Eine Woche, ein Beispiel

10.2 equivariant K-theory of Steinberg variety

Ref:
[Ginz] Ginzburg's book "Representation Theory and Complex Geometry"
[LCBE] Langlands correspondence and Bezrukavnikov's equivalence
[LW-BWB] The notes by Liao Wang: The Borel-Weil-Bott theorem in examples (can not be found on the internet)
https://people.math.harvard.edu/~gross/preprints/sat.pdf

Task. Complete the following tables:

$K^-(-)$	pt	$\mathcal{B}$ $T^*\mathcal{B}$	$\mathcal{B}\times\mathcal{B}$ $T^*(\mathcal{B}\times\mathcal{B})$	St
G	$\mathbb{Z}[X^*(T)]^W$	$\mathbb{Z}[X^*(T)]$	$\mathbb{Z}[X^*(T)]\otimes_{\mathbb{Z}[X^*(T)]^W}\mathbb{Z}[X^*(T)]$	$\mathbb{Z}[W_{ext}]$
B	$\mathbb{Z}[X^*(T)]$	$\mathbb{Z}[X^*(T)]\otimes_{\mathbb{Z}[X^*(T)]^W}\mathbb{Z}[X^*(T)]$	$\mathbb{Z}[X^*(T)]\otimes_{\mathbb{Z}[X^*(T)]^W}\mathbb{Z}[X^*(T)]\otimes_{\mathbb{Z}[X^*(T)]^W}\mathbb{Z}[X^*(T)]$	
Id	$\mathbb{Z}$			$\mathbb{Z}[X^*(T)]/_{I_T}\rtimes\mathbb{Z}[W_f]$
$G\times\mathbb{C}^\times$	$\mathbb{Z}[X^*(T)]^W[t^{\pm 1}]$			$\mathcal{H}_{ext}$
$B\times\mathbb{C}^\times$	$\mathbb{Z}[X^*(T)][t^{\pm 1}]$			
$\mathbb{C}^\times$	$\mathbb{Z}[t^{\pm 1}]$			

We use the shorthand.

$K^-(-)$	pt	$\mathcal{B}$ $T^*\mathcal{B}$	$\mathcal{B}\times\mathcal{B}$ $T^*(\mathcal{B}\times\mathcal{B})$	St
G	$R(T)^W$	$R(T)$	$R(T)\otimes_{R(G)}R(T)$	$\mathbb{Z}[W_{ext}]$
B	$R(T)$	$R(T)\otimes_{R(G)}R(T)$	$R(T)\otimes_{R(G)}R(T)\otimes_{R(G)}R(T)$	
Id	$\mathbb{Z}$			$R(T)/_{I_T}\rtimes\mathbb{Z}[W_f]$
$G\times\mathbb{C}^\times$	$R(G)[t^{\pm 1}]$			$\mathcal{H}_{ext}$
$B\times\mathbb{C}^\times$	$R(T)[t^{\pm 1}]$			
$\mathbb{C}^\times$	$\mathbb{Z}[t^{\pm 1}]$			

$$R(B) = \mathbb{Z}[X^*(T)] \quad = \mathcal{H}(\hat{T}(F), \hat{T}(\mathcal{O}_F))$$

$$R(G) = \mathbb{Z}[X^*(T)]^W \quad \neq \mathcal{H}(\hat{G}(F), \hat{G}(\mathcal{O}_F))$$

$$R(G)[q^{\pm\frac{1}{2}}] = \mathbb{Z}[X^*(T)]^W[q^{\pm\frac{1}{2}}] = \mathcal{H}_{sph}[q^{\pm\frac{1}{2}}]$$

$$R(G\times\mathbb{C}^\times) = \mathbb{Z}[X^*(T)]^W[t^{\pm 1}]$$

$$K^{G\times\mathbb{C}^\times}(St) = \mathcal{H}_{ext} \quad \overset{?}{=} \mathcal{H}(\hat{G}(F), I)$$

Here is an initial example.

