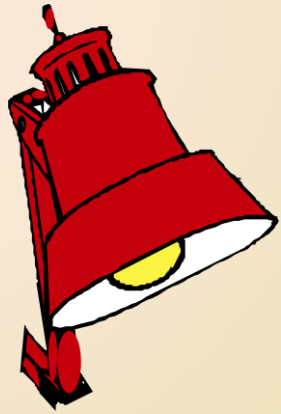# Towards an understanding of the quantum nature of gravity

SWAMPLAND PROGRAM, STRING THEORY & CFTs, COSMOLOGY, AMPLITUDES AND BLACK HOLES

Why formal string theory/ quantum gravity research?

When an effective field theory can be consistently extended to the UV?

QFT, particle physics

Non-perturbative regime (amplitudes structure, theory formulation..)

General relativity

What are the fundamental principles of quantum gravity?

Evolution of the Universe

Black hole evaporation

de Sitter QFT

In caso di nebbia

se vedete così

40 km/h

The group

Director **Dieter Lüst**

Stringtheorie

Gravitationstheorie

Students:

Rafael Alvarez-García, Daniel Bockisch, Christian Kneißl, Arina Kuznetsova

PhD students:

Philip Betzler, Andeas Bischof, Max Brinkmann, Davide de Biasio, Julian Freigang, Andriana Makridou, Seyed Pouria Mazloumi, David Osten, Sebatian Salgado Rebolledo, Lorenz Schlechter, Marc Syväri, Matthias Traube, Michael Zantedeschi

Angelo Caravano, Brage Gording, Marvin Lueben,

Postdocs:

Dmitry Bykov, Saskia Demulder, Alessandra Gnecchi, Marco Scalisi

Vero Errasti Diez, Chrisoula Markou, Julio Mendez-Zavaleta

Scientists:

Ralph Blumenhagen, Stephan Stieberger

Administrative support: Vera Kudrin, Annette Sturm

Impact of the group's research

> ➤ The swampland program and the weak gravity conjecture

> ➤ String phenomenology (cosmology, particle physics, machine learning)

> > > Group leaders Dieter Lüst, Ralph Blumenhagen

> ➤ Cosmology and Modified theories of gravity

> > > Group leader Dieter Lüst

> ➤ String amplitudes and celestial amplitudes

> > > Group leader Stephan Stieberger

The members of the String Theory and Gravitation group actively interact and collaborate with international researchers and play a leading role on advancing research in String Theory, String Phenomenology, Cosmology and Gravitational Physics.

Swampland program

One known UV example: String Theory.

What constraints can be derived from String Theory, that the EFT have to satisfy?

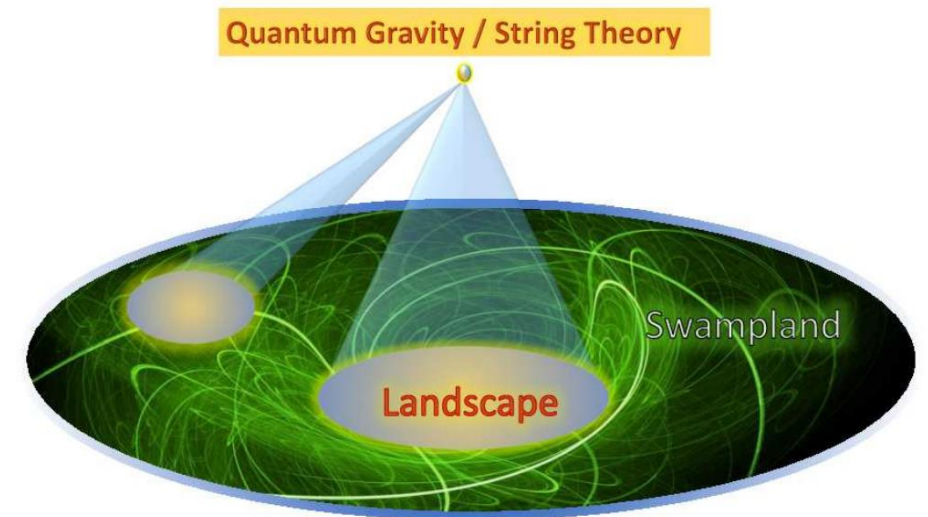Recently, swampland constraints have been derived from the Weak Gravity Conjecture

