arXiv : 2505.23340

Quantum Cohomology & Shift Operators & Coulomb Branches

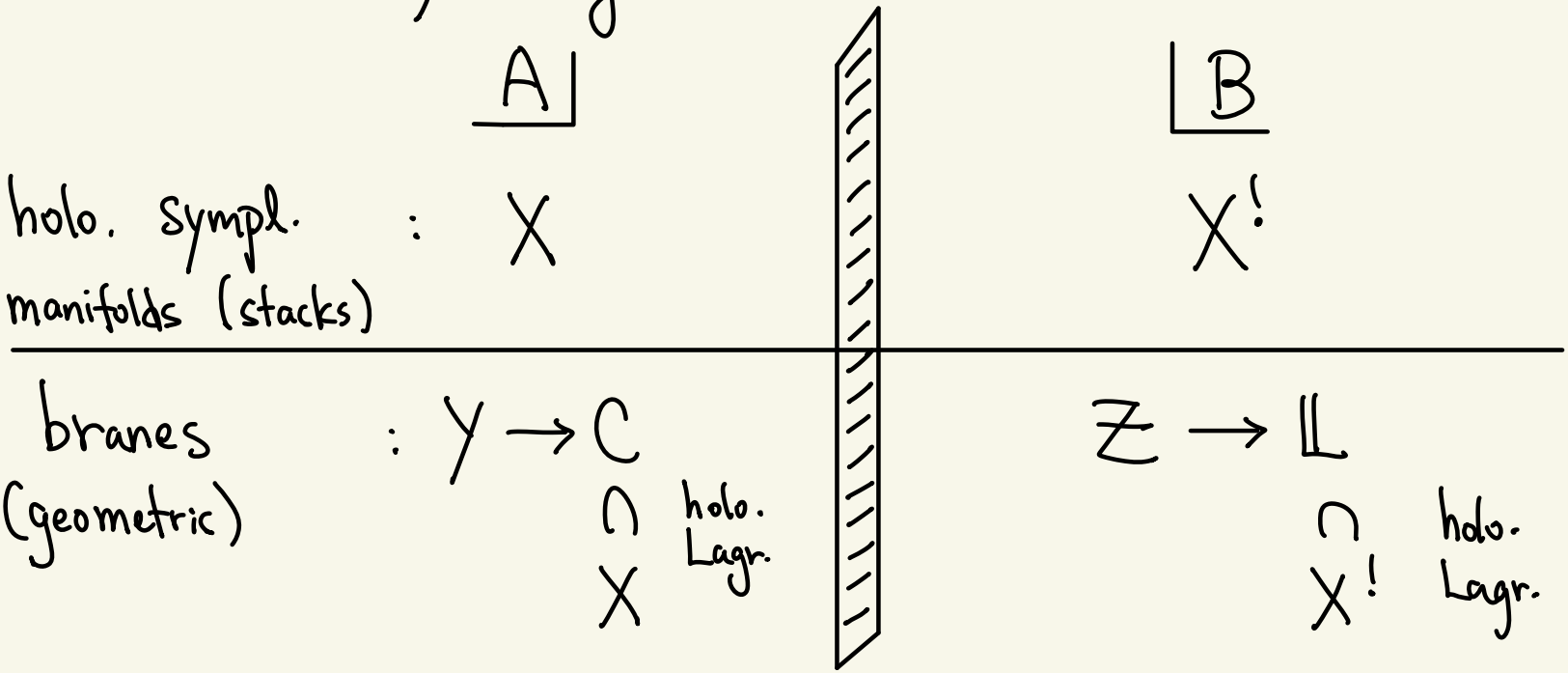
28th Sep at EASC 2025

jt. w. { Kwok Wai Chan
Ki Fung Chan

① Introduction

Recall in Ki Fung's talk:

3D Mirror Symmetry



Given G : cpx reductive $\curvearrowright$ N : G-rep

$\Updownarrow$

3D pair : $X = T^*[N/G]$ (Higgs), $X^! = \mathcal{M}_{G,N}$ (Coulomb) [BFN]

Here $\mathcal{M}_{G,N} := \operatorname{Spec} A_{G,N}$ is a Poisson variety.

