IAS Group Meeting: Review Of GMN Papers

Sept. 18, 2019

Outline

PUT UP BEFORE TALK

1. Introduction
2. $N=2$ $d=4$
3. Wall Crossing
4. Defects & New BPS Degeneracies
5. Hyperkähler Geometry
6. Derivation Of KSWCF
7. Important Special Case: Class S
8. Defects In Class S
9. Spectral Networks
10. W.I.P.
    a.) Categorification of WCF
    b.) Number Theory
11. Further Reading

1. Introduction

Juan asked me to give a review of a project I worked on with A. Neitzke and D. Gaiotto here at IAS from 2008-2012. There were 6 papers, 739 pages plus a minor follow-up by Gaiotto, Witten and myself - another 475 pages. No one wants to read all that, but allegedly there are some results. So I'll sketch some of what's there.

Juan didn't want one particular point, but a broad - necessarily superficial - overview. After some back and forth about what he wanted he told me he wouldn't actually be here - so blame him if this is not what *you* want!

So for these papers some of the keywords would be:

PUT UP BEFORE TALK!

$d=4$, $N=2$ field theory; BPS Spectrum; Wall-crossing; hyperkähler geometry; hyperholomorphic bundles; WKB analysis; Stokes phenomenon; M5 branes; 6d (2,0); Class S theories; Hitchin systems/Higgs bundles; Cluster coordinates; Fock-Goncharov coordinates; line & surface defects; interfaces; Spectral networks; quantum holonomy; quantized character varieties; Landau-Ginzburg models; A/B models; Categorified wall-crossing; Fukaya-Seidel cat's.

Project starts w/ BPS states + W.C. in $d=4$, $N=2$

2. Quick $d=4, \mathcal{N}=2$ review

$$\{Q^i_\alpha, \bar{Q}_{\dot\beta j}\} = 2\sigma^\mu_{\alpha\dot\beta} P_\mu \delta^i_j$$

$$\{Q^i_\alpha, Q^j_\beta\} = \epsilon_{\alpha\beta}\epsilon^{ij} \bar{Z}$$

[Do I need to explain notation?]

$$\mathcal{H}_{BPS} := \{\psi \mid H\psi = |Z|\psi\}$$

Olive + Witten '77 ; Seiberg + Witten '94

$$\mathcal{M}_{vac} = \mathcal{M}_{Higgs} \cup \cdots \cup \underbrace{\mathcal{M}_{Coulomb}}$$

broken $SU(2)_R$

Unbroken abelian gauge symmetry

U(1) VM $\quad A_\mu \quad \lambda^1_\alpha \quad \lambda^2_\alpha \quad \varphi \longrightarrow \langle\varphi\rangle$

$U(1)^r \Longrightarrow$ r-diml space of vacua (cplx)

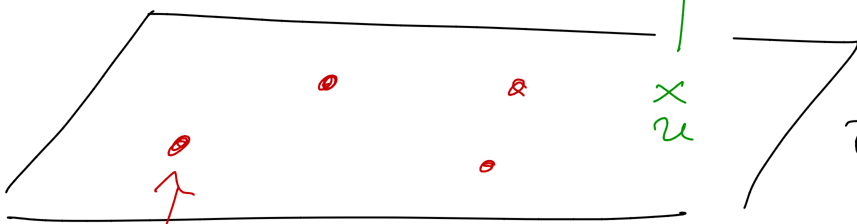
Two Basic Problems

<u>Problem 1</u>: Describe LEET on Coulomb branch.

<u>Problem 2</u>: Describe BPS spectrum

* SW '94 + 10^4 followup papers solves Problem 1 for a large class of theories
* GMN solves Problem 2 for "class S"

Γ_u = lattice of e-m charges for abelian gauge fields $\cong H_1(\Sigma_u)/\ldots$



$\mathcal{B} = \mathcal{M}_{coul}$.

$\mathcal{B}_{sing}$: Cplx codimension one: New massless particles

- $\Gamma \to \mathcal{B}^* = \mathcal{B} - \mathcal{B}_{sing}$ local system with monodromy
- $\langle \gamma_1, \gamma_2 \rangle \in \mathbb{Z}$ antisymmetric
- $\mathcal{H}_u = \bigoplus_{\gamma \in \Gamma_u} \mathcal{H}_{\gamma,u}$ $\qquad Z\big|_{\mathcal{H}_{\gamma,u}} = Z_\gamma(u)\mathbb{1}$

$$Z_{\gamma_1+\gamma_2} = Z_{\gamma_1} + Z_{\gamma_2}$$

$N=2, d=4 \Rightarrow$

$\boxed{\text{Functions } Z_\gamma \text{ completely determine LEET.}}$

Discovery of Seiberg-Witten + follow up:

For a large class of $d=4, \mathcal{N}=2$ field theories

$$\exists \text{ holo family } (\underset{\substack{\uparrow \\ \text{R.S.}}}{\Sigma_u}, \underset{\substack{\uparrow \\ \text{mero 1-form}}}{\lambda_u})$$

s.t. $$\Gamma = H_1(\Sigma_u, \mathbb{Z}) \quad (2)$$

$$Z_\gamma(u) = \oint_\gamma \lambda_u$$

$\Longrightarrow$ Solution to Problem 1, BUT

I do not know a general construction of (Σ_u, λ_u) for a general $d=4, \mathcal{N}=2$ field theory.

<u>Problem 2</u>:

$$\mathcal{H}_u = \bigoplus \mathcal{H}_{\gamma,u}$$

$$\cup$$

$$\mathcal{H}_{BPS,u} = \bigoplus_\gamma \mathcal{H}_{BPS,\gamma,u}$$

Give explicit construction of $\mathcal{H}_{BPS,\gamma,u}$.

3. WALL CROSSING

$\mathcal{H}_{BPS,\gamma}$ depend on $u \in \mathcal{B}$

They can change discontinuously for two reasons:

1.) VM + HM BPS reps pair up to become nonBPS.

2.) Wall-crossing.

