

INTEGRAL COHOMOLOGY OF $K_2(A)$

SIMON KAPFER AND GRÉGOIRE MENET

ABSTRACT. What we know already

1. PRELIMINARIES

Definition 1.1. Let n be a natural number. A partition of n is a decreasing sequence $\lambda = (\lambda_1, \dots, \lambda_k)$, $\lambda_1 \geq \dots \geq \lambda_k > 0$ of natural numbers such that $\sum_i \lambda_i = n$. Sometimes it is convenient to write $\lambda = (\dots, 2^{m_2}, 1^{m_1})$ with multiplicities in the exponent. We define the weight $\|\lambda\| := \sum m_i i = n$ and the length $|\lambda| := \sum_i m_i = k$. We also define $z_\lambda := \prod_i i^{m_i} m_i!$.

Definition 1.2. Let $\Lambda_n := \mathbb{Q}[x_1, \dots, x_n]^{S_n}$ be the graded ring of symmetric polynomials. There are canonical projections $\Lambda_{n+1} \rightarrow \Lambda_n$ which send x_{n+1} to zero. The graded projective limit $\Lambda := \varprojlim \Lambda_n$ is called the ring of symmetric functions.

Let m_λ and p_λ denote the monomial and the power sum symmetric functions. They are defined as follows: For a monomial $x_{i_1}^{\lambda_1} x_{i_2}^{\lambda_2} \dots x_{i_k}^{\lambda_k}$ of total degree n , the (ordered) sequence of exponents $(\lambda_1, \dots, \lambda_k)$ defines a partition λ of n , which is called the shape of the monomial. Then we define m_λ being the sum of all monomials of shape λ . For the power sums, first define $p_n := x_1^n + x_2^n + \dots$. Then $p_\lambda := p_{\lambda_1} p_{\lambda_2} \dots p_{\lambda_k}$. The families $(m_\lambda)_\lambda$ and $(p_\lambda)_\lambda$ form two \mathbb{Q} -bases of Λ , so they are linearly related by $p_\lambda = \sum_\mu \psi_{\lambda\mu} m_\mu$. It turns out that the base change matrix $(\psi_{\lambda\mu})$ has integral entries, but its inverse $(\psi_{\lambda\mu}^{-1})$ has not.

2. HILBERT SCHEMES OF POINTS ON SURFACES

Let A be a smooth projective complex surface. Let $A^{[n]}$ the Hilbert scheme of n points on the surface, *i.e.* the moduli space of finite subschemes of A of length n . $A^{[n]}$ is again smooth and projective of dimension $2n$.

Their rational cohomology can be described in terms of Nakajima's operators. First consider the direct sum

$$\mathbb{H} := \bigoplus_{n=0}^{\infty} H^*(A^{[n]}, \mathbb{Q})$$

This space is bigraded by cohomological *degree* and the *weight*, which is given by the number of points n . The unit element in $H^0(A^{[0]}, \mathbb{Q}) \cong \mathbb{Q}$ is denoted by $|0\rangle$, called the *vacuum*. There are linear operators $\mathbf{q}_m(a)$, for each $m \geq 1$ and $a \in H^*(A, \mathbb{Q})$, acting on \mathbb{H} which have the following properties: They depend linearly on a , and if $a \in H^k(A, \mathbb{Q})$ is homogeneous, the operator $\mathbf{q}_m(a)$ is bihomogeneous of degree $k + 2(|m| - 1)$ and weight m :

$$\mathbf{q}_m(a) : H^l(A^{[n]}) \rightarrow H^{l+k+2(|m|-1)}(A^{[n+m]})$$

To construct them, first define incidence varieties $Z_m \subset A^{[n]} \times A \times A^{[n+m]}$ by

$$Z_m := \{(\xi, x, \xi') \mid \xi \subset \xi', \text{supp}(\xi') - \text{supp}(\xi) = mx\}.$$

Then $\mathfrak{q}_m(a)(\beta)$ is defined as the Poincaré dual of

$$pr_{3*}((pr_2^*(\alpha) \cdot pr_3^*(\beta)) \cap [Z_m]).$$

Every element in \mathbb{H} can be decomposed uniquely as a linear combination of products of operators $\mathfrak{q}_m(a)$, acting on the vacuum.