$A_{G,N}$: defined via convolution prod.

e.g. 3D branes on X incl. $G \curvearrowright \begin{pmatrix} Y \\ \downarrow f \\ N \end{pmatrix}$: f proper

[Chan - Leung] : Construction of 3D mirror branes via SYZ mirror, for $G = T$ or $N = 0$ cases.

Thm 1 [Chan - Chan - L.]

Given a 3D brane $G \curvearrowright \begin{pmatrix} Y \\ \downarrow f \\ N \end{pmatrix}$: f proper,

$\exists$ closed string construction of the mirror

Lagrangian $\mathbb{L}_Y^G \subset \mathcal{M}_{G,N} = \operatorname{Spec} A_{G,N}$.

More Precisely:

For $G \curvearrowright \begin{pmatrix} Y \\ \downarrow f \\ N \end{pmatrix}$: f proper + mild assumptions on Y,

$\exists$ quantizable module action $A_{G,N} \curvearrowright QH_G^*(Y)$.

S_N : Shift Operator

Rmk: Coulomb branch algebras admit natural quantization $\mathcal{A}^{\hbar}_{G,N}$, quantizable means $\exists$ lift

$$\mathcal{S}^{\hbar}_{N} : \mathcal{A}^{\hbar}_{G,N} \overset{\mathbb{C}[\hbar]\text{-lin.}}{\curvearrowright} QH^*_G(Y)[\hbar].$$

Rmk: Here $QH^*_G(Y)$ can be big quantum cohomology, but we focus on small QH.

Rmk: If Y^T is compact, even without properness of $f: Y \to N$, one can still define $\mathcal{S}$ but only on localized QH.

Rmk: Our construction is very general and does not assume Y^T compact. In particular localization is not required for def^n of $\mathcal{S}_N$.

Rmk: There is also K-theoretic analogue by replacing $\mathcal{A}_{G,N}$ with k-th. Coulomb branch and QH by Quantum K-rings.

E.g. $G = \mathbb{C}^\times \curvearrowright N = \mathbb{C}$, $QH^*_{\mathbb{C}^\times}(\mathbb{C}) \simeq \mathbb{C}[a]$

$$\begin{cases} \mathcal{A}_{\mathbb{C}^\times, 0} \simeq \mathbb{C}[z^{\pm}, a] & \xrightarrow{\text{Spec}} T^*\mathbb{C}^\times \\ \mathcal{A}_{\mathbb{C}^\times, \mathbb{C}} \simeq \mathbb{C}[z, z^{-1}a] & \xrightarrow{\text{Spec}} T^*\mathbb{C} \end{cases}$$

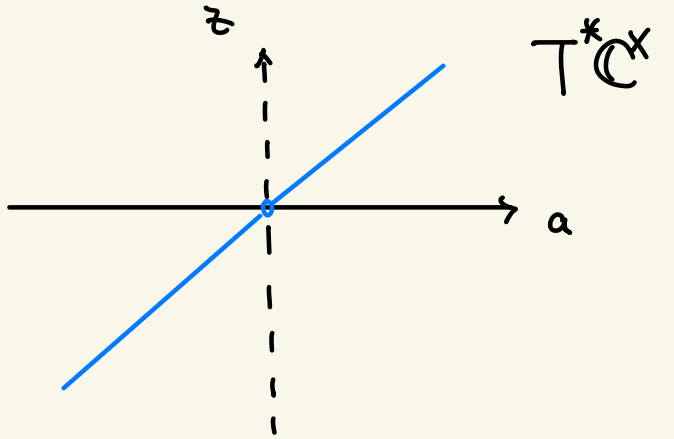
$\mathcal{S}_N$ extends to $\mathcal{S}_{loc} : \mathcal{A}_{\mathbb{C}^\times, 0} \curvearrowright QH^*_{\mathbb{C}^\times}(\mathbb{C})_{loc} \simeq \mathbb{C}[a^{\pm}]$.

explicitly: $\mathcal{S}_{loc}(z^n)(1) = a^n$, $\forall n \in \mathbb{Z}$

then $\mathcal{S}_N(z^{-n}a^n)(1) = 1$, $n \geq 0$.

