On the A-packets for genuine representations of Mp(2n)

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Outline

Local metaplectic covering

- $\boldsymbol{\mu}_m := \mu_m(\mathbb{C})$, all rep are over $\mathbb{C}$.
- F: local field, $\mathrm{char}(F) = 0$; let $\mathcal{L}_F$ denote its Weil–Deligne group.
- W: symplectic F-vector space, $\dim W = 2n$.
- $\mathrm{Sp}(W) = \mathbf{Sp}(W, F)$ (or $\mathbf{Sp}(2n, F)$): the symplectic group.

Definition

If $F \neq \mathbb{C}$, the metaplectic group is THE non-trivial central extension of locally compact groups

$$1 \to \boldsymbol{\mu}_2 \to \mathrm{Mp}(W) \to \mathrm{Sp}(W) \to 1.$$

If $F = \mathbb{C}$ we put $\mathrm{Mp}(W) = \boldsymbol{\mu}_2 \times \mathrm{Sp}(W)$.

It is customary to write $\mathrm{Mp}(2n)$ or $\mathrm{Mp}(2n, F)$.

Genuine representations

Fixing an additive character ψ of F and the symplectic form $\langle\cdot|\cdot\rangle$ on W, one can describe $\mathsf{Mp}(W)$ by explicit 2-cocycles (Rao, Lion–Perrin).

Representations of $\mathsf{Mp}(W)$: HC-modules or Casselman–Wallach representations if $F \supset \mathbb{R}$; smooth if $F \supset \mathbb{Q}_p$.

Definition

A representation (π, V_π) of $\mathsf{Mp}(W)$ is *genuine* if $\pi(z) = z \cdot \mathrm{id}_{V_\pi}$ for all $z \in \boldsymbol{\mu}_2$.

For instance, the Weil/oscillator representation $\omega_\psi = \omega_\psi^+ \oplus \omega_\psi^-$ of $\mathsf{Mp}(W)$ is genuine. They depend on $\psi \circ \langle\cdot|\cdot\rangle$.

Goal

Understand the genuine representation theory of $\mathsf{Mp}(W)$.

The L-group

Question: Langlands program for genuine representations of $\mathrm{Mp}(W)$?

Fix $\psi \circ \langle \cdot | \cdot \rangle$. There are strong evidences (from Θ-correspondence, geometric Satake, etc.) for the

Definition

The L-group of $\mathrm{Mp}(W)$ is $\mathrm{Sp}(2n, \mathbb{C}) \times \mathrm{Weil}_F$, i.e. same as the L-group of the split $\mathrm{SO}(2n+1)$.

This is also compatible with Weissman's definition of L-groups for coverings.

- L-parameters for $\mathrm{Mp}(W)$ = symplectic representations $\phi = \bigoplus_{i\in I} m_i\phi_i$ of $\mathcal{L}_F$, where $m_i \geqslant 1$, the ϕ_i's are distinct simple representations of $\mathcal{L}_F$, and $\sum_i m_i \dim \phi_i = 2n$.
- A-parameters for $\mathrm{Mp}(W)$ = symplectic representations $\psi = \bigoplus_{i\in I} m_i\psi_i$ of dimension $2n$ of $\mathcal{L}_F \times \mathrm{SL}(2,\mathbb{C})$ as above; the $\mathcal{L}_F$ factor of each ψ_i is bounded.
- S_ϕ = centralizer of ϕ in $\mathrm{Sp}(2n,\mathbb{C})$ (same for S_ψ).
- $\mathcal{S}_\phi = \pi_0(S_\phi)$ (same for $\mathcal{S}_\psi$).

One can describe S_ϕ and $\mathcal{S}_\phi$ explicitly; $\mathcal{S}_\phi$ is finite abelian, and:

$$\mathcal{S}_\phi^\vee = \boldsymbol{\mu}_2^{I^+}, \quad I^+ := \{i \in I : \phi_i \text{ symplectic.}\}$$

Same for S_ψ, $\mathcal{S}_\psi$ and $\mathcal{S}_\psi^\vee$.

Local Langlands correspondences

Let $\Phi_{\mathrm{symp}}(2n)$ be the set of equivalence classes of L-parameters for $\mathrm{Mp}(W)$ (= those for $\mathrm{SO}(2n+1)$). The following is due to Adams–Barbasch ($F \supset \mathbb{R}$) and Gan–Savin ($F \supset \mathbb{Q}_p$).

