Title: Moore-Tachikawa conjecture, affine Grassmannian and Coulomb branches of star-shaped quivers

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Abstract: <p>Moore and Tachikawa conjecture that there exists a functor from the category of 2-bordisms to a certain category whose objects are algebraic groups and morphisms between G and H are given by affine symplectic varieties with an action of $G\times H$. I will explain a proof of this conjecture due to Ginsburg and Kazhdan, and its relation to Coulomb branches of certain quiver gauge theories which allows to make interesting calculations.</p>

Moore - Tachikawa conj

Category $\mathcal{C}$

Objects = affine alg. groups

Morphisms $\mathrm{Hom}_{\mathcal{C}}(G_1, G_2)$ = Isom classes of "symplectic varieties with Hamiltonian $G_1 \times G_2$-action"

affine, Poisson, generically symplectic (normal)

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$\downarrow$

affine, Poisson, generically symplectic
(normal)

Hamiltonian — chosen moment map

"$G_1 \times G_2$-action"

Composition

$$G_1 \xrightarrow{X_1} G_2 \xrightarrow{X_3} G_3$$

Composition: $X_1 \times X_2 /\!/ G_2 = \operatorname{Spec} \mathbb{C}\left[\mu^{-1}_{X_1 \times X_2}(0)\right]^{G_2}$

$(G_1 \times G_2) \times (G_2 \times G_3)$

$\circlearrowleft \Delta$

G_2

ep

What is $\mathrm{id} : G \to G$?

Answer T^*G

Exercise

Show that indeed T^*G is identity

Moore – Tachikawa

Given a reductive (connected) G

$\exists$ functor oriented 2-bordisms $\longrightarrow \mathcal{C}$

 $\longmapsto G$

S^2 

$\mathfrak{g} \simeq \mathfrak{g}^*$.

Given $G \rightsquigarrow Z_G$ = "the universal centralizer".

$\shortparallel$

"moduli space" of pairs (x, g) $x \in \mathfrak{g} = \text{Lie}$ regular

$g \in G$

$\text{ad}_g(x) = x$

$K \subset \mathfrak{g}$ (e, h, f) - principal sl_2-triple in $\mathfrak{g}$

Kostant slice $K = e + Z(f)$ $Z(f)$ = centralizer of f in $\mathfrak{g}$

$Z_G = \left\{ (g, x) \middle| \begin{array}{l} g \in G \\ x \in K \end{array} \ \text{ad}_g(x) = x \right\}$ - smooth and carries canonical symplectic structure