To give the cup product structure of \mathbb{H} , define operators $\mathfrak{G}(a)$ for $a \in H^*(A)$. Let $\Xi_n \subset A^{[n]} \times A$ be the universal subscheme. Then the action of $\mathfrak{G}(a)$ on $H^*(A^{[n]})$ is multiplication with the class

$$pr_{1*}(\text{ch}(\mathcal{O}_{\Xi_n}) \cdot pr_2^*(\text{td}(X) \cdot a)) \in H^*(A^{[n]}).$$

For $a \in H^k(A)$, we define $\mathfrak{G}_i(a)$ to be the component of $\mathfrak{G}(a)$ of cohomological degree $k + 2i$. A differential operator \mathfrak{d} is given by $\mathfrak{G}_1(1)$. It means multiplication with the first Chern class of the tautological sheaf $pr_{1*}(\mathcal{O}_{\Xi_n})$.

In [6] and [7] there are various commutation relations between these operators, that allow to determine all multiplications in the cohomology of the Hilbert scheme. First of all, if X and Y are operators of degree d and d' , their commutator is defined as

$$[X, Y] := XY - (-1)^{dd'} YX.$$

The integral on $A^{[n]}$ induces a bilinear form on \mathbb{H} : for classes $\alpha, \beta \in H^*(A^{[n]})$ it is given by

$$(\alpha, \beta) \mapsto \int_{A^{[n]}} \alpha \cdot \beta.$$

If X is a homogeneous linear operator of degree d and weight m , acting on \mathbb{H} , define its adjoint X^\dagger by

$$\int_{A^{[n+m]}} X(\alpha) \cdot \beta = (-1)^{d \deg(\alpha)} \int_{A^{[n]}} \alpha \cdot X^\dagger(\beta).$$

Define $\mathfrak{q}_0(a) := 0$ and for $m < 0$, define $\mathfrak{q}_m(a) := (-1)^n \mathfrak{q}_{-m}(a)^\dagger$. Then define

$$\mathfrak{L}_m(a) := \dots$$

Then we have ([7, Thm. 2.16]):

- (1) $[\mathfrak{q}_m(a), \mathfrak{q}_l(b)] = m \cdot \delta_{m+l} \cdot \int_A ab$
- (2) $[\mathfrak{L}_m(a), \mathfrak{q}_l(b)] = -m \cdot \mathfrak{q}_{m+l}(ab)$
- (3) $[\mathfrak{d}, \mathfrak{q}_m(b)] = m \cdot \mathfrak{L}_m(a) + \frac{m(|m|-1)}{2} \mathfrak{q}_m(K\alpha)$
- (4) $[\mathfrak{G}(a), \mathfrak{q}_1(b)] = \exp(\text{ad}(\mathfrak{d}))(\mathfrak{q}_1(ab))$

Note (cf. [6, Thm. 3.8]) that this implies that

$$\mathfrak{q}_{m+1}(a) = \frac{(-1)^m}{m!} \text{ad}^m([\mathfrak{d}, \mathfrak{q}_1(1)])(\mathfrak{q}_1(a)),$$

so there are two ways of writing an element of \mathbb{H} : As a linear combination of products of creation operators $\mathfrak{q}_m(a)$ or as a linear combination of products of the operators \mathfrak{d} and $\mathfrak{q}_1(a)$. While the first one is more intuitive, the second one is more suitable for computing cup-products.