(1) $\Rightarrow$ study index: "protected spin character"

$$\Omega(\gamma; y; u) = \frac{1}{y - y^{-1}} \mathrm{Tr}_{\mathcal{H}_{BPS,\gamma,u}} (2J_3)(-1)^{2J_3}(-y)^{2J_3+2I_3}$$

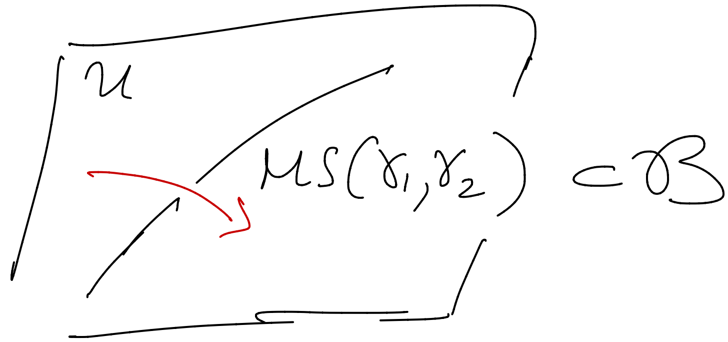
Piecewise constant — sometimes can even be identified with an index of an elliptic operator - surprise! it jumps:

$$\boxed{\text{BPS particles can form BPS boundstates}}$$

CFIV & CV 1992; Seiberg-Witten 1994

$$\gamma_1 \longleftrightarrow \gamma_2$$

$$R_{12}(u) \longrightarrow \infty$$



$$MS(\gamma_1,\gamma_2) := \{ u \mid Z_{\gamma_1} \parallel Z_{\gamma_2} \}$$

γ_1, γ_2 prim:

$$\Delta\Omega = \Omega_1 \Omega_2 \, \chi_j(y)$$

Denef Moore 2006

$$j = \frac{1}{2}\left(|\langle \gamma_1, \gamma_2 \rangle| - 1 \right)$$

γ_1, γ_2 nonprimitive: complicated boundstates —

$\exists$ complicated generalization: (2007)
"Kontsevich - Soibelman WCF" - will derive it in a nice physical way later.

To do that, and get interesting generalizations it is quite useful to broaden our perspective and introduce defects + their BPS states

4. DEFECTS & THEIR BPS STATES

- Line defects : Cod $= 3$

Preserve $\frac{1}{2} = \frac{4}{8}$ SUSY $\Longrightarrow$ CHOICE OF PHASE ζ

e.g. $$L = P\exp \int_{\{\vec{x}=0\}\times\mathbb{R}_t} \left(\zeta^{-1}\varphi + A + \zeta\bar{\varphi}\right)$$

$$\mathcal{H}_L = \bigoplus_{\gamma_L \in \Gamma + s_L} \underbrace{\mathcal{H}_{L,\gamma_L}}_{E \geq -\mathrm{Re}\left(\zeta^{-1} Z_{\gamma_L}\right)}$$

$\Longrightarrow$ New kind of BPS state:
"framed BPS state" $\Psi \in \mathcal{H}_L$ saturating bnd

Framed index:

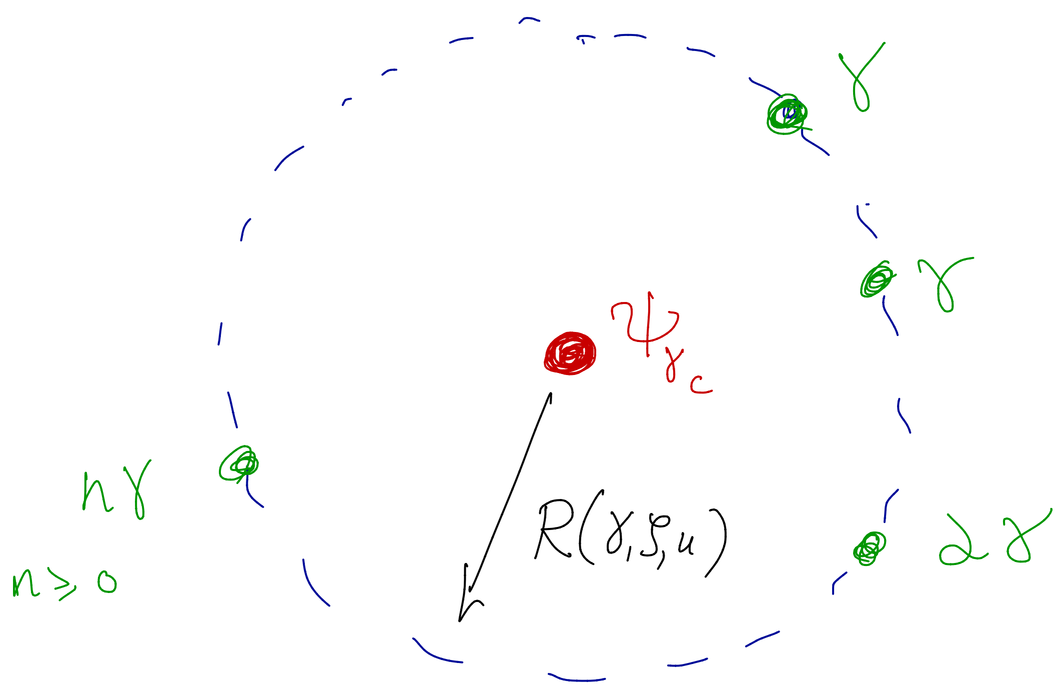
$$\overline{\underline{\Omega}}(L_\zeta, \gamma, y; u) := \mathrm{Tr}_{(\mathcal{H}_L)_{BPS,\gamma}} (-1)^{2J_3} (-y)^{2J_3 + 2I_3}$$

Also have wall-crossing – now as functions of (u, ζ)

$$W(\gamma) := \left\{ (u,\zeta) \;\middle|\; \zeta^{-1} Z_\gamma < 0 \text{ and } \mathcal{H}_{BPS,\gamma,u} \neq 0 \right\}$$

"K-wall" or "BPS wall"

near a K-wall there are halo Fock spaces :-



No interaction $\Rightarrow$ Fock space

$\psi_{\gamma_c} \in \mathcal{H}_{L_\zeta,\gamma_c,u}$

$$R(\gamma,\zeta,u) = \frac{\langle \gamma, \gamma_c \rangle}{2\,\mathrm{Im}\,(Z_\gamma(u)/\zeta)}$$

For total charge $\gamma_c + N\gamma$

$\Rightarrow$ Fock space appears/disappears across $W(\gamma)$

Surface Defects :