Theorem (LLC)

There is a decomposition

$$\mathrm{Irr}_{\mathrm{gen}}(\mathrm{Mp}(W)) = \bigsqcup_{\phi \in \Phi_{\mathrm{sympl}(2n)}} \Pi_\phi,$$

together with bijections $\Pi_\phi \leftrightarrow \mathcal{S}_\phi^\vee$ + various properties, eg.

- $\pi \in \Pi_\phi$ is tempered (resp. discrete series) $\iff$ ϕ is bounded (resp. does not factor through proper Levi);
- LLC reduces to tempered/bounded case via Langlands quotients;
- if ϕ is bounded, then $\mathbf{1} \in \mathcal{S}_\phi^\vee$ corresponds to generic representation.

- The LLC depends on ψ and the symplectic form $\langle\cdot|\cdot\rangle$ on W.
- It is proved by reduction to the LLC of $\mathrm{SO}(V^{\pm})$ (Arthur, Ishimoto) where $V^{\pm}$ is the quadratic vector space with
  - dimension $2n+1$,
  - discriminant 1,
  - Hasse invariant ± 1,

  via Θ-correspondence for the reductive dual pair $(\mathrm{Sp}(W), \mathrm{O}(V^{\pm}))$.
- Note: $\mathcal{S}_\phi^\vee$ is also in bijection with the packet $\Pi_\phi^{\mathrm{Vogan}}$ for $\mathrm{SO}(V^{\pm})$.
- There is a more direct proof for $F = \mathbb{C}$.

The endoscopic viewpoint (Adams, Renard, L.)

The set of elliptic endoscopic data of $\mathrm{Mp}(W)$ is defined as

$$\begin{aligned}\mathcal{E}_{\mathrm{ell}}(\mathrm{Mp}(W)) &:= \{s \in \mathrm{Sp}(2n, \mathbb{C}) : s^2 = 1\} / \mathrm{conj}.\\ &= \{(\underbrace{n'}_{+}, \underbrace{n''}_{-}) \in \mathbb{Z}^2_{\geqslant 0} : n' + n'' = n\}.\end{aligned}$$

The endoscopic group is $\mathrm{SO}(2n'+1) \times \mathrm{SO}(2n''+1)$.

Similar to elliptic endoscopic data for $\mathrm{SO}(2n+1)$, but without symmetry $(n', n'') \leftrightarrow (n'', n')$.

Known results

- Transfer of orbital integrals (Renard for $F = \mathbb{R}$, L. '11 for $F \supset \mathbb{Q}_p$)
- Fundamental lemma for units, including the weighted case (L. '11)
- Fundamental lemma for spherical Hecke algebra (C. Luo '18).

Let $\mathbf{G}^! \in \mathcal{E}_{\mathrm{ell}}(\mathrm{Mp}(W))$ with endoscopic group $G^!$. The transfer of orbital integrals dualizes to a map

$$\check{\mathcal{T}}_{\mathbf{G}^!, \mathrm{Mp}(W)} : \{\text{st. dist. on } G^!(F)\} \to \{\text{genuine dist. on } \mathrm{Mp}(W)\}$$

sending stable virtual characters to genuine virtual characters.

- For every BOUNDED L-parameter $\phi^!$ for $G^!$, we have a stable tempered distribution $S\Theta^{G^!}_{\phi^!}$.
- $(G^!)^\vee = \mathrm{Sp}(2n', \mathbb{C}) \times \mathrm{Sp}(2n'', \mathbb{C}) \hookrightarrow \mathrm{Sp}(2n, \mathbb{C})$ up to conjugacy, hence $\phi^!$ maps to a bounded $\phi \in \Phi_{\mathrm{symp}}(2n)$.

Endoscopic character relations (ECR) — C. Luo

Let $\phi \in \Phi_{\mathrm{symp}}(2n)$ be bounded. The L-packet Π_ϕ for $\mathrm{Mp}(W)$ can be characterized in terms of $\check{\mathcal{T}}_{\mathbf{G}^!, \mathrm{Mp}(W)}\left(S\Theta^{G^!}_{\phi^!}\right)$ for various $(\mathbf{G}^!, \phi^!)$ such that $\phi^! \mapsto \phi$, and some ϵ-factors.

