CERN Retreat: String Theory Group Presentations

Benjamin Assel

(Sincere apologies for not being present today)

I have done my PhD in Ecole Normale Supérieure in Paris and then I have been a postdoc for three years at King's College in London.

My main fields of interest so far have been **supersymmetric** and **super-conformal gauge theories** in dimensions one to six and the **holographic correspondence** (AdS/CFT).

More specifically I have been studying:

- Supersymmetry in curved spaces (without gravity) and **localization computations**, e.g. exact computation of the partition function of 4d $\mathcal{N}=1$ supersymmetric gauge theories on $S^1 \times S^3$;
- The **holographic correspondence** between 3d $\mathcal{N}=4$ super-conformal theories and their AdS_4 gravity duals in type IIB string theory;
- Non-perturbative **dualities in gauge theories**, e.g. mirror symmetry in 3d $\mathcal{N}=4$ theories, electro-magnetic duality in 4d $\mathcal{N}=4$ SYM.
- **Defects preserving supersymmetry**: Supersymmetric Wilson loops, surface defects, ...

Supersymmetric localization across dimensions

Cyril Closset

CERN

CERN-TH retreat
November 3, 2016

Ten years in a slide:

- 2006-2010: PhD at ULB (Belgium)
- 2010: Weizmann Institute (Israel)
- 2013: Simons Center (NY, USA)
- 2016: CERN
- What I did: AdS/CFT, brane physics, exact results in SUSY QFT

Cyril N. M. Closset

Personal

Name :	Cyril N. M. Closset
Birthdate :	August 13, 1983
Nationality :	Belgian
Mail :	CERN dep TH 1211 Geneve 23 Switzerland

Academic positions

2016-2019	CERN-COFUND Fellow at the **CERN Theoretical Physics** Department, Geneva, Switzerland.
2013-2016	Research Assistant Professor at the **Simons Center for Geometry and Physics**, State University of New York at Stony Brook, Stony Brook, NY, USA.
2010-2013	Postdoctoral Feinberg Fellow at the **Weizmann Institute of Science** (Department of Particle Physics and Astronomy), Rehovot, Israel.

Education

2006-2010	**Doctoral studies at Université Libre de Bruxelles (ULB)**, Brussels, Belgium. Scholarship FRIA-FNRS. Thesis defended on June 11, 2010. Thesis advisor: Dr Riccardo Argurio. Thesis title: *"Studies of fractional D-branes in the gauge/gravity correspondence & Flavored Chern-Simons quivers for M2-branes."*
2004-2006	*Licence en Physique* (Physics master degree) at ULB.
2004-2005	Exchange student (Erasmus program) at the Universidad Complutense de Madrid (UCM), Madrid, Spain.
2002-2004	*Candidature en Physique* (Physics bachelor degree) at ULB.

Main research interests

Exact results in supersymmetric QFT. Curved space supersymmetry. Supersymmetric GLSM in two dimensions. Field theory dualities. Conformal field theories. Chern-Simons theory. *AdS*/CFT correspondence. D-branes and M-branes in string/M-theory.

My current obsession:

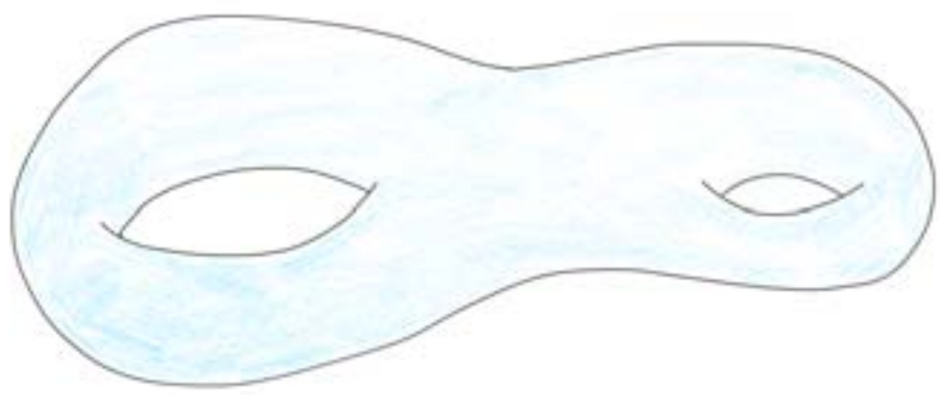
- ◇ Take a supersymmetric theory in d dimensions.
  Don't throw in too many supercharges. (To taste.)
- ◇ Place it on a curved manifold $\mathcal{M}_d$ (preserve SUSY).
- ◇ Perform the path integral using supersymmetric localization.

It leads to many exact results for 'supersymmetric enough' observables.

This is particularly interesting for superconformal theories.

Revisiting 2d A-twisted (gauge) theories

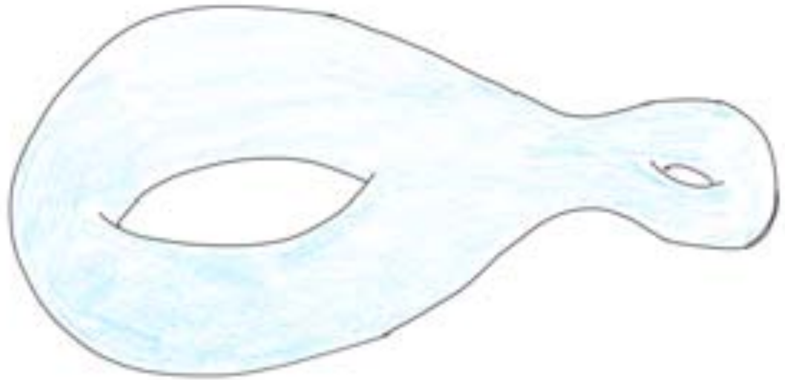
Two-dimensional field theories with $\mathcal{N} = (2,2)$ supersymmetry can be 'twisted' and placed on curved space.



Topological field theories 'of cohomological type'. [Witten, 1988]

Revisiting 2d A-twisted (gauge) theories

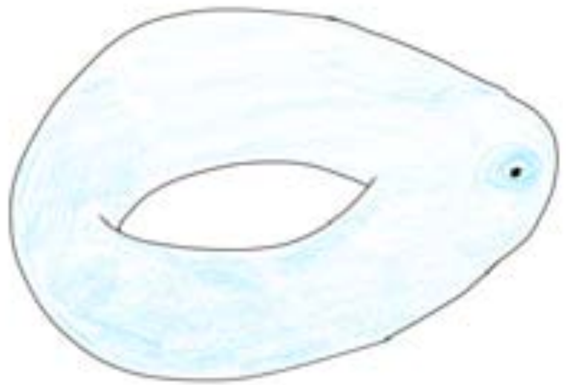
Two-dimensional field theories with $\mathcal{N} = (2, 2)$ supersymmetry can be 'twisted' and placed on curved space.



Topological field theories 'of cohomological type'. [Witten, 1988]

Revisiting 2d A-twisted (gauge) theories

Two-dimensional field theories with $\mathcal{N} = (2, 2)$ supersymmetry can be 'twisted' and placed on curved space.



Topological field theories 'of cohomological type'. [Witten, 1988]

Revisiting 2d A-twisted (gauge) theories

Recent progress in computing correlation function of 'Coulomb branch operators' for any standard $\mathcal{N}=(2,2)$ gauge theory.

[C.C., Cremonesi, Park, 2015; C.C., Kim, 2016]

$$\langle \mathcal{O}(\sigma) \rangle_{\Sigma_g} = \sum_{\mathfrak{m} \in \Gamma_{\mathbf{G}^\vee}} q^{\mathfrak{m}} \oint_{\mathrm{JK}(\eta)} \frac{d\sigma}{2\pi i} Z^{\text{1-loop}}_{g,\mathfrak{m}}(\sigma)\, H(\sigma)^g\, \mathcal{O}(\sigma)$$

- ◇ Mathematically, it computes 'quasimap invariants'.

  [Kim, Oh, Ueda, Yoshida, 2016]

- ◇ Leads to new results for CY manifolds.

- ◇ More observables are captured by the A-twist, which have not yet been computed. It will be very interesting to compute the most general A-twist (twisted chiral ring) correlator.

The A-twist in three dimensions

We recently computed the quantum algebra of Wilson loops in very large classes of three-dimensional gauge theories with $\mathcal{N} = 2$ supersymmetry. [C.C., Kim, 2016]

It generalizes the Verlinde algebra of pure Chern-Simons theory.

Like for pure Chern-Simons, there is a beautiful topological story and a direct relation to two-dimensional physics.

The A-twist in three dimensions

The quasi-topological structure of 3d $\mathcal{N} = 2$ gauge theories can be uncovered by explicit localization computations. For instance, we find: [C.C., Kim, Willett, to appear]

$$Z_{S^3} = \left\langle \mathcal{F}^p \right\rangle_{S^2 \times S^1}$$

with Z_{S^3} the S^3 partition function of [Kapustin, Willett, Yaakov, 2009]

- There are more TFT-like structure to explore in these theories.
- It gives powerful tool to study 3d dualities.
- It might shed new light on the 3d/3d correspondence of [Dimofte, Gaiotto, Gukov, 2011].

Current projects

In 4d $\mathcal{N} = 1$ theories:

- ◇ Study half-BPS surface operators and their fusion algebra.
- ◇ Study quarter-BPS local operators by localization on complex manifolds.

In 2d $\mathcal{N} = (0, 2)$ theories:

- ◇ Study the chiral algebra of half-BPS local operators in 2d $\mathcal{N} = (0, 2)$ theories.
- ◇ Study $\mathcal{N} = (0, 2)$ quivers that arise on CY fourfold singularities using B-branes.

Research Interests & Scientific Activities

Denis Klevers

CERN Theory Group Retreat 2016
St. Genis

3th of November 2016

My background & research interests in short

Background:

- PhD in 2011 from universitätbonn.
- Postdoc 2011-2014 at Penn UNIVERSITY of PENNSYLVANIA.
- Fellow at CERN since September 2014.

Future:

- January 2017: MPI Munich

Research field:

String Phenomenology broadly defined.

- Development of techniques to determine effective physics of String Theory.
- Work at interface between physics/mathematics.

The effective physics of string theory

UV theory

String Theory in 10/11 dimensions

Compactification + Low energies →

IR theories

Effective theories in 4 (6) dimensions

Goal: obtain all data of effective theories from data of UV theory

- Focus of my talk: Classify particle physics in String Theory/F-theory.
- Successful alternative application: strongly coupled gauge theories in 6D

Problems:

1. Many **vacua** of string theory.

2. realistic solutions very complex.

→ F-theory: Formulation of String Theory that constructs largest class of string vacua with promising particle physics & provides powerful tool in mathematics.

