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<th>Title</th>
<th>RESTRICTION OF HERMITIAN MAASS LIFTS AND THE GROSS-PRASAD CONJECTURE: JOINT WITH T. IKEDA</th>
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</thead>
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<td>Icino, Atsushi</td>
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RESTRICTION OF HERMITIAN MAASS LIFTS AND
THE GROSS-PRASAD CONJECTURE
(JOINT WITH T. IKEDA)

ATSUSHI ICHINO

This note is a report on a joint work with Tamotsu Ikeda [12].
After the discovery of the integral representation of triple product L-functions by Garrett [5], Harris and Kudla [10] determined the transcendental parts of the central critical values of triple product L-functions. The transcendental parts behaves differently according to whether the weights are “balanced” or not. In the “balanced” case, the critical values of triple product L-functions have also been studied by Garrett [5], Orloff [18], Satoh [20], Garrett and Harris [6], Gross and Kudla [7], Böcherer and Schulze-Pillot [4], and so on. By contrast, in the “imbalanced” case, there are no results on the critical values of triple product L-functions except [10] to our knowledge. We express certain period integrals of Maass lifts which appear in the Gross-Prasad conjecture [8], [9], as the algebraic parts of the central critical values in the “imbalanced” case.

1. THE GROSS-PRASAD CONJECTURE

In [8], [9], Gross and Prasad suggested that the central values of certain L-functions control a global obstruction of blanching rules for automorphic representations of special orthogonal groups. Let $V$ be a non-degenerate quadratic space of dimension $n$ over a number field $k$ and $H = \text{SO}(V)$ the special orthogonal group of $V$. Take a non-degenerate quadratic subspace $V'$ of $V$ of dimension $n-1$ and regard $H' = \text{SO}(V')$ as a subgroup of $H$. Let $\tau \simeq \bigotimes_v \tau_v$ (resp. $\tau' \simeq \bigotimes_v \tau'_v$) be an irreducible cuspidal automorphic representation of $H(A_k)$ (resp. $H'(A_k)$).

**Conjecture 1.1** (Gross-Prasad). Assume that $\tau$ and $\tau'$ are both tempered. Then the period integral

$$\langle G|_{H'}, F \rangle = \int_{H'(k) \backslash H'(A_k)} G(h) \overline{F(h)} \, dh$$

does not vanish for some $G \in \tau$ and some $F \in \tau'$ if and only if

(i) $\text{Hom}_{H'(k_v)}(\tau_v, \tau'_v) \neq 0$ for all places $v$ of $k$.

(ii) $L(1/2, \tau \times \tau') \neq 0$. 

Remark that a meromorphic continuation of the $L$-function $L(s, \tau \times \tau')$ has not been established in general, however, it could be described in terms of $L$-functions of general linear groups by the functoriality. We also note that the conjecture is supported by the results of Waldspurger [22] for $n = 3$, Harris and Kudla [10], [11] for $n = 4$, Böcherer, Furusawa, and Schulze-Pillot [3] for $n = 5$.

Gross and Prasad restricted their conjecture to the tempered cases. According to the Arthur conjecture [2], non-tempered cuspidal automorphic representations exist, and if $\tau$ or $\tau'$ is non-tempered, then the $L$-function $L(s, \tau \times \tau')$ could have a pole at $s = 1/2$. Hence a modification to the condition (ii) would be inevitable if one consider the Gross-Prasad conjecture in general (see [3] for $n = 5$). Our result provides an example for $n = 6$ when $\tau$, $\tau'$ are both non-tempered. Remark that the triple product $L$-function considered in this note is only of degree 8 and is a part of the $L$-function $L(s, \tau \times \tau')$ of degree 24.