$K^-(-)$	pt	$\mathcal{B}$ $T^*\mathcal{B}$	$\mathcal{B}\times\mathcal{B}$ $T^*(\mathcal{B}\times\mathcal{B})$	St
SL_2	$\mathbb{Z}[x]$	$\mathbb{Z}[z^{\pm 1}]$	$\mathbb{Z}[z_1^{\pm 1}, z_2^{\pm 1}]/((z_1-z_2)(z_1-z_2^{-1}))$	$\mathbb{Z}[W_{ext}] = \bigoplus_{w\in W}\mathbb{Z}[z_w^{\pm 1}]$
B	$\mathbb{Z}[y^{\pm 1}]$	$\mathbb{Z}[y^{\pm 1}, z]/(z-y)(z-y^{-1})$	$\mathbb{Z}[y^{\pm 1}, z_1, z_2]/((z_1-y)(z_1-y^{-1}), (z_2-y)(z_2-y^{-1}))$	
Id	$\mathbb{Z}$	$\mathbb{Z}[z]/(z-1)^2$	$\mathbb{Z}[z_1, z_2]/((z_1-1)^2, (z_2-1)^2)$	$R(T)/_{I_T}\rtimes\mathbb{Z}[W_f] = \bigoplus_{w\in W}\mathbb{Z}[z_w^{\pm 1}]/(z_w-1)^2$
$SL_2\times\mathbb{C}^\times$	$\mathbb{Z}[x, t^{\pm 1}]$			$\mathcal{H}_{ext} = \bigoplus_{w\in W}\mathbb{Z}[z_w^{\pm 1}, t^{\pm 1}]$
$B\times\mathbb{C}^\times$	$\mathbb{Z}[y^{\pm 1}, t^{\pm 1}]$			
$\mathbb{C}^\times$	$\mathbb{Z}[t^{\pm 1}]$			

This is our final task. Most of the notations are still not fixed.

$K^{-}(-)$	pt	$\mathcal{F}_{\underline{d}}$ $\quad\widetilde{Rep}_{\underline{d}}(Q)$	$\mathcal{F}_{\underline{d}} \times \mathcal{F}_{\underline{d}'}$	$\mathcal{Z}_{\underline{d},\underline{d}'}$
G_d	$R(T_d)^{W_d}$	$R(T_d)$	$R(T_d)\otimes_{R(G_d)}R(T_d)$	
B_d	$R(T_d)$ $\bigoplus_{w\in W_d} R(G_d)$	$R(T_d)\otimes_{R(G_d)}R(T_d)$ $\bigoplus_{w\in W_d} R(T_d)[\overline{\Omega_w}]^{T_d}$	$R(T_d)\otimes_{R(G_d)}R(T_d)\otimes_{R(G_d)}R(T_d)$ $\bigoplus_{w,w'\in W_d} R(T_d)[\overline{\Omega_{w,w'}}]^{T_d}$	$\bigoplus_{w,w'\in W_d} R(T_d)[\overline{\widetilde{\Omega}_{w,w'}}]^{T_d}$
Id	$\mathbb{Z}$	$\bigoplus_{w\in W_d} \mathbb{Z}[\overline{\Omega_w}]$	$\bigoplus_{w,w'\in W_d} \mathbb{Z}[\overline{\Omega_{w,w'}}]$	$\bigoplus_{w,w'\in W_d} \mathbb{Z}[\overline{\widetilde{\Omega}_{w,w'}}]$
$G_d\times\mathbb{C}^{\times}$	$R(G_d)[t^{\pm 1}]$			
$B_d\times\mathbb{C}^{\times}$	$R(T_d)[t^{\pm 1}]$ $\bigoplus_{w\in W_d} R(G_d\times\mathbb{C}^{\times})$	$\bigoplus_{w\in W_d} R(T_d\times\mathbb{C}^{\times})[\overline{\Omega_w}]^{T_d\times\mathbb{C}^{\times}}$	$\bigoplus_{w,w'\in W_d} R(T_d\times\mathbb{C}^{\times})[\overline{\Omega_{w,w'}}]^{T_d\times\mathbb{C}^{\times}}$	$\bigoplus_{w,w'\in W_d} R(T_d\times\mathbb{C}^{\times})[\overline{\widetilde{\Omega}_{w,w'}}]^{T_d\times\mathbb{C}^{\times}}$
$\mathbb{C}^{\times}$	$\mathbb{Z}[t^{\pm 1}]$	$\bigoplus_{w\in W_d} R(\mathbb{C}^{\times})[\overline{\Omega_w}]^{\mathbb{C}^{\times}}$	$\bigoplus_{w,w'\in W_d} R(\mathbb{C}^{\times})[\overline{\Omega_{w,w'}}]^{\mathbb{C}^{\times}}$	$\bigoplus_{w,w'\in W_d} R(\mathbb{C}^{\times})[\overline{\widetilde{\Omega}_{w,w'}}]^{\mathbb{C}^{\times}}$

