LMU

MAX-PLANCK-GESELLSCHAFT

20 Years of String Theory In Munich

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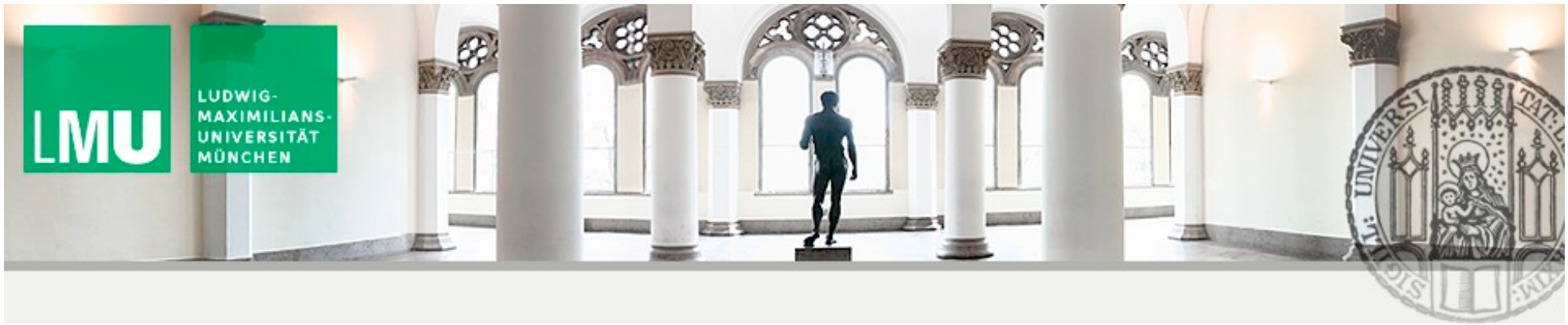

Course Summer Term 2025 at LMU

Outline

08. May: Intersecting Brane Worlds Models (Chios, 2004)

15. May: Moduli Stabilisation and Entropy Maximization in Type II Calabi-Yau compactifications (Eurostrings Cambridge, 2006)

21. May: String Amplitudes for the LHC in D-brane Compactifications (Dublin, 2009)

28. May: Emergent String Geometry from Particles Species (Corfu, 2011)

12. June: Strings and non-commutative/non-associative geometry (Corfu, 2012)

18. June: Classical and Quantum Black Hole Hair (Cuba, 2016)

3. July: Higher Spin Theories, AdS Distance and the Swampland (StringPheno CERN, 2019)

17. July: Minimal Black Holes and Species Thermodynamics (Harvard, 2023)

Intersecting Brane Models

(8. May 2025)

Primary Goals:

- Derive the (supersymmetric) Standard Model from String Compactifications.
- Derive the couplings and the low energy effective action of the SM fields.

State of the art in 2003/2004:

- Heterotic string constructions: Calabi-Yau compactifications, orbifolds, fermionic and bosonic constructions.
- Effective SUGRA models, SUSY breaking by non-perturbative gaugino condensation.

Intersecting Brane Models

(8. May 2025)

Further progress in the field:

- Moduli stabilization and SUSY breaking by fluxes (KKLT)
- F-theory compactifications
- Swampland constraints (exclusion from bottom-up)

Yet no fully complete derivation of the SM from string theory.

Intersecting Brane Models

(8. May 2025)

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Moduli Stabilisation and Entropy Maximisation in Type II Calabi-Yau Compactifications

(15. May 2025)

Primary Goals:

- Stabilization of all moduli and mass generation for all scalar field
- Breaking of space-time supersymmetry
- Search for de Sitter vacua with a small positive cosmological constant

State of the art in 2006:

- Construction of flux vacua for type IIB (GKP)
- Non-perturbative superpotentials (also known from heterotic strings in the 90's)
- KKLT anti-brane uplift (also known from DT)

Moduli Stabilisation and Entropy Maximisation in Type II Calabi-Yau Compactifications

Further progress in the field: (15. May 2025)

- A lot of challenges for KKLT were identified:
  - Stability problems of the anti-brane uplift, tadpole constraints, scale separation, …
  - Swampland constraints against de Sitter and scale separation
  - General quantum gravity arguments against de Sitter
- Many explicit KKLT constructions
- Swampland: the Dark Dimension scenario

Still a lot of controversial debate about KKLT and de Sitter vacua. So after 22 years the issue is not yet settled !

Moduli Stabilisation and Entropy Maximisation in Type II Calabi-Yau Compactifications

(15. May 2025)

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String Amplitudes for the LHC in D-brane Compactifications

(21. May 2025)

Primary Goals:

- Explore the generic signatures of 4-dimensional string vacua.

