Theoretical High Energy Physics

with emphasis on (my personal perspective on) the particle/string duality

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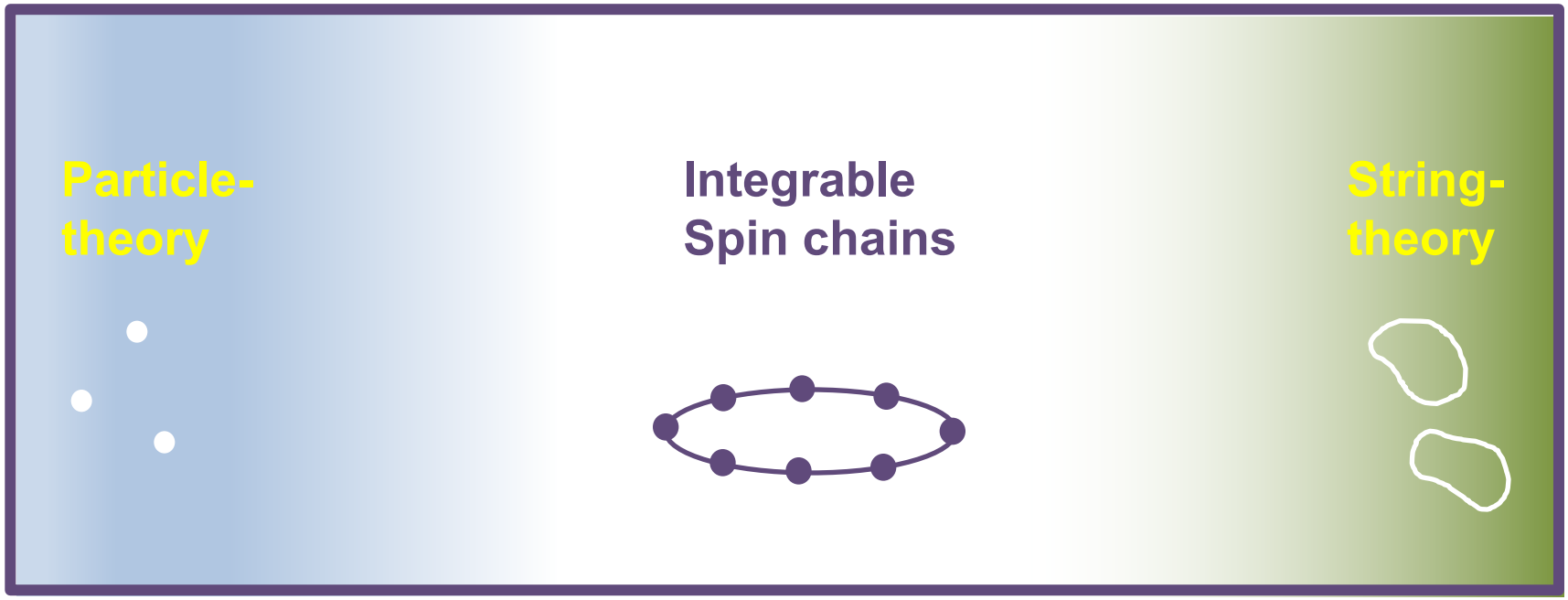
NBIA