F-Theory: Physics from geometry

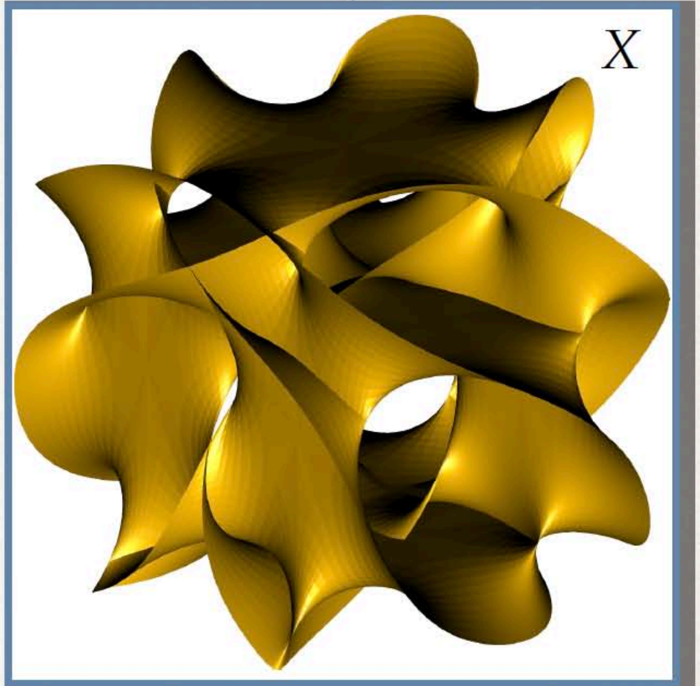
<u>Physics of Branes</u>
described by interesting effective theories in IR

F-Theory
Physics/Geometry

geometry of Calabi-Yau manifold X

1. Gauge group
2. Matter sector
3. Coupling functions

F-Theory
Physics/Geometry



<u>My research:</u> geometric techniques for physics/geometry dictionary

F-theory: Physics at geometrical singularities

F-theory = Duality + Geometrisation in Type IIB String Theory.

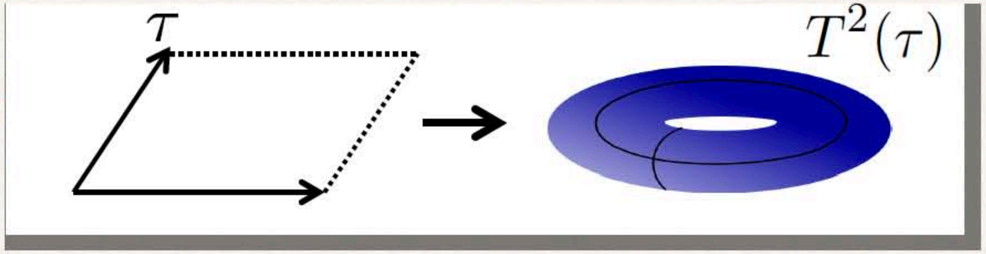
- Type IIB has S-duality acting on complexified string coupling $\tau = i g_S^{-1} + C_0$ as

Dehn-twist

$$\tau \mapsto \frac{a\tau + b}{c\tau + d} \qquad \text{with} \qquad \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in \mathrm{SL}(2, \mathbb{Z})$$

- Natural object to consider is not τ but two-torus $T^2(\tau)$ associated to it.

➡ $\mathrm{SL}(2,\mathbb{Z})$ "gauge-invariant"



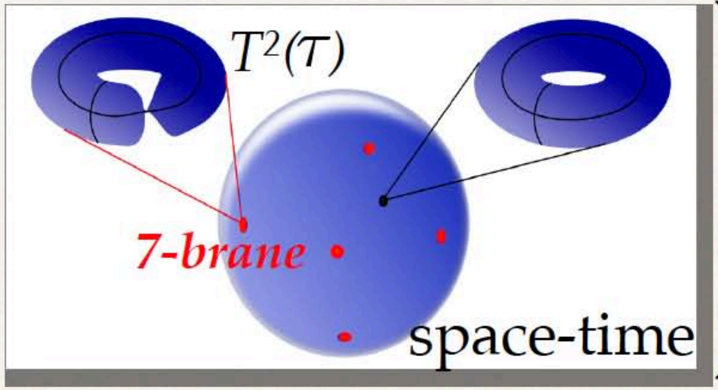
➡ S-duality invariant description requires replacing τ by geometry $T^2(\tau)$

F-theory: Physics at geometrical singularities

Important: $\tau = ig_S^{-1} + C_0$ has sources in String Theory = 7- branes

Varying field profile of τ ⟶

- $T^2(\tau)$ varies over space-time.
- at sources: $|\tau| \to \infty$



⟶ X defines higher-dim. manifold: Calabi-Yau manifold

⟶ 7-branes replaced by singularities in geometry X

- 7-branes carry physical theories: Constructing models of particle physics

Classification of particle physics

Goal: Use F-theory to

- Directly construct semi-realistic theories of particle physics.

➡ **Application:** construction of MSSM, Pati-Salam & trinification models

M.Cvetic, D.K., D.Mayorga-Pena, P.Oehlmann, J.Reuter arXiv:1503.02068

- Classify what physics is geometrically/mathematically allowed.

➡ Allowed Abelian sector (#(U(1), charges) ⟺ Rational points on elliptic curves.

M.Cvetic, A.Grassi, D.K., H.Piragua, P.Song: arXiv:1303.6970, arXiv: 1306.3987, arXiv:1307.6425, arXiv:1310.0463, M.Cvetic, D.K., H.Piragua, W. Taylor arXiv:1507.05954.

➡ Allowed discrete groups (Z_n groups) ⟺ Tate-Shafarevich group.

D.K.,D.Mayorga-Pena,P.Oehlmann,J.Reuter,H.Piragua arXiv:1408.4808 M.Cvetic,R.Donagi,D.K., H.Piragua, M.Poretschkin arXiv1502.06953

} Number theory

➡ Exotic matter representations ⟺ Novel math-construction of singularities (non-UFD rings): extended Kodaira classification

D.K., W. Taylor: arXiv:1604.01030; D.K., D.Morrison, N. Raghuram, W. Taylor: in progress

Summary and Outlook

1. <u>Geometry / Physics:</u>

- Classify physics of effective theories of String Theory using F-theory.
- Construct wide class of vacua of String Theory in one framework.
- Rich reciprocal interplay between physics / math:

Physical questions ⟺ New geometrical structure

2. <u>Conceptual questions:</u>

- Defining data of F-theory: CY X, G_4-flux, Hitchin system on discriminant locus of Calabi-Yau X, T-branes / gluing branes, matrix factorization, generalization of categories… ?
- Microscopics of F-theory: D3-branes, M2-branes, (p,q)-webs…?

Quantum Geometry

Daniel Krefl

based on

0: arXiv: 1105.0630
(with Aganagic, Cheng, Dijkgraaf & Vafa)

I: arXiv: 1311.0584
II: arXiv: 1410.7116
III: arXiv: 1605.00182 ←

Quantum Geometry ?

Quantum Geometry

Classical geometry:

$$\Sigma : f(x,p) = 0$$

Quantum Geometry

Classical geometry:

$$\Sigma : f(x,p) = 0$$

$\in \mathbb{C}^2$ or $(\mathbb{C}^*)^2$

Algebraic curve (not necessarily polynomial)

Classical geometry:

$$\Sigma : f(x,p) = 0$$

May depend on auxiliary parameters z_i

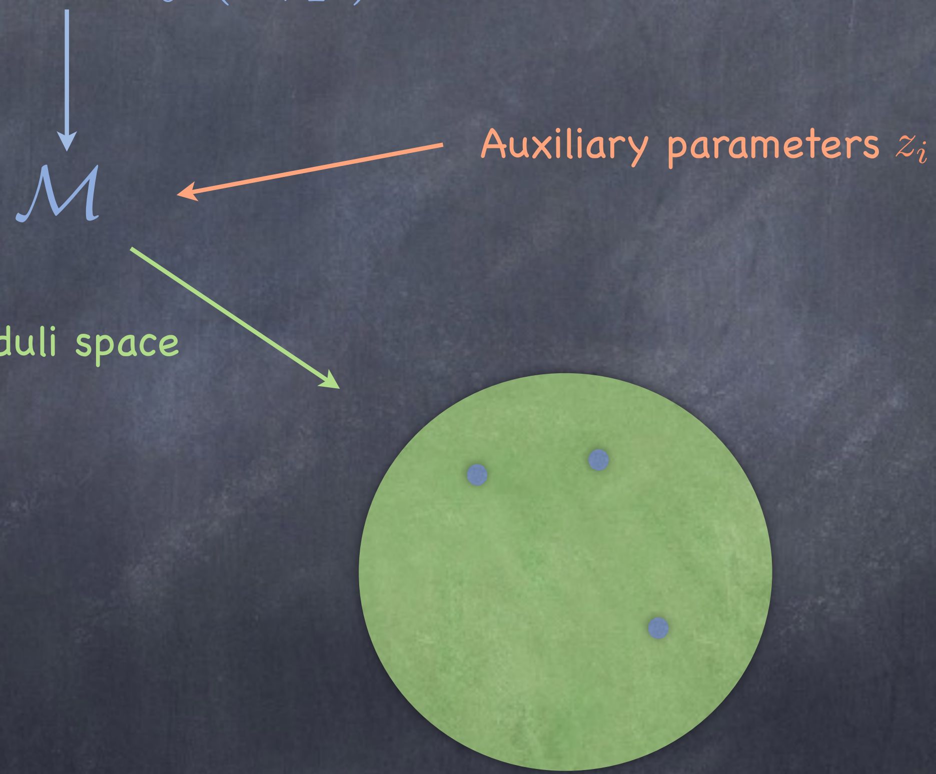
$\in \mathbb{C}^2$ or $(\mathbb{C}^*)^2$

Algebraic curve (not necessarily polynomial)

Quantum Geometry

Classical geometry:

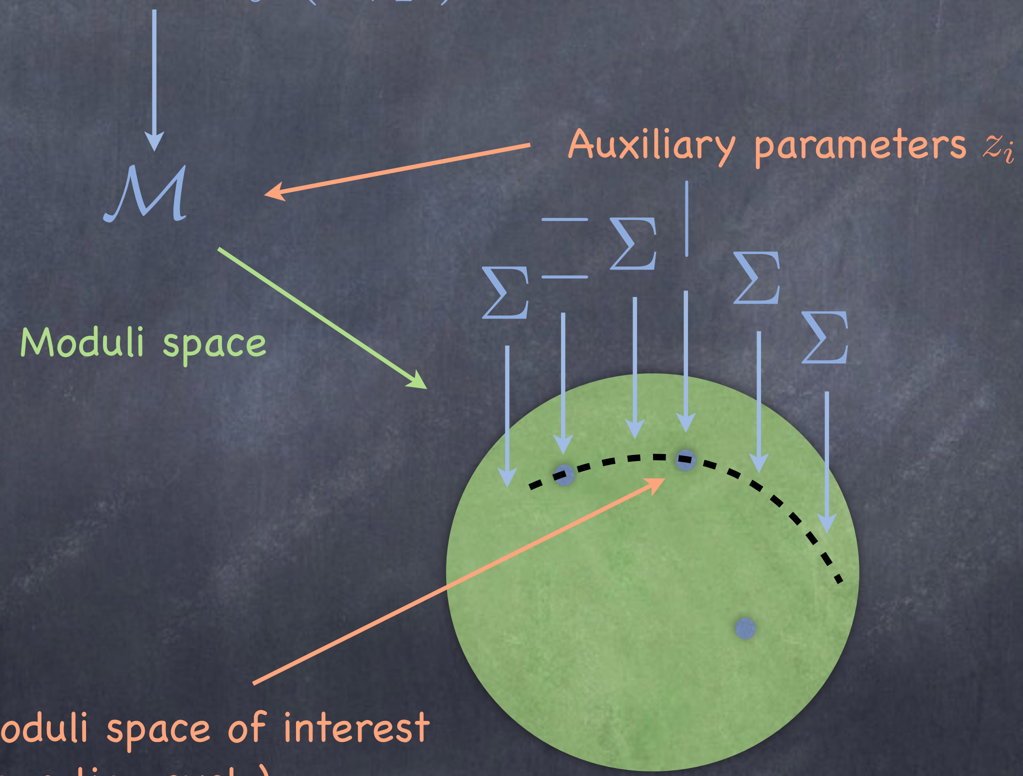
$$\Sigma : f(x,p) = 0$$



Quantum Geometry

Classical geometry:

$$\Sigma : f(x,p) = 0$$



Quantum Geometry

Classical geometry:

$$\Sigma : f(x,p) = 0$$

$$\downarrow$$

$$\mathcal{M}$$

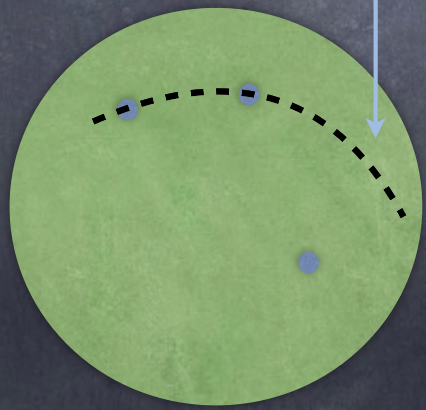
Prepotential (free energy)

$$\mathcal{F}_0(z)$$

"Geometrification" of physics

Prime example:

- Seiberg-Witten solution of $\mathcal{N} = 2$ supersymmetric gauge theories in 4d



$$\Pi(z) = \oint d\lambda$$

(meromorphic) 1-form

Quantum Geometry

Classical geometry:

$$\Sigma : f(x,p) = 0$$

$$\downarrow$$

$$\mathcal{M}$$

→ "Geometrification" of physics

Conceptually identical for:

- Topological strings on toric Calabi-Yaus
- Matrix Models
- ...

Quantum Geometry:

$$\Sigma : f(x,p) = 0$$

Perform canonical quantization, i.e., $[x,p] = i|\hbar|e^{i\theta} \in \mathbb{C}$

Quantum Geometry

Quantum Geometry:

$$\Sigma : f(x,p) = 0$$

Perform canonical quantization, i.e., $[x,p] = i|\hbar|e^{i\theta} \in \mathbb{C}$
(with right ordering prescription as for quantum integrable systems)

$\Sigma \to \widehat{\Sigma}$

$$\widehat{\Sigma} : \widehat{f}\,\Psi(x) = 0$$

General solution: $\Psi(x) = \sum_i c_i \Psi^{(i)}(x)$

Quantum Geometry

Quantum Geometry:

$$\widehat{\Sigma} : \widehat{f}\,\Psi(x) = 0$$

Remark:

In general this is *not* just ordinary quantum mechanics

- Can be differential or difference operator of higher order
- Lives intrinsically in the complex domain

Quantum Geometry

Quantum Geometry:

$$\widehat{\Sigma} : \widehat{f}\,\Psi(x) = 0$$

Key observation:

The wave-function defines a quantum differential:

$$dS \sim \partial_x \log \Psi$$

Note: A priori no unique differential

↓

Quantum periods $\Pi = \oint dS$

→ "Quantum" free energy

Quantum Geometry

Quantum Geometry:

$$\widehat{\Sigma} : \widehat{f}\,\Psi(x) = 0$$

Astonishingly, the so constructed quantum free energies have (perturbative) physical realisations [see our `11 work]

Key observation:

The wave-function defines a quantum differential:

$$dS \sim \partial_x \log \Psi$$

Note: A priori no unique differential

↓

Quantum periods $\Pi = \oint dS$

→ "Quantum" free energy

Quantum Geometry

Quantum Geometry:

$$\widehat{\Sigma} : \widehat{f}\,\Psi(x) = 0$$

Astonishingly, the so constructed quantum free energies have (perturbative) physical realisations [see our `11 work]

Key point:

This definition of quantum differential, and so free energy, is intrinsically *non-perturbative* !

→ Yields a non-perturbative definition (or completion) to physical partition functions

Quantum Geometry

Quantum Geometry:

$$\widehat{\Sigma} : \widehat{f}\,\Psi(x) = 0$$

Astonishingly, the so constructed quantum free energies have (perturbative) physical realisations [see our `11 work]

Key point:

This definition of quantum differential, and so free energy, is intrinsically *non-perturbative* !

→ Yields a non-perturbative definition (or completion) to physical partition functions

Quantum Geometry

Quantum Geometry:

$$\widehat{\Sigma} : \widehat{f}\,\Psi(x) = 0$$

Key point:

This definition of quantum differential, and so free energy, is intrinsically *non-perturbative* !

Caveat:

Need to understand the exact solutions of generalized quantum mechanical systems

Quantum Geometry

Quantum Geometry:

$$\widehat{\Sigma} : \widehat{f}\,\boxed{\Psi(x)} = 0$$

Key point:

This definition of quantum differential, and so free energy, is intrinsically *non-perturbative* !

Caveat:

Need to understand the exact solutions of generalized quantum mechanical systems

↑

One of the main topics of my more recent and current research projects !

Quantum Geometry

Quantum Geometry:

$$\widehat{\Sigma} : \widehat{f}\,\Psi(x) = 0$$

Key point:

This definition of quantum differential, and so free energy, is intrinsically *non-perturbative* !

Caveat:

Need to understand the exact solutions of generalized quantum mechanical systems

↑

One of the main topics of my more recent and current research projects !

Significant progress has been achieved in recent years. (Resurgence, etc.)

Quantum Geometry:

$$\widehat{\Sigma} : \widehat{f}\,\Psi(x) = 0$$

Example to illustrate the subtleties one may encounter:

$$p^2 + \omega^2 x^2 = E$$

$$\longrightarrow \quad \hat{f} : \frac{\partial^2}{\partial x^2} - \kappa^2 x^2 + \frac{E}{\hbar^2}$$

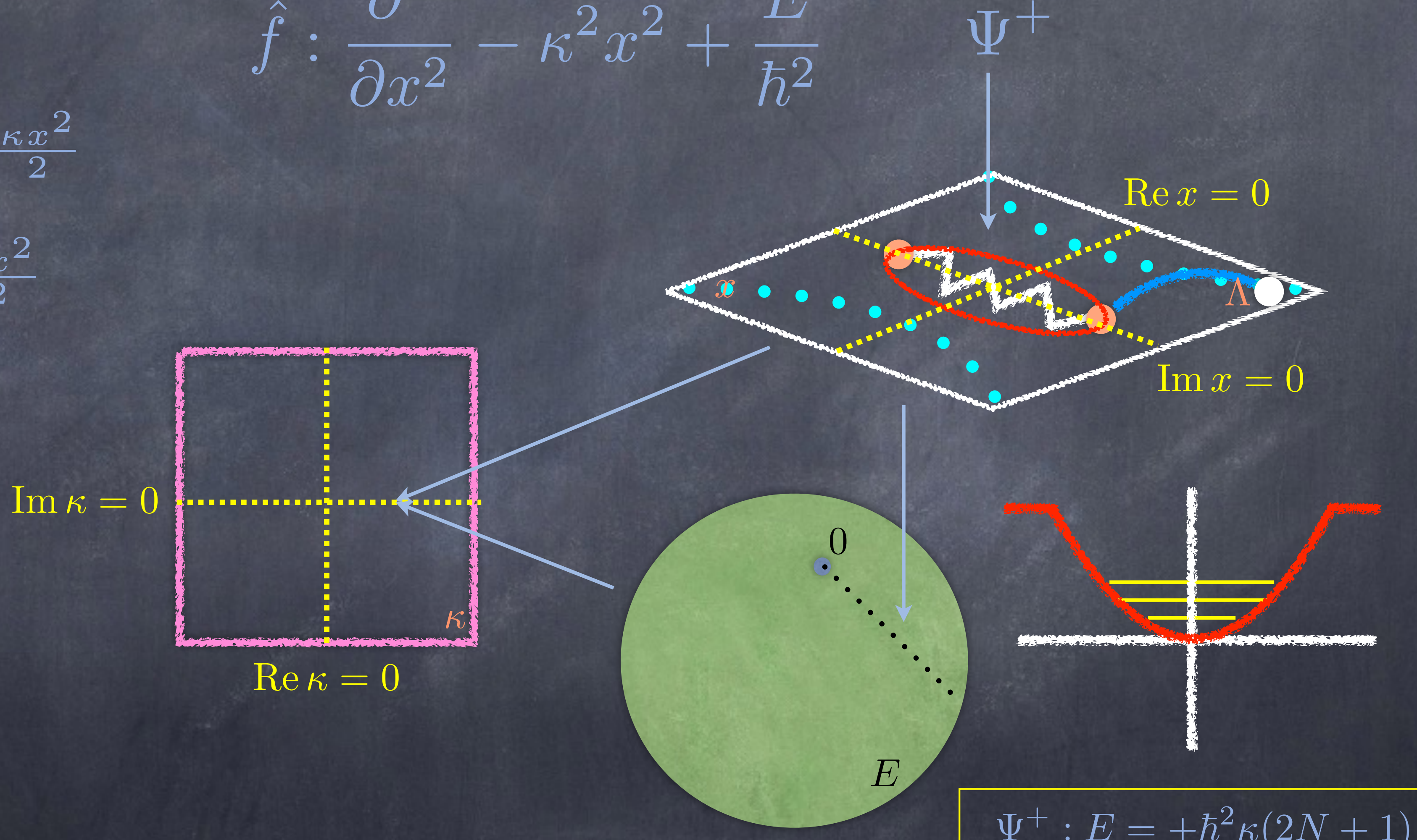
Quantum Geometry

Example:

$$\hat{f} : \frac{\partial^2}{\partial x^2} - \kappa^2 x^2 + \frac{E}{\hbar^2}$$

$$\Psi^+ \sim e^{-\frac{\kappa x^2}{2}}$$

$$\Psi^- \sim e^{\frac{\kappa x^2}{2}}$$



$$\Psi^+ : E = +\hbar^2 \kappa (2N + 1)$$

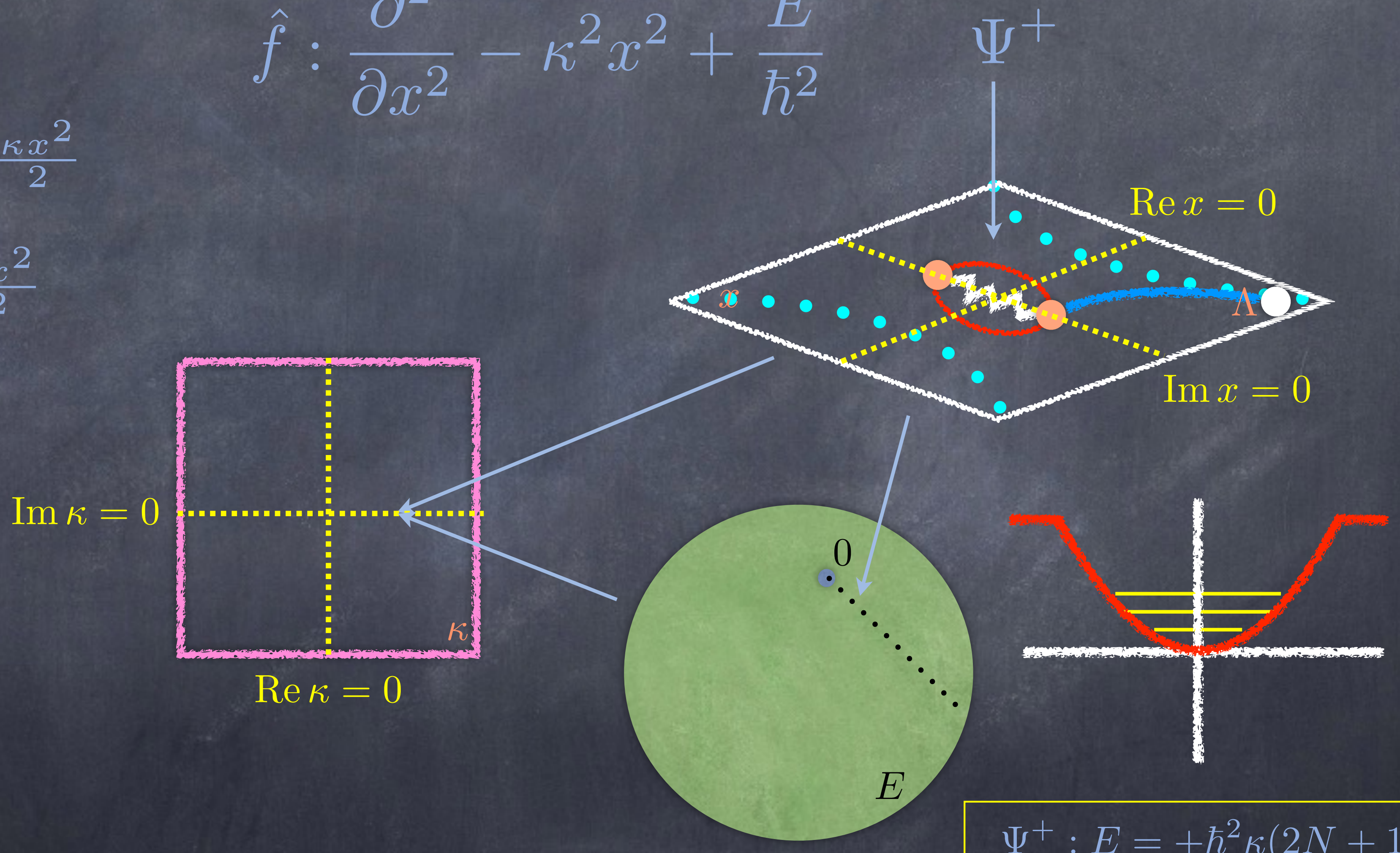
Quantum Geometry

Example:

$$\hat{f} : \frac{\partial^2}{\partial x^2} - \kappa^2 x^2 + \frac{E}{\hbar^2}$$

$$\Psi^+ \sim e^{-\frac{\kappa x^2}{2}}$$

$$\Psi^- \sim e^{\frac{\kappa x^2}{2}}$$



$$\Psi^+ : E = +\hbar^2 \kappa (2N+1)$$

Quantum Geometry

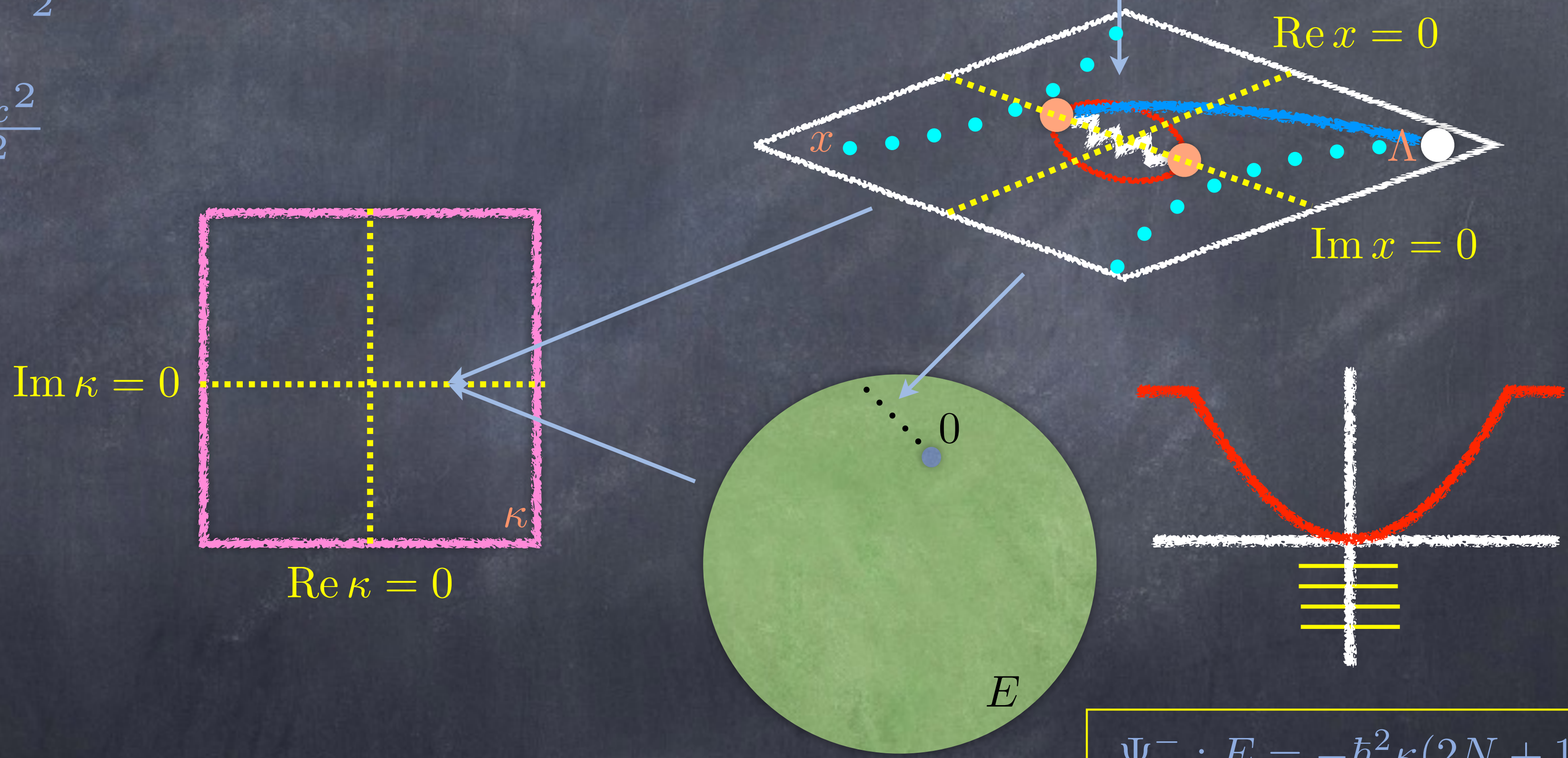
Example:

$$\hat{f} : \frac{\partial^2}{\partial x^2} - \kappa^2 x^2 + \frac{E}{\hbar^2}$$

$$\Psi^+ \sim e^{-\frac{\kappa x^2}{2}}$$

$$\Psi^- \sim e^{\frac{\kappa x^2}{2}}$$

Ψ^-



$$\Psi^- : E = -\hbar^2 \kappa (2N + 1)$$

Quantum Geometry

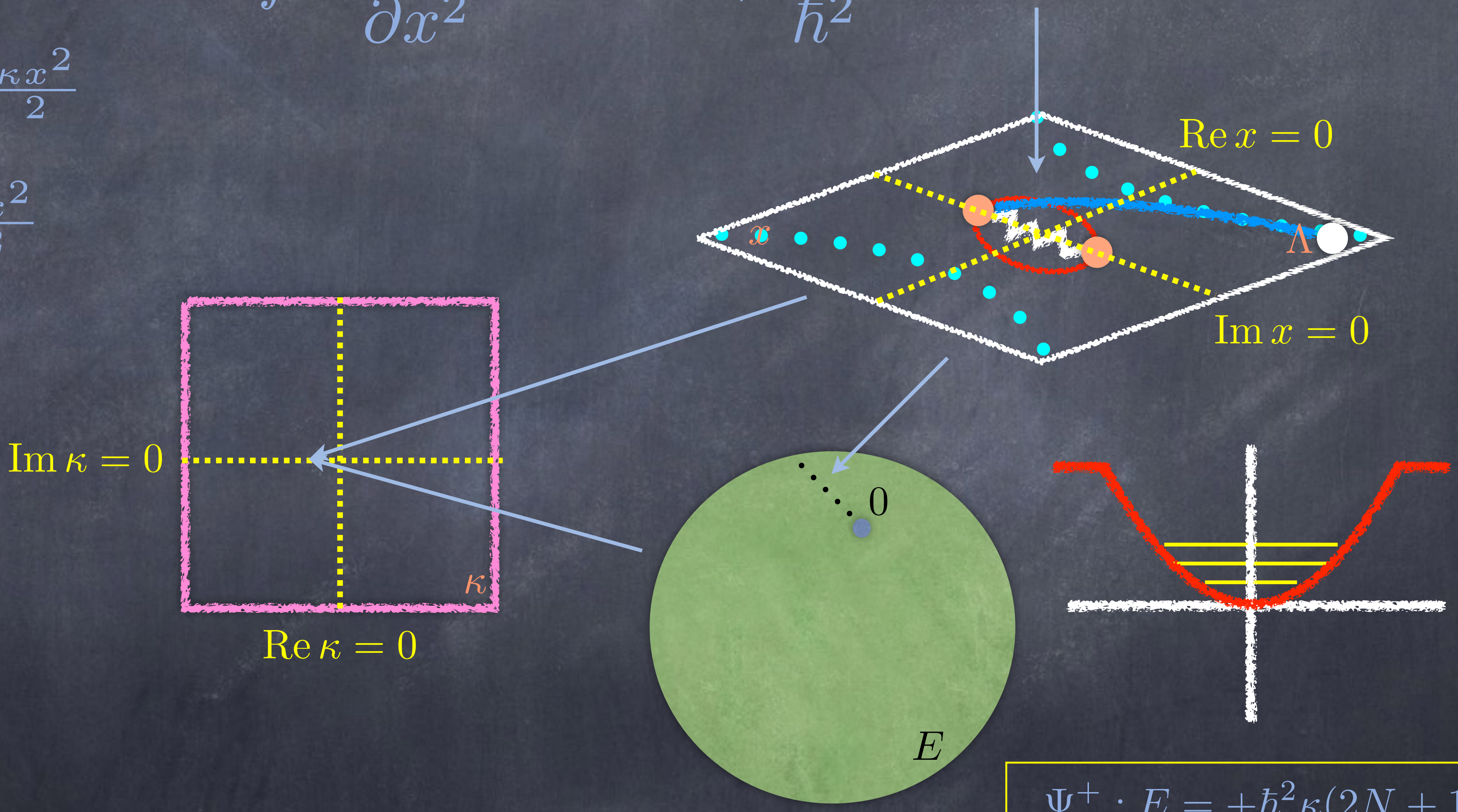
Example:

$$\hat{f} : \frac{\partial^2}{\partial x^2} - \kappa^2 x^2 + \frac{E}{\hbar^2}$$

$$\Psi^+ \sim e^{-\frac{\kappa x^2}{2}}$$

$$\Psi^- \sim e^{\frac{\kappa x^2}{2}}$$

Ψ^+



$$\Psi^+ : E = +\hbar^2 \kappa (2N + 1)$$

Quantum Geometry

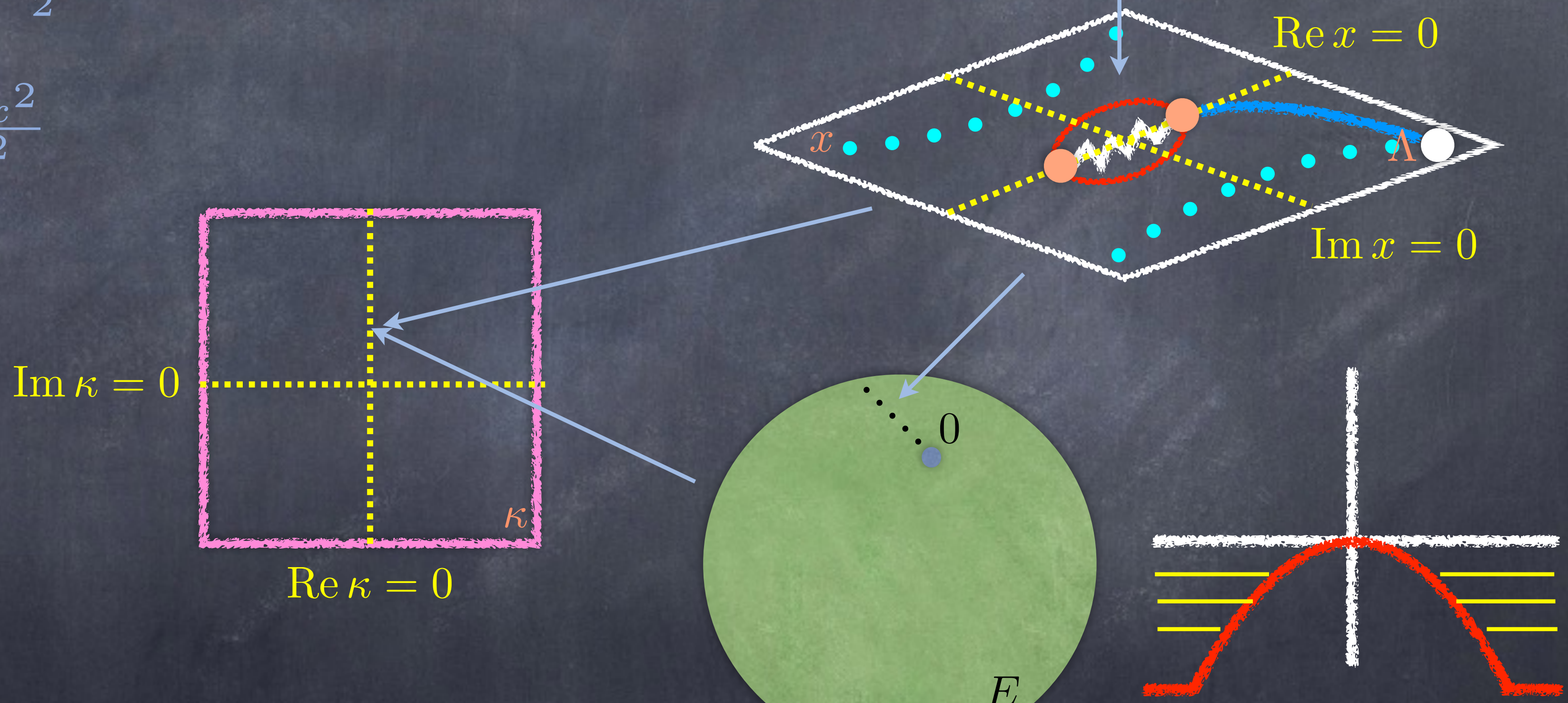
Example:

$$\hat{f} : \frac{\partial^2}{\partial x^2} - \kappa^2 x^2 + \frac{E}{\hbar^2}$$

$$\Psi^+ \sim e^{-\frac{\kappa x^2}{2}}$$

$$\Psi^- \sim e^{\frac{\kappa x^2}{2}}$$

Ψ^-



$$\Psi^- : E = -\hbar^2 \kappa (2N + 1)$$

Quantum Geometry

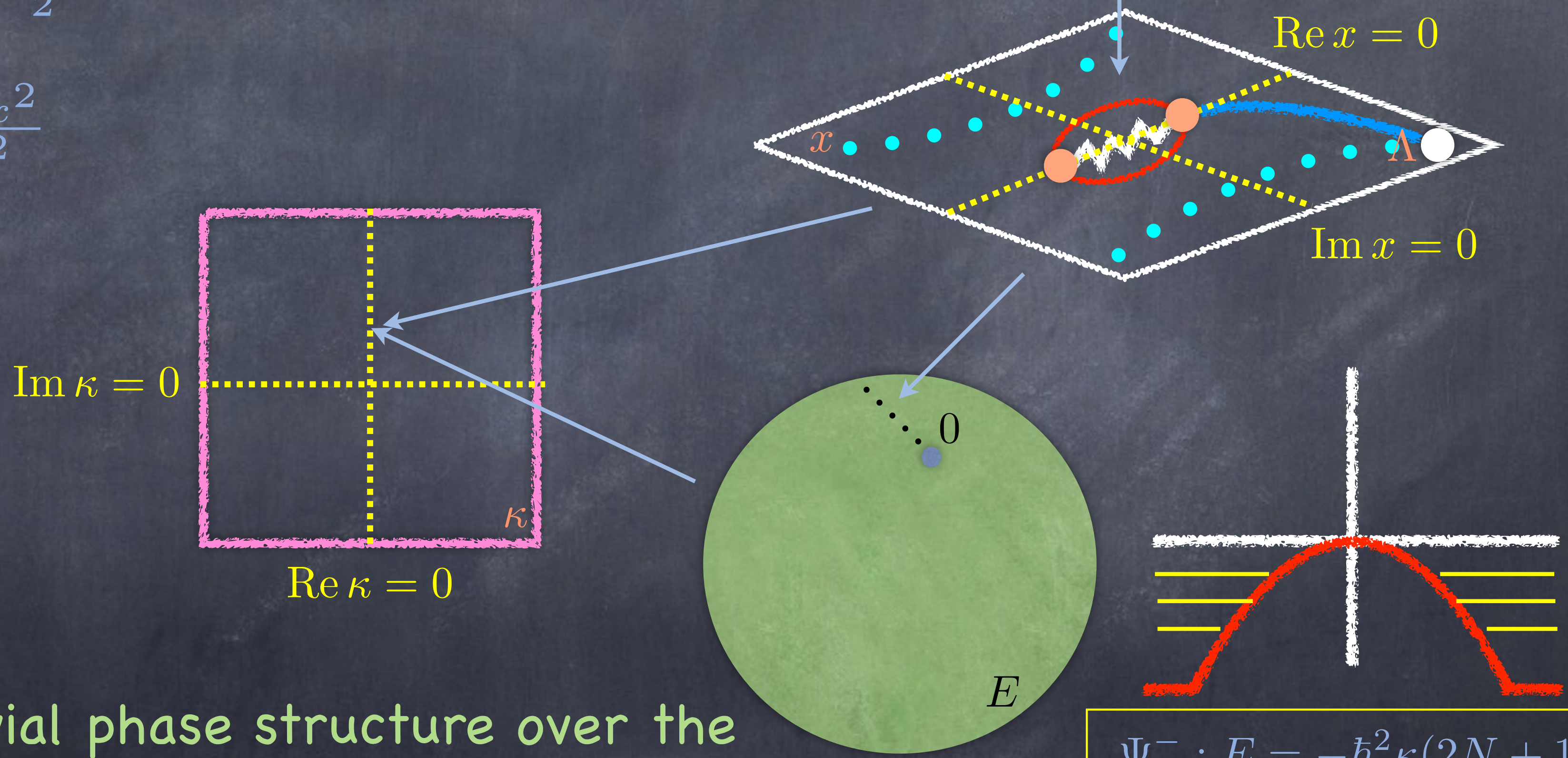
Example:

$$\hat{f} : \frac{\partial^2}{\partial x^2} - \kappa^2 x^2 + \frac{E}{\hbar^2}$$

$$\Psi^+ \sim e^{-\frac{\kappa x^2}{2}}$$

$$\Psi^- \sim e^{\frac{\kappa x^2}{2}}$$

Ψ^-



→ Non-trivial phase structure over the extended moduli space !