Remark 2.1. We adopted the notation from [7], which differs from the conventions in [6]. Here is part of a dictionary:

Notation from [7]	Notation from [6]
operator of bidegree (w, d)	operator of bidegree $(w, d - 2w)$
$\mathfrak{q}_m(a)$	$\mathfrak{p}_{-m}(a)$
$\mathfrak{L}_m(a)$	$-L_{-m}(a)$
\mathfrak{d}	∂
$\tau_{2*}(a)$	$-\Delta(a)$

3. COHOMOLOGY OF HILBERT SCHEMES OF POINTS ON A TORUS SURFACE

For the study of integral cohomology, first note that if $\alpha \in H^*(A, \mathbb{Z})$ is an integral class, then $\mathfrak{p}_{-m}(\alpha)$ maps integral classes to integral classes. Moreover, there is the following theorem:

Theorem 3.1. [11] *The following operators map integral classes in \mathbb{H} to integral classes:*

- $\frac{1}{z_\lambda} \mathfrak{q}_\lambda(1)$
- $\mathfrak{m}_\lambda(\alpha)$ for $\alpha \in H^2(A, \mathbb{Z})$

Here, \mathfrak{m}_λ is defined as $\mathfrak{m}_\lambda(\alpha) := \sum_\mu \psi_{\lambda\mu}^{-1} \mathfrak{q}_{-\mu}(\alpha)$ (see Definition 1.2)

To obtain the multiplicative structure of \mathbb{H} , given by the cup-products, there is a description in [6] and [7] in terms of multiplication operators $\mathfrak{G}_k(a)$, $a \in H^*(A)$ [7, Def. 5.1], related to chern characters. There is the following commutation relation:

$$[\mathfrak{G}_k(a), \mathfrak{q}_1(b)] = \frac{1}{k!} \text{ad}(\mathfrak{d})^k(\mathfrak{q}_1(ab)),$$

where the operator \mathfrak{d} means multiplication with the first Chern class of the tautological sheaf. We set $a^{(k)} := \mathfrak{G}_k(a)(1)$.

Next we focus on the structure of $H^2(A^{[n]}, \mathbb{Z})$ for $n \geq 2$. It has rank 13, and there is a basis consisting of:

- $\frac{1}{(n-1)!} \mathfrak{p}_{-1}(1)^{n-1} \mathfrak{p}_{-1}(a_{ij})|0\rangle$, $1 \leq i < j \leq 4$,
- $\frac{1}{(n-2)!} \mathfrak{p}_{-1}(1)^{n-2} \mathfrak{p}_{-1}(a_i) \mathfrak{p}_{-1}(a_j)|0\rangle$, $1 \leq i < j \leq 4$,
- $\frac{1}{2(n-2)!} \mathfrak{p}_{-1}(1)^{n-2} \mathfrak{p}_{-2}(1)|0\rangle$. We denote this class by δ .

It is clear that these classes form a basis of $H^2(A^{[n]}, \mathbb{Q})$. By [11, Thm. 4.6, Lemma 5.2], they also form a basis for $H^2(A^{[n]}, \mathbb{Z})$. TODO: refine this argument

The first 6 classes give an injection $j : H^2(A, \mathbb{Z}) \rightarrow H^2(A^{[n]}, \mathbb{Z})$.

4. GENERALIZED KUMMER VARIETIES

Let A be a complex projective torus of dimension 2. Its first cohomology $H^1(A, \mathbb{Z})$ is freely generated by four elements a_1, a_2, a_3, a_4 , corresponding to the four different circles on the torus. The cohomology ring is isomorphic to the exterior algebra:

$$H^*(A, \mathbb{Z}) = \Lambda^* H^1(A, \mathbb{Z}).$$

We abbreviate for the products $a_i \cdot a_j =: a_{ij}$ and $a_i \cdot a_j \cdot a_k =: a_{ijk}$. We write $a_1 \cdot a_2 \cdot a_3 \cdot a_4 =: x$ for the class corresponding to a point on A . We choose the a_i such that $\int_A x = 1$. We set $a_{\bar{i}}$ for the dual class of a_i , i.e. $a_i \cdot a_{\bar{i}} = x$. The bilinear form, given by $(a_{ij}, a_{kl}) \mapsto \int_A a_{ij} a_{kl}$ gives $H^2(A, \mathbb{Z})$ the structure of a unimodular lattice, isomorphic to $U^{\oplus 3}$, three copies of the hyperbolic lattice.