2. Saito-Kurokawa Lifts

First, we review the notion of Saito-Kurokawa lifts [16], [17], [1], [23]. Let $k$ be a positive even integer. Let

$$F(Z) = \sum_{B > 0} A(B)e^{2\pi \sqrt{-1} \text{tr}(BZ)} \in S_k(\text{Sp}_2(\mathbb{Z})), \quad Z \in \mathfrak{h}_2$$

be a Siegel modular form of degree 2. Here $\mathfrak{h}_2$ is the Siegel upper half plane given by

$$\mathfrak{h}_2 = \{Z = {}^tZ \in M_2(\mathbb{C}) \mid \text{Im}(Z) > 0\}.$$

We say that $F$ satisfies the Maass relation if there exists a function $\beta_F^* : \mathbb{N} \to \mathbb{C}$ such that

$$A \left( \left( \begin{array}{cc} n & r/2 \\ r/2 & m \end{array} \right) \right) = \sum_{d \mid (n,r,m)} d^{k-1} \beta_F^* \left( \frac{4nm - r^2}{d^2} \right).$$

We denote by $S_k^{\text{Maass}}(\text{Sp}_2(\mathbb{Z}))$ the space of Siegel cusp forms which satisfy the Maass relation.

Kohnen [13] introduced the plus subspace $S_{k-1/2}^+(\Gamma_0(4))$ given by

$$S_{k-1/2}^+(\Gamma_0(4)) = \{h(\tau) = \sum_{N > 0} c(N)q^N \in S_{k-1/2}(\Gamma_0(4)) \mid c(N) = 0 \text{ if } -N \not\equiv 0, 1 \mod 4\}.$$
For $F \in S_k^{\text{Maass}}(\text{Sp}_2(\mathbb{Z}))$, put
\[
\Omega_{k}^{SK}(F)(\tau) = \sum_{N \geq 0, -N \equiv \beta \mod 4} \beta_p(N) q^N.
\]
Then $\Omega_{k}^{SK}(F) \in S_{k-1/2}^{+}(\Gamma_0(4))$, and the linear map
\[
\Omega_{k}^{SK} : S_k^{\text{Maass}}(\text{Sp}_2(\mathbb{Z})) \rightarrow S_{k-1/2}^{+}(\Gamma_0(4))
\]
is an isomorphism.

3. HERMITIAN MAASS LIFTS

Next, we recall an analogue of Saito-Kurokawa lifts for hermitian modular forms by Kojima [14], Sugano [21], and Krieg [15]. Let $K = \mathbb{Q}(\sqrt{-D})$ be an imaginary quadratic field with discriminant $-D < 0$, $\mathcal{O}$ the ring of integers of $K$, $w_K$ the number of roots of unity contained in $K$, and $\chi$ the primitive Dirichlet character corresponding to $K/\mathbb{Q}$. Write
\[
\chi = \prod_{q \in Q_D} \chi_q,
\]
where $Q_D$ is the set of all primes dividing $D$ and $\chi_q$ is a primitive Dirichlet character mod $q^{\nu_q D}$ for each $q \in Q_D$.

Let $k$ be a positive integer such that $w_K | k$. Let $G(Z) = \sum_{H \in \Lambda_2(\mathcal{O})^+} A(H)e^{2\pi \sqrt{-1} \text{tr}(HZ)} \in S_k(U(2, 2))$, $Z \in \mathcal{H}_2$ be a hermitian modular form of degree 2. Here $\mathcal{H}_2$ is the hermitian upper half plane given by
\[
\mathcal{H}_2 = \left\{ Z \in M_2(\mathbb{C}) \left| \frac{1}{2\sqrt{-1}}(Z - \bar{Z}) > 0 \right\} \right.,
\]
and
\[
\Lambda_2(\mathcal{O})^+ = \left\{ H = {}^t\bar{H} \in \mathbb{M}_2(\mathcal{O}) \left| \text{diag}(H) \in \mathbb{Z}^2, H > 0 \right\} \right..
\]
We say that $G$ satisfies the Maass relation if there exists a function $\alpha_G^* : \mathbb{N} \rightarrow \mathbb{C}$ such that
\[
A(H) = \sum_{d | \epsilon(H)} d^{k-1} \alpha_G^* \left( \frac{D \text{det}(H)}{d^2} \right),
\]
where
\[
\epsilon(H) = \max\{ n \in \mathbb{N} \mid n^{-1}H \in \Lambda_2(\mathcal{O})^+ \}.\]
ATSUSHI ICHINO

We denote by $S_k^{\text{Maass}}(U(2, 2))$ the space of hermitian cusp forms which satisfy the Maass relation.