$$\Psi^- : E = -\hbar^2 \kappa (2N + 1)$$

Quantum Geometry

→ Quantum periods & free energy

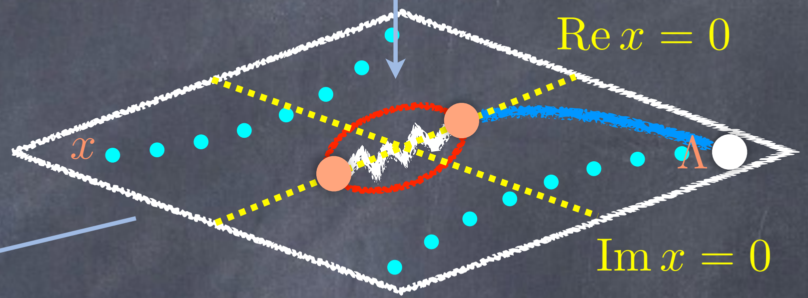
Example:

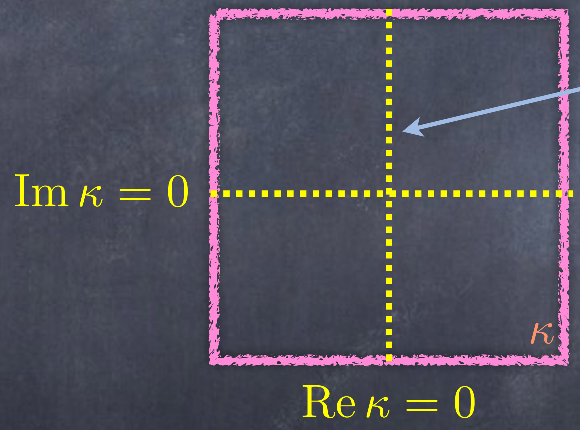
$$\hat{f} : \frac{\partial^2}{\partial x^2} - \kappa^2 x^2 + \frac{E}{\hbar^2}$$

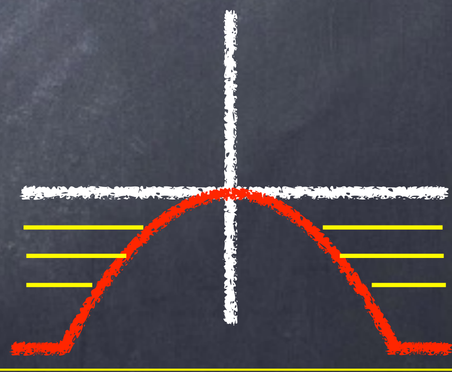
Ψ^-

$$\Psi^+ \sim e^{-\frac{\kappa x^2}{2}}$$

$$\Psi^- \sim e^{\frac{\kappa x^2}{2}}$$







$$\Psi^- : E = -\hbar^2 \kappa (2N+1)$$

→ Non-trivial phase structure over the extended moduli space !

Quantum Geometry

Example:

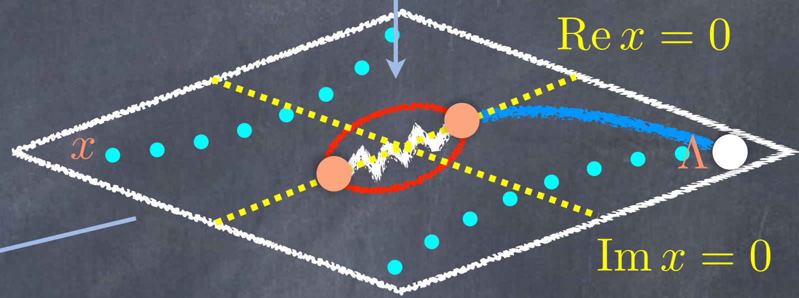
→ Quantum periods & free energy

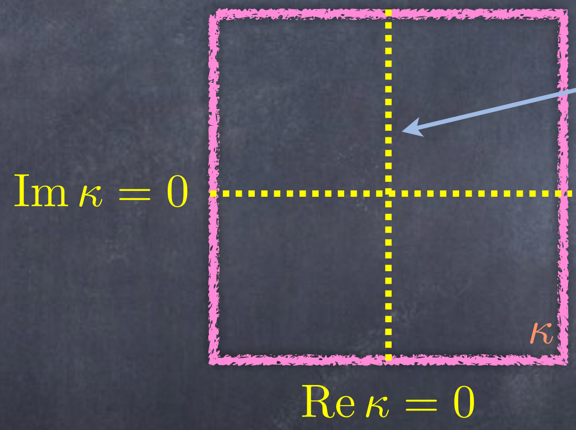
$$\hat{f} : \frac{\partial^2}{\partial x^2} - \kappa^2 x^2 + \frac{E}{\hbar^2}$$

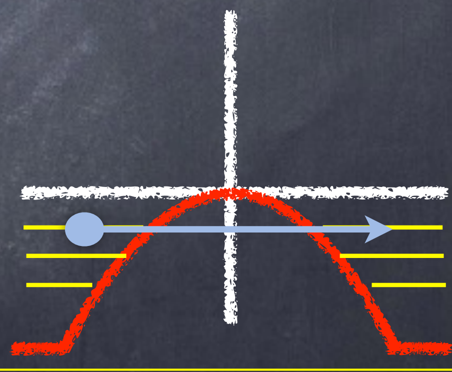
Ψ^-

$$\Psi^+ \sim e^{-\frac{\kappa x^2}{2}}$$

$$\Psi^- \sim e^{\frac{\kappa x^2}{2}}$$







$$\Psi^- : E = -\hbar^2 \kappa (2N + 1)$$

→ Non-trivial phase structure over the extended moduli space !

Quantum Geometry

→ Quantum periods & free energy

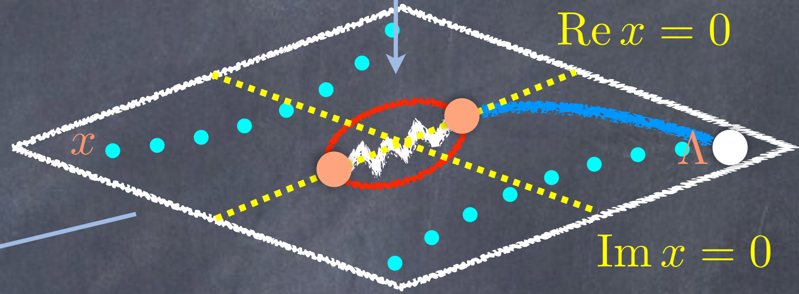
Example:

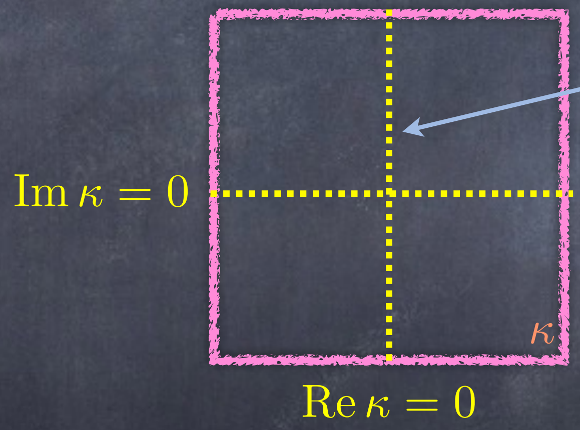
$$\hat{f} : \frac{\partial^2}{\partial x^2} - \kappa^2 x^2 + \frac{E}{\hbar^2}$$

Ψ^-

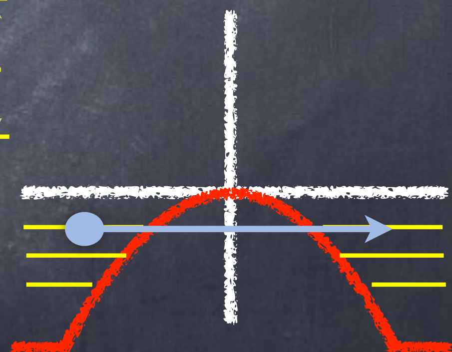
$$\Psi^+ \sim e^{-\frac{\kappa x^2}{2}}$$

$$\Psi^- \sim e^{\frac{\kappa x^2}{2}}$$





New effects like for example band splitting occur !



$$\Psi^- : E = -\hbar^2 \kappa (2N+1)$$

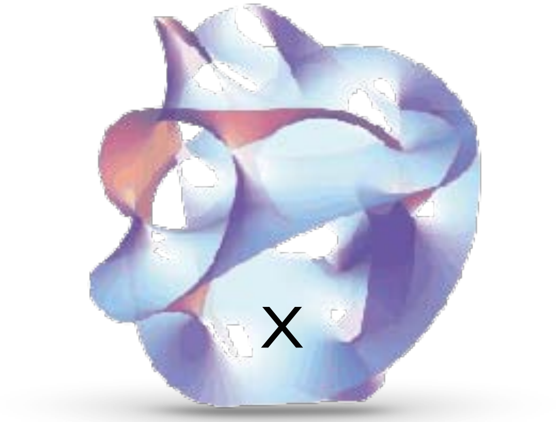
→ Non-trivial phase structure over the extended moduli space !

… Thank you …

Quantum Geometry of Strings & Branes

Physics motivation: string compactifications to 4d

Typical brane + flux configuration on a Calabi-Yau space X:



closed string (bulk) moduli t

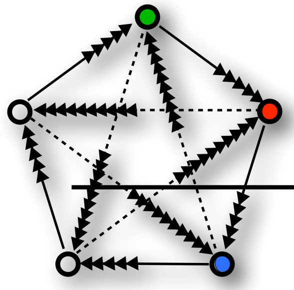
open string (brane location + bundle) moduli u

3+1 dim world volume with effective N=1 SUSY theory

What are the **exact** effective superpotential, the vacuum states, gauge couplings (general F-terms), etc, as functions of moduli ?

$$\mathcal{W}_{\mathrm{eff}}(\Phi, t, u) \; = ?$$

....well developed geometrical techniques mostly for non-generic brane configurations (non-compact, -intersecting) branes only !
(mirror symmetry, localization, integrable matrix models...)