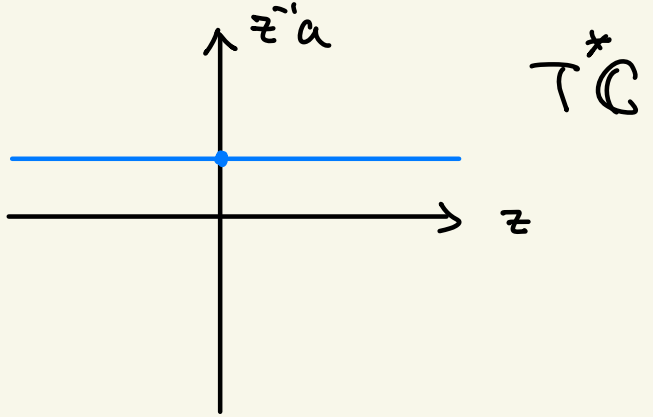
$\Rightarrow$ $\mathcal{A}_{\mathbb{C}^\times, \mathbb{C}}$ is precisely the largest $\subset \mathcal{A}_{\mathbb{C}^\times, 0}$ such that $\mathcal{S}_N$ preserves $\mathbb{C}[a]$.

$\mathcal{A}_{\mathbb{C}^\times,0} \curvearrowright \mathbb{C}[a^{\pm}]$:



compactify

$\mathcal{A}_{\mathbb{C}^\times,\mathbb{C}} \curvearrowright \mathbb{C}[a]$:



In general, $M_{G,0}$ is a group scheme which naturally acts on $M_{G,N} \iff A_{G,0}$ is a coalgebra and $A_{G,N}$ is an $A_{G,0}$ – comodule.

The following uniquely characterize $A_{G,N}$.

Thm 2. [Chan – Chan – L.]

$A_{G,N} \subset A_{G,0}$ is the largest sub-comodule such that $A_{G,N} \curvearrowright QH_G^*(Y)$ is defined without localization, for all $f: Y \to N$ proper. (+ flavor symmetry)

Applications :

One can input $1 \in QH_G(Y)$ to get the generalized Seidel homomorphism

$$\mathfrak{S}_N : \mathcal{A}_{G,N} \longrightarrow QH_G^*(Y) .$$

The fact that it's defined without localization allows one to take non-equivariant limits.

$\rightsquigarrow$ together with gradedness, useful in calculations.

(i) $Y = G/P$ flag variety, $N = 0$

$\rightsquigarrow$ Ψ_N gives a generalization of Peterson's isomorphism

(ii) $Y = T^*G/P$, $N = \mathfrak{g}$ adjoint rep. [Chan-Chan-Chow-L.]

$\rightsquigarrow$ A further generalization of $\mathbb{S}_N$ gives a geometric construction of trig. degenerate DAHA action on $QH^*_{T \times \mathbb{C}^\times_{dil}}(T^*G/P)$.

(iii) The maps $\mathbb{S}_N$ for (ii) and (i) are compatible under a certain limiting process.

Thm 3. (generalization of Teleman's gluing)

If the non-zero T-weights of N are not negative multiples of each other, then $A_{G,N}$ is the fibre product:

$$\begin{array}{ccccc} A_{G,N} & \xrightarrow{\text{comod.}} & A_{G,0} \otimes_{H_G(pt)} A_{G,N} & \xrightarrow{id \otimes \Psi_N} & A_{G,0} \otimes_{H_G(pt)} QH_G^*(N) \\ \downarrow & & & & \downarrow \\ A_{G,0} & \xrightarrow{\text{coalg.}} & A_{G,0} \otimes_{H_G(pt)} A_{G,0} & \xrightarrow{id \otimes \Psi_{loc}} & A_{G,0} \otimes_{H_G(pt)} QH_G(N)_{loc} \end{array}$$

② Shift Operators

(i) Abelian case $G = T \simeq (\mathbb{C}^\times)^n$, $N = 0$.

$$\mathcal{A}_{T,0} \simeq H_*^T(\Omega T) \simeq H_T^*(pt) \otimes_{\mathbb{Z}} \mathrm{Hom}(\mathbb{C}^\times, T).$$

$$\simeq \mathbb{C}[\underbrace{z_1^{\pm}, \dots, z_n^{\pm}}_{\mathrm{Hom}(\mathbb{C}^\times, T).}, \underbrace{a_1, \dots, a_n}_{H_T^*(pt).}] \xleftarrow{\text{Spec}} T^{*\vee}T$$