$\mu^{-1}_{X_1 \times X_2}(0)\Big]^{G_2}$

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(0) $\longmapsto G$

(1) $S^2 \longmapsto Z_G$

(3) $\longmapsto T^*G$

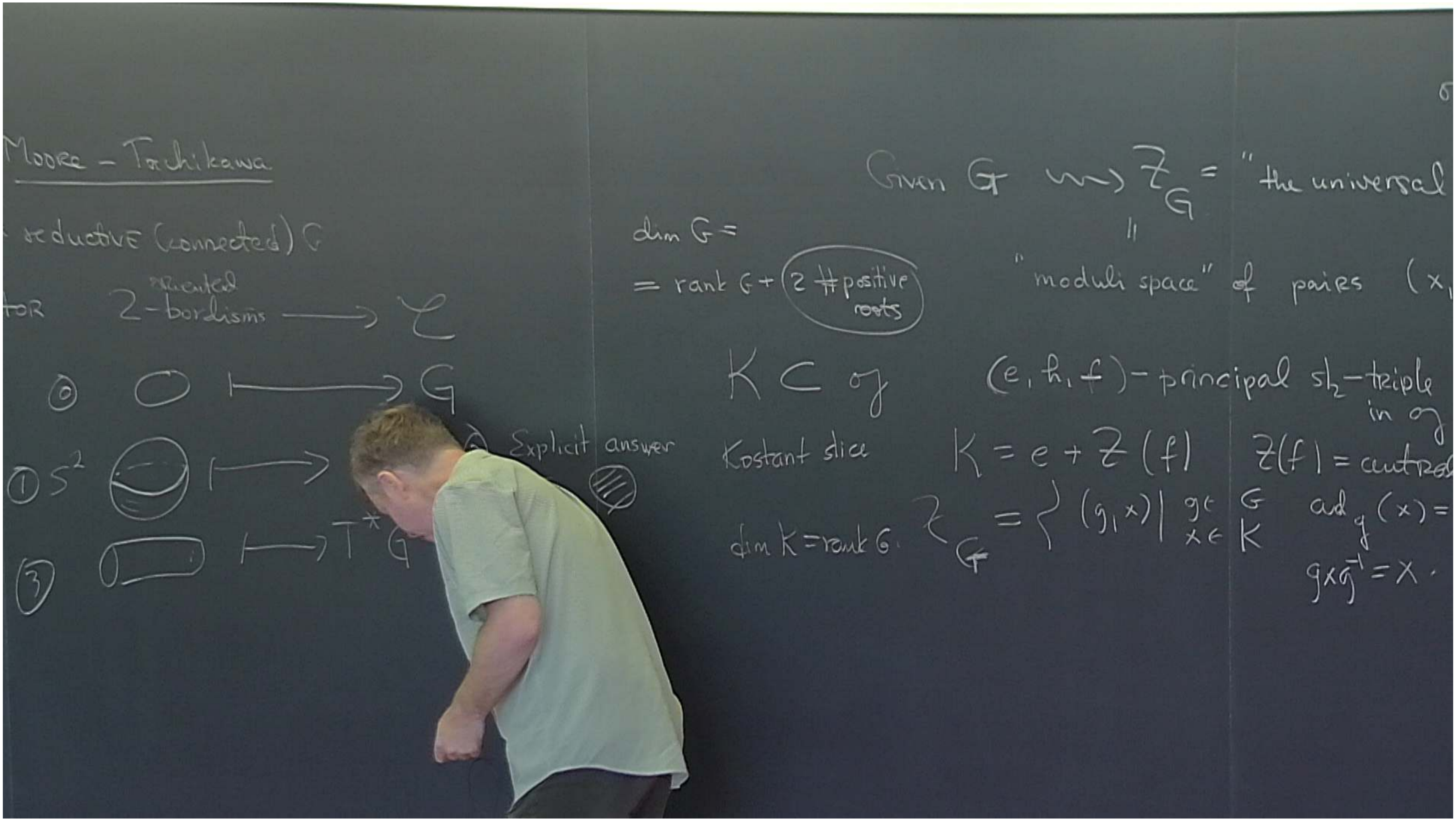
(2) Explicit answer for

$\downarrow$

$G \times K$

$K \subset$

Kostant sli


Moore – Tachikawa
reductive (connected) G
tor
oriented
2-bordisms ⟶ C
⓪ ⟼ G
① S² ⟼
Explicit answer
③ ⟼ T*G
dim G =
= rank G + 2 #positive roots
K ⊂ g
Kostant slice
dim K = rank G
Given G ⇝ Z_G = "the universal
"moduli space" of pairs (x,
(e, h, f) – principal sl₂–triple in g
K = e + Z(f)
Z(f) = centrali
Z_G = { (g, x) | g ∈ G, x ∈ K
ad_g (x) =
gxg⁻¹ = x.

Moore – Tachikawa

Given a reductive (connected) G

$\exists$ functor (monoidal): oriented 2-bordisms $\longrightarrow \mathcal{C}$

(0) $\longmapsto G$

(1) S^2 $\longmapsto Z_G$

$\longmapsto T^*G$

(3)

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$G \times K$

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= rank G + 2 #positive roots

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G_2-action"

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$(G_1 \times G_2) \times (G_2 \times G_3)$
$\circlearrowright \Delta$
G_2

Monoidal category

$G_1 \otimes_e G_2 = G_1 \times G_2$

Wha
Answ
Exer
Sho
T^*

Σ - Riemann surface whose boundary has n components

$\rightsquigarrow$

Symplectic variety X with an action of G^n

? "symplectic varieties with Hamiltonian $G_1 \times G_2$ - acti

$\downarrow$

affine, Poisson, generically symplectic (NORMAL)

Hamiltonian — chosen moment map

Moore – Tachikawa

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monoidal

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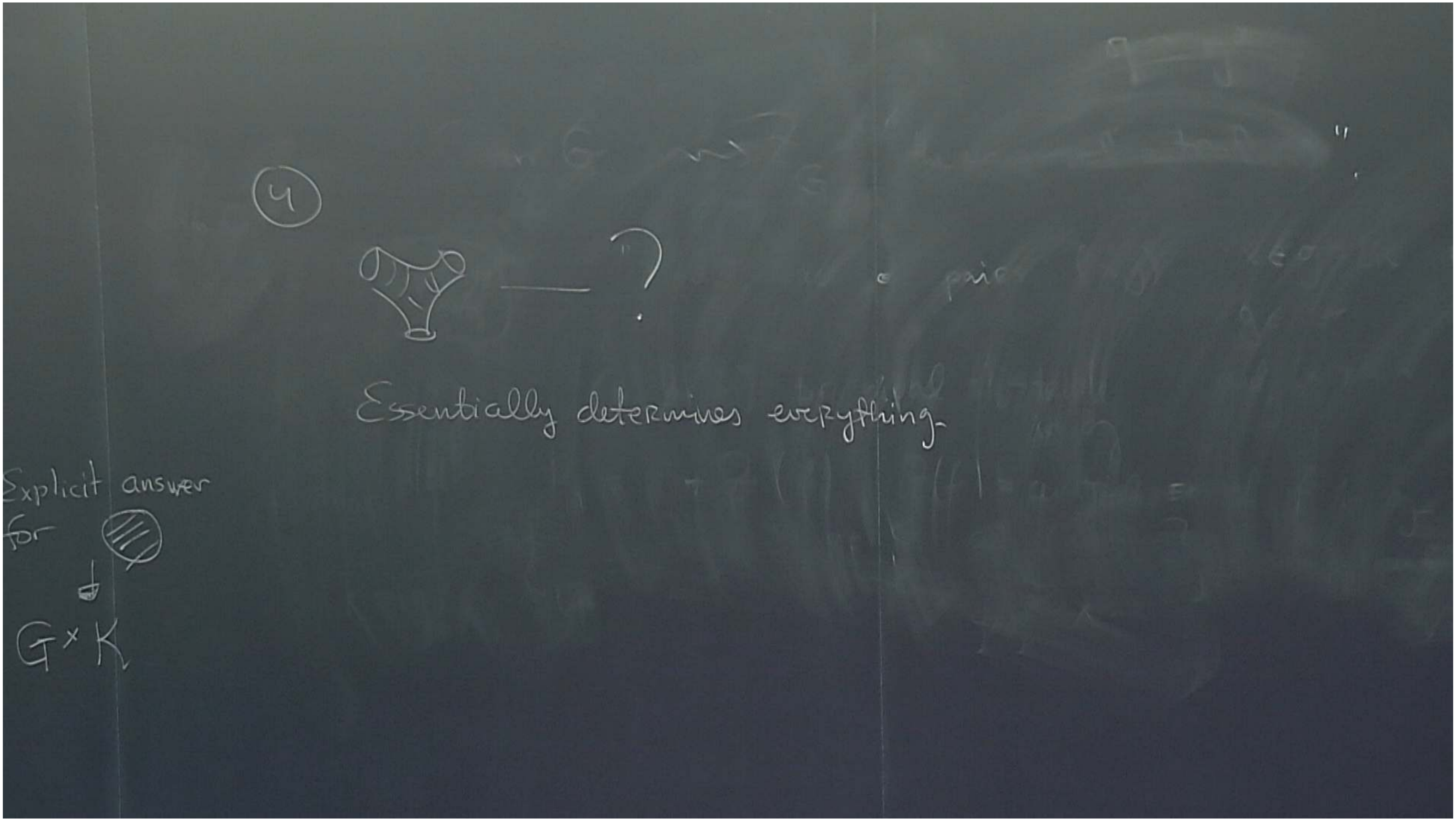
① $S^2 \longmapsto Z_G$

③ $\longmapsto T^*G$

② Explicit answer for

$G \times K$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?
Essentially determines everything.
Explicit answer
for
G x K

Σ - Riemann surface whose boundary has n components

Symplectic variety X with an action of G^n

(G simple, ADE).

