

Koszul duality between generalized Takiff Lie algebras and superalgebras

(joint work with Jacob Greenstein)

Volodymyr Mazorchuk
(Uppsala University)

Lie Superalgebras
December 11, 2012, Rome, Italy

Beilinson-Ginzburg-Soergel setup

Beilinson-Ginzburg-Soergel setup

$\mathbb{k} = \bar{\mathbb{k}}$ — field

Beilinson-Ginzburg-Soergel setup

$\mathbb{k} = \bar{\mathbb{k}}$ — field

In this talk: **graded** = \mathbb{Z} -graded

Beilinson-Ginzburg-Soergel setup

$\mathbb{k} = \bar{\mathbb{k}}$ — field

In this talk: **graded** = \mathbb{Z} -graded

$A = \bigoplus_{i \in \mathbb{Z}} A_i$ — graded associative \mathbb{k} -algebra

Beilinson-Ginzburg-Soergel setup

$\mathbb{k} = \bar{\mathbb{k}}$ — field

In this talk: **graded** = \mathbb{Z} -graded

$A = \bigoplus_{i \in \mathbb{Z}} A_i$ — graded associative \mathbb{k} -algebra

Assume that the grading is **positive** in the following sense:

Beilinson-Ginzburg-Soergel setup

$\mathbb{k} = \bar{\mathbb{k}}$ — field

In this talk: **graded** = \mathbb{Z} -graded

$A = \bigoplus_{i \in \mathbb{Z}} A_i$ — graded associative \mathbb{k} -algebra

Assume that the grading is **positive** in the following sense:

- ▶ $A_i = 0$ for $i < 0$;

Beilinson-Ginzburg-Soergel setup

$\mathbb{k} = \bar{\mathbb{k}}$ — field

In this talk: **graded** = \mathbb{Z} -graded

$A = \bigoplus_{i \in \mathbb{Z}} A_i$ — graded associative \mathbb{k} -algebra

Assume that the grading is **positive** in the following sense:

- ▶ $A_i = 0$ for $i < 0$;
- ▶ all A_i are finite dimensional;

Beilinson-Ginzburg-Soergel setup

$\mathbb{k} = \bar{\mathbb{k}}$ — field

In this talk: **graded** = \mathbb{Z} -graded

$A = \bigoplus_{i \in \mathbb{Z}} A_i$ — graded associative \mathbb{k} -algebra

Assume that the grading is **positive** in the following sense:

- ▶ $A_i = 0$ for $i < 0$;
- ▶ all A_i are finite dimensional;
- ▶ A_0 is split semisimple.

Beilinson-Ginzburg-Soergel setup

$\mathbb{k} = \bar{\mathbb{k}}$ — field

In this talk: **graded** = \mathbb{Z} -graded

$A = \bigoplus_{i \in \mathbb{Z}} A_i$ — graded associative \mathbb{k} -algebra

Assume that the grading is **positive** in the following sense:

- ▶ $A_i = 0$ for $i < 0$;
- ▶ all A_i are finite dimensional;
- ▶ A_0 is split semisimple.

Quadratic dual

Quadratic dual

A_1 is an A_0 - A_0 – bimodule

Quadratic dual

A_1 is an A_0 - A_0 - bimodule

$A_0[A_1] = \bigoplus_{i \geq 0} A_1^{\otimes i}$ — the corresponding tensor algebra

Quadratic dual

A_1 is an A_0 - A_0 - bimodule

$A_0[A_1] = \bigoplus_{i \geq 0} A_1^{\otimes i}$ — the corresponding tensor algebra

$\varphi : A_0[A_1] \rightarrow A$ the natural map (the identity on A_0 and A_1)

Quadratic dual

A_1 is an A_0 - A_0 - bimodule

$A_0[A_1] = \bigoplus_{i \geq 0} A_1^{\otimes i}$ — the corresponding tensor algebra

$\varphi : A_0[A_1] \rightarrow A$ the natural map (the identity on A_0 and A_1)

$\mu : A_1 \otimes_{A_0} A_1 \rightarrow A_2$ — the multiplication map (equals $\varphi|_{A_1 \otimes_{A_0} A_1}$)

Quadratic dual

A_1 is an A_0 - A_0 - bimodule

$A_0[A_1] = \bigoplus_{i \geq 0} A_1^{\otimes i}$ — the corresponding tensor algebra

$\varphi : A_0[A_1] \rightarrow A$ the natural map (the identity on A_0 and A_1)

$\mu : A_1 \otimes_{A_0} A_1 \rightarrow A_2$ — the multiplication map (equals $\varphi|_{A_1 \otimes_{A_0} A_1}$)

$A_1^* = \text{Hom}_{\mathbb{k}}(A_1, \mathbb{k})$ — the dual A_0 - A_0 - bimodule

Quadratic dual

A_1 is an A_0 - A_0 - bimodule

$A_0[A_1] = \bigoplus_{i \geq 0} A_1^{\otimes i}$ — the corresponding tensor algebra

$\varphi : A_0[A_1] \rightarrow A$ the natural map (the identity on A_0 and A_1)

$\mu : A_1 \otimes_{A_0} A_1 \rightarrow A_2$ — the multiplication map (equals $\varphi|_{A_1 \otimes_{A_0} A_1}$)

$A_1^* = \text{Hom}_{\mathbb{k}}(A_1, \mathbb{k})$ — the dual A_0 - A_0 - bimodule

Identify $(A_1 \otimes_{A_0} A_1)^*$ with $A_1^* \otimes_{A_0} A_1^*$

Quadratic dual

A_1 is an A_0 - A_0 - bimodule

$A_0[A_1] = \bigoplus_{i \geq 0} A_1^{\otimes i}$ — the corresponding tensor algebra

$\varphi : A_0[A_1] \rightarrow A$ the natural map (the identity on A_0 and A_1)

$\mu : A_1 \otimes_{A_0} A_1 \rightarrow A_2$ — the multiplication map (equals $\varphi|_{A_1 \otimes_{A_0} A_1}$)

$A_1^* = \text{Hom}_{\mathbb{k}}(A_1, \mathbb{k})$ — the dual A_0 - A_0 - bimodule