$K^{-}(-)$	pt	$\mathcal{F}_d$ $\quad\widetilde{Rep}_d(Q)$	$\mathcal{F}_d \times \mathcal{F}_d$	$\mathcal{Z}_d = \coprod_{\underline{d},\underline{d}'} \mathcal{Z}_{\underline{d},\underline{d}'}$
G_d	$R(T_d)^{W_d}$	$\bigoplus_{\underline{d}} R(T_d)$	$\bigoplus_{\underline{d}} R(T_d)\otimes_{R(G_d)}R(T_d)$	
B_d	$R(T_d)$ $\bigoplus_{w\in W_d} R(G_d)$	$\bigoplus_{\underline{d}} R(T_d)\otimes_{R(G_d)}R(T_d)$ $\bigoplus_{\varpi\in \mathbb{W}_{\lvert d\rvert}} R(T_d)[\overline{\mathcal{O}_{\varpi}}]^{T_d}$	$\bigoplus_{\underline{d}} R(T_d)\otimes_{R(G_d)}R(T_d)\otimes_{R(G_d)}R(T_d)$ $\bigoplus_{\varpi,\varpi'\in \mathbb{W}_{\lvert d\rvert}} R(T_d)[\overline{\mathcal{O}_{\varpi,\varpi'}}]^{T_d}$	$\bigoplus_{\varpi,\varpi'\in \mathbb{W}_{\lvert d\rvert}} R(T_d)[\overline{\widetilde{\mathcal{O}}_{\varpi,\varpi'}}]^{T_d}$
Id	$\mathbb{Z}$	$\bigoplus_{\varpi\in \mathbb{W}_{\lvert d\rvert}} \mathbb{Z}[\overline{\mathcal{O}_{\varpi}}]$	$\bigoplus_{\varpi,\varpi'\in \mathbb{W}_{\lvert d\rvert}} \mathbb{Z}[\overline{\mathcal{O}_{\varpi,\varpi'}}]$	$\bigoplus_{\varpi,\varpi'\in \mathbb{W}_{\lvert d\rvert}} \mathbb{Z}[\overline{\widetilde{\mathcal{O}}_{\varpi,\varpi'}}]$
$G_d\times\mathbb{C}^{\times}$	$R(G_d)[t^{\pm 1}]$			
$B_d\times\mathbb{C}^{\times}$	$R(T_d)[t^{\pm 1}]$ $\bigoplus_{w\in W_d} R(G_d\times\mathbb{C}^{\times})$	$\bigoplus_{\varpi\in \mathbb{W}_{\lvert d\rvert}} R(T_d\times\mathbb{C}^{\times})[\overline{\mathcal{O}_{\varpi}}]^{T_d\times\mathbb{C}^{\times}}$	$\bigoplus_{\varpi,\varpi'\in \mathbb{W}_{\lvert d\rvert}} R(T_d\times\mathbb{C}^{\times})[\overline{\mathcal{O}_{\varpi,\varpi'}}]^{T_d\times\mathbb{C}^{\times}}$	$\bigoplus_{\varpi,\varpi'\in \mathbb{W}_{\lvert d\rvert}} R(T_d\times\mathbb{C}^{\times})[\overline{\widetilde{\mathcal{O}}_{\varpi,\varpi'}}]^{T_d\times\mathbb{C}^{\times}}$
$\mathbb{C}^{\times}$	$\mathbb{Z}[t^{\pm 1}]$	$\bigoplus_{\varpi\in \mathbb{W}_{\lvert d\rvert}} R(\mathbb{C}^{\times})[\overline{\mathcal{O}_{\varpi}}]^{\mathbb{C}^{\times}}$	$\bigoplus_{\varpi,\varpi'\in \mathbb{W}_{\lvert d\rvert}} R(\mathbb{C}^{\times})[\overline{\mathcal{O}_{\varpi,\varpi'}}]^{\mathbb{C}^{\times}}$	$\bigoplus_{\varpi,\varpi'\in \mathbb{W}_{\lvert d\rvert}} R(\mathbb{C}^{\times})[\overline{\widetilde{\mathcal{O}}_{\varpi,\varpi'}}]^{\mathbb{C}^{\times}}$

$$H_*^{G_d}(\mathcal{Z}_{\underline{d},\underline{d}}) \cong \bigotimes_i NH_{d_i}$$