NBIA MSc Day 2023

Particle/string duality=Gauge/gravity duality

Common framework for particles and strings

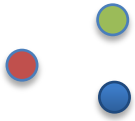


Complexity, particle theory

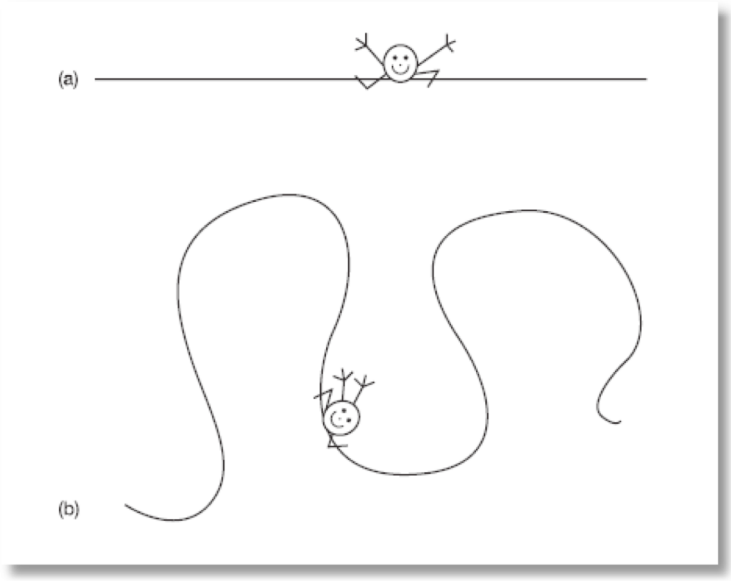
Complexity, string theory

Particles

Point like:



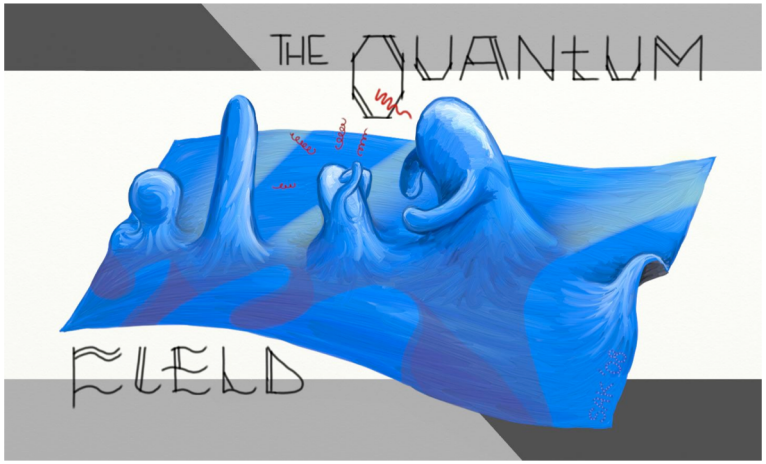
Motion described by world line:



Quantization :

Discrete set of states

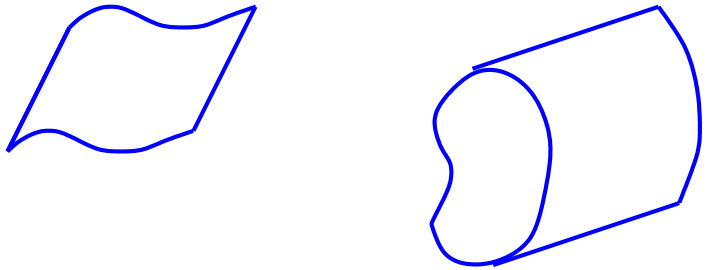
Particles = Excitations of field



Strings

One-dimensional

Motion described
by world sheet

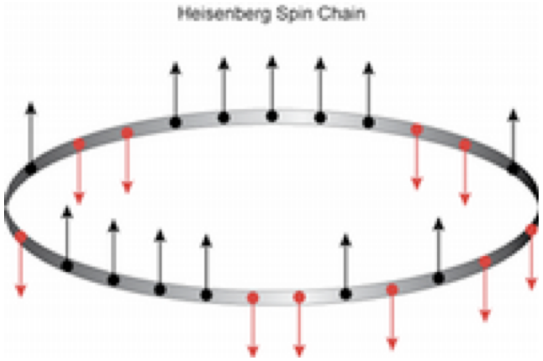


Quantization $\Longrightarrow$ Discrete set of states

Strings= world sheets with excitations

Spin Chains

One-dimensional lattice:

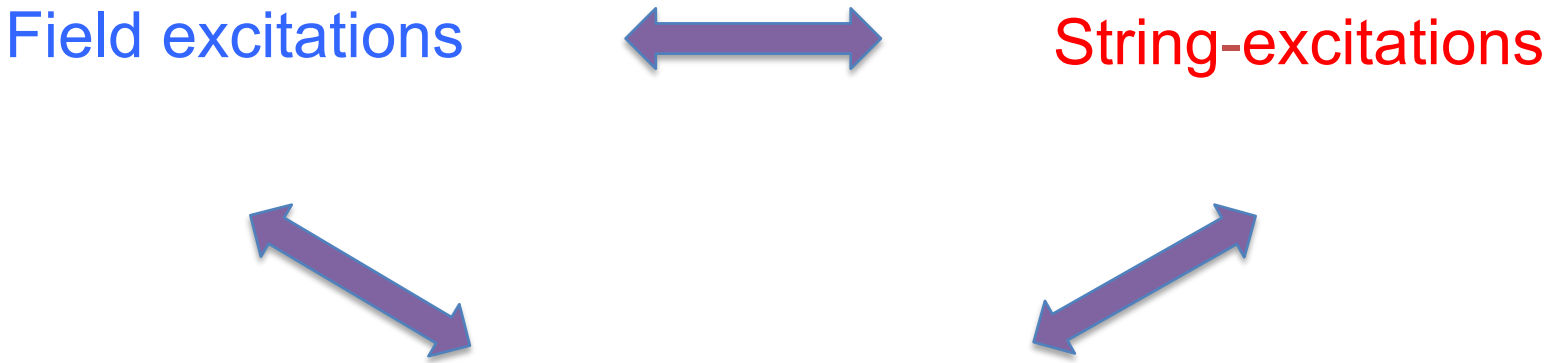


Discrete set of states: Spin up or spin down.

Vacuum state: All spins pointing down

Flipped spins = Excitations of the vacuum

Spin Chains as the connecting link between particles and strings



Interactions between excitations determined by symmetries alone

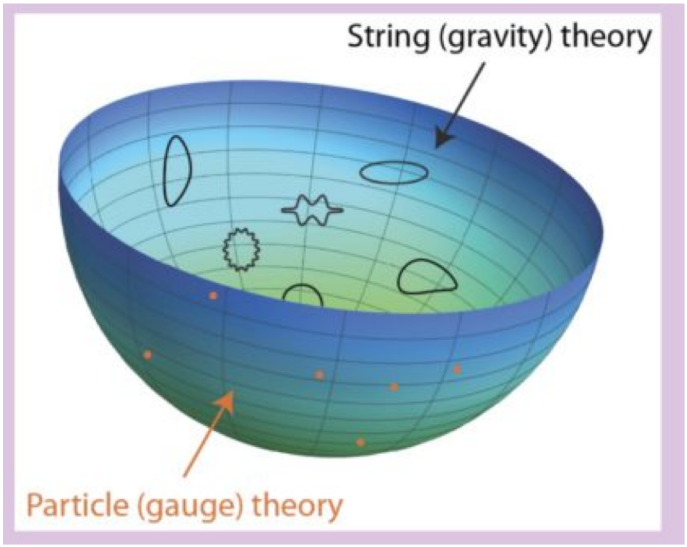
Spin chain exactly solvable, dvs. particle and string theory exactly solvable