Definition 4.1. Let A be a complex projective torus of dimension 2 and $A^{[n]}$, $n \geq 1$, the corresponding Hilbert scheme of points. Denote $\Sigma : A^{[n]} \rightarrow A$ the summation morphism, a smooth submersion that factorizes via the Hilbert–Chow morphism $A^{[n]} \rightarrow \text{Sym}^n(A) \rightarrow A$. Then the generalized Kummer $K^{n-1}A$ is defined as the fiber over 0:

$$(5) \quad \begin{array}{ccc} K^{n-1}A & \xrightarrow{\theta} & A^{[n]} \\ \downarrow & & \downarrow \Sigma \\ \{0\} & \longrightarrow & A \end{array}$$

Our first objective is to collect some information about this pullback diagram. We recall Theorem 2 of [12].

Theorem 4.2. *The cohomology of $K_2(A)$ is torsion free.*

Proposition 4.3. *Recall that $a_i^{(0)} = \frac{1}{(n-1)!} \mathbf{q}_1(1)^{n-1} \mathbf{q}_1(a_i) | 0 \rangle$. The class of the Poincaré dual of $K_{n-1}(A)$ in $H^4(A^{[n]}, \mathbb{Z})$ is given by*

$$a_1^{(0)} \cdot a_2^{(0)} \cdot a_3^{(0)} \cdot a_4^{(0)}.$$

Proof. Since the generalized Kummer variety is the fiber over a point, its Poincaré dual must be the pullback of $x \in H^4(A)$ under Σ . But $\Sigma^*(x) = \Sigma^*(a_1) \cdot \Sigma^*(a_2) \cdot \Sigma^*(a_3) \cdot \Sigma^*(a_4)$, so we have to verify that $\Sigma^*(a_i) = a_i^{(0)}$. Since this identity is of degree 1, we may replace $A^{[n]}$ by $\text{Sym}^n(A)$, whose first cohomologies are isomorphic. \square

Our main reference is [1] where it is shown, that K^{n-1} is an irreducible holomorphically symplectic manifold. So $H^2(K_{n-1}(A), \mathbb{Z})$ admits an integer-valued nondegenerated quadratic form (called Beauville–Bogomolov form) q which gives $H^2(K_{n-1}(A), \mathbb{Z})$ the structure of a lattice isomorphic to $U^{\oplus 3} \oplus \langle -2n \rangle$, for $n \geq 3$. We have the following formula for $\alpha \in H^2(K_{n-1}(A), \mathbb{Z})$:

$$(6) \quad \int_{K_{n-1}(A)} \alpha^{2n-2} = n \frac{(2n-2)!}{2^{n-1}(n-1)!} q(\alpha)^{n-1}$$

The morphism θ induces a homomorphism of graded rings

$$(7) \quad \theta^* : H^*(A^{[n]}, \mathbb{Z}) \longrightarrow H^*(K_{n-1}(A), \mathbb{Z}).$$

Proposition 4.4. *Let $n \geq 3$.*

- (1) θ^* maps $H^1(A^{[n]}, \mathbb{Z})$ to zero.
- (2) θ^* is surjective on $H^2(A^{[n]}, \mathbb{Z})$ with kernel $\Lambda^2 H^1(A^{[n]}, \mathbb{Z})$.