Higgs branch of certain 3d QFT

6d (0,2)-theory

compactify on $S^1 \times \Sigma$

3d theory

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Hamiltonian — close

(G simple, ADE).

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...kawa

...onnected) G

...ected
...ordisms $\longrightarrow \mathcal{C}$

$\longmapsto G$

$\longmapsto Z_G$

$\longmapsto T^*G$

filling in a hole corresponds to KW_G

② Explicit answer for

$G \times K$

④

— ?

Essentially determines everything.

$Z_G \simeq KW_{G\times G}(T^*G)$

$G\times K = KW_{G^\vee}(T^*G)$

$KW_G(G\times K) = Z_G.$

X - variety with G-action (symp)

Let $N \subset G$ be a maximal unip

Let $\chi: N \to \mathbb{C}$ be a non-deg homomorphism

$N/[N,N] \simeq \bigoplus_{\alpha_i} \mathbb{C}_{\alpha_i}$ simple roots

$KW_G(X) = \mu_N^{-1}(\chi)/N.$

$\chi: \mathfrak{n} \longrightarrow \mathbb{C}$

(4)

 —— ?

Essentially determines everything.

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$$\chi : \mathfrak{n} \longrightarrow \mathbb{C}$$

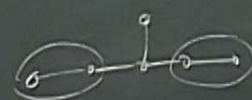
$\times G_2$ - action"

 $\longrightarrow$?

$G = SL(2)$ $\quad ? = \mathbb{C}^2 \otimes \mathbb{C}^2 \otimes \mathbb{C}^2$

$G = SL(3)$ $\quad ?$ = the closure of the minimal nilpotent orbit in E_6

Exercise Invent a Hamiltonian action of $SL(3)^3$ on this



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$G = SL(4)$ $\quad$ I don't know

What is $id : G \to G$?

Answer T^*G

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Construction

Ginzburg-Kazhdan + Bapat

$G = SL(N)$ or $GL(N)$

there is a different way of looking at it.

$)^3$ on this

Change of notation.

Fix a reductive group G

Construct the sought-for functor for $G^\vee$ (Langlands dual group).

functor for $G^\vee$ (Langlands dual group).

$$Gr_G = G((t)) / G[[t]] = \qquad \mathcal{O} = \mathbb{C}[[t]]$$

= moduli space of principal G-bundles on $D = \operatorname{Spec} \mathbb{C}[[t]]$ + triv on $D^* = \operatorname{Spec} \mathbb{C}((t))$

Going to study $\mathcal{D}_{G(\mathcal{O})}(Gr_G)$.

X-sympl variety with G

Let $N \subseteq G$ be a

Let

functor for $G^\vee$
(Langlands dual group).

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Going to study $\mathcal{D}_{G(\mathcal{O})}(Gr_G)$

carries a canonical monoidal structure
symmetric

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Going to study $\mathcal{D}_{G(\mathcal{O})}(Gr_G)$

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symmetric convolution of sheaves

Given an object $\mathcal{A} \in D_{G(\mathcal{O})}(Gr_G)$

it makes sense to say that $\mathcal{A}$ is ring object.

$$\mathcal{A} * \mathcal{A} \xrightarrow{m} \mathcal{A}$$

structure

onvolution of sheaves

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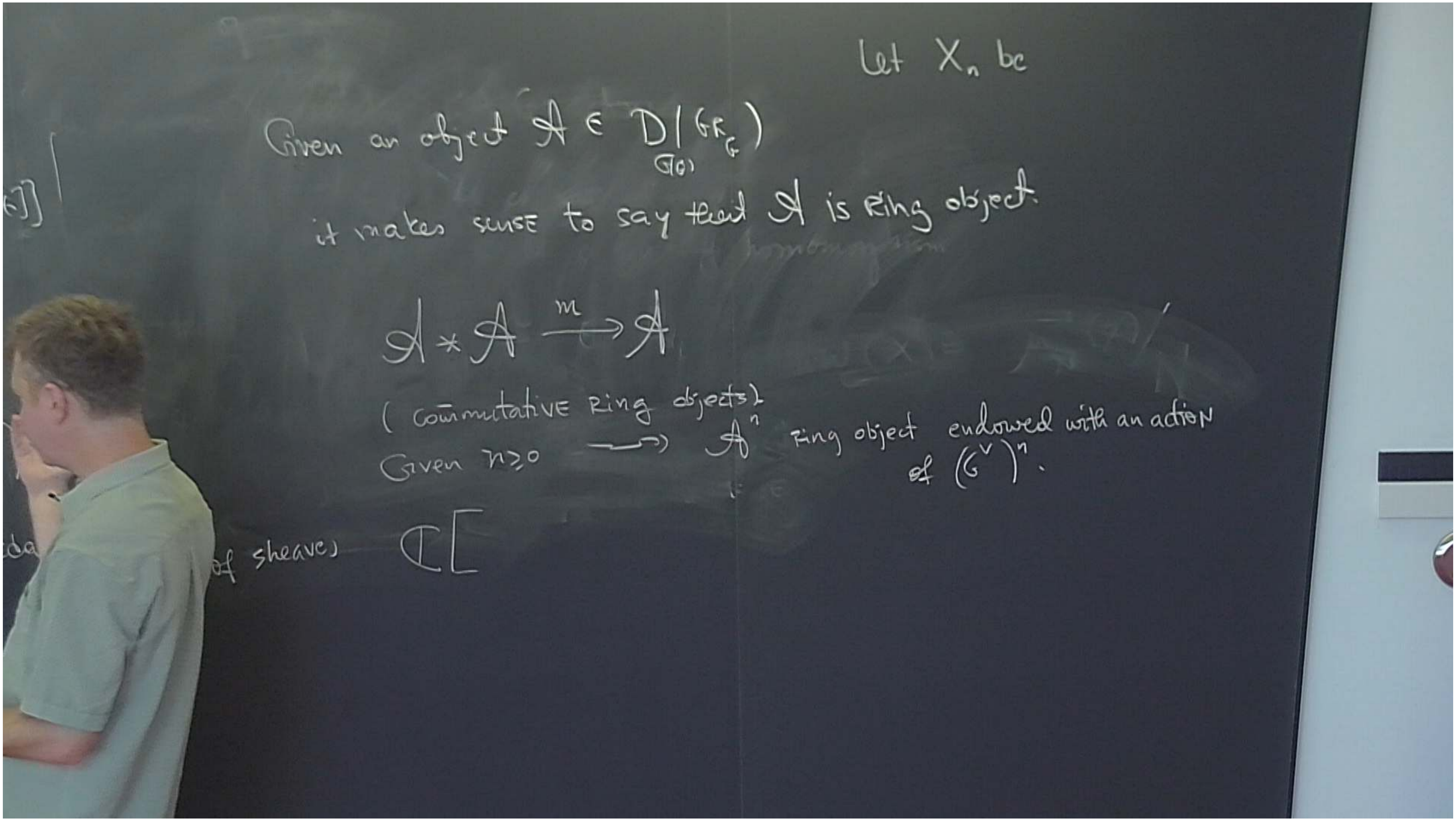
(commutative Ring objects)