Fundamental ideas

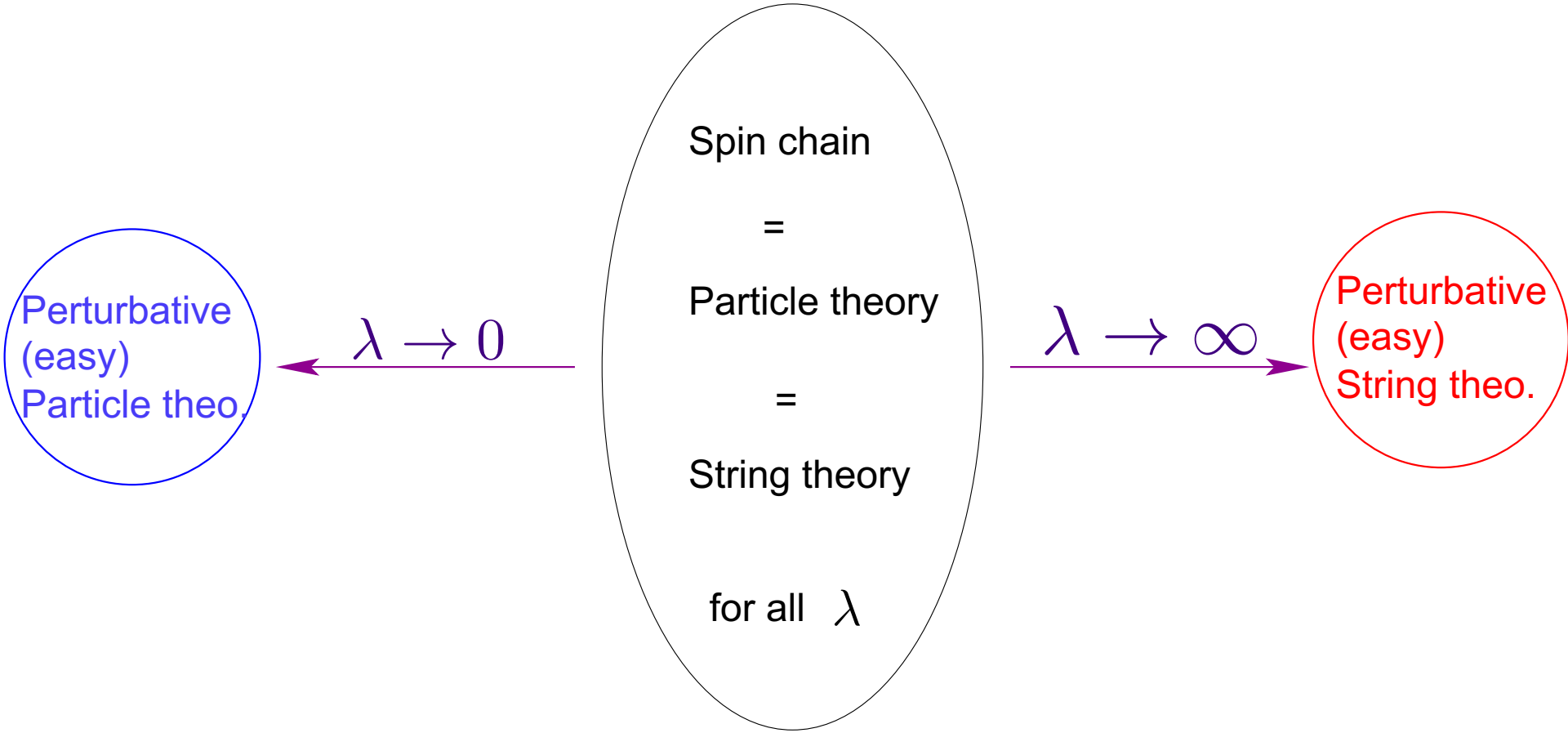
- Number of parameters reduced to one, λ
  (describes the strength of interactions between excitations)

- Extra symmetries introduced
  (super symmetry, conformal symmetry)

- String theory defined on special 10d space,
  which has our 4D Minkowski space as boundary: holography
  $(AdS_5 \times S^5)$



Summary


Perturbative
(easy)
Particle theo.
$\lambda \to 0$
Spin chain
=
Particle theory
=
String theory
for all λ
$\lambda \to \infty$
Perturbative
(easy)
String theo.