Assoc. to cocharacter $\lambda \in \mathrm{Hom}(\mathbb{C}^\times, T)$

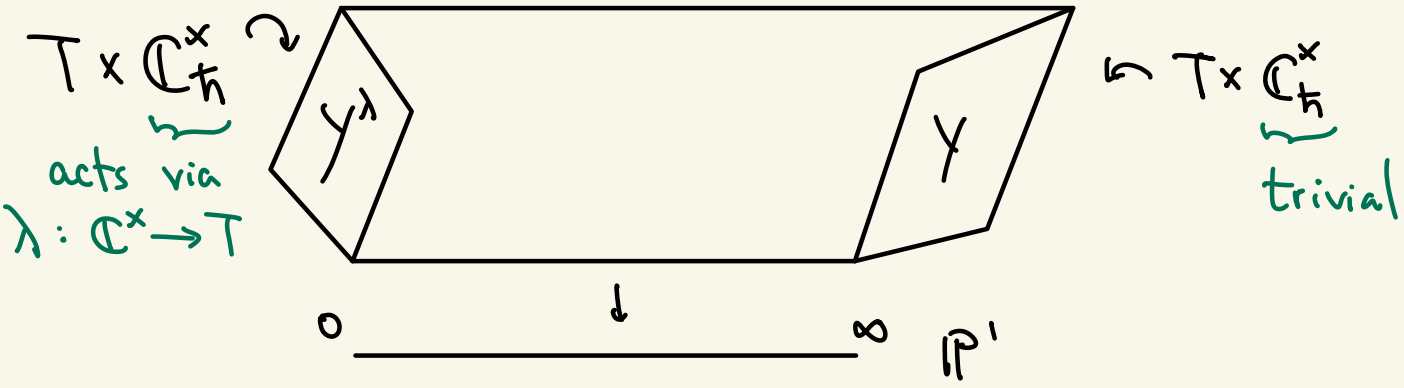
$$\rightsquigarrow \quad B\lambda : B\mathbb{C}^\times \simeq \mathbb{CP}^\infty \longrightarrow BT$$

Then $\mathbb{CP}^1 \subset \mathbb{CP}^\infty \xrightarrow{B\lambda} BT$ gives

a T-bundle $T \to \mathcal{E}_\lambda \downarrow \mathbb{CP}^1$.

Let Y be sm. projective, $T \curvearrowright Y$.

$\rightsquigarrow$ The Seidel space is $\mathcal{E}_\lambda(Y) = \mathcal{E}_\lambda \times^T Y \xrightarrow{\pi} \mathbb{CP}^1$.



$\beta \in H_2(\mathcal{E}_\lambda(Y);\mathbb{Z})$ an effective class is called a section class if $\pi_*\beta = [\mathbb{P}^1]$.

For β section class, consider

$$\overline{\mathcal{M}}_\lambda(\beta) = \left\{ \begin{array}{l} \text{genus } 0,\ 2 \text{ marks stable maps to} \\ \mathcal{E}_\lambda(Y) \text{ with curve class } \beta, \\ \text{s.t. } \pi(0) = 0 \in \mathbb{P}^1,\ \pi(\infty) = \infty \in \mathbb{P}^1 \end{array} \right\}$$

$$\begin{array}{ccc} & \overline{\mathcal{M}}_\lambda(\beta) & \\ {\scriptstyle ev_0^\beta}\swarrow & & \searrow{\scriptstyle ev_\infty^\beta} \\ Y^\lambda & & Y \end{array}$$

<u>Rmk:</u> We keep track of section class using equiv. Novikov parameters $q^{\bar{\beta}} \in \mathbb{C}[[H_2^T(Y;\mathbb{Z})]]$, via

$$H_2(\mathcal{E}_\lambda(Y);\mathbb{Z}) \longrightarrow H_2^T(Y;\mathbb{Z}).$$

The shift operator $S^{\hbar}(z^{\lambda})$ is the map

$$S^{\hbar}_{\lambda} : H^{*}_{T\times\mathbb{C}^{\times}_{\hbar}}(Y) \longrightarrow H^{*}_{T\times\mathbb{C}^{\times}_{\hbar}}(Y)[\![q_T]\!]$$