dal structure

convolution of sheaves


Let X_n be
Given an object $\mathcal{A} \in D_{G(O)}(Gr_G)$
it makes sense to say that $\mathcal{A}$ is Ring object.
$\mathcal{A} * \mathcal{A} \xrightarrow{m} \mathcal{A}$
(commutative Ring objects)
Given $n \geq 0$ $\longrightarrow$ $\mathcal{A}^n$ Ring object endowed with an action of $(G^\vee)^n$.
of sheaves
$\mathbb{C}[$

$= G((t)) / G[[t]] =$ $\qquad \mathcal{O} = \mathbb{C}[[t]]$

moduli space of principal G-bundles on $D = \mathrm{Spec}\,\mathbb{C}[[t]]$

+ triv at $D^* = \mathrm{Spec}\,\mathbb{C}((t))$

to study $D_{G(\mathcal{O})}(Gr_G)$

carries a canonical monoidal structure (convolution of sheaves)

symmetric

Given an object $\mathcal{A} \in D_{G(\mathcal{O})}(Gr_G)$

it makes sense to say that $\mathcal{A}$ is ring object.

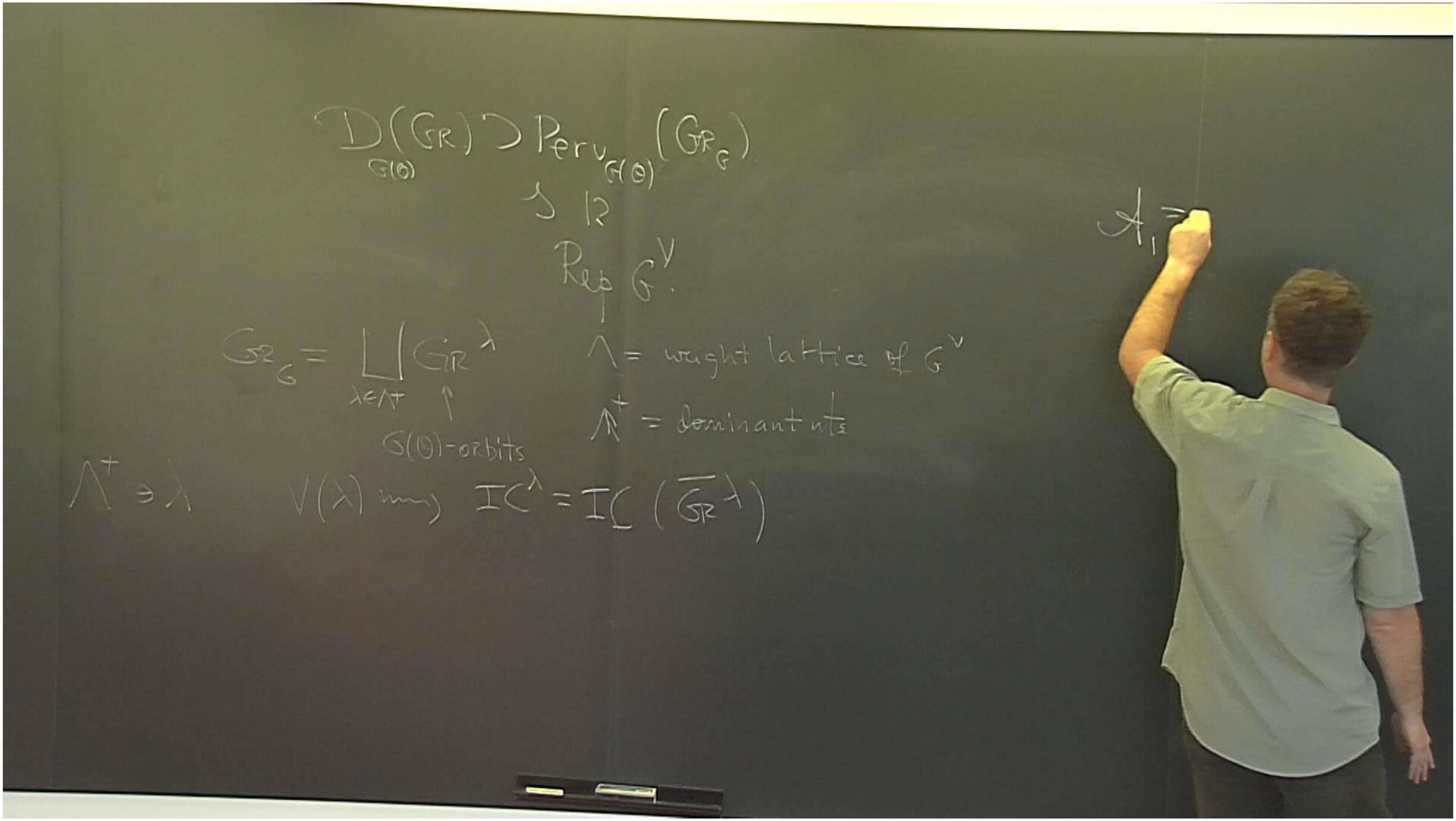
$$\mathcal{A} * \mathcal{A} \xrightarrow{m} \mathcal{A}$$