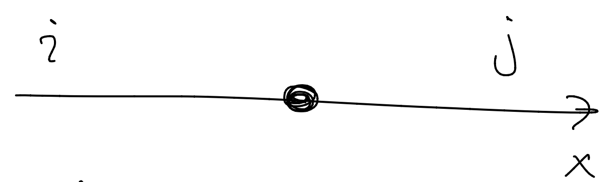
Begin with a 2d $\mathcal{N}=(2,2)$ QFT

e.g. $LG(X, W)$

X: kähler, W: holo superpotential

Massive Vacua $\quad i, j, k, \ldots \qquad dW(\phi_i) = 0$

Solitons



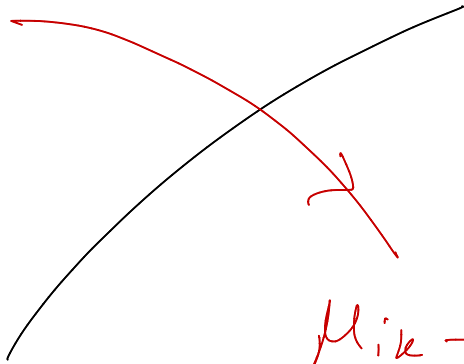
Central charge $\quad Z_{ij} = W(\phi_i) - W(\phi_j)$

index $\quad \mu_{ij} = \mathrm{Tr}_{\mathcal{H}_{ij}} (2J)(-1)^{2J} e^{-\beta H}$

Wall-crossing :

$MS(ij, jk) \subset$ Space of W's .

$$:= \{ W \mid Z_{ij} \parallel Z_{jk} \}$$



$MS(ij, jk)$

$$\mu_{ik} \longrightarrow \mu_{ik} + \mu_{ij}\mu_{jk}$$

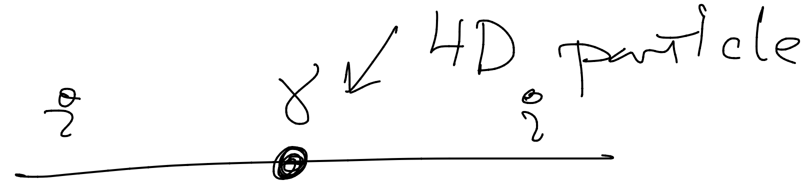
C–V '92

Now suppose 2d $\mathcal{N}=(2,2)$ QFT has continuous Lie group global G symmetry: Embed on dim $=2$ surface in $\mathbb{M}^{1,3}$ and couple to SYM with G-gauge symmetry

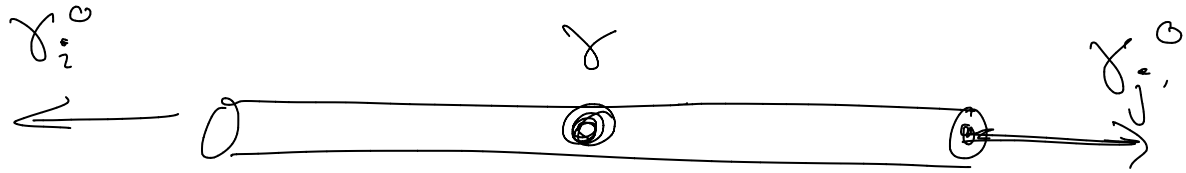
$$\mathbb{M}^{1,1}_{t,x} \times \{(y,z)=(0,0)\} \subset \mathbb{M}^{1,3}$$

"2d-4d system"

$\Longrightarrow$ New phenomena



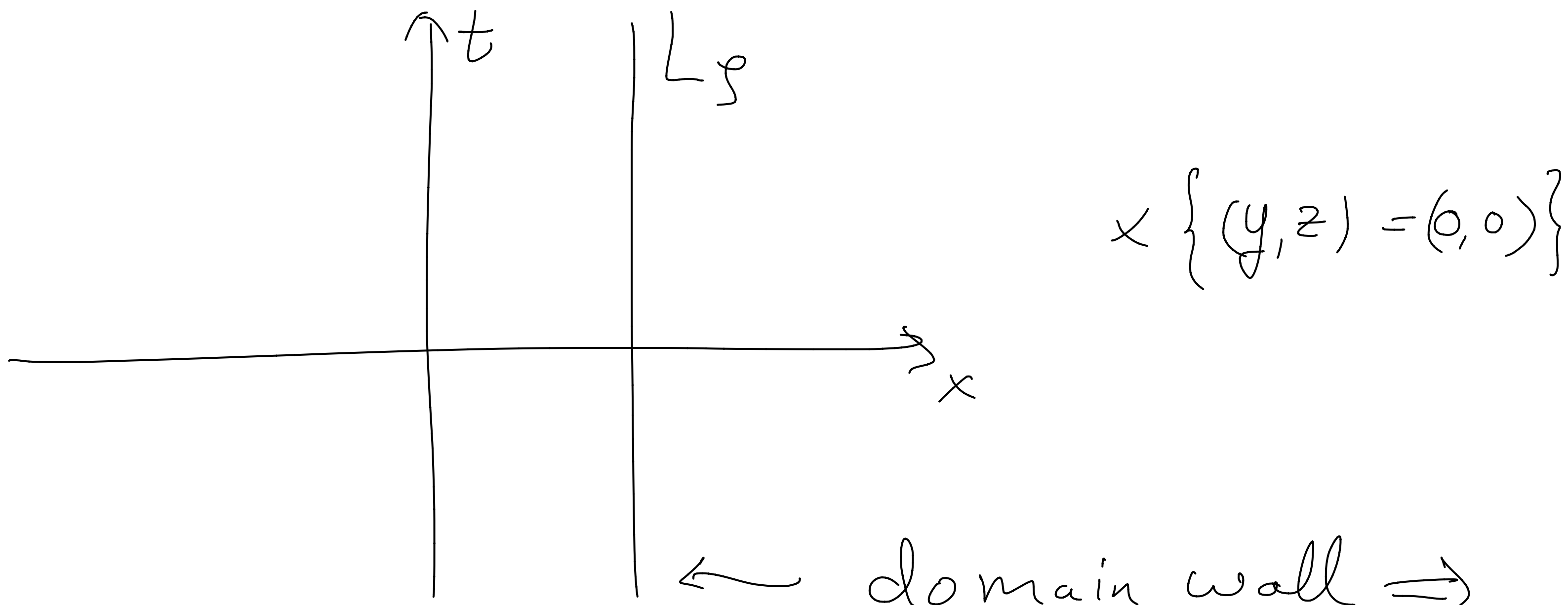
Surface defect functions like a solenoid



$\Rightarrow$ New mixed degeneracies $\omega(\gamma; \gamma_{ij}^{a})$

$\exists$ 2d4d wcf for μ_{ij}, ω

- Line defects inside surface defects



$\Rightarrow$ Framed BPS states in the context of 2d QFT: BPS states of $1/2$-susy interfaces

SCORECARD

5. Hyperkähler Geometry

Compactify : $\mathbb{M}^{1,2} \times S^1_R$

LEET: σ-model with target $\mathcal{M} \to \mathcal{B}$, $T_u \to \mathcal{B} \ni u$