is the composition of

(I) twisting map $\Phi_{\lambda} : H^{*}_{T\times\mathbb{C}^{\times}_{\hbar}}(Y) \xrightarrow{\sim} H^{*}_{T\times\mathbb{C}^{\times}_{\hbar}}(Y^{\lambda})$

defined via automorphism $T\times\mathbb{C}^{\times}_{\hbar} \longrightarrow T\times\mathbb{C}^{\times}_{\hbar}$

$$(t,\ k) \longmapsto (\lambda^{-1}(k)t,\ k).$$

(II) Section-counting : $H^{*}_{T\times\mathbb{C}^{\times}_{\hbar}}(Y^{\lambda}) \longrightarrow H^{*}_{T\times\mathbb{C}^{\times}_{\hbar}}(Y)[\![q_T]\!]$

$$\alpha \longmapsto \sum_{\beta} q^{\beta} \cdot ev^{\beta}_{\infty *}\left(ev_0^{\beta *}(\alpha) \cap [\mathcal{M}_{\lambda}(\beta)]^{vir} \right)$$

(ii) General G and N case.

$\mathcal{O} = \mathbb{C}[\![t]\!]$
$K = \mathbb{C}((t))$
$\mathrm{Gr}_G = G_K / G_{\mathcal{O}}$

Main differences:

(a) Non-Abelian Coulomb branch $\mathcal{A}_{G,N}$ is in general a subalgebra of $\mathcal{A}_{G,0} = \left(H_*^{G_{\mathcal{O}}}(\mathrm{Gr}_G), *\right)$.

(b) $Y \to N$ is proper, but Y is in general not, so pushforward $\mathrm{ev}^{\beta}_{\infty *}$ may not be defined.

Rmk: For (b), if Y^T is proper, one can still proceeds using localizations.

Solution to (b) requires a better understanding of (a):

Thm. (CCL) $\exists$ "stratified vector bundle" $\mathcal{V}_N \longrightarrow Gr_G$ s.t. $A_{G,N} \simeq e(\mathcal{V}_N) \cap H_*^{G_O}(Gr_G) \subset H_*^{G_O}(Gr_G)$.

$\| A_{G,O}$

More precisely, the Coulomb branch is defined to be $H_*^{G_O}(R_N)$, where it fits into

$$R_N \subset \mathcal{T}_N : \infty \text{ rank VB}$$

fiberwise linear

$\mathcal{T}_N \downarrow Gr_G$

Heuristically, V_N is the fiberwise quotient

$$V_N := \mathcal{T}_N / R_N .$$

Then the pullback of V_N on $\mathcal{T}_N$ has a canonical section whose zero locus $= R_N$.

In practice, V_N is not constant rank on affine Schubert varieties (closed strata),

BUT $\exists$ resolutions s.t. $V_N|_{\text{cells}}$ extends to VB.

(of aff. Schubert varieties)

Proceeding to define $\mathfrak{S}_N : e(V_N) \cap H^{G_0}(Gr_G) \curvearrowright QH^*_G(y)$.

Functor of points description of Gr_G

$\Longrightarrow$ $\exists$ principal G – bundle

$$G \to \mathcal{E} \downarrow Gr_G \times \mathbb{P}^1$$

equipped with $\mathcal{E}\big|_{Gr_G \times \mathbb{C}_\infty} \xrightarrow{\varphi}{\sim} G \times Gr_G \times \mathbb{C}_\infty$.

where $\mathbb{C}_\infty \subset \mathbb{P}^1$ is chart around ∞.

The Seidel space is then $\mathcal{E}(Y) := \mathcal{E} \times^G Y \leftarrow Y$

$$\downarrow \pi$$

$$Gr_G \times \mathbb{P}^1$$

Note that $\pi^{-1}(Gr_G \times \{0\}) \simeq G_K \times^{G_O} Y$, $\pi^{-1}(Gr_G \times \{\infty\}) \simeq Gr_G \times Y$.