Image courtesy of Ralph Blumenhagen

Swampland program

❑ By studying black hole evaporation, extend the infinite distance conjecture for black holes in de Sitter
Marvin Lüben Dieter Lüst, Ariadna Ribes Metidieri, 2011.12331 [hep-th]

❑ Bounds on AdS spacetime dimensions from swampland constraints from studies at large-D
Quentin Bonnefoy, Luca Ciambelli, Dieter Lüst, Severin Lüst, 2011.06610 [hep-th]

❑ Breakdown scale of EFT with massive gravitons realized in IIB string theory related to an infinite tower of massive states in string theory becoming light
Ioannis Lavdas, Dieter Lüst, 2007.08913 [hep-th]

❑ Infinite distance conjecture: gravity flow equations as a Ricci flow towards a fixed point where an infinite tower of states becomes light
Davide De Biasio, Dieter Lüst, Fortsch.Phys. 68 (2020) 8, 2000053

❑ No scale separation proved for a class of AdS_2 solutions of String Theory without fluxes
Dieter Lüst, Dimitrios Tsimpis JHEP 07 (2020) 060

❑ New bounds on the derivative of the scalar potential for de Sitter by studying generalized Higuchi bounds (on the mass of higher spin fields in a cosmological scenario)
Marvin Lüben, Dieter Lust JHEP 09 (2020) 055

Swampland program

Research group leader: Ralph Blumenhagen

☐ De Sitter quantum breakdown from String Theory: relating the TCC and de Sitter swampland conjecture from a coarse graining approach to de Sitter decoherence and the high temperature regime of string theory.
Ralph Blumenhagen Christian Kneissl Andriana Makridou, 2011.13956 [hep-th]

☐ Can de Sitter be constructed from String Theory? Improved analysis of KKLT necessary assumptions for the existence of Minkowski vacuum on which induce the uplift to de Sitter. More precisely, studies if it exists a controllable mechanism close to a conifold point in the complex structure moduli space where large warping can occur, which is the setup needed for the de Sitter uplift.
Rafael Álvarez-García, Ralph Blumenhagen, Max Brinkmann, Lorenz Schlechte, 2009.03325 [hep-th]

☐ Generalization of the de Sitter Swampland conjecture for the ghost-free brane worlds of Hull's exotic supersting theories
Ralph Blumenhagen, Max Brinkmann, Andriana Makridou, Lorenz Schlechter, Matthias Traube JHEP 06 (2020), 077

☐ Logarithmic quantum corrections to AdS Swampland conjectures
Ralph Blumenhagen, Max Brinkmann, Andriana Makridou, JHEP 02 (2020), 064

String phenomenology, dark matter and particle physics

String Theory at low energies allows for various particle physics scenarios, in which to look for possible dark matter candidates or generic extensions to the standard model to a unification of particle physics and cosmology, e.g.

❑ Dark Energy constraints on EFT in a concrete setup: Salam-Sezgin model and its stringy realization
Luis A. Anchordoqui, Ignatios Antoniadis, Dieter Lüst, Jorge F. Soriano 2005.10075 [hep-th]

❑ Extending the SM particle contents via extra (anomalous) U(1) gauge fields from open strings ending on D-branes and chiral matter: realistic candidate of Dark Matter compatible with LHC bounds as massive dark bosons
Luis A. Anchordoqui, Ignatios Antoniadis, Karim Benakli, Dieter Lust, Phys.Lett.B 810 (2020) 135838

➡️   New postdocs: Marco Scalisi, extensive work in inflation, swampland program, string cosmology

Cosmology, theories of massive/higher curvature gravity and phenomenology

Extension to theories of gravity with additional massive gravitons, higher curvature terms..

What are the effects on large scale and cosmological observables?

