1 Introduction

The eigencurve $\mathcal{E}$ is a rigid analytic space parameterizing overconvergent and therefore classical modular eigenforms of finite slope. Since Coleman and Mazur’s original work [10], there have been numerous generalizations [4, 6, 14], as well as alternative constructions using modular symbols [1] and $p$-adic representation theory [12]. In spite of these advances, several elementary questions about the geometry of $\mathcal{E}$ remain. One such question was raised by Coleman and Mazur: does there exist a $p$-adic family of finite slope overconvergent eigenforms over a punctured disk, and converging, at the puncture, to an overconvergent eigenform of infinite slope? Another way of phrasing this question is to ask whether the projection $\pi : \mathcal{E} \to W$ satisfies the valuative criterion for properness\(^1\).

In [5], this was proved in the affirmative for the particular case of tame level $N = 1$ and $p = 2$. The proof, however, was quite explicit and required (at least indirectly) that the curve $X_0(Np)$ have genus zero. In this paper, we work with general $p$ and arbitrary tame level, although our result only applies at certain arithmetic weights in the center of weight space.

Recall that the $C_p$-points of $W$ are the continuous homomorphisms from the Iwasawa algebra $\Lambda := \mathbb{Z}[\lim\leftarrow (\mathbb{Z}/Np^k\mathbb{Z})^\times]$ to $C_p$. Let $\chi$ denote the cyclotomic character. Our main theorem is:

**Theorem 1.1.** Let $\mathcal{E}$ be the $p$-adic eigencurve of tame level $N$. Let $D$ denote the closed unit disk, and let $D^\times$ denote $D$ with the origin removed. Let $h : D^\times \to \mathcal{E}$ be a morphism such that $\pi \circ h$ extends to $D$. Suppose, moreover, that $(\pi \circ h)(0) = \kappa$, where $\kappa$ is of the form

$$\kappa = \chi^k \cdot \psi,$$

for $k \in \mathbb{Z}$ and $\psi$ a finite order character of conductor dividing $N$. Then there exists a map $\tilde{h} : D \to \mathcal{E}$ making the following diagram commute:

\[
\begin{array}{c}
D^\times \xrightarrow{h} \mathcal{E} \\
\downarrow \quad \downarrow \pi \\
D \xrightarrow{\tilde{h}} W
\end{array}
\]

\(^1\)The curve $\mathcal{E}$ has infinite degree over weight space $W$, and so, the projection $\pi : \mathcal{E} \to W$ cannot technically be proper.
The new idea of this paper is, roughly speaking, to specialize the family $h$ of overconvergent modular forms to an infinitesimal neighbourhood of the punctured point. Using the techniques of [5], we conclude that the limiting form \( h(0) \) will be an overconvergent modular form $G_0$, and thus, it suffices to prove that the $U_p$ eigenvalue of this form is not 0. However, if $U_pG_0 = 0$, the infinitesimal deformations of $G_0$ will have nilpotent but nonzero $U_p$ eigenvalue. We are able to deduce a contradiction by combining this idea with the philosophy of [5] that finite slope forms will have large radius of convergence while infinite slope forms will have small radius of convergence. This idea was inspired by work of Bellaíche and Chenevier [2], who study deformations of trianguline $\text{Gal}(\mathbb{F}_p/\mathbb{Q}_p)$-representations by considering deformations of finite dimensional $(\varphi, \Gamma)$-modules over Artinian extensions of $\mathbb{Q}_p$. Their goal was to study the tangent spaces of eigencurves using local techniques from $p$-adic Hodge theory. It is plausible that the properness of the eigencurve is a global manifestation of a purely local theorem; such an idea was suggested to the author — at least at integral weights — by Mark Kisin in 2001 and was discussed in several tea room conversations during the Durham symposium on Galois representations in 2004 and the eigenvarieties semester at Harvard in 2006. However, even with current advances in the technology of local Galois representations, a natural conjectural statement implying properness has not yet been formulated. One issue to bear in mind is that slightly stronger statements one may conjecture are false. For example, there exists a pointwise sequence of finite slope forms converging to an infinite slope form [9].

It is a pleasure to thank Kevin Buzzard for many fruitful discussions; the debt this paper owes to [5] is clear. I would also like to thank Matthew Emerton, Toby Gee, and Mark Kisin for useful conversations.