To define S_N:

(i) Twisting map, restricted from topological

$$H_*^{G_O}(Gr_G) \otimes H_G^*(Y) \longrightarrow H_*^{G_O}(G_K \times^{G_O} Y)$$

$$\cup \qquad\qquad\qquad\qquad \cup$$

$$e(V_N) \cap H_*^{G_O}(Gr_G) \otimes H_G^*(Y) \longrightarrow e(V_N) \cap H_*^{G_O}(G_K \times_{G_O} Y)$$

(ii) Section-counting : (requires solving (b), properness of ev_∞)

Let β be a section class on $\mathcal{E}(y)$, i.e. $\pi_* \beta = [pt] \otimes [\mathbb{P}^1]$

let $\mathcal{M}(\beta)$ be the moduli space of $g=0$ stable maps with 2 marked pts lying over $\pi^{-1}(Gr_G \times \{0\})$ & $\pi^{-1}(Gr_G \times \{\infty\})$ respectively.

Key Lemma. $\exists$ canonical section $\mathcal{Y}$ of pullback of $\mathcal{V}_N$ over $\mathcal{M}(\beta)$, s.t. the restriction of ev_∞^β to

$$Z(\beta) := Zero(\mathcal{Y})$$

is proper.

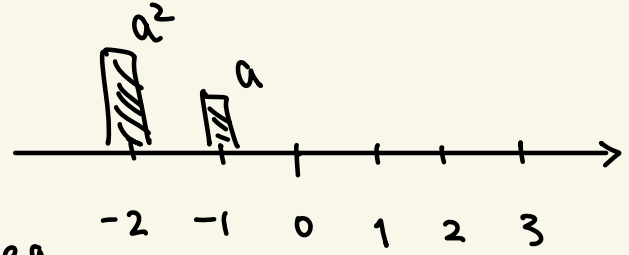
$\rightsquigarrow$ Section counting : $e(\mathcal{V}_N) \cap H_*^{G_O}(G_K \times^{G_O} Y) \longrightarrow H_G^*(Y)[\![g_G]\!]$.

Define $e(\mathcal{V}_N) \cap \alpha \longmapsto \sum q^{\beta} \, pr_* \, \widetilde{ev}_{\infty *}^{\beta} \left(\widetilde{ev}_0^{\beta *}(\alpha) \cap [Z(\beta)]^{vir} \right)$

where $pr : Gr_G \times Y \to Y$.

Idea of key lemma:

For $G = T \simeq (\mathbb{C}^\times)^n$, $Gr_T = Hom(\mathbb{C}^\times, T) \simeq \mathbb{Z}^n$.



e.g. $(\mathbb{C}^\times \curvearrowright \mathbb{C}_1)$ $\qquad Gr_T$

$\rightsquigarrow$ $\mathcal{V}_N\big|_\lambda$ is just a T-rep.

$\hat{\mathbb{C}}_0 = \operatorname{Spec} \mathcal{O}_{\cdot}$
$= \operatorname{Spec} \mathbb{C}[\![t]\!]$

Explicitly :

$$\mathcal{V}_N\big|_\lambda = \left\{ \begin{array}{l} \text{negative degree} \\ \text{(in } t\text{) part of } t^\lambda \cdot s \end{array} \;\middle|\; s: \text{section of } \begin{array}{c} \xi_\lambda(N)\big|_{\hat{\mathbb{C}}_0} \\ \downarrow \\ \hat{\mathbb{C}}_0 \end{array} \right\}.$$

(here t coord. near $0 \in \mathbb{P}^1$)

$\Updownarrow$

$s \in N_0$

Therefore we have a canonical section (for $Y = N$).

$$\mathcal{Z} : \mathcal{M}_\lambda(N,0) \longrightarrow \mathcal{V}_N\big|_\lambda$$

$\Downarrow$

$\sigma \longmapsto$ negative deg part of $t^\lambda \cdot \sigma\big|_{\hat{\mathbb{C}}_0}$.

Since t^λ is transition function of $\mathcal{E}_\lambda(N) \to \mathbb{P}^1$,

$\Rightarrow$ $t^\lambda \cdot \sigma|_{\hat{\mathbb{C}}_0} \in N_{\mathbb{C}[t^{-1}]}$ automatically

$\Rightarrow$ $z(\sigma) = 0$ if and only if σ is constant on $\mathbb{P}^1$.

$\rightsquigarrow$ $ev_\infty|_{Z(z)}$ is simply an inclusion of vector spaces.