Krieg [15] introduced the space $S_{k-1}^{*}(\Gamma_0(D), \chi)$ which is an analogue of the Kohnen plus subspace and is given by

$$S_{k-1}^{*}(\Gamma_0(D), \chi) = \{ g^*(\tau) = \sum_{N > 0} a_{g^*}(N)q^N \in S_{k-1}(\Gamma_0(D), \chi) \mid a_{g^*}(N) = 0 \text{ if } a_D(N) = 0 \},$$

where

$$a_D(N) = \prod_{q \in Q_D} (1 + \chi_q(-N)).$$

Let

$$g(\tau) = \sum_{N > 0} a_g(N)q^N \in S_{k-1}(\Gamma_0(D), \chi)$$

be a primitive form. For each $Q \subset Q_D$, set

$$\chi_Q = \prod_{q \in Q} \chi_q, \quad \chi' = \prod_{q \in Q_D - Q} \chi_q.$$

Then there exists a primitive form

$$g_Q(\tau) = \sum_{N \geq 0} a_{g_Q}(N)q^N \in S_{k-1}(\Gamma_0(D), \chi)$$

such that

$$a_{g_Q}(p) = \begin{cases} \chi_Q(p)a_g(p) & \text{if } p \notin Q, \\ \chi'(p)a_g(p) & \text{if } p \in Q, \end{cases}$$

for each prime $p$. Put

$$(3.1) \quad g^* = \sum_{Q \subset Q_D} \chi_Q(-1)g_Q.$$ 

Then $g^* \in S_{k-1}^{*}(\Gamma_0(D), \chi)$. When $g$ runs over primitive forms in $S_{k-1}(\Gamma_0(D), \chi)$, the forms $g^*$ span $S_{k-1}^{*}(\Gamma_0(D), \chi)$.

For $G \in S_k^{\text{Maass}}(U(2, 2))$, put

$$\Omega(G)(\tau) = \sum_{N > 0} a_D(N)\alpha_G^*(N)q^N.$$

Then $\Omega(G) \in S_{k-1}^{*}(\Gamma_0(D), \chi)$, and the linear map

$$\Omega : S_k^{\text{Maass}}(U(2, 2)) \rightarrow S_{k-1}^{*}(\Gamma_0(D), \chi)$$

is an isomorphism.
4. STATEMENT OF THE MAIN THEOREM

Let $k$ be a positive integer such that $w_K \mid k$. Let $f \in S_{2k-2}(\text{SL}_2(\mathbb{Z}))$ be a primitive form and $h(\tau) = \sum_{N>0} c(N)q^N \in S_{k-1/2}^+(\Gamma_0(4))$ a Hecke eigenform which corresponds to $f$ by the Shimura correspondence. Note that $h$ is unique up to scalars. Let $F = (\Omega^{8k})^{-1}(h) \in S_{k}^{\text{Maass}}(\text{Sp}_2(\mathbb{Z}))$ be the Saito-Kurokawa lift of $f$. Define the Petersson norms of $f$ and $F$ by

$$\langle f, f \rangle = \int_{\text{SL}_2(\mathbb{Z}) \backslash \mathfrak{h}_1} |f(\tau)|^2 y^{2k-4} d\tau,$$

$$\langle F, F \rangle = \int_{\text{Sp}_2(\mathbb{Z}) \backslash \mathfrak{g}} |F(Z)|^2 |\det \text{Im}(Z)|^{k-3} dZ,$$

respectively.

Let $g(\tau) = \sum_{N>0} a_g(N)q^N \in S_{k-1}(\Gamma_0(D), \chi)$ be a primitive form and $G = \Omega^{-1}(g^*) \in S_{k}^{\text{Maass}}(\text{Sp}_2(\mathbb{Z}))$ the hermitian Maass lift of $g$, where $g^* \in S_{k-1}^+(\Gamma_0(D), \chi)$ is given by (3.1). Observe that $\mathfrak{h}_2 \subset H_2$, and by [15], the restriction $G|_{\mathfrak{h}_2}$ belongs to $S_{k}^{\text{Maass}}(\text{Sp}_2(\mathbb{Z}))$.