## 2 Overconvergent Modular Forms

Let $N \geq 5$ be an integer co-prime to $p$; let $X = X_1(N)$; and let $X_0(p) = X(\Gamma_1(N) \cap \Gamma_0(p))$. Since $N \geq 5$, the curves $X$ and $X_0(p)$ are the compactifications of a smooth moduli spaces. The curve $X$ comes equipped with a natural sheaf $\omega$, which, away from the cusps, is the pushforward of the sheaf of differentials on the universal modular curve. Let $A$ be a characteristic zero lift of the Hasse invariant with coefficients in $W(\mathbb{F}_p)[[g]]$, and thus, $A \in H^0(X/W(\mathbb{F}_p), \omega^{\otimes(p-1)})$ by the $q$-expansion principle. We further insist that $A$ has trivial character if $p > 2$, and that $A^2$ has trivial character if $p = 2$; this is possible since $N > 1$. Let $X_0(p, r) \subseteq X_0^\infty(p)$ denote the connected component containing $\infty$ of the affinoid \( \{ x \in X_0^\infty(p); |A(x)| \geq |r| \} \). Standard arguments imply that $|A(x)|$ on $X_0(p, r)$ is independent of the choice of $A$, provided that $v(r) < p/(p + 1)$.

Let $r \in \mathbb{C}_p$ be an element with $p/(p + 1) > v(r) > 0$. Let $\chi$ denote the cyclotomic character; let $\psi$ denote a finite order character of conductor dividing $N$; and let $k \in \mathbb{Z}$.

**Definition 2.1.** The overconvergent modular forms of weight $\chi^k \cdot \psi$, level $N$, and radius of convergence $r$ are sections of $H^0(X_0(p, r), \omega^{\otimes k})$ on which the diamond operators act via $\psi$. We denote this space by $M(C_p, N, \chi^k \cdot \psi; r)$. The space of overconvergent modular forms of weight $\chi^k \cdot \psi$ and level $N$ is

$$M(C_p, N, \chi^k \cdot \psi) := \bigcup_{|r| < 1} M(C_p, N, \chi^k \cdot \psi; r).$$

The space $M(C_p, N, \chi^k \cdot \psi; r)$ has a natural Banach space structure. If $\chi^k = 1$, the norm $\| \cdot \|$ is the supremum norm.
Let \( \kappa \in W(C_p) \) denote a point in weight space. Recall that the Eisenstein series \( E(\kappa) \) is defined away from zeroes of the Kubota–Leopoldt zeta function by the following formulas:

\[
E(\kappa) = 1 + \frac{2}{\zeta(\kappa)} \sum_{n=1}^{\infty} \sigma_\kappa^*(n)q^n, \quad \sigma_\kappa^*(n) = \sum_{(d,p)=1}^{d|n} \kappa(d)d^{-1}.
\]

The coefficients of \( E(\kappa) \) are rigid analytic functions on \( W \). If \( \kappa \) is trivial on the roots of unity in \( \mathbb{Q}_p \), then, as a \( q \)-expansion, \( E(\kappa) \) is congruent to 1 modulo the maximal ideal of \( \mathbb{Z}_p \). Coleman’s idea is to define overconvergent forms of weight \( \kappa \) using the formal \( q \)-expansion \( E(\kappa) \). Before we recall the definition, we also recall some elementary constructions related to weight space. If \( \mathbb{Z}_{p,N} := \lim_{\leftarrow}(\mathbb{Z}/Np^k\mathbb{Z}) \times (1 + q\mathbb{Z}_p) \), then there is a natural isomorphism \( \mathbb{Z}_{p,N} \cong (\mathbb{Z}/Nq\mathbb{Z}) \times (1 + q\mathbb{Z}_p) \), where \( q = p \) if \( p \) is odd, and \( q = 4 \) otherwise. If \( a \in \mathbb{Z}_{p,N} \), then \( \langle a \rangle \) denotes the projection of \( a \) onto the second factor, and \( \tau(a) = a/\langle a \rangle \) the projection onto the first. The rigid analytic space \( W \) has a natural group structure. Denote the connected component of \( W \) by \( B \); the component group of \( W \) is \( (\mathbb{Z}/Nq\mathbb{Z}) \times (1 + q\mathbb{Z}_p) \).