(commutative ring objects)

Given $n \geq 0 \longrightarrow \mathcal{A}_n$ ring object endowed with an action of $(G^\vee)^n$.

$$\mathbb{C}[X_n] = H^*_{G(\mathcal{O})}(\mathcal{A}_n).$$

Let X_n be the image of S^2 with n punctures under MT functor.


$D_{G(\mathcal{O})}(Gr) \supset Perv_{G(\mathcal{O})}(Gr_G)$
$\wr\!\cong$
$Rep\, G^\vee$
$Gr_G = \bigsqcup_{\lambda \in \Lambda^+} Gr^\lambda$
$G(\mathcal{O})$-orbits
Λ = weight lattice of $G^\vee$
Λ^+ = dominant wts
$\Lambda^+ \ni \lambda \qquad V(\lambda) \rightsquigarrow IC^\lambda = IC(\overline{Gr^\lambda})$
$A_1 =$

$$D_{G(\mathcal{O})}(Gr) \supset \mathrm{Perv}_{G(\mathcal{O})}(Gr_G)$$

$$\mathcal{S} \;\wr\!\!\downarrow \quad \text{equiv of monoidal categories}$$

$$\mathrm{Rep}\, G^\vee$$

$$Gr_G = \bigsqcup_{\lambda \in \Lambda^+} Gr^\lambda$$

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$$\Lambda^+ \ni \lambda \qquad V(\lambda) \rightsquigarrow IC^\lambda = IC(\overline{Gr}^\lambda)$$

$$\mathcal{A}_1 = \mathcal{S}^{-1}(\text{Regular representation})$$

$$\| $$

$$\bigoplus_{\lambda \in \Lambda^+} IC^\lambda \otimes V(\lambda)^*$$

of
oidal
egorica
lattice of $G^\vee$
nt nts

$$A_1 = \mathcal{S}^{-1}(\text{Regular representation}) = \bigoplus_{\lambda \in \Lambda^+} IC^\lambda \otimes V(\lambda)^*$$

$G = SL(2)$

$G = SL(3)$

Exercise Inve

$G = SL(4)$? don

$\mathcal{F} \in \mathrm{Perv}_{G(\mathcal{O})}(\mathrm{Gr}_G)$

$S(\mathcal{F})$ as a vector space

it is $H^*(\mathrm{Gr}_G, \mathcal{F})$

$$D_{G(\mathcal{O})}(\mathrm{Gr}) \supset \mathrm{Perv}_{G(\mathcal{O})}(\mathrm{Gr}_G)$$

$$S \;\wr\!\!|$$

$$\mathrm{Rep}\, G^\vee.$$

equiv of monoidal categoric

$$\mathrm{Gr}_G = \bigsqcup_{\lambda \in \Lambda^+} \mathrm{Gr}^\lambda$$

$G(\mathcal{O})$-orbits

$\Lambda =$ weight latt

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(Gr_G)

equiv of monoidal categories

weight lattice of $G^\vee$

dominant wts

$(\overline{\mathrm{Gr}^\lambda})$

$G \times K$

$$\mathcal{A}_1 = \mathcal{S}^{-1}(\text{Regular representation})$$

$$\| $$

$$\bigoplus_{\lambda \in \Lambda^+} IC^\lambda \otimes V(\lambda)^*$$

$K = \mathfrak{t}/W$ $\quad \mathfrak{t} \subset \mathfrak{g}$ Cartan

(Gr_G)

$G(\mathcal{O})$

equiv of monoidal categories

$G^\vee$.