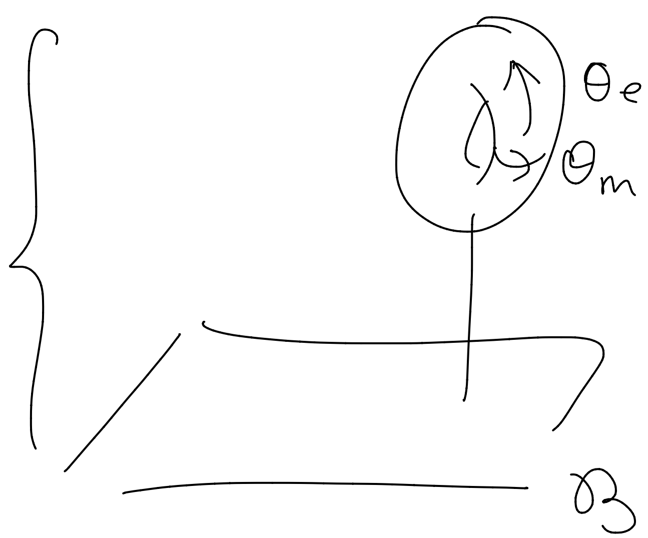
T_u = torus

$$\theta_{el} = \lim_{\vec{x}\to\infty} \oint_{S^1} A_t(\vec{x},t)\,dt$$

$d\theta_m = *_3 F$ $\quad$ θ_m = periodic scalar

$$\theta_m = \lim_{\vec{x}\to\infty} \theta_m(\vec{x})$$

$\mathcal{M}$



Poisson torus (no flavor $\Rightarrow$ Symplectic)

$\mathcal{M}$ = Space of 3D vacua has HK metric: S+W '96

Wrap line defects on S^1:

$\langle L_\wp \rangle$ is a function on $\mathcal{M}$

GMN claim:

$$\langle L_\wp \rangle(u,\theta) = \sum_{\gamma_L \in \Gamma_L} \underbrace{\overline{\Omega}(L_\wp, \gamma_L, u)}_{@\, y=-1} \mathcal{Y}_{\gamma_L}(u,\theta,\zeta)$$

$\mathcal{Y}_{\gamma_L}(u,\theta,\zeta)$ locally defined but jump as functions of (u,ζ)

$\langle L_\wp \rangle$ has no wall-crossing

$\overline{\Omega}$ has wall-crossing, due to halo Fock spaces,

$\Longrightarrow$ (u,ζ) crosses W_γ:

$$\mathcal{Y}_{\gamma_L} \longrightarrow \left(1+\sigma_\gamma \mathcal{Y}_\gamma\right)^{\langle \gamma,\gamma_L\rangle \Omega(\gamma)} \mathcal{Y}_{\gamma_L}$$

$$:= K_\gamma^{\Omega(\gamma)} \mathcal{Y}_{\gamma_L}$$

Cluster-like tmn: KS tmn.

S.C. limit: $R \to \infty$, $u \to \infty$

$$\mathcal{Y}_\gamma(u,\theta,\zeta) \sim \underbrace{\exp\left(\frac{R Z_\gamma}{\zeta} + i\theta\cdot\gamma + R\zeta\bar{Z}_\gamma\right)}_{:= \mathcal{Y}_\gamma^{sf}}$$

These two conditions essentially determine $\mathcal{Y}_\gamma$ as a solution to a RH problem $\Longrightarrow$

$$\log \mathcal{Y}_\gamma(u,\theta,\zeta) = \log \mathcal{Y}_\gamma^{sf}(u,\theta,\zeta)$$

$$+ \sum_{\gamma'\in\Gamma} \Omega(\gamma') \int_{-\infty}^{\infty} d\rho' \, K_{\gamma,\gamma'}(\zeta,\zeta') \cdot$$

$$\cdot \log\left[1 + \sigma_\gamma \mathcal{Y}_{\gamma'}(u,\theta,\zeta' = e^{i\alpha_{\gamma'} - \rho'})\right]$$

$$Z_{\gamma'} = e^{i\alpha_{\gamma'}} |Z_{\gamma'}|, \quad \underbrace{\sigma_\gamma \in \{\pm 1\}}_{\text{Q.R of i.p.}}$$

* The $\mathcal{Y}_\gamma$ allow the construction of the HK metric on $\mathcal{M}$:

$$\omega_\zeta^{(2,0)} = \epsilon^{ij}\, d\log \mathcal{Y}_{\gamma_i} \wedge d\log \mathcal{Y}_{\gamma_j}$$

$$= \zeta^{-1}\omega^{2,0} + \omega^{1,1} + \zeta\,\omega^{0,2}$$

$\gamma_i \sim$ basis for Γ $\Rightarrow$ $\mathcal{Y}_{\gamma_i} \sim$ Darboux coordinates

KSWCF ensures the metric is continuous across $MS(\gamma_1, \gamma_2)$

* The equation is formally identical to Zamolodchikov's TBA - noone knows why.

* $\exists$ similar statements for 2d4d. leads to constructions of hyperholo vector bundles.

* $\exists$ nice generalization of "Darboux expansion" to $y \neq -1$ $\Rightarrow$ Noncommutative geometry.

6. DERIVATION OF KSWCF

It is useful to introduce a formal line defect ver:

$$F(L_\zeta) = \sum_{\gamma_L \in \Gamma_L} \overline{\Omega}(L_\zeta, \gamma_L, y, u)\, X_{\gamma_L}$$

$$X_{\gamma_1} X_{\gamma_2} = y^{\langle \gamma_1, \gamma_2 \rangle} X_{\gamma_1 + \gamma_2}$$