<u>E.g.</u> $T = \mathbb{C}^\times$, $N = \mathbb{C}$

$$V_N|_{\lambda=-1} = \{ \text{negative deg part of } t^{-1}\cdot s \mid s \in \mathbb{C}[\![t]\!] \}$$
$$= \mathbb{C}\cdot t^{-1} \simeq N.$$

So $$e(V_N|_{\lambda=-1}) \cdot z^{-1} = a \cdot z^{-1} \in A_{\mathbb{C}^\times, \mathbb{C}}$$

$$\cong \mathbb{C}[z, z^{-1}a].$$

The argument for non-Abelian G is similar.

For general Y, we use the compatibility

$$\begin{array}{ccccc} Z_\lambda(Y,\beta) & \subset & M_\lambda(Y,\beta) & \xrightarrow{ev_\infty} & Y \\ \downarrow & & \downarrow \bar{f} & & \downarrow f \\ Z_\lambda(N,0) & \subset & M_\lambda(N,0) & \xrightarrow{ev_\infty} & N \end{array}.$$

③ Applications & Examples.

(i) Abelian case : $T = (\mathbb{C}^\times)^n$. $Y = N = \bigoplus_{i=1}^{k} \mathbb{C}_{\xi_i}$.

Explicitly : $A_{T,N} = \bigoplus_{\lambda \in \Lambda} H_T^*(pt) \cdot e(V_N|_\lambda)\, z^\lambda$.

where $e(V_N|_\lambda) = \prod_{\xi_i : \xi_i(\lambda) < 0} \xi_i^{-\xi_i(\lambda)}$.

$\rightsquigarrow$ $\Psi_N\left(e(V_N|_\lambda)\, z^\lambda\right) = q^\lambda \prod_{\xi_i : \xi_i(\lambda) > 0} \xi_i^{\xi_i(\lambda)}$.

If N is gluable $\iff$ $\xi_i \neq$ negative multiple of ξ_j for nonzero ξ_i,

$\Rightarrow$ $\mathcal{A}_{T,N}$ is the largest subspace of $\mathcal{A}_{T,0}$ s.t. $\mathcal{I}_N$ has no denominators.

In general, one turns on Flavor symmetry $\curvearrowright N$

Thm $\mathcal{A}_{G,N} \subset \mathcal{A}_{G,0}$ is the largest sub-comodule of $\mathcal{A}_{G,0}$ s.t. $\mathcal{S}_N$, $\mathcal{I}_N$ are defined without localizations.

(ii) For $Y = G/B$, $N = 0$, inputting $1 \in QH^*_G(G/B)$

gives ring map $\Psi_N : H^{G_O}_*(Gr_G) \longrightarrow QH^*_G(G/B)$.

Ψ : Affine Schubert classes $\longmapsto$ quantum Schubert classes

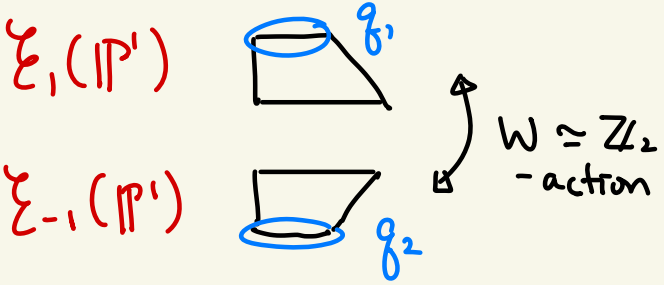
For G general reductive, the use of equiv. Novikov variables is essential.

$\rightsquigarrow$ Generalizes Peterson's isomorphism.

E.g. For $G = PGL_2 \curvearrowright \mathbb{P}^1$, then T & G - Novikov variables are related $H_2^T(\mathbb{P}^1;\mathbb{Z}) \simeq \mathbb{Z}^2 \longrightarrow H_2^G(\mathbb{P}^1;\mathbb{Z}) \simeq \mathbb{Z}$.

$q_1, q_2 \longmapsto q_1 = q_2$.

Weyl Coinv.



$z \longmapsto q_1(x+a)$

$z^{-1} \longmapsto q_2 x$

$\dfrac{\mathbb{C}[x,a]((q_1,q_2))}{x(x+a) = q_1^{-1}q_2^{-1}}$

$\mathcal{A}_{\mathbb{C}^\times,0} = \mathbb{C}[z^{\pm}, a] \longrightarrow QH^*_{\mathbb{C}^\times}(\mathbb{P}^1)[\![q_T]\!]$

$\mathcal{A}_{PGL_2,0} = \mathbb{C}[z^{\pm}, a, \frac{z-z^{-1}}{a}] \longrightarrow QH^*_{\mathbb{C}^\times}(\mathbb{P}^1)[\![q_G]\!]$

$\frac{z-z^{-1}}{a} \longmapsto q$.