Identify $(A_1 \otimes_{A_0} A_1)^*$ with $A_1^* \otimes_{A_0} A_1^*$

$\mu^* : A_2^* \rightarrow (A_1 \otimes_{A_0} A_1)^* = A_1^* \otimes_{A_0} A_1^*$ — the dual map

Quadratic dual

A_1 is an A_0 - A_0 - bimodule

$A_0[A_1] = \bigoplus_{i \geq 0} A_1^{\otimes i}$ — the corresponding tensor algebra

$\varphi : A_0[A_1] \rightarrow A$ the natural map (the identity on A_0 and A_1)

$\mu : A_1 \otimes_{A_0} A_1 \rightarrow A_2$ — the multiplication map (equals $\varphi|_{A_1 \otimes_{A_0} A_1}$)

$A_1^* = \text{Hom}_{\mathbb{k}}(A_1, \mathbb{k})$ — the dual A_0 - A_0 - bimodule

Identify $(A_1 \otimes_{A_0} A_1)^*$ with $A_1^* \otimes_{A_0} A_1^*$

$\mu^* : A_2^* \rightarrow (A_1 \otimes_{A_0} A_1)^* = A_1^* \otimes_{A_0} A_1^*$ — the dual map

$A^! := A_0[A_1^*]/(\text{Im}(\mu^*))$ — the **quadratic dual** of A

Quadratic dual

A_1 is an A_0 - A_0 - bimodule

$A_0[A_1] = \bigoplus_{i \geq 0} A_1^{\otimes i}$ — the corresponding tensor algebra

$\varphi : A_0[A_1] \rightarrow A$ the natural map (the identity on A_0 and A_1)

$\mu : A_1 \otimes_{A_0} A_1 \rightarrow A_2$ — the multiplication map (equals $\varphi|_{A_1 \otimes_{A_0} A_1}$)

$A_1^* = \text{Hom}_{\mathbb{k}}(A_1, \mathbb{k})$ — the dual A_0 - A_0 - bimodule

Identify $(A_1 \otimes_{A_0} A_1)^*$ with $A_1^* \otimes_{A_0} A_1^*$

$\mu^* : A_2^* \rightarrow (A_1 \otimes_{A_0} A_1)^* = A_1^* \otimes_{A_0} A_1^*$ — the dual map

$A^! := A_0[A_1^*]/(\text{Im}(\mu^*))$ — the **quadratic dual** of A

Example

Example

$$A = \mathbb{C}[t]$$

Example

$$A = \mathbb{C}[t]$$

$$A_i = \mathbb{C}\{t^i\}$$

Example

$$A = \mathbb{C}[t]$$

$$A_i = \mathbb{C}\{t^i\} \quad A_0 = \mathbb{C}$$

Example

$$A = \mathbb{C}[t]$$

$$A_i = \mathbb{C}\{t^i\}$$

$$A_0 = \mathbb{C}$$

$$A_1 = \mathbb{C}\{t\}$$

Example

$$A = \mathbb{C}[t]$$

$$A_i = \mathbb{C}\{t^i\}$$

$$A_0 = \mathbb{C}$$

$$A_1 = \mathbb{C}\{t\}$$

$$A_1^* = \mathbb{C}\{t^*\}$$

Example

$$A = \mathbb{C}[t]$$

$$A_i = \mathbb{C}\{t^i\} \quad A_0 = \mathbb{C} \quad A_1 = \mathbb{C}\{t\}$$

$$A_1^* = \mathbb{C}\{t^*\}$$

$\mu : \mathbb{C}\{t\} \otimes_{\mathbb{C}} \mathbb{C}\{t\} \rightarrow \mathbb{C}\{t^2\}$ is an isomorphism

Example

$$A = \mathbb{C}[t]$$

$$A_i = \mathbb{C}\{t^i\} \quad A_0 = \mathbb{C} \quad A_1 = \mathbb{C}\{t\}$$

$$A_1^* = \mathbb{C}\{t^*\}$$

$\mu : \mathbb{C}\{t\} \otimes_{\mathbb{C}} \mathbb{C}\{t\} \rightarrow \mathbb{C}\{t^2\}$ is an isomorphism

$\mu^* : \mathbb{C}\{(t^*)^2\} \rightarrow \mathbb{C}\{t^*\} \otimes_{\mathbb{C}} \mathbb{C}\{t^*\}$ is an isomorphism

Example

$$A = \mathbb{C}[t]$$

$$A_i = \mathbb{C}\{t^i\} \quad A_0 = \mathbb{C} \quad A_1 = \mathbb{C}\{t\}$$

$$A_1^* = \mathbb{C}\{t^*\}$$

$\mu : \mathbb{C}\{t\} \otimes_{\mathbb{C}} \mathbb{C}\{t\} \rightarrow \mathbb{C}\{t^2\}$ is an isomorphism

$\mu^* : \mathbb{C}\{(t^*)^2\} \rightarrow \mathbb{C}\{t^*\} \otimes_{\mathbb{C}} \mathbb{C}\{t^*\}$ is an isomorphism

$$A^! = \mathbb{C}[\mathbb{C}\{t^*\}] / (\mathbb{C}\{t^*\} \otimes_{\mathbb{C}} \mathbb{C}\{t^*\}) \cong \mathbb{C}[t^*] / ((t^*)^2)$$

Example

$$A = \mathbb{C}[t]$$

$$A_i = \mathbb{C}\{t^i\} \quad A_0 = \mathbb{C} \quad A_1 = \mathbb{C}\{t\}$$

$$A_1^* = \mathbb{C}\{t^*\}$$

$\mu : \mathbb{C}\{t\} \otimes_{\mathbb{C}} \mathbb{C}\{t\} \rightarrow \mathbb{C}\{t^2\}$ is an isomorphism

$\mu^* : \mathbb{C}\{(t^*)^2\} \rightarrow \mathbb{C}\{t^*\} \otimes_{\mathbb{C}} \mathbb{C}\{t^*\}$ is an isomorphism

$$A^! = \mathbb{C}[\mathbb{C}\{t^*\}] / (\mathbb{C}\{t^*\} \otimes_{\mathbb{C}} \mathbb{C}\{t^*\}) \cong \mathbb{C}[t^*] / ((t^*)^2)$$