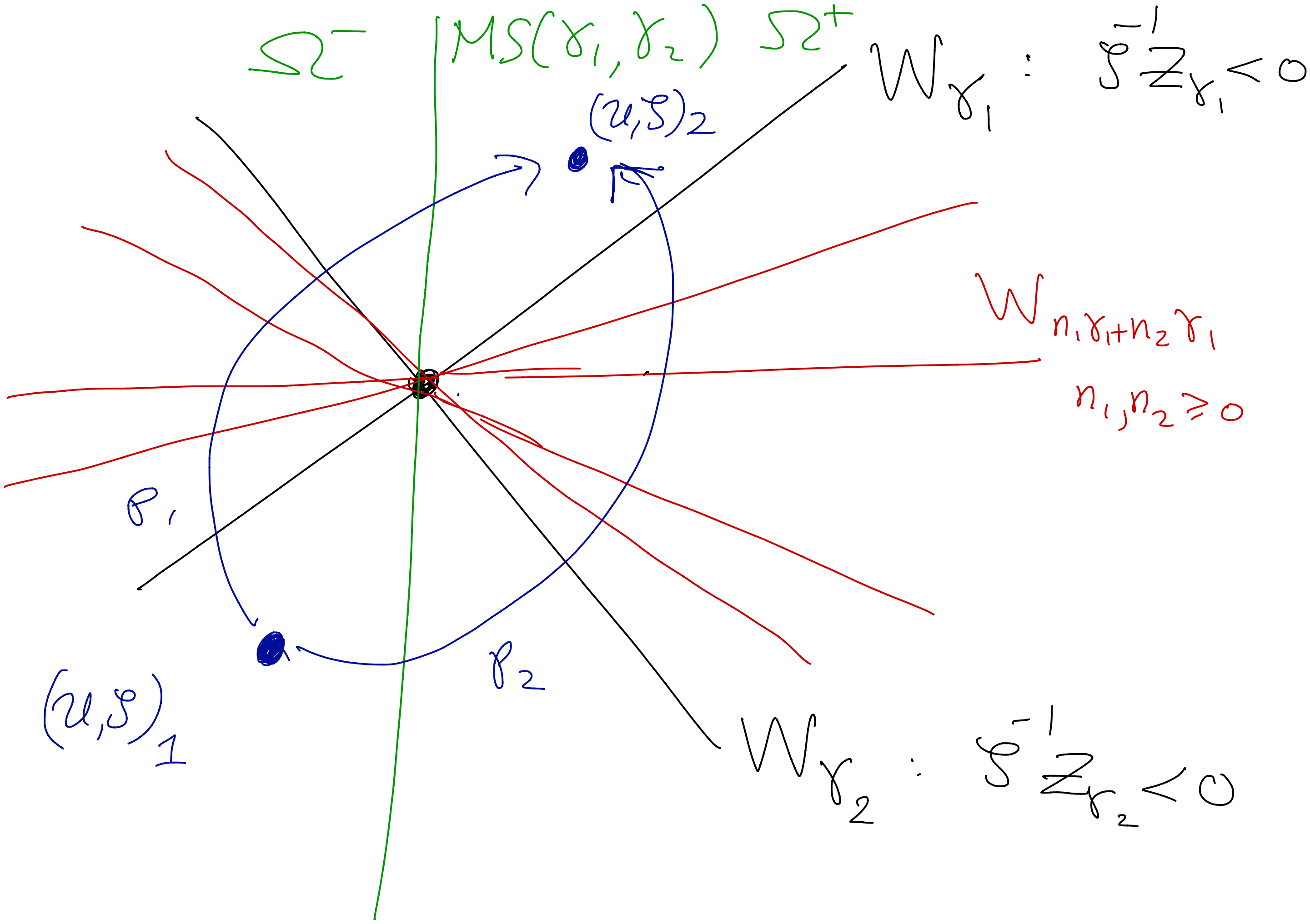
Crossing $W(\gamma)$

$$F(L_\zeta) \longrightarrow K(\gamma) F(L_\zeta) K(\gamma)^{-1}$$

Takes into account the creation/ann. of Fock spaces of BPS particles of charge $n\gamma$, $n > 0$.

example: If $\mathcal{H}_{BPS,\gamma,u}$ only HM's:

$$K(\gamma) = \prod_{k=1}^{\infty} \left(1 + y^{2k-1} X_\gamma\right)^{-\Omega(\gamma)}$$



FRAMED BPS DEG'S ONLY A FUNCTION OF POSITION $\Longrightarrow$

$\wp_1$: $\quad F(2) = K(\wp_1) F(1) K(\wp_1)^{-1}$

$\wp_2$: $\quad F(2) = K(\wp_2) F(2) K(\wp_2)^{-1}$

$$K(P_1) = K(\gamma_1) \cdots\cdots K(\gamma_2) \Big\} \text{ using } \Omega^-$$

$$K(P_2) = K(\gamma_2) \cdots\cdots K(\gamma_1) \Big\} \text{ using } \Omega^+$$

Will hold if

$$\underbrace{\overrightarrow{\prod} K(n_1\gamma_1+n_2\gamma_2)}_{\text{using } \Omega^-} = \underbrace{\overleftarrow{\prod} K(n_1\gamma_1+n_2\gamma_2)}_{\text{using } \Omega^+}$$

This is the (motivic) KSWCF.

(Unipotent property of $K(\gamma)$ rules out potential central term.)

7. Important Special Case: Class S

Here we can say much more.
It involves interesting questions associated to Hitchin systems and flat bundles on Riemann surfaces, hyperbolic geometry of 3-manifolds and more.

"S" is for six because these theories are constructed by starting with a 6d (2,0) theory. [Witten'98; GMN 2009; Gaiotto 2009]

<u>Data:</u>

$\mathfrak{g}$: A-D-E Lie algebra (or sum thereof)

C : Punctured Riemann surface

D : "defect data" at the punctures
explain more below.

Physically: 6d (2,0) theory has cod = 2 ½-BPS defects. We consider theory on

$M^{1,3} \times C$ putting defects @ punctures filling $M^{1,3}$

Partial topological twist ("class S twist")

$\Rightarrow$
- independence of Kähler class of metric on C
- preservation of 8/16 susy's.

$$\lim_{A(C)\to 0} 6d[\mathfrak{g}, C, D] := \underbrace{S[\mathfrak{g}, C, D]}_{4d\ \mathcal{N}=2 \text{ theory.}}$$

Vacua of this theory are closely related to Hitchin systems:

$$\begin{tikzcd}
 & S_{6d}(\mathfrak{g}) \arrow[dl, "{C, D}"'] \arrow[dr, "S^1_R"] & \\
S[\mathfrak{g}, C, D] \arrow[dr, "S^1_R"'] & & 5d\ \text{SYM} \arrow[dl, "{C, D}"] \\
 & \begin{array}{c}\sigma\text{-model}\\ \text{target } \mathcal{M}\end{array} &
\end{tikzcd}$$

Moduli of vacua: Hitchin system

5d SYM $\Longrightarrow$ (with class $\mathcal{S}$ twist)

$\mathfrak{g}$ - gauge field A on C

φ - cplex $\mathfrak{g}$-valued 1-form on C

$$F + R^2[\varphi, \bar{\varphi}] = 0$$

$$\bar{\partial}_A \varphi := (\partial_{\bar{z}} \varphi_z + [A_{\bar{z}}, \varphi_z]) dz \wedge d\bar{z} = 0$$

Effect of defect at $z = 0$:

$$\varphi \sim \frac{r}{z} dz + \text{reg.}$$

$$A \sim \alpha \, d\theta + \text{reg}$$

$\text{Orbit}(r) \subset \mathfrak{g}_{\mathbb{C}}$ partly characterizes the defect.