Fit the theories parameters with constraints arising mostly from observations and causality

Only recent combined observations between gravitational waves and astroparticle observatories have confirmed that GW propagate at the speed of light, highly constraining theories of modified gravity

Cosmology, theories of massive gravity and phenomenology

❑ Cosmological constraints on parameters of bi-metric theories of gravity and compatibility of this theory with local tests of gravity.
Marvin Lüben, Angnis Schmidt-May, Jochen Weller, JCAP 09 (2020), 024
Marvin Lüben, Edvard Mörtsell, Angnis Schmidt-May, Class.Quant.Grav. 37 (2020) 4, 047001

❑ + Work in progress: extend the bound from Supernovae on spin-2 mass and coupling to CMB and BAO constraints
Angelo Caravano, Marvin Lüben, Jochen Weller

❑ Construction of a Lagrangian methodology that allows to identify the independent degrees of freedom in first order theories, much simpler than the Hamiltonian methods
Verónica Errasti, Markus Maier, Julio A. Méndez-Zavaleta, Mojtaba Taslimi Tehrani, Phys.Rev.D 102 (2020), 065015

❑ Construction of a theory of Maxwell and Proca fields
Verónica Errasti Díez, Brage Gording, Julio A. Méndez-Zavaleta, Angnis Schmidt-May Phys.Rev.D 101 (2020) 4, 045009 and Phys.Rev.D 101 (2020) 4, 045008

❑ Attempts at a unified description of SM particles through 8dim algebra of complex matrices *Brage Gording, Agnis Schmidt-May, Adv.Appl.Clifford Algebras 30 (2020) 4, 55 and Brage Gording, 2005.06974*

String theory backgrounds with fluxes and worldsheet CFTs

☐ Current algebras, generalised fluxes and non-geometry
David Osten, J.Phys.A 53 (2020) 26, 265402

☐ Open-String Non-Associativity in an R-flux Background
Dieter Lüst, Emanuel Malek, Erik Plauschinn, Mark Syväry JHEP 05 (2020), 157

☐ Cardy Algebras, Sewing Constraints and String-Nets
Mathias Traube, 2009.11895 [math-ph]

Machine learning applications to high energy physics

One of the difficulties in extracting predictions on low energy physics from String Theory it's the mathematical complexity of its solutions. Finding generic, explicit compactification geometries is highly nontrivial. Recently, these problems have been tackled through computational algorithm like machine learning ones, that nowadays find many applications between high energy theory and pure mathematics.

☐ Connecting dualities and machine learning
Philip Betzler, Sven Krippendorf, Fortsch.Phys. 68 (2020) 5, 2000022

☐ Detecting Symmetries with Neural Networks
Sven Krippendorf, Marc Syvaeri 2003.13679 [physics.comp-ph]

T-duality, integrability, TQFT and nlσ-models

❑ Deformed σ-models, Ricci flow and Toda field theories
 Dmitri Bykov, Dieter Lust, 2005.01812 [hep-th]

❑ On the formulation of CP^{n-1} sigma model as a Gross-Neveu model with fermions
Dmitri Bykov, 2009.04608 [hep-th]

❑ Conjecture on the integrability of gauge sigma models on flag manifolds
Dmitri Bykov, 2006.14124 [hep-th]

❑ T-duality, deformation of integrable systems towards a realization in supergravity, and generalized cosets
 Saskia Demulder, Falk Hassler, Giacomo Piccinini, Daniel C. Thompson
JHEP 10 (2020) 086 and JHEP 09 (2020) 044

❑ + Work in progress: S. Demulder and D. Osten on deformation of integrable models

❑ Quantization of N=1 SYM theory matrix model via BO approximation, which is shown not to be trivially compatible with SUSY
Verónica Errasti, Mahul Pandey, Sachindeo Vaidya Phys.Rev.D 102 (2020) 7, 074024

String Amplitudes

Investigating the mathematical structure of QFT amplitudes has revealed new properties - **color kinematic duality** and deep connections between gravity and gauge theory - **double copy**

String theory allows to explain the origin of mathematical identities observed in QFT scattering amplitudes.