Proof. The first statement is clear since $H^1(K_{n-1}(A))$ is always zero [1, Thm. 3]. Furthermore, by [1, Sect. 7], $\theta^* : H^2(A^{[n]}, \mathbb{C}) \rightarrow H^2(K_{n-1}(A), \mathbb{C})$ is surjective. The second Betti numbers of $A^{[n]}$ and $K_{n-1}(A)$ are 13 and 7, respectively. It is clear that $\Lambda^2 H^1(A^{[n]}, \mathbb{Z})$ is contained in the kernel, and since the dimension of the kernel has to be 6, it must be all.

It remains to show that θ^* is surjective for integral coefficients, too. We do it only for $n = 3$. We use a formula in [4, p. 8], namely:

$$(8) \quad \int_{A^{[3]}} j(a)^6 = \frac{5}{3} \int_A a^2 \int_{K_2(A)} \theta^* j(a)^4$$

for all $a \in H^2(A)$. One computes $\int_{A^{[3]}} j(a)^6 = 15 \left(\int_A a^2 \right)^3$. Comparing this with (6), we see that the sublattice given by the image of $\theta^* \circ j$ is unimodular. Secondly, we must show that $q(\theta^* \delta) = -6$. TODO: show this! Remark: $\theta^* \delta$ seems to be indivisible (because of (6)), but every product with $\theta^* \delta$ is divisible by 3. Indeed, the value of (6) for $\alpha = \theta^* \delta$ is 324. \square

Remark 4.5. This allows us to better understand the morphism θ^* . Since the Poincaré pairing is nondegenerated, $[K_{n-1}(A)] \cdot \alpha = 0$ implies $\theta^* \alpha = 0$.

Let us summarize our results on θ^* for the case $n = 3$:

Theorem 4.6. *The homomorphism $\theta^* : H^*(A^{[3]}, \mathbb{Q}) \rightarrow H^*(K_2(A), \mathbb{Q})$ of graded rings is surjective in every degree except 4. Moreover, the image of $H^4(A^{[3]}, \mathbb{Q})$ is equal to $\text{Sym}^2(H^2(K_2(A), \mathbb{Q}))$. The kernel of θ^* is the ideal generated by $H^1(A^{[3]}, \mathbb{Q})$.*

Now we focus on classes of cohomological degree 4.

Proposition 4.7. *The classes $\theta^*(\mathfrak{p}_{-2}(a_{ij})\mathfrak{p}_{-1}(1)|0\rangle)$ and $\theta^*(\mathfrak{p}_{-2}(1)\mathfrak{p}_{-1}(a_{ij})|0\rangle)$ are linearly dependent.*

Proof. We can compute the product of these two classes with $[K_2(A)]$ in $H^*(A^{[3]})$. The two results are linearly dependent. Is there a direct geometric proof? \square

Proposition 4.8. $\theta^*(\mathfrak{p}_{-3}(x)|0\rangle) = 0$

Corollary 4.9. $\theta^*(\mathfrak{p}_{-2}(a_{ij})\mathfrak{p}_{-1}(1)|0\rangle) = \frac{1}{4}\theta^*(\mathfrak{p}_{-2}(1)\mathfrak{p}_{-1}(a_{ij})|0\rangle)$

Proof. Let a_{ij} and a_{kl} be complementary, i.e. $a_{ij}a_{kl} = 1$. We have $a_{kl}^{(1)} = -\frac{1}{2}\mathfrak{p}_{-2}(a_{kl})\mathfrak{p}_{-1}(1)|0\rangle$. Then:

$$\theta^*\left(a_{ij}^{(1)} \cdot a_{kl}^{(1)}\right) = \theta^*\left(\mathfrak{p}_{-3}(1)|0\rangle + \frac{1}{2}\mathfrak{p}_{-1}(x)^2\mathfrak{p}_{-1}(1)|0\rangle\right)$$