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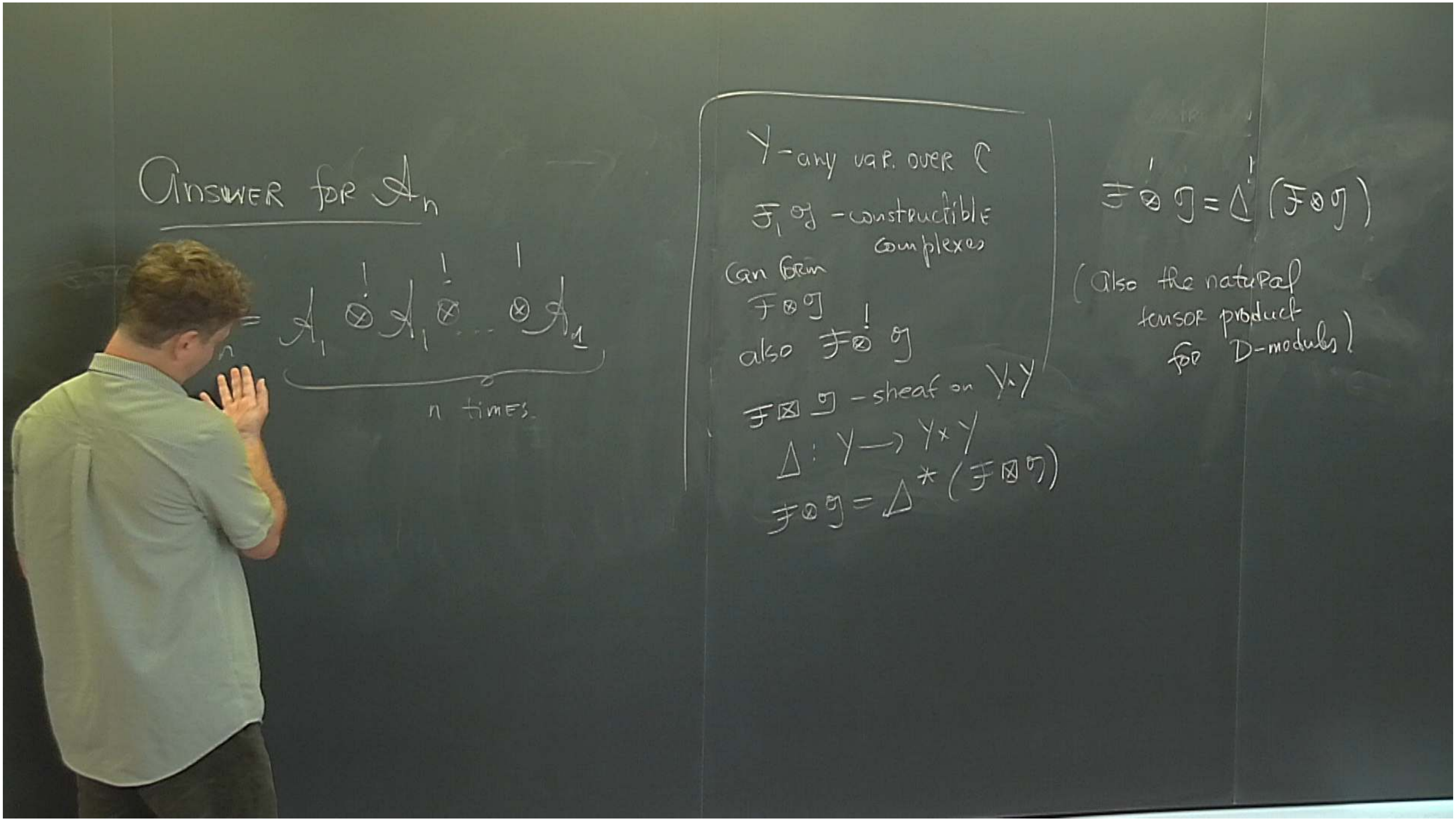

Answer for $\mathcal{A}_n$
$\mathcal{A}_n = \underbrace{\mathcal{A}_1 \overset{!}{\otimes} \mathcal{A}_1 \overset{!}{\otimes} \cdots \overset{!}{\otimes} \mathcal{A}_1}_{n \text{ times}}$
Y - any var. over $\mathbb{C}$
$\mathcal{F}, \mathcal{G}$ - constructible complexes
Can form $\mathcal{F} \otimes \mathcal{G}$
also $\mathcal{F} \overset{!}{\otimes} \mathcal{G}$
$\mathcal{F} \boxtimes \mathcal{G}$ - sheaf on $Y \times Y$
$\Delta : Y \to Y \times Y$
$\mathcal{F} \otimes \mathcal{G} = \Delta^*(\mathcal{F} \boxtimes \mathcal{G})$
$\mathcal{F} \overset{!}{\otimes} \mathcal{G} = \Delta^!(\mathcal{F} \boxtimes \mathcal{G})$
(also the natural tensor product for D-modules)

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$$\mathcal{A}_0 = \omega_{\mathrm{Gr}_G}$$

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(also the natural tensor product for D-modules)

$H^*_c(Y, \omega_Y)$ = homology of Y

$H^*(Y, \omega_Y)$ = Borel-Moore hom. of Y.

$G^\vee$

(Langlands dual group).