$\mathbb{C}[t^*] / ((t^*)^2)$ — the algebra of dual numbers

Example

$$A = \mathbb{C}[t]$$

$$A_i = \mathbb{C}\{t^i\} \quad A_0 = \mathbb{C} \quad A_1 = \mathbb{C}\{t\}$$

$$A_1^* = \mathbb{C}\{t^*\}$$

$\mu : \mathbb{C}\{t\} \otimes_{\mathbb{C}} \mathbb{C}\{t\} \rightarrow \mathbb{C}\{t^2\}$ is an isomorphism

$\mu^* : \mathbb{C}\{(t^*)^2\} \rightarrow \mathbb{C}\{t^*\} \otimes_{\mathbb{C}} \mathbb{C}\{t^*\}$ is an isomorphism

$$A^! = \mathbb{C}[\mathbb{C}\{t^*\}] / (\mathbb{C}\{t^*\} \otimes_{\mathbb{C}} \mathbb{C}\{t^*\}) \cong \mathbb{C}[t^*] / ((t^*)^2)$$

$\mathbb{C}[t^*] / ((t^*)^2)$ — the algebra of dual numbers

Linear complexes of projective A -module

Linear complexes of projective A -module

$A\text{-gmod}$ — category of finitely generated graded A -modules

Linear complexes of projective A -module

$A\text{-gmod}$ — category of finitely generated graded A -modules

$\langle 1 \rangle$ — shift or grading (decreases the grading by 1)

Linear complexes of projective A -module

$A\text{-gmod}$ — category of finitely generated graded A -modules

$\langle 1 \rangle$ — shift or grading (decreases the grading by 1)

$$\mathcal{X}^\bullet: \quad \dots \rightarrow \mathcal{X}^{-1} \rightarrow \mathcal{X}^0 \rightarrow \mathcal{X}^1 \rightarrow \dots$$

Linear complexes of projective A -module

$A\text{-gmod}$ — category of finitely generated graded A -modules

$\langle 1 \rangle$ — shift or grading (decreases the grading by 1)

$$\mathcal{X}^\bullet: \quad \dots \rightarrow \mathcal{X}^{-1} \rightarrow \mathcal{X}^0 \rightarrow \mathcal{X}^1 \rightarrow \dots$$

complex of graded projective A -modules

Linear complexes of projective A -module

$A\text{-gmod}$ — category of finitely generated graded A -modules

$\langle 1 \rangle$ — shift or grading (decreases the grading by 1)

\mathcal{X}^\bullet : $\dots \rightarrow \mathcal{X}^{-1} \rightarrow \mathcal{X}^0 \rightarrow \mathcal{X}^1 \rightarrow \dots$

complex of graded projective A -modules

\mathcal{X}^\bullet is **linear** if $\mathcal{X}^i \in \text{add}(A\langle i \rangle)$

Linear complexes of projective A -module

$A\text{-gmod}$ — category of finitely generated graded A -modules

$\langle 1 \rangle$ — shift or grading (decreases the grading by 1)

$$\mathcal{X}^\bullet: \quad \dots \rightarrow \mathcal{X}^{-1} \rightarrow \mathcal{X}^0 \rightarrow \mathcal{X}^1 \rightarrow \dots$$

complex of graded projective A -modules

\mathcal{X}^\bullet is **linear** if $\mathcal{X}^i \in \text{add}(A\langle i \rangle)$ pictorially:

Linear complexes of projective A -module

$A\text{-gmod}$ — category of finitely generated graded A -modules

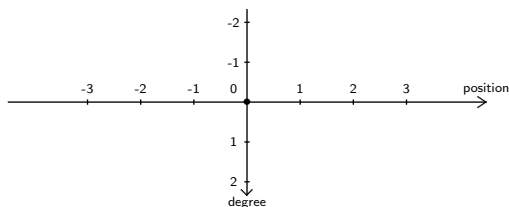
$\langle 1 \rangle$ — shift or grading (decreases the grading by 1)

$$\mathcal{X}^\bullet: \quad \dots \rightarrow \mathcal{X}^{-1} \rightarrow \mathcal{X}^0 \rightarrow \mathcal{X}^1 \rightarrow \dots$$

complex of graded projective A -modules

\mathcal{X}^\bullet is **linear** if $\mathcal{X}^i \in \text{add}(A\langle i \rangle)$

pictorially:



Linear complexes of projective A -module

$A\text{-gmod}$ — category of finitely generated graded A -modules

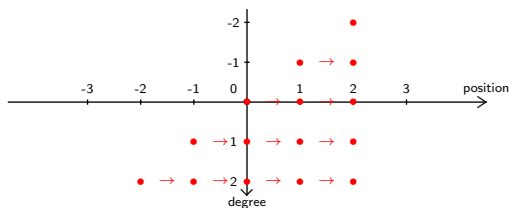
$\langle 1 \rangle$ — shift or grading (decreases the grading by 1)

$$\mathcal{X}^\bullet: \quad \dots \rightarrow \mathcal{X}^{-1} \rightarrow \mathcal{X}^0 \rightarrow \mathcal{X}^1 \rightarrow \dots$$

complex of graded projective A -modules

\mathcal{X}^\bullet is **linear** if $\mathcal{X}^i \in \text{add}(A\langle i \rangle)$

pictorially:



Linear complexes of projective A -module

$A\text{-gmod}$ — category of finitely generated graded A -modules

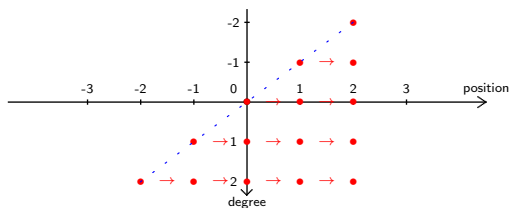
$\langle 1 \rangle$ — shift or grading (decreases the grading by 1)

$$\mathcal{X}^\bullet: \quad \dots \rightarrow \mathcal{X}^{-1} \rightarrow \mathcal{X}^0 \rightarrow \mathcal{X}^1 \rightarrow \dots$$

complex of graded projective A -modules

\mathcal{X}^\bullet is **linear** if $\mathcal{X}^i \in \text{add}(A\langle i \rangle)$

pictorially:



Linear complexes of projective A -module

$A\text{-gmod}$ — category of finitely generated graded A -modules

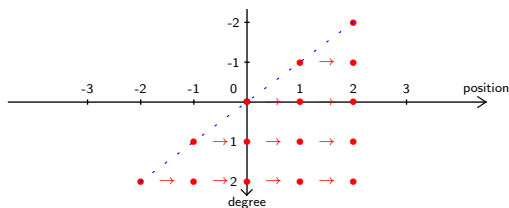
$\langle 1 \rangle$ — shift or grading (decreases the grading by 1)

$$\mathcal{X}^\bullet: \quad \dots \rightarrow \mathcal{X}^{-1} \rightarrow \mathcal{X}^0 \rightarrow \mathcal{X}^1 \rightarrow \dots$$

complex of graded projective A -modules

\mathcal{X}^\bullet is **linear** if $\mathcal{X}^i \in \text{add}(A\langle i \rangle)$

pictorially:



Abelian quadratic duality

Abelian quadratic duality

$\mathcal{L}(P)$ — the category of linear complexes of projective graded A -modules

Abelian quadratic duality

$\mathcal{L}(P)$ — the category of linear complexes of projective graded A -modules

Note: no homotopies are possible between linear complexes!

Abelian quadratic duality

$\mathcal{L}(P)$ — the category of linear complexes of projective graded A -modules

Note: no homotopies are possible between linear complexes!

$\mathcal{L}(P)$ — a subcategory of the derived category

Abelian quadratic duality

$\mathcal{L}(P)$ — the category of linear complexes of projective graded A -modules

Note: no homotopies are possible between linear complexes!

$\mathcal{L}(P)$ — a subcategory of the derived category

Abelian quadratic duality theorem. [Martinez-Villa – Saorin; M. – Ovsienko] The category $\mathcal{L}(P)$ is equivalent to the category of locally finite dimensional graded right $A^!$ -modules.

Abelian quadratic duality

$\mathcal{L}(P)$ — the category of linear complexes of projective graded A -modules

Note: no homotopies are possible between linear complexes!

$\mathcal{L}(P)$ — a subcategory of the derived category

Abelian quadratic duality theorem. [Martinez-Villa – Saorin; M. – Ovsienko] The category $\mathcal{L}(P)$ is equivalent to the category of locally finite dimensional graded right $A^!$ -modules.

Derived quadratic duality – setup

Derived quadratic duality – setup

\mathbb{P}^\bullet — the subcategory of $\mathcal{L}(P)$ given by representatives of indecomposable projectives

Derived quadratic duality – setup

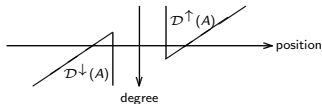
\mathbb{P}^\bullet — the subcategory of $\mathcal{L}(P)$ given by representatives of indecomposable projectives

$\mathcal{D}^\downarrow(A)$ and $\mathcal{D}^\uparrow(A)$ — subcategories of the corresponding derived categories of graded modules with modules concentrated in the following regions:

Derived quadratic duality – setup

\mathbb{P}^\bullet — the subcategory of $\mathcal{L}(P)$ given by representatives of indecomposable projectives

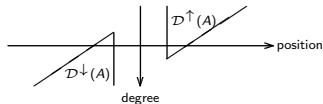
$\mathcal{D}^\downarrow(A)$ and $\mathcal{D}^\uparrow(A)$ — subcategories of the corresponding derived categories of graded modules with modules concentrated in the following regions:



Derived quadratic duality – setup

\mathbb{P}^\bullet — the subcategory of $\mathcal{L}(P)$ given by representatives of indecomposable projectives

$\mathcal{D}^\downarrow(A)$ and $\mathcal{D}^\uparrow(A)$ — subcategories of the corresponding derived categories of graded modules with modules concentrated in the following regions:



Derived quadratic duality

Derived quadratic duality

A is *quadratic* if it is generated by A_0 and A_1 (i.e. φ is surjective) and $\text{Ker}(\varphi)$ is generated in degree 2.

Derived quadratic duality

A is *quadratic* if it is generated by A_0 and A_1 (i.e. φ is surjective) and $\text{Ker}(\varphi)$ is generated in degree 2.

Derived quadratic duality theorem. [M. – Ovsineko – Stroppel]

Derived quadratic duality

A is *quadratic* if it is generated by A_0 and A_1 (i.e. φ is surjective) and $\text{Ker}(\varphi)$ is generated in degree 2.

Derived quadratic duality theorem. [M. – Ovsineko – Stroppel]

- ▶ $K' := \mathbb{P}^\bullet \overset{\mathcal{L}}{\otimes}_{A^!} -$ and $K := \mathcal{R}\text{Hom}(\mathbb{P}^\bullet, -)$ form a pair of adjoint functors between $\mathcal{D}^\downarrow(A)$ and $\mathcal{D}^\uparrow(A^!)$.

Derived quadratic duality

A is *quadratic* if it is generated by A_0 and A_1 (i.e. φ is surjective) and $\text{Ker}(\varphi)$ is generated in degree 2.

Derived quadratic duality theorem. [M. – Ovsineko – Stroppel]

- ▶ $K' := \mathbb{P}^\bullet \overset{\mathcal{L}}{\otimes}_{A^!} -$ and $K := \mathcal{R}\text{Hom}(\mathbb{P}^\bullet, -)$ form a pair of adjoint functors between $\mathcal{D}^\downarrow(A)$ and $\mathcal{D}^\uparrow(A^!)$.
- ▶ $K(\mathcal{X}^\bullet \langle j \rangle [i]) = (K \mathcal{X}^\bullet) \langle -j \rangle [i + j]$ and similarly for K' .

Derived quadratic duality

A is *quadratic* if it is generated by A_0 and A_1 (i.e. φ is surjective) and $\text{Ker}(\varphi)$ is generated in degree 2.

Derived quadratic duality theorem. [M. – Ovsineko – Stroppel]

- ▶ $K' := \mathbb{P}^\bullet \overset{\mathcal{L}}{\otimes}_{A^!} -$ and $K := \mathcal{R}\text{Hom}(\mathbb{P}^\bullet, -)$ form a pair of adjoint functors between $\mathcal{D}^\downarrow(A)$ and $\mathcal{D}^\uparrow(A^!)$.
- ▶ $K(\mathcal{X}^\bullet \langle j \rangle [i]) = (K \mathcal{X}^\bullet) \langle -j \rangle [i + j]$ and similarly for K' .
- ▶ K maps simples to injectives and K' maps simples to projectives.