$/\, q_1 = q_2 =: q$

(iii) $Y = T^*G/B$, $N = \mathfrak{g}$ adj. rep.

$\exists$ Affine flag variety version of Coulomb branch,
from the data (G, N, V) where V = B-subrep.
of $N \longrightarrow \mathcal{A}_{G,N,V}^{\mathbb{C}^\times_{dil}}$ ($\mathbb{C}^\times_{dil}$ refers to extra dilation action)

<u>Prop.</u> For $(G, N, V) = (G, \mathfrak{g}, \mathfrak{b}^\perp)$,
$\mathcal{A}^{dil}_{G,N,V}$ has a natural basis $\{D_{(w,\lambda)}\}$ indexed by the Iwahori-Weyl group, and is isomorphic to trig. deg. DAHA.
Rmk: $\mathcal{A}_{G,N}$ is the spherical subalg of $\mathcal{A}_{G,N,V}$.

As vector space, the DAHA is given by

$$\mathbb{C}[\mathfrak{t} \oplus \mathbb{C}_{dil}] \otimes \mathbb{C}[\check{T}] \otimes \mathbb{C}[W]$$

$\mathbb{C}[\mathfrak{t} \oplus \mathbb{C}_{dil}]$: $\times$ equivariant parameters

$\mathbb{C}[\check{T}]$: $\times$ equivariant Novikov variables

$\mathbb{C}[W]$: (left) Demazure-Lusztig operators.

E.g. $QH^*_{\mathbb{C}^\times \times \mathbb{C}^\times_{dil}}(T^*\mathbb{P}^1)[\![q_T]\!] \simeq$

$\mathbb{C}^\times$, $\mathbb{C}^\times_{dil}$ - parameter

$$\frac{\mathbb{C}[x, a, k](q_1, q_2)}{x(x+a) = \frac{q_1 q_2}{1 - q_1 q_2} \cdot k(k - 2x - a)}$$

DL operator $D_\sigma(x) = \sigma(x) - k \cdot \frac{x - \sigma(x)}{a} = k - x - a.$

$\sigma \in \mathbb{Z}_2 \simeq W$

Prop. (In progress) $\forall\ \Gamma \in \mathcal{A}_{G,N,V}$ and α, α' cycles on X s.t. $f(\alpha) \subset V$ and $f(\alpha') \cap V \subset \{0\}$, then $\langle \mathbb{S}_{G,N,V}(\Gamma)(\alpha), \alpha' \rangle \in H_T^*(pt)[\![q_T]\!]$ without localize.

Thm. (In progress) $\exists$ (graded)- module action

$$\mathcal{A}^{\mathbb{C}^\times_{dil}}_{G,0,b^\perp} \curvearrowright QH^*_T(T^*G/B)_{loc}[\![q_T]\!]$$

$$\| $$

$$\bigoplus_{\substack{w\in W \\ \lambda \in \Lambda}} H^*_{T\times\mathbb{C}^\times_{dil}}(pt)\cdot D_{(w,\lambda)}$$

Stable envelopes

s.t. $D_{(w,\lambda)}(Stab_+(v)) = q^{w\lambda} Stab_+(wv)$.

Idea: The elements $\{D_{(w,\lambda)}\}$ are degree 0 classes.

By proposition $\langle D_{(w,\lambda)}\, \mathrm{Stab}_+(v)\,,\, \mathrm{Stab}_-(v') \rangle$ is then degree 0 in $H^*_{T\times\mathbb{C}^\times_{dil}}(pt)\,[\![q_T]\!]$,

i.e., only involving q_T's.

$\Rightarrow$ Can compute after setting k = equivariant parameters of $\mathbb{C}^\times_{dil} \longrightarrow 0$.

$\Rightarrow$ Then, $D_{(w,\lambda)}$, Stab_+ all become fixed point classes.

Comment: Talk about 3D mirror DAHA action next time.

THANK

You.