The precise formulation will be given later on.

The adélic covering

Let F be a number field, and W a symplectic F-vector space of dimension $2n$. The metaplectic group is the non-trivial central extension

$$1 \to \boldsymbol{\mu}_2 \to \mathsf{Mp}(W, \mathbb{A}_F) \to \mathbf{Sp}(W, \mathbb{A}_F) \to 1.$$

- It splits uniquely over $\mathbf{Sp}(W, F)$, hence it makes sense to study
  - *genuine automorphic forms* on $\mathsf{Mp}(W, \mathbb{A}_F)$, eg. Siegel modular forms of $\frac{1}{2} + \mathbb{Z}$-weights,
  - genuine L^2-automorphic spectrum.
- It is the quotient of $\prod'_v \mathsf{Mp}(W_v)$ by $\{(z_v)_v \in \bigoplus_v \boldsymbol{\mu}_2 : \prod_v z_v = 1\}$, hence irreducible admissibles of $\mathsf{Mp}(W, \mathbb{A}_F)$ decompose into $\bigotimes'_v \pi_v$.

Here we use the fact that $\mathsf{Mp}(W_v)$ splits over $\mathbf{Sp}(W_v, \mathcal{O}_v)$ with commutative Hecke algebras, for almost all v.

Local desiderata for Arthur packets

Let F be local, $\dim_F W = 2n$ and ψ is fixed. For the study of

1. unitary duals,
2. Gelfand–Kirillov dimensions, or
3. global L^2-automorphic spectrum,

the LLC is not enough: one has to go beyond tempered L-packets and study Arthur packets. My main motivation is 3.

Recall: *A-parameters* for $\mathrm{Mp}(W)$ are symplectic representations

$$\psi = \bigoplus_{i \in I} m_i \phi_i \boxtimes r(b_i) : \mathcal{L}_F \times \mathrm{SL}(2, \mathbb{C}) \to \mathrm{GL}(2n, \mathbb{C}),$$

where $r(b_i) := \mathrm{Sym}^{b_i - 1}(\mathrm{std})$ and ϕ_i is bounded. Let $\Psi_{\mathrm{symp}}(2n) = \{\text{such } \psi\}$. Define $\Psi^+_{\mathrm{symp}}(2n)$ by dropping boundedness.

Characterization via ECR

Given a pair $(\mathbf{G}^!, \psi^!)$ where $\mathbf{G}^! \in \mathcal{E}_{\mathrm{ell}}(\mathrm{Mp}(W))$ and $\psi^! \in \Psi^+(G^!)$, we obtain (ψ, s) where $\psi^! \mapsto \psi$ and $s \in S_{\psi,\text{2-tors}}/\text{conj}$ corresponds to $\mathbf{G}^!$. This is actually a bijection.

Given (ψ, s), Arthur's theory for $G^!$ provides stable virtual characters $S\Theta^{G^!}_{\psi^!}$ on $G^!(F)$. Consider the (-1)-eigenspace of $\mathrm{std} \circ \psi$ under s and set

$$\epsilon(\psi^{s=-1}) := \epsilon\left(\frac{1}{2}, \psi^{s=-1}\big|_{\mathcal{L}_F}, \psi\right).$$

Definition-Lemma

The following depends only on ψ and the image x of s in $\mathcal{S}_\psi$.

$$T_{\psi,s} := \epsilon\left(\psi^{s=-1}\right) \cdot \check{\mathcal{T}}_{\mathbf{G}^!,\mathrm{Mp}(W)}\left(S\Theta^{G^!}_{\psi^!}\right).$$

Every $x \in \mathcal{S}_\psi$ arises from some $s \in S_{\psi,\text{2-tors}}$, hence we may write $T_{\psi,x} = T_{\psi,s}$, and consider the Fourier expansion of $x \mapsto T_{\psi,x}$ or its translates.

Main local Theorem (L.)