Use String Theory to better understand the structure of the quantum field theories describing our universe
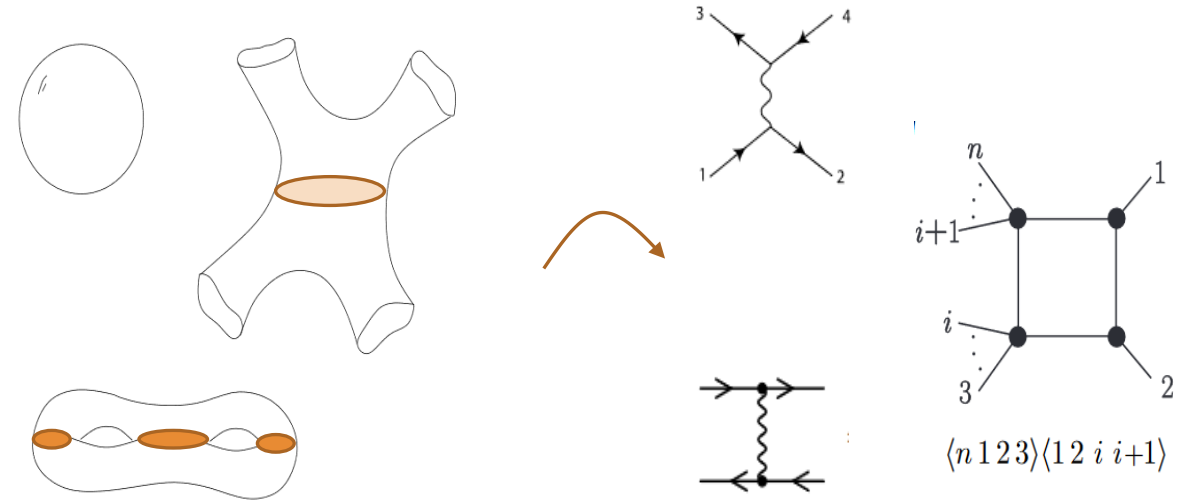
Deriving quantum field theory scattering amplitudes from worldsheet amplitudes
Seyed Pouria Mazloumi, Stephan Stieberger - w.i.p.

Can bi-metric gravity be captured by string theory? Analysing scattering amplitudes to shed light on the origin of the bi-metric potential
Dieter Lüst, Chrysoula Markou, Seyed Pouria Mazloumi, Stephan Stieberger 2012.xxxxx

Closed string disk amplitudes in the pure spinor formalism
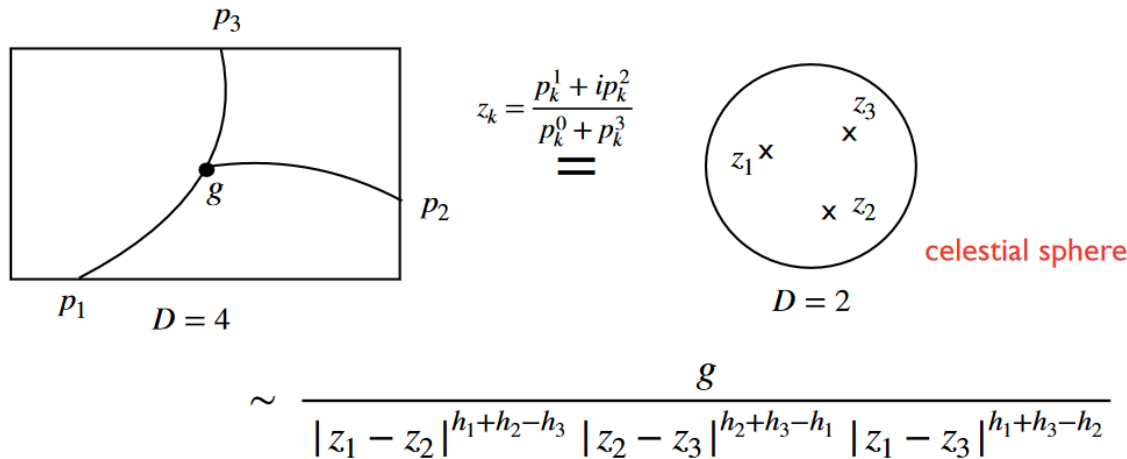*Andreas Bischof, Michael Haack, 2011.10392 [hep-th]*