$Gr_G = G((t))$

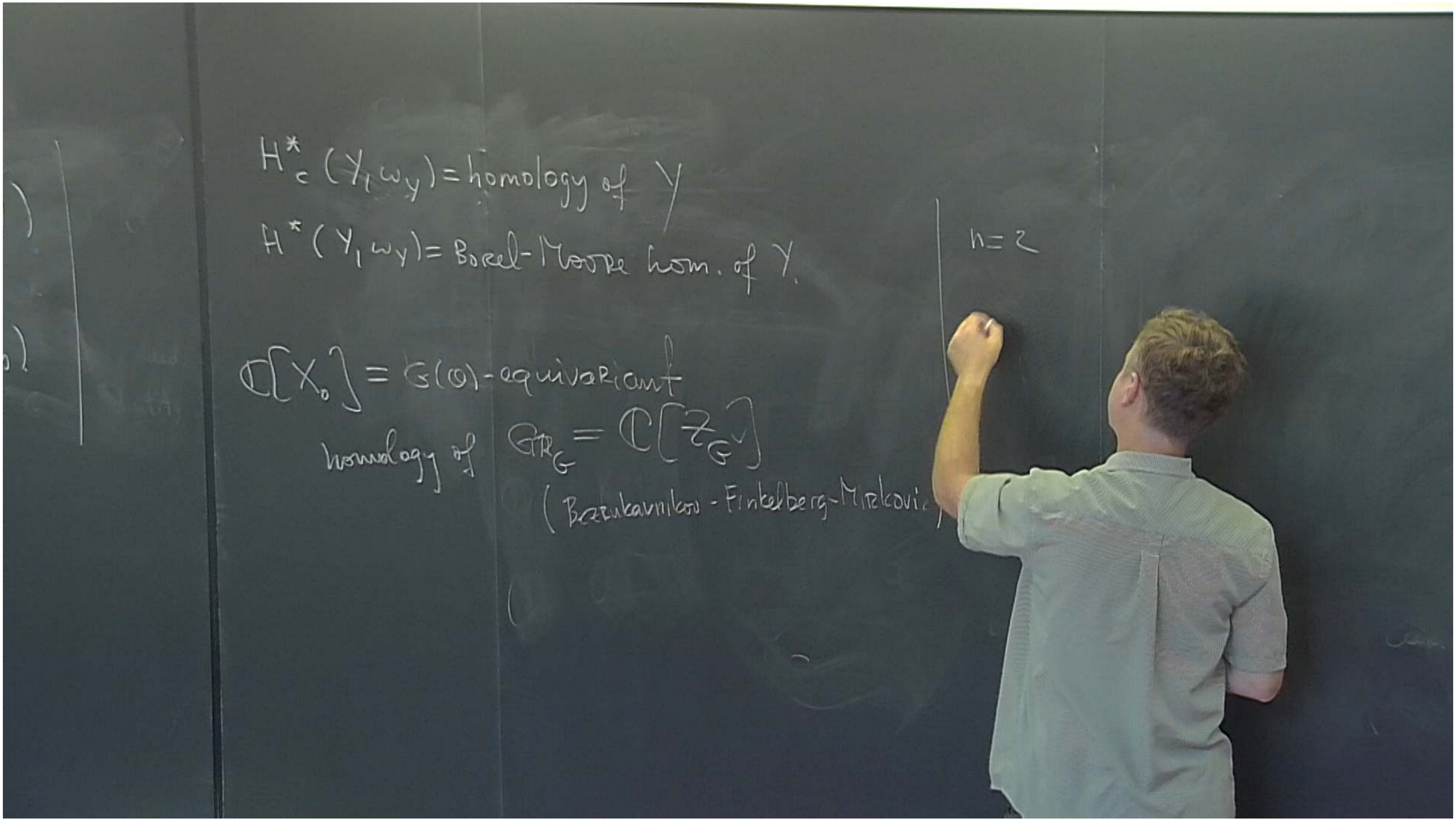
= moduli spa

G - bundles

+ triv

Going to study

Carr


$H^*_c(Y, \omega_Y)$ = homology of Y
$H^*(Y, \omega_Y)$ = Borel-Moore hom. of Y.
$\mathbb{C}[X_0]$ = $G(\mathcal{O})$-equivariant
homology of Gr_G = $\mathbb{C}[Z_{G^\vee}]$
(Bezrukavnikov - Finkelberg - Mirkovic)
n=2

of Y.

$G^\vee]$

Finkelberg-Mirkovic)

$n=2$

$$\mathcal{A}_1 \overset{!}{\otimes} \mathcal{A}_1$$

$$H^*_{G(\mathcal{O})}(\mathcal{A}_1 \overset{!}{\otimes} \mathcal{A}_1) = \mathbb{C}[T^* G^\vee]$$

sheaves

Given an

it mak

Answer for $\mathcal{A}_n$

$$\mathcal{A}_n = \underbrace{\mathcal{A}_1 \overset{!}{\otimes} \mathcal{A}_1 \overset{!}{\otimes} \cdots \overset{!}{\otimes} \mathcal{A}_1}_{n \text{ times}}$$

$$\mathcal{A}_0 = \omega_{Gr_G}$$

$\mathbb{C}[X_n]$ has a canonical quantization

$$H^*_{G(\mathcal{O}) \rtimes \mathbb{C}^*}(\mathcal{A}_n)$$

a canonical

$\times \mathbb{C}^*$ (A_n)

Q, I - vertices

Given G_{gauge} - reductive

N - rep of G_{gauge}

$\mathcal{M}_C$ - affine singular symp. variety

$\vec{v}, \vec{w} \in \mathbb{Z}_{\geq 0}$

$\dim V_i = v_i$

$\dim W_i = w_i$

$$G_{gauge} = \prod_{i \in I} GL(V_i)$$

$$N = \bigoplus_{i \to j} \mathrm{Hom}(V_i, V_j) \oplus \Big(\bigoplus_i \mathrm{Hom}(V_i, W_i) \Big)$$

The

$\bigoplus_i \mathrm{Hom}(V_i, W_i))$

Theorem

$G = GL(N)$

Then X_n is the Coulomb branch of the quiver theory for $*$-shaped quiver.

$n = \#\text{legs}$.

$N =$ length of each leg

sheave

$\oplus\left(\bigoplus_i \mathrm{Hom}(V_i, W_i)\right)$

Theorem

$G = GL(N)$

Then X_n is the Coulomb branch

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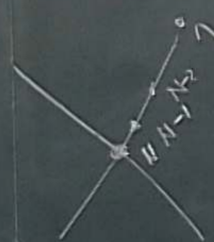


$n = \#$legs.

$N =$ length of each leg

$(1) - (2) - (3) - (4) - \cdots (N-1) - (N)$

$GL(N) \times \mathbb{C}^N$.

shea

$\mathcal{R}_{G_{gauge}, \mathbb{N}}$

$\downarrow$

$Gr_{G_{gauge}, \mathbb{N}}$

$G_{gauge} = \prod GL(i)$, $i=1$

$\mathbb{N} = \bigoplus_{i=0}^{N-1} Hom(\mathbb{C}^i, \mathbb{C}^{i+1})$

...ped quiver

legs

...th of each leg

$\textcircled{N}$

$\times \mathbb{C}^N$

$\mathcal{P}$ - principal G-bundle on D

κ :- triv. of $\mathcal{P}$ on D^*

φ - section of $\mathcal{P}_{\mathbb{N}}$ on D

which has no pole w.r.t. to κ.