But on the other hand, $\delta \cdot j(a) = \frac{1}{2}\mathfrak{p}_{-2}(1)\mathfrak{p}_{-1}(a_{ij})|0\rangle + \mathfrak{p}_{-2}(a_{ij})\mathfrak{p}_{-1}(1)|0\rangle$, and

$$\theta^*\left(a_{kl}^{(1)} \cdot \delta \cdot j(a)\right) = \theta^*\left(-3\mathfrak{p}_{-3}(1)|0\rangle - 3\mathfrak{p}_{-1}(x)^2\mathfrak{p}_{-1}(1)|0\rangle\right).$$

\square

Corollary 4.10. $\theta^*(\delta \cdot j(a_{ij})) = \theta^*\left(\frac{3}{4}\mathfrak{p}_{-2}(1)\mathfrak{p}_{-1}(a_{ij})|0\rangle\right)$ is divisible by 3. \square

Proposition 4.11. *The classes $\theta^*(j(a_{ij})^2 - \frac{1}{3}j(a_{ij}) \cdot \delta)$ are divisible by 2.*

Proof. By [11], the classes $\frac{1}{2}\mathfrak{p}_{-1}(a_{ij})^2\mathfrak{p}_{-1}(1)|0\rangle - \frac{1}{2}\mathfrak{p}_{-2}(a_{ij})\mathfrak{p}_{-1}(1)|0\rangle$ are integral in $H^4(A^{[n]})$. But $j(a_{ij})^2 = \mathfrak{p}_{-1}(a_{ij})^2\mathfrak{p}_{-1}(1)|0\rangle$ and $\theta^*\left(\frac{1}{3}j(a_{ij}) \cdot \delta\right) = \theta^*(\mathfrak{p}_{-2}(a_{ij})\mathfrak{p}_{-1}(1)|0\rangle)$. \square

Proposition 4.12. *The class $\theta^*(\delta^2 + j(a_{12}) \cdot j(a_{34}) - j(a_{13}) \cdot j(a_{24}) + j(a_{14}) \cdot j(a_{23}))$ is divisible by 3.*

Proof. It is equal to $\theta^*(\mathfrak{p}_{-3}(1)|0\rangle - \frac{3}{2}\mathfrak{p}_{-1}(x)\mathfrak{p}_{-1}(1)^2|0\rangle)$. \square

Proposition 4.13. *We have:*

$$H^4(K_2(A), \mathbb{Q}) = \text{Sym}^2 H^2(K_2(A), \mathbb{Q}) \oplus {}^\perp \Pi' \otimes \mathbb{Q}.$$

Proof. In Section 4 of [5], we can find the following formula:

$$(9) \quad Z_\tau \cdot D_1 \cdot D_2 = 2 \cdot q(D_1, D_2),$$

for all D_1, D_2 in $H^2(K_2(A), \mathbb{Z})$, $\tau \in A[3]$ and q the Beauville-Bogomolov form. It follows that $\Pi' \subset \text{Sym}^2 H^2(K_2(A), \mathbb{Z})^\perp$. Since the cup-product is non-degenerated and by Proposition 4.3 of [5], we have:

$$\begin{aligned} \text{rk}(\text{Sym}^2 H^2(K_2(A), \mathbb{Z}) \oplus \Pi') &= \text{rk} \text{Sym}^2 H^2(K_2(A), \mathbb{Z}) + \text{rk} \Pi' \\ &= 28 + 80 \\ &= \text{rk} H^4(K_2(A), \mathbb{Z}). \end{aligned}$$

It follows that

$$H^4(K_2(A), \mathbb{Q}) = \text{Sym}^2 H^2(K_2(A), \mathbb{Q}) \oplus^\perp \Pi' \otimes \mathbb{Q}.$$