String Amplitudes

New way of looking at scattering amplitudes
4d scattering amplitudes have interpretation as Euclidean 2d conformal correlators

Change of coordinates to points on the *Celestial Sphere*

$$z_k = \frac{p_k^1 + i p_k^2}{p_k^0 + p_k^3}$$

celestial sphere

$D = 4$

$D = 2$

$$\sim \frac{g}{|z_1 - z_2|^{h_1 + h_2 - h_3} \, |z_2 - z_3|^{h_2 + h_3 - h_1} \, |z_1 - z_3|^{h_1 + h_3 - h_2}}$$

From S. Stieberger, talk at Amplitudes 2020

Extended Super BMS Algebra of Celestial CFT
JHEP 09 (2020), 198

On Sugawara construction on Celestial Sphere
JHEP 09 (2020), 139

Extended BMS Algebra of Celestial CFT
JHEP 03 (2020), 130

Stephan Stieberger & collaborators from Northeastern U. and Jiangsu U. Sci. Technol.

Holography and Anti de Sitter black holes

New postdocs: Alessandra Gnecchi

String theory on Anti de Sitter vacuum in d+1 dimensions ⟷ Dual Superconformal Field theory in d dimensions

➤ Study the holographic dual attractor equations for AdS vacua and AdS black holes

➤ Black hole microstates for Anti de Sitter black holes can be described as states of the dual SCFT

➤ Describe evaporating black holes via holographic CFT data: what are the operators that describe the interior of the black hole?

New directions: what are the Euclidean saddle points of the gravity action? What is the role of Euclidean wormholes in our understanding of black holes?

Future directions

∞ No more social distancing!

∞ Taming the swampland

∞ Euclidean saddle points of the gravitational action. What Euclidean Wormholes really are? And what are they telling us about the evaporation of black holes?

∞ How much the conjectures born in a string theory context extend to modified theories of gravity?

∞ Soft theorems and celestial amplitudes.

∞ Precise connection between string theory amplitudes and quantum field theory processes