The completed triple product $L$-function $\Lambda(s, g \times g \times f)$ is given by

$$\Lambda(s, g \times g \times f) = (2\pi)^{-4s+4k-8}\Gamma(s)\Gamma(s-2k+4)\Gamma(s-k+2)^2L(s, g \times g \times f),$$

and satisfies a functional equation which replaces $s$ with $4k - 6 - s$.

Our main result is as follows.

**Theorem 4.1.**

$$\frac{\Lambda(2k-3, g \times g \times f)}{\langle f, f \rangle^2} = -2^{4k-6}D^{-2k+3}c(D)^2\frac{\langle G|_{\mathfrak{h}_2}, F \rangle^2}{\langle F, F \rangle^2}$$

5. PROOF

Theorem 4.1 follows from the following seesaws.

(5.1) \begin{align*}
&\text{O}(4, 2) \bigg/ \bigg/ \text{SL}_2 \times \text{SL}_2 \bigg/ \bigg/ \text{O}(2, 2) \\
&\text{O}(3, 2) \times \text{O}(1) \big/ \big/ \text{SL}_2 \big/ \big/ \text{O}(2, 1) \times \text{O}(1)
\end{align*}

(5.2) \begin{align*}
&\text{Sp}_6 \big/ \big/ \text{O}(2, 2)^3 \\
&\text{SL}_2^3 \big/ \big/ \text{O}(2, 2)
\end{align*}
To explain these seesaws more precisely, we introduce some notation. In [13], Kohnen defined a linear map

\[ S_{k}^{+} : S_{k-1/2}^{+}(\Gamma_{0}(4)) \rightarrow S_{2k-2}(\text{SL}_{2}(\mathbb{Z})), \]

\[ \sum_{N>0} c(N)q^{N} \mapsto \sum_{N>0} \sum_{d|N} \chi(d)d^{k-2}c \left( \frac{N^{2}}{d^{2}} \right) \frac{d}{D} q^{N}. \]

If \( h(\tau) = \sum_{N>0} c(N)q^{N} \in S_{k-1/2}^{+}(\Gamma_{0}(4)) \) is a Hecke eigenform and corresponds to \( f \in S_{2k-2}(\text{SL}_{2}(\mathbb{Z})) \) by the Shimura correspondence, then

\[ S_{k}^{+}(h) = c(D)f. \]

Let \( \text{Tr}^{D}_{1} \) denote the trace operator given by

\[ \text{Tr}^{D}_{1} : S_{2k-2}(\Gamma_{0}(D)) \rightarrow S_{2k-2}(\text{SL}_{2}(\mathbb{Z})), \]

\[ f \mapsto \sum_{\gamma \in \Gamma_{0}(D) \backslash \text{SL}_{2}(\mathbb{Z})} f|\gamma. \]

The seesaw (5.1) accounts for the following identity.

**Proposition 5.1.**

\[ S_{k}^{+}(\Omega^{SK}(G|_{b_{2}})) = a_{g}(D)^{2} \text{Tr}^{D}_{1}(g^{2}). \]

This identity is proved by computing the Fourier coefficients of the both sides explicitly.

The seesaw (5.2) accounts for the following refinement of the main identity by Harris and Kudla [10].

**Proposition 5.2.**

\[ \Lambda(2k-3, g \times g \times f) = -2^{4k-6}D^{-2k+3}a_{g}(D)^{4}\langle \text{Tr}^{D}_{1}(g^{2}), f \rangle^{2} \]

This identity is proved by computing the local zeta integrals which arise in the integral representation of triple product \( L \)-functions by Garrett [5], Piatetski-Shapiro and Rallis [19] at bad primes.

Now Theorem 4.1 follows from Propositions 5.1 and 5.2.

**REFERENCES**


**Department of Mathematics, Graduate School of Science, Osaka City University, 3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan**

**E-mail address:** ichino@sci.osaka-cu.ac.jp