Orange: only know the $R(G)$-module structure, and the alg structure is yet not known

Light yellow: $R(G_d)$-module + W_d-equiv iso

$d = (1,2)$ $\qquad$ $a \longrightarrow b$, $\langle v_1 \rangle \longrightarrow \langle v_2, v_3 \rangle$

⚠ The action on $\mathcal{F}lag$ is not the same as in http://www.math.uni-bonn.de/ag/stroppel/Master%27s%20Thesis_Tomasz%20Przezdziecki.pdf

	$\varpi = wu$			w	$\underline{d} = u$	order of basis	$l(\varpi)$	$l(w)$	$\mathbb{B}_\varpi$	B_ϖ	$\varpi B \varpi^{-1}$
Id	Id	$\begin{pmatrix}1&2&3\\1&2&3\end{pmatrix}$	$\begin{bmatrix}1&&\\&1&\\&&1\end{bmatrix}$		abb	$\{v_1, v_2, v_3\}$	0	0	$\begin{bmatrix}*&*&*\\&*&*\\&&*\end{bmatrix}$	$\begin{bmatrix}*&&\\&*&*\\&&*\end{bmatrix}$	$\begin{bmatrix}*&&\\&*&*\\&&*\end{bmatrix}$
t	(23)	$\begin{pmatrix}1&2&3\\1&3&2\end{pmatrix}$	$\begin{bmatrix}1&&\\&&1\\&1&\end{bmatrix}$		abb	$\{v_1, v_3, v_2\}$	1	1	$\begin{bmatrix}*&*&*\\&*&\\&*&*\end{bmatrix}$	$\begin{bmatrix}*&&\\&*&\\&*&*\end{bmatrix}$	$\begin{bmatrix}*&&\\&*&\\&*&*\end{bmatrix}$
s	(12)	$\begin{pmatrix}1&2&3\\2&1&3\end{pmatrix}$	$\begin{bmatrix}&1&\\1&&\\&&1\end{bmatrix}$		bab	$\{v_2, v_1, v_3\}$	1	0	$\begin{bmatrix}*&&*\\*&*&*\\&&*\end{bmatrix}$	$\begin{bmatrix}*&&\\&*&*\\&&*\end{bmatrix}$	$\begin{bmatrix}*&&*\\&*&\\&&*\end{bmatrix}$
ts	(132)	$\begin{pmatrix}1&2&3\\3&1&2\end{pmatrix}$	$\begin{bmatrix}&1&\\&&1\\1&&\end{bmatrix}$		bab	$\{v_3, v_1, v_2\}$	2	1	$\begin{bmatrix}*&*&\\&*&\\*&*&*\end{bmatrix}$	$\begin{bmatrix}*&&\\&*&\\&*&*\end{bmatrix}$	$\begin{bmatrix}*&*&\\&*&\\&&*\end{bmatrix}$
st	(123)	$\begin{pmatrix}1&2&3\\2&3&1\end{pmatrix}$	$\begin{bmatrix}&&1\\1&&\\&1&\end{bmatrix}$		bba	$\{v_2, v_3, v_1\}$	2	0	$\begin{bmatrix}*&&\\*&*&*\\*&&*\end{bmatrix}$	$\begin{bmatrix}*&&\\&*&*\\&&*\end{bmatrix}$	$\begin{bmatrix}*&&\\&*&\\*&&*\end{bmatrix}$
sts	(13)	$\begin{pmatrix}1&2&3\\3&2&1\end{pmatrix}$	$\begin{bmatrix}&&1\\&1&\\1&&\end{bmatrix}$		bba	$\{v_3, v_2, v_1\}$	3	1	$\begin{bmatrix}*&&\\*&*&\\*&*&*\end{bmatrix}$	$\begin{bmatrix}*&&\\&*&\\&*&*\end{bmatrix}$	$\begin{bmatrix}*&&\\*&*&\\&&*\end{bmatrix}$

Conclusions on the summer vacation.