Given $\psi \in \Psi^+_{\text{symp}}(2n)$, set $s_\psi := \psi\left(1, \begin{pmatrix} -1 & \\ & -1 \end{pmatrix}\right) \in S_\psi$ and let x_ψ be its image in $\mathcal{S}_\psi$. Then

$$\pi_{\psi,\chi} := |\mathcal{S}_\psi|^{-1} \sum_{x \in \mathcal{S}_\psi} \chi(x_\psi x) T_{\psi,x}$$

is a $\mathbb{Z}_{\geqslant 0}$-linear combination (possibly zero) of genuine irreducible characters of $\mathrm{Mp}(W)$, for all $\chi \in \mathcal{S}_\psi^\vee$. If $\psi \in \Psi_{\text{symp}}(2n)$, then these irreducible characters arise from unitary representations.

We also call it the *endoscopic character relation* (ECR) associated with ψ.

Definition of A-packets

Collecting the constituents of $\pi_{\psi,\chi}$ for various χ), we obtain the A-packet Π_ψ as a multi-set of genuine irreducibles. Rigorously, Π_ψ is a finite set equipped with two maps

$$\mathrm{Irr}_{\mathrm{gen}}(\mathrm{Mp}(W)) \leftarrow \Pi_\psi \rightarrow \mathcal{S}_\psi^\vee.$$

- The structure above is characterized completely by ECR.
- The ϵ-factor in $T_{\psi,s}$ is a metaplectic feature: it does not appear in Arthur's original version.
- If ψ is a bounded L-parameter (i.e. all $b_i = 1$), then we recover the L-packet and Luo's ECR for the tempered LLC for $\mathrm{Mp}(W)$.

Furthermore, $\pi_{\psi,\chi}$ has the following properties established in [L.].

1. Reduction to good parity case (i.e. each simple summand in ψ is symplectic) via full parabolic induction.
2. Infinitesimal characters expressed in terms of ψ when $F \supset \mathbb{R}$.
3. Assume the covering is unramified. If ψ is trivial on $I_F \times \mathrm{SL}(2,\mathbb{C}) \subset \mathcal{L}_F$, then Π_ψ has a unique spherical member, which is multiplicity-free and parametrized by $\chi = \mathbf{1}$. If ψ is not unramified then Π_ψ has no spherical members.
4. Central characters expressed in terms of ϵ-factors and (ψ, χ).
5. Π_{ϕ_ψ} embeds canonically into $\Pi_\psi^{\mathrm{mult}=1}$, where for all $w \in \mathcal{L}_F$,

$$\phi_\psi(w) = \psi\left(w, \begin{pmatrix} |w|^{1/2} & \\ & |w|^{-1/2} \end{pmatrix}\right) \quad \text{(L-parameter)}.$$

6. The effect of variation of ψ can be explicitly described, generalizing the recipe for L-packets due to Gan–Savin.
7. Normalization of int. op. via A-parameters.

Global desiderata

Let F be a number field. As before, $\dim_F W = 2n$ and $\psi = \bigotimes_v \psi_v : F\backslash\mathbb{A}_F \to \mathbb{C}^\times$ is fixed. Put $L^2_{\mathrm{gen,disc}} := L^2_{\mathrm{genuine,discrete}}(\mathbf{Sp}(W,F)\backslash \mathrm{Mp}(W,\mathbb{A}_F))$.

- A-parameters ψ are defined as formal sums of $\phi_i \boxtimes r(b_i)$ where ϕ_i: cuspidal automorphic representations of $\mathrm{GL}(n_i, \mathbb{A}_F)$, and $b_i \in \mathbb{Z}_{\geqslant 1}$ with parity conditions (Arthur).
  They are defined without resort to the hypothetical automorphic Langlands group $\mathcal{L}_F$.
- Also defined: S_ψ and $\mathcal{S}_\psi$ equipped with localization maps, $\forall v$.
- Given ψ, can define the summand L^2_ψ of $L^2_{\mathrm{gen,disc}}$ via "near equivalence classes", using the Satake parameters attached to ψ_v for almost all v.
- We say ψ is *elliptic* if $\psi = \bigoplus_{i\in I} \phi_i \boxtimes r(b_i)$ where all the $\phi_i \boxtimes r(b_i)$ are distinct and symplectic.

Theorem 1 (Gan–Ichino)

$L^2_{\mathrm{gen,disc}} = \widehat{\bigoplus}_{\psi:\mathrm{elliptic}} L^2_\psi$.