Nilpotent orbits $\Rightarrow$ $\exists$ $\mathbb{C}^*$ action $\Rightarrow$ superconformal

$\exists$ important gen's with higher order poles.

$\mathcal{M}_{g,n}(C)$ — space of coupling constants

$\Gamma_{g,n,D}$ — duality group

Coulomb branch:

$$\underbrace{\{\det(\lambda \mathbb{1} - \varphi) = 0\}}_{\text{turns out to be the Seiberg–Witten curve}} \subset T^*C \qquad \lambda = p\,dq$$

turns out to be the Seiberg–Witten curve; λ = canonical SW diffl

$$\det(\mathbb{1}\lambda - \varphi) = \lambda^n + q_2 \lambda^{n-2} + q_3 \lambda^{n-3} + \cdots + q_n$$

$q_k \sim k^{th}$ diffl's. holomorphic with sings @ D

ex.

A_1: $\det(\lambda \mathbb{1} - \varphi) = \lambda^2 + q_2$

8. LINE DEFECTS IN CLASS S

Vacua of $\left(S[\mathfrak{g}, C, D] / S^1_R \right)$

$= \mathcal{M}_{Hitchin}$ with R- dependent hk metric

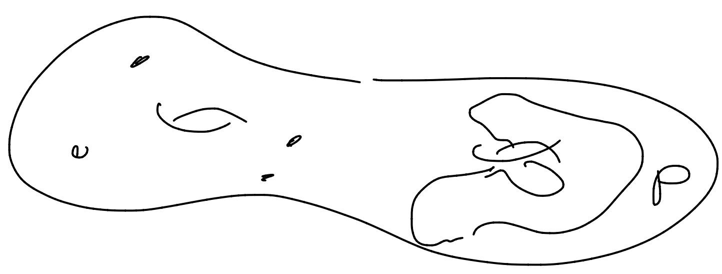
$\langle L_\zeta \rangle =$ halo function on $\mathcal{M}$ in cplx str. ζ.

$\mathcal{M}_\zeta \underset{\text{cplx mfld}}{=}$ moduli of flat $G_{\mathbb{C}}$- connections with specified "monodromy" @ punctures

$\mathcal{A} = \zeta^{-1} \varphi + A + \zeta \bar{\varphi}$ is flat.

From $(2,0)_{6d}$ theory we expect $\exists$ surface defects labeled by reps $\mathcal{R}$ of $\mathfrak{g}$. $\Rightarrow$ produce a line defect associated to closed curve $\wp \subset C$

$L_\zeta(\mathcal{R}, \wp)$



GMN argue:

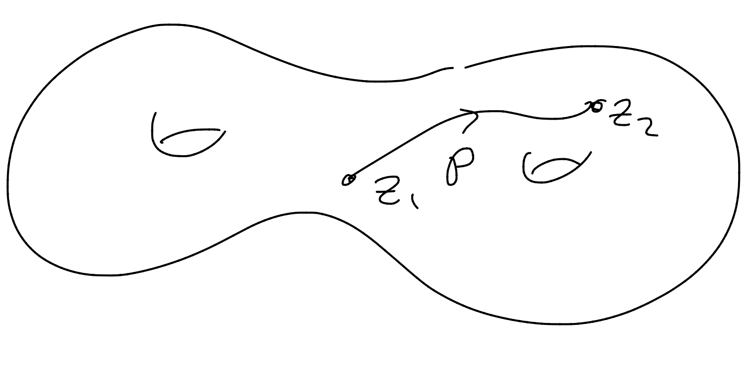
$$\langle L_{\wp}(\mathcal{R},\rho)\rangle = \mathrm{Tr}_{\mathcal{R}}\left(\mathrm{Pexp}\oint_{\rho}\mathcal{A}\right)$$

We saw that jumps in the IR/Darboux expansion of line defects lets us derive the 4d BPS spectrum.

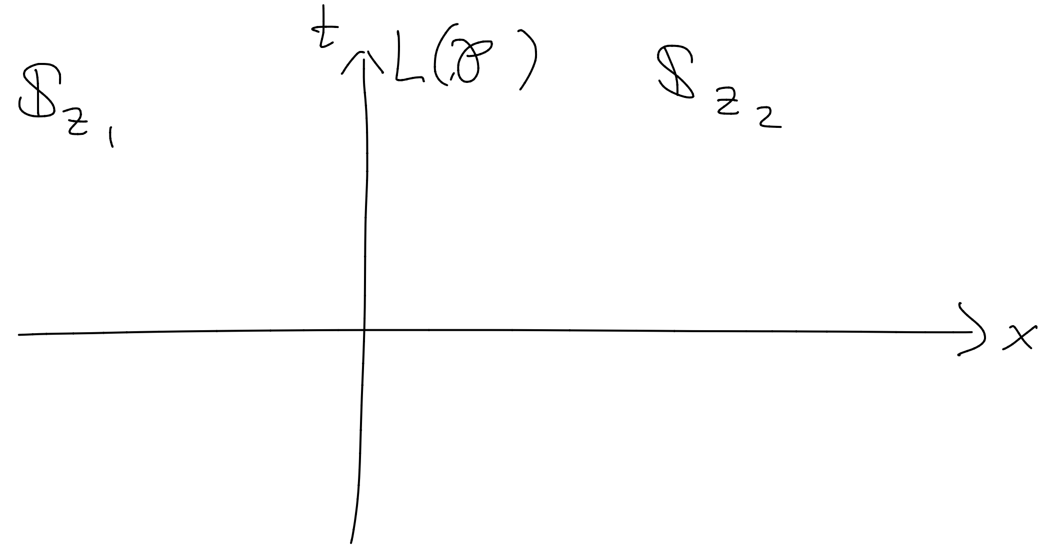
To implement that here it is useful to get at the parallel transport:

$$\mathrm{Pexp}\int_{z_1}^{z_2}\mathcal{A}$$

Putting 6d (2,0) surface defect @ $z \in C$ defines a surface defect $\mathbb{S}_z$ in 4d theory



defines an interface

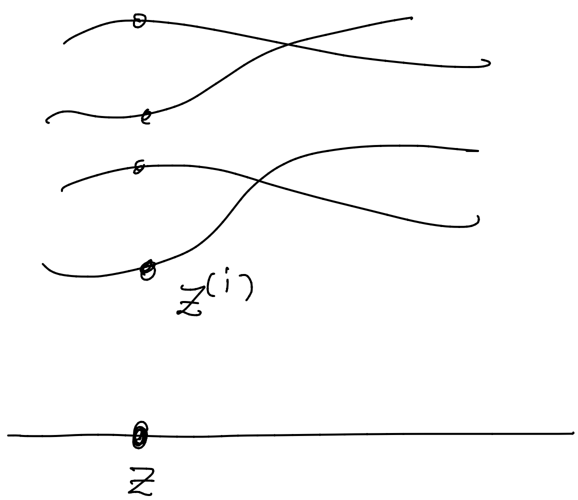


We found a way to construct $P\exp\int A$ using soliton degeneracies on $\mathbb{S}_z$:
"Spectral networks" —

leads to more math connections and in this case an explicit algorithm for computing $\Omega(\gamma)$.