If \( \kappa \in W(C_p) \), then let \( \langle \kappa \rangle \) denote the weight \( a \mapsto \kappa(\langle a \rangle) \) and \( \tau(\kappa) \) the weight \( a \mapsto \kappa(\tau(a)) \); \( \langle \kappa \rangle \) is the natural projection of \( \kappa \) onto \( B \). If \( \chi \) denotes the cyclotomic character, then for any character \( \psi \) of \( (\mathbb{Z}/Nq\mathbb{Z}) \times (1 + q\mathbb{Z}_p) \), there is a unique congruence class modulo \( p-1 \) (or modulo 2 if \( p = 2 \)) such that for any \( k \in \mathbb{Z} \) in this congruence class, \( \tau(\eta \cdot \chi^{-k}) \) has conductor dividing \( N \). We fix once and for all a choice of representative \( k \in \mathbb{Z} \) for this congruence class.

We recall now the definition of overconvergent modular forms of weight \( \kappa \):

**Definition 2.2.** Overconvergent modular forms of weight \( \kappa \) and tame level \( N \) are \( q \)-expansions of the form \( VE_{\langle \kappa \rangle \chi^{-k}} \cdot F \), where \( F \in M(C_p, N, \chi^k \cdot \tau(\kappa \cdot \chi^{-k})) \).

Note that this is not the exact definition that occurs on [10], §2.4, since we have chosen to work with \( \Gamma_0(p) \) structure rather than \( \Gamma_1(p) \) structure. Yet both definitions are easily seen to be equivalent, using, for example, Theorem 2.2.2 of ibid. We do not define the radius of convergence of an overconvergent form of general weight.

**3 Hasse Invariants**

In this section, we prove some estimates for the convergence of certain overconvergent modular forms related to Hasse invariants. As in Section 2, let \( A \) be a characteristic zero lift of the Hasse invariant with coefficients in \( W(\mathbb{F}_p)[[q]] \).

**Lemma 3.1.** Let \( v(r) < 1/(p+1) \), and let \( x \) be a point on \( X_0(p, r) \). Then

\[
\frac{A(x)}{VA(x)} \equiv 1 \mod \frac{p}{A(x)p^k+1}.
\]

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Proof. The weight of $A$ is $p - 1$. Let $E$ be the elliptic curve associated to $x$, and $H$ the canonical subgroup. Let $\omega_E$ be a Néron differential of $E$, and let $a = A(E, \omega_E)$ (we implicitly trivialize $H^0(E, \Omega^1)$). By Theorem 3.1 of Katz (13, p.113), we deduce that $E/H$ is isomorphic to $E^{(p)}$ modulo $p/a$, where $E^{(p)}$ is the image of $E$ under Frobenius. Hence,

$$A(E/H, \omega_{E/H}) \equiv a^p \mod p/a,$$

where $\omega_{E/H}$ is any differential that can be identified with the inverse image of $\omega_E$ under Frobenius modulo $p/a$. By definition,

$$VA(E, \omega_E) = p^{1-p} \cdot A(E/H, \pi^*\omega_E) = p^{1-p} \cdot \lambda^{1-p} \cdot A(E, \omega_{E/H}),$$

where $\pi^*\omega_E = \lambda \cdot \omega_{E/H}$. Remark 3.6.5.0 of Katz (13, p.116) identifies $\lambda$ with

$$a_{p-1/p} \equiv A(E, \omega_E)/p \mod 1 \equiv a/p \mod 1.$$

The factor of $p$ comes from the identity $dx^p/x^p = p(dx/x)$. It follows directly that $VA(E) \equiv a \mod p/a^p$, and the lemma follows after dividing by $a$. 

Corollary 3.2. Suppose that $v(r) < 1/(p + 1)$. Then $\log(A/VA) \in M(C_p, N, 1, r)$. If $s \in C_p$ is sufficiently small, then $(A/VA)^s \in M(C_p, N, 1, r)$.

Proof. From Lemma 3.1 we deduce that $A/VA - 1$ has norm $< 1$ on $X_0(p, r)$, which implies the first claim. Moreover, $\|s \cdot \log(A/VA)\| \ll 1$ for sufficiently small $s$, and hence, if $s$ is sufficiently small,

$$(A/VA)^s = \exp(s \cdot \log(A/VA))$$

is well-defined and lies in $M(C_p, N, 1, r)$. 