The above is proved using Θ-correspondence in stable range. Define

$$\Pi_\psi := \left\{ \pi = (\pi_v)_v \;\middle|\; \begin{array}{l} \pi_v \in \Pi_{\psi_v} \text{ (multi-set!)}, \\ \text{spherical for almost all } v \end{array} \right\},$$

and let $\Pi_\psi(\epsilon_\psi)$ be the subset given by

$$\prod_v \langle s_v, \pi_v \rangle = \underbrace{\epsilon_\psi^{\mathrm{Art}}(s)}_{\text{same as } \mathrm{SO}(2n+1)} \quad \epsilon\left(\frac{1}{2}, \psi^{s=-1}\big|_{\mathcal{L}_F}, \psi\right), \quad \forall s \in S_\psi = \mathcal{S}_\psi.$$

Main global Theorem (L., conjectured by Gan in ICM 2014)

Grosso modo, $L^2_\psi \simeq \bigoplus_{\pi \in \Pi_\psi(\epsilon_\psi)} \bigotimes'_v \pi_v$ for all elliptic ψ.

Remark. Levi subgroups of $\mathbf{Sp}(W)$ are of the form

$$\mathbf{M} = \mathbf{Sp}(W^\flat) \times \prod_{k=1}^{r} \mathbf{GL}(n_k), \qquad \begin{array}{l} W^\flat \subset W: \text{ symp. subspace,} \\ \dim W^\flat + 2\sum_k n_k = \dim W. \end{array}$$

One has to formulate and prove these assertions for preimages of $\mathbf{M}(F)$ (resp. $\mathbf{M}(\mathbb{A}_F)$) in $\mathrm{Mp}(W)$ (resp. $\mathrm{Mp}(W, \mathbb{A}_F)$).

1. The twofold covering does not split over $\mathbf{GL}$ factors, but this can be handled as in Hanzer–Muić ('10), using some genuine characters made from Weil constants.
2. Alternatively, $\mathrm{Mp}(W)$ can be enlarged to $\widetilde{\mathrm{Sp}}(W)$ by pushing out via $\boldsymbol{\mu}_2 \hookrightarrow \boldsymbol{\mu}_8$. Genuine representation theory is unaffected, but the preimage of $\mathbf{M}(F)$ becomes $\widetilde{\mathrm{Sp}}(W^\flat) \times \prod_{k=1}^{r} \mathrm{GL}(n_k, F)$.

Both approaches rely on the choice of ψ and symplectic forms.

Waldspurger and Gan–Ichino

Consider both the local and global settings.

- When $n = 1$, these are known to Waldspurger.
- When ψ is generic (i.e. all $b_i = 1$), the main global theorem is due to Gan–Ichino.
- When $n = 2$, Gan–Ichino ('21) obtained both main theorems "by hand" with the help of Hanzer–Matić ('10).

These are all based on Θ-correspondence, not endoscopy.
Compatibilities are shown in [L.]

Example: the most degenerate case

Take $\psi = \mathbf{1} \boxtimes r(2n)$.

- Locally, $\Pi_{\psi_v} = \left\{ \omega^+_{\psi_v}, \omega^-_{\psi_v} \right\}$, $\forall v$ (known to Adams).
- Globally, L^2_ψ are generated by *elementary* ϑ*-series*.

Proofs: Strategy à la Arthur

Try to imitate Arthur's *endoscopic classification* (Chapters 4 and 7) to prove the local and global theorems altogether. Ingredients:

- Stabilization of trace formula. Done for $\mathrm{Mp}(W)$ (L. '21).
- Spectral decomposition of the stable side. Done by Arthur since the endoscopic groups are $\mathbf{SO}(2n'+1) \times \mathbf{SO}(2n''+1)$.
- Local intertwining relation (LIR). Difficult, only known for generic ψ (due to Ishimoto).

Specifically, Arthur used LIR to prove that the L^2-automorphic spectrum involves only elliptic A-parameters (the "no embedded Hecke eigenvalues" property), for quasi-split classical groups.

It seems difficult to prove LIR directly for $\mathrm{Mp}(W_v)$.

Shortcut (+ suggestions from Waldspurger)

Thanks to Gan–Ichino, $L^2_{\mathrm{gen,disc}} = \widehat{\bigoplus}_{\psi:\mathrm{ell.}} L^2_\psi$ is directly available to us.