I guess that most part of my tasks coincide with this paper:
http://www.math.uni-bonn.de/ag/stroppel/Master%27s%20Thesis_Tomasz%20Przezdziecki.pdf
Sadly, I only found it in the last week of the vacation.

Some possible tasks to work on.

1. Work out what $K_0^{Id}(\mathcal{B})$ is.

ref:
In [3264], the author computes the Chow group of G(2,4).
https://pbelmans.ncag.info/blog/2018/08/22/rank-flag-varieties/
http://www.math.tau.ac.il/~bernstei/Publication_list/publication_texts/BGG-SchubCells-Usp.pdf

The module structure is easy, see
[https://math.stackexchange.com/questions/1012699/when-does-a-smooth-projective-variety-x-have-a-free-grothendieck-group]

2. Work out what $\mathcal{H}(G(F), I)$ is, i.e.
   - Bernstein presentation
   - try to understand the center of $\mathcal{H}(G(F), I)$
   - How does $\mathcal{H}(G(F), I)$ reflect informations on the rep theory
   - How can the Hecke algebra be realized as a Hecke algebra?

   ref. [Hecke, Sec 10-17], [Williamson 11.4-12.2]

3. Try to understand what the Hall algebra / Quantum group is.

ref: [Lec 1-4, Appendix 4, https://arxiv.org/pdf/math/0611617.pdf]

- understand $\mathcal{H}_{Rep_k^{nil}(Q)}$ where $Q = \bullet \quad \bullet \to \bullet \quad \bullet\circlearrowleft$ [Lec 2-3]
- understand [Lec 4]

$$\begin{array}{ccc} \mathcal{H}_{\mathbb{P}^1} & \cong & \mathcal{U}_v(\widehat{sl_2}) \\ \cup & & \cup \\ \mathcal{H}_{Tor(\mathbb{P}^1)} & \cong & \bigotimes_{x \in \mathbb{P}^1} \mathcal{H}_{Tor\, x} \end{array}$$

- define (Quantum) Kac-Moody / loop algs [Appendix 4]
- Why is that

graded

$$K_0(Rep^{\mathbb{Z}}(R)) = \mathcal{U}_q(n(Q))$$

where

$$R = \bigoplus_{\underline{d}} H_{\cdot}^{G \times \mathbb{C}^\times, BM}(Z_{\underline{d}})$$

and what is

$$K_0\left(Rep^{\mathbb{Z}}\left(\bigoplus_{\underline{d}} K_0^{G \times \mathbb{C}^\times}(Z_{\underline{d}})\right)\right) ?$$

4. Work out the big picture

$$\begin{tikzcd}
 & & \text{Hall alg} \arrow[r, "\text{realize}"] & \begin{array}{c}\text{Universal enveloping alg}\\ \text{(half) quantum gp}\end{array} & \text{Verma module} \\
 & K_0(R\text{-mod}) \arrow[ur, "\sim"] & & & \\
 & & \begin{array}{c}\text{Hecke alg}\\ \text{KLR alg = quiver Hecke alg}\\ \text{Nil Hecke ring}\end{array} \arrow[ul, "\text{get}"'] & & \text{modular form} \\
\text{Chow group} \arrow[r, phantom, "\sim"] & K_0^{Grp} \arrow[ur] \arrow[dr, "\sim"] & & & \\
 & & \text{convolution alg} & & K_0^{Grp}(\text{Springer fiber})
\end{tikzcd}$$

5. A closer check of Satake iso

$$\begin{array}{rcl}
K_0 & \text{combinations} & \text{Hecke alg} \\
R(B) = & \mathbb{Z}[X^*(T)] & = \mathcal{H}(\hat{T}(F), \hat{T}(\mathcal{O}_F)) \\
R(G) = & \mathbb{Z}[X^*(T)]^W & \neq \mathcal{H}(\hat{G}(F), \hat{G}(\mathcal{O}_F)) \\
R(G)[q^{\pm\frac{1}{2}}] = & \mathbb{Z}[X^*(T)]^W[q^{\pm\frac{1}{2}}] & = \mathcal{H}_{sph}[q^{\pm\frac{1}{2}}] \\
R(G\times\mathbb{C}^\times) = & \mathbb{Z}[X^*(T)]^W[t^{\pm 1}] & \\
K^{G\times\mathbb{C}^\times}(St) = & \mathcal{H}_{ext} & \overset{?}{=} \mathcal{H}(\hat{G}(F), I)
\end{array}$$

