Research Statement

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My research sits at the intersection of algebraic geometry, the arithmetic of function fields, and representation theory. In particular, my interests lie along the interplay between

- the geometry of moduli spaces of geometric representation theory (affine Springer fibers, Hitchin fibers, Deligne–Lusztig varieties, etc.) and
- their number-theoretic avatars (orbital integrals, representations of $G(F)$ for F a finite, local, or global field).

In the first section, I discuss topics related to my thesis: the proof of the Weighted Fundamental Lemma (WFL) for nonsplit groups. A number of major results in automorphic theory, including the untwisted and twisted stable trace formulae of Arthur (see [Art02], [Art01], [Art03], [MW16a], [MW16b]) and the massive endoscopic classification for classical groups (see [Art13], [AGIKMS25]), are conditional upon the WFL and its "nonstandard version." In the second section, I propose four directions for my future work:

1. deduction of the nonstandard WFL,
2. arithmetic study of the Hitchin fibration outside the generically regular-semisimple locus,
3. proof of comparison theorems between Yu-type and affine Deligne–Lustzig constructions of tame supercuspidal representations, and
4. investigation of the automorphic consequences of the theory of conformal blocks.

1 Stabilization and Fundamental Lemmas

1.1 Background

My work on the WFL rests upon monumental prior contributions. Building on the pioneering work on endoscopy of Langlands–Shelstad [LS87], Waldspurger's reduction to the equal-characteristic Lie algebra setting [Wal09], and numerous special cases [LN08], Ngô Bảo Châu's proof of the long-open Fundamental Lemma (FL) [Ngô10] drew striking new connections between global arithmetic and geometry. We briefly recall the shape of the theory below as prior context for my work.

Let G be a quasi-split reductive group scheme over a curve C with base field k. For example, a global quasi-split unitary group or special orthogonal group. Let $D > 0$ be a divisor, and define the moduli of D-twisted Higgs bundles $M = M_{G,D,X}$ as the stack of pairs $(\mathcal{E} \in \mathrm{Bun}_{G,X}, \theta \in H^0(X, \mathrm{Ad}_D(\mathcal{E})))$. This stack is equipped with a natural global Chevalley morphism f to an affine space A. Restricting θ to the generic point $\eta = \mathrm{Spec}(F)$ gives an element $X \in \mathfrak{g}(F)$, and so $f : M \to A$ provides a natural global moduli setting for studying the arithmetic of characteristic polynomials for function fields.

Although the FL is an arithmetic statement over a local field, the introduction of global methods allowed the application of powerful geometric techniques. In particular, Ngô described the decomposition of Beilinson, Bernstein, Deligne, and Gabber [BBDG18] for the perverse cohomology sheaves $K^n = {}^pH^n(f_\star^{\mathrm{ani}}\overline{\mathbb{Q}}_l)$. Ngô shows that their decomposition into simple pieces corresponds to that appearing in the stabilization of the trace formula, i.e. $K^n = \bigoplus_{[\kappa]} K^n_{[\kappa]}$ decomposes as a sum over semisimple conjugacy classes in $\widehat{G}$. Then he shows roughly that the κ-twisted factor of this decomposition for G is isomorphic to the untwisted part of the decomposition for the corresponding endoscopic group H_κ (see [Ngô10, Theorem 6.4.3]). In this way, his work not only proves the FL, it provides a geometric framework underlying the entire stabilization process. Counting k-points ($k = \mathbb{F}_q$) on fibers via Grothendieck–Lefschetz and applying a local-to-global argument deduces the FL.

The proof by Chaudouard and Laumon of the *Weighted* Fundamental Lemma [CL10], [CL12] in the case where G is *split* (and in particular *constant*, $G = \mathbb{G} \times_k C$) was a natural next step for automorphic applications. First, they needed to extend Ngô's geometric theory across $A^{\mathrm{rs}} \supset A^{\mathrm{ani}}$, the generically regular semisimple locus. Here there are two geometric difficulties: the Hitchin fibration is no longer proper, and its total space is not Deligne–Mumford. In order to be able to apply the Decomposition Theorem, Chaudouard and Laumon truncate the total space M by imposing ξ-weighted slope-stability conditions (closely related to the *complementary polygon* of Behrend [Beh95]) on parabolic reductions of the Higgs bundles in question. The corresponding ξ-truncated Hitchin fibration $f^\xi : M^\xi \to A^{\mathrm{rs}}$ is geometrically well-behaved (smooth, proper, Deligne–Mumford). Miraculously, the weighted stability conditions appearing in the definition correspond to regularizing weight functions introduced by Arthur when defining weighted orbital integrals, so counting $\mathbb{F}_q$-points computes weighted local orbital integrals.