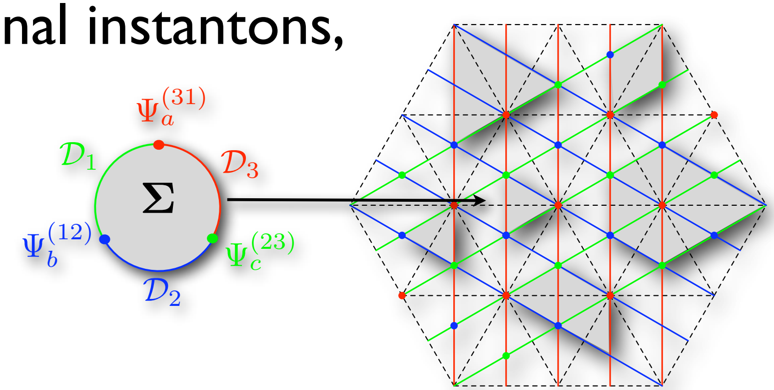
Open-String Amplitudes and D-branes

Generic amplitudes are highly non-trivial, esp. for intersecting branes (quivers)

$$\mathcal{W}_{eff}(T,u,t) = T_aT_bT_c \underbrace{\langle \Psi_a^{(A,B)}\Psi_b^{(B,C)}\Psi_c^{(C,A)}\rangle}_{C_{abc}(t,u)} + T_aT_bT_cT_d \underbrace{\langle \Psi_a^{(A,B)}\Psi_b^{(B,C)}\Psi_c^{(C,D)}\Psi_d^{(D,A)}\rangle}_{C_{abcd}(t,u)} + \ldots$$

Disk correlator counts polygonal instantons, weighted by area

$$C_{abc} \sim e^{-S_{\rm inst}} \sim q^{\Delta_{abc}} + \ldots..$$

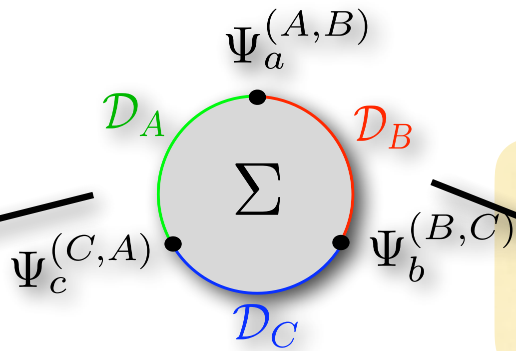


There is an **infinitely** richer diversity of world-sheet instantons, and "Gromov-Witten" invariants, as compared to closed string

However, almost nothing of that sort has ever been computed!

D-branes: Homological Mirror Symmetry

- **Math. framework**: HMS (Kontsevich): map complicated problem (A-model, Fukaya category) to simpler one (B-model, category of coh. sheaves)

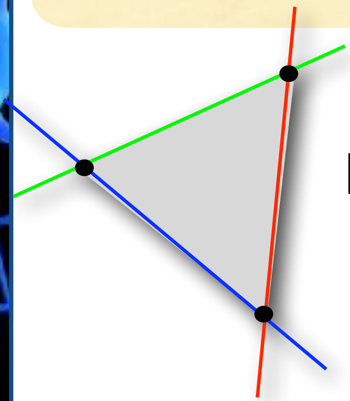


A-Model

localizes on holomorphic maps: world-sheet instantons $\Sigma \to X$

B-Model

localizes on constant maps: classical



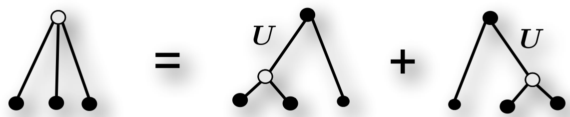
Fukaya products

$$C_{abc} \sim e^{-S_{\rm Inst}}$$

$$S_{\rm Inst.} \sim {\rm Area}$$

mirror symmetry

Massey products



$$\lambda_m(\Psi^{\otimes m}) = \Psi_{a_0} C^{a_0}_{a_1 \ldots a_m}$$

- **Phys. framework**: B-model = boundary LG model based on matrix factorizations

$$Q(x) \cdot Q(x) = W_{LG}(x)\,1$$

generates infinitely many new GW invariants

Ricardo Monteiro

Area: QFT and Strings

CERN Theory retreat

November 3, 2016

Career

Education

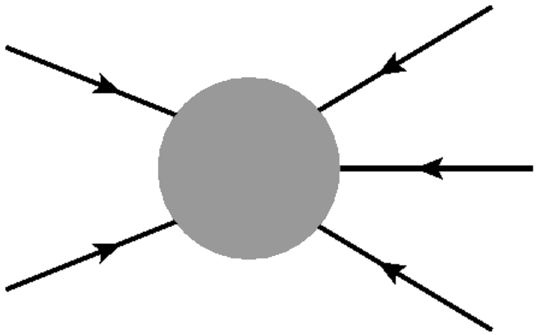
- 2005 – Degree in IST, Lisbon
- 2010 – Master and PhD in DAMTP, Cambridge

Employment

- 2010-13 – Niels Bohr Institute, Copenhagen
- 2013-15 – Mathematical Institute, Oxford
- 2015 – CERN

Current work

Scattering amplitudes of gauge theory and gravity.



Motivation

- Perturbative gravity, UV behaviour?
- Gravity versus gauge theory?
- Feynman diagrams hard. New formulations of QFT?

Gravity $\sim$ YM ^{2}

[with O'Connell, White, ...]

Free fields

- polarisations: $\epsilon_\mu \, \tilde{\epsilon}_\nu = \varepsilon_{\mu\nu}$ (graviton + dilaton + B-field)

Amplitudes

- Einstein-Hilbert action: infinite number of horrible vertices!
- **double copy** $\mathcal{A}_{\text{grav}}(\varepsilon_i^{\mu\nu}) \sim \mathcal{A}_{\text{YM}}(\epsilon_i^{\mu}) \times \mathcal{A}_{\text{YM}}(\tilde{\epsilon}_i^{\mu}) \Big|_{\text{colour stripped}}$
- most efficient using the colour-kinematics duality [Bern, Carrasco, Johansson]

Q: Kinematic algebra? Loop level?

Classical solutions

Q: Extends to exact solutions? Yes!

E.g. Schwarzschild $\sim$ (Coulomb)^2 , Taub-NUT $\sim$ (dyon)^2 .

General map? Applications?

Worldsheet models of QFTs

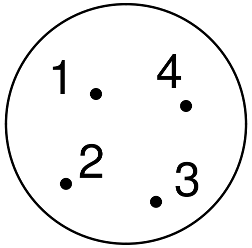
[with Geyer, Mason, Tourkine, ...]

Scattering equations

$$\sum_{j\neq i} \frac{k_i \cdot k_j}{\sigma_i - \sigma_j} = 0, \quad \forall i$$

[Cachazo, He, Yuan]

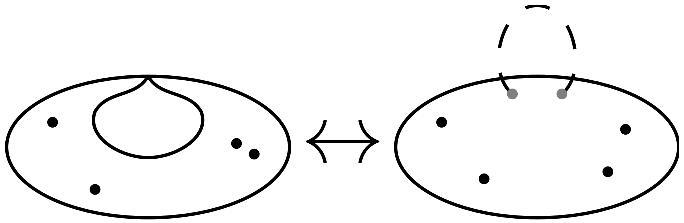
Map: kinematic invariants (massless) $\rightarrow$ points σ_i on S^2



New formulas $\mathcal{A} = \int d\mu\, \mathcal{I}(\sigma_i) = \sum_{\text{solutions } \{\sigma_i\}} A(\sigma_i)$

Amplitudes are worldsheet correlators of
ambitwistor string theories [Mason, Skinner]
(upgrade on Witten's twistor string theory)

$$\mathcal{A} = \left\langle \prod_{i=1}^{n} V_i \right\rangle$$



Q: Loop level? Progress up to two loops!
Q: Other observables, e.g. correlators?
Wednesday seminar next week!

Boris Pioline

- Staff since June 2011, on leave from CNRS, LPTHE, Paris
- Formal / mathematical aspects of string theory
  - Higher loop amplitudes in string theory
  - String dualities, instanton calculus
  - Black hole precision counting, wall-crossing...
  - Math applications: automorphic forms, algebraic geometry...
- Co-organizer of the Tuesday String Seminar
- Co-organizer of the CERN Winter School on Strings and Fields since 2012, *mark the next edition: 6-10 Feb 2017 !*

Slava Rychkov

Whereabouts:

- ENS Paris Oct 2016-Mar 2017 & Oct 2017-Mar 2018
- CERN in between and after

Research programs:

- Quantum Field Theory at Strong Coupling
  (Hamiltonian truncation)

- Conformal Field Theory in D≥3
  (Conformal bootstrap)

Member of Simons Collaboration on Non-perturbative bootstrap
(funded 2016)

Current Research activities

Marine Samsonyan

03 November 2016

- *2007–2011 Ph.D. on "Non-perturbative aspects of gauge and string theories and their holographic relations " at University of Rome "Tor Vergata" .*
- *2014–2017 Post Career Break Fellow at CERN*

$\mathcal{N} = 2$ *mass and* Ω *deformed theories*

With C. Angelantonj and I. Antoniadis

$$\mathcal{N} = 4 \xleftarrow[m \to 0]{} \mathcal{N} = 2^* \xrightarrow[m \to \infty]{} \mathcal{N} = 2$$

The $4D$ *and* $5D$ *theories with massive adjoint hypermultiplet are UV complete.*
For $U(1)$ *the instanton partition function has a compact form.*

$$\mathcal{F} = \mathcal{F}_{class} + \mathcal{F}_{1-loop} + \mathcal{F}_{inst}$$

We constructed

- $4D$ *and* $5D$ $U(1)$ $\mathcal{N}=2^*$
  by placing a single $D5$*-brane on* $\mathcal{M}_{1,3}\times S^1_m\times S^1_R\times\mathbb{C}^2/\mathbb{Z}_N$
- $4D$ *and* $5D$ $U(1)$ $\mathcal{N}=2^*$, $\epsilon_1=-\epsilon_2=\hbar$
  $\mathcal{A}_g=\left\langle (V^+_{\mathrm{grav}})^2\,(V^-_{\mathrm{grav}})^2\,V^{2g-2}_{\mathrm{gph}}\right\rangle$
- $4D$ *and* $5D$ $U(1)$ $\mathcal{N}=2^*$ *for general* ϵ_1 *and* ϵ_2
  $\mathcal{A}_{g,n}=\left\langle (V^+_{\mathrm{grav}})^2\,(V^-_{\mathrm{grav}})^2\,V^{2g-2}_{\mathrm{gph}}V^{2n}_{S'_+}\right\rangle$

Next:

- *Instantons*
  Construct in string theory, compute the amplitudes and take the field theory limit
- $\mathcal{N} = 2$ *with hypermultiplets in other representations*

Supercurrents in Supergravity

With S. Ferrara and A. van Proeyen

Understanding the Supercurrents multiplet in the presence of gravity.
We derived

- *Simplified expression for the supercurrent and its conservation in curved* $\mathcal{N} = 1, D = 4$ *superspace using the superconformal approach.*

$$\bar{\mathcal{D}}^{\dot{\alpha}} E_{\alpha\dot{\alpha}} = -\bar{\mathcal{D}}^{\dot{\alpha}} \mathcal{J}_{\alpha\dot{\alpha}} = X_0^3 \mathcal{D}_\alpha R'$$

with $R' = \frac{1}{X_0^2} \bar{D}^2 \bar{X}_0 = W - \frac{1}{3} S W_S - \frac{1}{3} \bar{D}^2 \left(\frac{\Delta K}{X_0^2} \bar{X}_0 \right)$