Derived quadratic duality

A is *quadratic* if it is generated by A_0 and A_1 (i.e. φ is surjective) and $\text{Ker}(\varphi)$ is generated in degree 2.

Derived quadratic duality theorem. [M. – Ovsineko – Stroppel]

- ▶ $K' := \mathbb{P}^\bullet \overset{\mathcal{L}}{\otimes}_{A^!} -$ and $K := \mathcal{R}\text{Hom}(\mathbb{P}^\bullet, -)$ form a pair of adjoint functors between $\mathcal{D}^\downarrow(A)$ and $\mathcal{D}^\uparrow(A^!)$.
- ▶ $K(\mathcal{X}^\bullet \langle j \rangle [i]) = (K \mathcal{X}^\bullet) \langle -j \rangle [i + j]$ and similarly for K' .
- ▶ K maps simples to injectives and K' maps simples to projectives.
- ▶ K' maps injectives to the “linear part” of the projective resolution of the corresponding simple.

Derived quadratic duality

A is *quadratic* if it is generated by A_0 and A_1 (i.e. φ is surjective) and $\text{Ker}(\varphi)$ is generated in degree 2.

Derived quadratic duality theorem. [M. – Ovsineko – Stroppel]

- ▶ $K' := \mathbb{P}^\bullet \overset{\mathcal{L}}{\otimes}_{A^!} -$ and $K := \mathcal{R}\text{Hom}(\mathbb{P}^\bullet, -)$ form a pair of adjoint functors between $\mathcal{D}^\downarrow(A)$ and $\mathcal{D}^\uparrow(A^!)$.
- ▶ $K(\mathcal{X}^\bullet \langle j \rangle [i]) = (K \mathcal{X}^\bullet) \langle -j \rangle [i + j]$ and similarly for K' .
- ▶ K maps simples to injectives and K' maps simples to projectives.
- ▶ K' maps injectives to the “linear part” of the projective resolution of the corresponding simple.
- ▶ If A is quadratic, then K maps projectives to the “linear part” of the injective resolution of the corresponding simple.

Derived quadratic duality

A is *quadratic* if it is generated by A_0 and A_1 (i.e. φ is surjective) and $\text{Ker}(\varphi)$ is generated in degree 2.

Derived quadratic duality theorem. [M. – Ovsineko – Stroppel]

- ▶ $K' := \mathbb{P}^\bullet \overset{\mathcal{L}}{\otimes}_{A^!} -$ and $K := \mathcal{R}\text{Hom}(\mathbb{P}^\bullet, -)$ form a pair of adjoint functors between $\mathcal{D}^\downarrow(A)$ and $\mathcal{D}^\uparrow(A^!)$.
- ▶ $K(\mathcal{X}^\bullet \langle j \rangle [i]) = (K \mathcal{X}^\bullet) \langle -j \rangle [i + j]$ and similarly for K' .
- ▶ K maps simples to injectives and K' maps simples to projectives.
- ▶ K' maps injectives to the “linear part” of the projective resolution of the corresponding simple.
- ▶ If A is quadratic, then K maps projectives to the “linear part” of the injective resolution of the corresponding simple.

Koszul duality

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

Koszul duality theorem. [Beilinson – Ginzburg – Soergel]

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

Koszul duality theorem. [Beilinson – Ginzburg – Soergel] If A is Koszul, then K and K' are mutually inverse equivalences of categories.

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

Koszul duality theorem. [Beilinson – Ginzburg – Soergel] If A is Koszul, then K and K' are mutually inverse equivalences of categories.

Extended Koszul duality theorem. [MOS]

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

Koszul duality theorem. [Beilinson – Ginzburg – Soergel] If A is Koszul, then K and K' are mutually inverse equivalences of categories.

Extended Koszul duality theorem. [MOS] If A is positively graded then the following statements are equivalent:

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

Koszul duality theorem. [Beilinson – Ginzburg – Soergel] If A is Koszul, then K and K' are mutually inverse equivalences of categories.

Extended Koszul duality theorem. [MOS] If A is positively graded then the following statements are equivalent:

- ▶ A is Koszul.

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

Koszul duality theorem. [Beilinson – Ginzburg – Soergel] If A is Koszul, then K and K' are mutually inverse equivalences of categories.

Extended Koszul duality theorem. [MOS] If A is positively graded then the following statements are equivalent:

- ▶ A is Koszul.
- ▶ K and K' are mutually inverse equivalences of categories.

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

Koszul duality theorem. [Beilinson – Ginzburg – Soergel] If A is Koszul, then K and K' are mutually inverse equivalences of categories.

Extended Koszul duality theorem. [MOS] If A is positively graded then the following statements are equivalent:

- ▶ A is Koszul.
- ▶ K and K' are mutually inverse equivalences of categories.
- ▶ K maps simples to injectives and K' maps simples to projectives.

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

Koszul duality theorem. [Beilinson – Ginzburg – Soergel] If A is Koszul, then K and K' are mutually inverse equivalences of categories.

Extended Koszul duality theorem. [MOS] If A is positively graded then the following statements are equivalent:

- ▶ A is Koszul.
- ▶ K and K' are mutually inverse equivalences of categories.
- ▶ K maps simples to injectives and K' maps simples to projectives.
- ▶ K maps projectives to simples.

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

Koszul duality theorem. [Beilinson – Ginzburg – Soergel] If A is Koszul, then K and K' are mutually inverse equivalences of categories.

Extended Koszul duality theorem. [MOS] If A is positively graded then the following statements are equivalent:

- ▶ A is Koszul.
- ▶ K and K' are mutually inverse equivalences of categories.
- ▶ K maps simples to injectives and K' maps simples to projectives.
- ▶ K maps projectives to simples.
- ▶ K' maps injectives to simples.

A is *Koszul* if the minimal projective resolution of A_0 belongs to $\mathcal{L}(P)$

Koszul duality theorem. [Beilinson – Ginzburg – Soergel] If A is Koszul, then K and K' are mutually inverse equivalences of categories.

Extended Koszul duality theorem. [MOS] If A is positively graded then the following statements are equivalent:

- ▶ A is Koszul.
- ▶ K and K' are mutually inverse equivalences of categories.
- ▶ K maps simples to injectives and K' maps simples to projectives.
- ▶ K maps projectives to simples.
- ▶ K' maps injectives to simples.