4 Families of Eigenforms

Let $h : D^\times \to E$ denote an analytic family of overconvergent modular eigenforms of finite slope such that $\pi \circ h$ extends to $D$, and suppose that $(\pi \circ h)(0) = \kappa$, where $\kappa$ is of the form $\kappa = \lambda^k \cdot \psi$ with $k \in \mathbb{Z}$ and a finite order character $\psi$ of conductor dividing $N$. We assume that the image of $h$ lies in the cuspidal locus since the Eisenstein locus is easily seen to be proper (cf [5, Theorem 8.2]). Any weight in $W(C_p)$ sufficiently close to $\kappa$ is of the form $\kappa \cdot B^*$, where

$$B^* := \left\{ \eta(s) : a \mapsto \langle a \rangle^{s(p-1)} \mid s \in C_p, v(s) > -1 + \frac{1}{p-1} \right\},$$

(the inequality should be $v(s) > -1$ when $p = 2$). Our definition of $B^*$ is normalized slightly differently from [10, p.28], as we have included an extra factor of $p - 1$ in the exponent. After shrinking $D$, if necessary, we may assume that $(\pi \circ h)(D^\times) \subset \kappa \cdot B^*$. Given $t \in D$, we may consider $h(t)$ to be a normalized eigenform in $M(C_p, N \cdot \eta(s(t)))$, for some $\eta(s(t)) \in B^*(C_p)$ and analytic function $s(t)$. By assumption, $Uh(t) = \lambda(t)h(t)$ for some analytic function $\lambda(t)$ which does not vanish on $D^\times$. By considering $q$-expansions, we deduce that $h(0)$ exists as a $p$-adic modular form in the sense of Katz [13] (for a more detailed proof, see [5, p.229]). The modular form $A$ has weight

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χ^{p-1} = η(1) if p > 2, and A^2 has weight χ^2 = η(2) if p = 2. Thus (shrinking D again if necessary), we may construct a map

\[ g : D^× \to M(\mathbb{C}_p, N, \kappa) \]

via the formula \( g(t) = h(t)/VA^{s(t)} \). This map is well-defined as an easy consequence of Corollary B4.2.5 of [7], namely that \( E_s/A^s \) is overconvergent of weight zero where \( E_s \) is the Eisenstein series of weight \( η(s) \).

**Lemma 4.1.** Suppose that \( v(r) < 1/(p + 1) \). After shrinking \( D \), if necessary, the image of \( g \) lands in \( M(\mathbb{C}_p, N, \kappa, r) \).

**Proof.** By construction, \( g(t) \) lies in \( M(\mathbb{C}_p, N, \kappa, \mu) \) for some \( \mu \) with \( v(\mu) > 0 \). Since \( \kappa \) is of the form \( χ^k \cdot ψ \), we may therefore realize \( g(t) \) as a section of \( H^0(X_0(p, \mu), ω^{⊗k}) \). Here we use the fact that \( ψ \) has conductor co-prime to \( p \). Consider the operator \( U_t = (A/VA)^{s(t)}U \), where \( U \) is the usual operator on overconvergent modular forms [7, 8]. If \( s(t) \) is sufficiently small, then by Corollary 3.2, the factor \( (A/VA)^{s(t)} \) lies in \( M(\mathbb{C}_p, N, 1, r) \). On the other hand,

\[ U_t(g(t)) = (A/VA)^{s(t)}U(g(t))/VA^{s(t)} = (A/VA)^{s(t)}(\lambda(t)g(t))/A^{s(t)} = \lambda(t)g(t). \]

If \( v(\mu) < v(r) \), then \( U \) maps \( M(\mathbb{C}_p, N, \kappa, \mu) \) to \( M(\mathbb{C}_p, N, \kappa, \mu^p) \). Thus, since \( \lambda(t) \neq 0 \) for \( t \in D^× \), we deduce from the equality \( g(t) = \lambda(t)^{-1}U_t(g(t)) \) that if \( g(t) \) lies in \( M(\mathbb{C}_p, N, \kappa, \mu) \), then \( g(t) \) lies in \( M(\mathbb{C}_p, N, \kappa, \text{max}\{\mu^p, r\}) \). Thus, by induction, \( g(t) \) lies in \( M(\mathbb{C}_p, N, \kappa, r) \).

Let \( Y \) be a connected affinoid variety, and let \( V \) be a non-empty admissible open affinoid subdomain of \( X \). Let \( B = \text{Spf}(\mathbb{C}_p(T)) \), and \( A = \text{Spf}(\mathbb{C}_p(T^{-1})) \). Let \( F \) denote a sheaf on \( Y \) such that \( F(Y) \to F(V) \) is an inclusion. The following is an immediate generalization of [5], Lemma 8.1.

