

# THE STRUCTURE OF KOSZUL ALGEBRAS DEFINED BY FOUR QUADRICS

PAOLO MANTERO AND MATTHEW MASTROENI

**ABSTRACT.** Avramov, Conca, and Iyengar ask whether  $\beta_i^S(R) \leq \binom{g}{i}$  for all  $i$  when  $R = S/I$  is a Koszul algebra minimally defined by  $g$  quadrics. In recent work, we give an affirmative answer to this question when  $g \leq 4$  by completely classifying the possible Betti tables of Koszul algebras defined by height-two ideals of four quadrics. Continuing this work, the current paper proves a structure theorem for Koszul algebras defined by four quadrics. We show that all these Koszul algebras are LG-quadratic, proving that an example of Conca of a Koszul algebra that is not LG-quadratic is minimal in terms of number of defining equations. We then characterize precisely when these rings are absolutely Koszul, and establish the equivalence of the absolutely Koszul and Backelin–Rooz properties up to field extensions for such rings (in characteristic zero). The combination of the above paper with the current one provides a fairly complete picture of all Koszul algebras defined by  $g \leq 4$  quadrics.

## 1. INTRODUCTION

A graded ideal  $I$  in a standard graded polynomial ring  $S$  over a field  $k$  defines a Koszul algebra  $R = S/I$  if  $k \cong R/R_+$  has a linear free resolution over  $R$ . This extraordinary homological condition leads to numerous other restrictions on the Hilbert series and Betti numbers of  $R$  over  $S$ ; see [Fro99] and [Con14]. In particular, a question of Avramov, Conca, and Iyengar asks:

**Question 1.1** ([ACI10, 6.5]). If  $R$  is Koszul and  $I$  is minimally generated by  $g$  quadrics, does the following inequality hold for all  $i$ ?

$$\beta_i^S(R) \leq \binom{g}{i}$$

In particular, is  $\text{pd}_S R \leq g$ ?

This question is known to have an affirmative answer when  $R$  is LG-quadratic. We say that  $R$  or  $I$  is *G-quadratic* if, after a suitable linear change of coordinates  $\varphi : S \rightarrow S$ , the ideal  $\varphi(I)$  has a Gröbner basis consisting of quadrics. We also say that  $R$  or  $I$  is *LG-quadratic* if  $R$  is a quotient of a G-quadratic algebra  $A$  by an  $A$ -sequence of linear forms. Every G-quadratic algebra is Koszul by upper semicontinuity of the Betti numbers; see [BC03, 3.13]. Since deforming by a regular sequence of linear forms preserves Koszulness (see Proposition 2.1), every LG-quadratic algebra is also Koszul.

# Dualities On Generalized Koszul Algebras

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## Dualities On Generalized Koszul Algebras:

**Dualities on Generalized Koszul Algebras** Edward L. Green, Idun Reiten, Øyvind Solberg, 2002 Koszul rings are graded rings which have played an important role in algebraic topology noncommutative algebraic geometry and in the theory of quantum groups One aspect of the theory is to compare the module theory for a Koszul ring and its Koszul dual There are dualities between subcategories of graded modules the Koszul modules

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