9. SPECTRAL NETWORKS

Identify vacua of $\mathbb{S}_z$ with the points in the fiber $\pi : \Sigma \to C$



Solitons have a charge γ_{ij} associated to homology class of a curve $z^{(i)} \rightsquigarrow z^{(j)}$

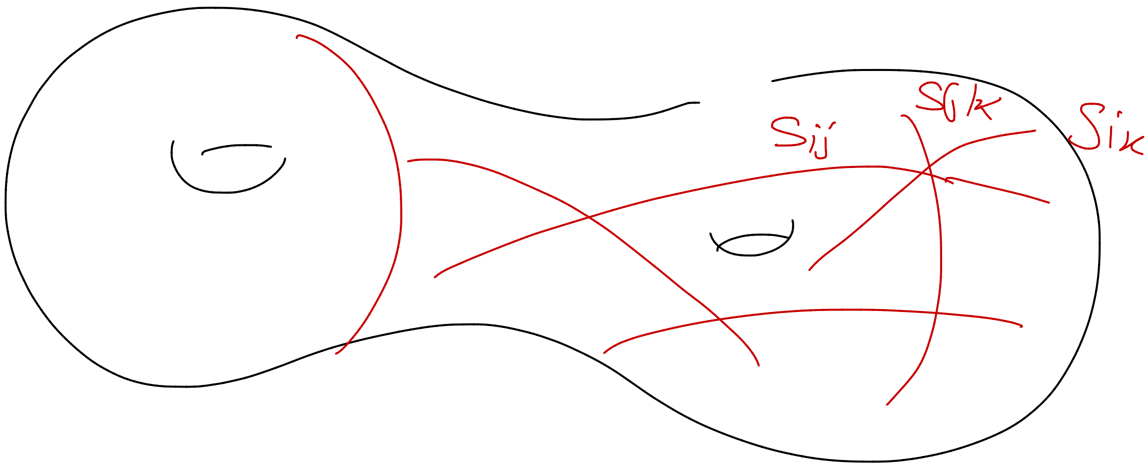
- $$Z_{\gamma_{ij}} := \oint_{\gamma_{ij}} \lambda \quad " = W_i - W_j "$$

  $N=2$ central charge

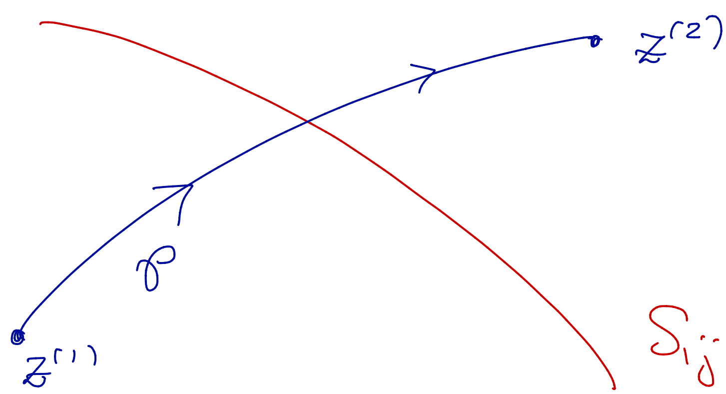
- $$\mu(\gamma_{ij}) = \operatorname{Tr}_{\mathcal{H}(\mathbb{S}_z)} (-1)^F e^{-\beta H}$$

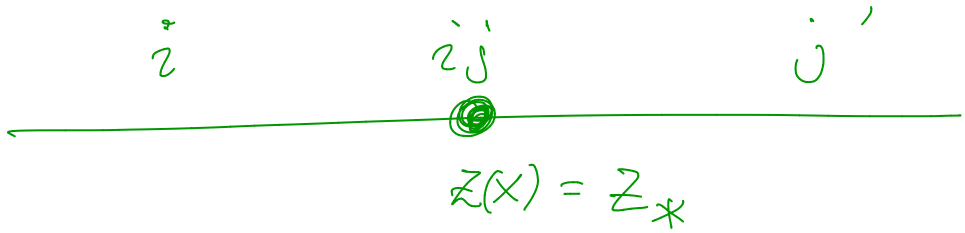
S-WALLS

$$S(\gamma_{ij}) = \left\{ (z, \zeta) \;\middle|\; \zeta^{-1} Z_{\gamma_{ij}} < 0 \;\; \& \;\; \mathcal{H}_{BPS, \gamma_{ij}} \neq 0 \right\}$$



Framed BPS states of interfaces jump when crossing $S(\gamma_{ij})$ walls:





Spectral network is

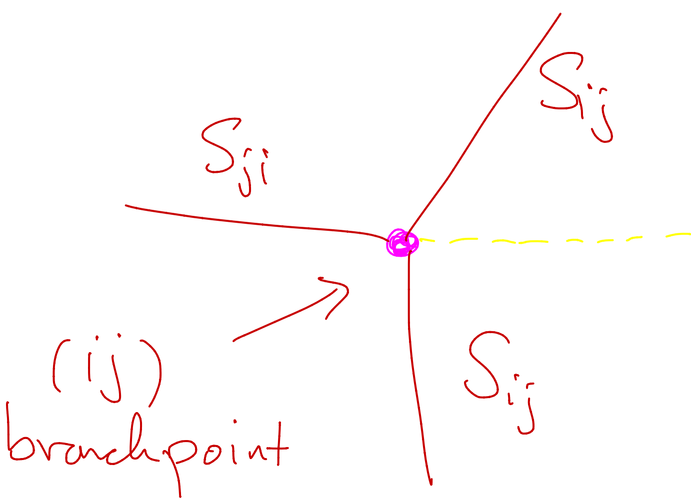
$$SN(\vartheta) = \{ z \mid \exists \text{ soliton with } \bar{\vartheta}' Z < 0 \text{ for theory } \mathfrak{T}_z \}$$