□

Next we look at the Chern classes of the tangent sheaves. Since the morphism Σ from the defining pullback diagram (5) is a submersion, the normal bundle of $K_{n-1}(A)$ in $A^{[n]}$ is trivial. Hence $c(K_2(A)) = \theta^* c(A^{[3]})$. Looking in [2, Sect. 8], we find a general formula for Chern classes of Hilbert schemes of points on surfaces. So we deduce

$$\begin{aligned} c_2(A^{[3]}) &= \left(\frac{3}{2} \mathfrak{q}_{*(1,1)}(1) \mathfrak{q}_1(1) - \frac{1}{3} \mathfrak{q}_3 \right) |0\rangle \\ &= 10 \binom{[\bullet]}{(4)} - 2 \binom{[\bullet]}{(2)}^2 \\ c_4(A^{[3]}) &= \frac{4}{3} \mathfrak{q}_{*(1,1,1)}(1) |0\rangle = 4 \binom{[\bullet]}{(4)}^2. \end{aligned}$$

Proposition 4.14. *We have:*

$$c_2(K_2(A)) = \theta^* \left(4j(a_{12}) \cdot j(a_{34}) - 4j(a_{13}) \cdot j(a_{24}) + 4j(a_{14}) \cdot j(a_{23}) - \frac{1}{3} \delta^2 \right).$$

In particular $c_2(K_2(A)) \in \text{Sym}^2 H^2(K_2(A), \mathbb{Z})$.

Proof. We can write:

$$c_2(K_2(A)) = a + b,$$

with $a \in \text{Sym}^2 H^2(K_2(A), \mathbb{Q})$ and $b \in \Pi'$. First, we prove that $b = 0$. We have $c_2(K_2(A)) \in \Pi'^\perp$ and also $a \in \Pi'^\perp$, it follows that $b \in \Pi'^\perp$. Since the cup-product is non-degenerated, it follows that b is of torsion. Then by Theorem 4.2, $b = 0$.

By (9) and Proposition 5.1 of [5], we can see that for all D_1 and D_2 in $H^2(K_2(A), \mathbb{Z})$, we have:

$$c_2(K_2(A)) \cdot D_1 \cdot D_2 = 54 \cdot q(D_1, D_2),$$

where q is the Beauville-Bogomolov form. Then we can calculate that:

$$c_2(K_2(A)) = \theta^* \left(4j(a_{12}) \cdot j(a_{34}) - 4j(a_{13}) \cdot j(a_{24}) + 4j(a_{14}) \cdot j(a_{23}) - \frac{1}{3} \delta^2 \right).$$

□

Corollary 4.15. *The class $\theta^* \delta^2$ is divisible by 3.*

Proposition 4.16. *The element*

$$\theta^* (j(a_{12}) \cdot j(a_{34}) - j(a_{13}) \cdot j(a_{24}) + j(a_{14}) \cdot j(a_{23}))$$

is divisible by 6. More precisely, it is equal to $6 Y_p$ (see [5]).

Proof. Again by Section 4 of [5], we have:

$$W = \frac{3}{8}(c_2(K_2(A)) + 3\theta^*(\delta)^2).$$

It follows:

$$(10) \quad W = \frac{3}{8}\theta^* \left(4j(a_{12}) \cdot j(a_{34}) - 4j(a_{13}) \cdot j(a_{24}) + 4j(a_{14}) \cdot j(a_{23}) + \frac{8}{3}\delta^2 \right).$$

It follows that

$$\theta^*(j(a_{12}) \cdot j(a_{34}) - j(a_{13}) \cdot j(a_{24}) + j(a_{14}) \cdot j(a_{23})).$$

is divisible by 2. For the divisibility by 3, combine Proposition 4.12 with Corollary 4.15. \square

Remark 4.17. We also have the following formulas:

$$(11) \quad W = \theta^*(\mathfrak{p}_{-3}(1)|0\rangle)$$

$$(12) \quad Y_p = -\frac{1}{9}\theta^*(\mathfrak{p}_{-1}(1)L_{-2}(1)|0\rangle)$$

Let us now look at cohomology classes of odd degree. Since $H^1(K_2(A)) = H^7(K_2(A)) = 0$, we only need to consider the degrees 3 and 5.