1.2 My Work

In my thesis [Hal], in progress, I extend the arguments of Chaudouard and Laumon to prove the WFL for quasisplit (but possibly nonsplit) G. As in the previous work, this consists of two parts, one part geometric and one part arithmetic.

On the geometric side, I give definitions for weighted stability of (∞-rigidified) Higgs bundles outside the split case. Due to the fact that endoscopic groups can become Levi subgroups upon pullback, this definition is *not* stable along a splitting cover. The complementary polygons of Behrend are defined only for torsors for split groups, so the definitions in my setting are novel. It is crucial to understand the interplay between *relative* data, i.e. that defined directly over C and living in the relative cocharacter space $\mathrm{Hom}(X^\star(S), \mathbb{R})$ in the style of Borel and Tits [BT65], and *absolute* data living over a geometric point where the group becomes split.

With the framework of ξ-stability defined correctly, I prove the fundamental geometric results required to obtain a well-behaved theory.

Theorem 1. *Let G/C be a quasisplit semisimple group scheme over a curve C satisfying mild technical assumptions and ξ a parameter in general position.*

1. *The moduli of ξ-stable Higgs bundles M^ξ is a finite type, Deligne–Mumford, open substack of M^{rs}.*
2. *The ξ-stable Hitchin morphism $f^\xi : M^\xi \to A^{\mathrm{rs}}$ is proper.*

The first theorem requires generalized results, due to Harder [Har68] in the split case, on the existence of Borel reductions for G-torsors of bounded stability. The second theorem is a proof of existence and uniqueness for ξ-semistable reductions of Higgs bundles over a DVR. The strategy is the same as that in Chaudouard and Laumon's work, with a mixture of arguments performed relatively and absolutely. Stronger uniformization theorems on torsors are applied from the modern literature, and a Weyl-twist is tracked throughout the proof.

This gives the necessary ingredients to extend the geometric endoscopic decomposition of Ngô outside the anisotropic locus, and I adapt the theorem of Chaudouard and Laumon proving that all closed subsets of $\mathcal{A}$ arising in the decomposition theorem for $Rf_\star^{\xi,rs}\overline{\mathbb{Q}}_l$ intersect the anisotropic locus. I then deduce the cohomological version of the WFL on this larger truncated locus from Ngô's theorem.

Theorem 2. *The cohomological WFL holds for quasisplit semisimple group schemes.*

On the arithmetic side, a Beauville–Laszlo decomposition confirms that point-counting on the Hitchin fibers corresponds to the computation of weighted orbital integrals. The cohomological FL on this locus then induces, via a Grothendieck–Lefschetz point count, a global incarnation of the stabilization of the trace formula à la Moeglin–Waldspurger (see [MW16b, p. VII.2.2]). A local-to-global argument completes the proof.

2 Proposed Projects

2.1 Completion of the twisted stabilization program.

For applications in automorphic theory and the Langlands program, it is important to have not only the weighted fundamental lemma, but also the *twisted* weighted fundamental lemma. It has been proven by Waldspurger [Wal08] that this generalization follows from the usual weighted fundamental lemma as well as a *nonstandard* version. The geometric framework developed by Chaudouard and Laumon in the split case, and by myself in the non-split case, provides the necessary tools to prove this nonstandard version as well, but it has not yet appeared in the literature in either case. Alongside my thesis, these are the only missing pieces needed to complete the proof of Arthur's twisted stable trace formula, see [MW16a] and [MW16b].

Problem 1. *Deduce the nonstandard weighted fundamental lemma from the geometric framework of [CL10] and [Hal].*

2.2 Hitchin fibers outside A^{rs}.

From the perspective of a geometric representation theorist, the entirety of the endoscopic decomposition happens over the nicest part of the Hitchin fibration A^{rs}. It is believed that the endoscopic decomposition has geometric significance on the entire Hitchin base A. For example, the global nilpotent cone $f^{-1}(0)$, a highly singular stack central in the Geometric Langlands program, can be thought of as a kind of compactification of $\mathrm{Bun}_G(X)$. Correspondingly its Grothendieck–Lefschetz trace formula should extend that for $\mathrm{Bun}_G(X)$ introduced in the work of Behrend ([Beh91], [Beh93]) and generalized by Lurie and Gaitsgory ([GL19]). Some existing work has analyzed the geometry of the global nilpotent cone (c.f. [Boz22] and the references therein), but arithmetic applications are mostly unexplored. Simple examples such as the computations appearing in [Cha15], [Cha17] suggest that it should be possible to give a definition of weighted stability over all of A and extract orbital integral information outside of A^{rs}, but this is unexplored outside the case of GL_n.