**Lemma 4.2.** Let \( G \) be the pullback of \( F \) to \( Y \times B \). If \( g \) is a section of \( G(V \times B) \) that extends to a section of \( G(Y \times A) \), then \( g \) extends to \( G(Y \times B) \).

**Proof.** By assumption \( g \in G(V \times B) = F(V)(T) \) and \( g \in G(Y \times A) = F(Y)(T, T^{-1}) \). Since \( F(Y) \subset F(V) \), the intersection of these two modules inside \( G(V \times A) = F(V)(T, T^{-1}) \) is \( F(Y)(T) = G(Y \times B) \).

As remarked above, the \( q \)-expansion \( g(0) = h(0) \) is a Katz \( p \)-adic modular form of weight \( \kappa \). Let \( Y = X_0(p, r) \); let \( V = Y^{\text{ord}} \) be the ordinary locus of \( Y \); and, let \( F = ω^{⊗k} \). Since \( B(\mathbb{C}_p) = D \), the map \( g \) extends to a morphism \( B \to F(Y) \). On the “boundary” \( A \) of \( B \) (or on any annulus contained in \( B \) and not containing zero), \( g \) extends to a morphism \( A \to F(Y) \). Since morphisms from \( B \) to \( F(Y) \) may be identified with \( G(Y \times B) \), we deduce from Lemma 4.2 that \( g \) extends to a morphism \( B \to F(Y) = M(\mathbb{C}_p, N, \kappa, r) \). Thus, to complete the proof of Theorem 1.1, it suffices to prove that \( g(0) \) has finite slope or, equivalently, that \( \lambda(0) \neq 0 \). Hence, we assume that \( \lambda(0) = 0 \). Since \( \lambda \) doesn’t vanish on \( D^× \), it is not identically zero, and thus,

\[ \lambda(T) = λ_mT^m + \ldots, \]

for some \( m \in \mathbb{N}_{>0} \) such that \( λ_m \neq 0 \). There is, moreover, an identity

\[ U_T(g(T)) = \exp \left( s(T) \cdot \log \left( \frac{A}{VA} \right) \right) U(g(T)) = \lambda(T)g(T). \]
We now specialize this identity to \( C_p[e]/e^{m+1} \) via the map \( T \mapsto \epsilon \). This specialization is not strictly necessary, as one could simply work with the first \( m \) coefficients of the Taylor expansion of \( g(T) \). We persist, however, for psychological reasons, in order to view \( g(\epsilon) \) as associated to a form with weight in some infinitesimal neighbourhood of \( \kappa \). Suppose that \( g(\epsilon) = \sum_{k=0}^{m} G_k \cdot \epsilon^k \). Then, since \( s(0) = 0 \), it follows that \( s(\epsilon) \equiv 0 \mod \epsilon \), and thus,

\[
U g(\epsilon) = \exp \left( -s(\epsilon) \cdot \log \left( \frac{A}{VA} \right) \right) \cdot \lambda(\epsilon) \cdot g(\epsilon) = \lambda_m \epsilon^m G_0.
\]

By equating coefficients, we find that \( UG_0 = 0 \), and \( UG_m = \lambda_m G_0 \). Since \( U \) increases overconvergence (and \( \lambda_m \neq 0 \)), it follows that \( G_0 \in M(C_p, N, \kappa, r^p) \). Our only condition on \( r \) so far is that \( v(r) < 1/(p+1) \). Thus, we take \( p \cdot v(r) = v(r^p) = 1/(p+1) \).

**Lemma 4.3.** If \( g(0) = G_0 \) does not have finite slope, then

1. \( G_0 \in M(C_p, N, \chi^k \cdot \psi, p^{1/(p+1)}) = H^0(X_0(p, p^{1/(p+1)}), \omega^\otimes k) \).
2. \( UG_0 = 0 \).
3. \( G_0 = q + \ldots \neq 0 \).

**Proof.** The first two claims are proved above. For the final claim, note that \( g(0) \) is a limit of normalized cuspidal eigenforms, and so the first coefficient is \( q \).

To complete the proof, we note that the conclusions of Lemma 3 are in contradiction with the following result from [5].

**Lemma 4.4.** If \( k \in \mathbb{Z} \) and \( G \in H^0(X_0(p, p^{1/(p+1)}), \omega^\otimes k) \) is in the kernel of \( U \), then \( G = 0 \).