Concretely: Locally, choose a pair of sheets i, j

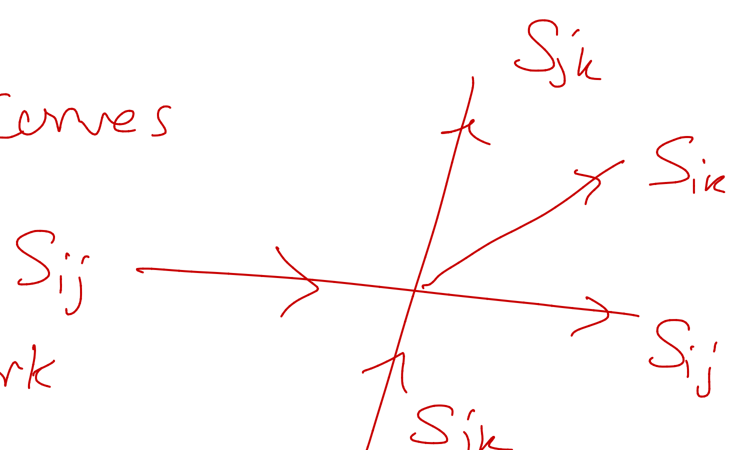
Then $\langle \lambda_i - \lambda_j, \partial_t \rangle = -\vartheta$

defines a foliation of C

Look at critical foliation



Grow these curves



$\Rightarrow$ Spectral network $\mathcal{W}(\vartheta)$

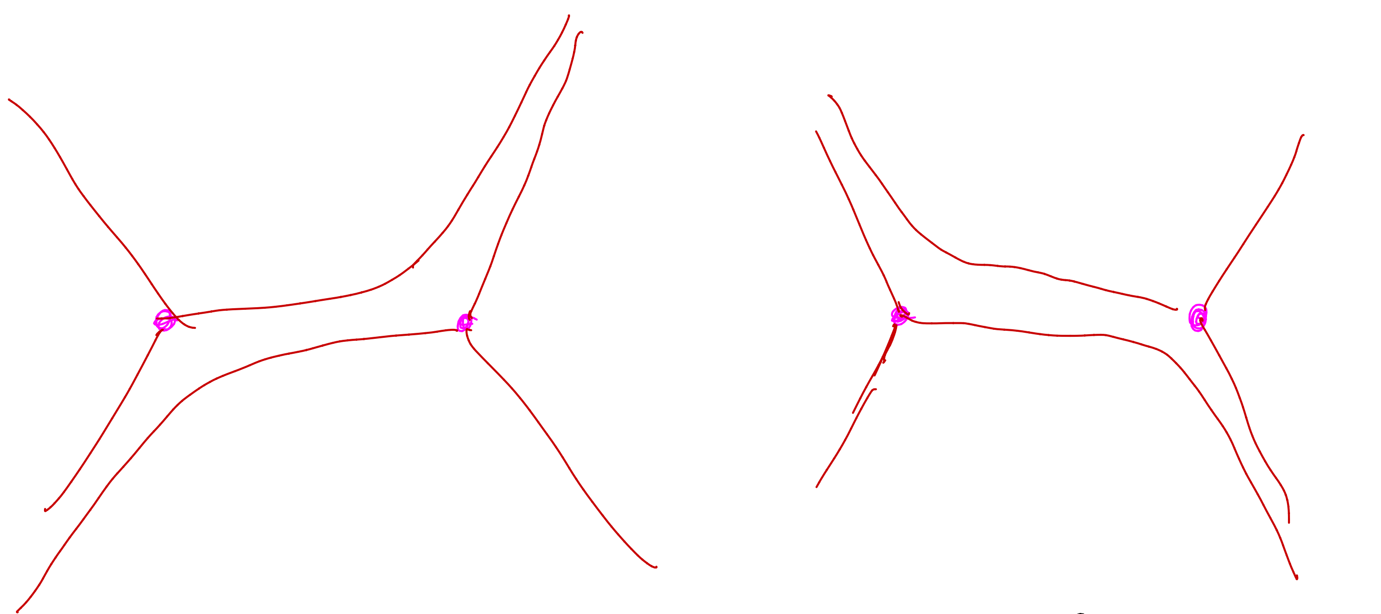
Write $P\exp \int_{z_1}^{z_2} \mathcal{A}$ in terms of μ:

The μ are determined from the SN.

Defines nonabelian connection $\nabla^{\mathcal{W}(\vartheta), u}$

We call this the "nonabelianization map"

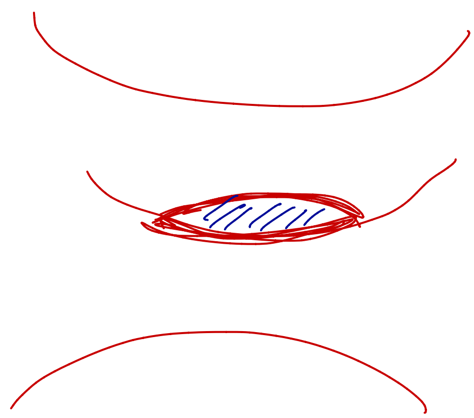
Then the change in the SN as we vary ϑ is due to 4D BPS states:



$\vartheta < \vartheta_c$

$\vartheta > \vartheta_c$

In M-Theory we can fill in a calibrated disk



$\Longrightarrow$ 4D BPS State

The connection $\nabla^{W_{\zeta},u}$ as defined by its parallel transport jumps in a way that depends on $\Omega(\gamma;u)$

The jumps depend on Ω in a specified way that allows one to derive Ω.

This is the solution of Problem 2 above for theories of class S.

10. Work In Progress

a.) Categorification

b.) Number Theory

In GMW we wanted to go further — beyond indices — and construct the BPS states themselves and understand how they change under wall-crossing.

It led to an elaborate theory of interfaces between 2 $d=2$ $\mathcal{N}=(2,2)$ theories — and a categorification of the C-V WCF.

Open problem: Generalize to full 2d4d system: Recently we've been making some good progress on that with A. Khan.

Stress here that there is a categorification of S-wall crossing and now we have one for K-wall crossing

11. FURTHER READING

- GMN papers are all on the arXiv
- Short summary of review talk at Intl. Cong. of Maths. 2012: 1211.2331
- Two short reviews by A. Neitzke: 1308.2198 and 1412.7120

Summer school lecture notes:
G. Moore homepage:

#31 GGI Lectures
#35 PiTP Lectures on Wall Crossing
#47 Felix Klein Lectures
#84 Hamburg Higgs Bundles

A. Neitzke: IAS/Park City PCMI lectures July 2019