It's claimed by my schoolmate that

$$K_0(\mathrm{Perv}_B(G/B)) \cong \mathcal{H}(G, B)$$

sym monoidal structure induced from the convolution

then, what is

$$\begin{array}{ccc}
K_0^B(\mathcal{B}) & \cong & ? \\
K_0^{Id}(\mathcal{B}) & \cong & ? \\
? & \cong & \mathcal{H}(S_{m+n}, S_m\times S_n)
\end{array}$$

Now, about Steinberg varieties.

6. Draw a picture, indicating the shape/generalization of the following spaces:
(e.g. in the case of $\cdot$, $\cdot \circlearrowleft$, $\cdot \to \cdot$)

G, B, T

$\mathcal{B}, T^*\mathcal{B}, St$

$\mathfrak{g}, \tilde{\mathfrak{g}}, \mathfrak{g}^{sr}, \tilde{\mathfrak{g}}^{sr}, \mathcal{N}, \tilde{\mathcal{N}}, \mathfrak{h}, n$

$\tilde{\mathfrak{g}}^h, \mathcal{O}_h, \Lambda^h_w$

7. Try to understand what Kazhdan-Lusztig polynomials are [KL2], and
   - Compute the transformation matrix between
     $\{[T^*_w], w \in W_f\}$ and $\{[\Lambda^h_w], w \in W_f\}$? [KaSai]?
   - understand what standard/crystal basis is
   - understand the relationship between KL poly and crystal basis
   - see if it is related to two basis in Rep(G) (irr reps & multiplicative basis)

Answer from my schoolmate:

standard basis $\xleftrightarrow{\text{KL-poly}}$ canonical basis $\overset{\text{fix } q}{\rightsquigarrow}$ crystal basis

$\{[T^*_w], w \in W_f\}$ $\qquad$ $\{[\Lambda^h_w], w \in W_f\}$

irr reps $\qquad$ multiplicative basis

8. Try to understand the module part, i.e.,
   - numbers of components of the Springer fiber
   - how does $K_0^{Grp}(St)$ act on K_0^{Grp}(Springer fiber) also act on $K_0^{Grp}(Rep_{\mathrm{d}}(Q))$
   - does that occupy "all rep" of $K_0^{Grp}(St)$

9. Ways of finding multiplication structure

1 By direct computation (with techniques)

Hecke algebra — double coset calculus

2. By formulas as alg-isos

$K_0^G(\mathcal{B})$ — induction formula

3. By geometrical computation

cohomology — cup product ? de Rham calculus

Chow group — intersection theory

4. By deformation (indirect)

$H_{top}^{BM}(St)$

$K_0^{G\times\mathbb{C}^*}(St)$

10. Different views on the double coset

$$B\backslash G/B = (*/B)\times_{*/G}(*/B)$$

- as a set
- as flag variety quotient B-action
- as a stack
- groupoid structure

Some excuses for not working a lot on the project:

Preparation for summer school	2 weeks
Summer school of the modular form	1 week
Tourism in Paris	1 week
Conference in Antwerp	1 week
Reading [Ginz, Chap 5]	2 weeks
Computing $\mathcal{H}(G,B)$, $\mathcal{H}_{sph}$, ($\mathcal{H}_{aff}$)	1 week
Applying for tutorials, extend the residence permit, preparation for TOEFL exam, Klein AG, ...	2 weeks
Summer school on Langlands & ICM watch (part)	1 week
In total	11 weeks

tough new semester:

- 3 Seminars (+ Master Thesis Seminar)
- Tutorial
- TOEFL exam on 15th Oct.
- The seminar handout and other materials are not completed.
    - L-parameters
    - moduli in AG
    - some following developments of the modular form (different type of gps, Hecke operators, ...)
    - reps of $GL_2(\mathbb{Q}_p)$
- applying for the PhD program.