Problem 2. *Define weighted-stability for Hitchin fibers outside the generically regular-semisimple locus, and deduce formulae for local or adelic orbital integrals from their Grothendieck–Lefschetz trace formulae.*

More broadly, I think it possible to connect much of the above theory with the general notion of Θ-stability due to Halpern-Leistner [Hal14] and the conjectural geometric stabilization framework proposed by Frenkel, Ngô, and Laumon [FN11], [FLC10].

2.3 Geometrization of p-adic representation theory

Let F be a nonarchimedean local field and G a reductive group over F. There has been a recent flurry of development in tamely ramified supercuspidal representations of $G(F)$, both in harmonic analysis and in geometry. However, comparison theorems between the two have not matched this development. We outline now the current state of affairs and propose to strengthen the link between the two.

On the side of local representation theory, the construction of supercuspidal representations by parahoric induction developed by Moy–Prasad [MP94; MP96] and Yu [Yu01] has seen great recent development. It is known that at least most supercuspidals arise by this construction ([Kim07], [Fin21]) and, with the Fintzen–Kaletha–Spice twist, that the constructions are compatible with L-packets and many cases of endoscopy (c.f. [FKS23]).

There has been parallel progress in geometric constructions extending the Deligne–Lusztig theory at the core of parahoric induction. There is a well-developed theory of positive-depth parahoric Deligne–Lusztig induction, which also produces supercuspidal representations ([CO25]). Deligne–Lusztig varieties can also be defined as infinite-type varieties directly at infinite-depth, as proposed by Lusztig [Lus79] and formalized by Boyarchenko [Boy12], among others. The cohomology of such varieties is understood in some special cases (see [CI21] for inner forms of GL_n, [Iva18], [Gör19], etc.), and supercuspidal representations can be shown to be found in the cohomology of these varieties ([CI23]).

The supercuspidals constructed by these high-depth geometric methods have been compared to the constructions of Yu–Fintzen–Kaletha–Spice in [CO25], but only in the case where the toral datum on either side is *unramified*. This restriction is striking given that both the Yu–type constructions and the geometric constructions allow for arbitrary tamely ramified data. The restriction is demanded by their application of a strategy—dating at least to [Hen92] in the p-adic case and [Har65] for real groups—in which unramified supercuspidal representations are determined by the restriction of their characters to a sufficiently regular locus. On this locus, character formulae in the style of Adler–DeBacker–Spice ([AS09], [DS18]) simplify substantially, so one can avoid most of the complexity of supercuspidal characters. It is believed that tamely ramified supercuspidal characters should likewise be characterized by their behavior on a sufficiently regular locus, and a similar technique is leveraged for GL_2 in [Iva18]. To my knowledge this strategy has not been developed more broadly, and the comparison between geometric and representation-theoretic constructions of supercuspidals is ripe for further development.

Problem 3. *Prove comparisons between the Yu–type and affine Deligne–Lusztig constructions of supercuspidal representations by identifying their character formulae on an appropriate domain of regular semisimple elements.*

2.4 Conformal Blocks and Connections to the Langlands Program

Many of the techniques for studying torsors under a relative reductive or parahoric group scheme G over a curve have been developed for the purposes of studying *twisted conformal blocks* (see [Hei10], [BL94], [PR10]). These are certain representation-theoretic vector spaces associated to G/C known to satisfy *fusion rules* when varying the curve over $\overline{\mathcal{M}}_{g,n}$ (c.f. [HK24], [DHG25]).

From its origin in mathematical physics, the theory of conformal blocks is developed mostly over the complex numbers, using the formalism of vertex operator algebras ([FB04]) and, more abstractly, chiral homology ([BD04]). When working over $\mathbb{F}_q$ or $\overline{\mathbb{F}}_q$, many foundational geometric results remain the same ([PR08]), and there should be strong links to the kinds of nonarchimedean representation theory arising in the Langlands correspondence for global function fields.

Problem 4. *Extract automorphic consequences from the fusion structure of conformal blocks.*

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