**Proof.** Suppose \( G \in H^0(X_0(p, p^{1/(p+1)}), \omega^\otimes k) \) is arbitrary. Let \( E \) be an elliptic curve over a finite extension of \( \mathbb{Q}_p \), equipped with a subgroup \( C \) of order \( p \) and with level \( N \) structure \( L \). If the corresponding point \( (E, C, L) \in Y \) is in \( X_0(p, p^{1/(p+1)}) \), then one can regard \( F(E, C, L) \) as an element of \( H^0(E, \Omega^1)^\otimes k \). Now define \( F \in H^0(X_0(p, p^{p/(p+1)}), \omega^\otimes k) \) by

\[
F(E, L) = \sum_{D \neq C} \pi^* G(E/D, C, L),
\]

where the sum is over the subgroups \( D \neq C \) of \( E \) of order \( p \); \( \pi \) denotes the projection map \( E \to E/D \); \( \pi^* \) denotes the pullback from \( H^0(E/D, \Omega^1)^\otimes k \) to \( H^0(E, \Omega^1)^\otimes k \); and, a bar over a level structure denotes its natural pushforward. An easy calculation using Tate curves (see, for example, Proposition 5.1 of [3]) shows that \( F = pU G \), and hence, if \( UG = 0 \), then \( F = 0 \). If \( E \) is an elliptic curve with no canonical subgroup, and we fix a level \( N \) structure \( L \) on \( E \), then \( (E, C, L) \in X_0(p, p^{p/(p+1)}) \) for all \( C \). Thus, \( F(E, C, L) = 0 \) for such \( E \), and hence,

\[
\sum_{D \neq C} \pi^* G(E/D, E[p]/D, L) = 0.
\]

for all \( C \). Summing, one deduces that \( G(E/D, E[p]/D, L) = 0 \) for all \( D \) of order \( p \). This implies that \( G \) is identically zero on the “boundary” of \( X_0(p, p^{1/(p+1)}) \) and, hence, that \( G \) is identically zero.

\[ \square \]
References

[1] A. Ash, G. Stevens. $p$-adic Deformations of Cohomology on $GL(n)$: the non-ordinary case, preprint.

[2] J. Bellaïche, G. Chenevier, $p$-adic families of Galois representations and higher rank Selmer groups, book in preparation.

[3] K. Buzzard, Analytic Continuation of Overconvergent Eigenforms, J. Amer. Math. Soc. 16 (2003), no.1, 29–55.

[4] K. Buzzard, Eigenvarieties, To appear in the proceedings of the 2004 Durham Symposium on $L$-functions and arithmetic.

[5] K. Buzzard, F. Calegari, The 2-adic Eigencurve is Proper, to appear in Documenta Mathematica, Special Volume in Honour of John Coates.

[6] G. Chenevier, Familles $p$-adiques de formes automorphes pour $GL_n$. J. Reine Angew. Math. 570 (2004), 143–217.

[7] R. Coleman, $p$-adic Banach spaces and families of modular forms, Invent. Math. 127 (1997) no. 3, 417–479.

[8] R. Coleman, Classical and overconvergent modular forms. Invent. Math. 124 (1996), no. 1-3, 215–241.

[9] R. Coleman, W. Stein. Approximation of eigenforms of infinite slope by eigenforms of finite slope, Geometric aspects of Dwork theory. Vol. I, II, 437–449, 2004.

[10] R. Coleman, B. Mazur. The Eigencurve, Galois representations in arithmetic algebraic geometry (Durham, 1996), 1–113, London Math. Soc. Lecture Note Ser., 254, Cambridge Univ. Press, Cambridge, 1998.

[11] P. Colmez, Série principale unitaire pour $GL_2(Q_p)$ et représentations triangulines de dimension 2, Preprint.

[12] M. Emerton, On the interpolation of systems of eigenvalues attached to automorphic Hecke eigenforms. Invent. Math. 164 (2006), no. 1, 1–84.

[13] N. Katz, $p$-adic properties of modular schemes and modular forms. Modular functions of one variable, III (Proc. Internat. Summer School, Univ. Antwerp, Antwerp, 1972), pp. 69–190. Lecture Notes in Mathematics, Vol. 350, Springer, Berlin, 1973.

[14] E. Urban, Eigenvarieties for reductive groups, preprint.