1. Main global theorem (= decomposition of L^2_ψ) follows easily from STF for $\mathrm{Mp}(W, \mathbb{A}_F)$. Though A-packets are not yet available, the global theorem can be formulated as a character relation involving various π_{ψ_v, χ_v}.
2. The main local theorem is proved by global means via the main global theorem (phrased as above). Data put at the auxiliary places:
   - either from the L-packet inside an A-packet, or
   - suitable co-tempered representations ($v \nmid \infty$).

Theorem (F. Chen, '24)

Transfer for $\mathrm{Mp}(W)$ commutes with Aubert dual for $F \supset \mathbb{Q}_p$.

To get the co-tempered ECR from Luo's ECR via Aubert dual, some sign equality is needed; we globalize carefully and reduce it to SO case (AGIKMS, Ishimoto, Liu–Lou–Shaihidi…) via Θ.

To-do list

- Explicit construction of A-packets when $F \supset \mathbb{Q}_p$, after Moeglin, Xu, Atobe..., and multiplicity-one (work in progress by J. Chen).
- Relation to Θ-correspondence (Xu's student?).
- Relation to translation functors and cohomological induction when $F = \mathbb{R}$, à la Moeglin–Renard; Adams–Johnson packets.
- Explicit construction for $F = \mathbb{C}$ as predicted by Moeglin–Renard.
- Prove LIR.
- Application to number theory, eg. Ikeda–Yamana lifting from $\mathrm{PGL}(2)$ to $\mathrm{Mp}(2n)$ for n odd and F totally real.
- Can we use these results to study global root numbers?

Postscript: affine Hecke algebras

Suppose $F \supset \mathbb{Q}_p$ and ψ has conductor $4\mathcal{O}_F$. Let $\mathcal{G}^{\pm}_{\psi}$ be the Bernstein block $\ni \omega^{\pm}_{\psi}$. Let $\mathcal{G}^{\pm}$ be the Bernstein block $\ni \mathbf{1}_{\mathrm{SO}(V^{\pm})}$.

- Gan–Savin ($p > 2$) and Takeda–Wood ($p = 2$) showed $\mathcal{G}^{\pm}_{\psi} \simeq \mathcal{G}^{\pm}$ by constructing types for $\mathcal{G}^{\pm}_{\psi}$ and giving an explicit isomorphism between Hecke algebras.
- It is stronger (being a categorical equivalence) and looks more natural than LLC in many aspects. It also preserves unitarity, temperedness and discrete series.
- $\mathrm{Mp}(W)$ and $\mathrm{SO}(V^{\pm})$ share the same L-group; $\mathcal{G}^{\pm}_{\psi} \simeq \mathcal{G}^{\pm}$ preserves L-parameters ϕ but not the $\chi \in \mathcal{S}^{\vee}_{\phi}$.

Natural question 1: How do the χ's differ under $\mathcal{G}^{\pm}_{\psi} \simeq \mathcal{G}^{\pm}$?

Suppose that $\pi \in \mathcal{G}^{\pm}_{\psi}$ is irreducible and corresponds to $\sigma \in \mathcal{G}^{\pm}$;

$$\pi = \pi_{\phi,\chi}, \quad \sigma = \sigma_{\phi^\circ,\chi^\circ} \quad \text{under LLC.}$$

Write $\phi = \bigoplus_{i \in I} m_i \phi_i$. Identify $\mathcal{S}_\phi^\vee$ with $\boldsymbol{\mu}_2^{I^+}$ where $I^+ \subset I$ indexes the symplectic summands in ϕ.

Theorem (F. Chen–L. '25)

We have $\phi^\circ = \phi$ (known to GS+TW) and $\chi^\circ = \chi\nu_\phi$, where

$$\nu_\phi = (\nu_{\phi,i})_{i \in I^+} \in \mathcal{S}_\phi^\vee, \quad \nu_{\phi,i} = \epsilon\left(\frac{1}{2}, \phi_i, \psi\right).$$

Modulo [Chen–L. '23], the argument is largely "endoscopic".

Naive question 2: How about A-packets?

Naive question 3: Other blocks?

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Thanks for your attention

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