1+1 CFT

near AdS2
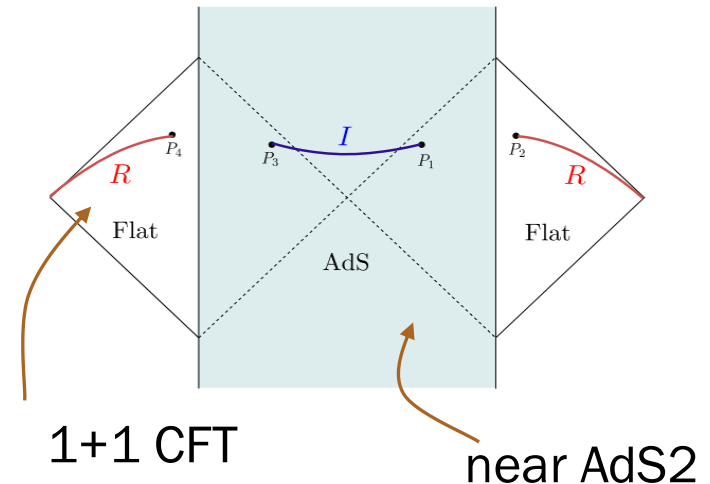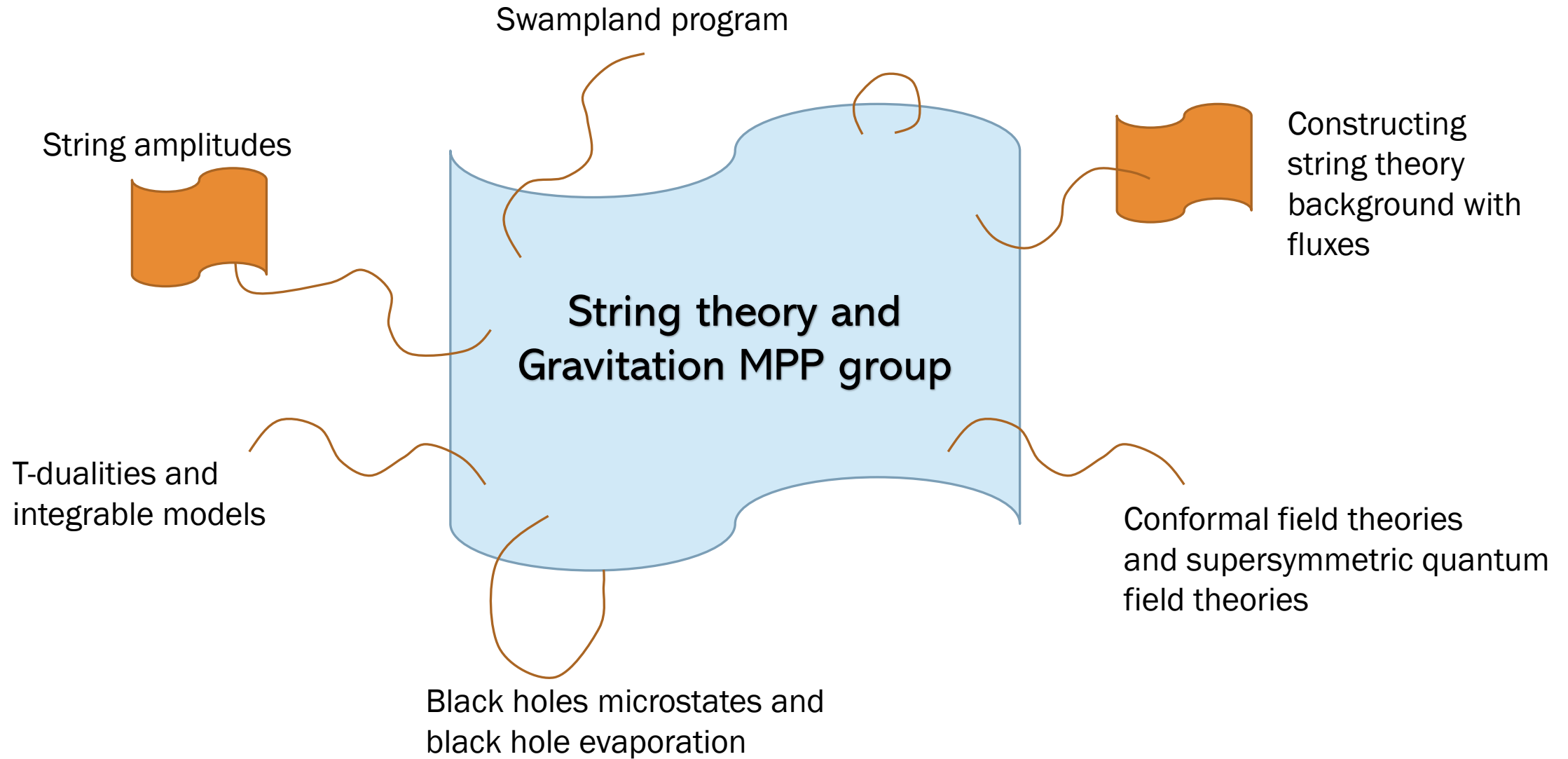
Conferences, workshops, meetings and networking

♦ 15-17 Feb 2021, online program: "**Junior duality and integrability workshop**" (S. Demulder)

♦ June 2021, GRS meeting in Boston on "String Theory, Cosmology and Particle Astrophysics" (M.Scalisi)

♦ Fall 2021, at Ringberg Castle, Conference on "**Geometry, Gravity and Strings**" (R. Blumenhagen, D. Lüst, external E. Palti).

♦ 2021, Workshop on Celestial Amplitudes and Flat Space Holography, Corfu (S. Stieberger)

♦ 202x? Lots of efforts in organizing a «**Female network**» that got postponed due to 👑
(X. Li, S. Demulder, V. Errasti Diez, A. Markidou, A. J. Zsgimond)

♦ 202x? Talks on **Gender issues in academia** should have been part of the 2020 regular Colloquia Series, thanks to the help of G. Zanderighi and U. Haisch, this also got postponed due to 👑
(X. Li, S. Demulder, V. Errasti Diez, A. Markidou, A. J. Zsgimond)

Thank you!