Breaking the symmetries, keeping the duality

String theory: Introducing higher dimensional brane

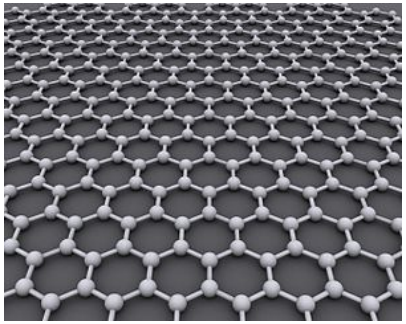
	t	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
$D3$	$\times$	$\times$	$\times$	$\times$						
$D5$	$\times$	$\times$	$\times$		$\times$		$\times$	$\times$		
$D7$	$\times$	$\times$	$\times$		$\times$		$\times$	$\times$	$\times$	$\times$

Field theory: Introducing domain wall separating different vacua

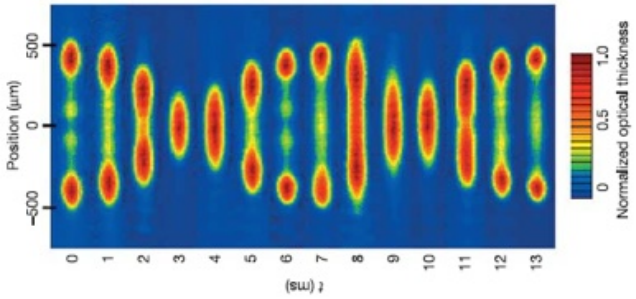
Spin chain: Introducing boundary state

Connections to condensed matter physics

The defect can model a sheet of graphene



The boundary state can serve as initial state for a quantum quench

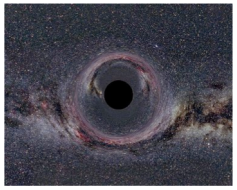


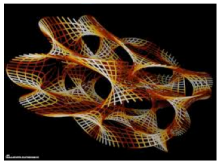
Matrix product states are used to compute correlation functions

Other ways to break the symmetries

Research interests, Niels Obers (NBIA MSc day 2023)

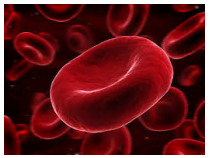
- Non-relativistic/Carroll gravity from large/small speed of light expansions of GR & applications to:
  - real-world GR (BH horizons, mergers, ..)
  - cosmology
  - non-relativistic (quantum) gravity
  - holography





- Non-relativistic strings and limits of AdS/CFT correspondence & connections with spin Matrix theory
  non-relativistic corners of M-theory/non-perturbative dualities

- Hydrodynamics of non-boost invariant (quantum critical) systems and fluid/gravity correspondence



- Newton-Cartan submanifolds and applications to soft CMT

- blackfolds and the construction of SUSY-breaking (anti-brane) solutions in string theory

Recent MSc thesis with Niels Obers (since 2016)

- Dennis Hansen, On non-relativistic field theory and geometry (2016)
- Emil Have, On charged Lifshitz holography (2017)
- Marieke van Beest, Newton-Cartan Gravity and 3D Chern-Simons Theory (2018)
- Bjarke Nielsen, Non-relativistic submanifolds and fluid dynamics (2018)
- Matthew Steinberg, MERA tensor networks, quantum error correction, & AdS/CFT (2018)
- Jörgen Sandøe Musaeus, 2+1 Dimensional non-relativistic gravity (2020)
- Yibo Zhong, Bulk reconstruction (2021)
- Frederik Holdt-Sørensen, Aspects of conformal field theories and gravity in large dimensions (2021)
- Roberto Forbicia León, On non-Lorentzian geometry and the weak field limit of non-relativistic gravity (2022)

Recommended study track

High Energy Theory and Cosmology

	Block 1	Block 2	Block 3	Block 4
Year 1	Advanced Quantum Mechanics	General Relativity and Cosmology	Quantum Field Theory 1	Fundaments of High-Energy Astrophysics and Particle Astrophysics
	Elementary Particle Physics	Particle Physics and the Early Universe	Modern Methods for Particle Scattering	*Choose one of:* Introduction to String Theory* Introduction to Gauge/Gravity Duality** Advanced Topics in QFT & Gravity***

Year -1: Mat F3 (Group theory for physicists :-)

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