Carrillo González, W. T. Emond, N. Moynihan, J. Rumbutis and C. D. White, “Mini-twistors and the Cotton double copy,” JHEP **03**, 177 (2023) doi:10.1007/JHEP03(2023)177 [[arXiv:2212.04783 \[hep-th\]](#)].
- [334] D. W. Chiou, O. J. Ganor, Y. P. Hong, B. S. Kim and I. Mitra, “Massless and massive three dimensional super Yang-Mills theory and mini-twistor string theory,” Phys. Rev. D **71**, 125016 (2005) doi:10.1103/PhysRevD.71.125016 [[arXiv:hep-th/0502076 \[hep-th\]](#)].

- [335] Nobuhiro Honda and Fuminori Nakata, “Minitwistor spaces, Severi varieties, and Einstein-Weyl structure,” [[arXiv:0901.2264](#) [[math.DG](#)]].
- [336] M. Dunajski, “Equivalence principle, de-Sitter space, and cosmological twistors,” *Int. J. Mod. Phys. D* **32**, no.14, 2341001 (2023) doi:10.1142/S0218271823410018 [[arXiv:2304.08574](#) [[gr-qc](#)]].
- [337] P. Woit, “Notes on the Twistor \mathbf{P}^1 ,” [[arXiv:2202.02657](#) [[math-ph](#)]].
- [338] Peter Scholze, “ p -adic geometry,” [[arXiv:1712.03708](#) [[math.AG](#)]].
-
- [339] F. Cianfrani, O. M. Lecian and G. Montani, “Fundamentals and recent developments in non-perturbative canonical Quantum Gravity,” [[arXiv:0805.2503](#) [[gr-qc](#)]].
- [340] F. Cianfrani, O. M. Lecian, M. Lulli and G. Montani, “Canonical Quantum Gravity Fundamentals and Recent Developments,” <https://doi.org/10.1142/8957> — July 2014
- [341] A. Corichi and D. Núñez, “Introduction to the ADM formalism,” *Rev. Mex. Fis.* **37**, 720-747 (1991) [[arXiv:2210.10103](#) [[gr-qc](#)]].
- [342] A. Ashtekar and E. Bianchi, “A short review of loop quantum gravity,” *Rept. Prog. Phys.* **84**, no.4, 042001 (2021) doi:10.1088/1361-6633/abed91 [[arXiv:2104.04394](#) [[gr-qc](#)]].
- [343] N. Bodendorfer, “An elementary introduction to loop quantum gravity,” [[arXiv:1607.05129](#) [[gr-qc](#)]].
- [344] A. Ashtekar, M. Reuter and C. Rovelli, “From General Relativity to Quantum Gravity,” [[arXiv:1408.4336](#) [[gr-qc](#)]].
- [345] C. Rovelli and F. Vidotto, “Covariant Loop Quantum Gravity: An Elementary Introduction to Quantum Gravity and Spinfoam Theory,” Cambridge University Press, 2014, ISBN 978-1-107-06962-6, 978-1-316-14729-0 doi:10.1017/CBO9781107706910
- [346] C. Rovelli, “Zakopane lectures on loop gravity,” *PoS QGQGS2011*, 003 (2011) doi:10.22323/1.140.0003 [[arXiv:1102.3660](#) [[gr-qc](#)]].
- [347] C. Rovelli, “Quantum gravity,” *Univ. Pr.*, 2004, doi:10.1017/CBO9780511755804
- [348] T. Thiemann, “Modern canonical quantum general relativity,” [[arXiv:gr-qc/0110034](#) [[gr-qc](#)]].
- [349] H. Nicolai, K. Peeters and M. Zamaklar, “Loop quantum gravity: An Outside view,” *Class. Quant. Grav.* **22**, R193 (2005) doi:10.1088/0264-9381/22/19/R01 [[arXiv:hep-th/0501114](#) [[hep-th](#)]].
- [350] T. Thiemann, “Loop Quantum Gravity: An Inside View,” *Lect. Notes Phys.* **721**, 185-263 (2007) doi:10.1007/978-3-540-71117-9_10 [[arXiv:hep-th/0608210](#) [[hep-th](#)]].
- [351] A. Ashtekar and P. Singh, “Loop Quantum Cosmology: A Status Report,” *Class. Quant. Grav.* **28**, 213001 (2011) doi:10.1088/0264-9381/28/21/213001 [[arXiv:1108.0893](#) [[gr-qc](#)]].
-
- [352] A. Bonanno, A. Eichhorn, H. Gies, J. M. Pawłowski, R. Percacci, M. Reuter, F. Saueressig and G. P. Vacca, “Critical reflections on asymptotically safe gravity,” *Front. in Phys.* **8**, 269 (2020) doi:10.3389/fphy.2020.00269 [[arXiv:2004.06810](#) [[gr-qc](#)]].
- [353] R. Percacci, “Asymptotic Safety,” [[arXiv:0709.3851](#) [[hep-th](#)]].
- [354] A. Platania, “Black Holes in Asymptotically Safe Gravity,” doi:10.1007/978-981-19-3079-9_24-1 [[arXiv:2302.04272](#) [[gr-qc](#)]].

- [355] S. Surya, “The causal set approach to quantum gravity,” *Living Rev. Rel.* **22**, no.1, 5 (2019) doi:10.1007/s41114-019-0023-1 [[arXiv:1903.11544](#) [[gr-qc](#)]].
- [356] Y. K. Yazdi, “Everything you always wanted to know about how causal set theory can help with open questions in cosmology, but were afraid to ask,” *Mod. Phys. Lett. A* **39**, no.01, 2330003 (2024) doi:10.1142/S0217732323300033 [[arXiv:2311.14881](#) [[gr-qc](#)]].
- [357] F. Finster, “Causal fermion systems: Classical gravity and beyond,” doi:10.1142/9789811269776_0050 [[arXiv:2109.05906](#) [[gr-qc](#)]].
- [358] F. Finster, “The Continuum Limit of Causal Fermion Systems,” Springer, 2016, doi:10.1007/978-3-319-42067-7 [[arXiv:1605.04742](#) [[math-ph](#)]].
- [359] R. Loll, “Quantum Gravity from Causal Dynamical Triangulations: A Review,” *Class. Quant. Grav.* **37**, no.1, 013002 (2020) doi:10.1088/1361-6382/ab57c7 [[arXiv:1905.08669](#) [[hep-th](#)]].
- [360] L. Freidel, “Group field theory: An Overview,” *Int. J. Theor. Phys.* **44**, 1769-1783 (2005) doi:10.1007/s10773-005-8894-1 [[arXiv:hep-th/0505016](#) [[hep-th](#)]].
- [361] D. Oriti, “The Group field theory approach to quantum gravity,” [[arXiv:gr-qc/0607032](#) [[gr-qc](#)]].
- [362] E. Alvarez and E. Velasco-Aja, “A Primer on Unimodular Gravity,” doi:10.1007/978-981-19-3079-9_15-1 [[arXiv:2301.07641](#) [[gr-qc](#)]].
- [363] M. Herrero-Valea, “The status of Hořava gravity,” *Eur. Phys. J. Plus* **138**, no.11, 968 (2023) doi:10.1140/epjp/s13360-023-04593-y [[arXiv:2307.13039](#) [[gr-qc](#)]].

Acknowledgments