State of the art in 2009:

- LHC was not yet running: a lot of hope for SUSY
- Large extra dimension (millimeter) and TeV string scale scenarios by ADD: electroweak hierarchy problem
- Large volume string constructions (LVS)

String Amplitudes for the LHC in D-brane Compactifications

(21. May 2025)

Further progress in the field:

- LHC took a lot of data
  - Higgs discovery in 2012
  - No discovery of SUSY, strings or extra dimensions at LHC
- Dark Dimension scenario with micro scale extra dimension:
  cosmological hierarchy problem

String Amplitudes for the LHC in D-brane Compactifications

(21. May 2025)

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Emergent String Geometry from Particles Species

(28. May 2025)

Primary Goals:

- Understanding of the quantum nature of gravity and of space-time. Is gravity a fundamental force or does it emerge as an effective force (in the IR) from some underlying basic description (in the UV)?

State of the art in 2011:

- The phenomenon of emerge was discussed in the literature in many instances: effective gauge theories with composite gauge bosons, composite hadrons, statistical physics, biophysics, …..

Emergent String Geometry from Particles Species

(28. May 2025)

Further progress in the field:

- Swampland considerations gave a new perspective on emergence in quantum gravity
  - Integration over species
  - Emergence of gauge kinetic terms
  - Emergence of higher order curvature terms

Emergent String Geometry from Particles Species

(28. May 2025)

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Emergent String Geometry from Particles Species

(28. May 2025)

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``Emergence of F^4-couplings in Heterotic/Type IIA Dual String Theories,''
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Strings and non-commutative/non-associative Geometry

(12. June 2025)

Primary Goals:

- Understanding of non-geometric backgrounds and their effective actions in string theory
- Understanding of the quantum structure of space for non-geometric backgrounds

State of the art in 2012:

- Formulation of non-geometric flux compatifications
- Formulation of double field theory
- Non-commutative space for open strings with F-flux

Strings and non-commutative/non-associative Geometry

(12. June 2025)

Further progress in the field:

- Some attempts to formulate non-associative gravity
- Some recent discussion about non-geometric spaces and swampland
- Not too much further progress

$\Longrightarrow$ Non-geometric backgrounds are still a largely unexplored part of the landscape

Strings and non-commutative/non-associative Geometry

(12. June 2025)

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Strings and non-commutative/non-associative Geometry

(12. June 2025)

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Classical and quantum black hole hair

(18. June 2025)

Primary Goals:

- Understanding of black hole charges/hair
- Understanding of black hole information problem

State of the art in 2016:

- No-hair theorems
- Microscopic calculation of BH entropy (Strominger/Vafa)
- BMS transformations and the work of Hawking/ Strominger/Perry

Classical and quantum black hole hair

(18. June 2025)

Further progress in the field:

- EFT computation of Page curve via holographic entanglement entropy (entanglement islands)
- String embedding of entanglement islands via Karch/Randall branes $\Longrightarrow$ massive gravity
- Resolution of information puzzle for higher-dimensional (4d) BHs is still not completely understood.
- It is not clear if a UV complete theory like string theory needs islands, resp. There is some kind of UV/IR mixing

Classical and quantum black hole hair

(18. June 2025)

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Classical and quantum black hole hair

(18. June 2025)

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S.~Demulder, A.~Gnecchi, I.~Lavdas and D.~Lüst, ``Islands and light gravitons in type IIB string theory,'' JHEP \textbf{02}, 016 (2023)

Higher spin theories, AdS distance and the Swampland

(3. July 2025)

Primary Goals:

- Can there be a consistent EFT of higher spin theories (coupled to gravity)?
- Can there be a consistent EFT of massive gravity?
- Can there be scale separation in (A)dS vacua?

State of the art in 2019:

- Work of Vasiliev on higher spin theories
- Work on scale separation: Van Riet, KKLT, DGKT, …..
- Work on massive gravity and biometric gravity

Higher spin theories, AdS distance and the Swampland

(3. July 2025)

Further progress in the field:

- Not so much further work on massive gravity (except in connection with entanglement islands)
- A lot of work on the question of scale separation, but no final answer.
- The dark dimension scenario.

Higher spin theories, AdS distance and the Swampland

(3. July 2025)

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Higher spin theories, AdS distance and the Swampland

(3. July 2025)

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Minimal Black Holes and Species Thermodynamics

(17. July 2025)

Primary Goals:

- What is the UV cutoff of an EFT coupled to gravity?
- How is the UV cutoff related to black holes?
- Can one derive the emergent string conjecture from the bottom-up, e.g. from black hole physics?

State of the art in 2023:

- HP black hole - string correspondence
- Infinite distance conjecture and emergent string conjectures
- Work on species scale, black holes and higher curvature corrections

Minimal Black Holes and Species Thermodynamics (17. July 2025)

Further progress in the field:

- Further work on bottom-up derivation of distance and emergent string conjecture
- Further work on the species scale and the EFT cut-off
- Further work on species thermodynamics

Minimal Black Holes and Species Thermodynamics

(17. July 2025)

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