Proposition 4.18. *The map $\theta^* : H^*(A^{[3]}, \mathbb{Q}) \rightarrow H^*(K_2(A), \mathbb{Q})$ is surjective in degrees 3 and 5. If we set*

$$(13) \quad B_3 := \{a_i^{(0)}, 1 \leq i \leq 4\} \cup \{a_i^{(1)}, 1 \leq i \leq 4\}$$

$$(14) \quad B_5 := \{a_i^{(1)}, 1 \leq i \leq 4\} \cup \{a_i^{(2)}, 1 \leq i \leq 4\},$$

then the images of B_3 and B_5 give bases of $H^3(K_2(A), \mathbb{Q})$ and $H^5(K_2(A), \mathbb{Q})$ that are orthogonal under the intersection pairing. We have

$$(15) \quad \int \theta^*(a_i^{(0)} \cdot a_i^{(2)}) = \pm \frac{3}{2}$$

$$(16) \quad \int \theta^*(a_i^{(1)} \cdot a_i^{(1)}) = \pm \frac{1}{2}.$$

*Moreover, $a_i^{(0)} \cdot [K_2(A)]$ and $\frac{2}{3}a_i^{(2)} \cdot [K_2(A)]$ are integral classes. This implies (by Poincaré duality) that $\theta^*a_i^{(0)}$ and $\frac{2}{3}\theta^*a_i^{(2)}$ are integral.*

*Question: Which of $\theta^*a_i^{(1)}$ and $\theta^*a_i^{(1)}$ is not integral?*

REFERENCES

1. A. Beauville, *Varités khleriennes dont la première classe de Chern est nulle*, J. Differential geometry, 18 (1983) 755-782
2. S. Boissière and M. Nieper-Wißkirchen, *Generating series in the cohomology of Hilbert schemes of points on surfaces*, LMS J. of Computation and Mathematics 10 (2007), 254–270 .
3. S. Boissière, M. Nieper-Wißkirchen, and A. Sarti, *Smith theory and Irreducible Holomorphic Symplectic Manifolds*, Journal of Topology 6 (2013), no. 2, 361390.
4. M. Britze, *On the cohomology of generalized Kummer varieties*, (2003)
5. B. Hassett and Y. Tschinkel, *Hodge theory and Lagrangian planes on generalized Kummer fourfolds*, Moscow Math. Journal, 13, no. 1, 33-56, (2013)
6. M. Lehn and C. Sorger, *The cup product of Hilbert schemes for K3 surfaces*, Invent. Math. 152 (2003), no. 2, 305–329.
7. W. Li, Z. Qin and W. Wang, *Vertex algebras and the cohomology ring structure of Hilbert schemes of points on surfaces* (2002)

8. E. Markman, *Integral generators for the cohomology ring of moduli spaces of sheaves over Poisson surfaces*, Adv. Math. **208** (2007), no. 2, 622–646.
9. E. Markman, *Integral constraints on the monodromy group of the hyperKähler resolution of a symmetric product of a K3 surface*, Internat. J. Math. **21** (2010), no. 2, 169–223.
10. H. Nakajima, *Heisenberg algebra and Hilbert schemes of points on projective surfaces*, Ann. of Math. (2) **145** (1997), no. 2, 379–388.
11. Z. Qin and W. Wang, *Integral operators and integral cohomology classes of Hilbert schemes*, Math. Ann. **331** (2005), no. 3, 669–692.
12. E. Spanier, *The homology of Kummer manifolds*, Proc. Amer. Math. Soc. **7**, (1956), 155–160.

SIMON KAPFER, LABORATOIRE DE MATHÉMATIQUES ET APPLICATIONS, UMR CNRS 6086, UNIVERSITÉ DE POITIERS, TÉLÉPORT 2, BOULEVARD MARIE ET PIERRE CURIE, F-86962 FUTUROSCOPE CHASSENEUIL

E-mail address: `simon.kapfer@math.univ-poitiers.fr`