Koszul algebras from category \mathcal{O}

Koszul algebras from category \mathcal{O}

\mathfrak{g} — simple finite dimensional complex Lie algebra

Koszul algebras from category \mathcal{O}

\mathfrak{g} — simple finite dimensional complex Lie algebra

$\mathfrak{g} = \mathfrak{n}_- \oplus \mathfrak{h} \oplus \mathfrak{n}_+$ — triangular decomposition

Koszul algebras from category \mathcal{O}

\mathfrak{g} — simple finite dimensional complex Lie algebra

$\mathfrak{g} = \mathfrak{n}_- \oplus \mathfrak{h} \oplus \mathfrak{n}_+$ — triangular decomposition

\mathcal{O} — the corresponding BGG category \mathcal{O}

Koszul algebras from category \mathcal{O}

\mathfrak{g} — simple finite dimensional complex Lie algebra

$\mathfrak{g} = \mathfrak{n}_- \oplus \mathfrak{h} \oplus \mathfrak{n}_+$ — triangular decomposition

\mathcal{O} — the corresponding BGG category \mathcal{O}

\mathcal{O}_0 — the principal block of \mathcal{O} (containing the trivial module)

Koszul algebras from category \mathcal{O}

\mathfrak{g} — simple finite dimensional complex Lie algebra

$\mathfrak{g} = \mathfrak{n}_- \oplus \mathfrak{h} \oplus \mathfrak{n}_+$ — triangular decomposition

\mathcal{O} — the corresponding BGG category \mathcal{O}

\mathcal{O}_0 — the principal block of \mathcal{O} (containing the trivial module)

A — the associative algebra describing \mathcal{O}_0

Koszul algebras from category \mathcal{O}

\mathfrak{g} — simple finite dimensional complex Lie algebra

$\mathfrak{g} = \mathfrak{n}_- \oplus \mathfrak{h} \oplus \mathfrak{n}_+$ — triangular decomposition

\mathcal{O} — the corresponding BGG category \mathcal{O}

\mathcal{O}_0 — the principal block of \mathcal{O} (containing the trivial module)

A — the associative algebra describing \mathcal{O}_0

Theorem. [Soergel]

Koszul algebras from category \mathcal{O}

\mathfrak{g} — simple finite dimensional complex Lie algebra

$\mathfrak{g} = \mathfrak{n}_- \oplus \mathfrak{h} \oplus \mathfrak{n}_+$ — triangular decomposition

\mathcal{O} — the corresponding BGG category \mathcal{O}

\mathcal{O}_0 — the principal block of \mathcal{O} (containing the trivial module)

A — the associative algebra describing \mathcal{O}_0

Theorem. [Soergel] A is Koszul, moreover, $A^! \cong A$.

Koszul algebras from category \mathcal{O}

\mathfrak{g} — simple finite dimensional complex Lie algebra

$\mathfrak{g} = \mathfrak{n}_- \oplus \mathfrak{h} \oplus \mathfrak{n}_+$ — triangular decomposition

\mathcal{O} — the corresponding BGG category \mathcal{O}

\mathcal{O}_0 — the principal block of \mathcal{O} (containing the trivial module)

A — the associative algebra describing \mathcal{O}_0

Theorem. [Soergel] A is Koszul, moreover, $A^! \cong A$.

Koszul algebras for $GL(m|n)$

Koszul algebras for $GL(m|n)$

$G := GL(m|n)$ — the general linear supergroup

Koszul algebras for $GL(m|n)$

$G := GL(m|n)$ — the general linear supergroup

$\mathcal{F}(m|n)$ — the category of finite dimensional representations of G

Koszul algebras for $GL(m|n)$

$G := GL(m|n)$ — the general linear supergroup

$\mathcal{F}(m|n)$ — the category of finite dimensional representations of G

\mathcal{B} — a block of $\mathcal{F}(m|n)$

Koszul algebras for $GL(m|n)$

$G := GL(m|n)$ — the general linear supergroup

$\mathcal{F}(m|n)$ — the category of finite dimensional representations of G

\mathcal{B} — a block of $\mathcal{F}(m|n)$

\mathcal{A} — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Koszul algebras for $GL(m|n)$

$G := GL(m|n)$ — the general linear supergroup

$\mathcal{F}(m|n)$ — the category of finite dimensional representations of G

\mathcal{B} — a block of $\mathcal{F}(m|n)$

\mathcal{A} — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Theorem. [Brundan-Stroppel]

Koszul algebras for $GL(m|n)$

$G := GL(m|n)$ — the general linear supergroup

$\mathcal{F}(m|n)$ — the category of finite dimensional representations of G

\mathcal{B} — a block of $\mathcal{F}(m|n)$

\mathcal{A} — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Theorem. [Brundan-Stroppel] \mathcal{A} is Koszul.

Koszul algebras for $GL(m|n)$

$G := GL(m|n)$ — the general linear supergroup

$\mathcal{F}(m|n)$ — the category of finite dimensional representations of G

\mathcal{B} — a block of $\mathcal{F}(m|n)$

\mathcal{A} — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Theorem. [Brundan-Stroppel] \mathcal{A} is Koszul.

Note: Graded \mathbb{k} -linear categories are defined similarly to algebras.

Koszul algebras for $GL(m|n)$

$G := GL(m|n)$ — the general linear supergroup

$\mathcal{F}(m|n)$ — the category of finite dimensional representations of G

\mathcal{B} — a block of $\mathcal{F}(m|n)$

A — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Theorem. [Brundan-Stroppel] A is Koszul.

Note: Graded \mathbb{k} -linear categories are defined similarly to algebras.

Note: A_0 is not finite dimensional in general, so the above requires some extension of the setup.

Koszul algebras for $GL(m|n)$

$G := GL(m|n)$ — the general linear supergroup

$\mathcal{F}(m|n)$ — the category of finite dimensional representations of G

\mathcal{B} — a block of $\mathcal{F}(m|n)$

A — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Theorem. [Brundan-Stroppel] A is Koszul.

Note: Graded \mathbb{k} -linear categories are defined similarly to algebras.

Note: A_0 is not finite dimensional in general, so the above requires some extension of the setup.