Let X_n be the image of

S^2 with n p... under

$\mathbb{C}[\mathcal{M}_C] =$

$= H^{BM}_{G_{gauge}(\mathcal{O})}(\mathcal{R}_{G_{gauge}, \mathbb{N}})$

$\pi: \mathcal{R}_{G_{gauge}, \mathbb{N}} \to Gr_{GL(N)}$

$$\boxed{\pi_* \omega = \mathcal{A}_1 \supset GL(N)}$$

Theorem

$G = GL(N)$

Then X_n is the Coulomb branch of the quiver theory for $*$-shaped quiver.

$(v_i, w_i))$

$n = \#$legs.

$N = $ le... each leg

$\mathcal{R}_{G_{gauge}, \mathbb{N}}$

$\downarrow$

$Gr_{G_{gauge}, \mathbb{N}}$

$G_{gauge} = \prod_{i=1} GL(i)$

$\mathbb{N} = \bigoplus_{i=0}^{N-1} Hom(\mathbb{C}^i, \mathbb{C}^{i+1})$

$\mathcal{P}$ - principal G - b...

κ :- triv. of $\mathcal{P}$

φ - section of ...

which has no ...

$$\pi : \mathcal{R}_{G_{gauge}, N} \to Gr_{GL(N)}.$$

Theorem

$G = GL(N)$

Then X_n is the Coulomb branch of the quiver theory for $*$-shaped quiver

$$\boxed{\pi_* \omega = \mathcal{A}_1 \supset GL(N)}$$

$Hom(V_i, W_i))$

$n = \#$legs

$N =$ length of each leg

$$① - ② - ③ - ④ - \cdots (N-1) - (N)$$

$GL(N) \times \mathbb{C}^N$

$$\begin{array}{c} \mathcal{R}_{G_{gauge}, \mathbb{N}} \\ \downarrow \\ Gr_{G_{gauge}} \end{array}$$

$\mathbb{N}$

$$G_{gauge} = \prod_{i=1} GL(i)$$

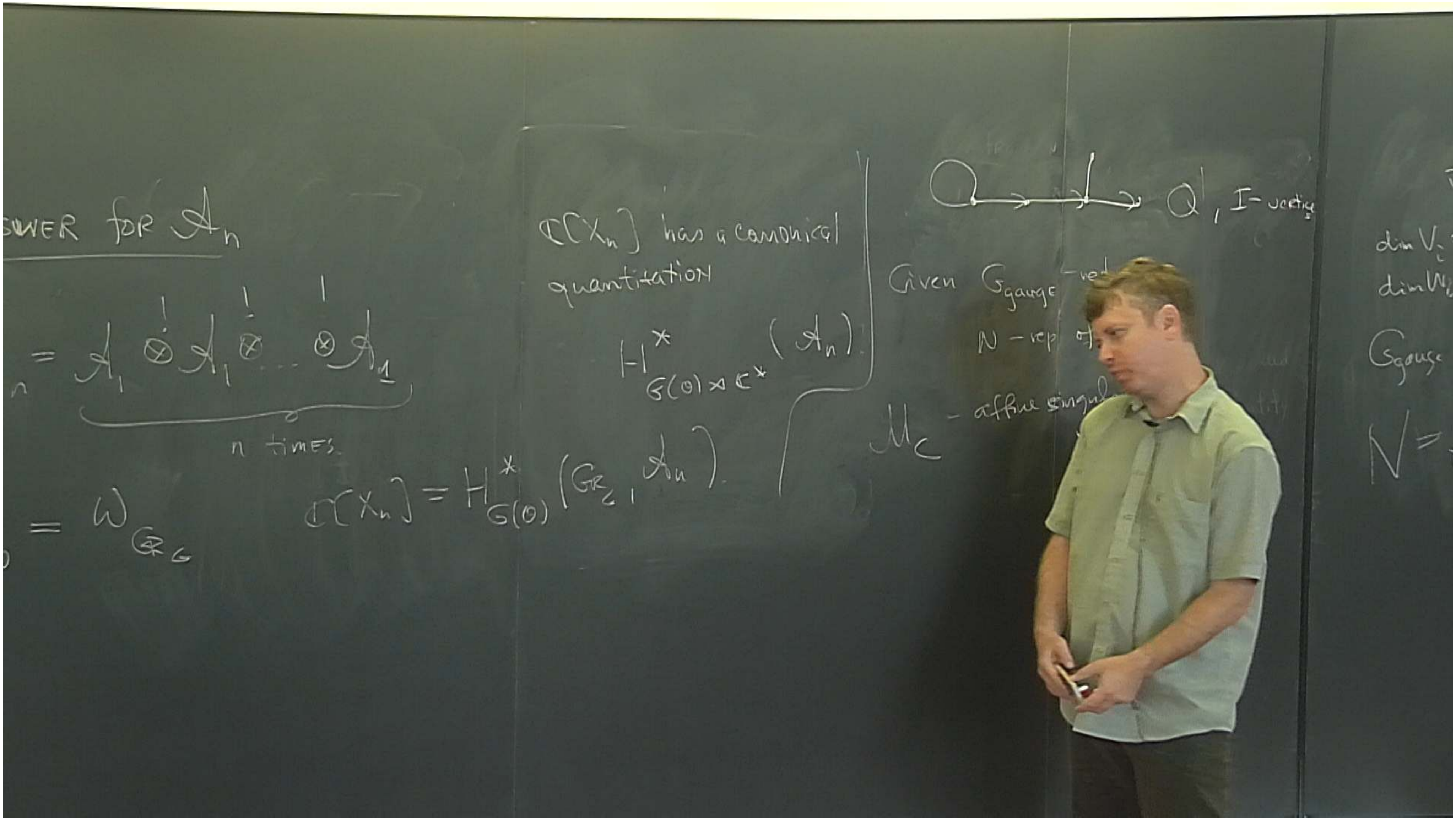
$$\mathbb{N} = \bigoplus_{i=0}^{N-1} Hom(\mathbb{C}^i, \mathbb{C}^{i+1})$$

P - principal G

κ :- triv. of

φ - section of

which has


n times
has a canonical quantitation
Given
N - rep
affine singul
I- vertic