- *The trace of (super)Einstein equation and the coupling to conformal matter is presented*
  $E_{\alpha\dot{\alpha}} = -2(D_\alpha X_0)(\bar{D}_{\dot{\alpha}}\bar{X}_0) + 4iX_0 \overleftrightarrow{\partial}_{\alpha\dot{\alpha}}\bar{X}_0$
  and
  $\mathcal{J}_{\alpha\dot{\alpha}} =$
  $-E_{\alpha\dot{\alpha}} + 2N_{I\bar{J}}D_\alpha X^I\,\bar{D}_{\dot{\alpha}}\bar{X}^{\bar{J}} + 4\,i\left(N_I\partial_{\alpha\dot{\alpha}}X^I - N_{\bar{I}}\partial_{\alpha\dot{\alpha}}\bar{X}^{\bar{I}}\right)$
  for the Lagrangian $\mathcal{L} = N(X,\bar{X})_D + WX_0^3|_F$

Next:

- *Separate the supergravity multiplet from the matter in the case of non-conformal matter*
- *Applications to early time cosmology*

Thank you

Andreas Stergiou

2013: PhD at UC San Diego

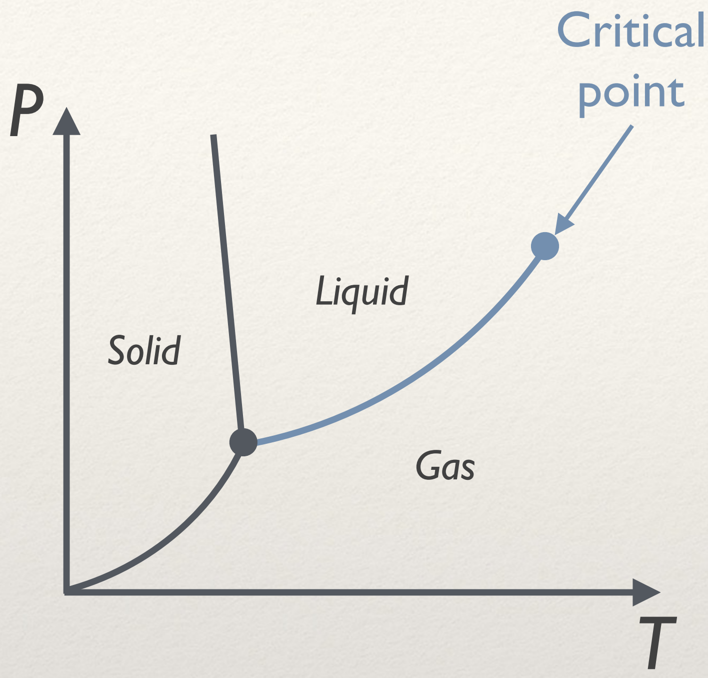
2013–2016: Yale University

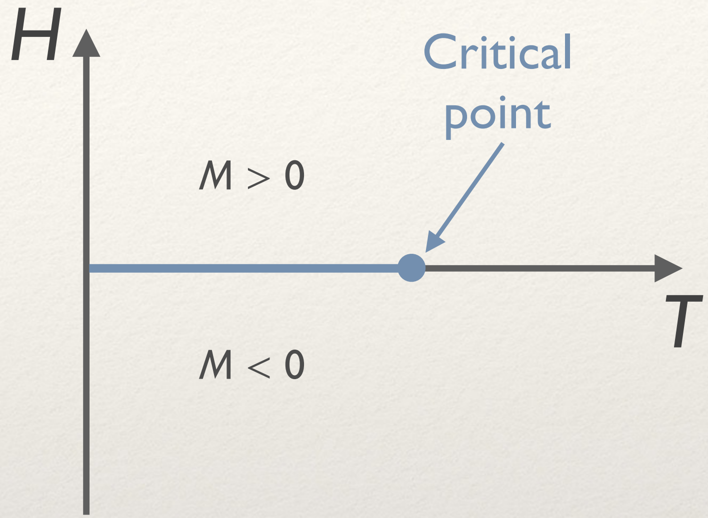
Now: New fellow at CERN

Interests:

- RG flows and CFTs
- Supersymmetry
- Strong coupling physics

Critical Phenomena





Critical Phenomena

Approach to critical points displays universality!

A theory describing gases and a theory describing magnets have the same critical exponents, for example

Compressibility	Magnetic susceptibility
$\kappa \sim (T - T_c)^{-\gamma}$	$\chi \sim (T - T_c)^{-\gamma}$

$$\gamma \approx 1.2$$

This is a reflection of the fact that at critical points only the most essential effects of interactions survive.

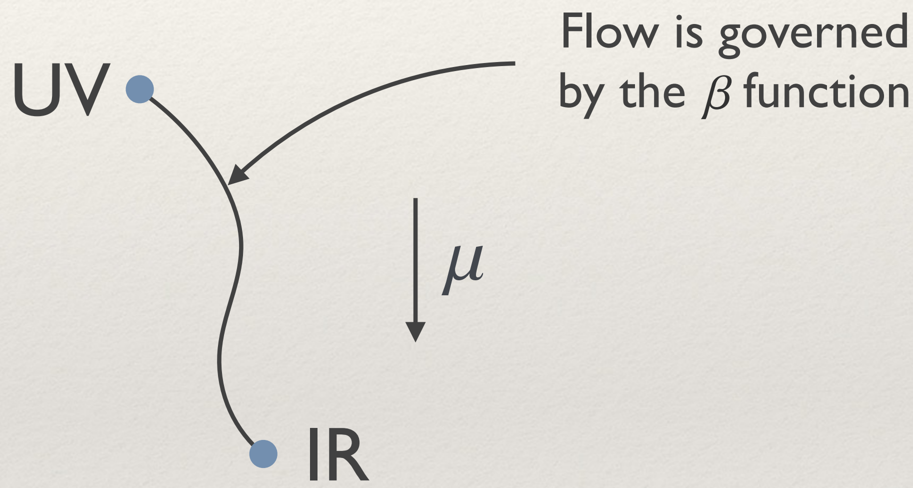
CFTs

CFTs are ubiquitous in high-energy and condensed matter physics.

They are important in the context of the AdS/CFT correspondence.

How do we study CFTs?

One way is to view CFTs as endpoints of renormalization group flows.



Conformal Bootstrap

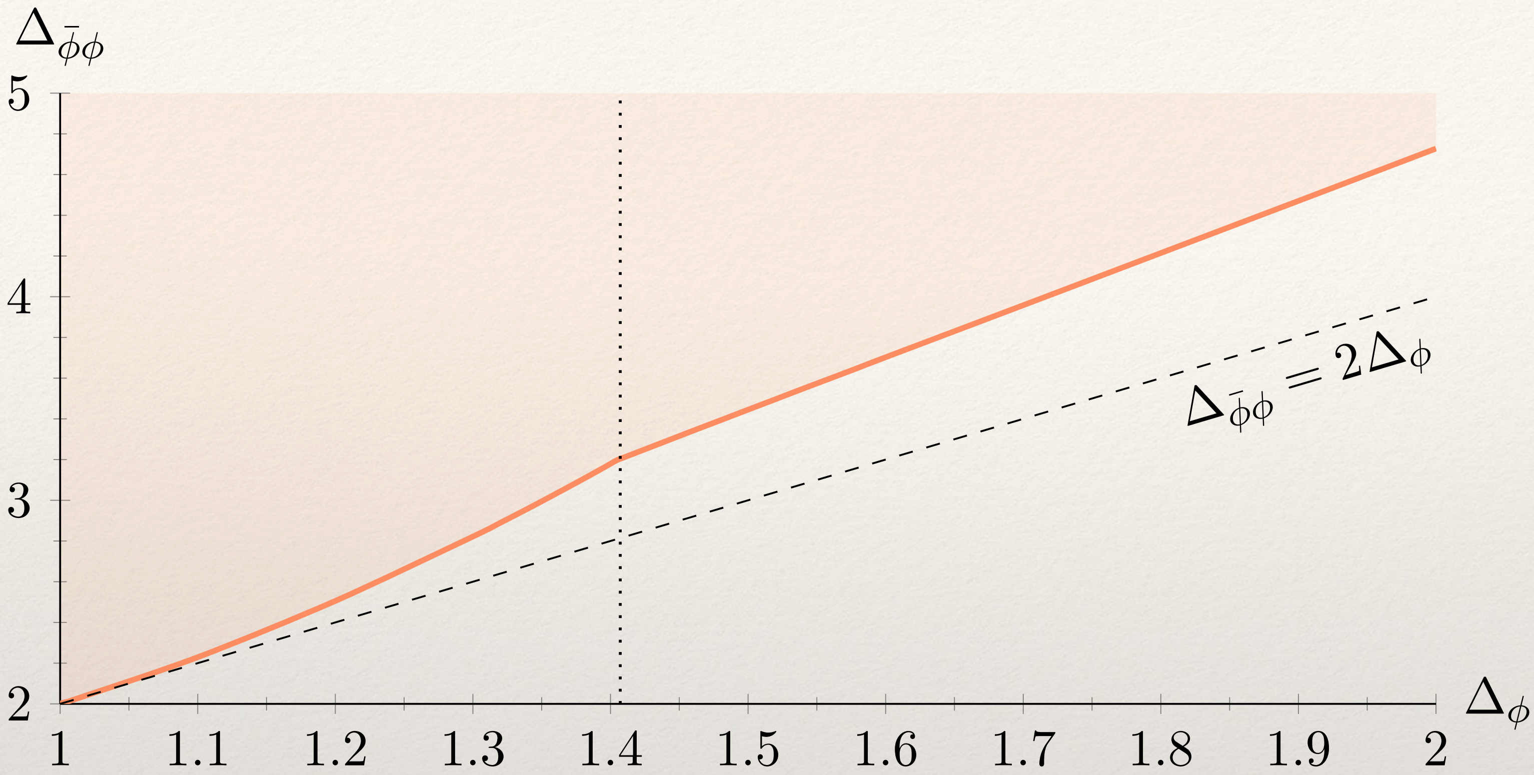
The conformal bootstrap method was first proposed by Polyakov in 1974 as a way to “solve” CFTs.

The first successful numerical implementation of the method appeared in 2008. (Rattazzi, Rychkov, Tonni & Vichi)

The numerical conformal bootstrap:

- Gives constraints on the operator spectrum and interaction strength of CFTs.
- Is non-perturbative.
- Is not specific to any theory (does not need a Lagrangian).
- Can be used in any spacetime dimension.
- Uses the power of conformal symmetry.
- Has errors that are under control.

4D $\mathcal{N}=1$ Superconformal Bootstrap



(Poland, Simmons-Duffin & Vichi, 2011)

(Poland & AS, 2015)

Other Research Interests

CFTs in higher spacetime dimensions.

Aspects of supersymmetric and superconformal theories.

AdS/CFT, black holes, and the information paradox.

Other Research Interests

CFTs in higher spacetime dimensions.

Aspects of supersymmetric and superconformal theories.

AdS/CFT, black holes, and the information paradox.

Thank you!