Generalized Takiff Lie algebras

Generalized Takiff Lie algebras

\mathfrak{g} — simple finite dimensional complex Lie algebra

Generalized Takiff Lie algebras

\mathfrak{g} — simple finite dimensional complex Lie algebra

V — finite dimensional \mathfrak{g} -module

Generalized Takiff Lie algebras

\mathfrak{g} — simple finite dimensional complex Lie algebra

V — finite dimensional \mathfrak{g} -module

$\mathfrak{g}_V := \mathfrak{g} \oplus V$ — generalized Takiff Lie algebra

Generalized Takiff Lie algebras

\mathfrak{g} — simple finite dimensional complex Lie algebra

V — finite dimensional \mathfrak{g} -module

$\mathfrak{g}_V := \mathfrak{g} \oplus V$ — generalized Takiff Lie algebra

$[V, V] := 0$

Generalized Takiff Lie algebras

\mathfrak{g} — simple finite dimensional complex Lie algebra

V — finite dimensional \mathfrak{g} -module

$\mathfrak{g}_V := \mathfrak{g} \oplus V$ — generalized Takiff Lie algebra

$[V, V] := 0$

$U(\mathfrak{g}_V)$ is graded with $\deg(V) = 1$ and $\deg(\mathfrak{g}) = 0$

Generalized Takiff Lie algebras

\mathfrak{g} — simple finite dimensional complex Lie algebra

V — finite dimensional \mathfrak{g} -module

$\mathfrak{g}_V := \mathfrak{g} \oplus V$ — generalized Takiff Lie algebra

$[V, V] := 0$

$U(\mathfrak{g}_V)$ is graded with $\deg(V) = 1$ and $\deg(\mathfrak{g}) = 0$

$\mathfrak{g}_V\text{-gmod}$ — the corresponding category of locally finite dimensional graded modules

Generalized Takiff Lie algebras

\mathfrak{g} — simple finite dimensional complex Lie algebra

V — finite dimensional \mathfrak{g} -module

$\mathfrak{g}_V := \mathfrak{g} \oplus V$ — generalized Takiff Lie algebra

$[V, V] := 0$

$U(\mathfrak{g}_V)$ is graded with $\deg(V) = 1$ and $\deg(\mathfrak{g}) = 0$

$\mathfrak{g}_V\text{-gmod}$ — the corresponding category of locally finite dimensional graded modules

Koszul algebra from generalized Takiff Lie algebras

Koszul algebra from generalized Takiff Lie algebras

\mathcal{B} — a block of \mathfrak{g}_V -gmod

Koszul algebra from generalized Takiff Lie algebras

\mathcal{B} — a block of $\mathfrak{g}_V\text{-gmod}$

\mathcal{A} — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Koszul algebra from generalized Takiff Lie algebras

\mathcal{B} — a block of \mathfrak{g}_V -gmod

A — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Theorem. [Chari – Greenstein]

Koszul algebra from generalized Takiff Lie algebras

\mathcal{B} — a block of \mathfrak{g}_V -gmod

A — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Theorem. [Chari – Greenstein] A is Koszul.

Koszul algebra from generalized Takiff Lie algebras

\mathcal{B} — a block of \mathfrak{g}_V -gmod

A — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Theorem. [Chari – Greenstein] A is Koszul.

Note: again, A_0 is not finite dimensional

Koszul algebra from generalized Takiff Lie algebras

\mathcal{B} — a block of \mathfrak{g}_V -gmod

A — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Theorem. [Chari – Greenstein] A is Koszul.

Note: again, A_0 is not finite dimensional

Question: What is the Koszul dual of A ?

Koszul algebra from generalized Takiff Lie algebras

\mathcal{B} — a block of \mathfrak{g}_V -gmod

A — the full subcategory of \mathcal{B} given by representatives of indecomposable projectives

Theorem. [Chari – Greenstein] A is Koszul.

Note: again, A_0 is not finite dimensional

Question: What is the Koszul dual of A ?

Idea for the answer

Idea for the answer

Recall: $\mathbb{k}[t]^! \cong \mathbb{k}[t^*]/((t^*)^2)$

Idea for the answer

Recall: $\mathbb{k}[t]^! \cong \mathbb{k}[t^*]/((t^*)^2)$

More generally: V — \mathbb{k} -vector space

Idea for the answer

Recall: $\mathbb{k}[t]^! \cong \mathbb{k}[t^*]/((t^*)^2)$

More generally: V — \mathbb{k} -vector space

$\text{Sym}(V)$ — the symmetric algebra of V

Idea for the answer

Recall: $\mathbb{k}[t]^! \cong \mathbb{k}[t^*]/((t^*)^2)$

More generally: V — \mathbb{k} -vector space

$\text{Sym}(V)$ — the symmetric algebra of V

$\bigwedge V$ — the exterior algebra of V

Idea for the answer

Recall: $\mathbb{k}[t]^! \cong \mathbb{k}[t^*]/((t^*)^2)$

More generally: V — \mathbb{k} -vector space

$\text{Sym}(V)$ — the symmetric algebra of V

$\wedge V$ — the exterior algebra of V

Claim: $\text{Sym}(V)^! \cong \wedge V$ and both are Koszul

Idea for the answer

Recall: $\mathbb{k}[t]^! \cong \mathbb{k}[t^*]/((t^*)^2)$

More generally: V — \mathbb{k} -vector space

$\text{Sym}(V)$ — the symmetric algebra of V

$\bigwedge V$ — the exterior algebra of V

Claim: $\text{Sym}(V)^! \cong \bigwedge V$ and both are Koszul

$U(\mathfrak{g}_V) \cong U(\mathfrak{g}) \otimes \text{Sym}(V)$

Idea for the answer

Recall: $\mathbb{k}[t]^! \cong \mathbb{k}[t^*]/((t^*)^2)$

More generally: V — \mathbb{k} -vector space

$\text{Sym}(V)$ — the symmetric algebra of V

$\bigwedge V$ — the exterior algebra of V

Claim: $\text{Sym}(V)^! \cong \bigwedge V$ and both are Koszul

$U(\mathfrak{g}_V) \cong U(\mathfrak{g}) \otimes \text{Sym}(V)$

Expect: The “Koszul dual” should be $U(\mathfrak{g}) \otimes \bigwedge V$

Idea for the answer

Recall: $\mathbb{k}[t]^! \cong \mathbb{k}[t^*]/((t^*)^2)$

More generally: V — \mathbb{k} -vector space

$\text{Sym}(V)$ — the symmetric algebra of V

$\bigwedge V$ — the exterior algebra of V

Claim: $\text{Sym}(V)^! \cong \bigwedge V$ and both are Koszul

$U(\mathfrak{g}_V) \cong U(\mathfrak{g}) \otimes \text{Sym}(V)$

Expect: The “Koszul dual” should be $U(\mathfrak{g}) \otimes \bigwedge V$

Koszul algebra from generalized Takiff Lie superalgebras

Koszul algebra from generalized Takiff Lie superalgebras

$\mathfrak{s} = \mathfrak{s}(\mathfrak{g}, V)$ — the generalized Takiff Lie superalgebra

Koszul algebra from generalized Takiff Lie superalgebras

$\mathfrak{s} = \mathfrak{s}(\mathfrak{g}, V)$ — the generalized Takiff Lie superalgebra

$$\mathfrak{s}_0 := \mathfrak{g}, \quad \mathfrak{s}_1 := V, \quad \{V, V\} = 0.$$

Koszul algebra from generalized Takiff Lie superalgebras

$\mathfrak{s} = \mathfrak{s}(\mathfrak{g}, V)$ — the generalized Takiff Lie superalgebra

$$\mathfrak{s}_0 := \mathfrak{g}, \quad \mathfrak{s}_1 := V, \quad \{V, V\} = 0.$$

\mathcal{B}' — a block of $\mathfrak{s}\text{-gmod}$, \mathcal{A}' — the full subcategory of \mathcal{B}' given by representatives of indecomposable projectives

Koszul algebra from generalized Takiff Lie superalgebras

$\mathfrak{s} = \mathfrak{s}(\mathfrak{g}, V)$ — the generalized Takiff Lie superalgebra

$$\mathfrak{s}_0 := \mathfrak{g}, \quad \mathfrak{s}_1 := V, \quad \{V, V\} = 0.$$

\mathcal{B}' — a block of $\mathfrak{s}\text{-gmod}$, A' — the full subcategory of \mathcal{B}' given by representatives of indecomposable projectives

Main Result. [Greenstein – M.]

Koszul algebra from generalized Takiff Lie superalgebras

$\mathfrak{s} = \mathfrak{s}(\mathfrak{g}, V)$ — the generalized Takiff Lie superalgebra

$$\mathfrak{s}_0 := \mathfrak{g}, \quad \mathfrak{s}_1 := V, \quad \{V, V\} = 0.$$

\mathcal{B}' — a block of $\mathfrak{s}\text{-gmod}$, A' — the full subcategory of \mathcal{B}' given by representatives of indecomposable projectives

Main Result. [Greenstein – M.]

For an appropriate \mathcal{B}' we have that A' is the Koszul dual of A .

Koszul algebra from generalized Takiff Lie superalgebras

$\mathfrak{s} = \mathfrak{s}(\mathfrak{g}, V)$ — the generalized Takiff Lie superalgebra

$$\mathfrak{s}_0 := \mathfrak{g}, \quad \mathfrak{s}_1 := V, \quad \{V, V\} = 0.$$

\mathcal{B}' — a block of $\mathfrak{s}\text{-gmod}$, A' — the full subcategory of \mathcal{B}' given by representatives of indecomposable projectives

Main Result. [Greenstein – M.]

For an appropriate \mathcal{B}' we have that A' is the Koszul dual of A .

Corollary. There is an equivalence between the corresponding derived categories of modules.

Koszul algebra from generalized Takiff Lie superalgebras

$\mathfrak{s} = \mathfrak{s}(\mathfrak{g}, V)$ — the generalized Takiff Lie superalgebra

$$\mathfrak{s}_0 := \mathfrak{g}, \quad \mathfrak{s}_1 := V, \quad \{V, V\} = 0.$$

\mathcal{B}' — a block of $\mathfrak{s}\text{-gmod}$, A' — the full subcategory of \mathcal{B}' given by representatives of indecomposable projectives

Main Result. [Greenstein – M.]

For an appropriate \mathcal{B}' we have that A' is the Koszul dual of A .

Corollary. There is an equivalence between the corresponding derived categories of modules.

Note: Extends to “locally category \mathcal{O} -modules” in the setup of T -Koszul algebras of Madsen.

Koszul algebra from generalized Takiff Lie superalgebras

$\mathfrak{s} = \mathfrak{s}(\mathfrak{g}, V)$ — the generalized Takiff Lie superalgebra

$$\mathfrak{s}_0 := \mathfrak{g}, \quad \mathfrak{s}_1 := V, \quad \{V, V\} = 0.$$

\mathcal{B}' — a block of $\mathfrak{s}\text{-gmod}$, A' — the full subcategory of \mathcal{B}' given by representatives of indecomposable projectives

Main Result. [Greenstein – M.]

For an appropriate \mathcal{B}' we have that A' is the Koszul dual of A .

Corollary. There is an equivalence between the corresponding derived categories of modules.

Note: Extends to “locally category \mathcal{O} -modules” in the setup of T -Koszul algebras of Madsen.

Note: $\mathfrak{s}\text{-gmod}$ is not all supermodules, but only those which are extendable to \mathbb{Z} -graded modules

Koszul algebra from generalized Takiff Lie superalgebras

$\mathfrak{s} = \mathfrak{s}(\mathfrak{g}, V)$ — the generalized Takiff Lie superalgebra

$$\mathfrak{s}_0 := \mathfrak{g}, \quad \mathfrak{s}_1 := V, \quad \{V, V\} = 0.$$

\mathcal{B}' — a block of $\mathfrak{s}\text{-gmod}$, A' — the full subcategory of \mathcal{B}' given by representatives of indecomposable projectives

Main Result. [Greenstein – M.]

For an appropriate \mathcal{B}' we have that A' is the Koszul dual of A .

Corollary. There is an equivalence between the corresponding derived categories of modules.

Note: Extends to “locally category \mathcal{O} -modules” in the setup of T -Koszul algebras of Madsen.

Note: $\mathfrak{s}\text{-gmod}$ is not all supermodules, but only those which are extendable to \mathbb{Z} -graded modules